Wyrowski VirtualLab Fusion
User's Manual

June 2024

Wyrowski Photonics GmbH

Kahlaische Straße 4
07745 Jena
Germany

www.wyrowski-photonics.com

VirtualLab Fusion 2024.1 (Build 1.134)

Wyrowski VirtualLab Fusion
is developed by Wyrowski Photonics GmbH and
is distributed by LightTrans GmbH (www.lighttrans.com, support@lighttrans.com).

Contents

I Introduction

In this part you can find some general notes about the concept of VirtualLab Fusion and this manual.

1 VirtualLab Fusion Packages

VirtualLab Fusion Standard can be extended with various *packages*:

- **Grating Package**: Grating Optical Setup, LLGA Results Generator, Fourier Modal Method / Rigorous Coupled-Wave Analysis
- **Diffractive Optics Package**: Session Editors, IFTA Optimization, Beam Shaper Design
- **Flat Lens Package**: Functional Meta Lens, Functional Modulated Metasurface, Diffractive Lens, Holographic Optical Element
- **Light Shaping Package**: Light Shaping Optical Setup, Cells Array Design
- **Laser Resonator Package**: Laser Resonator Optical Setup, Session Editors
- **AR/VR/XR Package**: Light Guide Optical Setup, Custom Fourier Modal Method, Footprint and Grating Analysis, Light Guide Grating Design, k-Layout Visualization, Layout Design Calculator
- **Distributed Computing Package**: Distributed Computing
- **optiSLang Package**: optiSLang Package .

2 VirtualLab Fusion and External Tools

VirtualLab Fusion is a powerful software with a focus on designing and analyzing optical systems. There are many external programs with a different focus that extend VirtualLab Fusion's functionality even further.
Some recommended programs:

- VirtualLab Fusion allows you to transform light into arbitrary *desired output fields* using either the IFTA optimization (↪Sec. 98) or the Cells Array Design (↪Sec. 101). Polygonal or elliptical shapes can be generated within VirtualLab Fusion. More complex patterns like logos can be generated as monochromatic images using raster graphics editors like Windows™ Paint or GIMP (free); and then be imported into VirtualLab Fusion (↪Sec. 122).

- VirtualLab Fusion offers many ways to extend its functionality by simply writing snippets in a powerful source code editor (↪Sec. 7.3). However, complex projects can be developed more easily using an Integrated Development Environment (IDE), for example Visual Studio or Visual Studio Code.

- If your simulations run more than a few minutes and you want to continue with your work in the mean time, we recommend the following procedure.

  1. Set the execution priority of your current VirtualLab Fusion instance to something like *Below Normal*, *Low* or *Idle*. This avoids that your PC reacts sluggishly due to heavy CPU usage but leads to slightly longer simulation times. This can be done with the Windows™ Task Manager or the Process Explorer (free).
  2. Start a new instance of VirtualLab Fusion where you can prepare new simulations.

- If you want to take screenshots of VirtualLab Fusion document windows for e. g. presentations, you can use Greenshot (free) or SnagIt (the program with which all screenshots in this manual have been made).

- If you want to do advanced calculations on e. g. a data array (↪Sec. 13), you can transfer the data to a spreadsheet software (e. g. Excel or LibreOffice Calc (free)) and do your calculations there. The transfer can be done by copying the data from a table to the Windows™ Clipboard or by exporting the data via File > Export.

- VirtualLab Fusion can export data into various file formats (↪Part XVI). We recommend the following software to view or process this data.

FILE FORMAT	RECOMMENDED SOFTWARE
Text Files	Notepad++ (free) and PSPad (free) can handle larger files than the Windows™ Notepad and offer advanced editing options like column-wise selections. V can open very large text files (with a size of several GB) very fast by opening just a view lines at once.
Videos	Animations (↪Sec. 20) can be exported to avi videos which can be edited and converted to other file formats using for example avidemux (free).
CIF / GDSII	With KLayout (free), CIF and GDSII files can be opened, edited, and converted to e. g. OASIS and DXF format.
IGES / STL	Many CAD formats can be viewed online with the Autodesk Viewer (free, registration required).
IGES	IGES files can be opened for example with the IGS Viewer (free).
STL	STL files can be opened and converted with Meshlab (free).
XML	XML files can be opened with any Internet browser.

3 How to Use this Manual

The following formattings are used in the manual.

EXAMPLE	USED FOR …
File > Open	An entry in the ribbon (↪Sec. 4.2).
Close	Other elements of the graphical user interface, for example an entry within an edit dialog or document window.
`Example.txt`	A file name or a source code example.
PE, PC, PV, or PE	A parameter available for parameter extraction. See Sec. 44.6 for details.
Key	A key to press.

II User Interface

This part explains the main window of VirtualLab Fusion and other commonly used controls.

4 Structure of User Interface

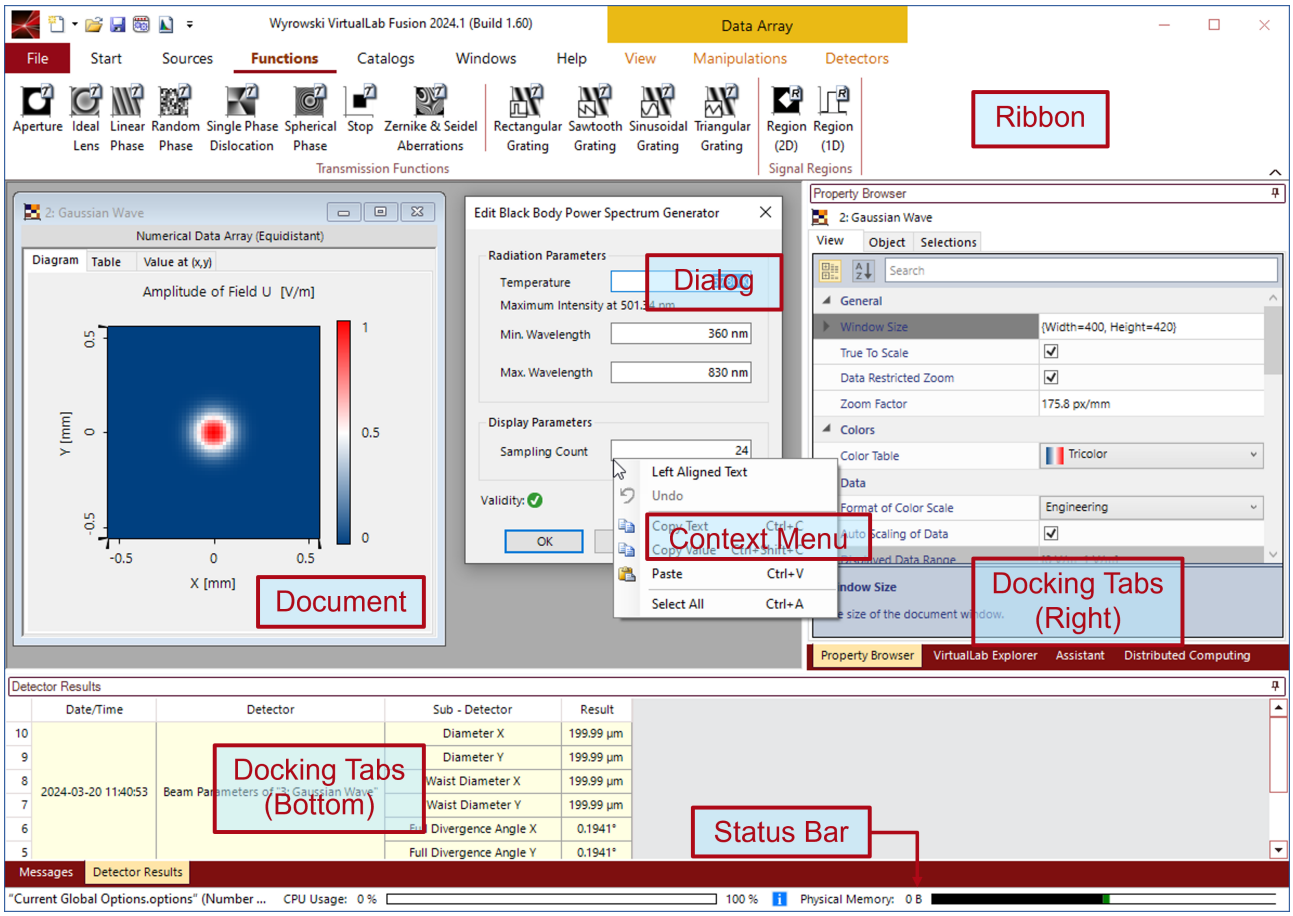


Figure 1. *General structure of the user interface of VirtualLab Fusion.*

A VirtualLab Fusion window (↪Fig. 1) consists of the following areas: the ribbon (↪Sec. 4.2) with the Quick Access Toolbar at the top, Docking Tabs (↪Sec. 4.3) at the right and at the bottom and a status bar (↪Sec. 4.4) at the very bottom. The color scheme of these controls can be set in the Global Options Dialog (↪Sec. 6.3). The main area of the user interface is used for document windows. A document window is also denoted as a view. Several types of documents are supported by VirtualLab Fusion, for example optical systems and harmonic fields. Sec. 4.1 gives an overview of all available document types. Document windows can be closed by double clicking on the icon in their top left corner.

> Redrawing a document window can be very computationally intensive. Thus we strongly recommend to switch off redrawing during resizing via the Windows™ Control Panel (Choose *Display*, then the *Appearance* panel, press *Effects* and uncheck *Show windows content while dragging*). In this case, any window is only drawn anew if you stop resizing it with the mouse.

Several user interface operations, such as the invocation of certain menu items, cause the appearance of modal dialog boxes. In contrast to document windows, modal dialog boxes lock the whole program, that is, such a dialog box has to be closed for other user interface elements to become accessible again. Use the *Help* button in the respective dialog to get context sensitive help.
In various dialogs and views context menus are supported, which are accessible by the right mouse button. The menu items displayed within a context menu depend upon the position of the mouse pointer when opening the menu.

4.1 Documents and Document Windows

VirtualLab Fusion provides an ever-growing variety of own document types. These documents are shown in document windows for which the main part of the VirtualLab Fusion user interface is reserved. Furthermore, VirtualLab Fusion can import and export many common file formats (↪Sec. XVI).
The following tables list all document types of VirtualLab Fusion, their file extensions, the relation between document types and document windows (sometimes different document types share the same document window or a document type has more than one document window), and which of the following general features the documents have.

- **Result document** means that the document somehow show data plotted against one or more coordinates. The corresponding *result windows* have their own resizing mechanism (↪Sec. 4.1.1) and a document specific ribbon group in orange (instead of in dark red).
- **Warn on Close** means that a warning is shown if you try to close the corresponding document window with unsaved changes. These windows show a "*" on the beginning of their window title if there are unsaved changes.
- **Automatic Saving** means that the document is saved automatically after a certain time interval. You can configure this in the Property Browser (↪Sec. 4.3) of the document; by default the settings from the Global Options dialog (↪Sec. 6.17) are used. For this mechanism to work the document must have been saved at least once before so that a file name is known.

Data Arrays and derived documents

DOCUMENT TYPE	DOCUMENT WINDOW	FEATURES
(Numerical) Data Array (*.da) ↪**Sec. 13**	Numerical Data Array View, ↪Sec. 13.4	Result Document
Chromatic Fields Set (*.cfs)	Chromatic Fields Set View, ↪Sec. 14	Result Document
Light Field Object (*.lfo)	View for field components and pulses, ↪Sec. 15.	Result Document
Non-Equidistant Field Values (*.nefv)	Ray Distribution View, ↪Sec. 17	Result Document
Positions, Directions & Wavefront Phase (*.ppd)	Ray Distribution View, ↪Sec. 17	Result Document
Set of Data Arrays (*.soda)	View for Set of Objects, ↪Sec. 16	Result Document

Legacy result documents

DOCUMENT TYPE	DOCUMENT WINDOW	FEATURES
Harmonic Field (*.ca2) ↪**Sec. 12.1**	Harmonic Field View, ↪Sec. 12.2	Result Document
Harmonic Fields Set (*.hfs)	Harmonic Fields Set View, ↪Sec. 12.2	Result Document
Transmission (*.ca2)	Slightly adapted Harmonic Field View, ↪Sec. 12.2	Result Document

Other result documents

DOCUMENT TYPE	DOCUMENT WINDOW	FEATURES
Animation (*.bms)	Animation View, ↪Sec. 20	Result Document
Ray Distribution 3D (*.rays)[1]	Ray Distribution View, ↪Sec. 17	Result Document
Region (*.rgn) ↪Sec. 21	Region View, ↪Sec. 21.3	Result Document

Optical Setups and their variation

DOCUMENT TYPE	DOCUMENT WINDOW	FEATURES
Optical Setup (*.os, *.lpd)	Two linked document windows: Optical Setup View (↪Sec. 44.1) and Optical Setup Editor (↪Sec. 44.2)	Warn on Close
Parameter Run (*.run)	Parameter Run View, ↪Sec. 45	Warn on Close Automatic Saving
Parametric Optimization (*.opt)	Optimization Document View, ↪Sec. 103.1	Warn on Close Automatic Saving

Other documents

DOCUMENT TYPE	DOCUMENT WINDOW	FEATURES
Calculators (*.calc)	Various views, ↪Part XV	
C# / Visual Basic source code (*.cs / *.vb)	Modules View, ↪Sec. 7.2	Warn on Close
Geometry (*.3d)	3D View, ↪Sec. 5.16	
Session Editor (*.seditor)	Wizard view	Warn on Close[2]

Documents specific for the AR/VR/XR Package

DOCUMENT TYPE	DOCUMENT WINDOW	FEATURES
Footprint and Grating Analysis (*.fga)	Footprint and Grating Analysis Wizard, ↪Sec. 102.1	Warn on Close
k-Layout Visualization (*.calc)	Visualization view, ↪Sec. 112	
Light Guide Grating Design (*.lgDesign)	Light Guide Grating Design, ↪Sec. 102.2	Warn on Close
LUT Results Generator (*.lutGenerator)	LUT Results Generator, ↪Sec. 47	

[1] Up to VirtualLab Fusion 2021.1, Non-Equidistant Field Values documents; Positions, Directions & Wavefront Phase documents; and Ray Distributions 3D were all saved with the extension *.rays.

[2] A session editor can generate child document views (e. g. Optical Setups). These child views stay linked to the session editor so that clicking *Refresh* in the session editor updates these documents. This linkage can be removed if you close the session editor and click on *Keep Associated Documents* in the resulting dialog. If you click *Close Associated Documents* both the session editor and the child document views are closed.

Documents specific for the Diffractive Optics Package

DOCUMENT TYPE	DOCUMENT WINDOW	FEATURES
IFTA Optimization Document (*.dp, *.aps)	IFTA Optimization Document, ↪Sec. 98	Warn on Close

Documents specific for Grating Optical Setups

DOCUMENT TYPE	DOCUMENT WINDOW	FEATURES
Diffraction Orders Diagram Data (*.dodd)	Diffraction Orders Diagram, ↪Sec. 19	Result Document
Order Collection (*.oc)	Order Collection View, ↪Sec. 18	Result Document

Documents specific for Laser Resonator Optical Setups

DOCUMENT TYPE	DOCUMENT WINDOW	FEATURES
Iteration Document (*.iter)	Iteration Document View, ↪Sec. 45.6	Warn on Close

Documents specific for Light Shaping Optical Setups

DOCUMENT TYPE	DOCUMENT WINDOW	FEATURES
Cells Array Design (*.gcd)	Cells Array Design, ↪Sec. 101	Warn on Close
LLGA Results Generator (*.llga)	LLGA Results Generator, ↪Sec. 46	

Documents specific for the optiSLang Package

DOCUMENT TYPE	DOCUMENT WINDOW	FEATURES
optiSLang Optimization (*.oso)	optiSLang Optimization View, ↪Sec. 104	Warn on Close Automatic Saving

4.1.1 Resizing of Document Windows

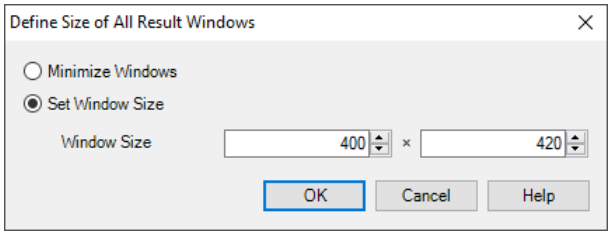


Figure 2. *Dialog for adjusting the window size of all currently open result windows.*

The size of all document windows can be changed via the usual mechanisms provided by Windows™ (dragging on the borders, using the minimize and maximize buttons). Furthermore there are several tools for this in the Windows tab of the ribbon (↪Sec. 4.2.4).
But for *result windows* (↪Sec. 4.1), VirtualLab Fusion offers special ways to set the window size in pixels, which can be helpful for doing screenshots for presentations:

1. Define a window size in the Global Options dialog (↪Sec. 6.7) which is used for newly created documents.
2. Via Windows > Change Size of Result Windows you can open a dialog (↪Fig. 2) to adapt the window size of all currently open result windows. This dialog allows you to choose between *Set Window Size* (in which case you can define the *Window Size*) and *Minimize Windows*. The latter can be useful if there are many results windows open which you do not need in the moment.
3. Change the size via the Property Browser (if available for the specific document type).

4.1.2 View Settings

All documents but Module Files and IFTA Optimization Documents also store the current view settings of their corresponding document window (window size, markers, color scale and alike) if saved to hard disc. For all of these document types which have a View ribbon, you can copy the view settings from another document window of the same type via the View > Copy View Settings button.

4.2 Ribbon

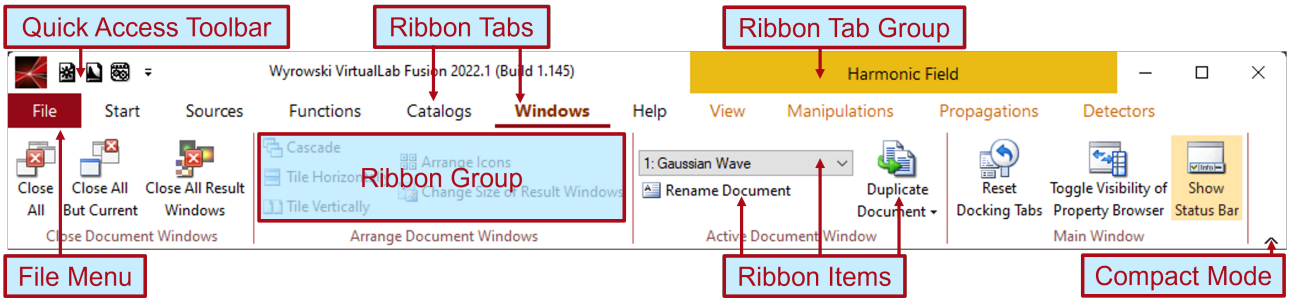


Figure 3. *Controls within a ribbon.*

The *ribbon* at the top of the main window is the main control for accessing the various features and document types of VirtualLab Fusion. As shown in Fig. 3, it consists of the File menu (↪Sec. 4.2.2) and six *ribbon tabs* (see table below). Various document types add a *ribbon tab group* to the ribbon containing further ribbon tabs. A ribbon tab has several *ribbon groups* each with several *ribbon items*, which can be buttons, menus, and the like.

Furthermore there is a *quick access toolbar* (↪Sec. 4.2.1) where you can place your most often used ribbon items. And with the *compact mode* button in the lower right corner of the ribbon you can reduce the icon sizes of the ribbon items and thus decrease the height of the ribbon.

When you press `Alt` or `F10`, *key tips* are shown which allow you to access almost all ribbon items via keyboard.

The following six ribbon tabs are always available:

RIBBON TAB	DESCRIPTION
Start	Allows you to create, load and save documents. Furthermore it contains various calculators and license information. ↪Sec. 4.2.3
Sources	Provides access to all Basic Source Models (↪Sec. 52), Partially Coherent Source Models (↪Sec. 53), and Spectrum Generators (↪Sec. 54).
Functions	Contains the generators for transmissions (↪Sec. 68.1) and region documents (↪Sec. 21).
Catalogs	All VirtualLab Fusion catalogs (↪Part V).
Windows	Allows you to configure the document windows and the main window as a whole. ↪Sec. 4.2.4
Help	Provides access to help files like the manual and the programming reference, some pre-configured Focus Topic files and tools for troubleshooting. ↪Sec. 4.2.5

The menu of the quick access toolbar and the context menu of the actual ribbon both have the following two entries:

ITEM	DESCRIPTION
Show (Quick Access Toolbar) **Below / Above the Ribbon**	The quick access toolbar can be shown at two different locations: in the title bar of the main window (“above the ribbon”) or in a separate row below the ribbon. In the first case the space available for the quick access toolbar is limited, and thus some ribbon items might not be shown in the quick access toolbar itself but in its menu.
Minimize the Ribbon	If this option is active, the ribbon groups are only shown if you click on the caption of a ribbon tab. This option can also be toggled by double-clicking on the caption of a ribbon tab.

4.2.1 Quick Access Toolbar

You can place ribbon groups and most of the ribbon items in the quick access toolbar by right-clicking on them and then selecting *Add to Quick Access Toolbar*. Items in the quick access toolbar can be

- Removed from the quick access toolbar by right-clicking on them and then selecting *Remove from Quick Access Toolbar*.
- Rearranged by clicking on the Rearrange Items in Quick Access Toolbar button . This button is only enabled if there are two or more items in the quick access toolbar. ↪Sec. 4.2.1.1

4.2.1.1 Rearranging Items in the Quick Access Toolbar

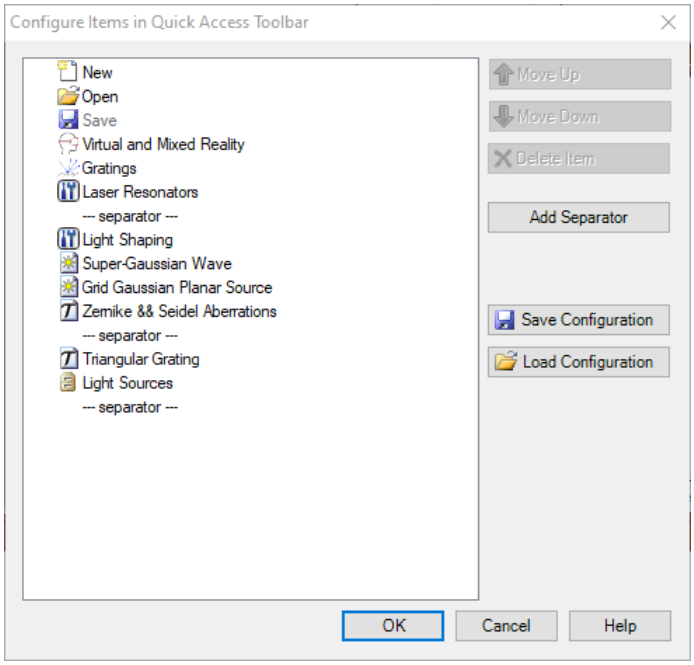


Figure 4. *The dialog for rearranging the items in the quick access toolbar. It contains a list of all available items at the left and two arrow buttons in the top right corner.*

The dialog shown in Fig. 4 allows you to rearrange the items in the quick access toolbar and to save and load the complete configuration of the quick access toolbar. This dialog lists all items in the quick access toolbar, even those which are currently invisible. You can select any entry of that list with the mouse and then move it up or down, or delete it.

ITEM	DESCRIPTION
Move Up	Moves the currently selected item one step up.
Move Down	Moves the currently selected item one step down.
Delete Item	Removes the currently selected item from the quick access toolbar.
Add Separator	Adds a separator to the bottom of the list which can be then be moved like all other items.
Save Configuration	Saves the current configuration of the items in the quick access toolbar to disk.
Load Configuration	Loads and applies a previously saved configuration. The file `Autosaved.qat` in the *Path for User Settings* (↪Sec. 6.17) contains the configuration valid the last time VirtualLab Fusion was closed.

4.2.2 File Menu

ITEM	DESCRIPTION
New	Creates an empty (General) Optical Setup (↪Sec. 44). If you click on the arrow, you can additionally create an IFTA Optimization document (↪Sec. 98) or a module (↪Sec. 7.2). Ctrl+L is the shortcut for a new Optical Setup and Ctrl+M is the shortcut for a new C# module.
Open	Opens one or more files in one of VirtualLab Fusion's document formats (↪Sec. 4.1). Shortcut Ctrl+O
Import	Imports text files, images, Zemax OpticStudio® lens and beam files and old VirtualLab Fusion formats. ↪Part XVI
Global Options	Opens a dialog for editing global options and parameters. ↪Sec. 6.
Exit	Closes all open documents and exits VirtualLab Fusion. Shortcut Alt+F4

When any document is open the file menu additionally contains the following menu items:

ITEM	DESCRIPTION
Save	Saves the currently active document to the same file the document was loaded from. For newly created documents it asks for a file name. Shortcut Ctrl+S
Save As	Asks for a file name and saves the document to this file. Shortcut Ctrl+Shift+S
Incremental Save	Allows you to quickly save a document under an automatically given file name, for example to keep the current state for reference. If the document has not been saved before, it is stored with a default name in the folder {Path for User Settings (↪Sec. 6.17)}\Autosaved Files. Otherwise the already given file name is used with a numeral suffix which is incremented by one with each saving in order to not overwrite files. Shortcut Ctrl+Alt+S

For some document types, there is also an Export menu item, which allows the user to save the currently active document in a non-standard file format.
Furthermore, the 20 most recently opened documents are listed at the right of the file menu. The first 10 of these documents can also be opened with the shortcuts Ctrl+1 … Ctrl+0. All entries of this list can be deleted using the × button at the top right corner of the recent files list.

4.2.3 Start Ribbon Tab

ITEM	DESCRIPTION
New	Creates an empty (General) Optical Setup (↪Sec. 44). If you click on the arrow, you can additionally create an IFTA Optimization document (↪Sec. 98) or a module (↪Sec. 7.2).
Open	Opens one or more files in one of VirtualLab Fusion's document formats (↪Sec. 4.1).
Save	Saves the currently active document to the same file the document was loaded from. For newly created documents it asks for a file name.

Calculators	This ribbon group contains a Calculators menu, ↪Part XV.
Diffractive Optics > "Gaussian → Top Hat" Transmission Design	Opens the dialog described in Sec. 100.1 which allows you to easily design a beam shaper transforming a (super-)Gaussian input field into another super-Gaussian top hat.
Diffractive Optics > Diffractive Beam Shaper	Helps you to setup the IFTA optimization document for beam shaping tasks. ↪Sec. 100.2
Diffractive Optics > Refractive Beam Shaper	Opens a Session Editor (↪Sec. 48) which helps you to design a refractive beam shaper. For details about the resulting documents see Sec. 44 (Optical Setup) and Sec. 103 (Parametric Optimization Document).
Diffractive Optics > Beam Splitter Design	This section contains various Session Editors (↪Sec. 48) which help you to design a beam splitter. For details about the resulting documents see Sec. 44 (Optical Setup) and Sec. 98 (IFTA Optimization Document).
Diffractive Optics > Diffuser Design	This section contains various Session Editors (↪Sec. 48) which help you to design a diffuser. For details about the resulting documents see Sec. 44 (Optical Setup) and Sec. 98 (IFTA Optimization Document).
Gratings	The ribbon item General Grating Optical Setup provides a preconfigured Optical Setup which is described in Sec. 44.11.1. Furthermore there are several ribbon items creating Optical Setups preconfigured with various grating types.
Gratings > LLGA Results Generator	After clicking on this ribbon item you must first specify a XML file containing data for a set of gratings. After the XML file has been successfully read, a LLGA Results Generator (↪Sec. 46) is opened containing the imported data.
Laser Resonators > Laser Resonator Session Editor	Opens a Session Editor (↪Sec. 48) to setup a Laser Resonator Optical Setup (↪Sec. 44.11.2).
Laser Resonators > Laser Resonator Optical Setup	Opens an empty Laser Resonator Optical Setup (↪Sec. 44.11.2).
Light Guides > Light Guide Optical Setup	Opens an Optical Setup which contains a default Light Guide component (↪Sec. 58.2).
Light Guides > k-Layout Visualization	Opens a new k-Layout Visualization calculator (↪Sec. 112).
Light Guides > Layout Design	Opens a new Layout Design calculator (↪Sec. 114).
Light Guides > Grating Design	Opens a new Light Guide Grating Design (↪Sec. 102.2) for a Light Guide Optical Setup.
Light Shaping > Light Shaping Optical Setup with . . . Cells	Opens a preconfigured Optical Setup using either a Grating Cells Array (↪Sec. 41.1.1), a Prism Cells Array (↪Sec. 41.1.2), or a Mirror Cells Array (↪Sec. 41.1.2) as light shaping element.
Light Shaping > Light Shaping Optical Setup	Opens an empty Light Shaping Optical Setup (↪Sec. 44.11.4).

4.2.4 Windows Ribbon Tab

ITEM	DESCRIPTION
Close All	Closes all currently open document windows.
Close All But Current	Closes all currently open document windows which are not active.
Close All Result Windows	Closes all currently open *result windows*. Sec. 4.1 lists which document types are shown in result windows.
Cascade	All document windows are cascaded.
Tile Horizontally	All document windows are tiled horizontally.
Tile Vertically	All document windows are tiled vertically.
Arrange Icons	All minimized document windows are arranged.
Change Size of Result Windows	Allows you to set the size of all open result windows (or to minimize them). ↪Sec. 4.1.1
{Active Document Window Selection}	A drop-down list to select one of the currently open documents as the active document.
Rename Document	Changes the title of the currently active document window (Shortcut: F2).
Duplicate Document	Duplicates the currently active document window. When you click on the arrow, you have the additional choice to copy only the actual document, not the view settings. In this way you can get rid of misconfigured or unwanted view settings. Examples are a diagram which shows nothing because the view range is wrong or when you get documents from colleagues but want to use your default windows size and color table configured in the Global Options dialog (↪Sec. 6).
Reset Docking Tabs	Resets all docking tabs (↪Sec. 4.3) to their default position and size.
Show / Hide Right Docking Tab	Shows the right docking tab if it is hidden – and vice versa. Shortcut: F4.
Show Status Bar	Toggles the visibility of the status bar (↪Sec. 4.4).

4.2.5 Help Ribbon Tab

ITEM	DESCRIPTION
Content	Opens the help system and shows the table of contents.
Index	Opens the help system and shows the index.
Programming Reference	Opens the VirtualLab Fusion programming reference documenting useful commands for programming.
Assistant	This ribbon group offers context sensitive help for the currently active document view.
Focus Topics	this ribbon group contains links to *Focus Topic Files* which demonstrate how certain tasks can be done in VirtualLab Fusion. They are grouped into several categories and updated dynamically, so that new focus topics appear in this menu as soon as they are available. The *Show Sample Files* button determines whether VirtualLab Fusion sample files are opened when you click on a focus topic item. Else only the corresponding web page is opened in your browser.
Diagnosis & CleanUp	Opens a dialog with three options: • Clean up the RAM from unused VirtualLab Fusion data. • Check the external components used by VirtualLab Fusion. • Write a support mail (see next item).
Mail Support Information	Prepares a mail to our support and shows it in your mail program. It contains some information we need to solve your issue.
First Steps	A dialog helping you getting started with VirtualLab Fusion.
What's New	A dialog explaining what is new in the current version.
Tips and Tricks	Link to tips and tricks which ease using our software.
About VirtualLab	Shows a dialog with license, version, contact, and legal information.
License Information	Opens the dialog for viewing and managing your VirtualLab Fusion license. ↪Sec. 10
Update Information	Opens a web link which shows whether updates are available. More information can be found in the administrator's manual.
Update Program Data	Updates the LightTrans defined catalogs (↪Part V), Optical Setup Trees (↪Sec. 44.1), and detector add-ons (↪Sec. 75.4.5) from the Internet. This button is disabled if these program data are up-to-date.
Trial Configuration	ONLY AVAILABLE IN THE TRIAL VERSION. Allows you to select the additional packages for VirtualLab Fusion (↪Sec. 1).

4.3 Docking Tabs

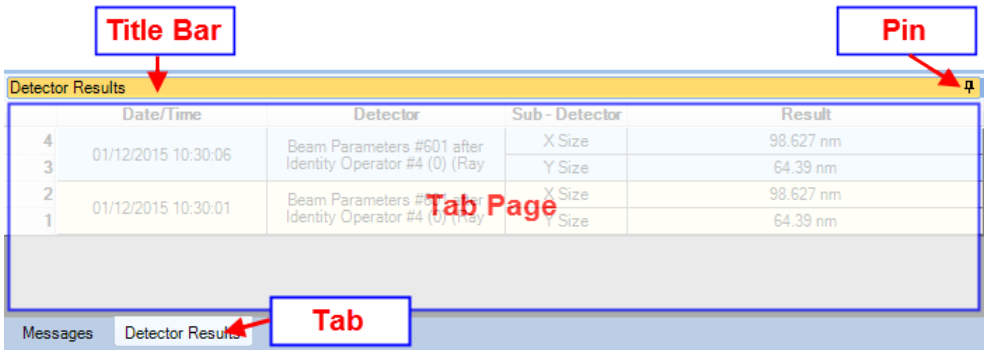


Figure 5. *Controls within a docked tab control.*

The user interface of VirtualLab Fusion contains five special tab pages:

TAB	DESCRIPTION
Parameter Overview Tree	ONLY FOR OPTICAL SETUPS Provides quick access to most parameters of a Optical Setup. ↪Sec. 44.6.2
Property Browser	Allows you to view and manipulate properties of the currently active document. Depending on the document type, the property browser will be divided into several panels.
VirtualLab Fusion Explorer	Offers a convenient way to toggle between the distinct open windows. ↪Sec. 4.3.1
Distributed Computing	Allows you to configure server and clients for distributed computing. ↪Sec. 8
Messages	Shows error, warning and status messages. It has its own context menu which allows the user to *Cut* (Ctrl+X), *Copy* (Ctrl+C), *Paste* (Ctrl+V) certain messages as well as to *Select All* (Ctrl+A) content and to *Clear* all text. If you hold the Ctrl-key while scrolling with the mouse wheel, the font size of this control changes.
Detector Results	Shows detector results in a tabular form whereas the latest entry is shown at the top of the table. Via its context menu you can • *Copy …*: ↪Sec. 5.8 • Usually the columns are automatically resized to show as much content as possible. But you can resize them to your likings by moving the mouse between two column headers. The cursor then switches to a double arrow with a bar and you can click and drag to change the column width. (The same is possible for the row heights.) If you switch to *Fixed Column Widths*, the current column widths remain even if this table is resized or new detector results are calculated (which else triggers a new automatic resizing). • *Clear Detector Results*, i. e. clear the entire table.

By default, the *Parameter Overview Tree*, the *Property Browser* and the *VirtualLab Fusion Explorer* tab pages are placed in a tab control which is docked at the right of the main window. The *Messages* and the *Detector Results* tab pages are placed in a tab control which is docked at the bottom of the main window. These two tabs are marked with a ⚠ if new data is written into them while another tab in the tab control they are placed in is visible.

The tab controls can be resized by dragging their borders. They also can be moved around by clicking onto their title bar and dragging them while keeping the left mouse button pressed. Usually such a moved tab control becomes a floating tab which is independent from the main window. But if you move a tab control onto a *guide* it becomes a docked tab control again which changes its position and size with the main window. A tab control can be docked at the left, at the right or at the bottom of the main window; besides any other docked tab control or inside any other tab control.
In the same way you can move a single tab page by clicking onto the tab and dragging it while keeping the left mouse button pressed. If you do not move a tab page into an already existing tab control it becomes its own tab control. Docked tab pages can be set into an *auto hide* mode which means that only its tab is shown unless you move the mouse onto the tab. This mode can be toggled with the pin at the right of its title bar.
By clicking onto the ribbon item Windows > Reset Docking Tabs all four tabs become docking tabs again and are set to their default position and size. By clicking Windows > Toggle Visibility of Property Browser (shortcut F4) you can always make the Property Browser visible, which means that it becomes the active tab of its tab control and that the *auto hide* is turned off if applicable. If the Property Browser is visible and you use this ribbon item, the tab control is set to *auto hide* mode if it is docked and another tab in its tab control becomes the active tab.

4.3.1 VirtualLab Explorer

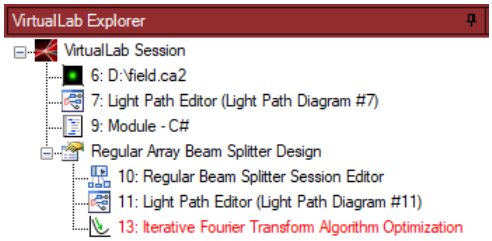


Figure 6. *The VirtualLab Fusion Explorer with some sample documents, among others a Regular Beam Splitter Session Editor with associated documents.*

The *VirtualLab Explorer* (↪Fig. 6) displays all currently open document windows under a central node named *VirtualLab Session*. For a better overview, session editors (↪Sec. 48) and documents generated by them are grouped under one node. The currently active document is marked red.
If you right-click with the mouse on a document window (= leaf node), this document is selected (but not activated) and a context menu with the following options opens.

ITEM	DESCRIPTION
Rename	Opens a dialog where you can change the caption of the selected document window (but not its number).
Minimize	Minimizes the selected document window to the lower left corner of the document area.
Bring to Front	Brings the selected document window to the front (which means that it is no longer obscured by other document windows) and makes it the active window. If a document window was minimized it is reverted to normal size. The same can be done by double-clicking on a tree node with the left mouse button.
Close	Closes the selected document window. This can also be done with Shift + Del.

For Optical Setups the context menu also contains a combo box with all saved snapshots (if any exist). If you click on one entry of the combo box, the corresponding snapshot is opened as new document window.

4.4 Status Bar

The bottom most part of the main window is reserved for the status bar. On the left it displays the number of CPU cores currently used for multi-core calculations. Furthermore it shows whether the Parameter Run (↪Sec. 45) itself runs parallel (*also for Parameter Run*) or only the simulation of each Optical Setup (*not for Parameter Run*). The multi-core configuration of VirtualLab Fusion can be changed in the Global options dialog (↪Sec. 6.15).

On the right of the status bar there are two gauges monitoring the current computer performance. The left one indicates the current CPU usage of VirtualLab Fusion (blue) and of all other processes (black). The right one shows the current usage of the *physical* memory. Memory used by other processes than the current instance of VirtualLab Fusion is indicated black. The memory used by the current instance of VirtualLab Fusion is marked green. If more than 95 % of the total physical memory are used, only one red bar is shown. You can switch these gauges on or off by right clicking on them and then either checking or unchecking *Use Monitoring*, respectively.

Note on CPU usage

Hyperthreading is a technique on most modern CPUs to faster switch between two threads when one is waiting for data. In this case, the operating system sees two *logical cores* for each *physical core*. Thus it is completely normal that fully parallelized algorithms use “only” all physical cores which results in a CPU usage of “only” 50 %.

4.5 Notifications and Notify Icon

If you work in other programs while long lasting simulations run in VirtualLab Fusion, you will miss when these simulations are finished. To solve this problem, VirtualLab Fusion uses Windows™ *notifications*, shown as popups in the bottom right of the main screen. Notifications need a *notify icon* in the right part of the task bar (the notification area).

How the notifications look and behave and how long they are shown depends on the used Windows version. For example in Windows 10 notifications play a sound and they are stored in the Action Center so that you can read them later.

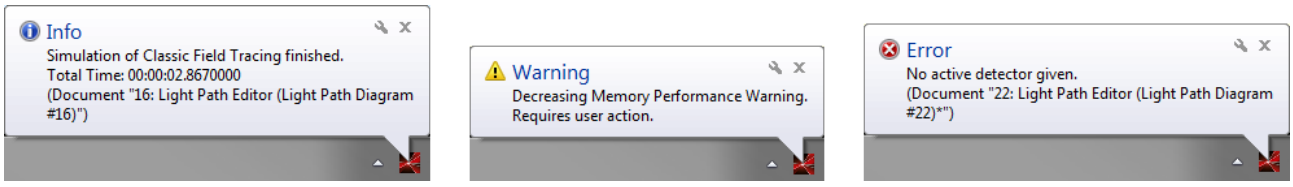


Figure 7. *The three types of notifications used by VirtualLab Fusion.*

VirtualLab Fusion offers three types of notifications (↪Fig. 7):

TYPE	DESCRIPTION
Info	Shown if a simulation was completed successfully. This applies to Optical Setups, Parameter Runs, Parametric Optimizations, and Iteration Documents.
Warning	Shown if a simulation is halted because the free RAM would fall short the *Guaranteed Amount of Remaining Physical Memory* (↪Sec. 6.14) if the simulation continued.
Error	Shown if an Optical Setup aborts its simulation due to errors. The other document types mentioned above always complete successfully – they just skip the current simulation if errors occur.

By double-clicking on the icon you can activate the corresponding VirtualLab Fusion main window, i. e. bring it to the front, “un-minimize” it, and give it the focus. The latter means that you can use for example the ribbon shortcuts with Alt + …
The notify icon has a context menu with some useful shortcuts:

ITEM	DESCRIPTION
Activate Main Window	Activates the corresponding VirtualLab Fusion main window, i. e. brings it to the front, “un-minimizes” it, and gives it the focus.
Global Options	Opens the Global Options dialog (↪Sec. 6).
Exit VirtualLab	Closes all open documents and exits VirtualLab Fusion.

Notifications and the notify icon can be switched off via the Global Options dialog (↪Sec. 6.3).

5 Common Controls

5.1 Control for Input of Values with Units

Text boxes for entering numerical values with units (in short: *value text boxes*) appear in numerous dialogs of VirtualLab Fusion, Fig. 8 shows an example.

Figure 8. *Sample control for entering a wavelength.*

Depending on the application of the control, the control is set to a certain measured quantity. If you enter a value without unit, the default unit (with no prefixes) of this physical property is used to interpret this value. If the interpreted value is less than 1 or greater or equal than 1000 then VirtualLab Fusion usually uses a unit with prefix to bring the value into that range. For example an entered length of “1234” is interpreted as 1234 meters and shown as “1.234 km”, but of course you can enter “1.234 km” as well.
The following table lists all measured properties and the corresponding units supported by VirtualLab Fusion. If two or more units are supported, the default unit is marked bold. Note that for the measured quantity “length”, the default unit can be set by the user in the Global Options dialog (↪Sec. 6.5).
There are also units which you can use for entering values but which are never used by VirtualLab Fusion for output. They are marked gray in the table.

PHYSICAL PROPERTY	UNITS
No Unit	–
Absorption Coefficient	**“m^{-1}”** (or “1/m”)

Angle (°)	**"°"** (or "deg"), "π" ("pi", "Pi", or "PI"), "rad", "mrad"
Angle (rad)	"°" (or "deg"), "π" ("pi", "Pi", or "PI"), **"rad"**, "mrad"
Arbitrary Unit	"A.U."
Area per Energy	"m²/J"
(Area per Energy)²	"m⁴/J²"
Electric Field Strength	"μV/m", "mV/m", **"V/m"**, "kV/m", "MV/m"
(Electric Field Strength)²	"(μV/m)²", "(mV/m)²", **"(V/m)²"**, "(kV/m)²", "(MV/m)²"
Energy (eV)	"meV", **"eV"**, "keV", "MeV", "GeV", "nJ", "μJ", "mJ", "J", "kJ", "MJ"
Energy (J)	"meV", "eV", "keV", "MeV", "GeV", "nJ", "μJ", "mJ", **"J"**, "kJ", "MJ"
Energy per Area	"J/m²"
Energy per Volume	"J/m³"
Illuminance	**"lx"** (or "lm/m²")
Information (Decimal)	**"B"**, "kB", "MB", "GB", "TB", "PB", "EB", "kiB", "MiB", "GiB", "TiB", "PiB", "EiB"
Information (Binary)	**"B"**, "kB", "MB", "GB", "TB", "PB", "EB", "kiB", "MiB", "GiB", "TiB", "PiB", "EiB"
k-Domain Electric Field Strength	"μV m", "mV m", **"V m"**, "kV m", "MV m"
(k-Domain Electric Field Strength)²	"(μV m)²", "(mV m)²", **"(V m)²"**, "(kV m)²", "(MV m)²"
k-Domain Magnetic Field Strength	"μA m", "mA m", **"A m"**, "kA m", "MA m"
(k-Domain Magnetic Field Strength)²	"(μA m)²", "(mA m)²", **"(A m)²"**, "(kA m)²", "(MA m)²"
Length	"fm", "pm", "nm", "μm", "mm", "cm", "dm", **"m"**, "km" "in" (or "inches", or "inch", or " " "), "mil" (1/1000 inch), "ft" (or "foot", or "feet", or " ' "), "yd" (or "yard", or "yards"), "mile" (or "miles")
Line Density	"cycles/mm"
Logarithmic Level	"dB"
Luminance	**"cd/m²"** (or "lm/sr/m²")
Luminous Energy	"(lm s)"
Luminous Energy Density	"(lm s)/m³"
Luminous Flux	"lm"
Luminous Intensity	**"cd"** (or "lm/sr")
Magnetic Field Strength	"μA/m", "mA/m", **"A/m"**, "kA/m", "MA/m"
(Magnetic Field Strength)²	"(μA/m)²", "(mA/m)²", **"(A/m)²"**, "(kA/m)²", "(MA/m)²"
Percentage	"%"
Per Volume	**"1/m³"**, "1/dm³", "1/cm³", "1/mm³", "1/μm³", "1/ft³", "1/in³"
Power	"pW", "nW", "μW", "mW", **"W"**, "kW", "MW", "GW"
Power per Area	"μW/m²", "mW/m²", **"W/m²"**, "mW/mm²", "W/mm²", "W/μm²"
(Power per Area)²	"(μW/m²)²", "(mW/m²)²", **"(W/m²)²"**, "(mW/mm²)²", "(W/mm²)²", "(W/μm²)²"
Power per Solid Angle	"μW/sr", "mW/sr", **"W/sr"**

Power per Solid Angle and per Area	“µW/sr/m²”, “mW/sr/m²”, **“W/sr/m²”**, “mW/sr/mm²”, “W/sr/mm²”, “W/sr/µm²”
Power per Volume	“W/m³”
Pressure	**“Pa”**, “hPa”, “kPa”, “MPa”, “GPa”, “mbar”, “bar”, “atm”
Spectral Radiant Energy	“J/m”
Spectral Radiant Energy Density	“J/m⁴”
Spectral Radiant Flux	“W/m”
Spectral Radiant Intensity	“W/(m sr)”
Temperature (°C)	“K”, **“°C”**, “°F”
Temperature (K)	**“K”**, “°C”, “°F”
Temporal Frequency	“mHz”, **“Hz”**, “kHz”, “MHz”, “GHz”, “THz”, “PHz”
Time	“as”, “fs”, “ps”, “ns”, “µs”, “ms”, **“s”**, “min”, “h”
Volume per Energy	“m³/J”
(Volume per Energy)²	“m⁶/J²”
Wave Number	**“m⁻¹”** (or “1/m”)

Some units contain characters which cannot be entered easily with every keyboard. Thus in addition to the replacements given in the table above, you can replace “µ” by “u” and superscript digits like “²” by “^2” when entering a unit. The narrow no-break space used for separating multiplied units can be omitted.

Note on Base Units

Usually values are stored internally in the default unit. For example a variable with a pressure value always contains the value in pascals, even if it was entered in kilopascals. The only exceptions to this rule are:

- Angle (°): Values are stored in radians.
- Energy (eV): Values are stored in joules.
- Length: Values are always stored in meters, even if another default unit is set in the Global Options (↪Sec. 6.5).
- Percentage: The actual values are stored (50 % → 0.5).

These units are called *base unit*.
In contrast, if you copy values to the Windows™ clipboard, the *apparent base unit* is used: an *Angle (°)* is copied as degrees, an *Energy (eV)* is copied as electronvolts, and a percentage of 50 % is copied as 50.
Note for developers: If you have a `MeasuredQuantity quantity`, you can get the `value` in the apparent base unit via `quantity.Definition.ApparentBaseUnit.GetValueInUnit(value)`.

By default, values are displayed with the *Number of Digits* specified in the *Display of Numbers* subcategory of the Global Options dialog (↪Sec. 6.5), but this can be changed via the context menu (see below).
Furthermore, a small indicator may be used in order to show whether a text box doesn’t display all available digits. This indicator has to be activated in the Global Options dialog. The appearance of this indicator is depicted in Fig. 9. If the mouse is moved over the indicator, a tooltip shows the number in full precision.

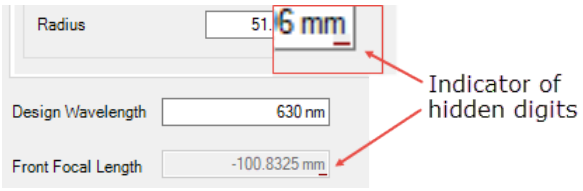


Figure 9. *The hidden digits indicator of a value text box.*

If you enter invalid data into a value text box, its text is marked red and the dialog containing this control is locked (this means *OK* button, *Next* button, etc. are disabled). If you move the mouse over the control a tooltip with the error message is displayed.
This control can also be used for the input of integer values with no unit. In this case a spinner can be used in addition to the actual text box.
The context menu of this control has the following entries.

ITEM	DESCRIPTION
{Unit Selection}	If the control is set to a measured quantity with more than one unit, there is a combo box with all available units (even those which are usually used only for input). You can select any of these units and the current value is then shown with this unit.
Precision	Defines how many digits are shown. You can switch between *Full (10 digits)* and the *Default* set in the Global Options dialog (↪Sec. 6.5).
Left Aligned Text	Shows the text in the text box left-aligned, which can be helpful in case not all digits can be shown at once.
Insert Infinity	In some cases, this control allows you to enter infinite values, where “inf” and “-inf” correspond to *Positive* and *Negative* infinity, respectively. For convenience these strings can also be entered via the context menu.
Undo	Allows you to undo the last text change.
Copy Text	Copies the text as shown in the text box into the Windows™ clipboard, for example “1.23 nm”. Shortcut: Ctrl+C.
Copy Value	Copies the actual value represented by the text box to the Windows™ clipboard, including also the non-shown digits. For example “1.234567e-9” if the text box shows “1.23 nm” (with 3 digits). Shortcut: Ctrl+Shift+C.
Paste	Pastes the content from the Windows™ clipboard into the text box if possible. If the value was copied from another text box, it might change the unit. For example if you paste the value “1.23” into a text box showing percentages, it becomes “123 %”. Shortcut: Ctrl+V.
Select All	Selects the complete content of the text box. Shortcut: Ctrl+A.

For copy & paste within VirtualLab Fusion always the same format is used which allows to paste the complete information – independent from whether *Copy Text* or *Copy Value* has been clicked. Note that copy & paste between tables and text boxes (↪Sec. 5.1) is possible.

5.2 Control for Input of Complex Values

Figure 10. *Example of a control to enter a complex value with physical units.*
Left: *Real and imaginary part of a complex number can be entered.* ***Right:*** *Amplitude and phase of a complex number can be entered.*

This control consists of two controls to enter a value with a unit as described in Sec. 5.1, and two buttons. If the $\mathcal{Re}/\mathcal{Im}$-button is pressed real and imaginary part, respectively, can be entered. In contrast, if the $\mathcal{A}_\varphi$-button is pressed amplitude and phase can be entered.

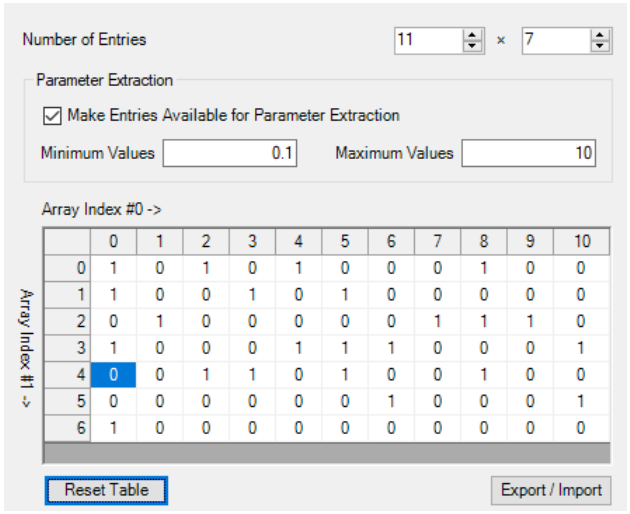
5.3 Control for Input of Two-Dimensional Vectors

Figure 11. *Example of a control to enter a two-dimensional vector.*

This control consists of two controls to enter a physical value (↪Sec. 5.1), one for the x-direction and one for the y-direction. If you double click into one of these controls, the value from the other control is copied into this control. If the control is used to enter value ranges instead of a point, a × is shown between the two controls.

5.4 Control for Input of Double Arrays

This control can be used to enter a one- or two-dimensional array of values with double precision.



	0	1	2	3	4	5	6	7	8	9	10
0	1	0	1	0	1	0	0	0	1	0	0
1	1	0	0	1	0	1	0	0	0	0	0
2	0	1	0	0	0	0	0	1	1	1	0
3	1	0	0	0	1	1	1	0	0	0	1
4	0	0	1	1	0	1	0	0	1	0	0
5	0	0	0	0	0	0	1	0	0	0	1
6	1	0	0	0	0	0	0	0	0	0	0

Figure 12. *Control to enter a two-dimensional array of values with double precision.*

Example for a text file for data import:

```
# Comment Line
1; 2; 3
3; 2; 1
5; 6; 7
```

The following settings can be made for an array of values:

ITEM	DESCRIPTION
Number of Entries	The number of entries in the array.
Make Entries Available for Parameter Extraction	If you check this option, each entry of the array can be varied via Parameter Extraction (↪Sec. 44.6) and thus used e. g. in the Parameter Run (↪Sec. 45). If the array contains more than 100 entries, a warning is shown that this might slow down the tables where the parameters to vary are configured.
Minimum Values / Maximum Values	If *Make Entries Available for Parameter Extraction* is checked, you can preset the minimum and maximum value for each entry here. In e. g. the Parameter Run you can later diminish the specified range, but not extend it (↪Sec. 45.2).
Table of entries	In the table you can specify the actual value of each entry.
Reset Table	After you have changed the *Number of Entries* you must reset the table, which means that the size of the table is adjusted and all cells are filled up with the default value of “1”.
Export / Import > Import Text File	You can import the values of the array from a .txt or .csv file. The file must have the format given in the marginal.
Export / Import > Export to Text File	You can export the values of the array into a .txt or .csv file.
Export / Import > Import Data Array	You can import the values from any open one- or two-dimensional data array. If the data array contains more than one subset, you can choose which subset to import. If the subset to import is complex-valued, only the real value is imported.
Export / Import > Export Data Array	You can export the values configured within the dialog into a data array. As a result of this operation the generated data array is shown as document within VirtualLab Fusion.

5.5 Control for Defining a Single Direction

In many cases where a direction vector in $\mathbb{R}^3$ has to be defined, a special control (see Fig. 13) can be used which is introduced here.

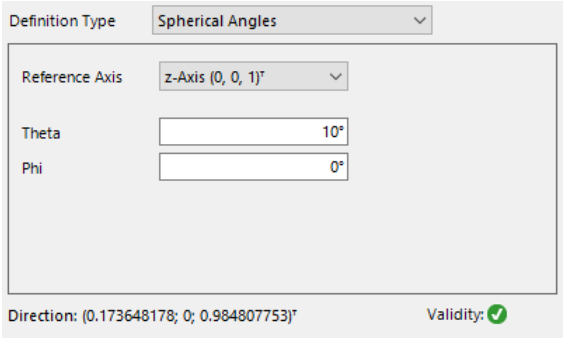


Figure 13. *Control for defining a direction vector.*

Since there are several kinds of direction definition conventions (↪Sec. 145.2), the appearance of the control can vary strongly. The only common controls always available are

ITEM	DESCRIPTION
Definition Type	The convention to use for defining the direction vector (↪Sec. 145.2) can be selected here.
Direction	The normalized direction vector which corresponds to the entered direction data.
Validity	An indicator which shows whether or not the entered data are consistent ↪Sec. 5.11.

All other controls are convention-specific and will be described in the following sections Sec. 5.5.1 to Sec. 5.5.6.

5.5.1 Direction Vector

See also Sec. 145.2.7 for more details on this convention.

ITEM	DESCRIPTION
X/Y/Z	The components of a (not necessarily normalized) direction vector.

5.5.2 Spherical Angles

See also Sec. 145.2.1.1 for more details on this convention.

ITEM	DESCRIPTION
Reference Axis	The coordinate system's base vector which is to be inclined by *Theta* and *Phi*.
Theta	Spherical angle θ, measured from the reference axis in a plane constructed by rotating the x-z-, y-x-, or z-y-plane (depending on the choice of the *Reference Axis*) by the other sphere angle ϕ.
Phi	Spherical angle ϕ, representing a rotation about the reference axis. It is measured in the plane perpendicular to the reference axis, between the y-, z- or x-axis (depending on the choice of the *Reference Axis*) and the line of nodes. The latter is identical to the axis the reference axis is rotated about by the inclination angle θ.

5.5.3 Direction Angles

See also Sec. 145.2.2.1 for more details on this convention.

ITEM	DESCRIPTION
Rho	The angle between the direction to be defined and the x-axis. This angle's cosine is identical to the x-component of the normed direction vector.
Sigma	The angle between the direction to be defined and the y-axis. This angle's cosine is identical to the y-component of the normed direction vector.
Tau	The angle between the direction to be defined and the z-axis. This angle's cosine is identical to the z-component of the normed direction vector.
Direction inside negative X/Y/Z half space	This check box indicates whether or not the x/y/z-component of the direction to be defined is negative.

5.5.4 Cartesian Angles

See also Sec. 145.2.3.1 for more details on this convention.

ITEM	DESCRIPTION
Reference Axis	The coordinate system's base vector which is to be inclined by *Alpha* and *Beta*.
Alpha	The angle between the reference axis and the projection of the direction to be defined onto the x-z- or x-y-plane (depending on the choice of the *Reference Axis*).
Beta	The angle between the reference axis and the projection of the direction to be defined onto the y-z- or x-z-plane (depending on the choice of the *Reference Axis*).

5.5.5 Sequence of Axis Rotations

See also Sec. 145.2.4.1 for more details on this convention.

ITEM	DESCRIPTION
Reference Axis	The coordinate system's base vector which is to be rotated by the rotation sequence.
X/Y/Z-Axis Rotation	Angle of rotation about the x-/y-/z-axis.
	Changes the sequence of rotation by lifting the current angle one position up.
	Changes the sequence of rotation by lowering the current angle one position down.
	Flips the sequence of rotation.
	Adds a new rotation.
	Deletes the currently selected rotation.

5.5.6 Rotation Matrix

See also Sec. 145.2.6.1 for more details on this convention.

ITEM	DESCRIPTION
Reference Axis	The coordinate system's base vector which is to be rotated by the rotation matrix.
Matrix Entries	The nine entries of the rotation matrix can bee set here.
> Copy	Copies the complete matrix to clipboard (as a string).
> Paste	Tries to paste a matrix from clipboard. It may have the format "s11; s12; s13; s21; s22; s23; s31; s32; s33" with s11 to s33 being strings for each of the nine matrix elements.
> Normalize	Normalizes the matrix.
> Set to Identity	Sets the matrix to the identity matrix.
> Transpose	Transposes the current matrix.

5.6 Control for Defining a Solid's Orientation

In many cases where a solid's orientation in $\mathbb{R}^3$ has to be defined, a special control can be used which is introduced here.

Since there are several kinds of orientation angle conventions (↪Sec. 145.2), the appearance of the control can vary strongly. The only common controls always available are

ITEM	DESCRIPTION
Orientation Definition Type	The convention to use for defining the orientation (↪Sec. 145.2) can be selected here.
	Pressing this button will calculate and show the rotation matrix which represents the currently entered orientation.

All other controls are convention-specific and will be described in the following sections Sec. 5.6.1 to Sec. 5.6.6.

5.6.1 Spherical Angles

See also Sec. 145.2.1.2 for more details on this convention.

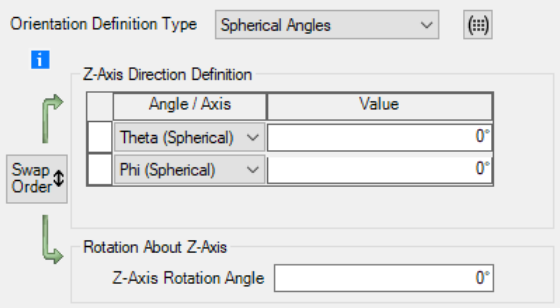


Figure 14. *Control for determining an orientation via spherical angles and a rotation about the z-axis.*

ITEM	DESCRIPTION
Theta (Spherical)	Spherical angle θ, measured from the z-axis in a plane constructed by rotating the x-z-plane by the other sphere angle ϕ.
Phi (Spherical)	Spherical angle ϕ, representing a rotation about the z-axis. It is measured in the x-y-plane between the y-axis and the line of nodes. The latter is identical to the axis the whole coordinate system is rotated about by the inclination angle θ.
Z-Axis Rotation Angle	Angle ζ of a rotation about the z-axis.
Swap Order	Using this button, the sequence of inclining the z-axis via θ and ϕ on the one hand and of rotating about the z-axis on the other hand can be flipped. If *Z-Axis Direction Definition* is above *Rotation About Z-Axis*, the z-axis inclination is done first, followed by the z'-axis rotation. If the sequence is the other way round, The z-axis rotation is done first, followed by the inclination in reference to the new rotated coordinate system.

5.6.2 Direction Angles

See also Sec. 145.2.2.2 for more details on this convention.

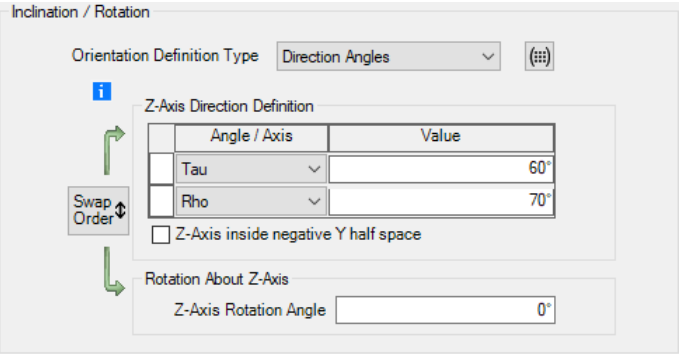


Figure 15. *Control for determining an orientation via direction angles and a rotation about the z-axis.*

ITEM	DESCRIPTION
Rho	The angle between the new z'-axis and the old x-axis. This angle's cosine is identical to the x component of the normed z'-vector.
Sigma	The angle between the new z'-axis and the old y-axis. This angle's cosine is identical to the y component of the normed z'-vector.
Tau	The angle between the new z'-axis and the old z-axis. This angle's cosine is identical to the z component of the normed z'-vector.
Z-Axis inside negative X/Y/Z half space	This check box indicates whether or not the x/y/z-component of the new z'-vector is negative.
Z-Axis Rotation Angle	Angle ζ of a rotation about the z-axis.
Swap Order	Using this button, the sequence of inclining the z-axis (via ρ, σ, and τ) and of rotating about the z-axis can be flipped. If *Z-Axis Direction Definition* is above *Rotation About Z-Axis*, the z-axis inclination is done first, followed by the z'-axis rotation. If the sequence is the other way round, The z-axis rotation is done first, followed by the inclination in reference to the new rotated coordinate system.

5.6.3 Cartesian Angles

See also Sec. 145.2.3.2 for more details on this convention.

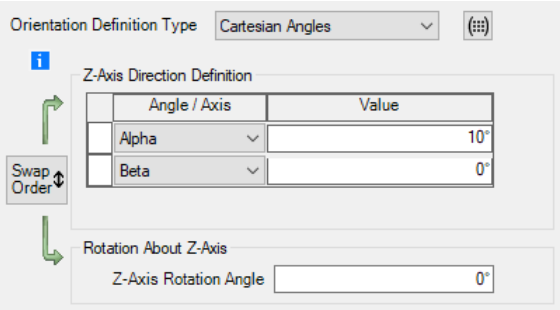


Figure 16. *Control for determining an orientation via Cartesian angles and a rotation about the z-axis.*

ITEM	DESCRIPTION
Alpha	The angle between the old z-axis and the projection of the new z'-axis onto the x-z-plane.
Beta	The angle between the projection of the new z'-axis onto the y-z-plane and the old z-axis.
Z-Axis Rotation Angle	Angle ζ of a rotation about the z-axis.
Swap Order	Using this button, the sequence of inclining the z-axis via α and β on the one hand and of rotating about the z-axis on the other hand can be flipped. If *Z-Axis Direction Definition* is above *Rotation About Z-Axis*, the z-axis inclination is done first, followed by the z'-axis rotation. If the sequence is the other way round, The z-axis rotation is done first, followed by the inclination in reference to the new rotated coordinate system.

5.6.4 Euler Angles

See also Sec. 145.2.5 for more details on this convention.

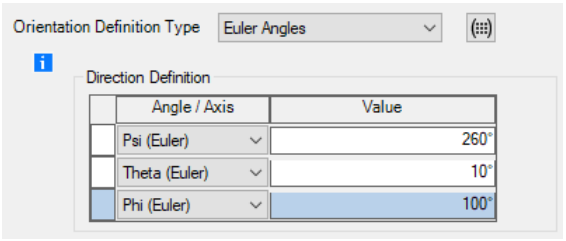


Figure 17. *Control for determining an orientation via Euler angles.*

ITEM	DESCRIPTION
Psi (Euler)	The angle of rotation about the z-axis.
Theta (Euler)	The angle of rotation about the new x'-axis, resulting from the former rotation.
Phi (Euler)	The angle of rotation about the new z'-axis, resulting from the former rotation.

5.6.5 Sequence of Axis Rotations

See also Sec. 145.2.4.2 for more details on this convention.

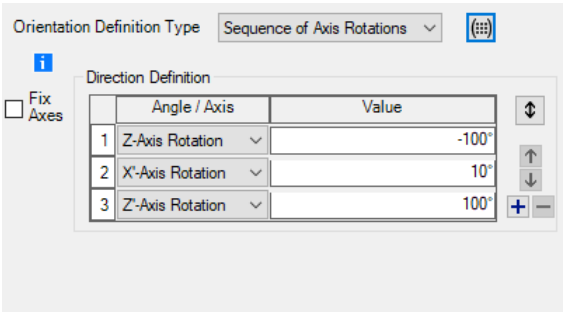


Figure 18. *Control for determining an orientation via a sequence of rotations about coordinate axes.*

ITEM	DESCRIPTION
Fix Axes	If checked, the sequence of rotations refer to fix axes. Otherwise, the non-first rotations are about axes resulting from former rotations.
X/Y/Z-Axis Rotation	Angle of rotation about the fix x-/y-/z-axis.
X'/X"/Y'/Y"/Z'/Z"-Axis Rotation	Angle of rotation about the current x'/x"/y'/y"/z'/z"-axis, resulting from former rotations.
	Changes the sequence of rotation by lifting the current angle one position up.
	Changes the sequence of rotation by lowering the current angle one position down.
	Flips the sequence of rotation.
	Adds a new rotation.
	Deletes the currently selected rotation.

5.6.6 Rotation Matrix

See also Sec. 145.2.6.2 for more details on this convention.

ITEM	DESCRIPTION
Matrix Entries	The nine entries of the rotation matrix can bee set here.
> Copy	Copies the complete matrix to clipboard (as a string).
> Paste	Tries to paste a matrix from clipboard. It may have the format "s11; s12; s13; s21; s22; s23; s31; s32; s33" with s11 to s33 being strings for each of the nine matrix elements.
> Normalize	Normalizes the matrix.
> Set to Identity	Sets the matrix to the identity matrix.
> Transpose	Transposes the current matrix.

5.7 Button to Set a Document

This button (↪Fig. 19) is usually labeled with *Set*. When you click on it a menu opens which allows you to set a specific document (↪Sec. 4.1) in various ways. Depending on the context not all entries might be available. Furthermore there might be constraints on which kind of document you can set, for example only equidistant two-dimensional data arrays with length coordinates.

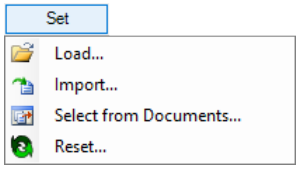


Figure 19. *Example of the button to set a document.*

MENU ENTRY	DESCRIPTION
Create New	Currently only used for calculators (↪Part XV). A new calculator is created, filled with matching data from the calling dialog, and then shown as dialog on top of the calling dialog. When you close this calculator dialog with *OK*, data is written back from the calculator to the calling dialog.
Load	Loads a document from file. If the loaded document does not match the constraints, it is shown as separate document but not set. So you may adapt it via the Manipulations ribbon tab.
Import	ONLY FOR GRIDDED DATA ARRAYS Text data are imported by means of the import wizard described in Sec. 121.1. Bitmap data are imported as described in Sec. 122.
Select from Documents	Allows you to select an already open document with matching properties.
Reset	Removes the currently set document.

5.8 Tables

Usually you can resize the column widths by moving the mouse between two column headers. Then the cursor changes and you can click and drag to change the column width.

Initially a table cell is always in *display mode*. If you want to change the content of a cell you can switch to the *edit mode* by double clicking on a cell or by pressing F2 when a cell is marked. It is also possible to simply start typing the new content. While in edit mode, a double click or Ctrl+A marks the whole content of a cell.

Quite often the content of a table cell is a physical value. Then the edit mode behaves similar to the control for input of physical values (↪Sec. 5.1). In particular values entered without a unit automatically get the default unit. But in contrast to this control, table cells usually not mark invalid values red but just restore the original value when you leave the edit mode. Furthermore in edit mode always all digits of a number are shown so that there is no loss of precision when editing a value.

In display mode, physical values are only shown with the number of digits set in the Global Options dialog (↪Sec. 6.5). However when the mouse hovers over a cell, a tooltip shows the value with all digits.

In display mode a table has a context menu which allows you to copy the content of the currently selected cells as text to the Windows™ clipboard so that they can be used in external programs like spreadsheet programs. For this there are four options, see table below. Often you can also *Paste* data into the table. For copy & paste within VirtualLab Fusion independent from the selected copy mode always the same format is used which allows to paste the complete information. Note that copy & paste between tables and text boxes (↪Sec. 5.1) is possible.

COPY MODE	DESCRIPTION
Copy Selected Text	Copies the selected physical values as shown in the table: with units and a limited number of digits. This is useful for presentations. Shortcut: Ctrl+C.
Copy Selected Text and Headers	Same as *Copy Selected Text* except that additionally the corresponding row and column headers are copied, too.
Copy Selected Values	Copies the selected physical values in their “apparent base unit” (e. g. meters for lengths) with all digits but without unit. In this way you can use them for further evaluations and diagram generations. Shortcut: Ctrl+Shift+C. “Apparent base unit” is defined in the note in Sec. 5.1.
Copy Selected Values and Headers	Same as *Copy Selected Values* except that additionally the corresponding row and column headers are copied, too.

In the copied text, table cells are separated by a tab.

5.9 Control for Selecting Multiple Entries

In various places a control is used to select one or more entries via a list of check boxes (↪Fig. 20).

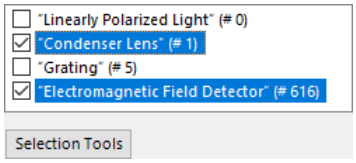


Figure 20. *Example of the control for selecting multiple entries.*

You can mark multiple entries in the following ways:

- Click with left mouse key on an area outside of every entry and hold it while dragging the mouse.
- Click entries while holding `Shift`.
- Clicking two entries while holding `Ctrl` marks a complete range of entries.
- `Ctrl`+`A` marks all entries.

All marked entries can then be selected / unselected at once by clicking on one of the marked check boxes. Usually below this control there is a button *Selection Tools* having a menu to *Select All* entries or *Unselect All* entries. It can also have more specific selection options.

5.10 Control for Input of Data Pairs

This control (↪Fig. 21) is used for the input of a sample of paired values.

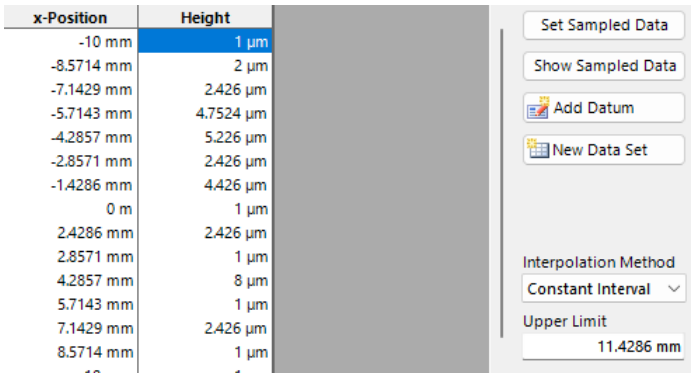


Figure 21. *Example of control for input of a table of data pairs.*

5.10.1 Adding New Data

There are three modes for the input of new data which are related to the following controls:

ITEM	DESCRIPTION
Set Sampled Data	Allows you to load an existing one-dimensional, real-valued data array (or to import equivalent data from disk) with matching properties into the table. ↪Sec. 5.7.
Add Datum	Clicking this button will open a dialog that allows to input one single new pair of values.
New Data Set	Clicking this button will open a dialog that allows to define the whole range of the first column by input of a start value, an end value, and the total number of values (see below). The second value is filled with a default value initially and has to be set to the desired values as described in Sec. 5.10.2.

5.10.1.1 Configuration of a New Set of Equidistant Data

Equidistant distributed data can be configured via the dialog described here.

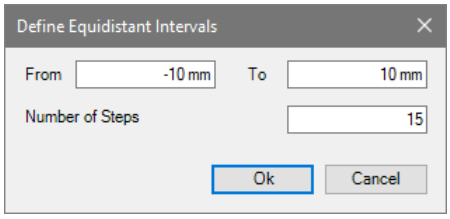


Figure 22. *Dialog for the definition of equidistant intervals.*

ITEM	DESCRIPTION
From	First (smallest) value for the first column.
To	Last (largest) value for the first column.
Number of Steps	Number of data pairs to enter.

5.10.2 Modifying Data

If you want to change any value in the table, you have to select the desired cell (by one left click or via arrow keys), then start to enter the new value. After editing just leave the cell.

5.10.3 Deleting Data

If you want to delete one or more rows, select these rows and press Del. The complete table can be selected by marking both column headers. If a single cell is selected, pressing Del deletes the content of that cell while Shift+Del deletes the complete row.
In any case there will be a prompt for confirmation before deleting rows.

5.10.4 Extracting Data

Marked cell contents can be copied to clipboard via Ctrl+C for further use e. g. in spreadsheet programs. *Show Data Array* shows the data as separate data array document (↪Sec. 13).

5.10.5 Interpolation Method

Sometimes, the user can define the interpolation method to be used. In this case, also the *Upper Limit* is shown, this is the maximum x-value for which the data is defined.
VirtualLab Fusion tries to evaluate whether the entered data are equidistant or not and shows only the suitable *Interpolation Method*s. Note that simply changing a x-value or adding data can change the data from equidistant to non-equidistant or vice versa, thus changing the *Interpolation Method*. A warning is shown in that case.
The actual value of the upper limit depends on the selected interpolation. For non-equidistant data and *Constant Interval* interpolation the *Upper Limit* can be set by the user. More information about interpolation method and the upper limit can be found in Sec. 13.2.

5.11 Validity Indicator

Figure 23. *The different states of the control used to indicate the validity of a whole control.*

In various places, a small symbol indicates the validity state of the current control (↔Fig. 23). The following table explains the various validity states.

VALIDITY STATE	DESCRIPTION
	Consistency check is still in progress.
	Everything is okay.
	There are several issues which might yield unexpected or unwanted results. The number of issues is shown as small red number. In this state an additional -button is shown. If you click this button a separate dialog explains all these warnings in detail.
	There are several issues which must be fixed before you can proceed (close the dialog with *OK* etc.). In this state an additional -button is shown. If you click this button a separate dialog explains all these errors in detail - and additional warnings if present.

In the dialog showing all warnings and errors you can double click on one explanation to copy it to the Window™ Clipboard. So you can use it for support requests.

5.12 Color Mapping

The Color Mapping Color control used at various locations in VirtualLab Fusion defines the mapping of a double value range to a color range and vice versa.

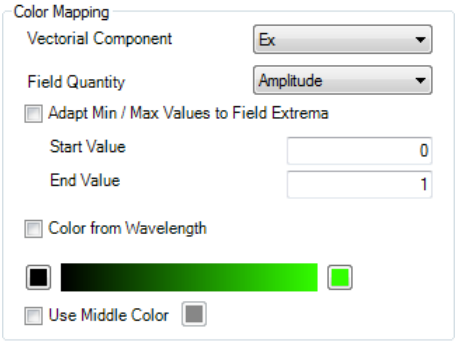


Figure 24. *Control to set color mapping properties.*

ITEM	DESCRIPTION
Vectorial Component	Choose the vectorial component of the complex amplitude to be exported. Note: This item is not always available.
Field Quantity	Choose the field quantity of the complex amplitude to be imported or exported.
Adapt Min / Max Values to Field Extrema	Adapt the color mapping to the min / max values of the specified complex component in the given complex amplitude. Note: This item is not always available.
Start [End] Value	User defined min / max values of the field quantity to import/export can be entered manually here.
Color buttons and color bar	Start and end color of the palette can be modified by the Windows Color Pick Dialog. The start and end colors correspond to the *Start Value* and *End Value* of the field quantity.
Color from Wavelength	If checked, the end color is determined from the wavelength in the same way as for the Camera Detector (Sec. 75.5.2). The whole color range is created as linear brightness gradient from start color (black) to this end color.
Use Middle Color	Enables use of an additional middle color. A middle color allows a three color gradient between the *Start Value* and the *End Value*.

5.13 Control for Defining Used Orders

The table in this control (↪Fig. 25) has two columns for 1D-periodic gratings (*Direction* and *Order Number*) and three columns for 2D-periodic gratings (*Direction*, *Order Number X*, and *Order Number Y*).
In the *Direction* column you can choose *T (+/+)* / *T (-/-)* for a transmission order and *R (+/-)* / *R (-/+)* for a reflection order. The expression in brackets indicates the sign of the z-component of the k-vector of the incident and the outgoing light (see also Sec. 44.10). Transmission orders have a blue background and reflection orders a red one.
In the order number column(s) you can enter the desired order number. In the *Function* tab of the Functional Grating (↪Sec. 60.1) there is an additional *Efficiency* column.

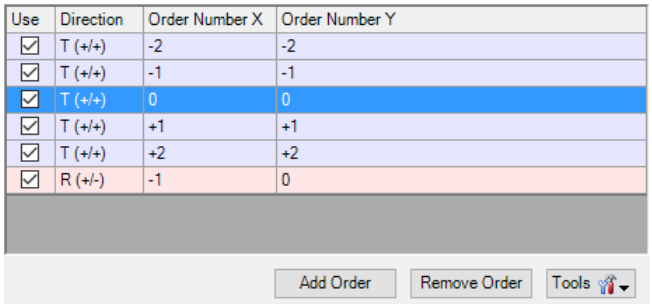


Figure 25. *Control for defining the used orders of a 2D-periodic grating.*

Below the table there are buttons to configure the table.

ITEM	DESCRIPTION
Add Order / Tools > Add Order	Adds a new row to the end of the table. The initial direction and order number is taken from the currently selected row. For 1D-periodic gratings this order number is then incremented by one to allow you to easily add a sequence of consecutive orders.
Tools > Add Order Range	Opens a dialog where you can enter a *Minimum Order* and a *Maximum Order* and whether you *Define Order Range for Reflection* or for transmission. For 2D-periodic gratings you can define a minimum / maximum for x- and y-direction separately. When you close the dialog with *OK*, all orders within the defined range (inclusive) are added to the end of the table; existing orders are overwritten.
Remove Order / Tools > Remove Current Order	Removes the currently selected order. This can also be done with the Del key.
Tools > Remove All Reflection / Transmission Orders	Removes all reflection / transmission orders currently present in the table.
Tools > Reset	Resets the table so that it only shows the zeroth transmitting order.
Tools > Sort	Sorts the table firstly so that transmission orders appear above of the reflection orders and then by order number(s). Sorting is also done when the dialog containing this control is closed and re-opened.
Tools > Synchronize Efficiencies	ONLY IF *EFFICIENCY* COLUMN IS SHOWN. Allows you to set one *Efficiency* for all reflection or transmission orders (depending on whether you *Synchronize Orders for Reflection*).

5.14 Control for Programmable and Databased Input

This control can be used to define either a list of value pairs $(x; y)$ or a function $f(x,y)$. If you select *Programmable Input* you have the following controls to program a snippet:

ITEM	DESCRIPTION
Definition	This group box allows you to program the actual snippet. *Edit* opens the Source Code Editor (↪Sec. 7.3) to edit this snippet, and a validity indicator (↪Sec. 5.11) shows whether this snippet is consistent.
Parameters PE	The controls in this group box allow you to set the values of the global parameters of the snippet. ↪Sec. 7.4

The *Databased Input* for value pairs offers a simple table for entering a preconfigured number of value pairs. Furthermore it has the following settings.

ITEM	DESCRIPTION
Set > Load	Loads a data array from a .da file. The data array must contain only one real-valued two-dimensional subset.
Set > Import	Imports a data array from a text file by means of the import wizard described in Sec. 121.1. The imported data array must contain only one real-valued two-dimensional subset.
Set > Select from Documents	Allows you to select an already open data array, which must contain only one real-valued two-dimensional subset.
Show	Shows the current data in a separate data array view (↪Sec. 13.4).
Preview Table	A preview table showing the current data.

5.15 Preview for Surface Media Sequences

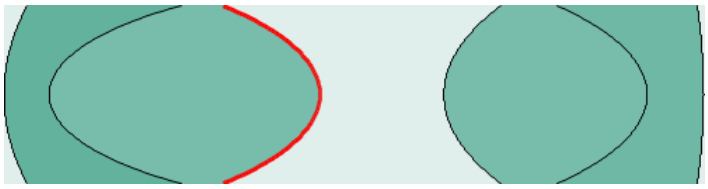


Figure 26. *Cross section of two lens pairs with the default color table "White and Mint". Air is marked light green. Glasses are marked by different shades of dark green. The third surface is currently selected and thus marked red.*

Both the edit dialogs for a Lens System component (↪Sec. 58.1) and for optical stacks (↪Sec. 40) comprise a preview of their respective sequence of surfaces and media. This preview either shows the x-z-plane for y = 0 or the y-z-plane for x = 0 in free aspect ratio. Fig. 26 shows a sample preview.
For surfaces the height profile in this plane is shown and for media the real refractive indices in this plane are visualized by different colors depending on the used color table. Surfaces are marked with *Color 2* of the color table, the currently selected surface is marked with its *Highlighting Color* and a bit more thick. ↪Sec. 11.2.4.2
Absorbing regions of a surface (↪Sec. 36.1.1.1) and the media before and after them are not shown.
Via the context menu of the preview you can open an dialog (↪Fig. 27) for defining both the shown plane and the coloring.

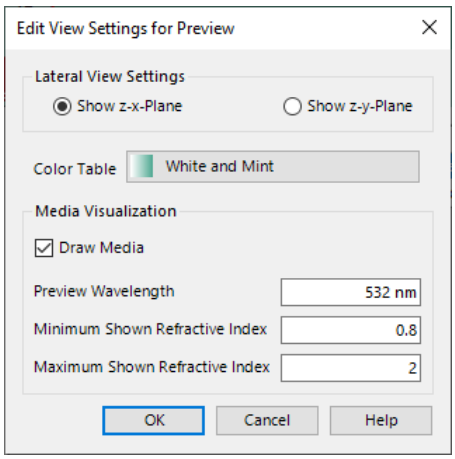


Figure 27. *The edit dialog to set up the view settings.*

ITEM	DESCRIPTION
Show z-x-Plane / Show z-y-Plane	This option allows you to choose whether you want to see a z-x-intersection (*Show z-x-plane*) or a z-y-intersection (*Show z-y-Plane*). This option is disabled for 1D-periodic stacks.
Color Table	The color table used for the preview. You can select any color table from the *Customized Color Tables Menu* (↪Sec. 11.2.4.1).
Draw Media	If you uncheck this option no media are drawn at all, but only the height profiles of the surfaces.
Preview Wavelength	The wavelength used for the calculation of the refractive indices. If this dialog is shown from within a grating component (↪Sec. 65), the default preview wavelength is the preview wavelength set directly in the grating component.
Minimum Shown Refractive Index	Defines the minimum refractive index. Refractive indices less or equal this value use the start color of the color table.
Maximum Shown Refractive Index	Defines the maximum refractive index. Refractive indices greater or equal this value use the end color of the color table.

5.16 3D View

The 3D view shows a *geometry* as seen with a virtual camera. The geometry can be any sequence of surfaces, thus a single surface (↪Sec. 36), a Real Component (↪Part IX), an Optical Stack (↪Sec. 40) or a complete Optical Setup (↪Sec. 44) where light sources, ideal components and detectors are indicated by a single plane surface. For each surface the size, the height profile and the Surface Layout (↪Sec. 41) are shown, but no coatings or materials.
This technology is also the foundation for the 3D Ray Distribution View (↪Sec. 17.1).
The 3D view window (↪Fig. 28) can usually be displayed by a button.

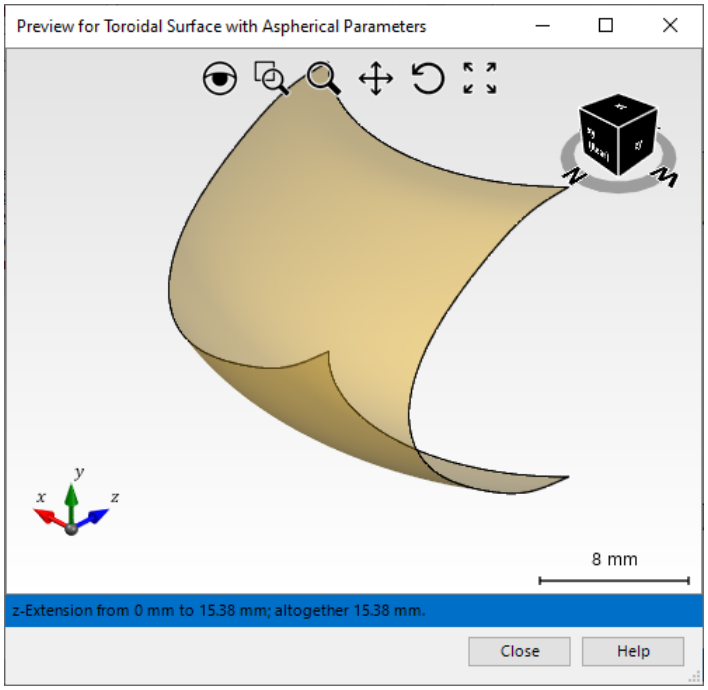


Figure 28. *3D view of a surface with tool bar (top middle), view cube (top right), Global Coordinate System (bottom left), simple scale (bottom right) and z-extension information (bottom).*

The position and orientation of the virtual camera that captures the 3D scene can be controlled via mouse,

keyboard, and touchscreen. By default the orientation of the virtual camera is as shown in Fig. 28. In the upper part of the view there is a *Tool Bar* with 6 buttons which define the *mouse mode*, i. e. how the view behaves if you left click into the view and move the mouse while keeping the left mouse button pressed.

ITEM	DESCRIPTION
Magnifying Glass	Always shows a magnifying glass zooming into the area around the current mouse position. In this mode, a mouse click has no effect.
Zoom Window	This button allows you to define a Zoom Window. If you release the left mouse button it is zoomed into this region.
Zoom	As long as you keep the left mouse button pressed, moving the mouse up zooms into the view and moving the mouse down zooms out.
Pan	Allows you to move the shown object within the view.
Rotate	Allows you to rotate the shown object.
Zoom Fit	If this button is clicked, the object is zoomed and moved so that it is shown completely and as large as possible. Afterwards no mouse mode is selected.

There is a *View Cube* in the upper left corner. If you click on a face, edge, or corner of this cube, the corresponding orientation is used. Clicking on the “ring” and keeping the left mouse button pressed allows you to rotate around the z-axis by moving the mouse.
In the lower left corner of the window there is a 3D icon that permanently shows the current axis directions of the *Global Coordinate System* of the geometry.
For a single surface, information about the z-extension of the surface is shown on the bottom of this control.

ITEM	DESCRIPTION
Left mouse button	Behavior defined by the buttons described above.
Ctrl + **Left mouse button**	Pan.
Shift + **Left mouse button**	Zoom in/out.
Mouse wheel	Coarse zooming in/out.
Ctrl + +	Zoom in.
Ctrl + -	Zoom out.
→, ↑, ←, ↓	Rotate right, up, left and down by 2.5° each.
Ctrl + F	Zoom scene to fit perfectly in the 3D view.

By right-clicking into the view a context menu with the following entries will open.

ITEM	DESCRIPTION
Select Elements to Show	ONLY AVAILABLE FOR OPTICAL SETUPS Opens a dialog where you can select which Optical Setup Elements shall be shown. ↪Sec. 5.16.1
View Settings	Opens a dialog where you can adjust the view to your liking. You can preset these settings for all future views in the Global Options dialog (↪Sec. 6.3).
Show as Separate Document	Shows the current geometry in a separate document window for comparing or storing 3D views. The resulting document behaves nearly identically like a "normal" 3D view, only that there instead of the menu item *Show as Separate Document*, there is the ribbon item Windows > Duplicate Window.
Export to IGES / Export to STL	Exports the 3D scene to a IGES / STL file after you have specified a path and name for it. Note that the scene is exported "as is", for example the outer planes are included in the file if they are visible within the scene. Furthermore, the *Accuracy Factor* of the view settings (↪Sec. 5.16.2.2) also influences the data in the resulting file. (If a Ray Distribution 3D is shown in the 3D view, rays are not exported into STL.) If there are exactly two surfaces connected by an envelope, you are asked whether you want to weld these three meshes to a single mesh representing a solid body. Some other programs require such meshes to work correctly.

5.16.1 Select Elements to Show

For the 3D visualization of systems VirtualLab Fusion enables the user to select the Optical Setup Elements which shall be shown. Fig. 29 shows the edit dialog of the corresponding configuration tool.

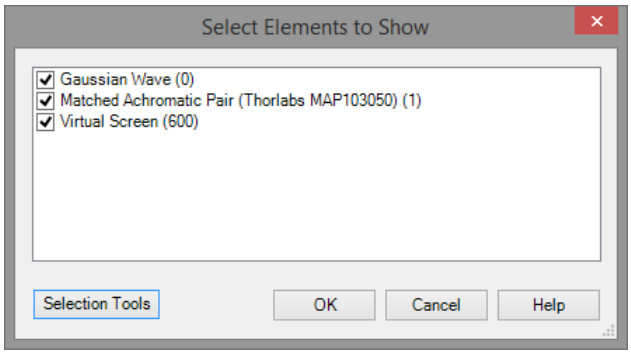


Figure 29. *The dialog to select the elements which shall be shown.*

The upper part of the edit dialog (↪Fig. 29) shows all elements which are available. The user can select individually which component shall be shown or not (↪Sec. 5.9).
The *Selection Tools* button offers the following four selection tools.

ITEM	DESCRIPTION
Select All	Selects all elements.
Unselect All	Unselects all elements.
Unselect Detectors and Source	Only Real and Ideal Components are selected.
Unselect Identity Operators and Coordinate Breaks	Elements are unselected which have no optical functionality but only aid in correctly setting up the Optical Setup.

5.16.2 View Settings

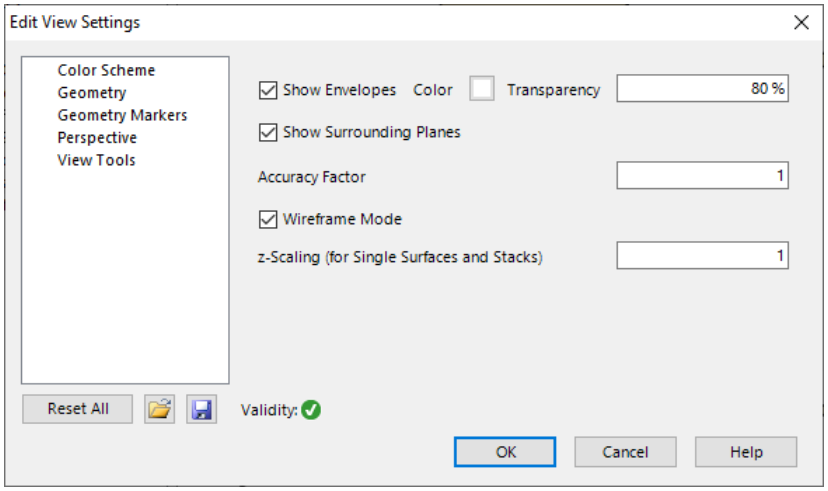


Figure 30. *The dialog to edit the view settings of the 3D view.*

This dialog (↪Fig. 30) offer various options to adjust the 3D view. In the lower left corner there are the following controls.

ITEM	DESCRIPTION
Reset All	Resets all options to the values defined in the Global Options dialog (↪Sec. 6.3). In the Global Options dialog itself, you then can reset to the initial defaults.
	With this button you can load view settings saved with the  button.
	With this button you can save the current view settings. In this way you can e. g. use different view settings for different application scenarios.
Validity	A validity indicator (↪Sec. 5.11) shows warnings if one feature disables another feature. For example, rulers will not be shown if perspective distortion is present because then the size of a surface changes with its distance from the virtual camera.

The actual view settings are grouped on the several pages which are described in the following subsections. (The page *Rays* is only used for the Ray Distribution View (↪Sec. 17) and thus explained in Sec. 17.1.3.)

5.16.2.1 Color Scheme

Various options to adjust the color of the background and of the surfaces.

ITEM	DESCRIPTION
Color Scheme	Primarily, this setting defines the brightness of the view background. But it also influences the color of the view tools (↪Sec. 5.16.2.5) and of the surfaces when they are *Uncolored*. You can select from *Bright*, *Medium* and *Dark*.
Background Color Gradient	If you select this option, the background is not shown with a solid color, but has a gradient to a slightly more dark color.
Surface Colors	There are two color schemes for the surfaces. • ***Colored***: The surfaces of a real component are all drawn with the same color which alternates between yellow and orange between subsequent components. Light sources are always drawn in green, ideal components in light blue, and detectors in red, respectively. Consequently, single surfaces or components are always drawn yellow. • ***Uncolored***: All surfaces are either drawn in dark gray (if *Color Scheme* is either *Bright* or *Medium*) or in light gray (for the *Dark Color Scheme*). Absorbing areas between the inner definition areas[1] of periodic surfaces are always drawn in dark gray.
Transparent Surfaces	If checked, the surfaces are shown semi-transparent.

5.16.2.2 Geometry

Options to define which and how triangle meshes are generated for the display of the geometry.

ITEM	DESCRIPTION
Show Envelopes	Toggles the visibility of the envelopes, meshes linking the borders of two consecutive surfaces within a component. There are no envelopes if the medium between the two surfaces is not solid. This feature has no effect for single surfaces or components consisting only of a single surface. If this option is checked, *Color* and *Transparency* of the envelopes can be set.
Show Surrounding Planes	All surfaces shown in the 3D scene will be displayed with their defined (outer) definition areas[1] (drawn in black if they are absorbing – otherwise the same colors as for surfaces are used). You can think of the apertures as infinitely expanded in x- and y-direction, however, they are cut to a proper size in this view.
Accuracy	The accuracy factor for the sampling of the optical surface(s). The maximum accuracy factor is 15.
Wireframe Mode	By default filled triangles are shown. If you check this option, the borders of the triangles are shown instead. In this way you can directly see the triangles making up the displayed geometry.
z-Scaling	ONLY AVAILABLE FOR SURFACES AND STACKS The heights of the shown surface(s) are scaled by this factor, but for a single surface the displayed z-Extension remains unchanged. If the z-Scaling is not equal to 1, envelopes, coordinate systems, and labels will not be shown. Then the Global Coordinate System shows the scaling factor.

[1] See Sec. 36.1.1 for details on definition areas.

5.16.2.3 Geometry Markers

Options to add additional markers to the shown geometry, i. e. they are moved and scaled together with the geometry.

ITEM	DESCRIPTION
Coordinate Systems	If checked, a coordinate system will indicate the position and orientation of each surface. You can scale them by the given factor.
Labels	If checked, for surfaces the name of the surface is shown. Else the names of the component(s) are shown next to their respective first surface. The font colors resemble the color with which the corresponding component is shown.
Origin	If checked, a ball symbol is drawn at the origin of the Internal Coordinate System (↪Sec. 44.9.1) of the displayed component or at the origin of the Global Coordinate System of the displayed geometry.
Semi-transparent Background	ONLY IF LABELS ARE SHOWN If checked, the labels are placed in a semi-transparent box to distinguish them more easily from the background.
Vary x-y-Position of Labels	ONLY IF LABELS ARE SHOWN By default, all labels are shown on top of the corresponding surface. So they might overlap when you look along the z-axis and the surfaces are all similar in size and orientation. So you can check this option to show them at different lateral angles (in the coordinate system of the corresponding boundary). 4 labels for example will then be shown on the right, top, left, and, bottom, respectively.
Font Size	ONLY IF LABELS ARE SHOWN The font size used for the labels.

5.16.2.4 Perspective

Directly in the 3D view you can change the orientation of the virtual camera in an arbitrary way (↪Sec. 5.16). This page shows the quaternion describing this orientation. However, sometimes you want to have a well-defined orientation, e. g. for screenshots. Then you can check *Pre-Defined Camera Orientation* and define the direction of the z-axis and x-axis of the shown geometry relatively to your screen. Note that when you change the direction of the z-axis, the available directions for the x-axis change, as z- and x-axis are perpendicular.
By default, the camera generates an orthographic projection. This means that two surfaces of the same physical size are always shown with the same size on the screen, even if one is one centimeter away from the camera and the other one meter. If you *Use Perspective Distortion*, surfaces farther away are shown smaller, as in reality. But then rulers will not be shown.

5.16.2.5 View Tools

On this page you can change the visibility of *Global Coordinate System*, *Tool Bar*, and *View Cube* (↪Fig. 28). Furthermore you can show *Rulers*, either a *Simple Scale* in the lower right corner, or *Full-Size* rulers along the left and bottom border. In the latter case a measurement tool becomes available in the toolbar of the 3D view:  . If this tool is active, first click anywhere in the 3D view starts drawing an arrow whose length is then shown. Second click fixes the end point of the arrow, third click starts a new measurement and so on.

5.17 Defining an ABCD Matrix

Simple optical elements can be described by so-called ABCD matrices e. g. $\left(\begin{smallmatrix}1 & d\\ 0 & 1\end{smallmatrix}\right)$ describes a free space propagation of distance d, or $\left(\begin{smallmatrix}1 & 0\\ -1/f & 1\end{smallmatrix}\right)$ describes an infinitely extended thin lens with focal length f. A system consisting of several optical elements is described by the product of their matrices (where the order of multiplication depends on the order in which the elements are passed by the light):

$$\mathcal{M}_{\text{system}} = \mathcal{M}_{n-1} \times \mathcal{M}_{n-2} \times \cdots \times \mathcal{M}_0. \tag{5.1}$$

In this equation $\mathcal{M}_0$ is the first of n elements passed through, $\mathcal{M}_{n-1}$ is the last.
In VirtualLab Fusion ABCD matrices can be used via the Ideal Component “ABCD Matrix Setup” (↪Sec. 74.1) and in the ABCD Law Calculator (↪Sec. 105).
In every case of application first the systems ABCD matrix has to be specified. This is done by the control shown in Fig. 31.

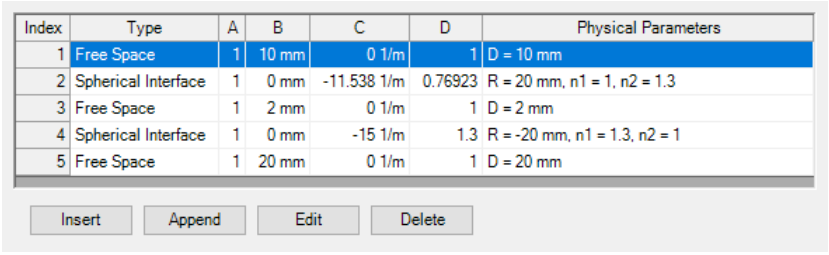


Figure 31. *Control for defining an ABCD matrix.*

In this control several optical elements can be defined by ABCD matrices to describe an optical system. These elements will be arranged in a list where the order corresponds to the order in which the light passes through the elements. The properties of these elements (e. g. the focal length of a lens) have to be entered and then the ABCD matrix of the element combination (this is $\mathcal{M}_{\text{system}}$ in Eq. (5.1)) is calculated automatically. The upper part of the control shows the list, where the top entry represents the first element which is entered by the light, the bottom entry is the one where the light leaves the system. The buttons at the bottom of the control are used to edit that list.
The meaning and the functions of the control’s buttons are the following:

ITEM	DESCRIPTION
Insert	Inserts a new element before the marked entry (↪Sec. 5.17.1).
Append	Appends a new element at the end of the table (↪Sec. 5.17.1).
Edit	Allows you to edit the marked element by opening the corresponding edit dialog.
Delete	Deletes the marked elements. The marking of more than one entry is possible.

You can reorder the elements by clicking on the *Index* cell of a certain row and dragging it to a new position. Double clicking on a certain row opens the corresponding edit dialog. You can mark multiple consecutive rows and delete them using the Del-key.

5.17.1 Inserting and Appending of Optical Elements

The element to be inserted or appended will be chosen by the dialog shown in Fig. 32, which will appear if the corresponding button (↪Fig. 31) is clicked.

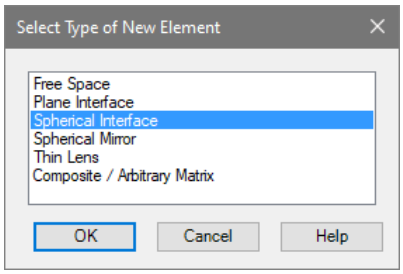


Figure 32. *Dialog for selecting an optical element to be included in the ABCD matrix.*

After selecting the desired element entry, followed by clicking *Ok* or, alternatively, just double clicking on the elements name, another modal dialog will appear, where the parameters of that element have to be entered.

5.17.2 Editing the Parameters of the Optical Elements

The parameters of the elements will be entered after choosing one in the dialog shown in Fig. 32 or can be changed if the button *Edit* in the control for creating an ABCD matrix system (Fig. 31) is pressed. Then a dialog will appear, where the needed parameters have to be entered and the corresponding ABCD matrix for that element ($\mathcal{M}_i, i = 0 \ldots (n-1)$, in Eq. (5.1)) will be calculated.

5.17.2.1 Editing a Free Space Propagation Element

Here the geometrical distance has to be entered. The dialog (see Fig. 33) shows the automatically calculated ABCD matrix in its lower part.

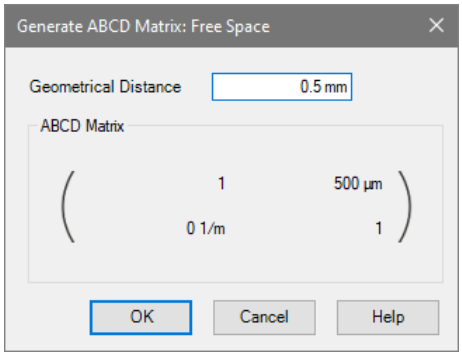


Figure 33. *Dialog for editing a free space element for ABCD matrix propagation simulation.*

5.17.2.2 Editing a Plane Interface Element

Here the real parts of the refractive indices of the preceding and the subsequent medium have to be entered. The dialog (↪Fig. 34) shows the automatically calculated ABCD matrix in its lower part.

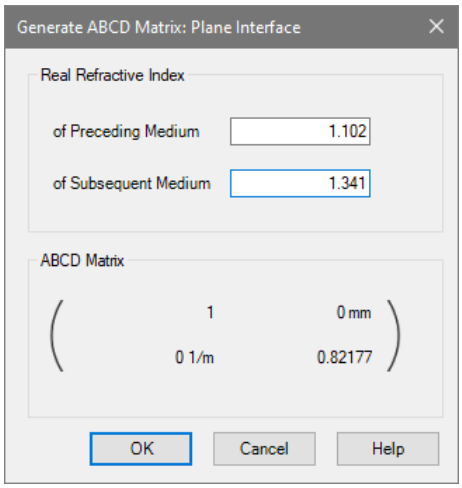


Figure 34. *Dialog for editing a plane interface element for ABCD matrix propagation simulation.*

5.17.2.3 Editing a Spherical Interface Element

Here the radius of the curved surface as well as the real parts of the refractive indices of the preceding and the subsequent medium have to be entered. A positive sign for the radius means that the center of curvature is on the side of the subsequent medium. The dialog (↪Fig. 35) shows the automatically calculated ABCD matrix in its lower part.

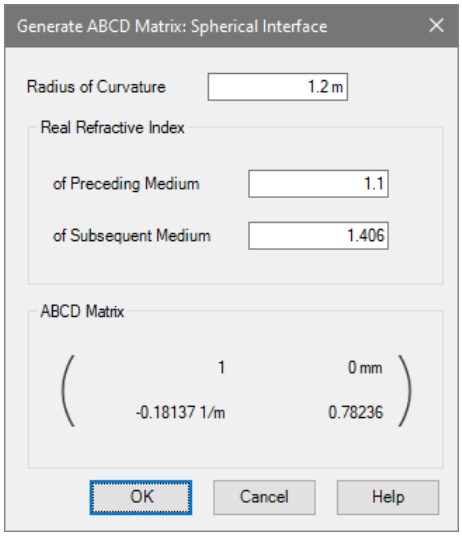


Figure 35. *Dialog for editing a spherical interface element for ABCD matrix propagation simulation.*

5.17.2.4 Editing a Spherical Mirror

Here the *Radius of Curvature* of a spherical mirror has to be entered. A negative radius of curvature defines a concave mirror and a positive radius defines a convex one.
The dialog (↪Fig. 36) shows the automatically calculated ABCD matrix in its lower part.

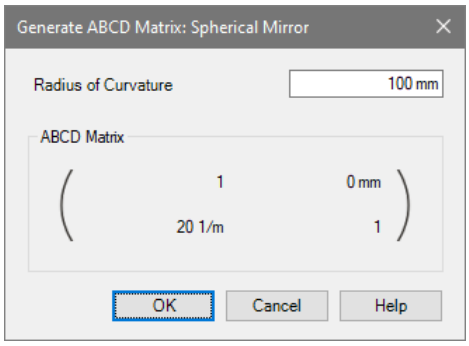


Figure 36. *Dialog for editing a spherical mirror for ABCD matrix propagation simulation.*

5.17.2.5 Editing a Thin Lens Element

Here the *Focal Length* of an infinitely extended thin lens has to be entered. A negative focal length defines a concave lens and a positive focal length defines a convex one.
The dialog (↪Fig. 37) shows the automatically calculated ABCD matrix in its lower part.

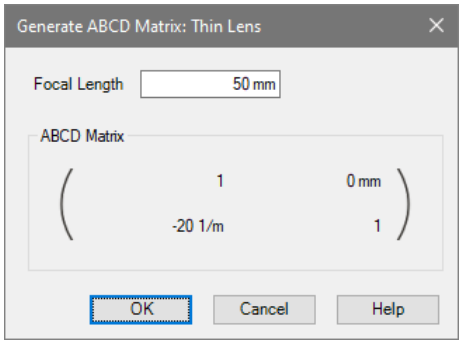


Figure 37. *Dialog for editing a thin lens element for ABCD matrix propagation simulation.*

5.17.2.6 Editing the Matrix of an Arbitrary or Composite Element

Here you can define an arbitrary matrix or an already known matrix of a more complex system, by entering the elements A, B, C and D directly. This is done by the dialog shown in Fig. 38.

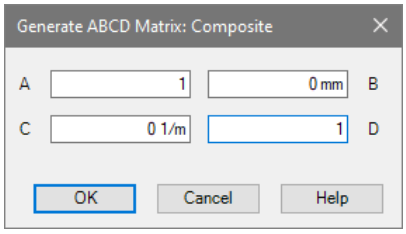


Figure 38. *Dialog for editing an arbitrary matrix for ABCD matrix propagation simulation.*

6 Global Options Dialog

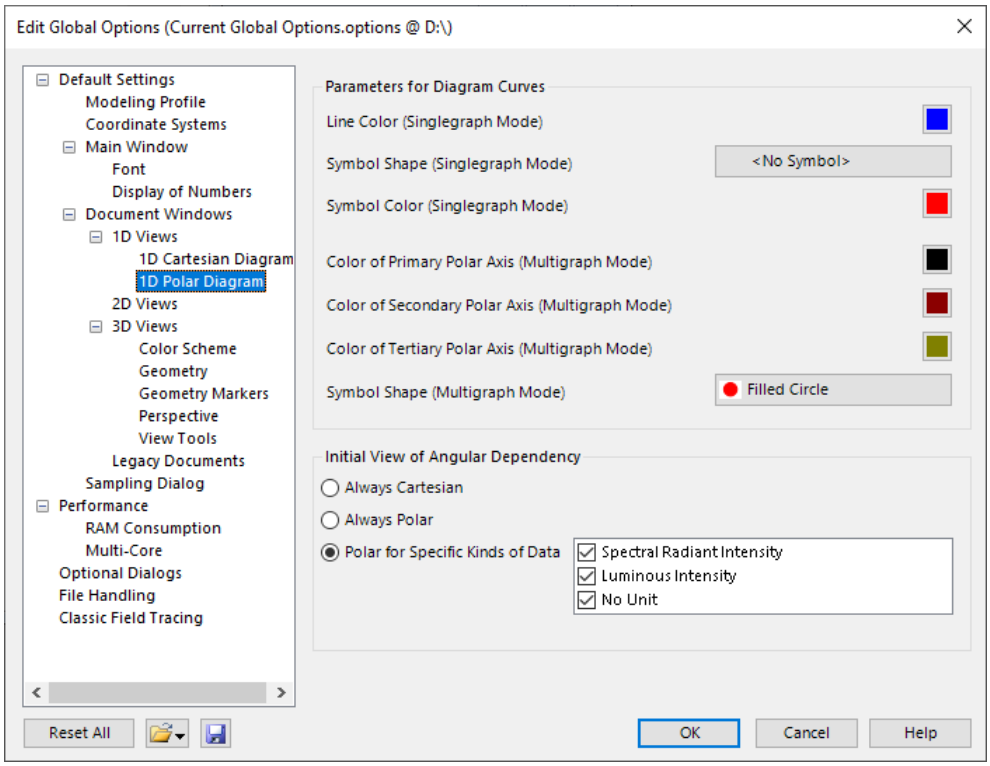


Figure 39. *Global Options dialog.*

Global program options can be edited by the dialog shown in Fig. 39.
The options are grouped in several categories and subcategories which are shown in the tree view at the left of the dialog. The subcategories with their specific settings are explained in the following subsections. The *Default Settings* usually can be altered in the corresponding specific edit dialogs and Property Browser tabs.
All settings but the file paths in the *File Handling* category can be reset, loaded, and saved with the following controls:

ITEM	DESCRIPTION
Reset All	Resets all global program options to their initial values. Also the file path were the Global Options are stores is reset.
Load Global Options	With this button you can load another Global Options file saved with the button. The 5 most recently used files are available in a shortlist.
Save Global Options	With this button you can save a copy of the current Global Options to another file path. In this way you can give your Global Options to colleagues or LightTrans in case of support requests.

The currently used Global Options file is also given in the title of the dialog and in the lower left corner of the main window.
Many of these Global Options influence the results of simulations, usually they represent a trade-off between accuracy and computational effort. Thus, in extreme cases you may obtain completely wrong results or no results at all because of too high computational effort. These settings are marked with [S] in the following subsections. And if you changed such settings, a "*Changed Simulation Results*" is shown also in the lower left part of the main window. Last but not least there you also see a short summary of the current multi-core settings (↪Sec. 6.15).

6.1 Default Settings > Modeling Profile[S]

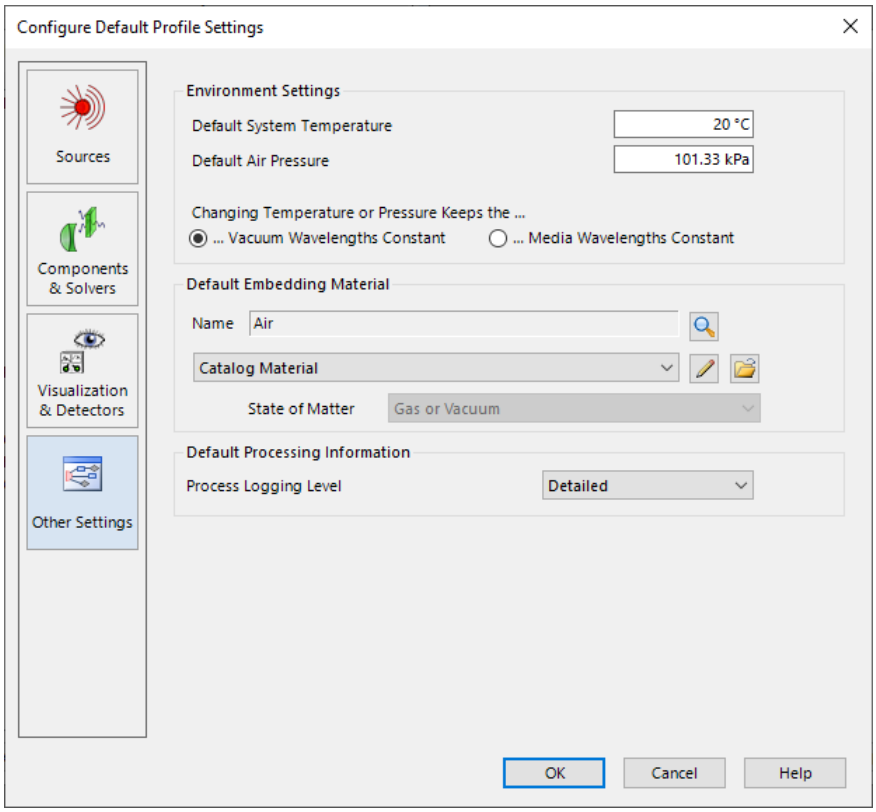


Figure 40. *The dialog to configure the default profile settings.*

In this category you can open a separate dialog (↪Fig. 40) where you can edit some default settings for the profile editor (↪Sec. 44.4). This dialog has the following tabs.

6.1.1 Sources

Here you can set the default *Wavelength* which is used among others as default for the sources within an Optical Setup, but also for the generators in the Sources and the Functions ribbon.

6.1.2 Components & Solvers

The settings on this tab page are explained in Sec. 44.5.1. They affect only real components (↪Part IX).

6.1.3 Visualization & Detectors

The *Evaluation & View* sub-tab contains the following controls.

ITEM	DESCRIPTION
Evaluated Field Components	Here you can set which vectorial components of a field a detector evaluates by default. You can choose between E_x, E_y, and / or E_z, whereas at least one component must be selected. This setting affects the Universal Detector (↪Sec. 75.4), the Camera Detector (↪Sec. 75.5.2), the PSF & MTF detector (↪Sec. 75.5.3), and the Power detector (↪Sec. 75.6.4).
Color Table	Here you can preset the Color Table used by the Universal Detector (↪Sec. 75.4), the Camera Detector (↪Sec. 75.5.2), the PSF & MTF detector (↪Sec. 75.5.3), and the Raw Data Detector (↪Sec. 75.5.5). For more information about color tables please see Sec. 11.2.4.

The controls on the *Free Space Propagation* sub-tab are explained in Sec. 44.5.1. They affect only detectors (↪Part XI).

6.1.4 Other Settings

ITEM	DESCRIPTION
Default System Temperature	The temperature which is used as default for all Optical Setups. Furthermore, it is used for all refractive index calculations which are independent of an Optical Setup, e. g. in the Fresnel calculator.
Default Air Pressure	The air pressure which is used as default for all Optical Setups. Furthermore, it is used for all refractive index calculations which are independent of an Optical Setup (e. g. in the Fresnel calculator) if air is involved as a surrounding medium.
Changing Temperature or Pressure Keeps the Vacuum Wavelengths Constant.	Changing the temperature of a medium will change its refractive index. A changed pressure alters the refractive index of air too. A changed medium wavelength will be the consequence. If this option is selected, the change of all media wavelengths in the system's light sources is accepted by the user.
Changing Temperature or Pressure Keeps the Media Wavelengths Constant.	Changing the temperature of a medium will change its refractive index. A changed pressure alters the refractive index of air too. A changed medium wavelength would be the consequence. If this option is selected on the other hand, VirtualLab Fusion will keep the media wavelengths constant by adapting all vacuum wavelengths in all of the system's light sources. **Please note:** This option is mainly supposed to allow a result comparison to simulations in Zemax OpticStudio®.
Default Embedding Material	Sets the material that is used as a default reference for relatively measured real parts of the refractive indices (↪Sec. 39.3). The individual controls are explained in Sec. 34.3.
Process Logging Level	The default logging level for optical simulations (↪Sec. 44.2.4).

6.2 Default Settings > Coordinate Systems

This subcategory has the following settings:

ITEM	DESCRIPTION
Default Definition Type	This option sets the default for defining an orientation for Optical Setup Elements as described in Sec. 44.9.2.3, Sec. 5.6 and Sec. 145.2.1.
Initial Axis Rotation	A so called Sequence of Axis Rotations (Sec. 145.2.4) provides no unambiguous way for defining an orientation. Thus, even the orientation of a coordinate system that is not rotated with respect to its reference coordinate system does not have a unique representation as a sequence of axis rotations. That's why this global option allows to define the value of an axis rotation sequence representing a non-rotation i.e. being in its initial state.
Use Component Coordinate System for Stack Preview	If this option is not checked, the stack preview always shows the stack in its own coordinate system. This means that the plane surface the stack is placed on is always left. This can be confusing if you place a stack on the front side of a component. So if you check this option, always a coordinate system is shown in the stack preview. And when the stack is on the front side of the component, the base surface is shown right and the coordinate system is adapted accordingly. ↪Sec. 40.1.2

6.3 Default Settings > General View Settings

This subcategory has the following settings:

ITEM	DESCRIPTION
Theme for Main Window	With this option you can select a color scheme applied to the elements of the main window (ribbon ↪Sec. 4.2, docking tabs ↪Sec. 4.3, and status bar ↪Sec. 4.4).
Show Notify Icon and Notifications	You can set that the notifications and the notify icon (↪Sec. 4.5) are shown *Always*, *If VirtualLab Inactive* or *Never*. Inactive means that • another application or Windows gets the focus by clicking into it with the Mouse or e. g. via Alt + Tab. • a dialog of VirtualLab Fusion gets opened or • a docking tab of VirtualLab Fusion gets the focus if it is detached from the main window. Note that notifications can also by switched off via Windows. So check also the Windows option if you cannot switch on the notifications with this option.
Display Duration of Tool Tips	The display duration of most tool tips, especially the ones in the ribbon (↪Sec. 4.2). Several other tool tips with much text have their own longer durations so that you can easily read them completely.

6.4 Default Settings > General View Settings > Font

You can set up the font which is used for all dialogs and document views except:

- Title bars
- The flowchart in the Optical Setup View (↪Sec. 44.1).
- The source code editor (↪Sec. 7.3.1) and the module view (↪Sec. 7.2) which use a monospaced font.

ITEM	DESCRIPTION
Use Recommended Font	If you click this option, the Global Font is set to “Segoe UI” and a font size suitable for the DPI scaling set up in the Windows system configuration.
Configure Font Individually	If you click *Change …* you can choose any suitable font installed on your system. You can also *Adjust Font Size* more precisely with the corresponding text box. Note that with these settings dialogs and views in VirtualLab Fusion may look ugly or even become unusable.
Font Size of Axis Labels	The default font size for the axis labels in 1D and 2D diagrams.
Font Size of Diagram Titles	The default font size for the subset titles in 2D diagrams.

6.5 Default Settings > General View Settings > Display of Numbers

This subcategory has the following settings:

ITEM	DESCRIPTION
Number of Significant Digits	Default number of significant digits for displaying floating point numbers. (Do not confuse significant with total digits: 847.34 µm formatted using two significant digits results in 850 µm.)
Use Special Number of Digits for Color Legends	If checked, a special number of digits can be set which will be used for the labels of color legends only. The expected precision of the color legend may be less than that of all other numerical strings, so a smaller number of digits may be defined here.
Use Indicator for Hidden Digits in Text Boxes	If checked, a small indicator shows if a physical value box (↪Sec. 5.1) or a positioning control (↪Sec. 44.9.2.4) doesn't display all available digits. If the mouse is moved over the indicator, a tooltip shows the number in full precision.
Default Length Unit	You can define a default length unit which is used in the following cases: • Interpret length values which were entered by the user without a unit. • Formatting of diagram axes. If they use the *Engineering* format, also units may be used which differ by a factor of 1000^n from the default unit. • Formatting of very large or very small values (including zero) for which no other length unit can be used in a meaningful way. • Export into text files. Usually just the plain number (in multiples of the default unit) is exported and the used unit is noted separately. This eases using the data in other programs which cannot handle measured quantities.
Format of Complex Numbers	Complex numbers can be formatted in different ways: • *Real Part / Imaginary Part*: {real part} + i{imaginary part} • *Amplitude / Phase*: {amplitude} · exp({phase} · i) • *MATLAB*, a more compact variant of the *Real Part / Imaginary Part* format: {real part}+{imaginary part}i • *PTF*, a format used for the PTF export (↪Sec. 121.2): ({real part}, {imaginary part}) This setting influences for example the appearance of Rayleigh coefficients output by the Grating Order Analyzer (↪Sec. 85) into the *Detector Results* tab (↪Sec. 4.3).
Format of Physical Values	In principal, large or small physical values on axes can be displayed in three different ways (↪Fig. 41): • *Engineering*: SI prefixes are used to make the actual numbers smaller. • *Scientific*: Powers of ten are used to make the actual numbers smaller. • *Standard*: The numbers are kept as they are. For a specific document window you can always change this via its Property Browser. However, you can set the default value here. In *Automatic* mode the suitable default mode is determined automatically, depending among others on the used unit (there are no k° [kilodegrees]).

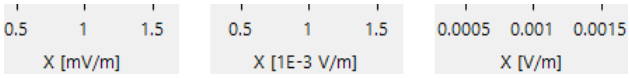


Figure 41. *Example of the different formats of physical values. From left to right:* Engineering, Scientific, Standard.

6.6 Default Settings > General View Settings > Source Code Editor

The settings in this sub-category apply to the source code editor (↪Sec. 7.1).

ITEM	DESCRIPTION
Theme for Source Code Editor	With this option you can select the color scheme of the source code editor.
Autocomplete Braces and Quotation Marks	When you enter an opening brace ({ [or quotation mark " ', the source code by default automatically inserts the corresponding closing character ' "] }). In case you are used to adding the closing character manually, you can switch off this behavior here. Note that changing this setting only becomes effective for new module views.
Show Minimap	Whether you want to see a minimap (11 in Fig. 44) in the source code editor.

6.7 Default Settings > Document Windows

This subcategory has the following settings:

ITEM	DESCRIPTION
Initial Window Size	Allows you to define the initial window size in pixels for all newly created *Result Windows*. (↪Sec. 4.1.1)
Use Transparent Background for Copy to Clipboard	If checked the gray background of the view is replaced by a transparent color when Copy View to Clipboard operation (↪Sec. 11.6) is executed. This setting doesn't affect Harmonic Fields and Harmonic Fields Set as these documents allow you to configure in detail what is how copied to the clipboard.
Show Legend	Sets whether or not a color legend is visible per default.
Color System	The color system (↪Sec. 6.7.1) used for real color views of Chromatic Fields Sets (↪Sec. 14.2).
Maximum Number of Table Cells	Maximum number of table cells that are displayed in the *Table* panel of a Data Array's view. If this value would be exceeded, no table is shown unless the user explicitly states to do so. This setting also influences the automatic resizing of table cells in certain tables: Only this number of cells is resized to the actual content, all other cells use a good estimate. This can increase performance significantly.
Maximum Number of Rays that Allow Marker Snapping	If the number of rays in a shown ray distribution exceeds this limit, no marker snapping (↪Sec. 11.3.2) will be available. The limit may be set to very high values but then one possibly has to wait for a long time until snapping is available.
Open Non-Numerical Data Arrays in Expert Mode	If checked, any non-numerical data array (↪Sec. 13.1) is opened with activated *Expert Mode* (↪Sec. 24.1.4) by default. However, this is just an initialization setting. If the expert mode is disabled for a view before saving the object to disk, it will be re-opened with disabled expert mode too.
Hide Phase Artifacts	If checked, phase artifacts below the *Initial Threshold* are hidden by default. ↪Sec. 11.8.
Initial Threshold	This is the default artifacts threshold. For a single document it can be changed in the view panel of the property browser. ↪Sec. 11.8.

6.7.1 Color System

In order to display the color of mono- or polychromatic light approximately natural, the wavelength or the spectrum of a field has to be converted to RGB values in a defined way. This algorithm uses a color space (RGB working space) which can be chosen in the Global Options dialog. The choice is valid for all real color views created afterwards.

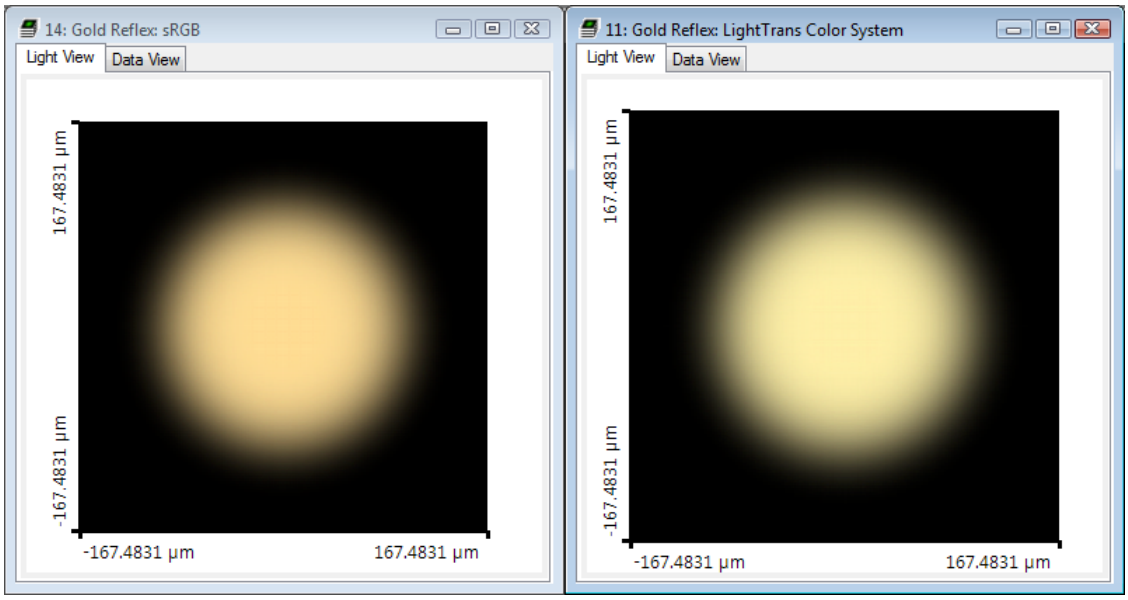


Figure 42. *Example for different color systems: Reflex at gold surface. Left: displayed with* sRGB*, right:* LightTrans Color System*.*

Real color views that already existed before will keep the color system of its creation point in time. If you want to update an existing view with a new color system, you have to duplicate it via Windows > Duplicate Document after changing this option.
The available non-common color system options are:

ITEM	DESCRIPTION
Wide Gamut (Illuminant C)	Common Wide Gamut system, but with Illuminant C as white point instead of D50.
Kodak Pro Photo (Illuminant C)	Common Pro Photo system, but with Illuminant C instead of D50.
From Monitor	Uses the ColorProfile.FromScreen() method by Aurigma GraphicsMill to get the color profile currently associated with the monitor.
XYZ	Color system that identifies R, G, and B with the normalized chromaticities X, Y, and Z respectively.
LightTrans Color System	Color system that was developed by LightTrans in order to fulfill the special needs of displaying light on a computer monitor as naturally as possible.

The specifications (chromaticities of R, G, B, and the white point) of all systems available in VirtualLab Fusion:

COLOR SYSTEM	RED	GREEN	BLUE	WHITE
NTSC	(0.66887, 0.33092)[1]	(0.210,0.710)	(0.14,0.08)	(0.31006,0.31616)
sRGB	(0.640, 0.330)	(0.300, 0.600)	(0.150, 0.060)	(0.3127, 0.3291)
CIE	(0.7355, 0.2645)	(0.2658, 0.7243)	(0.1669, 0.0085)	(0.3333, 0.3333)
SMPTE	(0.630, 0.340)	(0.310, 0.595)	(0.155, 0.070)	(0.3127, 0.3291)
P22 in KDS VS19	(0.625, 0.340)	(0.285, 0.605)	(0.150, 0.065)	(0.281, 0.311)
Adobe RGB	(0.640, 0.330)	(0.210, 0.710)	(0.15, 0.06)	(0.3127, 0.3290)
Wide Gamut (Illuminant C)	(0.73469, 0.26531)[2]	(0.11416, 0.82621)[3]	(0.15664, 0.01770)[4]	(0.31006, 0.31616)
Kodak Pro Photo (Illuminant C)	(0.7347, 0.2653)	(0.1596, 0.8404)	(0.0366, 0.0001)	(0.31006, 0.31616)
From Monitor[5]	(N/A)	(N/A)	(N/A)	(N/A)
XYZ	(1,0)	(0,1)	(0,0)	(0.33333, 0.33333)
LightTrans Color System	(0.73469, 0.26531)[6]	(0.15472,0.80586)[7]	(0.12412, 0.05780)[8]	(0.3127, 0.3291)[9]

6.8 Default Settings > Document Windows > 1D Views

This subcategory allows you to set the following parameters for diagram curves:

ITEM	DESCRIPTION
Line Thickness	The default line thickness for curves in x-y-diagrams.
Symbol Scaling Factor	The default scaling factor for symbols of data points in x-y-diagrams.
Use Smoothed Graphics	If checked, curves in x-y-diagrams will be smoothed per default. Usually, this may improve the diagram. But if a stepped line is shown, deactivating this property may yield a better result. Important: This smoothing is done on pixel level. This pixel smoothing is not to be confused with the smoothing interpolation methods described in Sec. 11.2.2!
Initial Color for Undefined Values in 1D Views	The color to be used for visualizing undefined values in diagrams initially. It can be changed for each individual view.
Opacity	Opacity of the color to be used for visualizing undefined values in diagrams.
Marker Line Thickness	The line thickness (in pixels) to be used for markers (↔Sec. 11.3) in 1D diagrams.

1 Adapted to fit to 611 nm
2 Adapted to fit to 700 nm
3 Adapted to fit to 525 nm
4 Adapted to fit to 450 nm
5 The data of the currently used color profile are determined during runtime.
6 Corresponds to 700 nm
7 Corresponds to 530 nm
8 Corresponds to 470 nm
9 Corresponds to illuminant D65

6.8.1 Default Settings > Document Windows > 1D Views > 1D Cartesian Diagram

ITEM	DESCRIPTION
Line Color (Singlegraph Mode)	The default color for curves in x-y-diagrams if not in Multigraph Mode.
Symbol Shape (Singlegraph Mode)	The default symbol shape for data points in x-y-diagrams if not in Multigraph Mode.
Symbol Color (Singlegraph Mode)	The default symbol color for data points in x-y-diagrams if not in Multigraph Mode.
Color of Left-Hand y-Axis (Multigraph Mode)	The default axis color for the left-hand y-axis of 1D Data Arrays in Multigraph Mode.
Color of Right-Hand y-Axis (Multigraph Mode)	The default axis color for the right-hand y-axis of 1D Data Arrays in Multigraph Mode.
Symbol Shape (Multigraph Mode)	The default symbol shape for data points in x-y-diagrams. This default will be used in Multigraph Mode as long as the different subsets can be distinguished by different colors. If all colors have been used, the symbol will be changed for the additional subset curves.

6.8.2 Default Settings > Document Windows > 1D Views > 1D Polar Diagram

ITEM	DESCRIPTION
Line Color (Singlegraph Mode)	The default color for curves in polar diagrams if not in Multigraph Mode.
Symbol Shape (Singlegraph Mode)	The default symbol shape for data points in polar diagrams if not in Multigraph Mode.
Symbol Color (Singlegraph Mode)	The default symbol color for data points in polar diagrams if not in Multigraph Mode.
Color of Primary Polar Axis (Multigraph Mode)	The default axis color for the primary polar axis of 1D Data Arrays in Multigraph Mode.
Color of Secondary Polar Axis (Multigraph Mode)	The default axis color for the secondary polar axis of 1D Data Arrays in Multigraph Mode.
Color of Tertiary Polar Axis (Multigraph Mode)	The default axis color for the tertiary polar axis of 1D Data Arrays in Multigraph Mode.
Symbol Shape (Multigraph Mode)	The default symbol shape for data points in polar diagrams. This default will be used in Multigraph Mode as long as the different subsets can be distinguished by different colors. If all colors have been used, the symbol will be changed for the additional subset curves.
Initial View of Angular Dependency > Always Cartesian	If checked, diagrams with angular dependency will never be initialized as polar.
Initial View of Angular Dependency > Always Polar	If checked, diagrams with angular dependency will always be initialized as polar.

Initial View of Angular Dependency > Polar for Specific Kinds of Data	If checked, diagrams with angular dependency will be initialized as polar if at least one of the contained subsets is of one of the checked physical properties in the list.

6.9 Default Settings > Document Windows > 2D Views

The button *Manage Color Tables* opens a dialog where you can choose which color tables are available and create new ones (↪Sec. 11.2.4.1).
Furthermore you can set the *Default Color Tables* with which the most false color views are initialized. That are e. g. the data array view (↪Sec. 13.4) and the medium preview (↪Sec. 38.2).
For complex data, each field quantity (↪Sec. 11.1) can be initialized with an individual color table.
Furthermore there are the following view options:

ITEM	DESCRIPTION
Initial Color for Undefined Values in 2D Views	The color to be used for visualizing undefined values in diagrams initially. It can be changed for each individual view.
Marker Line Thickness	The line thickness (in pixels) to be used for markers (↪Sec. 11.3) in 2D diagrams.

For more information, especially about editing color tables, please see Sec. 11.2.4.

6.10 Default Settings > Document Windows > 3D Views

Allows you to preset the view settings of the 3D view (↪Sec. 5.16). The sub-categories are the same as for the actual view settings dialog and are thus described in Sec. 5.16.2.1 – Sec. 5.16.2.5.

6.11 Default Settings > Document Windows > Legacy Documents

ITEM	DESCRIPTION
Automatic Resampling in Array - Array Operations	Determines whether fields are resampled automatically during addition, subtraction, multiplication, division, and convolution of fields. ↪Sec. 22.1.1.
Use Embedding for Field ×Transmission Operators	This option determines whether or not to embed the result of a multiplication of a field with a non-periodic transmission into a frame of zeros.
Use Standard Scaling Initially	For performance reasons, the initial scaling mode (↪Sec. 11.2.5) can be set to standard scaling, i. e. for newly created fields no minimum and maximum determination is done. It is still possible to switch to automatic scaling.
Show Polarization	Sets whether or not polarization shall be visualized in the Harmonic Field View per default.
Polarization Display Mode	The display mode for polarization visualization, as described in Sec. 12.2.3.
Show Grid	Only available if the display mode is set to *Polarization Ellipses.* Sets whether or not a grid shall be shown which visualizes the ellipse's positions.
Show Arrows	Only available if the display mode is set to *Polarization Ellipses.* Sets whether or not arrows shall indicate the direction of rotation for the ellipses.
Scaling	Only available if the display mode is set to *Polarization Ellipses.* A scaling factor for the ellipses.
Polarization Plane	What plane of polarization shall be visualized?

6.12 Default Settings > Sampling Dialog[S]

This subcategory has the following settings:

ITEM	DESCRIPTION
Sampling Points	The number of sampling points in x- and y-direction, used if these values cannot be determined automatically.
Sampling Distance	Default sampling distance in x- and y-direction, used if these values cannot be determined automatically.
Array Size	Default array size in x- and y-direction for a newly created field, used if these values cannot be determined automatically.
Oversampling Factor	The default oversampling factor used for sources (↪Part VIII), transmissions (↪Sec. 68) and propagation operators (↪Part XIII). The suggested sampling distance will be divided by this value.
Size of Embedding Frame (Sampling Points)	A zeroized frame with the given width (in sampling points) is added to newly generated light distributions, unless specified otherwise in the edit dialog of the light source.
Field Size Factor	The greater this factor the larger the generated field will be. A factor of 1 (default) means the field size VirtualLab Fusion uses normally as automatic setting. Increasing this factor increases the field size. Vice versa, setting this factor to values between 0 and 1 decreases field size.
Relative Edge Width	Newly created harmonic fields or transmissions have a soft edge whose width can be pre-defined by this value (relative to the smaller of the both values of the aperture size).

If you have filled the text boxes for one direction, you can copy the values over to the other direction by double clicking on the text boxes for the other direction. This behavior is also implemented in many other dialogs.

Any two of the three parameter pairs labeled *Sampling Points*, *Sampling Distance*, and *Array Size* are editable at the same time. Which parameters are editable can be chosen by the corresponding check boxes. The unchecked third parameter pair is calculated as the array size is always equal to the product of the number of sampling points and the sampling distance.

6.13 Performance

This subcategory has the following settings:

ITEM	DESCRIPTION
FFT Algorithm	Since VirtualLab Fusion 4.10 the Intel Math Kernel Library is included in VirtualLab Fusion offering better performance for Fast Fourier Transform (FFT) calculations. However, if you want to do your simulations with the previously used *VirtualLab FFT* library you can check this option.
Field Size Truncation Factor for Accelerated Sinc Interpolation[S]	Determines the behavior of the Accelerated Sinc Interpolation operator, which is also used for *Automatic Resampling in Array - Array Operations*. ↪Sec. 13.2.2

6.14 Performance > RAM Consumption

This subcategory has the following settings:

ITEM	DESCRIPTION
Warn Before Exceeding Specified Limits	VirtualLab Fusion allows to check certain performance constraints before a data field is created. If such a constraint is violated it means that the resulting data field might be too large for the computer's RAM. In this case, the user is asked to confirm that such a field should really be created because creating too large fields can freeze your PC for quite a while. With the *Warn Before Exceeding Specified Limits* check box, the user can enable or disable this mechanism completely. The settings *Maximum Number of Sampling Points per Field*, *Maximum Number of Field Set Members*, and *Guaranteed Amount of Remaining Physical Memory* allow to adjust the performance constraints individually.
Maximum Number of Modes	If this option is enabled and a field to be generated would have more than the number of modes specified here, a warning is shown. In case a Harmonic Fields Set is to be generated then you are asked whether this fields set shall really be created.
Guaranteed Amount of Remaining Physical Memory	If this option is enabled, it is ensured that the specified amount of **physical** memory is still free after the creation of a new field. If this would not be the case, a warning dialog (↪Fig. 43) is shown asking you to confirm that the new field should really be created. In this dialog you can also disable further *Guaranteed Amount of Remaining Physical Memory* warnings by checking the *Don't warn again* check box. Note that this value is given in gibibytes.
Switch to less memory intensive algorithms [...] S	The Automatic Propagation Operator (↪Sec. 94.2) can choose less memory intensive (but also less accurate) propagation operators when the resulting field would exceed a certain size. The *Default Value* for this field size is the size of your physical memory minus 4 GiB reserved for the operating system and VirtualLab Fusion. But you can also set a *User-Defined Value* if you want. But note that field sizes exceeding the physical memory can extremely slow down your computer. Additionally this parameter also influences the conversion from non-equidistant field to equidistant field data, e. g. for detector outputs.

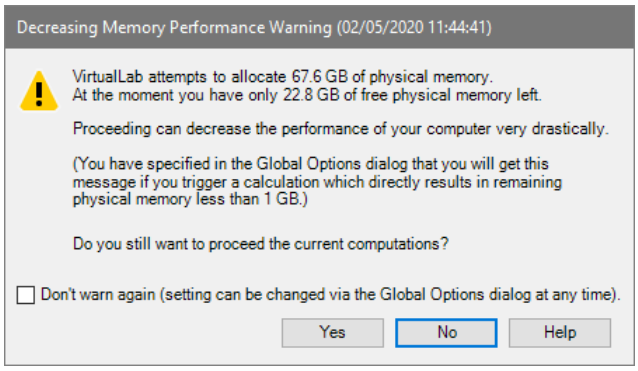


Figure 43. *The warning dialog shown if due to the creation of a new field the used physical memory would exceed the warning level.*

6.15 Performance > Multi-Core

This subcategory has the following settings:

ITEM	DESCRIPTION
Use Multiple Cores	You can enable multi-threading with this option. If enabled, parts of the Fourier Modal Method used for grating simulation always use all cores that are available on the system and cannot be controlled by the value of *Number of Cores To Use*. This setting also influences whether the math library used for the Fourier Modal Method runs in a parallelized version or not. But for this setting to take effect a restart is required.
Number of Cores To Use	If you *Use Multiple Cores*, this number controls how many cores are used for parallel processing for tasks (design, simulation, parameter run). But as there can be parallelized tasks running within parallelized tasks or because of tasks running in the background, VirtualLab Fusion can use more than the set number of cores. You can increase this number if VirtualLab Fusion doesn't use all physical cores. You should decrease this number if VirtualLab Fusion doesn't respond anymore during calculations.
Number of Parallel Iterations for Parameter Run Loop	If you *Use Multiple Cores*, by default the Parameter Run (↪Sec. 45) starts n parallel simulations of the underlying Optical Setup (↪Sec. 44) where n is the *Number of Cores To Use*. Then however for example your RAM consumption might get too high, so you can set a lower number instead. $n = 1$ means that one simulation is done after each other, only the simulation of each Optical Setup runs in parallel. This option can be set globally here – or for each Parameter Run separately via its Property Browser.
Optimize Performance for Very Fast Iterations	There is a performance optimization for parallel execution of short lasting iterations in VirtualLab Fusion. However, it turned out that this optimization then slows down certain more long lasting simulations. Thus if you perform e. g. a parallel Parameter Run with very many short simulations which are unexpectedly slow, you can try to switch on this setting.

6.16 Optional Dialogs

This subcategory has the following settings:

ITEM	DESCRIPTION
Pop up Warning Messages	Warning messages are always printed in the Messages panel. If this option is checked warning messages are additionally shown in a message box.
Pop up Error Messages	Error messages are always printed in the Messages panel. If this option is checked error messages are additionally shown in a message box.
Duplication State for Operations on Data Arrays	These settings are used for manipulations of Numerical Data Arrays as described in Sec. 24.3. If *Operate on Calling Object* is selected, the original data will be manipulated. This will be not the case if *Duplicate* is chosen. *Ask Every Time* means that a dialog will ask whether duplication is desired every time a manipulation is called.
What to Do With the Data in the Temporary Folder After ZAR Unpacking	The unpacked contents of a Zemax ZAR archive will be deleted after closing VirtualLab Fusion. If *Ask For Save* is activated, the dialog described in Sec. 130.4.5 will open every time a ZAR file has been imported, which allows to save the unpacked archive contents before deleting. If *Discard and Delete on Program Closing* is checked on the other hand, the temporary folder containing the unpacked archive will be deleted without further notice.

6.17 File Handling

ITEM	DESCRIPTION
Full Import / Simple and Limited Import	Normally import of Zemax OpticStudio® Lens Files is done using the so-called ZOS-API, i. e. direct access to an installed Zemax OpticStudio®. If Zemax OpticStudio® is not installed or not licensed we fall back on a simple and limited import instead, which directly reads the Lens Files. However, the check whether Zemax OpticStudio® is installed can take quite a while so you can set to always use the simple and limited import without prior initialization of the ZOS-API. Further details can be found in Sec. 130.4.
Path for 'Zemax OpticStudio® ' User Data	A path needed for import of Zemax OpticStudio® lens files. The path can be changed with the ...-button. If you want to access the path directly you can click on the path label.
Path for User Settings	Path where among others user-defined catalogs are saved. It can be changed with the ...-button. If you want to access the path directly, e. g. for backup, you can click on the path label.
Path for Temporary Files	Path where temporary files are stored. The path can be changed with the ...-button. If you want to access the path directly, e. g. for cleanup, you can click on the path label.
Automatic Saving	Whether certain documents will be saved automatically after the specified time interval to avoid data loss. Only affects Parameter Runs, Parametric Optimizations, and optiSLang Optimizations which have already been saved at least once. This default can be overwritten via the Property Browser (↪Sec. 4.3) of these documents.

Store Snapshot Files for Optical Setups	In the Property Browser of an Optical Setup you can activate that snapshot files are stored in a temporary folder every time something changes in the Optical Setup. You can go back to a certain snapshot via right click on the corresponding entry in the VirtualLab Explorer (↪Sec. 4.3.1) or via Ctrl+Z. This check box defines the default for newly created Optical Setups.
Use New File Format	By default, a new file format is used for storing files because the old one is no longer supported by Microsoft. But in case errors occur, you can still uncheck this option to use the old format. But note that probably files stored in this old format cannot be loaded anymore in the next version of VirtualLab Fusion. When this option is checked, you can use the `convert` command line switch (↪Sec. 9) to convert all your files into the new format.
Save Backup Files in Old Format	ONLY WHEN *USE NEW FILE FORMAT* IS CHECKED. When this option is checked always a backup file in the old file format is saved in the same folder as the original file. These backup files are indicated by a ⌚ in the file name.

6.18 Classic Field Tracing

This subcategory has the following settings:

ITEM	DESCRIPTION
Default Free Space Propagation Method for Linkages	The entry *Default Free Space Propagation Method for Linkages* allows to select a free space propagation method. The selected method is used as default operator for any new linkage of an Optical Setup.
Enable Logging of Automatic Propagation Operator in Message Window	If this option is checked, the logging of the Automatic Propagation Operator to the Message Window is enabled during the processing of an Optical Setup or a Parameter Run, otherwise this logging is suppressed.
Deviation Threshold S	The default deviation threshold used for the Automatic Propagation operator (↪Sec. 94.2).
Power Portion for Field Size Estimation	Some automation techniques estimate the field size (for example the Automatic Propagation Operator described in Sec. 94.2). For these techniques, the *Power Portion for Field Size Estimation* specifies how much of the energy of the incoming field is present in the output field. This value must be below 100 %. A higher value means both increased accuracy and computational effort.

7 Programming

VirtualLab Fusion offers two ways of programming own functionality:

1. VirtualLab Fusion Modules provide an opportunity to automatize or provide arbitrary processes done within VirtualLab Fusion, for example customized export routines. C# and Visual Basic syntax is supported. A module must contain a method “Run” in a class “VLModule” as this is the starting point for the execution of a module. Newly generated modules contain such a method by default.

2. In Programmable Items you just return a value depending on certain input parameters. For example in the Programmable Light Source (↪Sec. 52.8) you define the complex field value in dependance on the

position $(x; y)$. Other parameters like sampling and Jones vector are handled by VirtualLab Fusion and thus there is no need to program it yourself. These so-called “snippets” are much simpler than VirtualLab Fusion modules. Only C# syntax is supported for snippets.

For both modules and snippets, you can use all “public” functions and properties of the VirtualLabAPI.dll and the VirtualLab.Programming.dll by Wyrowski Photonics as well as of the .Net Framework of Microsoft Corp. The VirtualLabAPI.dll contains the complete programming interface of VirtualLab Fusion which underlies continuous changes. Modules and snippets using functionality from this DLL may require changes with a new version of VirtualLab Fusion. In contrast, the VirtualLab.Programming.dll has been especially designed for the needs of external users – all classes in this file are kept stable. Thus there is no need for code changes with a new version of VirtualLab Fusion if you use only methods from this file.

Keep in mind that in your code you must precede a class name with the “namespace” the class is located in. This is needed to distinguish classes with the same name. For example *VirtualLabAPI.Core.Numerics.MathFunctions.DivisionRemainder(a,b)* calls the function DivisionRemainder in the MathFunctions class located in the VirtualLabAPI.Core.Numerics namespace.
If you insert a line like *using VirtualLabAPI.Core.Numerics;* in the header of your module file, you can use the class names of the specified namespace directly, e. g. *MathFunctions.DivisionRemainder*.
Some often required namespaces as for example *System*, *System.Drawing*, *VirtualLabAPI.Core.Common*, and *VirtualLabAPI.Core.FieldRepresentations* are always predefined.

The following documents and web sites give further information.

DOCUMENT	DESCRIPTION
MSDN Library	General introduction to C#
.Net Class Library Reference (MSDN)	All functions and properties of the .Net Framework 4.8 by Microsoft Corp. The members of the often needed System.Math class can be found here.
Programming Reference for VirtualLab Fusion	Description of public members of both the VirtualLab.Programming.dll (stable methods created especially for external users) and other DLLs programmed by Wyrowski Photonics. The current version of the programming reference can also be accessed via Help > Programming Reference.

The Modules View is described in Sec. 7.2, the Source Code Editor for snippets is described in Sec. 7.3. Both share the same control to enter the actual source code, ↪Sec. 7.1

7.1 Source Code Editor Control

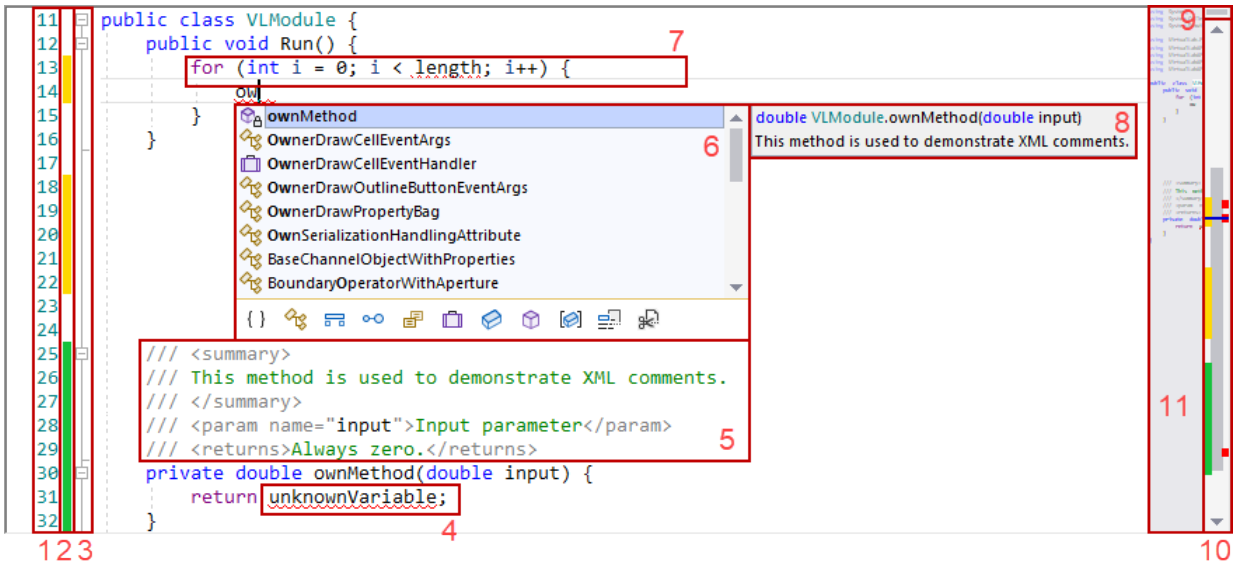


Figure 44. *This screenshot shows some of the features of the control to enter source code. The numbers are explained in the text.*

The control itself (↪Fig. 44) has the following features which support you in programming in a fast and convenient way.

FEATURE	DESCRIPTION
Line Numbers (1)	This column shows the line numbers. Syntax errors are always given with the line number where they occur. You can go to a specific line with the *Go To* entry of the context menu. The line number column is also the place where bookmarks (↪Sec. 7.1.1) are shown. If you click on a line number the whole line is selected.
Line Modificators (2)	In this column, changed lines are marked yellow (green if they have been saved).
Outlining (3)	By clicking on any ⊟ button in the outlining column, you can collapse the corresponding code block (for example a complete method) to a small rectangle with a gray outline. If the cursor hovers above said rectangle, you see a preview of the code block. You can expand a collapsed code block using the ⊞ button next to it. Own code blocks can be defined by embracing them with `#region <Name>` and `#endregion`. The context menu (and the ribbon of modules) offer functionality to collapse / expand all code blocks.
Syntax Highlighting	To maintain readability, strings, numbers, keywords, identifiers and so on all have their own color. In the Global Options dialog (↪Sec. 6.3) you can choose among many predefined color themes. Obvious syntax errors are marked with a red wiggle line (4).
XML Comments (5)	Methods, class variables and so on should be commented with XML comments. They are then shown in the Syntax Tooltips (8) if you use them somewhere else. If you enter `///` directly above the variable or method, a XML comment skeleton is generated automatically.

Code Completion	If you start entering e. g. a variable name and then press Ctrl + Space, it is completed automatically if the letters you have already entered identify the wanted name uniquely. If this is not the case, a menu (6) opens where you can select the desired name with the arrow keys or Page Up and Page Down and use it with Enter. If you type further letters the selection is narrowed down. In the bottom of that menu you can activate filters so that for example only methods are shown.
Code Snippets (7)	In the Code Completion menu (6) there are also some code snippets, marked by  . Example: The `for` snippet is expanded to `for (int i = 0; i < length; i++) { }`. After this snippet has been expanded, all occurrences of the variable `i` are highlighted. If you now change that variable name, all three occurrences are changed at the same time. If you press Tab, you jump to the variable `length` which you can also change. If you press Enter you leave the snippet.
Syntax Tooltips (8)	If you are entering the name of a method and then an open round bracket (which means that you start entering the parameters of the method), a Syntax Tooltip is shown. It shows the XML comment (5) of the method itself and of the currently entered parameter. Syntax Tooltips are also shown if you navigate in the Code Completion menu (6) or if you move the mouse over a variable or method name.
Horizontal Split	If you click on the button marked with 9 in Fig. 44 and drag your mouse, you can create and move a gray *splitter bar* separating two views of the source code editor. In this way you can work on two parts of the source code at the same time. If you want to remove the split view, simply drag the splitter bar to the very top of the editor.
Scrollbar Annotations (10)	Different colors in the scrollbar mark for example saved changes (yellow squares), unsaved changes (green squares), syntax errors (red squares), bookmarks (black squares), occurrences of the current search string (orange squares), and the current line (dark blue line).
Minimap (11)	Left to the scrollbar is the minimap which gives you an overview of the complete source code. You can use it like a scrollbar (click on the desired place or click and and drag around). If you hold Ctrl and left-click and drag the mouse at the border of the minimap you can change its width. You can switch off the minimap completely in the Global Options dialog (↪Sec. 6.6).
Smart Indentation	If you finish a code block (by entering a semicolon or a closing curly bracket in C#), all lines in the block are aligned automatically so that child code blocks are indented with respect to the parent code block. If you start a new line with Enter, it is also indented automatically.
Brace Matching	If you place the cursor directly behind a opening / closing bracket, the matching closing / opening bracket is marked by a frame.
Autocomplete Braces and Quotation Marks	When you enter an opening brace ({ [or quotation mark " ', the corresponding closing character ' "] }) is inserted automatically. You can switch off this feature in the Global Options dialog (↪Sec. 6.6).

Useful keyboard and mouse commands

- You can change the font size in this control via the mouse wheel while pressing the Ctrl key.
- When you press the Ctrl key and move the mouse over the name of a variable or method defined in the current module, you can click it to jump to the position where this element was declared.
- The control supports selection of rectangular code blocks (= a certain column range in consecutive lines). You create such a selection by navigating to the desired start point and then expand the selection via Alt+Shift+←/→/↑/↓ or holding Alt while creating the selection with the mouse. Such a block selection also allows you to write in consecutive lines at once.

7.1.1 Context Menu

The context menu of the Source Code Editor Control has the following entries.

ITEM	DESCRIPTION
Undo	Undoes the last edit(s). Shortcut Ctrl+Z.
Redo	Redoes the last undone action(s). Shortcut Ctrl+Y.
Cut	Copies the current selection to the Windows™ Clipboard and then deletes it. Shortcut Ctrl+X.
Copy	Copies the current selection to the Windows™ Clipboard. Shortcut Ctrl+C.
Paste	Pastes the current (text) content of the Windows™ Clipboard to the cursor position. Shortcut Ctrl+V.
Select All	Selects the whole source code. Shortcut Ctrl+A
Find	All occurrences of the word the cursor is currently placed on are marked orange. Furthermore, a resizable pop-up in the bottom right corner opens where you can change the search string and the search options. For example if there is an active selection, you can switch here whether to search in the *Current Document* or in the *Selection Only*. Shortcut Ctrl+F.
Replace	Behaves very similar to the *Find* functionality. In fact the same pop-up is used, it just shows an additional line with the *Replace With* string. You can toggle this pop-up between Find and Replace mode using the arrow in its top left corner. Shortcut Ctrl+H.
Go To	Allows you to jump to a certain line by entering its line number. Shortcut Ctrl+G.
Collapse All / Expand All	The source code editor supports outlining, i. e. code blocks like a method can be collapsed to a single line to gain a better overview of the source code. *Collapse All* collapses all such blocks and *Expand All* expands all such blocks.
Comment Lines	*Comment Lines* marks all currently selected lines with a comment symbol, so that they are not part of the actual source code. Shortcut Ctrl+Shift+C
Uncomment Lines	Removes all comment symbols from the beginning of the currently selected lines. Shortcut Ctrl+Shift+U

Bookmarks	This sub-menu provides support for bookmarks allowing you to jump between regions of your source code. Bookmarked lines are indicated by a blue rectangle in the line number column. *Toogle Bookmark* creates a bookmark in the current line if there is no bookmark present. Otherwise, the already existing bookmark is removed. With *Next Bookmark* and *Previous Bookmark* you can jump to the next and previous bookmark in your source code, respectively. *Clear All Bookmarks* deletes all bookmarks.
Print	Opens a dialog specifying which region of the source code is to be printed with which printer. Clicking *OK* in this dialog starts the printing process. Shortcut Ctrl+P.

7.1.2 Quick Actions

Sometimes, you may notice a light bulb next to the line numbers. This means that for the current cursor position one or more so-called *quick actions* are available. These quick actions can make the code easier to read or maintain. You can trigger them by clicking on the light bulb or via Ctrl+.

Two examples are shown in Fig. 45.

Figure 45. *Two sample quick actions.* ***Left:*** *Invert "if" statement.* ***Right:*** *Convert "for" statement to a "foreach" statement. The opposite is also possible.*

7.2 Module View

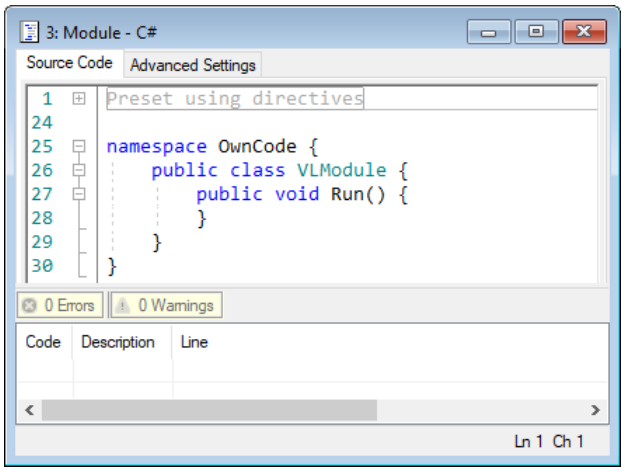


Figure 46. *Example of a VirtualLab Fusion module document.*

In Fig. 46 the view of a newly created C# module is shown as an example of the general view of VirtualLab Fusion modules. It comprises the following three parts (from top to bottom).

ITEM	DESCRIPTION
{Source Code Editor}	↪Sec. 7.1
{Error Panel}	Displays possible compiling errors and warnings, including the line in which they occurred and an error code by which you can find further information online. When you double-click on a message the cursor in the source code editor jumps to the corresponding line. With the yellow buttons on top of this panel you can filter to see either only warnings or only errors.
{Status Bar}	The left part gives general status messages, which are also logged into the Messages tab (↪Sec. 4.3). The right part shows the current position of the cursor, counted in lines (*Ln*) and characters (*Ch*).

The size of the module view can be changed freely by mouse drag, as well as the size of the error panel and its columns.

7.2.1 Advanced Settings

The Module View can be also used to specify additional external reference DLLs. Fig. 47 shows the tab page that can be used to specify external references for modules.

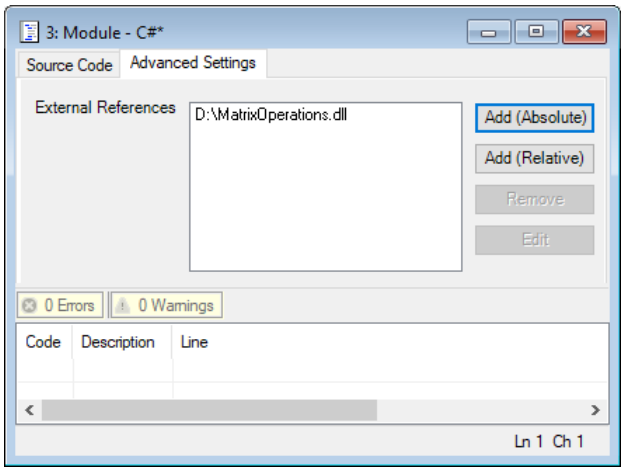


Figure 47. *The* Advanced Settings *tab of a module.*

The definition of external references is described in more detail in Sec. 7.3.4.

7.2.2 File Menu

If you click Save or Save As in the File menu the correct file extension (.cs for C# and .vb for Visual Basic) is set automatically. Print opens a dialog specifying which region of the source code is to be printed with which printer. Clicking *OK* in this dialog starts the printing process.

> The shortcut Ctrl+M can be used to create a new C# module.

7.2.3 Ribbon Items

ITEM	DESCRIPTION
Run	Compiles and then executes the correct source code (Shortcut F5). If you click this button it turns into a Stop button (Shortcut Shift+F5) to stop the execution of the code.
Compile	Compiles the implemented source code and shows the resulting compiler errors and warnings both in the errors panel and in the messages panel of the main window. Shortcut F6.
Select All	Selects the whole source code. Shortcut Ctrl+A
Cut	Copies the current selection to the Windows™ Clipboard and then deletes it. Shortcut Ctrl+X.
Copy	Copies the current selection to the Windows™ Clipboard. Shortcut Ctrl+C.
Paste	Pastes the current (text) content of the Windows™ Clipboard to the cursor position. Shortcut Ctrl+V.
Undo	Undoes the last edit(s). Shortcut Ctrl+Z.
Redo	Redoes the last undone action(s). Shortcut Ctrl+Shift+Y.
Find	Opens a dialog where you can enter an arbitrary string. The *Find Options* allow you to configure the behavior of this dialog in detail. By pressing the *Bookmark All* button all matching lines in the source code are marked as bookmark (see below). Shortcut Ctrl+F.
Replace	Opens a dialog with which you can replace an arbitrary string by another arbitrary string. The *Find Options* allow you to configure the behavior of this dialog in detail. Shortcut Ctrl+H.
Comment Lines	Comment Lines marks all currently selected lines with a comment symbol, so that they are not part of the actual source code. Shortcut Ctrl+Shift+C
Uncomment Lines	Removes all comment symbols from the beginning of the currently selected lines. Shortcut Ctrl+Shift+U
Collapse All / **Expand All**	The source code editor supports outlining, i. e. code blocks like a method can be collapsed to a single line to gain a better overview of the source code. Collapse All collapses all such blocks and Expand All expands all such blocks.
Bookmarks	This ribbon group provides support for bookmarks allowing you to jump between regions of your source code. Bookmarked lines are indicated by a blue rectangle in the line number column. Toogle Bookmark creates a bookmark in the current line if there is no bookmark present. Otherwise, the already existing bookmark is removed. With Next Bookmark and Previous Bookmark you can jump to the next and previous bookmark in your source code, respectively. Clear All Bookmarks deletes all bookmarks.

7.3 Source Code Editor for Snippets

This dialog (↪Fig. 48) consists of various tabs which are explained in the following sections and the following controls at its bottom:

ITEM	DESCRIPTION
Import Snippet	Imports a snippet from a .snp-file. A dialog lets you select which parts of the snippets are imported (all by default, see Sec. 5.9 for details). In this way you can for example keep your source code unchanged while importing the global parameters.
Export Snippet	Exports a snippet into a .snp-file. This file can then be used to import the snippet or parts of it into another programmable item.
Check Consistency	Checks whether the implemented snippet is in correct C# syntax. Compiler errors and warnings are shown in the validity indicator (↪Sec. 5.11) right to the *Check Consistency* button. Clicking the ℹ-button displays further information including the exact location of the error or warning. Shortcut: F6, or Shift + F6 if you want to see the errors or warnings immediately.

7.3.1 Source Code Tab

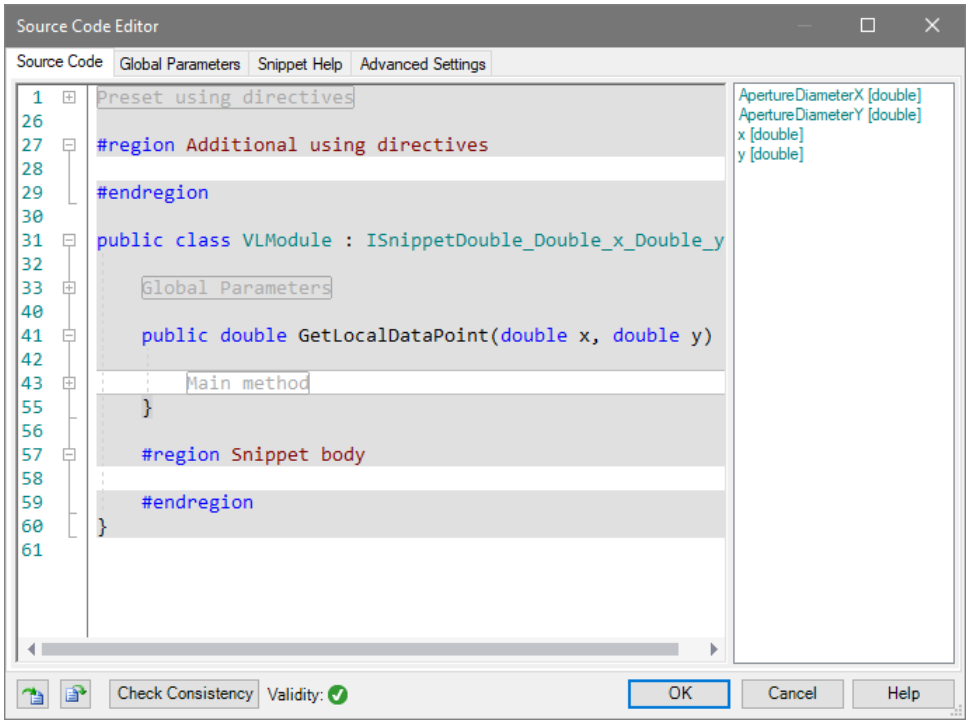


Figure 48. *The Source Code Tab for snippets.*

The *Source Code* tab of the Source Code Editor (↪Fig. 48) shows two panels.
The left panel contains the source code. Some regions of the source code are made read-only to ensure that it is suitable for the intended purpose. You can only edit the following regions:

- **Additional using directives:** Allows you to define additional namespaces containing classes you need. See also the box in Sec. 7.
- **Main method:** The actual snippet function that *must* be implemented (Example: In case of a programmable optical surface this method has to return a height value in dependency of the position $(x; y)$).
- **Snippet body:** Additional methods, properties or variables *can* be specified here. They can be used for example to store some intermediate results between consecutive executions of the main method.

You can use functionality from the .NET framework and from the classes documented in the VirtualLab Programming Reference which you can find in the Help ribbon. The code must be entered in C# syntax.
The features of the actual source code editor are explained in Sec. 7.1.
The right panel contains a list of global parameters. By double clicking on them you can insert them at the cursor position in the source code.

7.3.2 Global Parameters Tab

Most snippets have predefined global parameters, for example `x` and `y` where the function is evaluated. The *Global Parameters* tab allows you to define further global parameters. These parameters can then be changed by the end users without using the Source Code Editor (↪Sec. 7.4).

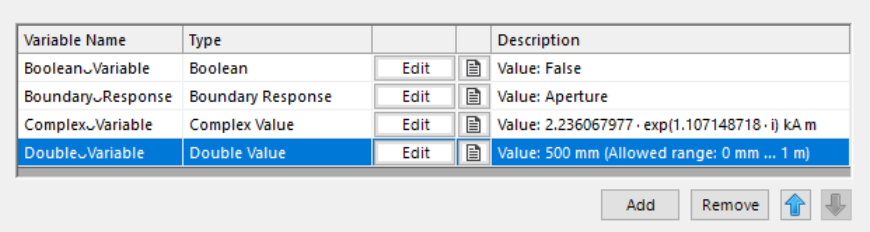


Figure 49. *The table to edit the Global Parameters.*

This tab has the following controls (↪Fig. 49).

ITEM	DESCRIPTION
{Table}	A table with all Global Parameters, see below.
Add	Adds a new variable with the initial type *Double Value* to the bottom of the table.
Remove	Removes the currently selected variable from the table after inquiring whether you really want to do so.
(Move Up)	Moves the currently selected variable up by one row.
(Move Down)	Moves the currently selected variable down by one row.

The table with the Global Parameters has the following columns:

COLUMN	DESCRIPTION
Variable Name	A variable name must be unique and a valid C# identifier – which mainly means that it must not contain spaces and special characters like '/' and that it must not start with a number. To make the names shown in the control for end users (↪Sec. 7.4) more legible, you can add the special character '␣' which will there be replaced by a space and a double underscore which will be replaced by a hyphen. So for example the variable "`Sub__Sampling␣FMM`" becomes "Sub-Sampling FMM" for the end user.
Type	The type of the parameter. The available types are listed in the next table.
Edit	Opens an edit dialog where you can edit the *Variable Name* and the value of the parameter. See below.
🗎	Opens a simple text editor where you can enter a help text for the parameter. This editor optionally allows you to specify HTML formatting. This information is then available in the syntax tooltips of the source code editor and for the end user via the *Help*-button at the bottom of the *Parameters* tab of the programmable item (↪Sec. 7.4).
Description	Shows the current value of the parameter and additional information.

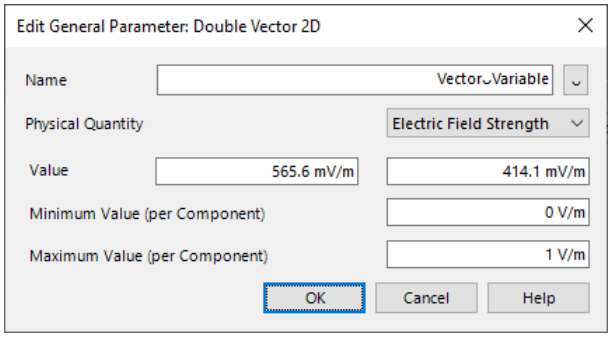


Figure 50. *Edit dialog for a general parameter of type* Double Vector 2D.

The edit dialog for a general parameter has the following entries (Fig. 50 shows an example).

ITEM	DESCRIPTION
Name	The unique name of the variable which must be a valid C# identifier (see note in Sec. 7.3.2).
␣	Allows you to enter the special character '␣' which will be replaced by a space in the control for end users (↪Sec. 7.4). Short cut Shift+Space, which also works in the source code editor (↪Sec. 7.1).
Physical Quantity	ONLY FOR DOUBLES, COMPLEX VALUES, AND DOUBLE VECTORS. Allows you to choose any of the physical quantities listed in Sec. 5.1. Note that in the source code tab (↪Sec. 7.3.1) all variables are always given in their respective base unit (e. g. meters for a length and radians for an angle).
Value	A control to define the actual value of the parameter. Depends on the type of the parameter: • *Boolean*[PC]: A drop-down list to select between *True* and *False*. • *Complex*[PV]: ↪Sec. 5.2 • *Double Array 1D*[PE] and *Double Array 2D*[PE]: ↪Sec. 5.4 • *Double Value*[PV]: ↪Sec. 5.1 • *Enumeration*: ↪Sec. 7.3.2.1 • *Integer Value*[PV]: A spinner where invalid input is marked red and explained with a tooltip. • *Integer Vector 2D*[PV] and *Double Vector 2D*[PV]: ↪Sec. 5.3 • *Double Vector 3D*[PV]: Three controls for entering a physical value (↪Sec. 5.1), one for x-, y-, and z-dimension, respectively. • *String*[PC]: A text box • *Data Array 1D*, *Data Array 2D*, *Data Array Gridless*, *Region 1D*[PE] and *Region 2D*[PE]: A *Set* button (↪Sec. 5.7) to load the document from a file or to use an already open document as well as a button to *Show* the currently set document in a separate window. • *Boundary Response*[PE], *Material*[PE], *Medium*[PE], *Stack*[PE], *Surface*[PE]: ↪Sec. 34.1
Minimum Value / Maximum Value	ONLY FOR DOUBLES, INTEGERS AND VECTOR TYPES These values are used to restrict the allowed input values in the *Parameters* group box of programmable items and in the Parameter Run. For vectors, each component of the vector gets this value range constraint.

7.3.2.1 Defining Enumerations

An enumeration is a list of pre-defined values from which the end user can choose one. Internally it is a list of strings. In the source code, you can use its members `SelectedIndex` and `SelectedEnumerationEntry()` to get the entry the end user has chosen.

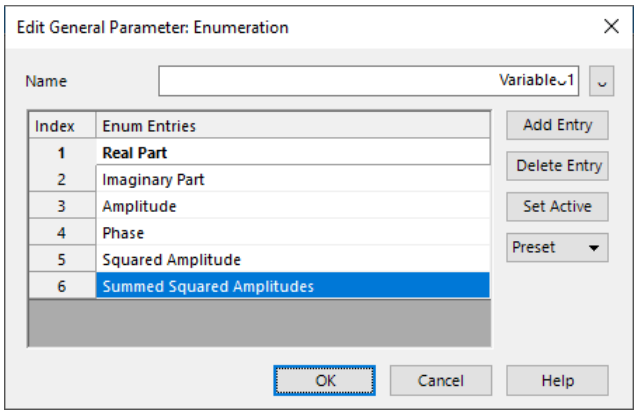


Figure 51. *Edit dialog for a general parameter of type* Enumeration.

You can define an enumeration with the dialog shown in Fig. 51 which has the following controls.

ITEM	DESCRIPTION
Name	The unique name of the variable which must be a valid C# identifier (see note in Sec. 7.3.2).
␣	Allows you to enter the special character '␣' which will be replaced by a space in the control for end users (↪Sec. 7.4). Short cut `Shift`+`Space`, which also works in the source code editor (↪Sec. 7.1).
{Table}	In the table you can edit the current list of enumeration entries.
Add Entry	Adds an entry to the table of enumeration entries.
Delete Entry	Deletes the currently selected enumeration entry from the table.
Set Active	Defines the currently selected entry as "active", which means that this entry is returned by the aforementioned `SelectedIndex` and `SelectedEnumerationEntry()`. This entry is marked bold in the table.
Preset	Opens a menu where you can select several presets. Selecting a preset overwrites all entries currently in the table. Besides the *Default* preset there a various presets matching "enums" from the VirtualLab Fusion source code. In this case you can additionally use the member `SelectedEnumerationEntry<T>()` where `T` is the type of the enum (e. g. `FieldQuantity`). This member returns directly the enum entry which then can be used in VirtualLab Fusion methods.

7.3.3 Snippet Help Tab

On the *Snippet Help* tab you enter a help text and additional helpful information concerning the whole snippet. This information is then available for the end user via the *Read Me*-button at the bottom of the *Parameters* tab of the programmable item (↪Sec. 7.4).

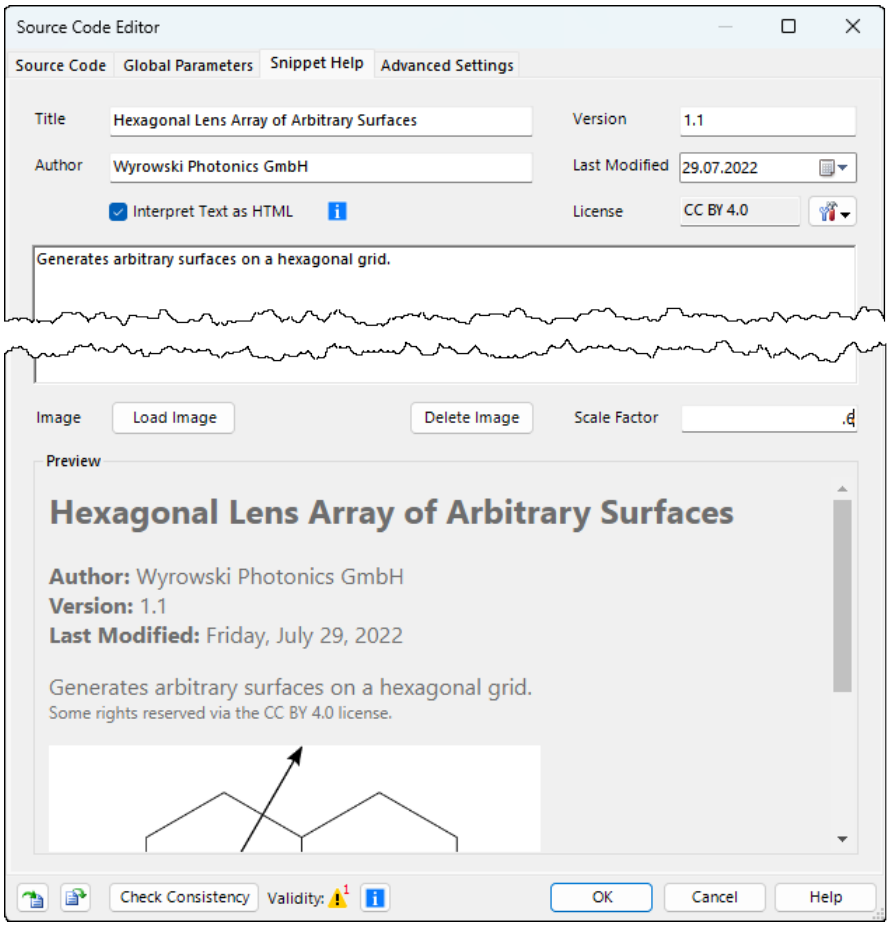


Figure 52. *The* Snippet Help *tab of the Source Code Editor.*

It has the following controls (↪Fig. 52).

ITEM	DESCRIPTION
Title	Control to enter the title of the snippet.
Author	Control to enter the author(s) of the snippet.
Version	Control to enter the version of the snippet, e. g. “1.1a”.
Last Modified	Allows you to enter the date the snippet was last modified. You can either enter the date directly in your local date format or use the control to choose the date visually.
Interpret Text as HTML	If checked, the text inside the {Help Text Box} is interpreted as being HTML. So, HTML tags can be used for formatting (For example you can use `<b>…<b/>` to make some text bold and `<i>…<i/>` to make it italic.). If not checked, such tags will be ignored but line breaks will occur in the result just as entered in the defining text box. Please note: The state of this option will apply to the help texts of global parameters (↪Sec. 7.3.2) as well.
License	A license can be specified here to be applied to the source code. Pressing the tools buttons allows to select from a couple of predefined licenses. If *User Defined* is chosen, a license can be entered freely. The license description will appear in the Preview and Snippet help view below the text entered in the {Help Text Box}.
{Help Text Box}	Control to enter a description of the snippet. Scrolling with the mouse wheel while holding the `Ctrl` key changes the font size of this control.
Load Image	Loads an image from disk which will be part of the snippet help and which serves for illustrating relations, variable meanings etc.
Delete Image	Deletes a previously inserted image.
Scale Factor	Scales an inserted image.
Preview	The help of the snippet as the end user will see it.

7.3.4 Advanced Settings Tab

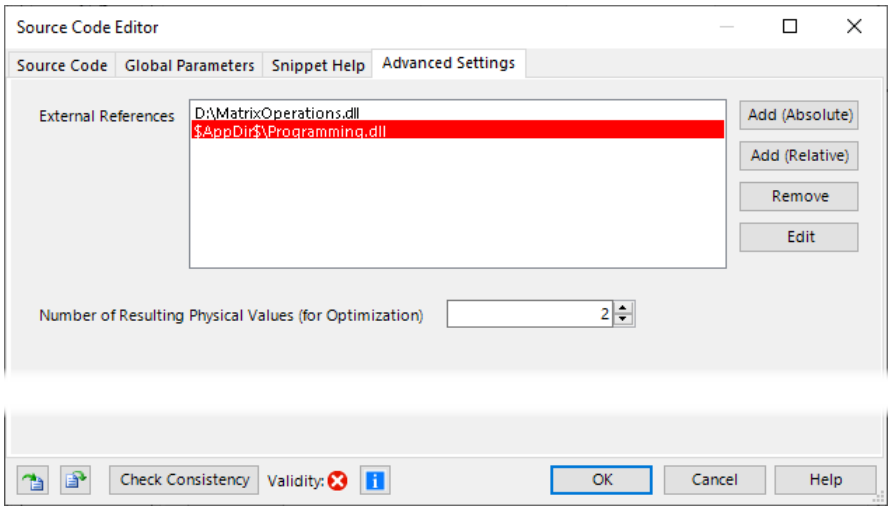


Figure 53. *The Advanced Settings tab of the source code editor. As one of the given External References is invalid (marked red), the Validity control shows an error. The text box Number of Resulting Physical Values (for Optimization) is only visible for Programmable Items returning a list of* `DetectorResultObject`*.*

This tab (↪Fig. 53) allows you to load *External References*, i. e. managed DLLs whose classes you want to use. “Managed” refers to a special type of DLLs created with the .Net framework. This tab has the following controls:

ITEM	DESCRIPTION
List of References	The list of already defined external references.
Add (Absolute)	Opens a file open dialog where you can select a new managed DLL to be added to the list.
Add (Relative)	Adds a new managed DLL to the list. The reference DLL can be specified by a relative path. The set up is done within an additional dialog, which is described below. If the specified DLL cannot be found the corresponding row in the List of References is marked red and the validity control shows an error (↪Fig. 53).
Remove	Removes the selected DLL from the List of References.
Edit	Editing of the path of the selected DLL.

By clicking on the *Add (Relative)* button a dialog is shown which can be used to specify a relative path to a managed DLL.
Fig. 54 shows the edit dialog for relatively linked references.

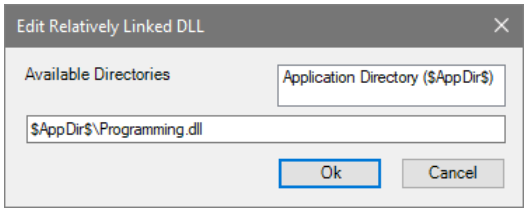


Figure 54. *Dialog for specifying relative links to referenced DLLs.*

The user can enter the relative path directly within the text box at the bottom of the dialog. Additionally the list box at the top of the dialog can be used which assists the user in specifying the correct syntax for the relative links. By double clicking on an item within the list the selected directory key is added to the name of the reference DLL. The following relative directories are available

ITEM	DESCRIPTION
$AppDir$	The directory from which VirtualLab Fusion is started (typically the installation directory).
$ModuleDir$	The directory where the module is stored. This option is only available in the Module View. ↪Sec. 7.2.

7.4 Programmable Items for End Users

Programmable items usually have two distinct user groups: The *developer* which can use the source code editor described in Sec. 7.3 and the *end user* who just wants to change the parameters. The former can also be LightTrans or your local distributor.
The controls for the end user are in a *Parameters* group box (↪Fig. 55) directly in the edit dialog of the programmable item itself, thus he needs not to enter the source code editor.

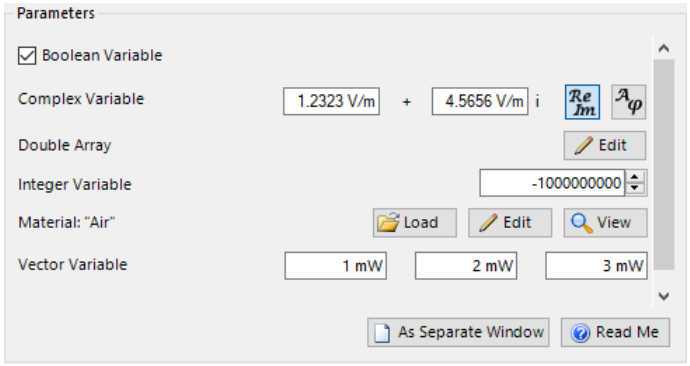


Figure 55. *Example for the Parameters group box of a programmable item. The scrollbar indicates that there are more parameters to be set than can be shown at once.*

Each global parameter (↪Sec. 7.3.2) of the snippet defining the programmable item has its own type-depending control(s) to change the value:

TYPE OF PARAMETER	CONTROL(S)
Boolean	A checkbox
Complex	↪Sec. 5.2
Double Array 1D PE **/ Double Array 2D** PE	↪Sec. 5.4
Double Value PV	↪Sec. 5.1
Double Vector 3D PV	Three controls for entering a physical value (↪Sec. 5.1), one for x-, y-, and z-dimension, respectively.
Enumeration	A combo box to select one entry from the list of available enumeration entries.
Integer Value PV	A spinner where invalid input is marked red and explained with a tooltip.
Integer Vector 2D PV **/ Double Vector 2D** PV	↪Sec. 5.3
String	A text box
Boundary Response PE **/ Material** PE **/ Medium** PE **/ Stack** PE **/ Surface** PE	↪Sec. 34.1
Data Array 1D / Data Array 2D / Data Array Gridless / Region 1D / Region 2D	A *Set* button (↪Sec. 5.7) to load the document from a file or to use an already open document as well as a button to *Show* the currently set document in a separate window.

Furthermore there are two buttons at the bottom of this control.

ITEM	DESCRIPTION
As Separate Window	Allows you to show all parameters in a separate resizable window for a better overview.
Read Me	Displays help information for the whole snippet and / or the individual parameters (if provided by the developer).

Note that this group box is not visible if the snippet contains neither global parameters nor help information.

8 Distributed Computing

VirtualLab Fusion can be used to perform parameter run evaluations using *Distributed Computing*. To enable this technique the user needs to start a server directly in VirtualLab Fusion and configure the calculation network (meaning the calculation clients that shall be used for the simulations).
Fig. 56 show the control panel for the configuration of the distributed computing server inside VirtualLab Fusion.

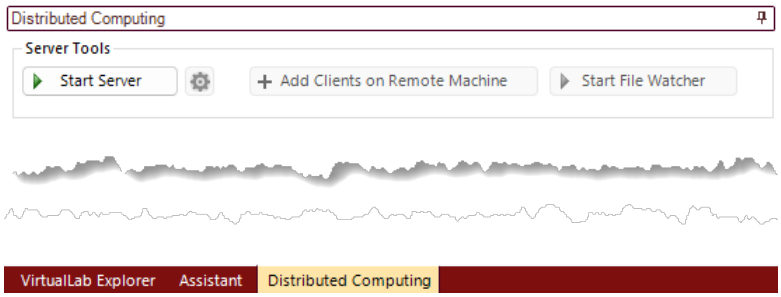


Figure 56. *The network for distributed computing can be configured directly in VirtualLab Fusion. The user can start a server and configure the client network.*

By pushing the *Start Server* button a new server will start in the running VirtualLab Fusion instance. It should be noticed that per machine only one server can be started, because the communication between server and clients is done via network and for that the different ports will be used.
For the communication between server and clients (and the server support tool) the following ports should be accessible:

- 23001 [TCP & UDP]
- 23002 [TCP & UDP]
- 23003 [TCP & UDP]

After the server is started the caption of the *Start Server* button will be changed to *Stop Server*. In addition, several additional buttons and controls get visible or active.
Fig. 57 show the user interface after the server was started.

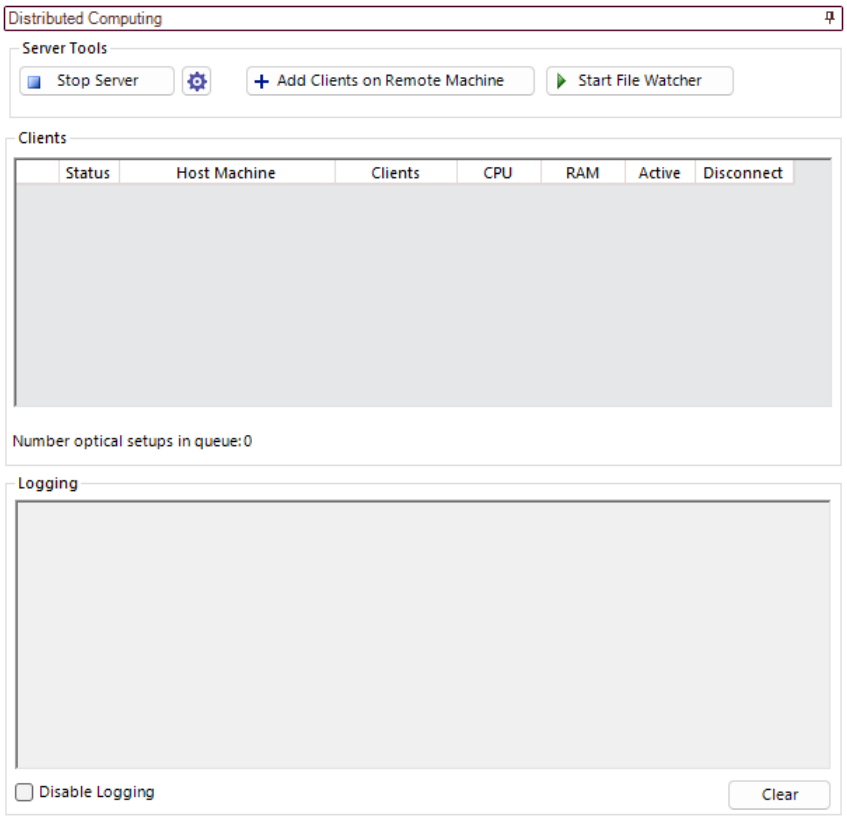


Figure 57. *After starting the server inside VirtualLab Fusion the user can modify the calculation network using the available controls.*

If the server is running three different regions will be available for modification and investigation of the calculation network.

- Server Tools - In this section of the user interface the user can stop the server, adapt the calculation network, start a file watcher and specify some setting of the server. A detailed explanation of the server tools can be found in Sec. 8.1.
- Clients - Below the server tool section a table listing all connected clients is displayed. Within this table the user can investigate the current status of all clients per remote machine. Details on the client list can be found in Sec. 8.2.
- Logging - On the bottom of the control panel for distributed computing the user can find a text box, in which the communication within the calculation network is logged. Here it will be shown when a new calculation is given to the server, a calculation is distributed to a client within the network and also when a simulation is finished and the results are returned from the calculation client to the server. Below the logging window there is a button to clear the logging information. In addition, the user has the option to disable the logging checking the box *Disable Logging* below the logging window. It is recommended to deactivate the logging for a large number calculations, because the logging would slow down the performance of the server.

8.1 Server Tools

In the user interface section *Server Tools* several tools are available to start/stop or modify the server and the connected calculation network. The following tools can be accessed here:

ITEM	DESCRIPTION
Start Server	If no server is actually running you have the option to start the server. Please note that you can only start one server per machine. In case a server is already running, VirtualLab Fusion offers the option to attach to the running server. In this case it is possible to use an existing calculation network. The calculation network can only be modified within the VirtualLab Fusion instance which started the server.
Stop Server	If a server was started, the *Start Server* button is changed to a *Stop Server* button. If you click on the *Stop Server* button, VirtualLab Fusion will ask for a confirmation that you really like to stop the server. If you confirm your choice, the server and all connected clients will be closed.
Configure Server	By clicking on the configuration wheel next to the *Stop Server* button a dialog is opened in which you can specify some processing parameters for the running server. The settings you can do here are explained in the Sec. 8.1.1.
Add Clients on Remote Machine	The server supports to start clients on remote machines. There for a server support tool needs to run in the machines on which you like to enable the start of clients. In Sec. 8.1.2 the work flow how to add clients on a remote machine in a user-friendly way is explained.
Start File Watcher	In addition to the parameter run, we also offer the option to feed new simulation tasks to the distributed computing network via hard disc. Therefor you simply need to use the *Start File Watcher* tool. Here the user can select a folder which is checked regular by VirtualLab Fusion. This option can be useful if you are working with external programs (like python) and like to benefit from the automatic distribution of calculations. In case a new os file is stored in the folder watched by VirtualLab Fusion, the task is distributed in the calculation network and as soon as the results are present they are available in a sub folder as XML file.

8.1.1 Server Options

By clicking on *Server Options* a dialog is shown in which several options can be configured.
Fig. 58 show the dialog to configure the server options.

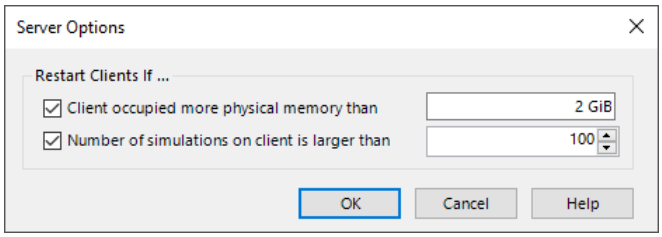


Figure 58. *The dialog to configure the server options.*

In general VirtualLab Fusion support to restart a client automatically after a specified number of calculations was done on the client, or if the RAM usage of one client is above a user defined threshold. It is recommended to keep the options as they are set by default. In case you are facing some irregular behavior of the clients these options could be adapted to solve the irregularity.

8.1.2 Add Clients on Remote Machine

VirtualLab Fusion supports to add clients to a running distributed computing server directly from the server side. This can be done by clicking on the *Add Clients on Remote Machine* button. Fig. 59 shows the dialog to add clients on remote machines.

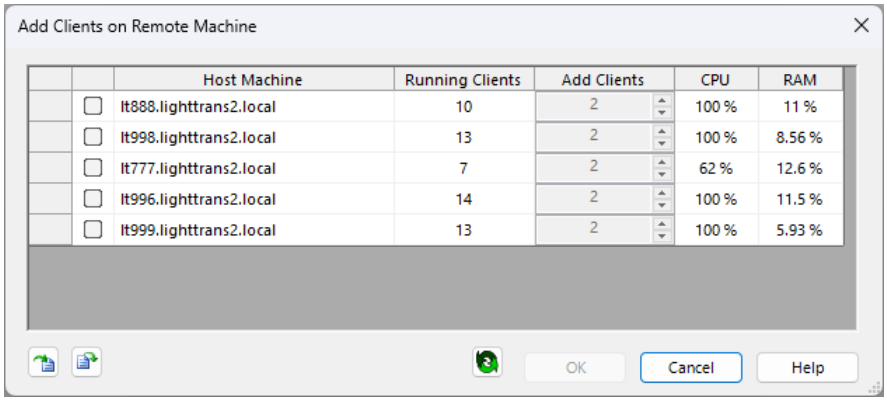


Figure 59. *The dialog which can be used to select the host machine on which the clients shall be started*

On the top of the dialog you find a table which list all available host machines on which the server can start clients. To enable a host machine to start clients automatically, the server support tool has to run on the host machine. The server support tool is a special executable which can be found in the installation directory of VirtualLab Fusion. Simply start the file *VirtualLab.DistributedComputing.ServerSupportService.exe* and keep it open.

In the server support tool you will find a logging box which displays the information when a server requested to start a user defined number of clients.

In the table each host machine is represented by one line in the table. The following columns are available within the table:

ITEM	DESCRIPTION
Select	The first column can be used to select whether you like to start one or more clients on the host machine. If you select a host machine within the table you can specify how many clients shall be started on the host machine.
Host Machine	The host machine name is used to identify the host machine.
Running Clients	In the column *Running Clients* you can see how many clients are already running on the corresponding host machine. This information includes all clients that are connected to all running VirtualLab Fusion server in your network.
Add Clients	If you select a host machine within the table, the cell entry for specifying the number of clients to start will become active. The number of clients per remote machine which is reasonable depends on the host machine (and its current usage) as well on the simulation tasks you like to distribute.
CPU	The table provides the information of the current CPU usage of the host machine. This information is updated frequently.
RAM	The table provides the information of the current RAM usage of the host machine. This information is updated frequently.

On the bottom of the dialog two buttons are located to save and load the settings for the configuration of the calculation network. By clicking on the save button a text file is generated, which contains all necessary information given in the table above. When loading a previously stored configuration file, the information will be read again from the text file and all matching information will be synchronized with the table settings. In

case the information within the text file does not match the found host machines, per mismatch a warning is displayed. Only the matching information will be used for synchronization.

8.2 Clients

In the section *Clients* a list of all connected clients to the current server is shown. Fig. 60 shows the table for a sample situation where 17 calculation clients are connected on 5 different host machines.

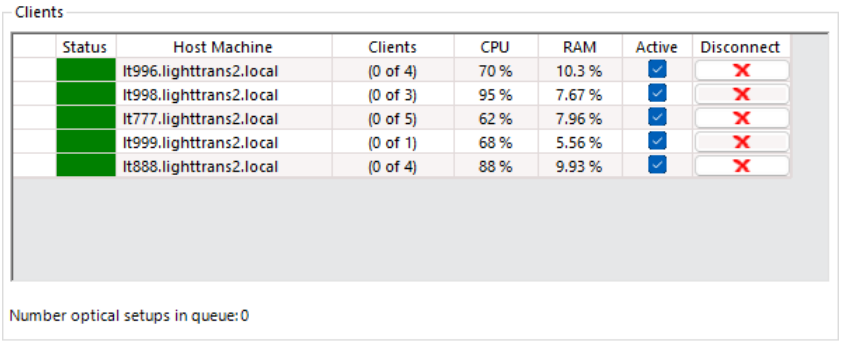


Figure 60. *The* Clients *control contains a list of all connected clients in the current calculation network.*

In the table each host machine is represented by one line. Per host machine multiple clients could be running, which is displayed in the corresponding table entry. The table provides the following information.

ITEM	DESCRIPTION
Status	The status column is used to mark that status of each host machine by an intuitive color. The used colors have the following meaning: • **Green**: No connected client on the corresponding host machine is performing a calculation task. • **Yellow**: Some (but not all) connected clients on the corresponding host machine are performing a calculation task. • **Red**: All connected clients on the corresponding host machine are performing a calculation task. • **Gray**: The clients on the corresponding host machine are set to in active (which means they are connected but are not used for distribution of calculation tasks)
Host Machine	In this column the name of the host machine is plotted.
Clients	In the *Clients* column, the user can check how many clients are connected for the corresponding host machine. In addition you can also find the information how many of the connected clients are currently performing a calculation job provided by the server.
CPU	For monitoring purposes it is important to see the current CPU usage of the host machine. This information is given here.
RAM	For monitoring purposes it is important to see the current RAM usage of the host machine. This information is given here.

Active	In the *Active* column you can check whether a host machine is active or not. By default the machines are all set to active, but there could be situation where the user might decide to don't use a specific host machine (e. g. if this machine is needed for some other calculations). In this case one could remove all clients from the corresponding host machine, or set them to inactive. If the user set the clients on the host machine to be inactive and the clients are currently already doing some calculations, the calculations will be finished and there will be no newly distributed calculation tasks to the clients of the host machine. The inactive status is also visible via the *Status* column within the client list (color is set to gray).
Disconnect	In the last column a button is available to disconnect all clients on the corresponding host machine. By clicking the *Disconnect* button the user is asked for confirmation whether he really likes to close all connected clients on the selected host machine. In case of confirmation the clients are closed and if there would be running calculation tasks the calculation would be re-distributed to the other clients within your calculation network.

It is a very typical situation, that there are more calculation tasks provided to the distributed computing network than there are available clients. In case all clients are already occupied and a new calculation task if given to the server for distributed computing, this simulation will be added to the calculation queue. As soon as a client is ready with the calculation task assigned to it the next task from the queue is automatically assigned to this client. Below the table listing all client information you can find the *Number optical setups in queue*.

9 Command Line Arguments

VirtualLab Fusion can be controlled not only via the graphical user interface but also via command line arguments. Multiple such commands can then be collected in a batch file.
The ribbon item File > Export > Create Batch Mode Files asks for a folder and creates there a sample batch file from the current Optical Setup which calculates the results for the current simulation engine. Furthermore a sample XML file is created containing the original values of all variable parameters of the Optical Setup.

Restrictions on the passed arguments

Note that as batch files use another code page than Windows™ programs, paths in the batch file containing non-ASCII characters are passed to VirtualLab Fusion incorrectly. Thus the result and logging files might be stored in a wrong folder or the Optical Setup might not be simulated at all. Thus the paths should only contain the standard Latin characters a-z and A-Z, numbers, spaces and the special characters !#$%&'()+,-.;=@ ^_‘{}~ .
Furthermore the letter combination \" yields unexpected results. Thus path arguments must not end with \ .

Hints

- The commands are case insensitive. For example you can use `-performOs`, `-PerformOs`, or `-performOS`.
- In the parameters you can use any environment variable like `%TEMP%` (= path to the temp folder) or `%VirtualLab_AppDir%` (= path to the VirtualLab.exe from which the last export to batch mode or to optiSLang was executed).
- All commands described below can be used only exclusively. Only file names, `-startUpModule`, and `-globalOptions` can be used together.

The available commands are listed below. (The arguments in curly brackets are user-defined parameters, the arguments in square brackets indicate optional arguments.)

`virtuallab.exe {1} [{2} [{3} …]]`

Opens the specified files in VirtualLab Fusion. VirtualLab Fusion documents (↪Sec. 4.1) are opened as document windows. For files which can be imported (↪Part XVI) the corresponding import dialog is opened. After you close this dialog, the dialog for the next importable file is opened, if specified.

`virtuallab.exe {1} [{2} [{3} …]] -convert {4}`

This command allows you to save a bunch of files in the most recent file format and file extension.
The specified files ({1}, {2}, …) are opened and saved to the specified output directory {4}. You can also specify directories, then all files in this directory and its subdirectories are converted. Duplicate file names are made unique by adding ".bak" and maybe a number.
Errors are logged to an `errors.log` file in the output directory.
With this command VirtualLab Fusion is started in the "batch mode" where no VirtualLab Fusion windows are opened.

`virtuallab.exe -performOS {1} {2} [-parameters {3}] [-engine {4}] [-subfolder] [-noLogfile]`

This command allows you to simulate an arbitrary Optical Setup (↪Sec. 44); its results are then saved automatically. With this command VirtualLab Fusion is started in the "batch mode" where no VirtualLab Fusion windows are opened.

ARGUMENT(S)	DESCRIPTION
-performOS {1} {2}	The mandatory argument `-performOS` must be followed by the path and file name of the Optical Setup to be simulated ({1}) and the folder where all output is stored ({2}). Results are written into a `results.xml` file. Complex documents which cannot be saved into this XML file are stored as separate documents, the `results.xml` file then contains only a reference to that file. If warnings or errors occur during the simulation, they are written into a `ProcessingInfo.log` file (unless `-noLogFile` is specified). If *Pop up Error Messages* or *Pop up Warning Messages* is activated in the Global Options dialog (↪Sec. 6.16), the corresponding messages are also shown in a message box. `-performLPD` is a synonym for this command.
-parameters {3}	With this optional argument you can specify a XML file with parameter values. These values are then used for the simulation instead of the original parameter values. You can use File > Export > Create Batch Mode Files to create a sample XML file named `parameters.xml` with the correct format (↪Sec. 130.1).
-engine {4}	With this optional argument you can specify the simulation engine (↪Sec. 44.5) to be used. "0" refers to Classic Field Tracing, "1" to General Profile, "2" to Ray Results Profile, "4" to *System: 3D* visualization, and "6" to Near Field Analysis. Other numbers refer to the index of the analyzer to be used for the simulation. If this parameter is not specified, a suitable default engine is used.
-subfolder	If this optional parameter is specified, a subfolder in the output folder `{2}` is generated where the result and logging files are stored. In this way consecutive calls of the `virtuallab.exe` do not overwrite already calculated results. The name of the subfolder is `<Name of simulation engine> (<Date and Time>)`.
-noLogfile	If this optional parameter is specified, a `ProcessingInfo.log` file is not created and thus errors and warnings get lost. This avoids problems occurring when hundreds of consecutive iterations are started via batch mode.

`virtuallab.exe -performModule {1}`

With this command a module (↪Sec. 7) instead of an Optical Setup can be processed in "batch mode" without VirtualLab Fusion windows. Compiler warnings and errors as well as text messages are written to a `ProcessingInfo.log` file in the same folder as the module. Note that showing results in the VirtualLab Fusion User Interface does not work in the batch mode, so you have to save them to your hard drive.
The parameter {1} is the path and file name of the module.
`-run` is a synonym for this command.

`virtuallab.exe -startupModule {1}`

Loads, compiles and executes an arbitrary module (↪Sec. 7) during startup of VirtualLab Fusion. Afterwards execution of VirtualLab Fusion continues normally. This allows you among others to ensure that certain Global

Options are set during start up, program a timer to remind you every 30 minutes that you need a break or open VirtualLab Fusion files you always need.
The parameter {1} is the path and file name of the module executed during startup.

```
virtuallab.exe -globalOptions {1}
```

Specifies the Global Options file (↪Sec. 6) to be loaded. So you can setup two VirtualLab links on your desktop each using their own Global Options; e. g. one with many digits for numbers and big result windows for setting up systems and the other one with only three digits and default window size for screenshots.

10 License Information Dialog

The licenses of VirtualLab Fusion can be managed using an integrated dialog, which can be found at the Start > License Information ribbon item (↪Fig. 61). Fig. 62 shows the dialog that displays the current license information that is stored in the USB dongle.

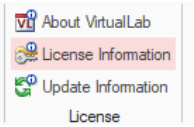


Figure 61. *The License and Update ribbon items of VirtualLab Fusion.*

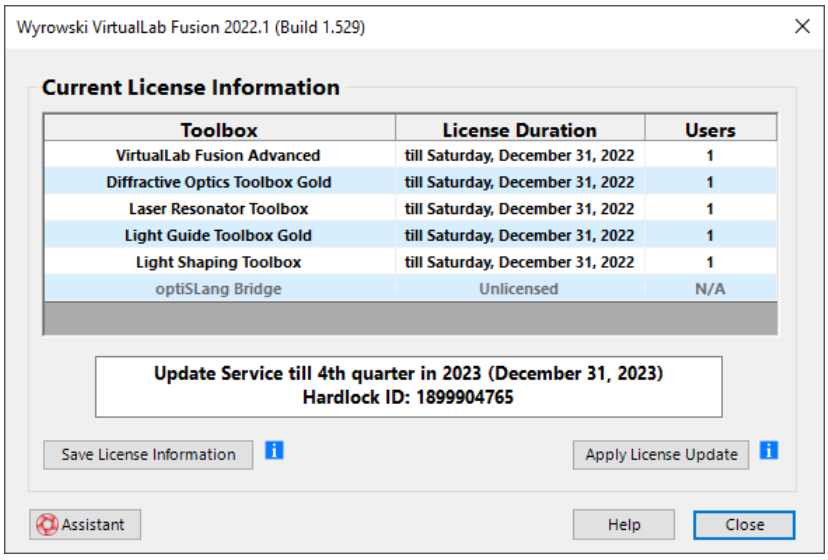


Figure 62. *The dongle dialog to manage the licensing of VirtualLab Fusion.*

The current license status is displayed in the upper section of the dialog. Depending on the license model, the *License Duration* can be

- “Unlimited” or
- an expiration date until which the package can be used .

Also shown is the last quarter the update service is valid for, the number of users for each package and the internal Dongle ID.

In the following we explain how licenses can be added or renewed.
After you have bought additional licenses we will ask you to send us your current license file. This file is obtained by pressing the button *Save License Information* (↪Fig. 63).

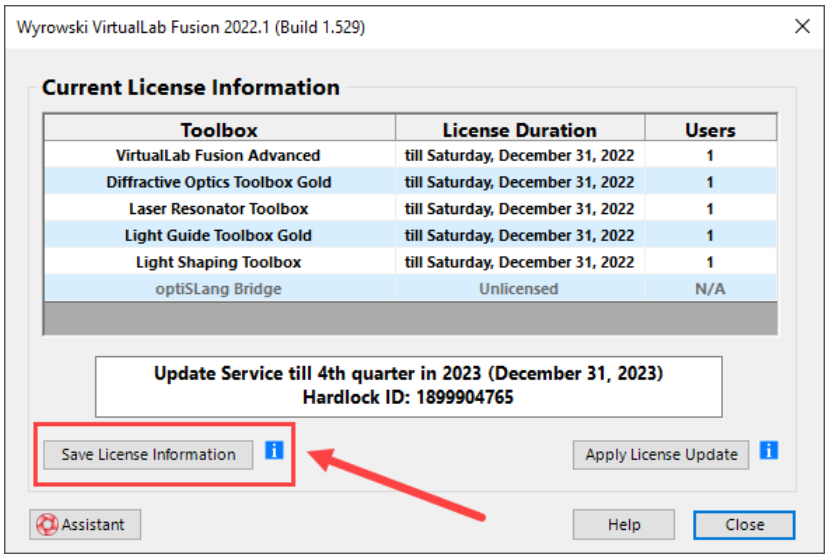


Figure 63. *Press the button “Save License Information”.*

Then a file dialog will be opened, where you can choose the destination for saving the license file (↪Fig. 64). The resulting file has the extension “c2v” and has to be sent by email or ftp to LightTrans.

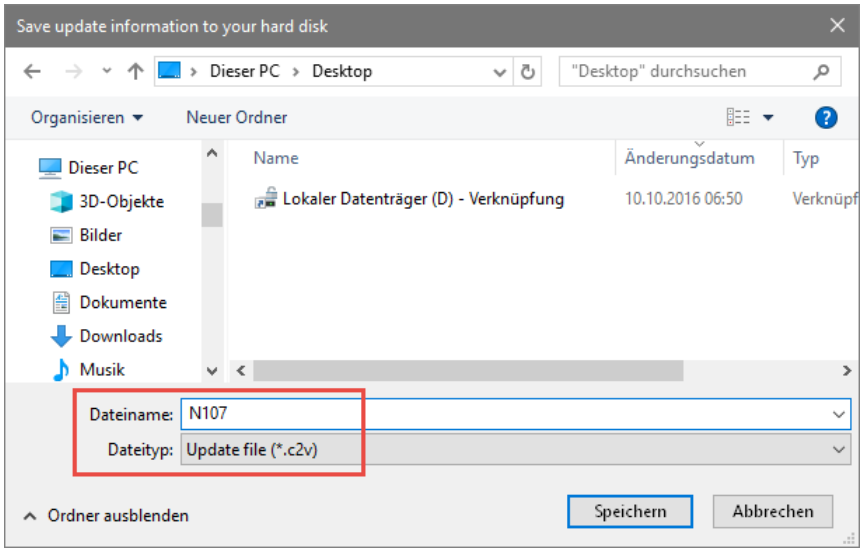


Figure 64. *File dialog for saving the “c2v”.*

You will receive the modified license file from us. In order to activate the new licenses, the file has to be opened by pressing the *Apply License Update* button (↪Fig. 65) in the license information panel.

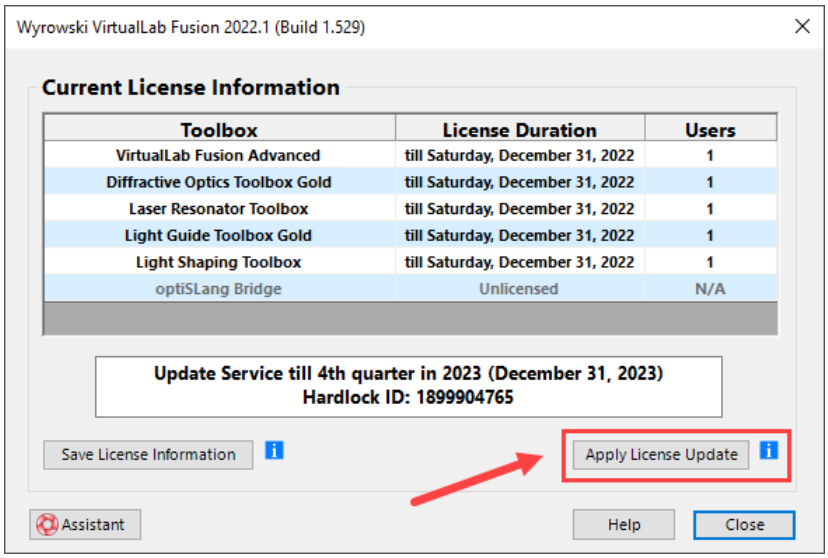


Figure 65. *Press the button “Apply License Update”.*

Thereby another file dialog is shown (↪Fig. 66) and you have to select the received “v2c” file. After this step the license on the USB key is updated and the new license conditions are active for VirtualLab Fusion.

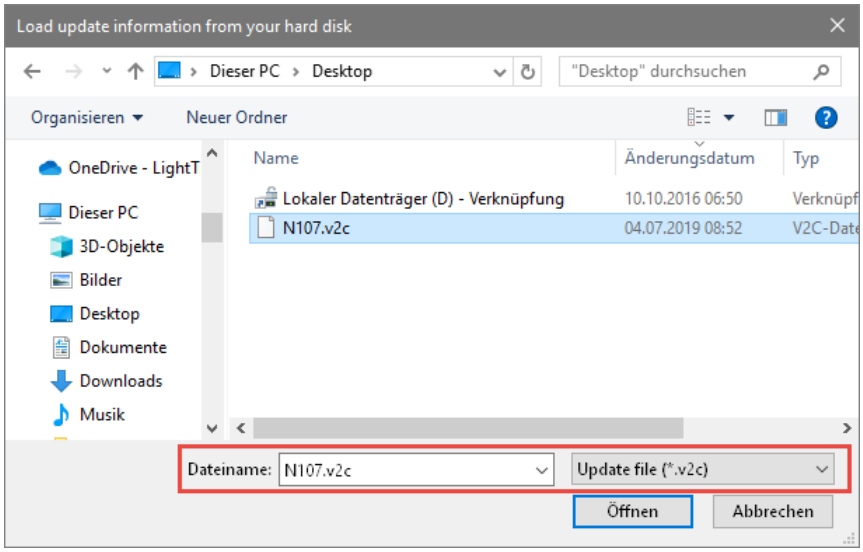


Figure 66. *File dialog for applying the “v2c”.*

III Result Documents

In VirtualLab Fusion there are several document types which show data plotted against one or more coordinates. This part explains these *Result Documents*.

All Result Documents (but Animations) have a View ribbon. Sec. 11 explains most of the entries in that ribbon. The x-axis of all these views points to the right and the y-axis to the top. As a result, if the data represents a light field, its z-axis is directed out of the monitor. Thus you see light always as it would look like through a transparent screen, as least if the light propagates in positive z-direction, ↪Sec. 136.3.

11 Basic Concepts

11.1 Field Quantity

Availability

Only for complex-valued data

Accessible:

- Ribbon: View > Field Quantity ribbon group
- Property browser: *View > Field Quantity*
- Context menu: *Field Quantity*

Often complex-valued data are to be shown, but only real-valued data can be shown in an intuitive way. The *Field Quantity* of a view determines which real-valued data are extracted from the complex-valued data. The following choices are available:

ITEM	DESCRIPTION
$\mathcal{Re}$ **Real part**	Real part a of a complex number $z = a + ib$
$\mathcal{Im}$ **Imaginary part**	Imaginary part b of a complex number $z = a + ib$
$\mathcal{A}$ **Amplitude**	Amplitude A of a complex number $z = A\exp[i\phi]$
φ **Phase**	Phase ϕ of a complex number $z = A\exp[i\phi]$
A^2 **Squared Amplitude**	Squared amplitude A^2 of a complex number $z = A\exp[i\phi]$
A^2_Σ **Summed Squared Amplitudes**	ONLY FOR HARMONIC FIELDS AND HARMONIC FIELDS SETS Sum of the Squared Amplitudes of multiple vectorial components (↪Sec. 12.2.2). If you select this option, there is an additional combobox in the property browser and the context menu, respectively, where you can select which vectorial components are to be combined: E_x and E_y, E_z and E_x, E_z and E_y, as well as all vectorial components, respectively. In the ribbon this can be done via the launcher button ⌟ of the Field Quantity group.

The current field quantity is also displayed in the center of the status bar of each harmonic field view.

11.2 Value Scaling

There are several features which influence the scaling of the values.

11.2.1 Interpolated View

Availability

Only for harmonic fields, harmonic fields sets and 2D chromatic fields sets.

Accessible:

- Ribbon: View > Interpolated View
- Property browser: *View > Interpolated View*
- Context menu: *Interpolated View*

You can apply an interpolation on the view without manipulating the underlying data.

- **If view interpolation is deactivated**, this corresponds to the nearest neighbor interpolation (↪Sec. 13.2.2). The shown value of each screen pixel is determined according to the value of the nearest corresponding data point.
- **If view interpolation is activated**, the output is smoothed using the following interpolation methods (↪Sec. 136.4):
  - Cubic 4 point for two-dimensional data,
  - Cubic 6 point for one-dimensional data.

11.2.2 View Interpolation Modes

Availability

Only for 1D or gridded 2D data array based documents except for 2D chromatic fields sets.

Accessible:

- Ribbon: View > Value Scaling > No Interpolation / Pixelated View / Interpolated View / (Real-Valued) Smoothing
- Property browser: *View > View Interpolation > No Interpolation / Pixelated View / Interpolated View / Real-Valued Smoothing*
- Context menu: *View Interpolation > No Interpolation / Pixelated View / Interpolated View / (Real-Valued) Smoothing*

The views of data-array based documents (↪Sec. 13) can be smoothed without changing the contained data. The following options are available:

- **No Interpolation:** AVAILABLE FOR 1D DOCUMENTS ONLY
  Only the values at the data point coordinates will be drawn.
- **Pixelated View:** The value of the nearest neighbor (in equidistant case) or of the neighbor with the nearest lower coordinate (in non-equidistant case) will be shown. This will result in some kind of ”stepped” curve (1D) or pixelated diagram.
- **Interpolated View:** ONLY AVAILABLE IF A SMOOTHING INTERPOLATION METHOD IS STORED WITH THE DOCUMENT
  The interpolation which is stored at the displayed object will be used for smoothing the view.
- **(Real-Valued) Smoothing:** AVAILABLE IF THE DOCUMENT IS COMPLEX-VALUED OR IF NO SMOOTHING INTERPOLATION METHOD IS STORED WITH THE DOCUMENT
  A cubic 6 point interpolation (in equidistant case) or a linear interpolation (in non-equidistant case) is applied for smoothing the shown data. In case of complex-valued data the interpolation will be applied to

the currently shown field quantity (amplitude, phase, real part, imaginary part, squared amplitude) only, i.e. the smoothing works real-valued.

11.2.3 Triangle Interpolation

Availability

Only for dot diagrams

Accessible:

- Ribbon: View > Show Triangles
- Property browser: *View > Show Triangles*

Using *Show Triangles* you can obtain a smooth data representation out of dot diagram. In this mode, the *View* tab of the property browser has an additional option to *Show Triangles Borders*. The effect of these two options is illustrated in Fig. 67.

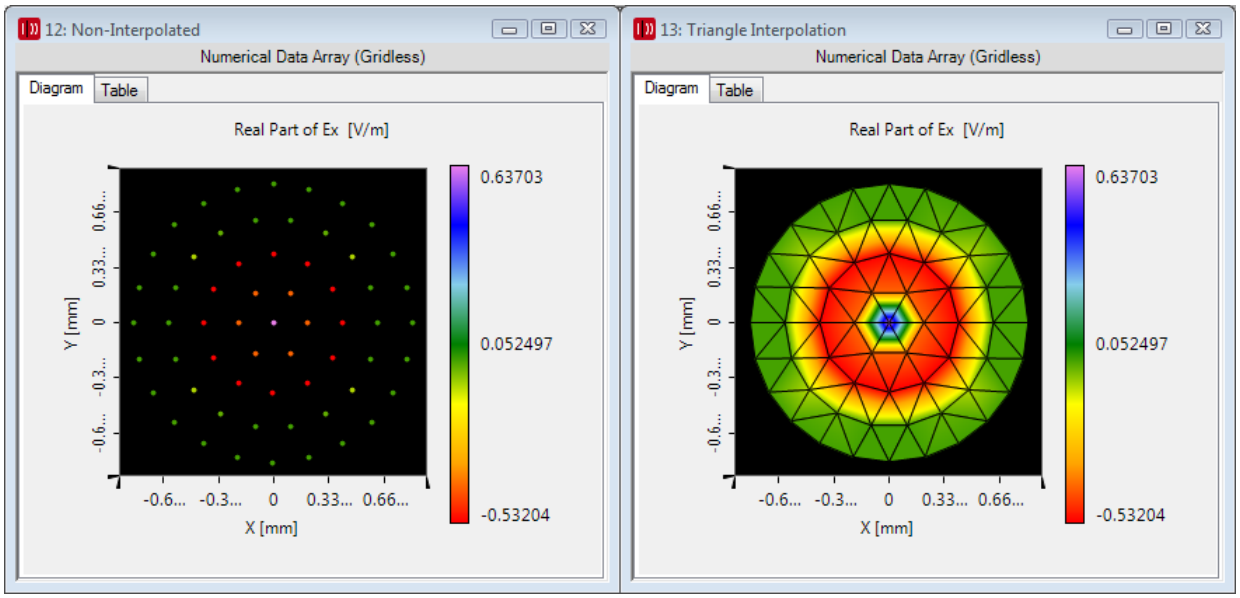


Figure 67. *The left window shows the normal dot diagram. The right window shows the same data with* Show Triangles *and* Show Triangles Borders*.*

11.2.4 Color Tables

Availability

For documents based on 2D data arrays, Jones Matrix Transmissions, Harmonic Fields, and Harmonic Fields Sets

Accessible:

- Ribbon: View > Value Scaling group
- Property Browser: *View > Color Table*
- Context menu: *Color Table*

For two-dimensional views, several color tables are available. The principle of the mapping of colors to data values in the range $[x_{\min}, x_{\max}]$, is shown in Fig. 68.

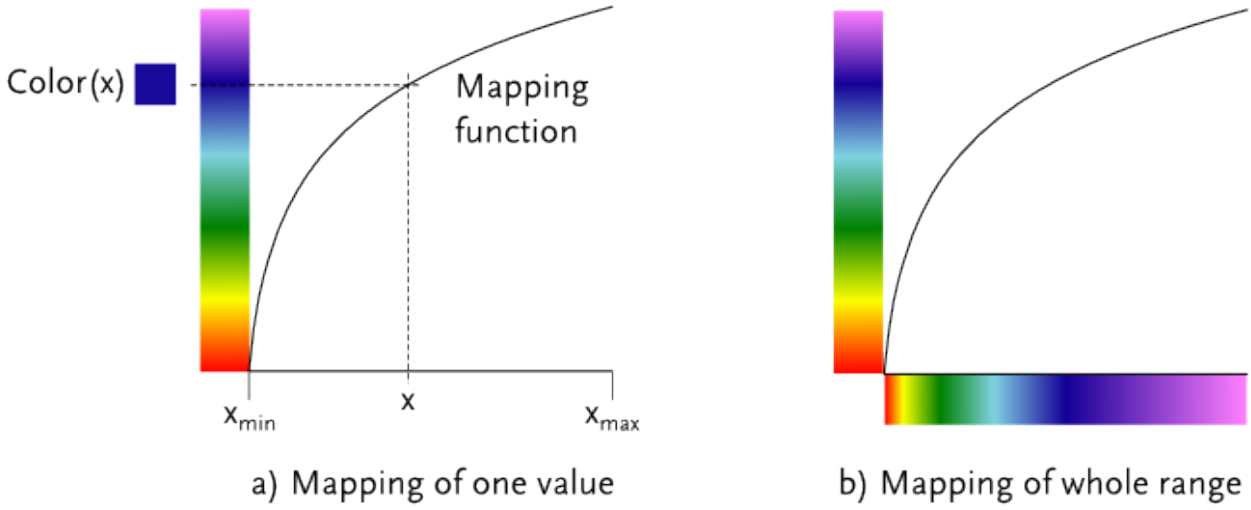


Figure 68. *Principle of color mapping via color table. a) Mapping of one value x, b) Mapping of the whole range $[x_{min}, x_{max}]$*

Via the View ribbon, the Property Browser or the context menu you can choose from a list of color tables. The tables can be managed via View > Manage Color Tables or the Global Options dialog (↪Sec. 6.9). The corresponding dialog is described in Sec. 11.2.4.1.
You can edit the current table via the ribbon item Start > Edit Color Table or via context menu item *Color Table > Edit Color Table...*. In this case the dialog described in Sec. 11.2.4.2 opens.
For the view of two-dimensional Numerical Data Arrays or some view modes of objects that contain Data Arrays, a distinct color table per field quantity (↪Sec. 11.1) can be set.

11.2.4.1 Managing Color Tables

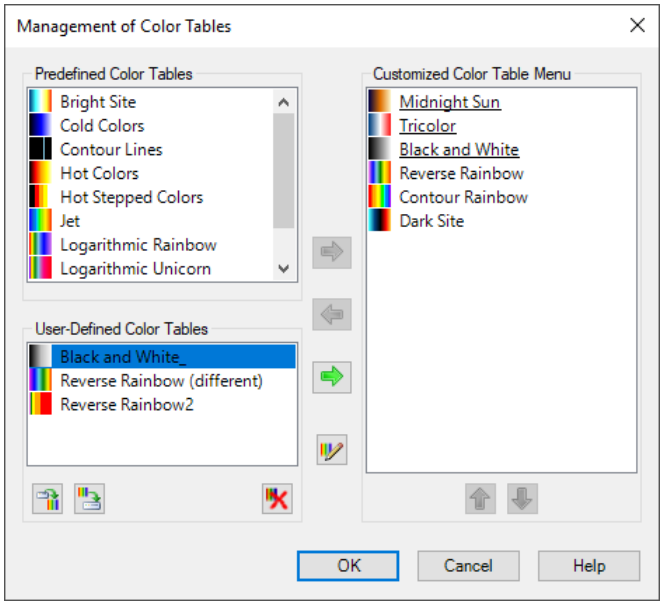


Figure 69. *Dialog for managing the color tables.*

On the left-hand side of this dialog (↪Fig. 69) you have two lists of color tables: *Predefined Color Tables* provided by Wyrowski Photonics and *User-Defined Color Tables*. On the right-hand side you have the *Customized Color Tables Menu*. This is the menu shown among others in the View ribbon, the Property Browser, and the context menu. You can add a color table to this menu from any of the lists on the left-hand side using the

corresponding button or by double-clicking. Conversely, you can move an entry from the customized menu back to the “stock” with the button or by double-clicking.
The entries in the *Customized Color Table Menu* can be sorted with the and the button, respectively. Entries which are used as default for certain field quantities (↪Sec. 6.9) are underlined.
The currently selected color table can be edited with the button. Then the dialog described in Sec. 11.2.4.2 opens. Each color table has to have a unique name.
The *User-Defined Color Tables* section has the following additional buttons:

BUTTON	DESCRIPTION
	Imports a previously exported color table from a file. If the name of the imported color table is already used, a “ (1)” is appended to its name.
	Exports a color table to a file.
	Deletes the currently selected user-defined color table.

11.2.4.2 Editing a Color Table

Each color table can be edited via the dialog shown in Fig. 70.

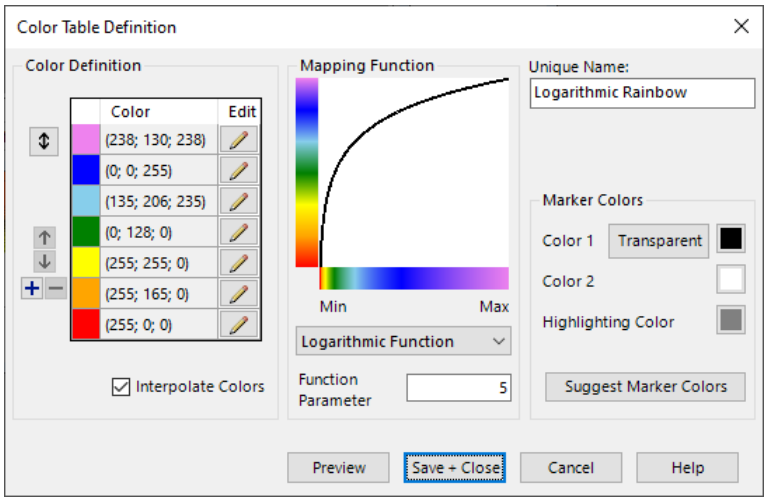


Figure 70. *Edit dialog for a color table.*

ITEM	DESCRIPTION
	Inverts the color sequence.
	Moves the selected color up.
	Moves the selected color down.
	Inserts a new color to the sequence.
	Removes the selected color from the sequence.
	Allows to edit the selected color.
Interpolate Colors	If checked, a linear interpolation is applied to the color sequence, so a smooth color profile is mapped to continuous data values. Otherwise, discrete colors are mapped.

Mapping Function	The type of the function that maps colors to data values can be selected here. • *Linear Function*: The color index c_{lin} for a given value v and normalized to the range $[0 \ldots 1]$, is calculated via $c_{lin} = (v - \min)/(\max - \min)$. The values $\min$ and $\max$ define the data value range to be shown in the view ($\min <= v <= \max$). • *Exponential Function*: At first, the linear color index c_{lin} is calculated from value v according to the formula given for the *Linear Function*. At second, the color index c_{exp} is calculated via $c_{exp} = (e^{c_{lin} \cdot p} - 1) \,/\, (e^p - 1)$. The parameter p is the *Function Parameter* which has to be defined separately. • *Logarithmic Function*: At first, the linear color index c_{lin} is calculated from value v according to the formula given for the *Linear Function*. At second, the color index c_{log} is calculated via $c_{log} = \ln(c_{lin}(e^p - 1) + 1) \,/\, p$. The parameter p is the *Function Parameter* which has to be defined separately. • *Power Function*: At first, the linear color index c_{lin} is calculated from value v according to the formula given for the *Linear Function*. At second, the color index c_{pow} is calculated via $c_{pow} = c_{lin}^p$. The parameter p is the *Function Parameter* which has to be defined separately.
Function Parameter	All available types of mapping functions, except from *Linear Function*, allow to specify one parameter p which can be set here. It influences the slope of the selected mapping function and has to lie within the interval $]0 \ldots 100]$.
Unique Name	The unique name of the color table. This is the name under which it is stored in the list of user-defined color tables (↪Sec. 11.2.4.1). If you close the dialog and there is already a user-defined color table with the same name, you can choose whether to change the name or to overwrite the old color table.
Marker Color 1	First color to be used for selection markers like rectangular / elliptic marker or line marker.
Transparent	The *Color 1* may be transparent. So transparency can be switched on and off here.
Marker Color 2	Second color to be used for selection markers like rectangular / elliptic marker or line marker.
Highlighting Color	Sometimes some parts of a marker have to be highlighted. The color to be used for this can be set here.
Suggest Marker Colors	Pressing this button will suggest some colors which can be used as marker colors.
Preview	When you edit the color table of a document window, there is a *Preview* button. If you click it, the current color table is directly applied to the document window (but *Cancel* still reverts it back to the original color table).

Note on marker colors

For Jones Matrix Transmissions, Harmonic Fields, and Harmonic Fields Sets, *Marker Color 2* is used to draw the markers. For drawing polarization ellipses (↪Sec. 12.2.3), marker color 1 and 2 are used (depending on their direction of rotation). The polarization grid is drawn with the *Highlighting Color*.

11.2.4.3 Display of Undefined Values

In some cases, a data point of a Data Array, Chromatic Fields Set etc. does not contain a defined numerical value. This may be e. g. a result of a division by zero.
Since this kind of value can not be mapped onto a color via a color table, it will be marked by an independently defined color. This may look like shown in Fig. 71.

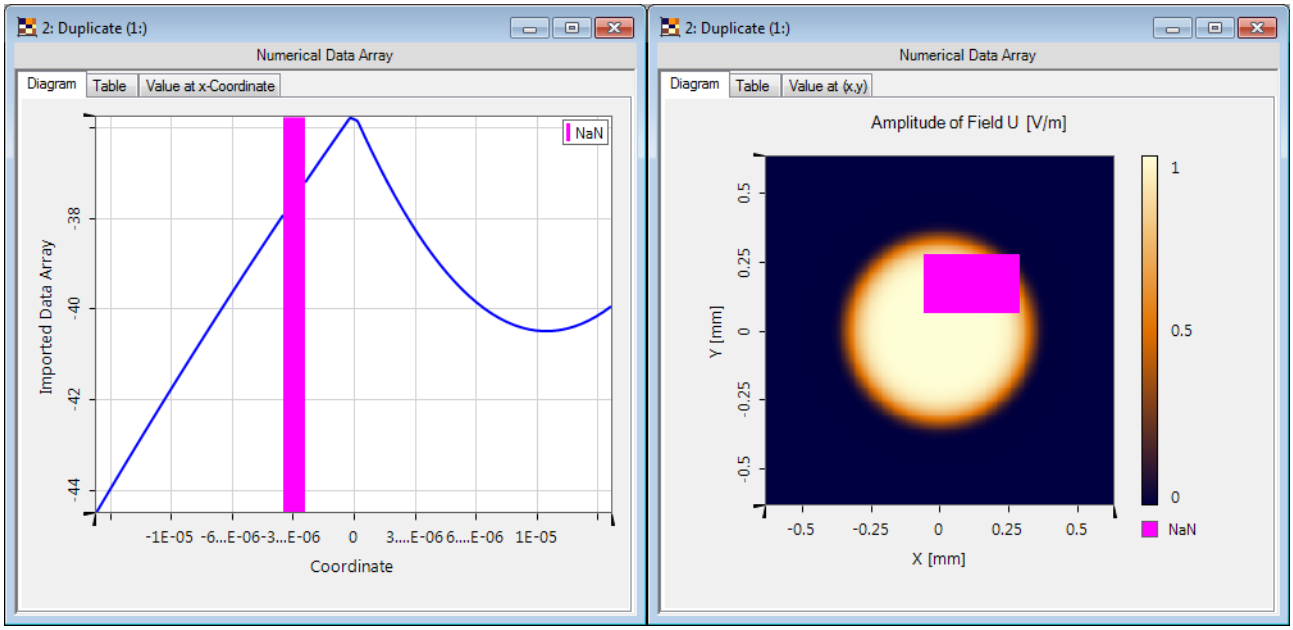


Figure 71. *Example for the color indicator of undefined values.*

The color which indicates undefined values can be set via property browser (↪Sec. 13.4.1.2 and Sec. 13.4.1.3). The Global Options dialog allows to define the default colors to be used for 1D views and 2D views (↪Sec. 6.8 and Sec. 6.9).

11.2.5 Scaling Mode

Availability

Accessible:

- Ribbon: View > Scaling Mode ribbon menu
- Property browser: *View > Scaling Mode* (for Harmonic Fields and Harmonic Fields Sets)
  View > Auto Scaling of Data (for data array based documents)
- Context menu: *Scaling Mode* (for Harmonic Fields and Harmonic Fields Sets)

The upper and the lower limit of the chosen color palette (↪Sec. 11.2.4) are mapped to the minimum and maximum value of the currently visible field quantity (↪Sec. 11.1). There are three possibilities of how the minimum and maximum values are determined:

ITEM	DESCRIPTION
Automatic Scaling	The minimum and maximum values are calculated from the field.
Standard scaling	ONLY FOR HARMONIC FIELDS AND HARMONIC FIELDS SETS This mode depends on the selected field quantity (↪Sec. 11.1). For real and imaginary part the value range [-1, 1] is used. The standard value range for amplitude and intensity is [0, 1], and for phase it is $[-\pi, \pi]$.
User-Defined Scaling	The *Displayed Data Range* can be specified within the *View* panel of the property browser.

There is also the possibility to use *User-Defined Scaling* in a way that a marked rectangular / elliptical or one-dimensional range is scaled optimally:

ITEM	DESCRIPTION
Selection Based Scaling	The minimum and maximum values of the view are set to the value range within the current rectangle / elliptical or range selection (↪Sec. 11.3.4).

In one-dimensional views, the value range determines the range of the y-axis. In two-dimensional views, the value range is displayed besides the color scale on the right hand side.

11.2.6 Brightness

Availability

For the two-dimensional views showing real colors

Accessible:

- Ribbon: see below
- Property browser: *View* > *Brightness Factor*

For documents showing real colors a brightness factor can be used to make darker regions visible. A factor of 1.0 refers to the brightest image where the colors are not yet distorted due to overexposure.
You can enter the brightness factor directly in the View tab of the ribbon or the property browser. Or you use the controls shown in Fig. 72. The left bulb decreases the brightness by 0.1, while the left bulb increases it by the same amount.

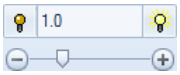


Figure 72. *The controls for adjusting the brightness in the View tab of the ribbon*

However, the eye is a logarithmic “detector” (Weber-Fechner law). Thus you often need quite large brightness factors to see the desired dark regions. To compensate this, there is an exponential trackbar below the bulbs. With it you can set the brightness to powers of $\sqrt[5]{10}$.
The minimum brightness is 0.1 and the maximum brightness is 1000.

11.3 Markers and Selections

Availability

…for Selection Mode

Accessible:

- Ribbon: View > Selection Mode ribbon menu
- Property browser: *View > Selection Mode* (for data array based documents)
- Context menu: *Selection Mode*

Within a diagram view, a portion of the displayed data can be selected for further evaluations and operations, e. g. the *Selection Based Scaling* (↪Sec. 11.2.5) or the *Normalize with Respect to Selection* (↪Sec. 22.9). Fig. 73 shows a selection example for a 1D data array, Fig. 74 an example for the 2D view of a 2D data array.

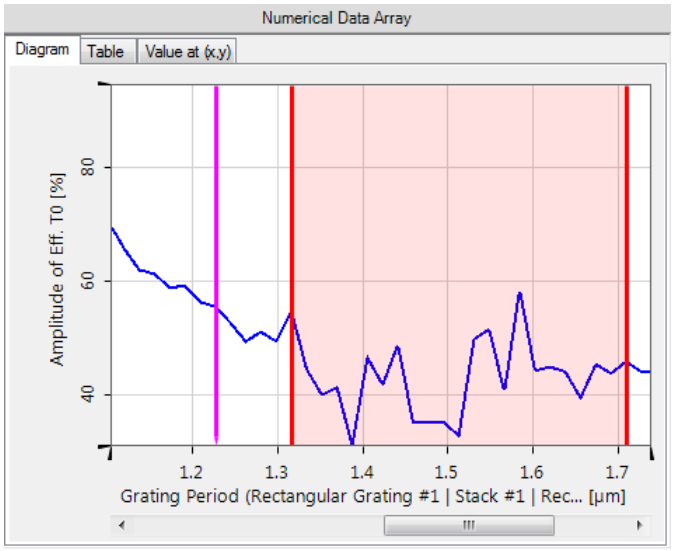


Figure 73. *Example for the point marker (Magenta) and the range marker (Red) in a 1D Numerical Data Array view.*

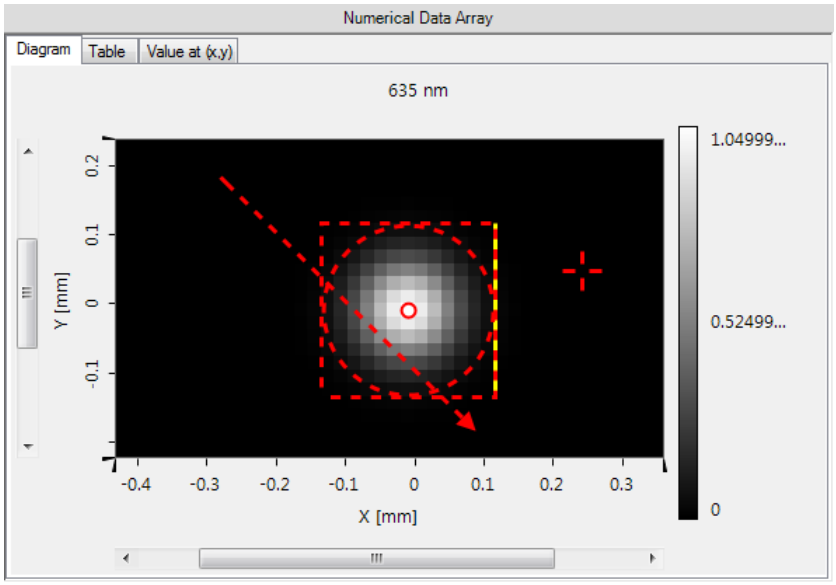


Figure 74. *Example for the point marker, the line marker, and the elliptic / rectangular marker in a 2D Numerical Data Array view.*

Each kind of marker can be drawn into a view with the mouse if the corresponding *Selection Mode* is selected. There are four modes for 2D views:

- *Rectangle or Ellipse Marker*[1]
- *Line Marker*
- *Point Marker*
- *No Marker*

And there are three modes for 1D views:

- *Range Marker*
- *Point Marker*
- *No Marker*

If the corresponding mouse mode is selected, then the markers can be configured with the mouse as follows:

MARKER	MANIPULATION POSSIBILITIES
Point Marker	• Set the point marker at a certain position by left-clicking there. • Move the point marker either via arrow keys or by dragging with the mouse.
Line Marker	• Set the line marker by left-clicking on the desired start position, keeping the left mouse button pressed while moving to the desired end position. The end position of the resulting line marker is marked with an arrow head. Restricted line angles can be achieved holding Ctrl pressed while dragging. • Change either the start or the end position by dragging with the mouse. Restricted line angles can be achieved holding Ctrl pressed while dragging. • Move the line marker either via arrow keys or by dragging the line center (marked by a circle) with the mouse. • Create a maximized default line marker by double-clicking on the view.
Range Marker	• Set the range marker by left-clicking on the desired position of one border, keeping the left mouse button pressed while moving to the desired opposite border. • Change any of the borders by dragging with the mouse. • Move the range marker either via arrow keys or by dragging the range center (marked by a half-circle). • Create a maximized range marker by double-clicking on the view.
Rectangle Marker	• Set the rectangle marker by left-clicking on the desired position of one corner, keeping the left mouse button pressed while moving to the desired opposite corner. • Change any of the borders by dragging with the mouse. • Change any of the corners by dragging with the mouse. • Move the rectangle marker either via arrow keys or by dragging the center of the rectangle (marked by a circle) with the mouse. • Create a maximized rectangle marker by double-clicking on the view.

Note that the *Selection Mode* is the same for all document windows. If you change it for a one- / two-dimensional document, you change it for all other one- / two-dimensional documents as well.

[1] The ellipse marker is only available for gridded data array based documents. You can switch between elliptic marker and and rectangular marker with the *Selections > Elliptic Selection* entry of the Property browser.

For Harmonic Fields and Harmonic Fields Sets, the markers are drawn red or black, the latter for rainbow or reverse rainbow color scale. For 1D data array based documents the point marker is drawn magenta and the range marker is drawn red. For 2D data array based documents the colors of the markers can be set in the edit dialog of the currently used Color Table (↪Sec. 11.2.4.2).
If a line marker is visible, the current cross section defined by the marker is shown below the 2D data.
After you have defined a marker (↪Sec. 11.3) it stays visible in the view until you turn it off. This can be done as follows.

Availability

…for Marker Visibility

Accessible:

- Ribbon: View > Show … Marker
- Property browser:
  - For Harmonic Fields and Harmonic Fields Sets: *View > Display Selection Marker*, *View > Display Profile Line*, and *Point Manipulation > Display Marker*, respectively
  - For data array based documents: *View | Selections > Show Rectangle or Ellipse Marker*, *View | Selections > Display Range Marker*, *View | Selections > Display Line Marker*, and *View | Selections > Display Point Marker*, respectively
- Context menu: *Marker Visibility*

11.3.1 Setting Exact Marker Coordinates

In the Property Browser you can set the exact coordinates either in point or in physical coordinates. This can be done at different locations for data array based documents or for Harmonic Fields and Harmonic Fields Sets which are summarized in the following table.

MARKER	DATA ARRAY BASED DOCUMENTS	HARMONIC FIELDS (SETS)
Point Marker	Property Browser: *Selections > Selection (Point)*	Property Browser: *Point Manipulation > Clicked Position*
Line Marker	Property Browser: *Selections > Selection (Line)*	Property Browser: *View > Profile Line*
Range Marker	Property Browser: *Selections > Selection (Range)*. The … button opens the dialog described in Sec. 11.3.1.1. Ribbon: View > Selection Tools > Edit Range Marker Coordinates (↪Sec. 11.3.1.1)	Property Browser: *View > Selection (Range)* Ribbon: View > Selection Tools > Edit Range Marker Coordinates (↪Sec. 11.3.1.1)
Region Marker	Property Browser: *Selections > Selection (Region)*. The … button opens the dialog described in Sec. 11.3.1.2. Ribbon: View > Selection Tools > Edit Rectangular Marker Coordinates (↪Sec. 11.3.1.2)	Property Browser: *View > Selection (Region)* Ribbon: View > Selection Tools > Edit Rectangular Marker Coordinates (↪Sec. 11.3.1.2)

In the Property Browser of data array based documents you can set *Selections > Coordinate Snapping Selection* to false. Then the markers no longer “snap” to the sampling points. Consequently, you then can enter the marker coordinates only in physical coordinates, not in point coordinates.

For gridless 2D data arrays and ray tracing results, coordinate snapping is **never** active for the rectangle marker and always active for the line and the point marker. Thus in the Property Browser this option is not shown. Furthermore, you cannot change the coordinates of the line and the point marker in the Property Browser, and elliptic selections are not available.

11.3.1.1 Edit Range Marker Coordinates

By clicking View > Selection Tools > Edit Range Marker Coordinates an edit dialog for editing the range marker coordinates opens.

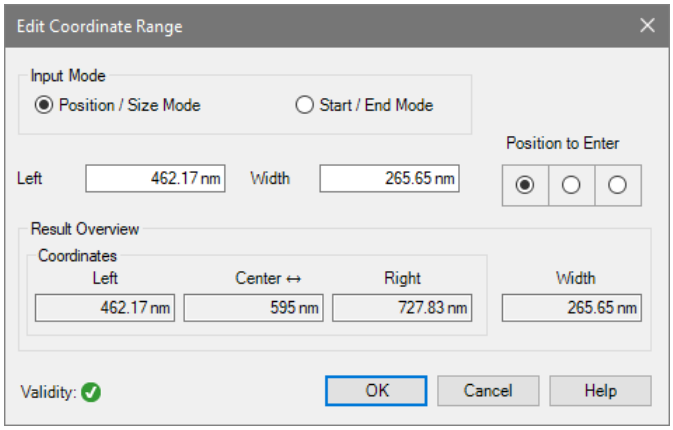


Figure 75. *Dialog for editing the coordinates of a range marker in the view of a Numerical Data Array or Data Array based document.*

Available options:

ITEM	DESCRIPTION
Position / Size Mode	If selected, the input values will be one coordinate and size of the range.
Start / End Mode	If selected, the input values will be the left coordinate and the right coordinate of the range.
Position to Enter	AVAILABLE IN *POSITION / SIZE MODE* ONLY. The coordinate which is to be set can be specified here.
Left / Right	The left or right border coordinate.
Center ↔	The center coordinate.
Width	The width spanned by the range.
The coordinates are descending.	A note which indicates that the coordinates to be edited are descending coordinates.

11.3.1.2 Edit Rectangular Marker Coordinates

By clicking the ribbon item View > Selection Tools > Edit Rectangular Marker Coordinates an edit dialog for editing the rectangular marker coordinates opens.

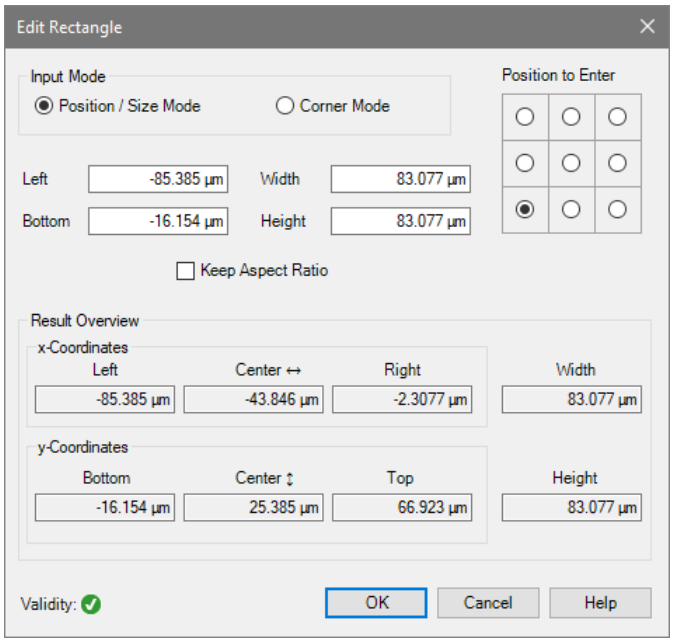


Figure 76. *Dialog for editing the coordinates of a rectangular or elliptic marker in the view of a Numerical Data Array or Data Array based document.*

Available options:

ITEM	DESCRIPTION
Position / Size Mode	If selected, the input values will be one pair of coordinates and width and height of the rectangle.
Corner Mode	If selected, the input values will be the bottom-left-coordinates and the top-right-coordinates of the rectangle.
Position to Enter	AVAILABLE IN *POSITION / SIZE MODE* ONLY. The pair of coordinates which are to be set can be specified here.
Left / Right	The left or right border coordinate.
Bottom / Top	The bottom or top coordinate.
Center ↔ / Center ↕	The horizontal center or vertical center coordinate.
Width / Height	The width or height.
Keep Aspect Ratio	If selected, changing the width or height will adapt the corresponding size in order to keep the aspect ratio constant.

11.3.2 Point Information

If a point marker is visible, the *Selections* tab of the Property Browser (it is named *Point Manipulation* for Harmonic Fields and Harmonic Fields Sets) shows the data at the selected location as shown in Fig. 77.

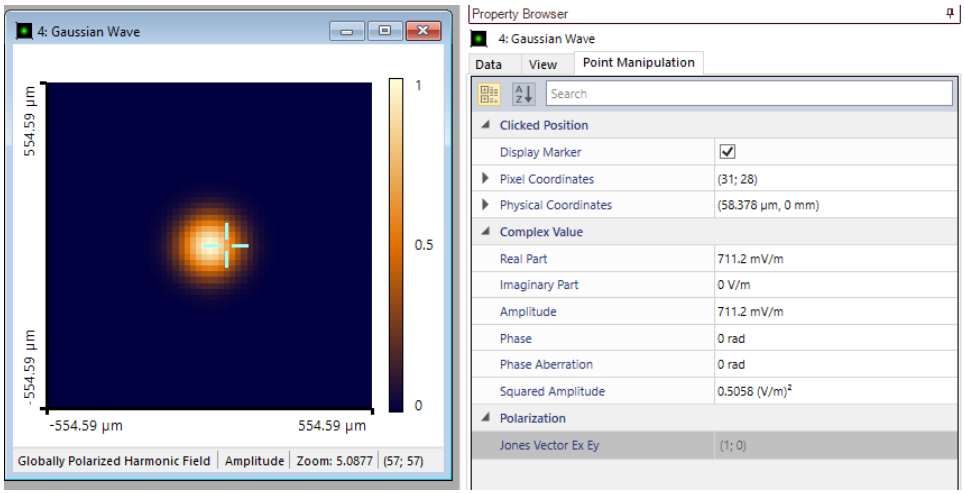


Figure 77. *Example for using the point marker. In the left, there is a field with activated point marker. The corresponding values at this position are displayed in the property browser (right).*

For complex data, real and imaginary part, amplitude, squared amplitude, and phase are shown. For real color display (↪Sec. 14.2) of Chromatic Fields Sets, the RGB values at the current position are shown.

For data array based documents, you can also retrieve interpolated values between adjacent data points if *Selections > Coordinate Snapping Selection* in the Property Browser is set to 'false'. Usually the interpolation method (↪Sec. 13.2) of the data array is used. If *Selections > Use Own Interpolation Method* is set to 'false' instead, nearest neighbor interpolation (or constant interval interpolation, in case of non-equidistant data) will be used.

For data array based documents there is another, faster access to a point's value however. One has to hover the mouse cursor above the point of interest holding the `Shift` button pressed. A tooltip-kind-of label will appear then, showing the coordinates currently hovered above as well as the data value(s) at this position as shown in Fig. 78.

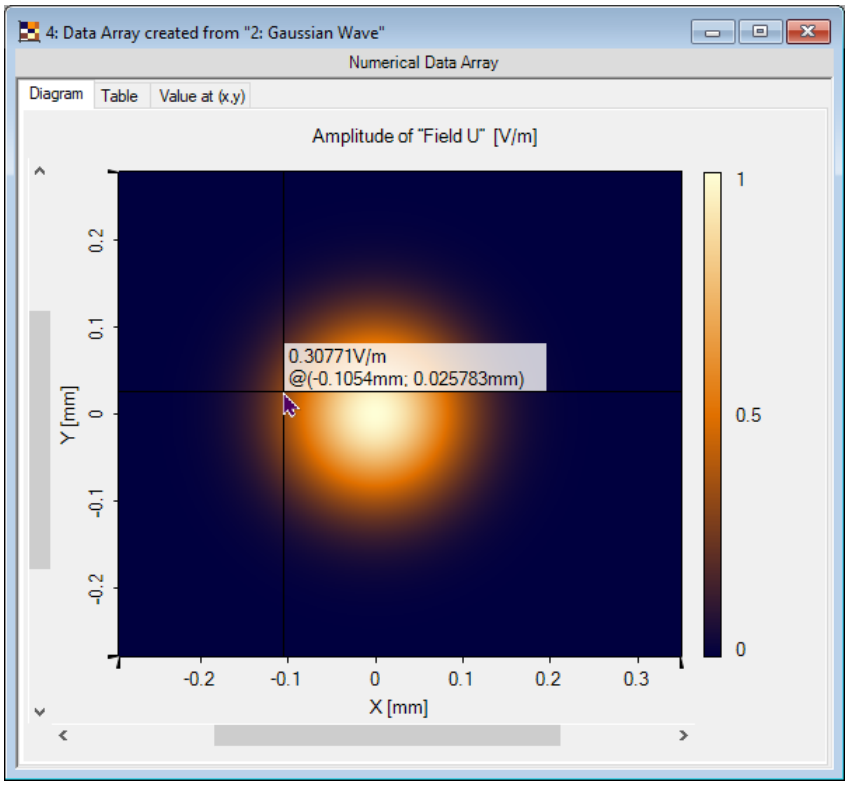


Figure 78. *If the mouse cursor is moved over the view of a data array based document, a tooltip-like label shows value and coordinates.*

11.3.3 Point Manipulation

For Harmonic Fields and Harmonic Fields Sets, single point data may be manipulated via the property browser tab named *Point Manipulation*, shown in Fig. 77 (right-hand side). The new value just has to be entered there. In case of data array based documents, the workflow is different. The values on the *Selections* tab of the Property Browser are read-only, but single point values can be edited in the *Value at (x, y)* tab of the document view itself as described in ↪Sec. 13.4.3.

11.3.4 Selection Tools

Within the View > Selection Tools menu there are various selection tools which ease setting up a selection:

ITEM	DESCRIPTION
Select All	Sets a rectangle or range marker which includes the whole data.
Center Range / Rectangular Selection	The center of the selection is set to e. g. $(0\,\mathrm{m}; 0\,\mathrm{m})$ if both axes have the physical quantity *Length*.
Edit Range Marker Coordinates	Opens a dialog for editing the coordinates of the marker (↪Sec. 11.3.1.1).
Edit Rectangular Marker Coordinates	Opens a dialog for editing the coordinates of the marker (↪Sec. 11.3.1.2).
Detect Rectangular / Range Selection	Detects a selection containing a given power portion (↪Sec. 11.3.4.1).
Retrieve Marker Coordinates for Data Array Based Documents	Copies the physical coordinates of all markers from another document window. If a marker to copy does not fully fit into the coordinate ranges of the axes, it is truncated accordingly. But if it lies completely out of the data, it is not copied. Note that coordinate snapping (↪Sec. 11.3.1) and different physical units might cause the copied markers to be not at the expected location.
Retrieve Rectangular Marker Coordinates for Harmonic Fields (Sets)	Copies the physical coordinates of the rectangular (or range) marker from another document window. If the marker to copy does not fully fit into the coordinate ranges of the axes, it is truncated accordingly.

The exact coordinates of a selection can also be edited using the Property Browser (↪Sec. 11.3.2).

11.3.4.1 Detect Rectangular / Range Selection

By using either the ribbon item View > Selection Tools > Detect Rectangular Selection or View > Selection Tools > Detect Range Selection, the selection within a view can be set to the smallest possible selection which contains a given portion of the amplitudes sum or the squared amplitudes sum of the whole data. Which of the two ribbon items is available depends on the dimensionality of the data in the current document.

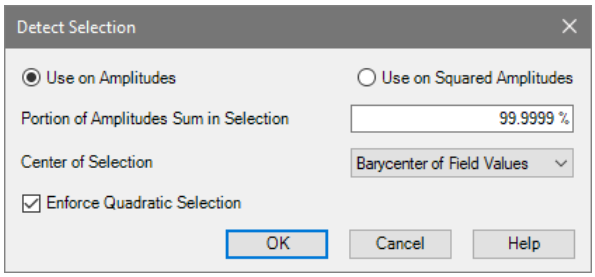


Figure 79. *Dialog for detecting selections (for a Numerical Data Array).*

The dialog shown in Fig. 79 allows you to set the following parameters for this operation.

ITEM	DESCRIPTION
Use on Amplitudes / Use on Squared Amplitudes	Allows you to set whether the amplitudes sum or the squared amplitudes sum is evaluated. This choice is only available for certain document types (see below).
Portion of (Squared) Amplitudes Sum in Selection	Portion of the (squared) amplitudes sum of the whole data to be contained in the selection.
Center of Selection	You can choose between three options: • *Automatic*: No specific center point is used. The algorithm just tries to minimize the resulting selection. • *Barycenter of Field Values*: The selection will be centered around the barycenter of the field values (= the power center for Harmonic Fields and Harmonic Fields Sets). • *Window Center*: The resulting selection will be in the center of the window.
Enforce Quadratic Selection	ONLY FOR EQUIDISTANT DATA If checked, the number of contained sampling points in x- and y-direction is equal and odd (which maintains an eventual symmetry better).

Depending on from where this selection tool is executed the names and visibility of the controls mentioned above differs. For example Harmonic Fields and Harmonic Fields Sets **always** contain electric field strength data. In this case it is more intuitive to use a certain portion of the power of the whole field, which is proportional to the squared amplitudes sum. Thus:

- For a Harmonic Field you always determine a portion of the power.
- For a Jones Matrix Transmission you always determine a portion of the squared values sum.
- For a complex-valued Numerical Data Array or data array based document you can choose whether you want to determine a portion of the amplitudes sum or of the squared amplitudes sum (as described above).
- For a real-valued data array based document you always determine a portion of the values sum.
- For a real-valued Numerical Data Array you can choose whether you want to determine a portion of the values sum or of the squared values sum.

11.4 Zoom

Availability

Accessible:

- Ribbon: View > Zoom In, View > Zoom Out, View > Show All, View > Zoom Into Selection, View > Data Restricted Zoom
- Property Browser: see below
- Context menu: *Zoom*
- Shortcuts: Ctrl++ (numpad) to zoom in, Ctrl+- (numpad) to zoom out, and Ctrl+0 (numpad) to show all.

Four operations are available to change the zoom factor:

ITEM	DESCRIPTION
Zoom In	Increase zoom factor by factor $\sqrt{2}$.
Zoom Out	Decrease zoom factor by factor $\sqrt{2}$.
Show All	Show the whole field. This is the default for newly created fields.
Zoom Into Selection	Set the visible area equal to the current range / rectangle selection.
Center to Origin	AVAILABLE FOR ALL VIEWS EXCEPT THAT OF HARMONIC FIELDS, HARMONIC FIELDS SETS AND JONES MATRIX TRANSMISSIONS Centers the view to the coordinate origin (0, 0) in case of 2D data, 0 in case of 1D data, no matter whether or not the origin lies within the coordinate range of the sampled data. If it lies outside, *Data Restricted Zoom* is deactivated automatically.
Data Restricted Zoom	AVAILABLE FOR ALL VIEWS EXCEPT THAT OF HARMONIC FIELDS, HARMONIC FIELDS SETS AND JONES MATRIX TRANSMISSIONS Toggles the *Data Restricted Zoom* state, see Sec. 11.4.1.

Inside the *View* panel of the Property Browser, you can set the visible view area using the following options:

- *Coordinate Range*: Allows to set the coordinate range of 1D diagrams directly.
- *x-Axis Range / y-Axis Range*: Allows to set the coordinate ranges of 2D diagrams directly.
- *Zoom Factor*: Allows to set the zoom factor, given in *Zoom Factor Unit/s*. That means that a zoom factor of z corresponds to z screen pixels covering the physical value range given in *Zoom Factor Unit/s*.
- *Data Restricted Zoom*: AVAILABLE FOR ALL VIEWS EXCEPT THAT OF HARMONIC FIELDS, HARMONIC FIELDS SETS AND JONES MATRIX TRANSMISSIONS
  Toggles the *Data Restricted Zoom* state, see Sec. 11.4.1.
- *Show Rectangle/Markers for Whole Extension*: If *Data Restricted Zoom* is deactivated, this option allows to toggle the visibility of a rectangular/range marker which shows the domain covered by the actual given data.

Furthermore, you can use the mouse wheel to zoom in or out by a factor $\sqrt{2}$ at the position of the mouse cursor.

11.4.1 Data Restricted Zoom

With a few exceptions, most of the diagram views provide the feature of toggling the *Data Restricted Zoom* state. If activated (the default), the maximum view area for a diagram is the range covered by the underlying data. So, if the complete domain with defined data is shown, no more zoom out is possible. However, if the *Data Restricted Zoom* is deactivated, the user may zoom out (nearly) unlimited. An example is shown in Fig. 80.

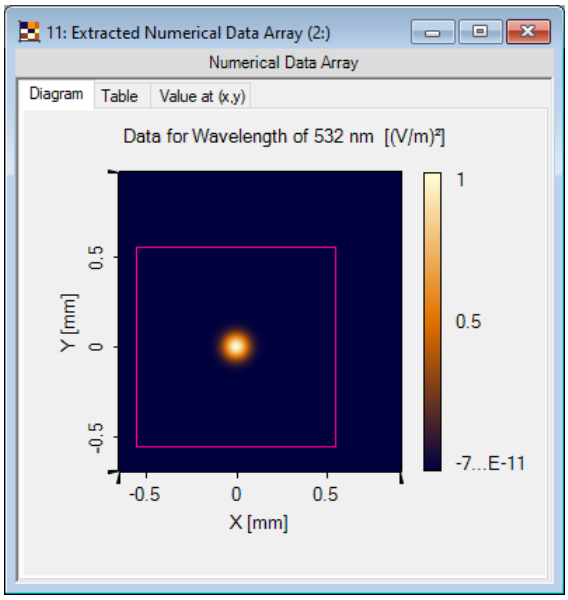


Figure 80. *Example for unrestricted zoom out. The actual domain of the underlying data is marked by the magenta rectangle (which can be switched off via Property Browser).*

Such a view beyond the limits of the data domain provides some benefits: For example, comparing of diagrams with different domains of definition is much easier. Furthermore, sometimes there is a need to see how the data are extrapolated outside the actual coordinate range.

11.5 Aspect Ratio

Availability

Accessible:

- Ribbon: View > Aspect Ratio ribbon menu
- Property browser: *View > Aspect Ratio* (for harmonic fields and harmonic fields sets)
  View > True To Scale (for data array based documents)
- Context menu: *Aspect Ratio*

In views showing two-dimensional data, VirtualLab Fusion supports three ways how the aspect ratio between the two axes is determined.

ITEM	DESCRIPTION
True To Physical Scale	The data is displayed on the screen so that the same physical extent on the x- and y-axis corresponds to the same number of pixels on the screen. That means the data is displayed as it would be visible within an experiment, with true to scale representation.
True To Pixel Scale	ONLY FOR HARMONIC FIELDS AND HARMONIC FIELDS SETS Each sampling point of the data is mapped to a pixel square on the screen. If the vertical and horizontal sampling distances are not equal, the same distance on the screen in x- and y-direction corresponds to different physical extents.
Free Aspect Ratio	The aspect ratio is chosen for optimal fitting of the data into the document window. Thus, resizing the document window changes the aspect ratio. The same distance on the screen in x- and y-direction may correspond to different physical extents as well as to a different number of sampling points.

11.6 Copy View to Clipboard

Availability

Accessible:

- Ribbon: View >  Copy View to Clipboard
- Context menu: *Copy to Clipboard* (for harmonic fields and harmonic fields sets)
- Shortcut: Ctrl+C

Copies the current view to the Windows™ clipboard.
For data array based documents the view is copied as shown. In the Global Options dialog (↪Sec. 6.7) you can set whether the gray background of the view is copied or transparency is used instead.
For harmonic fields and harmonic fields set you can configure the generated graphics using the dialog described in the following section.

11.6.1 Copy View to Clipboard (Dialog for Harmonic Fields and Harmonic Fields Sets)

Several options are available for copying a field view to the clipboard, which can be set by using the dialog shown in Fig. 81. There are several groups of controls within this dialog, which are described in the following.

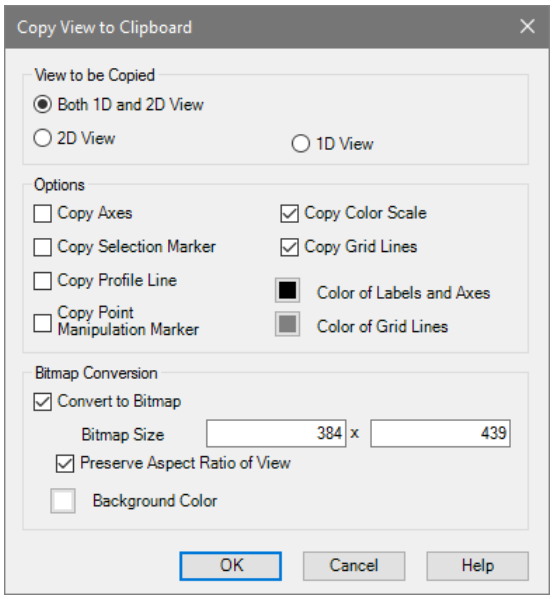


Figure 81. *Dialog to adjust settings for copying a harmonic field view to clipboard.*

The controls of the group *View to be Copied* determine which parts of the harmonic fields view are to be copied to the clipboard.

ITEM	DESCRIPTION
Both 1D and 2D View	Copy two-dimensional view and one-dimensional profile line view.
2D View	Copy only two-dimensional view.
1D View	Copy one-dimensional view.

The following *Options* group controls which features of the view are included when copying to the clipboard.

ITEM	DESCRIPTION
Copy Axes	Determines whether the labels at the corners of the two-dimensional view are copied.
Copy Selection Marker	Determines whether the lines representing the rectangle / range marker (↪Sec. 11.3) are copied.
Copy Profile Line	Determines whether the red arrow representing the line marker (↪Sec. 11.3) in the two-dimensional view is copied.
Copy Point Manipulation Cross	Determines whether the cross hair representing the point marker (↪Sec. 11.3) is copied.
Copy Color Scale	Determines whether the legend on the right hand side of the two-dimensional view is copied.
Copy Grid Lines	Determines whether grid lines are copied in the one-dimensional view.
Color of Labels and Axes	Edit color of axis lines and labels of one and two-dimensional view.
Color of Grid Lines	Color of optional grid lines in one-dimensional view.

A field view can be copied to the clipboard in two different ways: as windows meta file and as bitmap. Since windows meta file export corresponds to a vector graphics, the graphics is highly resolved. However, for some target programs, the result of the clipboard import of meta files can look erroneous due to incompatibilities. In such cases, exporting the view via a bitmap object in the clipboard can give better results.

When using windows meta file clipboard export, the background is always transparent.

ITEM	DESCRIPTION
Convert to Bitmap	Bitmap mode of clipboard copying.
Bitmap Size	Size of the generated bitmap in pixels.
Preserve Aspect Ratio of View	If checked, the bitmap size in X and Y direction are coupled for ensuring that the aspect ratio of the view is maintained.
Background Color	Background Color to be used in the bitmap.

11.7 Graphics Add-Ons

Availability

Only for data array based documents.

Accessible:

- Ribbon: View >  Configure All

All data array (based) views may show additional information, called ”graphics add-ons” or simply ”add-ons”, which overlay the actual data. These add-ons may e.g. be regions, point clouds, polarization ellipses etc. If there are more than one add-on, all are layered in an order which can be user-specified.
The ribbon button Graphics Add-ons >  Configure All calls the dialog shown in Fig. 82 which allows to configure all contained graphics add-ons.

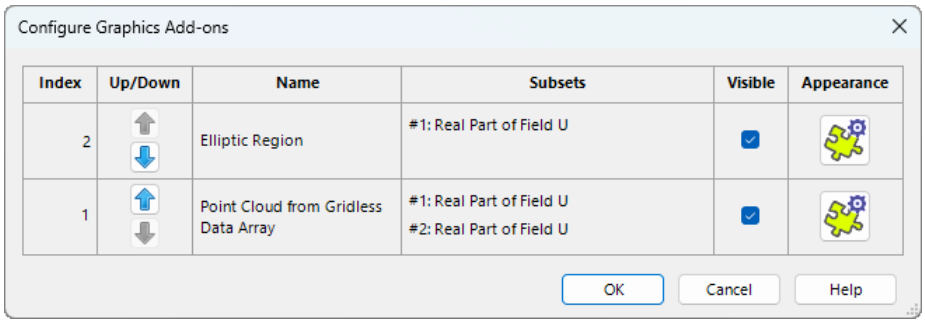


Figure 82. *Dialog for configuring the graphics add-ons of a view.*

ITEM	DESCRIPTION
Index	The layer index. Index #1 corresponds to the bottom layer which is drawn above the data first. The row with the highest index will be the upmost layer which is drawn at last.
Up/Down	Moves the add-on up or down in the layer order.
Name	Name of the add-on.
Subsets	Shows for which subsets the add-on is available.
Visible	Allows to show or hide the add-on.
Appearance	Opens another dialog for editing the individual view settings for the add-on. See Sec. 11.7.1-Sec. 11.7.3.

11.7.1 Configuration of Common Graphics Add-ons

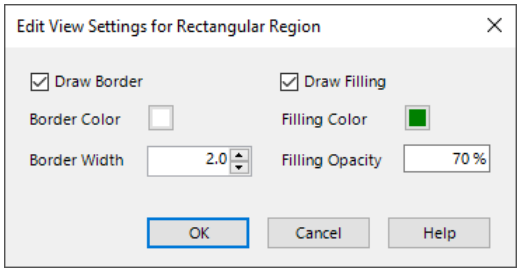


Figure 83. *Dialog for configuring the view settings of common graphics add-ons like regions or meshes.*

ITEM	DESCRIPTION
Draw Border	If checked, a border will be drawn.
Border Color	If *Draw Border* is selected, this sets the color of the border line.
Border Width	If *Draw Border* is selected, this sets the width of the border line.
Draw Filling	If checked, the shown areas will be filled.
Filling Color	If *Draw Filling* is selected, this sets the color of the filling.
Filling Opacity	If *Draw Filling* is selected, this sets the opacity of the filling: 0% means full transparency, 100% will create completely non-transparent fillings.

11.7.2 Configuration of Point Cloud Add-Ons

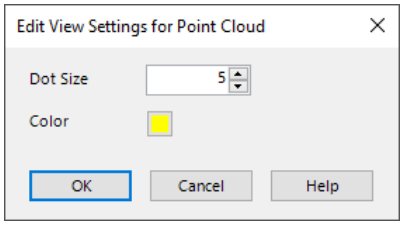


Figure 84. *Dialog for configuring the view settings of point cloud add-ons.*

ITEM	DESCRIPTION
Dot Size	The size of the points.
Color	The color of the points.

11.7.3 Configuration of Polarization Ellipse Add-Ons

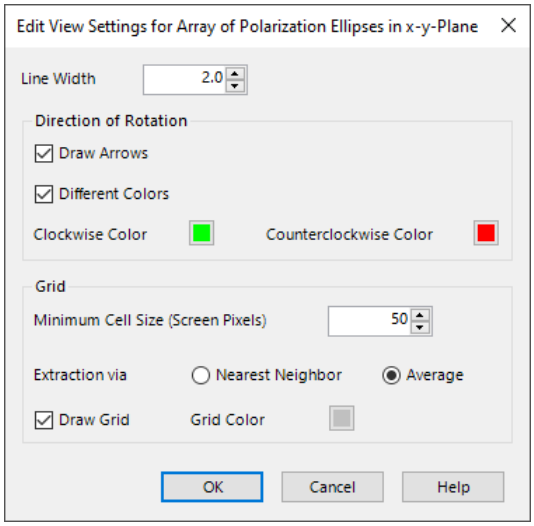


Figure 85. *Dialog for configuring the view settings of polarization ellipses.*

ITEM	DESCRIPTION
Line Width	The thickness of the drawn lines.
Draw Arrows	If chosen, the *Direction of Rotation* will be indicated by small arrows.
Different Colors	If chosen, the *Direction of Rotation* will be indicated by different colors.
Clockwise Color	If *Different Colors* is selected, this sets the color for clockwise ellipses.
Counterclockwise Color	If *Different Colors* is selected, this sets the color for counterclockwise ellipses.
Minimum Cell Size (Screen Pixels)	Size on the screen which shall be occupied by the ellipses *at least*. If the zoom factor is high enough, the ellipses of each single sampling point are shown and may be even larger than this minimum size. Please see the note below for more information.
Extraction via Nearest Neighbor / Average	If an extraction is necessary because more than one sampling point is covered by *Minimum Cell Size (Screen Pixels)*, this parameter determines the extraction strategy. Either only the point with the position nearest to the ellipse's center is used alone or the Jones vectors of all points covered by the cell are averaged. Please see the note below for more information.
Draw Grid	If chosen, a grid indicates the areas each ellipse is calculated from.
Grid Color	If *Draw Grid* is selected, this sets the color of the grid.

Note on the extraction (calculation) of the shown polarization ellipses:
It is only possible to see every single polarization ellipse in the data if the zoom factor is high enough. Only if the display of a single sampling point occupies a minimum number of screen pixels, there is enough space to draw the ellipse which corresponds to this sampling point. This case can be seen in Fig. 86, on the left-hand side. The (cell) size which shall be used to draw an ellipse at least can be set in the view settings dialog: *Minimum Cell Size (Screen Pixels)*.
In many cases the minimum screen area to draw an ellipse will cover more than one single sampling point. This is shown in Fig. 86, on the right-hand side. There are two possibilities for determining the contributions of the sampling points to each ellipse: Either the average Jones vector of all covered points is used to calculate the ellipse or only that sampling point is used which is located nearest to the ellipse's center position. These alternatives can be chosen in the view settings dialog by selecting either *Extraction via Average* or *Extraction via Nearest Neighbor*.

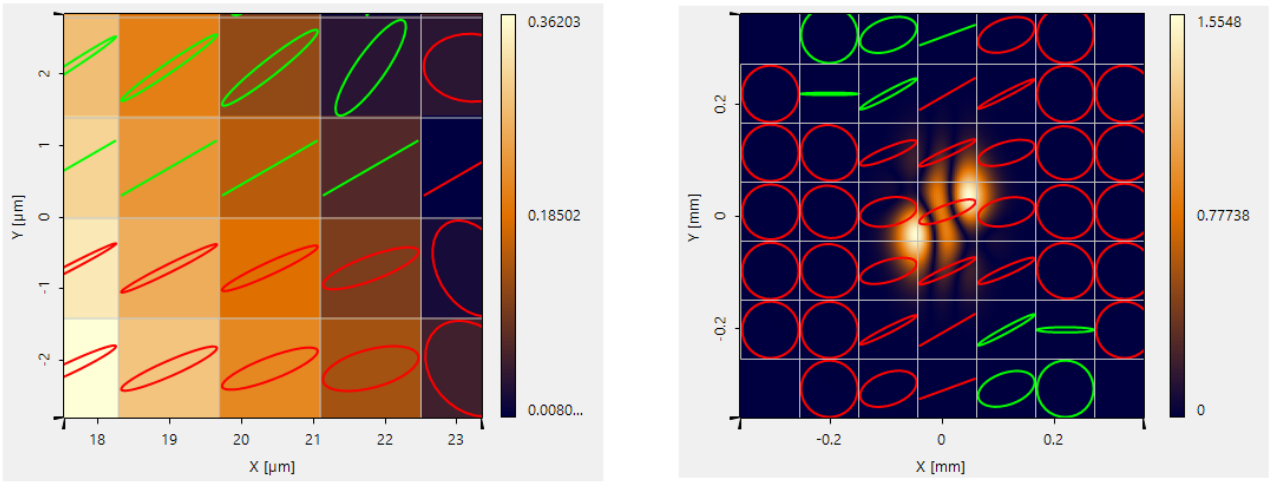


Figure 86. *The display of the polarization ellipses depends on the zoom factor. Left-hand side: The zoom is large enough to show each single ellipse for each sampling point. Right-hand side: For a smaller zoom factor, the ellipse is extracted (either via averaging or by nearest neighbor selection) from the points covered by the minimum ellipse cell size.*

11.8 Suppressing Numerical Phase Artifacts

Availability

Only available for Harmonic Fields, Harmonic Fields Sets, Numerical Data Arrays or Data Arrays with the physical meaning Electric Field or Electromagnetic Field (↪Sec. 24.1.4). This feature applies only if either the phase is shown as field quantity (↪Sec. 11.1) or if polarization ellipses (↪Sec. 12.2.3, ↪Sec. (c)) are visible.

Accessible:

- Ribbon: View > Hide Phase Artifacts
- Property browser: *View > Hide Phase Artifacts*
- Context menu: *Hide Phase Artifacts*

11.8.1 Numerical Artifacts in Phase View of Diagrams

Some calculations produce numerical inaccuracies in the real and imaginary part of complex numbers. The phase ϕ of a complex number may be sensitive to such inaccuracies due to its dependence on both of these parts. In VirtualLab Fusion the phase is defined as follows:

$$\phi = \begin{cases} \arctan\left(\frac{\mathrm{Im}}{\mathrm{Re}}\right) & : \mathrm{Re} > 0 \\ \arctan\left(\frac{\mathrm{Im}}{\mathrm{Re}}\right) + \pi & : \mathrm{Re} < 0 \quad \text{and} \quad \mathrm{Im} > 0 \\ \arctan\left(\frac{\mathrm{Im}}{\mathrm{Re}}\right) - \pi & : \mathrm{Re} < 0 \quad \text{and} \quad \mathrm{Im} \leq 0 \\ +\frac{\pi}{2} & : \mathrm{Re} = 0 \quad \text{and} \quad \mathrm{Im} > 0 \\ -\frac{\pi}{2} & : \mathrm{Re} = 0 \quad \text{and} \quad \mathrm{Im} < 0 \\ 0 & : \mathrm{Re} = 0 \quad \text{and} \quad \mathrm{Im} = 0 \end{cases}$$

Normally there is no visible effect on a diagram view of these data because of the very small magnitude of numerical inaccuracies, but there are two cases where artifacts in the phase values may appear:

1. If both the real and the imaginary part are nearly zero (i. e. the amplitude is nearly zero too), these inaccuracies have consequences for the phase (due to the fraction (Im / Re) in the arctangent), though not for the amplitude $\left(\mathrm{Re}^2 + \mathrm{Im}^2 \approx 0\right)$. So despite the vanishing amplitude the phase has randomly distributed values.

2. If the real part is less than zero but the imaginary part is nearly zero ($-\epsilon < \mathrm{Im} < +\epsilon$), the amplitude is not affected $\left(\mathrm{Re}^2 + \mathrm{Im}^2 \approx \mathrm{Re}^2\right)$, but the phase is (see case no. 2 and no. 3 in the definition of ϕ above). Thus the phase jumps accidentally between π and $-\pi$.

An artifacts threshold t can be set in the *View* panel of the property browser.
This parameter t has the following meanings:

1. A phase value in a diagram is displayed as zero if its amplitude value A satisfies $A < t \cdot A_{\mathrm{max}}$, where A_{max} is the maximum amplitude value in the data.
2. The phase value is displayed as $-\pi$ in the display if its imaginary part value Im satisfies $t \cdot \mathrm{Re} < \mathrm{Im} < 0$.

If *Hide Phase Artifacts* is activated for a diagram view, both conditions will be tested and the view will hide these kinds of artifacts. The data of the field document itself will remain unchanged.

11.8.2 Numerical Artifacts in Polarization Ellipses

If the amplitude for both of the vectorial components used for calculating a polarization ellipse is nearly zero, numerical artifacts have a strong effect on that ellipse.

So these artifacts can be suppressed as well: Polarization ellipses are calculated only if the amplitudes of both of the respective vectorial components are below $t \cdot A_{\text{max}}$, where A_{max} is the maximum amplitude over the complete data of both vectorial components.
In case of ellipses shown in a Harmonic Field view or a Harmonic Fields Set view (↪Sec. 12.2.3), the threshold t can be set dynamically via property browser.
If polarization ellipses shall be calculated by an EM detector (↪Sec. 75.4.5.1) or as a manipulation for an already existing electric or electromagnetic field (↪Sec. 32.3), then the threshold has to be specified in the respective dialog.

11.8.3 Default Settings for Suppression of Numerical Phase Artifacts

In the Global Options dialog (↪Sec. 6.11), one can set whether phase artifacts are hidden by default and set a default threshold t as well.

12 Harmonic Fields and Harmonic Fields Sets

12.1 Harmonic Field Data

For locally polarized harmonic fields the two electric field components E_x and E_y are stored, from which all other field components can be reconstructed. For globally polarized fields, only the scalar field $U(x, y)$ (↪Sec. 136.1) is stored.
The field data are stored as field values on an equidistantly sampled grid. The number of sampling points in x- and y-direction, N_x and N_y can be chosen freely in the x- and y-direction respectively. For storing two-dimensional fields both N_x and N_y are greater than 1. One-dimensional fields are typically stored with $N_y = 1$. More technical notes can be found in Sec. 136.
The *Data* tab of the property browser (*Current Data* for harmonic fields sets) allows you to view and alter these settings, among others:

ITEM	DESCRIPTION
Complex Amplitude Type	Shows whether the field is locally or globally polarized and whether it is in spatial or spectral domain.
Embedding Material	The material of the homogeneous medium in which the field is defined.
Jones Vector	ONLY FOR GLOBALLY POLARIZED FIELDS Allows you to change the Jones vector. ↪Fig. 87
Wavelength	With this parameter you can change the wavelength of the field.
Is Complex	Shows whether the imaginary part is stored as explained above.
Array Size	Allows you to change the overall size of field. The number of sampling points and the actual data remains unchanged.
Sampling Distance	Allows you to change the distance between consecutive sampling points. The number of sampling points and the actual data remains unchanged.
Sampling Points	Shows the number of sampling points. To change it, use the interpolation manipulation described in Sec. 22.8.1.
Has Spherical Phase Radius	An analytical stored spherical phase factor allows to not fully sample a spherical phase and thus reduce the number of required sampling points. With this property you can remove or set this analytical factor. The overall phase is not changed by this as long as the sampling is sufficiently fine.
Spherical Phase Factor	With this setting you can change the analytically stored spherical phase factor. The overall phase is not changed by this as long as the sampling is sufficiently fine.

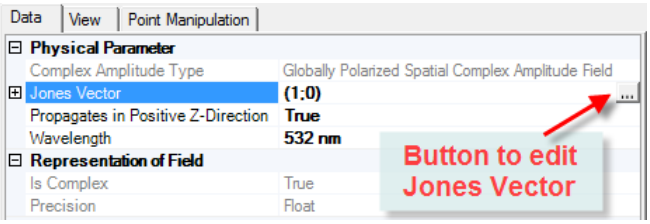


Figure 87. *How to edit the Jones vector via the property browser. The controls of the resulting dialog are the same as for setting the Jones vector of a newly generated field, ↪Sec. 49.3.*

12.1.1 Spherical Phase Radius

Sampling of a large spherical phase (e. g. a lens with short focal length) would require a very small sampling distance and thus many sampling points for correctly sampling the spherical phase in the border areas of the field. Therefore, VirtualLab Fusion can handle the spherical phase radius as a separate factor multiplied to the sampled aberrations of the spherical phase. This means that the sampling distance has to be chosen only for accurate sampling of the aberrations.

Many of the internal operations of VirtualLab Fusion, as for example the homogeneous medium propagation operators (↪Sec. 94), take into account the stored spherical phase radius.

For newly created harmonic fields, VirtualLab Fusion detects and stores the spherical phase radius automatically.

If you want to change this stored value, you can use several entries in the Manipulations > φ Phase Manipulations ribbon item:

- Set Analytical Parameter: Sets the analytical spherical phase radius to a new value. The corresponding dialog is explained in Sec. 22.5.2.

- Remove Analytical Parameter: Removes the analytical spherical phase radius.

These manipulations do not change the resulting phase, at least as long as the sampling distance is fine enough for the new aberrations (phase minus analytical spherical phase radius).
The property browser (↪Sec. 4) offers similar functionality: In the *Data* panel (for harmonic fields) or the *Current Data* panel (for harmonic fields sets), you can set *Has Spherical Phase Radius* to false or true. Setting to false corresponds to removing the spherical phase radius. Furthermore you can set the *Spherical Phase Radius*.
If you want not only to remove the stored value, but also the spherical phase information present in the sampled phase data, you can use the entry Manipulations > Phase Manipulations > Remove Sampled Spherical Phase. Manipulations > Sampling Manipulations > Resample According to Spherical Phase allows to resample a field so that the spherical phase radius can be removed without resulting undersampling. Detectors > Spherical Phase Radius detects the optimal value of the spherical phase radius.
How the spherical phase radius is determined from sampled data is describe in Sec. 142.6.

12.2 View for Harmonic Fields and Harmonic Fields Sets

These documents allow you to use markers and selections (↪Sec. 11.3), zoom into the view (↪Sec. 11.4), change its aspect ratio (↪Sec. 11.5), copy the view to clipboard (↪Sec. 11.6).
Furthermore, View > Copy View Settings allows you to copy the view settings (value scaling, markers and so on) from another matching document window.
If a line marker (↪Sec. 11.3) is shown for two-dimensional fields, also a one-dimensional cross section is shown in one common view window (↪Fig. 88).

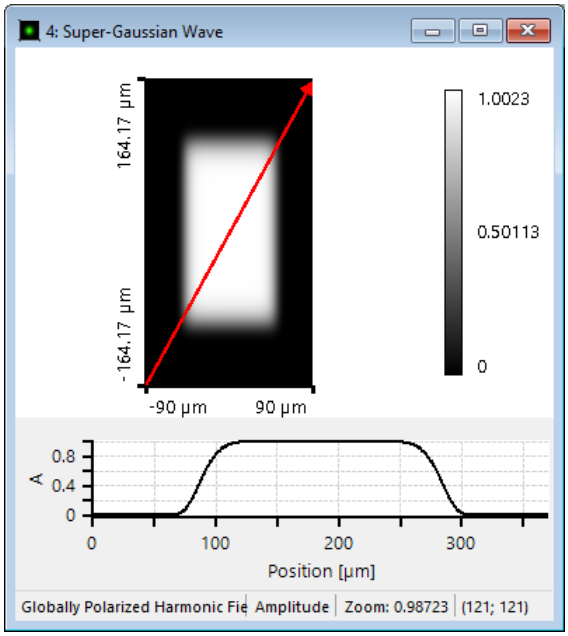


Figure 88. *Harmonic Field View with Profile Line.*

A Harmonic Fields Set usually contains more than one harmonic field.

12.2.1 Harmonic Field Selection

Availability

For Harmonic Fields Sets

Accessible:

- Ribbon: View > Harmonic Field Selection ribbon group (see below)
- Property browser: *Document > Current Member*

In the ribbon you can go through all harmonic fields within a Harmonic Fields Set with the control shown in Fig. 89, either by using the arrow buttons or by entering the index of the harmonic field directly.

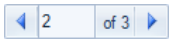


Figure 89. *The controls to select an harmonic field in the ribbon.*

12.2.2 Vectorial Component

Availability

Accessible:

- Ribbon: View > E-Field ribbon group
- Property browser: *View > Vectorial Component*
- Context menu: *Vectorial Component*

If the field quantity (↪Sec. 11.1) is not set to Summed Squared Amplitudes, one of the three vectorial components E_x, E_y, or E_z can be selected for being displayed.
In VirtualLab Fusion E_z is calculated according to

$$E_z(x,y) = \left[\mathcal{F}^{-1}\left(-\frac{1}{k_z}\left(k_x \cdot [\mathcal{F}\,E_x(x,y)](k_x,k_y) + k_y \cdot [\mathcal{F}\,E_y(x,y)](k_x,k_y)\right)\right)\right](x,y) \quad . \tag{12.1}$$

where $\mathcal{F}$ denotes a Fourier transform and $\mathcal{F}^{-1}$ an inverse Fourier transform.

12.2.3 Polarization

Availability

Not for Jones Matrix Transmissions

Accessible:

- Ribbon: View > Polarization ribbon group
- Property browser: *View > Show Polarization*
- Context menu: *Polarization*

It's possible to display the polarization of harmonic fields or fields sets in three different modes.

MODE	DESCRIPTION
Ellipses	Ellipses are drawn over the data view as shown in Fig. 91. This display mode shows the complete polarization ellipses, but only with coarse sampling.
Angles of Ellipses	Shows the angles of the major axis of the ellipses to the x-axis with finer sampling.
Eccentricities of Ellipses	Shows the (numerical) eccentricity e of the ellipses with finer sampling.

For all these modes you can specify the plane for which you want to see the polarization via a combo box. If you select the currently selected polarization display mode again, you switch off the polarization view – which can also be done in the property browser via *View > Show Polarization group > Show*.
You can open a dialog with specific polarization view settings (↪Fig. 90), either via the context menu (*Polarization > View Settings*) or the launcher button of the View > Polarization ribbon group.

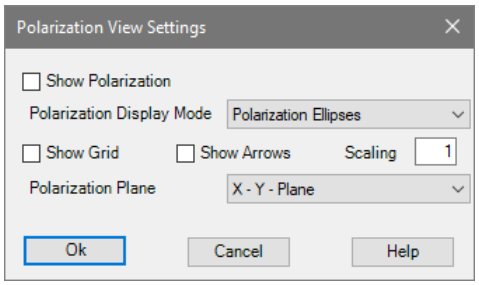


Figure 90. *Dialog for changing the polarization view settings.*

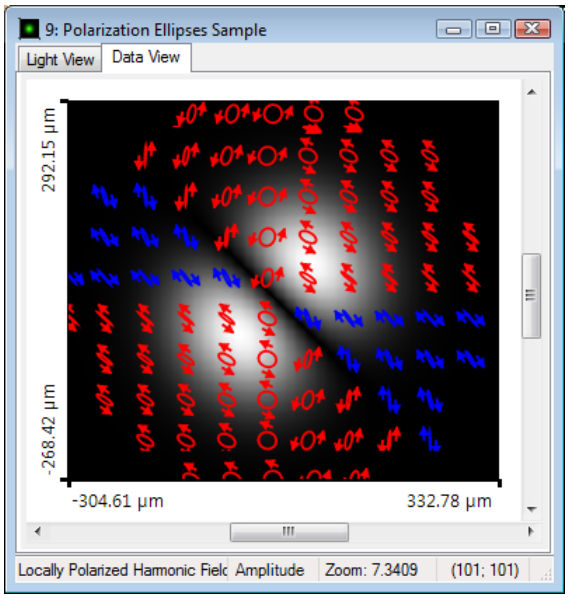


Figure 91. *Example of a view with polarization ellipses.*

This dialog has the following items:

ITEM	DESCRIPTION
Show Polarization	Toggles the display of any *Polarization Display Mode* on or off.
Polarization Display Mode	As described above, there are three polarization display modes: *Polarization Ellipses*, *Angles of Ellipses*, and *Eccentricities of Ellipses*.
Show Grid	Displays a grid between the *Polarization Ellipses*.
Show Arrows	Displays arrows which indicate the rotational direction of the electrical field vector E_{xy} vector in the *Polarization Plane*.
Scaling	Factor to scale up and scale down the polarization ellipses. The standard value is 1.0, the minimum value is 0.5.
Polarization Plane	The plane for which the polarization is displayed.

Default values for these settings can be defined in the *Harmonic Field View* tab of the Global Options dialog (↪Sec. 6).
The display of the polarization is influenced by the phase artifacts setting (↪Sec. 11.8).

12.2.4 Norm and Power

The *View* panel of the property browser of harmonic fields and harmonic fields sets has the section *Norm and Power*. This section contains the following entries:

ITEM	DESCRIPTION
Norm in Selection	Shows the norm N within the current selection for the displayed vectorial component (↪Sec. 12.2.2). See Sec. 76.4.7 for details on the calculation of the norm N. Furthermore the ratio between *Norm in Selection* and *Norm of Whole Component* is shown in percent. This entry is only shown if a selection is visible (↪Sec. 11.3.4).
Norm of Whole Component.	Shows the norm N of the displayed vectorial component as defined in Sec. 76.4.7.
Power in Selection (Component)	This value is calculated from the *Norm in Selection* and Eq. (12.2). Furthermore the ratio between *Power in Selection (Component)* and *Power in Whole Component* is shown in percent. This entry is only shown if a selection is visible.
Power in Selection (Field)	Sum of *Power in Selection (Component)* for both E_x- and E_y-component. Furthermore the ratio between *Power in Selection (Field)* and *Power in Whole Field* is shown in percent. This entry is only shown if a selection is visible.
Power in Whole Component	This value is calculated from the *Norm of Whole Component* and Eq. (12.2).
Power in Whole Field	Sum of *Power in Whole Component* for both E_x- and E_y-component.

The power properties are not shown for harmonic fields and harmonic fields sets in spectral domain.
From a given norm N of a certain region the power P is calculated as

$$P = n\frac{\epsilon_0}{2}c\delta x\delta y N \tag{12.2}$$

with δx is the sampling distance in x-direction and δy is the sampling distance in y-direction. For one-dimensional fields the sampling distance in the unmodulated direction is assumed to be 1 meter. n is the refractive index derived from the *Embedding Medium* of the field, ϵ_0 is the dielectric constant and c is the vacuum speed of light.

13 Data Arrays

Data Arrays are designed as containers for any data that represent mappings from any N-dimensional real space $\mathbb{R}^N$ (more specific from a domain $X \subset \mathbb{R}^N$) to any M-dimensional complex space $\mathbb{C}^M$ (more specific to a co-domain $Y \subset \mathbb{C}^M$). An example is shown in Fig. 92 for $N = 2$ and $M = 3$.

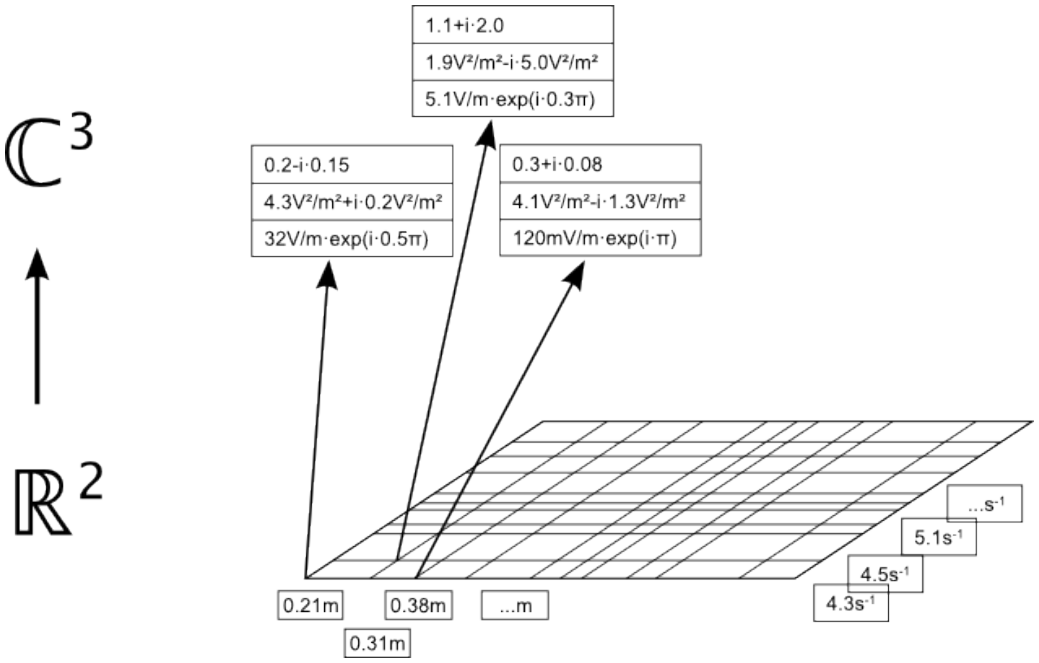


Figure 92. *Example for mapping* $\mathbb{R}^2 \rightarrow \mathbb{C}^3$.

The components $x_1, x_2, \ldots, x_N$ of the variable $\boldsymbol{x} \in X$ are usually called “coordinates”, while $\boldsymbol{y} \in Y$ is named “dependent variable” or simply “data”. Each set of all values of a certain dimension $Y_i = y_i(x_1, x_2, \ldots, x_N)(1 \leq i \leq M)$ is called “Data Array Subset” or “Data Subset”.
Although not all data structures in VirtualLab Fusion are based on Data Arrays at the moment, we plan to introduce them systematically and successively as standard data container.
The most important types of data arrays are gridded 1D and 2D data as illustrated in Fig. 93 and Fig. 94. They show equidistantly sampled data, which is no restricting condition for Data Arrays in general.

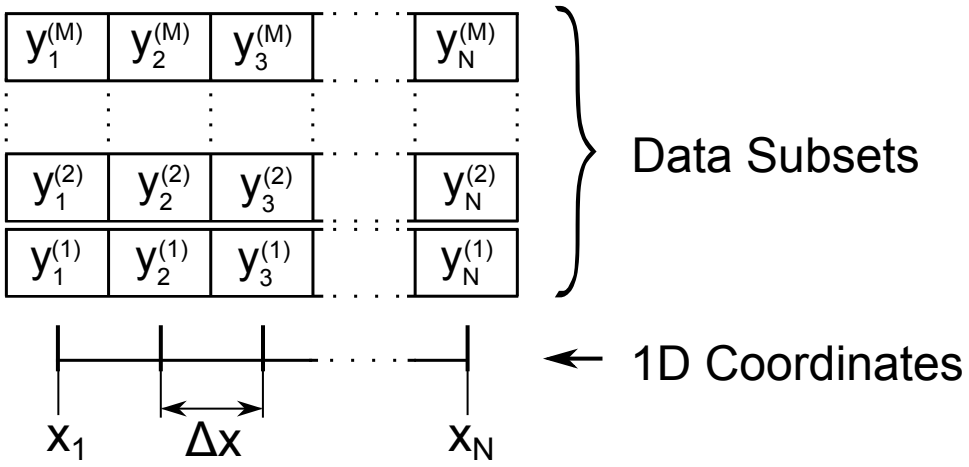


Figure 93. *Example for equidistant 1D Data Array.*

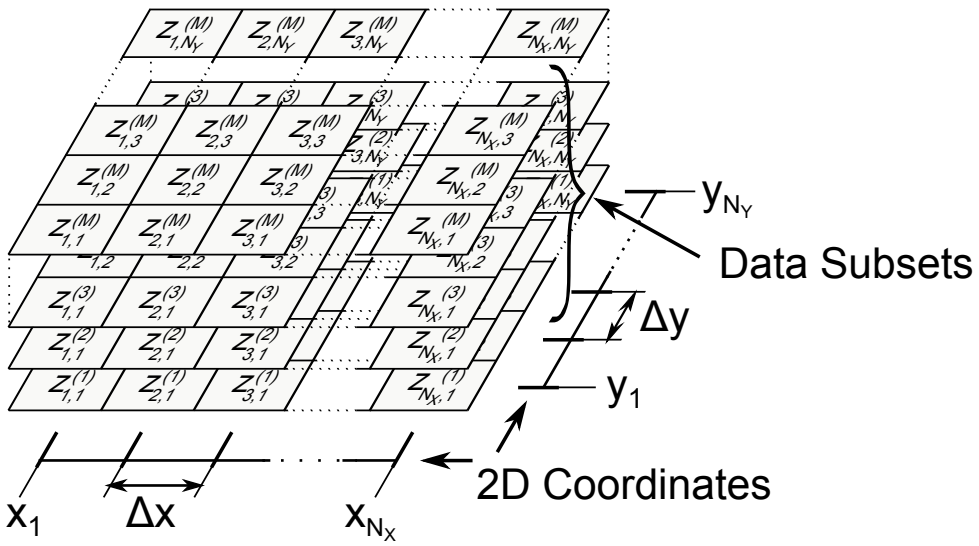


Figure 94. *Example for equidistant 2D Data Array.*

For small N as in the figures Fig. 93 ($N = 1$) and Fig. 94 ($N = 2$), the notations for the variables usually differ slightly: For 1D data the coordinate is called x and the data variable is y, while for 2D data usually the coordinates are marked by x and y, whereas the dependent variable is called z.
In some cases, two-dimensional data are not distributed on a grid but completely irregular (↪Fig. 95). We call this type *Gridless Data Array*. Gridless Data Arrays may contain several subsets, same as gridded (i. e. equidistant and non equidistant) ones. No interpolation is available for this kind of array.

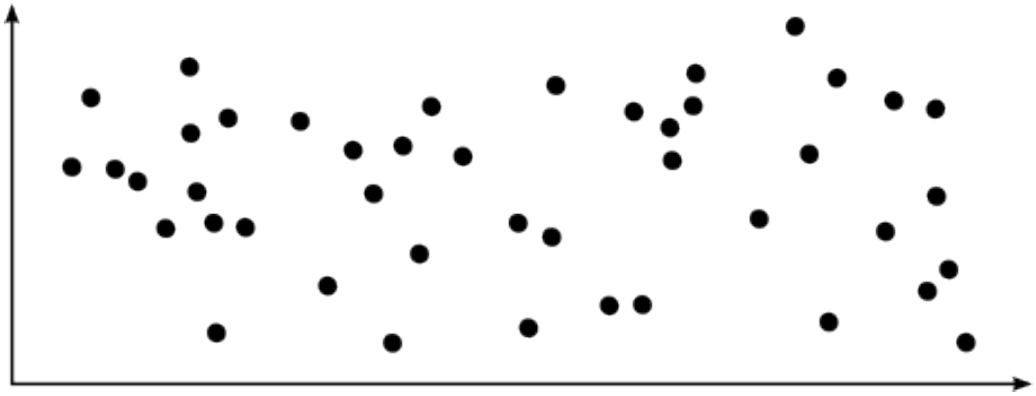


Figure 95. *Example for a Gridless Data Array.*

The view for data arrays is explained in Sec. 13.4.

13.1 Types of Data Arrays

In many cases, there is no specific physical meaning associated with a Data Array. Although coordinates and subset values got physical units (↪Sec. 5.1, ↪Sec. 24.4, ↪Sec. 24.5.1), the object itself is not interpreted as having a physical meaning in any case.
Nonetheless, in some cases such a specific meaning is given to a Data Array. An Electric Field object is such a Data Array with a specific interpretation. Whether or not there is a physical meaning given to a data array is indicated by its caption, as shown in Fig. 96. All general, i.e. non-specific, Data Arrays are called *Numerical Data Arrays* and got a gray caption. All other Data Array objects have a different, type specific caption color.

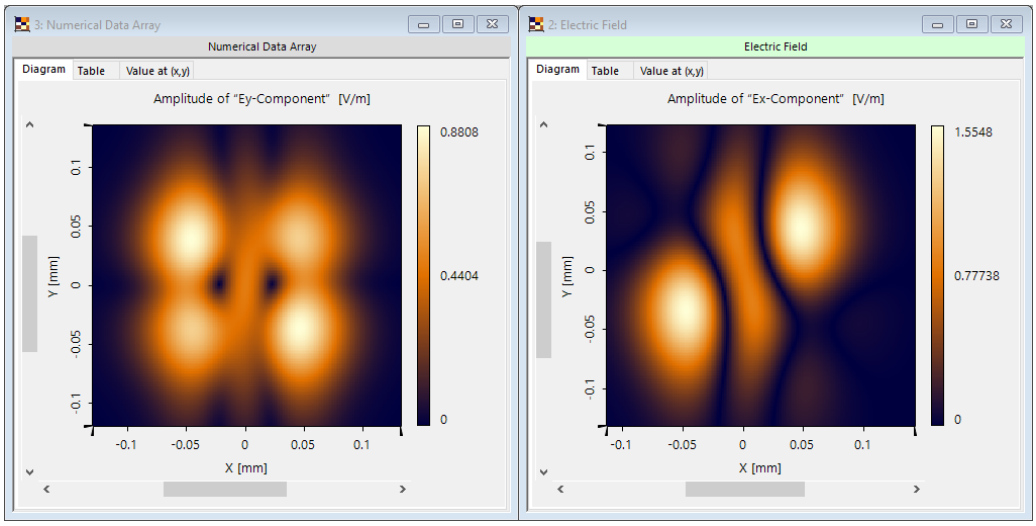


Figure 96. *Example for two different types of Data Arrays. Left: Numerical Data Array. Right: Electric Field.*

The most important difference in handling between Numerical Data Arrays and more specific Data Arrays is the availability of manipulations (↪Sec. 24). The handling of specific Data Arrays is restricted to features and properties which make sense for the given physical meaning type.

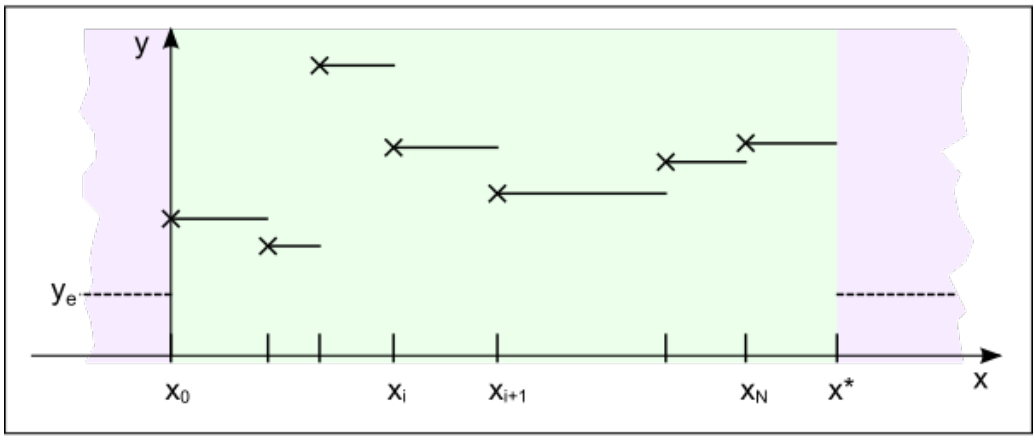
13.2 Interpolation Methods

Distinct interpolation methods are available for equidistant and non-equidistant data arrays. For two-dimensional data arrays, the described rules are applied separately to x- and y-direction, respectively.
The interpolation methods for non-equidistant data are given in Sec. 13.2.1, the interpolation methods for equidistantly sampled data in Sec. 13.2.2.

13.2.1 Interpolation Methods for Non-Equidistant Data

If the data array does not contain equidistantly sampled data, there are two different non-equidistant interpolation methods available: *Constant Interval* interpolation and *Linear* interpolation.
In case of complex data, a *Real Part / Imaginary Part* linear interpolation is distinguished from an *Amplitude / Phase* linear interpolation. This is due to the fact that, generally, a linear interpolation on real part and imaginary part doesn't result in a linear interpolation in amplitude and phase and vice versa.
The principle of the non-equidistant interpolation methods is shown in Fig. 97.

a) Non-equidistant 'Constant Interval' interpolation method



b) Non-equidistant linear interpolation method

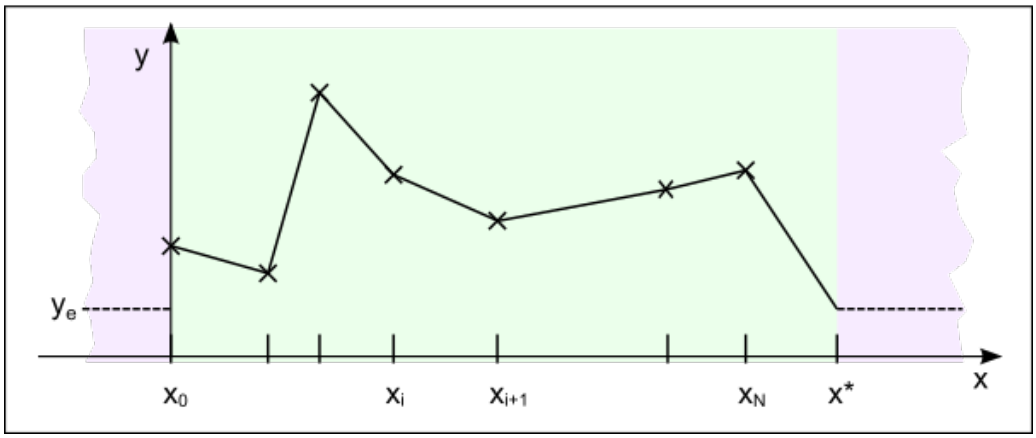


Figure 97. *The two non-equidistant interpolation methods. In case of Constant Interval interpolation (upper part a)), each data point at coordinate x_i defines a constant value for the interval $[x_i, x_{i+1}[$. The value x^* marks the upper limit of the last coordinate interval.*
The coordinate extent (colored in light green) is identical to that coordinate range where interpolation is possible. Values outside the coordinate extent (i.e. lying in the range colored in pale violet) are accessible via extrapolation (Sec. 13.3). In this example, a Constant with Value *extrapolation is shown, using a constant value of y_e. Please note that y_e is used for the linear interpolation in the interval $[x_N, x^*[$ as well (lower part b)).*

13.2.2 Interpolation Methods for Equidistant Data

From the interpolation methods explained in detail in Sec. 136.4, for performance reasons only the following can be used for the view of data arrays:

- Nearest Neighbor Interpolation
- Linear (Amplitude/Phase): Only for complex-valued data.[1]
- Linear (Real/Imaginary Part)
- Cubic 4 Point
- Cubic 6 Point
- Cubic 8 Point
- Truncated Sinc

The appropriate interpolation method has to be chosen according to the physical meaning of the data which

[1] Generally, a linear interpolation on real part and imaginary part doesn't result in a linear interpolation in amplitude and phase and vice versa.

shall be interpolated, and according to the acceptable computational effort. It can be changed for example with the manipulation explained in Sec. 24.4.

13.3 Extrapolation

In certain circumstances, it is possible that a Data Array has to deliver values outside its coordinate range (aka. coordinate extent).
The following extrapolation modes are available (for equidistant as well as non-equidistant data):

- *Equal to the Nearest Border Data Point*: A constant extrapolation of the outmost data points is done.
- *Zero*: All outlying points are considered to be of value 0.
- *Constant with Value*: All outlying points are considered to be of a value to be specified by the user.
- *Periodically Continued*: The whole data of the array are periodically continued, using a period of the array's 'coordinate extent'.

13.4 Data Array View

There are three types of Data Arrays, each having a different view.

TYPE	DESCRIPTION
Data Array 1D	Data are distributed over one-dimensional coordinates. From this data, interpolation methods can create a continuous function.
Data Array 2D	Data are distributed over a two-dimensional grid. From this data, interpolation methods can create a continuous function.
Gridless Data Array	The data are given at arbitrary positions in a two-dimensional plane. Either the data are shown non-interpolated which results in a dot diagram. If mesh data are available, a linear interpolation inside the mesh triangles can be used as well.

The document window of a Data Array consists of three panels: the *Diagram* panel (↪Sec. 13.4.1), the *Table* panel (↪Sec. 13.4.2), and the *Value at (x,y)* (↪Sec. 13.4.3) panel. The latter is not available for Gridless Data Arrays.

13.4.1 Diagram Panel

The *Diagram* panel contains a diagram that visualizes the contained data. There are different views for Data Arrays 1D, Data Arrays 2D, and Gridless Data Arrays, respectively, see Fig. 98 to Fig. 101.
These views allow you to

- specify which subset is to be shown (↪Sec. 13.4.1.1)
- set the shown field quantity (↪Sec. 11.1)
- switch between interpolated and non-interpolated view (↪Sec. 11.2.1)
- set the scaling mode (↪Sec. 11.2.5)
- use markers and selections (↪Sec. 11.3)
- zoom into the view (↪Sec. 11.4)
- change its aspect ratio (↪Sec. 11.5) and
- copy the view to clipboard (↪Sec. 11.6) .

In case of Data Arrays with more than one subset, the ribbon button View > Equalize Scaling switches the scaling mode for the current Field Quantity to *User-Defined Scaling* (↪Sec. 11.2.5) and copies the value range of the currently shown subset to all other subsets.

Furthermore the appearance of the diagrams can be adjusted in the following ways via the *View* tab of the Property Browser.

ITEM	DESCRIPTION
Font Size of Axis Labels	The size of the axis labels and tick labels in points.
Font Size of Title	The size of the title in points.
Format	The format for the label and the tick values of the respective axis can be specified here as *Engineering* where a prefix in front of the unit is used, or as *Scientific* where an exponential description is used, or as *Standard* where SI units and thus no prefixes are used.

For the settings which are specific for 1D Data Arrays see Sec. 13.4.1.2, for 2D Data Arrays see Sec. 13.4.1.3 and for Gridless Data Arrays see Sec. 13.4.1.4.

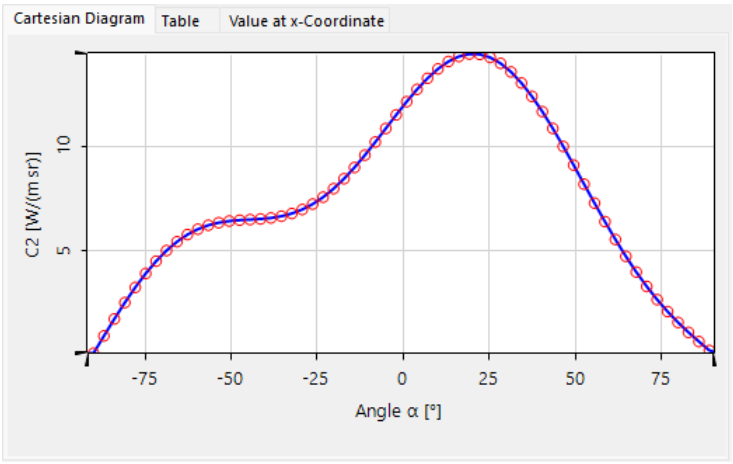


Figure 98. *Example for a Cartesian diagram view of a 1D data array.*

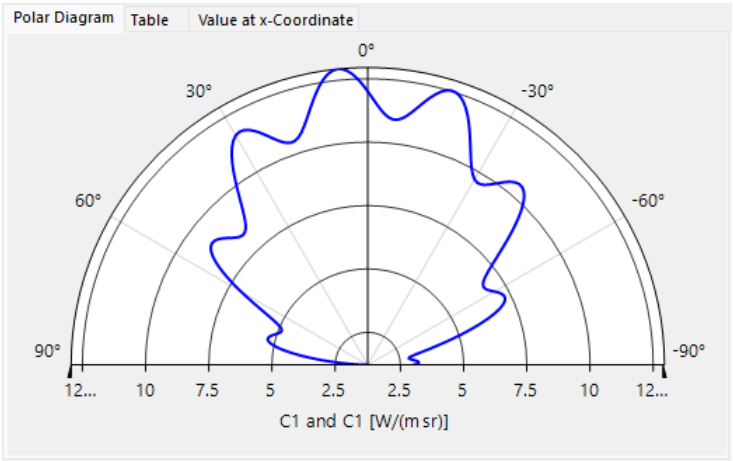


Figure 99. *Example for a polar diagram view of a 1D data array.*

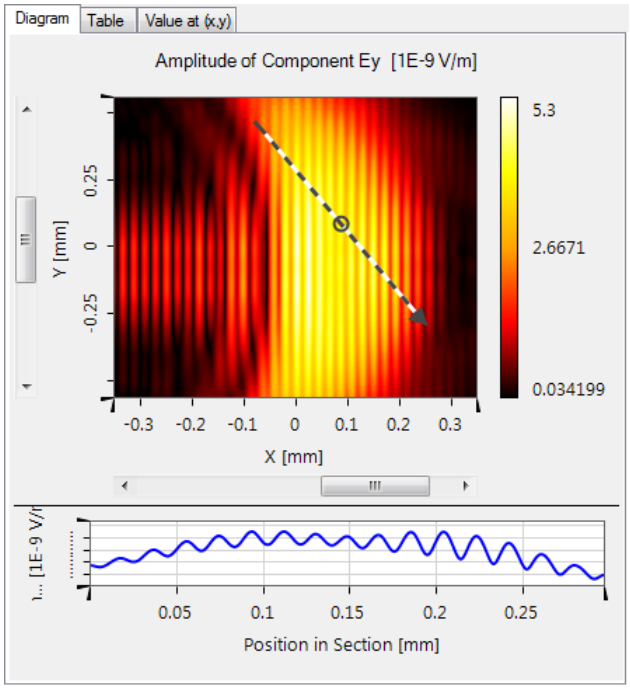


Figure 100. *Example for the diagram view of a 2D data array in 2D mode, including a profile line (↪Sec. (b)).*

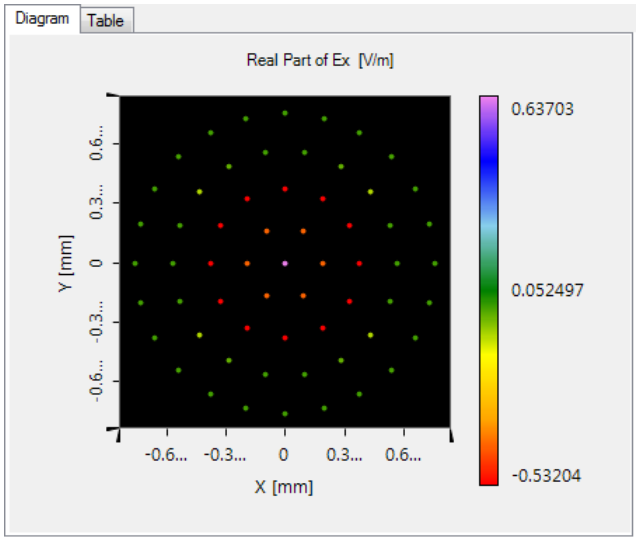


Figure 101. *Example for the diagram view of a gridless data array.*

13.4.1.1 Subset Selection

Availability

For data arrays with more than one subset and disabled Multigraph Mode (in case of 1D data)

Accessible:

- Ribbon: View > Subset Selection group (see below)
- Property browser: *View > Subset Index*
- Context menu: *Data Subset Index*
- Shortcuts: `Page Up` and `Page Down`

In the ribbon you can go through all subsets of a data array with the control shown in Fig. 102, either by using

the arrow buttons or by entering the subset index directly. Below this control the description of the current subset is given.

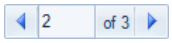


Figure 102. *The controls to select a specific subset in the ribbon.*

13.4.1.2 Specific View Features for 1D Data Arrays

(a) Cartesian 1D Diagram in Singlegraph Mode

The ribbon item View > Multigraph Mode allows to switch between the display of one single subset and multiple subsets ↪Sec. (b) if more than one subset is given.
View > Axes Options > Descending Coordinates (x-Axis) allows to show an inverted coordinate axis.
The item View > Axes Options > Transposed View will swap the directions of the independent (x-) and the dependent (y-)axis.
The ribbon item View > Axes Options > Logarithmic Scaling (x-axis) toggles between a logarithmic and a linear scaling of the coordinate axis if the complete coordinate range is positive.
View > Axes Options > Logarithmic Scaling (y-axis) is a switch between a logarithmic and a linear scaling of the y-axis if the values to be displayed are completely positive.
The following specific parameters can be set via the *View* tab of the Property Browser:

ITEM	DESCRIPTION
General > Show Polar Diagram	ONLY IF THE DATA ARRAY REPRESENTS AN ANGULAR DEPENDENCY. Switches between a polar diagram view (↪Sec. (c)) and a Cartesian diagram view.
General > Transposed View	If *True*, the vertical axis and the horizontal axis of the diagram will be transposed. The independent variable will then be shown in the vertical direction.
General > Legend Visible	ONLY AVAILABLE IF AT LEAST ONE UNDEFINED VALUE IN DATA ARRAY. The visibility of the legend for the color which visualizes undefined values can be set here.
Lines and Symbols > Line Color	Color of line which connects the displayed data points. If set to *Transparent*, the line will not be shown.
Lines and Symbols > Line Thickness	Thickness of line which connects the displayed data points. Has to be a positive integer.
Lines and Symbols > Symbol Color	ONLY AVAILABLE IF *SYMBOL SHAPE* IS NOT *NO SYMBOL*. Color of the symbols which mark the data points.
Lines and Symbols > Symbol Scaling Factor	ONLY AVAILABLE IF *SYMBOL SHAPE* IS NOT *NO SYMBOL*. The size of the symbols (except *Small Dot*) can be scaled using this factor.
Lines and Symbols > Symbol Shape	Shape of the symbols which mark the data points. If set to *No Symbol*, symbols will be switched off.
Lines and Symbols > Use Smoothed Graphics	If activated, the graphics will be smoothed. Usually, this may improve the diagram. But if a stepped line is shown, deactivating this property may yield a better result. Important: This smoothing is done on pixel level. This pixel smoothing is not to be confused with the smoothing interpolation methods described in Sec. 11.2.2!

Lines and Symbols > Alignment of Undefined Color Legend	ONLY AVAILABLE IF AT LEAST ONE UNDEFINED VALUE IN DATA ARRAY. Allows to set the position of the legend for the color which visualizes undefined values within the diagram.
Lines and Symbols > Color for Undefined Value	ONLY AVAILABLE IF AT LEAST ONE UNDEFINED VALUE IN DATA ARRAY. Color to be used for visualizing undefined values.
Lines and Symbols > Opacity for Undefined Value	ONLY AVAILABLE IF AT LEAST ONE UNDEFINED VALUE IN DATA ARRAY. The opacity of the visualization of undefined values can be set here.
Multigraph Options > Multigraph Mode	ONLY AVAILABLE IF MORE THAN ONE SUBSET GIVEN IN THE DATA ARRAY. Via the Multigraph Mode it is possible to switch between the display of one single subset and multiple subsets. ↪Sec. (b)
X-Axis > Descending Coordinates	If selected, the diagram will be shown with descending coordinates. Otherwise the coordinates will be ascending.
X-Axis > Logarithmic Scaling	If set to *True*, the x-axis scaling will be logarithmic instead of linear.
X-Axis > Minimum Number of Ticks	A guiding value for the automatic tick labeling of the x-axis can be set here. The axis will have at least the number of ticks which is set by this value.
Y-Axis > Description	If *Is Description User Defined* is set to *True*, a user-defined axis label can be set here. Otherwise the currently shown subset's description is displayed here.
Y-Axis > Is Description User Defined	If *True*, a user defined label can be set instead of showing a label based on the respective subset description.
Y-Axis > Logarithmic Scaling	If set to *True*, the y-axis scaling will be logarithmic instead of linear.
Y-Axis > Minimum Number of y-Axis Ticks	A guiding value for the automatic tick labeling of the y-axis can be set here. The axis will have at least the number of ticks which is set by this value.
Y-Axis > Read Labels from Inside	The orientation of the y-axis labels can be specified here.

(b) Cartesian 1D Diagram in Multigraph Mode

Availability

For data arrays with more than one subset

Accessible:

- Ribbon: View > Multigraph Mode
- Property browser: *View > Multigraph Options > Multigraph Mode*

The *Multigraph Mode* allows to display more than one subset at once in the diagram of a 1D Data Array. Fig. 103 shows an example.

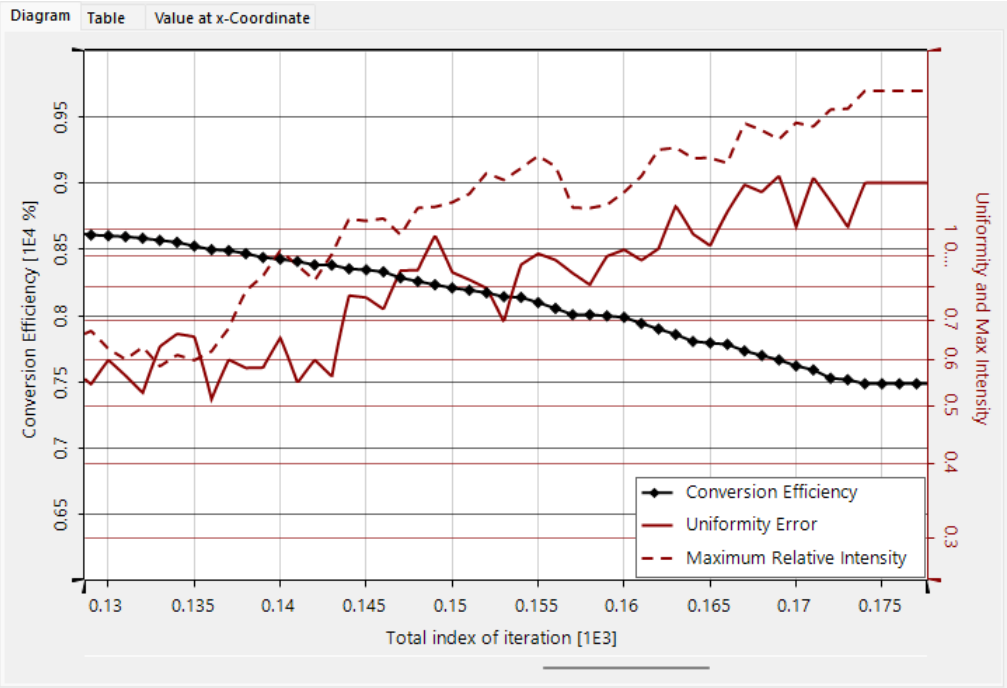


Figure 103. *Example for the Multigraph Mode.*

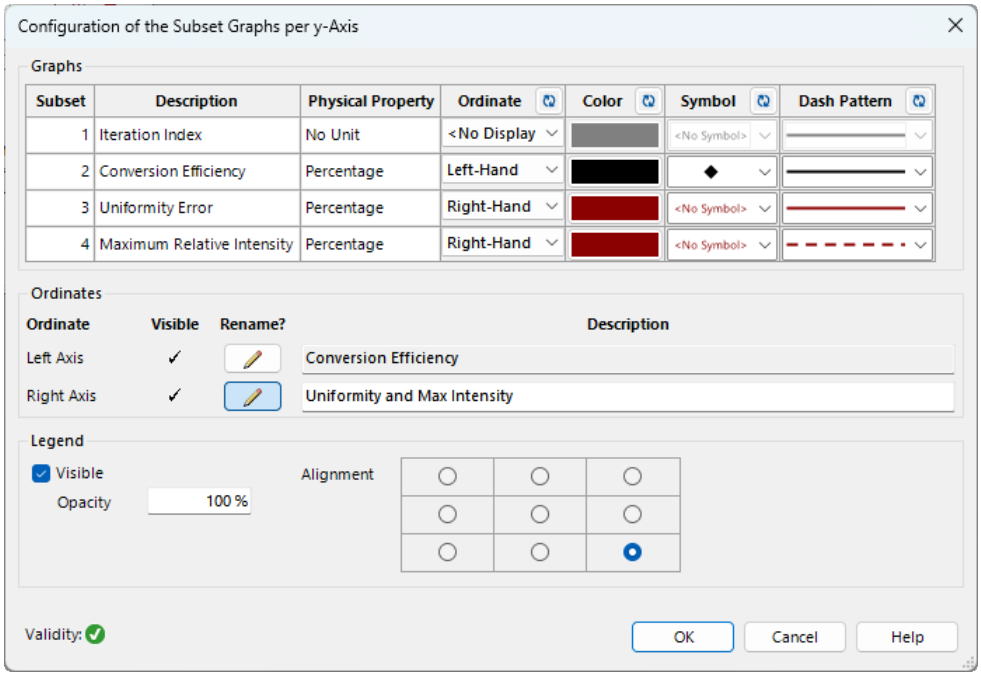


Figure 104. *Dialog for configuring the Multigraph Mode.*

Via View > Multigraph Settings, the Multigraph Mode can be configured. The dialog shown in Fig. 104 provides the following settings:

ITEM	DESCRIPTION
Graphs > Subset #	The index of the subset represented by that table row. This column is **read-only**.
Graphs > Description	The description of the subset. This column is **read-only**. (Sec. 24.5.1 shows how to edit the description.)
Graphs > Physical Property	The physical property of the subset. This column is **read-only**. (Sec. 24.5.1 shows how to edit the physical property.)
Graphs > Ordinate	This option allows to choose whether the curve shall be associated to the *Left-Hand* y-axis, the *Right-Hand* y-axis or shall be *<Not Displayed>* at all. **Important:** All subsets to be displayed with respect to the same axis has to have the same physical property! Furthermore, there has to be one subset for the left-hand y-axis at least. If the button is pressed, the synchronization of the ordinate is enforced for all subsets.
Graphs > Color	This allows to select a color for the curve which represents the subset. Initially, it is identical to the color of the associated y-axis in order to depict the association. If the button is pressed, the synchronization of the color is enforced for all subsets.
Graphs > Symbol	A symbol for displaying the data points can be selected here. If the button is pressed, the synchronization of the symbol is enforced for all subsets.
Graphs > Dash Pattern	This allows to select a dash pattern for the curve which represents the subset. If the button is pressed, the synchronization of the dash pattern is enforced for all subsets.
Ordinates > Left/Right Axis > Rename?	If this button is pressed, a user-defined *Description* can be set for the respective ordinate.
Legend > Visible	The visibility of the graphs legend can be set here.
Legend > Alignment	AVAILABLE IF THE LEGEND IS VISIBLE. The position of the legend inside the diagram can be set.
Legend > Opacity	AVAILABLE IF THE LEGEND IS VISIBLE. The legend's opacity in the range between 0 and 100%.

The ribbon item View > Show Legend allows to toggle the visibility of the multigraph legend. In case of undefined values in the diagram, the visibility of the legend for the color which visualizes undefined values is toggled as well.
View > Axes Options > Descending Coordinates (x-Axis) allows to show an inverted coordinate axis.
The item View > Axes Options > Transposed View will swap the directions of the independent (x-) and the dependent (y-)axis if no right-hand axis is used.
The ribbon item View > Axes Options > Logarithmic Scaling (x-axis) toggles between a logarithmic and a linear scaling of the coordinate axis if the complete coordinate range is positive.
View > Axes Options > Logarithmic Scaling (Left / Right y-axis) is a switch between a logarithmic and a linear scaling of the left-hand (or right-hand) y-axis if the values to be displayed are completely positive.
In multigraph mode, there are several specific settings accessible via the *View* tab of the Property Browser:

ITEM	DESCRIPTION
General > Show Polar Diagram	ONLY IF THE DATA ARRAY REPRESENTS AN ANGULAR DEPENDENCY. Switches between a polar diagram view (↪Sec. (d)) and a Cartesian diagram view.
General > Transposed View	ONLY IF NO RIGHT-HAND Y-AXIS IS USED. If *True*, the vertical axis and the horizontal axis of the diagram will be transposed. The independent variable will then be shown in the vertical direction.
General > Legend Visible	The visibility of the multigraph legend can be toggled here. Furthermore, in case of undefined values in the diagram, the visibility of the legend for the color which visualizes undefined values is toggled as well.
Lines and Symbols > Line Thickness	Thickness of the lines which connect the displayed data points of one subset. Has to be a positive integer.
Lines and Symbols > Symbol Scaling Factor	ONLY AVAILABLE IF *SYMBOL SHAPE* IS NOT *NO SYMBOL*. The size of the symbols (except *Small Dot*) can be scaled using this factor.
Lines and Symbols > Use Smoothed Graphics	If activated, the graphics will be smoothed. Usually, this may improve the diagram. But if a stepped line is shown, deactivating this property may yield a better result. Important: This smoothing is done on pixel level. This pixel smoothing is not to be confused with the smoothing interpolation methods described in Sec. 11.2.2!
Lines and Symbols > Alignment of Undefined Color Legend	ONLY AVAILABLE IF AT LEAST ONE UNDEFINED VALUE IN DATA ARRAY. Allows to set the position of the legend for the color which visualizes undefined values within the diagram.
Lines and Symbols > Color for Undefined Value	ONLY AVAILABLE IF AT LEAST ONE UNDEFINED VALUE IN DATA ARRAY. Color to be used for visualizing undefined values.
Lines and Symbols > Opacity for Undefined Value	ONLY AVAILABLE IF AT LEAST ONE UNDEFINED VALUE IN DATA ARRAY. The opacity of the visualization of undefined values can be set here.
Multigraph Options > Multigraph Mode	ONLY AVAILABLE IF MORE THAN ONE SUBSET GIVEN IN THE DATA ARRAY. Via the Multigraph Mode it is possible to switch between the display of multiple subsets and one single subset. ↪Sec. (a)
Multigraph Options > Legend Alignment	ONLY AVAILABLE IF THE LEGEND IS VISIBLE. Allows to set the alignment of the multigraph legend.
Multigraph Options > Opacity	ONLY AVAILABLE IF THE LEGEND IS VISIBLE. The multigraph legend's opacity in the range between 0 and 100%.
X-Axis > Descending Coordinates	If selected, the diagram will be shown with descending coordinates. Otherwise the coordinates will be ascending.
X-Axis > Logarithmic Scaling	If set to *True*, the x-axis scaling will be logarithmic instead of linear.
X-Axis > Minimum Number of Ticks	A guiding value for the automatic tick labeling of the x-axis can be set here. The axis will have at least the number of ticks which is set by this value.
Y-Axis Left / Right-Hand > Description	If *Is Description User Defined* is set to *True*, a user-defined axis label can be set here. Otherwise the currently shown subset's description is displayed here.

Y-Axis Left / Right-Hand > Is Description User Defined	If *True*, a user defined label can be set instead of showing a label based on the respective subset description.
Y-Axis Left / Right-Hand > Color	The color of the left-hand or right-hand y-axis.
Y-Axis Left / Right-Hand > Logarithmic Scaling	If set to *True*, the y-axis scaling will be logarithmic instead of linear.
Y-Axis Left / Right-Hand > Minimum Number of y-Axis Ticks	A guiding value for the automatic tick labeling of the y-axes can be set here. The axes will have at least the number of ticks which is set by this value. Important: Changing the value for one axis, that of the other y-axis will be changed as well.
Y-Axis Left / Right-Hand > Read Labels from Inside	The orientation of the axis labels can be specified here.

(c) Polar Diagram in Singlegraph Mode

Availability

For data arrays with angular dependency

Accessible:

- Ribbon: View > Axes Options > Polar Diagram
- Property browser: *View > General > Show Polar Diagram*

The ribbon item View > Axes Options > Polar Diagram allows to switch between the display of a polar diagram and a Cartesian diagram in case an angular dependency is shown.
View > Axes Options > Logarithmic Scaling (Radial Axis) toggles between a logarithmic and a linear scaling of the radial axis *if the values to be displayed are completely positive*.
The following specific parameters can be set via the *View* tab of the Property Browser:

ITEM	DESCRIPTION
General > Show Polar Diagram	Switches between a Cartesian diagram view (↪Sec. (a)) and a polar diagram view.
General > Orientation of Half Circle	The orientation of the half circle (*Top*, *Bottom*, *Left*, *Right*) can be set here.
General > Legend Visible	ONLY AVAILABLE IF AT LEAST ONE UNDEFINED VALUE IN DATA ARRAY. The visibility of the legend for the color which visualizes undefined values can be set here.
Azimuthal Axis > Number of Grid Lines/Quadrant	How many angular tick lines shall be visible per quadrant?
Azimuthal Axis > Orientation of Angular Labels	The orientation (*Horizontal*, *Radial*, *Tangential*) of the angular labels can be set here.
Azimuthal Axis > Show Angles in Radian	If *True*, the angular labels are shown in radian, otherwise in degrees.

Lines and Symbols > Line Color	Color of line which connects the displayed data points. If set to *Transparent*, the line will not be shown.
Lines and Symbols > Line Thickness	Thickness of line which connects the displayed data points. Has to be a positive integer.
Lines and Symbols > Symbol Color	Only available if *Symbol Shape* is not *No Symbol*. Color of the symbols which mark the data points.
Lines and Symbols > Symbol Scaling Factor	Only available if *Symbol Shape* is not *No Symbol*. The size of the symbols (except *Small Dot*) can be scaled using this factor.
Lines and Symbols > Symbol Shape	Shape of the symbols which mark the data points. If set to *No Symbol*, symbols will be switched off.
Lines and Symbols > Use Smoothed Graphics	If activated, the graphics will be smoothed. Usually, this may improve the diagram. But if a stepped line is shown, deactivating this property may yield a better result. Important: This smoothing is done on pixel level. This pixel smoothing is not to be confused with the smoothing interpolation methods described in Sec. 11.2.2!
Lines and Symbols > Alignment of Undefined Color Legend	Only available if at least one undefined value in data array. The position / alignment of the legend for the color to be used for visualizing undefined values.
Lines and Symbols > Color for Undefined Value	Only available if at least one undefined value in data array. Color to be used for visualizing undefined values.
Lines and Symbols > Opacity for Undefined Value	Only available if at least one undefined value in data array. The opacity of the visualization of undefined values can be set here.
Multigraph Options > Multigraph Mode	Only available if more than one subset given in the data array. Via the Multigraph Mode it is possible to switch between the display of one single subset and multiple subsets. ↪Sec. (d)
Radial Axis > Description	If *Is Description User Defined* is set to *True*, a user-defined axis label can be set here. Otherwise the currently shown subset's description is displayed here.
Radial Axis > Is Description User Defined	If *True*, a user defined label can be set instead of showing a label based on the respective subset description.
Radial Axis > Logarithmic Scaling	If set to *True*, the radial axis scaling will be logarithmic instead of linear.
Radial Axis > Minimum Number of Radial Axis Ticks	A guiding value for the automatic tick labeling of the radial axis can be set here. The axis will have at least the number of ticks which is set by this value.

(d) Polar Diagram in Multigraph Mode

Availability

For data arrays with angular dependency and more than one subset

Accessible:

- Ribbon: View > Multigraph Mode
- Ribbon: View > Axes Options > Polar Diagram
- Property browser: *View > Multigraph Options > Multigraph Mode*
- Property browser: *View > General > Show Polar Diagram*

The *Multigraph Mode* allows to display more than one subset at once in the diagram of a 1D Data Array. Fig. 105 shows an example.

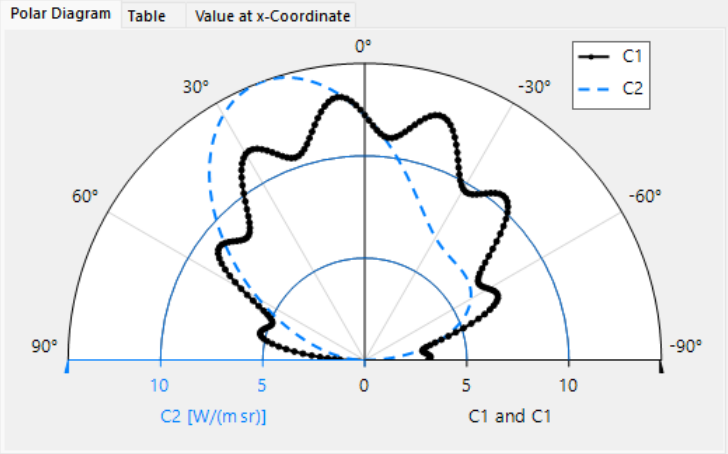


Figure 105. *Example for the Multigraph Mode of a polar diagram.*

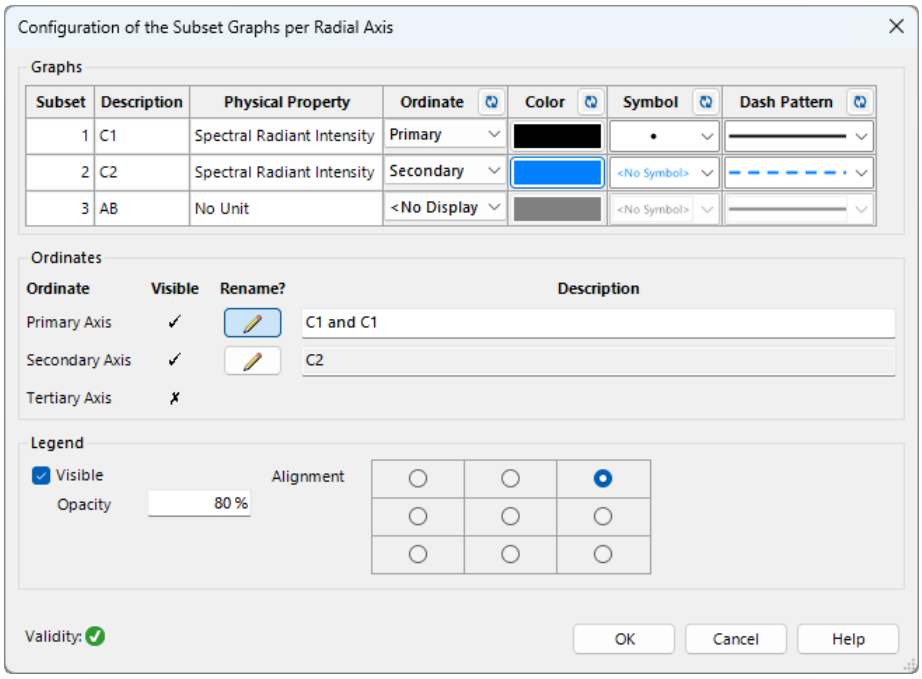


Figure 106. *Dialog for configuring the Multigraph Mode for a polar diagram.*

Via View > Multigraph Settings, the Multigraph Mode can be configured. The dialog shown in Fig. 106 provides the following settings:

ITEM	DESCRIPTION
Graphs > Subset #	The index of the subset represented by that table row. This column is **read-only**.
Graphs > Description	The description of the subset. This column is **read-only**. (Sec. 24.5.1 shows how to edit the description.)
Graphs > Physical Property	The physical property of the subset. This column is **read-only**. (Sec. 24.5.1 shows how to edit the physical property.)
Graphs > Ordinate	This option allows to choose whether the curve shall be associated to the *Primary*, the *Secondary*, or the *Tertiary* radial axis or whether the subset shall be *<Not Displayed>* at all. **Important:** All subsets to be displayed with respect to the same axis has to have the same physical property! Furthermore, there has to be one subset for the primary radial axis at least. If the tertiary axis is supposed to be used, at least one subset has to be associated with the secondary axis, additionally. If the button is pressed, the synchronization of the ordinate is enforced for all subsets.
Graphs > Color	This allows to select a color for the curve which represents the subset. Initially, it is identical to the color of the associated radial axis in order to depict the association. If the button is pressed, the synchronization of the color is enforced for all subsets.
Graphs > Symbol	A symbol for displaying the data points can be selected here. If the button is pressed, the synchronization of the symbol is enforced for all subsets.
Graphs > Dash Pattern	This allows to select a dash pattern for the curve which represents the subset. If the button is pressed, the synchronization of the dash pattern is enforced for all subsets.
Ordinates > Primary / Secondary / Tertiary Axis > Rename?	If this button is pressed, a user-defined *Description* can be set for the respective ordinate.
Legend > Visible	The visibility of the graphs legend can be set here.
Legend > Alignment	AVAILABLE IF THE LEGEND IS VISIBLE. The position of the legend inside the diagram can be set.
Legend > Opacity	AVAILABLE IF THE LEGEND IS VISIBLE. The legend's opacity in the range between 0 and 100%.

The ribbon item View > Show Legend allows to toggle the visibility of the multigraph legend. In case of undefined values in the diagram, the visibility of legend for the color which visualizes undefined values is toggled as well.

The ribbon item View > Axes Options > Polar Diagram allows to switch between the display of a polar diagram and a Cartesian diagram in case an angular dependency is shown.

View > Axes Options > Logarithmic Scaling (Primary / Secondary / Tertiary Radial Axis) toggles between a logarithmic and a linear scaling of a certain radial axis *if the values to be displayed are completely positive (and if the respective axis is in use, of course)*.

In multigraph mode, there are several specific settings accessible via the *View* tab of the Property Browser:

ITEM	DESCRIPTION
General > Show Polar Diagram	Switches between a Cartesian diagram view (↪Sec. (b)) and a polar diagram view.
General > Orientation of Half Circle	The orientation of the half circle (*Top*, *Bottom*, *Left*, *Right*) can be set here.
General > Legend Visible	The visibility of the multigraph legend can be toggled here. Furthermore, in case of undefined values in the diagram, the visibility of the legend for the color which visualizes undefined values is toggled as well.
Azimuthal Axis > Number of Grid Lines/Quadrant	How many angular tick lines shall be visible per quadrant?
Azimuthal Axis > Orientation of Angular Labels	The orientation (*Horizontal*, *Radial*, *Tangential*) of the angular labels can be set here.
Azimuthal Axis > Show Angles in Radian	If *True*, the angular labels are shown in radian, otherwise in degrees.
Lines and Symbols > Line Thickness	Thickness of line which connects the displayed data points. Has to be a positive integer.
Lines and Symbols > Symbol Scaling Factor	Only available if *Symbol Shape* is not *No Symbol*. The size of the symbols (except *Small Dot*) can be scaled using this factor.
Lines and Symbols > Use Smoothed Graphics	If activated, the graphics will be smoothed. Usually, this may improve the diagram. But if a stepped line is shown, deactivating this property may yield a better result. Important: This smoothing is done on pixel level. This pixel smoothing is not to be confused with the smoothing interpolation methods described in Sec. 11.2.2!
Lines and Symbols > Alignment of Undefined Color Legend	Only available if at least one undefined value in data array. The position / alignment of the legend for the color to be used for visualizing undefined values.
Lines and Symbols > Color for Undefined Value	Only available if at least one undefined value in data array. Color to be used for visualizing undefined values.
Lines and Symbols > Opacity for Undefined Value	Only available if at least one undefined value in data array. The opacity of the visualization of undefined values can be set here.
Multigraph Options > Multigraph Mode	Only available if more than one subset given in the data array. Via the Multigraph Mode it is possible to switch between the display of multiple subsets and one single subset. ↪Sec. (c)
Multigraph Options > Legend Alignment	Only available if the legend is visible. Allows to set the alignment of the multigraph legend.
Multigraph Options > Opacity	Only available if the legend is visible. The multigraph legend's opacity in the range between 0 and 100%.
Radial Axis (Primary / Secondary / Tertiary) > Description	If *Is Description User Defined* is set to *True*, a user-defined axis label can be set here. Otherwise the currently shown subset's description is displayed here.

Radial Axis (Primary / Secondary / Tertiary) > Is Description User Defined	If *True*, a user defined label can be set instead of showing a label based on the respective subset description.
Radial Axis (Primary / Secondary / Tertiary) > Color	The color of the respective radial axis.
Radial Axis (Primary / Secondary / Tertiary) > Logarithmic Scaling	If set to *True*, the respective radial axis scaling will be logarithmic instead of linear.
Radial Axis (Primary / Secondary / Tertiary) > Minimum Number of Radial Axis Ticks	A guiding value for the automatic tick labeling of the radial axes can be set here. The axes will have at least the number of ticks which is set by this value. Important: Changing the value for one axis, that of the other radial axes will be changed as well.

13.4.1.3 Specific View Features for 2D Data Arrays

The features described in this section are available for 2D Data Arrays only.

ITEM	DESCRIPTION
Color Table	↪Sec. 11.2.4
Color for Undefined Values	The color to be used for visualizing undefined values. (Can be set via Property Browser only.)
3D Mode	↪Sec. (a)
Show Legend	Allows to switch off the color legend.
Show 1D Profile	Shows or hides the 1D profile which shows a section along the line marker below the 2D diagram. ↪Sec. (b)

(a) 3D Mode

Availability

Accessible:

- Ribbon: View >  Diagram in 3D Mode
- Property browser: *View > 3D Mode*

Visualization of a 2D data array can be done either in 2D mode (as shown in Fig. 100) or in 3D mode (as in Fig. 107).

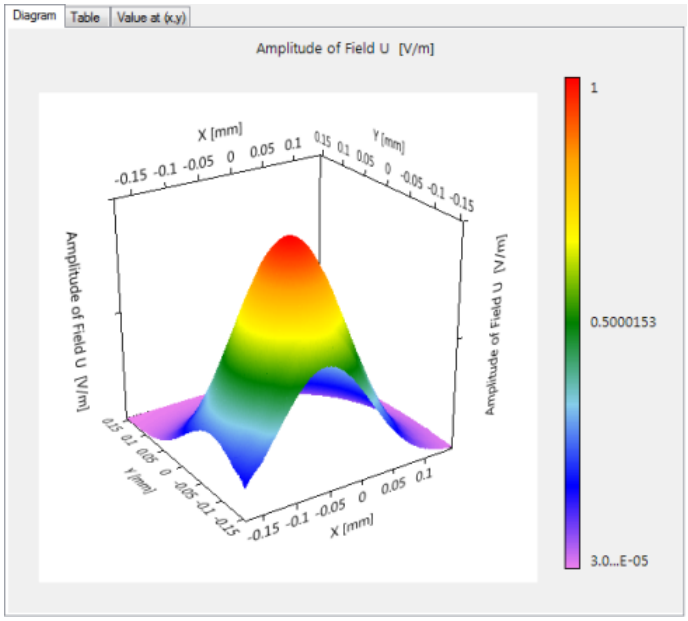


Figure 107. *Example for the diagram view of a 2D data array in 3D mode.*

The 3D mode offers some specific mouse interactions:

MOUSE (+ KEYBOARD) ACTION	VIEW OPERATION
Left button + move	Free rotation
X / Y / Z key + left button + move	Constrained rotation
Shift + left button + move	Translation
Ctrl + left button + move up/down	Zoom

You can adjust the view in the property browser (*View > 3D Options group*):

ITEM	DESCRIPTION
Camera Direction	Sets the perspective (i.e. the direction) of the view.
Camera Distance Parameter	Decimal number that describes the camera distance in an arbitrary unit. It affects the spatial distortion of the view and has to be larger than 1.0.
Camera Rotation Angle X/Y/Z	Via these angles the direction of the view can be set in an alternative way to *Camera Direction*
Draw Contours	Only available if the currently set *Color Table* is stepped, i. e. if it isn't interpolated. If set to *True*, contour lines are drawn at the borders between two different colors.
Font Size Factor	A value for rescaling the labels inside the 3D view.
Show Data While Interacting	If set to *True*, the diagram will be visible during mouse interaction.
Show Mesh	If set to *True*, a mesh grid will be displayed instead of colors.

Zone Method	The type of drawing the zones. Possible values are *Contours*, which looks nice but is slow, and *Cells*, which doesn't look as nice, but is faster.
Zoom Factor	Factor that determines the zoom of the view.

(b) Profile Lines ONLY ENABLED IF THE LINE MARKER IS VISIBLE.

If a line marker is visible in the 2D diagram, by default the data along the selected line is shown as a profile line in a 1D diagram below the 2D diagram. This 1D diagram shares many of the features of a normal 1D diagram (↪Sec. 13.4.1.2).
Please note that the starting coordinate of the 1D diagram corresponds to the line coordinates in the 2D diagram only if the line is oriented exactly vertically or horizontally (which can easily be achieved holding Ctrl pressed while dragging the mouse). In case of a sloping line, no reasonable starting coordinate can be extracted, so the 1D diagram will start at the value 0.
If point marker and rectangle or ellipse marker intersect with the profile line, they are also shown there. Vice versa, if the point marker is moved within the profile line, this change is also shown in the 2D diagram.
Via mouse wheel, you can zoom into the shown 1D diagram independently from the 2D diagram.
The separator line between 1D diagram and 2D diagram can be dragged with the mouse to change the relative sizes of these diagrams. This can also be done via the Property browser (*View > General > Height of 1D Profile*). Or you can disable the profile completely there (*View > Selection (Line) > Show 1D Profile*).

(c) Polarization Ellipses

Availability

Available only for Electric Fields or Electromagnetic Fields

Accessible:

- Ribbon: View > Show xy-/yz-/zx-Ellipses

The ribbon menu item View > Graphics Add-ons > Show xy-/yz-/zx-Ellipses is only available if a vectorial component of an electric field is currently shown and if the graphics add-on for visualizing polarization ellipses is available for the corresponding subset. It allows to toggle the visibility of the ellipses for this vectorial field component.
The corresponding configuration button allows to configure the view settings of the currently shown polarization ellipses via the dialog described in Sec. 11.7.3.

13.4.1.4 Specific View Features for Gridless Data Arrays

ITEM	DESCRIPTION
Color Table	Allows to set the color table to use. ↪Sec. 11.2.4
Dot Size	NOT AVAILABLE FOR VIEWS OF TYPE 'DISTRIBUTION OF PUPILS WITH VALUES'. The size of the dots. Can be set either via the ribbon item View > Dot Size or the *View* tab of the property browser.
Background Color	Usually the dots do not fill the whole diagram region so the background can be seen. By clicking on View > Background Color, either a predefined color can be chosen or a new color can be defined via *More Colors*. The entry *Background Color* in the *View* tab of the property browser has more predefined colors. There you can also directly enter the name or the RGB values (separated by comma **and** space) of the desired color.
Show Triangles	AVAILABLE ONLY IF MESH DATA ARE STORED WITH THE DATA ARRAY. If checked, the triangles of the mesh are shown as described in Sec. 11.2.3.
Pupils Rendering	AVAILABLE ONLY FOR VIEWS OF TYPE 'DISTRIBUTION OF PUPILS WITH VALUES'. Allows to configure the view settings for the pupils shown as described below in Sec. (a).

(a) Configuration of a Distribution of Pupils With Values

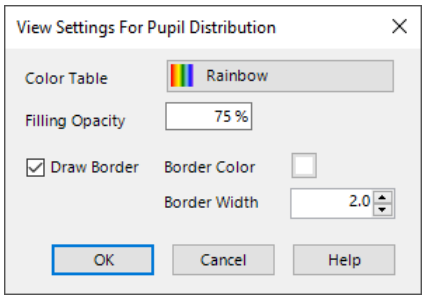


Figure 108. *Dialog for configuring a Distribution of Pupils With Values.*

ITEM	DESCRIPTION
Color Table	The color table used for mapping the pupil's values to colors
Filling Opacity	Opacity of the filling colors. 0% means complete transparency, 100% means no transparency at all.
Draw Border	If checked, the pupil's borders are drawn.
Border Color	VISIBLE ONLY IF *DRAW BORDER* IS SELECTED. The color of the borders.
Border Width	VISIBLE ONLY IF *DRAW BORDER* IS SELECTED. The line width of the borders.

13.4.2 Table Panel

The *Table* panel provides a table showing the data points for each coordinate or pair of coordinates.

There is an upper limit for the number of table cells that are displayed. If this threshold which can be set via the Global Options dialog (↪Sec. 6.7) is exceeded, no table will be displayed for performance reasons. The display of the table can be enforced despite the bad performance by pushing the button *Show Table Anyway*, which will be visible in this case.

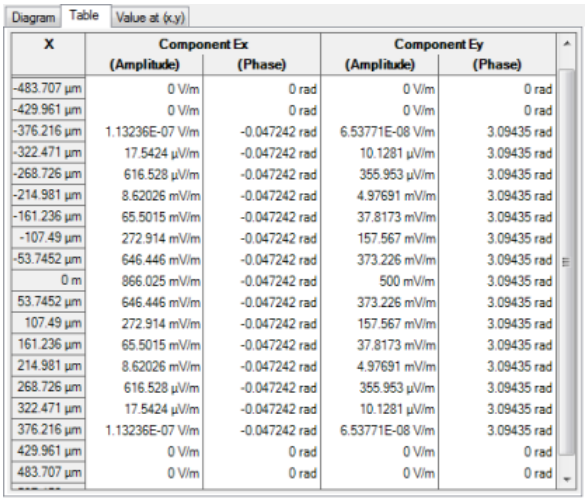


Diagram | Table | Value at (x,y)

X	Component Ex		Component Ey	
	(Amplitude)	(Phase)	(Amplitude)	(Phase)
-483.707 µm	0 V/m	0 rad	0 V/m	0 rad
-429.961 µm	0 V/m	0 rad	0 V/m	0 rad
-376.216 µm	1.13236E-07 V/m	-0.047242 rad	6.53771E-08 V/m	3.09435 rad
-322.471 µm	17.5424 µV/m	-0.047242 rad	10.1281 µV/m	3.09435 rad
-268.726 µm	616.528 µV/m	-0.047242 rad	355.953 µV/m	3.09435 rad
-214.981 µm	8.62026 mV/m	-0.047242 rad	4.97691 mV/m	3.09435 rad
-161.236 µm	65.5015 mV/m	-0.047242 rad	37.8173 mV/m	3.09435 rad
-107.49 µm	272.914 mV/m	-0.047242 rad	157.567 mV/m	3.09435 rad
-53.7452 µm	646.446 mV/m	-0.047242 rad	373.226 mV/m	3.09435 rad
0 m	866.025 mV/m	-0.047242 rad	500 mV/m	3.09435 rad
53.7452 µm	646.446 mV/m	-0.047242 rad	373.226 mV/m	3.09435 rad
107.49 µm	272.914 mV/m	-0.047242 rad	157.567 mV/m	3.09435 rad
161.236 µm	65.5015 mV/m	-0.047242 rad	37.8173 mV/m	3.09435 rad
214.981 µm	8.62026 mV/m	-0.047242 rad	4.97691 mV/m	3.09435 rad
268.726 µm	616.528 µV/m	-0.047242 rad	355.953 µV/m	3.09435 rad
322.471 µm	17.5424 µV/m	-0.047242 rad	10.1281 µV/m	3.09435 rad
376.216 µm	1.13236E-07 V/m	-0.047242 rad	6.53771E-08 V/m	3.09435 rad
429.961 µm	0 V/m	0 rad	0 V/m	0 rad
483.707 µm	0 V/m	0 rad	0 V/m	0 rad

Figure 109. *Example for the table view of a 1D data array.*

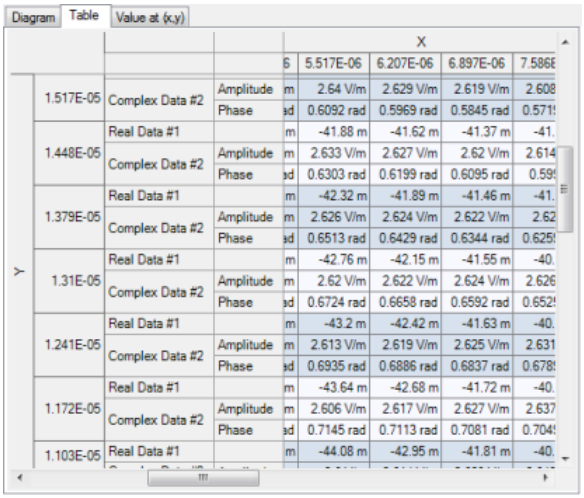


Diagram | Table | Value at (x,y)

				X			
			6	5.517E-06	6.207E-06	6.897E-06	7.586E
Y	1.517E-05	Complex Data #2	Amplitude	m	2.64 V/m	2.629 V/m	2.619 V/m	2.608
			Phase	ad	0.6092 rad	0.5969 rad	0.5845 rad	0.571
	1.448E-05	Real Data #1		m	-41.88 m	-41.62 m	-41.37 m	-41.
		Complex Data #2	Amplitude	m	2.633 V/m	2.627 V/m	2.62 V/m	2.614
			Phase	ad	0.6303 rad	0.6199 rad	0.6095 rad	0.59
	1.379E-05	Real Data #1		m	-42.32 m	-41.89 m	-41.46 m	-41.
		Complex Data #2	Amplitude	m	2.626 V/m	2.624 V/m	2.622 V/m	2.62
			Phase	ad	0.6513 rad	0.6429 rad	0.6344 rad	0.625
	1.31E-05	Real Data #1		m	-42.76 m	-42.15 m	-41.55 m	-40.
		Complex Data #2	Amplitude	m	2.62 V/m	2.622 V/m	2.624 V/m	2.626
			Phase	ad	0.6724 rad	0.6658 rad	0.6592 rad	0.652
	1.241E-05	Real Data #1		m	-43.2 m	-42.42 m	-41.63 m	-40.
		Complex Data #2	Amplitude	m	2.613 V/m	2.619 V/m	2.625 V/m	2.631
			Phase	ad	0.6935 rad	0.6886 rad	0.6837 rad	0.678
	1.172E-05	Real Data #1		m	-43.64 m	-42.68 m	-41.72 m	-40.
		Complex Data #2	Amplitude	m	2.606 V/m	2.617 V/m	2.627 V/m	2.637
			Phase	ad	0.7145 rad	0.7113 rad	0.7081 rad	0.704
	1.103E-05	Real Data #1		m	-44.08 m	-42.95 m	-41.81 m	-40.

Figure 110. *Example for the table view of a 2D data array.*

The context menu in the table panel contains the following entries:

ITEM	DESCRIPTION
Edit Selected Data Point...	Opens a dialog for editing the value(s) of the data point which is associated with the currently selected cell(s) (↪Sec. 24.16).
Mark Selected Range in Diagram	ONLY AVAILABLE FOR ONE-DIMENSIONAL DATA. If a range of rows is selected within the table, this menu item will mark the corresponding coordinate range in the diagram.
Mark Selected Point in Diagram	ONLY AVAILABLE FOR ONE-DIMENSIONAL DATA. If a single row is selected within the table, this menu item will mark the corresponding coordinate in the diagram.
Copy Selection	This will copy the content of the selected table cells to the clipboard.

The *View* panel of the property browser has the following entries for the table panel:

ITEM	DESCRIPTION
Field Quantity	ONLY ENABLED FOR COMPLEX DATA ARRAYS AND IF THE OPTION *SHOW TWO COMPLEX PARTS* IS FALSE. The field quantity (↪Sec. 11.1) to show in the table.
Show Two Complex Parts	ONLY ENABLED FOR COMPLEX DATA ARRAYS. If *True*, the table shows both complex parts for each data point. Otherwise, only one field quantity is shown at a time.
Amplitude Phase Mode	ONLY ENABLED FOR COMPLEX DATA ARRAYS AND IF THE OPTION *SHOW TWO COMPLEX PARTS* IS TRUE. Here can be set whether the table shall show amplitude and phase (*True*) or real and imaginary part (*False*).
Number of Digits	The number of significant digits to be shown for the entries in the table.
Show Units	With this option you can show the entries in the table without physical units. In this way copied entries can be more easily processed in external programs like e. g. spreadsheet software.

13.4.3 Value at (x,y) Panel

If the value (or the values of more than one subset) at one certain position has (have) to be identified, this can be done via this *Value at (x,y)* panel. Here, simply the coordinates have to be entered, than the value(s) is (are) displayed as shown in Fig. 111 for 1D and Fig. 112 for 2D data. If a point marker (↪Sec. 11.3) is visible in the *View Panel*, its position will be filled in here automatically.

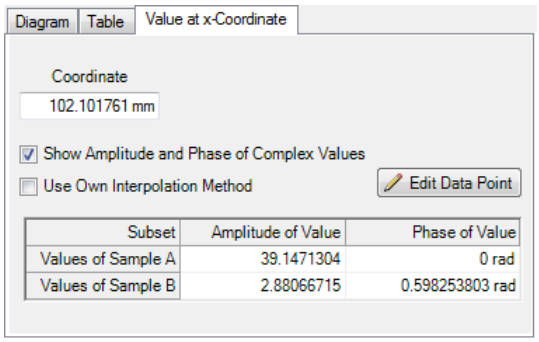


Figure 111. *Example for the view for a value at a position (x, y) of a 1D data array.*

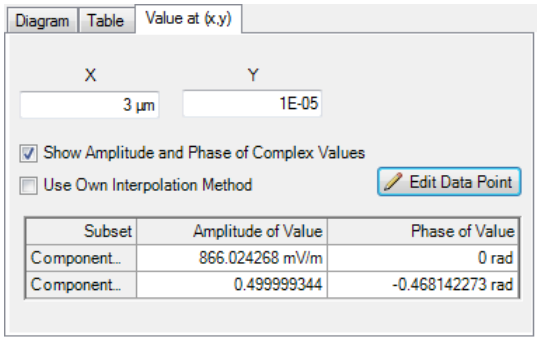


Figure 112. *Example for the view for a value at a position (x, y) of a 2D data array.*

ITEM	DESCRIPTION
First Coordinate	First coordinate to get the value(s) for.

Second Coordinate	ONLY AVAILABLE FOR TWO-DIMENSIONAL DATA. Second coordinate to get the value(s) for.
Show Amplitude and Phase of Complex Values	If checked, complex data will be displayed as amplitude and phase instead of real part and imaginary part.
Use Own Interpolation Method	ONLY AVAILABLE IF THE INTERPOLATION METHOD IS NOT SINC (FOURIER TRANSFORM). If checked, the interpolation method of the data array will be used in order to calculate the value(s) at a position that lies between adjacent data points. Otherwise, nearest neighbor interpolation (or constant interval interpolation, in case of non equidistant data) will be used.
Edit Data Point	Opens a dialog for editing the value(s) of the currently shown data point (↪Sec. 24.16).

14 Chromatic Fields Set View

The Chromatic Fields Set View can display the squared amplitude distribution of one- or two-dimensional fields. This view is also used as preview in the Light Sources Catalog, in particular the same context menu is used there. However the preview uses a special toolbar is show which is described in Sec. 14.4.
There are two settings which strongly influence the available view settings: the wavelengths mode (↪Sec. 14.1) and the color mode (↪Sec. 14.2).
Interpolated view (↪Sec. 11.2.1), markers and selections (↪Sec. 11.3), zoom (↪Sec. 11.4), aspect ratio (↪Sec. 11.5), and Copy View To Clipboard (↪Sec. 11.6) are available independently from these modes.

14.1 Wavelength Selection

Availability

Accessible:
- Ribbon: View > Wavelength Selection group
- Property browser: *View > Summation Mode* and *View > Wavelength Index*
- Context menu: *Wavelengths Mode* and *Wavelength Index*

There are two *Wavelength Modes* available:

MODE	DESCRIPTION
Summed Wavelengths	Adds the values of all wavelengths to one field.
Single Wavelengths Mode	Only one wavelength is shown at a time. In the ribbon you can go through all wavelengths of a Chromatic Fields Set with the control shown in Fig. 113, either by using the arrow buttons or by entering the wavelength index directly. Below this control the currently selected wavelength is given.

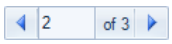


Figure 113. *The controls to select a wavelength index in the ribbon.*

14.2 Color Mode

Availability

Only for two-dimensional Chromatic Fields Sets

Accessible:

- Ribbon: View > Color Mode menu
- Property browser: *View > Color Mode*
- Context menu: *Color Mode*

There are two *Color Modes* available:

MODE	DESCRIPTION
False Color	The squared amplitudes are shown as data arrays. Thus this mode has the same view functionality as for Numerical Data Arrays (↪Sec. 13.4). Adds the values of all wavelengths to one field.
Real Color	Only available if at least one of the wavelengths in the Chromatic Fields Set is in the visible range (360 – 830 nm). Considers the field as an intensity distribution (which, in general, can be polychromatic) and displays it as the human eye would perceive it. This mode allows you to adjust its brightness (↪Sec. 11.2.6). Consequently, if a point marker is shown the *Selections* tab of the property browser not only shows the squared amplitude at its current position, but also the red-green-blue values.

14.3 Maximum Lightness

Availability

Only for two-dimensional Chromatic Fields Sets in *Single Wavelength* and *Real Color* mode

Accessible:

- Ribbon: View > Maximum Lightness
- Property browser: *View > Maximum Lightness*
- Context menu: *Maximum Lightness*

If a chromatic fields set is displayed in *Single Wavelength* and *Real Color* mode, there are two lightness modes available: The *Maximum Lightness* may be switched ON or OFF.

ITEM	DESCRIPTION
Maximum Lightness	Only available in *Single Wavelength* and *Real Color* mode. Toggles the usage of the *Maximum Lightness* mode. If the button is pressed, all single wavelength views will be scaled to maximum lightness independently. If it is not pressed, no maximum scaling is done which allows to compare all single wavelengths views with each other.

As an example, a chromatic fields set is shown in Fig. 114 (in *Summed Wavelengths* mode) and in Fig. 115 (in *Single Wavelengths* mode with and without *Maximum Lightness* activated).

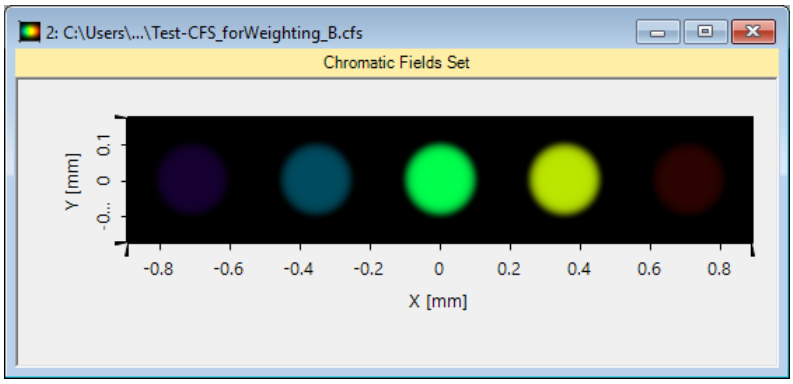


Figure 114. Real Color *view of a chromatic fields set with five different wavelengths in* Summed Wavelengths *mode.*

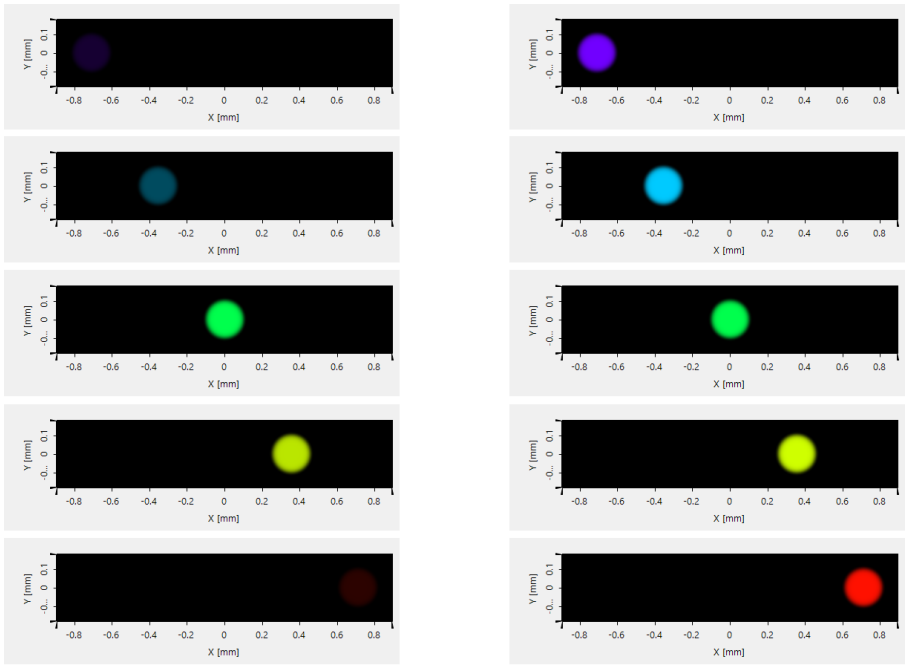


Figure 115. *All single wavelengths views of the chromatic fields set shown in Fig. 114.* Left hand side: *Deactivated* Maximum Lightness *allows comparison of the different wavelengths.* Right hand side: *Activated* Maximum Lightness *scales every wavelength view to its maximum which allows a better examination of faint regions.*

14.4 Toolbar (For the Preview in the Light Sources Catalog)

ITEM	DESCRIPTION
Color Mode	Switches the color mode, ↪Sec. 14.2.
Wavelength Mode	Switches the wavelengths mode, ↪Sec. 14.1.
Previous Wavelength Index	ONLY AVAILABLE IN *SINGLE WAVELENGTH* MODE. Show the field with the next smaller wavelength.
Wavelength Index #9: 735.4 nm	ONLY AVAILABLE IN *SINGLE WAVELENGTH* MODE. Show the field with the wavelength corresponding to the specified index.
Next Wavelength Index	ONLY AVAILABLE IN *SINGLE WAVELENGTH* MODE. Show the field with the next larger wavelength.
Separate Chromatic Fields Set	Shows the preview as separate Chromatic Fields Set which you can save or convert to a Numerical Data Array.

15 Pulse and Field Vector Component

For the display of pulses (↪Sec. 75.6.5), spectra (↪Sec. 54) and the results of the Extraction Tools (↪Sec. 23.2) a special document type *Light Field Object* is available which plots complex-valued field data versus wavelength, frequency, or time. The following 6 display variants are possible.

DISPLAY VARIANT	DESCRIPTION
Field Vector Component At One Point	Plots field data versus an index or the wavelength. This results in a one-dimensional diagram.
Pulse Component At One Point	Plots field data versus wavelength, frequency, or time. This results in a one-dimensional diagram, Fig. 116 shows an example. Carrier wavelength, carrier angular frequency, or time shift are stored as additional information.
Field Vector Component At Line	Plots field data along a line versus an index. This results in a two-dimensional diagram, Fig. 116 shows an example.
Pulse Component At Line	Plots field data along a line versus wavelength, frequency, or time. This results in a two-dimensional diagram. Carrier wavelength, carrier angular frequency, or time shift are stored as additional information.
Field Vector Component	Contains multiple subsets each storing two-dimensional field data at a certain index. This results in a two-dimensional diagram.
Pulse Component	Contains multiple subsets each storing two-dimensional field data at a certain wavelength, frequency, or time. This results in a two-dimensional diagram. Carrier wavelength, carrier angular frequency, or time shift are stored as additional information.

The view is essentially the same as for 1D or 2D Numerical Data Arrays (↪Sec. 13.4).

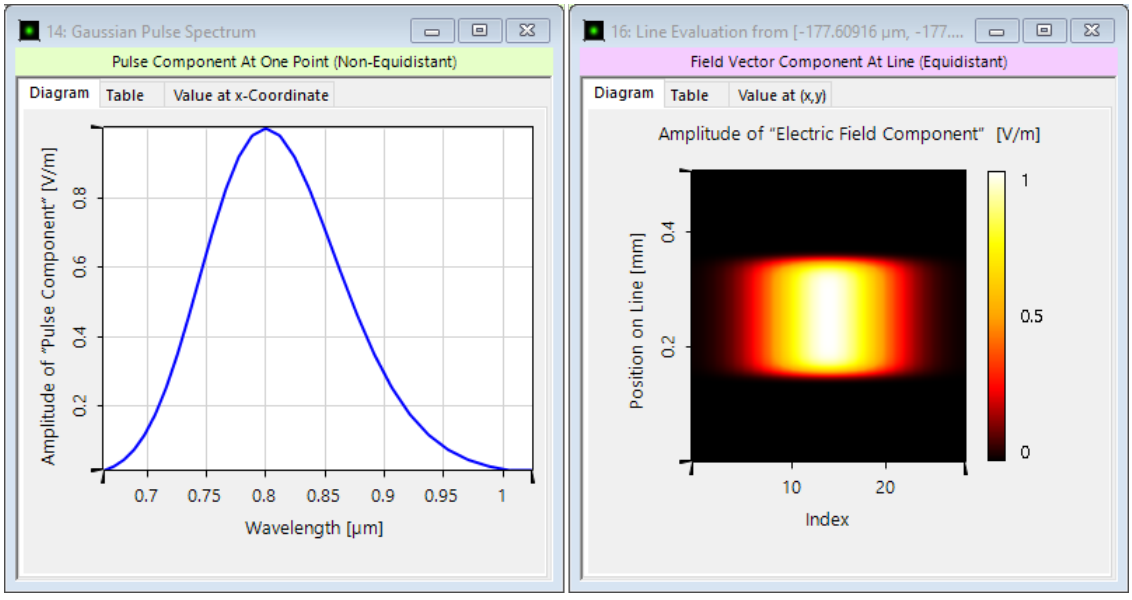


Figure 116. *A* Pulse Component At One Point *showing a Gaussian pulse (**left**) and a* Field Vector Component at Line *showing data extracted from a field with a Gaussian pulse spectrum (**right**).*

16 Set of Objects

Sometimes it is useful to group various objects of the same type together. For example a detector might yield several data arrays with different sampling. Besides the settings inherited from the underlying objects this view allows to switch between the contained objects.
Currently only a set of data arrays is supported. Note that for your convenience, a set of data arrays with only one data array is converted automatically to a single numerical data array.

Availability

…of the controls to switch between the data arrays:

Accessible:

- Ribbon: View > Data Array Selection ribbon group
- Property browser: *View > Data Array Index*

In the very top of the document view (↪Fig. 117), there is a double label. The left part indicates the name of the object, the right part the name of the current subset. The gray area between the two labels can be used to change their relative sizes by dragging with the mouse.

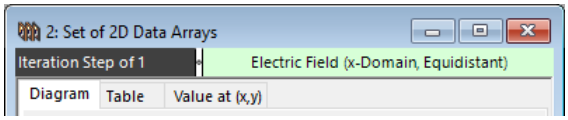


Figure 117. *Example for the double label of a Set of 2D Data Arrays. Here the* Electric Field *subset for* Iteration Step of 1 *is shown.*

The view settings for data arrays are explained in Sec. 13.4.

16.1 The View Area and Switching Between Objects

Different objects may own different definition areas. Usually, the view area is restricted to this definition area. So, switching between objects with differing definition areas may lead to ”jumping” view ranges if the definition areas overlap only partial or not at all.
If, however, the option *Data Restricted Zoom* is deactivated (↪Sec. 11.4.1), the zoom factor is not limited anymore and jumping view areas are avoided.
An additional feature leads to a more convenient switching behavior even if *Data Restricted Zoom* is kept activated: If the option called *Unified Max Extension* is checked, one unified definition area is calculated from all single definition areas of the contained objects.

Availability

…of the *Unified Max Extension* feature:

Accessible:

- Ribbon: View > Zoom & Aspect Ratio ribbon group > Unified Max Extension

17 Ray Distribution Views

A ray distribution can be visualized in two ways:

- *3D View*: the rays are drawn directly in the three-dimensional system view (↪Sec. 17.1).
- *2D View*: the intersections of the rays with a certain plane are drawn (↪Sec. 17.2).

Depending on how the ray distribution has been generated, one or two of these views are available.

- If the ray distribution is the result of certain detectors for the **General Profile**, it contains a 2D View of the rays in the detector plane with both Field Properties (↪Sec. 17.2.1) and Ray Properties (↪Sec. 17.2.2). Such *Non Equidistant Field Data* can be saved with the file extension .nefv.
- If the ray distribution is the result of the faster **Ray Results Profile**, it contains only Ray Properties in the 2D View, i. e. *Positions, Directions & Wavefront Phase*. The extension of this document type is .ppd.
- If the ray distribution has been generated with the **Ray Results Profile: 3D System**, the result is a *Ray Distribution 3D* (.rays). Usually it shows the 3D View and additionally the 2D View of the Ray Properties at the different boundaries. But if the Optical Setup was configured to use Manual Channel Configuration (↪Sec. 44.10), light can come from different directions and thus the wavefront is not well-defined. Thus in this case, 2D Views are not available.

17.1 3D View

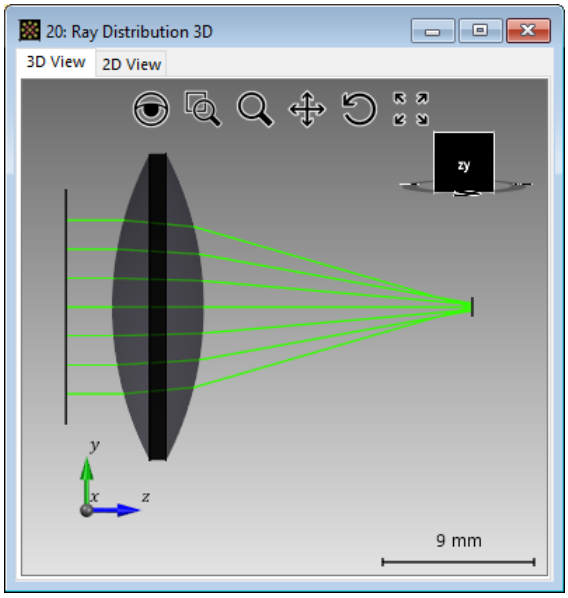


Figure 118. *Ray Distribution for a focusing lens showing the* 3D View *tab page.*

Into the 3D view the surfaces of an optical setup can be drawn together with rays passing through them. This view is essentially the same as the standard 3D view (↪Sec. 5.16), except for the following differences:

- The context menu has the additional options *Select Tracing Sequence* (↪Sec. 17.1.1) and *Filter Blocked Rays* (↪Sec. 17.1.2).
- The view settings dialog has the additional page *Rays* with which you can define the layout of the rays. ↪Sec. 17.1.3
- If you export the view to the IGES format via the context menu, the rays are also exported into this file.
- The document window has a property browser and a *View* ribbon tab.

In the View ribbon you can

- specify which subset is to be shown (↪Sec. 17.3)
- adjust the colors of the rays (↪Sec. 17.4) and
- copy the view to clipboard (↪Sec. 11.6) .

Furthermore this ribbon tab has the following controls specific to the 3D View of Ray Distributions:

ITEM	DESCRIPTION
Stride	For a better overview you can define a stride n which means that only every n^{th} ray is drawn.
Ray Thickness	With this option you can make the rays be drawn larger or smaller.
Settings	Opens the view settings dialog. ↪Sec. 5.16.2
{Predefined Camera Orientations}	There are 6 predefined camera orientations available: View orthogonal to xy-Plane and xy-Plane (Rear) (anti-parallel and parallel to the z-Axis, respectively), view orthogonal to zx-Plane and zx-Plane (Rear) (anti-parallel and parallel to the y-Axis, respectively), view orthogonal to zy-Plane and zy-Plane (Rear) (parallel and anti-parallel to the x-Axis, respectively).
Filter Blocked Rays	Filters all rays blocked by a certain aperture. ↪Sec. 17.1.2

Most of these options can also be set via the *View* tab of the property browser.

17.1.1 Select Tracing Sequence

If a complex optical system is shown in the Ray Distribution 3D view, it may be hard to keep track of all ray paths. Thus this tool, available via the context menu of the view, allows you to define the shown tracing sequence by switching off ray paths.

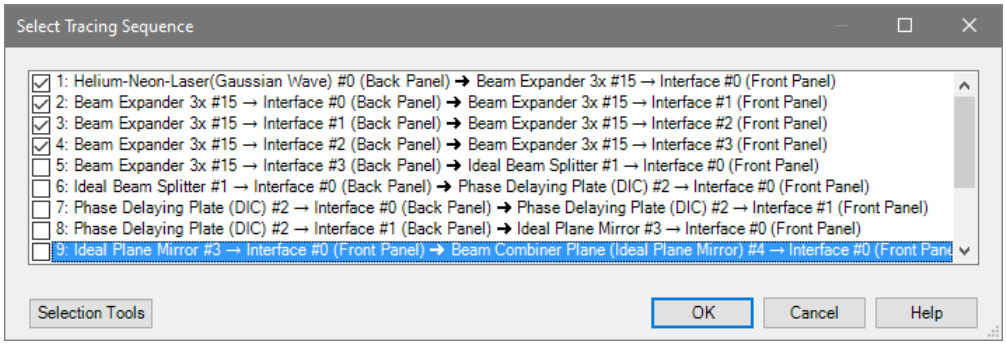


Figure 119. *The dialog to select the shown tracing sequence.*

The upper part of its edit dialog (↪Fig. 119) shows all ray paths in execution order. A *ray path* either runs

- between two Optical Setup Elements,
- between two surfaces of a real component, or
- through one surface of a real component.

See Sec. 5.9 for details about the used control.

17.1.2 Filter Blocked Rays

With this tool you can define that all rays blocked at the aperture of a certain surface are not shown at all. This can make the relevant ray paths more clear.

In the edit dialog of this tool you can select whether you want to apply that filter and if so, which boundary defines the blocking aperture. Fig. 120 shows an example.

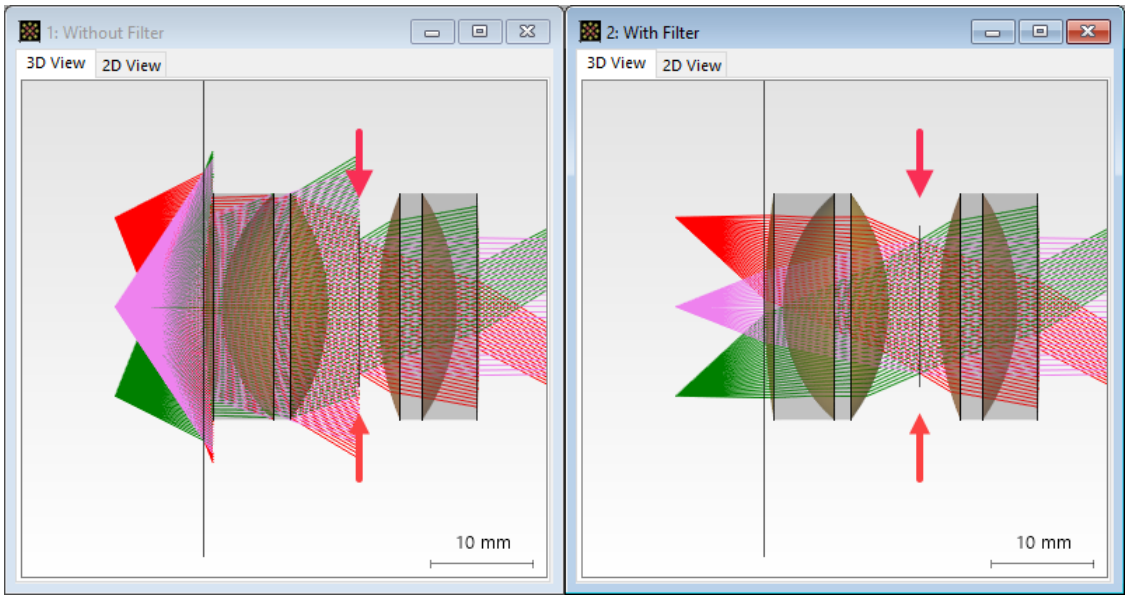


Figure 120. *In the left view all rays are shown. In the right view all rays not passing the selected aperture (marked by the red arrows) are* ***not*** *shown.*

17.1.3 Rays Page

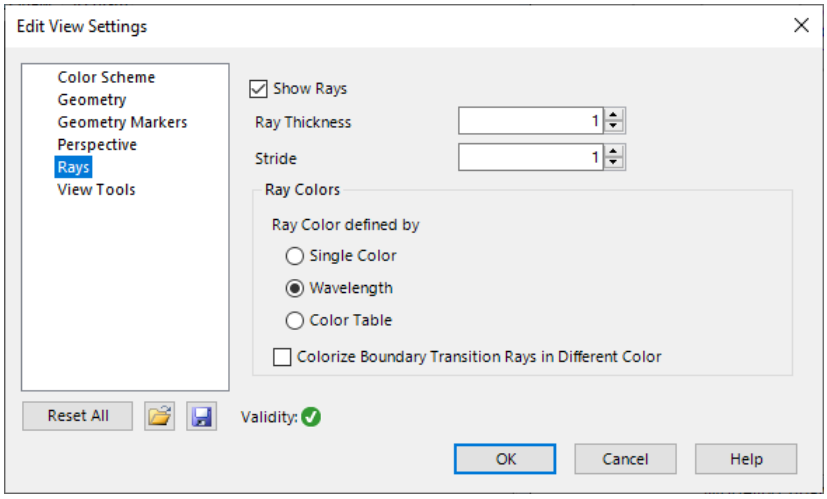


Figure 121. *The* Rays *page of the View Settings dialog.*

With this page (↪Fig. 121) of the View Settings dialog (↪Sec. 5.16.2) you can define how the rays are visualized.

ITEM	DESCRIPTION
Show Rays	If this options is unchecked, you see only the pure Optical Setup without any rays.
Ray Thickness	With this option you can make the rays be drawn larger or smaller.
Stride	For a better overview you can define a stride n which means that only every n^{th} ray is drawn.
Single Color	If you select this option, all rays are drawn with the same color. If you click on the ■-button you can either choose a predefined color or define your own.
Wavelength	With this option, all rays are colored as the human eye would perceive the corresponding wavelength. Invisible wavelengths are drawn black.
Color Table	With this option, the different wavelengths are drawn with different colors defined by the selected color table.
Colorize Boundary Transition Rays in Different Color	With this option you can define that rays within a boundary operator are emphasized by a different color. Such rays can occur if e. g. a programmable boundary operator considers the Goos-Hänchen shift.

17.2 2D View

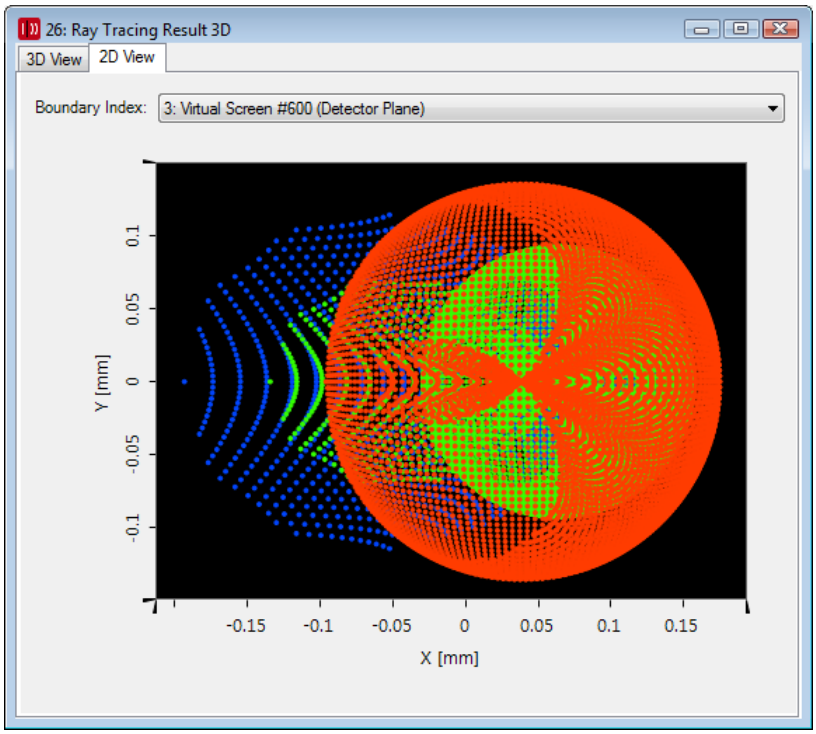


Figure 122. *2D View tab page of the Ray Distribution view with visible* Boundary Index *control.*

The *2D View* of a Raytracing Result view (↪Fig. 122) is based on gridless data arrays. It allows you to

- specify which mode is to be shown (↪Sec. 17.3)
- set the scaling mode (↪Sec. 11.2.5)
- adjust the colors of the rays (↪Sec. 17.4)
- use markers and selections (↪Sec. 11.3)
- zoom into the view (↪Sec. 11.4)
- change its aspect ratio (↪Sec. 11.5) and

- copy the view to clipboard (↪Sec. 11.6) .

Furthermore this view has the following features specific to the 2D View of Ray Distributions:

ITEM	DESCRIPTION
Field Properties / Ray Properties	ONLY AVAILABLE IF THE RAY DISTRIBUTION HAS BEEN CALCULATED VIA GENERAL PROFILE (↪SEC. 44.5) With this ribbon menu you can define whether the field properties (↪Sec. 17.2.1) or the ray properties (↪Sec. 17.2.2) shall be displayed. If this ribbon item is not visible only ray properties are available. This option can also be set via the property browser (*View > Show Field Quantities*).
Dot Size	Allows you to adjust the size of the dots. Can be set either via the ribbon item View > Dot Size or the *View* tab of the property browser.
Background Color	Usually the dots do not fill the whole diagram region and thus you see its background color. If you click on View > Background Color, you can either choose a predefined color or define your own using *More Colors*. The entry *Background Color* in the *View* tab of the property browser has more predefined colors. There you can also directly enter the name or the RGB values (separated by comma **and** space) of the desired color.
Show Triangles	Switches the triangle interpolation (↪Sec. 11.2.3) on and off. This feature is not available if the ray property *Direction* is shown. If the ray property *Position* is shown, only the triangles borders are shown. For further information about ray properties see Sec. 17.2.2.

If the Ray Distribution was obtained with the Raytracing System Analyzer (↪Sec. 44.5.4), the view contains an additional control to select the *Boundary Index* (↪Fig. 122). Using this control you can visualize the ray distribution at various boundaries.

If a point marker is visible, the *Ray Selection* tab of the property browser shows both the field and the ray properties of the currently selected ray.

17.2.1 Field Properties

If the 2D view of a raytracing result is in the *Field Properties* mode, you can select the *Field Component* (E_x, E_y, and so on; ↪Sec. 17.2.1.1) and the *Field Quantity* (↪Sec. 11.1).

In the *View* tab of the property browser you can define whether to *Apply Energy Conservation*. The energy conservation is based on the size of the triangles spanned by the rays which usually does not work if you are in the focus.

17.2.1.1 Field Component

Availability

Accessible:

- Ribbon: View > Field Component ribbon group
- Property browser: *View > Field Component*
- Context menu: *Edit View Settings* (↪Sec. 17.2.3)

The field component can be either E_x, E_y, E_z H_x, H_y, or H_z. The formulas for calculating the distinct field components are given in Sec. 136.

17.2.2 Ray Properties

Availability

Accessible:

- Ribbon: View > Ray Quantity ribbon group
- Property browser: *View > Quantity*
- Context menu: *Edit View Settings* (↪Sec. 17.2.3)

If it is in the *Ray Properties* mode, the 2D view of a Ray Distribution can visualize one of the following ray quantities.

RAY QUANTITY	DESCRIPTION
Position 	Plots the rays at their actual positions in the shown x-y-plane. If there is more than one mode given and the coloring mode is set to *Color by Table*, the colors indicate the respective mode index of each ray.
Direction 	The direction of a ray can be described by the direction vector s which has an absolute value of 1. If you select this ray quantity, you can change the *Direction Visualization Mode* in the *View* tab of the property browser. This option allows you to plot the rays either into the s_x-s_y-plane, or to color the rays according to the s_x-, s_y-, or s_z-component while plotting them into the x-y-plane.
Optical Path Length 	The rays are plotted at their actual positions in the shown x-y-plane and colored according to their optical path length.
Absorption 	The rays are plotted at their actual positions in the shown x-y-plane and colored according to the absorption.

17.2.3 View Settings Dialog

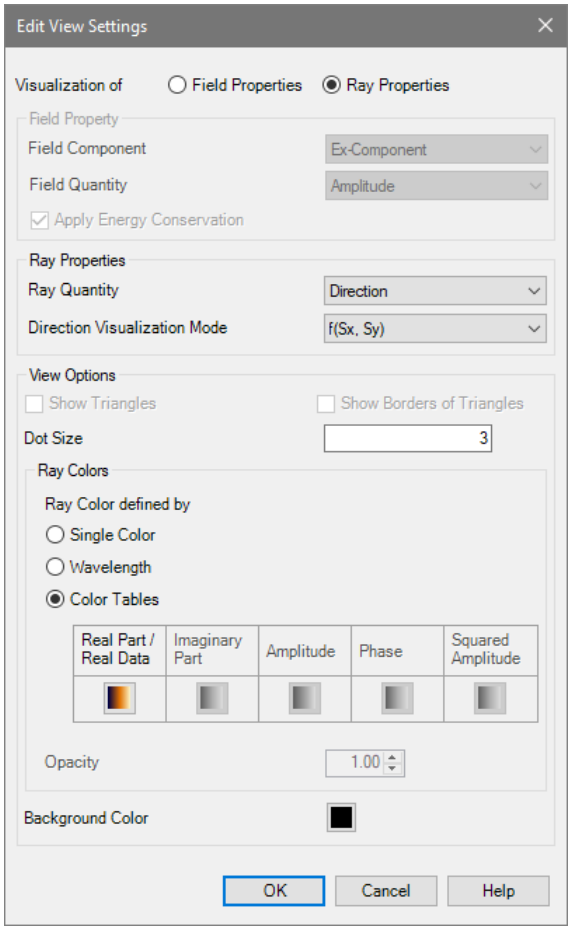


Figure 123. *The dialog to edit the view settings of a Ray Distribution.*

This dialog (↪Fig. 123) allows you to set the most important view parameters at once. It can be opened via the context menu of the view.

ITEM	DESCRIPTION
Visualization of	ONLY AVAILABLE FOR DOCUMENTS CALCULATED WITH GENERAL PROFILE, OTHERWISE ONLY RAY PROPERTIES ARE SHOWN Allows you to determine whether you want to see any of the *Field Properties* or any of the *Ray Properties*.
Field Component	ONLY AVAILABLE IN *FIELD PROPERTIES* MODE The field component (↪Sec. 17.2.1.1) to show.
Field Quantity	ONLY AVAILABLE IN *FIELD PROPERTIES* MODE The field quantity (↪Sec. 11.1) to show.
Apply energy conservation	ONLY AVAILABLE IN *FIELD PROPERTIES* MODE The energy conservation is based on the size of the triangles spanned by the rays which usually does not work if you are in the focus. Thus you can switch it off in this case.
Ray Quantity	ONLY AVAILABLE IN *RAY PROPERTIES* MODE The ray quantity (↪Sec. 17.2.2) to show.

Direction Visualization Mode	ONLY AVAILABLE FOR *DIRECTION* AS *RAY QUANTITY* The direction of a ray can be described by the direction vector s. This option allows you to plot the rays either into the s_x-s_y-plane, or to color the rays according to the s_x-, s_y-, or s_z-component while plotting them into the x-y-plane.
Add Wavefront Response to Optical Path Length	ONLY AVAILABLE FOR *OPTICAL PATH LENGTH* AS *RAY QUANTITY* Ideal components and light sources might add a wavefront response independent from the actual optical path length. By checking this option the wavefront response is added to the shown optical path length.
Show Triangles	NOT FOR THE *RAY QUANTITY DIRECTION* IN *F(SX, SY)* MODE If checked the triangle interpolation (↪Sec. 11.2.3) is applied.
Show Borders of Triangles	ONLY AVAILABLE IF *SHOW TRIANGLES* IS CHECKED Draws the borders of the triangles used for the triangle interpolation.
Dot Size	NOT AVAILABLE IF *SHOW TRIANGLES* IS CHECKED Allows you to adjust the size of the dots representing the rays.
Single Color	NOT FOR THE RAY PROPERTIES *ABSORPTION*, *OPTICAL PATH LENGTH*, AND *DIRECTION* (IN *SX(X, Y)*, *SY(X, Y)*, OR *SZ(X, Y)*) MODE If you select this option, all rays are drawn with the selected color.
Wavelength	NOT FOR THE RAY PROPERTIES *ABSORPTION*, *OPTICAL PATH LENGTH*, AND *DIRECTION* (IN *SX(X, Y)*, *SY(X, Y)*, OR *SZ(X, Y)*) MODE With this option, all rays are colored as the human eye would perceive the corresponding wavelength. Invisible wavelengths are drawn black.
Color Tables	With this option, the different rays are drawn with different colors defined by the selected color table. For complex data, this can be set per field quantity. Please note that the shown colors do not map onto any quantity of some physical meaning in some cases: If ray positions or directions in the s_x-s_y-plane are shown, the color indicates the mode index of each ray (in case there is more than one mode).
Opacity	ONLY AVAILABLE IN *FIELD PROPERTIES* MODE If the default opacity of 1 is lowered, the rays become more and more transparent and thus also rays “below” the topmost rays become more and more visible.
Background Color	Usually the dots do not fill the whole diagram region and thus you see its background color. If you click on this button, you can either choose a predefined color or define your own.

17.3 Mode Selection

Availability

For Ray Distributions with more than one subset

Accessible:

- Ribbon: View > Subset Selection group
- Property browser: *View > Subset Selection group*

A Ray Distribution can have multiple wavelengths and incoherent modes. For each combination of wavelength and incoherent modes there can be multiple coherent modes. In the view ribbon there is the control shown in Fig. 124 with which you can set *Wavelength #*, *Incoherent Mode #* and *Coherent Mode #*, either by using the arrow buttons or by entering the index directly. If you check the corresponding check box all modes of the respective type are shown.
The same can be done with the *View > Subset Selection group* of the property browser. It also shows the currently selected wavelength, not only the wavelength index.

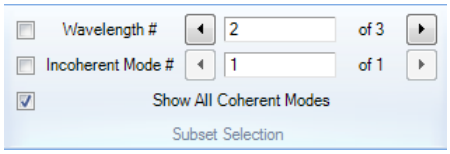


Figure 124. *The controls to select specific mode(s) in the ribbon. The second wavelength out of three possible wavelengths is selected. There is only one incoherent mode so the corresponding arrow buttons are disabled. All coherent modes for the currently selected wavelength and for the currently selected incoherent mode are shown.*

17.4 Coloring Rays

Availability

Accessible:

- Ribbon: View > Color by Wavelength, View > Color by Table, View > Single Color
- Property browser: *View > Color Mode*
- Context menu (3D View): *View Settings > Rays* (↪Sec. 17.1.3)
- Context menu (2D View): *Edit View Settings* (↪Sec. 17.2.3)

You can color rays in the following ways:

MODE	DESCRIPTION
Color by Wavelength	With this option, all rays are colored as the human eye would perceive the corresponding wavelength. Invisible wavelengths are drawn black.
Color by Table	With this option, the different rays are drawn with different colors defined by the selected color table and the shown quantity. If the shown quantity is the position or the direction in the s_x-s_y-plane or if the 3D view is shown, each distinct wavelength or incoherent mode gets its own color from the selected color table.
Single Color	If you select this option, all rays are drawn with the selected color.

18 Order Collection View

An Order Collection document contains the coordinates, efficiencies and Rayleigh coefficients of all (transmitted or reflected) diffraction orders of a grating. What exactly is shown depends on the settings on the *Data to Show* tab of the Property Browser. There you have the following settings:

ITEM	DESCRIPTION
Coordinate Type	The coordinates versus which the individual orders are plotted: either the order numbers, the spherical angles θ and ϕ, the Cartesian angles α and β, the wave vector components k_x and k_y, or the position $(x; y)$. In the latter case you can set a *Distance* for which the positions are calculated.
Show All Data	By default, all data (efficiencies and Rayleigh coefficients) are shown at once. But for example to obtain a clearer overview in the table, you can uncheck this option and then select the *Data to Show*.
Data to Show	ONLY VISIBLE IF *SHOW ALL DATA* IS CHECKED. Allows you to set whether the efficiencies or certain Rayleigh coefficients (E_x, E_y, E_z, TE, TM) of the orders are shown.
Strategy	With this option you can restrict the shown orders. The following three strategies are available: • ***All***: No restrictions apply • ***Above Efficiency Threshold***: Only (propagating) orders above the given *Efficiency Threshold* are shown. • ***Order Range***: All orders in the range between *Minimum Order* (inclusive) and *Maximum Order* (inclusive) are shown.

If angles or positions are used as coordinates, evanescent orders are never shown, regardless of the selection strategy.

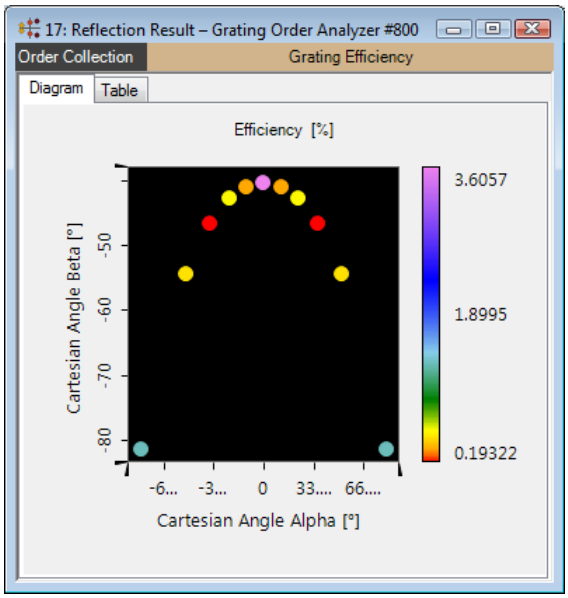


Figure 125. *Efficiencies of a grating invariant in y-direction for conical incidence, plotted versus Cartesian angles.*

The selected data is shown in a Gridless Data Array and shares most of its features (↪Sec. 13.4). Fig. 125 shows an example.
In contrast to Gridless Data Arrays, the Order Collection view has the following additional features:

- You can convert the complete data and all coordinates into an equidistant data array, plotted versus the equidistant order numbers. This allows easier comparisons. It can be done via the ribbon item Manipulations > Create Equidistant Data Array or by pressing F3.

- In the table always the order numbers are shown, even if the coordinates are spherical coordinates for example.
- If you extract 1D data along a selected line (↪Sec. 24.14.1), the order numbers are added as labels to the resulting data array.
- If you select a certain order with the Point Marker (↪Sec. 11.3), all coordinates and all data (efficiency and Rayleigh coefficients) are shown in the *Selections* tab of the Property Browser.

When further manipulation possibilities are required, you can extract the Gridless Data Array currently visible in the Order Collection View via the ribbon entry Extract Current Grating Order Data or via Shift+F3.

19 Diffraction Orders Diagrams

The diffraction orders diagram visualizes angles and efficiencies of diffraction orders (↪Fig. 127). The incident wave is drawn in green, the transmitted orders in blue, and the reflected orders in red.

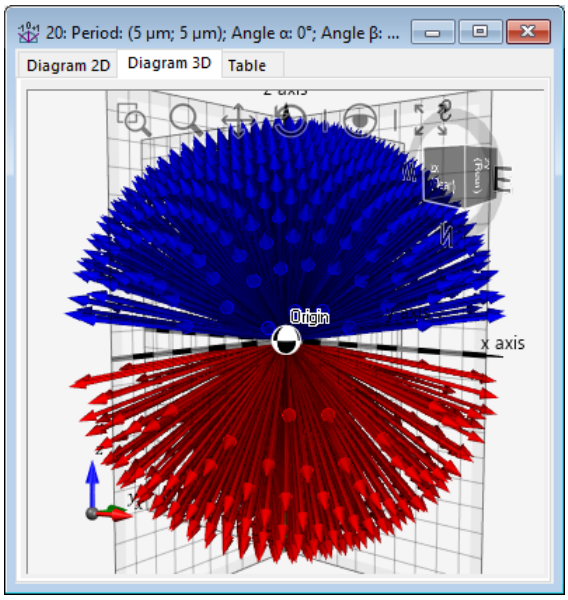


Figure 126. *Example for a Diffraction Orders Diagram showing a 3D diagram.*

The document window has three tabs.

TAB	DESCRIPTION
2D Diagram	The projection of the orders on either the x-z- or the y-z-plane, shown in a polar diagram. ↪Sec. 19.1
3D Diagram	All orders are shown as arrows in a 3D view. This view offers the same interactions as the standard 3D view (↪Sec. 5.16), but context menu. When you hover the mouse over a certain arrow, a tooltip with order number and efficiency is shown. With + and − you can scale the diameter of the arrows, which also influences how small vectors are shown. You can set further view settings of this control via context menu, ↪Sec. 19.3.
Table	A read-only table (↪Sec. 5.8) showing order number, Cartesian angle α and β as well as efficiency for all orders.

All tabs have an entry *Select Data Points* in their context menu, ↪Sec. 19.2.
In the Property Browser you set a *Maximum Number of Points per Data Series*. This ensures that the user interface does not freeze if too many orders are to be shown.

19.1 2D Diagram Tab

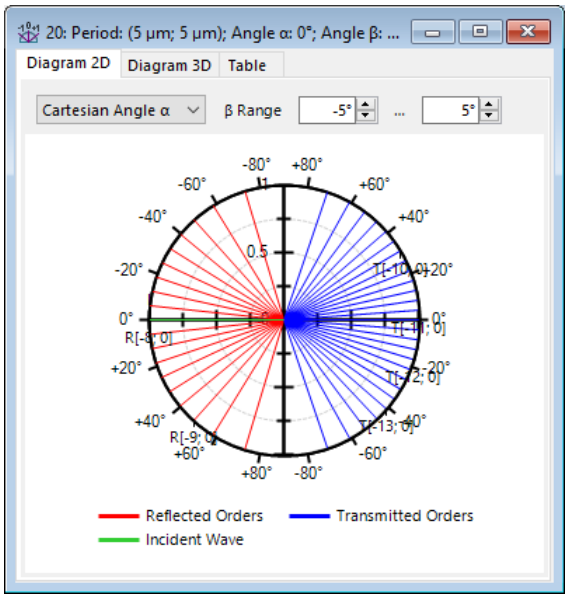


Figure 127. *Example for a Diffraction Orders Diagram showing a 2D diagram.*

On the top of this tab you can choose whether you want to plot the *Cartesian Angle α* or the *Cartesian Angle β*. In the first case you see in principle an x-z-plane and all orders having an angle β in the specified *β Range* are projected into this plane. Analogously, in the *Cartesian Angle β* case you see all orders in a certain *α Range* projected into a y-z-plane.

With `Ctrl`+mouse wheel you can shift the shown range, with `Shift`+mouse wheel you can extend or reduce the shown range.

The range is automatically adjusted so that

- you see at least one order,
- the minimum is less than the maximum, and
- you do not exceed the range of all angles that occur .

You can adjust the maximum of the radial value axis with the mouse wheel or the Property Browser. Furthermore you can set the *Line Thickness* in the Property Browser.

19.2 Select Diffraction Orders to Show

For a better overview, you can reduce the number of orders shown in a Diffraction Orders Diagrams with the dialog shown in Fig. 128.

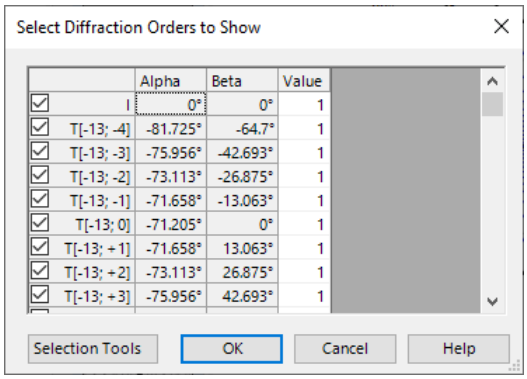


Figure 128. *The Dialog for selecting the diffraction orders to show.*

It shows a table of **all** orders which you can select or unselect as desired. Furthermore, the following *Selection Tools* are available.

TOOL	DESCRIPTION
Select All	Selects all orders.
Unselect All	Unselects all orders.
Select / Unselect by Angle	Opens a dialog where you can define the valid range both for the Cartesian angle α and for the Cartesian angle β. All orders having angles in this range are selected / unselected; all other orders remain unchanged.
Select / Unselect by Name	Opens a dialog where you can define a search string. All orders having this search string in their description are selected / unselected; all other orders remain unchanged. This search is done case insensitive. For example “T[0” matches all transmitted orders with a order number in x-direction of 0.

19.3 View Settings for 3D Diagram Tab

This dialog allows you set whether view tools shall be shown on top of the arrows in the 3D diagram.

VIEW TOOL	DESCRIPTION
Global Coordinate System	A 3D icon in the lower left corner that permanently shows the current orientation of the diagram.
Tool Bar	6 buttons in the upper part of the diagram which define the *mouse mode*, i. e. how the diagram behaves if you left click into the view and move the mouse while keeping the left mouse button pressed.
View Cube	A cube in the upper left corner which you can use to change the orientation of the diagram.

Details about the view tools can be found in Sec. 5.16.

20 Animation View

An *animation* is a sequence of raster graphics images which can be shown smoothly one after another. A single image is also referred to as *frame*.

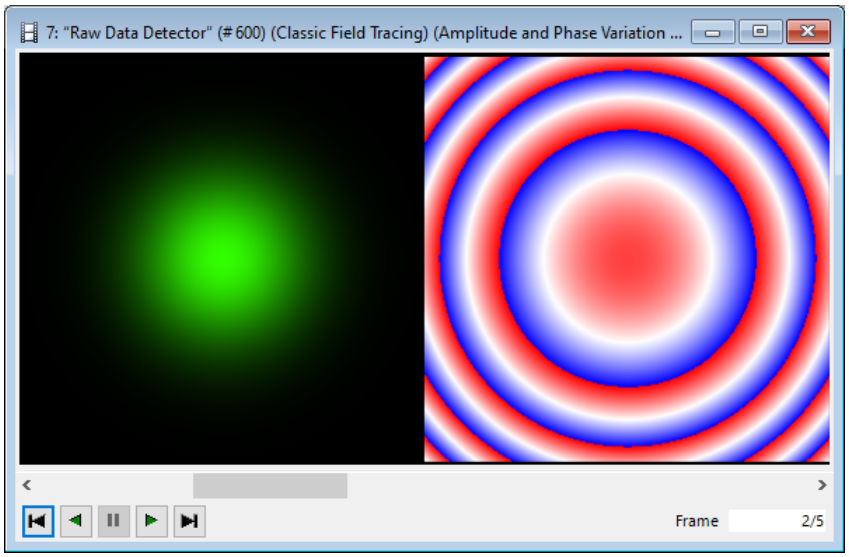


Figure 129. *Example of an Animation View.*

Fig. 129 shows the animation view which contains the following controls:

ITEM	DESCRIPTION
/	Allows you to run the animation in forward / reverse order. If *Repeat Animation* is set in the Animation Options dialog (↪Sec. 20.3), the animation will be started again automatically if the end is reached.
	Pauses a running animation.
/	With these buttons you can jump to the first and the last frame of the animation, respectively.

The button corresponding to the currently active “action” (pause / play forwards / play backwards) is disabled. There is also the possibility to go through the animation using the scrollbar. In the bottom-right corner you can see the index of the current frame and the overall number of frames.
An animation can be exported into various file formats (↪Sec. 129).

20.1 Ribbon Items

The following ribbon items are available on the Animation ribbon tab:

ITEM	DESCRIPTION
Copy Frame	Copies the current frame into the Windows™ clipboard (as an image).
Cut Frame	Moves the current frame into the Windows™ clipboard (as an image).
Paste Frame	Pastes an image from the clipboard into the animation. The image can be inserted (Paste > Insert Frame) before the currently selected frame or appended (Paste > Append) to the end of the animation. In both cases the number of frames will increase by one. If the size of the pasted image does not match the size of those images already in the animation, a resizing is done which maintains the aspect ratio of the pasted image.
Delete Frame	Deletes the current frame.
Swap Frames	Swaps two frames. The source frame and the destination frame can be chosen in a separate dialog.
Stitch Animations	Stitches two animations, i. e. places them either side by side or one below the other. ↪Sec. 20.2
Animation Options	Opens the animation options. ↪Sec. 20.3

All of these items but Stitch Animations are also accessible via the context menu of the animation view.

20.2 Stitch Animations

Using the ribbon item Animation > Stitch Animations stitches two animations, i. e. places them either side by side (= “horizontally”) or one below the other (= “vertically”). The animations to stitch must have the same number of frames.

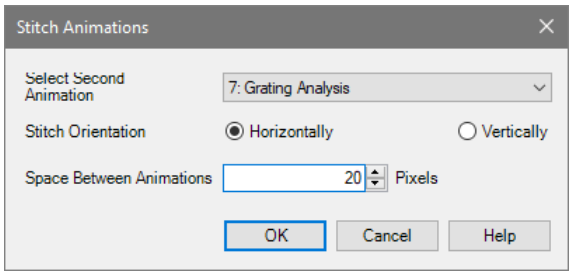


Figure 130. *The dialog with the options for stitching animations.*

This tool is applied on one animation. Then a dialog (↔Fig. 130) opens where you can set the second animation and other options.

ITEM	DESCRIPTION
Select Second Animation	Allows you to select the second animation from any other already opened animation.
Stitch Orientation	If you select *Horizontally* the two animations are placed side by side. If the two animations do not have the same height in pixels, the animation with the smaller height is resized accordingly. If you select *Vertically* the two animations are placed one below the other. If the two animations do not have the same width in pixels, the animation with the smaller width is resized accordingly.
Space Between Animations	You can add up to 1000 pixels of black space between the two animations to separate them more clearly.

Note that you can apply this tool recursively to stitch more than two animations. Fig. 131 shows an example.

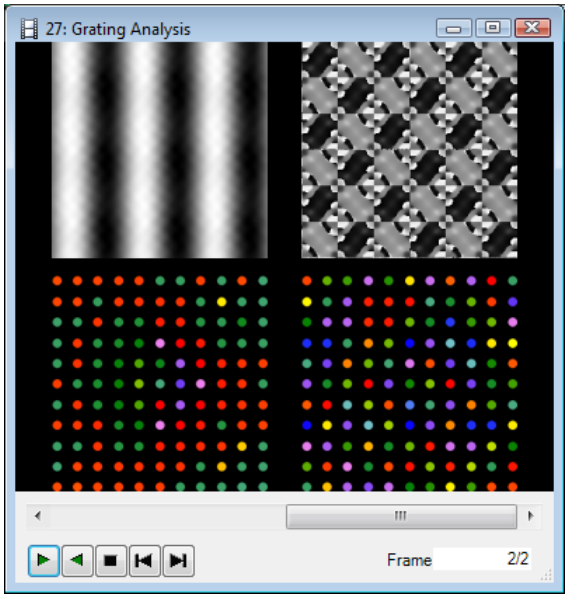


Figure 131. *Four stitched animations: First the two upper and the two lower animations, respectively, were stitched horizontally with a Space Between Animations of 40 pixels. Then the two resulting animations were stitched vertically with a Space Between Animations of 20 pixels.*
The upper part shows the phase of the near field of the grating, the lower the phase of the Rayleigh coefficients. Left: transmission, right: reflection.

20.3 Animation Options

Using the ribbon item Animation > Animation Options or the context menu the dialog shown in Fig. 132 can be opened.

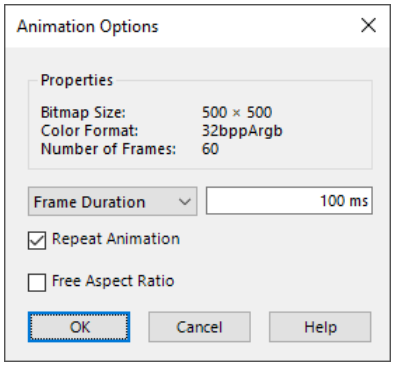


Figure 132. *Dialog to adjust the settings for the Animation View.*

The following settings are available:

ITEM	DESCRIPTION
Properties	The bitmap size, the used color format, and the number of frames are shown.
Frames per Second / Frame Duration / Whole Duration	Allows you to enter the animation speed.
Repeat Animation	If checked a running animation will automatically be started again if it reaches the last frame.
Free Aspect Ratio	If checked the animation will be stretched to use the complete available space. Otherwise the aspect ratio of the animation will be maintained and unused parts of the view are colored black.

21 Regions

Region documents simply store the information whether a certain position belongs to (lies inside) a certain *region* or not. Such a region document can be used as *Evaluation Region* in the Diffractive Optics Merit Functions detector (↪Sec. 75.6.2) or as *Optimization Region* in the IFTA Optimization document (↪Sec. 98).
A region can be generated in the following ways:

METHOD	DESCRIPTION
Create a new region document	Create a new rectangular, elliptical, polynomial, sampled or composed 2D region (↪Sec. 21.1), or an interval, sampled or composed 1D region (↪Sec. 21.2).
Create signal region document from selection	Manipulations > Selection Related Operations > Create Signal Region from Selection creates a sampled region which has the same sampling parameters as the current harmonic field or Jones matrix transmission document. The current range or rectangle marker defines the actual signal region, independent from the values in the original document.
Convert to sampled region document	A harmonic field or a Jones matrix transmission can be converted to a sampled region document using Manipulations > Create Sampled Region. In this case you are asked for a relative threshold and all values having a squared amplitude larger than the maximum squared amplitude times this value are regarded as being 'inside' the region.

21.1 Generating a 2D Region

Via Functions > Region (2D) 2D regions can be generated. The dialog is shown in Fig. 133.

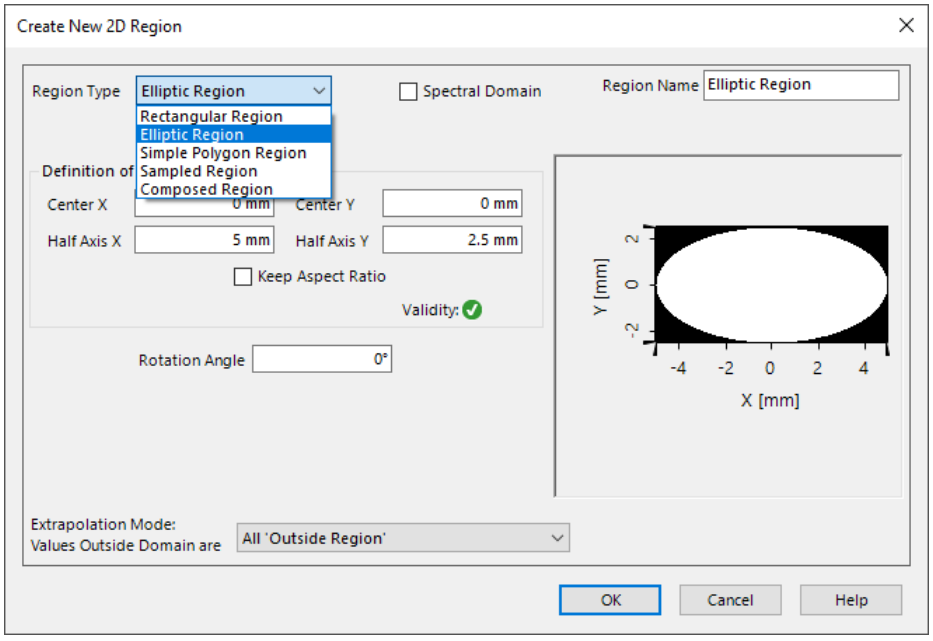


Figure 133. *Dialog for generation of a two-dimensional region document.*

The following general parameters are used for the specification of each 2D region, independent from its respective type:

ITEM	DESCRIPTION
Region Type	The type of the region to be created. This can be *Rectangular Region*, *Elliptic Region*, *Simple Polygon Region*, *Sampled Region*, or *Composed Region*. These types are described below (↪Sec. 21.1.1 to Sec. 21.1.5.
Spectral Domain	Determines whether or not the region is intended for using in the spectral or spatial domain.
Region Name	A user defined name for the region to be created.
Extrapolation Mode: Values Outside Domain are	This setting defines how to handle points which lie outside the domain of the actual region. The following options can be set: • *All 'Outside Region'*: All outlying points do *not* belong to the region. • *All 'Inside Region'*: All outlying points do belong to the region, despite lying outside the domain. • *Periodically Continued*: The whole domain of the region is continued periodically in every direction. • *Equal to the Nearest Border Data Point*: A constant extrapolation of the outmost data points is done. Meaning, if the nearest border point belongs to the region, the considered outlying point belongs to the region too.

21.1.1 Generating a Rectangular Region

The specific parameters for creating a rectangular region are listed in the following table:

ITEM	DESCRIPTION
Center X / Y PV	These values specify the center point of the rectangle.
Width / Height PV	The extension of the rectangle.
Keep Aspect Ratio	If checked, a change in width or height will change the other extension value in a way keeping the ratio of the sides, resp.
Rotation Angle PV	An angle for rotating the rectangle around its *Center*.

21.1.2 Generating an Elliptic Region

The specific parameters for creating an elliptic region are listed in the following table:

ITEM	DESCRIPTION
Center X / Y PV	These values specify the center point of the ellipse.
Half Axis X / Y PV	The half axes of the ellipse in each dimension.
Keep Aspect Ratio	If checked, a change in one of the half axes will change the other half axis in a way keeping the ratio of the sides, resp.
Rotation Angle PV	An angle for rotating the ellipse around its *Center*.

21.1.3 Generating a Simple Polygon Region

A *simple* polygon is a polygon without intersecting edges. Such polygons, containing an arbitrary number of points, can be defined here.
The specific parameters for creating a simple polygon region are listed in the following table:

ITEM	DESCRIPTION
Polygon Vertices table	In this table the *Name*, *x-Coordinate*[PV], and *y-Coordinate*[PV] of each vertex can be edited.
Append New	Opens a dialog for specifying a new polygon vertex and appends it to the list.
Insert New	Opens a dialog for specifying a new polygon vertex and inserts it into the list, above the currently selected row.
Remove	Removes the currently selected polygon vertex.
Move Up / Down	Moves the currently selected row up or down, resp.
Transform > Scale (Keep Center)	Allows to scale the whole polygon by means of a (to be entered) factor. The center of the polygon's axis aligned bounding box will be kept constant.
Transform > Rotate (Around Center)	Allows to rotate the whole polygon by means of a (to be entered) angle. The rotation will be done around the center of the polygon's axis aligned bounding box.
Transform > Shift (Translate)	Allows to shift / translate the complete polygon by means of a (to be entered) vector.

Please note: The order of the vertices is important for each polygon with more than three vertex points.

21.1.4 Generating a Sampled 2D Region

A sampled region is defined by a finite number of sampling points on a grid, each point defining its area being either inside of outside the actual region.
The specific parameters for creating a sampled region are listed in the following table:

ITEM	DESCRIPTION
Sampled Region Data	The sampled region data can be set or shown here. This region data has to be defined via a real-valued Numerical Data Array (2D) with one single subset (↪Sec. 13). All values unequal zero will be interpreted as being 'inside' the region.

21.1.5 Generating a Composed 2D Region

A composed region is built by one or more subregions[PE]. The combination is defined by a composition mode which corresponds to one of several logical operations. These operations and their meanings are shown in the following list:

OPERATOR	REGION COMPOSITION
Intersection (AND)	A given point is inside the actual region if and only if it lies in each of the subregions respectively.
Union (OR)	A given point is inside the actual region if and only if it lies in one of the subregions at least.
Antivalence (XOR)	A given point is inside the actual region if and only if it lies in an odd number of subregions.
Difference	A given point is inside the actual region if it lies only in the first subregion in the table but in none of the other subregions.

Since composed regions may be used as subregions as well, a combination of several different composition modes is possible.

The specific parameters for creating a composed region are listed in the following table:

ITEM	DESCRIPTION
Subregions table	The unique index (#), the region *Type*, as well as the *Name* of each subregion are shown here.
Edit Subregion	Opens a dialog for editing the currently selected subregion.
New Subregion	Opens a dialog for creating a new subregion which will be appended to the table entries.
Delete Subregion	Deletes the currently selected subregion.
Move Up / Down	Moves the currently selected subregion one row up or down resp. This is needed in case of the *Composition Mode* 'Difference' only.
Composition Mode	The mode for combining the subregions. See the list above.

The edit dialog for creating or changing subregions provides the following additional options: provides a new default region for each of the region types, allows to select an open region document or to load a region document from hard disc, allows to save the current region, and will show the current region as new document.

21.2 Generating a 1D Region

Via Functions > Region (1D) 1D regions can be generated. The dialog is shown in Fig. 134.

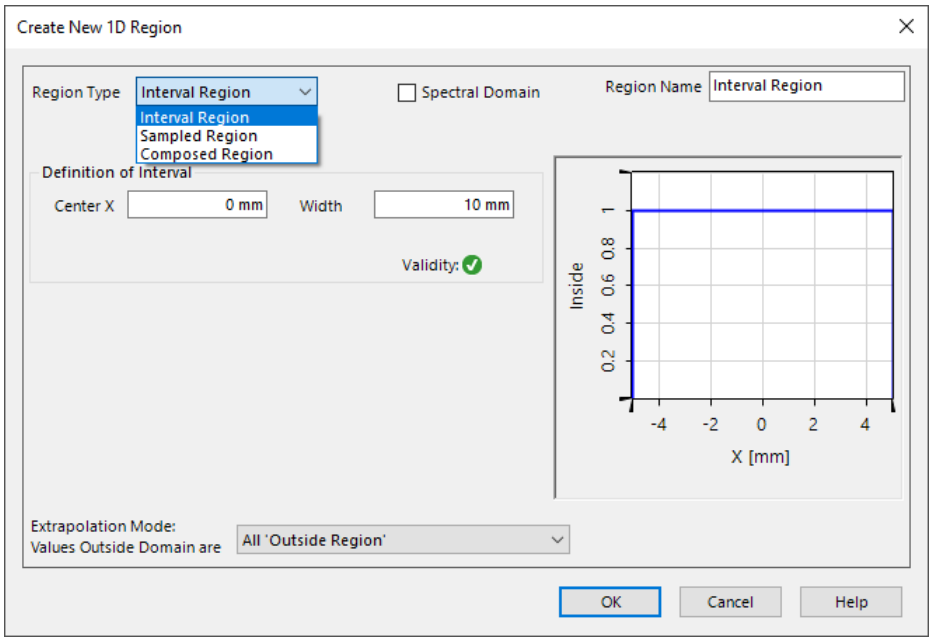


Figure 134. *Dialog for generation of a one-dimensional region document.*

The following general parameters are used for the specification of each 1D region, independent from its respective type:

ITEM	DESCRIPTION
Region Type	The type of the region to be created. This can be *Interval Region*, *Sampled Region*, or *Composed Region*. These types are described below (↪Sec. 21.2.1 to Sec. 21.2.3.
Spectral Domain	Determines whether or not the region is intended for using in the spectral or spatial domain.
Region Name	A user defined name for the region to be created.
Extrapolation Mode: Values Outside Domain are	This setting defines how to handle points which lie outside the domain of the actual region. The following options can be set: • *All 'Outside Region'*: All outlying points do *not* belong to the region. • *All 'Inside Region'*: All outlying points do belong to the region, despite lying outside the domain. • *Periodically Continued*: The whole domain of the region is continued periodically in every direction. • *Equal to the Nearest Border Data Point*: A constant extrapolation of the outmost data points is done. Meaning, if the point with the smallest coordinate inside the domain belongs to the region, all points with smaller coordinates belong to the region too. The same applies for the point with the largest coordinate in the domain and all points with larger coordinates as well.

21.2.1 Generating an Interval Region

The specific parameters for creating an interval region are listed in the following table:

ITEM	DESCRIPTION
Center X PV	This value specifies the center point of the interval.
Width PV	The extension of the interval.

21.2.2 Generating a Sampled 1D Region

A sampled region is defined by a finite number of sampling points, each point defining its interval being either inside of outside the actual region.

The specific parameters for creating a sampled region are listed in the following table:

ITEM	DESCRIPTION
Sampled Region Data	The sampled region data can be set or shown here. This region data has to be defined via a real-valued Numerical Data Array (1D) with one single subset (↪Sec. 13). All values unequal zero will be interpreted as being 'inside' the region.

21.2.3 Generating a Composed 1D Region

A composed region is built by one or more subregions PE. The combination is defined by a composition mode which corresponds to one of several logical operations. These operations and their meanings are shown in the following list:

OPERATOR	REGION COMPOSITION
Intersection (AND)	A given point is inside the actual region if and only if it lies in each of the subregions respectively.
Union (OR)	A given point is inside the actual region if and only if it lies in one of the subregions at least.
Antivalence (XOR)	A given point is inside the actual region if and only if it lies in an odd number of subregions.
Difference	A given point is inside the actual region if it lies only in the first subregion in the table but in none of the other subregions.

> Since composed regions may be used as subregions as well, a combination of several different composition modes is possible.

The specific parameters for creating a composed region are listed in the following table:

ITEM	DESCRIPTION
Subregions table	The unique index (#), the region *Type*, as well as the *Name* of each subregion are shown here.
Edit Subregion	Opens a dialog for editing the currently selected subregion.
New Subregion	Opens a dialog for creating a new subregion which will be appended to the table entries.
Delete Subregion	Deletes the currently selected subregion.
Move Up / Down	Moves the currently selected subregion one row up or down resp. This is needed in case of the *Composition Mode* 'Difference' only.
Composition Mode	The mode for combining the subregions. See the list above.

The edit dialog for creating or changing subregions provides the following additional options:  provides a new default region for each of the region types,  allows to select an open region document or to load a region document from hard disc,  allows to save the current region, and  will show the current region as new document.

21.3 Region View

The region view visualizes region documents (↪Sec. 21). The user can see what points lie inside or outside the actual regions respectively.
The views provide options for zooming as described in Sec. 11.4 and for copying the view to the clipboard as described in Sec. 11.6. For two-dimensional regions, the aspect ratio behavior can be specified (↪Sec. 11.5).
Markers as described in Sec. 11.3 can be used in views for sampled regions only.
For 2D regions, a smoothing option can be (de)activated via property browser.
Furthermore, the view settings of different region views can be copied among regions of the same dimensionality.

IV Manipulations: Processing Data

In VirtualLab Fusion there are several document types which store one- or two-dimensional data.
Their *Manipulations* ribbon tab contains several operations to modify this (mostly) sampled data which are described in this part of the manual. Furthermore it contains *Conversions* (↪Sec. 30) to convert one document type into another.

22 Manipulations of Complex Amplitude Documents

Complex Amplitude Documents, namely Harmonic Fields and Jones Matrix Transmissions, have the manipulations available which are described in the following subsections. The ribbon group Manipulations > Conversions is explained in Sec. 30.1, the ribbon group Manipulations > Fourier Transformation (Space) in Sec. 31.1.

22.1 Array - Array Operations

Via the ribbon menu Manipulations > Array - Array Operations several operations for two array operands are available:

- The four basic operations Addition, Subtraction, Multiplication, and Division as well as the convolution of two fields, all of which are explained in Sec. 22.1.1.
- Inserting of one array into another, ↪Sec. 22.1.2.

22.1.1 Arithmetic Operations

There are four basic arithmetic operations for arrays: addition, subtraction, multiplication, and division. Furthermore there is the convolution of two Complex Amplitude Documents U_1 and U_2, calculated by

$$U_1 \star U_2 = \mathcal{F}^{-1}[(\mathcal{F}\,U_1) \cdot (\mathcal{F}\,U_2)]. \tag{22.1}$$

The first operand is always the currently selected Complex Amplitude Document; the second operand can be selected from any open Complex Amplitude Document.
These operations can also be invoked by using the corresponding keys: +, −, *, /, and #, respectively. In this case the currently selected document is taken as the **second** operand while the previously selected Complex Amplitude Document is taken as first operand.
In case that the two arrays of an arithmetic array-array operation have not the same sampling distance or the same array size, at least one of the fields or transmissions has to be resampled before the calculation, because the underlying operation works pointwise.
The following table shows which parameter has to be adjusted in what case for each operation. The second and the third column show how the sampling distance Δ_{new} and the array size S_{new} of the resulting array are determined by the sampling parameters of the operands (indices 1 and 2). Before starting the calculation, the array(s) that has got sampling parameters different from that of the result field will be resampled.

Important: The sampling parameters for the directions x and y are checked and adjusted independently!

Operation	Δ_{new}	S_{new}
Addition	$\Delta_{\text{new}} = \min(\Delta_1, \Delta_2)$	$S_{\text{new}} = \max(S_1, S_2)$
Subtraction	$\Delta_{\text{new}} = \min(\Delta_1, \Delta_2)$	$S_{\text{new}} = \max(S_1, S_2)$
Multiplication	$\Delta_{\text{new}} = \min(\Delta_1, \Delta_2)$	$S_{\text{new}} = \min(S_1, S_2)$
Division	$\Delta_{\text{new}} = \min(\Delta_1, \Delta_2)$	$S_{\text{new}} = \min(S_1, S_2)$
Convolution	$\Delta_{\text{new}} = \min(\Delta_1, \Delta_2)$	$S_{\text{new}} = \max(S_1, S_2)$

If a Transmission has to be resampled, the user can choose one out of two possible types of interpolation. For this reason a dialog will appear, shown in Fig. 135.

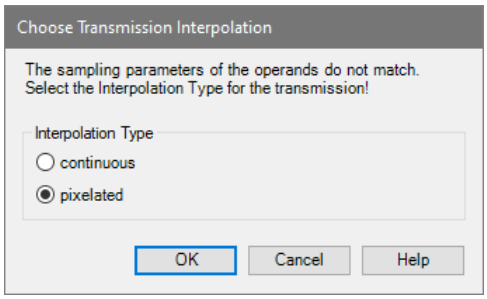


Figure 135. *Dialog for determining the interpolation type for resampling of a transmission.*

The options are:

ITEM	DESCRIPTION
continuous	If chosen, the transmission will be interpolated using the Cubic 8 Point Interpolation (↪Sec. 13.2.2).
pixelated	If chosen, the transmission will be interpolated using the Nearest Neighbor Interpolation (↪Sec. 13.2.2).

Different types of Complex Amplitude Documents (Harmonic Field vs. Transmission) cannot be used as operands in every possible combination; Sec. 137.1 gives a summary of all combinable types and their result for all operations.

22.1.2 Insert Array

Inserts a selected array into the current array at a certain position whereas the corresponding data of the current array will be overwritten. This operation is done in pixel coordinates, the position $(0; 0)$ corresponds to the bottom left corner. The dialog is shown in Fig. 136. The array size of the original Complex Amplitude Document is not changed, which means that the inserted array might be cut off.

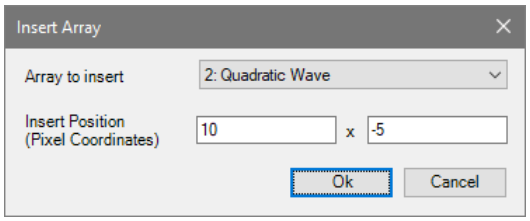


Figure 136. *Dialog for inserting an array.*

ITEM	DESCRIPTION
Array to insert	The array to be inserted into the currently active array.
Insert Position (Pixel Coordinates)	Position, where the bottom left corner of the inserted array shall be located. Can be negative.

22.2 Operations with Constant

Via the ribbon menu Manipulations > Operations with Constant several operations with one field operand are available, which are described in the following.

ITEM	DESCRIPTION
Set to Constant	Set field to the given constant value.
Addition	Add the given constant value to all field positions.
Multiplication	Multiply the given constant value to all field positions.
Division	Divide all field positions by the given constant.
Raise to Power	Raise all field positions to the power of the given constant value.

For setting the constant values to operate with, the dialog shown in Fig. 137 appears. Here you can enter a complex number by specifying either real part and imaginary part or amplitude and phase.

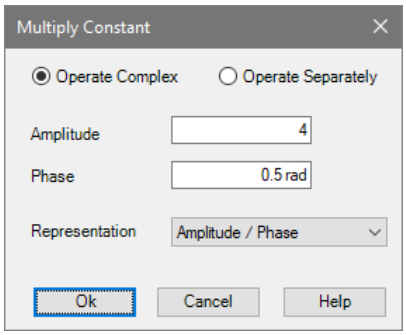


Figure 137. *Dialog for operation with one field operand.*

If you choose the mode *Operate Complex*, the two double numbers to enter are treated as the parts of one complex number, either in *Real / Imaginary* or in *Amplitude / Phase* Representation. Then the operations are done as a complex addition, multiplication or raise-to-power for each sampling point. If *Operate Separately* is chosen, the first entry operates only on the real part / amplitude of the field and the second number only on the imaginary part / phase, depending on the choice of *Representation*. In the following table you can see how these operations work and what the respective meanings of c_1 and c_2 are. The original complex value of a sampling point ($z = a + ib \equiv A\exp[i\phi]$) is changed by the operation with the constants c_1 and c_2 to the result shown in the two last columns.

OPERATION	REPRESENTATION	RESULT OF OPERATION	
		Operate Complex	**Operate Separately**
Add Constant	Real / Imaginary	$(a+ib)+(c_1+ic_2)$	$(a+c_1)+i(b+c_2)$
	Amplitude / Phase	$A\exp[i\phi]+c_1\exp[i\tilde{c_2}]$	$(A+c_1)\exp[i(\phi+\tilde{c_2})]$
Multiply Constant	Real / Imaginary	$(a+ib)\cdot(c_1+ic_2)$	$(a\cdot c_1)+i(b\cdot c_2)$
	Amplitude / Phase	$A\exp[i\phi]\cdot c_1\exp[i\tilde{c_2}]$	$(A\cdot c_1)\exp[i(\phi\cdot c_2)]$
Divide by Constant	Real / Imaginary	$(a+ib):(c_1+ic_2)$	$(a:c_1)+i(b:c_2)$
	Amplitude / Phase	$A\exp[i\phi]:(c_1\exp[i\tilde{c_2}])$	$(A:c_1)\exp[i(\phi:c_2)]$
Raise to the Power of Constant	Real / Imaginary	$(a+ib)^{c_1+ic_2}$	$(a^{c_1})+i\,(b^{c_2})$
	Amplitude / Phase	$(A\exp[i\phi])^{c_1\exp[i\tilde{c_2}]}$	$(A^{c_1})\exp[i\phi^{c_2}]$

$\tilde{c_2}$ indicates that this value is an angle, i. e. you can enter it with the unit 'rad', 'pi', or '°' (↪Sec. 5.1).

22.3 Field Quantity Operations

For real-valued data, the ribbon menu Manipulations > Field Quantity Operations contains only the option to convert it to a complex-valued one.

For complex-valued data, this ribbon menu provides several transformations with respect to field quantities. Field quantities are explained in Sec. 11.1.

ITEM	DESCRIPTION
Extract	This submenu contains entries for all field quantities. The entry Imaginary Part constructs a field, where the real part is set to zero and the imaginary part is copied from the current field. Phase creates a field with the same phase as the current field, whereby the amplitude is set to one. All remaining submenu entries copy the corresponding field quantity to the real part of the resulting field, whereby the imaginary part of the resulting field is equal to zero.
Move	The submenu entries are labeled according to which field quantity of the resulting field is filled from which field quantity of the current field. For example, Phase to Real Part copies the phase of the current field to the real part of the resulting field, whereby the imaginary part of the resulting field is set to zero.
Swap	The corresponding submenu entry allows to swap real part and imaginary part.

22.4 Amplitude / Real Part Manipulations

The ribbon menu Manipulations > Amplitude / Real Part Manipulations lets you perform the following operations with respect to amplitudes:

ITEM	DESCRIPTION
Normalize	Normalize the current field by dividing the field at all positions by the globally maximal amplitude.
Normalize According to Range Selection / Normalize According to Rectangular Selection	Normalizes the current array by dividing it (at all sampling points) by the maximum amplitude within the current selection.
Clip	Clips the current field to a given maximum amplitude. At all positions, where the amplitude is above this maximum value, the amplitude is set to the maximum value preserving the original phase. At all remaining positions the field is not changed. The scaling mode (↪Sec. 11.2.5) of the newly generated field is set to *Automatic Scaling*.
Lift Positive	Searches for the minimum value of the real part of the field and subtracts that value from all field positions. For a real-valued field this corresponds to adding the minimum value which ensures a non-negative field.
Simulate Sinc Modulation Due to Pixelation	Analytical simulation of the pixelation effect of a transmission in the far field for a plane wave illumination. This function is to be applied on a harmonic field already being in the far field. ↪Sec. 144.1.2
Compensate Sinc Modulation Due to Pixelation	Analytical compensation of the pixelation effect of a transmission in the far field for a plane wave illumination. This function can be used to make a compensation of the sinc-effect for the desired output field (far field) before starting a transmission design. ↪Sec. 144.1.2

22.5 Phase Manipulations

The ribbon menu Manipulations > Phase Manipulations contains several operations for manipulating the phase of the current field.

ITEM	DESCRIPTION
z^* Conjugate	Performs a transformation in which each complex number $z = a + ib$ is replaced by $z^\star = a - ib$.
Unwrap Phase	This operation tries to generate a real valued data array which contains the unwrapped smooth phase of the current field, i. e. to remove 2π jumps. During unwrapping, a simple line by line phase unwrapping algorithm is used. However, for two-dimensional fields unwrapping is neither unique nor always possible. For example, fields containing phase dislocations (↪Sec. 68.8.2) are generally unwrappable. A precondition for successful unwrapping is a sufficient sampling of the phase information. If the current complex amplitude contains information about a dominating spherical phase (↪Sec. 12.1.1), this information is taken into account during the unwrapping process.
Remove Phase Dislocations in Rectangular Selection	Phase dislocations (↪Sec. 68.8.2) are searched and tried to be removed in the current selection. For removing a certain phase dislocation with charge c (↪Sec. 68.8.2), a transmission of a phase dislocation with charge $-c$ is multiplied to the array at the same position. This operation is repeated for all phase dislocations which were found within the current selection.
Modify Phase	The operations which can be done via the appearing dialog are described below (↪Sec. 22.5.1).
Set Analytical Parameter	Sets the analytical spherical phase radius to a new value. This manipulation does not change the resulting phase, at least as long as the sampling distance is fine enough for the new aberrations (phase minus analytical spherical phase radius). The corresponding dialog is explained in Sec. 22.5.2, the concept of the spherical phase radius in Sec. 12.1.1.
Remove Analytical Parameter	Removes the analytical spherical phase radius. This manipulation does not change the resulting phase, at least as long as the sampling distance is fine enough for complete phase information. This can be ensured by using Manipulations > Sampling Manipulations > Resample According to Spherical Phase first. The concept of the spherical phase radius is explained in Sec. 12.1.1.
Remove Sampled Spherical Phase	If a spherical phase radius is set, the corresponding spherical phase will be subtracted. For that purpose, the array will be divided by an appropriate spherical phase function (see Eqs. (42.25)-(42.26)).

22.5.1 Modify Phase

Some phase modifying operations can be done via the dialog shown in Fig. 138.

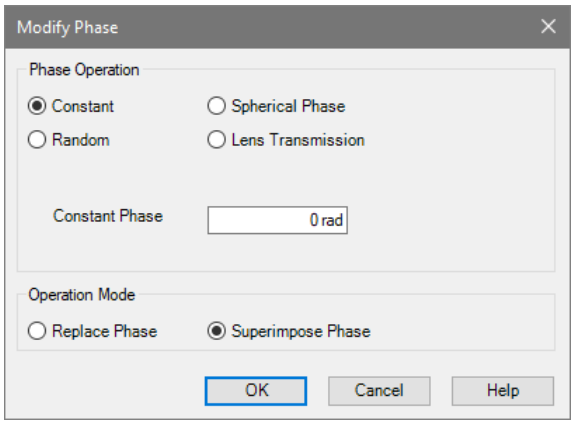


Figure 138. *Dialog for phase manipulation operations.*

The options are:

ITEM	DESCRIPTION
Constant	Replace or superimpose given constant phase.
Lens Transmission	Replace or superimpose lens transmission with the given focal length (see also Sec. 68.5.2).
Spherical Phase	Replace or superimpose spherical phase with given radius (see also Sec. 42.3.7). If you set the spherical phase radius to a value greater than 10^5 m, the harmonic field is set to have no spherical phase radius.
Random	Replace phase by random phase. The additional parameters correspond to those of the random phase transmission generator as described in Sec. 68.7.2.
Replace Phase	If selected, the current phase is replaced by the newly created phase.
Superimpose Phase	If selected, the newly created phase is superimposed to the current field by multiplying the corresponding complex transmission function.

22.5.2 Set Spherical Phase Radius

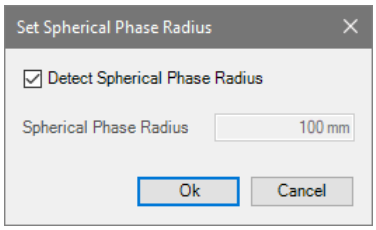


Figure 139. *Dialog for setting the spherical phase radius.*

The dialog for changing the analytical spherical phase radius of a harmonic field (↪Fig. 139) has the following entries:

ITEM	DESCRIPTION
Detect Spherical Phase Radius	If this check box is checked, VirtualLab Fusion tries to detect a dominating spherical phase radius in the field.
Spherical Phase Radius	If the check box *Detect Spherical Phase Radius* is unchecked, you can set the radius to a specific value. If you set the spherical phase radius to a value greater than 10^5 m, the harmonic field is set to have no spherical phase radius.

Further details about the detection of a spherical phase factor can be found in Sec. 142.6.

22.6 Lateral Displacement

The ribbon menu Manipulations > Lateral Displacement allows you to do some transformations with regard to the x- and y-coordinates of the array.

ITEM	DESCRIPTION
Mirror Horizontally	Applies transformation $u(x,y) \rightarrow u(-x,y)$, that is the field is mirrored horizontally by a mirror that corresponds to the y-axis.
Mirror Vertically	Applies transformation $u(x,y) \rightarrow u(x,-y)$, that is the field is mirrored vertically by a mirror that corresponds to the x-axis.
Rotate in x-y-Plane	Rotates the field by the given angle (↪Sec. 22.6.1).
Shift	Shifts content of the current field by a given number of sampling points.
Transpose	Applies transformation $u(x,y) \rightarrow u(y,x)$, that is the field is mirrored by a mirror that corresponds to a diagonal in the x-y-plane.

22.6.1 Rotation in x-y-plane

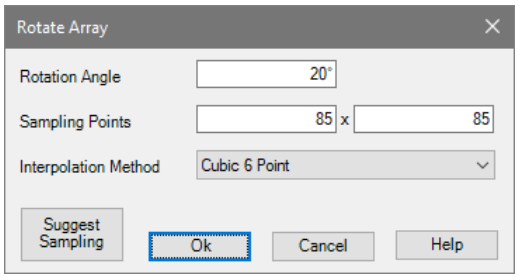


Figure 140. *Settings for Rotation in x-y-Plane.*

The dialog shown in Fig. 140 allows you to enter settings for the rotation of complex amplitudes in the x-y-plane.

ITEM	DESCRIPTION
Rotation Angle	Angle by which the field is to be rotated around the z-axis.
Sampling Points	Number of sampling points after rotation. The sampling distance of the original field is retained.
Interpolation Method	Interpolation method to be used (↪Sec. 13.2.2)
Suggest Sampling	Suggest number of sampling points which is necessary for preserving field information depending on the entered rotation angle

22.7 Array Size Manipulations

The ribbon menu Manipulations > Array Size Manipulations provides the following operations that change the size of an one- or two-dimensional array:

ITEM	DESCRIPTION
Embed / Extract (Pixel Dimensions)	Changes the number of sampling points. If the number of sampling points is increased then the array is embedded, that means the newly created surrounding sampling points are filled with zero values. Otherwise, i. e. if the number of sampling points is decreased then the new array is extracted. Embedding as well as extracting is done centered.
Embed / Extract (Physical Dimensions)	This option works like Embed / Extract (Pixel Dimensions), but the size of the new array is defined in physical units.
Embed in Double Sized Array (Center)	This operation corresponds to using Embed / Extract (Pixel Dimensions) with embedding to the double array size. The original array will be centered in the result array. The new sampling points are set to zero.
Embed in Double Sized Array (Corner)	This operation corresponds to using Embed / Extract (Pixel Dimensions) with embedding to the double array size. But the original array will be the bottom left quadrant in the resulting array. The new sampling points are set to zero.
Make Hermitian	This operation corresponds to Embed in Double Sized Array (Corner), but in addition the upper right quadrant is filled by the complex conjugate of the original array in order to ensure that the result is Hermitian (↪Sec. 68.7.2).
Replicate Twice	Fill the resulting array by 2 (one-dimensional case) or 2×2 (two-dimensional case) replications of the original array. This operation is equivalent to use Replicate Periodically with the double array size and a shift of $(0, 0)$.
Replicate Periodically	This operation is typically used for increasing the number of sampling points to the given array size. The newly created array is filled by periodically replicating the contents of the current one (↪Sec. 22.7.1).
Extract Range Selection / Extract Rectangular Selection	Creates a new array which contains the selected portion of the current array.
Extract Profile Line	Extracts the one-dimensional cross-section defined by the line marker (↪Sec. 11.3) to a separate one-dimensional harmonic field (↪Sec. 22.7.2).

22.7.1 Replicate Periodically

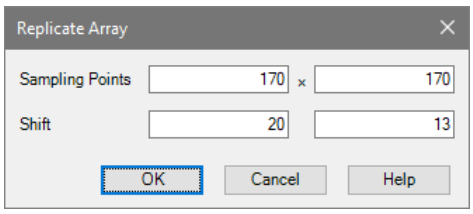


Figure 141. *Dialog for periodic replication.*

A new array is created, filled by periodically replicating the contents of the current array. In the dialog (↪Fig. 141) the following parameters have to be entered:

ITEM	DESCRIPTION
Sampling Points	Size of the new array (in number of sampling points).
Shift	This value indicates which point of the current array is set at the lower left corner of the replicated one. So the value has to lie inside the source array.

22.7.2 Extract Profile Line

The one-dimensional cross section marked by a Profile Line in a two-dimensional array can be extracted using Manipulations > Array Size Manipulations > Extract Profile Line.

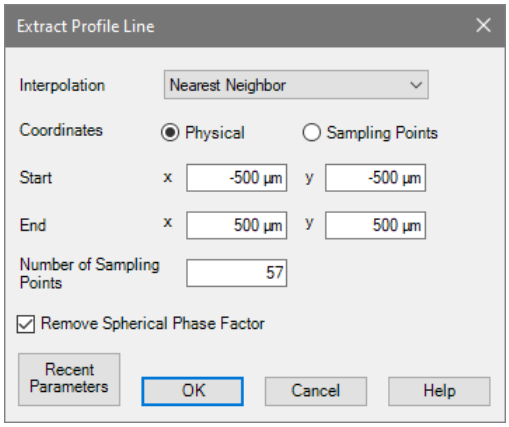


Figure 142. *Dialog for extraction of a profile.*

The dialog shown in Fig. 142 is used to define the extraction. The following parameters can be entered:

ITEM	DESCRIPTION
Interpolation	The type of interpolation that shall be used to find the equidistant sampling points of the resulting array if the points on the line in the initial array are not equidistant.
Coordinates	Determines whether the *Start* and *End* coordinates shall be given in physical units or as the indices of sampling points.
Start	Starting point of the line to extract. Initially the start coordinates of the profile line are filled in here.
End	End point of the line to extract. Initially the end coordinates of the profile line are filled in here.
Number of Sampling Points	The number of sampling points the resulting array shall contain.
Remove Spherical Phase Factor	If checked and a Spherical Phase Factor is given for the array, it will be removed from the phase of the resulting array.
Recent Parameters	Restores the values which were stored for the last call of this operation, i. e. if the dialog was last closed using *OK*. With this option you can easily extract the same profile line from various harmonic fields. If these recent values do not fit in the current array, this button is disabled and a warning is shown.

22.8 Sampling Manipulations

The ribbon menu Manipulations > Sampling Manipulations provides the following operations that change the sampling distance:

ITEM	DESCRIPTION
Interpolate	Using this manipulation (↪Sec. 22.8.1), the sampling parameters of an array can be changed, whereby the originally stored physical information shall be preserved. This operation can also be executed by clicking directly on the upper part of the Manipulations > Sampling Manipulations menu.
Oversample Twice (Zeroized)	The number of sampling points is doubled by splitting each sampling point into 2 × 2 new points of half the original sampling distance. The new point with the same physical position contains the old complex value, the remaining sampling points are filled with zero.
Oversample Twice (Sinc FFT Interpolation)	This is equivalent to use Interpolate with the interpolation method *Sinc (Fourier Transformation)*-interpolation, half the original sampling distance, and a zero point of $(0,0)$.
Oversample Twice (Nearest Neighbor Interpolation)	The number of sampling points is doubled by splitting each sampling point into 2 × 2 new points of half the original sampling distance. All new points contain the value of the original sampling point. In this way propagation methods consider the original data as pixelated data.
Oversample 3× (Nearest Neighbor Interpolation)	The number of sampling points is tripled by splitting each sampling point into 3 × 3 new points of one third the original sampling distance, containing the value of the original sampling point. In this way propagation methods consider the original data as pixelated data.
Resample According to Spherical Phase	If a spherical phase radius is set, this option resamples the array in a way that the corresponding spherical phase will be sampled correctly (according to the Whittaker Shannon theorem, see [Goo68]). In the Optical Setup, this can be done with the ideal component *Ideal Components > Manipulators > Sample Spherical Phase Radius*.

22.8.1 Interpolation

This operation is available via Manipulations > Sampling Manipulations > Interpolate.
Its edit dialog (↪Fig. 143) has the following settings:

ITEM	DESCRIPTION
Interpolation Method	The used interpolation method. ↪Sec. 13.2.2
Sampling Points	The number of sampling points the new array shall contain.
Sampling Distance	The sampling distance of the new array.
Array Size	The array size of the new array.
Copy from...	By pressing this button a dialog will appear where another harmonic field can be selected to copy the sampling parameters from.
Zero Point	Zero point of the resulting field relative to the zero point of the original array.
Document Parameters	Fills the controls according to the sampling parameters of the currently selected array.

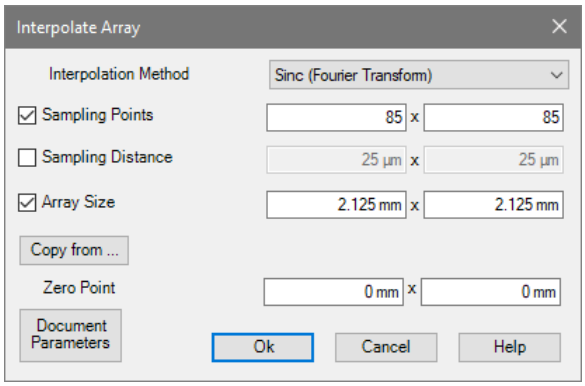


Figure 143. *Dialog for adjusting the interpolation settings.*

22.8.2 Field Size and Sampling Manipulation in the Optical Setup

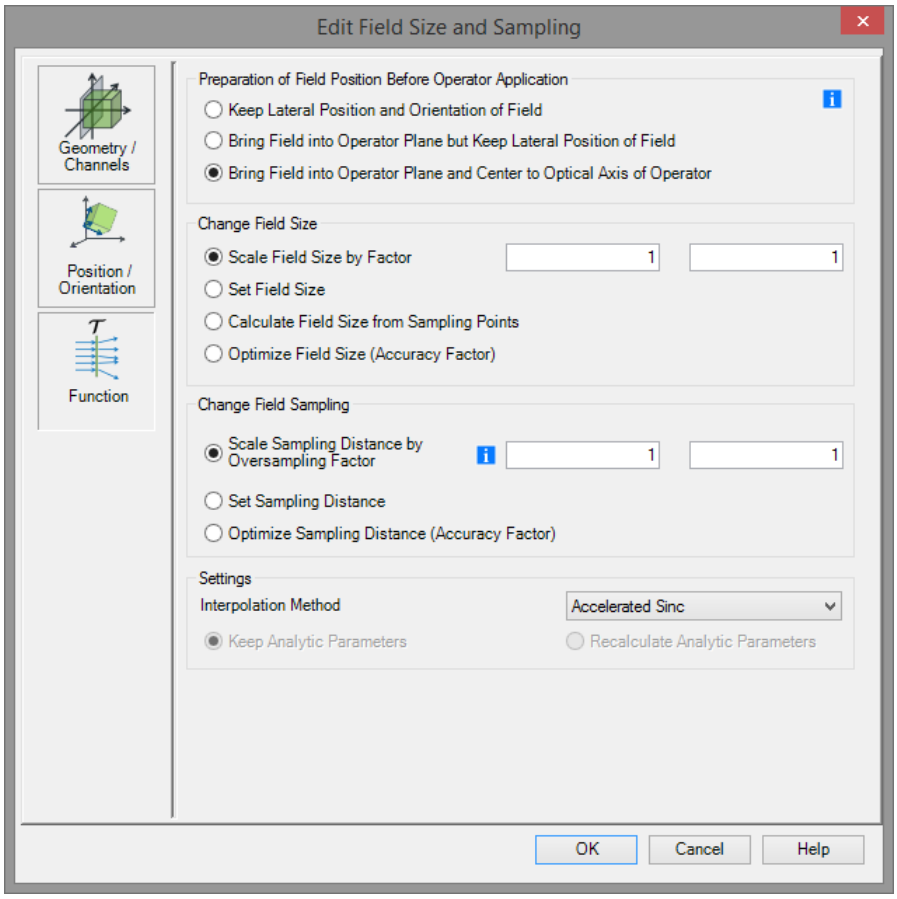


Figure 144. *The Field Size and Sampling Manipulation dialog.*

As you can see in Fig. 144, the Field Size and Sampling Manipulation dialog has four group boxes: *Preparation of Field Position Before Operator Application*, *Change Field Size*, *Change Field Sampling*, and *Settings*. Within the region *Preparation of Field Position Before Operator Application* the user can specify how the incident field position of the *Field Size And Sampling* operator shall be defined. The has three different options:

- Keep Lateral Position and Orientation of Field
- Bring Field into Operator Plane but Keep Lateral Position of Field
- Bring Field into Operator Plane and Center to Optical Axis of Operator

The meaning of each option is explained within a sketch accessible by clicking on the info label in more detail.

The *Change Field Size* box has the following entries:

ITEM	DESCRIPTION
Scale Field Size PV	The size of the output field is n times larger than of the incoming field. n is a vector to allow different scaling for x- and y-direction.
Set Field Size PV	You can directly set the field size in physical coordinates.
Calculate Field Size from Sampling Points PV	The field size is calculated from the specified number of sampling points (x- and y-direction) and the sampling distance of the incoming field.
Optimize Field Size (Accuracy Factor) PV	The field size is calculated automatically according to the power portion specified in the Global Options dialog (↪Sec. 6.12). The given accuracy factor enlarges the field by the given factor.

The *Change Field Sampling* box has the following entries:

ITEM	DESCRIPTION
Scale Sampling Distance by Oversampling Factor PV	The sampling distance in the output field is n times smaller than in the incoming field. n is a vector to allow different sampling for x- and y-direction.
Set Sampling Distance PV	You can directly set the sampling distance for both x- and y-direction.
Optimize Sampling Distance (Accuracy Factor) PV	The sampling distance is calculated automatically. With the accuracy factor you can reduce the sampling distance by the given factor. In this case the *Interpolation Method* is fixed to *Accelerated Sinc Interpolation* (↪Sec. 13.2.2).

The *Settings* box has the following entries:

ITEM	DESCRIPTION
Interpolation Method	The used interpolation method. ↪Sec. 13.2.2.
Keep Analytic Parameter Recalculate Analytic Parameter	Specify whether analytic parameters like the spherical phase radius are taken from the incoming field or calculated anew.

The remaining controls of this dialog are explained in Sec. 67.

22.9 Selection Related Operations

All operations in the ribbon menu Manipulations > Selection Related Operations affect the selected area of the array only. These are:

ITEM	DESCRIPTION
Fill Range Selection / Fill Rectangular Selection	Sets the sampling points within the selection to a user-defined complex value c. Keep in mind that for globally polarized fields the new E_x values within the selection are $J_x \cdot c$ and the new E_y values are $J_y \cdot c$, with $\boldsymbol{J}$ being the Jones vector.
Clear Range Selection / Clear Rectangular Selection	Sets the sampling points within the selection to zero.
Clear Inverse of Range Selection / Clear Inverse of Rectangular Selection	Sets the sampling points outside the selection to zero.
Extract Range Selection / Extract Rectangular Selection	Creates a new array which contains the selected portion of the current array.
Extract Profile Line	Extracts the one-dimensional cross-section defined by the line marker (↪Sec. 11.3) to a separate one-dimensional harmonic field (↪Sec. 22.7.2).
Normalize According to Range Selection / Normalize According to Rectangular Selection	Normalizes the current array by dividing it (at all sampling points) by the maximum amplitude within the current selection.
Remove Phase Dislocations in Rectangular Selection	Phase dislocations (↪Sec. 68.8.2) are searched and tried to be removed in the current selection. For removing a certain phase dislocation with charge c (↪Sec. 68.8.2), a transmission of a phase dislocation with charge $-c$ is multiplied to the array at the same position. This operation is repeated for all phase dislocations which were found within the current selection.
Create Signal Region from Selection	This item creates a region document (↪Sec. 21). The result will be a sampled region which has the same sampling parameters as the current harmonic field or Jones matrix transmission document. The selected range or rectangle marker will define the actual signal region, independent of the values inside the original selection.

22.10 Polarization Change

All operations in the ribbon menu Manipulations > Polarization Change affect somehow the Jones Vector $\boldsymbol{J}$ of a globally polarized field (↪Sec. 136.1).

ITEM	DESCRIPTION
Convert to Locally Polarized Field	Converts the current globally polarized field to the more general type of a locally polarized one corresponding to $$E_x(x,y) = J_x U(x,y) \quad (22.2)$$ $$E_y(x,y) = J_y U(x,y) \quad . \quad (22.3)$$

Split into Globally Polarized Fields	Splits a locally polarized field into two globally polarized fields which correspond to the E_x and the E_y component of the original field. The new Jones vectors are $(1,0)^T$ and $(0,1)^T$. This option can be used to reduce memory and time consumption if you have a locally polarized field with negligible E_y field (e. g. after geometric optics propagation with Fresnel effects considered).
Change Jones Vector	Opens a dialog (↪Fig. 145) which allows you to set the Jones Vector. The controls of this dialog are the same as for setting the Jones vector of a newly generated field, ↪Sec. 49.3. This operation can also be done via the *(Current) Data* tab of the property browser (↪Fig. 146).
General	A general Jones Matrix Multiplication (↪Sec. 22.10.1). Its edit dialog is explained in Sec. 22.10.1.1.
Linear Polarization	A Jones Matrix Multiplication (↪Sec. 22.10.1) describing a linear polarization. Its edit dialog is explained in Sec. 22.10.1.2.
Phase Shift	A Jones Matrix Multiplication (↪Sec. 22.10.1) describing a phase shift. Its edit dialog is described in Sec. 22.10.1.3.
Retardation	A Jones Matrix Multiplication (↪Sec. 22.10.1) describing a retardation. Its edit dialog is described in Sec. 22.10.1.4.
Rotation	A Jones Matrix Multiplication (↪Sec. 22.10.1) describing a rotation. Its edit dialog is described in Sec. 22.10.1.5.

Application on Harmonic Fields Sets

For a Harmonic Fields Sets these manipulations are applied separately on each member field. The resulting fields are then combined into a new Harmonic Fields Sets (two for *Split into Globally Polarized Fields*).
Note that a Harmonic Fields set can contain both globally and locally polarized fields. In this case both *Convert to [Pure] Locally Polarized Field* and *Split into [Pure] Globally Polarized Fields* are available.

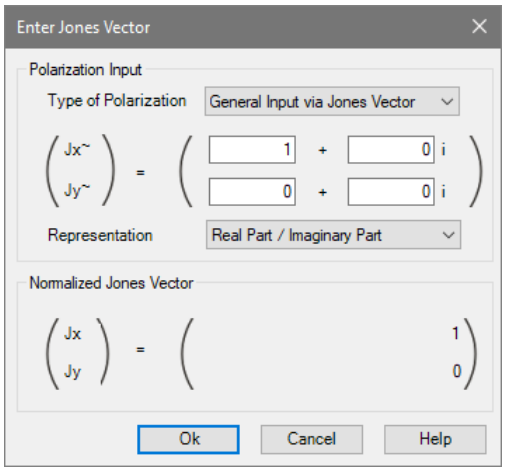


Figure 145. *Dialog used to edit the Jones vector.*

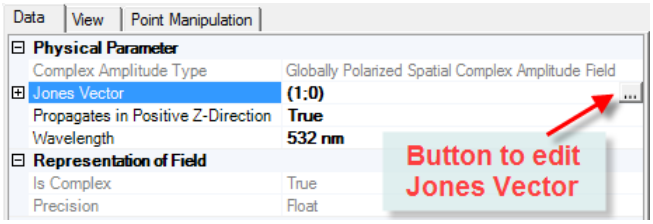


Figure 146. *How to edit the Jones vector via the property browser.*

22.10.1 Jones Matrix Multiplication

Some optical elements and devices influence the polarization state of light. Mathematically this process can be described by a change of the electric field vector by a matrix, called Jones matrix $\mathcal{J}$

$$E_{xy}^{out} = \mathcal{J} \cdot E_{xy}^{in}. \tag{22.4}$$

For globally polarized fields, this means a change of the Jones vector:

$$J_{out} = \mathcal{J} \cdot J_{in}. \tag{22.5}$$

Since Transmissions contain their own Jones matrix $\mathcal{J}^{(T)}$, the effect of a Jones Matrix Multiplication can be "added" to the transmission by applying former to the latter, which corresponds to the mathematical operation

$$\mathcal{J}_{out}^{(T)} = \mathcal{J} \cdot \mathcal{J}_{in}^{(T)}. \tag{22.6}$$

For your convenience, the four important cases of Linear Polarization, Phase Shift, Retardation, and Rotation are implemented as separate manipulations in VirtualLab Fusion (described in the following sections Sec. 22.10.1.2 to Sec. 22.10.1.5). That means, the user does not have to enter the Jones matrix but only one single parameter describing the appropriate physical effect. For other cases a General Jones matrix can be defined (↪Sec. 22.10.1.1).

22.10.1.1 General

For the multiplication of an arbitrary Jones matrix this manipulation is used.

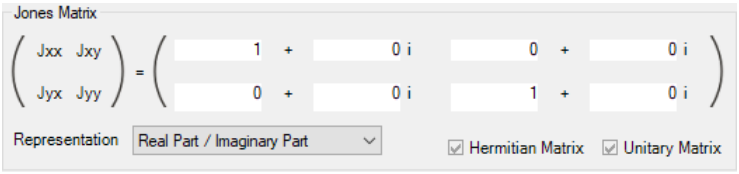


Figure 147. *Controls for defining the parameters of an arbitrary Jones matrix multiplication.*

The following parameters are available for a General Jones Matrix Multiplication (↪Fig. 147):

ITEM	DESCRIPTION
Jones Matrix	Matrix with four complex entries.
Representation	Representation of the complex values in the Jones matrix.
Hermitian Matrix	Indicates whether the matrix is Hermitian.
Unitary Matrix	Indicates whether the matrix is unitary.

22.10.1.2 Linear Polarization

A linear polarizer is a kind of optical filter that will pass only that part of E_{xy} which oscillates in a certain direction. If this direction is given by an angle α, the corresponding Jones matrix is given by

$$\mathcal{J} = \begin{pmatrix} \cos^2\alpha & \sin\alpha\cos\alpha \\ \sin\alpha\cos\alpha & \sin^2\alpha \end{pmatrix}. \tag{22.7}$$

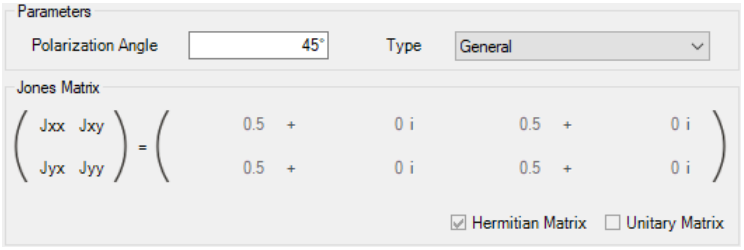


Figure 148. *Controls for defining the parameters of a linearly polarizing Jones matrix multiplication.*

The following parameters are available for a Linear Polarization function (↪Fig. 148):

ITEM	DESCRIPTION
Polarization Angle	The angle of the plane of polarization of the filtered, linearly polarized light.
Type	Here you can select one of the two special cases *Along x Direction*, which corresponds to a polarization angle of α = 0°, which means that the component E_y is set to 0, or *Along y Direction*, which corresponds to a polarization angle of α = 90°, which means that the component E_x is set to 0. The case of an arbitrary polarization angle is called *General*.
Jones Matrix	The resulting Jones matrix that describes the linear polarization.
Hermitian Matrix	Indicates whether the matrix is Hermitian.
Unitary Matrix	Indicates whether the matrix is unitary.

22.10.1.3 Phase Shift

A Phase Shift adds a phase difference ϕ to both E_x and E_y. The appropriate Jones matrix is

$$\mathcal{J} = \begin{pmatrix} \exp(i\phi) & 0 \\ 0 & \exp(i\phi) \end{pmatrix}. \tag{22.8}$$

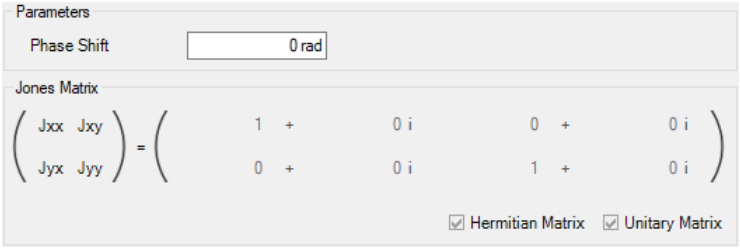


Figure 149. *Controls for defining the parameters of a Phase Shift.*

The following parameters are available for a Phase Shift function (↪Fig. 149):

ITEM	DESCRIPTION
Phase Shift	The phase shift ϕ for both E_x and E_y.
Jones Matrix	The resulting Jones matrix that describes the phase shift.
Hermitian Matrix	Indicates whether the matrix is Hermitian.
Unitary Matrix	Indicates whether the matrix is unitary.

22.10.1.4 Retardation

Retarders as e. g. quarter-wave plates or half-wave plates "retard" E_y against E_x by a phase difference ϕ. Thereby linearly polarized light can be transformed into circularly polarized and vice versa, for example. The appropriate Jones matrix is

$$\mathcal{J} = \begin{pmatrix} 1 & 0 \\ 0 & \exp(-i\phi) \end{pmatrix}. \tag{22.9}$$

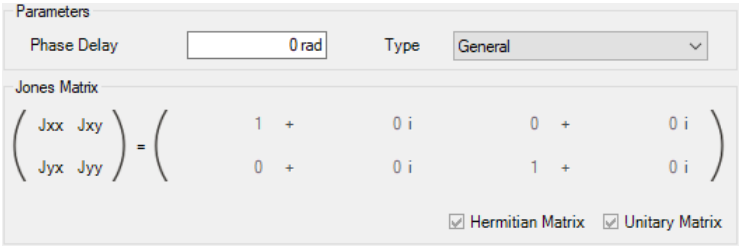


Figure 150. *Controls for defining the parameters of a Jones matrix retardation.*

The following parameters are available for a Retardation function (↔Fig. 150):

ITEM	DESCRIPTION
Phase Delay	The phase shift E_y shall get.
Type	Here you can select one of the two important special cases *Quarter-Wave Retarder*, which corresponds to a phase delay of $\pi/2$, used for transforming linearly polarized light to circularly polarized and vice versa, or *Quarter-Wave Retarder*, which corresponds to a phase delay of π, used for transforming right-circularly polarized light into left-circularly and vice versa. The case of an arbitrary phase delay is called *General*.
Jones Matrix	The resulting Jones matrix that describes the retardation.
Hermitian Matrix	Indicates whether the matrix is Hermitian.
Unitary Matrix	Indicates whether the matrix is unitary.

22.10.1.5 Rotation

The angle of rotation θ of the plane of polarization determines the Jones matrix as follows

$$\mathcal{J} = \begin{pmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{pmatrix}. \tag{22.10}$$

Figure 151. *Controls for defining the parameters of a Jones matrix rotation.*

The following parameters are available for a phase rotation function (↪Fig. 151):

ITEM	DESCRIPTION
Rotation Angle	The angle by which the plane of polarization shall be rotated.
Jones Matrix	The resulting Jones matrix that describes the rotation of the plane of polarization.
Hermitian Matrix	Indicates whether the matrix is Hermitian.
Unitary Matrix	Indicates whether the matrix is unitary.

22.11 Miscellaneous

The ribbon menu Manipulations > Miscellaneous contains various special manipulations e. g. to introduce discrete value levels.

22.11.1 Resample to Angular Coordinates

This manipulation converts a given Harmonic Field into a Data Array with angular coordinates. To this end for a spatial field first a Fourier transform is done.
to Angular Coordinates.pdf to Angular Coordinates.png to Angular Coordinates.eps

Figure 152. *Options for resampling a harmonic field to angular coordinates.*

The edit dialog (↪Fig. 152) for this manipulation has the following settings.

ITEM	DESCRIPTION
Vectorial Components	Allows you to select any combination of E_x, E_y and E_z.
Coordinate Type	Whether you want to use *Cartesian Angles* or *Spherical Angles*.
Oversampling Factors	By default a good automatic sampling is used. However you can create more sampling points for *Alpha* and *Beta* or *Phi* and *Theta*, respectively, by increasing the oversampling factors.

22.11.2 Hard Quantization

The menu item Manipulations > Quantization > Hard Quantization opens a dialog which allows you to enter the numbers q and Q of amplitude and phase levels, respectively.
The quantization is performed independently for amplitude and phase. For each position (x, y) the original field value $u(x, y) = A \exp[i\phi]$ is replaced by $A' \exp[i\phi']$, where

$$A' = \begin{cases} A & \textbf{if } \; q = 0 \\ A_{\max} & \textbf{if } \; q = 1 \\ \frac{A_{\max}}{q-1} \cdot \lfloor (q-1) \frac{A}{A_{\max}} \rceil & \textbf{otherwise} \end{cases} \tag{22.11}$$

(where $\lfloor \cdot \rceil$ denotes the rounding-to-nearest-integer operation) and

$$\phi' = \begin{cases} \phi & \textbf{if } Q = 0 \\ \frac{2\pi}{Q} \cdot \lfloor \frac{Q(\phi+\pi)}{2\pi} \rceil - \pi & \textbf{otherwise} \end{cases} \tag{22.12}$$

A_{max} is the maximum amplitude within the input field. Compared to the definition of the phase quantization operator $\Pi_{\text{quant},Q}$ used during IFTA optimization (↪Sec. 98), which corresponds to the case of $q = 1$, the definition given in this section allows simultaneous amplitude and phase quantization. Furthermore, the special cases for $q = 0$ and $Q = 0$ have been included for maintaining the original amplitude and phase, respectively. In cases of $q = 1$ the amplitude is set to one. If $Q = 1$, the resulting field has a zero phase.

22.11.3 Soft Quantization

The menu item Manipulations > Quantization > Soft Quantization opens a dialog which allows you to enter the numbers q and Q of amplitude and phase levels, respectively. Furthermore a projection strength λ can be entered.

The quantization is performed independently for amplitude and phase. For each position (x, y) the original field value $u(x, y) = A \exp[i\phi]$ is replaced by $A' \exp[i\phi']$. The amplitude A' is obtained by

$$A' = \begin{cases} A & \textbf{if } q = 0 \\ A_{\text{max}} & \textbf{if } q = 1 \wedge C_1 = \text{true} \\ \frac{A_{\text{max}}}{q-1} \cdot \lfloor (q-1) \frac{A}{A_{\text{max}}} \rceil & \textbf{if } q > 1 \wedge C_2 = \text{true} \\ A & \textbf{otherwise} \end{cases} \tag{22.13}$$

with the Boolean terms

$$C_1 = \left(|\frac{A}{A_{\text{max}}} - 1| \geq 0.5\lambda \right), \tag{22.14}$$

$$C_2 = \left(\left| \frac{A}{A_{\text{max}}} - \frac{1}{q-1} \cdot \lfloor (q-1) \frac{A}{A_{\text{max}}} \rceil \right| \geq \frac{\lambda}{2(q-1)} \right). \tag{22.15}$$

The phase ϕ' is calculated from

$$\phi' = \begin{cases} \phi & \textbf{if } Q = 0 \vee C_3 = \text{true} \\ \frac{2\pi}{Q} \cdot \lfloor \frac{Q(\phi+\pi)}{2\pi} \rceil - \pi & \textbf{otherwise} \end{cases} \tag{22.16}$$

with the Boolean term

$$C_3 = \left(Q > 0 \wedge \left| \phi - \frac{2\pi}{Q} \cdot \lfloor Q/(2\pi)\phi \rceil \right| > \lambda\pi/Q \right). \tag{22.17}$$

A_{max} is the maximum amplitude within the complex amplitude field.

Compared to the definition of the phase quantization operator $\Pi^{\lambda}_{\text{softquant},Q}$ used during IFTA optimization (↪Sec. 98), which corresponds to the case of $q = 1$, the definition given in this section allows for simultaneous amplitude and phase quantization. Furthermore, the special cases for $q = 0$ and $Q = 0$ have been included for maintaining the original amplitude and phase, respectively. If $Q = 1$, the resulting field has a zero phase.

22.11.4 Floyd-Steinberg Quantization

The menu item Manipulations > Quantization > Floyd-Steinberg Quantization opens a dialog which allows you to enter the numbers q and Q of amplitude and phase levels, respectively.

The result of the Floyd-Steinberg quantization contains only field values from the set

$$M_{(q,Q)} = \{A \exp[i\phi] : A \in M_q \wedge \exp[i\phi] \in M_Q\}, \tag{22.18}$$

where the sets M_q and M_Q are given by

$$M_q = \left\{ \frac{jA_{\max}}{q-1} : j = 0 \ldots q-1 \right\} \tag{22.19}$$

and

$$M_Q = \left\{ \exp\left[-i\pi \left(-1 + \frac{2\pi j}{Q} \right) \right] : j = 0, 1, \ldots, Q-1 \right\}. \tag{22.20}$$

$A_{\max}$ is the maximum amplitude within the complex amplitude field.

In contrast to the quantization types described in the previous two sections, the Floyd-Steinberg quantization is not a pointwise operation. That is, the quantization result at a position (x,y) does not depend only on the field value $u(x,y)$ but also on the field values on neighboring positions. The basic idea of the Floyd-Steinberg quantization is to distribute the error, which was made by the quantization at a certain position, to the neighboring positions.

During the application of the Floyd-Steinberg quantization an iteration through all field positions is performed row by row, whereby within each row positions are considered consecutively from left to right. At a considered position (x,y) firstly a hard quantization is performed (↪Sec. 22.11.2). After that the quantization error is calculated from the difference between $u(x,y)$ and the obtained quantization value.

This difference is spread using the weighting factors shown in Fig. 153 to four neighboring positions, which are considered in following iterations.

Figure 153. *Weighting factors for distribution of quantization errors to neighboring positions during Floyd-Steinberg quantization.*

22.12 Conversions

For a detailed discussion of all possible conversions ↪Sec. 30.

22.13 Fourier Transform

For a detailed discussion of Fourier transforms ↪Sec. 31.

23 Manipulations of Harmonic Fields Sets

Harmonic Fields Sets support the following manipulations.

ITEM	DESCRIPTION
Indexwise Addition	The current and the last active Harmonic Fields Set can be summed indexwise. That means simply to add their member harmonic fields with the same index respectively. So the fields of the result set are calculated by $u_{\text{new},i} = u_{1,i} + u_{2,i}$. If one of the initial fields sets has more members than the other one, the surplus fields are just appended. This operation can also be done with the + key.
Coherent Summation	All member fields having the same wavelength are summed up coherently.
Remove Sampled Spherical Phases	If a spherical phase radius is set for any member field, the corresponding spherical phase will be subtracted. For that purpose, the member field will be divided by an appropriate spherical phase function (see Eqs. (42.25)-(42.26)).
Sampling Manipulations	Provides operations that change the sampling distance of all member fields. ↪Sec. 23.1.
Extraction Tools	These tools can be used to extract partial information from a Harmonic Fields Set. ↪Sec. 23.2
Polarization Change	Either converts all member fields to globally or locally polarized ones or applies a Jones Matrix Multiplication on each member field. (↪Sec. 22.10)

The ribbon group Manipulations > Member Harmonic Fields is explained in Sec. 23.3, the ribbon group Manipulations > Conversions in Sec. 30.2, and the ribbon group Manipulations > Fourier Transformation (Space) in Sec. 31.1.

23.1 Sampling Manipulations

The ribbon menu Manipulations > Sampling Manipulations provides the following operations that change the sampling distance of all member fields:

ITEM	DESCRIPTION
Oversample Twice (Sinc FFT Interpolation)	Uses the interpolation method *Sinc (Fourier Transformation)* (↪Sec. 13.2.2) to halve the original sampling distance of each member field.
Resample According to Spherical Phase	If a spherical phase radius is set for a member field, this option resamples the field in a way that the corresponding spherical phase will be sampled correctly (according to the Whittaker Shannon theorem, see [Goo68]). In the Optical Setup, this can be done with the ideal component *Ideal Components > Manipulators > Sample Spherical Phase Radius*.

23.2 Extraction Tools

The following tools can be used to extract partial information from a Harmonic Fields Set.

ITEM	DESCRIPTION
Point Profile Extraction	Extracts the complex value on a user-defined position and plots this value versus the index or the wavelength of each Harmonic Fields Set member. ↪Sec. 23.2.1
Line Profile Extraction	Extracts the complex values along a user-defined line and plots these values versus the index or the wavelength of each Harmonic Fields Set member. ↪Sec. 23.2.2
Rectangle Extraction	Converts the Harmonic Fields Set into a *Field Vector Component* (member fields versus field index) or into a *Pulse Component* (member fields versus wavelength). ↪Sec. 23.2.3

23.2.1 Point Profile Extraction

The *Point Profile Extraction* extracts the complex value on a user-defined position and plots this value versus the index or the wavelength of each Harmonic Fields Set member.
Fig. 154 shows the edit dialog of the Point Profile Extraction tool.

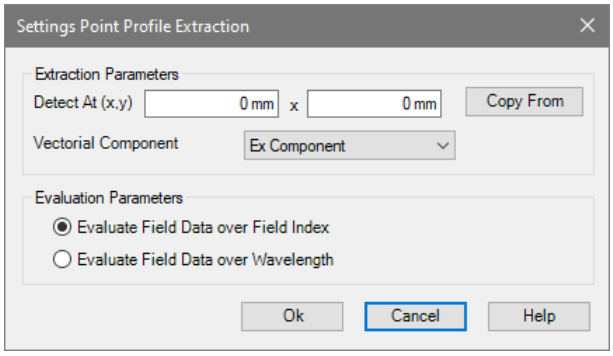


Figure 154. *Edit dialog for the Point Profile Extraction tool.*

The following parameters can be specified by the user:

ITEM	DESCRIPTION
Detect At (x,y)	The position from which the data shall be extracted. Initially, the current cross position is set. The button *Copy From* can be used to copy the cross position from a present Harmonic Fields Set in VirtualLab Fusion.
Vectorial Component	The vectorial component (*Ex Component*, *Ey Component*, or *Ez Component*) to be evaluated by the evaluation tool.
Evaluate Field Data over Field Index	Defines whether the complex value shall be shown in dependency on the index in the Harmonic Fields Set.
Evaluate Field Data over Wavelength	Defines whether the complex value shall be shown in dependency on the wavelength of each Harmonic Field. This option is only available if each wavelength in the Harmonic Fields Set is unique.

The resulting diagram contains the complex value in dependence on the user-defined independent variable (index or wavelength). This diagram supports to switch between the different field quantities. More details can be found in Sec. 15.
Fig. 155 shows a sample output of the Point Profile Extraction.

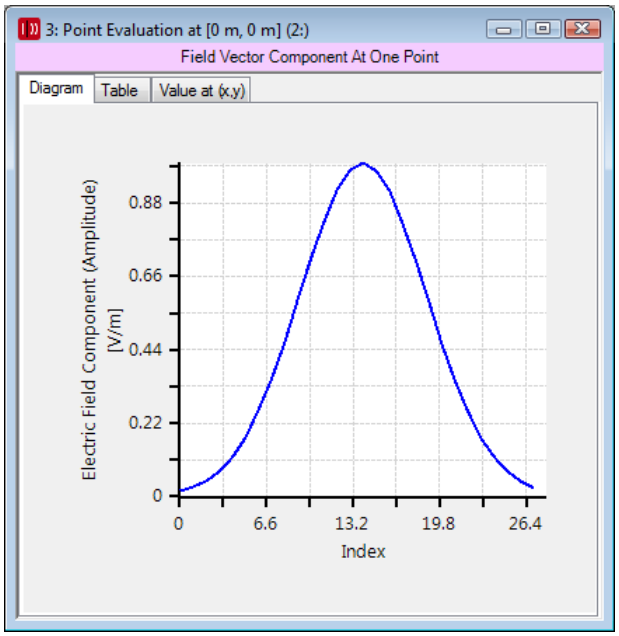


Figure 155. *Sample result of a Point Profile Extraction.*

23.2.2 Line Profile Extraction

The *Line Profile Extraction* extracts the complex values along a user-defined line and plots these values versus the index or the wavelength of each Harmonic Fields Set member.

Fig. 156 shows the edit dialog of the Line Profile Extraction tool.

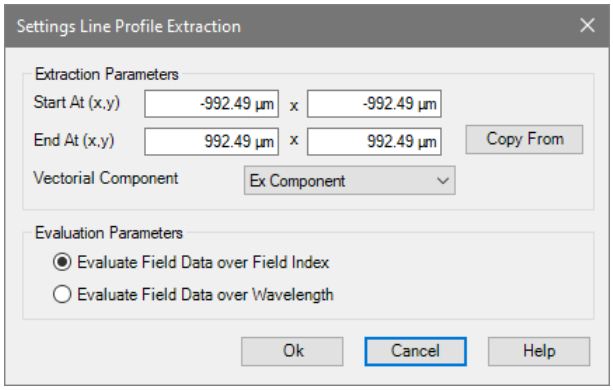


Figure 156. *Edit dialog for the Line Profile Extraction tool.*

The following parameters can be configured in the edit dialog.

ITEM	DESCRIPTION
Start At (x,y)	The start position of the line to be extracted. Initially, the start position of the current profile line is set. The button *Copy From* can be used to copy the starting point of the line from a present Harmonic Fields Set in VirtualLab Fusion.
End At (x,y)	The end position of the line to be extracted. Initially, the end position of the current profile line is set. The button *Copy From* can be used to copy the end point of the line from a present Harmonic Fields Set in VirtualLab Fusion.
Vectorial Component	The vectorial component (*Ex Component*, *Ey Component*, or *Ez Component*) to be evaluated by the evaluation tool.
Evaluate Field Data over Field Index	Defines whether the complex value shall be shown in dependency on the index in the Harmonic Fields Set.
Evaluate Field Data over Wavelength	Defines whether the complex value shall be shown in dependency on the wavelength of each Harmonic Field. This option is only available if each wavelength in the Harmonic Fields Set is unique.

The resulting diagram contains the complex value in dependence on the user defined independent variable (index or wavelength). This diagram supports to switch between the different field quantities. More details can be found in Sec. 15.

23.2.3 Rectangle Extraction

The *Rectangle Extraction* converts the Harmonic Fields Set into a *Field Vector Component* (member fields versus field index) or into a *Pulse Component* (member fields versus wavelength).
Fig. 157 shows the edit dialog of the Rectangle Extraction tool.

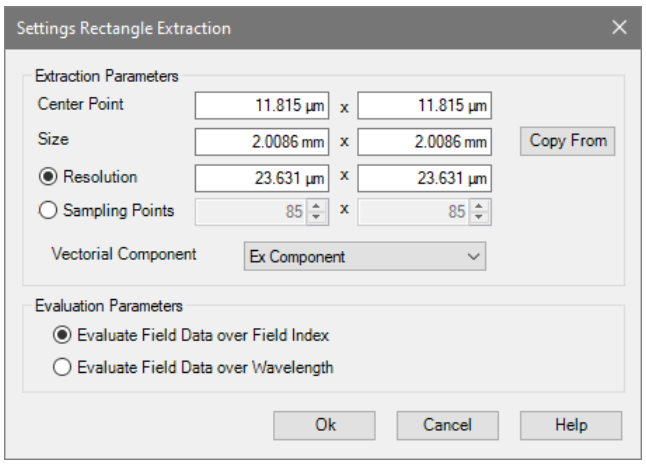


Figure 157. *Edit dialog for the Rectangle Extraction tool.*

The following parameters can be configured in the edit dialog.

ITEM	DESCRIPTION
Center Point	The user can specify the center point of the rectangle which should be evaluated.
Size	The size of the rectangle which should be extracted. The button *Copy From* can be used to copy the *Center Point* and the *Size* of the rectangle from a present Harmonic Fields Set in VirtualLab Fusion.
Resolution	The user can select whether he like to specify the resolution or the sampling points of the rectangle which should be generated by the tool.
Sampling Points	The user can select whether he like to specify the resolution or the sampling points of the rectangle which should be generated by the tool.
Vectorial Component	The vectorial component (*Ex Component*, *Ey Component*, or *Ez Component*) to be evaluated by the evaluation tool.
Evaluate Field Data over Field Index	Defines whether the complex value shall be shown in dependency on the index in the Harmonic Fields Set.
Evaluate Field Data over Wavelength	Defines whether the complex value shall be shown in dependency on the wavelength of each Harmonic Field. This option is only available if each wavelength in the Harmonic Fields Set is unique.

The resulting document (↪Sec. 15) contains the complex values in dependence on the user defined independent variable (index or wavelength). It supports to switch between the different field quantities.

23.3 Accessing the Members of a Harmonic Fields Set

The ribbon group Manipulations > Member Harmonic Fields contains the following items to access the member fields of the current Harmonic Fields Set.

ITEM	DESCRIPTION
Append Field	Appends either the selected Harmonic Field or all members of the selected Harmonic Fields Set to the current Harmonic Fields Set as last element(s). Note that parameters must be suitable as mentioned below. The dialog is shown in Fig. 158.
Insert Field	Inserts either the selected Harmonic Field or all members of the selected Harmonic Fields Set to the current Harmonic Fields Set at the given *Index*. Note that parameters must be suitable as mentioned below. The dialog is shown in Fig. 159.
Replace Field	Replaces the member field at the given *Index* in the Harmonic Fields Set by a different one. Note that parameters must be suitable as mentioned below. The dialog is shown in Fig. 160.
Delete Field	Deletes the member field at the specified *Index of Harmonic Field*. The dialog is shown in Fig. 161.
Extract Field	Displays the member field with the specified *Index of Harmonic Field* as separate document. The dialog is shown in Fig. 162.

All members of a Harmonic Fields Set must

- be all either in spatial or in spectral domain (↪Sec. 31.1),
- all propagate in either positive or negative z-direction (↪Sec. 136.3), and

- be all either one or two-dimensional.

The embedding material of the harmonic fields set is determined from the very first member field added to a harmonic fields set.

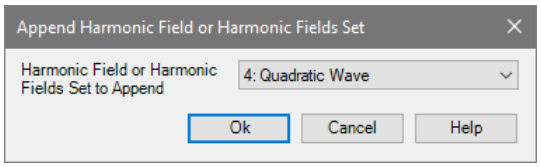


Figure 158. *Dialog for appending a field.*

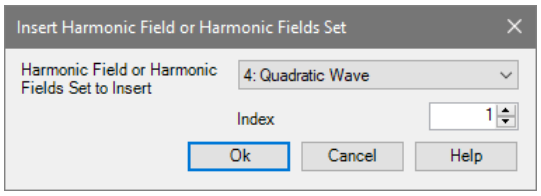


Figure 159. *Dialog for inserting a field.*

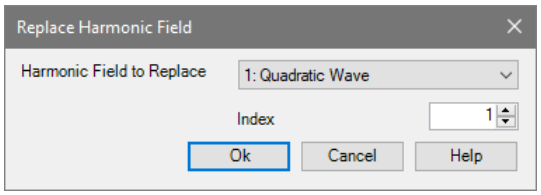


Figure 160. *Dialog for replacing a field.*

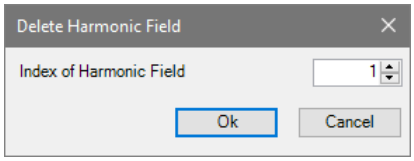


Figure 161. *Dialog for deleting a field.*

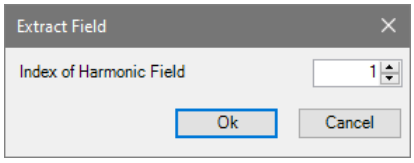


Figure 162. *Dialog for extracting a field.*

23.4 Conversions

For a detailed discussion of all possible conversions ↪Sec. 30.

23.5 Fourier Transform

For a detailed discussion of Fourier transforms ↪Sec. 31.

24 Manipulations of Data Arrays

24.1 Manipulations for Different Types of Data Arrays

There are very different kinds of manipulations for the different types of Data Arrays available. The most important distinctions which can be made regarding Data Arrays are with reference to:

- the dimensions of the coordinates (usually 1D vs. 2D),

- complex-valued data vs. real-valued data,
- the regularity of the value distribution (equidistant vs. non-equidistant [but gridded] vs. non-gridded [i.e. ”gridless”]),
- the physical meaning of the object (e.g. Numerical Data Array vs. Electric Field vs. Magnetic Field, etc.).

For more details about these properties please see Sec. 13.

24.1.1 Distinction of 1D vs. 2D

Whether or not a specific manipulation is available for 1D or 2D data is indicated in each of the sections which describe the manipulations and conversions.

24.1.2 Distinction of Complex-Valued Data vs. Real-Valued Data

Whether or not a specific manipulation is available for complex-valued or real-valued data is indicated in each of the sections which describe the manipulations and conversions.

24.1.3 Regularity of Value Distribution

Whether or not a specific manipulation is available for equidistant or non-equidistant (but gridded) data is indicated in each of the sections which describe the manipulations and conversions.
For gridless data only a few operations are available: Manipulations > Selection Related Operations > Extract 1D Data Along Selected Line (↪Sec. 24.12) and Manipulations > Lateral Displacement > Transpose (↪Sec. 24.11).

24.1.4 Distinction With Respect to the Physical Meaning of a Data Array / Using the Expert Mode

Numerical Data Arrays are predestined objects for arbitrary manipulations because they lack any fixed physical meaning but are mere data containers (↪Sec. 13.1). So one does not have to care whether a desired operation makes sense in a physical way and if it will be possible.
On the other hand, Data Arrays with a specific physical meaning provide only those manipulations which make sense in the specific physical context.
Consequentially, the full spectrum of manipulations and conversions are available for Numerical Data Arrays only.
If you want to manipulate a physical object in a kind not directly available to the given type of object anyway, there are two ways to achieve that:

- Either the object is converted to a Numerical Data Array first (↪Sec. 30.1.1),
- or the *Expert Mode* is activated first: Manipulations > Expert. This will enable all operations.

24.2 Handling of Subsets

Many manipulations can be done either for the *Current Subset* or for *All Subsets*. In this case the corresponding ribbon item is kind of a menu with said two entries. However, if you click directly on the ribbon item, this manipulation is invoked directly for the current subset.

24.3 Manipulate a Data Copy or the Original Data?

For each single manipulation of a Numerical Data Array object one can decide whether or not this operation shall create a new object and leave the source object unchanged. This decision is requested via the dialog shown in Fig. 163.

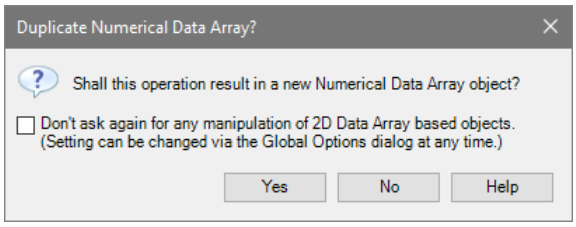


Figure 163. *Dialog asking whether or not a Numerical Data Array manipulation shall operate on a duplicate.*

The dialog will appear every time a manipulation is called, unless *Don't ask again for any manipulation of 1D/2D Numerical Data Arrays.* has been checked eventually. In this case, the last choice will be remembered and used for any manipulation of a Numerical Data Array of the same dimension (either 1D or 2D).
If a stored duplication setting has to be changed, this can be done via the Global Options Dialog as described in Sec. 6.16.

24.4 Editing the Coordinate and Interpolation Settings

The ribbon item Manipulations > Coordinate and Interpolation Settings allows to edit the coordinate range(s), to change the meaning of the coordinates, and to switch between the interpolation methods as well. These settings differ for equidistantly and non-equidistantly sampled coordinates and can be set via the dialogs described in the next sections.

24.4.1 Settings for Equidistant Coordinates

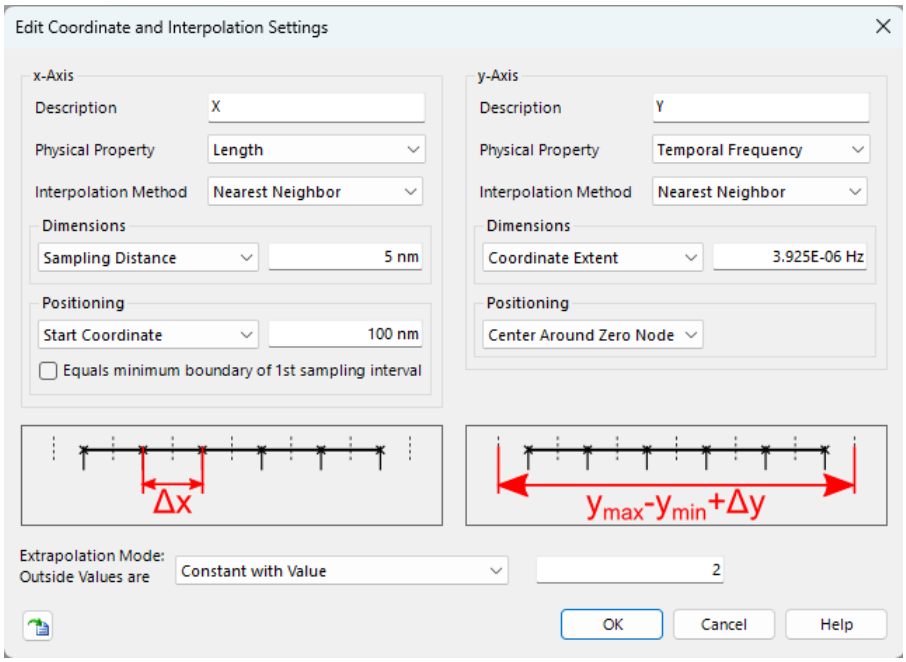


Figure 164. *Dialog for changing the coordinate and interpolation settings of an equidistantly sampled, two-dimensional Numerical Data Array.*

ITEM	DESCRIPTION
Description	The caption of the coordinate axis, i. e. the name or meaning of the coordinate.
Physical Property	The physical property (e. g. *Length*) of the coordinates. An overview of all supported physical properties and the corresponding units is given in Sec. 5.1.

Interpolation Method	The type of interpolation which is used if a value between adjacent sampling points has to be interpolated. The available interpolation methods are explained in Sec. 13.2.
Dimensions	The dimensions along the axis can be determined either via *Sampling Distance*, *Array Size*, or *Coordinate Extent*.
Sampling Distance	For equidistantly sampled data, the distance Δx or Δy between two adjacent coordinates. Important: Changing this value will not result in a resampled Numerical Data Array. This can be done by the resampling operation though, described in Sec. 24.13.1.
Array Size	The distance between the coordinates of the first and the last data point.
Coordinate Extent	AVAILABLE ONLY IF THE *INTERPOLATION METHOD* IS SET TO *NEAREST NEIGHBOR*. The distance between the lower boundary of the nearest neighbor interval of the first data point and the upper boundary of the interval of the last data point.
Positioning	The position of the axis can be determined either via entering a *Start Coordinate* or by defining that the axis range shall be centered. This can be done referring to the exact center (*Center Around Zero*) or to the coordinate of the data point which has the next higher coordinate to the exact center (*Center Around Zero Node*).
Center Around Zero	If chosen, the coordinate range will be centered around 0.
Center Around Zero Node	For an odd number of sampling points, this will be the same as *Center Around Zero*. If chosen for an even number N of sampling points, the coordinate range will be set in the following way: That sampling point whose (zero based!) index equals $N/2$ will get the coordinate 0.
Start Coordinate	The coordinate of the first sampling point.
Equals minimum boundary of first interval	AVAILABLE ONLY IF THE *POSITIONING* MODE IS SET TO *SAMPLING DISTANCE* AND THE *INTERPOLATION METHOD* IS SET TO *NEAREST NEIGHBOR*. If checked, the start coordinate refers to the lower boundary of the nearest neighbor interval of the first data point instead of the coordinate of the first data point itself.

Extrapolation Mode	In certain circumstances, it is possible that a Data Array has to deliver values outside its genuine coordinate range. The following options can be set for *Extrapolation Mode: Outside Values are*: • *Equal to the Nearest Border Data Point*: A constant extrapolation of the outmost data points is done. • *Zero*: All outlying points are considered to be of value 0. • *Constant with Value*: All outlying points are considered to be of a value to be specified. In case of a complex-valued data array, a complex constant may be defined here. • *Periodically Continued*: The whole data of the data array are periodically continued, using a period of the array's 'coordinate extent'.
	This button allows to copy settings from another Numerical Data Array as described in ↪Sec. 24.4.3.

24.4.2 Settings for Non-Equidistant Coordinates

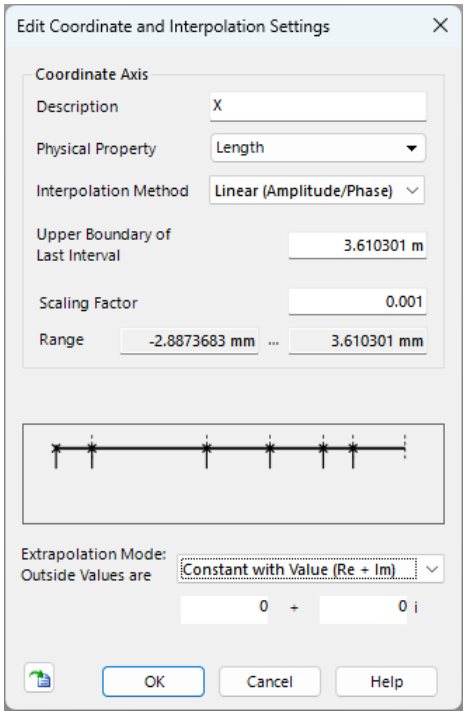


Figure 165. *Dialog for changing the coordinate and interpolation settings of a non-equidistantly sampled, one-dimensional Numerical Data Array.*

ITEM	DESCRIPTION
Description	The caption of the coordinate axis, i. e. the name or meaning of the coordinate.
Physical Property	The physical property (e. g. *Length*) of the coordinates. An overview of all supported physical properties and the corresponding units is given in Sec. 5.1.

Interpolation Method	The type of interpolation which is used if a value between adjacent sampling points has to be interpolated. The available interpolation methods are explained in Sec. 13.2.
Upper Boundary of Last Interval	This value defines the upper boundary coordinate of the last interval (↪Sec. 13.2.1).
Scaling Factor	A positive factor which is to be applied to all coordinate values including the *Upper Boundary of Last Interval*.
Range	The complete resulting coordinate range, considering the *Scaling Factor* as well as the *Upper Boundary of Last Interval*.
Extrapolation Mode	In certain circumstances, it is possible that a Data Array has to deliver values outside its genuine coordinate range. The following options can be set for *Extrapolation Mode: Outside Values are*: • *Equal to the Nearest Border Data Point*: A constant extrapolation of the outmost data points is done. • *Zero*: All outlying points are considered to be of value 0. • *Constant with Value*: All outlying points are considered to be of a value to be specified. In case of a complex-valued data array, a complex constant may be defined here. • *Periodically Continued*: The whole data of the data array are periodically continued, using a period of the array's 'coordinate extent'.
	This button allows to copy settings from another Numerical Data Array as described in ↪Sec. 24.4.3.

24.4.3 Copying Coordinate and Interpolation Settings

If the coordinate and interpolation parameters of one Numerical Data Array shall be copied to another one, this can be done by using the button  .

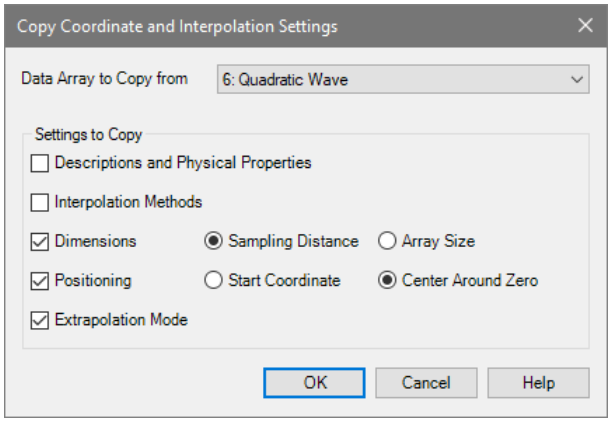


Figure 166. *Dialog for copying the coordinate and interpolation settings of another Numerical Data Array.*

ITEM	DESCRIPTION

Data Array to Copy from	The Numerical Data Array to be copied from can be chosen here.
Settings to Copy	Which of the parameters shall be copied are to be specified.

24.5 Editing Subsets

The list of subsets of a Numerical Data Array can be edited as well as some of the subsets' parameters themselves.

24.5.1 Change Subset Parameters

Some subset specific parameters can be edited via the dialog shown in Fig. 167.

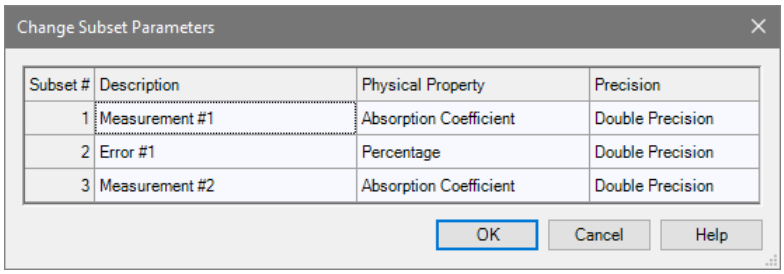


Figure 167. *Dialog for editing the subset specific parameters.*

ITEM	DESCRIPTION
Description	The name or meaning of the respective subset.
Physical Property	The kind of physical quantity of the respective subset's data.

24.5.2 Append Subset(s) from Another Data Array

At first, another Numerical Data Array (the source array) has to be selected for copying the subsets from. This may be the object to be manipulated (the target array) itself. Then, the subsets to be copied and appended can be chosen in the dialog shown in Fig. 168.

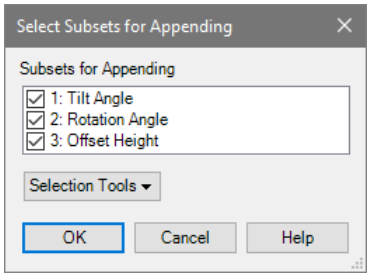


Figure 168. *Dialog for selecting the subsets to be appended.*

ITEM	DESCRIPTION
Subsets for Appending	The subsets to be appended can be chosen here by name.
Selection Tools > Select All	This tool will mark all subsets as selected at once.
Selection Tools > Unselect All	This tool will mark all subsets as not selected at once.

If the coordinates of the data points in the source array are not identical to that in the target array, the user may choose between two options as described in Sec. 24.6.2.

24.5.3 Delete Subset(s)

The subsets to be removed can be chosen in the dialog shown in Fig. 169.

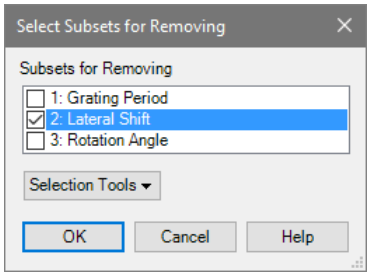


Figure 169. *Dialog for selecting the subsets to be removed.*

ITEM	DESCRIPTION
Subsets for Removing	The subsets to be removed can be chosen here by name.
Selection Tools > Select All but Current	This tool will mark all subsets as selected, except the currently shown.
Selection Tools > Unselect All	This tool will mark all subsets as not selected at once.

24.5.4 Extract Subset(s)

The subsets to be extracted can be chosen in a similar dialog as shown in Fig. 169.

ITEM	DESCRIPTION
Subsets for Extracting	The subsets to be extracted can be chosen here by name.
Selection Tools > Select All but Current	This tool will mark all subsets as selected, except the currently shown.
Selection Tools > Unselect All	This tool will mark all subsets as not selected at once.

24.5.5 Sum all Subsets

This operation will calculate the sum of all contained subsets. If the data are complex, the user can choose whether to do a complex addition or to do a real-valued addition of one of the field quantities.

24.6 Array-Array Operations

Via the ribbon menu Manipulations > Array - Array Operations several operations for two array operands are available:

ITEM	DESCRIPTION
Addition	Calculates the sum of two Numerical Data Arrays.
Subtraction	Calculates the difference of two Numerical Data Arrays.
Multiplication	Calculates the product of two Numerical Data Arrays.
Division	Calculates the quotient of two Numerical Data Arrays.
Convolution	Calculates the convolution $A_1 \star A_2 = \mathcal{F}^{-1}[(\mathcal{F} A_1) \cdot (\mathcal{F} A_2)]$ of two Numerical Data Arrays A_1 and A_2.

The operations Addition, Subtraction, Multiplication, and Division can also be invoked by using the corresponding keys: [+], [−], [*], and [/], respectively. In this case the *currently* selected document is taken as the *second* operand while the *previously* selected Numerical Data Array is taken as *first* operand.

24.6.1 Handling Multiple Subsets

Numerical Data Arrays may contain more than one subset. Table 24.4 shows the behavior of the array-array operations for all possible cases of subset numbers.

No. of subsets m in 1st operand	No. of subsets n in 2nd operand	
	n = 1	n > 1
m = 1	$s_1 \circ s_2$	*User query*
m > 1	*User query*	n = m: $s_1 \circ s_2$ n ≠ m: *Error*

Table 24.4: *Array-Array Operation modes depending on the respective numbers of subsets.*

The expression $s_1 \circ s_2$ means that the desired operation simply will be done on the corresponding subsets of the Data Arrays A_1 and A_2. *User query* stands for a dialog which asks the user how to proceed (Fig. 170).

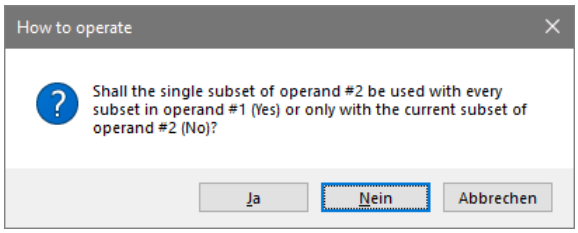


Figure 170. *Dialog which asks the user how to operate if one of the operands contains more than one subset.*

The user may decide whether the single subset of the operand A_1 shall be processed with all N subsets of the other operand A_2 $\left(s_1 \circ s_2^{(1)},\quad s_1 \circ s_2^{(2)},\quad \ldots,\quad s_1 \circ s_2^{(N)}\right)$ or just with the currently visible subset i of the operand with more than one subset $\left(s_1 \circ s_2^{(i)}\right)$. The array-array operations are undefined if both of the operating arrays contain a different number of subsets ($n \neq m,\quad n > 1,\quad m > 1$).

24.6.2 Handling Differing Coordinate Grids

If the coordinate grids of the two operands are not identical, there's no straightforward determination of the resulting coordinate grid. The dialog shown in Fig. 171 helps to make a decision.

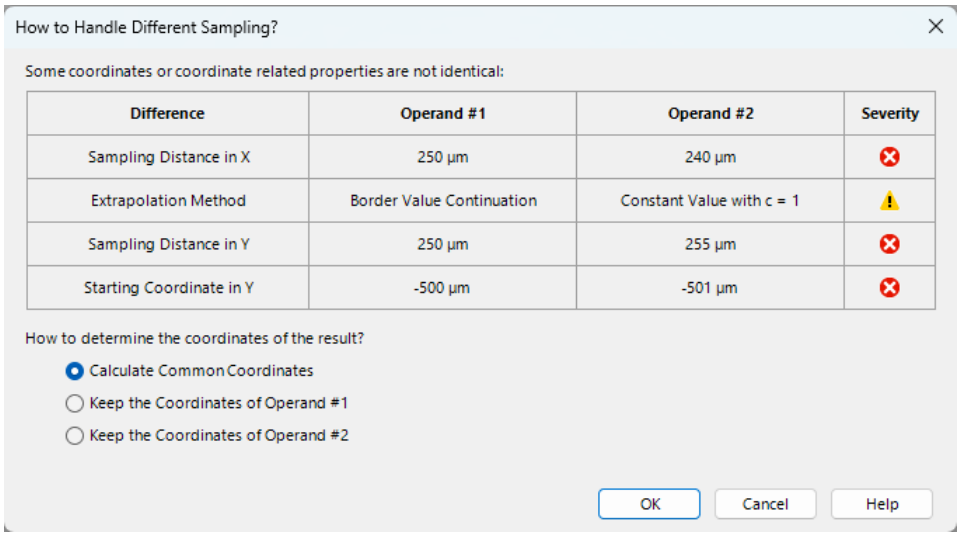


Figure 171. *Dialog which informs about coordinate related differences between the operands. It allows to choose between two options as well.*

ITEM	DESCRIPTION
Difference	What parameter is different?
Operand #1	The parameter values of operand #1.
Operand #2	The parameter values of operand #2.
Severity	Indicates whether the difference is critical or non-critical.
Calculate Common Coordinates	The set of coordinates of the resulting array will be a union of the coordinate sets of both of the original arrays. The data of both of the operands will be interpolated to this new grid. Usually, this merge mode will lead to a non-equidistant coordinate grid.
Keep the Coordinates of Operand #1	Available only for an Array-Array operation ↪Sec. 24.6. The set of coordinates of the resulting array will be identical to that of operand #1. In order to get the values from operand #2 for executing the operation, interpolation will be used.
Keep the Coordinates of Operand #2	Available only for an Array-Array operation ↪Sec. 24.6. The set of coordinates of the resulting array will be identical to that of operand #2. In order to get the values from operand #1 for executing the operation, interpolation will be used.
Keep the Coordinates of the Target Data Array	Available only for an Append Subsets operation ↪Sec. 24.5.2. The set of coordinates of the resulting array will be identical to that of the target array (which is modified by the operation). In order to get the values from the source array for executing the operation, interpolation will be used.

24.7 Operations with Constant

Via the ribbon menu Manipulations > Operations with Constant several operations with one field operand are available. In case of operating on a Numerical Data Array containing more than one subset, it is possible to do each of these operations either on a single subset (i.e. the currently shown subset) or on all of the subsets.

ITEM	DESCRIPTION
Set to Constant	Sets all data points to the given constant value.
Add Constant	Adds the given constant value to all data points.
Multiply Constant	Multiplies the given constant value to all data points.
Divide by Constant	Divides all data points by the given constant.
Raise to Power of Constant	Raises all data points to the power of the given constant value.

For setting the constant values to operate with, the dialog shown in Fig. 172 is used.

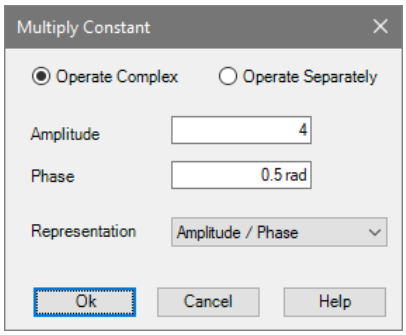


Figure 172. *Dialog for operation with one field operand.*

If you choose the mode *Operate Complex*, the two double numbers to enter are treated as the parts of one complex number, either in *Real / Imaginary* or in *Amplitude / Phase* Representation. Then the operations are done as a complex addition, multiplication or raise-to-power for each data point. If *Operate Separately* is chosen, the first entry operates only on the real part / amplitude of the field and the second number only on the imaginary part / phase, depending on the choice of *Representation*. In the following table you can see how these operations work and what the respective meanings of c_1 and c_2 are. The original complex value of a data point ($z = a + ib \equiv A\exp[i\phi]$) is changed by the operation with the constants c_1 and c_2 to the result shown in the two last columns.

OPERATION	REPRESENTATION	RESULT OF OPERATION	
		Mode: Operate Complex	**Mode: Operate Separately**
Add Constant	Real / Imaginary	$(a+ib)+(c_1+ic_2)$	$(a+c_1)+i(b+c_2)$
	Amplitude / Phase	$A\exp[i\phi]+c_1\exp[i\widetilde{c_2}]$	$(A+c_1)\exp[i(\phi+\widetilde{c_2})]$
Multiply Constant	Real / Imaginary	$(a+ib)\cdot(c_1+ic_2)$	$(a\cdot c_1)+i(b\cdot c_2)$
	Amplitude / Phase	$A\exp[i\phi]\cdot c_1\exp[i\widetilde{c_2}]$	$(A\cdot c_1)\exp[i(\phi\cdot c_2)]$
Divide by Constant	Real / Imaginary	$(a+ib):(c_1+ic_2)$	$(a:c_1)+i(b:c_2)$
	Amplitude / Phase	$A\exp[i\phi]:(c_1\exp[i\widetilde{c_2}])$	$(A:c_1)\exp[i(\phi:c_2)]$
Raise to the Power of Constant	Real / Imaginary	$(a+ib)^{c_1+ic_2}$	$(a^{c_1})+i\,(b^{c_2})$
	Amplitude / Phase	$(A\exp[i\phi])^{c_1\exp[i\widetilde{c_2}]}$	$(A^{c_1})\exp[i\phi^{c_2}]$

$\widetilde{c_2}$ indicates that this value is an angle, i. e. you can enter it with the unit 'rad', 'pi', or '°' (see Sec. 5.1 for details).

24.8 Field Quantity Operations

For real-valued data arrays, the ribbon menu Manipulations > Field Quantity Operations contains only the option to convert it to a complex-valued one.

For complex-valued data arrays, this ribbon menu provides several transformations with respect to field quantities. Field quantities are explained in Sec. 11.1.

ITEM	DESCRIPTION
Extract	The chosen field quantity will be extracted as real value and stored into the resulting object.
Move	The entries in this submenu are labeled according to which field quantity of the resultant is filled from which field quantity of the source object. For example, Manipulations > Field Quantity Operations > Phase to Real Part copies the phase of the current Numerical Data Array to the real part of the resultant one, whereby the imaginary part of the resultant object is set to zero.
Swap	The entry in this submenu allows you to swap real part and imaginary part.

24.9 Value Scaling

The ribbon menu Manipulations > Value Scaling allows you to perform the following operations with respect to the data values (the amplitudes in case of complex-valued data):

ITEM	DESCRIPTION
Scale to Given Range	In a separate dialog you are asked for the new minimum and maximum of the values in the array. *Normalize* for example corresponds to setting the minimum to zero and the maximum to one.
Normalize	Normalize the current array by dividing the array at all positions by the maximum value / amplitude.
Normalize According to Range Selection / Normalize According to Rectangular / Elliptical Selection	Normalizes the current array by dividing it (at all data points!) by the maximum value/amplitude within the current selection.
Clip Values	Clips the current array to a given maximum value / amplitude. At all positions, where the value/amplitude is above this maximum value, the value / amplitude is set to the maximum value (preserving the original phase for complex valued data). At all remaining positions the array is not changed. The scaling mode of the view (↪Sec. 11.2.5) of the newly generated array is set to *Automatic Scaling*.
Lift Positive	Searches for the minimum value (of the real part) of the array and subtracts that value at all array positions. For a real-valued array this corresponds to adding the minimum value which ensures a non-negative array.
Delete Numerical Phase Artifacts	Removes the numerical artifacts described in Sec. 11.8.1 permanently, which mainly means that amplitudes having less than t times the maximum amplitude are set to zero. In a dialog you can enter this relative threshold t.

24.10 Phase Manipulations

These manipulations are only available for complex-valued Numerical Data Arrays.

The ribbon menu Manipulations > φ Phase Manipulations contains several operations for manipulating the phase of the current array.

ITEM	DESCRIPTION
z^* Conjugate	Performs a transformation in which each complex data value $z = a + ib$ is replaced by $z^\star = a - ib$.
Unwrap Phase	This operation tries to generate an array which contains the unwrapped phase of the current array, i. e. to remove 2π jumps. During unwrapping, a simple line by line phase unwrapping algorithm is used. However, for two-dimensional arrays unwrapping is neither unique nor always possible. For example, arrays containing phase dislocations (↪Sec. 68.8.2) are generally unwrappable. A precondition for successful unwrapping is a sufficient sampling of the phase information.
Remove Phase Dislocations in Rectangular / Elliptical Selection	Phase dislocations (↪Sec. 68.8.2) are searched and tried to be removed inside the currently marked selection. For removing a certain phase dislocation with charge c (↪Sec. 68.8.2), a transmission of a phase dislocation with charge $-c$ is multiplied to the array at the same position. This operation is repeated for all phase dislocations which were found within the current selection.
Modify Phase	The operations which can be done are described in Sec. 22.5.1.

24.11 Lateral Displacement

The ribbon menu Manipulations > Lateral Displacement allows you to do some transformations with regard to the x- and y-coordinates of the array.

ITEM	DESCRIPTION
Mirror Horizontally	Applies the transformation $u(x,y) \to u(-x,y)$, so the array is mirrored horizontally by a mirror that corresponds to the y-axis.
Mirror Vertically	THIS MANIPULATION IS AVAILABLE FOR TWO-DIMENSIONAL NUMERICAL DATA ARRAYS ONLY. Applies the transformation $u(x,y) \to u(x,-y)$, so the array is mirrored vertically by a mirror that corresponds to the x-axis.
Rotate in x-y-Plane	THIS MANIPULATION IS AVAILABLE FOR TWO-DIMENSIONAL, EQUIDISTANTLY SAMPLED NUMERICAL DATA ARRAYS ONLY. Rotates the array by the given angle (↪Sec. 22.6.1).
Sampled Shift	THIS MANIPULATION IS AVAILABLE FOR EQUIDISTANTLY SAMPLED NUMERICAL DATA ARRAYS ONLY. Shifts the data of the current array by a given number of data points.
Transpose	THIS MANIPULATION IS AVAILABLE FOR TWO-DIMENSIONAL NUMERICAL DATA ARRAYS ONLY. Applies the transformation $u(x,y) \to u(y,x)$, so the array is mirrored by a mirror that corresponds to a diagonal in the x-y-plane.

24.12 Array Size Manipulations

The ribbon menu Manipulations > Array Size Manipulations provides the following operations that change the size of an one- or two-dimensional array:

ITEM	DESCRIPTION
Change Array Size (Pixel Dimensions)	AVAILABLE FOR EQUIDISTANTLY SAMPLED NUMERICAL DATA ARRAYS ONLY. Changes the number of data points. If the number is increased then the newly created surrounding data points are filled according to the extrapolation settings of the array (↪Sec. 24.4). Otherwise, i. e. if the number of data points is decreased then the new array is extracted. Both operations are done centered.
Change Array Size (Physical Dimensions)	AVAILABLE FOR EQUIDISTANTLY SAMPLED NUMERICAL DATA ARRAYS ONLY. This option works like Change Array Size (Pixel Dimensions), but the size of the new array is defined in physical units.
Double Size (Center)	AVAILABLE FOR EQUIDISTANTLY SAMPLED NUMERICAL DATA ARRAYS ONLY. This operation corresponds to using Change Array Size (Pixel Dimensions) with embedding to the double array size. The original array will be centered in the result array. The new data points are set according to the extrapolation settings of the array (↪Sec. 24.4).
Double Size (Corner)	AVAILABLE FOR EQUIDISTANTLY SAMPLED NUMERICAL DATA ARRAYS ONLY. This operation corresponds to using Change Array Size (Pixel Dimensions) with embedding to the double array size. But the original array will be the bottom left quadrant in the resulting array. The new data points are set according to the extrapolation settings of the array (↪Sec. 24.4).
Make Hermitian	AVAILABLE FOR EQUIDISTANTLY SAMPLED NUMERICAL DATA ARRAYS ONLY. At first, the array size will be doubled and the original data shifted to the lower left quadrant of the new array (just like Double Size (Corner) does). In addition, the upper right quadrant is filled by the complex conjugate of the original array in order to ensure that the result is Hermitian (↪Sec. 68.7.2). The upper left and lower right quadrant are filled with zero values.
Replicate Twice	Fill the resulting array by 2 (one-dimensional case) or 2×2 (two-dimensional case) replications of the original array. This operation is equivalent to use Replicate Periodically with the double array size and a shift of $(0, 0)$.
Replicate Periodically	This operation creates a new array which is filled by periodically replicating the contents of the current one (↪Sec. 24.12.1).
Extract Range Selection / Extract Rectangular / Elliptical Selection	Creates a new array which contains the selected portion of the current array.
Extract Equidistant 1D Data Along Selected Line	THIS MANIPULATION IS AVAILABLE FOR TWO-DIMENSIONAL NUMERICAL DATA ARRAYS ONLY. Extracts a one-dimensional cross-section defined by the line marker (↪Sec. 11.3) to a separate one-dimensional harmonic field (↪Sec. 24.14.1).

24.12.1 Replicate Periodically

With this manipulation you can replicate a data array periodically along the x- and / or y-direction. This can be useful if the data array shows something which is periodic or invariant in at least one direction. Fig. 173 shows an example.

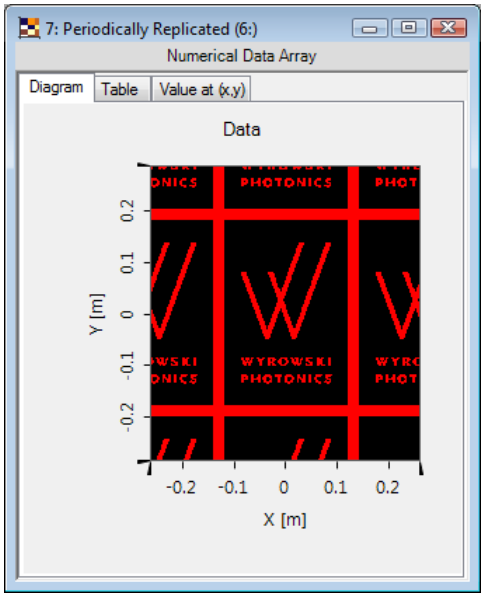


Figure 173. *The Wyrowski Photonics logo replicated periodically using the settings shown in Fig. 174.*

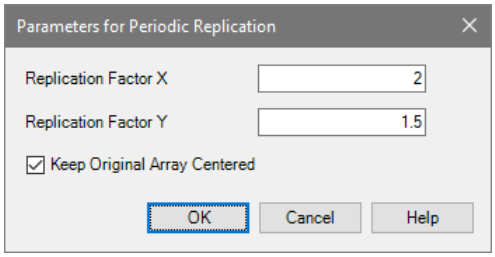


Figure 174. *Dialog for replicating a Numerical Data Array periodically.*

The dialog shown in Fig. 174 has the following options.

ITEM	DESCRIPTION
Replication Factor X	Specifies how often the data is replicated in x-direction. Can be an arbitrary value larger than or equal to 1 if the x-axis is sampled equidistantly. Otherwise you are restricted to integer values, which is also stated by an ℹ-icon having a tooltip.
Replication Factor Y	ONLY FOR TWO-DIMENSIONAL DATA ARRAYS Specifies how often the data is replicated in y-direction. Can be an arbitrary value larger than or equal to 1 if the y-axis is sampled equidistantly. Otherwise you are restricted to integer values, which is also stated by an ℹ-icon having a tooltip.
Keep Original Array Centered	ONLY FOR EQUIDISTANT DATA ARRAYS If you check this option, the original data array is placed in the center of the resulting data array. Otherwise (and for data arrays being non-equidistant in at least one direction) it is placed in the bottom-left corner in case of two-dimensional data arrays and on the left side in case of one-dimensional data arrays.

24.13 Sampling Manipulations

These manipulations are only available for equidistantly sampled Numerical Data Arrays.

The ribbon menu Manipulations > Sampling Manipulations provides the following operations that change the sampling distance:

ITEM	DESCRIPTION
Equidistant Resampling	Using this manipulation (↪Sec. 24.13.1), the sampling parameters of an array can be changed, whereby the originally stored physical information shall be preserved. This operation can also be executed by clicking directly on the upper part of the Manipulations > Sampling Manipulations menu.
Oversample Twice (Zeroized)	The number of data points is doubled by splitting each data point into 2 × 2 new points of half the original sampling distance. The new point with the same physical position contains the old complex value, the remaining data points are filled with zero.
Oversample Twice (Sinc FFT Interpolation)	This is equivalent to use Interpolate with the interpolation method *Sinc (Fourier Transformation)*-interpolation, half the original sampling distance, and a zero point of $(0, 0)$.
Oversample Twice (Nearest Neighbor Interpolation)	The number of data points is doubled by splitting each data point into 2 × 2 new points of half the original sampling distance. All new points contain the value of the original data point.
Oversample 3× (Nearest Neighbor Interpolation)	The number of data points is tripled by splitting each data point into 3 × 3 new points of one third the original sampling distance, containing the value of the original data point.

24.13.1 Equidistant Resampling

Equidistant Numerical Data Arrays can be resampled using an interpolation method. This operation's parameter are specified via the dialog shown in Fig. 175.

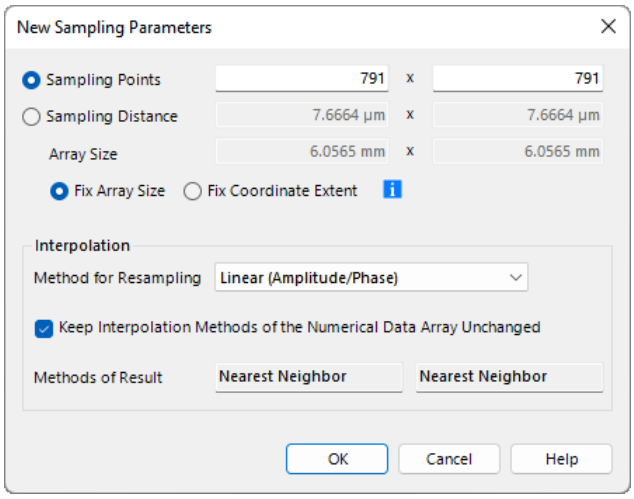


Figure 175. *Dialog for resampling an equidistant Numerical Data Array.*

ITEM	DESCRIPTION
Sampling Points	The new number of sampling points.
Sampling Distance	The new distance between the coordinates of two adjacent sampling points.
Array Size	AVAILABLE ONLY IF NOT *FIX COORDINATE EXTENT* IS ACTIVATED. The resulting new array size, defined as the distance between the coordinates of the last data point and the first data point (see Fig. 176).
Coordinate Extent	AVAILABLE ONLY IF THE *FIX COORDINATE EXTENT* IS ACTIVATED. The resulting new coordinate extent, defined as the complete range covered by all sampling points including the whole sampling distances around first and last coordinate. So this range is one sampling distance greater than *Array Size* (see Fig. 176). Relevant only if input and output data array contain the Nearest Neighbor Interpolation method.
Fix Array Size	AVAILABLE ONLY IF THE INPUT AND OUTPUT DATA ARRAY CONTAIN THE NEAREST NEIGHBOR INTERPOLATION METHOD. If activated, the array size (instead of the coordinate extent) will be kept constant (see Fig. 176).
Fix Coordinate Extent	AVAILABLE ONLY IF THE INPUT AND OUTPUT DATA ARRAY CONTAIN THE NEAREST NEIGHBOR INTERPOLATION METHOD. If activated, the coordinate extent (instead of the array size) will be kept constant (see Fig. 176).
Interpolation Method	The type of interpolation that is used to calculate the sampling points of the result. A method different from that contained in the input data array can be selected here. Which method will be stored with the output depends on the selected state of the option *Keep Interpolation Method of the Numerical Data Array Unchanged*.
Keep Interpolation Method of the Numerical Data Array Unchanged	If *Interpolation Method* differs from the Numerical Data Arrays inherent interpolation method, this box allows to decide whether or not the used method shall be adopted by the resulting Data Array.

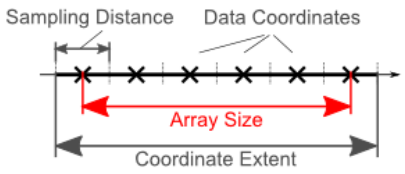


Figure 176. *Difference between array size and coordinate extent for data arrays with nearest neighbor interpolation method.*

24.14 Selection Related Operations

All operations in the ribbon menu Manipulations > Selection Related Operations depend on the currently selected point, range, line, rectangle, or ellipse (↪Sec. 11.3). Thus they are only available if the corresponding marker is visible.

For one-dimensional data arrays the following manipulations are available:

MANIPULATION	DESCRIPTION
Fill Range Selection	Sets the sampling points within the selection to a user-defined value c.
Clear Range Selection	Sets the sampling points within the selection to zero.
Clear Inverse of Range Selection	Sets the sampling points outside the selection to zero.
Extract Range Selection	Creates a new data array which contains only the selected portion of the current data array.
Extract Subset Data at One Point	This operation extracts the value(s) a data array has at a certain position. ↪Sec. 24.14.2
Normalize According to Range Selection	Normalizes the current array by dividing it (at all sampling points!) by the maximum amplitude within the current selection.

For two-dimensional data arrays the following manipulations are available:

MANIPULATION	DESCRIPTION
Fill Rectangular / Elliptical Selection	Sets the sampling points within the selection to a user-defined value c.
Clear Rectangular / Elliptical Selection	Sets the sampling points within the selection to zero.
Clear Inverse of Rectangular / Elliptical Selection	Sets the sampling points outside the selection to zero.
Extract Rectangular / Elliptical Selection	Creates a new data array which contains only the selected portion of the current data array.
Extract Equidistant 1D Data Along Selected Line	Extracts the one-dimensional cross-section defined by the line marker (↪Sec. 11.3) to a separate one-dimensional data array. ↪Sec. 24.14.1
Extract Subset Data at One Point	This operation extracts the value(s) a data array has at a certain position. ↪Sec. 24.14.2
Extract Cross Profile at Point	Out of the current position of the point marker, two one-dimensional cross sections are extracted: one along the x-position of the marker and one along the y-position of the marker. The two cross sections are shown as separate data arrays.
Normalize According to Rectangular / Elliptical Selection	Normalizes the current array by dividing it (at all sampling points!) by the maximum amplitude within the current selection.
Remove Phase Dislocations in Rectangular / Elliptical Selection	ONLY AVAILABLE FOR EQUIDISTANTLY SAMPLED DATA ARRAYS. Phase dislocations (↪Sec. 68.8.2) are searched and tried to be removed in the current selection. For removing a certain phase dislocation with charge c (↪Sec. 68.8.2), a phase dislocation with charge $-c$ is multiplied to the array at the same position. This operation is repeated for all phase dislocations which were found within the current selection.

For gridless data arrays the following manipulation is available:

MANIPULATION	DESCRIPTION
Extract 1D Data Along Selected Line	Extracts all data points lying exactly on the line marker (↪Sec. 11.3) to a separate one-dimensional, non-equidistant data array.

24.14.1 Extraction of 1D Data Along Line

This manipulation is available for two-dimensional Numerical Data Arrays only.

Via Manipulations > Selection Related Operations > Extract Equidistant 1D Data Along Selected Line or via Manipulations > Array Size Manipulations > Extract Equidistant 1D Data Along Selected Line, an equidistantly sampled 1D Numerical Data Array can be extracted out of a 2D Numerical Data Array. This will be done along a previously defined line marker (↪Sec. 11.3). The dialog shown in Fig. 177 allows you to define more extraction parameters.

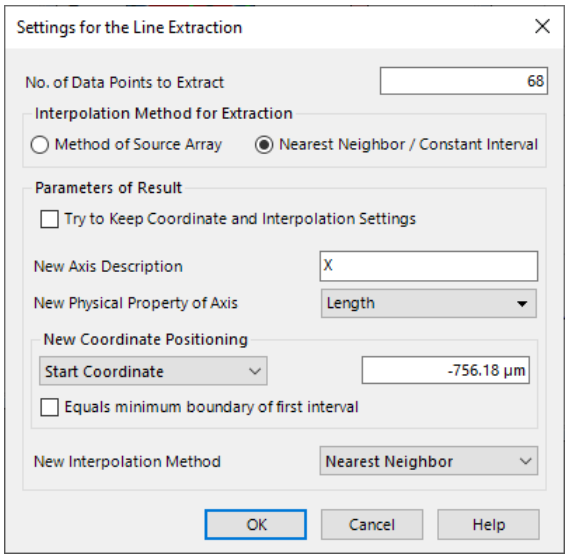


Figure 177. *Dialog for defining the parameters for extracting an equidistantly sampled 1D Numerical Data Array out of a 2D Numerical Data Array.*

The following parameters can be set, largely to define the new coordinate axis:

ITEM	DESCRIPTION
No. of Data Points to Extract	The number of equidistantly distributed data points in the resulting 1D Numerical Data Array.
Method of Source Array	If chosen, the extraction method uses the interpolation method of the 2D source array for getting each data point's value.
Nearest Neighbor / Constant Interval	If chosen, the extraction method uses nearest neighbor interpolation (constant interval interpolation in case of non-equidistant data) for getting each data point's value.
Try to Keep Coordinate and Interpolation Settings	If checked, the physical property and the interpolation of the axis of the new data array are equal to the original ones (if they are the same for both axes). Furthermore, the new axis description is the same as the original axis description if the line is parallel to one of the two axes.

New Axis Description	The description of the target Numerical Data Array's coordinate can be set here.
New Axis Physical Property of Axis	The physical property of the target Numerical Data Array's coordinate can be set here.
New Coordinate Positioning	The mode for calculating the coordinates in the 1D target array has to be defined here. • *Center Around Zero* will calculate the new coordinates in a way that zero will be exactly in the center. • *Center Around Zero Node* is the same in case of an odd number of resulting data points, but in case of an even number, the data point at the left of the exact center of the coordinate range will get the coordinate zero. • The mode *Start Coordinate* allows you to define the value of the start / the lowest coordinate.
New Coordinate Positioning > Equals minimum boundary of first interval	If the mode *Start Coordinate* is chosen, the target interpolation method is set to *Nearest Neighbor*, and this option is set, the given coordinate will refer to the minimum boundary of the first data point. If not set, it refers to the center of the first nearest neighbor interval.
New Interpolation Method	The interpolation method of the 1D target array can be set here.

24.14.2 Extraction of 1D Data at One Point

This operation extracts the value(s) a data array has at a certain position. The position is specified by the point marker (↪Sec. 11.3).

If the data array contains only one subset, the value at the given position is simply logged into the Messages tab (↪Sec. 4.3). In this case always the interpolation method of the source array is used to get the value if the marker is placed between data points.

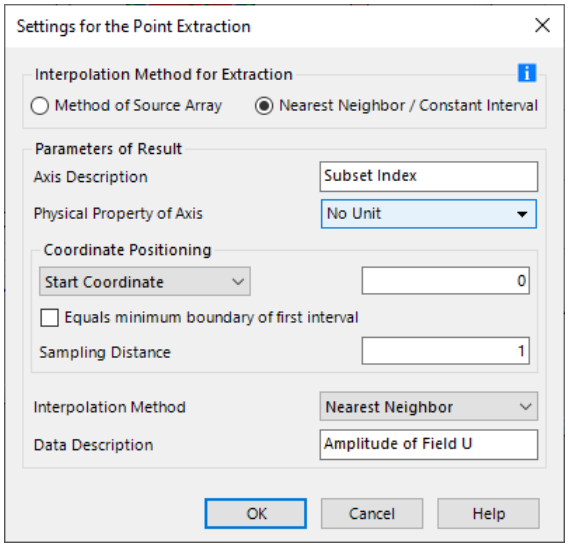


Figure 178. *Dialog for defining the parameters for extracting an equidistantly sampled 1D Numerical Data Array from the data at one point.*

If the data array contains more than one subset, the data within each subset at the given position becomes one

data point in the resulting one-dimensional data array. In this case the dialog shown in Fig. 178 opens where the following parameters can be set, largely to define the new coordinate axis:

ITEM	DESCRIPTION
Method of Source Array	ONLY VISIBLE IF THE POINT MARKER IS NOT SNAPPED TO THE CENTER OF A PIXEL (↪SEC. 11.3.1). If chosen, the extraction method uses the interpolation method of the 2D source array for getting each data point's value.
Nearest Neighbor / Constant Interval	ONLY VISIBLE IF THE POINT MARKER IS NOT SNAPPED TO THE CENTER OF A PIXEL (↪SEC. 11.3.1). If chosen, the extraction method uses nearest neighbor interpolation (constant interval interpolation in case of non-equidistant data) for getting each data point's value.
Axis Description	The description of the target Numerical Data Array's coordinate can be set here.
Axis Physical Property of Axis	The physical property of the target Numerical Data Array's coordinate can be set here.
Coordinate Positioning	The mode for calculating the coordinates in the 1D target array has to be defined here. • *Center Around Zero* will calculate the new coordinates in a way that zero will be exactly in the center. • *Center Around Zero Node* is the same in case of an odd number of resulting data points, but in case of an even number, the data point at the left of the exact center of the coordinate range will get the coordinate zero. • The mode *Start Coordinate* allows you to define the value of the start / the lowest coordinate.
Coordinate Positioning > Equals minimum boundary of first interval	If the mode *Start Coordinate* is chosen, the target interpolation method is set to *Nearest Neighbor*, and this option is set, the given coordinate will refer to the minimum boundary of the first data point. If not set, it refers to the center of the first nearest neighbor interval.
Coordinate Positioning > Sampling Distance	The sampling distance of the new coordinate axis.
Interpolation Method	The interpolation method of the 1D target array can be set here.
Data Description	The data description of the resulting array.

24.15 Miscellaneous

The ribbon menu Manipulations > Miscellaneous contains various special manipulations e. g. to smooth data or to introduce discrete value levels.

24.15.1 Savitzky-Golay Filter

The Savitzky-Golay filter is a commonly used filter to remove noise from measured data while retaining information like the position of the extrema as good as possible. It is a special *moving window filter* where a window of given size k is moved over the data and the data point in the center is then replaced by the value of

a polynomial of order n fitted to the data in the window. The implementation in VirtualLab Fusion supports both one- and two-dimensional data.

ITEM	DESCRIPTION
Window Size	The window size k. If it is even, internally 1 is added to ensure that there is always a data point in the center of the window. For two-dimensional data the same window size is used for x- and y-direction.
Order	The order n of the polynomials to fit. For $k = 0$ you obtain a *moving average filter*. If $n \geq k - 1$ the fitted polynomial reproduces exactly the data points in the window and thus no smoothing is done.

24.15.2 Temporal Sampling of Real Part

This manipulation is only available for Numerical Data Arrays that contain a single subset.

This operation considers the input being static data which will be transformed into time dependent data. The input will be treated either as being the complex amplitude of a harmonic electric field or just as numerical data without electromagnetic meaning.
The calculation is done for different time indices within one period and the resulting sampled values are stored within a numerical data array with a number of subsets, one for each point of time.
The following options are available:

ITEM	DESCRIPTION
Sampling Count of T	Number of equidistant points of time n within the temporal period $T = 2\pi/\omega_0$. The real part will be extracted at $t = \frac{1}{n}T, \frac{2}{n}T, \ldots, T$.
Treat the Data as Electric Field	If true, the input will be considered being the complex amplitude of a harmonic electric field $\boldsymbol{E}(\boldsymbol{r})$ and the result will be calculated to $\boldsymbol{E}(\boldsymbol{r},t) = 2\,\mathrm{Re}\,(\boldsymbol{E}(\boldsymbol{r})exp(-i\omega_0 t))$. Physical unities and interpolation method will be taken into account in this case. If false, the input will be considered being just numerical data $f_c(\boldsymbol{r})$ and the result will be calculated to $g(\boldsymbol{r},t) = \mathrm{Re}\,(f_c(\boldsymbol{r})exp(-i\omega_0 t))$.

With harmonic field data, this operation can be used to get the field components of the electric or the magnetic field at different points of time.
After conversion of the result into an animation (via Manipulations > Create Animation), one can visualize the temporal field sampling in a movie.
Note, this operation is available only with data arrays with one subset. However, you can always extract a subset from a data array with multiple subsets via Manipulations > Change Subset Parameters > Remove Subset(s) (↪Sec. 24.5.3).

24.15.3 Quantization

The quantization of a Numerical Data Array means to introduce discrete value levels for real-valued data as well as discrete amplitude and phase levels for complex-valued data. The following entries are available at Manipulations > Miscellaneous > Quantization:

ITEM	DESCRIPTION
Hard Quantization	This calls the *Hard Quantization* algorithm described in Sec. 22.11.2.
Soft Quantization	This calls the *Soft Quantization* algorithm described in Sec. 22.11.3.
Floyd-Steinberg Quantization	This calls the *Floyd-Steinberg Quantization* algorithm described in Sec. 22.11.4.

24.16 Editing Single Data Points

It is possible to edit the value of a single data point in a Numerical Data Array. In order to open the dialog shown in Fig. 179, either the context menu in the *Table* panel (↪Sec. 13.4.2) or the *Edit Data Point* button in the *Value at (x,y)* panel (↪Sec. 13.4.3) has to be used.

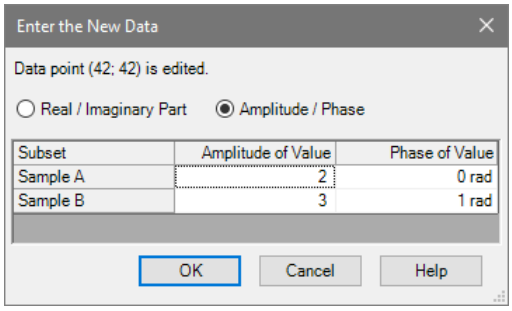


Figure 179. *Dialog for editing the value(s) of a single data point.*

For complex data, the representation of the complex values (*Real / Imaginary Part* vs. *Amplitude / Phase*) can be chosen. Each table row contains the value of one subset for the data point to be edited.

24.17 Conversions

For a detailed discussion of all possible conversions ↪Sec. 30.

24.18 Fourier Transform

For a detailed discussion of Fourier transforms ↪Sec. 31.

24.19 Graphics Add-on

For a detailed discussion of graphics add-ons ↪Sec. 32.

24.20 Expert Mode

ONLY FOR DATA ARRAYS WITH FIXED PHYSICAL MEANING.

Usually, only a few manipulations are available for data arrays with a fixed physical meaning (↪Sec. 24.1.4). In case more manipulations are needed, activating the *Expert Mode* allows to access a lot more operations on the contained sampled data.

25 Manipulation of Chromatic Fields Sets

25.1 Selection Related Operations

ITEM	DESCRIPTION
Extract Equidistant 1D Data Along Selected Line	ONLY FOR TWO-DIMENSIONAL CHROMATIC FIELDS SETS WITH A VISIBLE PROFILE LINE This operation works as described in Sec. 24.14.1 with the difference that it is not possible to change the interpolation settings for the extraction. Can be accessed via Manipulations > Array Size Manipulations and via Manipulations > Selection Related Operations.

25.2 Conversions

For a detailed discussion of all possible conversions ↪Sec. 30.

25.3 Graphics Add-on

For a detailed discussion of graphics add-ons ↪Sec. 32.

25.4 Expert Mode

Usually, only a few manipulations are available for chromatic fields sets. In case more manipulations are needed, activating the *Expert Mode* allows to access a lot more operations on the contained sampled data.

26 Manipulations of Pulse and Field Components

26.1 Array Size Manipulations

ITEM	DESCRIPTION
Change Array Size (Pixel Dimensions)	AVAILABLE FOR EQUIDISTANTLY SAMPLED DATA ONLY. Changes the number of data points. If the number of data points is increased then the array is embedded, that means the newly created surrounding data points are filled with zero values. Otherwise, i. e. if the number of data points is decreased then the new array is extracted. Embedding as well as extracting is done centered. Can be accessed via Manipulations > Array Size Manipulations. A pulse in time domain is usually sampled equidistantly and thus this operation can be used to increase the sampling within the frequency domain. See Sec. 31.2 for the conversion from frequency to time domain and vice versa.

26.2 Conversions

For a detailed discussion of all possible conversions ↪Sec. 30.

26.3 Fourier Transform

For a detailed discussion of Fourier transforms ↪Sec. 31.

26.4 Graphics Add-on

For a detailed discussion of graphics add-ons ↪Sec. 32.

27 Manipulation of Order Collections

27.1 Selection Related Operations

ITEM	DESCRIPTION
Extract 1D Data Along Selected Line	Extracts all data points of the currently shown Gridless Data Array which lie exactly on the line marker (↪Sec. 11.3) to a separate one-dimensional, non-equidistant data array. The order numbers are added as labels to the resulting data array. Can be accessed via Manipulations > Selection Related Operations.

27.2 Conversions

For a detailed discussion of all possible conversions ↪Sec. 30.

28 Manipulations of Regions

28.1 Edit Region

The edit of an existing region can be done using the dialogs which will open via Manipulations > Edit Region and which are described in Sec. 21.

28.2 Selection Related Operations

AVAILABLE FOR SAMPLED REGIONS ONLY.

All operations in the ribbon menu Manipulations > Selection Related Operations affect the selected area of the region. These are:

ITEM	DESCRIPTION
Fill Selection	Sets the data points within the selection to being 'inside' the actual region.
Clear Selection	Sets the data points within the selection to being 'outside' the actual region.
Clear Inverse Selection	Sets the data points outside the selection to being 'outside' the actual region.
Extract Selection	Creates a new region object which contains only the selected portion of the current region.

28.3 Conversions

For a detailed discussion of all possible conversions ↪Sec. 30.

29 Manipulation of Sets of Data Arrays

29.1 Selection Related Operations

ITEM	DESCRIPTION
Extract 1D Data Along Selected Line	ONLY FOR SETS OF GRIDLESS DATA ARRAYS Extracts all data points of the currently shown Gridless Data Array which lie exactly on the line marker (↪Sec. 11.3) to a separate one-dimensional, non-equidistant data array. Can be accessed via Manipulations > Selection Related Operations.

29.2 Conversions

For a detailed discussion of all possible conversions ↪Sec. 30.

29.3 Graphics Add-on

For a detailed discussion of graphics add-ons ↪Sec. 32.

30 Conversions

Conversions are manipulations whose result is of another document type than the input document.

30.1 Conversions for Complex Amplitude Documents

Complex Amplitude Documents, namely Harmonic Fields and Jones Matrix Transmissions, allow the following conversions, which can be found in the ribbon group Manipulations > Conversions.

ITEM	DESCRIPTION
Create Numerical Data Array	Converts the document to a Numerical Data Array. ↪Sec. 30.1.1, Shortcut: F3
Create Harmonic Field	ONLY FOR JONES MATRIX TRANSMISSIONS Converts the document to a Harmonic Field.
Create Transmission	ONLY FOR GLOBALLY POLARIZED HARMONIC FIELDS Converts the document to a Jones Matrix Transmission.
Create Sampled Region	Converts the document to a sampled region (↪Sec. 21). You are asked for a relative threshold and all values having a squared amplitude larger than the maximum squared amplitude times this value are regarded as being 'inside' the region.
Create Harmonic Fields Set	ONLY FOR HARMONIC FIELDS Converts the harmonic field to a harmonic fields set with one member field. Then you can add further member fields as required (↪Sec. 23.3).
Convert to Spectral Coordinates / Convert to Spatial Coordinates	Converts the coordinate axes from *Length* to *Wave Number* and vice versa according to the formulas given at the end of Sec. 137.5.1.1. As a stored analytical spherical phase is not allowed for spectral fields, you are asked whether you want to sample or remove that spherical phase factor prior to converting to spectral coordinates.
Dimension Separation	The operations in this menu convert between one- and two-dimensional fields. ↪Sec. 30.3.5

To convert globally polarized fields into locally polarized ones and vice versa use Manipulations > Polarization Change (↪Sec. 22.10).

30.1.1 Conversion to Numerical Data Arrays

If a Harmonic Field, a Transmission, or a Harmonic Fields Set is to be converted to a Numerical Data Array then the dialog shown in Fig. 180 is used to determine the conversion parameters. For Harmonic Fields Set all member fields are interpolated to a common sampling using the "Sinc Interpolation (Fourier Transform)". The common sampling is derived from the largest field size and the smallest sampling distance of all member fields.

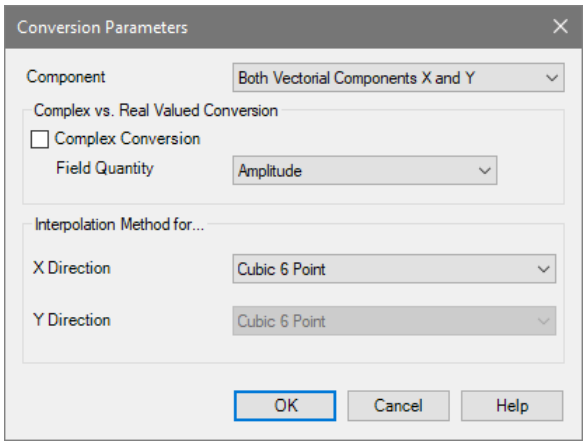


Figure 180. *Dialog for the parameters needed for converting a Harmonic Field or a Transmission into a Numerical Data Array.*

ITEM	DESCRIPTION
Component	For locally polarized Harmonic Fields, here can be chosen whether the vectorial component E_x or E_y or both of them are to be converted to a subset in the new Numerical Data Array. For globally polarized fields, as well as for Transmissions, this choice is not provided.
Complex Conversion	If checked, the whole complex information will be converted to a complex Numerical Data Array. If not, a *Field Quantity* has to be chosen which will be extracted into a real valued Data Array.
Field Quantity	For a non-complex conversion, here the field quantity has to be selected that shall be extracted for the Numerical Data Array.
Interpolation Method for X Direction	The interpolation method for the X direction in the Numerical Data Array to be created is set here.
Interpolation Method for Y Direction	Despite the synchronization of the interpolation methods for X and Y direction, the interpolation method for the latter is given here for the sake of completeness.

30.2 Conversions for Harmonic Fields Sets

The ribbon group Manipulations > Conversions of Harmonic Fields Sets has the following entries.

ITEM	DESCRIPTION
Create Numerical Data Array	Converts the document to a Numerical Data Array. ↪Sec. 30.1.1, Shortcut: F3
Create Animation	Converts the document to an Animation. Then, each member of the Harmonic Fields Set becomes one frame in the animation. It works in the same way as the corresponding Combined Output (↪Sec. 45.5.1.3).

30.3 Conversions for Data Arrays

The ribbon group Manipulations > Conversions of Data Arrays has the following entries.

ITEM	DESCRIPTION
Create Animation	VirtualLab Fusion allows you to convert the subsets of a two-dimensional Data Array into the frames of an animation. ↪Sec. 30.3.1
Create Numerical Data Array	Sometimes a Data Array document is not a Numerical Data Array but has a physical meaning, for example if you apply the Electric Field detector (↪Sec. 76.3.1) on a Harmonic Field. Then the caption of the document differs (↪Fig. 181). This manipulation can be used to convert such a document to a Numerical Data Array. Shortcut: F3
Create Harmonic Field	Converts the data array to a Harmonic Field. ↪Sec. 30.3.2, Shortcut: F3
Dimension Reduction > Extract All Rows	ONLY FOR TWO-DIMENSIONAL DATA ARRAYS WITH EXACTLY ONE SUBSET. Each data row becomes one subset of a one-dimensional data array.
Dimension Reduction > Extract All Columns	ONLY FOR TWO-DIMENSIONAL DATA ARRAYS WITH EXACTLY ONE SUBSET. Each data column becomes one subset of a one-dimensional data array.
Dimension Reduction > Extract Cross Profile at Point	ONLY FOR TWO-DIMENSIONAL DATA ARRAYS WITH VISIBLE POINT MARKER. Out of the current position of the point marker, two one-dimensional cross sections are extracted: one along the x-position of the marker and one along the y-position of the marker. The two cross sections are shown as separate data arrays.
Create 2D Data Array	ONLY FOR ONE-DIMENSIONAL DATA ARRAYS WITH MORE THAN ONE SUBSET. Creates a two-dimensional data array out of the subsets of a one-dimensional data array. ↪Sec. 30.3.3
Extrude to 2D Data Array	ONLY FOR ONE-DIMENSIONAL DATA ARRAYS. Creates a two-dimensional data array via extruding a one-dimensional data array. The result will contain the same number of subsets as the original. ↪Sec. 30.3.4
Dimension Separation	The operations in this menu convert between one- and two-dimensional fields. ↪Sec. 30.3.5

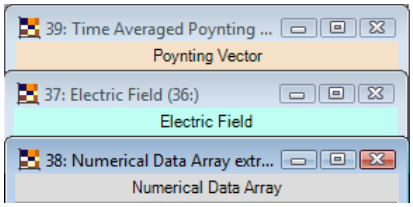


Figure 181. *Sample captions for a Data Array with physical meaning (top and center) and for a Numerical Data Array (bottom).*

30.3.1 Create Animation from Numerical Data Arrays

ONLY FOR TWO-DIMENSIONAL GRIDDED OR GRIDLESS DATA ARRAYS.

This conversion creates one bitmap from each subset of the currently used data array or set of data arrays. This bitmap contains the data as shown in the diagram panel (↪Sec. 13.4.1), it does not contain the axes, the legend and other additional information. Especially the following settings from the current configuration of the diagram panel influence the generated bitmaps:

- the color table (↪Sec. 11.2.4)
- the field quantity (↪Sec. 11.1)
- whether the view is interpolated (for gridded data arrays, ↪Sec. 11.2.1)

- the dot size in pixels (for gridless data arrays, ↪Sec. 13.4.1.4)
- whether triangles are shown (for gridless data arrays, ↪Sec. 11.2.3) .

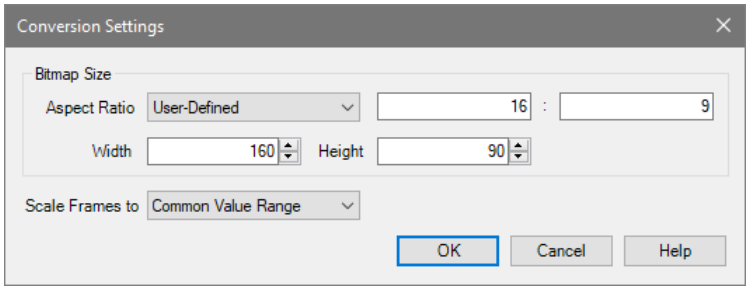


Figure 182. *The settings for the conversion to an animation.*

There is an edit dialog for this conversion where you can set the bitmap size and the data scaling (↪Fig. 182). It has the following controls.

ITEM	DESCRIPTION
Aspect Ratio	The aspect ratio of the resulting animation is determined in different ways: • *True to Physical Scale*: The aspect ratio is determined from the ratio of the x-axis range of the data array to its y-axis range. This option is not available if the two coordinate axes have different physical properties. • *User-Defined*: If you choose this option you can define a suitable aspect ratio. For example you can use 16 : 9 to ensure that the animation (and a video possibly generated out of it via File > Export) looks nicely on matching monitors or projectors. For gridded data arrays the default user-defined aspect ratio is calculated from the number of data points in the data array. • *Free*: You can set *Width* and *Height* of the single bitmaps as you want.
Width / Height	The width and height of the resulting bitmaps. If the *Aspect Ratio* is not *Free* and you change one dimension, then the other dimension is always changed automatically.
Scale Frames to	• *Common Value Range*: The global minimum and maximum value of all subsets is used to scale the color table. As a result you can see in which subsets there are smaller values then in others. • *Individual Value Range*: The color table for each frame is adapted to the minimum and maximum value of the individual data. As a result all subsets use all colors of the color table.

If True To Physical Scale is set in the View ribbon of the data array, then *True to Physical Scale* is set as default. Otherwise *User-Defined* is the default.
For sets of data arrays the overall extension, i. e. the union of the ranges of all included data arrays, is shown in the resulting animation. Subsets from data arrays which have a smaller extension are filled up with black pixels accordingly.

30.3.2 Conversion of Numerical Data Arrays to Harmonic Fields

The data of a Data Array can be used for creating a new Harmonic Field of course. This can be done via Manipulations > Create Harmonic Field.
Since some of the parameters have to be specified additionally, the conversion dialog shown in Fig. 183 will open.

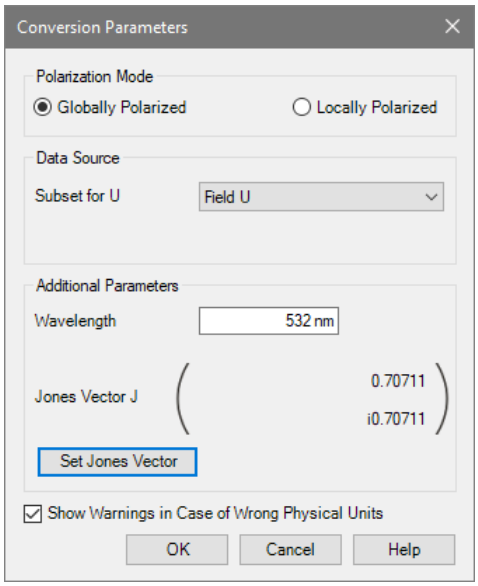


Figure 183. *Dialog for the parameters needed for creating a Harmonic Field from a Numerical Data Array.*

ITEM	DESCRIPTION
Polarization Mode	The resulting field can be *Globally Polarized* or *Locally Polarized*.
Subset for U	In case of a *Globally Polarized* resulting field, the Data Array's subset to be used as lateral field distribution U can be chosen here.
Subset for Ex/Ey	In case of a *Locally Polarized* resulting field, the Data Array's subset to be used as lateral field distribution of the component Ex/Ey can be chosen here.
Wavelength	The wavelength of the Harmonic Field to be created.
Jones Vector J	In case of a *Globally Polarized* resulting field, the currently set Jones vector is shown here. It can be changed via the button *Set Jones Vector*.
Set Jones Vector	The Jones vector for a *Globally Polarized* resulting field can be set via a dialog, that opens when this button is pressed.
Show Warnings in Case of Wrong Physical Units	VirtualLab Fusion will check the Numerical Data Array for valid physical units for the stored data and its coordinates. Valid means: Electric field strength as unit for the data and a length or reciprocal length for the coordinates. However, if this option is unchecked, no warnings will be displayed in case of wrong units.

30.3.3 Create 2D Data Array from 1D

If it makes sense to order all subsets of a one-dimensional Numerical Data Array on another dimension, a two-dimensional Numerical Data Array can be created from that data. For this, the new dimension has to be defined using the dialog shown in Fig. 184. The subsets will be concatenated along this new dimension, then.

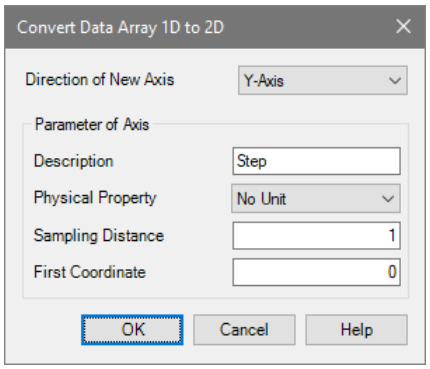


Figure 184. *Dialog for defining a new dimension for creating a 2D Numerical Data Array from 1D data.*

The following parameters are necessary in order to define the second dimension:

ITEM	DESCRIPTION
Direction of New Axis	Determines whether the new dimension shall be in x or y.
Description	The meaning of the new dimension. This will be the label for the new axis of the resulting Numerical Data Array.
Physical Property	The physical property of the new dimension's coordinate.
Sampling Distance	The distance of two adjacent 1D subsets on the new dimension.
First Coordinate	The coordinate which corresponds to the first 1D subset on the new dimension.

30.3.4 Extrude 2D Data Array from 1D

Besides creating a 2D data array from a 1D data array by concatenating its subsets (↪Sec. 30.3.3), there exists another possibility of adding another dimension. The dialog shown in Fig. 185 can be used for extruding the 1D data along a new coordinate axis.

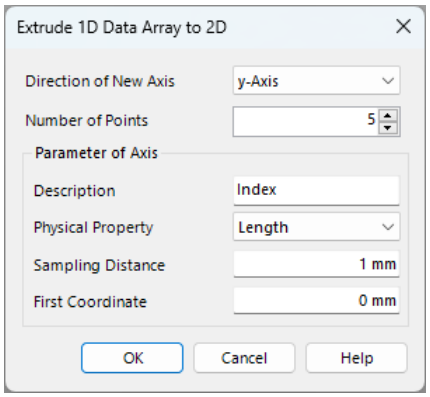


Figure 185. *Dialog for defining an extrusion of 1D data for creating a 2D Numerical Data Array.*

The following parameters are necessary in order to define the extrusion:

ITEM	DESCRIPTION
Direction of New Axis	Determines whether the new dimension shall be in x or y.
Number of Points	To what number of new data points shall the result be extruded (along the *Direction of New Axis*)?
Description	The meaning of the new dimension. This will be the label for the new axis of the resulting Numerical Data Array.
Physical Property	The physical property of the new dimension's coordinate.
Sampling Distance	The distance of two adjacent sampling points on the new dimension.
First Coordinate	The coordinate which corresponds to the first data point on the new dimension.

30.3.5 Dimension Separation

The ribbon menu Manipulations > Dimension Separation offers the option to separate a two-dimensional complex array or to recombine the parts of a previously separated array. A two-dimensional separable array $u_{\text{sep}}(x,y)$ fulfills the property

$$u_{\text{sep}}(x,y) = u_x(x)u_y(y), \tag{30.1}$$

with the one-dimensional arrays u_x and u_y which are calculated from the (not necessarily separable) current array $u(x,y)$ by

$$u_x(x) = f_x u'_x(x), \tag{30.2}$$
$$u_y(y) = f_y u'_y(y) \tag{30.3}$$

with

$$u'_x(x) = \sum_{j=0}^{N_y-1} u(x,y_j), \tag{30.4}$$
$$u'_y(y) = \sum_{i=0}^{N_x-1} u(x_i,y) \tag{30.5}$$

and

$$f_x = \sqrt{f_0 \frac{N_x}{N_y}}, \tag{30.6}$$
$$f_y = \sqrt{f_0 \frac{N_y}{N_x}}, \tag{30.7}$$

where N_x and N_y denote the number of sampling points and f_0 is calculated as

$$f_0 = \frac{\sum_{j=0}^{N_y-1}\sum_{i=0}^{N_x-1} u(x_i,y_j)\overline{u_x(x_i)u_y(y_j)}}{\sum_{j=0}^{N_y-1}\sum_{i=0}^{N_x-1} \|u_x(x_i)u_y(y_j)\|^2}. \tag{30.8}$$

ITEM	DESCRIPTION
Make Field Separable	Works similar to Separate into x- and y-Direction (see below) with the exception that the output of this operation is the two-dimensional separable array $u(x,y)$ which is calculated according to Eq. (30.1).
Separate into x- and y-Direction	Constructs two one-dimensional arrays u_x and u_y, with the goal that the array $u_{\text{sep}}(x,y)$ according to Eq. (30.1) differs as little as possible from the current one. The error criterion is to minimize the squared amplitude sum of the difference between the original and the approximated array. The arrays u_x and u_y are calculated by integrating the current array in Y or X direction, respectively (see Eqs. (30.4)-(30.5)). Afterwards a rescaling factor is applied to u_x and u_y, respectively (according to Eqs. (30.6)-(30.8)).
Combine 1D Fields	Constructs a two-dimensional separable array according to Eq. (30.1) from the two given one-dimensional arrays.

30.4 Conversion for Chromatic Fields Sets

ITEM	DESCRIPTION
Create Numerical Data Array	Extracts the underlying Data Array (↪Sec. 13) and displays it as separate document. Shortcut: F3

30.5 Conversions for Pulse and Field Components

ITEM	DESCRIPTION
Create Animation	ONLY FOR TWO-DIMENSIONAL DOCUMENTS WITH MORE THAN ONE SUBSET, I. E. FOR PULSE COMPONENT AND FIELD VECTOR COMPONENT. VirtualLab Fusion allows to convert the subsets of a Pulse and Field Component document into the frames of an animation. The current view settings *Field Quantity* and *Color Table* will be used for the conversion.
Create Numerical Data Array	Extracts the underlying Data Array (↪Sec. 13) and displays it as separate document. Shortcut: F3

30.6 Conversion for Order Collections

ITEM	DESCRIPTION
Convert to Equidistant Data Array	Converts all information (coordinates, efficiencies, and Rayleigh coefficients) into distinct subsets of an equidistant data array, plotted versus order numbers. Shortcut: F3
Extract Current Grating Efficiencies	Extracts the currently visible grating efficiencies diagram into a gridless data array (↪Sec. 13) and displays it as separate document. Shortcut: Shift + F3

30.7 Conversion for Regions

ITEM	DESCRIPTION
Convert to Sampled Region	ONLY AVAILABLE FOR NON-SAMPLED REGIONS. Opens a dialog for sampling the current region (↪Sec. 30.7.1).
Create Numerical Data Array	ONLY AVAILABLE FOR SAMPLED REGIONS. Extracts the underlying Data Array (↪Sec. 13) and displays it as separate document. Shortcut: F3

30.7.1 Conversion to Sampled Regions

Converting non-sampled into sampled regions require input of the sampling parameters. This has to be done via the dialog shown in Fig. 186.

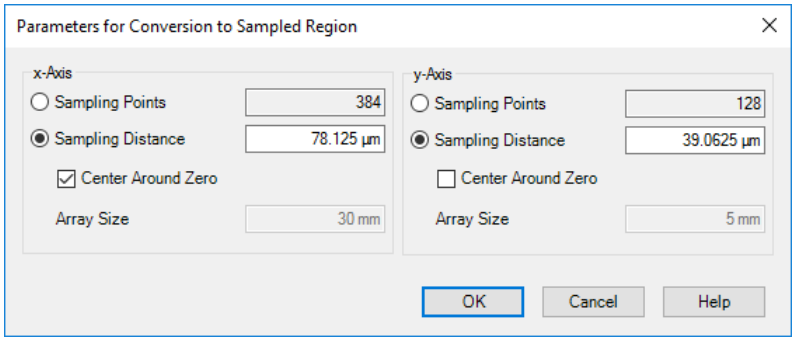


Figure 186. *Dialog for defining the sampling parameters for converting a non-sampled region into a sampled one.*

The sampling parameters are the following:

ITEM	DESCRIPTION
Sampling Points	The number of sampling points to be used in the respective dimension.
Sampling Distance	The sampling distance to be used in the respective dimension.
Center Around Zero	If checked, the result will be zero centered in the respective dimension. In order to achieve this, the data will be embedded if necessary.
Array Size	Information about the resulting array size.

30.8 Conversions for Sets of Data Arrays

ITEM	DESCRIPTION
Create Animation	ONLY FOR DATA ARRAYS 2D AND DATA ARRAYS GRIDLESS VirtualLab Fusion allows you to convert all subsets of a two-dimensional Set of Data Arrays into the frames of an animation. In the resulting animation first come the subsets of the first data array, then the subsets of the second data array and so on. The edit dialog for this conversion is described in Sec. 30.3.1.
Convert to Single Data Array	ONLY FOR DATA ARRAYS 1D AND DATA ARRAYS 2D Converts the Set of Data Arrays into a single data array containing all subsets. If necessary, the data is resampled to a common grid. Shortcut: F3
Extract Current Numerical Data Array / Electromagnetic Field / ...	Extracts the currently visible Data Array (↪Sec. 13) and displays it as separate document. Shortcut: Shift + F3

31 Fourier Transforms

31.1 Fourier Transform (Space)

The Fourier transform has many applications in wave-optical simulations. Examples are the usage in free space propagation operators (↪Sec. 94) and the simulation of Fourier transforming optical setups (↪Sec. 31.1.1).
It is available via various ribbon items in the ribbon group Manipulations > Fourier Transform (Space):

- Manipulations > Forward: x → k,
- Manipulations > Backward: k → x,
- Manipulations > Numerical FFT > Forward: x → k, and
- Manipulations > Numerical FFT Backward: k → x .

The *numerical* and the "*normal*" or *physical* Fourier transform differ in their scaling: The *numerical* variants ensure that the summed norm of the field (↪Sec. 76.4.7) is not changed by the transform. This leads to the effect that if you embed the Fourier transform of a field in a zeroized frame and then perform the backward transform, the power and maximum amplitude of the field has changed. This is circumvented if you use the *physical* transforms.
The Fourier transform cannot handle fields having a stored analytical spherical phase. Thus in this case you are asked whether you want to sample or remove that spherical phase factor prior to the actual Fourier transform.
The used equations are given in Sec. 137.5.1. The Fourier transform can also be done using a focusing lens (↪Sec. 31.1.1).

31.1.1 Fourier Setups

Availability

Toolboxes: All

Accessible:

- Harmonic Field, Harmonic Fields Set, or Jones Matrix Transmission: Manipulations > 1f 1f-Setup and Manipulations > 2f 2f-Setup
- Harmonic Field and Harmonic Fields Set: Propagations > 1f 1f-Setup and Propagations > 2f 2f-Setup
- Optical Setup: *Ideal Components > Special Components > 1f-Setup* and *Ideal Components > Special Components > 2f-Setup*

A Fourier transform can be done experimentally with an (ideal) focusing lens. The principal setup is shown in Fig. 187. It is mainly used for optical filtering problems like high-pass and low-pass filters. In the output plane, the Fourier plane, a filter to truncate high or low frequencies can be placed.

A Far Field Propagation of a paraxial field can also be used to create experimentally the Fourier transform.

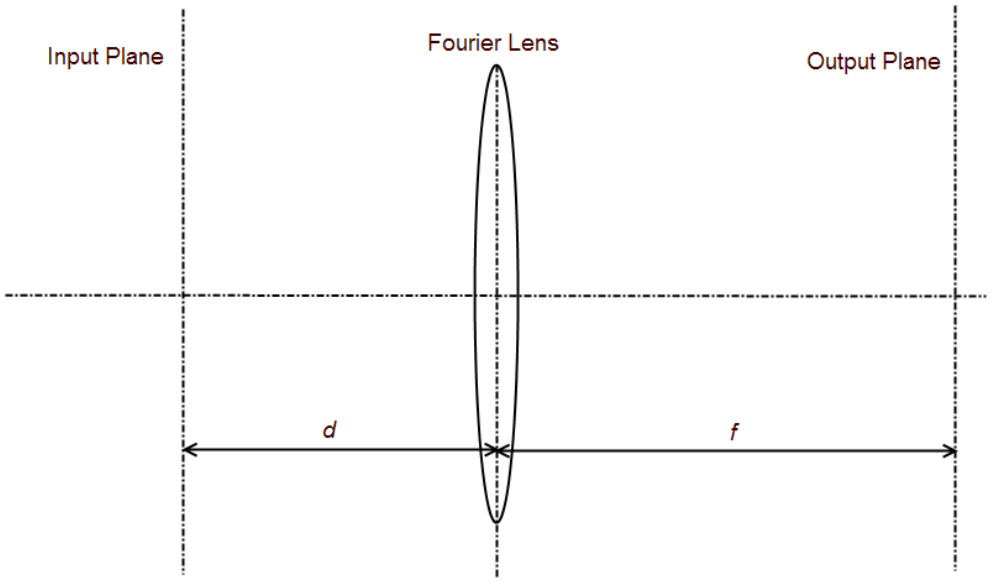


Figure 187. *Principal setup for a Fourier transform with a focusing lens. f is the "Focal Length" of the lens and d is the "Distance to Lens".*

If the *Distance to Lens* d equals the *Focal Length* f, the setup is called 2f-Setup. In this case the phase in the output plane vanishes. The other special case, if d is nearly zero, is called 1f-Setup.

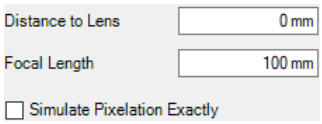


Figure 188. *Control for editing the 1f-setup function.*

Both special cases are available as operators in VirtualLab Fusion. These two operators have nearly identical dialogs (↪Fig. 188) with the following parameters:

ITEM	DESCRIPTION
Distance to Lens	The distance to the lens (d in Fig. 187) which is identical to the focal length. This text box is only editable for the *1f-Setup* operator.
Focal Length PV	The focal length f of the lens.
Simulate Pixelation Exactly	If this box is checked pixelation effects are considered. This is done by performing a Sinc Modulation (↪Sec. 144.1.2) to the output field, which is equal to the functionality of Manipulations > Amplitude / Real Part Manipulations > Simulate Sinc Modulation Due to Pixelation.

If these operators are used in the Optical Setup, the control shown in Fig. 188 is embedded in the general dialog for Ideal Components which is described in Sec. 67.

31.2 Fourier Transform (Temporal)

31.2.1 Inverse Temporal Fourier Transform

The ribbon item Manipulations > $\mathcal{F}_t^{-1}$ Inverse Temporal Fourier Transform can be used to calculate the pulse form of the underlying data field. This transformation is only possible if the active document contains a data field which is defined in the frequency domain. In VirtualLab Fusion these fields can be functions of the frequencies ν or the wavelengths λ. The resulting function in the time domain will be displayed in a new document.
The edit dialog of the Inverse Temporal Fourier Transform allows you to configure the exclusion of the time shift within the inverse temporal Fourier Transform. Also the increase of the time window can be specified. Additionally the user can define an accuracy factor which will influence the sampling in the time domain.

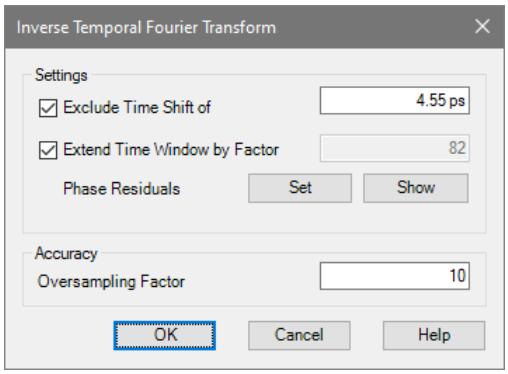


Figure 189. *Dialog for the settings of the inverse temporal Fourier transform.*

Fig. 189 shows the edit dialog of the Inverse Temporal Fourier Transform. The following parameters can be specified:

ITEM	DESCRIPTION
Exclude Time Shift of	You can exclude the time shift by the inverse temporal Fourier transform. The position in time of the pulse can be evaluated with the *Optical Path Length Analyzer* (↪Sec. 83).
Extend Time Window by Factor	For pulse evaluation VirtualLab Fusion implements a smart algorithm to extend the time window during the inverse temporal Fourier Transform. Therefor the *Optical Path Length Analyzer* has to be used. The residuals of the fitted linear phase function and the correct phase function can be used for the interpolation of the underlying data set. A larger time window can be realized by increasing the *Oversampling Factor (Frequencies)* of the *Optical Path Length Analyzer*(↪Sec. 83). The resulting residual function has to be set into the edit dialog of the Inverse Temporal Fourier Transform. This can be done by clicking on the *Set* button in the dialog. The accuracy of the selected residual function defines the time window extension factor. This factor is displayed and cannot be edited directly by the user.
Oversampling Factor	Uses n times the number of preset sampling points, where n is the given *Oversampling Factor*.

31.2.2 Temporal Fourier Transform

By clicking on the ribbon item Manipulations > $\mathcal{F}_t$ Temporal Fourier Transform a temporal Fourier transform of the underlying data field is performed. This operation is only available for fields which are defined in the time domain. The result of this operation is the field in the frequency domain. This field is displayed as function over ν and also as function over λ.

31.2.3 Envelope to Real Function Converter

If the pulse is displayed in time domain, you can show the real field instead of the envelope using the ribbon item Manipulations > Envelope to Real Function Converter.

32 Graphics Add-Ons

The manipulations in the category Graphic Add-Ons do not cause changes to the actual data but add some more graphical information to the view of the currently active object instead.

32.1 Add Region

The ribbon button Manipulations > Add Region allows to select any open region object as source for a region to be drawn to the currently active view.
In case there is more than one subset present in the current object, an additional dialog will ask for the subsets to apply the add-on to.

32.2 Add Point Cloud

ONLY FOR TWO-DIMENSIONAL VIEWS.

The ribbon button Manipulations > Add Region allows to select any open gridless data array or ray distribution as source for a point cloud to be drawn to the currently active view.
In case there is more than one subset present in the current object, an additional dialog will ask for the subsets to apply the add-on to.

32.3 Add Polarization Ellipses

ONLY FOR ELECTRIC OR ELECTROMAGNETIC FIELDS.

The ribbon button Manipulations > Add Polarization Ellipses allows you to calculate polarization ellipses for Electric or Electromagnetic Fields (↪Sec. 13.1) either if none were calculated by the Universal Detector (↪Sec. 75.4) or if the ellipses shall be calculated anew for whatever reason.

The dialog shown in Fig. 190 will open in order to allow the specification of the calculation of the ellipses.

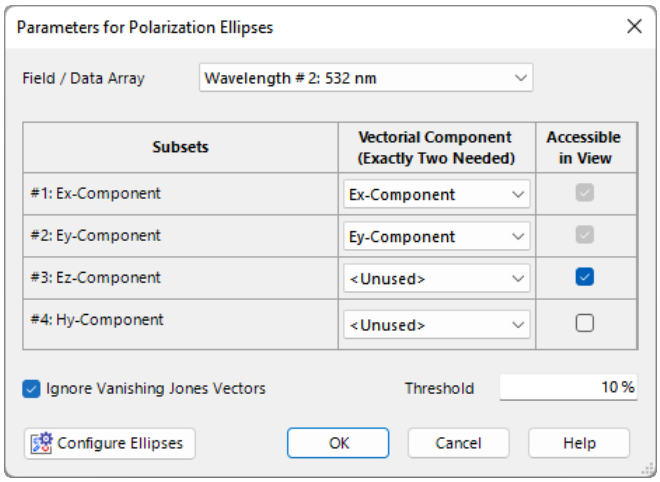


Figure 190. *Dialog for the settings the parameters for calculating polarization ellipses for an existing electric or electromagnetic field.*

The following parameters are to be specified:

ITEM	DESCRIPTION
Field / Data Array	ONLY FOR FIELDS WITH MORE THAN ONE MODE / WAVELENGTH. The (sub)field for which the ellipses shall be calculated can be selected here.
Subsets	Each Electric or Electromagnetic Field contains one or more subsets representing the contained vectorial component. This column lists all available components with names.
Vectorial Component (Exactly Two Needed)	In this column, exactly two vectorial components have to be selected to be used for calculating the ellipses. Possible combinations are E_x/E_y, E_x/E_z, E_y/E_z.
Accessible in View	Shall the ellipses be available for the view of the respective component? If so, the visibility of the ellipses can be toggled anyway.
Ignore Vanishing Jones Vectors	If checked, no polarization ellipses will be calculated at positions where the amplitudes of both of the Jones vector's components are below a certain fraction (given be *Threshold*) of the maximum field amplitude (see also Sec. 11.8).
Threshold	ONLY AVAILABLE IF *IGNORE VANISHING JONES VECTORS* IS CHECKED. The threshold for identifying vanishing Jones vectors.
Configure Ellipses	Pressing this button opens the dialog for configuring the appearance of the polarization ellipses (↪Sec. 11.7.3).

32.4 Edit List

Since more than one graphics add-on may be associated with a data array (or data array based object), there is a list of it which can be edited via Manipulations > Edit List.

The dialog shown in Fig. 191 allows this editing.

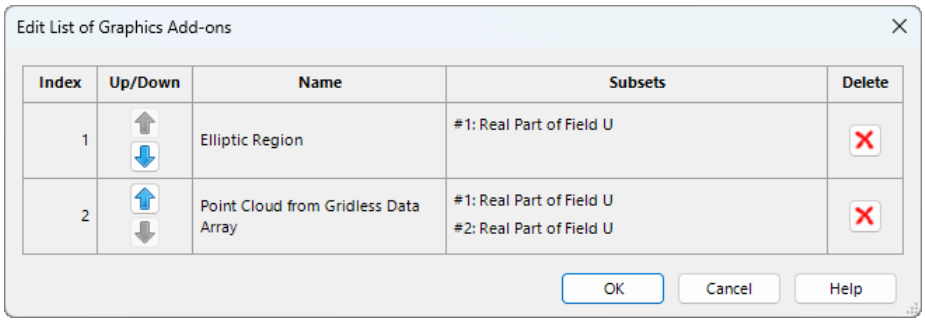
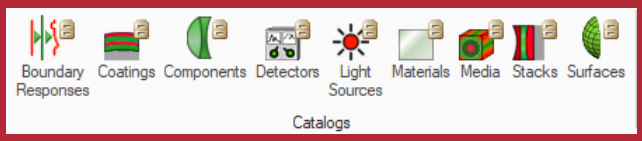


Figure 191. *Dialog for editing the list of graphics add-ons.*

ITEM	DESCRIPTION
Index	The layer index. Index #1 corresponds to the bottom layer which is drawn above the data first. The row with the highest index will be the upmost layer which is drawn at last.
Up/Down	Moves the add-on up or down in the layer order.
Name	Name of the add-on.
Subsets	Shows for which subsets the add-on is available.
Delete	Deletes the add-on in this row.

V Catalogs



The figure above shows the *Catalogs* ribbon tab. As you can see, catalogs are available for

- boundary responses (↪Sec. 42)
- coatings (↪Sec. 37)
- components (↪Part IX)
- detectors (↪Part XI)
- light sources (↪Part VIII)
- materials (↪Sec. 39)
- media (↪Sec. 38)
- stacks (↪Sec. 40) and
- surfaces (↪Sec. 36) .

These catalogs are accessible via the dialog described in Sec. 33. It serves for adding, viewing, editing, or removing of catalog entries, or for the selection of an entry. Sec. 34 describes the controls which open that dialog so that you can apply catalog entries where needed.

33 Catalog Dialog

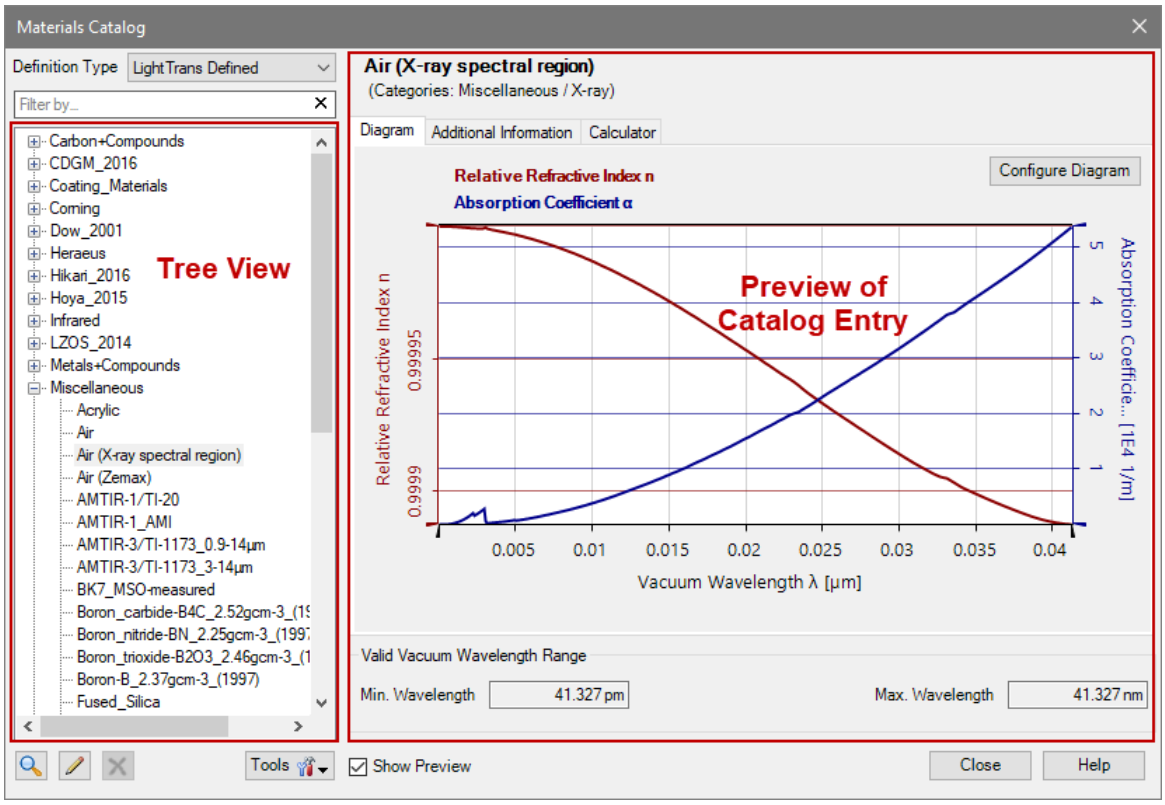


Figure 192. *The main form for VirtualLab Fusion catalogs.*

Fig. 192 shows the main form for catalogs. It contains the following controls:

ITEM	DESCRIPTION
Definition Type	There are three definition types 1. *Templates*: Catalog entries with either unspecified parameters or parameters with default values. These entries are read-only. 2. *LightTrans Defined*: The parameters are preset to represent a real structure (e. g. the material “Gold”). These entries are read-only. 3. *User Defined*: The place where the user can store own entries. These entries are saved in the path for user settings specified in the Global Options dialog (Sec. 6.17).
Filter by…	If you enter text in this text box, only catalog entries are shown whose name contains this text. The filter is not case sensitive, i. e. “glass”, “Glass”, and “GLASS” yield the same results. It is possible to search for multiple words and word groups embraced by quotation marks.
{Tree View}	Shows the categories and entries of the currently selected *Definition Type*. Each catalog entry must be within at least one category. If you have opened the catalog via a *Load* button, double-clicking on a catalog entry loads this entry.

{Preview}	Shows a preview of the currently selected catalog entry. The corresponding previews are as follows: • Boundary Responses: ↪Sec. 42.2 • Coatings: ↪Sec. 37.4 • Components: 3D view as described in Sec. 5.16 • Detectors: a description of the detector • Light Sources: a Chromatic Fields Set View (↪Sec. 14) of the resulting light • Materials: ↪Sec. 39.3 • Media: ↪Sec. 38.2 • Stacks: a read-only version of the edit dialog (↪Sec. 40.2) • Surfaces: ↪Sec. 36.3
/ View	Shows the preview as separate resizable dialog. Not available for the detectors catalog.
Edit	Opens the edit dialog of the currently selected catalog entry. If you edit a template or a LightTrans defined entry, you are asked to specify name and categories for saving the entry as user defined entry (↪Sec. 33.1). User defined entries can be either overwritten or saved under a new name and or category.
Remove	Removes a user defined catalog entry.
Tools	The following catalog tools are available: • View, Edit, Remove (see above) • Rename, Edit Categories (available for user defined catalog entries only. ↪Sec. 33.1) • Save to Catalog File (↪Sec. 33.2) / Load from Catalog File (↪Sec. 33.3) • Import Zemax OpticStudio® Glass Catalog (available within the material catalog only. ↪Sec. 135) • Import Material Data from Text File (available within the material catalog only. ↪Sec. 33.4) • Import Macleod Coating Data (available within the coating catalog only. ↪Sec. 134) • Extract Material(s) from Medium/Coating into Catalog (available within the medium or coating catalog only. ↪Sec. 33.5) • Reload from Hard Disc: If the saved catalogs have changed (e. g. by another instance of VirtualLab Fusion), you can reload them with this catalog tool. Also saving new entries sometimes requires a reload.
Show Preview	For performance reasons you can disable the preview with this checkbox.
Keep View Range (If Medium Changed)	ONLY AVAILABLE FOR THE MEDIA CATALOG AND IF *SHOW PREVIEW* IS ACTIVATED. If checked, changing the shown medium will not change the displayed view range. In this case, the medium's own default view range will be ignored and the media views can be better compared.

33.1 Specify Name and Categories

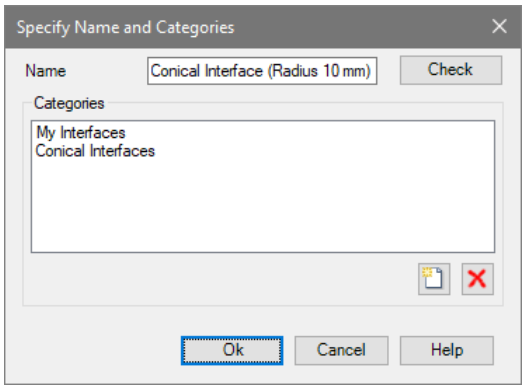


Figure 193. *Dialog for specifying the name and the categories of a catalog entry.*

The dialog shown in Fig. 193 opens if you want to save a new catalog entry, rename an existing catalog entry or change its categories. It has the following entries, whereas some of them might be disabled due to the actual purpose of the dialog.

ITEM	DESCRIPTION
Name	Shows the name of the catalog entry and allows you to enter a new name. Each name must be unique for one type of building block (e. g. only one user defined surface can have the name “Cylindrical Surface”.)
Check	Checks whether the name is unique. This check is also done if you press *Ok* – if the name is not unique, the dialog does not close.
Categories	Shows a list of all categories the catalog entry is sorted into.
New Category	Asks for the name of the new category and adds it to the list of *Categories*. Two categories with the same name are merged.
Remove Category	Removes the currently selected category from the list of *Categories*. At least one category must be in this list.

33.2 Save to Catalog File

Selected entries from the *User Defined* catalog can be saved to a separate catalog file which can then be loaded (↪Sec. 33.3) on other computers. This tool first opens a dialog (↪Fig. 194) where you can select which entries to save and give them other names. The names in the saved file must be unique, otherwise they are marked red and the dialog becomes invalid. The dialog also offers two *Selection Tools* to *Select All* or *Unselect All* entries.

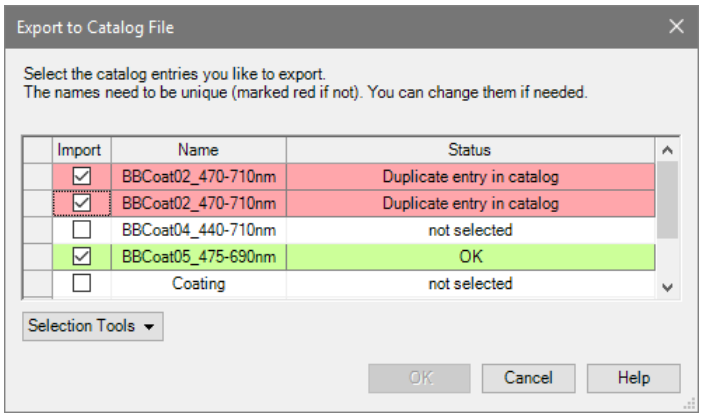


Figure 194. *Dialog for saving selected entries to another catalog file. Two selected entries have the same name and thus the dialog cannot be closed with* OK*.*

After closing this dialog with *OK* you can then specify path and name of the new catalog file.

33.3 Load from Catalog File

Selected entries can be loaded from any catalog file (*.ctlg) into the *User Defined* catalog. This tool first opens a dialog where you can specify path and name of the catalog file to be loaded. In the subsequent dialog (↪Fig. 195) you can then select which entries to load and assign additional categories to them.

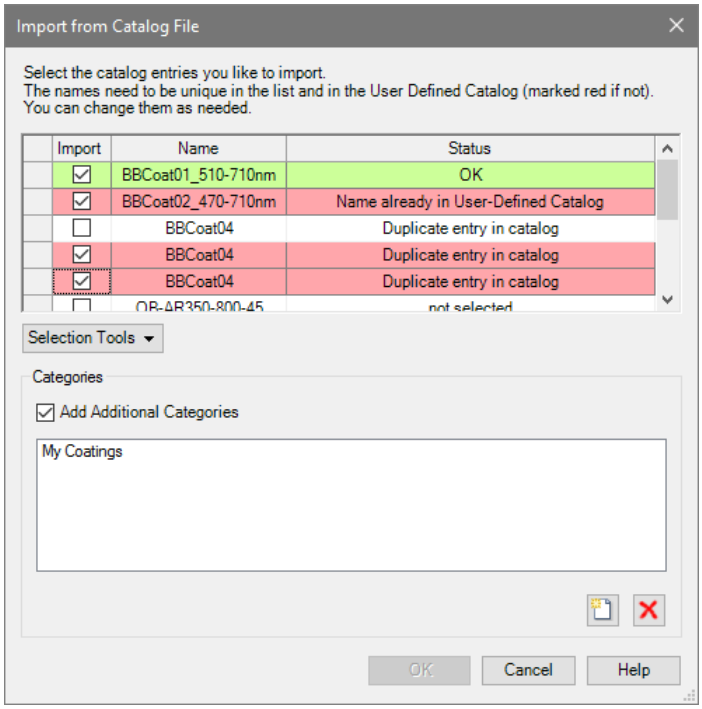


Figure 195. *Dialog for loading selected entries from another catalog file.*

This dialog has the following options.

ITEM	DESCRIPTION
{Table of Catalog Entries}	This table has the following columns: • *Load*: Allows you to select which entries of the file shall be loaded. Entries whose names are not unique, already present in the user defined catalog, or empty cannot be loaded. If such an entry is selected, the corresponding row is marked red. Otherwise, it is marked green and "OK" is shown in the *Status* column. • *Name*: Shows the name of the entry and allows to change it. • *Status*: Shows error messages for those entries that cannot be loaded. Entries without issues have the status "not selected" or "OK" if already marked for loading.
Selection Tools	Allows you to either *Select All* entries in the table or to *Unselect All*.
Add Additional Categories	All loaded entries keep their original categories. But you can add *additional* categories if you check this option.
{List of Categories}	List of all additional categories where you can select one to delete it.
New Category	Opens a separate dialog to define a new category.
Delete Category	Deletes the currently selected category.

33.4 Import Material Data from Text File

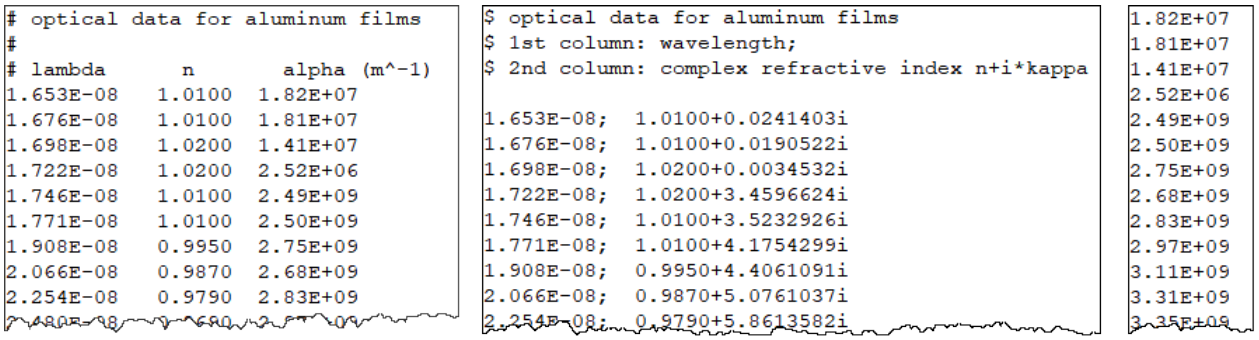
If dispersion data and / or absorption data are given in one or two text files, they can be imported into a new material with this tool.

33.4.1 Supported Text Formats

Several formats of text (ASCII) files are supported. An overview is given in the following table:

Column / Row #			Meaning / Interpretation
1	2	3	
λ	n	α or κ	non-equidistantly sampled dispersion and absorption curve ↪Fig. 196 a)
λ	α or κ	n	non-equidistantly sampled absorption and dispersion curve
λ	$n + \kappa \cdot i$		non-equidistantly sampled complex refractive index curve ↪Fig. 196 b)
n	α or κ		dispersion and absorption curve, to be equidistantly sampled
α or κ	n		absorption and dispersion curve, to be equidistantly sampled
$n + \kappa \cdot i$			complex refractive index curve, to be equidistantly sampled
n			dispersion curve, to be equidistantly sampled
α or κ			absorption curve, to be equidistantly sampled. ↪Fig. 196 c)

Symbols: λ = wavelength, n = real-valued refractive index, α = absorption coefficient, κ = absorption index.



a)

```
# optical data for aluminum films
#
# lambda       n        alpha (m^-1)
1.653E-08    1.0100   1.82E+07
1.676E-08    1.0100   1.81E+07
1.698E-08    1.0200   1.41E+07
1.722E-08    1.0200   2.52E+06
1.746E-08    1.0100   2.49E+09
1.771E-08    1.0100   2.50E+09
1.908E-08    0.9950   2.75E+09
2.066E-08    0.9870   2.68E+09
2.254E-08    0.9790   2.83E+09
```

b)

```
$ optical data for aluminum films
$ 1st column: wavelength;
$ 2nd column: complex refractive index n+i*kappa

1.653E-08;   1.0100+0.0241403i
1.676E-08;   1.0100+0.0190522i
1.698E-08;   1.0200+0.0034532i
1.722E-08;   1.0200+3.4596624i
1.746E-08;   1.0100+3.5232926i
1.771E-08;   1.0100+4.1754299i
1.908E-08;   0.9950+4.4061091i
2.066E-08;   0.9870+5.0761037i
2.254E-08;   0.9790+5.8613582i
```

c)

```
1.82E+07
1.81E+07
1.41E+07
2.52E+06
2.49E+09
2.50E+09
2.75E+09
2.68E+09
2.83E+09
2.97E+09
3.11E+09
3.31E+09
3.35E+09
```

Figure 196. *Examples for different data and formats in text files to be used in material's import. a) Non-equidistantly sampled dispersion and absorption curve. b) Non-equidistantly sampled complex refractive index curve. c) Sampled absorption curve, to be equidistantly sampled.*

Please note: For all data where the wavelengths are not imported along with the n-, α-, or κ-values, an equidistant sampling is assumed. The needed parameters (sampling distance and starting coordinate) are to be defined via the import dialog as described in Sec. 121.1.

33.4.2 Import via Wizard

Choosing *Import Material Data from Text File* from the tools menu of the catalog dialog opens the import wizard for text files, described in Sec. 121.1. After closing this wizard, the dialogs described in the next section Sec. 33.4.3 may appear. When the questions in these dialogs have been answered and the import of a new material succeeded, this new material may contain a sampled dispersion, a sampled absorption function, or both. The latter is only the case if both kinds of data were present in the file which has been imported.

> If only one of both wavelength dependent functions – either refractive index or absorption – could have been imported via wizard, the respective missing function can be set into the same new material as well. This can be achieved via the import function of the material's edit dialog (see Sec. 39.2 and Sec. 5.7).

33.4.3 Additional Options After Actual Import

After reading the data from the text file, it may be necessary to enter further, material specific information.

In case two (real-valued) sets of data have been read, the mapping of these sets to the two functions (dispersion and absorption) has to be determined. This can be done with the dialog shown in Fig. 197. For each set the user may specify whether it is to be interpreted as *Refractive Index* or as *Absorption* or whether to *Ignore* the data set. Each option may be selected only once at most. In case of absorption, the additional information whether the data represent an *Absorption Coefficient* α or an *Absorption Index* κ has to be set.

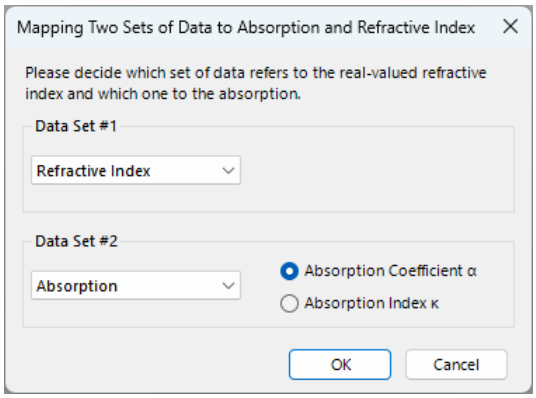


Figure 197. *Dialog for mapping two real-valued data sets to the dispersion function and the absorption function.*

Since any material needs to have a unique *Material Name* and a certain *State of Matter*, the dialog shown in Fig. 198 asks for these properties. Additionally, the *Origin of the Data* may be stored.

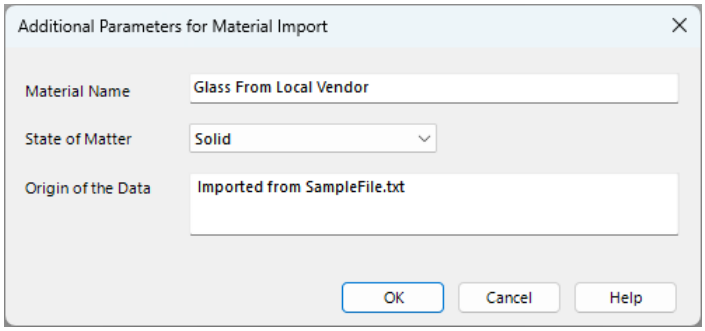


Figure 198. *Dialog for setting some material specific information.*

33.5 Extraction of Materials stored in Media or Coatings

Optical media as well as thin film coatings usually contain materials. If, for any reason, such a material is not stored in the materials catalog yet, the tool *Catalog Tools > Extract Material(s) from Medium/Coating into Catalog* allows you to extract it.
The tool will examine the selected medium or coating. Then a dialog to select the material(s) to extract is shown (↪Sec. 135). The selected materials will be extracted to the user defined materials catalog.

34 Application of Catalog Entries

The following sections describe the controls which are used to access and apply catalog entries in order to build up superordinate building blocks or real components.

34.1 Load and Edit of Catalog Entries

The controls shown in Fig. 199 are e. g. used for the definition of optical surfaces, media, stacks, and / or boundary operators of real components (↪Part IX).
These controls are also used within table cells (for example in the table defining the surfaces within a Lens System component). Then they are compactified as shown in Fig. 200 and shown only if the user enters that row.
Furthermore there is a “one line version” as shown in Fig. 201.

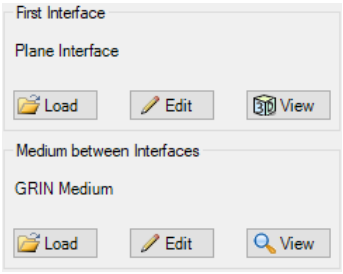


Figure 199. *Control for loading, editing and viewing optical surfaces (above) and media (below).*

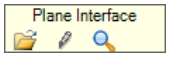


Figure 200. *Control for loading, editing and viewing building blocks within a table.*

Figure 201. *One line version of the control for loading, editing and viewing building blocks*

ITEM	DESCRIPTION
Load	Load an entry form the corresponding dialog. In the moment, this not possible for boundary operators.
Edit	Edit the current entry.
/ View	Shows the currently set entry.

34.2 Application of Coatings

Optical surfaces may be coated in order to change their reflection and transmission behavior. So each edit dialog for a surface allows to define such a coating via the coating panel, shown in Fig. 202.

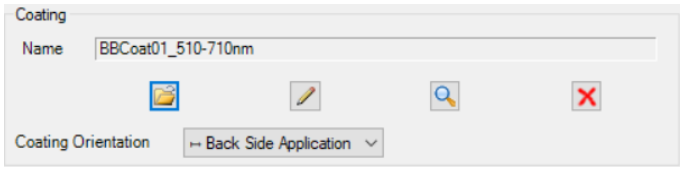


Figure 202. *The control for loading, viewing and removing of coatings.*

ITEM	DESCRIPTION
Name	Name of the currently set coating.
Load	Load a coating from the coating catalog.
Edit	Edit the currently set coating.
View	Shows the currently set coating.
Remove	Removes the coating.
Coating Orientation	The orientation of the coating in relation to the surface it is applied to. There are three orientation types: • ↔ Automatic Decision: The orientation will be determined automatically, depending on the states of matter in front of the surface and behind the surface. If there is one solid material and one non-solid (i.e. fluid, gaseous or vacuum) material involved, the solid material will serve as substrate. If there is not exactly one solid material, an error is given. • ↤ Front Side Application: The coating will be applied onto the front side of the surface. • ↦ Back Side Application: The coating will be applied onto the back side of the surface.

34.3 Application of Materials

Each medium contains at least one material. So whenever a medium is to be specified, a material has to be set. This is done via the control shown in Fig. 203.

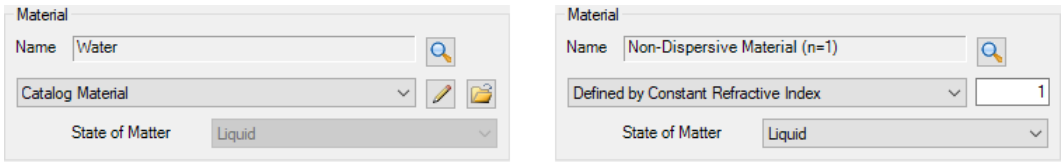


Figure 203. *The control for loading or defining and viewing of materials. Left side: Accessing a catalog material. Right side: Defining a material with constant refractive index.*

This control (↔Fig. 203) allows you to either load a material from the catalog or to define a material with constant refractive index directly. It contains the following controls:

ITEM	DESCRIPTION
Name	Shows the name of the current material.
View	Shows the view of the currently set material.
Catalog Material PE / **Defined by Constant Refractive Index**	If you set this combo box to *Catalog Material*, the materials catalog is shown where you can select the material. The button opens the materials catalog again. With the button you can edit the material. In contrast, if you set the combo box to *Defined by Constant Refractive Index* you can enter the real refractive index directly.
{Value} PV	AVAILABLE ONLY IF *DEFINED BY CONSTANT REFRACTIVE INDEX* IS SELECTED. The constant value of the real refractive index. It is defined absolutely (i. e. referring to vacuum) and applies for a wavelength range of 10 pm…0.1 m.
State of Matter	Shows the state of matter of the current material. If the material is *Defined by Constant Refractive Index*, you can change this entry. This information is needed for the orientation of coatings on surfaces.

35 Catalogs of Files

Detector add-ons (↪Sec. 75.4.5) are stored in files, whereat LightTrans defined and user defined add-ons are stored in files in different directories. To show these files in a unified way, they are presented in a special *file catalog* dialog (↪Fig. 204).

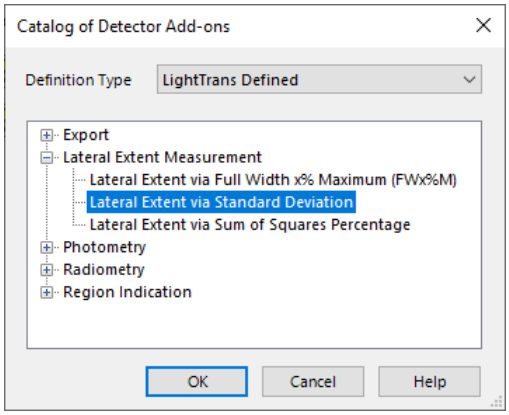


Figure 204. *The dialog for loading files from a file catalog.*

The dialog has the following controls.

ITEM	DESCRIPTION
Definition Type	There are two definition types 1. *LightTrans Defined*: Files defined by LightTrans GmbH. 2. *User Defined*: User defined files. These entries are saved in the path for user settings specified in the Global Options dialog (Sec. 6.17).
{Tree View}	Shows all available files, sorted into categories (which correspond to sub-directories on hard disc).

35.1 Saving Files to User Defined File Catalog

There is a special dialog for saving a file into a user-defined file catalog (↪Fig. 205).

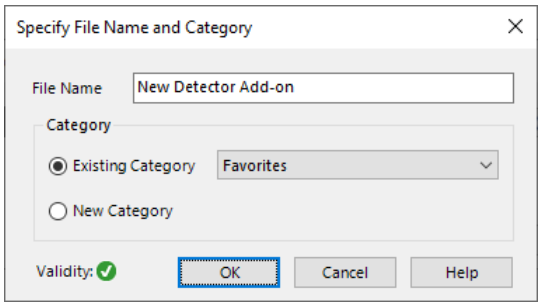


Figure 205. *Dialog for saving into a user-defined file catalog.*

The dialog has the following controls.

ITEM	DESCRIPTION
File Name	The name of the file. You don't need to add a path or a file extension.
Existing Category	If you select this option you can choose one of the existing categories (which are represented by sub-directories on hard disc). The category can also be *{Empty}*.
New Category	Allows you to enter the name of the new category.
{Validity Indicator}	A validity indicator (↪Sec. 5.11) shows warnings when the file already exists or when file name or category contain characters not allowed for file names. (These characters are replaced by an underscore in the final file path.)

VI Building Blocks: Media, Materials, Surfaces, …

Complex optical components are built up from simple Building Blocks:

- Optical Surfaces (↪Sec. 36)
- Coatings (↪Sec. 37)
- Media (↪Sec. 38)
- Materials (↪Sec. 39)
- Stacks (↪Sec. 40)
- Surface Layouts (↪Sec. 41)
- Boundary Responses (↪Sec. 42) and
- Surface Regions (↪Sec. 43) .

Some types of Optical Building Blocks contain other Building Blocks (e. g. a medium contains materials). In VirtualLab Fusion most Building Block categories have their own catalog. The general catalog concept is explained in Part V.

36 Optical Surfaces

Optical Surfaces separate two optical media (↪Sec. 38) and represent the borders of real optical components (↪Part IX). Every Optical Surface can be provided with an optical thin film coating (↪Sec. 37). There is a Surface Catalog, storing several predefined Optical Surfaces as well as a variety of templates of different surface types.

Please note: If you save a coated Optical Surface to the catalog, the coating will not be saved.

The following (template) types of Optical Surfaces are available in VirtualLab Fusion.

ITEM	DESCRIPTION
Anamorphic Asphere Surface	A biconic surface with additional coefficients describing a deviation in radial and azimuthal direction. ↪Sec. 36.2.1
Aspherical Surface	Allows you to define a rotational symmetric surface using asphere parameters. ↪Sec. 36.2.2
Combined Surface	Allows you to combine the height profiles of two distinct surface. ↪Sec. 36.2.3
Conical Surface	A surface that can be described as a rotating conic section. ↪Sec. 36.2.4
Cylindrical Surface	Allows you to define a axially symmetric surface using asphere parameters. ↪Sec. 36.2.5
Plane Surface	Describes a plane surface which can be tilted around the x-axis and the y-axis. ↪Sec. 36.2.7
Polynomial Surface	A conical surface which is modulated by a polynomial separable in x- and y-direction. ↪Sec. 36.2.8
Programmable Surface	Allows you to enter the height profile as a formula. ↪Sec. 36.2.9
Q-Type Asphere Surface	An asphere described by the polynomials proposed in [For07]. ↪Sec. 36.2.10
Sampled Surface	Allows you to set an arbitrary height profile. ↪Sec. 36.2.11.
Toroidal Asphere Surface	An aspherical cross section rotated about the y-axis. ↪Sec. 36.2.12
Transition Point List Surface	This surface allows you to define arbitrary heights at arbitrary positions along a line. ↪Sec. 36.2.13
Zernike Standard Surface	Defines an surface by Zernike polynomials $Z_i(\rho,\phi)$ using polar coordinates (ρ,ϕ). ↪Sec. 36.2.14
Grating Surfaces	↪Sec. 36.2.6. Rectangular gratings (↪Sec. 36.2.6.1), sawtooth gratings (↪Sec. 36.2.6.2), sinusoidal gratings (↪Sec. 36.2.6.3), and triangular gratings (↪Sec. 36.2.6.4) are available.

36.1 Edit Dialog for Optical Surfaces

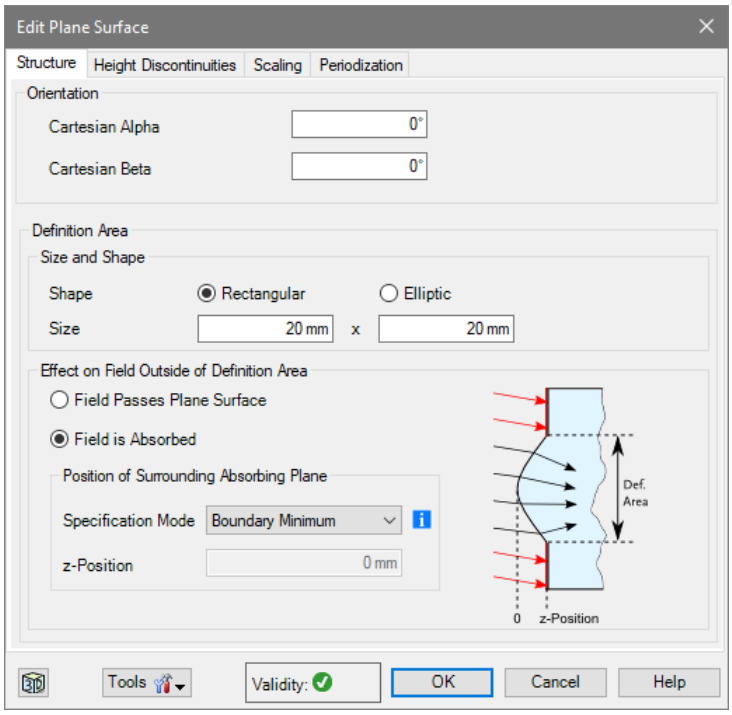


Figure 206. *Edit dialog for an optical surface (here: plane surface)*

The edit dialogs for all surface types (see for example Fig. 206) have the following controls in common:

ITEM	DESCRIPTION
Definition Area	↪Sec. 36.1.1.1.
View	Shows a 3D view of the surface as described in Sec. 36.3.
Save	Saves the surface to the catalog (↪Sec. 33). Not visible if the edit dialog is shown from within the surfaces catalog.
Tools	↪Sec. 36.1.3.
Validity Indicator	The parameters of a surface must fulfill some complex constraints. For example the conical constant of a surface determines its maximum definition area. If any of these constraints is breached, the green check mark on the bottom of the surface dialog turns into a red diagonal cross. If you click on the -button to the right, an info dialog is shown which lists all error messages. For constraints concerning the definition area and periodization, this dialog offers a link to a visualization of the current (approximated) function domain, the definition areas and the period of the surface (↪Sec. 36.1.1).
Coating tab	The controls on the *Coating*[PE] tab are explained in Sec. 34.2. Not visible if the edit dialog is shown from within the Surfaces Catalog or from within a stack (↪Sec. 40).
Discretization tab	↪Sec. 36.1.2
Scaling tab	↪Sec. 36.1.2
Periodization tab	↪Sec. 36.1.1.2

36.1.1 Definition Area and Periodization

A surface can be set to be periodical. In the non-periodical case you can set up the *(Inner) Definition Area*[PE] of the surface. This means that you define the *Size and Shape* of the definition area and how it behaves *Outside* of the definition area. The corresponding control is described in more detail in Sec. 36.1.1.1.

The specified definition area should lie completely within the *Approximated Function Domain* (↪Sec. 138.1.1) which depends on the type and the parameters of the actual surface. If this constraint is breached, it is shown as ⚠ in the *Validity* indicator. It is ensured that a definition area exceeding the function domain yields still a valid surface, but possibly with sharp “bends” or very large height values. For example the function domain of a spherical surface is a circle with a radius equal to its radius of curvature. But for a toroidal surface only an approximated function domain can be calculated numerically.

On the *Periodization* tab you can define whether to *Use Periodization* and if yes, what *Period*[PV] the surface has. In this case the height profile as defined in the *Structure* tab is replicated periodically whereas only rectangular “elementary cells” are supported. If the inner definition area is smaller than the period, the surface does not fill the whole elementary cell.

The *Outer Definition Area*[PE] which can be also set up on the *Periodization* tab (↪Sec. 36.1.1.2) defines the overall size of the surface. Fig. 207 shows an example for a periodical surface.

The inner definition must not be larger than the period and the period must not be larger than the outer definition area. This is also shown by the *Validity* indicator.

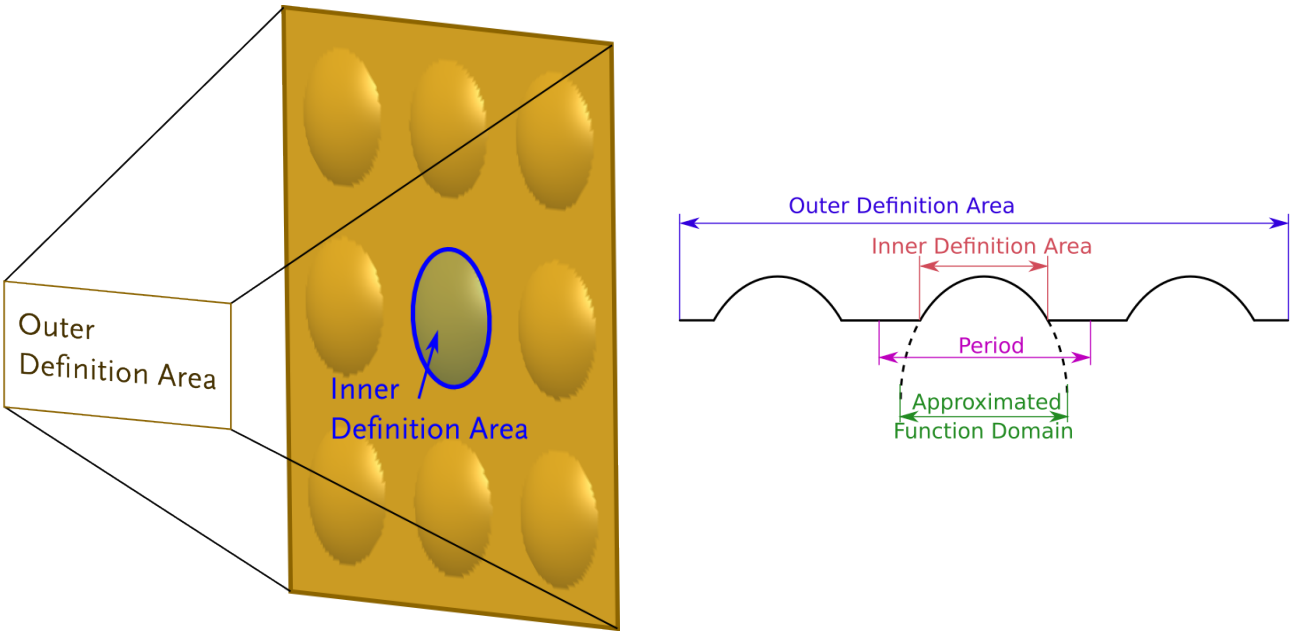


Figure 207. *Definition of Inner and Outer Definition Area, Period and Approximated Function Domain using the example of a periodical conical surface.* ***Left:*** *3D view.* ***Right:*** *Section*

Grating surfaces are always periodical and have an inner definition which is always equal to the period.

36.1.1.1 Definition Area Control

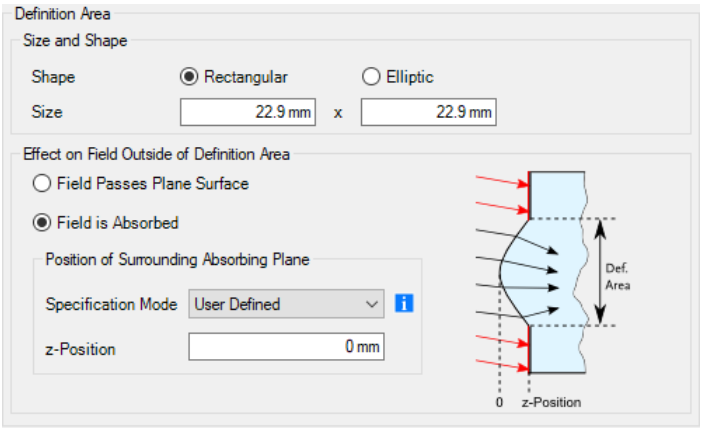


Figure 208. *Definition area control used for setup of definition areas of optical surfaces.*

This control (↪Fig. 208) lets you specify *Size and Shape* of the definition area of a surface and how it behaves outside, i. e. the *Effect on Field Outside of Definition Area*.

ITEM	DESCRIPTION
Shape PE	You can choose whether the actual definition area of the control has a *Rectangular* or an *Elliptical* shape.
Size PV	Specify x- and y-extension of the actual definition area. With a double-click on either the x- or the y-extension box you can turn the definition area into a circular or quadratic one, respectively.
Effect on Field Outside of Definition Area	Outside of the definition area always a plane surface is added. This plane surface either behaves as normal surface (i. e. *Field Passes Plane Surface*) or as completely absorbing surface (i. e. *Field is Absorbed*).
Position of Surrounding Absorbing Plane / Position of Surrounding Surface Plane	The value *z-Position* gives the position of the plane that surrounds the definition area and which either absorbs the field or lets it pass, depending on the setting of *Effect on Field Outside of Definition Area*. A value of *0 m* is identical to the surface's location at the lateral position (0 m; 0 m). If the *Specification Mode* is set to *User Defined*, you can set an arbitrary value. For the other specification modes, the height is determined automatically, see below.
Specification Mode	The mode to specify the *Position of Surrounding Surface / Absorbing Plane*. This can be equal to one of the following positions, that are also shown in Fig. 209: • The maximum height value in the definition area (*Area Maximum*), • the minimum height value in the definition area (*Area Minimum*), • the maximum height value along the boundary of the definition area (*Boundary Maximum*), or • the minimum height value along the boundary of the definition area (*Boundary Minimum*).

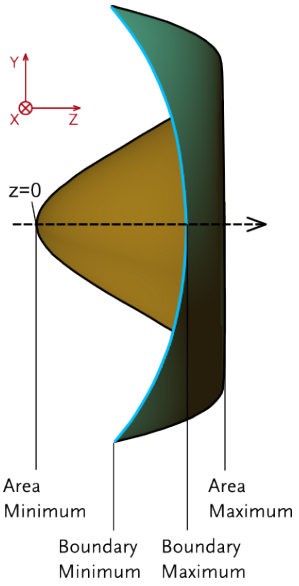


Figure 209. *The different specification modes for the position of that plane which surrounds the definition area of a surface.*

36.1.1.2 Periodization

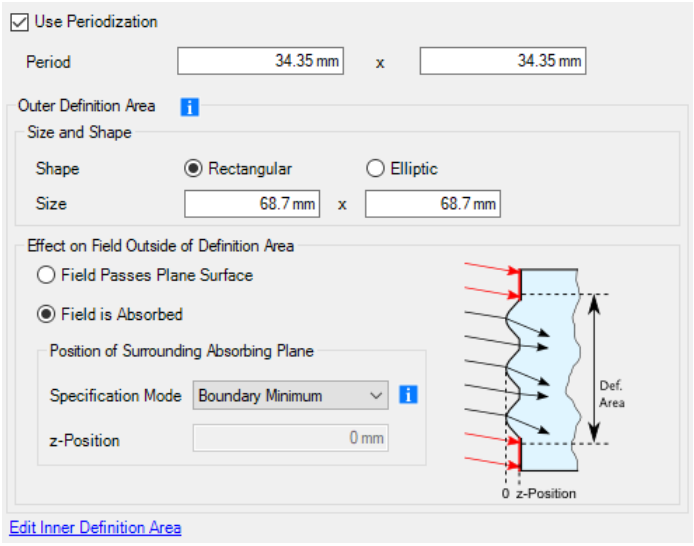


Figure 210. *The periodization tab of the edit dialog for surfaces.*

This tab (↪Fig. 210) allows you to specify the parameters for the periodization of optical surfaces.

ITEM	DESCRIPTION
Period PV	Specify x- and y-extension of the period.
Shape	You can choose whether the outer definition area of the control has a *Rectangular* or an *Elliptical* shape.
Size PV	Specify x- and y-extension of the outer definition area.
Effect on Field Outside of Definition Area	Outside of the definition area always a plane surface is added. This plane surface either behaves as normal surface (i. e. *Field Passes Plane Surface*) or as completely absorbing surface (i. e. *Field is Absorbed*).
Position of Surrounding Absorbing Plane / Position of Surrounding Surface Plane	The value *z-Position* gives the position of the plane that surrounds the definition area and which either absorbs the field or lets it pass, depending on the setting of *Effect on Field Outside of Definition Area*. A value of *0 m* is identical to the surfaces location at the lateral position (0 m; 0 m). If the *Specification Mode* is set to *User Defined*, you can set an arbitrary value. For the other specification modes, the height is determined automatically, see below.
Specification Mode	The mode to specify the *Position of Surrounding/Surface Absorbing Plane*. This can be equal to one of the following positions, that are also shown in Fig. 209: • The maximum height value in the definition area (*Area Maximum*), • the minimum height value in the definition area (*Area Minimum*), • the maximum height value along the boundary of the definition area (*Boundary Maximum*), or • the minimum height value along the boundary of the definition area (*Boundary Minimum*).
Edit Inner Definition Area	This link is a shortcut to the *Structure* tab, where you can set the Inner Definition Area as described above in Sec. 36.1.1.1.

36.1.2 Height Discontinuities and Rescaling of Surfaces

VirtualLab Fusion allows to scale any surface in x-, y-, and z-direction, respectively. Furthermore, VirtualLab Fusion offers three mathematical operations which introduce height discontinuities into the height profile of an optical surface.

1. **Pixelation** introduces rectangular pixels. The height within one pixel remains constant. ↪Sec. 36.1.2.1.
2. **Height Quantization** introduces a limited number of equidistant discrete height levels. The height at a certain position is set to the nearest height level. ↪Sec. 36.1.2.2.
3. Using **Fresnel zones**, the height profile is wrapped so that all height values lie within a certain interval. ↪Sec. 36.1.2.3.

The following equation shows how and in which order these surface manipulations are applied.

$$h(x,y) = \mathcal{Q}\left(\zeta\mathcal{R}\left(h'\left[\mathcal{P}\left(\frac{x}{\xi}\right),\mathcal{P}\left(\frac{y}{\eta}\right)\right]\right)\right) \tag{36.1}$$

$h'(x,y)$ is the original height profile, e. g. that of a conical surface. $h(x,y)$ is the height profile after applying the aforementioned manipulations. ξ,η and ζ represent a *Scaling in x-Direction*, *Scaling in y-Direction*, and *Scaling in z-Direction*, respectively. These settings can be found on the *Scaling* tab of a surface dialog (↪Fig. 211). Obviously, the *Scaling in x-Direction* and the *Scaling in y-Direction* effect the Approximated Function Domain (↪Sec. 36.1.1). The *Scaling in z-Direction* must not be zero, a negative *Scaling in z-Direction* means that the height profile is inverted.

$\mathcal{P}(a)$ refers to the pixelation operator (↪Sec. 36.1.2.1), $\mathcal{Q}(h)$ to the quantization operator (↪Sec. 36.1.2.2), $\mathcal{R}(h)$ to the fresnelization operator (↪Sec. 36.1.2.3).

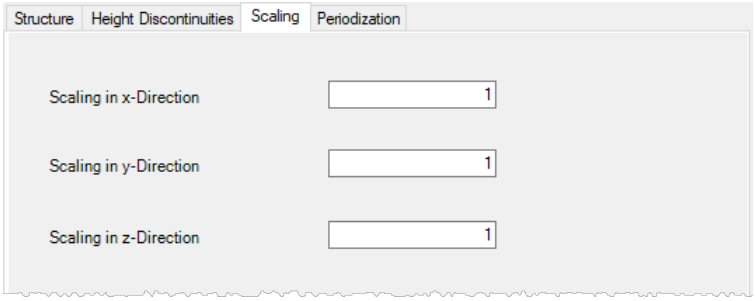


Figure 211. *The Scaling tab of the edit dialog for surfaces.*

36.1.2.1 Pixelation

The pixelation function $p(a)$ introduces discrete rectangular pixels in the height profile and is defined as

$$p(a) = \begin{cases} \text{round}\left(\frac{a}{\Delta a}\right)\Delta a & ;\text{if } \textit{Use Pixelation} \text{ is set.} \\ a & ;\text{else} \end{cases}. \tag{36.2}$$

Δa represents the *Pixel Size* [PV] along the x- or y-axis. The pixel size is in general different along both axes. Note, according to Eq. (36.1), the resulting pixelation effect (the size of a region for which the height is constant) is influenced by the scaling parameters β (scaling in x-direction) and γ (scaling in y-direction).
Use Pixelation and the *Pixel Size* can be set on the *Height Discontinuities* tab of a surface dialog (↪Fig. 212).

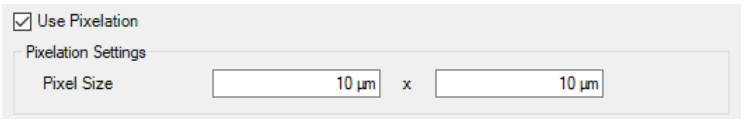


Figure 212. *The pixelation settings for a surface which can be found on the Height Discontinuities tab of its edit dialog.*

The Sampled Surface contains discrete, equidistantly sampled height values with sampling distances δx and δy along the x- and y-axis, respectively. An additional interpolation method creates a continuous surface profile from these sampling points. If a user selects *Nearest Neighbor* as *Interpolation Method* in the sampled surface, rectangular pixels will always appear. Hence pixelation cannot be disabled then and the pixel sizes are fixed to $\delta x \cdot \delta y$.

36.1.2.2 Use Discrete Height Levels (Height Quantization)

The function $q(h)$ introduces discrete height levels in an optical surface and is defined as

$$q(h) = \begin{cases} h & \text{if } \textit{Use Discrete Height Levels (Height Quantization)} \text{ is not set.} \\ q_{\text{min}} & \text{if } h_{\text{min}} \leq h < q_{\text{min}}. \\ q_{\text{max}} & \text{if } q_{\text{max}} < h \leq h_{\text{max}}. \\ \text{round}\left(\frac{h-q_{\text{min}}}{\Delta h}\right)\Delta h + q_{\text{min}} & \text{else} \end{cases}. \tag{36.3}$$

q_{min} and q_{max} are the minimum and the maximum height level of the discretized height profile, respectively. Δh is the height difference between two consecutive height levels and is defined as

$$\Delta h = \frac{q_{\text{max}} - q_{\text{min}}}{n-1}. \tag{36.4}$$

h_{min} represents the minimum height of the original non-discretized surface and h_{max} its maximum height. n is the *Number of Discrete Height Levels* between and including q_{min} and q_{max}. The function round(x) returns the integer value closest to x.
VirtualLab Fusion offers three quantization modes differing in the choice of q_{min} and q_{max}.

QUANTIZATION MODE	Q_{MIN}	Q_{MAX}
Min-Max-Tread	h_{min}	h_{max}
Min-Max-Riser	$h_{\text{min}} + \frac{h_{\text{max}} - h_{\text{min}}}{2n} = h_{\text{min}} + \frac{\Delta h}{2}$	$h_{\text{max}} - \frac{h_{\text{max}} - h_{\text{min}}}{2n} = h_{\text{max}} - \frac{\Delta h}{2}$
User Defined Min- and Max-Levels	User Defined	User Defined
	$h_{\text{min}} \leq q_{\text{min}} < q_{\text{max}} \leq h_{\text{max}}$	

Mathematical details can be found in Sec. 138.1.2.2.
The quantization of a surface can be configured on the *Height Discontinuities* tab of its dialog. The corresponding controls are shown in Fig. 213 and described below.

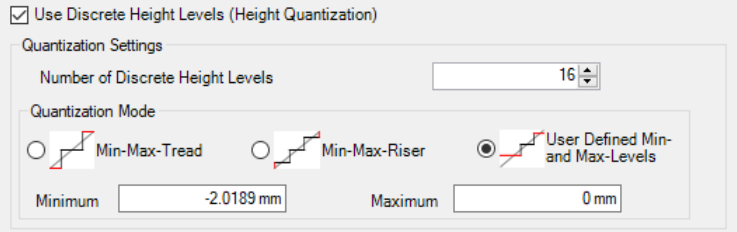


Figure 213. *The controls which can be used to configure the quantization of a surface.*

ITEM	DESCRIPTION
Use Discrete Height Levels (Height Quantization)	Switches the height quantization of a surface on and off.
Number of Discrete Height Levels PV	The number n of discrete height levels. Must not exceed 4096.
Quantization Mode	Allows you to select any of the three quantization modes explained in Sec. 138.1.2.2 (*Min-Max-Tread*, *Min-Max-Riser*, or *User Defined Min- and Max-Levels*).
Minimum / Maximum	Allows you to set $h_{\text{q,min}}$ and $h_{\text{q,max}}$, if in user defined mode. The dialog ensures that $q_{\text{min}} < q_{\text{max}}$. Note that according to Eq. (36.1), the allowed values for q_{min} and q_{max} are influenced by the *Scaling in z-Direction*.

36.1.2.3 Fresnel Zones

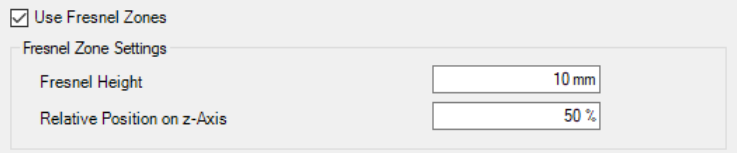


Figure 214. *The controls for configuring the Fresnel zones of a surface. They can be found on the* Height Discontinuities *tab of a surface edit dialog.*

The following table describes the controls (↪Fig. 214) which can be used to introduce Fresnel zones. A mathematical description and some explaining figures are given below.

ITEM	DESCRIPTION
Use Fresnel Zones	"Folds" the height profile so that the resulting surface contains so-called Fresnel zones.
Fresnel Height PV	The difference between the maximum and the minimum height values in the surface after Fresnel zones have been introduced.
Relative Position on z-Axis	The size of the innermost Fresnel zone can be adjusted by the *Relative Position on z-Axis*.

If you *Use Fresnel Zones* the height profile is "folded" so that all height values lie in the interval $-p \cdot h_\mathrm{t} \ldots (1-p)h_\mathrm{t}$. h_t refers to the *Fresnel Height* and p refers to the *Relative Position on z-Axis*.
Thus, if the *Relative Position on z-Axis* is set to 0 % the height values range from 0 to $+h_\mathrm{t}$. This is the recommended setting for a height profile containing only positive height values (e. g. a conical surface with positive radius of curvature).
Vice versa, a *Relative Position on z-Axis* of 100 % is recommended for surfaces with only negative height values as then the height values are in the range $-h_\mathrm{t} \ldots 0$.
Any intermediate relative position is of course also feasible. Fig. 215 shows an example for the effect of the relative position.

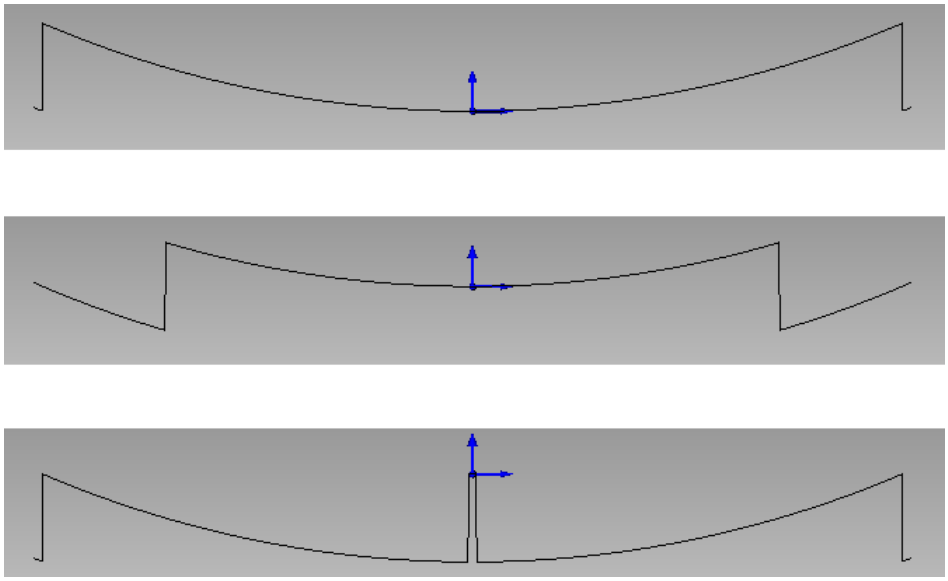


Figure 215. *Cross section of a cylindrical surface with positive radius of curvature and Fresnel zones. The subfigures illustrate the effect of different values for the* Relative Position on z-Axis p.
Top: $p = 0\,\%$. *Height values range from 0 to 2 mm.* **Middle:** $p = 50\,\%$. *Height values range from -1 to 1 mm.* **Bottom:** $p = 99.99\,\%$. *Height values range from (nearly) -2 to (nearly) 0 mm.*

Note that the *Scaling in z-Direction* is applied after introducing the Fresnel zones. Thus the scaling in z-direction does not influence the positions of the Fresnel "jumps" but the total profile height of a surface with Fresnel "jumps" is the scaling factor α times the set *Fresnel Height*.

36.1.3 Surface Tools

The *Tools*-button opens a menu containing the following items:

ITEM	DESCRIPTION
View Surface	Shows the surface in the dialog described in Sec. 36.3.
Save to Catalog	Saves the surface to the catalog (↪Sec. 33). Not visible if the edit dialog is shown from within the surfaces catalog.
Import	In the moment, this item is only available for the sampled surface (↪Sec. 36.2.11): Either GDSII, CIF, text or bitmap data can be imported if a parameter summary file is provided in the XML format explained in Sec. 133.4.
Export	Exports the surface to various text and binary formats. ↪Sec. 133.1.

36.2 Surface Types

In this section, the types of Optical Surfaces provided by VirtualLab Fusion are described. They can be accessed as templates in the Surface Catalog.

36.2.1 Anamorphic Asphere Surface

This surface is a biconic surface with additional coefficients describing a deviation in radial and azimuthal direction.

Its height function is defined by

$$h(x,y) = \frac{c_x^2 + c_y^2}{1 + \sqrt{1 - (1+\kappa_x)c_x^2 x^2 - (1+\kappa_y)c_y^2 y^2}} + \sum_{i=2}^{n} a_{\mathrm{r},i} \left((1 - a_{\mathrm{p},i})x^2 + (1 + a_{\mathrm{p},i})y^2 \right)^i \tag{36.5}$$

c_x and c_y are the curvatures in x- and y-direction, respectively, with

$$c_x = \frac{1}{R_x} \quad \text{and} \quad c_y = \frac{1}{R_y} \quad . \tag{36.6}$$

R_x and R_y are the radii of curvature of the surface and κ_x and κ_y the conical constants in x and y direction. $a_{\mathrm{r},i}$ are the radial and $a_{\mathrm{p},i}$ the azimuthal coefficients of the surface.

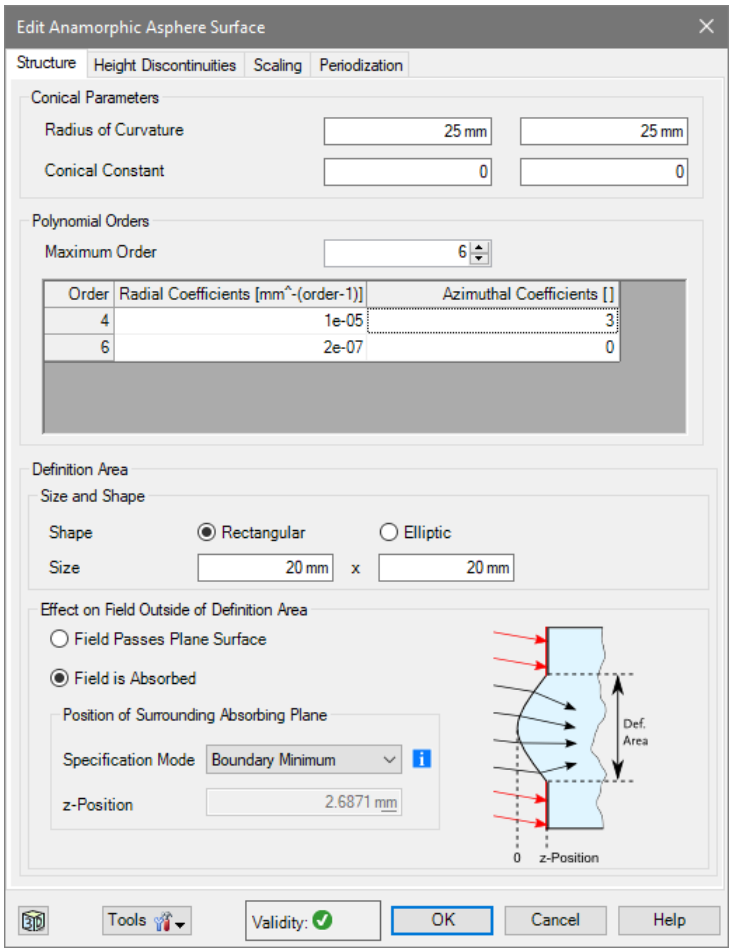


Figure 216. *Dialog for defining an anamorphic asphere surface.*

Fig. 216 shows the edit dialog where the specific parameters of the anamorphic asphere surface can be set.

ITEM	DESCRIPTION
Radius of Curvature PV	The radii of curvature R_x and R_y (↪Eq. (36.6)) of the surface in meters.
Conical Constant PV	The conical constants κ_x and κ_y. ↪Eq. (36.5); see also Sec. 36.2.4
Maximum Order	The maximum order $2n$ of the additional polynomial. ↪Eq. (36.5)
{Coefficients Table}	In this table you can specify the radial coefficient $a_{r,i}$ PV and the azimuthal coefficients $a_{r,i}$ PV of each order $2i$. Its physical units are given in square brackets in the column headers. ↪Eq. (36.5)

Via the context menu of the table you can copy and paste the parameter list.
The remaining controls are explained in Sec. 36.1.

36.2.2 Aspherical Surface

The profile height $h(x,y)$ of an aspherical surface is defined by an expression of the form

$$h(x,y) = \underbrace{\frac{cr^2}{1+\sqrt{1-(1+\kappa)c^2r^2}}}_{\hookrightarrow \text{Sec. 36.2.4}} + a_1 r + a_2 r^2 + a_3 r^3 + \ldots + a_n r^n \tag{36.7}$$

where the first part is the height function of a conical surface which is explained in detail in Sec. 36.2.4. $r = \sqrt{x^2+y^2}$; $a_1 \ldots a_n$ are the additional asphere parameters.
Fig. 217 shows the edit dialog where the specific parameters of the aspherical surface can be set.

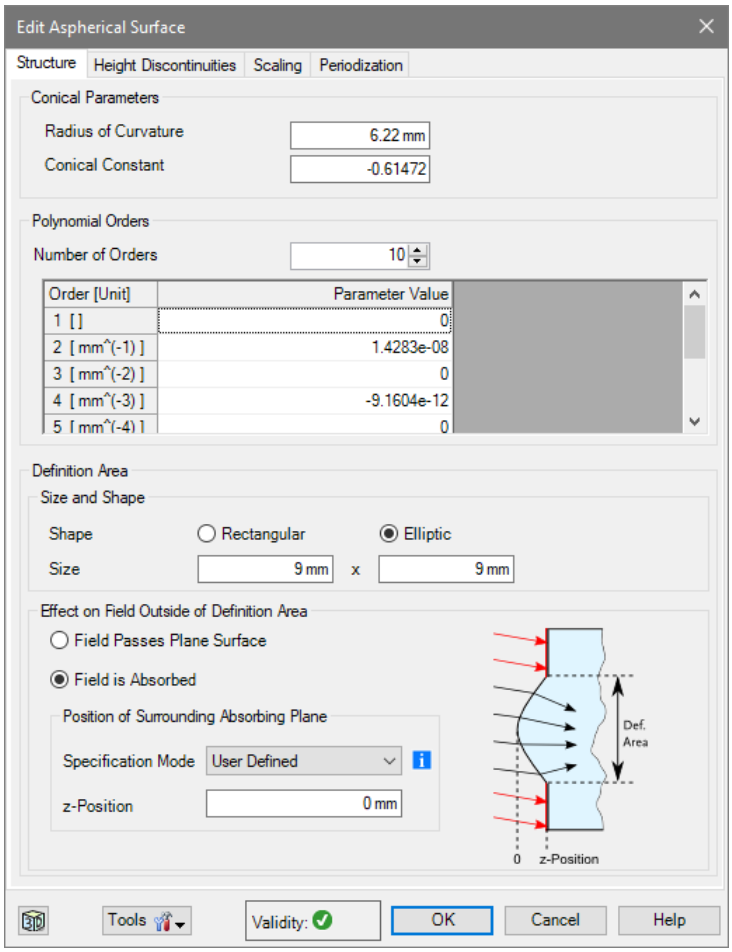


Figure 217. *Dialog for defining an aspherical surface.*

ITEM	DESCRIPTION
Radius of Curvature PV	The radius of curvature R (↪Sec. 36.2.4) of the surface in metric units.
Conical Constant PV	The conical constant κ (↪Sec. 36.2.4)
Number of Orders	The number n of the additional *Aspherical Parameters* PV a_i. The length of the table for entering these parameters depends on this number.
Order	The order i of the asphere parameter a_i, that is specified by *Parameter Value*. Its physical unit is given in square brackets: [*unit*].
Parameter Value	Value of the asphere parameter a_i (↪Eq. (36.7)), whereas i is given by *Order*.

Via the context menu of the table you can copy and paste the parameter list.
The remaining controls are explained in Sec. 36.1.

36.2.3 Combined Surface

A combined surface is the result of adding the profile heights of two sub-surfaces. As an example, sophisticated optical surfaces can be achieved by combining an asphere with a sampled surface.
Fig. 218 shows the Edit dialog, where the specific parameters of the combined surface can be set.

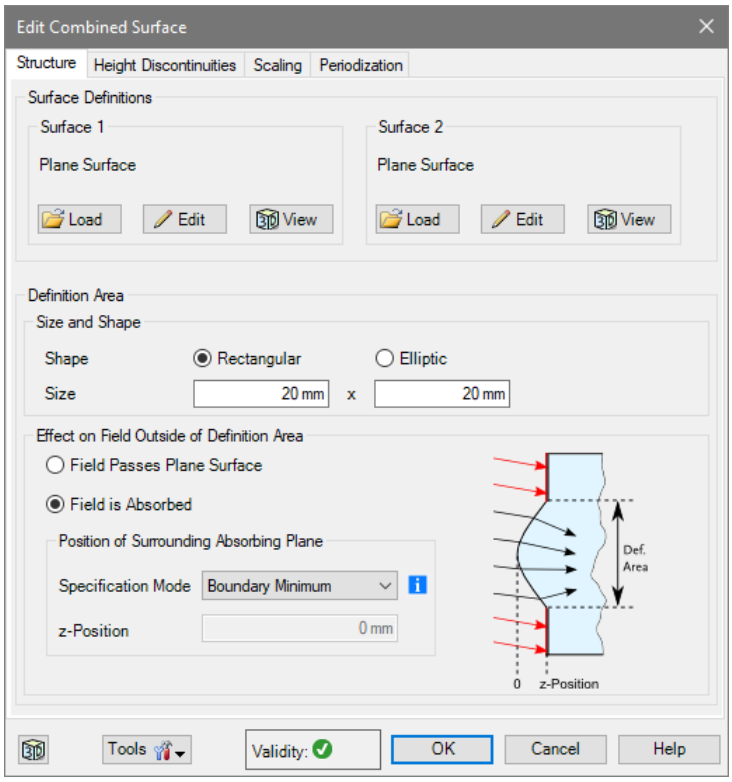


Figure 218. *Dialog for defining a combined surface.*

ITEM	DESCRIPTION
Surface 1 / 2 PE	The surfaces which shall be combined can be specified by standard catalog access[1] in VirtualLab Fusion. The user can also edit and view the selected surfaces. For these surfaces, always *Field Passes Plane Surface* is selected as *Effect on Field Outside of Definition Area* – an addition of an absorbing and a transparent height profile is not well defined.

The remaining controls are explained in Sec. 36.1.

36.2.4 Conical Surface

Conical surfaces are a special kind of second order surfaces, that can be described as rotating conic sections. They are also well known as hyperboloid, paraboloid, ellipsoid and sphere and are defined by

$$h(x,y) = \frac{cr^2}{1+\sqrt{1-(1+\kappa)c^2r^2}} \tag{36.8}$$

where c denotes the curvature, κ the conical constant and $r = \sqrt{x^2+y^2}$ the lateral distance to the optical axis. The value of the conical constant determines the type of the surface, i. e. $\kappa < -1$ gives a hyperboloid, $\kappa = -1$ a paraboloid, $-1 < \kappa < 0$ gives a prolate ellipsoid, $\kappa = 0$ a sphere and $\kappa > 0$ an oblate ellipsoid.
The curvature is connected to the radius of a sphere ($R = \sqrt{x^2+y^2+z^2}$) or to the vertex radius of a paraboloid ($R = (x^2+y^2)/(2z)$) by $c = 1/R$. This radius is also called *Radius of Curvature*.
For an ellipsoid or a hyperboloid the parameters c and κ can be calculated from its semi axes a and b using the relationships

$$\frac{1}{c} = \pm\frac{b^2}{a} \quad \text{and} \quad \kappa = -\frac{(a^2-b^2)}{a^2}. \tag{36.9}$$

The intersection points of the light and the surface are calculated analytically.

[1] Part V explains the general catalog concept, its subsection Sec. 34.1 explains the control for loading, editing, and viewing catalog entries.

Fig. 219 shows the Edit dialog, where the required values to define a conical surface can be entered.

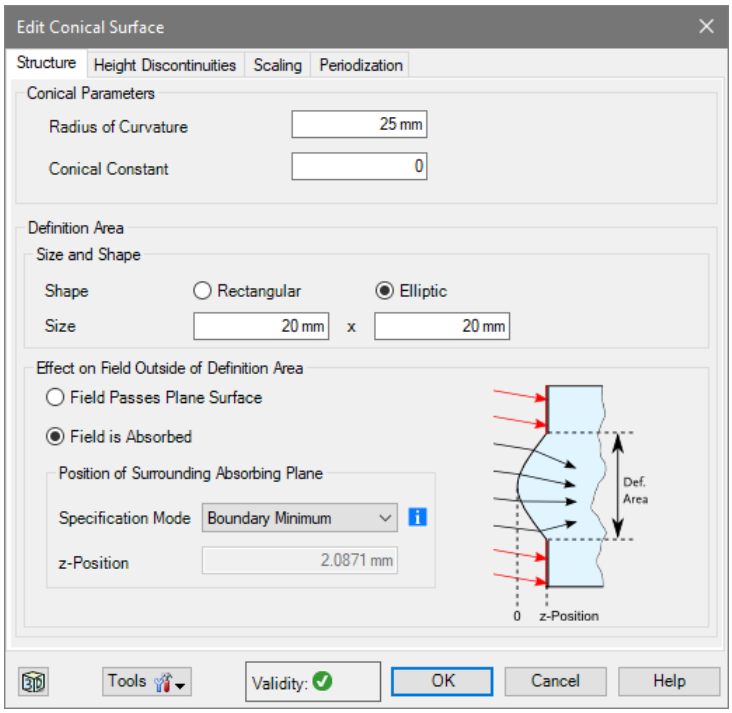


Figure 219. *Dialog for defining a conical surface.*

ITEM	DESCRIPTION
Radius of Curvature PV	The radius of curvature (in the vertex) r (↪Eq. (36.8)) of the conical surface in metric units.
Conical Constant PV	The conical constant κ. ↪Eq. (36.8).

The remaining controls are explained in Sec. 36.1.

36.2.5 Cylindrical Surface

The only difference between the Cylindrical and the Aspherical Surface is the symmetry. While the last one is circular symmetric, the first one has one prime axis (axis of symmetry). So the surface is defined by Eq. (36.7) too, but with the substitution $r = |x\cos(\alpha) + y\sin(\alpha)|$, where α denotes the rotation angle of the axis of symmetry relative to the y-axis (↪Fig. 220). Please note that there is a refraction effect perpendicular to the axis of symmetry only, i. e. parallel to the direction given by α.

Fig. 221 shows the edit dialog, where the specific parameters of the cylindrical surface can be set.

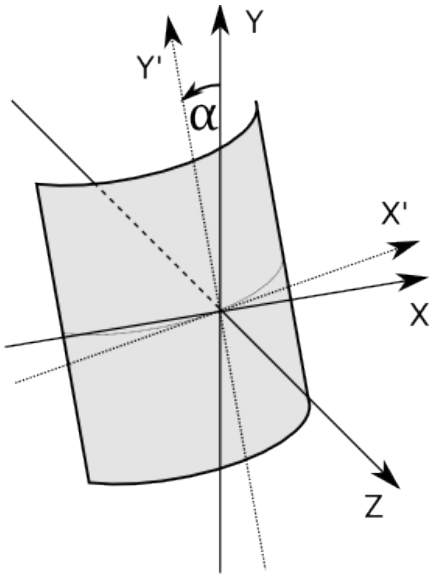


Figure 220. *Sketch of a cylindrical surface, rotated by an angle α.*

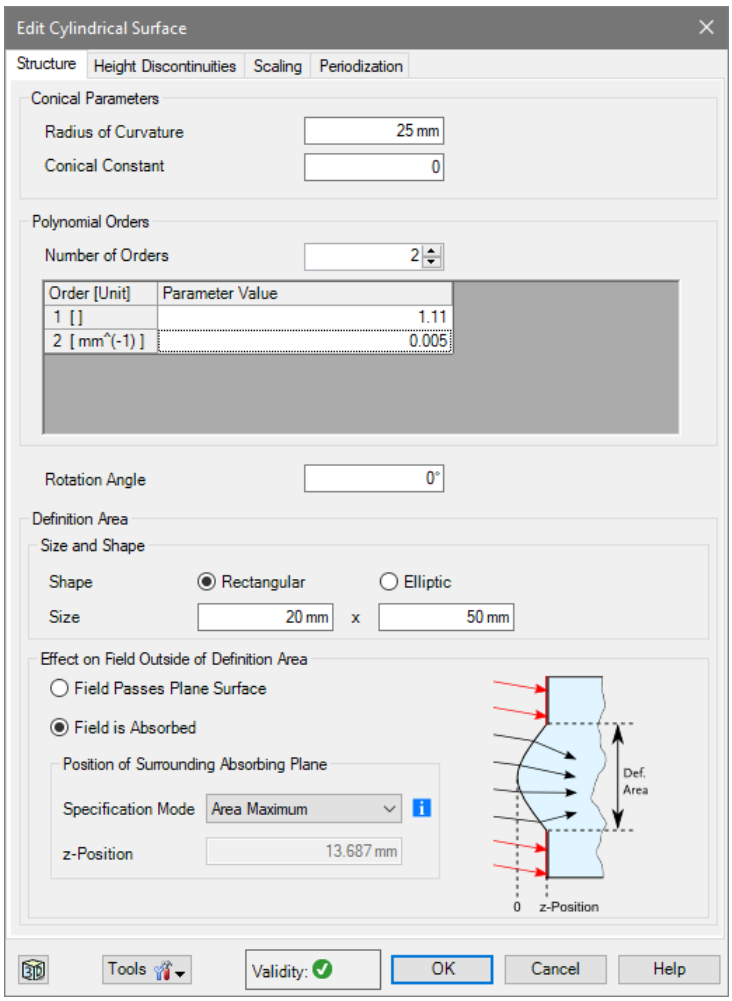


Figure 221. *Dialog for defining a cylindrical surface.*

ITEM	DESCRIPTION
Radius of Curvature PV	The radius of curvature r (↪Eq. (36.7)) of the cylindrical surface in metric units.
Conical Constant PV	The conical constant κ. ↪Eq. (36.7); see also Sec. 36.2.4
Number of Orders	The number of orders, i. e. the number of the additional *Aspherical Parameters* PV a_n. The length of the table for entering these parameters depends on this number.
Order	The order n of the asphere parameter a_n, that is specified by *Parameter Value*. Its physical unit is given in square brackets: [*unit*].
Parameter Value	Value of the asphere parameter a_n (↪Eq. (36.7)), whereas n is given by *Order*.
Rotation Angle PV	The angle (α in Fig. 220) between the axis of symmetry y' and the y-axis. The rotation is done in the x-y-plane and is defined as positive rotation about the z-axis.

Via the context menu of the table you can copy and paste the parameter list.
The remaining controls are explained in Sec. 36.1.

36.2.6 Grating Surfaces

To simulate the optical behavior of gratings, it is possible to use different types of one-dimensional and periodically varying profiles. All of these have some basic values in common:

ITEM	DESCRIPTION
Grating Period PV	The period of the surface's height profile in metric units.
Modulation Depth PV	The amplitude of the height modulation. Please see also the "Note on quantization" below.
Lateral Shift PV	A shift of the surface in the direction of the modulation. Please pay attention: Usually this lateral shift will also cause a change of the surface position on the optical axis (which means a change in the distances to other surfaces too). This is due to the definition of the object position as the intersection point of the surface with the optical axis.
Rotation Angle PV	Per default, the periodical modulation is defined along the x-axis. By using this parameter, the modulation direction can be changed by rotation about the z-axis.

Grating surfaces are always periodical and have an inner definition area which is always equal to the period. The *Period* on the *Periodization* tab is always determined from the *Grating Period* and *Rotation Angle*.
The remaining controls are explained in Sec. 36.1.
As an example Fig. 222 shows the Edit dialog for a sinusoidal grating surface.

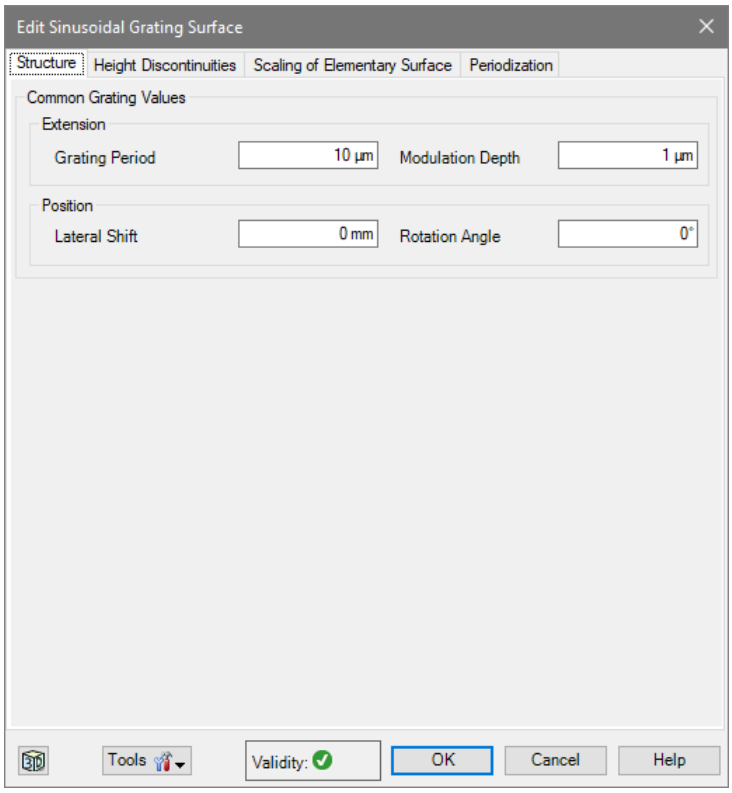


Figure 222. *Edit dialog for a sinusoidal grating surface showing the basic grating parameters.*

36.2.6.1 Rectangular Grating Surface

A rectangular grating surface is shaped as shown in Fig. 223.

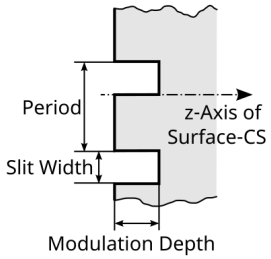


Figure 223. *Shape of an unshifted rectangular modulated grating surface.*

The user can either specify the *Slit Width* PV in meters or the *Relative Slit Width* PV as fraction of the period (→Fig. 224). For the basic grating surface parameters see Sec. 36.2.6, for the general surface dialog see Sec. 36.1.

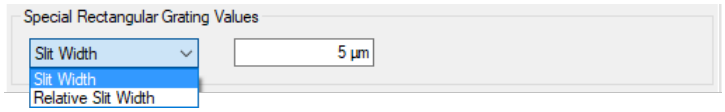


Figure 224. *Control for defining the rectangular grating surface parameters.*

36.2.6.2 Sawtooth Grating Surface

The surface has a shape as shown in Fig. 225.

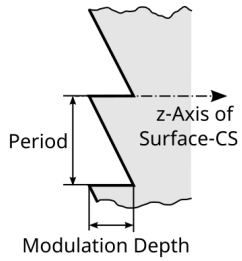


Figure 225. *Shape of an unshifted sawtooth grating surface.*

For the basic grating surface parameters see Sec. 36.2.6, additionally the inclination of the plane surface sections has to be specified (↪Fig. 226).

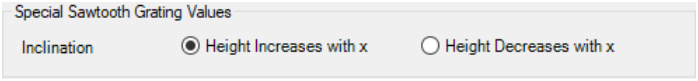


Figure 226. *Radio buttons for defining the inclination (orientation) of a sawtooth grating.*

36.2.6.3 Sinusoidal Grating Surface

Such kinds of grating surfaces have a sinusoidal height profile (↪Fig. 227).

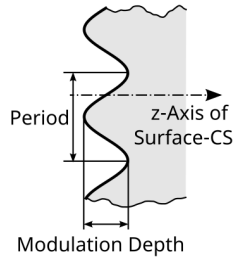


Figure 227. *Shape of an unshifted sinusoidal grating surface.*

There are no further parameters needed to specify this surface, for the basic grating surface parameters see Sec. 36.2.6, for the general surface dialog see Sec. 36.1.

36.2.6.4 Triangular Grating Surface

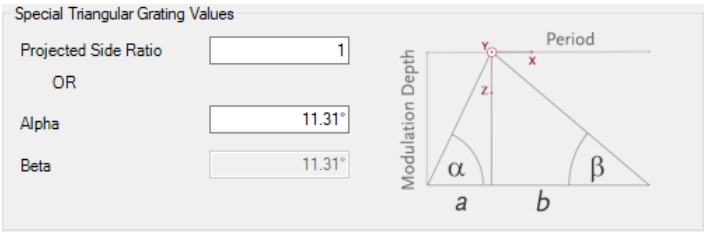


Figure 228. *Controls for defining the specific settings for a triangular grating surface.*

A Triangular Grating Surface can be defined by either the *Projected Side Ratio*[PV] = b/a or the angle *Alpha* (↪Fig. 228). The angle *Beta* is just given as information.
For the basic grating surface parameters see Sec. 36.2.6, for the general surface dialog see Sec. 36.1.

36.2.7 Plane Surface

The profile height $h(x, y)$ of a plane surface, which may be tilted with respect to the optical axis, is calculated by

$$h(x, y) = m_x x + m_y y, \tag{36.10}$$

where x and y indicate the lateral position and m_x and m_y represent the inclinations of the surface in the specific directions.

The intersection points of the light and the surface are calculated using an analytical formula.

Fig. 229 shows the edit dialog, where the parameters for a plane surface can be entered.

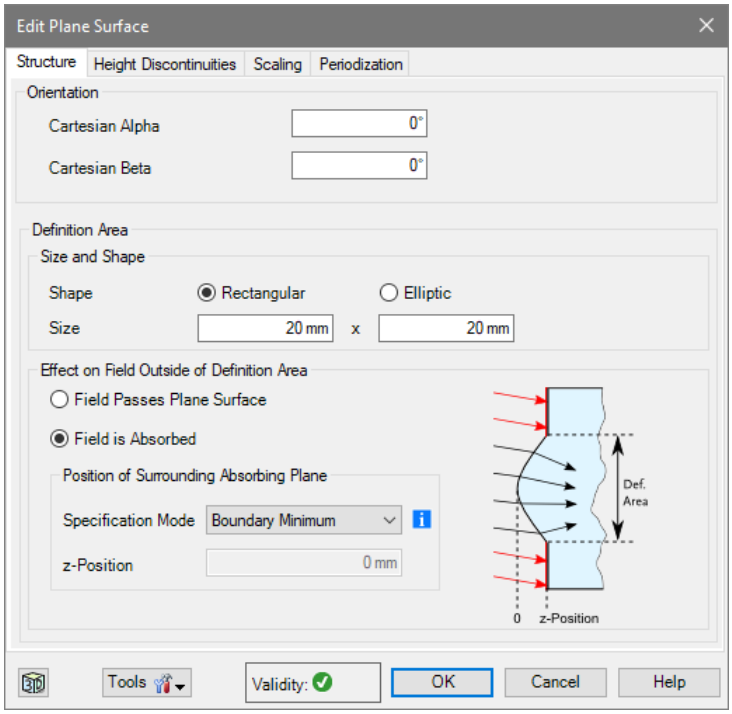


Figure 229. *Dialog for defining a plane surface.*

ITEM	DESCRIPTION
Alpha PV	Angle of the plane surface, measured from the x-axis, representing a rotation about the y-axis. $m_y = \tan$ *Alpha*. ↪Eq. (36.10)
Beta PV	Angle of the plane surface, measured from the y-axis, representing a rotation about the x-axis. $m_x = \tan$ *Beta*. ↪Eq. (36.10)

The remaining controls are explained in Sec. 36.1.

36.2.8 Polynomial Surface

Defines a surface consisting of a rotationally symmetric conical base surface and an additional two-dimensional polynomial. It is defined by the equation:

$$h(x, y) = \underbrace{\frac{cr^2}{1 + \sqrt{1 - (1 + \kappa)c^2 r^2}}}_{\hookrightarrow \text{Sec. 36.2.4}} + \sum_{i=0}^{m} \sum_{j=0}^{n} a_{ij} x^i y^j \quad \text{with} \quad r = \sqrt{x^2 + y^2} \tag{36.11}$$

where the first part is the height function of a conical surface which is explained in detail in Sec. 36.2.4.

Fig. 230 shows the edit dialog where the specific parameters of the polynomial surface can be set.

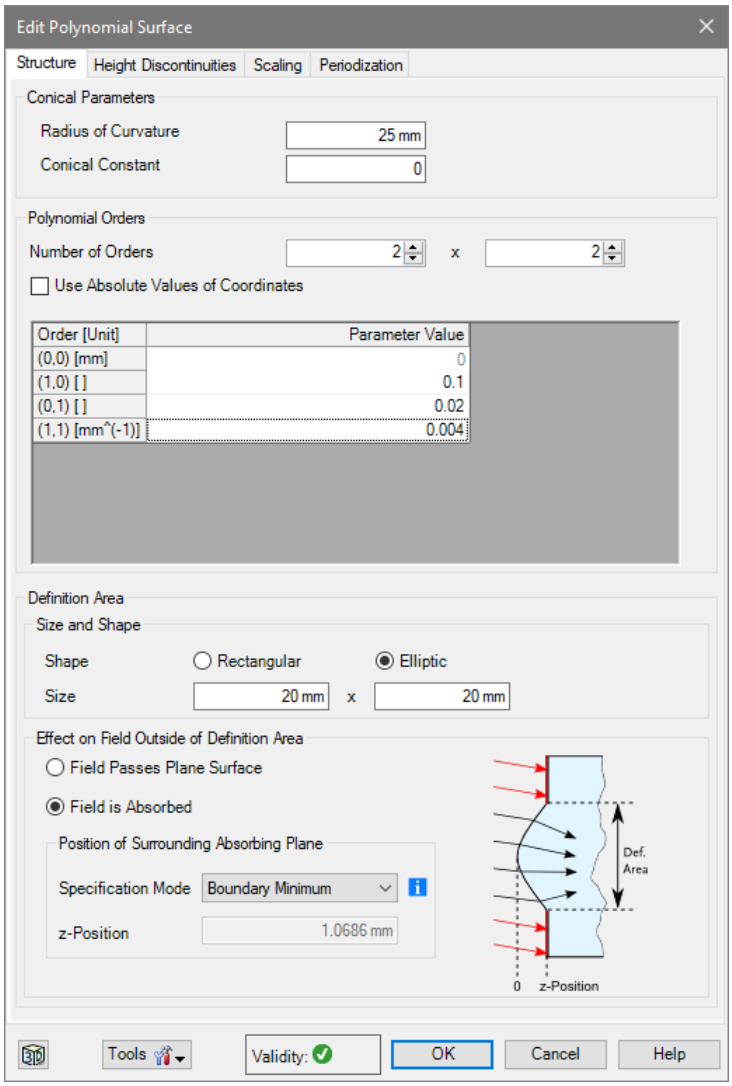


Figure 230. *The edit dialog for polynomial surfaces.*

ITEM	DESCRIPTION
Radius of Curvature PV	The radius of curvature R (↪Sec. 36.2.4) of the surface in metric units.
Conical Constant PV	The conical constant κ (↪Sec. 36.2.4).
Number of Orders	The number $m \times n$ of the additional *Polynomial Parameters* PV a_{ij}. The length of the table for entering these parameters depends on this number.
Use Absolute Values of Coordinates	When you check this option, $\lvert x\rvert^i \lvert y\rvert^j$ are used in Eq. (36.11).
Order	The order (i, j) of the polynomial parameter a_{ij}, that is specified by *Parameter Value*. Its physical unit is given in square brackets: [*unit*].
Parameter Value	Value of the polynomial parameter a_{ij} (↪Eq. (36.11)), whereas i and j are given by *Order*.

Via the context menu of the table you can copy and paste the parameter list.
The remaining controls are explained in Sec. 36.1.

36.2.9 Programmable Surface

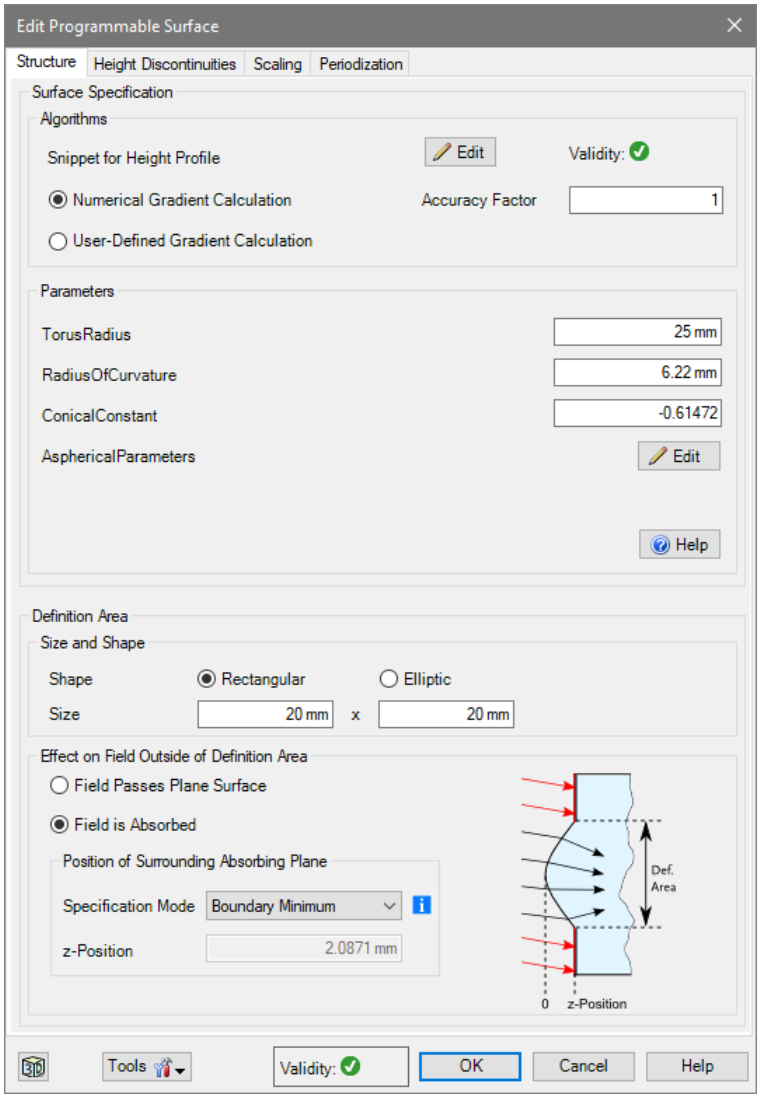


Figure 231. *Sample edit dialog for a programmable surface.*

The programmable surface allows you to define your own surface. The *Structure* tab of its edit dialog (↪Fig. 231) contains the following controls:

ITEM	DESCRIPTION
Snippet for Height Profile	Allows you to program a little code snippet defining the height (in meters) at a certain position $(x; y)$ (in meters). *Edit* opens the Source Code Editor (↪Sec. 7.3) to edit this snippet, and a validity indicator (↪Sec. 5.11) shows whether this snippet is consistent.
Numerical Gradient Calculation	For visualization and some propagation operators, not just the height profile but also its gradient is needed. If this option is selected, the gradient is calculated numerically with a given *Accuracy Factor*.
User-Defined Gradient Calculation	If this option is selected, you can program the gradient in dependency from a certain position $(x; y)$ (in meters). *Edit* opens the Source Code Editor (↪Sec. 7.3) to edit this snippet, and a validity indicator (↪Sec. 5.11) shows whether this snippet is consistent.
Parameters PE	The controls in this group box allow you to set the values of the global parameters of the snippet(s). ↪Sec. 7.4

The remaining controls are explained in Sec. 36.1. General information about programming in VirtualLab Fusion can be found in Sec. 7.

36.2.10 Q-Type Asphere Surface

A Q-Type Asphere Surface is the combination of a conical surface (↪Sec. 36.2.4) and so-called Q-polynomials proposed in [For07]. There are two sets of such polynomials: the Q^{con} describing strong deviations from a conical surface and the Q^{bfs} describing mild deviations from a spherical surface. The coefficients of these polynomials give the deviation directly as a length.

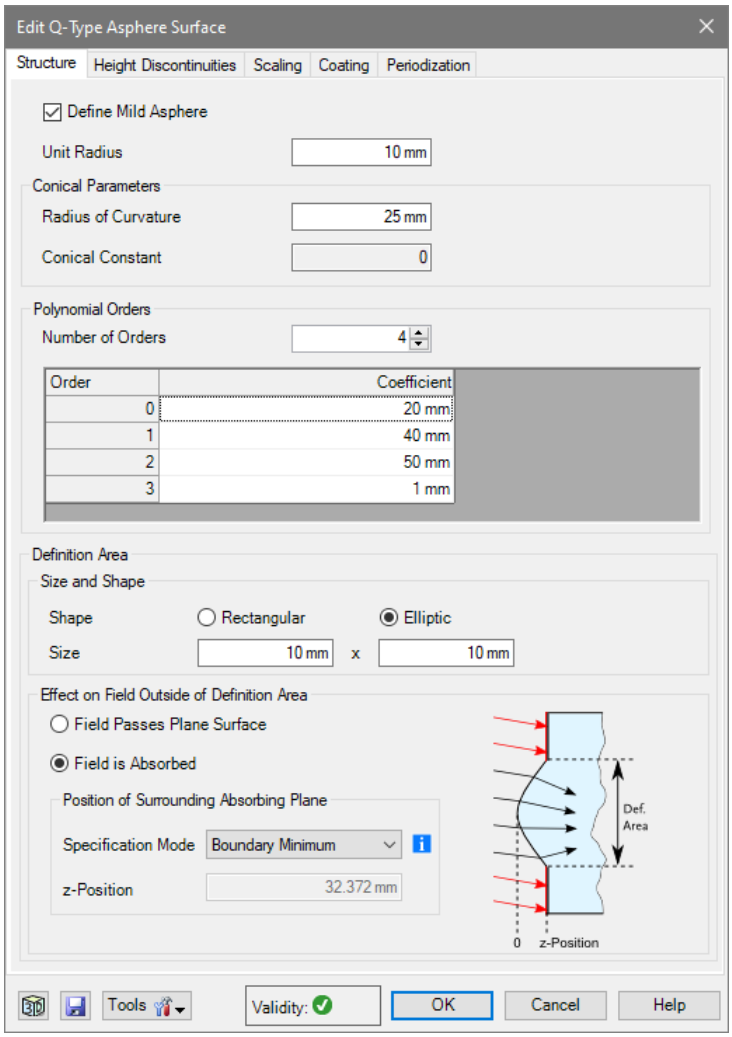


Figure 232. *The edit dialog for a Q-Type Asphere Surface.*

The edit dialog for this surface (↪Fig. 232) has the following controls.

ITEM	DESCRIPTION
Define Mild Asphere PE	Defines whether the Q^{bfs} for mild aspheres or the Q^{con} for strong aspheres are used.
Unit Radius PV	The polynomials are polynomials in ρ/ρ_{max} with $\rho = \sqrt{x^2 + y^2}$ and ρ_{max} being the *Unit Radius*. Within the unit radius the z-extension of the surface is in the range defined by the coefficients. Outside of the unit radius it can become much larger.
Radius of Curvature PV	The radius of curvature R (↪Sec. 36.2.4) of the surface in metric units.
Conical Constant PV	The conical constant κ (↪Sec. 36.2.4). Always zero for mild aspheres which describe the deviation from a sphere.
Number of Orders	The number of monomials used, starting with the constant term. The length of the table for entering these parameters depends on this number.
Order	The order n of the Q-polynomial. Note that because of the convention $h(0\,\text{m}; 0\,\text{m}) = 0\,\text{m}$, the first order has no effect for strong aspheres (but for mild aspheres).
Coefficient PV	Coefficient of the n-th monomial of the Q-polynomial in meters.

The remaining controls are explained in Sec. 36.1.

36.2.11 Sampled Surface

A sampled surface is defined by a height profile $h(x, y)$ that represents discrete sampling points. These sampling points can be interpreted as rectangular pixels or they can be interpolated using different interpolation methods.

Fig. 233 shows the Edit dialog, where the specifications for the chosen sampled surface can be set.

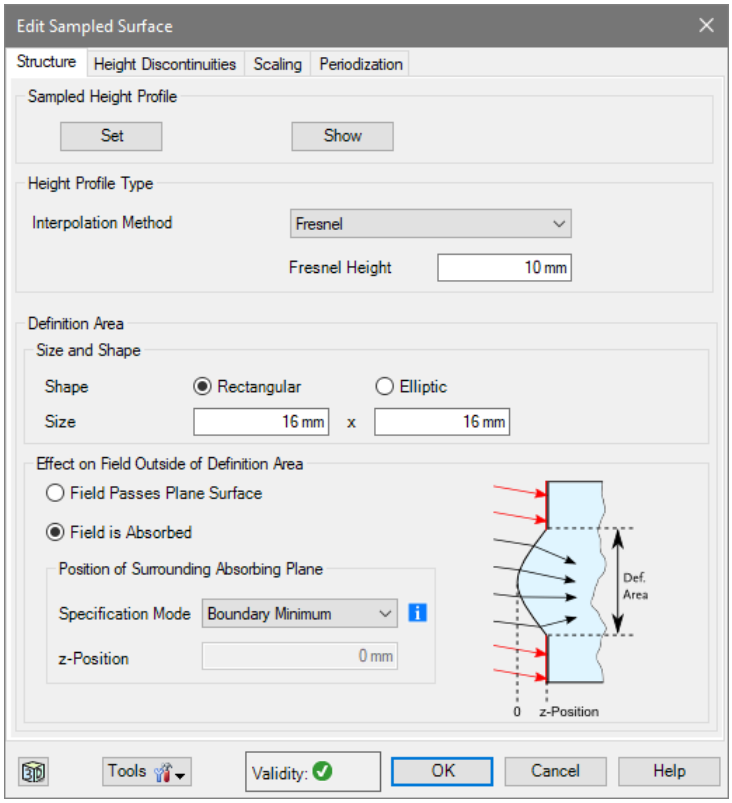


Figure 233. *Dialog for defining a sampled surface.*

ITEM	DESCRIPTION
Set	Offers you three ways to set a data array describing the height profile (see below). It is assumed that the height profile is centered around the optical axis. The data array must contain only one real-valued, equidistantly sampled subset where both the coordinates and the data have the unit length. The definition area is set to the coordinate extent of the data and the interpolation according to the interpolation of the data array. See also the chapter about interpolation methods (↪Sec. 136.4) for reference. The settings on the *Periodization* tab are reset. If you set a one-dimensional profile it is assumed to be unmodulated in the y-direction.
Set > Load	Loads a data array from a .da file.
Set > Import	Imports a data array from a text file by means of the import wizard described in Sec. 121.1.
Set > Select from Documents	Allows you to select an already open data array.
Set > Reset	Resets the height profile to its default (a plane surface sampled with 5 × 5 sampling points).
Show	Shows the currently set height profile as data array. The height in the center (0 m; 0 m) is always zero as this is the way the height profile is interpreted by VirtualLab Fusion.
Interpolation Method	The four available interpolation methods determine how the height data is interpreted. • **Nearest Neighbor:** If the data represents a pixelated surface. On the *Height Discontinuities* tab, *Use Pixelation* is always true and the *Pixel Size* is equal to the sampling distance of the imported diagram. • **Linear:** If the surface consists of areas with constant slope. • **Cubic 8 Point:** If the data represents a smooth surface. • **Fresnel:** This interpolation method avoids interpolation artifacts at Fresnel jumps and is thus only to be used for a smooth surface which contains Fresnel zones. If you select this interpolation method, *Use Fresnel Zones* on the *Height Discontinuities* tab is always checked and you can enter the *Fresnel Height* directly below the interpolation selection.
Import	Either GDSII, text or bitmap data can be imported if a parameter summary file is provided in the XML format explained in Sec. 133.4.

The remaining controls are explained in Sec. 36.1.
If the *Interpolation Method* is not set to *Nearest Neighbor* there is an additional surface tool (↪Sec. 36.1.3) for fitting a smooth surface to the given data. This tool is described in Sec. 36.2.11.1.

36.2.11.1 Fit Smooth Surface

VirtualLab Fusion allows you to fit a polynomial to a sampled height profile resulting in either a *Cylindrical Surface* (↪Sec. 36.2.5), *Aspherical Surface* (↪Sec. 36.2.2), or *Polynomial Surface* (↪Sec. 36.2.8). The dialog shown in Fig. 234 allows you to set the options for this fit. The resulting surface is stored in the user-defined surface catalog (↪Sec. 33).

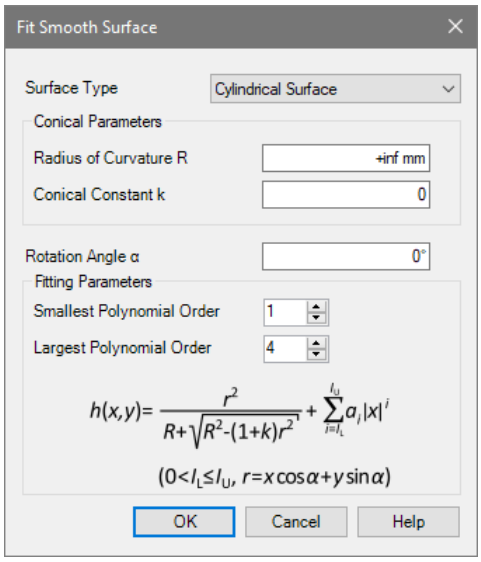


Figure 234. *The edit dialog for the fit smooth surface tool if the surface type is set to cylindrical surface.*

For all surface types you can specify *Radius of Curvature* and *Conical Constant* as these parameters are not handled by the fitting algorithm. However, if the number of fitted polynomial orders is sufficiently large a reasonably good fit can be achieved, even if these parameters are the default values.
The *Fitting Parameters* allow you to set the minimum and the maximum orders taken into account for the polynomial fit. Depending on the selected *Surface Type*, the actual layout of this group box varies. For the fit of a cylindrical surface you can also preset the *Rotation Angle*.

36.2.12 Toroidal Asphere Surface

This surface originates from an aspherical cross section rotated about the y-axis which results in a section of a torus (↪Fig. 235).

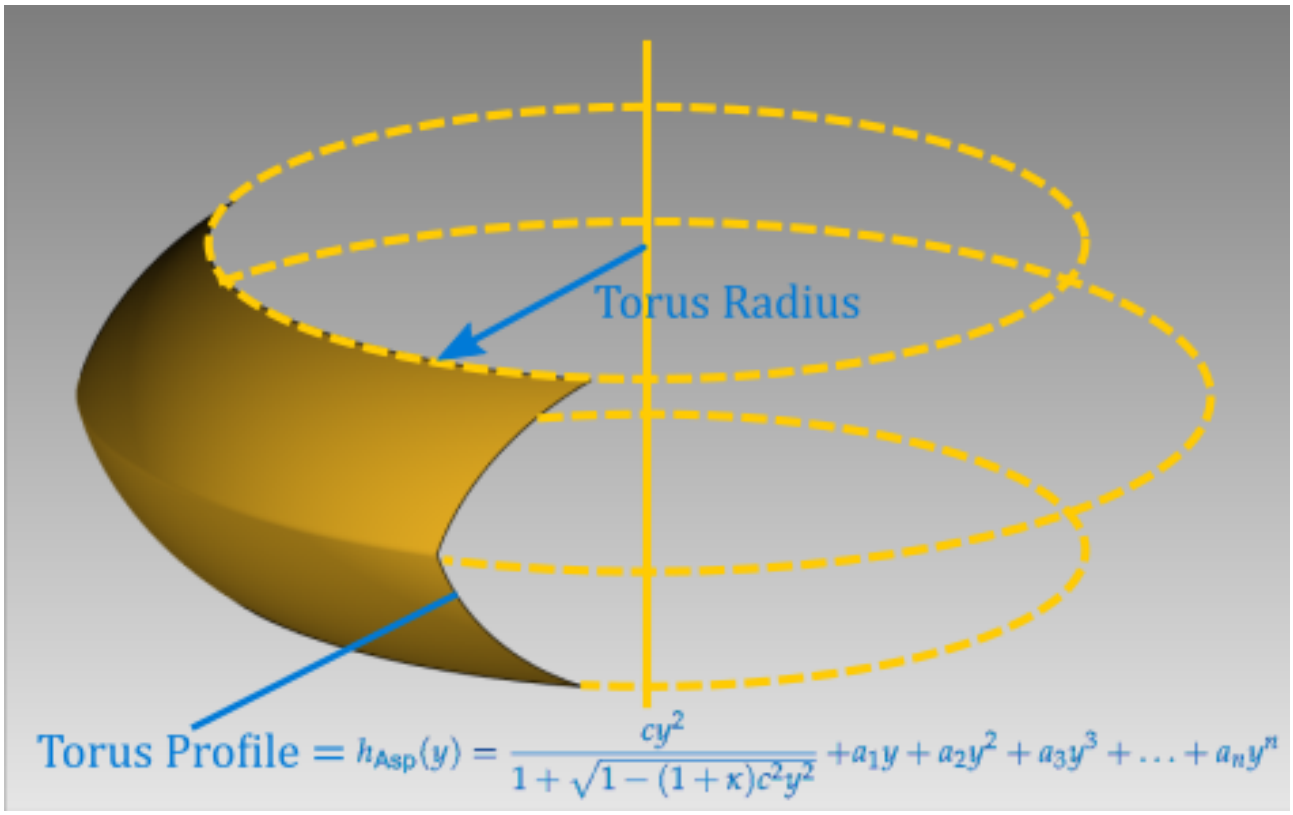


Figure 235. *Principle of a Toroidal Asphere Surface.*

Mathematically the cross section with the y-z-plane is described by the asphere formula:

$$h_{Asp}(y) = \underbrace{\frac{cy^2}{1+\sqrt{1-(1+\kappa)c^2y^2}}}_{\hookrightarrow \text{Sec. 36.2.4}} + a_1y + a_2y^2 + a_3y^3 + \ldots + a_ny^n \tag{36.12}$$

whereas c is the inverse *Radius of Curvature* and κ the *Conical Constant*.
This height profile is shifted by the *Toroidal Radius* r_T in z-direction and then rotated about the y-axis. The so-generated surface of revolution is shifted back by $-r_T$ in z-direction, so that $h(0\,\text{m};\,0\,\text{m}) = 0\,\text{m}$.
$h(x,y)$ can be described by the following formulas and parameters:

$$h'_{Asp}(y) = r_T - h_{Asp}(y) \tag{36.13}$$

$$h'(x,y) = \sqrt{h'^2_{Asp}(y) - x^2} \tag{36.14}$$

$$h(x,y) = r_T - \text{sgn}(r_T) \cdot h'(x,y) \tag{36.15}$$

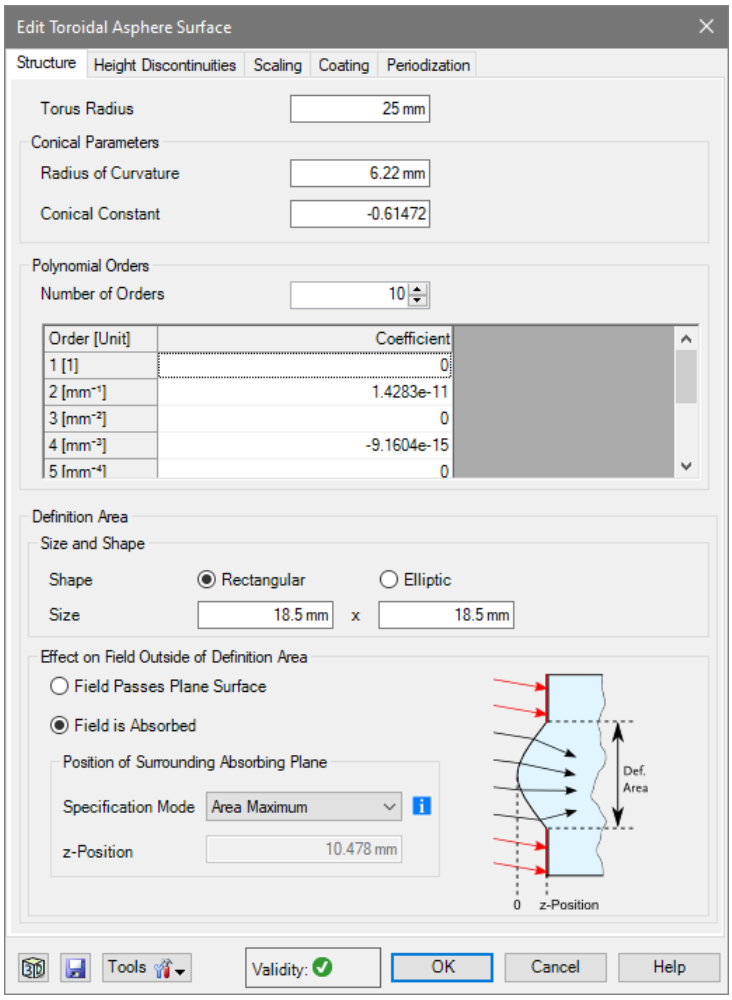


Figure 236. *The edit dialog for a Toroidal Asphere Surface.*

Its edit dialog (↪Fig. 236) has the following parameters.

ITEM	DESCRIPTION
Torus Radius	The toroidal radius r_T.
Radius of Curvature PV	The radius of curvature R of the aspherical height profile $h_{Asp}(y)$. ↪Sec. 36.2.4.
Conical Constant PV	The conical constant κ of the aspherical height profile $h_{Asp}(y)$. ↪Sec. 36.2.4
Number of Orders	The number n of the additional *Polynomial Orders* a_i. The length of the table for entering these parameters depends on this number.
Order	The order i of the asphere parameter a_i. Its physical unit is given in square brackets.
Parameter Value PV	Value of the asphere parameter a_n (↪Eq. (36.12)) with the *Order* n.

The remaining controls are explained in Sec. 36.1.

36.2.13 Transition Point List Surface

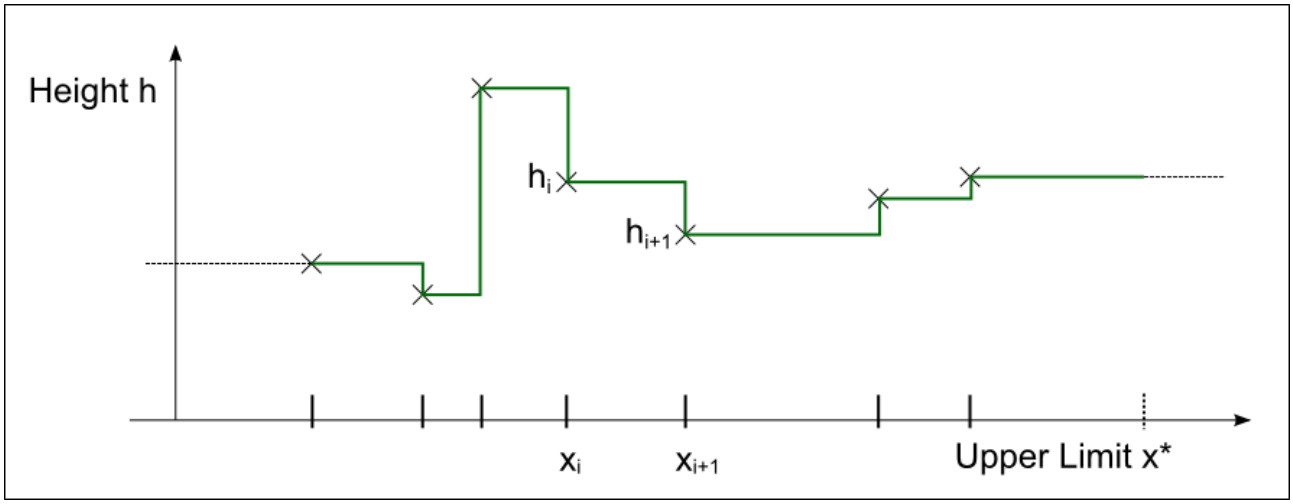


Figure 237. *Example for a Transition Point List Surface where the data points (marked by crosses) are distributed non-equidistantly. Between the x-positions that give the height values, the Constant Interval interpolation method is used here.*

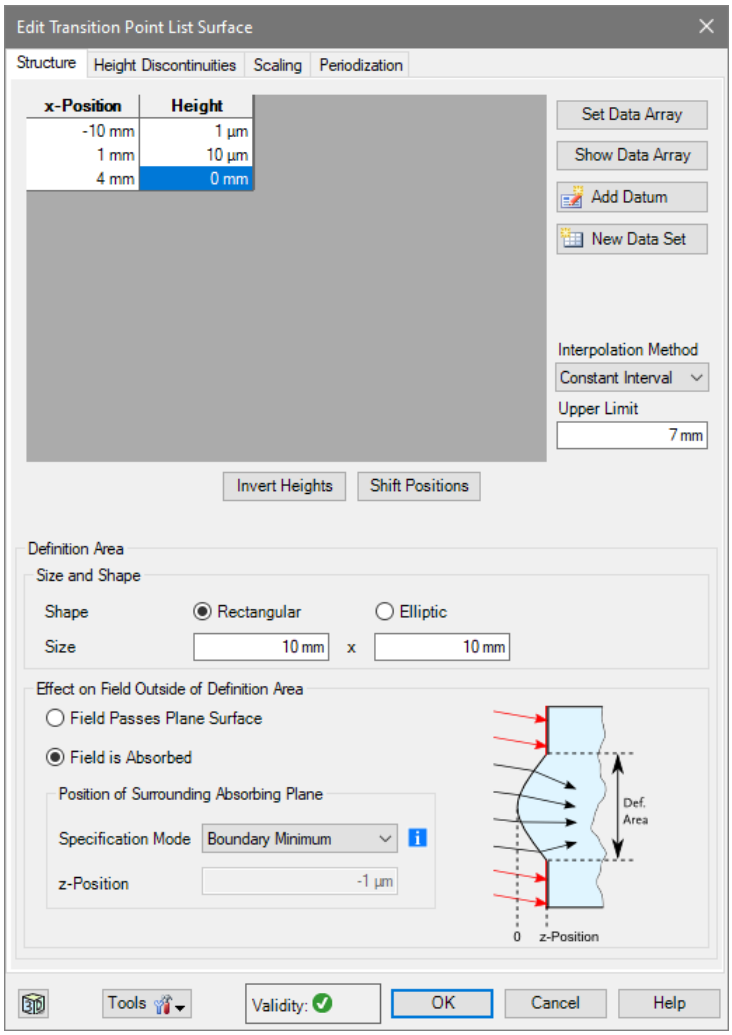


Figure 238. *The edit dialog for a transition point list surface.*

The Transition Points List Surface is defined by one-dimensional data specifying the *Height*[PV] at certain *x-Position*s[PV]. That data are not necessarily equidistant (see Fig. 237 for an example). The Approximated Function Domain (↪Sec. 36.1.1) of a Transition Point List Surface corresponds to the range of given values, possibly

extrapolated by the current *Interpolation Method*. See also the chapter about interpolation methods Sec. 13.2 for reference.

Notes on Parameter Extraction of Positions

For Parameter Extraction, the positions are *always* considered as non-equidistant. This enables the variation of a single position.
However, the first position is always fixed because it defines among others the allowed value ranges for the other positions and the Approximated Function Domain (↪Sec. 36.1.1). For the same reason, the last position is fixed if in the dialog another interpolation than *Constant Interval* is used, because then no separate *Upper Limit* is defined.

If you optimize the positions within the parametric optimization (↪Sec. 103), there is a general *Minimum Feature Size* constraint. The value of this constraint becomes negative if the order of the transition points changes. Thus you can use this constraint to enforce an unchanged order of the transition points. Features in a periodic surface where one part of the feature is on the beginning of the period and one part is on the end of the period are correctly considered as one feature.

The dialog is shown in Fig. 238, while the control for the input of the data points is described in Sec. 5.10 in detail.
There are two additional buttons specific for this surface:

ITEM	DESCRIPTION
Invert Heights	$h(x)$ is replaced by $-h(x)$.
Shift Positions	Opens a dialog where you can enter a shift s. Each x-position x is then replaced by $x + s$.

Furthermore there is an additional surface tool, namely *Set Period to Doubled Upper Limit*. Before using this tool you should check that your data fills the range $-\chi \ldots +\chi$ as in VirtualLab Fusion periods are always centered around the position $(0; 0)$. If this is not the case you might use *Shift Positions* prior to using this surface tool. This tool is a short cut for doing the following steps:

1. Set the definition area in x-direction to twice the *Upper Limit* $+\chi$.
2. Make the surface periodical and set the x-period to twice the *Upper Limit*.
3. Set the outer definition area in x-direction to six times the *Upper Limit*.

The remaining controls are explained in Sec. 36.1.

36.2.14 Zernike & Seidel Surface

Zernike fringe, Zernike standard, and Seidel aberrations are often used to describe aberrations within an imaging optical system. The corresponding formulas are given in Sec. 140.2.

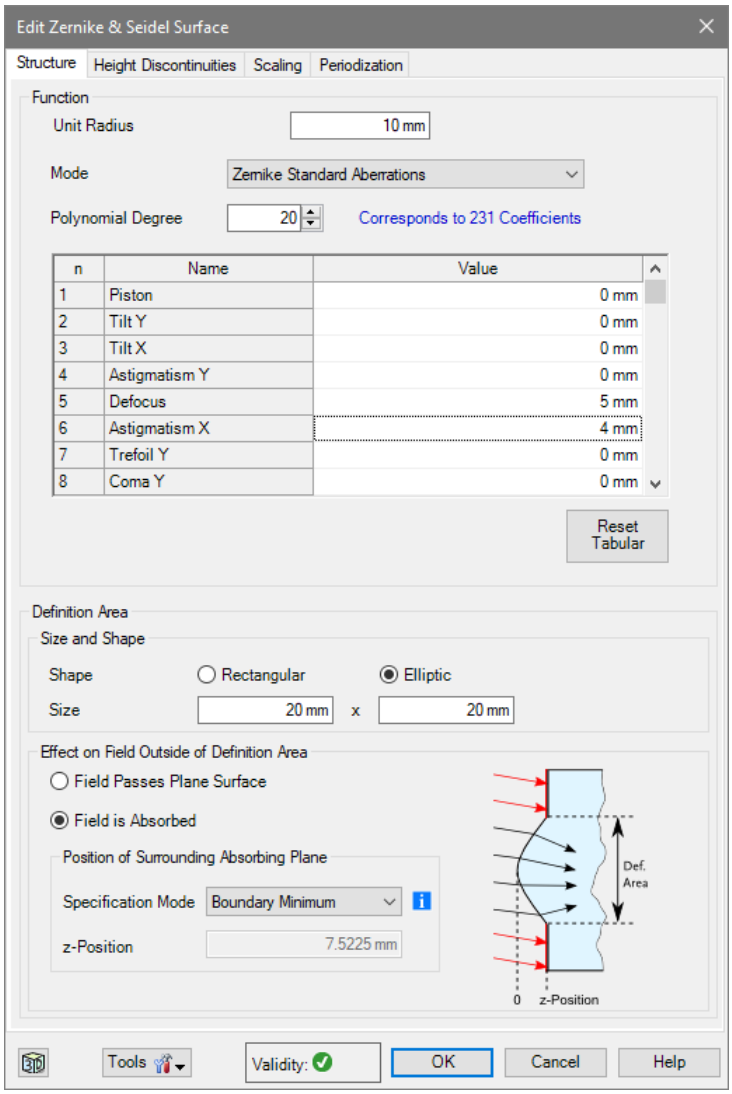


Figure 239. *The edit dialog for a Zernike & Seidel Surface in* Zernike Standard Aberrations *mode.*

The *Structure* tab of the Zernike & Seidel Surface (↪Fig. 239) allows the following settings.

ITEM	DESCRIPTION
Unit Radius	Radius which refers to the value $\rho = 1$ in the Zernike polynomial.
Mode	You can choose between *Zernike Fringe Aberrations*, *Zernike Standard Aberrations*, and *Seidel Aberrations*.
Polynomial Degree	ONLY FOR *ZERNIKE STANDARD ABERRATIONS* Allows you to set the maximum polynomial degree of the used Zernike terms, and thus indirectly the number of coefficients.
{Coefficients Table}	Allows you to enter the coefficients of the polynomial describing the aberrations. Via the context menu of the table you can copy and paste the parameter list.
Reset Tabular	Resets all table entries to 0.

The remaining controls are explained in Sec. 36.1.

36.3 Surface View

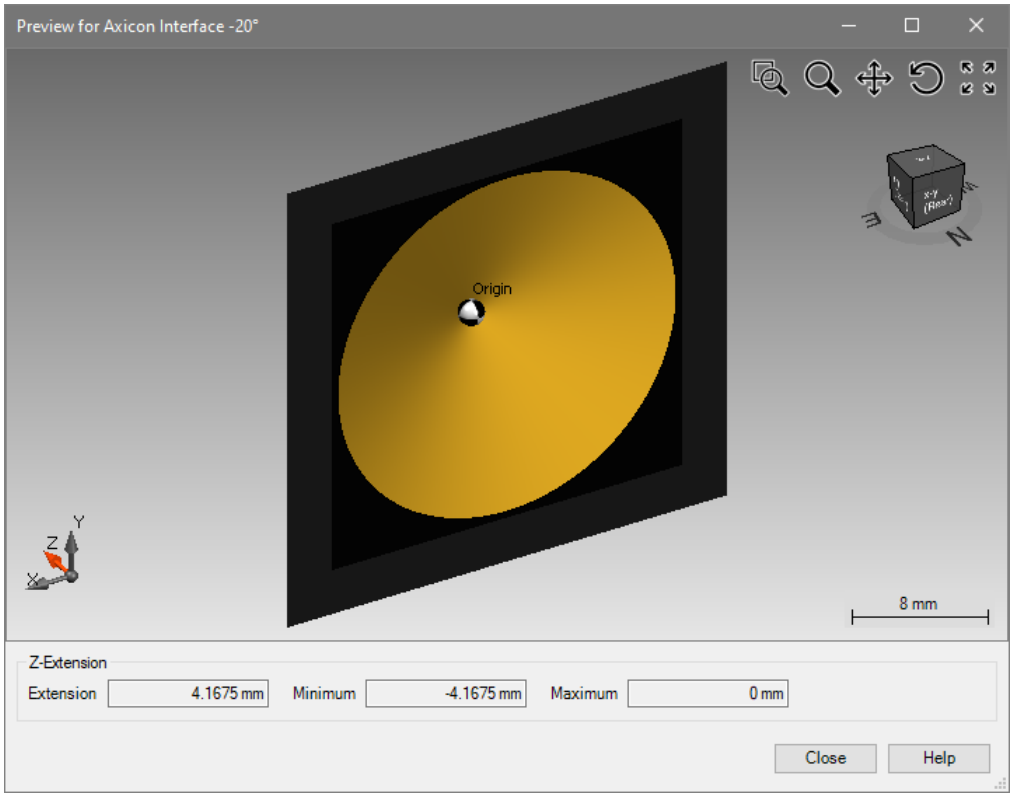


Figure 240. *Sample surface view.*

The surface view (↪Fig. 240) contains the 3D view control described in Sec. 5.16. On the bottom of the view the z-extension of the surface is shown. Furthermore the *Minimum* and *Maximum* Height of the surface are given, whereas a height of zero means the height at the lateral position (0 m; 0 m).

37 Optical Coatings

For plenty of practical applications of optical systems it is important to have optical coatings on the setup's surfaces at one's disposal. Usually, there are two kinds of effects intended that shall be caused by coatings, which are suppression of reflection on the one hand and maximum reflectivity on the other. For these purposes, a coating is built in the production process by one or more thin films of materials of defined thickness and index of refraction. The necessary combination of the layer parameters is determined by the wavelength the desired effect shall be maximized for. For further information please read [Her90], [Mac01], or [Ran96].
In order to give the user the possibility to work with correct values of reflectance and transmittance of coated elements, there is the Building Block type *Coating*, which can be applied to most of the surfaces.
Inside the edit dialog of an Optical Surface, a coating can be selected from the catalog as described in Sec. 34.2. While propagating through the system, any type of propagation operator will regard the coating when crossing the surface – provided that the operator is able to consider Fresnel effects.

37.1 Types of Optical Coatings

VirtualLab Fusion provides three different kinds of coatings. The first type contains layers of homogeneous, isotropic media only. Processing data which influence the layer thickness in dependence on some process parameters (↪Sec. 37.2.2) can be defined as well. The regarding template can be found in the coatings catalog as 'Standard Coating'. The second type of coating may contain layers of homogeneous isotropic *as well as anisotropic media*. However, processing parameters cannot be specified here. The template for this kind of coating can be found as 'Anisotropic Layer Stack' in the catalog. Both kinds of coating mentioned can be called

'Structural Coating'. The third coating type is not defined by a layer structure but by Fresnel coefficients instead (which may depend on polarization, incidence angle and wavelength) and is called 'Functional Coating'. The following table compares all coating types:

	Standard Coating	Anisotropic Layer Stack	Functional Coating
Inhomogeneous Layer Media	✘	✘	✘
Anisotropic Layer Media	✘	✔	✘
Isotropic Layer Media	✔	✔	✘
Processing Parameters	✔	✘	✘

37.2 Definition and Edit of Structural Optical Coatings

If a new structural coating (i.e. a Standard Coating or an Anisotropic Layer Stack) is to be created, the coating template (which is part of the Coatings Catalog) has to be provided with a layer system of different media and thicknesses.

In case of Standard Coatings, the edit dialog consists of two panels, the *Layer Definition Panel* and the *Process Data Panel*, both described in the following sections. While the layer definition is very similar for both types of coatings, there is no process data definition for Anisotropic Layer Stacks.

Regardless of the type of coating, the following buttons can be found on the bottom of the dialog:

ITEM	DESCRIPTION
	Shows the coating view. ↪Sec. 37.4
	Saves the coating to the catalog. Not available if the coating is edited from within the catalog.
	In case of Standard Coatings, an import for Macleod Coating Data ↪Sec. 134 is called by this button. In case of Anisotropic Layer Stacks, a Standard Coating can be imported (i.e. converted) by this button.

37.2.1 Layer Definition

The definition of coatings as stacks of thin layers is done via the edit dialogs shown in Fig. 241.

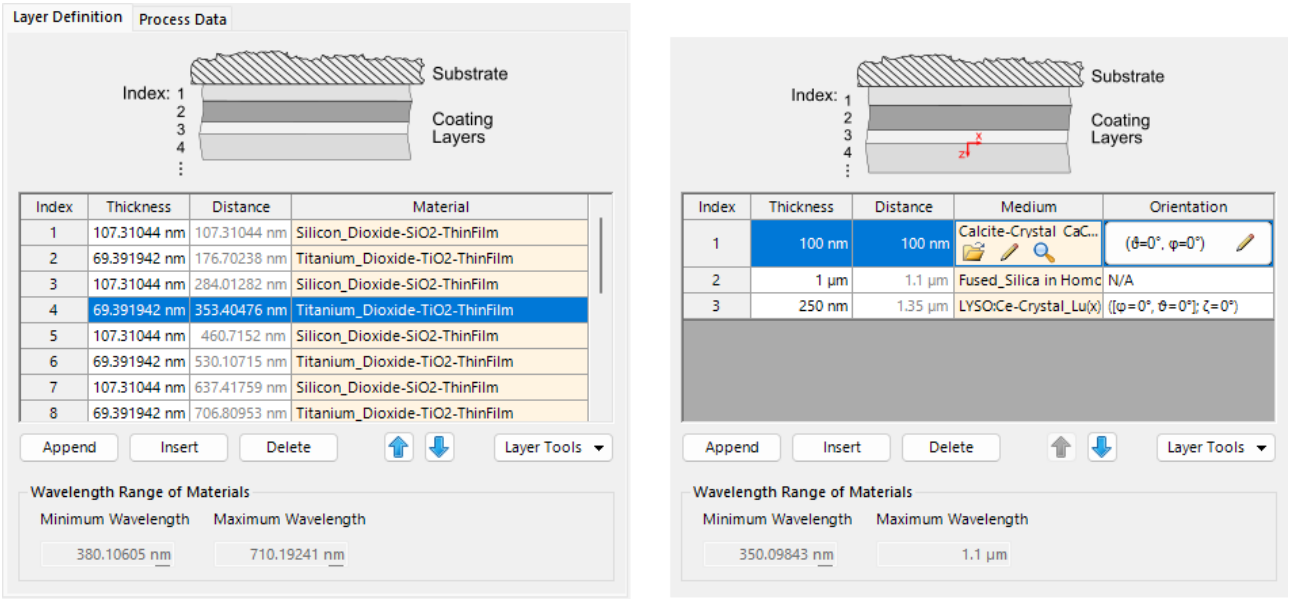


Figure 241. *Layer definition controls of the edit dialog for coatings. Left: The layer definition control for a Standard Coating. Right: The layer definition control for an Anisotropic Layer Stack.*

There are two important differences in the definition of Standard Coatings on the one hand and Anisotropic Layer Stacks on the other hand: Since a Standard Coating allows isotropic homogeneous media only, its layer media can always be defined by a single material (↪Sec. 39), respectively. Anisotropic Layer Stacks, in contrast, need an Optical Medium (↪Sec. 38) specification for each layer. The other difference is the need for a definition of the anisotropic medium's orientation in case of an Anisotropic Layer Stack.
All layer definition parameters are described in the following:

ITEM	DESCRIPTION
Index	Index of the layer, counted from the substrate. That means: the higher the index, the higher is the distance of the layer to the substrate's surface.
Thickness PV	Thickness of the layer. For a Standard Coating, this is the initial thickness before applying any process parameters to the coating.
Distance	Distance of the upper border of the layer to the substrate. This value can not be changed and is calculated from all thicknesses of the layers with a smaller index.
Material PE	STANDARD COATINGS ONLY. The material the layer consists of is to be set here. It can be loaded from a catalog, edited or shown via the buttons, , and which appear inside the table cell when the corresponding row is active.
Medium	ANISOTROPIC LAYER STACKS ONLY. The optical medium the layer consists of is to be set here. It can be loaded from a catalog, edited or shown via the buttons, , and which appear inside the table cell when the corresponding row is active.
Orientation	ANISOTROPIC LAYER STACKS ONLY. The orientation of an anisotropic layer medium. In case of uniaxial crystals, only the direction of the optical axis is to be specified (↪Sec. 5.5). For other types of anisotropic media, a full orientation has to be defined (↪Sec. 5.6). The z-axis of the reference system points always away from the substrate. The y-axis of the reference is identical to that of the surface's coordinate system.
Append	Appends a new layer at the end of the table.
Insert	Inserts a new layer before the selected one.
Delete	Deletes the selected layers. Selecting more than one layer is possible. You can also delete using the Del key.
	Moves the currently selected layer(s) up.
	Moves the currently selected layer(s) down.
Layer Tools > Append Repeated Layer Sequence	Allows you to append a (sub)sequence of the already defined layers, for several times, if required. ↪Sec. 37.2.1.1
Minimum Wavelength	Minimum wavelength the coating can be used with. This value is equal to the highest minimum wavelength of all layer materials.
Maximum Wavelength	Maximum wavelength the coating can be used with. This value is equal to the lowest maximum wavelength of all layer materials.

37.2.1.1 Repeated Appending of Layer Sequences

Especially high reflection coatings consist of many thin film layers. The stack is built of a replication of the same elementary layer sequence, like for instance $SiO_2 - TiO_2 - SiO_2 - TiO_2 - \cdots - SiO_2 - TiO_2$.
In order to make the definition of that kind of coatings easier, VirtualLab Fusion provides a tool for the replication of layer sequences (*Layer Tools > Append Repeated Layer Sequence*). Its configuration dialog is shown in Fig. 242.

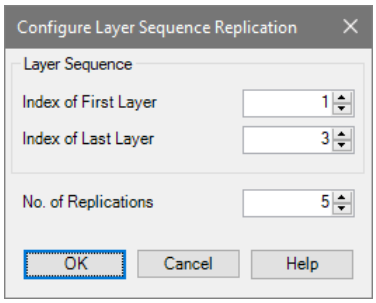


Figure 242. *Configuration of the* Append Repeated Layer Sequence *tool.*

ITEM	DESCRIPTION
Index of First Layer	Index of that layer, the sequence to append shall start with.
Index of Last Layer	Index of that layer, the sequence to append shall end with.
No. of Replications	Number of replications of the defined sequence to be appended to the current stack.

37.2.2 Process Data

ONLY FOR STANDARD COATINGS

The properties of a real coating naturally depend on the conditions of the process it was produced in. First of all, its thickness depends on the deposition parameters, like the flow direction of the material. Therefore VirtualLab Fusion allows to specify some of these parameters in case of Standard Coatings. The modeling is done according to the Hertz-Knudsen-Law (↔Sec. 138.2).

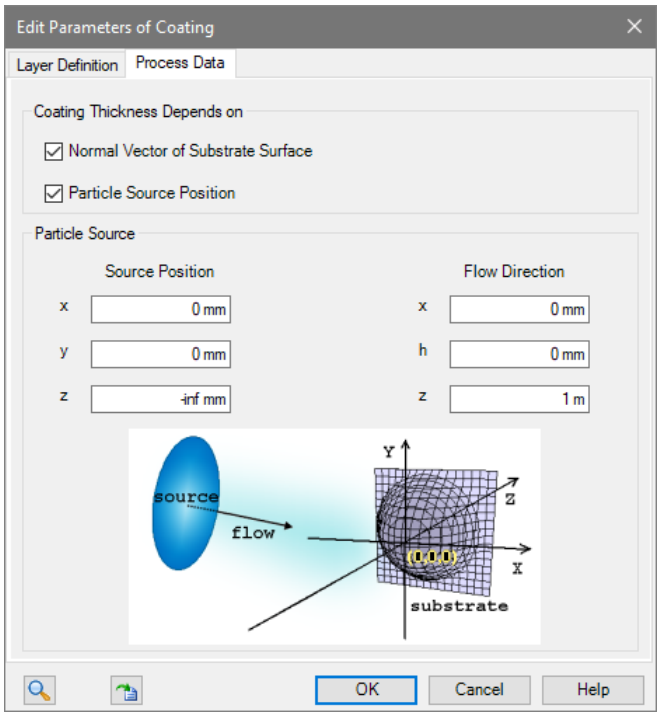


Figure 243. *Process data panel of the edit dialog of coatings.*

The panel shown in Fig. 243 contains the parameters to adapt the simulated coating to its processing. They are summarized in the following table.

ITEM	DESCRIPTION
Coating Thickness Depends on Normal Vector of Substrate Surface	If checked, consider the normal vector of the surface, i. e. the surface of the substrate, for the calculation of the coating thickness.
Coating Thickness Depends on Particle Source Position	If checked, consider position of the particle source and direction of the particle flow for the calculation of the coating thickness.
Source Position	Position of the particle source relative to the intersection point of optical axis and surface (point $(0, 0, 0)$ in Fig. 244).
Flow Direction	Main direction of the particle flow, i. e. direction with the highest flux density (vector f in Fig. 244).

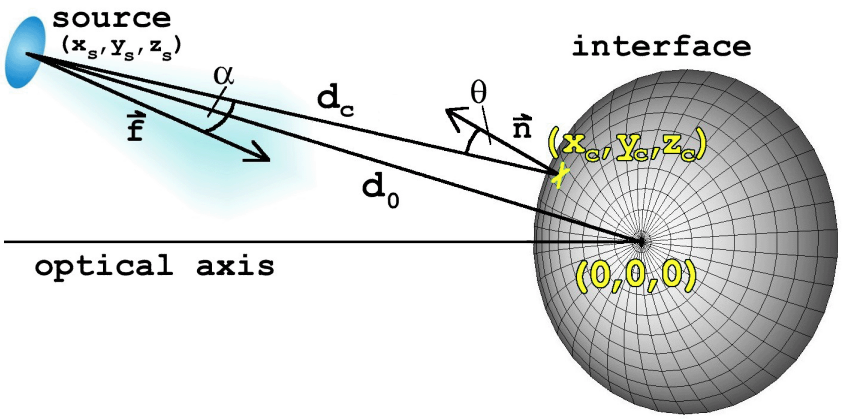


Figure 244. *Sketch of the meaning of the processing parameters of coatings.*

37.3 Definition and Edit of Functional Optical Coatings

A Functional Coating will modify amplitude and phase of transmitted and reflected light at a surface independently from the involved media on either side. It is defined by the Fresnel coefficients which will be multiplied to the electrical field by the propagation operator that handles the surface.
The user can specify the extent to which the coefficients are invariant or dependent on polarization, angle of incidence and wavelength.

37.3.1 Coatings With Constant Coefficients (Over Incidence Angle and Wavelength)

If no dependence of the Fresnel coefficients on incidence angle and wavelength are known, or if the coefficients are to be varied within a Parameter Run ↪Sec. 45, they can be set as described in this section.

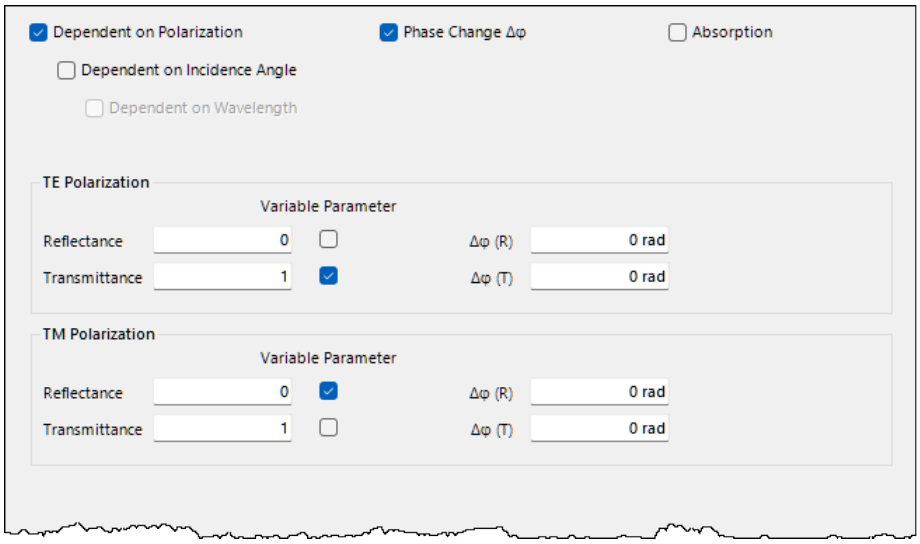


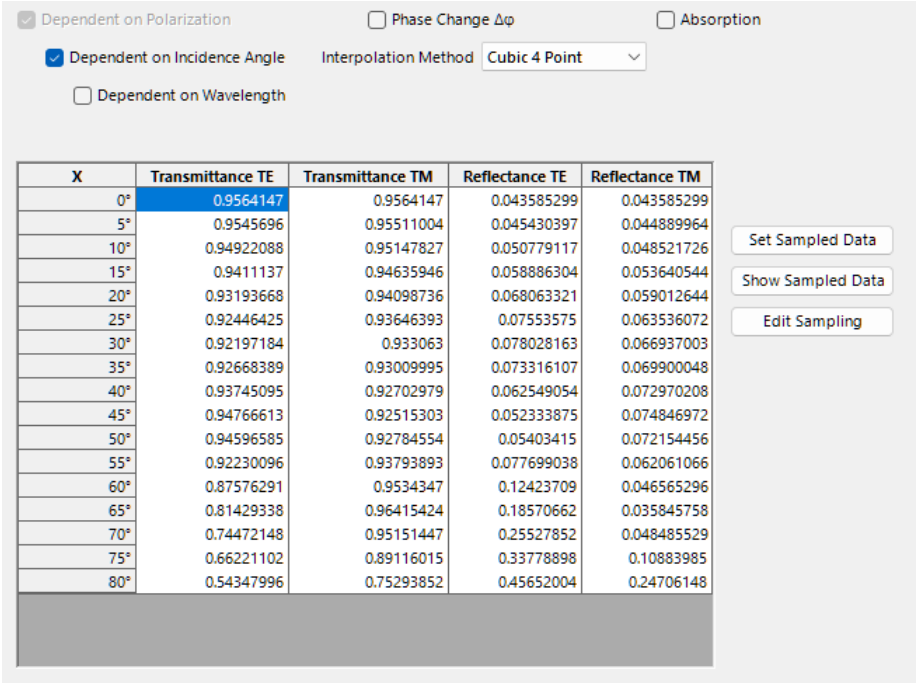
Figure 245. *Dialog for defining constant Fresnel coefficients.*

The following parameters are available:

ITEM	DESCRIPTION
Dependent on Polarization	If checked, different coefficients for TE and TM polarization can be defined.
Phase Change Δφ	If checked, not only intensity coefficients may be used but phase effects will be considered as well.
Absorption	If *not* checked, *Reflectance* and *Transmittance* are not independent. The values will always sum up to one, then. So if this option is activated, on the other hand, both coefficients are mutually independent.
Dependent on Incidence Angle	ONLY AVAILABLE IF *DEPENDENT ON POLARIZATION* IS CHECKED. If checked, angular dependent coefficients may be provided ↪Sec. 37.3.2.
Reflectance	The reflectance coefficient(s).
Transmittance	The transmittance coefficient(s).
Variable Parameter	If no *Absorption* is allowed, either *Reflectance* or *Transmittance* may be varied within a Parameter Run, but not both. This checkbox allows to determine which one can be varied.
Δφ (R)	ONLY AVAILABLE IF *PHASE CHANGE Δφ* IS ACTIVATED. The phase change which affects reflected light.
Δφ (T)	ONLY AVAILABLE IF *PHASE CHANGE Δφ* IS ACTIVATED. The phase change which affects transmitted light.

37.3.2 Coatings With Coefficients Depending on the Incidence Angle (Constant Over Wavelength)

If the dependence of the Fresnel coefficients on the incidence angle is known (but not on wavelength), they can be set as described in this section.



X	Transmittance TE	Transmittance TM	Reflectance TE	Reflectance TM
0°	0.9564147	0.9564147	0.043585299	0.043585299
5°	0.9545696	0.95511004	0.045430397	0.044889964
10°	0.94922088	0.95147827	0.050779117	0.048521726
15°	0.9411137	0.94635946	0.058886304	0.053640544
20°	0.93193668	0.94098736	0.068063321	0.059012644
25°	0.92446425	0.93646393	0.07553575	0.063536072
30°	0.92197184	0.933063	0.078028163	0.066937003
35°	0.92668389	0.93009995	0.073316107	0.069900048
40°	0.93745095	0.92702979	0.062549054	0.072970208
45°	0.94766613	0.92515303	0.052333875	0.074846972
50°	0.94596585	0.92784554	0.05403415	0.072154456
55°	0.92230096	0.93793893	0.077699038	0.062061066
60°	0.87576291	0.9534347	0.12423709	0.046565296
65°	0.81429338	0.96415424	0.18570662	0.035845758
70°	0.74472148	0.95151447	0.25527852	0.048485529
75°	0.66221102	0.89116015	0.33778898	0.10883985
80°	0.54347996	0.75293852	0.45652004	0.24706148

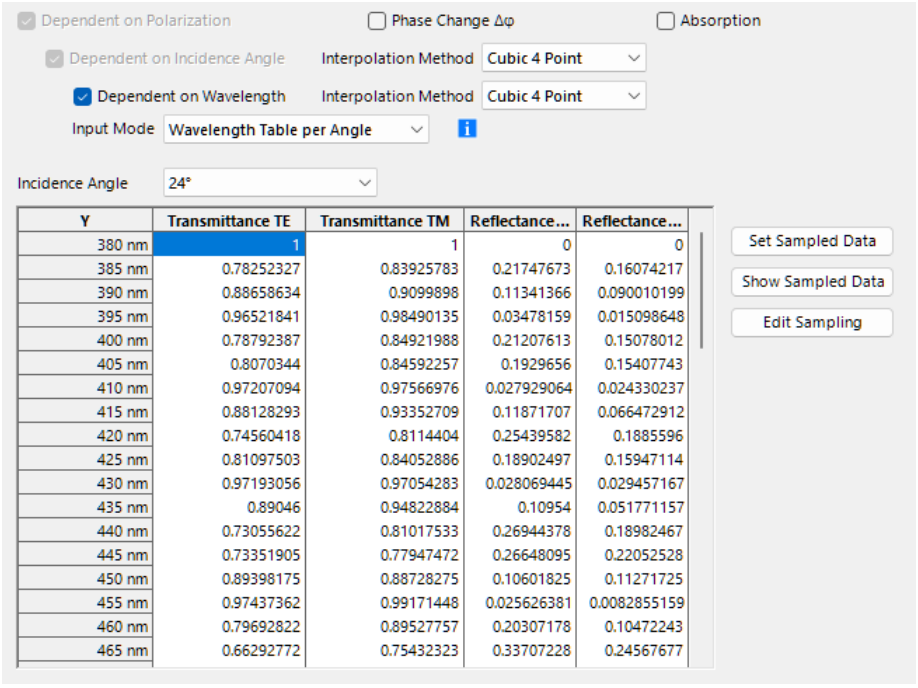
Figure 246. *Dialog for Fresnel coefficients which depend on the angle of incidence.*

The following parameters are available:

ITEM	DESCRIPTION
Phase Change Δφ	If checked, not only intensity coefficients may be used but phase effects will be considered as well.
Absorption	If *not* checked, *Reflectance* and *Transmittance* are not independent. The values will always sum up to one, then. So if this option is activated, on the other hand, both coefficients are mutually independent.
Interpolation Method	The method for interpolating coefficients between sampled angular values can be set here.
Dependent on Wavelength	ONLY AVAILABLE IF *DEPENDENT ON INCIDENCE ANGLE* IS CHECKED. If checked, coefficients may be provided that depend on wavelength *and* angle of incidence ↪Sec. 37.3.3.
Set Sampled Data	This button will open a menu containing the following actions: • *Load...* Allows to load a Data Array which contains the coefficient dependencies (in different subsets). • *Import...* Allows to import the coefficient dependencies from text files ↪Sec. 37.3.5. • *Select from Documents...* Allows to select an open Data Array which contains the coefficient dependencies (in different subsets).
Show Sampled Data	Creates a new Data Array which shows the currently set curves of coefficients which depend on the angle of incidence.
Edit Sampling	Opens a dialog for editing the sampling properties of the angular dependency ↪Sec. 37.3.4. Please note: This option is not needed in case the data are imported or loaded via *Set Sampled Data*.

37.3.3 Coatings With Coefficients Depending on Incidence Angle and Wavelength

If the dependence of the Fresnel coefficients on the incidence angle *and* on wavelength is known, they can be set as described in this section.



Y	Transmittance TE	Transmittance TM	Reflectance...	Reflectance...
380 nm	1	1	0	0
385 nm	0.78252327	0.83925783	0.21747673	0.16074217
390 nm	0.88658634	0.9099898	0.11341366	0.090010199
395 nm	0.96521841	0.98490135	0.03478159	0.015098648
400 nm	0.78792387	0.84921988	0.21207613	0.15078012
405 nm	0.8070344	0.84592257	0.1929656	0.15407743
410 nm	0.97207094	0.97566976	0.027929064	0.024330237
415 nm	0.88128293	0.93352709	0.11871707	0.066472912
420 nm	0.74560418	0.8114404	0.25439582	0.1885596
425 nm	0.81097503	0.84052886	0.18902497	0.15947114
430 nm	0.97193056	0.97054283	0.028069445	0.029457167
435 nm	0.89046	0.94822884	0.10954	0.051771157
440 nm	0.73055622	0.81017533	0.26944378	0.18982467
445 nm	0.73351905	0.77947472	0.26648095	0.22052528
450 nm	0.89398175	0.88728275	0.10601825	0.11271725
455 nm	0.97437362	0.99171448	0.025626381	0.0082855159
460 nm	0.79692822	0.89527757	0.20307178	0.10472243
465 nm	0.66292772	0.75432323	0.33707228	0.24567677

Figure 247. *Dialog for Fresnel coefficients which depend on the angle of incidence and on the wavelength.*

The following parameters are available:

ITEM	DESCRIPTION
Phase Change Δφ	If checked, not only intensity coefficients may be used but phase effects will be considered as well.
Absorption	If *not* checked, *Reflectance* and *Transmittance* are not independent. The values will always sum up to one, then. So if this option is activated, on the other hand, both coefficients are mutually independent.
Interpolation Method	The method for interpolating coefficients between sampled angular or wavelength values can be set here, respectively.
Input Mode	One of three *equivalent* input modes can be set here (see Fig. 248): • *Angle Table per Wavelength*: All coefficients are listed with their angular dependency for one single *Wavelength*. • *Wavelength Table per Angle*: All coefficients are listed with their wavelength dependency for one single *Incidence Angle*. • *Angle and Wavelength at Once*: All coefficients are listed with their angle and wavelength dependency.
Wavelength	ONLY AVAILABLE IF THE *INPUT MODE* HAS BEEN SET TO *ANGLE TABLE PER WAVELENGTH*. The wavelength the angular dependency is to be shown for.
Incidence Angle	ONLY AVAILABLE IF THE *INPUT MODE* HAS BEEN SET TO *WAVELENGTH TABLE PER ANGLE*. The angle the wavelength dependency is to be shown for.
Set Sampled Data	This button will open a menu containing the following actions: • *Load...* Allows to load a Data Array which contains *all(!)* coefficient dependencies (within different subsets). • *Import...* Allows to import the coefficient dependencies from text files ↪Sec. 37.3.6. • *Select from Documents...* Allows to select an open Data Array which contains *all(!)* coefficient dependencies (within different subsets).
Show Sampled Data	Creates a new Data Array which shows the currently set coefficients which depend on the angle of incidence and wavelength.
Edit Sampling	Opens a dialog for editing the sampling properties of the angular dependency and the wavelength dependency↪Sec. 37.3.4. Please note: This option is not needed in case the data are imported or loaded via *Set Sampled Data*.

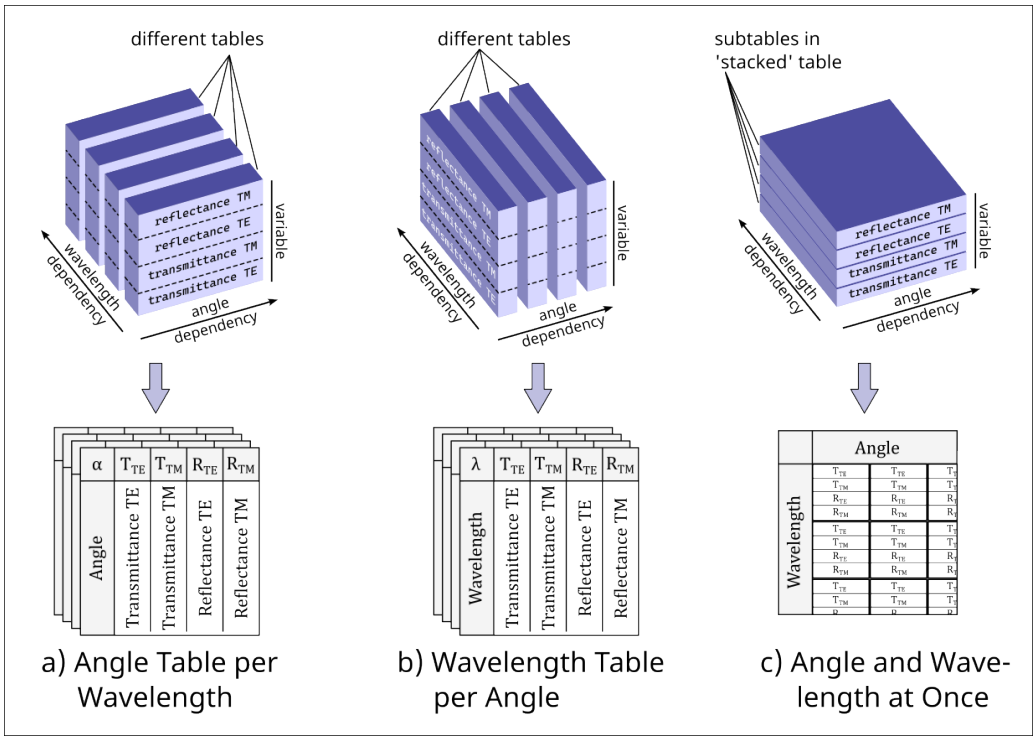


Figure 248. *The three equivalent* Input Modes *for defining angular and wavelength dependent Fresnel coefficients.*

37.3.4 Changing Sampling Parameters of Non-Constant Coatings

The sampling parameters for the coefficient dependencies can be set using the dialog shown in Fig. 249.

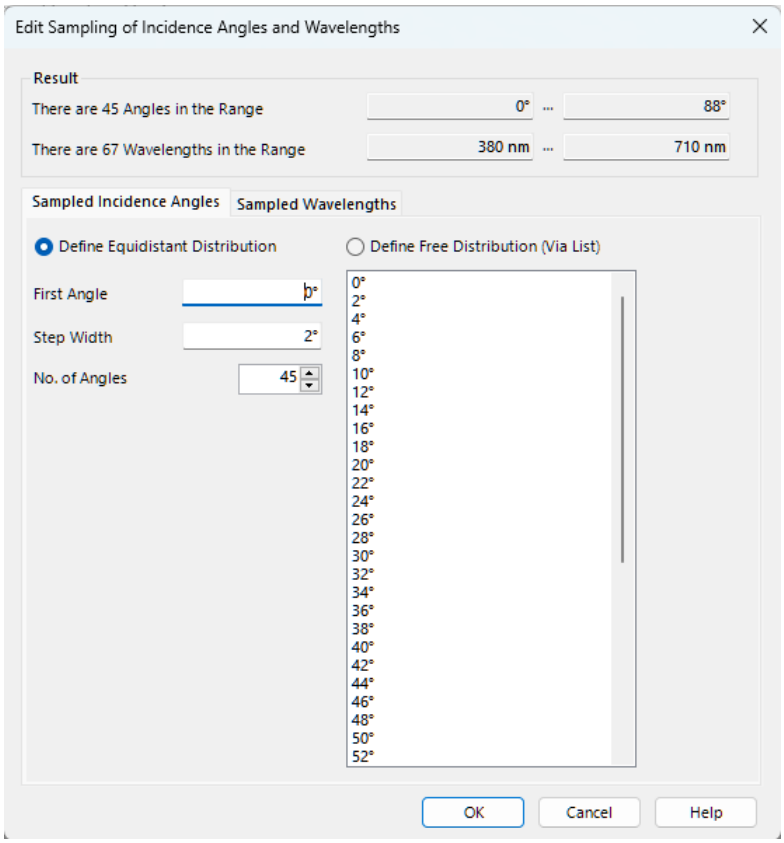


Figure 249. *Dialog for setting the sampling parameters of the coefficient dependencies.*

The following parameters are available:

ITEM	DESCRIPTION
Result	Shows the currently resulting coordinate ranges. Note: This item is read-only.
Define Equidistant Distribution	If checked, an equidistant coordinate distribution can be defined via first value, step width, and number of values.
First Angle / Wavelength	ONLY AVAILABLE IF *DEFINE EQUIDISTANT DISTRIBUTION* IS SELECTED. The first value of the equidistant coordinate range.
Step Width	ONLY AVAILABLE IF *DEFINE EQUIDISTANT DISTRIBUTION* IS SELECTED. The step width of the equidistant coordinate range.
No. of Angles / Wavelengths	ONLY AVAILABLE IF *DEFINE EQUIDISTANT DISTRIBUTION* IS SELECTED. The number of values of the equidistant coordinate range.
Define Free Distribution (Via List)	If checked, a free (i.e. equidistant or non-equidistant) coordinate distribution can be defined via a list of values.
Add / Delete / Clear	ONLY AVAILABLE IF *DEFINE FREE DISTRIBUTION (VIA LIST)* IS SELECTED. Allows to add or delete single values or to clear all values, resp.

37.3.5 Importing Coefficients That Only Depend on the Incidence Angle

At the top of the import dialog, there is a read-only box *Properties (from Edit Dialog)* summarizing the needed coefficients as required by the edit dialog that called the import.

There are two kinds of file storage supported for importing Fresnel coefficients: On the one hand each coefficient may be stored in a separate file ↪Sec. 37.3.5.1. On the other hand all coefficients may be stored in one single file ↪Sec. 37.3.5.2. So the first decision to be made is to choose between *One File Per Variable* and *All Data Exist in One Single File*. After selecting one of these options, a blue colored label informs about the data expected to be stored within the files.

In case absorption is not present, the option *Ensure T+R=1 by Calculating* has to be set either to *Reflectances From Transmittances* or to *Transmittances From Reflectances*.

At the bottom of the dialog, a validity icon informs about the consistency of the entered data. If problems occur, an additional button allows to get additional details.

37.3.5.1 Importing Coefficients From Separate Files

The dialog for importing from several files look like shown in Fig. 250.

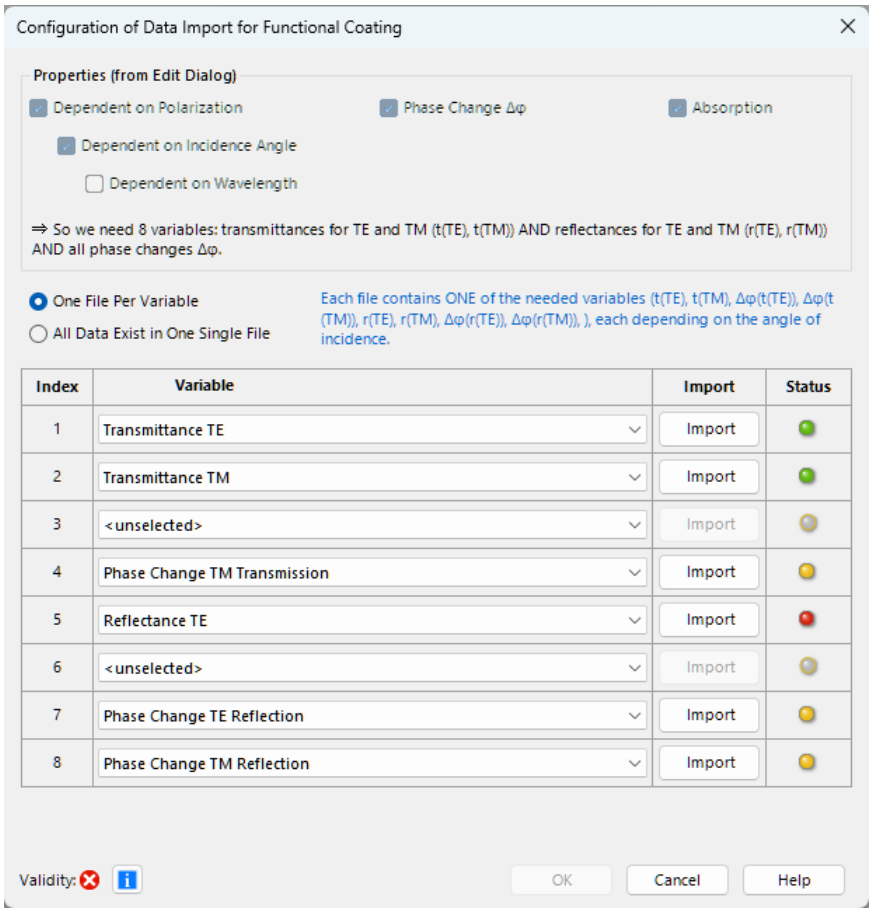


Figure 250. *Dialog for importing Fresnel coefficients from files. Option* One File Per Variable *is selected here.*

The input table contains one row for each of the files and provides the following columns:

ITEM	DESCRIPTION
Index	Row index, needed for validity / consistency communication.
Variable	Which of the needed coefficients shall be imported in this row?
Import	Button for starting the actual importing process for the coefficient selected in the *Variable* column. At first, a file open dialog will allow to select any text file which may contain Fresnel coefficients. Depending on the chosen file, one of two procedures will be started: • If a file is opened which contains data exported from the software Zemax OpticStudio® (as result of that software's feature Analyze > Coatings > *... vs. Angle* or > *... vs. Wavelength*), the type of the file will be identified automatically. Since no additional information is needed in this case, VirtualLab Fusion will import all needed coefficients without any additional dialog. • A 'usual' text file is imported as described in Sec. 121.1.
Status	The status of the row's coefficient dependency data. Hovering the mouse cursor above the symbol will open a tooltip with status information and the used file path, if already given. The symbols' meanings are the following: • No coefficient selected in the column *Variable* yet. • Invalid or inconsistent data imported. Clicking the button at the dialog's bottom will provide more information. • No data imported yet. • Imported data are valid.

37.3.5.2 Importing Coefficients From One Single File

The dialog for importing from a single file look like shown in Fig. 251.

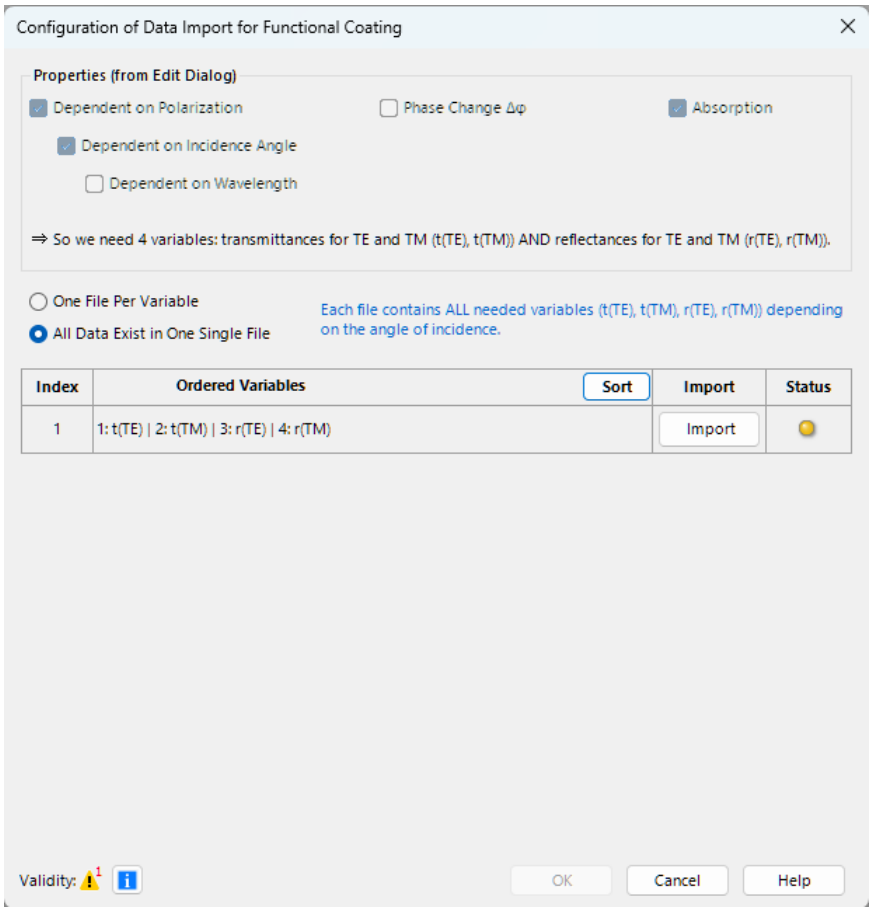


Figure 251. *Dialog for importing Fresnel coefficients from files. Option* All Data Exist in One Single File *is selected here.*

The input table contains only one single row and provides the following columns:

ITEM	DESCRIPTION
Index	Not needed index, but visible for consistence to the other option described in Sec. 37.3.5.1.
Ordered Variables	List of all coefficients expected to be in the file to import. *Important:* The order in this list has to be exactly as the order in the file! Pressing the *Sort* button allows to adapt the expected order to that actually given in the file to be imported.
Import	Button for starting the actual importing process for all coefficients. At first, a file open dialog will allow to select the text file. Then, this is imported as described in Sec. 121.1.
Status	The status of the imported data. Hovering the mouse cursor above the symbol will open a tooltip with status information and the used file path, if already given. The symbols' meanings are the following: • Invalid or inconsistent data imported. Clicking the button at the dialog's bottom will provide more information. • No data imported yet. • Imported data are valid.

37.3.6 Importing Coefficients That Depend on the Incidence Angle and Wavelength

At the top of the import dialog, there is a read-only box *Properties (from Edit Dialog)* summarizing the needed coefficients as required by the edit dialog that called the import.

If Fresnel coefficients shall be imported which depend on the angle of incidence as well as on the wavelength, VirtualLab Fusion always expects the data to be distributed over several files. This is because the complete set of needed data has a certain complexity and many entries: There are two independent variables (angle and wavelength) and between two (no phase change, no absorption) and eight (with phase change and absorption) different coefficients needed.

The workflow within VirtualLab Fusion differs between importing files which contain one coefficient and both dependencies (angle *and* wavelength) respectively on the one hand and files which contain all coefficients but only one dependency (angle *or* wavelength) on the other hand. The possible distribution of data over files are illustrated by Fig. 252.

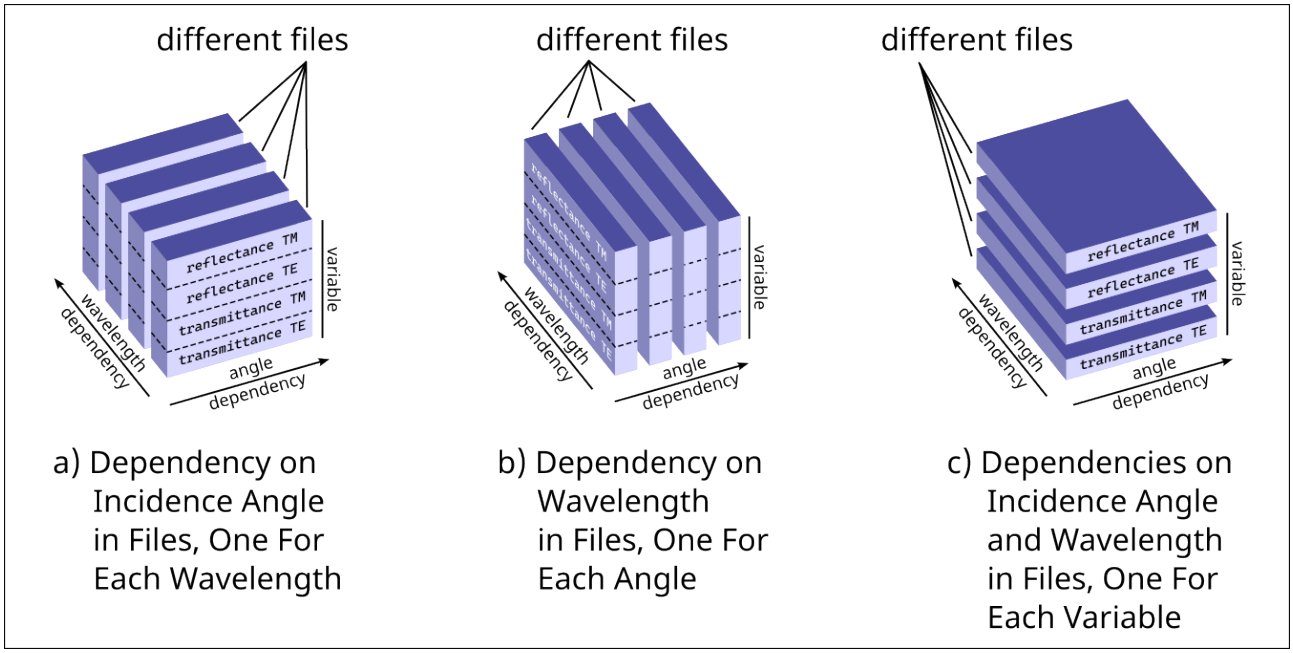


Figure 252. *The various possibilities for splitting the required data into several files. a) Each file represents one wavelength and contains all coefficients (variables) in dependence on the angle of incidence. b) Each file represents one incidence angle and contains all coefficients (variables) in dependence on the wavelength. c) Each file represents one coefficient and contains its complete twofold dependency on angle and wavelength.*

Please note: The selection of the *Input Mode* in the Functional Coating's edit dialog ↪Sec. 37.3.3 does *not* restrict the import of data. On the contrary, the import process as described here *always expects the complete data* (all needed coefficients with both dependencies) as a result. The selected *Input Mode* just pre-selects the *Dependencies in Files*, which is required to be chosen before the actual file import(s) but which can be freely selected by the user. The following combinations are possible:

Dependencies in Files	☑ *Incidence Angle*	☐ *Incidence Angle*
☑ *Wavelength*	✔ Files With One Coefficient Over Both Coordinates ↪Sec. 37.3.6.2	✔ Files With All Coefficients Over Wavelength ↪Sec. 37.3.6.1
☐ *Wavelength*	✔ Files With All Coefficients Over Incidence Angle ↪Sec. 37.3.6.1	✘

In case absorption is not present, the option *Ensure T+R=1 (Absence of Absorption) by Calculating* has to be set either to *Reflectances From Transmittances* or to *Transmittances From Reflectances*.

At the bottom of the dialog, a validity icon informs about the consistency of the entered data. If problems occur, an additional button ⓘ allows to get additional details.

37.3.6.1 Importing From Files With All Coefficients Over One Coordinate (Angle or Wavelength)

This section deals with the case that either *Incidence Angle* or *Wavelength* is selected for *Dependencies in Files*, but not both. The dialog is shown in Fig. 253.

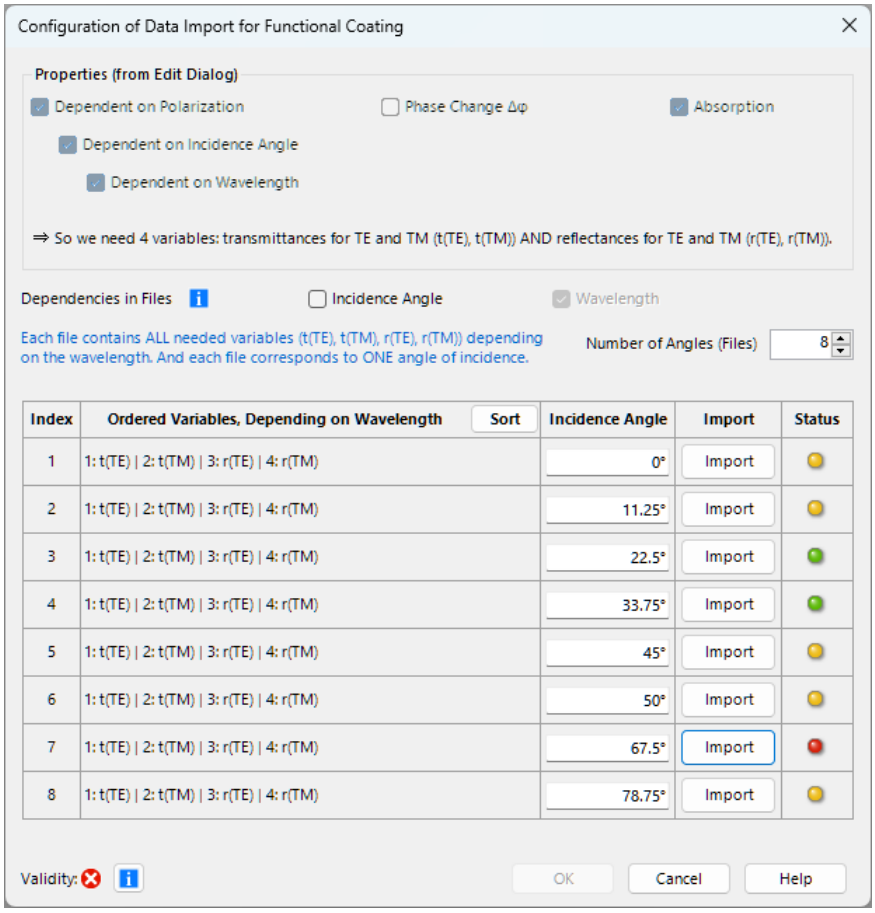


Figure 253. *Dialog for importing files with all needed coefficients depending either on the incidence angle or the wavelength.*

The parameter *Number of Angles / Wavelengths (Files)* determines how many different angles (or wavelengths) shall be used, i.e. how many files shall be imported. The table will have the same number of (non-header) rows and provides the following columns:

ITEM	DESCRIPTION
Index	The row index.
Ordered Variables, Depending on Wavelength / Incidence Angle	List of all coefficients expected to be in the file to import. *Important:* The order in this list has to be exactly as the order in the file! Pressing the *Sort* button allows to adapt the expected order to that actually given in the file to be imported.
Incidence Angle / Wavelength	The angle of incidence / wavelength represented by this row and the corresponding file.
Import	Button for starting the actual importing process for the coefficient selected in the *Variable* column. At first, a file open dialog will allow to select any text file which may contain Fresnel coefficients. Depending on the chosen file, one of two procedures will be started: • If a file is opened which contains data exported from the software Zemax OpticStudio® (as result of that software's feature Analyze > Coatings > *... vs. Angle* or > *... vs. Wavelength*), the type of the file will be identified automatically. Since no additional information is needed in this case, VirtualLab Fusion will import all needed coefficients without any additional dialog. • A 'usual' text file is imported as described in Sec. 121.1.
Status	The status of the imported data. Hovering the mouse cursor above the symbol will open a tooltip with status information and the used file path, if already given. The symbols' meanings are the following: • Invalid or inconsistent data imported. Clicking the button at the dialog's bottom will provide more information. • No data imported yet. • Imported data are valid.

37.3.6.2 Importing From Files With One Coefficient Over Both Coordinates (Angle and Wavelength)

This section deals with the case that *Incidence Angle and Wavelength* are selected for *Dependencies in Files*. The dialog is shown in Fig. 254.

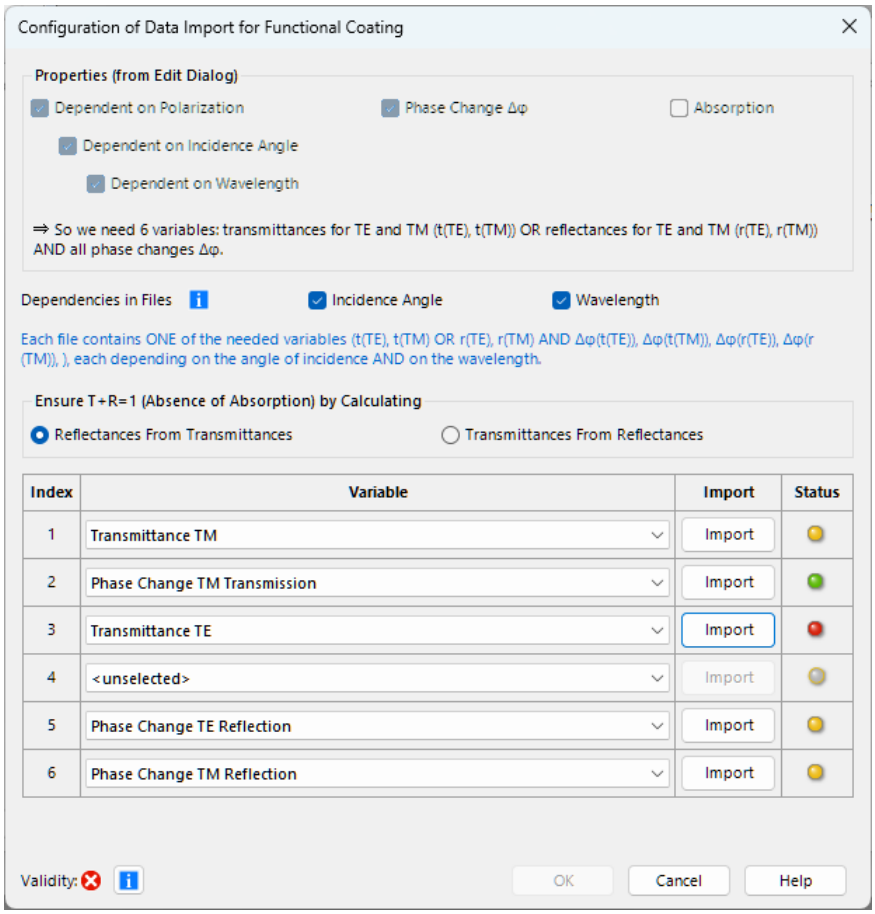


Figure 254. *Dialog for importing files which contain one coefficient depending on incidence angle and wavelength respectively.*

The table contains as many (non-header) rows as the number of needed coefficients. It provides the following columns:

ITEM	DESCRIPTION
Index	Row index, needed for validity / consistency communication.
Variable	Which of the needed coefficients shall be imported in this row?
Import	Button for starting the actual importing process for the coefficient selected in the *Variable* column. At first, a file open dialog will allow to select any text file which may contain Fresnel coefficients. Then, this is imported as described in Sec. 121.1.
Status	The status of the row's coefficient dependency data. Hovering the mouse cursor above the symbol will open a tooltip with status information and the used file path, if already given. The symbols' meanings are the following: • No coefficient selected in the column *Variable* yet. • Invalid or inconsistent data imported. Clicking the button at the dialog's bottom will provide more information. • No data imported yet. • Imported data are valid.

37.4 Coating View

The view for coatings is shown in Fig. 255 (*Diagram* tab) and Fig. 256 (*Coefficients Calculator* tab).

Please note: Even if the same view is used for Standard Coatings and Anisotropic Layer Stacks, the shown values and the diagram are only of limited value in case of the latter. There are two reasons for this restriction: At first, The incident wave is always assumed to lie in the x-z-plane. Secondly, only the main diagonal values of the complete Fresnel matrix are used for the view. So, in case of Anisotropic Layer Stacks, the view should only be used cautiously.

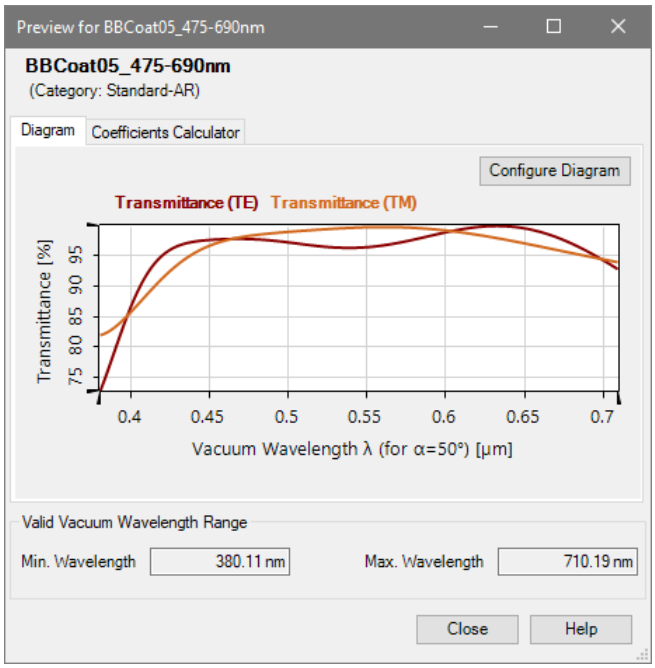


Figure 255. *Example for a coating view, showing the dependence of the transmittance on the wavelength for an angle of incidence of* 50° *for TE and TM polarization.*

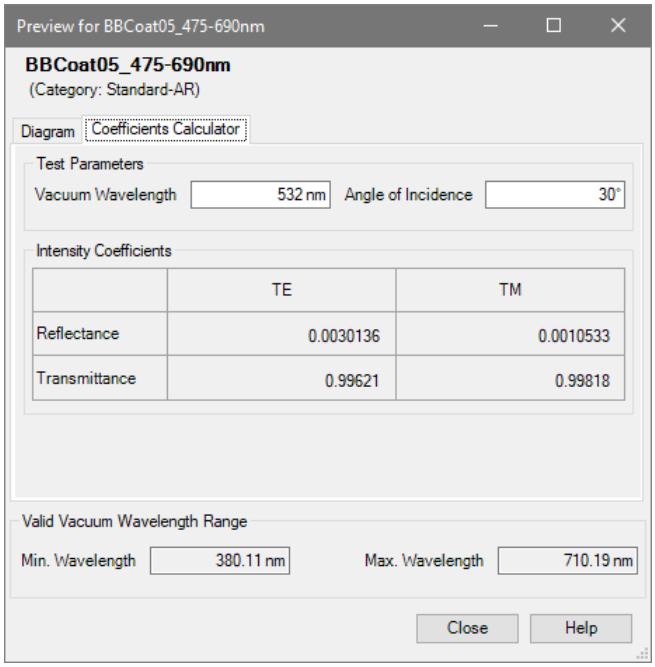


Figure 256. *Example for the coating coefficients calculator.*

Besides the name of the coating and the categories it belongs to, the document always shows the wavelength range, the coating data are defined for:

ITEM	DESCRIPTION
Min. Wavelength	The minimum vacuum wavelength the materials in the coating layers are defined for.
Max. Wavelength	The maximum vacuum wavelength the materials in the coating layers are defined for.

The *Diagram* tab shows the wavelength or the angular dependency of the reflectance or the transmittance for TE and/or TM polarization. The diagram view can be configured via a configuration dialog (↪Sec. 37.4.1) which is called by the button *Configure Diagram*.
The *Coefficient Calculator* tab allows calculating reflectance and transmittance for a given wavelength and angle of incidence:

ITEM	DESCRIPTION
Vacuum Wavelength	Wavelength to calculate reflectance *R* and transmittance *T* of this coating for.
Angle of Incidence	Angle of incidence to calculate reflectance *R* and transmittance *T* of this coating for.
Reflectance	Reflectance for the *Vacuum Wavelength* and the *Angle of Incidence*.
Transmittance	Transmittance for the *Vacuum Wavelength* and the *Angle of Incidence*.

37.4.1 Configuration of the Coating View

The dialog for the coating diagram configuration is described in the following sections.

37.4.1.1 Parameter Selection Panel

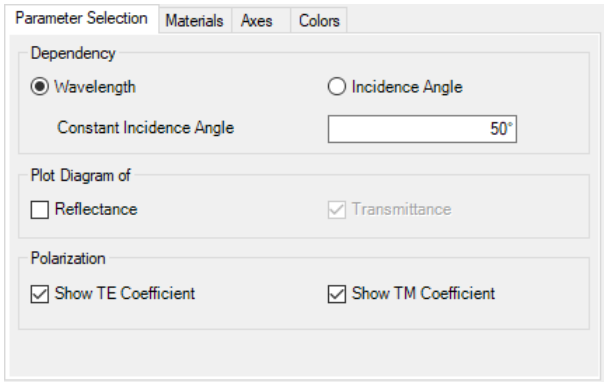


Figure 257. *The panel for the selection of the parameters to be drawn.*

ITEM	DESCRIPTION
Wavelength / Incidence Angle	Choose whether the dependency on the wavelength or the angle of incidence shall be drawn.
Constant Incidence Angle	The incidence angle to show the diagram for, if dependency on *Wavelength* is chosen.
Constant Wavelength	The wavelength to show the diagram for, if dependency on *Incidence Angle* is chosen.
Reflectance / Transmittance	Choose whether the reflectance or the transmittance shall be shown.
Show TE Coefficient	THIS CAN BE SELECTED ONLY FOR AN ANGLE OF INCIDENCE WHICH IS DIFFERENT FROM 0. If selected, one curve for TE polarization is plotted.
Show TM Coefficient	THIS CAN BE SELECTED ONLY FOR AN ANGLE OF INCIDENCE WHICH IS DIFFERENT FROM 0. If selected, one curve for TM polarization is plotted.

37.4.1.2 Materials Panel

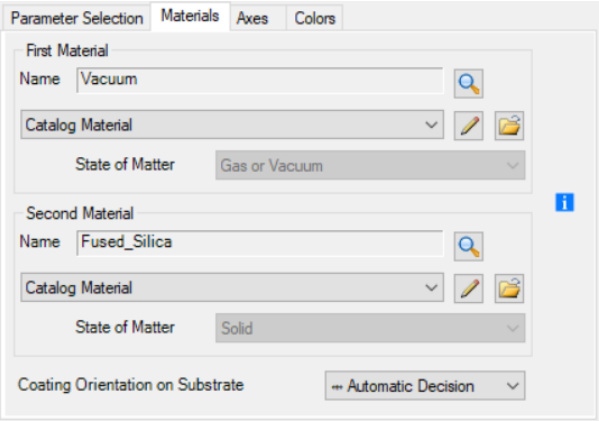


Figure 258. *The panel for the definition of the materials to be used for the calculation.*

ITEM	DESCRIPTION
First Material	Set the material on the incidence side. ↪Sec. 34.3
Second Material	Set the material on the transmitting side. ↪Sec. 34.3
Coating Orientation on Substrate	Defines the orientation of the coating. ↪Sec. 34.2

37.4.1.3 Axes Panel

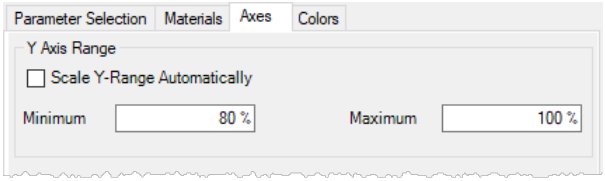


Figure 259. *The panel for the configuration of the axes.*

ITEM	DESCRIPTION
Scale Y-Range Automatically.	If selected, the range for the y axis is calculated automatically.
Minimum	If *Automatic Detection* is not chosen, the minimum of the y-axis range can be set here.
Maximum	If *Automatic Detection* is not chosen, the maximum of the y-axis range can be set here.

37.4.1.4 Colors

The colors of the curves can be set via this control. Only the color of those curves can be set, which have been selected in the *Parameter Selection* panel (↪Sec. 37.4.1.1).

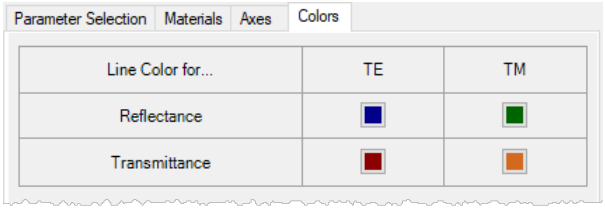


Figure 260. *The panel for the curve colors.*

38 Optical Media

The structural information of an optical system can be understood as a sequence of different homogeneous or inhomogeneous media, separated by optical surfaces (↪Sec. 36). The first medium in the system is always defined in connection with the light source.
VirtualLab Fusion supports different types of optical media: homogeneous, isotropic media (↪Sec. 38.3.1) as well as different kinds of inhomogeneous (but isotropic) or anisotropic (but homogeneous) media (Sec. 38.3.2 – Sec. 38.3.14). Homogeneous, isotropic media consist of exactly one material (↪Sec. 39), while inhomogeneous, isotropic media usually are defined either by several, spatially distributed materials or by one material and a function that gives the spatial variation of the refractive index. The anisotropic, homogeneous media are defined either by two materials (uniaxial crystals), three materials (biaxial crystals) or by two wavelength dependent tensors for permittivity and permeability (general anisotropic media).
The application of media is described in Sec. 34.1.

38.1 Common Controls for Editing Inhomogeneous Optical Media

All inhomogeneous optical media have their edit dialog divided into three tab pages. The *Basic Parameters* tab is specific for the particular medium (↪Sec. 38.3).

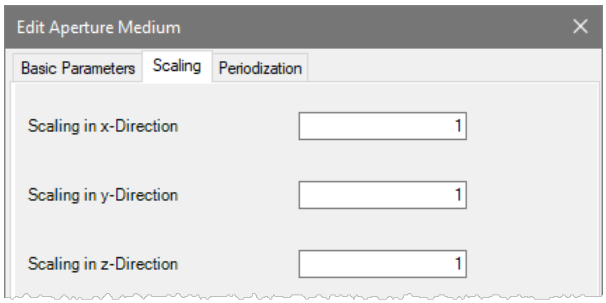


Figure 261. *The edit dialog of optical media showing the scaling tab.*

The *Scaling* tab (↪Fig. 261) has the following controls.

ITEM	DESCRIPTION
Scaling in x-Direction PV	The scaling factor for x-direction as defined in Sec. 138.3.1.
Scaling in y-Direction PV	The scaling factor for y-direction as defined in Sec. 138.3.1.
Scaling in z-Direction PV	The scaling factor for z-direction as defined in Sec. 138.3.1.

These three factors must be larger than zero.

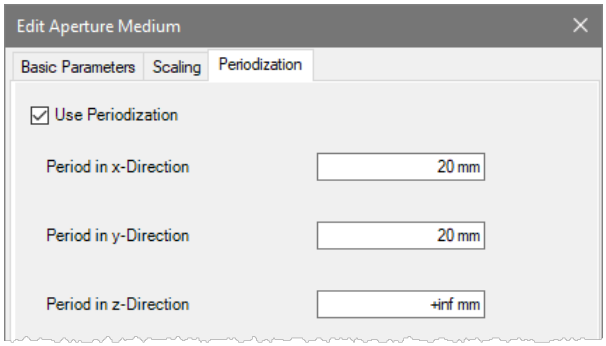


Figure 262. *The edit dialog of optical media showing the periodization tab.*

The *Periodization* tab (↪Fig. 262) has the following controls.

ITEM	DESCRIPTION
Use Periodization	If checked, a period for x-, y-, and / or z-direction can be set. If you do not want periodization for a certain direction, you can set the period to *infinity* for that direction.
Period in x-Direction PV	The period P_x as defined in Sec. 138.3.1.
Period in y-Direction PV	The period P_y as defined in Sec. 138.3.1.
Period in z-Direction PV	The period P_z as defined in Sec. 138.3.1.

The aforementioned controls are disabled if a medium cannot be modulated in the corresponding direction. For example a Sampled Medium (↪Sec. 38.3.11) can never be modulated in z-direction and thus *Scaling in z-Direction* and *Period in z-Direction* are disabled and cannot be changed by the user. Furthermore, if a medium is always periodically, its period is calculated from the specific medium parameters and the scaling factors. In this case, all periodization controls are disabled. This affects Pillar Medium (z-Independent) (↪Sec. 38.3.9) and the Volume Grating Medium (↪Sec. 38.3.14).
Additionally the edit dialog has a 🔍-button to show the medium preview (↪Sec. 38.2) and a 💾-button to save the medium to the medium catalog.

38.2 Medium View

Different types of media need different kinds of views. The next sections will describe these different views.

38.2.1 View for Inhomogeneous, Isotropic Media

This medium view (↪Fig. 263) shows a cross section through the spatial distribution of the refractive index of a medium.

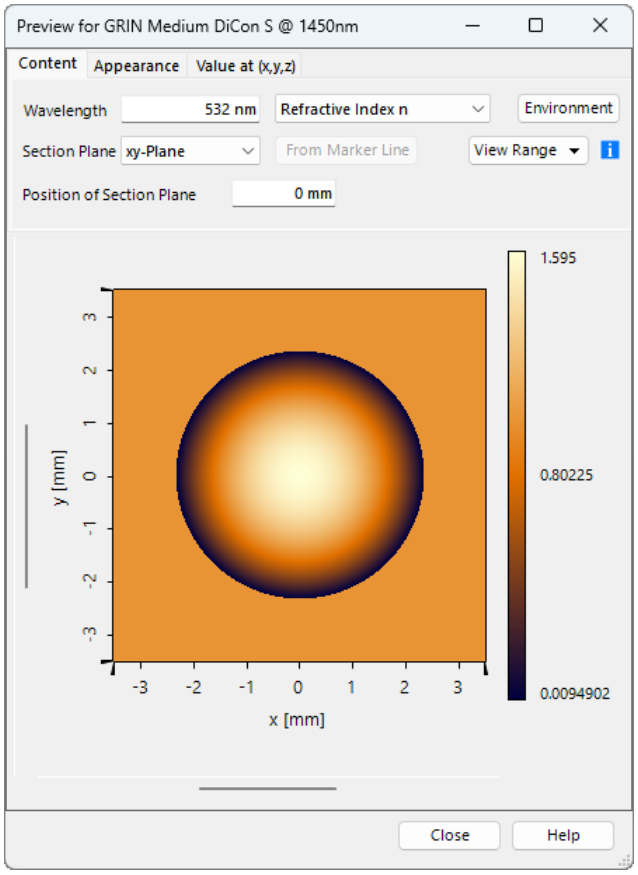


Figure 263. *The view for inhomogeneous, isotropic media. This example shows a x-y-plane through a GRIN medium (↪Sec. 38.3.6).*

Please note: Since optical media are inherently unlimited (spatial limits in modeled optical setups are always defined by surfaces, ↪Sec. 36), the view allows unlimited zoom and scrolling as well. That's why the scroll bars behave somewhat unusual: They always jump back to the center position after scrolling and they don't change their size during zooming as well.

38.2.1.1 Context Menu

ITEM	DESCRIPTION
Aspect Ratio	The aspect ratio of the diagram can be changed here (↪Sec. 11.5).
Zoom	These items allow to zoom in or out or into a marked rectangular selection (↪Sec. 11.4).
Selection Mode	This option allows to define what happens if mouse clicking or drawing in the diagram is done (↪Sec. 11.3). The rectangular marker can be used for defining a zoom window. The line marker allows to define an arbitrary section plane (see Sec. 38.2.1.2 below). The point marker is useful for reading medium data at a certain point (↪Sec. 38.2.1.4).
Marker Visibility	A selection which markers ((↪Sec. 11.3)) are to be visible can be done.

38.2.1.2 Panel 'Content'

The *Content* panel allows to specify what medium data are to be shown in the diagram.

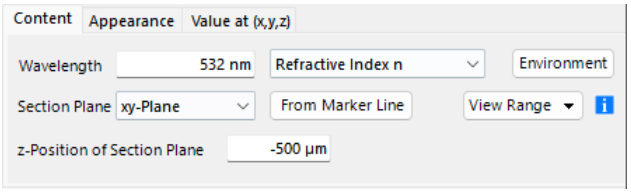


Figure 264. *Panel for the configuration of the view content.*

ITEM	DESCRIPTION
Wavelength	Wavelength to be used for calculating refractive index or absorption data.
Refractive Index n / Absorption Coefficient α / Absorption Index κ	Which quantity shall be shown?
Environment	ONLY VISIBLE IF *REFRACTIVE INDEX N* IS SELECTED. Opens a small dialog for defining temperature and pressure for refractive index calculation.
Section Plane	The plane to be intersected with the medium is to be selected here. *Arbitrary* refers to the last plane which has been created via *From Marker Line*.
From Marker Line	ONLY ENABLED IF A LINE MARKER IS SHOWN. (TO BE ACTIVATED VIA CONTEXT MENU, ↪SEC. 38.2.1.1) An arbitrary section plane can be created by pressing this button. The plane is defined by the current marker line and the normal direction to the currently visible plane. The new view range to be shown is determined by the length of the line marker which will be used as horizontal and vertical extension resp.
View Range > Default View	ONLY AVAILABLE IF *SECTION PLANE* IS DIFFERENT FROM *ARBITRARY*. (Re-)Sets the visible view range to default values.
View Range > Multiple Periods	ONLY AVAILABLE IF THE MEDIUM IS PERIODICALLY DEFINED. Opens a dialog where the numbers of horizontal and vertical periods to be shown can be defined. If *Section Plane* is set to *Arbitrary*, the view range will be approximated.
View Range > Free Range Definition	Opens a dialog (↪Sec. 11.3.1.2) for direct editing of the view range to be shown.
x-/y-/z-Position of Section Plane	Allows to set the position for the section plane along its own normal direction. If *Section Plane* is set to *Arbitrary*, the normal and the starting point for the measurement is written to an informational label.

38.2.1.3 Panel 'Appearance'

The *Appearance* panel allows to specify the color scaling of the diagram.

Figure 265. *The panel for the configuration of the color scaling.*

ITEM	DESCRIPTION
Automatic Scaling	If checked, the diagram's value range will be adapted automatically to the range of the currently selected quantity to be shown.
Minimum	ONLY VISIBLE IF *AUTOMATIC SCALING* IS NOT SELECTED. The minimum of the selected quantity to be shown.
Maximum	ONLY VISIBLE IF *AUTOMATIC SCALING* IS NOT SELECTED. The maximum of the selected quantity to be shown.
Color Table	The color table (↪Sec. 11.2.4) to be used can be chosen here.

38.2.1.4 Panel 'Value at (x,y,z)'

This panel allows reading all stored media information at one given position (x, y, z) in space.

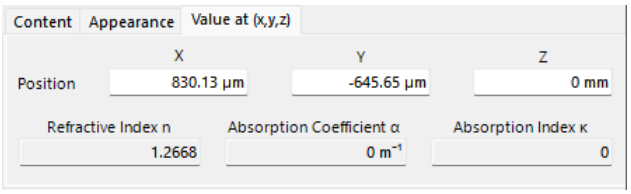


Figure 266. *Panel for reading.*

ITEM	DESCRIPTION
Position X/Y/Z	The position (x, y, z) to read all quantities for.
Refractive Index n / Absorption Coefficient α / Absorption Index κ	The real valued refractive index n, the absorption coefficient α, and the absorption index κ for the position (x, y, z).

The reading position (x, y, z) can be selected by setting the point marker within the diagram. If the position is defined via text-boxes, the marker will be visualized in the diagram. If the position happens to lie outside the shown section plane, the user will be asked whether or not it should be projected onto the plane. Independently from the user's choice, the extracted quantities refer to the given position (x, y, z).

38.2.2 View for Anisotropic, Homogeneous Media

This medium view (↪Fig. 267) shows the index ellipsoid which represent the dependency of the refractive index on the wave direction through an anisotropic medium.

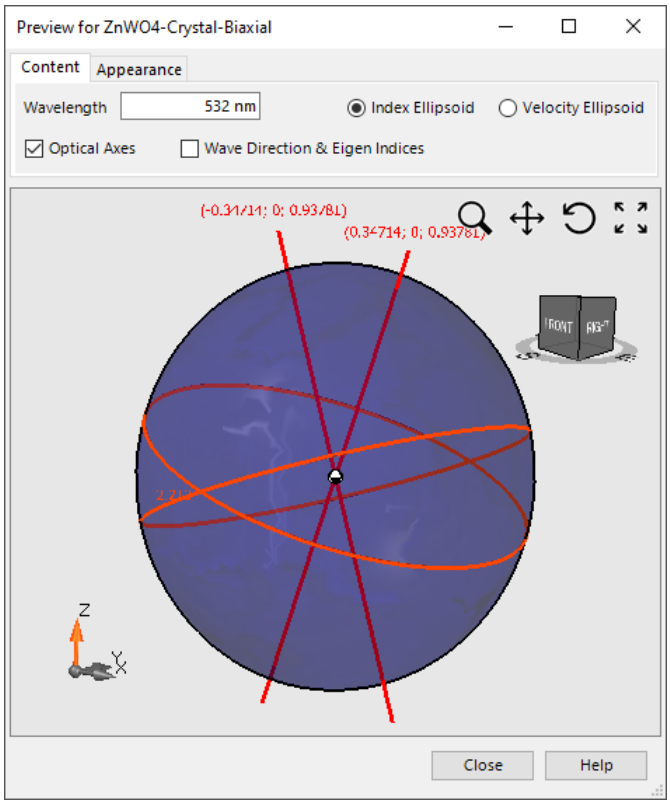


Figure 267. *The View for Homogeneous, Anisotropic Media.*

The view contains the 3D view control described in Sec. 5.16. The display can be configured with the parameters described in the following sections.

38.2.2.1 Content

Figure 268. *The panel for the configuration of the content of the view.*

ITEM	DESCRIPTION
Wavelength	The vacuum wavelength to show the ellipsoid for.
Index Ellipsoid / Velocity Ellipsoid	Either the refractive index ellipsoid or the velocity ellipsoid can be shown.
Optical Axis / Axes	If selected, the single optical axis of a uniaxial crystal or the two optical axes of a biaxial crystal are drawn. The circular ellipsoid section each of the axes is perpendicular to is drawn and labeled (with the refractive index which corresponds to the effect of traveling parallel to the axis) as well.
Wave Direction & Eigen Indices	If selected, an arbitrary wave direction can be set via *Set Direction*. It will be visualized in the ellipsoid in conjunction with the elliptical ellipsoid section the direction is perpendicular to. The effective refractive Eigen indices are given as well.
Set Direction	In case *Wave Direction & Eigen Indices* are selected, the wave direction can be set via a dialog (described in Sec. 5.5) opening when this button is pressed.

If neither *Optical Axes* nor *Wave Direction & Eigen Indices* are shown, the ellipsoid's principal semi-axes are drawn and labeled.

38.2.2.2 Appearance

Figure 269. *The panel for the configuration of the appearance of the view.*

ITEM	DESCRIPTION
Wireframe	If selected, the ellipsoid will be drawn as wireframe.
Density	if *Wireframe* has been selected, the density of the lines can be set here.
Digits	The number of digits to be used for all labels inside the view.

38.2.3 View for Homogeneous, Isotropic Media

For homogeneous, isotropic media, the user can choose whether to visualize the homogeneity or the isotropy of the medium.

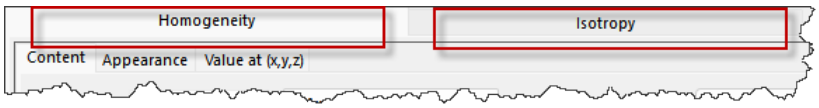


Figure 270. *The tabs for choosing between visualizing the homogeneity or the isotropy of the medium.*

Using the control shown in Fig. 270, the user may select the view described in Sec. 38.2.1 or the one described in Sec. 38.2.2.

38.3 Optical Media Types

In this section, the types of Optical Media provided by VirtualLab Fusion are described. They can be accessed as templates in the Media Catalog.

38.3.1 Homogeneous Medium

Homogeneous media (which, for the sake of completeness, should be called 'homogeneous and isotropic media') are media which are completely defined by a single *Material*[PE]. Thus their refractive index is independent of the spatial position as well as from the wave direction through the medium. The control for setting this material for the medium is described in Sec. 34.3. The remaining controls are explained in Sec. 38.1.

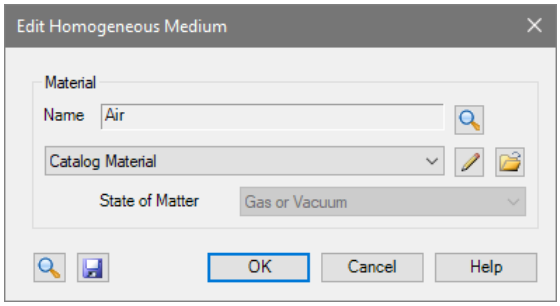


Figure 271. *Dialog for setting up a homogeneous medium.*

38.3.2 Aperture Medium

The aperture medium consists of two different materials arranged in a way that the lateral cross section looks like an aperture. That means the *Outer Material* envelops the elliptically or rectangularly shaped *Inner Material*. For detailed information about materials please see Sec. 39.
The edit dialog of this type of media is shown in Fig. 272.

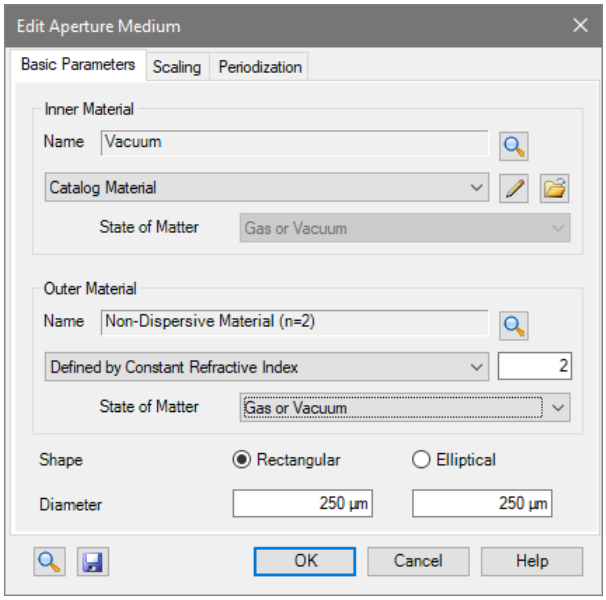


Figure 272. *Dialog for the specification of an aperture medium.*

ITEM	DESCRIPTION
Inner Material PE	Control which defines the material inside the aperture. ↪Sec. 34.3
Outer Material PE	Control which defines the material outside the aperture. ↪Sec. 34.3
Shape	Shape of the *Inner Material* in a cross section lateral to the optical axis.
Diameter PV	Determines the diameter of the *Inner Material* in x- and y-direction.

The remaining controls are explained in Sec. 38.1.

38.3.3 Biaxial Crystal

Biaxial crystals are anisotropic media which are specified by three principal refractive indices.

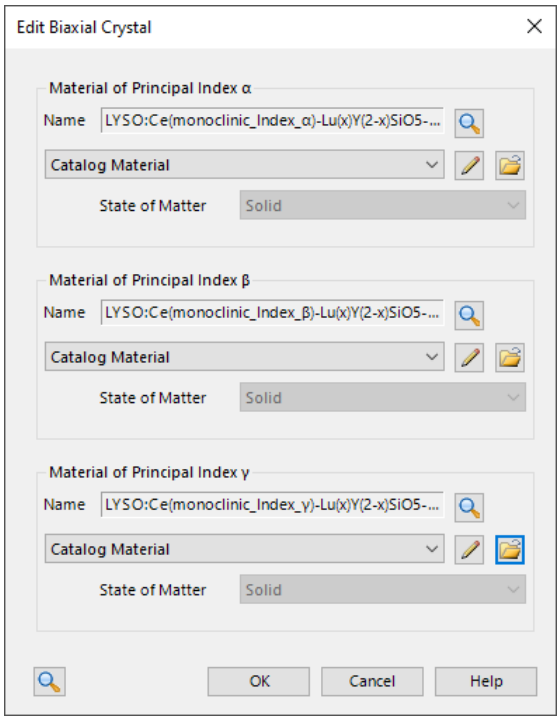


Figure 273. *Dialog for the specification of a biaxial crystal.*

The edit dialog for this kind of medium (shown in Fig. 273) needs the following parameters:

ITEM	DESCRIPTION
Material of Principal Index $\alpha I \beta I \gamma$	The dispersion relations for the three principal indices α, β, and γ are represented by three materials. The control for setting a material is described in Sec. 34.3.

38.3.4 Fiber Medium

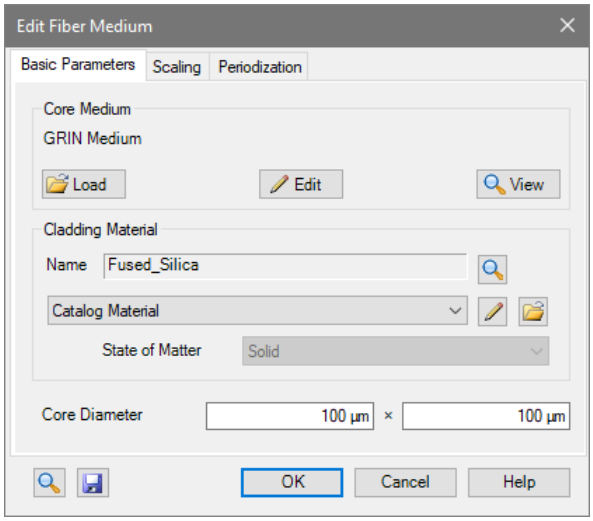


Figure 274. *Dialog for the specification of a fiber medium.*

A fiber can be described as a round core (made of an arbitrary medium) which is surrounded by a cladding (made of a homogeneous medium).
The edit dialog of this medium (↪Fig. 274) has thus the following parameters.

ITEM	DESCRIPTION
Core Medium	Here you can define the medium of the core using the control described in Sec. 34.1.
Cladding Material	Allows you to define the material of the homogeneous cladding medium. This control is described in Sec. 34.3.
Core diameter	The diameter of the core. If you enter different values for the x- and y-direction, you can define an elliptical core. Double-clicking into one of the two text boxes inserts the value from the other text box.

The remaining controls are explained in Sec. 38.1.

38.3.5 General Anisotropic Medium

If some anisotropic medium has to be described which cannot be considered being an uniaxial or biaxial crystal, a General Anisotropic Medium can be defined. It is not based on different materials (describing dispersion relations for different principal directions) but provides wavelength dependencies for the permittivity tensor and permeability tensor instead.

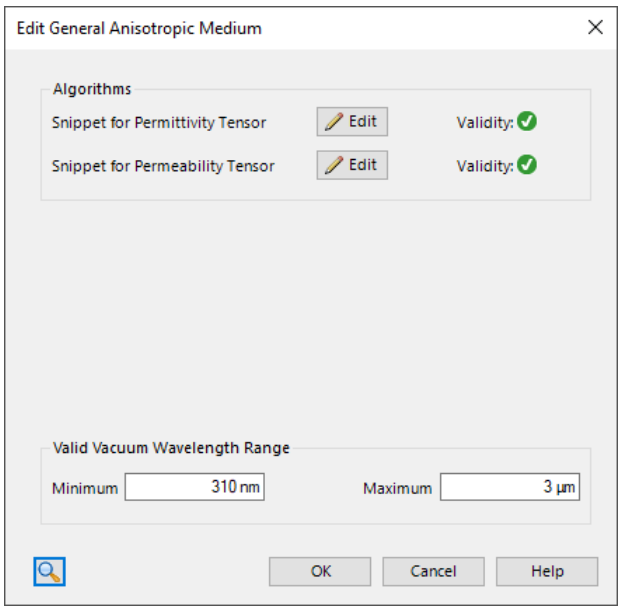


Figure 275. *Dialog for the specification of a general anisotropic medium.*

The edit dialog for this kind of medium (shown in Fig. 275) works with the following parameters:

ITEM	DESCRIPTION
Snippet for Permittivity / Permeability Tensor	The wavelength dependency of the permittivity and permeability tensor has to be programmed by code snippets, resp. *Edit* opens the Source Code Editor (↪Sec. 7.3) to edit this snippet, and a validity indicator (↪Sec. 5.11) shows whether this snippet is consistent.
Valid Vacuum Wavelength Range	The wavelength range the defined tensors hold valid for is to be defined via *Minimum* and *Maximum* here.

38.3.6 GRIN Medium

A GRIN medium is described by a base material and an analytical formula which alters the (complex-valued) refractive index n_0 of this base material.

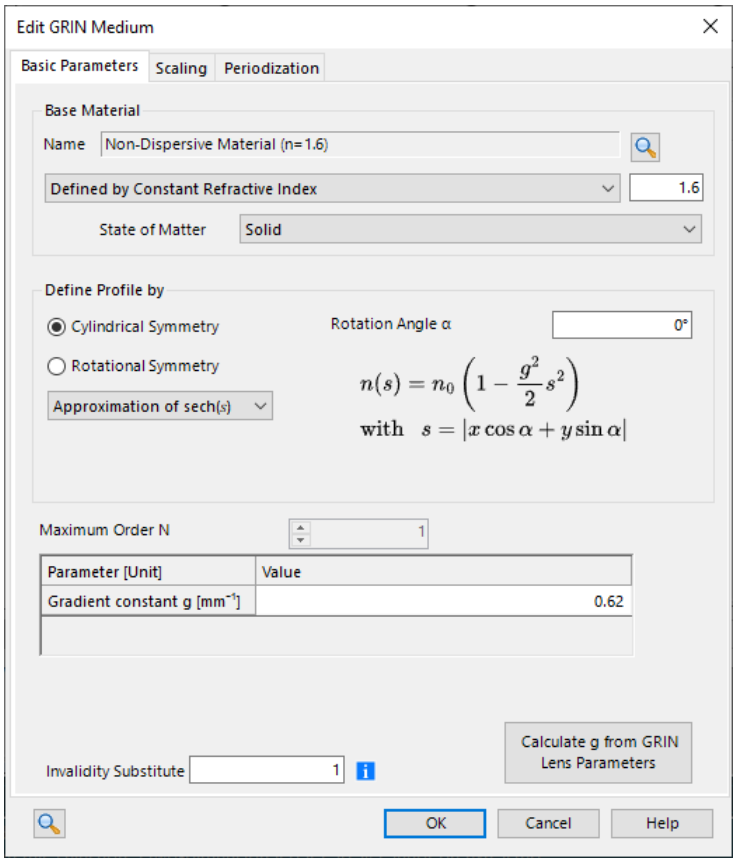


Figure 276. *Dialog for editing a GRIN medium.*

The edit dialog (↪Fig. 276) has the following controls.

ITEM	DESCRIPTION
Base Material PE	Defines the base material of the GRIN medium. For a detailed description of the controls within this group box see Sec. 34.3.
Rotational Symmetry / Cylindrical Symmetry	You can define a GRIN lens with either *Rotational Symmetry* (modulation along the radius $r = \sqrt{x^2 + y^2}$) or with *Cylindrical Symmetry* (modulation only along one direction). In the latter case you can additionally set the *Rotation Angle* PV α. α = 0° refers to modulation in x-direction only and α = 90° refers to modulation in y-direction only.
{Formula}	This list box lets you choose the equation used for the calculation of the refractive index modulation. The available formulas are described in Sec. 138.3.2. Each equation has different parameters and thus different input controls.
Maximum Order N	ONLY FOR THE EQUATIONS *POLYNOMIAL* AND *SQUARE ROOT OF POLYNOMIAL* The maximum order N of the polynomial.
{Table} PV	FOR ALL EQUATIONS BUT *POWER LAW INDEX PROFILE* Allows you the enter the parameters of the polynomial.
Invalidity Substitute PV	The resulting refractive index is equal to the *Invalidity Substitute* in case the actual formula yields zero or negative values (or roots of negative values in case of *Square Root of Polynomial*).
Calculate g from GRIN Lens Parameters	ONLY FOR THE EQUATION *APPROXIMATION OF SECH(s)* Opens a dialog where you can calculate the gradient constant g from the so-called *pitch* P of a GRIN lens and its length z.
Decrease Δ PV **/ Outside Value n_1** PV	ONLY FOR THE EQUATION *POWER LAW INDEX PROFILE* The decrease Δ describes how much the refractive index is decreased till the border b. Alternatively you can directly enter the refractive index n_1 at and outside of the border. The two values are related via $n_1 = n_0\sqrt{1 - 2\Delta}$.
Border b PV	ONLY FOR THE EQUATION *POWER LAW INDEX PROFILE* The *Power Law Index Profile* is usually used to describe an optical fiber with a GRIN profile. In this case, the border b is equal to the core radius of the fiber.
Exponent p PV	ONLY FOR THE EQUATION *POWER LAW INDEX PROFILE* The (positive) exponent p of the equation is usually close to 2 for GRIN fibers and infinity for step-index fibers.

The remaining controls are explained in Sec. 38.1.

38.3.7 Medium with Inclusions

In the base material of a *Medium with Inclusions*, spherical[1] inclusions of another material are embedded. These inclusions are placed at random positions in the elementary cell of the medium (↪Sec. 138.3.1). Thus, the *Medium with Inclusions* must always be periodical, which is ensured by its edit dialog. Both the positions and the radii of the inclusions follow a uniform random distribution.

[1] By using different scaling values for x, y and z (↪Sec. 138.3.1), the spheres may be dilated or compressed to become ellipsoids.

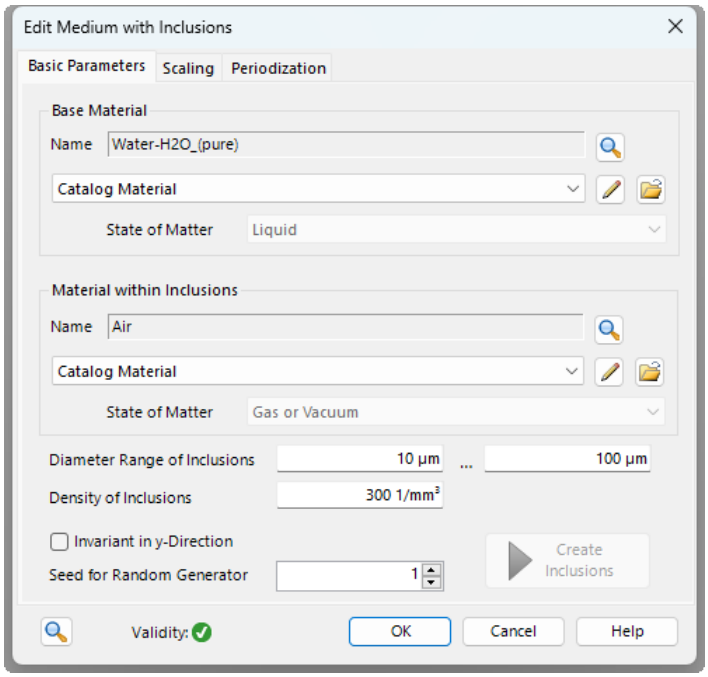


Figure 277. *Dialog for editing a* Medium with Inclusions.

The edit dialog (↪Fig. 277) contains the following controls:

ITEM	DESCRIPTION
Base Material PE	Defines the material the inclusions are embedded within. For a detailed description of the controls within this group box see Sec. 34.3.
Material within Inclusions PE	Defines the material the inclusions consist of. For a detailed description of the controls within this group box see Sec. 34.3.
Diameter Range of Inclusions	Allows to specify the *Minimum Inclusion Diameter* PV and the *Maximum Inclusion Diameter* PV for the diameter random distribution. Both values may be equal in case no size variation is needed.
Density of Inclusions PV	The mean density ρ of the inclusions. The number of inclusions N within the elementary cell is $N = \rho \cdot V$, with V being the volume of the elementary cell. Note that even if the medium is *Invariant in y-Direction*, the media period in y-direction influences the volume V and thus the number of inclusions. A warning is shown in case • the desired density is so low that less than 0.5 inclusions are to be placed in the elementary cell. • the desired density cannot be achieved due to a too high density or a too small media period.
Invariant in y-Direction	If this option is checked, the centers of all inclusions are placed at $y = 0$ so the positions vary in the x-z-plane only.
Seed for Random Generator PV	A value which is needed for the generation of the random distribution of the inclusions: With the same value and the same physical settings listed above always the same refractive index distribution will be generated.

Create Inclusions	Pressing this button will start the generation of the inclusions. Please note: *Every parameter change (except for changed materials) requires a new creation in order to become effective!*

The remaining controls are explained in Sec. 38.1.

38.3.8 Pillar Medium (General)

The *Pillar Medium (General)* is a periodical medium consisting of a base material with periodically distributed *pillars* of another material (↪Sec. 39). In contrast to the *Pillar Medium (z-Independent)* it supports parameter variation, slanted pillars and round edges; but not elliptical pillars.

An arbitrary amount of pillars can be freely distributed, each with its own lateral extension. The pillars must be well-separated. This means that refractive indices are determined only by the nearest pillar, if at all.

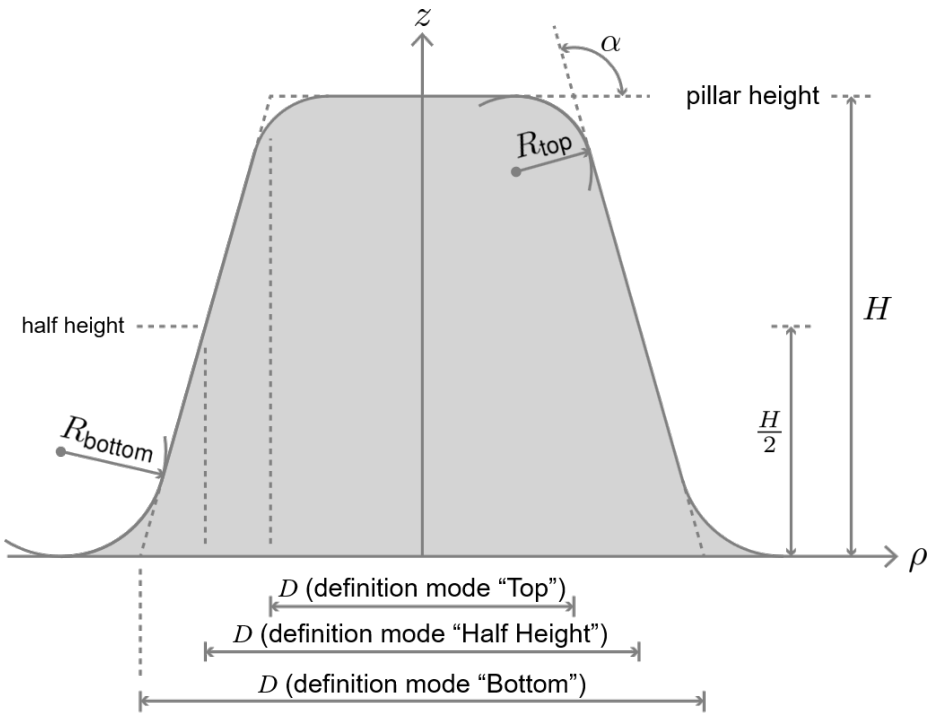


Figure 278. *The parameters defining the geometry of a single (circular) pillar.*

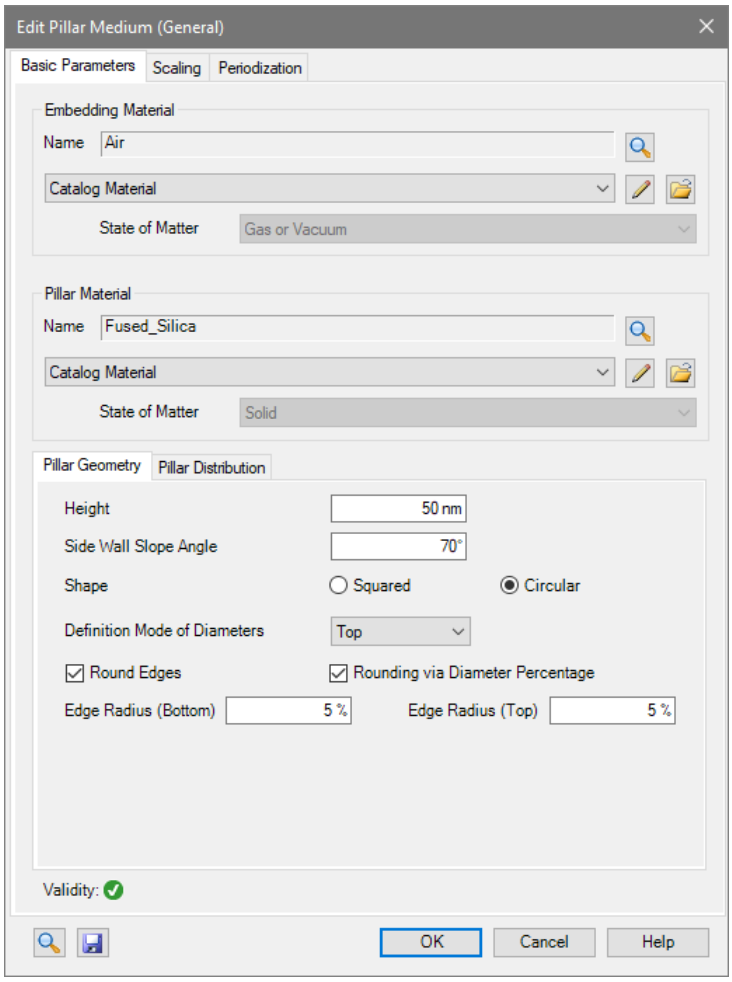


Figure 279. Basic Parameters *tab of the Pillar Medium (General).*

The *Basic Parameters* tab (↪Fig. 279) has the controls explained below. The other tab pages are explained in Sec. 38.1.

ITEM	DESCRIPTION
Embedding Material PE	Allows the user to define the material outside the pillars by means of the control described in Sec. 34.3.
Pillar Material PE	Allows the user to define the material inside the pillars by means of the control described in Sec. 34.3.
Pillar Geometry	This tab page contains settings for the geometry of all pillars. They are explained in a separate table below.
Pillar Distribution	The table on this tab page allows you to define *x-Position*, *y-Position*, and *Side Length* / *Diameter* D of each pillar. There are several *Table Tools* which help you to set up the table (for example add or remove rows). They are explained in a separate table. Furthermore this tab page contains the *Import Diameter Data* button which allows you to import diameter values on an equidistant grid from a two-dimensional data array or (via *Import…*) from a text file by means of the import wizard described in Sec. 121.1.
Validity	Indicates problems with the current configuration of the medium by means of the control explained in Sec. 5.11.

On the *Pillar Geometry* sub-tab there are the following settings for the geometry of all pillars.

ITEM	DESCRIPTION
Height PV	The height H of all pillars.
Side Wall Slope Angle PV	The angle α defining the slope of the side walls. As you can see in Fig. 278 an angle between 0° and 90° means that the side length / diameter of a pillar becomes larger with increasing z, and an angle between 90° and 180° means that the side length / diameter of a pillar becomes smaller with increasing z.
Shape PE	A pillar can either have a *Squared* or *Circular* shape. In the former case you define the side lengths of the pillars, in the latter the diameters.
Definition Mode of Side Lengths / Diameters PE	ONLY IF THE *SIDE WALL SLOPE ANGLE* IS NOT 90°, I. E. IF THE SIDE WALLS ARE NOT PERPENDICULAR. As shown in Fig. 278 there are three possible heights where the side length / diameter D can be measured: at the *Bottom*, the *Half Height*, or the *Top*. In case of perpendicular side walls all three values are the same.
Round Edges	ONLY FOR *CIRCULAR* PILLARS. Allows you to define round edges at the top and the bottom, respectively, of the side wall.
Rounding via Diameter Percentage	ONLY FOR *ROUND EDGES*. If this option is checked, the edge radii are defined relatively to the diameter D of each pillar. Otherwise they are defined absolutely.
Edge Radius (Bottom) PV	ONLY FOR *ROUND EDGES*. The edge radius R_{bottom}. Note that this radius can also be negative to define an overhanging pillar.
Edge Radius (Top) PV	ONLY FOR *ROUND EDGES*. The edge radius R_{top}. Note that this radius can also be negative to define an overhang.

The following table tools are available:

TOOL	DESCRIPTION
Add Pillar…	Opens a separate dialog where you can enter *Position* and *Side Length* / *Diameter* of a new pillar which is the added to the end of the table.
Remove Current Pillar	Removes the currently selected pillar. The same can be done by pressing the Del key while the table is has the input focus.
Reset Table	Resets the table to its initial state (one pillar at position $(0\,\mathrm{m};\ 0\,\mathrm{m})$ with a side length / diameter of 100 nm).
Add Equidistant Pillars…	Opens a separate dialog where you can enter the *Number of Pillars* and their *Center-to-Center Distance* as well as their *Side Length* / *Diameter*. If you check *Overwrite Existing Data* the table contains only these new pillars after you close the dialog with *OK*. Otherwise the new pillars are simply added to the table.
Set Common Side Length / Diameter…	Sets the side length / diameter of all already defined pillars to the same value.
Configure Parameter Variation…	Defines how the values in the table are made available for Parameter Extraction. ↪Sec. 38.3.8.1

38.3.8.1 Parameter Variation

There are several ways how the positions and side lengths / diameters of the pillars can be made available for Parameter Extraction (↪Sec. 44.6).

- **Original Values:** The values defined in the table are directly made available for parameter extraction. This means that for each pillar *Position X*, *Position Y*, and *Side Length* / *Diameter* can be varied e. g. in the Parameter Run.
- **Deviation of Original Values:** For each pillar you can vary the deviation from the original values defined in the table. For example you then can make the side length / diameter of the first pillar 5 nm smaller and the side length / diameter of the first pillar 5 nm smaller.
- **Scaling of all Values:** The values of **all** pillars are multiplied with the same scaling factor, whereas there is one *Scaling Factor for Positions* and one *Scaling Factor for Side Lengths / Diameters*.

The table tool *Configure Parameter Variation…* allows you to set this separately for the pillar positions and the pillar side lengths / diameters.
To increase performance in case of very many pillars (> 1000), consider choosing *Scaling of all Values* instead of the other two options, especially if Parameter Extraction is not needed for the positions or side lengths / diameters. You can also exclude these parameters completely from Parameter Extraction via an Optical Setup Tool (↪Sec. 44.6).

38.3.9 Pillar Medium (z-Independent)

The *Pillar Medium (z-Independent)* is a periodical medium consisting of a base material with periodically distributed *pillars* of another material (↪Sec. 39). In contrast to the *Pillar Medium (General)* it supports elliptical pillars; but not parameter variation, slanted pillars and round edges.
The position and shape of the pillars are z-independent. That means that all x-y cross sections through the medium are equal. The shape all pillars of the x-y cross section is either rectangular or elliptical. The pillars are distributed periodically on the x-y cross section. They are grouped in equal rows (along x-direction), whereas two consecutive rows can be x-shifted to each other, but every other row has the same x-shift (↪Fig. 280).

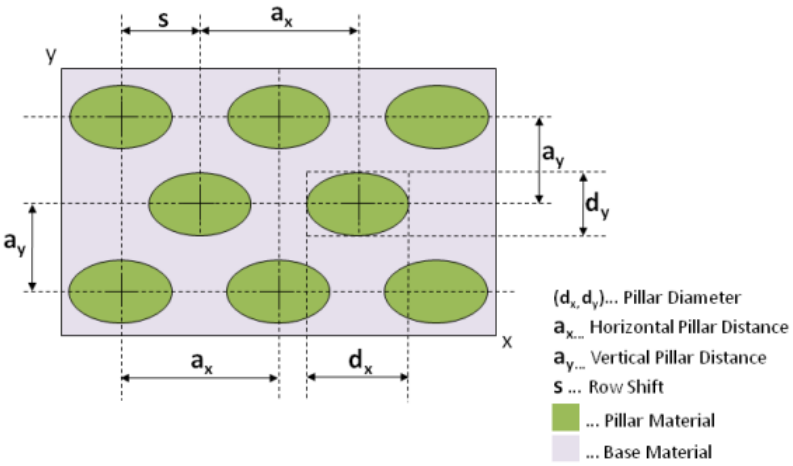


Figure 280. *x-y cross section through a Pillar Medium (z-Independent) with all parameters that can be edited.*

Via the edit dialog (↪Fig. 281) the materials and the geometrical parameters of the medium can be adjusted.

ITEM	DESCRIPTION
Base Material PE	There the user can define the base material (↪Fig. 281). It is loadable from a material catalog (if *Catalog Material* is selected) or can be defined by a constant refractive index (if *Defined by Constant Refractive Index* is selected).
Pillar Material PE	The pillar material (↪Fig. 281) is adjustable in the same manner as the base material.
Pillar Size and Shape	The size and shape of pillars in the x-y cross section of the medium can be defined there. The pillar cross sections can be of *Elliptical* or *Rectangular* shape. The *Diameter* PV is adjustable in x- and y-direction.
Horizontal Pillar Distance PV	x-distance between two consecutive pillars within a row of pillars in the x-y cross section (↪Fig. 281)
Vertical Pillar Distance PV	y-distance between two consecutive rows of pillars in the x-y cross section (↪Fig. 281)
Row Shift PV	Via this parameter the x-shift between two consecutive rows of pillars (↪Fig. 281) can be adjusted. Any real value can be entered there, but it is internally transformed to the smallest equivalent positive value (smaller than the period in x-direction.
Period	The size of a 2D periodical x-y-section through the medium can not be entered directly but is calculated from the other geometrical parameters. Both values (x and y) are updated after each parameter change.

The remaining controls are explained in Sec. 38.1.

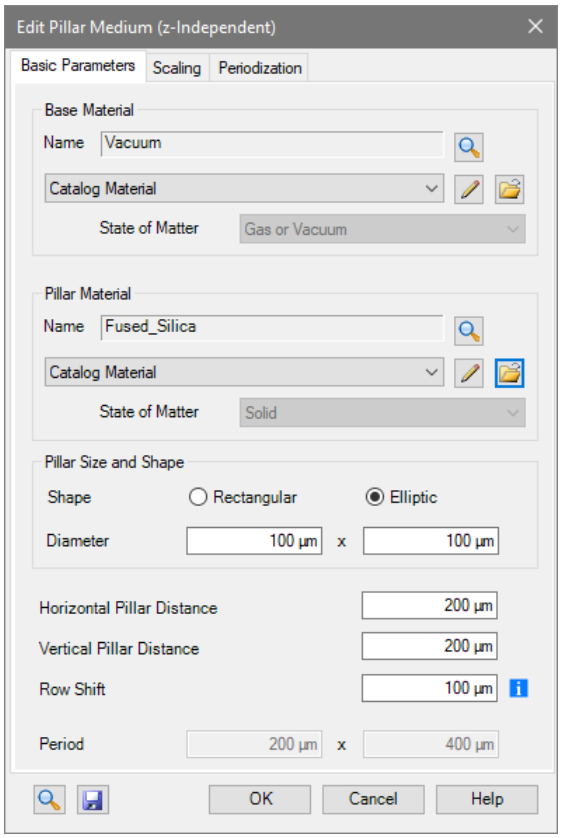


Figure 281. *Dialog for the specification of a Pillar Medium (z-Independent).*

38.3.10 Programmable Medium

The programmable medium allows you to define an arbitrary, complex-valued refractive index distribution $\tilde{n}(x,y,z)$ by writing its formula into a little code snippet. If the medium is set to periodic, you can use the variables *MediaPeriodX*, *MediaPeriodY*, and *MediaPeriodZ* in your snippet.

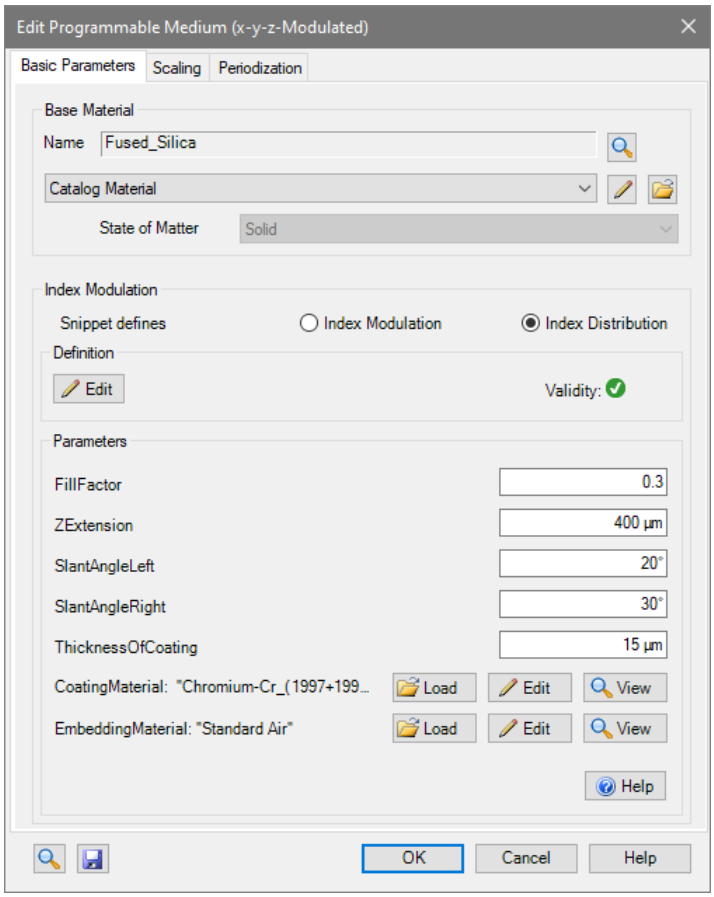


Figure 282. *Sample edit dialog for the programmable medium.*

The corresponding edit dialog (↪Fig. 282) contains:

ITEM	DESCRIPTION
Base Material PE	↪Sec. 34.3 The refractive index of the *Base Material* is always added to the function defined by the snippet if the snippet defines *Index Modulation*.It is also taken into account for the optical path length calculated by the Optical Path Length Analyzer (↪Sec. 83).
Snippet defines…	If you select *Index Modulation* the refractive index of the *Base Material* is always added to the function defined by the snippet. Otherwise you directly define the refractive index distribution $\tilde{n}(x, y, z)$.
Definition	This group box allows you to program the actual code snippet. *Edit* opens the Source Code Editor (↪Sec. 7.3) to edit this snippet, and a validity indicator (↪Sec. 5.11) shows whether this snippet is consistent.
Parameters PE	The controls in this group box allow you to set the values of the global parameters of the snippet. ↪Sec. 7.4

General information about programming in VirtualLab Fusion can be found in Sec. 7. The remaining controls are explained in Sec. 38.1.

38.3.11 Sampled Medium

This medium allows you to set a 1D or 2D data array (↪Sec. 13) with a sampled refractive index profile. The edit dialog of this optical medium is shown in Fig. 283.

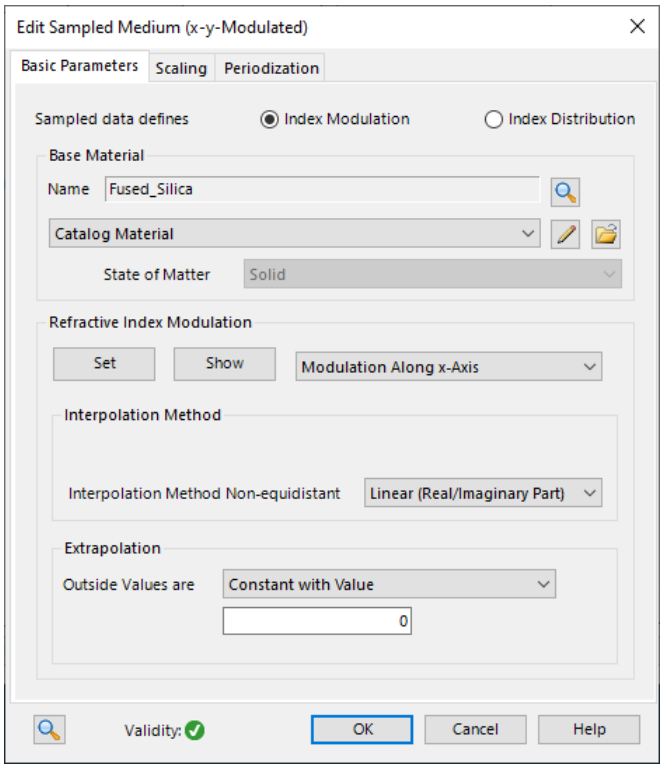


Figure 283. *Dialog for the specification of a sampled medium.*

The following options can be entered:

ITEM	DESCRIPTION
Sampled data defines	Defines whether the sampled refractive index profile is interpreted as *Index Modulation*, i. e. it is added to the refractive index defined by the *Base Material*. Or it can be interpreted as *Index Distribution*, i. e. the values in the data array are directly the final refractive indices.
Base Material PE	ONLY FOR INDEX MODULATION The controls in this group box are explained in Sec. 34.3. They define the complex refractive index added to the refractive index profile.
Set	Offers you three ways to set a data array with the refractive index modulation (see below). The data array must contain exactly one subset where the coordinates have the unit length and the data have no unit.
Set > Load	Loads a data array from a .da file.
Set > Import	Imports a data array from a text file by means of the import wizard described in Sec. 121.1.
Set > Select from Documents	Allows you to select an already open data array.
Show	Shows the currently set refractive index definition / modulation as separate document.
{Interpretation of 1D Data}	When you set 1D data, you can define whether the coordinates are interpreted as being x- or y-values. When the data contain only positive values, the coordinates can additionally be interpreted as $\rho = \sqrt{x^2 + y^2}$ yielding rotationally symmetric refractive indices.

Interpolation Method	Lets you select the *Interpolation Method Equidistant* and/or the *Interpolation Method Non-equidistant*, dependent on the data. ↪Sec. 13.2
Extrapolation	Lets you select how coordinates outside of the coordinate range of the given data are interpreted (↪Sec. 13.3). In particular, you can select periodic extrapolation. This is in the very most cases more suitable then choosing the normal medium periodization (↪Sec. 138.3.1) – where periods have to be entered by the user and are restricted to be always centered around the coordinate origin which might yield unexpected results.

The remaining controls are explained in Sec. 38.1.

38.3.12 Slanted Grating Medium

This kind of medium represents a periodic grating with ridges. A ridge has two flanks which both are slanted with respect to the vertical by a certain angle. the edges can be rounded and a coating with a single layer can be applied to the flanks, the bottom, and the top of the grating.

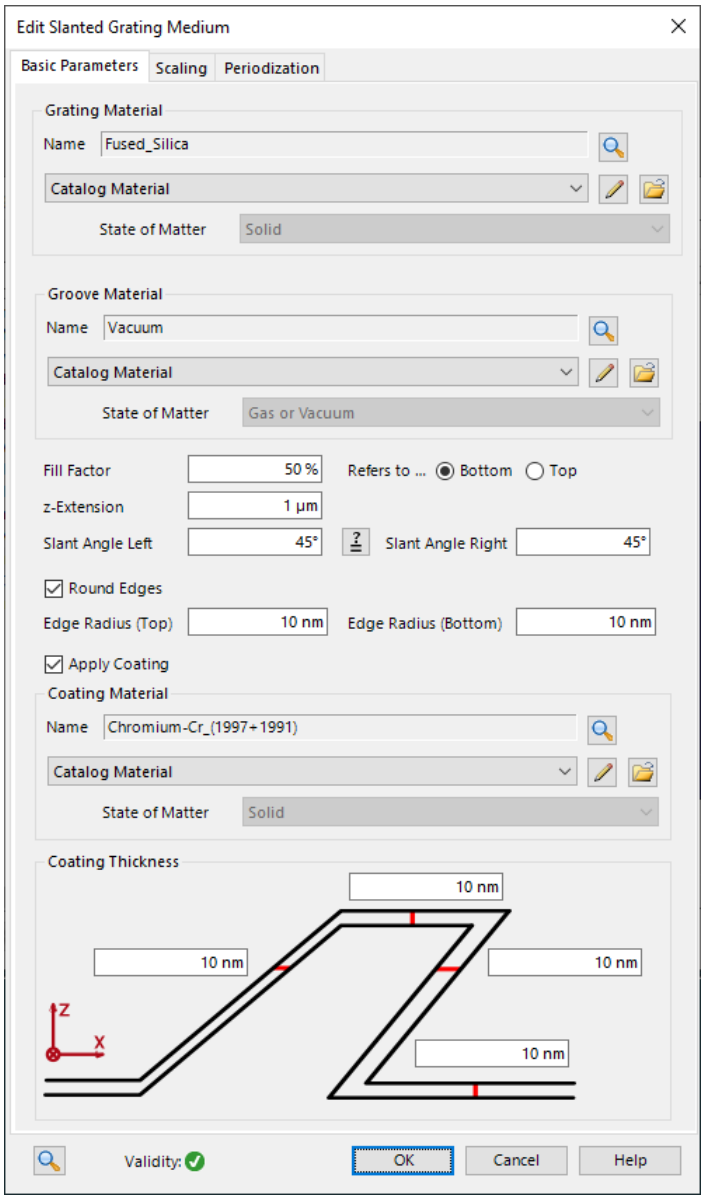


Figure 284. *Dialog for the specification of a Slanted Grating Medium.*

The edit dialog of this medium (↪Fig. 284) has the following controls:

ITEM	DESCRIPTION
Grating Material PE	The material of the grating ridges. Also used to fill the area in front of the modulated region. The controls in this group box are explained in Sec. 34.3.
Groove Material PE	The material of the grating grooves. Also used to fill the area behind the modulated region. The controls in this group box are explained in Sec. 34.3.
Fill Factor PV	The ratio of the grating ridges to the period in x-direction of the medium. If the slant angles of the flanks differ, the width of the ridges changes with z. In this case it makes a difference whether the fill factor *Refers to …* the bottom ($z = 0$) or the top ($z =$ *z-Extension*) of the grating.
z-Extension PV	The extension of the ridges (without coating) in z-direction. Note that if a Slanted Grating Medium is used within an Optical Stack (↪Sec. 40), its z-extension (with coating) determines the thickness of the stack layer where it is placed in. Thus you cannot set the *z-Distance* of the subsequent layer.

Slant Angle Left PV	The angle to the vertical of the left flank. “Left” refers to the flank with the smaller x-position.
? / !	If you click on the ? button it turns into a ! button which means that the two slant angles are always the same, even during e. g. Parametric Optimization (↪Sec. 103). Clicking on this button again allows you to set different angles again.
Slant Angle Right PV	The angle to the vertical of the right flank. “Right” refers to the flank with the larger x-position.
Apply Round Edges	If you click this check box you can define rounded edges by entering *Edge Radius (Top)* and *Edge Radius (Bottom)*. If a coating is applied, edge rounding is also applied to it.
Edge Radius (Top)	ONLY VISIBLE IF *APPLY ROUND EDGES* IS CHECKED. The edge radius applied to the two edges on the top of the ridge.
Edge Radius (Bottom)	ONLY VISIBLE IF *APPLY ROUND EDGES* IS CHECKED. The edge radius applied to the two edges on the bottom of the ridge.
Apply Coating	If you click this check box the dialog extends so that you can apply a coating (consisting of a single material) on the grating.
Coating Material PE	ONLY VISIBLE IF *APPLY COATING* IS CHECKED. The material in the coating layer. The controls in this group box are explained in Sec. 34.3.
Coating Thickness PV	ONLY VISIBLE IF *APPLY COATING* IS CHECKED. Allows you to set the thickness of the coating layer on the flanks, the bottom, and the top of the grating (measured along x- and z-direction, respectively).
Validity	An indicator which shows whether or not the entered data are consistent (↪Sec. 5.11). For example the flanks might intersect or the edge radii might be too large for the given ridge width.

38.3.13 Uniaxial Crystal

Uniaxial crystals are anisotropic media which can be described by two different refractive indices.

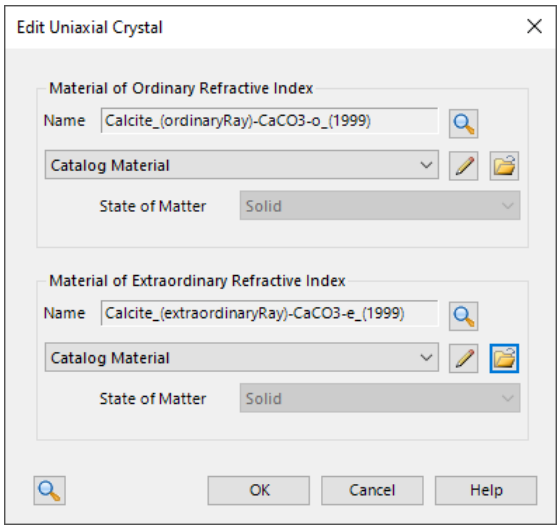


Figure 285. *Dialog for the specification of a uniaxial crystal.*

The edit dialog for this kind of medium (shown in Fig. 285) needs the following parameters:

ITEM	DESCRIPTION
Material of Ordinary / Extraordinary Refractive Index	The dispersion relations for the two refractive indices are represented by two materials. The control for setting a material is described in Sec. 34.3.

38.3.14 Volume Grating Medium

The volume grating medium is designed for analyzing interferograms recorded into a photosensitive *Holographic Material*[PE]. In VirtualLab Fusion the interferograms can be synthesized by the superposition of an arbitrary number of plane waves. See Sec. 138.3.3 for the implemented formulas.

The angles of incidence and the wavelengths of the superposing plane waves can be freely defined by the user. It is assumed that only waves of exactly the same wavelength will interfere with each other.

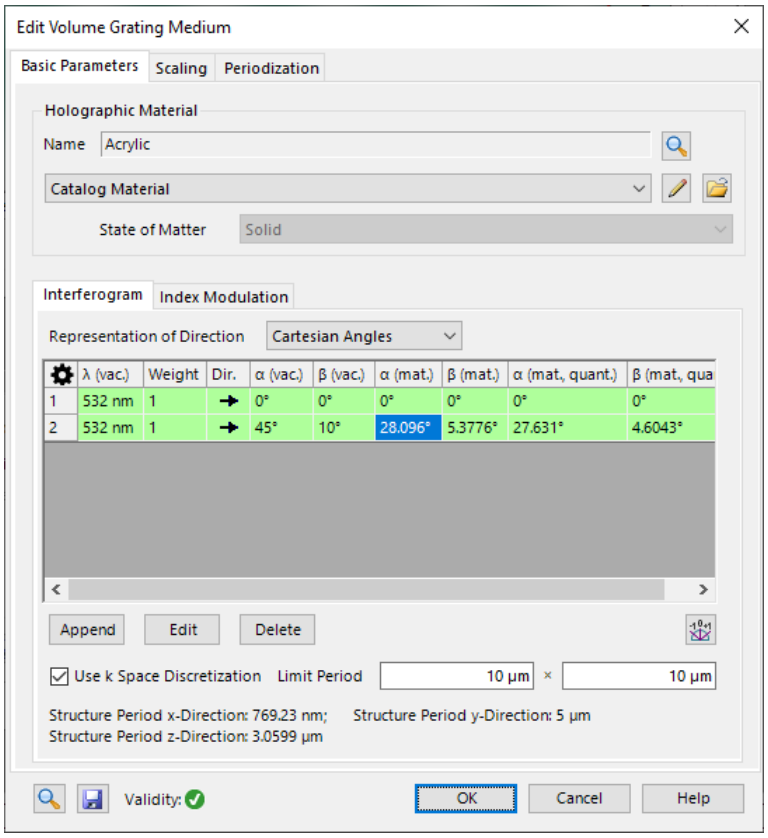


Figure 286. *The edit dialog for a volume grating medium.*

The *Basic Parameters* tab of the edit dialog (↪Fig. 286) comprises a control for specifying the *Holographic Material* which is explained in Sec. 34.3 and two sub-tab pages which are explained in the following subsections. The remaining controls are explained in Sec. 38.1.

38.3.14.1 Interferogram

The main part of the *Interferogram* panel is a table showing vacuum, relative power (*Weight*), and direction of all superposing plane waves (Fig. 287). The directions are shown in the specified *Representation of Direction* (*Cartesian Angles*, *Spherical Angles*, *Wave Numbers*, or *Spatial Frequencies*). To obtain a better overview, you can hide columns using the gear symbol in the top left corner of the table. Which columns are avaial The

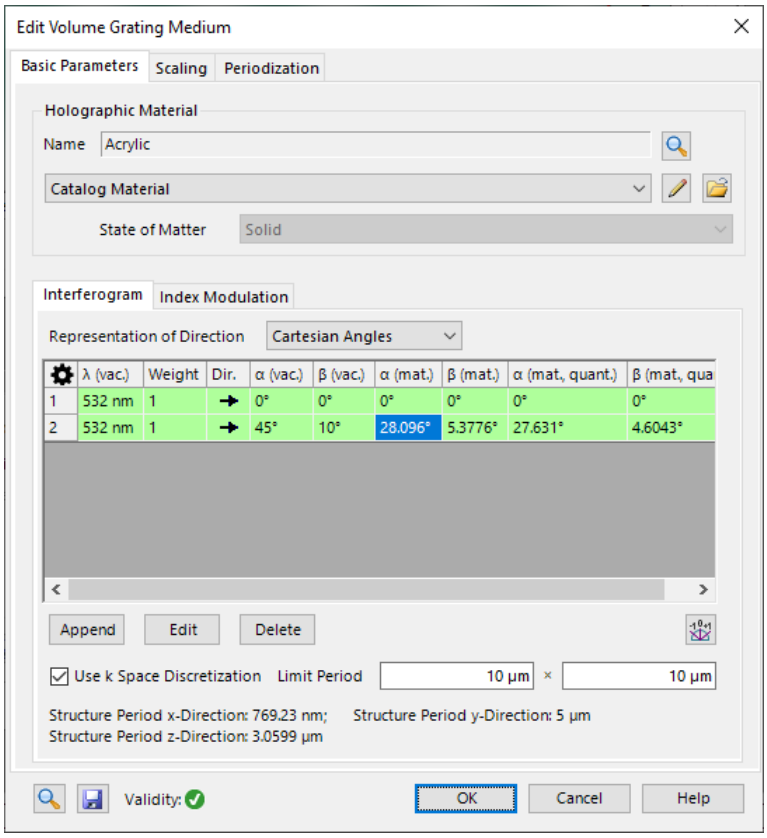


Figure 287. *The* Interferogram *tab for a volume grating medium.*

> The following abbreviations are used in the table: *vac.* refers to the vacuum, *mat.* to the *Holographic Material*. *quant.* refers to the k space quantization introduced by the *Limit Period*. *Dir.* means direction. The arrows in this column indicate whether the wave comes from positive or negative z-direction.

The *Append* button adds a new default wave, the *Delete* button deletes the currently selected plane wave. If you double click on a plane wave or press *Edit*, the dialog explained in subsection (a) opens.
If there are exactly two interfering waves per wavelength, the button gets enabled. It opens a visualization of the interfering wave vectors and the respective resulting wave vectors (↪Sec. (b)).
When you *Use k Space Discretization*, the *Limit Period* specifies the maximum possible period in x- and y-direction, as large periods heavily increase the numerical effort for the Fourier Modal Method (↪Sec. 97.3). On the downside, it introduces a quantization of the specified angles. Mathematical details can be found in Sec. 138.3.3.
For your information, the resulting structure periods are also given.

(a) Editing the Interfering Plane Waves

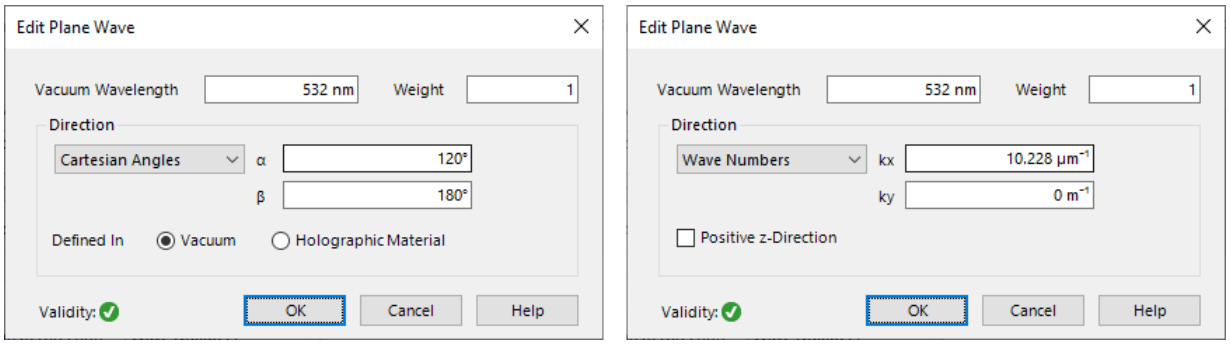


Figure 288. *The dialog for setting up the interfering plane waves. It shows the same plane wave, left when defined via* Cartesian Angles *and right when defined via* Wave Numbers.

The dialog for editing one of the interfering plane waves (↪Fig. 288) has the following options:

ITEM	DESCRIPTION
Weight[PV]	Specifies the relative squared amplitude of the wave. See Eq. (138.14) for details.
Wavelength[PV]	The vacuum wavelength of the plane wave.
Direction[PV]	The direction of the plane wave can be specified as *Cartesian Angles*, *Spherical Angles*, *Wave Numbers*, or *Spatial Frequencies*. For the angles, you can specify arbitrary values and thus indirectly wave vectors with a positive or negative z-component. Furthermore you can specify whether the angles are defined in *Vacuum* or in the *Holographic Material*. In case of *Wave Numbers* or *Spatial Frequencies* you can specify the x- and y-component of the wave vector (or the wave vector divided by 2π) and the sign of the z-component (*Positive z-Direction*).

(b) Preview of the Interfering Plane Waves

If there are exactly two interfering waves per wavelength, you can visualize the interfering plane waves and the resulting grating vectors with the dialog shown in Fig. 289. The interfering plane waves are colored according to their wavelengths, the resulting grating vectors are colored pink.

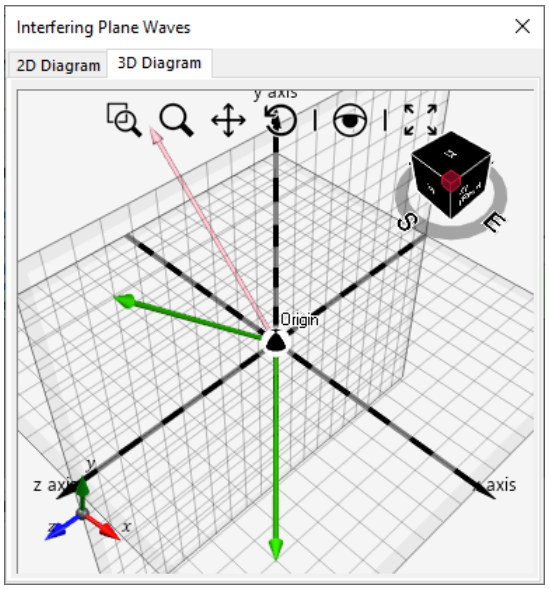


Figure 289. *The preview dialog showing two interfering plane waves of 532 nm (green) and the resulting grating vector (pink).*

The dialog has two tabs.

TAB	DESCRIPTION
2D Diagram	The projection of the wave vectors on the x-z-plane, shown in a polar diagram. You can adjust the maximum of the radial value axis with the mouse wheel.
3D Diagram	All vectors are shown as arrows in a 3D view. This view offers the same interactions as the standard 3D view (↪Sec. 5.16). Only the context menu has just one entry to set the view settings, ↪Sec. 19.3. When you hover the mouse over a certain arrow, a tooltip with the description of the vector is shown.

38.3.14.2 Index Modulation

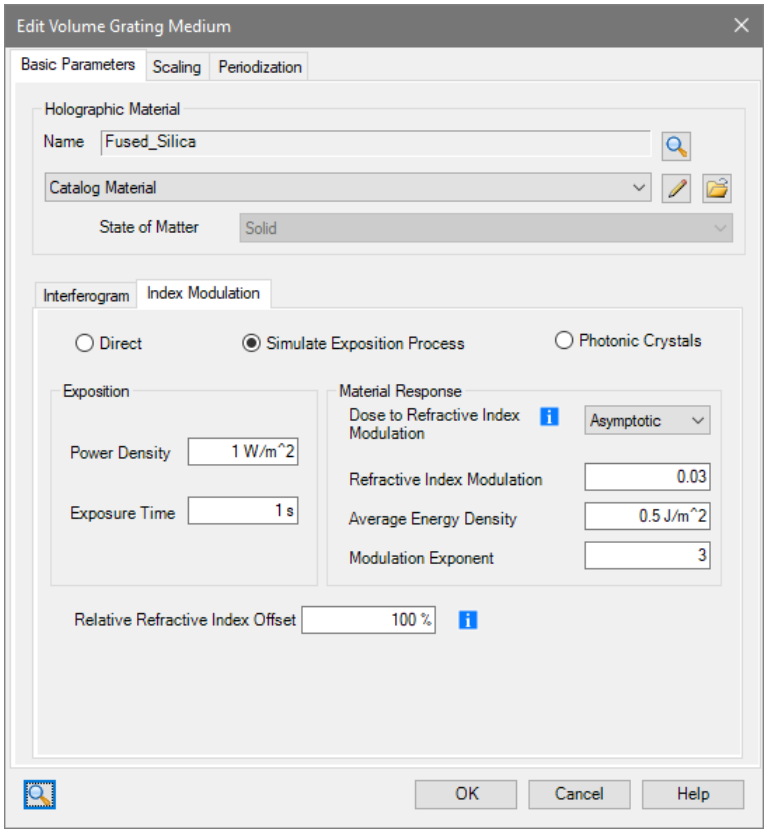


Figure 290. *The* Index Modulation *tab of the volume grating dialog.*

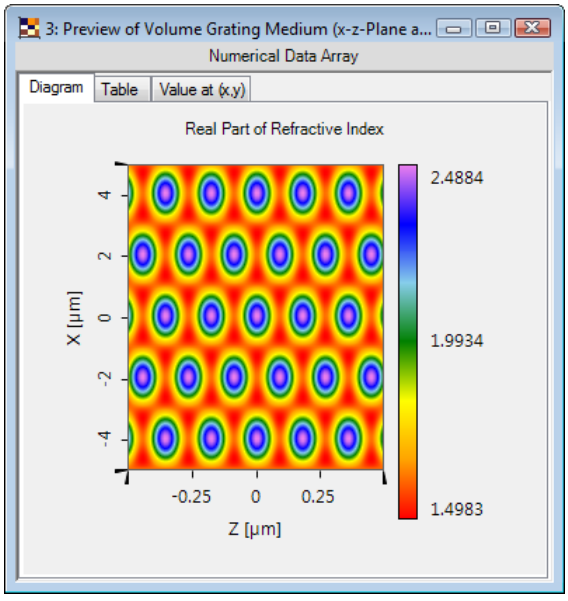


Figure 291. *Example structure if direct refractive index modulation is used.*

This panel specifies how the local electrical field density $\overline{w}(x, y, z)$ (↪Eq. (138.13)) is converted into a change of the refractive index. The volume grating medium offers three different modes therefor:

(a) Direct

In this case you just specify the desired *Refractive Index Modulation*[PV] Δn and the *Relative Refractive Index*

Offset R. The refractive index $n(x,y,z)$ at a certain position is then calculated via

$$n(x,y,z) = n_{\text{holo}} + \left(\frac{\overline{w}(x,y,z)}{w_{\text{max}}} + \frac{R-1}{2} \right) \cdot \Delta n \tag{38.1}$$

w_{max} can be an arbitrary value, as it cancels out in this case (see Eqs. (138.13)-(138.14)). n_{holo} is the refractive index of the *Holographic Material*.

For $R = +100\%$ the refractive index modulation is added to n_{holo}, for $R = -100\%$ it is subtracted from n_{holo} and for intermediate values it is something in between. In particular the case $R = 0$ means that the refractive indices range from $n_{\text{holo}} - \frac{\Delta n}{2}$ to $n_{\text{holo}} + \frac{\Delta n}{2}$.

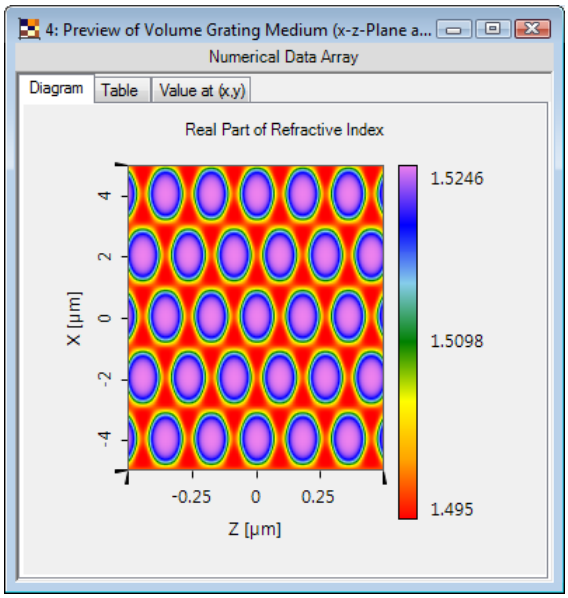


Figure 292. *Example structure if asymptotic dose to refractive index modulation is used with slight over-exposure.*

(b) Simulate Exposition Process

In this case you simulate the real exposition process. This means you can set up the overall *Power Density*[PV] P of all superposing waves, the *Exposure Time*[PV] t_{exp} and the *Material Response*.

Then, the overall energy density is calculated as follows:

$$w_{\text{max}} = P \cdot t_{\text{exp}} \tag{38.2}$$

On the left side of the panel you can choose between three equations how the *Dose to Refractive Index Modulation* is modeled:

MODEL	EQUATION	PARAMETERS
Linear	$n(x,y,z) = n_{\text{holo}} + l\overline{w}(x,y,z) + C$	l: *Linear Factor* C: refractive index offset, see below
Quadratic	$n(x,y,z) = n_{\text{holo}} + l\overline{w}(x,y,z) + p\overline{w}(x,y,z)^2 + C$	l: *Linear Factor* p: *Squared Factor* C: refractive index offset, see below
Asymptotic	$n(x,y,z) = n_{\text{holo}} + \Delta n - \frac{\Delta n}{1+(\overline{w}(x,y,z)/w_0)^\gamma} + C$	Δn: *Refractive Index Modulation* w_0: *Average Energy Density* γ: *Modulation Exponent* C: refractive index offset, see below ↪Fig. 293

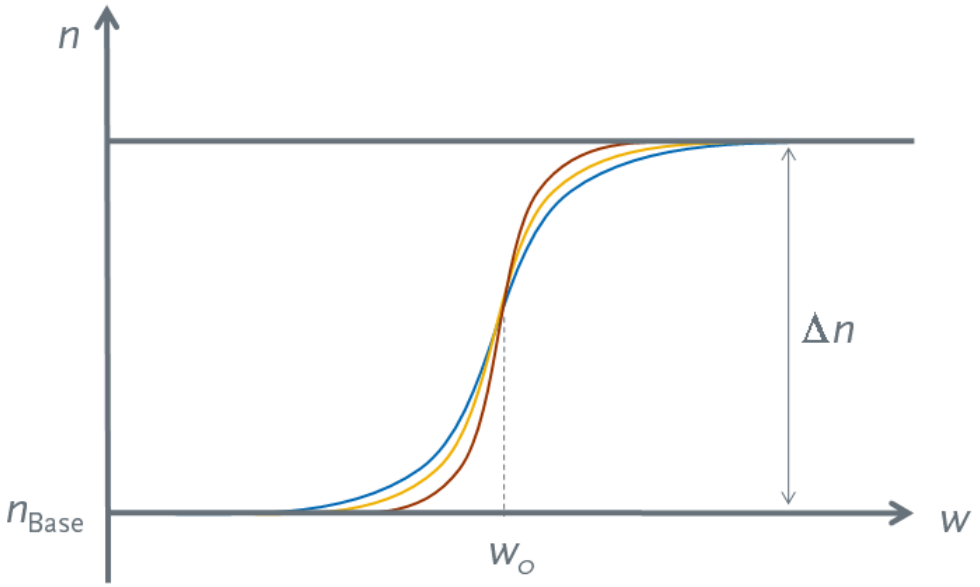


Figure 293. *The refractive indices $n(w)$ if asymptotic dose to refractive index modulation is chosen. The blue curve has the smallest modulation exponent and the red curve the largest.*

The *Relative Refractive Index Offset* R allows you to define whether the refractive index modulation is added to n_{holo} (for $R = +100\%$), subtracted from n_{holo} (for $R = -100\%$) or something in between. In particular the case $R = 0$ means that the refractive indices range from $n_{\text{holo}} - \frac{\Delta n}{2}$ to $n_{\text{holo}} + \frac{\Delta n}{2}$ where Δn is the overall refractive index modulation. This is achieved by adding $C = \frac{R-1}{2}\Delta n$ to the formulas given above.

(c) Photonic Crystals

In this case it is assumed that above a certain energy density w_t the original *Holographic Material* is replaced by a *Second Material*. In VirtualLab Fusion you enter the relative *Threshold*[PV], i. e. $\frac{w_t}{w_{\max}}$.

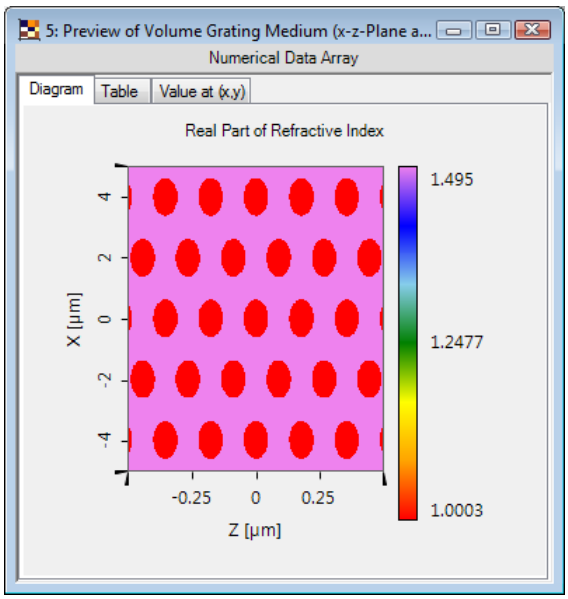


Figure 294. *Example structure if refractive index modulation for photonic crystals is used.*

39 Materials

39.1 Using Materials

Materials are used for defining Optical Media (↪Sec. 38). They hold all relevant optical material data, as described in the following.

39.1.1 Material Data

The complex refractive index $\hat{n}$ of a material can be expressed as

$$\hat{n} = n + i\kappa \,, \tag{39.1}$$

where n is the (real part of the complex) refractive index, and κ the absorption index. Here the absorption index κ must not be mixed up with the absorption coefficient α which is stored in the Material and that is related to κ by

$$\alpha = \frac{4\pi\kappa}{\lambda_0} = 2k_0\kappa \,. \tag{39.2}$$

In Eq. (39.2) λ_0 represents the vacuum wavelength and k_0 the wave number in vacuum. The absorption coefficient α is introduced in Beer's law, which is denoted as

$$I = I_0 \cdot \mathrm{e}^{-\alpha\Delta z} \,, \tag{39.3}$$

where I is the intensity after a propagation distance Δz through an absorbing material.
The dependency of the two parameters n and α on the wavelength are stored in each Material and can be given as sampled data or as one constant value. Additionally, the real refractive index n can be specified by some parameters that are related to a certain selected dispersion formula.

39.2 Defining and Editing Materials

Materials can be created or edited from the dialog of the Materials Catalog (↪Sec. 33). Additional the user can modify a material where it is needed. The edit dialog is described in detail now. Besides the panels *Refractive Index*, *Absorption*, and *Additional Information* described below, it contains the following controls:

ITEM	DESCRIPTION
Usable Vacuum Wavelength Range	The intersection of the wavelength ranges of the absorption coefficient, the real refractive index and, if given, the reference material's real refractive index.
	Opens the view of the current material.
	Saves the current material into the material catalog.
Tools > Reset All Data	Discards all changes made in this dialog and resets to the previous state of the material.
Validity	This control (↪Sec. 5.11) indicates whether there are issues with the current configuration. If this is the case you can click on the -button for further information.

If both the real refractive indices and the absorption coefficients are defined via a *Programmable* function, they share the same set of Global Parameters.

39.2.1 Refractive Index Panel

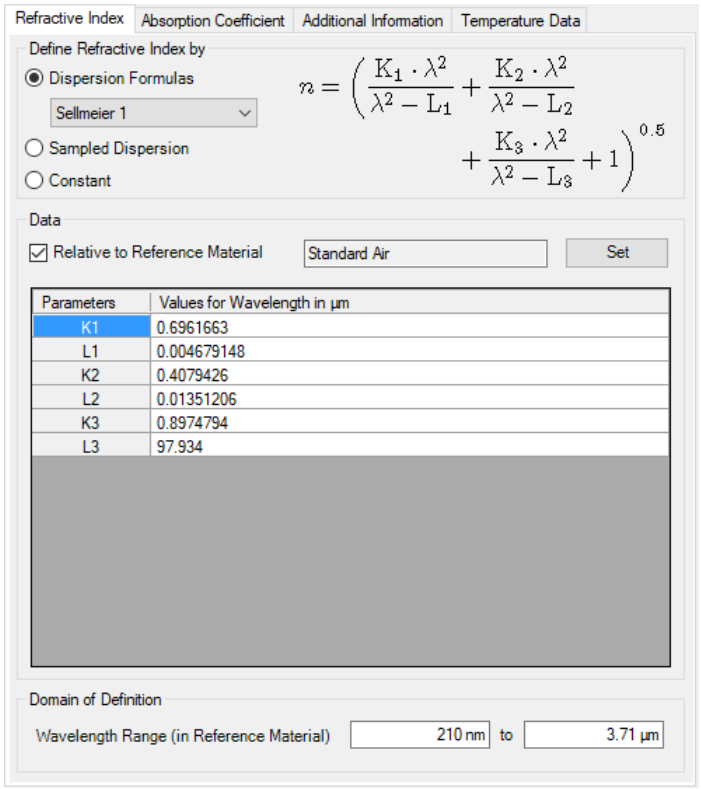


Figure 295. *The panel for the input of the real refractive index, dependent on wavelength.*

The real refractive index dependency from wavelength is defined in the panel *Refractive Index* which is shown in Fig. 295. It has the following controls:

ITEM	DESCRIPTION
Dispersion Formulas	After choosing this option, the user can select one of the dispersion formulas summarized in Sec. 138.4. Then the corresponding formula is shown to the right. And the lower part of the refractive index panel shows a table where you can enter the values[PV] of the parameters, scaled for the wavelength given in micrometers.
Sampled Dispersion	If you check this option, the lower part of the panel shows a table control (↪Sec. 5.10) where you can enter measured data, i. e. pairs of wavelengths and the respective refractive indices. If VirtualLab Fusion needs a refractive index for a wavelength value which lies between two of the stored ones, a cubic 6-point interpolation is used for equidistant sampling, while linear interpolation is used for non-equidistant sampling.
Constant	Choosing this option means that you define a *Constant Refractive Index*[PV] for the whole *Valid Wavelength Range*.
Relative to Reference Material	If checked, the real part of the refractive index is defined relatively to a reference material, i. e. as relation of the phase velocities $n^{\text{rel}}_{\text{Material}} = n^{\text{abs}}_{\text{Material}} / n^{\text{abs}}_{\text{Reference}} = c_{\text{Reference}} / c_{\text{Material}}$. It can be changed after pressing the *Set* button. Only materials with absolutely defined refractive indices can serve for reference. If this option is not set, the real part of the refractive index is considered to be defined absolutely, i. e. as relation of the phase velocities $n^{\text{abs}}_{\text{Material}} = c_{\text{Vacuum}} / c_{\text{Material}}$.
Wavelength Range	The minimum and maximum wavelength for which the refractive index data are valid. In case of *Sampled Dispersion* these values are determined automatically from the sampled data.

39.2.2 Absorption Panel

If the absorption properties of a material are unknown, you can try to use it anyhow by setting the absorption coefficient to $\alpha = 0 =$ constant.

The absorption coefficient dependency from wavelength is defined in the panel *Absorption* which is shown in Fig. 296.

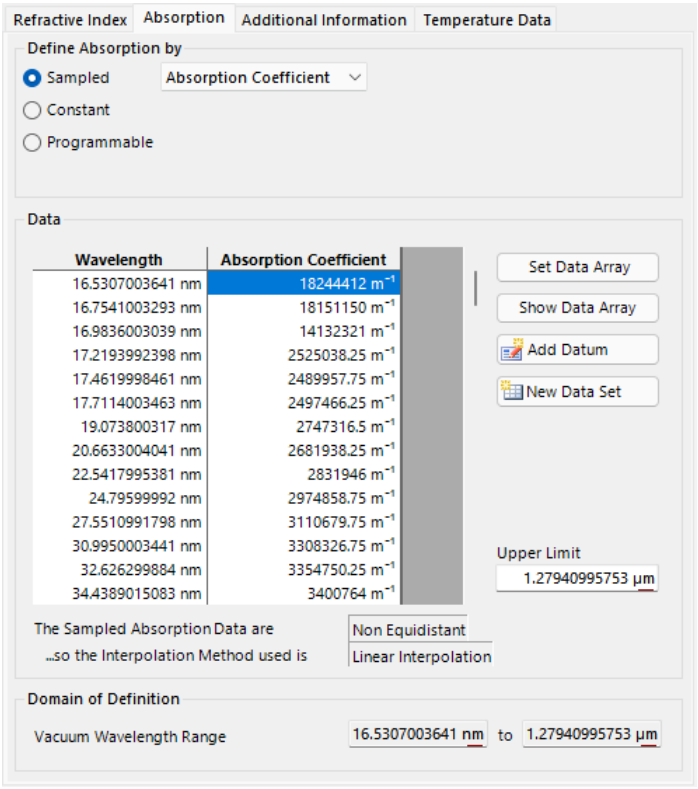


Figure 296. *The panel for the input of the absorption coefficient in* Sampled *mode.*

There are three different quantities describing the absorption which can be entered in three different modes:

Mode	Absorption Coefficient	Internal Transmittance	Absorption Index
Sampled	✔	✔	✔
Constant	✔	✔	✘
Programmable	✔	✘	✘

The three quantities *Absorption Coefficient*, *Absorption Index* and *Internal Transmittance* are defined as α, κ and I/I_0 in the equations 39.1 to 39.3 respectively. The latter requires to enter some additional reference *Thickness*.

The three modes for entering are the following:

ITEM	DESCRIPTION
Sampled Absorption	If you check this option, the lower part of the panel shows a table control where you can enter pairs of wavelengths and the respective absorption quantity. For details see Sec. 5.10. If VirtualLab Fusion needs an absorption coefficient for a wavelength value which lies between two of the stored ones, a cubic 6-point interpolation is used for equidistant sampling, while linear interpolation is used for non-equidistant sampling.
Constant	Choosing this option means to define a single *Constant Absorption Coefficient*[PV] or a *Constant Internal Transmittance* for the whole *Wavelength Range*.
Programmable	The *Definition* group box allows to program an arbitrary formula for the absorption coefficient $\alpha(\lambda)$ with a code snippet. *Edit* opens the Source Code Editor (↪Sec. 7.3) to edit this snippet, and a validity indicator (↪Sec. 5.11) shows whether this snippet is consistent. The *Parameters*[PE] group box is explained in Sec. 7.4.

The following control is visible independently from these three modes:

ITEM	DESCRIPTION
Wavelength Range	The minimum and maximum wavelength for which the absorption coefficient data are valid. In case of *Sampled Absorption* these values are determined automatically from the sampled data.

39.2.3 Additional Information

In this panel the *State of Matter* for the material can be set.

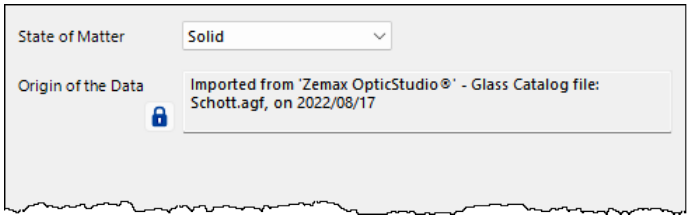


Figure 297. *The panel for the additional information.*

ITEM	DESCRIPTION
State of Matter	The state of matter of this material can be *Solid*, *Liquid*, or *Gas or Vacuum*.
Origin of the Data	The data source can be entered here (if unlocked 🔓).
🔒 / 🔓	This button toggles the locked state of the textbox for *Origin of the Data*. The box is locked by default.

39.2.4 Temperature Data

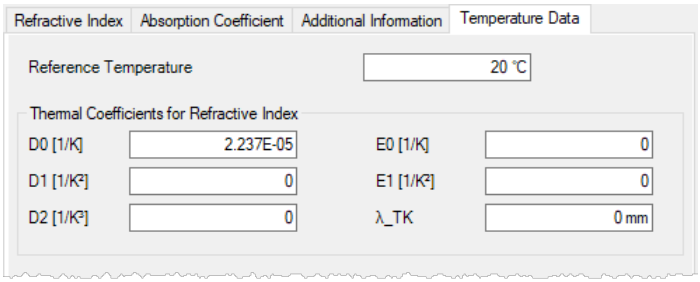


Figure 298. *The panel to specify the temperature data.*

The parameters which determine the temperature dependence of the real part of the refractive index can be defined here.

ITEM	DESCRIPTION
Reference Temperature	This is the temperature T_0 (in °C) the refractive index measurement has been done at.
D0 [1/K]	The parameter D_0 as used in Eq. (39.4).
D1 [1/K^2]	The parameter D_1 as used in Eq. (39.4).
D2 [1/K^3]	The parameter D_2 as used in Eq. (39.4).
E0 [1/K]	The parameter E_0 as used in Eq. (39.4).
E1 [1/K^2]	The parameter E_1 as used in Eq. (39.4).
λ_TK	The parameter λ_{TK} as used in Eq. (39.4).

The change of the real part of the refractive index which is caused by its temperature dependence is calculated by

$$\Delta n(\lambda, T) = \frac{n^2(\lambda, T) - 1}{2 \cdot n(\lambda, T_0)} \cdot \left(D_0 \cdot \Delta T + D_1 \cdot \Delta T^2 + D_2 \cdot \Delta T^3 + \frac{E_0 \cdot \Delta T + E_1 \cdot \Delta T^2}{\lambda^2 - \lambda_{TK}^2} \right). \tag{39.4}$$

The value n is the real valued refractive index of the material as measured at the reference temperature T_0. If the calculation shall be done for a temperature T and for a vacuum wavelength λ, the temperature difference $\Delta T = T - T_0$ has to be put into the equation. The refractive index as modified by the different temperature is

$$n(\lambda, T) = n(\lambda, T_0) + \Delta n(\lambda, T). \tag{39.5}$$

All these relations can be found in [SCH08].

39.3 Material View

The material view consists of three pages, *Diagram*, *Additional Information*, and *Calculator*. Besides the name of the material and the categories it belongs to, the dialog always shows the wavelength range the material's data are defined for:

ITEM	DESCRIPTION
Min. Wavelength	The minimum vacuum wavelength which the real refractive index as well as the absorption data are known for.
Max. Wavelength	The maximum vacuum wavelength which the real refractive index as well as the absorption data are known for.

39.3.1 Diagram

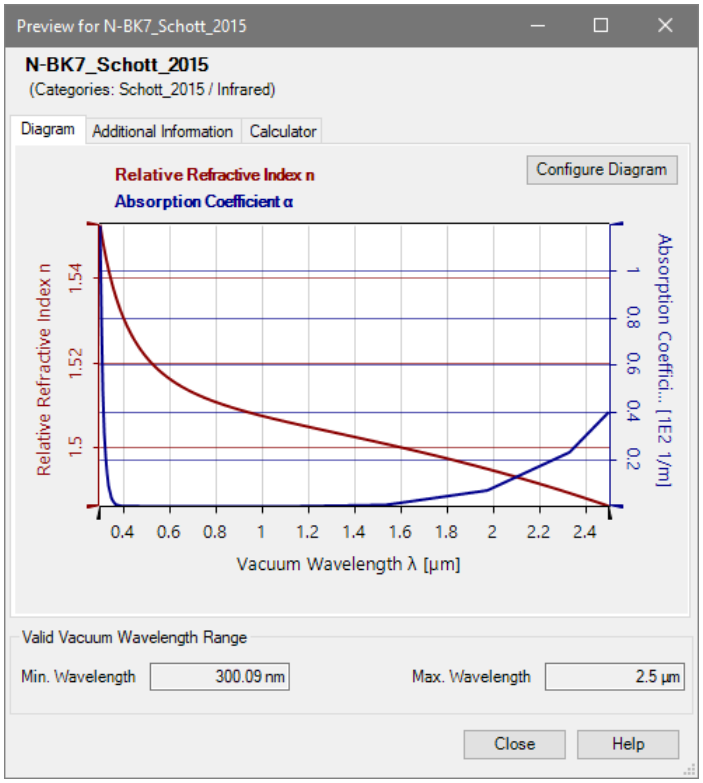


Figure 299. *The* Diagram *tab of the Material View.*

The *Diagram* tab shows the wavelength dependency of the real refractive index n and/or the dependency of the absorption coefficient α or the absorption index κ. The diagram view can be configured via a configuration dialog (↪Sec. 39.3.1.1) which is called by the button *Configure Diagram*.
If `Shift` is pressed while the mouse is moved over the diagram, the values of the displayed curve(s) at the cursor position are shown near the mouse cursor.

39.3.1.1 Configuring the Material Diagram

The dialog shown in Fig. 300 is used to configure the diagram of the wavelength dependent material data.

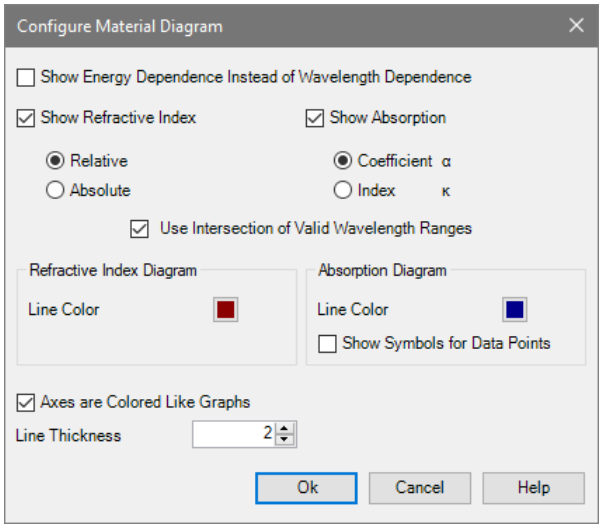


Figure 300. *The Edit dialog for configuring the material's diagram.*

It contains the following controls:

ITEM	DESCRIPTION
Show Energy Dependence Instead of Wavelength Dependence	If chosen, the diagram will show the dependence of the optical data from the photon energy E which is related to the vacuum wavelength λ_{vac} via $E = h\frac{c}{\lambda_{vac}}$ with h being Planck's constant and c being the vacuum speed of light.
Show Refractive Index	Shall the refractive indices be drawn in the diagram?
Relative	THIS OPTION IS AVAILABLE FOR RELATIVELY DEFINED REFRACTIVE INDEX DATA. Show the real refractive index relative to the reference material.
Absolute	THIS OPTION IS AVAILABLE FOR RELATIVELY DEFINED REFRACTIVE INDEX DATA. Show the absolute real refractive index.
Show Absorption	Shall absorption data be drawn in the diagram?
Coefficient α	If chosen, the wavelength dependency of the absorption coefficient is drawn in the diagram.
Index κ	If chosen, the wavelength dependency of the absorption index is drawn in the diagram.
Use Intersection of Valid Wavelength Ranges	If true, only the wavelength range that can be used during the simulation in VirtualLab Fusion is displayed. Otherwise the conjunction of the wavelength ranges of n and α/κ is displayed.
Line Color	Sets the color of the drawn line.
Show Symbols for Data Points	THIS CAN BE CHOSEN ONLY IF THE DATA ARE DEFINED AS SAMPLED DISPERSION OR ABSORPTION. Shall symbols, marking the actual data points, be shown additionally to the line?
Significant Digits	Number of digits used for the axis labels.
Axes are Colored Like Graphs	If checked, the diagram's y-axes are colored like the corresponding curve.
Line Thickness	The thickness the curves will be drawn with.

39.3.2 Additional Information

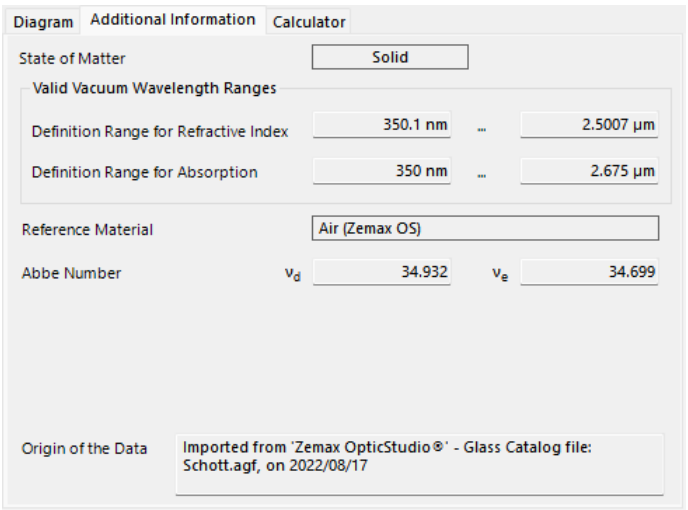


Figure 301. *The Additional Information of the Material View.*

The *Additional Information* tab gives some important parameters of the material:

ITEM	DESCRIPTION
State of Matter	The state of matter of the material. This is important for the usage with optical coatings (↪Sec. 37).
Definition Range for Refractive Index	The vacuum wavelength range for which the real refractive index n is known.
Definition Range for Absorption	The vacuum wavelength range for which the absorption coefficient α and the absorption index κ are known.
Reference Material	The name of the reference material, if the real part of the refractive index is defined relatively.
Abbe Number	The Abbe number ν_d and the Abbe number ν_e for a temperature of 20°C and an air pressure of 101325 Pa.
Origin of the Data	The source of the material's data.

39.3.3 Calculator

The calculator can be used in order to get refractive index and absorption information for a given vacuum wavelength and at a given temperature.

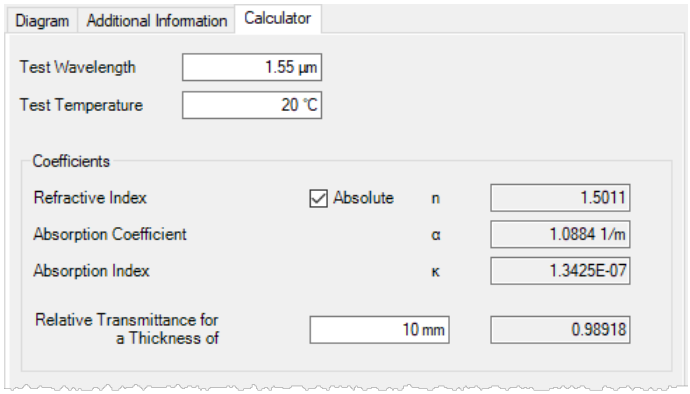


Figure 302. *The Calculator of the Material View.*

The input and output parameters of the calculator are the following:

ITEM	DESCRIPTION
Test Wavelength	Wavelength to calculate *n*, α, κ and the *Relative Transmittance* of this material for.
Test Temperature	Temperature to calculate *n* of this material for.
Test Air Pressure	THIS PARAMETER APPLIES TO MATERIALS WHICH USE THE EDLÉN EQUATION FOR THE REFRACTIVE INDEX OF AIR ONLY. The air pressure to calculate *n* of this material for.
n	Calculated refractive index of the material.
Absolute	THIS OPTION IS AVAILABLE FOR RELATIVELY DEFINED REFRACTIVE INDEX DATA. If checked, the absolute real refractive index is calculated, otherwise the refractive index relative to the material's reference material will be given.
α	Calculated absorption coefficient of the material.
κ	Calculated absorption index of the material.
Thickness	Thickness of the material to calculate the *Relative Transmittance* for.
Relative Transmittance for a Thickness of …	Calculated relative transmittance of the material for the given *Thickness*.

39.4 Material Data Sources

A large variety of different materials are delivered with VirtualLab Fusion. This includes a number of glass types as well as some other substances often used in optics. All materials can be found in the Materials Catalog. The data for the refractive indices and absorption coefficients used in the Material Documents that are provided by VirtualLab Fusion are taken from several publications.

WARNING: There may be errors in the data, e. g. due to measurement, publishing, or transcription. So **please verify** these data, especially if you are considering to fabricate the optics designed with VirtualLab Fusion.

The information for the glass catalogs CDGM_…, Corning, Dow_…, Heraeus, Hikari_…, Hoya_…, LZOS_…, Ohara_…, Schott_…and Sumita_…were given by the manufacturers. The sources of the other catalogs are listed in Sec. A.4.5.

40 Optical Stacks

On the boundaries of a solid (called *base block*), stacks of micro-structured surfaces and media can be applied. Stacks are usually assumed to be periodic and they are orientated "outwards", i. e. the solid is always at $z = 0$ and the embedding medium starts at $z = d$, where d is the z-extension of the stack.
A stack can consist of an arbitrary number of so-called "stack segments". Each segment consists of an optical surface and a subsequent medium.

40.1 Usage Principle of Optical Stacks

Using a new optical stack needs two independent steps. At first, a new stack has to be built. Secondly, the stack is attached to a plane optical surface which serves as boundary of a solid base block. These two steps don't have to be done separately in each case of use, e. g. it is possible to edit a stack already attached to an optical surface. But in principle, the stack *definition* is independent of its *application* to a base block boundary, so there exists a catalog of stacks, storing defined stacks that can be (re-)used any time.

40.1.1 Defining an Optical Stack

Any stack consists of an alternating sequence of a number of indexed optical surfaces and optical media. These are positioned on one single axis. This is identical to the z-axis of the stack's own coordinate system. So the positions of the single optical surfaces are determined by a distance value, measured on the stack's z-axis. The origin of the stack coordinate system is the point $(0; 0)$ of the first surface, so this one has always a z-position of zero. This convention is shown in Fig. 303.

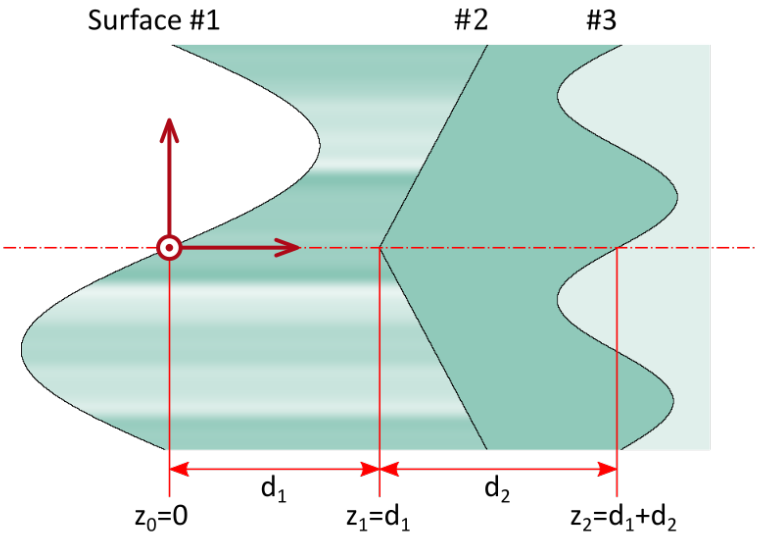


Figure 303. *Positioning of optical surfaces inside an optical stack.*

40.1.2 Application of an Optical Stack

If a defined optical stack has to be attached to the boundary surface of a base block, the following considerations are important.

A stack is attached to a base block in a way, that the first optical surface of the stack touches the block without entering it. The medium of the base block fills possible gaps between the base block boundary and the first stack surface. Furthermore, stacks are always orientated "outwards". Fig. 304 shows these relationships.

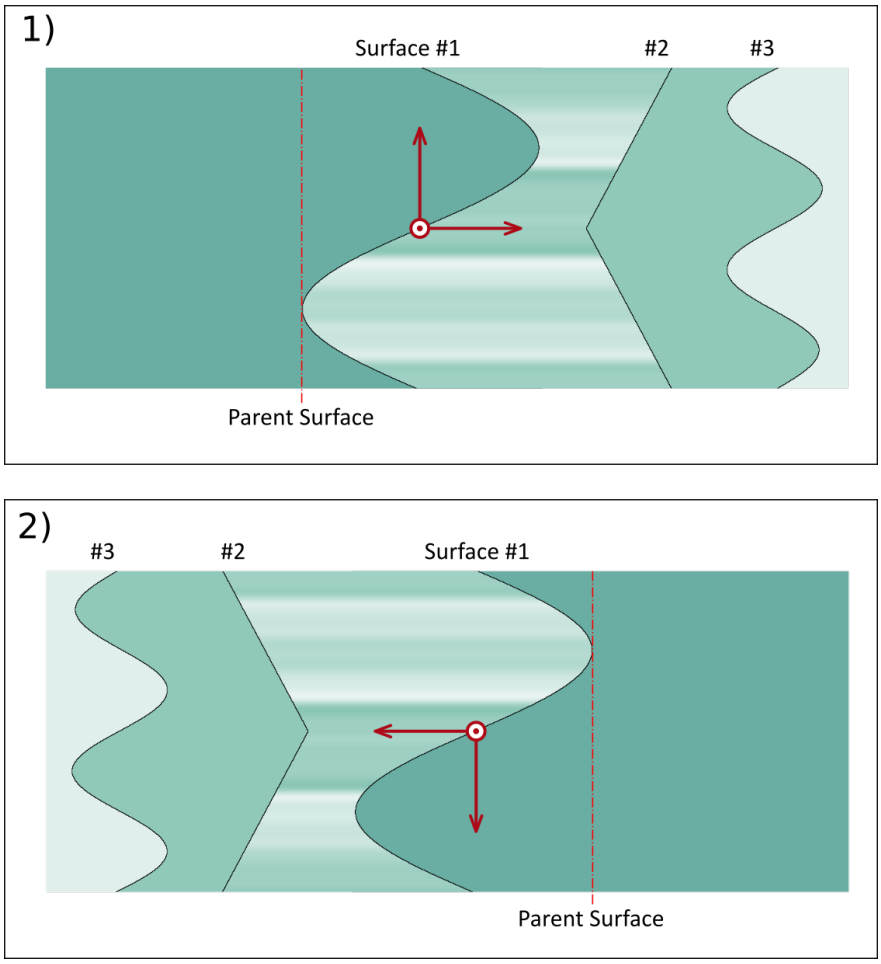


Figure 304. *Positioning of an optical stack relative to the base block's boundary.*
1) Stack on the back side of a base block.
2) Stack on the front side of a base block.

For each side of the base block (front side and back side) there are two possible orientations for the stack. It can be rotated by 180° about the z-axis or be used unrotated, respectively. These two orientations are shown in Fig. 305 and Fig. 306.

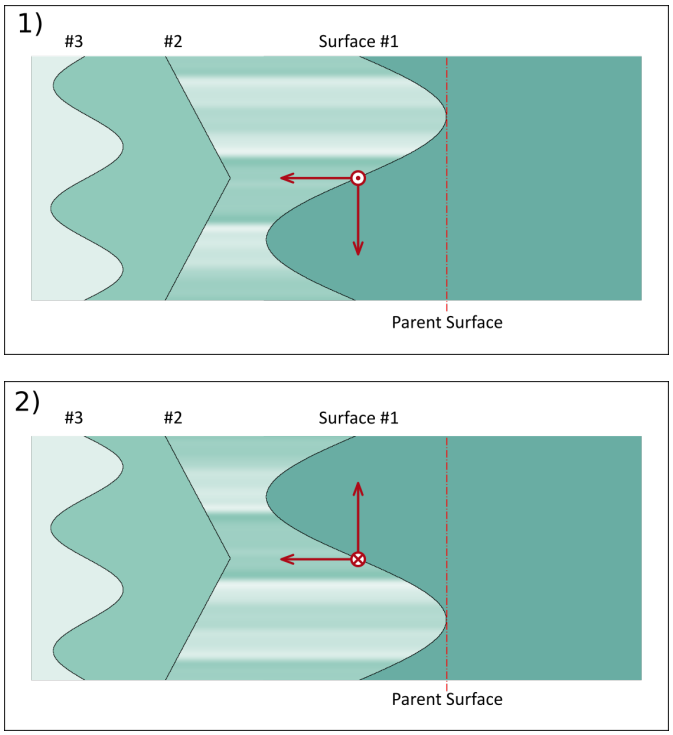


Figure 305. *Orientation of an optical stack on the front side of a base block.*
1) Unrotated.
2) Rotated about z-axis by 180°.

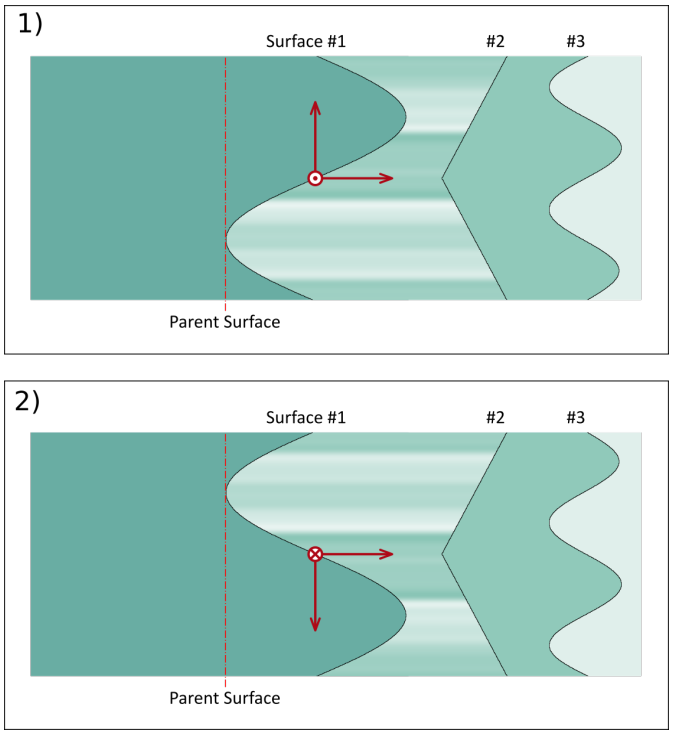


Figure 306. *Orientation of an optical stack on the back side of a base block.*
1) Unrotated.
2) Rotated about z-axis by 180°.

40.2 Edit Dialog for Stacks

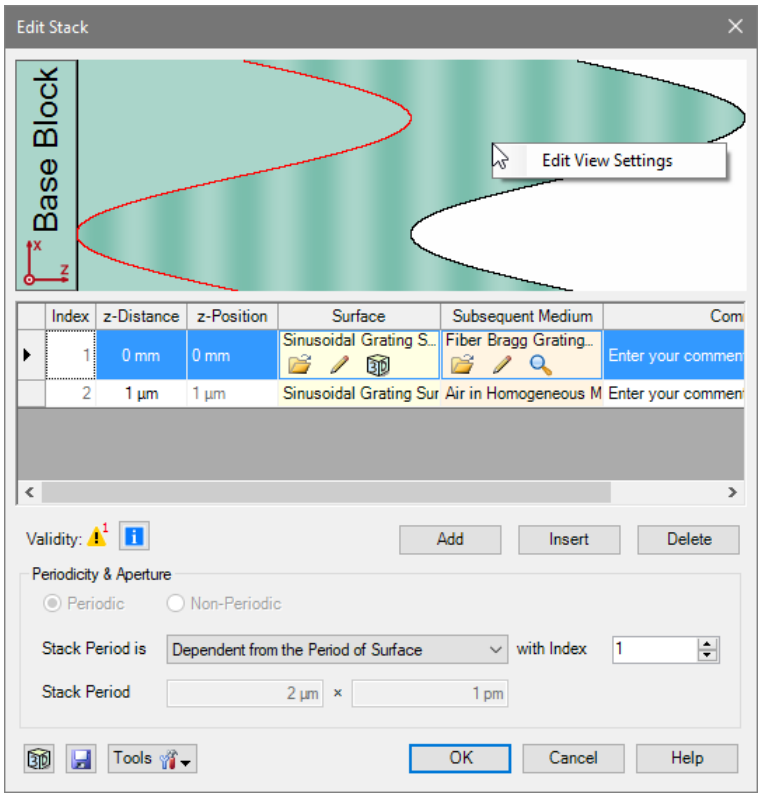


Figure 307. *The edit dialog for stacks. Note that the base block is only shown in the upper part if* Use Component Coordinate System for Stack Preview *is checked in the Global Options dialog (↪Sec. 6.2). The* Validity *control shows a warning because the period of the surface* with Index *1 has actually a period of infinity in y-direction.*

The edit dialog for stacks (↪Fig. 307) comprises three parts: The upper part shows an intersection of the surface media sequence of the stack (↪Sec. 5.15). The middle part is a table listing the stack segments. The topmost entry is closest to the solid, the bottommost entry is closest to the embedding medium. This table has the following columns:

COLUMN	DESCRIPTION
Index	The index of the segment.
z-Distance PV	Allows to enter the distance of the surface to the previous surface. It is measured in positive z-direction.
z-Position	Display of the absolute z-position of the surface in the stack.
Surface PE	Edit control for the surface in the segment (↪Sec. 34.1).
Subsequent Medium PE	Edit control for the medium in the segment (↪Sec. 34.1).
Comment	One can enter a descriptive comment for each segment.

The *Index* and the *z-Position* column are always read-only. Also, the *z-Distance* of the first segment and the *Subsequent Medium* of the last segment are fixed.
The lower part of the edit dialog contains the following controls:

ITEM	DESCRIPTION
Validity	This control (↪Sec. 5.11) indicates whether the currently defined stack is valid, i. e. whether it contains a least one surface and whether it has an extension greater zero.

Add	Adds a new stack segment to the end of the table. The surface catalog is opened automatically to define the surface of the segment.
Insert	Inserts a new stack segment before the currently selected table row, indicated by a triangle in the first column. The surface catalog is opened automatically to define the surface of the segment.
Delete	Deletes all currently selected table rows.
Periodic / Non-Periodic	ONLY ACTIVATED IF THE STACK IS USED WITHIN A DIFFRACTIVE OPTICAL ELEMENT (↪SEC. 61.1)
Period	ONLY FOR *PERIODIC* STACKS Defines the stack period. The stack period can be either taken from a certain surface or medium within the stack. If this reference is not periodical or has a period of infinity in one direction, a period of 100 pm is assumed instead and a warning is shown in the validity control. This way the calculation of an infinite number of orders is avoided. If the stack period is *Independent of Surface/Media Period*, the user can set the *Stack Period* PV by oneself.
Aperture Size	ONLY FOR *NON-PERIODIC* STACKS Defines the size of the stack. • *Dependent on the Definition Area of Surface*: The aperture size is taken from the (outer) definition area of a certain surface within the stack. • *Independent of Surfaces*: The user can set the *Aperture Size* PV by oneself.
(View)	Displays a preview of the stack.
(Save To Catalog)	Saves the stack to the user-defined stack catalog.
Stack Tools	Several tools are available to modify the stack in a user-friendly way. More information can be found in Sec. 40.3.

When the stack is used from within a Light Guide (↪Sec. 58.2), the edit dialog has an extra tab page *Additional Parameters*. There you can define parameters you might need if you want to use you own custom Fourier Modal Method (↪Sec. 97.4), using the control described in Sec. 7.3.2.

40.3 Stack Tools

There are *stack tools* implemented in VirtualLab Fusion to give the user a comfortable way for configuring a stack.

40.3.1 Insert Coating Tool

The *Insert Coating Tool* can be used to insert a coating (loaded from the *Coating Catalog*) on a user-specified position. The coating is translated into a surface sequence. This surface sequence is inserted into the stack.
Note: The set up process data is ignored for the insert algorithm into the stack. Only the coating layers are converted.

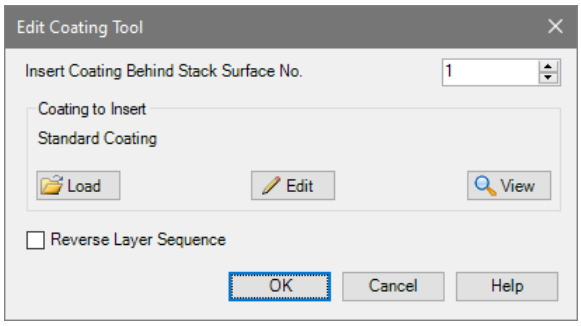


Figure 308. *The edit dialog for configuring the Insert Coating Tool*

This tool can be found at *Tools > Insert Coating*. Fig. 308 shows its edit dialog which has the following settings:

ITEM	DESCRIPTION
Insert Coating Behind Stack Surface No.	Defines the index of the surface within the stack on which the coating shall be set. Only visible if the stack contains at least one surface.
Coating To Insert	The user can specify a coating which shall be translated into the stack.
Reverse Layer Sequence	If this option is checked, the coating is inserted in the "wrong" order, i. e. the last coating layer is inserted directly after the specified surface.

40.3.2 Insert Stack Tool

The *Insert Stack Tool* can be used to insert a stack (loaded from the *Stack Catalog*) on a user-specified position.

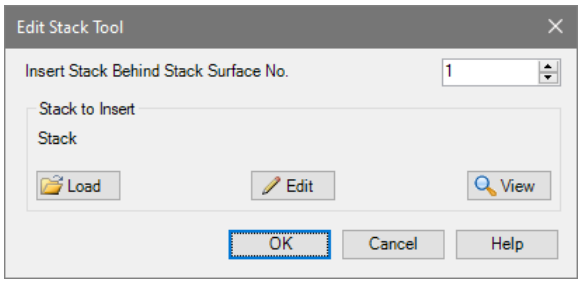


Figure 309. *The edit dialog for configuring the Insert Stack Tool*

This tool can be found at *Tools > Insert Stack*. Fig. 309 shows its edit dialog which has the following settings:

ITEM	DESCRIPTION
Insert Stack Behind Stack Surface No.	Defines the index of the surface within the stack after which the stack shall be set. Only visible if the stack contains at least one surface.
Stack To Insert	The user can select a stack from the catalog, which shall be added.

40.3.3 Reduce Definition Area to Stack Periods

Via the stack period you define the region of each surface (and medium) which is evaluated. However, if the definition area (↪Sec. 36.1.1) of a surface is much larger than the stack period, the z-extension of the surface might be larger than expected leading to a seemingly too thick stack (↪Fig. 310).
Thus the *Reduce Definition Area to Stack Periods* tool allows you to limit the definition area of all surfaces to the stack period, whereas the following rules apply:

- For grating surfaces the inner definition area, and the outer definition area are adapted. Setting the period would change the structure definition.

- For all other periodical surfaces the inner definition area, the period, and the outer definition area are adapted.
- The definition areas are set to a rectangular shape.
- If the definition area (or period) of the surface was set by the user to a value smaller than the stack period, it is kept unchanged. This check is done separately for x- and y-dimension.
- For stacks of 1D-periodic grating surfaces the definition area (or period) in y-direction is set to 10 % of the stack period. In this way a nice-looking stack preview is ensured.

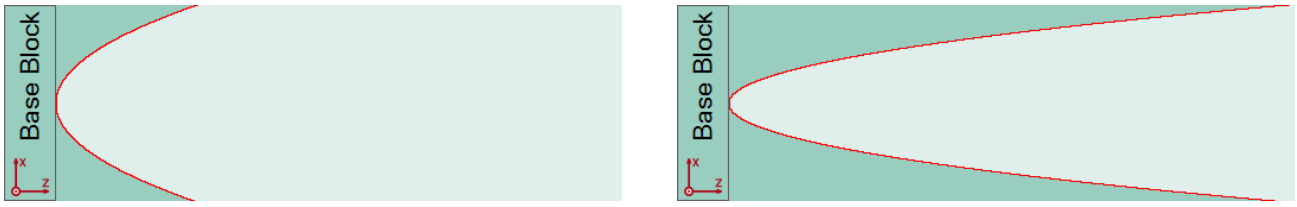


Figure 310. ***Left:*** *A conical surface in a 2D stack having a definition area twice the size of the stack period. The maximum z-extension is reached outside of the stack period.* ***Right:*** *The same surface after the* Reduce Definition Area to Stack Periods *tool has been applied.*

40.3.4 Change External Name

When stacks are used within other controls (↪Sec. 34.1), their (external) name is shown to easier identify them. With this tool you can simply change this name, e. g. if you have changed the sinusoidal grating surface within a stack to a triangular one.

41 Surface Layouts

On the surfaces of a solid, VirtualLab Fusion offers the possibility to specify *surface layouts*, which consist of several regions on an Optical Surface (↪Sec. 36) behaving differently than just a plain surface. Each type of surface layout usually provides its own algorithm to propagate light through it, a so-called *boundary operator*. A boundary operator can change the position, the direction and the complex value of the incident wave and even generate new modes (e. g. multiple grating orders).

41.1 Cells Arrays

A Cells Array boundary operator consists of a set of cells. All cells have the same size. Every cell has a specific optical function defined by a small set of parameters.
Two types of cells arrays are available:

1. Grating Cells Array ↪Sec. 41.1.1
2. Prism Cells Array ↪Sec. 41.1.2

Sec. 41.1.3 explains how a cells arrays can be configured.

41.1.1 Grating Cells Array

The Grating Cells Array (GCA) boundary operator consists of a set of grating cells arranged in an equidistant grid. In every cell a grating function can be specified by the following parameters:

- Period
- Rotation Angle
- Lateral Shift

The boundary operator uses the local grating parameters to change the parameters of the incident wave. The rotation angle and the period directly influence the direction of the incident wave. The lateral shift defines an additional phase shift which shall be applied to the specific grating cell.

The way how the grating parameters of the individual cells can be configured is described in Sec. 41.1.3.

41.1.2 Prism Cells Array

The Prism Cells Array (PCA) consists of cells arranged in an equidistant grid. In each cell there is a slanted plane surface defined by the following three parameters:

PARAMETER	DESCRIPTION
Tilt Angle	The spherical angle θ (↪Sec. 145.2.1) describing the tilt of the plane surface.
Rotation Angle	The spherical angle ϕ (↪Sec. 145.2.1) describing the rotation of the plane surface in the x-y-plane.
Offset Height	The height of the plane surface at the center of the cell (relative to the surface the boundary operator is placed on). Introduces an additional phase shift.

If a Prism Cells Array is used in reflection it is referred to as *Mirror Cells Array* (MCA).
The way how the surface parameters of the individual cells can be configured is described in Sec. 41.1.3.

41.1.3 Configuring a Cells Array

Fig. 311 shows the edit dialog of the Prism Cells Array with the controls that all types of Cells Arrays have in common.

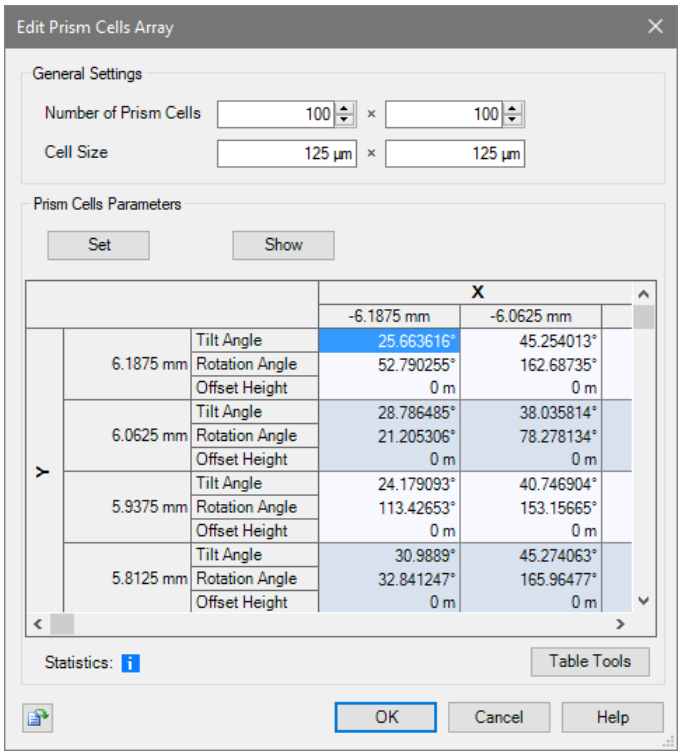


Figure 311. *The edit dialog of the Prism Cells Array boundary operator*

The dialog enables the user to configure

ITEM	DESCRIPTION
Number of Grating / Prism Cells	The number of cells within the Cells Array can be specified. After changing the number of cells within the boundary operator a *Refresh* button appears and has to be clicked to trigger the resizing of the cell array.
Cell Size	The user can specify the size of the cells in x- and y-dimension. All cells have the same size.

In the middle part of the dialog the cells parameters of the boundary operator can be changed. The following possibilities can be used to specify the cells parameters:

ITEM	DESCRIPTION
Set	The set button can be used to set an open data array, which contains the cells parameters in different subsets. This option can be very helpful to use an already designed Cells Array function within a new boundary operator.
Get	By clicking the *Get* button, the cells parameters of the Cells Array operator are extracted into a data array. The extracted data array is displayed within the VirtualLab Fusion main window and can be used for post processing steps (like usage in another boundary operator, or graphical evaluation of the parameter distribution).
{Table}	Additionally VirtualLab Fusion offers to directly edit the cells parameters within the table at the bottom of the edit dialog.

If the mouse hovers over the *Statistics* icon a tooltip is shown which gives the minimum and maximum of each parameter in the cells array and the corresponding locations. For grating cells also the minimum and maximum period in x- and y-direction is given for reference.
By pressing the *Table Tools* button the user can select *Vary Grating Cells* / *Vary Prism Cells*. Fig. 312 shows the dialog to configure this tool. The button allows you to export the cells data (↪Sec. 132).

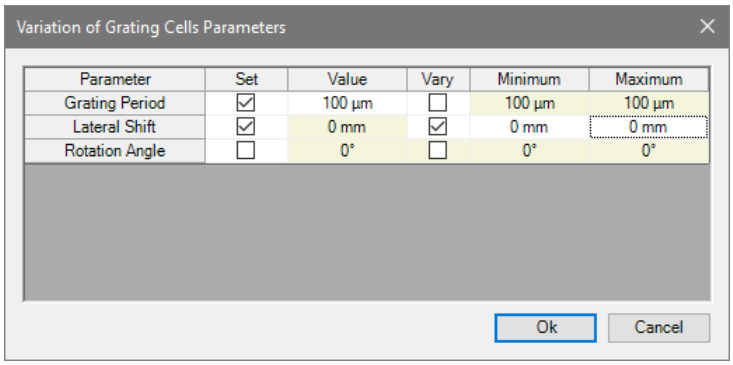


Figure 312. *The dialog for the Vary Grating Cells table tool. The dialog for the Vary Prism Cells tool is the same but uses different cells parameters.*

The Vary Grating Parameters / Vary Prism Cells tool can be used to vary the parameters within the Cells Array systematically. The user can specify whether he likes to set a parameter to a special value or whether he likes to make a random distribution of a parameter in a user-defined value range. The user can edit the following options for each available cells parameter:

ITEM	DESCRIPTION
Set	The column *Set* can be used to select the parameters which shall be specified / varied. After selecting the *Set* option within the table the *Value* and the *Vary* column will be enabled.
Value	In this column the user can specify the value of the parameter which shall be set. This column is only enabled if the *Set* option is selected.
Vary	The option *Vary* can be used if the parameter shall be varied in a specific user range. The variation will be randomly. The *Vary* option is only available if the *Set* option is selected.
Minimum	Defines the minimum of the value range if the parameter shall be varied. This option is only available if the *Vary* option is set.
Maximum	Defines the maximum of the value range if the parameter shall be varied. This option is only available if the *Vary* option is set.

41.1.3.1 Order Configuration

The *Order Configuration* tab page allows the user to specify which orders of the grating cells shall be considered during the simulation of the Grating Cells Arrays.
Fig. 313 shows the page to set up the order configuration for the simulation.

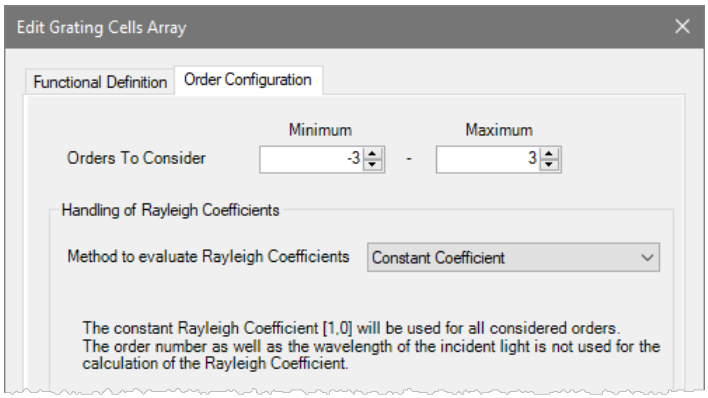


Figure 313. *The orders to consider during the simulation can be specified within the Grating Cells Array edit dialog on the Order Configuration tab page.*

> The design of a Grating Cells Array only uses the first order to generate the target pattern. The other orders are not considered in the design but in the analysis of the system.

The user can specify the following parameters on the *Order Configuration* tab page:

ITEM	DESCRIPTION
Minimum	The user can specify the *Minimum* order to be considered during the simulation of the Grating Cells Array.
Maximum	The user can specify the *Maximum* order to be considered during the simulation of the Grating Cells Array.
Method to evaluate Rayleigh Coefficients	It is possible to specify different complex weights for the orders to consider. VirtualLab Fusion offers three different ways to specify the order weighting. The following possibilities are available: *Constant Weight* (↪Sec. (a)), *Simple Lookup Table for Coefficients* (↪Sec. (b)) or *Rigorous Lookup Table for Coefficients* (↪Sec. (c))

(a) Constant Coefficient

The user can select the *Constant Coefficient* method to evaluate the weights for each order. The weights of all specified orders within the simulation are set to 1. This could be used for a first approximation of the GCA function.

(b) Simple Lookup Table for Coefficients

The *Simple Lookup Table for Coefficients* option allows the user to configure the real valued weight for each order. Fig. 314 shows the table to configure the amplitude weights for each order.

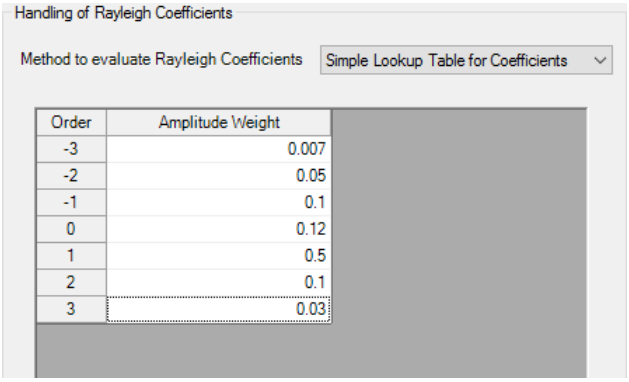


Figure 314. *The Simple Lookup Table for Coefficients option enables the user to specify the amplitude weight for each order*

The table contains two columns. The following settings can be viewed / edited:

ITEM	DESCRIPTION
Order	This column shows the order for which the weight can be specified. It is not editable. The orders to consider within the simulation are specified above within the dialog.
Amplitude Weight PV	In the *Amplitude Weight* column the user can enter the real valued amplitude weight for the specific order.

Note: Changing the numbers of *Orders To Consider* will reset the table – all weights will be set to 1.

(c) Rigorous Lookup Table for Coefficients

The evaluation of the efficiencies / Rayleigh coefficients requires VirtualLab Fusion Advanced which might not be available on the computer where the cells array simulation is done. Therefor the user needs to trigger the *Local Linear Grating Approximation Analyzer* (↪Sec. 91) within the Light Shaping Optical Setup. This analyzer uses the current configuration of the GCA boundary operator to generate a *LLGA Results Generator* (↪Sec. 46). This generator can then be used to calculate efficiencies / Rayleigh coefficients rigorously for each wavelength, period, rotation angle, and incident direction occurring in your Light Shaping Optical Setup, possibly on another computer. Finally the generator with the calculated results can be set into the *Order Configuration* tab (↪Fig. 315).

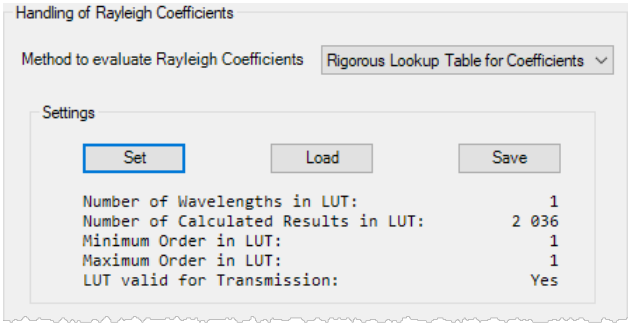


Figure 315. *The* Rigorous Lookup Table for Coefficients *option enables the usage of rigorously calculated Rayleigh coefficients.*

The user can modify the *Rigorous Lookup Table for Coefficients* by the following options:

ITEM	DESCRIPTION
Set	By clicking on the *Set* button an open LLGA Results Generator document can be selected and set as the rigorous lookup table for the simulation.
Load	The *Load* button can be used to load an XML file which is a possible output of the LLGA Results Generator. The XML file contains all necessary information for the lookup table.
Save	The user can save the lookup table information to an XML file by clicking on the *Save* button. This option is helpful to extract the lookup table information for some post processing steps.
{Lookup Table Information}	In the bottom part of the dialog some information about the lookup table is shown. The user can see • the number of wavelengths which are represented within the lookup table • the total number of results where at least one Rayleigh coefficient of one order has been calculated. • the minimum and maximum order of the specified lookup table • the information whether the lookup table is valid for transmission or for reflection

After specifying the *Rigorous Lookup Table for Coefficients* the simulation uses the lookup table data for the evaluation of the considered orders. If no valid lookup table entry is found for a specific parameter set, the simulation stops with an error message.

41.2 Arbitrary Surface Layouts

Light guide components (↪Sec. 58.2) can have surface layouts consisting of an arbitrary number of regions of arbitrary shape filled with an idealized or real grating.[1]

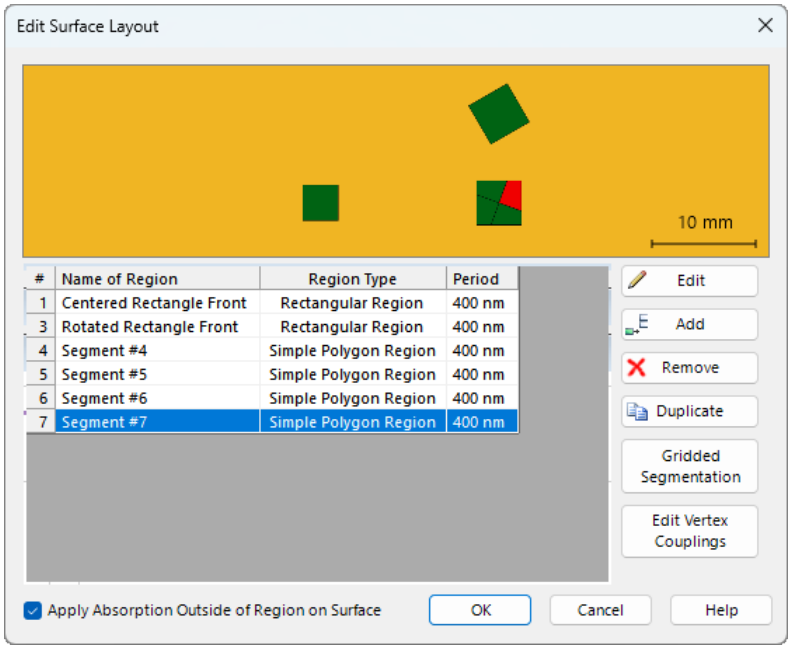


Figure 316. *The edit dialog for surface layouts.*

These surface layouts can be edited with the dialog shown in Fig. 316, which contains the following controls:

[1] In a General Optical Setup only three surface regions per surface layout are allowed.

ITEM	DESCRIPTION
{Layout Overview}	A specially configured 3D view (↪Sec. 17.1) which gives an overview of all regions in the surface layout. The region currently selected in the table is marked red.
{Overview Table}	Table that provides an overview of all regions in the layout, including the unique index (column #), *Name of Region*, *Region Type*, and *Period*.
Edit	Allows to edit the currently selected surface region using the dialog described in Sec. 43.1.
Add	Adds a new surface region to the layout. The new region has to be defined via the dialog described in Sec. 43.1 first.
Remove	Removes the currently selected region from the layout. Shortcut: Del
Duplicate	Duplicates the currently selected region.
Gridded Segmentation	AVAILABLE FOR RECTANGULAR AND SIMPLE POLYGON REGIONS ONLY. This button opens a dialog which allows to segment the currently selected region into several new regions by defining a segmentation grid. The dialog is described in Sec. 41.2.1.
Edit Vertex Couplings	AVAILABLE ONLY FOR SIMPLE POLYGON REGIONS WHICH SHARE COUPLED VERTICES WITH AT LEAST ANOTHER POLYGON. The coupling of vertices of two or more polygons can be edited using the dialog described in Sec. 41.2.2.
Apply Absorption Outside of Region on Surface	If checked, the parts of the surface which are not covered by grating regions will absorb the light. If unchecked, the non-grating surface parts will transmit and reflect the light depending on the optical properties of the involved materials.

41.2.1 Gridded Segmentation of Regions

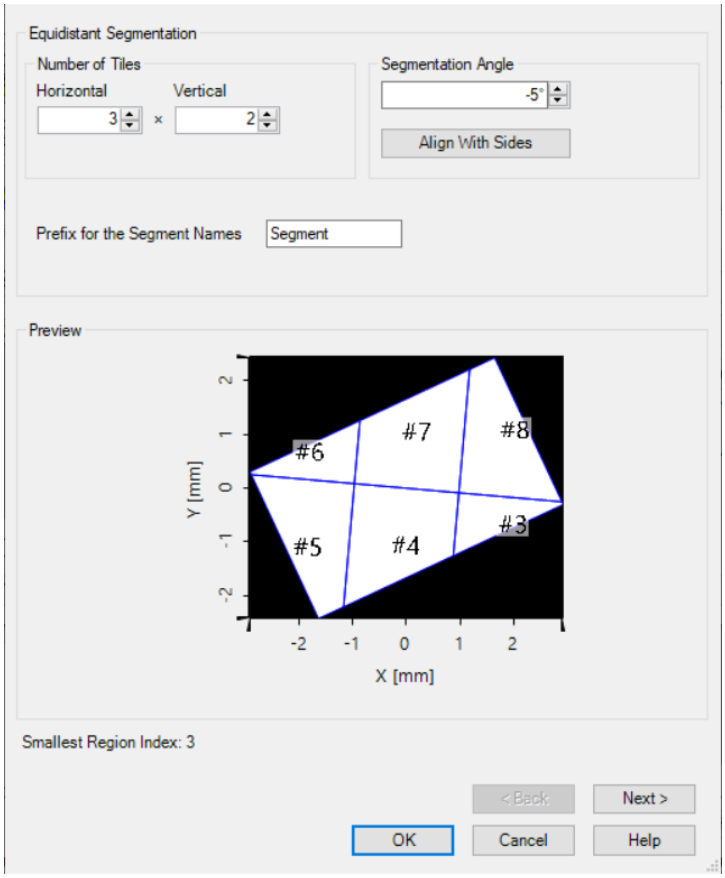


Figure 317. *Dialog for doing a gridded region segmentation.*

Rectangular or polygonal grating regions may be decomposed into smaller regions by applying an equidistant grid of n x m tiles to the original region, using the dialog shown in Fig. 317. The result will be n x m new segments of the type 'simple polygon region'. The following parameters define the segmentation:

ITEM	DESCRIPTION
Number of Tiles	The axis aligned bounding box of the original region will be segmented into n x m tiles. These numbers of the x- and y-segments can be defined here.
Prefix for the Segment Names	A prefix for the automatically generated names of the new regions can be given here. The names of the new segments will be ”{prefix} #{index}”.
Segmentation Angle	The segmentation doesn’t have to be axis aligned. A rotation angle which determines the direction of horizontal and vertical segmentation can be defined here instead.
Align With Sides	ONLY AVAILABLE FOR RECTANGULAR REGIONS. Since a rectangular region may be rotated itself, pushing this button will preselect the rotation angle of the segmentation in a way which results in a side alignment. So the resulting rectangles after the segmentation will have the same orientation as the original rectangle.
Preview	This view shows the result of the segmentation process using the currently set parameters. The new region indices are given within the view as well.
Smallest Region Index	Since all region indices inside the edited surface layout (including the new regions after segmentation) has to be unique, the new indices will never start with #1. The smallest new region index is given here instead.

41.2.1.1 Segmentation of Regions with a Real Grating Structure

If a region is to be decomposed which contains a real grating structure, the parameters of the gratings of the new segments may vary. That’s why there will be a *Next >* button at the bottom of the dialog which allows to select grating parameters for variation after the tiles have been specified. After selecting the variation parameters, the parameter values can be set for each of the new segments on the last page of the dialog.

41.2.2 Changing Polygon Vertex Couplings

The vertices of adjacent simple polygon regions may be coupled if they share the same coordinates. ’Coupling’ means that a change in the coordinates of the vertex in one polygon will change the coordinates of the coupled vertex in the other polygon as well. This is shown in Fig. 318.

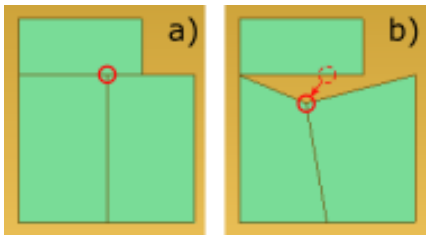


Figure 318. *The principle of vertex coupling. The left picture shows the polygons before editing the coordinates of the vertex in the red circle. The right picture shows how editing its coordinates change the shape of the left as well as that of the right polygon at once.*

Whenever the editing of the vertex of one polygon results in identical coordinates to that of another polygon, the user will be asked whether to activate coupling.
If a coupling is not needed anymore, it can be changed by the dialog shown in Fig. 319.

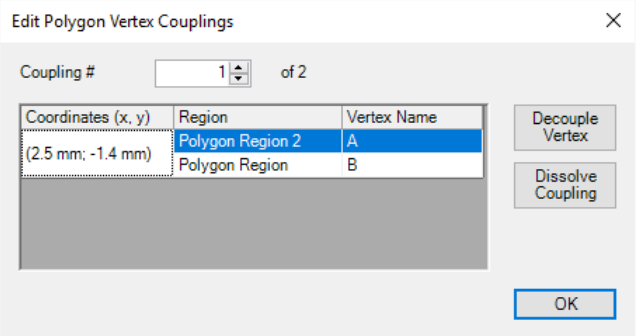


Figure 319. *Dialog for decoupling one or more vertices from each other.*

ITEM	DESCRIPTION
Coupling #	The index of the coupling that shall be edited.
Coordinates (x, y)	The coordinates of the coupling to be currently edited.
Region	The region the vertex in the column *Vertex Name* belongs to.
Vertex Name	The name of the selected vertex.
Decouple Vertex	When pressed, the selected vertex will be removed from the current coupling. If there are no more than two vertices then the coupling will be completely dissolved.
Dissolve Coupling	When pressed, the current coupling will be completely dissolved, no matter how many vertices are coupled at this coordinates.

42 Boundary Responses

A Boundary Response is described by a complex-valued function $\mathcal{B} = f(x, y, \lambda, n(\lambda))$ which is applied to an incoming field.

$$E_{xy}^{out}(x, y) = \mathcal{B} E_{xy}^{in}(x, y) \tag{42.1}$$

$(x; y)$ is the lateral position, λ is the wavelength of the incoming field and $n(\lambda)$ is the complex refractive index of the homogeneous medium associated with the boundary response.

42.1 Edit Dialog for Boundary Responses

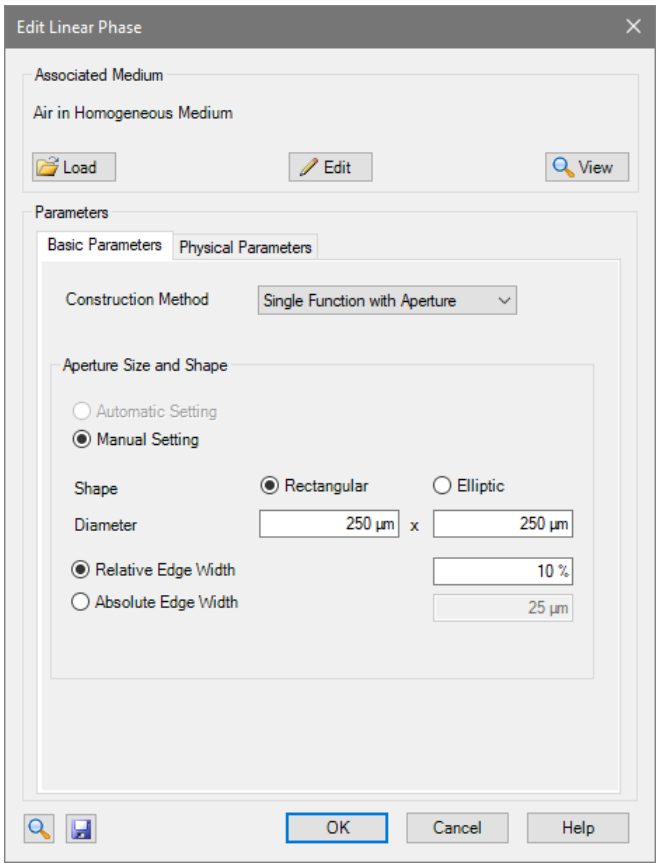


Figure 320. *The edit dialog for Boundary responses showing the* Basic Parameters *if* Single Function with Aperture *is selected.*

The edit dialogs for all boundary responses (↪Fig. 320) have the following controls in common:

ITEM	DESCRIPTION
Associated Medium	The homogeneous medium associated with the boundary response. This is from which refractive indices are being calculated if required by the function $\mathcal{B}$.
Parameters	This box contains two tab pages. The *Basic Parameters* allows you to select one out of three *Construction Method*s. Depending on the selected *Construction Method* this tab page changes, which is explained below in more detail. The *Physical Parameters* tab is specific for the distinct types of boundary responses (↪Sec. 42.3).
View	Shows the boundary response view. ↪Sec. 42.2
Save	Saves the boundary response to the catalog. Not available if the boundary response is edited from within the catalog.

The following *Construction Method*s are available:

CONSTRUCTION METHOD	DESCRIPTION
Single Function without Aperture	NOT AVAILABLE FOR APERTURE AND ZERNIKE FRINGE / SEIDEL ABERRATIONS BOUNDARY RESPONSE. There are no specific controls for this construction method.
Single Function with Aperture	The aperture is applied by multiplying the actual function value f by 1 inside and by 0 outside the specified aperture. The edge of the aperture can be defined smooth, then the values don't "jump" from 1 to 0 but follow a Gaussian function (decreasing to a value of 0.01) as shown in Fig. 321. The controls to setup the aperture are explained in a separate table below. In case of an Aperture boundary response, this option is named just *Single Function*.
Periodic Function	NOT AVAILABLE FOR ZERNIKE FRINGE / SEIDEL ABERRATIONS BOUNDARY RESPONSE. In this case you can set the *Period*[PV] of the function.

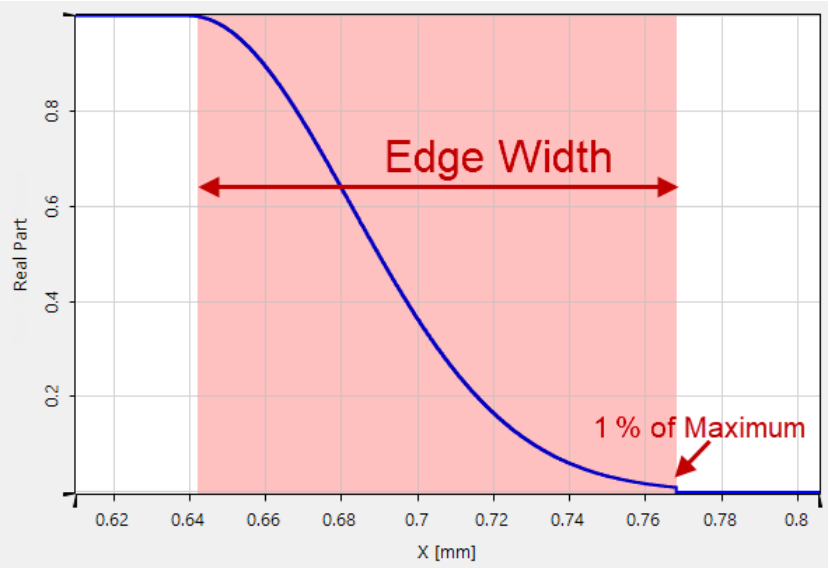


Figure 321. *Definition of the edge width of an aperture.*

The following controls (↪Fig. 320) are specific for the *Single Function with Aperture* construction method:

ITEM	DESCRIPTION
Automatic Setting	If checked, a reasonable size of the aperture for the boundary response is determined automatically. This option is available for some boundary responses only, e. g. exponentially decreasing ones.
Manual Setting	If checked, the aperture size is to be entered by the user.
Shape	The aperture may be *Rectangular*ly or *Elliptic*ally shaped.
Diameter[PV]	Size of the aperture.
Relative Edge Width	The width of the aperture edge, defined relatively to the (smaller of the both values of) *diameter*.
Absolute Edge Width	The width of the aperture edge, defined in physical units. See Fig. 321.

For an Aperture boundary response, a separate aperture cannot be set on the *Basic Parameters* tab. For a Zernike Fringe / Seidel Aberrations boundary response, only circular apertures are allowed.

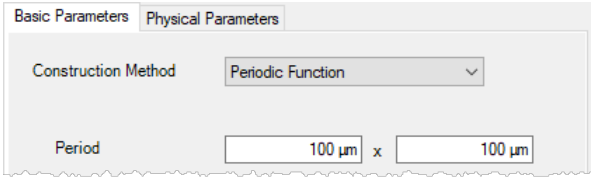


Figure 322. *Tab page for setting the* Basic Parameters *of a boundary response with the construction method* Periodic Function

The following controls (↪Fig. 322) are specific for the *Single Function with Aperture* construction method:

ITEM	DESCRIPTION
Period PV	If *Periodic Function* was chosen as *Construction Method*, here the length of the period for the replication is set. The first value is used for replication in x-direction, the second one for the y-direction. **Specific for grating boundary responses:** For gratings, the *Period* will be determined automatically from the *Grating Period* and the *Rotation Angle*, both to be specified at the *Physical Parameters* panel.

42.2 Boundary Response View

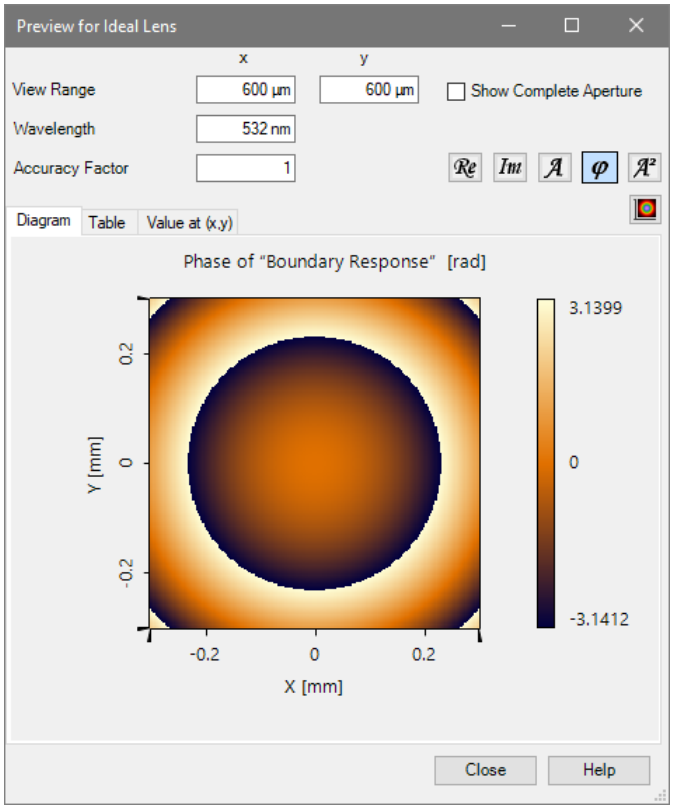


Figure 323. *The preview dialog for boundary responses*

The view for boundary responses (↪Fig. 323) shows the complex values of the function $\mathcal{B}$ within the specified *View Range*. A data array view (↪Sec. 13.4) is used to this end. In particular, the view has the same context menu which allows you to change the shown field quantity (↪Sec. 11.1) to e. g. imaginary part, change the aspect ratio (↪Sec. 11.5) or the color table (↪Sec. 11.2.4).

The following controls can be used to configure the data array view:

ITEM	DESCRIPTION
View Range	The extension of the shown region, which is centered around the position $(0\,\mathrm{m};\,0\,\mathrm{m})$.
Show Complete Aperture	If this option is checked, the *View Range* is set to the aperture size of the boundary response. Obviously, this option is only enabled if the boundary response uses the construction method *Single Function with Aperture*.
Wavelength	If the boundary response depends on the wavelength, you can set the wavelength used to calculate the preview here. If the boundary response does **not** depend on the wavelength, an information label is shown instead.
Accuracy Factor	The preview shows $(A \cdot 200;\, A \cdot 200)$ sampling points, where A is the *Accuracy Factor*.
$\mathcal{Re}$	If pressed, the real part of the complex boundary response is shown in the preview.
$\mathcal{Im}$	If pressed, the imaginary part of the complex boundary response is shown in the preview.
$\mathcal{A}$	If pressed, the amplitude of the complex boundary response is shown in the preview.
φ	If pressed, the phase of the complex boundary response is shown in the preview.
A^2	If pressed, the squared amplitude of the complex boundary response is shown in the preview.
	Shows the diagram as separate data array document (↪Sec. 13.4) which can be saved for later use.

42.3 Types of Boundary Responses

42.3.1 Aperture

This boundary response allows to apply a rectangular or elliptical aperture on the incoming field. An aperture function has the value 1 inside and 0 outside the defined *Diameter*. The edge of the "hole" can be defined smooth, then the values don't "jump" from 1 (inside the aperture) to 0 (outside the aperture). Instead they follow a Gaussian function (starting at 1 and cut off at a value of 0.01) as shown in Fig. 324.

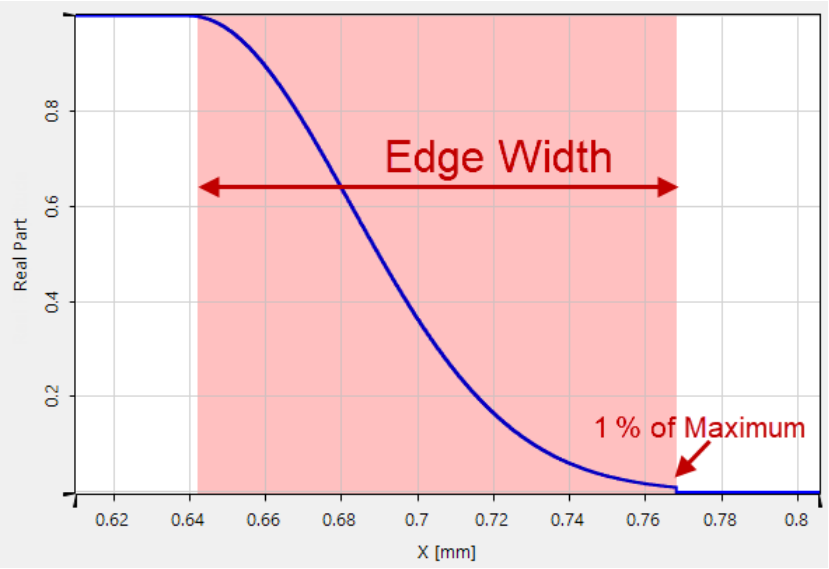


Figure 324. *Definition of the edge width of an aperture. The aperture is at the left part of the graph.*

The panel to enter the parameters for the boundary response is shown in Fig. 325.

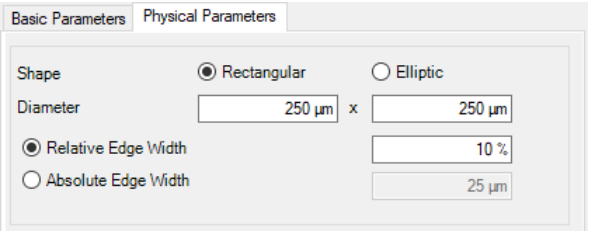


Figure 325. Physical Parameters *for the Aperture boundary response.*

The parameters are:

ITEM	DESCRIPTION
Shape	Possible options for the aperture shape are *Rectangular* and *Elliptical*.
Diameter PV	Determines the diameter of the aperture in x- and y-direction.
Relative Edge Width	The width of the aperture edge, defined relatively to the (smaller of the both values of) *Diameter*.
Absolute Edge Width	The width of the aperture edge, defined in physical units. ↪Fig. 324.

The controls that all boundary responses have in common are described in Sec. 42.1.

42.3.2 Grating Boundary Responses

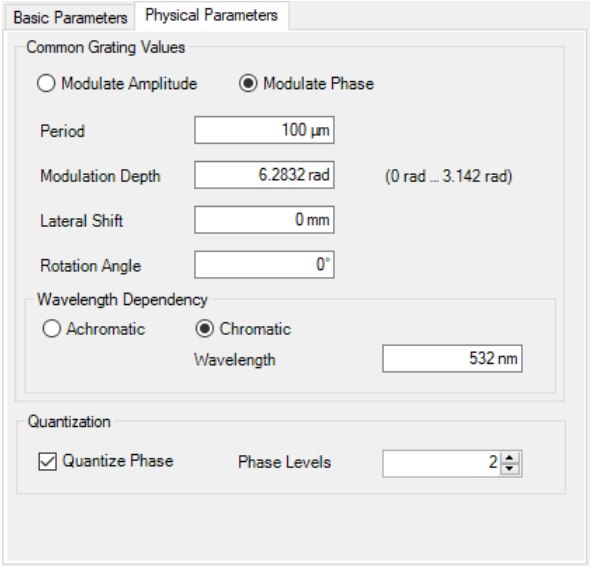


Figure 326. *Example for the* Physical Parameters *tab of a grating boundary response (here Sinusoidal Grating which has no specific parameters).*

There are four boundary responses which represent a periodic grating invariant in y-direction: Rectangular Grating (↪Sec. 42.3.2.1), Sawtooth Grating (↪Sec. 42.3.2.2), Sinusoidal Grating (↪Sec. 42.3.2.3), and Triangular Grating (↪Sec. 42.3.2.4). Their *Physical Parameters* tab (↪Fig. 326) always has the following parameters.

ITEM	DESCRIPTION
Modulate Amplitude / Phase	Shall the amplitude or the phase be modulated?
Period PV	The period P of the modulation.
Modulation Depth PV	Range of the modulation D. Please see also 'Note on Phase quantization' below.
Lateral Shift PV	A shift of the zero point of the modulation Δx in the direction of *Rotation Angle*.
Rotation Angle PV	The direction of the modulation will be rotated by this angle θ about the z-axis.
Achromatic / Chromatic	In the case of phase modulation the user can choose here whether the transmission shall work in the same way for all wavelengths (*Achromatic*) or if the defined *Modulation Depth* D_0 shall be considered as defined for one reference wavelength λ_0 (*Chromatic*), so the modulation depth D applied with a field of wavelength λ is calculated by $D = D_0\lambda_0/\lambda$.
Wavelength	Reference wavelength λ_0 for the modulation depth in *Chromatic* mode.
Quantize Amplitude / Phase	NOT FOR RECTANGULAR GRATINGS. If checked, the amplitude / phase is modulated discrete. Note that quantization is done in the following way: If N is the number of *Amplitude / Phase Levels* and Δh is the step height, then the quantization levels will be $0, \Delta h, \ldots, (N-1)\cdot\Delta h$. Please see also 'Note on Phase quantization' below.
Amplitude / Phase Levels	NOT FOR RECTANGULAR GRATINGS. The number of discrete height steps (if *Quantize Amplitude / Phase* is checked).

Note on Phase quantization

In most cases, a quantized phase modulated grating would have a modulation depth equal to 2π, i. e. the lowest level ($= -\pi$) and the highest level ($= +\pi$) would be the same. In order to preserve the number of phase levels, the following phase levels ϕ_k are used:

$$\phi_k = \frac{d_\mathrm{m}}{2} - k\frac{d_\mathrm{m}}{n} \qquad \text{with} \quad k = 0, \ldots, n-1. \tag{42.2}$$

where d_m means the given modulation depth and n the number of phase levels. Therefore the total phase modulation depth is just $d_\mathrm{m}^\mathrm{total} = \phi_0 - \phi_{n-1} = d_\mathrm{m} \cdot \frac{n-1}{n}$, which corresponds to the total modulation depth in a Structure Design (↪Sec. 99). For your information, the total modulation range is given to the right of the *Modulation Depth* in the dialog.

The controls that all boundary responses have in common are described in Sec. 42.1.

42.3.2.1 Rectangular Grating

The effect of a grating transmission with a rectangular phase or amplitude profile can be simulated by this boundary response. The modulated value $t(x')$ is computed from the modulation depth D and the slit width w by

$$t(x') = \begin{cases} D, & \textbf{if } \xi - w \le 0 \\ 0, & \textbf{if } \xi - w > 0 \end{cases} \tag{42.3}$$

for the case of amplitude modulation and by

$$t(x') = \begin{cases} \exp(iD/2), & \textbf{if } \xi - w \le 0 \\ \exp(-iD/2), & \textbf{if } \xi - w > 0 \end{cases} \tag{42.4}$$

for modulation of the phase.
With $\xi = x' - P\lfloor \frac{x'}{P} \rfloor$. P is the grating period and x' is the shifted and rotated position $x' = x\cos\theta + y\sin\theta - \Delta x$ (with the lateral position $(x; y)$, the rotation angle θ, and the lateral shift Δx).

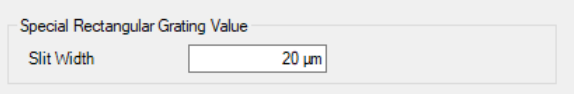


Figure 327. Special Rectangular Grating Value *for a Rectangular Grating boundary response.*

ITEM	DESCRIPTION
Slit Width PV	The width w of the slits within the grating.

The *Common Grating Values* are explained in Sec. 42.3.2, the other tab pages in Sec. 42.1.

42.3.2.2 Sawtooth Grating

The effect of a sawtooth like phase or amplitude profile can be simulated with this boundary response. The modulated value $t(x')$ is computed from the modulation depth D and the grating period P by

$$t(x') = \begin{cases} D\xi/P, & \textbf{if } \textit{Amplitude / Phase Increases with x} \\ D(P-\xi)/P, & \textbf{if } \textit{Amplitude / Phase Decreases with x} \end{cases} \tag{42.5}$$

for the case of amplitude modulation and by

$$t(x') = \begin{cases} \exp\left[iD\xi/(2P)\right], & \textbf{if } \textit{Amplitude / Phase Increases with x} \\ \exp\left[iD(P-\xi)/(2P)\right], & \textbf{if } \textit{Amplitude / Phase Decreases with x} \end{cases} \tag{42.6}$$

for modulation of the phase.
With $\xi = x' - P\lfloor\frac{x'}{P}\rfloor$. P is the grating period and x' is the shifted and rotated position $x' = x\cos\theta + y\sin\theta - \Delta x$ (with the lateral position $(x;\, y)$, the rotation angle θ, and the lateral shift Δx).

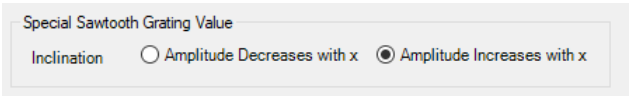


Figure 328. Special Sawtooth Grating Value *for a Sawtooth Grating boundary response.*

ITEM	DESCRIPTION
Amplitude / Phase Decreases with x	If checked, the amplitude / phase of the *unrotated* grating transmission descends in positive x-direction.
Amplitude / Phase Increases with x	If checked, the amplitude / phase of the *unrotated* grating transmission ascends in positive x-direction.

The *Common Grating Values* are explained in Sec. 42.3.2, the other tab pages in Sec. 42.1.

42.3.2.3 Sinusoidal Grating

The effect of a sinusoidal modulated phase or amplitude can be simulated with this boundary response. The modulated value $t(x')$ is computed from modulation depth D, grating period P, and lateral shift Δx by

$$t(x') = D/2\left(\sin\left(2\pi(x'-\Delta x)/P\right) + 1\right) \tag{42.7}$$

for the case of amplitude modulation and by

$$t(x') = \exp\left[iD/2\sin\left(2\pi(x'-\Delta x)/P\right)\right] \tag{42.8}$$

for modulation of the phase.
x' is calculated from the lateral position $(x;\, y)$ and the rotation angle θ via $x' = x\cos\theta + y\sin\theta$.
This grating boundary response has no specific parameters. The *Common Grating Values* are explained in Sec. 42.3.2, the other tab pages in Sec. 42.1.

42.3.2.4 Triangular Grating

In a triangular phase or amplitude profile the modulation increases linearly along a certain part a of the grating period P and then decreases linearly to the original value along $b = P - a$. The modulated value $t(x')$ is computed from the modulation depth D, the period P and the triangle side ratio $\sigma = {}^{b}/_{a}$ by

$$t(x') = \begin{cases} D\xi(1+\sigma)/P, & \textbf{if } x' < P/(1+\sigma) \\ D(P-\xi)(1+\sigma)/(\sigma P), & \textbf{if } x' \geq P/(1+\sigma) \end{cases} \tag{42.9}$$

for the case of amplitude modulation and by

$$t(x') = \begin{cases} \exp\left[iD\xi(1+\sigma)/(2P)\right], & \textbf{if } x' < P/(1+\sigma) \\ \exp\left[iD(P-\xi)(1+\sigma)/(\sigma 2P)\right], & \textbf{if } x' \geq P/(1+\sigma) \end{cases} \tag{42.10}$$

for modulation of the phase.
With $\xi = x' - P\lfloor \frac{x'}{P} \rfloor$. P is the grating period and x' is the shifted and rotated position $x' = x\cos\theta + y\sin\theta - \Delta x$ (with the lateral position $(x; y)$, the rotation angle θ, and the lateral shift Δx).

Figure 329. Special Triangular Grating Value *for a Triangular Grating boundary response.*

ITEM	DESCRIPTION
Triangle Side Ratio PV	Ratio σ of the projections of the sides of the triangle on its baseline.

The *Common Grating Values* are explained in Sec. 42.3.2, the other tab pages in Sec. 42.1.

42.3.3 Ideal Lens

This boundary response applies the effect of a thin lens with the *Focal Length* PV f to the incoming field. One has to distinguish between a paraxial and the more general non-paraxial application. The first case is given by

$$t_{\text{par}}(x,y) = \exp\left[-ik\left(\frac{(x-x_0)^2}{2f_x} + \frac{(y-y_0)^2}{2f_y}\right)\right] \tag{42.11}$$

while the non-paraxial relation is described by

$$t(x,y) = \exp[ikr] \tag{42.12}$$

with

$$r = -\sqrt{(x-x_0)^2 + (y-y_0)^2 + f^2}. \tag{42.13}$$

The wave number k is defined by

$$k = \frac{2\pi n}{\lambda} \quad . \tag{42.14}$$

The *Lateral Offset* relative to the optical axis is represented by (x_0, y_0).

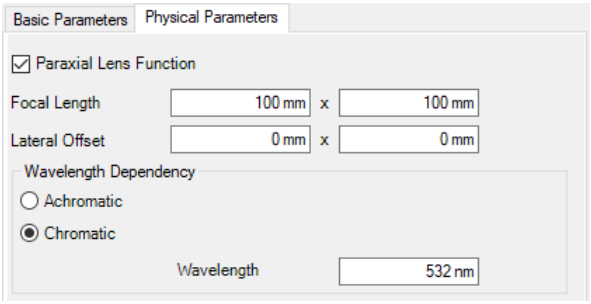


Figure 330. Physical Parameters *for an Ideal Lens transmission.*

These parameters have to be entered to the dialog shown in Fig. 330 and are listed in the following table:

ITEM	DESCRIPTION
Paraxial Lens Function	If checked, the paraxial equation Eq. (42.11) is used, otherwise the non-paraxial Eq. (42.12).
Focal Length PV	Corresponds to f in Eq. (42.12) and to f_x and f_y in Eq. (42.11) respectively. It represents the focal length of a real lens. It can differ in x- and y-direction in the case of a *Paraxial Lens Function*, which represents different curvature radii in a real lens.
Lateral Offset PV	Corresponds to x_0 and y_0 in Eq. (42.11) and Eq. (42.13). It determines the displacement of the radial symmetric function, perpendicular to the optical axis.
Achromatic Function / Chromatic Function	If the function is defined as achromatic, then the wavelength λ used in Eq. (42.14) is always the wavelength of the incoming (member) field and thus the *effect* of the ideal lens function is always the same. In contrast, in chromatic mode, the *Wavelength* λ used in Eq. (42.14) is set to a fixed value in the tab page. This is closer to the behavior of a real lens.
Wavelength	The fixed wavelength used for *Chromatic Function* mode. Only for this wavelength the chromatic lens has exactly the entered *Focal Length*.

The controls that all boundary responses have in common are described in Sec. 42.1.

42.3.4 Linear Phase

By using a linear phase boundary response, a wave can be deflected by a certain angle.
The direction of the linear phase can be entered as *Cartesian Angles*, *Spherical Angles*, *Wave Number Vector*, and *Spatial Frequency*.
The lateral transmission function is defined by:

$$t(x,y) = \exp[i(k_x x + k_y y)]. \tag{42.15}$$

Here you can find the *Wave Number Vector* $\boldsymbol{k} = (k_x, k_y, k_z)^T$, which has the length

$$k = \frac{2\pi}{\lambda} = \sqrt{k_x^2 + k_y^2 + k_z^2}, \tag{42.16}$$

The *Cartesian Angles* α and β (*Alpha* and *Beta*) are related to k_x and k_y by

$$\tan\alpha = \frac{k_x}{k_z}, \tag{42.17}$$

$$\tan\beta = \frac{k_y}{k_z}, \tag{42.18}$$

$$\tag{42.19}$$

whereas the *Spherical Angles* ϕ and θ (*Phi* and *Theta*) are related to the wave number coordinates k_x and k_y by

$$k_x = k\cos\phi\sin\theta, \tag{42.20}$$

and

$$k_y = k\sin\phi\sin\theta. \tag{42.21}$$

In case of *Spatial Frequency* the given parameters u and v are related to k_x and k_y by

$$u = k_x/(2\pi), \tag{42.22}$$

and

$$v = k_y / (2\pi). \tag{42.23}$$

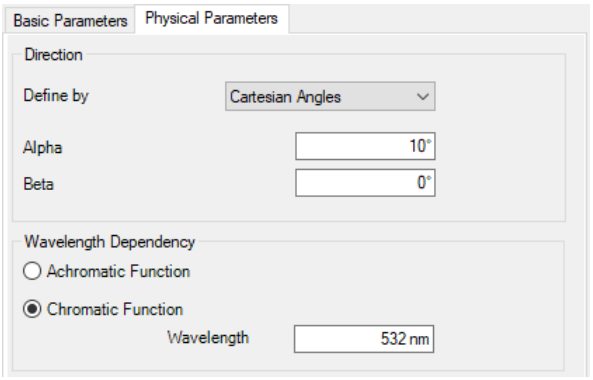


Figure 331. Physical Parameters *for a Linear Phase boundary response.*

The following physical parameters are available for a Linear Phase boundary response (↪Fig. 331):

ITEM	DESCRIPTION
Cartesian Angles	Defines the tilt angles α and β (*Alpha*[PV] and *Beta*[PV]) of the linear phase. The angle unit is degrees. For the definition see Eq. (42.17) and Eq. (42.18).
Spherical Angles	Defines the tilt angles in spherical coordinates ϕ and θ (*Phi* and *Theta*). The angle unit is degrees. For the definition see Eq. (42.20) and Eq. (42.21).
Wave Number Vector	Defines the direction of the linear phase in terms of the components k_x and k_y of the wave number vector k. For the physical meaning on it see Eq. (42.15).
Spatial Frequency	Defines the direction of the plane wave in spatial frequencies *u* and *v* for x and y-direction, in units of 1/m (see Eq. (42.22) and Eq. (42.23)).
Achromatic Function / Chromatic Function	If the function is defined as achromatic, then the wavelength λ used in Eq. (42.16) is always the wavelength of the incoming (member) field and thus the deflection is always the same. In contrast, in chromatic mode, the *Wavelength* λ used in Eq. (42.16) is set to a fixed value in the tab page. As you can see from Eq. (42.15), Eq. (42.22), and Eq. (42.23), setting the wavelength has no effect if the linear phase is defined by *Wave Number Vector* or *Spatial Frequency*. Thus, the group box *Wavelength Dependency* is not visible in these cases.
Wavelength	The wavelength the *Cartesian Angles* and the *Spherical Angles* refer to in *Chromatic Function* mode.

The controls that all boundary responses have in common are described in Sec. 42.1.

42.3.5 Programmable Function

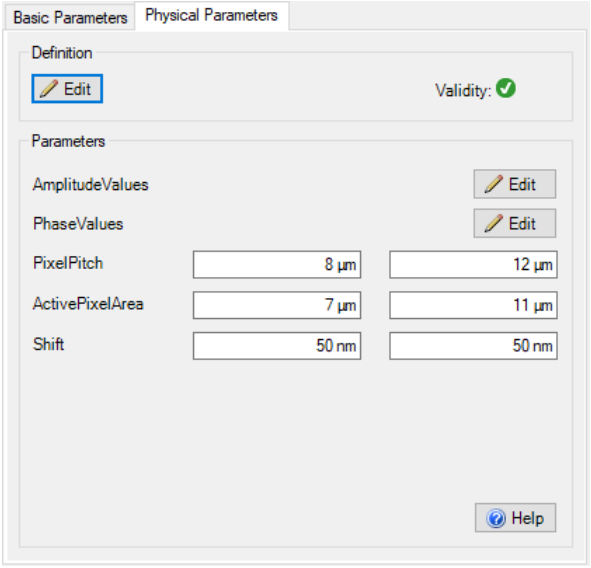


Figure 332. Physical Parameters *for a programmable boundary response.*

The programmable function allows you to define your own boundary response. This means you write a little code snippet defining the function $\mathcal{B} = f(x, y, \lambda, n(\lambda))$. The *Physical Parameters* tab (↪Fig. 332) contains:

ITEM	DESCRIPTION
Definition	This group box allows you to program the actual code snippet. *Edit* opens the Source Code Editor (↪Sec. 7.3) to edit this snippet, and a validity indicator (↪Sec. 5.11) shows whether this snippet is consistent.
Parameters PE	The controls in this group box allow you to set the values of the global parameters of the snippet. ↪Sec. 7.4

General information about programming in VirtualLab Fusion can be found in Sec. 7. The controls that all boundary responses have in common are described in Sec. 42.1.

42.3.6 Single Phase Dislocation

This boundary response can be used to simulate the effect of a special type of phase dislocations. Around phase dislocations the phase distribution of a field has a shape like a spiral staircase (see example in Fig. 333). A circle integral over the phase around a single phase dislocation results in a multiple of 2π.
The boundary response function $\mathcal{B}(x, y)$ of the generated type of phase dislocations is given by

$$\mathcal{B}(x, y) = 1 \cdot \exp\left(\mathrm{i} \cdot c\varphi\right) = 1 \cdot \exp\left(\mathrm{i} \cdot c \arctan \frac{y - y_0}{x - x_0}\right), \tag{42.24}$$

where c denotes the *Charge* of the phase dislocation and (x_0, y_0) marks its *Position*.

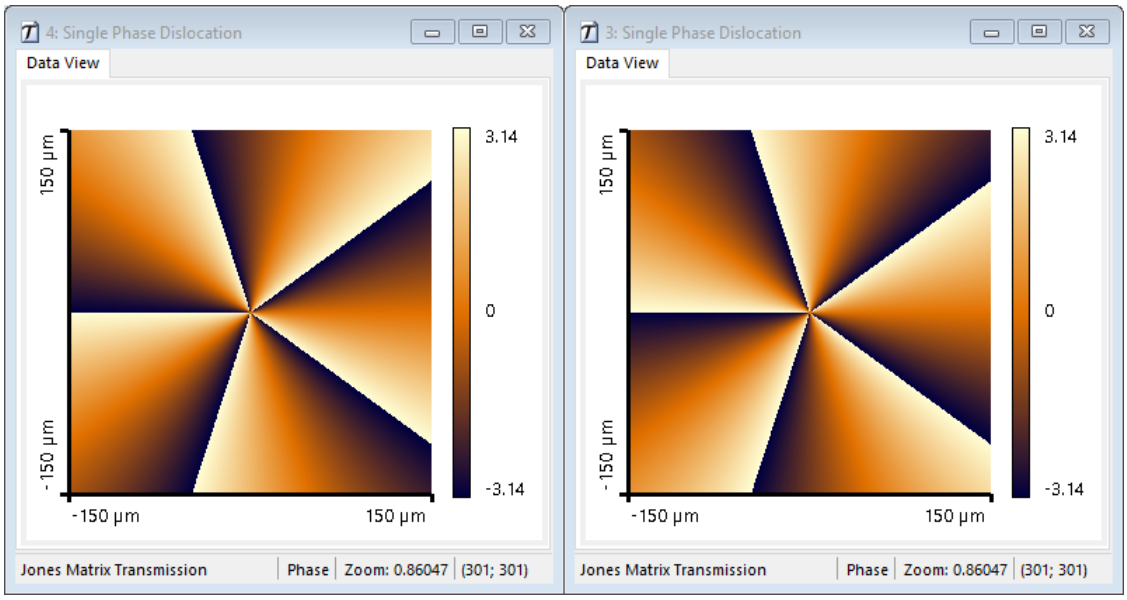


Figure 333. *Two examples of a single phase dislocation transmission with a charge c of -5 (left) and +5 (right).*

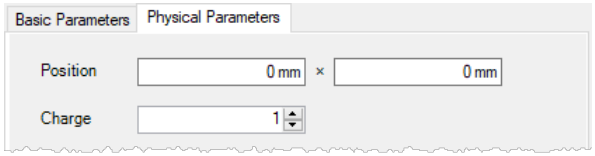


Figure 334. Physical Parameters *for a Single Phase Dislocation boundary response.*

The following physical parameters are available for a Single Phase Dislocation boundary response (↪Fig. 334):

ITEM	DESCRIPTION
Position	Corresponds to x_0 and y_0 in Eq. (42.24). It defines the lateral displacement of the phase dislocation in physical coordinates with respect to the center of the field.
Charge PV	Determines the charge c of the phase dislocation (↪Eq. (42.24)). It gives the number of 2π jumps. Its sign specifies whether the phase increases or decreases with angle φ (↪Fig. 333).

The controls that all boundary responses have in common are described in Sec. 42.1.

42.3.7 Spherical Phase

A radially converging or diverging wave has a spherical phase, which can be simulated by using this boundary response. It is defined by

$$t(x,y) = \exp[ikr], \tag{42.25}$$

with

$$r = \sqrt{(x-x_0)^2 + (y-y_0)^2 + z^2}. \tag{42.26}$$

and the wave number

$$k = \frac{2\pi n}{\lambda} \tag{42.27}$$

n is the refractive index of the embedding medium.

The *Lateral Offset* (x_0, y_0) relative to the optical axis as well as the *Distance to Source Plane* z has to be entered in the *Physical Parameters* tab (↪Fig. 335).

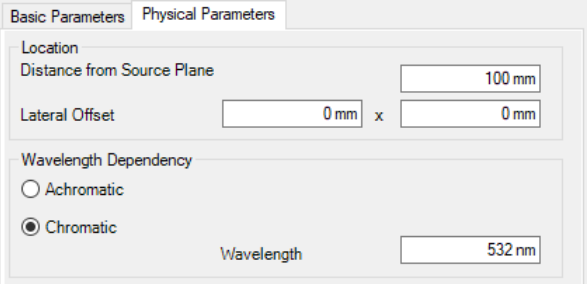


Figure 335. Physical Parameters *for a Spherical Phase boundary response.*

ITEM	DESCRIPTION
Distance from Source Plane [PV]	Corresponds to z in Eq. (42.26). A wave, propagating in positive z-direction, would have the desired spherical phase if it is this distance (measured on the optical axis) away from its (point) source.
Lateral Offset [PV]	Corresponds to x_0 and y_0 in Eq. (42.26). It determines the displacement of the radial symmetric transmission function, perpendicular to the optical axis.
Achromatic Function / Chromatic Function	If the function is defined as achromatic, then the wavelength λ used in Eq. (42.27) is always the wavelength of the incoming (member) field and thus the *effect* of the spherical phase function is always the same. In contrast, in chromatic mode, the *Wavelength* λ used in Eq. (42.27) is set to a fixed value in the tab page.
Wavelength	The fixed wavelength used for *Chromatic Function* mode. Only for this wavelength a plane wave having a spherical phase as defined by Eqs. (42.25)-(42.27) would be completely focused if propagated a distance of $-z$.

42.3.8 Stop

This boundary response allows you to apply a rectangular or elliptical stop function on the incoming field. Such a function has the value 0 inside and 1 outside the defined *Diameter*. The edge of the stop can be defined smooth, then the values don't "jump" from 1 (outside of the stop) to 0 (the blocking stop). Instead they follow a Gaussian function (starting at 1 and cut off at a value of 0.01) as shown in Fig. 336.

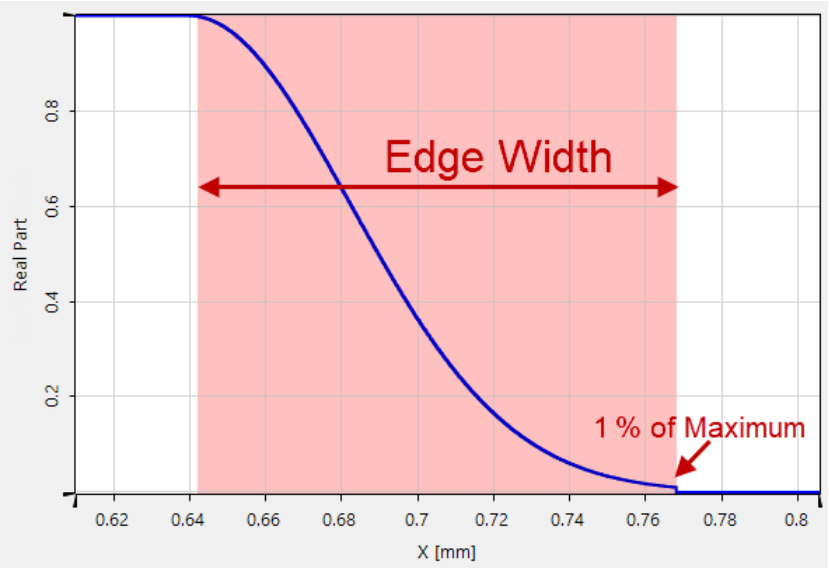


Figure 336. *Definition of the edge width of a stop. The stop is at the right part of the graph.*

The panel to enter the parameters for the boundary response is shown in Fig. 337.

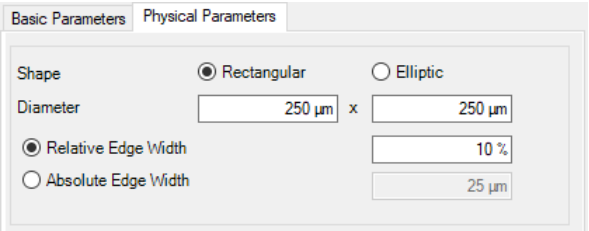


Figure 337. Physical Parameters *for the Stop boundary response.*

The parameters are:

ITEM	DESCRIPTION
Shape	Possible options for the aperture shape are *Rectangular* and *Elliptical*.
Diameter PV	Determines the diameter of the stop in x- and y-direction.
Relative Edge Width	The width of the aperture edge, defined relatively to the (smaller of the both values of) *diameter*.
Absolute Edge Width	The width of the aperture edge, defined in physical units. ↪Fig. 336.

The controls that all boundary responses have in common are described in Sec. 42.1.

42.3.9 Zernike & Seidel Aberrations

Zernike fringe, Zernike standard, and Seidel aberrations are often used to describe aberrations within an imaging optical system. The corresponding formulas are given in Sec. 140.2.

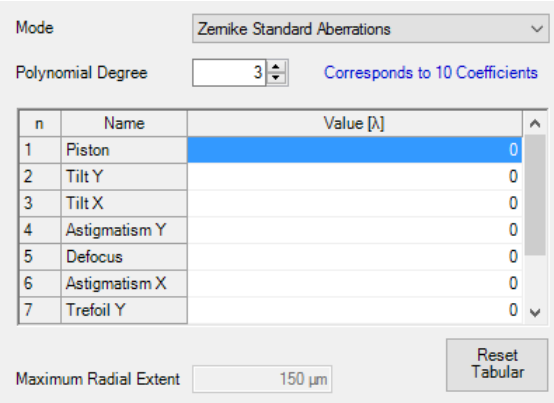


Figure 338. *Parameters for a* Zernike Standard Aberrations *boundary response.*

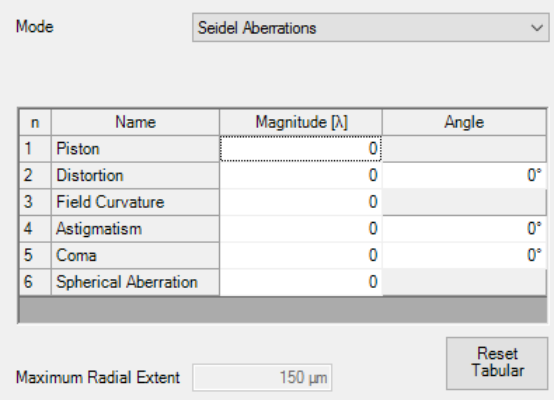


Figure 339. *Parameters for a* Seidel Aberrations *boundary response.*

The *Physical Parameters* tab (see Fig. 338 and Fig. 339) allows the following settings.

ITEM	DESCRIPTION
Mode	You can choose between *Zernike Fringe Aberrations*, *Zernike Standard Aberrations*, and *Seidel Aberrations*.
Polynomial Degree	ONLY FOR *ZERNIKE STANDARD ABERRATIONS* Allows you to set the maximum polynomial degree of the used Zernike terms, and thus indirectly the number of coefficients.
{Coefficients Table}	Allows you to enter the coefficients of the polynomial describing the aberrations. They refer to wavelengths. For example a Zernike fringe tilt of 1 leads to phase values in the range $-1\lambda(=-2\pi)\ldots+1\lambda(=+2\pi)$. Via the context menu of the table you can copy and paste the parameter list.
Maximum Radial Extent	The radii $r=\sqrt{x^2+y^2}$ are divided by this value. It is equal to half the *Diameter* plus the *Absolute Edge Width* as set up in the *Basic Parameters* tab. This parameter is sometimes also referred to as maximum radius, radius of unit pupil, or radius of unit disc.
Reset Tabular	Resets all table entries to 0.

42.3.10 Stored Function

By using the *Stored Function* it is possible to include an arbitrary sampled transmission function into an optical system. Fig. 340 shows the dialog where the transmission and the other parameters can be set.

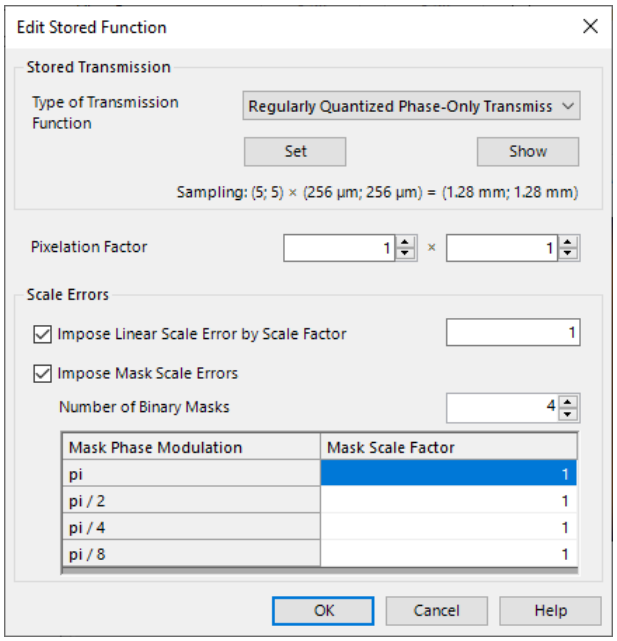


Figure 340. *Parameters of a stored function.*

All parameters of the dialog are listed in the following table:

ITEM	DESCRIPTION
Type of Transmission Function	The chosen type determines which interpolation is used to retrieve function values at a certain position and what scale errors can be simulated. A *Continuous* function uses Cubic 8 Point Interpolation, while *Pixelated* or *Quantized* transmissions use Nearest Neighbor. Details on these interpolations can be found in Sec. 13.2.2. Furthermore a *Phase-Only* function allows to apply a linear scale factor on the phase. A *Regularly Quantized Phase-Only Transmission* assumes 2^n equidistant phase levels with distances of $2\pi/2^n$. In this case one can assume a binary mask fabrication process and apply an error to each mask. Note that any *Phase-Only* option will not cause any amplitude modulation that may be present to be ignored.
Set	Sets the desired Jones Matrix Transmission. When you click on this button you can do the following: • *Load* a Jones Matrix Transmission from a .ca2 file. Note that the Jones matrix of that transmission is ignored. • *Select from Documents* allows you to select an already open Jones Matrix Transmission. • *Reset* the data to the default transmission.
Show	Shows the Complex Amplitude containing the currently set transmission as separate document.
Sampling	Gives information about the number of sampling points, the sampling distance, and the diameter of the currently set transmission.
Pixelation Factor PV	If these factors $(F_x; F_y)$ are larger than one, every pixel in the original transmission is replaced by $F_x \times F_y$ pixels with the same value. This ensures that a pixelated transmission is really simulated as pixelated.

Impose Linear Scale Error by Scale Factor	Takes a specific scale error into account, the *Linear Scale Factor*[PV]. It is considered by $$T_{\text{new}}(x,y) = \exp(i\phi_{\text{new}}(x,y)) = \exp(i\phi_{\text{old}}(x,y)f), \quad (42.28)$$ whereby f denotes the Linear Scale Factor.
Impose Mask Scale Errors	This option is available for *Regularly Quantized Phase-Only Transmission* only and simulates separate single mask scale errors during a binary mask fabrication process. To this end, a *Mask Scale Factor*[PV] can be applied to each mask. The ideal phase modulation of the corresponding mask (π, $\pi/2$, $\pi/4$, and so on) is multiplied with that factor. Via the context menu of the table you can copy the scale factors.
Number of Binary Masks	If *Impose Mask Scale Errors* is checked, it is assumed that the function has been composed out of "binary masks". Then to each binary masks a scale error can be applied. This feature can only be used only for a *Regularly Quantized Phase-Only Transmission* with 2^n height levels. The integer n is the *Number of Binary Masks*.

43 Surface Regions

Surface Regions are regions on a surface (↪Sec. 36) which behave differently than just a plain surface. As such they consist of the actual geometric region and the functionality to be applied in that region. In the moment only surface regions with an idealized or real grating are implemented. These grating regions are described in Sec. 43.1.
Multiple regions on a surface form a so-called Surface Layout (↪Sec. 41).

43.1 Grating Regions

Grating Regions describe the effect of an idealized or real grating within a certain geometric region.
The edit dialog for grating regions has the following three tab pages:

TAB PAGE	DESCRIPTION
Shape	Describes the actual geometric region in which the grating is located. ↪Sec. 43.1.1
Region Channels	Allows you to define which propagation channels are used for this region. The names of the channels refer to the sign the z-component of the direction vector the incident and outgoing light has, respectively. *Plus-Plus-Direction* for example refers to transmitted light going along the optical axis while *Minus-Plus-Direction* refers to reflected light going initially against the optical axis. Note that this settings might be overwritten by the settings on the *Channel Configuration* tab (↪Sec. 44.10) of the parent component.
Grating	Describes the idealized or real grating. ↪Sec. 43.1.2

Additionally it has a validity indicator (↪Sec. 5.11) in the bottom-left corner.

43.1.1 Shape Tab

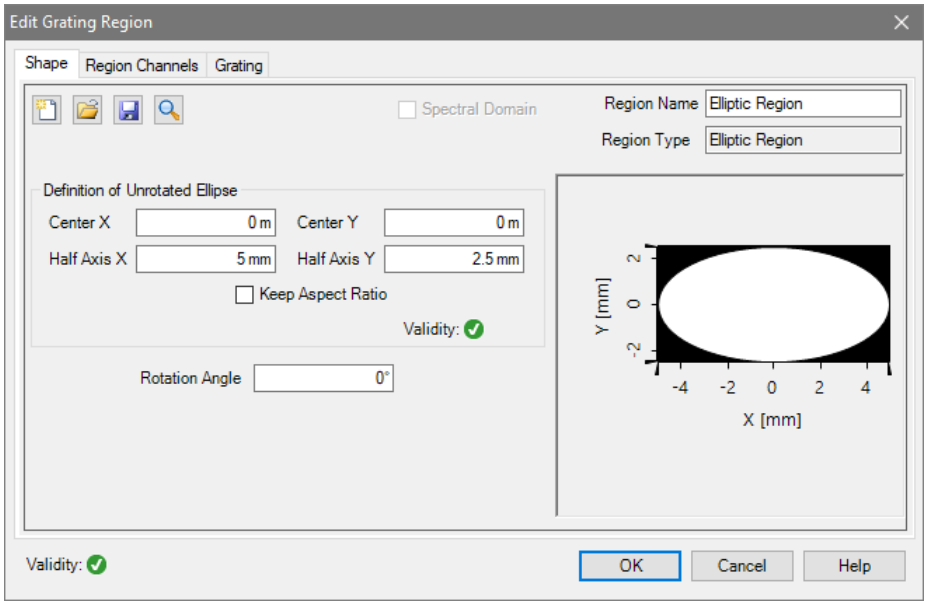


Figure 341. Shape *tab of a grating region.*

In the top of this tab (↪Fig. 341) there are the following controls.

ITEM	DESCRIPTION
	Creates a new geometric region, which can be either a *New Rectangular Region* (↪Sec. 21.1.1), *New Elliptic Region* (↪Sec. 21.1.2), *New Simple Polygon Region* (↪Sec. 21.1.3), *New Sampled Region* (↪Sec. 21.1.4), or *New Composed Region* (↪Sec. 21.1.5).
	If you click on this button you can do the following: • *Load* a region document (↪Sec. 21) from a .rgn file. • *Select from Documents* allows you to select an already open region document.
	Saves the current region definition as region document.
	Displays the current region definition as separate region view (↪Sec. 21.3).
Region Name	You can give the region an arbitrary name which for example identifies this region in the edit dialog of the parent surface layout.
Spectral Domain / Region Type	These two controls provide useful information about the current region.

In the lower part there are controls specific to the current *Region Type* (see sections given above for details) and a preview of the region.

43.1.2 Grating Tab

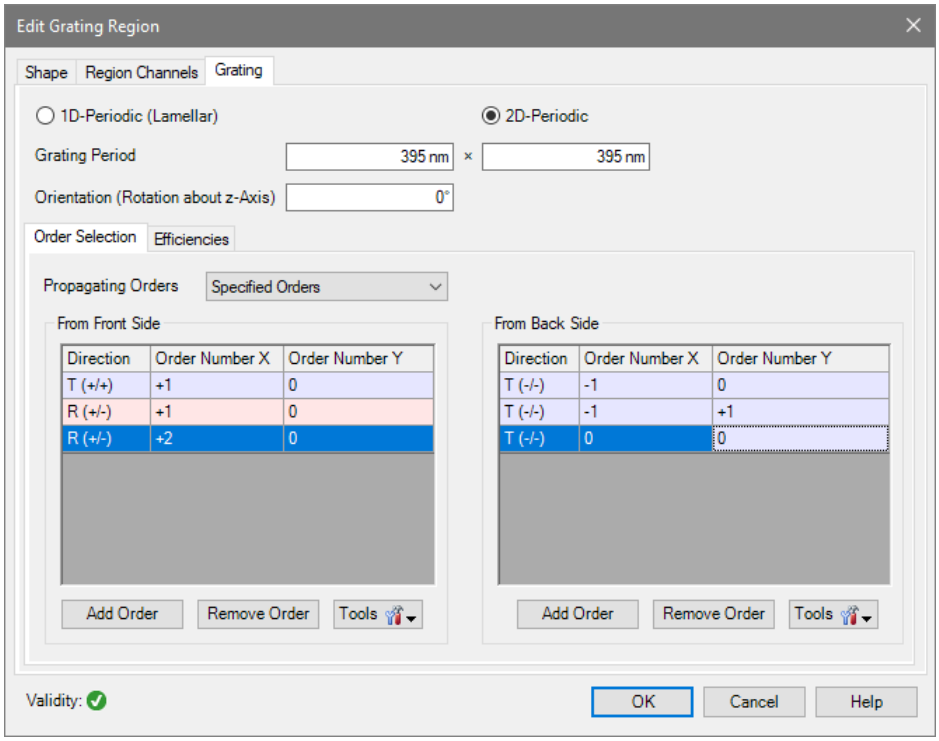


Figure 342. Order Selection *tab of a grating region.*

On this tab (↪Fig. 342) you first specify the general parameters of the grating.

ITEM	DESCRIPTION
1D-Periodic (Lamellar) / 2D-Periodic	Determines the periodicity of the grating. Influences some controls on this tab page and in the end also the computational effort.
Grating Period PV	The period of the grating.
Orientation PV	Rotates the whole grating around the z-axis and so determines into which direction the grating orders go.

Furthermore this tab contains two sub-tabs. On the *Order Selection* tab (↪Sec. 43.1.2.1) you define which orders shall be used for the simulation. On the *Efficiencies* tab (↪Sec. 43.1.2.2) you either specify the efficiencies directly or via a snippet or you define a real grating whose efficiencies are used.

43.1.2.1 Order Selection Tab

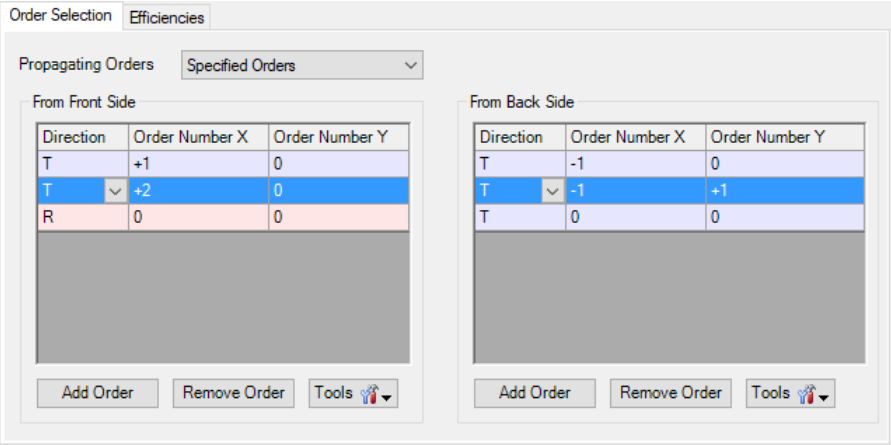


Figure 343. Order Selection *tab of a grating region with a* 2D-Periodic *grating.*

This tab page (↪Fig. 343) has the following controls.

ITEM	DESCRIPTION
Propagating Orders	There are three ways how the orders specified by the user are taken into account during the simulation of the optical setup. • *All Orders*: All orders are taken into account, independent of the user specification. • *Specified Orders*: Only the orders specified by the user are taken into account. • *All but Specified Orders*: Only the orders **not** specified by the user are taken into account.
From Front Side	Table with all propagating orders if the grating is illuminated from the front side, i. e. with light whose z-component of the direction vector has a positive sign. ↪Sec. 5.13
From Back Side	Table with all propagating orders if the grating is illuminated from the back side, i. e. with light whose z-component of the direction vector has a negative sign. ↪Sec. 5.13

43.1.2.2 Efficiencies Tab

This tab offers you three ways how the efficiencies of the distinct orders are determined:

- *Constant*: The efficiencies of an idealized grating are specified via a table. ↪Sec. (a)
- *Programmable*: The efficiencies of an idealized grating are specified via a snippet in dependency from e. g. direction or wavelength. ↪Sec. (b)
- *From Real Grating*: The efficiencies are calculated from a real grating stack. In this case the *Grating Period* and the period of the stack defining the real grating are synchronized so that they are always the same. ↪Sec. (c)

If you switch from a real grating to an idealized grating you are asked whether the *Grating Period* shall be the period of the stack or the value you last entered as *Grating Period*.

(a) Constant Efficiencies

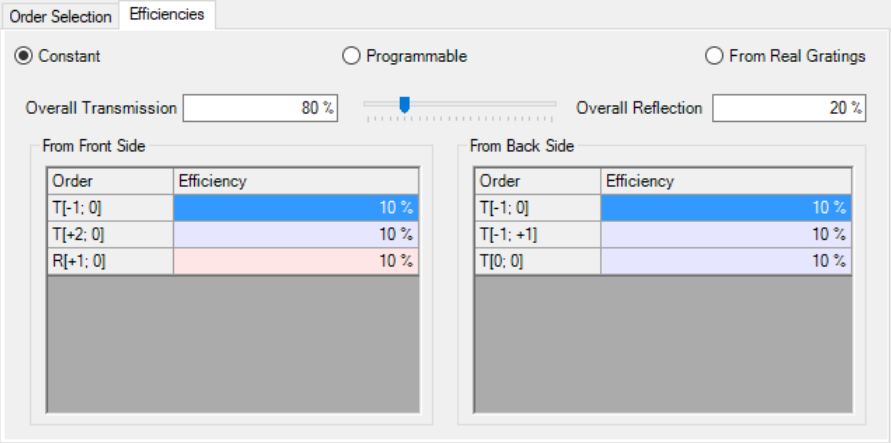


Figure 344. *The* Efficiencies *tab of a grating region if* Constant *efficiencies are specified.*

For *Constant Efficiencies* there are the following controls.

ITEM	DESCRIPTION
Overall Transmission / Overall Reflection	For consistency the sum of all grating orders must not be larger than 100 %. With these controls you can divide this 100 % between transmission and reflection. If then the sum of the efficiencies for either the transmitted or the reflected orders exceeds the specified limit, the validity indicator (↪Sec. 5.11) of the dialog indicates a warning.
From Front Side / From Back Side	Table where you can enter efficiencies[PV] for all orders specified in the *From Front Side* / *From Back Side* table of the *Order Selection* tab. If *All Orders* or *All but Specified Orders* was set on this tab, then all entered efficiencies are subtracted from the overall transmission / reflection efficiency and this remaining efficiency is then distributed evenly among the unspecified orders.

Example

You have specified that the order “T+1” for the light coming from the front side has an efficiency of 50 % whereas the overall transmission is 80 %. You have set to use *All Orders* and the orders “T-1”, “T0”, and “T+1” are propagating ones. Thus the remaining 30 % are distributed evenly among “T-1” and “T0” and thus both orders have 15 % efficiency.

(b) Programmable Efficiencies

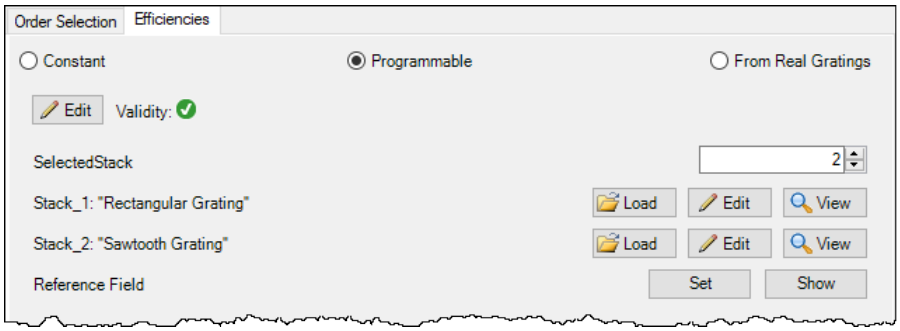


Figure 345. *The Efficiencies tab of a grating region if Programmable efficiencies are specified. The snippet is valid and some general parameters are available.*

For *Programmable Efficiencies* you can program a snippet returning a list of order numbers and corresponding efficiencies in dependency from e. g. wavelength, direction of the incident light and whether the light is reflected or transmitted. *Edit* opens the Source Code Editor (↪Sec. 7.3) to edit this snippet, and a validity indicator (↪Sec. 5.11) shows whether this snippet is consistent. Below these two controls you can edit the values of the global parameters of the snippet (↪Sec. 7.4).

(c) Efficiencies From Real Gratings

The efficiencies can also be calculated from a real grating stack (↪Sec. 40). The efficiencies of this stack are then calculated rigorously with the Fourier Modal Method (FMM, ↪Sec. 97.3) when the Grating Channel Analyzer (↪Sec. 92) is used. Alternatively you can load an already calculated lookup table with efficiencies from file.
Note that in case of a *2D Grating* only a one-dimensional section of the orders is used. I. e. only orders are taken into account having an order number of zero in y-direction (of the unrotated grating).

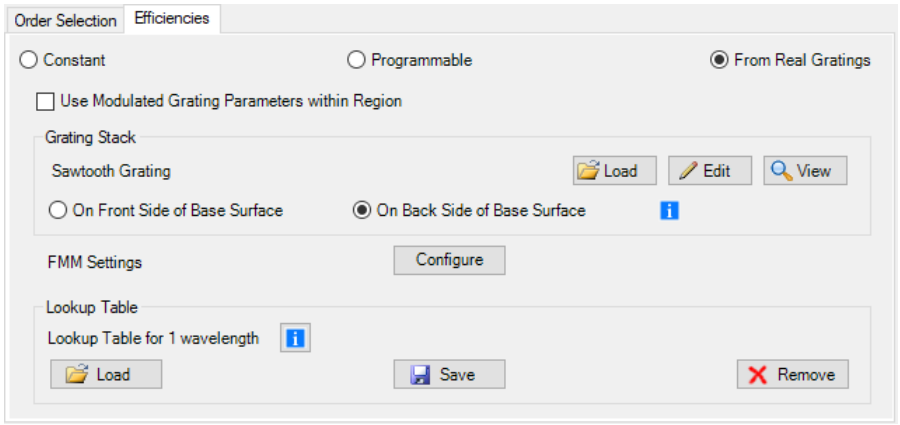


Figure 346. *The Efficiencies tab of a grating region if the efficiencies are calculated From Real Gratings.*

For *Efficiencies From Real Gratings* there are the following controls.

ITEM	DESCRIPTION
Use Modulated Grating Parameters within Region	Switches to a mode where not a well-defined grating is used but a grating where parameters vary over the region. This mode is explained in Sec. 43.1.3.
{Actual Grating Stack} PE	Control for loading a stack with a grating from catalog, for editing and viewing it. ↪Sec. 34.1
On Front Side of Base Surface	If checked it is assumed that the stack is placed on the front side of the base surface. This means that in comparison to its normal orientation it is rotated by 180° about the y-axis and thus points against the optical axis. Sec. 40.1.2 shows an example.
On Back Side of Base Surface	If checked it is assumed that the stack is placed on the back side of the base surface. This means that it is used in its normal orientation.
FMM Settings PE	The FMM does not evaluate the real grating but an approximated structure decomposed into layers and transition points. By clicking on the *Configure* button you can adjust and preview this decomposition and set the number of calculated orders. ↪Sec. 97.3.1
Lookup Table	Normally the lookup table with the efficiencies is filled by the LUT Result Generator (↪Sec. 47). But the controls in this section allow you to *Save* a lookup table into a file so that you can *Load* it into other grating regions. Or you can *Remove* the lookup table to enforce a new calculation by the Grating Channel Analyzer (↪Sec. 92) / LUT Result Generator. A label gives you some additional information about the current lookup table – or informs you that no lookup table is set. The ℹ button right to it shows all wavelengths and directions for which the lookup table contains Rayleigh coefficients.

43.1.3 Modulated Grating Parameters

If *Use Modulated Grating Parameters within Region* is checked the parameters of the grating used within the region are modulated. Currently we support the 1D or 2D variation for grating parameters (reason for this is the usage of a 1D or 2D data array to store the Rayleigh matrices in dependency of the grating parameters which are varied). In order to use a modulated grating within a region, two things need to be specified:

1. The function how the grating parameter is changed inside the region in dependency of the lateral position $(x; y)$.
2. The lookup tables which define the grating effect in dependency of the grating parameters. (note: the grating effect is defined by a complex 2×2 matrix (Rayleigh matrix) per grating parameter, so all polarization effects are included, because we do not deal “only” with efficiencies.

The lookup tables should typically be filled by using the *Footprint and Grating Analysis* tool (↪Sec. 102.1). Fig. 347 shows the edit dialog for activated *Use Modulated Grating Parameters within Region*.

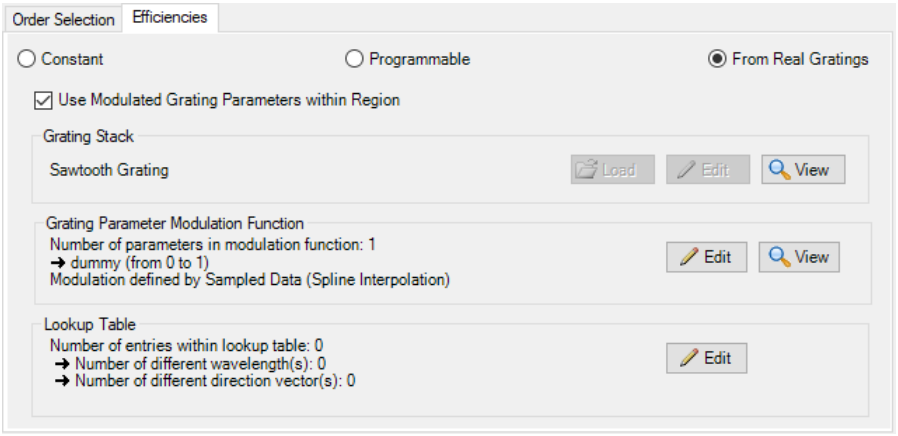


Figure 347. *The* Efficiencies *tab of a grating region if the efficiencies are calculated* From Real Gratings *with modulated grating parameters.*

The following options are available in this section of the region edit dialog:

ITEM	DESCRIPTION
Grating Stack	The grating stack which is associated with this region. In modulated parameter mode the grating stack cannot be edited and also won't be used during propagation, because all required information is given in the lookup tables. The stack can only be displayed.
Grating Parameter Modulation Function	In this group box several information about the configured modulation function is displayed (like number of parameters that are defined for the modulation, name of the parameter(s) and type of modulation, e. g. sampled or programmable. In addition the user can edit the grating parameter modulation function by clicking on the *Edit* button (↪Sec. 43.1.3.1). It is also possible to display the parameter variation function in the region. This is triggered by clicking on the *View* button (↪Sec. (a)).
Lookup Table	The effect of the modulated grating is defined by a special lookup table concept. Here the Rayleigh matrices per grating parameter is stored. The user can edit the lookup tables by clicking on the corresponding *Edit* button (↪Sec. 43.1.3.2).

43.1.3.1 Edit Grating Parameter Modulation Function

The grating parameter modulation function defines the dependency of the grating parameter(s) in dependency of the lateral position in the grating region. Currently we support that one or two grating parameters can be varied.
Fig. 348 shows the edit dialog of the grating parameter modulation function.

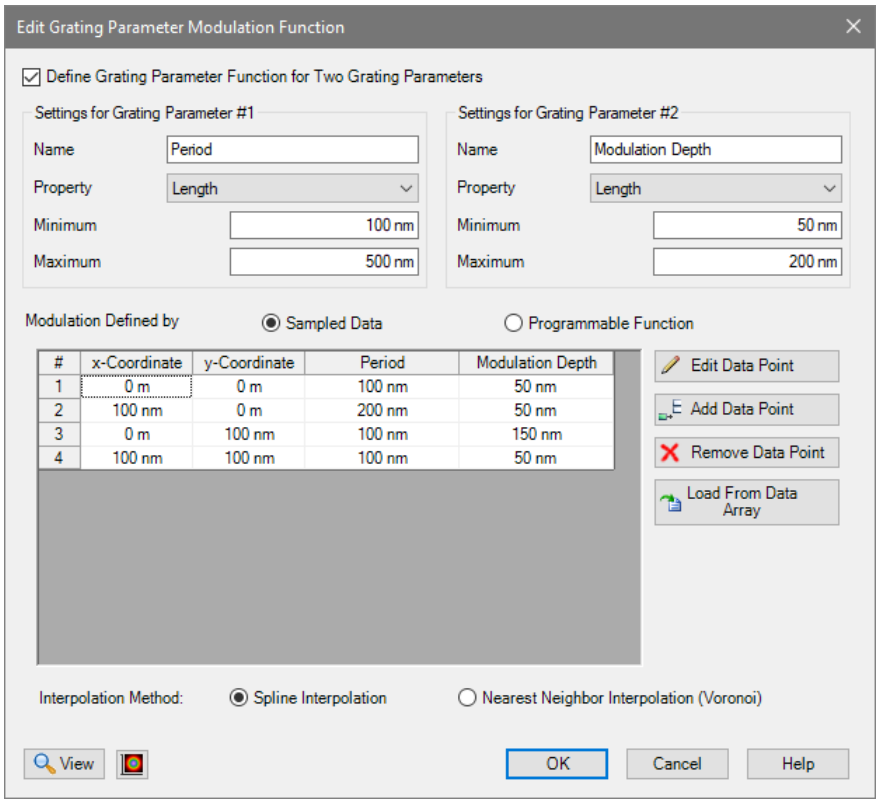


Figure 348. *The dialog to edit the grating parameter modulation function.*

In the top part of the dialog the following options can be configured by the user:

ITEM	DESCRIPTION
Define Grating Parameter Function for Two Grating Parameters	Currently we allow the definition for one or two grating parameters that are varied. By checking this option the variation of two parameters is enabled. If the option is unchecked only one parameter is available for modulation.
Settings for Grating Parameter #1	The user needs to specify several information for parameter #1 that shall be used for parameter variation: • The name of the parameter (string format) • The physical property of the parameter (selection by a drop-down list) • Minimum and maximum of the parameter This information is used within the display of the grating parameter function and within the parameter extraction in case of sampled function definition.
Settings for Grating Parameter #2	The user needs to specify several information for parameter #2 that shall be used for parameter variation: • The name of the parameter (string format) • The physical property of the parameter (selection by drop-down list) • Minimum and maximum of the parameter This information is used within the display of the grating parameter function and within the parameter extraction in case of sampled function definition.

VirtualLab Fusion provides two options for the specification of the grating parameter dependency from x-y-coordinates:

1. Programmable Function: The user has to implement a snippet which returns an array of parameters in

dependency of the position. If only one parameter is to be varied the length of the array is 1, otherwise it is 2. The configuration of the snippet can be done by the standard input methods provided by VirtualLab Fusion (↪Sec. 7.3).

2. Sampled Data: A table is displayed where the coordinates of the data points and the corresponding values are listed. This table can be edited by several tools, which can be accessed by clicking on the corresponding buttons on the right side of the table:

ITEM	DESCRIPTION
Edit Data Point	By clicking this button a dialog will be displayed which contains the parameters of the currently selected row. The user can modify the coordinate of the data points as well as the value(s) at the coordinate.
Add Data Point	To add a new data point, click this button. A dialog will be displayed where you can enter the coordinate as well as the value(s) at the coordinate. After pressing *OK* the data point will be added to the list and the table will be updated.
Remove Data Point	By clicking on the *Remove Data Point* button the currently selected data point will be deleted from the list of coordinates. Afterward the table will be updated.
Load from Data Array	In addition to the previously mentioned options it is also possible to load data points from a gridless data array. This operation will delete all present data points and add all data points from the selected data array. Note: this operation is essential if you like to transfer for example a programmable grating parameter modulation function into a sampled one, or you like to increase or decrease the resolution of the data points. This tool is especially helpful in combination with the tool described in Sec. (b).

The information of the discrete data points has to be converted into a continuous function by interpolation. For this purpose we offer here the interpolation by

- Spline interpolation
- Nearest neighbor interpolation (in non-equidistant case this is also known as Voronoi interpolation)

The interpolation method can be selected by checking the corresponding option on the bottom of the dialog.

(a) Show Grating Parameter Variation Function

On the bottom of the dialog shown in Fig. 348 the user can click on *View* to visualize the grating parameter modulation function. A dialog is shown, in which the user can select the (varied) grating parameter to be displayed. Below the drop-down list for selection of the parameter to show, a graph is displayed which visualizes the grating parameter variation within the region. The *Minimum* and *Maximum* value configured for the selected grating parameter are used here also for visualization.
Fig. 349 shows the output of the grating parameter modulation function visualization tool (in this example the parameter modulation function was defined by a snippet which represents a linear modulation in dependency of the positions).

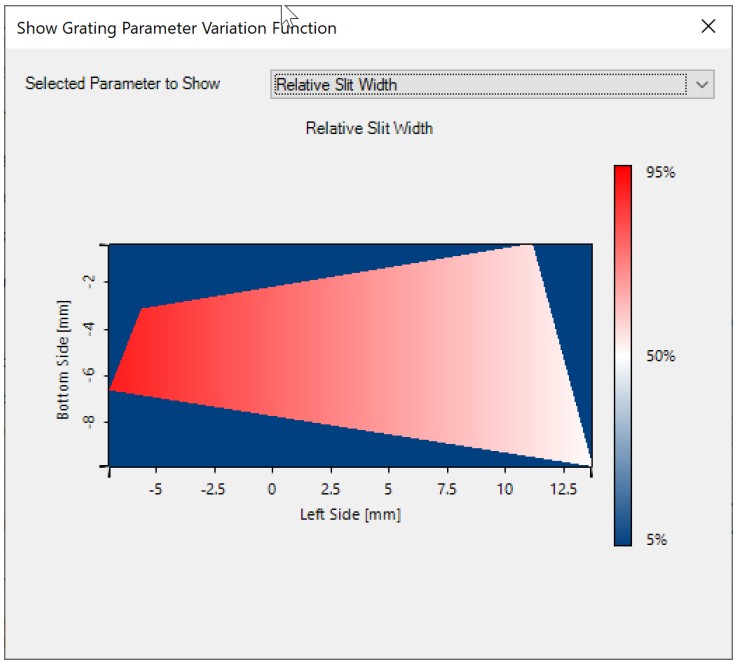


Figure 349. *Visualization of the grating parameter modulation for a linear parameter dependency.*

(b) Show Grating Parameter Modulation Values As Data Array

Additionally to the visualization tool, the user can also extract the parameters for the grating parameter modulation function as data array. By clicking on the corresponding button at the bottom a dialog is shown which offers several options for the extraction.
Fig. 350 shows the edit dialog which can be used to define the parameters for the sample selection for the extraction into a data array.

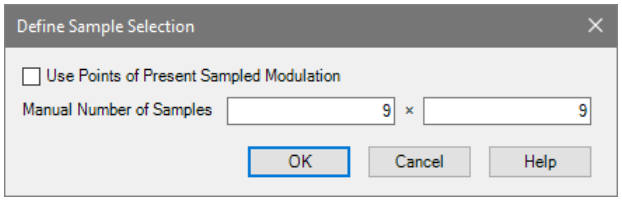


Figure 350. *The dialog to define the sample selection.*

The following parameters can be configured for extraction:

ITEM	DESCRIPTION
Use Samples of Present Sampled Modulation	If this option is checked the original data points are used for extraction. This option is only available if the modulation is defined by sampled data. It is recommended to use this option to transfer the parameters from one modulation function to another one.
Add Data Point	If *Use Samples of Present Sampled Modulation* is false, the user can define the number of sampling points manually. Then VirtualLab Fusion will use the extension of the underlying region and perform an equidistant evaluation of the grating parameter modulation function according to the number of data points defined in the dialog.

Note on workflows: The extraction tool can be used to convert a *Programmable Function* into a sampled grating

parameter modulation function. In addition it can be also applied to change the resolution of the sampled grating parameter modulation function.

43.1.3.2 Edit Lookup Tables

In addition to the configuration of the grating parameter modulation function also the specification of the lookup tables to use is necessary to enable the simulation of a region with modulated grating parameters. This is done within the dialog displayed in Fig. 351.
The definition of the lookup tables for the modulated grating region is typically done automatically by the footprint and grating analysis tool (↪Sec. 102.1). In case you need to adapt the lookup table data manually the tools described below can be used.

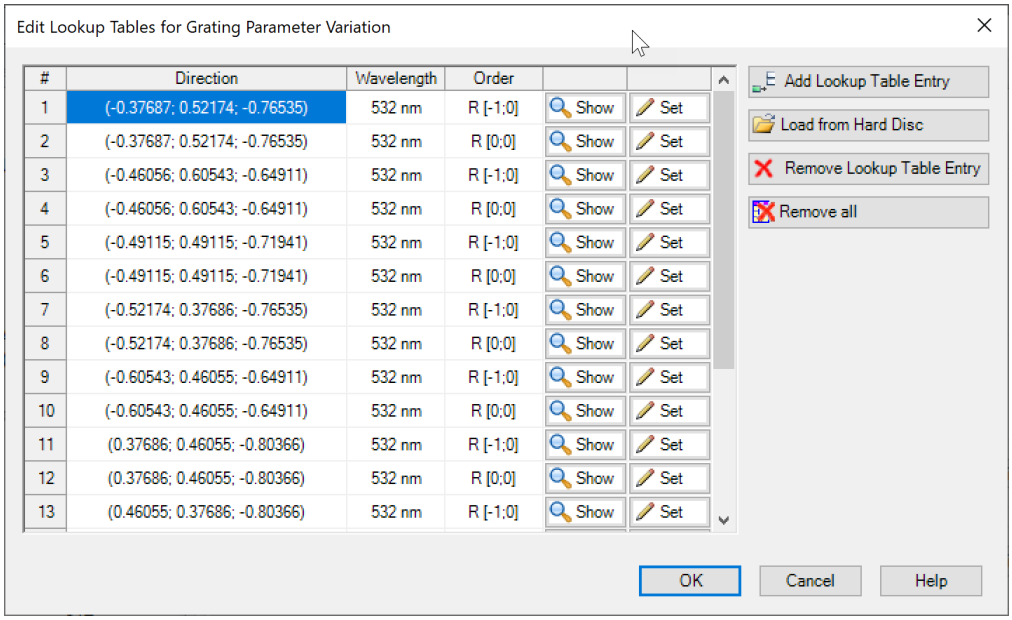


Figure 351. *Edit dialog to configure the lookup tables for the modulated grating region.*

The following information is displayed in the table inside the edit dialog of the lookup tables per entry:

ITEM	DESCRIPTION
Index	The index of the lookup table entry within the configuration.
Direction	The incident direction associated with the lookup table entry. The incident direction is given in the grating coordinate system (including the rotation of the grating along z-direction relative to the grating region).
Wavelength	The wavelength for which the lookup table is defined.
Order	The order information for which the lookup table entry is defined. In combination with the sign of the incident direction we have a full 4-channel definition (including transmission and reflection from front and behind). The order number in general is two-dimensional. In case of 1D-periodic gratings the second value of the order index will be always zero.
Show	The lookup table entry is stored as a data array (1D data array for variation of one grating parameter and 2D data array for two parameters). By clicking on the *Show* button the lookup table is displayed as data array in VirtualLab Fusion.
Set	The lookup table entry is stored as data array (1D data array for variation of one grating parameter and 2D data array for two parameters). It has to have four subsets, due to the fact that for each grating parameter a complex 2 $\times$ 2 matrix (Rayleigh matrix) has to be stored. The subsets represent the entries of the Rayleigh matrix (R_{xx}, R_{xy}, R_{yx} and R_{yy}). By clicking the *Set* button, the user can select a data array from the VirtualLab Fusion main window and define it as underlying data for the corresponding lookup table entry. VirtualLab Fusion will check the validity of the data to be set.

Several additional tools are available to modify the lookup table data defined in the dialog. These tools can be accessed by clicking on the corresponding buttons on the right side of the table:

ITEM	DESCRIPTION
Add Lookup Table Entry	By clicking on this button a dialog is shown, where the user can enter all necessary information for one lookup table entry. The options available within the edit dialog are described in Sec. (a).
Load from Hard Disc	Additionally the user has the option to load the lookup table data (all entries) from hard disc. Therefor a folder has to be selected where all lookup tables to load are stored. The file names of the da-files within the folder encode all necessary information. Usually these files will be created by the footprint and grating analysis tool (↪Sec. 102.1.2), where the calculated lookup table data is automatically stored on hard disc.
Remove Lookup Table Entry	By clicking on this button the selected lookup table entry will be removed from the underlying data set.
Remove All	To remove all lookup tables, press the *Remove All* button.

(a) Add Lookup Table Entry

Fig. 352 shows the edit dialog to add a new lookup table entry to the grating region with modulated grating parameters.

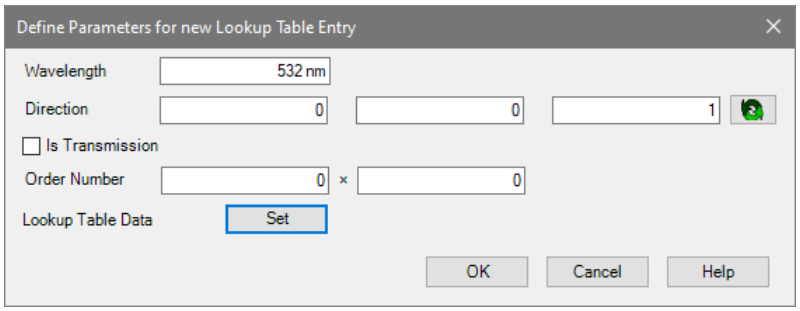


Figure 352. *Edit dialog to add a new lookup table entry.*

The user has to define the following parameters:

ITEM	DESCRIPTION
Wavelength	The wavelength for which the lookup table to add will be used.
Direction	Normalized direction vector in the grating coordinate system. It is possible to enter an arbitrary 3D vector and afterward perform normalization by pressing on the update button ( ).
Is Transmission	Boolean flag whether the lookup table entry is defined in transmission (true) or reflection (false). The illumination from in front or behind is encoded in the sign of s_z.
Order Number	The user needs to define the order number associated with the lookup table entry.
Lookup Table Data	The lookup table entry is stored as data array (1D data array for variation of one grating parameter and 2D data array for two parameters). It has to have four subsets, due to the fact that for each grating parameter a complex 2×2 matrix (Rayleigh matrix) has to be stored. The subsets represent the entries of the Rayleigh matrix (R_{xx}, R_{xy}, R_{yx} and R_{yy}). By pressing on the *Set* button a data array which fulfills these restrictions can be set.

After clicking the *OK* button, the entered data will be checked for validity (to ensure unique entries) and the input will be added to the lookup tables of the grating region.

VII Optical Systems

In VirtualLab Fusion optical systems are defined using the *Optical Setup* document (↪Sec. 44). The parameters of an optical setup can be varied using the *Parameter Run* (↪Sec. 45). *Session Editors* (↪Sec. 48) are a special way how optical setups can be created.

44 Optical Setup

In VirtualLab Fusion optical systems are defined using the *Optical Setup* document. It can contain different *Optical Setup Elements* (light sources, components, detectors, and so on) which are linked to define an execution sequence.

This document is represented by two document windows. The *Optical Setup View* (↪Sec. 44.1) contains a two-dimensional flowchart where the user can add, place and link the Optical Setup Elements. The *Optical Setup Editor* window (↪Sec. 44.2) allows to configure the linkages, start the simulation and change various settings.

Closing one of both documents will close the other window automatically, so the associated Optical Setup is no longer available.

A sample Optical Setup is shown in Fig. 353.

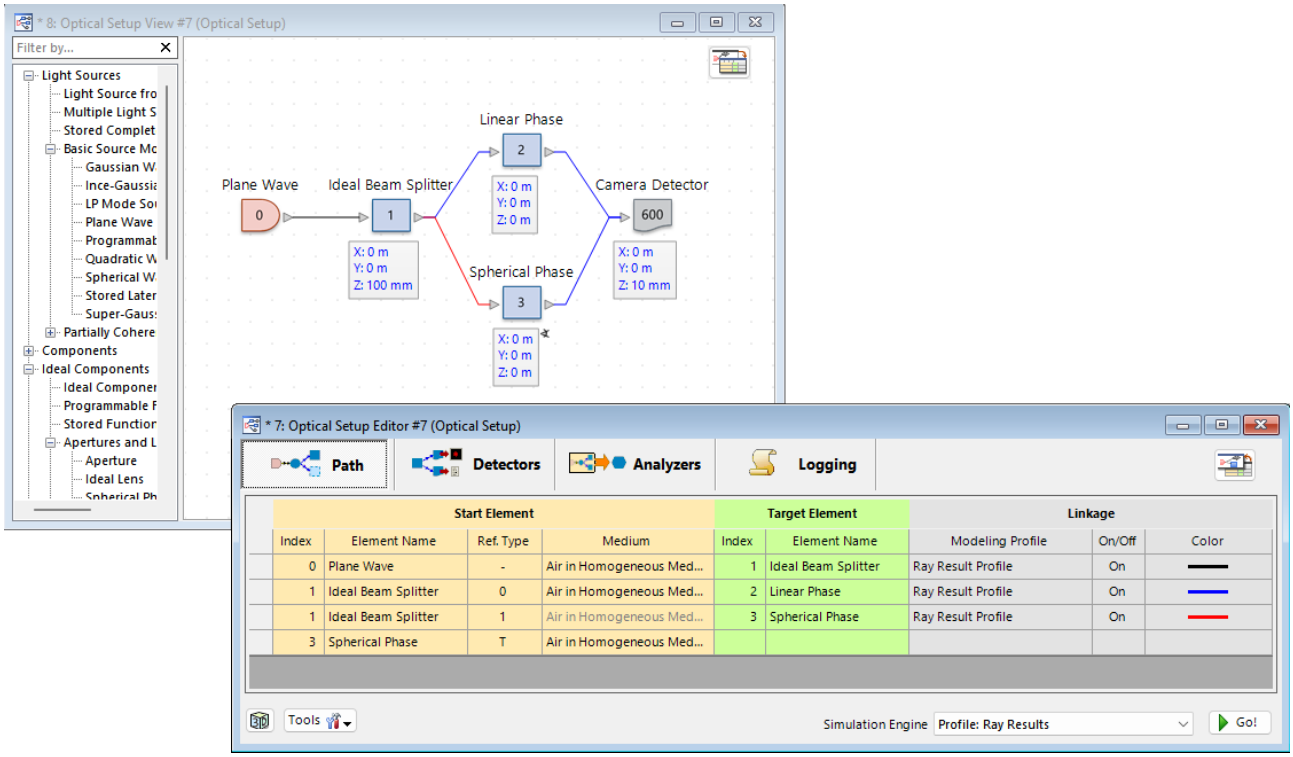


Figure 353. *A sample Optical Setup.*

In the Property Browser you can activate that snapshot files are stored in a temporary folder every time something changes in the Optical Setup. You can go back to a certain snapshot via right click on the corresponding entry in the VirtualLab Explorer (↪Sec. 4.3.1) or via Ctrl+Z.

44.1 Optical Setup View

The Optical Setup View is one of the two document windows in VirtualLab Fusion which is used for configuring an Optical Setup.

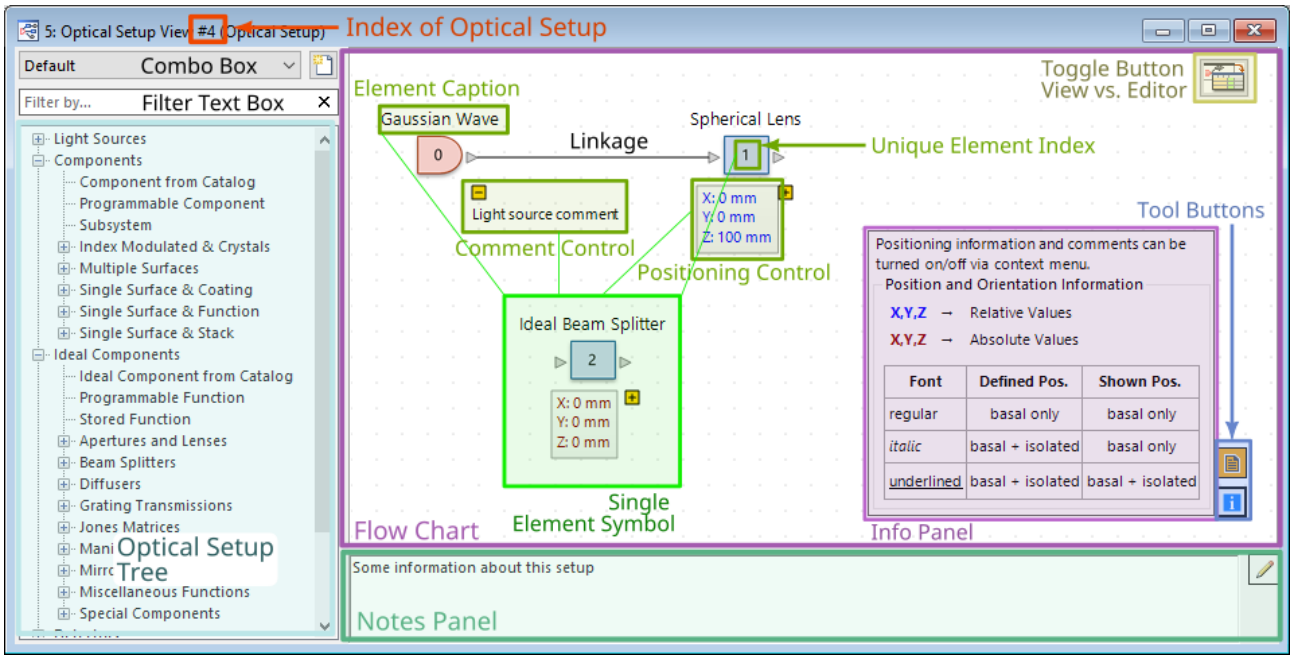


Figure 354. *The Optical Setup View.*

The window (↪Fig. 354) is divided into two areas. On the left side you have the following controls.

ITEM	DESCRIPTION
{Combo Box with Optical Setup Trees}	Combo box containing several predefined and possibly also user-defined *Optical Setup Trees* (see below). With the button a template module opens which allows you to program your own Optical Setup Tree.
{Filter Text Box}	There you can enter a filter string. Only elements containing the given string or being in a category matching the given string are shown. The matching is case insensitive. It is possible to search for multiple words and word groups embraced by quotation marks.
{Optical Setup Tree}	A tree view with the available types of Optical Setup Elements, sorted into categories (light sources, components, detectors, and so on). Depending on the type of the Optical Setup (↪Sec. 44.11) not all categories and Optical Setup Elements may be available.

The right side of the window is used for showing the two-dimensional flowchart which visualizes the current optical setup.

In order to add a new element to the Optical Setup, the user simply drags the Optical Setup Element from the tree view on the left side and drops it onto the flowchart area on the right side. Alternatively, the user can double click an item in the tree view. After doing this, the selected element's symbol will be added to a default position on the flowchart.

While adding an element to the Optical Setup, a unique index is assigned. Therefor the following rules are used:

- The active light source always gets the index 0.
- There is always only one active light source at the same time. If there is more than one light source in an Optical Setup, the non-active sources get indices of 500 and higher.
- All ideal and real components are enumerated with indices between 1 and 499.
- The indices of detectors start at 600 and are increased till 799.
- Indices higher than 799 are reserved for indexing analyzers in the Optical Setup.

After adding an Optical Setup Element, its properties can be edited by double clicking the associated symbol in the Optical Setup View.

Figure 355. *The button in the Optical Setup View to toggle to the Optical Setup Editor.*

The following tools for the Optical Setup View are available in its bottom right corner:

ITEM	DESCRIPTION
	Shows a resizable panel on the bottom of the form where you can enter arbitrary notes, e. g. for documentation purposes. Clicking on this button again hides this panel again. An orange background of this button indicates the presence of notes. The notes panel can have two modes: One (with gray background) shows the text in a formatted, but read-only way. The other mode (with white background) allows you to edit the text and format it using HTML (and CSS) syntax. For example you can use `<b>…<b/>` to make some text bold and `<i>…<i/>` to make it italic. You can toggle between these two modes with the button. In both modes you can change the displayed font size by pressing Ctrl and scrolling with the mouse wheel.
	Toggles the visibility of the info panel (↪Fig. 354).

To toggle between the Optical Setup View window and the Optical Setup Editor window, the button in the upper right corner of the Optical Setup View can be used. (↪Fig. 355)

44.1.1 Customizing the Optical Setup View

For a good visualization elements in the flowchart area can be arranged by using drag and drop.

> **Important:** The positions of the Optical Setup Element symbols in the flowchart have nothing to do with the locations of the elements in the actual optical setup. This position is set via the edit dialog of each element or by clicking the *Positioning Control*. Details about positioning can be found in Sec. 44.9.2.

The Positioning Control is available for all (real) Components, Ideal Components, and Detectors. Light Sources and Analyzers don't have a position to configure. For grating components illuminated by an ideal plane wave, the position cannot be changed.
Furthermore, each Optical Setup Element has a *Comment Control* where you can enter an arbitrary comment to describe the corresponding element. You can extend this control by clicking on the ⊞ button and minimize it again by clicking ⊟. To change the comment simply click on its text. A small *T...* next to the ⊞ indicates that the comment has been changed, i. e. that it is not the default comment.
The caption of each Optical Setup Element can be changed.
Sometimes (e. g. for presentations) it is helpful to hide the Positioning Controls and / or the Comment Controls. This can be done via the context menu of the flowchart. This context menu contains the following items:

ITEM	DESCRIPTION
Show Comments	This toggles the visibility of the Comment Controls.
Paste Optical Setup Elements	Allows to paste Optical Setup Elements from the Windows™ clipboard to the current position of the mouse cursor. You can copy one or more Optical Setup Elements to the Windows™ clipboard by selecting them and then using the context menu entry *Copy Selected Optical Setup Elements*.
Improve Node Locations	The locations of the flowchart nodes, i.e. the symbols of the Optical Setup Element, are reset automatically.
Show Position Controls	The visibility of the positioning controls can be set here.
Show Only z-Positions	If checked, only the z-Positions of the elements are shown. This menu item is a shortcut to the more detailed advanced option described in Sec. 44.9.2.4.
Advanced Position Control Settings	Opens a sub-menu for advanced configuring of the Positioning Controls. It is described in Sec. 44.9.2.4.

You can change the zoom factor (i. e. the size of all symbols and fonts) by pressing and holding Ctrl and scrolling via mouse wheel.

44.1.2 Mouse and Keyboard Interactions

The following list summarizes all actions that can be done with mouse and keyboard:

- Drag an item from the tree view to the flowchart: Adds a new element to the Optical Setup View.
- Drag an item in the flow chart: Moves the element in the flowchart (Does not affect its real position!).
- Click on an Optical Setup Element or linkage: Selects this element or linkage.
- Click on / : Extends / minimizes a comment.
- Click on an element caption: Makes the element caption editable.
- Click on a comment: Makes the comment editable.
- Double click on an Optical Setup Element: Opens the corresponding edit dialog.
- Double click on a linkage: Switches the linkage on or off. An off linkage is not executed during simulation of the Optical Setup and is indicated by a dashed line.
- Double click on a Position Control: Opens a dialog to edit the position of the Optical Setup Element in the optical setup (↪Sec. 44.9.2.4).
- Click and drag: Selects multiple Optical Setup Elements and linkages.
- Ctrl+A: Selects all Optical Setup Elements and linkages.
- Del: Removes the currently selected Optical Setup Element(s) and linkage(s) from the optical setup. If a removed element was connected with other Optical Setup Elements the according linkages are deleted too.
- Ctrl+C: Copies the currently selected Optical Setup Elements to the clipboard, to paste them into the same or another Optical Setup View.
- Ctrl+V: Pastes the Optical Setup Element(s) which are currently in the clipboard to the current mouse position (to the upper left corner if the mouse is outside the flowchart).
- Ctrl+D: Opens a dialog to select a result window with a rectangular marker (↪Sec. 11.3). For each selected detector the size of this marker is then set as *Window Size* and its (central) position is set as *Center Position*. ↪Sec. 75.1.1
- Scrolling with the mouse wheel: Moves the currently visible region of the Optical Setup View up and down.
- Shift and scrolling with the mouse wheel: Moves the currently visible region of the Optical Setup View left and right.

- Ctrl and scrolling with the mouse wheel: Changes the zoom factor (i. e. the size of all symbols and fonts).
- Click with the right mouse button on an Optical Setup Element: Opens a context menu.
  - The current element can be copied to the clipboard to be pasted to another Optical Setup.
  - Inactive light sources can be made the active one. ↪Sec. 44.8.1.2
  - Suitable components can be turned by 180° about the y-axis. ↪Sec. 44.8.2.3
  - Detectors have one entry to copy window size and position (↪Sec. 75.1.1) from a result window with a rectangle marker and one entry to copy certain settings from another detector (↪Sec. 75.2).
  - Some real and ideal components have additional entries for converting this component to another type (↪Sec. 56).
- Click with the right mouse button on an unoccupied region of the flowchart: Opens a context menu to configure the Optical Setup View and to paste elements from the clipboard to the current position.

"Click" or "double click" means always clicking with the left mouse button unless otherwise noted.

> The following elements can be neither deleted nor copied:
> - all elements but analyzers in a Grating Optical Setup
> - the Eigenmode Analyzer

The symbol of each Optical Setup Element which is not a light source or analyzer has one gray *input connector triangle* at its left side representing its input. Vice versa, each symbol of an Optical Setup Element which is not a detector or analyzer has one gray *output connector* at its right side, representing its output. Linkages always go from an output connector to an input connector triangle of another Optical Setup Element. Note that all Optical Setup Elements but detectors can have only one incoming linkage. If you click and drag from one connector triangle to another free connector triangle, you can create a new linkage. A selected linkage has two green diamonds with which you can move the start or end of this linkage to another free connector triangle of the same type (input or output triangle, respectively). Fig. 356 shows an example.

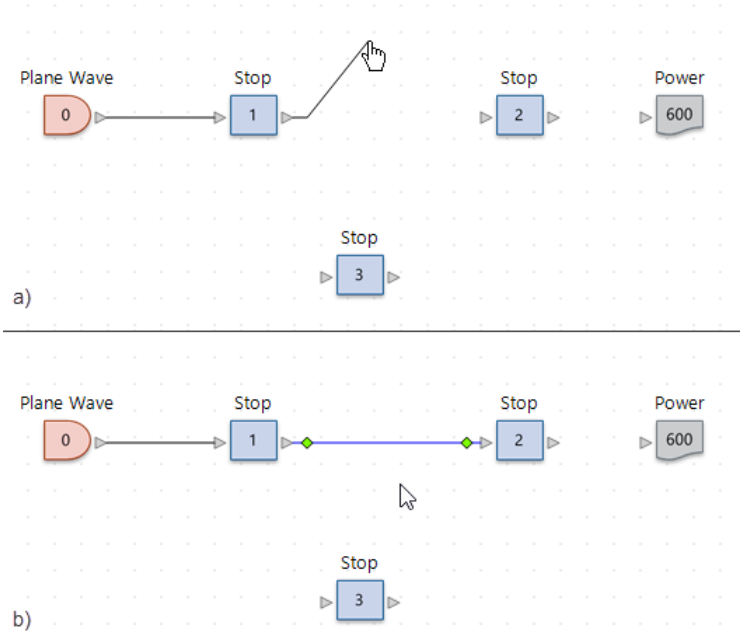


Figure 356. *Figure a) shows how to create a new linkage by clicking on the (output) connector triangle of Stop #1 followed by dragging the line to the left (input) connector triangle of the Stop #2 symbol.*
Figure b) shows an activated linkage, indicated by two green diamonds. Clicking on one of these and dragging the lose end of the line to another connector triangle allows to change the linkage.

44.2 Optical Setup Editor

The Optical Setup Editor is the window for configuring the linkages and other simulation settings. The most essential parts of this window are the different tables for displaying the linkages between Optical Setup Elements. The main navigation in the Optical Setup Editor is done by the four buttons at the top of the window. By clicking the button *Path*, a table with all linkages is shown (↪Sec. 44.2.1) which define the execution order of the elements. All linkages which end at a detector can be listed by clicking the *Detectors* button (↪Sec. 44.2.2). The button *Analyzers* displays a list of all analyzers in the Optical Setup (↪Sec. 44.2.3). There is an additional *Logging* button (↪Sec. 44.2.4), showing the single steps done during a simulation.

44.2.1 Path Table

The *Path* table in the Optical Setup Editor can be used for configuring the connections between Optical Setup Elements except for connections to detectors. (This handling is done by the *Detectors* table ↪Sec. 44.2.2.) Every row in the *Path* table represents one connection in the Optical Setup. Fig. 357 shows a typical example of the *Path* table.

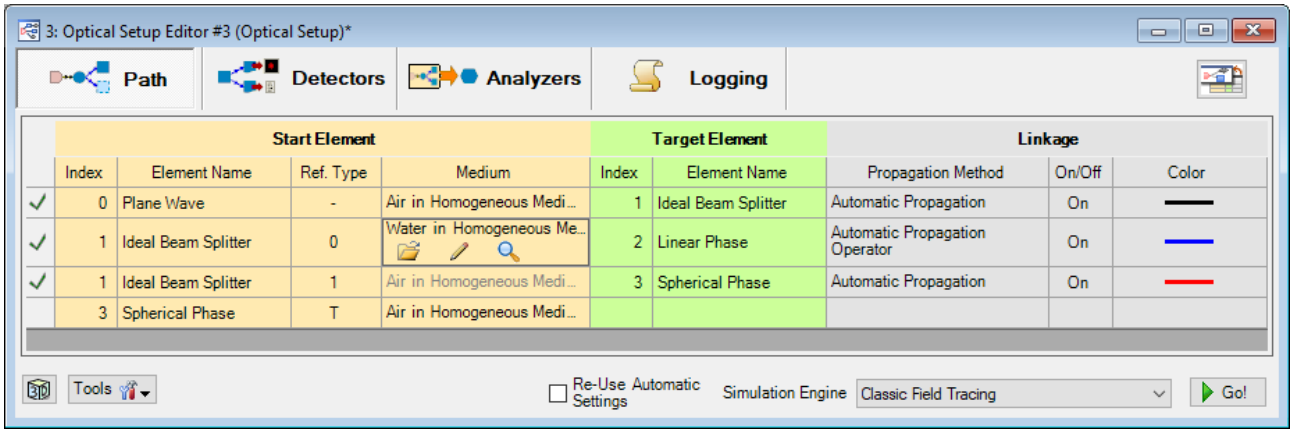


Figure 357. *The linkages between Optical Setup Elements are displayed in the* Path *table of the Optical Setup Editor.*

The *Path* table is organized in three regions, differentiated by three different background colors. On the left side, all necessary information of the start element of a linkage is available. The middle part of the table enables the user to configure the end element of the linkages, while on the right side several linkage settings can be done.

The following columns are available:

REGION	COLUMN	DESCRIPTION
Start Element	Index	The index of the start element of the linkage.
	Element Name	The name of the start element of the linkage. By double clicking on this cell, the settings of the selected Optical Setup Element can be edited.
	Ref. Type	The type of the reference output coordinate system where the linkage starts. Typically (but not in every case), the transmission type *T* and the reflection type *R* are available. Sources have the reference output CS type *"-"* only. Several Ideal Components have specific reference output coordinate systems. (↪Part X.)
	Medium PE	The embedding medium behind the Optical Setup Element. It can be changed via double clicking in the specific cell (↪Sec. 38.3.1).
Target Element	Index	The index of the end element of the linkage.
	Element Name	The name of the end element of the linkage. By double clicking on this cell the settings of the selected Optical Setup Element can be edited.
Linkage	Propagation Method	The propagation method used for propagating through the free space between the start and the target element. If Classic Field Tracing is used and the propagation method is not *None*, you can open the edit dialog of the used propagation operator (↪Sec. 94) by double clicking on a cell in this column.
	On/Off	By toggling the entry in the On/Off column, the linkage is turned on/off. If the linkage state is switched to *off*, it is not simulated when simulating the Optical Setup.
	Color	The color of the arrow in the Optical Setup View. It can be changed by double clicking on the *Color* cell.

Important: Every Optical Setup Element has only one referring input coordinate system. So, a specific element can be set as end element of one single linkage only. Detectors are excluded from that rule, their position are handled as "virtual", so detectors can be end elements of more than one linkage (see Sec. 44.2.2 for details).

In order to create a linkage, the start element has to be selected at first. This can be done by clicking in the column *Index* in the region *Start Element*. VirtualLab Fusion shows a list of all Optical Setup Elements which are available as start elements. After the user's selection VirtualLab Fusion inserts all other available information in the *Start Element* region automatically. To define the end element, the index of the end element has to be chosen by clicking in the column *Index* in the region *Target Element*. If Start and Target Element are configured, the link is created and drawn in the Optical Setup View.
Linkages can be deleted by selecting the corresponding row in the *Path* Table and pressing Del on the keyboard.

44.2.2 Detector Table

The *Detectors* table in the Optical Setup Editor is used for configuring the linkages from Optical Setup Elements to detectors. Fig. 358 shows the *Detectors* table of a sample Optical Setup.

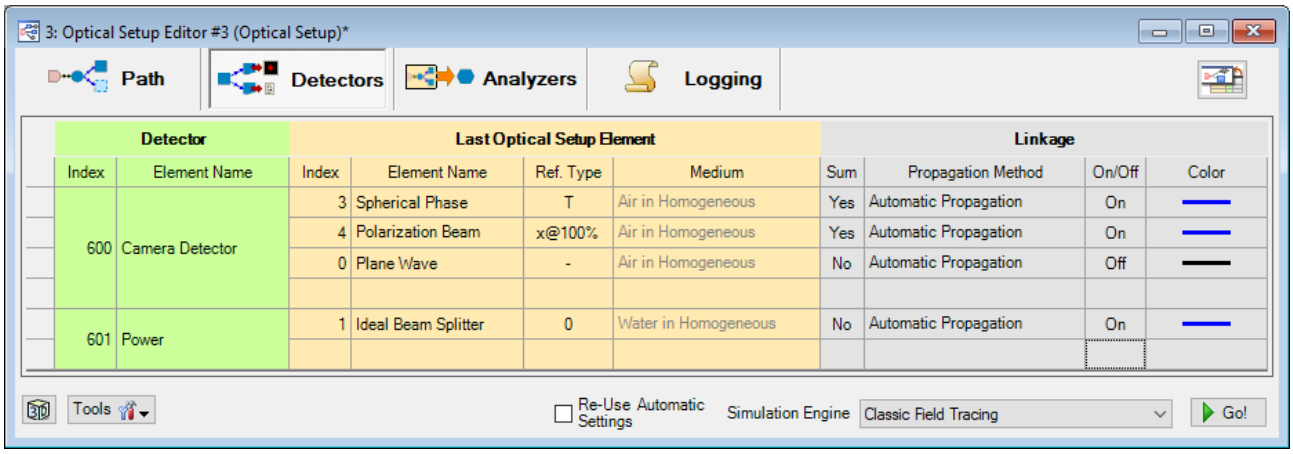


Figure 358. *The linkages between Optical Setup Elements and detectors are configured and listed in the* Detectors *table of the Optical Setup Editor.*

In VirtualLab Fusion, Detectors are regarded as kind of “virtual”. That means that the assignment of a detector does not cause any loss of energy in the further Optical Setup simulation. Detectors can also be set as end elements of more than one linkage. Thus they don’t have a defined absolute position (↪Sec. 44.9).

Because Detectors can be configured as end elements of multiple linkages, the configuration of detector linkages is done in the *Detectors* table, containing the following columns:

REGION	COLUMN	DESCRIPTION
Detector	Index	The index of the detector of the linkage.
	Element Name	The name of the detector to be linked. By double clicking a cell in this column, the settings of the selected detector can be edited.
Last Optical Setup Element	Index	The index of the start element of the linkage.
	Element Name	The name of the start element of the linkage. By double clicking a cell in this column, the settings of the selected Optical Setup Element can be edited.
	Ref. Type	The name of the reference output coordinate system where the linkage starts. Typically (but not in every case), the transmission type *T* and the reflection type *R* are available. Sources have the reference output CS type *“-”* only. Several Ideal Components have specific reference output coordinate systems. (↪Part X.)
	Medium	The embedding medium which is behind the Optical Setup Element. The medium cannot be changed in the *Detectors* table. This has to be done in the *Path* table or the element’s edit dialog.
Linkage	Sum	Shall this linkage be simulated in summation mode? This mode is a special feature of detectors. By enabling the summation mode, the detector collects the input signals of all linkages where the summation is activated. Then the detector function is applied to the coherent addition of all incoming fields.

	Propagation Method	The propagation method to use for simulating the linkage. If Classic Field Tracing is used and the propagation method is not *None*, you can open the edit dialog of the used propagation operator (↪Sec. 94) by double clicking on a cell in this column.
	On/Off	By toggling the entry in the On/Off column, the linkage is turned on/off. If the linkage state is switched to *off*, it is not simulated when running the Optical Setup.
	Color	The color of the arrow in the Optical Setup View. It can be changed by double clicking on the Color cell.

Important: If a detector is added to the Optical Setup via the Optical Setup View, a new row, filled with default values, is automatically inserted in the Detector Table. The user simply has to select the element which shall be the start element for the linkage to the detector. If a linkage is established, a new row is added to the detector section and can be configured for additional linkages to this detector.

Detector linkages can be deleted by selecting the corresponding row in the *Detectors* Table and press `Del` key on the keyboard. If all linkages to a detector are erased, an empty row will be displayed in the table. It can be used to set new linkages to the detector.

44.2.3 Analyzer Table

The *Analyzers* table contains a list of all analyzers in the current Optical Setup. Analyzers cannot be connected with other Optical Setup Elements. They are used for analyzing parts of the system or the whole system. More information about analyzers can be found in Part XII.
Fig. 359 shows the *Analyzers* table of a sample Optical Setup.

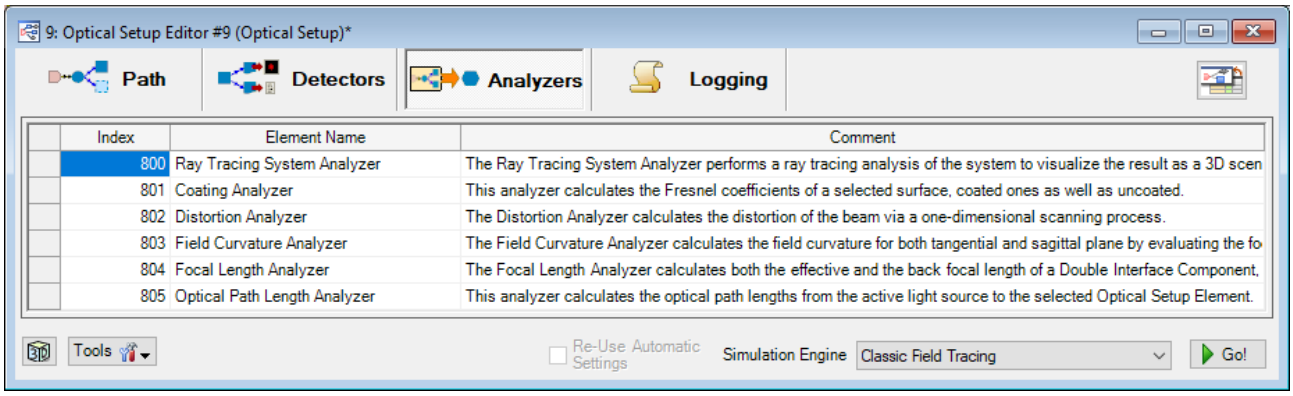


Figure 359. *All analyzers included in the Optical Setup are listed in the* Analyzers *table.*

The *Analyzers* table provides the following information:

COLUMN	DESCRIPTION
Index	The index of the analyzer. Unlike the other tables in the Optical Setup Editor, the user cannot choose which analyzers shall be shown in the *Analyzers* table; it always contains all analyzers in the Optical Setup.
Element Name	The name of the analyzer. By double clicking on this cell, the selected analyzer can be edited.
Comment	A short description of the function of the Analyzer. For detailed information about available analyzers in VirtualLab Fusion please see Part XII.

The *Analyzers* table is mainly for information about but not for editing of the Optical Setup. The user has only the possibility to edit the properties of the analyzer by double clicking in the *Type* column.

44.2.4 Process Logging

There is an additional *Logging* button in the top row of the Optical Setup Editor. It shows the single steps done during simulating the optical setup and thus helps you to identify problems within your setup. Fig. 360 shows an example.

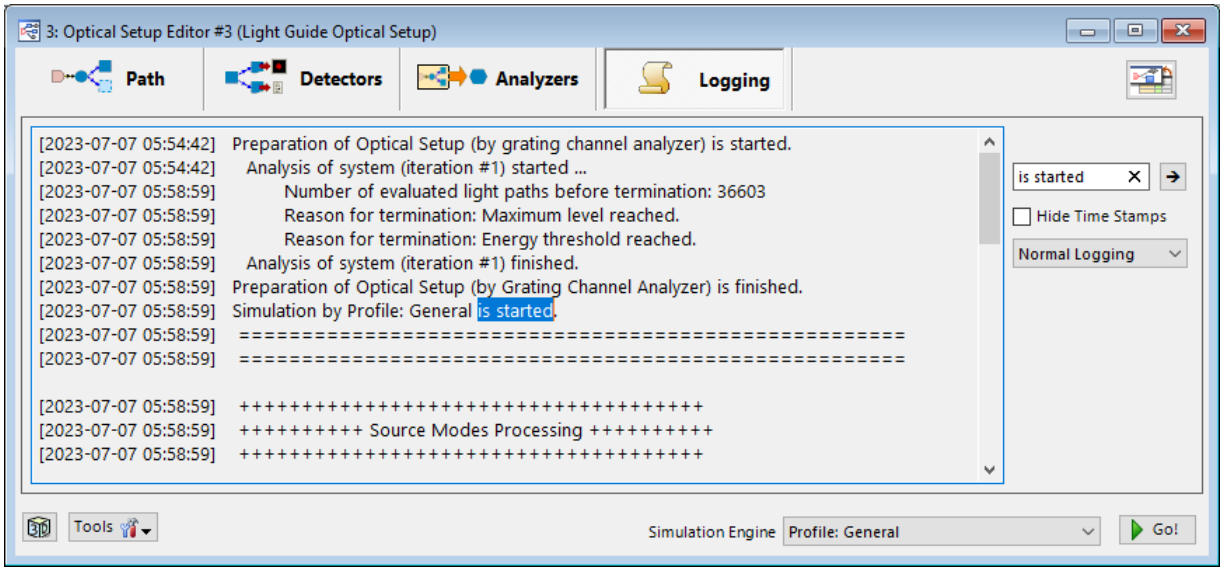


Figure 360. *Sample output of the process logging.*

The actual logging panel has a context menu where you can

- *Copy* the currently selected text to the Windows™ Clipboard,
- *Select All* logging information,
- delete all logging information using the *Clear Logging* item or
- *Set Tab Width* in pixels according to your liking .

If you start a new simulation, the logging information is deleted so that the *Logging* only shows information about the most recent simulation run.

The detail level of the logging can be set in the *Other Settings > System* tab of the Profile Editor dialog (↪Sec. 44.4.5.1), in the Property Browser of the Optical Setup or in the side panel (see table below). The default level for new Optical Setups can be set in the Global Options (↪Sec. 6.1.4).

There is also a side panel with the following additional settings. Unless otherwise noted, the options are only available if there is no simulation in progress.

ITEM	DESCRIPTION
Suspend Logging	ONLY IF A SIMULATION IS RUNNING. If you check this option, logging is suspended which means that no new messages are added until you uncheck this option again. This allows you to read and search the current messages undisturbedly.
Search	ONLY IF THERE IS NO SIMULATION IN PROGRESS OR IF LOGGING IS SUSPENDED. Searches for the given word or word group. The matching is case insensitive. Clicking on → marks the (next) occurrence of the entered word group.
Hide Time Stamps	Each message in the logging starts with the exact time when this message was created. While this allows performance analysis, it can make reading and comparing different loggings more complicated. Thus you can hide these time stamps with this option.
{Logging Level}	Defines how much details you want to see during logging – or whether you want to completely disable logging.

44.3 Optical Setup Ribbon

The Profile Editing & Run group can be used to perform and configure the simulation of the active optical setup. For the configuration of the simulation settings VirtualLab Fusion provides a variety of tools which are also available in the Profile Editing & Run ribbon group.
The ribbon has the following main categories:

- *Execution*: In this section you can select the modeling profile you like to process. VirtualLab Fusion has two build-in modeling profiles: *Ray Results Profile* and the *General Profile*. VirtualLab Fusion performs in all modeling profiles physical optics simulation. The *Ray Results Profile* allow the access to results the user knows from typical ray tracing software. There are several limitations of the *Ray Results Profile*, which are explained in more detail in Sec. 44.5.2. In addition to the selection, which modeling profile shall be used, the user can start a simulation by clicking on the *Go!* button. If a simulation is running the *Go!* button will become a *Stop* button, which enables the cancellation of a running simulation.

- *Settings*: In the *Settings* section VirtualLab Fusion provides a set of tools to configure the underlying optical setup. The center of the modeling configuration is the *Profile Editor*. It enable the configuration of modeling and geometry parameters in a systematic and structured way. Detailed information on the *Profile Editor* can be found in Sec. 44.4. Next to the profile editor VirtualLab Fusion also offers the *Parameter Overview*, which enable the access of all numerical parameters of the underlying system in table format (↪Sec. 44.6.1). The last entry in the category *Settings* is the tool for parameter coupling. This tool enables the user of VirtualLab Fusion to define parameter dependencies. A detailed explanation of *Parameter Coupling* can be found it Sec. 44.7. By clicking on *Use Parameter Coupling* the parameter coupling is activated. The parameter coupling can be edited by clicking on the gear symbol next to the *User Parameter Coupling* button.

- *Result Visualization*: In this section the user needs to select the result visualization type. Depending on the profile different type are available. If the user select the *Ray Results Profile* he can select whether to use *System: 3D* or *Detectors* as result output. In case the user selects the *General Profile* can define to use *Detectors* or the *Modeling Analyzer* as the result visualization output. The result visualization can be configured alternatively in the *Profile Editor*. Details on the *Result Visualization* can be found in Sec. 44.4.4.1.

- *Light Path Finder*: VirtualLab Fusion provides several options to determine which paths the light will go through the configured optical setup. These path are determined by the *Light Path Finder*. A more detailed discussion of the options of the *Light Path Finder* can be found in Sec. 44.3.1.
- *Profile Editing Tools*: In this section the user can find a variety of tools for a user-friendly configuration of modeling parameters. The tools are described in more detail in Sec. 44.3.2.
- *Parameter Variation*: In the section *Parameter Variation* the user triggers the generation of *New Parameter Run* documents, *New Parametric Optimization* documents or select to perform a system optimization using *optiSlang*. The starting point for all these parameter variation documents is always the active system. You can find detailed information for the *New Parameter Run* in Sec. 45. For the *Parametric Optimization* please check Sec. 103. The optimization using *optiSlang* is described in detail within Sec. 130.1.1.
- *View*: By clicking on the button *View System* in the section *View* the user can trigger VirtualLab Fusion to generate a 3D view of the underlying optical setup within a dialog. This can be used for visualization and as a check of the system geometry configuration.

Fig. 361 shows the Profile Editing & Run, which is visible if the active document is an optical setup.

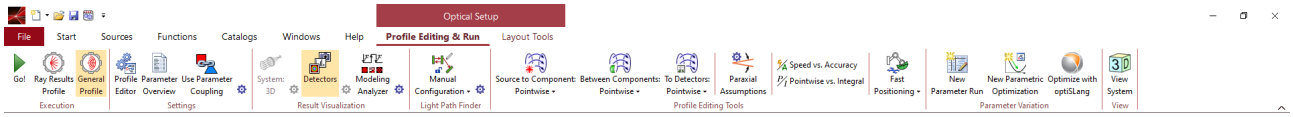


Figure 361. *The Profile Editing & Go! which enable the user to perform the simulation, select the modeling profile and it parameters and enable a set of tools for a user-friendly configuration of system parameters.*

44.3.1 Light Path Finder

One major tool to perform optical simulations is the *Light Path Finder*. It enables the evaluation of the paths that light will go through the optical setup. In general we differ between two general configurations: *Pre-Selected* and *Manual* Channel Configuration. In practice this means that for *Pre-Selected* configuration the surface channels of the components are defined by VirtualLab Fusion directly and the user can not change the detailed channel configuration. In case *Manual* channel configuration is selected, the user has the option to define at each surface in each component, which channels should be active.

The section *Light Path Finder* in the Profile Editing & Go! enable the selection of the channel configuration and the corresponding detail settings.

Fig. 362 shows section *Light Path Finder* in the Profile Editing & Go!.

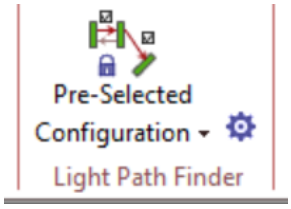


Figure 362. *The ribbon entries to select the channel configuration and to edit the detailed parameters within the section* Light Path Finder.

In the ribbon section the user can directly switch between *Pre-Selected Configuration* and *Manual Configuration*. In addition he can click on the small gear button to open the edit dialog for the detailed specification of the *Light Path Finder*.

Fig. 363 show edit dialog to configure the parameter of the *Light Path Finder*.

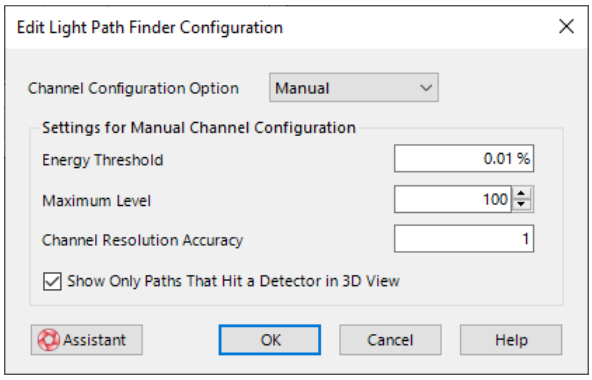


Figure 363. *The edit dialog to configure the parameters of the* Light Path Finder.

The following settings can be done within the edit dialog of the *Light Path Finder*:

ITEM	DESCRIPTION
Channel Configuration Option	The user can select the channel configuration. The user can select between *Manual* and *Pre-Selected* channel configuration. In case of *Manual* channel configuration the user can specify several advanced options for the *Light Path Finder* in the group Settings for *Manual Channel Configuration*.
Settings for Manual Channel Configuration	If the user selects *Manual* channel configuration, several advanced configuration options can be configured. These settings are available in the section *Settings for Manual Channel Configuration*. The detailed explanation of these settings can be found below.

The following advanced configuration options for *Manual* channel configuration are available:

ITEM	DESCRIPTION
Energy Threshold	In *Manual* channel configuration the light path finder evaluated all paths through the optical setup according to the manually configured channel configuration. The *Energy Threshold* is used to define which path shall be aborted. VirtualLab Fusion evaluates the energy which should be traced. If it is below the specified threshold the path will not followed further.
Maximum Level	Additionally to the *Energy Threshold* there is another criteria to stop a light path if a certain level is reached. Each interaction with a surface will increase the current level. If the level is larger the the *Maximum Level* the light path will not be followed further.
Channel Resolution Accuracy	If light hits a surface, which contains surface regions, VirtualLab Fusion will check which regions are hit. Therefore the user can define the *Channel Resolution Accuracy*. In case a surface region is not resolved by the light path finder, you need to increase the *Channel Resolution Accuracy*.
Show Only Paths That Hit a Detector in 3D View	To enable the user more insides of the light path finder result, the option *Show Only Paths That Hit a Detector in 3D View* can be deactivated.

44.3.2 Profile Editing Tools

Within the ribbon section *Profile Editing Tools* VirtualLab Fusion provides several tools which enable a user-friendly configuration of modeling and geometry parameters within the active optical setup.
Fig. 364 show the ribbon section *Profile Editing Tools* within Profile Editing & Go!.

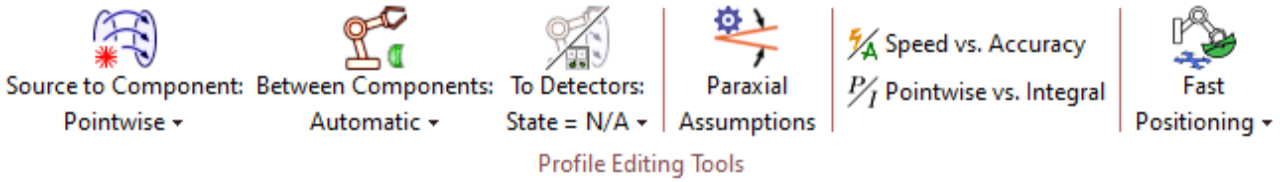


Figure 364. *The ribbon section to access the* Profile Editing Tools *within the* *Profile Editing & Go!*.

The following tools for the configuration and analysis of the parameters of the underlying optical setup are available in this section

ITEM	DESCRIPTION
Source to Component	The tool *Source to Component* has two general functions: (1) Analysis of the current settings for the propagation settings from source to components and (2) Fast access to configure/synchronize the settings for the propagation from source to components. If case the user configured the propagation to be pointwise the caption of the button will be changed to *Source to Component: Pointwise* and the corresponding icon is adapted to visualize the pointwise setting. In case the optical system is configured to select the Fourier transforms automatically for the propagation from the source to the components the caption of the ribbon button will be changed to *Source to Component: Automatic* and the icon is adapted to mark the automatic settings. There might be also settings which are not pointwise and not automatic but some intermediate setting. In Addition it is possible that the settings for different components is different. In these cases the icon will be also adapted and the caption will be *Source to Component: State = N/A*. The ribbon button can be also be used to have a fast configuration to *Pointwise* or *Automatic* by clicking on the corresponding drop down button on the ribbon button. Fig. 365 shows the different possible states of the ribbon button.
Between Components	This tool has the same functionality as *Source to Component*, but does not analyze or configure the propagation from the source to the components, but the propagation between components or inside components. The different button states are the same: (1) *Pointwise*, (2) *Automatic* or *State = N/A*.
To Detectors	This tool has the same functionality as *Source to Component*, but does not analyze or configure the propagation from the source to the components, but the propagation from the source to detector of from components to detectors. The different button states are the same: (1) *Pointwise*, (2) *Automatic* or *State = N/A*.
Paraxial Assumptions	The tool *Paraxial Assumptions* can be used to set and analyze the current settings of the system with respect to paraxial assumptions during propagation and also paraxial assumptions for detector evaluations. A detailed explanation can be found in Sec. 44.3.2.1.
Speed vs. Accuracy	The editing tool *Speed vs. Accuracy* enables the user to analyze and configure propagation parameters which will influence the accuracy and the simulation speed of your configuration. Detailed information can be found in Sec. 44.3.2.2.
Pointwise vs. Integral	In VirtualLab Fusion we differ typically between pointwise or integral modeling steps. These settings can be configured in a user-friendly way on system level by the tool *Pointwise vs. Integral*. The functionality and edit options of this tool are explained in more detail in Sec. 44.3.2.3.
Fast Positioning	In the category *Fast Positioning* VirtualLab Fusion provides two tools: (1) *Optimize Detector Positions* and (2) the *Find Focus Position* tool. The tools can be used to perform an automatized adaption of detector positions by applying several rule. The tool *Optimize Detector Positions* is described in Sec. 44.8.6 in more detail. In Sec. 44.8.5 you can find further information on the tool *Find Focus Position*.

Figure 365. *The different states of the ribbon buttons to analyze the settings for propagation from source to components. The propagation between components and to detector follow the same logic.*

It shall be mentioned at this point, that the settings for free space propagation (and also geometry) can be configured per component/detector. The *Profile Editing Tools* enables an alternative way for a fast configuration and analysis of these parameters.

44.3.2.1 Profile Editing Tool: Paraxial Assumptions

With the profile editing tool *Paraxial Assumptions* the user gets a fast access to the parameters for paraxial assumptions for field component evaluation within all *Universal Detectors* within your optical setup. In addition to the option for synchronizing the settings for all *Universal Detectors*, the edit dialog of the *Paraxial Assumptions* tool provides an analysis of the actual settings of these parameters for all *Universal Detectors* within the optical setup.

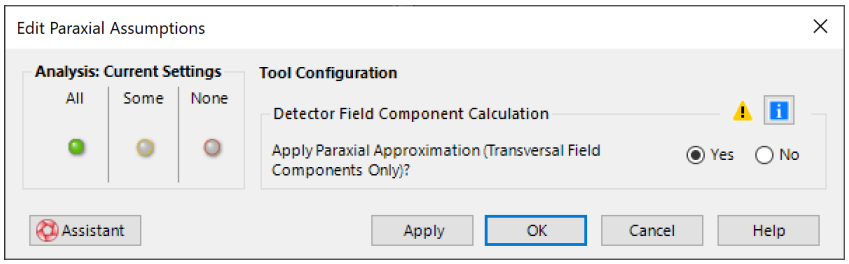


Figure 366. *The edit dialog of the profile editing tool* Paraxial Assumptions*.*

Fig. 366 shows the edit dialog to configure and analyze the settings for *Paraxial Assumptions*. On the right side of the dialog the user can make the definition of the parameters he likes to be configured by the *Paraxial Assumption* profile editing tool. The group box on the left side is used to get an overview of the current parameter configuration within the underlying system (which can be configured inside this tool). The user can see here whether the setting is currently set to all (identified by the green bubble in the *All* column), none (identified by the red bubble in the *None* column) or some elements (the yellow bubble in the *Some* column). *Some* means that for different detectors different settings are currently configured.
The following parameters can be done by the *Paraxial Assumptions* tool:

ITEM	DESCRIPTION
Apply Paraxial Approximation (Transversal Field Components Only)	The *Universal Detector* allows to use paraxial approximations for the calculation of field components at its input. This will easy up the calculation of the field components (*Ez*, *Hx*, *Hy* and *Hz*) because no additional Fourier transforms will be use for their calculation, but simplified formulas. This will speed up your simulation.

After the configuration of the desired parameters the *Paraxial Assumptions* tool can be applied by clicking on the *Apply* button at the bottom of the dialog or by clicking on the *OK* button. By clicking on *Apply* the tool is applied, the dialog will be kept open and the actual settings will be analyzed again and the corresponding status is displayed on the right side of the dialog. By clicking on *OK* the dialog will be closed and the tool will be applied.

44.3.2.2 Profile Editing Tool: Speed vs. Accuracy

The configuration of several parameters which affect the accuracy and speed behavior of the free space propagation the user can make several settings per component/detector. As an alternative he can also use the profile editing tool *Speed vs. Accuracy* to define some selected parameter and trigger their setting for all components and detectors at once.
The *Speed vs. Accuracy* tool has two main sections: (1) on the right side the user can specify the parameters for the tool before it is applied and (2) on the left side we provide the analysis of the actual settings analyzed from the underlying system.

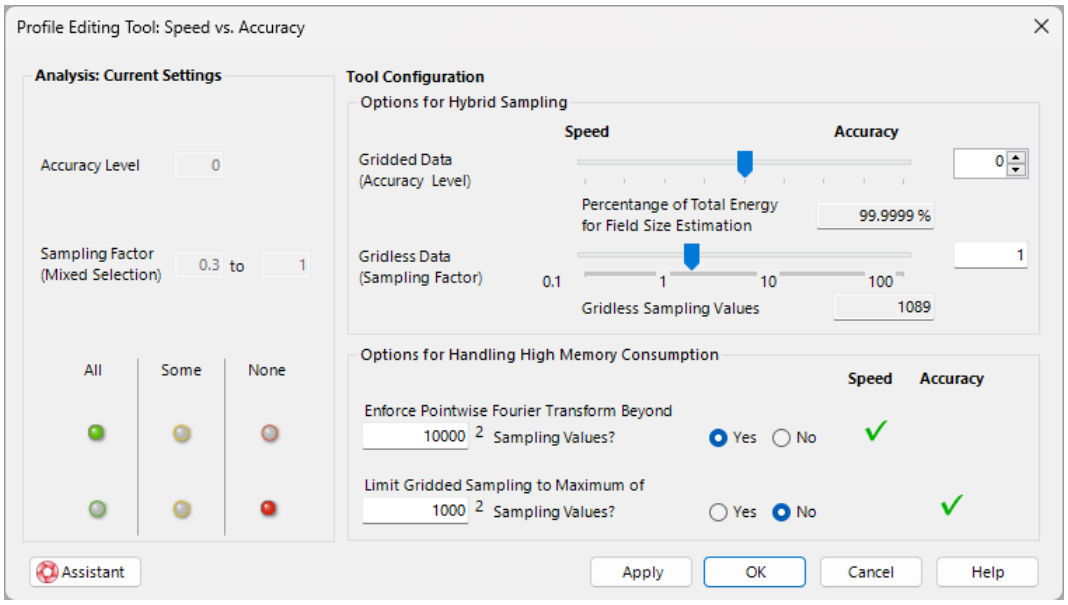


Figure 367. *The edit dialog of the profile editing tool* Speed vs. Accuracy.

The edit dialog of the tool is shown in Fig. 367 and provides the following parameters to configure:

ITEM	DESCRIPTION
Gridded Data (Accuracy Level)	For the conversion of gridless to gridded data format VirtualLab Fusion will apply an automatic sampling algorithm which internally determines the bandwidth of field. For the sampling estimation algorithm the user can configure the *Accuracy Level*. Detailed information can be found in Sec. 44.5.1.2. The analysis tool on the right side will show you the current setting of the accuracy level for all components. If there is a non-unique specification of the accuracy level we will show the information about the range of the accuracy levels configured within your system.
Gridless Data (Sampling Factor)	The number of gridless samples to used within the simulation can be controlled by the *Sampling Factor*. The higher the factor the more points will be used. Detailed information on gridless sampling can be found in Sec. 44.5.1.3. The analysis tool in the right side shows again the range of *Sampling Factor* values for all components and detectors within your system. In case a unique setting is used for all elements the value for it will be displayed.
Enforce Pointwise Fourier Transform Beyond XXXX² Sampling Values	To ensure that the numerical effort is not to high to perform an integral Fourier transform, the user can activate the option *Enforce Pointwise Fourier Transform Beyond XXXX² Sampling Values*. If the numerical effort during the simulation for an integral Fourier transform is higher than the limit and the user activated this option VirtualLab Fusion will automatically use a pointwise Fourier transform instead of the integral one. For further details you can check Sec. 44.5.1.1.
Limit Gridded Sampling to Maximum of XXXX² Sampling Values	For automatic sampling estimation VirtualLab Fusion can be configured to use not more than xxxx² sampling points. This option can be used for the activation and configuration of this option. Additional details can be found in Sec. 44.5.1.2.

After the configuration of the desired parameters the *Speed vs. Accuracy* tool can be applied by clicking on the *Apply* button at the bottom of the dialog or by clicking on the *OK* button. By clicking on *Apply* the tool is applied, the dialog will be kept open and the actual settings will be analyzed again and the corresponding status is displayed on the right side of the dialog. By clicking on *OK* the dialog will be closed and the tool will be applied.

44.3.2.3 Profile Editing Tool: Pointwise vs. Integral

The profile editing tool *Pointwise vs. Integral* can be used to configure the the Fourier transform selection for all components/detectors within your optical setup simultaneous. These settings can be also done individually per component or detector, but in case the user likes to define a synchronized configuration the *Pointwise vs. Integral* can be used in a user-friendly way.
Fig. 368 shows the edit dialog of the *Pointwise vs. Integral* tool.

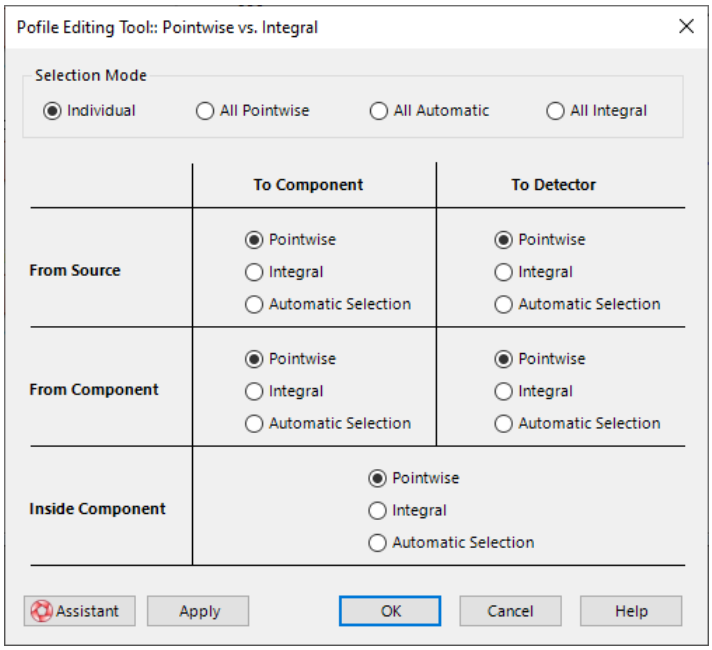


Figure 368. *The edit dialog of the profile editing tool* Pointwise vs. Integral.

On the top of the dialog the user can select the selection mode for the Fourier transforms. The following selection modes are available

ITEM	DESCRIPTION
Individual	In *Individual* mode the settings can be defined directly in the matrix on the central part of the dialog. The user can select between *Pointwise*, *Integral* and *Automatic Selection* for all combinations between source, components and detectors.
All Pointwise	If *All Pointwise* is selected as selection mode, the controls for the configuration of the detailed Fourier transform are deactivated and set to be in all combinations to *Pointwise*.
All Automatic	If *All Automatic* is selected as selection mode, the controls for the configuration of the detailed Fourier transform are deactivated and set to be in all combinations to *Automatic Selection*.
All Integral	If *All Integral* is selected as selection mode, the controls for the configuration of the detailed Fourier transform are deactivated and set to be in all combinations to *Integral*.

In case the user selected *Individual* selection mode the control in the center of the dialog are editable. The configuration of the Fourier transforms can be done for

- From Source To Component
- From Source To Detector
- From Component To Component
- From Component To Detector
- Inside Component

For each of these scenarios the user can select between

ITEM	DESCRIPTION
Pointwise	If the user select *Pointwise* only the pointwise Fourier transform (PFT) will be used for forward and inverse Fourier transform. There will be no selection between different Fourier transforms.
Integral	In case the user defines *Integral*, VirtualLab Fusion will configure for the scenario (source/component/detector) to use for Fourier selection only to use fast Fourier transform (FFT) or semi-analytical Fourier transform (SFT). The pointwise Fourier transform will be not be used as an option for the free space propagation.
Automatic Selection	By selecting *Automatic Selection* the free space propagation will be configured to select freely between PFT, FFT or SFT. The selection is based on an automatic algorithm based on mathematical decision criteria.

After the configuration of the desired parameters the *Pointwise vs. Integral* tool can be applied by clicking on the *Apply* button at the bottom of the dialog or by clicking on the *OK* button. By clicking on *Apply* the tool is applied and the dialog will be kept open. By clicking on *OK* the dialog will be closed and the tool will be applied.

44.4 Profile Editor

The *Profile Editor* can be used to configure the optical setup in an alternative way. In former versions it was only possible to edit most of the configuration parameter (structural parameters as well as modeling parameters) via the edit dialogs of the sources/components/detectors within the optical setup. With the *Profile Editor* the configuration of all important parameter is provided in a more structured way.
The dialog of the *Profile Editor* is separated in four main sections:

- *Source*: The *Sources* section of the dialog contain all parameters regarding the active light source. For a detailed explanation please check Sec. 44.4.2.
- *Components & Solvers*: In the section *Components & Solvers* you may find all parameters for (real and ideal) component that are connected to the active light source within the underlying system. Detailed information can be found in Sec. 44.4.3.
- *Visualization & Detectors*: Under *Visualization & Detectors* you can find the parameters for detectors and also for the visualization type that shall be used for evaluation. A detailed description of the parameters to configured can be found in Sec. 44.4.4.
- *Other Settings*: Finally a collection of all other important parameters can be found under *Other Settings*. These settings are explained in detail in Sec. 44.4.5.

Fig. 369 shows the edit dialog of the *Profile Editor*.

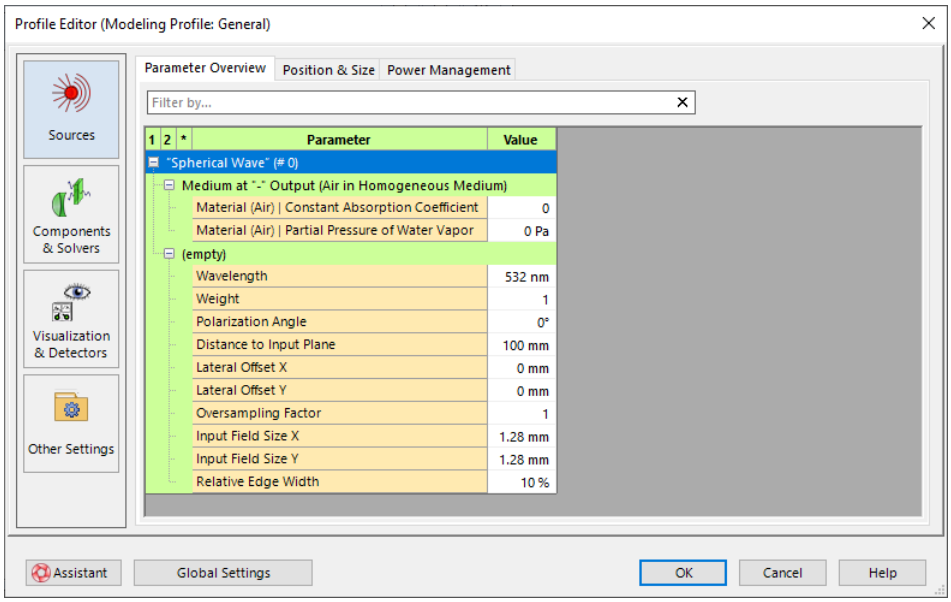


Figure 369. *Dialog of the* Profile Editor*.*

For the configuration of parameters we use some standard techniques. These common techniques are explained in the next sections. Afterward the detailed configuration options for the different section of the *Profile Editor* are explained in detail.

44.4.1 Common Controls

For the specification of parameters and their configuration options we support different standard techniques, which shall be explained next. The following user interface concepts will be discussed in detail

- *Parameter Overview Tables*: Is a table which provides an overview of all numerical parameters of the connected elements within the underlying optical system.
- *Table Layout/Tree View*: VirtualLab Fusion provides a innovative concept to show for selected parameters (e. g. *Fourier Transforms* for *Free Space Propagation*. The configuration is done also via different types of controls. Detailed information can be found in Sec. 44.4.1.2.
- *Master-Client-Individual (MCI) Configuration*: The configuration of parameters could be quite complex. So VirtualLab Fusion supports the selection of a master configuration, which can be use to serve other configuration that are configured as *Client*. A detailed discussion on the *MCI* concept can be found in Sec. 44.4.1.3.

44.4.1.1 Parameter Overview Tables

One universal user interface concept that is used within the *Profile Editor* are the *Parameter Overview Tables*. Fig. 370 shows such a table for the configuration of parameters for *Components and Solvers*.

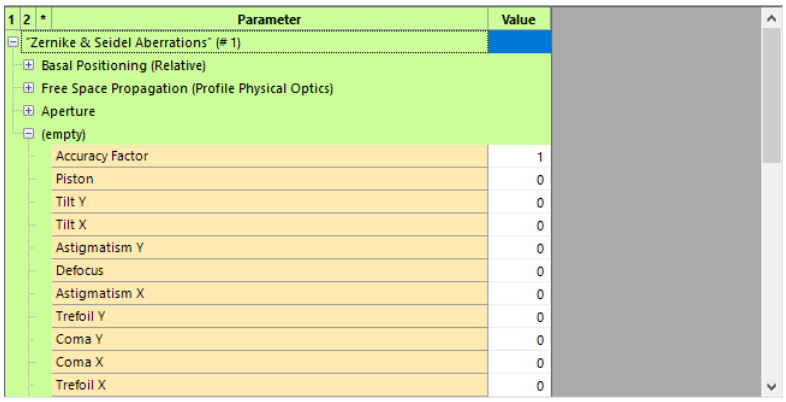


Figure 370. *A typical* Parameter Overview Table *used for the showing all parameters of the components in the underlying optical system.*

These tables display all numerical parameters of the sources/components/detectors and allow its modification directly in the table. The table has the following columns:

ITEM	DESCRIPTION
{Unnamed}	The *Parameter*s are first grouped by the name of the source/component/detector for which the parameters are given. And then by the first category (which can be *{empty}*). The first column allows you to collapse / expand all these groups. Simply click on the ⊟ and ⊞ symbols, respectively. At the top of this column you can select to collapse all groups (*1*), collapse only the category groups (*2*) or expand all groups (*).
Object	In this column you will find the name of the source/component/detector for which the parameters are given. There are typically more than one parameter per element, so the cells are merged together for a better graphical overview. By double clicking in the cell within the *Object* column the edit dialog of the element will be opened and the parameters can also entered in the edit dialog instead of the *Parameter Overview Table*.
Category	Due to the complexity of parameters within a single optical setup, the parameters are categorized. This categorization is done on one hierarchy level only.
Parameter	In the column *Parameter* the name of the parameter is listed. By that you can identify the parameter you like to modify or investigate.
Value	Finally the user can set the value of the numerical parameter within the *Value* column. VirtualLab Fusion will automatically check whether the entered value is valid. If the value is not valid the cell will be marked by red text color.

Due to the fact that such overview lists can be quite long, VirtualLab Fusion offers a user friendly way to apply a filter on the table. By entering a string value into the *Filter by ...* text box a full text search in the table will be applied on the table (full text search on all but not the entries in the *Value* column).

44.4.1.2 Table Layout/Tree View

The *Parameter Overview Tables* enable the systematic display and modification of all numerical parameters within the optical systems. For important parameter sets VirtualLab Fusion provides an alternative approach to configure them using the *Table Layout/Tree View*. Fig. 371 shows a sample for *Table Layout/Tree View*. Here the *Table Layout* configuration is selected, which is the standard when you open the *Profile Editor* the first time.

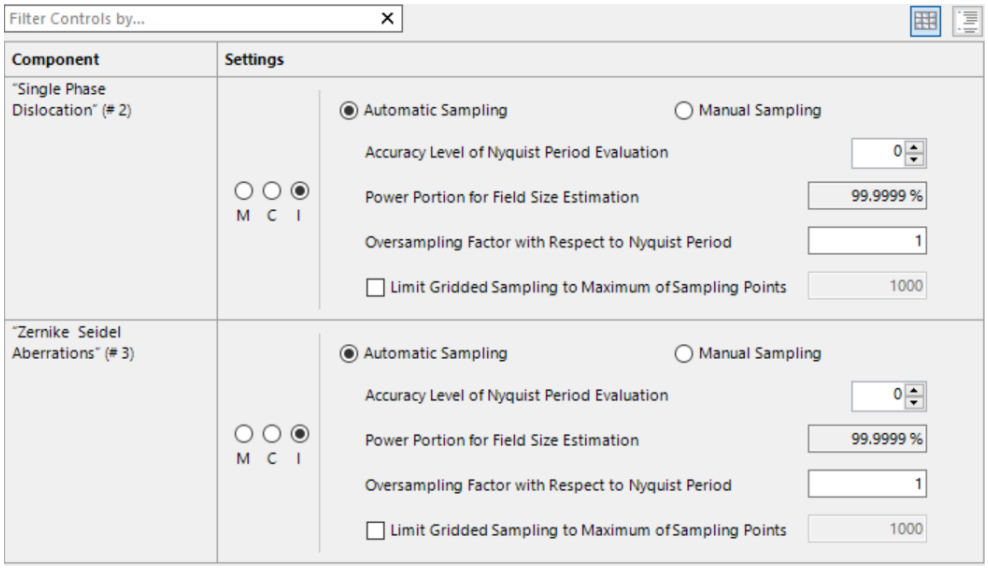


Figure 371. *A sample* Table Layout. *In this example the parameters for* Sampling Gridded Data *within the* Free Space Propagation *parameters for* Component *are displayed*

The *Table Layout/Tree View* contains a list of controls for specific settings. Each source(mode)/component/detector comes with a set of parameters that can be configured within the corresponding control. The list of controls can be visualized in a *Table Layout* or as a *Tree View*.
Within the *Table Layout* VirtualLab Fusion generates a table with the following columns

ITEM	DESCRIPTION
Source/Component/Detector	In the first column you can find the name of the element (source/component or detector) which provides the data set. By double clicking on the cell within the first column the edit dialog of the element is opened and the user can alternatively configure the parameters directly in the edit dialog. After closing the edit dialog with *Ok* the parameters in the *Profile Editor* will be updated.
Settings	In the column *Settings* VirtualLab Fusion will place the control that is used for configuration the corresponding parameter set. This control is quite different for different parameter sets and explained in the later paragraphs when we discuss their concrete usage within the *Profile Editor*.

Alternatively to the *Table Layout* the user can switch to the *Tree View* mode. Fig. 372 shows a sample *Tree View* in which also the buttons are marked to switch between the view modes.

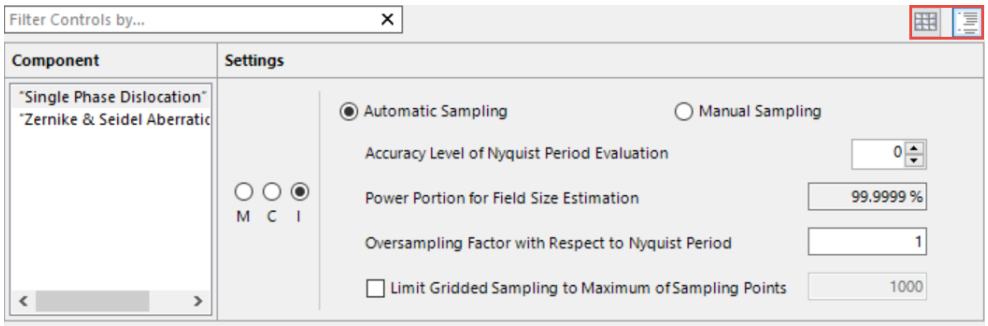


Figure 372. *A sample* Tree View *visualization. In this example the parameters for* Sampling Gridded Data *within the* Free Space Propagation *parameters for* Component *are displayed*

In comparison to the *Table Layout* the controls are not arranged in a table, but the user can navigate through the settings of different elements by selecting the element of interest in the tree view on the left side of the

component. If you double clicks on the entry within the tree on the left side, the edit dialog of the selected element will be opened and the configuration of all parameters of the element can be done this dialog.
To get a better overview for a specific parameter VirtualLab Fusion supports also the filtering of parameters. Therefore the user has to enter the filter string in the text box above the *Table Layout/Tree View*. After entering the the filter string VirtualLab Fusion will check, which parameter matches with the filter. The graphical user interface is adapted completely automatically. By that you can get a good overview of parameters in the system which you like to check in detail.
Fig. 373 shows a the resulting user interface after applying the filter mechanism on a sample *Table Layout* view.

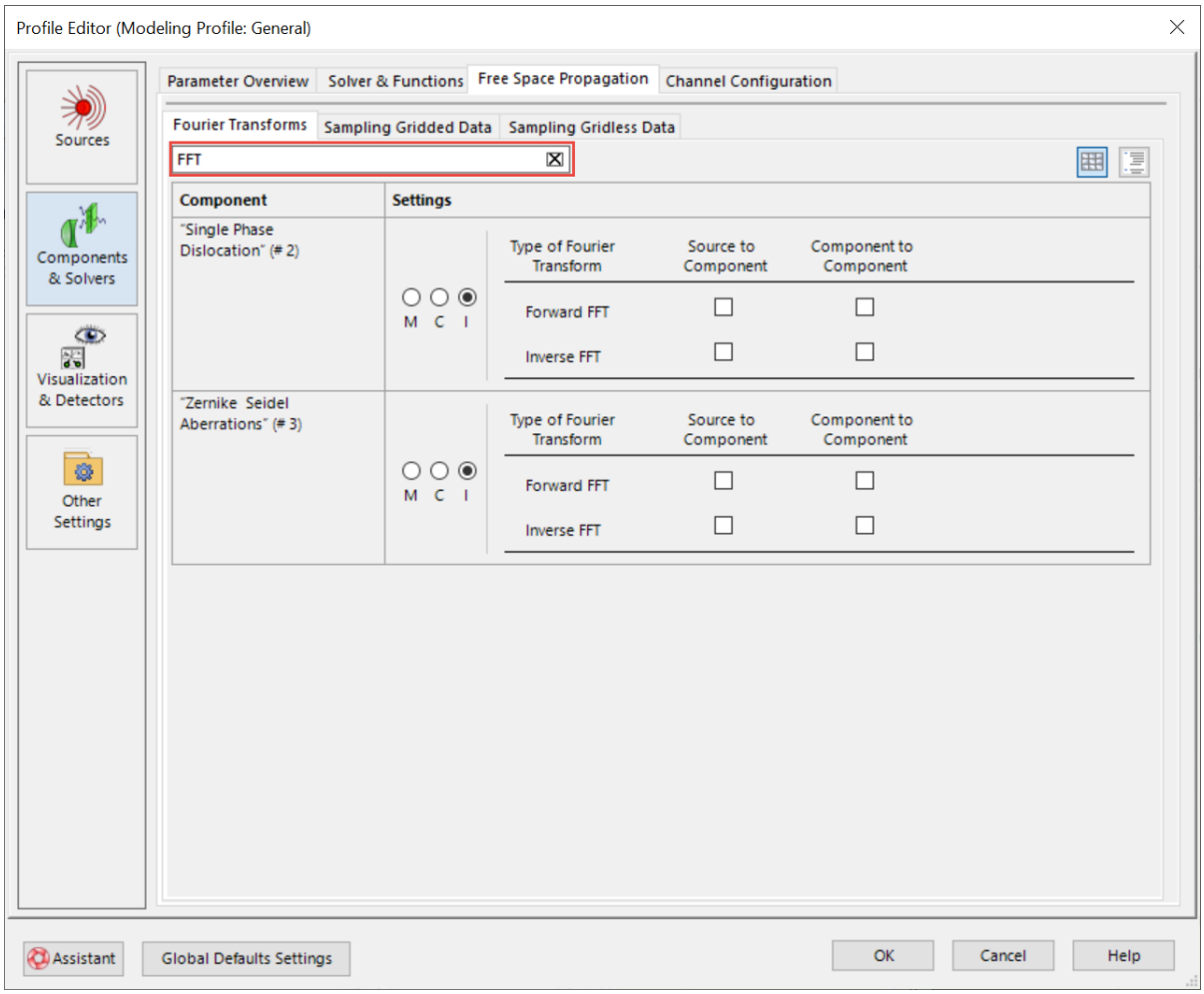


Figure 373. *A sample Table Layout visualization after filtering. In this example the parameters for Fourier Transform selection within the Free Space Propagation parameters for Component are displayed*

44.4.1.3 Master-Client-Individual (MCI) Configuration

VirtualLab Fusion supports the use of a so-called *Master-Client-Individual (MCI)* configuration. This enables the user to select one parameter set (e.g. *Sampling Gridless Data* for *Free Space Propagation* parameters of *Components*) to serve as *Master*. If a parameter set in the same group is defined as *Client* it will automatically take over the parameter configuration of the *Master*. In each parameter set the user can select only one *Master*. Alternatively to the master and client selection the user can also specify that the parameter set should be configured *Individually*. In this case changing the *Master* will have no effect on the parameter set. In case that no *Master* is selected all settings will be handled as *Individual*.
Fig. 374 shows a *Table Layout* view in which the *MCI* configuration is marked by a red rectangle.

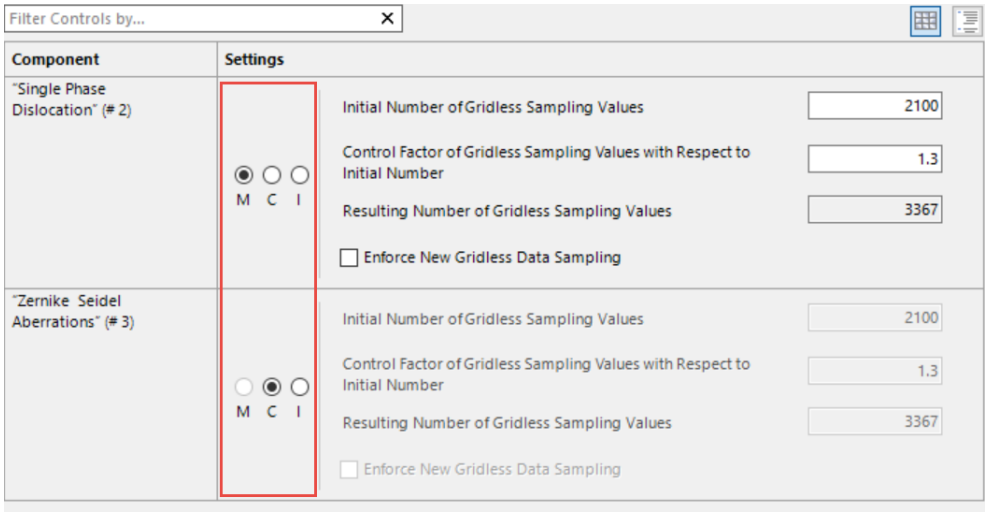


Figure 374. Table Layout *view in which the selection of* Master-Client-Individual (MCI) *is marked.*

44.4.2 Sources Tab

In the *Sources* tab of the *Profile Editor* the user can find all important setting of the active source. On this tab page three sub pages are available:

- *Parameter Overview*: Here the user can access the all numerical parameters of the active source in a *Parameter Overview Table*. The user can filter the parameters he like to see. A detailed explanation of the *Parameter Overview Table* can be found in Sec. 44.4.1.1.
- *Position & Size*: On this page of the *Profile Editor* we offer you a *Table Layout/Tree View* control, which contains parameters for position and size of the active sources. The parameters which can be entered here are explained below. In case a *Multiple Source* is active in the underlying system you will get an entry per source within the *Multiple Source*.
- *Power Management*: Here the user can define the parameters which are used for the power management of the source. The user can activate the *Power Management* and specify the power of the source that shall be used for the configuration. If the *Power Management* is not activated VirtualLab Fusion will normalize the amplitudes of the scattered fields of the active light source. In addition, the user has to specify the type of the spectrum which is used.

Fig. 375 shows the *Position & Size* page for *Sources* within the *Profile Editor*.

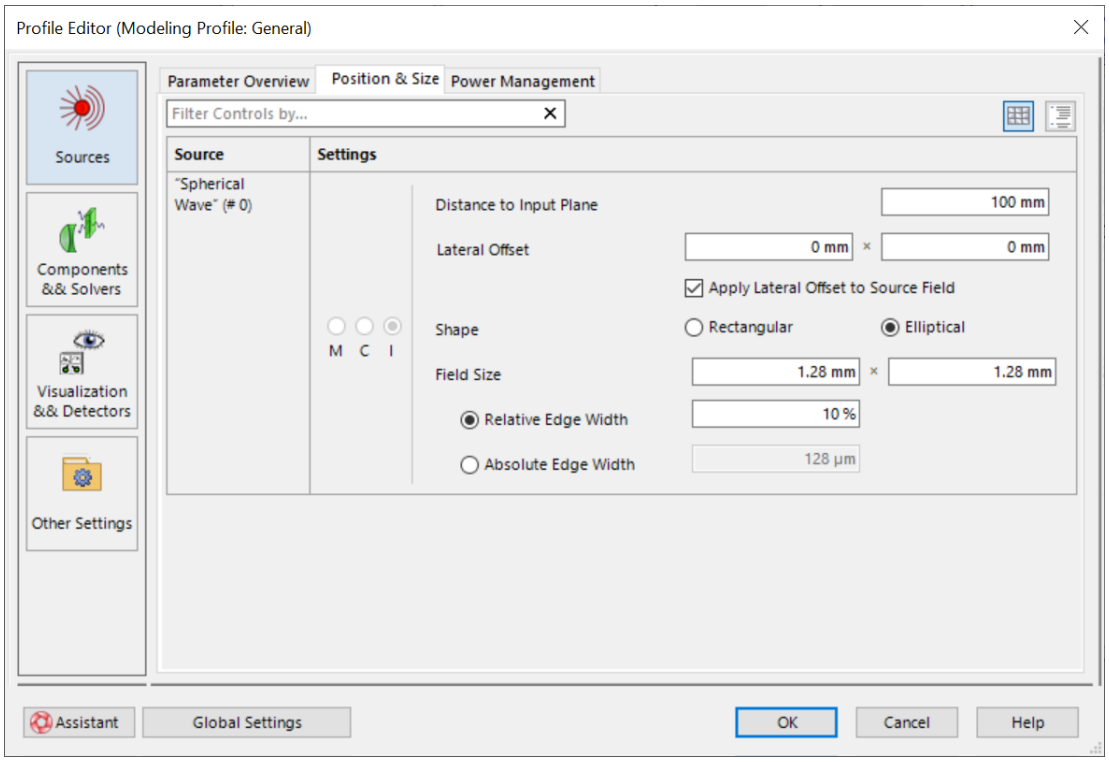


Figure 375. *The Position & Size page for Sources. In this example the active light source is a Spherical Wave, so the Table Layout/Tree View only contains one parameter set.*

The control to configure the *Position & Size* parameters of a light source have the following parameters that can be configured by the user

ITEM	DESCRIPTION
Distance to Input Plane	This value describes the distance between input plane and source plane along the z-axis: distance $= z_{\text{Input Plane}} - z_{\text{Source Plane}}$. For some of the sources this value is fixed to zero. In the case of spherical and quadratic waves this value must not be zero and the spherical phase radius is set to this value.
Lateral Offset	This value describes the offset between the origins of the coordinates for the source and the input plane.
Apply Lateral Offset to Source Field	By default, the resulting input field is centered at the position $(0\,\text{m};\, 0\,\text{m})$ in the input plane. By checking this box, the field is shifted by the *Lateral Offset* of the source plane (↪Sec. 49.2.1.1). Note, the resulting numerical array (sampled field) will still be centered at $(0\,\text{m};\, 0\,\text{m})$, so additional zero-values will be generated. An example is given in Fig. 471 and Fig. 472.
Shape	You can choose whether the single modes have a *Rectangular* or an *Elliptical* shape.
Field Size	The size or diameter of the aperture. If the light source determines the aperture size automatically, this control is disabled.
Relative Edge Width	The width of the smoothing edges defined relatively to the lateral extension of the mode. If the extension in x- and y-direction differ, the minimum of both values is taken.
Absolute Edge Width	The width of the smoothing edges in meters (↪Fig. 467). If the light source determines the aperture size automatically, this control is disabled.

The *Position & Size* parameters of light sources is discussed in Sec. 49.2.1.2 in more detail. Fig. 376 show the parameter that can be configured on the tab page *Power Management*.

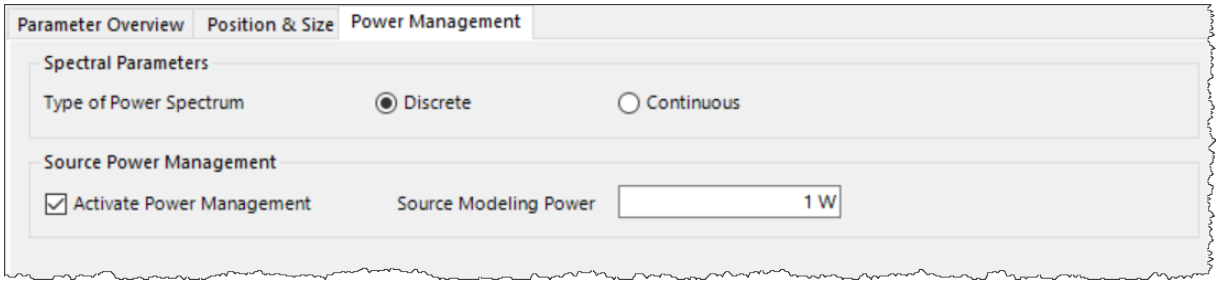


Figure 376. *The* Power Management *page for* Sources.

In the section *Power Management* the user can define the following parameters to configure the power of the active source:

ITEM	DESCRIPTION
Type of Spectrum	For the power management is done by calculation of the initial power of the source, calculating a corresponding scaling factor and then adding this scaling factor automatically into the light source. For this calculation the user need to specify whether the spectrum in use is *Discrete* or *Continuous*. This information is then used to calculate the integrated power over all wavelength emitted by the source.
Activate Power Management	The user can activate or deactivate the power management. In case the *Power Management* is not activated, VirtualLab Fusion will generate the source fields with normalized amplitude (which is the same workflow as done in previous versions). If the *Power Management* option is checked, VirtualLab Fusion will analyze the source field before simulation, calculate a scaling factor by measuring the power of the normalized output field of the source and apply the evaluated scaling factor within the following simulation to the source field. Within the process logging the information about the *Power Management* evaluation can be checked by the user.
Source Modeling Power PE	If the option *Activate Power Management* is selected, the user can specify the *Source Modeling Power* he like to be emitted by the active source. This value is used for calculation of the scaling factor mentioned before.

44.4.3 Components & Solvers Tab

In the *Components & Solvers* tab all important parameters for ideal component and real components can be accessed. This section has the following tab pages in which different parameters are accessible.

- *Parameter Overview*: On this tab page the user can access all numerical parameters of the connected components within the underlying optical system. More information can be found in Sec. 44.4.3.1.
- *Solver & Functions*: Each real component has an associated solver and for each ideal component comes with an associated function. On the tab page *Solver & Functions* you can access the parameters for these solvers/functions. The numerical parameters of the solver/functions are communicated by a *Parameter Overview Table* (details can found in Sec. 44.4.1.1).
- *Free Space Propagation*: Next to the parameters for the solvers/functions it is important to define the parameter to propagate to components through free space. These parameters are available in the page

Free Space Propagation. Sec. 44.4.3.2 contains a detail explanation of control to configure the free space propagation parameters.

- *Channel Configuration*: Within the section *Channel Configuration* the user gets an overview of the current surface channel settings for all components within the system. Detailed information of the controls to specify the *Channel Configuration* can be found in Sec. 44.4.3.3.

Fig. 377 shows the *Component & Solver* which is accessible in the *Profile Editor*.

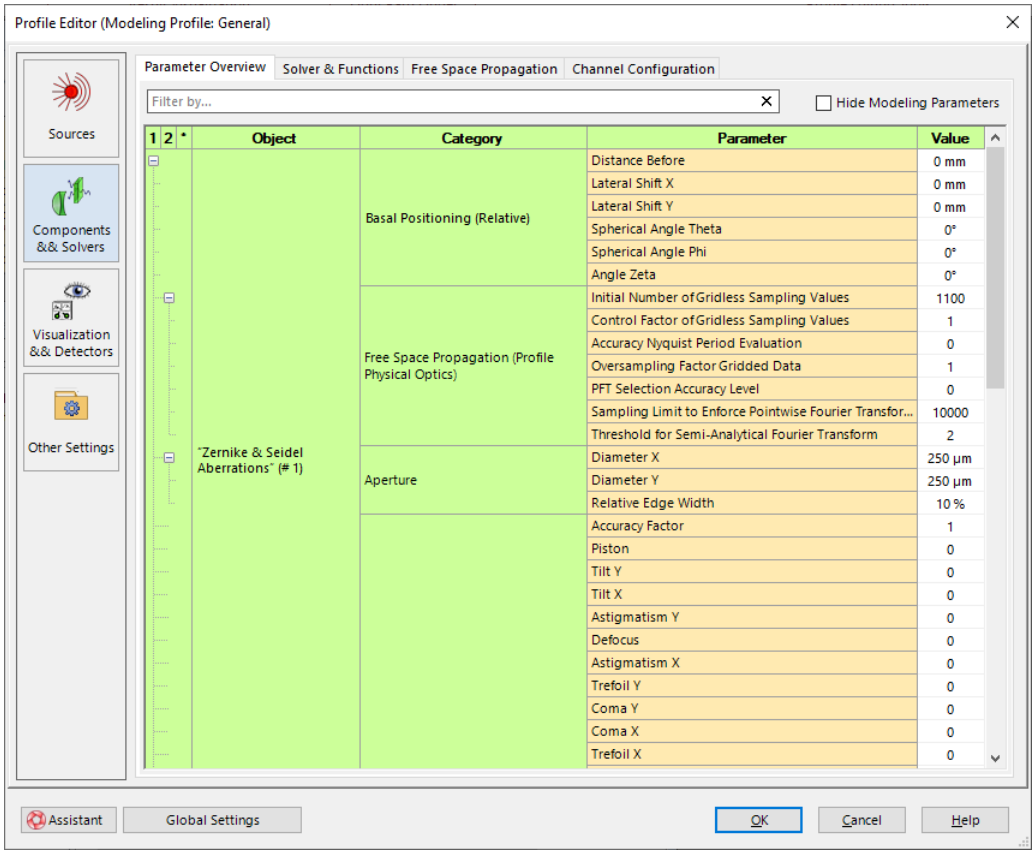


Figure 377. *The* Component & Solver *section of the* Profile Editor.

44.4.3.1 Parameter Overview

For the display of all numerical parameters of the components within the underlying system a *Parameter Overview Table* is used. Detailed information on the common user interface of *Parameter Overview Table* can be found in Sec. 44.4.1.1.
Fig. 378 shows *Parameter Overview* tab for components within the *Profile Editor*.

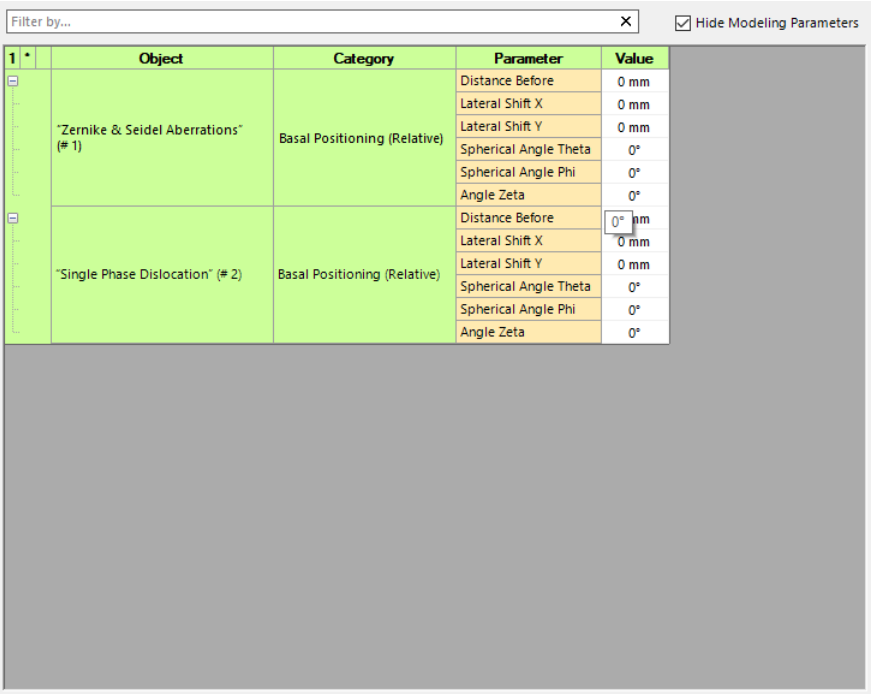


Figure 378. *The* Parameter Overview *of the* Component & Solver *section within the* Profile Editor*.*

In general the table list all numerical parameters for the components of the underlying optical setup. But by checking *Hide Modeling Parameters* all modeling parameters are not included in the listing. The modeling parameters are parameters of the solver/function (which are also on the *Solver & Functions* tab) and parameters of the free space propagation (which are also on the *Free Space Propagation* tab).

44.4.3.2 Free Space Propagation

Within this section of the *Profile Editor* the user can configure all parameters that are important to be used within the free space propagation from source to component, from component to component or inside components (in case that a component contains several surfaces).
Fig. 379 shows the control to configure the *Free Space Propagation* parameters for components.

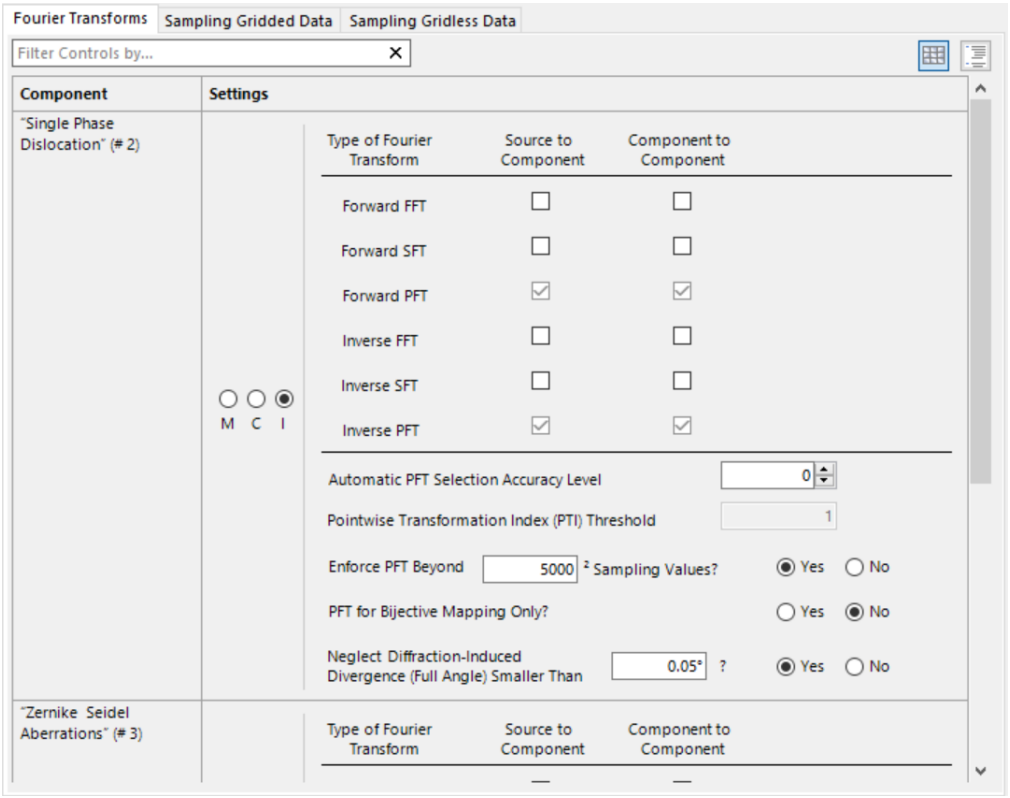


Figure 379. *The section to configure the* Free Space Propagation *parameters for components within the* Profile Editor.

For the communication of the *Free Space Propagation* parameters the parameters are displayed within several *Table Layout/Tree View* are used. Detailed information on this common user interface can be found in Sec. 44.4.1.2. The section within the dialog contains a tab page for

- *Fourier Transform*: The controls for specification are described in Sec. 44.5.1.1.
- *Sampling Gridded Data*: Details on the user controls for the configuration of gridded data can be found in Sec. 44.5.1.2.
- *Sampling Gridless Data*: In Sec. 44.5.1.3 the controls for the configuration of gridless data are explain in detail.

44.4.3.3 Channel Configuration

In the section *Channel Configuration* the user can get an overview of the current surface channel settings. This configuration is done via a compact table, which has the following entries:

ITEM	DESCRIPTION
Name	The name of the component (including the index of the component).
Surface	The name of the surface within the component. If more than one surface is present in one component, an additional line will be available to configure all channels for the component at once to be active or inactive.
+/+	Defines whether the plus-plus channel is active/open.
+/-	Defines whether the plus-minus channel is active/open.
-/-	Defines whether the minus-minus channel is active/open.
-/+	Defines whether the minus-plus channel is active/open.

Fig. 380 shows the control to configure the *Channel Configuration* for all components of the underlying optical setup.

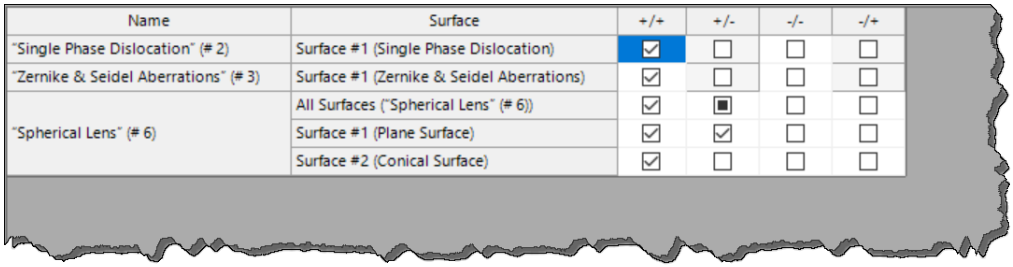


Figure 380. *The section to configure the* Channel Configuration *for components within the* Profile Editor*.*

The *Channel Configuration* is read-only if the *Channel Configuration Option* is set to *Pre-Selected*. In case of *Manual Channel Configuration* the user can select freely which channels should be open or closed for automatic analysis the light propagation through the optical setup.

44.4.4 Visualization & Detectors Tab

Within the *Visualization & Detectors* tab the user can find all settings which are accessible for detectors and general result visualization. This section has the following tab pages in which different parameters are accessible.

- *Result Visualization*: On this tab page the user can select the result visualization type. Depending on the selected result visualization different tab pages will be available within the section *Visualization & Detectors*. A detailed information on the *Result Visualization* section can be found in Sec. 44.4.4.1.
- *3D View*: This tab page is only available if the user selects *System: 3D* as *Result Visualization*. On this tab page the user can configure the number of points that shall be used for processing and also pre-configure the 3D system view. More information see in Sec. 44.4.4.2.
- *Detector Setting*: If the user selects *Detectors* as *Result Visualization* type he can use the controls within this section to specify the parameters of the detectors within the optical setup. The configuration can be done per detector. In Sec. 44.4.4.3 you can find a detailed description of the controls to define the parameters for the detectors.
- *Modeling Analysis*: VirtualLab Fusion provides access of the intermediate fields during propagation through the system. This can be done by selecting *Modeling Analyzer* as *Result Visualization*. On the tab page *Modeling Analysis* you configure the generation of the intermediate output. This tab is only available if *Modeling Analyzer* is selected. More information can be found in Sec. 44.4.4.4.
- *Parameter Overview*: This tab page provides an overview of all numerical parameters for detectors. Please check Sec. 44.4.4.5 for more information.
- *Propagation to Detector*: In this section the user can define the parameters that are used to propagate the light to the detector. A detailed explanation of all user control that are available under *Propagation to Detector* can be found in Sec. 44.4.4.6.

Fig. 381 shows the control to configure the *Visualization & Detectors* settings of the underlying optical setup.

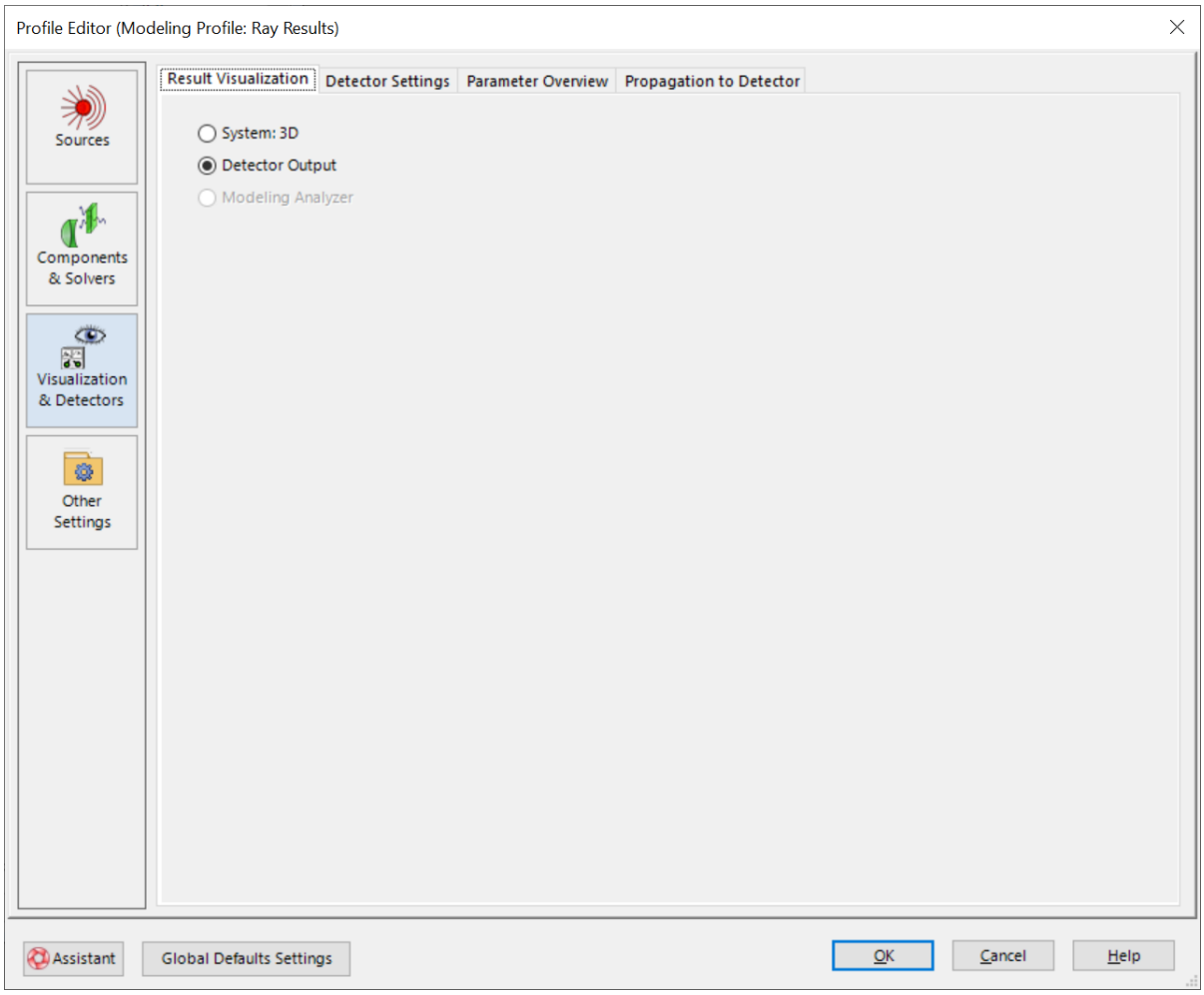


Figure 381. *The section to configure the* Visualization & Detectors *settings within the* Profile Editor.

On the next pages we will explain the settings for *Visualization & Detectors* more in detail.

44.4.4.1 Result Visualization

On the tab page *Result Visualization* the user can select the result visualization type that shall be used for system analysis. Fig. 382 show the content of the tab page *Result Visualization*.

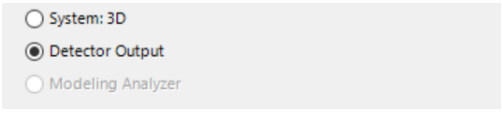


Figure 382. *The user interface to select the* Result Visualization *type.*

Depending on the selected profile the available *Result Visualization* type will be enabled. For the *Ray Results* profile VirtualLab Fusion supports the evaluation *System: 3D* or the *Detector Output*. The *General Profile* allows the evaluation of *Detector Output* or the *Modeling Analyzer*.
The following parameters can be configured within the user interface of the *Result Visualization*:

ITEM	DESCRIPTION
System: 3D	This visualization is currently only available for the *Ray Results* profile. By selecting this output type, performing the simulation will generate a result document which contain the 3D system information including ray information. By activating this option the tab page *3D View* will be available for further configurations.
Detector Output	Each detector will generate an output. The output can be in gridless and/or gridded format. Within the *Ray Results* profile the output is restricted to be gridless. The settings for the detectors can be adapted on the tab page *Detector Settings*.
Modeling Analyzer	For the *General* profile the visualization type *Modeling Analyzer* can be used. This allow the access to intermediate information during propagation through the optical setup. Further configuration can be done on the tab page *Modeling Analysis*.

44.4.4.2 3D View

If the user selected the *System: 3D* as *Result Visualization* type the tab page *3D View* becomes visible. On this tab page the user can configure all settings that are related to the *System: 3D* view output.
Fig. 383 shows all control which can be used to configure the parameter for *System: 3D* view output generation.

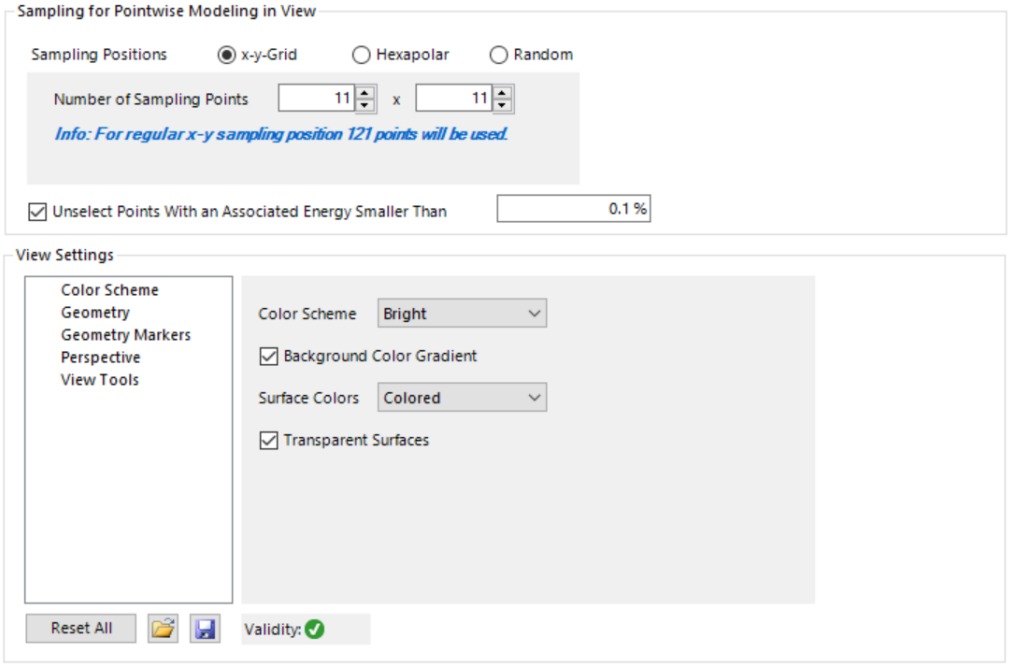


Figure 383. *The user controls to configure the visualization type* System: 3D.

The parameters to configure for *3D View* parameters can be found in Sec. 44.5.4. The *Result Visualization* type *System: 3D* are currently only available for the *Ray Results* profile.

44.4.4.3 Detector Settings

If the user selects *Detectors* as *Result Visualization* type, the tab page *Detector Settings* will be available. The user configure the detector output per detector. VirtualLab Fusion will use a set of *Table Layout/Tree View*

controls are used to provide a systematic overview of all available parameters of the *Universal Detectors* within the underlying system. Detailed information on this common user interface can be found in Sec. 44.4.1.2. Fig. 384 shows the controls to configure the *Detector Settings* of the detectors within the underlying system.

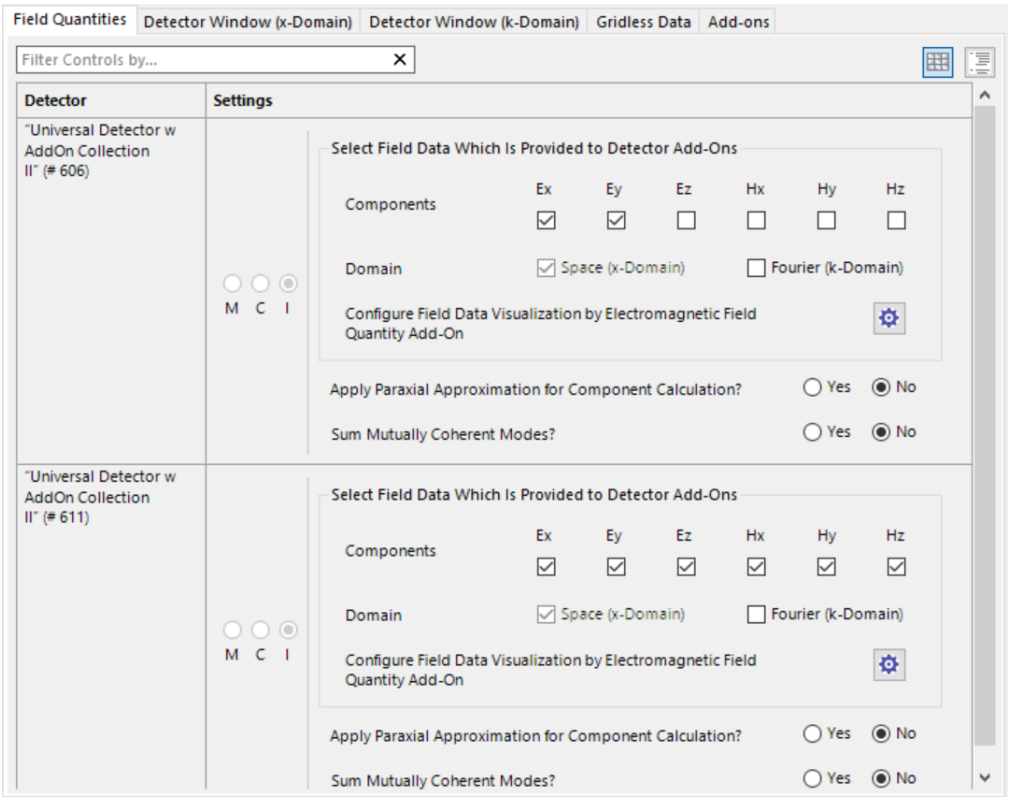


Figure 384. *The user can configure the parameters of the* Universal Detectors *within the underlying system in the section* Detector Settings.

The section within the *Profile Editor* contains a tab page for

- *Field Quantities*: The controls for the configuration of field values are described in Sec. 75.4.1. Within the *Ray Results* profile this tab page will be now shown.
- *Detector Window (x-Domain)*: The definition of the window size and the sampling of equidistant data can be defined here. Detailed information can be found in Sec. 75.4.2.
- *Detector Window (k-Domain)*: For the evaluation of field in k-domain the user can configure the size of the detector window and the resolution for equidistant data on the tab page *Detector Window (k-Domain)*. Detailed information can be found in Sec. 75.4.3.
- *Gridless Data*: Additional to gridded output the detector supports also the evaluation of gridless output. The parameters for the configuration of gridless data can be found in Sec. 75.4.3.
- *Add-Ons*: Adding, removing and the configuration of detector add-ons can be done in the section *Add-Ons*. You can find a detailed description of the user interface to configure the detector *Add-Ons* in Sec. 75.4.5.

44.4.4.4 Modeling Analysis

When selecting the *General* profile the *Result Visualization* type is available. This result visualization type allows the evaluation of intermediate results during propagation which enable you to get a detailed understanding what happens, when the light is propagated through the optical setup.

Fig. 385 shows the user interface to configure the *Modeling Analyzer* to analyze the process during propagation through the optical setup.

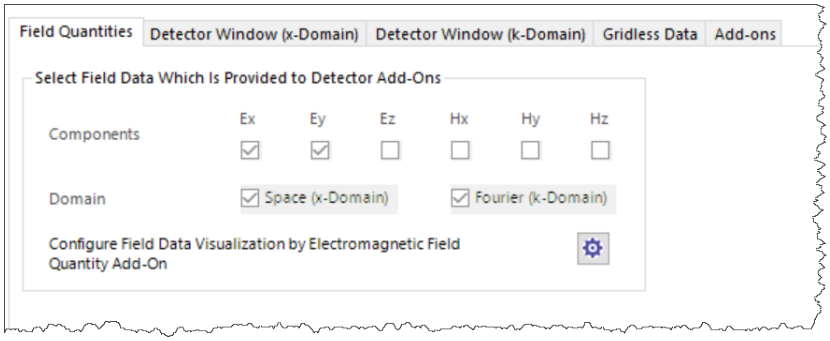
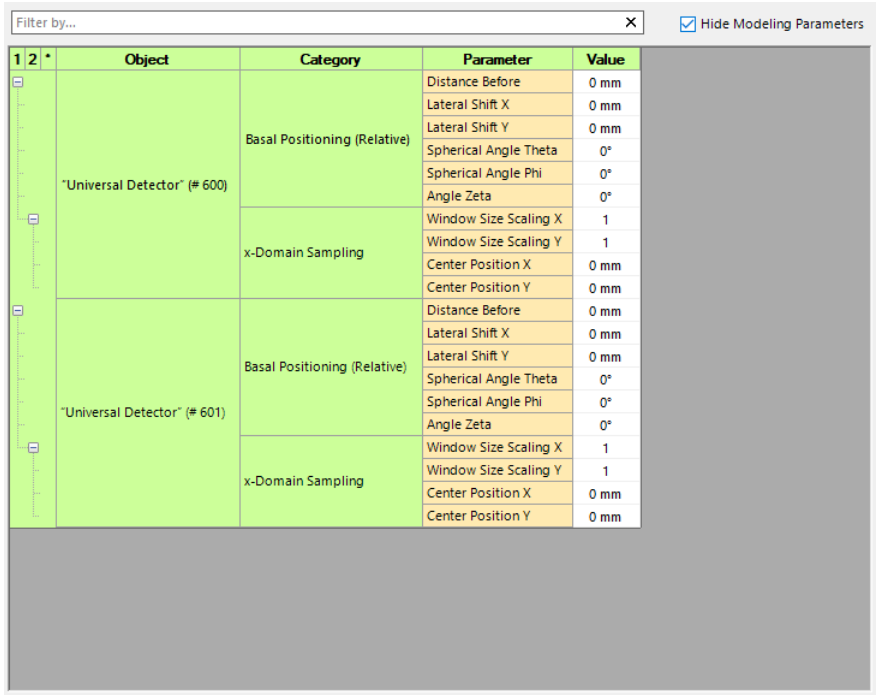


Figure 385. *The user controls to configure the parameters of the* Modeling Analyzer *within the section* Detector Settings*.*

The control to specify the settings of the *Modeling Analyzer* are explained in Sec. 44.5.5.

44.4.4.5 Parameter Overview

For the display of all numerical parameters of the detectors within the underlying system a *Parameter Overview Table* is used. Detailed information on the common user interface of *Parameter Overview Table* can be found in Sec. 44.4.1.1.
Fig. 386 shows the *Parameter Overview* tab for detectors within the *Profile Editor*.



1 2 *	Object	Category	Parameter	Value
	"Universal Detector" (# 600)	Basal Positioning (Relative)	Distance Before	0 mm
			Lateral Shift X	0 mm
			Lateral Shift Y	0 mm
			Spherical Angle Theta	0°
			Spherical Angle Phi	0°
			Angle Zeta	0°
		x-Domain Sampling	Window Size Scaling X	1
			Window Size Scaling Y	1
			Center Position X	0 mm
			Center Position Y	0 mm
	"Universal Detector" (# 601)	Basal Positioning (Relative)	Distance Before	0 mm
			Lateral Shift X	0 mm
			Lateral Shift Y	0 mm
			Spherical Angle Theta	0°
			Spherical Angle Phi	0°
			Angle Zeta	0°
		x-Domain Sampling	Window Size Scaling X	1
			Window Size Scaling Y	1
			Center Position X	0 mm
			Center Position Y	0 mm

Figure 386. *The* Parameter Overview *of the* Visualization & Detectors *section within the* Profile Editor*.*

In general the table list all numerical parameters for the detectors of the underlying optical setup. But by activating the check box *Hide Modeling Parameters* all modeling parameters are not included in the listing. The modeling parameters are parameters of the free space propagation to the detectors. These parameters can be accessed in the section *Propagation to Detector* in the *Visualization & Detectors* main section.

44.4.4.6 Propagation to Detector

Within this section of the *Profile Editor* the user can configure all parameters that are important to be used within the free space propagation to detectors.
Fig. 387 shows the control to configure the *Propagation to Detector* parameters.

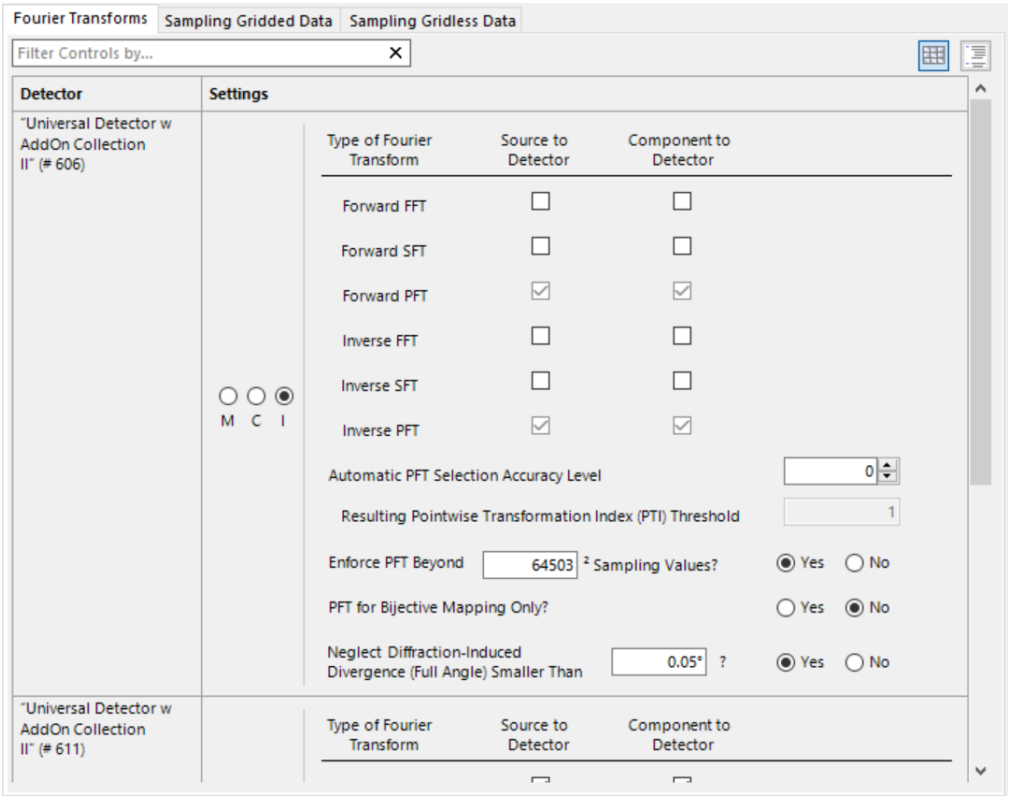


Figure 387. *The section to configure the* Propagation to Detector *within the* Profile Editor.

For the communication of the *Free Space Propagation* parameters the parameters are displayed within several *Table Layout/Tree View*. Detailed information on this common user interface can be found in Sec. 44.4.1.2. The section within the dialog contains a tab page for

- *Fourier Transform*: The controls for specification are described in Sec. 44.5.1.1.
- *Sampling Gridded Data*: Details on the user controls for the configuration of gridded data can be found in Sec. 44.5.1.2.
- *Sampling Gridless Data*: In Sec. 44.5.1.3 the controls for the configuration of gridless data are explain in detail.

44.4.5 Other Settings Tab

In the *Other Settings* tab a collection of parameters can be accessed which is valid for the complete system and not only for selected sources/components or detectors. This section is separated in the following sub sections:

- *System*: Here the user can enter some basic parameters like pressure and temperature which are provided as system parameters and used for system modeling. Detailed information on the *System* parameters can be found in Sec. 44.4.5.1.
- *Free Space Parameters*: On this tab page several global parameters are listed which are used for the propagation through homogeneous medium. These parameters are defined on system level and explained in detail in Sec. 44.4.5.2.

- *Light Path Finder*: For the evaluation of the tracing sequence through the setup, VirtualLab Fusion provides several options for determining the light paths (which paths the light goes within the system). These parameters can be configured here. Detailed information on the *Channel Configuration* can be found in Sec. 44.4.5.3.

In the following paragraphs the controls to define the *Other Settings* are explained in detail.

44.4.5.1 System

Fig. 388 shows the content of the tab page *System* in the section *Other Settings*.

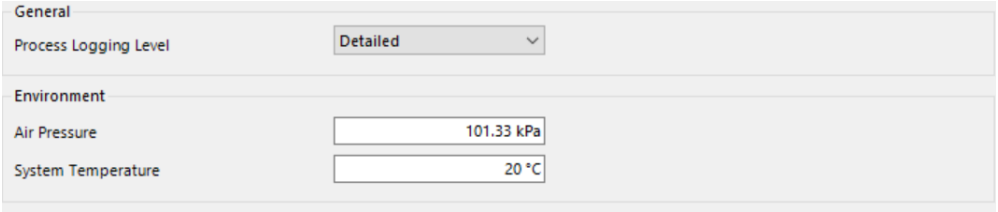


Figure 388. *The system parameters which can be configured within the section Other Parameters.*

The user can specify the following parameters via the controls of the tab page

ITEM	DESCRIPTION
Process Logging Level	During the processing of an optical setup, VirtualLab Fusion provides several logging information about the current step of the simulation. By selecting the *Process Logging Level* the user can define to which detail level he like to see this process information. The following levels are available: *None*, *Normal* and *Detailed*.
Environment	VirtualLab Fusion supports to define the *Environment* parameters for the system modeling. Here the user has to define the *Air Pressure* and the *System Temperature*. These parameters are used to evaluate the refractive index of the media within the system when propagating through it.

44.4.5.2 Free Space Parameters

In general the *Free Space Parameters* are configured per component/detector. There are several settings that you can configure which are defined only once within the system. Fig. 389 show the content of the tab page *Free Space Parameters* in the section *Other Settings*.

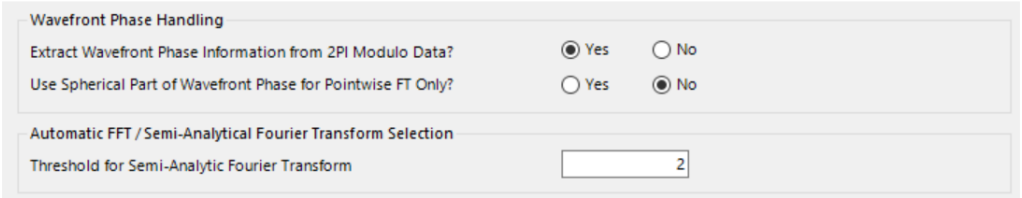


Figure 389. *The Free Space Parameters which can be configured for the complete system within the section Other Parameters.*

The following settings are available for the *Free Space Parameters* on system level

ITEM	DESCRIPTION
Wavefront Phase Handling	The handling of wavefront phases is a major challenge within optical simulation. Typically VirtualLab Fusion tries to handle the wavefront phase as smart as possible when propagating through an optical setup. By selecting to *Extract Wavefront Phase Information from 2PI Modulo Data* it is configured that VirtualLab Fusion tries to extract a smooth wavefront phase information after an integral Fourier transform. In this case the phase has to be typically sampled in 2PI modulo and after the integral Fourier transform is performed VirtualLab Fusion will apply smart unwrapping algorithms and interpolation techniques to extract a smooth wavefront from the 2PI modulo data. The default of this option is *Yes*. Another parameter also available in this section effect the result of a pointwise Fourier transformation. If the user defines to *Use Spherical Part of Wavefront Phase for Pointwise FT Only* VirtualLab Fusion will fit the spherical part before doing the PFT and use only this spherical part for the Fourier transform. This option is by default false.
Automatic FFT/Semi-Analytical Fourier Transform Selection	For the decision whether FFT or SFT is used a numerical criteria is applied. VirtualLab Fusion compares the numerical effort of the FFT and the SFT. In case of FFT a given quadratic phase of the field needs to be sampled, because it can only be handled analytically in the SFT. By defining the *Threshold for Semi-Analytic Fourier Transform* the user defines when to use FFT or SFT. The higher this threshold is, the later VirtualLab Fusion will use SFT.

44.4.5.3 Light Path Finder

Within the section *Light Path Finder* the user can define all parameters necessary for the evaluation of light paths to be processed during the simulation. The parameters and the user interface to configure the parameters for the *Light Path Finder* are explained within Sec. 44.3.1.

44.5 Propagating Through an Optical Setup

VirtualLab Fusion enables the simulation of optical systems by physical optics. By default an optical system comes with two modeling profiles: *Ray Results Profile* and *General*. The *Ray Results Profile* has several limitations and can be used to generate typical results the user are used to if they use traditional ray tracing software. The limitation of the *Ray Result Profile* are described in Sec. 44.5.2. Within the *General Profile* there are no limitations regarding the specification of the freespace propagation parameters (especially the selection of Fourier transform to be used). For the profile the user needs to select the result visualization to be used. For the *Ray Results Profile* can select whether he like to evaluate the information as *System: 3D* output or as *Detectors* output. For the *System: 3D* result the user can specify the sampling for gridless points as well as view options for the 3D result visualization. Detailed information about its configuration can be found in Sec. 44.5.4. In case of *Detectors* output within the *Ray Results Profile* the user need also to specify the sampling for gridless data and some selected view properties for the detector outputs.
For the *General Profile* the user can select between *Detectors* output and *Modeling Analyzer*. In case of *Detectors* the visualization/evaluation options are configured directly in the detectors within the underlying optical setup. The *Modeling Analyzer* offers the user the access to intermediate field information within the system simulation. Detailed information about the *Modeling Analyzer* can be found in Sec. 44.5.5.
In general the parameters for propagation through the optical setup can be made via the edit dialogs of the different elements (components, detector, etc.) within your optical system. Alternatively, we provide also options

to edit the parameter in a more organized form via the *Profile Editor*. The graphical user interface of the profile editor is described on Sec. 44.4

In addition to the innovative concept of modeling profiles we provide also the simulation of optical systems by *Classic Field Tracing* which is the first version of our implementation to do physical optics. The *Classic Field Tracing* is already working good for paraxial optical setups. In addition every Analyzer can be used as Simulation Engine because Analyzers process Optical Setups in their own special way. And Grating Optical Setups (↪Sec. 44.11.1) use their own *Near Field Analysis* engine.

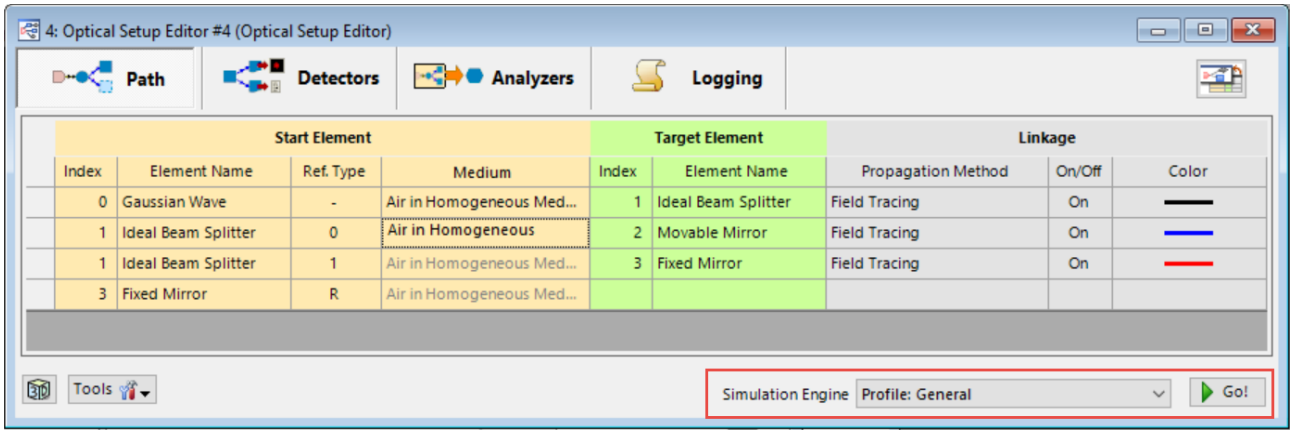


Figure 390. *Starting a simulation from the Optical Setup Editor. By selecting the* Simulation Engine *the user specifies how the source field should be traced through the complete Optical Setup, or whether only a certain analyzer shall be evaluated.*

In the bottom-right corner of the Optical Setup Editor (↪Fig. 390) you can choose which Simulation Engine is to be used and start a new simulation.

ITEM	DESCRIPTION
Simulation Engine	The Simulation Engine (or Analyzer) to be used. The selected Simulation Engine also influences the available settings in the edit dialogs of Components (↪Sec. 55), Ideal Components (↪Sec. 67), and Detectors (↪Sec. 75.1).
▶ **Go!**	Starts the simulation of the Optical Setup. Shortcut F5. During a simulation the ▶ *Go!* button turns into a ■ *Stop* button to stop the simulation. Shortcut Shift+F5.

For the modeling profiles there are several tools available which analyze the underlying configuration (on the fly or on demand) and that can be used to realize a fast reconfiguration of the modeling settings. Detailed information can be found in Sec. 44.3.

44.5.1 Free Space Propagation Parameters (Modeling Profiles)

The most important step for doing fast physical optics is the free space propagation, which is used to simulate the light propagation from the output of one component (or source) to the input of another component (or detector). Therefor, VirtualLab Fusion offers a variety of parameters that can be adapted by the user for the free space propagation. These parameter can be specified per component and detector. The user can enter the configuration settings by opening the edit dialog of the component or detector and go to the tab page *Free Space Propagation*. Alternatively, it is possible to configure these parameter using the *Profile Editor*. The *Profile Editor* enables the user to have an overview of setting of multiple components/detectors. Detailed information on the *Profile Editor* can be found in Sec. 44.4.

The configuration of the free space propagation parameters is divided into three sections

ITEM	DESCRIPTION
Fourier Transforms	Within this section the user can define several settings to select Fourier transforms within the free space propagation. Detailed information see Sec. 44.5.1.1.
Sampling Gridded Data	Next to the selection of Fourier transforms the specification for handling of gridded data is important. Therefore the section *Sampling Gridded Data* can be used. More information can be found in Sec. 44.5.1.2.
Sampling Gridless Data	Within our physical optics simulation approach we work also with gridless data (e.g. to represent wavefront information). The settings for gridless data can be configured in the section *Sampling Gridless Data*. A detailed explanation of the controls to configure the *Sampling Gridless Data* can be found in Sec. 44.5.1.3.

Fig. 391 shows the *Free Space Propagation* page of the edit dialog of a *Universal Detector*. Note: the graphical user interface for the configuration of the *Free Space Propagation* parameters is everywhere the same (for components/detectors and also in the edit dialogs or the *Profile Editor*).

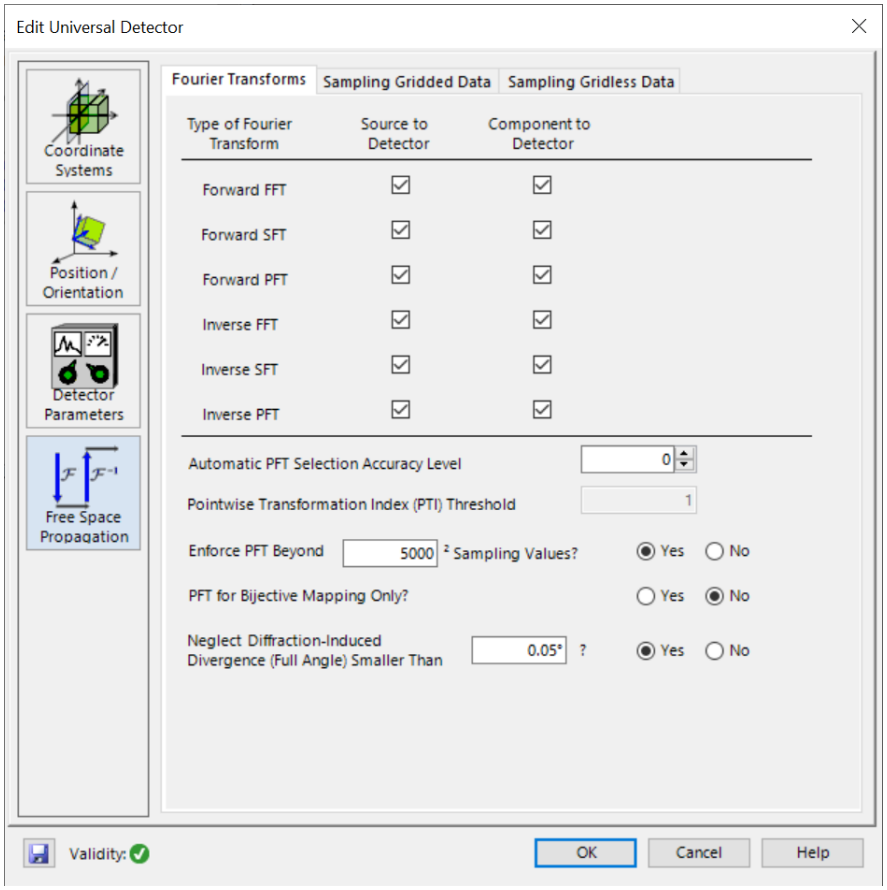


Figure 391. Free Space Propagation *page of the edit dialog of a detector / component.*

Within the following section the detailed configuration options for the *Free Space Propagation* parameters are explained.

44.5.1.1 Fourier Transforms

To enable fast physical optics it is a key technology to switch between different domains. In standard optical simulations we typically deal with x- and k-domain. This domain switching is very often done within the free space propagation.
VirtualLab Fusion comes with three different Fourier transform algorithms to enable a fast solution depending on the incident field:

- *Fast Fourier Transform (FFT)*: The fast Fourier transform is rigorous. Lateral shift and linear phase are handled analytically.
- *Semi-Analytical Fourier Transform (SFT)*: The semi-analytical Fourier transform is also rigorous. In addition to lateral shift of the field and linear phase it can also handle quadratic phase terms analytically. This method has numerical advantages if the quadratic phase term is significant.
- *Pointwise Fourier Transform (PFT)*: The pointwise Fourier transform is an approximation. Here the smooth phase of the field is evaluated and a pointwise transformation into the target domain is done. Mathematically this method is derived from the stationary phase. For the pointwise Fourier transform we check initially for singular cases (plane wave and cylindrical wave) and perform regularization if a singular case appears.

Fig. 392 show controls to define the parameters for the selection of *Fourier Transforms* within the *Free Space Propagation* parameters.

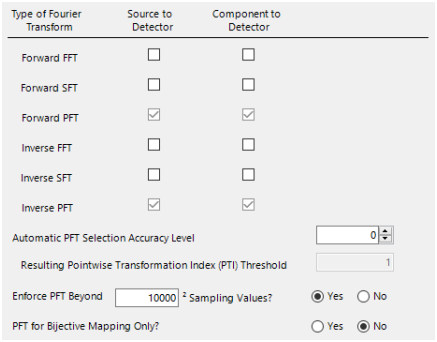


Figure 392. *The user interface to define the* Fourier Transforms *selection parameters.*

The following parameters can be specified by the user

ITEM	DESCRIPTION

Type of Fourier Transforms	VirtualLab Fusion supports the automatic selection of the Fourier transform to use dependent on the input field for which the domain shall be changed. This algorithm evaluates the pointwise transformation index (PTI) and first decides whether to use pointwise Fourier transform or an integral Fourier transform (SFT or FFT). If an integral Fourier transform is used the numerical effort for SFT and FFT is compared and the most suitable method is used. Nevertheless, it is not untypical that the user already pre-select the types of Fourier transforms which should be used for evaluation. If the user likes to enforce the usage of pointwise Fourier transform for example, it is possible to select only the PFT for the free space propagation. This makes the decision process faster and also enable the user to have a concrete control of the effects he likes to include in the simulation (e.g. diffraction). In the section *Type of Fourier Transform* the user can select whether to use FFT, SFT and or PFT for the usage within the free space propagation. This selection can be done independently for the forward (x to k) and the inverse (k to x) Fourier transform. In addition we differ between the selection for *Source to Component*, *Component to Component*, *Inside Components*, *Source to Detector* and *Component to Detector*. In dependency whether you edit a component (single surface or multiple surfaces) or a detector, VirtualLab Fusion will offer you a matrix, which enable a full flexibility to configure the modeling according to your needs.
Automatic PFT Selection Accuracy Level	As explained above VirtualLab Fusion evaluated how accurate the pointwise Fourier transform is in case not only *PFT* is marked as an option for automatic Fourier transform selection. The accuracy for this evaluation can be specified by the *Automatic PFT Selection Accuracy Level*. The higher the accuracy the later VirtualLab Fusion will decide to use PFT. Internally, VirtualLab Fusion calculate the pointwise transformation index (PTI), which is the relation between the size of the function after pointwise Fourier transform and the size of the function after an integral Fourier transform. The sizes for integral Fourier transform are evaluated by 1D cuts. This ratio is gauged by theoretical consideration with a factor ϵ. If the *PTI* is larger than 1 PFT is selected. By selecting the *Automatic PFT Selection Accuracy Level* the threshold for the PTI comparison will be changed. In the graphical user interface the user can check the resulting threshold value where VirtualLab Fusion switches between pointwise and integral Fourier transform in the box after *Pointwise Transformation Index (PTI) Threshold*.
Enforce PFT Beyond xxx² Sampling Points	VirtualLab Fusion provides also a fall-back solution to restrict the numerical effort of integral Fourier transforms. Therefor the option *Enforce PFT Beyond xxx² Sampling Points* is to be selected (by selecting *Yes*). If this option is activated VirtualLab Fusion will check the numerical effort to perform the integral Fourier transform. If it is larger than the value specified by the user, the integral Fourier transform is aborted and VirtualLab Fusion will use pointwise Fourier transform instead. This information can be seen also in the progress logging to make a transparent documentation of the decision making during propagation through the system.

PFT for Bijective Mapping Only?	The pointwise Fourier transform is typically valid only in bijective cases, which means that the mesh of gridless points in x-domain and in y-domain are well sorted. Nevertheless, it can be also applied in non-bijective/surjective cases. By activating the flag *PFT for Bijective Mappping Only* it is ensured that the pointwise Fourier transform is not applied in surjective cases.

44.5.1.2 Sampling Gridded Data

If an integral Fourier transform is used VirtualLab Fusion typically needs to switch from gridless (or hybrid) data format into gridded data format. For this operation the user has several new options to be configured in the section *Sampling Gridded Data*.
Fig. 393 shows controls to define the parameters for the configuration of *Sampling Gridded Data* within the *Free Space Propagation* parameters.

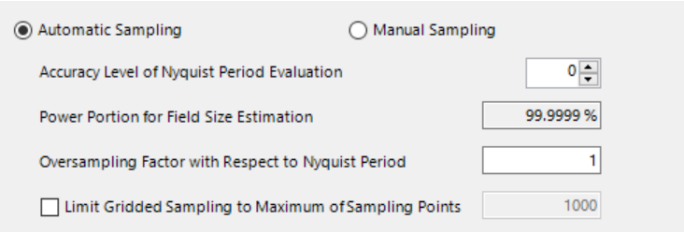


Figure 393. *The user interface to define the parameter for* Sampling Gridded Data.

The following configurations can be done in the user interface for *Sampling Gridded Data*:

ITEM	DESCRIPTION
Automatic Sampling/Manual Sampling	In general the user can decide whether the sampling should be evaluated automatically or a manual sampling configuration shall be used. Depending on the selection different options are display, e.g. only for *Manual Sampling* the user can define *Sampling Values for Gridded Data* directly.
Accuracy Level of Nyquist Period Evaluation	In case of *Automatic Sampling* VirtualLab Fusion first evaluates the Nyquist distance by a numerical algorithm. This algorithm extract 1D cuts from the given field data and evaluates the bandwidth of the extracted cross sections by performing a one-dimensional Fourier transform and measuring the size in the counter domain. The size measurement is done by detecting a rectangle which contains a certain power portion. The user can specify the power portion indirectly by the specification of the *Accuracy Level of Nyquist Period Evaluation*. This level can be selected between -4 and 4. The resulting power portion is calculated from the accuracy factor and displayed in the box behind *Power Portion for Field Size Estimation*.
Oversampling Factor with Respect to Nyquist Period	After VirtualLab Fusion evaluated the Nyquist period for given field data the sampling period for the conversion from gridless to gridded data can be additionally scaled. This is done by the *Oversampling Factor with Respect to Nyquist Distance*. A larger oversampling factor will result in a smaller grid for the generation of gridded data.
Limit Gridded Sampling to Maximum of Sampling Points	For some modeling situations it might be meaningful to set a limit for the number of gridded sampling points that shall be used for the conversion from gridless to gridded data. If the user select the option to limit the sampling numbers he can define the maximum number of pixels to be used. If the automatic algorithm for example result in 5000 x 5000 pixels and the limit option is activated with a limit of 2000, VirtualLab Fusion will use only use 2000 x 2000 sampling point for the conversion. The sampling estimation is based on numerical algorithms, so it could be some times quite helpful to enable this option. Nevertheless, the user of VirtualLab Fusion shall be careful because if the field is strongly undersampled it might cause follow up issues within the subsequent processing of the system.
Sampling Values for Gridded Data	If the user selects *Manual Sampling*, the option to configure the *Sampling Values for Gridded Data* is activated in the graphical user interface. Here the user can directly configure the number of pixels to be use in x and y direction.

44.5.1.3 Sampling Gridless Data

As already explained before VirtualLab Fusion typically needs to handle gridless and gridded data within the simulation of an optical setup. In Sec. 44.5.1.2 the free parameters for *Sampling Gridded Data* were explained. In the section *Sampling Gridless Data* of the *Free Space Propagation* parameters for the sampling for gridless data can be configured.
Fig. 394 show controls to define the parameters for the configuration of *Sampling Gridless Data*.

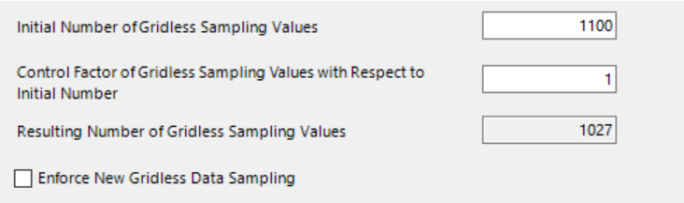


Figure 394. *The user interface to define the parameter for* Sampling Gridless Data.

The following options can be configured by the user in this section of the user interface:

ITEM	DESCRIPTION
Initial Number of Gridless Sampling Values	The user may enter an initial number for the gridless values to be used. VirtualLab Fusion uses the specification of the shape of the source aperture to generate a regular x-y mesh (in case of rectangular aperture) or a hexapolar mesh (in case of elliptical aperture). The initial number is used to define the number of points in x/y direction for a regular grid or the density for a hexapolar mesh.
Control Factor of Gridless Sampling Values with Respect to Initial Number	The evaluated density (of hexapolar mesh) or number of sampling points in x/y direction (for a regular x-y grid) can be scaled with the *Control Factor of Gridless Sampling Values with Respect to Initial Number*. The control factor is multiplied on the density or the number of sampling points in x/y direction.
Resulting Number of Gridless Sampling Values	To estimate the numerical effort, VirtualLab Fusion calculates the resulting number of points in dependency of the *Initial Number of Gridless Sampling Values* and the *Control Factor of Gridless Sampling Values with Respect to Initial Number*. The resulting number of gridless sampling values is logged into the corresponding text box.
Enforce New Gridless Data Sampling	In some situations it might be meaningful to restart the gridded sampling. This can be done by activating the option *Enforce New Gridless Sampling*. In case this flag is not checked and the operation sequence is completely pointwise the initial gridless sampling (after the source) will be used for the complete system. If the user selects to *Enforce New Gridless Sampling* VirtualLab Fusion will resample the gridless data values according to the configuration at the specific selection and a new pointwise sequence might start.

44.5.2 Restrictions of Ray Results Profile

In the current version VirtualLab Fusion comes with two build-in modeling profiles: (1) *Ray Results Profile* and *General Profile*. In both profiles VirtualLab Fusion performs physical optic simulation to obtain the results at detectors. For the *Ray Results Profile* several restriction are defined. This profile can be used to configure results users are typically used when using conventional ray tracing software tools. The *General Profile* is not restricted (beside the availability of the result visualization type *System: 3D*, which will be released in one of the upcoming releases). It should be stated clearly, that you can generate the same results with the *General Profile* as with the *Ray Results Profile* if you use the corresponding definition of modeling parameters.
The following restrictions are defined for the *Ray Results Profile*

- The Fourier transform selection for detector is fixed to be only pointwise (user interface is reduced to information of used Fourier transforms only).
- The Fourier transform selection between and inside components is fixed to be only pointwise.

- The result visualization type *Modeling Analyzer* is disabled.
- The *Universal Detector* is fixed to generate gridless data only, which contains only positions, directions and wavefront phase.
- Within the *Universal Detector* the user can not define the *Field Quantities* to be displayed.
- The *Universal Detector* can not configured to provide the field in k-domain. So also the tab page *Detector Window (k-Domain)* is not visible.
- The profile editing tool *Between Components: ...* is disabled.
- The profile editing tool *To Detectors: ...* is disabled.
- The profile editing tool *Speed vs. Accuracy* is disabled.
- The profile editing tool *Pointwise vs. Integral* is disabled.

To overcome these limitations we propose that you use the *General Profile* with the corresponding settings.d

44.5.3 Ray Results Profile: Detectors

Only available in a General or a Light Shaping Optical Setup.

In case the user selects the visualization type *Detectors* each detector will generate a detector result. Via the editor of the visualization type the user can specify the parameters for the point selection and other global view parameters. The edit dialog can be opened by clicking on the small gear symbol next to the *Detectors* ribbon icon.

Fig. 395 shows the edit dialog of the *Detectors* visualization type for the *Ray Results Profile*.

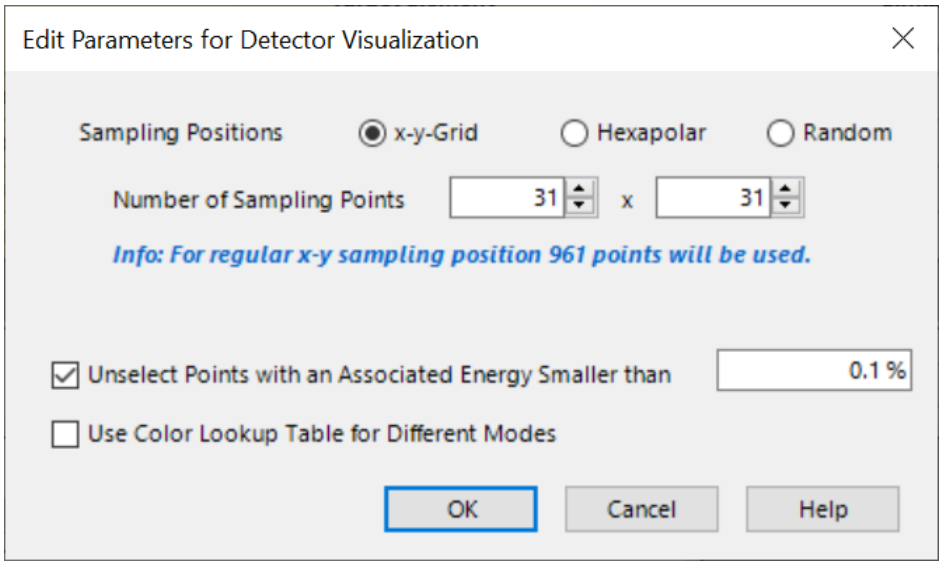


Figure 395. *Edit dialog of the* Detectors *visualization type for the* Ray Results Profile.

Within the dialog the user can configure the following options

ITEM	DESCRIPTION
Sampling Positions	The user needs to specify the number of samples that shall be used for the result generation. Several modes of operations are provided for this configuration, which have different free parameters. The different modes and their parameter are described in Sec. 44.5.3.1.
Unselect Points with an Associated Energy Smaller than	VirtualLab Fusion supports to apply a filter according to the maximum intensity on the point selection. This filtering can be activated by checking the flag *Unselect Points with an Associated Energy Smaller than* and definition of the desired minimum percentage value.
Use Color Table for Different Modes	If checked, a color table for the initial view of positions, wavefront phase and directions can be specified. In case of positions and directions, the colors refer to different modes instead of any field values. (This view option can be changed after the output has been done as well.)

44.5.3.1 Point Selection

For the *Ray Result Profile* one of the most important parameters to specify is the number of samples/positions to use in the pointwise processing sequence. This can be done by different modes of operations. In addition this specification is also possible for gridless data at the *Universal Detector*.
Fig. 396 shows the panel that is used to select the selection mode of positions and the selection dependent parameters.

Figure 396. *Panel to define the sampling positions (mode of operation and parameters) for the gridless data.*

Depending on the selection mode different distribution of position will be generated and are used to define the distribution of a gridless data set. Fig. 397 shows some sample distributions for different modes of operations with different (mode-dependent) parameters.

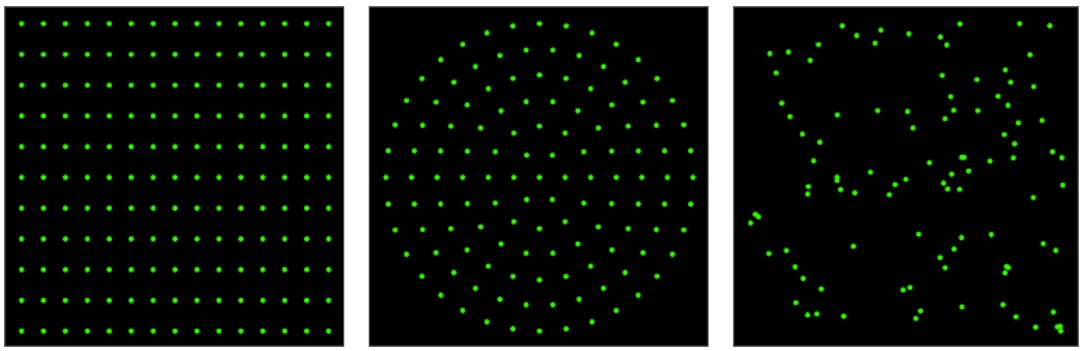


Figure 397. Left: *x-y-Grid with 15 times 11 points.* ***Middle:*** *Hexapolar pattern with a Density of 6.* ***Right:*** *100 points placed at Random positions*

For each mode there are different free parameters available that can be defined by the user. The following modes are supported:

(a) ***x-y-Grid***
The positions are placed on an equidistant grid.

ITEM	DESCRIPTION
Number of Sampling Points PV	The number of points in x- and y-direction, respectively. It is ensured that the numbers are odd so that there is always a ray is at the position $(0\,\mathrm{m};\,0\,\mathrm{m})$.

(b) ***Hexapolar***

The positions are placed on rings so that the overall structure has the symmetry of a regular hexagon. The n^{th} ring contains $6 \cdot n$ points. There is one additional sample in the center.

ITEM	DESCRIPTION
Density PV	The number of rings.

(c) ***Random***

The positions are placed uniformly at random positions.

ITEM	DESCRIPTION
Number of Sampling Points PV	The overall number of sampling points.
Use Seed of	If you check this option the position of the samples remain the same between consecutive simulations. You can change the seed value to obtain a different random pattern.
Generate Mesh	If you uncheck this option no mesh information will be generated. This will increase the performance for the random point generation, because the mesh is generated by a so called Delauney triangulation, which might be time consuming for large number of sampling points.

44.5.4 Ray Results Profile: 3D System

Only available in a General or a Light Shaping Optical Setup.

The evaluation of *System: 3D* output is only supported in the *Ray Results Profile*. By performing the *Ray Results Profile* with selected output *System: 3D* a Ray Distribution 3D document (↪Sec. 17.1) is generated, which shows the complete optical system and how light propagates through it.

The user can edit the parameters to be used within this configuration by clicking on the small gear symbol next to the *System: 3D* ribbon entry. The edit dialog is divided into two tab pages which are explained in the following subsections.

Using the *Copy From* button you can copy the view settings from any open Ray Distribution 3D document to the dialog.

44.5.4.1 *Ray Selection* Tab

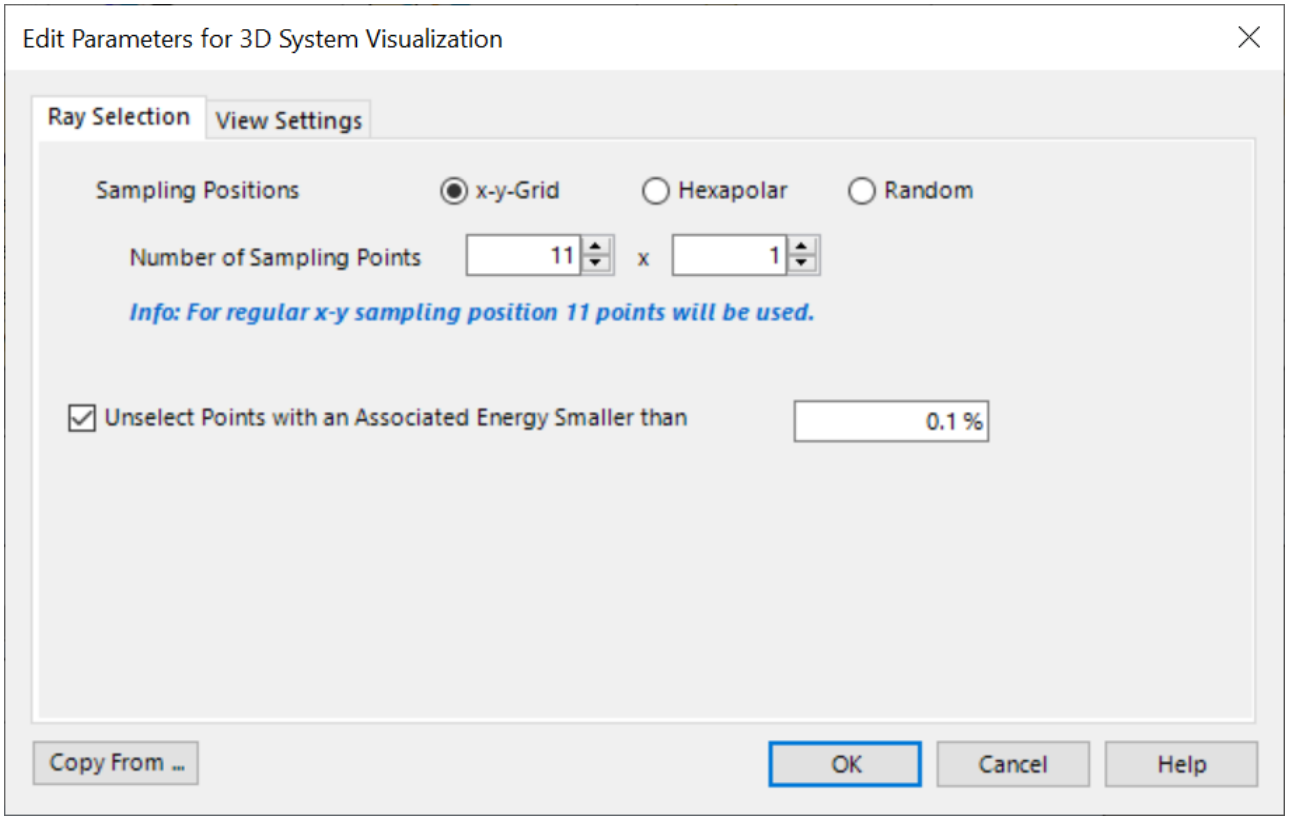


Figure 398. *The edit dialog to edit the* System: 3D *output of the* Ray Results Profile *showing the* Ray Selection *tab.*

This tab page (↪Fig. 398) has the following options.

ITEM	DESCRIPTION
Sampling Positions	The user needs to specify the number of samples that shall be used for the result generation. Several modes are provided for this configuration, which have different free parameters. They are described in Sec. 44.5.3.1.
Unselect Points with an Associated Energy Smaller than	VirtualLab Fusion supports to apply a filter according to the maximum intensity on the point selection. This filtering can be activated by checking the flag *Unselect Points with an Associated Energy Smaller than* and definition of the desired minimum percentage value.

44.5.4.2 *View Settings* Tab

This tab page is described in Sec. 5.16.2, the additional *Rays* page in Sec. 17.1.3.

44.5.5 General Profile: Modeling Analyzer

The Modeling Analyzer provides intermediate results of the light propagating through the Optical Setup using physical optics simulation. This helps you to understand and optimize the system modeling. As during propagation it is often switched between x- and k-domain using a Fourier Transform, the intermediate results are stored in a Set of Data Arrays (↪Sec. 16) which can contain results in both domains. The evaluation of the *Modeling Analyzer* is only supported in the *General Profile* as result visualization type.

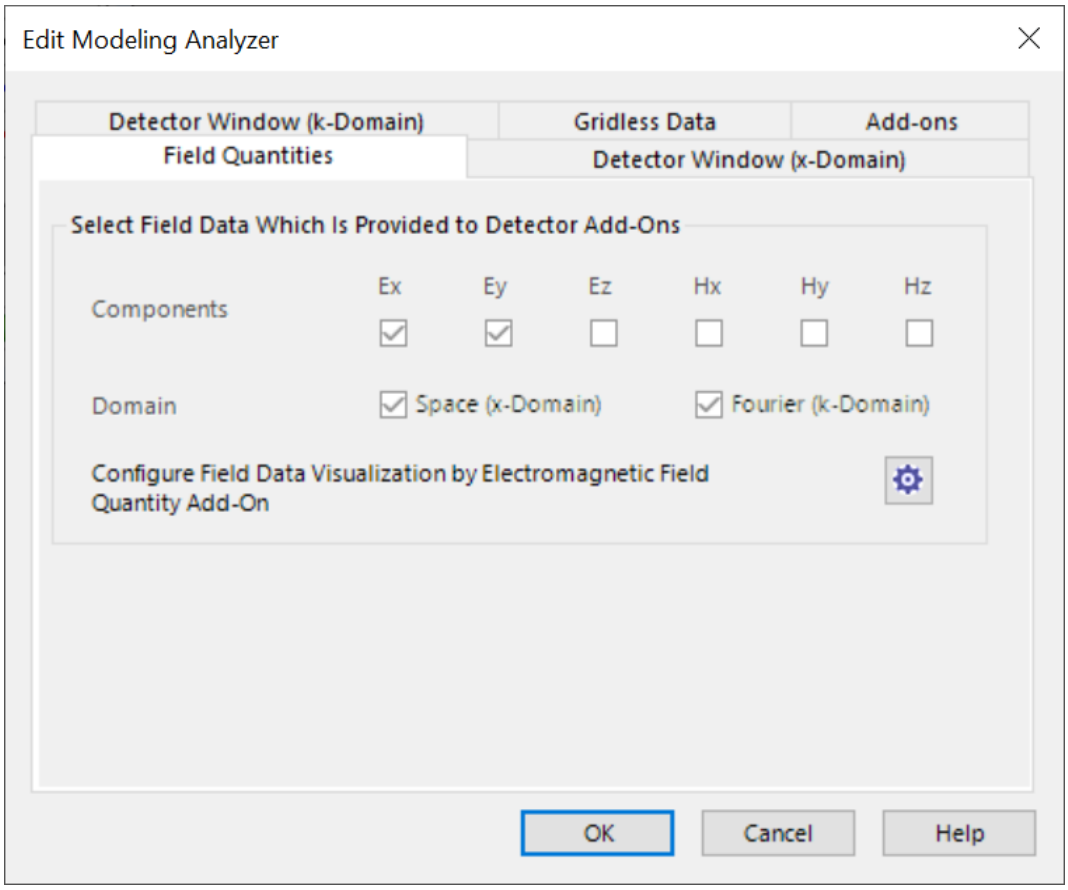


Figure 399. *The edit dialog of the Modeling Analyzer.*

The edit dialog of the *Modeling Analyzer* (↔Fig. 399) has the same structure as the *Universal Detector*. The following tab pages are available for configuration:

ITEM	DESCRIPTION
Field Quantities	On this tab page the user can define the field quantities and domains that shall be evaluated by the *Modeling Analyzer*. A detailed description of the user interface can be found in Sec. 75.4.1. Please note that in comparison to the *Universal Detector*, the *Modeling Analyzer* will always calculate *Ex* and *Ey* component in both domains, because they are provided within the system modeling. The selection of the quantities that shall be shown is done via *Configure Field Data Visualization by Electromagnetic Field Quantity Add-On*. The dialog to configure the field quantities to show (and their domains) and the available view options can be found in Sec. 75.4.5.1. The *Modeling Analyzer* provide the field information at different locations through the system. So the options for combination of modes is not provided here and the modes are shown separately. The current implementation of the *Modeling Analyzer* only support the evaluation of *Ex* and *Ey*, so there is also not the option to use paraxial assumption for field component calculation here.
Detector Window (x-Domain)	On the tab page *Detector Window (x-Domain)* the user can specify the size of the detector window which shall be used in x-domain. In addition he can select how the field information should be sampled (in case equidistant sampled data shall be generated). More information on the *Detector Window* can be found in Sec. 75.4.2.
Detector Window (k-Domain)	On the tab page *Detector Window (k-Domain)* the user can specify the size of the detector window which shall be used in k-domain. In addition he can select how the field information should be sampled (in case equidistant sampled data shall be generated). More information on the *Detector Window* can be found in Sec. 75.4.3.
Gridless Data	The *Modeling Analyzer* can also be configured to generate the output data in gridless format. Gridless format will be only provided if it is also available within the simulation (e.g. before and after pointwise Fourier transforms). Sec. 75.4.4 gives a detailed overview of the settings for gridless data. The *Modeling Analyzer* does not allow to configure manual sampling for gridless data, so you can access only the gridless data that is used within the engine processing.
Add-Ons	The edit dialog of the *Modeling Analyzer* also have a tab page to configure add-ons. For the *Modeling Analyzer* no customized detector add-ons can be specified. Only the standard add-on to show the *Electromagnetic Field Quantities* is available. The edit options for the *Electromagnetic Field Quantities* can be found in Sec. 75.4.5.1.

44.5.6 Classic Field Tracing

The Classic Field Tracing is our first implementation to do physical optics. Its implementation is typically limited to paraxial simulations or typical Fourier optical configurations. For the propagation between components (or to detectors) well-known and established diffraction integrals can be selected, which include for example *Spectrum of Plane Waves*, *Fresnel Integral* or *Far Field Integral*. In comparison to Classic Field Tracing the newly implemented way to do fast physical optics using our *Modeling Profile* technology is a generalization of all these techniques for free space propagation.

When applying the Classic Field Tracing engine the progress of the simulation can be tracked in the Optical Setup Editor. When the simulation of a linkage in the Optical Setup starts, the symbol is displayed in the very first column. When the simulation of the linkage is completed, the symbol is changed to .
The *Optical Setup Editor* also provide the special option to *Re-Use Automatic Settings* if Classic Field Tracing is selected as simulation engine. Here some settings automatically calculated during a simulation with Classic Field Tracing are written to a cache, for example the location of the Input Transface. For the next simulation these settings are then not calculated anew but the value from the cache is used, which can speed up the simulation. An example for such a setting is evaluation of the input transface (↪Sec. 94.1) by the geometrical optics component propagation (↪Sec. 97.1).
The *Re-Use* checkbox indicates whether the cache is filled and can be reused. If the check box is disabled the cache is empty. If the checkbox is enabled the user can select whether or not to use the cached settings by checking or unchecking the box.
In case that more than one mode is simulated and for each mode the automatic parameters are determined the *Re-Use* option stays disabled. This is because the size of the cache (only one parameter set is handled for each operator). To overcome this limitation, the user can select that only one member of the fields set is used to evaluate the automatic propagation parameters (↪Sec. 44.5.6.1).

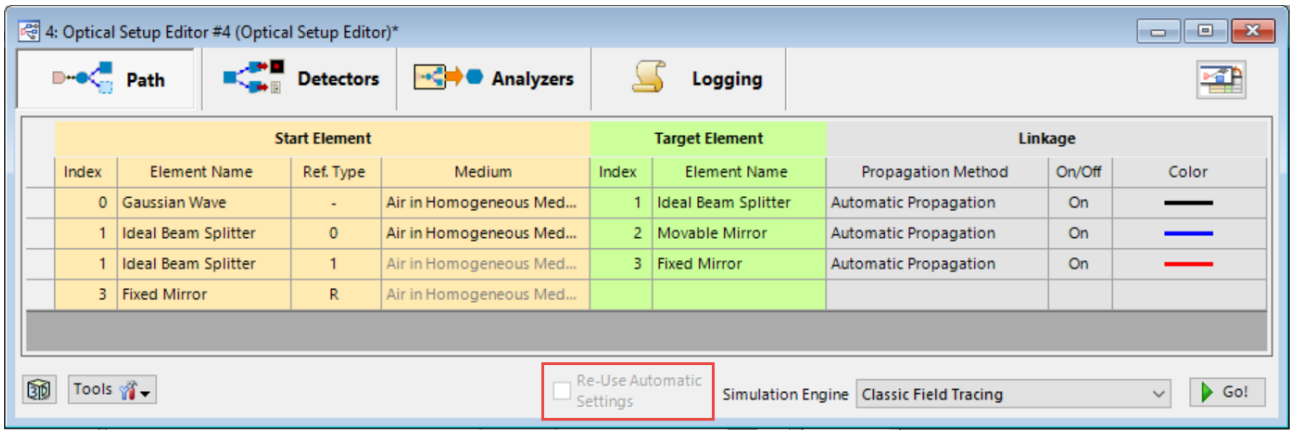


Figure 400. *The user interface which is used to communicate the state of the cache (filled or empty. If the cache is filled, the user can decide to re-use these settings from cache, which will speed up the simulation by* classicEngine*.*

Fig. 400 shows the option to *Re-Use Automatic Settings*, which is only available if Classic Field Tracing is selected as *Simulation Engine*.

44.5.6.1 Property Browser for Classic Field Tracing

ONLY AVAILABLE IN A GENERAL OPTICAL SETUP.

Only for Classic Field Tracing, the following options are available in the *Simulation Settings* tab of the Property Browser.

ITEM	DESCRIPTION
Use Global Accuracy PE	To use a global *Accuracy Factor* for automatic operations in VirtualLab Fusion, e. g. Automatic Propagation Operator, this option has to be set to *True*. Then the specific accuracy factors of the operation in the Optical Setup are ignored and the set global *Accuracy Factor* is used instead.
Accuracy Factor PV	The Optical Setup wide accuracy factor can be defined here. The default value is 1.0.

Use Global Deviation Threshold PE	If checked, the *Deviation Threshold* given here is used within each Automatic Propagation Operator present in the Optical Setup.
Deviation Threshold PE	Threshold value being used instead of values defined locally in the operators.
Optimize Field Before Propagating PE	If set to *True*, VirtualLab Fusion tries to optimize the field before propagating it between two subsequent Optical Setup Elements by truncating the field size and by rotating the field according to a possibly given analytical linear phase (i. e. a global direction vector). This option applies to the complete Optical Setup. The only exception, where no optimization will be tried, is the free space propagation behind a Field Size and Sampling Manipulation element. The meaning of this option for the free space propagation algorithm is shown in Fig. 401, where it is related to the first step.
Tilt Threshold PE	If there is an analytically given linear phase at the field, the field will be rotated according to this global direction vector during optimization only if the tilt angle is above this threshold. If the value is set to zero, a rotation will be done by the optimization algorithm for each direction vector which differs from $(0,0,1)$. The meaning of this option for the free space propagation algorithm is shown in Fig. 401, where it is related to the last step.
Pilot Ray Direction from Analytical Data Only PE	If this option is set to *True*, the calculation of the local pilot ray for the free space propagation between two subsequent elements will use the analytically stored linear phase direction of the field only. There will be no consideration of the sampled phase values in this case. So the calculation time for this special algorithm will be less, especially for large fields. On the other hand, a possibly incorrect pilot ray may lead to inefficient working of the subsequent algorithms with a bad overall performance. So use this option with caution. The meaning of this option for the free space propagation algorithm is shown in Fig. 402, where it is related to the second step.
Analysis for One Member Only PE	During the simulation of Optical Setups with a polychromatic or partially coherent source, several automatic operations (e. g. Automatic Propagation Operator) can be done by evaluating all sub-fields in the Harmonic Fields Set. This is very time consuming. VirtualLab Fusion enables the user to configure that these automatic operations are only done by evaluating one member of the Harmonic Fields Set. To enable this simulation mode, the user has to set this option to *True*.
Index of Analyzed Member PE	When the user defines that the decisions of the automatic operations are done only by evaluating one member of the Harmonic Fields Set, he also has to define the index of the sub-field in the Harmonic Fields Set which shall be used for the evaluation. This is done by setting the specific index here.

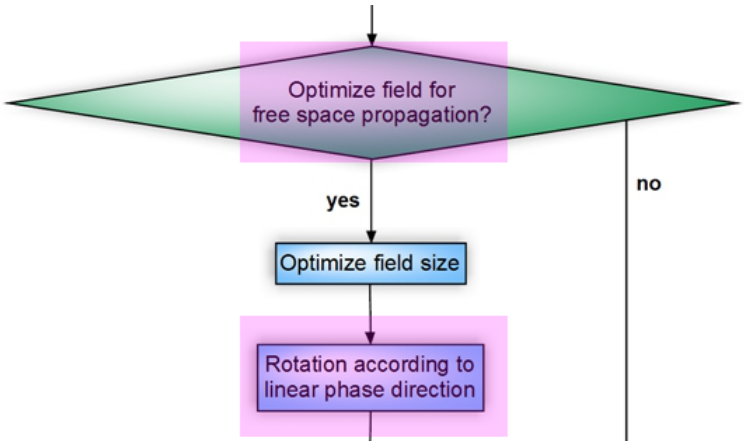


Figure 401. *Sub-algorithm for the free space propagation:* Optimization of the field. *(The colored steps refer to entries in the table shown above.)*

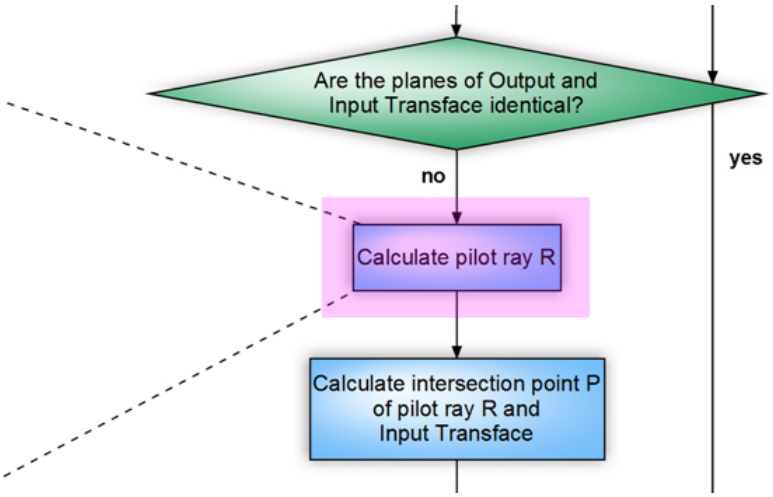


Figure 402. *Sub-algorithm for the free space propagation:* Pilot ray calculation. *(The colored step refers to an entry in the table shown above.)*

44.6 Parameter Extraction

VirtualLab Fusion allows that almost all parameters of an Optical Setup can be extracted and read out or varied externally.

- *All parameters* can be extracted to an XML file (↪Sec. 130.1).
- *Changeable parameters* are those parameters which when changed in the XML file can be re-imported into VirtualLab Fusion. This mainly affects Boolean, numerical, and string variables.
- *Variable parameters* are those changeable parameters which in addition can be varied externally. This is only possible for integer or real values. This mechanism is the foundation for special batch mode commands (↪Sec. 9), the Modulated Grating Parameters (↪Sec. 43.1.3), the Parameter Overview (↪Sec. 44.6.1), the Parameter Overview Tree (↪Sec. 44.6.2), the Parameter Coupling (↪Sec. 44.7), the Parameter Run (↪Sec. 45), the Grating Parameter Variation (↪Sec. 102.4), the Parametric Optimization (↪Sec. 103), the optiSLang Bridge (↪Sec. 104), and the export to optiSLang projects (↪Sec. 130.1.1).

Variable parameters are marked in the manual with a PV symbol, changeable but not variable parameters with a PC, and parameters which are only extractable with PE. Some properties marked by the PV symbol are represented by more than one numerical parameter. In general, only properties which are visible and activated in the corresponding edit dialog are extracted.

Example 1

If an optical stack (↪Sec. 40.2) is used for a General Grating in *1D-Periodic* mode, you can edit its *Period*[PV] in the corresponding edit dialog. This property is represented as “Period” in the parameter run. In contrast, if you set the grating to *2D-Periodic* mode, you can set two values for the *Period*[PV], namely one for the x- and one for the y-direction. Thus two parameters “Period X” and “Period Y” are available in the parameter run.
However, if the stack period is determined from a surface or media period, it cannot be changed by the user. In this case, **no** “Period” parameter for the stack is available in the parameter run.

More complex properties can have their own sub-properties. They are marked with a [PE] symbol. Clicking on this symbol leads to the corresponding manual section. In this section or subsections of it the available sub-properties can be found.

Example 2

An optical stack can comprise several *surfaces*[PE] and *subsequent media*[PE]. For example the *Conical Constant*[PV] of an *Aspherical Surface*[PE] within an *Optical Stack*[PE] of a *grating component*[PE] can be varied in the parameter run.

Parameters can be extracted from the following objects:

- The Optical Setup itself: For example the system temperature and the air pressure (↪Sec. 44.4.5.1) or the General Parameters of the Parameter Coupling snippet (↪Sec. 44.7.1.2).
- The Optical Setup Elements
- The linkages between the Optical Setup Elements: parameters of the rotation operators and the actual free space operators. Only for Classic Field Tracing. ↪Sec. 94

However, extraction of 10’000s of objects can decrease performance of VirtualLab Fusion significantly. Thus you can disable objects which can provide that many parameters via an Optical Setup Tool (↪Sec. 44.8). These objects are:

- A Surface Layout (↪Sec. 41.2) of a Light Guide with many regions.
- Coatings with many layers.
- For a Pillar Medium (General) (↪Sec. 38.3.8) with very many pillars, the pillar distribution parameters can be excluded.

44.6.1 Parameter Overview

Availability

Toolboxes: All

Accessible:

- Main window: Optical Setup > Parameter Overview
- Optical Setup Editor: *Tools* > *Parameter Overview*

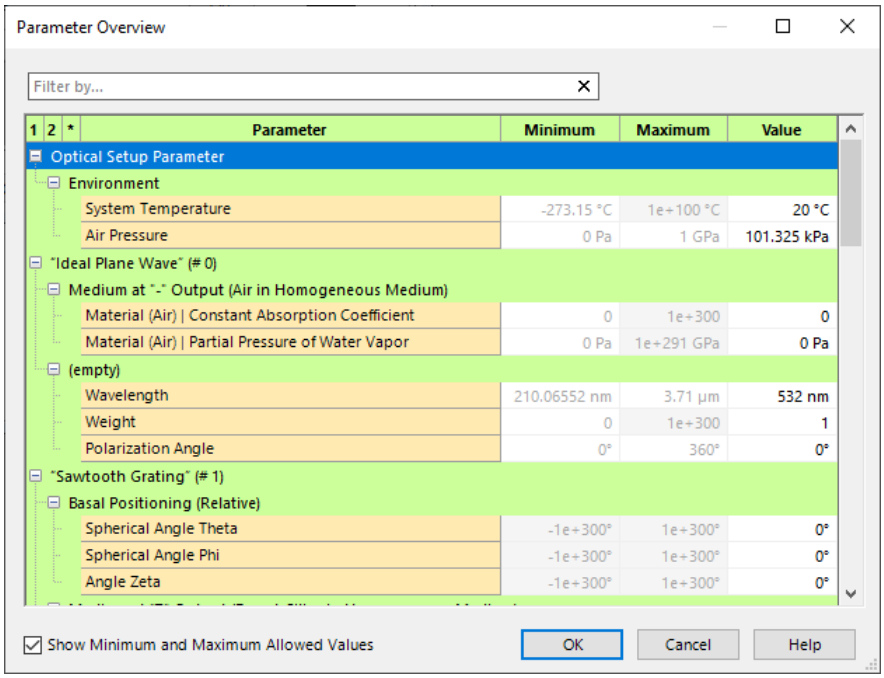


Figure 403. *The parameter overview dialog which also allows you to set new values for the given parameters.*

This tool opens a resizable dialog giving you an overview of most numerical parameters of all Optical Setup Elements. This dialog (↪Fig. 403) comprises a table with the following columns.

COLUMN	DESCRIPTION
{Unnamed}	The *Parameter*s are grouped by object (e. g. *"Ideal Plane Wave" (# 0)*) and then by the first category (which can be *{empty}*). The first column allows you to collapse / expand all these groups. Simply click on the ⊟ and ⊞ symbols, respectively. At the top of this column you can select to collapse all groups (*1*), collapse only the category groups (*2*) or expand all groups (*).
Parameter	Name of the parameter.
Value	By default the current value of the parameter is shown in this column. However, you can enter a new value here. It must be within the allowed *Minimum* – *Maximum* range (these columns can be made visible using *Show Minimum and Maximum Allowed Values*). Otherwise it is marked red. If you click *OK* the new value is set for the corresponding parameter.

Furthermore this dialog has the following controls:

ITEM	DESCRIPTION
Filter Table by	Only rows containing the given string either in the *Object*, *Category* (if applicable) or the *Parameter* column are shown. The matching is case insensitive. It is possible to search for multiple words and word groups embraced by quotation marks, for example: `"surface #1" scaling`.
Show Minimum and Maximum Allowed Values	If you check this option, two additional columns are displayed showing the absolute minimum and maximum values of the parameter – you must not enter a value outside of this range.

Sec. 44.6.2 describes a similar technique allowing you to change a single parameter without the need to open a separate dialog.

The available parameters are explained in Sec. 44.6.

44.6.2 Parameter Overview Tree

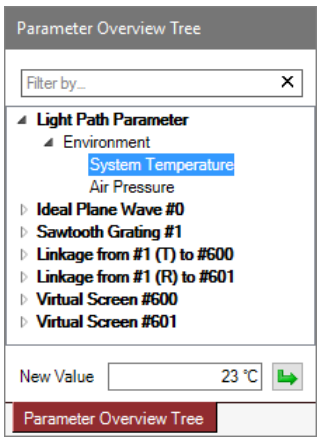


Figure 404. *The parameter overview tree which allows you to set new values for the given parameters.*

This docking tab page (↪Sec. 4.3) provides you with quick access to most numerical parameters of all Optical Setup Elements. It contains the following controls.

ITEM	DESCRIPTION
Filter Table by	Only parameters containing the given string or being in a category matching the given string are shown. The matching is case insensitive. It is possible to search for multiple words and word groups embraced by quotation marks, for example: `"surface #1" scaling`.
{Tree View}	Shows all parameters matching the current filter string. You can navigate through the tree with the arrow keys and `Page Up` and `Page Down`. You can expand / collapse nodes using `+`, `*` and `-`.
New Value	Shows the value of the currently selected parameter and allows you to change it (if it is not a coupled parameter, ↪Sec. 44.7). If the value is valid and different from the original value, you can submit it to the Optical Setup with the `Enter` key or the ↵-button.

You can move between the controls with the `Enter` key. The Optical Setup Element or linkage currently selected in the Optical Setup View (↪Sec. 44.1) is highlighted.
Sec. 44.6.1 describes a similar tool which allows you to set multiple parameters at once but within a separate dialog.
The available parameters are explained in Sec. 44.6.

44.7 Parameter Coupling

This expert tool allows you to define dependencies of selected Optical Setup parameters on others via a snippet. Changing the *independent parameter* leads to a change of the value of the dependent parameters, hence referred to as *coupled parameters*.
For any Optical Setup, you can switch on or off this mechanism via the Optical Setup > Use Parameter Coupling ribbon item or via the Property Browser. If parameter coupling is switched on, you can edit it via the Optical Setup > Edit Parameter Coupling ribbon item. The resulting edit dialog is explained in the subsection Sec. 44.7.1.

Note that any changes on coupled parameters in the Optical Setup are ignored as their value depends on the independent parameters. The effects of parameter coupling are explained in detail in subsection Sec. 44.7.2.

44.7.1 Edit Dialog for the Parameter Coupling

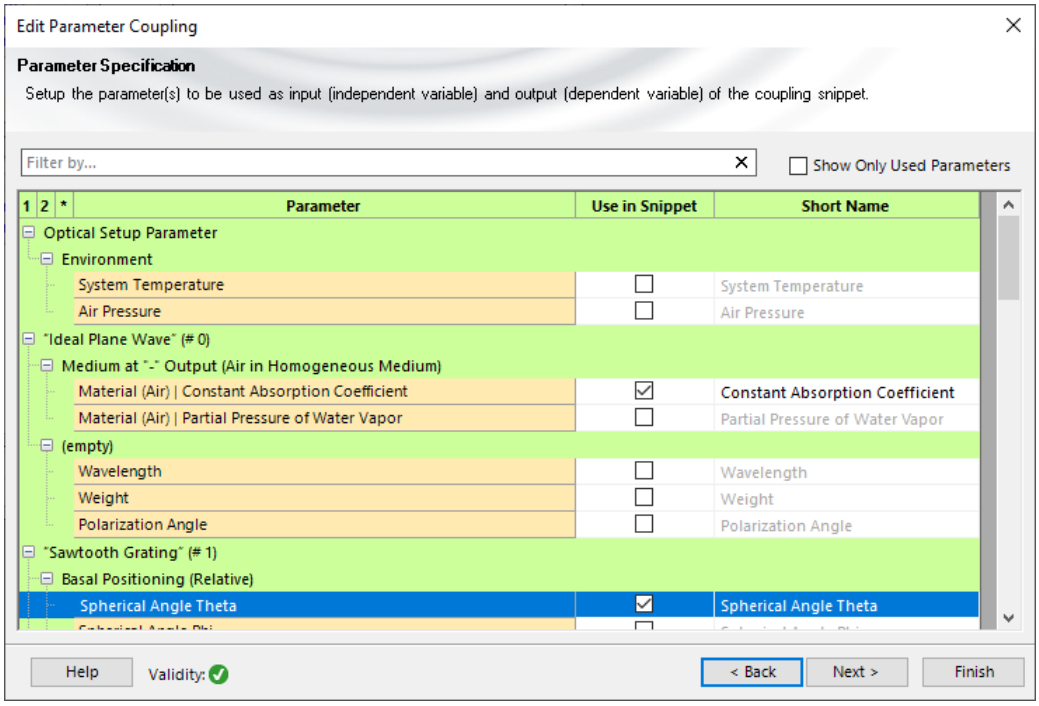


Figure 405. *The edit dialog for parameter coupling showing the Parameter Specification page.*

The edit dialog for the parameter coupling (↪Fig. 405) is a wizard with 4 pages:

1. The Welcome page giving you a short introduction.
2. The Parameter Specification page where you can setup the parameters to be used as input or output of the coupling snippet. (↪Sec. 44.7.1.1)
3. The Snippet Specification page where you define the snippet which does the actual parameter coupling. (↪Sec. 44.7.1.2)
4. The Summary Page which gives an overview of all coupled parameters you have added to the output dictionary of your snippet. Furthermore it gives for each coupled parameter the value it has if the snippet is executed with the current Optical Setup configuration.

Furthermore at the bottom of the edit dialog there is a validity control (↪Sec. 5.11) which shows current misconfigurations (invalid snippet and alike).
This dialog is resizable.

44.7.1.1 Parameter Specification page

This page comprises a table with the following columns.

COLUMN	DESCRIPTION
{Unnamed}	The *Parameter*s are grouped by object (e. g. *"Ideal Plane Wave" (# 0)*) and then by the first category (which can be *{empty}*). The first column allows you to collapse / expand all these groups. Simply click on the ⊟ and ⊞ symbols, respectively. At the top of this column you can select to collapse all groups (*1*), collapse only the category groups (*2*) or expand all groups (*).
Parameter	Name of the parameter.
Use in Snippet	In this column you can check which parameters are available in the snippet – either as input or as output parameters or as both. All selected rows are checked at once.
Short Name	The user can define a short name for the parameter which is used in the snippet. It can be an arbitrary non-empty string, but it must be unique. The short name proposed by VirtualLab Fusion is the *Parameter* name[1] – or the last part of it if the parameter name contains multiple parts separated by a '|'. Thus the proposed short name might not be unique.

This table contains all parameters made available by Parameter Extraction (↪Sec. 44.6) but integer values like the number of sampling points.
The table can be filtered with the following controls. Only rows passing all filters are shown.

ITEM	DESCRIPTION
Filter Table by	All rows containing the given string either in the group descriptions or in the *Parameter* column pass this filter. The matching is case insensitive.
Show Only Used Parameters	Only rows where the *Use in Snippet* column is checked pass this filter.

44.7.1.2 Snippet Specification page

On the Snippet Specification page you see the following controls:

ITEM	DESCRIPTION
Edit	Opens the Source Code Editor (↪Sec. 7.3) to edit the actual coupling snippet. The source code editor is the same as described in Sec. 7.3 with the only difference that it has a additional region on its *Source Code* tab (↪Fig. 406) where you see the short names of all parameters you have selected on the *Parameter Specification* page. These short names can be used as keys for the input and output dictionary, respectively, by double-clicking on them.
Validity	Shows whether the snippet is **syntactically** correct (↪Sec. 5.11). For example if you use non-existing short names in your snippet the syntax is correct and this validity indicator shows no issues. However, the snippet is nevertheless inconsistent and cannot be evaluated correctly. This kind of error is shown by the "global validity indicator" at the bottom of the form only.
{Global Parameters}	If you have defined Global Parameters in your snippet you can set them at the bottom of this page. ↪Sec. 7.4

[1] For the parameters within a Multiple Light Source (↪Sec. 50) the index of the sub light source is appended to the default short name; for the parameters of a Surface Layout (↪Sec. 41.2) the region index is appended.

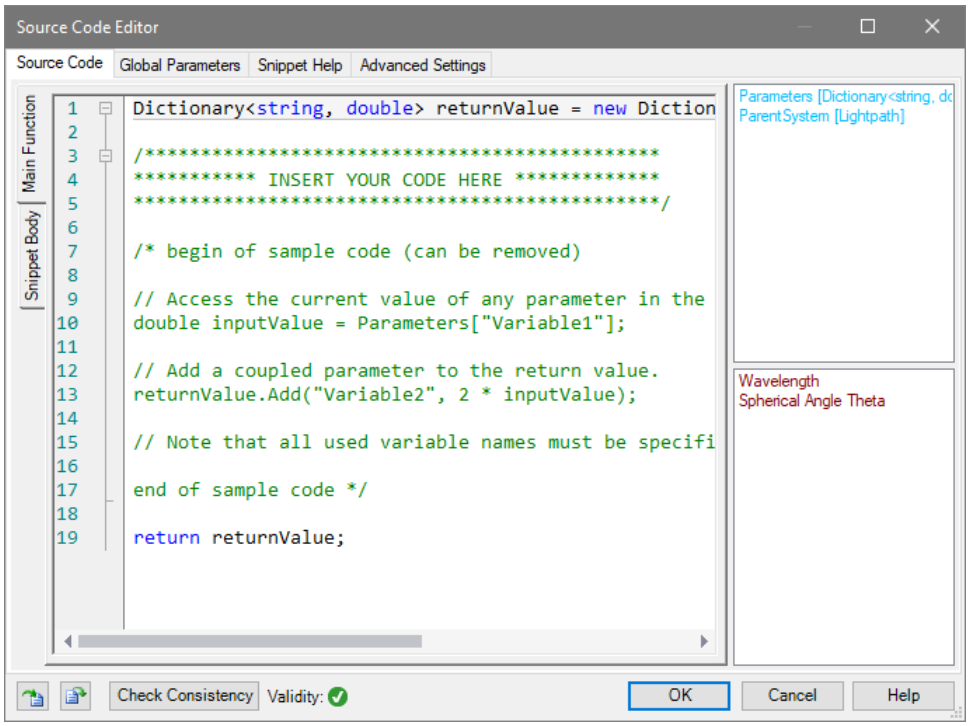


Figure 406. *The Source Code tab of the source code editor for Parameter Coupling. Note the list of short names in the lower right corner. Double-clicking on an entry in this list copies it to the current cursor position in your source code.*

44.7.2 Effects of the Parameter Coupling

The parameter coupling has the following effects:

- During each simulation of the Optical Setup, the coupled parameters are calculated according to the current configuration of the Optical Setup (especially the current value of those parameters used as input of the coupling snippet).
- Changes in the Optical Setup can make the Parameter Coupling invalid, for example if you delete an element which contains a parameter used in the coupling snippet. In this case Optical Setup simulations are no longer possible, you have to first adapt the Parameter Coupling via its edit dialog – or switch it off via the ribbon item Optical Setup > Use Parameter Coupling.
- You can still edit the coupled parameters via the edit dialogs of the Optical Setup Elements and the *Definition of Basal Position and Orientation* dialogs (↪Sec. 44.9.2.4). However, if you close such a dialog with *OK*, the coupled parameters you have just changed are reset and a warning is shown. Coupled parameters in other dialogs are adapted to your changes without further notice.
- There are various places with a parameter specification table similar to that of the Parameter Coupling dialog: Parameter Overview (↪Sec. 44.6.1), Parameter Run (↪Sec. 45), Polarization Analyzer (↪Sec. 88), Parametric Optimization (↪Sec. 103.1), and Export to optiSLang (↪Sec. 130.1.1).
  - In all these places, coupled parameters are grayed out as their actual values are determined by the coupling snippet. You cannot change anything for them.
  - In all these places but the Polarization Analyzer, the General Parameters (single values, vectors, arrays, …) of the coupling snippet are available as additional parameters.

  Fig. 407 shows an example.
- Also in the Parameter Overview Tree (↪Sec. 44.6.2) the coupled parameters are grayed out and read-only.

- Coupled Parameters are not exported to the `parameters.xml` file generated by the batch mode export (↪Sec. 9) or optiSLang export, respectively.
- In the result table of the Parameter Run or the Parametric Optimization, the values of the coupled parameters are logged per simulation step.

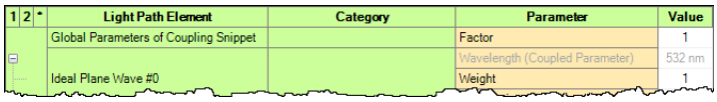


Figure 407. *The effect of Parameter Coupling in a parameter specification table (here: Parameter Overview).*
First line: *General Parameter of the coupling snippet*
Second line: *Coupled parameter (grayed out)*
Third line: *"Normal" parameter*

44.8 Tools

Besides the Profile Editing Tools (↪Sec. 44.3.2) there are much more tools which help you to configure an Optical Setup to your needs. Some of them are available in the ribbon tabs of the Optical Setup document, while the full set of tools is accessible via the menu that opens by clicking the button *Tools* in the left bottom corner of the Optical Setup Editor window. The following tools are available:

- Parameter Overview (↪Sec. 44.6.1)
- Configure Parameter Extraction: allows you to exclude performance critical objects from Parameter Extraction (↪Sec. 44.6)
- Optical Setup Tools which help you defining the optical setup, especially the execution sequence of the Optical Setup Elements (↪Sec. 44.8.1)
- Component Tools operate on specific types of Optical Setup Elements (↪Sec. 44.8.2)
- Catalog Support (↪Sec. 44.8.3)
- Import/Export of elements (↪Sec. 44.8.4)
- Import Parameters from XML: Imports an XML having the format described in Sec. 130.1 and sets all matching *variable parameters* (↪Sec. 44.6) to the values in the XML file
- Find Focus Position (↪Sec. 44.8.5)
- Optimize Detector Positions (↪Sec. 44.8.6)
- Show Simulation Report (↪Sec. 44.8.7)
- Create New Parameter Run (↪Sec. 44.8.8)
- Create New Parametric Optimization (↪Sec. 44.8.9)
- New Cells Array Design (↪Sec. 101)
- Remove All Lookup Tables (↪Sec. 44.8.10)
- Update Add-ons in Detectors (↪Sec. 44.8.11)

44.8.1 Optical Setup Tools

These tools assist you in defining the optical setup, especially the execution sequence of the Optical Setup Elements, by

- generating the sequence automatically (↪Sec. 44.8.1.1)
- toggling the active light source (↪Sec. 44.8.1.2)
- inserting elements into the sequence (↪Sec. 44.8.1.3)
- excluding elements from the sequence (↪Sec. 44.8.1.4)
- exchanging one element in the sequence by another (↪Sec. 44.8.1.5)
- synchronizing the sampling of the detectors (↪Sec. 44.8.1.6)
- converting a Grating Optical Setup into a General Optical Setup (↪Sec. 44.8.1.7)
- deleting all linkages (↪Sec. 44.8.1.8) or

- sorting the entries in the Optical Setup Editor (↪Sec. 44.8.1.9) .

44.8.1.1 Generate Sequence

Availability

Optical Setups: General, Laser Resonator, Light Guide, and Light Shaping Optical Setup

Accessible:

- Ribbon: Layout Tools > Complete Sequence Generation / Layout Tools > Partial Sequence Generation
- Optical Setup Editor: *Tools > Generate Sequence > Complete Sequence Generation* / *Tools > Generate Sequence > Partial Sequence Generation*

Configuring an Optical Setup requires the creation of all linkages between Optical Setup Elements which shall be simulated. This can be done manually or by using the Optical Setup Tool *Generate Sequence*. First the user has to drag all Optical Setup Elements to the Optical Setup View in an order which corresponds to the desired execution sequence. Then *Generate Sequence* can be used for creating the corresponding linkages between the Optical Setup Elements automatically.

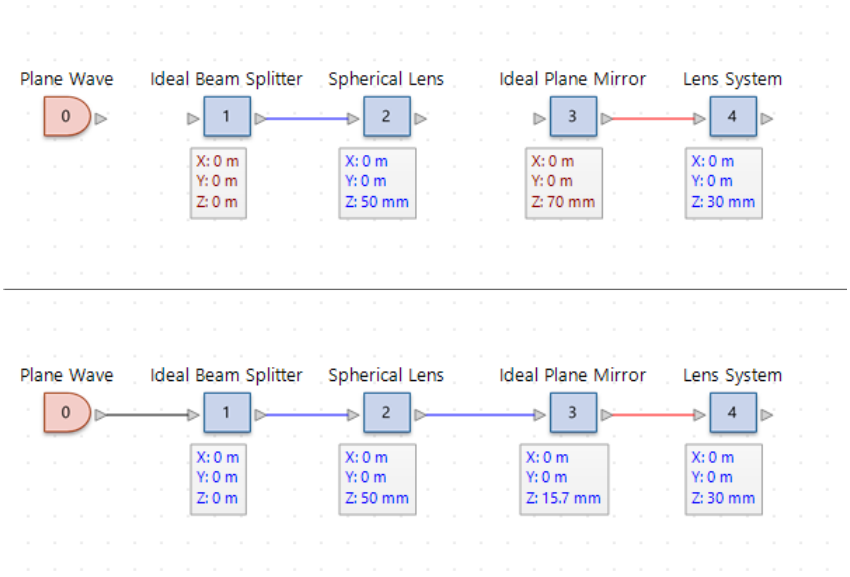


Figure 408. *The same optical setup before (top) and after (bottom) automatic sequence generation.*

This algorithm uses the following rules to connect the elements in the Optical Setup:

1. The algorithm only considers the light source with index 0, Components, and Ideal Components. Detectors are not included in the *Generate Sequence* algorithm, because they can be connected to more than one Optical Setup Element (↪Sec. 44.2.2). Analyzers cannot be linked at all.
2. The start element is the Optical Setup Element with the lowest index which is not connected to another element).
3. This start element is then connected to the element with the next larger index having a free input. Usually a transmission linkage is generated.
4. The 2nd and 3rd step are repeated until no element without output connection can be found anymore.

There are two options available for generating a sequence: *Complete Sequence Generation* means the connection of all free elements. *Partial Sequence Generation* allows the user to define the maximum end element of the sequence algorithm (↪Fig. 409).

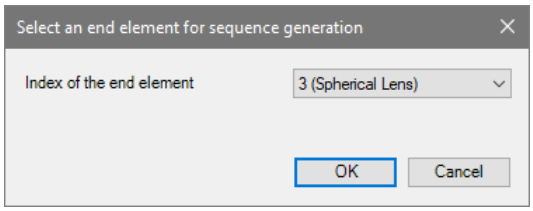


Figure 409. *If the user likes to apply the Generate Sequence algorithm only to a subset of the system, the index of the end element has to be configured in the* Partial Sequence Generation *dialog.*

This *Partial Sequence Generation* can be helpful when the Optical Setup the user likes to configure is split at one specific Optical Setup Element.

44.8.1.2 Toggle Light Source

Availability

Optical Setups: General, Laser Resonator, Light Guide, and Light Shaping Optical Setup

Accessible:

- Ribbon: Layout Tools > Toggle Light Source
- Optical Setup Editor: *Tools* > *Toggle Light Source*
- Optical Setup View: Via context menu of a currently inactive light source.

The configuration of a second light source in an Optical Setup that contains already an active light source can be helpful, e. g. to investigate the behavior of the defined optical system when another source is used for illumination. VirtualLab Fusion supports adding additional light sources to an existing Optical Setup. To ensure that only one light source is used for the simulation of the Optical Setup, the active source always gets the special index 0. All additionally added light sources get an index of 500 or higher. In the Optical Setup only linkages from the source with the index 0 are supported. Light sources with index 500 or higher cannot be connected with other Optical Setup Elements.
To change the active light source of a configured Optical Setup, one has to use the Optical Setup Tool *Toggle Light Source*. If only one other light source exists in the Optical Setup, the indices between this light source and the active one are toggled. If the Optical Setup contains more than one additional light source, the user has to select the index of the light source which shall be activated. This selection is done by the dialog shown in Fig. 410.

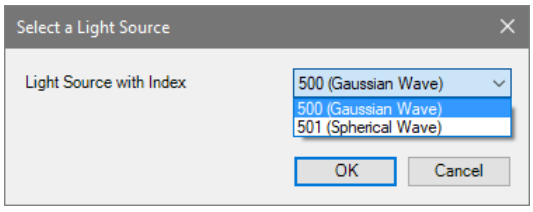


Figure 410. *Dialog for selecting the active light source.*

You can also use the context menu of an inactive light source in the Optical Setup View to make it the active one.

44.8.1.3 Insert Element into Optical Setup

Availability

Optical Setups: General, Laser Resonator, Light Guide, and Light Shaping Optical Setup

Accessible:

- Ribbon: Layout Tools > Insert Element
- Optical Setup Editor: *Tools* > *Insert Element into Optical Setup*

To insert a new Optical Setup Element into an already configured Optical Setup, the *Path* table of the Optical Setup Editor can be used to relink the corresponding connections manually. Or you can use the Optical Setup Tool *Insert Element into Optical Setup* which inserts a currently not linked element behind a given already linked element. The affected elements are relinked automatically. For the linkage from the precedent to the inserted element the used reference coordinate system is specified in the dialog. For the linkage from the inserted element to a possible subsequent element usually the "T" (transmission type) or "0" reference coordinate system is used. Detector linkages are not changed. Fig. 411 shows an example.

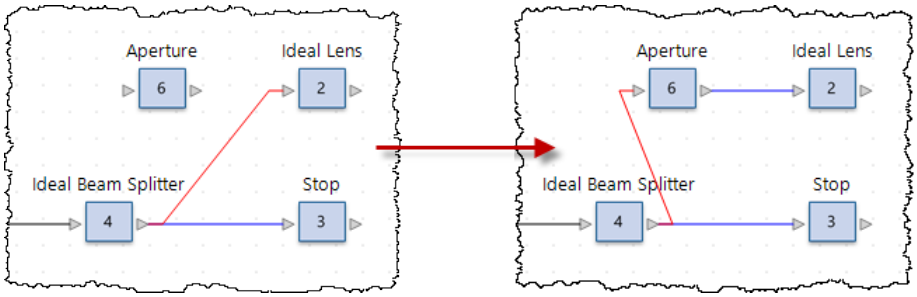


Figure 411. *Example how the* Insert Element into Optical Setup *tool works. The left image shows the initial situation. The right image shows the setup after the Aperture #6 has been linked to the reference coordinate system named "1" (red) of the Ideal Beam Splitter #4. Aperture #6 has been linked automatically to Ideal Lens #2 which was previously the subsequent element of the Ideal Beam Splitter #4. Therefor its reference coordinate system "T" (blue) is used.*

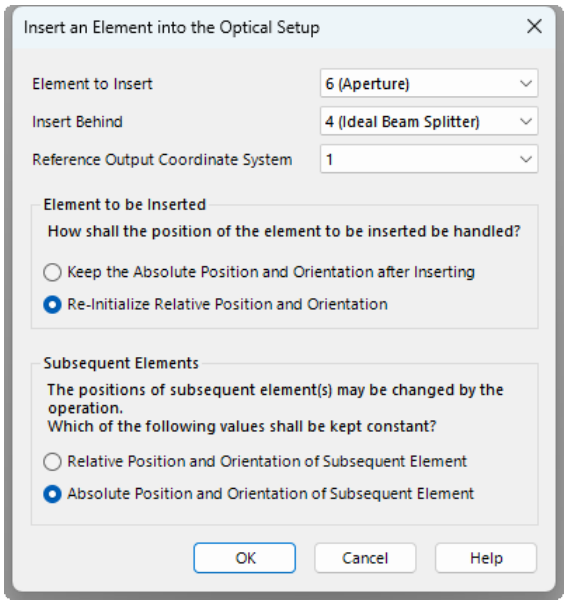


Figure 412. *For inserting a new Optical Setup Element into an existing Optical Setup, the element and its position in the execution sequence can be specified.*

Fig. 412 shows the edit dialog where the user can define the Optical Setup Element which shall be inserted as well as its position in the execution sequence.

ITEM	DESCRIPTION
Element to Insert	Select the index of the Optical Setup Element you like to insert into the existing Optical Setup.
Insert Behind	Select the index of the Optical Setup Element behind which the *Element to Insert* shall be inserted.
Reference Output Coordinate System	The output coordinate system of the element which is chosen as *Insert Behind* which will serve as reference for the *Element to Insert*.
How shall the position of the element to be inserted be handled?	If the *Element to Insert* has already got an absolute position / orientation, the user can decide whether it will be kept or be re-initialized.
Keep the Absolute Position and Orientation after Inserting	If selected, the absolute position / orientation of the *Element to Insert* will be kept.
Re-initialize Relative Position and Orientation	If selected, the relative position and orientation of the *Element to Insert* will be re-initialized after inserting.
Which of the following values shall be kept constant?	Since the position and orientation of the subsequent elements may be changed by the insert operation, the user may select the handling of these data.
Relative Position and Orientation of Subsequent Element	If selected, the relative positions and orientations of the subsequent elements will be kept constant.
Absolute Position and Orientation of Subsequent Element	If selected, the absolute positions and orientations of the subsequent elements will be kept constant.

This Optical Setup Tool is only available if there is at least one not linked Component or Ideal Component and at least one linkage.

44.8.1.4 Exclude Element from Optical Setup

Availability

Optical Setups: General, Laser Resonator, Light Guide, and Light Shaping Optical Setup

Accessible:

- Ribbon: Layout Tools > Exclude Element
- Optical Setup Editor: *Tools* > *Exclude Element from Optical Setup*

For fast excluding of an Optical Setup Element from a configured Optical Setup without losing its validity, the Optical Setup Tool *Exclude Element from Optical Setup* can be used. This tool removes all linkages of a selected Optical Setup Element. Fig. 413 shows the edit dialog of this tool.

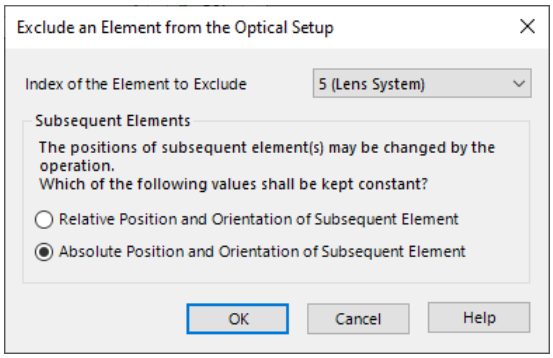


Figure 413. *Dialog for selecting the index of the Optical Setup Element to exclude.*

Important: The Optical Setup Element is excluded from the execution sequence only, it is not removed from the Optical Setup itself. Only all linkages which start or end at the selected Optical Setup Element are relinked and so the simulation is done without this Optical Setup Element.

ITEM	DESCRIPTION
Element to exclude	Select the index of Optical Setup Element you like to exclude from the Optical Setup.
Which of the following values shall be kept constant?	Since the position and orientation of the subsequent elements may be changed by the exclude operation, the user may select the handling of these data.
Relative Position and Orientation of Subsequent Element	If selected, the relative positions and orientations of the subsequent elements will be kept constant.
Absolute Position and Orientation of Subsequent Element	If selected, the absolute positions and orientations of the subsequent elements will be kept constant.

VirtualLab Fusion only supports to exclude Optical Setup Elements which are the end element of one linkage and the start element of one or more linkages. If no elements which meet this conditions are available, the Optical Setup Tool *Exclude Element from Optical Setup* cannot be applied.

Important: Only Ideal and Real Components can be excluded from Optical Setups, because all other elements can only be the start (light sources) or end (detectors) points of light paths.

44.8.1.5 Exchange Elements in Optical Setup

Availability

Optical Setups: General, Laser Resonator, Light Guide, and Light Shaping Optical Setup

Accessible:

- Ribbon: Layout Tools > Exchange Elements
- Optical Setup Editor: *Tools* > *Exchange Elements in Optical Setup*

Sometimes it is helpful to exchange an Optical Setup Element in a configured Optical Setup by another more

suited element. This can be done manually by using the *Path* table in the Optical Setup Editor and relinking of all corresponding linkages. Alternatively, the Optical Setup Tool *Exchange Elements in Optical Setup* can be used to solve this task. The user has to specify the element which shall be excluded from the Optical Setup and the element to substitute. This selection is done by the dialog shown in Fig. 414

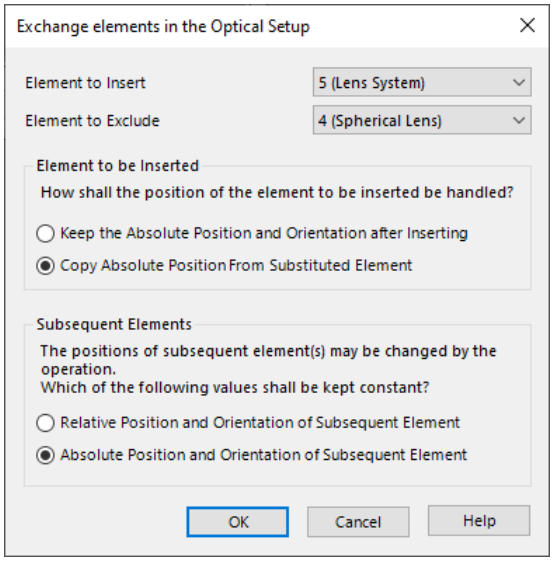


Figure 414. *To exchange an Optical Setup Element with a new one in an existing Optical Setup, use the Optical Setup Tool* Exchange Optical Setup Elements.

ITEM	DESCRIPTION
Element to insert	Select the index of the Optical Setup Element you like to insert into the Optical Setup.
Element to exclude	Select the index of the Optical Setup Element you like to exclude from the Optical Setup.
How shall the position of the element to be inserted be handled?	If the *Element to insert* has already got an absolute position / orientation, the user can decide whether it has to be kept or be re-initialized.
Keep the Absolute Position and Orientation after Inserting	If selected, the absolute position / orientation of the *Element to insert* will be kept.
Copy Absolute Position From Substituted Element	If selected, the absolute position and orientation of the *Element to exclude* will be copied to the *Element to insert* after inserting.
Which of the following values shall be kept constant?	Since the position and orientation of the subsequent elements may be changed by the insert operation, the user may select the handling of these data.
Relative Position and Orientation of Subsequent Element	If selected, the relative positions and orientations of the subsequent elements will be kept constant.
Absolute Position and Orientation of Subsequent Element	If selected, the absolute positions and orientations of the subsequent elements will be kept constant.

Fig. 415 shows a sample application of the *Exchange Elements in Optical Setup* tool.

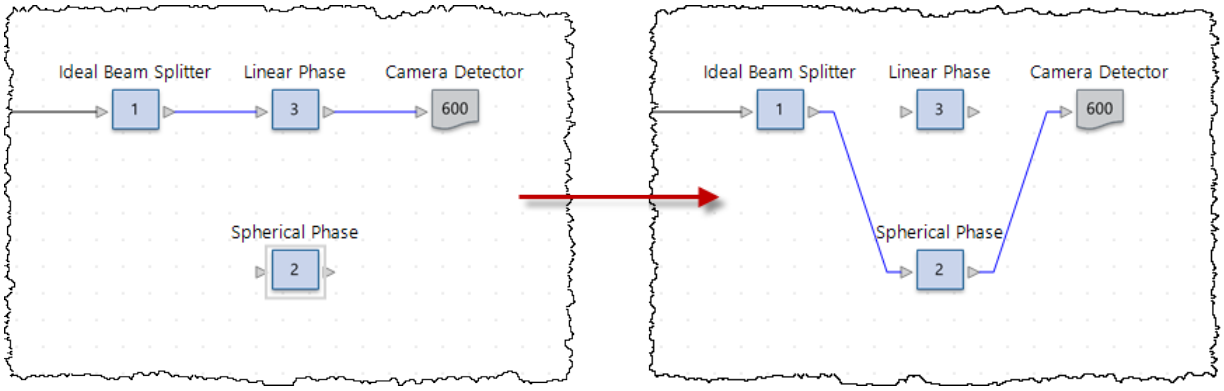


Figure 415. *An example for the usage of the Exchange Elements in Optical Setup tool. The Linear Phase Transmission with index #3 is exchanged by the Spherical Phase Transmission with index #2.*

44.8.1.6 Synchronize Detector Sampling

Availability

Toolboxes: All

Accessible:

- Ribbon: Layout Tools > Synchronize Detector Sampling
- Optical Setup Editor: *Tools* > *Synchronize Detector Sampling*

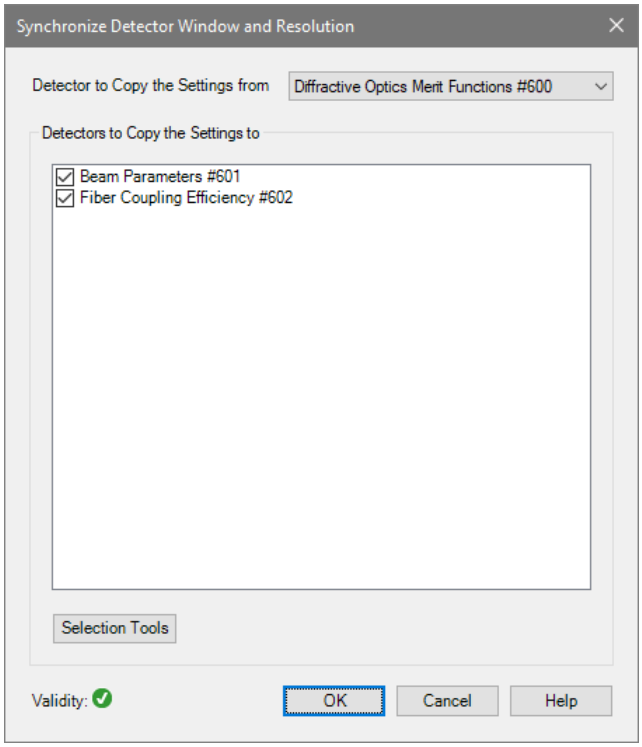


Figure 416. *The dialog for synchronizing detector window and resolution among detectors.*

Using this Optical Setup Tool you can copy the detector window and resolution settings (↪Sec. 75.1.1) from one detector to another. This tool opens a dialog (↪Fig. 416) with the following settings:

ITEM	DESCRIPTION
Detector to Copy the Settings from	The detector from which the detector window and resolution settings are copied.
Detectors to Copy the Settings to	This section of the dialog allows you to select one or more detectors to which the settings from the *Detector to Copy the Settings from* are copied (↪Sec. 5.9).
Validity	This control (↪Sec. 5.11) displays a red cross if no detector to copy the settings to is selected.

44.8.1.7 Convert to General Optical Setup

ONLY FOR GRATING OPTICAL SETUPS

This tool converts a complete Grating Optical Setup (↪Sec. 44.11.1) into a General Optical Setup by means of the following rules:

- The Ideal Plane Wave is converted into a Plane Wave (↪Sec. 52.2).
- Each stack of the grating component is converted into a Grating component (↪Sec. 61.3).
- The Raw Data Detectors are converted into Universal Detectors (↪Sec. 75.4).

As a result you obtain a General Optical Setup which produces nearly the same near field results as the original Grating Optical Setup. However, for all the analyzers of a Grating Optical Setup (but the Parameter Variation Analyzer; ↪Sec. 84) there are no equivalents in a General Optical Setup. So among others you cannot directly evaluate the efficiencies. But you can use the System Efficiency detector from the LightTrans Defined Detectors Catalog (↪Sec. 33) to this end.

44.8.1.8 Delete All Linkages

Availability

Optical Setups: General, Laser Resonator, Light Guide, and Light Shaping Optical Setup

Accessible:

- Ribbon: Layout Tools > Delete All Linkages
- Optical Setup Editor: *Tools* > *Delete All Linkages*

This Optical Setup Tool deletes all linkages (also linkages to the detectors) in the underlying Optical Setup.

44.8.1.9 Sort Table Entries

Availability

Optical Setups: General, Laser Resonator, Light Guide, and Light Shaping Optical Setup

Accessible:

- Optical Setup Editor: *Tools* > *Sort Table Entries*

This Optical Setup Tool can be used for sorting the *Path* table of the Optical Setup Editor in a well-defined way. This tool is very helpful if the linkages were set in a confused order, e. g. first the last two elements in the Optical Setup were connected and then the light source at the end of the light path configuration. Then this Optical

Setup Tool sorts the table entries in the *Path* table in the order of their execution when the Optical Setup is simulated. This tool is also automatically applied after loading a stored Optical Setup.

44.8.2 Component Tools

There are tools which operate on specific types of Optical Setup Elements.
The *Split Component* tool splits one Lens System or Light Guide component into distinct elements (↪Sec. 44.8.2.1). The *Combine Components* tools combines several consecutive Curved Surfaces, Spherical Lenses, and Lens Systems into a single Lens System (↪Sec. 44.8.2.2). The *Turn Component* tool turns a Curved Surface, Lens System, or Spherical Lens by 180° about its y-axis (↪Sec. 44.8.2.3).

44.8.2.1 Split Component

Availability

Optical Setups: General, Laser Resonator, Light Guide, and Light Shaping Optical Setup

Accessible:

- Ribbon: Layout Tools > Split Component
- Optical Setup Editor: *Tools* > *Split Component...*

If the user likes to evaluate a detector result within a Lens System or Light Guide component, VirtualLab Fusion provides the Optical Setup Tool *Split Component* to split the component after the specified surface(s). So the user can place a detector between the resulting components.

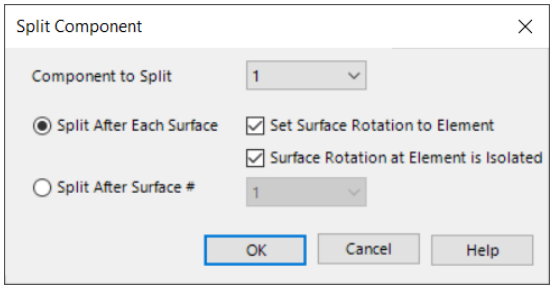


Figure 417. *Edit dialog of the Split Component tool*

The edit dialog of this tool (↪Fig. 417) has the following settings:

ITEM	DESCRIPTION
Component to Split	The index of the component to be split. Any Lens System or Light Guide with at least two surfaces is available in this list.
Split after Each Surface	If this option is active, the selected *Component to Split* is split after each surface, i. e. each resulting component contains exactly one surface.
Set Surface Rotation to Element	ONLY IF THE SELECTED *COMPONENT TO SPLIT* CONTAINS ANY SURFACES THAT ARE INCLINED / ROTATED. If checked, the rotation / inclination of the surfaces will be set to the new components. The single surface inside each new component will not be inclined anymore, then. If not checked, the new components will have the same orientation as the original one. The single surface inside each new component will keep its inclination as before.
Surface Rotation at Element is Isolated	ONLY IF *SET SURFACE ROTATION TO ELEMENT* IS SELECTED. If checked, the rotation / inclination of the element, which has been taken from the surface, will be set as isolated. So, subsequent elements which have a relative position and orientation to the inclined element are not affected.
Split after Surface	If this option is active, you can select the index of the surface after which the component shall be split into two. All indices of the surfaces of the selected *Component to Split* (except that of its last surface) are available.

After pressing the *OK* button of the edit dialog, the selected component is split into two or more components. The split components are connected by linkages. Fig. 418 shows an example: the resulting Optical Setup contains two Lens Systems which are connected.

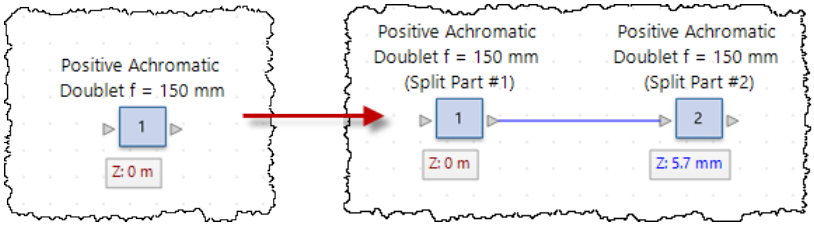


Figure 418. *An example for the usage of the Optical Setup Tool* Split Component.

If no valid component to split is available, VirtualLab Fusion displays an error message when executing the Split Component tool.

44.8.2.2 Combine Components

Availability

Optical Setups: General, Laser Resonator, Light Guide, and Light Shaping Optical Setup

Accessible:

- Ribbon: Layout Tools > [] Combine Component
- Optical Setup Editor: *Tools* > [] *Combine Component...*

Real Components of type Curved Surface (↪Sec. 59.1), Spherical Lens (↪Sec. 58.3), Lens System (↪Sec. 58.1), or Light Guide (↪Sec. 58.2) can be tried to be combined into new components of type Lens System. All optical surfaces inside the original components will form a new sequence if possible.
Calling this tool, the dialog shown in Fig. 419 allows to specify the operation.

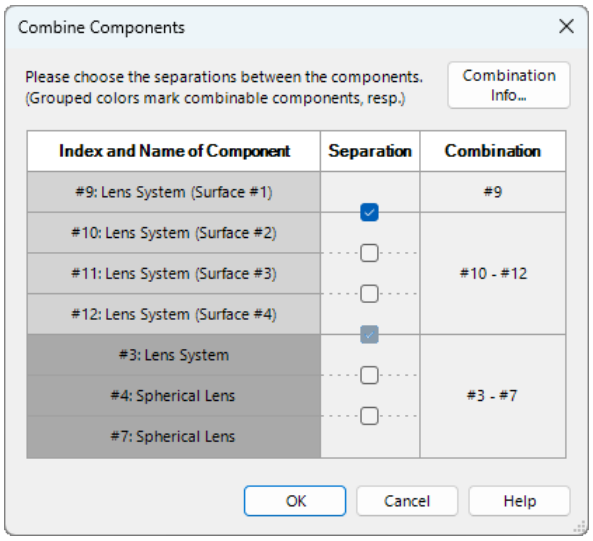


Figure 419. *Edit dialog of the Combine Components tool*

The edit dialog of this tool provides the following settings and information:

ITEM	DESCRIPTION
Index and Name of Component	The first column shows the indices and names of components which can be combined to a new component. Adjacent rows with the same background color mark those components which can be combined to the same resulting Lens System. Example from Fig. 419: The elements #9, #10, #11, and #12 can be combined to one Lens System, the elements #3, #4, and #7 can be combined to another Lens System.
Separation	In this column the user has to select which separations shall be kept. If a combination is not possible at one place, the box is checked read-only (like between #12 and #3 in Fig. 419). Each box which is *not* checked will result in a combination of the components above and below the dashed line.
Combination	This column gives the information about the new components which would result from the current selections.
Combination Info...	This opens a dialog that informs about the restrictions which determine what components can be combined with others (see below).

The restrictions for a Lens System component that determine the restrictions for combining existing components are the following:

- All optical surfaces have to be centered to one common optical axis.
- Optical surfaces in the sequence may not be tilted to the optical axis nor rotated about this axes in reference to the first surface in the sequence.

If it is not possible to combine any components in the current Optical Setup, an error message will be given.

44.8.2.3 Turn Component

Availability

Optical Setups: General, Laser Resonator, Light Guide, and Light Shaping Optical Setup

Accessible:

- Ribbon: Layout Tools > Turn Component
- Optical Setup Editor: *Tools* > *Turn Component*
- Optical Setup View: Via context menu.

If you execute this tool, there is first a dialog where you can select any Curved Surface, Lens System, or Spherical Lens component present in the Optical Setup. If no such component is available, an error message is shown instead.

Then this tool does the following steps on the selected component:

- Multiply the x- and z-scaling (↪Sec. 36.1.2) of all surfaces with -1. This means that they are rotated by 180° about their y-axis.
- Invert the order of the surfaces, their corresponding distances, and media.

In effect, the whole component is turned by 180° about its y-axis. Note that in contrast to rotating a component by 180° via its edit dialog (↪Sec. 5.6), this tool changes through which surface light enters the component as well as the position of the internal coordinate system relative to the component.

44.8.3 Catalog Support

Availability

Optical Setups: General, Laser Resonator, Light Guide, and Light Shaping Optical Setup

Accessible:

- Ribbon: Layout Tools > Catalog Support (ribbon group)
- Optical Setup Editor: *Tools* > *Catalog Support*

The menu items in this section allow you to save light sources (↪Part VIII), components (↪Part IX), and detectors (↪Part XI) to the corresponding catalogs.

The entries for light sources and detectors are only available for a General, a Light Guide, or a Laser Resonator Optical Setup.

ITEM	DESCRIPTION
Add Light Source from Catalog	Loads the selected item from the light sources catalog and adds it to the Optical Setup. See Sec. 33 for details on the catalog dialog.
Save Light Source to Catalog	Opens a dialog to select one light source. Saves the selected item to the light sources catalog after asking for name and categories (↪Sec. 33.1).
Add Component from Catalog	Loads the selected item from the components catalog and adds it to the Optical Setup. See Sec. 33 for details on the catalog dialog.
Save Component to Catalog	Opens a dialog to select one component. Saves the selected item to the components catalog after asking for name and categories (↪Sec. 33.1).
Add Detector from Catalog	Loads the selected item from the detectors catalog and adds it to the Optical Setup. See Sec. 33 for details on the catalog dialog.
Save Detector to Catalog	Opens a dialog to select one detector. Saves the selected item to the components catalog after asking for name and categories (↪Sec. 33.1).

44.8.4 Import / Export Elements

Availability

Optical Setups: General, Laser Resonator, Light Guide, and Light Shaping Optical Setup

Accessible:

- Optical Setup Editor: *Tools > Import/Export Elements*

It can be helpful to save an Optical Setup Element to hard disk. This allows you to later import them into another Optical Setup. Doing so, you can define kind of a catalog of often used Optical Setup Elements. In contrast to the Catalog Support tool (↪Sec. 44.8.3) this works also for light sources, Ideal Components, detectors, and analyzers. To export an Optical Setup Element from an Optical Setup, the user simply has to click the *Import/Export Elements > Export Optical Setup Element* item in the *Tools* menu. Then a dialog (↪Fig. 420) is shown where the index of the element to export has to be specified.

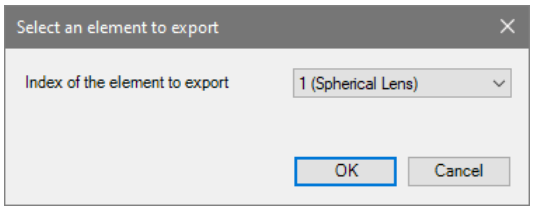


Figure 420. *To export an Optical Setup Element, the index of the element to export has to specified.*

VirtualLab Fusion supports only the export of one Optical Setup Element at a time. After pressing the *OK* button in the selection dialog, the user has to specify the file name and location to store the selected Optical Setup Element to. The Optical Setup Elements are saved with the file extension *.lpe.
To import a previously stored Optical Setup Element from hard disk, one has to select the *Import/Export Elements > Import Stored Optical Setup* item in the menu for the Optical Setup Tools. Then a file open dialog is shown where the user has to specify the element to be imported. The selected file must have the file extension *.lpe. If the import of the selected Optical Setup Element was successful, the new element is added to a default position in the flowchart area of the Optical Setup View and can subsequently be linked to other elements.

44.8.5 Find Focus Position

Availability

Optical Setups: General Optical Setup

Accessible:

- Ribbon: Optical Setup > Find Focus Position
- Optical Setup Editor: *Tools > Find Focus Position*

This Optical Setup Tool optimizes the position of one detector so that it is in the focus, i. e. the position where a Ray Results Profile simulation yields the smallest spot diameter. For evaluation of the size within the detector plane the RMS detector is used on the ray bundle. Only the position of detecting devices having exact one active linkage can be optimized.

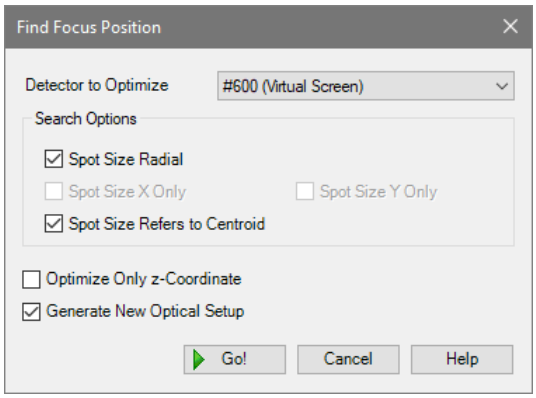


Figure 421. *The edit dialog of the Find Focus Position tool.*

Its edit dialog (↔Fig. 421) has the following options

ITEM	DESCRIPTION
Detector to Optimize	The detector whose position shall be optimized.
Spot Size Radial	Option for the detection of the RMS value. If this option is selected the radial size is determined by the detector.
Spot Size X Only	Option for the detection of the RMS value. If this option is selected only the extension in x-dimension is evaluated by the detector.
Spot Size Y Only	Option for the detection of the RMS value. If this option is selected only the extension in y-dimension is evaluated by the detector.
Spot Size Refers to Centroid	Flag whether the RMS value is measured to the centroid of the ray bundle. If this option is not selected the position of the central ray will be used as reference for the RMS calculation.
Optimize Only z-Coordinate	The focus finder can be used to detect the 3D position of the focus. The user can select whether only the z-coordinate of the focus position shall be used in the generated or updated Optical Setup, or whether the complete 3D information shall be used.
Generate New Optical Setup	The user can define whether a new Optical Setup shall be generated, or whether the optimized position shall be set into the active Optical Setup.

44.8.6 Optimize Detector Positions

Availability

Optical Setups: General Optical Setup

Accessible:

- Ribbon: Optical Setup > Optimize Detector Positions
- Optical Setup Editor: *Tools* > *Optimize Detector Positions*

If a detector is not placed at the optimal lateral position, an embedding of the incoming field might be necessary to match it with the detector position. This Optical Setup Tool generates a new Optical Setup where the positions of all detectors of the original Optical Setup are optimized so that they are placed right in the middle of the incoming light distribution. This optimization is done using Ray Results Profile simulations. Only the position of detectors having exact one active linkage can be optimized.

In case the detector is tilted in reference to the optical axis, there are two options available. The selection is done via the dialog shown in Fig. 422.

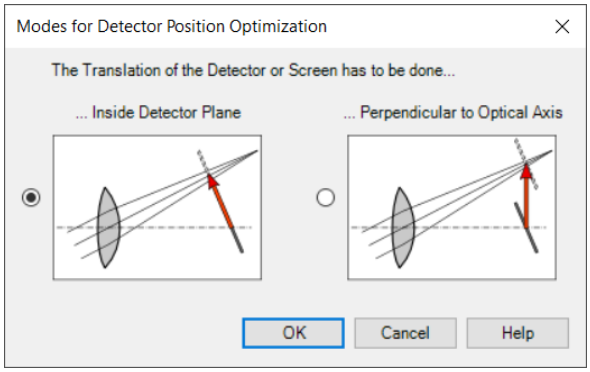


Figure 422. *Dialog for choosing an option for optimizing the position of a tilted detector.*

ITEM	DESCRIPTION
... Inside Detector Plane	If chosen, the optimization will do a lateral shift of the detector in its own plane.
... Perpendicular to Optical Axis	If chosen, the optimization will do a shift of the detector inside the plane perpendicular to the optical axis.

44.8.7 Show Simulation Report

Availability

Optical Setups: General Optical Setup with Classic Field Tracing & Light Shaping Optical Setup

Accessible:

- Optical Setup Editor: *Tools* > *Show Simulation Report*

After the simulation of an Optical Setup, it is possible to view and save several information about the simulation process in VirtualLab Fusion using this Optical Setup Tool. It shows a VirtualLab Fusion document which lists all available information, ↪Fig. 423.

This document works like a web browser. The initial page *Report Overview* shows a list of all Optical Setup Elements (as well as their processing durations) through which the light has been propagated. If a magnifier symbol is clicked on, a new page with the report of the associated element will be opened (↪Fig. 424).

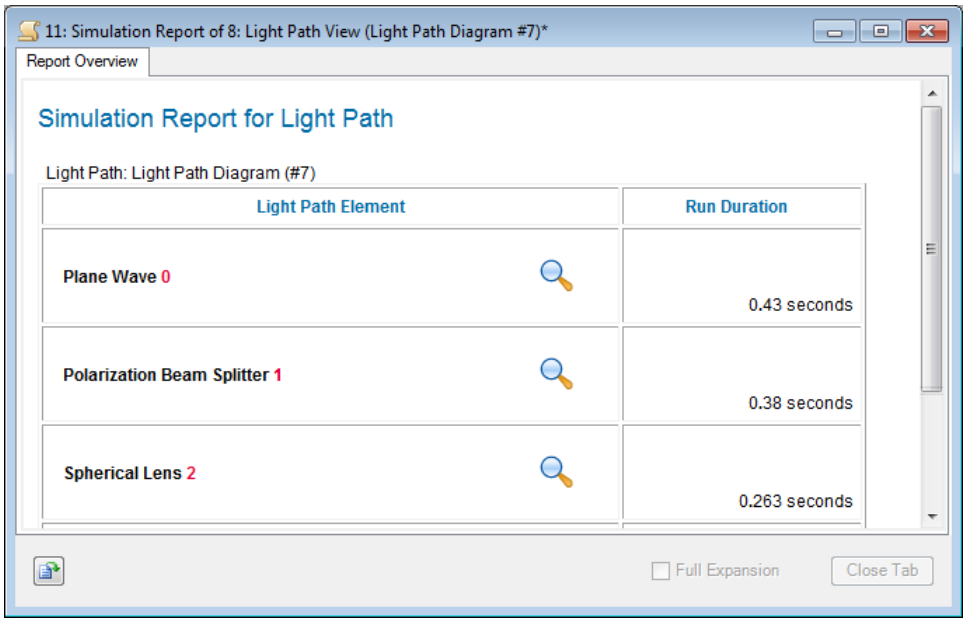


Figure 423. *Simulation report document showing a list of processed Optical Setup Elements.*

Initially only a rough overview of the processing of the selected Optical Setup Element is given. More details for the report entries can be explored by clicking on the associated magnifier symbol. For any selected page except the initial page (↪Fig. 423) the following controls are available:

ITEM	DESCRIPTION
(Export to XML)	By clicking on this button the report information is exported into a XML file as described below.
Full Expansion	If checked, the report tree expands completely, i. e. all report entries are visible.
Close Tab	If pushed, the currently selected page will be closed.

The entire simulation report can be exported to a XML file via the ribbon item File > Export > Export as XML or the button on the bottom of the report window. The XML file is stored along with the style file `lt_logstyle.xslt` that transforms the XML to a human-readable tabular form if opened in a web browser, looking similar to the report document itself. Additionally, some CSS files for formatting the text will be saved. Finally, an XML schema file (`lt_logstyle.xsd`) which contains the structure definition of the logging XML file will be created in the same directory.

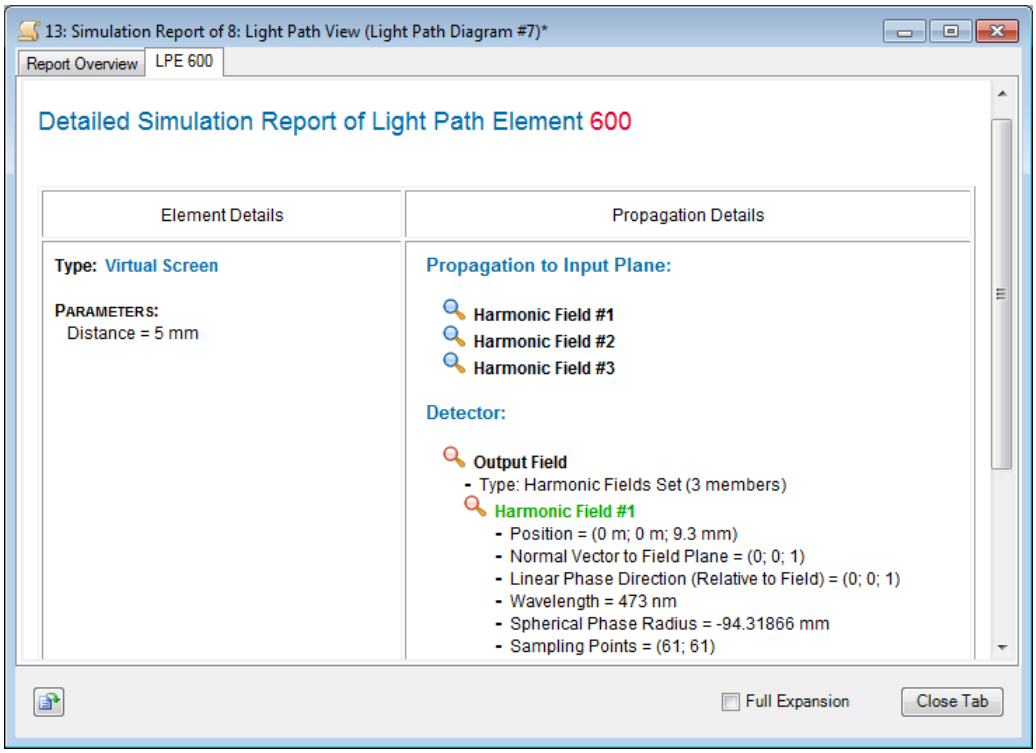


Figure 424. *Simulation report document showing details in a new page.*

Important: If the Optical Setup has not been simulated in the current VirtualLab Fusion session, the Simulation Report is not available. Reports are not stored with the Optical Setup.

44.8.8 Create New Parameter Run

Availability

Toolboxes: All

Accessible:

- Ribbon: Optical Setup > New Parameter Run
- Optical Setup Editor: *Tools* > *Create New Parameter Run*

This tool provides the simulation of an existing Optical Setup within a Parameter Run (↔Sec. 45). This allows the modification of one or more parameters of the optical setup and the evaluation of all included detectors in the Optical Setup.

For the generation of a Parameter Run, the Optical Setup has to be consistent.

If at least one parameter run is already open, the new parameter run obtains the view settings and (if possible) the parameter(s) to vary from the last opened parameter run.

44.8.9 Create New Parametric Optimization

Availability

Optical Setups: All but Light Shaping Optical Setup

Accessible:

- Ribbon: Optical Setup > New Parametric Optimization
- Optical Setup Editor: *Tools* > *Create New Parametric Optimization*

If the Optical Setup is consistent, a parametric optimization document (↪Sec. 103.1) can be opened using this Optical Setup Tool.

44.8.10 Remove All Lookup Tables

Availability

Toolboxes: AR/VR/XR Package

Accessible:

- Optical Setup Editor: *Tools* > *Remove All Lookup Tables*

This Optical Setup Tool deletes all lookup tables for all grating regions with real gratings (↪Sec. (c)) for all light guide components.

44.8.11 Update Add-ons in Detectors

Availability

Optical Setups: All that contain a Universal Detector (↪Sec. 75.4) with at least one snippet based Detector Add-on (↪Sec. 75.4.5).

Accessible:

- Ribbon: *Layout Tools* > *Update Add-ons in Detectors*

This tool updates all predefined Detector Add-ons in all Universal Detectors in the current Optical Setup. *Predefined* refers to all snippet based add-ons which have the same name as an Add-on provided by Wyrowski Photonics. *Update* means that the snippet is copied from the downloaded version of the add-on. It is recommended to keep the downloaded add-ons up-to-date by either clicking on the *Add-ons* tab of a Universal Detector or by clicking Detectors > Apply Detector Add-on > Update Predefined Add-ons if a Data Array or Chromatic Fields Set is open. The values of the parameters of the add-on are kept while updating.

44.9 Positions

The details of the positioning concept for Optical Setups can not be presented here extensively. So this section gives a short overview but you can learn more about the concepts of coordinate systems and positioning via a supplemental file available upon request.
An Optical Setup is associated with a global coordinate system (GCS), while every Optical Setup Element (OSE) owns two or three kinds of coordinate systems (CS):

1. Internal Coordinate System (ICS): Unambiguously specified coordinate system which is related to the inner structure of the OSE. Its origin is identical to the position of the element within the global coordinate system.

2. (Referring) Input Coordinate System (InCS, components and detectors only): The z-axis of this coordinate

system defines the typical input direction of light. The position of the origin and the orientation of the x- and y-axes are related to the structure of the OSE (↪Sec. 44.9.1).

3. Reference Output Coordinate Systems (OutCS, components and light sources only): The z-axis of an output coordinate system defines the typical direction for a special kind of output (e.g. transmission type or reflection type). The position of the origin and the orientation of the x- and y-axes are related to the structure of the OSE (↪Sec. 44.9.1).

Usually, the positioning of Optical Setup Elements is done by defining the *relative* position and orientation of the InCS with reference to the output CS of the previous Element in path. This principle is shown in the sketch below (↪Fig. 425) and explained in Sec. 44.9.2.

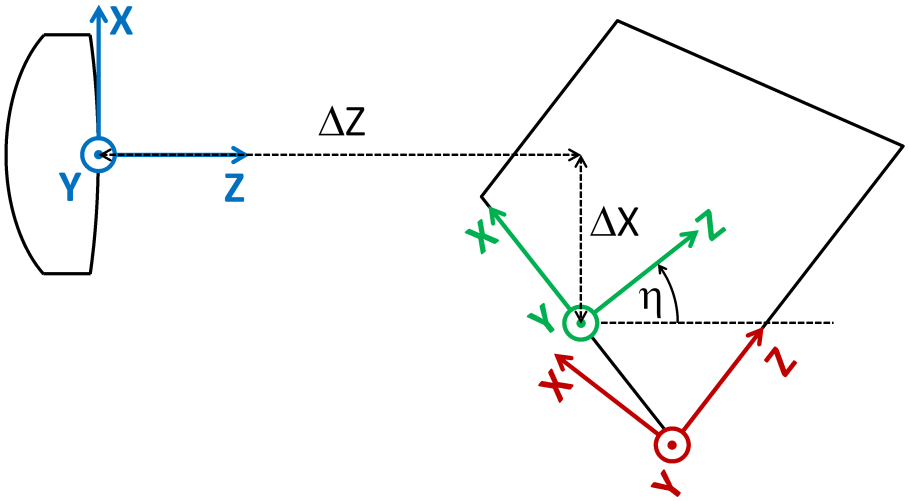


Figure 425. *Principle of positioning of Optical Setup Elements. The blue coordinate system is the output CS of the previous element while the green one indicates the input CS of the element to position. Its origin is translated by the axial distance ΔZ and a lateral shift ΔX. Its orientation is rotated by η, which means a rotation of the OSE about the y-axis. The red coordinate system is the Internal CS of the element.*

An alternative workflow is the positioning of Optical Setup Elements by defining the *absolute* position and orientation of either the InCS or the ICS with reference to the global coordinate system (GCS). The GCS is defined by the position and orientation of the currently active light source element.

44.9.1 Element Internal Definition of Axes, Coordinate Systems, and Reference Points

All information about the definitions of axes, coordinate systems and reference points can be got and (in some cases) set via the *Coordinate Systems* page (↪Fig. 426) of each Optical Setup Element's edit dialog.

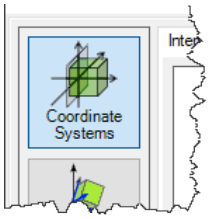


Figure 426. *Page selector for information about axes, coordinate systems and reference points of Optical Setup Elements.*

44.9.1.1 Internal Coordinate System

The Internal Coordinate System (ICS) is related to the inner structure of the OSE. Its position and orientation

relative to the geometry of the element are shown in the panel *Internal Coordinate System*. Furthermore, the geometrical parameters are described here. For an example see Fig. 427.
The position of the origin of the ICS in relation to the global coordinate system of the Optical Setup gives the absolute position of the element (↪Sec. 44.9.2).

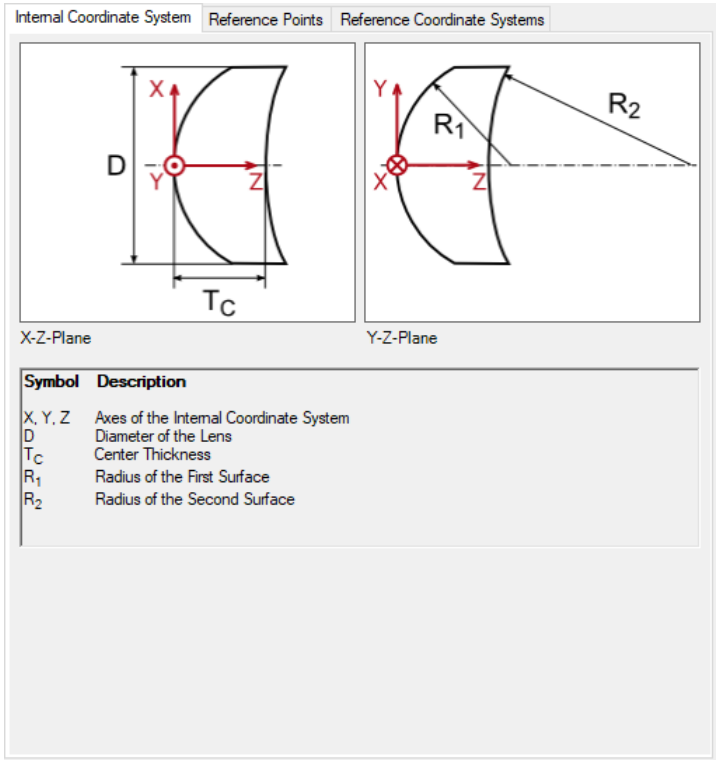


Figure 427. *Example (Spherical Lens) for the* Internal Coordinate System *panel with the description of the geometrical parameters.*

44.9.1.2 Reference Points

Although the orientations of the input and output coordinate systems are either fixed or calculated automatically, the internal position (i. e. referring to the ICS) of these coordinate systems can be chosen by the user from a list of reference points in order to have a great flexibility for the relative positioning (↪Sec. 44.9.2). These points are distinguished points of the element's structure which could come into consideration to serve as a reference for distance measurements. For a spherical lens, for instance, these are the vertices, the intersections of the principal planes with the symmetry axis, and the center of the lens. The list of all reference points of an element is shown in the panel *Reference Points*. For an example see Fig. 428.

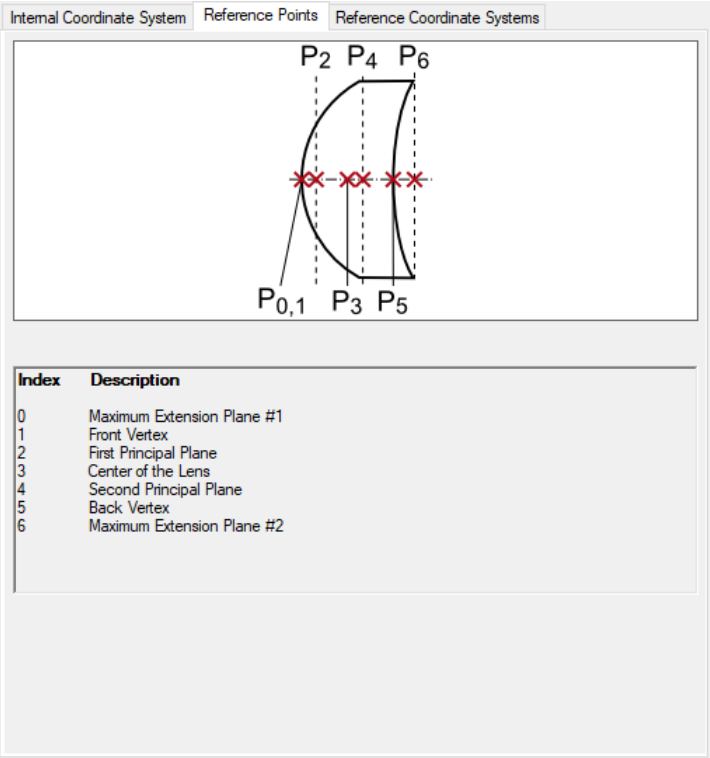


Figure 428. *Example (Spherical Lens) for the* Reference Points *panel with the description of all reference points.*

The Programmable Component allows to define new reference points by the user, see Sec. 62.3.

44.9.1.3 Reference Coordinate Systems

The information of all reference coordinate systems are given in the panel *Reference Coordinate Systems* (↪Fig. 429). Here you can see the orientation and meaning of the input coordinate system and of each output CS. Furthermore you can set the origin to one of the reference points.

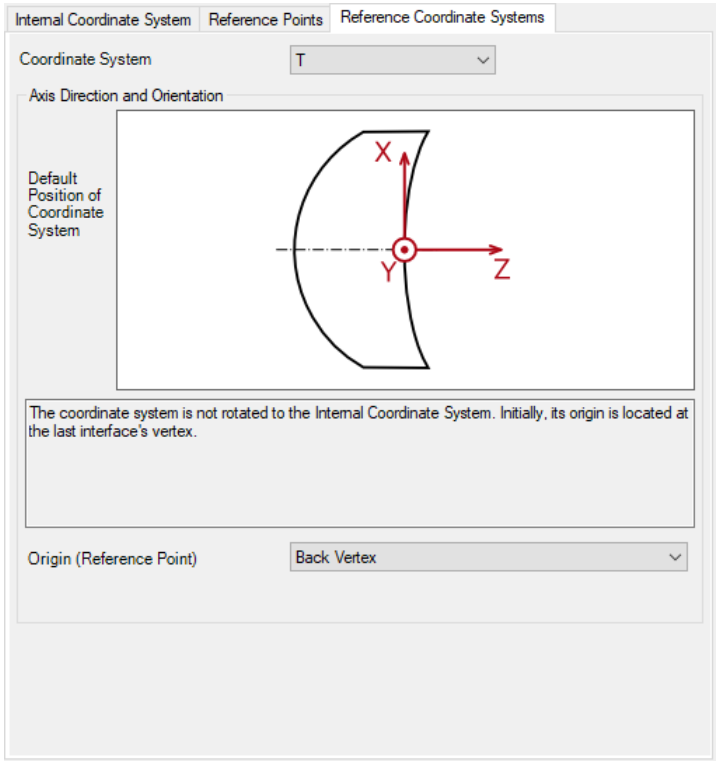


Figure 429. *Example (Spherical Lens) for the* Reference Coordinate System *panel with the description of the coordinate systems.*

ITEM	DESCRIPTION
Coordinate System	Which coordinate system shall be shown?
Default Position of Coordinate System	The sketch shows the position and orientation of the CS in relation to the element's structure. **Note:** Only a sample position is shown, that means there will be no update if the reference point is changed!
Origin (Reference Point) PE	Select the reference point which provides the position of the origin of the reference CS here. For grating components illuminated by an ideal plane wave, the reference point of the input coordinate system cannot be set. For the grating cells diffuser component no reference points can be set at all.

Note: Since the Programmable Component allows to define new reference coordinate systems, the edit control is completely different for Programmable Components (↪Sec. 62.3).

44.9.2 Positioning of Optical Setup Elements

All information about the position and orientation can be get and (in most cases) set via the *Position / Orientation* page (Fig. 430) of each Optical Setup Element's edit dialog.

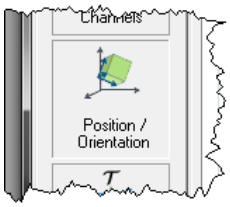


Figure 430. *Page selector for information about position and orientation of Optical Setup Elements.*

44.9.2.1 Basic Principles of Positioning

There are two modes of positioning for Optical Setup Elements which can be combined:

1. *Basal Positioning*: The basal positioning influences the positions of all of these Optical Setup Elements whose location and orientation refer to the current element.
2. *Isolated Positioning*: The isolated positioning of an element has no consequences for the position of any other Optical Setup Element. It is always applied additionally (i.e. after) doing the *Basal Positioning*.

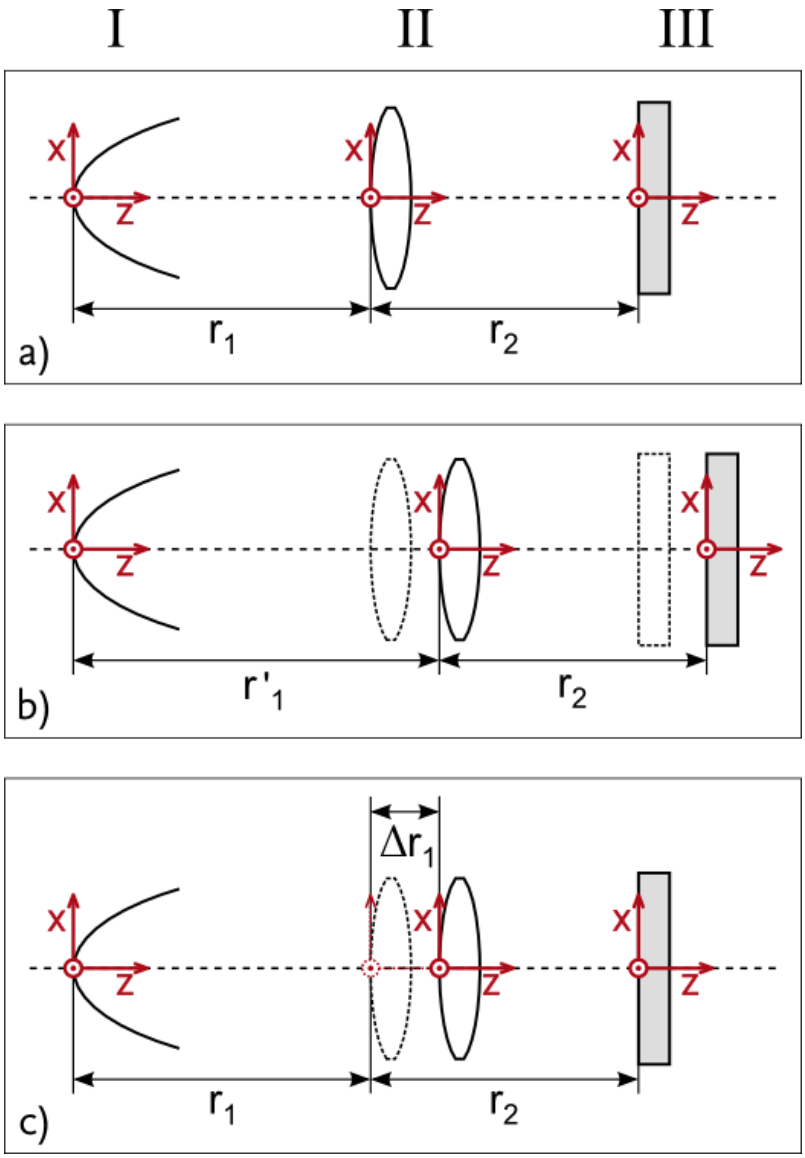


Figure 431. *Principles of positioning.*
a) The original positions of the three elements I, II and III. Element I is the reference element for element II, and at the same time, this is reference element for III.
b) If the position of II is changed by increasing r_1 to r_1' using Basal Positioning, the absolute position of element III is changed too. This is due to the fact that the relative distance r_2 is kept.
c) In contrast, a distance value of Δr_1 using Isolated Positioning shifts the element II (additionally to its basal positioning) without changing the position *of the following element III.*

If both modes of positioning are used for the same element, its resulting position and orientation are calculated by the consecutive application of *basal positioning first, followed by the isolated positioning*.

Please note: For the simulation of an Optical Setup, always the position and orientation which results from the described combination of both principles will be used.

44.9.2.2 Basal Positioning

The *relative* positioning of an Optical Setup Element is done by defining a translation and a rotation of the element's referring input coordinate system (InCS) in relation to the reference output coordinate system (OutCS) of the Optical Setup Element it is linked to (↪Fig. 425). The origin of the InCS is translated from the origin of the reference OutCS via a distance ΔZ on the z-axis of the OutCS and a lateral shift $(\Delta X, \Delta Y)$ perpendicular to that z-axis. This information can be entered in the control shown in Fig. 432. Furthermore, it contains a control for defining an inclination or rotation which can be used for certain types of elements and that is explained in detail in Sec. 5.6.

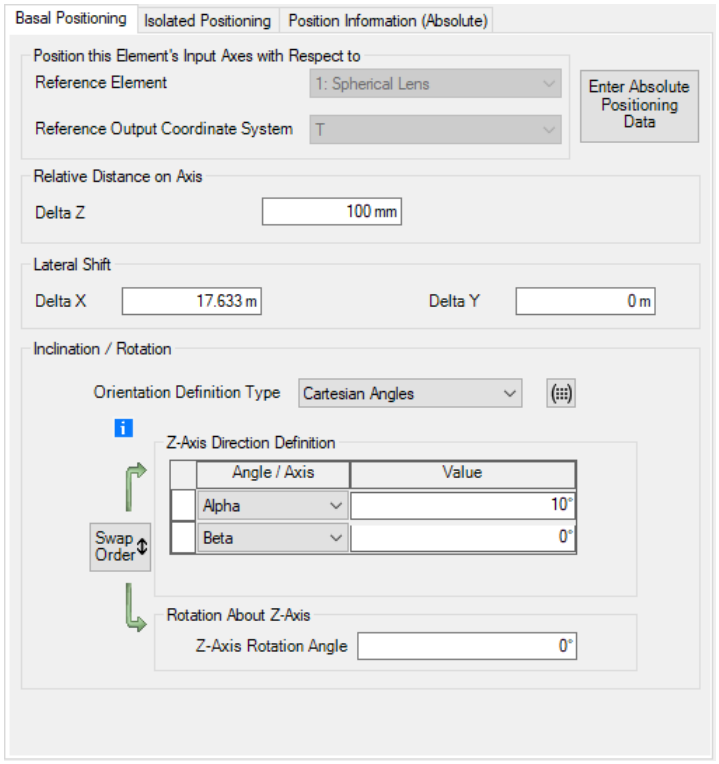


Figure 432. *Control for determining the basal position and orientation of an Optical Setup Element.*

ITEM	DESCRIPTION
Enter Absolute Positioning Data	Clicking this button will open an edit dialog where absolute position and orientation for the element can be entered.
Reference Element	Optical Setup Element that serves as reference for positioning. It is identical to the previous element in the path.
Reference Output Coordinate System	The name of that output coordinate system (OutCS) of the *Reference Element* which defines the reference for the relative distances and angles.
Delta Z PV	Distance to the reference element, measured on the z-axis of the OutCS. (This means the z-component of the distance vector from the OutCS origin to the InCS origin.)
Delta X PV	Shift of the element in x-direction, lateral to the z-axis of the OutCS. (This means the x-component of the distance vector from the OutCS origin to the InCS origin.)
Delta Y PV	Shift of the element in y-direction, lateral to the z-axis of the OutCS. (This means the y-component of the distance vector from the OutCS origin to the InCS origin.)
Inclination / Rotation PE	Control for defining the relative orientation of the Optical Setup Element. It defines the rotation angles of the input coordinate system of this element in reference to the OutCS of the reference element.↪Sec. 5.6

The *absolute* positioning of an Optical Setup Element is done by defining a translation and a rotation of the element's input coordinate system (InCS) or the elements internal coordinate system (ICS) in relation to the global coordinate system GCS of the Optical Setup. It can be entered after clicking the button *Enter Absolute Positioning Data*, which opens the dialog explained in Sec. 44.9.2.4.

44.9.2.3 Orientations of Optical Setup Elements

In many cases, the orientation of an Optical Setup Element can be set freely.
There are several ways to define the orientation of an Optical Setup element which are all equivalent (↪Sec. 145.2). Each of these conventions uses some rotations, applied to the input coordinate system InCS, referring to the reference output coordinate system OutCS. The rotation is centered around the origin of the InCS as pivotal point, in any case. This ensures that the translation values (z-distance and lateral shift in x and y) will be kept independent from the orientation.
The control for defining an orientation is described in Sec. 5.6.

44.9.2.4 Positioning Control

An alternative way to edit the basal position of an element is to use the positioning control of the Optical Setup Element in the Optical Setup View (↪Sec. 44.1 and Fig. 433).

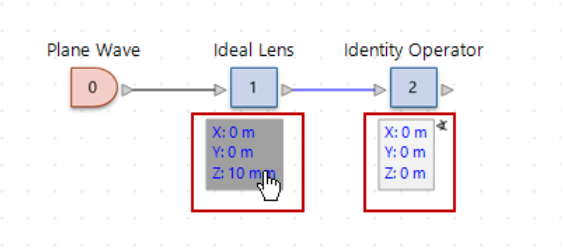


Figure 433. *The positioning control in the Optical Setup View.*

The layout of the control can be configured via the Optical Setup View's context menu. The following menu items refer to the positioning control:

ITEM	DESCRIPTION
Show Position Controls	The visibility of the positioning controls can be set here.
Show Only z-Positions	If checked, only the z-Positions of the elements are shown. This menu item is a shortcut to the more detailed advanced option described below.
Advanced Position Control Settings > Show Absolute Positions if Possible	If checked, absolute positions and orientations are shown if available. (Which will be not the case for detectors.) The absolute values are red colored. Relative values are blue.
Advanced Position Control Settings > Info for Internal CS / Info for Input CS	If *Show Absolute Positions if Possible* is chosen, this selection determines whether the absolute positioning information is shown for the internal coordinate system ICS or the input coordinate system InCS.
Advanced Position Control Settings > Include Isolated Positioning	If checked, the basal as well as the isolated positioning information will be shown. If unchecked, only the basal positioning information will be shown. In the latter case, the values will be written in an italic font.
Advanced Position Control Settings > z-Position Only / Position Only / Position & Orientation / Non-Zero Values Only	The display mode for the control. It determines how much information will be shown.

If one of the display modes is chosen which doesn't show all information (i. e. *z-Position Only* or *Position Only*), the control will indicate whether or not there are non-zero values hidden. If there are non-zero x- or y-translation values which are not visible in *z-Position Only* mode, the symbol + indicates that there is hidden information. If there are non-zero orientation values which are not visible in *z-Position Only* or *Position Only* mode, the symbol ∡ indicates that there is hidden information.

There can also be hidden information in case of isolated positioning. Whether or not the shown values include isolated positions or orientations is indicated by the font as shown in Fig. 434.

Figure 434. *A regular font (left hand side example) indicates that no isolated positioning has been used. An underlined font (center example) indicates that the shown values represent the combined resulting position of isolated and basal positioning. If the font is italic (right hand side example), the basal position is shown only, despite there is an isolated positioning given and effective in the simulation.*

Another indicator is shown in Fig. 435. It appears if the shown value is rounded. If so, hovering the mouse cursor over the control will open a tooltip giving the exact values. Please note: This feature has to be activated in the Global Options Dialog (↪Sec. 6.5).

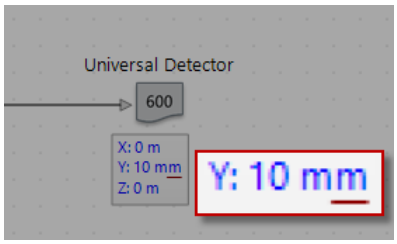


Figure 435. *The indicator for rounded values.*

A single click on the positioning control opens the dialog shown in Fig. 436.

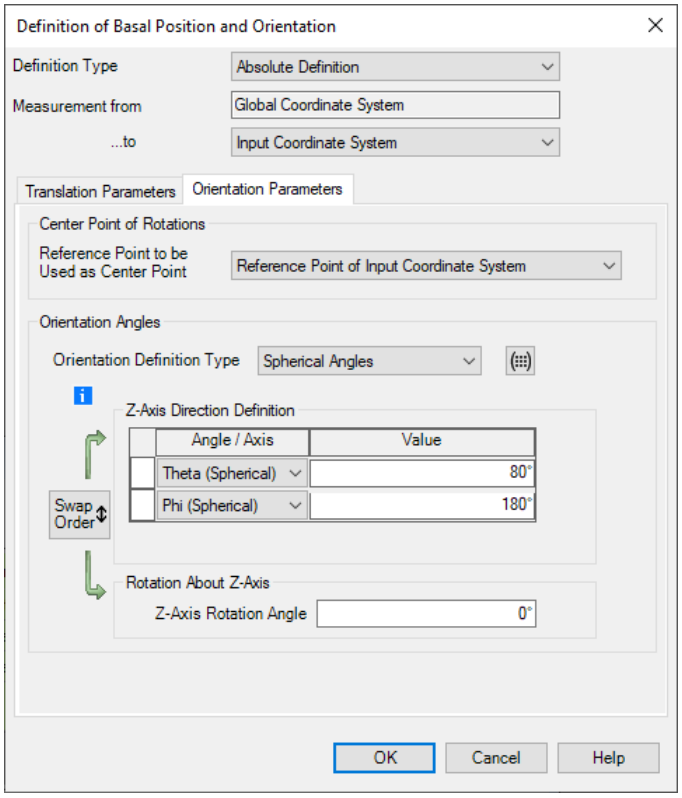


Figure 436. *Dialog for editing the basal Optical Setup Element position and orientation via external position control.*

ITEM	DESCRIPTION
Definition Type	This allows to define whether the position and orientation represent relative or absolute measurements.
Measurement from	The reference coordinate system to be used.
...to	The referring coordinate system to be defined here.
X/Y/Z PV	The basal translation of the element as described above (Sec. 44.9.2.2, where the values are named *Delta X/Y/Z*).
Reference Point to be Used as Center Point	The pivotal point for the rotations which specify the orientation.
Orientation Angles	The basal orientation of the element can be specified here, as described in Sec. 5.6.

44.9.3 Isolated Positioning of Optical Setup Elements

THE ISOLATED POSITIONING OF OPTICAL SETUP ELEMENTS CANNOT BE SET FOR LIGHT SOURCES OR DETECTORS.

Sometimes, one may want to vary the position or the orientation of a single Optical Setup Element without change of the absolute positions and orientations of the following elements whose distances refer to this element. In this case the variation has to be done as isolated positioning. The functionality is shown in Fig. 431c.
Basal and isolated positioning may be combined. The basal one is always applied first.
There are two different kinds of isolated positioning possible: Isolated translation and isolated orientation. At first, it has to be chosen which kind of isolated positioning shall be done, this selection is made via the control shown in Fig. 437. If isolated translation and isolated orientation shall be done, here the order of these two steps can be defined too.

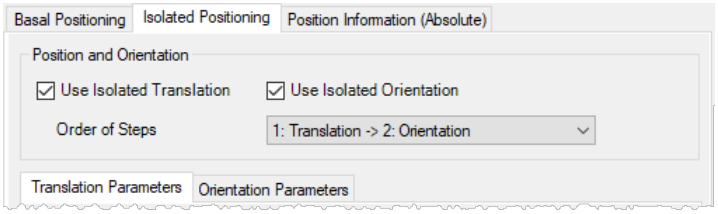


Figure 437. *Control to activate isolated positioning.*

ITEM	DESCRIPTION
Use Isolated Translation	If checked, isolated translation positioning is activated and the corresponding parameters can be entered (↪Sec. 44.9.3.1).
Use Isolated Orientation	If checked, isolated orientation positioning is activated and the corresponding parameters can be entered (↪Sec. 44.9.3.2).
Order of Steps	If set to *1: Translation -> 2: Orientation*, isolated translation positioning is done before isolated orientation positioning. If set to *1: Orientation -> 2: Translation*, isolated orientation positioning is done before isolated translation positioning.

44.9.3.1 Isolated Translation

Isolated translation positioning means dislocation of the element via translation from its former position, determined by basal positioning. The translation vector is defined via the control shown in Fig. 438.

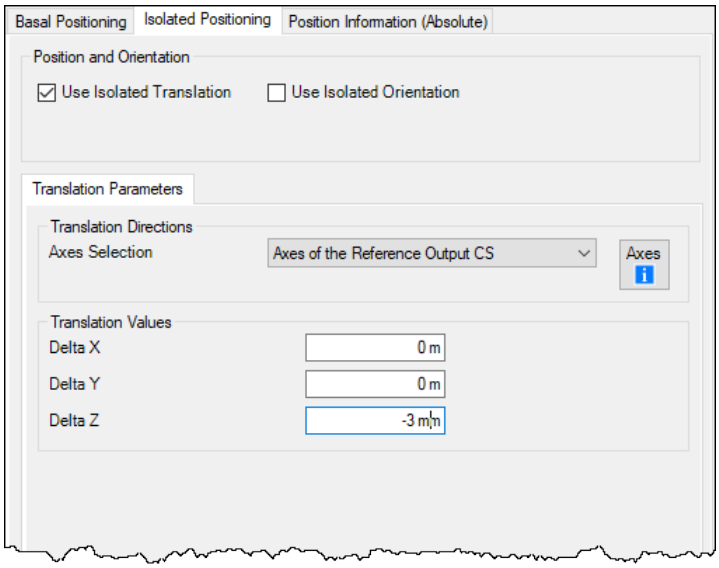


Figure 438. *Control to define the isolated translation values and directions.*

ITEM	DESCRIPTION
Axes Selection	Here the coordinate system can be selected in which the translation vector is defined. The selectable entries depend on the kind of Optical Setup Element which is edited.
Axes	Pushing this button will open an information window that displays the directions of the selected coordinate system axes in reference to the internal coordinate system of the element.
Delta X/Y/Z PV	These values define the vector which will be used for the isolated translation.

44.9.3.2 Isolated Orientation

Isolated orientation positioning means dislocation of the element via rotation, referring to its former orientation, which already has been determined by basal positioning. This rotation is defined via the control shown in Fig. 439.

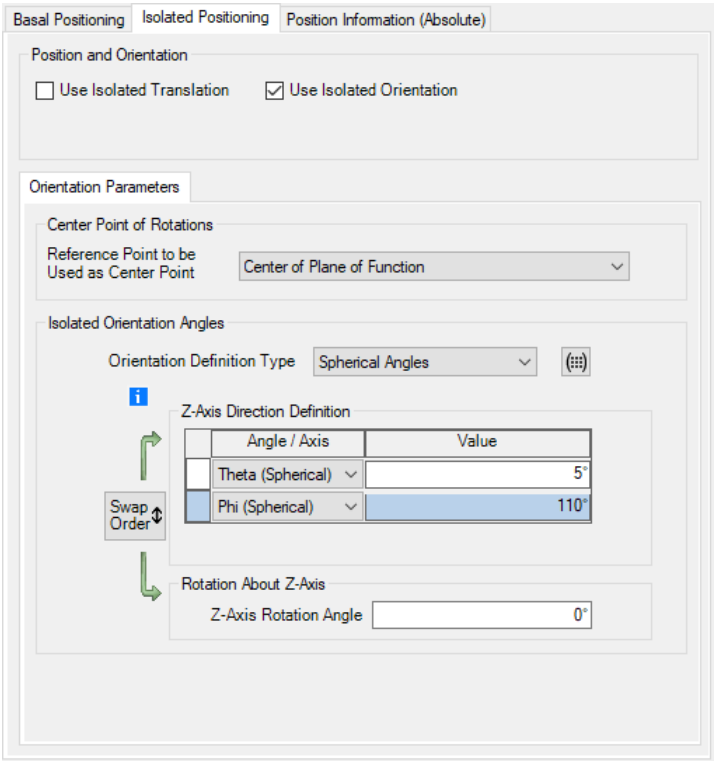


Figure 439. *Control to define the isolated orientation values and rotation center points.*

ITEM	DESCRIPTION
Reference Point to be Used as Center Point PE	Here the center point for the rotation that defines the isolated orientation can be selected. The selectable entries depend on the kind of Optical Setup Element which is edited.
Isolated Orientation Angles PE	This control (↪Sec. 5.6) is used to define the angles which determine the isolated orientation.

44.9.3.3 (Absolute) Position Information about an Optical Setup Element

The absolute position of an element in an Optical Setup is measured in the Global Coordinate System (GCS) of the Optical Setup. This is identical with the Internal Coordinate System of the currently active Light Source element.

All information about the absolute position and orientation of an Optical Setup Element can be found in the control shown in Fig. 440.

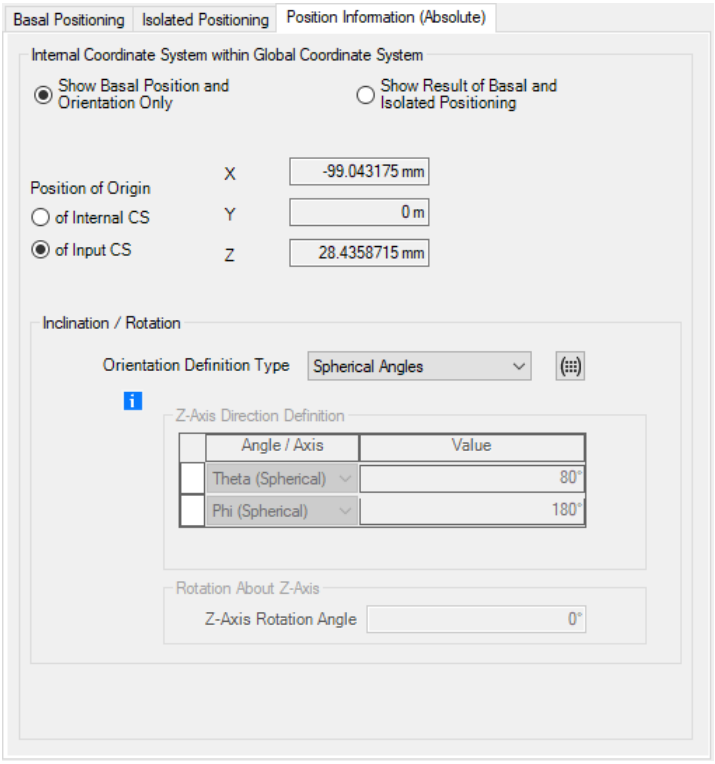


Figure 440. *Control that shows the absolute position and orientation of an Optical Setup Element.*

ITEM	DESCRIPTION
Show Basal Position and Orientation Only	If selected, the absolute position information is calculated from the basal position only. So one can see the position and orientation all other referring Optical Setup Elements will use. *Important:* This mode is for information purpose only. Every simulation will use the combined basal *and* isolated positioning.
Show Result of Basal and Isolated Positioning	If selected, the absolute position information is calculated from the basal position as well as the subsequent isolated positioning. So one can see the position and orientation as it will be used *during the simulation*.
Position of Origin > of Internal CS / of Input CS	This selection determines for which CS the values *X*, *Y*, and *Z* are given for.
Position of Origin > X/Y/Z	Position of the origin of the internal coordinate system or the input coordinate system (depending on the corresponding selection) of the element in the global coordinate system.
Inclination / Rotation	The orientation of the element's internal coordinate system, given via the *Orientation Definition Type* currently selected. For more information about these definition types and the associated angles please see Sec. 145.2.1.

44.10 Channel Configuration

A surface can be illuminated from the front (along the optical axis) or from behind (against the optical axis). Furthermore light can be reflected or transmitted. In consequence there are four ways light can take on a surface:

CHANNEL	DESCRIPTION
+/+	Light comes from the front and is transmitted through the surface.
+/-	Light comes from the front and is reflected at the surface.
-/-	Light comes from behind and is transmitted through the surface.
-/+	Light comes from behind and is reflected at the surface.

As you can see the channels refer to the sign the z-component of the direction vector of the incident and outgoing light has, respectively.

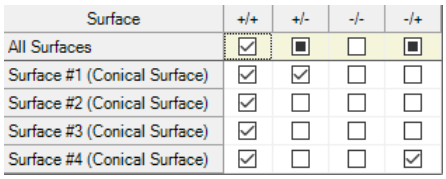


Figure 441. *The table for setting the propagation channels. Here light coming from the front and transmitted through the component is taken into account as well as light reflected at the respective outermost surfaces.*

The *Channel Configuration* tab page of Real and Ideal Components contains a table (↪Fig. 441) where you can configure which propagation channels are taken into account in case manual channel configuration is set (↪Sec. 44.3.1). In this way you can avoid that unnecessary light paths are calculated and so make the simulation faster.
If there are two or more surfaces there is an additional row *All Surfaces* where you can change the configuration of all surfaces at once.
For certain components certain channels might be unavailable. For example ideal mirrors have no transmission channels. In case of pre-selected channel configuration, the complete table is read-only.
For a light guide component you can configure the propagation channels in more detail in the edit dialog of the grating regions (↪Sec. 43.1).

44.11 Specific Optical Setups

Despite the General Optical Setup (which can be opened e. g. via the New button in the Start ribbon) there are some optical setups available which support specific components with specific propagation operators.
Grating, Laser Resonator, Light Guide, and Light Shaping Optical Setups require the corresponding package (↪Sec. 1).

44.11.1 Grating Optical Setup

Via the menu items below Start > Gratings you can obtain preconfigured Optical Setups containing the following Optical Setup Elements:

- Ideal Plane Wave (↪Sec. 52.7)
- A grating component (↪Sec. 65). Depending on the selected menu item this grating component contains a preconfigured stack with the actual grating.
- Two Universal Detectors (↪Sec. 75.4) for reflected and transmitted light, respectively
- Grating Order Analyzer (↪Sec. 85)

If needed, further analyzers can be added in the resulting Optical Setup View.
Such an Optical Setup uses a special simulation engine “*Near Field Analysis*”. It applies a “Rayleigh Expansion” (↪Sec. 94.8) for the propagation to the detectors to adapt for the periodic nature of the gratings.
The following restrictions apply to Grating Optical Setups.

- Optical Setup Elements but the analyzers cannot be deleted. The two detectors can be switched on and off by deactivating the linkages leading to them.

- The detectors are always parallel to the grating component. Thus isolated orientation of the grating component is disabled.
- The position of the grating component cannot be changed. For detectors, only the z-position can be changed.

44.11.2 Laser Resonator Optical Setup

For analyzing laser resonators an Optical Setup is required. This can be generated from the main window via Start > Laser Resonators > Laser Resonator Optical Setup or via the session editor that is available from Start > Laser Resonators > Laser Resonator Session Editor.
The Optical Setup will contain already the eigenmode analyzer that is not available in other Optical Setups. In this type of Optical Setup, only this eigenmode analyzer can be processed.
It can be configured similar to other types of Optical Setups. However, an element from the section *High Reflective (Start) Mirrors* has to be used as first element. In that category, ideal plane and spherical mirrors, the stored mirror function, and the double surface component.
There are some restrictions for building up a valid resonator system in VirtualLab Fusion. These restrictions are:

- The last element of the resonator has to be chosen from the category *Outcoupling Mirrors*. This category contains an ideal plane, an ideal spherical and an ideal micro-structured mirror. Next to these mirrors the user can select a double surface component or a programmable component for the element used for out coupling.
- Reflection type reference coordinate systems are admissible for ideal plane or ideal spherical mirrors only.

A special component for a Laser Resonator Optical Setup is the *Laser Crystal*. The *Laser Crystal* can be used stand alone as start and end element in a valid system definition for a laser resonator.

Figure 442. *The tree of the Optical Setup View for a Laser Resonator Optical Setup.*

Detectors that are used in the Optical Setup are computed once at the end of the eigenmode computation. For that, the fundamental mode that has been computed is used.

44.11.3 Light Guide Optical Setup

A Light Guide Optical Setup always contains a Light Guide component (↪Sec. 58.2) to which you can add a restricted selection of light sources, components, and detectors. The Uniformity Detector (↪Sec. 75.6.8) is specific for this kind of Optical Setup.
For a Light Guide Optical Setup always manual channel configuration (↪Sec. 44.10) is used.

44.11.4 Light Shaping Optical Setup

Via the menu item Start > Light Shaping > Light Shaping Light Shaping Optical Setup with Grating / Prism / Mirror Cells you obtain a preconfigured Optical Setup containing the following Optical Setup Elements:

- Far Field Source (↪Sec. 53.2)
- Plate (↪Sec. 64) labeled as Light Shaper
- Camera Detector (↪Sec. 75.5.2) which can be used either for the transmission type or the reflection type reference coordinate system and

- Local Linear Grating Analyzer (↪Sec. 91) for grating cells light shaper .

Start > Light Shaping > Light Shaping Optical Setup opens an empty Optical Setup which can be configured as Light Shaper. In any such Optical Setup the user can add any real optical component to the system, but it has to be ensured that the output of the system is always a Camera Detector which has one active connection to a light shaping component.
Light shaping component and Camera Detector must be parallel. Thus isolated orientation of the light shaping component is disabled and the Camera Detector cannot be rotated.
All Simulation Engines (↪Sec. 44.5) but Classic Field Tracing can be used. For General Profile the special Cells Array Propagation (↪Sec. 94.9) is used to reduce the numerical effort after the light shaping component.

45 Parameter Run

The Parameter Run document allows you to run several Optical Setup simulations (↪Sec. 44), whereas for each iteration one or more parameters have a different value. The results of the distinct Optical Setup simulations are shown in a special table which allows further analyses. The variable parameters are listed in Sec. 44.6.
There are three steps in using the Parameter Run document which can be performed with the *Next* button.

1. Define the parameter sets to be used for the distinct Optical Setup simulations (↪Sec. 45.2).
2. Set up the detecting devices whose results you want to analyze (↪Sec. 45.4).
3. Start the parameter run and analyze its results (↪Sec. 45.5). Only for this step the Parameter Run > Go! ribbon item is enabled.

The *Show* button shows either the original, unmodified Optical Setup or the Optical Setup with the parameters of a certain iteration step.
You can save the parameter run via the File menu or the Start ribbon tab. A newly opened parameter run derives its settings from the last activated parameter run, including the settings of the Combined Outputs (↪Sec. 45.5.1) and the parameter to vary if applicable.

Handling of Obsolete Parameters

If you load a Parameter Run which has been saved in a previous version of VirtualLab Fusion, there might be some obsolete parameters still present in the parameter specification table. On the other hand, newly added parameters might not yet be available.
If no results have been calculated yet, the parameters are updated automatically. Otherwise, updating the parameters would delete the results. Then or in case the Parameter Run is in Programmable mode, only a warning is shown in both the Messages tab (↪Sec. 4.3) and the window title ("⚠ Old Parameters ⚠").
If one of the *varied* parameters changed, the Parameter Run cannot be configured and simulated anymore. You can only analyze the results or Refresh the document via the ribbon (which deletes the results).

45.1 Ribbon of the Parameter Run Document

The ribbon of the Parameter Run document has the following entries:

ITEM	DESCRIPTION
Go!	Allows you to start the actual parameter run. Only enabled if you are on the *Results* page of the document window. During the parameter run, the button changes into a Stop button which allows you to stop the calculation.

After Completion	For long running parameter runs it can be useful if after completion the Parameter Run saves itself and optionally the computer shuts down. This can be defined with this option which is also available in the property browser (↪Sec. 4.3). If the Parameter Run has not been saved before it is saved at `{Path for User Settings}\Autosaved Files`. The *Path for User Settings* can be set on the *Saving* tab of the Global Options dialog (↪Sec. 6). Below this combo box the used file name is displayed. **Note that *Save & Shutdown Computer* can lead to data loss if there are unsaved documents but the Parameter Run for which this option is set.**
Refresh	Refreshes the document to use the current set of parameters. Note that this deletes existing results. See also the note on handling of obsolete parameters on page 521.
Show Optical Setup	This button has two sub-entries: • **Show Initial Optical Setup:** Shows the Optical Setup from which the Parameter Run was originally created. This can be invoked directly if the upper part of the *Show Optical Setup* button is clicked. • **Show Optical Setup for Certain Iteration Step...:** Shows the Optical Setup with the parameters of a certain iteration step which can be selected in a separate dialog.
Logging During Execution	If this button is pressed, the results of the individual iteration steps are written as soon as they are available. Else they are only written after the parameter run has finished. This improves performance especially in case of many fast iteration steps. Note that this button is disabled during an ongoing parameter run and that it can also be changed via the Property Browser.
Create Output from Selection	If you click this button, for each table row of the current selection a combined output is generated as defined by the settings in the matching combined output box (↪Sec. 45.5.1). During the output creation, the button changes into a Stop Output Creation button which allows you to stop the calculation. Double clicking on a row header is a short cut for selecting this row completely and clicking Create Output from Selection. Similarly, double-clicking a single table cell is a short cut for selecting this row and clicking Create Output from Selection. It is also possible to generate the combined output out of the current selection via the context menu or the *Create Output from Selection* button of the results table.
Delete Results	Simply deletes all already calculated results. This can be useful as Parameter Runs with results can be occupy much RAM or hard disc space.

45.2 Parameter Specification Page

The table on the *Parameter Specification* page shows you all parameters available for the underlying Optical Setup. You can select which parameters to *Vary* and the corresponding value ranges.
With these settings you define a “parameter space”. There are four modes how the parameter sets for the distinct iterations are determined from this parameter space.

1. **Standard Mode:** All selected parameters are varied equidistantly from the minimum to the maximum of the specified value range.
2. **Programmable Mode:** A snippet defines how the parameters are varied.
3. **Scanning Mode:** The parameter space is fully scanned in equidistant steps.
4. **Random Mode:** Uniformly distributed random combinations are used. Especially useful for Monte Carlo simulations and tolerance analysis.

Fig. 443 shows an illustration of the different modes for a two-dimensional parameter space. The combo box in the upper part of the *Parameter Specification* page (Fig. 444) allows you to select this *Usage Mode*.

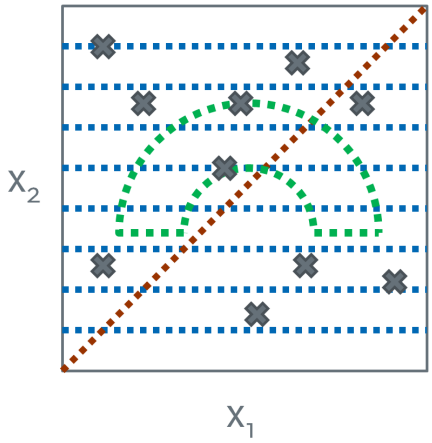


Figure 443. *Illustration of the different usage modes for the parameter run. A two-dimensional parameter space defined by two parameters X_1 and X_2 is shown.* **Red:** *Resulting parameter sets for the standard mode.* **Green:** *Example how the parameter sets can be generated by a snippet in the programmable mode.* **Blue:** *Resulting parameter sets for the scanning mode.* **Grey:** *Some randomly generated parameter sets.*

If you change the parameter specification page, the results table is cleared. But if applicable, results from previous runs are kept.

Example: You start a parameter run varying a *Length* from 200 mm to 400 mm in 3 steps. After this run has finished you decide that you want to use 4 steps. Then the results for a *Length* of 200 mm and 400 mm are kept as it is not necessary that they are calculated anew.

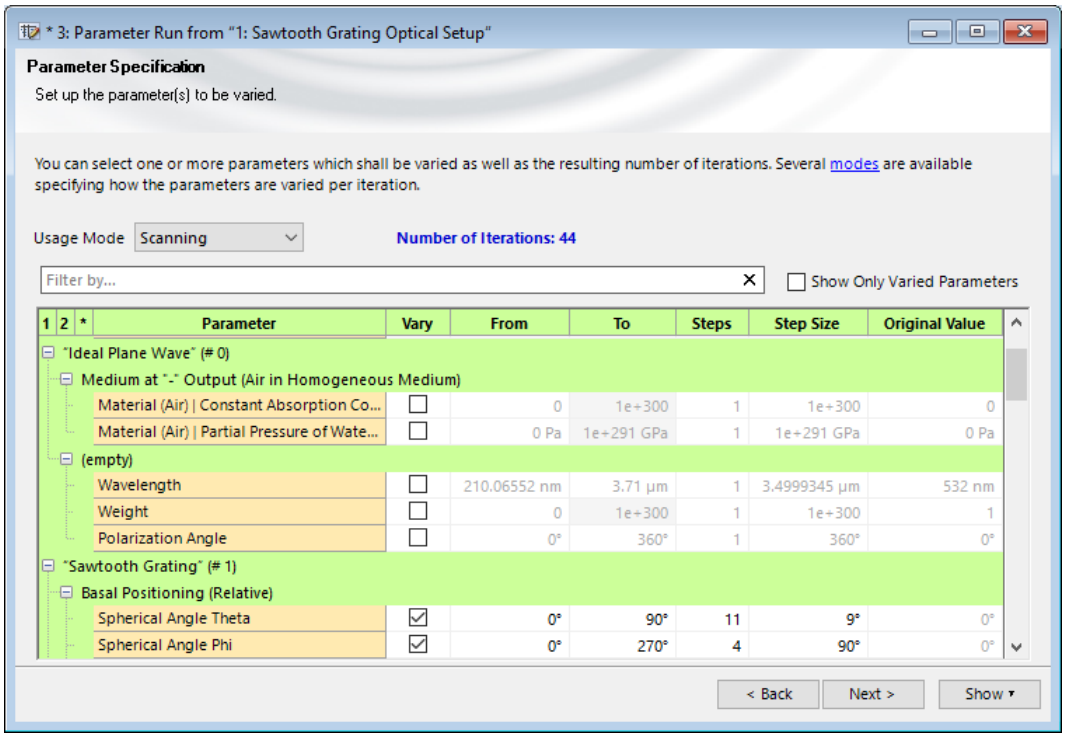


Figure 444. *The Parameter Specification Page of the Parameter Run Document in Scanning Mode.*

The table lists all *Parameter*s which can be altered in the parameter run. They are grouped by object (e. g. *"Ideal Plane Wave" (# 0)*) and then by the first category (which can be *{empty}*). The first column allows you to collapse / expand all these groups. Simply click on the ⊟ and ⊞ symbols, respectively. At the top of this column you can select to collapse all levels (*1*), collapse only the category groups (*2*) or expand all groups (*). In the *Vary* column you must check one or more parameters which you want to alter in the parameter run. All selected rows are checked at once.

For the varied parameters you can define the value range by setting the start (*From*) and end (*To*) value. The default *From* and *To* values for all parameters are their absolute minimum and maximum values – you must not enter a value outside of this range. It is possible to enter a *To* value which is smaller than the *From* value.

The *Steps* and the *Step Size* column are explained in the following subsections, as their meaning depends on the *Usage Mode*. For your information also the *Original Value*s of all parameters are given.

The table can be filtered with the following controls. Only rows passing all filters are shown.

ITEM	DESCRIPTION
Filter Table by	All rows containing the given string either in the group descriptions or in the *Parameter* column pass this filter. The matching is case insensitive. It is possible to search for multiple words and word groups embraced by quotation marks, for example: `"surface #1" scaling`.
Show Only Varied Parameters	Only rows where the *Vary* column is checked pass this filter.

45.2.1 Notes on Standard Mode

In *Standard* mode the number of *Steps* is the same for all varied parameters. The specified value ranges are split into equidistant sub-intervals. If you set *Steps* to 2, it means that a simulation is done for the *From* value and *To* value, respectively. Instead of setting the number of *Steps*, you can alternatively set the *Step Size*.

In case of an integer parameter, the step size can become a fractional number, too. In this case the values used for the distinct iterations are rounded to the closest integer.

45.2.2 Notes on Programmable Mode

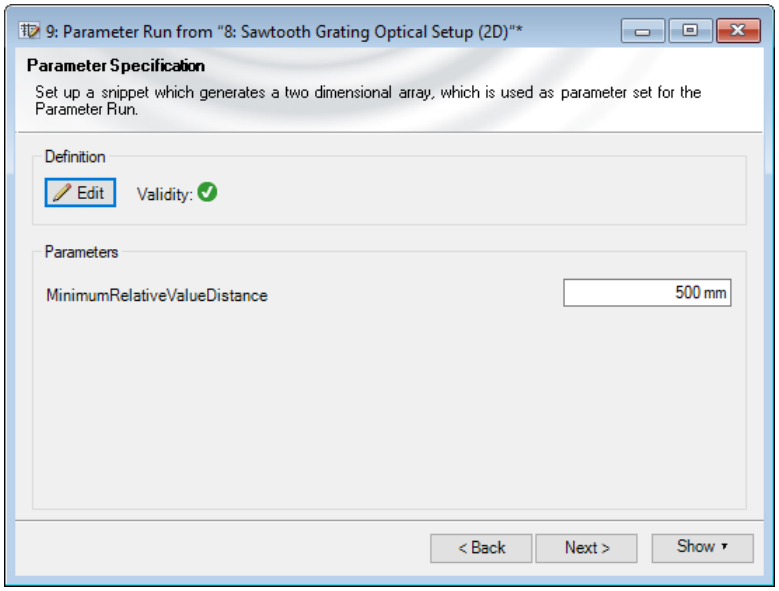


Figure 445. *The additional Parameter Specification page for the Programmable Mode of the Parameter Run.*

If you have chosen *Programmable* mode on the Parameter Specification page you can customize the individual steps of the parameter run by programming a code snippet on an additional page (↪Fig. 445). With this snippet you define array entries `parameters[i,j]`, which mean the value the i^{th} *varied* parameter should have in the j^{th} iteration step. Here, *varied* denotes a parameter where you have checked *Vary* on the previous page. Keep in mind that counting starts with zero: The value the second varied parameter should have in the fifth iteration step, for example, is entered in `parameters[1,4]`. The following global parameters are available by default:

ITEM	DESCRIPTION
NumberOfParameters	The number of parameters with checked *Vary* column on the parameter specification page.
NumberOfIterations	The number of *Steps* set on the parameter specification page.
MinimumValues	The *From* values set on the parameter specification page. Index 0 of the array represents the topmost parameter in the table.
MaximumValues	The *To* values set on the parameter specification page. Index 0 of the array represents the topmost parameter in the table.

This additional page has the following controls:

ITEM	DESCRIPTION
Definition	This group box allows you to program the actual code snippet. *Edit* opens the Source Code Editor (↪Sec. 7.3) to edit this snippet, and a validity indicator (↪Sec. 5.11) shows whether this snippet is consistent. In the lower right corner of the *Source Code* tab of the source code editor there is an additional button *Add System Parameter*. It opens a dialog where you can enter one or more words to search for one or more specific parameters of the underlying Optical Setup. The search is not case sensitive. When you then press *OK*, a statement is added at the current cursor position to retrieve the first of the selected parameters as `PhysicalValue`. (If you change the index in this statement, you can access others of the selected parameters but the first one.)
Parameters	The controls in this group box allow you to set the values of the global parameters of the snippet. ↪Sec. 7.4

More information about programming can be found in Sec. 7.
After you have set up the snippet, you can verify it on the subsequent *Parameter Visualization* page (↪Sec. 45.3). It shows a table visualizing the specified `parameters` array in a more readable form. If you have specified an array entry whose indices are not allowed (e. g. `parameters[-1,-1]`), the table remains empty. If you have specified a value which is out of the allowed value range (i. e. the default *From* - *To* interval) of the corresponding parameter, this value is marked red.

45.2.3 Notes on Scanning Mode

In *Scanning* mode each parameter can be varied with its own number of *Steps*. The specified value ranges are split into equidistant sub-intervals. All possible parameter combinations are calculated which means that the overall number of iterations is the product of the number of steps for each parameter.
If you set *Steps* to 2 for a certain parameter, it means that the *From* value and *To* value, respectively, are taken into account. Instead of setting the number of *Steps*, you can alternatively set the *Step Size*.
In case of an integer parameter, the step size can become a fractional number, too. In this case the values used for the distinct iterations are rounded to the closest integer.

45.2.4 Notes on Random Mode

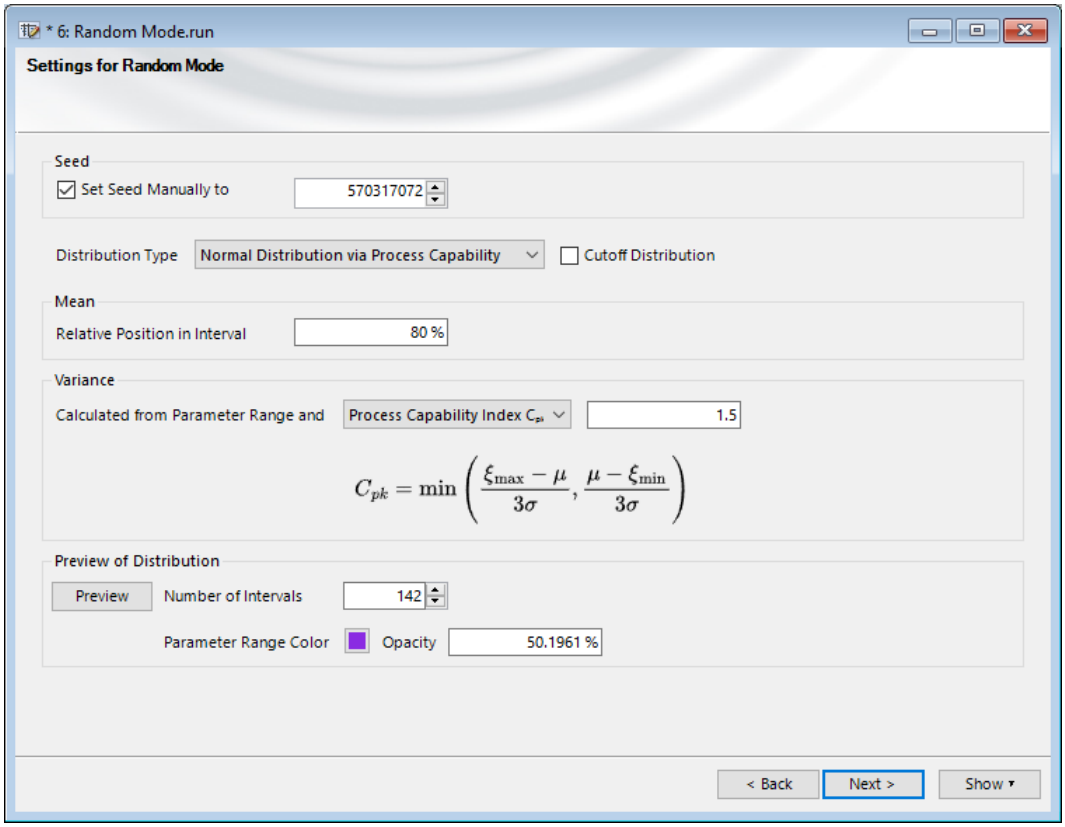


Figure 446. *The wizard page with additional settings for the random mode.*

In *Random* mode the number of *Steps* is the same for all varied parameters. For this mode the following settings are available on a separate page (↪Fig. 446):

ITEM	DESCRIPTION
Set Seed Manually (to)	Always a fixed *seed* is used with which the generation of the random numbers starts. If you check this option, you see the used *Seed* which then you can alter if you want to obtain different random number distributions.
{Distribution type}	The values distributed randomly within the specified parameter ranges can follow one of the following distributions • *Uniform Distribution*: All values of the specified parameter intervals have the same probability. • *Normal Distribution via Standard Deviation*: The values follow a Gaussian normal distribution having its mean μ in the center of the parameter interval. You can set the width of the distribution by specifying to how many standard deviations σ this interval corresponds. • *Normal Distribution via Process Capability*: The values follow a Gaussian normal distribution. Its mean μ can lie anywhere within the interval. You can set the width of the distribution via a process capability index.
Cutoff Distribution	ONLY FOR A NORMAL DISTRIBUTION A normal distribution is defined for an infinite value range and thus some values might be out of the actual parameter interval. If you want **all** values to lie within the specified intervals, you can check this box. Then in case a value lies outside the interval a new random inside the interval is taken instead.

The Parameter Range Corresponds to	ONLY FOR *NORMAL DISTRIBUTION VIA STANDARD DEVIATION* With this setting you can specify how broad the normal distribution is relatively to the parameter intervals defined by the user. If you keep the default value of 3, then the parameter ranges correspond to the 3σ interval of the normal distribution, i. e. 99.73 % of all values are within the parameter intervals.
Relative Position in Interval	ONLY FOR *NORMAL DISTRIBUTION VIA PROCESS CAPABILITY* Allows to shift the mean μ of the normal distribution within the interval.
{Process Capability Index drop down}	ONLY FOR *NORMAL DISTRIBUTION VIA PROCESS CAPABILITY* Two different process capability indices are implemented: • The Process Capability Index C_p has always the same variance, even if the mean is shifted in the parameter interval. • The Process Capability Index C_{pk} has a smaller variance if the mean is shifted toward the borders of the interval. So always the same percentage of values lies outside of the parameter ranges. $$C_p = \frac{\xi_{\text{max}} - \xi_{\text{min}}}{6\sigma} \quad (45.1)$$ $$C_{pk} = \min\left(\frac{\xi_{\text{max}} - \mu}{3\sigma}, \frac{\mu - \xi_{\text{min}}}{3\sigma}\right) \quad (45.2)$$ ξ_{min} is the *From* value of the respective parameter range and ξ_{max} the *To* value. Fig. 447 shows an example of the difference between the two indices.
Preview	Generates a preview histogram of the current distribution. Note that if two or more parameters are varied, this just shows an example as each parameter uses its own seed to generate the random distribution. The examples shown in Fig. 447 were generated with this feature.
Number of intervals	The number of intervals shown on the x-axis of the histogram. The default is the rounded up square root of the number of *Steps*.
Parameter Range Color	Color used to indicate the parameter range in the resulting diagram.

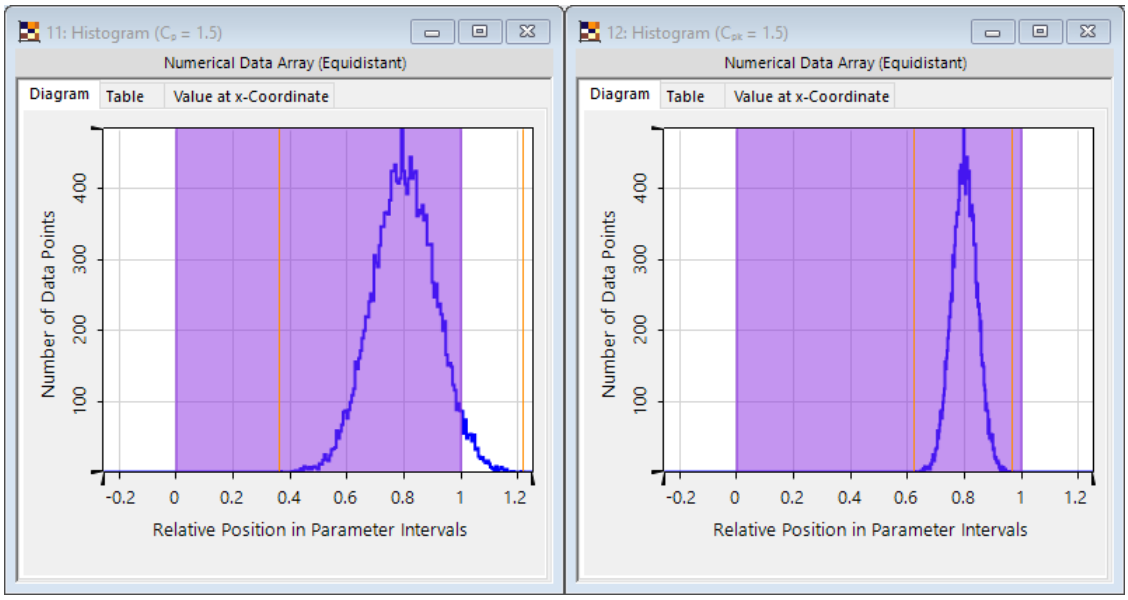


Figure 447. *Histogram of 20 000 values following a normal distribution whose mean μ lies at 80 % of the parameter interval.*
Left: *Process capability index $C_p = 1.5$. You can see that quite many parameter values lie outside of the specified range.*
Right: *The process capability index $C_{pk} = 1.5$ (instead of C_p). You can see that the distribution becomes smaller and thus the range of resulting parameter values (indicated by the yellow bars) lies completely within the specified parameter range.*

45.3 Parameter Visualization Page

This page simply shows the value of each varied parameter in each iteration of the Parameter Run. Invalid entries (especially resulting from wrong snippets in Programmable Mode) are marked red.

Note that if you enter this page, iterations having exactly the same varied parameters are merged into one. In this case you see fewer iteration steps than you have specified in the Parameter Specification Page (↪Sec. 45.2) and a warning is shown. This mechanism speeds up further calculations.

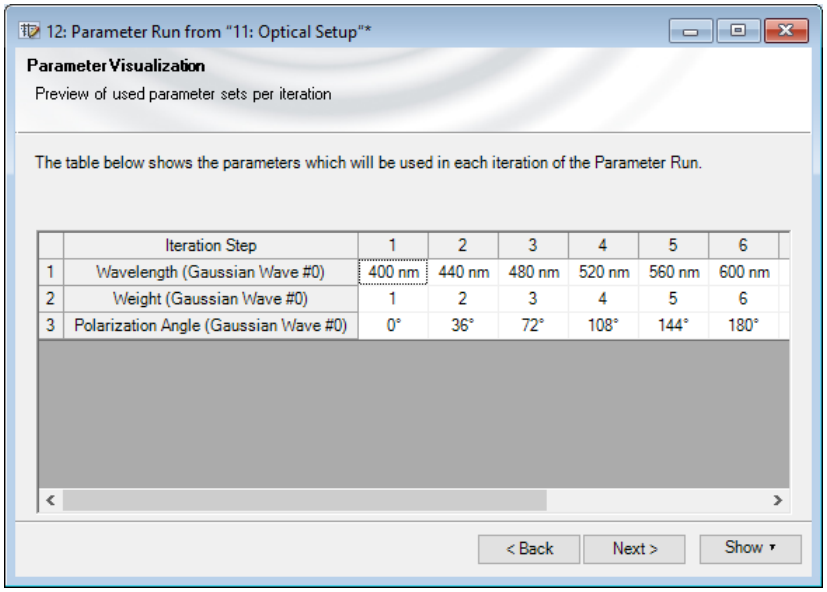


Figure 448. *The Parameter Visualization page if three parameters are varied randomly.*

45.4 Detecting Devices Specification

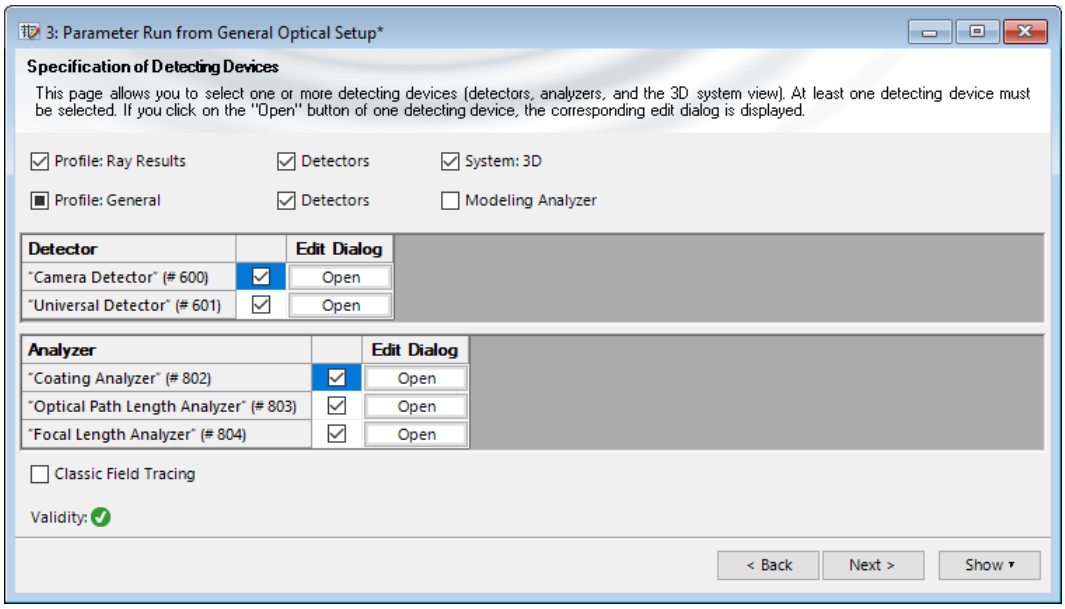


Figure 449. *The Detecting Devices Specification Page of the Parameter Run Document.*

On this page you can select one or more detecting devices whose results you want to analyze. It is ensured that at least one detecting device is selected.
It has the following controls.

ITEM	DESCRIPTION
Ray Results Profile	This check box allows you to check or uncheck both *Detectors* [Rays] and *System: 3D* at once. It is marked as ■ if only one of these two options has been selected.
Detectors [Rays]	If checked the detectors specified in the detector table (see below) are used for this profile.
System: 3D	If checked a 3D view of the rays propagating through the Optical Setup is generated for each iteration. ↪Sec. 17.1
General Profile	This check box allows you to check or uncheck both *Detectors* [General] and *Modeling Analyzer* at once. It is marked as ■ if only one of these two options has been selected.
Detectors [General]	If checked the detectors specified in the detector table (see below) are used for this profile.
Modeling Analyzer	If checked the modeling analyzer (↪Sec. 44.5.5) is executed for each iteration.
{Detector Table}	Lists all available detectors (↪Part XI). You can select which detectors shall be evaluated. If you click on the *Open* button of any detector, the corresponding edit dialog is displayed.
{Analyzer Table}	Lists all available analyzers (↪Part XII). You can select which analyzers shall be evaluated. If you click on the *Open* button of any analyzer, the corresponding edit dialog is displayed.
Classic Field Tracing	If you check this option, the selected detectors are also analyzed with Classic Field Tracing.
Validity	This control (↪Sec. 5.11) checks that at least one detector has been selected and warns if the current configuration might be other than intended.

Note that depending on context not all of these controls might be visible. For example the analyzer table vanishes if there are no analyzers in the Optical Setup.

If you change the Detecting Devices page, the results table is cleared.

45.5 Results Page

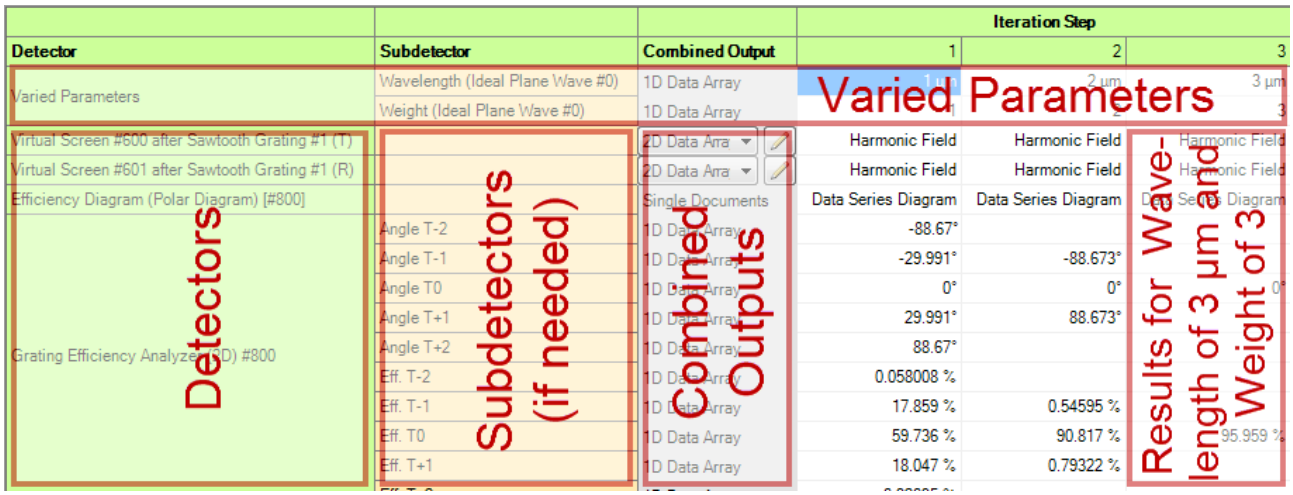


Figure 450. *The layout of the results table. In this example three iteration steps were calculated where the wavelength is varied from 1 µm to 3 µm and the weight is varied from 1 to 3 at the same time.*

The ▶ *Go!* button starts the parameter run. After clicking, the button changes into a ■ *Stop* button which allows you to stop the calculation. Then the *Stop* button becomes a ▶ *Go!* button again which allows you to continue the calculation later. The Parameter Run ribbon tab contains a button with the very same functionality.

In the upper right corner you can see and change the number of parallel iterations (↪Sec. 6.15) for this Parameter Run. In case distributed computing is activated (↪Sec. 8), you see the number of clients and can activate their configuration here.

The parameter run fills a table where the results of each Optical Setup simulation are shown in a separate column. Each detector is shown in a single row. If a detector consists of several sub-detectors (e. g. the beam parameters detector, ↪Sec. 75.6.1), their results are shown in separate rows. The columns are sorted ascending by iteration number and the rows are sorted numerically by the index of the detector and then alphabetically. Thus the position of a certain result can change while new results are being calculated. During calculation the table always scrolls to the most recent result. The table layout is illustrated in Fig. 450.

The varied parameters per iteration step are shown in separate rows at the top of the table.

The number of shown digits can be changed via the *Number of Digits* setting in the property browser. The *Format of Complex Numbers* can also be changed there. The default values of both settings are taken from the Global Options dialog (↪Sec. 6.5).

You can select a subset of all results by clicking on the column or row headers or by directly selecting a cell range. This selection can be copied to the Windows™ clipboard (↪Sec. 5.8).

By default the rows are sorted alphanumerically by the *Detector* and the *Subdetector*. Using the *Sort Rows* option of the property browser (↪Sec. 4.3) you can ensure that the same order as on the Parameter Specification page is used.

The *Combined Output* column contains a control to configure the *Combined Output* for each row separately. This control and which combined outputs are available is explained in Sec. 45.5.1. Additionally, the following controls are available:

ITEM	DESCRIPTION
▶ **Create Output from Selection**	For each table row of the current selection a combined output is generated as defined by the settings in the matching combined output box (↪Sec. 45.5.1). This button has the same functionality as the corresponding ribbon button (↪Sec. 45.1).
Use Already Calculated Results for Next Run	If you check this checkbox, already calculated results are kept for the next parameter run simulation. To ensure that this caching mechanism is used as often as possible, this checkbox is checked again after each simulation.
Filter Rows by …	Applies a search string to the table. Only rows matching the given string are shown, whereas the following rules apply: • The search is not case sensitive, i. e. `lens`, `Lens`, and `LENS` yield the same results. • It is possible to search for multiple words and word groups embraced by quotation marks. Rows containing at least one of these words or word groups in any of their cells are shown. • A - in front of a word or word group means 'not', e. g. `-lens` shows all lines **not** containing 'lens'. • Expressions in quotation marks are searched as entered. For example ``-2.5'' searches for the number -2.5, not for rows not containing 2.5. And ``Lens System'' searches for rows containing directly "lens system", not for rows containing "lens" or "system".

45.5.1 Combined Outputs

There are different types of parameter run results (e. g. physical values, harmonic fields (sets), or data arrays). Out of a one-dimensional selection of such parameter run results (that is a table row), various combined outputs can be derived. *Combined Output* means that the distinct parameter run results are plotted over the *iteration parameter* ξ. Because of this the combined output has always one dimension more than the individual parameter run results. For example out of several one-dimensional results $f(x)$ a two-dimensional combined output $f(\xi, x)$ is obtained (↪Fig. 451). The only exception from this rule is that you can plot single physical values into two-dimensional data arrays if there are exactly two varied parameters.

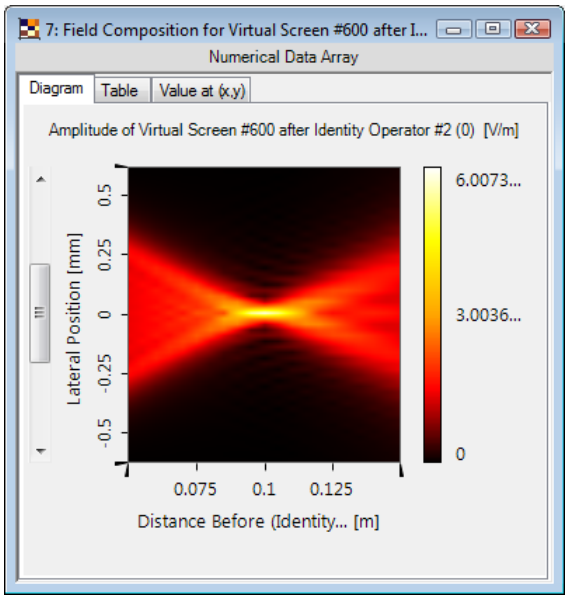


Figure 451. *Two-dimensional Data Array as combined output for one-dimensional fields. Here the iteration parameter is the distance behind a lens.*

Usually the iteration parameter is the *Iteration Step* (= the column headers). But if only one parameter is varied and you do not create a combined output for this varied parameter, then the iteration parameter is the varied parameter itself. With the option *Always Plot versus Iteration Step* in the Property Browser you can enforce that **always** the *Iteration Step* is used as iteration parameter. In the combined output the results are sorted by the iteration parameter.
The available types of combined outputs are summarized in the following table.

COMBINED OUTPUT	DESCRIPTION
Data Array **(For physical values)**	Combined output where the physical values are plotted on the y-axis versus the iteration parameter on the x-axis. Does not work for single physical values. If there are exactly two varied parameters you can also select other more understandable types of data arrays as output, ↪Sec. 45.5.1.1.
Harmonic Fields Set **(For harmonic fields)**	All selected (member) fields (of a harmonic fields set) are simply placed into one harmonic fields set.
2D Data Array **(For one-dimensional harmonic fields)**	For each value of the varied parameter (plotted along the x-axis), the field values are plotted along the y-axis. In case of harmonic fields sets, one subset per mode is created. Further information and an example for this combined output can be found in Sec. 45.5.1.2.
Animation **(For two-dimensional harmonic fields)**	The selected field quantities of the selected two-dimensional harmonic fields (sets) are shown as an animation (↪Sec. 20). Further information for this combined output can be found in Sec. 45.5.1.3.
Animation **(For 2D / gridless data arrays or corresponding sets of data arrays)**	Shows the selected subsets of the selected data arrays as an animation (↪Sec. 20). Further information for this combined output can be found in Sec. 45.5.1.4.

1D / 2D / Gridless Data Array **(For 1D / 2D / gridless data arrays or corresponding sets of data arrays)**	This combined output offers two modes: either all subsets are merged into a single data array which might require interpolation and embedding of the data. The other mode is that the subsets are put into different data arrays of a Set Of Data Arrays so that no interpolation is necessary. Furthermore you can choose which subsets are considered (and which data arrays for Sets of Data Arrays). Further information for this combined output can be found in Sec. 45.5.1.5.
2D Data Array **(For 1D data arrays)**	For each value of the varied parameter (plotted along the x-axis), the values of the resulting 1D data array are plotted along the y-axis. Different subsets in the original data arrays become different subsets in the resulting data array. The resulting data array inherits the interpolation from the original data arrays. In case the size of the original data arrays differs from iteration to iteration, the set of coordinates of the resulting array will be a union of the coordinate sets of all original arrays. The data of the source data arrays will be interpolated to this new grid. Usually, this merge mode will lead to a non-equidistant coordinate grid, but no data will be lost since all of the original data points will be kept.
1D / 2D Chromatic Fields Set **(For 1D / 2D Chromatic Fields Sets)**	All selected Chromatic Fields Sets are added incoherently to a new Chromatic Fields Set.
2D Chromatic Fields Set **(For 1D Chromatic Fields Sets)**	For each value of the varied parameter (plotted along the x-axis), the values of the resulting 1D Chromatic Fields Set are plotted along the y-axis. All original Chromatic Fields Sets must have the same sampling which can be achieved by configuring the detector generating these Chromatic Fields Sets accordingly (↪Sec. 75.1.1).
Animation **(For two-dimensional Chromatic Fields Sets)**	For each selected Chromatic Fields Set a bitmap is generated according to the settings in the edit dialog (↪Sec. 45.5.1.6) of the combined output. Each of these bitmaps then becomes one frame of the final animation.
Animation **(For Order Collections)**	For each Order Collection a bitmap is generated according to the settings in the edit dialog (↪Sec. 45.5.1.7) of the combined output. Each of these bitmaps then becomes one frame of the final animation.
Animation **(For Ray Distributions)**	For each Ray Distribution a bitmap is generated which resembles the actual document view (↪Sec. 17). Each of these bitmaps then becomes one frame of the final animation. You can set the view settings applied to the Ray Distribution document prior to the conversion into a bitmap using the dialog described in Sec. 17.2.3.
Ray Distribution **(For Ray Distributions)**	All Ray Distributions are merged into a single Ray Distribution as separate modes.
Single Documents **(For harmonic fields & data arrays)**	The selected documents are just shown as separate document windows. This combined output is always used if only a single document is to be shown. For harmonic fields (sets) the settings of the Raw Data Detector which generated these fields are used.

In the *Combined Output* column of the results table, there is a control where you can select one of the combined outputs suitable for the results in that column. If the currently selected combined output has specific options, they can be changed via a -button.

45.5.1.1 Data Array Combined Output for Physical Values and Two Varied Parameters.

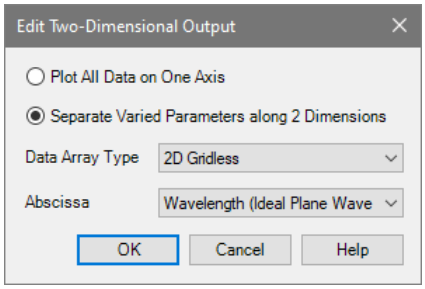


Figure 452. *The edit dialog for the combined output of physical values if exactly two parameters are varied.*

If there are exactly two varied parameters plotting the physical values in a somehow two-dimensional data array is far more understandable than plotting them in a simple one-dimensional data array.
Thus in this case you can open a dialog (↪Fig. 452) to select the output type most appropriate for your needs. Fig. 453 shows an example of the various output types.

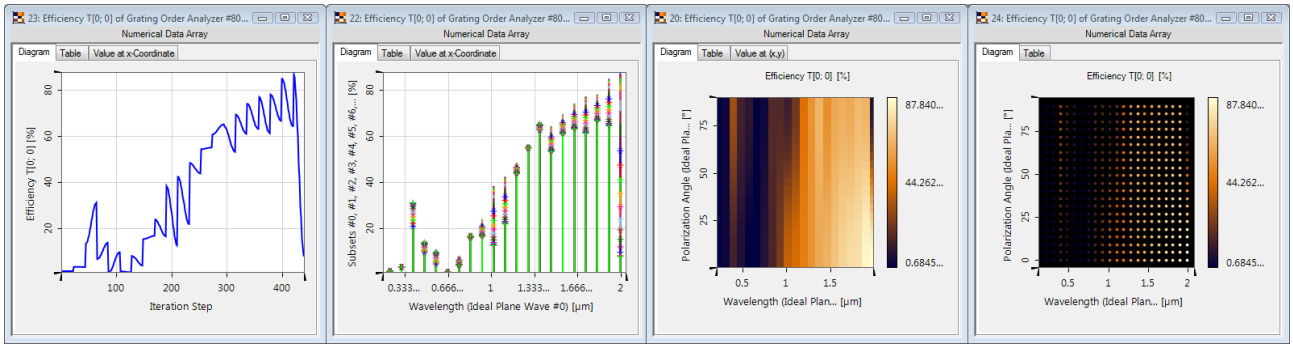


Figure 453. *The various output types for physical values. In this example both wavelength and polarization angle were varied for a grating and the efficiency of the zeroth transmitted order is shown. From left to right:* Plot All Data on One Axis*,* 1D Multigraph*,* 2D Gridded*, and* 2D Gridless*.*

The edit dialog has the following options.

ITEM	DESCRIPTION
Plot All Data on One Axis / Separate Varied Parameters along 2 Dimensions	If you select *Plot All Data on One Axis*, the data is simply plotted versus iteration step into a one-dimensional data array. This is the kind of output you obtain if there are not exactly two varied parameters. The left-most image of Fig. 453 shows an example for this. On the other hand, if you select *Separate Varied Parameters along 2 Dimensions* the data is shown in a somehow two-dimensional data array – how exactly is defined by the *Data Array Type* and *Abscissa* setting, respectively.
Data Array Type	There are three possibilities how the data can be plotted along 2 Dimensions. • *1D Multigraph*: One varied parameter is taken as abscissa. The other parameter is "stacked" into several subsets. In Multigraph mode (↪Sec. (b)), which is the default for this output type, you see them as separate data rows. In the second image of Fig. 453 the data is plotted versus wavelength and you see one data row per polarization angle. • *2D Gridded*: The data is plotted in a two-dimensional gridded data array (one parameter plotted on the abscissa, one on the ordinate. This type is appropriate if the data is on a regular grid, i. e. if it was obtained with the scanning mode of the Parameter Run (↪Sec. 45.2). • *2D Gridless*: The data is plotted in a two-dimensional gridded data array (one parameter plotted on the abscissa, one on the ordinate. This type is more appropriate if the data was not obtained with the scanning mode of the Parameter Run.
Abscissa	Defines which of the two varied parameters is plotted on the abscissa.

If the data was not obtained with the scanning mode of the Parameter Run or not all parameter combinations have been calculated, the data may not be on a regular grid. To create gridded data arrays nevertheless, missing grid positions are filled up with NaNs (= "Not a number"). This applies to the *1D Multigraph* and the *2D Gridded* type, respectively. In such a case, using linear interpolation is pointless. Thus these data array types are not shown with linear interpolation by default, which you can change later on (↪Sec. 11.2.1, Sec. 11.2.2).

45.5.1.2 2D Data Array Combined Output

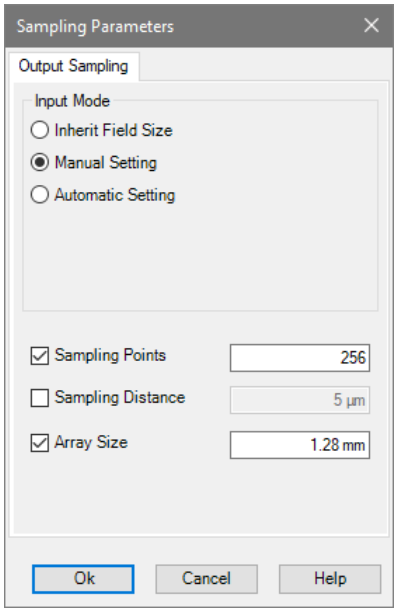


Figure 454. *Settings for the 2D Data Array combined output, here in* Manual Settings *mode.*

This combined output creates a two-dimensional data array by plotting the varied parameter along the x-axis and the field values of one-dimensional fields along the y-axis. However, each of the fields to be combined might have its own sampling – which is not allowed for data arrays. Thus the dialog shown in Fig. 454 offers the following ways to unify the field sampling:

ITEM	DESCRIPTION
Inherit Field Size	All fields are shown with the *default number of sampling points* and stretched to fill the data array window. This means that all fields are shown completely even if they have very different physical extensions.
Manual Setting	Allows you to set *Sampling Points*, *Sampling Distance* and / or *Array Size* of the y-dimension of the resulting data array manually. Only two of these three settings can be changed at the same time. The remaining property is calculated automatically.
Automatic Setting	The y-extension of the resulting data array is *Size Factor* times the size of the largest harmonic field (in physical coordinates). Size factors larger than 1 just embed the result while size factors between 0 and 1 cut off a part of the result. By default, the *default number of sampling points* is used to sample the lateral extension. A finer sampling with more sampling points can be defined with a larger *Oversampling Factor*.

The *default number of sampling points* is the number of sampling points as set up in the Global Options dialog (*Sampling* subcategory, ↪Sec. 6.12) for the x-direction.
Fig. 455 shows an example for *Inherit Field Size* and *Automatic Setting*.

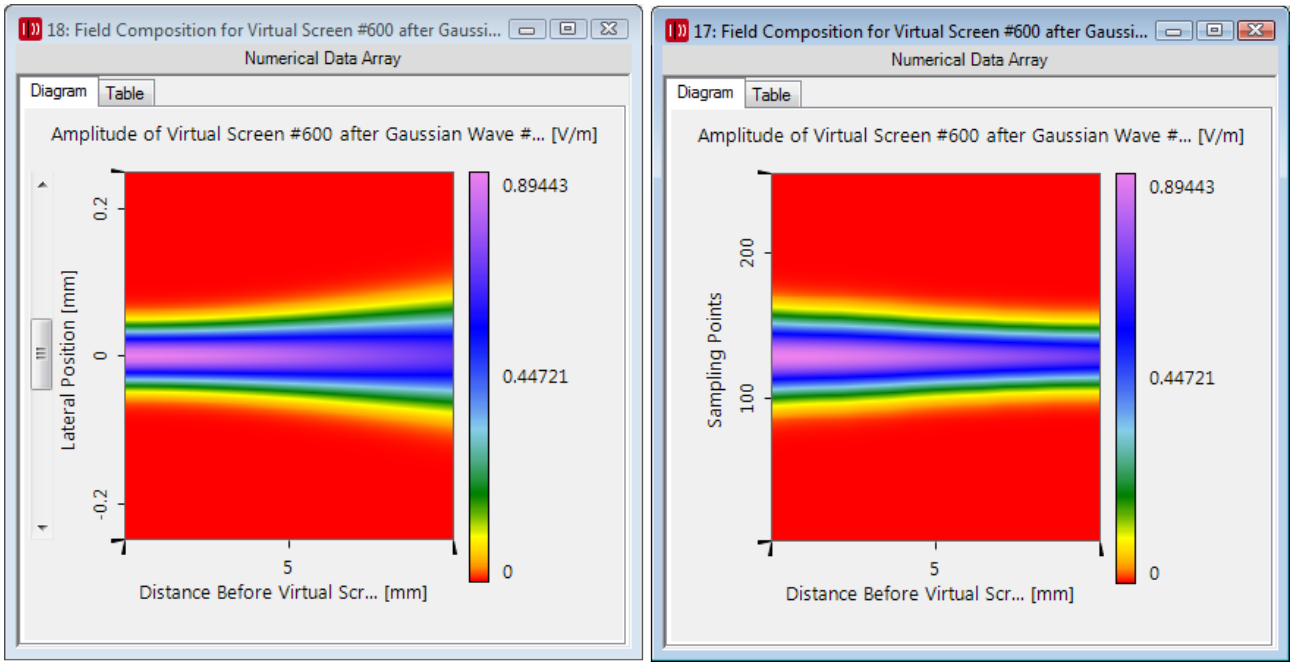


Figure 455. *Propagation of a divergent Gaussian beam, shown with "Automatic"* **(left)** *and "Inherit"* **(right)** *sampling. For larger beam diameters the amplitude becomes smaller. Thus the beam seems to get smaller in "Inherit" mode.*

45.5.1.3 Animation Combined Output for Harmonic Fields

In this dialog you can you can configure on the *Image Options* (↪Sec. (a)) tab which field quantities are to be shown in which way. And you can adjust the sampling on the *Bitmap Resolution* (↪Sec. (b)) tab.

(a) Image Options Tab

An animation is a sequence of individual bitmap images (↪Sec. 20). The controls of this tab (↪Fig. 456) determine how these individual bitmap images are created from the given harmonic fields.

ITEM	DESCRIPTION
Use Twin Image Representation	If checked, each bitmap image is composed of two images side by side, which are created from the same field using different color mapping settings (see below).
Set Options for Image	With this item, available if the check box *Use Twin Image Representation* is enabled, the part of the image (*Left* or *Right*) can be chosen for which the options shall be edited.
Color Mapping	The controls within this group are used for several dialogs and are therefore described in Sec. 5.12 in detail. If you create an animation of a phase distribution, an analytical spherical phase radius is ignored.

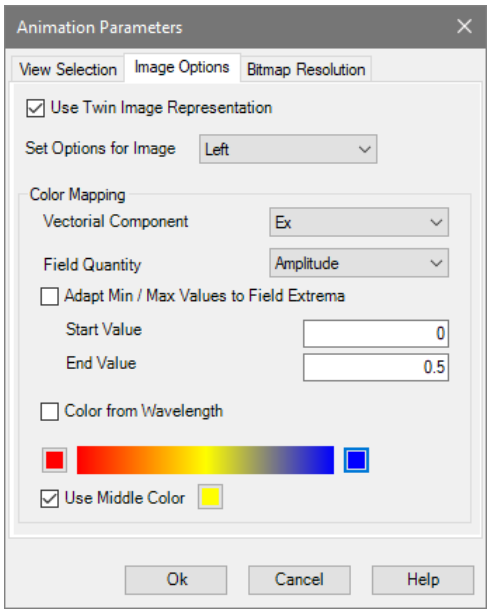


Figure 456. *Image options for animation combined output.*

(b) Bitmap Resolution Tab

This tab page (↪Fig. 457) determines the resolution of the resulting bitmaps. It offers three ways to define the field sampling:

ITEM	DESCRIPTION
Inherit Field Size	All fields are shown with the *default number of sampling points* and stretched to fill the animation view. This means that all fields are shown completely even if they have very different physical extensions.
Manual Setting	Allows you to set *Pixels*, (physical) *Pixel Size* and / or (physical) *Bitmap Size* manually. Only two of these three settings can be changed at the same time. The remaining property is calculated automatically.
Automatic Setting	The shown bitmap size is *Size Factor* times the size of the largest harmonic field (in physical coordinates). Size factors larger than 1 just embed the result while size factors between 0 and 1 cut off a part of the result. By default, the *default number of sampling points* is used. A finer sampling with more sampling points can be defined with a larger *Oversampling Factor*.

The *default number of sampling points* is two times the number of sampling points as set up in the Global Options dialog (*Sampling* subcategory, ↪Sec. 6.12).

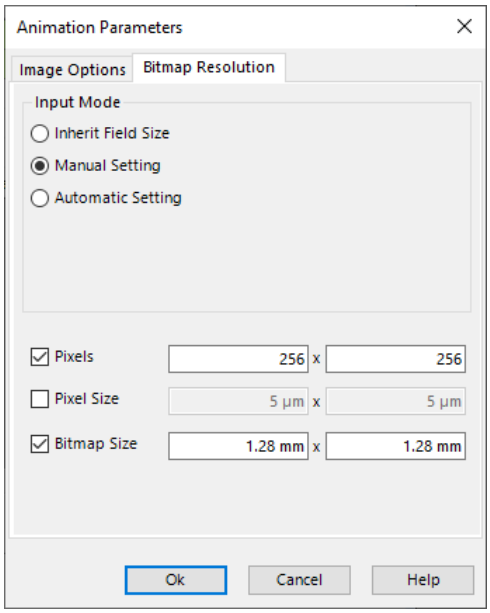


Figure 457. *Bitmap resolution settings for animation combined output.*

45.5.1.4 Animation Combined Output for Data Array and Sets of Data Arrays

This combined output allows you to show selected subsets of selected data arrays as frames of an animation (↪Sec. 20). To this end, the individual subsets are interpolated and filled up with zero values so that all subsets have the same coordinate range with the same sampling. The subsets are sorted so that all subsets of the first data array are shown first, then all subsets of the second data array and so on.

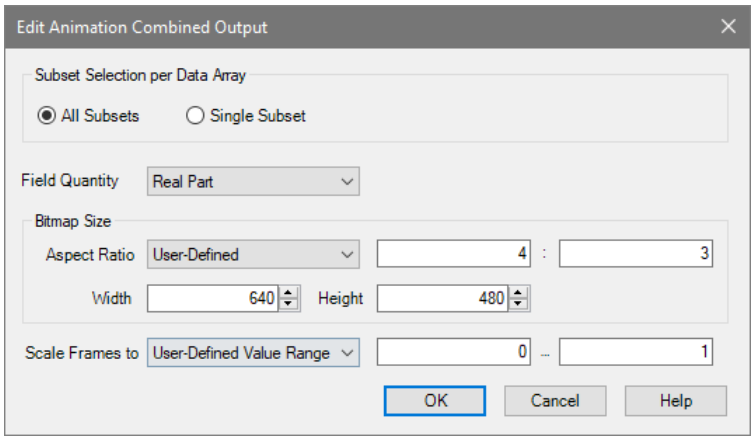


Figure 458. *Settings for animation combined output.*

The edit dialog of this combined output (↪Fig. 458) has the following controls:

ITEM	DESCRIPTION
All Data Arrays / Single Data Array	ONLY FOR SETS OF DATA ARRAYS With the *Single Data Array* option you can choose the index of one specific data array for which the animation is generated. Otherwise *All Data Arrays* are shown. ↪Sec. 45.5.1.5
All Subsets / Single Subset	With the *Single Subset* option you can choose the index of one specific subset for which the animation is generated. Otherwise *All Subsets* are shown. ↪Sec. 45.5.1.5
Field Quantity	Defines the field quantity to be shown in the resulting animation. Only has an effect if the input data arrays are complex-valued.
Aspect Ratio	The aspect ratio of the resulting animation is determined in different ways: • *True to Physical Scale*: The aspect ratio is determined from the ratio of the x-axis range of the data array to its y-axis range. This option is not available if the two coordinate axes have different physical properties. • *User-Defined*: If you choose this option you can define a suitable aspect ratio. For example you can use 16 : 9 to ensure that the animation (and a video possibly generated out of it via File > Export) looks nicely on matching monitors or projectors. For gridded data arrays the default user-defined aspect ratio is calculated from the number of data points in the data array. • *Free*: You can set *Width* and *Height* of the single bitmaps as you want.
Width / Height	The width and height of the resulting bitmaps. If the *Aspect Ratio* is not *Free* and you change one dimension, then the other dimension is always changed automatically.
Scale Frames to	• *Common Value Range*: The global minimum and maximum value of all subsets is used to scale the color table. As a result you can see in which subsets there are smaller values then in others. • *Individual Value Range*: The color table for each frame is adapted to the minimum and maximum value of the individual data. As a result all subsets use all colors of the color table. • *User-Defined Value Range*: The user can enter the minimum and maximum value which is used to scale the color table.

45.5.1.5 Data Arrays Combined Output for Data Array and Sets of Data Arrays

This combined output offers two modes:

1. All subsets are merged into a single data array. Because all subsets must have the same coordinate range with the same sampling, the individual subsets are interpolated and filled up with zero values if necessary. This is the same behavior as for the appending manipulation of data arrays (↪Sec. 24.5.2).
2. The subsets are put into different data arrays of a Set Of Data Arrays so that no interpolation is necessary. (If Sets of Data Arrays are combined, the subsets of one data array remain in one data array.)

The dialog shown in Fig. 459 also allows you to define that either one specific subset is taken from each iteration, or all subsets. In the same manner, you can define for Sets of Data Arrays that either one data array is taken from each iteration, or all data arrays.

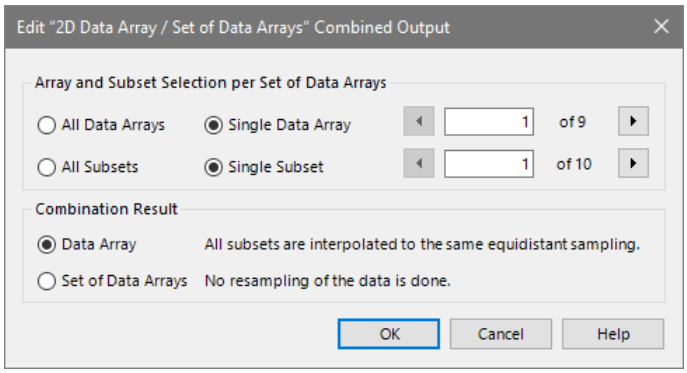


Figure 459. *The edit dialog for Sets of Data Arrays with gridded data arrays.*

Figure 460. *Control for entering the desired data array or subset index. With the arrow buttons you can decrease / increase the index by one. The control also shows the maximum index you can set.*

ITEM	DESCRIPTION
All Data Arrays	ONLY FOR SETS OF DATA ARRAYS. If you choose this option, all data arrays are used for the combined output.
Single Data Array	ONLY FOR SETS OF DATA ARRAYS WITH THE SAME NUMBER OF DATA ARRAYS. If you choose this option, one specific data array is extracted from the Set of Data Arrays result of each iteration. You can set the index of the data array to extract via entering it directly into the control shown in Fig. 460 or by using the arrow buttons in said control.
All Subsets	If you choose this option, all subsets are used for the combined output.
Single Subset	ONLY IF ALL DATA ARRAYS HAVE THE SAME NUMBER OF SUBSETS. If you choose this option, one specific subset is extracted from each data array. You can set the index of the subset to extract via entering it directly into the control shown in Fig. 460 or by using the arrow buttons in said control.
Data Array	NOT FOR GRIDLESS DATA ARRAYS In this case you obtain one single Numerical Data Array as combination result which contains all the data in separate subsets. The data is interpolated and embedded as described in Sec. 24.5.2. The order in that data arrays is as follows: First come all subsets from the first data array from the first iteration, then all subsets from the second data array of the first iteration and so on.
Set of Data Arrays	In this case you obtain one single Set of Data Arrays as combination result. The first data array of this document contains all subsets from the first data array from the first iteration, the second data array contains all subsets from the second data array from the first iteration and so on. In this way no data needs to be resampled.

An example illustrating the effect of the settings explained above: Assume we have 7 iterations. In each iteration a Set of Data Arrays with 3 data arrays is created; each data array has 2 subsets. Then you obtain the following results.

	DATA ARRAY AS COMBINATION RESULT	SET OF DATA ARRAYS AS COMBINATION RESULT
All Data Arrays*, *All Subsets	Data Array with 42 subsets	Set of Data Arrays with 21 data arrays, each having 2 subsets
All Data Arrays*, *Single Subset	Data Array with 21 subsets	Set of Data Arrays with 21 data arrays, each having 1 subset
Single Data Array*, *All Subsets	Data Array with 14 subsets	Set of Data Arrays with 7 data arrays, each having 2 subsets
Single Data Array*, *Single Subset	Data Array with 7 subsets	Set of Data Arrays with 7 data arrays, each having 1 subsets

45.5.1.6 Animation Combined Output for 2D Chromatic Fields Sets

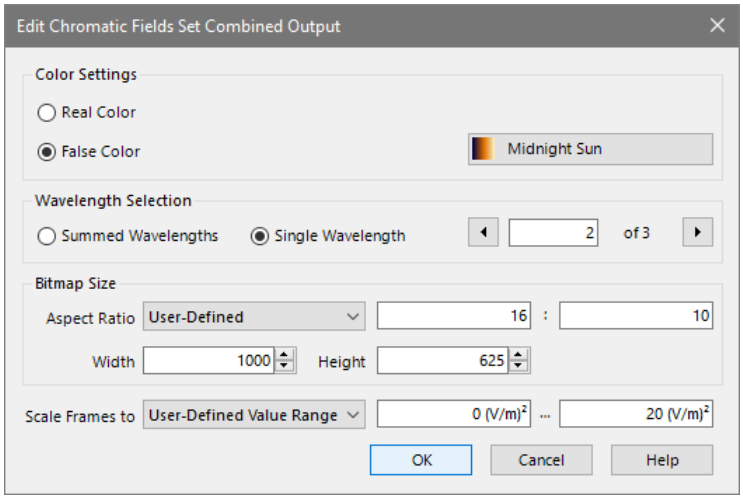


Figure 461. *Edit dialog of the Animation Combined Output for two-dimensional Chromatic Fields Sets.*

In the edit dialog of the Animation Combined Output for two-dimensional Chromatic Fields Sets (↪Fig. 462) you can set the following:

ITEM	DESCRIPTION
Real Color / False Color	Allows you to set the color mode (↪Sec. 14.2) used for the bitmap generation. In *Real Color* wavelengths out of the visible range are shown black.
{Color Table Button}	ONLY FOR *FALSE COLOR* MODE. Allows you to select the color table (↪Sec. 11.2.4).
All Wavelengths / Single Wavelength	Either *All Wavelengths* of the shown Chromatic Fields Up are summed in the resulting bitmap. Or you can select the index of the *Single Wavelength* to be shown either via the arrow buttons or by entering it directly.
Aspect Ratio	The aspect ratio of the resulting animation is determined in different ways: • *True to Physical Scale*: The aspect ratio is determined from the ratio of the x-axis range of the data array to its y-axis range. This option is not available if the two coordinate axes have different physical properties. • *User-Defined*: If you choose this option you can define a suitable aspect ratio. For example you can use 16 : 9 to ensure that the animation (and a video possibly generated out of it via File > Export) looks nicely on matching monitors or projectors. For gridded data arrays the default user-defined aspect ratio is calculated from the number of data points in the data array. • *Free*: You can set *Width* and *Height* of the single bitmaps as you want.
Width / Height	The width and height of the resulting bitmaps. If the *Aspect Ratio* is not *Free* and you change one dimension, then the other dimension is always changed automatically.
Scale Frames to	• *Common Value Range*: The global minimum and maximum value of all subsets is used to scale the color table. As a result you can see in which subsets there are smaller values then in others. • *Individual Value Range*: The color table for each frame is adapted to the minimum and maximum value of the individual data. As a result all subsets use all colors of the color table. • *User-Defined Value Range*: The user can enter the minimum and maximum value which is used to scale the color table. In *Real Color* mode zero values always correspond to black. Thus you cannot set the minimum value.

45.5.1.7 Animation Combined Output for Order Collections

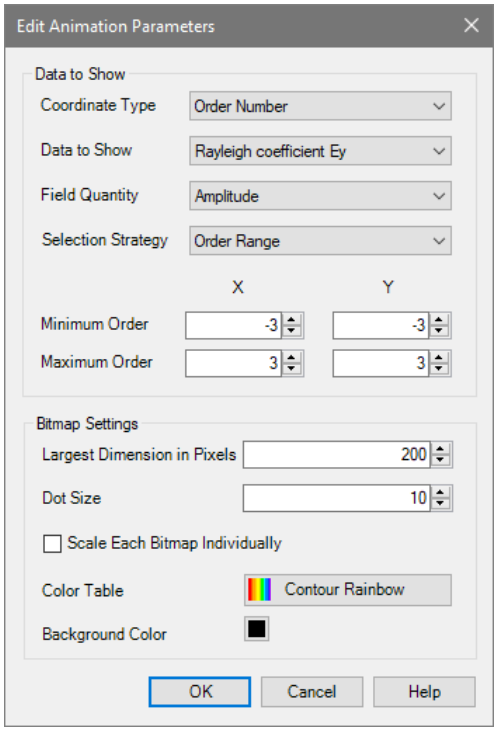


Figure 462. *Edit dialog of the Animation Combined Output for Order Collections.*

In the upper part of the edit dialog of the Animation Combined Output for Order Collections (↪Fig. 462) you can define which coordinates are used to plot which data of the individual orders. In the lower part you can define properties of the resulting bitmaps.
In detail:

ITEM	DESCRIPTION
Coordinate Type	The coordinates versus which the individual orders are plotted: either the order numbers, the spherical angles θ and ϕ, the Cartesian angles α and β, the wave vector components k_x and k_y, or the position $(x; y)$.
Data to Show	Allows to set whether the efficiencies or certain Rayleigh coefficients (E_x, E_y, E_z, TE, TM) of the orders are shown.
Field Quantity	If you want to show Rayleigh coefficients, you must also select which part of its complex value is to be shown.
Selection Strategy	With this option you can restrict the shown orders. The following three strategies are available: • ***All***: No restrictions apply • ***Above Efficiency Threshold***: Only (propagating) orders above the given *Efficiency Threshold* are shown. • ***Order Range***: All orders in the range between *Minimum Order* (inclusive) and *Maximum Order* (inclusive) are shown. **Note that evanescent orders are only shown if order numbers or wave vector components are used as *Coordinate Type*.**
Largest Dimension in Pixels	Either height or width (whatever is larger) of the resulting bitmaps in pixels.
Dot Size	The size of the dots representing the orders in pixels.
Scale Each Bitmap Individually	If checked each bitmap uses the complete color range defined by the *Color Table*. Otherwise a global scaling is applied so that you can see e. g. brightness differences between different bitmaps.
Color Table	If you click on this button you can select the color table to be used.
Background Color	The color used for those regions of the bitmap where no dots are drawn.

45.6 Iteration Document

The Eigenmode Analyzer (↪Sec. 90) generates iteration documents which simply consist of the *Results* page of the parameter run document (↪Sec. 45.5). It has the following ribbon entries:

ITEM	DESCRIPTION
Go!	Allows you to start the actual iteration. While the iteration is in progress, the button changes into a Stop button which allows you to stop the calculation.
After Completion	For long running iterations it can be useful if after completion the Iteration Document saves itself and optionally the computer shuts down. This can be defined with this option which is also available in the property browser (↪Sec. 4.3). If the Iteration Document has not been saved before it is saved at `{Path for User Settings}\Autosaved Files`. The *Path for User Settings* can be set on the *Saving* tab of the Global Options dialog (↪Sec. 6). Below this combo box the used file name is displayed. **Note that *Save & Shutdown Computer* can lead to data loss if there are unsaved documents but the Iteration Document for which this option is set.**

Show Optical Setup	Shows the Optical Setup from which the Iteration Document was originally created.
Logging During Execution	If this button is pressed, the results of the individual iteration steps are written as soon as they are available. Else they are only written after the iteration has finished. This improves performance especially in case of many fast iteration steps. Note that this button is disabled during an ongoing iteration and that it can also be changed via the Property Browser.
Create Output from Selection	If you click this button, for each table row of the current selection a combined output is generated as defined by the settings in the matching combined output box (↪Sec. 45.5.1). During the output creation, the button changes into a Stop Output Creation button which allows you to stop the calculation. Double clicking on a row header is a short cut for selecting this row completely and clicking Create Output from Selection. Similarly, double-clicking a single table cell is a short cut for selecting this row and clicking Create Output from Selection. It is also possible to generate the combined output out of the current selection via the context menu or the *Create Output from Selection* button of the results table.

46 LLGA Results Generator

Availability

Toolboxes: Grating Package

Accessible: Main Window: Start > Grating > LLGA Results Generator

The Local Linear Grating Approximation (LLGA) approach decomposes an arbitrary structure into a set of simple gratings. For such a set of simple gratings, the LLGA Results Generator can calculate rigorous results (Rayleigh coefficients per order for both E_x- and E_y-polarization) by means of the Fourier Modal Method (FMM, ↪Sec. 97.3). For each grating to analyze, the LLGA Results Generator requires period, rotation angle, and incident angle of the incoming light. Furthermore it has to know

- the wavelength of the incoming light
- the complex refractive index before and after the gratings and
- the range of diffraction orders for which results shall be calculated .

A LLGA Results Generator containing this *imported information* can be either obtained from the Local Linear Grating Analyzer (↪Sec. 91) or from a matching XML file via Start > Grating > LLGA Results Generator.
The results of the LLGA results generator are either added to the imported XML file or written in a new XML file with the same structure.

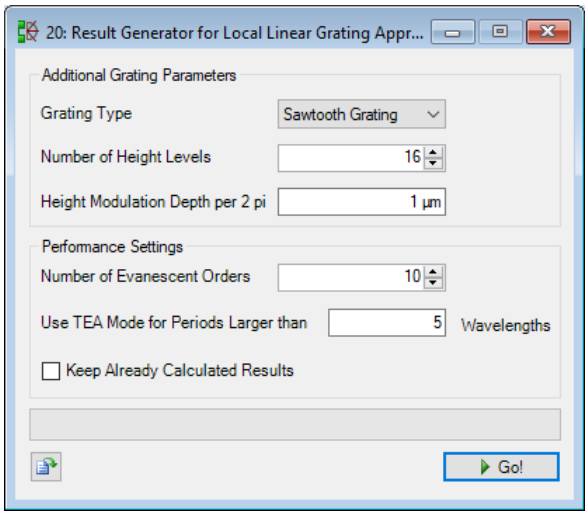


Figure 463. *The document window of the LLGA Results Generator.*

Some *Additional Grating Parameters* needed to build up the grating structure are not part of the imported information but can be specified in the document window of the LLGA Results Generator. This window has the following options.

ITEM	DESCRIPTION
Grating Type	The assumed type of the gratings. In the moment only sawtooth gratings are available.
Number of Height Levels	A continuous height profile is always converted into a quantized one for the FMM. More height levels mean a higher numerical effort of the FMM. If your structure will be fabricated quantized you may enter the fabricated number of height levels.
Modulation Depth	The modulation depth of all gratings; i. e. the height difference between lowest and highest height level.
Number of Evanescent Orders	The FMM calculates all propagating orders and the specified *Number of Evanescent Orders*. More evanescent orders lead to more accurate results, but both calculation time and memory consumption increase. The order range specified in the imported information only defines how many orders are written into the resulting XML file.
Use TEA Mode for Periods larger than	The computational effort of the FMM increases not only with the number of evanescent orders but also with the number of propagating orders. Thus large periods cannot be calculated well with the FMM. However, the thin element approximation (TEA) is sufficient for large periods (roughly five times the wavelength or larger). Thus TEA instead of FMM is used for periods larger than the given threshold.
Keep Already Calculated Results	If the imported XML file already contains some results, you can either choose to calculate all results anew or to *Keep Already Calculated Results*. Note that the latter should only be used if a calculation was stopped for some reason and you restart it with exactly the same settings.
Go!	If clicked the calculations are started and the *Go!*-button turns into a *Stop*-button to interrupt the calculations. As the LLGA Results Generator uses a document window you can continue to work with other documents or dialogs during the calculations.
(Export)	The button at the bottom of the dialog can be used to trigger the export of the calculated lookup table into an XML file. The file contains all parameter sets of the lookup table as well as the already calculated results. Attention: For large lookup tables the XML format can result in very large files.

The LLGA Results Generator calculates the efficiency of the grating cells array during the rigorous evaluation. This efficiency is defined by

$$\eta^{\text{total}} = \frac{\sum_s \sum_l \sum_j w_s \cdot \left| \boldsymbol{A}_{j,l,s}^{\text{before GCA}} \right|^2 \cdot \eta_{j,l,s}}{\sum_s \sum_l \sum_j w_s \cdot \left| \boldsymbol{A}_{j,l,s}^{\text{before GCA}} \right|^2} \tag{46.1}$$

using the following input variables

ITEM	DESCRIPTION
η^{total}	The averaged efficiency of the grating cells array.
$\eta_{j,l,s}$	The efficiency of the first order (working order) for one cell of the grating cells array for one wavelength and one lateral mode.
j	The index for all cells of the grating cells array.
l	The index of the lateral modes.
s	The index of the spectral modes.
w_s	The weights for the specific wavelength.
$A_{j,l,s}$	The field value of the electric field that hits the specific cell.

For the evaluation of the efficiency only the first order (working order) is taken into account. The result is logged into the *Detector Result* tab page of the main window.

47 LUT Results Generator

This document type is generated by the Grating Channel Analyzer (↪Sec. 92) if the light guides in the optical system contain channels for which rigorous results are still to be calculated. It allows you to continue your tasks while the rigorous calculations are done – or do these calculations on another computer. When the calculations are finished a copy of the original Optical Setup is generated with the calculated rigorous results set to the corresponding grating regions (↪Sec. 43).

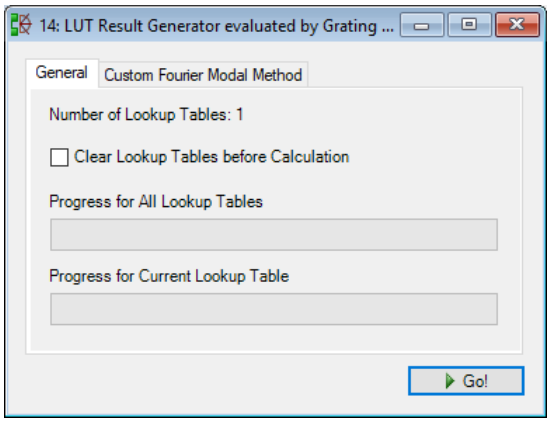


Figure 464. *The* General *tab of the document window of the LUT Results Generator.*

The corresponding document window (↪Fig. 464) has the following options.

ITEM	DESCRIPTION
{General tab}	On this tab you can define whether already calculated results are kept or whether to *Clear Lookup Tables before Calculation*. Furthermore this tab contains information about the *Number of Lookup Tables* and the progress of the running calculations.
{Custom Fourier Modal Method}	On this tab you can define whether you want to use your own Fourier Modal Method or the one implemented in VirtualLab Fusion. See Sec. 97.4 for details.
Go!	If clicked the calculations are started and the *Go!*-button turns into a *Stop*-button to interrupt the calculations. As the LUT Results Generator uses a document window you can continue to work with other documents or dialogs during the calculations.

48 Session Editors

Session Editors are wizard documents for specific application scenarios which allow you to set up all needed documents at once. They can be found in Start > Laser Resonators and Start > Diffractive Optics, respectively. Each Session Editor generates a new VirtualLab Fusion Session. Single documents within a Session cannot be closed separately. To close a Session close the Session Editor. To avoid unintended closing of dependent documents, an inquiry dialog is displayed before closing.
If you click *Finish* in the Session Editor, all necessary documents are generated. If you change the settings in the Session Editor, you have to click *Refresh* to bring these changes into the dependent documents. It is also possible to change the dependent documents directly.
All documents of a Session can be saved separately.

48.1 Annotations for Session Editors in the Diffractive Optics Package

This section contains annotations for certain wizard pages of the session editors in the Diffractive Optics Package.

48.1.1 Effect of Coherence and the M^2 Value on Beam Splitter and Diffuser Systems

The input beam of a beam splitting or diffusing system is modeled as coherent, monochromatic field with Gaussian amplitude distribution and a beam quality of $M^2 = 1$. Nevertheless beam splitting and diffuser elements will work also for laser beams with $M^2 > 1$ or spatially partial coherence. The input beam parameters specified in the session editors are just used for calculation of the spot diameter in the target plane and to check if the distance between the diffraction orders will be larger than the spot diameter. If a laser beam with $M^2 > 1$ should be used the spot diameter in the target plane may be larger than the diameter calculated by the session editor. Please check in this case that the distance between the diffraction orders is larger than the spot diameter of your beam in the target plane.

48.1.2 Supported Optical Setups for Beam Splitters and Diffusers

In order to simplify the parameter specification only four different optical setups are supported. Nevertheless the most of the real existing optical systems can be described by one of the idealized setups mentioned below.

- The **1f- and 2f-setups** are containing a lens creating the far field of the diffractive optical element in the focal plane of the lens. The lens is simulated using a lens transmission. The focal length of the lens transmission must be equal to the effective focal length of a real lens or lens system. To simulate the

effect of real lenses after the end of the optimization replace the lens transmission by a real lens or lens system in the resulting Optical Setup.

- The **paraxial far field setup** assumes a large distance between diffractive optical element and target plane. The light propagation to the target plane is modeled by Fraunhofer diffraction integral. Near field diffraction effects are not considered during the optimization but can be modeled in the resulting Optical Setup.
- **Angular spectrum setup** allows you to optimize a diffractive optical element creating the desired angular diffraction patterns.

All optical elements in the setups are surrounded by a medium that can be specified together with all other system parameters on the next page. For angular spectrum setup vacuum is always assumed as surrounding medium.

48.1.3 Supported Optical Setups for Beam Shapers

In order to simplify the parameter specification only three different optical setups are supported. Nevertheless the most of the real existing optical systems can be described by one of the idealized setups mentioned below.

- The **1f- and 2f-setups** are containing a lens creating the far field of the beam shaping element in the focal plane of the lens. The lens is simulated using a lens transmission. The focal length of the lens transmission must be equal to the effective focal length of a real lens or lens system. To simulate the effect of real lenses after the end of the optimization replace in the resulting Optical Setup the lens transmission by a real lens or lens system.
- The **Fresnel setup** assumes a large distance between beam shaping element and target plane.

All optical elements in the setups are surrounded by a medium that can be specified together with all other system parameters on the next page.

48.1.4 Output Field Parameters for Beam Splitters

The separation of diffraction orders is controlled during the design by the period of the beam splitting element. Depending on the fabrication constraints (pixel size and pixel size increment; see next pages) it is probably not possible to achieve exactly the calculated period of the element. This will lead to small deviations between the desired separation of orders and the practically achieved separation. Both values are displayed on the summary page at the end of the session editor.
An *Offset* of the desired diffraction orders can be specified on this page. The offset can be for example helpful to separate the zeroth order from the other diffraction orders. A zeroth order may appear because of fabrication tolerances of the surface profile of a diffractive optical element. Please take into account that in case of a height profile with two height levels, a transmission with two phase levels and amplitude-only transmissions always a diffraction pattern symmetric to the optical axis will appear. That means that the offset should be large enough so that all desired orders are shifted above or below the optical axis. Use the *Suggest Offset* button to get a suggestion for the offset that fulfills this condition.

Since the most diffractive optical elements do not diffract all light into the desired diffraction orders also higher orders will appear (stray light). In order to avoid disturbing effects in the application a *Maximum Relative Stray Light Intensity* can be specified. Please take into account that very small values could be unrealistic.

48.1.5 Output Field Parameters for Diffusers

An *Offset* of the desired diffraction orders can be specified on this page. The offset can be for example helpful to separate the zeroth order from the other diffraction orders. A zeroth order may appear because of fabrication

tolerances of the surface profile of a diffractive optical element. Please take into account that in case of height profiles with two height levels, transmissions with two phase levels or amplitude-only transmissions always a diffraction pattern symmetric to the optical axis will appear. This means that the offset should be large enough so that all desired orders are shifted above or below the optical axis. Use the *Suggest Optional Offset* button to get a suggestion for the offset that fulfills this condition.

Since the most diffractive optical elements do not diffract all light in the desired diffraction orders also higher orders will appear (stray light). In order to avoid disturbing effects in the application a *Maximum Relative Stray Light Intensity* can be specified. Please take into account that very small values could be unrealistic.

48.1.6 Output Field Diameter

A rectangular area symmetric to the optical axis is reserved in the target plane for the creation of the desired light pattern. Around this light pattern another rectangular region is used for the distribution of the stray light. The ratio between output field diameter and light pattern diameter is expressed by a *Diameter Factor*. The output field diameter should be approximately two times larger than the light pattern diameter for continuous DOEs and four times larger than the light pattern diameter for pixelated DOEs in order to reduce the energy loss because of diffraction at rectangular pixels.

Increasing the diameter factor helps to reduce the uniformity error. If a maximum stray light intensity limit was introduced increasing the diameter factor allows to distribute the energy of the stray light over a larger area and helps to reduce the maximum stray light intensity.

The output field diameter is controlled by the feature size of the diffractive optical element. Increasing the output field diameter requires smaller features of the diffractive optical element. Take into account that the feature size can be limited to a minimum value. This will limit the output field size to a maximum value. The manual or automatic selection of the output field size has only an effect if the automatic calculation of pixel size is activated (see later pages). In case of manual adjustment of the pixel size the user is responsible to ensure that sufficiently large output field diameters can be reached by the selected pixel size.

48.1.7 Merit Functions for the Iterative Fourier Transform Algorithm

The optimization principle of the Iterative Fourier Transform Algorithm (IFTA) used for optimization of diffractive optical elements differs from other parametric optimization algorithms. Other algorithms often analyze an spread sheet and evaluate the merit functions. In a second step parameters are varied and analysis of spread sheet and evaluation of merit functions is repeated. From the change of merit functions conclusions for further modifications of parameters can be done. The evaluation of the merit functions results is essential for the optimization.
In contrast, the IFTA performs an analysis of the system. It corrects intensity deviations of the output field from the desired output field. This means special constraints will be applied on the output field intensity. In a second step the corrected output field is back propagated in the plane of the diffractive optical element and the element parameters are calculated. Additional constraints must be applied on the element in order to fulfill all fabrication conditions (for example discrete height levels). These two steps are called iteration. All selected merit functions, specifications of the desired output field and specifications of the diffractive optical element are translated as constraints of the output field and the element. Thus an evaluation of the merit functions values is not required.
This means for example achieving a low uniformity error can be done by replacing the real output field intensity by the intensity of the desired output field. Doing this requires not the knowledge of the uniformity error value itself. The maximum relative intensity of stray light can be limited by cutting all intensity values of the stray light that are above a specified limit. Again, the exact value of the merit function is not required for optimization.

Therefore it is not required to evaluate the merit functions values during the optimization. Instead calculation of the values requires additional computational time and will thus reduce the performance of the optimization. The logging of the merit function results can be deactivated using *Disable Logging of Merit Functions during Optimization*. The optimized Optical Setup will contain detectors and analyzers for evaluation of the merit functions values after optimization.
Seven different merit functions can be used during the optimization of a diffractive optical element and final evaluation. It follows a short overview of available merit functions. The implemented formulas are given in Sec. 142.2.

ITEM	DESCRIPTION
Window Efficiency	Measures the amount of energy of the input field diffracted in a typically rectangular or circular signal region in the target plane. The signal region has the shape and the extension of the desired output intensity pattern. The achieved quality of the output field is not considered. This means that for example a lens concentrating all light in the signal region may reach an efficiency of 100 %. It is recommended to use the conversion efficiency instead.
Conversion Efficiency	Measures the amount of energy of the input field diffracted in a typically rectangular or circular signal region in the target plane. Any noise in the signal region is ignored. The signal region has the shape and the extension of the desired output intensity pattern. A lens focusing for example all light in the signal region would lead in contrast to the window efficiency to a very low efficiency since the generated spot is typically different from the desired output field and will be considered as noise.
Signal to Noise Ratio	The SNR is the ratio between the integral intensity of the output field to the integral intensity of the noise. It is expressed in dB.
Uniformity Error	The maximum error of the output field intensity compared to the desired output field intensity. The definition is similar to the definition of a contrast.
Maximum Relative Intensity of Stray Light	Diffractive optical elements achieve often a conversion efficiency below 100 %. This means that not all light is diffracted in the desired output field intensity pattern. The remaining light typically appears as stray light around a rectangular or circular signal region in the target plane. This merit function measures the ratio of the maximum intensity of the stray light relative to the mean intensity of the output field within the signal region.
Relative Zeroth Order Intensity	This merit function measures the intensity of the zero order relative to the mean intensity of the output field within a rectangular or circular signal region in the target plane. It is often a measure for the amount of undiffracted light.
Zeroth Order Efficiency	The amount of energy of the input field diffracted into the zeroth order.

48.1.8 Merit Functions for Refractive Beam Shapers

Five different merit functions can be used for analysis and optimization of a refractive beam shaping element. It follows a short overview of available merit functions. The implemented formulas are given in Sec. 142.2.

ITEM	DESCRIPTION
Window Efficiency	Measures the amount of energy of the input field diffracted in a typically rectangular or circular signal region in the target plane. The signal region has the shape and the extension of the desired output intensity pattern. The achieved quality of the output field is not considered. This means that for example a lens concentrating all light in the signal region may reach an efficiency of 100 %. It is recommended to use the conversion efficiency instead.
Conversion Efficiency	Measures the amount of energy of the input field diffracted in a typically rectangular or circular signal region in the target plane. Any noise in the signal region is ignored. The signal region has the shape and the extension of the desired output intensity pattern. A lens focusing for example all light in the signal region would lead in contrast to the window efficiency to a very low efficiency since the generated spot is typically different from the desired output field and will be considered as noise.
Signal to Noise Ratio	The SNR is the ratio between the integral intensity of the output field to the integral intensity of the noise. It is expressed in dB.
Uniformity Error	The maximum error of the output field intensity compared to the desired output field intensity. The definition is similar to the definition of a contrast.
Maximum Relative Intensity of Stray Light	A beam shaping elements probably does not reach a conversion efficiency of 100 %. This means that not all light is deflected in the desired output field intensity pattern. The remaining light is typically reflected or appears as stray light around a rectangular or circular signal region in the target plane. This merit function measures the ratio of the maximum intensity of the stray light relative to the mean intensity of the output field within the signal region.

48.1.9 Transmission Types

Three different types of transmissions are supported. That are:

- An *Amplitude-Only Transmission* just introduce an amplitude modulation between zero and one to incoming fields. Zero means absorption and one means that light may pass the transmission without change. No phase modulation is allowed. Diffractive optical elements can use for example chromium layers to create an amplitude-only transmission.
- A *Phase-Only Transmission* creates a phase modulation from -π to +π without changing the amplitude of an incoming field. Diffractive optical elements with micro structured height profiles can create an phase-only transmissions.
- A *Complex Transmission* allows modulation of amplitude and phase of an incoming field. Diffractive optical elements containing a micro structured height profile and additionally a chromium mask can create for example a complex transmission.

48.1.10 Period, Pixel Size and Number of Pixels

- The *Period* of the diffractive optical element is calculated from the angular resolution required for the desired output intensity.
- The *Pixel Size* of the diffractive optical element is calculated from the maximum deflection angle. This angle follows from the maximum angle of the desired output intensity and an additional frame that is used

for stray light that can not diffracted into the desired intensity pattern. Expert user can set the pixel size to an user defined value but must ensure that the pixel size is small enough to create the desired output intensity with sufficient high quality.

- The *Number of Pixels per Period* follows just from period and pixel size. Since only an integer number of pixels are allowed the pixel number must be rounded and the period may differ slightly from the optimal value. This rounding leads to small deviation of the output field angular resolution from the desired value. The deviation is displayed on the next page.

48.1.11 Import of Arbitrary Input Field

The power weights of the desired diffraction orders of the beam array can be imported from a harmonic field, from an ASCII file or from a bitmap file. Every sampling point in the data file represents one diffraction order. It is typically not necessary to introduce diffraction orders with zero weights in order to generate “free spaces” between the desired orders. These free spaces will result in the later application from illuminating several periods of the diffractive optical element. The weights of the beam array should be specified without a dark frame around the desired diffraction orders. Such a dark frame will be added by the session editor if required.

VIII Sources: Generating Fields

VirtualLab Fusion provides a growing set of source models. Each model describes an electromagnetic field in a plane. The theoretical background can be found in Sec. 139.

The following chapters explain how to use the generator dialogs, starting with the description of those controls that most source generator dialogs (except that for Stored Fields) have in common. The type specific parameters are described in Sections Sec. 52 and Sec. 53.

49 Common Controls of the Source Generator Dialogs

49.1 Dialog for Sources in the Optical Setup

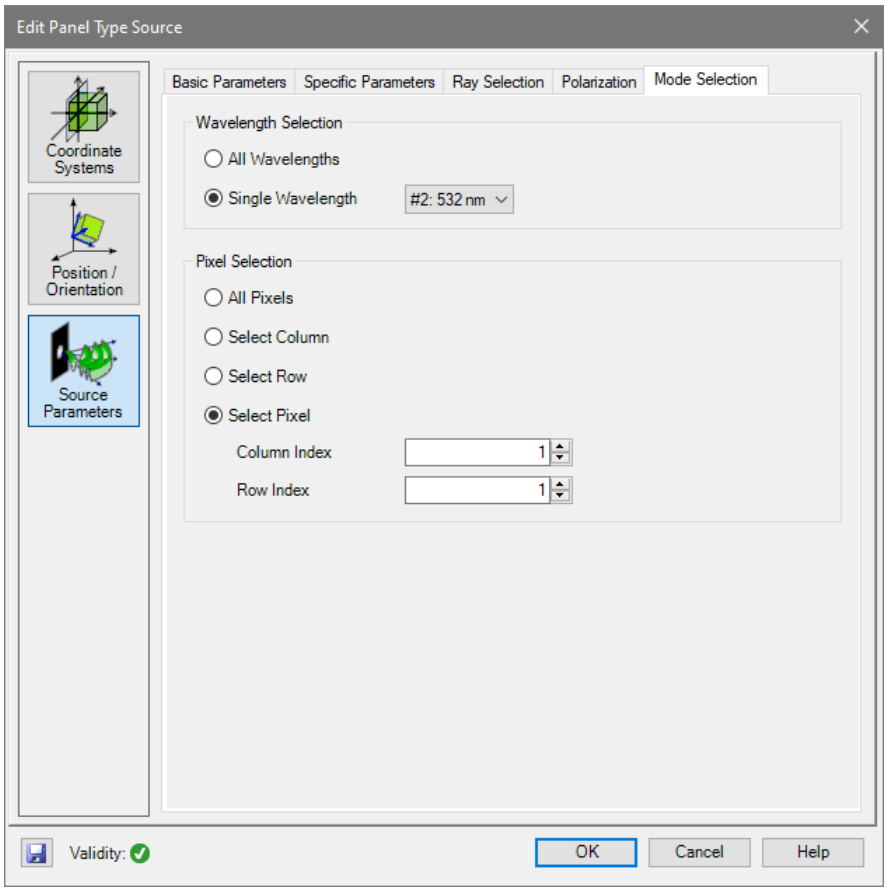


Figure 465. *Sample edit dialog for light sources in the Optical Setup.*

The edit dialogs for light sources in the Optical Setup (↪Fig. 524) are divided into 3 pages:

- *Coordinate Systems* ↪Sec. 44.9.1
- *Position / Orientation* ↪Sec. 44.9.2
- *Source Parameters*

The *Source Parameters* tab is again divided into the following tab pages:

- *Basic Parameters* ↪Sec. 49.1.1
- *Specific Parameters*; specific for the distinct light sources and thus explained in Sec. 52 to Sec. 53
- *Polarization* ↪Sec. 49.3
- *Mode Selection* ↪Sec. 49.1.2

In the lower left corner of the dialog there are the following controls:

ITEM	DESCRIPTION
	Saves the component into the user-defined light sources catalog (↪Part V).
Validity	This control (↪Sec. 5.11) indicates whether there are issues with the current configuration. If this is the case you can click on the -button for further information.

49.1.1 Basic Parameters

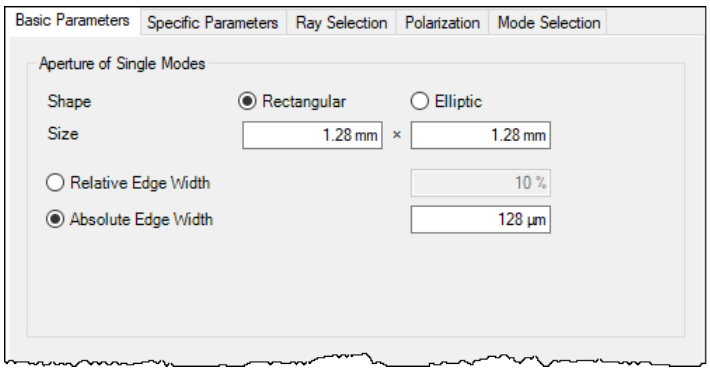


Figure 466. *Controls for defining the aperture of the single modes.*

On the *Basic Parameters* tab of the light source dialog (↪Fig. 466) you can set the aperture of the single modes.

ITEM	DESCRIPTION
Shape	You can choose whether the single modes have a *Rectangular* or an *Elliptical* shape.
Size	The size or diameter of the aperture. If the light source determines the aperture size automatically, this control is not visible.
Relative Edge Width PV	The width of the smoothing edges defined relatively to the lateral extension of the mode. If the extension in x- and y-direction differ, the minimum of both values is taken.
Absolute Edge Width PV	The width of the smoothing edges in meters (↪Fig. 467). If the light source determines the aperture size automatically, this control is not visible.

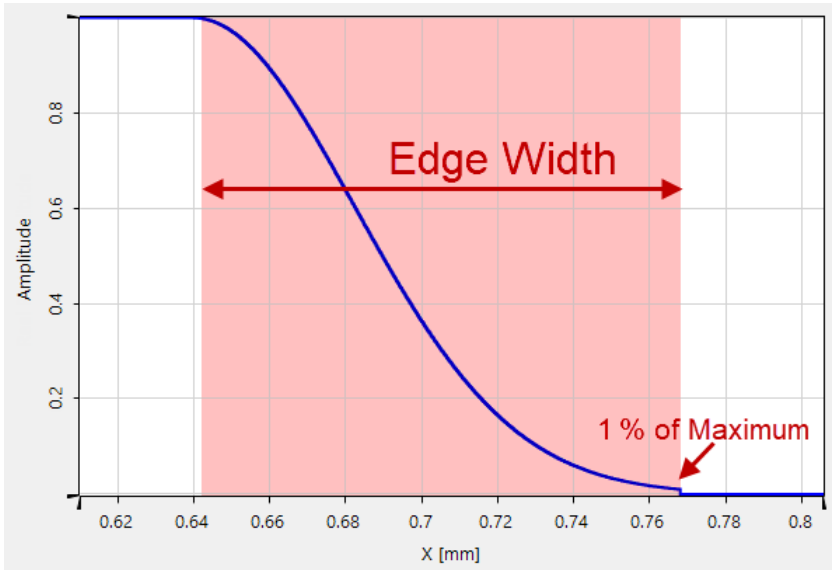


Figure 467. *Definition of the edge width of smoothing edge functions.*

For the Panel Type Source (↪Sec. 53.7.1) the aperture does not change the overall size of the modes. Thus you cannot set a relative edge width of more than 50 % which makes that the whole area of the mode is attenuated by the aperture.

49.1.2 Mode Selection

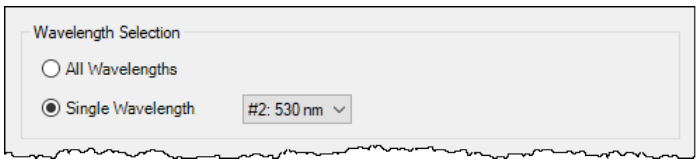


Figure 468. *Controls for the selection which wavelengths are to be generated.*

On the *Mode Selection* tab of the light source dialog (↪Fig. 468) you can set whether *All Wavelengths* are generated or only a *Single Wavelength*. In the latter case you can select which wavelength index[PV] is taken. Furthermore light sources can have their special way of selecting the generated lateral modes. This is explained in the light source specific chapters.

49.2 Dialog for Sources in the Main Window

The edit dialogs for sources in the main window (partly also used from within the Optical Setup) have some common controls for all types of source generators.
They define the

- definition of the field via the panel *Basic Parameters* (↪Sec. 49.2.1)
- definition of spectral parameters via the panel *Spectral Parameters* (↪Sec. 49.2.2)
- definition of the polarization via the panel *Polarization* (↪Sec. 49.3)
- selection of (fundamental) modes via the panel *Mode Selection* (↪Sec. 49.2.4)
- sampling of the fields via the panel *Sampling* (↪Sec. 49.2.5)

The panel *Spatial Parameters* is type specific, so its contents are described in the corresponding subsections of Sec. 52 and Sec. 53.
The *Default Parameters* button resets the parameters on all tabs to their default values.

49.2.1 Basic Parameters

The panel is shown in Fig. 469 for the selection *Automatic Setting*. It comprises three parts:

ITEM	DESCRIPTION
Medium at Source Plane	The medium in which the source field is generated. This control is explained in Sec. 34.1.
Source Field: Longitudinal and Lateral Offset	These settings are explained in subsection Sec. 49.2.1.1.
Input Field: Position, Size and Shape	These settings are explained in subsection Sec. 49.2.1.2.

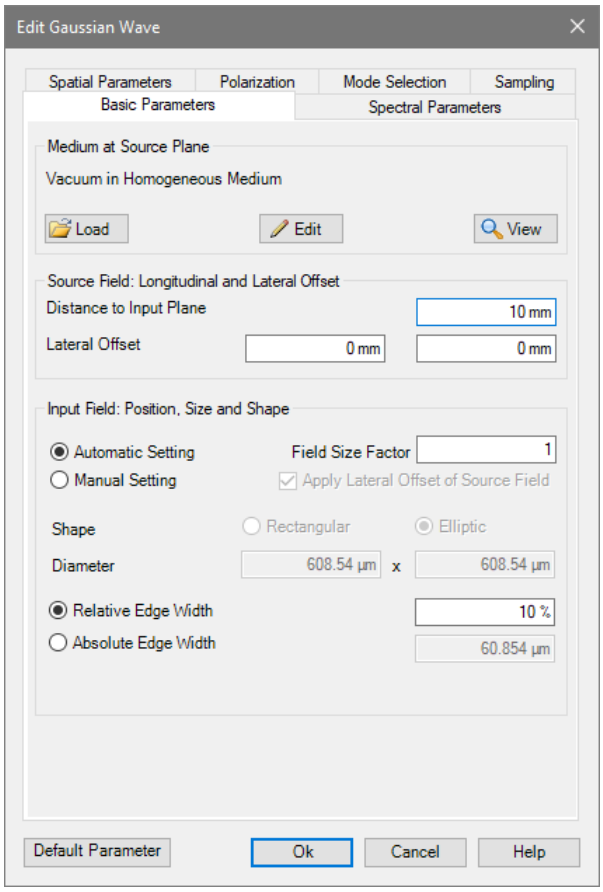


Figure 469. *Tab page for setting the basic parameters of a light source.*

49.2.1.1 Relation between Source Field and Input Field

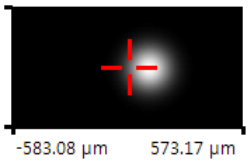


Figure 470. *Effect of a Lateral Offset of 100 μm in x-direction on a Gaussian Wave. The origin of coordinates of the input plane is marked.*

We distinguish between the field in the *source plane* and and the field in the *input plane*.
By the parameters on the *Spatial Parameters* tab the field is defined in a certain *source plane*. For example, this is the waist (plane) for a Gaussian wave.
However, the field put into VirtualLab Fusion by the source dialog might be defined in another plane parallel to the source plane: the *input plane*.
The group box *Source Field: Longitudinal and Lateral Offset* allows you to configure the relation between source plane and input plane:

ITEM	DESCRIPTION
Distance to Input Plane PV	This value describes the distance between input plane and source plane along the z-axis: distance $= z_{\text{Input Plane}} - z_{\text{Source Plane}}$. For some of the sources this value is fixed to zero. In the case of spherical and quadratic waves this value must not be zero and the spherical phase radius is set to this value.
Lateral Offset PV	This value describes the offset between the origins of the coordinates for the source and the input plane.

Within the Optical Setup the lateral offset specified within this region of the dialog is handled by the usage of coordinate systems.

49.2.1.2 Position, Size and Shape of the Input Field

VirtualLab Fusion follows the concept of smooth fields. For physically meaningful fields, jumps in the data should be avoided. Numerically this is achieved by using smoothing edge functions as shown in Fig. 473.

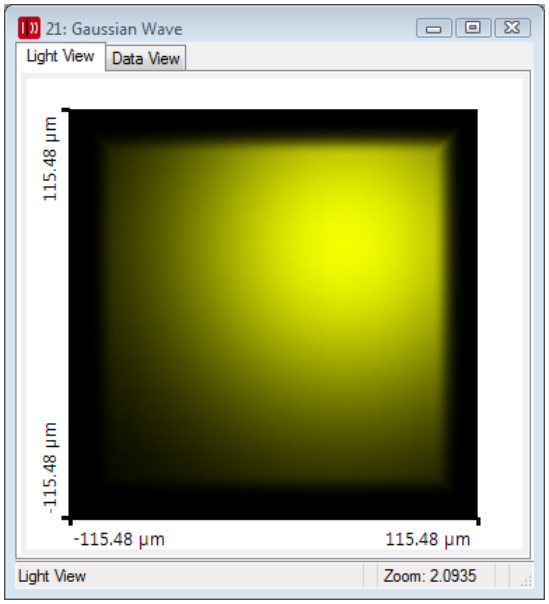


Figure 471. *Shifted Gaussian Wave with unchecked* Apply Lateral Offset of Source Field.

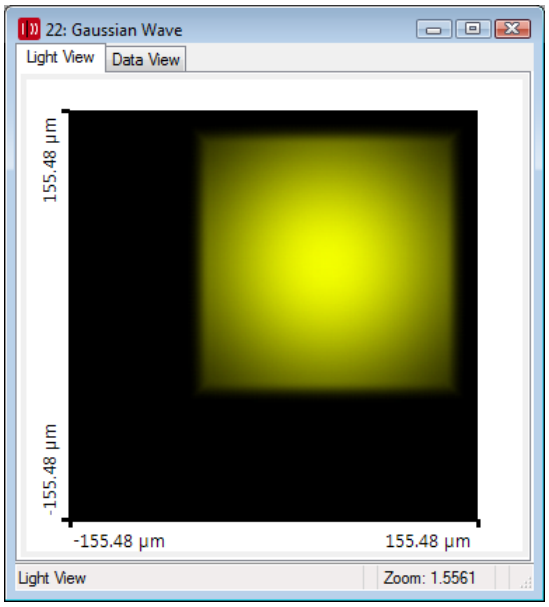


Figure 472. *Shifted Gaussian Wave with checked* Apply Lateral Offset of Source Field*. Note the larger overall field size.*

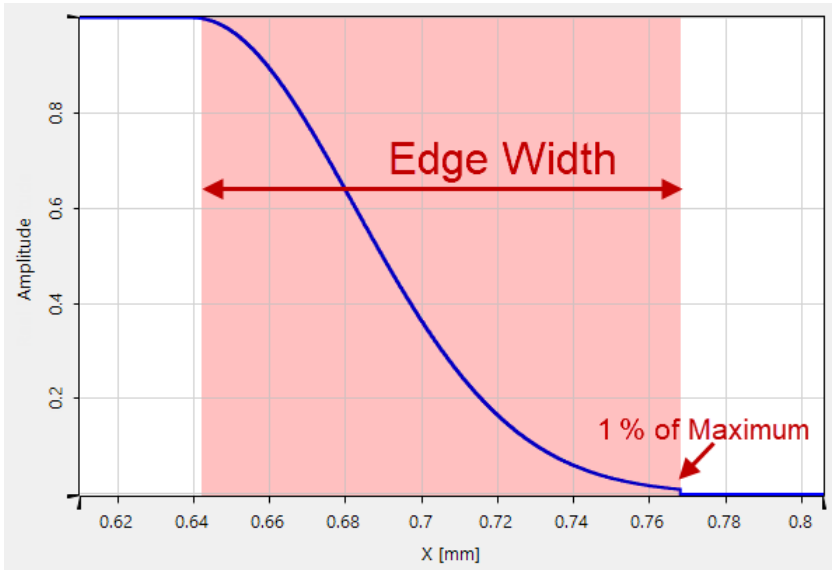


Figure 473. *Definition of the edge width of smoothing edge functions.*

The group box *Input Field: Position, Size and Shape* allows you to define position, size, and shape of this smooth edge in the input plane:

ITEM	DESCRIPTION
Automatic Setting	If checked, a reasonable size (suggested field size) of the field is determined automatically. This option is only available for some light sources, e. g. those defining exponentially decreasing fields.
Field Size Factor PV	The suggested field size is multiplied by this factor for *Automatic Setting*.
Manual Setting	If checked, the field size can be entered by the user.
Apply Lateral Offset of Source Field PE	By default, the resulting input field is centered at the position $(0\,\mathrm{m};\,0\,\mathrm{m})$ in the input plane. By checking this box, the field is shifted by the *Lateral Offset* of the source plane (↪Sec. 49.2.1.1). Note, the resulting numerical array (sampled field) will still be centered at $(0\,\mathrm{m};\,0\,\mathrm{m})$, so additional zero-values will be generated. An example is given in Fig. 471 and Fig. 472.
Shape PE	The field may be *Rectangular*ly or *Elliptic*ally shaped.
Diameter PV	Physical size of the field physical dimension in the input plane.
Relative Edge Width PV	The width of the smoothing edges defined relatively to the (smaller of the both values of) *Diameter*.
Absolute Edge Width PV	The width of the smoothing edges, defined in physical units. ↪Fig. 473.

49.2.2 Spectral Parameters

At this panel the spectral information for the field has to be defined. In the simplest case, using *Power Spectrum Type* > *Single Wavelength*, a single *Wavelength* PV can be defined yielding a monochromatic field. The remaining options, *Triplet of Wavelengths* and *List of Wavelengths*, result in polychromatic fields represented by a harmonic field set.

The *Weight* values are given as intensities, i. e. those values are scaling values for A^2 of the corresponding fields.

The panel adapts its design to the chosen *Type of Power Spectrum*. The types *Single Wavelength*, *Triplet of Wavelengths* and *List of Wavelengths* are explained in Sec. 49.2.2.1, Sec. 49.2.2.2, Sec. 49.2.2.3, respectively. The selection *Triplet of Wavelengths* is a special case of the more general selection *List of Wavelengths*.

49.2.2.1 Single Wavelength

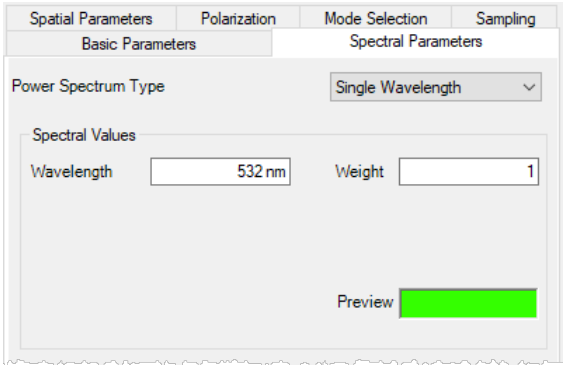


Figure 474. *Panel for setting the spectral parameters (*Single Wavelength*) of a source generator.*

Description of parameters:

ITEM	DESCRIPTION
Wavelength PV	The vacuum wavelength.
Weight PV	The intensity value (scaling of A^2).
Preview	Some approximate preview of the resulting color. A wavelength out of the visible range of the spectrum is marked black.

49.2.2.2 Triplet of Wavelengths

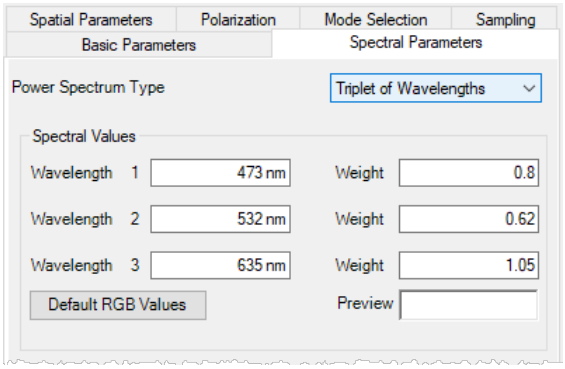


Figure 475. *Panel for setting the spectral parameters (*Triplet of Wavelengths*) of a source generator.*

Description of the Parameters:

ITEM	DESCRIPTION
Wavelength PE	The vacuum wavelengths.
Weight PV	The intensity values (scaling of A^2).
Preview	Some approximate preview of the resulting color according to the given values.
Default RGB Values	Resets the values of the wavelengths and their weights to the default values depending on the current color system (see Sec. 6.7.1), which will result in white light.

49.2.2.3 List of Wavelengths

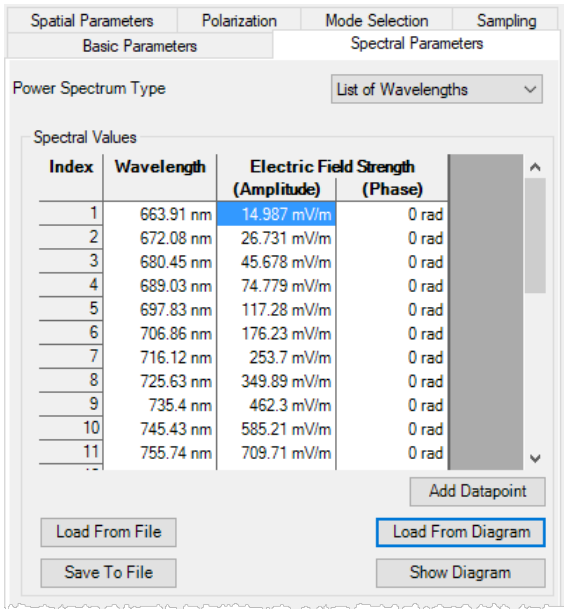


Figure 476. *Panel for setting the spectral parameters (List of Wavelengths) of a source generator.*

In this mode you have a table on the upper part of the dialog. There you can change already present data points or delete whole rows. `Del` deletes the content of the current cell (or the whole row if a complete row is selected). `Shift` + `Del` deletes the whole row in any case. This table has four columns:

COLUMN	DESCRIPTION
Index	The mode index.
Wavelength	The vacuum wavelengths.
Amplitude	The amplitude values for the wavelengths.
Phase	The phase values for the wavelengths.

In the lower part there are some additional buttons:

ITEM	DESCRIPTION
Add Datapoint	Add a data point to the list of wavelengths.
Load from File	Loads the wavelength and weight values from a .txt-file. The format is described below.
Save to File	The wavelength and weight values are saved to a .txt-file.
Load from Diagram	The wavelength and weight values are loaded from a diagram. Suitable diagrams can be generated via the spectrum generators described in Sec. 54.
Show Diagram	Shows the wavelength and weight values in a diagram.

For convenience, the spectral values can be defined also using diagrams or simple text files. An example of the format used for the text files is described below. Comment lines start with '#', columns must be separated by either spaces, tabs, semicolons, |, or &. The decimal separator must be a period.

```
# Spectrum Data
# Wavelength          Amplitude       Phase
4.1E-07               1               0
```

```
4.5E-07          2          0
4.8E-07          1          0
```

49.2.3 Spatial Parameters

Although this panel is specific to the particular source model, it contains the shared entry *Generate Cross Section* (↔Fig. 477).

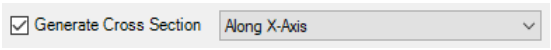


Figure 477. *Define a 1D simulation by using a cross section.*

By checking the box *Generate Cross Section*, for Classic Field Tracing a 1D cross section (either along x- or y-axis) will be generated instead of a 2D field. For the other simulation engines this setting has no effect.

ITEM	DESCRIPTION
Generate Cross Section PE	If checked, a 1D cross section *Along X-Axis* or *Along Y-Axis* is generated.

49.2.4 Mode Selection

In the case that a spectrum has been defined (more than one wavelength) or that laterally-shifted modes are used (non-coherent simulations), harmonic field sets with several members will be generated. This panel allows to define the number of modes being used for the simulation.

In general, the accuracy of the results increases with the number of modes. However the numerical effort increases as well. So a good compromise has to be found. Additionally, using less modes can already give a good insight into the behavior of optical systems.

The panel allows to define subsets of modes in order to control both accuracy and numerical effort. The spectral values and the laterally-shifted modes are selected independent of each other. However, once a selection of spectral values has been defined, each spectral value will be applied to every lateral mode.

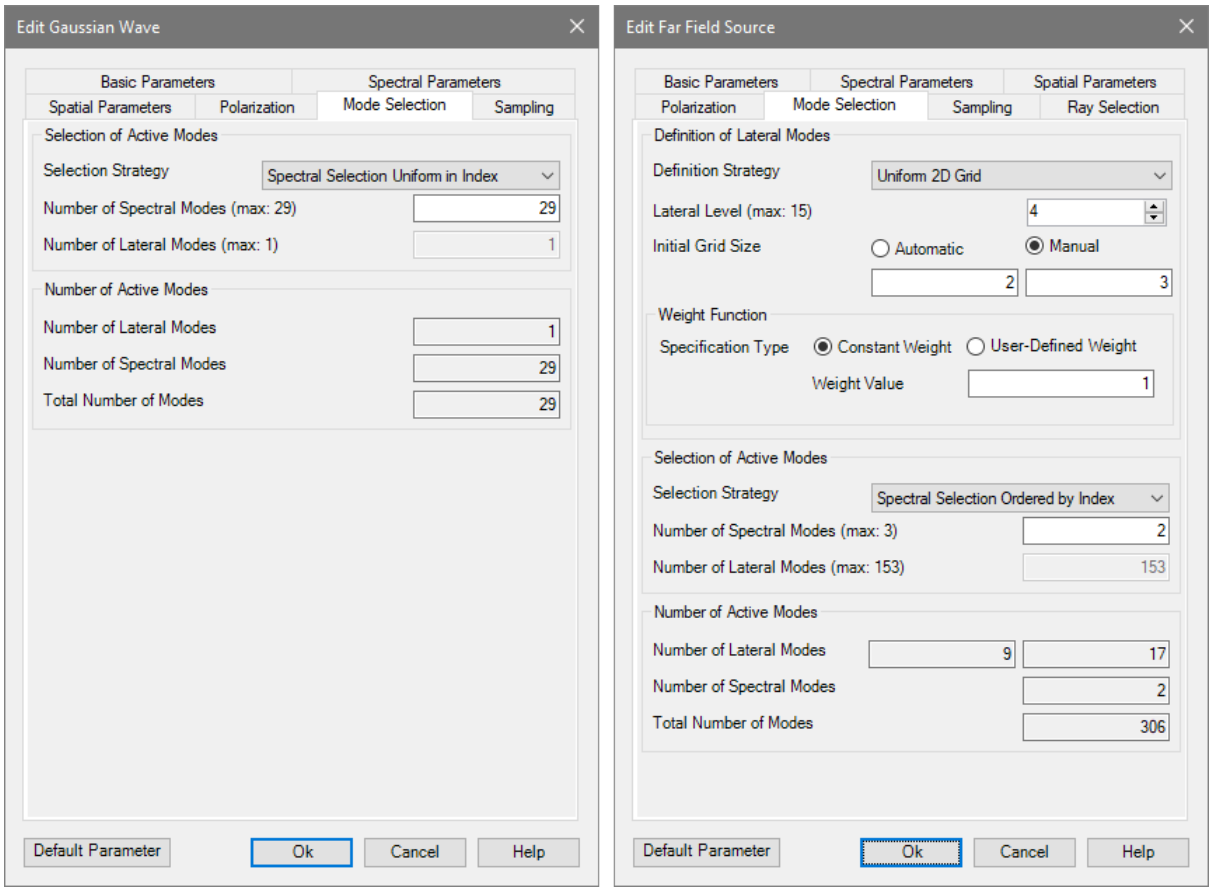


Figure 478. *The Mode Selection tab in two different configurations.* **Left:** *The mode selection tab for a basic source model having only wavelength modes.* **Right:** *The mode selection tab for a partially coherent source with Uniform 2D Grid as Selection Strategy for the lateral modes.*

The tab page shown in Fig. 478 is divided into two parts as described below. The first part is the definition of modes. For the definition of the lateral modes several selection strategies are available. The user can also specify the weight function that shall be applied to the lateral modes. The setting for the *Definition of Lateral Modes* are explained in the following table.

ITEM	DESCRIPTION
Definition Strategy	Five strategies are available to define the positions of the lateral modes. They are described below in a separate table. **This section is only visible for partially coherent light sources.** (↪Sec. 53)
Weight Function	You can either use a *Constant Weight* for all modes or *User-Defined Weights* per mode. For the latter there is an *Edit* button which opens a dialog. In this dialog you can define the intensity weights dependent on the lateral position either by programming a snippet[PE] or via a data table. See Sec. 5.14 for more details. **This section is only visible for partially coherent light sources.** (↪Sec. 53)

The following strategies can be used for the *Selection of Lateral Modes*.

SELECTION STRATEGY	DESCRIPTION
Uniform 2D Grid	A uniform rectangular grid of laterally-shifted modes is adjusted to the physical dimension of the emitting surface. The *Lateral Level*[PV] defines how often the initial grid is refined by bisection. The *Initial Grid Size*[PV] is 3×3 modes in *Automatic Mode* or a user-defined size in *Manual* mode.
Random	The lateral positions of the modes are distributed randomly across the emitting surface. For each consecutive simulation other mode positions are used. You can specify the *Number of Lateral Modes*[PV].
Random (seed=0)	The lateral positions of the modes are distributed randomly across the emitting surface whereas for each consecutive simulation the same mode positions are used. You can specify the *Number of Lateral Modes*[PV].
User Defined	The user can specify the positions of the modes either via a snippet[PE] or a data table. This can be done by clicking on *Edit* and setting up the dialog described in Sec. 5.14. In case of input via a snippet, you can also set the *Number of Lateral Modes*[PV] there.
None	Only one lateral mode at the position $(0\,\mathrm{m};\, 0\,\mathrm{m})$ is used.

The second part of the *Mode Selection* tab page can be used to select the lateral and spectral modes which shall be used for the simulation. The basis for the mode selection is given by the number of modes specified within the *Spectral Parameters* tab and the *Definition of Lateral Modes* group box.
The user can select between different selection strategies to specify which modes shall be used for the simulation. Within this part of the dialog the user can also see several information which allow to get an impression on accuracy and the numerical effort of the current simulation setup.
The following parameters can be accessed within this part of the dialog:

ITEM	DESCRIPTION
Selection Strategy	This defines the *Selection Strategy* for selecting certain wavelengths and lateral modes from the full set of modes specified in the *Spectral Parameters* tab and the *Definition of Lateral Modes* area on the *Mode Selection* tab. Four options are available: • *Full Set of Spectral and Lateral Modes*: All wavelengths given in the *Spectral Parameters* tab are used. All specified modes will be processed. • *Spectral Selection Ordered by Index*: The first n wavelengths given in the *Spectral Parameters* tab are used. n is the *Number of Spectral Modes*[PV]. For each wavelength all lateral modes defined within the above section will be processed. • *Spectral Selection Uniform in Index*: An algorithm selects n wavelengths which are well distributed across the index range. n is the *Number of Spectral Modes*[PV]. For each wavelength all lateral modes defined within the above section will be processed. • *Single Mode Selection*: Only one mode is generated by the light source. The user can enter an *Index of Spectral Mode* and an *Index of Lateral Mode* to specify which mode shall be generated by the light source. These parameters can be varied within the Parameter Run to perform a complex simulation and reduce the numerical effort (large data may be swapped to hard disc). n is the *Number of Spectral Modes*.
Number of Active Modes	For your information, this section shows the *Total Number of Modes* which is the product of the *Number of Lateral Modes* and the *Number of Wavelengths*. The number of lateral modes again can be the product of the lateral modes for x- and y-direction. Note that the dialog ensures that the *Total Number of Modes* does not exceed just over 2 billion.

49.2.5 Sampling

The generated field is represented by one or more arrays of sampled data. When using sampled fields, care has to be taken for ensuring that the original fields can always be reconstructed from the sampled fields with sufficient accuracy, that is the Whittaker Shannon theorem[Goo68] has to be taken into account. VirtualLab Fusion provides an automatic sampling mode which takes care of the sampling theorem and suggests corresponding sampling parameters. The user can scale these values or even modify them in the manual mode. The panel is shown in Fig. 479.

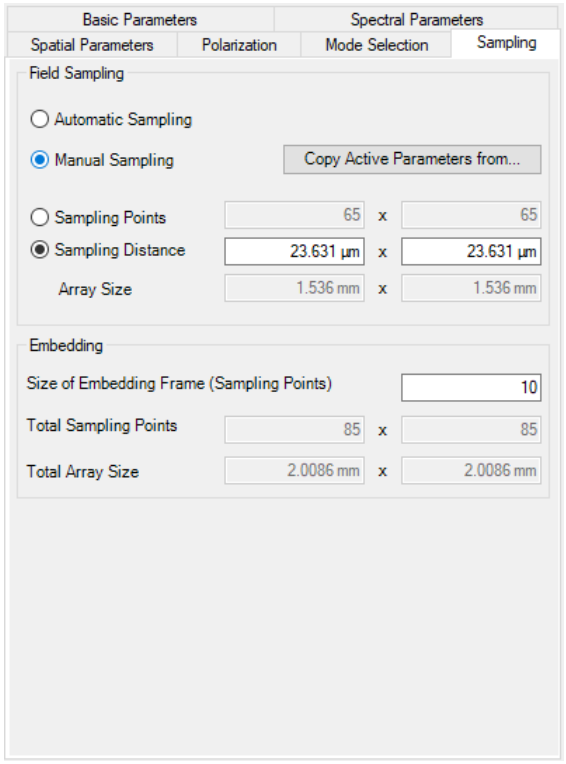


Figure 479. *Panel for* Sampling *of a source generator.*

Description of the parameters:

ITEM	DESCRIPTION
Automatic Sampling	If checked, the sampling parameters will be determined automatically.
Manual Sampling	If checked, the sampling parameters have to be entered by the user.
Oversampling Factor PV	This parameter can be entered for the *Automatic Sampling* mode only. The *Sampling Distance* will be divided by this value.
Copy Active Parameters from...	This option is available for the *Manual Sampling* mode only. If pressed, a window will appear where a document can be selected to copy the *Sampling Distance* or the number of *Sampling Points* from, depending on which of both is currently selected.
Sampling Points PV	In case of *Manual Sampling*, the number of sampling points can be entered here. This number refers to the array size.
Sampling Distance PV	In case of *Manual Sampling*, the sampling distance can be entered here.
Array Size	Read Only. The size of the complex array, automatically calculated from *Diameter* and (2×) *Absolute Edge Width* that are defined on the panel *Basic Parameters*.
Size of Embedding Frame (Sampling Points)	This value defines the size (in sampling points) of the embedding frame which is added to the array of sampled field data.
Total Sampling Points	Read Only. Number of sampling points of the resulting field including the embedding frame.
Total Array Size	Read Only. Size of the resulting array including the embedding frame.

49.3 Polarization

This panel allows you to enter the Jones vector that determines the relation of E_x and E_y to the scalar field U (↪Sec. 22.10). You can either enter the Jones vector directly or set the polarization parameters of either linearly, circularly or elliptically polarized light; depending on the selected *Type of Polarization*.
The following parameters are the same for all polarization types:

ITEM	DESCRIPTION
Type of Polarization	Can be either *Linearly Polarized*, *Circularly Polarized*, *Elliptically Polarized*, or *General Input via Jones vector*. Depending on this setting the panel changes as shown in Fig. 480 – Fig. 483. In any case, the resulting *Normalized Jones Vector* is displayed. For some light sources only a certain type of polarization is supported and the selection is disabled.
Jx	The x-component of the normalized complex Jones vector.
Jy	The y-component of the normalized complex Jones vector.

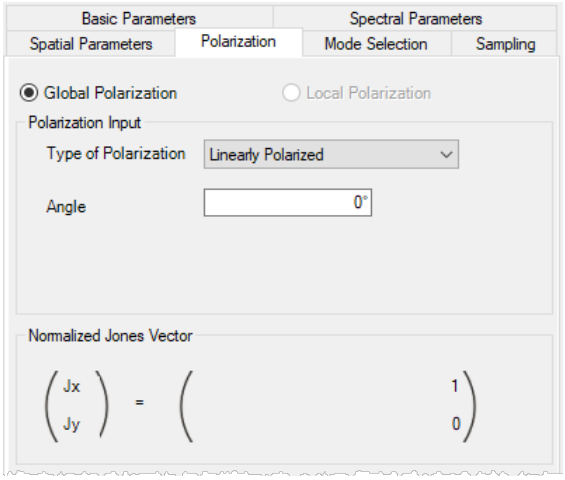


Figure 480. *Panel for setting the polarization parameters of* Linearly Polarized *light.*

ITEM FOR LINEAR POLARIZATION	DESCRIPTION
Angle PV	Angle between the electric field vector and the x-axis.

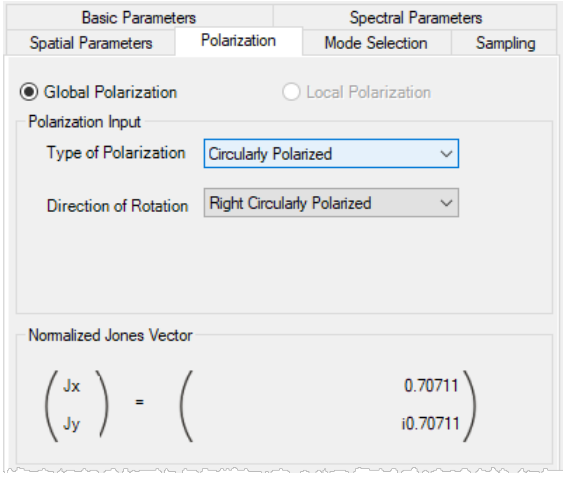


Figure 481. *Panel for setting the polarization parameters of* Circularly Polarized *light.*

ITEM FOR CIRCULAR POLARIZATION	DESCRIPTION
Direction of Rotation	The direction of rotation can be either *Right Circularly Polarized* or *Left Circularly Polarized*.

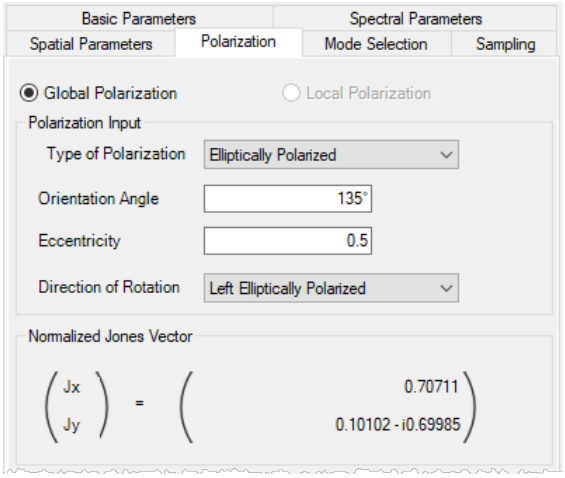


Figure 482. *Panel for setting the polarization parameters of* Elliptically Polarized *light.*

ITEMS FOR ELLIPTICAL POLARIZATION	DESCRIPTION
Orientation Angle PV	The angle between the semi-major axis of the polarization ellipse and the x-axis. Can be in the range between -180° and +180°.
Eccentricity PV	The (numerical) eccentricity of the polarization ellipse.
Direction of Rotation	The direction of rotation can be either *Right Elliptically Polarized* or *Left Elliptically Polarized*.

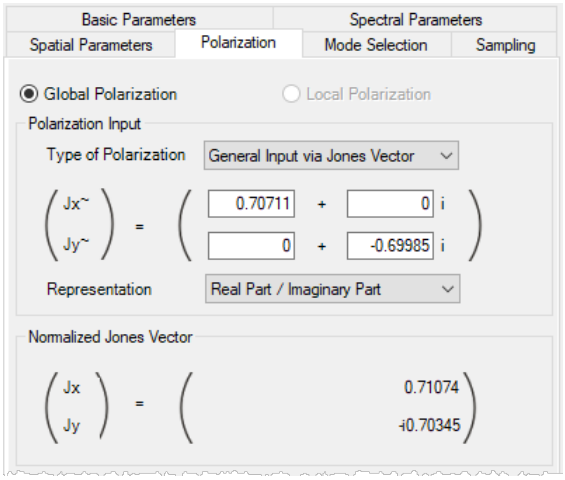


Figure 483. *Panel for* General Input via Jones Vector *of the polarization parameters.*

ITEMS FOR INPUT OF JONES VECTOR	DESCRIPTION
Jx~ PV	The x-component of the complex Jones vector. Although the Jones vector is defined as a normalized one (i. e. it has to have a norm of 1), it is not necessary to enter the vector in normalized form, the normalization is done automatically.
Jy~ PV	The y-component of the complex Jones vector.
Representation	You can choose to enter either *Real / Imaginary* or *Amplitude / Phase* of the complex numbers.

50 Multiple Light Source

Availability

Optical Setups: General Optical Setup, Light Guide Optical Setup, and Eigenmode Analyzer

Accessible:

- Optical Setup: *Light Sources > Multiple Light Source*
- Light Sources Catalog: *Templates > Multiple Light Source*

This source model allows you to combine an arbitrary number of other source models (but Image Light Sources, ↪Sec. 53.7).

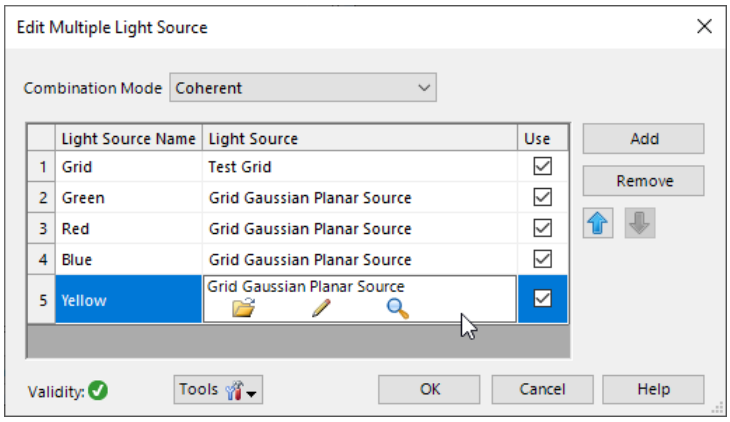


Figure 484. *Edit dialog of a Multiple Light Source.*

The edit dialog of this light source (↪Fig. 484) has the following options:

ITEM	DESCRIPTION
Combination Mode	• In *Coherent* mode, all modes for a certain wavelength are summed up coherently. • In *Incoherent* mode, all modes are generated and processed independently.
{Table}	Contains one row per light source and the following columns: • Index: The index of the source. • *Light Source Name*: A name which helps you to identify the sources. Can be changed after double clicking in the cell. • *Light Source*: Allows you to load, edit, and view the item represented by the table row. ↪Sec. 34.1 • Use: In this column you can switch off light source if needed.
Add	Lets you select a new light source from the corresponding catalog and adds it to the bottom of the table.
Remove	Removes the currently selected light sources from the table after inquiring whether you really want to do so.
(Move Up)	Moves the currently selected light sources up by one row.
(Move Down)	Moves the currently selected light sources down by one row.
Validity	This control (↪Sec. 5.11) indicates whether there are issues with the current configuration. If this is the case you can click on the -button for further information.
Tools	This button offers the following tools: • *Remove All Light Sources*: Clears the table. • *Duplicate One Light Source*, ↪Sec. 50.1 • *Synchronize Selected Parameters*, ↪Sec. 50.2 • *Use All Light Sources*: The *Use* flag for all light sources is checked. • *Use Only Selected Light Sources*: The *Use* flag for all currently selected light sources is checked, all others are unchecked. If no selection is active, the first light source is used.

Restrictions for Specific Simulation Engines

- For General Profile and Ray Results Profile, *Incoherent* mode is only possible if for each wavelength there are the same number of modes.
- In the Eigenmode Analyzer (↪Sec. 90.2), the result must be a single mode. Thus the Multiple Light Source is restricted to *Coherent* mode and all light sources must use the same one wavelength.

50.1 Duplicate One Light Source

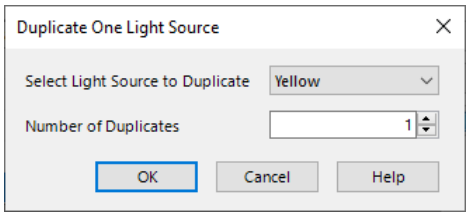


Figure 485. *Dialog for the* Duplicate One Light Source *tool.*

This tool for a Multiple Light Source allows you to select one light source by name and how often it is duplicated (*Number of Duplicates* n). n duplicates of the original light source are then inserted into the table right after the original one.

50.2 Synchronize Selected Parameters

This tool for a Multiple Light Source allows you to select one light source by name from which then *selected* parameters are copied to all other light sources.

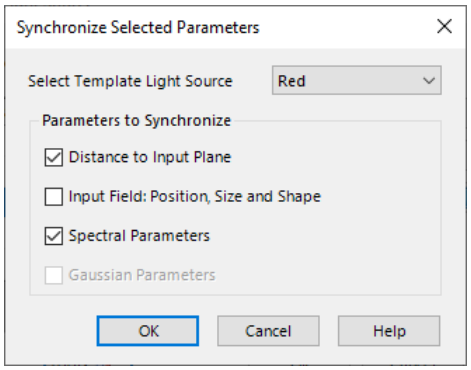


Figure 486. *Dialog for the* Synchronize Selected Parameters *tool.*

ITEM	DESCRIPTION
Select Template Light Source	Allows you to select one light source (by name) from which selected parameters are copied to all other light sources.
Distance to Input Plane	Copies the *Distance to Input Plane*, which can be found on the *Basic Parameters* tab of a light source (↪Sec. 49.2.1.1).
Input Field: Position Size and Shape	Copies all settings from the group box of the same name on the *Basic Parameters* tab (↪Sec. 49.2.1.2).
Spectral Parameters	Copies all settings from the *Spectral Parameters* tab (↪Sec. 49.2.2).
Gaussian Parameters	ONLY AVAILABLE IF THE TEMPLATE LIGHT SOURCE IS A GAUSSIAN WAVE. Copies all settings from the *Spatial Parameters* tab of a Gaussian Wave (↪Sec. 52.1) but *Generate Cross Section* and *Reference Wavelength*.

The dialog ensures that a least one of the *Parameters to Synchronize* is selected.

Some settings cannot be copied to all types of light sources. For example the *Distance to Input Plane* cannot be copied to a Super-Gaussian Wave and *Gaussian Parameters* can only be copied to other Gaussian Waves.

51 Stored Complete Field

Availability

Optical Setups: General Optical Setup

Accessible:

- Optical Setup: *Light Sources > Stored Complete Field*
- Light Sources Catalog: *Templates > Stored Complete Field*

With this light source a field that has been generated before can be inserted as source field into an Optical Setup. To use this light source for Classic Field Tracing, you need to set a spatial Harmonic Field or Harmonic Fields Set on the *Equidistant Field Data* tab. For General Profile and Ray Results Profile you need to set a Ray Distribution on the *Non-Equidistant Field Data* tab, whereas for General Profile this Ray Distribution must contain field values (↪Sec. 17.2).

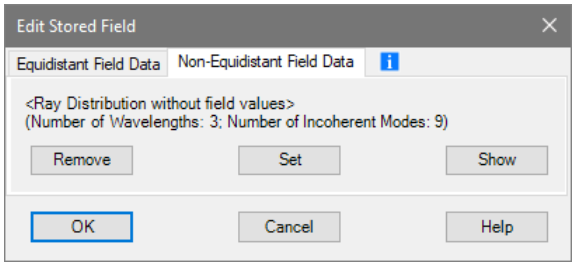


Figure 487. *Edit dialog of a stored field source.*

Description of the parameters:

ITEM	DESCRIPTION
Equidistant Field Data > Remove	Removes the currently set harmonic field or harmonic fields set. Note that then the light source cannot be used for Classic Field Tracing any longer.
Equidistant Field Data > Set	Sets the field information, i. e. any harmonic field or harmonic fields set which is in spatial domain. If you click on this button you can do the following: • *Load* a harmonic field from a .ca2 file or a harmonic fields set from a .hfs file. • *Select from Documents* allows you to select an already open harmonic field or harmonic fields set in spatial domain.
Equidistant Field Data > Show	Displays the field being used as separate document.
Non-Equidistant Field Data > Remove	Removes the currently set ray distribution. Note that then the light source cannot be used for General Profile or Ray Results Profile any longer.
Non-Equidistant Field Data > Set	Sets the ray distribution. If you click on this button you can do the following: • *Load* a ray distribution from a .rays file. • *Select from Documents* allows you to select an already open ray distribution.
Non-Equidistant Field Data > Show	Displays the ray distribution being used as separate document.

No further parameters can be defined, the stored field cannot be modified. Thus no additional panels are visible.

52 Basic Source Models

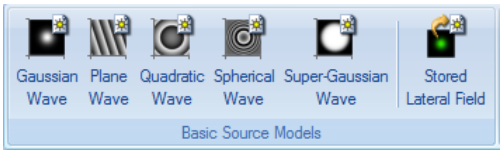


Figure 488. *Part of the Sources ribbon showing all Basic Source Models available in the main window. They are explained in the following sections.*

The following basic source models are available:

LIGHT SOURCE	DESCRIPTION
Gaussian Wave	A Hermite- or Laguerre-Gaussian wave. ↪Sec. 52.1
Plane Wave	A plane wave traveling in an arbitrary direction. ↪Sec. 52.2
Quadratic Wave	A quadratic wave, i. e. a paraxial approximation of a spherical wave. ↪Sec. 52.3
Spherical Wave	A spherical wave generated from a point source at a given distance. ↪Sec. 52.4
Super-Gaussian Wave	An isotropic and separable super-Gaussian field. ↪Sec. 52.5
Stored Lateral Field	Using this source model any lateral field can be used to define a polychromatic source. ↪Sec. 52.6
Ideal Plane Wave	A plane wave with an infinite size traveling in an arbitrary direction. ↪Sec. 52.7
Programmable Light Source	Allows you to define your own field generator. ↪Sec. 52.8

52.1 Gaussian Wave

Availability

Toolboxes: All

Accessible:

- Main window: Sources > Gaussian Wave 
- Optical Setup: *Light Sources > Basic Source Models > Gaussian Wave*
- Light Sources Catalog: *Templates > Gaussian Wave*

This source model allows you to generate a Hermite- or Laguerre-Gaussian wave (↪Sec. 139.1). In the following the settings of its edit dialog (↪Fig. 489) are described.

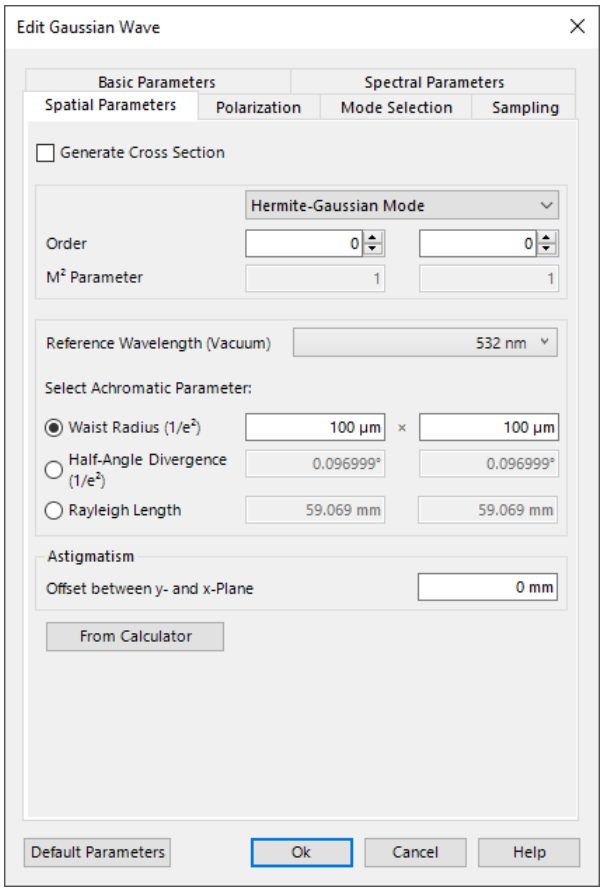


Figure 489. *Parameters for generating a Gaussian wave.*

Since the parameters waist, divergence and Rayleigh length depend on each other, one has to define which parameter is the primary choice. Only these values can be modified, the others are computed on the fly and are displayed in the dialog. For computing the values, the selected vacuum wavelength is used, if necessary. During computations, e. g. in an optical system, the primary value is kept fixed. If divergence or Rayleigh length is chosen, then the actual medium wavelength is used to compute the waist of the Gaussian which is generated. In that sense, the primary value is the achromatic constant for the Gaussian wave.
For a Hermite-Gaussian mode, some of the parameters are given for both x- and y-direction, which is not explicitly noted in the following table.
Description of the parameters on the *Spatial Parameters* tab:

ITEM	DESCRIPTION
Type	Selects whether a Hermite-Gaussian or a Laguerre-Gaussian mode is to be generated.
Order PV	ONLY FOR A *HERMITE-GAUSSIAN MODE* The orders m and n of the Hermite-Gaussian mode as defined in Eq. (139.9).
Radial Order PV **Azimuthal Order** PV	ONLY FOR A *LAGUERRE-GAUSSIAN MODE* The radial order p and the azimuthal order l of the Laguerre-Gaussian mode as defined in Eq. (139.11).
M² Parameter	M^2 parameter of the beam.
Reference Wavelength (Vacuum)	The wavelength to which the selected achromatic parameter (waist, divergence, or Rayleigh length) refers.
Waist Radius (1/e²) PV	Beam radius in waist position. The radius is determined by a relative intensity decay by $1/e^2$ for a Gaussian beam.
Half-Angle Divergence (1/e²) PV	Half far field divergence angle measured between the optical axis and the $1/e^2$ decay of the intensity.
Rayleigh Length PV	Rayleigh length of the Gaussian wave.
Offset between y- and x-plane PV	For Hermite-Gaussian modes different longitudinal waist distances can be specified in x- and y-direction, which corresponds to the effect of astigmatism. We define that the waist distance in x-direction is equal to the *Distance to Input Plane* and the waist distance in y-direction is the sum of *Distance to Input Plane* and the given *Offset between y- and x-plane*.
From Calculator	A button (↪Sec. 5.7) to set data from a Laser Beam Calculator (↪Sec. 113). Either a new calculator is created and shown as a dialog or an already existing calculator is loaded. If the calculator provides data for a Hermite-Gaussian, you are then asked whether you want to transfer the x-values, y-values, or both values from the calculator to the source dialog.

The remaining tabs of this dialog are explained in Sec. 49.2.

52.2 Plane Wave

Availability

Toolboxes: All

Accessible:

- Main window: Sources > Plane Wave 
- Optical Setup: *Light Sources > Basic Source Models > Plane Wave*
- Light Sources Catalog: *Templates > Plane Wave*

This source model allows you to generate a plane wave traveling in an arbitrary direction.

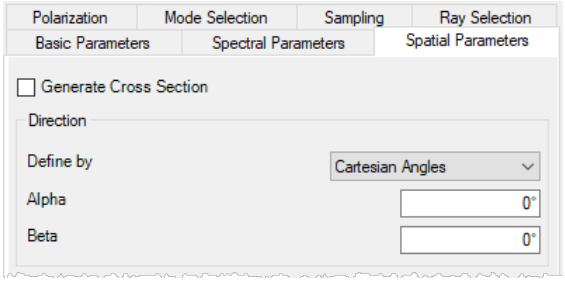


Figure 490. *Parameters for generating a plane wave.*

The propagation direction of the plane wave can be described in several ways. For this purpose, there are the options *Cartesian Angles*, *Spherical Angles*, *Wave Number Vector*, and *Spatial Frequency* which are explained in the table below.
Description of the parameters on the *Spatial Parameters* tab:

ITEM	DESCRIPTION
Define by	The selection allows different methods for defining the direction of the plane wave as described below.
Cartesian Angles	Defines the tilt angles α and β (*Alpha*[PV] and *Beta*[PV]) of the plane wave. The angle unit is degrees.
Spherical Angles	Defines the tilt angles in spherical coordinates ϕ and θ (*Phi*[PV] and *Theta*[PV]). The angle unit is degrees.
Wave Number Vector	Defines the direction of the plane wave in terms of components k_x[PV] and k_y[PV] of the wave number vector $\boldsymbol{k}$. For physical information on how the complex amplitude field is constructed from the components see Eq. (52.1).
Spatial Frequency	Defines the direction of the plane wave in spatial frequencies *u*[PV] and *v*[PV] for x and y-direction, in units of 1/m.

The resulting harmonic amplitude field $U(x,y)$ is constructed from the given X and Y components k_x and k_y of the wave number vector by

$$U(x,y) = \exp[i(k_x x + k_y y)]. \tag{52.1}$$

If the direction is given not as *Wave Number Vector* but in another representation, the conversion formulas as given in Sec. 145.3 are used.
If the Plane Wave is used within the Optical Setup the direction of the field is handled analytically. A sampling of the linear phase is not necessary at the output of the light source.
The remaining tabs of this dialog are explained in Sec. 49.2.

52.3 Quadratic Wave

Availability

Toolboxes: All

Accessible:

- Main window: Sources > Quadratic Wave 
- Optical Setup: *Light Sources > Basic Source Models > Quadratic Wave*
- Light Sources Catalog: *Templates > Quadratic Wave*

This source model represents a quadratic wave, i. e. a paraxial approximation of a spherical wave.

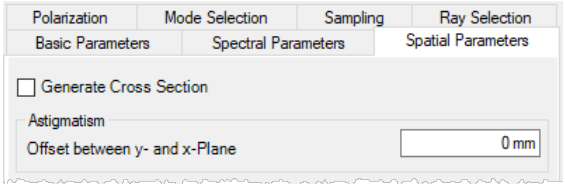


Figure 491. *Parameters for generating a quadratic wave.*

Description of the parameters on the *Spatial Parameters* tab:

ITEM	DESCRIPTION
Offset between y- and x-Plane PV	The radius in x- and y-direction can be different, which corresponds to the effect of astigmatism. We define that the radius in x-direction is equal to the *Distance to Input Plane* PV and the radius in y-direction is the sum between *Distance to Input Plane* and the given value *Offset between y- and x-plane*.

The remaining tabs of this dialog are explained in Sec. 49.2.

52.4 Spherical Wave

Availability

Toolboxes: All

Accessible:

- Main window: Sources > Spherical Wave 
- Optical Setup: *Light Sources > Basic Source Models > Spherical Wave*
- Light Sources Catalog: *Templates > Spherical Wave*

This source model represents a spherical wave generated from a point source at a given distance.

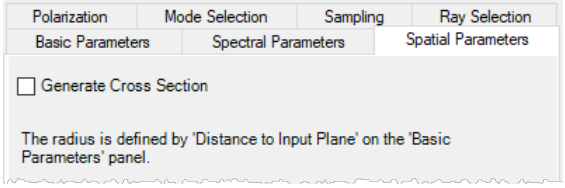


Figure 492. *No further parameters are required for generating a spherical wave. The spherical phase radius is given by* Distance to Input Plane.

A spherical wave $U(x,y)$ is defined by

$$U(x,y) = \frac{z}{r}\exp[ikr], \tag{52.2}$$

with

$$r = \sqrt{(x-x_0)^2 + (y-y_0)^2 + z^2}, \tag{52.3}$$

where (x_0, y_0) and z denote the lateral and longitudinal offset to the origin, respectively. Origin means the center of the spheres described by the equiphase values, and its distance on the z-axis is also denoted as *spherical phase radius*.

Note on convergence: Whether a spherical wave is convergent or divergent depends on the sign of the spherical phase radius and the sign of the principal propagation direction. If both are equal, the wave is divergent, if not, it is convergent. ↪Sec. 136.3.

The distance on the z-axis is represented by *Distance to Input Plane*[PV] at the *Basic Parameters* panel. Hence, no further parameters are to be described here, see Fig. 492. The remaining tabs of this dialog are explained in Sec. 49.2.

52.5 Super-Gaussian Wave

Availability

Toolboxes: All

Accessible:

- Main window: Sources > Super-Gaussian Wave 
- Optical Setup: *Light Sources* > *Basic Source Models* > *Super-Gaussian Wave*
- Light Sources Catalog: *Templates* > *Super Gaussian Wave*

This source model allows you to generate isotropic and separable super-Gaussian fields (↪Sec. 139.3).

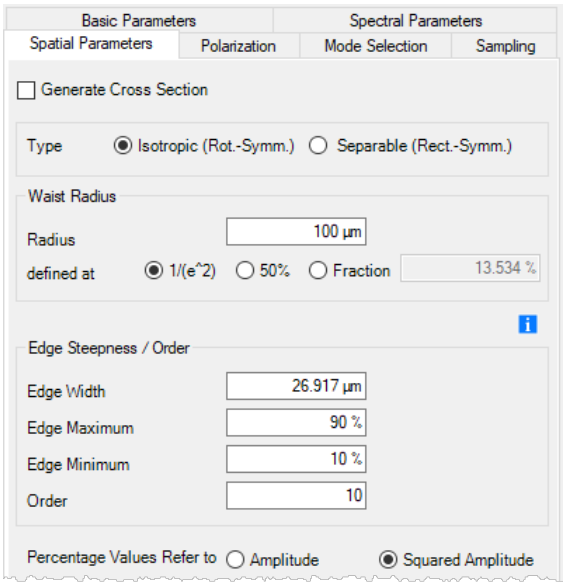


Figure 493. *Parameters for generating a super-Gaussian wave.*

The *Spatial Parameters* (↪Fig. 493) are explained in the following table.

ITEM	DESCRIPTION
Type	Determines the type of the Super Gaussian Wave whether it is *Isotropic* (rotationally symmetric) or *Separable* (rectangular symmetric). For the mathematical description see Sec. 139.3.
Radius PV	Determines the *Waist Radius* of the super Gaussian wave where the intensity of the wave is dropped down to the waist definition level (with respect to the maximum amplitude or intensity) entered below. In case of a separable wave there are also two independent waist radii for every direction.
Defined at	The definition level for the waist radius. Given as fraction of the maximum amplitude or intensity, depending on the choice of the percentage value reference.
Edge Width	Width of the edge of the super Gaussian function, limited by the minimum and the maximum level.
Edge Maximum	Upper definition level for the edge.
Edge Minimum	Lower definition level for the edge.
Order PV	Defines the order of the super Gaussian wave. If the type is separable, then two independent orders m_x and m_y for the x and y-direction are necessary. For numerical reasons, the order(s) must be in the range 0.1 to 100 000.
Percentage Values Refer to	Determines if the percentage values of the waist radius definition level, the maximum edge level and the minimum edge level refer to the maximum amplitude or the maximum intensity.

The remaining tabs of this dialog are explained in Sec. 49.2.

52.6 Stored Lateral Field

Availability

Toolboxes: All

Accessible:

- Main window: Sources > Stored Lateral Field 
- Optical Setup: *Light Sources* > *Basic Source Models* > *Stored Lateral Field*

In this source model, the lateral field distribution $U(x,y)$ of a globally polarized field (↪Sec. 136.1) is used as a base to define a complete polychromatic source. *Spectral Parameters* and *Polarization* of the resulting light source can and must be set independently from the set field.

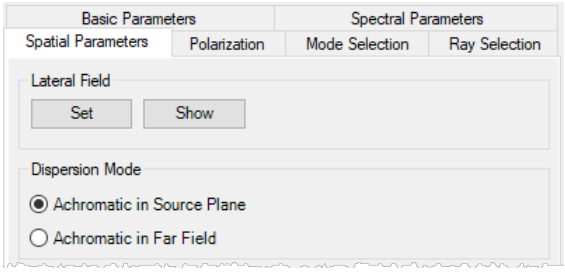


Figure 494. *Parameters for generating a source using a stored lateral field.*

Description of the parameters on the *Spatial Parameters* tab (↪Fig. 494):

ITEM	DESCRIPTION
Set	Sets the lateral field, which must be a globally polarized field in spatial domain. Wavelength and polarization of this field are ignored. When you click on this button you can do the following: • *Load* a lateral field from a .ca2 file. • *Select from Documents* allows you to select an already open globally polarized harmonic field which is in spatial domain. • *Reset* the data to the default field.
Show	Displays the lateral field being used.
Achromatic in Source Plane	Any wavelength is applied to the field without adapting the field in the source plane.
Achromatic in Far Field	In this case the sampling distance of the field is modified using the formula $\Delta x_{\text{current}} = \Delta x \cdot \lambda_{\text{current}}/\lambda_{\text{field}}$. Here $\Delta x_{\text{current}}$ is the resulting sampling distance, Δx is the sampling distance of the stored lateral field, λ_{field} is the vacuum wavelength of the stored lateral field and λ_{medium} is the vacuum wavelength of the current mode.

The *Sampling Parameters* tab is not available as the sampling is taken from the stored field. The remaining tabs of this dialog are explained in Sec. 49.2.

52.7 Ideal Plane Wave

Availability

Optical Setups: Grating Optical Setups

This source model allows you to generate a plane wave with an infinite size traveling in an arbitrary direction.

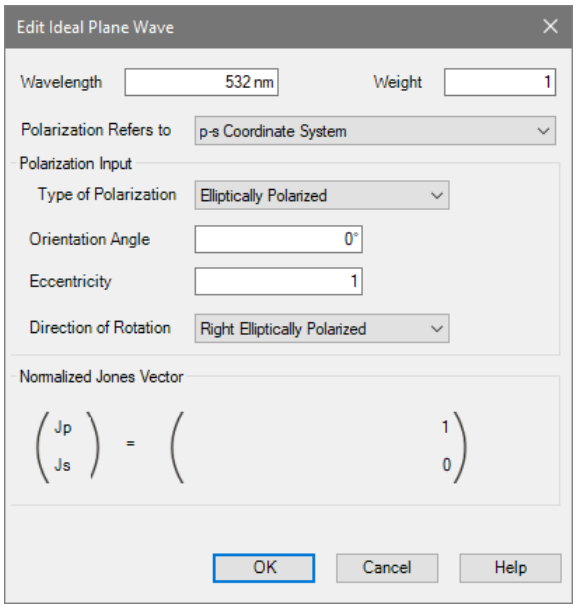


Figure 495. *Dialog for an ideal plane wave.*

The effects of unpolarized light can be approximated by using circular polarization.

An *Ideal Plane Wave* is fully specified by its *Wavelength*[PV], an intensity *Weight*[PV] and its polarization. The polarization control is the same as described in Sec. 49.3, but additionally it allows you to specify the coordinate system the polarization refers to:

COORDINATE SYSTEM	DESCRIPTION
Coordinate System of Grating	The Jones vector describes the electric field along x- and y-axis of the subsequent grating component, respectively.
Coordinate System of Light Source	The Jones vector describes the electric field along x- and y-axis of the light source, respectively. This is the coordinate system used in all other VirtualLab Fusion light sources.
p-s Coordinate System	In grating theory one often uses the nomenclature *parallel* and *senkrecht* (= perpendicular) polarization to describe how the electric field vector is orientated to a reference plane (or short p- and s-polarization). This reference plane is defined by the normal vector of the grating surface and the direction vector of the incident light. The conversion from the coordinate system of the light source (E_x/E_y) is done with the following equations: $$E_\mathrm{s} = \begin{pmatrix} E_x \\ E_y \end{pmatrix} \cdot \boldsymbol{n}_\mathrm{s} \quad \text{and} \quad E_\mathrm{p} = \begin{pmatrix} E_x \\ E_y \end{pmatrix} \cdot \boldsymbol{n}_\mathrm{p} \tag{52.4}$$ $\boldsymbol{n}_\mathrm{s}$ and $\boldsymbol{n}_\mathrm{p}$ are the normalized directions of s- and p- polarization, respectively (in the coordinate system of the light source). For perpendicular incident $\boldsymbol{n}_\mathrm{s}$ is equal to the y-axis of the light source.
TE-TM Coordinate System	Instead of p- and s-polarization also the nomenclature *transversal magnetic* and *transversal electric*, respectively, is used – or short TM / TE.

52.8 Programmable Light Source

Availability

Optical Setups: General Optical Setup, Light Guide Optical Setup, and Eigenmode Analyzer

Accessible:

- Optical Setup: *Light Sources > Basic Source Models > Programmable Light Source*
- Light Sources Catalog: *Templates > Programmable Light Source*

The programmable light source allows you to define your own field generator. This means you write a little *snippet* defining a complex value which represents the complex amplitude at a certain position $(x; y)$ in the source plane. In order to allow an analytically stored spherical phase the following concept is applied: if the *Distance to Input Plane* r is not equal to zero, a spherical phase $\exp(\mathrm{i}\,kr)$ is multiplied to the values defined in the snippet.

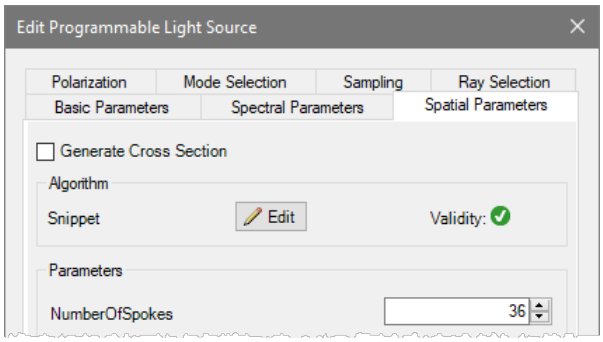


Figure 496. *Sample edit dialog for the programmable light source.*

Besides *Generate Cross Section* (↪Sec. 49.2.3), the spatial parameters tab (↪Fig. 496) contains the following controls:

ITEM	DESCRIPTION
Snippet	*Edit* opens the Source Code Editor (↪Sec. 7.3) to edit the snippet defining the source field. A validity indicator (↪Sec. 5.11) shows whether this snippet is consistent.
Parameters PE	The controls in this group box allow you to set the values of the global parameters of the snippet. ↪Sec. 7.4

The remaining tabs of this dialog are explained in Sec. 49.2.

53 Partially Coherent Source Models

VirtualLab Fusion models partially spatially coherent fields by a laterally shifted mode model [VT06; WSK07]. To this end a fundamental mode is generated and laterally shifted. For each lateral position a harmonic field is generated which forms a member of a harmonic fields set. The complete set models the partially coherent field. Theoretically the model requires an infinite number of shifted modes, but in practice, the simulation converges and needs only a limited number of modes.

Figure 497. *Part of the Sources ribbon showing all Partially Coherent Source Models available in the main window. They are explained in the following sections.*

The following sources can be used to model partially coherent light.

LIGHT SOURCE	DESCRIPTION
Customized Mode Planar Source	Several copies of the same arbitrary base mode can be placed on different positions of the source plane. The base mode is taken from an already open harmonic field. ↪Sec. 53.1
Far Field Source	Several copies of the same arbitrary base mode can be placed on different positions of the source plane. The base mode is calculated from its far field. ↪Sec. 53.2
Gaussian Type Planar Source	Several copies of the same Gaussian base mode can be placed on different positions of the source plane. Can be used to simulate LEDs and Excimer lasers. ↪Sec. 53.3
Grid Gaussian Planar Source	Several copies of the same Gaussian base mode are placed on a grid. ↪Sec. 53.4
Multimode Gaussian Source	Combines several orders of the same Gaussian mode. ↪Sec. 53.5
Panel Type Source	Allows you to generate a rectangular grid of pixels (e. g. from an imported image) whereas each pixel is represented by a spherical wave mode. ↪Sec. 53.7.1
Programmable Mode Planar Source	Several copies of the same arbitrary base mode can be placed on different positions of the source plane. The base mode is generated from a snippet. ↪Sec. 53.6
Scanning Source	Allows you to generate a rectangular grid of modes (e. g. from an imported image) whereas each mode is a plane wave mode propagating into another direction. ↪Sec. 53.7.2

53.1 Customized Mode Planar Source

Availability

Optical Setups: General Optical Setup

Accessible:

- Main window: Sources > Customized Mode Planar Source 
- Optical Setup: *Light Sources > Partially Coherent Light Sources > Customized Mode Planar Source*
- Light Sources Catalog: *Templates > Customized Mode Planar Source*

The *Customized Mode Planar Source* allows you to combine laterally shifted customized modes to a single source field in a simple way. The lateral positions of the modes are distributed in the source plane with given size. The modes are handled in an incoherent mode and are handled independently as members of a harmonic field set.

This source model supports globally polarized fields in spatial domain as customized modes. *Spectral Parameters* and *Polarization* of these modes can be changed.

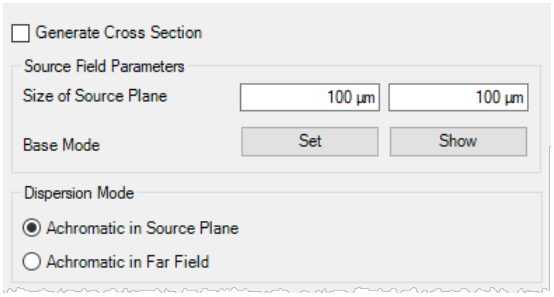


Figure 498. *Parameters for generating a source using a customized mode.*

The following parameters can be defined on the *Spatial Parameters* tab.

ITEM	DESCRIPTION
Size of Source Plane PV	Size of the source plane (emitting surface). The model assumes that the laterally shifted modes are distributed uniformly across that source plane.
Set	Sets the base mode, which must be a harmonic field in spatial domain. The wavelength of this field is ignored. When you click on this button you can do the following: • *Load* a spatial field from a .ca2 file. • *Select from Documents* allows you to select an already open spatial field. • *Reset* the data to the default field.
Show	Displays the base mode being used.
Achromatic in Source Plane	Any wavelength is applied to the field without adapting the field in the source plane.
Achromatic in Far Field	In this case the sampling distance of the field is modified using the formula $\Delta x_{\text{current}} = \Delta x \cdot \lambda_{\text{current}}/\lambda_{\text{field}}$. Here $\Delta x_{\text{current}}$ is the resulting sampling distance, Δx is the sampling distance of the stored base mode, λ_{field} is the vacuum wavelength of the stored base mode and λ_{medium} is the vacuum wavelength of the current mode.

The remaining tabs of this dialog are explained in Sec. 49.2.

53.2 Far Field Source

Availability

Optical Setups: General Optical Setup, Light Guide Optical Setup, and Light Shaping Optical Setup

Accessible:

- Optical Setup: *Light Sources > Partially Coherent Light Sources > Far Field Source*
- Light Sources Catalog: *Templates > Far Field Source*

The far field source allows you to define a spatially partially coherent light source by its far field. See Sec. 139.5 for physical details.

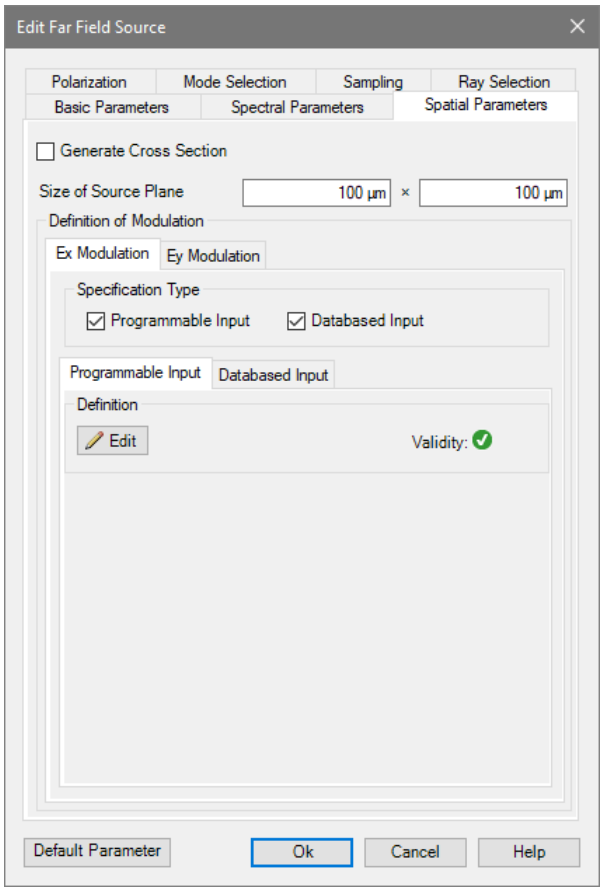


Figure 499. *The* Spatial Parameters *tab of a Far Field Source. (*Local Polarization *is defined on the* Polarization *tab.)*

The following parameters can be defined on the *Spatial Parameters* tab.

ITEM	DESCRIPTION
Size of Source Plane PV	Defines the area in which the distinct lateral modes are placed.
Definition of Modulation	Defines the complex direction weight functions D_l, either by *Programmable Input* or by *Databased Input*. If you use both input types, the two so defined values are multiplied. If the far field source has been set to *Local Polarization* on the *Polarization* tab, you can define two weight functions: the *Ex Modulation* and the *Ey Modulation*. The programmable input is described in subsection Sec. 53.2.1 and the databased input in subsection Sec. 53.2.2.

The lateral shifts of the modes can be defined on the *Mode Selection* tab. The remaining tabs of this dialog are explained in Sec. 49.2.

53.2.1 Programming the Complex Direction Weight Functions

For programming you can use either the spherical angles *theta* and *phi* or the Cartesian coordinates *x*, *y* and *Distance*, which is the *Distance to Input Plane* PV defined on the *Basic Parameters* tab. It is assumed that *theta* and *phi* are given in radians and that *phi* is in the range $-\pi \ldots +\pi$.

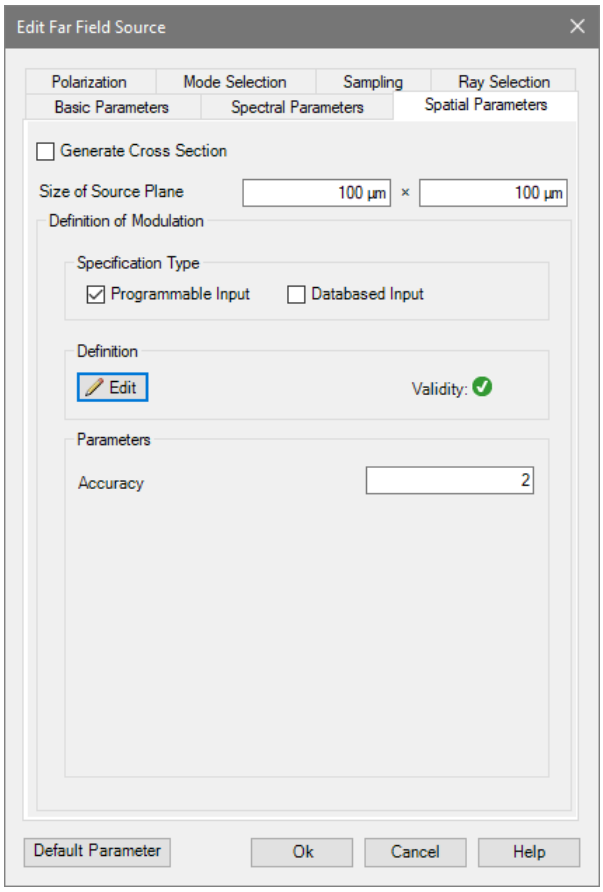


Figure 500. *The Spatial Parameters tab of a Far Field Source in Programmable Input mode. (Global Polarization is defined on the Polarization tab.)*

The following conversion formulas are used to calculate *theta* and *phi*. [1]

$$r = \sqrt{x^2 + y^2 + Distance^2} \tag{53.1}$$

$$theta = \arccos \frac{Distance}{r} \tag{53.2}$$

$$phi = \operatorname{atan2} \frac{y}{x} \tag{53.3}$$

The following controls are used for programming the complex weight functions.

ITEM	DESCRIPTION
Definition	This group box allows you to program a code snippet defining the complex weight functions. *Edit* opens the Source Code Editor (↪Sec. 7.3) to edit this snippet, and a validity indicator (↪Sec. 5.11) shows whether this snippet is consistent.
Parameters PE	The controls in this group box allow you to set the values of the global parameters of the snippet. ↪Sec. 7.4

General information about programming in VirtualLab Fusion can be found in Sec. 7.

[1] atan2 is a special implementation of the arctangent function for a fraction of two values. See Microsoft C# documentation or Wikipedia for reference.

53.2.2 Databased Complex Direction Weight Functions

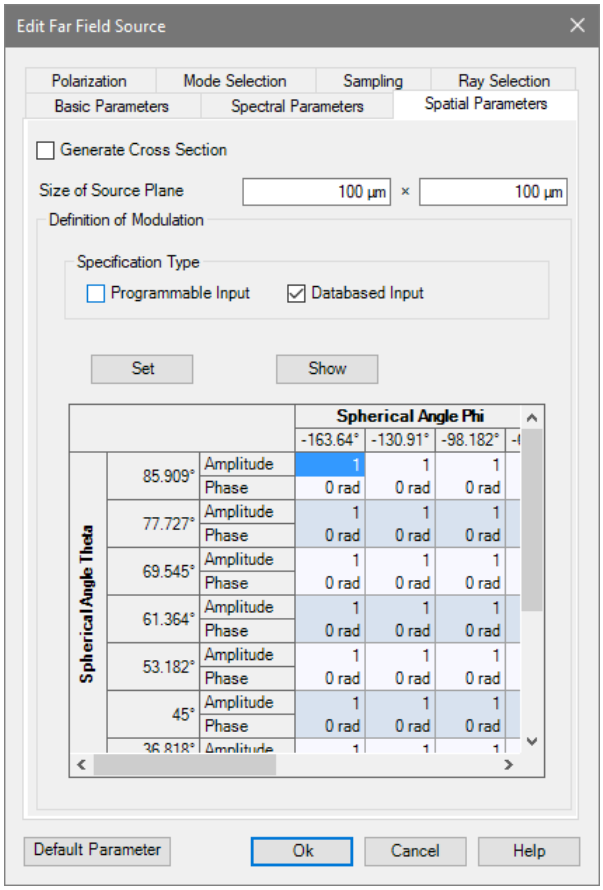


Figure 501. *The Spatial Parameters tab of a Far Field Source in Databased Input mode.*

For *Databased Input* of the complex direction weight functions the following controls can be used.

ITEM	DESCRIPTION
Set > Load	Loads a data array from a .da file.
Set > Import	Imports a data array from a text file by means of the import wizard described in Sec. 121.1.
Set > Select from Documents	Allows you to select an already open data array.
Set > Reset	Resets the modulation data to its default.
Show	Shows the current data in a separate data array view (↪Sec. 13.4).
Preview Table	A preview table showing the current data.

The data array to be set must contain only one complex-valued two-dimensional data subset. If both coordinates are given in degrees or radians the coordinates will be interpreted as spherical angles. In this case the x-coordinate is always interpreted as the spherical angle ϕ which is defined in the range $-\pi \ldots +\pi$. The y-coordinate is interpreted as the spherical angle θ within the value range $0 \ldots +\frac{\pi}{2}$.
In any other case the coordinates are used as x-y-coordinates.
The labels of the data array and the physical property of the coordinates are adapted automatically.

53.3 Gaussian Type Planar Source

Availability

Optical Setups: General Optical Setup

Accessible:

- Main window: Sources > Gaussian Type Planar Source 
- Optical Setup: *Light Sources > Partially Coherent Light Sources > Gaussian Type Planar Source*
- Light Sources Catalog: *Templates > Gaussian Type Planar Source*

This generator can be used to simulate LEDs and Excimer lasers. See Sec. 139.4 for physical details.

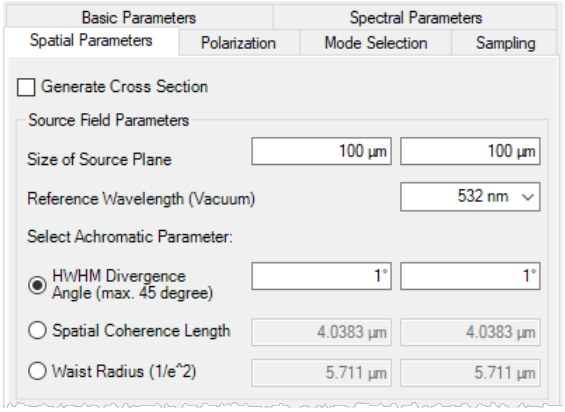


Figure 502. *Parameters for generating a Gaussian type source field.*

Description of the parameters on the *Spatial Parameters* (↪Fig. 502) tab:

ITEM	DESCRIPTION
Size of Source Plane PV	Size of the source plane (emitting surface). The model assumes that the laterally shifted modes are distributed uniformly across that source plane. In the limit of dense modes the size corresponds to the half maximum.
Achromatic Parameter	The chosen value is kept constant over set of wavelengths. The values depend on each other and are recomputed using the reference wavelength. During generation the achromatic parameter is used together with the refractive index and the vacuum wavelength to compute the waist of the fundamental Gaussian modes.
HWHM Divergence Angle PV	Half width at half maximum divergence angle of the source field (not that of a single fundamental mode).
Spatial Coherence Length PV	Spatial coherence length of the source field.
Waist Radius $(1/e^2)$ PV	Waist radius of the fundamental modes.

The remaining tabs of this dialog are explained in Sec. 49.2.

53.4 Grid Gaussian Planar Source

Availability

Optical Setups: General Optical Setup

Accessible:

- Main window: Sources > Grid Gaussian Planar Source 
- Optical Setup: *Light Sources > Partially Coherent Light Sources > Grid Gaussian Planar Source*
- Light Sources Catalog: *Templates > Grid Gaussian Planar Source*

The *Grid Gaussian Planar Source* source model allows you to combine laterally shifted Gaussian waves to a single source field in a simple way. The lateral positions are described by a regular grid centered at $(0,0)$ with given size and a given period (distance between the single waves). Two modes are available: coherent and non-coherent. In the coherent case the laterally shifted waves are added (complex number operation), whereas in the non-coherent case each wave is handled independently as member of a field set.

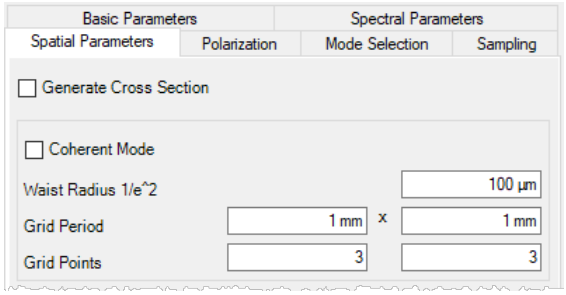


Figure 503. *Parameters for generating a gridded Gaussian wave.*

The corresponding edit dialog is shown in Fig. 503. Its *Spatial Parameters* tab has the following parameters:

ITEM	DESCRIPTION
Coherent Mode	Flag indicating whether the laterally shifted waves are considered to be in coherent mode or not.
Waist Radius $(1/e^2)$ PV	Waist radius of the single Gaussian waves.
Grid Period PV	Period of the waves, i. e. distance between them.
Grid Points PV	Size of the grid, i. e. number of Gaussian waves.

The remaining tabs of this dialog are explained in Sec. 49.2.

53.5 Multimode Gaussian Source

Availability

Optical Setups: General Optical Setup

Accessible:

- Main window: Sources > Multimode Gaussian Source 
- Optical Setup: *Light Sources > Partially Coherent Light Sources > Multimode Gaussian Source*
- Light Sources Catalog: *Templates > Multimode Gaussian Source*

The Multimode Gaussian Source allows you to combine several orders of the same Gaussian mode. First the maximum order has to be defined, then for each order the *Weight* PV (that refers to the intensity) and the absolute *Phase Offset* PV has to be given in the table at the bottom of the *Spatial Parameters* tab. This table

also allows you to set certain modes *Active* or inactive which means that they are not considered in the resulting field.

The fundamental Gaussian mode can be specified by an *achromatic parameter*: either the waist, the angle of divergence, or the Rayleigh length. This parameter is the same for all base modes. Note that base modes with different wavelengths (according to the settings on the *Spectral* tab, ↪Sec. 49.2.2) can have different waists if the achromatic parameter is the angle of divergence or the Rayleigh length.

In contrast, the higher-order modes have always the same Rayleigh length as the corresponding fundamental mode. This ensures that fundamental mode and corresponding higher-order modes do not diverge during propagation.

For the theory of Gaussian beams see Sec. 139.1.

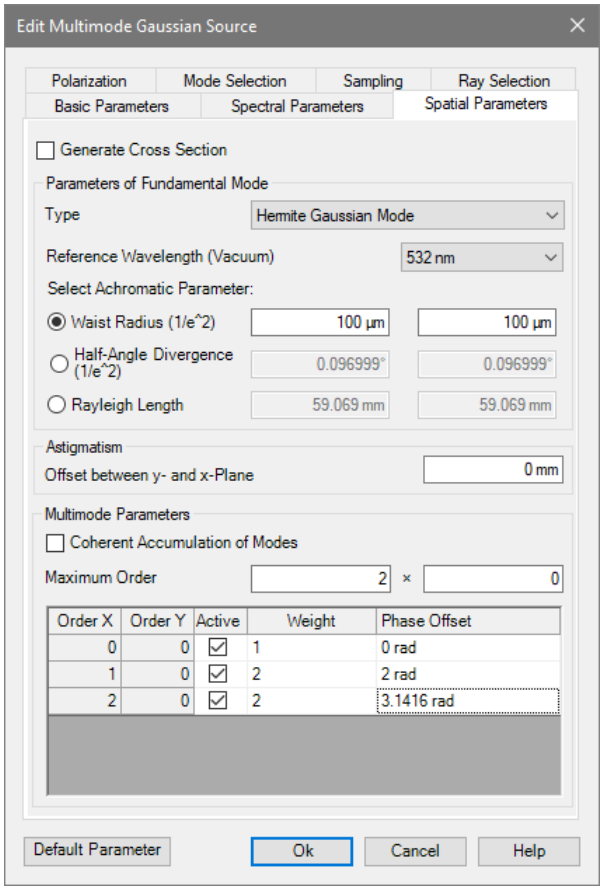


Figure 504. *Parameters for generating a Multimode Gaussian Source.*

The following parameters can be defined on the *Spatial Parameters* tab (↪Fig. 504).

ITEM	DESCRIPTION
Type	Selects whether Hermite-Gaussian or Laguerre-Gaussian modes are to be generated.
Waist Radius 1/(e^2) PV	Radius of the fundamental mode in waist position. The radius is determined by a relative intensity decay by $1/e^2$ for a Gaussian beam.
Reference Wavelength (Vacuum)	The wavelength to which the selected achromatic parameter refers.
Half-Angle Divergence 1/(e^2) PV	Half far field divergence angle of the fundamental mode measured between the optical axis and the $1/e^2$ decay of the intensity.
Rayleigh Length PV	Rayleigh length.
Offset between y- and x-plane PV	For Hermite-Gaussian modes different longitudinal waist distances can be specified in x- and y-direction, which corresponds to the effect of astigmatism. We define that the waist distance in x-direction is equal to the *Distance to Input Plane* and waist distance in y-direction is the sum between *Distance to Input Plane* and the given value *Offset between y- and x-plane*.
Coherent Accumulation of Modes	If you select *Coherent Accumulation of Modes* the modes of different orders are added (complex number operation). Otherwise each order is handled independently as member of a harmonic fields set.
Maximum Order	Defines the upper limit for the orders being used. Order 0 corresponds to a Gaussian fundamental mode. For a Laguerre-Gaussian mode, the left text box refers to the radial order while the right box specifies the angular order.

The remaining tabs of this dialog are explained in Sec. 49.2.

53.6 Programmable Mode Planar Source

Availability

Optical Setups: General Optical Setup, Light Guide Optical Setup, and Light Shaping Optical Setup

Accessible:

- Optical Setup: *Light Sources > Partially Coherent Light Sources > Programmable Mode Planar Source*
- Light Sources Catalog: *Templates > Programmable Mode Planar Source*

The *Programmable Mode Planar Source* allows you to program the base mode combine whose laterally shifted copies are distributed in the source plane with given size. The copies are handled in an incoherent mode and are handled independently as members of a harmonic field set. The programmed mode is assumed to be globally polarized. Spectral information can be added using the panel *Spectral Parameters*.
In order to allow an analytically stored spherical phase the following concept is applied: if the value entered at *Distance to Input Plane* is not equal to zero, a spherical phase $\exp(\mathrm{i}\,kr)$ is multiplied to the values defined in the snippet.

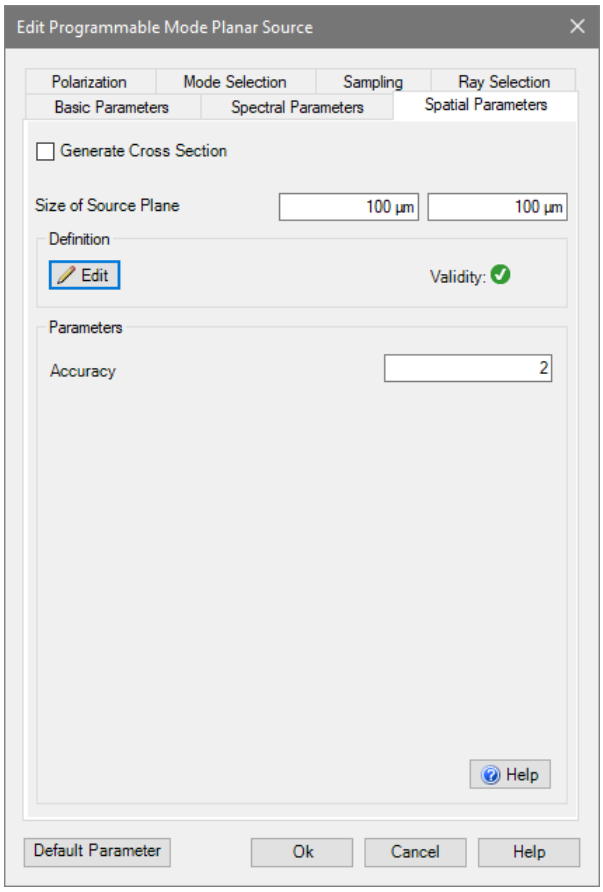


Figure 505. *The Spatial Parameters tab for a Programmable Mode Planar Source.*

Besides *Generate Cross Section* (↪Sec. 49.2.3), the spatial parameters tab (↪Fig. 505) contains

ITEM	DESCRIPTION
Size of Source Plane PV	Size of the source plane (emitting surface). The model assumes that the laterally shifted modes are distributed uniformly across that source plane. In the limit (dense modes) the size corresponds to half the maximum.
Definition	This group box allows you to program the code snippet defining the base mode. *Edit* opens the Source Code Editor (↪Sec. 7.3) to edit this snippet, and a validity indicator (↪Sec. 5.11) shows whether this snippet is consistent.
Parameters PE	The controls in this group box allow you to set the values of the global parameters of the snippet. ↪Sec. 7.4

General information about programming in VirtualLab Fusion can be found in Sec. 7. The remaining tabs of this dialog are explained in Sec. 49.2.

This source does not provide automatic sampling. However, the definition of the sampling distance is supported in the dialog. In particular we require a sampling of the phase residuals caused by mode shifts with respect to the spherical phase that is defined on axis (originating from the *Distance to Input Plane*). In the dialog of the source at the *Sampling* tab, the required sampling distance is displayed (↪Fig. 506). If the button *Copy Sampling Distance* is pressed, the sampling distance is entered into the corresponding fields.

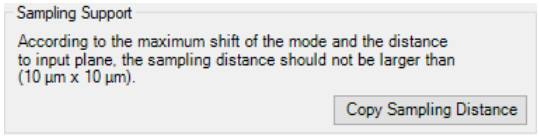


Figure 506. *Additional support for the sampling of programmable mode planar source.*

53.7 Image Light Sources

There are two light sources which allow you to generate a rectangular grid of distinct modes whereas each mode can have its own intensity weight. These weights can either be taken from an arbitrary image which the user specifies. Or they can be constant 1.

The *Panel Type Source* (↪Sec. 53.7.1) places the modes at different positions and thus you can see the pixels of the original image in the near field. The *Scanning Source* (↪Sec. 53.7.2) propagates the modes into different directions and thus you can see the original image in the far field.

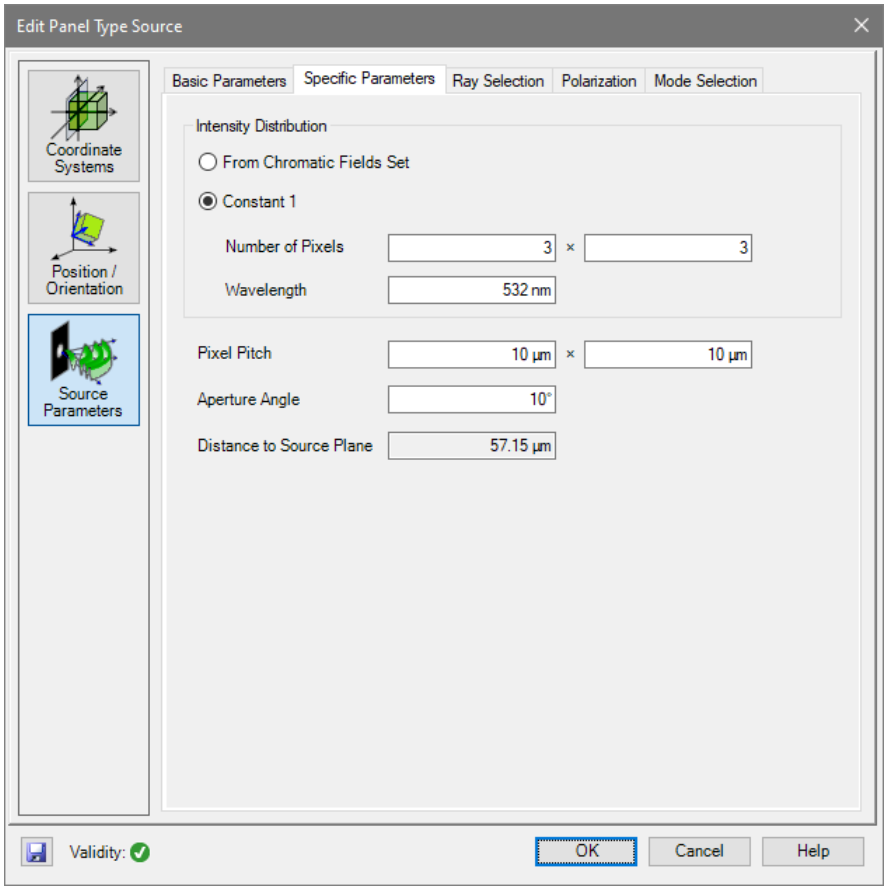


Figure 507. *The* Specific Parameters *tab of an image light source (here Panel Type Source).*

Both light sources have the following controls on the *Specific Parameters* tab (↪Fig. 507) in common.

ITEM	DESCRIPTION
From Chromatic Fields Set	The intensity of each mode is determined from a Chromatic Fields Set. Note that in this way you can define an intensity distribution for multiple wavelengths.
Set Image	ONLY VISIBLE IF *FROM CHROMATIC FIELDS SET* IS CHECKED. Allows you to load a Chromatic Fields Set into the dialog. When you click on this button you can do the following: • *Load* a Chromatic Fields Set from a .cfs file. • *Import* a Chromatic Fields Set from a bitmap file. ↪Sec. 53.7.3 • *Select from Documents* allows you to select an already open Chromatic Fields Set.
Show Image	ONLY VISIBLE IF *FROM CHROMATIC FIELDS SET* IS CHECKED. Shows the currently set Chromatic Fields Set as a separate document.
Constant 1	A constant intensity of 1 is assumed for each pixel.
Number of Pixels / Directions	ONLY VISIBLE IF *CONSTANT 1* IS CHECKED. The number of modes to be generated.
Wavelength	ONLY VISIBLE IF *CONSTANT 1* IS CHECKED. The wavelength the generated modes have.

If per wavelength there are more modes to be generated than specified in the Global Options Dialog (↪Sec. 6.14; *Maximum Number of Modes*), a warning is shown in the *Validity* control.

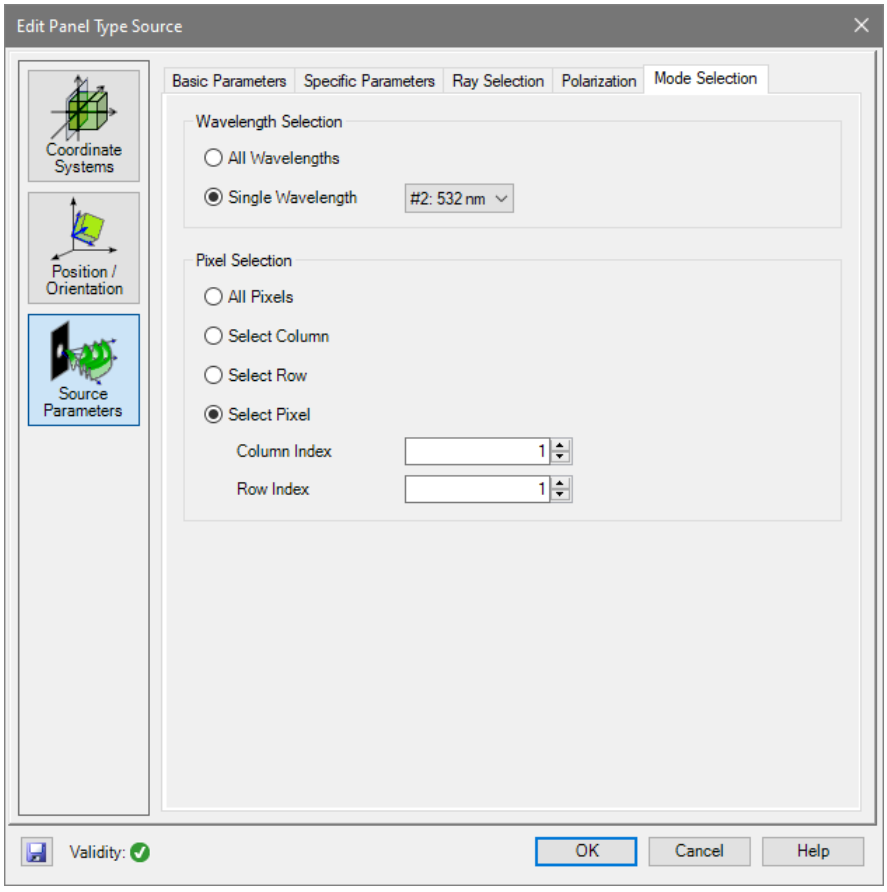


Figure 508. *The* Mode Selection *tab of an image light source (here Panel Type Source).*

These light sources also add functionality to the mode selection tab (↪Fig. 508):

ITEM	DESCRIPTION
All Pixels / Directions	All modes are generated as specified on the *Specific Parameters* tab.
Select Column	Only modes having the specified *Column Index* are generated.
Select Row	Only modes having the specified *Row Index* are generated.
Select Pixel / Direction	Only the mode with the specified *Column Index* and *Row Index* is generated.

The remaining controls of the edit dialogs are explained in Sec. 49.1.

53.7.1 Panel Type Source

Availability

Optical Setups: General Optical Setup, Light Guide Optical Setup, and Light Shaping Optical Setup

Accessible:

- Optical Setup: *Light Sources > Partially Coherent Light Sources > Panel Type Source*
- Light Sources Catalog: *Templates > Panel Type Source*

The Panel Type Source allows you to generate a rectangular grid of pixels (e. g. from an imported image) whereas each pixel is represented by a spherical wave mode.

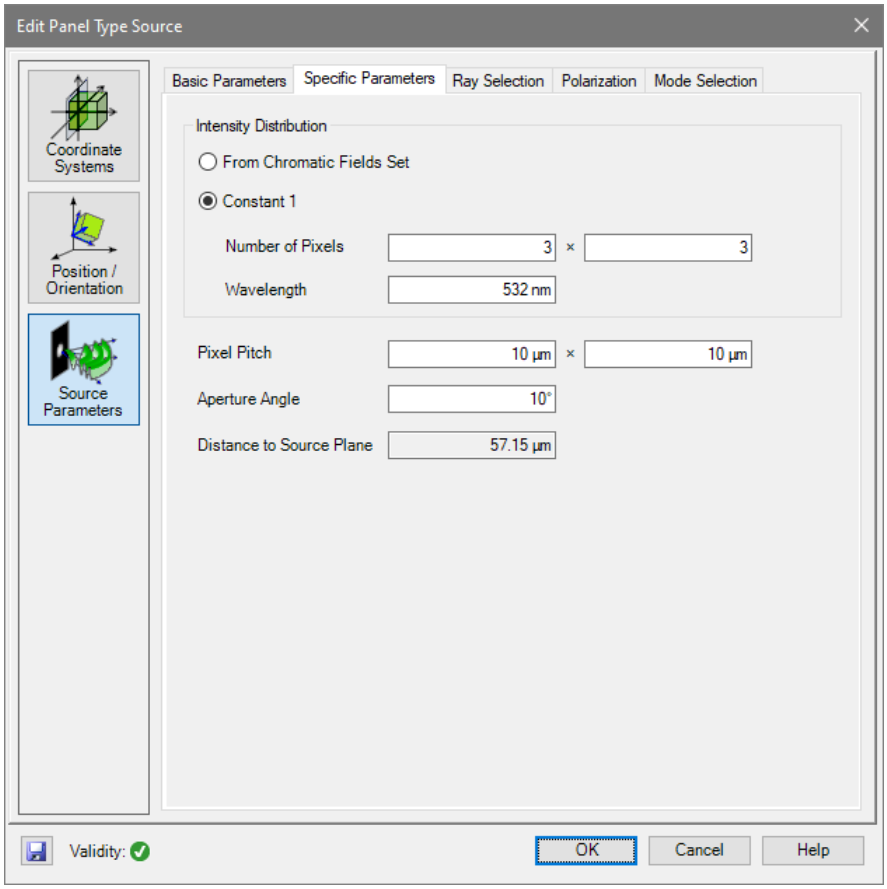


Figure 509. *The edit dialog of the Panel Type Source (Specific Parameters tab).*

The *Specific Parameters* tab of its dialog (↔Fig. 509) has the following controls specific to the Panel Type Source.

ITEM	DESCRIPTION
Pixel Pitch	The x- and y-distance of neighbored pixels.
Aperture Angle	The full aperture angle. Together with the pixel pitch this determines the *Distance to Source Plane*, i. e. how far behind the source plane the spherical wave starts from a single point. If the pixel pitch differs in x- and y-direction the larger of the two values is taken for this calculation.
Distance to Source Plane	For your information the distance to the source plane is also given.

The remaining controls of this dialog are explained in Sec. 53.7.

53.7.2 Scanning Source

Availability

Optical Setups: General Optical Setup, Light Guide Optical Setup, and Light Shaping Optical Setup

Accessible:

- Optical Setup: *Light Sources > Partially Coherent Light Sources > Scanning Source*
- Light Sources Catalog: *Templates > Scanning Source*

The Scanning Source allows you to generate a rectangular grid of modes (e. g. from an imported image) whereas each mode is a plane wave mode propagating into another direction. Modes more in the center of the original image have a smaller deviation from the central direction.

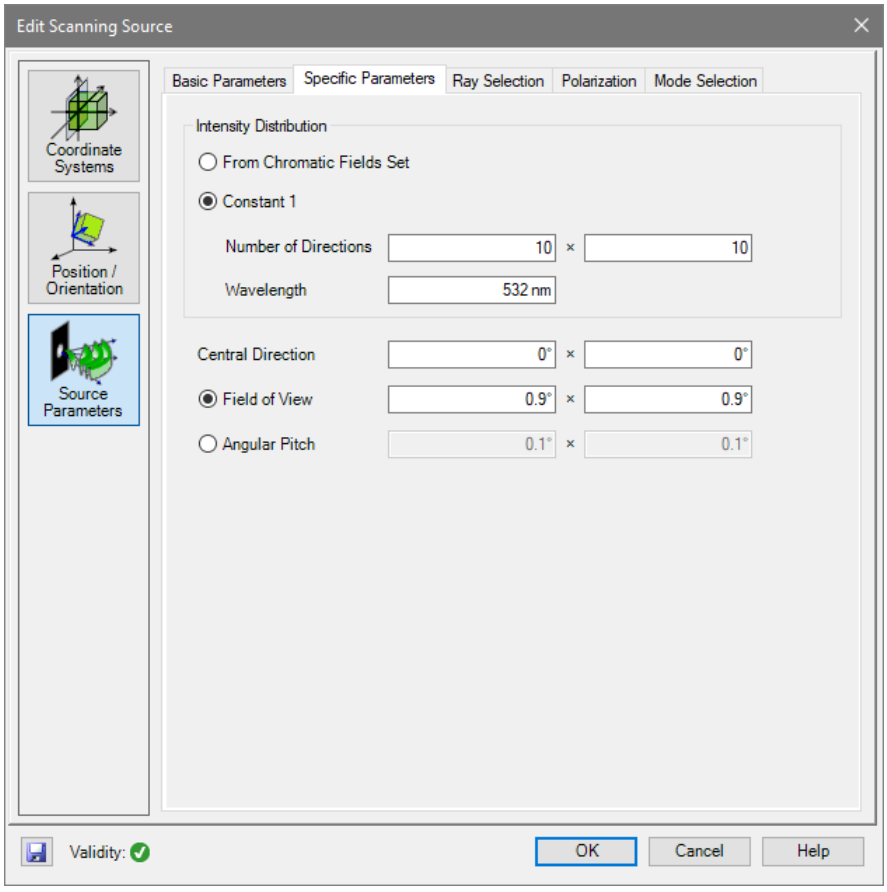


Figure 510. *The edit dialog of the Scanning Source (Specific Parameters tab).*

The *Specific Parameters* tab of its dialog (↪Fig. 510) has the following controls specific to the Scanning Source.

ITEM	DESCRIPTION
Central Direction	The direction into which the center of the overall field propagates.
Field of View	The full field of view, i. e. the difference in the x- and y-direction of the outermost pixels.
Angular Pitch	The difference in the x- and y-direction of neighbored pixels.

The remaining controls of this dialog are explained in Sec. 53.7.

53.7.3 Importing a Chromatic Fields Set from a Bitmap File

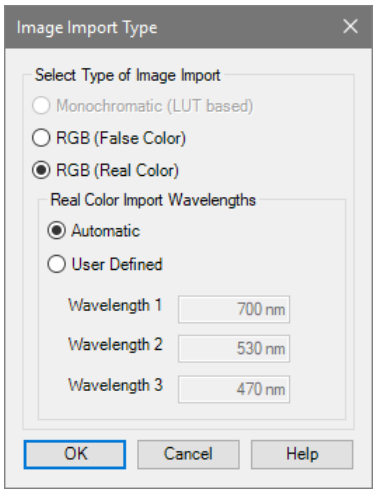


Figure 511. *Dialog to select how a bitmap shall be imported.*

Importing a bitmap file into a Chromatic Field Set to be used within an Image Light Source (using the *From Chromatic Fields Set* mode), provides two different options:

ITEM	DESCRIPTION
RGB (False Color)	Each of the channels R, G, and B is stored into one subset of the Chromatic Fields Set. Their wavelengths can be set and weighted freely. ↪Sec. 53.7.3.1
RGB (Real Color)	The bitmap is imported in a way that guarantees the best color fidelity when the resulting Chromatic Fields Set is viewed in the real color mode. ↪Sec. 53.7.3.2

Three bitmap formats are supported: Windows bitmap files (.bmp), JPEG images (.jpg, .jpeg), and portable network graphics (.png).
The sampling distance of the resulting Chromatic Fields Set is calculated from the resolution stored in the file. For example the bitmap export of VirtualLab Fusion sets this value according to the original sampling distance. If no resolution is stored in the bitmap file the resolution of the screen is taken.

53.7.3.1 Importing False Color RGB Images

The result of the import process is a Chromatic Fields Set with three fields of three different wavelengths. These wavelengths can be determined and weighted by the user.

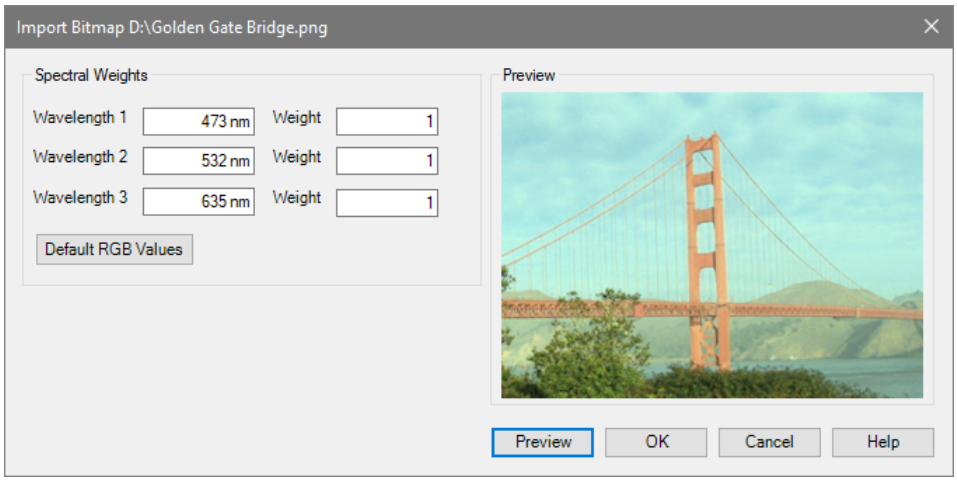


Figure 512. *Options dialog for false color bitmap import.*

ITEM	DESCRIPTION
Wavelength 1/2/3	The wavelengths of the three harmonic fields the bitmap channels are matched with.
Weight	The (intensity) weight the channel is multiplied with.
Default RGB Values	By clicking this button the *Wavelength*s and *Weight*s are set to the default values. These are values which produce the most natural false color image.
Preview	By clicking this button you can see how the real color view (↪Sec. 14.2) of the imported image will look like using the current parameters.

53.7.3.2 Importing Real Color RGB Images

The result of the import process is a Chromatic Fields Set with three fields of three different wavelengths. These wavelengths are determined from the used color system if *Automatic* is chosen. Then the real color view (↪Sec. 14.2) reproduces Hue and Saturation (H and S in the HSV color system) of the original image exactly (if no gamut errors occur). The Value (V in the HSV color system) may differ slightly due to the interpolation. This real color import is based upon a color transform from the bitmap's color space to the color space used in VirtualLab Fusion(usually 'VirtualLab Color Space').

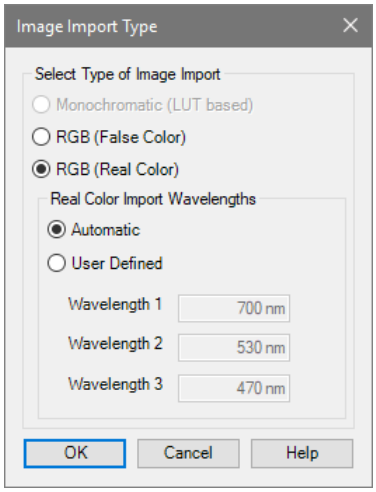


Figure 513. *Options dialog for real color bitmap import.*

ITEM	DESCRIPTION
Automatic	Use three wavelengths that are suitable for the color system used for display, so that minimal out-of-gamut errors occur.
User Defined	Choose three wavelengths (*Wavelength 1/2/3*) for the color space conversion. Warning: There is a very high probability for out-of-gamut errors while converting if these values differ from the automatically determined ones, so the result's colors may look strange.

54 Spectrum Generators

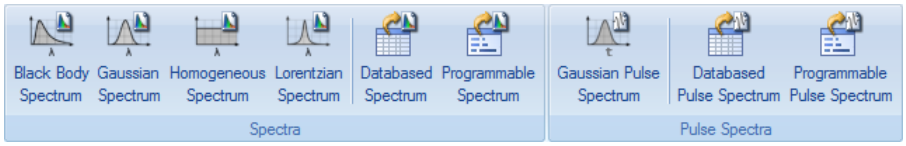


Figure 514. *Part of the Sources ribbon showing all available spectrum generators. They are explained in the following sections.*

SPECTRUM GENERATOR	DESCRIPTION
Black Body Spectrum	A discrete sample at equidistant wavelengths from the black body spectral intensity distribution governing the thermal radiation of an idealized black body. ↪Sec. 54.1
Gaussian Spectrum	A discrete sample at equidistant wavelengths of the Gaussian spectral intensity distribution which arises in Doppler broadening of a spectral line. ↪Sec. 54.2
Homogeneous Spectrum	A constant intensity sampled at equidistant wavelengths. ↪Sec. 54.3
Lorentzian Spectrum	A discrete sample at equidistant wavelengths of the Lorentzian spectral intensity distribution which arises in natural lifetime and collision broadening of a spectral line. ↪Sec. 54.4
Databased Spectrum	Allows the specification of data points for the generation of a spectrum. ↪Sec. 54.5
Programmable Spectrum	Allows you to program an arbitrary spectrum over wavelength or frequency. ↪Sec. 54.6
Gaussian Pulse Spectrum	An ultra-short pulse with a Gaussian envelope. ↪Sec. 54.7
Databased Pulse Spectrum	Allows the specification of data points for the generation of a pulse spectrum. ↪Sec. 54.8
Programmable Pulse Spectrum	Allows you to program an arbitrary pulse spectrum over wavelength or frequency. ↪Sec. 54.9

54.1 Black Body Spectrum

Availability

Toolboxes: All

Accessible: Sources > Black Body Spectrum 

The *Black Body Spectrum* generates a discrete sample at equidistant wavelengths from the black body spectral intensity distribution governing the thermal radiation of an idealized black body (↪Sec. 139.6.1). Any such distribution is simply depending on the temperature of the body. The edit dialog (↪Fig. 515) has the following parameters:

ITEM	DESCRIPTION
Temperature	Allows the selection of the absolute temperature in Kelvin. For your information also the wavelength is given at which the distribution peaks for the current temperature according to Wien's displacement law.
Min. Wavelength	The lower bound of the sampling interval is entered here.
Max. Wavelength	The upper bound of the sampling interval is entered here.
Sampling Count	The total number of sampled wavelengths is defined here.

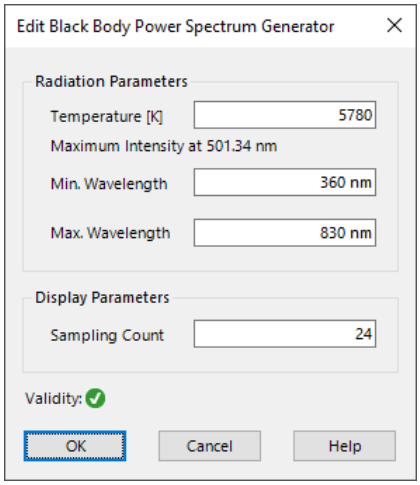


Figure 515. *Dialog for adjusting a black body spectrum.*

After finishing the dialog, the wavelengths between the given minimum and maximum are computed according to the sampling count with constant sampling increment.
Their intensity values are obtained by integrating the intensity function over an interval of half a sampling increment both at the left and at the right of the wavelength. Thus the sampled wavelengths get an intensity which is representative for a symmetric interval around them.
By re-scaling the computed values, the peak intensity for the sample is arbitrarily set to 1.
Output is a 2D diagram showing the distribution of the black body radiation at the chosen temperature. The diagram can be used as the spectrum of a polychromatic light source in the generating dialog of the light source.

54.2 Gaussian Spectrum

Availability

Toolboxes: All

Accessible: Sources > Gaussian Spectrum 

The *Gaussian Spectrum* generates a discrete equidistant sample of wavelengths with their intensities forming a Gaussian spectral intensity distribution (which arises from Doppler broadening of a spectral line). Any such distribution is characterized by a peak wavelength and by the half width wavelength increment at half-maximum. ↪Sec. 139.6.2.
The edit dialog (↪Fig. 516) has the following parameters:

ITEM	DESCRIPTION
Peak Wavelength	Allows the selection of the wavelength carrying the intensity maximum.
Half Width at Half-Max	The wavelength difference that defines the line broadening is entered here.
Sampling Count	The number of sampled wavelengths is entered here.
Clipping Intensity	Here the intensity ratio relative to peak intensity is determined which delimits the sampling interval.

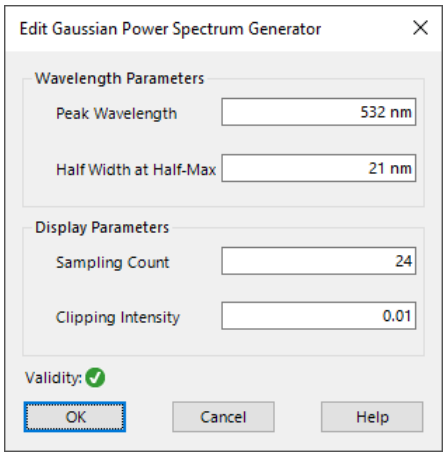


Figure 516. *Dialog for adjusting a Gaussian spectrum.*

After finishing the dialog, the minimal and maximal wavelengths to be included are calculated, and the remaining wavelengths according to the sampling count are computed with constant sampling increment.
Their intensity values are obtained by integrating the intensity function over an interval of half a sampling increment both at the left and at the right of the wavelength. Thus the sampled wavelengths get an intensity which is representative for a symmetric interval around them.
By re-scaling the computed values, the peak intensity for the sample is arbitrarily set to 1.
Output is a 2D diagram showing the Gaussian distribution. The diagram can be used as the spectrum of a polychromatic light source in the generating dialog of the light source.

54.3 Homogeneous Spectrum

Availability

Toolboxes: All

Accessible: Sources > Homogeneous Spectrum 

The *Homogeneous Spectrum* allows to generate a constant intensity sampled at equidistant wavelengths. Its edit dialog (↪Fig. 517) has the following parameters:

ITEM	DESCRIPTION
Central Wavelength	Allows the selection of the wavelength defining the middle of the wavelength band.
Spectral Bandwidth	The difference between maximal and minimal wavelength in the selected band is entered here.
Sampling Increment	The difference between two adjacent sampled wavelength values is entered here.

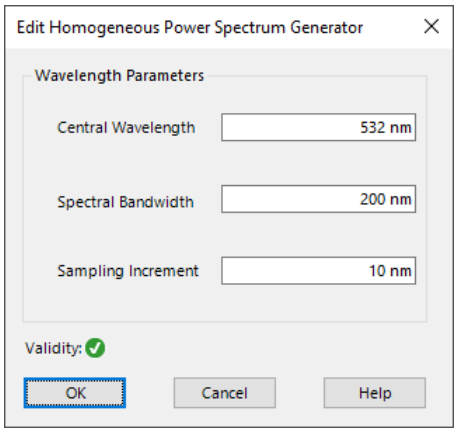


Figure 517. *Dialog for adjusting a homogeneous spectrum.*

Output is a 2D diagram showing the homogeneous distribution. The intensity values are arbitrarily set to 1. The diagram can be used as the spectrum of a polychromatic light source in the generating dialog of the light source.

If the bandwidth is not an integral multiple of the wavelength increment, then the wavelength samples are generated symmetrically around the central wavelength. The smallest wavelength in the sample is not larger than the lower band limit, and the largest wavelength in the sample is not smaller than the upper band limit.

54.4 Lorentzian Spectrum

Availability

Toolboxes: All

Accessible: Sources > Lorentzian Spectrum 

The *Lorentzian Spectrum* generates a discrete sample at equidistant wavelengths of the Lorentzian spectral intensity distribution which arises in natural lifetime and collision broadening of a spectral line. Any such distribution is characterized by a peak wavelength and by the half width wavelength increment at half-maximum. ↪Sec. 139.6.3.

The edit dialog (↪Fig. 518) has the following parameters:

ITEM	DESCRIPTION
Peak Wavelength	Allows the selection of the wavelength carrying the intensity maximum.
Half Width at Half-Max	The wavelength difference that defines the line broadening is entered here.
Sampling Count	The number of sampled wavelengths is entered here.
Clipping Intensity	Here the intensity ratio relative to peak intensity is determined which delimits the sampling interval.

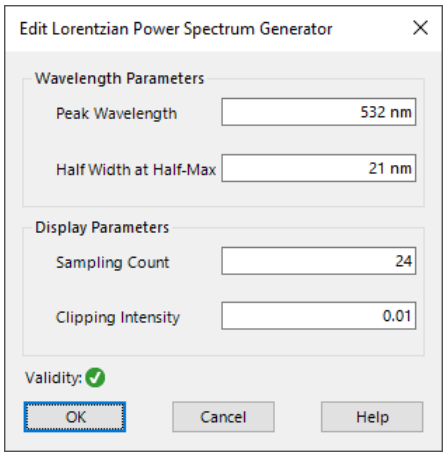


Figure 518. *Dialog for adjusting a Lorentzian spectrum.*

After finishing the dialog, the minimal and maximal wavelengths to be included are calculated, and the remaining wavelengths according to the sampling count are computed with constant sampling increment.
Their intensity values are obtained by integrating the intensity function over an interval of half a sampling increment both at the left and at the right of the wavelength. Thus the sampled wavelengths get an intensity which is representative for a symmetric interval around them.
By re-scaling the computed values, the peak intensity for the sample is arbitrarily set to 1.
Output is a 2D diagram showing the Lorentzian intensity distribution. The diagram can be used as the spectrum of a polychromatic light source in the generating dialog of the light source.

54.4.1 Used Formula

The Lorentzian power spectrum in dependence on the angular frequency ω is given by the formula

$$S(\omega) = \frac{S_0}{(\omega - \omega_0)^2 + \Delta\omega^2},$$

where ω_0 is the central angular frequency, $\Delta\omega$ the half width at half-maximum of the distribution.
In transforming the density to a function of the wavelength, the relations

$$\omega_0 = 2\pi c/\lambda_0,$$

$$\Delta\omega = -\omega_0/\lambda_0 \cdot \Delta\lambda,$$

were used.
If wavelengths with a minimal intensity S_{min} (relative to the peak intensity) shall limit the sampled wavelength interval, then corresponding lowest and highest angular frequencies are computed from

$$\omega_{min} = \omega_0 + \Delta\omega \cdot \sqrt{1/S_{min} - 1},$$

$$\omega_{max} = 2\omega_0 - \omega_{min},$$

and the equivalent wavelengths follow from $\lambda = 2\pi c/\omega$.

54.5 Databased Spectrum

Availability

Toolboxes: All

Accessible: Sources > Databased Spectrum 

The *Databased Spectrum* generator allows the specification of data points for the generation of a spectrum. The generator can be used for direct specification of the data points, or for reading data point values from a user defined file.
The following settings can be done within the edit dialog of the databased spectrum generator:

ITEM	DESCRIPTION
Specification in Wavelength / Frequency Domain	The user can select whether the values defined in the data table shall be used within the wavelength domain, or the frequency domain.
Central Wavelength / Frequency	To specify the position of the data points the user has to enter the central wavelength / frequency. Note that it is ensured that the spectrum covers the same spectral range, i. e. minimum and maximum are kept. Thus the central frequency ν_c **cannot** be calculated from the central wavelength λ_c via $\nu_c = c/\lambda_c$.
Data Table	The data table allows you to edit the amplitude and phase values of each data point. A data point can be added by clicking on the *Add Data Point* tool.
Size of the Wavelength / Frequency Window	The user can select whether he likes to define the array size of the wavelength / frequency window or the sampling distance within wavelength / frequency.
Number Data Points	The number of data points is visualized. The control to edit the number of data points is read only because the number of data points is specified by the number of entries in the data table.

Note: The databased spectrum generator is only configured correctly if at least two data points are within the data table.
The following data table tools are available :

ITEM	DESCRIPTION
Add Data Point	Data table tool to add a new data point. Clicking on this tools triggers the display of a dialog where the user has to enter the amplitude and the phase of the new data point.
Load from File	The user can specify a file which shall be used for filling the table of data values.
Clear Table	The user can reset the data table by clicking on the *Clear Table* tool.

Note: The data values in the table are always interpreted as equidistant data points.
Fig. 519 shows the edit dialog of the databased spectrum generator.

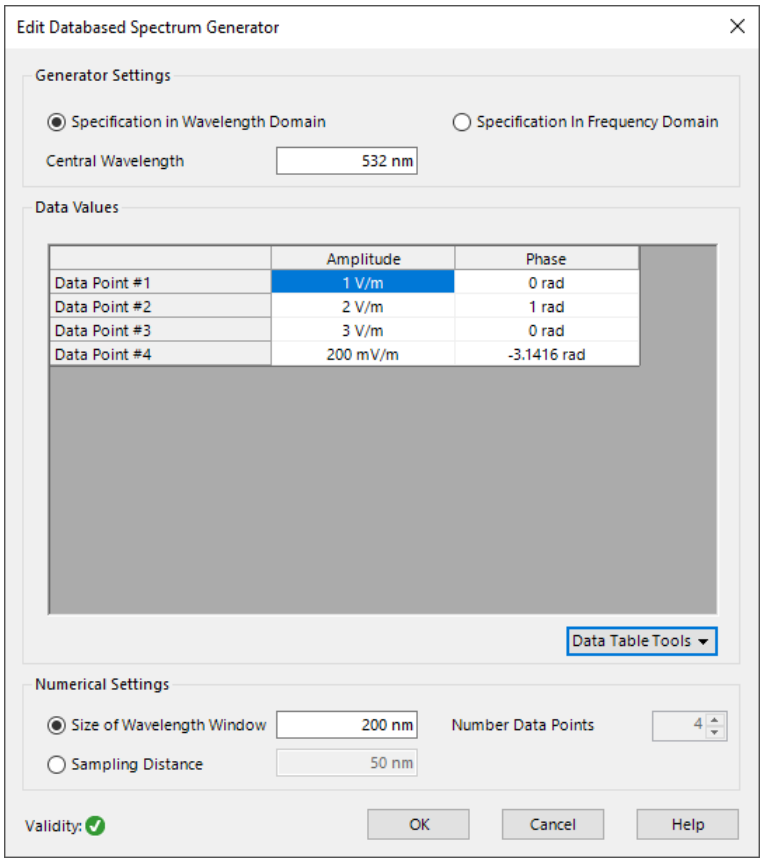


Figure 519. *Dialog of the databased spectrum generator.*

The result of the databased spectrum generator is a 1D Light Field Object which shows amplitude and phase values over wavelengths. This diagram can be used in polychromatic sources for the specification of the spectral parameters.

54.6 Programmable Spectrum

Availability

Toolboxes: All

Accessible: Sources > Programmable Spectrum 

The *Programmable Spectrum* generator allows the specification of a amplitude / phase function over wavelength or frequency. Within the generator the user has the possibility to program a simple snippet which describes the function which shall be realized by the spectrum generator.
Fig. 520 shows the edit dialog of the programmable spectrum generator.

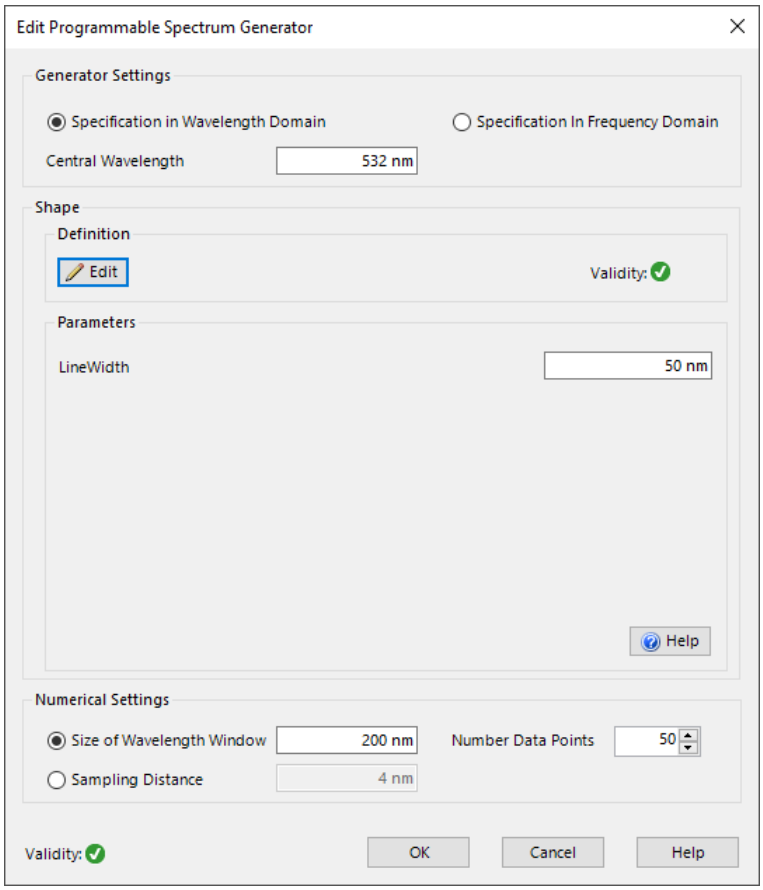


Figure 520. *Dialog of the programmable spectrum generator.*

The following settings can be done within the edit dialog of the programmable spectrum generator:

ITEM	DESCRIPTION
Specification in Wavelength / Frequency Domain	The user can select whether the return values of the function defined in the snippet shall be used within the wavelength domain, or the frequency domain.
Central Wavelength / Frequency	To specify the position of the data values the user has to enter the central wavelength / frequency. Note that it is ensured that the spectrum covers the same spectral range, i. e. minimum and maximum are kept. Thus the central frequency ν_c **cannot** be calculated from the central wavelength λ_c via $\nu_c = {}^c/\lambda_c$.
Definition	This group box allows you to program a snippet which generates a distribution of complex values. *Edit* opens the Source Code Editor (↪Sec. 7.3) to edit this snippet, and a validity indicator (↪Sec. 5.11) shows whether this snippet is consistent.
Parameters	The controls in this group box allow you to set the values of the global parameters of the snippet. ↪Sec. 7.4
Size of the Wavelength / Frequency Window	The user can select whether to define the array size of the wavelength / frequency window or the sampling distance within wavelength / frequency.
Number Data Points	The number of data points can be entered. The minimum number of data points to define a valid programmable spectrum generator is two.

The result of the programmable spectrum generator is a 1D Light Field Object which shows amplitude and

phase values over wavelengths. This diagram can be used in polychromatic sources for the specification of the spectral parameters.

54.7 Gaussian Pulse Spectrum

Availability

Toolboxes: All

Accessible: Sources > Programmable Spectrum 

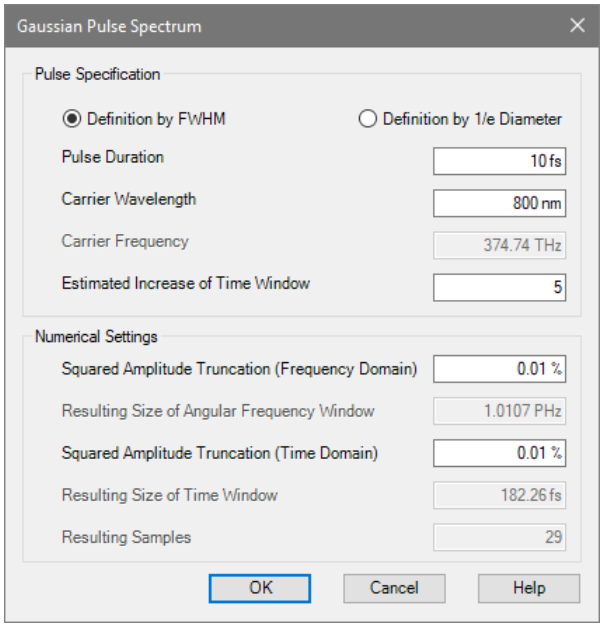


Figure 521. *Edit dialog for a Gaussian Pulse Spectrum*

The *Gaussian Pulse Spectrum* generator is intended to generate an ultra-short pulse with a Gaussian envelope. Thus its edit dialog (↪Fig. 521) asks for the parameters of the resulting pulse. As result you obtain a spectrum with a Gaussian shape if the amplitudes are plotted over frequency.

ITEM	DESCRIPTION
Definition by FWHM	*Pulse Duration* refers to half the maximum squared amplitude.
Definition by 1/e Diameter	*Pulse Duration* refers to $1/e$ times the maximum squared amplitude.
Pulse Duration	Specify the duration of the pulse in time.
Carrier Wavelength	The wavelength where the pulse spectrum reaches its maximum.
Carrier Frequency	For your information also the frequency where the pulse spectrum reaches its maximum is given.
Estimated Increase Of Time Window	With this factor you can enlarge the time window in which the pulse is displayed. This factor can be used to ensure that even the broadened pulse after propagation can be displayed correctly. As a side effect, the number of sampling points for the resulting spectrum is enlarged by the same factor.
Squared Amplitude Truncation (Frequency Domain)	In theory, a Gaussian spectrum has an infinite width. Thus you can specify a threshold relative to the maximum squared amplitude. Squared amplitudes smaller than this threshold are not taken into account.
Resulting Size of Angular Frequency Window	For your information, the resulting band width of the truncated spectrum is given.
Squared Amplitude Truncation (Time Domain)	In theory, also the Fourier-transformed pulse would have an infinite width. Thus, a further threshold relative to the maximum squared amplitude is needed for the time domain.
Resulting Size of Time Window	For your information, the resulting time window is given to illustrate the effect of the *Time Domain* threshold. The overall time window displayed after temporal Fourier transform (↪Sec. 31.2.1) is *Resulting Time Window* times *Estimated Increase Of Time Window*.
Resulting Samples	For your information; the resulting number of frequency samples which will be generated by the Gaussian Pulse Spectrum Generator.

54.8 Databased Pulse Spectrum

Availability

Toolboxes: All

Accessible: Sources > Databased Pulse Spectrum 

The *Databased Pulse Spectrum* generator allows the specification of data points for the generation of a pulse spectrum. The generator can be used for direct specification of the data points, or for importing data points from a user defined file.
Fig. 522 shows the edit dialog of the databased pulse spectrum generator.

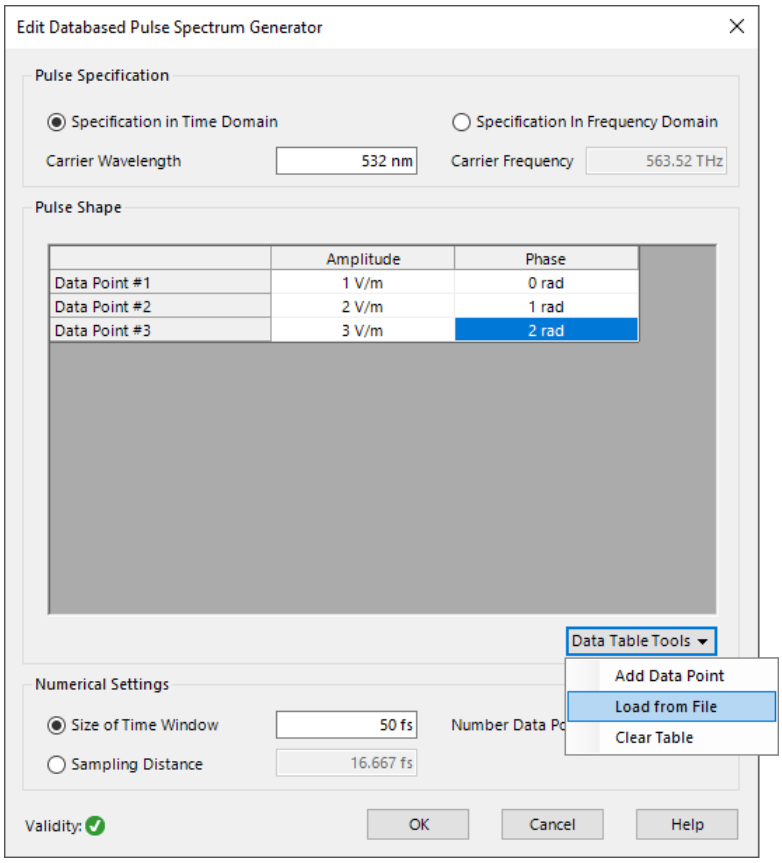


Figure 522. *Dialog of the databased pulse spectrum generator.*

The following settings can be done within the edit dialog of the databased pulse spectrum generator:

ITEM	DESCRIPTION
Specification in Time / Frequency Domain	The user can select whether the values defined in the data table shall be used within the time domain, or the frequency domain.
Carrier Wavelength	The carrier wavelength which shall be used for pulse shape generation.
Carrier Frequency	The carrier frequency is calculated from the *Carrier Wavelength*.
{Data Table}	The data table allows you to edit the amplitude and phase values of each data point. A data point can be added by clicking on the *Add Data Point* tool.
Data Table Tools	Clicking on this button opens a collection of various tools which help you in editing the data table. See below.
Size of the Time / Frequency Window	The user can select whether he likes to define the array size of the time / frequency window or the sampling distance within time / frequency.
Number Data Points	This control to show the number of data points is read only because the number of data points is specified by the number of entries in the data table.

Note: The databased pulse spectrum generator is only configured correctly if at least two data points are within the data table.
The following data table tools are available:

ITEM	DESCRIPTION
Add Data Point	Data table tool to add a new data point. Clicking on this tools triggers the display of a dialog where the user has to enter the amplitude and the phase of the new data point.
Load from File	The user can specify a file which shall be used for filling the table of data values. It must contain two columns (one for the amplitude values, one for the phase values, separated by a space). '.' must be the number separator and lines can be commented out by prepending '#'.
Clear Table	The user can reset the data table by clicking on the *Clear Table* tool.

Note: The data values in the table are always interpreted as equidistant data points.
The result of the databased pulse spectrum generator is a 1D Light Field Object which shows amplitude and phase values over wavelengths. This diagram can be used in polychromatic sources for the specification of the spectral parameters. The resulting pulse shape which is displayed over wavelength can be transformed to the pulse shape in time domain by performing an inverse Fourier transform. More information on that can be found in Sec. 31.2.1.

54.9 Programmable Pulse Spectrum

Availability

Toolboxes: All

Accessible: Sources > Programmable Pulse Spectrum 

The *Programmable Pulse Spectrum* generator allows the specification of a amplitude / phase function over time or frequency. Within the generator the user has the possibility to program a simple snippet which describes the function which shall be realized by the pulse spectrum generator.
The following settings can be done within the edit dialog of the programmable pulse spectrum generator:

ITEM	DESCRIPTION
Specification in Time / Frequency Domain	The user can select whether the return values of the function defined in the snippet shall be used within the time domain, or the frequency domain.
Carrier Wavelength	The carrier wavelength which shall be used for pulse shape generation.
Carrier Frequency	The carrier frequency is calculated from the *Carrier Wavelength*.
Definition	This group box allows you to program a snippet which generates a distribution of complex values. *Edit* opens the Source Code Editor (↪Sec. 7.3) to edit this snippet, and a validity indicator (↪Sec. 5.11) shows whether this snippet is consistent.
Parameters	The controls in this group box allow you to set the values of the global parameters of the snippet. ↪Sec. 7.4
Size of the Time / Frequency Window	The user can select whether he likes to define the array size of the time / frequency window or the sampling distance within time / frequency.
Number Data Points	The number of data points can be entered. The minimum number of data points to define a valid programmable pulse spectrum generator is two.

Fig. 523 shows the edit dialog of the generator.

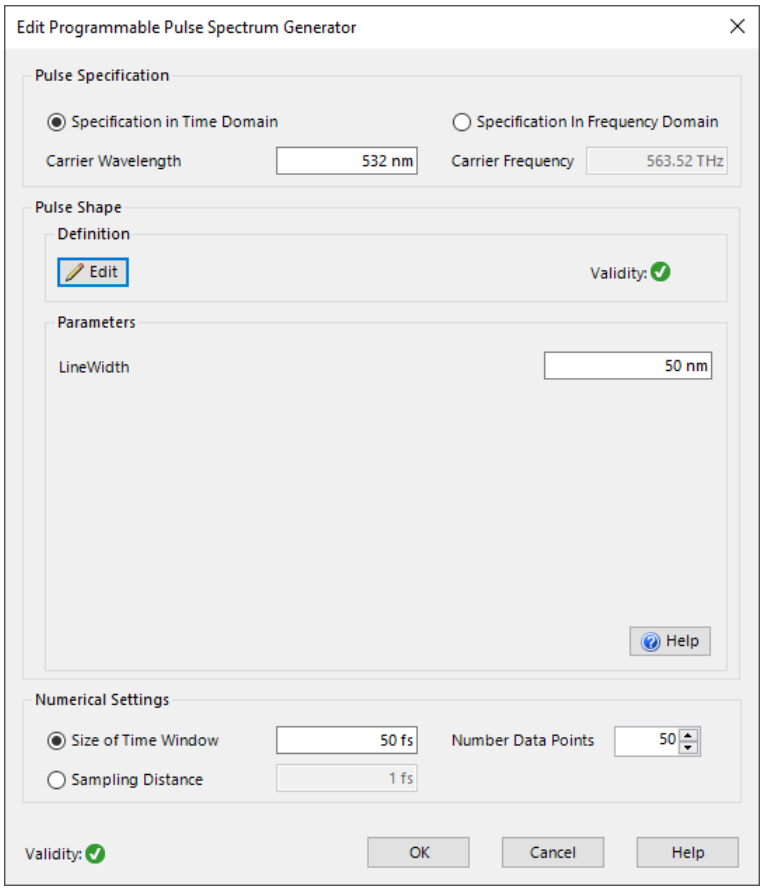


Figure 523. *Dialog of the programmable pulse spectrum generator.*

The result of the programmable pulse spectrum generator is a 1D Light Field Object which shows amplitude and phase values over wavelengths. This diagram can be used in polychromatic sources for the specification of the spectral parameters. The resulting pulse shape which is displayed over wavelength can be transformed to the pulse shape in time domain by performing an inverse Fourier transform. More information on that can be found in Sec. 31.2.1.

IX Real Components

This part documents all *Real Components* like lenses, fibers, holograms, or gratings which are available within the Optical Setup (↪Sec. 44) of VirtualLab Fusion.

55 Edit Dialog for Real Components (Common Controls)

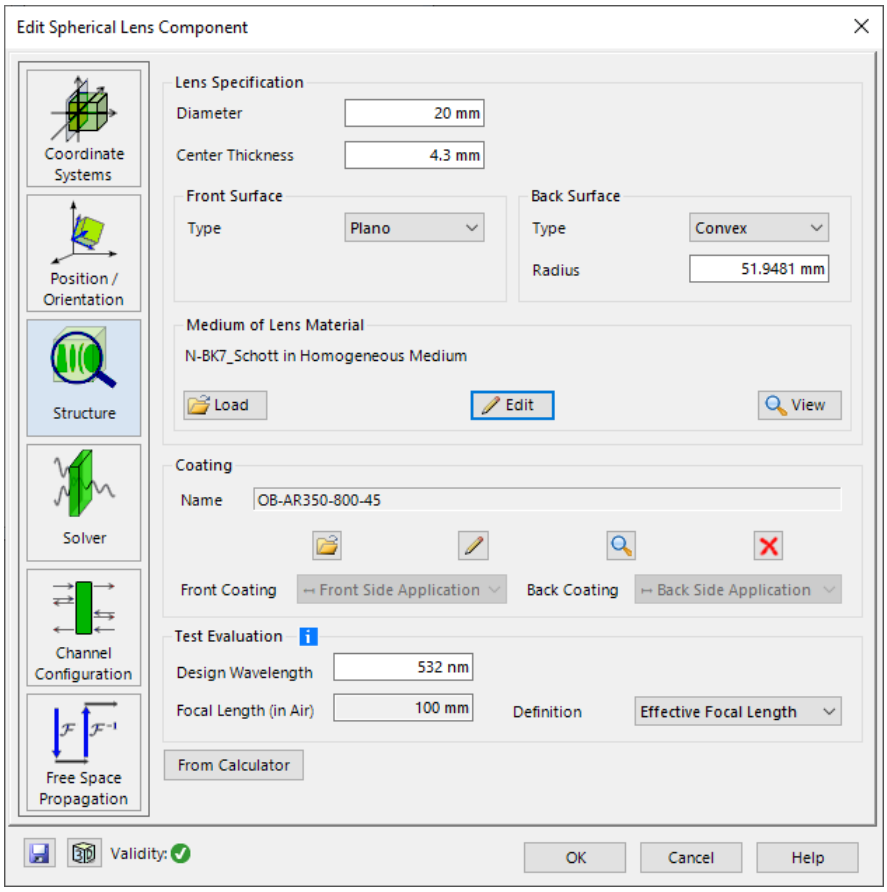


Figure 524. *Example for the edit dialog for real components.*

The edit dialogs for all real components (↪Fig. 524) are divided into several pages:

PAGE	DESCRIPTION
Coordinate Systems	↪Sec. 44.9.1
Position / Orientation	↪Sec. 44.9.2
Structure	The structure tab is specific for the distinct real components and is thus explained in the following chapters.
Solver / Function	Not for Classic Field Tracing and only for certain components. Explains the algorithm used to simulate the component.
Channel Configuration	Not for Classic Field Tracing. ↪Sec. 44.10
Fourier Transforms	Not for Classic Field Tracing. ↪Sec. 44.5.1
Propagation	Only for Classic Field Tracing and certain analyzers. ↪Sec. 55.1

In the lower left corner of the dialog there are the following controls:

ITEM	DESCRIPTION
	Saves the component into the user-defined component catalog (↪Part V).
	Opens a dialog that shows a three-dimensional view of the component. More information about the 3D view is available in Sec. 5.16.
{Validity Indicator}	Indicates whether the component is currently in a consistent state. Not visible for all components. ↪Sec. 5.11

55.1 Propagation Tab for Components

This tab is only visible if Classic Field Tracing or certain analyzers are used as simulation engine.

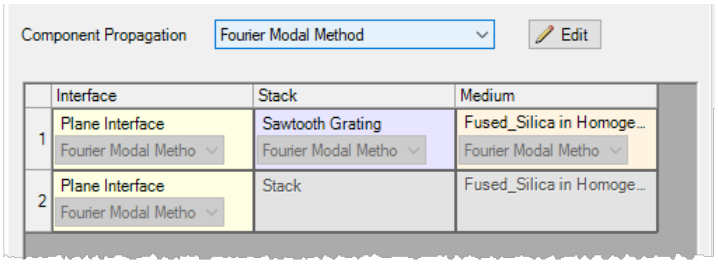


Figure 525. *Sample propagation tab for real components showing the propagation matrix (here: General Grating).*

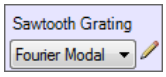


Figure 526. *One cell of the propagation table showing the name of the current building block (top), the currently selected type of propagation (bottom left), and the edit button (bottom right)*

The lower part of the propagation tab contains a table representing individual propagation methods for each building block in the component. Each row represents a so-called Boundary Segment, i. e. an Optical Surface with associated stack and the subsequent medium. Each cell (↪Fig. 526) has the following settings.

ITEM	DESCRIPTION
Name	The name of the corresponding building block.
Propagation Selection	Allows you to select the type of propagation for the corresponding building block.
Edit	Opens the edit dialog associated with the current propagation.

If a homogeneous medium is changed to an inhomogeneous one or vice versa, the propagation method for this medium will usually change.

The *Component Propagation* in the upper part of the tab is a short cut to setting all propagation methods at once. Depending on the type of the component and of the currently active component propagation, there might by some synchronization rules like “A medium has always the same propagation settings as the antecedent surface” or “All stacks have the same propagation settings”. The following table gives information about all possible component propagations.

COMPONENT PROPAGATION	ANNOTATIONS
Collins Integral by ABCD Matrix (For Spherical Lens & Lens System)	This operator uses the ABCD matrix of the component and thus can handle only certain surface types and homogeneous media. All propagation settings are synchronized. ↪Sec. 97.5
Customized Propagation (For Double Surface Component, Fiber Element, GRIN Component & Inhomogeneous Medium Component.)	Uses *Thin Element Approximation* (↪Sec. 97.2) propagations for surfaces; several paraxial free space propagations for homogeneous media (↪Sec. 94) and either the *Thin Element Approximation* or the *Split Step (BPM)* propagation (↪Sec. 97.6) for inhomogeneous media. The settings are synchronized separately for each building block type.
Fourier Modal Method (For General Grating)	All propagation settings are synchronized. ↪Sec. 97.3
Geometrical Optics (For Light Shaper)	–
Geometrical Optics Operator (For Curved Surface, Spherical Lens & Lens System)	This operator can handle smooth surfaces and homogeneous media. All propagation settings are synchronized. ↪Sec. 97.1

The *Geometrical Optics Operator* shows an additional *Advanced Settings* sub-tab which is explained in Sec. 97.1.1.
For *Customized Propagation* there are tools available to *Synchronize Surface / Medium Propagation Parameters* which means that the settings of the first surface / medium are written to all other surfaces / media.

55.2 Editing a Component in the 3D View

If you are in the 3D view of a component (↪Sec. 5.16) and you click on a surface with the right mouse button the same surface will appear in red color (signaling the selection) and a context menu with the following entries gets opened (↪Fig. 527).

ITEM	DESCRIPTION
Edit...	Opens the edit dialog (↪Sec. 36) of the selected surface.
Distance...	Opens a dialog for adjusting distance from precedent surface. This menu item is disabled for the first surface.
Show Separately	If checked all surfaces except selected one will be hidden. Other surfaces will get visible again by unchecking this item or by clicking *Reset View* in the general context menu.

If one performs a double click on a surface the corresponding edit dialog (↪Sec. 36) will open.
By clicking *OK* in the 3D view dialog all changes made will be inherited by the component.

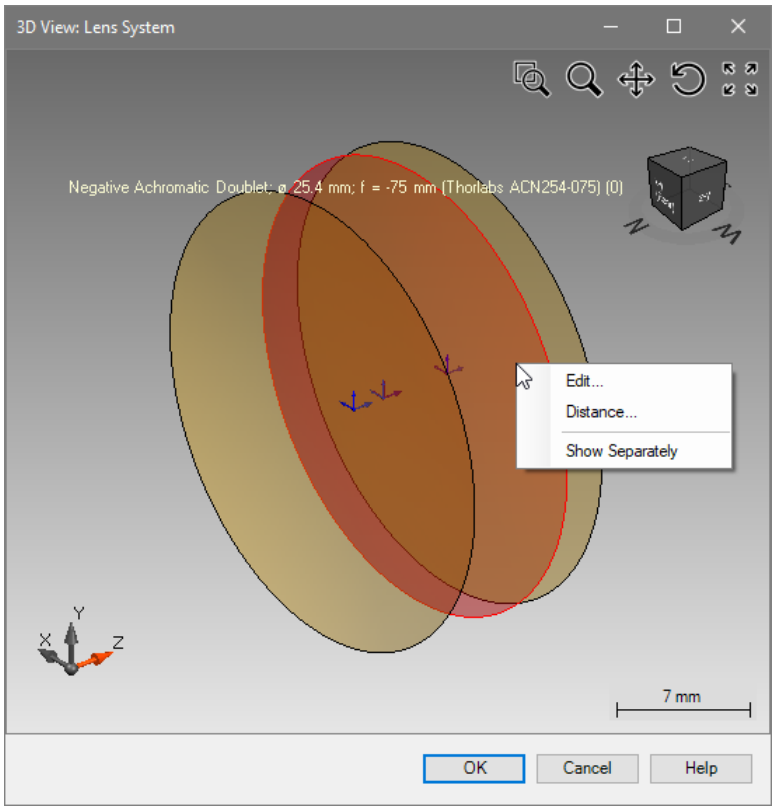


Figure 527. *Context menu of a selected surface in the 3D view.*

56 Conversion Between Components

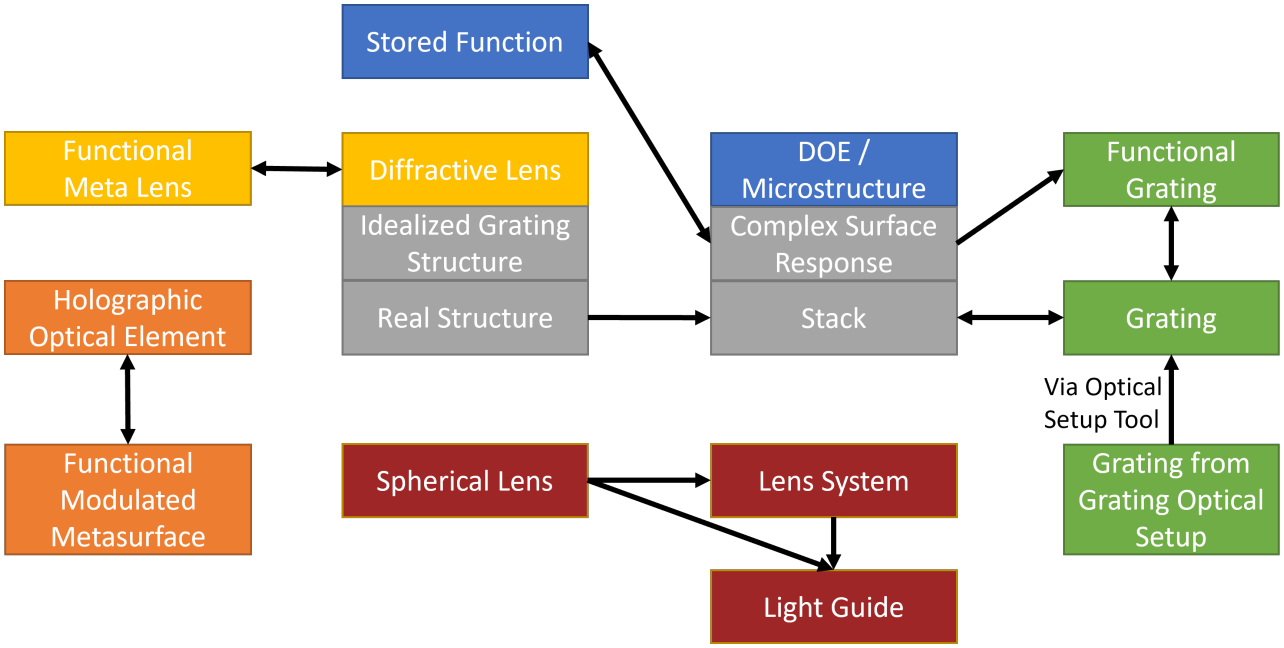


Figure 528. *Possible conversions between real and ideal components.*

Fig. 528 lists all possible conversions between real components (and the ideal component *Stored Function*). Note that for the Diffractive Lens (↪Sec. 61.2) and the Diffractive Optical Element (DOE) / Microstructure component (↪Sec. 61.1) the available conversions depend on their configuration (indicated by gray boxes). The optical setup tool to convert a complete Grating Optical Setup into a General Optical Setup with one or two grating components is explained in Sec. 44.8.1.7. All other conversions can be done via right click on the

icon of the original component in the Optical Setup View (↪Sec. 44.1). A new component is then added to the Optical Setup which gets all linkages of the original component.

The conversions are done as best as possible, but still the results obtained with the converted component can then differ very much from the results obtained with the original component.

57 Index Modulated & Crystal Components

57.1 Crystal Plate

Availability

Optical Setups: General Optical Setup

Accessible: Optical Setup: *Components > Index Modulated & Crystals > Crystal Plate*

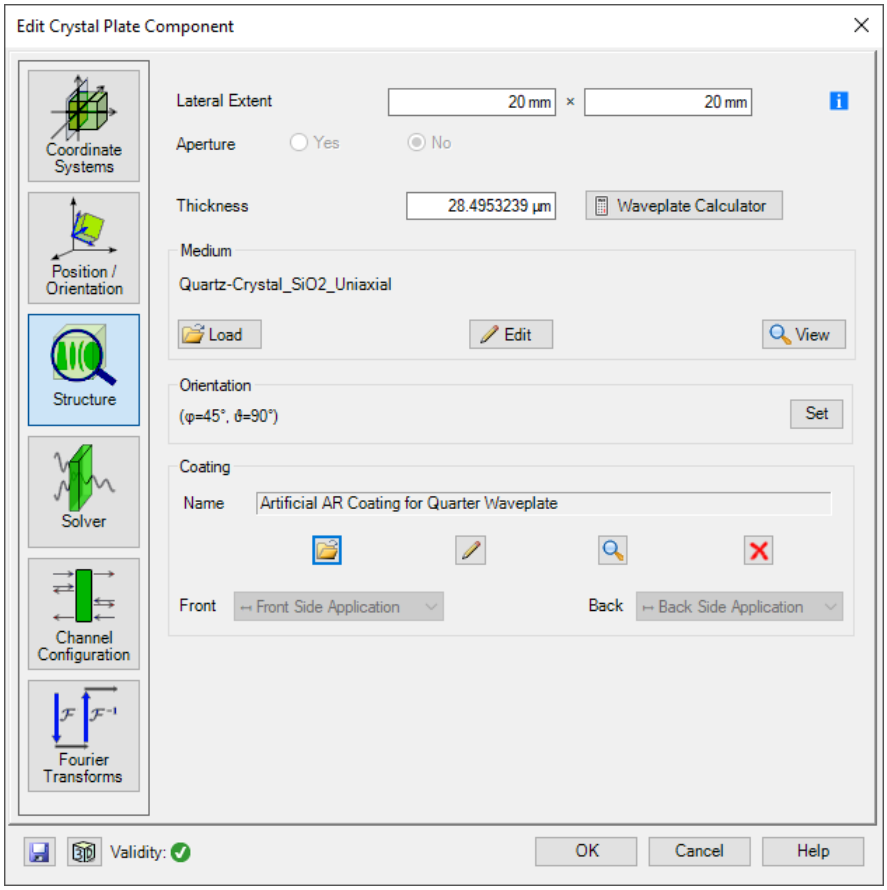


Figure 529. *The structure tab of the Crystal Plate component.*

The Crystal Plate component is intended for the rigorous analysis of an anisotropic medium, confined by two plane parallel infinite surfaces. The *Structure* tab of its edit dialog (↪Fig. 538) provides the following settings:

ITEM	DESCRIPTION
Lateral Extent	In principle, the Crystal Plate component has an infinite lateral extension. However, as this is not feasible for the 3D view (↪Sec. 5.16) and the light path finder for manual channel configuration (↪Sec. 44.3.1), a size can be entered here.
Aperture	Read-only control which indicates that the component has an infinite lateral extension when simulated.
Thickness PV	The thickness of the crystal can be set here.
Waveplate Calculator	FOR UNIAXIAL CRYSTALS AS *MEDIUM* ONLY. This button opens a Waveplate Calculator (↪Sec. 120). This will help to configure the uniaxial crystal plate as a waveplate with a certain retarding effect. After closing the calculator dialog with *Ok*, the calculated thickness will be set to *Thickness* and the *Orientation* will be adapted as well. That means that the optical axis of the crystal is set to the x-y-plane of the component automatically.
Medium	The optical medium (↪Sec. 38, ↪Sec. 34.1) the crystal consists of.
Orientation	FOR ANISOTROPIC *MEDIUM* ONLY. The orientation of an anisotropic crystal medium in reference to the component's internal coordinate system. In case of uniaxial crystals, only the direction of the optical axis is to be specified (↪Sec. 5.5). For other types of anisotropic media, a full orientation has to be defined (↪Sec. 5.6).
Coating	A coating (↪Sec. 37) for front and back face of the crystal can be defined here. It is applied to the outer side of both surfaces. ↪Sec. 34.2.

57.2 Index Modulated Components

Availability

Optical Setups: General Optical Setup & Laser Resonator Optical Setup

Accessible: Optical Setup: *Components > Index Modulated & Crystal*

These components consist of an index modulated medium between two arbitrary surfaces. There are three such components which differ only in their default settings and which media can be used.

- *Fiber Element*: The default settings resemble an optical fiber and by default a Fiber Medium (↪Sec. 38.3.4) is used.
- *GRIN Lens*: The default settings resemble a gradient index lens. Only GRIN Media (↪Sec. 38.3.6) can be used.
- *Inhomogeneous Medium Component*: By default a Programmable Medium (x-y-z-Modulated) (↪Sec. 38.3.10) is used.

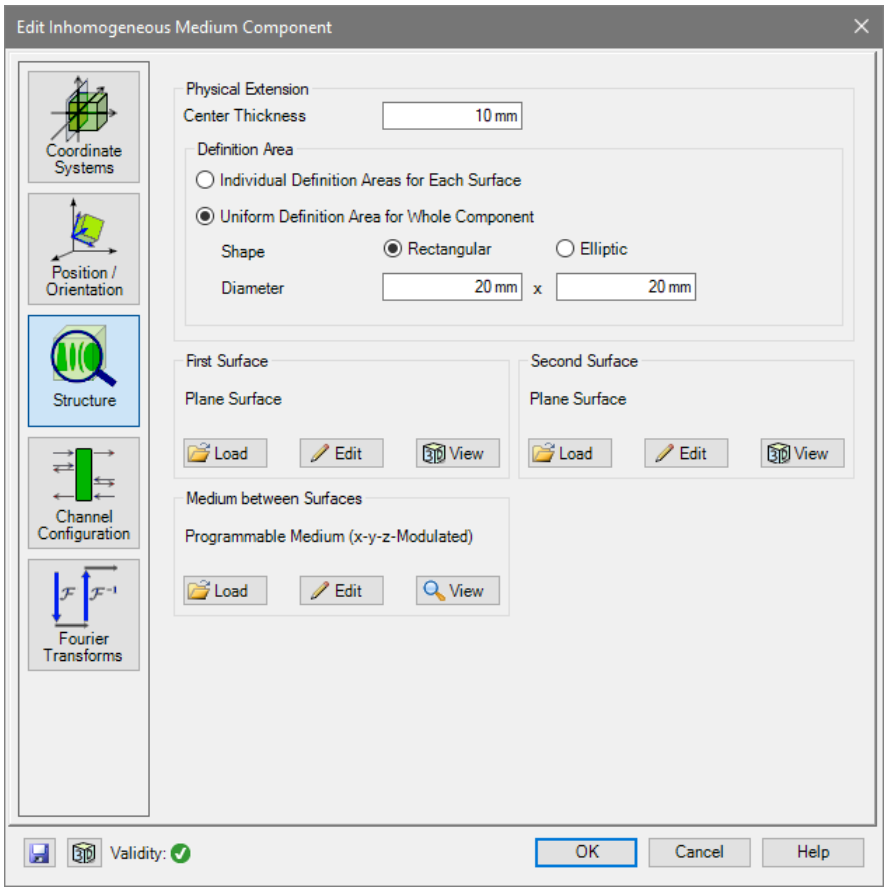


Figure 530. *The Structure tab of an Inhomogeneous Medium Component.*

The edit dialog of these components (↪Fig. 530) has the following controls.

ITEM	DESCRIPTION
Center Thickness[PV]**/ Fiber Length**[PV]	The distance of the two surfaces measured on the optical axis.
Individual Apertures for Each Surface	If you select this option the apertures of the surfaces are set via the *Edit* button of the *First Surface* and *Second Surface*, respectively.
Uniform Aperture for Whole Component	If you check this radio button, the same aperture is taken for both surfaces. The common aperture is then set via the *Shape* and *Diameter* controls below the radio button. If you double-click on one of the *Diameter* text boxes, the value from the other text box is being overtaken.
First Surface[PE]	Configures the first surface and displays its name. You can *Load* a new surface from the catalog (↪Sec. 33), *Edit* the current surface or *View* it with the three-dimensional view described in Sec. 36.3.
Second Surface[PE]	Configures the second surface and displays its name. You can *Load* a new surface from the catalog (↪Sec. 33), *Edit* the current surface or *View* it with the three-dimensional view described in Sec. 36.3.
Medium Between Surfaces[PE]	Configures the medium between the two surfaces and displays its name. You can *Load* a predefined medium from the catalog (↪Sec. 33), *Edit* the current medium (↪Sec. 38.3.1) or *View* it with the view described in Sec. 38.2.

The other tab pages are explained in Sec. 55.

58 Multiple Surfaces Components

58.1 Lens System

Availability

Optical Setups: General Optical Setup, Light Guide Optical Setup, and Laser Resonator Optical Setup

Accessible: Optical Setup: *Components > Multiple Surfaces > Lens System*

The *Structure* tab is divided into four sections (from top to bottom):

1. a preview of the current surface media sequence (↪Sec. 5.15)
2. a table with the current surface media sequence
3. a panel with new surfaces which you can drag into the table
4. a button row .

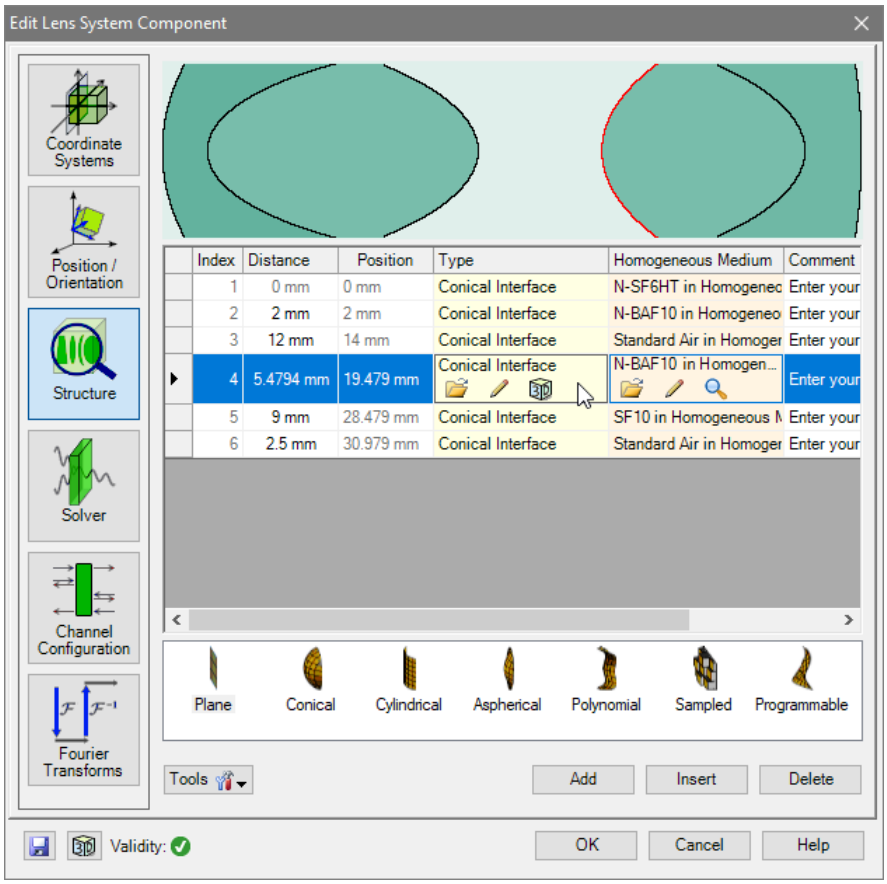


Figure 531. *The structure tab of the Lens System component showing a sample sequence.*

The buttons on this tab have the following functionality:

ITEM	DESCRIPTION
Tools	The tools for a Lens System are described below.
Add	Adds a new surface PE from the catalog at the end of the table. The same can be achieved by dragging the new surface into the table.
Insert	Places a new surface from the catalog before the current surface (which is marked by a triangle in the first table column).
Delete	Deletes the selected surface(s).

The table has the following columns:

ITEM	DESCRIPTION
Index	The index of the current surface. Note: This item is read-only.
Distance PV	The distance to the precedent surface. The first distance is always zero.
Position	The position of the current surface. Note: This item is read-only.
Type	The type (or name in case of catalog surface) of the current surface. If the mouse hovers above that column, you can edit or view the current surface PE or load a new one from the Surfaces Catalog. See also Sec. 34.1.
Homogeneous Medium PE	The homogeneous medium after the current surface. If the mouse hovers above that column, you can edit or view the medium behind the current surface or load a new one from the Media Catalog. See also Sec. 34.1. Important: The last medium is always identical to that of the transmission type reference coordinate system (see Sec. 44.9.1 for details). Changing that medium will change the embedding medium between this component and the next component (which is connected via the transmission type reference CS) too.
Comment	You can enter a comment for a specific surface by clicking into the corresponding comment cell.

You can select a single table row by clicking into it. By pressing Shift at the same time or with dragging the mouse you can mark consecutive rows. With clicking on the first table column and then drag & drop the selected rows can be moved (or copied if Shift is pressed at the same time). With Del you can delete the selected surfaces.
The following *Tools* are available:

ITEM	DESCRIPTION
Add Surface from Catalog	Allows loading a surface with preset parameters from the surface catalog (↪Sec. 33).
Duplicate Selected Surface(s)	The currently selected surfaces are duplicated (including their *Distance* and *Homogeneous Medium*). A simple dialog allows you to specify in which row (specified by its *Index*) the duplicated surfaces are inserted. When you enter $n+1$ with n being the currently highest row index, the surfaces are added at the end of the table.
Remove All Surfaces	Removes all surfaces currently set in the table.
Synchronize Definition Areas	The definition areas (size and shape) of all surfaces are set to the definition area of the first surface.
Apply Coating to All Surfaces	Loads a coating from the coating catalog and applies it to all (suitable) surfaces.
Remove All Coatings	Removes the coatings from all surfaces (if present).
Append Component from Catalog	This tool can be used to append the structural information (sequence of surfaces and media) of a component selected from the catalog. The user has to specify the component that shall be appended.
Import 'Zemax OpticStudio®' Lens File	You can open a Zemax OpticStudio® lens file which is appended at the end of the current surface sequence. More details about import from Zemax OpticStudio® can be found in Sec. 131.2.

The other tab pages are explained in Sec. 55.

58.2 Light Guide

Availability

Optical Setups: Light Guide Optical Setup & General Optical Setup (only three surface regions per surface layout)

Accessible: Optical Setup: *Components > Multiple Surfaces > Light Guide*

The *Structure > Solid* tab is explained in Sec. 58.2.1 and the *Structure / Function > Surface Layouts* tab in Sec. 58.2.2.
The other tab pages are explained in Sec. 55.

58.2.1 Structure > Solid Tab

The *Solid* tab is divided into four sections (from top to bottom):

1. a 3D preview of the solid (↪Sec. 5.16)
2. a table with the current surface media sequence
3. a panel with new surfaces which you can drag into the table
4. a button row .

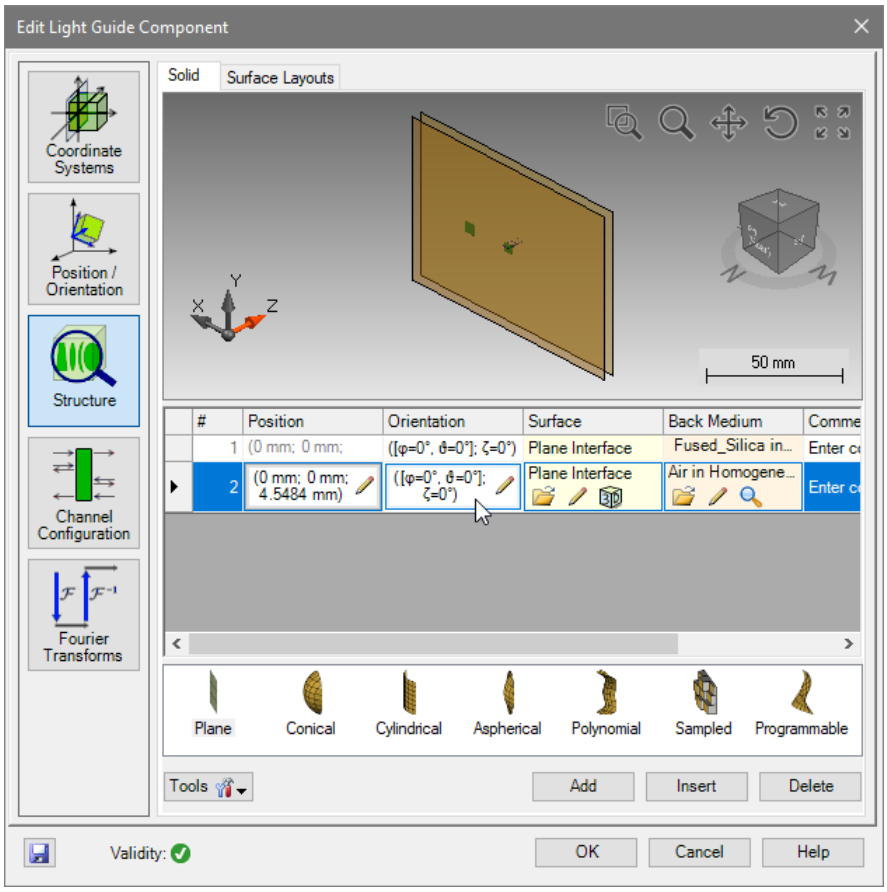


Figure 532. *The Solid tab of the Light Guide component showing a sample sequence.*

The buttons on this tab have the following functionality:

ITEM	DESCRIPTION
Tools	The tools are described below.
Add	Adds a new surface[PE] from the catalog at the end of the table. The same can be achieved by dragging the new surface into the table.
Insert	Places a new surface from the catalog before the current surface (which is marked by a triangle in the first table column).
Delete	Deletes the selected surface(s).

The table has the following columns:

ITEM	DESCRIPTION
#	The index of the current surface. Note: This item is read-only.
Position	Shows the absolute position of the surface and allows you to set the position by clicking on the button, either in absolute coordinates or relative to the previous surface. The first surface always has its position fixed to the origin of the internal coordinate system of the component.
Orientation	Shows the absolute orientation of the surface and allows you to edit it by clicking on the button, then a dialog with the control described in Sec. 5.6 opens.
Surface	The type (or name in case of catalog surfaces) of the current surface. If the mouse hovers above the selected row at that column, you can edit or view the current surface PE or load a new one from the Surfaces Catalog (↪Sec. 34.1).
Back Medium PE	The homogeneous medium after the current surface. If the mouse hovers above the selected row at that column, you can edit or view the medium of the current surface or load a new one from the Media Catalog (↪Sec. 34.1). Important: The last medium is always identical to that of the transmission type reference coordinate system (↪Sec. 44.9.1). Changing that medium will change the embedding medium between this component and the next component (which is connected via the transmission type reference CS) too.
Comment	You can enter a comment for a specific surface by clicking into the corresponding comment cell.

You can select a single table row by clicking into it. By pressing Shift at the same time you can mark consecutive rows. With Del you can delete the selected surfaces.
The following *Tools* are available:

ITEM	DESCRIPTION
Add Surface from Catalog	Allows loading a surface with preset parameters from the surface catalog (↪Sec. 33).
Duplicate Selected Surface(s)	The currectly selected surfaces are duplicated (including their *Position*, *Orientation*, and *Back Medium*) and inserted after the originally selected surfaces.
Remove All Surfaces	Removes all surfaces currently set in the table.
Synchronize Definition Areas	The definition areas (size and shape) of all surfaces are set to the definition area of the first surface.

58.2.2 Structure > Surface Layouts Tab

Every surface that has been specified on the *Structure > Solid* tab (↪Sec. 58.2.1) contains a surface layout which in turn may contain several grating regions. The *Structure > Surface Layouts* tab provides an overview of all that surface layouts as well as editing access to the layouts and their regions.

ITEM	DESCRIPTION
Surface Name	The name of the surface which has been specified on the *Structure > Solid* tab.
Edit	This button allows editing the layout of the currently selected surface. This has to be done using the dialog described in Sec. 41.2.
Info	Information about the number of regions contained by the layout of the currently selected surface.

58.3 Spherical Lens

Availability

Optical Setups: General Optical Setup, Light Guide Optical Setup, and Laser Resonator Optical Setup

Accessible: Optical Setup: *Components > Multiple Surfaces > Spherical Lens*

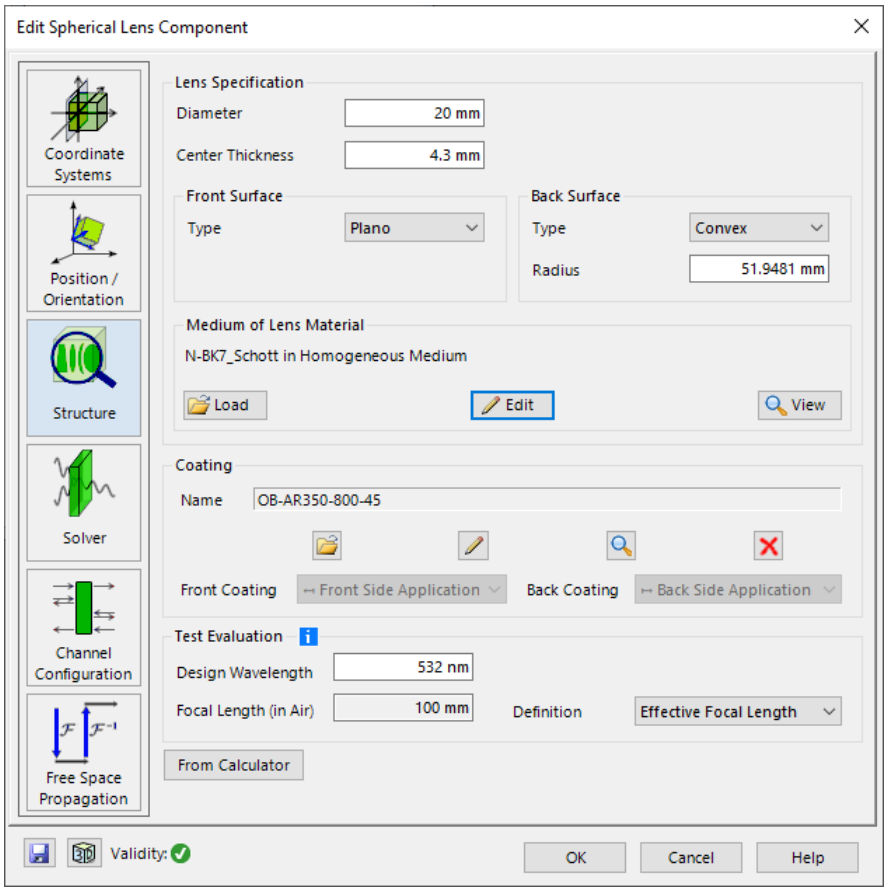


Figure 533. *The edit dialog of the Spherical Lens.*

ITEM	DESCRIPTION
Diameter PV	The (aperture) diameter of the lens.
Center Thickness PV	The center thickness of the lens. If you enter a thickness less than the minimum thickness (defined by the *Diameter* and the radii), the thickness is set to the minimum thickness.
First Surface	You can set the type of the first surface (*Plano*, *Convex*, and *Concave*, respectively). For a *Convex* or *Concave* surface you can set the absolute value of the *Radius* PV of curvature.
Second Surface	You can set the same parameters as for the *First Surface*.
Medium of Lens Material PE	Set the homogeneous medium the lens consists of here. See also Sec. 34.1.
Coating PE	You can define a coating (↪Sec. 37) for the surfaces here. It is applied to the outer side of both surfaces. ↪Sec. 34.2.
Test Evaluation	For your information, the *Focal Length (in Air)* for the specified *Design Wavelength* is shown. You can choose whether the focal length is defined as *Effective Focal Length* f_{eff}, *Back Focal Length* f_{b}, or *Front Focal Length* f_{f}. They are calculated with the formulas given in Sec. 141.1. *Please note:* Regardless of the specific embedding medium for the lens as well as the temperature and air pressure of the Optical Setup the lens may be part of: the focal length is always calculated for a lens being in air at standard conditions (20 °C, 101'325 Pa).
From Calculator	A button (↪Sec. 5.7) to set data from a Spherical Lens Calculator (↪Sec. 118). Either a new calculator is created and shown as a dialog or an already existing calculator is loaded.

This component uses a validity indicator (↪Sec. 5.11) to indicate if for example the lens is too thin for the current radii of curvature. The edit dialog cannot be closed with *OK* in this case.
The other tab pages are explained in Sec. 55.

59 Single Surface & Coating Components

59.1 Curved Surface

Availability

Optical Setups: General Optical Setup, Light Guide Optical Setup, and Laser Resonator Optical Setup

Accessible: Optical Setup: *Components > Single Surface & Coating > Curved Surface*

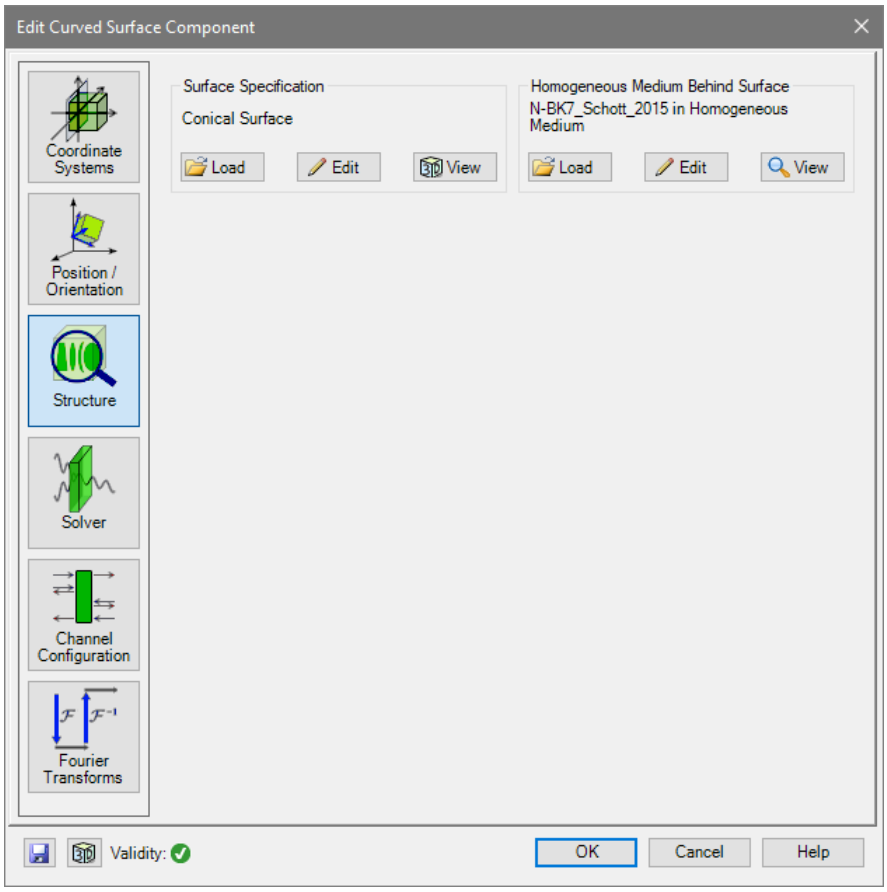


Figure 534. *The structure tab of a Curved Surface component.*

ITEM	DESCRIPTION
Surface Specification	This control (↪Sec. 34.1) allows you to set the optical surface[PE] this component consists of.
Homogeneous Medium Behind Surface	This control (↪Sec. 34.1) allows you to configure the homogeneous medium[PE] behind the surface.

The other tab pages are explained in Sec. 55.

59.2 Off-Axis Parabolic Mirror (Wedge Type)

Availability

Optical Setups: General Optical Setup & Light Guide Optical Setup

Accessible: Optical Setup: *Components > Single Surface & Coating > Off-Axis Parabolic Mirror (Wedge Type)*

This component describes an off-axis parabolic mirror used for focusing. Its first surface is a cutout of a paraboloid and its second surface is a plane.

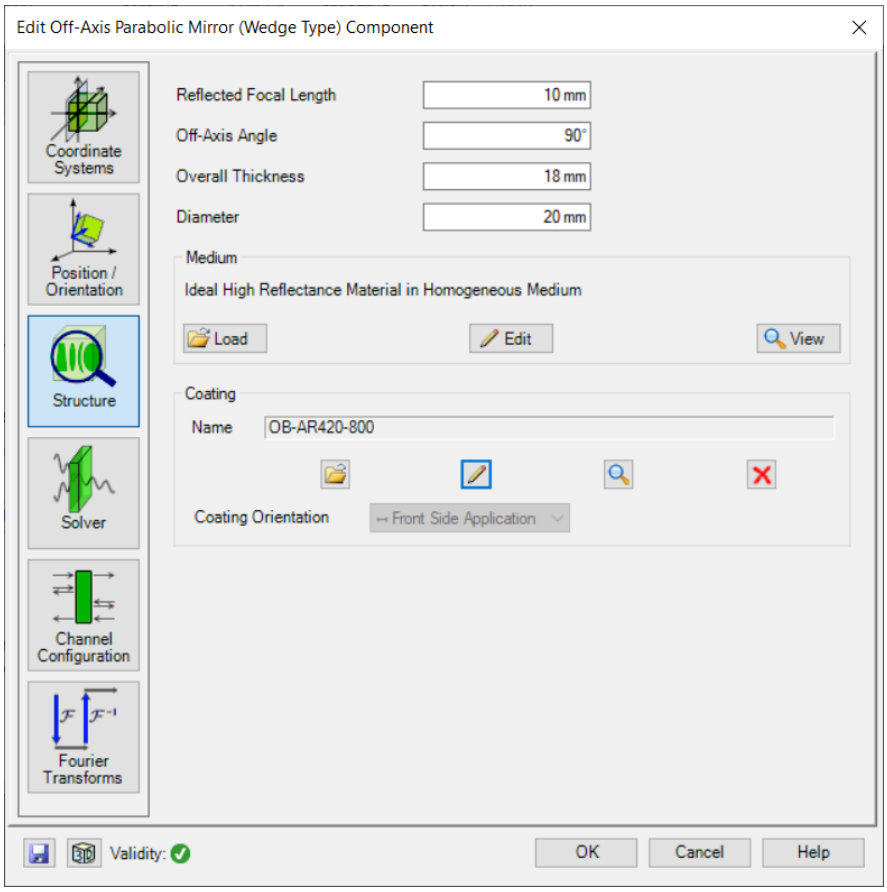


Figure 535. *The* Structure *tab of the Off-Axis Parabolic Mirror (Wedge Type) component.*

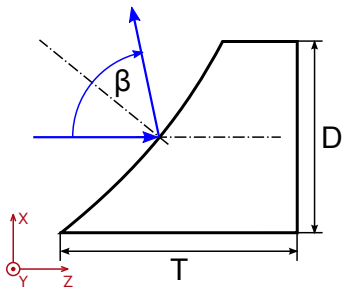


Figure 536. *The fundamental parameters of an Off-Axis Parabolic Mirror (Wedge Type) component.*

Its edit dialog (↪Fig. 535) has the following options on the *Structure* tab:

ITEM	DESCRIPTION
Reflected Focal Length	The focal length f of the component. Note that this is **not** the focal length f_0 of the parent parabola, which is $f_0 = f \cos^2 \beta/2$.
Off-Axis Angle	The angle β between incoming and reflected light. ↪Fig. 536
Overall Thickness	The maximum extension T of the component in z-direction. ↪Fig. 536
Diameter	The diameter D of the circular aperture perpendicular to the z-axis of the component. ↪Fig. 536
Medium	The homogeneous medium between the two surfaces. This control is described in Sec. 34.1.
Coating	If needed you can define a coating for the two surfaces. This control is described in Sec. 34.2.

The other controls are explained in Sec. 55.

59.3 Plane Surface

Availability

Optical Setups: General Optical Setup & Light Guide Optical Setup

Accessible: Optical Setup: *Components > Single Surface & Coating > Plane Surface*

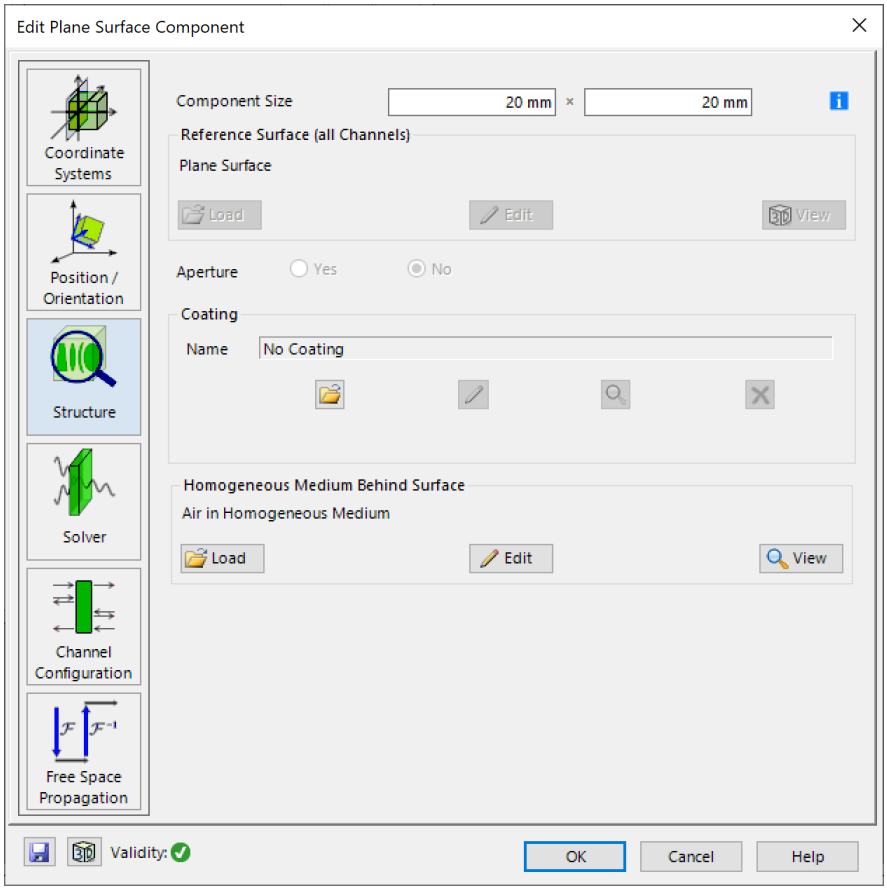


Figure 537. *The Structure tab of the edit dialog of the Plane Surface component.*

The Plane Surface component is intended for the rigorous and fast analysis of the medium transition at a single plane surface. The *Structure* tab of its edit dialog (↪Fig. 538) provides the following settings.

ITEM	DESCRIPTION
Component Size PV	In principle the Plane Surface component has an infinite lateral extension. However, as this is not feasible for the 3D view (↪Sec. 5.16) and the light path finder for manual channel configuration (↪Sec. 44.3.1), you can enter a *Component Size* here.
Reference Surface	Read-only control to show that the reference surface is a Plane Surface.
Aperture	Read-only control to show that the reference surface has an infinite lateral extension when simulated.
Coating PE	This control allows you to set the coating which stores the plane layers. ↪Sec. 34.2
Homogeneous Medium Behind Surface	This control (↪Sec. 34.1) allows you to configure the homogeneous medium PE behind the plane surface this component consists of.

The other tab pages are explained in Sec. 55.

59.4 Stratified Media

Availability

Optical Setups: General Optical Setup & Light Guide Optical Setup

Accessible: Optical Setup: *Components > Single Surface & Coating > Stratified Media*

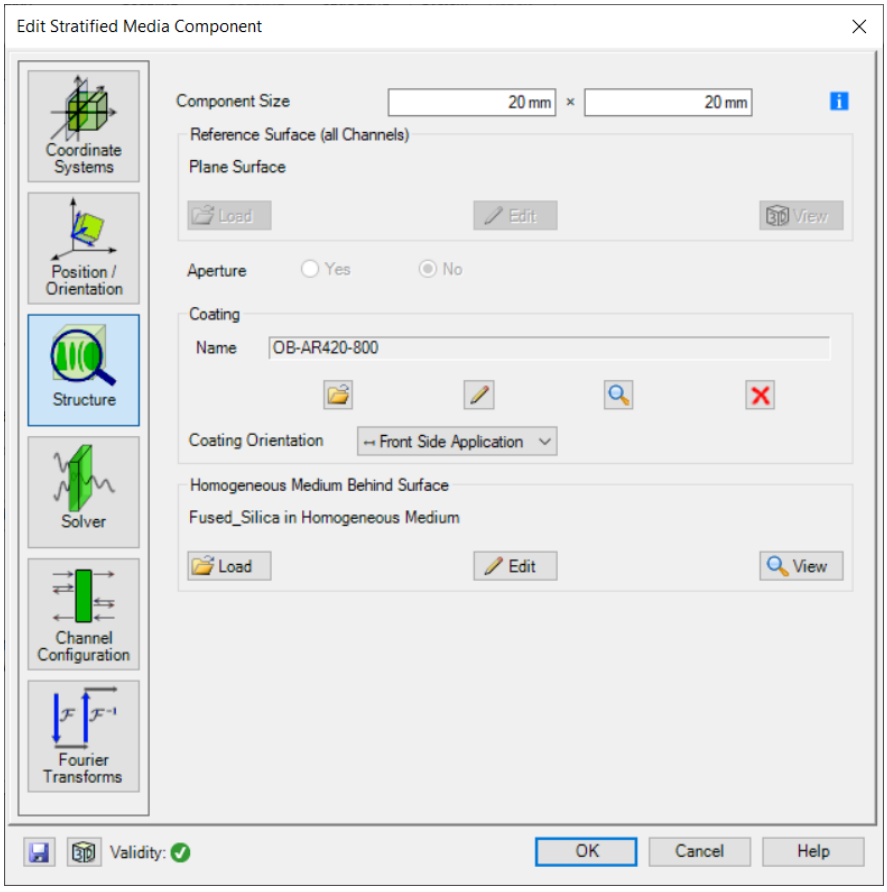


Figure 538. *The Structure tab of the edit dialog of the Stratified Media component.*

The Stratified Media component is intended for the rigorous and fast analysis of a sequence of plane layers each

followed by a homogeneous (isotropic or anisotropic) medium. The *Structure* tab of its edit dialog (↪Fig. 538) provides the following settings.

ITEM	DESCRIPTION
Component Size PV	In principle the Stratified Media component has an infinite lateral extension. However, as this is not feasible for the 3D view (↪Sec. 5.16) and the light path finder for manual channel configuration (↪Sec. 44.3.1), you can enter a *Component Size* here.
Reference Surface	Read-only control to show that the reference surface is a Plane Surface.
Aperture	Read-only control to show that the reference surface has an infinite lateral extension when simulated.
Coating PE	This control allows you to set the coating which stores the plane layers. ↪Sec. 34.2
Homogeneous Medium Behind Surface	This control (↪Sec. 34.1) allows you to configure the homogeneous medium PE behind the plane surface this component consists of.

The other tab pages are explained in Sec. 55.

60 Single Surface & Function Components

60.1 Functional Grating

Availability

Optical Setups: General Optical Setup

Accessible: Optical Setup: *Components > Functional Single Surface > Functional Grating*

The Functional Grating component analyzes an infinite periodic grating by directly defining the diffraction orders.

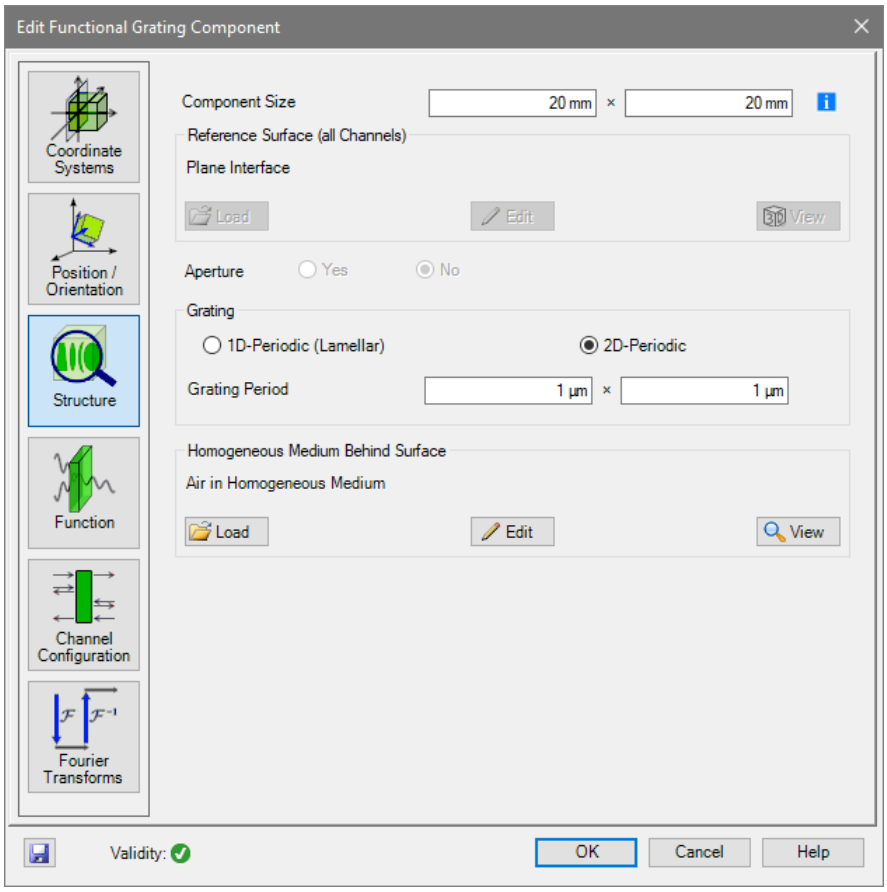


Figure 539. *The* Structure *tab of the Functional Grating component.*

On the *Structure* tab of the edit dialog of this component (↪Fig. 539) you can set the following.

ITEM	DESCRIPTION
Component Size PV	In principle the Grating Component has an infinite lateral extension. However, as this is not feasible for the 3D view (↪Sec. 5.16) and the light path finder for manual channel configuration (↪Sec. 44.3.1), you can enter a *Component Size* here.
Grating	Here you define the periodicity of the grating (*1D-Periodic (Lamellar)* or *2D-Periodic*) and the *Grating Period*.
Homogeneous Medium Behind Surface	For convenience you can set the homogeneous medium PE behind the component here which can also be done via the Optical Setup Editor (↪Sec. 44.2.1). This control is described in Sec. 34.1.

On the *Function* tab you can *Edit* which diffraction orders have which efficiency. This is done separately *For Illumination From Front Side* and *For Illumination From Back Side* using the control described in in Sec. 5.13.
On the *Channel Configuration > Grating Order Channels* sub-tab you then can define which these orders are considered for further simulation, separately *For Illumination From Front Side* and *For Illumination From Back Side*.
The remaining controls and tab pages are explained in Sec. 55.
In the Optical Setup View (↪Sec. 44.1), a Functional Grating has a specific context menu entry to convert it into a Grating (↪Sec. 61.3).

60.2 Functional Meta Lens

Availability

Optical Setups: General Optical Setup
(Only for General Profile or Ray Results Profile if Flat Lens Package is present.)

Accessible: Optical Setup: *Components > Functional Single Surface > Functional Meta Lens*

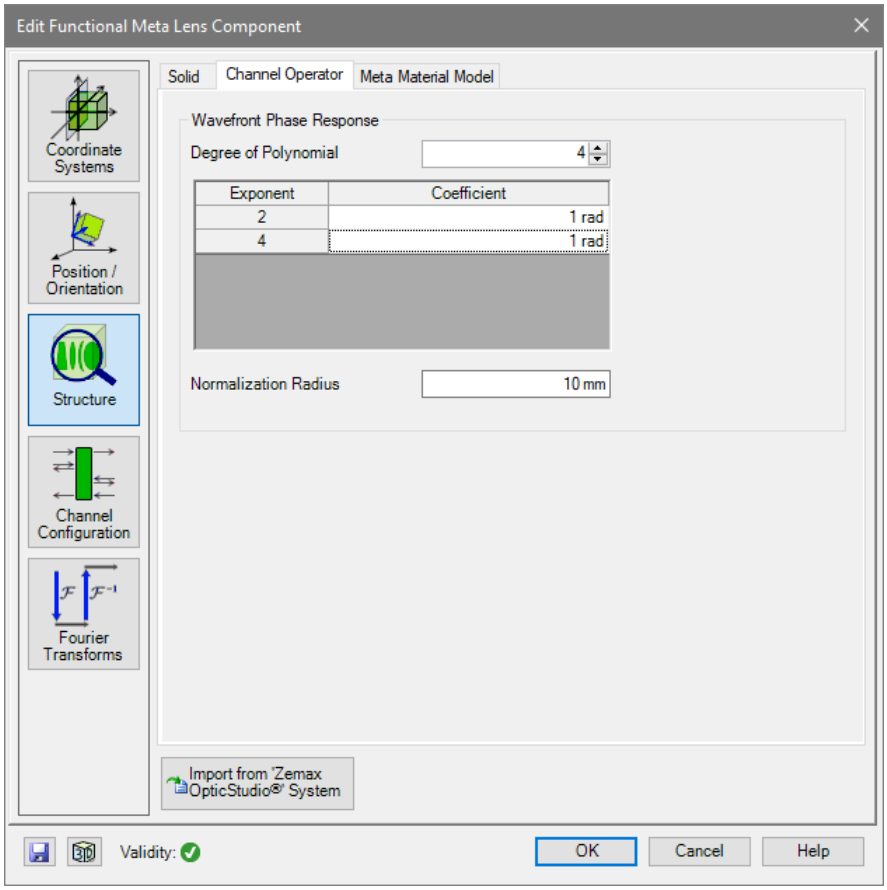


Figure 540. *The* Channel Operator *sub-tab of a Functional Meta Lens.*

A Functional Meta Lens consists of a single plane surface (↪Sec. 36.2.7) on which a *channel operator* describing a focusing meta material is applied. The structure tab of its edit dialog (↪Fig. 540) has three sub-tabs: the *Solid* sub-tab (↪Sec. 60.2.1), the *Channel Operator* sub-tab (↪Sec. 60.2.2), and the *Meta Material Model* sub-tab (↪Sec. 60.2.3).
Furthermore, this tab has a button *Import from 'Zemax OpticStudio®' System* to import a *Binary 2* surface into this component, ↪Sec. 131.3.
The remaining controls and tab pages are explained in Sec. 55.
In the Optical Setup View (↪Sec. 44.1), a Functional Meta Lens has a specific context menu entry to convert it into a Diffractive Lens (↪Sec. 61.2).

60.2.1 *Solid* Sub-Tab

The *Solid* sub-tab of the Functional Meta Lens component has the following controls.

ITEM	DESCRIPTION
Surface Specification	This control (↪Sec. 34.1) allows you to edit the plane surface[PE] this component consists of.
Homogeneous Medium Behind Surface	This control (↪Sec. 34.1) allows you to configure the homogeneous medium[PE] behind the surface.

60.2.2 *Channel Operator* Sub-Tab

The channel operator adds the following phase ϕ (in radians) to the phase of the incident light:

$$\phi = M \sum_i A_i \cdot \rho^{2i} \tag{60.1}$$

M is the index of the diffraction order, A_i the *Coefficient*[PV] of the i^{th} monomial, $2i$ is the *Exponent*, and ρ the normalized radius (the distance from the optical axis divided by the *Normalization Radius*[PV]).
The *Degree of Polynomial* sets the maximum exponent $2i$.

60.2.3 *Meta Material Model* Sub-Tab

This sub-tab defines whether the *Convergent Mode* and / or *Divergent Mode* are simulated assuming an idealized meta material.

60.3 Functional Modulated Metasurface

Availability

Optical Setups: General Optical Setup
(Only for General Profile or Ray Results Profile if Flat Lens Package is present.)

Accessible: Optical Setup: *Components > Functional Single Surface > Functional Modulated Metasurface*

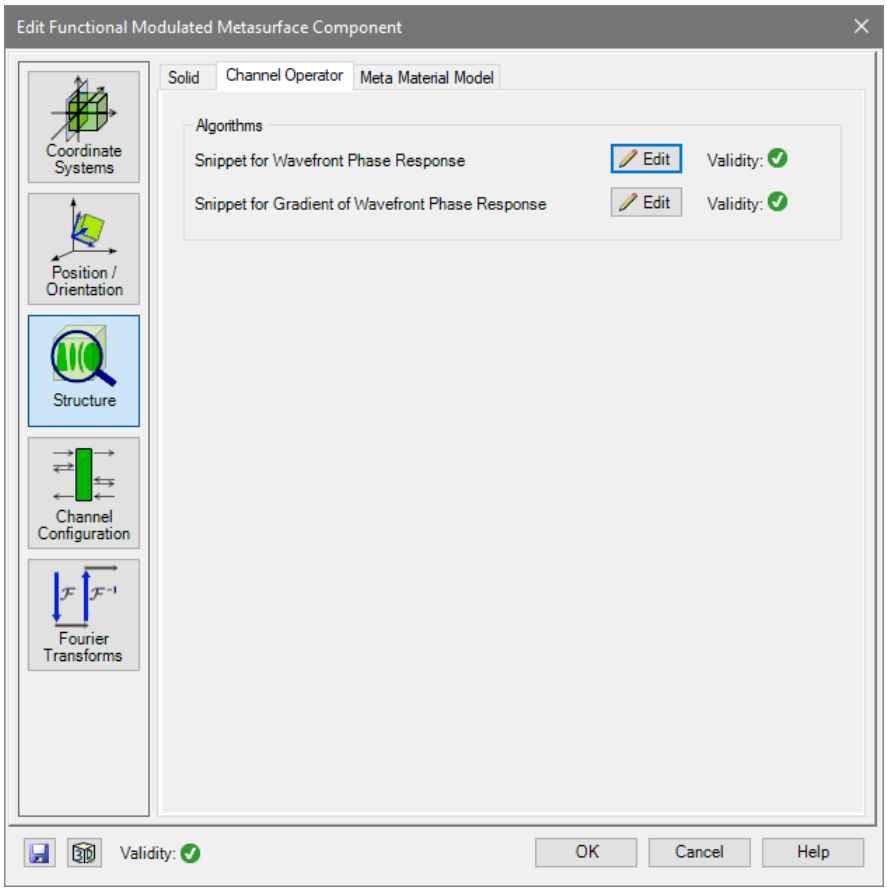


Figure 541. *The* Channel Operator *sub-tab of a Functional Modulated Metasurface.*

A Functional Modulated Metasurface consists of a single plane surface (↪Sec. 36.2.7) on which a programmable *channel operator* describing a metasurface hologram is applied. The structure tab of its edit dialog (↪Fig. 541) has three sub-tabs:

- the *Solid* sub-tab which is the same as for the Functional Meta Lens (↪Sec. 60.2.1)
- the *Channel Operator* sub-tab (↪Sec. 60.3.1) , and
- the *Meta Material Model* sub-tab (↪Sec. 60.3.2) .

The remaining controls and tab pages are explained in Sec. 55.
In the Optical Setup View (↪Sec. 44.1), a Functional Modulated Metasurface has a specific context menu entry to convert it into a Holographic Optical Element (↪Sec. 61.4).

60.3.1 *Channel Operator* Sub-Tab

You can program both the effect on the wavefront and the gradient of the wavefront using the corresponding *Edit* button which opens the Source Code Editor (↪Sec. 7.3). A validity indicator (↪Sec. 5.11) shows whether this snippet is consistent.

60.3.2 *Meta Material Model* Sub-Tab

This sub-tab defines whether the *Design Mode* and / or its *Conjugate Mode* are simulated assuming an idealized meta material.

61 Single Surface & Stack Components

61.1 Diffractive Optical Element (DOE) / Microstructure

Availability

Optical Setups: General Optical Setup (Only for General Profile and Ray Results Profile.)

Accessible: Optical Setup: *Components > Single Surface & Stack > Diffractive Optical Element (DOE) / Microstructure*

This component is listed under two names (*Diffractive Optical Element (DOE)* and *Microstructure*) for convenience.

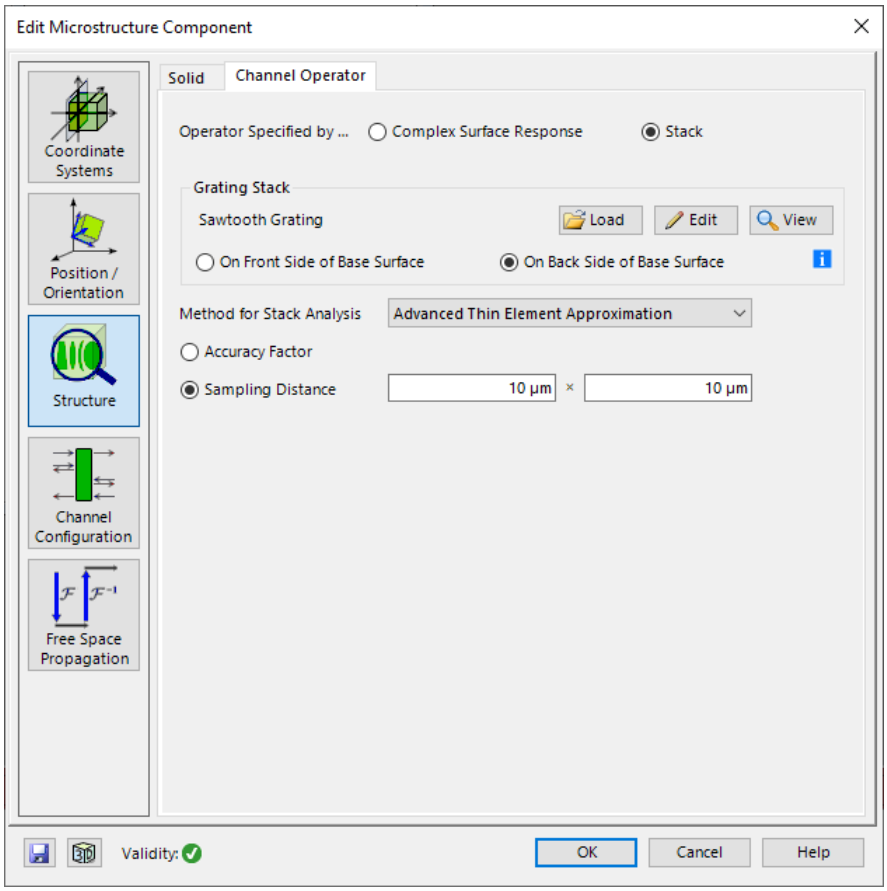


Figure 542. *The* Channel Operator *sub-tab of a Microstructure.*

Such a component consists of a single plane surface (↪Sec. 36.2.7) on which a *channel operator* describing a microstructure is applied. The structure tab of its edit dialog (↪Fig. 542) has two sub-tabs:

- the *Solid* sub-tab (↪Sec. 61.1.1)
- the *Channel Operator* sub-tab (↪Sec. 61.1.2) .

The remaining controls and tab pages are explained in Sec. 55.

In the Optical Setup View (↪Sec. 44.1), a Microstructure has specific context menu entries to convert it into other component types (↪Sec. 56).

61.1.1 *Solid* Sub-Tab

The *Solid* sub-tab of the Microstructure Component has the following controls.

ITEM	DESCRIPTION
Surface Specification	This control (↪Sec. 34.1) allows you to edit the plane surface[PE] this component consists of.
Homogeneous Medium Behind Surface	This control (↪Sec. 34.1) allows you to configure the homogeneous medium[PE] behind the surface.

61.1.2 *Channel Operator* Sub-Tab

The microstructure can be defined as ideal structure (*Complex Surface Response*) or as real structure (*Stack*). If defined as transmission, you can use the following controls:

ITEM	DESCRIPTION
Set	Sets the desired Jones Matrix Transmission. When you click on this button you can do the following: • *Load* a Jones Matrix Transmission from a .ca2 file. • *Select from Documents* allows you to select an already open Jones Matrix Transmission. • *Reset* the data to the default transmission.
Show	Shows the Complex Amplitude document containing the currently set transmission.
Interpolation Method	You can decide whether a *Continuous* or a *Pixelated* interpolation is used to interpolate the given data.

If defined as stack, you can use the following controls:

ITEM	DESCRIPTION
Stack[PE]	Configures a stack with one or more micro-structured surfaces and displays its name. You can *Load* another stack from the catalog (↪Sec. 33). Furthermore, you can *Edit* the current stack (↪Sec. 40.2) or *View* it.
On Front Side of Base Surface	If checked it is assumed that the stack is placed on the front side of the base surface. This means that in comparison to its normal orientation it is rotated by 180° about the y-axis and thus points against the optical axis. Sec. 40.1.2 shows an example.
On Back Side of Base Surface	If checked it is assumed that the stack is placed on the back side of the base surface. This means that it is used in its normal orientation.
Method for Stack Analysis	The propagation method used for the stack analysis. In contrast to *Thin Element Approximation*, the *Advanced Thin Element Approximation* additionally can handle parabasal effects and absorption.
Accuracy Factor[PV]	The accuracy factor used for the propagation through the stack, separately for x- and y-direction.
Sampling Distance[PV]	Instead of the *Accuracy Factor* you can also specify directly the used sampling distance for x- and y-direction.

61.2 Diffractive Lens

Availability

Optical Setups: General Optical Setup
(Only for General Profile or Ray Results Profile if Flat Lens Package is present.)

Accessible: Optical Setup: *Components > Single Surface & Stack > Diffractive Lens*

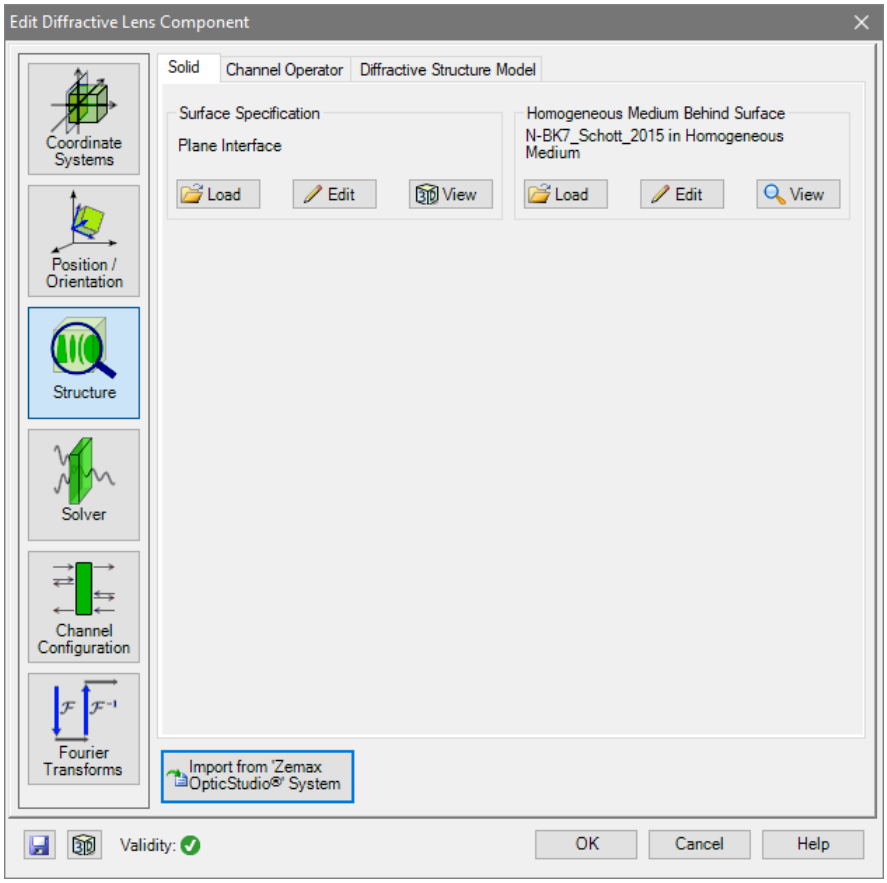


Figure 543. *The* Solid *sub-tab of a Diffractive Lens.*

A Diffractive Lens consists of a single plane surface (↪Sec. 36.2.7) on which a *channel operator* describing a diffractive focusing structure is applied. The structure tab of its edit dialog (↪Fig. 543) has three sub-tabs: the *Solid* sub-tab (↪Sec. 61.2.1), the *Channel Operator* sub-tab (↪Sec. 61.2.2), and the *Diffractive Structure Model* sub-tab (↪Sec. 61.2.3).
Furthermore, this tab has a button *Import from 'Zemax OpticStudio®' System* to import a *Binary 2* surface into this component, ↪Sec. 131.3.
The other tab pages are explained in Sec. 55.
In the Optical Setup View (↪Sec. 44.1), a Diffractive Lens has a specific context menu entry to convert it into a Functional Meta Lens (↪Sec. 60.2). A Diffractive Lens in *Real Structure* mode (↪Sec. 61.2.4.1) can additionally be converted into a Microstructure (↪Sec. 61.1).

61.2.1 *Solid* Sub-Tab

The *Solid* sub-tab of the Diffractive Lens component (↪Fig. 543) has the following controls.

ITEM	DESCRIPTION
Surface Specification	This control (↪Sec. 34.1) allows you to change the surface[PE] this component consists of.
Homogeneous Medium Behind Surface	This control (↪Sec. 34.1) allows you to configure the homogeneous medium[PE] behind the surface.

61.2.2 *Channel Operator* Sub-Tab

The channel operator adds the following phase ϕ (in radians) to the phase of the incident light:

$$\phi = M \sum_i A_i \cdot \rho^{2i} \tag{61.1}$$

M is the index of the diffraction order, A_i the *Coefficient*[PV] of the i^{th} monomial, $2i$ is the *Exponent*, and ρ the normalized radius (the distance from the optical axis divided by the *Normalization Radius*[PV]).
The *Degree of Polynomial* sets the maximum exponent $2i$.

61.2.3 *Diffractive Structure Model* Sub-Tab

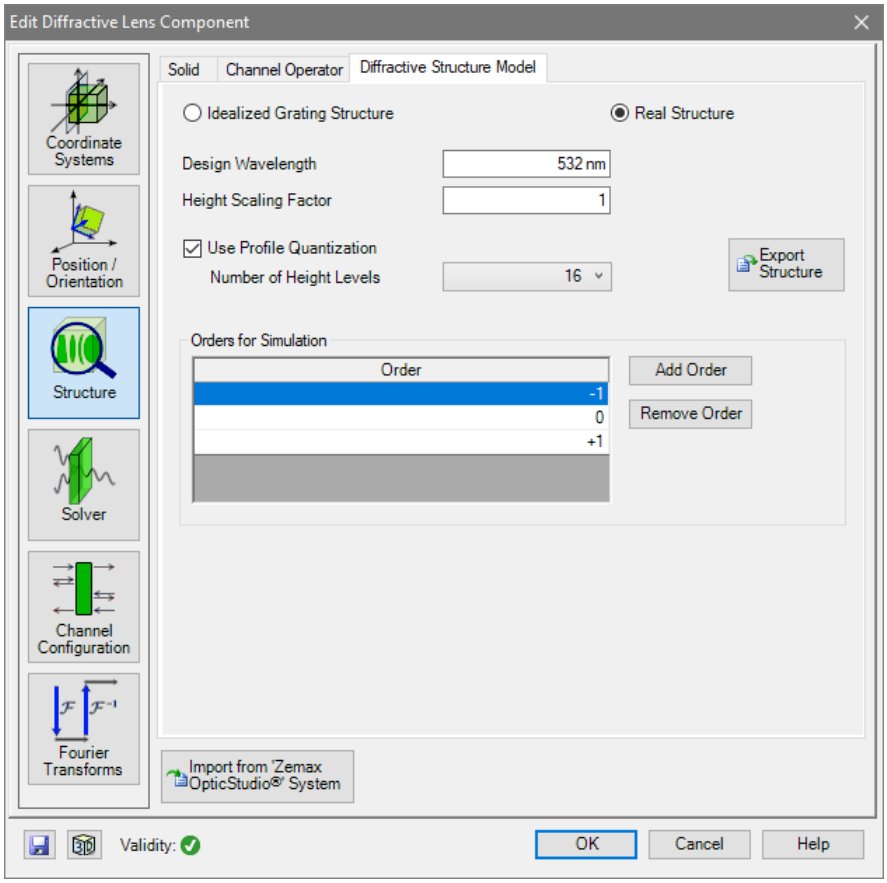


Figure 544. *The* Diffractive Structure Model *sub-tab of a Diffractive Lens if a* Real Structure *is assumed.*

Whereas the *Channel Operator* sub-tab defines the phase and thus the direction of the single diffraction orders, the *Diffractive Structure Model* (↪Fig. 544) defines the efficiencies of the diffraction orders. This can be done assuming either an *Idealized Grating Structure* (↪Sec. 61.2.4) or a *Real Structure* (↪Sec. 61.2.4.1).

61.2.4 Efficiencies from Idealized Grating Structure

In case of an *Idealized Grating Structure* you simply define the *Efficiency*[PV] per *Order* in a table. The table rows are sorted automatically by the *Order* number. With buttons you can add a new order to the end of the table or remove the currently selected order from the table.

61.2.4.1 Efficiencies from Real Structure

A *Real Structure* can be defined with the following controls (↪Fig. 544):

ITEM	DESCRIPTION
Design Wavelength[PV]	The (vacuum) wavelength used for the translation from the wavefront defined on the *Channel Operator* tab to a height profile.
Height Scaling Factor[PV]	Allows you to alter the modulation depth of the overall structure to change the efficiencies of the distinct orders.
Use Profile Quantization	If you check this option the diffractive structure is quantized according to the *Number of Height Levels*.
Export Structure	ONLY AVAILABLE IF *USE PROFILE QUANTIZATION* IS CHECKED. Allows you to export the diffractive structure into various file formats using the dialog described in Sec. 133.2.
Orders for Simulation	Allows you to define which of the diffractive orders is used for simulation. All other orders are suppressed to improve simulation performance and to get clearer results.

The structure is then analyzed by means of the Thin Element Approximation (↪Sec. 97.2) if the local grating period is larger than 5 times the wavelength. Otherwise the Fourier Modal Method (↪Sec. 97.3) is used.

61.3 Grating

Availability

Optical Setups: General Optical Setup
(Only for General Profile or Ray Results Profile if VirtualLab Fusion Advanced is present.)

Accessible: Optical Setup: *Components > Single Surface & Stack > Grating*

The Grating component analyzes an infinite periodic grating rigorously by means of the FMM / RCWA solver (↪Sec. 97.3).

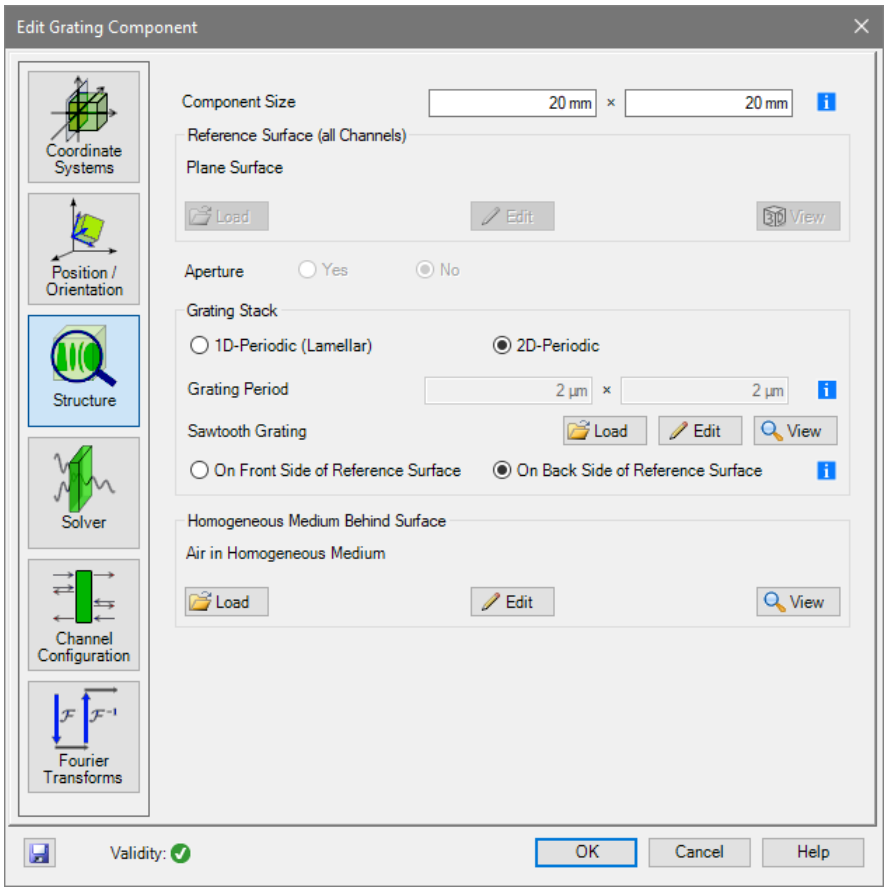


Figure 545. *The* Structure *tab of the Grating component.*

On the *Structure* tab of its edit dialog (↪Fig. 545) you can set the following.

ITEM	DESCRIPTION
Component Size PV	In principle the Grating Component has an infinite lateral extension. However, as this is not feasible for the 3D view (↪Sec. 5.16) and the light path finder for manual channel configuration (↪Sec. 44.3.1), you can enter a *Component Size* here.
Grating Stack	Here you first define the periodicity of the grating (*1D-Periodic (Lamellar)* or *2D-Periodic*), then the optical stack (↪Sec. 40) describing the grating. To this end the control described in Sec. 34.1 is used. Additionally you can define the orientation of the grating stack, i. e. whether it is placed *On Front Side of Reference Surface* or *On Back Side of Reference Surface*.
Homogeneous Medium Behind Surface	For convenience you can set the homogeneous medium PE behind the component here which can also be done via the Optical Setup Editor (↪Sec. 44.2.1). This control is described in Sec. 34.1.

On the *Channel Configuration > Grating Order Channels* sub-tab you can define which orders are considered for further simulation, separately *For Illumination From Front Side* and *For Illumination From Back Side*.
The efficiencies of the simulated orders are calculated by the FMM / RCWA solver PE (↪Sec. 97.3). You can *Edit* it on the *Solver* tab. On the *Solver > Sampling* sub-tab you can set the *Number of Sampling Points for Look-Up Table*, which means for how many incident directions efficiencies are calculated rigorously.

The other tab pages are explained in Sec. 55. In the Optical Setup View (↪Sec. 44.1), a Grating has specific context menu entries to convert it into other component types (↪Sec. 56).

Note that for simulations the thickness of the stack is ignored, a phase term e^{ikz} with z being the thickness of the stack is **not** applied.

61.4 Holographic Optical Element

Availability

Optical Setups: General Optical Setup
(Only for General Profile or Ray Results Profile if Flat Lens Package is present.)

Accessible: Optical Setup: *Components > Single Surface & Stack > Holographic Optical Element*

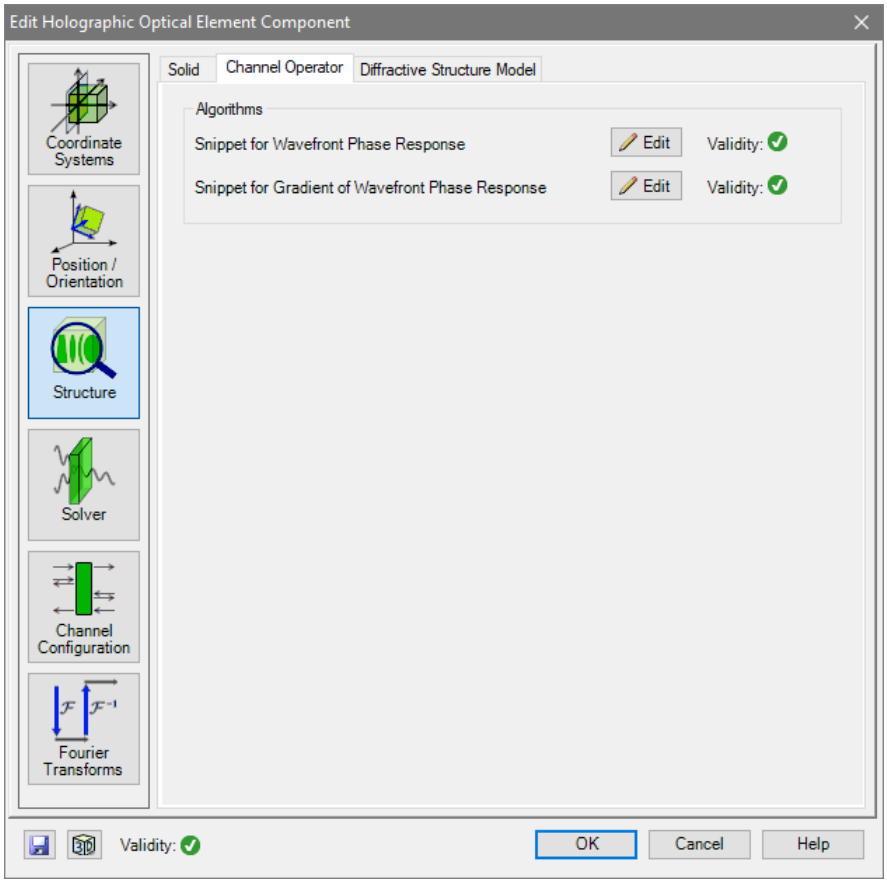


Figure 546. *The Channel Operator sub-tab of a Holographic Optical Element.*

A Holographic Optical Element consists of a single plane surface (↪Sec. 36.2.7) on which a programmable *channel operator* describing a hologram is applied. The structure tab of its edit dialog (↪Fig. 546) has three sub-tabs:

- the *Solid* sub-tab which is the same as for the Diffractive Lens (↪Sec. 61.2.1),
- the *Channel Operator* sub-tab (↪Sec. 61.4.1), and
- the *Diffractive Structure Model* sub-tab which is the same as for the Diffractive Lens (↪Sec. 61.2.3) .

The other tab pages are explained in Sec. 55.
In the Optical Setup View (↪Sec. 44.1), a Holographic Optical Element has a specific context menu entry to convert it into a Functional Modulated Metasurface (↪Sec. 60.3).

61.4.1 *Channel Operator* Sub-Tab

You can program both the effect on the wavefront and the gradient of the wavefront using the corresponding *Edit* button which opens the Source Code Editor (↪Sec. 7.3). A validity indicator (↪Sec. 5.11) shows whether this snippet is consistent.

61.5 Microlens Array

The *Microlens Array* component supports the specification of a microlens array using a reference surface and a stack. The stack is used to define the structure per period. In addition to the configuration for the structure, the component comes with an advanced channel handling. It supports a lateral channel decomposition, which means per illuminated microlens, a channel mode is generated, which is propagated through the subsequent system. The user can specify some additional options, which are also described within this chapter.

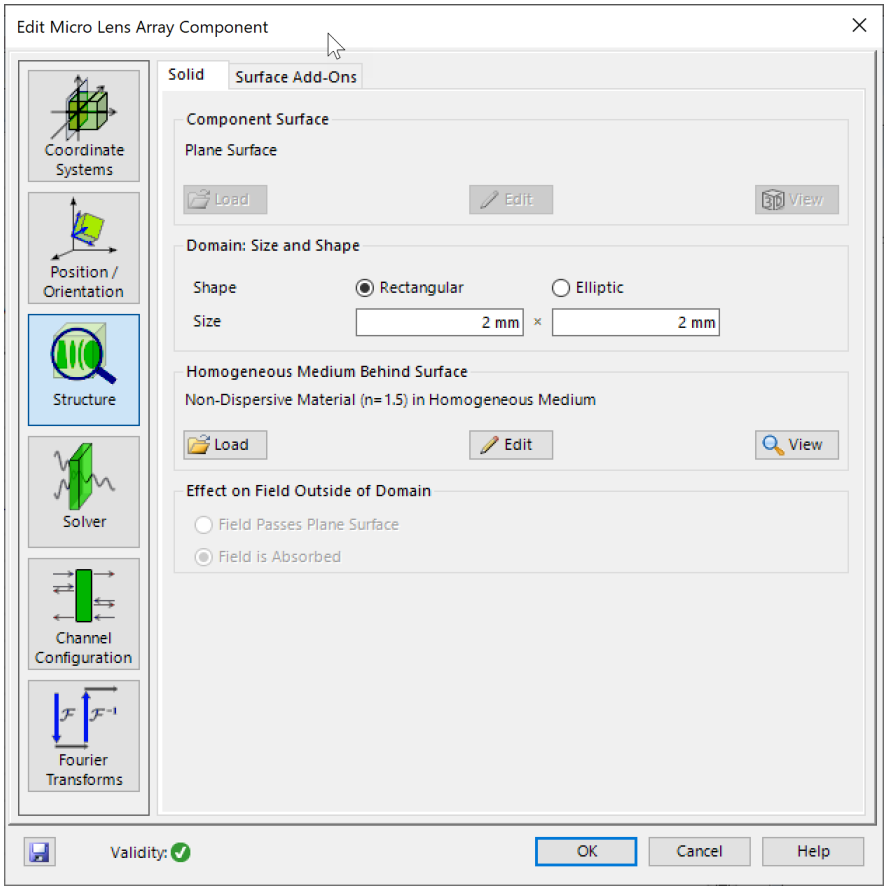


Figure 547. *The Solid page of the edit dialog of the Microlens Array component.*

Fig. 547 shows the solid page (on the structure slider) of the Microlens Array component. The following parameters can be specified by the user:

ITEM	DESCRIPTION
Component Surface	The microlens array structure is defined on a reference surface. Currently only plane reference surfaces are supported. This control is currently read-only.
Domain: Size and Shape	The user can specify the size of the domain / reference surface. The user can select between rectangular and elliptical shape.
Medium behind Surface	The medium specification after the surface / microlens array can be configured in this section of the dialog.
Effect on Field Outside of Domain	If light hits the component and is larger than the size of the domain of the component, it needs to be decided how the field outside is handled. In general blocking or passing is supported. In the current version of VirtualLab Fusion only blocking aperture is supported.

Next to the specification of the reference surface (and its domain) the user can define the surface add-ons on the corresponding tab page.

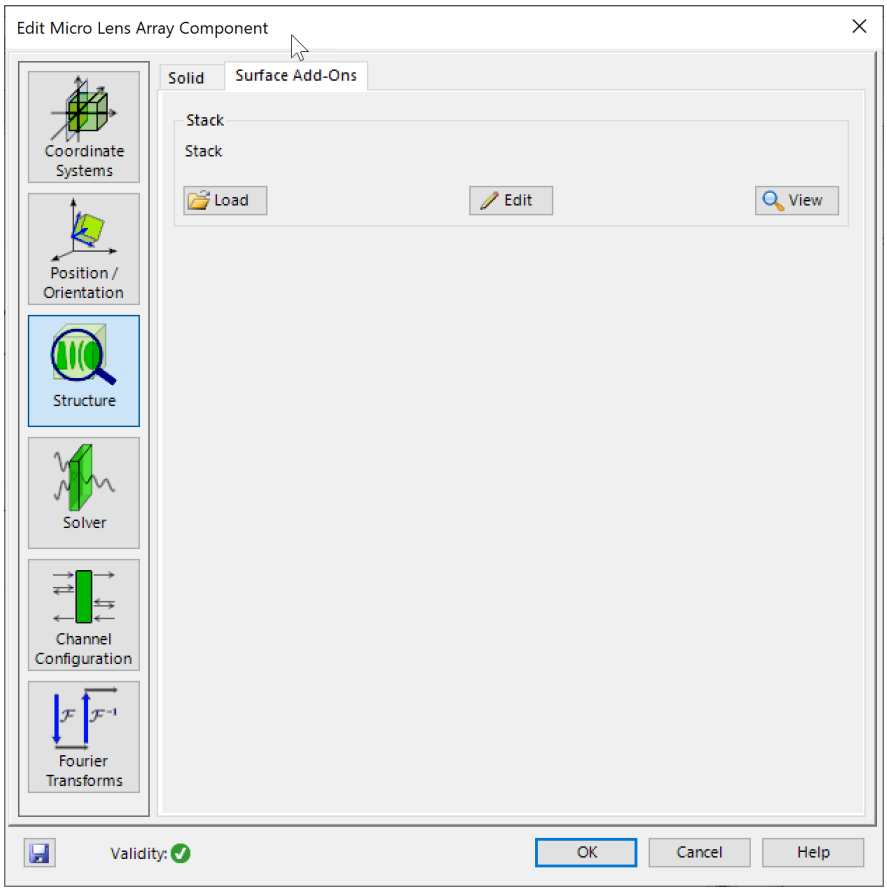


Figure 548. *The Surface Add-On page of the edit dialog of the Microlens Array component.*

Fig. 548 shows the location, where the user can specify the surface add-on. In this case we support the specification of a stack. The period of the stack is used to define the period of the microlens array. The stack should only contain one surface (at least in current implementation). It is recommended that the stack period and the period of the surface in the stack are defined synchronously.

In addition to the structure definition, the component supports an advanced channel configuration.
On the *Channel Configuration* page the following sub-pages are available:

PAGE	DESCRIPTION
Master Channels	On this page the user can specify the master channels that shall be used for field tracing (surface channels for +/+, +/-, -/+, and -/-).
Sub-Channels: x-Domain	Here the user can define the handling for the sub-channels in x-domain.
Sub-Channels: k-Domain	Here the user can define the handling for the sub-channels in k-domain.
Region Boundary Management	For the channels (master and sub-channels) the user can specify aperture settings in this section of the dialog.
Channel Mode Management	If the channel decomposition is activated there are several channel mode selection options, which can be selected/configured on this page.

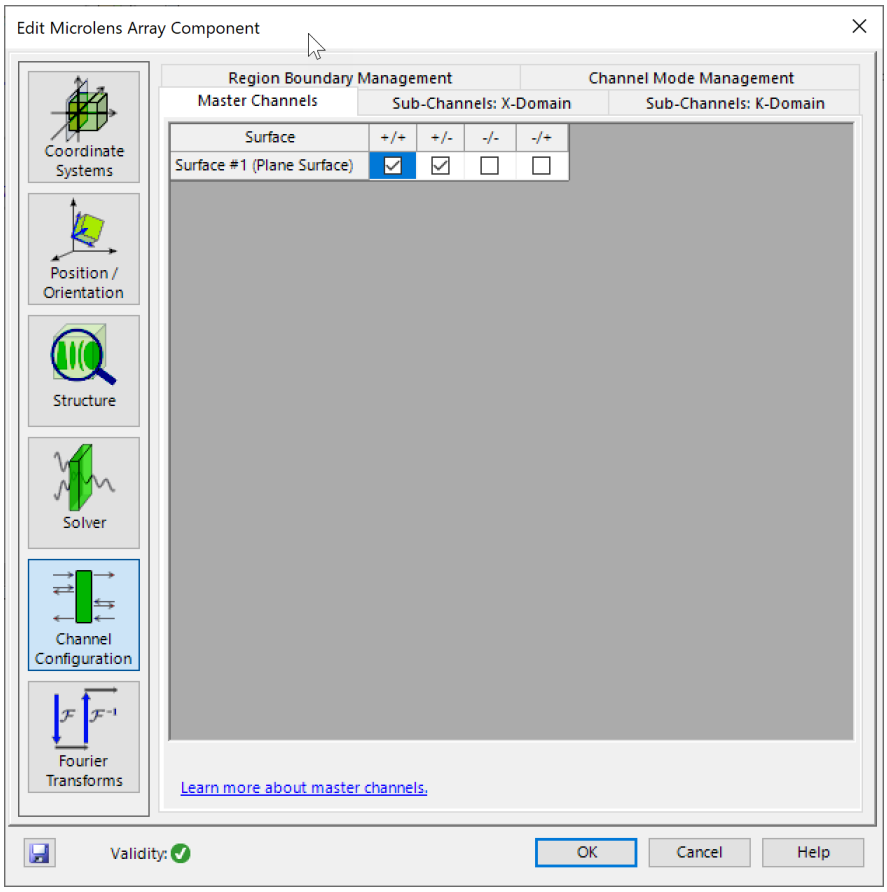


Figure 549. *The Master Channel page of the edit dialog of the Microlens Array component.*

Fig. 549 shows the table to configure the master/surface channels of the Microlens Array component. The configuration is the same as for all other components in VirtualLab Fusion. For the surface (here only one) the plus-plus, plus-minus, minus-minus and minus-plus channel can be opened or closed. This information will be evaluated by the light path finder. In case of pre-configured channel configuration the table is read-only and filled automatically from the system configuration.

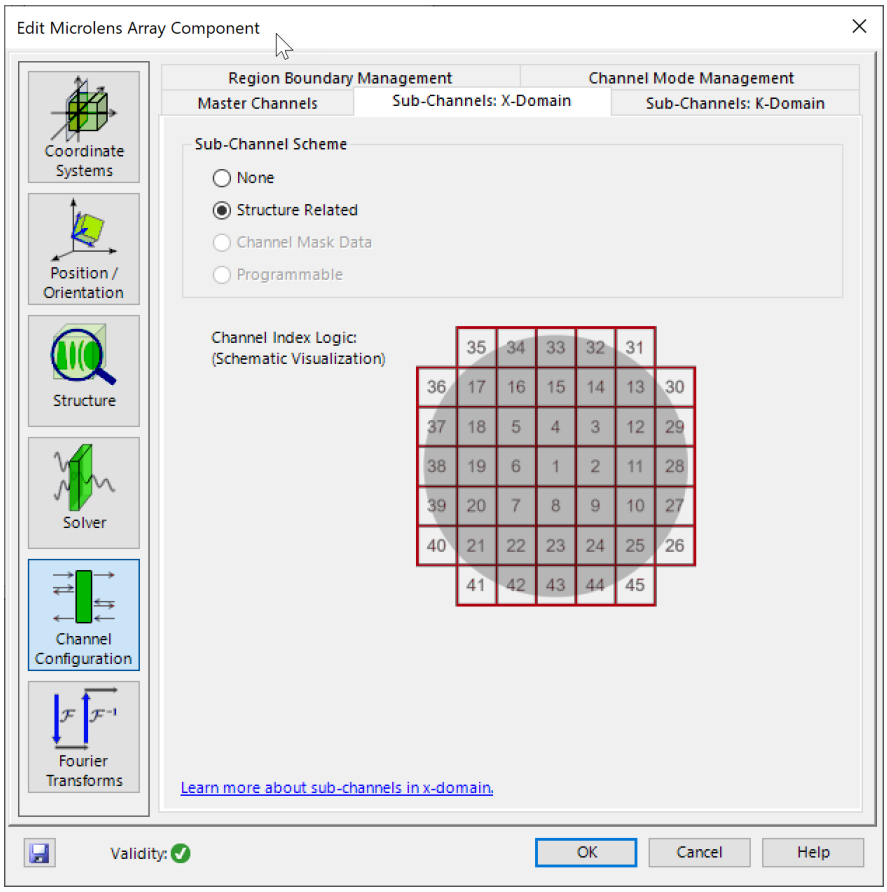


Figure 550. *The* Sub-Channel: X-Domain *page of the edit dialog of the Microlens Array component.*

Fig. 550 shows the tab page for the configuration of the sub-channels in x-domain.
The following options can be selected from the user:

PAGE	DESCRIPTION
None	If *None* mode is selected no channel decomposition will be performed. VirtualLab Fusion has a build-in channel decomposition, which is applied if a pointwise sequence is terminated and the mesh of the input field is non-bijective.
Structure-Related	In case of *Structure-Related* channel decomposition, the information of the sub-channels is extracted from the structure (in case of the microlens array the periodic rectangular cells of the stack on the size of the surface domain). If this option is selected a well-defined index logic (in form of a slug) is used to enumerate the channels. On the bottom of the page a schematic scheme is displayed to visualize the index logic of the channels.
Channel Mask Data	The user can also specify the channel mask for decomposition as a set of masks (regions). In this case the region information is used for the channel decomposition. This option is not available in current implementation.
Programmable	Alternatively the user can implement the channel mask using the VirtualLab Fusion snippet technology. This option is not available in current implementation.

On the *Sub-Channels: k-Domain* page there are several options for the channel decomposition in k-domain.

This is not available for the Microlens Array and all options are disabled. This is a preparation for further components that perform a channel decomposition in k-domain (and x-domain).
On the *Region Boundary Management* page there are several numerical parameters available to define the aperture handling of the master and the subchannel.

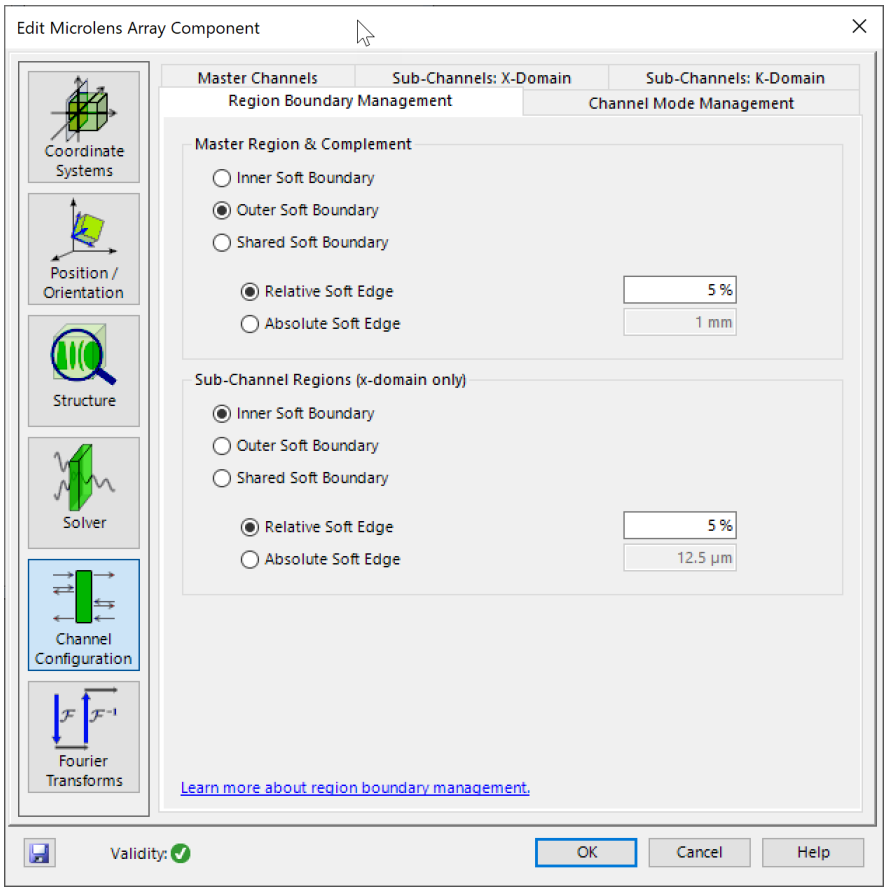


Figure 551. *The* Region Boundary Management *page of the edit dialog of the Microlens Array component.*

Fig. 551 shows the tab page for the configuration region boundary/aperture settings of the Microlens Array component. The tab page is divided into two parts:

REGION	DESCRIPTION
Master Region & Component	In this section the user can specify the parameters for the soft edge for the master region. The size of the master region is defined on the *Solid* page of the component. The user can define the location of the edge. The edge can be configure as *Inner Soft*, *Outer Soft* or *Shared Soft* edge. In addition the user needs to specify the size of the edge. This configuration can be done by specification of *Relative* or *Absolute* edge width.
Sub-Channel Regions	In this section the user can specify the parameters for the soft edge for the sub-regions (x-domain). The size of the sub-regions is implicitly defined by the period of the stack (for *Structure-Related* channel definition). The user can define the location of the edge. The edge can be configure as *Inner Soft*, *Outer Soft* or *Shared Soft* edge. In addition the user needs to specify the size of the edge. This configuration can be done by specification of *Relative* or *Absolute* edge width.

On the last page of the *Channel Configuration* main section of the edit dialog of the Microlens Array component the user has the option to specify the way how the evaluated channels are handled.

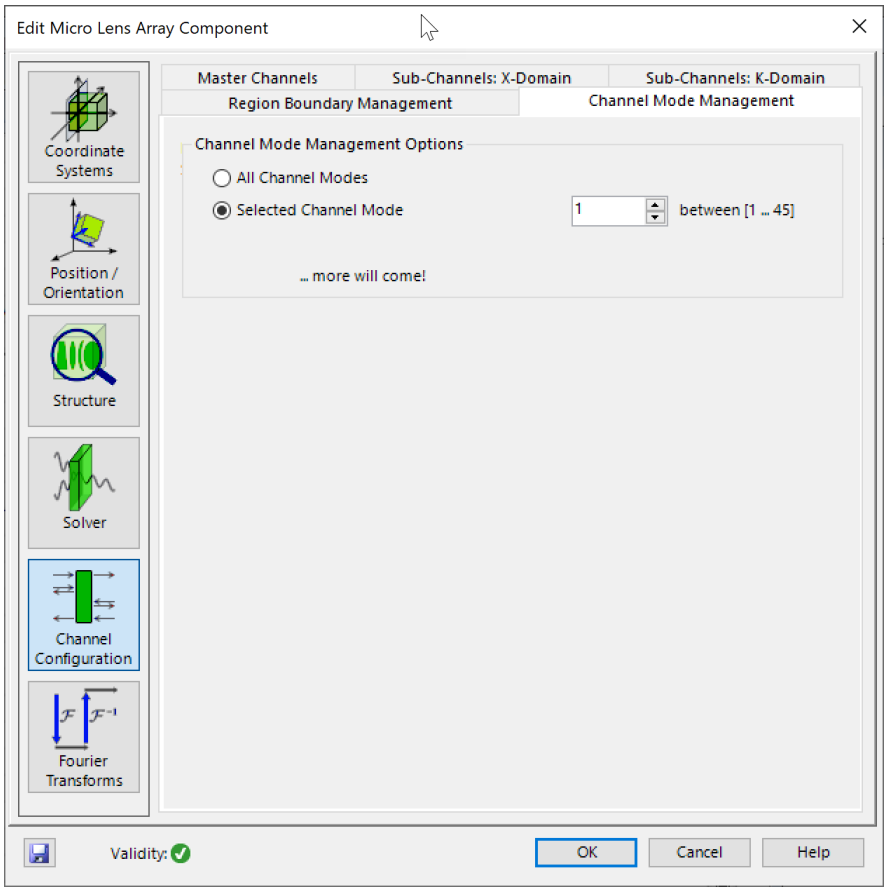


Figure 552. *The* Channel Mode Management *page of the edit dialog of the Microlens Array component.*

For the channel mode management the following options are currently available:

REGION	DESCRIPTION
All Channel Modes	If this option is selected, all channels, that are illuminated by the incident light will be processed as output modes. This might be the most consistent specification, but can be lead also to high numerical effort, because depending on the size of the incident light and the size of the channels a high number of channels might be generated.
Selected Channel Mode	In addition we also support the processing of one selected channel mode only. The channel mode that should be processed is selected by index of the channel. The index logic for *Structure-Related* channel definition is visualized (schematic) on the *Sub-Channels: x-Domain* tab page.

For the channel mode management more options will be added in future.

62 Programmable Component

Availability

Optical Setups: General Optical Setup & Light Guide Optical Setup

Accessible: Optical Setup: *Components > Programmable Component*

This component allows the user to define an own propagation through a user defined component, more precisely

to manipulate the incoming field in an arbitrary way. This can be done by programming so called *snippets*, which is some source code to be written by the user in C#.
Furthermore, there is complete freedom for positioning a Programmable Component, i. e. the reference coordinate systems (↪Sec. 44.9) as well as the input transface (↪Sec. 94.1) can be defined by the user.

62.1 Geometry of a Programmable Component

The geometry of a Programmable Component has to be defined by the user, so its definition is completely different from that of other real components. Every building block like optical surfaces, media and so on has to be defined as so called *Global Parameter* inside the source code editor. Even though there are three different kinds of snippets (described below in Sec. 62.2), each global parameter will be accessible from within each of the snippets, no matter where it has been defined first. For more information regarding the general use of snippets and the source code editor, please see Sec. 7.3.

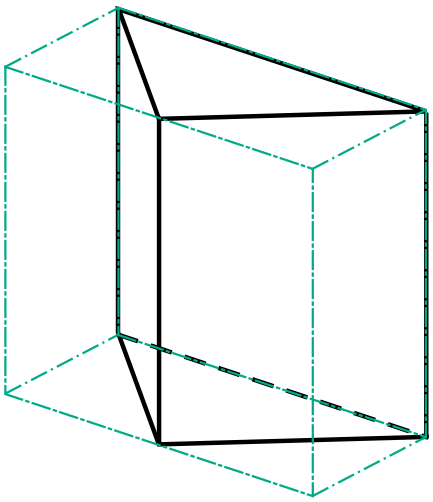


Figure 553. *Example for the bounding box of a prism.*

Since the geometry is defined by the user, there is no preview available for this kind of component. But it may be useful, mainly for the positioning (↪Sec. 62.3), to define a bounding box which is a cuboid meant to circumscribe the whole component (↪Fig. 553). It can be defined in the panel *Bounding Box* on page *Structure* of the edit dialog of the Programmable Component (↪Fig. 554).

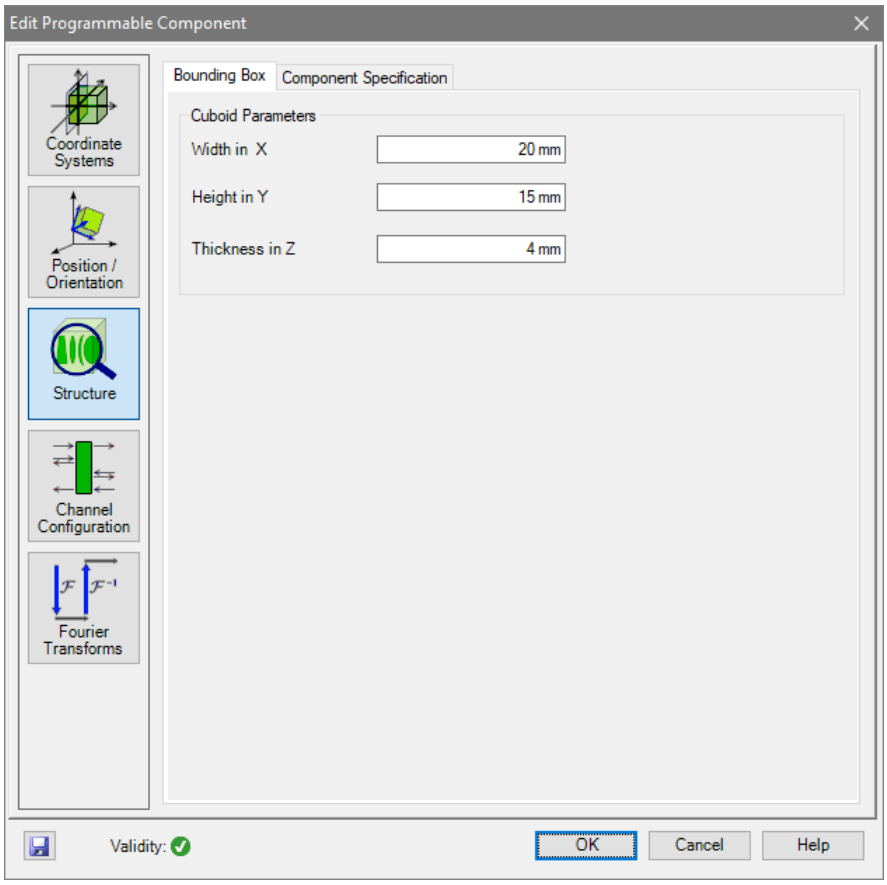


Figure 554. *The input controls for the bounding box of a Programmable Component.*

ITEM	DESCRIPTION
Width in X	Width of the bounding box.
Height in Y	Height of the bounding box.
Thickness in Z	Thickness of the bounding box, may be zero.

Note

The *Bounding Box* will have no effect for the propagation through the component or for any of its functionality. It serves two helpful purposes only. If the box is defined adequately, it allows to get an impression of the components dimensions inside the 3D view of the complete Optical Setup (↪Fig. 555). And it provides the positions of the two default reference points (↪Sec. 62.3): one is situated in the center of the front side of the bounding box and one in the center of the box's back side.

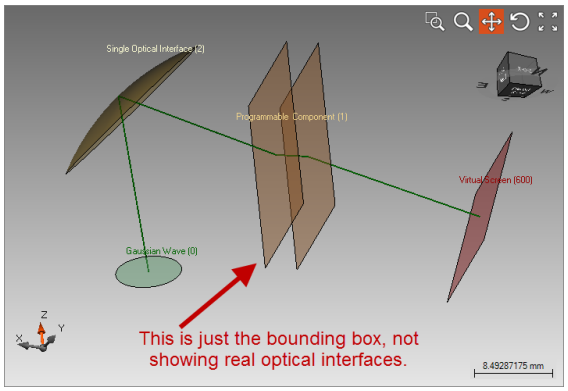


Figure 555. *Example for viewing the bounding box of a Programmable Component in the system's 3D view.*

62.2 Propagating through a Programmable Component

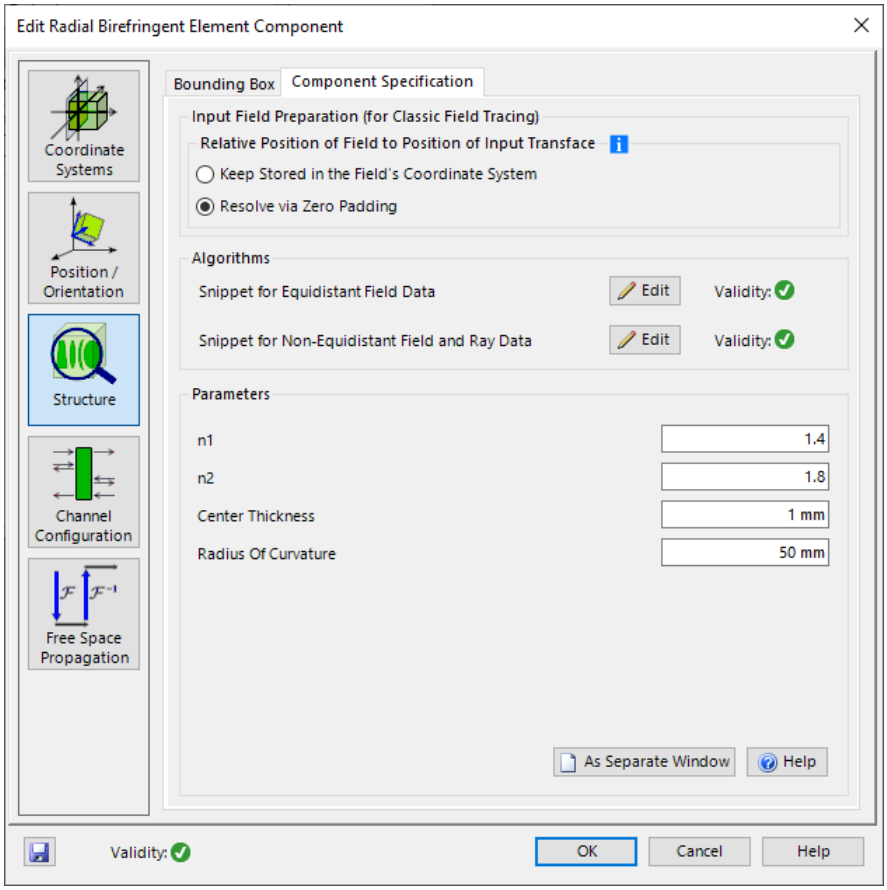


Figure 556. *The controls for defining the propagation through a Programmable Component.*

Defining the propagation through a Programmable Component requires the following controls which can be found on the tab page *Structure > Component Specification* (↪Fig. 556).

ITEM	DESCRIPTION
Relative Position of Field to Position of Input Transface	The field reaching the Programmable Component is always rotated into the *Input Transface* plane. But if the option *Resolve via Zero Padding* is checked, equidistant field data will be also padded into zeros in a way that the new origin of the field's coordinate system will be identical to that of the input transface. If the option *Keep Stored in the Field's Coordinate System* is chosen, no additional preparation will be done.
Snippet for Equidistant Field Data	The snippet defining the effect of the Programmable Component on the input field if equidistant field data enters the component. This always happens if the system is analyzed with Classic Field Tracing. *Edit* opens the Source Code Editor (↪Sec. 7.3), and a validity indicator (↪Sec. 5.11) shows whether this snippet is consistent. ↪Sec. 62.2.1
Snippet for Non-Equidistant Field and Ray Data	The snippet defining the effect of the Programmable Component on the input field if non-equidistant data enters the detector. This always happens if the system is analyzed with General Profile or Ray Results Profile. *Edit* opens the Source Code Editor (↪Sec. 7.3), and a validity indicator (↪Sec. 5.11) shows whether this snippet is consistent. ↪Sec. 62.2.2
Parameters PE	The controls in this group box allow you to set the values of the global parameters of the snippets. ↪Sec. 7.4

Programmable Components might be set to a mode where the source code cannot be changed and thus the *Input Field Preparation* and the *Algorithms* groupboxes are hidden.

More general information about programming in VirtualLab Fusion can be found in Sec. 7.

62.2.1 Snippet for Equidistant Field Data

Here, the effect of the Programmable Component on the `InputField` has to be programmed. This field is represented by a `HarmonicFieldsSet` inside the snippet. This kind of object may contain several single harmonic fields which can e. g. represent field data for different wavelengths. They are accessible via `InputField[0]`, `InputField[1]`, and so on.

The code in this snippet may contain any manipulation of the field. Especially, it has to describe the propagation of the field from the *Input Transface* of the Programmable Component to its *Output Transface*, including free space propagations and rotations as well as every effect caused by the building blocks of the element's geometry like surfaces and media. Input and Output Transface are the "*trans*fer inter*faces*" where the field is taken from the free space propagation operator before and given to the free space propagation operator behind the element, respectively. For more information about this concept have a look at Sec. 94.1.

62.2.2 Snippet for Non-Equidistant Field and Ray Data

Within the Optical Setup the Programmable Component has no well defined geometry because it is fixed within the source code. So the user has the possibility to implement how an `InputRay` is manipulated by the programmable component.

The user can specify the following parameters for each ray:

- Position

- Direction
- Optical Path Length / Absolute Phase
- Absorption
- Wavefront Surface Response
- Field Scaling Values
- Complex Surface Response
- Coherent Index

This snippet is used if the system is evaluated with either the *General Profile* or the *Ray Results Profile* engine. It is also used for the evaluation of optical path lengths of a system within pulse simulations.
The default implementation of this snippet defines that there is no effect on the incident ray. The user can define any method to modify the parameters of the ray but he is responsible that the implementation of the *Snippet for Equidistant Field Data* and the *Snippet for Non-Equidistant Field and Ray Data* provide the correct functionality.

62.3 Positioning a Programmable Component

As every other component, a programmable one is positioned via reference coordinate systems, defining relative positions and orientations. For more information about these concepts see Sec. 44.9. Here, the definition of user defined reference points and reference coordinate systems, available only for the Programmable Component, is described.

62.3.1 User-Defined Reference Points

There are always two predefined Reference Points for every Programmable Components which can neither be changed nor removed. These Reference Points lie in the center of the front and the back side of the Bounding Box. So every reference coordinate system can be located in one of these two points. By default, the front center is used for the referring “Input” coordinate system and the back center is used for the transmission type reference coordinate system (see Sec. 62.3.2 below).
If more reference points are needed, they can be added on the page *Coordinate Systems* of the Programmable Component’s edit dialog. In the panel *Reference Points* a list of all defined Reference Points as well as an *Edit* button can be found (↪Fig. 557).

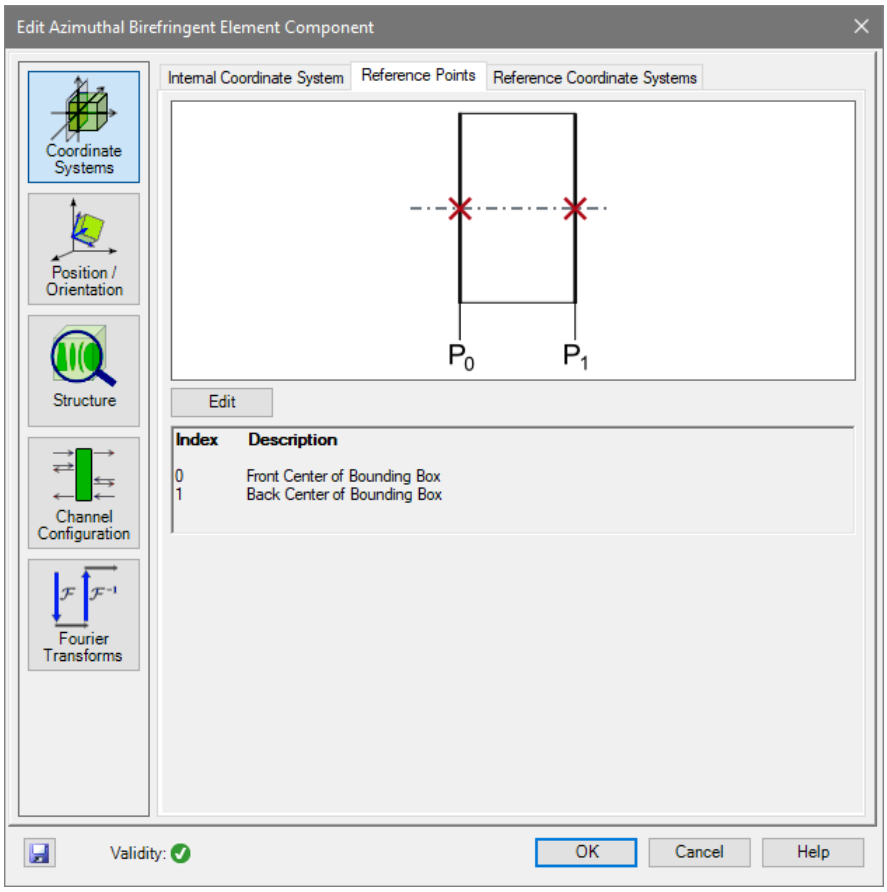


Figure 557. *The overview for the Reference Points of a Programmable Component.*

The *Edit* button will open the dialog for defining new Reference Points shown in Fig. 558.

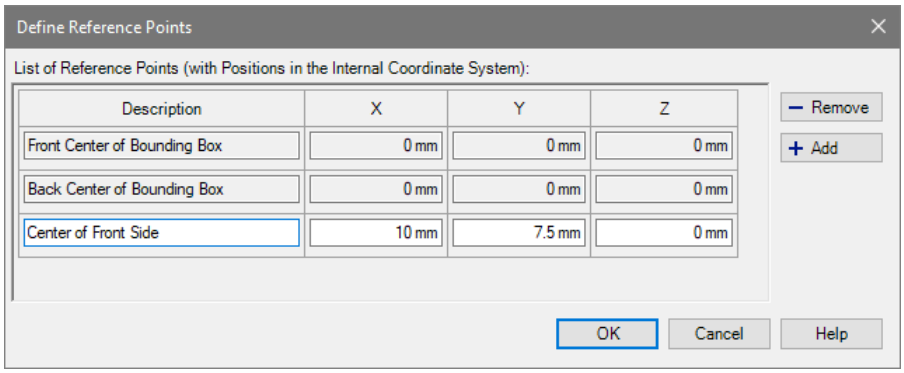


Figure 558. *The edit dialog for user defined Reference Points of a Programmable Component.*

The following options are available in this dialog:

ITEM	DESCRIPTION
Remove	Removes the selected user defined Reference Point.
Add	Adds a new user defined Reference Point.
Description	The unique name of the Reference Point.
X/Y/Z	The x/y/z-coordinate of the Reference Point (referring to the component's Internal Coordinate System).

62.3.2 User-Defined Reference Coordinate Systems

In order to have maximum freedom in positioning an Optical Setup Element, reference coordinate systems are used. For a Programmable Component, they can be added, changed and removed on the page *Coordinate Systems* of the Programmable Component's edit dialog, inside the panel *Reference Coordinate Systems* (↪Fig. 559).

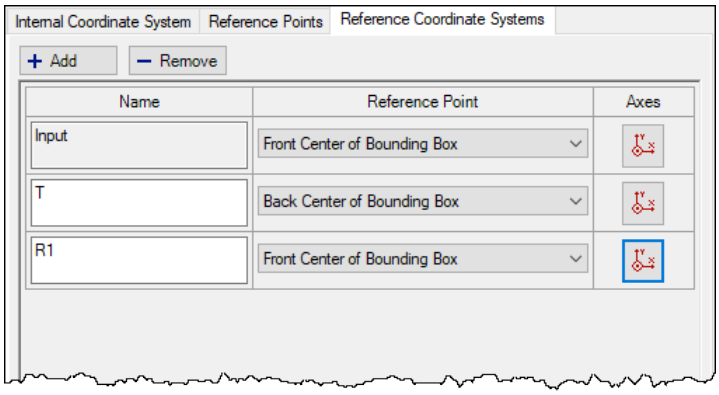


Figure 559. *The edit dialog for the Reference Coordinate Systems of a Programmable Component.*

The following options are available in this panel:

ITEM	DESCRIPTION
Add	Adds a new user defined reference coordinate systems.
Remove	Removes the selected reference coordinate systems. Can be used only if the reference CS is not already in use for positioning of subsequent Optical Setup Elements. Furthermore, removing is not possible for the referring "Input" coordinate systems and the last reference coordinate system besides "Input".
Name	The unique name of the reference coordinate systems. Can be changed only if it is not already in use for positioning of subsequent Optical Setup Elements. The name of the referring "Input" coordinate system cannot be changed as well.
Reference Point	The *Reference Point* for defining the origin of the reference coordinate system can be selected here. Please see also Sec. 62.3.1 and Sec. 44.9.
Axes	Pushing the button opens a new dialog (see Fig. 560 and description below) for setting the base vectors of the reference coordinate system. The axes have to form a right handed Cartesian coordinate system.

The axes of an reference coordinate system are to be defined using the dialog shown in Fig. 560.

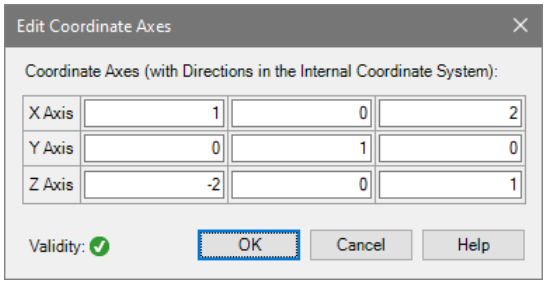


Figure 560. *Dialog for the definition of the axes of reference coordinate systems.*

The options in this dialog are:

ITEM	DESCRIPTION
X/Y/Z Axis	The x/y/z-axis of the reference coordinate system to be edited. All axes have to form a right-handed Cartesian coordinate system and are to be defined relative to the Internal Coordinate System of the Programmable Component.
Validity	This control (↔Sec. 5.11) indicates whether or not the entered axes are valid.

63 Subsystem

Availability

Optical Setups: General Optical Setup

Accessible: Optical Setup: *Components > Subsystem*

The Subsystem component can be configured to use a complete Optical Setup within an Optical Setup Element. The subsystem has to fulfill some restrictions to be used within the Subsystem Component.
Fig. 561 shows the edit dialog of the Subsystem Component.

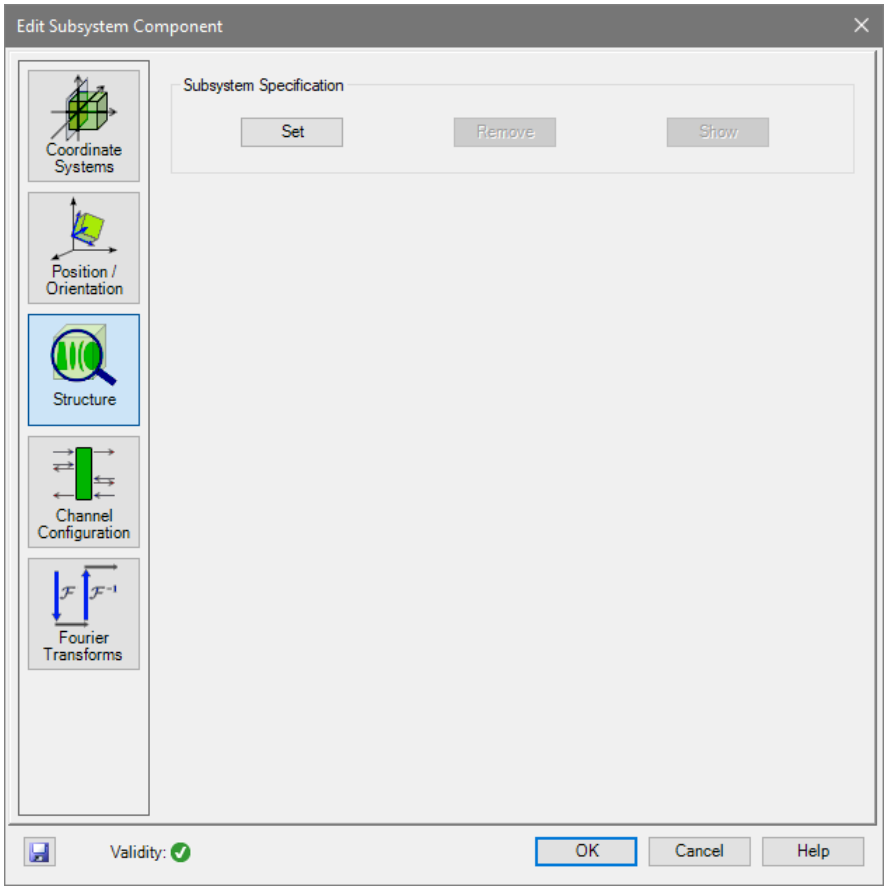


Figure 561. *The edit dialog of the Subsystem component. Within this example no subsystem is configured yet.*

The following settings are available:

ITEM	DESCRIPTION
Set	The *Set* button can be used to set a subsystem into the Subsystem component. The system has to fulfill several requirements which are explained below. After clicking the *Set* button and selecting the subsystem to set the requirements are checked and the Optical Setup is set into the Subsystem component.
Remove	By clicking on the *Remove* button the underlying system is removed.
Show	By clicking on the *Show* button the underlying system is displayed as VirtualLab Fusion document.

The following rules have to be fulfilled in order to set up a consistent subsystem into the Subsystem component:

1. There must be an active light source.
2. The system has to be configured consistently.
3. Only one detector which defines the output of the subsystem.
4. There has to be a unique path to the output detector.

All parameters of the Optical Setup Elements within the subsystem are available for Parameter Extraction (↪Sec. 44.6).

With Pre-Selected Channel Configuration (↪Sec. 44.3.1) all surfaces of a component but the first one have only one transmission channel open. As this affects also the subsystem component, subsystems with reflection work properly only with Manual Channel Configuration for General Profile and Ray Results Profile.

64 Light Shaper

Availability

Optical Setups: Light Shaping Optical Setup

Accessible: Optical Setup: *Components > Multiple Surfaces > Diffractive Light Shaper / Refractive Light Shaper*

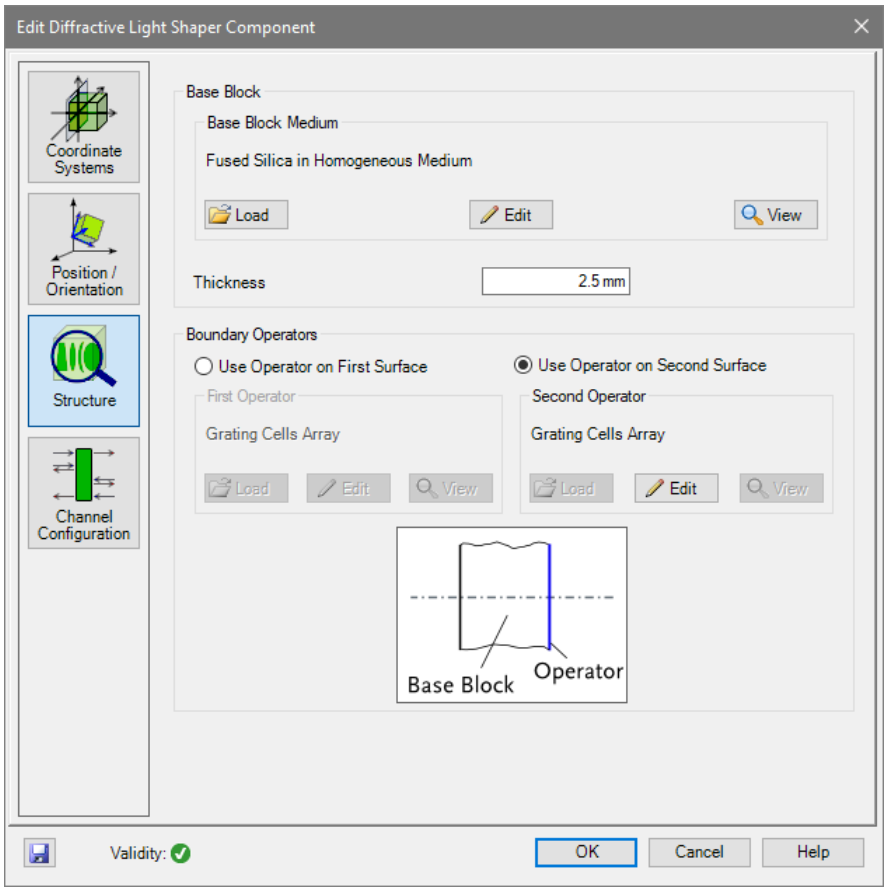


Figure 562. *The structure tab of the edit dialog for a diffractive light shaper.*

A light shaper consists of two plane surfaces on which one boundary operator can be placed. This operator can be either a Grating Cells Array (↪Sec. 41.1.1) for a *Diffractive Light Shaper* or a Prism Cells Array (↪Sec. 41.1.2) for a *Refractive Light Shaper*.
The homogeneous region between this two surfaces is referred to as base block. Therefor the user has to specify the homogeneous *Base Block Medium* and the *Thickness of Base Block*. Geometrical Optics is used to propagate through the component.
The *Structure* tab of the component has the following controls.

ITEM	DESCRIPTION
Base Block Medium PE	The homogeneous medium between the two surfaces. This control is described in Sec. 34.1.
Thickness PV	The thickness of the base block, i. e. the distance between the two plane surfaces along the z-direction.
Use Operator on First Surface / Use Operator on Second Surface	A Light Shaping Optical Setup allows the usage of diffractive, refractive and reflective cells array (↪Sec. 41.1) either on the first surface (pointing towards the light source) or on the second surface. The type of cell array which shall be used is selected by clicking on the corresponding menu item in the main menu. The currently active cells array can be edited with the corresponding *Edit* button.

The other tab pages are explained in Sec. 55.

65 General Grating Component in a Grating Optical Setup

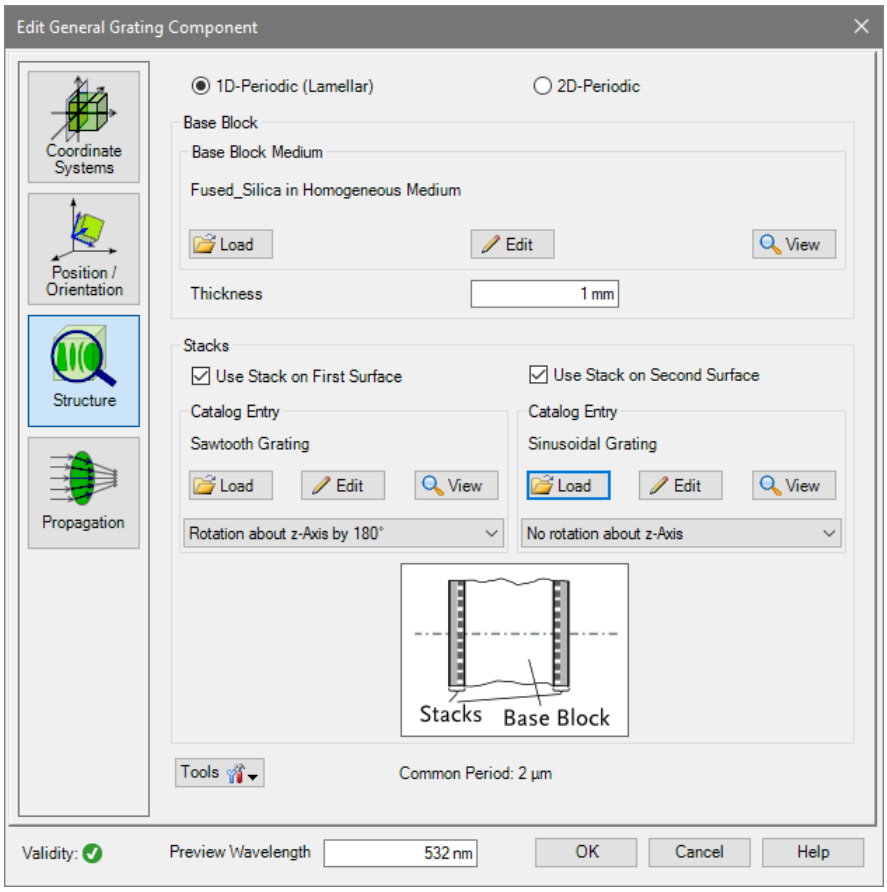


Figure 563. *The edit dialog for a General Grating component.*

This grating component consists of a base block on whose boundaries optical stacks[PV] (↪Sec. 40) can be placed. The base block is a homogeneous region. Therefor the user has to specify the homogeneous *Base Block Medium* and the *Thickness of Base Block*. The stacks can be an arbitrary combination of surfaces and media.

On the bottom of the edit dialog (↪Fig. 563) you can set up the *Preview Wavelength*. If you open the edit dialog it is set to the wavelength of the active light source, but you can alter it to any wavelength for which the materials used in the component provide refractive index data. The preview wavelength is used for the calculation of the refractive indices

- in the stack preview which can be accessed via the corresponding *View* buttons in the *Structure > Solid* tab.
- in the stack edit dialog which can be accessed via the corresponding *Edit* buttons in the *Structure > Solid* tab.
- in the diffraction order calculation and the transition point preview of the FMM edit dialog (↪Sec. 97.3.1).

65.1 Structure Tab

There are the following controls on the *Structure* tab (↪Fig. 563):

ITEM	DESCRIPTION
1D-Periodic (Lamellar) / 2D-Periodic	Defines the periodicity of the grating. Depending on this setting, several controls in the edit dialog of stacks (↪Sec. 40.2) and of the FMM (↪Sec. 97.3.1) change.
Base Block Medium PE	Allows to view and change the homogeneous medium of the base block. These controls are described in Sec. 34.1.
Thickness of Base Block PV	Allows to set the thickness of the base block. Can be also set to zero if the effects of the base block shall be ignored.
Use Stack on First Surface / Use Stack on Second Surface	Allows you to switch on / off the stack on the front and the rear side of the base block, respectively. If switched off, the stack is not used for the grating analysis but still stored in the component. If you switch it back on, the same stack is available again and can be viewed and changed with the controls described in Sec. 34.1. Both stacks can be used at the same time.
No rotation about z-axis / Rotation about z-axis by 180°	If a stack is placed on the front side of the base block, it is rotated by 180° about the y-axis – compared to placement on the rear side and the view displayed in the stack edit dialog (↪Sec. 40.2). With *Rotation about z-axis by 180°* you can apply an additional rotation about the z-axis. Sec. 40.1.2 discusses that in more detail with explanatory figures.
Tools	This button reveals two tools which ease the set-up of a grating component.
Tools > Swap Stacks	This tool swaps the stacks so that the first stack becomes the second stack and vice versa.
Tools > Reduce Component to First Stack	This tool is a short cut for the following steps: 1. Disable the second stack. 2. Set the thickness of the base block to zero. 3. Change the medium of the transmission type reference coordinate system to equal the *Base Block Medium*. This tool is only enabled if the thickness of the first stack is larger than zero, as otherwise this tool would make the component inconsistent.

The overall thickness of the grating component (= thickness of first stack + thickness of base block + thickness of second stack) must not be zero. Otherwise the validity indicator in the bottom left corner (↪Sec. 5.11) shows a white-red cross.
On the bottom of this page the *Common Period* of both stacks is shown for your information. This period influences the computational effort of the FMM.

Calculation of the Common Period

If both stacks are used:
1. Both stack periods are rounded to a multiple of 1 pm to deal with possible numerical errors.
2. The least common multiple of this rounded periods is taken as common period.

65.2 Propagation Tab

Grating components can be analyzed by means of the Fourier Modal Method (FMM; ↪Sec. 97.3). With its edit dialog the number of diffraction orders and the structure decomposition can be set.
You can also use a special version of the Thin Element Approximation operator (↪Sec. 97.2) which ensures that exactly one period is analyzed with sufficient resolution.

66 Double Surface Component

Availability

Optical Setups: Laser Resonator Optical Setup

Accessible: Optical Setup: *High Reflective (Start) Mirrors > Outer Surface of Double Surface Component*; *Laser Crystal*

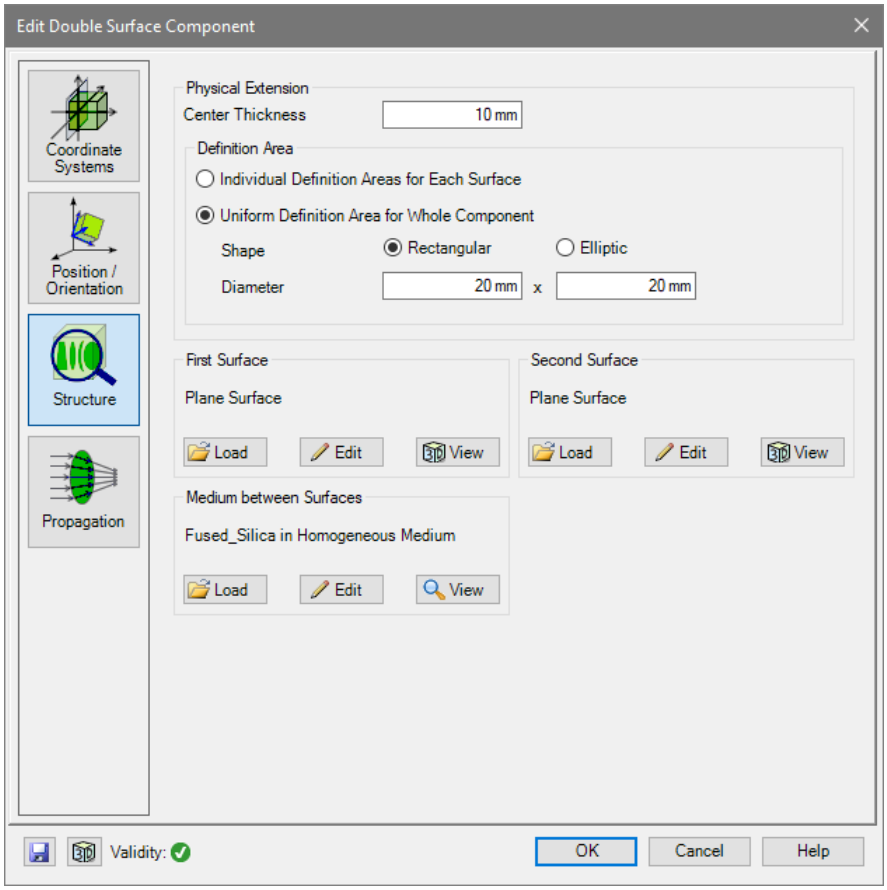


Figure 564. *The Structure tab of the Double Surface Component.*

This component consists of two surfaces with a medium in between. The structure tab of its edit dialog (↪Fig. 564) has the following controls.

ITEM	DESCRIPTION
Center Thickness PV	The distance of the two surfaces measured on the optical axis.
Individual Apertures for Each Surface	If you select this option the apertures of the surfaces are set via the *Edit* button of the *First Surface* and *Second Surface*, respectively.
Uniform Aperture for Whole Component	If you check this radio button, the same aperture is taken for both surfaces. The common aperture is then set via the *Shape* and *Diameter* controls below the radio button. If you double-click on one of the *Diameter* text boxes, the value from the other text box is being overtaken.
First Surface PE	Configures the first surface and displays its name. You can *Load* a new surface from the catalog (↪Sec. 33), *Edit* the current surface or *View* it with the three-dimensional view described in Sec. 36.3.
Second Surface PE	Configures the second surface and displays its name. You can *Load* a new surface from the catalog (↪Sec. 33), *Edit* the current surface or *View* it with the three-dimensional view described in Sec. 36.3.
Medium Between Surfaces PE	Configures the medium between the two surfaces and displays its name. You can *Load* a predefined medium from the catalog (↪Sec. 33), *Edit* the current medium (↪Sec. 38.3.1) or *View* it with the view described in Sec. 38.2.

The other tab pages are explained in Sec. 55.

X Ideal Components and Functions

In contrast to *Real Components* consisting of surfaces and media there are also *Ideal Components*. This name doesn't mean that these elements work without any numerical error or physical approximation but rather that they are idealized by some means.

Sec. 67 describes the controls that all Ideal Components have in common.

The functionality of *Transmission Functions* (↪Sec. 68) is completely defined by a single mathematical operator $\mathcal{T}(x,y)$ which is multiplied with the incoming field. These functions can also be used in the main window via the *Functions* ribbon tab to generate *Jones Matrix Transmission* documents which can then be manipulated or multiplied with harmonic fields.

The remaining Ideal Components are explained in Sec. 69 to Sec. 74.

67 Edit Dialog of Ideal Components

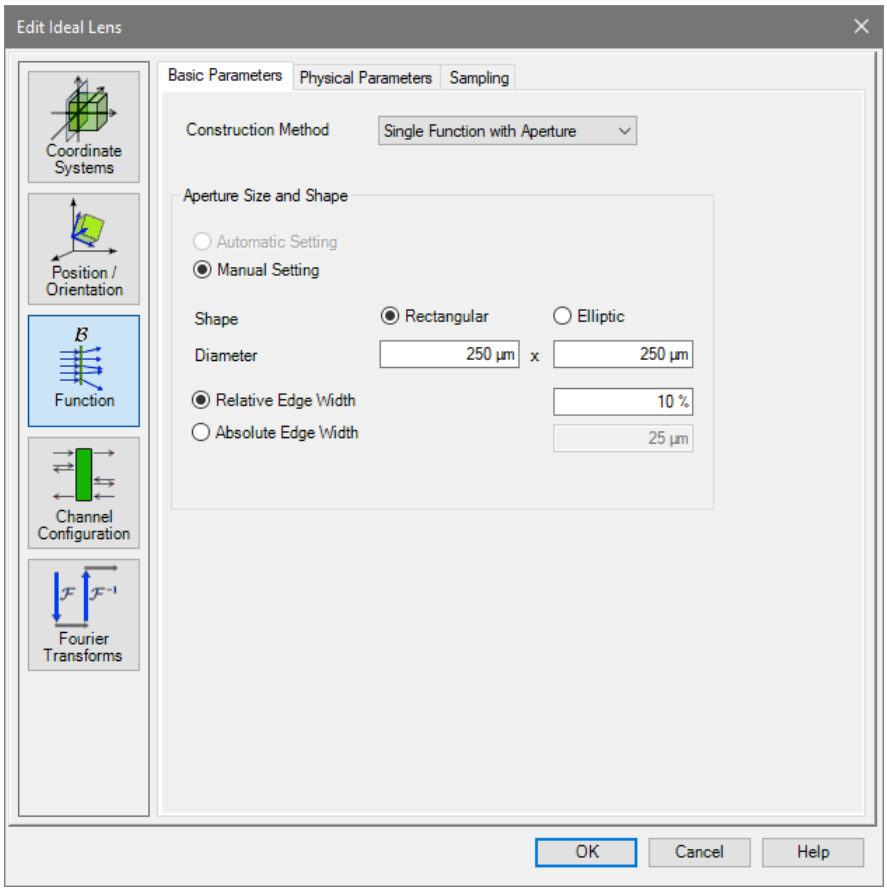


Figure 565. *Example for the edit dialog for Ideal Components.*

The edit dialogs for all Ideal Components (↪Fig. 524) are divided into several pages:

- *Coordinate Systems* ↪Sec. 44.9.1
- *Position / Orientation* ↪Sec. 44.9.2
- *Function*: This page is specific for the distinct ideal components and is thus explained in the following chapters. But it may contain a *Basic Parameters* tab as described in Sec. 67.1.
- *Channel Configuration* ↪Sec. 44.10
- *Fourier Transforms* ↪Sec. 44.5.1

67.1 Basic Parameters

In the upper part of this tab page you can select one out of three *Construction Method*s, which are explained in the table below. Depending on the construction method, the tab page looks like shown in Fig. 566 or like in Fig. 567.

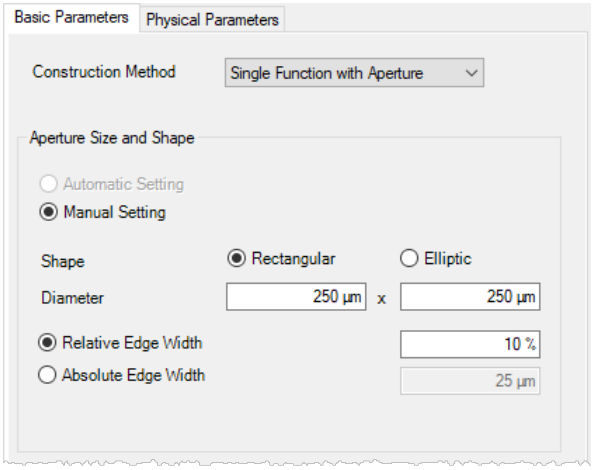


Figure 566. *Tab page for setting the* Basic Parameters *of a transmission function with the construction method* Single Function with Aperture*.*

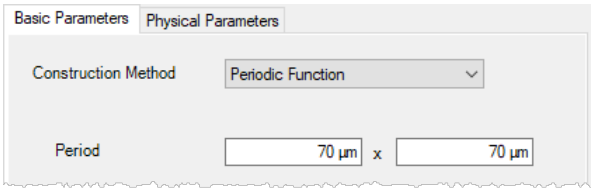


Figure 567. *Tab page for setting the* Basic Parameters *of a transmission function with the construction method* Periodic Function*.*

CONSTRUCTION METHOD	DESCRIPTION
Single Function without Aperture	ONLY AVAILABLE IN THE OPTICAL SETUP. NOT AVAILABLE FOR APERTURE AND ZERNIKE FRINGE / SEIDEL ABERRATIONS TRANSMISSION. There are no specific controls for this construction method.
Single Function with Aperture	The aperture is applied by multiplying the actual transmission value t by 1 inside and by 0 outside the specified aperture. The edge of the aperture can be defined smooth, then the values don't "jump" from 1 to 0 but follow a Gaussian function (decreasing to a value of 0.01) as shown in Fig. 568. The controls to setup the aperture are explained in a separate table below. In case of an Aperture transmission function, this option is named just *Single Function*.
Periodic Function	NOT AVAILABLE FOR ZERNIKE FRINGE / SEIDEL ABERRATIONS TRANSMISSION. In this case you can set the *Period*[PV] of the function.

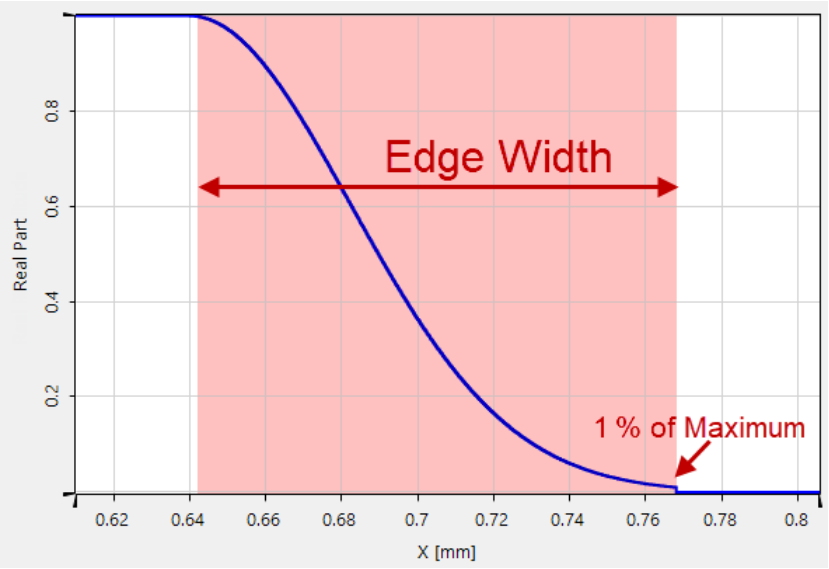


Figure 568. *Definition of the edge width of an aperture.*

The following controls (↪Fig. 566) are specific for the *Single Function with Aperture* construction method:

ITEM	DESCRIPTION
Automatic Setting	If checked, a reasonable size of the aperture for the transmission function is determined automatically. This option is available for some functions only, e. g. exponentially decreasing ones.
Manual Setting	If checked, the aperture size has to be entered by the user.
Shape	The aperture may be *Rectangular*ly or *Elliptic*ally shaped.
Diameter PV	Size of the aperture.
Relative Edge Width PV	The width of the aperture edge, defined relatively to the (smaller of the both values of) *diameter*.
Absolute Edge Width PV	The width of the aperture edge, defined in physical units. ↪Fig. 324.

For an Aperture transmission, a separate aperture cannot be set on the *Basic Parameters* tab. For a Zernike Fringe / Seidel Aberrations transmission, only circular apertures are allowed.
The following controls (↪Fig. 567) are specific for the *Single Function with Aperture* construction method:

ITEM	DESCRIPTION
Period PV	If *Periodic Function* was chosen as *Construction Method*, here the length of the period for the replication is set. The first value is used for replication in x-direction, the second one for the y-direction. **Specific for grating transmissions:** For gratings, the *Period* will be determined automatically from the *Grating Period* and the *Rotation Angle*, both to be specified at the *Physical Parameters* panel.

68 Transmission Functions

Generally, the change of amplitude, phase, and polarization of an electromagnetic field can be described by an operator $\mathcal{T}$ named *Transmission Operator*. Its function is mathematically described as

$$E_{xy}^{out}(x,y) = \mathcal{T}\, E_{xy}^{in}(x,y) \tag{68.1}$$

68.1 Transmission Functions in the Main Window

If you want to apply a transmission function to a harmonic field in the main window, you have to prepare this operation by first generating a document called *Jones Matrix Transmission* via the items in the ribbon group Functions > Transmission Functions. This document consists of a complex scalar component $t(x,y)$ that can change amplitude and phase of the input field, and the Jones matrix $\mathcal{J}$ (↪Sec. 70), that has an effect on the polarization (but in the most cases at least on amplitude or phase too). The transmission process, that means the application of the transmission operator onto the field, can then be simulated by multiplying the harmonic field with the Jones matrix transmission. This can be done via Manipulations > Array - Array Operation > Multiplication (↪Sec. 22.1.1).
The resulting output field is calculated by

$$\boldsymbol{E}_{xy}^{out} = t(\mathcal{J} \cdot \boldsymbol{E}_{xy}^{in}). \tag{68.2}$$

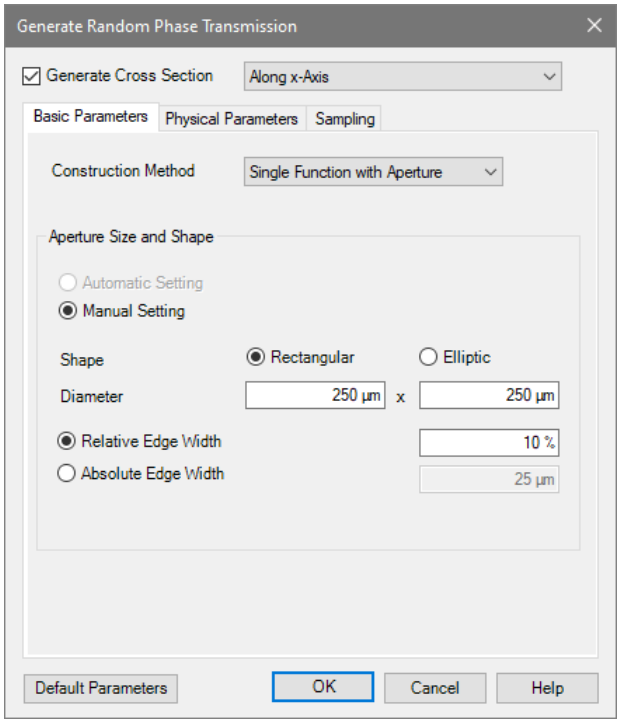


Figure 569. *The edit dialog for generating a Jones Matrix Transmission (here: Random Phase Transmission) in the main window.*

The edit dialog of transmission functions (↪Fig. 569) has the following controls specific to the main window.

ITEM	DESCRIPTION
Generate Cross Section	If checked, a one-dimensional cross section either *Along x-Axis* or *Along y-Axis* through the defined two-dimensional value distribution will be generated.
Default Parameters	Resets all settings in the dialog to their default values.

The remaining controls that all types of transmissions have in common are explained in Sec. 67.1 (*Basic Parameters* tab) and Sec. 68.3.1.1 (*Sampling* tab), respectively. The type specific parameters are described in Sec. 68.5.1 to Sec. 68.6.4.

68.2 Transmission Functions in the Optical Setup

If you want to apply a transmission function to a harmonic field inside an Optical Setup, you can do this by adding the corresponding Ideal Component. The controls specific to transmissions are embedded in the general Ideal

Components dialog (↪Sec. 67). The controls that all types of transmissions have in common are explained in Sec. 67.1 (*Basic Parameters* tab) and Sec. 68.3.1.2 (*Sampling* tab), respectively. The type specific parameters are described in Sec. 68.5.1 to Sec. 68.6.4.

68.3 Common Controls of the Transmission Generator Dialogs

Some parameters are common for all types of transmission generator. They regard the lateral sampling of the function, the size and shape of the aperture and the periodicity and are entered via the two tab pages *Basic Parameters* (Sec. 67.1) and *Sampling* (Sec. 68.3.1). The third panel *Physical Parameters* is type specific, so its contents are described in the appropriate sections below.

68.3.1 Sampling

As in the Optical Setup transmission functions are applied directly on an incoming harmonic field, the *Sampling* tab of a transmission function looks and behaves differently in the main window (↪Sec. 68.3.1.1) and in the Optical Setup (↪Sec. 68.3.1.2).

68.3.1.1 Sampling in the Main Window

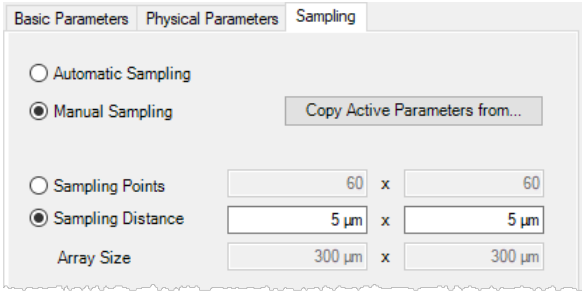


Figure 570. *Tab page for setting the* Sampling *parameters of a transmission function in the main window.*

Description of the parameters:

ITEM	DESCRIPTION
Automatic Sampling	If checked, the sampling parameters will be determined automatically.
Manual Sampling	If checked, the sampling parameters have to be entered by the user.
Accuracy Factor	This parameter can be entered for the *Automatic Sampling* mode only. The *Sampling Distance* will be divided by this value.
Copy Active Parameters from...	This option is available for the *Manual Sampling* mode only. If pressed, a window will appear where a document can be selected to copy the *Sampling Distance* or the number of *Sampling Points* from, depending on which of both is currently selected.
Sampling Points	In case of *Manual Sampling*, the number of sampling points can be entered here.
Sampling Distance	In case of *Manual Sampling*, the sampling distance can be entered here.
Array Size	The size of the transmission function, automatically calculated from the settings on the *Basic Parameters* tab: • In case of a *Single Function with Aperture*: *Diameter* plus two times the *Absolute Edge Width* . • In case of a *Periodic Function*: Equal to the *Period*.

68.3.1.2 Sampling in the Optical Setup

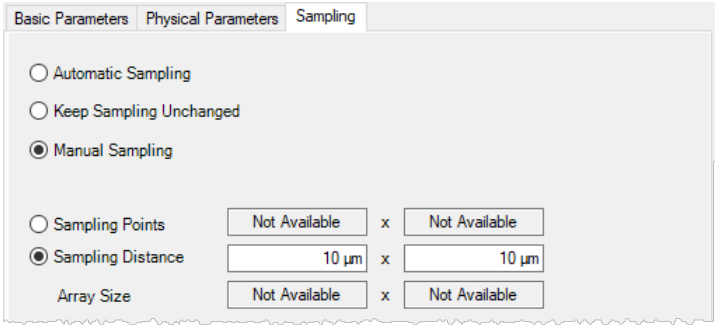


Figure 571. *Tab page for setting the* Sampling *parameters of a transmission function in the Optical Setup.*

Description of the parameters:

ITEM	DESCRIPTION
Automatic Sampling	If checked, the sampling parameters will be determined automatically.
Keep Sampling	The sampling parameters of the incoming harmonic field are used.
Manual Sampling	If checked, the sampling parameters have to be entered by the user.
Accuracy Factor	This parameter can be entered for the *Automatic Sampling* mode only. The suggested sampling distance will be divided by this value. However, if the sampling distance of the incoming harmonic field is smaller, it will be taken instead.
Sampling Points	In case of *Manual Sampling*, the number of sampling points can be entered here.
Sampling Distance	In case of *Manual Sampling*, the sampling distance can be entered here.

68.4 Programmable Function

Availability

Optical Setups: General Optical Setup, Light Guide Optical Setup, and Laser Resonator Optical Setup

Accessible: Optical Setup: *Ideal Components > Programmable Function*

The controls specific for this transmission function are identical to those of the corresponding boundary response (↪Sec. 42.3.5). The controls that all transmission functions have in common are described in Sec. 68.3.

68.5 Apertures and Lenses

68.5.1 Aperture

Availability

Toolboxes: All

Accessible:

- Main window: Functions > Aperture 
- Optical Setup: *Ideal Components > Apertures and Lenses > Aperture*

The controls specific for this transmission function are identical to those of the corresponding boundary response (↪Sec. 42.3.1). The controls that all transmission functions have in common are described in Sec. 68.3.

68.5.2 Ideal Lens

Availability

Toolboxes: All

Accessible:

- Main window: Functions > Ideal Lens 
- Optical Setup: *Ideal Components* > *Apertures and Lenses* > *Ideal Lens*

The controls specific for this transmission function are identical to those of the corresponding boundary response (↪Sec. 42.3.3). If this transmission is created in the main window, the *Wavelength Dependency* is fixed to *Chromatic*.
The controls that all transmission functions have in common are described in Sec. 68.3.

68.5.3 Spherical Phase

Availability

Toolboxes: All

Accessible:

- Main window: Functions > Spherical Phase 
- Optical Setup: *Ideal Components* > *Apertures and Lenses* > *Spherical Phase*

The controls specific for this transmission function are identical to those of the corresponding boundary response (↪Sec. 42.3.7). If this transmission is created in the main window, the *Wavelength Dependency* is fixed to *Chromatic*.
The controls that all transmission functions have in common are described in Sec. 68.3.

68.5.4 Stop

Availability

Toolboxes: All

Accessible:

- Main window: Functions > Stop 
- Optical Setup: *Ideal Components* > *Apertures and Lenses* > *Stop*

The controls specific for this transmission function are identical to those of the corresponding boundary response (↪Sec. 42.3.8). The controls that all transmission functions have in common are described in Sec. 68.3.

68.5.5 Zernike & Seidel Aberrations

Availability

Toolboxes: All

Accessible:

- Main window: Functions > Zernike & Seidel Aberrations 
- Optical Setup: *Ideal Components* > *Apertures and Lenses* > *Zernike & Seidel Aberrations*

The controls specific for this transmission function are identical to those of the corresponding boundary response (↪Sec. 42.3.9).
The controls that all transmission functions have in common are described in Sec. 68.3.

68.6 Grating Transmissions

68.6.1 Rectangular Grating Transmission

Availability

Toolboxes: All

Accessible:

- Main window: Functions > Rectangular Grating 
- Optical Setup: *Ideal Components* > *Grating Transmissions* > *Rectangular Grating Transmission*

The controls specific for this transmission function are identical to those of the corresponding boundary response (↪Sec. 42.3.2.1). If this transmission is created in the main window, the *Wavelength Dependency* is not available – always the set up *Modulation Depth* is used.
The controls that all transmission functions have in common are described in Sec. 68.3.

68.6.2 Sawtooth Grating Transmission

Availability

Toolboxes: All

Accessible:

- Main window: Functions > Sawtooth Grating 
- Optical Setup: *Ideal Components* > *Grating Transmissions* > *Sawtooth Grating Transmission*

The controls specific for this transmission function are identical to those of the corresponding boundary response (↪Sec. 42.3.2.2). If this transmission is created in the main window, the *Wavelength Dependency* is not available – always the set up *Modulation Depth* is used.
The controls that all transmission functions have in common are described in Sec. 68.3.

68.6.3 Sinusoidal Grating Transmission

Availability

Toolboxes: All

Accessible:

- Main window: Functions > Sinusoidal Grating 
- Optical Setup: *Ideal Components* > *Grating Transmissions* > *Sinusoidal Grating Transmission*

The controls specific for this transmission function are identical to those of the corresponding boundary response (↪Sec. 42.3.2.3). If this transmission is created in the main window, the *Wavelength Dependency* is not available – always the set up *Modulation Depth* is used.
The controls that all transmission functions have in common are described in Sec. 68.3.

68.6.4 Triangular Grating Transmission

Availability

Toolboxes: All

Accessible:

- Main window: Functions > Triangular Grating 
- Optical Setup: *Ideal Components* > *Grating Transmissions* > *Triangular Grating Transmission*

The controls specific for this transmission function are identical to those of the corresponding boundary response (↪Sec. 42.3.2.4). If this transmission is created in the main window, the *Wavelength Dependency* is not available – always the set up *Modulation Depth* is used.
The controls that all transmission functions have in common are described in Sec. 68.3.

68.7 Random Diffusers

68.7.1 Random Cells Diffuser and Speckle Type Diffuser

Availability

Optical Setups: General Optical Setup

Accessible: Optical Setup: *Ideal Components* > *Diffusers* > *Random Cells Diffuser* and *Ideal Components* > *Diffusers* > *Speckle Type Diffuser*

The Random Cells Diffuser generates a pattern of cells with a fixed *Cell Size* but random amplitude and / or phase. The Speckle Type Diffuser applies an interpolation between the cells – thus you see speckles as in reality.

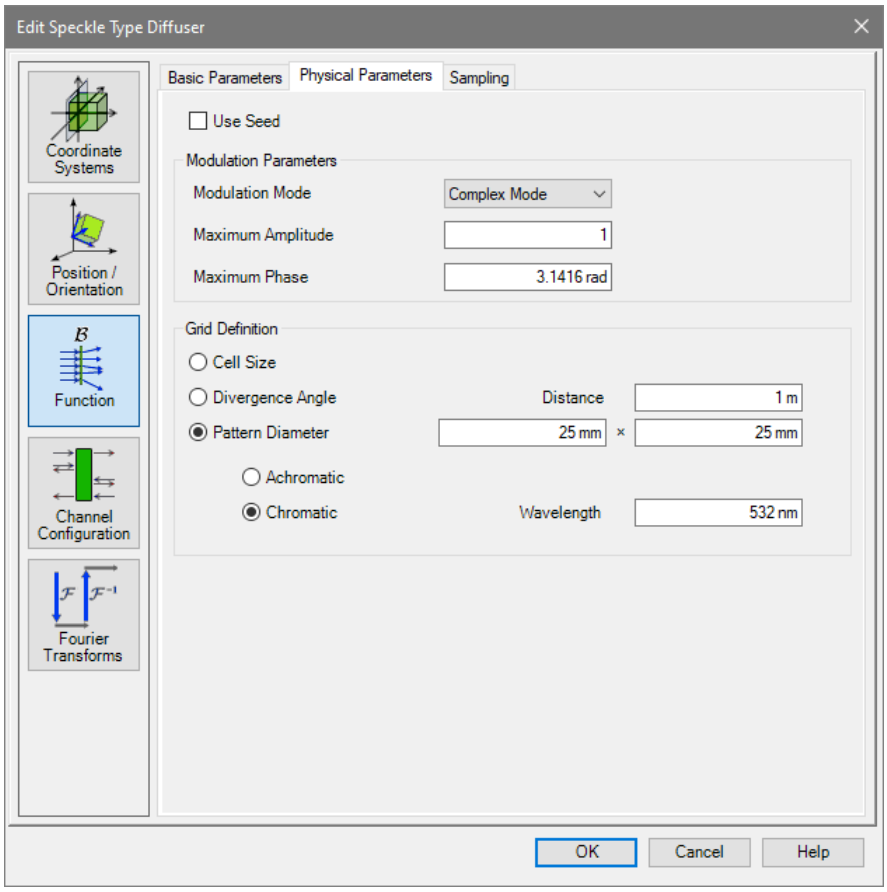


Figure 572. Physical Parameters *for a Random Cells Diffuser and a Speckle Type Diffuser.*

ITEM	DESCRIPTION
Use Seed	You can use this option to obtain reproducible results despite the random distribution of the amplitude and / or phase values: With the same *Seed*[PV] and the same physical settings you always obtain the same pattern.
Modulation Mode	The *Amplitude Mode* generates a random amplitude distribution, the *Phase Mode* generates a random phase distribution. In *Complex Mode* both amplitude and phase are altered independently.
Maximum Amplitude[PV]	In *Amplitude Mode* or *Complex Mode*, a random amplitude between zero and *Maximum Amplitude* is chosen per cell / speckle.
Maximum Phase[PV]	In *Phase Mode* or *Complex Mode*, a random phase between -*Maximum Phase* and +*Maximum Phase* is chosen per cell / speckle.
Cell Size[PV]	If you select this *Grid Definition*, you enter the cell size directly.
Divergence Angle[PV]	In this mode, the cell size is calculated from the full divergence angle using the grating equation Eq. (68.3).
Pattern Diameter[PV]	In this mode, you define the overall size of the diffraction pattern at a certain *Distance*. These values yield the divergence angle and thus the cell size.
Achromatic	For the grating equation Eq. (68.3), the wavelength of the incoming harmonic field is taken.
Chromatic	The given *Wavelength* is used for the grating equation Eq. (68.3).

The following relation is used for the conversion from divergence angle α to cell size d_{grid}, where n is the

refractive index and λ is the wavelength.

$$d_{\text{grid}} = \frac{\lambda}{2n\sin(0.5\alpha)} \tag{68.3}$$

68.7.2 Random Phase

Availability

Toolboxes: All

Accessible: Functions > Random Phase 

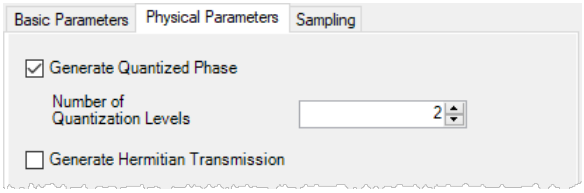


Figure 573. Physical Parameters *for a Random Phase transmission.*

The following options and parameters (↪Fig. 573) are available:

ITEM	DESCRIPTION
Generate Quantized Phase	If checked, the generated transmission is quantized, which means that it contains only phase values that are elements of the set $\{-\pi + 2\pi j/Q : j = 0, 1, \ldots, Q-1\}$, where Q denotes the *Number of Quantization Levels*.
Number of Quantization Levels	Number of quantization levels used for generating quantized transmissions.
Generate Hermitean Transmission	If checked, the generated transmission is Hermitean, i. e. $t(x,y) = t^{\star}(-x,-y)$, where * denotes the Hermitean conjugate.

68.8 Miscellaneous Functions

68.8.1 Linear Phase

Availability

Toolboxes: All

Accessible:

- Main window: Functions > Linear Phase 
- Optical Setup: *Ideal Components > Miscellaneous Functions > Linear Phase*

The controls specific for this transmission function are identical to those of the corresponding boundary response (↪Sec. 42.3.4). If this transmission is created in the main window, the *Wavelength Dependency* is fixed to *Chromatic*.
Within the Optical Setup the linear phase which is applied by the functional operator is handled as analytical parameter.
The controls that all transmission functions have in common are described in Sec. 68.3.

68.8.2 Single Phase Dislocation

Availability

Toolboxes: All

Accessible:
- Main window: Functions > Single Phase Dislocation 
- Optical Setup: *Ideal Components > Miscellaneous Functions > Single Phase Dislocation*

The controls specific for this transmission function are identical to those of the corresponding boundary response (↪Sec. 42.3.6).
The controls that all transmission functions have in common are described in Sec. 68.3.

69 Stored Function

Availability

Optical Setups: General Optical Setup, Light Guide Optical Setup, and Laser Resonator Optical Setup

Accessible: Optical Setup: *Ideal Components > Stored Function*

The controls specific for this transmission function are identical to those of the corresponding boundary response (↪Sec. 42.3.10).
The controls that all transmission functions have in common are described in Sec. 68.3.
In the Optical Setup View (↪Sec. 44.1), a Stored Function has a specific context menu entry to convert it into a Microstructure (↪Sec. 61.1).

70 Jones Matrix Multiplication

Availability

Optical Setups: General Optical Setup & Light Guide Optical Setup

Accessible: Optical Setup: *Ideal Components > Jones Matrices*

Some optical elements and devices influence the polarization state of light. Mathematically this process can be described by a change of the electric field vector by a matrix, called Jones matrix $\mathcal{J}$

$$E_{xy}^{out} = \mathcal{J} \cdot E_{xy}^{in}. \tag{70.1}$$

For globally polarized fields, this means a change of the Jones vector:

$$J_{out} = \mathcal{J} \cdot J_{in}. \tag{70.2}$$

For your convenience, the four important cases of *Phase Shift*, *Polarizer*, *Retarder*, and *Rotator* are implemented as separate components in VirtualLab Fusion (described in the following sections Sec. 70.2 to Sec. 70.5). That means, the user does not have to enter the Jones matrix but only one single parameter describing the appropriate physical effect. For other cases an arbitrary *Jones Matrix* component can be used. The controls described in Sec. 70.1 to Sec. 70.5 are embedded in the general dialog for Ideal Components which is described in Sec. 67.

70.1 Jones Matrix

For the multiplication of an arbitrary Jones matrix this function is used.

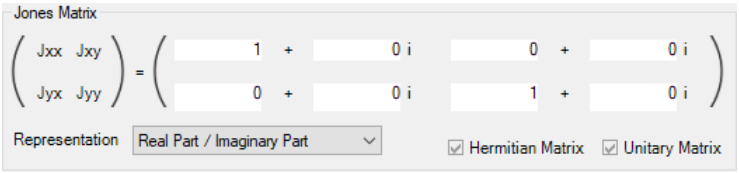


Figure 574. *Controls for defining the parameters of an arbitrary Jones matrix multiplication.*

The following parameters are available for a General Jones Matrix Multiplication (↪Fig. 574):

ITEM	DESCRIPTION
Jones Matrix PV	Matrix with four complex entries.
Representation	Representation of the complex values in the Jones matrix.
Hermitian Matrix	Indicates whether the matrix is Hermitian.
Unitary Matrix	Indicates whether the matrix is unitary.

The control shown in Fig. 574 is embedded in the general dialog for Ideal Components which is described in Sec. 67.

70.2 Phase Shift

A Phase Shift adds a phase difference ϕ to both E_x and E_y. The appropriate Jones matrix is

$$\mathcal{J} = \begin{pmatrix} \exp(i\phi) & 0 \\ 0 & \exp(i\phi) \end{pmatrix}. \tag{70.3}$$

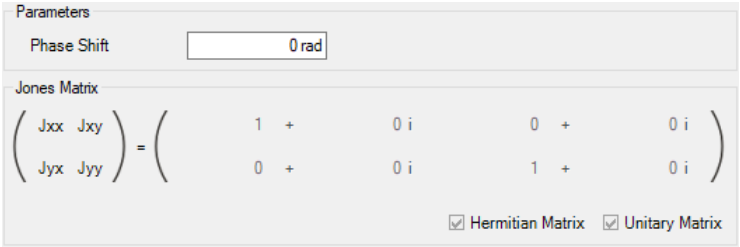


Figure 575. *Controls for defining the parameters of a Phase Shift.*

The following parameters are available for a Phase Shift component (↪Fig. 575):

ITEM	DESCRIPTION
Phase Shift PV	The phase shift ϕ for both E_x and E_y.
Jones Matrix	The resulting Jones matrix that describes the phase shift.
Hermitian Matrix	Indicates whether the matrix is Hermitian.
Unitary Matrix	Indicates whether the matrix is unitary.

The control shown in Fig. 575 is embedded in the general dialog for Ideal Components which is described in Sec. 67.

70.3 Polarizer

A linear polarizer is a kind of optical filter that will pass only that part of E_{xy} which oscillates in a certain direction. If this direction is given by an angle α, the corresponding Jones matrix is given by

$$\mathcal{J} = \begin{pmatrix} \cos^2\alpha & \sin\alpha\cos\alpha \\ \sin\alpha\cos\alpha & \sin^2\alpha \end{pmatrix}. \tag{70.4}$$

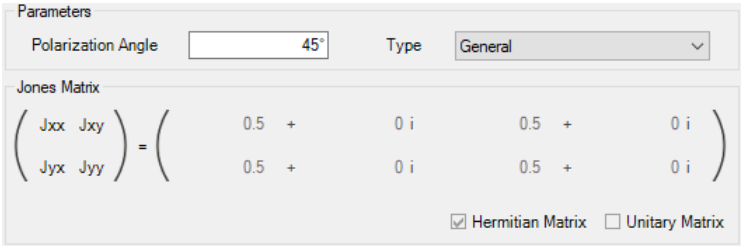


Figure 576. *Controls for defining the parameters of a linearly polarizing Jones matrix multiplication.*

The following parameters are available for a Polarizer component (↪Fig. 576):

ITEM	DESCRIPTION
Polarization Angle PV	The angle of the plane of polarization of the filtered, linearly polarized light.
Type	Here you can select one of the two special cases *Along x Direction*, which corresponds to a polarization angle of α = 0°, which means that the component E_y is set to 0, or *Along y Direction*, which corresponds to a polarization angle of α = 90°, which means that the component E_x is set to 0. The case of an arbitrary polarization angle is called *General*.
Jones Matrix	The resulting Jones matrix that describes the linear polarization.
Hermitian Matrix	Indicates whether the matrix is Hermitian.
Unitary Matrix	Indicates whether the matrix is unitary.

The control shown in Fig. 576 is embedded in the general dialog for Ideal Components which is described in Sec. 67.

70.4 Retarder

Retarders as e. g. quarter-wave plates or half-wave plates "retard" E_y against E_x by a phase difference ϕ. Thereby linearly polarized light can be transformed into circularly polarized and vice versa, for example. The appropriate Jones matrix is

$$\mathcal{J} = \begin{pmatrix} 1 & 0 \\ 0 & \exp(-i\phi) \end{pmatrix}. \tag{70.5}$$

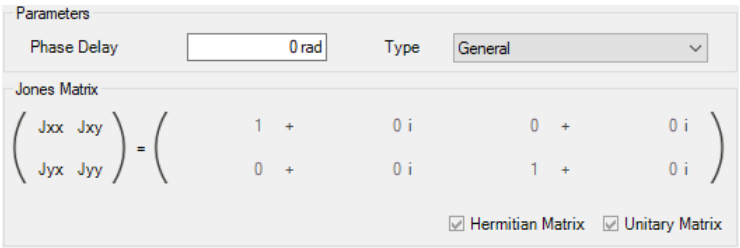


Figure 577. *Controls for defining the parameters of a Jones matrix retardation.*

The following parameters are available for a Retarder component (↪Fig. 577):

ITEM	DESCRIPTION
Phase Delay PV	The phase shift E_y shall get.
Type	Here you can select one of the two important special cases *Quarter-Wave Retarder*, which corresponds to a phase delay of $\pi/2$, used for transforming linearly polarized light to circularly polarized and vice versa, or *Quarter-Wave Retarder*, which corresponds to a phase delay of π, used for transforming right-circularly polarized light into left-circularly and vice versa. The case of an arbitrary phase delay is called *General*.
Jones Matrix	The resulting Jones matrix that describes the retardation.
Hermitian Matrix	Indicates whether the matrix is Hermitian.
Unitary Matrix	Indicates whether the matrix is unitary.

The control shown in Fig. 577 is embedded in the general dialog for Ideal Components which is described in Sec. 67.

70.5 Rotator

The angle of rotation θ of the plane of polarization determines the Jones matrix as follows

$$\mathcal{J} = \begin{pmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{pmatrix}. \tag{70.6}$$

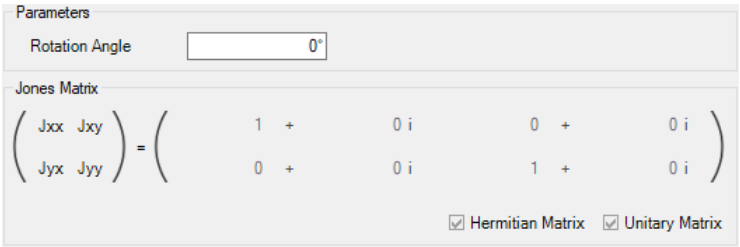


Figure 578. *Controls for defining the parameters of a Jones matrix rotation.*

The following parameters are available for a Rotator component (↪Fig. 578):

ITEM	DESCRIPTION
Rotation Angle PV	The angle by which the plane of polarization shall be rotated.
Jones Matrix	The resulting Jones matrix that describes the rotation of the plane of polarization.
Hermitian Matrix	Indicates whether the matrix is Hermitian.
Unitary Matrix	Indicates whether the matrix is unitary.

The control shown in Fig. 578 is embedded in the general dialog for Ideal Components which is described in Sec. 67.

71 Beam Splitters

Both kinds of idealized beam splitters (Ideal Beam Splitter ↪Sec. 71.1 as well as Polarization Beam Splitter ↪Sec. 71.2) can be regarded as being infinitely thin semi-transparent mirrors, splitting the incident light into

two different directions. One fraction of light is transmitted straight forward without any direction change. The remaining fraction is reflected following the law of reflection.
The transmitted part can be obtained by connecting the next setup element to the *transmission type reference coordinate system*. The reflected part is provided to a setup element connected to the *reflection type reference coordinate system* correspondingly.
The only difference between both types of beam splitters is the calculation of the fractions provided by each of the output reference coordinate system connections.
The following sketches illustrate the functions of the two output reference coordinate systems in three different positioning setups: The first figure Fig. 579 shows the output directions if the beam splitter is not rotated at all. The second figure Fig. 580 illustrates the output directions in case of a basal rotation of the splitter. In the third figure Fig. 581 the effect of an isolated rotation of the splitter on the output directions can be seen.

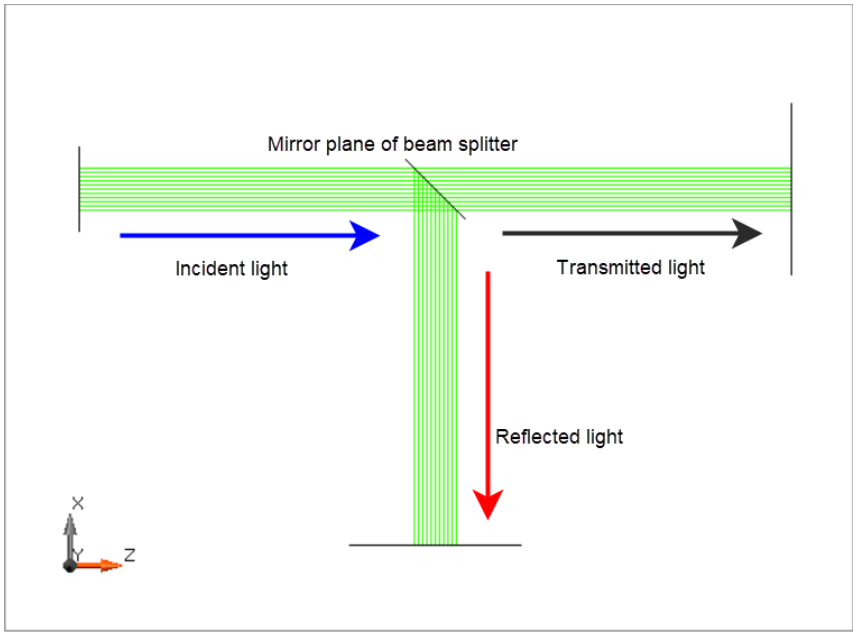


Figure 579. *If the beam splitter is not rotated at all, the mirror normal is the direction vector* $(+\sqrt{0.5}, 0, +\sqrt{0.5})^T$. *A field which travels into local positive z-direction will be split into one transmitted part, running unmodified into local positive z-direction further on and a reflected part, traveling into local negative x-direction.*

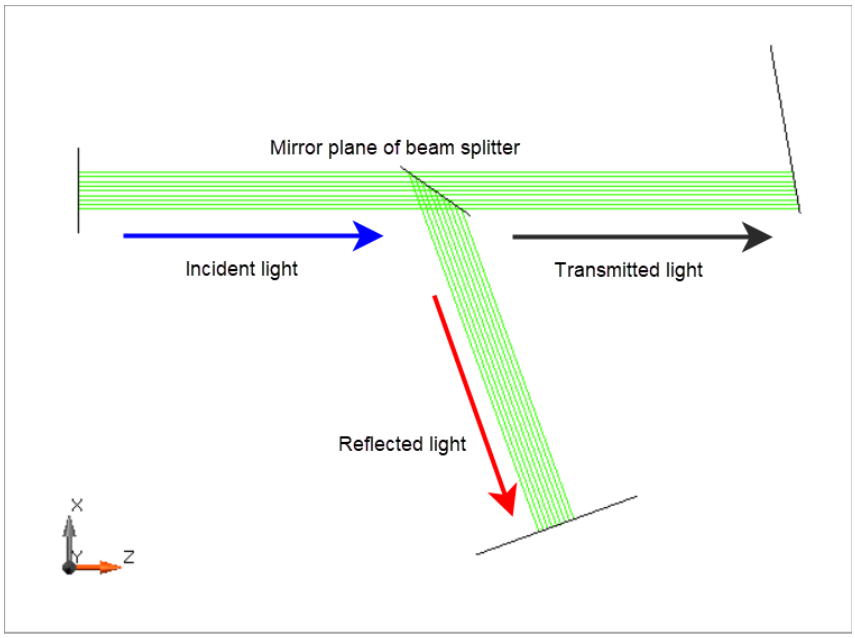


Figure 580. *If the beam splitter is rotated* basal *using a rotation matrix* M*, the mirror normal is the direction vector* $M \cdot (+\sqrt{0.5}, 0, +\sqrt{0.5})^T$*. Due to the rotation being basal, the elements connected to the reference coordinate systems are rotated (referring to global coordinates) as well. A field which travels into local positive z-direction will be split into one transmitted part, running unmodified into local positive z-direction further on and a reflected part. The latter one follows the law of reflection, depending on the mirror's orientation.*

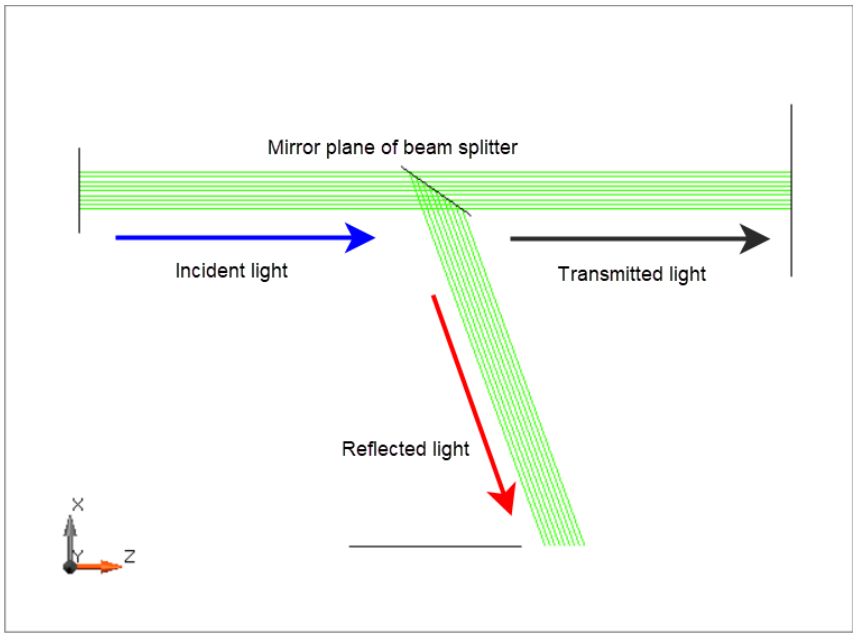


Figure 581. *If the beam splitter is rotated* isolated *using a rotation matrix* M*, the mirror normal is the direction vector* $M \cdot (+\sqrt{0.5}, 0, +\sqrt{0.5})^T$*. Due to the rotation being isolated, the elements connected to the reference coordinate systems are* not *rotated as well. A field which travels into local positive z-direction will be split into one transmitted part, running unmodified into local positive z-direction further on and a reflected part. The latter one follows the law of reflection, depending on the mirror's orientation.*

71.1 Ideal Beam Splitter

Availability

Optical Setups: General Optical Setup

Accessible: Optical Setup: *Ideal Components > beam Splitters > Ideal Beam Splitter*

The Ideal Beam Splitter has two types of reference output coordinate systems: *Output 0* and *Output 1*. The output 0 is a transmission type system which provides an unmodified field as described above. The output 1 is a reflection type system that gives a mirrored field which follows the law of reflection as mentioned above.
The energy of the incoming field is split up between both of the outputs. With a slider control you can set the specific *Ratio*[PV] of distributing the energy of the input field to the output fields. Or you can directly set the percentage for one of the two output coordinate systems.

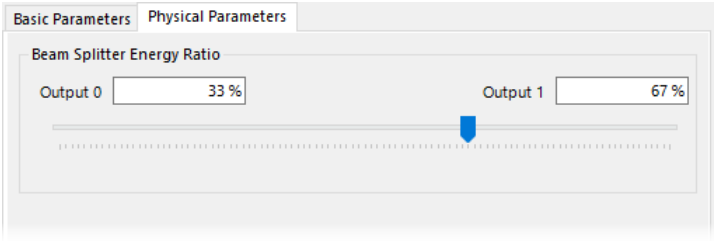


Figure 582. *The edit controls for an Ideal Beam Splitter.*

The other tab pages are explained in Sec. 67.

71.2 Polarization Beam Splitter

Availability

Optical Setups: General Optical Setup

Accessible: Optical Setup: *Ideal Components > beam Splitters > Polarization Beam Splitter*

The output reference coordinate system “y@100%” is a reflection type system which gives a mirrored field following the law of reflection. The output reference coordinate system “x@100%” is a transmission type system, leaving the field’s orientation unchanged. See also Fig. 579 to Fig. 581.

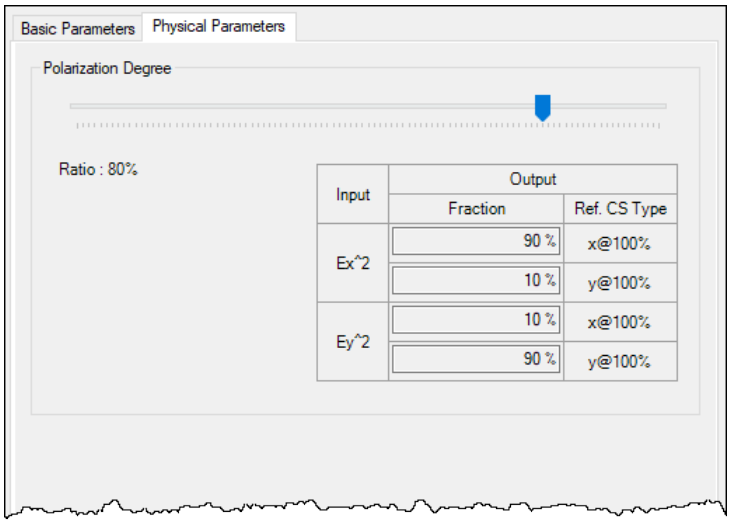


Figure 583. *The edit controls for a Polarization Beam Splitter.*

A polarization beam splitter splits the incoming light according to its degree of polarization. The amplitudes of the different outputs at each of the output reference coordinate systems (“x@100%” and “y@100%”) are

calculated as follows.

$$E_{\text{x@100\%}} = \begin{pmatrix} \sqrt{0.5+0.5p} \cdot E_x \\ \sqrt{0.5-0.5p} \cdot E_y \end{pmatrix} \tag{71.1}$$

$$E_{\text{y@100\%}} = \begin{pmatrix} \sqrt{0.5-0.5p} \cdot E_x \\ \sqrt{0.5+0.5p} \cdot E_y \end{pmatrix} \tag{71.2}$$

p is the *Polarization Degree*[PV].
For $p = 0$, the polarization beam splitter behaves just like a normal ideal beam splitter with an energy ratio of 50%, while for $p = 100\%$, the field is split into pure E_x and pure E_y polarization.
The other tab pages are explained in Sec. 67.

72 Manipulators

The following manipulation functions are available as Ideal Components in the Optical Setup.

- Field Size and Sampling (↪Sec. 22.8.2)
- Identity Operator (↪Sec. 72.1)
- Lateral Shift (↪Sec. 72.2)
- Sample Spherical Phase (↪Sec. 72.3)

72.1 Identity Operator / Coordinate Break

Availability

Optical Setups: General Optical Setup & Light Guide Optical Setup

Accessible: Optical Setup: *Ideal Components > Manipulators > Identity Operator*; *Coordinate Break*

This Ideal Component just returns the incoming field. It can be helpful if you want to change the position of a set of detectors at the same time: Just connect the detectors with the Identity Operator and change the position of the Identity Operator. Fig. 584 shows the edit dialog of the identity operator.

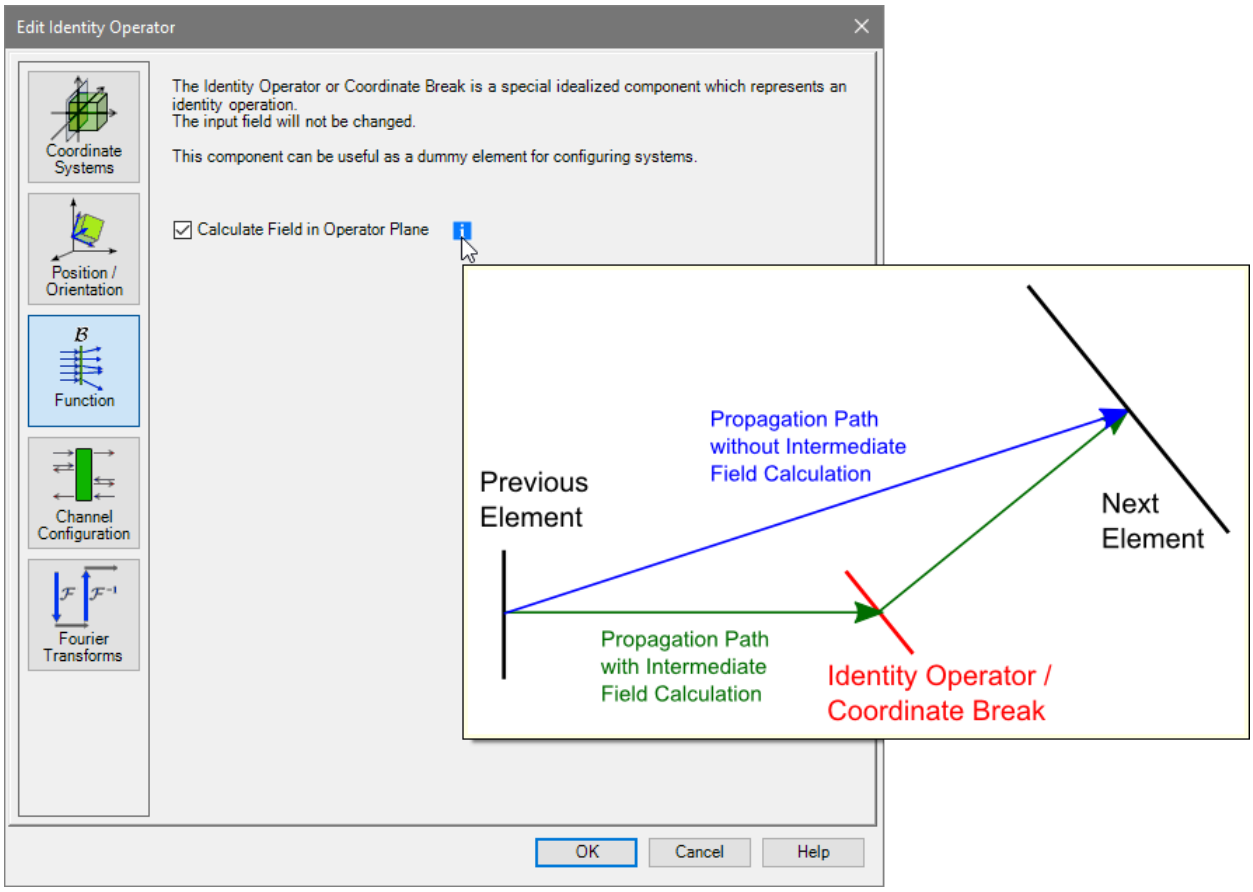


Figure 584. *The dialog for an Identity Operator.*

ITEM	DESCRIPTION
Calculate Field in Operator Plane	With this option the user can specify for the Classic Field Tracing whether the field shall be calculated in the plane of the identity operator or not. If this checkbox is switched off the ideal component is used for positioning only. The *Coordinate Break* element which can be found in the Optical Setup Tree is actually an Identity Operator where this option is switched off by default.

72.2 Lateral Shift

Availability

Optical Setups: General Optical Setup

Accessible: Optical Setup: *Ideal Components* > *Manipulators* > *Lateral Shift*

This operator allows you to shift the incoming field both in x- and y-direction by the specified *Lateral Shift*[PV]. The other settings are explained in Sec. 67.

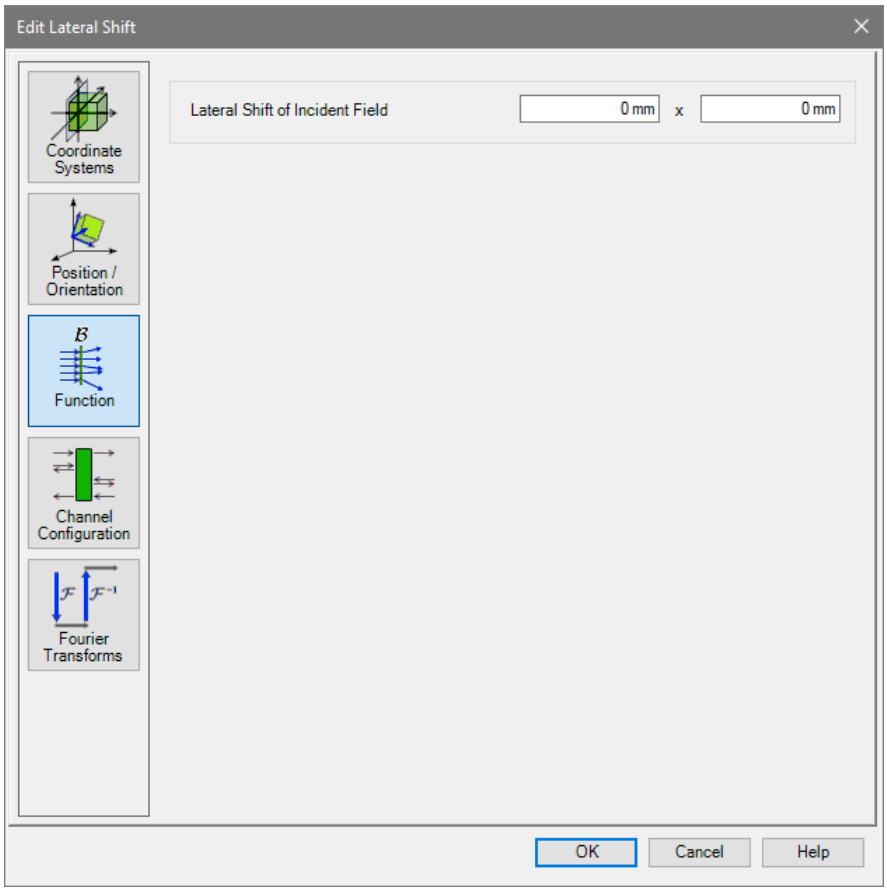


Figure 585. *The dialog for setting up a Lateral Shift.*

72.3 Sample Spherical Phase

Availability

Optical Setups: General Optical Setup

Accessible: Optical Setup: *Ideal Components > Manipulators > Sample Spherical Phase*

This Ideal Component just resamples the incoming harmonic field so that the spherical phase radius can be removed by a subsequent Optical Setup Element without loss of information. It has no specific settings; the general edit dialog for Ideal Components is explained in Sec. 67.
See also Sec. 12.1.1 for the concept of the spherical phase radius.

73 Mirrors

73.1 Ideal Plane Mirror

Availability

Optical Setups: General Optical Setup, Light Guide Optical Setup, and Laser Resonator Optical Setup

Accessible: Optical Setup: *Ideal Components > Mirrors > Ideal Plane Mirror*

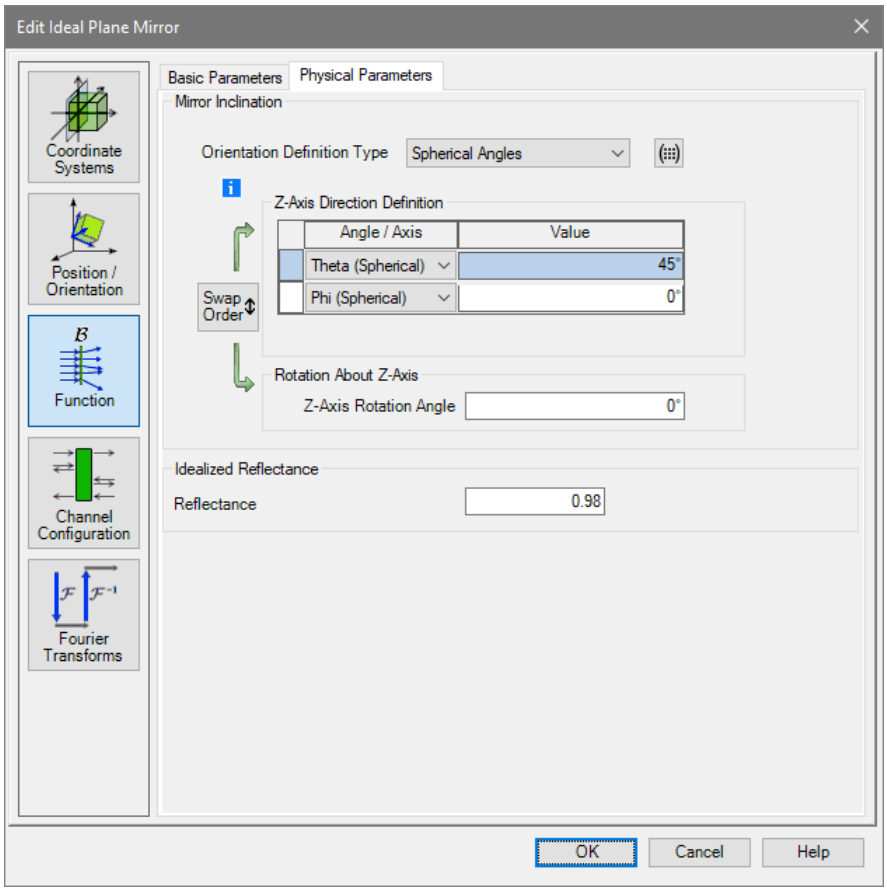


Figure 586. *The edit dialog for an Ideal Plane Mirror with* Function *tab selected.*

The Ideal Plane Mirror is an idealized plane mirror with the specified *Reflectance*[PV]. You can determine the *Mirror Inclination* via the control for defining an element's orientation (↪Sec. 5.6).
The other tab pages are explained in Sec. 67.

73.2 Ideal Spherical Mirror

Availability

Optical Setups: General Optical Setup, Light Guide Optical Setup, and Laser Resonator Optical Setup

Accessible: Optical Setup: *Ideal Components > Mirrors > Spherical Mirror*

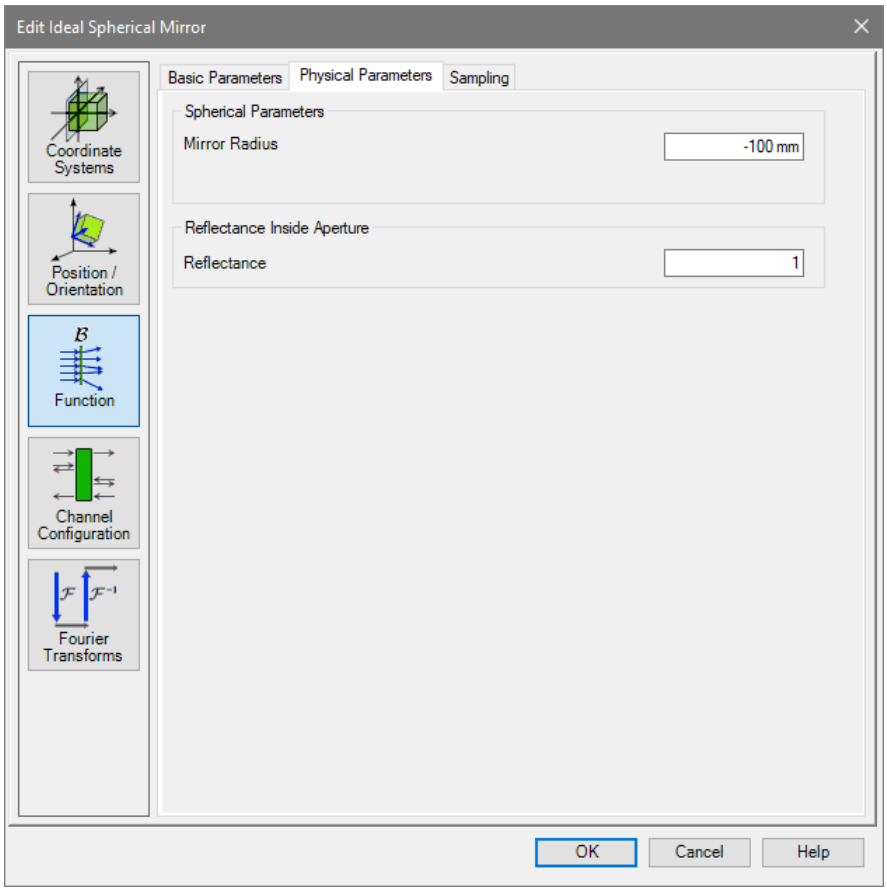


Figure 587. *Appearance of the* Physical Parameters *tab in a General Optical Setup.*

The *Function* tab of the edit dialog of a spherical mirror (↪Fig. 587) has three sub-tabs. The *Basic Parameters* sub-tab is explained in Sec. 67.1 and the *Sampling* tab is explained in Sec. 68.3.1.2.
The *Physical Parameters* sub-tab allows you to enter the following parameters:

ITEM	DESCRIPTION
Mirror Radius PV	The radius of curvature if the mirror was a real mirror. A negative value means a concave mirror, i. e. a incident plane wave is converging after reflection.
Reflectance PV	Allows you to consider the absorption of a real mirror inside the specified aperture. This factor, which must be between 0 and 1, is multiplied to the intensity values of the incident field. The reflectance outside the aperture (if one is specified) is always zero.

Additional settings for outcoupling are available on this tab in a Laser Resonator Optical Setup (if the mirror is not used as start mirror):

ITEM	DESCRIPTION
Transmittance Inside Aperture PV	Via this value the user sets the transmittance inside the aperture at the outcoupling mirror. If *Resulting from Reflectance* is chosen, the transmittance is adapted via $T = 1 - R$ automatically. In case of *Manual Setting* an arbitrary value between 0 and 1 can be adjusted. The value of *Reflectance* will be leaved unchanged in this case.
Transmittance Outside Aperture PV	Herewith the transmittance outside the aperture can be adjusted. This setting allows the user to build up *unstable resonators*.

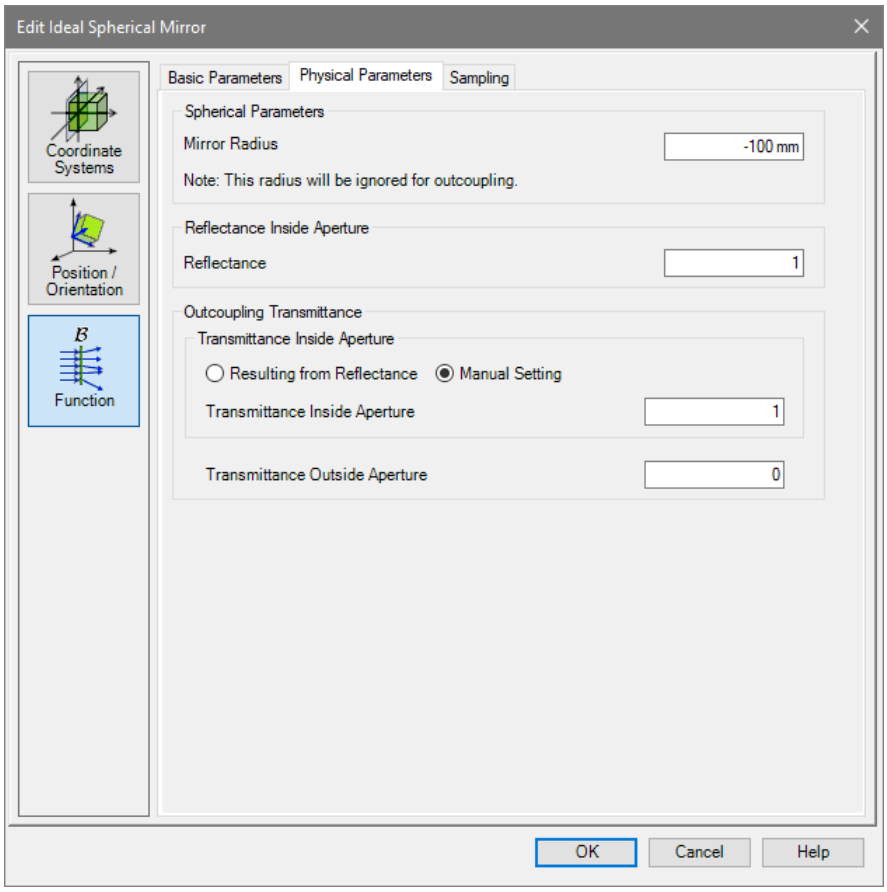


Figure 588. *Appearance of the* Physical Parameters *tab in a Laser Resonator Optical Setup.*

The other tab pages are explained in Sec. 67.

73.3 Ideal Stored Mirror Function

Availability

Optical Setups: Laser Resonator Optical Setup

Accessible: Optical Setup: *Ideal Components > Mirrors > Ideal Stored Mirror Function*

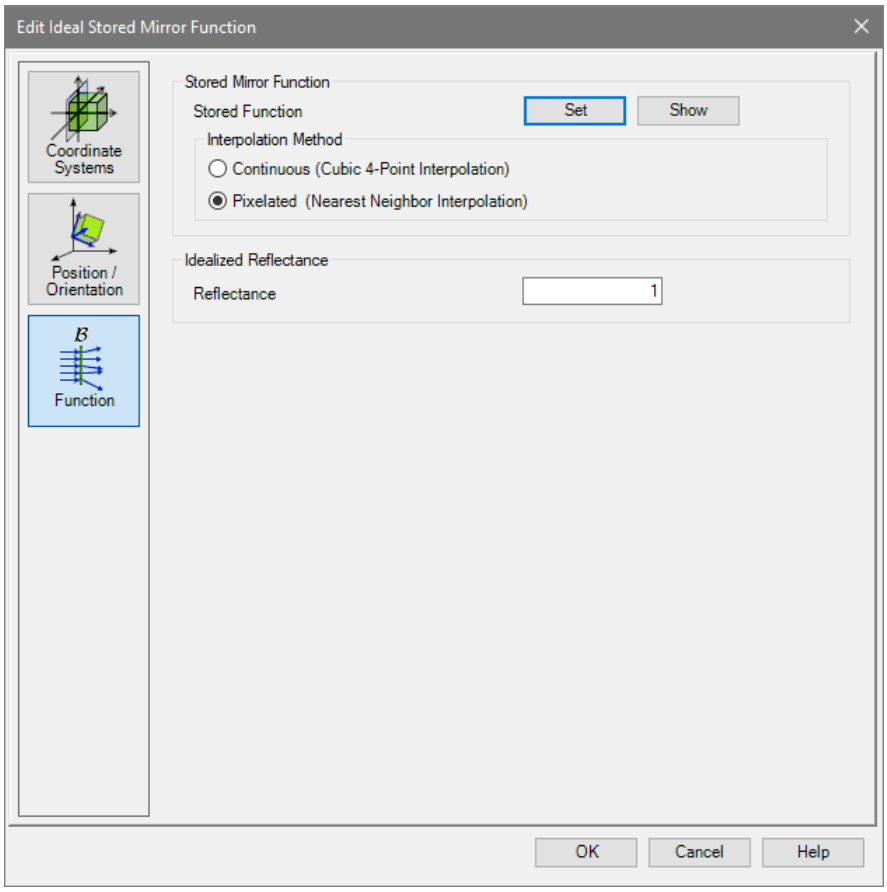


Figure 589. *The edit dialog for an Ideal Stored Mirror with Function tab selected.*

The *Function* tab of the edit dialog of the Ideal Stored Mirror Function (Fig. 589) has the following options:

ITEM	DESCRIPTION
Set	Sets a Jones Matrix Transmission which represents the mirror function.
Show	Shows the stored mirror function as Jones Matrix Transmission.
Interpolation Method	Specifies whether the given sampled data is interpolated or not.
Reflectance	The reflectance of the mirror, i. e. a value between 0 and 1.

The other tab pages are explained in Sec. 67.

74 Special Components

The following ideal components are available at *Ideal Components > Special Components* in the Optical Setup Tree.

- 1f-Setup (↪Sec. 31.1.1)
- 2f-Setup (↪Sec. 31.1.1)
- ABCD Matrix Setup (↪Sec. 74.1)
- Evanescent Field Filter (↪Sec. 74.2)
- Field Decomposition (↪Sec. 74.3)

74.1 ABCD Matrix Setup

Availability

Optical Setups: General Optical Setup & Light Guide Optical Setup

Accessible: Optical Setup: *Ideal Components > Special Components > ABCD Matrix Setup*

This Ideal Component allows you to define an ABCD matrix from an arbitrary number of optical elements. The effect of this ABCD matrix on the incoming field is then simulated

- for General Profile and Ray Results Profile with the ray transfer equation Eq. (140.1) and
- for Classic Field Tracing with the propagation algorithm given by Collins Eq. (140.3). For this propagation technique the matrix elements A and B of the resulting ABCD matrix must not be zero.

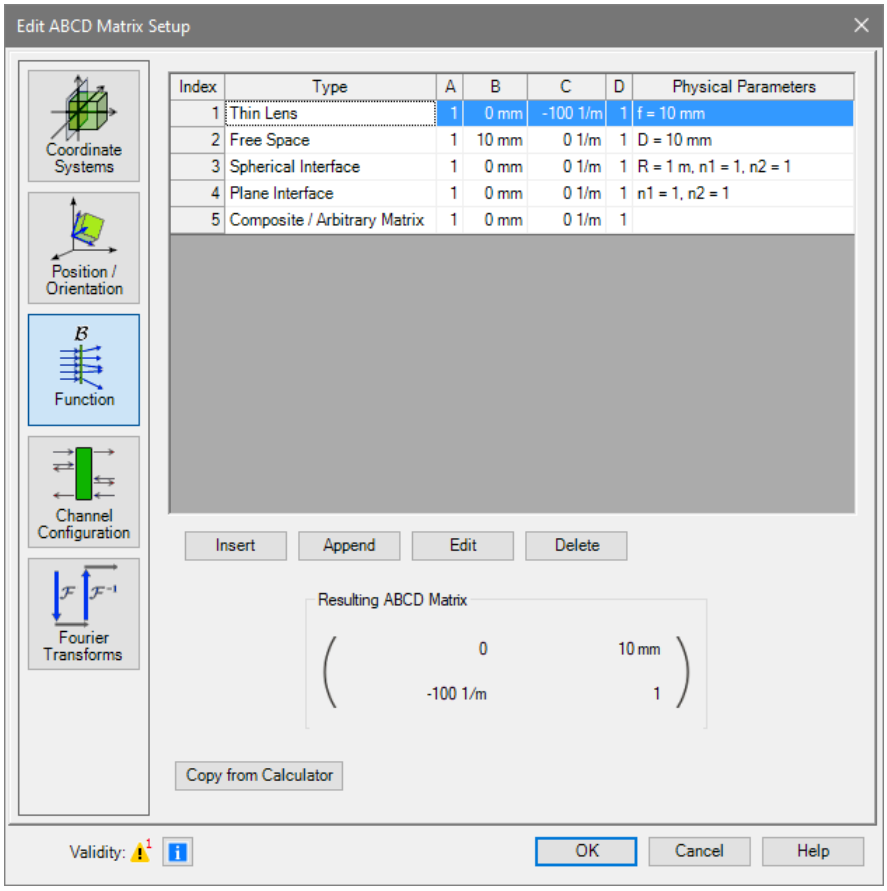


Figure 590. *The edit dialog for the ABCD Matrix Setup. The validity indicator (↪Sec. 5.11) shows a warning because matrix element A is zero and thus Classic Field Tracing cannot be used to propagate through this Ideal Component.*

The edit dialog of this component is the general edit dialog for Ideal Components (↪Sec. 67). Its *Function* tab (↪Fig. 590) comprises the control to define the ABCD matrix (↪Sec. 5.17) and additionally the following controls:

ITEM	DESCRIPTION
Resulting ABCD Matrix	Shows the resulting ABCD matrix.
From Calculator	A button (↪Sec. 5.7) to copy the ABCD matrix elements from an ABCD Law Calculator (↪Sec. 105). Either a new calculator is created and shown as a dialog or an already existing calculator is loaded.

74.2 Evanescent Field Filter

Availability

Optical Setups: General Optical Setup

Accessible: Optical Setup: *Ideal Components > Special Components > Evanescent Field Filter*

This Ideal Component just eliminates the evanescent part of the field and reduces the sampling accordingly. Only propagating plane waves remain in the spectrum of plane waves representation of the field. It can be helpful to study the importance of evanescent fields. It has no specific settings; the general edit dialog for Ideal Components is explained in Sec. 67.

74.3 Field Decomposition

Availability

Optical Setups: General Optical Setup & Light Guide Optical Setup

Accessible: Optical Setup: *Ideal Components > Special Components > Field Decomposition*

This Ideal Component decomposes a field laterally into distinct modes which can improve performance.

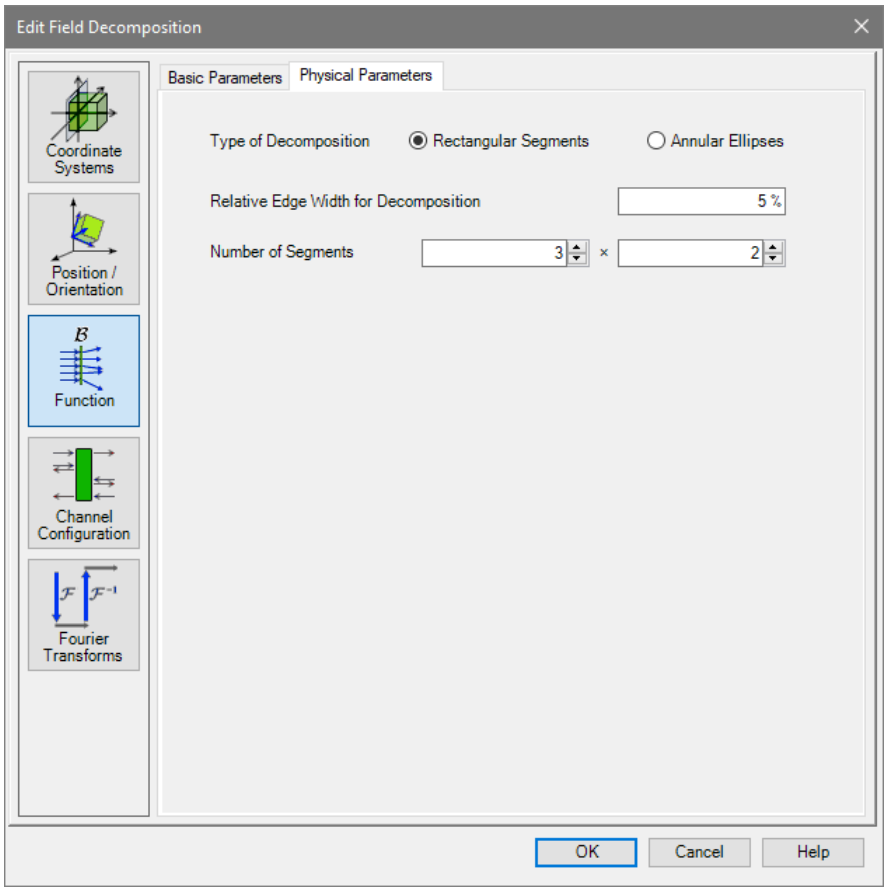


Figure 591. *The Physical Parameters sub-tab of the Field Decomposition component.*

The *Function* tab of the edit dialog of a Field Decomposition component (↪Fig. 591) has two sub-tabs. The *Basic Parameters* sub-tab is explained in Sec. 67.1. The *Physical Parameters* sub-tab allows you to enter the following parameters:

ITEM	DESCRIPTION
Type of Decomposition PE	Allows you to choose between *Rectangular Segments* and *Annular Ellipses*. Fig. 592 illustrates the two decomposition types.
Relative Edge Width for Decomposition PV	Hard edges in a mode can lead to unwanted effects. Thus you have the opportunity to define a relative edge width during which the field values decrease from their original values to zero. The larger this value, the softer the edge becomes but also the larger the overlap of the modes becomes, which leads to higher numerical effort.
Number of Segments PV	ONLY FOR *RECTANGULAR SEGMENTS* Defines the number of segments in both x- and y-direction, respectively.
Number of Annuli PV	ONLY FOR *ANNULAR ELLIPSES* Defines the number of “rings”.

The other tab pages are explained in Sec. 67.

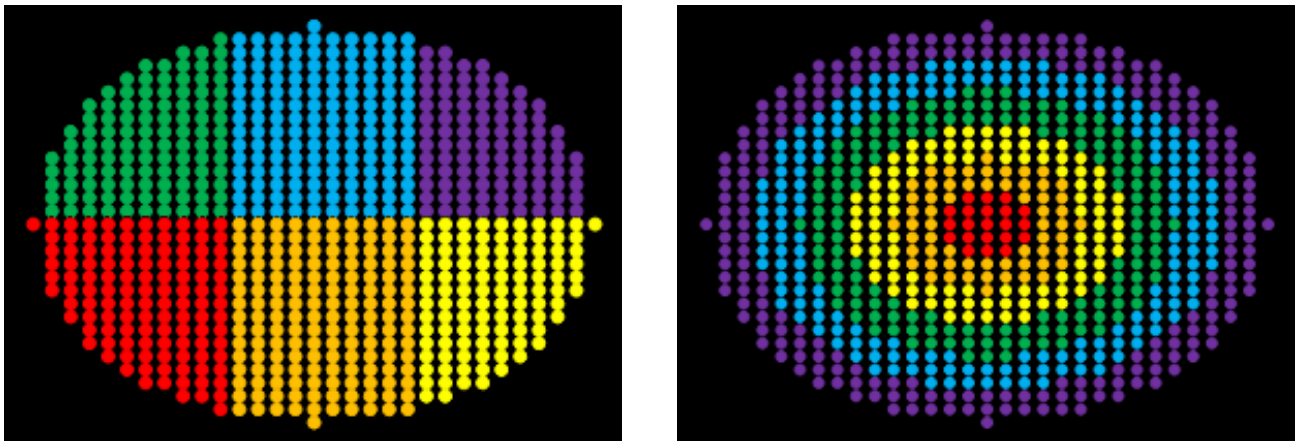


Figure 592. *A field decomposed into lateral segments (to which different colors were assigned). Left: 3 × 2 Rectangular Segments, right: 6 Annular Ellipses.*

XI Detectors: Evaluating Data

Detectors evaluate field data or even a numerical data array in various ways. For example you can extract the value at a certain point, determine the spot size, or calculate the magnetic field.

75 Detectors in the Optical Setup

75.1 Base Dialog

All detectors in the Optical Setup use the same base dialog which has the following controls.

ITEM	DESCRIPTION
Coordinate Systems	↪Sec. 44.9.1
Position / Orientation	↪Sec. 44.9.2
Detector Parameters > Detector Window and Resolution	↪Sec. 75.1.1
Detector Parameters > Detector Function	Contains the specific settings for the respective detector.
Free Space Parameters	↪Sec. 44.5.1
Save	Saves the detector to the catalog (↪Sec. 33). Not visible if the edit dialog is shown from within the detectors catalog. For technical reasons the Pulse Evaluation detector cannot be saved.

75.1.1 Detector Window and Resolution

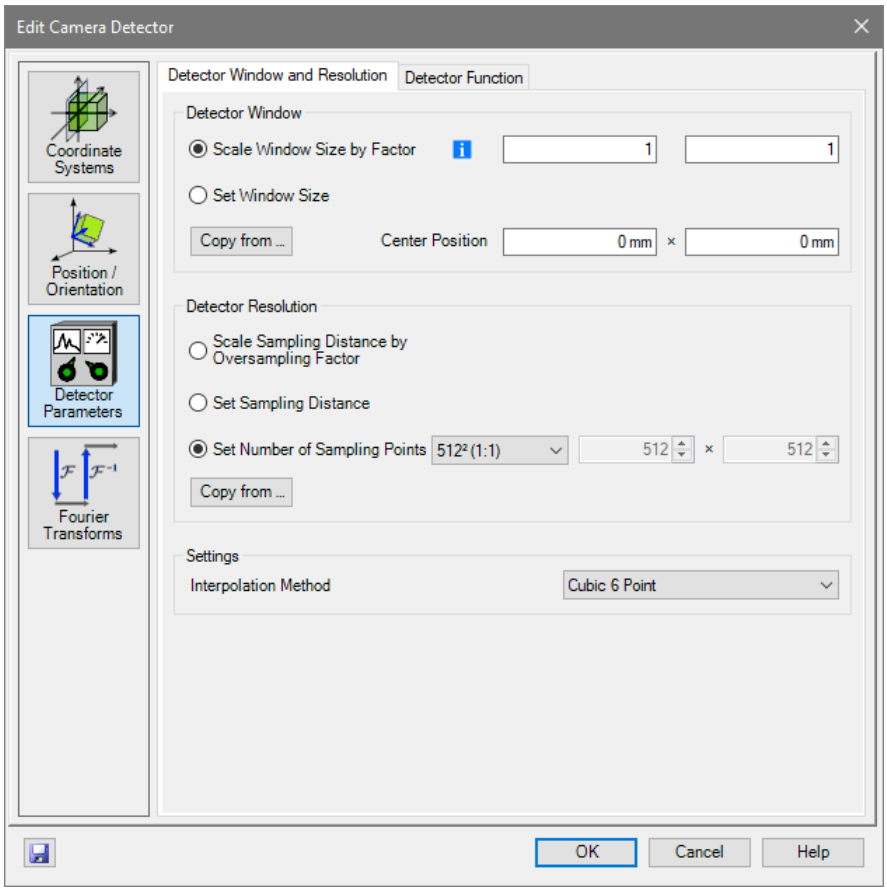


Figure 593. *The* Detector Window and Resolution *sub-tab page.*

The *Detector Window and Resolution* sub-tab page of a detector (↪Fig. 593) allows you to configure both size and position of the detector window as well as the resolution of the detector. The incident field is interpolated accordingly.

ITEM	DESCRIPTION
Scale Window Size by Factor	If this option is checked, you can define a scaling factor separately for x- and y-direction. A scaling factor larger than one means that the incident field is embedded, a factor smaller than one means that it is cropped.
Set Window Size	If this option is checked, you can directly set the size of the detector window.
Copy from … {Detector Window}	Copies the detector window from an open document window with a rectangle marker. The size and the position of the selection in that document are set into the dialog. This can also be done via right click on the detector icon in the Optical Setup View (↪Sec. 44.1).
Center Position	The center position of the detector window relative to the internal coordinate system of the detector.
Scale Sampling Distance by Oversampling Factor	If this option is checked, you can define a scaling factor separately for both x- and y-direction. A scaling factor larger than one makes the sampling of the incident field finer, a factor smaller than makes it coarser.
Set Sampling Distance	If this option is checked, you can directly set the resolution of the detector.
Set Number of Sampling Points	With this option you can choose from various predefined resolutions. *Global Options* refers to the default number of sampling points defined in the Global options dialog (↪Sec. 6.12). If you select *User-Defined* you can choose an arbitrary number of sampling points. Independent from the number of sampling points a one-dimensional input field always stays one-dimensional. In contrast, if you specify only one sampling point for one direction, you can make a two-dimensional field one-dimensional.
Copy from … {Detector Resolution}	Copies the resolution from an open document window displaying either a harmonic field or a harmonic fields set. The sampling distance of that document is used for it.
Interpolation Method	Defines which interpolation method is to be used if resampling of the incident field is necessary.

The functionality of the *Copy from …* button for the detector window can also be accessed from the context menu of a detector in the Optical Setup View (↪Sec. 44.1).

75.2 Copy Settings from Other Detector

This tool can be accessed via the context menu of a detector symbol in the Optical Setup View (↪Sec. 44.1). It copies certain settings from a *template detector* to the currently selected detector.

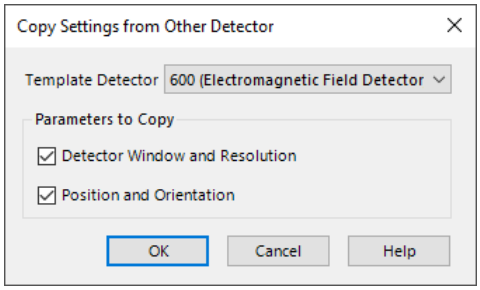


Figure 594. *The dialog to copy certain settings from another detector.*

Its edit dialog (↪Fig. 594) has the following settings.

ITEM	DESCRIPTION
Template Detector	Here you can select the detector from which the settings are copied. The currently selected detector is excluded from that list because it is the target of the copy operation.
Detector Window and Resolution	If this option is checked, all settings on the *Detector Window and Resolution* tab (↪Sec. 75.1.1) are copied from the template detector.
Position and Orientation	If this option is checked, the basal position and orientation settings (↪Sec. 44.9.2.2) are copied from the template detector.

75.3 Programmable Detector

Availability

Optical Setups: General Optical Setup & Light Guide Optical Setup

Accessible: Optical Setup: *Detectors > Programmable Detector*

The Programmable Detector allows you to evaluate the incoming field with a snippet.
The *Detector Parameters* tab contains two sub-tabs: the *Detector Window and Resolution* sub-tab which is explained in Sec. 75.1.1 and the *Detector Function* sub-tab which is explained below.
The remaining tab pages are explained in Sec. 75.1. General information about programming in VirtualLab Fusion can be found in Sec. 7.

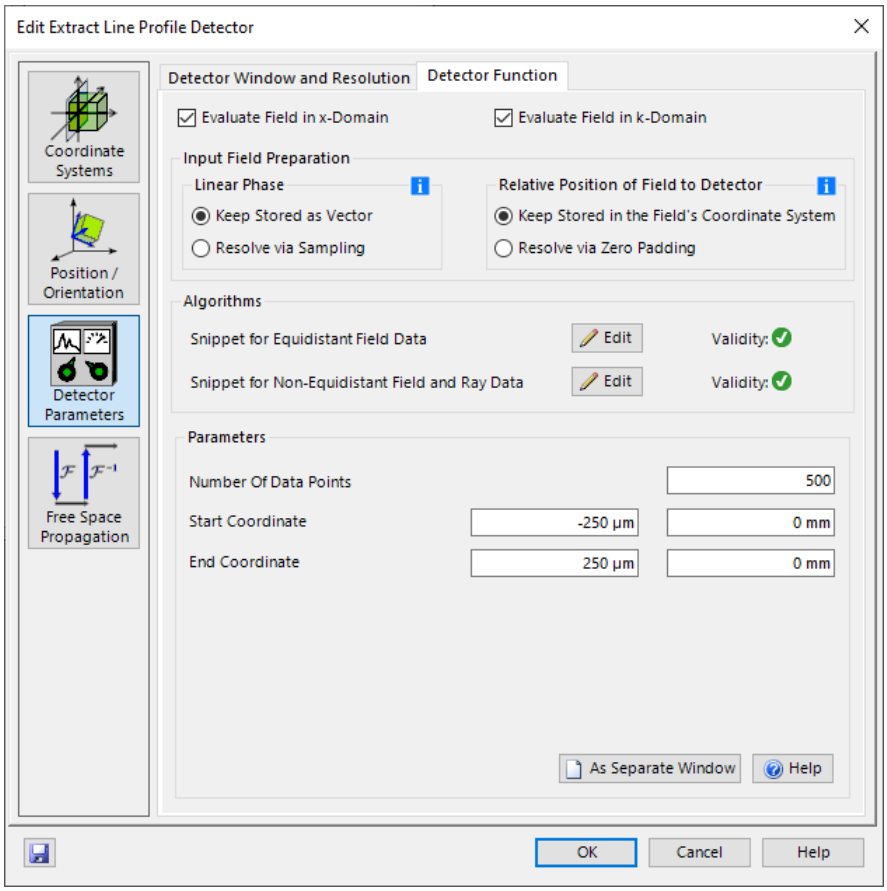


Figure 595. *The Detector Function page of the Programmable Detector.*

On this tab page you can define the detector function by two snippets (for equidistant and non-equidistant data,

respectively). In these snippets you have access to the incoming field in spatial domain via the `InputField` variable in case of equidistant data and the `RayTracingResult` variable in case of non-equidistant data, respectively. In both cases the field in spectral domain is available via the `SpectralField` variable, a `ModeCollection` which can contain a mix of equidistant and non-equidistant member fields. The settings on the *Detector Window and Resolution* tab are already applied to the fields available within the snippets.
For equidistant data the user can specify whether the incident field shall be calculated centered to the optical system and whether the linear phase of the incident field shall be handled analytically or be sampled before applying the snippet of the Programmable Detector.
The *Detector Function* tab (↪Fig. 595) contains the following controls:

ITEM	DESCRIPTION
Evaluate Field in x-Domain	If you check this option, the field in x-domain is calculated and available as `InputField` or `RayTracingResult` variable in the snippets. Otherwise these variables are `null`.
Evaluate Field in k-Domain	If you check this option, the field in k-domain is calculated and available as `SpectralField` variable in the snippets. Otherwise this variable is `null`. The dialog ensures that at least the spatial or the spectral field is evaluated.
Linear Phase	The user can specify whether the linear phase of the incident equidistant field shall be sampled (option *Resolve via Sampling*) or whether it is handled analytically by the snippets (option *Keep Stored as Vector*).
Relative Position of Field to Position of Input Transface	The field reaching the Programmable Detector is always rotated into the detector plane. But if the option *Resolve via Zero Padding* is checked, equidistant field data will be also padded into zeros in a way that the new origin of the field's coordinate system will be identical to that of the detector. If the option *Keep Stored in the Field's Coordinate System* is chosen, no additional preparation will be done.
Snippet for Equidistant Field Data	The snippet evaluated by the Programmable Detector if equidistant field data enters the detector. This happens if the system is analyzed with Classic Field Tracing or if the system is analyzed with General Profileand the last Fourier transform done is not a pointwise one. *Edit* opens the Source Code Editor (↪Sec. 7.3), and a validity indicator (↪Sec. 5.11) shows whether this snippet is consistent.
Snippet for Non-Equidistant Field and Ray Data	The snippet evaluated by the Programmable Detector if non-equidistant data enters the detector. This happens if the system is analyzed with General Profile and the last Fourier transform done is a pointwise one or if the system is analyzed with Ray Results Profile. *Edit* opens the Source Code Editor (↪Sec. 7.3), and a validity indicator (↪Sec. 5.11) shows whether this snippet is consistent.
Parameters PE	The controls in this group box allow you to set the values of the global parameters of the snippets. ↪Sec. 7.4

Programmable Detectors might be set to a mode where the source code cannot be changed and thus the *Input Field Preparation* group box, the *Use Field in Spatial / Spectral Domain* check boxes, and the *Algorithms* groupbox are hidden.

Notes for Snippet Developers

A Programmable Detector can also be used in the main window (↪Sec. 76.1). Then the `ParentSystem` / `ParentLightPath` is `null` and the `IndexOfDetector` is `-1`, which must be handled in the snippets.

75.4 Universal Detector

Availability

Optical Setups: General Optical Setup & Light Guide Optical Setup

Accessible: Optical Setup: *Detectors > Field Visualization > Universal Detector*

This detector can be used to evaluate any vectorial component (E_x, E_y, E_z, H_x, H_y, or H_z) of an incoming light distribution. These components are given as different subsets of an Electric, Magnetic or Electromagnetic Field (↪Sec. 13.1, ↪Sec. 13). If the incoming light has multiple modes, one field is generated per mode and all resulting data are collected in one Set Of Objects (↪Sec. 16). Depending on the subsequent configuration coherent modes can be added up (with different settings) or not.
The implemented formulas for the calculation of the magnetic field are given in Sec. 142.7.1.
Based on the Electromagnetic Field any merit function can be evaluated. This is realized in VirtualLab Fusion by detector Add-ons which are available in the *Universal Detector*.

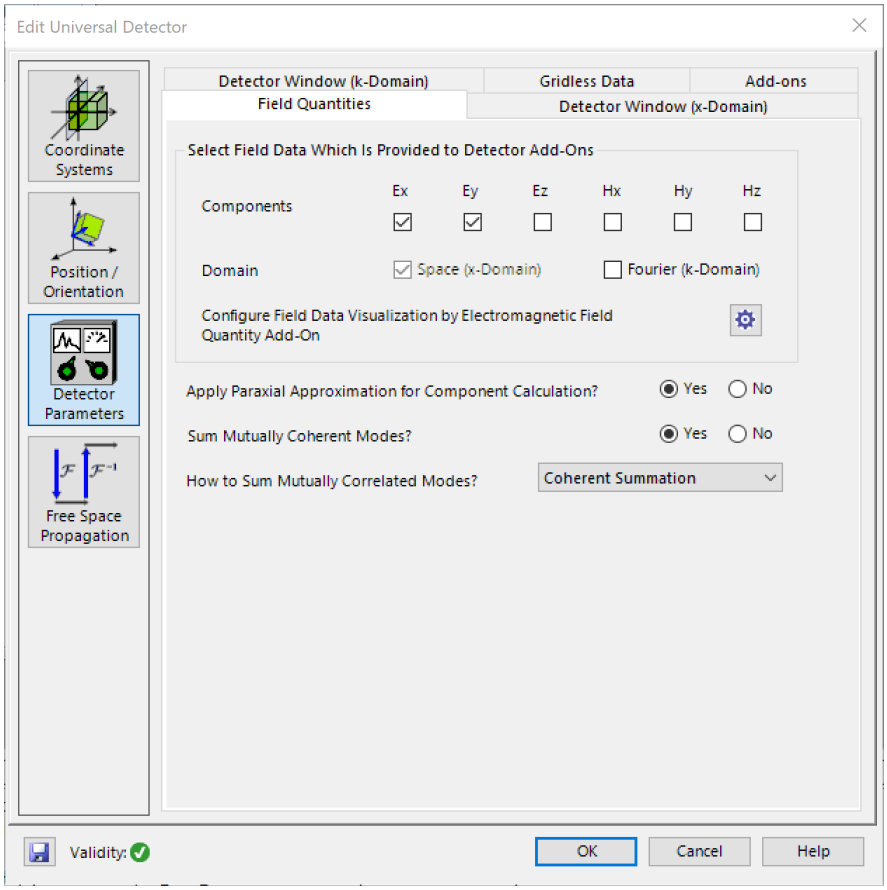


Figure 596. *The edit dialog of the Universal Detector.*

The edit dialog of this detector (↪Fig. 596) provides the following sub pages for different configuration settings:

ITEM	DESCRIPTION
Field Quantities	Via the controls on this tab page the user can define which field quantities in which domain shall be evaluated. A detailed description of the parameters can be found under Sec. 75.4.1
Detector Window (x-Domain)	On this tab page the user specifies the detector window and the resolution (for gridded data) for the evaluated field in x-domain. For details please check Sec. 75.4.2.
Detector Window (k-Domain)	On this tab page the user specifies the detector window and the resolution (for gridded data) for the evaluated field in k-domain. For details please check Sec. 75.4.3.
Gridless Data	The universal detector also allow the evaluation of the field data in gridless format. The settings for the gridless data output can be specified here.
Add-ons	As stated above it is supported to evaluate any detector function based on the evaluated Electromagnetic Field. On the *Add-ons* page the user can specify a tree of detector add-ons which are processed after the *Universal Detector* calculated the Electromagnet Field.

In the following sections the controls on the tab pages are explained more in detail.

75.4.1 Field Quantities

The tab page *Field Quantities* allows the user to specify the electromagnetic field components to evaluate as well as the domains in which the component shall be calculated. A selection of advanced configuration options are also available which are explained below.
Fig. 597 shows the controls to configure the field quantities.

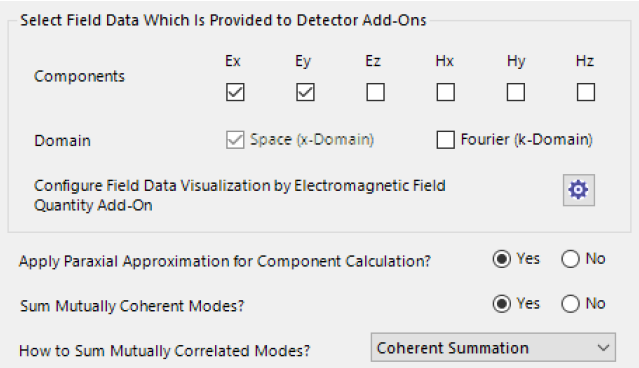


Figure 597. *The user interface to configure the field quantities within the universal detector (and the system modeling analyzer).*

The following settings can be configured

ITEM	DESCRIPTION
Components	Allows the user to select which vectorial components of the field are evaluated. The dialog ensures that at least one component is selected.
Domain	The user can select whether to evaluate the electromagnetic field in x-domain and/or k-domain. The dialog ensures that at least one option is selected.
Configure Field Data Visualization by Electromagnetic Field Quantity Add-On	In the controls explained above the user configures which quantities/domains shall be calculated by the detector. This input data is provided to the detector Add-Ons of the *Universal Detector*. A standard add-on is the output of the data. Here the user can select what of the evaluated quantities should be generated as document windows in VirtualLab Fusion. By clicking on the configuration button a dialog opens in which the mentioned configuration can be done. More information on that see Sec. 75.4.5.1.
Apply Paraxial Approximation for Component Calculation	The *Universal Detector* provides an option to calculate field components by paraxial assumptions. Typically the field components *Ex* and *Ey* are provided by the engine. All other components can be calculated from these two field component. To speed up detector evaluation VirtualLab Fusion provides an option to use simplified formulas for the field component calculation. This enable also that there is no need to have special versions of detector add-ons with paraxial assumptions.
Sum Mutual Coherent Modes	Source modes in VirtualLab Fusion are typically incoherent (different or same wavelength). During propagation through an optical setup a source mode could be split into different modes (e.g. at a grating), where the modes are typically coherently to each other. The *Universal Detector* provides an option whether the coherent modes should be summed up before further processing via *Detector Add-ons*. If the user decides to *Sum Mutual Coherent Modes* additional options will be available to define how the modes shall be summed up.
How to Sum Mutually Coherent Modes	If the user selected to *Sum Mutual Coherent Modes*, he needs to specify the summation type how the modes shall be summed up. There are various *Summation Type*s how coherent modes can be summed up: *Coherent Summation*, *Incoherent Summation*, and *Partial Coherent Summation*. For the latter you can specify the degree of coherence by entering a *Coherence Time*[PV] (or copying it from a Coherence Time & Length Calculator ↪Sec. 106). .

Note: The settings in these control define which field component in which domain shall be calculated. This is not identical with the result visualization of the *Universal Detector*. The values to show as data array are configured under *Electromagnetic Field Quantities*. Detailed information see Sec. 75.4.5.1.

75.4.2 Detector Window (x-Domain)

The user can specify the detector window and the resolution (for gridded data) in x-domain for the *Universal Detector*. The configurations are done in the tab page *Detector Window (x-Domain)*.
Fig. 598 shows the user interface to configure the detector window in x-domain.

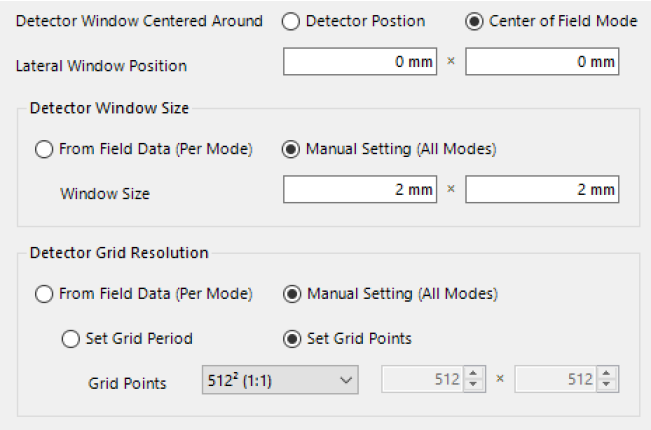


Figure 598. *The user interface to configure the detector window (x-domain) within the universal detector (and the system modeling analyzer).*

In these controls the user can specify the following parameters:

ITEM	DESCRIPTION
Detector Window Centered Around	The user has to specify where the output data of the detector shall be given. VirtualLab Fusion provides two options to the user: *Detector Position* and *Center of Field Mode*.
Lateral Window Position	In x-domain the user has an additional freedom to define also a lateral shift of the coordinate system. This option is independent to the general positioning control of each optical system element.
Detector Window Size	In the group box *Detector Window Size* the user can specify the window size for evaluation of the field component. The window size can be specified *From Field Data* or via *Manual Setting*. In case of *From Field Data* the field size might be different for each mode that illuminates the detector. In that case the user can specify an additional *Size Scaling Factor*. In case of *Manual Setting* the same detector window size is applied on each incident field mode. In this case the user needs to specify the *Window Size* directly.
Detector Grid Resolution	Finally the user can specify in the section *Detector Grid Resolution* the grid which is used to generate gridded data by the *Universal Detector*. The user has again two options for the general specification of the resolution: *From Field Data* or *Manual Setting*. In case *From Field Data* each incident mode is analyzed and the input sampling is used as detector grid. The user can optionally enter a *Grid Period Scaling Factor*. If the user selects *Manual Setting* all incident modes will converted on the same grid. In case *Manual Setting* is selected the user has the option to select whether to *Set Grid Period* (which corresponds to the sampling distance) or to *Set Grid Points*.

75.4.3 Detector Window (k-Domain)

The user can also specify the detector window and the resolution (for gridded data) in k-domain for the *Universal Detector*. The configurations are done in the tab page *Detector Window (k-Domain)*. The configuration is quite similar to the *Detector Window (x-Domain)*. Main difference is that size and grid period are specified in wave numbers and not in length unit.

Fig. 599 shows the user interface to configure the detector window in k-domain.

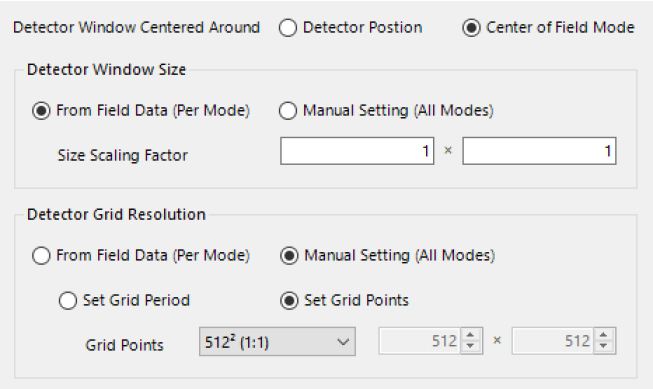


Figure 599. *The user interface to configure the detector window (k-domain) within the universal detector (and the system modeling analyzer).*

In these controls the user can specify the following parameters:

ITEM	DESCRIPTION
Detector Window Centered Around	The user has to specify where the output data of the detector shall be given. VirtualLab Fusion provides two options to the user: *Detector Position* and *Center of Field Mode*.
Detector Window Size	In the group box *Detector Window Size* the user can specify the window size for evaluation of the field component. The window size can be specified *From Field Data* or via *Manual Setting*. In case of *From Field Data* the field size might be different for each mode that illuminates the detector. In that case the user can specify an additional *Size Scaling Factor*. In case of *Manual Setting* the same detector window size is applied on each incident field mode. In this case the user needs to specify the *Window Size* directly.
Detector Grid Resolution	Finally the user can specify in the section *Detector Grid Resolution* the grid which is used to generate gridded data by the *Universal Detector*. The user has again two options for the general specification of the resolution: *From Field Data* or *Manual Setting*. In case *From Field Data* each incident mode is analyzed and the input sampling is used as detector grid. The user can optionally enter a *Grid Period Scaling Factor*. If the user selects *Manual Setting* all incident modes will converted on the same grid. In case *Manual Setting* is selected the user has the option to select whether to *Set Grid Period* (which corresponds to the sampling distance) or to *Set Grid Points*.

75.4.4 Gridless Data

VirtualLab Fusion supports also the evaluation of the electromagnetic field of gridless data by the *Universal Detector*. The gridless output is only possible if the incident light at the detector comes in gridless format. In addition there is another limitation, which will not allow the generation of gridless data output of the *Universal Detector*: In case more than one coherent mode illuminates the detector and the user has defined to sum up the coherent modes this summation can also be only done on an equidistant grid. In case the input data is gridded but the user defined to show only gridless data the detector will fall back to gridded data output.
Fig. 600 shows the user interface to configure the gridless data output of the *Universal Detector*.

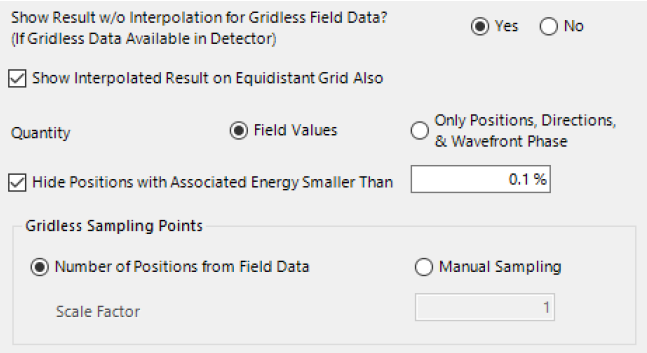


Figure 600. *The user interface to configure the gridless data output of the universal detector (and the system modeling analyzer).*

The user can specify the following options in the section *Gridless Data*:

ITEM	DESCRIPTION
Show Result w/o Interpolation for Gridless Data	By selecting *Yes* for *Show Result w/o Interpolation for Gridless Data* the user defines that he likes to generate gridless data as detector output. If the incident light of the detector comes in gridded format gridless data will not be generated by the detector. If *Yes* is selected additional options are shown below the decision controls.
Show Interpolated Result on Equidistant Grid	If the user selects to generate gridless data he can activate to generate also gridded data. If this option is checked and the input field comes in gridless format the *Universal Detector* will generate gridless as well as gridded data.
Quantity	For gridless data VirtualLab Fusion supports to select whether the gridless data shall contain *Field Values* or only *Positions, Directions and Wavefront* data. The generation of *Positions, Directions and Wavefront* corresponds to the standard results generated in classical ray tracing software. Note: In the modeling profile *Ray Result* the universal detector is restricted to generate always *Positions, Directions and Wavefront* data.
Gridless Sampling Points	Finally the user can specify the gridless sampling points that shall be generated. The user has two options: Use *Number of Points from Field Data* or to use *Manual Sampling*. In case of *Number of Points from Field Data* the number and location of points for gridless data is directly used from the input field of the detector. If the user decides to use *Manual Sampling* the point selection mode has to be specified. VirtualLab Fusion supports the following selection modes: *x-y-Grid*, *Hexapolar* and *Random*. For the specification of *x-y-Grid* the user needs to specify the number of points in x- and y-direction. In case of *Hexapolar* the density has to specified. In *Random* point selection mode the user need to specify the number of points, the seed value for random generation and also whether a mesh shall be generated for the random generated points. Detailed information can be found in Sec. 44.5.3.1.

75.4.5 Detector Add-ons

In the tab page *Add-ons* the user has the option to define a tree of Detector Add-ons. ↪Fig. 601 shows the user interface to specify the detector *Add-ons*.

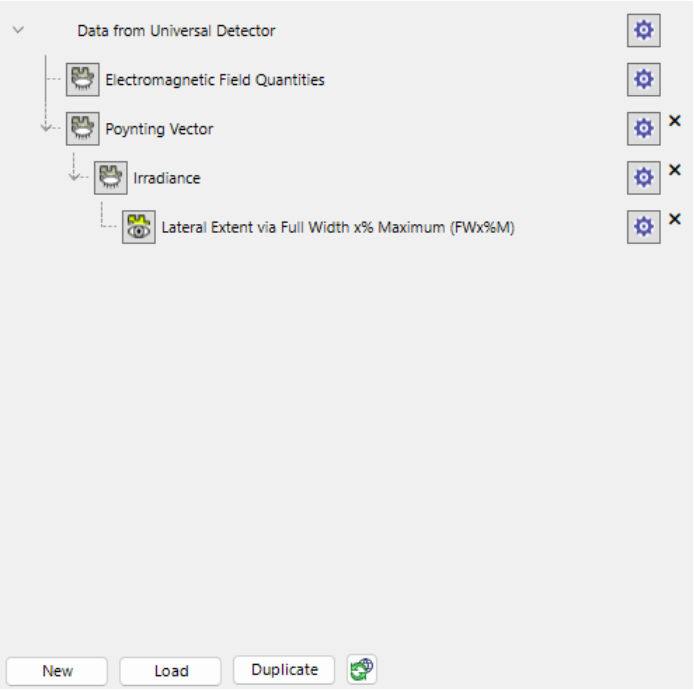


Figure 601. *The user interface to define the detector add-ons which can be used within the universal detector.*

A detector add-on is typically defined by a user-defined/customized snippet. This enables the full flexibility to develop any merit function the user has in mind even if the merit function is not yet available as prepared add-on. VirtualLab Fusion comes with a variety of predefined detector add-ons which can be easily synchronized via pushing the corresponding button (via internet).
Note that you can chain the add-ons: One add-on can use the output of another add-on as input. Thus in the end you have a tree of add-ons with the *Data from Universal Detector* as root. There is a pre-defined add-on *Electromagnetic Field Quantities* (↔Sec. 75.4.5.1) directly dependent on *Data from Universal Detector*.
In the tree view on top of the tab page you can use drag & drop to resort the add-ons and change their dependencies (a child entry always gets its input from the direct parent). For each add-on there are the following controls available in the tree view.

ITEM	DESCRIPTION
/	Allows you to toggle whether the output of this add-on is shown () or not (). Note that even if the output is not shown, the add-on is still processed if its output is required as input for another add-on.
	For the *Electromagnetic Field Quantities* this button opens the dialog described in Sec. 75.4.5.1. For all other add-ons the dialog described in Sec. 75.4.5.2 allows you to edit and save the add-on.
×	Closes the add-on. Before, you are asked whether you want to save the add-on snippet.

On the bottom of this tab page there are the following buttons.

ITEM	DESCRIPTION
New	Adds a new default add-on.
Load	Loads and adds an add-on from the catalog of available add-ons (↪Sec. 35).
Duplicate	Duplicates the selected add-on and append it to the detector add-on tree. For this operation a detector add-on has to be selected in the tree above. Note: The default add-on (Electromagnet Field Quantities) cannot be duplicated.
	The folder with the add-ons prepared by LightTrans is updated via Internet. Optionally also the snippets of all favorites (↪Sec. 77.9) are then updated if they have the same name as a predefined addon. The values of your favorites's snippet parameters are kept.

Note for Snippet Developers

Note that an Universal Detector can also be used in the main window (↪Sec. 76.1). Then the `ParentSystem` is `null` and the `DetectorIndex` is `-1`, which must be handled in the snippet.

75.4.5.1 Electromagnetic Field Quantities

The *Universal Detector* comes always with the *Electromagnet Field Quantities* add-on by default. This add-on can not be removed from the tree. It is also not possible to change its position in the tree of detector add-ons. The task of the *Electromagnet Field Quantities* add-on is to show the available field components in its domains. The detector add-on could be disabled. In addition it allows to define a subset of the information evaluated by the *Universal Detector*.
↪Fig. 602 shows the edit dialog of the *Electromagnetic Field Quantities* add-on.

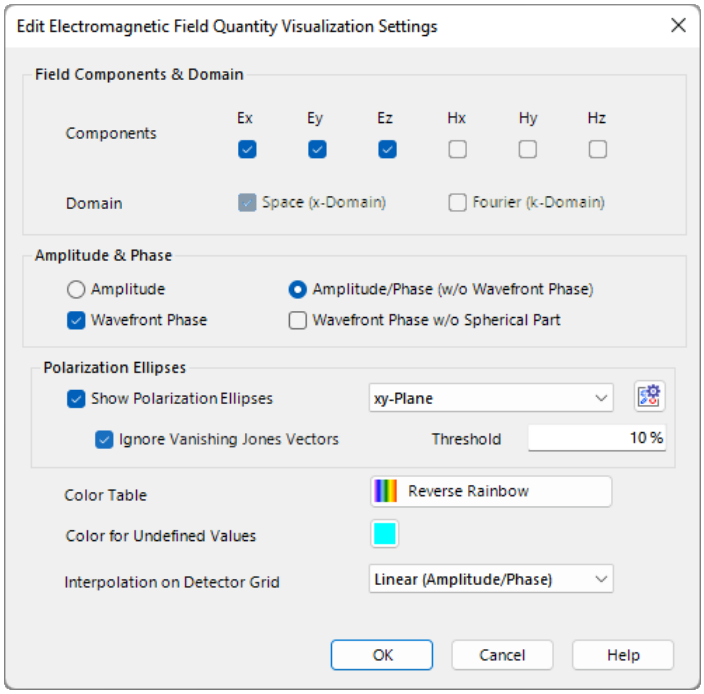


Figure 602. *The edit dialog of the* Electromagnet Field Quantities *add-on.*

Within the edit dialog the following options can be configured

ITEM	DESCRIPTION
Field Components	Allows you to select which vectorial components of the field shall be displayed. Only calculated field components (from *Universal Detector* or *System Modeling Analyzer* can be selected. The dialog ensures that at least one component is selected.
Domain	The user can select whether to show the field in x-domain and/or k-domain. Only domains which are calculated can be selected
Amplitude	If selected only the amplitude of the field will be generated as output.
Amplitude/Phase (w/o Wavefront Phase)	The user can also select whether to show amplitude and phase of the calculated field component. The phase will be given in 2PI modulo format and will not include the smooth wavefront phase.
Wavefront Phase	In addition to the amplitude (and 2PI modulo phase) of the field component, it is also supported to show the wavefront phase. The wavefront phase will be displayed as a separate data array and is common for all field components.
Wavefront Phase w/o Spherical Part	For many applications it might be meaningful to investigate only the residuals of the wavefront phase. Therefore the user can select whether to show the wavefront phase without the spherical part. The spherical part is evaluated by fitting of the given wavefront phase data.
Show Polarization Ellipses	ONLY AVAILABLE IF AT LEAST TWO E-*FIELD COMPONENTS* ARE SELECTED. If checked, polarization ellipses for the E-field will be calculated and added to the output.
Plane	ONLY AVAILABLE IF *SHOW POLARIZATION ELLIPSES* IS CHECKED. If all three E-*Field Components* are selected, the plane to calculate the ellipses for can be chosen here.
	ONLY VISIBLE IF *SHOW POLARIZATION ELLIPSES* IS CHECKED. This button will open a dialog for configuring the view settings for the graphics add-on which visualizes the polarization ellipses. It is described in Sec. 11.7.3.
Ignore Vanishing Jones Vectors	If checked, no polarization ellipses will be calculated at positions where the amplitudes of both of the Jones vector's components are below a certain fraction (given be *Threshold*) of the maximum field amplitude (see also Sec. 11.8).
Threshold	ONLY AVAILABLE IF *IGNORE VANISHING JONES VECTORS* IS CHECKED. The threshold for identifying vanishing Jones vectors.
Color Table	The color table (↔Sec. 11.2.4) to be used (initially) in the resulting document window.
Color for Undefined Values	The user can select a color for undefined values. This will be used (initially) in the resulting document window.
Interpolation Method	The interpolation method of the resulting data array(s).

75.4.5.2 Edit Dialog for Detector Add-ons

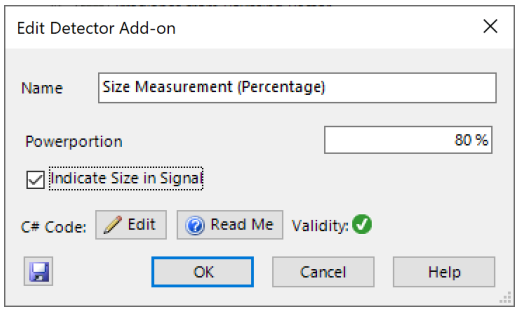


Figure 603. *The edit dialog for a (sample) detector add-on.*

The edit dialog for detector add-ons (↪Fig. 603) has the following standard controls.

ITEM	DESCRIPTION
Name	The name of the detector add-on. It is equal to the *Title* defined on the *Snippet Help* tab when you click on *Edit*.
Edit	Opens the Source Code Editor (↪Sec. 7.3).
Read Me	Shows the Snippet Help (↪Sec. 7.3.3) in a separate window.
Validity	The validity indicator (↪Sec. 5.11) shows whether the snippet defining the detector add-on is consistent.
	Saves the detector add-on to the user defined catalog so that it can be loaded into another detector. ↪Sec. 35.1. If you save a detector add-on into the "Favorites" category, it is added to the Favorites in the ribbon for Data Arrays and Harmonic Fields Sets (↪Sec. 77.9).

In addition to the standard controls mentioned in the table above the dialog may contain a list of user controls which are dynamically defined by the type of global parameters of the detector add-on, ↪Sec. 7.4.

75.5 Field Visualization

75.5.1 Angular Spectrum Visualizer

Availability

Optical Setups: General Optical Setup

Accessible: Optical Setup: *Detectors > Field Visualization > Angular Spectrum Visualizer*

This detector shows the angular spectrum, i. e. the (physical) Fourier transform (↪Sec. 31.1) of the field. The used dialog is nearly the same as for the Raw Data Detector, described in Sec. 75.5.5.

75.5.2 Camera Detector

Availability

Optical Setups: General Optical Setup, Light Guide Optical Setup, and Light Shaping Optical Setup

Accessible:

- Optical Setup: *Camera Detector; Detectors > Field Visualization > Camera Detector*
- Ribbon: Detectors > Camera Detector

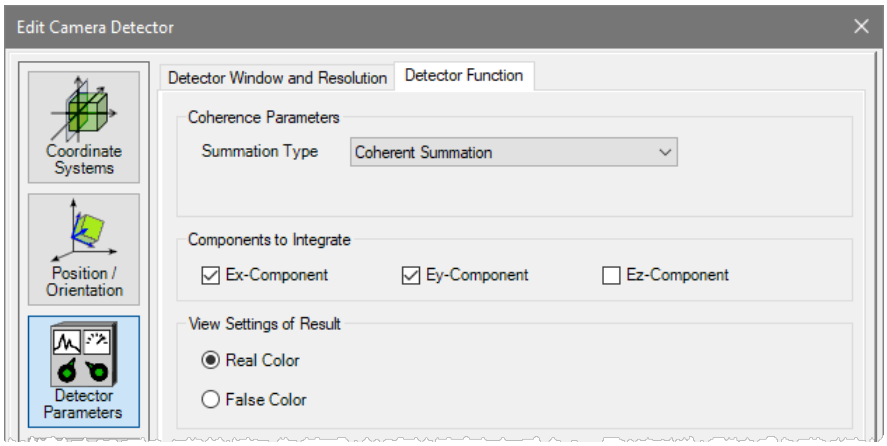


Figure 604. *The specific settings for the camera detector in a General or a Light Guide Optical Setup.*

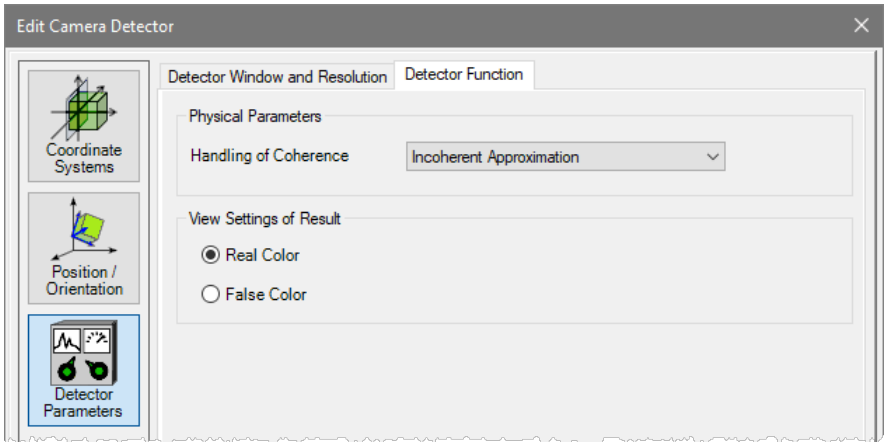


Figure 605. *The specific settings for the camera detector in a Light Shaping Optical Setup.*

The settings of the Camera Detector depend on the type of Optical Setup it is used in. It can also be applied on harmonic fields and harmonic fields set via Detectors > Camera Detector. In this case it behaves as if it would be used in a General Optical Setup.

ITEM	DESCRIPTION
Handling of Coherence	ONLY AVAILABLE IN A LIGHT SHAPING OPTICAL SETUP The camera detector supports two operation modes to evaluate the distinct modes of the incident field. In *Standard Mode* the coherent modes are interpreted coherently. The *Incoherent Approximation* evaluates the incident coherent modes by incoherent superposition which can speed up calculations.
Coherence Parameters	ONLY AVAILABLE IN A GENERAL OR A LIGHT GUIDE OPTICAL SETUP There are various *Summation Type*s how coherent modes can be summed up: *Coherent Summation*, *Incoherent Summation*, and *Partial Coherent Summation*. For the latter you can specify the degree of coherence by entering a *Coherence Time*[PV] (or copying it from a Coherence Time & Length Calculator ↪Sec. 106). These settings have no effect for Classic Field Tracing as this engine only supports incoherent modes.
Components to Integrate	ONLY AVAILABLE IN A GENERAL OR A LIGHT GUIDE OPTICAL SETUP You can select one or more vectorial components which are shown in the result. In a Light Shaping Optical Setup always *Ex-Component* and *Ey-Component* are used and thus this group box is invisible.
Real Color / False Color	Allows you to preset the color mode (↪Sec. 14.2) of the resulting Chromatic Fields Set if it is a two-dimensional one.
{Color Table Button}	ONLY FOR *FALSE COLOR* MODE. Allows you to select one color table (↪Sec. 11.2.4).

If the Camera Detector is used in a Light Shaping Optical Setup, both the size of the *Detector Window* and the *Detector Resolution* can only be set manually.

The remaining controls of this dialog are explained in Sec. 75.1.

75.5.3 PSF & MTF

Availability

Optical Setups: General Optical Setup & Light Guide Optical Setup

Accessible: Optical Setup: *Detectors > Field Visualization > PSF & MTF*

This detector calculates both the Point Spread Function (PSF) and the Modulation Transfer Function (MTF). The user is responsible to place the detector at the appropriate evaluation position (= focus), which is expected to be different depending on the system's settings (e. g. illumination).

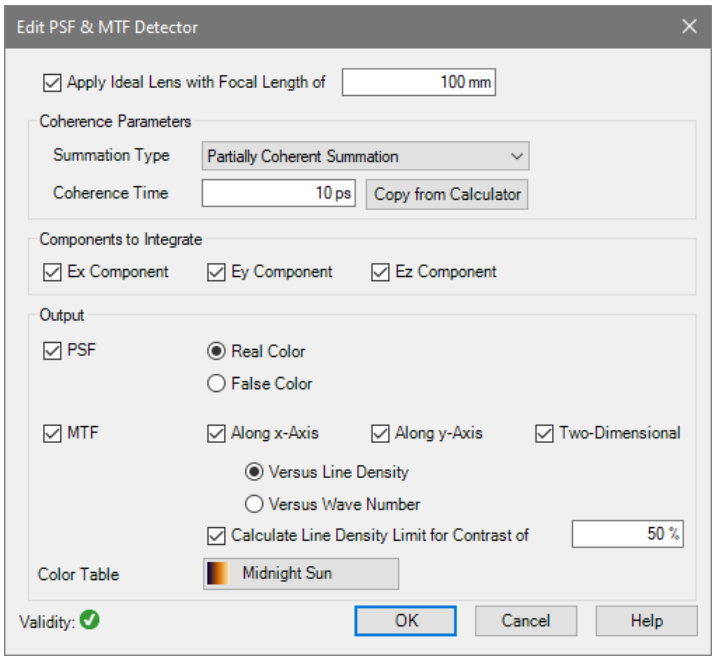


Figure 606. *The edit dialog for the PSF & MTF detector.*

Its edit dialog (↪Fig. 606) has the following settings.

ITEM	DESCRIPTION
Apply Ideal Lens	If this option is checked you can set a focal length. Then the field is propagated into the focus of an Ideal Lens with that focal length. Otherwise it is assumed that the field entering the detector is already in the focus.
Summation Type	If there is more than one coherent mode, the modes can be added coherently, incoherently, or partially coherently. For the latter you can specify the degree of coherence by entering a *Coherence Time*[PV] (or copying it from a Coherence Time & Length Calculator ↪Sec. 106). This setting has no effect for Classic Field Tracing as this engine only supports incoherent modes.
Components to Integrate	Allows you to select which vectorial components of the field are integrated and thus taken into account for the PSF and MTF calculation. E_x, E_y and / or E_z can be used whereas the dialog ensures that at least one component is selected.
PSF	Allows you to set whether the PSF is returned as Chromatic Fields Set (↪Sec. 14) by the detector.
Real Color / False Color	ONLY VISIBLE IF *PSF* IS CHECKED. Allows you to preset the color mode (↪Sec. 14.2) of the resulting Chromatic Fields Set with the PSF data. Only has an effect if the incident field is two-dimensional.
MTF	Allows you to set whether the MTF is returned as Data Array(s) by the detector.
Along x-Axis / Along y-Axis / Two-Dimensional	ONLY VISIBLE IF *MTF* IS CHECKED. By default the two-dimensional MTF is shown. But you can also select that an cross section *Along x-Axis* or *Along y-Axis* is shown additionally. This cross section always starts with a spatial frequency or line density of zero.
Versus Line Density / Versus Wave Number	ONLY VISIBLE IF *MTF* IS CHECKED. The MTF can be plotted either *Versus Line Density* with the unit cycles or line pairs per millimeter. Or it can be plotted *Versus Wave Number* with the unit 1/m.
Calculate Line Density / Wave Number Limit	ONLY IF *ALONG X-AXIS* OR *ALONG Y-AXIS* IS CHECKED If checked, the line density or wave number is calculated where the contrast first falls below the specified limit.
Color Table	Allows you to preset the color table for the two-dimensional Chromatic Fields Set with the PSF data in *False Color* mode and the two-dimensional Data Array with the MTF Data.

The dialog ensures that you cannot unselect all output possibilities.

Fig. 619 shows how the edit dialog looks like if the detector is used in the main window (via Detector from Catalog; ↪Sec. 76.1). If this detector is used in an Optical Setup, a dialog with additional controls is used (↪Sec. 75.1).

75.5.4 Radial / Azimuthal Polarization

Availability

Optical Setups: General Optical Setup & Light Guide Optical Setup

Accessible: Optical Setup: *Detectors > Field Visualization > Radial / Azimuthal Polarization*

This detector plots the radial component E_ρ and / or the azimuthal component E_ϕ (↪Fig. 607) of a field into a data array. If the field consists of multiple modes the data arrays for the distinct modes are collected in a Set of Data Arrays (↪Sec. 16).

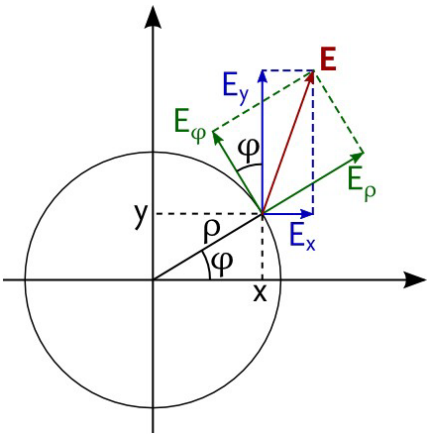


Figure 607. *Decomposition of the electric field vector $\mathbf{E}$ into Cartesian components (blue) and polar coordinate components (green).*

The conversion from E_x and E_y to E_ϕ and E_ρ is done by the following equations:

$$E_\rho(\rho,\phi) = \quad \cos\phi E_x(x,y) + \sin\phi E_y(x,y) \tag{75.1}$$

$$E_\phi(\rho,\phi) = -\sin\phi E_x(x,y) + \cos\phi E_y(x,y) \tag{75.2}$$

The polar coordinates are given by $\rho = \sqrt{x^2+y^2}$ and $\phi = \mathrm{atan2}\, y/x$ [1].

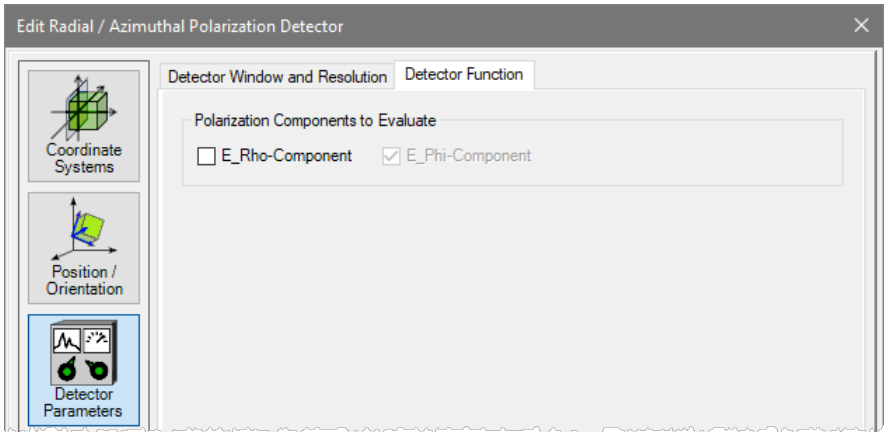


Figure 608. *The edit dialog of the Polarization Detector. Note that you cannot uncheck the only selected polarization component as then no component would be selected.*

The edit dialog for the detector is shown in Fig. 608 and has the following controls and the *Detector Function* sub-tab.

[1] atan2 is a special implementation of the arctangent function for a fraction of two values. See Microsoft C# documentation or Wikipedia for reference.

ITEM	DESCRIPTION
Polarization Components to Evaluate	You can select either the *E_Rho-Component* E_ρ, the *E_Phi-Component* E_ϕ, or both. The dialog ensures that at least one polarization component is selected.

The remaining controls of this dialog are explained in Sec. 75.1.

75.5.5 Raw Data Detector

Availability

Optical Setups: General Optical Setup, Grating Optical Setup, and Laser Resonator Optical Setup

Accessible: Optical Setup: *Detectors > Field Visualization > Raw Data Detector*

A *Raw Data Detector* gives the raw field data at the position where it is placed. These raw data can be either equidistant or non-equidistant. Its edit dialog (↪Fig. 609) allows you to preset several view settings like the visible region for equidistant data.

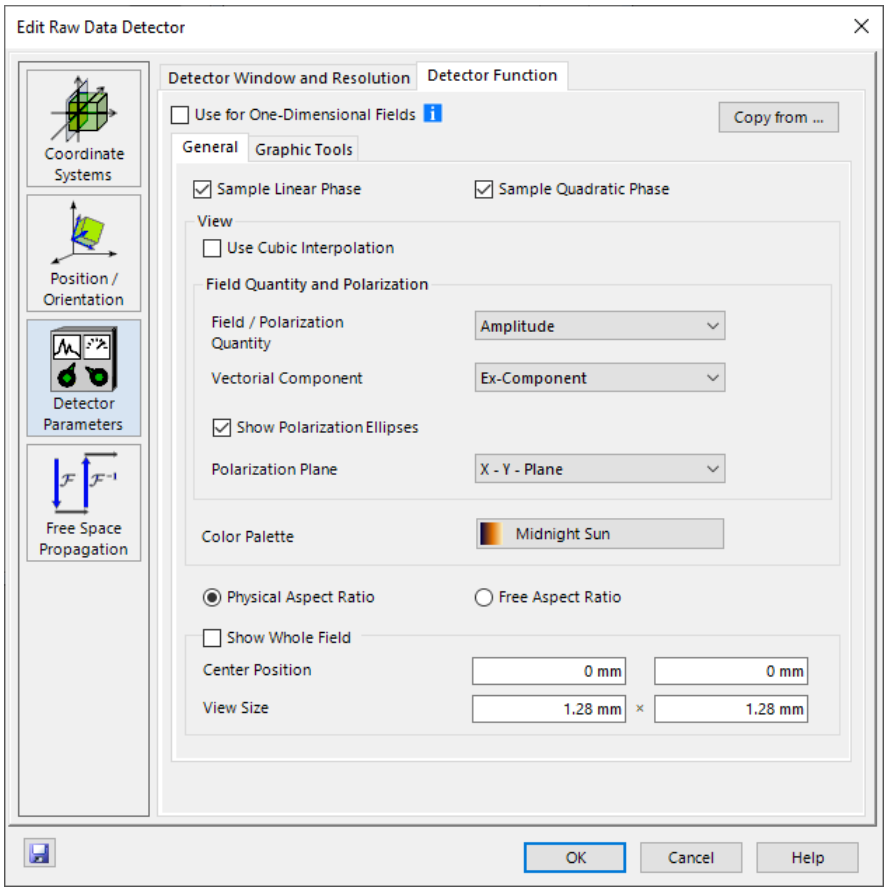


Figure 609. *Dialog with the Settings for the Raw Data Detector.*

The *Use for One-Dimensional Fields* adapts the dialog to either one-dimensional or two-dimensional harmonic fields.

If you click on the *Copy from ...* button a dialog appears where you can select any open Harmonic Field or Harmonic Fields Set document. The view settings of this document determine the values within the dialog (the visible region specifies the settings for the *View Size*).

Furthermore there are two tab pages.

The *General* tab of the dialog (↪Fig. 609) has the following controls:

ITEM	DESCRIPTION
Sample Linear Phase	Flag that indicates whether the analytically stored linear phase of the input field shall be sampled. If this option is not selected the linear phase is removed from the field and an information about the removed linear phase term is plotted into the *Messages* tab of the VirtualLab Fusion main window.
Sample Quadratic Phase	Flag that indicates whether the analytically stored quadratic phase of the input field shall be sampled. If this option is not selected the quadratic phase is removed from the field and an information about the removed quadratic phase term is plotted into the *Messages* tab of the VirtualLab Fusion main window.
Use Cubic Interpolation	If checked, the cubic interpolation for the view (↪Sec. 11.2.1) is used.
Field / Polarization Quantity	Either the Field Quantity (↪Sec. 11.1) or the eccentricities or angles of the polarization ellipses (↪Fig. 12.2.3) can be displayed by the Raw Data Detector.
Vectorial Component / Combined Component	Depending on the selected *Field / Polarization Quantity*, you can either select the Vectorial Component (for Field Quantities except Summed Squared Amplitudes, ↪Sec. 12.2.2) or the Combined Component for Summed Squared Amplitudes (↪Sec. 11.1). This control is not visible if *Polarization Eccentricities* or *Polarization Angles* are set as *Field / Polarization Quantity*.
Show Polarization Ellipses	If neither *Polarization Eccentricities* nor *Polarization Angles* are selected as *Field / Polarization Quantity*, polarization ellipses can be shown as overlay in the view (see Fig. 91 for an example).
Polarization Plane	Actually, the field vector at a certain point describes a polarization ellipse in the plane perpendicular to the propagation direction. For clarity, VirtualLab Fusion only shows polarization ellipses which result from projecting this ellipse onto one of the coordinate planes. This *Polarization Plane* can be defined by the user if polarization ellipses are shown – either as *Show Polarization Ellipses* overlay or as *Field / Polarization Quantity*.
Color Palette	You can choose one out of several color tables (↪Sec. 11.2.4). This color table is used for the shown mode and the shown field quantity only. All other color tables are taken from the Global Options dialog (↪Sec. 6.9).
Physical Aspect Ratio / Free Aspect Ratio	The Aspect Ratio (↪Sec. 11.5) used for displaying the field.
Show Whole Field	If checked, it is not zoomed into the field, i. e. you will see the whole field. Thus, *Center Position* and *View Size* are disabled.
Center Position	These two text boxes allow you to specify the center (x- and y-position) of the region you want to see. If you have checked *Use for One-Dimensional Fields* only one text box is shown.
View Size	These two text boxes allow you to specify the size in x- and y-direction of the region you want to see. If you have checked *Use for One-Dimensional Fields* only one text box is shown.

The *Graphic Tools* page (↪Fig. 610) allows you to preset the visibility, position and extension (if applicable) of the three marker types (↪Sec. 11.3). If you have checked *Use for One-Dimensional Fields* only one input box is shown for all entries and a profile line cannot be specified.

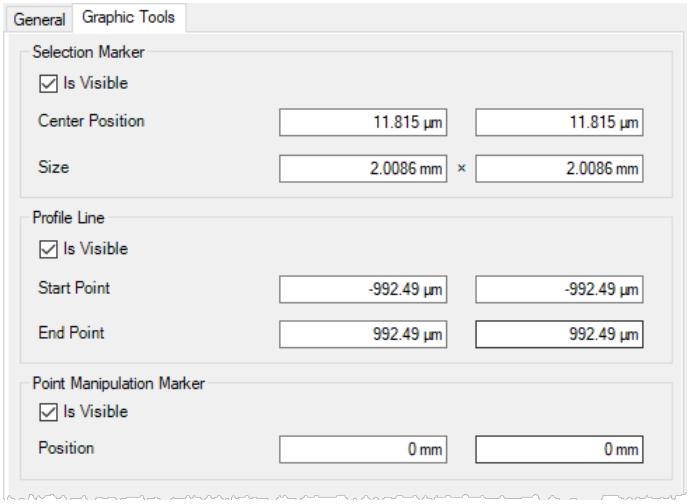


Figure 610. *Graphic Tools page of the Raw Data Detector dialog.*

The remaining controls of this dialog are explained in Sec. 75.1. Note that in a Grating Optical Setup the Raw Data Detector cannot be tilted and shifted.

For view settings which are not set by this dialog, always the settings from the Global Options dialog (↪Sec. 6.11) are taken into account. This applies for e.g. the *Artifacts Threshold* and the *Scaling* of the polarization ellipses.

75.6 Merit Functions

75.6.1 Beam Parameters

Availability

Toolboxes: All

Accessible:

- Optical Setup: *Detectors* > *Basic Detectors* > *Beam Parameters*
- Ribbon: Detectors > Beam Parameters

The beam parameters of a wave are calculated based on the second momentum theory (↪Sec. 142.1).
If the ribbon item Detectors > Beam Parameters is clicked the dialog shown in Fig. 611 will appear. The following beam parameters can be calculated (for the underlying formulas see Sec. 142.1):

ITEM	DESCRIPTION
Diameter X	The diameter measured from the optical axis along the x-axis.
Diameter Y	The diameter measured from the optical axis along the y-axis.
Waist Diameter X	The waist diameter measured from the optical axis along the x-axis.
Waist Diameter Y	The waist diameter measured from the optical axis along the y-axis.
Full Divergence Angle X	The full angle of divergence angle measured from the optical axis along the x-axis.
Full Divergence Angle Y	The full angle of divergence angle measured from the optical axis along the y-axis.
Waist Distance X	The distance of the present z-position of the wave from the waist measured along the x-axis.
Waist Distance Y	The distance of the present z-position of the wave from the waist measured along the y-axis.
M^2-Parameter in x-Direction	The M^2 parameter of the wave measured along the x-axis.
M^2-Parameter in y-Direction	The M^2 parameter of the wave measured along the y-axis.
Centroid X	The x-position of the centroid.
Centroid Y	The y-position of the centroid.
Rotation Angle of the Principal Axis	The angle between the principal axis of the wave and the x-axis.

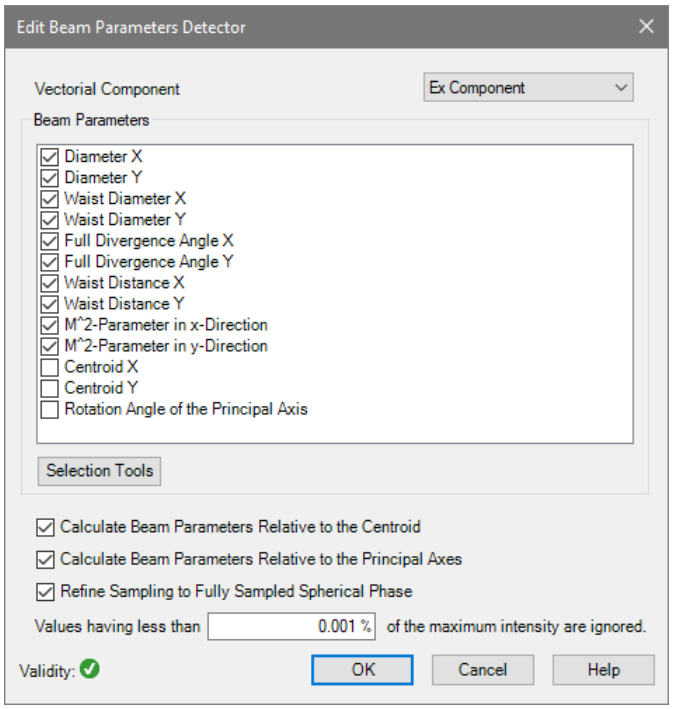


Figure 611. *Edit dialog if the Beam Parameters detector is used in the main window.*

The edit dialog of this detector (↪Fig. 611) offers the following settings:

ITEM	DESCRIPTION
Vectorial Component	Selects the complex amplitude (E_x or E_y) for which the beam parameters shall be calculated.
Beam Parameters	This section of the dialog allows you to select the beam parameters to be evaluated (↪Sec. 5.9).
Calculate Beam Parameters Relative to the Centroid	If checked, then in a first step always the centroid of the wave is determined and in a second step all beam parameters are calculated relative to the centroid.
Calculate Beam Parameters Relative to the Principal Axis.	If not checked all beam parameters are calculated along the x- and y-axis. If checked, then in a first step the rotation angle of the principal axis of the wave measured to the x-axis is determined. In a second step all beam parameters are calculated relative to the principal axis and not to the x- and y-axis.
Refine Sampling to Fully Sampled Spherical Phase	Harmonic fields may contain analytical spherical phase factors. In the paraxial case, the detector truly accounts for the spherical phase without actually measuring it on the sampling points of the field. In the non-paraxial case, analytical spherical phase factors must be sampled in a correct manner in order to ensure an unbiased evaluation of the beam parameters. If checked, VirtualLab Fusion is forced to interpolate the field for a lossless sampling of the spherical phase factor. In presence of a spherical phase factor with small radius this option can dramatically increase the computing time and memory resources needed. This option has an effect only for Classic Field Tracing or in the main window. To get the analogous behavior for General Profile, you should activate the option *Scale Sampling Distance by Oversampling Factor* on the *Detector Window and Resolution* tab (↪Sec. 75.1.1). Then the sampling is refined to completely sample the analytic quadratic phase of the field.
Values having less than … of the maximum intensity are ignored.	For mathematical reasons the beam parameters detector is very sensitive to noise which can change the results by a factor 10 or more. Thus this setting allows you to ignore all field values having less than the given percentage of the maximum squared amplitude in the field. You can set this value to zero to switch off this noise filtering.

Fig. 611 shows how the edit dialog looks like if the detector is used in the main window. If this detector is used in an Optical Setup, a dialog with additional controls is used (↪Sec. 75.1).

75.6.2 Diffractive Optics Merit Functions

Availability

Toolboxes: All

Accessible:

- Optical Setup: *Detectors* > *Basic Detectors* > *Diffractive Optics Merit Functions*
- Ribbon: Detectors > Diffractive Optics Merit Functions

Diffractive Optics Merit Functions are a collection of merit functions that are typically used to evaluate beam shaping, beam splitting and light diffusing systems. VirtualLab Fusion supports the following merit functions. The corresponding formulas are given in Sec. 142.2.

ITEM	DESCRIPTION
Window Efficiency	The part of the paraxial power of the input field diffracted inside the signal region.
Conversion Efficiency	The part of the paraxial power of the input field diffracted in the part of the signal that is inside the signal region. Noises inside the signal region are ignored.
Signal to Noise Ratio (SNR)	The strength of the signal relative to the noises measured in dB.
Uniformity Error	The maximum deviation of the output field squared amplitude from the signal field squared amplitude inside the signal region.
Relative Zeroth Order Intensity	The paraxial intensity of a field component (squared amplitude) of the zeroth order of the output field related to somewhat like the mean value of the intensities of the desired output orders.
Zeroth Order Efficiency	The part of the paraxial power of the input field diffracted into the zeroth order.
Maximum Relative Intensity of Stray Light	The relative maximum intensity outside of the signal region.
Optimal Scale Factor	A real valued or complex scaling factor between the complex amplitude of the output field in the signal region and the complex amplitude of the desired output field. The optimal scale factor is typically used for the calculation of the most standard merit functions.

These merit functions can be calculated via Detectors > Diffractive Optics Merit Functions or in an Optical Setup. Most of the Diffractive Optics merit functions can also be logged during the IFTA optimization (↪Sec. 98).

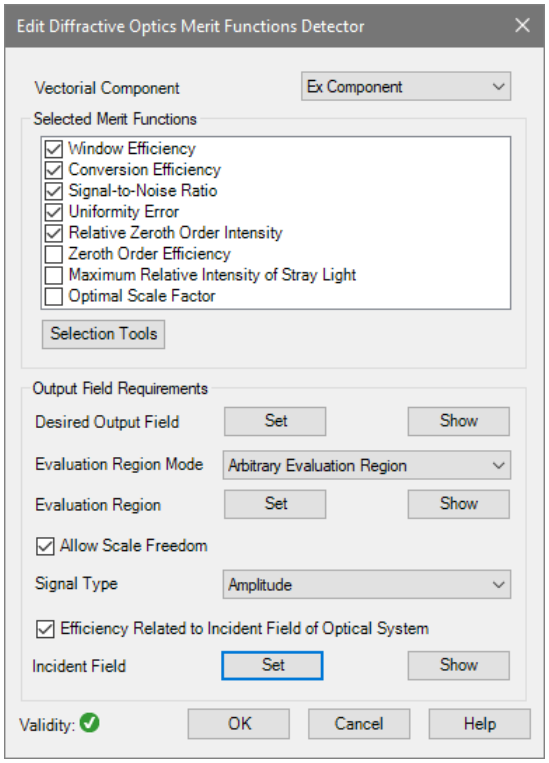


Figure 612. *Edit dialog if the Diffractive Optics Merit Functions detector is used in the main window.*

The edit dialog of this detector (↪Fig. 612) offers the following settings:

ITEM	DESCRIPTION
Vectorial Component	Selects the vectorial component (E_x or E_y) for which the merit functions shall be calculated.
Selected Merit Functions	Allows the selection of the standard merit functions that shall be calculated (↪Sec. 5.9).
Desired Output Field	Allows the selection of the desired output field used for the calculations.
Evaluation Region Mode	Allows you to define the way how the *Evaluation Region* is determined. There are four possibilities: 1. *Arbitrary Evaluation Region*: Allows you to *Set* an arbitrary harmonic field as evaluation region. 2. *Create from Desired Output Field*: The chosen *Vectorial Component* of the *Desired Output Field* is used as evaluation region, whereby all absolute values larger than zero are taken into account for computing the merit functions. 3. *Equal to Incident Field Selection*: If you choose this option (which is only available in the main window), you must select an open harmonic field document as *Incident Field*. The evaluation region is then created from the physical coordinates of the selection in this field. 4. *Equal to Desired Output Field Selection*: If you choose this option (which is only available in the main window), you must select an open harmonic field document as *Desired Output Field*. The evaluation region is then created from the physical coordinates of the selection in this field.
Evaluation Region	If you have chosen *Arbitrary Evaluation Region* as *Evaluation Region Mode*, the *Set* button allows to either • *Load* a suitable Complex Amplitude File from hard disc or • select a harmonic field document which is already opened in the main window. The *Show* button allows you to to view the currently set evaluation region.
Allow Scale Freedom	If checked the scale factor (↪Sec. 144.1.1) is calculated for all merit functions calculations, otherwise the scale factor is set to one.
Signal Type	Sets the specific type of the signal, i. e. for which field quantity the merit functions are being evaluated. Can be either *Amplitude*, *Squared Amplitude*, *Complex Amplitude* or *Phase*.
Efficiency Related to Incident Field of Optical System	If this item is checked all efficiency calculations are related to the power of the incident field. In this way, possible energy losses in the optical system (e. g. caused by absorption or reflection) can be considered. If this detector is used in the Optical Setup, the incident field is the field directly after the light source. If this detector is used in the main window, you can define an arbitrary *Incident Field*.

Incident Field	ONLY AVAILABLE IN THE MAIN WINDOW. There are two buttons to define an arbitrary incident field. The *Set* button allows you to either • *Load* a suitable Complex Amplitude File from hard disc or • select a suitable document which is already opened in the main window. In both cases the set incident field must be a spatial harmonic field. The *Show* button allows you to to view the currently set incident field.

Fig. 612 shows how the edit dialog looks like if the detector is used in the main window. If this detector is used in an Optical Setup, a dialog with additional controls is used (↪Sec. 75.1).

75.6.3 Multimode Fiber Coupling Efficiency

Availability

Optical Setups: General Optical Setup & Light Guide Optical Setup

Accessible: Optical Setup: *Detectors > Merit Functions > Multimode Fiber Coupling Efficiency*

This detector calculates how much of the incident light can couple into either a step-index fiber or a gradient index fiber. This evaluation is done per wavelength.

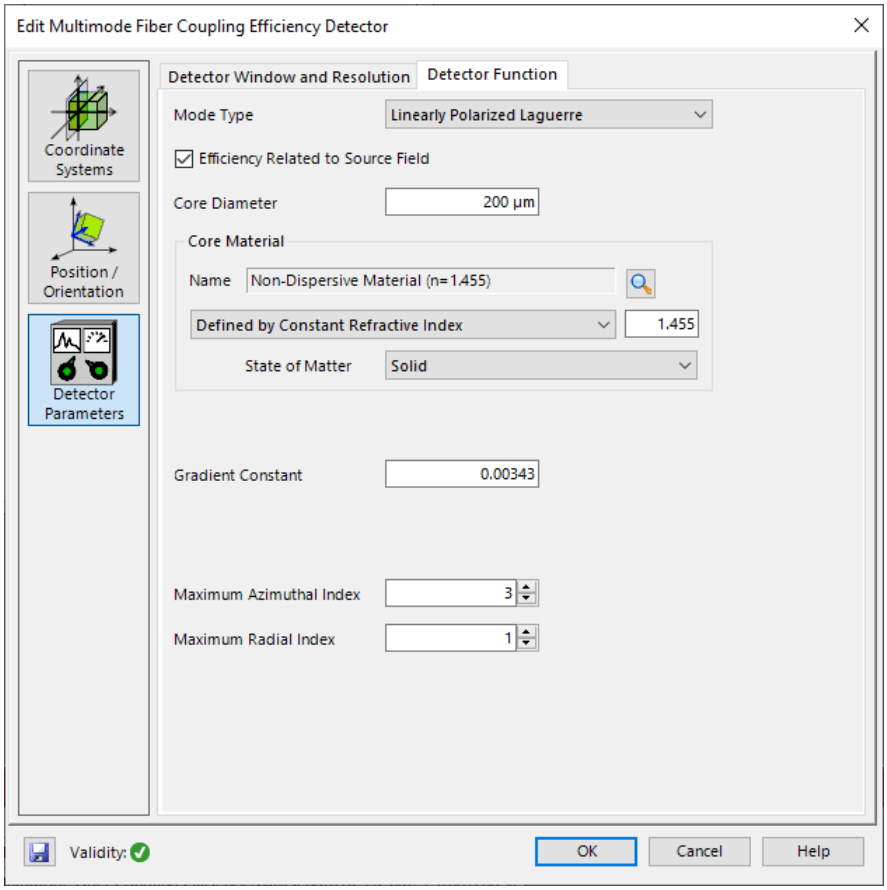


Figure 613. *The edit dialog for the Multimode Fiber Coupling Efficiency detector.*

Its edit dialog (↪Fig. 613) has the following settings.

ITEM	DESCRIPTION
Mode Type	Allows you to select between *Linearly Polarized Bessel* modes which occur in step-index fibers and *Linearly Polarized Laguerre* modes which occur in gradient index fibers. (↪Sec. 139.2)
Efficiency Related to Source Field	If this item is checked the calculated efficiency will be related to the power of the field directly after the light source. This means that the efficiency will become smaller due to e. g. absorption and reflections in the optical setup.
Core Diameter	The core diameter d of the fiber.
Core Material	Allows you to set the material in the fiber core with the control described in Sec. 34.3. Only the real-valued refractive index $n_{\text{core}}(\lambda)$ is used.
Cladding Material	ONLY FOR *LINEARLY POLARIZED BESSEL* MODES Allows you to set the material of the fiber cladding with the control described in Sec. 34.3. Only the real-valued refractive index $n_{\text{cladding}}(\lambda)$ is used.
Gradient Constant	ONLY FOR *LINEARLY POLARIZED LAGUERRE* MODES For gradient index fibers the refractive index distribution is given by $$n^2(r) = n_{\text{core}}(\lambda)^2 \left(1 - 2\Delta \left(\frac{r}{r_0}\right)^2\right) \quad (75.3)$$ whereas n_{core} is the refractive index in the center given by the *Core Material*; $r_0 = {}^{d}/_{2}$ is the core radius; and Δ is the gradient constant.
Maximum Azimuthal Order / Maximum Radial Order	Defines how many modes are considered for the calculation of the coupling efficiency.
Validity	This control indicates whether the current configuration is valid, ↪Sec. 5.11. Error messages can be shown in a separate dialog. For example it is checked that the modes are not cut off, which would be the case if the cutoff parameter $V = {}^{\pi}/_{\lambda} \cdot d\sqrt{n_{\text{core}}^2 - n_{\text{cladding}}^2}$ is less than 1. Also $V > 300$ is not practical.

75.6.4 Power

Availability

Optical Setups: General Optical Setup, Light Guide Optical Setup, and Laser Resonator Optical Setup

Accessible: Optical Setup: *Detectors > Merit Functions > Power*

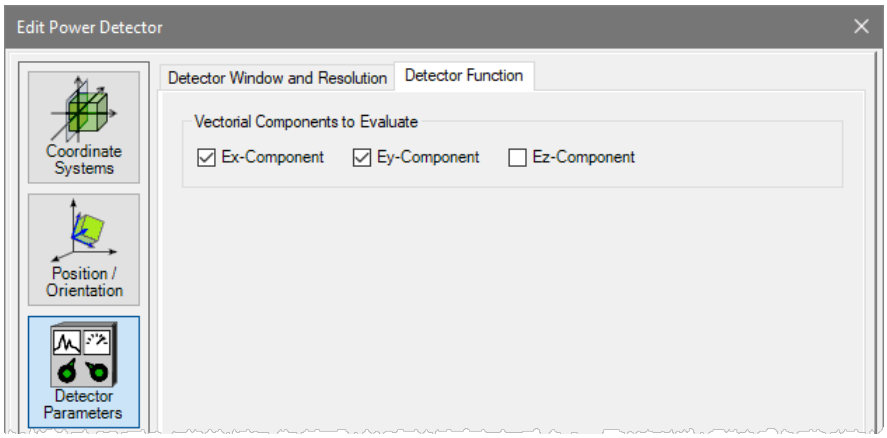


Figure 614. *The edit dialog for the power detector.*

This detector calculates the power P in watts, either for the complete field in the detector plane or for a region of it. It is calculated via

$$P = n\frac{\epsilon_0}{2}c\sum_i \Delta_i \cdot A_i^2. \tag{75.4}$$

n is the refractive index derived from the embedding medium of the field, ϵ_0 is the dielectric constant and c is the vacuum speed of light. A_i is the squared amplitude of the data point i and Δ_i is the area this data point occupies (sampling distance in x-direction times sampling distance in y-direction for equidistant data).

ITEM	DESCRIPTION
Vectorial Components to Evaluate	You can select any combination of *Ex-Component*, *Ey-Component*, and *Ez-Component*. The dialog ensures that at least one vectorial component is selected. The squared amplitudes of all selected components are summed up to the A_i in Eq. (75.4).

The remaining controls of this dialog are explained in Sec. 75.1.

75.6.5 Pulse Evaluation

Availability

Optical Setups: General Optical Setup

Accessible: Optical Setup: *Detectors > Merit Functions > Pulse Evaluation*

This detector combines several settings for both the evaluation of pulses (↪Sec. 75.6.5.1) and of the optical path length for distinct wavelengths (↪Sec. 75.6.5.2).
A validity control in the bottom left corner (↪Sec. 5.11) indicates whether there are issues with the current configuration. If this is the case you can click on the ℹ-button for further information.
The remaining controls of this dialog are explained in Sec. 75.1.

75.6.5.1 Pulse Evaluation

The actual *Pulse Evaluation* tab page (↪Fig. 615) allows you to plot the field data of a polychromatic fields set over wavelength and over time. In this way you can examine the pulse shape if the incoming harmonic fields set represents a laser pulse.
To this end, you can choose to extract the field

1. at a specific position, resulting in 1D Data Arrays with wavelength / time being the x-axis,
2. at a line, resulting in 2D Data Arrays with wavelength / time being the x-axis, and / or

3. at a specific region, resulting in 2D Data Arrays with one subset per wavelength / time value. Out of such a data array, an animation can be generated using Manipulations > Create Animation

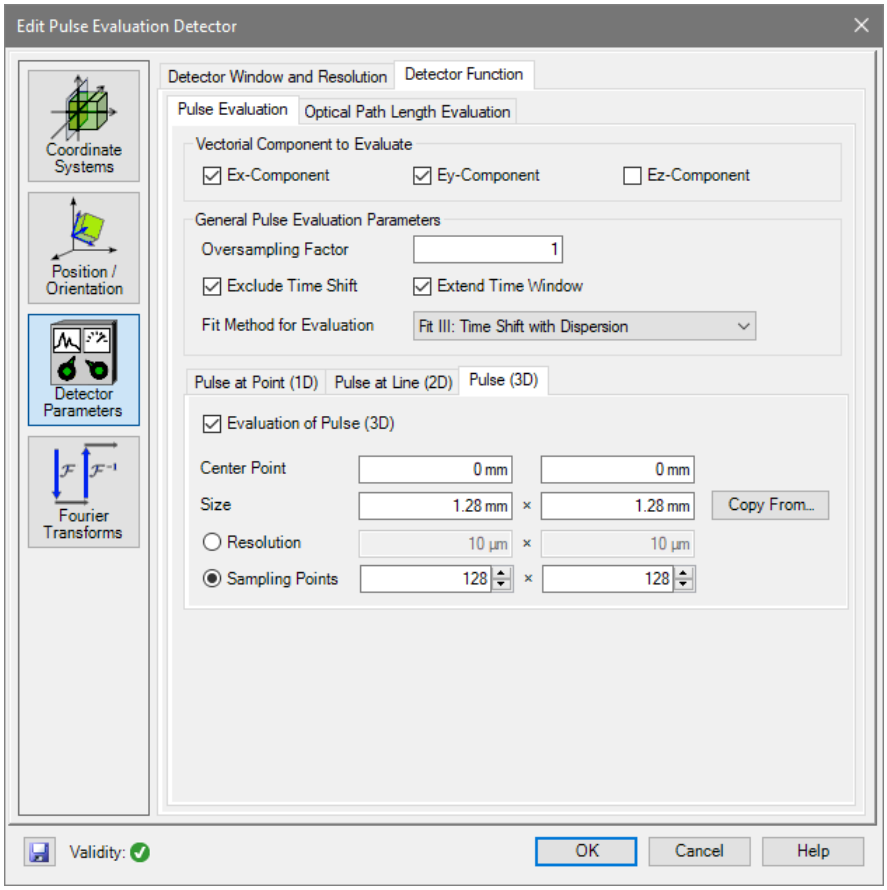


Figure 615. *The settings for the actual pulse evaluation, here for the* Pulse (3D) *mode.*

More specifically, the *Pulse Evaluation* tab page has the following options:

ITEM	DESCRIPTION
Vectorial Component to Evaluate	You can select at least one of the vectorial components E_x, E_y, and E_z. For each selected vectorial component separate data arrays are shown.
Oversampling Factor	With this factor you can adjust the sampling and thus the accuracy in the *time* domain. A higher oversampling factor leads to a smaller sampling distance.
Exclude Time Shift	The pulse needs a certain time t_s to propagate through the system. If you check this option, the shown pulse reaches its peak at the time t_s. Otherwise the pulse is centered around the time of 0 s. The time t_s is the time shift as calculated by the set *Fit Method for Evaluation*.
Extend Time Window	If you check this option, an oversampling in *frequency* domain is introduced depending on the settings on the *Frequency Sampling* on the *Optical Path Length Evaluation* tab. The residuals of the fitted linear phase function and the correct phase function are used for this oversampling. Thus the set *Fit Method for Evaluation* also alters the effect this setting. An oversampling in frequency domain leads to an embedding in time domain, thus a larger time window is shown.

Fit Method for Evaluation	Allows you to select any of the three fit methods explained in Sec. 75.6.5.2. The fit method influences the effect of *Exclude Time Shift* and *Extend Time Window*.
Pulse at Point (1D)	On this tab page you can select and configure the *Evaluation of Pulse at Point (1D)*. This means you extract the field data at a specific *Position (x,y)* [PV] resulting in 1D Data Arrays with wavelength / time being the x-axis. If you click the *Copy From…* button, you can select a document window showing two-dimensional (field) data from whose *point marker* (↪Sec. 11.3) the new *Position (x,y)* is taken. For the 1D evaluation, you can also choose to calculate the *Minimum*, *Maximum* and / or *Full Width Half Maximum* of the resulting data arrays.
Pulse at Line (2D)	On this tab page you can select and configure the *Evaluation of Pulse at Line (2D)*. This means you extract the field data at a certain line (defined by *Start Point (x,y)* and *End Point (x,y)*). The result of this evaluation are 2D Data Arrays with wavelength / time being the x-axis. If you click the *Copy From…* button, you can select a document window showing two-dimensional (field) data from whose *line marker* (↪Sec. 11.3) the new *Start Point (x,y)* and *End Point (x,y)* are taken.
Pulse (3D)	On this tab page you can select and configure the *Evaluation of Pulse (3D)*. This means you extract the field data from a certain region (defined by *Center Point* [PV] and *Size*). The result of this evaluation are 2D Data Arrays with one subset per wavelength / time value. If you click the *Copy From…* button, you can select a document window showing two-dimensional (field) data from whose *rectangle or ellipse marker* (↪Sec. 11.3) the new *Center Position* and *Size* are taken. As the 3D evaluation can be quite costly, you can adjust the sampling defining either the *Resolution* or the number of *Sampling Points*.

75.6.5.2 Optical Path Length Evaluation

As explained in Sec. 75.6.5.1, the pulse evaluation depends on a fit method. This refers to several methods of fitting a linear function to optical path lengths (or more precisely: absolute phases) versus frequency ν. The *Optical Path Length Evaluation* tab (↪Fig. 616) allows you to configure the Pulse Evaluation detector so that it shows these fitted functions.

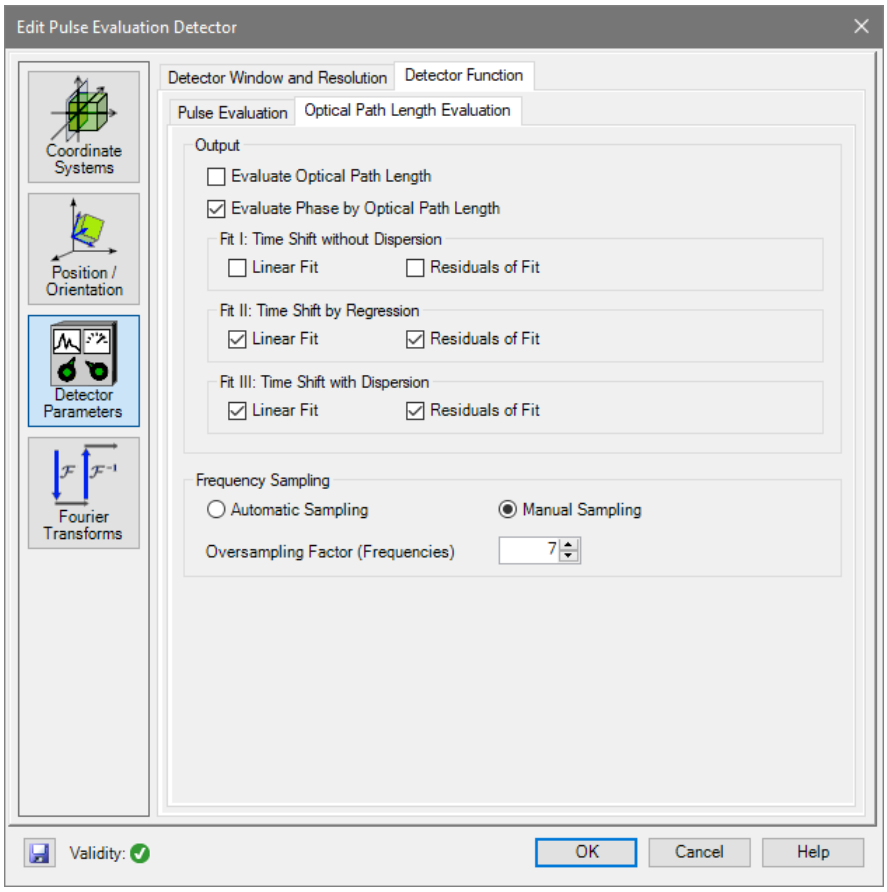


Figure 616. *The settings for the optical path length evaluation.*

ITEM	DESCRIPTION
Evaluate Optical Path Length	This checkbox defines whether the optical path length over the frequencies ν shall be shown.
Evaluate Phase by Optical Path Length	This checkbox defines whether the absolute versus the frequencies ν shall be shown.
Fit I: Time Shift without Dispersion	The first type of linear fit does not consider dispersion effects in the optical system the detector is placed in. The user can specify whether the fitted linear function shall be drawn additionally in the phase diagram and whether the residuals shall be evaluated.
Fit II: Time Shift by Regression	The second type of linear fit does consider dispersion effects in the optical system the detector is placed in. The dispersion effect is fitted by a linear regression to the absolute phase curve. The user can specify whether the fitted linear function shall be drawn additionally in the phase diagram and whether the residuals shall be evaluated.
Fit III: Time Shift with Dispersion	The third type of linear fit does consider dispersion effects in the in the optical system the detector is placed in. The dispersion effect is evaluated by the group velocity of the pulse. The user can specify whether the fitted linear function shall be drawn additionally in the phase diagram and whether the residuals shall be evaluated.

Automatic Sampling	VirtualLab Fusion estimates the frequency sampling for the selected light path. The calculated oversampling factor will be logged into the logging window of VirtualLab Fusion.
Manual Sampling	The manual sampling mode allows the user to enter a self-defined *Oversampling Factor (Frequencies)*.
Oversampling Factor (Frequencies)	For *Manual Sampling* the oversampling factor can be configured to use more frequencies for the OPL analysis. This oversampling factor will also influence the *Extend Time Window* option on the *Pulse Evaluation* tab (↪Sec. 75.6.5.1).

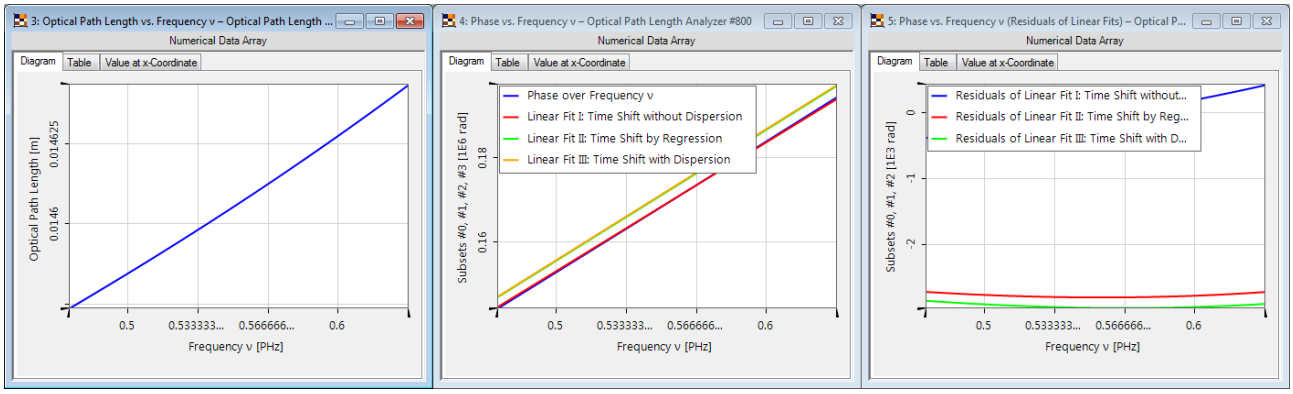


Figure 617. *Resulting diagrams of the* Optical Path Length Evaluation *of a sample Optical Setup.*

Fig. 617 shows some sample results generated by the *Optical Path Length Evaluation* tab.
The slopes of the fitted linear functions give the time shift, i. e. the time the pulse needed to propagate through the (sub-)system. The *Optical Path Length Evaluation* logs the obtained time shifts into the detector window (one per selected fit method), see Fig. 618 for an example. The time shifts can be used for further investigations of pulses in VirtualLab Fusion, especially for the temporal Fourier Transformation (↪Sec. 31.2.1).
The residual functions calculated by the *Optical Path Length Evaluation* can be used to increase the time window for the *Inverse Temporal Fourier Transformation*, see Sec. 31.2.1.

Detector	Sub - Detector	Result
OPL Analyzer	Linear Fit I: Time Shift without Dispersion	19.246 ps
	Linear Fit II: Time Shift by Regression	18.941 ps
	Linear Fit III: Time Shift with Dispersion	18.945 ps

Figure 618. *The slope of the linear fits is logged into the* Detector Results *tab of the VirtualLab Fusion main window.*

75.6.6 Singlemode Fiber Coupling Efficiency

Availability

Toolboxes: All

Accessible:

- Optical Setup: *Detectors > Basic Detectors > Singlemode Fiber Coupling Efficiency*
- Ribbon: Detectors > Fiber Coupling Efficiency

This detector allows the calculation of the coupling efficiency of the incident field into a single mode fiber. Actually this function does not calculate the modes of a fiber. The fiber mode must be specified separately. For a description of the physical background see Sec. 142.3.

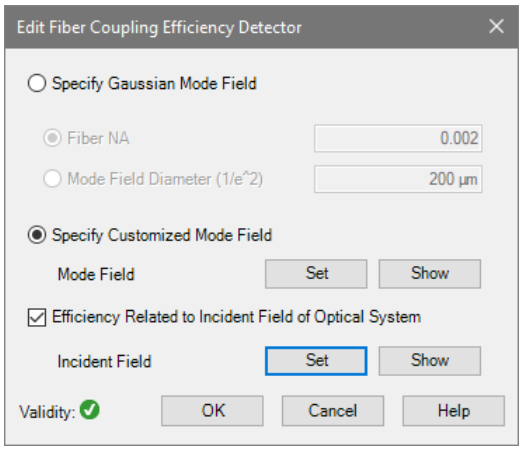


Figure 619. *Dialog for the calculation of the fiber coupling efficiency of a harmonic field in the main window.*

The edit dialog of this detector (↪Fig. 619) offers the following settings:

ITEM	DESCRIPTION
Specify Gaussian Mode Field	If you check this option, a Gaussian mode field is calculated directly from either the numerical aperture of the fiber or the diameter of the fiber mode.
Fiber NA PV	Allows you to enter the numerical aperture of the fiber if you want to *Specify Gaussian Mode Field*.
Mode Field Diameter (1/e^2) PV	Allows you to enter the $1/e^2$ diameter of the Gaussian mode field.
Specify Customized Mode Field	Instead of specifying a Gaussian mode field you can also use an arbitrary *Mode Field*.
Mode Field	There are two buttons to define an arbitrary mode field. The *Set* button allows you to either • *Load* a suitable Complex Amplitude File from hard disc or • select a suitable document which is already opened in the main window. In both cases the set mode field must be a spatial harmonic field. The *Show* button allows you to to view the currently set mode field.
Efficiency Related to Incident Field of Optical System	If this item is checked the calculated efficiency will be related to the power of the incident field. In this way, possible energy losses in the optical system (e. g. caused by absorption or reflection) can be considered. If this detector is used in the Optical Setup, the incident field is the field directly after the light source. If this detector is used in the main window, you can define an arbitrary *Incident Field*.
Incident Field	ONLY AVAILABLE IN THE MAIN WINDOW. There are two buttons to define an arbitrary incident field. The *Set* button allows to either • *Load* a suitable Complex Amplitude File from hard disc or • select a suitable document which is already opened in the main window. In both cases the set incident field must be a spatial harmonic field. The *Show* button allows you to to view the currently set incident field.

Fig. 619 shows how the edit dialog looks like if the detector is used in the main window. If this detector is used in an Optical Setup, a dialog with additional controls is used (↪Sec. 75.1).

75.6.7 Spot Size

Availability

Optical Setups: General Optical Setup & Light Guide Optical Setup

Accessible: Optical Setup: *Detectors > Merit Functions > Spot Size*

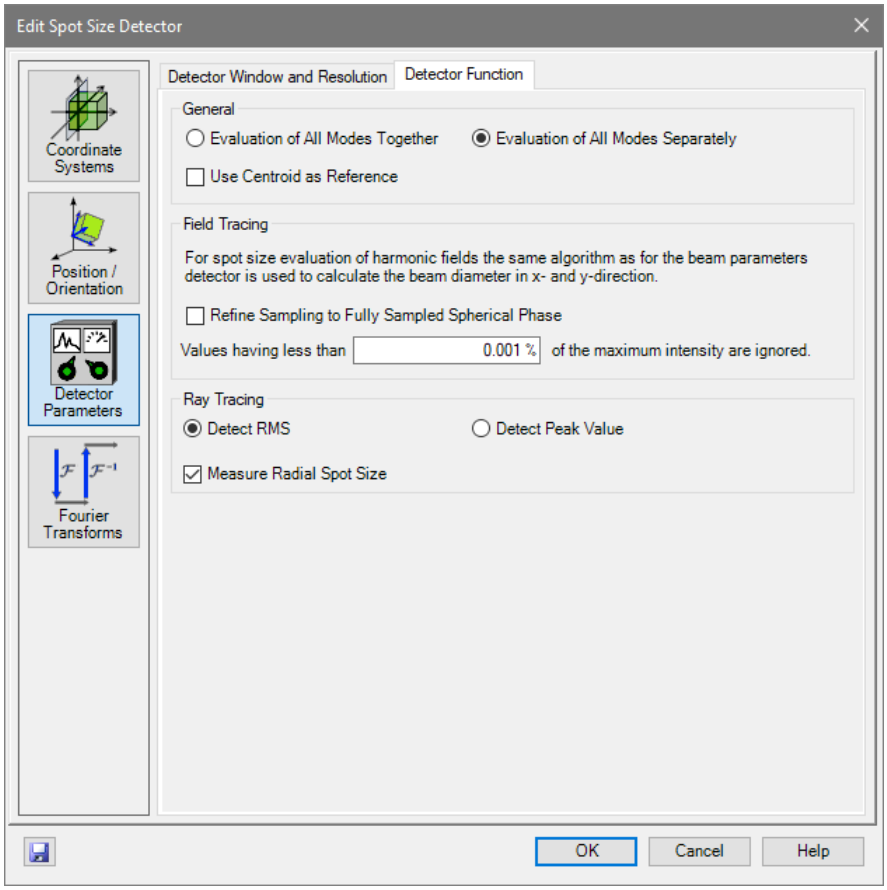


Figure 620. *The edit dialog of the Spot Size detector.*

This detector can be used to measure the spot size of the incident beam with different measurement algorithms. For Classic Field Tracing and General Profile the beam diameter algorithms of the beam parameters detector are used (↪Sec. 75.6.1), whereas for locally polarized fields the amplitudes of E_x and E_y are summed up. For Ray Results Profile the user can select whether he likes to measure the RMS or the peak value of the incident ray bundle.

The edit dialog (↪Fig. 620) of this detector has the following options.

ITEM	DESCRIPTION
Evaluation of All Modes Together	If this option is checked, all modes are regarded as one ensemble for which one spot size is determined.
Evaluation of All Modes Separately	If this option is checked, the spot size is determined separately for each individual mode.
Use Centroid as Reference	Flag whether the spot size is measured relatively to the centroid of the field. If this option is not selected, the position of the central ray (General Profile and Ray Results Profile) or the center of the field (Classic Field Tracing) will be used as reference.
Refine Sampling to Fully Sampled Spherical Phase	Harmonic fields may contain analytical spherical phase factors. If this option is checked, VirtualLab Fusion is forced to interpolate the field for a lossless sampling of the spherical phase factor. In presence of a spherical phase factor with small radius this option can dramatically increase the computing time and memory resources needed.
Values having less than … of the maximum intensity are ignored.	For mathematical reasons the beam parameters detector is very sensitive to noise which can change the results by a factor 10 or more. Thus this setting allows you to ignore all field values having less than the given percentage of the maximum squared amplitude in the field. You can set this value to zero to switch off this noise filtering.
Detect RMS	The user can select whether the RMS definition shall be used for size measurement.
Detect Peak Value	The user can select whether the peak value definition shall be used for size measurement.
Measure Radial Spot Size	Option for the detection of the RMS or peak value. If this option is selected the radial size is determined by the detector and thus the detector generates only one output value for the size. If this option is not selected the detector will calculate the RMS or peak value separately for x- and y-direction.

The remaining controls of this dialog are explained in Sec. 75.1.

75.6.8 Uniformity Detector

Availability

Optical Setups: Light Guide Optical Setup

Accessible: Optical Setup: *Detectors > Merit Functions > Uniformity Detector*

This detector calculates the average summed squared amplitude I_i within small pupils around various positions ρ_i. The pupils all have the same size and shape (rectangular or elliptical). From these I_i the following values are calculated:

- The minimum value I_{min} and the maximum value I_{max}
- Uniformity error $U = \frac{I_{\text{max}} - I_{\text{min}}}{I_{\text{max}} + I_{\text{min}}}$
- Arithmetic mean and standard deviation .

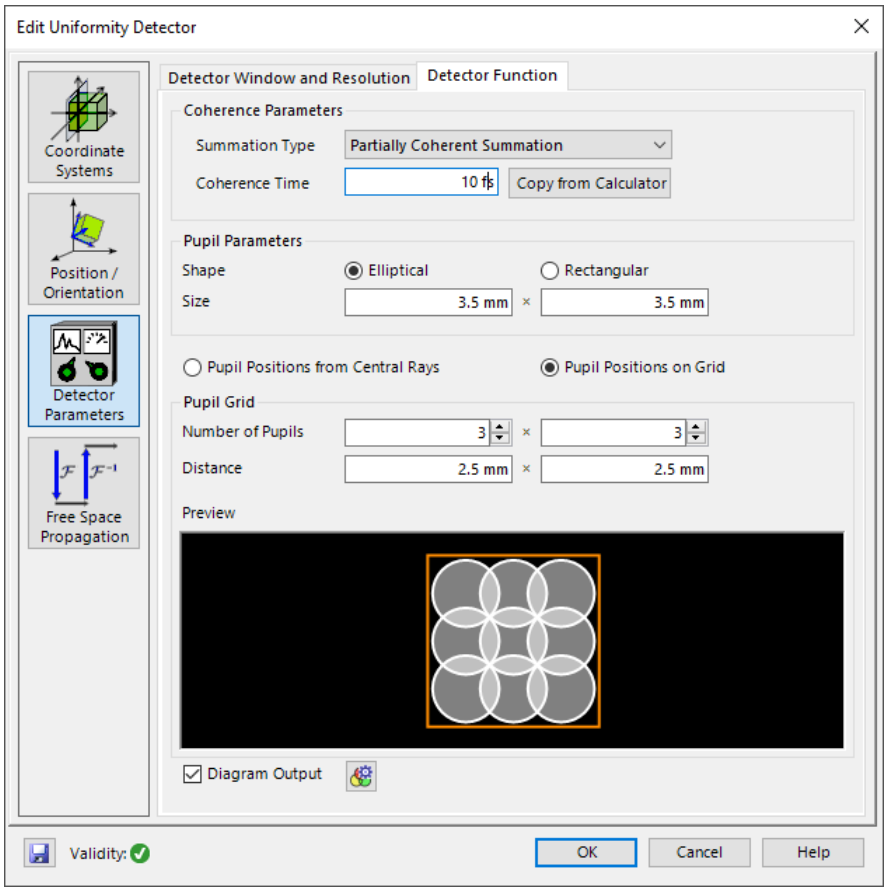


Figure 621. *The edit dialog of the Uniformity Detector.*

The edit dialog (↪Fig. 621) has the following settings.

ITEM	DESCRIPTION
Summation Type	If there is more than one coherent mode, the overlaying modes can be added coherently, incoherently, or partially coherently. For the latter you can specify the degree of coherence by entering a *Coherence Time*[PV] (or copying it from a Coherence Time & Length Calculator ↪Sec. 106). This setting has no effect for Classic Field Tracing as this engine only supports incoherent modes.
Pupil Parameters	Here you can define *Shape* and *Size*[PV] of the pupils.
Pupil Positions from Central Rays / Pupil Positions on Grid	If the first option is checked the positions of the pupils are determined automatically from the central rays of the incident ray bundles. Otherwise you can define an equidistant rectangular grid on which the pupils are placed. This grid is centered around the origin of the field.
Pupil Grid	ONLY AVAILABLE IF *PUPIL POSITIONS ON GRID* IS CHECKED. Here you can define the *Number of Pupils*[PV] and the *Distance*[PV] of the pupils for both x- and y-direction. Note that the defined grid is always centered around the origin of the detector coordinate system. Thus is not influenced by the position of the detector window (↪Sec. 75.1.1).
Preview	ONLY VISIBLE IF *PUPIL GRID* IS SELECTED. A preview of the lateral distribution of the pupils on the grid. If pupils are lying outside the detector window, this will be indicated.
Diagram Output	If checked, an additional diagram output will be generated.
	ONLY AVAILABLE IF *DIAGRAM OUTPUT* IS SELECTED. If pressed, a dialog for configuring the shown Distribution of Pupils With Values as described in Sec. (a).

75.7 Point Evaluation

75.7.1 Two Point Contrast

Availability

Optical Setups: General Optical Setup, Light Guide Optical Setup, and Laser Resonator Optical Setup

Accessible: Optical Setup: *Detectors > Point Evaluation > Two Point Contrast*

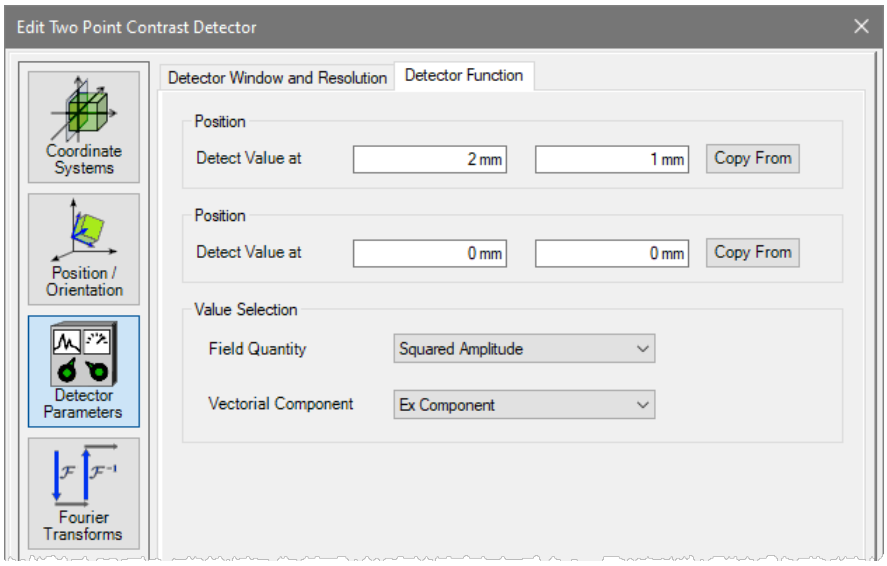


Figure 622. *The dialog for the Two Point Contrast detector.*

This detector allows you to calculate the contrast between the values (a certain field quantity of a certain vectorial component) at two specified positions in the detector plane. If V_1 is the larger value and V_2 the smaller one, the contrast C is defined by

$$C = \frac{V_1 - V_2}{V_1 + V_2} \quad . \tag{75.5}$$

On the *Detector Parameters* tab page of its dialog (↪Fig. 622), the following settings can be made.

ITEM	DESCRIPTION
Position 1 PV	The first position in physical coordinates. With the *Copy From* button you can copy the physical position from the Point Manipulation Cross of the selected harmonic field or harmonic field set.
Position 2 PV	The second position in physical coordinates. With the *Copy From* button you can copy the physical position from the Point Manipulation Cross of the selected harmonic field or harmonic field set.
Field Quantity	The Field Quantity (↪Sec. 11.1) for which the contrast is calculated.
Vectorial Component / Combined Component	Depending on the selected *Field Quantity*, you can either select the Vectorial Component (↪Sec. 12.2.2) or the Combined Component (for Summed Squared Amplitudes, ↪Sec. 11.1).

The remaining tab pages are explained in Sec. 75.1.

75.7.2 Value Monitoring

Availability

Optical Setups: General Optical Setup, Light Guide Optical Setup, and Laser Resonator Optical Setup

Accessible: Optical Setup: *Detectors > Point Evaluation > Value Monitoring*

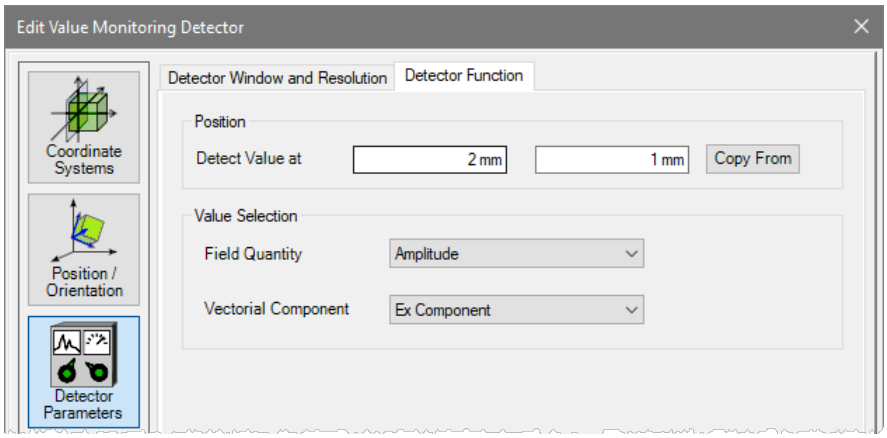


Figure 623. *The dialog for the Value Monitoring detector.*

This detector calculates a value (a certain field quantity of a certain vectorial component) at a specific position in the detector plane. To this end a pointwise sinc interpolation is used in case of Classic Field Tracing.
It can be especially helpful for the Parameter Run (↪Sec. 45). On the *Detector Parameters* tab page of its dialog (↪Fig. 623), the following settings can be made.

ITEM	DESCRIPTION
Detect Value at[PV]	The position in physical coordinates for which the specified *Field Quantity* and component shall be given.
Copy From	You can copy the physical position from the Point Manipulation Cross of the selected harmonic field or harmonic field set.
Field Quantity	The Field Quantity (↪Sec. 11.1) which shall be shown.
Vectorial Component / Combined Component	Depending on the selected *Field Quantity*, you can either select the Vectorial Component (↪Sec. 12.2.2) or the Combined Component (for Summed Squared Amplitudes, ↪Sec. 11.1).

The remaining tab pages are explained in Sec. 75.1.

75.8 Wavefront Detectors

These detectors all evaluate the smooth wavefront and thus allow to remove an off-axis spherical phase from the phase of a field. To this end the control described in Sec. 75.8.1.
They are evaluated per mode, in case of locally polarized fields the wavefront of the vectorial component (E_x or E_y) with the larger power is used.
Assume Geometric Field Zone for Detector Evaluation is always checked for these detectors as a wavefront is only well defined if there are no diffraction effects.

75.8.1 Control for Setting the Reference Wavefront

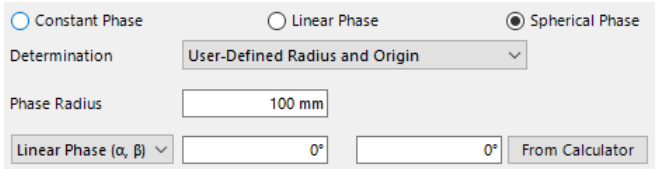


Figure 624. *The control for setting the reference wavefront.*

This control (↪Fig. 624) allows you to define a reference wavefront which is subtracted from the incident field prior to further analysis. It has the following settings.

ITEM	DESCRIPTION
Constant Phase	The phase front is evaluated unchanged. (The *Piston* coefficient of the Zernike & Seidel Aberrations Detector (↪Sec. 75.8.5) contains the average phase.) This mode has no additional parameters.
Linear Phase	The average phase and a possible linear phase is subtracted from the phase front before the actual evaluation. In this case you have two *Determination* options for the linear phase: *Fitted Direction* and *User-Defined Direction*; see table below.
Spherical Phase	An off-axis spherical phase is subtracted from the phase front before the actual evaluation. In this case you have three *Determination* options for the radius and the origin of the spherical phase: *Fitted Radius and Origin*, *User-Defined Radius at Optimized Origin*, and *User-Defined Radius and Origin*; see table below.

DETERMINATION MODE	DESCRIPTION
Fitted Direction / Fitted Radius and Origin	All parameters are determined automatically by VirtualLab Fusion.
User-Defined Direction	FOR *LINEAR PHASE* The average phase is determined by VirtualLab Fusion. The *Linear Phase* is entered by the user as Cartesian angles α and β. The direction in other direction conventions can be copied from a Direction Converter (↪Sec. 109) using the *From Calculator* button (↪Sec. 5.7).
User-Defined Radius at Optimized Origin	FOR *SPHERICAL PHASE* The average phase and the origin of the spherical phase are determined by VirtualLab Fusion. The *Phase Radius* is entered by the user.
User-Defined Radius and Origin	FOR *SPHERICAL PHASE* The average phase is determined by VirtualLab Fusion. The *Phase Radius* and the *Origin* of the spherical phase are entered by the user. As mathematically a spherical phase with an offset corresponds to a spherical phase plus a linear phase, you can also enter *Linear Phase (α, β)* instead of *Origin (x, y)*. If you want to enter the direction in another convention than Cartesian angles α and β you can use the *From Calculator* button to copy it from a Direction Converter (↪Sec. 109).

75.8.2 Polynomial Aberrations Fit

Availability

Optical Setups: General Optical Setup & Light Guide Optical Setup

Accessible: Optical Setup: *Detectors > Wavefront Detectors > Polynomial Aberrations Fit*

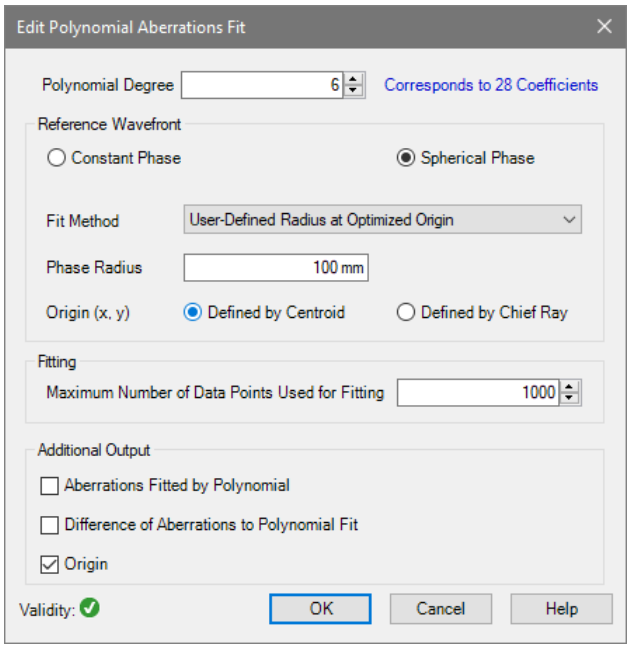


Figure 625. *Dialog for the calculation of a polynomial phase or aberrations approximation in the main window (via Detector from Catalog; ↪Sec. 76.1).*

This detector performs a least squares polynomial fit to the phase of the evaluated harmonic field with selectable degree of the polynomial (between 1 and 12, inclusively).
Its edit dialog (↪Fig. 625) has the following settings:

ITEM	DESCRIPTION
Polynomial Degree	The maximal exponent sum $m+n$ of the basis monomials $x^m \cdot y^n$ to be used.
{Reference Wavefront} PE	This control is explained in Sec. 75.8.1.
Maximum Number of Data Points Used For Fitting PV	For fields with many sampling points or rays fitting can be *very* time consuming. Thus by default only 1000 random data points with non-zero amplitude are extracted from the mode. But you can change this for speed up or convergence tests.
Phase Fitted by Polynomial / Aberrations Fitted by Polynomial	If checked, the fitted polynomial is displayed in a data array.
Difference of Phase to Polynomial Fit / Difference of Aberrations to Polynomial Fit	If checked, the difference of the original phase (relative to reference wavefront) to the fitted phase of the selected field, i. e. the fitting error, is displayed in a data array.
Phase Radius & Origin	ONLY FOR *OPTIMIZED RADIUS AND ORIGIN* The phase radius and the origin of the spherical phase are given as detector results.
Origin	ONLY FOR *USER-DEFINED RADIUS AT OPTIMIZED ORIGIN* The origin of the spherical phase is given as detector result.

Fig. 628 shows how the edit dialog looks like if the detector is used in the main window. If this detector is used in an Optical Setup, a dialog with additional controls is used (↪Sec. 75.1).

75.8.3 RMS of Phase

THIS DETECTOR HAS BEEN SUPERSEDED BY THE WAVEFRONT ERROR DETECTOR (↪SEC. 75.8.4) AND MIGHT BE REMOVED IN A FUTURE VERSION.

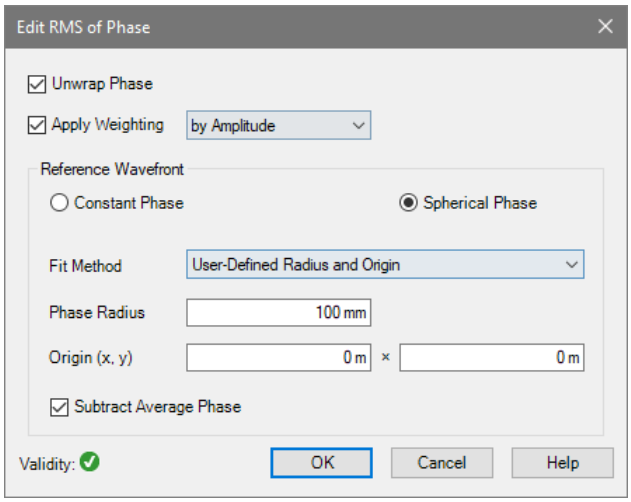


Figure 626. *Dialog for the calculation of the root mean square of the phase in the main window.*

This detector enables the user to calculate the Root Mean Square (RMS) of the phase.
If used in the main window the dialog shown in Fig. 626 will appear. The following table gives an overview over the possible settings of the dialog:

ITEM	DESCRIPTION
Unwrap Phase	Phase is unwrapped before RMS calculation.
Apply Weighting	If checked, the phase values are weighted according to the corresponding amplitude or squared amplitude.
{Reference Wavefront} PE	This control is explained in Sec. 75.8.1.
Subtract Average Phase	Average phase is subtracted before RMS calculation.

If this detector is used in an Optical Setup, a dialog with additional controls is used (↪Sec. 75.1).

75.8.4 Wavefront Error

Availability

Optical Setups: General Optical Setup, Light Guide Optical Setup, and Laser Resonator Optical Setup

Accessible: Optical Setup: *Detectors > Wavefront Detectors > Wavefront Error*

This detector calculates the deviation of the wavefront in the incoming field distribution from a reference wavefront (in wavelengths).
For the simulation engines General Profile and Ray Results Profile, the evaluation is done per coherent mode.

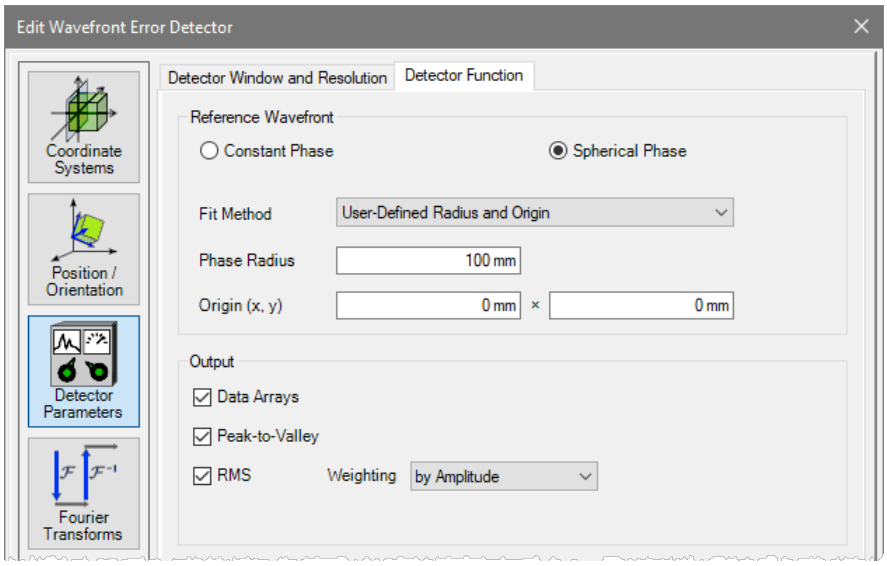


Figure 627. *The dialog for the Wavefront Error detector.*

On the *Detector Parameters* tab page of its dialog (↪Fig. 623), the following settings can be made.

ITEM	DESCRIPTION
{Reference Wavefront} PE	This control is explained in Sec. 75.8.1.
Data Arrays	The deviation of the phase from the reference wavefront is given as data array. It is given in multiples of the wavelength and as one subset per coherent mode.
Peak-to-Valley	The peak-to-valley value (i. e. the maximum deviation minus the minimum deviation) of the wavefront error is output. It is given in multiples of the wavelength and as one value per coherent mode.
RMS	The root mean square of the wavefront error is output. It is given in multiples of the wavelength and as one value per coherent mode. You can either apply a *Weighting by Amplitude* or *by Squared Amplitude* to ensure that phase values from almost dark regions of the field do not influence the resulting RMS value.
Phase Radius & Origin	ONLY FOR *OPTIMIZED RADIUS AND ORIGIN* The phase radius and the origin of the spherical phase are given as detector results.
Origin	ONLY FOR *USER-DEFINED RADIUS AT OPTIMIZED ORIGIN* The origin of the spherical phase is given as detector result.

The phase radius is the distance between the detector plane and the source plane of the spherical phase. The remaining controls are explained in Sec. 75.1.

75.8.5 Zernike & Seidel Aberrations Detector

Availability

Toolboxes: All

Accessible:

- Optical Setup: *Detectors > Basic Detectors > Zernike Fringe / Seidel Aberrations*
- Ribbon: Detectors > Zernike Fringe / Seidel Aberrations

This detector allows the calculation of the Zernike fringe, Zernike standard, and Seidel aberrations within a circular pupil. They refer to wavelengths. For example a Zernike fringe tilt of 1 corresponds to phase values in the range $-1\lambda(=-2\pi)\ldots+1\lambda(=+2\pi)$. The corresponding formulas are given in Sec. 140.2.
The evaluation is done per mode. A spherical phase factor can be separated from the phase front to be fitted.

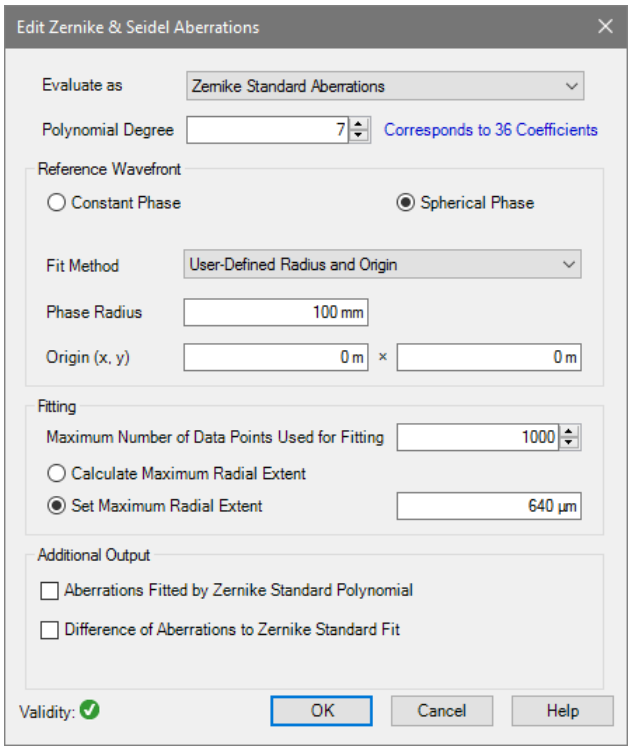


Figure 628. *Dialog of the Zernike & Seidel Aberrations Detector in the main window.*

If the ribbon item Detectors > Zernike Fringe / Seidel Aberrations is clicked, the dialog shown in Fig. 628 will appear. It allows the following settings:

ITEM	DESCRIPTION
Evaluate as	You can choose between *Zernike Fringe Aberrations*, *Zernike Standard Aberrations*, and *Seidel Aberrations*.
Polynomial Degree	ONLY FOR *ZERNIKE STANDARD ABERRATIONS* Allows you to set the maximum polynomial degree of the used Zernike terms, and thus indirectly the number of coefficients to be detected.
{Reference Wavefront} PE	This control is explained in Sec. 75.8.1.
Maximum Number of Data Points Used For Fitting PV	For mode fields with many sampling points or rays fitting can be *very* time consuming. Thus by default only 1000 random data points with non-zero amplitude are extracted from the mode. But you change this for speed up or convergence tests.

Calculate Maximum Radial Extent	If you select this option the maximum radial extent of the fitted polynomial is determined automatically from the smallest centered circle containing all data points with non-zero amplitude.
Set Maximum Radial Extent	The maximum radial extent can influence the actual coefficients of the polynomial quite strongly. Thus if e. g. the aperture of a Zernike & Seidel Aberrations Ideal Component (↪Sec. 68.5.5) is not fully illuminated by the mode field you can obtain unexpected results. To avoid this you can set a certain maximum radial extent manually.
Aberrations / Phase Fitted by Zernike Fringe / Zernike Standard / Seidel Polynomial	If checked, the unwrapped aberrations fit respective the phase fit is displayed in a data array per mode.
Difference of Aberrations / Phase to Zernike Fringe / Zernike Standard / Seidel Fit	If checked, the difference of the original phase to the fitted phase of the selected field (i. e. the fitting error) is displayed in a data array per mode.
Phase Radius & Origin	ONLY FOR *OPTIMIZED RADIUS AND ORIGIN* The phase radius and the origin of the spherical phase are given as detector results.
Origin	ONLY FOR *USER-DEFINED RADIUS AT OPTIMIZED ORIGIN* The origin of the spherical phase is given as detector result.

The phase radius is the distance between the detector plane and the source plane of the spherical phase. Fig. 628 shows how the edit dialog looks like if the detector is used in the main window. If this detector is used in an Optical Setup, a dialog with additional controls is used (↪Sec. 75.1).

Note that coefficients being less than 10^{-8} the maximum coefficient are set to zero.

76 Detectors for Harmonic Fields and Harmonic Fields Sets

Several detectors can be applied to harmonic fields or harmonic fields sets via the *Detectors* ribbon. In case of a Harmonic Fields Set you can decide whether you want to apply the detector to all member fields or only to the currently visible one, either via a separate dialog or a checkbox at the very bottom of the edit dialog. The Camera Detector and the Complex Histogram detector are an exception: they are *always* applied to all member fields.

76.1 Detector from Catalog

Via Detectors > Detector from Catalog you can apply any detector from the detector catalog (but pulse evaluation detectors) on the current harmonic field or harmonic fields set.
If you click on this ribbon item, first the catalog dialog (↪Sec. 33) opens where you can select a detector. Then a dialog (↪Fig. 629) with further options opens.

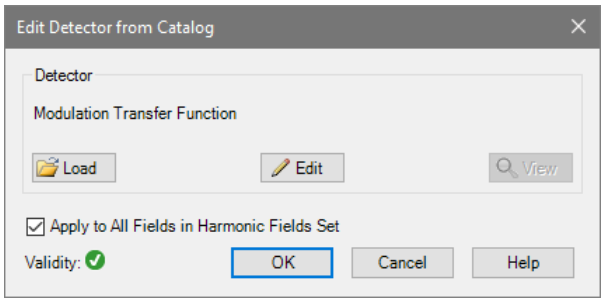


Figure 629. *The edit dialog for the Detector from Catalog ribbon item.*

ITEM	DESCRIPTION
Load	Loads another detector from the catalog (↪Sec. 33).
Edit	Edits the current detector.
View	Always disabled as detectors have no distinct view.
Apply to All Fields in Harmonic Fields Set	ONLY FOR HARMONIC FIELDS SETS If checked, the detector is evaluated for all member fields of the Harmonic Fields Set. Otherwise only the currently visible member field is evaluated.
Validity	Indicates whether a valid detector is currently selected. ↪Sec. 5.11

Hint

Programmable Detectors using the `ParentLightPath` variable cannot be used in the main window.

76.2 Physical Detectors

The following physical detectors are available for harmonic fields and harmonic fields sets in the main window.

- Beam Parameters; ↪Sec. 75.6.1
- Diffractive Optics Merit Functions; ↪Sec. 75.6.2
- Fiber Coupling Efficiency; ↪Sec. 75.6.6
- Wavefront Error; ↪Sec. 75.8.4
- Spherical Phase Radius; ↪Sec. 142.6
- Zernike Fringe / Seidel Aberrations; ↪Sec. 75.8.5

76.3 Field Components

76.3.1 Electric Field

This option enables you to extract the electric field components (E_x, E_y, and E_z) of a harmonic field and to store them into different subsets of a data array.

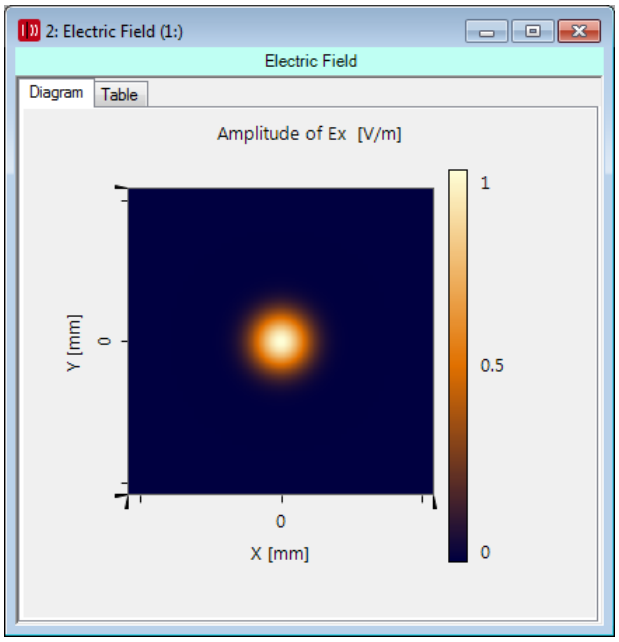


Figure 630. *X-component of the electric field of a Gaussian wave, linearly polarized in x-direction.*

76.3.2 Magnetic Field (H-Field)

This detector allows you to calculate the magnetic field components H_x, H_y, and H_z from a harmonic field. The components of the magnetic field (H_x, H_y, and H_z) are stored in different subsets of a data array.

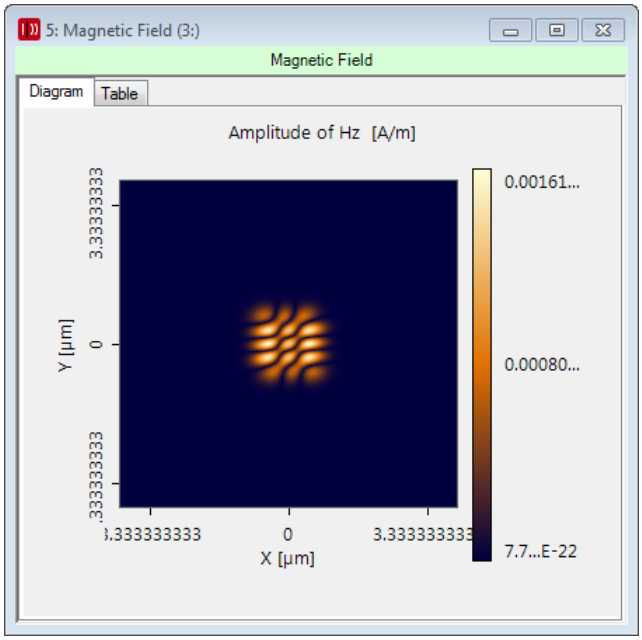


Figure 631. *X-component of the magnetic field of a Gaussian wave, linearly polarized in x-direction.*

The data array supports the configuration of view settings as described in Sec. 13.4.
The implemented formulas are given in Sec. 142.7.1.

76.3.3 Poynting Vector

This detector displays the components of the time averaged Poynting vector of a harmonic field. In the data array contains the x-component, the y-component, and the z-component of the Poynting vector. The z-component of the time averaged Poynting vector is in general the intensity of the electrical field. Only for paraxial fields the

intensity is proportional to the sum of the squared amplitudes of the x- and y-field component. The components of the averaged Poynting vector are stored in different subsets of the data array.

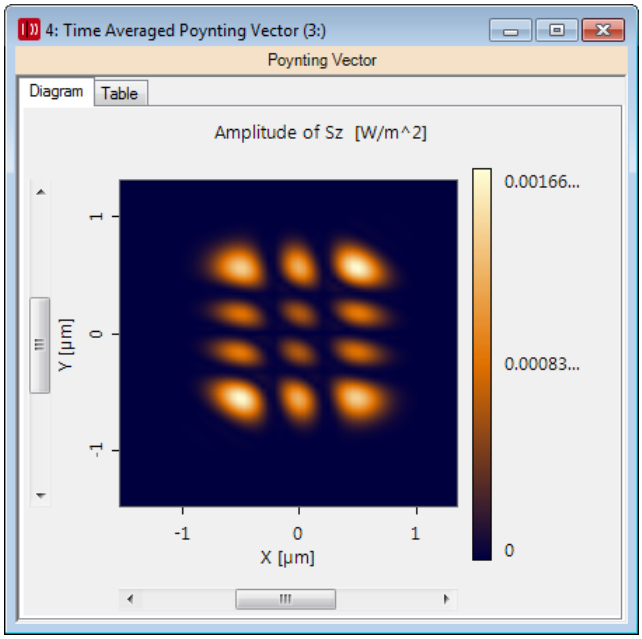


Figure 632. *Z-component of the Poynting vector of a Gaussian wave.*

The data array supports the configuration of view settings as described in Sec. 13.4.
The implemented formulas are given in Sec. 142.7.2.

76.4 Numerical Detectors

All detectors described in this section show their output in the Detector Results window. Unless otherwise noted, they are applicable for harmonic fields, harmonic fields sets, transmissions, and signal regions.

76.4.1 Average

Via Detectors > Average the average of every field quantity (squared amplitude, amplitude, phase, real and imaginary part) will be calculated. The average $\bar{c}$ is defined by

$$\bar{c} = \frac{1}{N_x N_y} \sum_{i=0,j=0}^{N_x,N_y} c_{i,j}. \tag{76.1}$$

N_x and N_y are the number of sampling points in x- and y-direction. $c_{i,j}$ stands for any field quantity of the sampling point $[i, j]$.

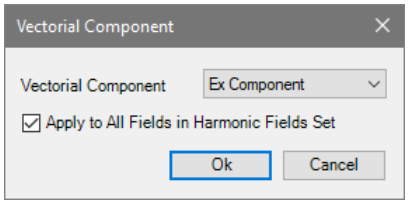


Figure 633. *The edit dialog shown if the average detector is applied on harmonic fields sets.*

For harmonic fields or harmonic fields sets this detector has an edit dialog (↪Fig. 633) with the following options:

ITEM	DESCRIPTION
Vectorial Component	The vectorial component to be evaluated. Either E_x or E_y can be selected.
Apply to All Fields in Harmonic Fields Set	ONLY FOR HARMONIC FIELDS SETS If checked, the detector is evaluated for all member fields of the Harmonic Fields Set. Otherwise only the currently visible member field is evaluated.

76.4.2 Complex Histogram

Creates a histogram showing how often complex numbers in certain equidistant intervals occur within a harmonic field. The histogram shows a selectable part of the complex number plane. The creation of a one-dimensional histogram showing just how often certain real or imaginary parts occur is also possible.
In addition it is output how many distinct values occur, i. e. how many of the intervals in the complex histogram are non-zero. In this way you can for example count to how many levels the data was quantized.
For locally polarized fields a histogram for both the E_x- and the E_y-component of the field is generated.

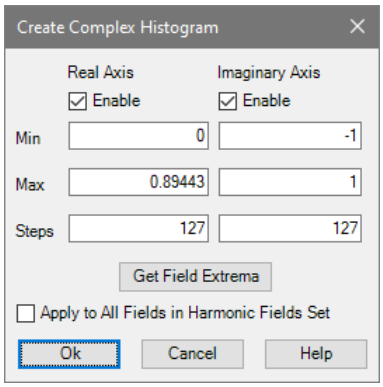


Figure 634. *Dialog for the Complex Histogram detector.*

After the selection of this menu item the dialog shown in Fig. 634 will appear. It allows the following settings:

ITEM	DESCRIPTION
Real Axis Enable	Enables or disables the real axis in the complex histogram. If the real axis and the imaginary axis are enabled a two-dimensional histogram will be created. If one axis is disabled a one-dimensional histogram will be created.
Real Axis Min	The minimum real value of all complex numbers of the harmonic field that is taken into account for the calculation of the histogram.
Real Axis Max	The maximum real value of all complex numbers of the harmonic field that is taken into account for the calculation of the histogram.
Real Axis Steps	The number of intervals used between *Real Axis Min* and *Real Axis Max* for the creation of the histogram.
Imaginary Axis Enable	Enables or disables the imaginary axis in the complex histogram. If the real axis and the imaginary axis are enabled a two-dimensional histogram will be created. If one axis is disabled a one-dimensional histogram will be created.
Imaginary Axis Min	The minimum imaginary value of all complex numbers of the harmonic field that is taken into account for the calculation of the histogram.
Imaginary Axis Max	The maximum imaginary value of all complex numbers of the harmonic field that is taken into account for the calculation of the histogram.

Imaginary Axis Steps	The number of intervals used between *Imaginary Axis Min* and *Imaginary Axis Max* for the creation of the histogram.
Get Field Extrema	Detects automatically the minimum and maximum real and imaginary value and sets the results in the dialog.
Apply to All Fields in Harmonic Fields Set	ONLY FOR HARMONIC FIELDS SETS If checked, the detector is evaluated for all member fields of the Harmonic Fields Set. Otherwise only the currently visible member field is evaluated. If the Harmonic Fields Set contains both locally and globally polarized fields, this option is not shown as in this case it is not possible to evaluate all fields at once.

76.4.3 Field Deviation

This detector provides a convenient way to calculate the absolute differences between the amplitudes and phases of two harmonic fields or two harmonic fields sets, respectively. The results are written into different subsets of a Data Array. For harmonic fields sets one data array per member field is returned, bundled into a Set of Data Arrays.

This detector can be used via Detectors > Field Deviation. Then a dialog opens where you can select the second harmonic field / harmonic fields set. In case of harmonic fields sets, the number of member fields must be the same for the two documents. If the two fields to compare do not have the same sampling, they are resampled to a common sampling (largest field size and smallest sampling distance).

76.4.4 Minimum / Maximum Value

Via Detectors > Minimum / Maximum Value maximum and minimum value of every field quantity and their respective position in the field will be calculated.

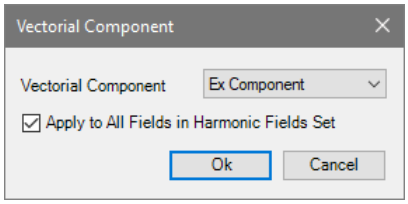


Figure 635. *The edit dialog shown if the minimum / maximum detector is applied on harmonic fields or harmonic fields sets.*

For harmonic fields or harmonic fields sets this detector has an edit dialog (↪Fig. 635) with the following options:

ITEM	DESCRIPTION
Vectorial Component	The vectorial component to be evaluated. Either E_x or E_y can be selected.
Apply to All Fields in Harmonic Fields Set	ONLY FOR HARMONIC FIELDS SETS If checked, the detector is evaluated for all member fields of the Harmonic Fields Set. Otherwise only the currently visible member field is evaluated.

76.4.5 Momentum

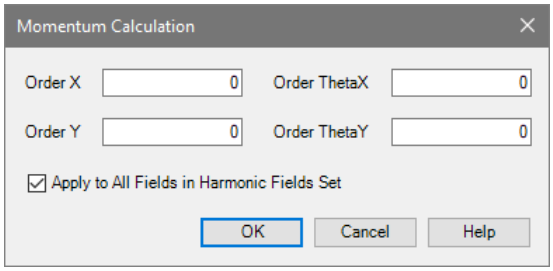


Figure 636. *Dialog for momentum calculation*

The dialog in Fig. 636 can be accessed via Detectors > Momentum. It has the following entries.

ITEM	DESCRIPTION
Vectorial Component	ONLY FOR LOCALLY POLARIZED FIELDS Selects the vectorial component (E_x or E_y) for which the momenta shall be calculated.
Order X	The order in x of the momentum which shall be calculated (see below).
Order Y	The order in y of the momentum which shall be calculated (see below).
Order ThetaX	The order in Θ_x of the momentum which shall be calculated (see below).
Order ThetaY	The order in Θ_y of the momentum which shall be calculated (see below).
Apply to All Fields in Harmonic Fields Set	ONLY FOR HARMONIC FIELDS SETS If checked, the detector is evaluated for all member fields of the Harmonic Fields Set. Otherwise only the currently visible member field is evaluated.

All values have to be positive integers inclusive zero. The calculated momenta will be shown in the *Detector Results* tab page.
The momentum theory is very useful to determine the beam parameters (↪Sec. 75.6.1) of an arbitrary wave with global polarization. The formulas are given in Sec. 142.8

76.4.6 Standard Deviation

Via Detectors > Standard Deviation the standard deviation σ from the average $\bar{c}$ (↪Sec. 76.4.1) can be calculated for every field quantity (squared amplitude, amplitude, phase, real and imaginary part). It is defined by

$$\sigma = \sqrt{\frac{1}{N_x N_y} \sum_{i=0,j=0}^{N_x,N_y} (c_{i,j} - \bar{c})^2}. \tag{76.2}$$

N_x and N_y are the number of sampling points in x- and y-direction. $c_{i,j}$ stands for any field quantity of the sampling point $[i,j]$.

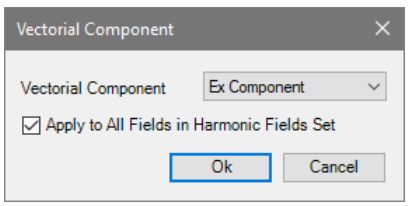


Figure 637. *The edit dialog shown if the standard deviation detector is applied on harmonic fields or harmonic fields sets.*

This detector has an edit dialog (↪Fig. 637) with the following options:

ITEM	DESCRIPTION
Vectorial Component	The vectorial component to be evaluated. Either E_x or E_y can be selected.
Apply to All Fields in Harmonic Fields Set	ONLY FOR HARMONIC FIELDS SETS If checked, the detector is evaluated for all member fields of the Harmonic Fields Set. Otherwise only the currently visible member field is evaluated.

76.4.7 Summed Norm

Via Detectors > Summed Norm the summed norm of the whole field component can be calculated. Additionally, if a range or rectangle marker is visible, the summed norm within the current selection and the ratio between these two values is calculated.

The summed norm S of a certain region is defined as the sum of the squared amplitude A^2 of each pixel in this region:

$$S = \sum_{i=0,j=0}^{N_x,N_y} A^2. \tag{76.3}$$

N_x and N_y are the number of sampling points in x- and y-direction, respectively. A^2 is the squared amplitude of either E_x or E_y.

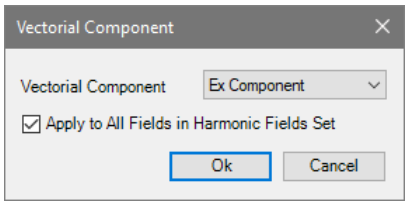


Figure 638. *The edit dialog of the summed norm detector.*

When you apply this detector a dialog (↪Fig. 638) with the following options is shown:

ITEM	DESCRIPTION
Vectorial Component	The vectorial component to be evaluated. Either E_x or E_y can be selected.
Apply to All Fields in Harmonic Fields Set	ONLY HARMONIC FIELDS SETS If checked, the detector is evaluated for all member fields of the Harmonic Fields Set. Otherwise only the currently visible member field is evaluated.

77 Detectors for Data Arrays

All the detectors in this section work for (gridded) Numerical Data Arrays (↪Sec. 13.4) as well as for document types based on gridded data arrays (chromatic fields sets [↪Sec. 14] and pulse and field components [↪Sec. 15]).

77.1 Data Point Average

Via Detectors > Data Point Average the average of one or more selected field quantities will be calculated. The average $\bar{c}$ refers to the set of all data points (instead of a unit area like m^2 or mm^2 or the like) and is defined by

$$\bar{c} = \frac{1}{N_x \cdot N_y} \sum_{i=0,j=0}^{N_x,N_y} c_{i,j}. \tag{77.1}$$

N_x and N_y are the number of data points in x- and y-direction. $c_{i,j}$ stands for any field quantity of the data point $[i,j]$.

For objects with complex-valued data or with more than one subset, a dialog opens where you can select one or more field quantities (↔Sec. 11.1) for which the data point average is calculated. If you select/unselect *All*, all/no field quantities are selected. Furthermore, you can select whether the calculation shall be done on all of the subsets or only on the currently visible one.

77.2 Complex Histogram

Creates a histogram showing how often complex numbers in certain equidistant intervals occur within the data. The histogram shows a selectable part of the complex number plane. The creation of a one-dimensional histogram showing just how often certain real or imaginary parts occur is also possible.
In addition it is output how many distinct values occur, i. e. how many of the intervals in the complex histogram are non-zero. In this way you can for example count to how many levels the data was quantized.

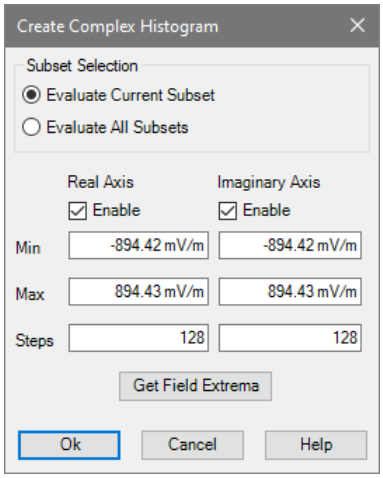


Figure 639. *Dialog for the Complex Histogram Detector for Data Arrays.*

After the selection of this menu item the dialog shown in Fig. 639 will open. It allows the following settings:

ITEM	DESCRIPTION
Evaluate Current Subset / All Subsets	Allows to select whether the calculation shall be done for all subsets or only for the currently visible one. Note: If *Evaluate All Subsets* is selected, no *Min* or *Max* values can be entered because they could strongly vary in range and meaning for the different subsets.
Real Axis Enable	Enables or disables the real axis in the complex histogram. If the real axis *and* the imaginary axis are enabled, a two-dimensional histogram will be created. If one axis is disabled a one-dimensional histogram will be created.
Real Axis Min	FOR *EVALUATE CURRENT SUBSET* MODE ONLY. The minimum real value that is used for the calculation of the histogram.
Real Axis Max	FOR *EVALUATE CURRENT SUBSET* MODE ONLY. The maximum real value that is used for the calculation of the histogram.
Real Axis Steps	The number of intervals used between *Real Axis Min* and *Real Axis Max* for the creation of the histogram.
Imaginary Axis Enable	FOR COMPLEX DATA ONLY. Enables or disables the imaginary axis in the complex histogram. If the real axis *and* the imaginary axis are enabled, a two-dimensional histogram will be created. If one axis is disabled a one-dimensional histogram will be created.

Imaginary Axis Min	FOR COMPLEX DATA AND THE *EVALUATE CURRENT SUBSET* MODE ONLY. The minimum imaginary value that is used for the calculation of the histogram.
Imaginary Axis Max	FOR COMPLEX DATA AND THE *EVALUATE CURRENT SUBSET* MODE ONLY. The maximum imaginary value that is used for the calculation of the histogram.
Imaginary Axis Steps	FOR COMPLEX DATA ONLY. The number of intervals used between *Imaginary Axis Min* and *Imaginary Axis Max* for the creation of the histogram.
Get Field Extrema	FOR *EVALUATE CURRENT SUBSET* MODE ONLY. Detects automatically the minimum and maximum real and imaginary value and sets the results into the dialog.

77.3 Full Width at Half Maximum

For real-valued data, this detector calculates the width which corresponds to half of the maximum value of a lateral data distribution. Therefor the position of the first maximum in the field is calculated. Starting from this position, the innermost positions are searched in both (i. e. x- and y-) directions for these positions where the function falls below the half of the maximum value.

For objects with complex-valued data or with more than one subset, a dialog opens where you can select one or more field quantities (↪Sec. 11.1) for which the full width at half of the maximum is calculated. If you select/unselect *All*, all/no field quantities are selected. Furthermore, you can select whether the calculation shall be done on all of the subsets or only on the currently visible one.

77.4 Minimum / Maximum (Position and Value)

For real-valued data, this detector searches for the minimum / maximum value and the (smallest) x-(y-)position where the minimum / maximum is reached.

For objects with complex-valued data or with more than one subset, a dialog opens where you can select one or more field quantities (↪Sec. 11.1) for which the minimum / maximum is calculated. If you select/unselect *All*, all/no field quantities are selected. Furthermore, you can select whether the calculation shall be done on all of the subsets or only on the currently visible one.

77.5 Standard Deviation

Via Detectors > Standard Deviation the standard deviation σ from the average $\bar{c}$ (↪Sec. 77.1) can be calculated for one or more given field quantities. It is defined by

$$\sigma = \sqrt{\frac{1}{N_x \cdot N_y} \sum_{i=0,j=0}^{N_x,N_y} \left(c_{i,j} - \bar{c}\right)^2}. \tag{77.2}$$

N_x and N_y are the number of data points in x- and y-direction. $c_{i,j}$ stands for any field quantity of the data point $[i, j]$.

For objects with complex-valued data or with more than one subset, a dialog opens where you can select one or more field quantities (↪Sec. 11.1) for which the standard deviation is calculated. If you select/unselect *All*, all/no field quantities are selected. Furthermore, you can select whether the calculation shall be done on all of the subsets or only on the currently visible one.

77.6 Uniformity Error

ONLY FOR TWO-DIMENSIONAL DATA ARRAYS.

The uniformity error detector can be applied by clicking on the ribbon item Detectors > Uniformity Error. The user needs to specify a *desired output field* that is used to evaluate the uniformity error. The uniformity error E_{unif} is defined as follows:

$$E_{\text{unif}} = \frac{Q_{\text{max}} - Q_{\text{min}}}{Q_{\text{max}} + Q_{\text{min}}}. \tag{77.3}$$

$Q_{\text{min/max}}$ is the smallest / largest occurring quotient of the values in the data array divided by the values in the desired output field.

The output of the detector are the minimum quotient Q_{min}, the maximum quotient Q_{max} and the calculated uniformity error.

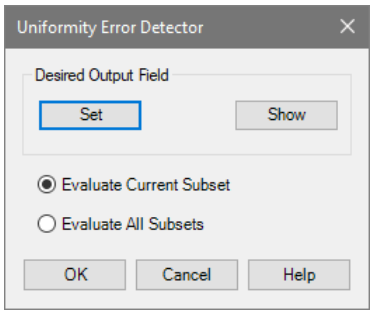


Figure 640. *The edit dialog of the Uniformity Error Detector.*

Fig. 640 shows the edit dialog of the uniformity detector. The following setting can be done by the user:

ITEM	DESCRIPTION
Desired Output Field > Set	The user has to specify a desired output field as data array. If you click on this button you can do the following: • *Load* a data array from a .da file. • *Import* a data array from a text file by means of the import wizard described in Sec. 121.1. • *Select from Documents* allows you to select an already open data array. In any case the data array has to contain only one subset. It has to be equidistant and the data has to be real-valued.
Desired Output Field > Show	Shows the desired output field as separate Data Array document.
Evaluate Current Subset / Evaluate All Subsets	If you click on the first control, only the currently visible subset is evaluated. If you click on the latter, all subsets of the Data Array are evaluated separately. These controls are only visible if the Data Array contains more than one subset.

77.7 Sum within Selection

Using Detectors > Sum Within Selection, the sum of all values inside a previously marked selection can be obtained.

This detection works for one-dimensional as well as for two-dimensional Numerical Data Arrays. As described in Sec. 11.3, a coordinate range has to be selected in the 1D case, a rectangle or elliptic selection is prerequisite in the 2D case.

In each of the cases, data points which are covered only partially by the selection are considered according to the intersection between the data point's coordinate range and the selection.

77.8 Add Polarization Ellipses

The ribbon button Detectors > Add Polarization Ellipses allows you to calculate polarization ellipses for Electric or Electromagnetic Fields (↪Sec. 13.1) either if none were calculated by the Universal Detector (↪Sec. 75.4) or if the ellipses shall be calculated anew for whatever reason. This functionality is described in Sec. 32.3 in more detail.

77.9 Apply Detector Add-on

The ribbon button Detectors > Apply Detector Add-on allows you to apply any detector add-on onto Data Arrays (↪Sec. 13) and Chromatic Fields Sets (↪Sec. 14) just like the Universal Detector does (↪Sec. 75.4.5). Via clicking on the upper part of the split button or on Apply Detector Add-on in its lower part, you can load a detector add-on from hard disc. Then the dialog explained in Sec. 641 opens where you can change the loaded snippet or create a new one.
In addition the lower part of the button contains those add-ons that you have stored as *favorite* in the edit dialog for detector add-ons (↪Sec. 77.9.1, Sec. 75.4.5.2). And it has the additional entry Update Predefined Add-ons which loads the most up-to-date addons from the Wyrowski Photonics Website. Optionally also the snippets of all favorites are then updated if they have the same name as a predefined addon. The values of your favorites's snippet parameters are kept.

77.9.1 Dialog for Applying a Detector Add-on on a Data Array

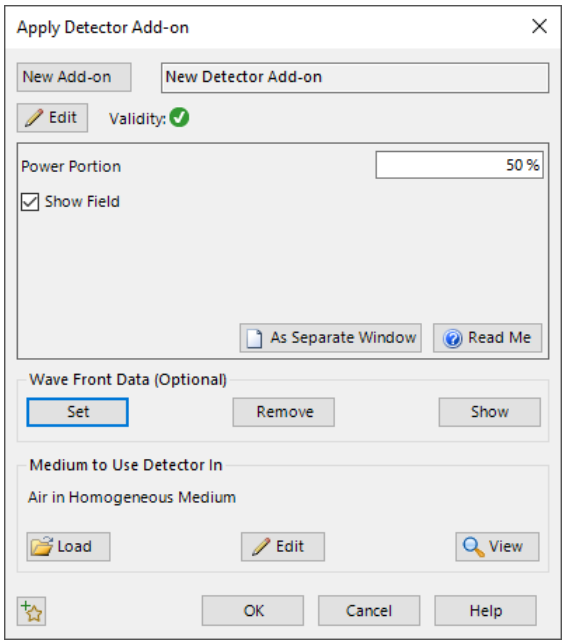


Figure 641. *Edit dialog for a detector add-on.*

ITEM	DESCRIPTION
New Add-on	Allows you to load the add-on to be applied, either *From Template* or *From File*.
Edit	Opens the source code editor for the add-on's snippet.
{Parameter Box}	This box contains the parameters defined in the snippet if there are any. ↪Sec. 7.4
Wave Front Data (Optional)	Data which describe the wave front of a electric / magnetic / electromagnetic field can be set, removed or shown here if needed. *Wave Front Data* means the *Wavefront Phase* mentioned in Sec. 75.4 which is the smooth part of the phase of the field in the detector plane. Only this data, extracted by the Universal Detector shall be used if needed (because the data have to correspond to the calling field by all means). Whether or not this data are to be set at all depends on the actual add-on's snippet.
Medium to Use Detector In	The optical medium the add-on shall be applied in can be defined here (↪Sec. 38.3.1, ↪Sec. 34).
	Saves the add-on as separate file into the *Favorites* folder. Shortcuts to these files are shown when you click on the lower part of the Apply Detector Add-on button (↪Sec. 77.9).

XII Analyzers: Evaluating Optical Systems

Analyzers evaluate an Optical Setup or a single Optical Setup Element in a special way, independent from the simulation engines described in Sec. 44.5.

For example the Distortion Analyzer (↪Sec. 79) calculates the distortion introduced by one Optical Setup Element, whereas the Eigenmode Analyzer (↪Sec. 90) calculates the eigenmode of a complete laser resonator optical setup.

78 Coating Analyzer

Only available in a General Optical Setup.

Knowing the reflection properties of a certain surface is very important for many applications. If these properties don't meet the needs of the optical setup, it may be necessary to equip the surface with a coating.

The function of the Coating Analyzer is the evaluation of the reflection and transmission values of an optical surface in order to provide a base for the decision on applying a coating. The improvement achieved by a certain coating can be evaluated too. Supported outputs are tables with Fresnel coefficients as well as data arrays (↪Sec. 13.4) showing the dependencies of a certain coefficient on wavelength and angle of incidence.

The analyzer element has to be configured before each use via its edit dialog which is called by double click on the element's symbol in the Optical Setup View or on the corresponding table entry in the Optical Setup Table. It has a wizard structure and has to be filled by the sequential steps described in the following subsections.

78.1 Selection of the Surface to Analyze

At first, the component that contains the surface to analyze has to be selected. The component can be a Curved Surface (↪Sec. 59.1), Lens System (↪Sec. 58.1), or Spherical Lens (↪Sec. 58.3) which must be linked to the active light source. Then, the surface itself can be selected.

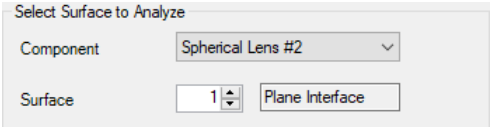


Figure 642. *Controls for selecting the surface to analyze.*

ITEM	DESCRIPTION
Component	The component the surface to be analyzed belongs to. This may be either a Curved Surface, a Lens System, or a Spherical Lens.
Surface	The surface to be analyzed. It is selected by its index inside its component.

78.2 Selection of Analyzer Output

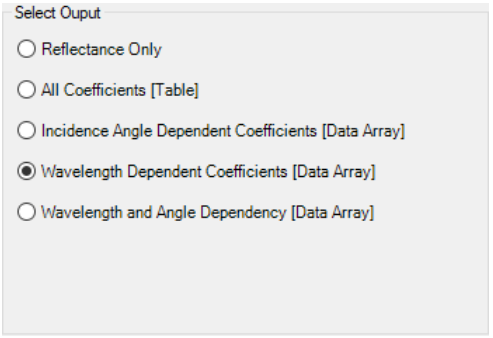


Figure 643. *Controls for selecting the analyzer's output.*

The following types of output are available:

ITEM	DESCRIPTION
Reflectance Only	Only the reflectance for TE and TM is calculated and shown in the *Detector Results* tab of the main window.
All Coefficients [Table]	The reflectance, transmittance, and the complex Fresnel coefficients will be calculated for TE as well as for TM for a given wavelength, angle of incidence and lateral position on the surface.
Incidence Angle Dependent Coefficients [Data Array]	The user will have to select up to four parameters to calculate a 1D data array for. It will show the dependency of this parameter on the angle of incidence for a given wavelength.
Wavelength Dependent Coefficients [Data Array]	The user will have to select up to four parameters to calculate a 1D data array for. It will show the dependency of this parameter on the wavelength for a given angle of incidence.
Wavelength and Angle Dependency [Data Array]	The user will have to select up to four parameters to calculate a 2D data array for. It will show the dependencies of this parameter on the wavelength and the angle of incidence.

Note on Optimization

This analyzer can be used for Parametric Optimization (↪Sec. 103) under the following conditions:

1. *Reflectance Only* is used as output mode. In this case you can optimize the reflectance for one specific wavelength and incidence angle.
2. For any of the data array outputs you can use the Parametric Optimization if you select that the reflectance (= reflection intensity coefficient) is calculated. Because then the minimum and maximum reflectance as well as the arithmetic mean of all reflectance values in the resulting data arrays are being calculated and those values can be used as optimization constraints.

78.3 Configuring the Analyzer Output

Each type of output requires certain parameters that are described in the following.

78.3.1 Reflectance Only and All Coefficients [Table]

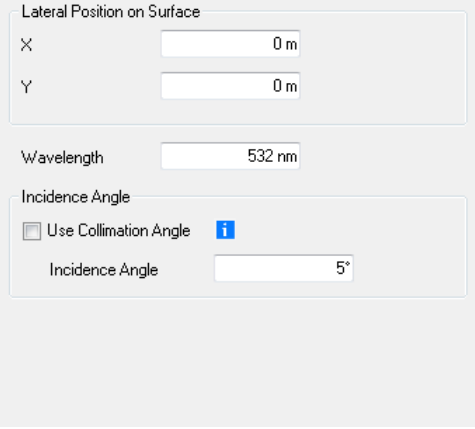


Figure 644. *Configuration of the* Reflectance Only *or the* All Coefficients *output.*

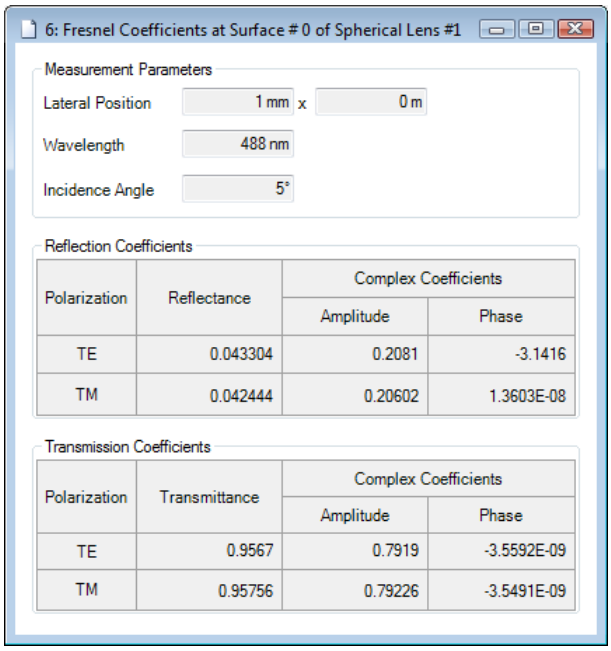


Figure 645. *Example for an output of all Fresnel coefficients in one table.*

ITEM	DESCRIPTION
Lateral Position on Surface	Coordinates of the position on the surface where the Fresnel coefficients shall be calculated for.
Wavelength	Wavelength the coefficients shall be calculated for.
Incidence Angle	Incidence angle the calculation shall be done for. It is defined in relation to the normal vector of the surface to analyze.
Use Collimation Angle	If this box is checked, the incidence angle is determined from the angle between the normal vector of the surface to be analyzed and the output axis of the Optical Setup Element which prepends it in the execution sequence of the Optical Setup. ↪Fig. 646.

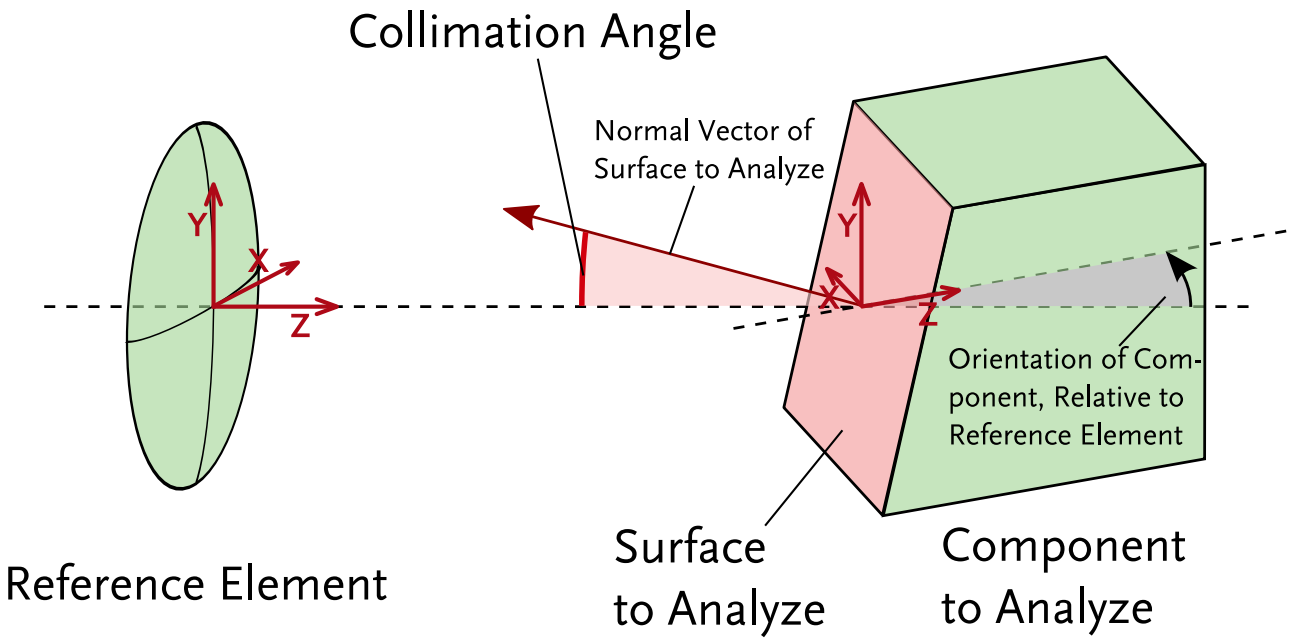


Figure 646. *Meaning of the collimation angle: Angle between the normal vector of the surface to analyze and the output axis of its prepended element in the Optical Setup (Reference Element).*

78.3.2 Incidence Angle Dependent Coefficients [Data Array]

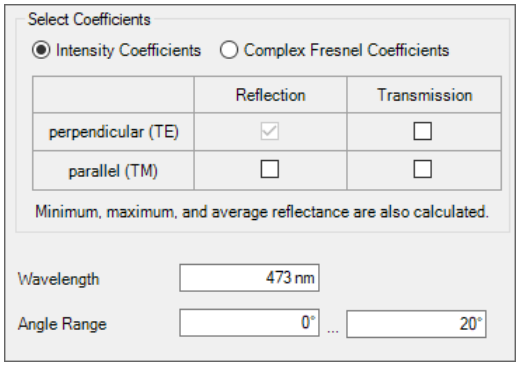


Figure 647. *Configuration of the* Incidence Angle Dependent Coefficients *output.*

ITEM	DESCRIPTION
Intensity Coefficients	Select this option if you want to calculate reflectance or transmittance.
Complex Fresnel Coefficients	Select this option if you want to calculate the complex reflection and transmission coefficients.
Reflection / Transmission	Select here if reflection and / or transmission coefficients shall be calculated and returned as separate subsets in the resulting data array.
perpendicular (TE) / parallel (TM)	Select here which polarization state(s) shall be calculated and returned as separate subsets in the resulting data array.
Wavelength	Wavelength the coefficients shall be calculated for.
Angle Range	Range of incidence angles the calculation shall be done for.

78.3.3 Wavelength Dependent Coefficients [Data Array]

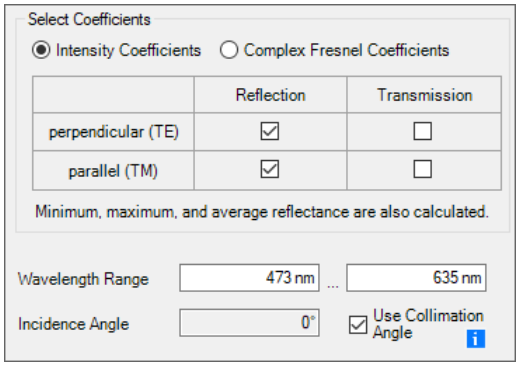


Figure 648. *Configuration of the* Wavelength Dependent Coefficients *output.*

ITEM	DESCRIPTION
Intensity Coefficients	Select this option if you want to calculate reflectance or transmittance.
Complex Fresnel Coefficients	Select this option if you want to calculate the complex reflection and transmission coefficients.
Reflection / Transmission	Select here if reflection and / or transmission coefficients shall be calculated and returned as separate subsets in the resulting data array.
perpendicular (TE) / parallel (TM)	Select here which polarization state(s) shall be calculated and returned as separate subsets in the resulting data array.
Wavelength Range	Range of wavelengths the coefficients shall be calculated for.
Incidence Angle	Angle of light incidence the calculation shall be done for.
Use Collimation Angle	If this box is checked, the incidence angle is determined from the angle between the normal vector of the surface to be analyzed and the output axis of the Optical Setup Element which prepends it in the execution sequence of the Optical Setup. ↪Fig. 646.

78.3.4 Wavelength and Angle Dependency [Data Array]

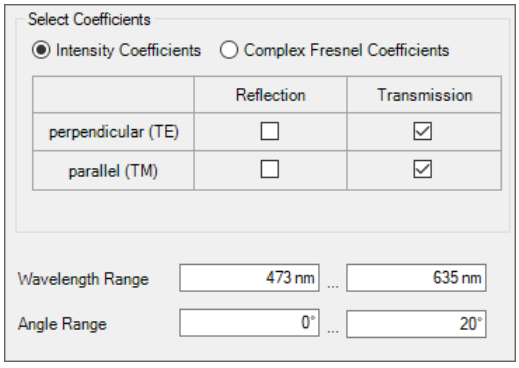


Figure 649. *Configuration of the* Wavelength and Angle Dependency *output.*

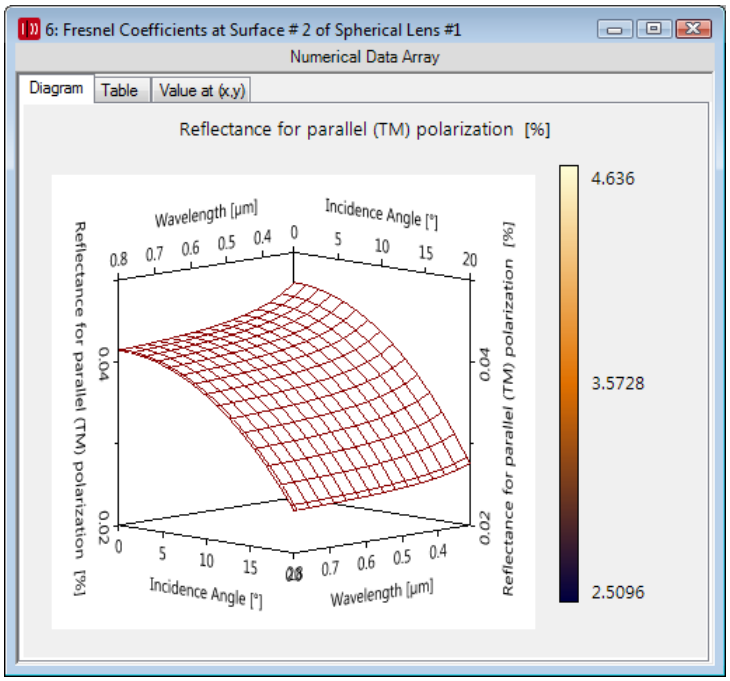


Figure 650. *Example for a 2D data array output of the reflectance for TM polarization.*

ITEM	DESCRIPTION
Intensity Coefficients	Select this option if you want to calculate reflectance or transmittance.
Complex Fresnel Coefficients	Select this option if you want to calculate the complex reflection and transmission coefficients.
Reflection / Transmission	Select here if reflection and / or transmission coefficients shall be calculated and returned as separate subsets in the resulting data array.
perpendicular (TE) / parallel (TM)	Select here which polarization state(s) shall be calculated and returned as separate subsets in the resulting data array.
Wavelength Range	Range of wavelengths the coefficients shall be calculated for.
Angle Range	Range of incidence angles the calculation shall be done for.

79 Distortion Analyzer

Only available in a General Optical Setup.

The *Distortion Analyzer* calculates the distortion of a laser beam introduced by one component for various angles in one direction. It works for the index modulated components (↪Sec. 57.2), a Lens System (↪Sec. 58.1), a Spherical Lens (↪Sec. 58.3), or a Curved Surface (↪Sec. 59.1).

For each angle a small ray bundle is propagated through the selected component and the so calculated deflection y_{real} compared to the reference deflection y_{ref} yields the distortion D for this angle.

$$D = \frac{y_{\text{real}} - y_{\text{ref}}}{y_{\text{ref}}} \tag{79.1}$$

whereas $y_{\text{ref}} = f \cdot \tan\alpha$ for *Tan(Theta) distortion* and $y_{\text{ref}} = f \cdot \alpha$ for *Theta distortion*. f is the effective focal length of the analyzed component.

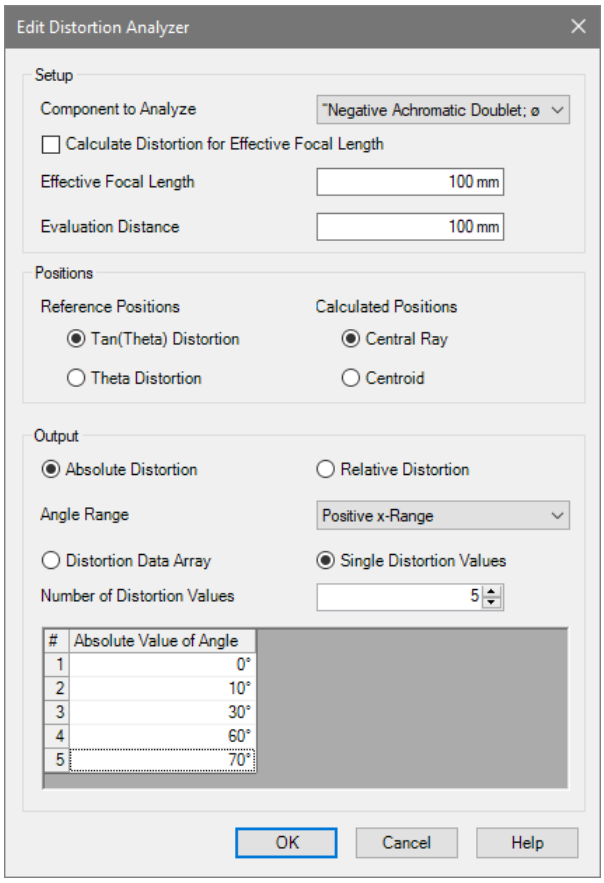


Figure 651. *The edit dialog for the distortion analyzer in* Single Distortion Values *mode.*

The edit dialog of this analyzer (↪Fig. 651) has the following options.

ITEM	DESCRIPTION
Component to Analyze	Allows you to select any allowed component. If there is only one suitable component in the Optical Setup, it is used automatically without the necessity to edit the dialog first.
Calculate Distortion for Effective Focal Length	If this option is checked, the effective focal length f is determined automatically by evaluating the selected component. Otherwise the user can set the *Effective Focal Length*.
Effective Focal Length	ONLY IF *CALCULATE DISTORTION FOR EFFECTIVE FOCAL LENGTH* IS NOT CHECKED. The effective focal length of the component.
Evaluation Distance	ONLY IF *CALCULATE DISTORTION FOR EFFECTIVE FOCAL LENGTH* IS NOT CHECKED. If you want to get the deflection y_{real} of a component it must be measured in a certain evaluation distance behind the component. If the reference deflection y_{ref} refers to the effective focal length, this evaluation distance is the back focal length. If *Calculate Distortion for Effective Focal Length* is not checked, the user must not only specify the *Effective Focal Length*, but also this *Evaluation Distance*.
Reference Positions	Defines whether y_{ref} is the *Tan(Theta) Distortion* or the *Theta Distortion* as defined above.
Calculated Positions	Defines whether y_{real} is the position of the *Central Ray* or of the *Centroid* of the ray bundle with which the component is analyzed.
Absolute Distortion / Relative Distortion	In case of *Absolute Distortion*, the distortion is defined as $D = y_{\text{real}} - y_{\text{ref}}$, otherwise it is $D = (y_{\text{real}} - y_{\text{ref}})/y_{\text{ref}}$ as defined in Eq. (79.1).
Angle Range	Defines along which direction the distortion is scanned (x- or y-axis of the component, whereas in both cases the positive or the negative range can be used).
Distortion Data Array	You can scan a complete angle range and the results are returned as data array – or as set of data arrays if the light source of the system emits more than one wavelength.
Single Distortion Values	In this case you directly enter the angles you want to analyze. This mode allows you to optimize the distortion of certain angles with the Parametric Optimization (↪Sec. 103).
Maximum Angle	ONLY FOR *DISTORTION DATA ARRAY* The maximum angle of the scanned range. The minimum angle always equals the *Scanning Step Size*.
Scanning Step Size	ONLY FOR *DISTORTION DATA ARRAY* The distance between two consecutive angles in the scanned range.
Number of Distortion Values	ONLY FOR *SINGLE DISTORTION VALUES* The number of angles for which you want to calculate the distortion. Then you can enter the concrete angle values in a simple table.

Independent of whether *Distortion Data Array* or *Single Distortion Values* is selected, the maximum distortion and the angle of maximum distortion are additionally calculated.

80 Field Curvature Analyzer

Only available in a General Optical Setup.

The *Field Curvature Analyzer* calculates the field curvature for both tangential and sagittal plane by evaluating the focus position for various incident angles or positions. It works for the index modulated components (↪Sec. 57.2), a Lens System (↪Sec. 58.1), a Spherical Lens (↪Sec. 58.3), or a Curved Surface (↪Sec. 59.1). For each angle or position a small ray bundle is propagated through the selected component and its focus position is determined.

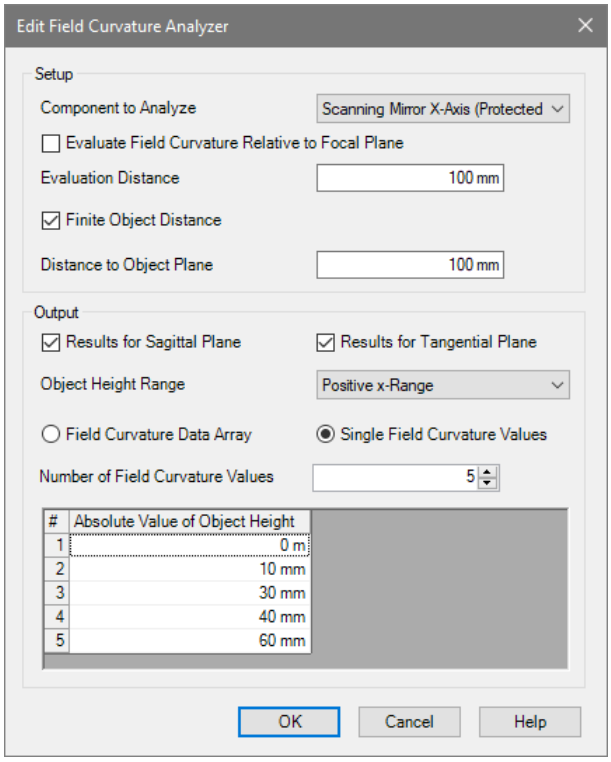


Figure 652. *The edit dialog for the field curvature analyzer for a* Finite Object Distance *in* Single Field Curvature Values *mode.*

The edit dialog of this analyzer (↪Fig. 652) has the following options.

ITEM	DESCRIPTION
Component to Analyze	Allows you to select any allowed component. Note that this component needs not to be connected to a light source. If there is only one suitable component in the Optical Setup, it is used automatically without the necessity to edit the dialog first.
Evaluate Field Curvature Relative to Focal Plane	If this option is checked, the evaluation is done in the focal plane $z = f_0$ of the component where f_0 is the effective focal length for on-axis incidence. In case the active light source has more than one wavelength you can choose the *Reference Wavelength* which is used for the calculation of f_0. Otherwise the user can set the *Evaluation Distance*, measured from the reference point of the transmission coordinate system of the *Component to Analyze* (↪Sec. 44.9.1.3).
Finite Object Distance	If this option is not checked, the evaluation is done with collimated ray bundles entering the component with certain angles. Otherwise ray bundles are created which originate in the given *Distance to Object Plane* at a certain *object height* (= distance from optical axis).
Results for Sagittal Plane / Results for Tangential Plane	Allows you to define whether the results for the tangential plane (contains the optical axis) and / or the sagittal plane (perpendicular to the tangential plane) are calculated. The dialog ensures that at least one plane is selected.
Angle Range / Object Height Range	Defines along which direction the field curvature is calculated (x- or y-axis of the component, whereas in both cases the positive or the negative range can be used).
Field Curvature Data Array	You can scan a complete angle range and the results are returned as data array – or as set of data arrays if the light source of the system emits more than one wavelength.
Single Field Curvature Values	In this case you directly enter the angles or object heights you want to analyze. This mode allows you to optimize the field curvature of certain angles or object heights with the Parametric Optimization (↪Sec. 103).
Maximum Angle / Maximum Object Height	ONLY FOR *FIELD CURVATURE DATA ARRAY* The maximum angle or object height of the scanned range. The minimum angle always equals the *Scanning Step Size*.
Scanning Step Size	ONLY FOR *FIELD CURVATURE DATA ARRAY* The distance between two consecutive angles or object heights in the scanned range.
Number of Field Curvature Values	ONLY FOR *SINGLE FIELD CURVATURE VALUES* The number of angles or object heights for which you want to calculate the field curvature. Then you can enter the concrete values of the angles or object heights in a simple table.

Independent of whether *Field Curvature Data Array* or *Single Field Curvature Values* is selected, the maximum field curvature and the angle or object height of maximum field curvature are additionally calculated.

81 Field Inside Component Analyzer: Split Step

ONLY AVAILABLE IN A GENERAL OPTICAL SETUP.

The *Field Inside Component Analyzer: Split Step* can be used to visualize the field components inside an

inhomogeneous region of the optical system. To enable this analysis the split step propagation needs to be selected within an index-modulated component (↪Sec. 57.2) or a *Double Surface Component* (↪Sec. 66). For each step of the split step propagation along the z-direction an *intermediate result* is calculated which is then processed further by this analyzer.

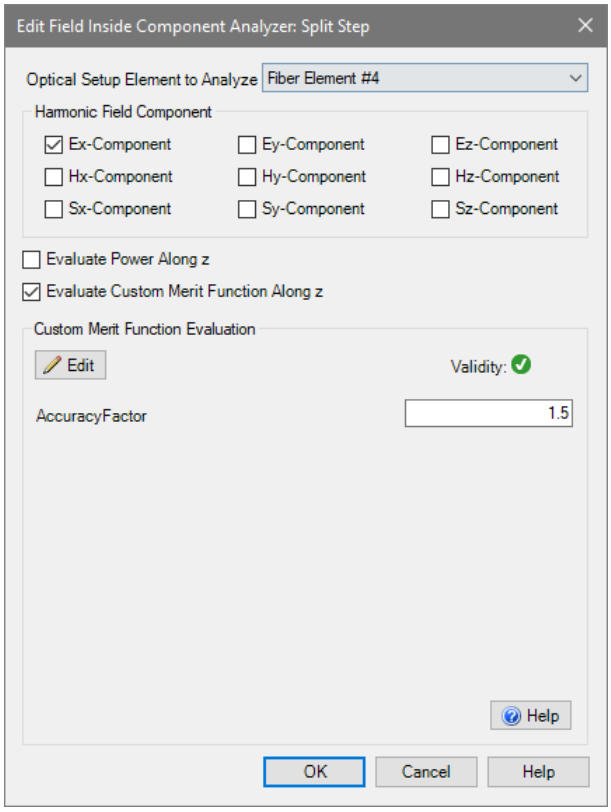


Figure 653. *The edit dialog of the Field Inside Component Analyzer for the split step propagation.*

Fig. 653 shows the edit dialog of the analyzer which allows the following settings:

ITEM	DESCRIPTION
Optical Setup Element To Analyze	The user needs to select the Optical Setup Element that shall be evaluated. Within the combobox all available components in the underlying Optical Setup will be listed.
Harmonic Field Component	In this group box you can set up which harmonic field components (E_x, E_y, E_z, H_x, H_y, H_z, S_x, S_y and / or S_z) are extracted from the intermediate fields. Each field component is shown in a data array in a Set of Data Arrays (↪Sec. 16). In case of two-dimensional fields a subset is generated for each z-position. In case of one-dimensional fields the components are plotted along the z-direction in a single two-dimensional subset.
Evaluate Power Along z	The user can specify whether the power shall be calculated per z-slab. The resulting function will be visualized within a one-dimensional data array.
Evaluate Custom Merit Function	For several applications it can be helpful to define customized merit functions for the propagation through inhomogeneous media. The user can define a snippet which calculates a list of physical values out of each intermediate result. The result is a one-dimensional data array where the physical values are plotted versus the z-position in individual subsets.
Custom Merit Function Evaluation	ONLY IF *EVALUATE CUSTOM MERIT FUNCTION* IS CHECKED. This group box allows you to program the evaluation snippet. *Edit* opens the Source Code Editor (↪Sec. 7.3) to edit this snippet, and a validity indicator (↪Sec. 5.11) shows whether this snippet is consistent. Below there is a region where you can set the values of the global parameters of the snippet (if present); ↪Sec. 7.4.

The dialog ensures that at least one output is selected.

82 Focal Length Analyzer

ONLY AVAILABLE IN A GENERAL OPTICAL SETUP.
This analyzer calculates both the effective and the back focal length of the index modulated components (↪Sec. 57.2), a Lens System (↪Sec. 58.1), a Spherical Lens (↪Sec. 58.3), or Curved Surface (↪Sec. 59.1). This is done by ray tracing and evaluating a **paraxial** ray bundle.

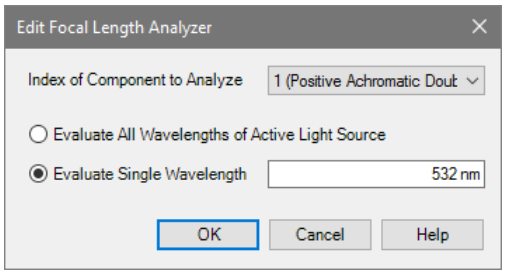


Figure 654. *The edit dialog of the Focal Length Analyzer.*

Its edit dialog, shown in Fig. 654, has the following options.

ITEM	DESCRIPTION
Component to Analyze	Allows you to select any allowed component. Note that this component needs not to be connected to a light source. If there is only one suitable component in the Optical Setup, it is used automatically without the necessity to edit the dialog first.
Evaluate All Wavelengths of Active Light Source	In this mode the focal lengths are calculated for all wavelengths specified in the active light source (those with index 0).
Evaluate Single Wavelength	In this mode you can set the wavelength for which the focal lengths are calculated.

83 Optical Path Length Analyzer

Only available in a General Optical Setup.

The *Optical Path Length Analyzer* can be used to evaluate the optical path lengths of a sub-path in the underlying Optical Setup. The active source in the Optical Setup must be configured as a polychromatic source, because otherwise this analyzer would generate no valuable output. The sampling in the frequency domain has to be adapted for the specified sub-path. Therefor the user can select the Automatic Sampling mode. In this case, VirtualLab Fusion will estimate the oversampling factor for the frequency domain. Alternatively the user can specify an oversampling factor for the frequencies manually. This oversampling factor will increase the accuracy of further investigations, e. g. the Inverse Temporal Fourier Transformation (↪Sec. 31.2.1).

The user can specify the end element (= detector) of the sub-path to be evaluated and as well as the output of the analyzer. The Optical Path Length Analyzer can display the optical path length over frequencies ν or the absolute phase over the frequencies ν. Additionally a linear function can be fitted to the absolute phase. For the linear fit the Optical Path Length Analyzer provides three different methods.

Fig. 655 shows the edit dialog of the Optical Path Length Analyzer.

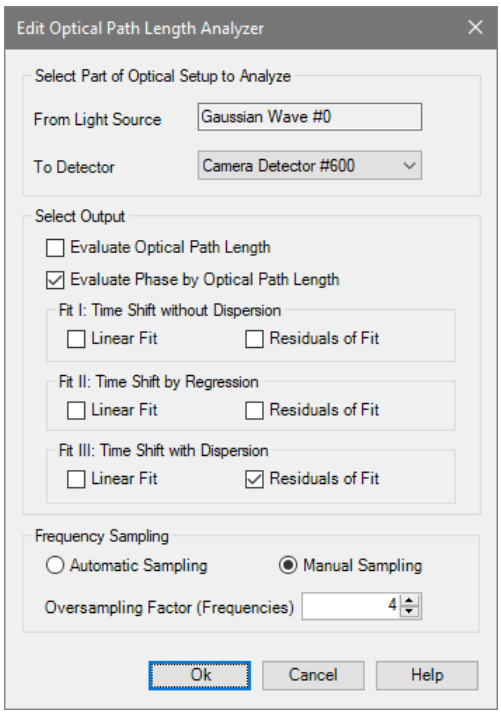


Figure 655. *The edit dialog of the Optical Path Length Analyzer. The user can set up the sub-path which shall be evaluated as well as the output of the analyzer.*

ITEM	DESCRIPTION
From Light Source	The active light source in the Optical Setup the analyzer is placed in. This light source must be polychromatic, otherwise an error will be shown if the analyzer processed.
To Detector	The user can specify the end element (= detector) of the sub-path for which the optical path length shall be evaluated. The end element must be connected with the active light source by a unique path.
Evaluate Optical Path Length	This checkbox defines whether the optical path length versus the frequencies ν shall be shown.
Evaluate Phase by Optical Path Length	The Optical Path Length Analyzer can also calculate the absolute phase. By checking this option a diagram is shown where the phase over ν can be investigated.
Fit I: Time Shift without Dispersion	The first type of linear fit does not consider dispersion effects in the system which shall be analyzed. The user can specify whether the fitted linear function shall be drawn additionally in the phase diagram and whether the residuals shall be evaluated.
Fit II: Time Shift by Regression	The second type of linear fit does consider dispersion effects in the system which shall be analyzed. The dispersion effect is fitted by a linear regression to the absolute phase curve. The user can specify whether the fitted linear function shall be drawn additionally in the phase diagram and whether the residuals shall be evaluated.
Fit III: Time Shift with Dispersion	The third type of linear fit does consider dispersion effects in the system which shall be analyzed. The dispersion effect is evaluated by the group velocity of the pulse. The user can specify whether the fitted linear function shall be drawn additionally in the phase diagram and whether the residuals shall be evaluated.
Automatic Sampling	VirtualLab Fusion estimates the frequency sampling for the selected light path. The calculated oversampling factor will be logged into the logging window of VirtualLab Fusion and additionally be shown when the dialog is opened the next time.
Manual Sampling	The manual sampling mode allows the user to enter a self-defined oversampling factor (of frequencies).
Oversampling Factor (Frequencies)	The oversampling factor can be configured to use more frequencies for the OPL analysis. This oversampling factor will also increase the accuracy of further investigations, e. g. the Inverse Temporal Fourier Transformation (↪Sec. 31.2.1).

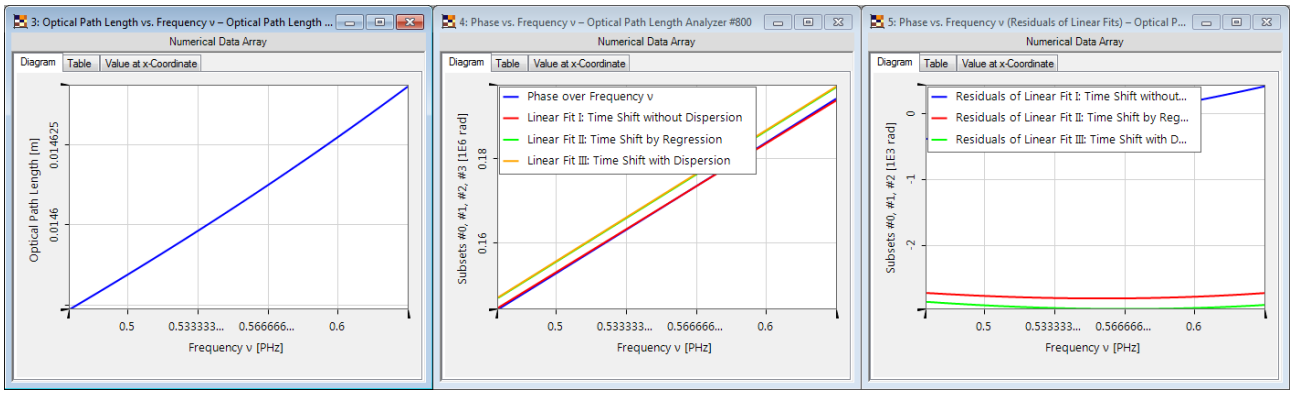


Figure 656. *Diagrams generated by the Optical Path Length Analyzer for a sample Optical Setup.*

Fig. 656 shows some sample results of the Optical Path Length Analyzer for a sample system.
The slopes of the fitted linear functions give the time shift, i. e. the time the pulse needed to propagate through the (sub-)system. The Optical Path Length Analyzer logs the obtained time shifts into the detector window (one per selected fit method, ↪Fig. 657). The time shifts can be used for further investigations of pulses in VirtualLab Fusion, especially for the temporal Fourier Transformation (↪Sec. 31.2.1).
The residual functions calculated by the Optical Path Length Analyzer can be used to increase the time window for the Inverse Temporal Fourier Transformation (↪Sec. 31.2.1).

Detector	Sub - Detector	Result
OPL Analyzer	Linear Fit I: Time Shift without Dispersion	19.246 ps
	Linear Fit II: Time Shift by Regression	18.941 ps
	Linear Fit III: Time Shift with Dispersion	18.945 ps

Figure 657. *The slope of the linear fits is logged into the Detector Results tab on the bottom of the VirtualLab Fusion main window.*

84 Parameter Variation Analyzer

NOT FOR A LASER RESONATOR SETUP.

This analyzer allows you to define a parameter variation for the underlying Optical Setup and then evaluate the results of that variation with a snippet.

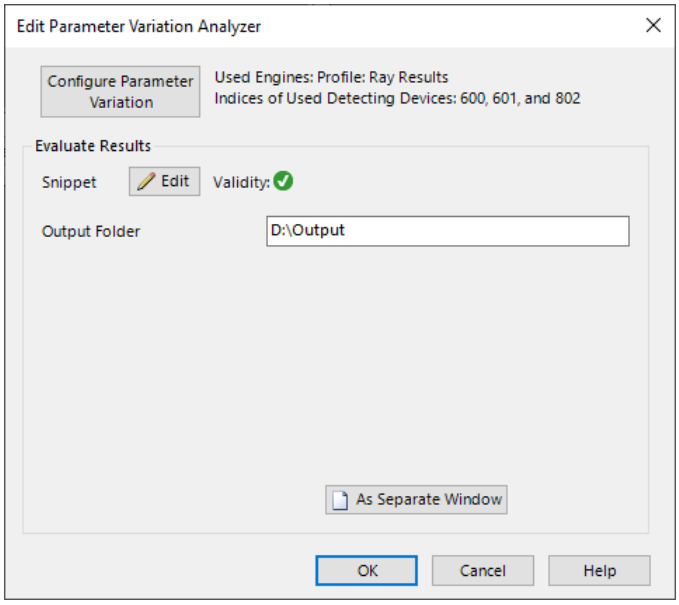


Figure 658. *The dialog of the Parameter Variation Analyzer.*

Fig. 658 shows its dialog. In the upper part there is a button to *Configure Parameter Variation*. It opens a dialog with the same pages as for the Parameter Run (but welcome page and results table). ↪Sec. 45.2 – Sec. 45.4. After configuring the parameter variation, some basic information about it are shown next to the button.
Below there is a group box *Evaluate Results* to program the evaluation snippet. In this snippet you can change and start the parameter variation (if necessary multiple times), then retrieve the results from this variation and evaluate them.
Edit opens the Source Code Editor (↪Sec. 7.3) to edit this snippet, and a validity indicator (↪Sec. 5.11) shows whether this snippet is consistent. Below there is a region where you can set the values of the global parameters[PE] of the snippet (if present); ↪Sec. 7.4.

85 Grating Order Analyzer

Only available in a Grating Setup.

The Grating Order Analyzer (↪Fig. 659) calculates the coordinates, Rayleigh coefficients, and efficiencies of all diffraction orders of a grating.
The edit dialog of the analyzer contains two tabs, the *General* tab (↪Fig. 659), and the *Single Orders* tab described in Sec. 85.1. The *General* tab allows you to select which kind of output you want to obtain. The dialog ensures that always at least one output is specified – you cannot uncheck the last checked check box.

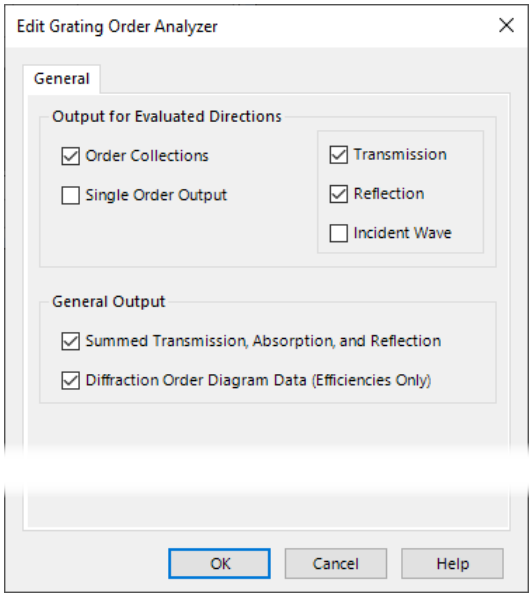


Figure 659. *The* General *tab of the Grating Order Analyzer.*

OUTPUT	DESCRIPTION
Order Collections	If checked, an Order Collection is generated, one each for *Transmission*, *Reflection*, and / or the *Incident Wave* (as reference). An Order Collection document (↪Sec. 18) contains the coordinates, efficiencies, and Rayleigh coefficients of all the respective orders.
Single Order Output	If checked, the coordinates, efficiencies, and Rayleigh coefficients of single orders are output as physical values into the Detector Results Panel (↪Sec. 4.3). In this case a new tab page *Single Order Output* (↪Sec. 85.1) is shown where you can define what data is shown for which orders. You can select whether you are interested in the orders for *Transmission*, *Reflection*, and / or the *Incident Wave* (as reference).
Summed Transmission, Absorption, and Reflection	If checked, the sum R of all reflection efficiencies as well as the sum T of all transmission efficiencies is calculated. The absorption A is then $1 - R - T$. These values are shown in the Detector Results Panel (↪Sec. 4.3).
Diffraction Order Diagram Data (Efficiencies Only)	If checked, a Diffraction Order Diagram Data (↪Sec. 19) is generated where the efficiencies of **all** propagating orders are plotted versus their Cartesian angles α and β.

The directions are calculated by means of the grating equation (↪Sec. 145.5) and if necessary converted by the formulas given in Sec. 145.3. The Rayleigh coefficients are calculated by the propagation method set up in the edit dialog of the component (↪Sec. 65.2). The calculation of the efficiencies is explained in Sec. 145.6.

85.1 Single Order Output

ONLY AVAILABLE IF *SINGLE ORDER OUTPUT* IS CHECKED ON THE *GENERAL* TAB.

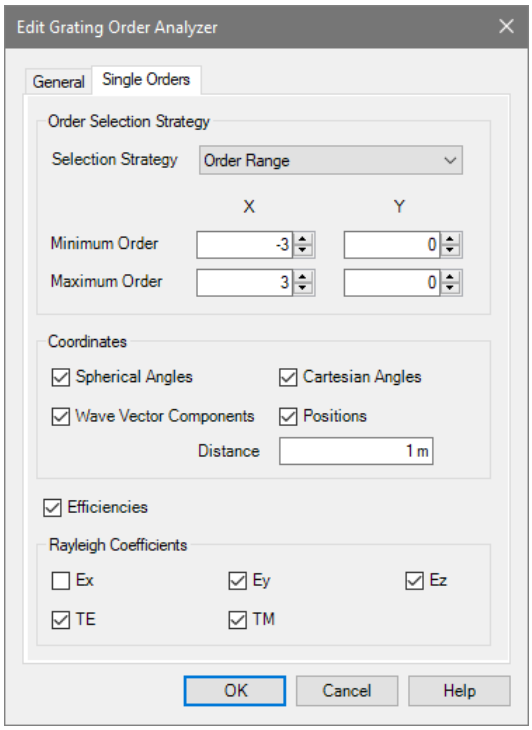


Figure 660. *The Single Orders tab of the Grating Order Analyzer.*

The *Single Orders* tab (↪Fig. 660) of the Grating Order Analyzer allows you to configure which data about single orders is shown in the Detector Results Panel (↪Sec. 4.3). It has the following options.

ITEM	DESCRIPTION
Selection Strategy	With this option you can restrict the shown orders. The following three strategies are available: • ***All***: No restrictions apply • ***Above Efficiency Threshold***: Only (propagating) orders above the given *Efficiency Threshold* are shown. • ***Order Range***: All orders in the range between *Minimum Order* (inclusive) and *Maximum Order* (inclusive) are shown. This is the recommended mode for the Parametric Optimization (↪Sec. 103) and the optiSLang Bridge (↪Sec. 104).
Coordinates	This group box allows you to select which coordinates of the individual orders are shown in the Detector Results Panel. If you select *Positions* you can set a *Distance* for which the positions are calculated. **Note that angles and positions are only shown for propagating orders, not for evanescent ones.**
Efficiencies / Rayleigh Coefficients	Allows you to select which data of the individual orders is shown.

The dialog ensures that you select at least one of the *Coordinates* or one of the *Rayleigh Coefficients* or the *Efficiencies*.

86 Ellipsometry Analyzer

Only available in a Grating Optical Setup.

This analyzer calculates the Rayleigh coefficient $R = Ae^{i\phi}$ of one selected order for both TM and TE polarization (or p and s polarization). From this derived properties such as the resulting polarization ellipse are calculated – in dependency from wavelength and angle.

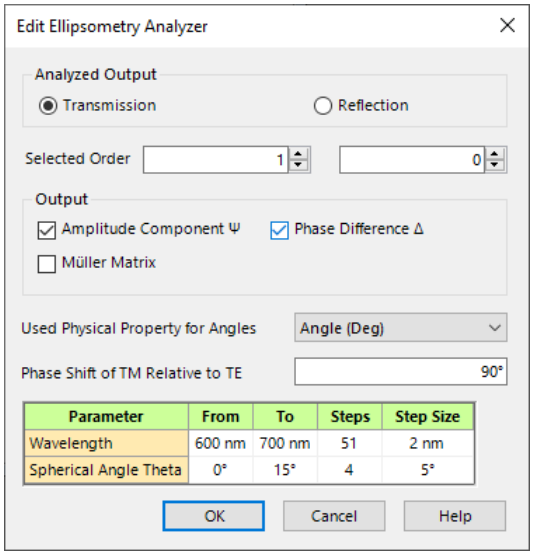


Figure 661. *The dialog for the Ellipsometry Analyzer.*

Its edit dialog (↪Fig. 661) has the following settings.

ITEM	DESCRIPTION
Analyzed Output	This analyzer can be either applied to the Rayleigh coefficients for *Reflection* or *Transmission*.
Selected Order	Index of the selected order. For 1D-periodic gratings the second index should be zero.
Output	*Amplitude Component* Ψ and *Phase Difference* Δ can be used to calculate the resulting polarization ellipse for linearly polarized incident light. They are defined by the equation $$\frac{R_{\mathrm{TM}}}{R_{\mathrm{TE}}} = \tan\Psi \cdot \mathrm{e}^{\mathrm{i}\Delta} \quad .$$ The *Müller Matrix* $\mathcal{M}$ describes the transformation of the Stokes parameters by the analyzed element. $$\mathcal{M} = \begin{pmatrix} 1/2(A_{\mathrm{p}} + A_{\mathrm{s}}) & 1/2(A_{\mathrm{p}} - A_{\mathrm{s}}) & 0 & 0 \\ 1/2(A_{\mathrm{p}} - A_{\mathrm{s}}) & 1/2(A_{\mathrm{p}} + A_{\mathrm{s}}) & 0 & 0 \\ 0 & 0 & A_{\mathrm{p}} \cdot A_{\mathrm{s}} \cdot \cos\Delta & A_{\mathrm{p}} \cdot A_{\mathrm{s}} \cdot \sin\Delta \\ 0 & 0 & -A_{\mathrm{p}} \cdot A_{\mathrm{s}} \cdot \sin\Delta & A_{\mathrm{p}} \cdot A_{\mathrm{s}} \cdot \cos\Delta \end{pmatrix}$$
Used Physical Property for Angles	Both Ψ and Δ are in principle angles. You can determine whether their unit should be degrees or radians.
Phase Shift of TM Relative to TE	The given value is added to Δ. This can make the calculated diagrams more comparable with those found in the literature or obtained by measurements.
{Parameter Variation}	This table allows you to start kind of a parameter run (↪Sec. 45) over wavelength and spherical angle ϑ. This means that for each combination of the specified wavelengths and angles the desired *Output* is being calculated and then plotted versus wavelength into a 1D data array. The different angles form distinct subsets. This means that at least 2 wavelengths *Steps* must be specified, but its possible to specify only one angle.

87 Field Inside Component Analyzer: FMM

Only available in a Grating Optical Setup.

This analyzer calculates the field inside a grating rigorously by means of the Fourier Modal Method (↪Sec. 97.3). If the grating component (↪Sec. 65.1) is 1D-periodic, the result is a single Data Array showing the field in the x-z-plane at y = 0. If the grating component is 2D-periodic, the result is a Set of Data Arrays with one Data Array for each z-layer.

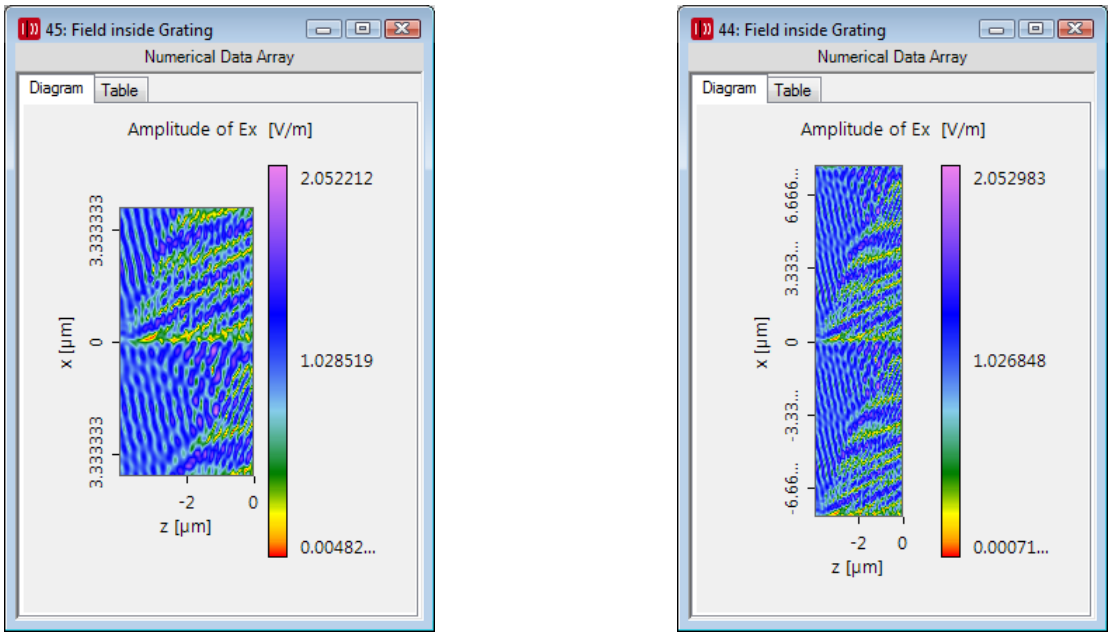


Figure 662. *Field inside a dielectric sawtooth grating for an incidence angle $\theta = 20°$. Left: 1 period shown, right: 2 periods shown. Then the sawtooth structure is more clearly recognizable.*

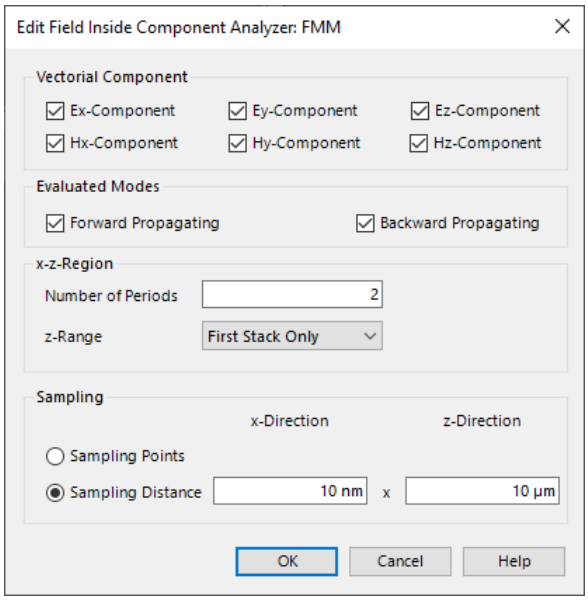


Figure 663. *The dialog for the Field Inside Component Analyzer: FMM.*

Its edit dialog (↪Fig. 663) has the following settings.

ITEM	DESCRIPTION
Vectorial Component	In this group box you can set up which vectorial components (E_x, E_y, E_z, H_x, H_y and / or H_z) are shown in the resulting data array (↪Sec. 13.4). The dialog ensures that at least one vectorial component is selected.
Forward Propagating / Backward Propagating	For detailed analyses you can switch off the influence of either the forward or the backward propagating modes.
Number of Periods	Sometimes the structure of the field inside a grating can be recognized more easily if more than one period is shown (See Fig. 662 for an example). Thus you can set the *Number of Periods* which can be any real number greater than or equal to 1.
z-Range	Usually the base block of a grating component is much larger than the grating stacks. Thus the special effects of the stacks might not be resolved in the result field. To circumvent this problem, you can can restrict the *z-Range* to *First Stack Only* or *Second Stack Only*. Showing the *Whole Component* or *Base Block Only* is also possible. For example, Fig. 662 was made with the option *First Stack Only*.
Sampling	This group box allows you to set up an equidistant sampling separately for *x-Direction* and *z-Direction*, either by specifying the *Sampling Distance* or the number of *Sampling Points*. Accurate results can be expected for an resolution of $\lambda/5$ or less, but this might lead to high memory consumption and / or calculation time. If a 2D-periodic is analyzed, the sampling for the x-direction is also used for the y-direction.

88 Polarization Analyzer

Only available in a Grating Optical Setup.

This analyzer can be used for optimizing polarizers and anti-reflection structures. It computes either the summed reflection or transmission efficiency for two orthogonal polarization directions and calculates advanced merit functions like the polarization contrast out of it. To this end, the propagation currently configured in the grating component is used. The summed efficiency is either calculated from all (propagating) orders or from a user-defined order range.
The polarization directions can be given in the following coordinate systems:

COORDINATE SYSTEM	DESCRIPTION
Coordinate System of Grating	The Jones vector describes the electric field along x- and y-axis of the grating component, respectively.
Coordinate System of Light Source	The Jones vector describes the electric field along x- and y-axis of the light source, respectively.
p-s Coordinate System	In grating theory one often uses the nomenclature *parallel* and *senkrecht* (= perpendicular) polarization to describe how the electric field vector is orientated to a reference plane (or short p- and s-polarization). This reference plane is defined by the normal vector of the grating surface and the direction vector of the incident light. The conversion from the coordinate system of the light source (E_x/E_y) is done with the following equations: $$E_\mathrm{s} = \begin{pmatrix} E_x \\ E_y \end{pmatrix} \cdot \boldsymbol{n}_\mathrm{s} \quad \text{and} \quad E_\mathrm{p} = \begin{pmatrix} E_x \\ E_y \end{pmatrix} \cdot \boldsymbol{n}_\mathrm{p} \tag{88.1}$$ $\boldsymbol{n}_\mathrm{s}$ and $\boldsymbol{n}_\mathrm{p}$ are the normalized directions of s- and p- polarization, respectively (in the coordinate system of the light source). For perpendicular incident $\boldsymbol{n}_\mathrm{s}$ is equal to the y-axis of the light source.
TE-TM Coordinate System	Instead of p- and s-polarization also the nomenclature *transversal magnetic* and *transversal electric*, respectively, is used – or short TM / TE.

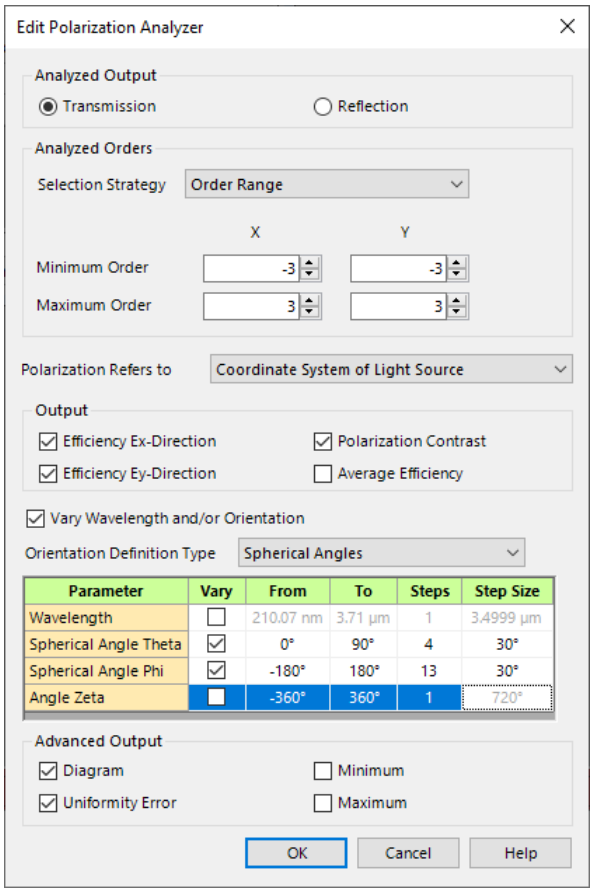


Figure 664. *The edit dialog for the polarization analyzer.*

The edit dialog for this analyzer (↪Fig. 664) has the following settings.

ITEM	DESCRIPTION
Analyzed Output	This analyzer can be either applied to the efficiencies for *Reflection* or *Transmission*.
Analyzed Orders	With this option you can restrict the analyzed orders. The following two strategies are available: • ***All***: The summed efficiency of all propagating orders is evaluated. • ***Order Range***: All orders in the range between *Minimum Order* (inclusive) and *Maximum Order* (inclusive) are taken into account for the summed efficiency.
Polarization Refers to	Allows you to specify the coordinate system the polarization refers to, see table above.
Output	The following outputs can be calculated: • *Efficiency Ex-Direction* I_x, that is the overall reflection / transmission efficiency for E_x-polarization. • *Efficiency Ey-Direction* I_y, that is the overall reflection / transmission efficiency for E_y-polarization. • *Polarization Contrast* $P = {}^{I_x}/_{I_y}$ • *Average Efficiency* $A = \frac{(I_x+I_y)}{2}$
Vary Wavelength and/or Orientation	Shows some additional controls allowing you to start kind of a parameter run (↪Sec. 45) over wavelength and / or the available orientation angles. This means that for each combination of the specified wavelengths or orientation angles the desired *Output* is being calculated and stored in a data array. Fig. 664 shows a sample configuration of the dialog where the spherical angles θ and ϕ are varied. See also the note below.
Advanced Output	If you check *Diagram* the resulting data array is shown as separate data array view (↪Sec. 13.4): 1D data array if one parameter is varied, 2D data array if two parameters are varied, 1D data array with data plotted versus iteration number if more than two parameters are varied. For each selected output ω (i. e. either I_x, I_y, A and / or P) you can calculate additional merit functions: the *Minimum* ω_{min}, the *Maximum* ω_{max} and the *Uniformity Error* $U = \frac{\omega_{\text{max}}-\omega_{\text{min}}}{\omega_{\text{max}}+\omega_{\text{min}}}$. With the results shown in Fig. 664 the maximum polarization contrast would be 107.35 (for a wavelength of 500 nm and an incident angle of 4°), the minimum polarization contrast would be 10.125 (for a wavelength of 400 nm and an incident angle of 0°) and thus the uniformity error of the polarization contrast would be 82.763 %.

The dialog ensures that always at least one output is checked.

Note on the available angles

If you create a new Polarization Analyzer in your Optical Setup, the available angles in the Polarization Analyzer are set according to the *Orientation Definition Type* of the grating component in that Optical Setup. But you change it with the *Orientation Definition* control.
See Sec. 145.2 for details about the various orientation definition types.

Note on using the analyzer with Parameter Extraction

If the wavelength and / or the orientation are varied, it is not possible to vary the same parameter(s) via normal parameter extraction (Parameter Run, Parametric Optimization, Parameter Overview, …) at the same time.

89 Programmable Grating Analyzer

Only available in a Grating Optical Setup.

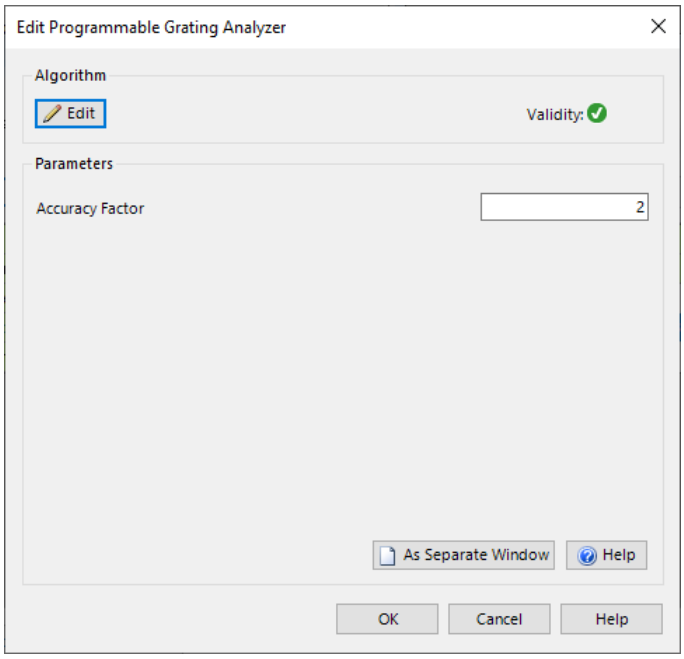


Figure 665. *The dialog for the Programmable Grating Analyzer.*

This analyzer can be used to define a user-defined merit function on the rigorous calculated result of the Fourier Modal Method. The analyzer allows the access to the rigorous calculated Rayleigh coefficients as well on the calculated efficiencies. The following settings can be configured

ITEM	DESCRIPTION
Algorithm	This group box allows you to program a code snippet defining the merit function. *Edit* opens the Source Code Editor (↪Sec. 7.3) to edit this snippet, and a validity indicator (↪Sec. 5.11) shows whether this snippet is consistent.
Parameters PE	The controls in this group box allow you to set the values of the global parameters of the snippet. ↪Sec. 7.4

90 Eigenmode Analyzer

Only available in a Laser Resonator Optical Setup.

The eigenmode analyzer calculates eigenmodes and eigenvalues of resonator systems.

90.1 Eigenmode Algorithms

For computing eigenmodes two iterative algorithms from numerical linear algebra are available:

- Fox-Li algorithm, also known as power iteration
- Arnoldi algorithm

Both methods are being discussed in general books on linear algebra. The algorithm of Fox-Li is discussed in [Sie86] also from the physical point of view. General information about these algorithms can be found e. g. on Wikipedia (here for the power iteration and here for the Arnoldi algorithm). Usually one can expect that the Arnoldi algorithm requires much less iterations compared to the Fox-Li algorithm. Further the Arnoldi algorithm provides the option to compute estimates for higher order modes.
The eigenmode computation is based on applying these operators to a system that represents a round trip of the resonator. Such a system is generated internally from the resonator system that is being defined in the Optical Setup by the user. After each round trip the resulting mode is resampled according to the sampling defined by the initial mode and the additional resampling operator (↪Sec. 90.2).

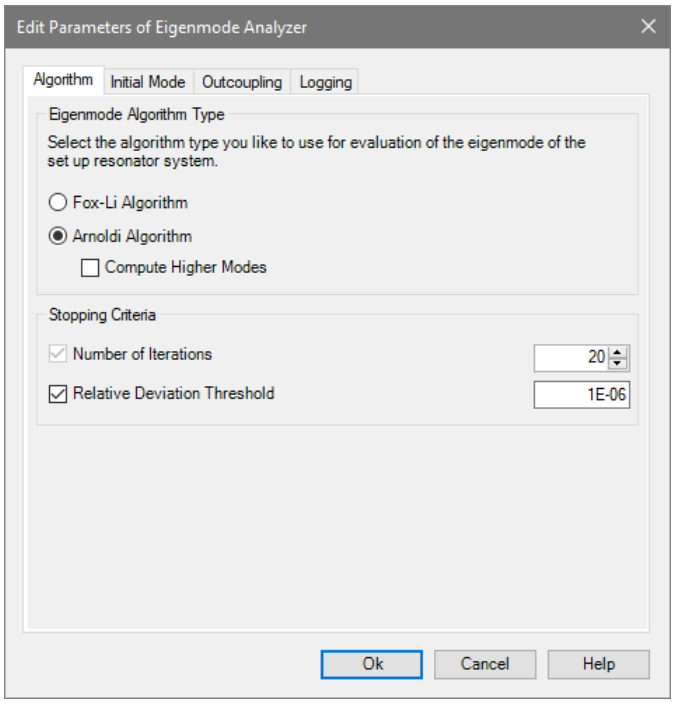


Figure 666. *The dialog for the Eigenmode Analyzer.*

In the *Algorithm* panel (↪Fig. 666) you can select the algorithm to be used. In both cases, the *Number of Iterations*[PE] must be given as stopping criterion of the iteration. Additionally, the stopping criterion based on the *Relative Deviation Threshold*[PE] can be activated. Then the iteration stops as soon as one of the criteria is fulfilled. The deviation value (default 1e-6) refers to a relative deviation (rescaled) d_R between two successive iterates f_{i+1}, f_i:

$$d_R = \frac{\|\tilde{f}_{i+1} - f_i\|}{\|f_i\|} \tag{90.1}$$

where $\tilde{f}_{i+1} := c \cdot f_{i+1}$ with a complex constant c that is chosen such that the absolute deviation (rescaled) d_A is minimal:

$$d_A = \|\tilde{f}_{i+1} - f_i\| \tag{90.2}$$

If the Arnoldi algorithm is selected, also the option *Compute Higher Modes* is available. The number of higher modes being computed is restricted by the number of iterations. Only those modes with an eigenvalue above 10 per cent of the largest eigenvalue are computed. Note, the numerical accuracy decreases for higher modes.

90.2 Initial Mode Parameters and Sampling

The iterative algorithm requires some initial mode. This mode can be defined at the corresponding tab page of the analyzer, see Fig. 667.

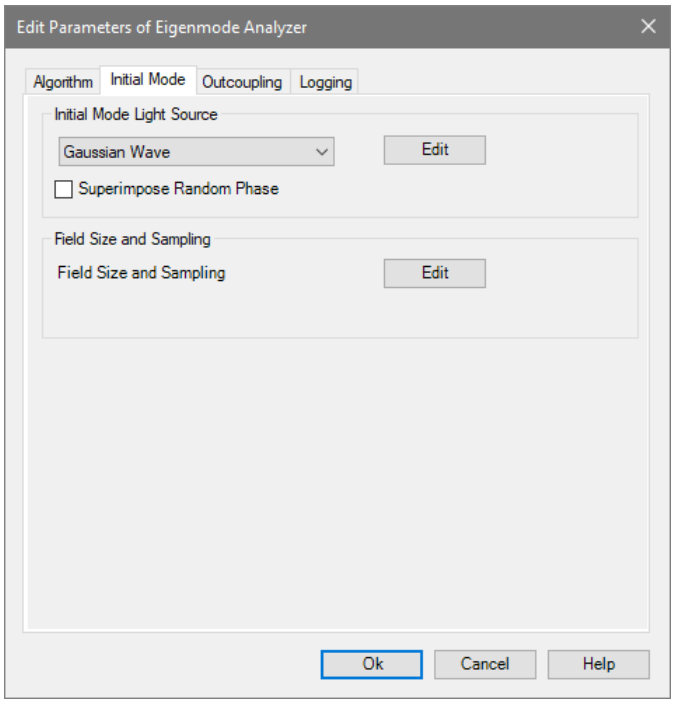


Figure 667. *The Initial Mode tab of the dialog for the Eigenmode Analyzer.*

The initial mode is used as start mode of the iteration. Further this mode defines the wavelength of the resonator and the initial state of polarization. The medium that is associated with the initial mode is used as embedding medium behind the left mirror element of the resonator.

Several types of an initial mode are available: Multiple Light Source (↪Sec. 50), Gaussian Wave (↪Sec. 52.1), Plane Wave (↪Sec. 52.2), Programmable Light Source (↪Sec. 52.8), Quadratic Wave (↪Sec. 52.3), Spherical Wave (↪Sec. 52.4), Stored Lateral Field (↪Sec. 52.6) and Super-Gaussian Wave (↪Sec. 52.5). It can be defined via the *Edit* button. The wavelength of the mode is available for Parameter Extraction (↪Sec. 44.6).

The initial mode is placed right of the most left element (mirror) of the resonator. This position is called *reference plane*. We define a reference sampling in this reference plane that is applied after each round trip iteration. The reference sampling is defined from the initial mode together with the resampling operator. This operator PE can be configured via the *Edit* button and behaves like the Field Size and Sampling manipulation in the Optical Setup (↪Sec. 22.8.2).

After starting the iteration the sampling is written into the *Messages* tab. The sampling should be chosen to match the resulting mode. If it is to small or undersampled no convergence will be achieved. Otherwise the computation effort might be too large.

90.3 Outcoupling Mode

At the end of the eigenmode computation the outcoupling mode is being computed. In case of an ideal spherical mirror as right boundary of the resonator, the outcoupling is defined by transmittance settings of the mirror (↪Fig. 588). The medium specified here (↪Fig. 668) will just be used as embedding medium of the outcoupling mode.

Otherwise the right mirror of the resonator is ignored and replaced by a simple change of media considering preservation of energy in paraxial approximation without Fresnel effects (i. e. $T = 1$):

$$|\mathbf{E}'|^2 = |\mathbf{E}|^2 \left| \frac{n_1}{n_2} \right| , \tag{90.3}$$

where n_1 and n_2 are the real parts of the refractive indices before and after the media change.
For this purpose the external medium is specified on the outcoupling tab (↪Fig. 668).

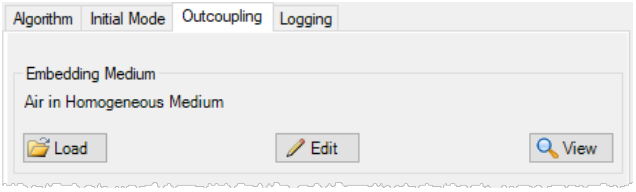


Figure 668. *The Outcoupling tab of the dialog for the Eigenmode Analyzer.*

How to enter the homogeneous medium is described in Sec. 34.1.

90.4 Logging

During iteration logging is available. This logging can be configured at the logging tab (↪Fig. 669).

Figure 669. *The Logging tab of the dialog for the Eigenmode Analyzer.*

The logging refers to the reference plane. After each round trip the current iterate of the eigenmode, the corresponding beam radius and the deviation of successive iterates (↪Sec. 90.1) can be computed. Switching off the logging will slightly reduce the computation time.
The *Edit View Settings* button allows you to set the way how the eigenmodes are shown. To this end the same settings as for the Raw Data Detector (↪Sec. 75.5.5) can be used.

90.5 Iteration Document

Starting the eigenmode analyzer results in an Iteration Document (↪Fig. 670). This document simply consists of the *Results* page of the parameter run document (↪Sec. 45.5).

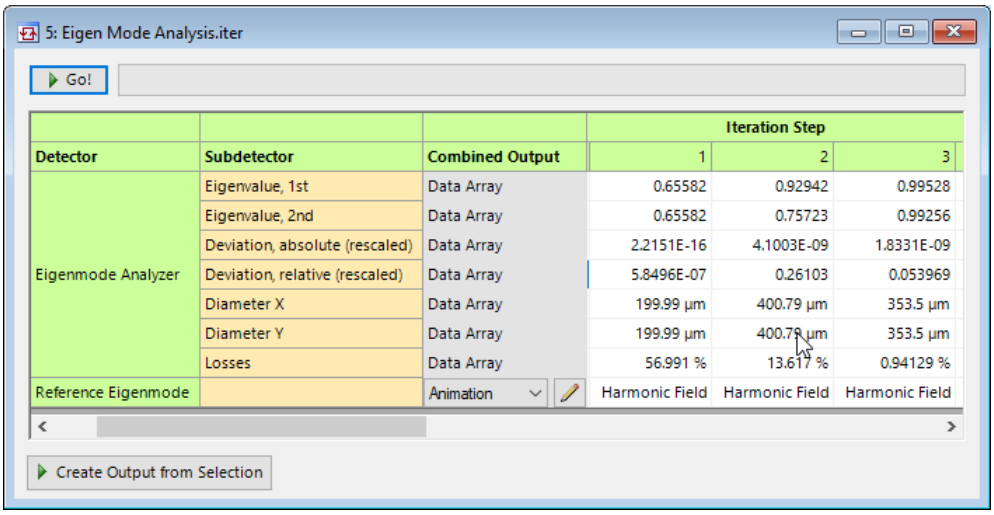


Figure 670. *The Iteration Document of the Eigenmode Analyzer.*

The document contains the logging of the iteration. Eigenmode at reference plane, eigenvalues (first and second), deviation, losses ($(1 - \text{eigenvalue})^2$) and beam radius at reference plane are included. These values

support convergence control. Additional data can be computed at the end of each iteration step using detectors, see Sec. 44.11.2.
With the *Go!* button or the Iteration > Go! ribbon item you can start the calculation of the iterations. Then these buttons turn into a *Stop* button allowing you to stop the calculation.

91 Local Linear Grating Approximation Analyzer

Availability

Optical Setups: Light Shaping Optical Setup (↪Sec. 44.11.4)

Accessible: In the Optical Setup: *Analyzers > Local Linear Grating Analyzer*

The diffraction efficiencies of the gratings in a Grating Cells Array (↪Sec. 41.1.1) can be given by the user. Or they can be calculated rigorously by means of the Fourier Modal Method. However, these rigorous simulations can be quite time consuming and they require VirtualLab Fusion Advanced. Thus they have been separated from the actual simulation by implementing the following workflow.

1. To a Light Shaping Optical Setup with **one** Diffractive Light Shaper (↪Sec. 64) you add a Local Linear Grating Approximation (LLGA) Analyzer.
2. You execute this analyzer which extracts all grating parameters present in the Grating Cells Array of the Light Shaper.
3. You configure the resulting LLGA Results Generator (↪Sec. 46) and start the rigorous simulations, if necessary on a more powerful PC or workstation or on a computer which is eligible to run VirtualLab Fusion Advanced.
4. You load the results from the LLGA Results Generator into the *Order Configuration* tab of the Grating Cells Array.

92 Grating Channel Analyzer

Only available in a Light Guide Optical Setup.

This analyzer examines the grating regions to determine which orders are propagating in the light guide. For real gratings it also generates a LUT Results Generator (↪Sec. 47) which then analyzes the efficiencies of these orders rigorously.
It has an edit dialog to predefine whether a custom Fourier Modal Method shall be used for the rigorous analyses, ↪Sec. 97.4.

XIII Propagations: Operators for Propagating Fields

VirtualLab Fusion offers a large variety of free space propagation operators which can only be used for homogeneous, isotropic media (↪Sec. 94). Real components (↪Part IX) can contain surfaces and both homogeneous and inhomogeneous media. Thus they need special propagations (↪Sec. 97).

93 Common Controls

These controls are active for those operators that provide controls for modifying the output field size and sampling in order to simplify their handling. The button *Full Automating* indicates whether each of the panels described in the following subsections is set to *Automatic Sampling*. Furthermore, with this button you can reset all panels to *Automatic Sampling* , i. e. to the default values.

93.1 Accuracy Settings

This panel (↪Fig. 671) is used to adapt the sampling of the input field to minimize numerical errors. There are different ways to determine the sampling parameters:

ITEM	DESCRIPTION
Automatic Sampling	The correct sampling of the input field is ensured by VirtualLab Fusion. You can adjust the automatic sampling with the *Accuracy Factor*[PV]. The greater this factor the more sampling points will be in the input field. A factor of 1 (default) means the number of sampling points VirtualLab Fusion uses normally for automatic sampling. If you want to further minimize numerical errors you can set this factor to values greater than 1. In this case the propagation will be more time consuming. Vice versa, if you set the factor to values between 0 and 1 you can speed up propagation, but more numerical errors will be present.
Keep Sampling Unchanged	The sampling of the input field is not changed.
Calculate from Input Field Sampling	The original sampling of the input is taken as reference, but you can decrease the sampling distance with the *Sampling Factor* and embed the field with the *Embedding Factor*. Both factors can be set separately for x- and y-direction. A factor of 1 refers to the original parameters of the input field and a factor larger than 1 increases both accuracy and numerical effort. Only available for the thin element approximation (Sec. 97.2) and the split-step propagation (↪Sec. 97.6), where it replaces the *Keep Sampling Unchanged* setting.
Manual Sampling	In this mode you can adapt either the *Sampling Points* or the *Sampling Distance* if you want to find the best compromise between numerical errors and calculation time. The *Array Size* is just given for your information. If you check this item, *Manual Sampling* is also selected for the *Output Field Sampling* and the *Size and Shape of Output Field* panel (Sec. 93.2 and Sec. 93.3). For some propagation operators you can decrease numerical errors if you embed the field into a zeroized frame. Therefore these operators have additional *Embedding Factor*s for x- and y-direction which can be changed only together with the *Sampling Distance*. An embedding factor of 1 refers to the original size of the input field. The *Copy Active Parameters from* button allows you to select another harmonic field, from which either the *Sampling Points* or the *Sampling Distance* are copied, depending on what item is activated.

Depending on the propagation operator and whether it is used in the main window or in the Optical Setup, certain items may not be available. Two examples are given in Fig. 671 and Fig. 672. Furthermore, if you select *Manual*

Sampling in the Optical Setup only the activated entries (*Sampling Points* or the *Sampling Distance*) are shown as the other parameters are not calculated until you propagate through the Optical Setup (↪Fig. 672).
If a propagation operator dialog has no accuracy panel, the sampling is kept unchanged.

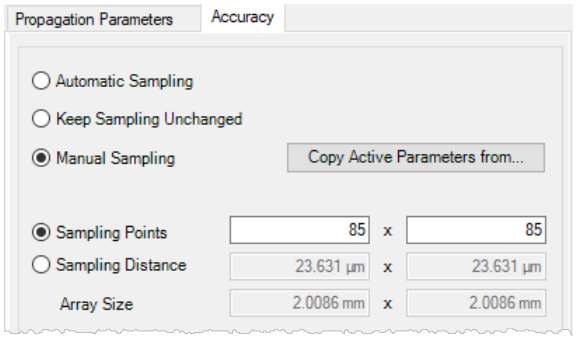


Figure 671. Accuracy *tab for Fresnel propagation in the main window in* Manual Sampling Mode.

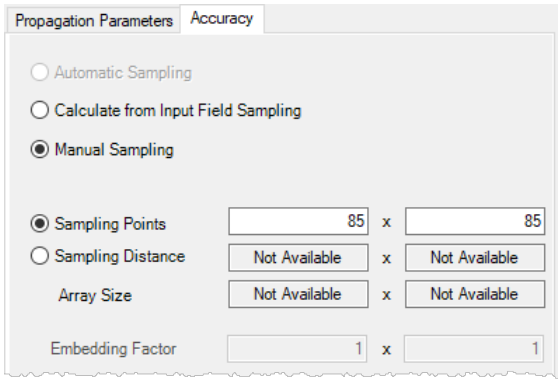


Figure 672. Accuracy *tab for thin element approximation in* Manual Sampling Mode.

93.2 Output Field Sampling

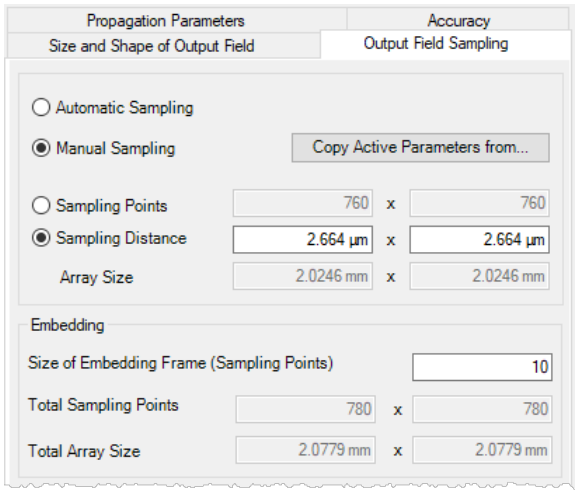


Figure 673. *Panel for adjusting the output field sampling.*

For the two *Rayleigh Sommerfeld Operators* the sampling of the resulting field can be adjusted via the panel shown in Fig. 673.

ITEM	DESCRIPTION
Automatic Sampling	The correct sampling of the output field is ensured by VirtualLab Fusion.
Oversampling Factor PV	The greater this factor the more sampling points will be in the output field. A factor of 1 (default) means the number of sampling points VirtualLab Fusion uses normally for automatic sampling. Increasing this factor increases the number of sampling points and decreases the sampling distance accordingly. Vice versa, setting this factor to values between 0 and 1 decreases the number of sampling points. This item is only visible if *Automatic Sampling* is selected.
Manual Sampling	In this mode you can adapt either the *Sampling Points* or the *Sampling Distance* if you want to find the best compromise between numerical errors and calculation time. The *Array Size* is just given for information.
Copy Active Parameters from	This button allows you to select another harmonic field, from which either the *Sampling Points* or the *Sampling Distance* are copied, depending on what items are activated.
Sampling Points	Allows you to specify the number of sampling points for both directions.
Sampling Distance	Allows you to specify the sampling distance for both directions.
Array Size	For your information, the array size (i. e. *Sampling Points* $\times$ *Sampling Distance*) is given.
Size of Embedding Frame (Sampling Points)	You can add a zeroized frame around the output with the given width in sampling points.
Total Sampling Points	This value corresponds to *Sampling Points* + 2 $\times$ *Size of Embedding Frame*.
Total Array Size	This value gives the total array size, i. e. the *Array Size* plus the size of the embedding frame.

93.3 Size and Shape of Output Field

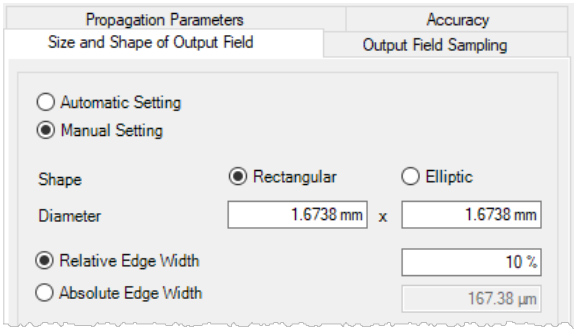


Figure 674. *Panel for setting size and shape of output field.*

For the two *Rayleigh Sommerfeld Operators* as well as the *Geometrical Optics Operator*, the size and shape of the resulting field is adjustable. The concerning dialog tab is shown in Fig. 674.

ITEM	DESCRIPTION
Automatic Setting	The correct size of the output field is ensured by VirtualLab Fusion.
Field Size Factor PV	The greater this factor the larger the output field will be. A factor of 1 (default) means the field size VirtualLab Fusion uses normally as automatic setting. Increasing this factor increases the field size. Vice versa, setting this factor to values between 0 and 1 decreases field size. This item is only visible if *Automatic Setting* is selected.
Manual Setting	In this mode you can adapt the *Shape*, the *Diameter*, and the *Edge Width*.
Shape	You can choose whether a *Rectangular* or *Elliptical* virtual aperture is applied to the output field. Standard for automatic sampling is a rectangular virtual aperture.
Diameter	Determines the field size for both x- and y-direction.
Relative Edge Width	The width of the virtual aperture relative to the field size.
Absolute Edge Width	The width of the virtual aperture in physical coordinates.
Size of Embedding Frame (Sampling Points)	You can add a zeroized frame around the output with the given width in sampling points. This parameter is only available for the Geometrical Optics Operator.

94 Free Space Operators

VirtualLab Fusion offers a large variety of free space propagation operators which can be used for homogeneous, isotropic media. These operators can be used for the linkages of the Optical Setup (↪Sec. 94.1). All operators having an icon in the following table can be used via the Propagations ribbon tab of Harmonic Fields and Harmonic Fields Set as well.

OPERATOR	DESCRIPTION
Automatic Propagation Operator	Automatic selection of light propagation method that is physical sufficiently accurate but also as fast as possible. The propagation method tests the physical accuracy of *Spectrum of Plane Waves Operator*, *Fresnel Operator*, *Far Field Operator*, and *Geometrical Optics Operator*. ↪Sec. 94.2
Far Field Operator	Paraxial and non-paraxial light propagation from beam waist to far field, far field to beam waist and from far field to any other far field plane. ↪Sec. 94.3
Geometrical Optics Operator	Light propagation in geometrical optics approximation. Diffraction and interference effects are neglected. ↪Sec. 97.1
Spectrum of Plane Waves Operator	Rigorous light propagation. ↪Sec. 94.4
Rayleigh Sommerfeld Operator (Convolution & Summation)	Rigorous light propagation. ↪Sec. 94.5
Fresnel Operator	Light propagation in paraxial approximation. ↪Sec. 94.6
Combined SPW/Fresnel Operator	Light propagation in paraxial approximation that combines *Spectrum of Plane Waves Operator* and *Fresnel Operator* to improve the calculation speed and reduce the required RAM memory. ↪Sec. 94.7
Rayleigh Expansion Propagation	Only available in a Grating Optical Setup. Rigorous light propagation of propagating and evanescent diffraction orders behind a grating. ↪Sec. 94.8
Cells Array Propagation	Only available in a Light Shaping Optical Setup. Light propagation after grating cells arrays. ↪Sec. 94.9
Geometric Rotation Operator	Only available for 2D fields, not for propagating 1D field sections. An operator for rotating fields in geometrical optics approximation. ↪Sec. 94.1.1
Diffractive Rotation Operator	Only available for 2D fields, not for propagating 1D field sections. A rigorous operator for rotating fields. ↪Sec. 94.1.2

94.1 Propagation between Optical Setup Elements

Only valid for Classic Field Tracing in a General or Laser Resonator Optical Setup.

Generally, the propagation of a field between Optical Setup Elements is equivalent to propagating the field between two arbitrarily positioned planes. These planes are related to the Optical Setup Elements involved and are called *transfaces*. This is a special shortcut for "*trans*fer inter*face*" and means the location of the field transfer between two kinds of operators. The *output transface* τ_1 of the *start element* is the plane where the output of the propagation through this element is given to the homogeneous medium free space operator. The *input transface* τ_2 of the *target element* is the plane where the output of the free space operator is given to the propagation operator of the second element.
The position and orientation of the output transface – the starting point for the homogeneous medium free space operator – is determined by the propagation through the start element and the type of the reference output coordinate system chosen for this element (but the output coordinate system does not have to be identical to this transface's position and orientation). It is stored after the element's propagation in the coordinate system of

the field itself: the origin of this coordinate system is identical to the position of the transface and the orientation is given by the coordinate system's x-y-plane.
The position and orientation of the input transface – the end point for the homogeneous medium free space operator – is determined by the geometry of the target element and, of course, the relative position of the target element to the start element.
There are two general cases to be distinguished for the propagation between Optical Setup Elements, related to two different algorithms used for propagating the field from output transface τ_1 to input transface τ_2:

1. The planes τ_1 and τ_2 are parallel. The algorithm used for this configuration is shown in Fig. 675.
2. The planes τ_1 and τ_2 are not parallel. The algorithm used for this configuration is shown in Fig. 676. **Please note:** this case cannot be simulated with 1D fields.

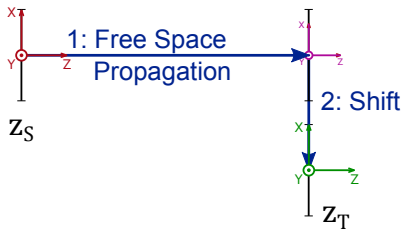


Figure 675. *Algorithm for the propagation between Optical Setup Elements where output transface and input transface are parallel. There are two operations at most: the actual free space propagation followed by a lateral shift.*

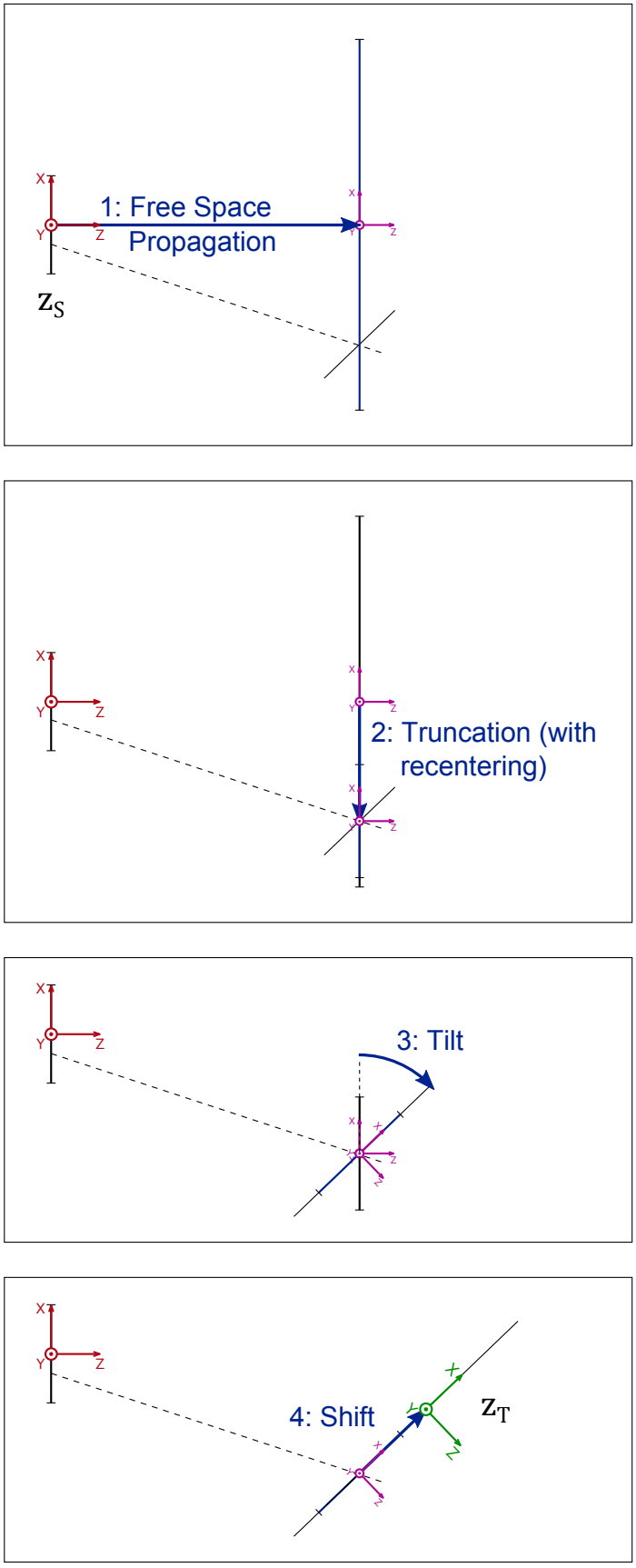


Figure 676. *Algorithm for the propagation between Optical Setup Elements where output transface and input transface are not parallel. The operators 1: actual free space propagation and 3: rotation operation can be configured by the user.*

In the following, only those two steps of the complete algorithm will be described which can be configured by the user himself:

1. The free space operator used to propagate the free space distance between two parallel planes.
2. The rotation operator which is used if the input transface of the target element is rotated relative to the output transface of the start element. **Please note:** This operator cannot be used with 1D fields.

More information on coordinate systems can be found in Sec. 44.9.

The configuration dialogs of both of these operators can be accessed via the dialog shown in Fig. 677, having two tab pages.

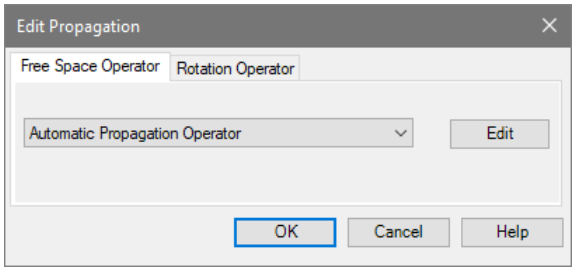


Figure 677. *The dialog to select the propagation method which shall be used for simulating the free space between the start element and the target element of a linkage.*

TAB PAGE	DESCRIPTION
Free Space Operator	On this tab page you can select one of the available free space operators. Depending on the type of the Optical Setup (↪Sec. 44.11) different operators are available. The *Edit* button opens the edit dialog of the currently selected operator, explained in the corresponding help chapter (see below).
Rotation Operator	On this tab page you can choose between the *Geometric Rotation Operator* (↪Sec. 94.1.1) and the *Diffractive Rotation Operator* (↪Sec. 94.1.2). The *Edit* button opens the edit dialog of the currently selected operator which is explained in the corresponding help chapter.

94.1.1 Geometrical Rotation Operator

Fig. 678 shows the edit dialog of the Geometric Rotation Operator.

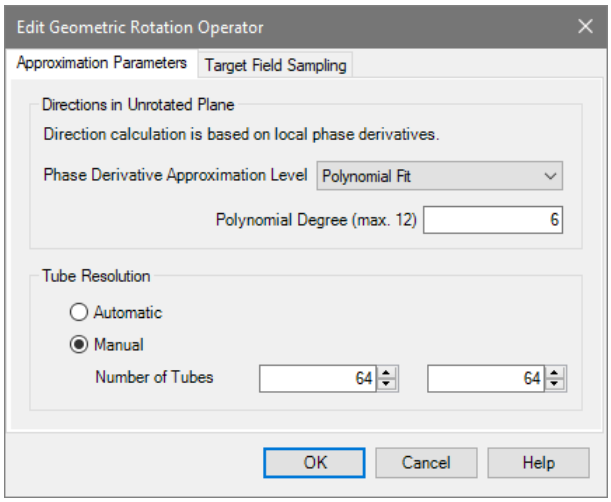


Figure 678. *Dialog for setting the approximation parameters for the Geometric Rotation Operator.*

The following parameters can be specified on the *Approximation Parameters* tab page:

ITEM	DESCRIPTION
Phase Derivative Approximation Level	The Geometric Rotation Operator works with direction information that is derived from the phase of the incident light. The directions are typically evaluated by fitting a smooth function into the phase of the incident field. The user can define which type of smooth phase function shall be fitted. Alternatively the local derivative can be used to evaluate the direction data numerically.
Polynomial Degree	In case of polynomial fit this number defines the maximal exponent sum $m+n$ of the basis monomials $x^m \cdot y^n$ used for the phase fit. The default value is 6.
Tube Resolution	The user can specify whether the tubes shall be defined automatically or manually. In *Automatic* mode the user can specify an *Accuracy Factor*[PV] which increases the number of tubes that are used within the geometrical optics operator. Alternatively the user can specify the *Number of Tubes*[PV] directly in *Manual* mode.

The size and sampling of the target field can be specified on the *Target Field Sampling* tab page which is shown in Fig. 679.

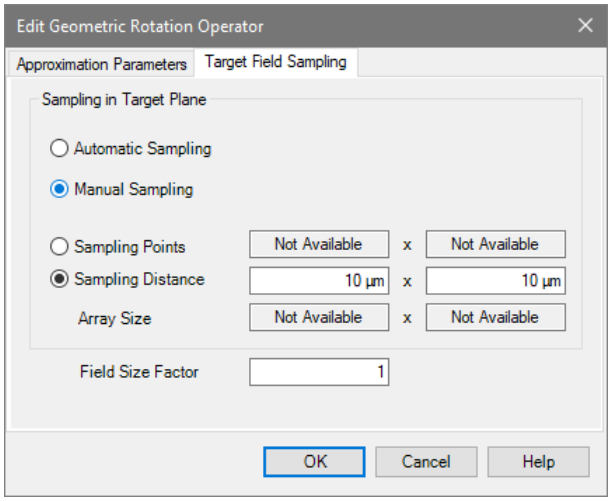


Figure 679. *Dialog for setting the target field size and sampling for the Geometric Rotation Operator.*

The user can enter the following parameters:

ITEM	DESCRIPTION
Sampling in Target Plane	The user can specify whether the sampling distance / number of sampling points of the target field shall be set automatically. In *Automatic* mode the user can specify an *Oversampling Factor*[PV] which can be used to increase the resolution of the output field. Alternatively the user can specify the number of *Sampling Points*[PV] or the *Sampling Distance*[PV] directly in *Manual* mode.
Field Size Factor[PV]	The Geometric Rotation Operator uses the same algorithm to estimate the field size of the output field as the Diffractive Rotation Operator. By adapting the *Field Size Factor* this field size can be increased or decreased.

94.1.2 Diffractive Rotation Operator

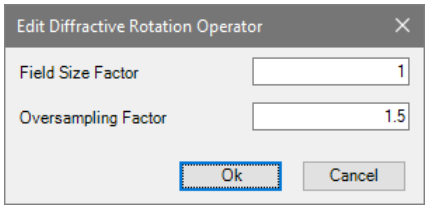


Figure 680. *Dialog for setting the parameters for the Diffractive Rotation Operator.*

There are only two parameters which can be set for the Diffractive Rotation Operator in its edit dialog (↪Fig. 680):

ITEM	DESCRIPTION
Field Size Factor PV	Factor by which the field size of the resulting field of the rotation operation will be enlarged in each direction.
Oversampling Factor PV	Factor by which the sampling distance of the resulting field of the rotation operation will be reduced in each direction.

94.2 Automatic Propagation Operator

The Automatic Propagation Operator selects the appropriate propagation operator from either SPW Operator (↪Sec. 94.4), Fresnel Propagation Operator (↪Sec. 94.6), Far Field Operator[1] (↪Sec. 94.3), and Geometrical Optics Operator (↪Sec. 97.1). The selection is based on finding a compromise between numerical accuracy and numerical effort required for computing the propagated field. The selection algorithm is shown in Fig. 681.

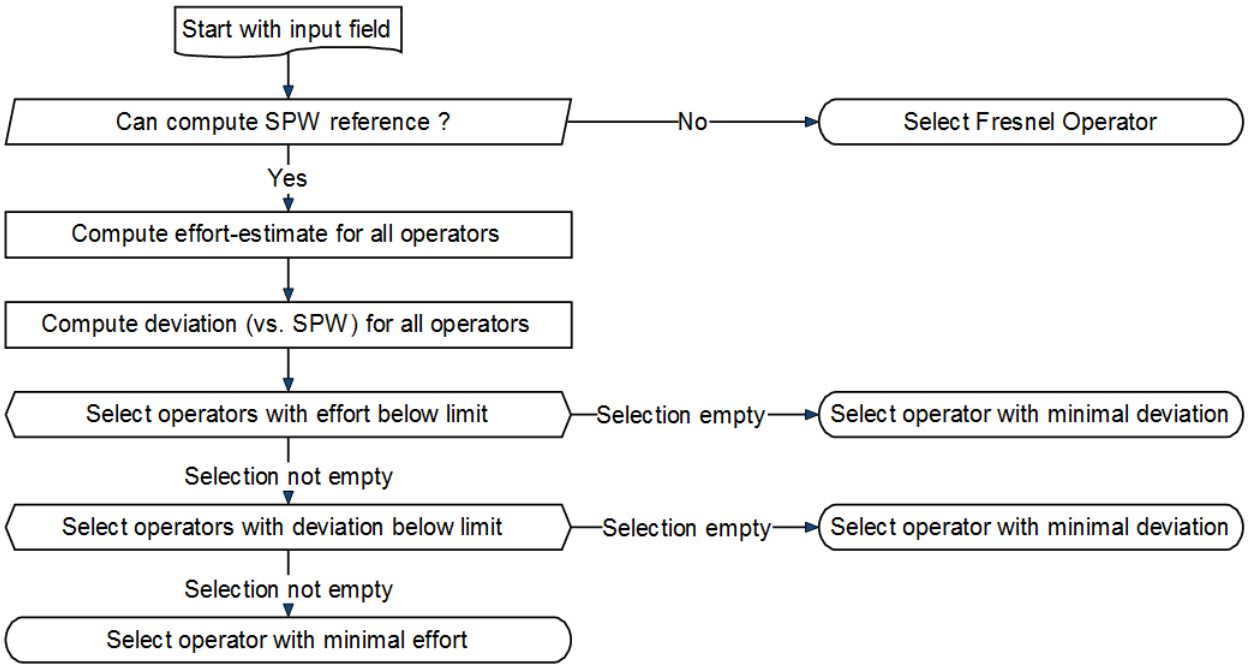


Figure 681. *Flowchart for the selection algorithm applied by the automatic propagation operator.*

Both the deviation of the propagation operator and its numerical effort are estimated by one-dimensional calculations and a comparison with a SPW reference result in 1D. The primary criterion for selecting the operator

[1] All three modes of the non-paraxial Far Field Operator are tested.

is that the deviation must not exceed a certain fraction of the total energy of the field. This is the *Deviation Threshold* specified in the *Accuracy* tab. From the admissible set of operators (deviation below limit), the operator with the lowest numerical effort is selected. Further, the numerical effort is assumed to be some limit (number of sampling points). The effort limit is taken from the value *Maximum Number of Sampling Points per Field* defined in the *Global Options*, ↪Sec. 6.14. Furthermore, the parameter *Power Portion for Field Size Estimation* (↪Sec. 6.12) is used to estimate the field size of the propagated field. A more detailed description is given in [WK11].
The different implementations of this operator for the main window and the Optical Setup (↪Sec. 44) are discussed in the following subsections.

94.2.1 Implementation in the Main Window

If the automatic propagation is used in the main window you can do an analysis prior to the actual propagation by clicking on the *Analyze* button. The resulting window as shown in Fig. 682 displays the estimated values for deviation and numerical effort and the estimated sampling of the propagated field. In the case of a Harmonic Fields Set, the analysis can be done per member field by selecting the index of the member and *Analyze* it. The operator used for the actual propagation can depend on the selected member.

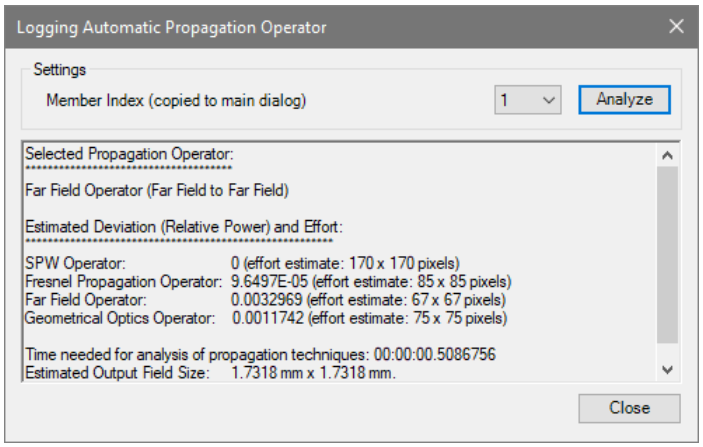


Figure 682. *Results of the analysis if the automatic propagation is used in the main window.*

The tab for editing the general *Propagation Parameters* is shown in Fig. 683.

ITEM	DESCRIPTION
Propagation Distance	The propagation distance.
SPW Operator	If checked, the SPW Operator can be selected.
Fresnel Propagation Operator	If checked, the Fresnel Propagation Operator can be selected.
Far Field Operator	If checked, the Far Field Operator can be selected.
Geometrical Optics Operator	If checked, the Geometrical Optics Operator can be selected.
Analyze	Press this button to perform the analysis, compute estimates for deviation and numerical effort. Displays the results and the selected operator.
Ok	Starts the actual propagation.

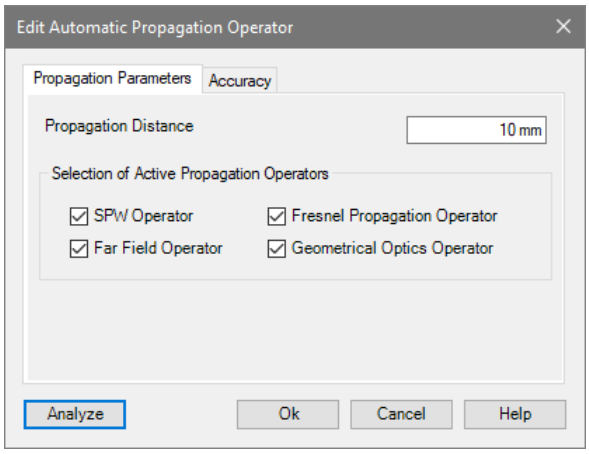


Figure 683. *Dialog for editing the settings of the Automatic Propagation Operator.*

Via the *Accuracy* tab you can set the following:

ITEM	DESCRIPTION
Accuracy Factor	The accuracy factor for the individual operators. It also influences the estimate of the size of the propagated field.
Deviation Threshold	The fraction of the total energy of the field which "suitable" propagation techniques must not exceed.
Power Portion for Field Size Estimation	The *Power Portion for Field Size Estimation* specifies how much of the energy of the incoming field is present in the output field. This value must be below 100 %. A higher value means both increased accuracy and computational effort.
Analysis for one member only	If checked, you can select which member field determines the used propagation operator. If unchecked, the propagation operator is determined independently for each member field.

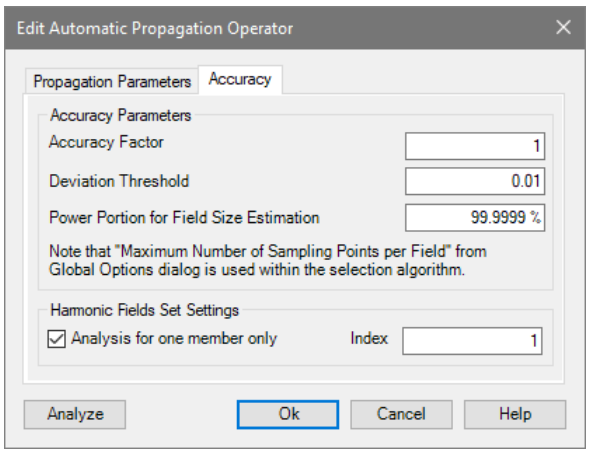


Figure 684. *Panel for accuracy settings.*

94.2.2 Implementation in the Optical Setup

If the automatic propagation is used within the Optical Setup (↪Sec. 44), no separate analysis can be done. However, corresponding information can be found in the logging window (↪Sec. 44.8.7) after the simulation is finished.

The tab for editing the general *Propagation Parameters* has the following parameters.

ITEM	DESCRIPTION
SPW Operator	If checked, the SPW Operator can be selected.
Fresnel Propagation Operator	If checked, the Fresnel Propagation Operator can be selected.
Far Field Operator	If checked, the Far Field Operator can be selected.
Geometrical Optics Operator	If checked, the Geometrical Optics Operator can be selected.

Via the *Accuracy* tab you can set the following:

ITEM	DESCRIPTION
Accuracy Factor PV	The accuracy factor for the individual operators. It also influences the estimate of the size of the propagated field. This setting might also be set for the whole Optical Setup via the Property Browser (↪Sec. 44.5.6.1).
Deviation Threshold PV	The fraction of the total energy of the field which “suitable” propagation techniques must not exceed. This setting might also be set for the whole Optical Setup via the Property Browser (↪Sec. 44.5.6.1).
Power Portion for Field Size Estimation PV	The *Power Portion for Field Size Estimation* specifies how much of the energy of the incoming field is present in the output field. This value must be below 100 %. A higher value means both increased accuracy and computational effort.
Analysis for one member only	If checked, you can select which member field determines the used propagation operator. If unchecked, the propagation operator is determined independently for each member field.

The setting *Analysis for one member only* available in the main window can be set **only** for the whole Optical Setup via the Property Browser (↪Sec. 44.5.6.1).

94.3 Far Field Operator

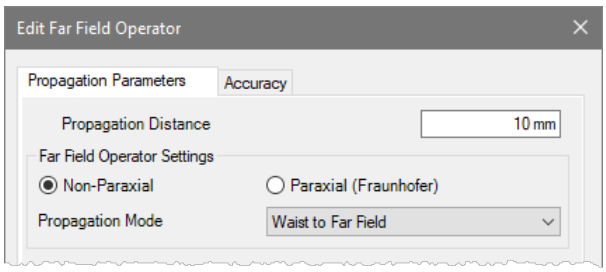


Figure 685. *Dialog of the Far Field Operator.*

The *Far Field Operator* has the dialog shown in Fig. 685. Its *Propagation Parameters* tab allows the user to enter the propagation distance and the propagation mode. Three different propagation modes are supported: propagation from *Waist to Far Field*, *Far Field to Waist*, and *Far Field to Far Field*. Additionally it is possible to select between the general Far Field Operator (*Non-Paraxial*) and a *Paraxial (Fraunhofer)* approximation. The *Accuracy* tab is explained in Sec. 93.1.

If used in the Optical Setup, the *Propagation Distance* cannot be set as it is determined from the positions of the Optical Setup Elements. Thus, the corresponding controls are not visible.

The implemented formulas are given in Sec. 143.1.2.

94.4 Spectrum of Plane Waves Operator

Figure 686. *Dialog of the propagation with spectrum of plane waves (SPW), Fresnel transform or a combination of both.*

If this operator is used for a linkage (↪Sec. 94.1) its edit dialog has only the *Accuracy* tab explained in Sec. 93.1. If used in the main window, there is an additional *Propagation Parameters* tab with the following controls:

ITEM	DESCRIPTION
Propagation Distance	The propagation distance. Can be positive and negative.

The implemented formulas are given in Sec. 143.1.3.

94.5 Rayleigh Sommerfeld Operator

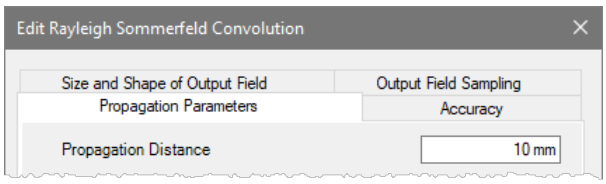


Figure 687. *Dialog of the propagation with Rayleigh Sommerfeld Convolution operator showing the* Propagation Parameters *tab. The dialog for the Rayleigh Sommerfeld Summation operator is equivalent.*

For this propagation operator two distinct numerical implementations are available (↪Sec. 143.1.4), namely *Rayleigh Sommerfeld Convolution* and *Rayleigh Sommerfeld Summation*. The corresponding dialog (↪Fig. 686) has three tab pages which are explained in ↪Sec. 93.
If used in the main window, there is an additional *Propagation Parameters* tab with the following controls:

ITEM	DESCRIPTION
Propagation Distance	The propagation distance. Can be positive and negative.

94.6 Fresnel Propagation Operator

If the *Fresnel Propagation Operator* is used for a linkage (↪Sec. 94.1) its edit dialog (↪Fig. 686) has only the *Accuracy* tab explained in Sec. 93.1. If used in the main window, there is an additional *Propagation Parameters* tab with the following controls:

ITEM	DESCRIPTION
Propagation Distance	The propagation distance. Can be positive and negative.

The implemented formulas are given in Sec. 143.1.5.

94.7 Combined SPW / Fresnel Operator

This propagation operator automatically combines the spectrum of plane waves propagation (↪Sec. 94.4) and the Fresnel propagation (↪Sec. 94.6) to achieve an efficient propagation of paraxial waves free of numerical

errors. For propagation of harmonic fields close to the waist of a wave, spectrum of plane waves is used. For larger distances the Fresnel propagation is used. Sec. 143.1.6 explains in more detail when which propagation is used.
If this operator is used for a linkage (↪Sec. 94.1) its edit dialog (↪Fig. 686) has only an *Accuracy* tab where you can set the accuracy factor (↪Sec. 93.1). If used in the main window, there is an additional *Propagation Parameters* tab with the following controls:

ITEM	DESCRIPTION
Propagation Distance	The propagation distance. Can be positive and negative.

94.8 Rayleigh Expansion Propagation

Only available in a Grating Optical Setup.

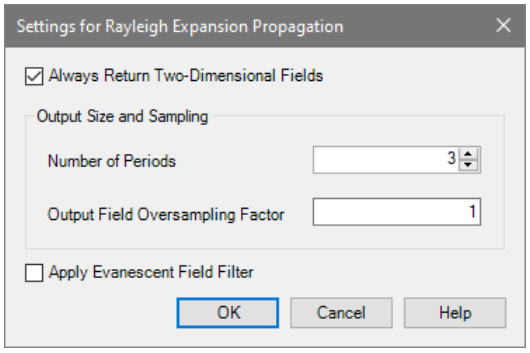


Figure 688. *The Dialog for the Rayleigh Expansion Propagation.*

This free space operator can take advantage of the Rayleigh coefficients calculated by rigorous methods. It has the following options:

ITEM	DESCRIPTION
Always Return Two-Dimensional Fields	If the grating component is set to 1D-periodic mode (↪Sec. 65.1) or if for one direction only one order is calculated by the FMM (↪Sec. 97.3.1.1), the resulting fields will be one-dimensional. However, the two-dimensional field view can be more intuitive. Thus you can enforce two-dimensional fields by checking this option.
Number of Periods PV	Sometimes it can be more intuitive if more than one period is shown, which can be set with this option. For 2D-periodic gratings this setting affects both x- and y-direction of the resulting field.
Output Field Oversampling Factor PV	The number of sampling points per period is the number of calculated diffraction orders times the *Output Field Oversampling Factor*.
Apply Evanescent Field Filter	Evanescent waves vanish after a very short propagation distance. By checking this option you can enforce that they vanish even for a propagation distance of zero.

The implemented algorithm is documented in Sec. 143.1.7.

94.9 Cells Array Propagation

Only available in a Light Shaping Optical Setup.

This free space operator is available after the Light Shaper component. The Grating Cells Array performs a mode decomposition, where all modes have the same intensity distribution but are located in different positions and have different propagation directions. The free space operator uses these analytic information of the light field object in the input plane and calculate the positions of the modes in the output plane. Additionally the intensity distribution of all modes is propagated by wave optical propagation techniques into the target plane. This propagation operator can be selected by the user. The user can use the *Far Field Operator* (↪Sec. 94.3) or the *Automatic Propagation Operator* (↪Sec. 94.2). By default the Far Field Operator is used. The output of the free space operator is a new light field object which contains the propagated mode and the analytic stored positions and directions for all modes. This light distribution can be used for further investigations within the Camera Detector (↪Sec. 75.5.2).

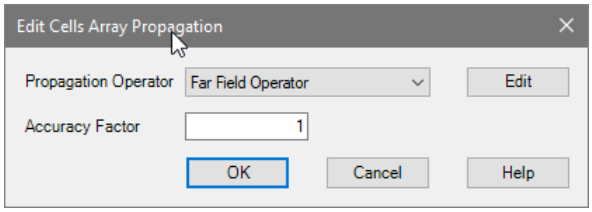


Figure 689. *The Dialog for the Cells Array Propagation*

Fig. 689 shows the edit dialog of the *Cells Array Propagation*. Its has the following controls.

ITEM	DESCRIPTION
Propagation Operator	Here you can choose between *Far Field Operator* or *Automatic Propagation Operator* as wave optical propagation.
Edit	Edits the currently selected propagation operator.
Accuracy Factor	Influences the spot size in the target plane of the propagated wave. An accuracy factor of 1 means that 95 % of the power of the propagated spots will be used for further investigation. Increasing the *Accuracy Factor* by 1 means that 0.5 % will be added to this power portion. So an *Accuracy Factor* of 11 means that 100 % of the propagated field will be used.

95 2D / 3D Propagation

For Harmonic Fields, Harmonic Fields Sets, and Ray Distributions in the main window there is the ribbon button Propagations > 2D Propagation / Propagations > 3D Propagation (depending on the dimensionality of the field). This button opens a dialog to create a Parameter Run in which the field is propagated by different distances. From this Parameter Run you then can generate instructive diagrams or animations showing how the field evolves, see Fig. 690 for an example.

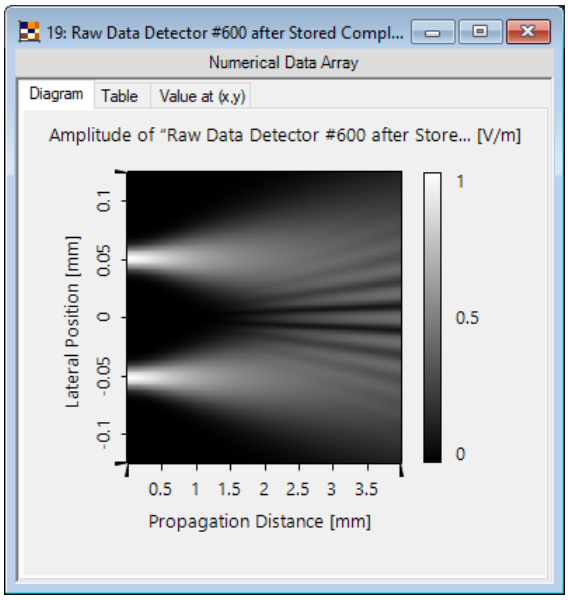


Figure 690. *Interference of two Gaussian beams. This is the result of a one-dimensional Harmonic Field propagated to different distances with the 2D Propagation feature. The results where then combined into a two-dimensional data array.*

Said dialog (↪Fig. 691) has the following options.

ITEM	DESCRIPTION
Propagation Method	ONLY FOR HARMONIC FIELDS AND HARMONIC FIELDS SETS You can select and *Edit* any of the operators listed in Sec. 94 which are suitable for both one- and two-dimensional harmonic fields.
Start Point	The minimum propagation distance.
End Point	The maximum propagation distance.
Number of Propagation Steps	The number of propagation steps between the start point and the end point (including).
Remove Constant Phase Factor exp(ikz)	ONLY FOR HARMONIC FIELDS AND HARMONIC FIELDS SETS During the propagation typically a constant phase factor $\exp(ik\Delta z)$ depending on the propagation distance will occur. Its fast oscillation along the optical axis makes it difficult to notice the change of the phase, the real and imaginary part of the harmonic field during the propagation. Enable this option to remove the constant phase factor (recommended for real and imaginary part and phase display).

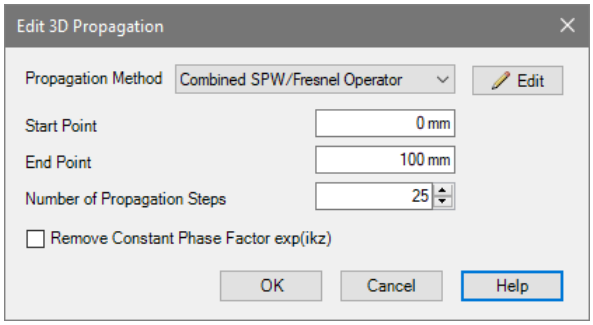


Figure 691. *The dialog for defining a 3D Propagation for a Harmonic Field or Harmonic Fields Set.*

When this dialog is closed with *OK*, a Parameter Run (↪Sec. 45) with the appropriate settings is created

and started automatically. After the Parameter Run completes you can create a nice-looking combined output (↪Sec. 45.5.1).

96 Propagation through Idealized Systems

The Propagations tab for Harmonic Fields and Harmonic Fields Sets also offers the possibility to propagate through simple, idealized setups. 1f-Setup and 2f-Setup are described in Sec. 31.1.1. ABCD Matrix Simulation is described in the following section.

96.1 ABCD Matrix Simulation

Availability

Toolboxes: All

Accessible: Harmonic Field and Harmonic Fields Set: Propagations > ABCD Matrix Simulation

This function is a generalization of the 1f-Setup / 2f-Setup (↪Sec. 31.1.1): You can define an arbitrary system as ABCD matrix through which the current Harmonic Field or Harmonic Fields Set is propagated in an idealized way. VirtualLab Fusion also offers the ABCD Law Calculator (↪Sec. 105) which has similar functionality for Gaussian waves. Furthermore, in an Optical Setup you can use the ABCD Matrix Setup component (↪Sec. 74.1).

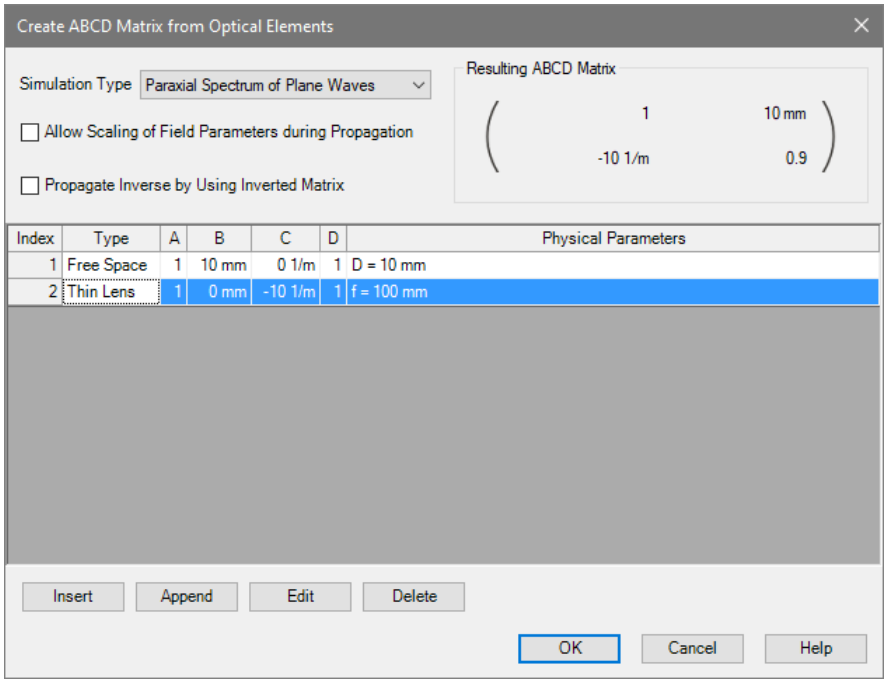


Figure 692. *Dialog for defining the parameters of an ABCD matrix propagation.*

Fig. 692 shows the edit dialog for an ABCD matrix simulation. It has the following controls:

ITEM	DESCRIPTION
Simulation Type	You can choose between three methods (*Collins Integral*, *Spectrum of Plane Waves*, and *Rayleigh-Sommerfeld Convolution*). See Sec. 140.1 for an explanation of these methods.
Allow Scaling of Field Parameters during Propagation	If checked, the field will be resampled to avoid numerical problems. This option is only available if the matrix element B is not zero.
Propagate Inverse by Using Inverted Matrix	Using the inverse ABCD matrix corresponds to an inverse propagation. Thus this checkbox allows you to invert the ABCD matrix being used for the simulation.
Resulting ABCD Matrix	Shows the automatically calculated ABCD Matrix of the combination of the optical elements.
ABCD Matrix Control	Allows you to define the system ABCD matrix by composing it of an arbitrary number of optical elements. ↪Sec. 5.17

97 Propagation Operators for Real Components

For real components in the Optical Setup (↪Sec. 44), the following propagation operators are available:

COMPONENT PROPAGATION	ANNOTATIONS
Collins Integral by ABCD Matrix (For Spherical Lens & Lens System)	This operator uses the ABCD matrix of the component and thus can handle only certain surface types and homogeneous media. All propagation settings are synchronized. ↪Sec. 97.5
Customized Propagation (For Double Surface Component, Fiber Element, GRIN Component & Inhomogeneous Medium Component.)	Uses *Thin Element Approximation* (↪Sec. 97.2) propagations for surfaces; several paraxial free space propagations for homogeneous media (↪Sec. 94) and either the *Thin Element Approximation* or the *Split Step (BPM)* propagation (↪Sec. 97.6) for inhomogeneous media. The settings are synchronized separately for each building block type.
Fourier Modal Method (For General Grating)	All propagation settings are synchronized. ↪Sec. 97.3
Geometrical Optics (For Light Shaper)	–
Geometrical Optics Operator (For Curved Surface, Spherical Lens & Lens System)	This operator can handle smooth surfaces and homogeneous media. All propagation settings are synchronized. ↪Sec. 97.1

97.1 Geometrical Optics Operator

The Geometrical Optics Propagation Operator is available both for free space propagation through homogeneous media and for propagation through real components. It is based on the principles of geometrical optics. The propagation is performed along rays. In our case, the direction of rays is defined by so called Channels. Rays within one channel have different position but the same direction. The operator first builds up the channels. In a second step, rays are propagated. In the first step, the directions of the channels have to be computed in the initial plane from the field data. In particular the phase of the field is used. The actual phase of the field

is replaced by a fitted phase using different levels of approximation: *Constant* phase, *Linear* phase, linear and *Spherical* phase, linear, spherical and *Cylindrical* phase. From this phase approximation the directions of the channels are computed. Alternatively the *Local Gradient* of the phase can be used to define the channel directions. Further, the channels are defined throughout the system by stepping from surface to surface. Depending on the settings of the operator, this procedures takes *Refraction* into account or not. Once the channels are defined, the rays carrying the field information are propagated through the system. The path of the rays is defined by the channels. Depending on the settings of the operator *Fresnel Effects* and *Cross Talk* is taken into account or not.

A detailed description of the operator is given in an external paper. An explanation of the *Size and Shape of Output Field* tab is given in Sec. 93.3.

The *Propagation Parameters* tab (↪Fig. 693) has the following parameters:

ITEM	DESCRIPTION
A: Constant	Take $(0, 0, 1)$ as direction of rays in the input plane.
B: Linear	Perform a fit of a linear phase for defining the directions of rays in the input plane.
C: B + Spherical	Perform a fit of a linear and spherical phase for defining the directions of rays in the input plane.
D: C + Cylindrical	Perform a fit of a linear, spherical and cylindrical phase for defining the directions of rays in the input plane.
E: Polynomial	Perform a general polynomial fit of the phase for defining the directions of rays in the input plane. The maximal exponent sum $m + n$ of the basis monomials $x^m \cdot y^n$ can be set on the *Accuracy* tab
F: Local Gradient	Take the local gradient for defining the directions of rays in the input plane.
I: Optical Path Length	Consider the optical path length only during tracing rays through the system.
II: I + Fresnel	Consider the optical path length and Fresnel effects during tracing rays through the system.
III: I + Refraction	Consider the optical path length and refraction during tracing rays through the system.
IV: III + Fresnel	Consider the optical path length, refraction and Fresnel effects during tracing rays through the system.
V: IV + Cross Talk:	Consider the optical path length, refraction, Fresnel effects and cross-talk between E_x and E_y during tracing rays through the system.

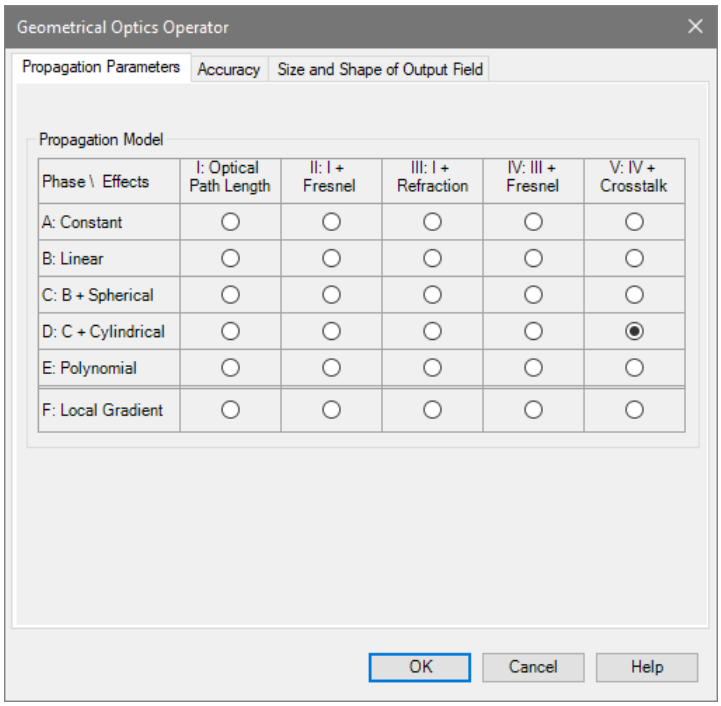


Figure 693. *Dialog for editing the Geometrical Optics Operator showing the tab with propagation parameters.*

The *Accuracy* tab (↪Fig. 694) has the following parameters:

ITEM	DESCRIPTION
Number of Channels	Number of channels being used.
Accuracy Factor PV	In the automatic mode, the accuracy factor (I) scales the number of channels being used.
Number of Rays to Be Traced	Sets the number of rays that are to be traced. These numbers correspond to the number of sampling points of the output field.
Accuracy Factor PV	In the automatic mode, the accuracy factor (II) scales the number of rays being traced.
Polynomial Degree	In case that option *E: Polynomial* is being selected, this number defines the maximal exponent sum $m + n$ of the basis monomials $x^m \cdot y^n$ used for the phase fit.

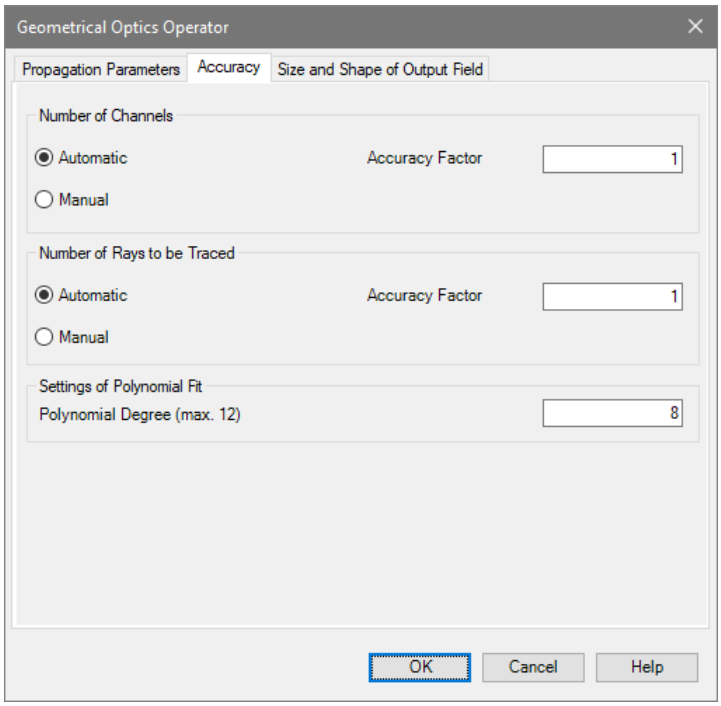


Figure 694. *Tab for editing the accuracy settings.*

97.1.1 Advanced Settings

If for a Curved Surface, Lens System, or Spherical Lens you have selected *Geometrical Optics Operator* as *Component Propagation*, the *Advanced Settings* sub-tab of the *Propagation* tab allows you to choose whether you want to *Minimize Use of Geometric Optics* or not (↪Fig. 695). This is important for concave surfaces only, as there is no difference between these options in the case of non-concave ones.

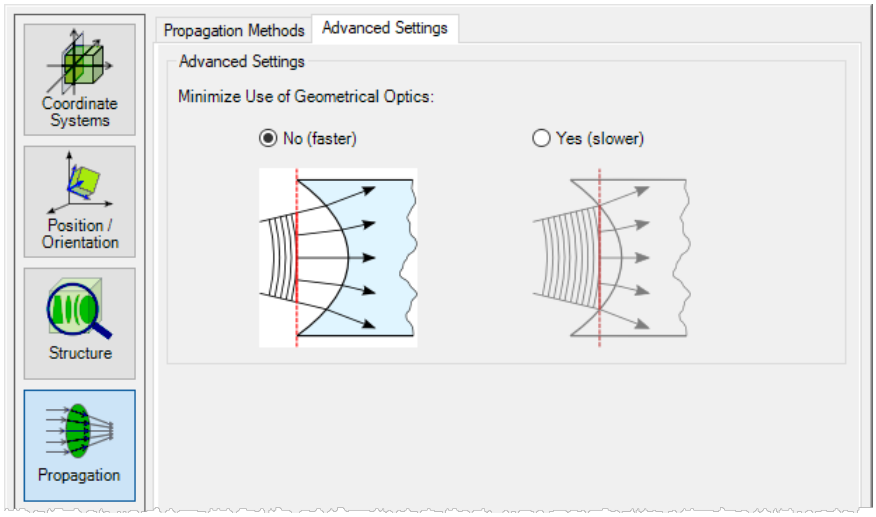


Figure 695. Advanced Settings *tab for the geometrical optics operator.*

ITEM	DESCRIPTION
No (faster)	Wave-optical propagation techniques are used till the aperture plane is reached, then geometrical optics is applied. This is the faster option, but at the expense of less accuracy.
Yes (slower)	The use of wave-optical propagation techniques is maximized, but at the expense of a slower calculation.

97.2 Thin Element Approximation

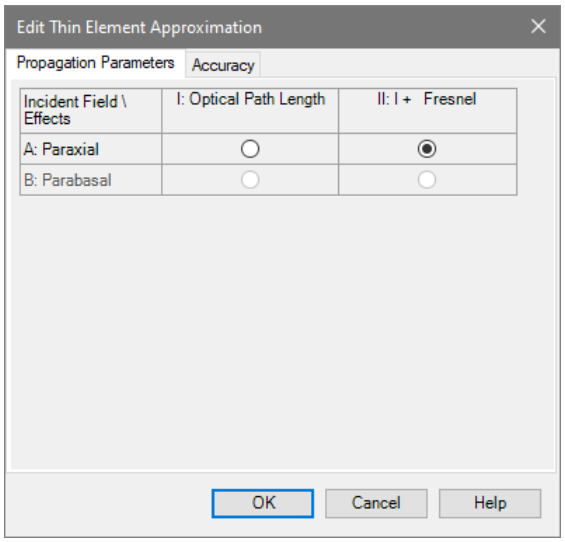


Figure 696. Propagation Parameters *tab for the thin element approximation operator.*

The thin element approximation can be used for propagating through surfaces, homogeneous and inhomogeneous (index modulated) media. It is assumed that paraxial/parabasal conditions hold. The paraxial mode is documented by [Goo68]. Using the paraxial mode, the method is identical to the mode AI/AII of the geometrical optics operator, see Sec. 97.1. The implemented algorithm is documented in Sec. 143.2.1.
The edit dialog (↪Fig. 696) has two tabs: The *Propagation Parameters* tab explained below and the *Accuracy* tab explained in Sec. 93.1.
The *Propagation Parameters* tab consists of a table with the following options:

ITEM	DESCRIPTION
A: Paraxial	Take $(0, 0, 1)$ as direction of rays in the input plane.
B: Parabasal	Perform a fit of a linear phase for defining the directions of rays in the input plane. This option will be available in a future version of VirtualLab Fusion.
I: Optical Path Length	Consider the optical path length only during tracing rays through the system.
II: I + Fresnel	Consider the optical path length and Fresnel effects during tracing rays through the system. This option is *not available* if the parabasal operator is used for inhomogeneous or homogeneous media.

97.3 Fourier Modal Method / Rigorous Coupled-Wave Analysis

Only available in the Grating Package.

The Fourier Modal Method (FMM) or Rigorous Coupled-Wave Analysis (RCWA) is a rigorous propagation technique. This method demands the periodicity of all physical values that are involved in the associated setup, i. e. the analyzed structure and the input field and consequently also the output field have to be periodical[1] (↪Fig. 697). For more details about the FMM see [Kno78; Li96; Tur97; Li01].

[1] A grating component is per definition periodical and an ideal plane wave fulfills the appropriate condition too.

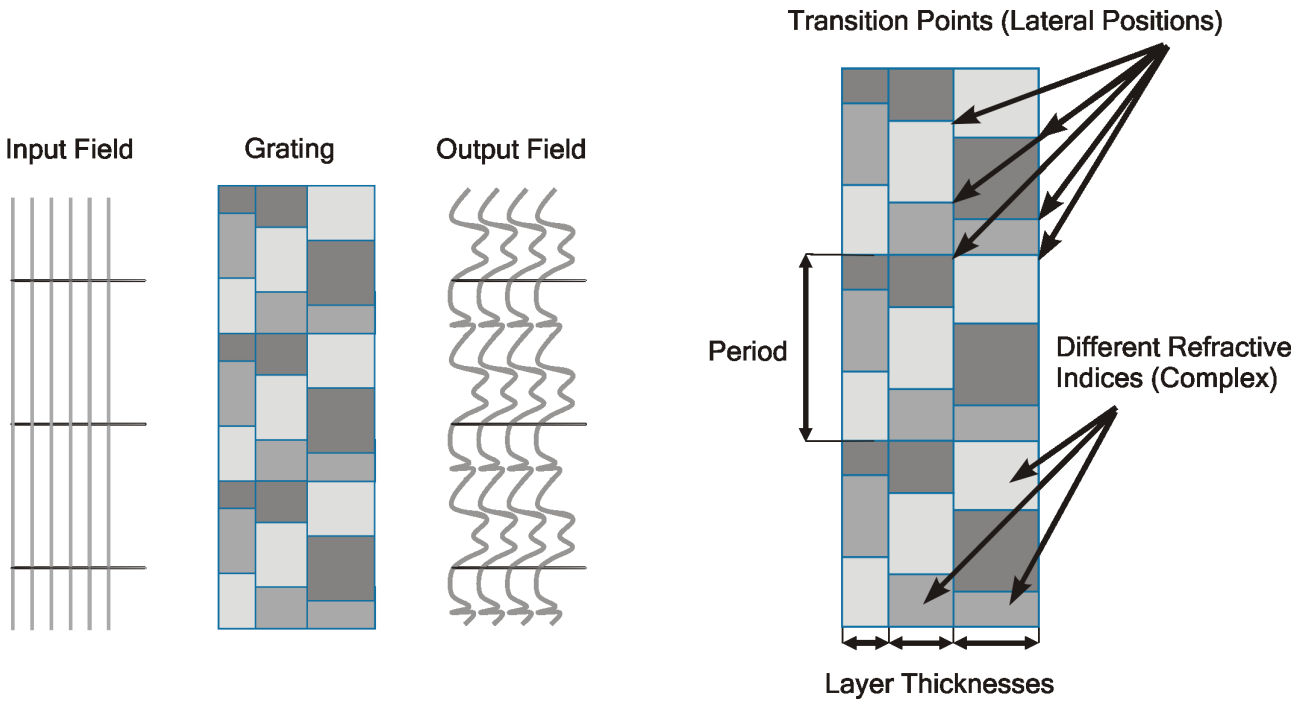


Figure 697. *Physical setup which is expected for analyses using the Fourier Modal Method.*

The FMM requires a structure built up by a sequence of discrete arbitrary cells which are characterized by their complex refractive index (↪Fig. 697). The sizes of these cells define so called transition points in lateral direction which create a sequence of layers in longitudinal direction on their part[1]. To analyze non-discrete structures configure the FMM to use a sufficient large number of layers and transition points.

Order Limit of the FMM

A maximum of 23 170 grating orders can be analyzed by the FMM. For 1D-periodic gratings this corresponds in best case to a period of roughly 12 000 × wavelength. But for 2D-periodic gratings this limit translates to e. g. 152 × 152 orders or at most (75 × wavelength)^2. However, RAM consumption and computational effort increase very rapidly with the number of orders, so that the practical limit is much lower.

97.3.1 Editing the Fourier Modal Method

There are in principle two things you can edit for the FMM: the number of diffraction orders (↪Sec. 97.3.1.1) and how the grating to analyze is decomposed into blocks of constant refractive indices (↪Sec. 97.3.1.2). In the edit dialog of the FMM they can be edited on different tab pages.

97.3.1.1 Setting the Number of Diffraction Orders

One numerical parameter for the FMM is the overall number of diffraction orders considered during calculation. A higher number means increased accuracy but higher numerical effort. Fig. 698 show the controls to edit this as well as the additional information label.

[1] Hereby one period can also contain any periodical substructures.

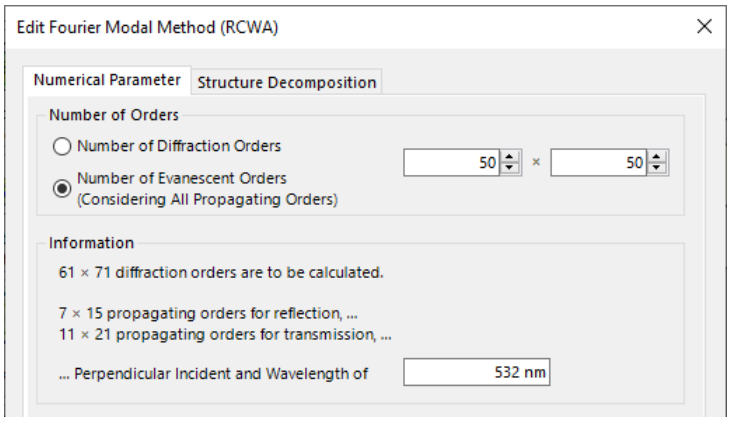


Figure 698. *The Numerical Parameters tab of the FMM where you can adjust the number of calculated orders in case of a 2D-periodic grating.*

You can either specify the *Number of Diffraction Orders*[PV] or the *Number of Evanescent Orders*[PV]. In the first case you can specify the number of diffraction orders directly. In the latter case, the overall number of diffraction orders calculated by the Fourier Modal Method is the number of evanescent orders plus the number of propagating orders. The dialog ensures that always an odd number (greater or equal 3) of diffraction orders is calculated.
The information gives the following information:

ITEM	DESCRIPTION
Number of calculated diffraction orders	The number of orders calculated by the FMM.
Number of propagating orders	This number is calculated for reflection and transmission from the grating equation (↪Sec. 145.5) for perpendicular incident. As this information depends on the wavelength, you can set the preview wavelength which is then also used for the decomposition preview (↪Sec. 97.3.1.3, Sec. 97.3.1.4).

For a 2D periodic grating you can specify the numbers of orders separately for the x- and the y-direction.

97.3.1.2 Decomposition into Layers and Transition Points

The transition points are always generated for the range $-Period/2 \ldots +Period/2$, but are stored internally with positive positions. Thus, the x-coordinates in the decomposition preview are shifted by half a period in comparison to all other previews and results.

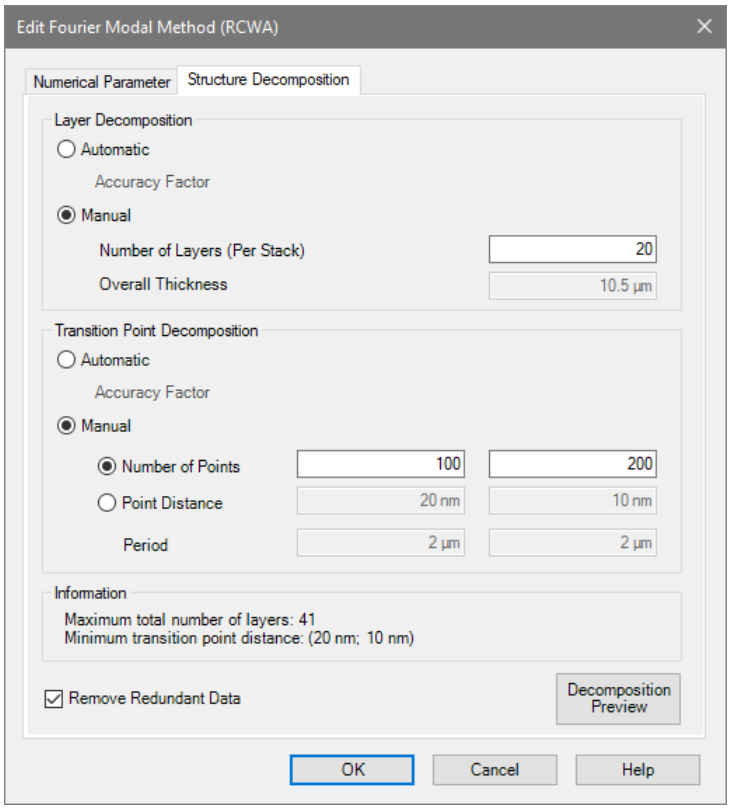


Figure 699. *The* Structure Decomposition *tab of the FMM in case of a 2D-periodic grating component with two stacks.*

With the controls shown in Fig. 699, you can adjust the decomposition of a real structure into *Layers* and *Transition Points* on the *Advanced Settings* sub-tab.
This tab page comprises three parts. In the upper part you can adjust the layer decomposition with the following settings:

ITEM	DESCRIPTION
Automatic	The layer decomposition is done automatically.
Accuracy Factor PV	A greater value means that the decomposition lasts longer and that more layers are generated, which increases the calculation time of the Fourier Modal Method. (Doubling the number of layers means roughly double the calculation time.)
Manual	An equidistant layer decomposition is used.
Number of Layers PV	The specified number of layers is distributed equidistantly over the modulated region. If stacks are placed on both surfaces of the grating component, the number of layers is used per stack.
Overall Thickness	The overall thickness of the modulated region, which is is the sum of the extensions of the two stacks.

In the middle part of the tab page you can adjust the transition point decomposition with the following settings:

ITEM	DESCRIPTION
Automatic	The transition point decomposition is done automatically as described in a technical note. The size of the smallest detectable features is given in the info label.
Accuracy Factor PV	A greater value means that smaller features are detectable but also that the decomposition lasts longer.
Manual	The transition points are distributed equidistantly. Each layer has the same number of transition points.
Number of Points	The specified number of transition points is distributed equidistantly over one *Period* of the structure.
Point Distance PV	Instead of the *Number of Points* the user can also specify the distance between transition points. Then, the number of points is calculated from this value and the *Period*.
Period	The period of the modulated region.

The lower part contains an information label and the following controls:

ITEM	DESCRIPTION
Remove Redundant Data	Especially if you have set the decomposition to *Manual* redundant data may occur (i. e. transitions between identical refractive indices or layers with the same refractive index distribution). If you check this item, such redundant data is removed after the decomposition.
Decomposition Preview	Opens a preview of the resulting decomposition. The preview for 1D-periodic gratings is explained in Sec. 97.3.1.3 and the preview for 2D-periodic gratings in Sec. 97.3.1.4.

The information label gives the following information:

ITEM	DESCRIPTION
(Maximum) Total number of layers	The total number of layers including one layer for the base block. In case *Remove Redundant Data* is checked this gives the maximum number of layers – which is only reached if there are no redundant layers.
Minimum transition point distance	The size of the smallest detectable feature. If no such small features are present in the structure, *Automatic* decomposition yields only larger distances between consecutive transition points.

Transition point distances of less than 0.1 nm can only be resolved in *Manual* mode without *Remove Redundant Data*.

97.3.1.3 Decomposition Preview for 1D-Periodic Gratings

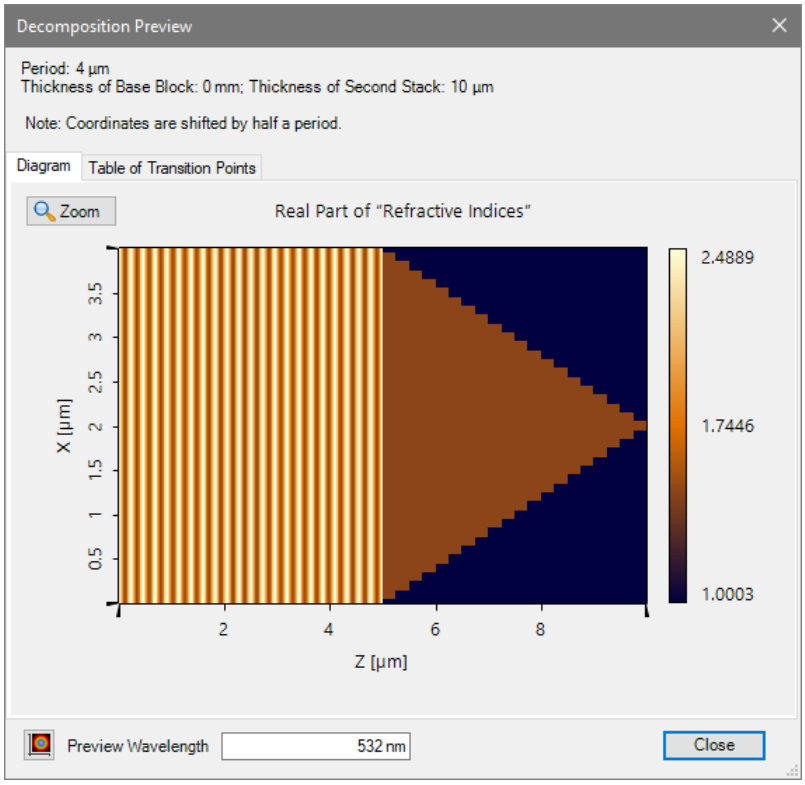


Figure 700. *The Transition Point Preview showing a combination of a volume grating with a triangular grating.*

The decomposition preview (↪Fig. 700) has a diagram tab and a table tab showing the layers and transition points used for the Fourier Modal Method. Furthermore, the overall dimensions of the grating component are given.

The positions in the table tab are “up-to-positions”. In the example given in Fig. 701, the refractive index 1.4611 is in the range from 1.3989 µm to 1.6011 µm. The *Reference Wavelength* used for the calculation of the refractive indices can be set on the bottom of the dialog.

Layer #0	
Thickness	
50 nm	
Position	Refractive Index
1.3989 µm	1.0003
1.6011 µm	1.4611
2 µm	1.0003

Figure 701. *Example showing a part of the table tab of the decomposition preview for 1D-periodic gratings*

In the diagram tab, the data is shown in a data array view (↪Sec. 13.4). In particular, the view has the same context menu which allows you to change the shown field quantity (↪Sec. 11.1) to e. g. imaginary part, change the aspect ratio (↪Sec. 11.5) or the color table (↪Sec. 11.2.4).

Furthermore you can zoom via mouse wheel or via the context menu, exactly as for data arrays (↪Sec. 11.4). However, this zooming always scales both dimensions of the data array. Thus a better suited *Zoom* tool is available for this preview: If you click on the *Zoom* button, a separate dialog is shown where you can specify exactly the rectangular region to be shown in the diagram. If you click *Show Whole Component* on said dialog, you can reset the view to show the complete data. If the grating component contains only one stack, then this stack is shown by default. Otherwise the whole component is shown. The table always shows the complete data.

The -button shows the currently set up diagram as separate data array view (↪Sec. 13.4).

97.3.1.4 Decomposition Preview for 2D-Periodic Gratings

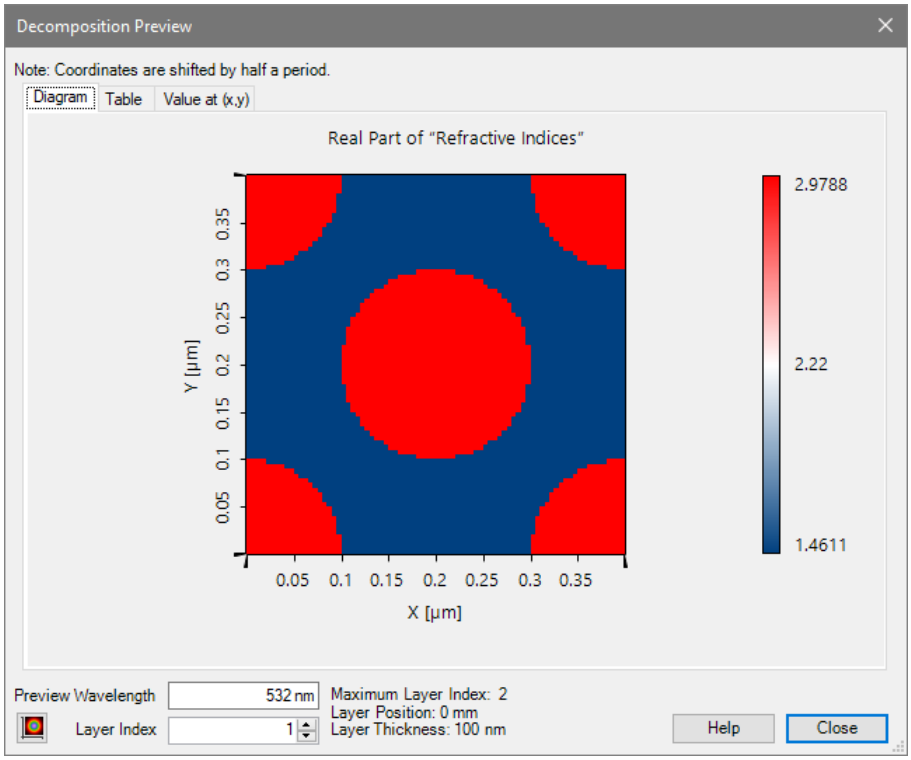


Figure 702. *The decomposition preview for 2D-periodic gratings.*

The decomposition preview for 2D-periodic gratings shows the refractive index distribution of one period in the currently selected layer, either as *Diagram* or as *Table*. In the lower section of the dialog you can set up the *Reference Wavelength* used for the calculation of the refractive indices as well as the *Layer Index*. As further information the position and thickness of this layer are given.

		X		
		0 m	323.4 nm	676.6 nm
>	0 m	1.0003	1.4611	1.0003

Figure 703. *Example showing a part of the table tab of the decomposition preview for 2D-periodic gratings.*

Non-equidistant data arrays are used for the preview (↪Sec. 13). In particular, the view has the same context menu which allows you to change the shown field quantity (↪Sec. 11.1) to e. g. imaginary part, zoom into the view (↪Sec. 11.4), change its aspect ratio (↪Sec. 11.5) or the color table (↪Sec. 11.2.4).
Via the context menu of the table you can copy the current selection to the Windows™ clipboard. Via the -button you can generate a separate data array document of the current view.
The constant interval interpolation is used (↪Sec. 13.2.1) and thus the positions in the table are “from-positions”. In the example given in Fig. 703, the block with the refractive index of 1.4611 covers the x-range from 323.4 nm to 676.6 nm.

97.4 Custom Fourier Modal Method

Only available in the AR/VR/XR Package.

You can analyze the efficiencies of the grating regions rigorously with the Fourier Modal Method (FMM) implemented in VirtualLab Fusion (↪Sec. 97.3). However, if you want you can also use your own FMM available in a separate dynamic link library (DLL) programmed with the .Net framework of Microsoft.
This DLL must contain at least a namespace of arbitrary name with a class of arbitrary name in which a static

method with arbitrary name is included. But this method must have parameters of the following types in the given order:

TYPE	DESCRIPTION
OpticalStack	The stack with correctly set medium in front of the stack (`MediumBefore`) and medium behind the stack (`MediumAfter`).
double	The vacuum wavelength with which the stack is illuminated.
Vector3D	The incident wave vector.
VectorC	E_x- and E_y-component of the input plane wave.

The return value of this method must be of type `RigorousSimulationResultsForPlaneWaveInput`, a type containing both efficiencies and Rayleigh coefficients for both transmitted and reflected light.
Most of the data types mentioned above are defined in the VirtualLabAPI.dll.

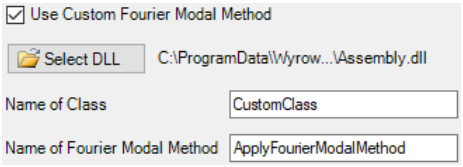


Figure 704. *The control to define a custom FMM.*

There is a control (↪Fig. 704) to define the location of the custom FMM. It has the following settings:

ITEM	DESCRIPTION
Use Customized Fourier Modal Method	If this option is not checked, the VirtualLab FMM is used to calculate rigorous results of gratings.
Select DLL	ONLY IF *USE CUSTOMIZED FOURIER MODAL METHOD* IS CHECKED. The user can select the DLL which provides the customized FMM.
Name of Class	ONLY IF *USE CUSTOMIZED FOURIER MODAL METHOD* IS CHECKED. It is necessary to define the class which contains the FMM function to apply for FMM. The name of the class has to be unique within the selected DLL.
Name of Fourier Modal Method	ONLY IF *USE CUSTOMIZED FOURIER MODAL METHOD* IS CHECKED. In addition the user needs to specify the function name which contains the FMM calculation. This method must have the input and output parameters as described above.

Tip

You might want to define for example accuracy factors for your FMM. This can be done on the *Additional Parameters* tab of the stacks in the Light Guide component (↪Sec. 58.2). The parameters defined there are then also available for Parameter Extraction, thus e. g. for Parameter Run and Parametric Optimization.

97.5 Collins Integral by ABCD Matrix

If the optical surfaces of a component or rather their optical effects can be described by the ABCD matrix formalism, one can decide to use the propagation algorithm given by Collins [Col70]. For a Lens System or a Spherical Lens this method can be selected as *Component Propagation* on the *Propagation Methods* sub-tab (↪Sec. 55.1).

In this case the *Propagation Methods* sub-tab has one additional control:

ITEM	DESCRIPTION
Info	This will write some information to the *Messages* tab of the main window: The ABCD matrix for transmission as well as the complex transmission coefficient (for the whole component). All these values are determined for the default wavelength (↪Sec. 6.1.1) and assume air in front of the component.

The Collins integral cannot be used for reflection as always a propagation distance is required which is not present for reflection on the first surface.
The controls in the edit dialog (↪Sec. 93.1) allow you to adjust the accuracy of the calculation.

97.6 Split Step (BPM) Propagation

THIS PROPAGATION OPERATOR IS ONLY AVAILABLE AS PART OF THE CUSTOMIZED PROPAGATION FOR INHOMOGENEOUS MEDIA.

This propagation operator is applicable for inhomogeneous media with small refractive index modulation $\delta n \ll n$. Furthermore, paraxial conditions are assumed to hold and the influence of reflected waves is assumed to be negligible. The operator is based on the classical ideas of paraxial beam propagation methods, see e. g. [YL92] and [TY82]. The implemented algorithm is documented in Sec. 143.2.2.

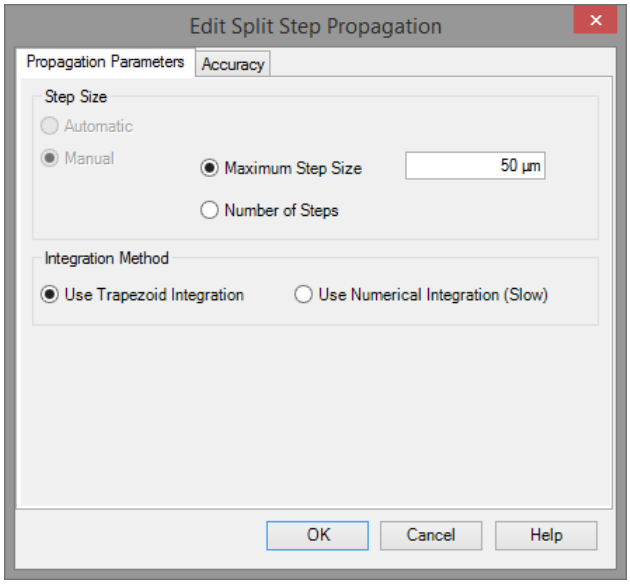


Figure 705. Propagation Parameters *tab for the split step (BPM) propagation.*

The *Propagation Parameters* tab of its edit dialog (↪Fig. 705) allows you to either set the *Number of Steps*[PV] (n) used for the propagation or the *Maximum Step Size*[PV] (Δz). The automatic selection of the step size will be added in a future version of VirtualLab Fusion. In the bottom part of the dialog the user can select the integration method which shall be used to include the refractive index modulation during the split step propagation. The user can select between *Use Trapezoid Integration* and *Use Numerical Integration*. The trapezoid integration is faster because only three points will be used to calculate the refractive index integral. We recommend the usage of the trapezoid integration for very slow index modulations and especially for z-invariant media. The *Accuracy* tab can be used to define the numerical parameters of the split step propagation. Fig. 706 shows the user control which can be used to control the split step propagation numerically.

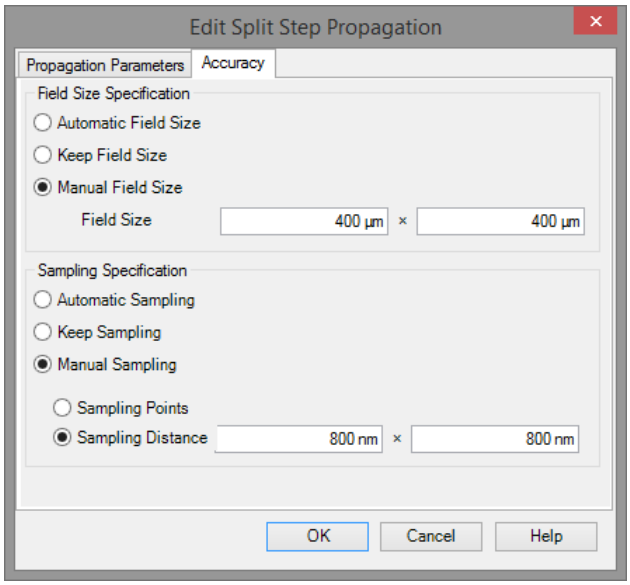


Figure 706. Accuracy *tab for the split step (BPM) propagation.*

The following parameters can be entered by the user:

ITEM	DESCRIPTION
Automatic Field Size	For automatic field size determination the incident field size and the media specification is taken into account. For several media field size estimation rules are implemented. If the *Automatic Field Size* mode is selected the user can enter a *Field Size Factor*[PV] which influences the field size estimation directly.
Keep Field Size	The keep field size mode can be used if the incident field size shall be kept. In that case the user can enter the *Embedding Factor*[PV] which will be multiplied on the field size of the incident field.
Manual Field Size	For manually defining the field size used for propagation the *Manual Field Size* mode can be selected. The user has to specify the *Field Size*[PV] for x- and y-direction.
Automatic Sampling	The automatic sampling mode can be used to adapt the sampling of the incident field automatically to the size of the features in the inhomogeneous medium. If this mode is selected the user can enter an *Oversampling Factor*[PV] which influences the sampling adaption of the incident field.
Keep Sampling	If the user selects the keep sampling mode the sampling of the incident field is kept for the simulation through the index modulated media. The user can enter a *Sampling Factor*[PV] which is applied on on the incident field.
Manual Sampling	The manual sampling mode allows the specification of the *Sampling Distance*[PV] or the *Number of Sampling Points*[PV] manually.

k

XIV Design & Optimization

VirtualLab Fusion offers four algorithms to design the optimal optical elements for your needs:

- *IFTA Optimization*: You can design transmissions acting for example as paraxial beam splitters and beam shapers. ↪Sec. 98
- *Cells Array Design*: A special design approach where the desired functionality is achieved by many small optical elements (gratings, prisms, or mirrors). ↪Sec. 101
- *Light Guide Design*: Special design algorithm for light guides used in AR & VR devices. ↪Sec. 102.2
- *Parametric Optimization:* Intended for the optimization of selected parameters of an Optical Setup (↪Sec. 44). The merit function used therefor can be freely configured. ↪Sec. 103

98 IFTA Optimization

Availability

Toolboxes: Diffractive Optics Package

Accessible: Ribbon: File > New > IFTA Optimization or Start > New > IFTA Optimization

The IFTA optimization document supports two transmission design methods (the actual *Iterative Fourier Transform Algorithm Approach* or IFTA [AWS97] and *Geometrical Optics Beam Shaping*) as well as basic analysis features. The designed transmissions can be exported to a real structure or to fabrication data using the structure design (↪Sec. 99).
The corresponding document window is divided into three panels which are described in the following.

98.1 Specification Panel

The specification panel contains data for specifying the transmission design problem. The consistency of these values can be checked via IFTA Optimization > Check Consistency.
All the data contained in the specification panel is stored when saving a transmission design document.
The controls of the specification panel (↪Fig. 707) are ordered in several groups, which are described in the following subsections.

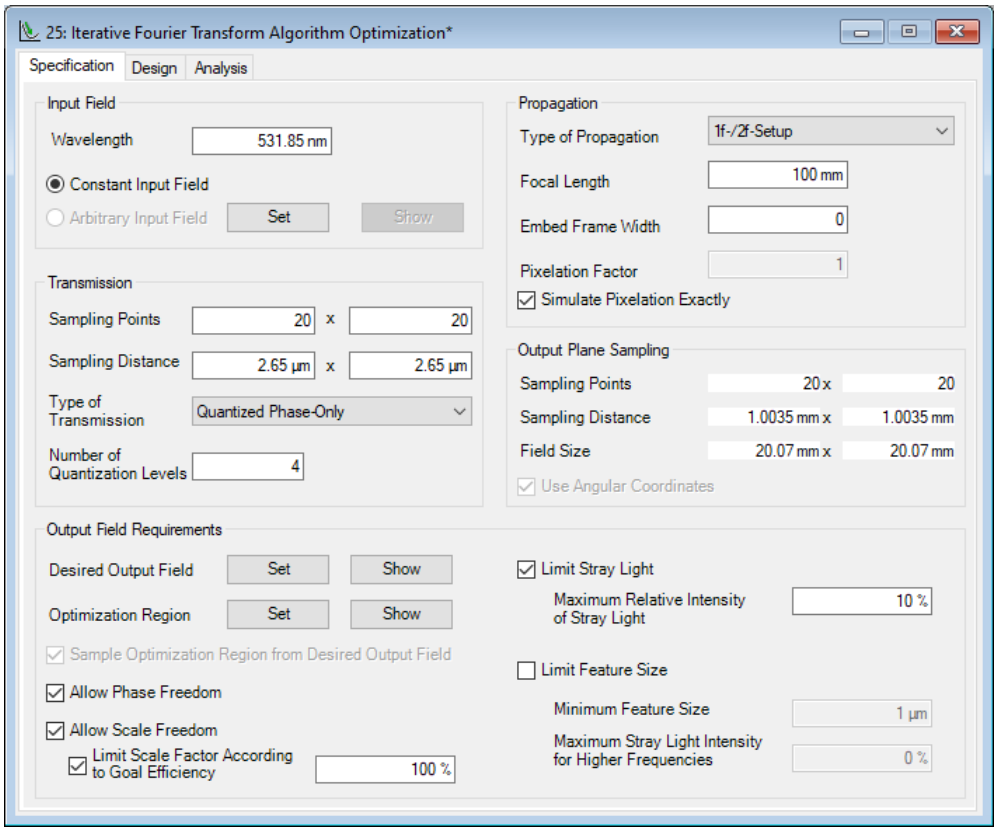


Figure 707. *Specification panel of the standard transmission design.*

98.1.1 Input Field

The input field can be chosen either to be constant or it can be set to any single globally polarized harmonic field.

ITEM	DESCRIPTION
Wavelength	Wavelength of input field.
Constant Input Field	For selecting a constant input field with the given wavelength. This corresponds to the illumination of the transmission by an untilted plane wave.
Arbitrary Input Field	Selected when the input field was set to a given harmonic field (see below).
Set	After pressing this button, the user is asked for selecting a globally polarized harmonic field, a copy of which is included into the design problem document as input field.
Show	Show a copy of the current input field.

The input field can be adapted to the sampling of the transmission (↪Sec. 98.1.2) via IFTA Optimization > Embed / Extract Input Field. This function is especially useful after changing the embed frame width in the specification panel (↪Sec. 98.1).

98.1.2 Transmission

The Transmission group box enables you to choose sampling parameters and the type of the transmission function to be optimized.

ITEM	DESCRIPTION
Sampling Points	Number of sampling points in x- and y-direction.
Sampling Distance	Sampling distance in x-and y-direction.
Type of Transmission	The available types of transmission functions are documented below.
Number of Quantization Levels	Contains the number of quantization values for quantized transmission types.

The following transmission types are supported:

ITEM	DESCRIPTION
Continuous Phase-Only	The transmission $\mathcal{T}(x)$ is a continuous phase-only function, i. e. at each position x the condition $\lvert\mathcal{T}(x)\rvert = 1$ is fulfilled.
Quantized Phase-Only	The transmission $\mathcal{T}(x)$ is an equidistantly quantized phase-only function, i. e. at each position x the condition $\mathcal{T}(x) \in \widetilde{\mathcal{M}}_{\text{phase},Q}$ is fulfilled, where $\widetilde{\mathcal{M}}_{\text{phase},Q}$ is given in Eq. (98.1).
Continuous Amplitude-Only	The transmission $\mathcal{T}(x)$ is a normalized amplitude-only function, i. e. at each position x the conditions $\lvert\mathcal{T}(x)\rvert < 1$ and $\arg[\mathcal{T}(x)] = 0$ are fulfilled.
Quantized Amplitude-Only	The transmission $\mathcal{T}(x)$ is an equidistantly quantized amplitude-only function, i. e. at each position x the condition $\mathcal{T}(x) \in \widetilde{\mathcal{M}}_{\text{ampl},Q}$ is fulfilled, where $\widetilde{\mathcal{M}}_{\text{ampl},Q}$ is given in Eq. (98.2).
Complex	The transmission $t(x)$ is a normalized complex-valued function, i. e. at each position x the condition $\lvert t(x)\rvert < 1$ is fulfilled.

Possible quantization values for quantization to Q equidistant phase-only values:

$$\widetilde{\mathcal{M}}_{\text{phase},Q} = \{\exp(i2\pi j/Q) : j \in \mathbb{Z}\}\,. \tag{98.1}$$

Possible quantization values for quantization to Q equidistant amplitude-only values:

$$\widetilde{\mathcal{M}}_{\text{ampl},Q} = \{j/(Q-1) : j \in [0, Q-1]\}\,. \tag{98.2}$$

98.1.3 Propagation

The settings within this group box determine the propagation operator which is to be used between transmission and signal plane.

ITEM	DESCRIPTION
Type of Propagation	The supported propagation operators are explained below.
Propagation Distance / Focal Length	Propagation distance between transmission and output plane or focal distance of considered $2f$-setup.
Embed Frame Width	If this value is greater than 0, the transmission field is embedded into a frame of zero-samples of the given width before applying the propagation operator. If in x-direction N_x sampling values are specified for the transmission function (↪Sec. 98.1.2) and an embed frame width N_{embed} is specified, then the transmission is embedded to a size of $(N_x + 2N_{\text{embed}})$.
Pixelation Factor	For the propagation operators which do not correspond to Fourier transforms, it can be necessary to simulate pixelation effects (↪Sec. 144.1.2) by replacing each sampling point by $N_{\text{pix}} \times N_{\text{pix}}$ sampling points, where N_{pix} is the given pixelation factor. Pixelation is applied after embedding.
Simulate Pixelation Exactly	For the propagation operators which correspond to Fourier transforms, pixelation effects can be simulated exactly by using the method explained in Sec. 144.1.2.

The following propagation operators are supported:

ITEM	DESCRIPTION
Far Field (Angular Spectrum)	Corresponds to performing a spatial Fourier transform (↪Sec. 31.1). The output plane coordinates are given in angular spectrum domain.
1f-/2f-Setup	Corresponds to performing a spatial Fourier transform (↪Sec. 31.1). The output plane coordinate system is related to the back focal plane of a 2f-setup (↪Sec. 31.1.1). This setting applies also for 1f-setups.
Fresnel Transform	Corresponds to the Fresnel transform propagation (↪Sec. 94.6) with output coordinate scaling as given in *Output Field Sampling* (↪Sec. 98.1.4).
Spectrum of Plane Waves	Corresponds to the spectrum of plane waves propagation operator as explained in Sec. 94.4. The output plane sampling distance is equal to the transmission plane sampling distance divided by the given pixelation factor.

98.1.4 Output Plane Sampling

In this group box the output plane sampling parameters are given, which follow from the transmission plane sampling (↪Sec. 98.1.2) and the propagation operator settings (↪Sec. 98.1.3).

If the propagation operator *Far Field (Angular Spectrum)* is selected, by checking *Use Angular Coordinates* it can be determined whether the output plane sampling is to be given in degrees instead of the internally used wave number coordinates (1/m). The calculation of the output plane parameters in degrees is done in paraxial approximation assuming a linear dependency between the angles in degrees and the angles in wave number coordinates. For non-paraxial designs the display in degrees should not be used.

98.1.5 Output Field Requirements

The constraints on the resulting output field as given in this group box determine the signal plane projection operator to be used for the IFTA design method.

ITEM	DESCRIPTION
Desired Output Field	Set or show the desired output field. For setting a new Desired Output Field, all currently open globally polarized harmonic fields can be selected in a separate dialog. This dialog also allows you to create the *Optimization Region* from the selection (↪Sec. 11.3.4) in the selected field. In case of using a harmonic field, it has to have the sampling parameters as specified in the *Output Plane Sampling* box. If the number of sampling points do not match, you cannot start the optimization. If the sampling distances do not match, they are set to the values shown in the *Output Plane Sampling* box. The wavelength and other physical parameters of the specified field are ignored.
Optimization Region	To *Set* a new Optimization Region, any currently opened region document (↪Sec. 21) can be selected. The IFTA optimizes only this region of the output field to match the *Desired Output Field*. Note that if you set an analytic region, it is sampled internally: Only those sampling points of the desired output field are optimized whose center point lies within the analytic region. ↪Fig. 708
Sample Optimization Region from Desired Output Field	If checked, a sampled *Optimization Region* is created from all positions where the current *Desired Output Field* is not exactly equal to zero.
Allow Phase Freedom	Determines whether the phase of the *Desired Output Field* is significant or whether it can be set freely by the IFTA.
Allow Scale Freedom	If this control is checked, during each iteration the current result field is scaled by a factor α to match the desired output field. As a result usually the stray light decreases at the cost of also decreased conversion efficiency. Otherwise α is always 1.
Limit Scale Factor According to Goal Efficiency	When this option is checked, a lower bound for the amplitude of the scale factor α is imposed, which corresponds to the given goal efficiency. This option can be helpful for increasing the achieved conversion efficiency.
Limit Stray Light	When this option is checked, the IFTA restricts the amplitude of the output field for positions outside of the *Optimization Region* to a certain upper threshold, which corresponds to the given *Maximum Relative Intensity of Stray Light* (↪Sec. 142.2).
Limit Feature Size	Enables imposing a limitation to the minimum feature size in the transmission using the method of [AW98]. From the given *Minimum Feature Size* a corresponding maximum spatial frequency in the output field is calculated. The stray light in the region with spatial frequencies higher than this maximum frequency must not exceed the *Maximum Stray Light Intensity for Higher Frequencies* (which is calculated analogly to the *Maximum Relative Intensity of Stray Light*).

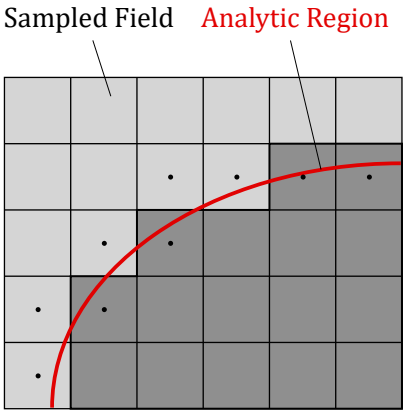


Figure 708. *Effect if an elliptic optimization region (red) is applied on a sampled desired output field (gray). Only the dark gray sampling points constitute the actual optimization region because their center is within the ellipse.*

98.2 Design Panel

The design panel is for selecting and controlling the transmission design algorithm.
When saving a transmission design document, all parameters of the used design algorithms as set in the design panel are stored. In contrast, any logging data is not saved.
The controls within the upper row of the design panel (↪Fig. 709) are described in the following table. The lower part of the design panel depends on the selected design algorithm (see following subsections).

ITEM	DESCRIPTION
Design Method	Combo box for selecting the transmission design method to be used. The available design methods are documented in the following subsections.
Set	After clicking this button, the user is asked to select a transmission function, which will be considered as the current solution of the transmission design problem. This function can be used for selecting a transmission to be analyzed within the Analysis panel (↪Sec. 98.3), or to be set as an initial solution for the chosen optimization algorithm.
Show	Shows a copy of the current solution for the transmission function to be optimized.

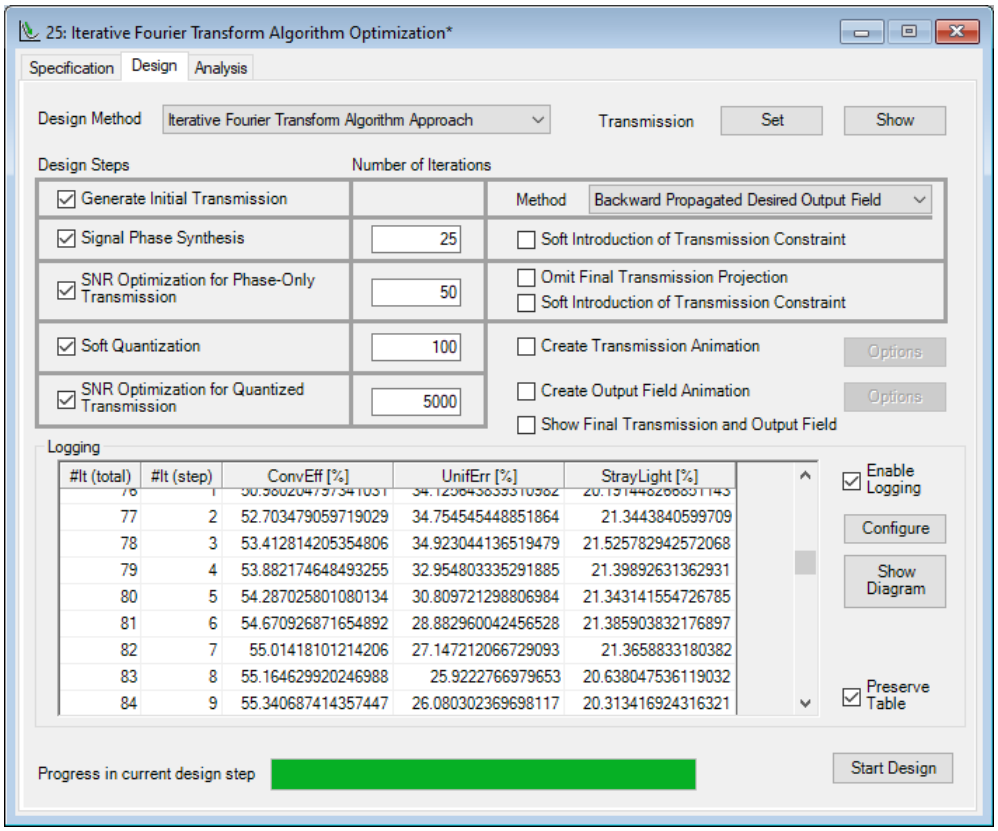


Figure 709. *Design panel of the standard transmission design with iterative Fourier transform algorithm approach selected as design method.*

98.2.1 Iterative Fourier Transform Algorithm Approach

IFTA iteration has to begin with some initial transmission $\mathcal{T}_0$ that is created in the so-called initialization step, which has to be chosen according to the considered design problem. For beam splitting designs, $\mathcal{T}_0$ is typically obtained from backward propagation of the desired output field with ideal spot intensities and randomly chosen phases. For beam shaper designs other strategies for choosing $\mathcal{T}_0$ are used. ([AWS97])
VirtualLab Fusion supports the following methods for creating the initial transmission function $\mathcal{T}_0$:

ITEM	DESCRIPTION
Constant 1	Constant initial transmission function $\mathcal{T}_0 \equiv 1$.
Random Phase	The initial transmission $\mathcal{T}_0$ is chosen to have a random phase distribution and the amplitude $\lvert\mathcal{T}_0(x)\rvert \equiv 1$.
Backward Propagated Desired Output Field	The initial transmission is obtained from propagating the *Desired Output Field* backward to the transmission plane. In this operation the phase of the desired output field is not neglected, even if phase freedom is selected (↪Sec. 98.1.5).
Backward Propagated Desired Output Field (Random Phase)	The initial transmission is obtained from propagating the current desired output field with a superimposed random phase backward to the transmission plane.

When using the IFTA, best results are typically obtained by introducing the transmission and signal constraints step by step. In the phase synthesis step, iterations are performed without amplitude freedom. In the subsequent SNR optimization step, amplitude freedom is *switched on* to optimize the signal-to-noise ratio. If

quantization is necessary, one or two further iteration steps are required, which are described in the following subsection.

The rows in the table appearing in the upper part of the design panel (↪Fig. 709) correspond to the design steps explained above. The design steps can be switched on and off by the corresponding check boxes. For the iterative design steps the corresponding number of iterations can be specified in the second column of that table.

The controls within the *Logging* group box are documented in Sec. 98.2.1.1. The following table contains all remaining controls of the design panel as shown in Fig. 709:

ITEM	DESCRIPTION
Soft Introduction of Transmission Constraint	Determines whether the transmission constraint is to be introduced softly by using relaxed projections with projection strength λ linearly increasing from 0 to 1. This option may be useful for avoiding the creation of speckles during the design of beam shapers.
Omit Final Transmission Projection	Omitting the final transmission plane projection can be helpful for examining the impact of the signal plane projection.
Create Transmission Animation	Creates an animation for showing the evolution of the transmission function during the design iterations. Several options are available by the *Options* button (↪Sec. 98.2.1.2).
Create Output Field Animation	Creates an animation for showing the evolution of the output field during the design iterations. Several options are available by the *Options* button (↪Sec. 98.2.1.2).
Show Final Transmission and Output Field	Shows final transmission and output field after the transmission design algorithm has completed.
Start Design	Starts the design algorithm. After this button has been pressed, it turns into a *Stop* button. If you click this button one time, the current iteration is finished and then the design is stopped. If you cannot wait so long, click again on the now *Stop Immediately* button to cancel the design immediately. But then the design is in an inconsistent state and further evaluations on the *Analysis* tab might lead to wrong results. While a design is in progress, the progress bar indicates the progress in the current design step while in the title of the document window the overall progress in percent and an estimation of the remaining calculation time is shown.

98.2.1.1 Logging

Within the logging table, the most important merit functions and some further parameters can be observed during iteration.

ITEM	DESCRIPTION
Enable Logging	By unchecking this option you can turn off the logging completely. This can increase performance, especially in the case of many fast iterations. If this option is checked, at least the total number of iteration steps is logged. When logging is enabled and a design is running, a *Suspend Logging* button is shown which allows to suspend logging for the currently running design. If this button is pressed again, logging continues normally.
Configure	Configure which merit functions and parameters are to be logged (see below). Less merit functions to log result in increased performance.
Show Diagram	Transfer selected columns of the table to a newly created one-dimensional data array with one subset per merit function (↪Sec. 13.4).
Preserve Table	If checked, the contents of the table is not cleared when starting (or continuing) the design by pressing *Start Design*.

The following merit functions and parameters are supported for logging:

ITEM	DESCRIPTION
Iteration Index in Current Design Step	Iteration counter for current design step.
Window Efficiency	The part of the paraxial power of the input field diffracted inside the signal region.
Conversion Efficiency	The part of the paraxial power of the input field diffracted in the part of the signal that is inside the signal region. Noises inside the signal region are ignored.
Signal-to-Noise Ratio	The strength of the signal relative to the noises measured in dB.
Uniformity Error	The maximum deviation of the output field squared amplitude from the signal field squared amplitude inside the signal region.
Relative Zeroth Order Intensity	The squared amplitude of the zeroth order of the output field related to somewhat like the mean value of the intensities of the desired output orders.
Maximum Relative Intensity of Stray Light	The relative maximum intensity outside of the signal region.
Projection Strength	Projection strength parameter λ which may vary due to a softly introduced transmission constraint or during the quantization steps.
Magnitude of Optimal Scale Factor	Amplitude $\lvert\alpha\rvert$ of the optimal scale factor α.
Argument of Optimal Scale Factor	Phase $\arg[\alpha]$ of the optimal scale factor α.
Zeroth Order Efficiency	The part of the paraxial power of the input field diffracted into the zeroth order.

The formulas behind the merit functions are given in Sec. 142.2.

98.2.1.2 Options for Creating Animations

Animations correspond to a sequence of individual bitmap images (↪Sec. 20). The controls of the dialog shown in Fig. 710 determine how these individual bitmap images are created from the given transmissions or output fields.

ITEM	DESCRIPTION
Apply Interpolation	Determines whether the complex amplitude is to be interpolated before it is converted to a bitmap image. The interpolation settings available via the *Options* button are described in Sec. 22.8.1.
Use Twin Image Representation	If checked, each bitmap image is composed of two images side by side, which are created from the same transmission or output field using different color mapping settings (see below).
Edited Image Options	With this item, available if the check box *Use Twin Image Representation* is enabled, the part of the image (left or right) can be chosen for which the options shall be edited.
Color Mapping	The controls within this group are described in Sec. 5.12.

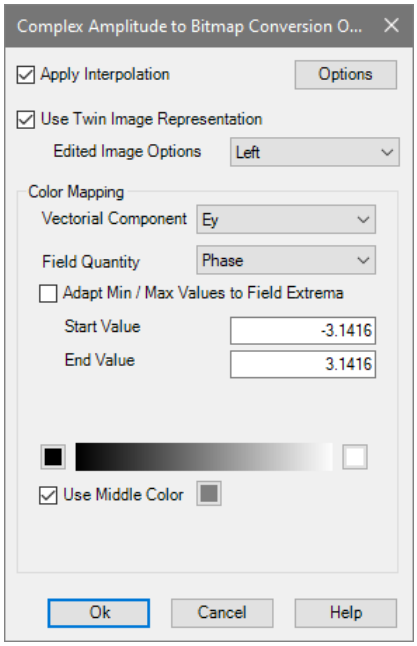


Figure 710. *Settings for generation of animations.*

98.2.2 Geometrical Optics Beam Shaping

This design approach can be used only for designing continuous phase-only transmission functions using phase and scale freedom. Therefore, some of the settings in the specification panel need to have appropriate values. The energy mapping between transmission plane and signal plane can be calculated analytically (i. e. in one non-iterative step) only for one-dimensional problems. In case of two-dimensional design problems one of the following separability types has to be selected:

ITEM	DESCRIPTION
Cartesian Coordinates	Input field, desired output field, and the resulting transmission obey Cartesian separability. For the transmission function $\mathcal{T}(x,y)$ this means that two one-dimensional functions $\mathcal{T}_x(x)$ and $\mathcal{T}_y(y)$ exist, so that $\mathcal{T}(x,y) = \mathcal{T}_x(x)\,\mathcal{T}_y(y)$.
Rotational Symmetry	Input field, desired output field, and the resulting transmission are rotationally symmetric. For the transmission function $\mathcal{T}(x,y)$ this means, that a one-dimensional function $\mathcal{T}_r(r)$ exists, so that $\mathcal{T}(x,y) = \mathcal{T}_r(r)$, where $r = \sqrt{x^2+y^2}$.

98.3 Analysis Panel

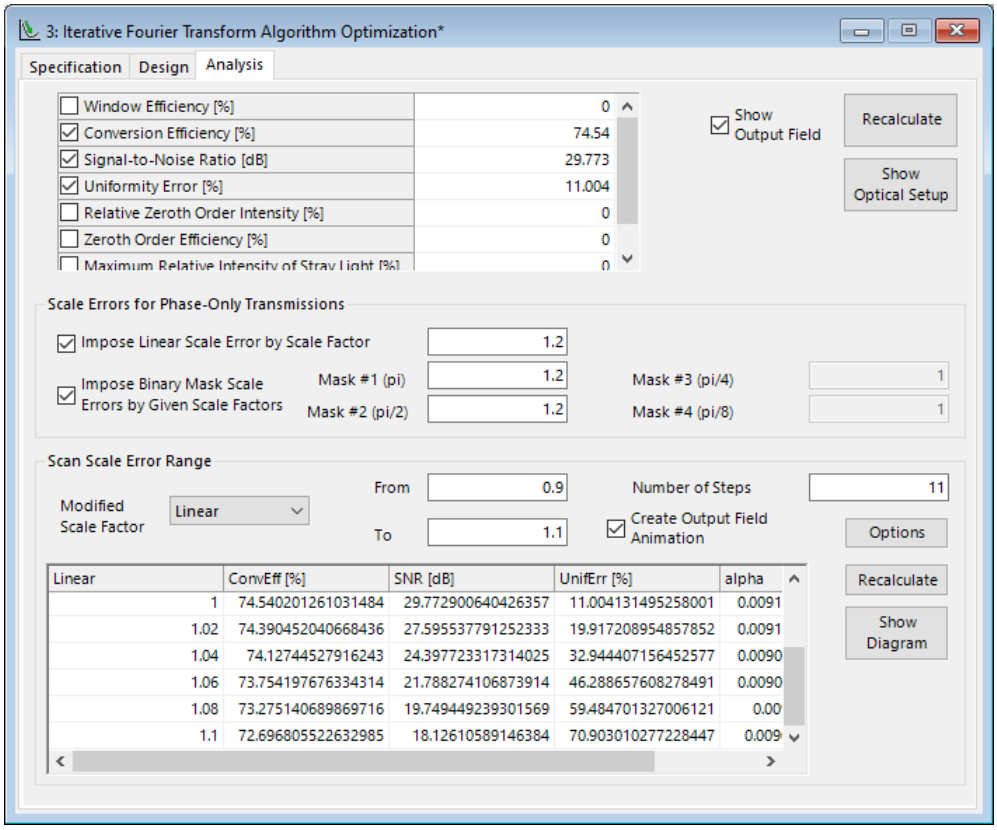


Figure 711. *Analysis panel of the standard transmission design.*

The analysis panel (↪Fig. 711) is used for analyzing the current solution of the transmission design problem. It supports the following features:

- Calculation of common merit functions (↪Sec. 75.6.2),
- Performing tolerancing analyses with respect to linear and binary mask scaling errors (↪Sec. 98.3.2),
- Obtaining the optical setup which is represented by the current solution of the transmission design problem.

ITEM	DESCRIPTION
Show Output Field	Shows output field when recalculating values of merit functions. The output field is calculated under consideration of the scale error values currently set (↪Sec. 98.3.1).
Recalculate	Recalculates merit functions (↪Sec. 75.6.2) which are checked in the table on the left hand side. The merit function values are calculated under consideration of the scale error values (↪Sec. 98.3.1) currently set.
Show Optical Setup	Shows an Optical Setup (↪Sec. 44) which corresponds to the current solution of the transmission design problem.

Note that the shown output field is more or less just a Fourier Transform of the current transmission. It does not include Fresnel effects, non-paraxial distortion effects, diffraction effects; and depending on the *Type of Propagation* set on the *Specification* tab also not the pixelation effect. To see these effects you should use the optical setup created by *Show Optical Setup* or even convert the transmission into a real structure (↪Sec. 99).

98.3.1 Scale Errors for Phase-only Transmissions

By using the thin element approximation [WB91], phase-only transmission functions can be transformed to a corresponding height profile. Within this approximation several error types are equivalent and can be described by the linear scale error γ:

- There are several possible reasons for linear scaling errors of the realized height profile, which can be described by the parameter γ. Examples are wrong etching times, wrong etching rates, or thermal expansion or shrinking effects when using hot embossing.
- Deviations between the actual wavelength λ_{act} and the wavelength λ_{ref} which was assumed during the design cause a linear scale error $\gamma = \lambda_{\text{ref}}/\lambda_{\text{act}}$.
- Deviations between the actual refractive index n_{act} of the structured material and the refractive n_{ref} which was assumed during the design cause a linear scale error $\gamma = n_{\text{act}}/n_{\text{ref}}$.

ITEM	DESCRIPTION
Impose Linear Scale Error by Scale Factor	If checked, the given linear scale error is imposed. A value of 1 corresponds to the ideal case of no scale error. This feature can be used only if the designed transmission is phase-only.
Impose Binary Mask Scale Errors	If checked, the given binary mask scale errors are imposed. This feature can be used only if the designed transmission is phase-only quantized to 2^q levels. The integer q is the number of binary mask steps. The scale errors for the up to four most important binary masks steps, corresponding to phase modulations of π, $\pi/2$, $\pi/4$, and $\pi/8$, can be given. Values of 1 correspond to the ideal case of no scale errors.

98.3.2 Scan Scale Error Range

By using the controls within this group box, basic tolerancing analysis can be performed by modifying the value of a selected scale error within a given range, while all other scale errors keep their value as specified by the controls within the group box *Scale Errors for Phase-Only Transmissions* (↪Sec. 98.3.1).

ITEM	DESCRIPTION
Modify Scale Error	Selection of scale error to be modified. All scale errors that can be entered in the group box *Scale Errors for Phase-Only Transmissions* (↪Sec. 98.3.1) are available for selection.
From	First scale error value to be considered.
To	Last scale error value to be considered.
Number of Steps	Number of values to be considered in the given value range.
Create Output Field Animation	Creates an animation for showing the behavior of the output field during the changing of the selected scale factor. Several options are available via the *Options* button (↪Sec. 98.2.1.2).
Recalculate	Recalculates the table containing the results of the tolerancing analysis. This table contains rows for each considered scale error value and columns for each merit function which is selected in the top left table of the analysis panel. After this button has been pressed, it turns into a *Stop* button to cancel the tolerancing analysis immediately. While an analysis is in progress, in the title of the document window the progress in percent and an estimation of the remaining calculation time is displayed.
Show Diagram	Shows a one-dimensional data array (↪Sec. 13.4) where each subset shows the dependency of one of the selected merit functions from the modified scale error.

98.4 Multiple Runs of the IFTA Optimization Document

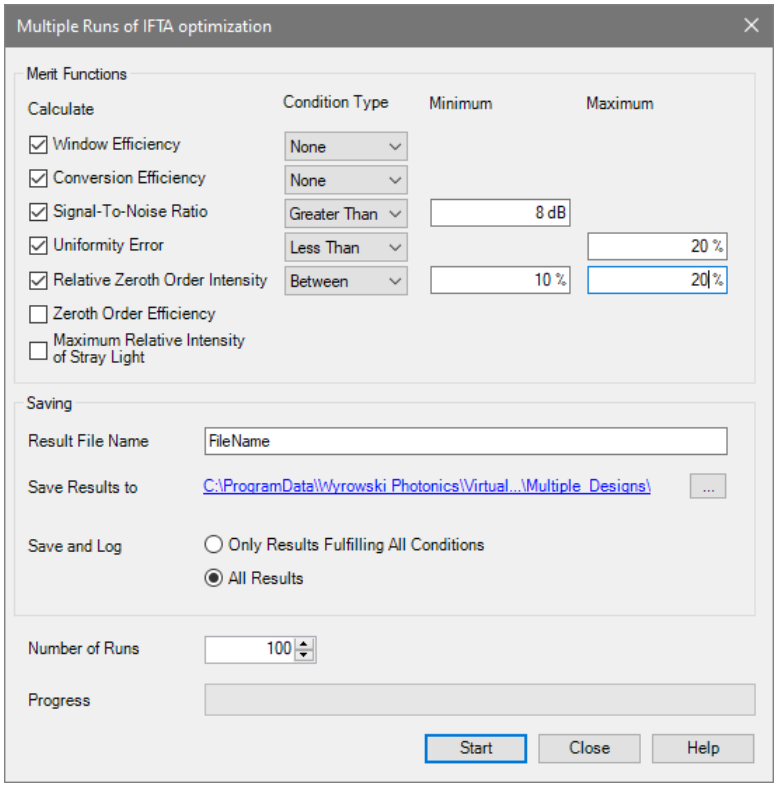


Figure 712. *The dialog to start multiple runs of the IFTA optimization document.*

Via the ribbon item IFTA Optimization > Multiple Runs you can run the currently open IFTA optimization

document multiple times which is useful if the IFTA design starts with a random phase. After completion of each run the resulting merit functions are being calculated and logged to a file in *comma separated value* (CSV) format. Furthermore, the resulting transmissions are saved into the same folder as the CSV file.
In the upper part of the corresponding dialog (↪Fig. 33.1) you can configure which *Merit Functions* are logged to the CSV file. For each merit function you can set up three different kinds of conditions:

- *Between*: The merit function must be between the given *Minimum* and *Maximum* value.
- *Less Than*: The merit function must be less than the given *Maximum* value.
- *Greater Than*: The merit function must be greater than the given *Minimum* value.

The *Saving* group box allows the following settings.

ITEM	DESCRIPTION
Result File Name	The file name used for the resulting transmission and the summary CSV file. For the transmissions, to this file name the run number is appended. For the summary file, *Summary* is appended as well as the date and time in brackets. Keep in mind that characters like '*' and '?' are not allowed in file names.
Save Result to	The path where the results are stored. It can be changed with the ...-button. If you want the results to be shown in the Windows Explorer you can click on the path label.
Save and Log	You can choose whether *All Results* or *Only Results Fulfilling All Conditions* are saved as transmission files and logged into the CSV file. If all results are saved, the CSV file has an extra *Conditions* column indicating whether the design *passed* all conditions or whether at least one condition *failed*. Furthermore, *passed* and *failed*, respectively, is appended to the file names of the transmissions.

In the bottom of the dialog you can specify the *Number of Runs*.
If you click on the *Start* button it turns into a *Stop* button and no further settings are allowed. Clicking on *Close* simply closes the dialog and stops the simulations.

98.5 Preparing the Desired Output Field

The following ribbon items allow you to set a specific *Desired Output Field*.

ITEM	DESCRIPTION
IFTA Optimization > Regular Beam Splitter Pattern	↪Sec. 98.5.1
IFTA Optimization > Sinc Compensation	Allows you to select a harmonic field via a dialog. Then the sinc modulation due to pixelation is compensated (↪Sec. 144.1.2) and the resulting field is inserted as *Desired Output Field*. If you want to see a copy of the resulting field, simply check *Show Resulting Field*.

98.5.1 Preparation of the Desired Output Field for Regular Patterns

By this dialog the desired output field can be set up for design of regular beam splitters, that is

- All signal orders have equal intensity,
- The signal orders are equidistant, and
- The signal orders are centered around the optical axis.

ITEM	DESCRIPTION
Number of Signal Orders	Number of signal orders in x- and y-direction. This number must not be larger than the number of sampling points within one period of the transmission function as set in the specification panel (↪Sec. 98.1).
Even Orders Missing	This can be applied if the desired output orders have got even splitting ratios. By checking this option a symmetric signal order configuration is achieved, where only odd output orders are used for signal orders. If this option is not checked, all signal orders are consecutive. If the desired output field has an odd number of orders in one direction and an even number in the other direction, this symmetrization is only done for the “even” direction (↪Fig. 713).

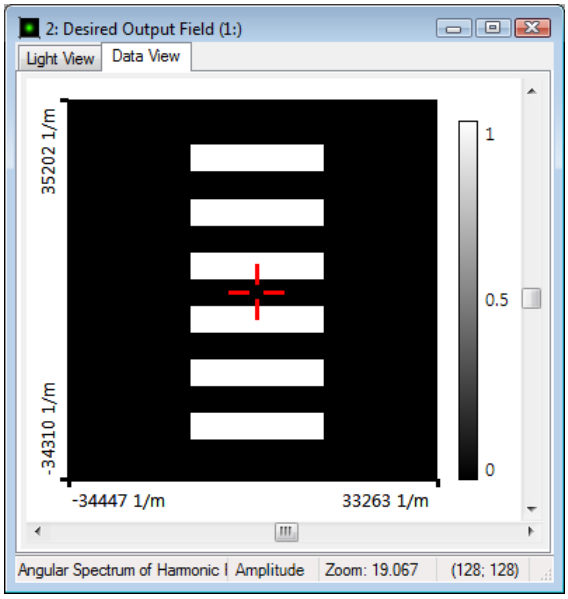


Figure 713. *Desired output field with 5 × 6 orders and* Even Orders Missing*. As you can see, it is symmetric to the point* $(0; 0)$ *marked with a cross.*

99 Structure Design

A Jones matrix transmission – e. g. calculated by the standard transmission design of VirtualLab Fusion – has the additional ribbon item Design > Structure Design. It opens the structure design dialog which allows you to calculate a pixelated surface profile from this transmission using the thin element approximation [Goo68]. This means the surface profile height is proportional to the phase values of the transmission.

Smooth or micro-structured surfaces with or without discrete height steps can be created. The calculated surface profile is returned as a Sampled Surface (↪Sec. 36.2.11). This Sampled Surface is then placed in a Microstructure Component (↪Sec. 61.1) which is either added to an existing or a new Optical Setup.

If the transmission is periodical, then the resulting Sampled Surface is periodized accordingly.

The edit dialog of the structure design consists of three tab pages. Each tab page contains a selection of parameters for the structure design. The following tab pages are available:

1. *Target*
2. *Optical Setup*
3. *Surface Parameters*

The subsequent sections describe the setting entries on each tab page.

99.1 Target

On the first page of the structure design dialog, the user can specify the target of the structure design. Fig. 714 shows the first page of the structure design dialog. The following targets can be selected:

ITEM	DESCRIPTION
New Optical Setup	The output of the Structure Design can also be a *New Optical Setup*. You can adapt the generated Optical Setup to make further simulations. (e. g. tolerancing).
Add to Existing Optical Setup	You can also add the generated Real Components to an existing Optical Setup.

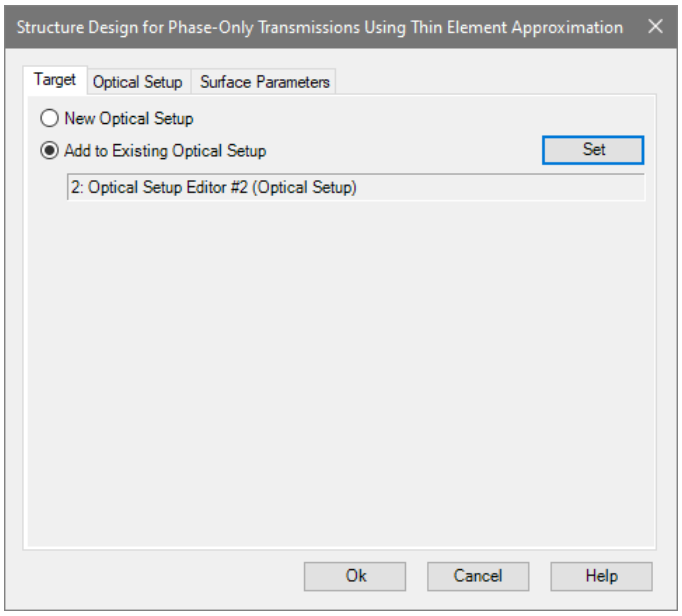


Figure 714. *Target page of the structure design edit dialog*

99.2 Optical Setup

The resulting structure can either work in a transmission or a reflection *Setup*.
If you select *Height Profile of Transparent Plate* you obtain a transmission setup consisting of two components: a Curved Surface (↪Sec. 59.1) with the front surface and the Microstructure Component. In this setup you have the following settings.

ITEM	DESCRIPTION
Substrate Medium	The medium between the two surfaces. The controls are described in Sec. 34.1.
Surrounding Medium	The medium behind the microstructure. The controls are described in Sec. 34.1.
Thickness of Substrate	The distance between the two surfaces.
Wavelength	The vacuum wavelength for which the phase function shall be translated into a height profile.

If you select *Height Profile of Mirror* you obtain a reflection setup containing only the Microstructure Component. In this setup you have the following settings.

ITEM	DESCRIPTION
Substrate Medium	The medium between behind the microstructure. This medium always consists of the Ideal High Reflectance Material.
Surrounding Medium	The medium in front of the microstructure. Only used for the calculations of the heights in the microstructure. The controls are described in Sec. 34.1.
Wavelength	The vacuum wavelength for which the phase function shall be translated into a height profile.

Fig. 715 shows the *Optical Setup* page of the structure design in case of *Height Profile of Transparent Plate*.

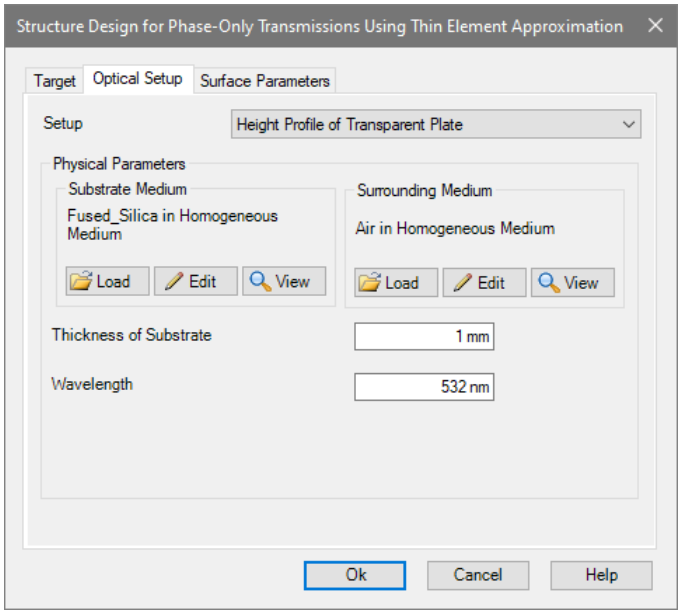


Figure 715. *Settings for optical setup parameters of the structure design edit dialog.*

The refractive index of the substrate medium must not be equal to the refractive index of the surrounding medium. Otherwise an error message is shown and the dialog is locked. The shown error message can be seen in Fig. 716.

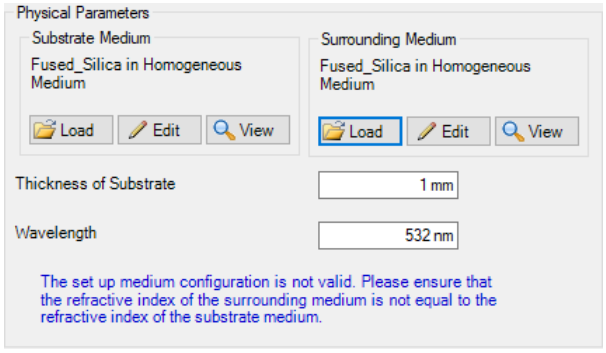


Figure 716. *Error message which is shown when the user sets up surrounding medium and substrate medium which are not valid. The dialog is also locked.*

99.3 Surface Parameters

Fig. 717 shows the *Surface Parameters* tab page of the structure edit dialog.

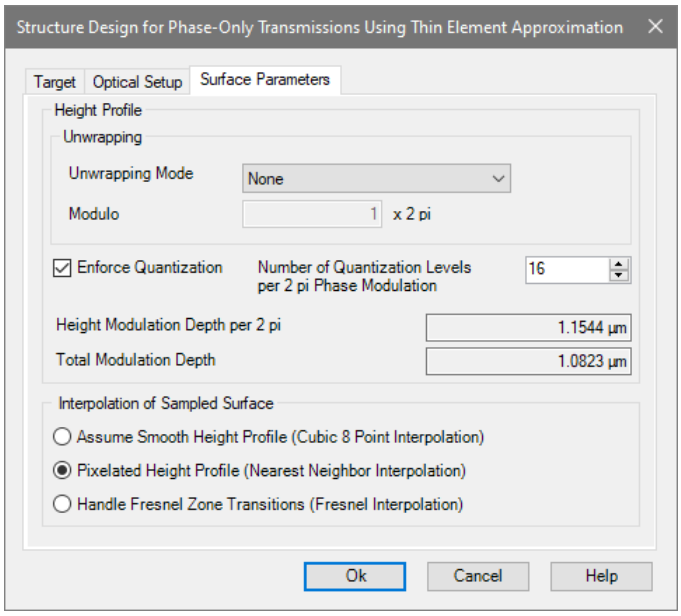


Figure 717. *The user can specify the parameters of the optical surface which shall be calculated from the given phase function.*

The *Surface Parameters* tab has the following entries:

ITEM	DESCRIPTION
Unwrapping	Allows the complete or partial unwrapping of the phase in order to generate a smooth surface profile with heights larger than the height equivalent to 2π. For the unwrapping a line by line unwrapping method is used. The transmission should not contain phase dislocations. The following selections are possible: *None* – no unwrapping. *Partially (Neglecting Spherical Phase)* – a partial unwrapping without considering the spherical phase factor information. If the unwrapped phase would be larger than the *Modulo*, it is wrapped. *Full (Neglecting Spherical Phase)* – the phase is unwrapped completely without considering the spherical phase factor information. Not available for *File Export*. *Full (Considering Spherical Phase)* – the phase is unwrapped completely while considering the spherical phase factor information. This option should be used if a transmission contains a strongly undersampled spherical phase factor. Not available for *File Export*.
Modulo	The maximum phase value in case of *Partially (Neglecting Spherical Phase)* unwrapping. Only multiples of 2π are supported.
Enforce Quantization	If checked a hard quantization of the transmission is introduced. Enable this to calculate surface profiles with discrete height steps.
Number of Quantization Levels per 2 pi Phase Modulation	The number of quantization levels that should be introduced for discrete height profiles. This parameter is only active if *Enforce Quantization* is checked.
Height Modulation Depth per 2 pi	Displays the profile height corresponding to a 2π phase modulation for the wavelength of the transmission.
Total Modulation Depth	Displays the total profile height. This value is for quantized, not unwrapped surface profiles always smaller than the height modulation depth per 2π.
Assume Smooth Height Profile (Cubic 8 Point Interpolation)	Check this for non-quantized, non-periodic profiles that do not contain jumps, steps, and high frequency variations. Thus, the resulting sampled surface uses cubic 8 point interpolation.
Pixelated Height Profile (Nearest Neighbor Interpolation)	Check this for quantized profiles that are composed of rectangular pixels. Thus, the resulting sampled surface uses nearest neighbor interpolation.
Handle Fresnel Zone Transitions (Fresnel Interpolation)	Check this for profiles containing jumps corresponding to 2π, 4π, ...phase steps. Those profiles should not contain discrete height levels. This parameter is only visible if *Unwrapping* is set to *None* or *Partially (Neglecting Spherical Phase)*. The resulting sampled surface uses a special interpolation which avoids interpolation artifacts at the Fresnel jumps.

100 Beam Shaper Design

Only available in the Diffractive Optics Package.

VirtualLab Fusion offers three possibilities to design a beam shaping element (see table). They can be found in the Beam Shaper Design group of the Start > Diffractive Optics menu of the ribbon.

DESIGN METHOD	DESCRIPTION
"Gaussian → Top Hat" Transmission Design	Allows you to easily solve a subset of beam shaping design problems: transforming a (super-)Gaussian input field into another super-Gaussian top hat using a geometrical optics approach. Only the transmission is calculated which can be converted into a surface by using the structure design (↪Sec. 99). The corresponding dialog is described in Sec. 100.1.
Diffractive Beam Shaper	Opens a session editor for the design of refractive beam shapers. ↪Sec. 100.2.
Refractive Beam Shaper	Opens a session editor for the design of refractive beam shapers. This session editor returns an Optical Setup (↪Sec. 44) with an initial beam shaper component designed by the geometrical optics approach. This component can then be further optimized with the parametric optimization (↪Sec. 103).

100.1 "Gaussian → Top Hat" Transmission Design

The dialog for a "Gaussian → Top Hat" transmission design allows you to easily solve a subset of beam shaping design problems: transforming a (super-)Gaussian input field into another super-Gaussian top hat using a geometrical optics approach. By clicking *OK* you obtain the transmission for transforming the specified *Input Field* into the *Desired Output Field*, and optionally also other *Output* (↪Sec. 100.1.3).
You can select one of the following optical *Setup Type*s:

ITEM	DESCRIPTION
1f-/2f-Setup	The resulting transmission can be used both in a 1f- and a 2f-setup. The *Focal Length* of the lens used in this setup can be given.
Fresnel Setup	The resulting transmission generates the desired output field in the far field. The *Distance* between the transmission and the desired output field can be given.
Angular Spectrum	The desired output field is generated in the far field of the resulting transmission. It is given in angular coordinates.

In principal the used design approach can be used only for *One-dimensional* problems. In case of two-dimensional design problems one of the following *Symmetry* types has to be selected:

ITEM	DESCRIPTION
Rectangular	Input field, desired output field, and the resulting transmission obey Cartesian separability. For the resulting transmission function $\mathcal{T}(x,y)$ this means that two one-dimensional functions $\mathcal{T}_x(x)$ and $\mathcal{T}_y(y)$ exist, so that $\mathcal{T}(x,y) = \mathcal{T}_x(x)\,\mathcal{T}_y(y)$.
Circular	Input field, desired output field, and the resulting transmission are rotationally symmetric. For the resulting transmission function $\mathcal{T}(x,y)$ this means, that a one-dimensional function $\mathcal{T}_r(r)$ exists, so that $\mathcal{T}(x,y) = \mathcal{T}_r(r)$, where $r = \sqrt{x^2+y^2}$.

Depending on the symmetry type, the layout of the dialog changes.

Furthermore the *Setup* tab allows you to specify the *Embedding Medium* the beam shaper is placed in, i. e. you can *Load* a predefined homogeneous medium from the catalog (↪Sec. 33), *Edit* the current medium (↪Sec. 38.3.1) or *View* it with the view described in Sec. 38.2. And you can choose whether you *Design Transmission for Refractive Beam Shaper* or *Diffractive Beam Shaper*. In the latter case an eventual spherical phase is sampled in the transmission.

100.1.1 Setting up Input Field and Desired Output Field

The *Input Field* and *Desired Output Field* tab of the dialog are quite similar. In both tab pages you can set the *Waist Radius* of the field referring to $1/e^2$ of the maximum squared amplitude and the order of the super-Gaussian function (↪Sec. 139.3). An order of two corresponds to a Gaussian function. For the input field you can also specify the *Wavelength* which is also taken for the desired output field.

100.1.2 Setting up the Transmission

The aperture of the transmission can be adjusted with the following settings:

ITEM	DESCRIPTION
Automatic Setting	If checked, a reasonable aperture size of the transmission is determined automatically.
Field Size Factor	This factor is applied to the suggested transmission size computed for automatic setting. A greater factor cuts off less of the input field.
Manual Setting	If checked, the aperture size has to be entered by the user.
Shape	The aperture may be *Rectangular*ly or *Elliptic*ally shaped.
Diameter	Size of the aperture.

The sampling of the transmission can be adjusted with the following settings:

ITEM	DESCRIPTION
Automatic Sampling	If checked, the sampling parameters will be determined automatically.
Manual Sampling	If checked, the sampling parameters have to be entered by the user.
Accuracy Factor	This parameter can be entered for the *Automatic Sampling* mode only. A greater factor increases the number of sampling points.
Sampling Points	In case of *Manual Sampling*, the number of sampling points can be entered here.
Sampling Distance	In case of *Manual Sampling*, the sampling distance can be entered here.
Array Size	Read Only. The size of the resulting transmission.

100.1.3 Output Specification

On the *Output* tab page you can specify that either an Optical Setup is generated by the dialog, containing a light source with the input field and a transmission storing the calculated transmission. Depending on the current *Setup Type* some additional Optical Setup Elements are included needed to obtain the desired output field in the target plane. If the setup type is not *Angular Spectrum* there is also a preconfigured diffractive optics merit functions detector inserted into the Optical Setup.

As alternative or in addition to *Show Optical Setup* the dialog can return input field, transmission, and desired output field as separate field documents.

100.2 Design of Diffractive Beam Shaper

The IFTA optimization document requires setting up input field and desired output field with correct sampling parameters. The sampling parameters of both fields depend on the optical setup and on the distance between the diffractive optical element (DOE) and the target plane. The document shown in Fig. 718 helps you setting up the IFTA optimization document for diffractive beam shapers.

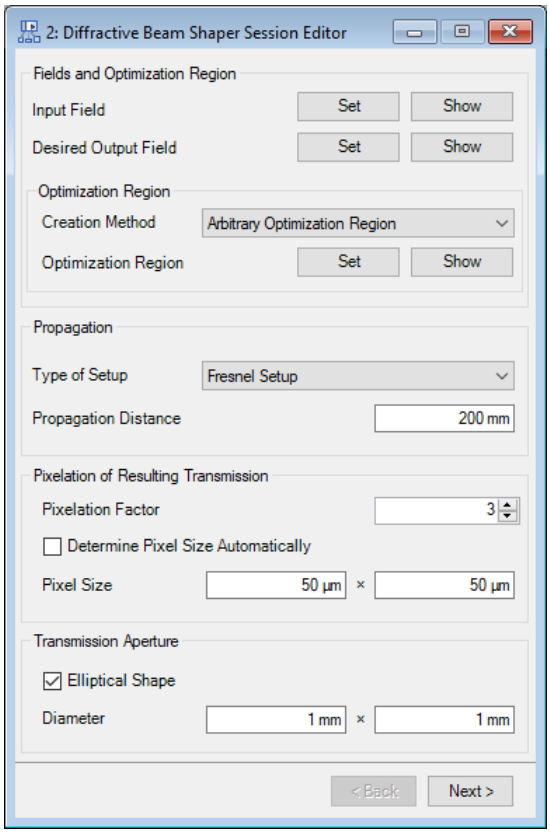


Figure 718. *First page of the document for setting up an IFTA optimization document for diffractive beam shapers.*

The user has to specify at least the *Input Field* and the *Desired Output Field*. The user should make sure before the specification of the desired output field that there is a frame of zero-valued sampling points around the desired light distribution so that the size of the *Desired Output Field* is at least 4 times the size of the *desired light distribution*. Additionally the setup type (*1f-/2f-setup* or *Fresnel setup*) and the distance between the element and the target plane can be specified in the dialog.
Further settings:

ITEM	DESCRIPTION
Optimization Region	The optimization of beam shapers and other diffractive optical elements (DOEs) requires the specification of a so called optimization region which describes an area in the target plane in which stray light will be minimized during optimization. Outside of this area stray light is allowed. If you select *Arbitrary Optimization Region* as *Creation Method*, you can *Set* any already open region document as optimization region. With the option *Create from Desired Output Field* an optimization region will be created containing all parts of the desired output field with amplitude values larger than 10 % of the maximum amplitude. The last option *Equal to Selection in Desired Output Field* means that the optimization region will be generated from the rectangular selection marker (↪Sec. 11.3.4) which was present in the Desired Output Field at the time you have set it into the setup dialog.
Rectangular Pixelation	By checking this check box you indicate that the element designed by the IFTA will contain rectangular pixels after fabrication. In this case the "pixelation effect" (↪Sec. 144.1.2) will be simulated exactly. **This option is only available if the *Optical Setup* is set to *1f-/2f-setup*.**
Pixelation Factor	In case of *Fresnel Setup*, the "pixelation effect" (↪Sec. 144.1.2) cannot be simulated exactly. Thus a *Pixelation Factor* n_{pix} must be set. Consequently, each pixel in the resulting element is simulated by $n_{\text{pix}} \times n_{\text{pix}}$ sampling points. A pixelation factor **This option is only available if the *Optical Setup* is set to *Fresnel Setup*.**
Determine Pixels Size Automatically	If this option is checked, the pixel size in the resulting element is determined automatically, but it is a multiple of the *Pixel Size Increment* of the machine used for exposure of the structures. Alternatively, you can specify an arbitrary *Pixel Size*.
Transmission Aperture	Allows you to set size and shape of the resulting transmission which represents the element.

After specification of the parameters click the *Next* button. A new page will show the sampling parameters of input field, desired output field and DOE transmission. The *Create Optimization Document* button allows you to create the IFTA optimization document. If the optimization is finished, press *Next* again. The correct document should be preset. The *Extract* button generates a new transmission reduced to the *Transmission Aperture* defined on the first page.

101 Cells Array Design

Availability

Toolboxes: Light Shaping Package

Accessible: Optical Setup: Optical Setup > New Cells Array Design

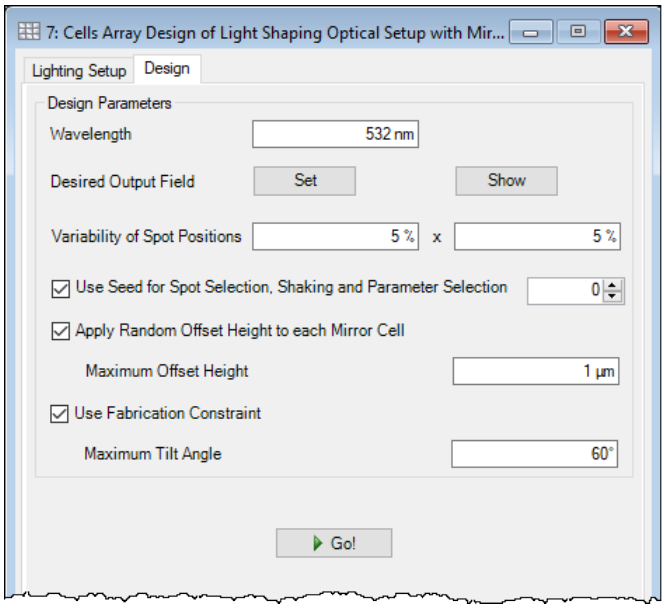


Figure 719. *The* Design *tab of a Cells Array Design document if a Mirror Cells Array is to be designed.*

Using this approach you can design a Cells Array (↪Sec. 41.1) to generate the desired light pattern for a given optical setup. To this end a random position in the light pattern is selected for each cell in the Cells Array and the outgoing direction is calculated from this position and the cell's position. The optical parameters of the cell are then determined so that the cell deflects the incoming light into the outgoing direction.

- For a Grating Cells Array (↪Sec. 41.1.1), Grating Period and Rotation Angle are determined so that the light of the first order is diffracted into the desired direction. A random lateral offset can be used to introduce random phases in the target plane.
- For a Prism Cells Array (↪Sec. 41.1.2), Tilt Angle and Rotation Angle are determined so that the incoming light is refracted into the desired direction. A random offset height can be used to introduce random phases in the target plane. The change in the resulting direction caused by different offset heights is considered correctly.
- For a Mirror Cells Array (= a Prism Cells Array used in reflection), Tilt Angle and Rotation Angle are determined so that the incoming light is reflected into the desired direction. A random offset height can be used to introduce random phases in the target plane. The change in the resulting direction caused by different offset heights is considered correctly.

The number of possible spot positions in the light pattern is taken directly from the sampling of the data defining the pattern. The design algorithm assumes that the light pattern is a binary one, i. e. every pixel with less than half the maximum amplitude is set to zero; all other pixels are set to the maximum amplitude. In this way, every spot position is illuminated by nearly the same number of cells.
A new Cells Array Design can only be created from an existing Light Shaping Optical Setup (↪Sec. 44.11.4). The design document window (↪Fig. 719) has two tab pages. The *Lighting Setup* tab summarizes the most essential parameters of the initial Optical Setup. The *Show Initial Optical Setup* allows you to show the initial Optical Setup again in case it has been closed.
The *Design* tab contains the following controls.

ITEM	DESCRIPTION
Wavelength	The wavelength for which the cells are designed. By default this is the wavelength of the active light source in the Optical Setup.

Set	Allows you to set a data array describing the light pattern in three different ways (see below). It is assumed that the light pattern is centered around the position of the camera detector in the Optical Setup. The data array must contain only one two-dimensional subset.
Set > Load	Loads a data array from a .da file.
Set > Select from Documents	Allows you to select an already open data array.
Show	Shows the current light pattern in a separate data array view (↪Sec. 13.4).
Variability of Spot Positions	If one certain position in the light pattern is illuminated by different cells, they all aim at the very same position. However, if you set a *Variability of Spot Positions* greater than zero the actual spot positions "are shook" around the pattern position. The variability can be set independently for x- and y-direction. The given percentage refers to the distance to neighboring spots. See Fig. 720 for an example.
Use Seed for Spot Selection, Shaking, and Parameter Selection	A Cells Array Design uses random numbers to • define which cell illuminates which position, • how much the actual spot position is altered if *Variability of Spot Positions* is used, and • to select a random lateral shift or offset height (depending on the type of the cells array). Thus the design differs every time you click on *Go!*. If this shall not be the case, you can set a fixed arbitrary seed value with this option.
Apply Random Lateral Shift to Each Grating Cell	ONLY AVAILABLE FOR GRATING CELLS ARRAYS. If checked, a random lateral shift is applied to each grating cell resulting in random linear phases in the target pattern.
Apply Random Offset Height to Each Prism / Mirror Cell	ONLY AVAILABLE FOR PRISM AND MIRROR CELLS ARRAYS. If checked, a random offset height is applied to each cell resulting in random phase offsets in the target pattern.
Maximum Offset Height	ONLY AVAILABLE FOR PRISM AND MIRROR CELLS ARRAYS. If *Apply Random Offset Height* is checked, each cell gets a random offset height between zero and this value. Note that for technical reasons, the resulting offset height of certain cells can be slightly larger than this value.
Use Fabrication Constraint	If checked, you can either specify the *Maximum Tilt Angle* (for Mirror and Prism Cells Array) or the *Minimum Grating Period* (for Grating Cells Array). If this constraint is violated for one cell, the design algorithm tries up to ten times to find another random solution for that cell.
Go!	Starts the actual design. While the design is running, a progress bar is shown. The result is a new Optical Setup containing the designed cells array.

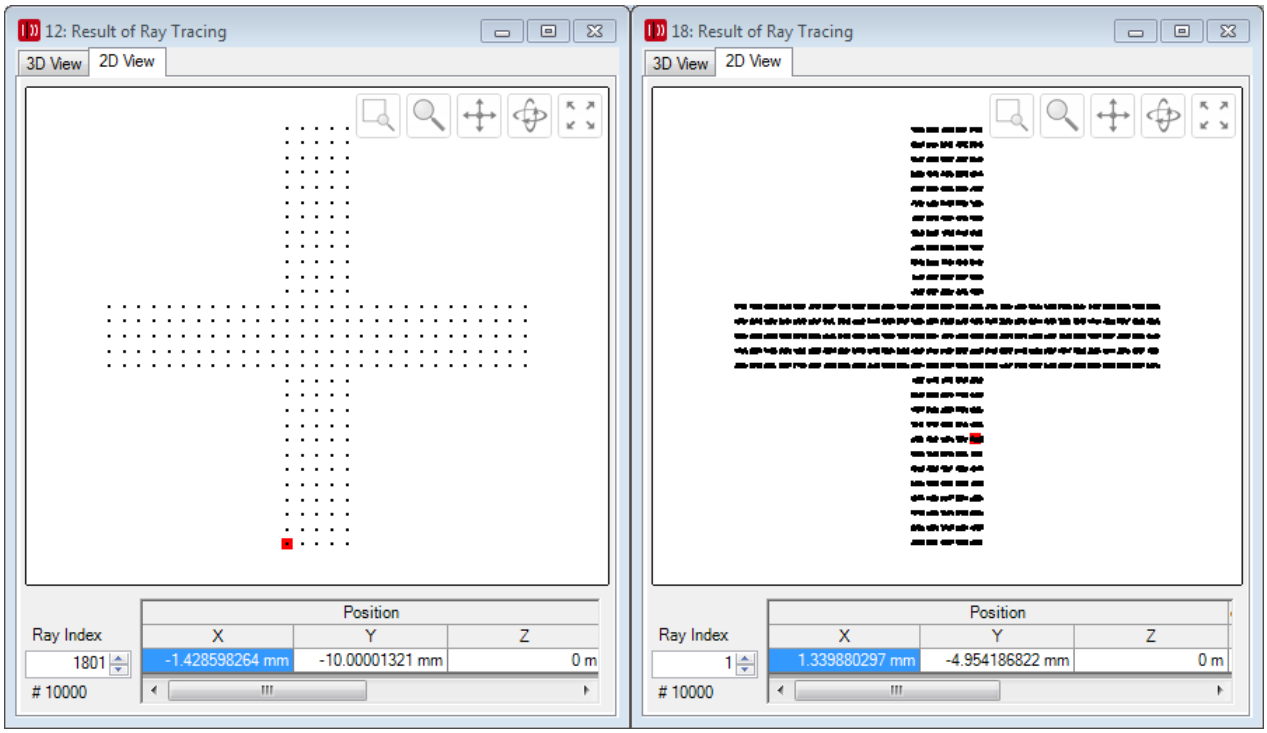


Figure 720. *Two diagrams of the spot positions for different* Variability of Spot Positions. **Left:** *A variability of* $(0\,\%;\,0\,\%)$. **Right:** *A variability of* $(75\,\%;\,25\,\%)$.

102 Design of Light Guides

102.1 Footprint and Grating Analysis

ONLY AVAILABLE IN THE AR/VR/XR PACKAGE.

This design tool allows you to analyze in-depth the footprints at regions in a light guide as well as the performance of gratings with variable grating parameters per grating region. The following workflow can be realized by the provided tool:

1. Select the optical setup you like to use for analysis of footprints and grating performance. The selected optical setup can contain an arbitrary number of light guide components. Per component there can be also an arbitrary number of surfaces in it. And per surface also an arbitrary number of grating regions is supported for the analysis. The active light source within the selected system should be a plane wave, because the tool will adapt the angles defined in the plane wave for the footprint analysis. The plane wave has to be monochromatic.

2. Define a list of field of view angles (Cartesian angles) that should be used for the analysis. The tool allows an arbitrary number of angles to be defined, but at least one angle must be specified.

3. Perform footprint analysis. Here VirtualLab Fusion performs per specified field of view angle an analysis of the underlying setup and evaluates per grating region the positions (footprints) where the light interacts with the gratings. In addition also the direction vectors are evaluated and stored, under which each grating region is illuminated.

4. After the footprint analysis is done, there are several tools to investigate the evaluated information (evaluation by interactive footprint tool, heatmap visualization or access to the raw data).

5. In addition to access to the footprint data, the user has the option to evaluate the performance of gratings per region. This is supported only for regions which contain real gratings. The user can define a value

range for one or two grating parameters per region and VirtualLab Fusion will automatically calculate lookup tables which contain the Rayleigh matrices per incident angle and order. These lookup tables can be also displayed as efficiency curves for different polarization states (note: each grating interaction inside the light guide might change the polarization of the light, which is completely included in the modeling of such a device by physical optics).

6. After all lookup tables are calculated and stored on the hard disc (as 1D or 2D data array) the user can generate a new optical setup, where the grating regions might contain a grating with variable grating parameters (so called grating parameter modulation function; ↪Sec. 43.1.3). By clicking on the corresponding button the user can define the regions which should pre-configured with the corresponding grating parameter variation function. All lookup tables, which were calculated per region, will be stored within the region automatically.

The resulting optical setup can be used for further investigations and optimizations. After configuring the system in that way there is no need to do rigorous analysis of gratings even for a local grating parameter variation, because all information is already stored in the lookup tables. This enables an efficient and performant usage of the system within a parametric optimization.

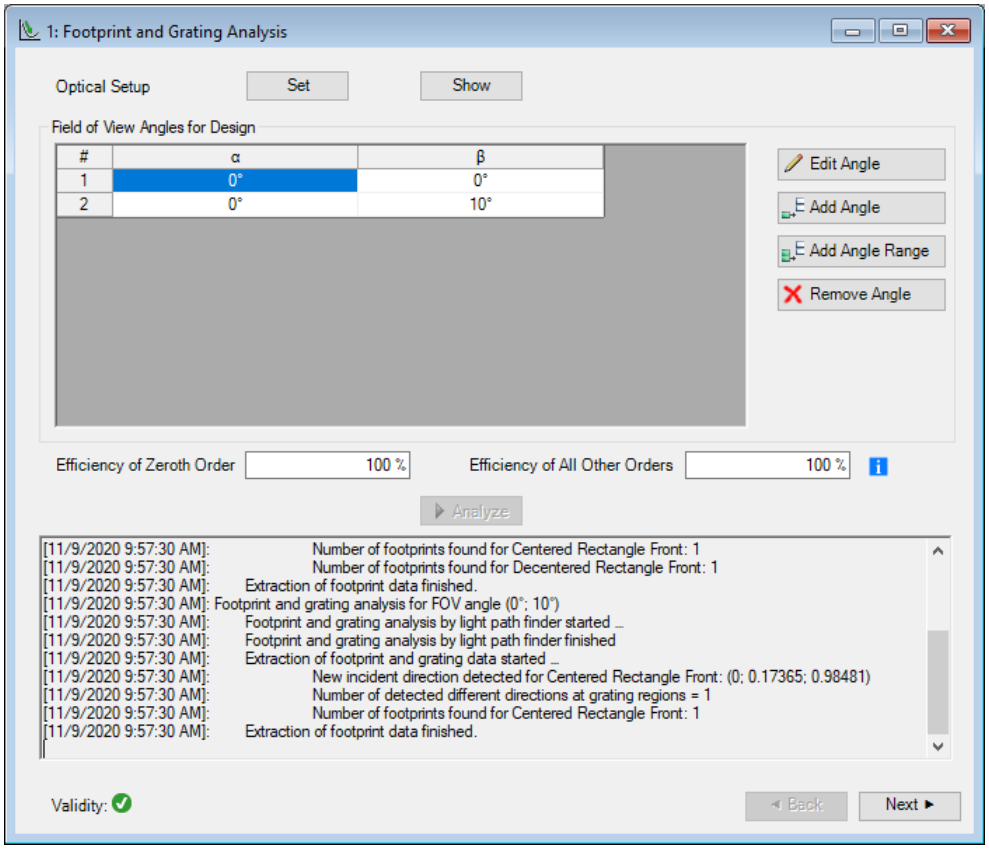


Figure 721. *The first page of the document window for the footprint and grating analysis.*

The corresponding document window consists of two pages. On the bottom you have a *Validity* indicator (↪Sec. 5.11) which shows errors and warnings and gives you hints how to solve these issues.
On the first page (↪Fig. 721) you can configure the following.

ITEM	DESCRIPTION
Set	Allows you to set an Optical Setup either from a document window of VirtualLab Fusion or from file. The Optical Setup must be a Light Guide Optical Setup (↪Sec. 44.11.3) with a Plane Wave light source (↪Sec. 52.2).
Show	Shows the currently set Optical Setup.
Field of View Angles for Design	Allows you to define a set of field of view angles (in Cartesian coordinates) that should be used for evaluation. This table can only be edited via the buttons next to its right side.
Efficiency of Zeroth Order / Efficiency of All Other Orders	By default efficiencies of all gratings orders are set to 100 %. This could lead to long computation times depending on the selected orders and maximum level for the light path finder. Therefore we offer the user to configure the efficiencies of the zeroth order (typically used to distribute the light over an area) and the other specified orders.
▶ **Analyze**	Starts the analysis of the footprints, i. e. the positions (and also direction) where the light hits the gratings. The text box below this button logs the progress of this analysis. When the analysis is running this button becomes a ■ *Stop* button to cancel the analysis. When the analysis finishes this button is disabled. It becomes enabled again when any of the above options changes.

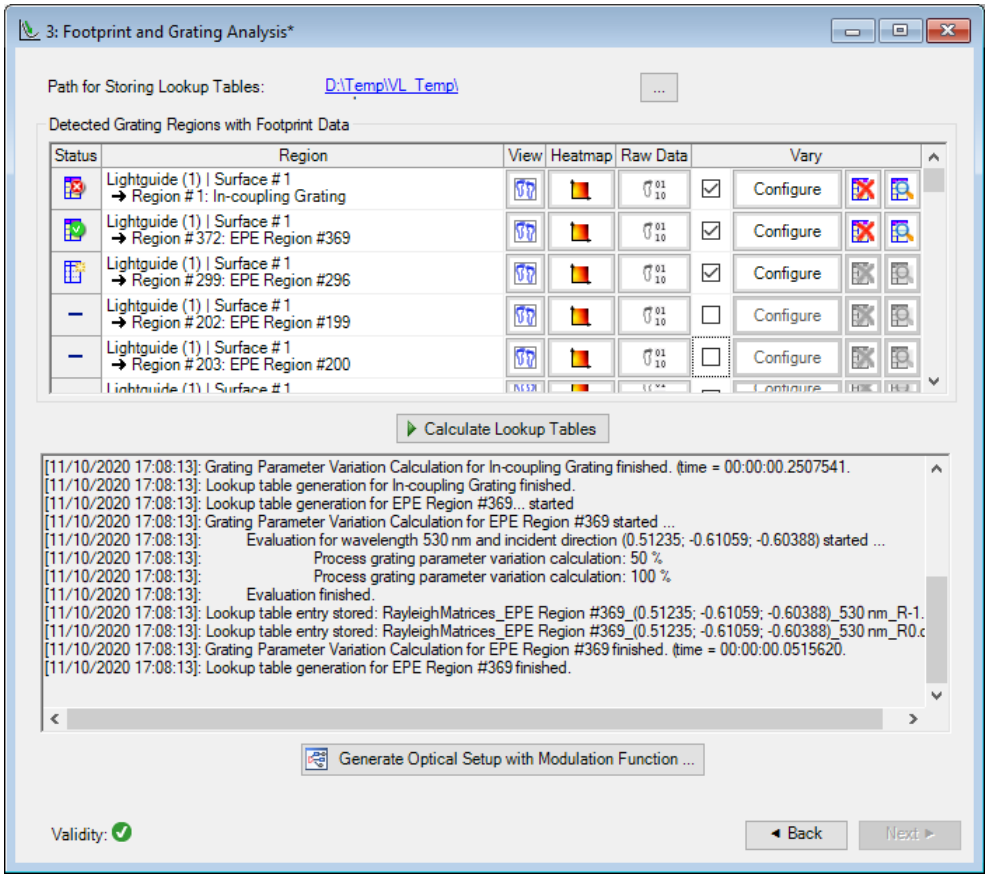


Figure 722. *The second page of the document window for the footprint and grating analysis.*

After the first page is successfully handled the next button will be enabled. The second page of the wizard consists mainly of a table with the following columns.

COLUMN	DESCRIPTION
Status	Shows the status of the *Vary* column at a glance. Fig. 722 shows the four possible states. • The first row in Fig. 722 has invalid lookup tables. They were calculated before, but the current configuration does not match the calculated lookup tables. A recalculation of the lookup tables solves this issue and will be done automatically if you press the Calculate Lookup Tables button. • For the second row a valid lookup table has been calculated. • For the third row a parameter configuration was configured but the corresponding lookup table has not been calculated yet. • For the fourth and fifth row no parameter variation is specified.
Region	The name of the analyzed grating region. ↪Sec. 43.1.
View	Shows the footprints in a separate dialog. ↪Sec. 102.3
Heatmap	Shows the "heatmap" of the region as separate Data Array 2D document.
Raw Data	Shows the raw data for both the footprints and the heat map as set of gridless data arrays.
Vary	This column allows you to define the variation of one or two parameters per grating. So first you have to check the box that you want to vary parameters, then choose the parameter(s) to vary in a separate dialog (↪Sec. 102.4). When then the lookup tables have been calculated with the *Calculate Lookup Tables* button, you can either delete ( ) the results or show them as separate Data Array document (, ↪Sec. 102.1.1). For visualization of the lookup table context, the information of the calculated Rayleigh coefficients is transferred into efficiencies for different polarization states (we show the efficiency for TE, TM, left circular, right circular polarization and unpolarized). Note: The state of polarization will change while the light travels through the light guide and interacts with several gratings.

Besides the table this page has the following controls.

ITEM	DESCRIPTION
Path for Storing Lookup Tables	The tool stores the lookup table information (Rayleigh matrices) in form of 1D or 2D data arrays. During the calculation of the lookup tables the data arrays are stored on the hard disc. The user can define the path, where the lookup tables shall be stored.
Calculate Lookup Tables	Starts the calculation of the selected lookup tables. The text box below this button logs the progress of this calculation. When the analysis is running this button becomes a *Stop* button to cancel the calculation.
Generate Optical Setup with Modulation Function	By pressing this button a dialog is opened, which is described in Sec. 102.1.2. After the dialog is closed with *Ok* an optical setup is generated, which contains pre-configured grating regions with modulated grating parameters according to the parameters defined in the previous dialog.

102.1.1 Select Lookup Tables to Show

This dialog shows a list of all directions and order information for which the lookup tables are already calculated. This information is extracted from the folder defined in the analysis tool. The user can select an arbitrary number of directions and order combination. At least one entry in the table has to be selected to enable the *OK*. After pressing the *OK* button VirtualLab Fusion will generate one data array per selected entry, which shows the efficiency distribution over the define parameter range. The information of the lookup tables (Rayleigh matrix

per grating parameter) will be transferred to efficiency values for different polarization states. Each polarization state is stored as a subset in the generated data array. The efficiency will be calculated for TE, TM, left circular, right circular polarization as well as unpolarized light. Note: The state of polarization will change while the light travels through the light guide and interacts with several gratings, but the visualization for different “standard” polarization states give you already an insight into the performance and the dynamic range of the gratings that are analyzed.[1]

Fig. 723 shows a sample output of the efficiency visualization tool for different polarization states.

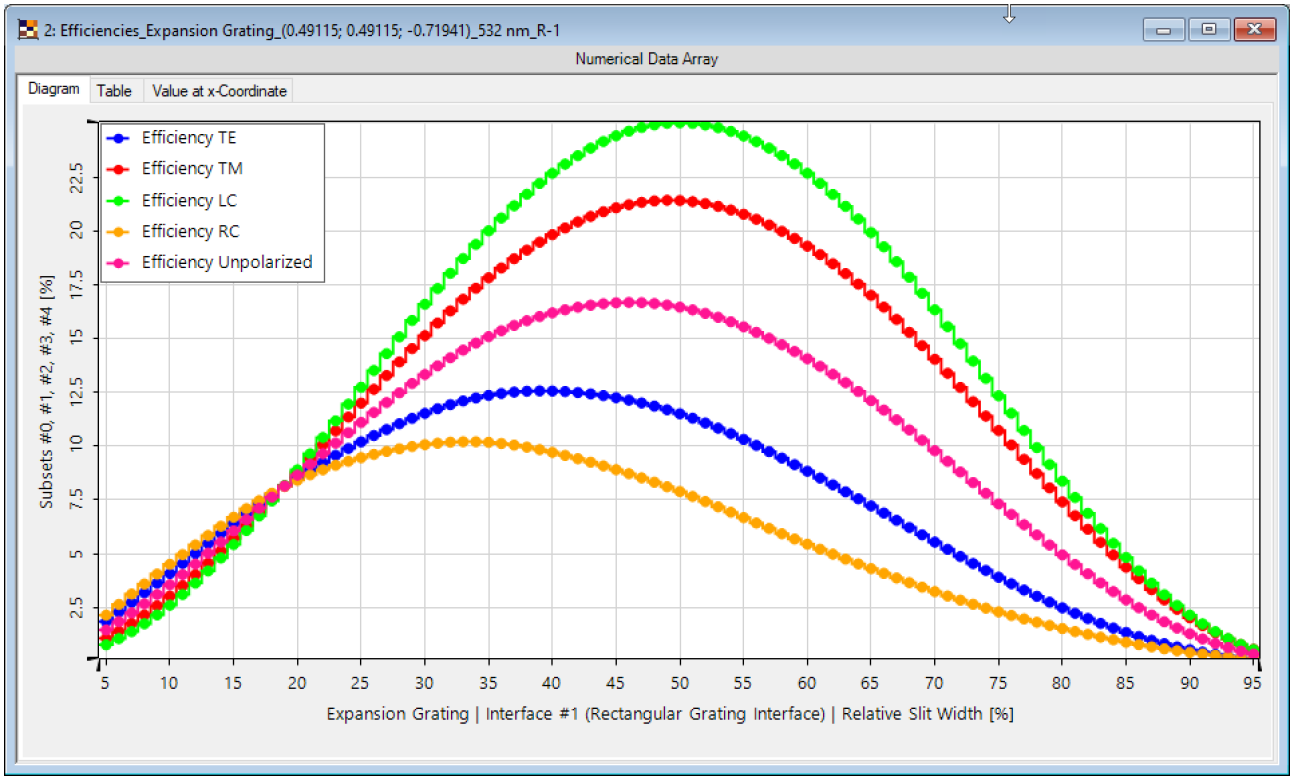


Figure 723. *Sample output for displaying the efficiencies for different polarization states of a 1D grating parameter variation.*

102.1.2 Select & Configure Grating Regions

After the tool has calculated the lookup tables it can be used to generate a new optical setup, where the gratings per region might be modulated. This can be triggered by clicking on the *Generate Optical Setup with Modulation Function* button. A dialog is shown, where the user can configure the parameters used for the pre-configuration of the optical setup.

The dialog is shown in Fig. 724.

[1] This feature was introduced on initiative of Yifeng Gao and Dr. Yuan Chen.

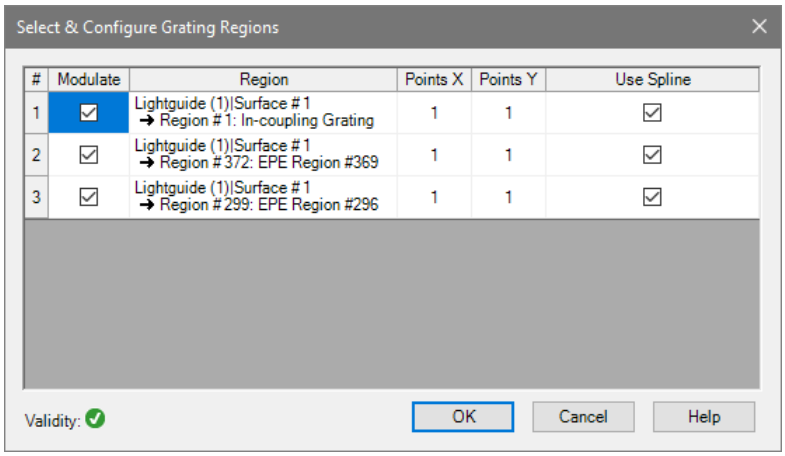


Figure 724. *Dialog to configure the parameters to use for generation of the optical setup with preconfigured grating parameter modulation functions.*

The following parameters can be configured within the table provided in the dialog:

ITEM	DESCRIPTION
Modulate	Select the grating region that should be pre-configured to contain modulated grating parameters.
Region	The name of the grating region. ↪Sec. 43.1.
Points X	The grating parameter modulation function for each function will be initially configured to be a sampled one. The number of points in x-direction can be selected here.
Points Y	The grating parameter modulation function for each function will be initially configured to be a sampled one. The number of points in y-direction can be selected here.
Use Spline	The grating parameter modulation function for each function will be initially configured to be a sampled one. The interpolation of the points can be done by nearest neighbor or spline interpolation. By checking this option, the interpolation method will be set to spline. This can be also changed afterward in the edit dialog of the grating parameter modulation function.

After pressing *OK* a new optical setup will be generated, that contains the configured grating parameter variation function.

102.2 Light Guide Grating Design

Only available in the AR/VR/XR Package.

With the light guide grating design wizard the user is enabled to optimize the grating parameters for a light guide setup including an eye pupil expander (EPE) grating and / or the grating region used for outcoupling. The typical initial starting point is the optical setup generated by the Layout Design Calculator (↪Sec. 114).
Within the wizard the user needs to first select the optical setup which should be used for optimization and identify the regions for incoupling, EPE and outcoupling. The document supports the design of ideal gratings as well as real gratings. For real gratings the wizard allow to select the grating parameters (maximum number 2) for EPE and outcoupling grating to be optimized. Furthermore the user can specify a set of field of view (FOV) angles which should be used for the optimization. Per FOV angle the user specifies the desired outcoupling efficiency in advanced. Several additional options for the EPE grating are provided, as well as a set of control parameters for the algorithm (like caching).
If the design is configured completely, VirtualLab Fusion will perform the optimization per FOV angle with the

desired outcoupling efficiency. Finally the results per FOV optimization are combined to a common solution. For the combination of all subresults a Voronoi algorithm is applied.
The resulting optical setup can be optimized further in a subsequent parametric optimization (↪Sec. 103).

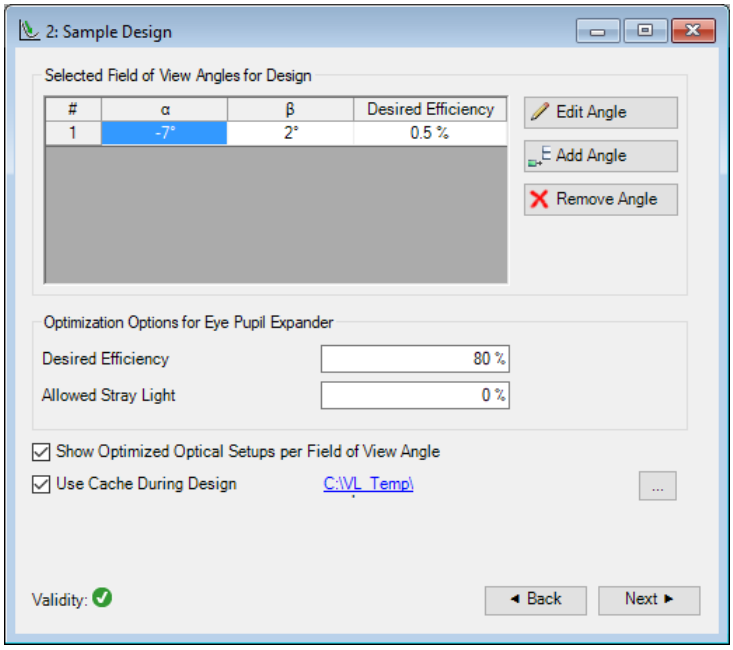


Figure 725. *The document window of the Light Guide Grating Design.*

The document window of the Light Guide Grating Design (↪Fig. 725) is divided into several pages (which are described below). On the bottom you have a validity indicator (↪Sec. 5.11) and buttons to navigate between the pages.
On the first page you have the following controls:

ITEM	DESCRIPTION
Set	Sets the Optical Setup to optimize. When you click on this button you can do the following: • *Load* an optical setup from a file. • *Select from Documents* allows you to select an already open optical setup.
Show	Shows the set optical setup in a separate document window.
Light Guide Component	Defines which element in the optical setup is the light guide to optimize.
Assign Regions	Defines which surface region of the selected light guide has which functionality (*Incoupling Grating*, *Eye Pupil Expander*, or *Outcoupling Grating*).

On the second page the user can select whether you want to optimize *Eye Pupil Expander* and / or *Outcoupling Grating*. For the selected regions you then can choose one or two grating parameters to *Vary* with the control described in Sec. 102.4.
In the upper part of the third page you can define for which (Cartesian) angles of the field of view the design is done. In addition to the field of view angle to use for optimization, the user has to specify a desired outcoupling efficiency. If *Eye Pupil Expander* is set on the second page, you can set *Optimization Options for Eye Pupil Expander* to define its *Desired Efficiency* and the *Allowed Stray Light* inside the eye pupil expander region. Furthermore this page has the following options:

ITEM	DESCRIPTION
Show Optimized Optical Setups per Field of View Angle	If checked for each angle defined in the upper part one optical setup is generated with which you can examine the performance of the optimized light guide for this angle.
Use Cache During Design	If checked you can set a directory into which caching data is written. When you cancel and restart the design this caching data is used whenever possible to speed up the design. If you notice strange behavior during the design, it might be because of inconsistent caching data. In this case simply uncheck this option. By default the *Path for Temporary Files* defined in the Global Options dialog (↪Sec. 6.17) is used.

On the last page you can start the configured design using the *Go!* button. As the design can be time consuming, you can first get an idea of the resulting Voronoi segmentation by clicking *Analyze* which runs much faster.
If you press the *Go!* button after the design has finished and no parameters are changed, just the resulting documents are created anew. If in this case you want to enforce a complete recalculation, click on the *Reset* button first.
Below these buttons there are two tabs. The *Logging* tab shows the progress of the design process. The *Diagrams* tab shows a visualization of the Eye Pupil Expander Region and / or the Outcoupling Region which you can *Configure* by means of the dialog described in the following section Sec. 102.3.1.

102.3 Footprint Diagrams

Footprint diagrams show where the light hits a grating region. For the Light Guide Grating Design (↪Sec. 102.2) they are shown directly in the design document, whereas for the Footprint and Grating Analysis (↪Sec. 102.1) they are shown in a separate dialog.
When you click on *Configure* the dialog described in Sec. 102.3.1 is shown.

102.3.1 Configuring a Grating Layout and Footprint Diagram

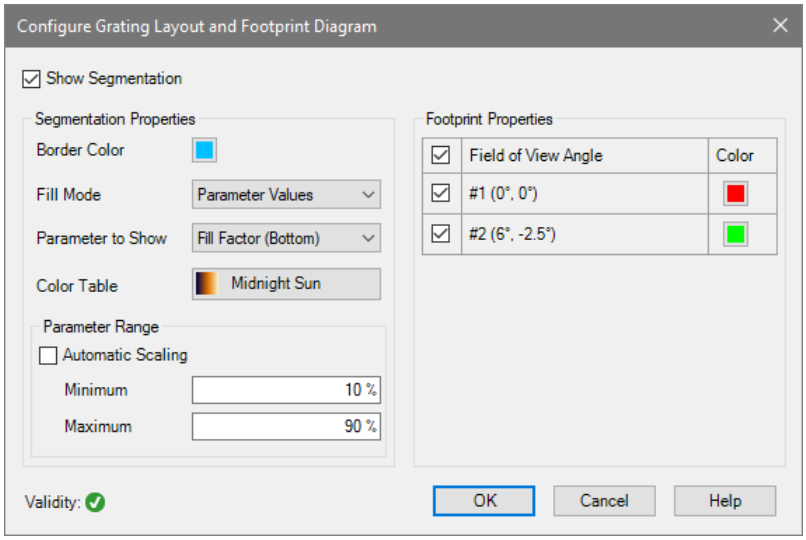


Figure 726. *The edit dialog for configuring a Grating Layout and Footprint Diagram.*

A Grating Layout and Footprint Diagram can be configured by a dialog (↪Fig. 726) with the following settings.

ITEM	DESCRIPTION
Show Segmentation	If you click this option, the Voronoi cells are show in the diagram. Their colors can be adjusted with the *Segmentation Properties* explained below. If this option is not used, you can only define the *Region Border Color* and the *Region Fill Color*.
Border Color	ONLY IF *SHOW SEGMENTATION* The color used to draw the borders of the Voronoi cells.
Fill Mode	ONLY IF *SHOW SEGMENTATION* Determines with which color the Voronoi cells are filled. Three modes are available: • **Footprint Colors:** The Voronoi cells are filled with the color of the corresponding footprint as defined in the *Footprint Properties* box. To ensure a good contrast between the Voronoi cell and the footprint (if shown), you can set the *Opacity of Filling*. • **Constant:** All cells are filled with the same *Fill Color*. • **Parameter Values:** All cells are filled according to the selected grating parameter. The settings for this mode are explained below. This mode is only available after a design was run where at least one parameter was varied in the corresponding region.
Parameter to Show	ONLY IF *FILL MODE* IS *PARAMETER VISUALIZATION* In case two parameters of the gratings are varied, you can select here which of the two parameters is used to determine the color of the distinct cells.
Color Table	ONLY IF *FILL MODE* IS *PARAMETER VISUALIZATION* Depending on the value the *Parameter to Show* has in a certain cell, this cell is filled with the matching color from the set *Color Table* (↪Sec. 11.2.4).
Automatic Scaling	ONLY IF *FILL MODE* IS *PARAMETER VISUALIZATION* If this option is checked, the minimum and maximum color of the *Color Table* are assigned to the minimum and maximum occurring value of the *Parameter to Show*, respectively. Otherwise you can set *Minimum* and *Maximum* according to your liking.
Footprint Properties	The center of the Voronoi cells are those positions where the center of a diffracted light beam enters the region. These positions can be marked by rings (*"footprints"*). This table allows you to select for which *Field of View Angle*s you want to see the footprints (left column, the uppermost check mark allows you to select all / no angles). In the right column you can change the color of the footprints for each angle.

102.4 Grating Parameter Variation

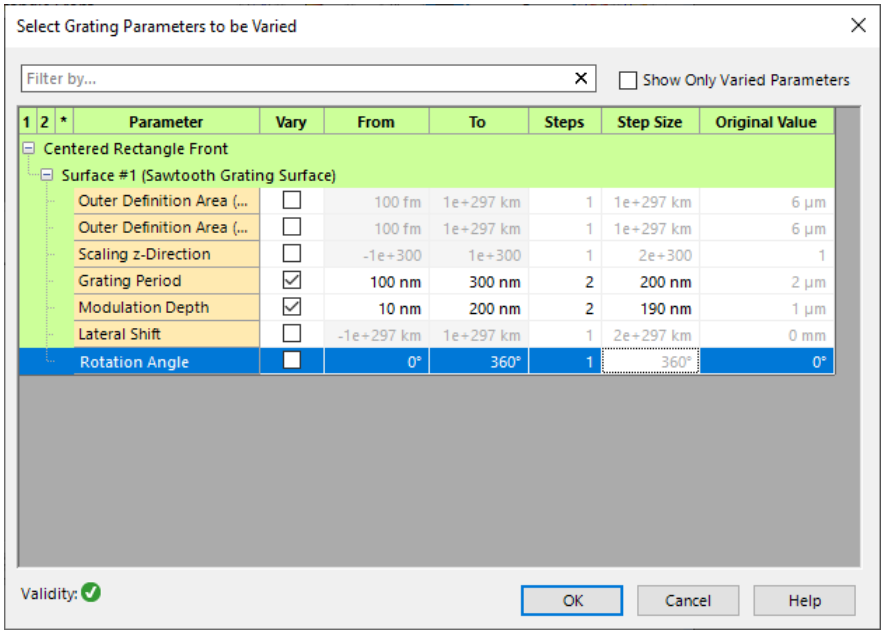


Figure 727. *The control to configure the variation of grating parameters.*

The control shown in Fig. 727 allows you to select one or two grating parameters which you want to *Vary*. For these parameters you can define the value range by setting the start (*From*) and end (*To*) value. The default *From* and *To* values for all parameters are their absolute minimum and maximum values – you must not enter a value outside of this range. It is possible to enter a *To* value which is smaller than the *From* value.
Furthermore you can enter either the number of *Steps* (which are not necessarily identical) or the *Step Size*. The defined value range(s) are then scanned with the resulting number of steps. See Sec. 45.2.3 for details.
The parameters are grouped by region name and then by surface or medium in the stack (↪Sec. 40). The first column allows you to collapse / expand these groups. Simply click on the ⊟ and ⊞ symbols, respectively. At the top of this column you can select to collapse all levels (*1*), collapse only the surface / medium groups (*2*) or expand all groups (*).
The table can be filtered with the following controls. Only rows passing all filters are shown.

ITEM	DESCRIPTION
Filter Table by	All rows containing the given string either in the group descriptions or in the *Parameter* column pass this filter. The matching is case insensitive. It is possible to search for multiple words and word groups embraced by quotation marks, for example: `"surface #1" scaling`.
Show Only Varied Parameters	Only rows where the *Vary* column is checked pass this filter.

103 Parametric Optimization

The parametric optimization in VirtualLab Fusion allows you to optimize optical setups by means of nonlinear optimization algorithms. For that purpose VirtualLab Fusion supports the definition of merit functions that are to be optimized. Merit functions can take into account detector results. Further several types of parameter constraints are formulated as merit functions as well. Finally a common merit function is constructed by a weighted sum of individual merit functions.
Parameters available for parametric optimization are marked with a PV in this manual (↪Sec. 44.6).

Implementation details are given in Sec. 144.2.

103.1 Parametric Optimization Document

The parametric optimization document can be generated for Optical Setups (↪Sec. 44) containing at least one analyzer or one detector linked to the active light source which calculates a fixed number of physical values. For some detectors or analyzers this is only the case in a specific configuration. For example the Grating Order Analyzer (↪Sec. 85) can only be used for Parametric Optimization if at least one of the following conditions is fulfilled:

- *Summed Transmission, Absorption, and Reflection* is checked. Then the *Overall Transmission Efficiency*, the *Overall Reflection Efficiency*, and the *Overall Reflection and Transmission Efficiency* can be optimized.
- *Single Order Output*, but only with *Order Range* as *Selection Strategy*, as only then the number of results is known prior to the Optical Setup simulation.

If the currently active Optical Setup is consistent, a parametric optimization document can be opened via the ribbon item Optical Setup > New Parametric Optimization or the Optical Setup Tool (↪Sec. 44.8) *Create New Parametric Optimization*.
As other documents in VirtualLab Fusion, the parametric optimization document is designed as a wizard. That means the user can switch between the different pages sequentially via the *Next* and *Back* buttons. The appearance of any page may depend on the settings made on preceding pages. All pages are documented in the next sections.
The parametric optimization document can be saved and loaded via the File menu of the main window of VirtualLab Fusion. The ribbon of this document is explained in Sec. 103.1.1.

Handling of Obsolete Parameters

If you load a Parametric Optimization which has been saved in a previous version of VirtualLab Fusion, there might be some obsolete parameters still present in the parameter specification table. On the other hand, newly added parameters might not yet be available.
If no results have been calculated yet, the parameters are updated automatically. Otherwise, updating the parameters would delete the results. Then, only a warning is shown in both the Messages tab (↪Sec. 4.3) and the window title ("⚠ Old Parameters ⚠").
If one of the *varied* parameters changed, the Parametric Optimization cannot be configured and simulated anymore. You can only analyze the results or Refresh the document via the ribbon (which deletes the results).

103.1.1 Ribbon

The ribbon of the Parametric Optimization document has the following entries:

ITEM	DESCRIPTION
Go!	Allows you to start the optimization. Only enabled if you are on the *Optimization Results* page of the document window. During the optimization, the button changes into a Stop button which allows you to stop the calculation.

After Completion	For long running optimizations it can be useful if after completion the Parametric Optimization saves itself and optionally the computer shuts down. This can be defined with this option which is also available in the property browser (↪Sec. 4.3). If the Parametric Optimization has not been saved before it is saved at `{Path for User Settings}\Autosaved Files`. The *Path for User Settings* can be set on the *Saving* tab of the Global Options dialog (↪Sec. 6). Below this combo box the used file name is displayed. **Note that *Save & Shutdown Computer* can lead to data loss if there are unsaved documents but the Parametric Optimization for which this option is set.**
Refresh	Refreshes the document to use the current set of parameters. Note that this deletes existing results. See also the note on handling of obsolete parameters on page 855.
Show Optical Setup	This button has three sub-entries: • **Show Initial Optical Setup:** Shows the Optical Setup from which the Parametric Optimization was originally created. This can be invoked directly if the upper part of the *Show Optical Setup* button is clicked. • **Show Optical Setup for Certain Simulation Step…:** Shows the Optical Setup with the parameters of a certain simulation step which can be selected in a separate dialog. • **Show Optimized Optical Setup:** Shows an Optical Setup with the optimal values of free parameters (that is the values yielding the minimum target function value) and with the start values of the fixed parameters. The start values of fixed parameters usually equal the initial values, but they might also be edited in the *Start Value* column of the constraint table (↪Sec. 103.1.4). If there are two or more simulation steps with the same target function value, the first one is taken automatically.
Logging During Execution	If this button is pressed, the results of the individual simulation steps are written as soon as they are available. Else they are only written after the optimization has finished. This improves performance especially in case of many fast simulation steps. Note that this button is disabled during an ongoing optimization and that it can also be changed via the Property Browser.
Create Output from Selection	If you click this button, for each table row of the current selection a *combined output* is generated, i. e. a separate one-dimensional data array where the data in this row is plotted versus the simulation step. During the output creation, the button changes into a Stop Output Creation button which allows you to stop the calculation. Double clicking on a row header is a short cut for selecting this row completely and clicking Create Output from Selection. It is also possible to generate the combined output out of the current selection via the context menu or the *Create Output from Selection* button of the results table.

103.1.2 Parameter Selection Page

If you change the Parameter Selection page, the results table is cleared.

By clicking *Next* on the welcome page of the document the parameter selection page (↪Fig. 728) is shown.

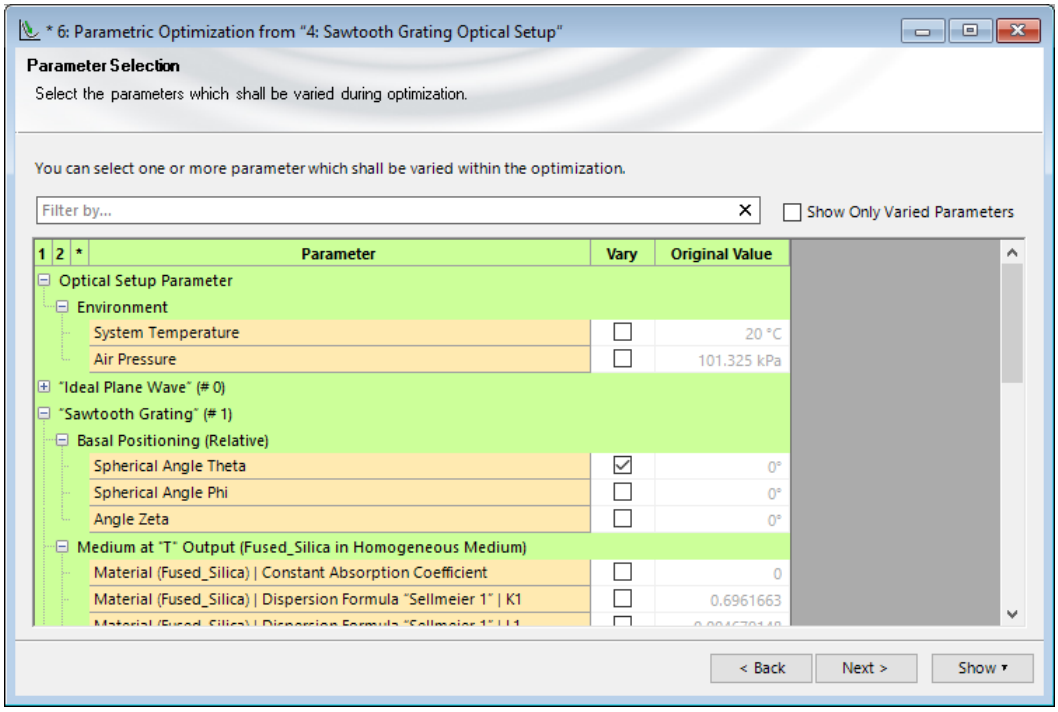


Figure 728. *Parameter selection page of the parametric optimization document. The parameter* Spherical Angle Theta *has been declared as variable for the optimization.*

The table lists all *Parameter*s which may be varied by the optimization algorithm. They are grouped by object (e. g. *"Ideal Plane Wave" (# 0)*) and then by the first category (which can be *{empty}*). The first column allows you to collapse / expand all these groups. Simply click on the ⊟ and ⊞ symbols, respectively. At the top of this column you can select to collapse all levels (*1*), collapse only the category groups (*2*) or expand all groups (*). In the *Vary* column you must check one or more parameters which can be varied during the optimization. All selected rows are checked at once.
For your information also the *Original Value*s of all parameters are given.
If at least one parameter has been checked, the *Next* button is enabled. By clicking *Next* one switches to the detector specification page (↪Sec. 103.1.3).
The table can be filtered with the following controls. Only rows passing all filters are shown.

ITEM	DESCRIPTION
Filter Table by	All rows containing the given string either in the group descriptions or in the *Parameter* column pass this filter. The matching is case insensitive. It is possible to search for multiple words and word groups embraced by quotation marks, for example: `"surface #1" scaling`.
Show Only Varied Parameters	Only rows where the *Vary* column is checked pass this filter.

103.1.3 Detecting Device Specifications Page

If you change the Detecting Device Specifications page, the results table is cleared and the constraints page needs to be updated again.

This page is the same as the corresponding page for the Parameter Run (↪Sec. 45.4) with the following exceptions.

- For a Parametric Optimization, you can only check one out of *Ray Results Profile*, *General Profile*, and *Classic Field Tracing*.
- Only detectors or analyzers which output physical values can be optimized and are thus shown in the corresponding tables. For the same reason, the check boxes *3D View* and *Modeling Analyzer* are disabled.

If the *Next* button is clicked, the constraint specification page will be displayed (↪Sec. 103.1.4).

103.1.4 Constraint Specification Page

If you change the Constraint Specification page, the results table is cleared.

The constraint specification page (↪Fig. 729) lists the constraints (↪Sec. 144.2.1) that have been implicitly defined on the previous pages of the document in a table. By means of that table the user defines the composition of the target function (↪Sec. 144.2.1).

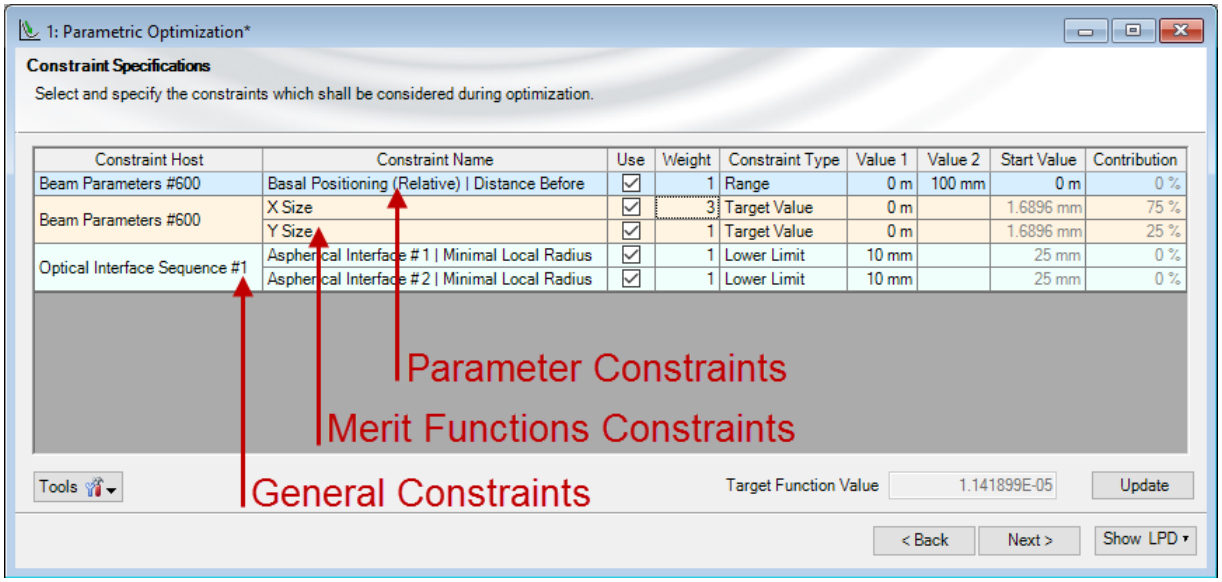


Figure 729. *Constraint specification page containing parameter constraints, merit function constraints and general constraints*

Each row stands for a constraint, whereupon the constraints are sorted into their classes:

1. The parameter constraints are listed with light blue background color. Every free parameter, which was selected on the parameter selection page (↪Sec. 103.1.2), implies a parameter constraint on this page.
2. The merit function constraints appear with light orange color. A merit function constraint is created for each detector merit function that gets evaluated during optimization. Note that the set of evaluated merit functions can be adjusted by editing or enabling/disabling of detectors. This is possible either in the initial Optical Setup or later on the detector specification page of the created optimization document (↪Sec. 103.1.3).

3. If there are general constraints predefined in the Optical Setup, they will be listed with light turquoise background color.

The constraint table consists of the following columns:

COLUMN	DESCRIPTION
Constraint Host	The Optical Setup Element that hosts the parameter(s) or the merit function, respectively, of the constraint. This column is read-only.
Constraint Name	The name of the constraint. This column is read-only.
Use	One can enable or disable constraints via this column.
Weight	Here the constraint weights g_i can be specified for the target function (↪Sec. 144.2.1).
Constraint Type	On this column one specifies the constraint type, which triggers the kind of contribution to the target function. Via clicking on a cell one can choose among *Lower Limit*, *Upper Limit*, *Range* and *Target Value* (↪Sec. 144.2.1.2). *Target Value* is not available for parameter constraints.
Value 1	Here the constraint values corresponding to constraint types *Lower Limit*, *Upper Limit* or *Target Value* or the lower bound of constraint type *Range*, respectively, are entered.
Value 2	If *Range* is chosen as *Constraint Type* the user can enter the upper bound here.
Start Value	Here the user can enter the start values of free parameters for optimization (each free parameter corresponds to a parameter constraint). In case of merit function or general constraints this column lists the merit function or general values, respectively, that correspond to the entered parameter start values. Changing any parameter start value invalidates the merit function or general start values (symbolized via *N/A*). In the case all values can be recalculated by clicking the *Update* button.
Contribution	On this column the relative contribution $\frac{100 g_i \hat{f}_i(s)}{F(\mathbf{x})}$ of a constraint value (s is the *Start Value*) to the target function F is displayed (F and the weights g_i are defined in Sec. 144.2.1, i is the constraint number, $\hat{f}_i$) is defined in Sec. 144.2.1.1. Contribution values will be updated by clicking the *Update* button. If values get invalid, *N/A* is displayed instead. This column is read-only. The overall *Target Function Value* is shown below the table.

Furthermore, the following controls buttons are available below the table:

ITEM	DESCRIPTION
Tools	Opens a menu containing the optimization tools (see below).
Target Function Value	Here the current value of the target function F (Eq. (144.4)) is displayed.
Update	Updates the *Start Value* and *Contribution* column if values got invalid (symbolized via *N/A*).

The following optimization tools are available:

ITEM	DESCRIPTION
Reset Start to Initial Values	Start values of *all* parameters (whether they are currently free or not) will be reset to their initial values that are stored in the initial Optical Setup.
Set Optimized Start Values	Parameter values that were found by the last run of the optimization algorithm (appearing in the last column of the results table [↪Fig. 733]) will be set as start values for another optimization run.
Set Values from Certain Simulation Step	Parameter values from any already calculated simulation step will be set as start values for another optimization run. Via a dialog you can select from which simulation step the values are taken.
Distribute Contributions Uniformly	Weights of constraints with a contribution greater zero will be adapted to get an uniform distribution of contribution.
Set Contribution...	Opens a dialog for setting a new target contribution of a single constraint whereupon the ratio of the other contributions remain unchanged (↪Sec. 103.1.4.1). This command is only available if the current contributions are up-to-date. If not, one has to press *Update* before.
Reset Weights	Resets weights of all contributions to their initial value 1.
Reset All Settings	Resets all constraints to their initial states.

103.1.4.1 Target Contribution Dialog

Via this dialog the user is able to set a new contribution for one of the constraints whose current contributions are unequal zero. To achieve the specified contribution the weights of all constraints will be adapted appropriately.

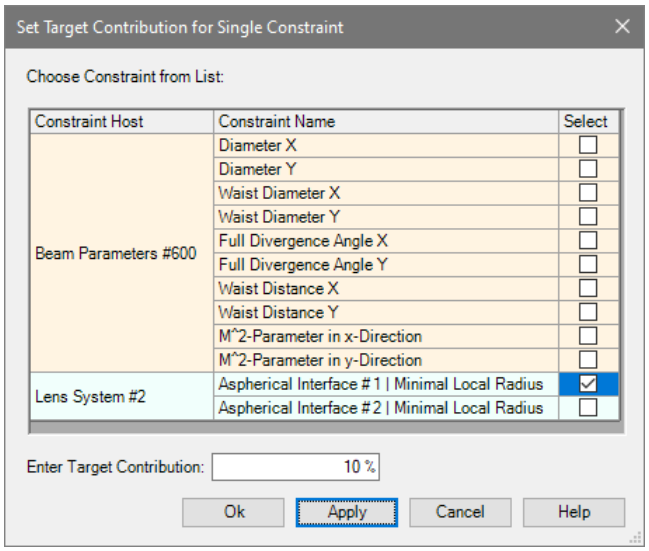


Figure 730. *Dialog for setting a target contribution for a selected constraint*

The available constraints are listed in a table. Like on the constraint specification page of the optimization document (↪Sec. 103.1.4) the constraints are sorted into parameter constraints, merit function constraints and general constraints (each group with different background color). The table has three columns:

ITEM	DESCRIPTION
Constraint Host	The Optical Setup Element that hosts the parameter(s) or the merit function, respectively, of the constraint. This column is read-only.
Constraint Name	The name of the constraint. This column is read-only.
Select	Herewith the user selects the constraint, for that a certain target contribution shall be achieved. There is only a single selection possible.

Below the constraint table the target contribution can be input:

ITEM	DESCRIPTION
Enter Target Contribution	For the selected constraint the current contribution (as shown in the optimization document, too) is displayed. The user can specify the wanted contribution in percent here. Please note that one has to press *OK* or *Apply* to validate the current input. Otherwise, the currently entered value will be forgotten if one selects another constraint.

If *OK* or *Apply* is pressed, the weights of all constraints are recalculated to achieve the wanted contribution for the selected constraint. Thereby the ratios of the other constraint's contributions among each other remain unchanged. The constraint table of the underlying optimization document is updated immediately.

103.1.5 General Settings Page

If you change the General Settings page, the results table is cleared.

On this page general settings concerning the optimization algorithm that is used for minimizing the target function (↪Sec. 144.2.1) can be adjusted.

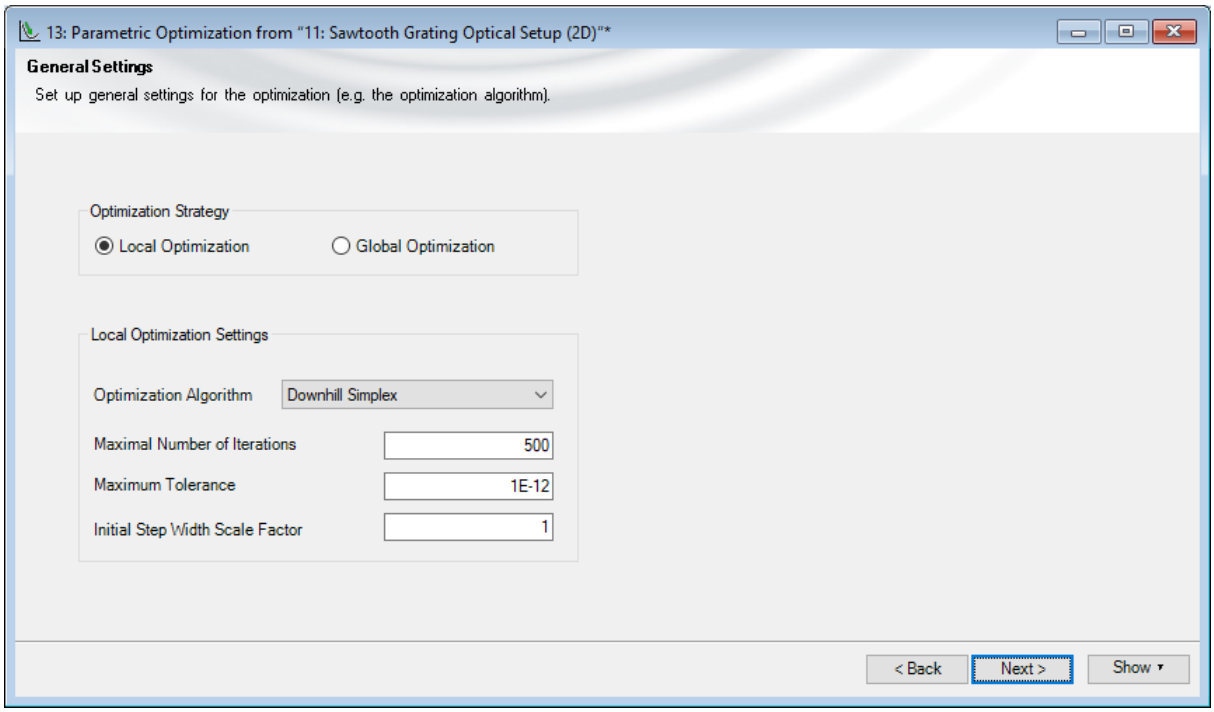


Figure 731. *General settings page of the parametric optimization document*

First of all one should decide on the *Optimization Strategy*:

ITEM	DESCRIPTION
Local Optimization	If selected, one of the local optimization algorithms is applied.
Global Optimization	If selected, the global optimization method of *simulated annealing* (↪Sec. 103.1.5.1) is applied.

Local optimization algorithms are fast but their success in finding the global minimum strongly depends on the choice of the start value – at least for functions that are not strictly convex in the area of interest. Therefore, in cases where no good start values are known, global optimization should be preferred (↪Sec. 103.1.5.1). Currently, three nonlinear local algorithms for minimizing a multivariate function are provided:

- Downhill Simplex method of Nelder and Mead [NM65]
- Powell's method [Pow64]
- Levenberg-Marquardt algorithm [Lev44][Mar63]

The first two methods do not make use of the derivatives of the target function, the third one calculates the derivatives numerically.
For local algorithms the following settings (*Local Optimization Settings*) are available:

ITEM	DESCRIPTION
Optimization Algorithm	Choose one of the three optimization algorithms given above.
Maximal Number of Iterations	Here the maximal number of iterations. The algorithm stops when either the estimated error is less than the *Maximal Tolerance*, or the maximal number of iterations is reached. Please consider that the number of function evaluations is higher than the number of iterations.
Maximal Tolerance	Herewith the stop criterion for the algorithm is specified. The algorithm stops when either the estimated error is less than the specified value $\varepsilon_{\max}$, or *Maximal Number of Iterations* was reached. See Sec. 144.2.2 for the definition of the estimated error.
Initial Step Width Scale Factor	Via this factor the step widths from the start values to the first iteration values of all free parameters are scaled. Thereby the user can control the search area around the start value. The step widths also depend on the constraint types and constraint values of the corresponding parameter constraints.

The iteration process of a local algorithm stops when either the estimated error ε is less than the tolerance $\varepsilon_{\max}$, or the maximum number of iterations is reached.

103.1.5.1 Simulated Annealing

The *simulated annealing* method is based on an analogy from materials science and enables the global search for the minimum by an random *temperature* term t that is added to the current target function value. It is obtained from

$$t = T \log r \,, \tag{103.1}$$

where r is a random value between 0 and 1. T is the temperature, which is gradually decreased according to an *annealing schedule*, which is specified on the *Global Optimization Settings* group box (↪Fig. 732). The selected local optimization algorithm is applied to the adapted target function at each annealing step. Currently, the downhill simplex algorithm is the only possible choice for the applied local optimization algorithm.

The following *Global Optimization Settings* can be specified:

ITEM	DESCRIPTION
Optimization Algorithm	The global optimization method. Only *Simulated Annealing* is available.
Number of Annealing Steps	The number of steps n at which the temperature is evenly decreased by $\Delta T = \frac{T_S}{n}$ to zero. At each annealing step, iteration stops if either the *Maximal Number of Iterations* of the applied local optimizer is reached or if the estimated error is less than the tolerance, but typically this only occurs during the final step, when the temperature is zero.
Start Temperature	Temperature T_S at which the annealing process is started.

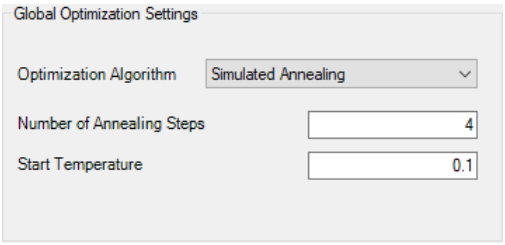


Figure 732. *Group box with global optimization settings. Only visible if* Global Optimization *strategy is chosen.*

For locating the global minimum successfully, appropriate values for *Start Temperature* and *Number of Annealing Steps* must be chosen. Unfortunately, this is something of a trial and error process in most cases. Generally, it is a good idea to do some iterations via a Parameter Run (↪Sec. 45) within the considered parameter range for better understanding the *target function* value range. If the *start temperature* is too low the algorithm will possibly get stuck in the surrounding of a local minimum. On the other hand, temperature values that are too high will increase the probability for "jumping out" of the surrounding of an already detected global minimum.

103.1.6 Optimization Results Page

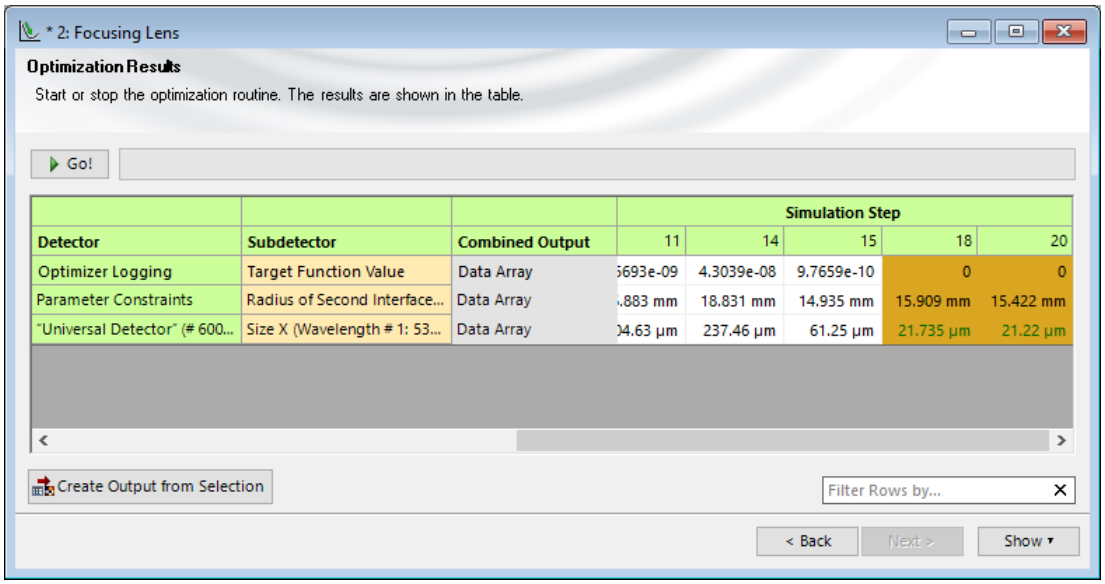


Figure 733. *Optimization results page of the parametric optimization document*

On this page the optimization can be started or stopped via the ▶ *Go!* button or the Parametric Optimization > ▶ Go! ribbon item and one can track the advance in the optimization progress via the results table (↪Fig. 733). The table shows the following information per simulation step:

- The resulting target function value of each simulation step (*Optimizer Logging* row). Sec. 144.2.1 explains how this value is calculated.
- The values of all varied parameters in the *Parameter Constraints* row.
- All enabled general constraints in the *General Constraints* row.
- All enabled merit functions.

Each simulation step, which is equal to an evaluation of the target function by the optimization algorithm, is logged in a new column. Note, that in general the simulation step number does not equal the iteration number. E. g. in *Powell's method* the target function can be evaluated more than 100 times during one iteration [Pow64]. If the optimization algorithm stops or is stopped by the user, the last column will always show the optimized parameters (for which the smallest target function value was obtained).

The appearance and the handling of this page is very similar to the results page of the parameter run document (↪Sec. 45.5), but it has less output options.

You can select a subset of all results by clicking on the column or row headers or by directly selecting a cell range. This selection can be copied to the Windows™ clipboard via the context menu or the shortcut Ctrl+C.

ITEM	DESCRIPTION
Create Output from Selection	If you click this button, for each table row of the current selection a *combined output* is generated, i. e. a separate one-dimensional data array where the data in this row is plotted versus the simulation step. This button has the same functionality as the corresponding ribbon button (↪Sec. 45.1).
Filter Rows by …	Applies a search string to the table. Only rows matching the given string are shown, whereas the following rules apply: • The search is not case sensitive, i. e. `lens`, `Lens`, and `LENS` yield the same results. • It is possible to search for multiple words and word groups embraced by quotation marks. Rows containing at least one of these words or word groups in any of their cells are shown. • A - in front of a word or word group means 'not', e. g. `-lens` shows all lines **not** containing 'lens'. • Expressions in quotation marks are searched as entered. For example ``` ``-2.5'' ``` searches for the number -2.5, not for rows not containing 2.5. And ``` ``Lens System'' ``` searches for rows containing directly "lens system", not for rows containing "lens" or "system".

The following options for the result table are available in the Property Browser (↪Sec. 4.3).

ITEM	DESCRIPTION
Always Plot versus Simulation Step	If you create a combined output of the values in a table row, usually these values are plotted versus the *Simulation Step* (= the column headers). But if there are only one or two parameter constraints and you do not create a combined output for these constraints, then you can choose to plot versus these constraints instead by setting the option *Always Plot versus Simulation Step* in the Property Browser to *False*. ↪Sec. 45.5.1.1
Log Contributions	If this option is enabled, not only the target function (↪Sec. 144.2.1) is logged for each optimization step, but also the contribution of each merit function to it. In this way you can easily recognize when one merit function dominates the optimization process.
Logging During Optimization	Provides the same functionality as the Logging During Execution ribbon item (↪Sec. 103.1.1).
Sort Rows	By default the rows are sorted alphanumerically by the *Detector* and the *Subdetector*. Using this option you can ensure the same order as in the Parameter Selection and the Constraint Specification page is used.
After Completion	For long running optimizations it can be useful if after completion the optimization document saves itself and optionally the computer shuts down. This can be defined with this option which is also available in the ribbon (↪Sec. 103.1.1). If the document has not been saved before it is saved at `{Path for User Settings}\Autosaved Files`. The *Path for User Settings* can be set on the *Saving* tab of the Global Options dialog (↪Sec. 6). **Note that *Save & Shutdown Computer* can lead to data loss if there are unsaved documents but the Parameter Run for which this option is set.**
Automatic Saving	Here you can enable or disable that the document is saved periodically after a certain time interval.
Interval for Automatic Saving	ONLY IF *AUTOMATIC SAVING* IS TRUE. The time interval after which the document is saved automatically.
Number of Digits	The number of digits of the shown values. The default is taken from the *Number of Digits* of the Global Options dialog (↪Sec. 6.5).

103.1.6.1 Additional Information in the Table

If only one parameter constraint is optimized, it might happen that the same parameter value is used in distinct simulation steps. Such duplicate simulations are not shown in the table.
If the optimizer chooses parameters which result in an inconsistent Optical Setup (e. g. negative thicknesses), the target function is set to NaN (an indicator for invalid values). If any of the chosen parameters violates its specified constraints it is marked with red font color. Both such simulation steps can be hidden by setting *Show Only Valid Simulation Steps* in the Property Browser to *False*.
Merit functions where the specified constraint is fulfilled are marked with green font color.
The currently best result(s), i. e. the simulation step(s) with the minimum target function value, are marked with golden background.

104 optiSLang Package

The optiSLang Optimization in VirtualLab Fusion allows you to optimize optical setups with additional optimizing algorithms. Just like Parametric Optimization (↪Sec. 103), in optiSLang Bridge defined merit functions are to be optimized. Merit functions can consider detector results. Many types of parameter constraints are formulated as merit functions as well. Parameters available for parametric optimization are marked with a PV in this manual (↪Sec. 44.6).

104.1 optiSLang Optimization Document

The optiSLang optimization document can be generated for Optical Setups (↪Sec. 44) containing at least one analyzer or one detector linked to the active light source which calculates a fixed number of physical values. For some detectors or analyzers this is only the case in a specific configuration. For example the Grating Order Analyzer (↪Sec. 85) can only be used for optiSLang Optimization if at least one of the following conditions is fulfilled:

- *Summed Transmission, Absorption, and Reflection* is checked. Then the *Overall Transmission Efficiency*, the *Overall Reflection Efficiency*, and the *Overall Reflection and Transmission Efficiency* can be optimized.
- *Single Order Output*, but only with *Order Range* as *Selection Strategy*, as only then the number of results is known prior to the Optical Setup simulation.

If the currently active Optical Setup is consistent, an optiSLang Optimization document can be opened via the ribbon item Optical Setup > Optimize with optiSLang.
As other documents in VirtualLab Fusion, the optiSLang Optimization document is designed as a wizard. That means the user can switch between the different pages sequentially via the *Next* and *Back* buttons. The appearance of any page may depend on the settings made on preceding pages. All pages are documented in the next sections.
The optiSLang Optimization document can be saved and loaded via the File menu of the main window of VirtualLab Fusion. The ribbon of this document is explained in Sec. 103.1.1.

Handling of Obsolete Parameters

If you load an optiSLang Optimization which has been saved in a previous version of VirtualLab Fusion, there might be some obsolete parameters still present in the parameter specification table. On the other hand, newly added parameters might not yet be available.
If no results have been calculated yet, the parameters are updated automatically. Otherwise, updating the parameters would delete the results. Then, only a warning is shown in both the Messages tab (↪Sec. 4.3) and the window title ("⚠ Old Parameters ⚠").
If one of the *varied* parameters changed, the optiSLang Optimization cannot be configured and simulated anymore. You can only analyze the results or Refresh the document via the ribbon (which deletes the results).

104.1.1 Ribbon

The ribbon of the optimization document has the following entries:

ITEM	DESCRIPTION
Go!	Allows you to start the optimization. Only enabled if you are on the results page of the document window. During the optimization, the button changes into a Stop button which allows you to stop the calculation.

After Completion	For long running optimizations it can be useful if after completion the Parametric Optimization saves itself and optionally the computer shuts down. This can be defined with this option which is also available in the property browser (↪Sec. 4.3). If the Parametric Optimization has not been saved before it is saved at `{Path for User Settings}\Autosaved Files`. The *Path for User Settings* can be set on the *Saving* tab of the Global Options dialog (↪Sec. 6). Below this combo box the used file name is displayed. **Note that *Save & Shutdown Computer* can lead to data loss if there are unsaved documents but the Parametric Optimization for which this option is set.**
Refresh	Refreshes the document to use the current set of parameters. Note that this deletes existing results. See also the note on handling of obsolete parameters on page 866.
Show Optical Setup	This button has three sub-entries: • **Show Initial Optical Setup:** Shows the Optical Setup from which the optiSLang Optimization was originally created. This can be invoked directly if the upper part of the *Show Optical Setup* button is clicked. • **Show Optical Setup for Certain Simulation Step…:** Shows the Optical Setup with the parameters of a certain simulation step which can be selected in a separate dialog. • **Show Best Design Optical Setups:** Allows you to select one of setups regarded as *best designs* from optiSLang.
Logging During Execution	If this button is pressed, the results of the individual simulation steps are written as soon as they are available. Else they are only written after the optimization has finished. This improves performance especially in case of many fast simulation steps. Note that this button is disabled during an ongoing optimization and that it can also be changed via the Property Browser.
Create Output from Selection	If you click this button, for each table row of the current selection a *combined output* is generated, i. e. a separate one-dimensional data array where the data in this row is plotted versus the simulation step. During the output creation, the button changes into a ■ Stop Output Creation button which allows you to stop the calculation. Double clicking on a row header is a short cut for selecting this row completely and clicking Create Output from Selection. It is also possible to generate the combined output out of the current selection via the context menu or the *Create Output from Selection* button of the results table.

104.1.2 Parameter Selection and Simulation Engine Selection Page

If you change this page, the results table is cleared.

When you create a new document the parameter selection page (↪Fig. 734) is shown.
The upper part of this page with simulation engine drop down lets you select the simulation engine (↪Sec. 44.5) or analyzer (↪Part XII) that is used for the optimization process. Analyzers can be edited using the *Edit* button.

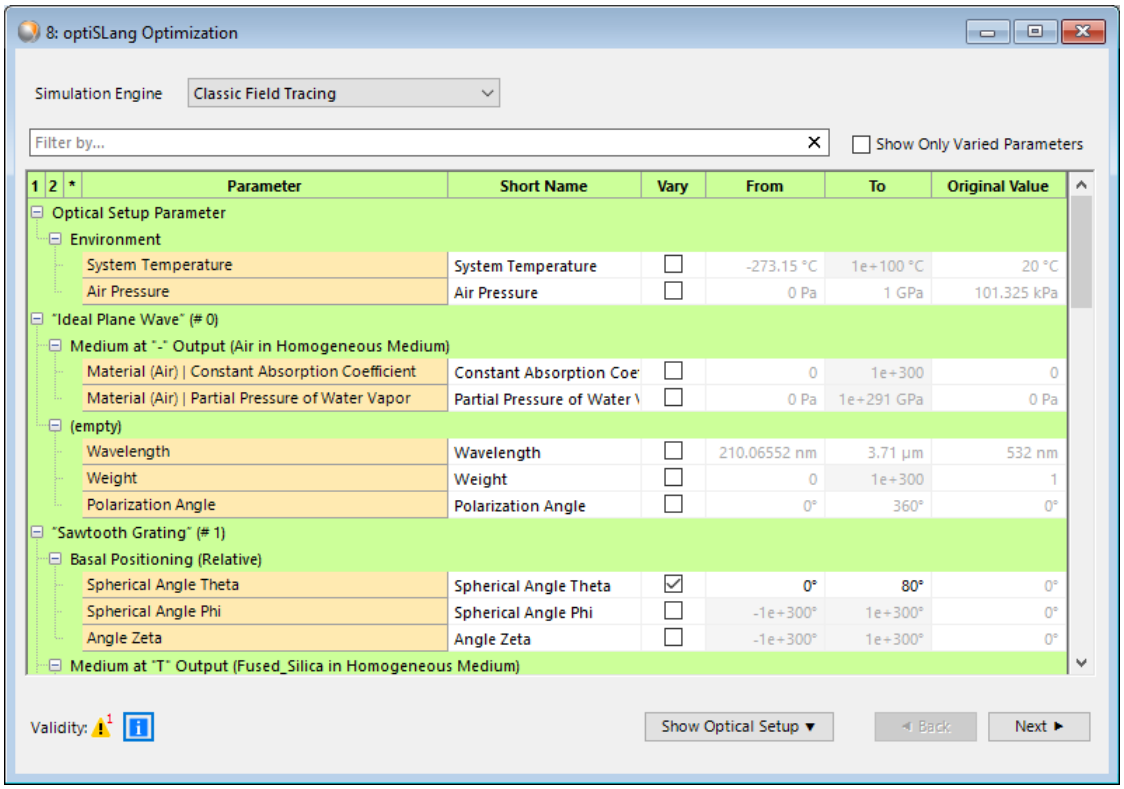


Figure 734. *Parameter selection page of the optiSLang optimization document. The parameter* Spherical Angle Theta *has been declared as variable for the optimization.*

The table in the middle part lists all *Parameter*s which may be varied by the optimization algorithm. They are grouped by object (e. g. *"Ideal Plane Wave" (# 0)*) and then by the first category (which can be *{empty}*). The first column allows you to collapse / expand all these groups. Simply click on the ⊟ and ⊞ symbols, respectively. At the top of this column you can select to collapse all levels (*1*), collapse only the category groups (*2*) or expand all groups (*).

In the *Vary* column you must check one or more parameters which can be varied during the optimization. All selected rows are checked at once.

For the varied parameters you can define the value range by setting the start (*From*) and end (*To*) value. The default *From* and *To* values for all parameters are their absolute minimum and maximum values – you must not enter a value outside of this range. It is possible to enter a *To* value which is smaller than the *From* value.

The *Short Name* of the varied parameters is by default derived from the *Parameter*[1]. However, it must be unique for the varied parameters so you can change it if needed.

For your information also the *Original Value*s of all parameters are given.

The table can be filtered with the following controls. Only rows passing all filters are shown.

ITEM	DESCRIPTION
Filter Table by	All rows containing the given string either in the group descriptions or in the *Parameter* column pass this filter. The matching is case insensitive. It is possible to search for multiple words and word groups embraced by quotation marks, for example: `"surface #1" scaling`.
Show Only Varied Parameters	Only rows where the *Vary* column is checked pass this filter.

[1] For the parameters within a Multiple Light Source (↪Sec. 50) the index of the sub light source is appended to the default short name; for the parameters of a Surface Layout (↪Sec. 41.2) the region index is appended.

If at least one parameter has been checked, the *Next* button is enabled. By clicking *Next* one switches to the constraints specification page (↪Sec. 104.1.3).
A validity indicator (↪Sec. 5.11) shows errors if for example

- the Optical Setup does not have merit functions for the currently selected *Simulation Engine*. This can happen if all detectors are in a state that they cannot be used for the optiSLang optimization, e. g. they are inconsistent or do not calculate physical values in the current configuration,
- no parameter to *Vary* is selected, or
- the value range of one varied parameter is too large .

104.1.3 Constraint Specification Page

If you change the constraint specification page, the results table is cleared.

The constraint specification page (↪Fig. 729) lists the constraints (↪Sec. 144.2.1) that have been implicitly defined on the previous page of the document in a table. By means of that table the user defines the composition of the target function (↪Sec. 144.2.1).

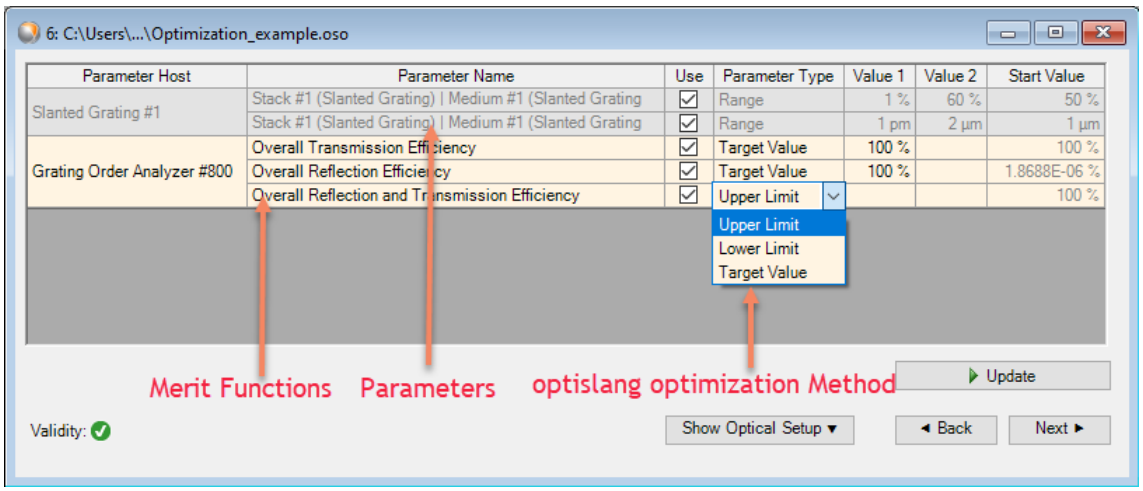


Figure 735. *Constraint specification page containing parameter constraints and merit function constraints.*

Each row stands for a constraint, whereupon the constraints are sorted into their classes:

1. Every free parameter, which was selected on the parameter selection page (↪Sec. 103.1.2), implies a parameter constraint on this page. They are listed with gray background color because they cannot be edited in this table.

2. The merit function constraints appear with light orange color. A merit function constraint is created for each detector merit function that gets evaluated during optimization.

The constraint table consists of the following columns:

COLUMN	DESCRIPTION
Parameter Host	The Optical Setup Element that hosts the parameter(s) or the merit function, respectively, of the constraint. This column is read-only.
Parameter Name	The name of the parameter. This column is read-only.
Use	One can enable or disable merit functions via this column, but not parameters.
Parameter Type	On this column one specifies the constraint type only for merit functions, which triggers the kind of contribution to the target function. Via clicking on a cell one can choose among *Lower Limit*, *Upper Limit*, and *Target Value*.
Value 1	For parameters the minimum allowed value is shown here. For merit functions, the *Lower Limit*, *Upper Limit*, or *Target Value* can be entered here.
Value 2	For parameters the maximum allowed value is shown here. For merit functions this column is unused by OptiSLang Optimization Document.
Start Value	Here the user can see the start values of both parameters and merit functions. The values for the merit functions can be calculated by clicking the *Update* button.

104.1.4 General Settings Page

On this page the optimization algorithm that is used for minimizing the target function can be defined. In the moment only the global optimization method *Evolutionary Algorithm* (EA 10000, ↪Sec. 144.2.3.2) is available.

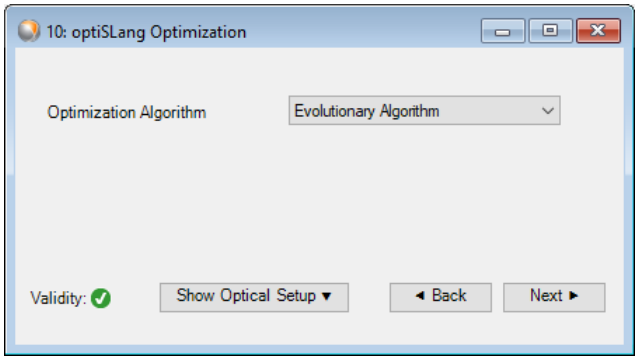


Figure 736. *General settings page of the optiSLang Optimization Document.*

104.1.5 Results Page

On this page the optimization can be started or stopped via the ▶ *Go!* button or the optiSLang Optimization > ▶ Go! ribbon item and one can track the advance in the optimization progress via the results table (↪Fig. 733). The table shows the following information per simulation step:

- The values of all varied parameters in the *Parameter Constraints* row.
- All enabled merit functions.

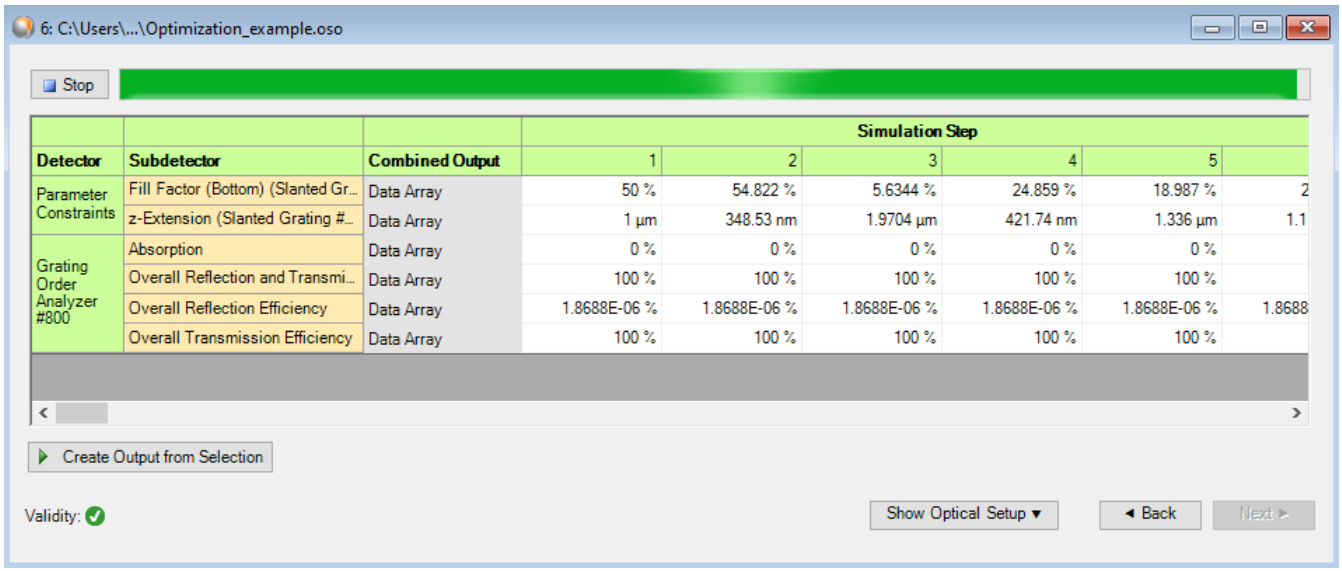


Figure 737. *Optimization results page of the parametric optimization document*

The appearance and the handling of this page is very similar to the results page of the parameter run document (↪Sec. 45.5), but it has less output options. Each simulation done by optiSLang is logged into a new column. You can select a subset of all results by clicking on the column or row headers or by directly selecting a cell range. This selection can be copied to the Windows™ clipboard via the context menu or the shortcut Ctrl+C.

ITEM	DESCRIPTION
Create Output from Selection	If you click this button, for each table row of the current selection a *combined output* is generated, i. e. a separate one-dimensional data array where the data in this row is plotted versus the simulation step. This button has the same functionality as the corresponding ribbon button (↪Sec. 45.1).

The following options for the result table are available in the Property Browser (↪Sec. 4.3).

ITEM	DESCRIPTION
Always Plot versus Simulation Step	If you create a combined output of the values in a table row, usually these values are plotted versus the *Simulation Step* (= the column headers). But if there is only one parameter constraint and you do not create a combined output for this constraint, then you can choose to plot versus this constraint instead by setting the option *Always Plot versus Simulation Step* in the Property Browser to *False*.
Sort Rows	By default the rows are sorted alphanumerically by the *Detector* and the *Subdetector*. Using this option you can ensure the same order as in the Parameter Selection and the Constraint Specification page is used.
After Completion	For long running optimizations it can be useful if after completion the optimization document saves itself and optionally the computer shuts down. This can be defined with this option which is also available in the ribbon (↪Sec. 104.1.1). If the document has not been saved before it is saved at `{Path for User Settings}\Autosaved Files`. The *Path for User Settings* can be set on the *Saving* tab of the Global Options dialog (↪Sec. 6). **Note that *Save & Shutdown Computer* can lead to data loss if there are unsaved documents but the Parameter Run for which this option is set.**
Automatic Saving	Here you can enable or disable that the document is saved periodically after a certain time interval.
Interval for Automatic Saving	ONLY IF *AUTOMATIC SAVING* IS TRUE. The time interval after which the document is saved automatically.
Number of Digits	The number of digits of the shown values. The default is taken from the *Number of Digits* of the Global Options dialog (↪Sec. 6.5).

XV Calculators

VirtualLab Fusion offers various *calculators* which implement formulas and algorithms often used in optics. Usually, they can be found in the *Calculators* menu of the *Start* ribbon.

CALCULATOR	DESCRIPTION
ABCD Law Calculator	Allows you to define a rotationally symmetric optical system and to calculate how a laser beam is altered by this system. The ABCD law is used to this end. ↪Sec. 105
Coherence Time & Length Calculator	Calculates the coherence time and the coherence length for different spectra. ↪Sec. 106
Debye-Wolf Integral Calculator	With this calculator one can easily calculate the field in or near the focus of an ideal lens which is illuminated with collimated light. ↪Sec. 107
Diffraction Angle Calculator	Calculates the diffraction angles for a given period, wavelength and angle of incidence. ↪Sec. 108
Direction Converter	Converts between Cartesian and spherical angles as well as wave numbers and spatial frequencies. ↪Sec. 109
Fiber Mode Calculator	Calculates the (linearly polarized) modes inside an optical fiber. ↪Sec. 110
Fresnel Effects Calculator	Calculates the Fresnel effects at a material transition for different wavelengths and angles of incidence. ↪Sec. 111
k-Layout Visualization	Shows the k-Layout diagram for a given grating setup. Available via the Start > Light Guide ribbon item. ↪Sec. 112
Laser Beam Calculator	A simple calculator which helps you to determine all fundamental parameters of a Gaussian beam from given parameters. ↪Sec. 113.
Layout Design	Creates an optical setup with a light guide fulfilling the given specifications. In particular, the grating regions have the correct positions and sizes. Available via the Start > Light Guide ribbon item. ↪Sec. 114
Memory Calculator	Calculates how much memory a certain field needs (depending on number of sampling points, polarization state, and so on). ↪Sec. 115
Modulation Depth Calculator	Allows you to calculate the modulation depth of a Diffractive Optical Element (DOE) generating a phase difference of 2π. ↪Sec. 116.
Rigorous Analysis of Slanted Gratings	Slanted gratings are an important sub-class of gratings but can be analyzed only inefficiently by the Fourier Modal Method. So this calculator allows you to analyze them by the Integral Method, and for reference also by the Fourier Modal Method. ↪Sec. 117
Spherical Lens Calculator	This calculator can be used for paraxial calculations based on the lens maker's equation as well as on the imaging equation of a spherical lens. ↪Sec. 118
Vector & Coordinate System Viewer	This tool visualizes coordinate system base vectors which are rotated in relation to a reference coordinate system in the 3D space. ↪Sec. 119.

105 ABCD Law Calculator

ABCD matrices give an easy way to describe the transformation of a Gaussian beam in radially symmetric optical systems without limiting apertures. Therefor the complex radius of curvature q of a Gaussian beam is defined as follows:

$$\frac{1}{q(z)} = \frac{1}{R(z)} - i\frac{M^2\lambda}{\pi w(z)^2} \tag{105.1}$$

$R(z)$ is the *Phase Radius* at a certain position z and $w(z)$ is the *Beam Radius* at the same position z. Furthermore, M^2 is the *M^2Parameter* of the Gaussian beam and λ its *Wavelength*. See also Sec. 52.1 for reference. The complex radius of curvature q_{in} of the *Input Gaussian Beam* is transformed by an ABCD matrix $\mathcal{M}$ into the complex radius of curvature q_{out} of the *Output Gaussian Beam* by the so-called ABCD law [ST91]:

$$q_{\text{out}} = \frac{Aq_{\text{in}} + B}{Cq_{\text{in}} + D} \tag{105.2}$$

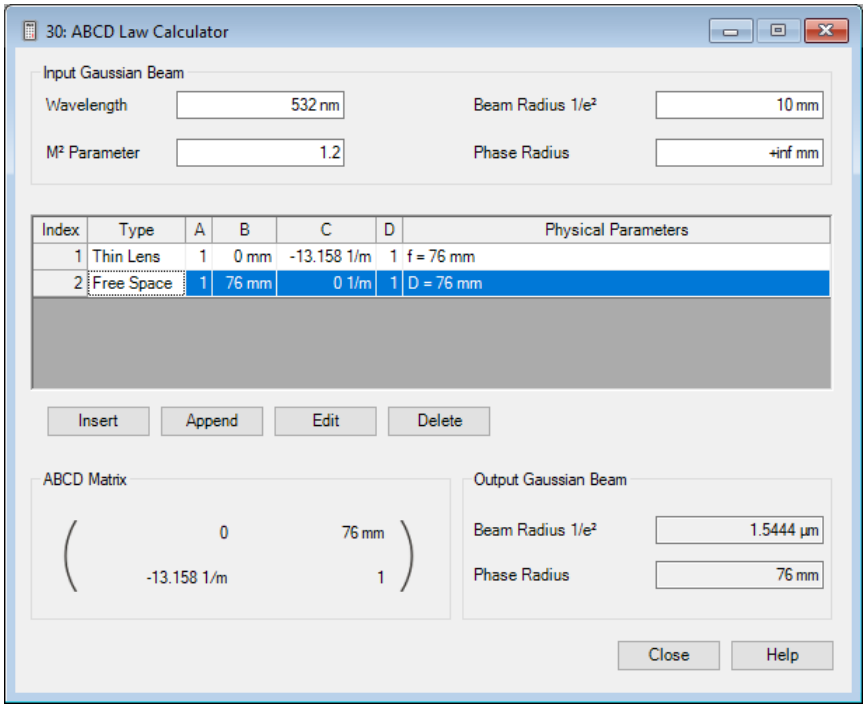


Figure 738. *The ABCD Law Calculator*

The dialog of this calculator is shown in Fig. 738 and has the following controls:

ITEM	DESCRIPTION
Input Gaussian Beam	Allows you to enter *Wavelength* λ, *M^2Parameter*, *Beam Radius* $w(z)$, and *Phase Radius 1/e²* $R(z)$ of the input beam. It is assumed that both beam and phase radius are given at the same position z.
ABCD Matrix Control	Allows you to define the system ABCD matrix by composing it of an arbitrary number of optical elements. ↪Sec. 5.17
Resulting ABCD Matrix	Shows the automatically calculated ABCD Matrix of the combination of the optical elements.
Output Gaussian Beam	Displays *Beam Radius 1/e²* and *Phase Radius* if the input beam has been propagated through the optical system represented by the ABCD matrix.

106 Coherence Time & Length Calculator

This calculator calculates the coherence time and the coherence length for different spectra. It has the following controls which can be set in the dialog shown in Fig. 739.

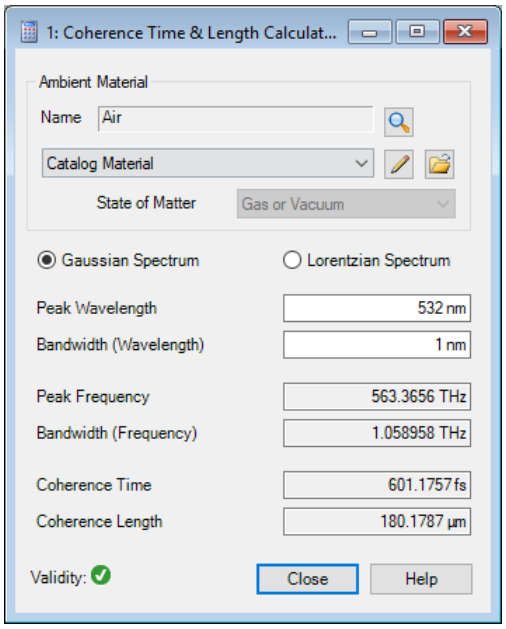


Figure 739. *Coherence Time & Length Calculator*

ITEM	DESCRIPTION
Ambient Material	Allows you to define the material in which the spectrum is defined. ↪Sec. 34.3
Gaussian Spectrum / Lorentzian Spectrum	The type of the spectrum.
Peak Wavelength	Allows you to set the peak (vacuum) wavelength λ of the spectrum.
Bandwidth (Wavelength)	Allows you to set the bandwidth $\Delta\lambda$ of the spectrum in the wavelength domain.
Peak Frequency	Shows the corresponding frequency ν of the peak wavelength.
Bandwidth (Frequency)	Shows the bandwidth $\Delta\nu$ of the spectrum in the frequency domain. $\Delta\nu = {}^{c\Delta\lambda}/_{\lambda^2}$ where c is the speed of light in the ambient material.
Coherence Time	Shows the coherence time $\tau = {}^{s}/_{\pi\Delta\nu}$. s is 2 for a Gaussian spectrum and 1 for a Lorentzian one.
Coherence Length	Shows the coherence length $l = c \cdot \tau$.
Validity	This control (↪Sec. 5.11) indicates whether there are issues with the current configuration, which happens for example if the wavelength is not valid for the given ambient material. In such a case, no calculated values are shown. You then can click on the ⓘ-button for further information.

107 Debye-Wolf Integral Calculator

With the Debye-Wolf Integral (↪Sec. 145.1) one can easily calculate the field in or near the focus of an ideal lens which is illuminated with collimated light.

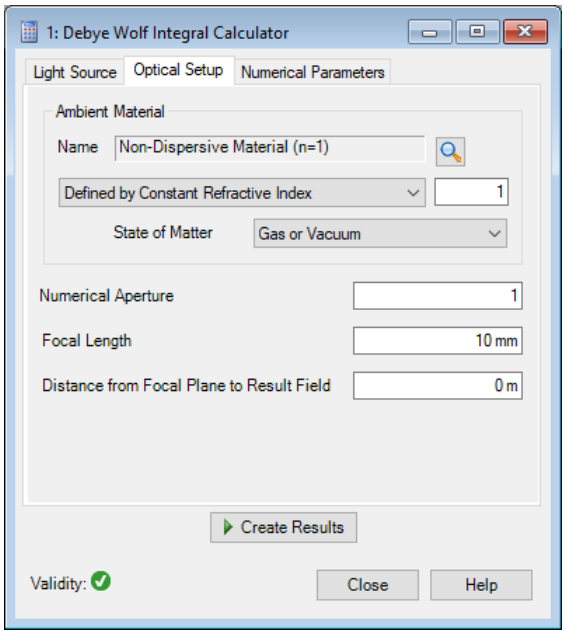


Figure 740. *The Debye-Wolf Integral Calculator*

VirtualLab Fusion offers a calculator to easily evaluate this integral (↪Fig. 740). It is separated into three tabs (see below). Furthermore it contains the following controls.

ITEM	DESCRIPTION
Create Results	Starts the generation of the results. The electromagnetic field (E_x, E_y, and E_z) and the electric energy density are calculated. After clicking, this button turns into a *Stop* button which allows you to cancel a long lasting calculation.
Validity	This control (↪Sec. 5.11) indicates whether there are issues with the current configuration. If this is the case you can click on the ℹ-button for further information.

The *Light Source* tab allows you to set the *Wavelength* and polarization of the incident collimated light. For setting the polarization the control described in Sec. 49.3 is used.
The *Optical Setup* tab has the following controls.

ITEM	DESCRIPTION
Ambient Material	Allows you to define the material around the focusing lens. ↪Sec. 34.3
Numerical Aperture	The numerical aperture of the focusing lens.
Focal Length	The focal length of the lens.
Distance from Focal Plane to Result Field	You can calculate the field in the focus (if this value is zero) or slightly out of the focus (if this value is unequal zero).

The *Numerical Parameters* tab contains those settings with which you can reduce the accuracy of the results to achieve faster calculations.

ITEM	DESCRIPTION
Field Size	The lateral extension of the results.
Estimate Field Size	Estimates the field size F according to $F = 6 \cdot (0.61\lambda \cdot \text{NA} + \lvert d \rvert \cdot \tan(\arcsin \text{NA}/n))$ with the *Wavelength* λ, the *Numerical Aperture* NA, the *Distance from Focal Plane to Result Field* d, and the refractive index n of the *Ambient Material*.
Sampling Points	The number of sampling points in the result fields.
Number of Directions	The Debye-Wolf integral over all angles (↪Sec. 145.1) is approximated by a sum over a certain number of discrete angles. This number can be set here.

108 Diffraction Angle Calculator

This calculator is a visualization of the grating equations given in Sec. 145.5, whereas only propagating orders are shown.

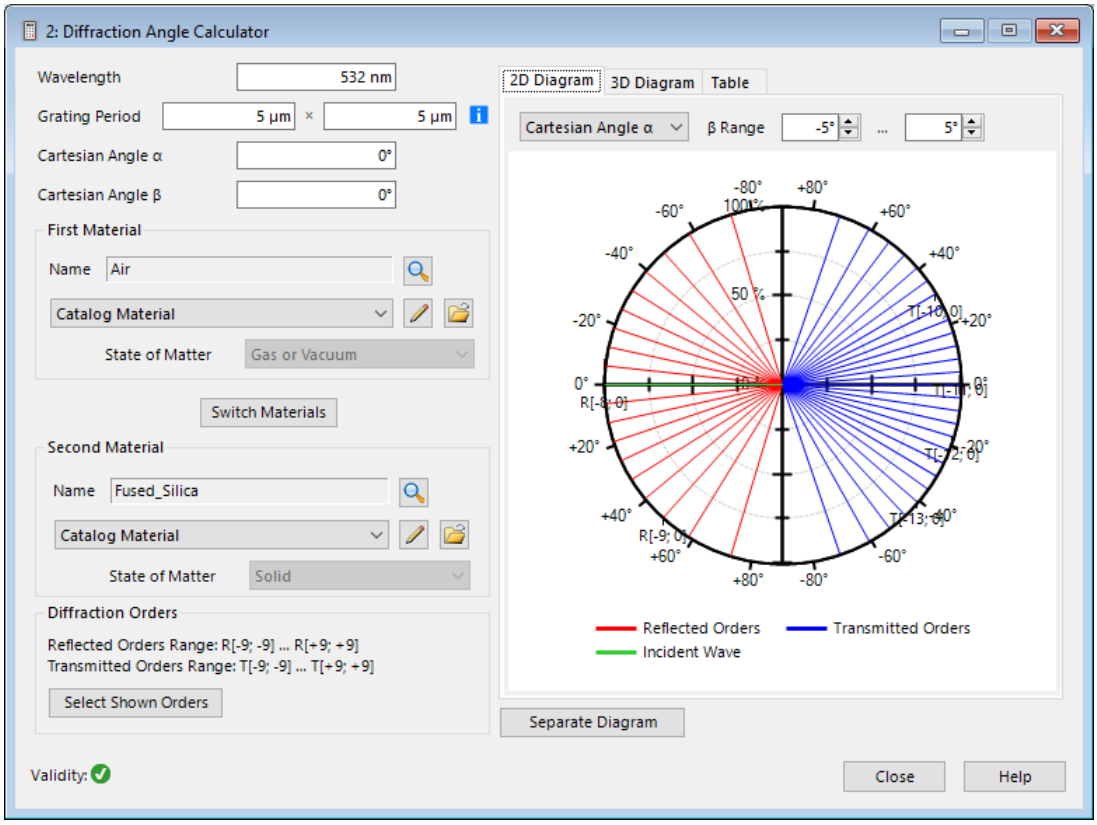


Figure 741. *The Diffraction Angle Calculator*

The *Wavelength* λ, the *Grating Period* $(P_x; P_y)$, and the *Cartesian Angles* α_{in} and β_{in} (out of which the incident wave vector is calculated) can be entered directly. The refractive indices n_{in} and n_{out} can be specified by setting the *First Material* and the *Second Material* using the control described in Sec. 34.3. Incident wave and reflected orders are in the first material, the transmitted orders are in the second material.

Using the *Switch Materials* button you can swap the two materials easily.

In the *Diffraction Orders* box, the order ranges are given. The button *Select Shown Orders* opens a dialog where you can select which orders are shown (↪Sec. 19.2).

The results are shown in a Diffraction Orders Diagram (↪Sec. 19) on the right side of the document window. For comparisons, you can generate a *Separate Diagram* document.

In the bottom left corner there is a validity indicator (↪Sec. 5.11) which explains why possibly no orders can be shown.

109 Direction Converter

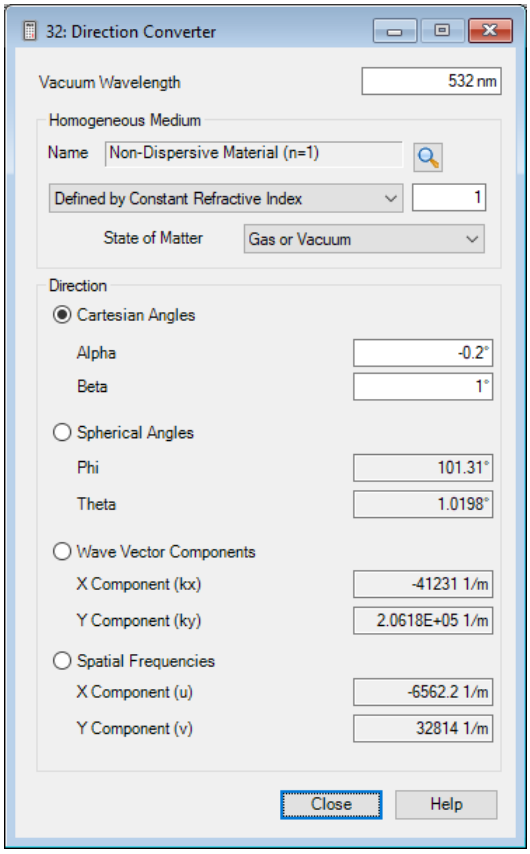


Figure 742. *Direction Converter*

There are different ways how angles can be specified. This calculator converts between the following four representations using the equations given in Sec. 145.3:

- *Cartesian Angles*
- *Spherical Angles*
- *Wave Vector Components* and
- *Spatial Frequencies* .

The independent parameters vacuum wavelength λ_{vac} and refractive index n have to be specified in the dialog:

ITEM	DESCRIPTION
Vacuum Wavelength	Vacuum wavelength λ_{vac} to calculate the wave number k from.
Homogeneous Medium	Defines the medium that provides the refractive index $n(\lambda_{\text{vac}})$ for the calculation of the wave number k. This control is described in Sec. 34.3.

110 Fiber Mode Calculator

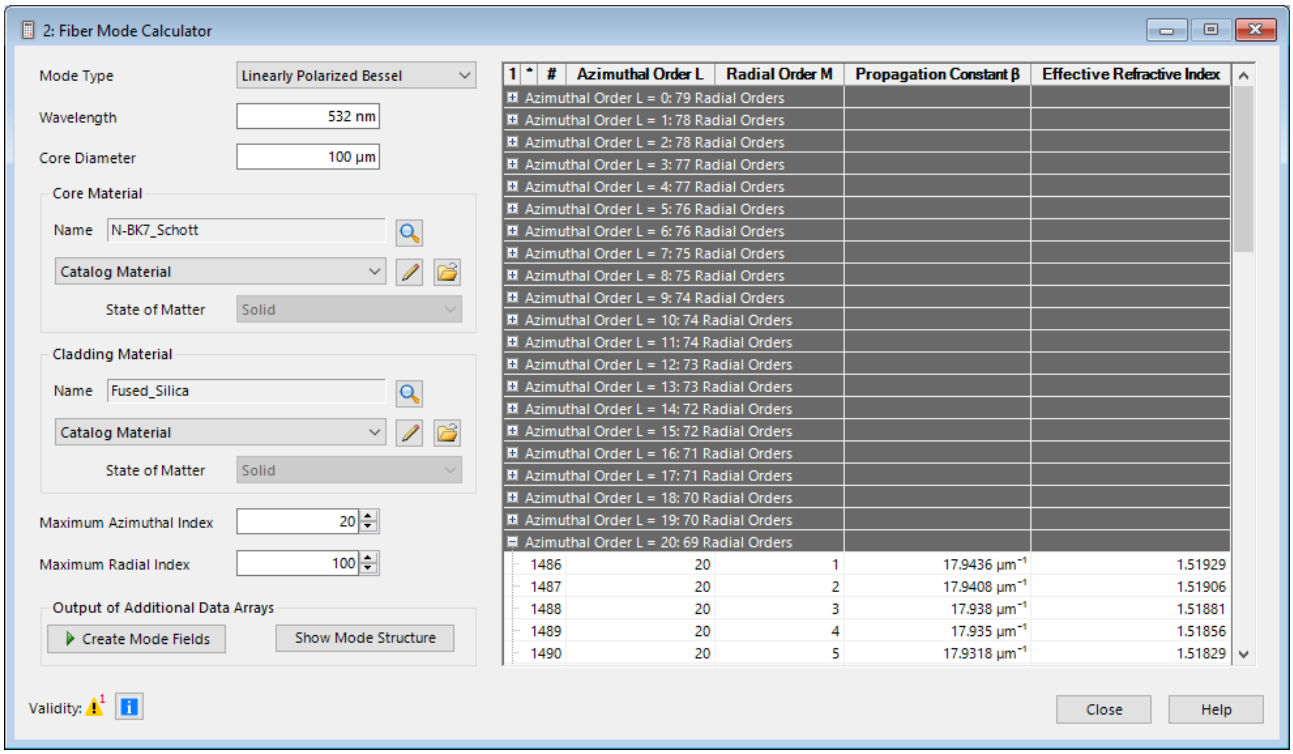


Figure 743. *The document window of the Fiber Mode Calculator. 100 Radial Orders are to be calculated, but only 79 (for L = 0) to 69 (for L = 20) exist. This is clearly indicated in the summary rows of the table and it's also the reason why the validity controls shows a warning.*

The Fiber Mode Calculator calculates the propagation constants, effective refractive indices and field distributions of the modes in a fiber.
It has the following controls:

ITEM	DESCRIPTION
Mode Type	Allows you to select between *Linearly Polarized Bessel* modes which occur in step-index fibers and *Linearly Polarized Laguerre* modes which occur in gradient index fibers.
Wavelength	The wavelength λ of the modes.
Core Diameter	The core diameter d of the fiber.
Core Material	Allows you to set the material in the fiber core with the control described in Sec. 34.3. Only the real-valued refractive index $n_{\text{core}}(\lambda)$ is used.
Cladding Material	ONLY FOR *LINEARLY POLARIZED BESSEL* MODES Allows you to set the material of the fiber cladding with the control described in Sec. 34.3. Only the real-valued refractive index $n_{\text{cladding}}(\lambda)$ is used.
Gradient Constant	ONLY FOR *LINEARLY POLARIZED LAGUERRE* MODES For gradient index fibers the refractive index distribution is given by $$n^2(r) = n_{\text{core}}(\lambda)^2 \left(1 - 2\Delta \left(\frac{r}{r_0}\right)^2\right) \quad (110.1)$$ whereas n_{core} is the refractive index in the center given by the *Core Material*; $r_0 = {}^{d}/_{2}$ is the core radius; and Δ is the gradient constant.

Maximum Azimuthal Order / Maximum Radial Order	The table with the mode structure is updated every time you change one of the parameters. By setting the maximum azimuthal or radial order you can influence how long this update takes (and how long to *Create Mode Fields*). Note that for the Bessel modes not all radial orders M exist for each azimuthal order L. Usually there is a maximum M which decreases with increasing L. The table shows the number of radial orders for each azimuthal order. Fig. 743 shows an example.
Create Mode Fields	Calculates for each mode the complex-valued field distribution and displays the result in a 2D Data Array with one subset per mode. If clicked the button turns into a *Stop*-button to cancel the calculation. As the calculator is a document window you can continue to work with other documents or dialogs during the calculation. You can adjust the sampling of the fields with Oversampling Factor and Field Size Factor from the Global Options dialog (↪Sec. 6.12).
Show Mode Structure	Displays the mode structure shown in the table as a separate 1D Data Array with one subset per column. This allows manipulations and comparisons.
Validity	This control indicates whether the current configuration is valid, ↪Sec. 5.11. Error messages can be shown in a separate dialog. For example a warning is shown if not all modes could be generated (↪Sec. 139.2).
{Table}	Shows information for each existing mode: azimuthal and radial order, propagation constant and effective refractive index. For sake of clarity, entries only differing by parity (↪Sec. 139.2) are not shown separately as they would always have the propagation constants and effective refractive indices. The entries are grouped by azimuthal index. If you click on column *1*, all these groups are collapsed. If you click on *, all groups are expanded.

111 Fresnel Effects Calculator

The Fresnel Effects calculator enables you to get the complex Fresnel Coefficients according to Fresnel's equations given in Sec. 145.4:

There is the possibility to get all coefficients at a glance for a given wavelength and incidence angle, but there is also the possibility to get a diagram of the dependencies on wavelength and angle of incidence. These both kinds of output (*Tables* ↪Sec. 111.2 and *Diagram* ↪Sec. 111.3) are described in the following, after the description of the materials setup of the calculator (Sec. 111.1).

111.1 Materials and Coating Setup

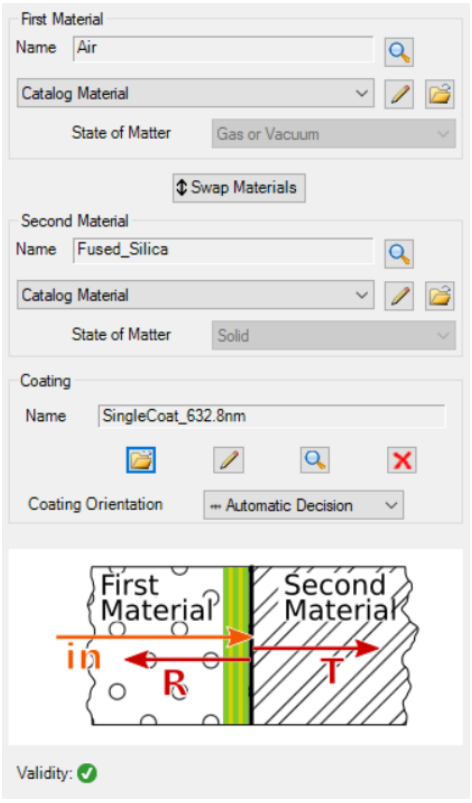


Figure 744. *The controls for the setup of the materials and an optional coating.*

The controls of the dialog are explained in detail in the following table:

ITEM	DESCRIPTION
First Material	Material in front of the surface to examine the Fresnel coefficients for. For the usage of the control see Sec. 34.3.
Switch Materials	Sets the *First Material* as *Second Material* and vice versa.
Second Material	Material behind the surface to examine the Fresnel coefficients for. For the usage of the control see Sec. 34.3.
Coating	A coating to be considered for the calculation. For the usage of the control see Sec. 34.2.

The image in the bottom of Fig. 744 shows the sequence of the materials, the coating and the surface. Solid material is symbolized by ///, liquid by ≡, and gaseous material or vacuum by ∴. Which side of the surface is coated is shown by the symbols ||| and |||.

111.2 Tables Output Panel

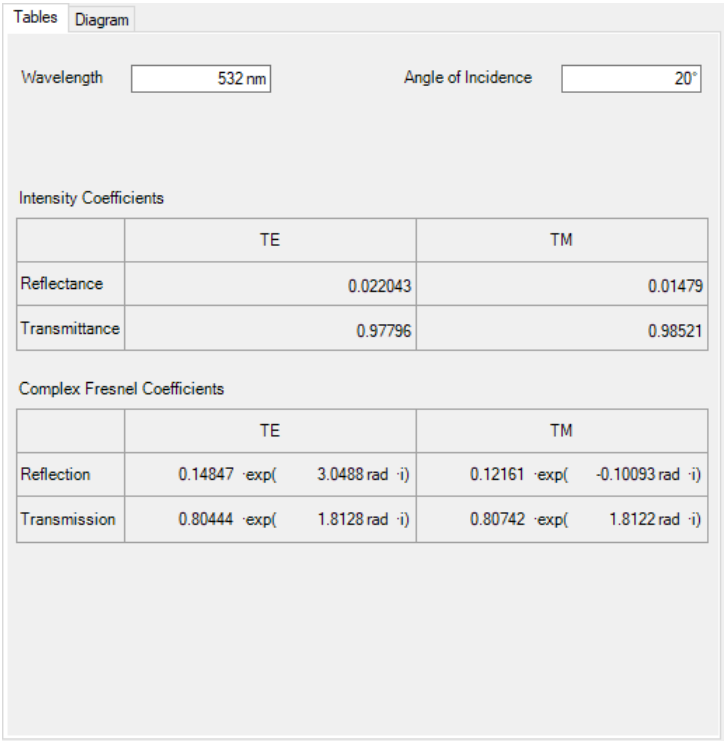


Figure 745. *The calculator's panel with the output of all Fresnel coefficients for one wavelength and one incidence angle at a glance.*

The controls of the dialog are explained in detail in the following table:

ITEM	DESCRIPTION
Wavelength	Wavelength λ to do the calculation for.
Angle of incidence	Angle of incidence θ to do the calculation for.
Intensity Coefficients	Reflectance R and transmittance T.
Complex Fresnel Coefficients	Reflection coefficient ρ and transmission coefficient τ in Amplitude/Phase notation.

111.3 Diagram Output Panel

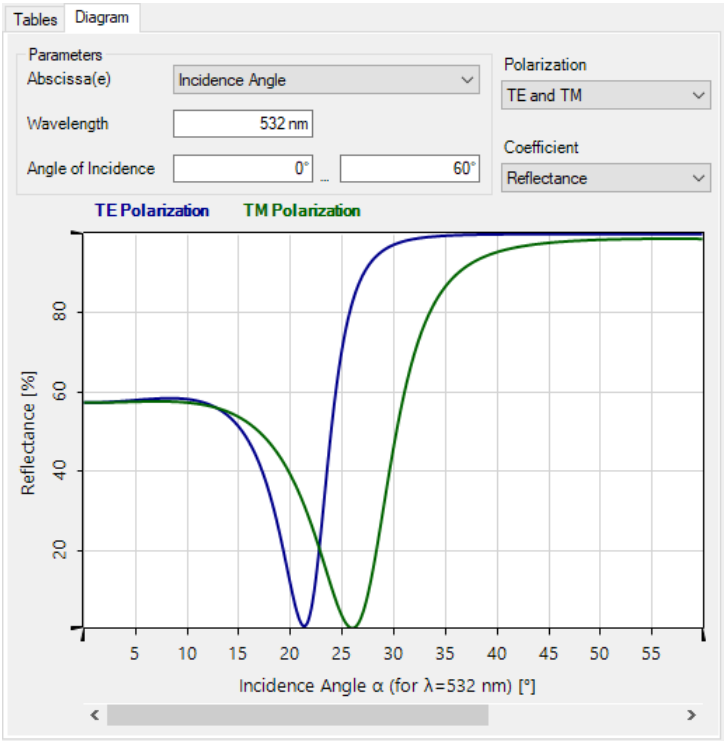


Figure 746. *The calculator's panel with the output of a diagram with wavelength or angular dependency.*

ITEM	DESCRIPTION
Abscissa(e)	What dependency shall be shown in the diagram? Dependency on *Wavelength*, *Incidence Angle*, *Energy*, or *Wavelength and Angle*?
Wavelength/Energy	Wavelength λ or wavelength range (energy range in case of *Energy* dependence) to do the calculation for.
Angle of Incidence	Angle of incidence θ or angle range to do the calculation for.
Polarization	Shall the coefficients be calculated for *Transverse Electric (TE)*, *Transverse Magnetic (TM)* polarization or both (*TE and TM*)?
Coefficient	Which coefficient shall be calculated? *Reflectance* R, *Transmittance* T, amplitude or phase of the complex reflection coefficient ρ (*Reflection Coeff (Amplitude)*, *Reflection Coeff (Phase)*), or amplitude or phase of the complex transmission coefficient τ (*Transmission Coeff (Amplitude)*, *Transmission Coeff (Phase)*).

112 k-Layout Visualization

ONLY AVAILABLE IN THE AR/VR/XR PACKAGE.

This calculator generates a k-Layout diagram for the specified grating setup. Its document window (↪Fig. 747) has two tabs, a zoomable diagram, and a validity indicator (↪Sec. 5.11).

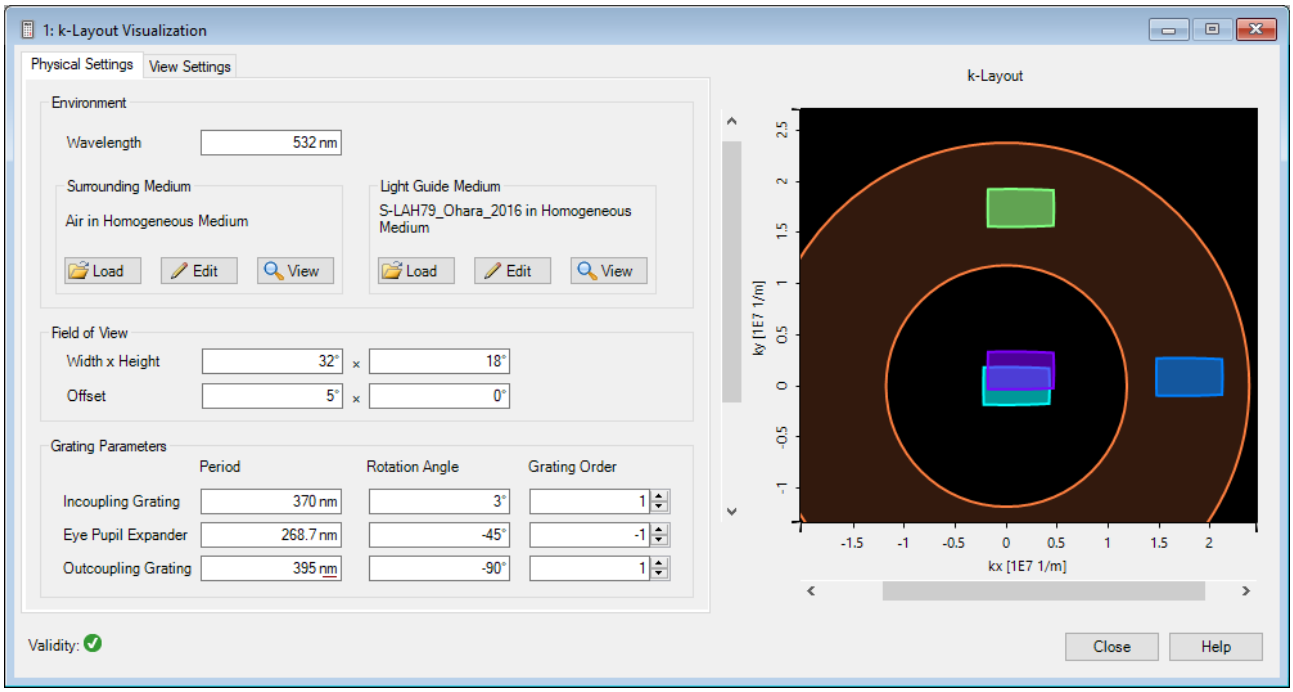


Figure 747. *The document window of the k-Layout Visualization.*

The *Physical Settings* tab has the following controls:

ITEM	DESCRIPTION
Wavelength	The (vacuum) wavelength for which the k-Layout is generated.
Surrounding Medium	Defines the surrounding medium by means of the control described in Sec. 34.1.
Light Guide Medium	Defines the light guide medium by means of the control described in Sec. 34.1.
Width x Height	The extension of the field of view in degrees for both x- and y-direction.
Offset	The offset of the field of view from perpendicular incidence in degrees for both x- and y-direction.
Grating Parameters	*Period*, *Rotation Angle*, and *Grating Order* of the three involved gratings: *Incoupling Grating*, *Eye Pupil Expander*, and *Outcoupling Grating*.

The *View Settings* tab has the following controls:

ITEM	DESCRIPTION
Colors	All colors to be used in the diagram can be set here.
Fill Field of View Boxes	Defines whether the “field of view boxes” are drawn filled or just as outline.
Opacity of Field of View Boxes	In case of filled boxes, the opacity of the filling can be set here. The maximum value of 1 means full opacity.

113 Laser Beam Calculator

The Laser Beam Calculator (↪Fig. 748) allows you to calculate all parameters of a laser beam (M^2, waist radius, divergence, Rayleigh length, waist distance, and beam radius) if only some of these parameters are known. To this end the equations given in Sec. 139.1 are used.

This calculator is designed as document, i. e. you can open more than one document and and then open a Gaussian generator dialog (↪Sec. 52.1) to import the data there.

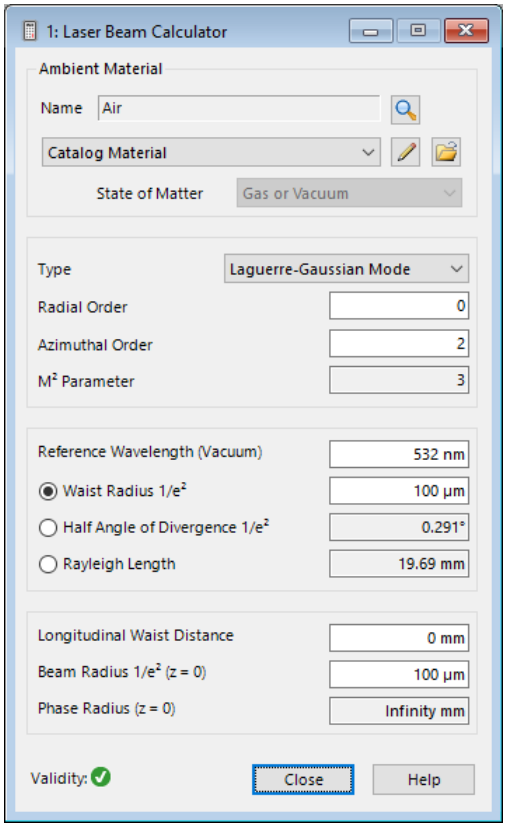


Figure 748. *Laser Beam Calculator*

The following parameters can be specified:

ITEM	DESCRIPTION
Ambient Material	The material in which the laser beam is created. The control described in Sec. 34.3 is used.
Type	You can choose among different types of a laser beam. Depending on the type the document windows slightly changes. The following types are available: • For an *Arbitrary Laser Beam*, the M^2 value can be set freely. • For a *Fundamental Gaussian Mode* M^2 is always 1. But in this case you can choose whether you want to enter $1/e^2$, FWHM, or HWHM values. • For a *Hermite-Gaussian Mode* and a *Laguerre-Gaussian Mode*, the M^2 value is calculated from the given order(s).

Parameters	ONLY FOR THE *FUNDAMENTAL GAUSSIAN MODE* Defines which parameters you actually set: • *1/e² Waist Radius, Divergence Half Angle*: The beam radius is determined by a relative intensity decay by 1/e² for a Gaussian beam. The divergence angle is measured between the optical axis and the 1/e² decay of the intensity. • *1/e² Waist Diameter, Divergence Full Angle*: The beam diameter is determined by a relative intensity decay by 1/e² for a Gaussian beam. The divergence angle is measured between the 1/e² decays of the intensity. • *FWHM Waist and Divergence Angle*: The waist and the divergence angle are defined as full width half maximum (FWHM) of the laser beam intensity. The conversion factor from 1/e² radius / half angle to FWHM is $\sqrt{2\ln 2}$. • *HWHM Waist and Divergence Angle*: The waist and the divergence angle are defined as half width half maximum (FWHM) of the laser beam intensity.
Order	ONLY FOR A *HERMITE-GAUSSIAN MODE* The orders m and n of the Hermite-Gaussian mode as defined in Eq. (139.9).
Radial Order **Azimuthal Order**	ONLY FOR A *LAGUERRE-GAUSSIAN MODE* The radial order p and the azimuthal order l of the Laguerre-Gaussian mode as defined in Eq. (139.11).
M² Parameter	M² parameter of the beam. Can be set only for *Arbitrary Laser Beam*s. Otherwise it is fixed to 1 (*Fundamental Gaussian Mode*) or calculated from the given order(s).
Reference Wavelength (Vacuum)	Vacuum wavelength of the Gaussian wave.
Waist Radius	Beam size in waist position.
Divergence Angle	The divergence angle in the far field.
Rayleigh Length	Rayleigh length of the Gaussian wave.
Longitudinal Waist Distance	Distance from the waist used for the calculation of *Beam Radius* and *Phase Radius*.
Beam Size (z = 0)	Beam size in a distance from the waist which is specified by *Longitudinal Waist Distance*.
Phase Radius (z = 0)	Radius of curvature of the phase in a distance from the waist which is specified by *Longitudinal Waist Distance*. In the waist position this radius is always infinity.
{Validity Indicator}	This control (↪Sec. 5.11) shows an error if the *Reference Wavelength* is not in the allowed wavelength range of the *Ambient Material*.

114 Layout Design Calculator

ONLY AVAILABLE IN THE AR/VR/XR PACKAGE.

This calculator creates an optical setup with a light guide fulfilling the given specifications. In particular, the grating regions have the correct positions and sizes.

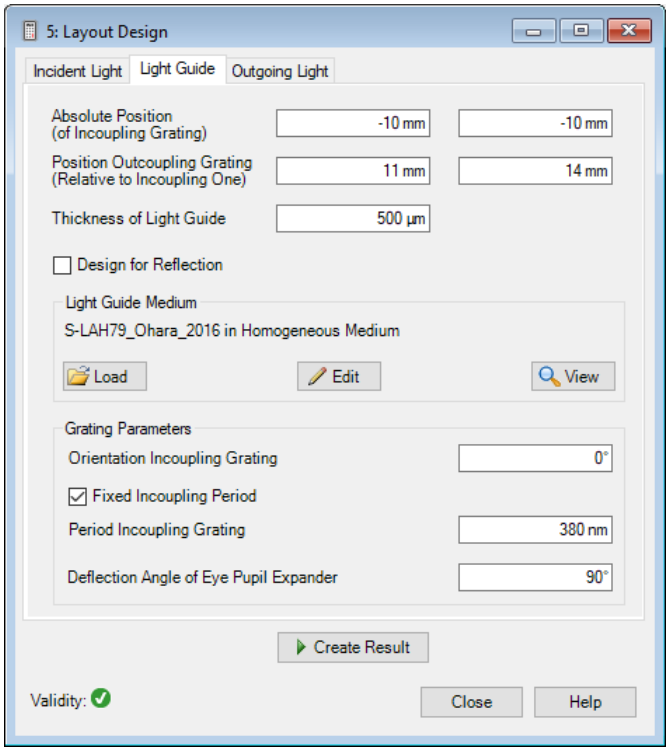


Figure 749. *The document window of the Layout Design Calculator.*

Its document window (↪Fig. 749) has three tabs, a button *Create Result* which creates the optical setup and the corresponding k-layout (↪Fig. 112), and a validity indicator (↪Sec. 5.11).
The *Incident Light* tab has the following controls.

ITEM	DESCRIPTION
Wavelength	The (vacuum) wavelength of the incident light.
Beam Size	The beam size in x- and y-direction.
Distance Source to Light Guide	The distance between the source and the light guide component.
Surrounding Medium	The medium outside of the light guide. The controls are described in Sec. 34.1.
Extension	The extension of the field of view in degrees for both x- and y-direction.
Offset	The offset of the field of view from perpendicular incidence in degrees for both x- and y-direction.

The *Light Guide* tab contains the specification of the actual light guide.

ITEM	DESCRIPTION
Absolute Position	The lateral position of the center of the incoupling grating relative to the internal coordinate system (↔Sec. 44.9.1.1) of the light guide component.
Position Outcoupling Grating	The lateral position of the outcoupling grating (and thus the output channel) relative to the center of the incoupling grating.
Thickness of Light Guide	The thickness of the light guide.
Design for Reflection	If this option is checked, the light leaves the light guide on the same side as the incident light.
Light Guide Medium	The medium within the light guide. The controls are described in Sec. 34.1.
Orientation Incoupling Grating	A value of 0° means that the incident light is deflected along the x-axis.
Fixed Incoupling Period	Determines whether the *Period Incoupling Grating* or the *Mode Density* is determined by the user.
Period Incoupling Grating	ONLY IF *FIXED INCOUPLING PERIOD* IS CHECKED. The period of the incoupling grating.
Desired Maximum Distance of Outcoupling Beams	ONLY IF *FIXED INCOUPLING PERIOD* IS NOT CHECKED. The period of the incoupling grating is determined so that the desired maximum distance for the outcoupling beams is reached. The maximum distance of the outcoupling beams is calculated for the field of view mode which has the smallest density. In case no period could be calculated for the entered value an error message will be displayed.
Deflection Angle Eye Pupil Expander	Specifies by how many degrees the Eye Pupil Expander changes the lateral direction of the light.

The *Outgoing Light* tab has the following controls.

ITEM	DESCRIPTION
Distance Light Guide to Eye	The distance between light guide and eye (represented by a Camera Detector).
Size of Eye Box	The size of the eye box (represented by the window size of the detector).

115 Memory Calculator

The Memory Calculator (↔Fig. 750) allows you to calculate how much memory a certain field needs (depending on number of sampling points, polarization state, and so on).

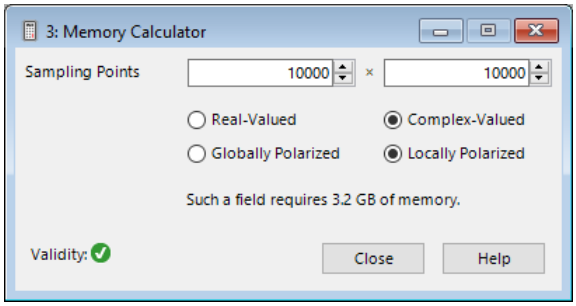


Figure 750. *Memory Calculator*

The required memory depends on the following parameters.

ITEM	DESCRIPTION
Sampling Points	The number of sampling points of a field.
Real-Valued / Complex-Valued	In contrast to *Real-Valued* numbers, *Complex-Valued* numbers store two numbers per pixel (real and imaginary part).
Globally Polarized / Locally Polarized	In contrast to a *Globally Field*, a *Locally Polarized* field contains two field components (E_x and E_y).

116 Modulation Depth Calculator

The Modulation Depth Calculator (↪Fig. 751) allows you to calculate the modulation depth of a Diffractive Optical Element (DOE) generating a phase difference of 2π. To this end the Thin Element Approximation (TEA) is used.

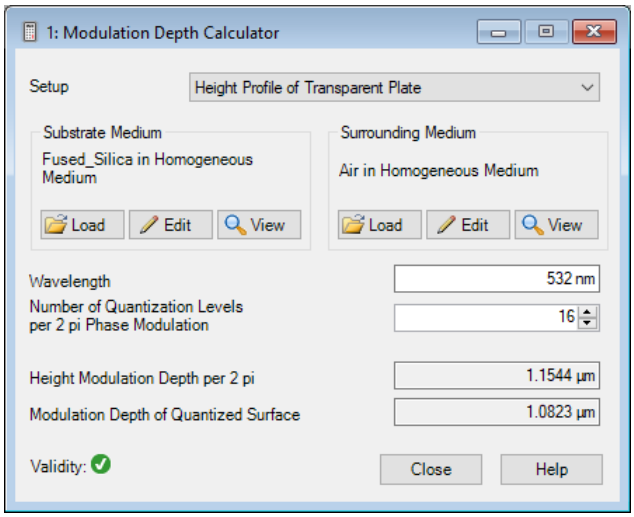


Figure 751. *Modulation Depth Calculator*

The following parameters can be specified:

ITEM	DESCRIPTION
Setup	The user can specify whether the modulation depth shall be calculated for a transparent plate which works in transmission, or for a *Height Profile of Mirror*.
Substrate Medium	The medium of the substrate block of the DOE. Note that the substrate can only be configured if the optical setup *Height Profile of Transparent Plate* is selected, otherwise it is set to *Ideal Mirror*.
Surrounding Medium	The surrounding medium of the DOE.
Wavelength	The vacuum wavelength for which the modulation depth shall be calculated.
Number of Quantization Levels per 2 pi Phase Modulation	The number of quantization levels that are used to generate a phase modulation of 2π.
Height Modulation Depth per 2 pi	Displays the profile height h corresponding to a 2π phase modulation. For a transparent plate this height is $h = \lambda/\Delta n$, where λ is the *Wavelength*, and Δn is the (positive) difference of the refractive indices of the two media. For a mirror this height is $h = \lambda/2n_s$ where n_s is the refractive index of the *Surrounding Medium*.
Modulation Depth of Quantized Surface	The highest level of a quantized surface never corresponds to a phase difference of 2π as then it would have the same effect as the lowest level. Thus the overall *Modulation Depth of Quantized Surface* h_q is only $h_q = h \cdot (l-1)/l$ where l is the *Number of Quantization Levels*.

The refractive index of the substrate medium must not be equal to the refractive index of the surrounding medium. Otherwise no results are displayed and the validity indicator in the bottom left corner shows an error message.

117 Rigorous Analysis of Slanted Gratings

Only available for VirtualLab Fusion Advanced.

Slanted gratings are an important sub-class of gratings but can be analyzed only inefficiently by the Fourier Modal Method (↪Sec. 97.3). So this calculator allows you to analyze them by the Integral Method ([SK11]), and for reference also by the Fourier Modal Method.

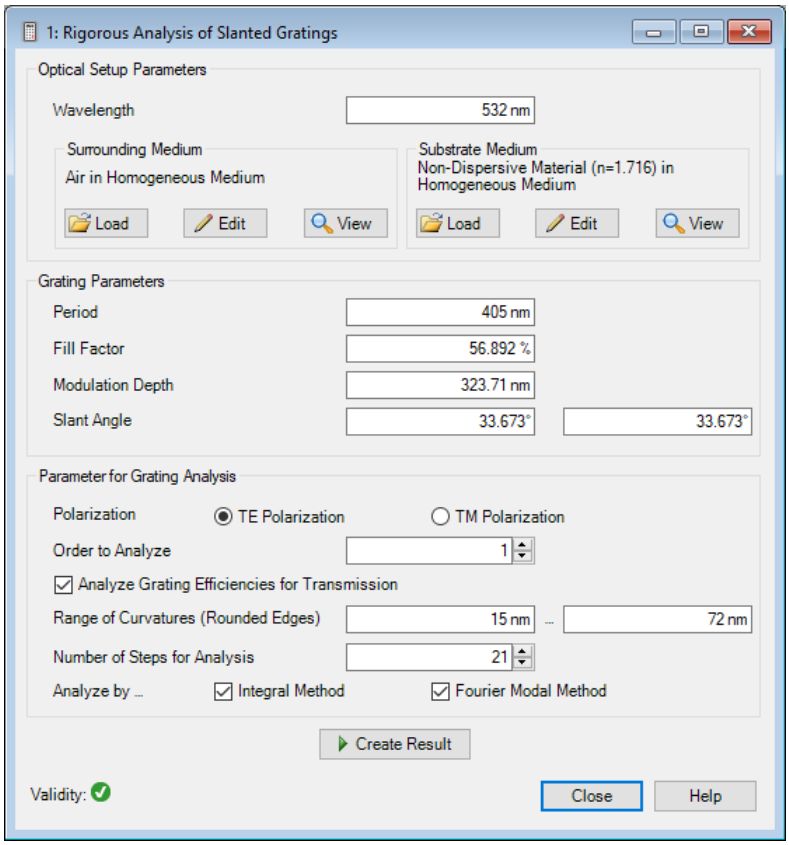


Figure 752. *Calculator for Rigorous Analysis of Slanted Gratings*

Its document window (↪Fig. 752) has the following controls:

ITEM	DESCRIPTION
Wavelength	The (vacuum) wavelength for which the analysis is done.
Surrounding Medium	Defines the medium in front of the grating. This control is described in Sec. 34.1.
Substrate Medium	Defines the medium behind the grating. This control is described in Sec. 34.1.
Period	The period of the grating.
Fill Factor	The width of the grating ridges relative to the period.
Slant Angle	The angle of the left and the right flank of the grating, respectively.
Polarization	Whether the analysis is done for the *TE Polarization* or the *TM Polarization*.
Order to Analyze	Which of the grating orders is analyzed.
Analyze Grating Efficiencies for Transmission	with this checkbox you can switch between analysis of transmitted and reflected orders.
Range of Curvatures	This calculator models the slanted grating with rounded edges of a certain curvature. More precisely a range of curvatures is scanned.
Number of Steps for Analysis	Defines how many curvatures in the given *Range of Curvatures* are analyzed.
Analyze by …	Defines whether the gratings are analyzed by the *Integral Method* and / or the *Fourier Modal Method*.

118 Spherical Lens Calculator

This calculator can be used for paraxial calculations based on the lens maker's equation as well as on the imaging equation of a spherical lens.

118.1 Lens Definition

In this page (↪Fig. 753), a spherical lens can be defined by using the following parameters:

ITEM	DESCRIPTION
Embedding Medium	The medium the lens is supposed to be used in.
Lens Medium	The medium the lens is made of.
First Surface Type	The type (convex, concave, or planar) of the first lens surface.
First Surface Radius	The curvature radius of the first spherical lens surface.
Center Thickness	The center thickness of the lens, i. e. the distance of one surface vertex to the other.
Second Surface Type	The type (convex, concave, or planar) of the second lens surface.
Second Surface Radius	The curvature radius of the second spherical lens surface.

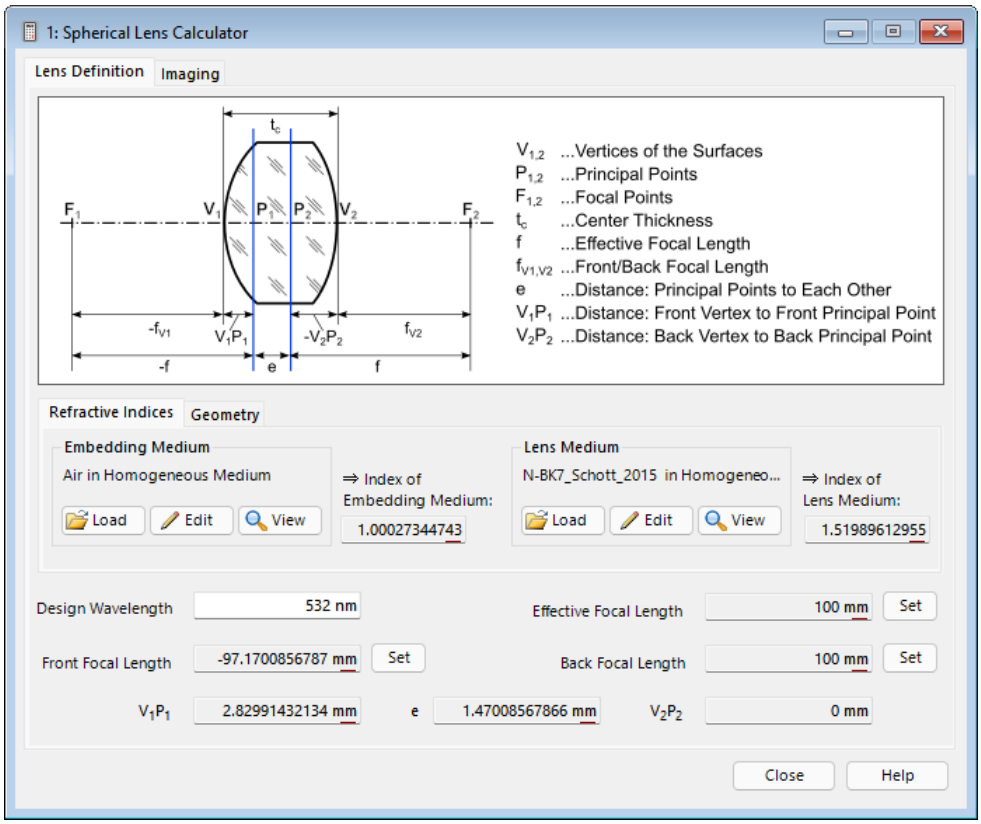


Figure 753. *The Lens Definition page of the Spherical Lens Calculator*

In the lower area of the dialog, some characteristic distances will be given for a certain *Design Wavelength*. These distances are:

ITEM	DESCRIPTION
Effective Focal Length	The effective focal length of the lens if used with the given *Design Wavelength* inside the given *Embedding Medium*.
Front Focal Length	The distance from the front vertex to the front focal point. For a converging lens, this will be negative.
Back Focal Length	The distance from the back vertex to the back focal point. For a converging lens, this will be positive.
$\mathbf{V_1P_1}$	The distance of the front principal point measured from the front vertex.
e	The distance of the two principal points to each other.
$\mathbf{V_2P_2}$	The distance of the back principal point measured from the back vertex.

The calculations are based on equations given in Sec. 141.1.

118.1.1 Setting a New Focal Length

If a certain effective, back, or front focal length shall be realized, the corresponding lens parameters can be calculated. By clicking *Set* to the right of the respective *Effective / Back / Front Focal Length* text box, a new dialog (↪Fig. 754) will open.

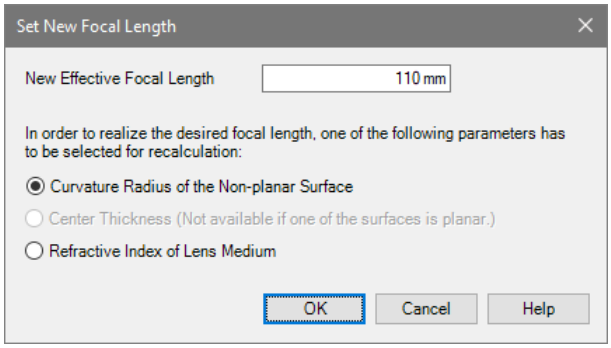


Figure 754. *Dialog for setting a new focal length for the Spherical Lens Calculator*

ITEM	DESCRIPTION
New Effective / Back / Front Focal Length	The desired focal length can be entered here.
Curvature Radius of the Surfaces / Non-planar Surface	If this option is chosen and one of the surfaces is defined to be planar then the curvature radius of the other surface which will realize the desired focal length will be calculated. If it is chosen and none of the surfaces is planar, the curvature radii of a *symmetric* lens will be calculated.
Center Thickness	In case of a desired *effective* focal length, this option is available only if both of the lens surfaces are non-planar. In case of a desired *back* focal length, this option is available only if the front lens surface is non-planar. In case of a desired *front* focal length, this option is available only if the back lens surface is non-planar. If this option is chosen, the center thickness which will realize the desired effective focal length will be calculated.
Refractive Index of Lens Medium	If this option is chosen, the refractive index of the lens which will realize the desired effective focal length inside the given *Embedding Medium* will be calculated. A new non-dispersive medium with this refractive index will be set as *Lens Medium*.

118.2 Paraxial Imaging with a Lens

Two equations are important for calculating distances and sizes for paraxial imaging.
The imaging equation describes the relation between the focal length f, the object distance s_o, and the image distance s_i:

$$\frac{1}{f} = \frac{1}{s_i} - \frac{1}{s_o}, \tag{118.1}$$

while the magnification y_i/y_o (i.e. the ratio of the image size y_i to the object size y_o) is related to the object and image distance as follows:

$$y_i/y_o = \frac{s_i}{s_o}. \tag{118.2}$$

All possible dependencies of these four quantities f, s_o, s_i, and y_i/y_o can be analyzed in the *Imaging* page of the calculator (↪Fig. 755).

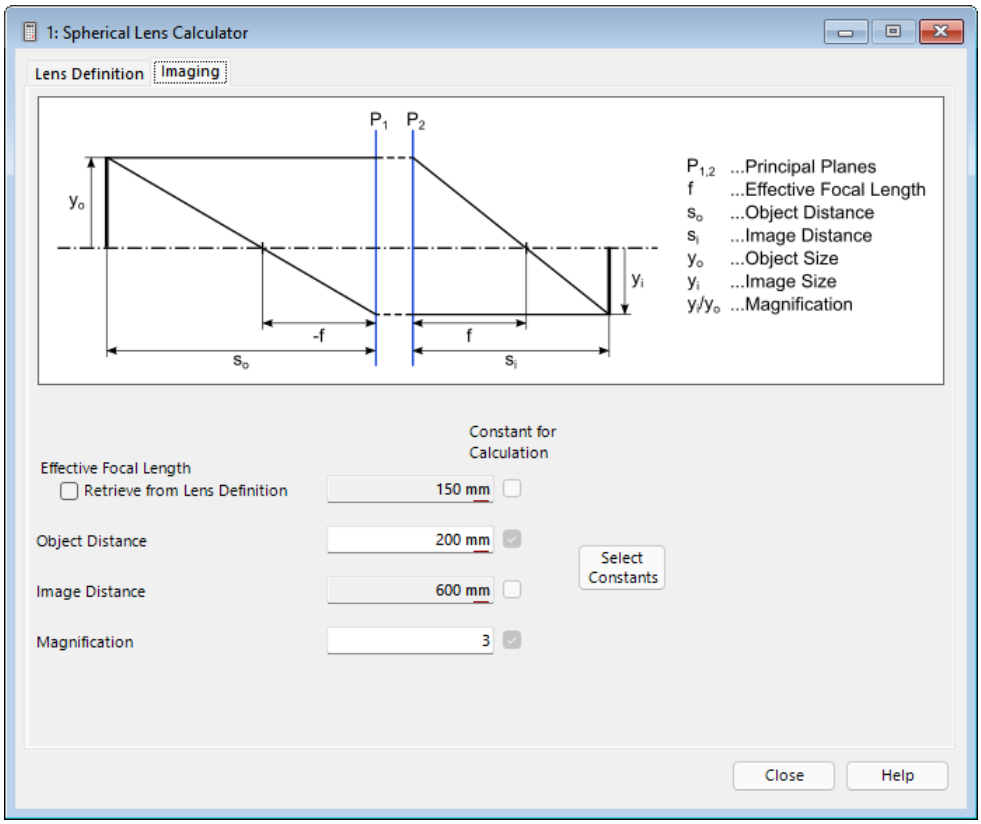


Figure 755. *The Imaging page of the Spherical Lens Calculator*

There are two modes for using the calculations in this page:

- If *Retrieve from Lens Definition* is *checked*, the *Effective Focal Length* is copied from the *Lens Definition* page and cannot be altered here. If one of the three other quantities is changed, the two remaining values are calculated.
- If *Retrieve from Lens Definition* is *unchecked*, the button *Select Constants* allows to decide which two of the four quantities shall be kept constant while a new value is entered.

119 Vector & Coordinate System Viewer

This tool serves the visualization of coordinate system base vectors which are rotated in relation to a reference coordinate system in the 3D space. It allows to understand the effect that has any value for any angle that belongs to any type of orientation definition. For an overview of all available orientation definition types see Sec. 145.2.

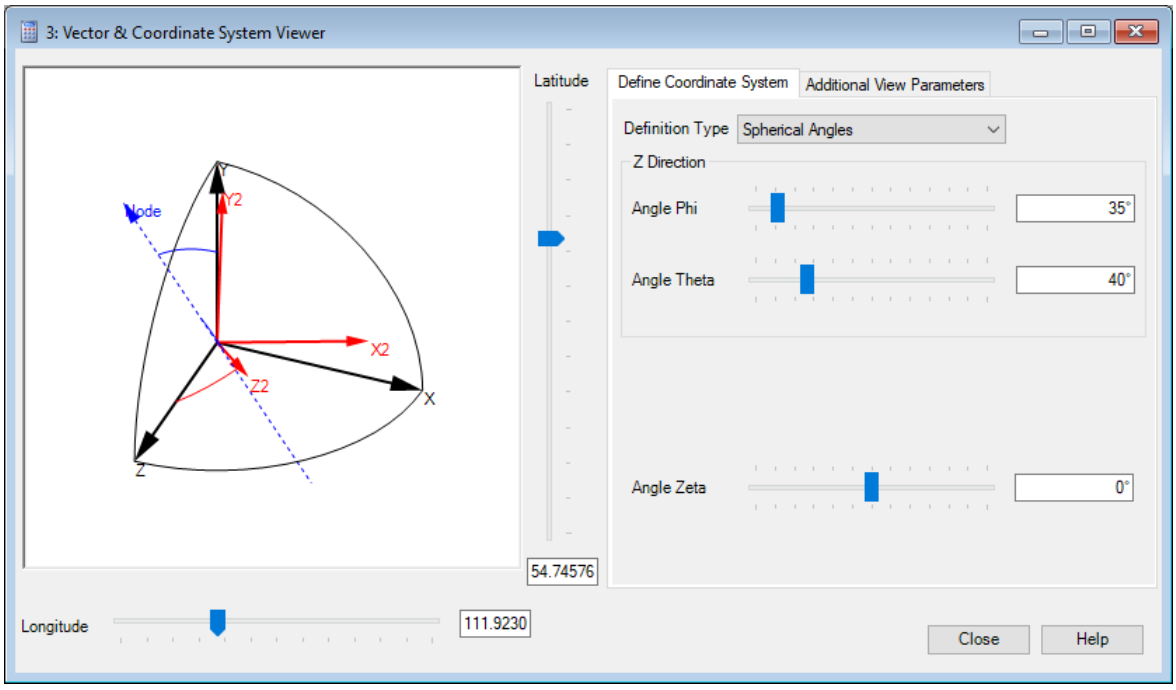


Figure 756. *Vector & Coordinate System Viewer*

The following parameters can be specified:

ITEM	DESCRIPTION
Longitude/Latitude	The view direction can be set via the values of *Longitude* and *Latitude*. An alternative is the rotation of the view by dragging via mouse inside the view.
Definition Type	The orientation definition type (see Sec. 145.2) can be chosen here.
Angle Phi / Theta / Alpha / Beta / Gamma / Rho / Sigma / Tau	The angles which belong to the definition types *Spherical Angles*, *Direction Angles*, and *Cartesian Angles*, resp. All these angles are used in order to define the orientation of the new z'-axis. The new directions of the x'- and y'-axis are defined by rotating the original x-y-z-system about the node line (marked blue in the view). The node line is the normal to the plane which is spanned by the old z- and the new z'-axis.
Angle Zeta	After defining a new z'-axis via spherical, Cartesian or direction angles, the new system x'-y'-z' can be rotated additionally about the new z'-axis by the *Angle Zeta*. This will result in a new system x"-y"-z'.
Euler Angle: Ψ / Θ / Φ	For the orientation definition type *Euler Angles*, the angles can be specified here.
Rotation Axis: x- / y- / z-axis	For the orientation definition type *Sequence of Axis Rotations*, this will define the axis rotation sequence.
Fixed Axes	If checked, the rotations are done about fix coordinate axes. Otherwise the second and third rotation are done about the new coordinate axes resp. Example: If *Fix Axes* is checked, the sequence Z-Y-Z means rotation about the old z-axis, followed by a rotation about the old y-axes, followed by another rotation about the old z-axis. If it is not checked, the sequence Z-Y-Z means a rotation about the old z-axis, followed by a rotation about the new y'-axes, followed by another rotation about the new z'-axis.
Latitude measured form x- / y- / z-axis	The axis which shall point upwards in the view can be chosen here.
Zoom Factor	This value allows to define a zoom into the view. An alternative is zooming via mouse wheel.
Axis Scale Factor	This values allows scaling of the (red) coordinate base vectors in the view.
Start/Stop Rotation about x- / y- / z-axis	In order to allow a better notion of the 3D relations, an animation can be started/stopped by clicking this button.
Rotation Speed	If an animation has been started, the rotation speed can be set here.

120 Waveplate Calculator

If a waveplate shall be designed with the objective of creating a certain phase retardation for polarized light of a given wavelength, then the correct thickness of the plate has to be known. The waveplate calculator (as shown in Fig. 757) serves that purpose.

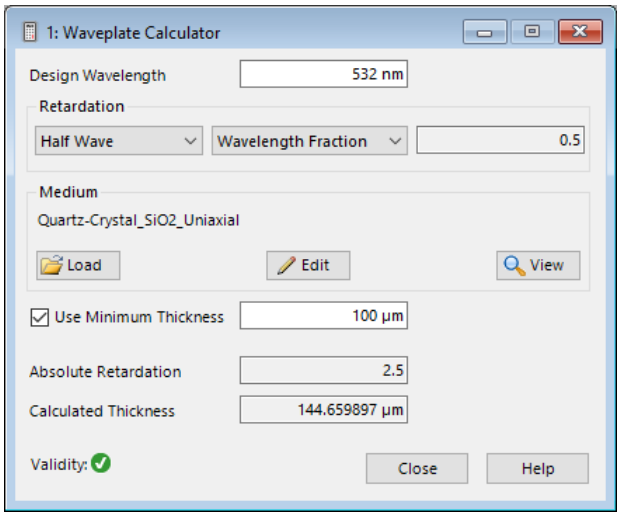


Figure 757. *Calculator for determining the thickness of a waveplate.*

The following parameters have to be specified:

ITEM	DESCRIPTION
Design Wavelength	The vacuum wavelength the waveplate shall be designed for.
Retardation	If the entry *Free Definition* is selected, either a certain *Wavelength Fraction* or *Phase Difference* can be set in the text-box as the desired value of retardation. Otherwise, a pre-defined value can be set here: A *Half Wave* can be chosen as well as a *Quarter Wave* which correspond to the well-known types of common waveplates.
Medium	The uniaxial, anisotropic medium the waveplate shall consist of.
Use Minimum Thickness	If checked, a minimum thickness for the waveplate can be defined.
Absolute Retardation	In case a certain minimum thickness is given, the ”absolute retardation” will describe the absolute phase effect of a waveplate of the calculated thickness on polarized light. This may be an integer multiple of the defined *Retardation*.
Calculated Thickness	The thickness a waveplate of the given *Medium* must have in order to produce the desired *Retardation*.

Please note: The formula for calculating the thickness is an approximation in that it only takes into account the optical path length differences for a single transition of light. Resonance effects due to multiple reflections are thus not included, although they naturally have an effect on the polarization of the transmitted light.

XVI Export and Import

Different programs use different file formats. This part of the user's manual explains the file formats which can be imported into or exported from VirtualLab Fusion.

In the following, VirtualLab Fusion objects are listed with possible file operations and their associated file formats.

VIRTUALLAB FUSION OBJECT	SUPPORTED FILE FORMATS
Animations	• Export the current frame to various raster graphics formats (*.bmp, *.png, *.jpg). ↪Sec. 129 • Export the whole animation as an animated GIF file (*.gif). ↪Sec. 129.1 • Export the whole animation as a video file (*.avi). ↪Sec. 129 • Create an overview image of all frames (*.bmp; *.jpg; *.png; *.tif). ↪Sec. 129.2
Boundary Operators	• Export of Grating Cells Arrays to text file (*.csv) or GDSII Data (*.gds). ↪Sec. 132.1 • Export of Prism or Mirror Cells Arrays to text file (*.csv) or stereolithography format (*.stl). ↪Sec. 132.2
Coatings	• Import of Macleod Coatings. ↪Sec. 134
Chromatic Fields Sets	• Export to Field Information format (*.fin). ↪Sec. 127 • Import of various raster graphics formats (*.bmp, *.png, *.jpg). ↪Sec. 122
Data Arrays	• Export to text file (*.txt, *.csv). ↪Sec. 126 • Import of various raster graphics formats (*.bmp, *.gif, *.png, *.jpg, *.pcx, *.tif) ↪Sec. 122 and of text files (*.txt, *.csv, *.fin) ↪Sec. 121.1.
Harmonic Fields	• Export to various raster graphics formats (*.bmp, *.png, *.jpg, *.tiff). ↪Sec. 128.1 • Import from various raster graphics formats (*.bmp, *.png, *.jpg, *.tiff). ↪Sec. 122 • Export of current view to vector format (*.emf). ↪Sec. 11.6.1 • Export to Field Information format (*.fin). ↪Sec. 128.2.3 • Import of Field Information format (*.fin). ↪Sec. 121.3 • Export to ASCII format (*.txt; *.csv). ↪Sec. 128.2.1 • Import of ASCII format (*.txt; *.csv). ↪Sec. 121.1 • Export to “Code V” format (*.dat). ↪Sec. 128.2.4 • Import of “Code V” format (*.dat). ↪Sec. 123 • Export to Plain Text format (*.ptf). ↪Sec. 128.2.2 • Import of Plain Text format (*.ptf). ↪Sec. 121.2 • Import of “Zemax OpticStudio® Beam File” binary format (*.zbf). ↪Sec. 124
Harmonic Fields Sets	• Export to various raster graphics formats (*.bmp, *.png, *.jpg, *.tiff). ↪Sec. 128.1 • Import from various raster graphics formats (*.bmp, *.png, *.jpg, *.tiff). ↪Sec. 122 • Export of current view to vector format (*.emf). ↪Sec. 11.6.1 • Export to Field Information format (*.fin). ↪Sec. 128.2.3 • Import of Field Information format (*.fin). ↪Sec. 121.3
Materials	• Import from Zemax OpticStudio® Glass Catalogs (*.agf). ↪Sec. 135

Optical Setups	• Export to XML / Batch Mode files / optiSLang Project ↪Sec. 130.1 • Import Parameters from XML. ↪Sec. 44.8 • Import of optiSLang Results. ↪Sec. 130.2 • Export to JCMsuite format. ↪Sec. 130.3 • Export to stereolithography format (*.stl) and to the IGES format (*.igs) via the 3D View. ↪Sec. 5.16 • Import of Zemax OpticStudio® Lens File format (*.zmx, *.zos) and archive format (*.zar). ↪Sec. 130.4
Real Components	• Export to stereolithography format (*.stl) and to the IGES format (*.igs) via the 3D View. ↪Sec. 5.16 • Import of Zemax OpticStudio® Lens Files (*.zmx, *.zos) and archives (*.zar) into a Lens System component. ↪Sec. 131.2 • Import of Zemax OpticStudio® Lens Files (*.zmx, *.zos) and archives (*.zar) into a Diffractive Lens or Meta Lens. ↪Sec. 131.3 • Export of diffractive components (Diffractive Lens or Holographic Optical Element with quantized real structure). ↪Sec. 133.2
Surfaces	• Export of pixelated data to plain text (*.ptf), ASCII (*.txt), CIF, GDSII, point cloud, stereolithography format (*.stl), bitmap (*.bmp), and 16-bit grayscale image (*.png). ↪Sec. 133 • Export to stereolithography format (*.stl) and to the IGES format (*.igs) via the 3D View. ↪Sec. 5.16 • Import of pixelated data into the Sampled Surface (↪Sec. 36.2.11). Supported formats: plain text (*.ptf), ASCII (*.txt), CIF, GDSII, and bitmap (*.bmp). ↪Sec. 133

- Some dialogs allow an import / export to their own specific formats which are explained in the corresponding sections (e. g. snippets, ↪Sec. 7.3).
- The file formats native of VirtualLab Fusion are given in Sec. 4.1.

121 Import of Text Files

We call 'text files' all file formats which are 'human-readable' (in contrast to e.g. binary formats which are 'machine-readable'). We further distinguish the import of general text formats (referred to as 'ASCII' files, ↪Sec. 121.1) from importing more specific formats, namely Plain Text Format ↪Sec. 121.2 and Field Information format ↪Sec. 121.3.

121.1 Import of ASCII Files (*.TXT, *.CSV)

All kinds of ASCII files (like e.g. *.txt, *.csv) can be used for importing data into VirtualLab Fusion. This feature provides the possibility of importing data to be used for several purposes like defining dispersion curves, spectra or 2D distributions. The data may be one- or two-dimensional, being equidistantly or non-equidistantly sampled. The import dialog will open via ribbon (File > Import > Import Text File) for general text data import but will also be used in specific contexts like a direct import into a material's edit dialog.
Please note: In such specific context there may be import restrictions (like "1D only" or "equidistant coordinates only") in order to fulfill the conditions of the target object the data are imported into.
The import dialog is structured as a "wizard" whose pages are described in the following sections in their order of appearance.

121.1.1 Parsing Text

The first step in creating VirtualLab Fusion data from the file's content is a process called 'parsing' which means to interpret text strings (separated by certain characters) as numbers.

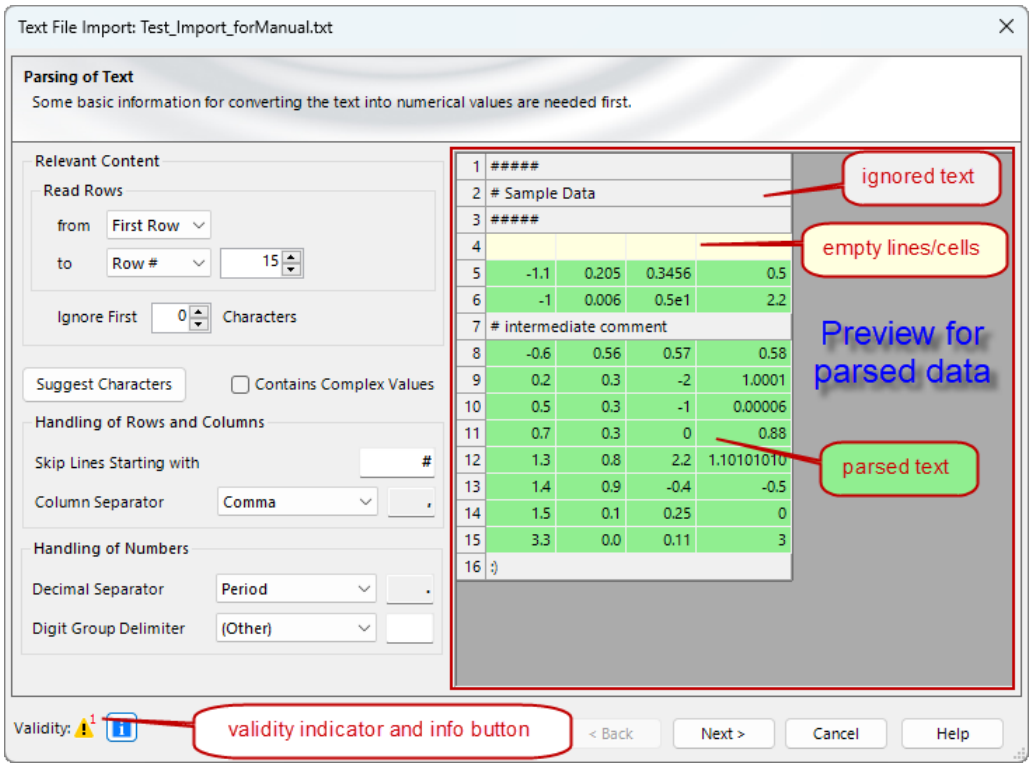


Figure 758. *The first page of the import wizard for text data. The preview on the right side allows to check whether the used parsing parameters are correct.*

The following parameters determine the parsing process:

ITEM	DESCRIPTION
Read Rows from	The index of the first row to be parsed. All rows with a lower index will be ignored.
Read Rows to	The index of the last row to be parsed. All rows with a higher index will be ignored.
Ignore First *n* Characters	If a certain number *n* of characters at the start of each line is to be ignored, this can be specified here.
Suggest Characters	If this button is pressed, VirtualLab Fusion tries to determine all parsing parameters automatically. This comprises the separating characters, comment indicators as well as the question whether or not the numbers are complex or real-valued. Please note: The same automatic detection is done the time the dialog is opened first.
Contains Complex Values	If checked, the strings in each cell are handled as representing complex numbers. If no imaginary part is parsed, the number is considered a complex number with an imaginary part of zero.
Skip Lines Starting with	If a line starts with the character(s) defined here, it will be treated as a comment line which is to be ignored, i.e. not parsed.
Column Separator	The character which splits a line into several cells is to be defined here (that allows to treat the text file's content as a table). Possible values are *Any Whitespace* (i.e. one or more spaces of arbitrary length, tabulators etc.), *Comma* (,), *Semicolon* (;), *Vertical Bar* (|), *Ampersand* (&), or any *Other* character specified by the user.
Decimal Separator	The character which separates the fractional part from the integer. Possible values are *Period* (.), *Comma* (,), or any *Other* character specified by the user.
Digit Group Delimiter	The character which is used for grouping digits in large numbers, also called 'Thousands Separator'. It has to be different from the *Decimal Separator*. Possible values are *Comma* (,), *Period* (.), *Apostrophe* ('), *Underscore* (_), or any *Other* character specified by the user.

121.1.1.1 Problems With Parsing

The validity indicator at the bottom of the dialog show whether there are no problems at all, some warnings or errors. Warnings and errors can be accessed via the info button. Warnings appear e.g. if there are empty cells but warnings do not prevent the wizard from enabling the next step.
An error may appear if there is a cell which cannot be parsed (indicated by a salmon cell background color within the preview) or if the lines contain different numbers of cells.
A first attempt to solve this problem may be pressing the button *Suggest Characters*. If this doesn't help, one can try different characters manually or to restrict the range of rows to read.

121.1.2 Numerical Interpretation of Imported Data

Once the parsing is finished, we got a matrix of real-valued or complex numbers. This matrix must be interpreted with regard to the type of data sampled by its values. This can be done on the page described in this section.

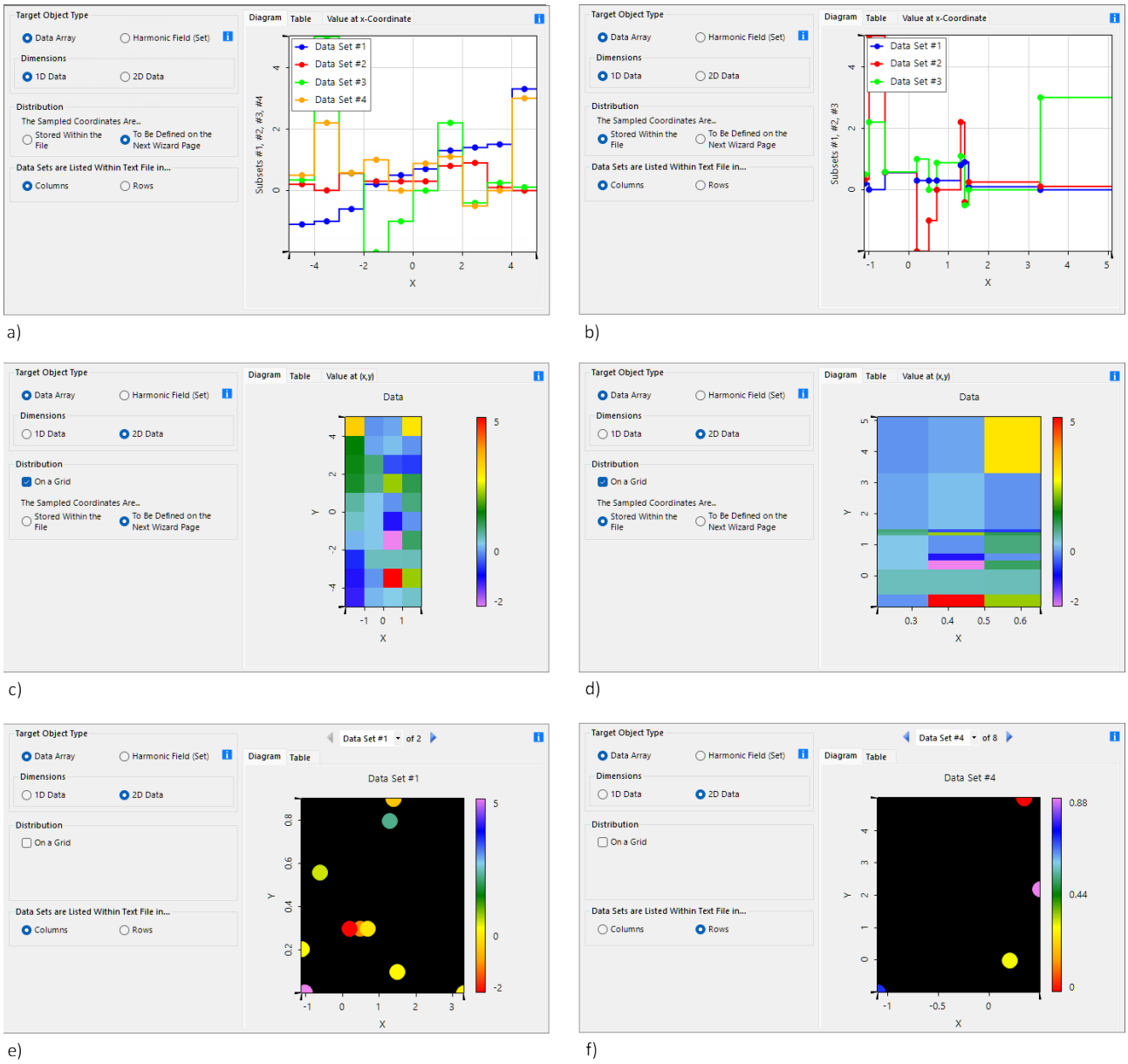


Figure 759. *Six completely different interpretations of the same (!) data matrix. a) Equidistantly sampled 1D data with four subsets (read from four columns). b) Non-equidistantly sampled 1D data with three subsets (the first column provides the coordinates while the remaining three columns provide the actual data values). c) Equidistantly sampled 2D data (on a grid). d) Non-equidistantly sampled 2D data (on a grid) where all coordinates are provided by the first row and column in the file. e) Freely distributed (i.e. 'grid-less' 2D data) with two subsets (read from two columns). f) Freely distributed (i. e. 'grid-less' 2D data) with eight subsets (read from eight rows).*

In order to use the correct interpretation out of a possibly great variety (see Fig. 759), there are several options to be set on this page of the import wizard:

ITEM	DESCRIPTION
Data Array / Harmonic Field (Set)	Determines the target type of the VirtualLab Fusion object to be imported. If *Data Array* is chosen, a Numerical Data Array ↪Sec. 13 will be created, the most flexible data object in VirtualLab Fusion. If *Harmonic Field (Set)* is selected, either a Harmonic Field is created (always in case of 2D data; only for a single data set in 1D case) or a Harmonic Fields Set (in case of 1D data with more than one data set) ↪Sec. 12. The pre-defined wavelengths for the single Harmonic Fields can be changed at a later point.
1D / 2D Data	AVAILABLE ONLY IF THERE IS MORE THAN ONE COLUMN OR MORE THAN ONE ROW OF DATA. Are the data to be interpreted as 2D (with x- and y-coordinates) or as 1D (with only x-coordinates but with possibly more than one set of data contained)?
The Sampled Coordinates Are... Stored Within the File	ONLY AVAILABLE IF AT LEAST THE FIRST ROW OR COLUMN IS STRICTLY MONOTONIC AND ONLY FOR *1D DATA* OR *2D DATA* WHICH IS DISTRIBUTED *ON A GRID*. If chosen, the first row and/or column of data is interpreted as ordered set of coordinates. In case of *2D Data* distributed *On a Grid*, both the first row *and* column have to be strictly monotonic. In case of *1D Data*, the first column needs to be strictly monotonic if the *Data Sets are Listed Within Text File in... Columns*, otherwise the first row needs to be strictly monotonic in order to enable this option.
The Sampled Coordinates Are... To Be Defined on the Next Wizard Page	If this option is selected, the data point distribution is assumed to be on an equidistantly sampled grid of coordinates. The grid's properties are to be specified on the next wizard page ↪Sec. 121.1.3.
Columns / Rows	AVAILABLE ONLY FOR 1D OR GRID-LESS 2D DATA WITH MORE THAN ONE COLUMN AND MORE THAN ONE ROW (WITHOUT CONSIDERATION OF COORDINATE COLUMNS/ROWS.) Are the different subsets of data (which correspond to the same coordinates resp.) given in the columns or the rows of the parsed data matrix (↪Sec. 121.1.2.1)?
On a Grid	AVAILABLE ONLY IF THERE ARE AT LEAST THREE ROWS OR THREE COLUMNS OF WHICH THE FIRST AND SECOND ONE MAY NOT CONTAIN INVALID NUMBERS ('NAN' VALUES). Toggles the 2D interpretation of the data as being distributed either on a grid or being distributed freely.

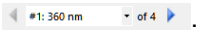
Important: VirtualLab Fusion identifies automatically which options are available. If, e.g. only one column of data is given, no 2D data interpretation is possible. If coordinates are to be read from the data, the first column (for column-wise interpretation) or the first row (for row-wise interpretation) has to contain strict monotonically ordered values.
If problems or inconsistencies occur, the info button ℹ besides the validity icon at the bottom will provide more information.

121.1.2.1 Preview of Multiple Subsets for 1D- and Gridless 2D Data Arrays

If the data are interpreted as a 1D data array and if there is more than one single set of data, there are two ways of (pre-) viewing these multiple subsets. Initially, the 1D view uses the so-called 'multigraph mode' (↪Sec. 13.4.1.2) which shows various subset graphs at once. In case the multigraph mode is disabled (via

context menu of the diagram), each single subset can be selected by the control above the actual preview.
In case the data are interpreted as a gridless 2D Data Array, the subset to be shown can be selected via the control as well.

121.1.2.2 Preview of Multiple Fields for 1D Harmonic Fields Sets

In case the data are interpreted as a 1D Harmonic Fields Set, the respective field to be shown can be selected via the control  .
Please note: The wavelengths shown within the selection control have just pre-defined values and can be changed on a later wizard page.

121.1.3 Coordinate Settings for the Imported Object

121.1.3.1 Coordinate Settings for an Imported Data Array

After defining how to convert the parsed text data into a data array, the properties of the coordinates can be adjusted. In case of one-dimensional data or gridded two-dimensional data arrays, the coordinate specifications can be done by using the parameters described in Sec. 24.4.
In case of gridless data, the description (i.e. the name or meaning of the coordinate) and the physical property (↪Sec. 5.1) of each axis can be set as well.
It is possible to copy coordinate settings by pressing the copy-button which allows to define an appropriate source data array for all coordinate parameters.

121.1.3.2 Coordinate Settings for an Imported Harmonic Field or Harmonic Fields Set

After defining how to convert the parsed text data into a Harmonic Field or Harmonic Fields Set, the properties of the coordinates can be adjusted.
The following parameters can be set:

ITEM	DESCRIPTION
Sampling Points	The number of sampling points in x- and y-direction. Note: This item is read-only.
Sampling Distance	The equidistant sampling distance between two adjacent data points in x-direction and y-direction (2D data only).
Array Size	The overall extension of the data in x-direction and y-direction (2D data only), symmetric to zero.

Since the number of data points is fixed, sampling distance and array size are not independent from each other. Changing one of the parameters will change the other one automatically and vice versa.

121.1.4 Value Properties for the Imported Object

121.1.4.1 Subset Settings for an Imported Data Array

The last step in the import wizard allows to specify properties of the imported subset(s). Each line in the table represents one subset for which the following parameters can be set:

ITEM	DESCRIPTION
Description	The name or meaning of the respective subset.
Physical Property	The kind of physical quantity (↪Sec. 5.1) of the respective subset's data.
Factor	A unit-less scaling factor to be multiplied to all values in the respective subset.

It is possible to copy subset settings by pressing the copy-button which allows to define an appropriate source data array for the subset parameters. If the source has less subsets than the imported one, only the parameters of the same number of subsets will be copied. If the source got more subsets than the imported one, the parameters of the supernumerary source subsets will be ignored.

121.1.4.2 Value Properties for an Imported Harmonic Field or Harmonic Fields Set

The last step in the import wizard allows to specify some more properties of the imported values:

ITEM	DESCRIPTION
Vectorial Component	Shall the imported values be interpreted as E_X or as E_Y component?
Field Quantity	What field quantity shall the data represent?
Wavelength	AVAILABLE IN CASE OF A SINGLE HARMONIC FIELD ONLY. The wavelength of the imported Harmonic Field.
Wavelength List	AVAILABLE IN CASE OF HARMONIC FIELDS SET ONLY. All wavelengths of the member Harmonic Fields.

121.2 Import of Plain Text Format (*.PTF)

The Plain Text Format (*.ptf) is a special text format, used only for field data (i.e. Harmonic Fields or Harmonic Fields Sets) and which is described in Sec. 128.2.2.
The import dialog is shown in Fig. 760.

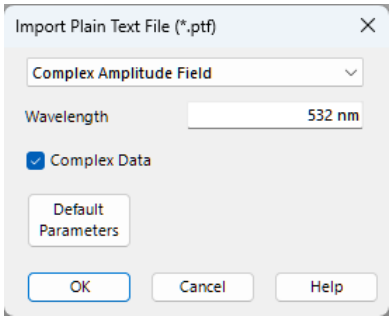


Figure 760. *The import dialog for the plain text format.*

It asks for the following parameters:

ITEM	DESCRIPTION
{Complex Amplitude Type}	Destination type of import: *Transmission* or *Complex Amplitude Field*.
Wavelength	Wavelength of the imported complex amplitude.
Complex Data	If checked the resulting complex amplitude stores real and imaginary part of the imported data. Otherwise only the real part is stored and the imaginary part is assumed to be zero.
Default Parameters	Resets the options above to their default values.

121.3 Import of Field Information Format (*.FIN)

The Field Information Format (*.fin) is a special text format, used only for field data (i.e. Harmonic Fields or Harmonic Fields Sets) and which is described in Sec. 128.2.3.
The import dialog is shown in Fig. 761.

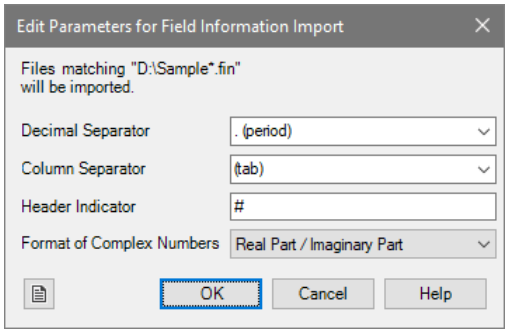


Figure 761. *The import dialog for the field information format.*

It asks for the following data:

ITEM	DESCRIPTION
Decimal Separator	You can either choose point or comma as decimal separator or enter an arbitrary character.
Column Separator	You can either choose one of the various predefined column separators or enter an arbitrary character.
Header Indicator	The first character of lines with additional information (e. g. the wavelength or the embedding material).
Format of Complex Numbers	The following formats are supported: • *Real Part / Imaginary Part*: {real part} + i{imaginary part} • *Amplitude / Phase*: {amplitude} · exp({phase} · i) • *MATLAB*, a more compact variant of the *Real Part / Imaginary Part* format: {real part}+{imaginary part}i • *PTF*, a format used for the PTF export (↪Sec. 121.2): ({real part}, {imaginary part})
(View Text File)	Opens an additional dialog allowing you to take a look into any of the files to be imported. In this way you can for example see what column separator is the correct one (“»” indicates a tab character).

At the top of the dialog the base file name is given. **All** files starting with the base file name are imported.

122 Import of Raster Graphic (Bitmap Image) Files

VirtualLab Fusion allows to import rastered image files, converting them into specific objects which can further be processed within the software. It can be done calling File > Import > Import Image File. This will open a wizard dialog which guides through the import process which collects all information needed for the conversion.

122.1 Image and Target Type

The first wizard page provides some information about the image's properties and asks for the target object type, the image should be converted to.

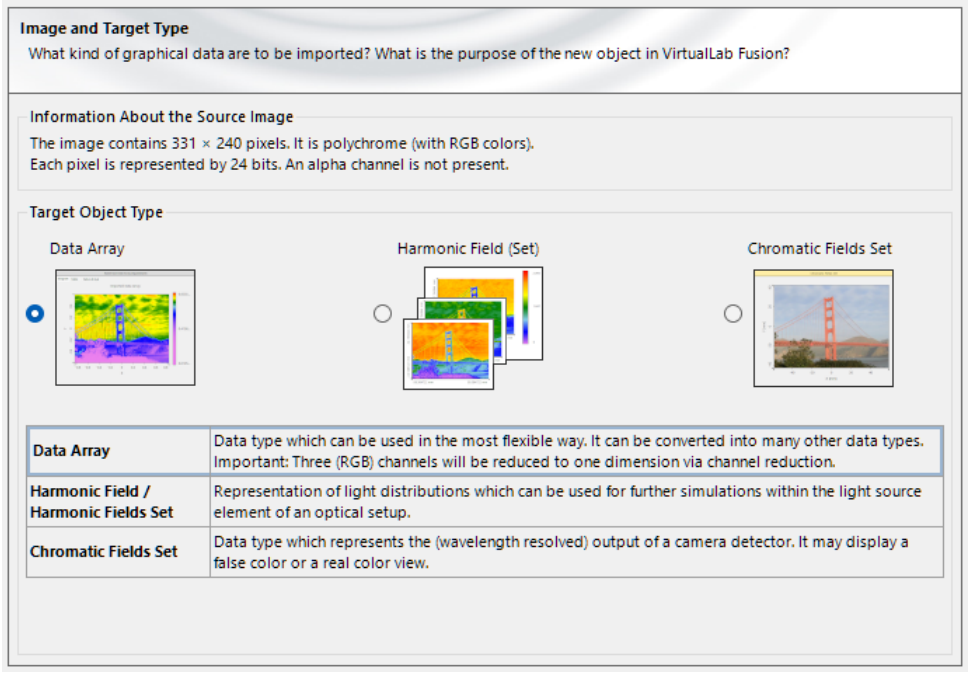


Figure 762. *First page of the import wizard. It provides some image information and asks for the target object type the image shall be converted into.*

ITEM	DESCRIPTION
Data Array	If chosen, the image will be converted into a Numerical Data Array ↪Sec. 13. This data type is the most flexible one, since it can be processed within VirtualLab Fusion in many scenarios and it can be converted into many other data types. However, if an image with three channels (RGB) is imported, the contained information will be reduced by some channel reduction method which extracts grayscale data to be stored as a single "channel" in the resulting data array.
Harmonic Field (Set)	If selected, the image will either be a Harmonic Field or a Harmonic Fields Set ↪Sec. 12, both representing lateral light distributions. Such objects can be used within light sources of optical setups.
Chromatic Fields Set	If chosen, the image will be converted into a Chromatic Fields Set ↪Sec. 14 which represents the wavelength resolved output of a Camera Detector.

122.2 Target Colors

The second wizard page asks for the kind of color-to-value-mapping which shall be used for converting the set of colors given in the source image to the range of values the target object will be filled with.

ITEM	DESCRIPTION
Monochromatic	AVAILABLE ONLY IF *DATA ARRAY* OR *HARMONIC FIELD (SET)* HAS BEEN CHOSEN AS TARGET OBJECT TYPE ON PAGE 1. All colors in the source image will be mapped onto one single, ordered set of values in the target object. In case of an RGB image, this means a channel reduction from three channels (R, G, and B) to one single channel is necessary before mapping.↪Sec. 122.2.1
General Polychromatic Mapping (3 Channels)	AVAILABLE ONLY IF *HARMONIC FIELD (SET)* OR *CHROMATIC FIELDS SET* HAS BEEN CHOSEN AS TARGET OBJECT TYPE ON PAGE 1. All colors in the source image will be mapped onto three sets of values (i.e. either three different Harmonic Fields in a Harmonic Fields Set or three different wavelength subsets in a Chromatic Fields Set) within the target object. The colors which can be calculated from the values in the target object may be (very) different from those in the source, so this mapping is particularly suitable for *false color views*. ↪Sec. 122.2.2
Real Color Mapping (RGB)	AVAILABLE ONLY IF *HARMONIC FIELD (SET)* OR *CHROMATIC FIELDS SET* HAS BEEN CHOSEN AS TARGET OBJECT TYPE ON PAGE 1. All colors in the source image will be mapped onto three sets of values (i.e. either three different Harmonic Fields in a Harmonic Fields Set or three different wavelength subsets in a Chromatic Fields Set) within the target object. The colors which can be calculated from the values in the target object are as close as possible to those in the source, so this mapping is particularly suitable for *real color views*. ↪Sec. 122.2.3

Each of these options will be discussed in detail in the following sections.

122.2.1 Monochromatic

This type of color mapping transfers all image colors to elements in a single, ordered set of values which is stored in the target object (i.e. a Data Array or a Harmonic Field).
In case of *monochromatic (grayscale) images*, this mapping is a simple assignment of a one-dimensional color scale to a one-dimensional value range: $\mathbb{R}^1 \rightarrow \mathbb{R}^1$. In case of *colored images*, we have to distinguish *indexed* images from *RGB* images, both requiring a mapping of a three-dimensional color scale to a one-dimensional value range: $\mathbb{R}^3 \rightarrow \mathbb{R}^1$.
In the following, these three kinds of color-to-value-mapping will be discussed shortly.

122.2.1.1 Importing a Grayscale Image Into a Monochromatic Object

The mapping of the colors of a grayscale image doesn't require any user input at all. The integer numbers within the single image channel are simply used as the values in the target object (but can be scaled at a later point).
In order to get an adequate idea of the imported data, the preview can be customized: A lot of view options are available via the context menu of the preview. Additionally, the display colors can be pre-selected via a menu which opens when the color table button in the line *Output Colors From 'Predefined Color Table'* is pressed. This display colors of the output object can be changed for its view at any later time ↪Sec. 11.2.4.

122.2.1.2 Importing an Indexed Color Image Into a Monochromatic Object

An indexed image contains an indexed color palette, which represents already a certain kind of a color-to-value-mapping: Each image pixel holds a palette index.
So, the mapping of the colors of an indexed color image doesn't require any user input at all on this wizard page. The integer numbers within the color palette are simply used as the values in the target object (but can be scaled at a later point).

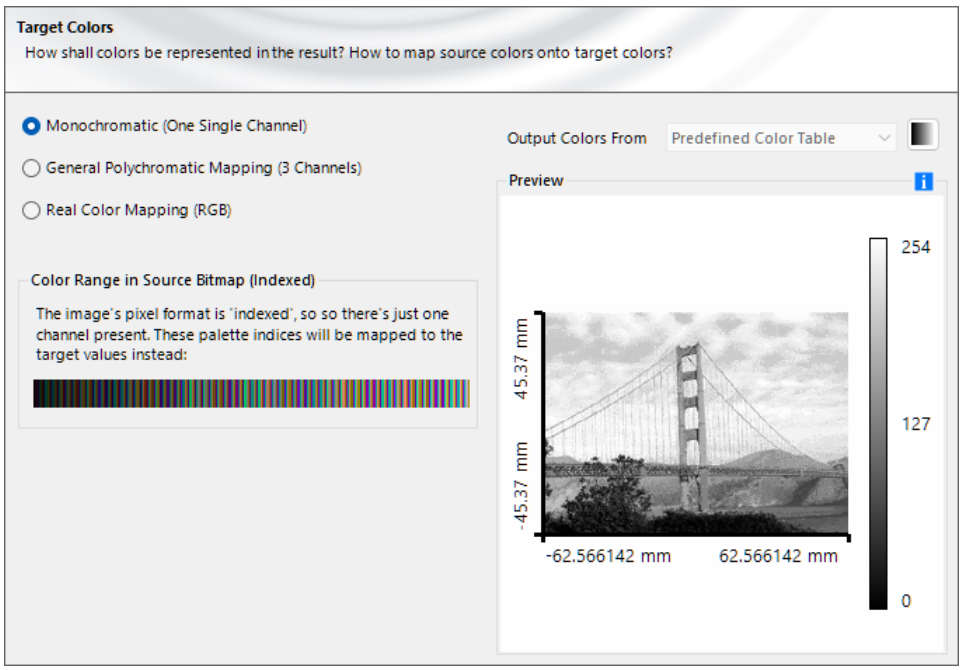


Figure 763. *Second page of the import wizard, showing the color mapping of the indexed palette of the source image.*

In order to get an adequate idea of the imported data, the preview can be customized: A lot of view options are available via the context menu of the preview. Additionally, the display colors can be pre-selected via a menu which opens when the color table button in the line *Output Colors From 'Predefined Color Table'* is pressed. This display colors of the output object can be changed for its view at any later time ↪Sec. 11.2.4.

122.2.1.3 Importing an RGB Color Image Into a Monochromatic Object

An RGB image contains three channels, i.e. three sets of coordinates in the RGB color space.
Since importing such an image requires a $\mathbb{R}^3 \rightarrow \mathbb{R}^1$ mapping of colors to values, the user has to define a *Channel Reduction Method* on this wizard page.

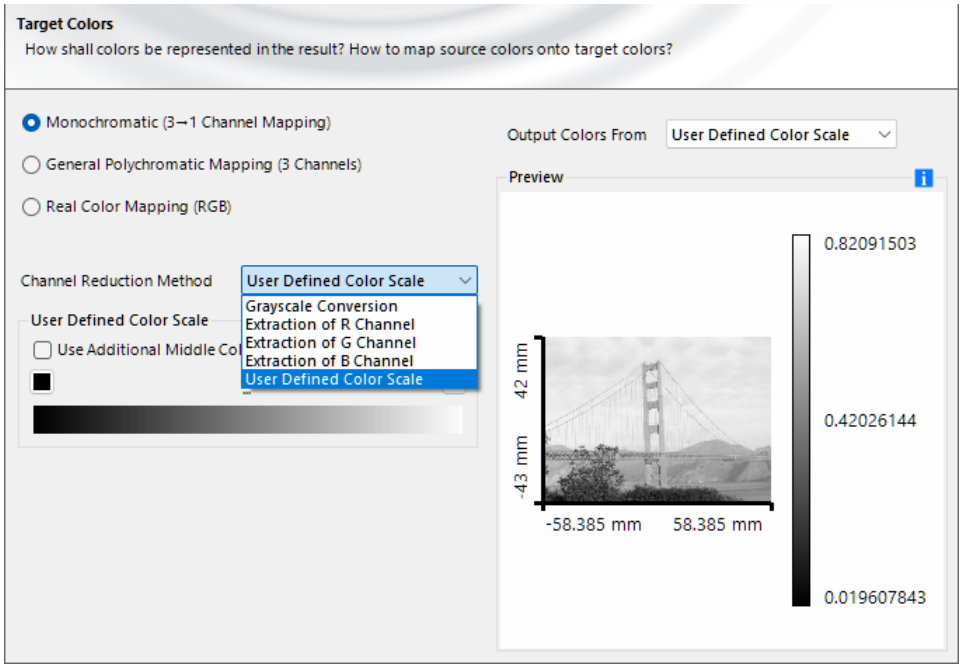


Figure 764. *Second page of the import wizard, providing channel reduction options for RGB images.*

The following channel reduction methods are available:

ITEM	DESCRIPTION
Grayscale Conversion	If selected, the color-to-grayscale-conversion of the Little CMS library is used to get a single channel which then will be mapped to the target value range $[0, 1]$ (re-scalable at a later point).
Extraction of R/G/B Channel	If this option is chosen, one of the three channels R, G, and B is separated. This single channel will be mapped to the target value range $[0, 1]$ (re-scalable at a later point).
User Defined Color Scale	If chosen, the user may define an own color scale based channel reduction ↪Sec. 145.8.

In order to get an adequate idea of the imported data, the preview can be customized: A lot of view options are available via the context menu of the preview. Additionally, the display colors can be pre-selected:

ITEM	DESCRIPTION
Output Colors From Predefined Color Table	A menu will open when the color table button is pressed. It allows to select a color table for the display colors.
Output Colors From User Defined Color Scale	AVAILABLE ONLY IF *USER DEFINED COLOR SCALE* IS SELECTED AS *CHANNEL REDUCTION METHOD*. The color scale defined for the channel reduction will be used as display colors as well.

The selected display colors of the output object can be changed at any later time ↪Sec. 11.2.4.

122.2.2 General Polychromatic Mapping (3 Channels)

In case this mapping is chosen, each of the three RGB channels within the image will be mapped to one wavelength. Each r-, g-, or b-value will be scaled into the interval $[0, 1]$ followed by a multiplication with a

certain, channel specific weight. Since arbitrary wavelengths and weights can be defined, this mapping is particularly suited for importing false-color images. The configuration dialog is shown in Fig. 765.

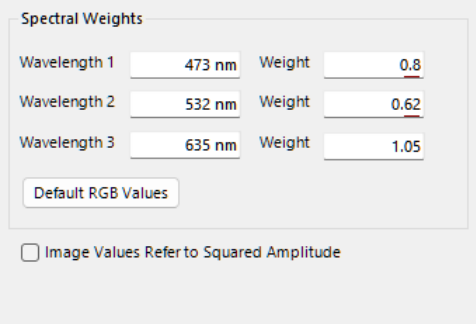


Figure 765. *Control for configuring the general polychromatic mapping.*

ITEM	DESCRIPTION
Wavelength 1/2/3	The wavelengths which shall correspond to each of the channels, resp. The first wavelength gets the values from the B channel and the third wavelength from the R channel values.
Weight	The multiplicative weights for the channels.
Default RGB Values	Pressing this button will reset the *Wavelength*s and *Weight*s to the default values for the currently set color system ↪Sec. 6.7.1. These defaults are chosen in a way that the RGB triple $(255, 255, 255)$ gives White after mapping to the three wavelengths.
Image Values Refer to Squared Amplitude	If checked, the image values are mapped to squared amplitude values rather than to amplitude values within the resulting field object.

122.2.3 Real Color Mapping (RGB)

This option is particularly suited for importing real-color images. The import process maps the three RGB channels to three wavelengths in a way that the original appearance of the image is kept if the target field object is shown in its real-color mode ↪Sec. 14.2. The dialog shown in Fig. 766 is used for the configuration.

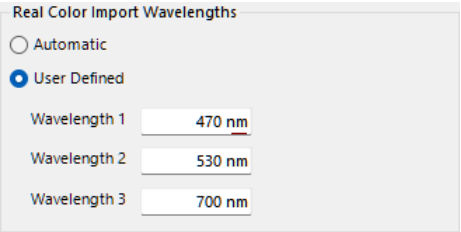


Figure 766. *Control for configuring the real color mapping.*

ITEM	DESCRIPTION
Automatic	If chosen, the mapping of the image channels to the three wavelengths is done fully automatic.
User Defined	If selected, the target wavelengths may be user defined.
Wavelength 1/2/3	ONLY AVAILABLE IF *USER DEFINED* IS SELECTED. The wavelengths which shall correspond to each of the channels, resp. The first wavelength gets the values from the B channel and the third wavelength from the R channel values. The weights will be calculated by VirtualLab Fusion for each of the wavelengths automatically. Warning: There is a high probability for out-of-gamut errors while converting if these values differ from the automatically determined ones – so the result's colors may look strange.

122.3 Coordinate Settings

The third wizard page allows to set coordinate specific options. These differ for Data Arrays and Chromatic Fields Sets on the one hand and Harmonic Fields and Harmonic Fields Sets on the other hand.

122.3.1 Coordinate Settings for Imported Data Arrays or Chromatic Field Sets

The coordinate settings can be changed via the dialog shown in Fig. 767.

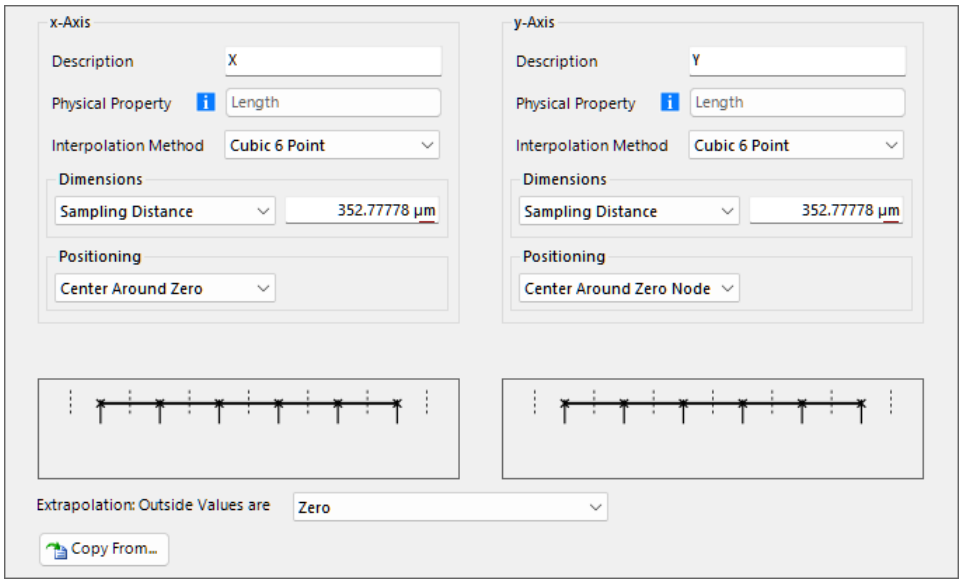


Figure 767. *Coordinate Settings for Imported Data Arrays or Chromatic Field Sets.*

For the description of these options please see Sec. 24.4.1.

122.3.2 Coordinate Settings for Imported Harmonic Fields or Harmonic Field Sets

The coordinate settings can be changed via the dialog shown in Fig. 768.

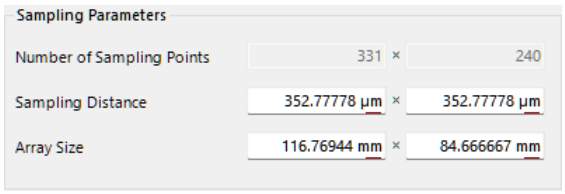


Figure 768. *Coordinate Settings for Imported Harmonic Fields or Harmonic Field Sets.*

The available options are the following:

ITEM	DESCRIPTION
Sampling Points	The number of sampling points in x- and y-direction. Note: This item is read-only.
Sampling Distance	The equidistant sampling distance between two adjacent data points in x-direction and y-direction (2D data only).
Array Size	The overall extension of the data in x-direction and y-direction (2D data only), symmetric to zero.

Since the number of data points is fixed, sampling distance and array size are not independent from each other. Changing one of the parameters will change the other one automatically and vice versa.

122.4 Data Value Properties

For Data Arrays, Harmonic Fields and Harmonic Fields Sets some more options for specifying the properties of the stored values are available.

122.4.1 Subset Properties for Imported Data Arrays

The dialog shown in Fig. 769 allows some data value properties to be set.

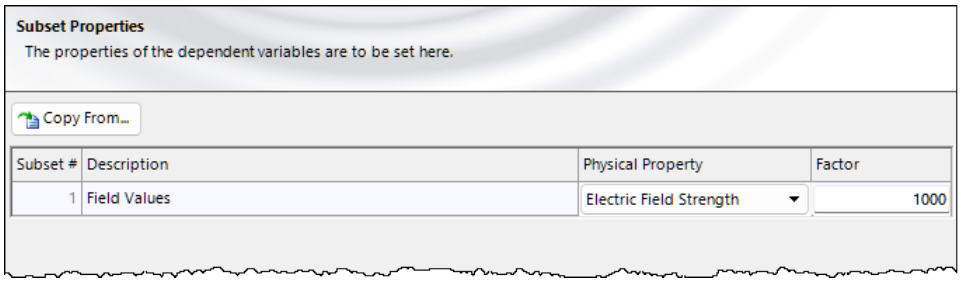


Figure 769. *Subset properties for Data Arrays.*

The available options are the following:

ITEM	DESCRIPTION
Description	A description for the kind of imported values. Will appear as axis title in the output view.
Physical Property	The physical property of the imported values.
Factor	A scaling factor which will be applied to all imported values.

122.4.2 Value Properties for Imported Harmonic Fields or Harmonic Field Sets

The dialog shown in Fig. 769 allows some field value properties to be set.

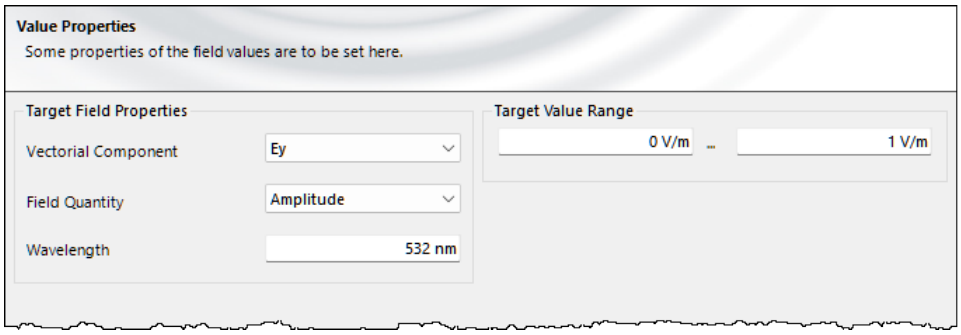


Figure 770. *Field value properties for Harmonic Fields.*

ITEM	DESCRIPTION
Vectorial Component	Shall the imported data be interpreted as E_X or E_Y component?
Field Quantity	ONLY FOR A SINGLE, MONOCHROMATIC HARMONIC FIELD. Which field property should the data be interpreted as?
Wavelength	ONLY FOR A SINGLE, MONOCHROMATIC HARMONIC FIELD. The wavelength belonging to the imported Harmonic Field.
Target Value Range	ONLY FOR A SINGLE, MONOCHROMATIC HARMONIC FIELD. The range the values shall be scaled to.

123 Import of Code V Format (*.DAT)

The file format of the ”CODE V optical design software” contains field data which are imported into VirtualLab Fusion as a Harmonic Field. For more information aboout this format ↪Sec. 128.2.4.
There is no import dialog for this text format.

124 Import of Zemax OpticStudio® Beam File Binary Format (*.ZBF)

Zemax OpticStudio® Beam Files are stored either in text format or in binary format. VirtualLab Fusion is able to import beam files in binary format. After importing the data of a *.zbf file into a harmonic field, some additional data are written into the messages tab.
There is no import dialog for this file format, but there is the possibility to let VirtualLab Fusion calculate the irradiance (↪Sec. 142.5.3) for the imported field data.

125 Legacy Import Methods For Field Data

There are some import methods still available in VirtualLab Fusion which will be replaced in the next version. These methods are explained in the following for the sake of completeness.

125.1 Legacy Import of Harmonic Field Data from Bitmap Files

The light source types Panel Type Source and Scanning Source allow to import a Chromatic Fields Set from an image file as described here.

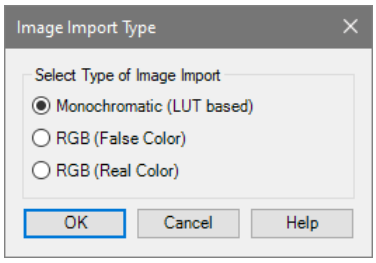


Figure 771. *Dialog to select how a bitmap shall be imported.*

If you want to import a RGB raster graphics file, you can choose between three options:

ITEM	DESCRIPTION
Monochromatic (LUT based)	A RGB image will undergo a channel reduction first: The three channels (R, G, and B) of the image are reduced using a color scale, also called look-up table (LUT). These new colors are linearly transformed to values of the selected field quantity and vectorial component, then. ↪Sec. 125.1.1 There is also a special variant for importing an intensity distribution into the Diffractive Optics Package, ↪Sec. 125.1.2.
RGB (False Color)	The bitmap is imported into a polychromatic Harmonic Fields Set. Each of the channels R, G, and B is stored into one Harmonic Field. Their wavelengths can be set and weighted freely. ↪Sec. 125.1.3
RGB (Real Color)	The bitmap is imported into a polychromatic Harmonic Fields Set in a way that guarantees the best color fidelity if evaluated with the Camera Detector (↪Sec. 75.5.2; in *Real Color* mode). ↪Sec. 125.1.4

The following image formats are supported: Windows Bitmap file (*.bmp); Portable Network Graphic (*.png); JPEG File Interchange Format (*.jpg, *.jpeg); and Tagged Image File Format (*.tif, *.tiff).
If you import a 16 bit grayscale image, the *Monochromatic (LUT based)* is started automatically.
The sampling distance of the resulting Harmonic Field or Harmonic Fields Set is calculated from the resolution stored in the file. For example the bitmap export of VirtualLab Fusion sets this value according to the original sampling distance. If no resolution is stored in the bitmap file the resolution of the screen is taken.

125.1.1 Importing Monochromatic Images

The necessary channel reduction from colored to monochrome using a color scale (or LUT) works exactly as described in Sec. 145.8.

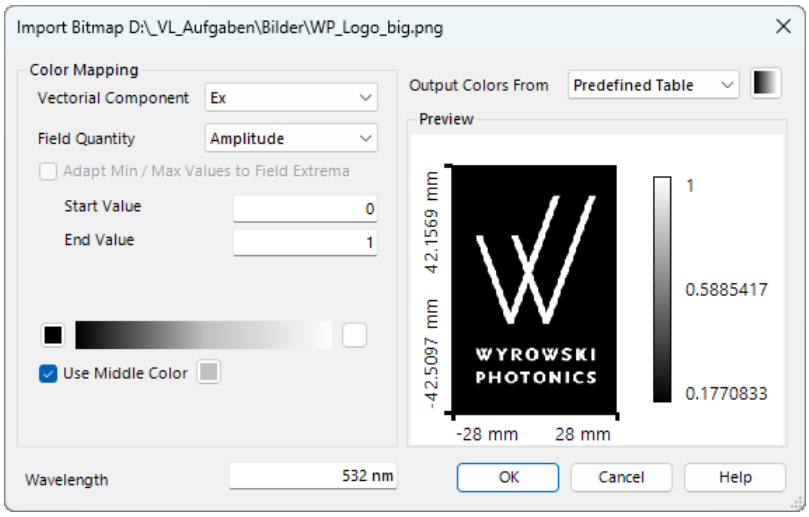


Figure 772. *Options dialog for monochromatic bitmap import.*

ITEM	DESCRIPTION
Vectorial Component	The vectorial component which is encoded in the bitmap data.
Field Quantity	The field quantity which is encoded in the bitmap data. After import, the selected *Field Quantity* is shown by default.
Start Value	The smallest value of the *Field Quantity*. The color at the left of the color scale is assumed to be this value.
End Value	The largest value of the *Field Quantity*. The color at the right of the color scale is assumed to be this value.
Use Middle Color	If checked, you can set a middle color for the color scale if the bitmap to be imported is given in a three-color scale.
Wavelength	The wavelength the generated harmonic field will have.
Output Colors From Predefined Table	If selected, the color table in the output's view can be specified independently from the color scale used for the input mapping color → value.
	ONLY AVAILABLE IF OUTPUT COLORS FROM *PREDEFINED TABLE* HAS BEEN SELECTED. The color table to be used in the output's view can be selected here.
Output Colors From Input Mapping	If selected, the color scale used for the input mapping will be used as color table in the output's view as well.

If you import a gray scale image, the options for defining a color scale are not visible. You can only import a gray scale.

125.1.2 Importing Monochromatic Images as Intensity Distribution

This import is only available for the Arbitrary Array Beam Splitter Session Editor as well as the Pattern Generating Diffuser Session Editor of the Diffractive Optics Package.

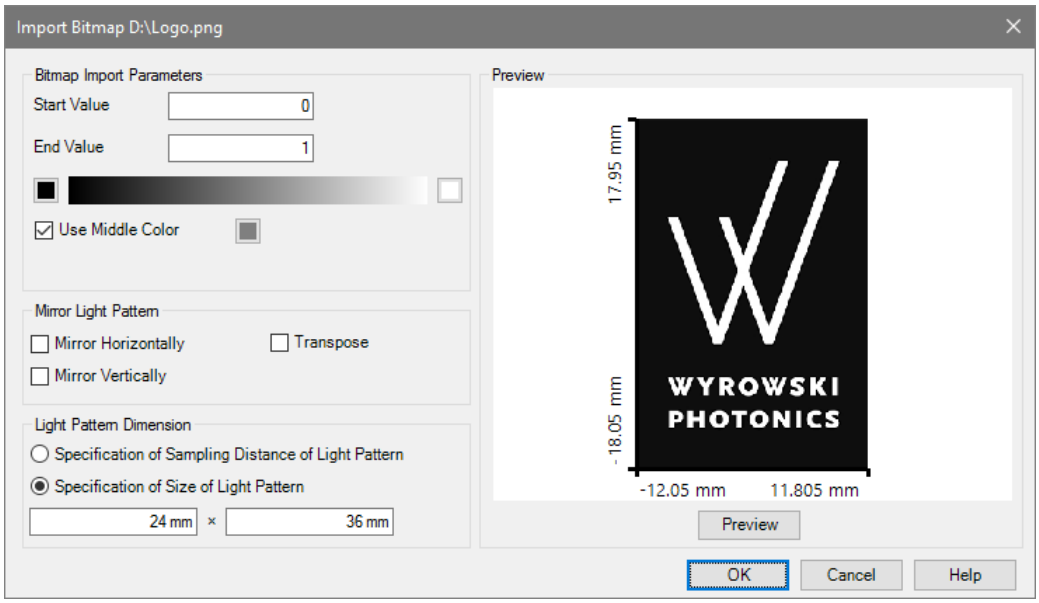


Figure 773. *Options dialog for importing intensities from a bitmap.*

The dialog shown in Fig. 773 provides the following options:

ITEM	DESCRIPTION
Start Value	The smallest intensity. The color at the left of the color scale is assumed to represent this value.
End Value	The largest intensity. The color at the right of the color scale is assumed to represent this value.
Use Middle Color	If checked, you can set a middle color for the color scale if the bitmap to be imported is given in a three-color scale.
Mirror Horizontally	Applies transformation $f(x,y) \rightarrow f(-x,y)$, that is the data is mirrored horizontally by a mirror that corresponds to the y-axis.
Mirror Vertically	Applies transformation $f(x,y) \rightarrow f(x,-y)$, that is the data is mirrored vertically by a mirror that corresponds to the x-axis.
Transpose	Applies transformation $f(x,y) \rightarrow f(y,x)$, that is the data is mirrored by a mirror that corresponds to a diagonal in the x-y-plane.
Light Pattern Dimension	ONLY FOR PATTERN GENERATING DIFFUSER SESSION EDITOR Allows you to specify the physical size of the imported light pattern. This can be done either by *Specification of Sampling Distance of Light Pattern* or by *Specification of Size of Light Pattern*.
Preview	If this button is pressed, a preview of the bitmap is (re)calculated. Recalculation is not done automatically as this can be very time-consuming.

The color scale which is defined here is needed for doing a channel reduction as described in Sec. 145.8.

125.1.3 Importing False Color RGB Images

The result of the import process is a polychromatic harmonic fields set with three fields of three different wavelengths. These wavelengths can be determined and weighted by the user.

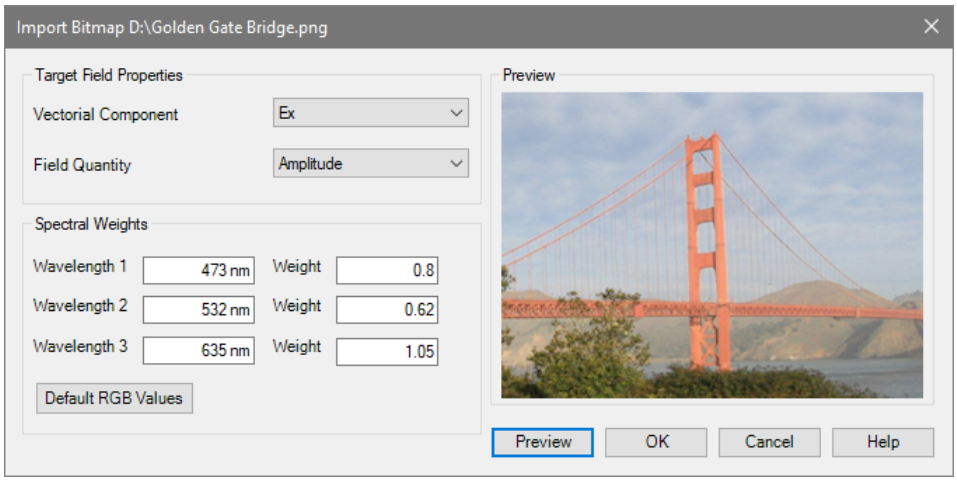


Figure 774. *Options dialog for false color bitmap import.*

ITEM	DESCRIPTION
Vectorial Component	The vectorial component the bitmap information shall be converted to.
Field Quantity	The field quantity the bitmap values stand for.
Wavelength 1/2/3	The wavelengths of the three harmonic fields the bitmap channels are matched with.
Weight	The (intensity) weight the channel is multiplied with.
Default RGB Values	By clicking this button the *Wavelength*s and *Weight*s are set to the default values. These are values which produce the most natural false color image.
Preview	By clicking this button you can see how the imported image would look like if evaluated with the Camera Detector (↪Sec. 75.5.2; in *Real Color* mode).

125.1.4 Importing Real Color RGB Images

The result of the import process is a polychromatic harmonic fields set with three fields of three different wavelengths. These wavelengths are determined from the used color system if *Automatic* is chosen. Then the Camera Detector (↪Sec. 75.5.2; in *Real Color* mode) reproduces Hue and Saturation (H and S in the HSV color system) of the original image exactly (if no gamut errors occur). The Value (V in the HSV color system) may differ slightly due to the interpolation. This real color import is based upon a color transform from the bitmap's color space to the color space used in VirtualLab Fusion (usually 'VirtualLab Color Space').

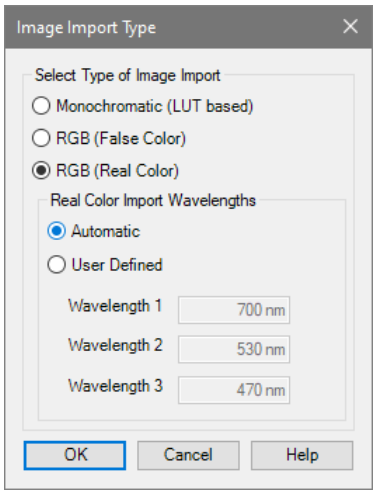


Figure 775. *Options dialog for real color bitmap import.*

ITEM	DESCRIPTION
Automatic	Use three wavelengths that are suitable for the color system used for display, so that minimal out-of-gamut errors occur.
User Defined	Choose three wavelengths (*Wavelength 1/2/3*) for the color space conversion. Warning: There is a very high probability for out-of-gamut errors while converting if these values differ from the automatically determined ones, so the result's colors may look strange.

125.2 Legacy Import of Intensities From Text Files

This import is only available for the Arbitrary Array Beam Splitter Session Editor as well as the Pattern Generating Diffuser Session Editor of the Diffractive Optics Package.

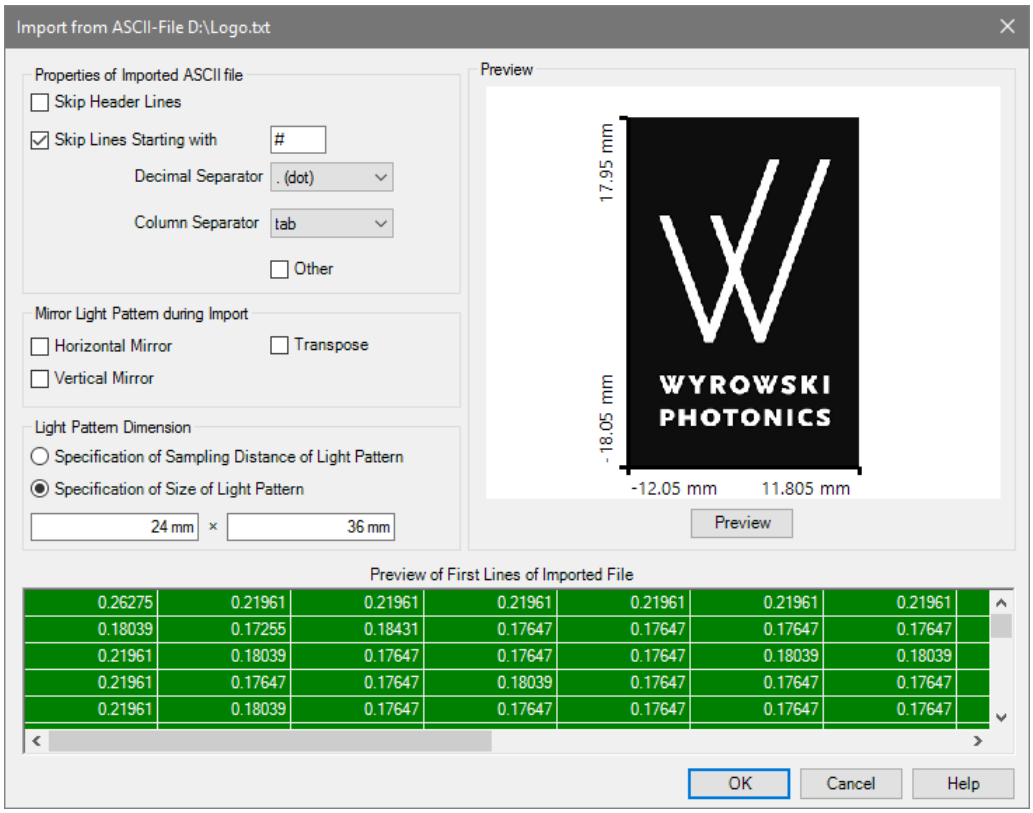


Figure 776. *Options dialog for importing intensities from an ASCII file.*

The dialog shown in Fig. 776 provides the following options:

ITEM	DESCRIPTION
Skip Header Lines	Feature to skip a given number of lines at the beginning of the file.
Skip Lines Starting with	Feature to skip lines starting with the given character.
Decimal Separator	Choose between "." and ",".
Column Separator	Choose form list of predefined characters or enter custom one.
Mirror Horizontally	Applies transformation $f(x,y) \rightarrow f(-x,y)$, that is the data is mirrored horizontally by a mirror that corresponds to the y-axis.
Mirror Vertically	Applies transformation $f(x,y) \rightarrow f(x,-y)$, that is the data is mirrored vertically by a mirror that corresponds to the x-axis.
Transpose	Applies transformation $f(x,y) \rightarrow f(y,x)$, that is the data is mirrored by a mirror that corresponds to a diagonal in the x-y-plane.
Light Pattern Dimension	ONLY FOR PATTERN GENERATING DIFFUSER SESSION EDITOR Allows you to specify the physical size of the imported light pattern. This can be done either by *Specification of Sampling Distance of Light Pattern* or by *Specification of Size of Light Pattern*.
Preview	If this button is pressed, a preview of the bitmap is (re)calculated. Recalculation is not done automatically as this can be very time-consuming.
{Preview of First Lines of Imported File}	Table showing the first lines of the imported text file as parsed by VirtualLab Fusion. Cells that cannot be parsed are marked red.

126 Export of Data Arrays

One subset of a VirtualLab Fusion Data Array can be exported to a text file in ASCII format. Fig. 777 shows the configuration dialog for this export.

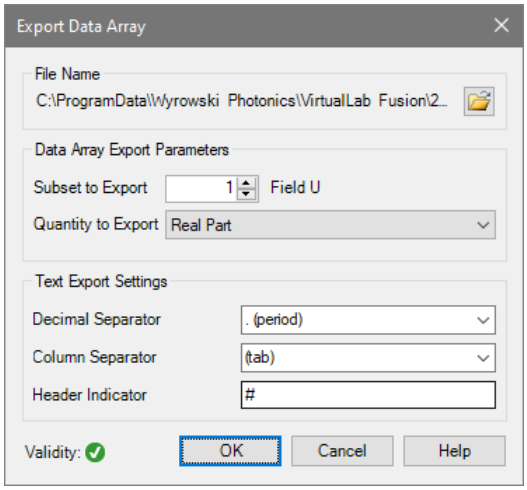


Figure 777. *The dialog to specify the text export for data arrays.*

The following parameters can be specified:

ITEM	DESCRIPTION
File Name	The user can specify the file name which shall be used to export the selected subset and the selected quantity.
Subset to export	You can specify which subset shall be exported. This option is only available if the data array has more than one subset. Otherwise the single subset within the data array will be exported.
Quantity to export	If the selected data subset is complex the user can specify which quantity shall be used for the export. The user can select between real part, imaginary part, amplitude, phase or squared amplitude.
Decimal Separator	You can either choose period or comma as decimal separator or enter an arbitrary character.
Column Separator	You can either choose one of the various predefined column separators or enter an arbitrary character.
Header Indicator	The ASCII export allows you to export additional information of the data array. These information (including sampling distance and number of sampling points) are shown at the beginning of the resulting text file in lines starting with the specified *Header Indicator*.

This dialog uses a validity indicator (↪Sec. 5.11) which shows a red-white cross and an info button if you enter an invalid decimal separator, column separator, or header indicator. Furthermore it shows a warning if the specified file already exists.

127 Export of Chromatic Fields Sets

Chromatic Fields Sets can be exported into a slightly modified Field Information format (↪Sec. 128.2.3).
It contains a header at the beginning of the file into which for example the wavelength and the sampling distance are written. Each header line starts with a specific character, the *header indicator*.

Then follows the actual data whereas a number (the squared amplitude) is written per sampling point. Each row in the field data is written to one line of the resulting text file.
Distinct wavelengths are exported into distinct files bearing the same base file name followed by the wavelength.

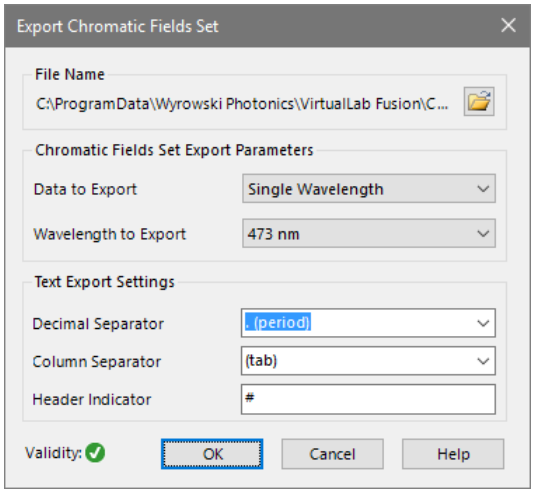


Figure 778. *The export dialog for Chromatic Fields Sets.*

The export dialog (↪Fig. 778) for the Field Information format has the following controls:

ITEM	DESCRIPTION
File Name	Shows the current file name. Via the button you can browse to the place where you want to store the file and change the actual file name.
Data to Export	ONLY FOR CHROMATIC FIELDS SET WITH MORE THAN ONE WAVELENGTH You can either export *All Wavelengths* into separate files, select a *Single Wavelength* to export or export the (incoherent) *Summation* of the data of all wavelengths.
Wavelength to Export	ONLY IN *SUMMATION* MODE FOR CHROMATIC FIELDS SET WITH MORE THAN ONE WAVELENGTH Allows you to select one distinct wavelength of the Chromatic Fields Set to export.
Decimal Separator	You can either choose period or comma as decimal separator or enter an arbitrary character.
Column Separator	You can either choose one of the various predefined column separators or enter an arbitrary character.
Header Indicator	The first character of lines with additional information (e. g. the wavelength or the sampling distance).
Validity	This control (↪Sec. 5.11) shows a red-white cross and an info button if you enter an invalid decimal separator, column separator, or header indicator.

128 Export of Harmonic Fields and Harmonic Field Sets

Field data (Harmonic Fields or members of Harmonic Field Sets) may be exported as rastered image files ↪Sec. 128.1 or as text files ↪Sec. 128.2.

128.1 Exporting Field Data as Raster Graphics (Bitmap Image) File

Exporting a Harmonic Field or Harmonic Fields Set as an image file allows choosing from three possible file formats:

IMAGE TYPE	DESCRIPTION
24 bit RGB Raster Graphics	Exports the field into a RGB color image with 8 bit or 256 different levels per color channel (red, green, blue). Supports the following file formats: Windows Bitmap file (*.bmp); Portable Network Graphic (*.png); JPEG File Interchange Format (*.jpg, *.jpeg); and Tagged Image File Format (*.tif, *.tiff). Opens the dialog shown in Fig. 779.
16 bit Grayscale Raster Graphics	24 bit RGB images can only contain 256 gray levels, whereas 16 bit gray scale images support 65 536 gray levels. Such a file can only be saved as Portable Network Graphic (*.png) or Tagged Image File Format (*.tif, *.tiff). Opens the dialog shown in Fig. 779.
Vector Graphics	Exports the currently visible view to an Enhanced Windows Metafile (*.emf), a vector format. In this case the dialog described Sec. 11.6.1 is shown.

The maximum size of an image file is 4 gigabytes, which restricts the image size to roughly 36 000 × 36 000 pixels for 24 bit RGB images and 44 000 × 44 000 pixels for 16 bit grayscale images.

Please note: Only one vectorial component and one field quantity can be exported at a time. In case of a Harmonic Fields Set, always the currently shown member field is exported.

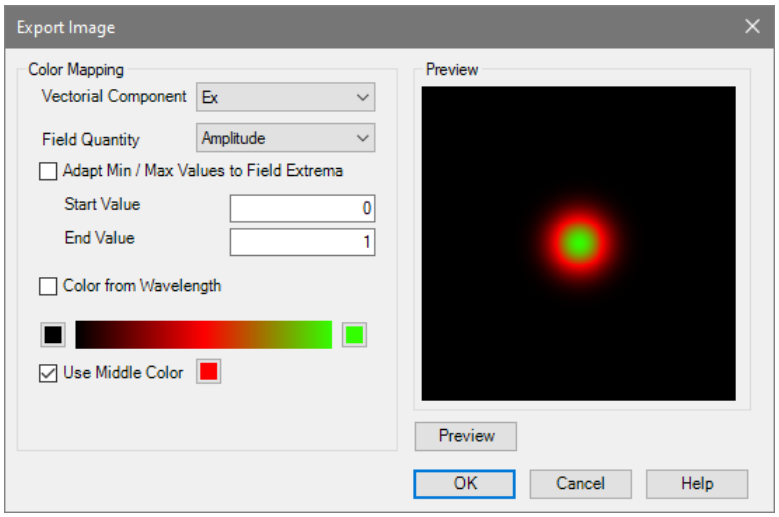


Figure 779. *The dialog for exporting a harmonic field to a raster graphics file.*

The *Field Quantity* of one *Vectorial Component* will be exported. If you export a phase distribution, an analytical spherical phase radius is not exported.
If a 24 bit RGB image is to be generated you can configure the color mapping via the control described in ↪Sec. 5.12.
Additionally a preview is available which can be updated with the *Preview* button.
The bitmap size is automatically calculated from the number of sampling points of the field. The resolution of the resulting bitmap file is set according to the sampling distance.

128.2 Exporting Field Data as Text File

We call 'text files' all file formats which are 'human-readable' (in contrast to e.g. binary formats which are 'machine-readable'). We further distinguish the export of general text formats (referred to as 'ASCII' files, ↪Sec. 128.2.1) from exporting more specific formats, namely Plain Text Format ↪Sec. 128.2.2 and Field Information format ↪Sec. 128.2.3.

128.2.1 Exporting Field Data in ASCII Format (*.TXT, *.CSV)

FOR HARMONIC FIELDS ONLY.

Text files in ASCII format must consist of separated real numbers.
A single field quantity of a harmonic field can be exported to an ASCII text file. Every line of the exported ASCII text consist of separated real numbers which represent one row of the complex amplitude. Several header lines may be prepended with the following information.

- file creation date and time
- complex amplitude type (Harmonic Field or Jones Matrix Transmission)
- number of sampling points and sampling distance (Introduction of Part VIII)
- whether the complex amplitude has an imaginary component or not
- spherical phase radius (↪Sec. 12.1.1)
- the wavelength of the harmonic field
- the stored field component (↪Sec. 12.2.2) and field quantity (↪Sec. 11.1)

The first character on header lines is always "#".

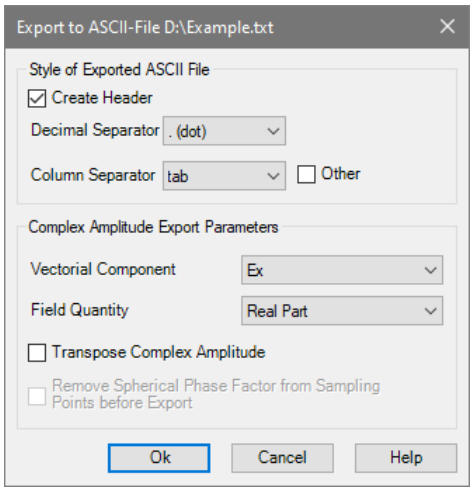


Figure 780. *Dialog to adjust options for ASCII export.*

The following options can be set in the dialog shown in Fig. 780.

ITEM	DESCRIPTION
Create header	Forces creation of a prepending header as described above.
Decimal Separator	Choose between "." and ",".
Column Separator	Choose either from a list of predefined characters or choose an arbitrary column separator by selecting *Other*.
Field Quantity	Sets the field quantity to be exported from the harmonic field or transmission.
Vectorial Component	Sets vectorial component to be exported from the complex amplitude. This item is only available for harmonic fields.
Transpose Complex Amplitude	The complex amplitude is transposed (↪Sec. 22.6) before exporting.
Remove Spherical Phase Factor from Sampling Points before Export	Removes spherical phase factor from sampling points before export.

128.2.2 Exporting Field Data in Plain Text Format (*.PTF)

FOR HARMONIC FIELDS ONLY.

PTF files use a special format to store complex or real fields: The first three lines contain header information including the date of creation. The first character of a header lines is always "#". The fifth line indicates the size of the field; for instance "128 128". All following lines until end of file store sampling points; beginning at the bottom left and ending at the top right corner of the complex amplitude. There are two different formats for representing either real or complex sampling points:

- Complex values $\rightarrow (Re(value), Im(value))$.
- Real values $\rightarrow value$.

Of course, all elements of a file must have the same representation.
There is no export dialog for this text format.

128.2.3 Exporting Field Data in Field Information Format (*.FIN)

The Field Information format is the only text format capable of storing the complete field information (all modes and all field quantities). But in most cases, VirtualLab Fusion is the only software capable of reading and interpreting all these information.
The format contains a header at the beginning of the file into which, for example, the wavelength, the embedding material, and the sampling distance are written. Each header line starts with a specific character, the *header indicator*.
Then follows the field data whereas a complex number is written per sampling point. Each row in the field data is written to one line of the resulting text file.
If the file to be exported is a Harmonic Fields Set with multiple modes or a locally polarized field, the data are split into multiple files bearing the same base file name followed by either "Mode#{number}_{wavelength}" or "_Ex" / "_Ey".
The export dialog for this format is shown in Fig. 781.

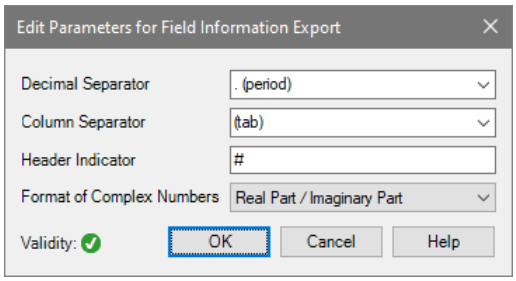


Figure 781. *The export dialog for the field information format.*

This dialog has the following controls:

ITEM	DESCRIPTION
Decimal Separator	You can either choose point or comma as decimal separator or enter an arbitrary character.
Column Separator	You can either choose one of the various predefined column separators or enter an arbitrary character.
Header Indicator	The first character of lines with additional information (e. g. the wavelength or the embedding material).
Format of Complex Numbers	The following formats are supported: • *Real Part / Imaginary Part*: {real part} + i{imaginary part} • *Amplitude / Phase*: {amplitude} · exp({phase} · i) • *MATLAB*, a more compact variant of the *Real Part / Imaginary Part* format: {real part}+{imaginary part}i • *PTF*, a format used for the PTF export (↪Sec. 121.2): ({real part}, {imaginary part})
Validity	This control (↪Sec. 5.11) shows a red-white cross and an info button if you enter an invalid decimal separator, column separator, or header indicator.

128.2.4 Exporting Field Data in Code V Format (*.DAT)

For Harmonic Fields only.

Code V files consist of two parts: the header contains information like data type and wavelength and so on, and the following second part contains the actual data. Lines starting with a '!' are ignored.
The header lines include the following information:

- creation date and exported field components as comments
- data type
- wavelength
- real part of the complex refractive index of the medium in which the harmonic field is embedded.
- grid spacing (in VirtualLab Fusion: sampling distance)
- array size (in VirtualLab Fusion: sampling points)

Note that the data is always exported as Code V DataType *VGridSpatial*, i. e. with 6 values per sampling point (real and imaginary part of E_x, E_y, and E_z, respectively). Each row of the field data in VirtualLab Fusion is exported to one line in the Code V file.
There is no export dialog for this text format.

129 Export of Animations

Via File > Export you can

- export the current frame of the animation to a bitmap, .png, or .jpg file
- export the whole animation as an animated GIF file (↪Sec. 129.1)
- export the whole animation as an .avi video file. Note that for technical reasons the frames per second set up in the options dialog (↪Sec. 20.3) are rounded internally to the next integer or
- create an overview image of all frames (↪Sec. 129.2).

129.1 Export as Animated GIF

Animated GIF files have two limitations:

1. The GIF format uses a color palette of 256 colors only, so the bitmaps in the animation (which use true colors) have to be converted. Thus if you start the export to animated GIF files, you are first asked whether you want to use an *Adaptive* color scale which generates a palette of 256 colors so that the converted bitmaps differ as little as possible from the original ones – or a *Grayscale* which uses 256 shades of gray, i. e. only the brightness information of the bitmaps in the animation is maintained.

2. The frame duration is taken from the animation options (↪Sec. 20.3). However, GIF is limited to frame durations being a multiple of 10 milliseconds. If this is not the case rounding is done automatically and a warning is shown.

After deciding about the color scale you can specify the name of the exported file.

129.2 Overview Image of an Animation

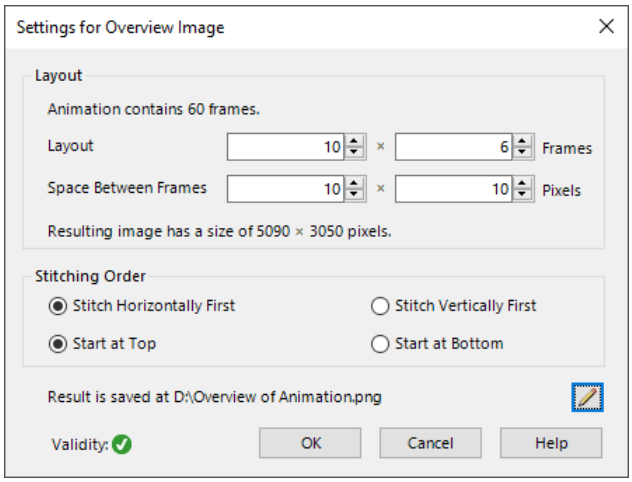


Figure 782. *Edit dialog for creating an overview image of an animation.*

Via File > Export > Overview Image you can create an image which shows all (or some, depending on the configuration) frames of an animation side by side – like an index print. In the corresponding edit dialog (↪Fig. 782) you can configure the following.

ITEM	DESCRIPTION
Layout	As an information, the number of frames in the animation is shown and the size of the resulting image. You can set the general *Layout*, i. e. the number of columns and rows into which the frames are written. If the number of frames does not match the number of columns times the number of rows, a warning is shown by the Validity Control in the bottom left corner of the dialog (↪Sec. 5.11). Furthermore you can define an additional *Space Between Frames* to separate the columns and rows. It is filled with an transparent color.
Stitching Order	Defines the order in which the individual frames are written into the columns and rows. A table below illustrates the different settings. *Stitch Horizontally First* means that one row is filled before a new row is started. *Stitch Vertically First* means that one column is filled before a new column is started. *Start at Top / Bottom* defines whether first the top most row is filled or the bottom most one.
Result is saved at …	With the button you can set the path and name of the resulting overview image. The extension of the file name defines the used image codec (bitmap, PNG with lossless compression, JPG with lossy compression, or TIF).

The following table illustrates how the different stitching orders influence the location of 6 frames on a 3 × 2 layout.

	Stitch Horizontally First	*Stitch Vertically First*
Start at Top	1; 2; 3 4; 5; 6	1; 3; 5 2; 4; 6
Start at Bottom	4; 5; 6 1; 2; 3	2; 4; 6 1; 3; 5

130 Export and Import of Optical Setups

Optical Setups can be used easily from within other programs using the batch mode described in Sec. 9. Sample batch mode files can be generated using File > Export > Create Batch Mode Files. The menu File > Export contains also various exports to specific target applications which are described in the following subsections. Optical Setups can also be exported into the stereolithography format (*.stl) via the 3D View (↪Sec. 5.16).

130.1 Export Parameters to XML

Most parameters of an Optical Setup can be exported to an XML file. Some of these are *changeable*, which means they can be re-imported into VirtualLab Fusion when changed in the XML file. And some of the changeable numerical parameters are also *variable* which means their value can be varied within a certain range. See also the chapter about Parameter Extraction Sec. 44.6.
For each parameter the following information is exported.

TAG	DESCRIPTION
Name	Name and category of the parameter. If changed, re-import into VirtualLab Fusion might fail.
ID	ONLY FOR CHANGEABLE PARAMETERS Facilitates re-import into VirtualLab Fusion.
ShortName	ONLY FOR VARIABLE PARAMETERS User-specified short name, e.g. set in the dialog described in Sec. 130.1.1. Not used during re-import.
PreSelectedByUser	ONLY FOR VARIABLE PARAMETERS Indicates a parameter preselected by the user, e.g. via the dialog described in Sec. 130.1.1. Not used during re-import.
Value	The value of the parameter.
PhysicalProperty	ONLY FOR PHYSICAL VALUES The physical property of the value. Not used during re-import.
Min	ONLY FOR VARIABLE VALUES The minimum of the range in which the value can be varied. Can be set in the dialog described in Sec. 130.1.1. Not used during re-import.
Max	ONLY FOR VARIABLE VALUES The maximum of the range in which the value can be varied. Can be set in the dialog described in Sec. 130.1.1. Not used during re-import.

In addition at the begin of the XML document the notes (↪Sec. 44.1) and all available simulation engines (↪Sec. 44.5) of the Optical Setup are given. As the available parameters depend on the selected simulation engine, the selected engine is marked by an `Used` tag.
The XML export can be triggered in three different ways.

RIBBON ITEM	DESCRIPTION
File > Export > Export as XML	Exports *all parameters*. You only have to specify path and name of the XML file.
File > Export > Create Batch Mode Files	Creates a `parameters.xml` file in the specified path and a sample batch file for external execution of VirtualLab Fusion. See Sec. 9 for details on the available command line arguments. The XML file contains only *changeable parameters* of Optical Setup Elements which are connected to the active light source (with index “0”).
File > Export > Export to optiSLang Project	Special variant of the batch mode export specifically tailored for optiSLang. Only *variable parameters* are exported from Optical Setup Elements which are connected to the active light source (with index “0”). The Optical Setup is executed during export to generate initial results. A special dialog (↪Sec. 130.1.1) is used to configure the export.

The parameter values in an XML file can be re-imported into an Optical Setup using an Optical Setup Tool (↪Sec. 44.8).

130.1.1 Export to optiSLang Project

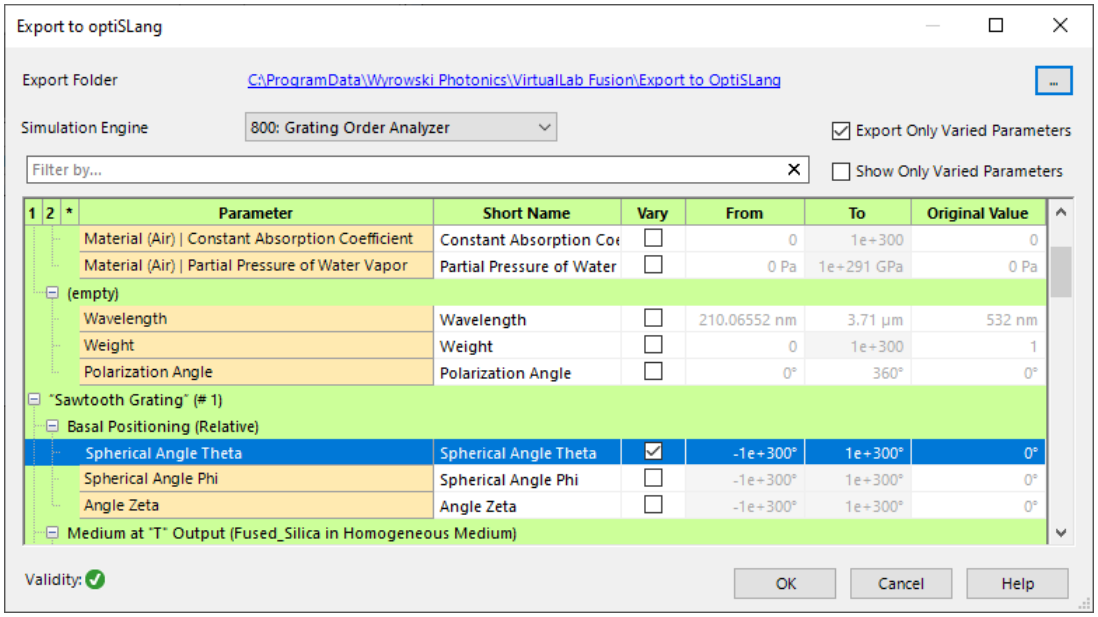


Figure 783. *Edit dialog for the export to an optiSLang project.*

If you click on File > Export > Export to optiSLang Project the dialog shown in Fig. 783 opens where you can configure the export.

ITEM	DESCRIPTION
Export Folder	The folder into which the files needed for the optimization in optiSLang are exported. It is recommended that this folder is empty. The path can be changed with the ...-button. If you want to access the path directly, e. g. for cleanup, you can click on the path label.
Simulation Engine	Allows you to select the simulation engine to be used for the optimization in optiSLang.
Export Only Varied Parameters	If checked only the varied parameters are exported. This yields a much smaller parameter file and thus much faster execution times.
{Parameter Table}	See below.
Validity	This control (↪Sec. 5.11) indicates whether there are issues with the current configuration. If this is the case you can click on the i-button for further information.

The table lists all *Parameter*s which may be varied in optiSLang. They are grouped by object (e. g. *"Ideal Plane Wave" (# 0)*) and then by the first category (which can be *{empty}*). The first column allows you to collapse / expand all these groups. Simply click on the − and + symbols, respectively. At the top of this column you can select to collapse all levels (*1*), collapse only the category groups (*2*) or expand all groups (*). In the *Vary* column you must check one or more parameters which can be varied during the optimization. All selected rows are checked at once.
For each parameter you can specify a *Short Name* identifying that parameter.
For the varied parameters you can define the value range by setting the start (*From*) and end (*To*) value. The default *From* and *To* values for all parameters are their absolute minimum and maximum values – you must not enter a value outside of this range. It is possible to enter a *To* value which is smaller than the *From* value.
For your information also the *Original Value*s of all parameters are given.

The table can be filtered with the following controls. Only rows passing all filters are shown.

ITEM	DESCRIPTION
Filter Table by	All rows containing the given string either in the group descriptions or in the *Parameter* column pass this filter. The matching is case insensitive. It is possible to search for multiple words and word groups embraced by quotation marks, for example: `"surface #1" scaling`.
Show Only Varied Parameters	Only rows where the *Vary* column is checked pass this filter.

130.2 Import optiSLang Results

If you click on File > Import > Import optiSLang Results a dialog opens where you can either enter a path directly or browse for it using the ...-button. This path must contain a `system.lpd` and a matching `parameters.xml` in the format used for the data exchange with optiSlang and the batch mode (↪Sec. 9). The parameters of the Optical Setup are then changed to the values in the `parameters.xml` and the resulting Optical Setup is shown as new document in VirtualLab Fusion.
Using this import you can re-import Optical Setups optimized by optiSLang.

130.3 Export to JCMsuite Format

Grating Optical Setups can be converted to JCMsuite files. These files allow you to analyze the structures rigorously by using the finite element method within JCMsuite. (In case of 2D-periodic structures, only the plane at $y = 0$ is exported.)

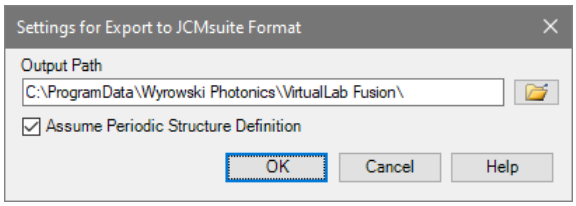


Figure 784. *The dialog for configuring the export to JCMsuite files.*

This feature can be accessed via File > Export > Export to JCMsuite Format if a Grating Optical Setup is active. This menu item opens the dialog shown in Fig. 784 and offers the following settings.

ITEM	DESCRIPTION
Output Path	Specifies the path where the resulting JCMsuite files are stored. You can either enter the path directly. If the path does not exist, it is created on inquiry. Or you can access the default Windows™ folder selection dialog via the -button.
Assume Periodic Structure Definition	JCMsuite can assume the outside of the structure to be either periodic or transparent. With this setting you can switch between these two possibilities.

130.4 Import of Zemax OpticStudio® Lens Files and Archive Files

File > Import > Import 'Zemax OpticStudio®' Lens File imports the surface data from a *.zmx, *.zos, or *.zar file into an Optical Setup.

Zemax OpticStudio® license needed
The import of *.zmx or *.zar files requires a valid Zemax OpticStudio® license of version ’19.4 SP2’ or newer. Importing *.zos files requires a version ’21.3’ or newer. It has to be a ’Professional’ or ’Premium’ edition in any case, a ’Standard’ edition will not work.
If no valid license can be found or the Global Options are configured accordingly (↪Sec. 6.16), VirtualLab Fusion may use a rudimentary import algorithm on *.zmx files which may produce unsatisfactory results. Import features which are not supported by the rudimentary algorithm are marked with the symbol ZOS Lic.

A new Optical Setup will be created by the import algorithm. It contains a light source, a Camera Detector as well as a Spot Size detector. All surfaces except for the object plane, the image plane and coordinate breaks will be imported into a VirtualLab Fusion component each (see below for a list of supported surface types). The media between the Optical Setup Elements are set to “Air (Zemax OS)” but the materials which are connected to the surfaces in the lens file are imported to VirtualLab Fusion materials (Sec. 130.4.2) and are used as subsequent media. Temperature and pressure are copied from the Zemax OpticStudio® lens file to the Optical Setup too (Sec. 130.4.3).
The type of the light source in the imported Optical Setup depends on the distance behind the object plane. If it is infinite, a Plane Wave light source is used, otherwise a Spherical Wave light source is inserted. The material behind the object plane determines the embedding medium of this source. The wavelengths of the light source are set to the wavelengths as found in the file after converting to vacuum. The field size is taken from the entrance pupil diameter. The ray pattern and the ray density for a ray tracing source are copied from a spot diagram, if there is one in the lens file.

130.4.1 Supported Zemax OpticStudio® Surface Types

VirtualLab Fusion can import some types of optical surfaces from a Zemax OpticStudio® lens file.
The supported surface types are summarized in the following table:

SURFACE TYPE IN ZEMAX OPTICSTUDIO®	REPRESENTATION IN VIRTUALLAB FUSION
Biconic	Anamorphic Surface
Binary 1	A Combined Surface, consisting of a Plane or Aspherical Surface and a Polynomial Surface. The latter may be height-scaled, see 130.4.1.1 for more information.
Binary 2	Two cases have to be distinguished: • *Valid OpticStudio® license present* ZOS Lic *and Flat Lens Package present and import called from main menu (instead of using the Lens System tool as described in Sec. 131.2)*: VirtualLab Fusion tries to determine whether the Binary 2 surface forms a diffractive lens together with its preceding or its subsequent surface by evaluating the involved materials. Both surfaces will be represented by a Diffractive Lens component (↪Sec. 61.2) in the imported optical setup. The Binary 2 surface will be a surface whose channel operator represents the diffractive properties of the Binary 2. • *Else*: The import creates a Combined Surface, consisting of a Plane or Aspherical Surface and an Aspherical Surface. The latter may be height-scaled, see 130.4.1.1 for more information.
Coordinate Break ZOS Lic	N/A (Coordinate breaks are not imported because they are not needed in the imported Optical Setup. All positions and orientations of the surfaces are set correctly without referring to theses virtual planes.)
Even Asphere Surface	Aspherical Surface
Extended Asphere	Aspherical Surface
Odd Asphere Surface	Aspherical Surface
Q-Type Asphere	Forbes Surface
Standard Surface	A Conical Surface or Plane Surface, depending on the radius of the Standard Surface.
Tilted Surface	Plane Surface
Toroidal	A couple of cases have to be distinguished: $Z > 0$: $R \neq 0$ → CS: Toroidal + Zernike Standard; $R = 0$ → CS: Cylindrical + Zernike Standard $Z = 0$: $R \neq 0$ → Toroidal Surface; $R = 0$ → Cylindrical Surface with R being the Radius of Rotation and Z being the number of Zernike coefficients given in the lens file. 'CS' stands for Combined Surface.
Zernike Fringe Sag ZOS Lic	AVAILABLE ONLY IF THE ZERNIKE DECENTER VALUES ARE ZERO. A Combined Surface, consisting of a Plane or Aspherical Surface and a Zernike Fringe Surface
Zernike Standard Phase	A Combined Surface, consisting of a Plane or Conical Surface and a Zernike Standard Surface. The latter may be height-scaled, see 130.4.1.1 for more information.
Zernike Standard Sag ZOS Lic	AVAILABLE ONLY IF THE ZERNIKE DECENTER VALUES ARE ZERO. A Combined Surface, consisting of a Plane or Aspherical Surface and a Zernike Standard Surface

Surfaces of unsupported types are considered to be Plane Surfaces.

130.4.1.1 Handling of Surfaces Which Define Phase Variations Directly

In the case of Binary 1, Binary 2 (if no OpticStudio® license present) and Zernike Standard Phase, the phase functions given in Zemax OpticStudio® are transformed into a height profile in VirtualLab Fusion. This height profile is always the second of the two sub-surfaces in the imported Combined Surface.
The height profile is computed using the thin element approximation [Goo68]. This means that the surface profile height is proportional to the phase values. To this end, the wavelength and the refractive indices of the media before and behind the surface are calculated from the data in the Zemax OpticStudio® lens file. (The refractive indices are relative to the *Air (Zemax OS)*, in order to resemble the behavior of Zemax OpticStudio®.) If necessary, the z-scaling of the height profile in VirtualLab Fusion can be used to compensate side effects, caused e. g. by using only the first wavelength of the Zemax OpticStudio® lens file.

130.4.2 Importing Materials from Zemax OpticStudio® Lens Files

There are different kinds of specifications for material data in Zemax OpticStudio®. The following specification types are supported by VirtualLab Fusion:

- *MIL Number Glasses* and
- *Model Glasses* are interpreted as representing a simple dispersion formula as described in the Zemax OpticStudio® user manual.
- The material *MIRROR* is imported as being an idealized material with a constant refractive index of 1 and a very high constant absorption coefficient of $10^{15}1/m$, leading to an almost perfect reflection behavior.
- All *table glasses* (file extension *.ztg) as well as
- all *catalog glasses* (file extension *.agf) are expected to be stored in the subdirectory “Glasscat” of the *Path for ’Zemax OpticStudio®’ User Data*. This search path can be specified in the Global Options dialog (↪Sec. 6.17).

Please note: Although Model Glasses as well as MIL Number Glasses are defined via Abbe number ν_d and refractive index n_d, these kinds of materials are not imported to a Virtual Lab material using the *Abbe Number (νd)* dispersion formula. Regarding Model Glasses, the reason is the additional partial dispersion parameter ΔP_{g^F} which can be defined there. MIL Number Glasses just use a different dispersion formula in Zemax OpticStudio® compared to our formula (↪Sec. A.4.1). So, a special programmable material is used for the import of Model Glasses and MIL Number Glasses.

130.4.3 Handling of the Environment Conditions

In Zemax OpticStudio®, all specified wavelengths are defined in air. The dispersion of this air is defined by an environment temperature and pressure. To fully represent this behavior in VirtualLab Fusion, the following steps are done during import:

1. A new material is defined using the Edlén equation given in Sec. 39.2.1. For the temperature and pressure which are parameters of this equation the values from the Zemax OpticStudio® lens file are used. This new material is hence referred to as *Air (Zemax OS)*.
2. The vacuum wavelength λ_{vac} is calculated by solving the equation $\lambda_{\text{air}} = \frac{\lambda_{\text{vac}}}{n_{\text{air}}(\lambda_{\text{vac}})}$ for λ_{vac}. n_{air} is the refractive index of the *Air (Zemax OS)* and λ_{air} is the first wavelength in the Zemax OpticStudio® lens file.
3. The reference material (↪Sec. 39.2.1) of all imported materials is set to the *Air (Zemax OS)*.

130.4.4 Combining Imported Surfaces

Each surface of the Zemax OpticStudio® lens file (except for object plane, image plane and coordinate breaks) is imported to a Curved Surface component. Subsequent to the actual import, the user is asked whether to combine these surfaces to one or more Lens System component(s). If desired, this combination will be tried as described in Sec. 44.8.2.2.

130.4.5 Handling Unpacked Data From ZAR Archives

In case a Zemax *.zar archive file shall be imported ZOS Lic, the contained files of the archive will be extracted into a temporary folder. The unpacked lens file will be used for the actual import then. The extraction folder will be deleted after VirtualLab Fusion has closed.
In case the unpacked data shall be stored for later use anyway, the files can be saved to a different, permanent folder via the dialog shown in Fig. 785.

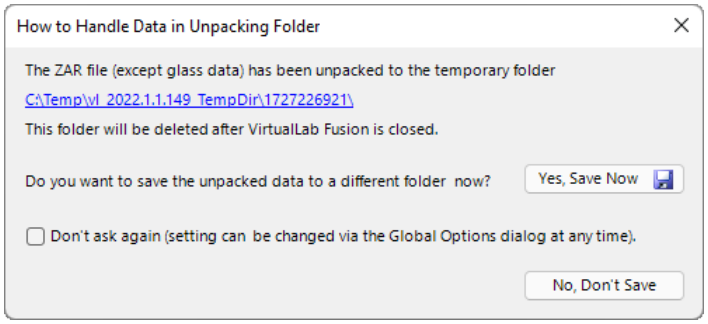


Figure 785. *Dialog for handling the extracted data from a Zemax *.zar archive.*

Clicking the underlined link will open the temporary folder, while pressing the *Yes, Save Now* button allows to specify a different, permanent folder for storing the data to.

131 Export and Import of Real Components

131.1 Stereolithography Format

All real components can be exported into the stereolithography format (*.stl) via their 3D View (↪Sec. 5.16).

131.2 Import of Zemax OpticStudio® Lens Files into a Lens System Component

A tool in the edit dialog of the Lens System component (↪Sec. 58.1) allows importing Zemax OpticStudio® lens file data into a lens system.

Zemax OpticStudio® license needed
The import of *.zmx or *.zar files requires a valid Zemax OpticStudio® license of version ’19.4 SP2’ or newer. Importing *.zos files requires a version ’21.3’ or newer. It has to be a ’Professional’ or ’Premium’ edition in any case, a ’Standard’ edtion will not work.
If no valid license can be found or the Global Options are configured accordingly (↪Sec. 6.16), VirtualLab Fusion may use a rudimentary import algorithm on *.zmx files which may produce unsatisfactory results.

At first, VirtualLab Fusion checks whether or not the surface data in the file fulfill the restrictions of a Lens System component. Most important are the following conditions:

- All positions have to be on one line which is considered to be the optical axis of the system to be imported.
- No surface, except for standard surfaces with infinite radius (considered to be plane surfaces), may be tilted to the optical axis.

All other properties of the import algorithm are explained in Sec. 130.4.
The imported surfaces are appended at the end of the current surface sequence. To maintain the overall structure, surfaces which could not be imported are replaced by a Plane Surface and materials which could not be imported are replaced by the “Air (Zemax OS)”.

131.3 Import of Zemax OpticStudio® Lens Files into a Diffractive Lens or Meta Lens

The edit dialogs for diffractive and meta lenses have a button *Import from ’Zemax OpticStudio®’ System* on their *Structure* page. Using this button, a .zmx, .zos or .zar file can be selected via ’file open’ dialog. This file will be searched for surfaces of type ’Binary 2’.

- If no ’Binary 2’ surface can be found, an error message will be given.
- If there is exactly one ’Binary 2’ surface contained in the lens file, it will be imported automatically into the diffractive or meta lens component.
- If more than one ’Binary 2’ surface are found, the user will be asked which of them is to be imported.

132 Export of Cells Arrays

132.1 Export of Grating Cells Arrays

The grating parameters can be exported by pressing on the -button on the bottom of the edit dialog of the Grating Cells Array. This triggers the *Export Grating Cells Array* dialog, which can be used for configuring the export parameters of the set up Grating Cell Array. The export to CSV (comma separated values) and GDSII is supported for the GCA.

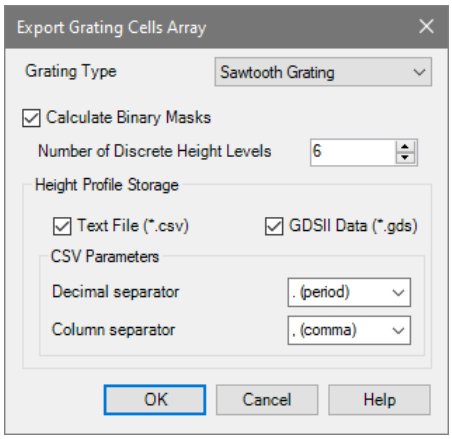


Figure 786. *The dialog to set up the export parameters for a Grating Cells Array.*

Fig. 786 shows the edit dialog to export a Grating Cells Array. It has the following settings:

ITEM	DESCRIPTION
Grating Type	For the export of the Grating Cells Array data the grating type need to be specified. Currently on sawtooth grating is supported for the fabrication export.
Calculate Binary Masks	The export allow to calculate binary masks. Checking this option allow the export to GDSII format. If this option is not selected, only CSV format is available.
Number of Discrete Height Levels	The export supports also a quantization of the gratings. Therefor the user need to specify the number of discrete height levels which he will use for the fabrication process.
Text File (*.csv)	The user can select to export the parameters of the Grating Cells Array into a comma separated value format. Within this format the analytic parameters of all grating cells are written into a text file in matrix form. The different grating parameters are written in three different blocks within the text file. The blocks are arranged under each other. Additional information about the GCA as the number of cells and the cell size are written in the header of the csv file. The csv format can be easily opened with a text editor or a spreadsheet.
GDSII Data (*.gds)	VirtualLab Fusion offers the possibility to export the Grating Cells Parameter into the GDSII format. Therefor the element has to be factorized into binary masks. The GDSII option is only available if the *Calculate Binary Masks* option is checked. The element within the GDSII format is not pixelated. This reduces the storage effort and increases the specification accuracy. Fig. 787 shows a typical Grating Cells Array exported to GDSII format.

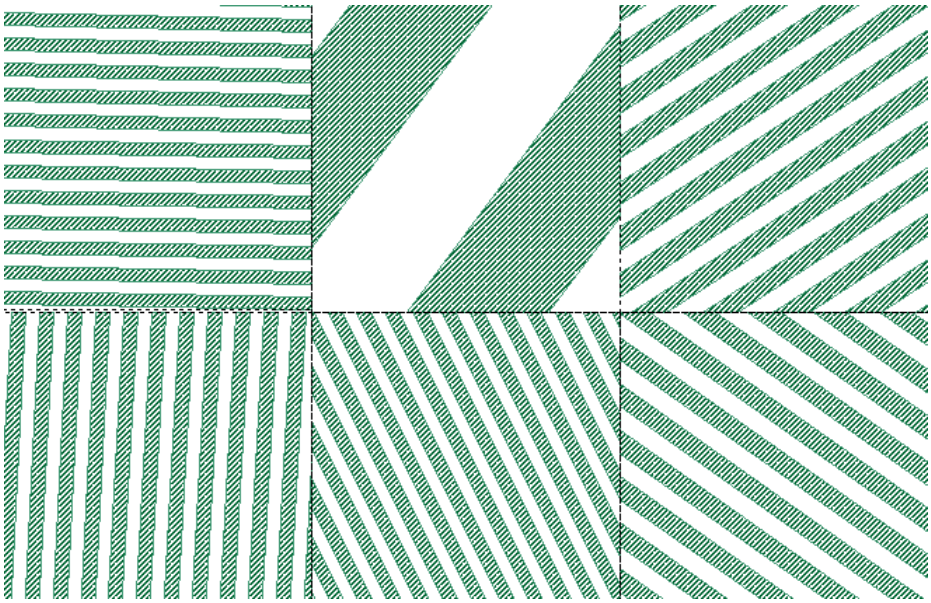


Figure 787. *The Grating Cells Array can be exported to GDSII.*

After pressing the *OK* button the user needs to specify the location and file name for both the .csv and the GDSII file.

132.2 Export of Prism Cells Arrays

The prism parameters can be exported by pressing on the -button on the bottom of the edit dialog of the Prism Cells Array (PCA). This triggers the *Export Prism Cells Array* dialog, which can be used for configuring the export parameters of the set up Prism Cell Array. The export to CSV (comma separated values) text files and to the STL format is supported for PCAs.

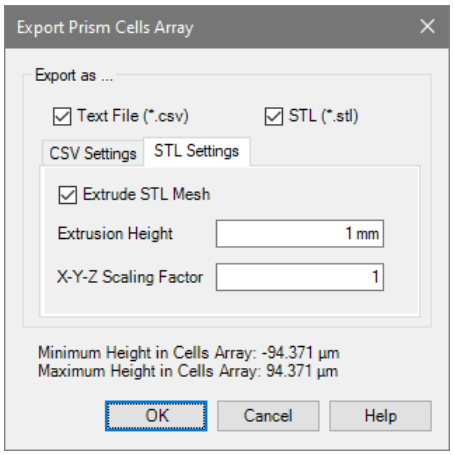


Figure 788. *The dialog to set up the export parameters for a Prism Cells Array. Here the settings for STL export are shown.*

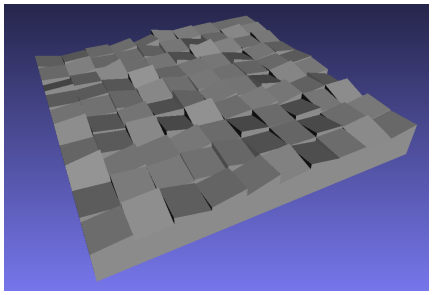


Figure 789. *A Prism Cells Array extruded to a solid.*

The following settings can be done within the *Export Prism Cells Array* dialog (↪Fig. 788):

ITEM	DESCRIPTION
Text File (*.csv)	The user can select to export the parameters of the Prism Cells Array into a comma separated value format. Within this format the analytic parameters of all prism cells are written into a text file in matrix form. The different grating parameters are written in three different blocks within the text file. The blocks are arranged under each other. Additional information about the PCA as the number of cells and the cell size are written in the header of the CSV file. The CSV format can be easily opened with a text editor or a spreadsheet.
STL (*.stl)	VirtualLab Fusion offers the possibility to export the whole Prism Cells Parameter into the standard STL format.
Decimal Separator	ONLY AVAILABLE FOR THE TEXT FILE EXPORT. Allows the user to choose either ',' or '.' as decimal separator or to enter a custom one.
Column Separator	ONLY AVAILABLE FOR THE TEXT FILE EXPORT. Allows the user to choose either among distinct customized column separators like space, tab stop, semicolon, …; or to enter a custom one.
Extrude STL Mesh	ONLY AVAILABLE FOR THE STL EXPORT. For the STL format you can extrude the surface to a real solid. To this end an additional plane surface is added at *Extrusion Distance* below the actual surface, ↪Fig. 789. With this checkbox you can switch the extrusion on or off.
Extrusion Distance	ONLY AVAILABLE FOR THE STL EXPORT. The additional plane surface is perpendicular to the optical axis and placed at a certain distance z from the negative z-extension of the actual surface (the "lowermost point"). This distance z is the *Extrusion Distance* which can be set by the user.
X-Y-Z Scaling Factor	ONLY AVAILABLE FOR THE STL EXPORT. You can use this factor to apply an overall scaling on the exported data if necessary.

At the bottom of the dialog the minimum and the maximum height of the Prism Cells Array are given.
After clicking on the *OK* button the user needs to specify the location and file name for both the CSV and the STL file.

The exported STL file will have slightly smaller numerical values for the minimum and the maximum height value of the full structure. This is due to the fact that some STL reading programs have problems if VirtualLab Fusion exports the edges from one prism cell to the next with ideal 90°; so the actual prism surface is reduced a tiny bit so that instead of totally vertical edges slightly slanted ones are exported. The difference is negligible for the optical effect.

133 Export of Optical Surfaces

In VirtualLab Fusion, optical surfaces are exported by first sampling the height profile with a given pixel size. This pixelated height profile can then be exported either directly into a single file. Or the height profile can be decomposed into several masks: One mask stores the binary information whether or not half the total profile

height shall be removed from the substrate, another mask stores whether or not a fourth of the total profile height shall be removed and so on.
The height level data can be exported to various text and binary formats. In addition to the actual data files, always a summary file in a specific XML format (↪Sec. 133.4) is created containing additional metadata, for example the pixel size. This summary file can additionally be generated as HTML, text, or rich text file. Together with the XML file always a file `summary.xslt` is saved which ensures that the XML file is shown in a more human-readable form if opened with a web browser.
All these formats (but the point cloud and the stereolithography (*.stl) format) can be imported into a Sampled Surface (↪Sec. 36.2.11) if a XML file in the format as specified in Sec. 133.4 is provided.
Sec. 133.1 explains the export dialog in detail.

133.1 Export Dialog (for Standard Surfaces)

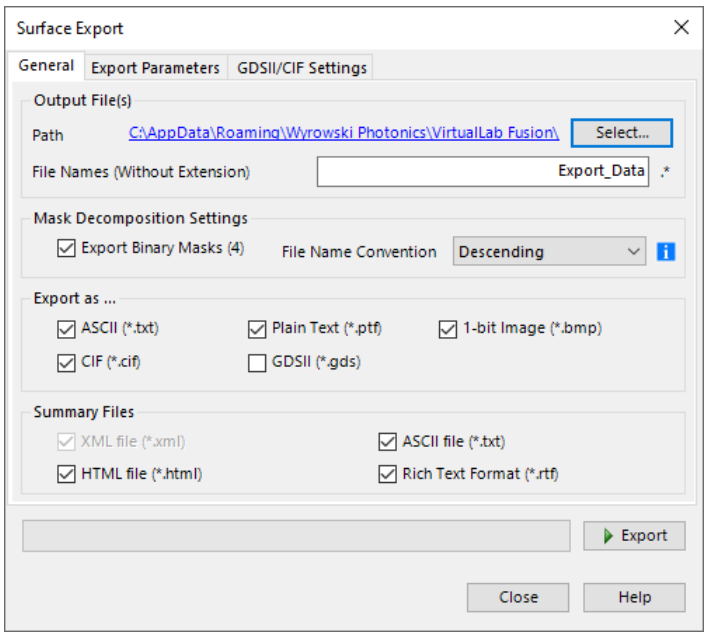


Figure 790. *The dialog for configuring the export of a surface (here:* General Parameters *tab).*

To configure the export to your needs a dialog opens during the export (↪Fig. 790). This dialog comprises up to three tab pages which are explained in the following subsections. Furthermore it contains a button for starting and stopping the actual export as well as a progress bar indicating the progress of the current export step (which is shown in a label below the progress bar).

ITEM	DESCRIPTION
Export	Starts the actual export. After the export has been started this button turns into a *Stop* button, allowing you to cancel the current export process. Furthermore, the *Close* button is disabled during the export.

133.1.1 General Parameters

The *General* tab page (↪Fig. 790) contains the following controls:

ITEM	DESCRIPTION
Path	The path into which the resulting files are saved. This path can be changed with the *Select* button. If you want to open that path in the Windows™ Explorer, you can click on the path label.
File Names	Allows you to set the file name used for all data and summary files (without the specific file extensions). Summary files are supplemented by "_summary" and data files representing masks are supplemented by "_MASK_#", where # is the number of the mask. The file name also defines the name of the main structure in GDSII and CIF files. It must not contain any of the following characters: \/ : * ? < > |.
Export Binary Masks	This option is only enabled for a surface with 2^n discrete height levels. n is the number of resulting masks (which is given in brackets) and can be in the range from 1 to 12.
File Name Convention	If *Export Binary Masks* is checked, one data file per mask is created. If you choose *Ascending* then the file `...MASK_1` contains the binary mask with the smallest height modulation. Otherwise it contains the largest height modulation – half the total profile height.
Export as ...	This group box allows you to select the file format(s) for the resulting data files. It is ensured that at least one format is selected. Not all file formats are always available: • Bitmap files can only be generated if the surface contains discrete height levels, but no more than 256. • CIF and GDSII format are only available if *Export Binary Masks* is checked. • The Point Cloud, the STL, and the 16-bit grayscale format are only available if *Export Binary Masks* is not checked. Sec. 133.3 gives some annotations for the used file formats.
Summary Files	At least a XML file with additional metadata is always generated, as this file is needed if you want to re-import the data into VirtualLab Fusion. But you can select HTML, text, and rich text as additional, more human-readable, formats. Sec. 133.4 explains the structure of the summary files and lists the metadata written during the export of surfaces. Sec. 133.3 gives some annotations for the used file formats.

133.1.2 Export Parameters

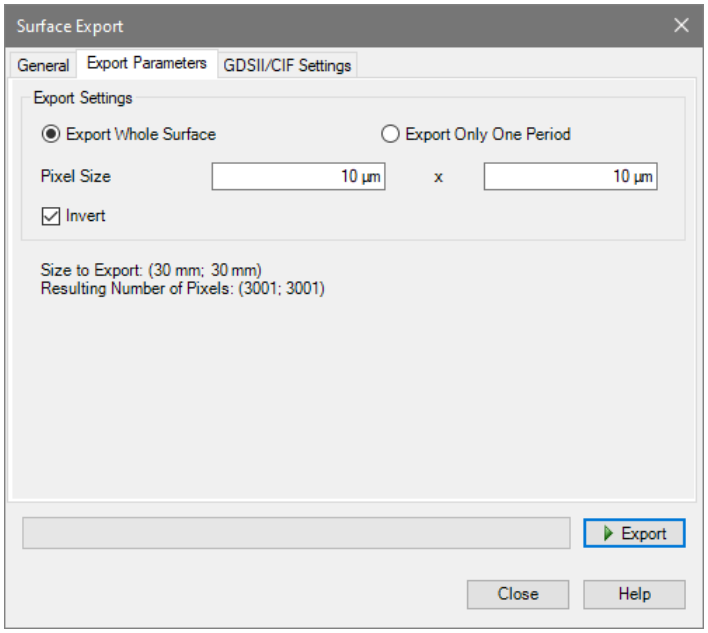


Figure 791. *The General Parameters tab for exporting a surface.*

The *Export Parameters* tab page (↪Fig. 791) contains the following controls:

ITEM	DESCRIPTION
Export Whole Surface / Export Only One Period	This item is only enabled if the surface is set to be periodic (↪Sec. 36.1.1). If you choose to *Export Whole Surface* then a rectangle with the size of the outer definition area is exported. Otherwise, only one period is exported.
Oversampling Factor	If the surface is already pixelated you can specify an integer oversampling factor. The pixel size used for the export is then the original pixel size of the surface divided by that oversampling factor.
Pixel Size	As all export formats support only pixelated data, a pixel size must be specified. If the surface is already pixelated, you cannot set the *Pixel Size* directly but only an *Oversampling Factor* as explained above. For one-dimensional pixelated surfaces the pixel size in the unmodulated direction is always equal to the overall size of the surface. Note that the internally used pixel size is always a multiple of 1 nm.
Invert	All heights are inverted. For the export of binary masks that means that if this option is not checked the written data (= the white areas in a bitmap) describes what remains after the production process. In contrast, if the heights are inverted the written data describes what is removed, e. g. etched away.

Additionally to these controls there is an info label giving the size of the exported region as well as the number of pixels in the resulting data files.

133.1.3 GDSII/CIF Settings

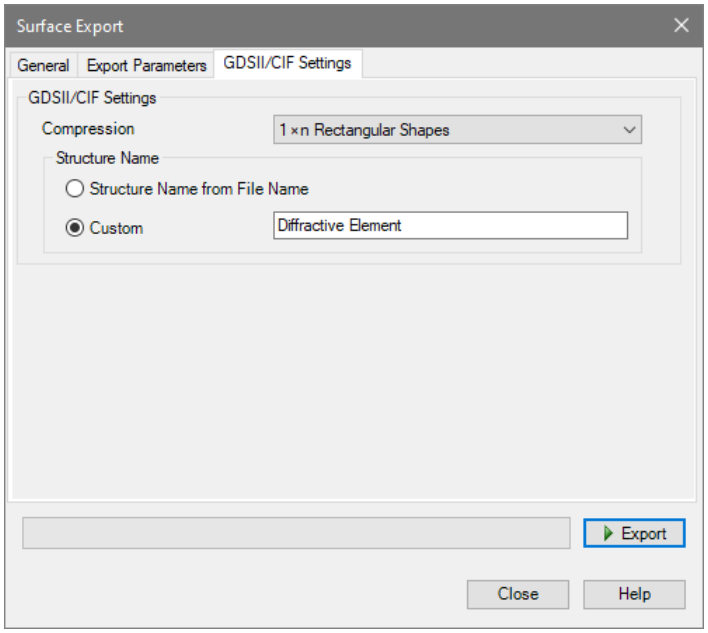


Figure 792. *The specific settings for the GDSII and the CIF export.*

If GDSII or CIF are selected as output format, you have the following options on an additional tab (↪Fig. 792).

ITEM	DESCRIPTION
Compression	For GDSII or CIF export a compression can be selected. In this case, the individual shapes are combined to *1 × n Rectangular Shapes*. Fig. 793 shows an example. This can lead to file sizes reduced by a factor 10 or more.
Structure Name from File Name	The structure name is used in a GDSII / CIF file to group the shapes which represent the structure. If the user checks this option the structure name is the file name specified by the user, succeeded by "_MASK_" and the mask number.
Custom	If the user checks this option, he can specify an arbitrary structure name. In this case, the same structure name is used for all masks.

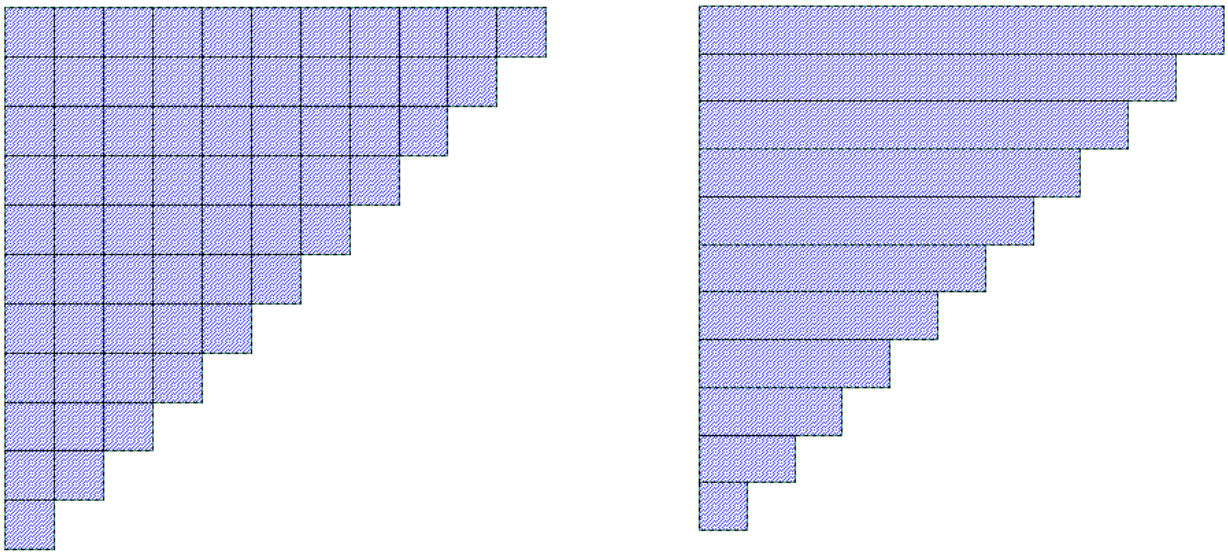


Figure 793. *Illustration for the effect of the Compression for GDSII or CIF export.*
Left: *Stored shapes if None (1×1 Square Shapes) are used.*
Right: *Stored shapes for the same region if 1 × n Rectangular Shapes are used.*

> See also notes on allowed file and structure names for GDSII in Sec. 133.3.

133.1.4 STL Settings

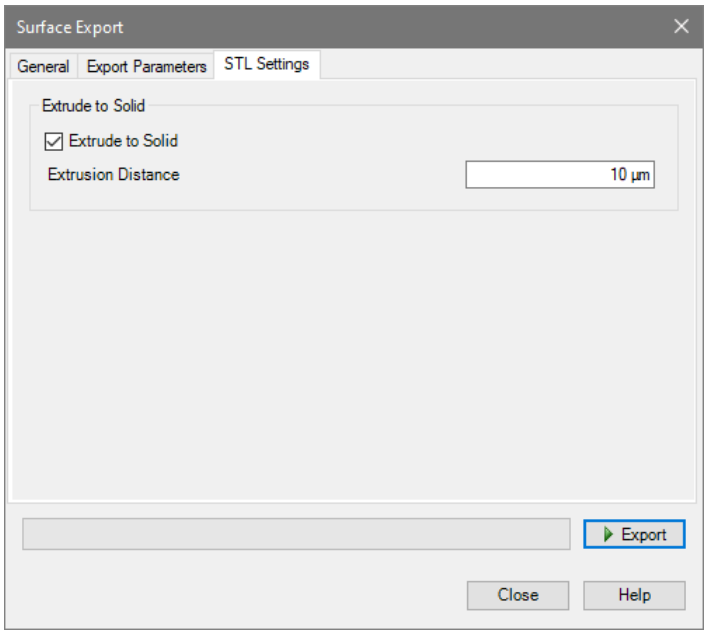


Figure 794. *The specific settings for the STL export.*

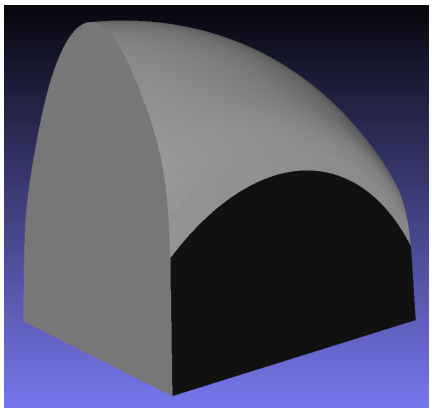


Figure 795. *A toroidal surface extruded to a solid.*

For the STL format you can extrude the surface to a real solid. To this end an additional plane surface is added at a certain position below the actual surface. Fig. 795 shows an example. There are two settings for this extrusion on a separate tab page (↪Fig. 794).

ITEM	DESCRIPTION
Extrude to Solid	With this checkbox you can switch the extrusion or or off.
Extrusion Distance	The additional plane surface is perpendicular to the optical axis and placed at a certain distance z from the negative z-extension of the surface (the "lowermost point"). This distance z is the *Extrusion Distance* which can be set by the user.

133.2 Export Dialog for Diffractive Structures

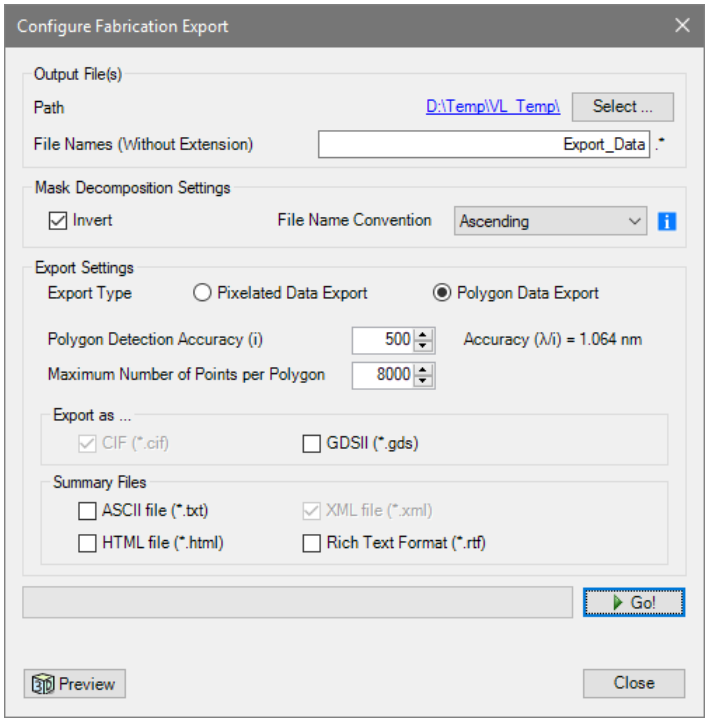


Figure 796. *The dialog for exporting a diffractive structure as polygons.*

In contrast to the export dialog for standard surfaces, this dialog (↪Fig. 796) allows not only the export of pixelated data but also of polygons. It contains the following controls:

ITEM	DESCRIPTION
Path	The path into which the resulting files are saved. This path can be changed with the *Select* button. If you want to open that path in the Windows™ Explorer, you can click on the path label.
File Names	Allows you to set the file name used for all data and summary files (without the specific file extensions). Summary files are supplemented by "_summary" and the data files representing masks are supplemented by "_MASK_#", where # is the number of the mask. The file name also defines the name of the main structure in GDSII and CIF files. It must not contain any of the following characters: \/ : * ? < > |.
Invert	Flag whether the masks shall be inverted. That means for example that you replace a positive resist by a negative one.
File Name Convention	One data file per mask is created. If you choose *Ascending* then the file `..._MASK_1` contains the binary mask with the smallest height modulation. Otherwise it contains the largest height modulation – half the total profile height.
Export Type	The user can define whether pixelated data or polygons are exported. After selecting the export type the dialog offers specific settings for the selected type.
Sampling Distance	ONLY FOR *PIXELATED DATA EXPORT*. The pixel size that should be used for the export.
Polygon Detection Accuracy	ONLY FOR *POLYGON DATA EXPORT*. The user can specify an integer value i. This integer value is used to calculate the accuracy of the polygon detection relative to the wavelength. The total accuracy (= maximum lateral distance between level curve and polygon line) is calculated by the formula (λ / i).
Maximum Number of Points per Polygon	ONLY FOR *POLYGON DATA EXPORT*. The user can specify the maximum number of points for a polygon. The default value for this option is 8 000 which is admissible for both CIF and GDSII. Furthermore, the lower limit is 100.
Export as ...	By defining the export types the user can specify in which format the files shall be exported. In case of pixelated data export the module supports the export to: bitmap, ASCII and plain text, GDSII and CIF format. For the polygon data export the formats GDSII and CIF are available. At least one of the data export file types has to be selected. Sec. 133.3 gives some annotations for the used file formats.
Summary Files	At least a XML file with additional metadata is always generated, as this file is needed if you want to re-import the data into VirtualLab Fusion. But you can select HTML, text, and rich text as additional, more human-readable, formats. Sec. 133.4 explains the structure of the summary files and lists the metadata written during the export of surfaces. Sec. 133.3 gives some annotations for the used file formats.
{Export Progress}	During the export the dialog informs you about the progress of the current export step. The current export step is displayed in the info label below the progress bar.

Go!	Starts (and stops) the export.
Preview	Shows a preview of the structure to be exported in the 3D view explained in Sec. 5.16.

See also notes on allowed file names in Sec. 133.3.

Tip

Export of polygons is **much** faster when done for rotationally symmetric surfaces. Thus if you export for example a Diffractive Lens (↪Sec. 61.2), ensure that the surface is a non-periodic Aspherical, Conical, or untilted Plane Surface with a circular definition area.

133.3 Annotations for the Various File Formats

FILE FORMAT	ANNOTATION
Bitmap	In this case an indexed Windows bitmap file with 256 gray values is created (8 bits per pixel). Its header contains the color definition for every height level and additional data. The color definition allows to display the bitmap in every painting program. After the header a byte matrix follows which contains the height levels directly as hexadecimal data. For example, if you have exported an element with eight height levels a byte value of 00 corresponds to the smallest height level and 07 to the largest one. The real height can be calculated by multiplying the height level with the height level difference given in the summary file. White is associated with the largest height, black with the lowest one. However, the gray values assigned to the height levels might not be equidistant. Thus, if you want to export the real heights from the bitmap, use the height levels directly, not the gray values.
ASCII format	The heights in meters are stored. The file contains a matrix of numbers with N_x columns and N_y rows (N_x and N_y being the number of sampling points in x- and y-direction, respectively). The columns are separated by a space. It is recommended to use ASCII instead of the Plain text format because ASCII files are smaller (roughly 33 % for binary masks) and they can be generated up to 5 times faster.
Plain text format	The height values in meters are stored. A line contains the data of one single pixel. The header contains information about the number of sampling points in x- and y-direction, respectively.

GDSII format	As explained in Sec. 133.1.3, both GDSII and CIF format use a structure name to identify the main structure which contains the actual data. However, the GDSII format only supports the following characters: a...z, A...Z, 0...9, underscore, question mark, and dollar sign. This means that the structure name can only contain these characters. Consequently, the *File Names* can only contain a...z, A...Z, 0...9, and underscore if the option *Structure Name from File Name* is used as described in Sec. 133.1.3.
Point Cloud format	This format stores the x- and y-positions in µm along with the corresponding height, also in µm. Not that the data is transformed so that only positive values occur.
STL format	This format often used for stereolithography stores a triangular mesh. Due to technical reasons, more than $3860 \cdot 3860 \approx 15 \cdot 10^6$ pixels cannot be exported with the STL format.
Rich Text Format	The rich text format only supports the characters of the Windows-1252 character set natively. Thus the *Path* and the *File Names* must not contain other characters than these if you want to use the rich text format as summary file.

133.3.1 Annotations for Binary Masks

If a standard surface is exported with the *Calculate Binary Masks* option (↪Sec. 133.1.1), some file formats are used a bit differently:

- Bitmap files use only 1 bit per pixel to store a black / white image of the mask.
- ASCII format and plain text format do not store height levels but “1” and “0” to indicate the binary mask information.

133.4 Metadata Summary Files

VirtualLab Fusion provides a general XML format for storing additional metadata for exported data files. The main idea of this format is that the XML file contains several metadata entries (which can be grouped) for a collection of data files (which can also be grouped). The metadata are stored as description (e. g. “Total Profile Height”) / value (e. g. 532 nm) pairs.

Up to now, such summary files are only used for the export of surfaces. In this case the following metadata is stored:

- Metadata Group “Element Parameters”
  - Element Size
  - Element Shape (elliptic / rectangular)
  - Height Outside Element
  - Absorbing Material Outside Element
  - Total Profile Height
  - Exported Binary Masks (yes/no)
  - Number of Height Levels (only if the surface *Contains Discrete Height Levels*)
  - Height Level Difference (only if the surface *Contains Discrete Height Levels*)
  - Pixel Size
  - Data Represents Only One Period (“yes”: *Export Only One Period* was selected during export; “no”: *Export Whole Surface* was selected during export)
  - Number of Exported Pixels

- Metadata Group “Period Parameters” (only if Data Represents Only One Period)
  - Size of One Period
  - Resulting Repetitions (Element Size / Size of One Period)
  - Size of Inner Definition Area
  - Shape of Inner Definition Area
  - Height Outside Inner Definition Area
  - Absorbing Material Outside Inner Definition Area
- Metadata Group “Mask Information” (only if Exported Binary Masks is “yes”)
  - Number of Masks
  - Height Modulation of Mask # 1
  - Height Modulation of Mask # 2
  - …
- Metadata Group “Specific Export Settings”
  - Invert Profile
  - Compression for GDSII / CIF (only if GDSII / CIF have been generated)

134 Import of Macleod Coatings

VirtualLab Fusion supports importing Macleod coatings in the following two ways.

1. You can import the data directly into VirtualLab Fusion’s coatings catalog by clicking on the *Import Macleod Coating Data* button, which is located within the *Catalog Tools* of the catalog. After the import you are prompted for a name and categories to insert the imported coating into the *User Defined* catalog (see also Sec. 33.1).

2. In the edit catalog of a coating you can replace the current data with the imported Macleod data by clicking the -button.

The order of the layer sequence of an optical thin film coating is important for its optical properties. When applied to any surface between a solid and a non-solid medium in automatic coating application mode, VirtualLab Fusion will put layer #1 automatically as the very next one to the solid substrate. As this convention is not used within Macleod, a dialog asks you to confirm the imported layer sequence for non-symmetrical layer structures. If necessary the order of the layer sequence can be inverted in the dialog in question.
Furthermore Macleod files contain also the substrate and the surrounding material. During the import you are prompted whether these two materials are to be saved into VirtualLab Fusion’s material catalog. If you want to do so, the dialog in Fig. 797 is shown.

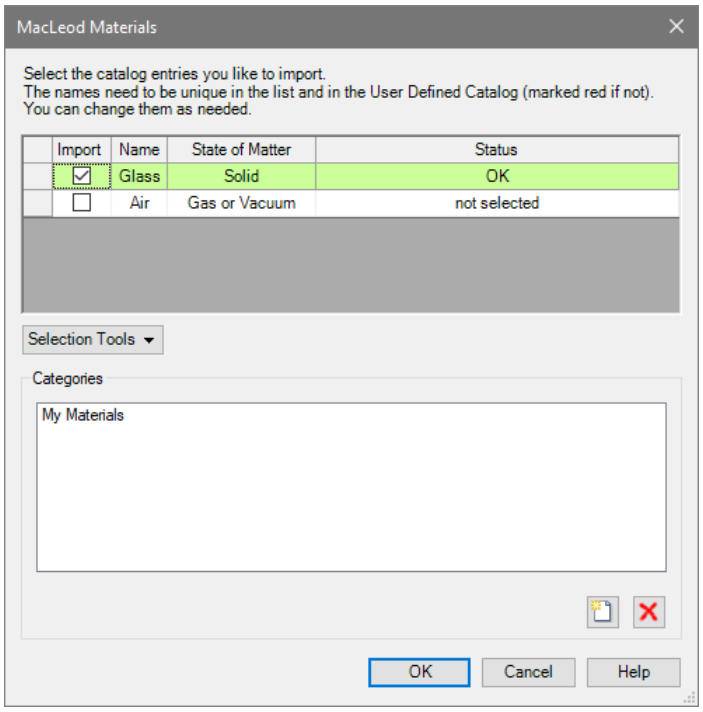


Figure 797. *Import dialog for Macleod substrate and surrounding material.*

In the upper part of this dialog there is a table with the following columns:

COLUMN	DESCRIPTION
Import	Allows you to select which materials shall be imported. If the selected item is marked red then its name is not unique, already present in the file for user defined entries, or empty. If it is marked green the file can be imported.
Name	Shows the name of the material and allows you to change it.
State of Matter	Macleod materials have no state of matter. Thus you can set it in this column whereas VirtualLab Fusion already provides an educated guess.

The lower part of the catalog defines the categories in which **all** entries are stored. You can add a new category with the -button and remove a category with the -button.
If you press *Ok* the chosen materials will be saved to the user defined materials catalog.

135 Import of Materials from Zemax OpticStudio® Glass Catalogs

Via the *Catalog Tools* of the catalog main form (Sec. 33) for materials you can *Import 'Zemax OpticStudio®' Glass Catalogs*.

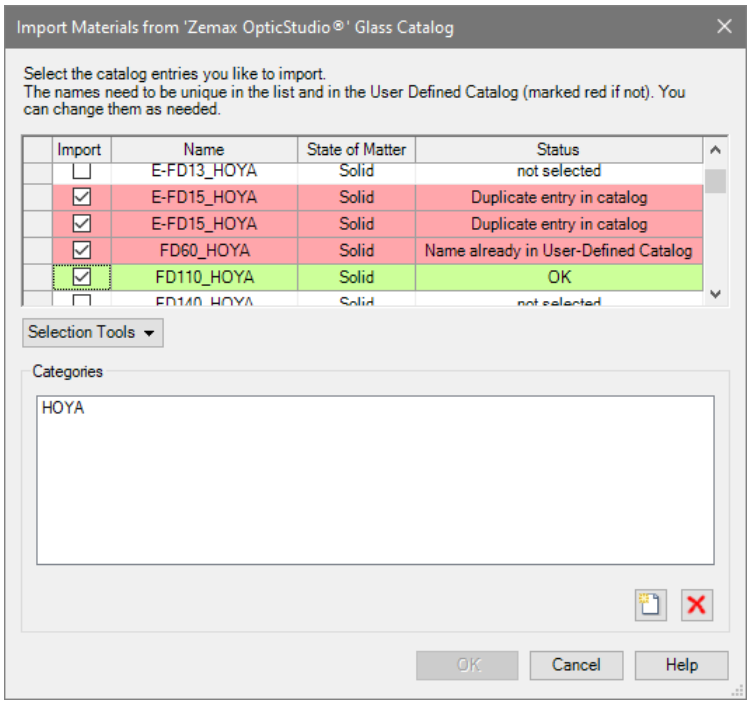


Figure 798. *Import dialog for a Zemax OpticStudio® glass catalog with some inconsistent entries.*

This catalog tool first shows the standard Windows dialog for opening one or more files with the file extension `.agf`. The preselected path in this dialog is the `GlassCat folder` in the *Path for 'Zemax OpticStudio®' User Data* as specified in the Global Options dialog. The selected files are then imported with the dialog shown in Fig. 798. In the upper part of this dialog there is a table with the following columns:

COLUMN	DESCRIPTION
Import	Allows you to select which materials shall be imported from the Zemax OpticStudio® glass catalog. Materials whose name is not unique, already present in the user defined catalog, or empty cannot be imported. If such a material is selected the corresponding row is marked red. Otherwise, it is marked green and *OK* is shown in the *Status* column.
Name	Shows the name of the material and allows you to change it.
State of Matter	Materials imported from Zemax OpticStudio® have no state of matter. By default they are assumed to be solids, but you can change it in this column.
Status	The following states are possible: • Error: An error message is shown for those materials that cannot be imported. • Warning: A warning message is shown in case the import cannot be done smoothly. (As an example, sometimes a wavelength is given more than once in a glass file. In that case the import is possible. But the data are cleaned by computing average data for the non-unique wavelengths.) • OK: If no problems occur, the status is *OK* if the respective material is marked for import.

By clicking on a column caption, you can sort by this column.
The *Selection Tools* allow you to either *Select All* materials in the table or to *Unselect All*.

The lower part of the catalog defines the categories into which **all** materials are stored. You can add a new category with the -button and remove a category with the -button.

XVII Algorithm Manual

This part of the manual gives physical and mathematical background information to the topics covered in the previous parts of the manual.

136 Field Data

For locally polarized harmonic fields the two electric field components E_x and E_y are stored, from which all other field components can be reconstructed. For globally polarized fields, only the scalar field $U(x,y)$ and the Jones vector $\boldsymbol{J}$ (↪Sec. 136.1) are stored.

The field data are stored as field values on an equidistantly sampled grid. The number of sampling points in x- and y-direction, N_x and N_y can be chosen freely in the x- and y-direction respectively. For storing two-dimensional fields both N_x and N_y are greater than 1. One-dimensional fields are typically stored with $N_y = 1$. For each sampling point a complex number is stored by two *double* precision numbers for the real and imaginary part. This corresponds to a memory requirement of 2×8 bytes per sampling point. It is also possible that only the real part is stored.

In VirtualLab Fusion E_z is calculated according to

$$E_z(x,y) = \left[\mathcal{F}^{-1}\left(-\frac{1}{k_z}\left(k_x \cdot [\mathcal{F}\,E_x(x,y)](k_x,k_y) + k_y \cdot [\mathcal{F}\,E_y(x,y)](k_x,k_y)\right)\right)\right](x,y) \quad . \tag{136.1}$$

where $\mathcal{F}$ denotes a Fourier transform and $\mathcal{F}^{-1}$ an inverse Fourier transform.

The components of the magnetic field are calculated with the following formulas:

$$H_\mathsf{x} = a_0(k_\mathsf{y}E_z - k_\mathsf{z}E_y) \tag{136.2}$$

$$H_\mathsf{y} = a_0(k_\mathsf{z}E_x - k_\mathsf{x}E_z) \tag{136.3}$$

$$H_\mathsf{z} = a_0(k_\mathsf{x}E_y - k_\mathsf{y}E_x) \tag{136.4}$$

with

$$a_0 = \frac{1}{k}\sqrt{\frac{\epsilon_0}{\mu_0}} \tag{136.5}$$

136.1 Global and Local Polarization

If the ratio of the two field components $E_x(x,y,z_j)/E_y(x,y,z_j)$ is independent of the position (x,y), we obtain

$$\boldsymbol{f}(x,y,z_j) = \boldsymbol{J}U(x,y,z_j) \tag{136.6}$$

with the Jones vector $\boldsymbol{J} = [J_x, J_y]$. Those fields are *uniformly* or *globally polarized* in the x-y-plane.

All other harmonic fields are *locally polarized*, that is only locally they are of the form shown in Eq. (136.6).

VirtualLab Fusion deals with both states of polarization and handles the change from global to local polarization automatically.

136.2 Spherical Phase Radius

Sampling of a large spherical phase (e. g. a lens with short focal length) would require a very small sampling distance and thus many sampling points for correctly sampling the spherical phase in the border areas of the field. Therefore, VirtualLab Fusion can handle the spherical phase radius as a separate factor multiplied to the sampled aberrations of the spherical phase. This means that the sampling distance has to be chosen only for accurate sampling of the aberrations.

Many of the internal operations of VirtualLab Fusion, as for example the homogeneous medium propagation operators, take into account the stored spherical phase radius.

For newly created harmonic fields, VirtualLab Fusion detects and stores the spherical phase radius automatically.

136.3 Propagation in Positive Z-Direction?

Part of a complete definition of a harmonic field at a position z' is the sign of the z-component of its principal propagation direction $\mathrm{sgn}(k_z)$. It determines whether the field propagates principally to the positive or the negative z-direction. For an example of the importance of this distinction see Fig. 799.

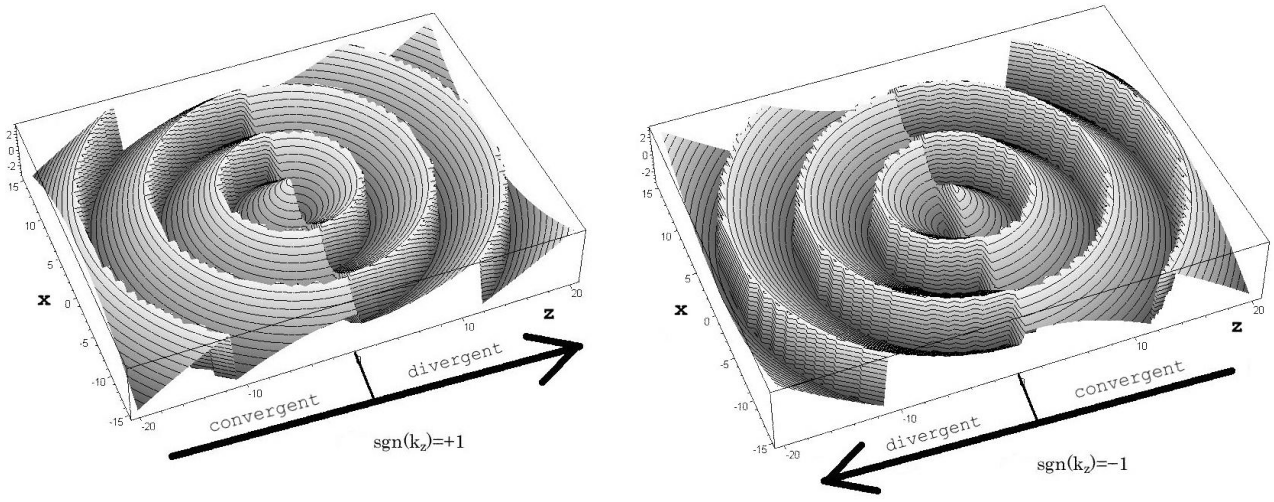


Figure 799. *Phase of Spherical Wave. Left: Propagating in Positive Z-Direction, Right: Propagating in Negative Z-Direction.*

Fields resulting from an Optical Setup (↪Sec. 44) always propagate in positive z-direction.

136.4 Interpolation Methods for Equidistant Data

The appropriate interpolation method has to be chosen according to the physical meaning of the data which shall be interpolated, and according to the acceptable computational effort. If the data represents a harmonic field, the standard reconstruction method is based on the Sinc interpolation [Goo68]. Unfortunately this method is typically connected with a relatively high computational effort. If the data represents a diffractive optical element, nearest neighbor interpolation is recommended.
The following interpolations for equidistant data are supported in VirtualLab Fusion:

ITEM	DESCRIPTION
Nearest Neighbor Interpolation	Each sampling point of the resultant field is set to the complex amplitude of the nearest sampling point of the original field.
Linear (Amplitude/Phase)	Linear interpolation with respect to the 2 (one-dimensional case) or 4 (two-dimensional case) adjacent sampling points. This interpolation is performed independently for amplitude and phase.
Linear (Real/Imaginary Part)	Linear interpolation with respect to the 2 (one-dimensional case) or 4 (two-dimensional case) adjacent sampling points. This interpolation is performed independently for real and imaginary part.
Cubic 4 Point	Complex cubic interpolation with respect to the 4 (one-dimensional case) or 4×4 (two-dimensional case) neighboring sampling points of the original field. ↪Fig. 800
Cubic 6 Point	Complex cubic interpolation with respect to the 6 (one-dimensional case) or 6×6 (two-dimensional case) neighboring sampling points of the original field. ↪Fig. 800

Cubic 8 Point	Complex cubic interpolation with respect to the 8 (one-dimensional case) or 8×8 (two-dimensional case) neighboring sampling points of the original field. ↪Fig. 800
Sinc (Fourier Transform)	Using this interpolation method finer sampling is achieved by embedding in the Fourier space. This interpolation method is equivalent to the following steps: 1. Remove the spherical phase radius (if present). ↪Sec. 12.1.1 2. Do a physical backward Fourier transformation. ↪Sec. 31.1 3. Embed the field according to the desired new sampling distance. ↪Sec. 22.7 4. Do a physical forward Fourier transformation. ↪Sec. 31.1 5. Embed or extract the field to achieve the desired new field size. ↪Sec. 22.7 6. Superimpose the previously removed spherical phase radius. ↪Sec. 22.5.1
Windowed Sinc	Variant of the *Sinc Interpolation (Fourier Transform)*, which does the embed or extract to the desired new field size before the first Fourier transform. This reduces the required computational effort if only a part of the original field should be interpolated but yields only a slightly approximated result. More precisely, first a little bit larger part (larger by 6 sampling points) is extracted out of the original field in order to reduce numerical errors on the borders of the interpolated field; the additional sampling points are then removed in a final step.
Accelerated Sinc	If you interpolate to a new field size $(x; y)$, then the original field is first truncated to $(t \cdot x; t \cdot y)$ using a soft aperture of that size. t is the *Field Size Truncation Factor for Accelerated Sinc Interpolation* of the Global Options dialog (↪Sec. 6.13). Afterwards a Sinc Interpolation (Fourier Transform) is performed on the truncated field.
Sinc (Pointwise)	Sinc interpolation using pointwise superposition of sinc functions, that is for each sampling point of the resulting field a summation is performed over the sinc functions of all sampling points of the original field. This interpolation method can be significantly slower but less memory consuming than *Sinc Interpolation (Fourier Transform)*, although besides of numerical errors it yields the same result.
Truncated Sinc	Approximation to the interpolation method *Sinc Interpolation (Pointwise)* in which the extent of the sinc function is limited to 6 sampling points.
Combined	Depending on the physical extension of the resultant field either cubic 6 point interpolation (small size) or Windowed Sinc Interpolation (larger size) is used. The cubic interpolation is used if the extension of the resultant field is smaller than three sampling points of the original field.

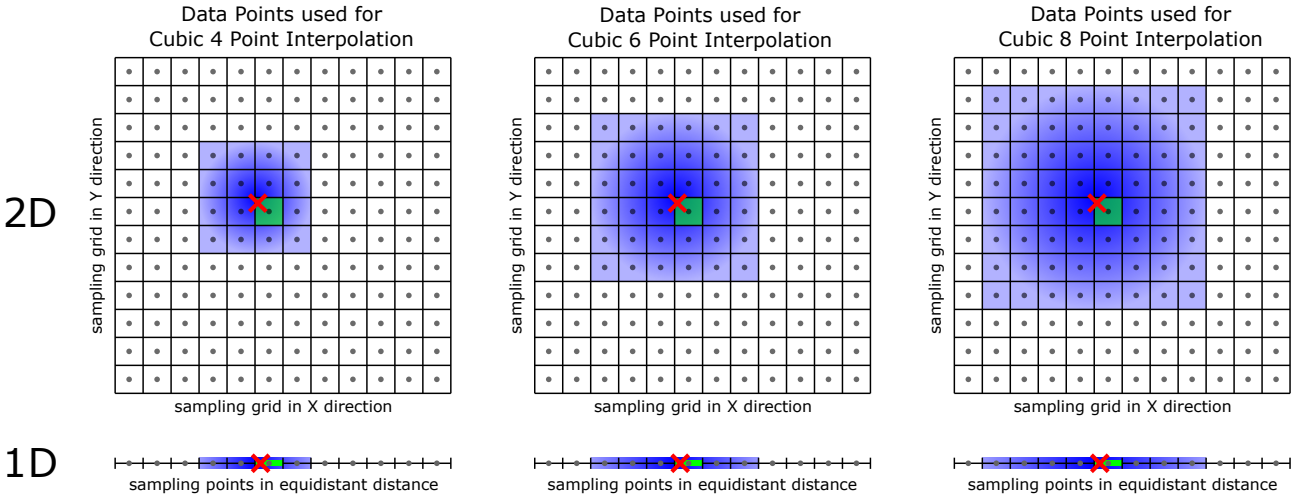


Figure 800. *Illustration which neighbor points are used for a Cubic n Point Interpolation.*

137 Manipulations

137.1 Array - Array Operations

There are four basic arithmetic operations for arrays: addition, subtraction, multiplication, and division and additionally the convolution.

In the case that the two arrays of a array-array operation have not the same sampling distance or the same array size, at least one of the fields or transmissions has to be resampled before the calculation, because the underlying operation works pointwise.

The following table shows which parameter has to be adjusted in what case for each operation. The second and the third column show how the sampling distance Δ_{new} and the array size S_{new} of the resulting array are determined by the sampling parameters of the operands (indices 1 and 2). Before starting the calculation, the array(s) that has got sampling parameters different from that of the result field must be resampled.

Important: The sampling parameters for the directions x and y are checked and adjusted independently!

Operation	Δ_{new}	S_{new}
Addition	$\Delta_{\text{new}} = \min(\Delta_1, \Delta_2)$	$S_{\text{new}} = \max(S_1, S_2)$
Subtraction	$\Delta_{\text{new}} = \min(\Delta_1, \Delta_2)$	$S_{\text{new}} = \max(S_1, S_2)$
Multiplication	$\Delta_{\text{new}} = \min(\Delta_1, \Delta_2)$	$S_{\text{new}} = \min(S_1, S_2)$
Division	$\Delta_{\text{new}} = \min(\Delta_1, \Delta_2)$	$S_{\text{new}} = \min(S_1, S_2)$
Convolution	$\Delta_{\text{new}} = \min(\Delta_1, \Delta_2)$	$S_{\text{new}} = \max(S_1, S_2)$

137.1.1 Basic Arithmetic Operations

Different types of Complex Amplitude Documents (Harmonic Field vs. Transmission) cannot be used as operands in every possible combination. A summary of all combinable types and their result for all operations is shown in the following tables 137.1 - 137.3. The used abbreviations are (GP) for globally polarized fields and (LP) for locally polarized fields.

Note: If the normalization factor of the Jones vector $\boldsymbol{J}'$ is zero, the resulting field is set to zero and the Jones vector to $(1,0)^T$. If for one sampling point a division by zero occurs, then the result is set to zero too.

1st Operand	2nd Operand: Transmission	2nd Operand: Harmonic Field (GP)	2nd Operand: Harmonic Field (LP)
Transmission	*Result:* Transmission $t = t_1 \pm t_2$ $\mathcal{J} = \mathcal{J}_1$	-	-
Harmonic Field (GP)	-	*if* $\boldsymbol{J_1} = \boldsymbol{J_2}$: *Result:* Harmonic Field (GP) $\boldsymbol{J} = \boldsymbol{J_1}$ $U = U_1 \pm U_2$ *else* *Result:* Harmonic Field (LP) $E_x = J_{1,x}U_1 \pm J_{2,x}U_2$ $E_y = J_{1,y}U_1 \pm J_{2,y}U_2$	*Result:* Harmonic Field (LP) $E_x = J_{1,x}U_1 \pm E_{2,x}$ $E_y = J_{1,y}U_1 \pm E_{2,y}$
Harmonic Field (LP)	-	*Result:* Harmonic Field (LP) $E_x = E_{1,x} \pm J_{2,x}U_2$ $E_y = E_{1,y} \pm J_{2,y}U_2$	*Result:* Harmonic Field (LP) $E_x = E_{1,x} \pm E_{2,x}$ $E_y = E_{1,y} \pm E_{2,y}$

Table 137.1: *Addition or Subtraction of two Complex Amplitudes*

1st Operand	2nd Operand: Transmission	2nd Operand: Harmonic Field (GP)	2nd Operand: Harmonic Field (LP)
Transmission	*Result:* Transmission $t = t_1 \cdot t_2$ $\boldsymbol{\mathcal{J}} = \boldsymbol{\mathcal{J}_1} \times \boldsymbol{\mathcal{J}_2}$	*Result:* Harmonic Field (GP)† $U = t_1 \cdot U_2 \cdot \lvert\boldsymbol{\mathcal{J}_1} \times \boldsymbol{J_2}\rvert$ $\boldsymbol{J} = (\boldsymbol{\mathcal{J}_1} \times \boldsymbol{J_2}) \,/\, \lvert\boldsymbol{\mathcal{J}_1} \times \boldsymbol{J_2}\rvert$	*Result:* Harmonic Field (LP)† $\boldsymbol{E}_{\text{xy}} = (\boldsymbol{\mathcal{J}_1} \times \boldsymbol{E}_{\text{xy},2})t_1$
Harmonic Field (GP)	*Result:* Same as for Transmission times Harmonic Field (GP), i. e. the operands are swapped internally.†	*Result:* Harmonic Field (GP) $U = U_1 \cdot U_2$ $J_x = J_{1,x}J_{2,x} \,/\, \lvert\boldsymbol{J}'\rvert$ $J_y = J_{1,y}J_{2,y} \,/\, \lvert\boldsymbol{J}'\rvert$ with $\lvert\boldsymbol{J}'\rvert = \sqrt{\lvert J_{1,x}J_{2,x}\rvert^2 + \lvert J_{1,y}J_{2,y}\rvert^2}$	*Result:* Harmonic Field (LP) $E_x = (J_{1,x} \cdot U_1)E_{2,x}$ $E_y = (J_{1,y} \cdot U_1)E_{2,y}$
Harmonic Field (LP)	*Result:* Harmonic Field (LP)† $\boldsymbol{E}_{\text{xy}} = (\boldsymbol{\mathcal{J}_2} \times \boldsymbol{E}_{\text{xy},1})t_2$	*Result:* Harmonic Field (LP) $E_x = E_{1,x}(J_{2,x} \cdot U_2)$ $E_y = E_{1,y}(J_{2,y} \cdot U_2)$	*Result:* Harmonic Field (LP) $E_x = E_{1,x} \cdot E_{2,x}$ $E_y = E_{1,y} \cdot E_{2,y}$

Table 137.2: *Multiplication of two Complex Amplitudes.*
$\times$ *refers to a matrix multiplication.*
†*Please note: There is a global option (↪Sec. 6.12) which allows to embed the result of a multiplication of harmonic field and transmission into an additional frame of zeros.*

	2nd Operand		
1st Operand	Transmission	Harmonic Field (GP)	Harmonic Field (LP)
Transmission	*Result:* Transmission $t = t_1 / t_2$ $\mathcal{J} = \mathcal{J}_1$	-	-
Harmonic Field (GP)	-	*Result:* Harmonic Field (GP) $U = U_1 / U_2$ $J_x = (J_{1,x} / J_{2,x}) \;/\; \lvert J' \rvert$ $J_y = (J_{1,y} / J_{2,y}) \;/\; \lvert J' \rvert$ with $\lvert J' \rvert = \sqrt{\lvert J_{1,x} / J_{2,x} \rvert^2 + \lvert J_{1,y} / J_{2,y} \rvert^2}$	*Result:* Harmonic Field (LP) $E_x = (J_{1,x} \cdot U_1) / E_{2,x}$ $E_y = (J_{1,y} \cdot U_1) / E_{2,y}$
Harmonic Field (LP)	-	*Result:* Harmonic Field (LP) $E_x = E_{1,x} / (J_{2,x} \cdot U_2)$ $E_y = E_{1,y} / (J_{2,y} \cdot U_2)$	*Result:* Harmonic Field (LP) $E_x = E_{1,x} / E_{2,x}$ $E_y = E_{1,y} / E_{2,y}$

Table 137.3: *Division of two Complex Amplitudes*

137.1.2 Convolution

The convolution of two Complex Amplitude Documents U_1 and U_2 is calculated by

$$U_1 \star U_2 = \mathcal{F}^{-1}[(\mathcal{F}\,U_1) \cdot (\mathcal{F}\,U_2)]. \tag{137.1}$$

What types of Complex Amplitude Documents (Harmonic Field vs. Transmission) can be combined as operands and their result for all operations is shown in the following table 137.4. The used abbreviations are (GP) for globally polarized fields and (LP) for locally polarized fields.

Note: If the normalization factor of the Jones vector $\boldsymbol{J}'$ is zero, the resulting field is set to zero and the Jones vector to $(1,0)^T$.

1st Operand	2nd Operand: Transmission	2nd Operand: Harmonic Field (GP)	2nd Operand: Harmonic Field (LP)
Transmission	*Result:* Transmission $t = t_1 \star t_2$ $\mathcal{J} = \mathcal{J}_1$	-	-
Harmonic Field (GP)	-	*Result:* Harmonic Field (GP) $U = U_1 \star U_2$ $J_x = J_{1,x} J_{2,x} \,/\, \lvert J' \rvert$ $J_y = J_{1,y} J_{2,y} \,/\, \lvert J' \rvert$ with $\lvert J' \rvert = \sqrt{\lvert J_{1,x} J_{2,x} \rvert^2 + \lvert J_{1,y} J_{2,y} \rvert^2}$	*Result:* Harmonic Field (LP) $E_x = (J_{1,x} \cdot U_1) \star E_{2,x}$ $E_y = (J_{1,y} \cdot U_1) \star E_{2,y}$
Harmonic Field (LP)	-	*Result:* Harmonic Field (LP) $E_x = E_{1,x} \star (J_{2,x} \cdot U_2)$ $E_y = E_{1,y} \star (J_{2,y} \cdot U_2)$	*Result:* Harmonic Field (LP) $E_x = E_{1,x} \star E_{2,x}$ $E_y = E_{1,y} \star E_{2,y}$

Table 137.4: *Convolution of two Complex Amplitudes*

137.2 Jones Matrix Multiplication

Some optical elements and devices influence the polarization state of light. Mathematically this process can be described by a change of the electric field vector by a matrix, called Jones matrix $\mathcal{J}$

$$\boldsymbol{E}_{\text{xy}}^{\text{out}} = \mathcal{J} \cdot \boldsymbol{E}_{\text{xy}}^{\text{in}}. \tag{137.2}$$

For globally polarized fields, this means a change of the Jones vector:

$$J_{\text{out}} = \mathcal{J} \cdot J_{\text{in}}. \tag{137.3}$$

Since Transmissions contain their own Jones matrix $\mathcal{J}^{(T)}$, the effect of a Jones Matrix Multiplication can be "added" to the transmission by applying former to the latter, which corresponds to the mathematical operation

$$\mathcal{J}_{\text{out}}^{(T)} = \mathcal{J} \cdot \mathcal{J}_{\text{in}}^{(T)}. \tag{137.4}$$

For your convenience, the four important cases of *Linear Polarization*, *Phase Shift*, *Retardation*, and *Rotation* are implemented as separate manipulations in VirtualLab Fusion.

- **Linear Polarization:** A linear polarizer is a kind of optical filter that will pass only that part of $\boldsymbol{E}_{\text{xy}}$ which oscillates in a certain direction. If this direction is given by an angle α, the corresponding Jones matrix is given by

$$\mathcal{J} = \begin{pmatrix} \cos^2\alpha & \sin\alpha\cos\alpha \\ \sin\alpha\cos\alpha & \sin^2\alpha \end{pmatrix}. \tag{137.5}$$

- **Phase Shift:** A phase shift adds a phase difference ϕ to both E_x and E_y. The appropriate Jones matrix is

$$\mathcal{J} = \begin{pmatrix} \exp(i\phi) & 0 \\ 0 & \exp(i\phi) \end{pmatrix}. \tag{137.6}$$

- **Retardation:** Retarders as e. g. quarter-wave plates or half-wave plates "retard" E_y against E_x by a phase difference ϕ. Thereby linearly polarized light can be transformed into circularly polarized and vice versa, for example. The appropriate Jones matrix is

$$\mathcal{J} = \begin{pmatrix} 1 & 0 \\ 0 & \exp(-i\phi) \end{pmatrix}. \tag{137.7}$$

- **Rotation:** The angle of rotation θ of the plane of polarization determines the Jones matrix as follows

$$\mathcal{J} = \begin{pmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{pmatrix}. \tag{137.8}$$

137.3 Quantization

Quantization of a complex amplitude field means to introduce discrete amplitude and phase levels.

137.3.1 Hard Quantization

You can enter the numbers q and Q of amplitude and phase levels, respectively.
The quantization is performed independently for amplitude and phase. For each position (x,y) the original field value $u(x,y) = A\exp[i\phi]$ is replaced by $A'\exp[i\phi']$, where

$$A' = \begin{cases} A & \textbf{if } q = 0 \\ A_{\text{max}} & \textbf{if } q = 1 \\ \frac{A_{\text{max}}}{q-1} \cdot \lfloor (q-1)\frac{A}{A_{\text{max}}} \rceil & \textbf{otherwise} \end{cases} \tag{137.9}$$

(where $\lfloor \cdot \rceil$ denotes the rounding-to-nearest-integer operation) and

$$\phi' = \begin{cases} \phi & \textbf{if } Q = 0 \\ \frac{2\pi}{Q} \cdot \lfloor \frac{Q(\phi+\pi)}{2\pi} \rceil - \pi & \textbf{otherwise} \end{cases} \tag{137.10}$$

A_{max} is the maximum amplitude within the input field. Compared to the definition of the phase quantization operator $\Pi_{\text{quant},Q}$ used during IFTA optimization (Sec. 98), which corresponds to the case of $q = 1$, the definition given in this section allows simultaneous amplitude and phase quantization. Furthermore, the special cases for $q = 0$ and $Q = 0$ have been included for maintaining the original amplitude and phase, respectively. In cases of $q = 1$ the amplitude is set to one. If $Q = 1$, the resulting field has a zero phase.

137.3.2 Soft Quantization

You can enter the numbers q and Q of amplitude and phase levels, respectively. Furthermore a projection strength λ can be entered.

The quantization is performed independently for amplitude and phase. For each position (x, y) the original field value $u(x, y) = A \exp[i\phi]$ is replaced by $A' \exp[i\phi']$. The amplitude A' is obtained by

$$A' = \begin{cases} A & \textbf{if } q = 0 \\ A_{\text{max}} & \textbf{if } q = 1 \wedge C_1 = \text{true} \\ \frac{A_{\text{max}}}{q-1} \cdot \lfloor (q-1)\frac{A}{A_{\text{max}}} \rceil & \textbf{if } q > 1 \wedge C_2 = \text{true} \\ A & \textbf{otherwise} \end{cases} \tag{137.11}$$

with the Boolean terms

$$C_1 = \left(|\frac{A}{A_{\text{max}}} - 1| \geq 0.5\lambda \right), \tag{137.12}$$

$$C_2 = \left(\left| \frac{A}{A_{\text{max}}} - \frac{1}{q-1} \cdot \lfloor (q-1)\frac{A}{A_{\text{max}}} \rceil \right| \geq \frac{\lambda}{2(q-1)} \right). \tag{137.13}$$

The phase ϕ' is calculated from

$$\phi' = \begin{cases} \phi & \textbf{if } Q = 0 \vee C_3 = \text{true} \\ \frac{2\pi}{Q} \cdot \lfloor \frac{Q(\phi+\pi)}{2\pi} \rceil - \pi & \textbf{otherwise} \end{cases} \tag{137.14}$$

with the Boolean term

$$C_3 = \left(Q > 0 \wedge \left| \phi - \frac{2\pi}{Q} \cdot \lfloor Q/(2\pi)\phi \rceil \right| > \lambda\pi/Q \right). \tag{137.15}$$

A_{max} is the maximum amplitude within the complex amplitude field.

Compared to the definition of the phase quantization operator $\Pi^{\lambda}_{\text{softquant},Q}$ used during IFTA optimization (↪Sec. 98), which corresponds to the case of $q = 1$, the definition given in this section allows for simultaneous amplitude and phase quantization. Furthermore, the special cases for $q = 0$ and $Q = 0$ have been included for maintaining the original amplitude and phase, respectively. If $Q = 1$, the resulting field has a zero phase.

137.3.3 Floyd-Steinberg Quantization

You can enter the numbers q and Q of amplitude and phase levels, respectively.

The result of the Floyd-Steinberg quantization contains only field values from the set

$$M_{(q,Q)} = \{A \exp[i\phi] : A \in M_q \wedge \exp[i\phi] \in M_Q\}, \tag{137.16}$$

where the sets M_q and M_Q are given by

$$M_q = \left\{ \frac{jA_{\max}}{q-1} : j = 0 \ldots q-1 \right\} \tag{137.17}$$

and

$$M_Q = \left\{ \exp\left[-i\pi \left(-1 + \frac{2\pi j}{Q} \right) \right] : j = 0, 1, \ldots, Q-1 \right\}. \tag{137.18}$$

$A_{\max}$ is the maximum amplitude within the complex amplitude field.

In contrast to the quantization types described in the previous two sections, the Floyd-Steinberg quantization is not a pointwise operation. That is, the quantization result at a position (x, y) does not depend only on the field value $u(x, y)$ but also on the field values on neighboring positions. The basic idea of the Floyd-Steinberg quantization is to distribute the error, which was made by the quantization at a certain position, to the neighboring positions.

During the application of the Floyd-Steinberg quantization an iteration through all field positions is performed row by row, whereby within each row positions are considered consecutively from left to right. At a considered position (x, y) firstly a hard quantization is performed (↪Sec. 137.3.1). After that the quantization error is calculated from the difference between $u(x, y)$ and the obtained quantization value.

This difference is spread using the weighting factors shown in Fig. 801 to four neighboring positions, which are considered in following iterations.

Figure 801. *Weighting factors for distribution of quantization errors to neighboring positions during Floyd-Steinberg quantization.*

137.4 Dimension Separation

You can separate a two-dimensional complex array or recombine the parts of a previously separated array. A two-dimensional separable array $u_{\text{sep}}(x, y)$ fulfills the property

$$u_{\text{sep}}(x, y) = u_x(x) u_y(y), \tag{137.19}$$

with the one-dimensional arrays u_x and u_y which are calculated from the (not necessarily separable) current array $u(x, y)$ by

$$u_x(x) = f_x u'_x(x), \tag{137.20}$$

$$u_y(y) = f_y u'_y(y) \tag{137.21}$$

with

$$u'_x(x) = \sum_{j=0}^{N_y-1} u(x, y_j), \tag{137.22}$$

$$u'_y(y) = \sum_{i=0}^{N_x-1} u(x_i, y) \tag{137.23}$$

and

$$f_x = \sqrt{f_0 \frac{N_x}{N_y}}, \tag{137.24}$$

$$f_y = \sqrt{f_0 \frac{N_y}{N_x}}, \tag{137.25}$$

where N_x and N_y denote the number of sampling points and f_0 is calculated as

$$f_0 = \frac{\sum_{j=0}^{N_y-1}\sum_{i=0}^{N_x-1} u(x_i,y_j)\overline{u_x(x_i)u_y(y_j)}}{\sum_{j=0}^{N_y-1}\sum_{i=0}^{N_x-1} \|u_x(x_i)u_y(y_j)\|^2}. \tag{137.26}$$

137.5 Fourier Transforms

137.5.1 Fourier Transform (Space)

The Fourier transform has many applications in wave-optical simulations. Examples are the usage in free space propagation operators (↪Sec. 94) and the simulation of Fourier transforming optical setups (↪Sec. 31.1.1).
There are four different Fourier transforms:

- (Physical) Forward: x $\rightarrow$ k,
- (Physical) Backward: k $\rightarrow$ x,
- Numerical Forward: x $\rightarrow$ k, and
- Numerical Backward: k $\rightarrow$ x .

The *numerical* and the "*normal*" or *physical* Fourier transform differ in their scaling: The *numerical* variants ensure that the summed norm of the field (↪Sec. 76.4.7) is not changed by the transform. This leads to the effect that if you embed the Fourier transform of a field in a zeroized frame and then perform the backward transform, the power and maximum amplitude of the field has changed. This is circumvented if you use the *physical* transforms.
The mathematical equations for the Fourier transform and its inverse operation are:
Fourier transform $\mathcal{F}$:

$$[\mathcal{F}\,U(x,y)](\hat{x},\hat{y}) = \int\int_{-\infty}^{\infty} \mathrm{d}x\mathrm{d}y \exp[-i2\pi\,(x\hat{x}+y\hat{y})]\,U(x,y) \tag{137.27}$$

Its inverse operation $\mathcal{F}^{-1}$:

$$[\mathcal{F}^{-1}U(\hat{x},\hat{y})](x,y) = \int\int_{-\infty}^{\infty} \mathrm{d}\hat{x}\mathrm{d}\hat{y} \exp[i2\pi\,(x\hat{x}+y\hat{y})]\,U(\hat{x},\hat{y}) \tag{137.28}$$

The used implementations of the Fourier transform and its inverse operation are using the technique of the Fast Fourier Transform (FFT) [Bra65] which is based on the discrete Fourier transform [Goo68]. They are given in the following subsections.

137.5.1.1 Forward: x $\rightarrow$ k

The discrete Fourier transform $\mathcal{F}$ calculates a complex array in the spectral representation with wave number coordinates (k_x, k_y) from an array with spatial coordinates (x, y) using the equation

$$\left[\mathcal{F}\,u(x,y)\right](k_x,k_y) = S\cdot\sum_x\sum_y \exp[-i(xk_x+yk_y)]\,u(x,y), \tag{137.29}$$

with the scaling factor

$$S = \begin{cases} \frac{1}{\sqrt{N_x N_y}} & \text{for the } \textit{numerical} \text{ variant} \\ \frac{\delta x\delta y}{2\pi} & \text{for the } \textit{physical} \text{ variant and two-dimensional fields} \\ \frac{\delta x}{\sqrt{2\pi}} & \text{for the } \textit{physical} \text{ variant and one-dimensional fields} \end{cases} \tag{137.30}$$

The two sums are calculated over the $(N_x;\, N_y)$ sampling points at a grid, which is defined by the sampling distance $(\delta x;\, \delta y)$. For constructing the resultant field, Eq. (137.29) is evaluated at $(N_x;\, N_y)$ sampling points

with a sampling distance $(\delta k_x; \delta k_y)$ given by

$$\delta k_x = \frac{2\pi}{N_x \delta x} \quad \text{and} \tag{137.31}$$

$$\delta k_y = \frac{2\pi}{N_y \delta y}. \tag{137.32}$$

137.5.1.2 Backward: k → x

The inverse discrete Fourier transform $\mathcal{F}^{-1}$ calculates a complex array in spatial representation from an array in spectral representation using the equation

$$\left[\mathcal{F}^{-1} u(k_x, k_y)\right](x, y) = S \cdot \sum_{k_x} \sum_{k_y} \exp[i(x k_x + y k_y)]\, u(k_x, k_y), \tag{137.33}$$

with the scaling factor

$$S = \begin{cases} \frac{1}{\sqrt{N_x N_y}} & \text{for the } \textit{numerical} \text{ variant} \\ \frac{\delta k_x \delta k_y}{2\pi} & \text{for the } \textit{physical} \text{ variant and two-dimensional fields} \\ \frac{\delta k_x}{\sqrt{2\pi}} & \text{for the } \textit{physical} \text{ variant and one-dimensional fields} \end{cases} \tag{137.34}$$

The sampling parameters of the two fields are related in the same way as stated above (Eqs. (137.31)-(137.32)).

138 Building Blocks

138.1 Surfaces

138.1.1 Approximated Function Domain of Surfaces

Internally all surfaces have an *Approximated Function Domain*, which is either elliptical or rectangular. If you extend the (inner) definition area of the surface beyond this limit, you may noticed unwanted “bends” or too large values for the following reasons.

- The formula used to describe the surface really becomes invalid beyond this range. Most likely reason is that the radicand of a square root in the formula becomes less than zero. These invalid values are then replaced by the *Position of Surrounding Plane* (↪Sec. 36.1.1.1). Example: Conical Surface (↪Sec. 36.2.4).
- The formula used to describe the surface becomes invalid *somewhere* beyond this range, but the exact shape of the boundary between valid and invalid values is unknown due to mathematical reasons. Then an Approximated Function Domain is used which for sure contains only valid values. Invalid values are replaced by the *Position of Surrounding Plane* (↪Sec. 36.1.1.1). This is the case for the Toroidal Asphere Surface (↪Sec. 36.2.12).
- The formula used to describe the surface is a polynomial which was designed to deliver height values within a certain range as long as you are in the *Unit Radius*. But outside of the unit radius the height values tend towards infinity. For these surfaces like the Zernike & Seidel Surface (↪Sec. 36.2.14) the unit radius defines the Approximated Function Domain.
- You exceed the range of given data for data-based surfaces like the Sampled Surface (↪Sec. 36.2.11). Then extrapolation (↪Sec. 13.3) is used, which can lead to overshooting in case of cubic interpolation of the data.
- Programmable Surfaces (↪Sec. 36.2.9) always have an infinite Approximated Function Domain. But in case your snippet yields invalid values (NaNs), they are replaced by the *Position of Surrounding Plane* (↪Sec. 36.1.1.1).

If along the boundary of the (inner) definition area there are only invalid values, the boundary minimum and maximum is regarded as zero.

138.1.2 Height Discontinuities and Rescaling of Surfaces

VirtualLab Fusion allows to scale any surface in x-, y-, and z-direction, respectively. Furthermore, VirtualLab Fusion offers three mathematical operations which introduce height discontinuities into the height profile of an optical surface.

1. **Pixelation** introduces rectangular pixels. The height within one pixel remains constant. ↪Sec. 138.1.2.1.
2. **Height Quantization** introduces a limited number of equidistant discrete height levels. The height at a certain position is set to the nearest height level. ↪Sec. 138.1.2.2.
3. Using **Fresnel zones**, the height profile is wrapped so that all height values lie within a certain interval. ↪Sec. 138.1.2.3.

The following equation shows how and in which order these surface manipulations are applied.

$$h(x,y) = \mathcal{Q}\left(\alpha\mathcal{R}\left(h'\left[\mathcal{P}\left(\frac{x}{\beta}\right),\mathcal{P}\left(\frac{y}{\gamma}\right)\right]\right)\right) \tag{138.1}$$

$h'(x,y)$ is the original height profile, e. g. that of a conical surface. $h(x,y)$ is the height profile after applying the aforementioned manipulations. β, γ and α represent a scaling in x-direction, scaling in y-direction, and scaling in z-direction, respectively.

The scaling in x-direction and the scaling in y-direction effect the domain of definition of the surface function (↪Sec. 36.1.1). Thus, you cannot enter values which are so small that the current size of the definition area exceeds the domain of definition of the surface function. The scaling in z-direction must not be zero, a negative scaling in z-Direction means that the height profile is inverted.

$\mathcal{P}(a)$ refers to the pixelation operator (↪Sec. 138.1.2.1), $\mathcal{Q}(h)$ to the quantization operator (↪Sec. 138.1.2.2), $\mathcal{R}(h)$ to the fresnelization operator (↪Sec. 138.1.2.3).

138.1.2.1 Pixelation

The pixelation function $p(a)$ introduces discrete rectangular pixels in the height profile and is defined as

$$p(a) = \begin{cases} \text{round}\left(\frac{a}{\Delta a}\right)\Delta a & ;\text{If pixelation is used.} \\ a & ;\text{else} \end{cases}. \tag{138.2}$$

Δa represents the pixel size along the x- or y-axis. The pixel size is in general different along both axes.

Note, according to Eq. (138.1), the resulting pixelation effect (the size of a region for which the height is constant) is influenced by the scaling parameters β (scaling in x-direction) and γ (scaling in y-direction).

The Sampled Surface contains discrete, equidistantly sampled height values with sampling distances δx and δy along the x- and y-axis, respectively. An additional interpolation method creates a continuous surface profile from these sampling points. If *Nearest Neighbor* is the interpolation method set in the sampled surface, rectangular pixels will always appear. Hence pixelation cannot be disabled then and the pixel sizes are fixed to $\delta x \cdot \delta y$.

138.1.2.2 Use Discrete Height Levels (Height Quantization)

The function $q(h)$ introduces discrete height levels in an optical surface and is defined as

$$q(h) = \begin{cases} h & \text{If quantization is not used.} \\ q_{\text{min}} & \text{if } h_{\text{min}} \leq h < q_{\text{min}}. \\ q_{\text{max}} & \text{if } q_{\text{max}} < h \leq h_{\text{max}}. \\ \text{round}\left(\frac{h-q_{\text{min}}}{\Delta h}\right)\Delta h + q_{\text{min}} & \text{else} \end{cases} . \tag{138.3}$$

q_{min} and q_{max} are the minimum and the maximum height level of the discretized height profile, respectively. Δh is the height difference between two consecutive height levels and is defined as

$$\Delta h = \frac{q_{\text{max}} - q_{\text{min}}}{n-1}. \tag{138.4}$$

h_{min} represents the minimum height of the original non-discretized surface and h_{max} its maximum height. n is the *Number of Discrete Height Levels* between and including q_{min} and q_{max}. The function round(x) returns the integer value closest to x.

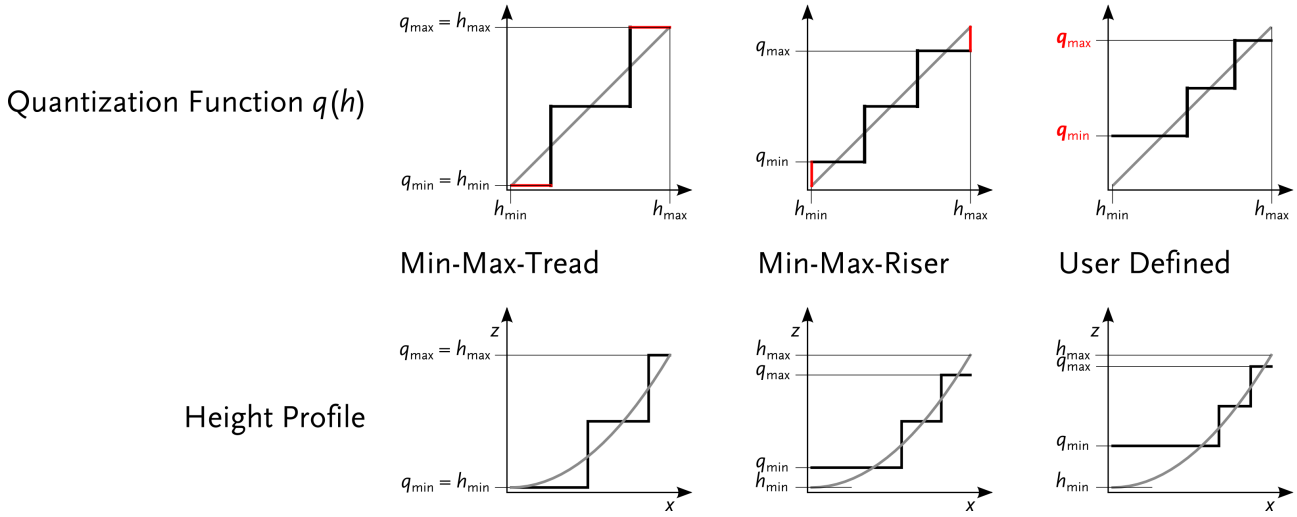


Figure 802. *Illustration of the three quantization modes supported by VirtualLab Fusion. The top row shows the respective quantization functions $q(h)$ and the bottom row shows the effect if this quantization function is applied on a sample height profile.*

The quantization mode *Min-Max-Tread* ensures that the z-extension does not change. To this end, q_{min} is set to the original minimum height h_{min} and q_{max} is set to the original maximum height h_{max}. As you can see in the left part of Fig. 802, the “stairway” representing the quantization function starts with a tread (a horizontal region).

However, the *Min-Max-Tread* mode has a maximum quantization error $q(h) - h$ of $\frac{h_{\text{max}}-h_{\text{min}}}{2(n-1)}$. If one resigns the conservation of the z-extension, this error can be reduced to $\frac{h_{\text{max}}-h_{\text{min}}}{2n}$. To this end, the mode *Min-Max-Riser* is available where $q_{\text{min}} = h_{\text{min}} + \frac{h_{\text{max}}-h_{\text{min}}}{2n}$ and $q_{\text{max}} = h_{\text{max}} - \frac{h_{\text{max}}-h_{\text{min}}}{2n}$. As you can see in the middle part of Fig. 802, the “quantization stairway” starts with a riser (a vertical line).

A third quantization mode named *User Defined Min- and Max-Levels* allows you to set arbitrary q_{min} and q_{max} values.

The following table summarizes the three modes.

QUANTIZATION MODE	Q_{MIN}	Q_{MAX}
Min-Max-Tread	h_{min}	h_{max}
Min-Max-Riser	$h_{\mathrm{min}} + \frac{h_{\mathrm{max}} - h_{\mathrm{min}}}{2n} = h_{\mathrm{min}} + \frac{\Delta h}{2}$	$h_{\mathrm{max}} - \frac{h_{\mathrm{max}} - h_{\mathrm{min}}}{2n} = h_{\mathrm{max}} - \frac{\Delta h}{2}$
User Defined Min- and Max-Levels	User Defined	User Defined
	$h_{\mathrm{min}} \leq q_{\mathrm{min}} < q_{\mathrm{max}} \leq h_{\mathrm{max}}$	

The default quantization mode for new surfaces is *Min-Max-Riser*, with the exception of those surfaces which are by default restricted to a discrete number of height levels (Rectangular Grating Surface, Sampled Surface, and Transition Point List Surface). Those surfaces are set to *Min-Max-Tread* quantization by default so that quantization does not change the predefined height levels (if they are equidistant). Furthermore, a Rectangular Grating Surface is always discretized to two height levels.

138.1.2.3 Fresnel Zones

If you use Fresnel zones the height profile is "folded" so that all height values lie in the interval $-p \cdot h_{\mathrm{t}} \ldots (1 - p)h_{\mathrm{t}}$. h_{t} refers to the *Fresnel Height* and p refers to the *Relative Position on z-Axis*.
Thus, if the *Relative Position on z-Axis* is set to 0 % the height values range from 0 to $+h_{\mathrm{t}}$. This is the recommended setting for a height profile containing only positive height values (e. g. a conical surface with positive radius of curvature).
Vice versa, a *Relative Position on z-Axis* of 100 % is recommended for surfaces with only negative height values as then the height values are in the range $-h_{\mathrm{t}} \ldots 0$.
Any intermediate relative position is of course also feasible. Fig. 803 shows an example for the effect of the relative position.

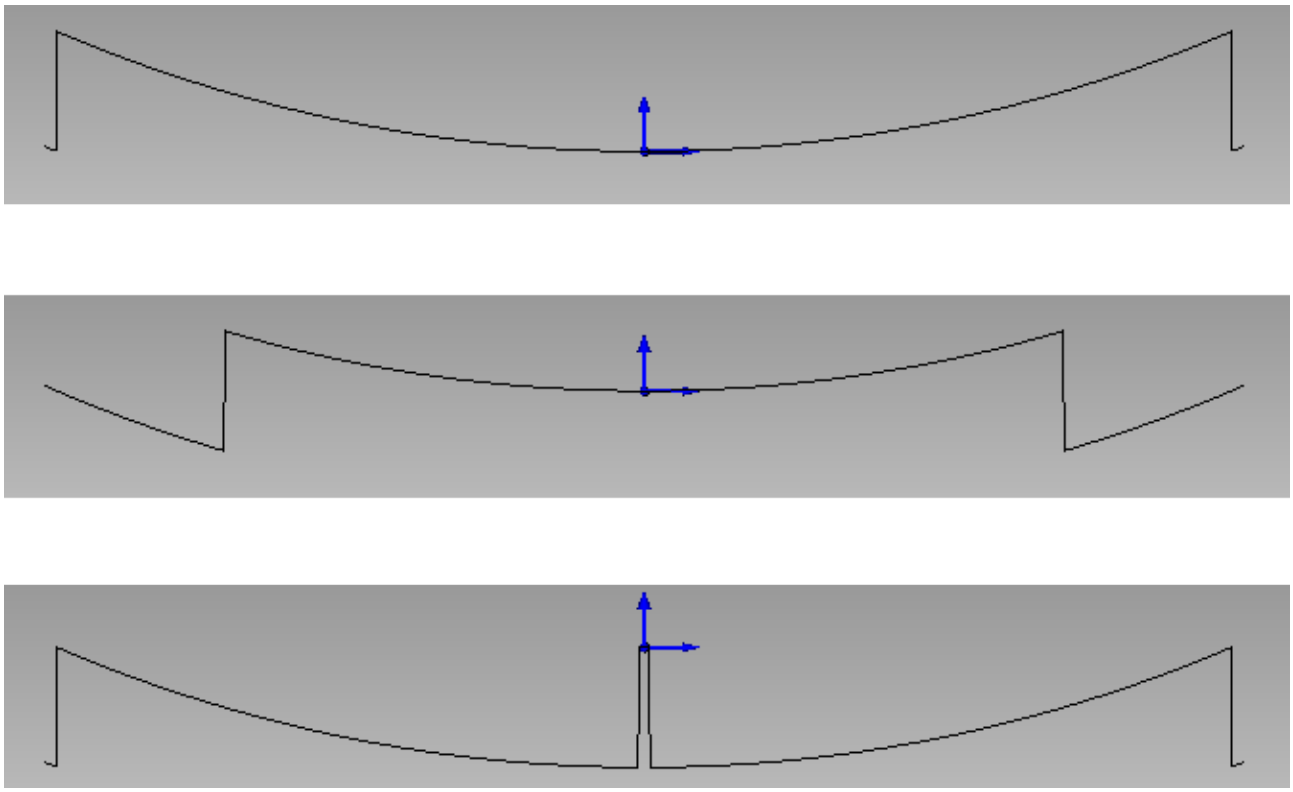


Figure 803. *A cylindrical surface with positive radius of curvature and Fresnel zones. The subfigures illustrate the effect of different values for the* Relative Position on z-Axis p.
Left: $p = 0\,\%$. *Height values range from 0 to 2 mm.* **Middle:** $p = 50\,\%$. *Height values range from -1 to 1 mm.* **Right:** $p = 99.99\,\%$. *Height values range from -2 to (nearly) 0 mm.*

Note that the scaling in z-direction is applied after introducing the Fresnel zones. Thus the scaling in z-direction does not influence the positions of the Fresnel "jumps" but the total profile height of a surface with Fresnel "jumps" is the scaling factor α times the set *Fresnel Height*.

138.2 Coatings

The properties of a real coating naturally depend on the conditions of the process it was produced in. First of all, its thickness depends on the deposition parameters, like the flow direction of the material. Therefore VirtualLab Fusion allows you to specify some of these parameters, to produce more realistic coatings. The thickness t_c of a coating at the position (x_c, y_c, z_c) is modified by a factor F_{HK} that is derived from the Hertz-Knudsen-Law (Please read [BE04] or [Bun82] for more information about the deposition of thin films for producing coatings.):

$$t_c(x_c, y_c, z_c) = t_0 \cdot F_{\mathrm{HK}} = t_0 \cdot \cos\alpha \cos\Theta \cdot 1/r_S^2 \tag{138.5}$$

In this equation, t_0 is the thickness of the coating as specified, that means without consideration of the processing parameters. The angle Θ is measured between the normal vector $\boldsymbol{n}$ of the optical surface at position (x_c, y_c, z_c) and the direction of the particle flow from the source at this point. α means the angle between this current flow and the direction of the maximum density flow $\boldsymbol{f}$. The ratio of the distances d_0/d_c equals r_S (where d_0 denotes the distance of the particle source to the origin of the coordinate system, where the optical axis intersects the surface; and d_c is measured from the particle source to the current position (x_c, y_c, z_c)). Please see also Fig. 804. As you can see, the Hertz-Knudsen-Law assumes a flux density, decreasing laterally with a cosine law, and decreasing axially with an $1/r^2$-law.

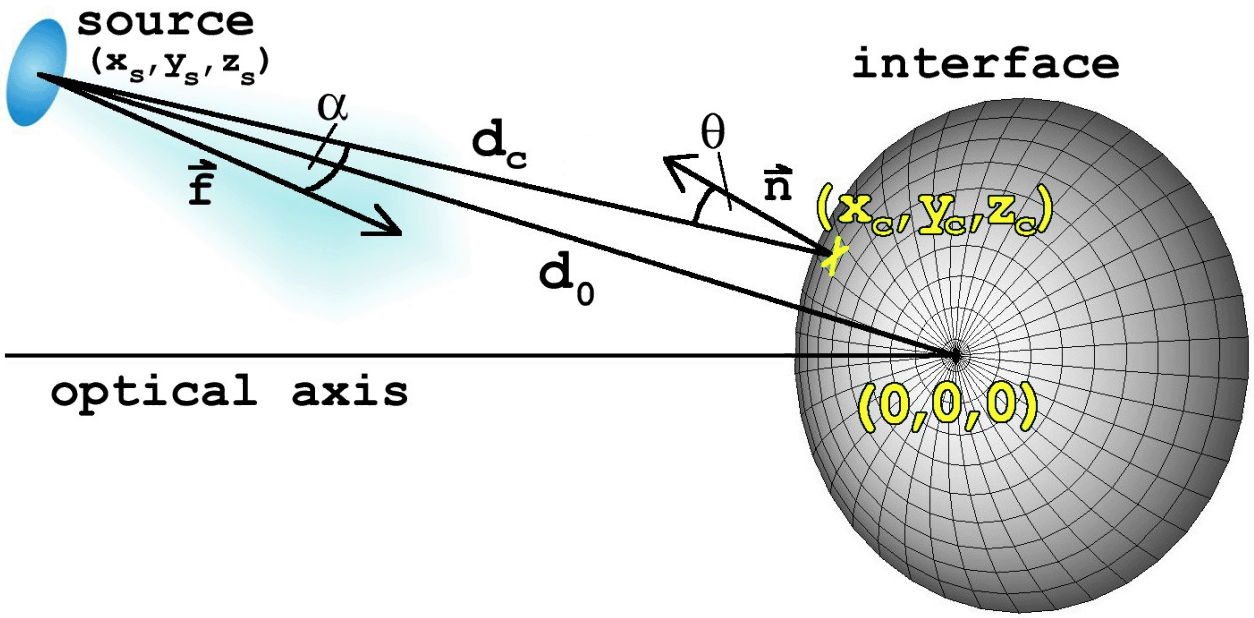


Figure 804. *Sketch of the meaning of the processing parameters of coatings.*

138.3 Media

138.3.1 Scaling and Periodization of Media

Inhomogeneous optical media in VirtualLab Fusion define an arbitrary refractive index distribution $n(x,y,z)$. From this index distribution one can derive a new index distribution $n'(x,y,z)$ that includes scaling and periodization along the x-, y- , and z-direction.

$$n'(x,y,z) = n\left(\frac{x\%P_x}{S_x}, \frac{y\%P_y}{S_y}, \frac{z\%P_z}{S_z}\right) \quad . \tag{138.6}$$

S_x, S_y and S_z represent a *Scaling in x-Direction*, *Scaling in y-Direction*, and *Scaling in z-Direction*, respectively. $\chi\%P$ is a modulo operator performing the operation $\chi' = \chi \pm \ell P;\ \ell \in \mathbb{Z}$ whereas the resulting χ' lies in the (cuboid shaped) elementary cell. This elementary cell is defined as $(-P_x/2 \ldots + P_x/2;\ -P_y/2 \ldots + P_y/2;\ 0 \ldots P_z)$.

138.3.2 GRIN Medium

A GRIN medium is described by a base material and an analytical formula which alters the refractive index of this base material.

There are several equations to describe the refractive index modulation. The following formulas are implemented:

$$n(s) = n_0 + \sum_{i=1}^{N} n_i s^i \tag{138.7}$$

$$n(s) = \sqrt{n_0 + \sum_{i=1}^{N} n_i s^i} \tag{138.8}$$

$$n(s) = \begin{cases} n_0\sqrt{1 - 2\Delta\left(\frac{s}{b}\right)^p} & , s \le b \\ n_1 = n_0\sqrt{1-2\Delta} & , s > b \end{cases} \tag{138.9}$$

$$n(s) = n_0\left(1 - \frac{g^2}{2}s^2\right) \tag{138.10}$$

n_0 is the wavelength dependent complex refractive index of the base material. In the first two cases you define the maximum order N and the individual parameters n_i.

Annotations

- n_0 is the wavelength dependent complex-valued refractive index of the base material.
- The actual meaning of s depends on the chosen symmetry. You can define a GRIN lens with either *rotational symmetry* ($s = \sqrt{x^2 + y^2}$) or with *cylindrical symmetry* ($s = |x \cos \alpha + y \sin \alpha|$ with the rotation angle α). α = 0° refers to modulation in x-direction only and α = 90° refers to modulation in y-direction only.
- For the *Polynomial* (Eq. (138.7)) and the *Square Root of Polynomial* (Eq. (138.8)) you define the maximum order N and the individual parameters n_i.
- The *Power Law Index Profile* is usually used to describe an optical fiber with a GRIN profile. Then the border b is equal to the core radius of the fiber. The decrease Δ describes how much the refractive index is decreased till the border. Alternatively one can use the refractive index n_1 at and outside of the border. The two values are related via $n_1 = n_0\sqrt{1 - 2\Delta}$. The (positive) exponent p of the equation is close to 2 for common GRIN fibers and infinity for step-index fibers. This formula is taken from [Nat].
- *Approximation of sech(s)* (Eq. (138.9)) is a commonly used formula to characterize GRIN media, whereas the parameter g is referred to as gradient constant. The also-used equation $n(\xi) = n_0 \cdot \operatorname{sech}(gr)$ yields nearly identical results for real GRIN lenses. Instead of the gradient constant g also the "pitch length" $P_L = {}^{2\pi}/_{g}$ can be used. In a lens with a length equal to the pitch length, light exits at the same position as it has entered the lens (↪Fig. 805). Manufacturers usually do not give the pitch length P_L but the length z of the lens and its "pitch" P.

$$P = \frac{z}{P_L} \quad \text{and thus} \tag{138.11}$$

$$g = \frac{2\pi P}{z} \tag{138.12}$$

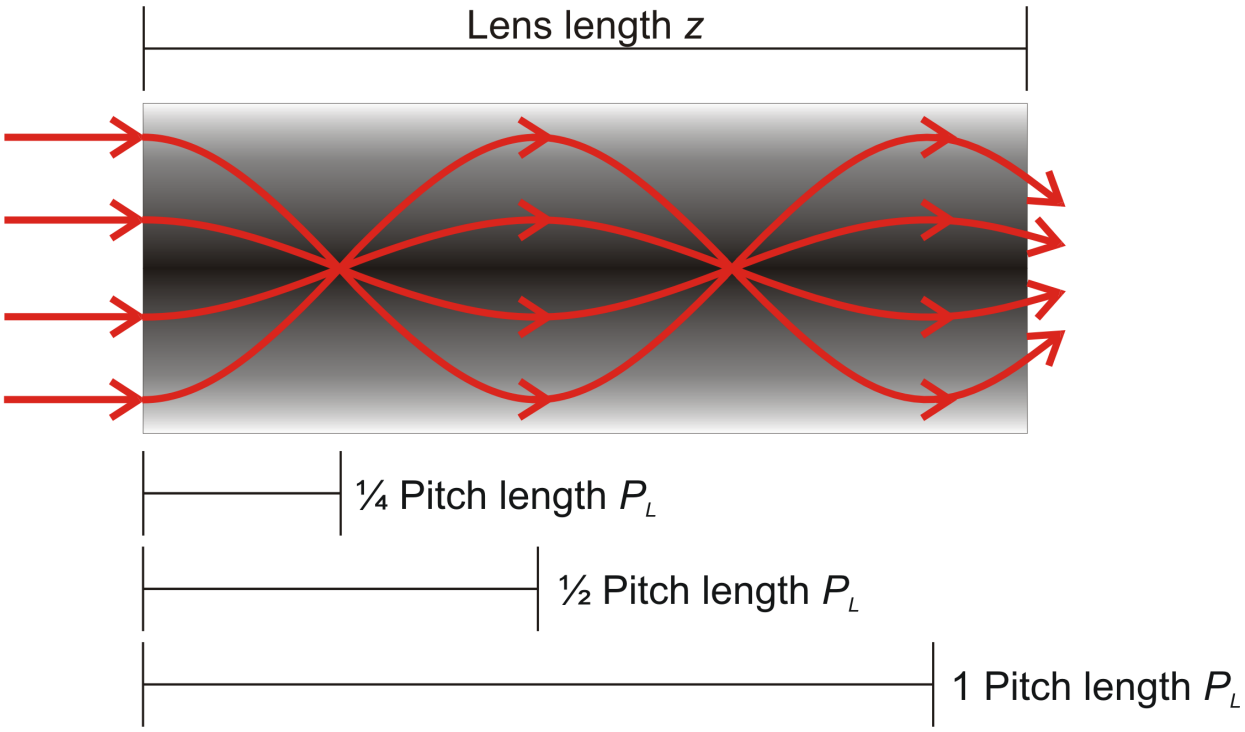


Figure 805. *Effect of a GRIN lens on collimated incident light. The pictured lens has a pitch of approximately 1.1. As you can see, a GRIN lens with a pitch of 0.25 would focus collimated light immediately after the lens.*

138.3.3 Volume Grating Medium

The volume grating medium is designed for analyzing interferograms recorded into a photosensitive *Holographic Material*. In VirtualLab Fusion the interferograms can be synthesized by the superposition of an arbitrary number of plane waves.

Mathematically, the x-period of the volume grating medium is the least common multiple of all subperiods $P_{nm} = 2\pi/(k_{x,n} - k_{x,m})$. As given angles α_n and α_m do not transfer linearly into wave numbers $k_{x,n}$ and $k_{x,m}$, even the simple case of three interfering waves with angles α of 0°, 10°, and 20° would lead to a period of far more than one meter. The same applies accordingly to the y-direction.

As periods this large are not used in reality, you can decide to *Use k Space Discretization* and then specify a *Limit Period* which leads to quantized wave numbers. The smaller this limit period, the larger the difference between original and quantized angles can become. Under certain conditions the resulting *Structure Period of Quantized Medium* can be $\frac{1}{n}$ the limit period, where n is an integer. This period is the one used in simulations, as smaller periods lead to less computational effort.

The interference pattern can be described as local time-averaged energy density $\overline{w}(x,y,z)$.

$$\overline{w}(x,y,z) = \epsilon_0 n_{\text{base}}^2 \left(\sum_n E_n e^{i\Phi_n(x,y,z)} \right)^2 \tag{138.13}$$

The phase function $\Phi_n(x,y,z)$ depends on the incident angle and wavelength of the n^{th} wave. It is assumed that only waves of exactly the same wavelength will interfere with each other.

E_n is the amplitude of the n^{th} wave. It is calculated as follows:

$$E_n = \sqrt{\frac{F_n}{\sum_n F_n} \frac{w_{\text{max}}}{\epsilon_0 n_{\text{base}}^2}} \tag{138.14}$$

w_{max} is the overall energy density of all superposing plane waves. F_n is the *Weight* factor of the n^{th} wave. Eqs. (138.13)-(138.14) follow from Maxwell's equations assuming $n = \sqrt{\epsilon}$ and $\mu = 1$.

138.3.3.1 Index Modulation

The following equations specify how the local electrical field density $\overline{w}(x,y,z)$ (↪Eq. (138.13)) is converted into a change of the refractive index. The volume grating medium offers three different modes therefor:

(a) Direct

In this case you just specify the desired *Refractive Index Modulation* Δn. The refractive index $n(x,y,z)$ at a certain position is then calculated via

$$n(x,y,z) = n_{\text{holo}} + \frac{\overline{w}(x,y,z)}{w_{\text{max}}} \cdot \Delta n \tag{138.15}$$

w_{max} can be an arbitrary value, as it cancels out in this case (see Eqs. (138.13)-(138.14)). n_{holo} is the refractive index of the *Holographic Material*.

(b) Simulate Exposition Process

In this case you simulate the real exposition process. This means you can set up the overall *Power Density* P of all superposing waves, the *Exposure Time* t_{exp} and the *Material Response*.

Then, the overall energy density is calculated as follows:

$$w_{\text{max}} = P \cdot t_{\text{exp}} \tag{138.16}$$

You can choose between three equations how the *Dose to Refractive Index Modulation* is modeled:

DOSE TO REFRACTIVE INDEX MODULATION	EQUATION	PARAMETERS
Linear	$n(x,y,z) = n_{\text{holo}} + l\overline{w}(x,y,z)$	l: *Linear Factor*
Quadratic	$n(x,y,z) = n_{\text{holo}} + l\overline{w}(x,y,z) + p\overline{w}(x,y,z)^2$	l: *Linear Factor* p: *Squared Factor*
Asymptotic	$n(x,y,z) = n_{\text{holo}} + \Delta n - \frac{\Delta n}{1+(\overline{w}(x,y,z)/w_0)^\gamma}$	Δn: *Refractive Index Modulation* w_0: *Average Energy Density* γ: *Modulation Exponent* ↪Fig. 806

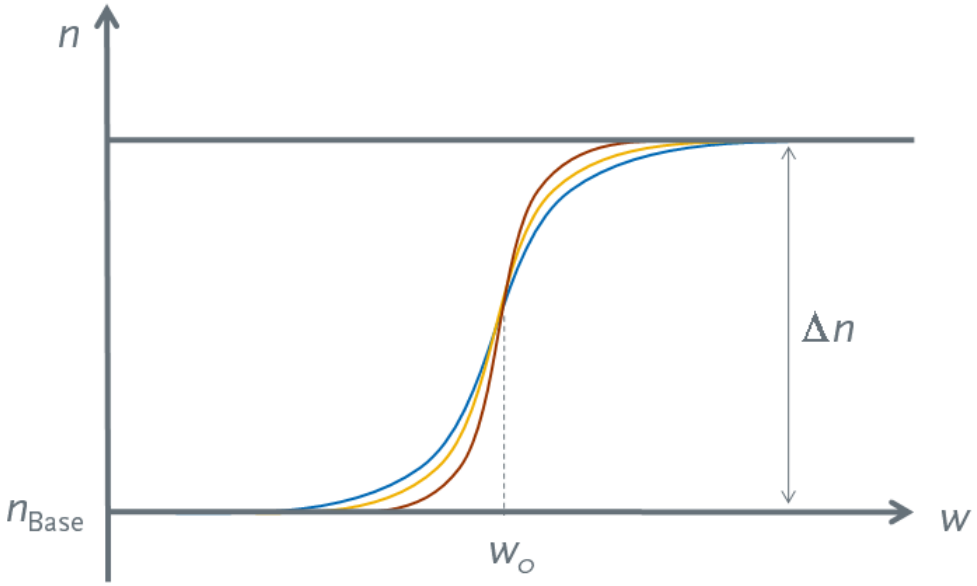


Figure 806. *The refractive indices $n(w)$ if asymptotic dose to refractive index modulation is chosen. The blue curve has the smallest modulation exponent and the red curve the largest.*

(c) Photonic Crystals

In this case it is assumed that above a certain energy density w_t the original *Holographic Material* is replaced by a second material. In VirtualLab Fusion you enter the relative *Threshold*, i. e. $\frac{w_t}{w_{\text{max}}}$.

138.4 Materials

The following dispersion formulas are implemented in VirtualLab Fusion to describe the wavelength dependency of the real part of the refractive index analytically:

FORMULA NAME	EQUATION
Sellmeier 1	$n = \sqrt{\frac{K_1 \cdot \lambda^2}{\lambda^2 - L_1} + \frac{K_2 \cdot \lambda^2}{\lambda^2 - L_2} + \frac{K_3 \cdot \lambda^2}{\lambda^2 - L_3} + 1}$

Sellmeier 2

$$n = \sqrt{A + \frac{B_1 \cdot \lambda^2}{\lambda^2 - \lambda_1^2} + \frac{B_2}{\lambda^2 - \lambda_2^2} + 1}$$

Sellmeier 3

$$n = \sqrt{\frac{K_1 \cdot \lambda^2}{\lambda^2 - L_1} + \frac{K_2 \cdot \lambda^2}{\lambda^2 - L_2} + \frac{K_3 \cdot \lambda^2}{\lambda^2 - L_3} + \frac{K_4 \cdot \lambda^2}{\lambda^2 - L_4} + 1}$$

Sellmeier 4

$$n = \sqrt{A + \frac{B \cdot \lambda^2}{\lambda^2 - C} + \frac{D \cdot \lambda^2}{\lambda^2 - E}}$$

Sellmeier 5

$$n = \sqrt{\frac{K_1 \cdot \lambda^2}{\lambda^2 - L_1} + \frac{K_2 \cdot \lambda^2}{\lambda^2 - L_2} + \frac{K_3 \cdot \lambda^2}{\lambda^2 - L_3} + \frac{K_4 \cdot \lambda^2}{\lambda^2 - L_4} + \frac{K_5 \cdot \lambda^2}{\lambda^2 - L_5} + 1}$$

Schott

$$n = \sqrt{A_0 + A_1 \cdot \lambda^2 + \frac{A_2}{\lambda^2} + \frac{A_3}{\lambda^4} + \frac{A_4}{\lambda^6} + \frac{A_5}{\lambda^8}}$$

This formula is no longer used by Schott itself but by many other glass manufacturers.

Herzberger

$$n = A + B \cdot L + C \cdot L^2 + D \cdot \lambda^2 + E \cdot \lambda^4 + F \cdot \lambda^6 \quad \text{with } L = \frac{1}{\lambda^2 - 0.028}$$

The Herzberger formula is mainly used in the infrared spectrum.

Conrady

$$n = n_0 + \frac{A}{\lambda} + \frac{B}{\lambda^{3.5}}$$

Useful formula to fit data with only few data points.

Handbook Optics 1

$$n = \sqrt{A + \frac{B}{\lambda^2 - C} - D \cdot \lambda^2}$$

Handbook Optics 2

$$n = \sqrt{A + \frac{B \cdot \lambda^2}{\lambda^2 - C} - D \cdot \lambda^2}$$

Cauchy

$$n = A + \frac{B}{\lambda^2} + \frac{C}{\lambda^4} + \frac{D}{\lambda^6}$$

Edlén 1994 (for Air)

$$n = 1 + \frac{p(n_{st} - 1)}{96095.43} \cdot \frac{1 + 10^{-8}(0.601 - 0.00972T)p}{1 + 0.0036610 \cdot T} - f(3.7345 - 0.0401\frac{1}{\lambda^2}) \cdot 10^{-10}$$

with

$$n_{st} = 8.34254 \cdot 10^{-5} + 0.02406147/(130 - \frac{1}{\lambda^2}) + 1.5998 \cdot 10^{-4}/(38.9 - \frac{1}{\lambda^2}) + 1,$$

p being the atmospheric pressure in Pa, T being the temperature in °C, and f being the *Partial Pressure of Water Vapor* in Pa. While the latter can be entered in the dialog, the pressure and temperature are taken from the Optical Setup which is simulated.

Edlén 1953 (for Air)

$$n = 1 + \frac{n_{st} - 1}{1 + 0.0034785 \cdot (T - 15)} \cdot p/101325 - 55 \cdot 10^{-9} \cdot 0.0075f/(1 + 0.00367 \cdot T)$$

with

$$n_{st} = 6.4328 \cdot 10^{-5} + 0.0294981/(146 - \frac{1}{\lambda^2}) + 2.554 \cdot 10^{-4}/(41 - \frac{1}{\lambda^2}) + 1,$$

p being the atmospheric pressure in Pa, T being the temperature in °C, and f being the *Partial Pressure of Water Vapor* in Pa. While the latter can be entered in the dialog, the pressure and temperature are taken from the Optical Setup which is simulated.

Power Series

$$n = \sqrt{\sum_{i=0}^{3} A_i \cdot \lambda^{2i} + \sum_{k=1}^{6} A_{k+3} \cdot \lambda^{-2k}}$$

Abbe Number (ν_d)

$$n(\lambda) = A + \frac{B}{\lambda^2}$$

with

$$B = \frac{n_\mathrm{d} - 1}{\nu_\mathrm{d}\left(\lambda_\mathrm{F}^{-2} - \lambda_\mathrm{C}^{-2}\right)}$$

and

$$A = n_\mathrm{d} - \frac{B}{\lambda_\mathrm{d}^2} \quad ,$$

ν_d being the (classic) Abbe number, n_d the refractive index at the Fraunhofer line d (λ_d = 587.5618 nm). Additionally, the Fraunhofer lines F and C (λ_F = H_β = 486.134 nm; λ_C = H_α = 656.281 nm) are used.

Abbe Number (ν_e)

$$n(\lambda) = A + \frac{B}{\lambda^2}$$

with

$$B = \frac{n_\mathrm{e} - 1}{\nu_\mathrm{e}\left(\lambda_{\mathrm{F'}}^{-2} - \lambda_{\mathrm{C'}}^{-2}\right)}$$

and

$$A = n_\mathrm{e} - \frac{B}{\lambda_\mathrm{e}^2} \quad ,$$

ν_e being the (alternative) Abbe number, n_e the refractive index at the Fraunhofer line e (λ_e = 546.07 nm). Additionally, the Fraunhofer lines F' and C' ($\lambda_{\mathrm{F'}}$ = 479.99 nm; $\lambda_{\mathrm{C'}}$ = 643.85 nm) are used.

139 Sources

VirtualLab Fusion provides a growing set of source models. Each model describes an electromagnetic field in a plane. The source generation results in a discretized field that is represented by a data array (sampled field) and additional parameters including, e. g., wavelength(s), physical coordinates and others, see below.
The fields resulting from the source generation are described in the input plane with $z = 0$. A source field can be represented by one or more complex amplitude fields. Each of those fields is globally polarized and is described by

$$\boldsymbol{E}_\mathrm{xy}(x, y, 0) = \boldsymbol{J} U(x, y, 0) \tag{139.1}$$

where $\boldsymbol{J}$ denotes the Jones vector and $U(x, y, 0)$ is a scalar complex function.
In order to handle arbitrary fields $U(x)$ numerically, $U(x)$ has to be sampled with a finite number of $(N_x; N_y)$ sampling points. In VirtualLab Fusion an equidistant sampling with the sampling distance $(\delta x; \delta y)$ corresponds to sampling points at the positions $(\mathrm{x_{min}}, \mathrm{x_{min}} + \delta x, \ldots, \mathrm{x_{min}} + (N_x - 1)\delta x, \mathrm{y_{min}}, \mathrm{y_{min}} + \delta y, \ldots, \mathrm{y_{min}} + (N_y - 1)\delta y)$ with

$$\mathrm{x_{min}} = -\lfloor \frac{N_x}{2} \rfloor \delta x, \quad \mathrm{y_{min}} = -\lfloor \frac{N_y}{2} \rfloor \delta y \tag{139.2}$$

where $\lfloor \cdot \rfloor$ denotes the rounding down operation.

139.1 Gaussian Wave

139.1.1 Formulas for an Ideal Gaussian Wave

An ideal one-dimensional Gaussian field is defined by

$$U_\mathrm{G}(x) = \exp\left[-\frac{x^2}{w^2(z)}\right] \exp\left[i\left(-\frac{kz}{2} - k\frac{x^2}{2R(z)} + \frac{1}{2}\arctan\left(\frac{z}{z_\mathrm{R}}\right)\right)\right]. \tag{139.3}$$

The variable $k = {}^{2\pi}/_{\lambda}$ refers to the wave number; λ is the medium wavelength. z is the *Distance to Input Plane*. In contrast to the "Laser Beam Calculator" (↪Sec. 113), you cannot enter the beam radius $w(z)$ directly in the generator dialog. It is calculated via

$$w(z) = w_0 \sqrt{1 + \left(\frac{z}{z_\mathrm{R}}\right)^2} \quad . \tag{139.4}$$

w_0 is the *Waist Radius* and z_R is the Rayleigh length

$$z_\mathrm{R} = \frac{\pi w_0^2}{\lambda} \tag{139.5}$$

Further fundamental parameters of a Gaussian beam are the *Phase Radius* $R(z)$ as well as the *Half Angle of Divergence* $\frac{\alpha}{2}$. These parameters can be calculated by the following equations.

$$R(z) = z\left[1 + \left(\frac{z_\mathsf{R}}{z}\right)^2\right] \tag{139.6}$$

$$\tan\left(\frac{\alpha}{2}\right) = \frac{\lambda}{\pi w_0} \approx \frac{\alpha}{2} \quad \text{valid in the far field} (z \gg z_\mathsf{R}) \tag{139.7}$$

Formula Eq. (139.7) states an ideal connection between waist and divergence of a Gaussian beam. But already significant parts of a small Gaussian (in the waist) with large divergence angles cannot propagate into the positive half space, because they are evanescent. Thus, the actual propagating light is not ideal Gaussian anymore and because of that, there is also a certain deviation from the result in the far field predicted by this formula. Furthermore, please keep in mind, that for very large angles, the z-component of the light might be of relevance.

For all the equations above, waist radius and half angle of divergence are referring to the point where the squared amplitude is reaching e^{-2} (≈ 0.135) times the maximum squared amplitude.
A two-dimensional Gaussian field can be constructed by multiplying two one-dimensional fields:

$$U_\mathsf{G}(x,y) = U_\mathsf{G}(x) \cdot U_\mathsf{G}(y) \tag{139.8}$$

whereas the beam parameters may be different for both directions. Different waist distances z lead to an astigmatic Gaussian field.

139.1.2 Beam Quality and Higher Order Modes

The Gaussian wave generator (↪Fig. 489) can also be used to generate fields that represent Hermite-Gaussian or Laguerre- Gaussian modes. A two-dimensional Hermite-Gaussian is derived by:

$$U_\mathsf{H}(x,y) = U_\mathsf{G}(x,y) \cdot \exp\left[\pm i(m+n)\arctan\left(\frac{z}{z_\mathsf{R}}\right)\right] \cdot \mathcal{H}_m\left(\frac{\sqrt{2}x}{w(z)}\right) \cdot \mathcal{H}_n\left(\frac{\sqrt{2}y}{w(z)}\right) \quad . \tag{139.9}$$

where m and n are the order for x- and y-direction, respectively. $\mathcal{H}_j$ is the Hermite polynomial for the order j.
The *M² Parameter* of a Hermite-Gaussian is calculated by

$$M^2 = \begin{cases} 2m+1 & \text{x-direction} \\ 2n+1 & \text{y-direction} \end{cases} \tag{139.10}$$

A two-dimensional Laguerre-Gaussian is derived by:

$$U_\mathsf{L}(x,y) = U_\mathsf{G}(x,y) \cdot \exp\left[\pm i\left(l\arctan\left(\frac{y}{x}\right) + M^2\arctan\left(\frac{z}{z_\mathsf{R}}\right)\right)\right] \cdot \mathcal{L}_p^{|l|}\left(\frac{2(x^2+y^2)}{w(z)^2}\right) \tag{139.11}$$

where p is the radial order and l is the azimuthal order. $\mathcal{L}_p^{|l|}$ is an associated Laguerre polynomial. The *M² Parameter* of a Laguerre-Gaussian is calculated by

$$M^2 = 2p + |l| + 1 \tag{139.12}$$

Further explanations for these formulas can be found for instance in [ST91].
As you can see from the formulas, in both cases you get the fundamental mode $U_\mathsf{G}(x,y)$ if both orders $(m;\, n)$ or $(p;\, l)$, respectively, are zero.

139.2 LP Modes

The field inside an optical fiber which is weakly guiding ($n_{\text{core}} \approx n_{\text{cladding}}$) and rotationally symmetric can be described as superposition of linearly polarized (LP) modes $f_{L,M,p}$.
In polar coordinates they are given by

$$f_{L,M,p}(\rho,\phi) = f_{L,p}(\phi) \cdot f_M(\rho) \quad \text{with} \tag{139.13}$$

$$f_{L,p}(\phi) = \begin{cases} 1 & L = 0 \\ \cos(L\phi) & p \text{ is even} \\ \sin(L\phi) & p \text{ is odd} \end{cases} \tag{139.14}$$

$f_M(\rho)$ is either a kind of Bessel function (for step-index fibers) or Laguerre function (for gradient-index fibers). L is the *Azimuthal Order*, M the *Radial Order* and p the parity.

Conditions for existing orders:

- For the Bessel modes, not all radial orders M exist for each azimuthal order L. Usually there is a maximum M which decreases with increasing L.
- Modes are cut off if the cutoff parameter $V = \pi/\lambda \cdot d\sqrt{n_{\text{core}}^2 - n_{\text{cladding}}^2}$ is less than 1.
- Also $V > 300$ is not practical.

139.3 Super-Gaussian Wave

This source model allows you to generate isotropic and separable super-Gaussian fields.
An isotropic super-Gaussian field $U(x,y)$ is given by

$$U(x,y) = \exp\left[-\left(\frac{r}{w_0}\right)^m\right], \tag{139.15}$$

where w_0 denotes the waist radius at the amplitude level of $1/e$, m denotes the order of the super Gaussian ($m = 2$ corresponds to a regular Gaussian) and

$$r = \sqrt{x^2 + y^2}. \tag{139.16}$$

A separable super Gaussian field $U(x,y)$ is defined by

$$U(x,y) = \exp\left[-\left(\frac{x}{w_{0,x}}\right)^{m_x} - \left(\frac{y}{w_{0,y}}\right)^{m_y}\right], \tag{139.17}$$

where order and waist radius are given for both x- and y-direction.
It is possible to define the waist radius w at any (amplitude or intensity) level k above the minimum edge level, i.e. different from w_0 as defined in Eq. (139.15). This waist radius w is connected to w_0 by

$$w_0 = \frac{w}{\sqrt[m]{-\ln k}}, \tag{139.18}$$

where the amplitude level $0 < k < 1$ is given as fraction of the maximum amplitude of the super Gaussian in its center.
If you want to create a field with a Top-Hat-like light distribution where only the ”sharpness” of the edges is known but not the required order of the super Gaussian, then it is possible to enter the width Δr_e of the edge between a lower (minimum) and an upper (maximum) level (y_l and y_u). The relation between edge width and order of the super Gaussian is

$$\Delta r_e = w\left(\sqrt[m]{\frac{\ln y_l}{\ln k}} - \sqrt[m]{\frac{\ln y_u}{\ln k}}\right). \tag{139.19}$$

The meaning of all these parameters w (waist radius), k (definition level for waist radius), Δr_e (edge width), y_l (minimum level of the edge) and y_u (maximum level of the edge) is shown in the sketch in Fig. 807.

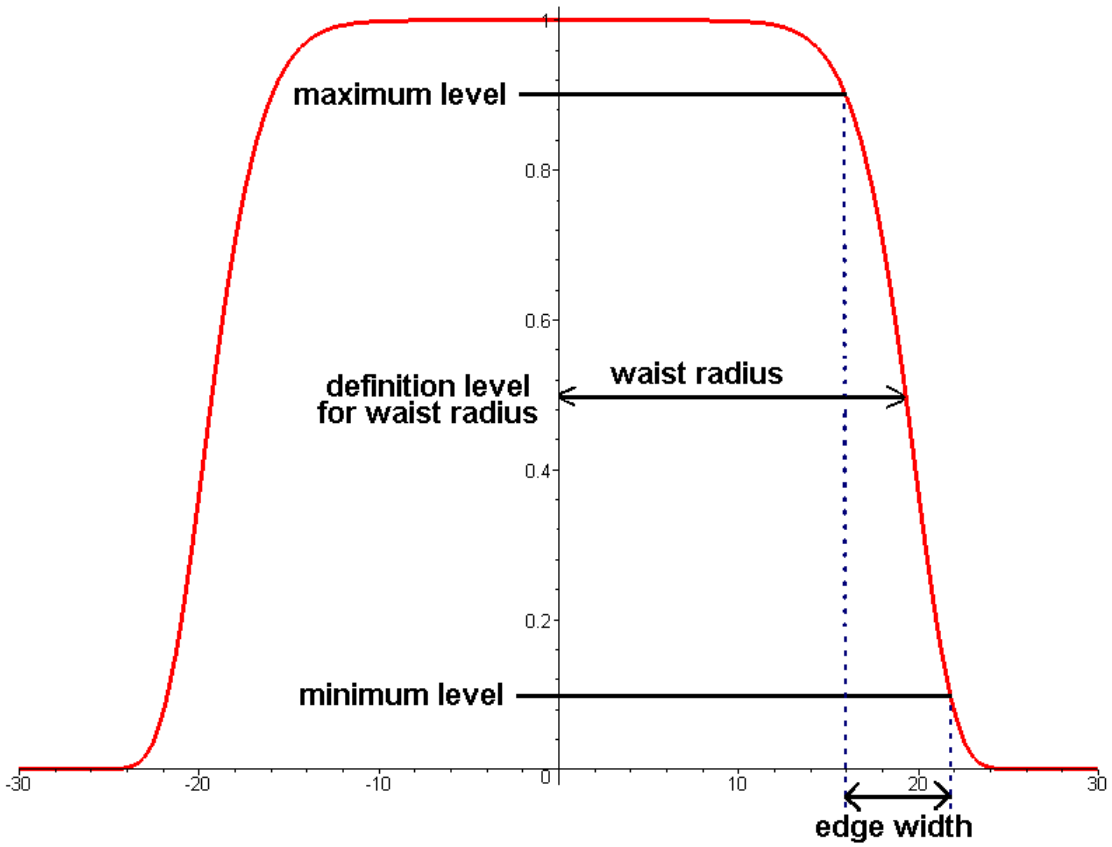


Figure 807. *Definition of a Super Gaussian by Edge Width and Waist Radius.*

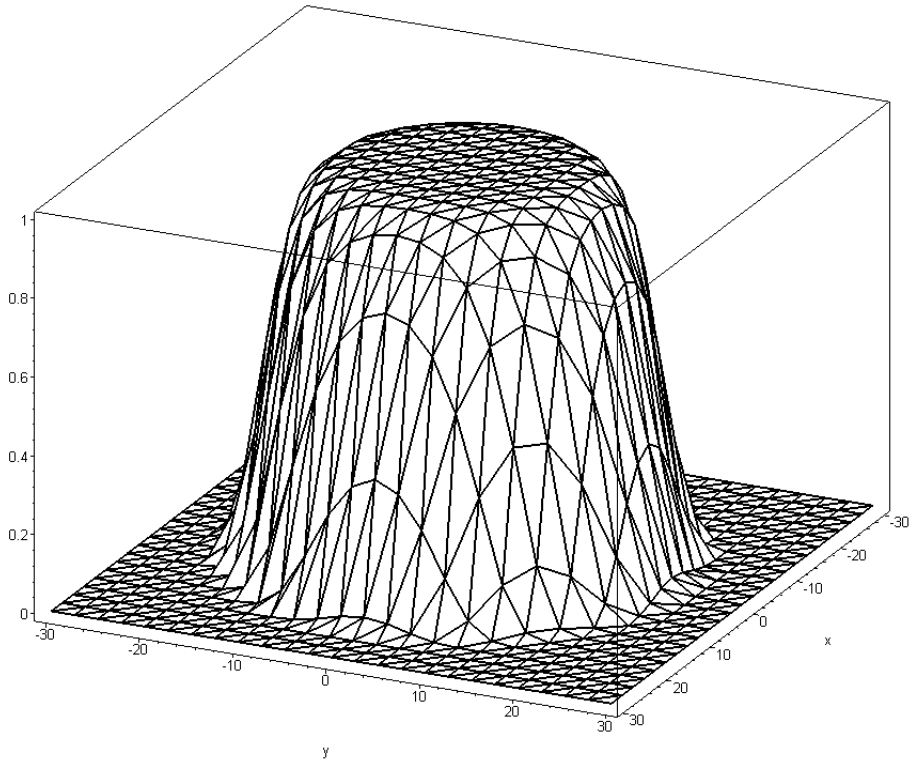


Figure 808. *Isotropic Super Gaussian Field as 3D View.*

139.4 Gaussian Type Planar Source

This generator can be used to simulate LEDs and Excimer lasers. The details of the model will be described in a separate paper which can be distributed on request.

The model is based on using a set of fundamental modes. In this case, Gaussian modes are used. The modes are laterally shifted across the emitting surface. The model assumes a dense set of modes. The computational model requires a finite set of modes which has to be defined by the user. Currently, the modes are scaled with the factor $1/\sqrt{n}$, where n is the number of lateral positions.

This source can be described by its divergence, by the coherence length or by the waist of the fundamental modes. Let us discuss the relationship between these values.

A single fundamental mode is a Gaussian field. The complex amplitude U in its waist plane ($z = 0$) is given by

$$U(x, y, z = 0) = U_0 \exp\left(-\rho^2 / w_0^2\right) \tag{139.20}$$

with $\rho^2 = x^2 + y^2$. The waist radius w_0 defines the radius for which the value of U is decreased by a factor of $1/\mathrm{e}$. Therefore, the squared amplitude is decreased by $1/\mathrm{e}^2$. In paraxial approximation a propagated Gaussian remains Gaussian and possesses the 1/e-beam radius $w(z)$. We may then define the half-width 1/e (HWE) angle divergence of the beam by

$$\theta_{\mathrm{HWE}} = \lim_{z > \infty} \arctan\left(\frac{w(z)}{z}\right) = \arctan\left(\frac{w_0}{z_0}\right) \tag{139.21}$$

with the Rayleigh length

$$z_0 = \pi w_0^2 / \lambda. \tag{139.22}$$

Finally we obtain

$$\theta_{\text{HWE}} = \arctan\left(\frac{\lambda}{\pi w_0}\right). \tag{139.23}$$

Because the derivation uses a paraxial assumption, the angles are small and the $\arctan$ is often omitted in literature. It is important to note, that the $\arctan$ in Eq. (139.23) does not ensure its validity in the non-paraxial domain.

If we consider non-paraxial beams, the definition of the waist w_0 remains unchanged. But for the definition of the divergence we must consider the far field of the beam in form of the radiant intensity which takes the form

$$J(\theta, \phi) = 4\pi^4 w_0^4 k^2 \cos^2\theta \exp\left(-\frac{1}{2}(k w_0)^2 \sin^2\theta\right). \tag{139.24}$$

For small angles we have $\sin\theta \approx \theta$ and $\cos\theta = 1$ and Eq. (139.24) reduces to the intensity of a paraxial far field, which is a Gaussian. The divergence is now defined by the extent of J in terms of θ. Obviously it makes no sense to define a $1/\mathrm{e}$ value, because of the $\cos^2\theta$ term. Thus, the half-width at half-maximum (HWHM) angle of $J(\theta)$ is defined as the divergence half-angle θ_{HWHM}. Evaluation of Eq. (139.24) results in the relationship between the waist w_0 and the divergence θ_{HWHM} according to

$$w_0 = \lambda \frac{\sqrt{\ln(2\cos^2\theta_{\text{HWHM}})}}{\sqrt{2}\pi \sin\theta_{\text{HWHM}}}. \tag{139.25}$$

The relation between waist and coherence length is given by

$$w_0 = \sqrt{2} \cdot \text{coherence length}. \tag{139.26}$$

139.5 Far Field Source

The far field source allows you to define a spatially partially coherent light source by its far field. $\left\{{}_u V_\ell(\boldsymbol{\rho}, z; \omega)\right\}_u$ refers to one vectorial component ℓ of a single mode u out of many uncorrelated modes. It is defined by

$$\left\{{}_u V_\ell(\boldsymbol{\rho}, z; \omega)\right\}_u = \left\{\alpha_u D_\ell(\theta, \phi)\frac{e^{\mathrm{i}kr}}{r}\right\}_u. \tag{139.27}$$

The following symbols are used in Eq. (139.27).

- $\omega = \frac{2\pi c}{\lambda}$: Angular frequency.
- k: Wave number.
- $\boldsymbol{\rho}$: The lateral position $(x; y)$.
- $r = \sqrt{x^2 + y^2 + z^2}$
- α_u is the weight of the mode.
- The complex direction weight functions $D_\ell(\theta, \phi)$.
- The braces with index u indicate the use of the mode coordinate system shifted by $\boldsymbol{\rho}_u$.

139.6 Spectrum Generators

139.6.1 Black Body Spectrum

The black body power spectrum uses the energy density distribution law in dependence on the wavelength λ

$$S(\lambda) = \frac{8\pi hc}{\lambda^5} \frac{1}{e^{\left(\frac{hc}{\lambda kT}\right)} - 1}$$

where T is the temperature in Kelvin, h denotes the Planck constant ($6.6260755 \cdot 10^{-34}$ Js), k is the Boltzmann constant ($1.3806505 \cdot 10^{-23}$ J/K), and c stands for the vacuum speed of light (299792458 m/s).

139.6.2 Gaussian Spectrum

A Gaussian spectrum arises in Doppler broadening of a spectral line.
Its dependence on the angular frequency ω is given by the formula

$$S(\omega) = S_0 \exp\left(-\ln 2 \cdot \frac{(\omega - \omega_0)^2}{\Delta\omega^2}\right), \tag{139.28}$$

where ω_0 is the central angular frequency, $\Delta\omega$ the half width at half-maximum of the distribution.
In transforming the density to a function of the wavelength, the relations

$$\omega_0 = 2\pi c/\lambda_0 \quad , \tag{139.29}$$

$$\Delta\omega = -\omega_0/\lambda_0 \cdot \Delta\lambda, \tag{139.30}$$

were used.
If wavelengths with a minimal intensity S_{min} (relative to the peak intensity) shall limit the sampled wavelength interval, then corresponding lowest and highest angular frequencies are computed from

$$\omega_{\text{min}} = \omega_0 + \Delta\omega \cdot \sqrt{\frac{-\ln S_{\text{min}}}{\ln 2}} \quad , \tag{139.31}$$

$$\omega_{\text{max}} = 2\omega_0 - \omega_{\text{min}} \quad , \tag{139.32}$$

and the equivalent wavelengths follow from $\lambda = {}^{2\pi c}/_{\omega}$.

139.6.3 Lorentzian Spectrum

The Lorentzian power spectrum arises in natural lifetime and collision broadening of a spectral line.
Its dependence on the angular frequency ω is given by the formula

$$S(\omega) = \frac{S_0}{(\omega - \omega_0)^2 + \Delta\omega^2},$$

where ω_0 is the central angular frequency, $\Delta\omega$ the half width at half-maximum of the distribution.
In transforming the density to a function of the wavelength, the relations

$$\omega_0 = 2\pi c/\lambda_0 \quad , \tag{139.33}$$

$$\Delta\omega = -\omega_0/\lambda_0 \cdot \Delta\lambda, \tag{139.34}$$

were used.
If wavelengths with a minimal intensity S_{min} (relative to the peak intensity) shall limit the sampled wavelength interval, then corresponding lowest and highest angular frequencies are computed from

$$\omega_{\text{min}} = \omega_0 + \Delta\omega \cdot \sqrt{\frac{1}{S_{\text{min}}} - 1} \quad , \tag{139.35}$$

$$\omega_{\text{max}} = 2\omega_0 - \omega_{\text{min}} \quad , \tag{139.36}$$

and the equivalent wavelengths follow from $\lambda = {}^{2\pi c}/_{\omega}$.

140 Functions

140.1 ABCD Matrix Simulation

ABCD matrices give an easy way to describe transformations in radial symmetric optical systems without limiting apertures, in paraxial approximation. Given a vector $\boldsymbol{r}_{\text{in}} = (x, \alpha)^T$ describing the distance x to the optical axis and the direction component α (direction cosine) of an incoming (local) plane wave it is transformed by an ABCD matrix $\mathcal{M}$ to the vector $\boldsymbol{r}_{\text{out}}$:

$$\boldsymbol{r}_{\text{out}} = \begin{pmatrix} x' \\ \alpha' \end{pmatrix} = \mathcal{M} \cdot \boldsymbol{r}_{\text{in}} = \begin{pmatrix} A & B \\ C & D \end{pmatrix} \begin{pmatrix} x \\ \alpha \end{pmatrix}. \tag{140.1}$$

Simple optical elements can be described by specific matrices e. g. $\left(\begin{smallmatrix}1 & d\\ 0 & 1\end{smallmatrix}\right)$ for a free space propagation of distance d, or $\left(\begin{smallmatrix}1 & 0\\ -f^{-1} & 1\end{smallmatrix}\right)$ for an infinitely extensive, thin lens with focal length f. A system consisting of several optical elements is described by the product of their matrices (where the order of multiplication depends on the order in which the elements are passed by the light):

$$\boldsymbol{\mathcal{M}}_{\text{system}} = \boldsymbol{\mathcal{M}}_{n-1} \times \boldsymbol{\mathcal{M}}_{n-2} \times \cdots \times \boldsymbol{\mathcal{M}}_{0}. \tag{140.2}$$

In this equation $\boldsymbol{\mathcal{M}}_0$ is the first of n elements passed through, $\boldsymbol{\mathcal{M}}_{n-1}$ is the last.
Collins [Col70] described a way to use ABCD matrices for wave optics by giving the following equation (Collins Integral, here simplified for one dimension),

$$\begin{aligned} U_{\text{out}}(x') = -\frac{ik}{2\pi B} \exp(ikL_0) \\ \int_{-\infty}^{\infty} U_{\text{in}}(x) \exp\left[\frac{ik}{2B}\left(Ax^2 - 2xx' + Dx'^2\right)\right] \mathrm{d}x, \end{aligned} \tag{140.3}$$

where L_0 is the axial optical distance of the system. Please note that Collins used a differing notation for the matrix elements, where A and D are interchanged as well as B and C. From the given equation (140.3), which can be understood as a kind of Fresnel transform, the propagation of spectrum of plane waves as well as the Rayleigh-Sommerfeld convolution can be derived. All three propagation types are physically equivalent (and paraxial approximations(!), due to the nature of ABCD matrix representations) and differ only in the numerical accuracy. For more information about the propagation types and their application read Sec. 94.
Important: As it is not possible to enter the axial optical distance L_0, the phase of the result of Eq. (140.3) has got a constant offset to the real phase, except the case of $B = 0$, that means the geometrical and optical axial distance is $= 0$.
Furthermore, ABCD matrices give an easy way to describe the transformation of a Gaussian beam in radially symmetric optical systems without limiting apertures. Therefor the complex radius of curvature q of a Gaussian beam is defined as follows:

$$\frac{1}{q(z)} = \frac{1}{R(z)} - i\frac{\mathrm{M}^2\lambda}{\pi w(z)^2} \tag{140.4}$$

$R(z)$ is the *Phase Radius* at a certain position z and $w(z)$ is the *Beam Radius* at the same position z. Furthermore, M^2 is the *M^2Parameter* of the Gaussian beam and λ its wavelength. See also Sec. 139.1 for reference.
The complex radius of curvature q_{in} of the input Gaussian beam is transformed by an ABCD matrix $\boldsymbol{\mathcal{M}}$ into the complex radius of curvature q_{out} of the output Gaussian beam by the so-called ABCD law [ST91]:

$$q_{\text{out}} = \frac{Aq_{\text{in}} + B}{Cq_{\text{in}} + D} \tag{140.5}$$

140.2 Zernike & Seidel Aberrations

140.2.1 Zernike Polynomials

Zernike Polynomials are usually defined in normalized polar coordinates (ρ, θ), where $0 \leq \rho \leq 1; 0 \leq \theta \leq 2\pi$. Thus the radii $r = \sqrt{x^2 + y^2}$ have to be converted into $\rho = {}^{r}/_{r_{\text{max}}}$ where r_{max} is the maximum radial extent of all positions.
Zernike polynomials are defined in standard form in Born and Wolf [BW83] as follows

$$Z_n^m(\rho, \theta) = N_n^m R_n^m(\rho)\Theta_m(\theta). \tag{140.6}$$

The normalization constant is

$$N_n^m = \sqrt{\frac{2(n+1)}{1+\delta_{m0}}}, \tag{140.7}$$

the radial polynomial is

$$R_n^m(\rho) = \sum_{s=0}^{\frac{n-|m|}{2}} \frac{(-1)^s (n-s)!}{s!(\frac{n+m}{2}-s)!(\frac{n-m}{2}-s)!} \rho^{n-2s}, \tag{140.8}$$

and azimuthal component is given by

$$\Theta_m(\theta) = \begin{cases} \cos(|m|\theta) & \text{for } m \geq 0 \\ \sin(|m|\theta) & \text{for } m < 0 \end{cases}.$$

m is the *azimuthal order* and n is the *radial order*. The following table lists the first 36 Zernike polynomials whereas the index i is the sequential OSA / ANSI standard index[1]. Fig. 809 illustrates the relation between the indices i, m, and n for the first 91 Zernike polynomials.

[1] Note that other optics software often use Noll's sequential indices.

i	n	m	$Z_i(r,\theta) = Z_n^m(r,\theta)$	Name
1	0	0	1	Piston
2	1	-1	$2\rho\sin\theta$	Tilt Y
3	1	1	$2\rho\cos\theta$	Tilt X
4	2	-2	$\sqrt{6}\rho^2\sin 2\theta$	Astigmatism Y
5	2	0	$\sqrt{3}(2\rho^2-1)$	Defocus
6	2	2	$\sqrt{6}\rho^2\cos 2\theta$	Astigmatism X
7	3	-3	$\sqrt{8}\rho^3\sin 3\theta$	Trefoil Y
8	3	-1	$\sqrt{8}(3\rho^3-2\rho)\sin\theta$	Coma Y
9	3	1	$\sqrt{8}(3\rho^3-2\rho)\cos\theta$	Coma X
10	3	3	$\sqrt{8}\rho^3\cos 3\theta$	Trefoil X
11	4	-4	$\sqrt{10}\rho^4\sin 4\theta$	Tetrafoil Y
12	4	-2	$\sqrt{10}(4\rho^4-3\rho^2)\sin 2\theta$	Secondary Astigmatism Y
13	4	0	$\sqrt{5}(6\rho^4-6\rho^2+1)$	Spherical
14	4	2	$\sqrt{10}(4\rho^4-3\rho^2)\cos 2\theta$	Secondary Astigmatism X
15	4	4	$\sqrt{10}\rho^4\cos 4\theta$	Tetrafoil X
16	5	-5	$\sqrt{12}\rho^5\sin 5\theta$	Pentafoil Y
17	5	-3	$\sqrt{12}(5\rho^5-4\rho^3)\sin 3\theta$	Secondary Trefoil Y
18	5	-1	$\sqrt{12}(10\rho^5-12\rho^3+3\rho)\sin\theta$	Secondary Coma Y
19	5	1	$\sqrt{12}(10\rho^5-12\rho^3+3\rho)\cos\theta$	Secondary Coma X
20	5	3	$\sqrt{12}(5\rho^5-4\rho^3)\cos 3\theta$	Secondary Trefoil X
21	5	5	$\sqrt{12}\rho^5\cos 5\theta$	Pentafoil X
22	6	-6	$\sqrt{14}\rho^6\sin 6\theta$	Hexafoil Y
23	6	-4	$\sqrt{14}(6\rho^6-5\rho^4)\sin 4\theta$	Secondary Tetrafoil Y
24	6	-2	$\sqrt{14}(15\rho^6-20\rho^4+6\rho^2)\sin 2\theta$	Tertiary Astigmatism Y
25	6	0	$\sqrt{7}(20\rho^6-30\rho^4+12\rho^2-1)$	Secondary Spherical
26	6	2	$\sqrt{14}(15\rho^6-20\rho^4+6\rho^2)\cos 2\theta$	Tertiary Astigmatism X
27	6	4	$\sqrt{14}(6\rho^6-5\rho^4)\cos 4\theta$	Secondary Tetrafoil X
28	6	6	$\sqrt{14}\rho^6\cos 6\theta$	Hexafoil X
29	7	-7	$4\rho^7\sin 7\theta$	Heptafoil Y
30	7	-5	$4(7\rho^7-6\rho^5)\sin 5\theta$	Secondary Pentafoil Y
31	7	-3	$4(21\rho^7-30\rho^5+10\rho^3)\sin 3\theta$	Tertiary Trefoil Y
32	7	-1	$4(35\rho^7-60\rho^5+30\rho^3-4\rho)\sin\theta$	Tertiary Coma Y
33	7	1	$4(35\rho^7-60\rho^5+30\rho^3-4\rho)\cos\theta$	Tertiary Coma X
34	7	3	$4(21\rho^7-30\rho^5+10\rho^3)\cos 3\theta$	Tertiary Trefoil X
35	7	5	$4(7\rho^7-6\rho^5)\cos 5\theta$	Secondary Pentafoil X
36	7	7	$4\rho^7\cos 7\theta$	Heptafoil X

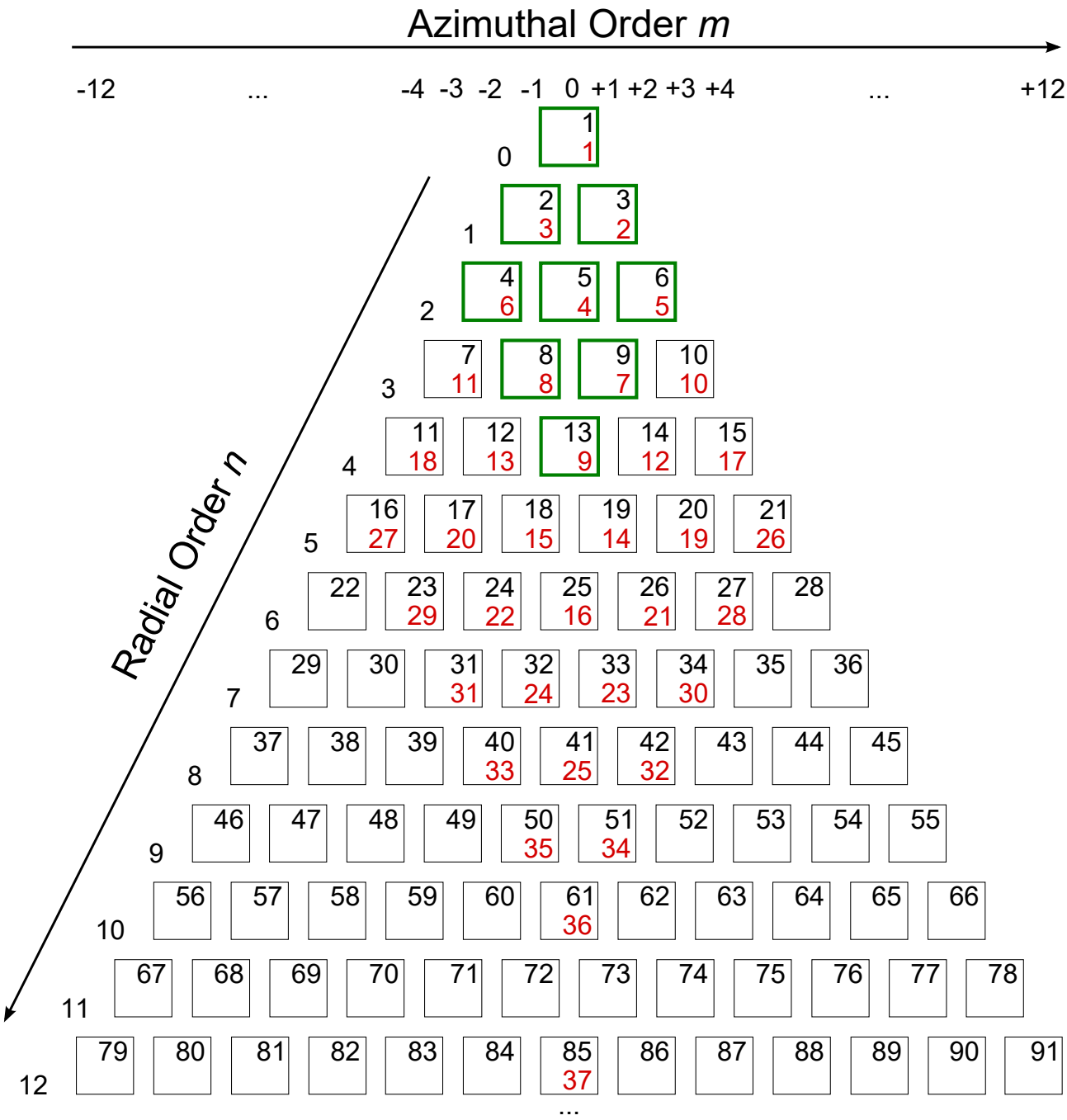


Figure 809. *This figure shows the first 91 Zernike polynomials and their corresponding radial order n and azimuthal order θ. The black numbers in the squares give the OSA / ANSI standard index i. The red numbers give the index of the corresponding Zernike fringe aberrations. Those Zernike polynomials which can be converted into Seidel aberrations are marked by a green frame.*

140.2.2 Zernike Fringe and Seidel Aberrations

Zernike fringe aberrations are a commonly used subset of 37 Zernike polynomials (↪Fig. 809) whereas for Zernike fringe aberrations the normalization constant N_n^m in Eq. (140.6) always equals 1.

There are six Seidel aberrations:

NAME	FORMULA
Piston	M_P
Distortion	$M_\mathsf{D} \cdot \rho \cos(\theta - \theta_\mathsf{D})$
Field Curvature	$M_\mathsf{F} \cdot \rho^2$
Astigmatism	$M_\mathsf{A} \cdot \rho^2 \cos^2(\theta - \theta_\mathsf{A})$
Coma	$M_\mathsf{C} \cdot \cos(\theta - \theta_\mathsf{C})$
Spherical Aberration	$M_\mathsf{S} \cdot \rho^4$

The $M_?$ and $\theta_?$ give the magnitude and the orientation angle of the corresponding Seidel aberrations. They can be derived out of the coefficients of the first nine Zernike fringe aberrations using the formulas given in table V of [WC92].

141 Real Components

141.1 Spherical Lens

The following equations can be used to calculate the effective focal length f_eff, the front focal length f_f, and the back focal length f_b, respectively.

$$\frac{1}{f_\mathsf{eff}} = (n-1)\left[\frac{1}{R_1} - \frac{1}{R_2} + \frac{(n-1)d}{nR_1R_2}\right] \tag{141.1}$$

$$f_\mathsf{f} = f_\mathsf{eff}\left(1 - \frac{(1-n)d}{nR_2}\right) \tag{141.2}$$

$$f_\mathsf{b} = f_\mathsf{eff}\left(1 - \frac{(n-1)d}{nR_1}\right) \tag{141.3}$$

R_1 is the curvature radius of the first surface (positive if convex), R_2 is the curvature radius of the second surface (positive if concave), and d is the center thickness. n is the ratio of the real refractive indices at the design wavelength (lens medium divided by embedding medium). Eq. (141.1) is the *lensmaker's equation*.

142 Detectors

142.1 Beam Parameters

For calculating the beam parameters of a globally polarized complex amplitude field we use a method based on the calculation of the second order momenta (↪Sec. 142.8). The ten momenta used to calculate the beam parameters are $\langle x^2\rangle$, $\langle y^2\rangle$, $\langle x\theta_x\rangle$, $\langle\theta_x^2\rangle$, $\langle xy\rangle$, $\langle x\theta_y\rangle$, $\langle y\theta_x\rangle$, $\langle\theta_x\theta_y\rangle$, $\langle y\theta_y\rangle$, and $\left\langle\theta_y^2\right\rangle$.
Beam parameters are well defined for harmonic fields having some finite lateral extension.
The calculation of beam parameters from the momenta is described by the following table:

ITEM	DESCRIPTION
$w_x(z_x) = 4\sqrt{\langle x^2 \rangle}$	Diameter in x-direction at the measured plane of the beam
$w_y(z_y) = 4\sqrt{\langle y^2 \rangle}$	Diameter in y-direction at the measured plane of the beam
$w_x^0 = 4\sqrt{\langle x^2 \rangle'}$	Waist diameter in x-direction of the beam
$w_y^0 = 4\sqrt{\langle y^2 \rangle'}$	Waist diameter in y-direction of the beam
$\theta_x = 4\sqrt{\langle \theta_x^2 \rangle}$	Full divergence angle of the beam in x-direction
$\theta_y = 4\sqrt{\left\langle \theta_y^2 \right\rangle}$	Full divergence angle of the beam in y-direction
$M_x^2 = 4\frac{\pi}{\lambda}\sqrt{\langle x^2 \rangle' \langle \theta_x^2 \rangle'}$	M^2 parameter for the x-axis
$M_y^2 = 4\frac{\pi}{\lambda}\sqrt{\langle y^2 \rangle' \left\langle \theta_y^2 \right\rangle'}$	M^2 parameter for the y-axis
$z_x^R = \left(w_x^0\right)^2 \frac{\pi}{\lambda}$	Rayleigh Length of the beam in x-direction
$z_y^R = \left(w_y^0\right)^2 \frac{\pi}{\lambda}$	Rayleigh Length of the beam in y-direction
$\frac{1}{2}\arctan\frac{2\langle xy \rangle}{\langle x^2 \rangle - \langle y^2 \rangle}$	Rotation angle of the principal axis

142.1.1 Calculation of the Momenta in the Waist

With the help of ABCD matrices, it is possible to calculate the beam parameters in the waist position of the beam. The changing of the momenta during a propagation is described by Eq. (142.39). The associated ABCD matrix

$$\begin{pmatrix} A & B \\ C & D \end{pmatrix} = \begin{pmatrix} 1 & z_{x/y} \\ 0 & 1 \end{pmatrix} \tag{142.1}$$

is used to simulate a free space propagation from the waist plane (marked with an apostrophe) to the measured plane of the beam. Using this matrix, there follows according to [Mär]

$$\left\langle x^2 \right\rangle' = \left\langle x^2 \right\rangle + 2z_x \left\langle x\theta_x \right\rangle + z_x^2 \left\langle \theta_x^2 \right\rangle \tag{142.2}$$

$$\langle xy \rangle' = \langle xy \rangle + z_a \left\langle x\theta_y \right\rangle + z_b \left\langle y\theta_x \right\rangle + z_a z_b \left\langle \theta_x \theta_y \right\rangle \tag{142.3}$$

$$\left\langle y^2 \right\rangle' = \left\langle y^2 \right\rangle + 2z_y \left\langle y\theta_y \right\rangle + z_y^2 \left\langle \theta_y^2 \right\rangle \tag{142.4}$$

$$\langle x\theta_x \rangle' = \langle x\theta_x \rangle + z_x \left\langle \theta_x^2 \right\rangle \tag{142.5}$$

$$\langle y\theta_y \rangle' = \langle y\theta_y \rangle + z_y \left\langle \theta_y^2 \right\rangle \tag{142.6}$$

$$\left\langle \theta_x^2 \right\rangle' = \left\langle \theta_x^2 \right\rangle \tag{142.7}$$

$$\langle \theta_x \theta_y \rangle' = \langle \theta_x \theta_y \rangle \tag{142.8}$$

$$\left\langle \theta_y^2 \right\rangle' = \left\langle \theta_y^2 \right\rangle. \tag{142.9}$$

The parameters z_x and z_y are the distances from the plane of the measured beam to the waist plane of the beam. The z parameters can be calculated from equations Eq. (142.5) and Eq. (142.6). It follows

$$z_x = -\frac{\langle x\theta_x \rangle}{\langle \theta_x^2 \rangle} \tag{142.10}$$

$$z_y = -\frac{\langle y\theta_y \rangle}{\left\langle \theta_y^2 \right\rangle}. \tag{142.11}$$

z_a and z_b can be calculated with the following two equations from [Mär].

$$z_a = -\frac{\langle x\theta_y \rangle'}{\langle \theta_x \theta_y \rangle} \tag{142.12}$$

$$z_b = -\frac{\langle y\theta_y \rangle'}{\langle \theta_x \theta_y \rangle} \tag{142.13}$$

142.1.2 Rotating Momenta according to Principal Axes

If the momentum $\langle xy \rangle$ is non-zero then the X and Y axes are not the principal axes of the beam. To calculate the beam parameters in the principal axes, a rotation of the momenta is necessary. The rotation angle can be calculated by

$$\phi = \frac{1}{2} \arctan\left(\frac{2\langle xy \rangle}{\langle x^2 \rangle - \langle y^2 \rangle} \right). \tag{142.14}$$

With the help of the rotation matrix

$$N = \begin{pmatrix} \cos^2\phi & 2\sin\phi\cos\phi & \sin^2\phi \\ -\sin\phi\cos\phi & \cos^2\phi - \sin^2\phi & \sin\phi\cos\phi \\ \sin^2\phi & -2\sin\phi\cos\phi & \cos^2\phi \end{pmatrix} \tag{142.15}$$

the rotated momenta in the principal axis are

$$\begin{pmatrix} \langle x^2 \rangle_r & \langle x\theta_x \rangle_r & \langle \theta_x^2 \rangle_r \\ \langle xy \rangle_r & (\langle x\theta_y \rangle_r + \langle y\theta_x \rangle_r)/2 & \langle \theta_x\theta_y \rangle_r \\ \langle y^2 \rangle_r & \langle y\theta_y \rangle_r & \langle \theta_y^2 \rangle_r \end{pmatrix} = N \begin{pmatrix} \langle x^2 \rangle & \langle x\theta_x \rangle & \langle \theta_x^2 \rangle \\ \langle xy \rangle & (\langle x\theta_y \rangle + \langle y\theta_x \rangle)/2 & \langle \theta_x\theta_y \rangle \\ \langle y^2 \rangle & \langle y\theta_y \rangle & \langle \theta_y^2 \rangle \end{pmatrix}. \tag{142.16}$$

The momenta marked with the subscript r are the momenta rotated in the principal axis. Now it is possible to calculate all beam parameters in relation to the principal axis by substituting all unrotated momenta in Sec. 142.1 and in Sec. 142.1.1 by the associated rotated ones.

142.2 Diffractive Optics Merit Functions

This section lists all merit functions and their defining equations which are used for the design and analysis of diffractive structures in VirtualLab Fusion.

In the equations, it is assumed that the output intensity at position x' is proportional to $|U_{\text{out}}(x')|^2$. This assumption is only valid in paraxial approximation.

The symbols α, U_{in}, U_{out}, U_{sig}, and $\mathcal{W}_{\text{sig}}$ are defined in Sec. 144.1.1. The *reference intensity* $I_{\text{R}} = \max_{x' \in \mathcal{W}_{\text{sig}}} |\alpha\, U_{\text{sig}}(x')|^2$ is the maximum intensity in the optimization region of the desired output field, scaled by α.

- The **window efficiency** η_{win} is defined as the ratio between the power of the output field in the evaluation region $\mathcal{W}_{\text{sig}}$ and the power of the incident field:

$$\eta_{\text{win}} = \frac{\int\limits_{x' \in \mathcal{W}_{\text{sig}}} \mathrm{d}x' \, |U_{\text{out}}(x')|^2}{\int_{-\infty}^{\infty} \mathrm{d}\xi \, |U_{\text{in}}(\xi)|^2}. \tag{142.17}$$

- The idea for calculating the ***conversion efficiency*** η_{conv} is to measure the portion of the incident field's power which flows into the Desired Output Field [WA98]. Its value is calculated by

$$\eta_{\text{conv}} = |\alpha|^2 \, \frac{\int\limits_{x' \in \mathcal{W}_{\text{sig}}} \mathrm{d}x' \, |U_{\text{sig}}(x')|^2}{\int_{-\infty}^{\infty} \mathrm{d}\xi \, |U_{\text{in}}(\xi)|^2}, \tag{142.18}$$

- The **signal-to-noise ratio** (SNR) measures the correspondence between a (complex-valued) desired function (here: $\alpha \, U_{\text{sig}}$) and a function which possesses errors in addition (here: U_{out}). The SNR is calculated by

$$\text{SNR} = \frac{\int\limits_{x' \in \mathcal{W}_{\text{sig}}} \mathrm{d}x' \, |U_{\text{out}}(x')|^2}{\int\limits_{x' \in \mathcal{W}_{\text{sig}}} \mathrm{d}x' \, |U_{\text{out}}(x') - \alpha \, U_{\text{sig}}(x')|^2} \quad . \tag{142.19}$$

  The numerical value of the SNR is often given in dB. For getting the corresponding dB value, the decadic logarithm of the result of Eq. (142.19) has to be multiplied by 10.

- Whereas during the calculation of the SNR all positions $x' \in \mathcal{W}_{\text{sig}}$ have influence on the result, the **uniformity error** is determined only by the positions with the maximum deviations between resulting and desired output field.

  If we denote the largest and smallest occurring values of the quotients between output intensity and (scaled) desired output intensity by $\widehat{I}_{\text{max}}$ and $\widehat{I}_{\text{min}}$, respectively, that is

$$\widehat{I}_{\text{max}} = \max_{x' \in \mathcal{W}_{\text{sig}}} \frac{|U_{\text{out}}(x')|^2}{|\alpha \, U_{\text{sig}}(x')|^2}, \tag{142.20}$$

  and

$$\widehat{I}_{\text{min}} = \min_{x' \in \mathcal{W}_{\text{sig}}} \frac{|U_{\text{out}}(x')|^2}{|\alpha \, U_{\text{sig}}(x')|^2} \tag{142.21}$$

  then the uniformity error E_{unif} can be calculated by [Ben97]

$$E_{\text{unif}} = \frac{\widehat{I}_{\text{max}} - \widehat{I}_{\text{min}}}{\widehat{I}_{\text{max}} + \widehat{I}_{\text{min}}}. \tag{142.22}$$

- The **relative zeroth order intensity** I_0 is calculated by

$$I_0 = \frac{|U_{\text{out}}(0)|^2}{I_{\text{R}}} \quad . \tag{142.23}$$

- The **zeroth order efficiency** η_0 is defined by

$$\eta_0 = \frac{|U_{\text{out}}(0)|^2}{\int_{-\infty}^{\infty} \mathrm{d}\xi \, |U_{\text{in}}(\xi)|^2}. \tag{142.24}$$

- The **maximum relative intensity of stray light** I_{stray} is calculated by

$$I_{\text{stray}} = \frac{\max_{x' \notin \mathcal{W}_{\text{sig}}} |U_{\text{out}}(x')|^2}{I_{\text{R}}}, \tag{142.25}$$

- The complex **optimal scale factor** α is defined in Eq. (144.1).

142.3 Fiber Coupling Efficiency

The coupling efficiency of an arbitrary harmonic field into a single mode fiber can be obtained by calculating the complex overlap integral between the fiber mode and the harmonic field. The overlap integral is defined by

$$\begin{aligned} \eta_{\text{coupl}} &= \eta_{\text{x,coupl}} + \eta_{\text{y,coupl}} \\ &= \frac{1}{\int_{\mathbb{R}^2} |\boldsymbol{E}_{\text{xy,in}}|^2 \,\mathrm{d}x\,\mathrm{d}y} \left[\frac{\left[\int_{\mathbb{R}^2} E_{x,\text{out}} E^*_{x,\text{sig}} \,\mathrm{d}x\,\mathrm{d}y\right]^2}{\int_{\mathbb{R}^2} |E_{x,\text{sig}}|^2 \,\mathrm{d}x\,\mathrm{d}y} + \frac{\left[\int_{\mathbb{R}^2} E_{y,\text{out}} E^*_{y,\text{sig}} \,\mathrm{d}x\,\mathrm{d}y\right]^2}{\int_{\mathbb{R}^2} |E_{y,\text{sig}}|^2 \,\mathrm{d}x\,\mathrm{d}y} \right]. \end{aligned} \tag{142.26}$$

$\boldsymbol{E}_{\text{xy,in}}$ is the complex amplitude of the incident field, $\binom{E_{x,\text{out}}}{E_{y,\text{out}}}$ is the complex amplitude of the field where the coupling efficiency should be calculated from and $\binom{E^*_{x,\text{sig}}}{E^*_{y,\text{sig}}}$ is the complex conjugate of the reference field - this means the harmonic field of the fiber mode. Typically as the reference field the Gaussian base mode of the fiber should be used.

142.4 Polarization

This detector plots either the azimuthal component E_ϕ or radial component E_ρ (please see Fig. 810 for the meaning) of a harmonic field into a data array.
The conversion from E_x and E_y to E_ϕ and E_ρ is done by the following equation:

$$\begin{pmatrix} E_\rho(\rho,\phi,z) \\ E_\phi(\rho,\phi,z) \end{pmatrix} = \begin{pmatrix} \cos\phi \sin\phi \\ -\sin\phi \cos\phi \end{pmatrix} \cdot \begin{pmatrix} E_x(x,y,z) \\ E_y(x,y,z) \end{pmatrix} \tag{142.27}$$

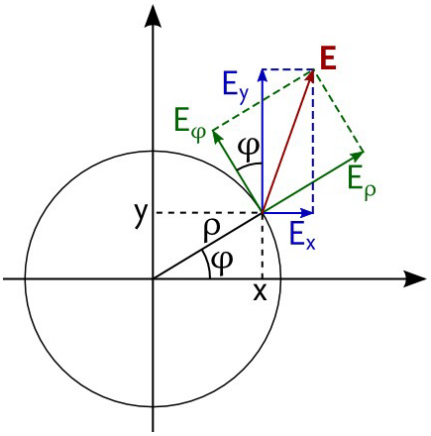


Figure 810. *Decomposition of the electric field vector $\boldsymbol{E}$ into Cartesian components (blue) and polar coordinate components (green).*

The polar coordinates are given by $\rho = \sqrt{x^2 + y^2}$ and $\phi = \operatorname{atan2} \frac{y}{x}$. [1]

142.5 Radiometry and Photometry

In the field of optics there are several physical properties considering the energy sent out by a light source or received by a detector or a surface.
At first let us define the radiant flux Φ_r (in watts) through an area A, which is a power value:

$$\Phi_r = \int \boldsymbol{S}\,\mathrm{d}\boldsymbol{A}, \qquad \text{where} \qquad \boldsymbol{S} = \boldsymbol{E} \times \boldsymbol{H} \qquad \text{the Poynting vector.} \tag{142.28}$$

Especially this applies for the total power sent out by a source:

$$\Phi_{r,tot} = \oint \boldsymbol{S}\,\mathrm{d}\boldsymbol{A}.$$

[1] atan2 is a special implementation of the arctangent function for a fraction of two values. See Microsoft C# documentation or Wikipedia for reference.

If the light is polychromatic, you have to distinguish between spectral (wavelength dependent) and integral (wavelength independent) values. They are connected by a relation of the form $\Phi_r = \int_0^\infty \Phi_r(\lambda)\,\mathrm{d}\lambda$, in this example Φ_r means the integral radiant flux and $\Phi_r(\lambda) = \frac{\mathrm{d}\Phi_r}{\mathrm{d}\lambda}$ the spectral radiant flux.
Furthermore these physical properties are divided into two kinds of values: physical (*radiometric*, subscript r) and psycho-physical (*photometric*, subscript p) values. For every radiometric value exists a photometric equivalent, which can be calculated from the first one (given in spectral form) by using the spectral luminous efficiency function y_λ. Here for instance the (spectral) radiant flux $\Phi_r(\lambda)$ and its photometric equivalent, the luminous flux Φ_p:

$$\Phi_p = 680\,\mathrm{lm/W} \int_0^\infty y_\lambda \Phi_r(\lambda)\,\mathrm{d}\lambda \tag{142.29}$$

142.5.1 Radiant Intensity

If you want to know what power is sent out by a point light source into a specific solid angle Ω, you have to calculate its radiant intensity (↪Fig. 811). This is defined by

$$I_r = \frac{\mathrm{d}\Phi_r}{\mathrm{d}\Omega}. \tag{142.30}$$

For the detection the distance to the source has to be known.

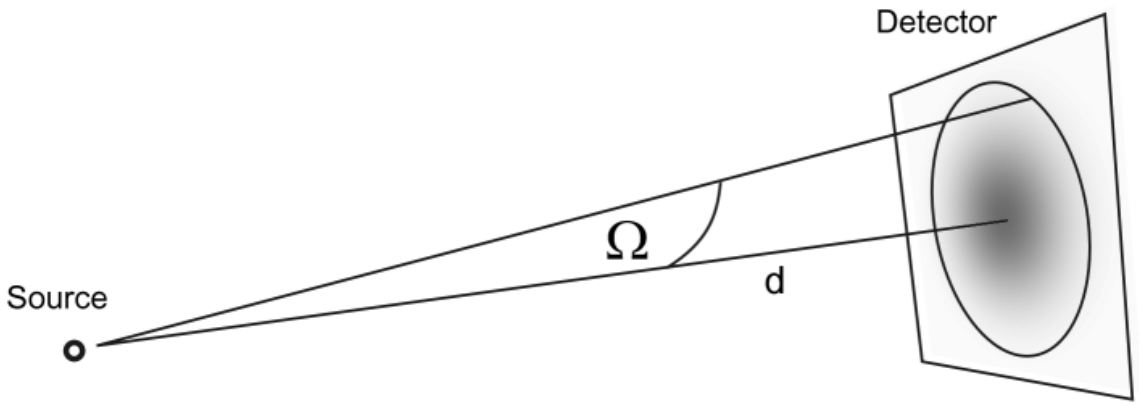


Figure 811. *Principle of Detecting the Radiant Intensity. d is the Distance to the Point Light Source.*

142.5.2 Radiance

For a non point source emission the radiance gives you the angular and spatial characteristics of the light source or reflecting area (↪Fig. 812). It is defined by

$$L_r = \frac{\mathrm{d}^2\Phi_r}{\cos\theta\,\mathrm{d}\Omega\,\mathrm{d}A} = \frac{\mathrm{d}S}{\mathrm{d}\Omega}, \tag{142.31}$$

where Ω gives the solid angle and A the radiating area you want the radiance to know for. θ is the angle between the Poynting vector S and the normal vector A.
To use this detector, its position related to the light source or the reflecting area has to be known, as well as the directionality of the source. This is a curve, giving the dependency of the relative intensity ($\frac{I}{I_0}$, where $I_0 = I(\theta = 0)$) from the angle of radiation θ. A special case is a so called Lambert characteristic, which has the form $\frac{I}{I_0} = \cos\theta$, and which leads to an angular independent radiance.

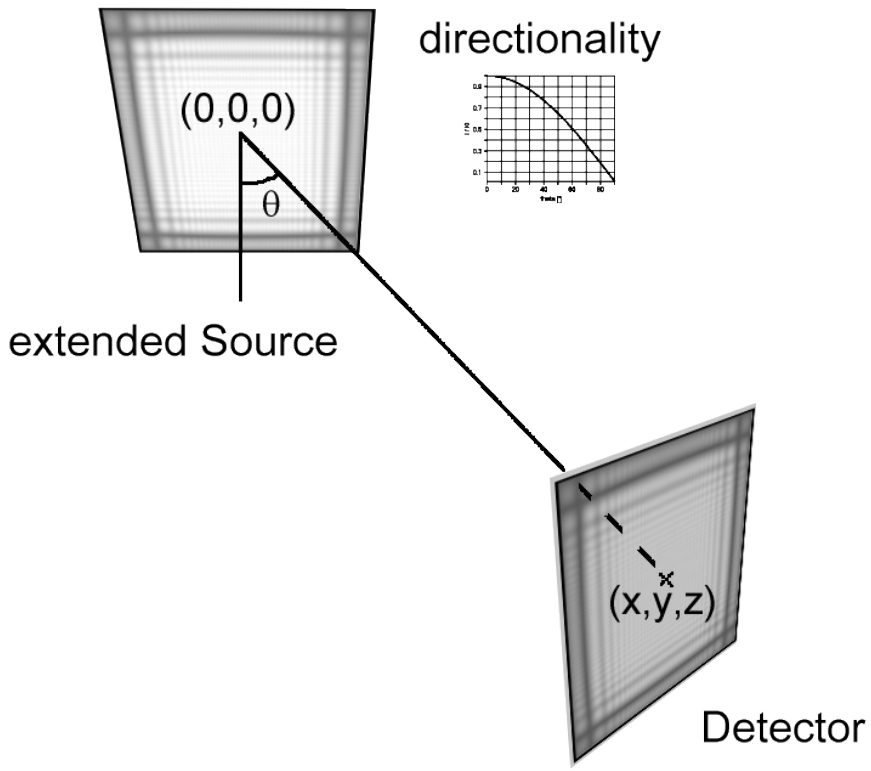


Figure 812. *Principle of Detecting the Radiance. (x,y,z) is the detector position.*

142.5.3 Irradiance

The irradiance is the total power going through an area A perpendicularly (↪Fig. 813) and it is defined by:

$$E_r = \frac{\mathrm{d}\Phi_r}{\cos\theta\,\mathrm{d}A} = S_\perp, \tag{142.32}$$

where $S_\perp$ is the magnitude of the component of the Poynting vector perpendicular to A.

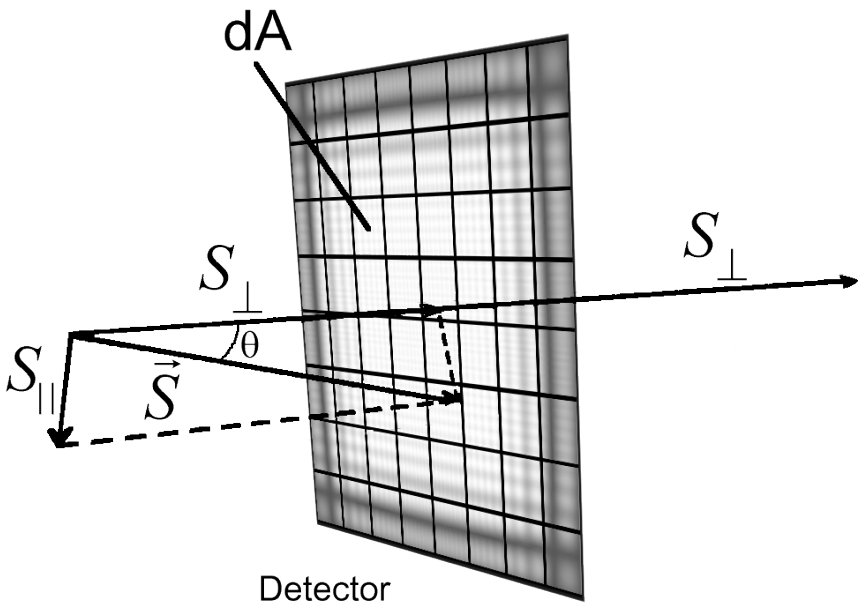


Figure 813. *Principle of Detecting the Irradiance*

142.5.4 Luminous Intensity

Luminous Intensity is the photometric, i. e. psycho-physical equivalent to the Radiant Intensity (↪Sec. 142.5.1) and is calculated from it analog to Eq. (142.29). Under daylight conditions a different spectral luminous efficiency function y_λ has to be used than for night conditions. This is due to the brightness dependency of the spectral sensitivity of the human eye.

142.5.5 Luminance

Luminance is the photometric, i. e. psycho-physical equivalent to the Radiance (↪Sec. 142.5.2) and is calculated from it analog to Eq. (142.29). Under daylight conditions a different spectral luminous efficiency function y_λ has to be used than for night conditions. This is due to the brightness dependency of the spectral sensitivity of the human eye.

142.5.6 Illuminance

Illuminance is the photometric, i. e. psycho-physical equivalent to the Irradiance (↪Sec. 142.5.3) and is calculated from it analog to Eq. (142.29). Under daylight conditions a different spectral luminous efficiency function y_λ has to be used than for night conditions. This is due to the brightness dependency of the spectral sensitivity of the human eye.

142.6 Spherical Phase

One important function is the detection of spherical phase from the phase information.
A correct detection is only possible if the sampled phase information is not undersampled. The detection is performed using a two step fitting process. A fitting is complicated due to the fact that the phase is generally in a modulo 2π representation. And since the additional aberrations to the spherical phase factor may contain dislocations, an unwrapping of the phase and a fitting of the unwrapped phase is not always possible. Therefore not the fitting of the phase $\phi(x,y)$ but the fitting of the phase derivatives $\frac{\partial\phi(x,y)}{\partial x} = \phi^x(x,y)$ and $\frac{\partial\phi(x,y)}{\partial y} = \phi^y(x,y)$ instead is performed. For the fitting a least squares method is used. Since an analytical fitting of the spherical phase by a least squares method is not possible in a first step, a quadratic phase is fitted. For the radius r_{quad} of the quadratic phase follows analytically

$$r_{\text{quad}} = \frac{k \sum_{i=0,j=0}^{N_x,N_y} \left(x_{i,j}^2 + y_{i,j}^2\right)}{\sum_{i=0,j=0}^{N_x,N_y} \left(\phi_{i,j}^x x_{i,j} + \phi_{i,j}^y y_{i,j}\right)} \tag{142.33}$$

with $k = \frac{2\pi n}{\lambda}$ and n is the real part of the refractive index. In a second step an iterative fit of a spherical phase $\phi = kr$ with $r = \sqrt{x^2 + y^2 + r_{\text{spher}}^2}$ follows, starting with the result of the quadratic phase fit for r_{spher}. Therefore r_{spher} has to be optimized in order to minimize the function

$$G = \sum_{i=0,j=0}^{N_x,N_y} \left[\left(\phi_{i,j}^x - \frac{kx_{i,i}}{r_{i,j}}\right) + \left(\phi_{i,j}^y - \frac{ky_{i,i}}{r_{i,j}}\right)\right]. \tag{142.34}$$

This optimization is done numerically.

142.7 Field Components

142.7.1 Magnetic Field (H-Field)

In VirtualLab Fusion the components of the magnetic field vector $\boldsymbol{H}(\boldsymbol{r},t)$ are calculated by the following equations:

$$H_x(x,y,z) = -\frac{1}{k_0}\sqrt{\frac{\varepsilon_0}{\mu_0}}\left[\mathcal{F}^{-1}\left(\frac{1}{k_z}\left(k_x k_y[\mathcal{F}\,E_x(x,y)] + (k_y^2+k_z^2)[\mathcal{F}\,E_y(x,y)]\right)\right)\right] \tag{142.35}$$

$$H_y(x,y,z) = \frac{1}{k_0}\sqrt{\frac{\varepsilon_0}{\mu_0}}\left[\mathcal{F}^{-1}\left(\frac{1}{k_z}\left((k_x^2+k_z^2)[\mathcal{F}\,E_x(x,y)] + k_x k_y[\mathcal{F}\,E_y(x,y)]\right)\right)\right] \tag{142.36}$$

$$H_z(x,y,z) = -\frac{1}{k_0}\sqrt{\frac{\varepsilon_0}{\mu_0}}\left[\mathcal{F}^{-1}\left(k_y[\mathcal{F}\,E_x(x,y)] - k_x[\mathcal{F}\,E_y(x,y)]\right)\right]\ . \tag{142.37}$$

with $k_0 = \frac{2\pi}{\lambda}$,
$k_x = k_0\sin(\theta)\cos(\varphi) = 2\pi u$,
$k_y = k_0\sin(\varphi) = 2\pi v$,
$k_z = k_0\cos(\theta)\cos(\varphi) = 2\pi w$ and $w = \sqrt{\frac{n^2}{\lambda^2} - u^2 - v^2}$.

142.7.2 Poynting Vector

In VirtualLab Fusion the components of the time averaged Poynting vector $< S\boldsymbol{r}(t) >$ are calculated by:

$$< S_x(t) >_t = \frac{1}{2}\left[Re\left[E_y \cdot H_z^*(E_x,E_y)\right] - Re\left[E_z(E_x,E_y)\cdot H_y^*(E_x,E_y)\right]\right]$$

$$< S_y(t) >_t = \frac{1}{2}\left[Re\left[E_z(E_x,E_y)\cdot H_x^*(E_x,E_y)\right] - Re\left[E_x \cdot H_z^*(E_x,E_y)\right]\right]$$

$$< S_z(t) >_t = \frac{1}{2}\left[Re\left[E_x \cdot H_y^*(E_x,E_y)\right] - Re\left[E_y \cdot H_x^*(E_x,E_y)\right]\right]$$

with $k_0 = \frac{2\pi}{\lambda}$,
$k_x = k_0\sin(\theta)\cos(\varphi) = 2\pi u$,
$k_y = k_0\sin(\varphi) = 2\pi v$,
$k_z = k_0\cos(\theta)\cos(\varphi) = 2\pi w$ and $w = \sqrt{\frac{n^2}{\lambda^2} - u^2 - v^2}$.

142.8 Momentum

The momentum theory is very useful to determine the beam parameters (↪Sec. 142.1) of an arbitrary wave with global polarization.
The momenta of a globally polarized harmonic field $U(x,y)$ are defined by

$$\left\langle x^n, y^m, \theta_x^k, \theta_y^l \right\rangle = \frac{(-i\bar{\lambda})^{k+l}}{2P}\cdot(I_1 + I_2)\,, \tag{142.38}$$

with

$$I_1 = \int\int dx\,dy\ \ x^n y^m\left[u(x,y)\frac{\partial^k}{\partial x^k}\frac{\partial^l}{\partial y^l}u^*(x,y)\right],$$

$$I_2 = (-1)^{(k+l)}\int\int dx\,dy\ \ x^n y^m\left[u^*(x,y)\frac{\partial^k}{\partial x^k}\frac{\partial^l}{\partial y^l}u(x,y)\right],$$

$$P = \int\int dx\,dy\ \ u(x,y)u^*(x,y),$$

$$\bar{\lambda} = \frac{\lambda}{2\pi}.$$

In a paraxial optical system the changing of the momenta during the propagation of the wave can be described by ABCD matrices (↪Sec. 105) in the following way.

$$\left\langle x^n, y^m, \theta_x^k, \theta_y^l \right\rangle' = \left\langle (Ax + B\theta_x)^n, (Ay + B\theta_y)^m, (Cx + D\theta_x)^k, (Cy + D\theta_y)^l \right\rangle . \tag{142.39}$$

143 Propagations

143.1 Free Space Operators

143.1.1 Propagation between Optical Setup Elements

Generally, the propagation of a field between Optical Setup Elements is equivalent to propagating the field between two arbitrarily positioned planes. These planes are related to the Optical Setup Elements involved and are called *transfaces*. This is a special shortcut for "*trans*fer inter*face*" and means the location of the field transfer between two kinds of operators. The *output transface* τ_1 of the *start element* is the plane where the output of the propagation through this element is given to the homogeneous medium free space operator. The *input transface* τ_2 of the *target element* is the plane where the output of the free space operator is given to the propagation operator of the second element.

The position and orientation of the output transface – the starting point for the homogeneous medium free space operator – is determined by the propagation through the start element and the type of the reference output coordinate system chosen for this element (but the output coordinate system does not have to be identical to this transface's position and orientation). It is stored after the element's propagation in the coordinate system of the field itself: the origin of this coordinate system is identical to the position of the transface and the orientation is given by the coordinate system's x-y-plane.

The position and orientation of the input transface – the end point for the homogeneous medium free space operator – is determined by the geometry of the target element and, of course, the relative position of the target element to the start element.

There are two general cases to be distinguished for the propagation between Optical Setup Elements, related to two different algorithms used for propagating the field from output transface τ_1 to input transface τ_2:

1. The planes τ_1 and τ_2 are parallel. The algorithm used for this configuration is shown in Fig. 814.
2. The planes τ_1 and τ_2 are not parallel. The algorithm used for this configuration is shown in Fig. 815. **Please note:** this case cannot be simulated with 1D fields.

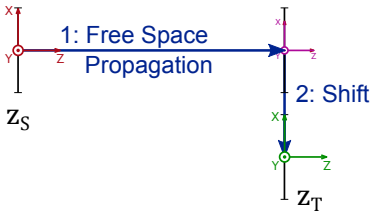


Figure 814. *Algorithm for the propagation between Optical Setup Elements where output transface and input transface are parallel. There are two operations at most: the actual free space propagation followed by a lateral shift.*

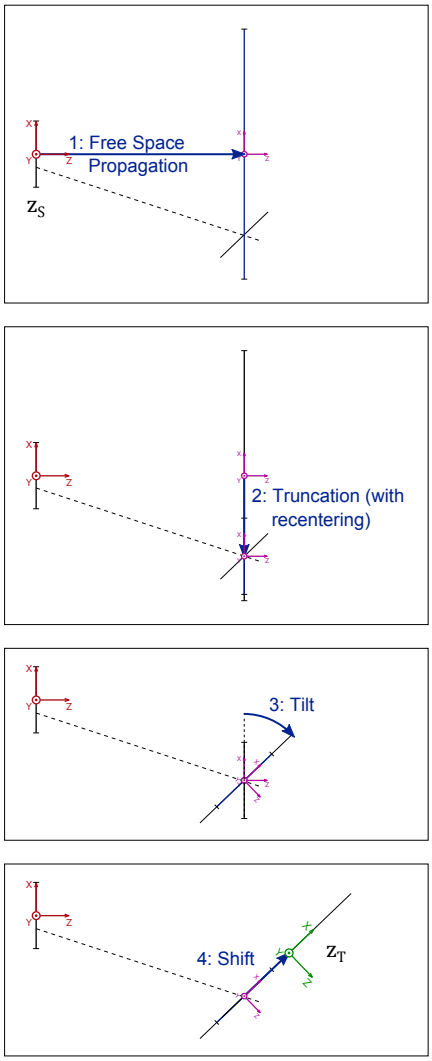


Figure 815. *Algorithm for the propagation between Optical Setup Elements where output transface and input transface are not parallel. The operators 1: actual free space propagation and 3: rotation operation can be configured by the user.*

143.1.2 Far Field Operator

The far field propagation simulates the propagation of a field $U(x,y)$ with a wavelength λ by a distance Δz through an infinite homogeneous medium with a given refractive index n. A propagation can be simulated from the waist to the far field, from the far field to the waist and from one far field distance to another. The far field propagation is the far field approximation of the Rayleigh Sommerfeld propagation integral [MW95] (see also Sec. 143.1.4). Thus it contains no paraxial approximation. The propagation is defined as:

$$\left[\mathcal{P}_{\Delta z}^{\text{FarField}} U(x,y)\right](x',y') \sim -\frac{ikz}{2\pi r}\frac{e^{ikr}}{r}\int\int_{-\infty}^{\infty} \mathrm{d}x\mathrm{d}y U(x,y) e^{-\frac{ik}{r}(xx'+yy')} \tag{143.1}$$

$$\text{with} \quad r = \sqrt{x'^2 + y'^2 + \Delta z^2} \tag{143.2}$$

$$\text{and} \quad k = \frac{2\pi n}{\lambda}. \tag{143.3}$$

For the estimation of the sampling distance Eq. (143.20) is used if the propagation mode is *Waist to Far Field* or *Far Field to Waist*. For the propagation mode *Far Field to Far Field* the sampling distance is calculated by

$$\Delta x' = \Delta x \frac{\Delta z + \Delta z_{\text{sph}}}{\Delta z_{\text{sph}}}. \tag{143.4}$$

Δz_{sph} is the radius of the spherical phase factor which in the far field equals the distance from the waist of the field. This means that a spherical phase radius (Sec. 136.2) must be set if you use the *Far Field to Far Field* mode.

In the paraxial case the following approximation (far field approximation of Eq. (143.17)) is used:

$$\left[\mathcal{P}_{\Delta z}^{\text{FarField-P}} U(x,y)\right](x',y') = \frac{A}{i}\exp(ik\Delta z)\exp\left(\frac{ik}{2\Delta z}\left(x'^2+y'^2\right)\right)\cdot \left[\mathcal{F}\left(U(x,y)\right)\right]\left(\frac{k}{2\pi\Delta z}x', \frac{k}{2\pi\Delta z}y'\right), \tag{143.5}$$

where A denotes a real-valued factor. The definitions of k and $\mathcal{F}$ correspond to those in Sec. 143.1.3.

143.1.3 Spectrum of Plane Waves Operator

The spectrum of plane waves propagation operator $\mathcal{P}_{\Delta z}^{\text{SPW}}$ is used for simulating the propagation of a field $U(x,y)$ with a wavelength λ by a distance Δz through an infinite homogeneous medium with a given refractive index n [MW95],

$$\mathcal{P}_{\Delta z}^{\text{SPW}} U = \mathcal{F}^{-1}\left(\exp\left[i2\pi\sqrt{\frac{n^2}{\lambda^2}-\hat{x}^2-\hat{y}^2}\Delta z\right]\mathcal{F}\,U(x,y)\right), \tag{143.6}$$

where $\hat{x}$ and $\hat{y}$ are spatial frequencies, i. e. pixel coordinates of the Fourier transformed field.

For more details about the Fourier transform used in this equation see Sec. 137.5.1.

The spectrum of plane waves propagation operator $\mathcal{P}_{\Delta z}^{\text{SPW}}$ as given in Eq. (143.6) can be derived without using any physical approximations, that is its accuracy is limited only by numerical errors.

The main reason for these numerical errors is the sampling of the phase term in Eq. (143.6) by a finite sampling distance δx, which can cause sampling problems during the numerical evaluation of Eq. (143.6). These issues vanish if the propagation distance Δz is sufficiently small. The following formula gives an approximate maximum value Δz_{max} for the propagation distance, that is in case of $\Delta z < \Delta z_{\text{max}}$ the numerical error in the application of $\mathcal{P}_{\Delta z}^{\text{SPW}}$ is often negligible,

$$\Delta z_{\text{max}} = \frac{1}{2}\left[\sqrt{\left(\frac{n}{\lambda}\right)^2-(U_0-\delta U)^2}-\sqrt{\left(\frac{n}{\lambda}\right)^2-U_0^2}\right]^{-1}, \tag{143.7}$$

where $U_0 = 1/(2\delta x)$ and $\delta U = 1/(N_x\delta x)$. It should be mentioned that in general the numerical error for all propagation distances $\Delta z > 0$ is never zero but just decreases with decreasing propagation distance.

The numerical error can be decreased for a given propagation distance Δz by appending sampling points (with value zero) at the borders of the field. The number of sampling points is increased from N_x to $N_{x,\text{min}}$ by doing so. The recommended value for $N_{x,\text{min}}$ can be calculated approximately by

$$N_{x,\text{min}} = \frac{2}{1-2\delta x\sqrt{\left(\frac{n}{\lambda}\right)^2-a^2}} \tag{143.8}$$

where

$$a = \frac{1}{2\Delta z}+\sqrt{\left(\frac{n}{\lambda}\right)^2-\left(\frac{1}{2\delta x}\right)^2}. \tag{143.9}$$

For the estimation of the number of sampling points Eq. (143.8) is used.

143.1.4 Rayleigh Sommerfeld Operator

The propagation integral used in Rayleigh Sommerfeld propagation simulates the propagation of a field $U(x,y)$ with a wavelength λ by a distance Δz through an infinite homogeneous medium with a given refractive index n. It is defined by [MW95] as:

$$\left[\mathcal{P}_{\Delta z}^{\text{RS}} U(x,y)\right](x',y') = \frac{1}{2\pi}\int_{-\infty}^{\infty} \mathrm{d}x\mathrm{d}y U(x,y)\frac{\partial \exp(ikR)/R}{\partial z}, \tag{143.10}$$

where

$$\frac{1}{2\pi}\frac{\partial \exp(ikR)/R}{\partial z} = \frac{z\exp(ikR)(1-ikR)}{2\pi R^3} \tag{143.11}$$

and

$$R = \sqrt{(x-x')^2+(y-y')^2+\Delta z^2}. \tag{143.12}$$

The Rayleigh Sommerfeld propagation integral can be derived without any physical approximation. Actually the propagation integral is a convolution of a harmonic field and a spherical phase function. It is possible to solve this convolution by using fast Fourier transforms. In this case the propagation integral has a form

$$\left[\mathcal{P}_{\Delta z}^{\mathrm{RS}} U(x)\right](x') = \boldsymbol{\mathcal{F}}\left[\boldsymbol{\mathcal{F}}^{-1}\left(\frac{z\exp(ikR)(1-ikR)}{2\pi R^3}\right)\boldsymbol{\mathcal{F}}^{-1}U(x)\right]. \tag{143.13}$$

If the convolution is evaluated by fast Fourier transforms it is also called Rayleigh Sommerfeld Convolution. In contrast the integral can also be numerically evaluated by simple summation. In difference to the calculation of the convolution by fast Fourier transforms, the pure summation is much more time consuming but has the advantage of a free choice of the number of sampling points and the sampling distance of the propagated field. This propagation method is accurate for large propagation distances. For smaller distances numerical errors will occur because of an undersampling of the spherical phase function in Eq. (143.12). The critical distance Δz_{min} can be estimated by

$$\Delta z_{\mathrm{min}} = \frac{n}{\lambda}\sqrt{\left[\left(\frac{\lambda}{2n}\right)^2 - x_0^2 - (x_0-\delta x)^2\right]^2 - 4x_0^2(x_0-\delta x)^2}. \tag{143.14}$$

x_0 is the radius of the field and is defined as $x_0 = \frac{N_x}{2}\Delta x$. It should be mentioned that for all propagation distances $\Delta z \neq 0$ the numerical errors never vanish but just decrease more and more with increasing distance. For propagation distances $\Delta z < \Delta z_{\mathrm{min}}$, numerical errors can be reduced by interpolating the harmonic field before the propagation. The necessary sampling distance δx_{min} can be estimated by

$$\delta x_{\mathrm{min}} = \frac{\pi}{k x_0}\sqrt{x_0^2+(\Delta z)^2}, \tag{143.15}$$

where

$$k = \frac{2\pi n}{\lambda}. \tag{143.16}$$

For the estimation of the sampling distance Eq. (143.15) is used.

143.1.5 Fresnel Propagation Operator

The Fresnel propagation operator $\mathcal{P}_{\Delta z}^{\mathrm{Fresnel}}$ for simulating the propagation of a field $U(x,y)$ with a wavelength λ by a distance Δz through an infinite homogeneous medium with a given refractive index n can be derived using the paraxial Fresnel approximation [Goo68]:

$$\begin{aligned}\left[\mathcal{P}_{\Delta z}^{\mathrm{Fresnel}} U(x,y)\right](x',y') = \frac{A}{i}\exp(ik\Delta z)\exp\left(\frac{ik}{2\Delta z}\left(x'^2+y'^2\right)\right)\cdot \\ \left[\boldsymbol{\mathcal{F}}\left(U(x,y)\exp\left[\frac{ik}{2\Delta z}\left(x^2+y^2\right)\right]\right)\right]\left(\frac{k}{2\pi\Delta z}x', \frac{k}{2\pi\Delta z}y'\right),\end{aligned} \tag{143.17}$$

where A denotes a real-valued factor. The definitions of k and $\boldsymbol{\mathcal{F}}$ correspond to those in Sec. 143.1.3.
In contrast to the spectrum of plane waves operator (↪Sec. 143.1.3), for the application of the Fresnel propagation operator the numerical errors become larger for shorter propagation distances Δz because of the quadratic

phase term in Eq. (143.17). The critical minimum distance Δz_{min} for a field with $(N_x;\, N_y)$ sampling points and a sampling distance $(\delta x;\, \delta y)$ can be estimated by

$$\Delta z_{\text{min}} = \frac{(\delta x)^2 n N_x}{\lambda}. \tag{143.18}$$

It should be mentioned that for all propagation distances $\Delta z \neq 0$ the numerical errors never vanish but just decrease more and more with increasing distance.

For propagation distances $\Delta z < \Delta z_{\text{min}}$ numerical errors can be reduced by interpolating the field before the propagation to a smaller sampling distance δx_{min}, which can be calculated approximately by

$$\delta x_{\text{min}} = \frac{N_x \delta x}{2} - \sqrt{\left(\frac{N_x \delta x}{2}\right)^2 - \frac{\Delta z \lambda}{n}}. \tag{143.19}$$

In difference to most of the other homogeneous medium propagation algorithms, the sampling distance of the field is scaled during the Fresnel propagation. The sampling distance of the propagated field follows from

$$\Delta x' = \frac{\lambda \Delta z}{n N_x \Delta x}. \tag{143.20}$$

For the estimation of the sampling distance Eq. (143.19) is used.

143.1.6 Combined SPW / Fresnel Operator

This propagation operator combines automatically the spectrum of plane waves propagation (↪Sec. 143.1.3) and the Fresnel propagation (↪Sec. 143.1.5) to achieve an efficient propagation of paraxial waves free of numerical errors. For propagation of harmonic fields close to the waist of a wave, spectrum of plane waves is used. For larger distances the Fresnel propagation is used. Since the Fresnel propagation is more efficient the automatic paraxial propagation tries always to use the Fresnel propagation if the distance from the waist is larger than the minimum distance Δz_{min} (↪Eq. (143.18)). If the spectrum of plane wave propagation is used the harmonic field will be automatically embedded in order to reduce numerical errors.

In general a combination of both propagation methods is necessary depending on the distances from the waist of the wave $\Delta z_{w,\text{start}}$ of the harmonic field before the propagation and $\Delta z_{w,\text{end}}$ of the harmonic field after the propagation. The following table shows which combinations of propagation operators may occur.

DISTANCE $\lvert\Delta Z_{W,\text{START}}\rvert$	DISTANCE $\lvert\Delta Z_{W,\text{END}}\rvert$	USED PROPAGATION ALGORITHMS
$= 0$	$< \Delta z_{\text{min}}$	SPW
$= 0$	$\geq \Delta z_{\text{min}}$	FRT
$< \Delta z_{\text{min}}$	$< \Delta z_{\text{min}}$	SPW
$< \Delta z_{\text{min}}$	$\geq \Delta z_{\text{min}}$	SPW to waist and FRT
$\geq \Delta z_{\text{min}}$	$\geq \Delta z_{\text{min}}$	FRT to waist and FRT
$\geq \Delta z_{\text{min}}$	$< \Delta z_{\text{min}}$	FRT to waist and SPW

143.1.7 Rayleigh Expansion Propagation

The Rayleigh coefficients $\mathcal{R}(k_x, k_y)$ calculated by the Fourier Modal Method correspond to the complex amplitudes of the individual grating orders. Thus a kind of SPW propagation (↪Sec. 143.1.3) can be used to calculate the near field in a certain propagation distance Δz.

$$\mathcal{P}_{\Delta z}^{\text{NF}} \boldsymbol{E}(x, y, z_0 + \Delta z) = \sqrt{N_x N_y}\, \mathcal{F}^{-1}\left(\exp\left[i k_z \Delta z\right] \mathcal{R}(k_x, k_y)\right), \tag{143.21}$$

$\mathcal{R}(k_x, k_y)$ are the Rayleigh coefficients for E_x- and E_y-component of the field. N_x and N_y are the sampling points in x- and y-direction, respectively. The factor $\sqrt{N_x N_y}$ is due to the fact that $\mathcal{R}(k_x, k_y)$ is not exactly $\mathcal{F}\, \boldsymbol{E}(x, y)$ as in VirtualLab Fusion the Fourier transform is defined with a factor $1/\sqrt{N_x N_y}$ (↪Sec. 137.5.1.1).

Notes

- To use geometrical optics alongside with the Rayleigh expansion propagation, the harmonic field calculated by the geometrical optics is transformed to Rayleigh coefficients first.
- As the Rayleigh coefficients represent ideal plane waves with infinite size, you are always in the near field, regardless of the set Δz. Thus you never see separate orders if you use the near field propagation.
- The *Output Field Oversampling Factor* of the Rayleigh Expansion Propagation is considered by an embedding prior to the inverse Fourier transform. The result is the same as if a sinc interpolation (↪Sec. 13.2.2) was applied.
- The *Number of Periods* parameter of the Rayleigh Expansion Propagation is considered by a zeroized oversampling prior to the inverse Fourier transform, i. e. by surrounding each pixel with a suitable amount of zeros.
- x, y, z_0, and Δz in Eq. (143.21) refer to the coordinate system of the grating, not the coordinate system of the incoming light.

143.2 Propagation Operators for Real Components

143.2.1 Thin Element Approximation

The thin element approximation can be used for propagating through surfaces, homogeneous and inhomogeneous (index modulated) media. It is assumed that paraxial / parabasal conditions hold. The paraxial mode is documented by [Goo68]. Using the paraxial mode, the method is identical to the mode AI/AII of the geometrical optics operator, see Sec. 97.1.
In principle the propagation of a field E by a distance Δz from z to $z + \Delta z$ is based on:

$$E(z + \Delta z) = Q \cdot E(z) \tag{143.22}$$

where

$$Q = \exp\{-ik_0\, I(n(x, y, \tilde{z}))\} \tag{143.23}$$

Here k_0 is the wavenumber with respect to the base-material (without index modulation), and $I(n(x, y, z))$ is the integral value of $n(x, y, z)$ along the propagation path, i. e. from $\tilde{z} = z$ to $\tilde{z} = z + \Delta z$. In case of surfaces, the propagation is applied for each medium (in front and behind the surface) separately, i. e. two consecutive propagation steps are applied. For the integration a summed trapezoidal rule (Romberg integration) with at most 4 integration points is used. Hence, only weak modulation of the refractive index along the propagation path are taken into account. In the case of stronger modulation along the z-variable, the split step propagation method (↪Sec. 143.2.2) is to be preferred.

143.2.2 Split Step (BPM) Propagation

This propagation operator is applicable for inhomogeneous media with small refractive index modulation $\delta n \ll n$. Furthermore, paraxial conditions are assumed to hold and the influence of reflected waves is assumed to be negligible. The operator is based on the classical ideas of paraxial beam propagation methods, see e. g. [YL92] and [TY82]. The field is propagated through a medium by sequence of two alternating propagation steps: a step assuming a homogeneous medium and a correction step taking into account the index modulation. Using the notation of [TY82] we can write for the propagation of a field E by distance Δz from z to $z + \Delta z$:

$$E(z + \Delta z) = P \cdot Q \cdot P \cdot E(z) \tag{143.24}$$

where

$$P = \exp\left\{-i\left(\frac{z}{2}\right)\nabla_{\perp}^{2}/[(\nabla_{\perp}^{2}+k^{2})^{1/2}+k]\right\} \tag{143.25}$$

and

$$Q = \exp\left\{-i\Delta z k_0 \delta n(x,y)\right\} \tag{143.26}$$

The effect of the operator P is to propagate the field through a distance $\Delta z/2$ in homogeneous medium of refractive index n_0. The operator Q subsequently imposes a phase change on the propagating field equal to $\Delta z k_0 \delta n$ taking into account the index modulation $\delta n(x,y)$. After that the field is propagated by another step of $\Delta z/2$ in homogeneous medium. This is repeated n-times, until the total propagation distance $Z = n\Delta z$ is reached.
Note, the z-dependence of $\delta n(x,y,z)$ is taken into account by the splitting along the z-distance which corresponds to a piecewise trapezoidal integration rule of $\delta n(x,y,z)$ with respect to the variable z.

144 Design

144.1 Iterative Fourier Transform Algorithm

144.1.1 Basic Concept and Terminology

The basic idea of the Iterative Fourier Transform Algorithm (IFTA) is to design a transmission $\mathcal{T}$ which transforms an *Input Field* U_{in} into a *Desired Output Field* U_{sig}. The real *Output Field* U_{out} will differ from U_{sig}, these differences can be measured with *Diffractive Optics Merit Functions* (↪Sec. 142.2). The IFTA optimizes these merit functions.
To make the design task easier and e. g. obtain larger structures in the resulting transmission, you can allow three types of design freedom in the output plane.

1. In the case of *amplitude freedom*, the correspondence between output field and desired output field is only measured within a given lateral region $x' \in \mathcal{W}_{\text{sig}}$, which is denoted as *evaluation region* or *optimization region*.

2. In the case of *phase freedom*, only the amplitudes of output field and desired output field are of concern, which mathematically corresponds to the substitutions $U_{\text{out}} \to |U_{\text{out}}|$ and $U_{\text{sig}} \to |U_{\text{sig}}|$.

3. In the case of *scale freedom*, U_{sig} can be scaled by a complex-valued factor α for getting a better correspondence to U_{out}. This *optimal scale factor* α is calculated by

$$\alpha = \frac{\int\limits_{x'\in\mathcal{W}_{\text{sig}}} \mathrm{d}x'\, U_{\text{out}}^{*}(x')\, U_{\text{sig}}(x')}{\int\limits_{x'\in\mathcal{W}_{\text{sig}}} \mathrm{d}x'\, |U_{\text{sig}}(x')|^{2}} \quad . \tag{144.1}$$

   U_{out}^{*} is the complex conjugate of U_{out}.

144.1.2 Sinc Modulation due to Pixelation

VirtualLab Fusion allows an analytical simulation and compensation of a sinc effect in the far field of pixelated transmissions.
This feature can be used to correct a desired output field prior to a transmission design and to simulate the pixelation effect of a transmission after the design.
Pixelation of a transmission function means that every discrete sampling point can be understood as a rectangular pixel. In a mathematical sense this is a convolution between a rect-function and the transmission function

$$\mathcal{T}_{\text{pix}}(x',y') = \int\int \mathcal{T}(x,y)\,\text{rect}\left(x-x',\frac{\Delta x}{2}\right)\text{rect}\left(y-y',\frac{\Delta y}{2}\right)dxdy. \tag{144.2}$$

In the far field this convolution gives a multiplication between a sinc-function and the far field of the transmission

$$\mathcal{F}(\mathcal{T}_{\text{pix}}(x',y')) = \mathcal{F}(\mathcal{T}(x,y))\text{sinc}(\frac{u\pi}{\Delta x})\text{sinc}(\frac{v\pi}{\Delta y}). \tag{144.3}$$

Δx and Δy are the pixel sizes in x- and y- direction of the transmission. If a sinc-compensation is performed, VirtualLab Fusion divides the far field by a sinc-function in order to avoid a modulation of the far field due to a pixelation.

144.2 Parametric Optimization

The parametric optimization in VirtualLab Fusion allows you to optimize optical systems by means of nonlinear optimization algorithms. For that purpose VirtualLab Fusion supports the definition of merit functions that are to be optimized. Merit functions can take into account detector results. Further several types of parameter constraints are formulated as merit functions as well. Finally a common merit function is constructed by a weighted sum of individual merit functions.

144.2.1 Definition of the Target Function

Basically, the *target function* is a summed combination of *constraints*. Constraints are functions of the parameter vector $\mathbf{x} = (x_1,\ldots,x_t)^T$ that can represent ranges or target values of

- the parameters itself (*parameter constraints*),
- merit functions calculated by detectors (*merit function constraints*) or
- general (arbitrary) functions (*general constraints*).

Let $\{f_i(\mathbf{x})\}_{i=1,\ldots,n}$ be the set of user-defined constraints. Then the target function $F(\mathbf{x})$ is defined as the weighted sum over all constraints:

$$F(\mathbf{x}) = \sum_{i=1}^{n} g_i f_i(\mathbf{x}) \ , \tag{144.4}$$

where g_i is the weight for the i-th constraint.
Each constraint $f_i(\mathbf{x})$ is a composition of an inner function $\sigma_i(\mathbf{x})$ and outer function $\hat{f}_i(s)$ which conveys the actual *constraint type*.

$$f_i(\mathbf{x}) = \hat{f}_i\left(\sigma_i(\mathbf{x})\right) \tag{144.5}$$

$\hat{f}_i(s)$ yields an positive value, if the constraint is violated and 0, if not.

144.2.1.1 Definition of the Inner Function $\sigma(\mathbf{x})$

The inner function $\sigma_i(x_1,\ldots,x_t)$ of the parameter constraint that corresponds to the k-th parameter ($1 \leq k \leq t$) is the identity function with respect to this parameter:

$$id^k(x_1,\ldots,x_t) = x_k \ . \tag{144.6}$$

The inner functions of merit function constraints are the underlying detector merit functions. An inner function $\sigma(\mathbf{x})$ of a general constraint can be an arbitrary function. Such a function, also called *general structure parameter*, is evaluated only during parametric optimization.
Each inner function is evaluated in SI derived units.

144.2.1.2 Definition of the Outer Function $\hat{f}(s)$

The outer function $\hat{f}_i(s)$ of a constraint f_i is quadratic in regions of constraint violation and constant zero if constraints are fulfilled. $\hat{f}_i(s)$ is continuous anyway. The actual definition depends on the *constraint type*. There are 4 different constraint types:

- *Lower Limit*, i.e. $\hat{f}_i(s)$ yields a positive value if $s = \sigma(x_1, \ldots, x_t)$ is smaller than $s_{\min}$:

$$\hat{f}_i(s) = h_1(s), \text{ where} \tag{144.7}$$

$$h_1(s) = \begin{cases} 0 & : s \geq s_{\min} \\ (s - s_{\min})^2 & : s < s_{\min} \end{cases}. \tag{144.8}$$

- *Upper Limit*, i.e. $\hat{f}_i(s)$ yields a positive value if s is greater than $s_{\max}$:

$$\hat{f}_i(s) = h_2(s), \text{ where} \tag{144.9}$$

$$h_2(s) = \begin{cases} 0 & : s \leq s_{\max} \\ (s - s_{\max})^2 & : s > s_{\max} \end{cases}. \tag{144.10}$$

- *Range*, i.e. $\hat{f}_i(s)$ yields a positive value if s is not in range $[s_{\min}, s_{\max}]$:

$$\hat{f}_i(s) = h_3(s), \text{ where} \tag{144.11}$$

$$h_3(s) = h_1(s) + h_2(s), \tag{144.12}$$

  and $h_1(s)$ and $h_2(s)$ correspond to Eq. (144.8) and Eq. (144.10), respectively.

- *Target Value*, i.e. $\hat{f}_i(s)$ conveys the distance of s to the target value s_t (which is allowed to be $\pm\infty$):

$$\hat{f}_i(s) = h_4(s), \text{ where} \tag{144.13}$$

$$h_4(s) = \begin{cases} \infty & : s_t = +\infty \text{ and } s \leq 0 \text{ or} \\ & \quad s_t = -\infty \text{ and } s \geq 0 \\ \frac{1}{s^2} & : s_t = +\infty \text{ and } s > 0 \text{ or} \\ & \quad s_t = -\infty \text{ and } s < 0 \\ (s - s_t)^2 & : \text{else} \end{cases}. \tag{144.14}$$

144.2.2 Calculation of the estimated error

For Powell's method the estimated error ε is calculated from

$$\varepsilon = \begin{cases} |y_i - y_{i+1}| & : |y_i| + |y_{i+1}| < 1 \\ \frac{2|y_i - y_{i+1}|}{|y_i| + |y_{i+1}|} & : \text{else} \end{cases}, \tag{144.15}$$

where $y_i = f(\mathbf{x}_i)$ and $y_{i+1} = f(\mathbf{x}_{i+1})$ are the target function evaluations in subsequent iterations. Note that the estimated error is absolute in the first case and relative in the second.
For the downhill simplex algorithm ε is calculated similarly:

$$\varepsilon = \begin{cases} |y_1 - y_2| & : |y_1| + |y_2| < 1 \\ \frac{10|y_1 - y_2|}{|y_1| + |y_2|} & : \text{else} \end{cases}, \tag{144.16}$$

However, y_1 and y_2 are the target function values of the worst and the best vertex of the simplex in each iteration step.

144.2.3 Global Optimization Algorithms

144.2.3.1 Simulated Annealing

The *simulated annealing* method is based on an analogy from materials science and enables the global search for the minimum by an random *temperature* term t that is added to the current target function value. It is obtained from

$$t = T \log r \,, \tag{144.17}$$

where r is a random value between 0 and 1. T is the *temperature*, which is gradually decreased according to an *annealing schedule*. The selected local optimization algorithm is applied to the adapted target function at each annealing step. Currently, the downhill simplex algorithm is the only possible choice for the applied local optimization algorithm.
For locating the global minimum successfully, appropriate values for *start temperature* and *number of annealing steps* must be chosen. Unfortunately, this is something of a trial and error process in most cases. If the *start temperature* is too low the algorithm will possibly get stuck in the surrounding of a local minimum. On the other hand, temperature values that are too high will increase the probability for "jumping out" of the surrounding of an already detected global minimum.

144.2.3.2 Evolutionary Algorithm

The *Evolutionary Algorithm* method is based on an analogy from population-based evolution and enables the global search for the minimum by a random *temperature* term that is added to the current target function value. An Evolutionary Algorithm is inspired by biological evolution. As such, reproduction, mutation, recombination, and selection act as operators. These operators are continuously used to find desired minimum, maximum or target value just like evolution of a population results in fittest species.

145 Miscellaneous

145.1 Debye-Wolf Integral

With the Debye-Wolf Integral [Wol59][FT11] one can easily calculate the field in or near the focus of an ideal aplanatic lens which is illuminated with collimated light.
In cylindrical coordinates (ρ, φ, z) the field can be expressed as:

$$\boldsymbol{E}(\rho,\varphi,z) = \begin{bmatrix} E_x(\rho,\varphi,z) \\ E_y(\rho,\varphi,z) \\ E_z(\rho,\varphi,z) \end{bmatrix} = -\mathrm{i}kf \begin{bmatrix} E_{x,\mathrm{in}}\left(I_0 - I_2\cos 2\varphi\right) - E_{y,\mathrm{in}} I_2 \sin 2\varphi \\ E_{y,\mathrm{in}}\left(I_0 + I_2\cos 2\varphi\right) - E_{x,\mathrm{in}} I_2 \sin 2\varphi \\ -2\mathrm{i}I_1\left(E_{x,\mathrm{in}}\cos\varphi + E_{y,\mathrm{in}}\sin\varphi\right) \end{bmatrix}, \tag{145.1}$$

where f is the focal length. $k = {}^{2\pi n}/_{\lambda}$. λ is the wavelength of the incident field. n is the refractive index of the material around the lens. The cylindrical coordinates ρ and φ are given by $\rho = \sqrt{x^2+y^2}$ and $\varphi = \mathrm{atan2}\,{}^{y}/_{x}$ [1]. $E_{x,\mathrm{in}}$ and $E_{y,\mathrm{in}}$ are the components of the Jones vector of the incident field.

$$I_0 = \int_0^{\alpha} \sqrt{\cos\theta}\,\sin\theta(\cos\theta+1)J_0(k\rho\sin\theta)\exp(\mathrm{i}kz\cos\theta)\mathrm{d}\theta, \tag{145.2a}$$

$$I_1 = \int_0^{\alpha} \sqrt{\cos\theta}\,\sin^2\theta J_1(k\rho\sin\theta)\exp(\mathrm{i}kz\cos\theta)\mathrm{d}\theta, \tag{145.2b}$$

$$I_2 = \int_0^{\alpha} \sqrt{\cos\theta}\,\sin\theta(\cos\theta-1)J_2(k\rho\sin\theta)\exp(\mathrm{i}kz\cos\theta)\mathrm{d}\theta. \tag{145.2c}$$

where J_0, J_1, J_2 are the Bessel functions of first kind. α is related to the numerical aperture NA by

$$\alpha = \arcsin\left(\frac{\mathrm{NA}}{n}\right) \tag{145.3}$$

[1] atan2 is a special implementation of the arctangent function for a fraction of two values. See Microsoft C# documentation or Wikipedia for reference.

145.2 Defining Directions and Orientations in $\mathbb{R}^3$

In general, we have to differentiate between defining a single direction vector in $\mathbb{R}^3$ and defining the orientation of a solid. The first task requires two angles while the latter one has got three degrees of freedom. Nonetheless, both purposes are strongly related.
There is a large variety of equivalent conventions which can be used to define spatial directions and orientations. This section described all conventions used inside VirtualLab Fusion.

145.2.1 Spherical Angles

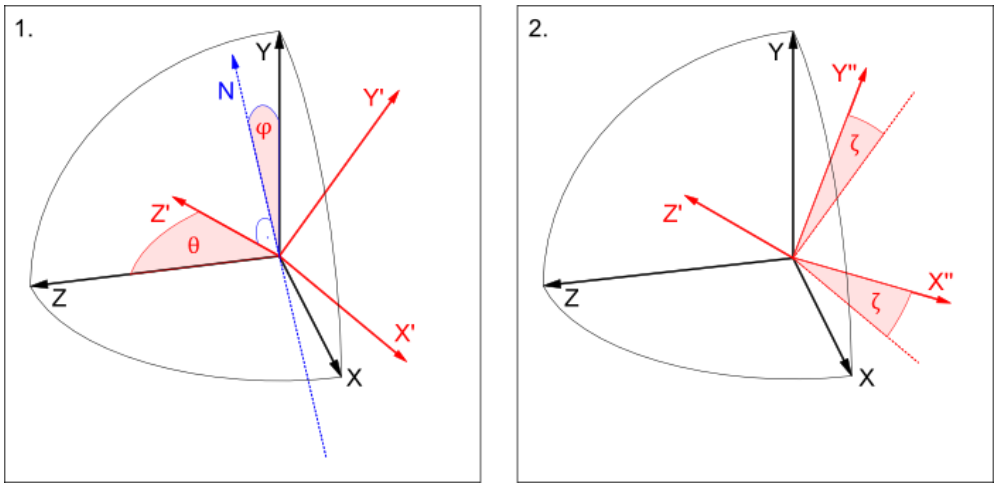


Figure 816. *Example for defining an orientation using spherical angles and a subsequent rotation about the z-axis.*

145.2.1.1 Defining a Single Direction via Spherical Angles

The ”Spherical Angles” convention can be used for defining a direction in reference to another direction using the spherical angles θ and ϕ. In VirtualLab Fusion, the reference direction may be given by the x-, y-, or z-axis if just a single direction is to be defined. The angle θ is the inclination angle between the defined direction and the reference axis. The plane which contains both the new direction and the reference axis is rotated by the other angle ϕ about the reference axis. One can describe the angle ϕ as the rotation angle of the node vector for θ as well.
In Fig. 816, the left picture shows the inclination of the vector Z' by θ and ϕ. While θ gives the angle between Z' and its reference direction Z, ϕ defines the angle between the node vector N and the Y-axis. It is identical to the angle between the plane which is defined by Z' and Z and the X-Z-plane.

145.2.1.2 Defining a Solid’s Orientation via Spherical Angles

The spherical angles θ and ϕ provide two out of three degrees of freedom a solid’s orientation in $\mathbb{R}^3$ has got. Only one of the solid’s axes can be set by those two angles as described in Sec. 145.2.1.1 above. The third degree of freedom can be fixed by an additional rotation of the solid about this axis. This additional rotation can be performed either before setting the solid’s axis via spherical angles or after it.
In VirtualLab Fusion, the axis which is inclined by the spherical angles θ and ϕ is always the solid’s z-axis. So, either the solid is rotated by an angle ζ about the z-axis first, followed by the inclination of the solid’s z-axis according to the spherical angles. Or, the inclination using θ and ϕ is performed in the first step and the solid is rotated by the angle ζ about the new z’-axis second.
In Fig. 816, both steps are shown. In the left picture, the z-axis is inclined using θ and ϕ. In the right picture, the subsequent rotation about ζ is shown.

145.2.2 Direction Angles

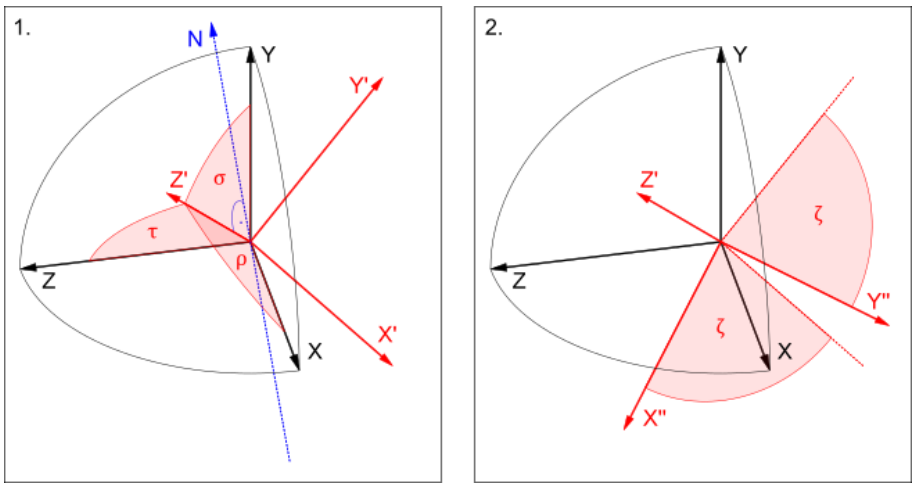


Figure 817. *Example for defining an orientation using direction angles and a subsequent rotation about the z-axis.*

145.2.2.1 Defining a Single Direction via Direction Angles

The direction angles ρ, σ, and τ determine a direction in $\mathbb{R}^3$. They are defined as the angles between the direction to be defined and the coordinate axes. Please note that only two of this three angles are independent. If, for instance, ρ and σ are set, the value of τ follows from ρ and σ, except for its sign. The angle's cosines are identical to x-, y- and z-component of the defined direction resp.
In Fig. 817, the left picture shows the definition of the vector Z' by ρ, σ and τ being the angles between Z' and X, Y and Z respectively.

145.2.2.2 Defining a Solid's Orientation via Direction Angles

The direction angles ρ, σ and τ provide two out of three degrees of freedom (because only two angles are independent) a solid's orientation in $\mathbb{R}^3$ has got. Only one of the solid's axes can be set by those angles as described in Sec. 145.2.2.1 above. The third degree of freedom can be fixed by an additional rotation of the solid about this axis. This additional rotation can be performed either before setting the solid's axis via spherical angles or after it.
In VirtualLab Fusion, the axis which is inclined by the direction angles ρ, σ and τ is always the solid's z-axis. So, either the solid is rotated by an angle ζ about the z-axis first, followed by the inclination of the solid's z-axis according to the direction angles. Or, the inclination using ρ, σ and τ is performed in the first step and the solid is rotated by the angle ζ about the new z'-axis second.
In Fig. 817, both steps are shown. In the left picture, the z-axis is inclined using ρ, σ and τ. In the right picture, the subsequent rotation about ζ is shown.

145.2.3 Cartesian Angles

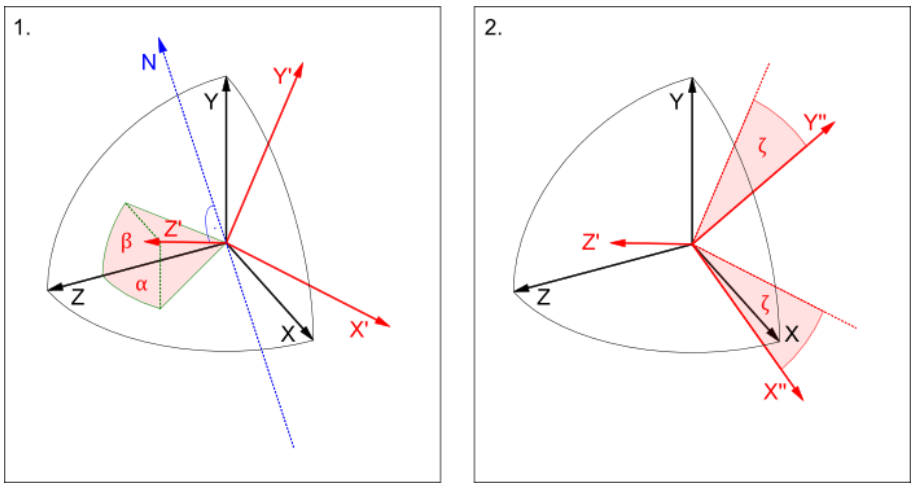


Figure 818. *Example for defining an orientation using Cartesian angles and a subsequent rotation about the z-axis.*

145.2.3.1 Defining a Single Direction via Cartesian Angles

The ”Cartesian Angles” convention can be used for defining a direction in reference to one of the coordinate system’s base axes. The angles α and β are defined as the angles of the projections of the direction onto the base planes of the coordinate system.
In Fig. 818, the left picture shows the definition of the vector Z' by α and β being the angles between Z and the projection of Z' onto the x-z-plane and the y-z-plane respectively.

145.2.3.2 Defining a Solid’s Orientation via Cartesian Angles

The Cartesian angles α and β provide two out of three degrees of freedom a solid’s orientation in $\mathbb{R}^3$ has got. Only one of the solid’s axes can be set by those two angles as described in Sec. 145.2.3.1 above. The third degree of freedom can be fixed by an additional rotation of the solid about this axis. This additional rotation can be performed either before setting the solid’s axis via Cartesian angles or after it.
In VirtualLab Fusion, the axis which is inclined by the Cartesian angles α and β is always the solid’s z-axis. So, either the solid is rotated by an angle ζ about the z-axis first, followed by the inclination of the solid’s z-axis according to the Cartesian angles. Or, the inclination using α and β is performed in the first step and the solid is rotated by the angle ζ about the new z’-axis second.
In Fig. 818, both steps are shown. In the left picture, the z-axis is inclined using α and β. In the right picture, the subsequent rotation about ζ is shown.

145.2.4 Sequence of Axis Rotations

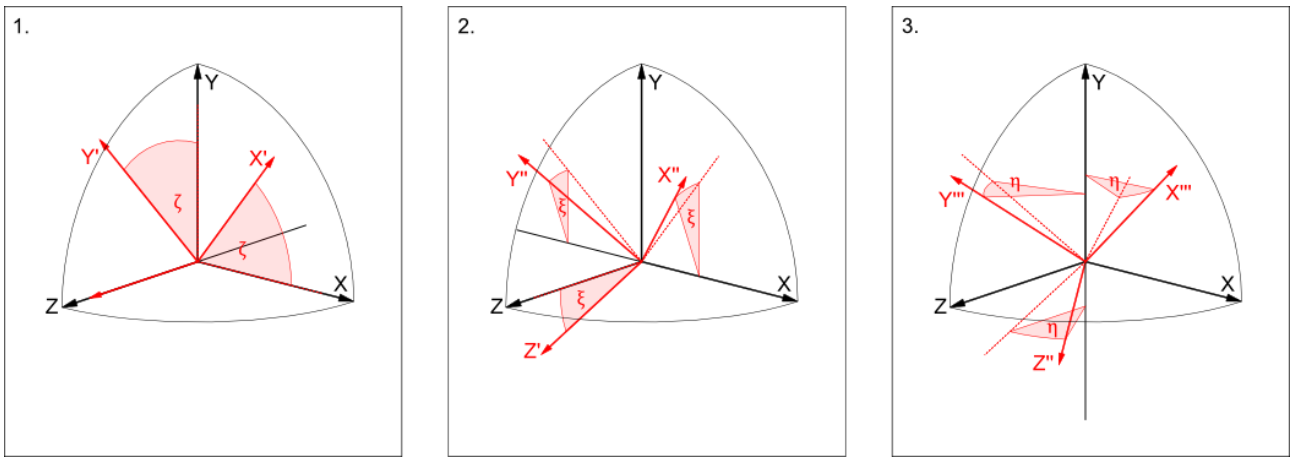


Figure 819. *Example for defining an orientation using an axis rotation sequence with fix axes.*

145.2.4.1 Defining a Single Direction via Sequence of Axis Rotations

The ”Sequence of Axis Rotations” convention can be used for defining a direction in reference to one of the coordinate system’s base axes. A sequence of rotations can be defined, each one performed about one of the coordinate system’s base axes.

In Fig. 819, the definition of the vector Y''' via a sequence of three rotations can be reconstructed. At first, a rotation by angle ζ about the z-axis transfers the reference axis Y into a new vector Y'. In a second step, Y' is transformed by a rotation of angle ξ about the x-axis into the vector Y''. The last step of rotating Y'' about the y-axis by using an angle η results in the final vector Y'''.

145.2.4.2 Defining a Solid’s Orientation via Sequence of Axis Rotations

There are two ways for defining the orientation of a solid using a sequence of axis rotations. On the one hand, the orientation can be given by a sequence of rotations about axes that are fix in space. On the other hand, the axes for any subsequent rotation can result from former rotations. These two cases are shown as examples in Fig. 819 and Fig. 820.

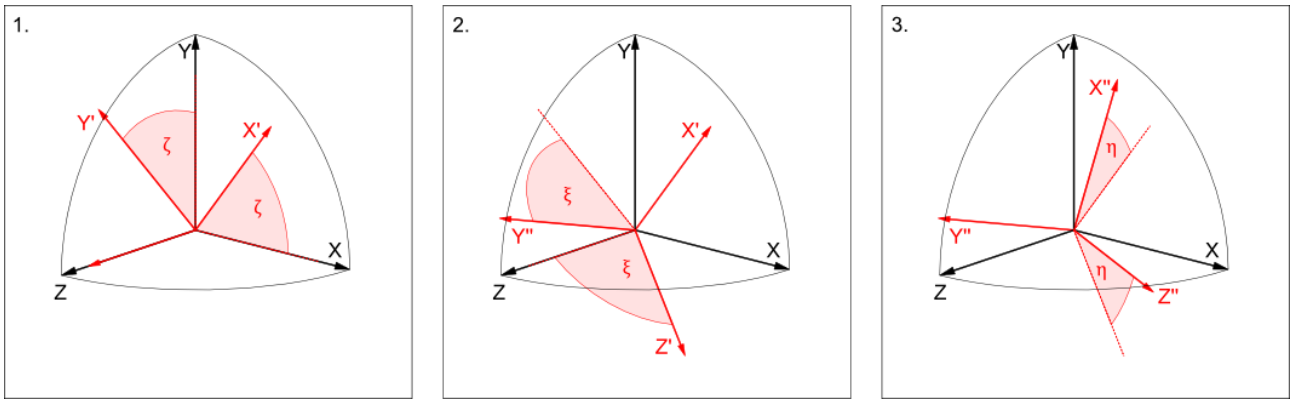


Figure 820. *Example for defining an orientation using an axis rotation sequence with non fix axes.*

145.2.5 Defining a Solid's Orientation via Euler Angles

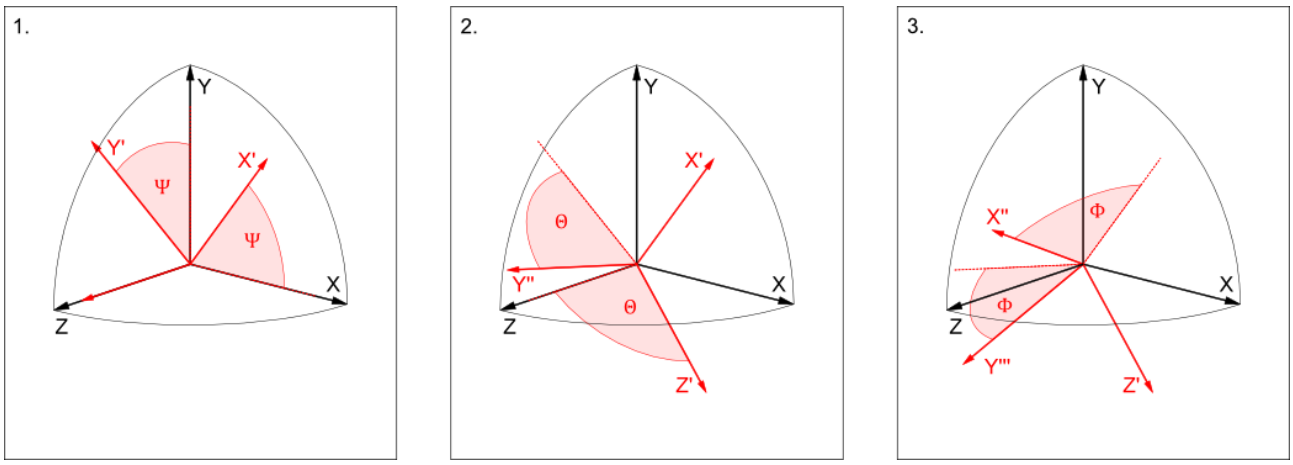


Figure 821. *Example for defining an orientation using Euler angles.*

The definition of the orientation of a solid via Euler angles is shown as an example in Fig. 821. The Euler angles Ψ, Θ, and Φ represent rotation angles applied to non-fix coordinate axes. The whole coordinate system is rotated about certain coordinate axes in a certain sequence, in this way, Euler angles can be seen as a special case of an axis rotation sequence (see Sec. 145.2.4.2). Ψ is the first rotation angle, performed about the z-axis. Θ represents the second rotation angle, applied to a rotation about the new x'-axis, resulting from the first (Ψ-) rotation. The last step, the Φ-rotation is performed about the new z'-axis, which is a result from the prior rotation about the x'-axis.

145.2.6 Rotation Matrix

145.2.6.1 Defining a Single Direction via Rotation Matrix

The "Rotation Matrix" convention can be used for defining a direction in reference to another direction using a 3×3 - rotation matrix M. In VirtualLab Fusion, the reference direction may be given by the x-, y-, or z-axis if just a single direction is to be defined.
The direction $\boldsymbol{d}$ is calculated by

$$\boldsymbol{d} = M \cdot \boldsymbol{r}, \tag{145.4}$$

where $\boldsymbol{r}$ is the reference direction, being $(0,0,1)$ (z-axis as reference), $(1,0,0)$ (x-axis as reference), or $(0,1,0)$ (y-axis as reference).

145.2.6.2 Defining a Solid's Orientation via Rotation Matrix

The orientation of a solid can be completely defined by a 3×3 - matrix. The solid's new axes can be calculated from the old axes just by applying matrix multiplications as described in Sec. 145.2.6.1.

145.2.7 Defining a Single Direction via Direction Vector

A normalized direction vector can be defined by an arbitrary (not-normalized) vector just by normalizing:

$$\boldsymbol{d} = \boldsymbol{r} / \sqrt{r_x^2 + r_y^2 + r_z^2}, \tag{145.5}$$

with $\boldsymbol{d}$ being the normalized direction vector and $\boldsymbol{r} = (r_x, r_y, r_z)^T$ representing the not-normalized vector.

145.3 Wave Direction Conversions

There are different ways how wave directions can be specified:

- Cartesian angles

- Spherical angles
- Wave vector components and
- Spatial frequencies .

The Cartesian angles α and β are related to the wave vector components k_x and k_y by

$$\tan\alpha = \frac{k_x}{k_z}, \tag{145.6}$$

$$\tan\beta = \frac{k_y}{k_z}, \tag{145.7}$$

with wave number

$$k = \frac{2\pi n(\lambda_{\text{vac}})}{\lambda_{\text{vac}}} = \sqrt{k_x^2 + k_y^2 + k_z^2}, \tag{145.8}$$

The spherical angles ϕ and θ are related to the wave vector components k_x and k_y by

$$k_x = k\cos\phi\sin\theta \quad \text{and} \tag{145.9}$$

$$k_y = k\sin\phi\sin\theta. \tag{145.10}$$

The spatial frequencies u and v are related to k_x and k_y by

$$u = k_x/(2\pi) \quad \text{and} \tag{145.11}$$

$$v = k_y/(2\pi). \tag{145.12}$$

145.4 Fresnel Equations

The complex Fresnel coefficients (the transmission coefficients τ_{TE} and τ_{TM} for perpendicular (TE) and parallel (TM) polarization as well as the reflection coefficients ρ_{TE} and ρ_{TM}) according to Fresnel's equations:

$$\tau_{\text{TE}} = \frac{2\sin\theta'\cos\theta}{\sin(\theta+\theta')} \tag{145.13}$$

$$\rho_{\text{TE}} = -\frac{\sin(\theta-\theta')}{\sin(\theta+\theta')} \tag{145.14}$$

$$\tau_{\text{TM}} = \frac{2\sin\theta'\cos\theta}{\sin(\theta+\theta')\cos(\theta-\theta')} \tag{145.15}$$

$$\rho_{\text{TM}} = \frac{\tan(\theta-\theta')}{\tan(\theta+\theta')} \tag{145.16}$$

The refraction angle θ' is given by the law of refraction: $\sin\theta' = \tilde{n}/\tilde{n}'\sin\theta$, where θ is the incidence angle and $\tilde{n}$ and $\tilde{n}'$ mean the complex refractive indices of the two media.
Furthermore the reflectance R and the transmittance T are calculated using:

$$R_{\text{TE/TM}} = |\rho_{\text{TE/TM}}|^2 \tag{145.17}$$

$$T_{\text{TE/TM}} = |\tau_{\text{TE/TM}}|^2 \frac{n'\cos\theta'}{n\cos\theta} \tag{145.18}$$

Here n and n' are the real parts of $\tilde{n}$ and $\tilde{n}'$, respectively.

145.5 Grating Equation

The components of the wave vector $\boldsymbol{k}_{\text{out}}$ of a diffraction order (l, m) are calculated by the following equations

$$k_{\text{out,x}} = k_{\text{in,x}} + \frac{2\pi l}{P_{\text{x}}} \tag{145.19}$$

$$k_{\text{out,y}} = k_{\text{in,y}} + \frac{2\pi m}{P_{\text{y}}} \tag{145.20}$$

$$k_{\text{out,z}} = \text{sign}\,(n_{\text{out}}) \sqrt{\left(\frac{2\pi n_{\text{out}}}{\lambda}\right)^2 - k_{\text{out,x}}^2 - k_{\text{out,y}}^2} \tag{145.21}$$

P_{x} / P_{y}	Period of the grating along the x- / y-axis of the grating coordinate system
	$P_{\text{y}} = \infty$ for 1D-periodic gratings
$\boldsymbol{k}_{\text{in}} = \boldsymbol{e}\frac{2\pi n_{\text{in}}}{\lambda}$	Wave vector of the incident field
$\boldsymbol{e}$	Normalized direction vector of the incident field in the grating coordinate system
λ	Vacuum wavelength
n_{in}	Refractive index the incident wave is defined in.
n_{out}	Refractive index the diffracted light is defined in.
	$n_{\text{out}} = -n_{\text{in}}$ for reflected diffraction orders.

145.6 Calculation of Efficiencies from Rayleigh Coefficients

The efficiency η of a grating order can be calculated from its Rayleigh coefficients vector $\boldsymbol{R}$ as follows.

$$\eta = \frac{n_{\text{out}}}{A_{\text{in}}^2 n_{\text{in}} \cos\vartheta_{\text{in}}} \cdot \cos\vartheta_{\text{out}} \left|\boldsymbol{R}\right|^2 \tag{145.22}$$

n_{in} / n_{out} is the refractive index of the medium in which the incident wave / outgoing order propagates (with an angle ϑ_{in} / ϑ_{out}). A_{in} is the amplitude of the incident plane wave. $\left|\boldsymbol{R}\right|^2 = R_x^2 + R_y^2 + R_z^2 = R_{\text{TE}}^2 + R_{\text{TM}}^2$.

145.7 Paraxial Imaging with a Lens

Two equations are important for calculating distances and sizes for paraxial imaging.
The imaging equation describes the relation between the focal length f, the object distance s_o, and the image distance s_i:

$$\frac{1}{f} = \frac{1}{s_i} - \frac{1}{s_o}, \tag{145.23}$$

while the magnification y_i/y_o (i. e. the ratio of the image size y_i to the object size y_o) is related to the object and image distance as follows:

$$y_i/y_o = \frac{s_i}{s_o}. \tag{145.24}$$

145.8 Using a User Defined Color Scale for Channel Reduction

In case a RGB image shall be converted into a grayscale (which can be mapped onto a value range subsequently), there are some different methods available. But if the pre-defined channel reduction methods for that conversion are not sufficient, the user may configure another one: Two (r,g,b)-triples are used as a start and an end color of a line (= color scale) within the complete RGB-cube of all displayable colors (see Fig. 823). This color scale is defined by a control like the one shown in Fig. 822.

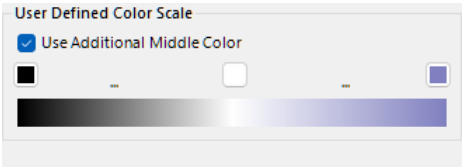


Figure 822. *Control for configuring a user defined color scale.*

ITEM	DESCRIPTION
Use Additional Middle Color	If checked, the middle color button is enabled and allows to define a middle color M, see Fig. 823, right.
Left/Middle/Right Color Button	These color buttons allow to define the three colors S, E, and M of the color scale as shown in Fig. 823.

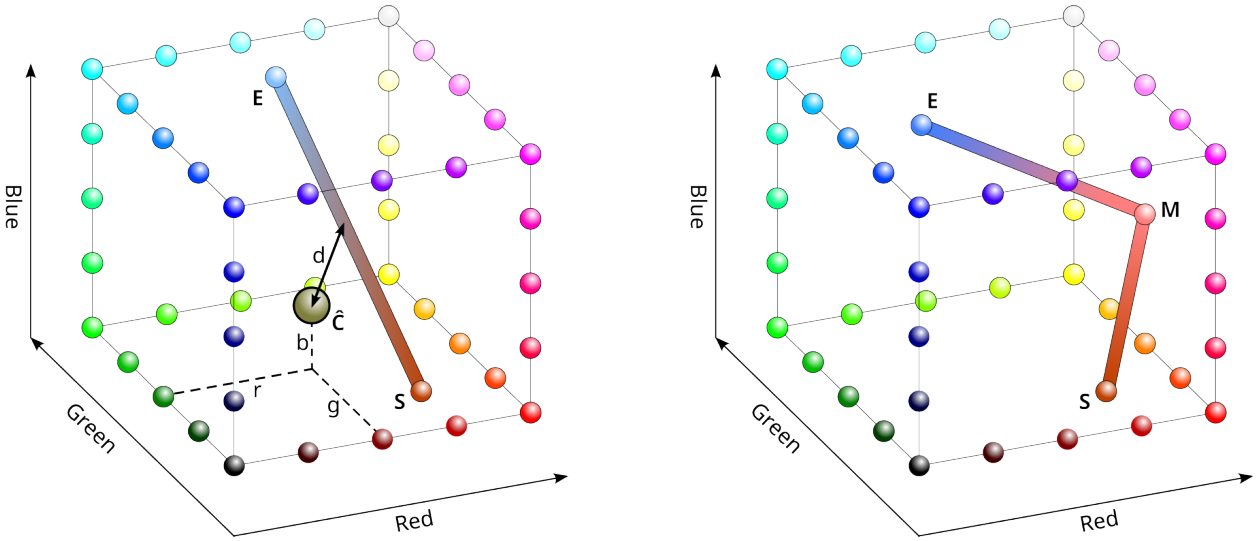


Figure 823. *Left: A color scale (without Additional Middle Color) is defined by the start color S and the end color E. The $\mathbb{R}^3 \rightarrow \mathbb{R}^1$ mapping is done by projecting each color $\hat{C} = (r, g, b)$ onto its nearest point (with distance d) on the color scale $\overline{SE}$. Right: A color scale with an Additional Middle Color M. As easily can be seen, not every color can be projected onto the scale $\overline{SME}$ unambiguously.*

Each color in the RGB image will be projected onto the color scale $\overline{SE}$ (or $\overline{SME}$ in case an *Additional Middle Color* is used) first. Subsequently this color will be transformed linearly into a value in the target interval ($[0, 1]$ if none other specified), where the start color S represents the first interval boundary, the middle color M represents the center of the interval (if used) and the end color E represents the upper interval boundary. By this means, all colors in the image will be mapped into the target value interval.

XVIII Appendix

A Annotations for Catalog Entries

A.1 Boundary Responses Catalog

A.1.1 LightTrans Defined: Axicon

For a given lateral position (x, y) and the vacuum wavelength λ this boundary response defines an axicon function $c(x, y, \lambda)$ for a given angle *Angle* using the following formula:

$$c(x, y, \lambda) = \exp(-ik_x r) = \cos k_x r + i \sin k_x r$$

where

$$k_x = \text{sign}(\textit{Angle}) \cdot \frac{2\pi |\tan \textit{Angle}|}{\lambda \sqrt{1 + \tan^2 \textit{Angle}}}$$

and

$$r = \sqrt{x^2 + y^2}$$

The parameter *Angle* is a Global Parameter and can also be varied by the parameter run document.

A.1.2 LightTrans Defined: Cylinder Lens

For a given lateral position (x, y) and the vacuum wavelength λ this boundary response defines a complex cylindrical lens function for given angle *Angle* and focal length *FocalLength*. The amplitude of the function is 1.0 and the phase $\phi(x, y, \lambda)$ is defined by the following formula:

$$\phi = \text{sign}(\textit{-FocalLength}) \cdot k \cdot \sqrt{r^2 + \textit{FocalLength}^2}$$

where

$$k = \frac{2\pi}{\lambda}$$

and

$$r = (x \sin \textit{Angle} + y \cos \textit{Angle}).$$

The parameters *Angle* and *FocalLength* are Global Parameters and can also be varied by the parameter run document.

A.1.3 LightTrans Defined: Double Pinhole

For a given lateral position (x, y), this boundary response defines a double pinhole function $f(x, y)$ with two pinholes with a given radius *Radius*. The pinholes are placed on the x-axis in a distance *Distance* to each other centered at the origin. So the pinholes are placed at positions $P_1 := (-\textit{Distance}/2, 0)$ and $P_2 := (\textit{Distance}/2, 0)$. The function $f(x, y)$ is real (imaginary part equals to zero) and is defined by

$$f(x, y) = \begin{cases} 1, \text{ if } dist((x, y), P_1) < \textit{Radius} \text{ or } dist((x, y), P_2) < \textit{Radius} \\ 0, \text{ otherwise} \end{cases}$$

where $dist(.,.)$ is the distance between two points. The parameters *Distance* and *Radius* are Global Parameters and can also be varied by the parameter run document.

A.1.4 LightTrans Defined: Double Slit

For a given lateral position (x, y), this snippet defines a double slit function $f(x, y)$ with two slits with a given width *SlitWidth*. The slits are infinite in y-direction and are placed on the x-axis in a distance *SlitDistance* to each other centered at the origin. So the slits are placed at positions $x_1 := (-\textit{SlitDistance}/2)$ and $x_2 := (\textit{SlitDistance}/2)$. The function $f(x, y)$ is real (imaginary part equals to zero), independent of y and is defined by

$$f(x, y) = \begin{cases} 1, \text{ if } |x - x_1| < \textit{SlitWidth}/2 \text{ or } |x - x_2| < \textit{SlitWidth}/2 \\ 0, \text{ otherwise} \end{cases}$$

The parameters *SlitDistance* and *SlitWidth* are Global Parameters and can also be varied by the parameter run document.

A.1.5 LightTrans Defined: Rotated Aperture

This boundary response describes a rotatable rectangular or elliptical aperture.
For the snippet defining this boundary response the internal VirtualLab Fusion-method “ApertureFactor” is used. This method checks if a point of the field which is handed over is within the defined (unrotated!) aperture and modifies its value accordingly.
The starting point is that the coordinate system of the field and the coordinate system in which the aperture is defined are identically oriented.
It is not possible to rotate the coordinate system of the aperture itself, instead this snippet rotates the points of the field in opposite direction before handing them over to the method.
Thus the whole process looks like the following: VirtualLab Fusion hands over all field points to the snippet one after another. The snippet rotates these points in the direction opposite to the desired angle α. These rotated points are handed over to the method “ApertureFactor” which compares their position with the unrotated aperture’s area and adds a factor in the range of $[0;1]$ to their values. For the method there is no difference whether the aperture is rotated counter-clockwise or the points are rotated clockwise. The method compares two areas rotated to each other. It only depends on the overlap which is the same for both rotating options. Finally the snippet returns all modified field values one after another.
In mathematical words: This means either the coordinate system in which the aperture is described has to be rotated (using the transposed rotational matrix) or the points of the complex field are rotated in opposite direction (using the rotational matrix with negative angle, i. e. the transposed rotational matrix again). Because the first option is not available the latter remains.
Thus the rotational matrix

$$\mathrm{R}_{ij} = \begin{pmatrix} \cos(-\alpha) & -\sin(-\alpha) \\ \sin(-\alpha) & \cos(-\alpha) \end{pmatrix} \tag{A.1}$$

is used according

$$\boldsymbol{a}_{rotated} = \mathrm{R}_{ij} \cdot \boldsymbol{a}_{unrotated} \tag{A.2}$$

with α as the desired rotation angle in counter-clockwise direction and $\boldsymbol{a}$ as the position vector to any point of the field. Fig. 824 illustrates the snippet’s approach.

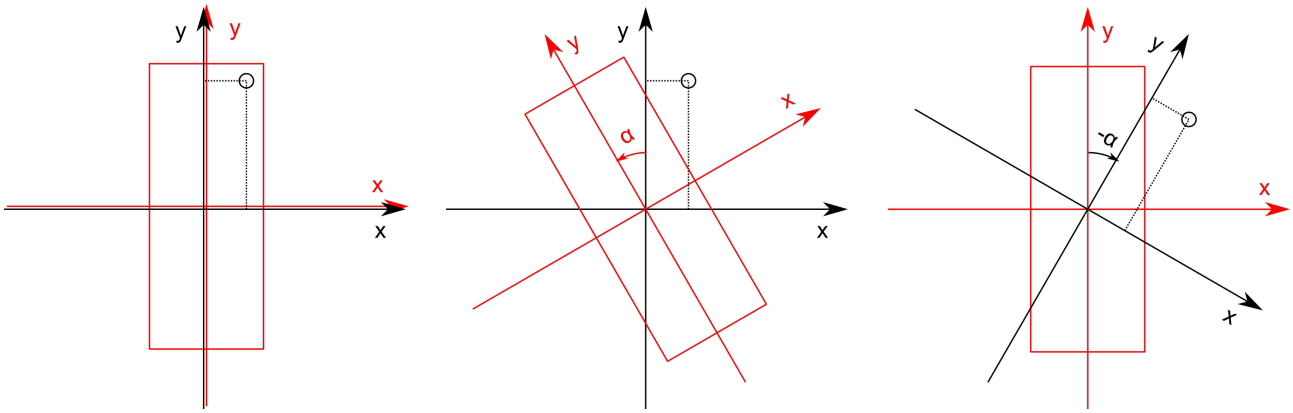


Figure 824. *Illustration of rotating approach. Red denotes the coordinate system for describing the aperture, black denotes the coordinate system of the field. The little circle denotes a point in the field plane which is only within the area of an unrotated aperture.* ***Left:*** *Identically oriented coordinate systems;* ***Middle:*** *Illustration of desired result;* ***Right:*** *Snippet’s approach.*

The snippet defining this boundary response has the following Global Parameters (which can also be varied by the parameter run document):

GLOBAL PARAMETER	VARIABLE NAME	PRESET VALUE
Angle	AngleCounterClockwise	0°
Rectangular or elliptical	IsRectangular	1 (TRUE)
x-extension of aperture	InitialDiameterX	250 μm
y-extension of aperture	InitialDiameterY	250 μm
Absolute edge width	AbsoluteEdgeWidth	0 m
Shift of the harmonic field in x-direction	OffsetX	0 m
Shift of the harmonic field in y-direction	OffsetY	0 m

Fig. 825 shows some apertures created with this boundary response.

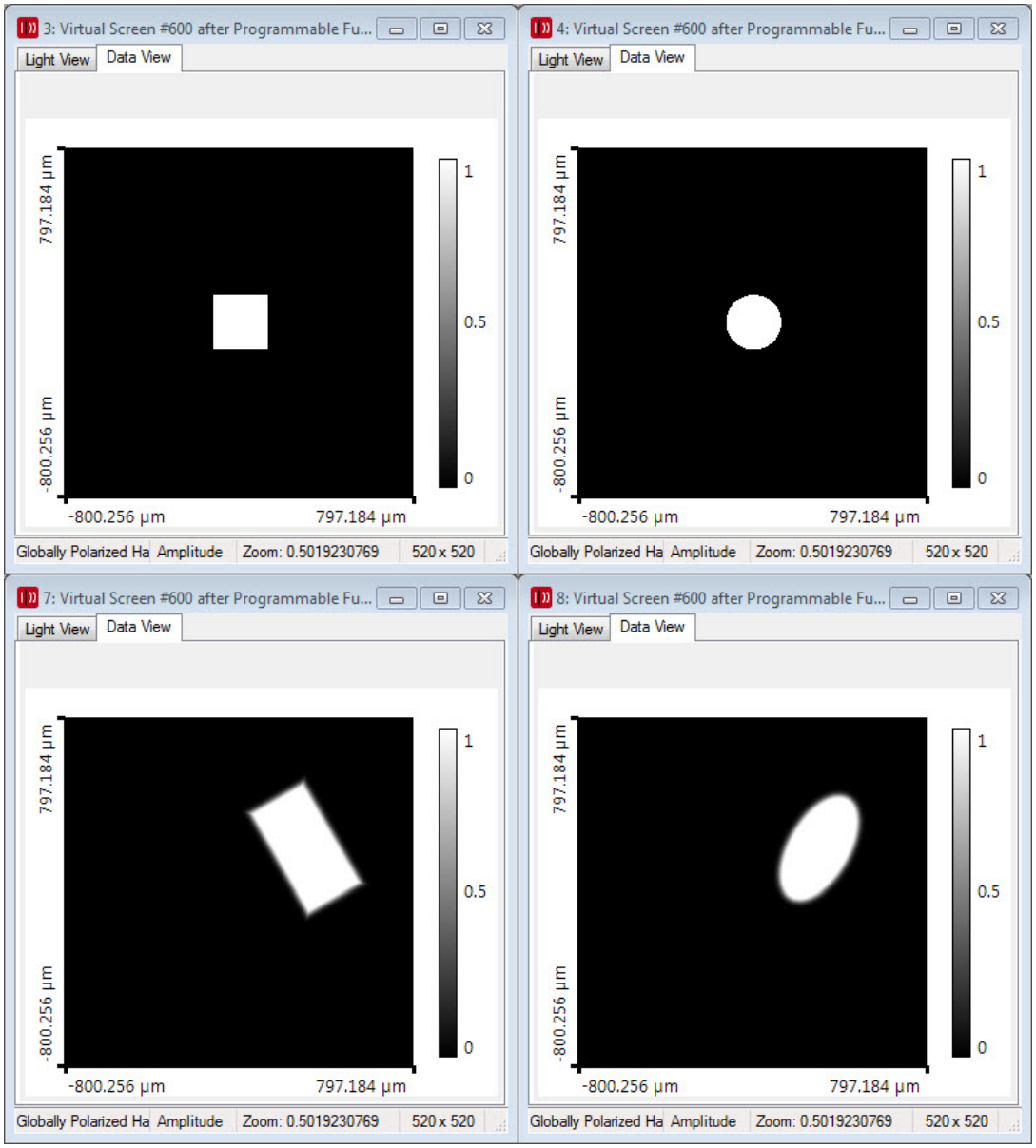


Figure 825. *Example results of this snippet.* ***Upper left:*** *Rectangular aperture with* $250\,\mu m \times 250\,\mu m$*;* ***Upper right:*** *Circular aperture with same dimensions as left;* ***Lower left:*** $250\,\mu m \times 500\,\mu m$*, edge width is set to 50 %, the offsets for* x *and* y *are* $300\,\mu m$ *and* $200\,\mu m$ *and* $\alpha = 30°$*;* ***Lower right:*** *Circular aperture with same parameters as left but with* $\alpha = -30°$*.*

A.1.6 LightTrans Defined: Multiple Slits

This boundary response allows you to define an arbitrary number of equidistant slits with an arbitrary width and distance. The resulting function is invariant in y-direction.

The snippet defining this boundary response has the following Global Parameters defined (which can also be varied by the parameter run document):

GLOBAL PARAMETER	DESCRIPTION
NumberOfSlits	The number of slits.
SlitWidth	The width of one slit. Within one slit, the amplitude of the function is 1, i. e. light passes unchanged. Outside, the amplitude is zero, which means that the light is blocked.
SlitDistance	The distance between two consecutive slits (measured from slit center to slit center).

A.1.7 LightTrans Defined: SLM/DMD Function

This boundary response enables the user to simulate a so-called “Digital Micromirror Device” (DMD) which is a type of “Spatial Light Modulator” (SLM).

The snippet defining this boundary response provides the following Global Parameters (which can also be varied by the Parameter Run):

CONFIGURABLE PARAMETER	VARIABLE NAME	PRESET VALUE
Values of desired amplitude for each DMD-pixel	AmplitudeValues	Example array with ascending and descending values
Values of desired phase for each DMD-pixel	PhaseValues	Example array with arbitrary values
Distance in x-direction from the center of one DMD-pixel to the next	PixelPitchX	8 μm
Distance in y-direction from the center of one DMD-pixel to the next	PixelPitchY	12 μm
Active size of DMD-pixel in x-direction	ActivePixelAreaX	7 μm
Active size of DMD-pixel in y-direction	ActivePixelAreaY	11 μm
Shift of the whole DMD-field in x-direction	ShiftX	50 nm
Shift of the whole DMD-field in y-direction	ShiftY	50 nm

Fig. 826 shows the resulting field distribution of an example DMD simulation.

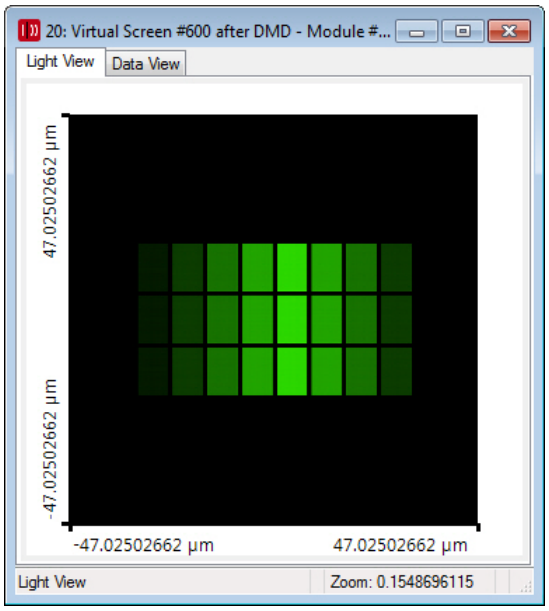


Figure 826. *Example of a small DMD simulation*

This boundary response works best if the parameters *PixelPitchX*, *PixelPitchY*, *ActivePixelAreaX* and *ActivePixelAreaY* are an integer multiple of the sampling distance of the incoming field. And for the parameter *ShiftX* and *ShiftY* a good choice is the negligible value of half of the sampling distance if an unshifted result is desired. In order to ensure a suitable sampling distance it is recommended to use the component “Field Size and Sampling” within the Optical Setup.

A.2 Components Catalog

A.2.1 LightTrans Defined: Set Spherical Phase Radius

This programmable component allows you to set the Spherical Phase Radius (↪Sec. 12.1.1). If the Global Parameter *DetectSphericalPhaseRadius* is set to 1, the spherical phase radius is determined automatically. Otherwise it is set to the *SphericalPhaseRadius* set by the user.

A.2.2 LightTrans Defined: Mirror Field in x/y Plane

This component does a mirror operation along the field’s x- or y-axis as described in Sec. 22.6. So it does not have to be confused with a component that represents a plane mirror. The operation is only a horizontal or vertical mirroring of the lateral field values but does not change the direction of propagation!

The value of the Global Parameter *mirror_horizontally* determines whether to mirror in horizontal or vertical direction. If its value equals zero, the mirror operation is done horizontally ($x_{min} \leftrightarrow x_{max}$), otherwise the operation is a vertical one ($y_{min} \leftrightarrow y_{max}$).

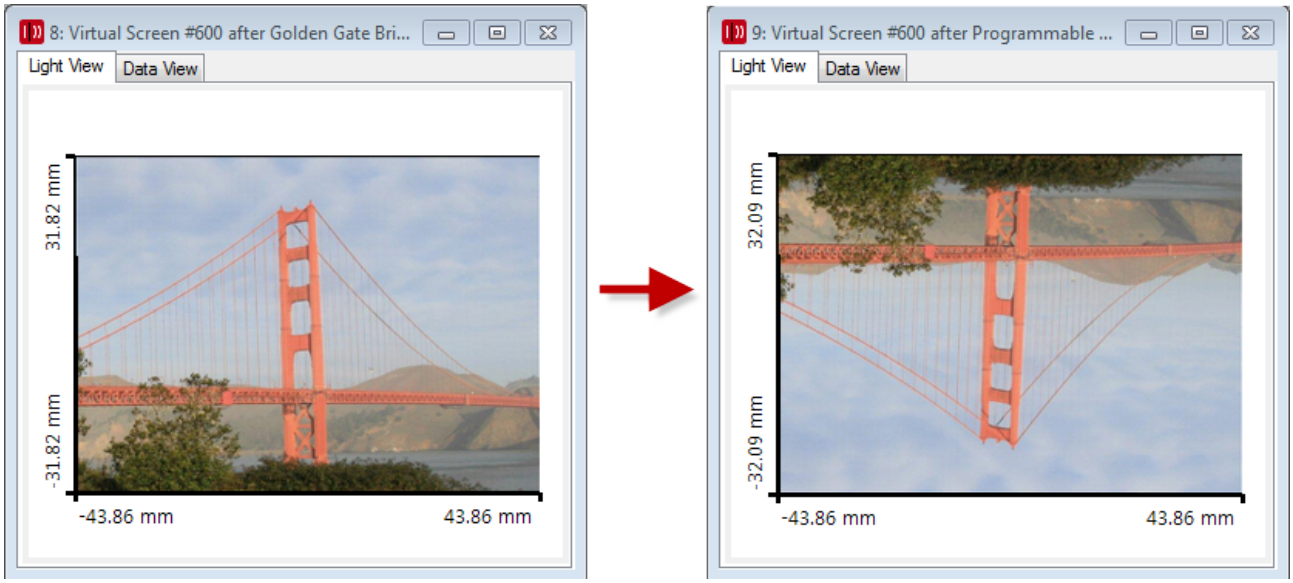


Figure 827. *Example for the effect of the Mirror x/y Component. The parameter was: mirror_horizontally = 1.*

A.2.3 LightTrans Defined: Rotate and Shift Field in x-y-Plane

This component does a rotation in the x-y-plane (i. e. about the z axis) by an arbitrary angle (↪Sec. 22.6.1) as well as a lateral shift by a vector (d_x, d_y) .

The rotation angle is determined by the Global Parameter *RotationAngle_Zeta*, while the lateral shift is given by the parameters *ShiftX* and *ShiftY*. The Global Parameter *EmbeddingFactor* determines a factor by which the field data are embedded into a larger coordinate range in order to avoid that rotation or shift yield to a result outside the field boundaries.

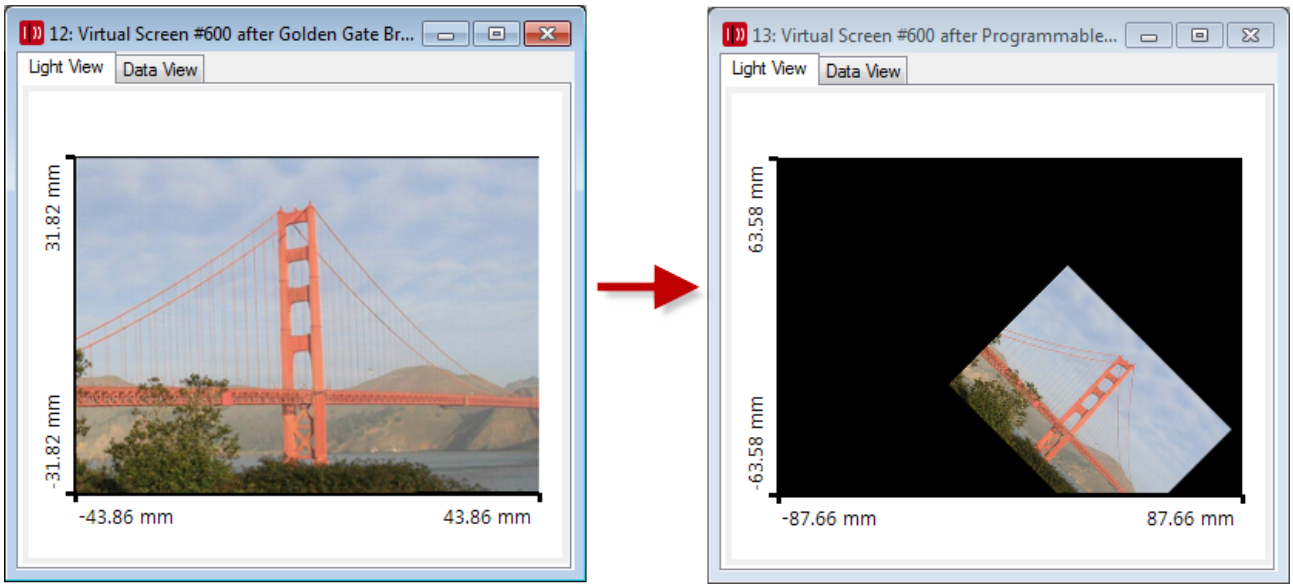


Figure 828. *Example for the effect of the Rotate and Shift Component. The parameters were: RotationAngle_Zeta = 45°; (ShiftX, ShiftY) = 30mm, -30mm; EmbeddingFactor = 2.*

A.2.4 LightTrans Defined: Radial Birefringent Element

This component represents a birefringent element where the thickness and thus the phase shift depends on the radius r. Therefore the following Jones matrix $\mathcal{J}$ is applied on the *InputField*:

$$\mathcal{J} = \begin{pmatrix} 1 & 0 \\ 0 & \exp\left(i\left(\delta_2(r) - \delta_1(r)\right)\right) \end{pmatrix} \tag{A.3}$$

with the phase shift

$$\delta_i(r) = \frac{2\pi}{\lambda} n_i \left(d + \frac{r^2}{2R}\right), \quad i = 1,2 \tag{A.4}$$

and

$$r = \sqrt{x^2 + y^2} \tag{A.5}$$

R is the *RadiusOfCurvature* and d is the *CenterThickness* of the element. n_1 and n_2 are the refractive indices along the crystal axes.
This formula is taken from [HW97].

A.2.5 LightTrans Defined: Azimuthal Birefringent Element

This component represents a birefringent element where the refractive indices differ for radially and azimuthally polarized light. This can be described by the following Jones matrix $\mathcal{J}$:

$$\mathcal{J} = \begin{pmatrix} e^{i\delta}\cos^2\theta + \sin^2\theta & \left(e^{i\delta} - 1\right)\cos\theta\sin\theta \\ \left(e^{i\delta} - 1\right)\cos\theta\sin\theta & e^{i\delta}\sin^2\theta + \cos^2\theta \end{pmatrix} \tag{A.6}$$

with the phase shift

$$\delta_i(r) = \frac{2\pi}{\lambda}(n_r - n_\theta)l \tag{A.7}$$

and

$$r = \sqrt{x^2 + y^2}; \quad \theta = \arctan\frac{y}{x} \tag{A.8}$$

l is the *Length* of the element. n_r is the refractive index for radially polarized light and n_θ is the refractive index for azimuthally polarized light.
This formula is taken from [HW97].

A.3 Surfaces Catalog

A.3.1 LightTrans Defined: Axicon Surfaces

In the surface catalog axicon surfaces are available. These surfaces are programmable surfaces with a special snippet. For a given lateral position (x, y) this snippet defines the height $h(x, y)$ of an axicon surface with a given angle *Angle* using the following formula:

$$h(x,y) = -(r_{\text{max}} - r) \cdot \tan \textit{Angle} \quad . \tag{A.9}$$

The minus sign indicates that the apex is orientated in negative z-direction, i. e. towards the light source. If you enter a negative angle the apex is orientated in positive z-direction.
r_{max} is the maximum of *ApertureDiameterX* and *ApertureDiameterY*, i. e. the largest diameter of the current definition area. The radius r is calculated as $r = \sqrt{x^2 + y^2}$. The parameter *Angle* is a global parameter and can be varied by the parameter run document.

A.4 Materials Catalog

A.4.1 Template: Abbe Number ν_d Material

This material calculates the dispersion $n(\lambda)$ from the Abbe number ν_d and the refractive index n_d.

$$\nu_d = \frac{n_d - 1}{n_F - n_C}. \tag{A.10}$$

n_F is the refractive index at the Fraunhofer line F (λ_F = 486.134 nm), n_d is the refractive index at the Fraunhofer line d (λ_d = 587.5618 nm) and n_C is the refractive index at the Fraunhofer line C (λ_C = 656.281 nm).
This material uses the reduced Cauchy formula

$$n(\lambda) = A + \frac{B}{\lambda^2} \tag{A.11}$$

to calculate the actual dispersion with

$$B = \frac{n_d - 1}{\nu_d \left(\lambda_F^{-2} - \lambda_C^{-2}\right)} \tag{A.12}$$

$$A = n_d - \frac{B}{\lambda_d^2} \tag{A.13}$$

A.4.2 Template: Fused_Silica

This template is identical to that Fused_Silica material which can be found in the LightTrans Defined Catalog “Miscellaneous”. It can be used as a base for defining other materials which use a dispersion formula like *Sellmeier*, *Herzberger* and so on.

A.4.3 Template: Sampled n-α-Data Material

This is a template for defining the optical data in form of sampled values for the real refractive index n and the absorption coefficient α. These data can be set via loading from a text file or via entering single data pairs for λ and n or for λ and α resp.

A.4.4 Template: Vacuum

This template represents vacuum and can be used to define other materials with a constant refractive index or constant absorption coefficient.

A.4.5 Sources for the Optical Material’s Data in the LightTrans Defined Catalog

The information for the glass catalogs CDGM, Corning, Dow, Heraeus, Hikari, Hoya, Isuzu, LZOS, NHG, Ohara, Schott, Sumita, and Tecnottica were given by the manufacturers. The sources of the materials in the remaining categories are listed below.

A.4.5.1 Carbon+Compounds

MATERIAL	DATA SOURCE
Acrylic	[BS94]
Carbon(amorphous)-a-C_(1975)	[HGK74], [HGK75]
Carbon(amorphous)-a-C_(1991+1988)	Concatenation of Carbon(sputtered)-a-C_(1991) [13.3 Å – 304 Å] and Carbon(amorphous_evap_thin-Film)-a-C_(1988) [327 Å – 1216 Å]

Carbon(amorphous)-a-C_(1997+1988+1991)	Concatenation of Carbon(amorphous)-a-C_2.2gcm-3_(1997) [0.124 Å – 413 Å] and Carbon(amorphous_evap_thinFilm)-a-C_(1988) [448 Å – 1216 Å] and Carbon(evap_thinFilm)-a-C_(1991) [1240 Å – 10663 Å]
Carbon(amorphous)-a-C_2.2gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Carbon(amorphous_evap_thinFilm)-a-C_(1988)	[Win+88a]
Carbon(diamond)-C_(1997+1985)	Concatenation of Carbon(diamond)-C_3.51gcm-3_(1997) [0.124 Å – 413 Å] and Carbon(diamond_cubic)-C_(1985) [413 Å – 6563 Å]
Carbon(diamond)-C_3.51gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Carbon(diamond_cubic)-C_(1985)	[Pal85]
Carbon(diamond_thinFilm)-C_(1988)	[Win+88a]
Carbon(evap_thinFilm)-a-C_(1991)	[Pal91]
Carbon(graphit)-g-C_2.25gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Carbon(sputtered)-a-C_(1991)	[Win91]
COC-(Celanese)	Celanese Spec Sheet
Mylar-(C10O4H8)n_1.38gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
PMMA-(C5O2H8)n_1.19gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Polycarbonate	[BS94]
PolyMethylMethAcrylate-PMMA	[BS94]
Polypropylene-C3H6_0.9gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Polystyrene	[BS94]
Saran-(CH2=CCl2)n_1.2129gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
StyreneAcryloNitrile-SAN	[BS94]
TOPAS-COC_5013L-10	Topas Spec Sheet
TOPAS-COC_6013L-17	Topas Spec Sheet

A.4.5.2 Coating_Materials

These material's data have been measured using thin film specimen. The data sources are listed in the category which represents the composition of the material respectively (e.g. in *Metals+Compounds* or in *Silicon+Compounds_(Non-Glass)*).

WARNING: As well-known from thin film physics (see e. g. *Handbook of Optical Constants of Solids Vol. II*, p. 71), the optical constants of thin layers not only differ from that of bulk material, but depend strongly on the technique of their fabrication. So please use the data provided by VirtualLab Fusion only for an orientation! The best way to get the optical properties of a specific layer is measurement on it.

A.4.5.3 Infrared

Each *Infrared* material is contained in one of the other categories at least. So the data sources for the non-glasses are listed in that category which represents the composition of the material respectively (e. g. in *Metals+Compounds* or in *Silicon+Compounds_(Non-Glass)*).

A.4.5.4 Metals+Compounds

MATERIAL	DATA SOURCE
Actinium-Ac_10.07gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Aluminium_antimonide(cubic)-AlSb_(1991)	[Pal91]
Aluminium_arsenide(cubic)-AlAs_(1991)	[Pal91]
Aluminium_gallium_arsenide(cubic)-Al0.3Ga0.7As_(1991)	[Pal91]
Aluminium_oxide(amorphous)-a-Al2O3_(1975)	[HGK74], [HGK75]
Aluminium_oxide(amorphous)-a-Al2O3_(1997+1991)	Concatenation of Aluminium_oxide(amorphous)-a-Al2O3_(1997) [0.124 Å – 413 Å] and Aluminium_oxide(amorphous/polyxtal)-a-Al2O3_(1991) [413 Å – 249960 Å]
Aluminium_oxide(amorphous)-a-Al2O3_3.965gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Aluminium_oxide(amorphous/polyxtal)-a-Al2O3_(1991)	[Pal91]
Aluminium_oxide(trigonal_extraordinaryRay)-Al2O3-e_(1991)	[Pal91]
Aluminium_oxide(trigonal_ordinaryRay)-Al2O3-o_(1991)	[Pal91]
Aluminium_Oxide-Al2O3-ThinFilm	[ESA93]
Aluminium_oxynitride-ALON	[BS94]
Aluminium-Al_(1980)	[Shi+80]
Aluminium-Al_(1985)	[Pal85]
Aluminium-Al_(1988)	[Win+88a]
Aluminum-Al_(1994)	[BS94]
Aluminium-Al_(1997+1985)	Concatenation of Aluminium-Al_2.699gcm-3_(1997) [0.124 Å – 413 Å] and Aluminium-Al_(1985) [413 Å – 12398 Å]
Aluminium-Al_2.699gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Aluminum_nitride-AlN	[BS94]
Aluminum-Al-ThinFilm	[Pal85]
Barium_fluoride-BaF2	[BS94]

Barium_titanate(tetragonal_extraordinaryRay)-BaTiO3-e_(1991)	[Pal91]
Barium_titanate(tetragonal_ordinaryRay)-BaTiO3-o_(1991)	[Pal91]
Beryllium(polyxtal)-Be_(1991)	[Pal91]
Beryllium_oxide(ceramic)-BeO_(1991)	[Pal91]
Beryllium_oxide(ordinaryRay)-BeO	[BS94]
Beryllium_oxide-BeO_3.02gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Beryllium-Be_(1997+1991)	Concatenation of Beryllium-Be_1.848gcm-3_(1997) [0.124 Å – 413 Å] and Beryllium(polyxtal)-Be_(1991) [413 Å – 619900 Å]
Beryllium-Be_1.848gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Cadmium_selenide(ordinaryRay)-CdSe	[BS94]
Cadmium_sulfide-CdS_(1994)	[BS94]
Cadmium_Sulphide-CdS-ThinFilm	[Pal91, p. 595]
Cadmium_telluride-CdTe	[BS94]
Caesium_iodide(cubic)-CsI_(1991)	[Pal91]
Caesium_iodide-CsI_6.68gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Calcite(ordinaryRay)-CaCO3	[BS94]
Calcium_fluoride(cubic)-CaF2_(1991)	[Pal91]
Calcium_fluoride-CaF2_(1994)	[BS94]
Calcium_fluoride-CaF2_(1997+1991)	Concatenation of Calcium_fluoride-CaF2_3.18gcm-3_(1997) [0.124 Å – 413 Å] and Calcium_fluoride(cubic)-CaF2_(1991) [500 Å – 5793458 Å]
Calcium_fluoride-CaF2_3.18gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Cerium_Fluoride-CeF3-ThinFilm	[SB79]
Cerium_Oxide-CeO2-ThinFilm	[SB79]
Cesium_bromide-CsBr	[BS94]
Chromium(III)_oxide-Cr2O3_5.21gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Chromium(poyxtal)-Cr_(1991)	[Pal91]
Chromium_carbide(sputtered)-Cr3C2_(1991)	[Win91]
Chromium_carbide-Cr3C2_(1997+1991)	Concatenation of Chromium_carbide-Cr3C2_6.68gcm-3_(1997) [0.124 Å – 413 Å] and Chromium_carbide(sputtered)-Cr3C2_(1991) [430 Å – 1302 Å]
Chromium_carbide-Cr3C2_6.68gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Chromium-Cr_(1994)	[BS94]

Chromium-Cr_(1997+1991)	Concatenation of Chromium-Cr_7.2gcm-3_(1997) [0.124 Å – 413 Å] and Chromium(poyxtal)-Cr_(1991) [421 Å – 309950 Å]
Chromium-Cr_7.2gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
CLEARTRAN-ZnS	Spec Sheet (Rohm and Haas)
CLEARTRAN-ZnS_old	Spec Sheet (Morton International)
Cobalt(hcp_bulk+polyxtalThin-Film)-Co_(1991)	[Pal91]
Cobalt(II)_oxide-CoO_6.45gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Cobalt(II,III)_oxide-Co3O4_6.07gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Cobalt(III)_oxide-Co2O3_5.18gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Cobalt_silicide-CoSi2_5.3gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Cobalt-Co_(1997+1991)	Concatenation of Cobalt-Co_8.9gcm-3_(1997) [0.124 Å – 413 Å] and Cobalt(hcp_bulk+polyxtalThinFilm)-Co_(1991) [500 Å – 169999 Å]
Cobalt-Co_8.9gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Copper(I)_oxide-Cu2O_(1991)	[Pal91]
Copper(I)_oxide-Cu2O_6.0gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Copper(II)_oxide(polyxtal)-CuO_(1991)	[Pal91]
Copper(II)_oxide-CuO_6.4gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Copper_silicide-Cu4Si_7.53gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Copper-Cu_(1985)	[Pal85]
Copper-Cu_(1994)	[BS94]
Copper-Cu_(1997+1985)	Concatenation of Copper-Cu_8.92gcm-3_(1997) [0.124 Å – 413 Å] and Copper-Cu_(1985) [413 Å – 95368 Å]
Copper-Cu_8.92gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Gallium_antimonide-GaSb_(1991)	[Pal91]
Gallium_antimonide-GaSb_5.612gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Gallium_arsenide(singleXtal)-GaAs_(1991)	[Win91]
Gallium_arsenide-GaAs	[BS94]
Gallium_arsenide-GaAs_(1985)	[Pal85]
Gallium_arsenide-GaAs_(1997+1991+1985)	Concatenation of Gallium_arsenide-GaAs_5.3gcm-3_(1997) [0.124 Å – 413 Å] and Gallium_arsenide(singleXtal)-GaAs_(1991) [430 Å – 1302 Å] and Gallium_arsenide-GaAs_(1985) [1378 Å – 9998390Å Å]
Gallium_arsenide-GaAs_5.3gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Gallium_phosphide-GaP_(1985)	[Pal85]

Gallium_phosphide-GaP_(1997+1985)	Concatenation of Gallium_phosphide-GaP_4.129gcm-3_(1997) [0.124 Å – 413 Å] and Gallium_phosphide-GaP_(1985) [775 Å – 9998390 Å]
Gallium_phosphide-GaP_4.129gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Gold(evap_thinFilm)-Au_(1988)	[Win+88b]
Gold(polyxtal)-Au_(1985)	[Pal85]
Gold-Au_(1964)	[CHH64]
Gold-Au_(1970+1980)	[Nil70], [ZAT80]
Gold-Au_(1975)	[HGK74], [HGK75]
Gold-Au_(1981)	[Wea+81]
Gold-Au_(1994)	[BS94]
Gold-Au_(1997+1985)	Concatenation of Gold-Au_19.32gcm-3_(1997) [0.124 Å – 413 Å] and Gold(polyxtal)-Au_(1985) [413 Å – 99184Å Å]
Gold-Au_19.32gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Hafnium(evap_thinFilm)-Hf_(1988)	[Win+88b]
Hafnium(IV)_oxide-HfO2_9.68gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Hafnium(singleXtal_TE)-Hf-te_(1981)	[Wea+81, p. 253]
Hafnium(singleXtal_TM)-Hf-tm_(1981)	[Wea+81, p. 253]
Hafnium_Dioxide-HfO2-ThinFilm	[BLP82]
Hafnium-Hf_(1997+1988)	Concatenation of Hafnium-Hf_13.31gcm-3_(1997) [0.124 Å – 413 Å] and Hafnium(evapThinFilm)-Hf_(1988) [448 Å – 1216 Å]
Hafnium-Hf_13.31gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Indium_antimonide-InSb_(1985)	[Pal85]
Indium_arsenide-InAs_(1985)	[Pal85]
Indium_phosphide-InP_(1985)	[Pal85]
Iridium(evap_thinFilm)-Ir_(1988)	[Win+88b]
Iridium-Ir_(1985)	[Pal85]
Iridium-Ir_(1997+1985)	Concatenation of Iridium-Ir_22.421gcm-3_(1997) [0.124 Å – 413 Å] and Iridium-Ir_(1985) [413 Å – 123980 Å]
Iridium-Ir_22.421gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Iron(II)_oxide-FeO_5.7gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Iron(II,III)_oxide-Fe3O4_5.18gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Iron(III)_oxide-Fe2O3_5.24gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Iron-Fe_(1991)	[Pal91]
Iron-Fe_(1994)	[BS94]

Iron-Fe_(1997+1991)	Concatenation of Iron-Fe_7.86gcm-3_(1997) [0.124 Å – 413 Å] and Iron-Fe_(1991) [477 Å – 2857340 Å]
Iron-Fe_7.86gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
KRS-5	[BS94]
Lanthanum_Fluoride-LaF3-ThinFilm	[SB79]
Lanthanum_Oxide-La2O3-ThinFilm	[SB79]
Lanthanum_trifluoride-LaF3_(1994)	[BS94]
Lead(II)_fluoride-PbF2	[BS94]
Lead(II)_selenide-PbSe_(1985)	[Pal85]
Lead(II)_sulfide(cubic)-PbS_(1985)	[Pal85]
Lead_Fluoride-PbF2-ThinFilm	[Pal97, pp. 771–773]
Lead_telluride(cubic)-PbTe_(1985)	[Pal85]
Lithium_fluoride-LiF	[BS94]
Lithium_fluoride-LiF_(1991)	[Pal91]
Lithium_niobate(extraordinaryRay)-LiNbO3-e_(1985)	[Pal85]
Lithium_niobate(ordinaryRay)-LiNbO3-o_(1985)	[Pal85]
Lithium-Li_(1991)	[Pal91]
Magnesium_fluoride(extraordinaryRay)-MgF2	[BS94]
Magnesium_fluoride(extraordinaryRay)-Mg-e_(1991)	[Pal91]
Magnesium_fluoride(ordinaryRay)-MgF2	[BS94]
Magnesium_fluoride(ordinaryRay)-Mg-o_(1991)	[Pal91]
Magnesium_Fluoride-MgF2-ThinFilm	[BLP82]
Magnesium_oxide-MgO	[BS94]
Magnesium_oxide-MgO_(1991)	[Pal91]
Magnesium_oxide-MgO_(1997+1991)	Concatenation of Magnesium_oxide-MgO_3.58gcm-3_(1997) [0.124 Å – 413 Å] and Magnesium_oxide-MgO_(1991) [413 Å – 6261620 Å]
Magnesium_oxide-MgO_3.58gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Magnesium-Mg_1.74gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Manganese(II,III)_oxide-Mn3O4_4.856gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Manganese(IV)_oxide-MnO2_5.026gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Manganese-Mn_7.2gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Mercury_telluride-HgTe_(1991)	[Pal91]

Mercury-Hg_(1991)	[Pal91]
Mercury-Hg_(1997+1991)	Concatenation of Mercury-Hg_13.5939gcm-3_(1997) [0.124 Å – 413 Å] and Mercury(liquid)-Hg_(1991) [636 Å – 61990 Å]
Mercury-Hg_13.5939gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Molybdenum(evap_thinFilm)-Mo_(1988)	[Win+88b]
Molybdenum(IV)_oxide-MoO2_6.47gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Molybdenum(sputtered)-Mo_(1991)	[Win91]
Molybdenum(sputtered)-Mo_(1992)	◇ (↪Sec. A.4.5.9)
Molybdenum_dicarbide-Mo2C_8.9gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Molybdenum_disilicide-MoSi2_(1992)	◇ (↪Sec. A.4.5.9)
Molybdenum_disilicide-MoSi2_6.31gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Molybdenum_disulfide-MoS2_4.8gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Molybdenum_monocarbide-MoC_8.2gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Molybdenum_trioxide-MoO3_4.692gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Molybdenum-Mo_(1985)	[Pal85]
Molybdenum-Mo_(1997+1985)	Concatenation of Molybdenum-Mo_10.2gcm-3_(1997) [0.124 Å – 413 Å] and Molybdenum-Mo_(1985) [413 Å – 123980 Å]
Molybdenum-Mo_10.2gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Neodymium_Fluoride-NdF3-ThinFilm	[SB79]
Nickel(II)_oxide-NiO_6.67gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Nickel-Ni_(1985)	[Pal85]
Nickel-Ni_(1997+1985)	Concatenation of Nickel-Ni_8.9gcm-3_(1997) [0.124 Å – 413 Å] and Nickel-Ni_(1985) [413 Å – 123980 Å]
Nickel-Ni_8.9gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Niobium(evap_thinFilm)-Nb_(1988)	[Win+88b]
Niobium(II)_oxide-NbO_7.3gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Niobium(IV)_oxide-NbO2_5.9gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Niobium(V)_oxide-Nb2O5_4.47gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Niobium-Nb_(1981)	[Wea+81]
Niobium-Nb_(1991)	[Pal91]

Niobium-Nb_(1997+1991)	Concatenation of Niobium-Nb_8.57gcm-3_(1997) [0.124 Å – 413 Å] and Niobium-Nb_(1991) [413 Å – 103317 Å]
Niobium-Nb_8.57gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Osmium(evap_thinFilm)-Os_(1988)	[Win+88b]
Osmium_dioxide-OsO2_11.37gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Osmium-Os_(1981)	[Wea+81, p. 253]
Osmium-Os_(1985)	[Pal85]
Osmium-Os_(1997+1988+1985)	Concatenation of Osmium-Os_22.48gcm-3_(1997) [0.124 Å – 413 Å] and Osmium(evap_thinFilm)-Os_(1988) [448 Å – 1216 Å] and Osmium-Os_(1985) [1250 Å – 2000 Å]
Osmium-Os_22.48gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Palladium(evap_thinFilm)_(1988)	[Win+88b]
Palladium(II)_oxide-PdO_8.70gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Palladium-Pd_(1981)	[Wea+81]
Palladium-Pd_(1991)	[Pal91]
Palladium-Pd_(1997+1991)	Concatenation of Palladium-Pd_12.02gcm-3_(1997) [0.124 Å – 413 Å] and Palladium-Pd_(1991) [448 Å – 123980 Å]
Palladium-Pd_12.02gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Platinum(evap_thinFilm)-Pt_(1988)	[Win+88b]
Platinum(II)_oxide-PtO_14.9gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Platinum(IV)_oxide-PtO2_10.2gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Platinum-Pt_(1981)	[Wea+81]
Platinum-Pt_(1985)	[Pal85]
Platinum-Pt_(1997+1985)	Concatenation of Platinum-Pt_21.45gcm-3_(1997) [0.124 Å – 413 Å] and Platinum-Pt_(1985) [420 Å – 123980 Å]
Platinum-Pt_21.45gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Potassium(polyxtal)-K_(1991)	[Pal91]
Potassium_bromide(cubic)-KBr_(1991)	[Pal91]
Potassium_chloride-KCl_(1985)	[Pal85]
Rhenium(evap_thinFilm)-Re_(1988)	[Win+88b]
Rhenium(IV)_oxide-ReO2_11.4gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Rhenium(singleXtal_TE)-Re-te_(1981)	[Wea+81, p. 253]
Rhenium(singleXtal_TM)-Re-tm_(1981)	[Wea+81, p. 253]
Rhenium(VI)_oxide-ReO3_7.0gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Rhenium(VII)_oxide-Re2O7_6.103gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)

Rhenium-Re_(1997+1988)	Concatenation of Rhenium-Re_20.53gcm-3_(1997) [0.124 Å – 413 Å] and Rhenium(evap_thinFilm)-Re_(1988) [448 Å – 1216 Å]
Rhenium-Re_20.53gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Rhodium(evap_thinFilm)-Rh_(1988)	[Win+88b]
Rhodium(III)_oxide-Rh2O3_8.2gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Rhodium-Rh_(1981)	[Wea+81]
Rhodium-Rh_(1985)	[Pal85]
Rhodium-Rh_(1997+1985)	Concatenation of Rhodium-Rh_12.4gcm-3_(1997) [0.124 Å – 413 Å] and Rhodium-Rh_(1985) [420 Å – 123980 Å]
Rhodium-Rh_12.4gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Ruthenium(evap_thinFilm)-Ru_(1988)	[Win+88b]
Ruthenium(IV)_oxide-RuO2_6.97gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Ruthenium(singleXtal_avg)-Ru_(1981)	Average of Ruthenium(singleXtal_TM)-Ru-tm_(1981) and Ruthenium(singleXtal_TE)-Ru-te_(1981)
Ruthenium(singleXtal_TE)-Ru-te_(1981)	[Wea+81]
Ruthenium(singleXtal_TM)-Ru-tm_(1981)	[Wea+81]
Ruthenium(sputtered)-Ru_(1992)	◇ (↪Sec. A.4.5.9)
Ruthenium(VIII)_oxide-RuO4_3.29gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Ruthenium_silicon-RuSi_5.4gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Ruthenium-Ru_(1974)	[Cox+74]
Ruthenium-Ru_(1997+1974)	Concatenation of Ruthenium-Ru_12.3gcm-3_(1997) [0.124 Å – 413 Å] and Ruthenium-Ru_(1974) [450 Å – 2000 Å]
Ruthenium-Ru_12.3gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Sapphire(ordinaryRay)-Al2O3	[BS94]
Silver(evap_thinFilm)-Ag_(1988)	[Win+88b]
Silver_chloride_AgCl	[BS94]
Silver_Oxide-Ag2O_7.143gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Silver-Ag_(1975)	[HGK74], [HGK75]
Silver-Ag_(1983)	[LOL83]
Silver-Ag_(1985)	[Pal85]
Silver-Ag_(1994)	[BS94]
Silver-Ag_(1997+1985)	Concatenation of Silver-Ag_10.50gcm-3_(1997) [0.124 Å – 413 Å] and Silver-Ag_(1985) [428 Å – 99190 Å]
Silver-Ag_10.50gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)

Sodium_chloride-NaCl	[Rog93]
Sodium_chloride-NaCl_(1985)	[Pal85]
Sodium_fluoride-NaF_(1991)	[Pal91]
Sodium_Fluoride-NaF-ThinFilm	[Pal91, pp. 1028–1031]
Sodium-Na_(1991)	[Pal91]
Spinel-MgAl2O4	[BS94]
Strontium_fluoride-SrF2	[BS94]
Strontium_titanate-SrTiO3	[BS94]
Strontium_titanate-SrTiO3_(1991)	[Pal91]
Ta2O5-ThinFilm_MSO-measured	[Jen10]
Tantalum(evap_thinFilm)-Ta_(1988)	[Win+88b]
Tantalum_carbide-TaC_13.9gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Tantalum_nitride-TaN_16.3gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Tantalum_pentoxide-Ta2O5_8.2gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Tantalum_Pentoxide-Ta2O5-ThinFilm	[SB79]
Tantalum-Ta_(1981)	[Wea+81]
Tantalum-Ta_(1991)	[Pal91]
Tantalum-Ta_(1997+1991)	Concatenation of Tantalum-Ta_16.6gcm-3_(1997) [0.124 Å – 413 Å] and Tantalum-Ta_(1991) [413 Å – 1249920 Å]
Tantalum-Ta_16.6gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Thorium(IV)_fluoride(polyxtal)-ThF4_(1991)	[Pal91]
Thorium_Fluoride-ThF4-BulkMaterial	[Pal91, pp. 1056–1057]
Thorium_Fluoride-ThF4-ThinFilm	[Pal91, pp. 1056–1057]
Tin(II)_oxide-SnO_6.446gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Tin(IV)_oxide-SnO2_6.95gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Tin_telluride-SnTe_(1991)	[Pal91]
Tin-Sn_7.28gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Titanium(evap_thinFilm)-Ti_(1988)	[Win+88b]
Titanium(IV)_oxide(tetragonal_extraordinaryRay)-TiO2-e_(1985)	[Pal85]
Titanium(IV)_oxide(tetragonal_ordinaryRay)-TiO2-o_(1985)	[Pal85]
Titanium(IV)_oxide-TiO2_4.26gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Titanium(sputtered_thinFilm)-Ti_(1989)	[Kih+89]
Titanium_carbide(polyxtal)-TiC_(1991)	[Pal91]
Titanium_carbide-TiC_(1997+1991)	Concatenation of Titanium_carbide-TiC_4.93gcm-3_(1997) [0.124 Å – 413 Å] and Titanium_carbide(polyxtal)-TiC_(1991) [413 Å – 24796 Å]

Titanium_carbide-TiC_4.93gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Titanium_Dioxide-TiO2-ThinFilm	[BLP82]
Titanium_nitride-TiN_(1991)	[Pal91]
Titanium_nitride-TiN_(1997+1991)	Concatenation of Titanium_nitride-TiN_5.22gcm-3_(1997) [0.124 Å – 413 Å] and Titanium_nitride-TiN_(1991) [413 Å – 24796 Å]
Titanium_nitride-TiN_5.22gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Titanium-Ti_(1981)	[Wea+81]
Titanium-Ti_(1997+1988)	Concatenation of Titanium-Ti_4.5gcm-3_(1997) [0.124 Å – 413 Å] and Titanium(evap_thinFilm)-Ti_(1988) [448 Å – 1216 Å]
Titanium-Ti_4.5gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Tungsten(evap_thinFilm)-W_(1988)	[Win+88b]
Tungsten(IV)_oxide-WO2_12.11gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Tungsten(polyxtal)-W_(1985)	[Pal85]
Tungsten(sputtered)-W_(1991)	[Win91]
Tungsten(VI)_oxide-WO3_7.16gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Tungsten_disilicide-WSi2_9.3gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Tungsten-W_(1981)	[Wea+81]
Tungsten-W_(1997+1985)	Concatenation of Tungsten-W_19.35gcm-3_(1997) [0.124 Å – 413 Å] and Tungsten(polyxtal)-W_(1985) [413 Å – 247960 Å]
Tungsten-W_19.35gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Vanadium(II)_oxide-VO_5.758gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Vanadium(III)_nitride-VN_(1991)	[Pal91]
Vanadium(III)_nitride-VN_(1997+1991)	Concatenation of Vanadium(III)_nitride-VN_6.13gcm-3_(1997) [0.124 Å – 413 Å] and Vanadium(III)_nitride-VN_(1991) [413 Å – 24796 Å]
Vanadium(III)_nitride-VN_6.13gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Vanadium(III)_oxide_4.87gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Vanadium(IV)_oxide-VO2_4.339gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Vanadium(sputtered_thinFilm)-V_(1989)	[Kih+89]
Vanadium(V)_oxide-V2O5_3.357gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Vanadium_carbide-VC_(1991)	[Pal91]
Vanadium_carbide-VC_(1997+1991)	Concatenation of Vanadium_carbide-VC_5.77gcm-3_(1997) [0.124 Å – 413 Å] and Vanadium_carbide-VC_(1991) [428 Å – 24796 Å]
Vanadium_carbide-VC_5.77gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Vanadium-V_(1981)	[Wea+81]

Vanadium-V_(1991)	[Pal91]
Vanadium-V_(1997+1991)	Concatenation of Vanadium-V_5.96gcm-3_(1997) [0.124 Å – 413 Å] and Vanadium-V_(1991) [413 Å – 123980 Å]
Vanadium-V_5.96gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Yttrium(III)_oxide(cubic)-Y2O3_(1991)	[Pal91]
Yttrium(III)_oxide-Y2O3_(1997+1991)	Concatenation of Yttrium(III)_oxide-Y2O3_5.01gcm-3_(1997) [0.124 Å – 413 Å] and Yttrium(III)_oxide(cubic)-Y2O3_(1991) [413 Å – 1.999E7 Å]
Yttrium(III)_oxide-Y2O3_5.01gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Yttrium(sputtered)-Y_(1992)	◇ (↪Sec. A.4.5.9)
Yttrium_Oxide-Y2O3-ThinFilm	[SB79]
Yttrium-Y_4.4689gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
ZBLA	[BS94]
ZBLAN	[BS94]
Zinc_oxide-ZnO_5.606gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Zinc_selenide(cubic)-ZnSe_(1991)	[Pal91]
Zinc_selenide(irtran-4)-ZnSe_(1991)	[Pal91]
Zinc_selenide-ZnSe	[BS94]
Zinc_sulfide(cubic)-ZnS_(1991)	[Pal91]
Zinc_sulfide(hexagonal_extraordinaryRay)-ZnS-e_(1985)	[Pal85]
Zinc_sulfide(hexagonal_ordinaryRay)-ZnS-o_(1985)	[Pal85]
Zinc_sulfide(irtran-2)-ZnS_(1985)	[Pal85]
Zinc_sulfide-ZnS_0.42-1.1µm	[Rog93]
Zinc_sulfide-ZnS_0.42-18.2µm	[Rog93]
Zinc_sulfide-ZnS_4-18µm	[Rog93]
Zinc_Sulfide-ZnS-ThinFilm	[BLP82] The curve in Fig.1 of the publication was used to sample the dispersion.
Zinc_telluride(cubic)-ZnTe_(1991)	[Pal91]
Zinc-Zn_7.14gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Zirconium(evap_thinFilm)-Zr_(1988)	[Win+88b]
Zirconium(IV)_oxide-ZrO2_5.89gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Zirconium(polyxtal)-Zr_(1981)	[Wea+81, p. 253]
Zirconium(singleXtal_TE)-Zr-te_(1981)	[Wea+81, p. 253]
Zirconium_Dioxide-ZrO2-ThinFilm	[SB79]

Zirconium-Zr_(1997+1988)	Concatenation of Zirconium-Zr_6.49gcm-3_(1997) [0.124 Å – 413 Å] and Zirconium(evap_thin-Film)-Zr_(1988) [448 Å – 1216 Å]
Zirconium-Zr_6.49gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)

A.4.5.5 Miscellaneous

MATERIAL	DATA SOURCE
Acrylic	[BS94]
Air	[BD94]; air without any water vapor (humidity 0 %).
Air (X-ray spectral region)	Calculated from $\tilde{n}^2 = \sum_i (V_i/V \cdot \tilde{\epsilon}_i)$ with V_i/V being the volume fraction of the ith gas compound of air. These percentage values are taken from [Lid08]. $\tilde{\epsilon}_i$ is the dielectric function of compound i as could be found at the source called *CXRO*, as described in Sec. A.4.5.9.
Air (Zemax OS)	The dispersion equation for air as used by Zemax OpticStudio®. It is identical to that in [Edl53].
AMTIR-1_AMI	Spec Sheet (Amorphous Materials Inc.)
AMTIR-1/TI-20	[BS94]
AMTIR-3/TI-1173_3-14µm	[BS94]
AMTIR-3/TI-1173_0.9-14µm	[BS94]
BK7_MSO-measured	[Jen10]
Boron_carbide-B4C_2.52gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Boron_nitride-BN_2.25gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Boron_trioxide-B2O3_2.46gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Boron-B_2.37gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Fused_Silica	[BS94]
Germanium_dioxide-GeO2	[BS94]
Germanium-Ge_(1957)	[SV57]
Germanium-Ge_(1985)	[Pal85]
Germanium-Ge_(1985)_2-12µm	[Pal85]
Germanium-Ge_5.323gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Ideal High Absorption Material	This is just an “ideal” material with extreme high absorption.
Ideal High Reflectance Material	This is just an “ideal” mirror material with extreme high absorption, which leads to a nearly perfect reflectance.
KDP(ordinaryRay)-KH2PO4	[BS94]
Seawater-H2O_3.5pct_Salinity	Dispersion parameters from [Lai06], absorption coefficients from [Ame94].
Selenium(extraordinaryRay)-Se-e_(1991)	[Pal91]

Selenium(ordinaryRay)-Se-o_(1991)	[Pal91]
Tellurium(trigonal_extraordinaryRay)-Te-e_(1991)	[Pal91]
Tellurium(trigonal_ordinaryRay)-Te-o_(1991)	[Pal91]
Tellurium_dioxide-TeO2_(1994)	[BS94]
Water-H2O_(1991)	[Pal91]
Water-H2O_(1997+1991)	Concatenation of Water-H2O_1.0gcm-3_(1997) [0.124 Å – 413 Å] and Water-H2O_(1991) [460 Å – 1.E11 Å]
Water-H2O_(pure)	Dispersion parameters from [Lai06], absorption coefficients from [Ame94].
Water-H2O_1.0gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)

A.4.5.6 Radiation_Hardened

This category contains glasses which are labeled as radiation hardened by the manufacturers.

A.4.5.7 Silicon+Compounds_(Non-Glass)

This category contains the element silicon as well as compounds of silicon which are no glasses.

MATERIAL	DATA SOURCE
Hydrogenated_Silicon(amorphous)-a-Si:H_(1985)	[Pal85]
Silicon(amorphous)-a-Si_(1997+1985)	Concatenation of Silicon(amorphous)-a-Si_2.189gcm-3_(1997) [0.124 Å – 413 Å] and Silicon(amorphous_evap)-a-Si_(1985) [413 Å – 355142 Å]
Silicon(amorphous)-a-Si_2.189gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Silicon(amorphous)-a-Si_sopra	`https://web.archive.org/web/20070101013854/http://www.sopra-sa.com/index2.htm`
Silicon(amorphous_evap)-a-Si_(1985)	[Pal85]
Silicon(crystalline)-Si_(1985)	[Pal85]
Silicon(evap_thinFilm)-a-Si_(1988)	[Win+88a]
Silicon(oxidized_(100)_Si_wafer)-Si_(1992)	◇ (↪Sec. A.4.5.9)
Silicon(sputtered)-a-Si_(1991)	[Win91]
Silicon(sputtered)-a-Si_(1992)	◇ (↪Sec. A.4.5.9)
Silicon_carbide(6H)-SiC_(1989)	[Yan+89]
Silicon_carbide(amorphous)-a-Sic_(1997+1988)	Concatenation of Silicon_carbide(amorphous)-a-SiC_3.112gcm-3_(1997) [0.124 Å – 413 Å] and Silicon_carbide(sputtered)-a-SiC_(1988) [448 Å – 1216 Å]
Silicon_carbide(amorphous)-a-SiC_3.112gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)

Silicon_carbide(CVD)-SiC_(1985)	[Osa85]
Silicon_carbide(CVD)-SiC_(1988)	[Win+88a]
Silicon_carbide(hex_xtal_ordinaryRay)-SiC-o_(1985)	[Pal85]
Silicon_carbide(sputtered)-a-SiC_(1988)	[KW88]
Silicon_carbide-SiC_(1997+1985)	Concatenation of Silicon_carbide-SiC_3.208gcm-3_(1997) [0.124 Å – 413 Å] and Silicon_carbide(hex_xtal_ordinaryRay)-SiC-o_(1985) [413 Å – 250010 Å]
Silicon_carbide-SiC_3.208gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Silicon_dioxide(amorphous)-SiO2_(1997+1991)	Concatenation of Silicon_dioxide(amorphous)-SiO2_2.19gcm-3_(1997) [0.124 Å – 413 Å] and Silicon_dioxide(amorphous_fused_quartz)-SiO2_(1991) [420 Å – 4999190 Å]
Silicon_dioxide(amorphous)-SiO2_2.19gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Silicon_dioxide(amorphous_fused_quartz)-SiO2_(1991)	[Pal91]
Silicon_dioxide(trigonal_quartz_extraordinaryRay)	[BS94]
Silicon_dioxide(trigonal_quartz_extraordinaryRay)-SiO2-e_(1985)	[Pal85]
Silicon_dioxide(trigonal_quartz_extraordinaryRay)-SiO2-e_(1999)	[Gho99]
Silicon_dioxide(trigonal_quartz_ordinaryRay)	[BS94]
Silicon_dioxide(trigonal_quartz_ordinaryRay)-SiO2-o_(1985)	[Pal85]
Silicon_dioxide(trigonal_quartz_ordinaryRay)-SiO2-o_(1999)	[Gho99]
Silicon_dioxide-SiO2_(1997+1985)	Concatenation of Silicon_dioxide-SiO2_2.65gcm-3_(1997) [0.124 Å – 413 Å] and Silicon_dioxide(trigonal_quartz_ordinaryRay)-SiO2-o_(1985) [420 Å – 4999190 Å]
Silicon_dioxide-SiO2_2.65gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Silicon_Dioxide-SiO2-ThinFilm	[BLP82] The curve in Fig.22 of the publication was used to sample the dispersion instead of the bad fitting Cauchy parameters given.
Silicon_monoxide-SiO_(1985)	[Pal85]
Silicon_monoxide-SiO_(1997+1985)	Concatenation of Silicon_monoxide-SiO_2.13gcm-3_(1997) [0.124 Å – 413 Å] and Silicon_monoxide-SiO_(1985) [496 Å – 139995 Å]

Silicon_monoxide-SiO_2.13gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Silicon_Monoxide-SiO-ThinFilm	[Pal85, p. 768]
Silicon_nitride(polyxtal)-Si3N4_(1985)	[Pal85]
Silicon_nitride-Si3N4_(1992)	◇ (↪Sec. A.4.5.9)
Silicon_nitride-Si3N4_(1997+1985)	Concatenation of Silicon_nitride-Si3N4_3.44gcm-3_(1997) [0.124 Å – 413 Å] and Silicon_nitride(polyxtal)-Si3N4_(1985) [517 Å – 12398 Å]
Silicon_nitride-Si3N4_3.44gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
Silicon-germanium(cubic)-Si0.25Ge0.75_(1991a)	[Pal91]
Silicon-germanium(cubic)-Si0.25Ge0.75_(1991b)	[Pal91]
Silicon-germanium(cubic)-Si0.5Ge0.5_(1991a)	[Pal91]
Silicon-germanium(cubic)-Si0.5Ge0.5_(1991b)	[Pal91]
Silicon-germanium(cubic)-Si0.8Ge0.2_(1991a)	[Pal91]
Silicon-germanium(cubic)-Si0.8Ge0.2_(1991b)	[Pal91]
Silicon-Si_(1997+1985)	Concatenation of Silicon-Si_2.329gcm-3_(1997) [0.124 Å – 413 Å] and Silicon(crystalline)-Si_(1985) [420 Å – 3332800 Å]
Silicon-Si_1.36-11µm	[BS94]
Silicon-Si_2.329gcm-3_(1997)	⋈ (↪Sec. A.4.5.9)
SiO2-ThinFilm_MSO-measured	[Jen10]

A.4.5.8 Birefringent

This category contains birefringent materials, namely uniaxial and biaxial crystals.

MATERIAL	DATA SOURCE
Calcite_(*extra*ordinaryRay)-CaCO3-*e/o*_(1999)	[Gho99]
CaMoO4(tetragonal_*extra*ordinaryRay)-CaMoO4-*e/o*_(1965)	[Bon65]
CaWO4(tetragonal_*extra*ordinaryRay)-CaWO4-*e/o*_(1965)	[Bon65][1]
LYSO:Ce(monoclinic_Index_$\alpha/\beta/\gamma$)-Lu(x)Y(2-x)SiO5-$\alpha/\beta/\gamma$_(2012)	[Erd+12]
Rutile(tetragonal_*extra*ordinaryRay)-TiO2-*e/o*_(1965)	[Bon65][2]

[1] The value for the extraordinary ray at 1.8 µm is obviously wrong. Since there is a good chance that there were transposed digits, the table value of 1.9848 has been replaced by 1.8948.

[2] The outlier for the ordinary ray at 500 nm of 2.4058 has been replaced by 2.7058. The outlier for the extraordinary ray at 1.6 µm of 2.6002 has been replaced by 2.6902.

SrMoO4(tetragonal_*extra*ordinaryRay)-SrMoO4-*e/o*_(1965)	[Bon65]
YAlO3(1.14%Nd_orthorhombic_Index_$\alpha/\beta/\gamma$)-YAlO3-$\alpha/\beta/\gamma$_(1973)	[MD73]
YAlO3(undoped_orthorhombic_Index_$\alpha/\beta/\gamma$)-YAlO3-$\alpha/\beta/\gamma$_(1973)	[MD73]
ZnWO4(monoclinic_Index_$\alpha/\beta/\gamma$)-ZnWO4-$\alpha/\beta/\gamma$_(1965)	[Bon65]
α-BismuthMolybdate(monoclinic_Index_$\alpha/\beta/\gamma$)-Bi2(MoO4)3-$\alpha/\beta/\gamma$_(2002)	[MV02]

A.4.5.9 X-ray

Each *X-ray* material is contained in one of the other categories at least. So the data sources for the non-glasses are listed in that category which represents the composition of the material respectively (e. g. in *Metals+Compounds* or in *Silicon+Compounds_(Non-Glass)*).
For all entries marked with ⋈ or ⋄ in the table above, the optical data are taken from David Windt's IMD software package (http://www.rxollc.com/imd).

- ⋄: For the materials marked with ⋄, only the source "D. L. Windt, unpublished (1992)" is given.
- ⋈: For the materials marked with ⋈, the user's manual ([Win13], p. 37) of this software states: "The atomic scattering factors f1 & f2 can be used to compute optical constants n & k for elemental or compound materials of known density, as described in [[HGD93]]. [...] Each file is a concatenation of high-energy X-ray data obtained from LLNL extending from 30 keV to 100 keV, and low-energy data from CXRO extending from 30 keV to 10 eV." The abbreviations LLNL and CXRO refer to data bases, formerly provided by websites of the following institutions:
  - LLNL: Lawrence Livermore National Laboratory (https://web.archive.org/web/20001030001803/http://www-phys.llnl.gov/V_Div/scattering/asf.html)
  - CXRO: Center for X-Ray Optics (CXRO), Lawrence Berkeley Laboratory (https://web.archive.org/web/20051117074606fw_/http://www.cxro.lbl.gov/optical_constants/asf.html)

  Note: A currently available data base for atomic scattering factors (if someone wants to calculate n-k-data for herself) can be found at https://physics.nist.gov/PhysRefData/FFast/html/form.html.

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Bibliography

[Ame94] Optical Society of America, ed. *Handbook of Optics, Volume I: Fundamentals, Techniques, and Design*. McGraw-Hill, 1994.

[AW98] H. Aagedal and F. Wyrowski. "On pixel-oriented structure parametrization for design of diffractive elements". In: *J. Mod. Optics* 45.7 (1998), pp. 1451–1464. DOI: 10.1080/09500349808230640.

[AWS97] H. Aagedal, F. Wyrowski, and M. Schmid. "Paraxial beam splitting and shaping". In: *Diffractive optics for industrial and commercial applications*. Ed. by J. Turunen and F. Wyrowski. Akademie Verlag, Berlin, 1997. Chap. 6, pp. 165–188.

[BD94] K.P. Birch and M.J. Downs. "Correction to the Updated Edlén Equation for the Refractive Index of Air". In: *Metrologia* 31 (1994), pp. 315–316. DOI: 10.1088/0026-1394/31/4/006.

[BE04] A. Bergauer and C. Eisenmenger-Sittner. *Vorlesungsskript: Physik und Technologie Dünner Schichten*. TU Wien, 2004.

[Ben97] J. Bengtsson. "Design of fan-out kinoforms in the entire scalar diffraction regime with an optimal-rotation-angle method". In: *Appl. Opt.* 36.32 (1997), pp. 8435–8444. DOI: 10.1364/ao.36.008435.

[BLP82] J.P. Borgogno, B. Lazarides, and E. Pelletier. "Automatic determination of the optical constants of inhomogeneous thin films". In: *Appl. Opt.* 21 (1982), pp. 4020–4029. DOI: 10.1364/ao.21.004020.

[Bon65] W. L. Bond. "Measurement of the Refractive Indices of Several Crystals". In: *Journal of Applied Physics* 36.5 (1965), pp. 1674–1677. DOI: 10.1063/1.1703106.

[Bra65] R. Bracewell. *The Fourier transform and its applications*. McGraw-Hill, Inc., 1965.

[BS94] Michael Bass and Eric W. Van Stryland, eds. *Handbook of Optics, Volume II: Devices, Measurements, and Properties*. McGraw-Hill, 1994.

[Bun82] R. F. Bunshah. *Deposition technologies for films and coatings: developments and applications*. Noyes Publications, 1982.

[BW83] M. Born and E. Wolf. *Principles of Optics*. 6th (corrected). Pergamon Press, 1983.

[CHH64] L.R. Canfield, G. Hass, and W.R. Hunter. "The optical properties of evaporated gold in the vacuum ultraviolet from 300 to 2000 Å". In: *J. de Physique* 25 (1964), p. 124. DOI: 10.1051/jphys:01964002501-2012401.

[Col70] S. A. Collins. "Lens-System Diffraction Integral Written in Terms of Matrix Optics". In: *J. Opt. Soc. Am.* 60.9 (1970), pp. 1168–1177. DOI: 10.1364/josa.60.001168.

[Cox+74] J.T. Cox et al. "Reflectance and optical constants of evaporated ruthenium in the vacuum ultraviolet from 300 Å to 2000 Å". In: *J. Opt. Soc. Am.* 64 (1974), p. 423.

[Edl53] Edlén. "Dispersion of standard air". In: *J.Opt. Soc. Amer.* 43 (1953), pp. 339–344.

[Erd+12] Gábor Erdei et al. "Refractive index measurement of cerium-doped Lu(x)Y(2-x)SiO5 single crystal". In: *Optical Materials* 34 (2012), pp. 781–785. DOI: 10.1016/j.optmat.2011.11.006.

[ESA93] S.M. Edlou, A. Smajkiewicz, and G.A. Al-Jumaily. "Optical properties and environmental stability of oxide coatings deposited by reactive sputtering". In: *Appl. Opt.* 32 (1993), pp. 5601–5605. DOI: 10.1364/ao.32.005601.

[For07] G. W. Forbes. "Shape specification for axially symmetric optical surfaces". In: *Optics Express* 15.8 (Apr. 2007), pp. 5218–5226. DOI: 10.1364/oe.15.005218.

[FT11] Matthew R Foreman and Peter Török. "Computational methods in vectorial imaging". In: *Journal of Modern Optics* 58.5-6 (2011), pp. 339–364. DOI: 10.1080/09500340.2010.525668.

[Gho99] Gorachand Ghosh. “Dispersion-equation coefficients for the refractive index and birefringence of calcite and quartz crystals”. In: *Optics Communications* 163.1-3 (1999), pp. 95–102. DOI: 10.1016/S0030-4018(99)00091-7.

[Goo68] J. W. Goodmann. *Introduction to Fourier optics*. McGraw-Hill, New York, 1968.

[Her90] Reinhard Herrmann, ed. *Optical thin films and applications*. The Hague: ECO 3, 1990.

[HGD93] B. L. Henke, E. M. Gullikson, and J. C. Davis. “X-ray interactions: photabsorption, scattering, transmission, and reflection at E=50-30,000 eV, Z=1-92”. In: *Atomic Data and Nuclear Tables* 54(2) (1993), pp. 181–342.

[HGK74] H. J. Hagemann, W. Gudat, and C. Kunz, eds. *DESY Report SR-74/7*. DESY Hamburg, 1974.

[HGK75] H.J. Hagemann, W. Gudat, and C. Kunz. “Optical constants from the far infrared to the x-ray region: Mg, Al, Cu, Ag, Au, Bi, C, and Al2O3”. In: *J. Opt. Soc. Am.* 65 (1975), p. 742. DOI: 10.1364/josa.65.000742.

[HW97] N. Hodgson and H. Weber. “Optical Resonators”. In: Springer, 1997. Chap. 8.2.

[Jen10] mso Jena Mikroschichtoptik GmbH. “Some optical data for thin films.” Personal communication. 2010.

[Kih+89] N. Kihara et al. “Optical constants for coated thin films in the soft x-ray region”. In: *Review of Scientific Instruments* 60.7 (1989), pp. 2227–2230. DOI: 10.1063/1.1140776.

[Kno78] K. Knop. “Rigorous diffraction theory for transmission phase gratings with deep rectangular grooves”. In: *J. Opt. Soc. Am.* 68.9 (1978), pp. 1206–1210. DOI: 10.1364/josa.68.001206.

[KW88] J.B. Kortright and D.L. Windt. “Amorphous silicon carbide coatings for extreme ultraviolet optics”. In: *Appl. Opt.* 27 (1988), p. 2841. DOI: 10.1364/ao.27.002841.

[Lai06] M. Laikin. *Lens Design, 4th Edition*. Taylor & Francis Group, LLC, 2006.

[Lev44] Kenneth Levenberg. “A Method for the Solution of Certain Non-Linear Problems in Least Squares”. In: *Quarterly of Applied Mathematics* 2 (1944), pp. 164–168. DOI: 10.1090/qam/10666.

[Li01] L. Li. “Mathematical Reflections on the Fourier Modal Method in Grating Theory”. In: *Mathematical Modeling in Optical Science*. Ed. by G. Bao, L. Cowsar, and W. Masters. Philadelphia: SIAM, 2001, pp. 111–139.

[Li96] L. Li. “Use of Fourier series in the analysis of discontinuous periodic structures”. In: *J. Opt. Soc. Am. A* 13.9 (1996), pp. 1870–1876. DOI: 10.1364/josaa.13.001870.

[Lid08] David R. Lide, ed. *CRC Handbook of Chemistry and Physics*. 89th. CRC Press / Taylor and Francis, 2008.

[LOL83] G. Leveque, C.G. Olson, and D.W. Lynch. “Reflectance spectra and dielectric functions for Ag in the region of interband transitions”. In: *Phys. Rev. B* 27 (1983), p. 4654. DOI: 10.1103/physrevb.27.4654.

[Mac01] Hugh A. MacLeod. *Thin-film optical filters*. 3th. Institute of Physics Publ., 2001.

[Mär] Otto Märten. “private communication”.

[Mar63] Donald W. Marquardt. “An Algorithm for Least-Squares Estimation of Nonlinear Parameters”. In: *Journal of the Society for Industrial and Applied Mathematics* 11.2 (June 1963), pp. 431–441. DOI: 10.1137/0111030.

[MD73] K. W. Martin and L. G. DeShazer. “Indices of Refraction of the Biaxial Crystal YAlO3”. In: *Applied Optics* 12.5 (1973), pp. 941–943. DOI: 10.1364/ao.12.000941.

[MV02] V. Marinova and M. Veleva. “Refractive index measurements and transmission spectra of Bi2(MoO4)3 single crystals”. In: *Optical Materials* 19 (2002), pp. 329–333. DOI: 10.1016/s0925-3467(01)00234-8.

[MW95] L. Mandel and E. Wolf. *Optical coherence and quantum optics*. Cambridge University Press, Cambridge, 1995.

[Nat] National Communications System Technology and Standards Division. *Telecommunications: Glossary of Telecommunication Terms. Federal Standard 1037C*. USA: General Services Administration Information Technology Service, P–18. URL: http://everyspec.com/FED-STD/FED-STD-1037C_4685/ (visited on 11/03/2022).

[Nil70] P.O. Nilsson. “Electronic structure of disordered alloys: optical and photoemission measurements on Ag-Au and Cu-Au alloys”. In: *Phys. Kondens. Mater.* 11 (1970), p. 1. DOI: 10.1007/bf02422633.

[NM65] John Ashworth Nelder and Roger Mead. “A Simplex Method for Function Minimization”. In: *Computer Journal* 7 (1965), pp. 308–313. DOI: 10.1093/comjnl/7.4.308.

[Osa85] J. Osantowski. “Data presented at the Glancing Incidence Optics Fabrication Workshop”. In: *Proceedings*. Optics Branch of the Goddard Space Flight Center, Annapolis, Maryland. 1985.

[Pal85] Edward D. Palik, ed. *Handbook of Optical Constants of Solids Vol. I*. Academic Press, 1985.

[Pal91] Edward D. Palik, ed. *Handbook of Optical Constants of Solids Vol. II*. Academic Press, 1991.

[Pal97] Edward D. Palik, ed. *Handbook of Optical Constants of Solids Vol. III*. Academic Press, 1997.

[Pow64] M. J. D. Powell. “An efficient method for finding the minimum of a function of several variables without calculating derivatives”. In: *Computer Journal* 7.2 (1964), pp. 155–162. DOI: 10.1093/comjnl/7.2.155.

[Ran96] James D. Rancourt. *Optical thin films: user handbook*. SPIE Optical Engineering Press, 1996.

[Rog93] W.D. Rogato, ed. *The Infrared & Electro Optical Systems Handbook Vol.III: Electro-Optical System Design, Analysis and Testing*. SPIE Optical Engineering Press, 1993.

[SB79] D. Smith and P. Baumeister. “Refractive Index of some oxide and fluoride coating materials”. In: *Appl. Opt.* 18 (1979), pp. 111–115. DOI: 10.1364/ao.18.000111.

[SCH08] SCHOTT. *TIE-19: Temperature Coefficient of the Refractive Index*. July 2008. URL: https://mss-p-009-delivery.stylelabs.cloud/api/public/content/0dcd87a2d36942a3946d033f0a9065e6?v=940fa3fb&download=true (visited on 08/16/2022).

[Shi+80] E. Shiles et al. “Self-consistency and sum-rule tests in the Kramers-Kronig analysis of optical data: Application to aluminum”. In: *Phys. Rev. B* 22 (1980), p. 1612. DOI: 10.1103/physrevb.22.1612.

[Sie86] A. E. Siegman. *Lasers*. University Science Books, Mill Valley, California, 1986.

[SK11] Gunther Schmidt and Bernd H. Kleemann. “Integral equation methods from grating theory to photonics: an overview and new approaches for conical diffraction”. In: *Journal of Modern Optics* 58.5-6 (Mar. 2011), pp. 407–423. DOI: 10.1080/09500340.2010.538734.

[ST91] B. A. E. Saleh and M. C. Teich. *Fundamentals of photonics*. John Wiley & Sons, 1991.

[SV57] C.D. Salzberg and J.J. Villa. “Infrared refractive indexes of silicon germanium and modified selenium glass”. In: *JOSA* 47 (1957), p. 244. DOI: 10.1364/josa.47.000244.

[Tur97] J. Turunen. “Diffraction theory of microrelief gratings”. In: *Micro-Optics: Elements, Systems, and Applications*. Ed. by H.P. Herzig. London: Taylor and Francis, 1997. Chap. 2.

[TY82] L. Thylen and D. Yevick. “Beam propagation method in anisotropic media”. In: *Applied Optics* 21.15 (1982), pp. 2751–2754. DOI: 10.1364/ao.21.002751.

[VT06] Pasi Vahimaa and Jari Turunen. “Finite-elementary-source model for partially coherent radiation”. In: *Opt. Express* 14.4 (2006), pp. 1376–1381. DOI: 10.1364/oe.14.001376.

[WA98] F. Wyrowski and H. Aagedal. “Wave transformation by physical-optics system design”. In: *International Journal of Optoelectronics* 12.4 (1998), pp. 127–143.

[WB91] F. Wyrowski and O. Bryngdahl. “Digital holography as part of diffractive optics”. In: *Rep. Prog. Phys.* 54 (1991), pp. 1481–1571. DOI: 10.1088/0034-4885/54/12/001.

[WC92] J. C. Wyant and K. Creath. “Basic Wavefront Aberration Theory for Optical Metrology”. In: *Applied Optics and Optical Engineering* XI (1992). chapter 1, pp. 27–39.

[Wea+81] J.H. Weaver et al., eds. *Physik Daten, Physics Data: Optical Properties of Metals*. Vol. 18-1, 18-2. Fachinformationszentrum, Karlsruhe, 1981.

[Win+88a] D.L. Windt et al. “Optical constants for thin films of C, diamond, Al, Si, and CVD SiC from 24 to 1216 Å”. In: *Appl. Opt.* 27 (1988), p. 279. DOI: 10.1364/ao.27.000279.

[Win+88b] D.L. Windt et al. “Optical constants for thin films of Ti, Zr, Nb, Mo, Ru, Rh, Pd, Ag, Hf, Ta, W, Re, Ir, Os, Pt, and Au from 24 to 1216 Å”. In: *Appl. Opt.* 27 (1988), p. 246. DOI: 10.1364/ao.27.000246.

[Win13] David L. Windt. *IMD Version 5.0 - Installation Guide & User’s Manual*. Nov. 2013. URL: http://www.rxollc.com/imd/IMD.pdf (visited on 08/16/2022).

[Win91] D.L. Windt. “XUV optical constants of single-crystal GaAs and sputtered C, Si, Cr3C2, Mo, and W”. In: *Appl. Opt.* 30 (1991), p. 15.

[WK11] Frank Wyrowski and Michael Kuhn. “Introduction to Field Tracing”. In: *Journal of Modern Optics* 58(5-6) (2011), pp. 449–466. DOI: 10.1080/09500340.2010.532237.

[Wol59] E Wolf. “Electromagnetic diffraction in optical systems. i. an integral representation of the image field”. In: *Proceedings of the Royal Society of London A: Mathematical, Physical and Engineering Sciences* 253.1274 (1959).

[WSK07] Frank Wyrowski, Hagen Schimmel, and Michael Kuhn. “Elektromagnetisches Optikrechnen - Modellierung realer Lichtquellen”. In: *Photonik* 2 (2007), pp. 66–70.

[Yan+89] M. Yanagihara et al. “Optical constants of SiC mirrors produced by different methods for photons of 60-1000 eV”. In: *Rev. Sci. Instrum.* 60 (1989), p. 2030. DOI: 10.1063/1.1140868.

[YL92] R.-Z. Yahel and I. Last. “Numerical simulation of laser beam propagation in three-dimensional random media: beam splitting and patch formation”. In: *Waves in random media* 2 (1992). DOI: 10.1088/0959-7174/2/1/007.

[ZAT80] M.V. Zombeck, G.K. Austin, and D.T. Torgerson. *High Resolution Mirror Assembly Optical System Study*. Smithsonian Astrophysical Observatory Report SAO-AXAF-80-003, Appendix B. Table B1. 1980.