

#### **Grating Order Analyzer**

#### Abstract



The analysis of the diffraction efficiencies of certain diffraction orders is the typical modeling task for optical grating structures. Due to the small feature sizes and periods regarding the used wavelength of light, the efficiencies must be calculated by rigorous approaches. The well-known FMM or RCWA is one commonly applied algorithm to solve this task and is also available in VirtualLab Fusion. The results of this fully vectorial method are the complex-valued Rayleigh coefficients, which contain all necessary field information per order, from which the corresponding efficiency can be obtained. The Grating Order Analyzer in VirtualLab Fusion helps us to generate and graphically display all this information for complex grating structures (both 1 and 2D-periodic).

#### **Grating Specification**



- For the demonstration of the *Grating Order Analyzer* a 1D grating with a sinusoidal grating shape in combination with multiple layers is used.
- The layers are indented to provide highreflective (HR) function.
- The grating parameters can be specified in the stack that can be accessed in the edit dialog of the grating component.

# **Grating Order Analyzer Settings**



- After the grating structure has been defined, the desired *Grating Order Analyzer* can be applied for calculating the Rayleigh coefficients and the regarding diffracting.
- In addition, various output options are available to display the results.
- This is done through the edit dialog of the analyzer, which is opened by double clicking on the corresponding element in the *Optical Setup View*.

#### **General Settings**

eneral Single Orders	
Calculated Orders	
Iransmission	Reflection
Output	
Order Collections	
Single Order Output	
Summed Transmission, A	bsorption, and Reflection
Polar Diagram (Angle g	Dnlv)

- In the General tab you can select whether transmission and/or reflection shall be analyzed.
- In addition, you can specify which outputs you would like the *Grating Analyzer* to generate.
  - Order Collections: generates a type of document that provides a visual representation of how the field/energy is distributed among the orders, as well as containing the displayed information in numerical form. Order Collections are generated separately for transmission and reflection. More information about the Order Collection document can be found in the next slides.
  - Single Order Output: activates the additional Single Orders tab, to the right of the General one. (see next page)
  - Summed Transmission, Absorption and Reflection: the corresponding information (i.e., how the energy is distributed among these three effects, without further breaking the results down into the individual grating orders but as aggregate values) will be displayed either in the Detector Results tab or as results in a Parameter Run or Parametric Optimization.
  - Polar Diagram (Angle α only): generates another document that provides a visualization of the different appearing grating orders, where the shown angle corresponds to the diffraction angle of the order, and the radius depicts the efficiency. This type of visualization is restricted to a single plane. More information about the Polar Diagram document can be found in the next slides.

# **Single Orders Settings**

Edit Grating Order Ana	lyzer	×
General Single Ord	iers rategy	
Selection Strategy	Order Range	~
	х	Y
Minimum Order	-1	0
Maximum Order	0	0 🜩
Coordinates		
Spherical Angle	es 🗌 Carte	esian Angles
Wave Vector Co	omponents 🗌 Posit	tions
Efficiencies		
- Rayleigh Coefficier	nts	
Ex Ex	Ey	Ez
TE TE	TM	
	OK Ca	ancel Help

- When the option *Single Order Output* is selected in the *General* tab, the *Single Orders* tab is activated. In it you can select what information about the single orders shall be logged.
- The Single Order Output controls whether information about the individual orders (diffraction angles, efficiency, Rayleigh coefficients...) will be delivered (depending on how the simulation is run, either in the Detector Results tab or as results in a Parameter Run or Parametric Optimization).
- This option is very helpful if you would like to use the Parameter Run or the Parametric Optimization of VirtualLab Fusion to analyze and optimize the grating for specific orders.

Edit Grating	Order Analyz	er		×
General	Single Order	s		
Order	Selection Strat	egy		
Selecti	ion Strategy	Order Range		$\sim$
		x	Y	
Minim	um Order	-1 🖕		0 🌲
Maxim	um Order	0		0
Coordi	inates			
Spl	herical Angles	🗌 Ca	irtesian Angl	es
🗌 Wa	ve Vector Com	ponents 🗌 Po	sitions	
Effic	iencies			
Rayleig	h Coefficients			
⊡ Ex		Ey		Ez
TE		TM		
	E	ОК	Cancel	Help

Parameter	Description
Order Selection Strategy	The user can define which order(s) shall be evaluated. The user can choose whether to analyze <i>All</i> orders, analyze only those orders which have an efficiency <i>Above a Given Threshold</i> or calculate only orders in a manually specified <i>Order Range</i> . Depending on the selection strategy the user may have to configure additional parameters.
Coordinates	Logging of the coordinates of the orders is also supported. The user can specify whether to show the coordinates in <i>Spherical Angles</i> , <i>Cartesian Angles</i> , <i>Wave Vector Components</i> or <i>Positions</i> . For the Position calculation a z-distance between the grating and the screen has to be specified.
Efficiencies	The user can select whether efficiencies shall be logged.
Rayleigh Coefficients	In addition, it is possible to log the Rayleigh coefficients. The user can select to show the coefficients of the diffraction orders according to the xyz-coordinate system (components $E_x$ , $E_y$ , $E_z$ ) or TE/TM.

#### **Outputs in Detector Tab**

Detec	tor Results			
	Date/Time	Detector	Sub - Detector	Result
132			Overall Reflection Efficiency	46.71935083 %
131	11/16/2021 12:04:25	"Crating Order Applycer" (# 200)	Overall Transmission Efficiency	53.28064917 %
130	11/10/2021 12:04:25	Grating Order Analyzer (# 600)	Overall Reflection and Transmission Efficiency	100 %
129			Absorption	0 %
128			Spherical Angle Theta R[-1; 0]	18.44015854°
127			Spherical Angle Phi R[-1; 0]	0°
126			Efficiency R[-1; 0]	1.544588438 %
125	11/16/2021 12:04:25	"Grating Order Analyzer" (# 800)	Rayleigh coefficient Ex R[-1; 0]	-14.9906794-120.1169758i mV/m
124	11/10/2021 12:04:23	(Results for Individual Orders)	Spherical Angle Theta R[0; 0]	0°
123			Spherical Angle Phi R[0; 0]	0°
122			Efficiency R[0; 0]	29.3 <mark>4</mark> 772296 %
121			Rayleigh coefficient Ex R[0; 0]	538.0671678-62.93609884i mV/m
Dete	ctor Results Message	25		

- If the *Grating Order Analyzer* is processed in the *Optical Setup*, the single order output values are logged in the *Detector Results* tab.
- These values are also available in the *Parameter Run* and the *Parametric Optimization*.

#### **Outputs in Polar Diagram**



Efficiency

3.683422342 %

17.75967444 %

2.344690955 %

0.8165360757 %

4.072001537 %

0.8165360757 %

2.344690955 %

17.75967444 %

3.683422342 %

0.8037078176 %

6.337517677 %

1.544588438 %

29.34772296 %

1.544588438 %

6.337517677 %

0.8037078176 9

100 %

- The polar diagram output of the *Grating Order Analyzer* plots the efficiencies of both the reflected and the transmitted orders versus the angles in the x-z-plane.
- It also provides a table of all angles and efficiencies of the displayed orders.

#### **Polar Diagram Settings**



- You can zoom into the polar diagram with the mouse wheel, or through the *Property Browser* or the ribbon menu.
- You can configure which orders are shown by right-clicking on the diagram.

	Incident W	ave 🔽 Transmit	tted Orders 🔽 R	eflected Orders
/ini	imum Angl	e -52.9°	Maximum An	gle 52.91
	Use Stride			
_	Order	Angle	Efficiency	^
$\checkmark$	1	0°	100 %	
	T[-3; 0]	-52.92°	0.349 %	
$\checkmark$		-32.13°	3.361 %	
2 2	T[-2; 0]			
N N N	T[-2; 0] T[-1; 0]	-15.42°	3.301 %	
2222	T[-2; 0] T[-1; 0] T[0; 0]	-15.42° 0°	3.301 % 7.325 %	
	T[-2; 0] T[-1; 0] T[0; 0] T[+1; 0]	-15.42° 0° 15.42°	3.301 % 7.325 % 3.301 %	
	T[-2; 0] T[-1; 0] T[0; 0] T[+ 1; 0] T[+ 2; 0]	-15.42° 0° 15.42° 32.13°	3.301 % 7.325 % 3.301 % 3.361 %	
	T[-2; 0] T[-1; 0] T[0; 0] T[+1; 0] T[+2; 0] T[+3; 0]	-15.42° 0° 15.42° 32.13° 52.92°	3.301 % 7.325 % 3.301 % 3.361 % 0.349 %	v

Pro	perty Browser	<b>–</b>
å	12: Polar Diagram – *(	Grating Order Analyzer" (# 800)
Vie	w	
~	General	
>	Window Size	400, 420
~	y-Axis	
	Maximum	25 %
	Minimum	0 %

#### **Outputs in Order Collection**



- The *Grating Order Collection* object is used to visualize the calculated grating efficiencies or the Rayleigh coefficients over different coordinates.
- The user can configure how the data is to be shown by setting different options via the *Property Browser*.



# **Order Collection Settings**

Property Browser 🚽		
11: Reflection Result – "Grating Order Analyzer" (#       Data to Show     View       Data Array     Selections	Option	Description
<ul> <li>General         <ul> <li>Coordinate Type</li> <li>Order Number</li> <li>Data to Show</li> <li>Efficiency</li> </ul> </li> <li>Order Selection Strategy         <ul> <li>Strategy</li> <li>Above Efficiency Threshold</li> <li>Efficiency Threshold</li> <li>1E-08 %</li> </ul> </li> </ul>	Coordinate Type	This property can be used to define the coordinates against which the data will be plotted. Currently the order collection supports the visualization over <i>Cartesian</i> <i>Angles</i> , <i>Spherical Angles</i> , <i>Wave Number Vectors</i> and <i>Positions</i> .
	Data to Show	It is possible to select the different data values that should be shown. The user can select to display the efficiency or the Rayleigh coefficient over the selected coordinate type. For Rayleigh coefficients $E_x$ , $E_y$ , $E_z$ , TM and TE are supported.
Coordinate Type The type of the coordinates.	Order Selection Strategy	The user can define which order(s) shall be displayed. In addition, it is possible to define whether to show <i>All</i> , show only orders which have an efficiency <i>Above a Given Threshold</i> or show only orders in a manually defined <i>Order Range</i> . Depending on the selection strategy the user may have to define additional parameters.

## **Order Collection Settings**



- In the *View* tab of the property browser, the user can further configure how the information is displayed.
- Most important from a visual standpoint are the color settings – it is possible to select the background color for the view, as well as the color lookup table that shall be used to represent the values of the displayed data.

## **Example of Customized Order Collection Settings**



# **Example of Customized Order Collection Settings**



## **Example of Customized Order Collection Settings**



## **Visualization of Conical Diffraction**

Position this Element's Input Axes with Respect to Reference Element  Reference Output Coordinate System  Relative Distance on Axis  Delta Z  0 mm  Lateral Shift  Delta X 0 mm Delta Y 0 mm  Inclination / Rotation  Orientation Definition Type Spherical Angles  (#)   C-Axis Direction Definition  Value  Theta (Spherical) ~ 40°  Phi (Spherical) ~ 40°	Basal Positioning	Isolated Positioning	Position Information (Ab	olute)	
Reference Element 0: Ideal Plane Wave   Reference Output Coordinate System   Relative Distance on Axis   Delta Z   0 mm     Lateral Shift   Delta X   0 mm   Delta Y   0 mm   Delta X   0 mm   Delta Y   0 mm   Delta X   0 mm   Delta Y   0 mm   Inclination / Rotation   Orientation Definition Type   Spherical Angles   (#)   Theta (Spherical)    40°   Phi (Spherical)	Position this Ele	ment's Input Axes wit	h Respect to		
Reference Output Coordinate System     Relative Distance on Axis   Delta Z     0 mm     Lateral Shift   Delta X   0 mm     Delta X     0 mm     Delta X     0 mm     Delta X     0 mm     Delta X     0 mm     Delta X     0 mm     Delta X     0 mm     Delta X     0 mm     Delta X     0 mm     Delta X     0 mm     Delta X     0 mm     Delta X     0 mm     Delta X     0 mm     Delta X     0 mm     Delta X     0 mm     Delta X     0 mm     Delta Y     0 mm     Delta Y     0 mm     Delta Y   0 mm   Delta X   0 mm   Delta X   0 mm   Delta Y   0 mm   Delta X   0 mm   Delta X   0 mm   Delta X   0 mm   Delta Y   0 mm   Delta Y   0 mm <t< td=""><td>Reference Eleme</td><td>ent 🛛</td><td>0: Ideal Plane Wave</td><td>~</td><td></td></t<>	Reference Eleme	ent 🛛	0: Ideal Plane Wave	~	
Relative Distance on Axis         Delta Z       0 mm         Lateral Shift         Delta X       0 mm         Inclination / Rotation         Orientation Definition Type       Spherical Angles         Z-Axis Direction Definition         Theta (Spherical) >         Swap Order	Reference Output	t Coordinate System		~	
Relative Distance on Axis         Delta Z       0 mm         Lateral Shift         Delta X       0 mm         Inclination / Rotation         Orientation Definition Type       Spherical Angles         Z-Axis Direction Definition         Year         Angle / Axis         Value         Theta (Spherical) >         40°         Phi (Spherical) >		a coordinate system			
Delta Z 0 mm Lateral Shift Delta X 0 mm Delta Y 0 mm Inclination / Rotation Orientation Definition Type Spherical Angles (iii)  Z-Axis Direction Definition  Z-Axis Direction Definition  Angle / Axis Value Theta (Spherical) ~ 40° Phi (Spherical) ~ 40°	Relative Distance	e on Axis			
Lateral Shift Delta X 0 mm Delta Y 0 mm Inclination / Rotation Orientation Definition Type Spherical Angles (;;;) Z-Axis Direction Definition Z-Axis Direction Definition Theta (Spherical) > 40° Phi (Spherical) > 40°	Delta Z		0 mm		
Delta X 0 mm Delta Y 0 mm Inclination / Rotation Orientation Definition Type Spherical Angles (;;;) Z-Axis Direction Definition Z-Axis Direction Definition	Lateral Shift				
Inclination / Rotation Orientation Definition Type Spherical Angles ( )	Delta X	0 mm	Delta V		0 mn
Angle / Axis     Value       Theta (Spherical)     40°       Swap Order     Phi (Spherical)	i	7 Avis Direction De	finition		
Swap Order ↓ Phi (Spherical) ✓ 40°	1	Z-Axis Direction De	finition		
Order 40	ľ	Z-Axis Direction De Angle / Ax	finition is Value	40*	
	۵ ۲)	Z-Axis Direction De Angle / Ax Theta (Spheric	finition is Value al) ~	40°	
	Swap Order≎	Z-Axis Direction De Angle / Ax Theta (Spheric Phi (Spherical)	finition is Value al) ~	40° 40°	
Rotation About Z-Axis	Swap Order	Z-Axis Direction De Angle / Ax Theta (Spherical) Phi (Spherical) Rotation About Z-A	finition is Value al) ~ 	40° 40°	

- In the *Position/Orientation* panel of the configuration dialog of the grating, it is possible to alter the orientation of the grating with respect to the source.
- For this use case we use *Theta* =  $40^{\circ}$  and *Phi* =  $40^{\circ}$  as an example.

# **Efficiencies vs Diffraction Order Number**





# **Efficiencies vs Diffraction Order Position at Given Distance**

Pro	perty Browse	er			Þ
÷	15: Reflectio	on Result	- "Grating Or	der Analyze	r" (#
Dat	a to Show	View	Data Array	Selections	
~	General				
	Coordinate	Туре	Position		
	Distance		1 m		
	Data to Sho	w	Efficiency		
~	Order Selec	tion Stra	ategy		
	Strategy		Above Efficie	ncy Thresho	bld
	Efficiency T	hreshold	1E-08 %		
Co	ordinate Typ	pe			
The	type of the	coordina	ates.		



#### settings

## **Efficiencies vs Diffraction Order Cartesian Angle**

Da	ta to Show	View	Data Array	Select	ions
v	General		ti Cart		
	Coordinate	Туре	Cartesian	Angle	
	Data to She	ow	Efficiency		
~	Order Sele	ction Stra	tegy		
	Strategy		Above Effi	ciency T	hreshold
	Efficiency T	hreshold	1E-100 %		



#### settings

title	Grating Order Analyzer
document code	GRT.0002
document version	2.0
software edition	VirtualLab Fusion Advanced
software version	2021.1 (Build 1.180)
category	Feature Use Case
further reading	<ul> <li>Analysis of Blazed Grating by Fourier Modal Method</li> <li>Optimization of Lightguide Coupling Grating for Single Incidence Direction</li> </ul>