

Introduction to the Parametric Optimization Document



The Parametric Optimization document of VirtualLab Fusion enables the user to apply non-linear optimization algorithms for their Optical Setups. The document guides you through the configuration of the optimization and outputs the results. This use case explains the different options and setting. Currently three local and one global optimization algorithms are included.

Parametric Optimization Document

The *Parametric Optimization* document can be generated for Optical Setups that output numbers to be optimized via an active detector or analyzer.

The *Parametric Optimization* document can be opened via

- the ribbon item Optical Setup > New Parametric Optimization
- the shortcut "Ctrl + T"
- the *Tools* button of the Optical Setup Editor







Parameter Selection

4: Parametric Optimization from "3: sample setup_laser guide star"* Parameter Selection Select the parameters which shall be varied during optimization. You can select one or more parameter which shall be varied within the optimization. Filter by.. X Show Only Varied Parameters ٠ 1 2 * Object Category Parameter Varv Original Value 🔥 Oversampling Factor Gridless Data Simulation Settings Oversampling Factor Gridded Data 1 • Optical Setup Fourier Transform Accuracy 1 Parameter System Temperature Environment \Box 101.325 kPa Air Pressure Material (Air) | Constant Absorption... ٠ Medium at "-" Output (Air in Homogeneou... 0 Wavelength 532 nm Weight Polarization Angle Distance to Input Pla "Gaussian Wave" (# 0) Lateral Offset X Lateral Offset Y Number of Rays X Number of Rays Y

Via the parameter list the user can select which parameters should be considered for the optimization. At least one needs to be selected.

Some features for a better overview

- By clicking the numerical column headers, the list entries can be folded and unfolded.
- It can be chosen that only the varied parameters are shown.
- The original value is always stated.

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	P	Parameter Selection											
	Select the parameters which shall be varied during optimization.												
-		You car	n select one	or more para	ameter which shi	all be var	ied within the optin	nization.					
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		1 2 *	Object	Category	Parameter	Vary	Original Value						
			"L1" (# 1)		Focal Length	\sim	150 mm	Chook Show Only Variad Parameters to					
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Specification of Detecting Device

▲ 4: Parametric Optimization from "3: sample setup_laser guide star"* - - X Depending on the Optical Setup an **Detecting Device Specifications** A validity indicator Set up the detecting devices whose results you want to optimize. optimization can be performed by using shows This page allows you to select one or more detecting devices (detectors or analyzers) whose measurem one warnings & errors detecting device must be selected. If you click on the "Open" button of one detecting device, the corresponding edit dialog is displayed. either \rightarrow a certain simulation engine In the upper part you can select the simulation engine that shall be used for the optimization. Furthermore you can select the detector hall be and a detector evaluated by the selected simulation engine. Validity: 📥 📘 Field Tracing Classic Field Tracing Ray Tracing Detector Edit Dialog \rightarrow an analyzer. or \sim "Beam Parameters" (# 600) Open Edit Beam Parameters Detector Detector Window and Resolution Detector Function Detector Window In the lower part you can select the analyzers that shall be Coordinate Scale Window Size by Factor Systems above. O Set Window Size Edit Dialog Position / Analyzer Copy from Center Position 0 mm 0 mm "Focal Length Analyzer" (# 802) Open Orientation Detector Resolution The detector and the analyzer, Scale Sampling Distance by M. Oversampling Factor 0 0 respectively, can be edited by Detector O Set Sampling Distance Parameters clicking **Open**. 512 🜩 🗙 512 ≑ Set Number of Sampling Points 512² (1:1) $\mathcal{F} = \mathcal{F}^{-1}$ Copy from Fourier Transforms Settings Interpolation Method Cubic 6 Point \sim

Constraints Specification

ion from "19: Optical Setup"*									
raints which shall be considered during optimization	1.								
Constraint Name	Use	Weight	Constraint Type	Value 1	Value 2	Start Value	Contribution	r	
e #1 (Aspherical Surface) Radius of Curvature	\checkmark	1	Range	-1E-300 mm	1E+303 mm	25 mm	N/A		free parameter constraints
e #1 (Aspherical Surface) Conical Constant	\checkmark	1	Range	-1000	1000	0	N/A		
e #1 (Aspherical Surface) Aspherical Parameter 1	\checkmark	1	Range	-1E+300	1E+300	0	N/A		
e #1 (Aspherical Surface) Aspherical Parameter 2	\checkmark	1	Range	-1E+300	1E+300	0	N/A		
Diameter X	\leq	3.8715	Target Value	0 mm		N/A	N/A		merit functions constraints
Diameter Y	\checkmark	1	Target Value	0 mm		N/A	N/A		
rical Surface # 1 Minimal Local Radius		1	Lower Limit	10 mm		N/A	N/A		
	Constraint Name constraint Name constraint Name e #1 (Aspherical Surface) Radius of Curvature e #1 (Aspherical Surface) Conical Constant e #1 (Aspherical Surface) Aspherical Parameter 1 e #1 (Aspherical Surface) Aspherical Parameter 2 Diameter X Diameter Y	raints which shall be considered during optimization. Constraint Name Use #1 (Aspherical Surface) Radius of Curvature #1 (Aspherical Surface) Conical Constant ##1 (Aspherical Surface) Aspherical Parameter 1 ##1 (Aspherical Surface) Aspherical Parameter 2 ##1 (Aspherical Surface) Aspherical Parameter 2 Diameter X Diameter Y	constraint Name Use Weight constraint Name Use Weight ce #1 (Aspherical Surface) Radius of Curvature 1 e #1 (Aspherical Surface) Conical Constant 1 ce #1 (Aspherical Surface) Aspherical Parameter 1 1 e #1 (Aspherical Surface) Aspherical Parameter 1 1 ie #1 (Aspherical Surface) Aspherical Parameter 2 1 Diameter X 3.8715 Diameter Y 1	In from 19: Optical Setup ** raints which shall be considered during optimization. Constraint Name Use Weight Constraint Type ie #1 (Aspherical Surface) Radius of Curvature I Range e #1 (Aspherical Surface) Conical Constant I Range ie #1 (Aspherical Surface) Conical Constant I Range ie #1 (Aspherical Surface) Aspherical Parameter 1 I Range ie #1 (Aspherical Surface) Aspherical Parameter 2 I Range Diameter X I 3.8715 Target Value Diameter Y I Target Value I	Constraint Name Use Weight Constraint Type Value 1 :e #1 (Aspherical Surface) Radius of Curvature I Range -1E-300 mm e #1 (Aspherical Surface) Conical Constant I 1 Range -1000 :e #1 (Aspherical Surface) Conical Constant I 1 Range -1E+300 mm :e #1 (Aspherical Surface) Conical Constant I 1 Range -1E+300 :e #1 (Aspherical Surface) Aspherical Parameter 1 I 1 Range -1E+300 :e #1 (Aspherical Surface) Aspherical Parameter 2 I 1 Range -1E+300 Diameter X I 3.8715 Target Value 0 mm Diameter Y I 1 Target Value 0 mm	Constraint Name Use Weight Constraint Type Value 1 Value 2 c #1 (Aspherical Surface) Radius of Curvature ✓ 1 Range -1E-300 mm 1E+303 mm e #1 (Aspherical Surface) Conical Constant ✓ 1 Range -1E+300 1000 ie #1 (Aspherical Surface) Aspherical Parameter 1 ✓ 1 Range -1E+300 1E+300 ie #1 (Aspherical Surface) Aspherical Parameter 2 ✓ 1 Range -1E+300 1E+300 ie #1 (Aspherical Surface) Aspherical Parameter 2 ✓ 1 Range -1E+300 1E+300 ie #1 (Aspherical Surface) Aspherical Parameter 2 ✓ 1 Range -1E+300 1E+300 ie #1 (Aspherical Surface) Aspherical Parameter 2 ✓ 1 Range -1E+300 1E+300 Diameter X ✓ 3.8715 Target Value 0 mm 0 0 0 Diameter Y ✓ 1 Target Value 0 mm 0 0 0	Constraint Name Use Weight Constraint Type Value 1 Value 2 Start Value re #1 (Aspherical Surface) Radius of Curvature ✓ 1 Range -1E-300 mm 1E+303 mm 25 mm e #1 (Aspherical Surface) Conical Constant ✓ 1 Range -1000 1000 0 e #1 (Aspherical Surface) Conical Constant ✓ 1 Range -1E+300 1000 0 e #1 (Aspherical Surface) Aspherical Parameter 1 ✓ 1 Range -1E+300 1E+300 0 e #1 (Aspherical Surface) Aspherical Parameter 2 ✓ 1 Range -1E+300 1E+300 0 ce #1 (Aspherical Surface) Aspherical Parameter 2 ✓ 1 Range -1E+300 1E+300 0 ce #1 (Aspherical Surface) Aspherical Parameter 2 ✓ 1 Range -1E+300 1E+300 0 ce #1 (Aspherical Surface) Aspherical Parameter 2 ✓ 1 Range -1E+300 1E+300 0 Diameter X ✓ 3.8715 Target Value 0 mm N/A Diameter Y ✓ 1	Constraint Name Use Weight Constraint Type Value 1 Value 2 Start Value Contribution e #1 (Aspherical Surface) Radius of Curvature I 1 Range -1E-300 mm 1E+303 mm 25 mm N/A e #1 (Aspherical Surface) Conical Constant I 1 Range -1000 1000 0 N/A e #1 (Aspherical Surface) Conical Constant I 1 Range -1E+300 1E+300 0 N/A e #1 (Aspherical Surface) Aspherical Parameter 1 I 1 Range -1E+300 1E+300 0 N/A e #1 (Aspherical Surface) Aspherical Parameter 2 I 1 Range -1E+300 1E+300 0 N/A e #1 (Aspherical Surface) Aspherical Parameter 2 I 1 Range -1E+300 1E+300 0 N/A piameter X I 3.8715 Target Value 0 mm N/A N/A Diameter Y I 1 Target Value 0 mm N/A N/A	Constraint Name Use Weight Constraint Type Value 1 Value 2 Start Value Contribution e #1 (Aspherical Surface) Radius of Curvature 1 Range -1E-300 mm 1E+303 mm 25 mm N/A e #1 (Aspherical Surface) Conical Constant 1 Range -1000 1000 0 N/A e #1 (Aspherical Surface) Conical Constant 1 1 Range -11E+300 1E+300 0 N/A e #1 (Aspherical Surface) Aspherical Parameter 1 1 1 Range -1E+300 1E+300 0 N/A e #1 (Aspherical Surface) Aspherical Parameter 2 1 1 Range -1E+300 1E+300 0 N/A e #1 (Aspherical Surface) Aspherical Parameter 2 1 1 Range -1E+300 1E+300 0 N/A e #1 (Aspherical Surface) Aspherical Parameter 2 1 1 Range -1E+300 0 N/A Diameter X 3.8715 Target Value 0 mm N/A N/A Diameter Y 1 1 Target Value 0 mm N/A N/A

On this page the user can specify the constraint types and associated value(s) for

- the selected free parameters of the system
- all the merit functions calculated by the detector or analyzer
- possible general structure quantities, that depend on free parameter(s) and cannot directly be modified.

Constraints Specification

处 24: Parametric Op	timization from "19: Optical Setup"*							- • •		
Constraint Specifical	ions									
Select and specify th	e constraints which shall be considered during optimization	1.								If any <i>Start Value</i> is initially in the allowed value range, the
Constraint Host	Constraint Name	Use	Weight	Constraint Type	Value 1	Value 2	Start Value	Contribution		Associated Contribution is
	Surface #1 (Aspherical Surface) Radius of Curvature	\checkmark	1	Range	-1E-300 mm	1E+303 mm	25 mm	0 %	X	regarded as 0%
"Lens System" (# 1)	Surface #1 (Aspherical Surface) Conical Constant	\checkmark	1	Range	-1000	1000	0	0 %	4	9
cens system (* 1)	Surface #1 (Aspherical Surface) Aspherical Parameter 1	\checkmark	1	Range	-1E+300	1E+300	0	0 %		
	Surface #1 (Aspherical Surface) Aspherical Parameter 2	\checkmark	1	Range	-1E+300	1E+300	0	0 %		
"Spot Size" (# 601)	Beam Diameter X	\checkmark	1	Target Value	0 mm		204.23 µm	20.528 %		
Spot Size (# 001)	Beam Diameter Y	\checkmark	1	Target Value	0 mm		401.84 µm	79.472 %		
"Lens System" (# 1)	Aspherical Surface # 1 Minimal Local Radius	\checkmark	1	Lower Limit	10 mm		25 mm	0 %		
<u>T</u> ools थ्थि ↓				Target	Function Value	< Back	.0318E-07 Next >	Update Show *]	

By clicking **Update**, the simulation of the Optical Setup with the set Start Values of the free parameters is triggered. The resulting the merit functions (i.e. their Start Values) are displayed as well as

- \rightarrow their contribution (relevance or priority) for the optimization
- → the Common Merit Function Value = Target Function Value, which is defined as the weighted sum over all constraints.

Weights & Contributions

№ 24: Parametric Optimization from "19: Optical Setup"*

Constraint Specifications

Select and specify the constraints which shall be considered during optimization.

Constraint Host	Constraint Name	Use	Weight	Constraint Type	Value 1	Value 2	Start Value	Contribution			
	Surface #1 (Aspherical Surface) Radius of Curvature		1	Range	-1E-300 mm	1E+303 mm	25 mm	0 %			
"Lens System" (# 1)	Surface #1 (Aspherical Surface) Conical Constant		1	Range	-1000	1000	0	0 %			
cens system (* 1)	Surface #1 (Aspherical Surface) Aspherical Paramet	er 1 🗹	1	Range	-1E+300	1E+300	0	0 %			
	Surface #1 (Aspherical Surface) Aspherical Paramet	er 2 🗹	1	Range	-1E+300	1E+300	0	0 %			
"Spot Size" (# 601)	Beam Diameter X		3.8715	Target Value	0 mm		204.23 µm	50 %			
Spot 5126 (# 001)	Beam Diameter Y	\checkmark	1	Target Value	0 mm		401.84 µm	50 %			
"Lens System" (# 1)	Aspherical Surface # 1 Minimal Local Radius	\checkmark	🔺 1	Lower Limit	10 mm		25 mm	/ 0%			
Tools 🎢 🗸 Reset Start to	Initial Values			Target	Function Value	3	.2294E-07	Update			
Tools 🎢 🗸				Target	Function Value	3	.2294E-07	Update			
Set Optimize	d Start Values	Constraint	× [< Back	Next >	Show •					
Set Values from Certain Simulation Step Choose Constraint from List:											
Distribute Co	ntributions Uniformly Constrain	onstraint Na am Diamet	me Select er X 🗹	l A	After a i	run opt	timizatio				
Set Contribut	tion	Be	am Diamet	er Y		ontimized values as					
Reset Weight	is a second s	_						105 05 0			
Reset All Sett	ings Enter Targ	et Contributio	on:	50 %	C	ptimiza	ation.				

The default *Weights* have the value 1. They can be altered directly in the table or via the *Tools*' options.

E.g. one can set all contributions uniformly or one can assign a distinct percentage for a single constraint.

After a run optimization it is possible to set the optimized values as *Start Values* for a subsequent optimization.

- - X

Choice of Optimization Method

All provided optimizations aim to minimize the target function value.

24: Parametric Optimization from "19: Optical Setup"*	
General Settings	
Set up general settings for the optimization (e.g. the optimization algorithm	m).
Optimization Strategy O Local Optimization	
Local Optimization Settings 2	-Global Optimization Settings
Optimization Algorithm Downhill Simplex 🗸	Optimization Algorithm Simulated Annealing ~
Maximal Number of Iterations 500 Maximum Tolerance 1E-12	Number of Annealing Steps 4 Start Temperature 0.1
Initial Step Width Scale Factor	
	< Back Next > Show *

- 1. Select optimization strategy (local or global)
- 2. Define settings for local optimization
 - Select optimization algorithm
 - The algorithm stops when either the *Maximal Number of Iterations* is reached* or the deviation of from the last simulation step is less than the *Maximum Tolerance***.
 - Via the *Initial Step Width Scale Factor*, the step widths from the *Start Values* to the first iteration's values of all free parameters are scaled. I.e. the search area around the initial configuration is controlled; e.g. by higher values one might jump out of a local minimum area.
- 3. Define settings for global optimization
- * The result table might list more iterations; this originates from the fact that some optimization algorithms also show interim function results. ** As a rule of thumb one can set a Maximum Tolerance value which is about 4-5 magnitudes smaller than the inital Target Function Value.

Local & Global Optimization



illustration of the target function for 2 variable (in 3D and 2D)

Local optimization algorithms are fast but their success in finding the global minimum often strongly depends on the choice of the start value. Therefore, in cases where no good start values are known, global optimization is preferable.



Algorithms for Local Optimization

ⓑ 6: Parametric Optimization from "19: Optical Setup"**
General Settings
Set up general settings for the optimization (e.g. the optimization algorithm).
Optimization Strategy
Local Optimization Global Optimization
Local Optimization Settings
Optimization Algorithm Downhill Simplex ~
Maximal Number of Iterati Levenberg-Marquardt Algorithm
Maximum Tolerance 1E-12
Initial Step Width Scale Factor

Currently, three non-linear local algorithms for minimizing a multivariate function are provided:

- **Downhill Simplex method by Nelder & Mead** it does not converge very fast, but is a simple and robust method. Typically, well suited for less than 6 free parameters.
- Powell's (direction set) method it might be better suited for larger numbers of free parameters (>10).

Levenberg-Marquardt algorithm

it "interpolates between the Gauss–Newton algorithm and the method of gradient descent. [...] in many cases it can find a solution even if it starts very far off the final minimum."* Convergence is likely but not guaranteed.

All local minimizing algorithms pose the risk of getting stuck in a local minimum. To minimize this risk one can try to use larger *Initial Step Width Scale Factors*, start with different initial conditions or use a global optimization algorithm.

source: <u>https://en.wikipedia.org/wiki/Levenberg%E2%80%93Marquardt_algorithm</u> from 2021-10-13

محمد معمد معمد معمد معمد معمد معمد معمد	local optimization algorithm
○ Local Optimization	Downhill-Simplex is applied.
ocal Optimization Settings	Global Optimization Settings
Optimization Algorithm Downhill Simplex	✓ Optimization Algorithm Simulated Annealing ✓
Maximal Number of Iterations	500 Number of Annealing Steps 4
Maximum Tolerance 1E	-12 Start Temperature 0.1
nitial Step Width Scale Factor	1

VirtualLab Fusion provides **Simulated Annealing** for a global optimization^{*}, which enables a search for the global minimum of the target function by adding a random temperature term t to the current value, with

$$t = T \log r$$

where r is a random value between 0 and 1 and T is the temperature, which is gradually decreased according to an annealing schedule with an adjustable *Start Temperature* and *Number of Annealing Steps*.

The success of the global search depends heavily on the chosen values for *Start Temperature* and *Number of Annealing*. 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.

* The names of this global optimization algorithms and its parameters are an anology to the annealing in metallurgy where a low energy state close to the optimum is reached if a wise cooling process is chosen.

Optimization Results

In the final table the parameters and associated results are shown.

Some optimization algorithms (such as e.g. *Downhill Simplex*) actually do not allow constraints. Instead penalty rules are applied. Currently all results cells, that originate from parameters that exceed the constraints settings, are empty.



title	Introduction to the Parametric Optimization Document
document code	MISC.0090
document version	1.1
software version	2021.1 (Build 1.180)
software edition	VirtualLab Fusion Basic
category	Feature Use Case
further reading	 <u>Rigorous Analysis and Design of Anti-Reflective Moth-Eye Structures</u> <u>Optimization of Lightguide with Continuously Modulated Grating Regions</u> <u>Design of 2D Non-Paraxial Beam-Splitting Metagrating</u>