

DO.002 Optimization of Diffractive Optical Element for diffuse illumination of rectangular area (Top Hat).

Example for the design of a diffractive diffuser for generation of a rectangular Top Hat.

Keywords: Diffractive Optics, Diffractive Optical Elements, Diffusers, Top Hat

Required Toolboxes: Diffractive Optics Toolbox

Related Application Scenarios: DO.001;DO.003

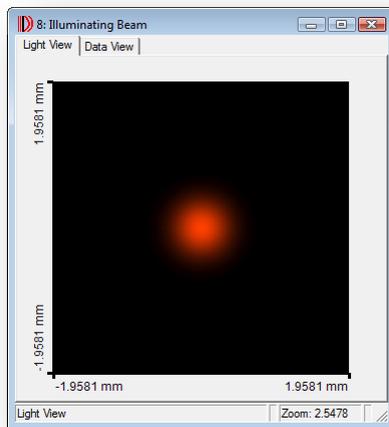
Related Tutorials: 144.01



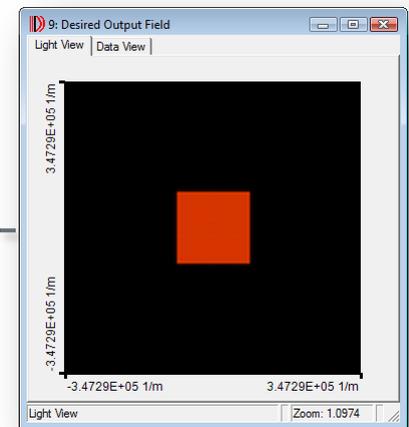
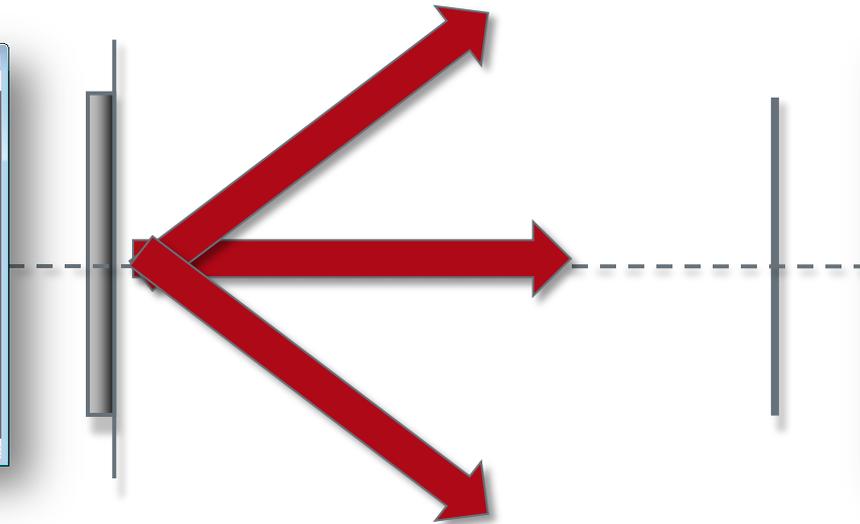
Modeling Task

Diffractive Diffuser
Diameter: 1.4 x 1.4 mm
Phase Levels: 2
Pixel Size: $>1\mu\text{m}$

Target
Plane



Illuminating Beam
Intensity

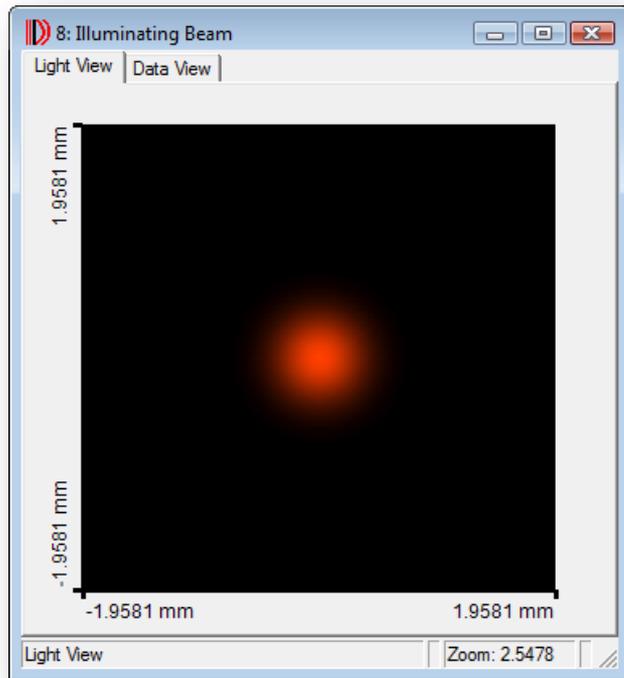


Top Hat Intensity

Angular Spectrum Setup

Modeling Task

Illuminating Beam Parameters

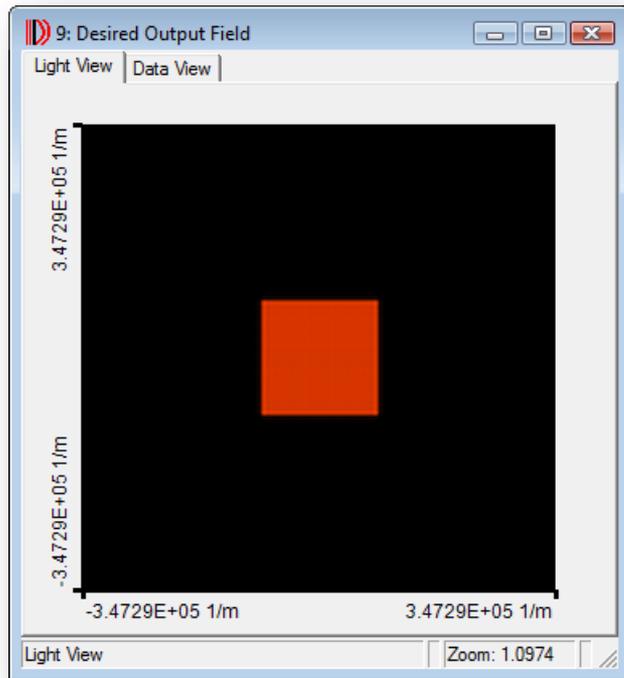


Wavelength: 632.8 nm

Laser Beam Diameter ($1/e^2$): 700 μm

Modeling Task

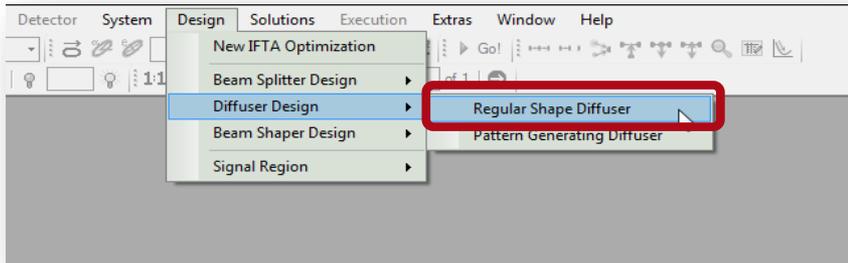
Desired Output Field Parameters



Diameter: 1°
Resolution: $\leq 0.03^\circ$
Efficiency: $>70\%$
Stray light: $<20\%$

Creation of New Session Editor

- *Regular Shape Diffuser* session editor can be used for the generation of lines, circular and rectangular Top Hats.
- Click the *Regular Shape Diffuser* menu item in the main menu to create a new session editor.

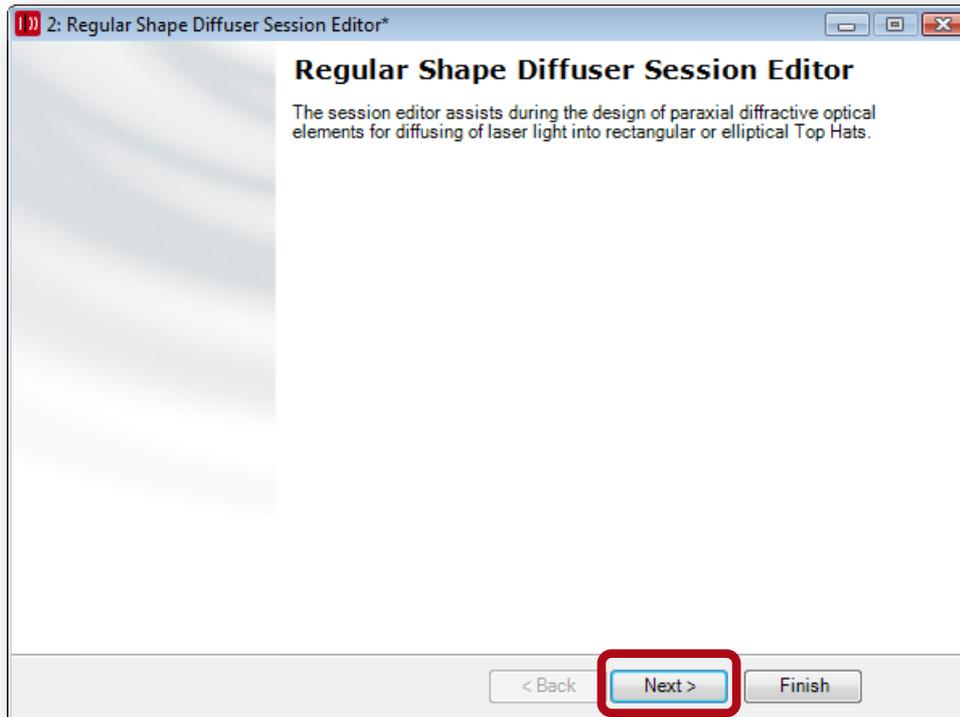


Results in



Specification of Illuminating Beam

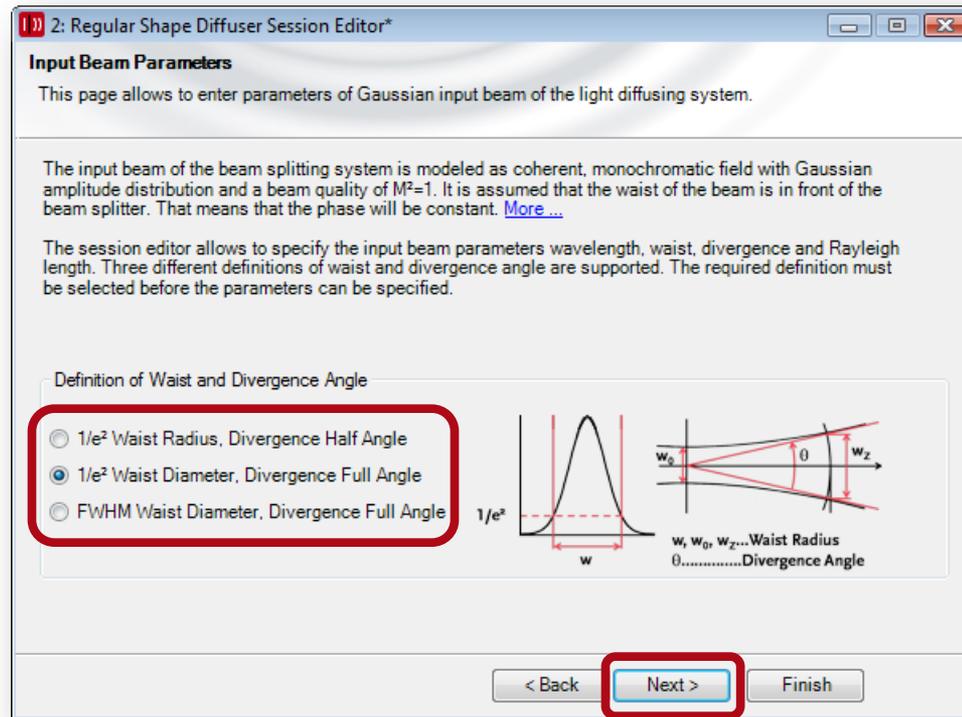
- Click *Next* button to start specification of illuminating beam.



Results in



Specification of Illuminating Beam



- This page allows to modify the definition of illuminating beam diameter and divergence angle.
- Select *1/e² Waist Diameter, Divergence Full Angle*.
- Click *Next* button.

Results in



Specification of Illuminating Beam

2: Regular Shape Diffuser Session Editor*

Input Beam Parameters

This page allows to enter parameters of Gaussian input beam of the light diffusing system.

The parameters of the input beam can be entered below. VirtualLab will use an input beam with $M^2=1$ and Gaussian amplitude profile for the simulation. This requires just the specification of waist, divergence angle or Rayleigh length since these parameters depend on each other.

Input Beam Parameters

Wavelength	632.8 nm	
<input checked="" type="radio"/> Waist	700 μm	700 μm
<input type="radio"/> Divergence Angle	0.065948°	0.065948°
<input type="radio"/> Rayleigh Length	608.16 mm	608.16 mm

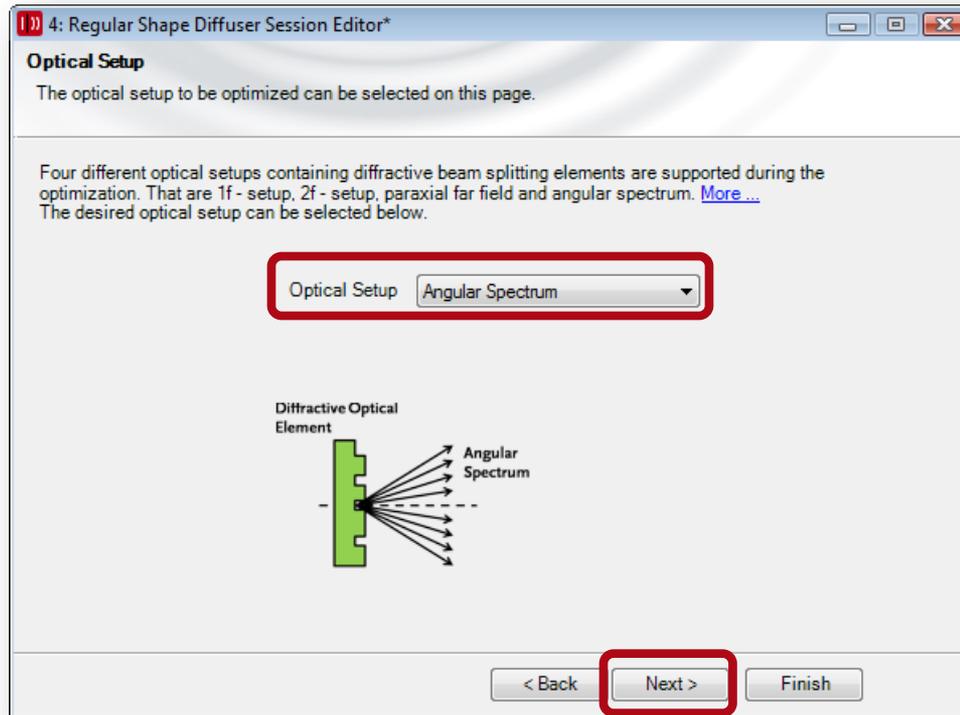
< Back **Next >** Finish

- On this page the illuminating beam can be specified.
- VIRTUALLAB™ assumes always a Gaussian beam.
- Enter the wavelength of 632.8 nm.
- Select waist specification and enter 700 μm x 700 μm .
- Click *Next* button.

Results in



Specification of Optical System Setup



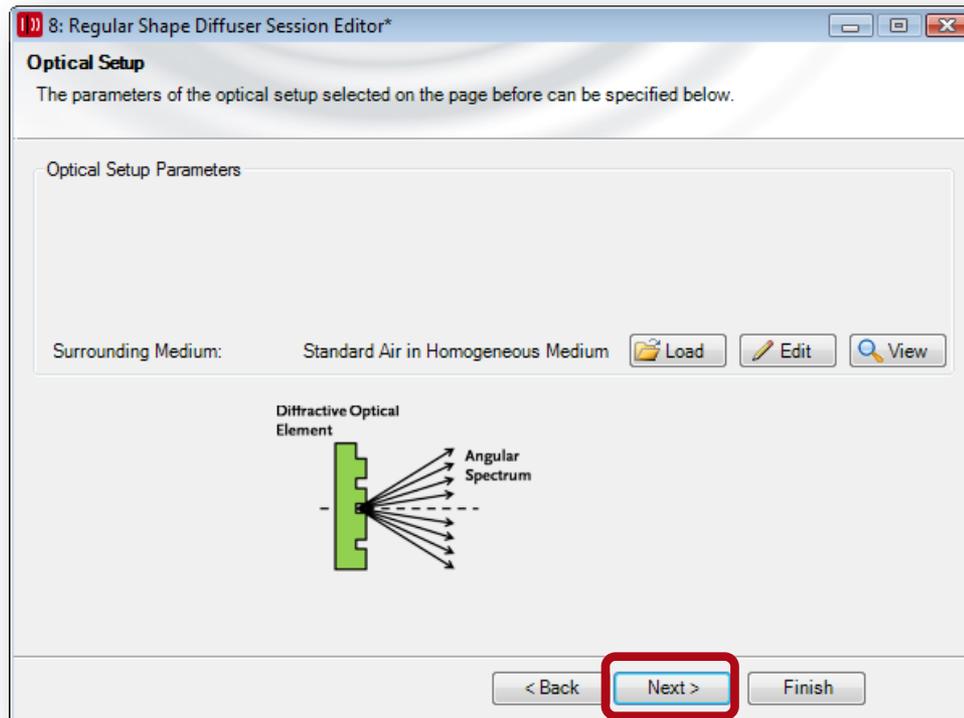
- On this page the fundamental optical setup can be selected.
- The session editor supports 1f/2f-setups, paraxial far field and angular spectrum.
- In case of 1f/2f-setup or paraxial far field further parameters must be specified on the following page.
- Select angular spectrum setup and click *Next*.

Results in

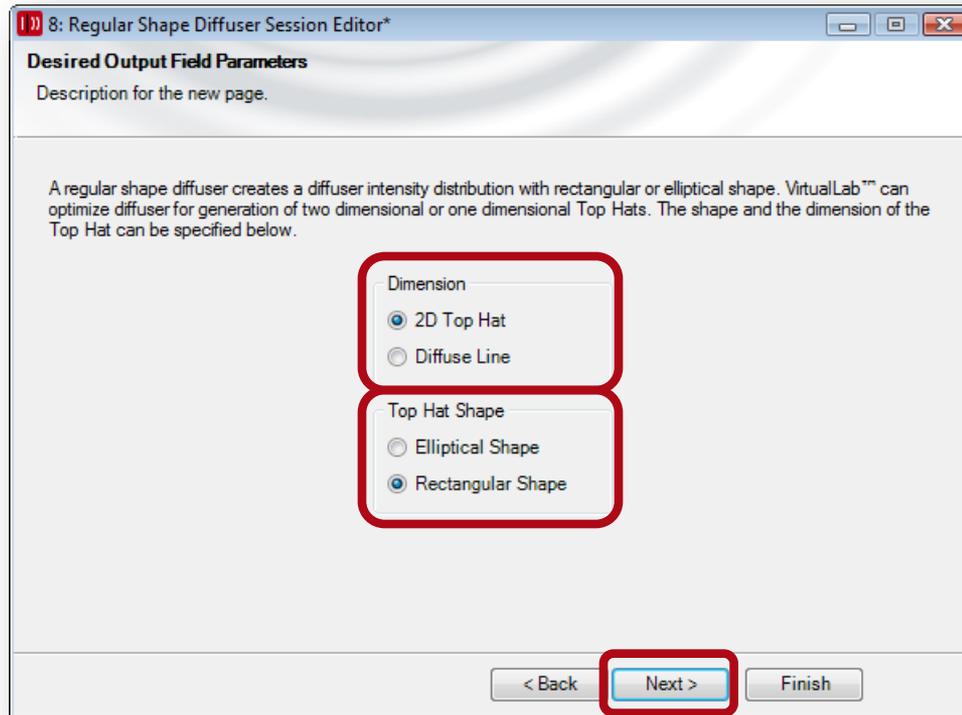


Specification of Optical System Setup

- Leave Standard Air as *Surrounding Medium*.
- Click *Next* button.



Specification of Desired Output Field



- The session editor allows the design of diffusers for generation of Top Hats and lines.
- Select *2D Top Hat*.
- Select *Rectangular Shape*.
- Click *Next* button.

Results in



Specification of Desired Output Field

8: Regular Shape Diffuser Session Editor*

Desired Output Field Parameters

Parameters of the diffuse light pattern can be specified below.

Top Hat diameter and resolution can be specified below. In order to get an optimal resolved speckle pattern the laser beam diameter ($1/e^2$) in the target plane should be approximately two times the resolution of the diffuser. It is recommended to use the 'Optimize Resolution' button to adapt the resolution on the beam diameter. Additionally an offset of the diffraction orders can be specified and the intensity of the higher orders relative to the desired orders can be limited. [More...](#)

Specification of Orders

Top Hat Diameter

Resolution

Off-Axis Design

Offset

Stray Light Intensity

Limit Intensity of Stray Light

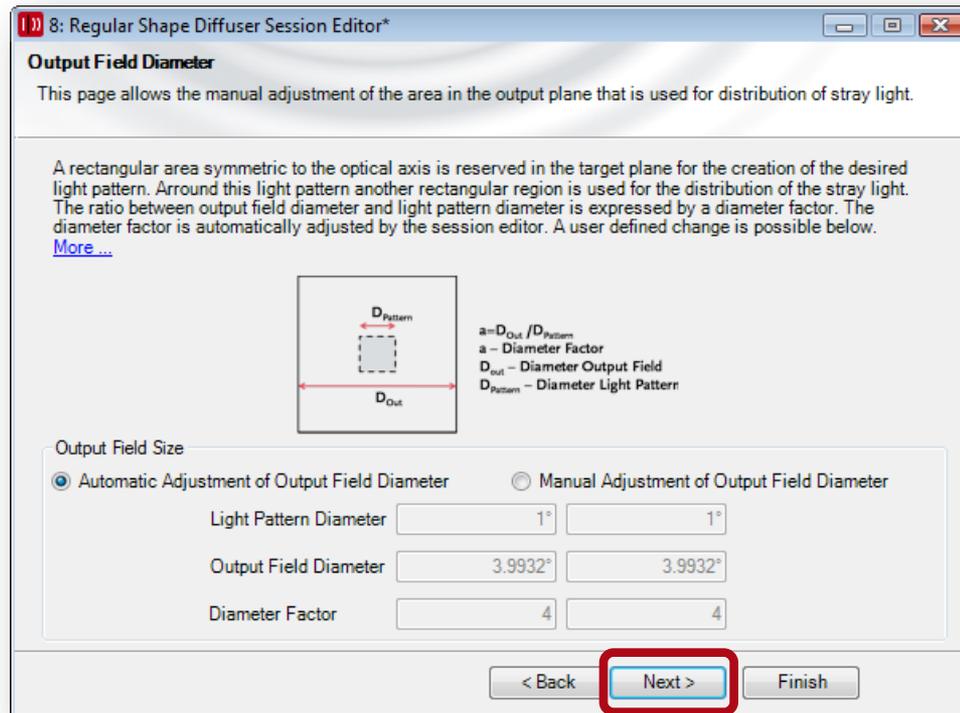
Maximum Relative Stray Light Intensity

- Specify a *Top Hat Diameter* of $1^\circ \times 1^\circ$.
- The *Top Hat Resolution* should be set to $0.03^\circ \times 0.03^\circ$.
- Since the maximum stray light should be smaller than 20% *Limit Intensity of Stray Light* must be activated. Set the *Maximum Relative Stray Intensity* to 15%.

Results in



Specification of Output Field Diameter

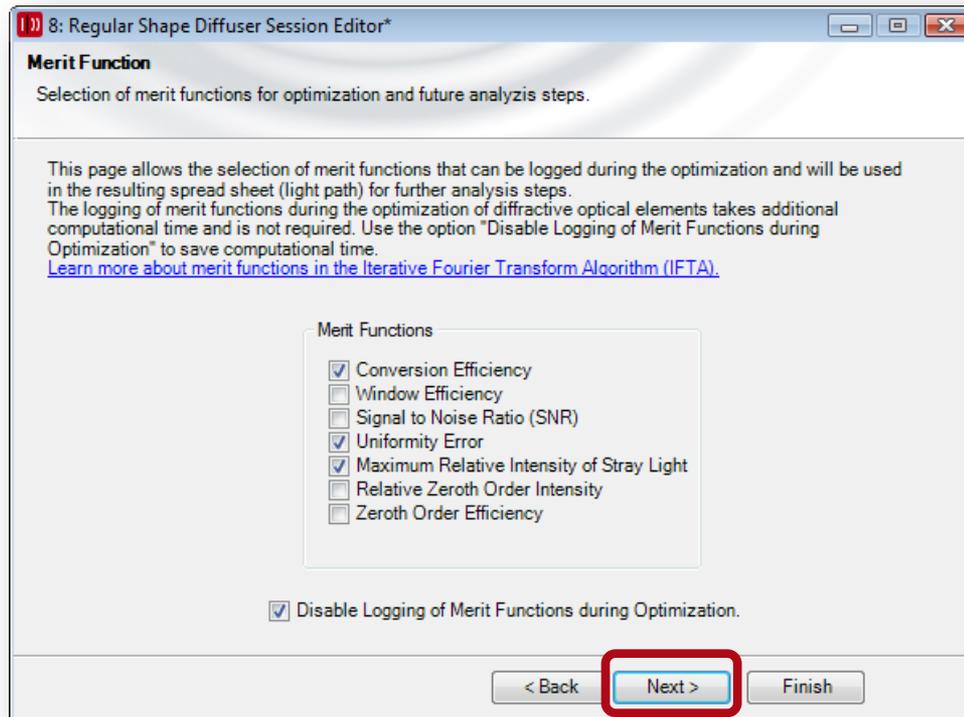


- Diffractive diffusers typically will not diffract all light in the desired pattern.
- Stray light will be diffracted to larger diffraction angles.
- Additional space is required in the target plane for stray light.
- The total diameter of the output field in the target plane can be seen here. In manual mode user defined adjustment is possible.

Results in



Selection of Merit Functions



- This page allows the selection of merit functions.
- The logging of merit functions during optimization can be disabled to speed up the optimization.

Results in



Specification of Diffuser Aperture

8: Regular Shape Diffuser Session Editor*

Diffractive Optical Element Aperture Parameters

Diameter and shaper of the aperture of the diffractive optical element can be specified below.

The diffractive optical element used for the creation of the desired output intensity distribution can have a rectangular or elliptical shape. The shape must be selected below. The aperture diameter diameter must be specified below in addition. An aperture diameter of at least 2 times the waist diameter of the input beam is recommended in order to avoid energy losses and diffraction at the aperture of the diffractive optical element.

Aperture Size and Shape

Aperture Shape Rectangular Elliptical

Aperture Diameter Automatic Setting Manual Setting

1.4 mm 1.4 mm

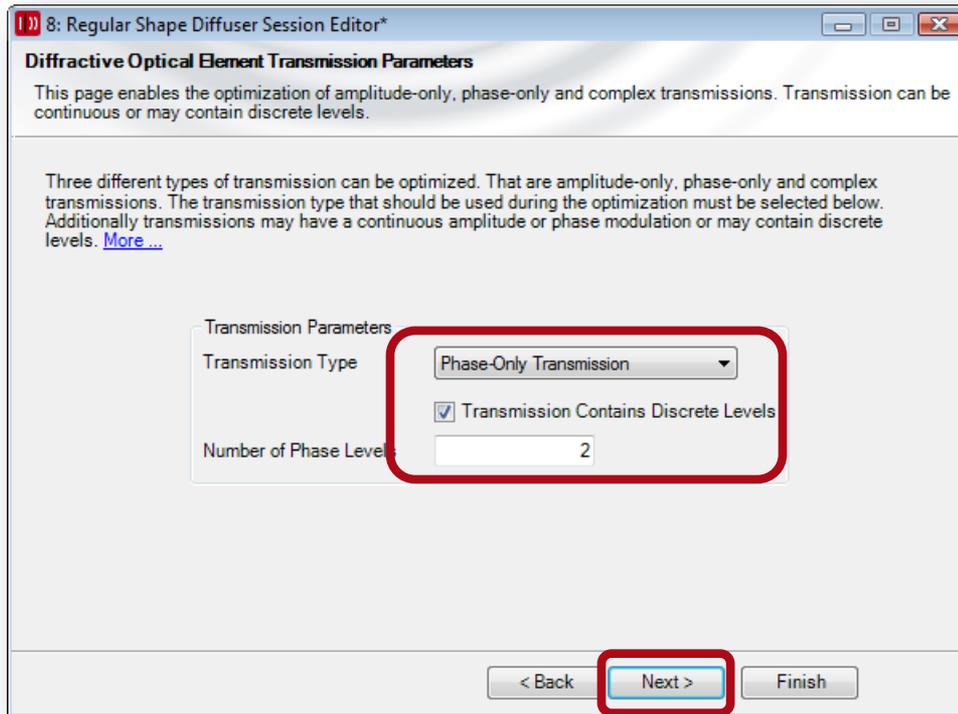
< Back **Next >** Finish

- Keep the diffuser *Aperture Shape* at *Rectangular* and the *Aperture Diameter* at *Automatic*.
- The Aperture diameter should be approximately 2-3 times larger than the $1/e^2$ diameter of the illuminating beam.

Results in



Specification of DOE Transmission Parameters



- VIRTUALLAB™ will optimize a diffuser transmission.
- In a second step a height profile can be calculated. See tutorial DO.8 for more details.
- Select *Phase-Only Transmission*.
- Activate *Transmission Contains Discrete Levels*.
- Set *Number of Phase Levels* to 2.

Results in



Specification of DOE Transmission Parameters

8: Regular Shape Diffuser Session Editor*

Diffractive Optical Element Period, Pixel Size and Number of Pixels

The required period diameter, pixel size and number of pixel per period are displayed on this page.

VirtualLab calculates from the specifications of the desired output intensity period, pixel size and number of pixels of the diffractive optical element. In order to take into account fabrication constraints a minimum pixel size and pixel size increment can be defined. [More...](#)

Automatic Setting of Pixel Size Manual Setting of Pixel Size

Pixel Size Increment: 10 nm

Minimum Pixel Size: 1 μ m

Pixel Size: 9.08 μ m

Transmission Consists of Rectangular Pixels

Period: 1.2076 mm

Number of Pixels per Period: 133

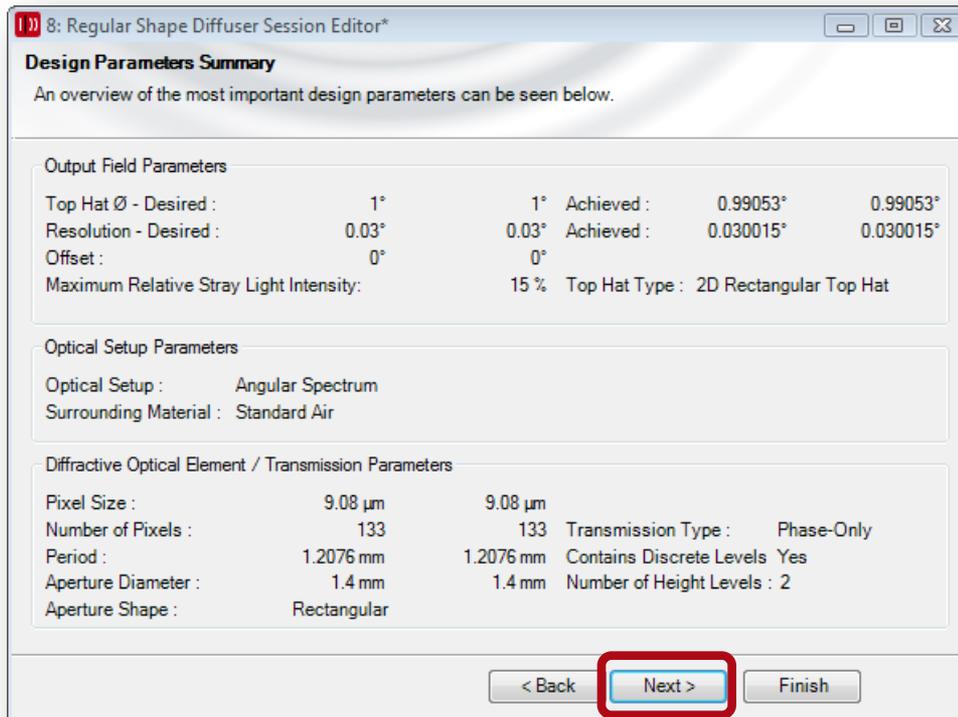
< Back Next > Finish

Results in



- Pixel size and period of the diffuser transmission are calculated automatically.
- Set the *Pixel Size Increment* to 10 nm and the *Minimum Pixel Size* to 1 μ m.
- The *Pixel Size Increment* indicates the step size in that the pixel size can be changed by the machine used for fabrication of the diffuser.
- Expert user may set a user defined pixel size.

Summary of Parameters

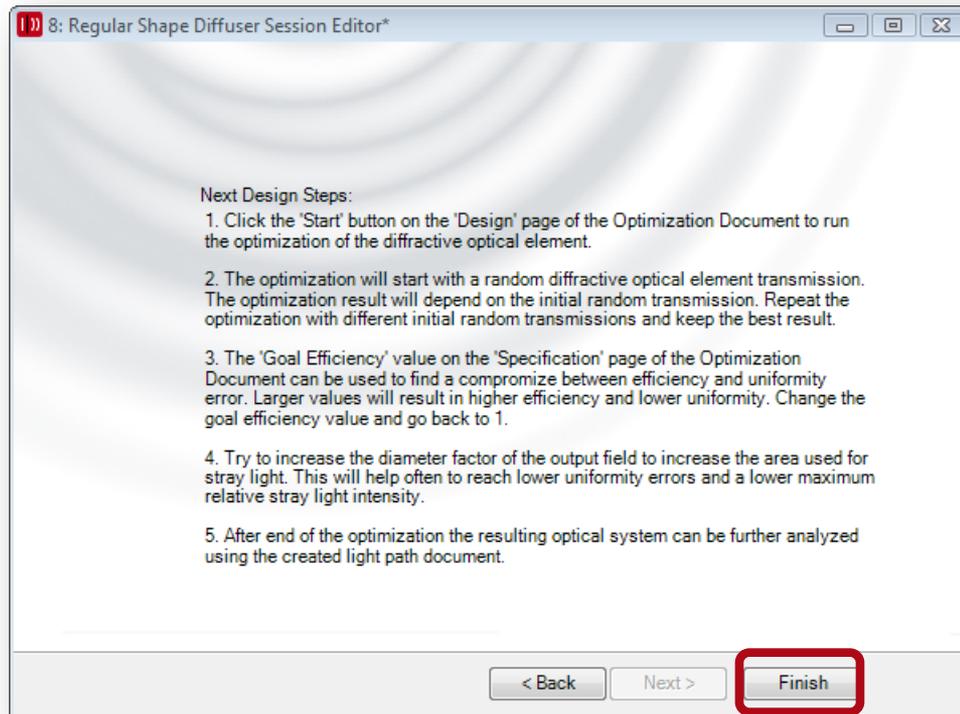


- This page shows a summary of the most important user defined and automatically calculated parameters.
- Most important are the desired and achieved Top Hat diameter and resolution.
- Because of specified pixel size increment and minimum pixel size probably the desired values can't exactly achieved.

Results in



Next Design Steps

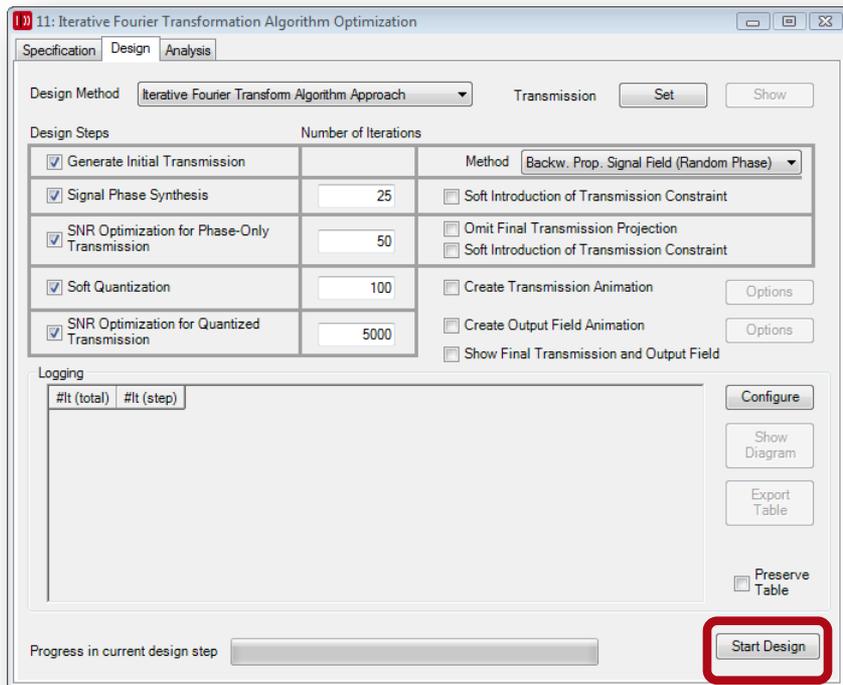


- The last page of the session editor suggests next steps for the design of the diffuser.
- Click the *Finish* button to create the *Optimization Document* used to optimize the diffuser and the *Light Path Diagram* used to simulate the complete optical system containing the diffuser.

Results in

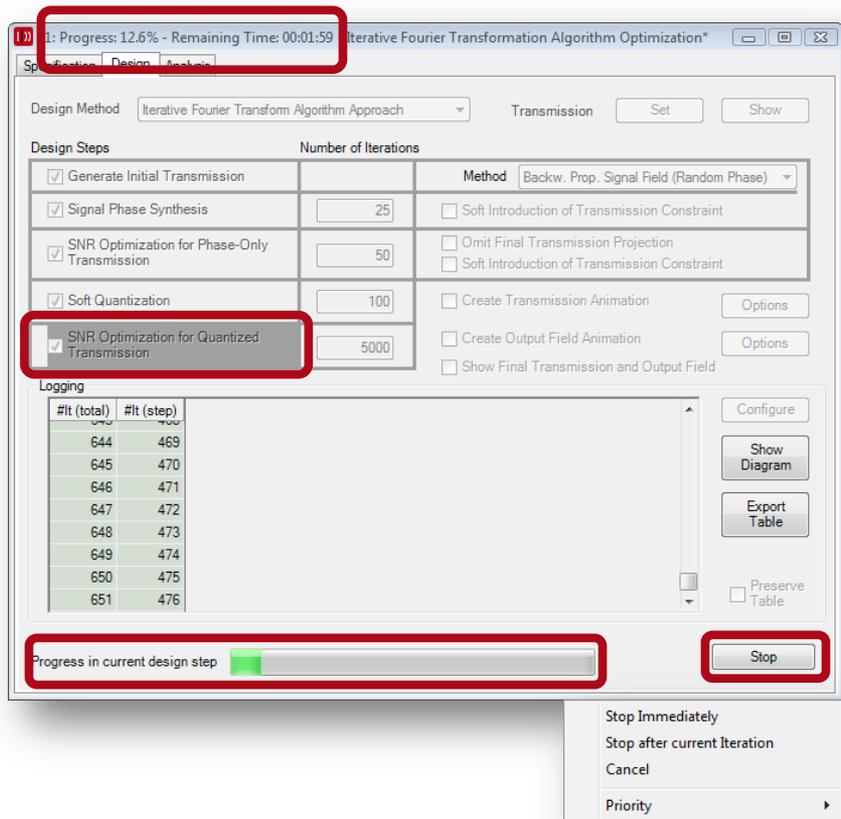


Diffuser Optimization



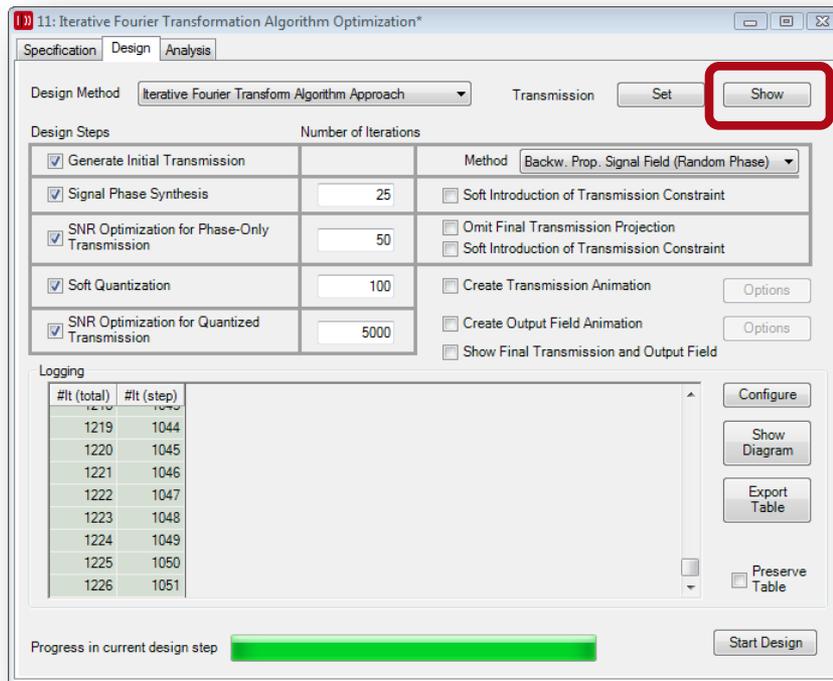
- Switch to the *Iterative Fourier Transformation Algorithm Document*
- The *Design* page allows the specification of the number of iterations per optimization steps.
- Click the *Start Design* button to start the optimization.
- The step *SNR Optimization for Quantized Transmission* will stop automatically if no improvement is achievable. Probably, the specified maximal number of iterations won't be performed.

Diffuser Optimization



- The optimization of a diffuser may take a while depending on the number of iterations and pixels.
- A running optimization can be stopped by clicking the *Stop* button.
- The total progress of the optimization is shown in the window caption.
- The current optimizations step is marked by grey color.
- The progress in current step is shown by the progress bar.

Diffuser Optimization

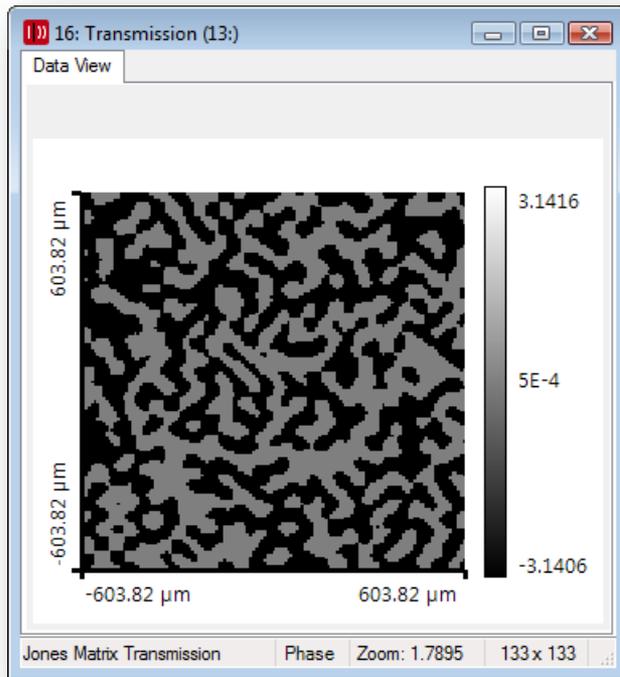


- Click the *Show* button after the end of the optimization to display the optimized diffuser transmission.
- The *Set* button allows to set any other user defined transmission. It can be used as a start point for an optimization or for further analysis.

Results in



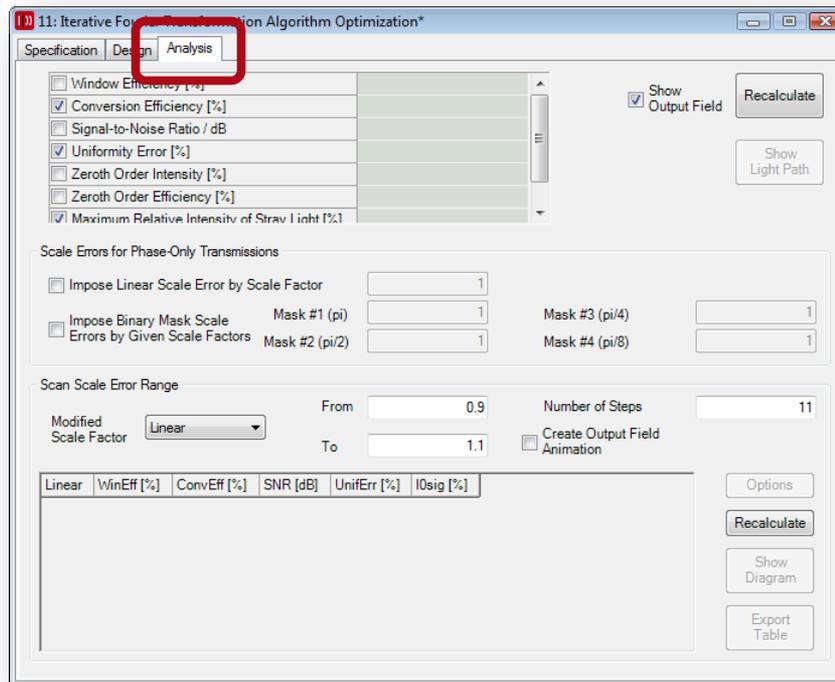
Optimized Transmission



- Data View with typical phase distribution (click φ on toolbar) of optimized transmission.
- Since the optimization of diffractive diffusers starts with random phases the resulting transmission phase differs between different optimizations.

Diffuser System Analysis

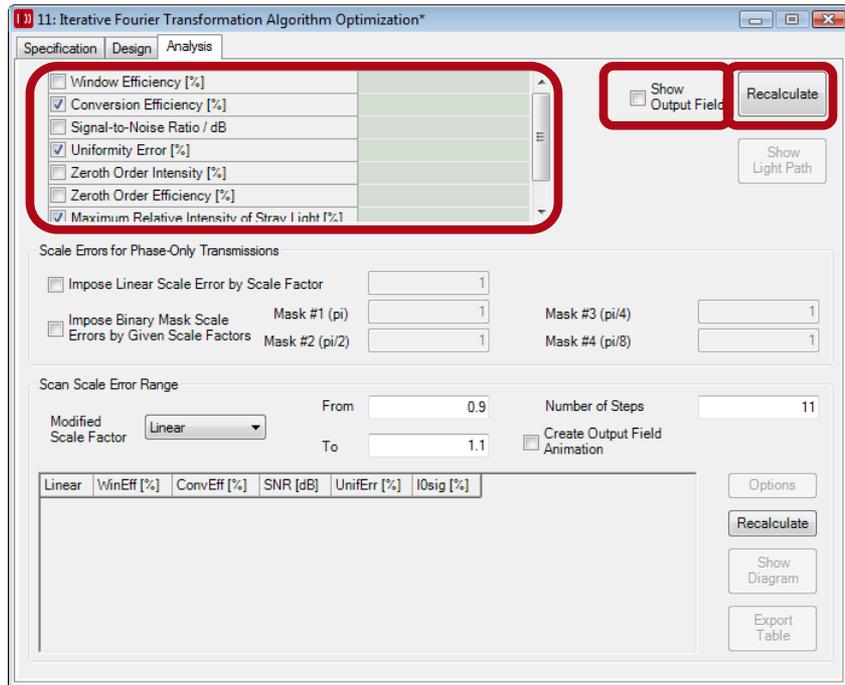
- Switch to Analysis page after the end of the optimization to calculate merit functions.



Results in



Diffuser System Analysis



- Select the merit functions desired for the evaluation of the output field.
- Deactivate the option *Show Output Field*. We will simulate the output field later using the *Light Path Diagram*.
- Click the *Recalculate* button to evaluate the merit functions values.

Diffuser System Analysis

11: Iterative Fourier Transformation Algorithm Optimization*

Specification | Design | Analysis

<input type="checkbox"/> Window Efficiency [%]	
<input checked="" type="checkbox"/> Conversion Efficiency [%]	73.620861399452323
<input type="checkbox"/> Signal-to-Noise Ratio / dB	
<input checked="" type="checkbox"/> Uniformity Error [%]	16.494892051481003
<input type="checkbox"/> Zeroth Order Intensity [%]	
<input type="checkbox"/> Zeroth Order Efficiency [%]	
<input checked="" type="checkbox"/> Maximum Relative Intensity of Stray Light [%]	21.434318711479406

Scale Errors for Phase-Only Transmissions

Impose Linear Scale Error by Scale Factor

Impose Binary Mask Scale Errors by Given Scale Factors

Mask #1 (pi) Mask #3 (pi/4)

Mask #2 (pi/2) Mask #4 (pi/8)

Scan Scale Error Range

Modified Scale Factor: Linear

From: To: Number of Steps:

Create Output Field Animation

Linear	ConvEff [%]	UnifErr [%]	StrayLight [%]

Options

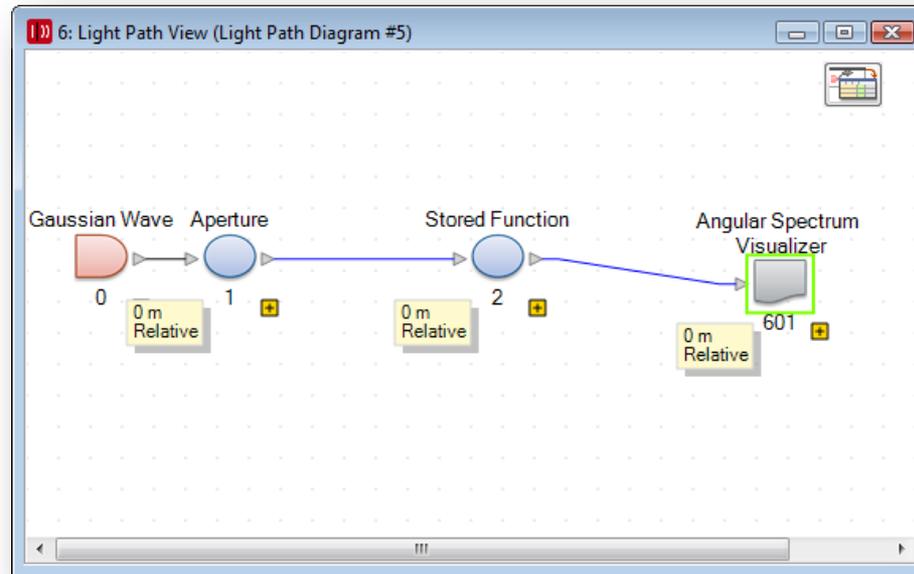
Recalculate

Show Diagram

Export Table

- The merit functions values will be displayed in the marked table.
- Since the optimization starts with random transmission phase the merit functions values may differ between different optimizations.
- The optimization should be repeated several times and the transmission with the best merit functions values should be kept.

Light Path



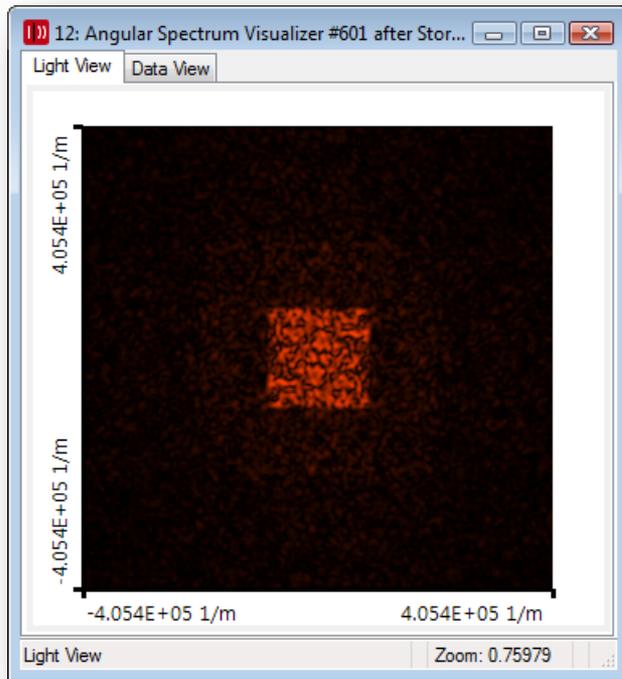
5: Light Path Editor (Light Path Diagram #5)

Path Detectors Analyzers

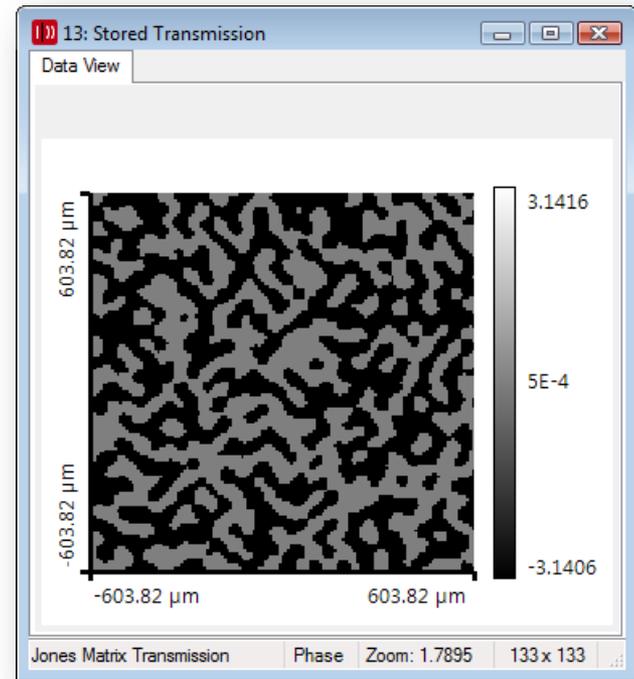
Start Element				Target Element		Linkage	
Index	Type	Channel	Medium	Index	Type	Propagation Method	On/Off
0	Gaussian Wave	-	Standard Air in Homogen...	1	Aperture	Combined SPW/Fresnel Operator	On
1	Aperture	T	Standard Air in Homogen...	2	Stored Function	Combined SPW/Fresnel Operator	On
2	Stored Function	T	Standard Air in Homogen...				

Tools Re-Use Automatic Settings Simulation Type: Field Tracing **Go!**

Simulation Results



Intensity Top Hat



Diffuser Transmission Phase

Conclusion

- VIRTUALLAB™ assists customer during design of diffractive optical elements for generation of diffuse lines or Top Hats.
- Assisted design steps enable also optical engineers inexperienced in diffractive optics to benefit from current developments.