LBS.001 (2.2)

Generation of a Rectangular Top Hat by Diffractive Beam Shaper

Author: Hartwig Crailsheim (LightTrans)

Related Application Scenarios: Scenario 307.01, LBS.003

Related Tutorials: Tutorial_144.01

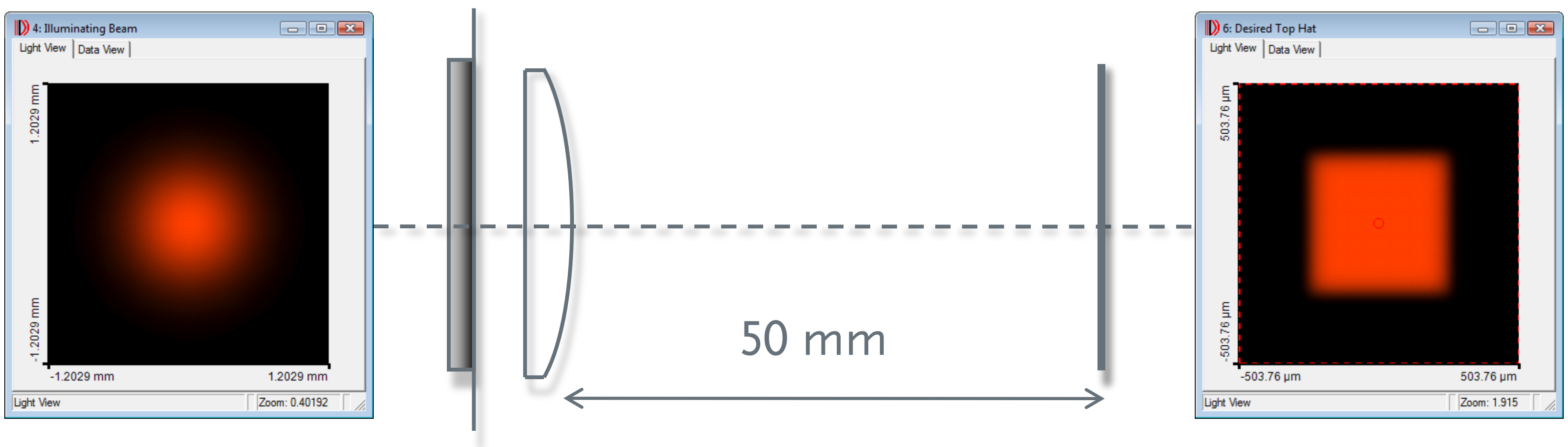
Requirements: Starter Toolbox, Diffractive Optics Toolbox

LIGHTTRANS

Modeling Task

Diffractive Beam shaper
Diameter: 2 × 2 mm
Phase Levels: 16

Target
Plane



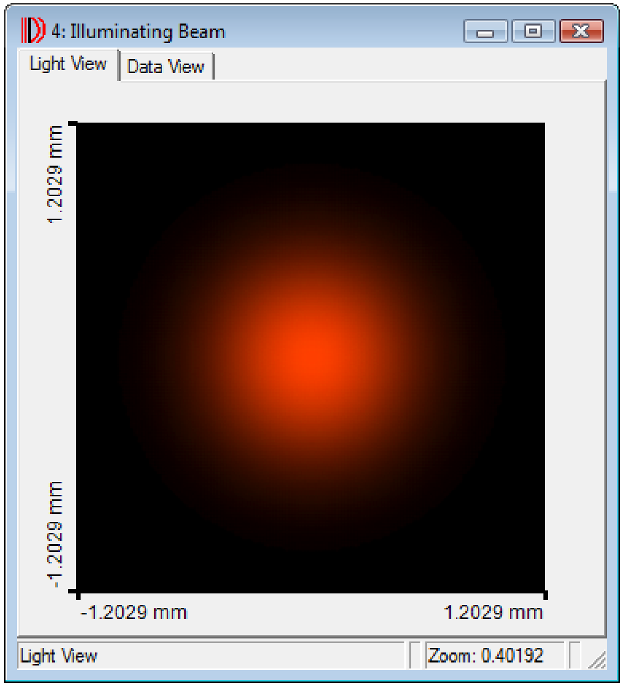
Illuminating Beam
Intensity

1f-Setup

Top Hat Intensity
(free of speckles)

Modeling Task: Input Light Field

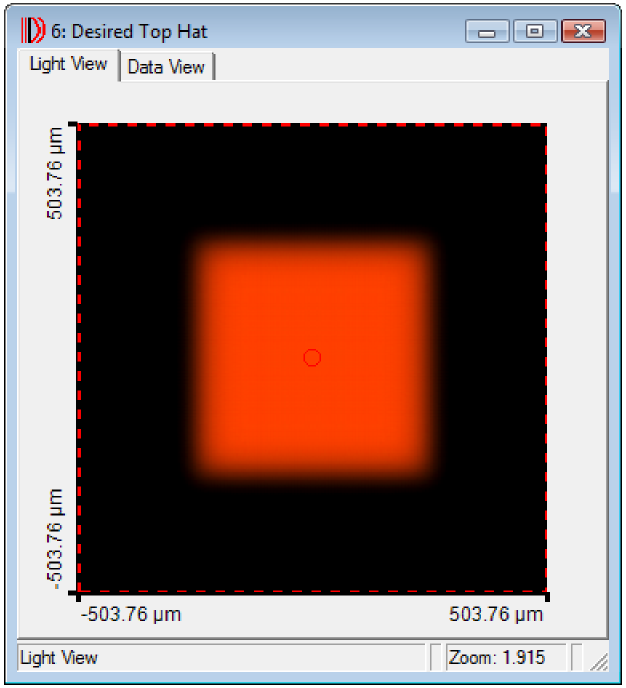
Illuminating Beam Parameters
of a Gaussian collimated laser beam



Wavelength: 632.8 nm
Laser Beam Diameter ($1/e^2$): 1 mm

Modeling Task: Desired Output Light Field

Desired Output Field Parameters



FWHM-Diameter: 0.5 mm
Edge Width: 67 µm
Efficiency: >95 %
SNR: >30 dB
Stray light: <5 %

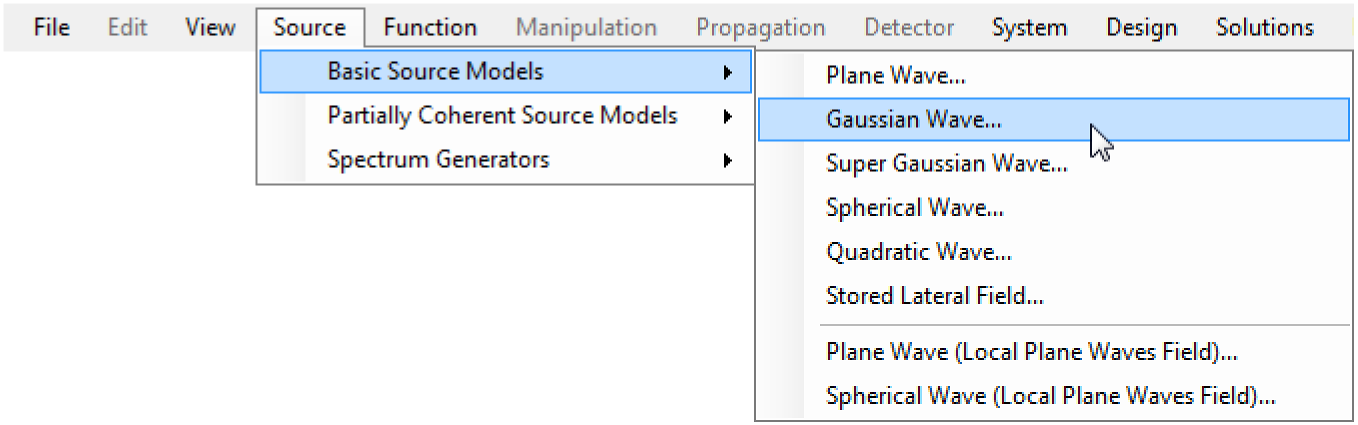
Demonstrated Steps

1. Configuration of input and desired output light field distribution.
2. Design Preparation: Defining of the complete optical setup.
3. Design: Calculation and optimization of a diffractive optical element (DOE).
4. Data Export for manufacturing of the DOE (just mentioned, details not part of this tutorial).

STEP 1

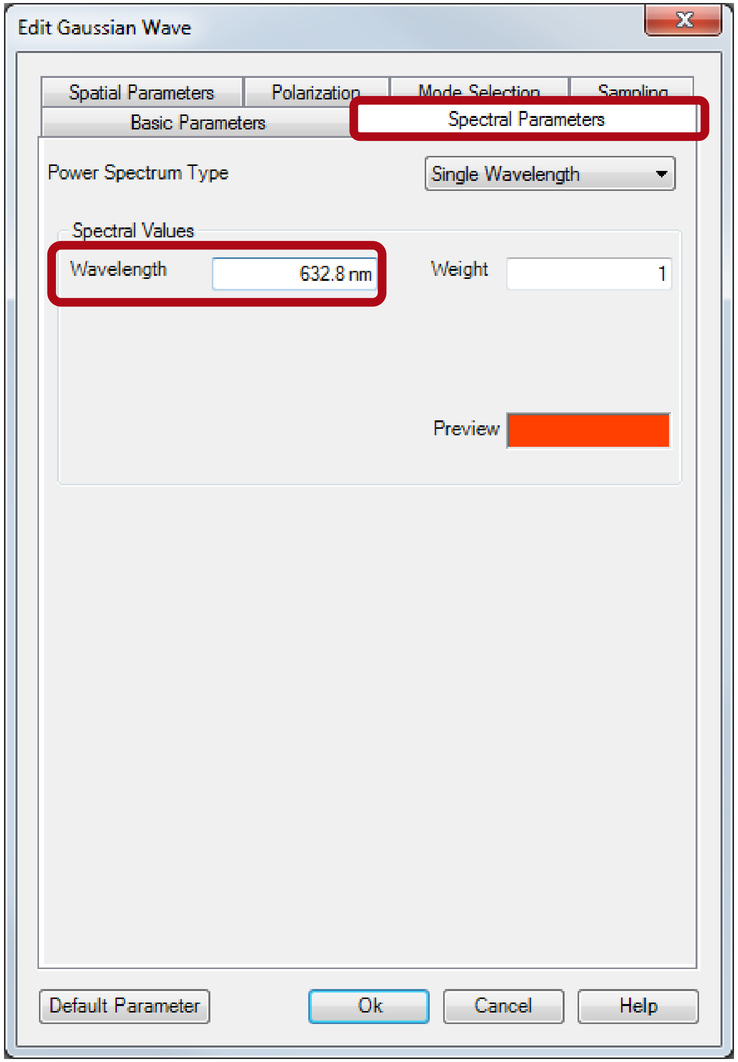
Configuration of Input and Desired Output Light Field Distribution

Generating of an Input Light Field



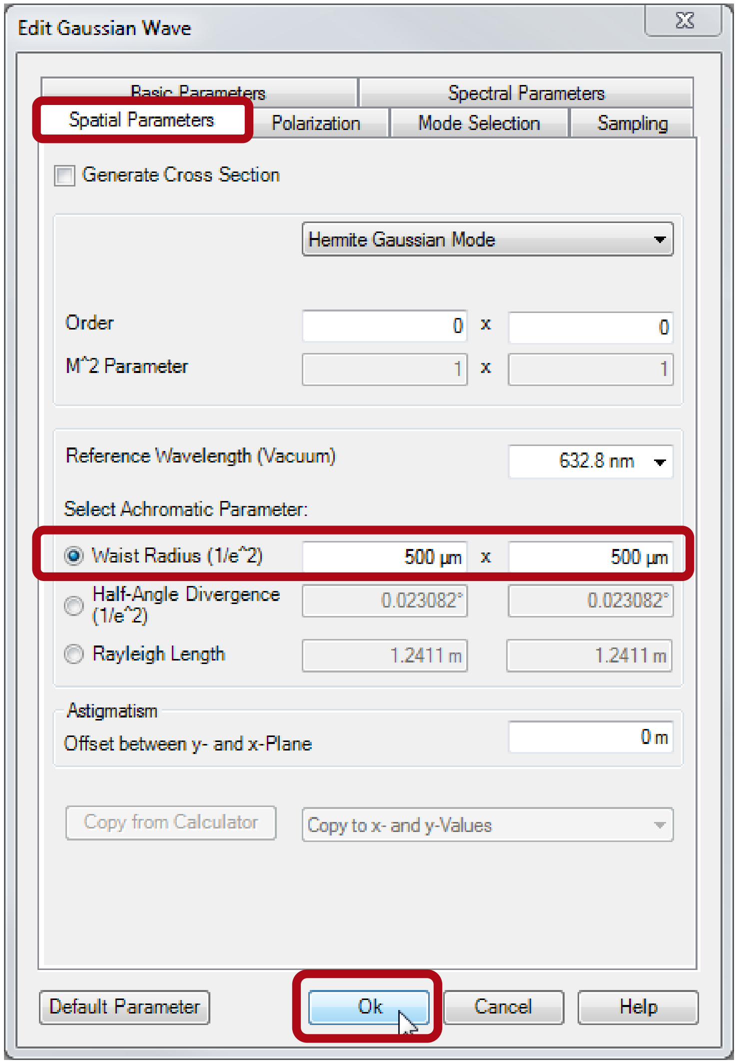
- First the complex amplitude of the illuminating input beam has to be generated.
- Therefore select “Gaussian Wave” from the menu: Source > Basic Source Models

Configuration of Desired Input Field 1



- Set the wavelength in the Spectral Parameters tab to 632.8 nm.

Configuration of Desired Input Field 2



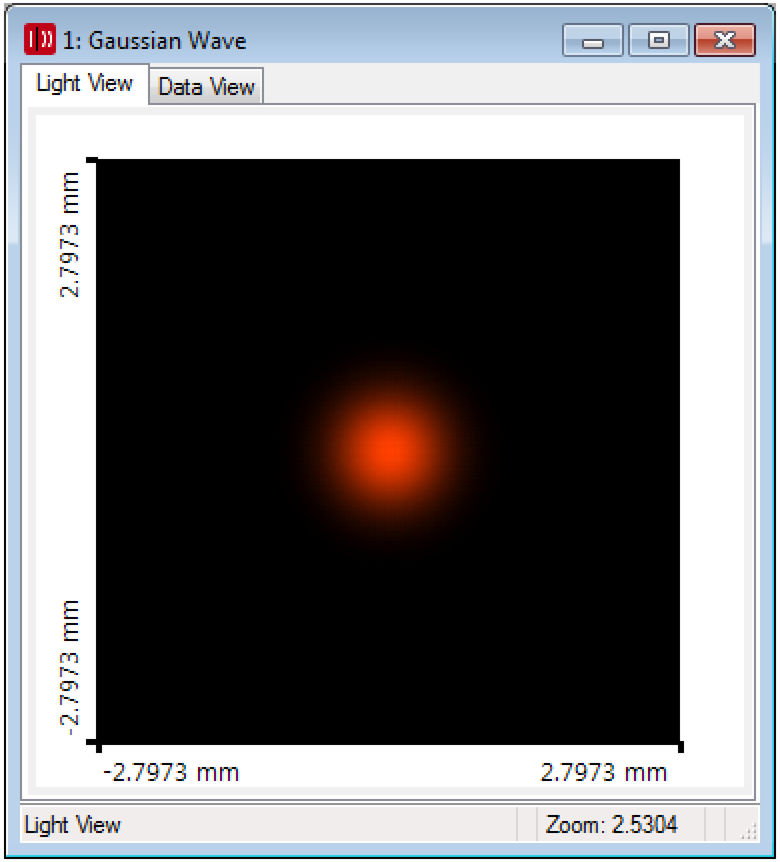
Adjust the spatial parameters in the according tab:

- Waist radius = 500 × 500 µm

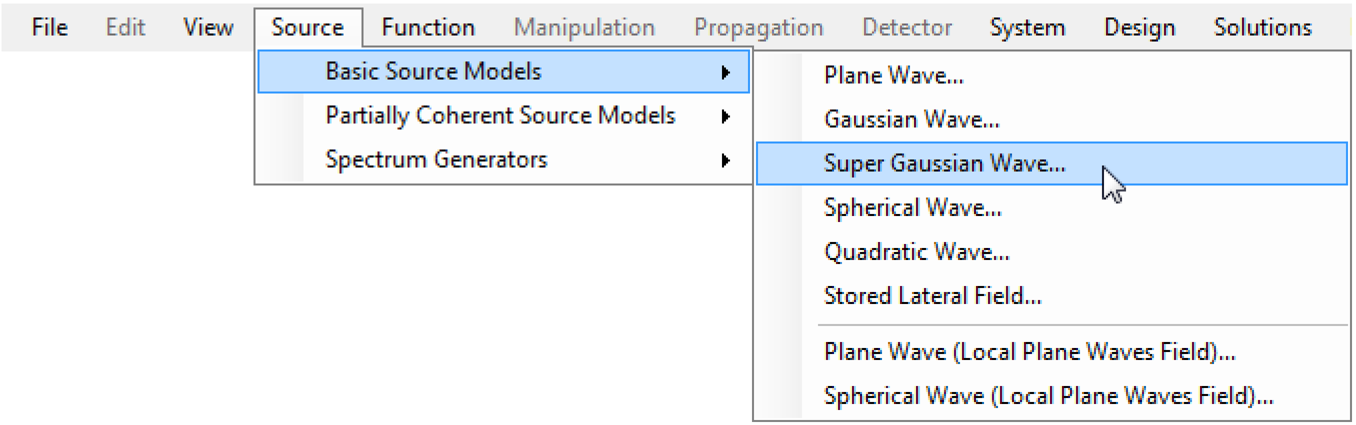
Then confirm with “Ok”.

Results in

Light Distribution of the Illuminating Beam

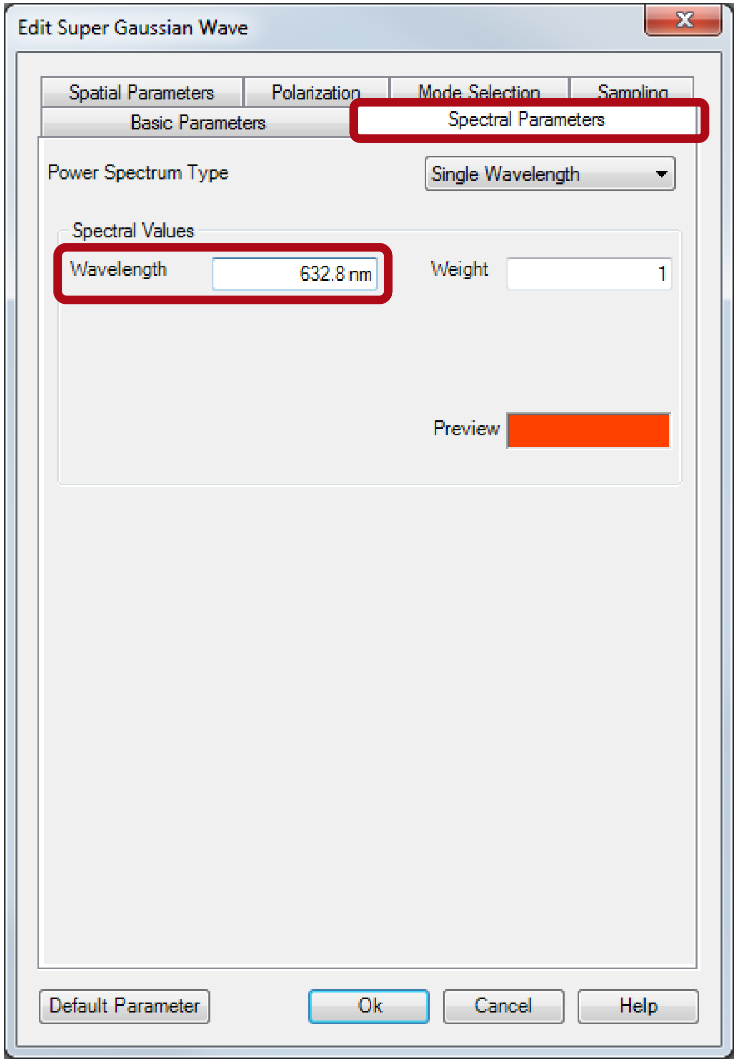


Generating of an Output Light Field



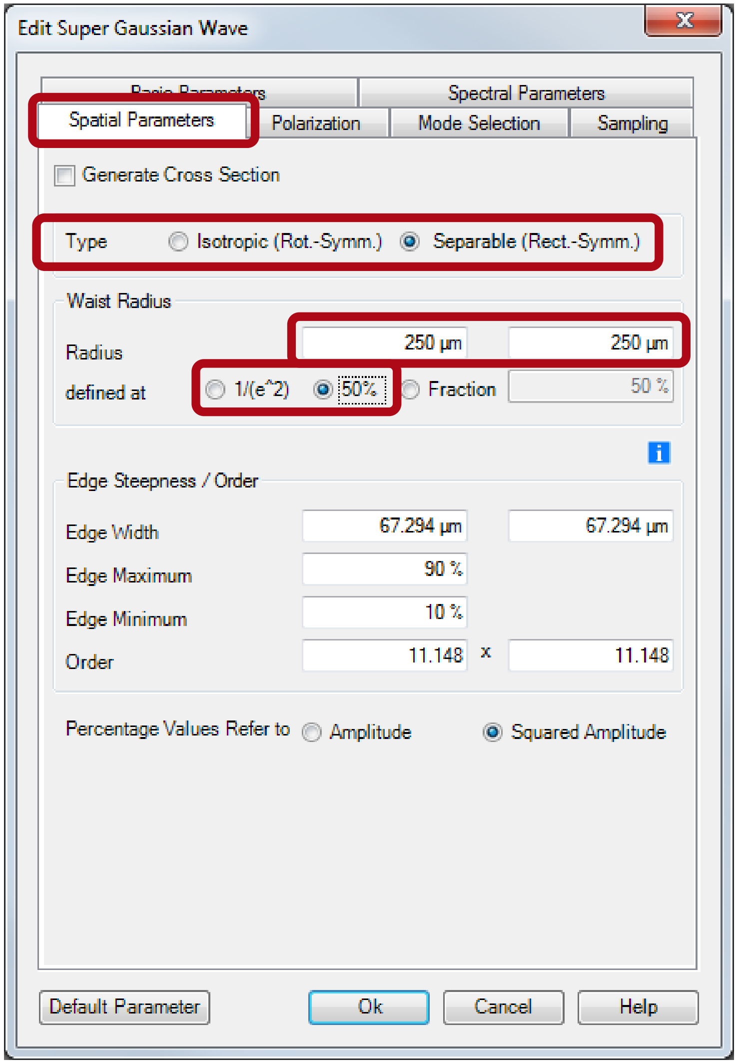
- Now the complex amplitude of the desired output light field distribution has to be generated.
- This signal field will serve as the target field for VirtualLab.
- This is also done by generating a new light source (so don’t be confused if you come across terms like “input(!) field”).
- Thus select “Super Gaussian Wave” from the menu Source > Basic Source Models

Configuration of Desired Output Field 1



- Change the wavelength in the Spectral Parameters tab to 632.8 nm.

Configuration of Desired Output Field 2

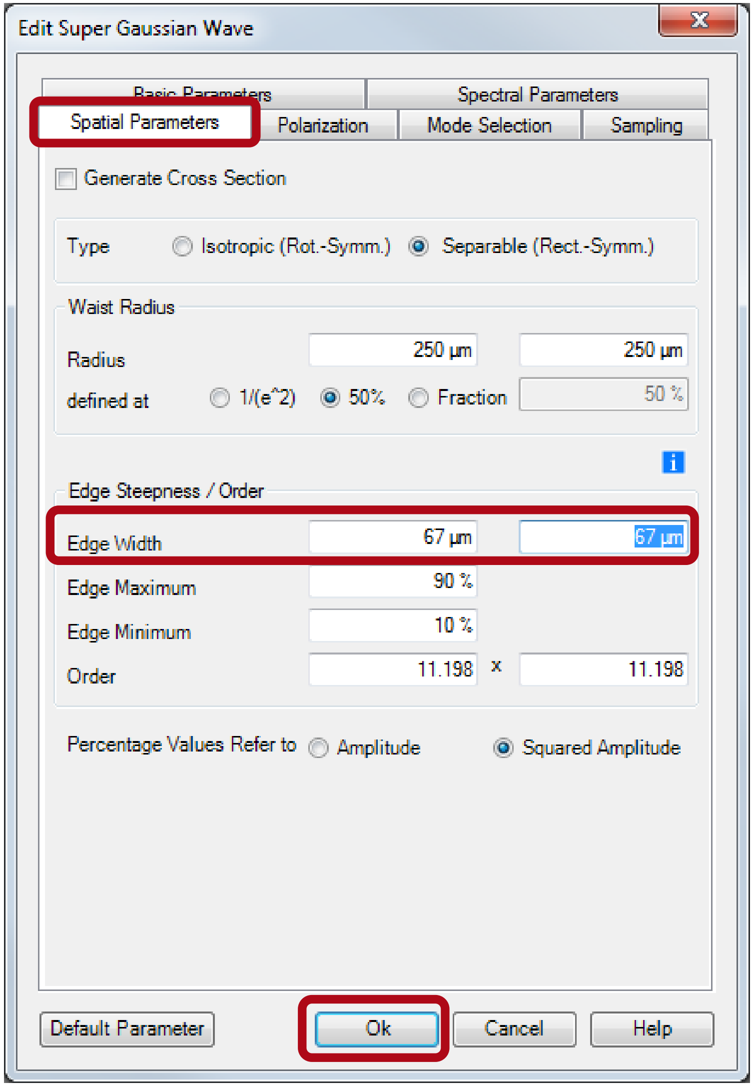


Adjust the spatial parameters in the according tab:

- A rectangular top hat should be generated so select the type “Separable (Rect.-Symm.)”
- Set the radius of the top hat to 250 × 250 µm
- Use the 50% definition which corresponds to the Full-Width-at-Half-Maximum value.

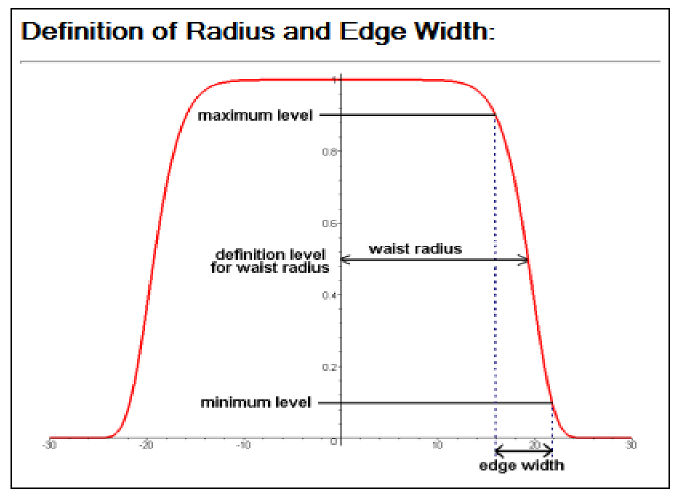
continued...

Configuration of Desired Output Field 3

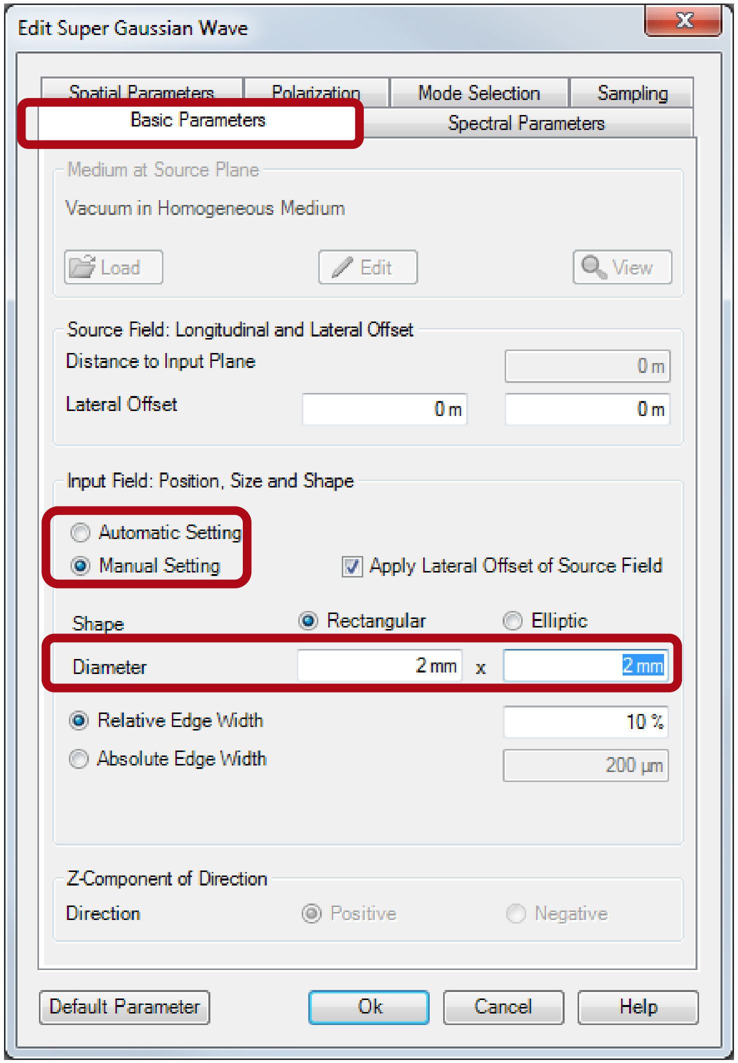


For there are no exact discontinuities in nature it is suggested to specify smooth edges for realistic diffraction effects:

- Change the edge width according the required specifications to 67 × 67 µm.
- Then confirm with “Ok”.



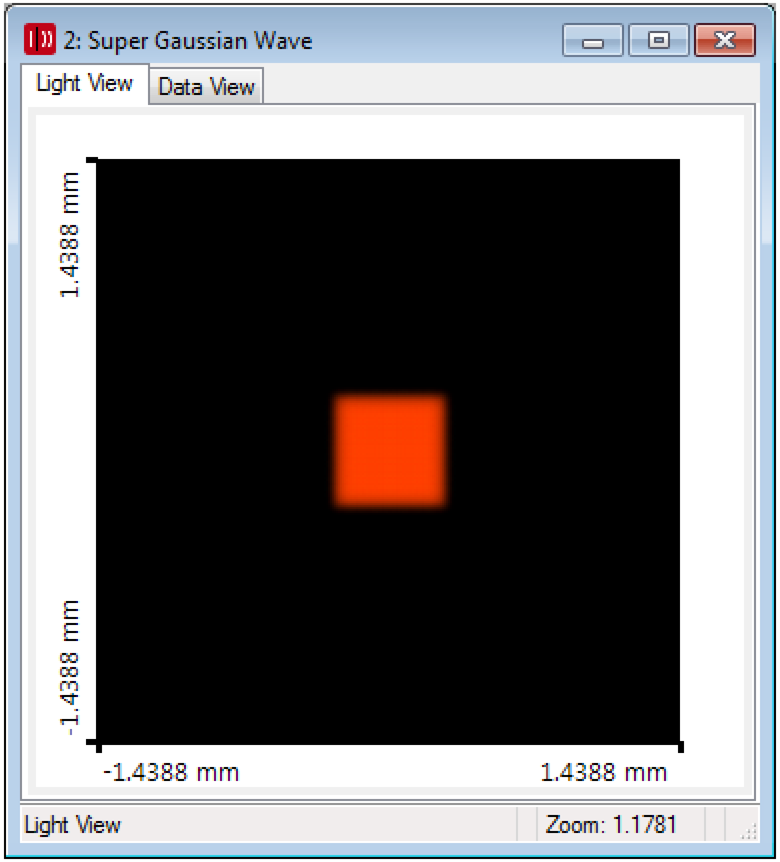
Configuration of Desired Output Field 4



- The DOE cannot diffract all light into the area of interest, i.e. the Top Hat region. There will always be remaining light which is distributed around the desired light distribution.
- So that VL is able to consider this remaining light to a fair and meaningful extent the output field to be simulated should be set to around 4 times larger than the Top Hat's diameter, i.e. in our case 2mm.
- Thus on the tab "Basic Parameters" switch to "Manual Setting" and change the shape to 2 × 2 mm.

Results in

Target Light Distribution



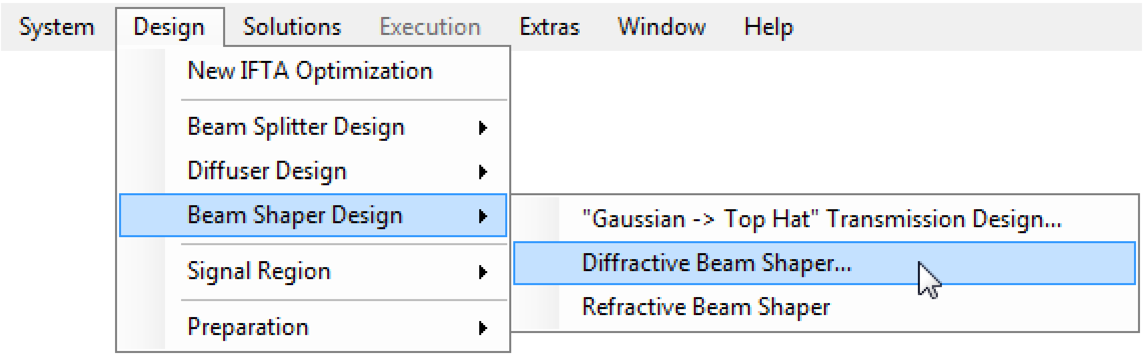
- The reason for the resulting dimension (larger as the set 2 × 2 mm) is due to the Relative Edge Width for which the standard value of 10% was kept.
- Additionally on the tab “Sampling” there is the setting for the “Size of Embedding Frame (Sampling Points)” whose standard value is 10. These frame points always have the value zero.

STEP 2

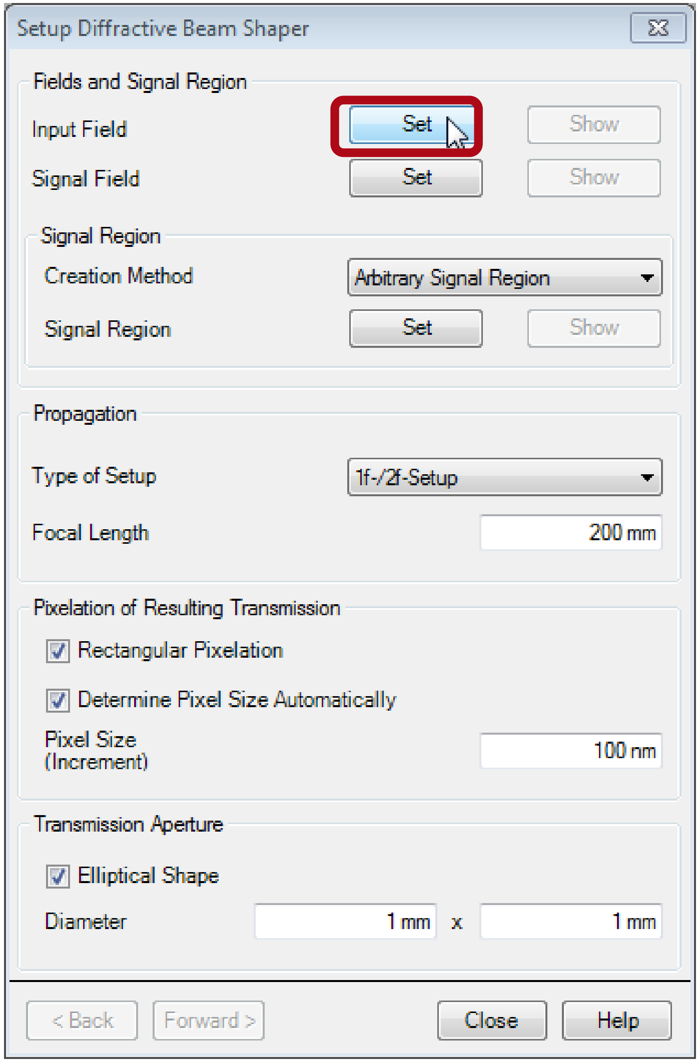
Design Preparation: Defining of the Complete Optical Setup

Preparation for Design 1

- In order to design the desired DOE the complete setup conditions have to be defined.
- Over the menu go to Design > Beam Shaper Design > Diffractive Beam Shaper... and a dialog will open that assists you with the design steps.

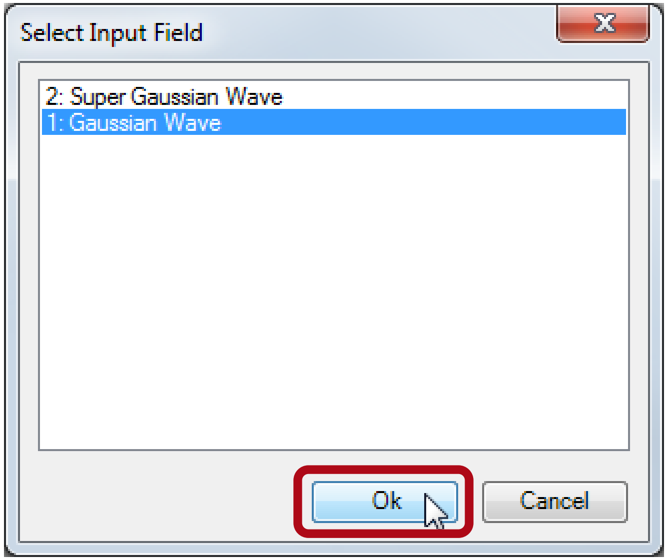


Preparation for Design 2



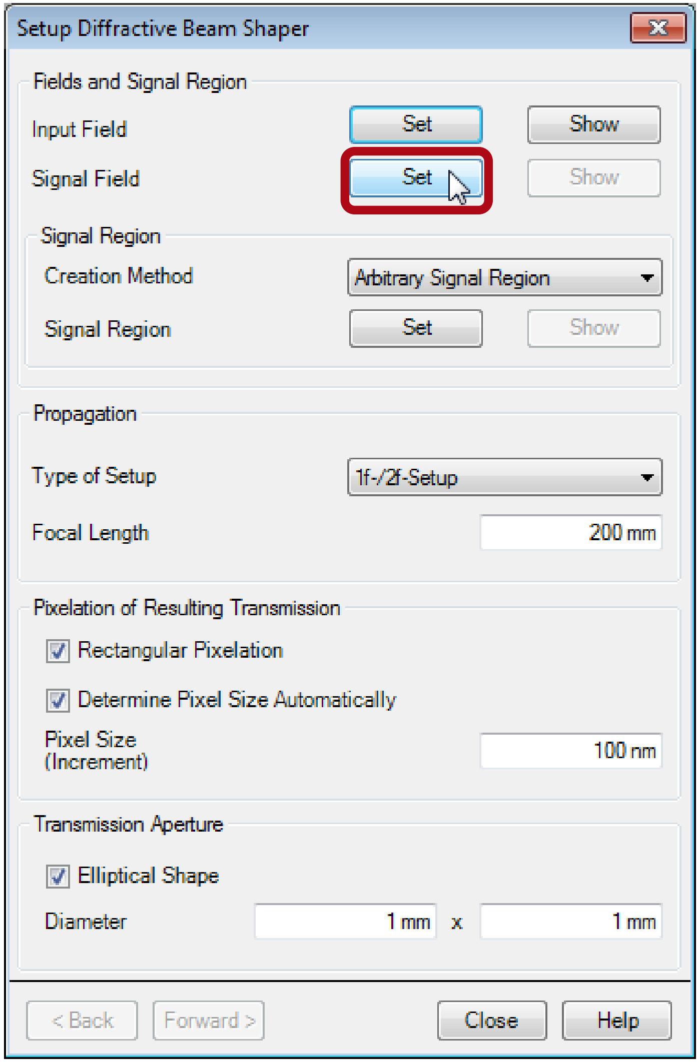
- First for the illuminating beam (Input Field) click "Set".
- In the so opened dialog select the prepared Gaussian wave and click "Ok".

Results in

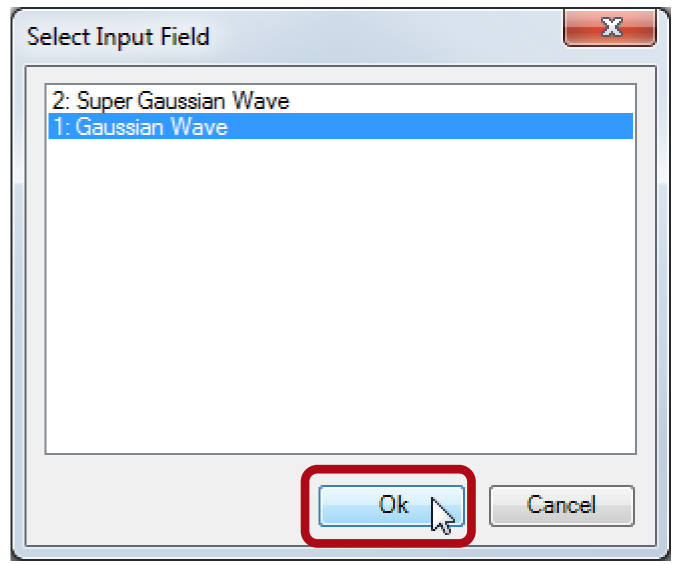


Preparation for Design 3

- Then for the desired target field (Signal Field) click “Set”.
- In the so opened dialog select the prepared super-Gaussian wave and click “Ok”.



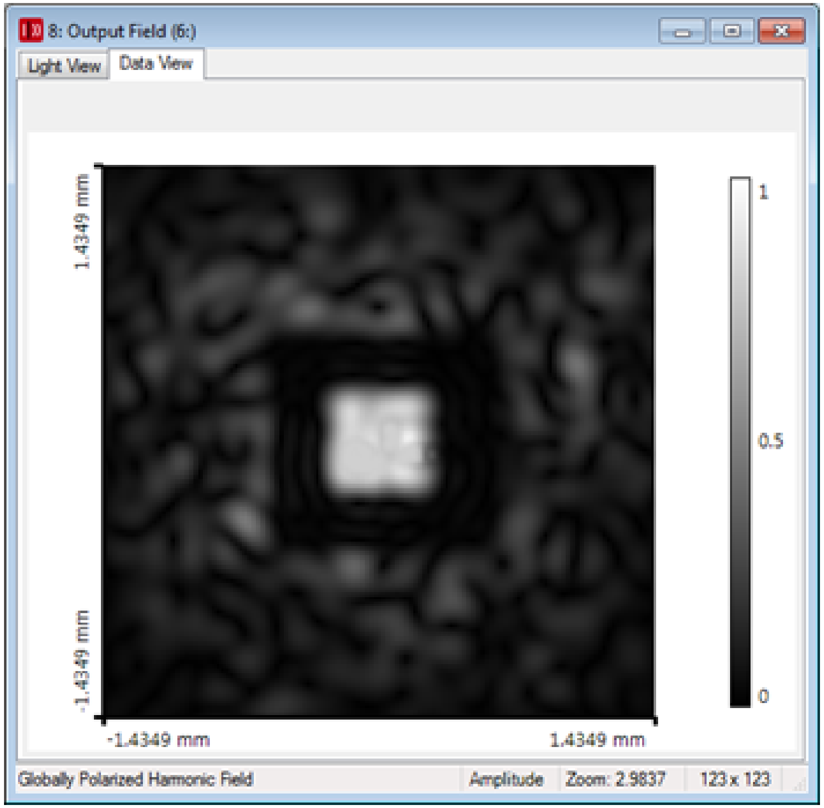
Results in



Preparation for Design 4

- Additionally the optimization of DOEs requires the specification of a so called signal region which describes an area in the target plane in that stray light will be minimized during optimization. Outside of this area stray light is allowed.
- VirtualLab tries to create a transmission function that shapes the input field best possible so that the output field resembles the desired target field.
- As there will never be an absolute correlation, there will always be stray light outside of the desired light distribution as well.
- The next 2 slides illustrate this configuration option.

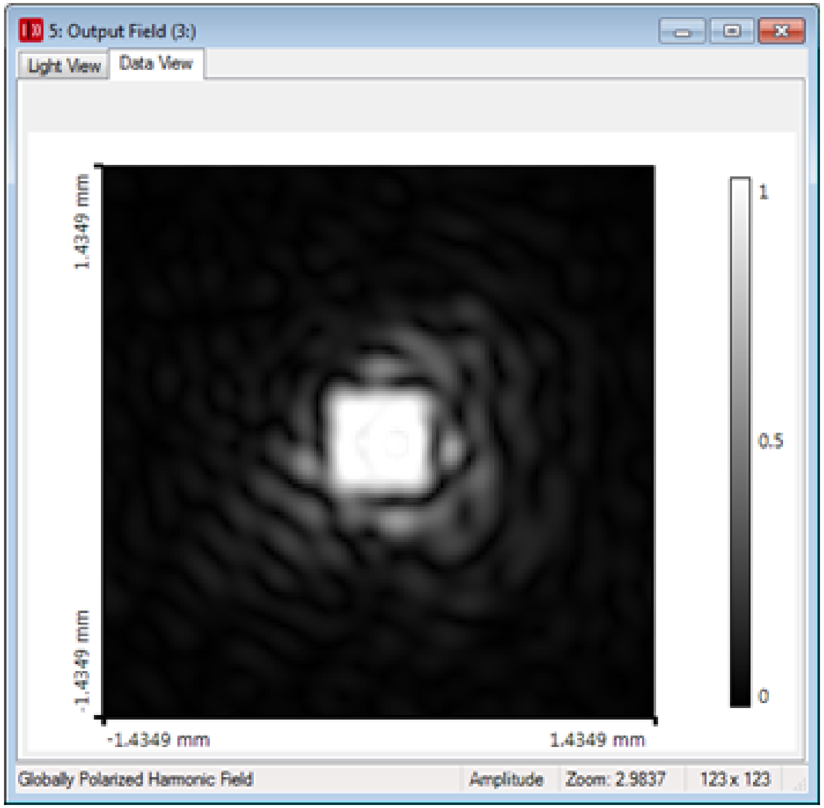
Preparation for Design 5



Roughly optimized example for a signal region distinctly larger than the desired light distribution.

- If the signal region is larger than the desired light distribution then VL's optimization algorithm is more strongly restricted, since there is less free space where the algorithm permits most of the inevitable stray light.
- Additionally because inside the signal region the noise optimization takes place and outside not there will be a distinct outline between those two regions.

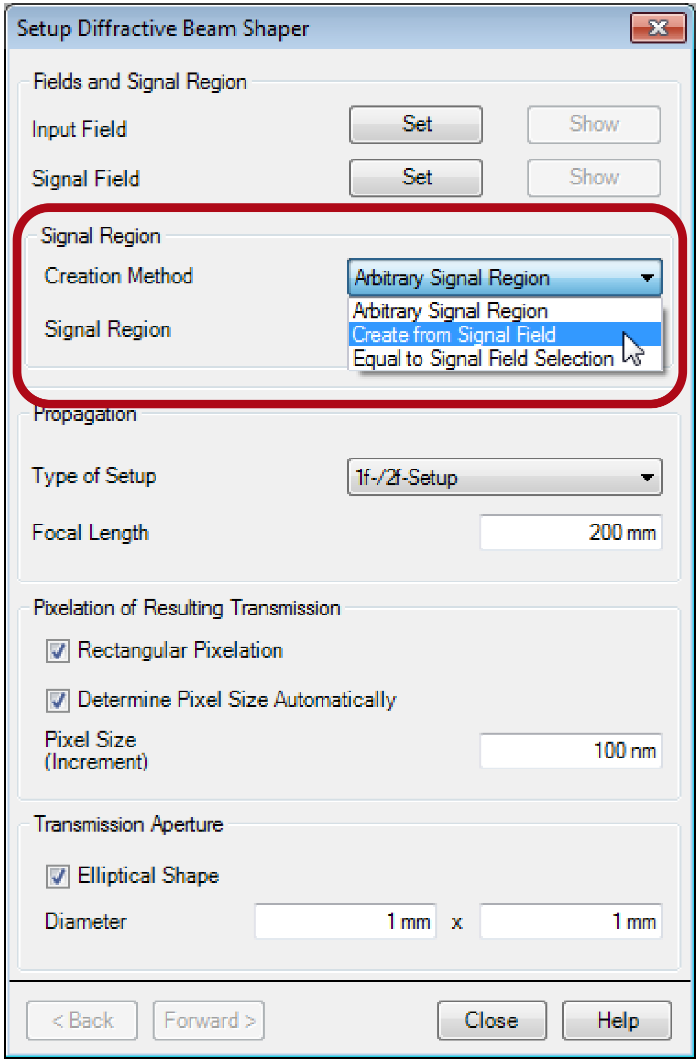
Preparation for Design 6



Roughly optimized example for a signal region created from signal field.

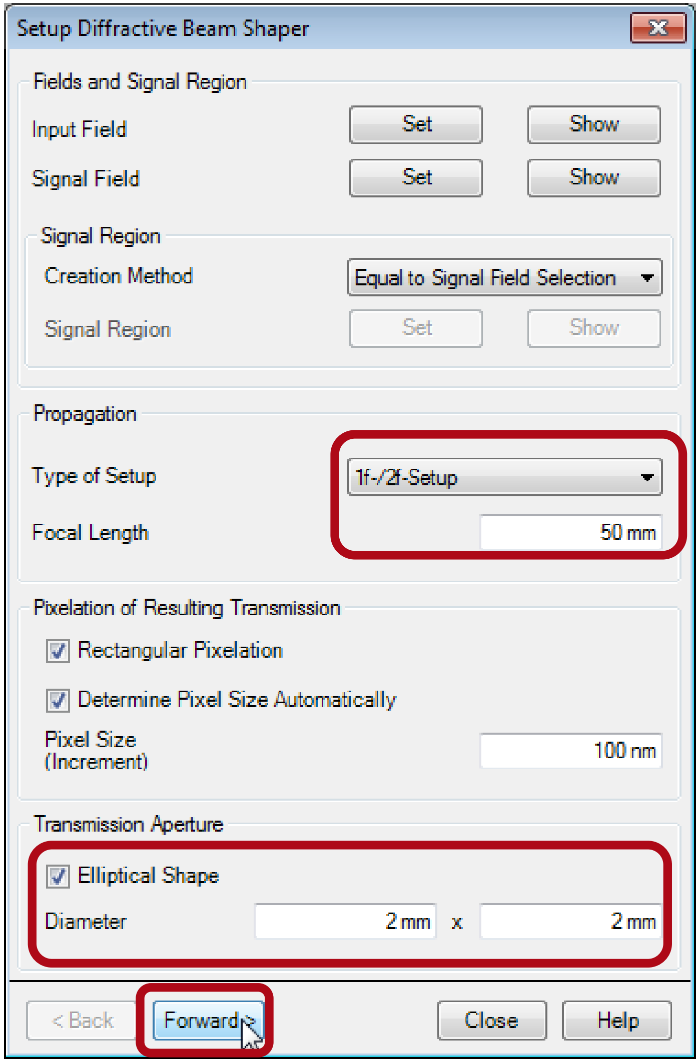
- If the signal region is calculated from the signal field as described in the next slide VL optimization algorithm is less restricted and the stray light will be distributed more homogenously.

Preparation for Design 7



- For this tutorial the Creation Method "Create from Signal Field" is to be selected.
- This means that a signal region will be created containing all parts of the signal field with amplitude values larger than 10% of the maximum amplitude.

Preparation for Design 8



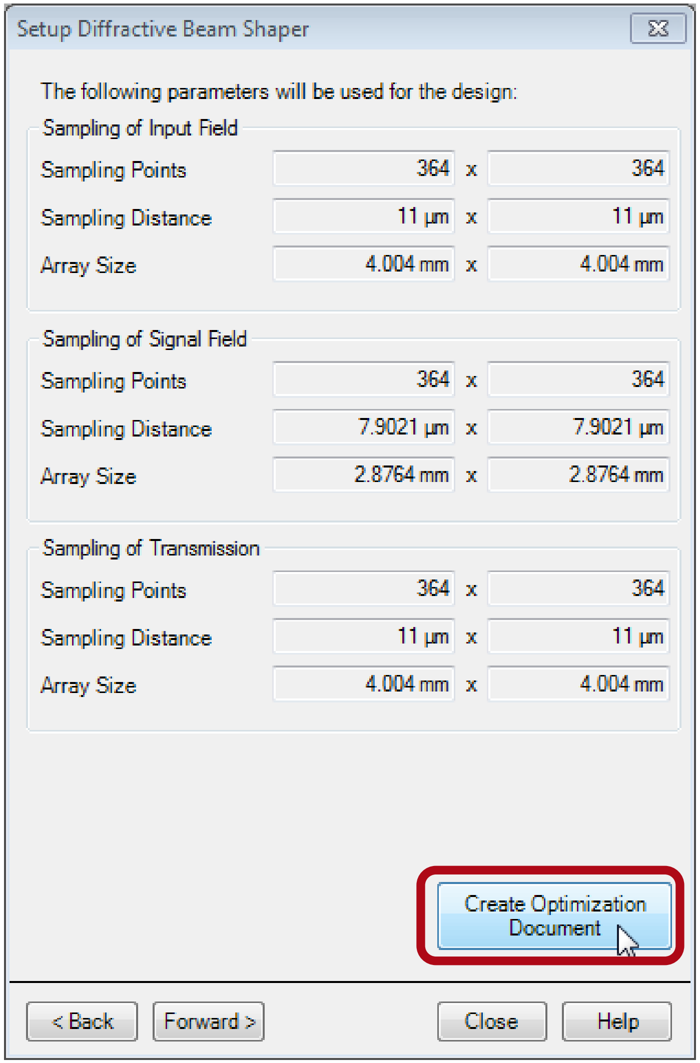
- The task at hand demands a "1f-/2f-Setup" with a focal length of 50 mm.
- For the aperture enter 2 × 2 mm.
- Then click "Forward >"

3. STEP

Design: Calculation and optimization of a diffractive optical element (DOE)

Explanation: The DOE to be calculated and optimized will be represented by an transmission function.

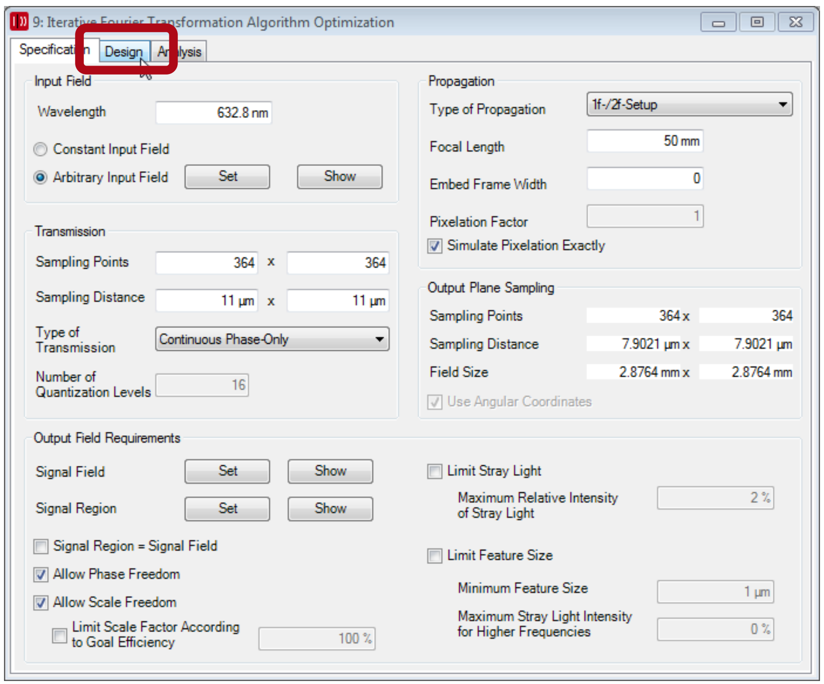
Starting Point for Optimization



- This page contains an overview of parameters that are automatically calculated by VirtualLab.
- VirtualLab adapts all parameters for the optimization of the beam shaping element.
- For example VirtualLab takes care that the number of sampling points is sufficient and the same everywhere (for the input field, the signal field and the transmission). This is necessary for the optimization algorithm.
- Then click "Create Optimization Document".

Results in

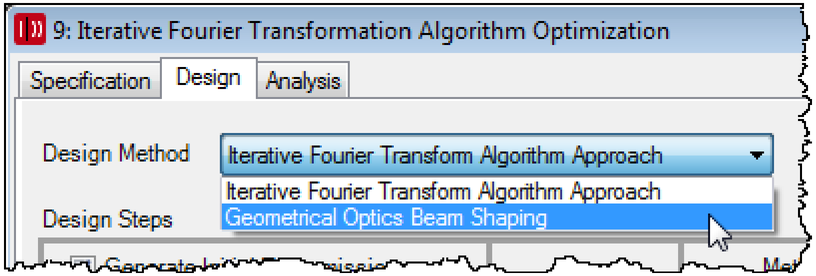
Geometrical Optimization 1



- You get this preset transmission design document named after its main designing method “Iterative Fourier Transformation Algorithm Optimization” (IFTA).
- Switch to the “Design” tab of this document.

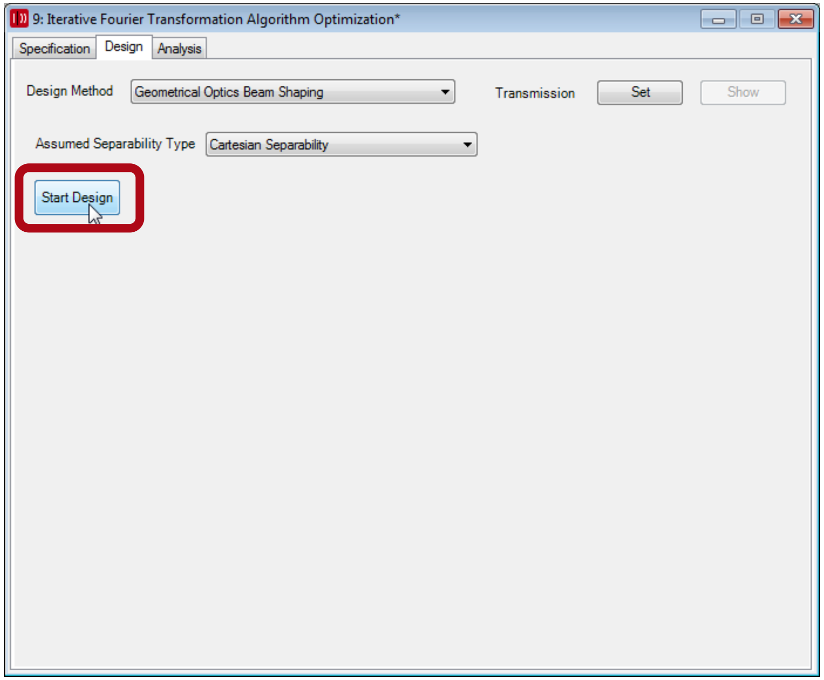
Geometrical Optimization 2

- For a high efficient and speckle-free result some optimization steps have to be performed.
- Typically one starts with a geometrical approach.
- Therefore change the “Design Method” to “Geometrical Optics Beam Shaping”.



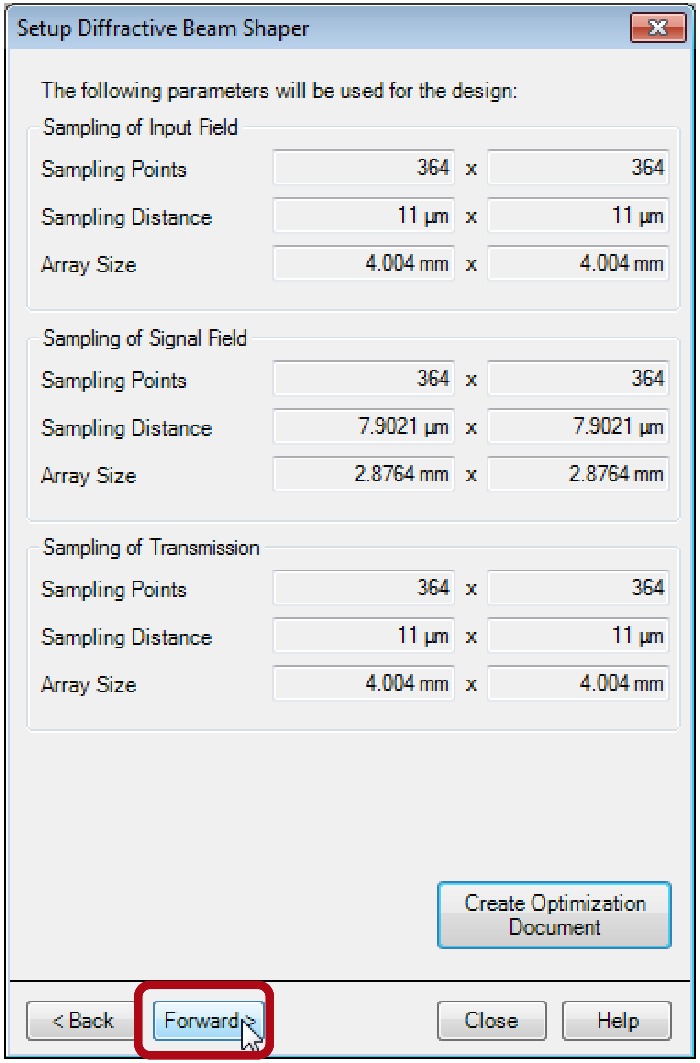
- This method will only produce an approximated solution to begin with. It is not possible to include discrete phase levels of the transmission function.

Geometrical Optimization 3



- Click “Start Design”.
- VL will now calculate and optimize the transmission function of the DOE.
- When VL has finished its geometrical optics beam shaping design it will be indicated in the messages panel at the bottom of the main window.

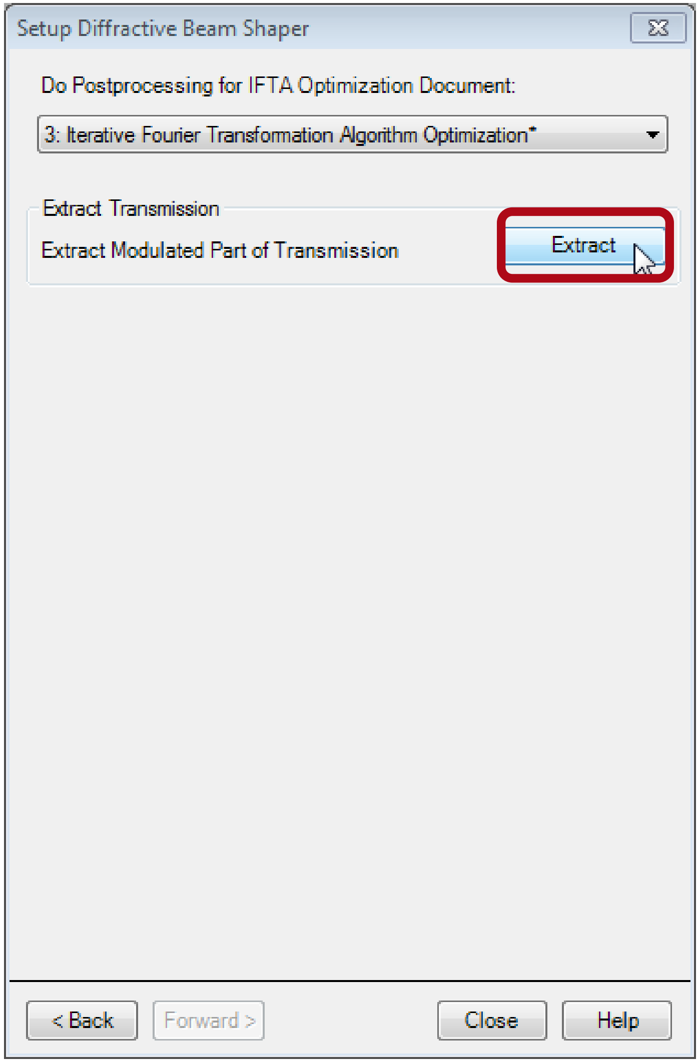
Geometrical Optimization 4



- After this geometrical design switch back to the dialog “Setup Diffractive Beam Shaper” where the relevant data of the just generated transmission function will be extracted.
- Thus click “Forward >”.

Results in

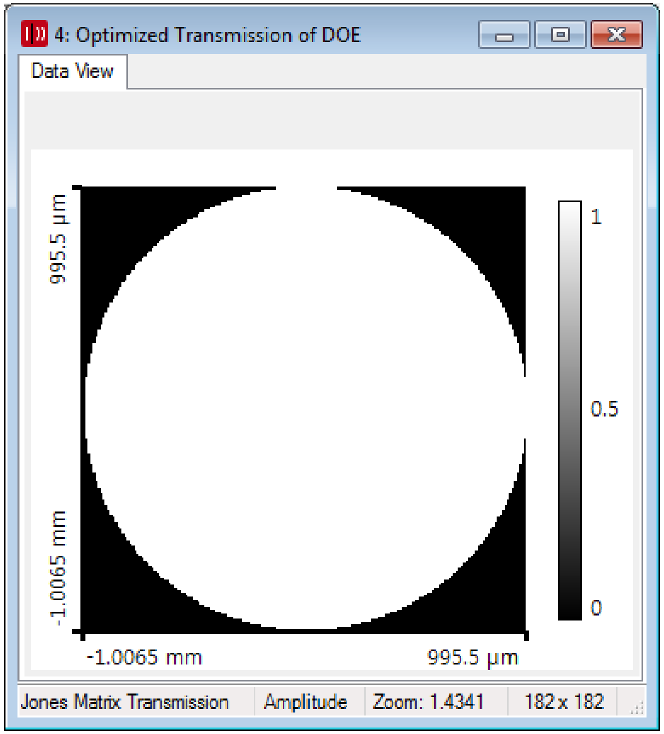
Geometrical Optimization 5



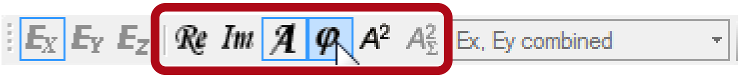
- Click “Extract”.

Results in

Geometrically Optimized Transmission 1

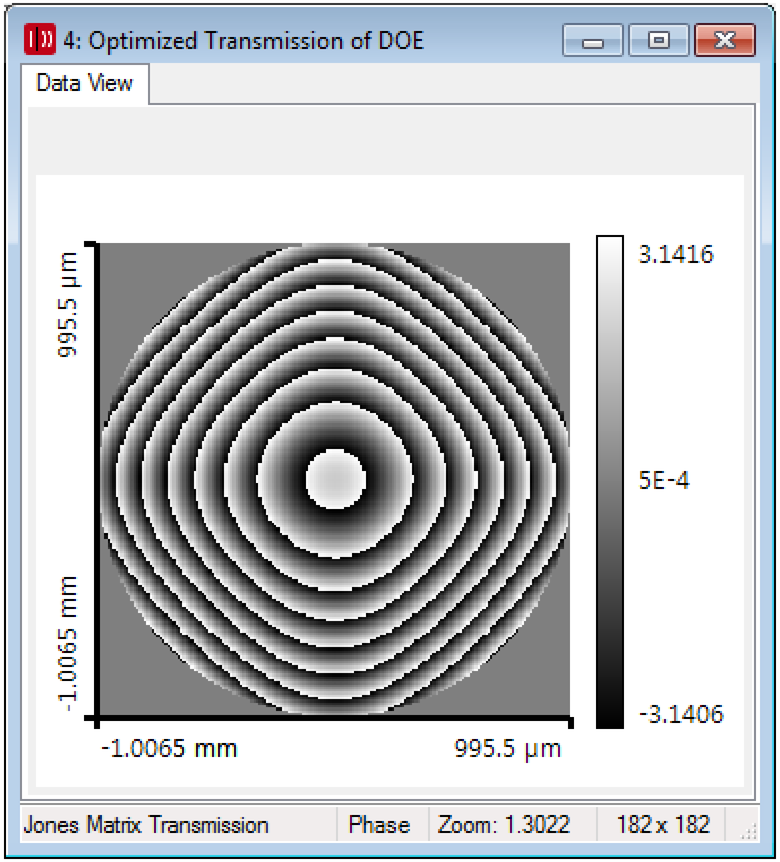


- The amplitude and the aperture respectively of the DOE, i.e. the distribution of the DOE’s amplitude modulating property.
- For the information regarding the phase click the accordant icon.



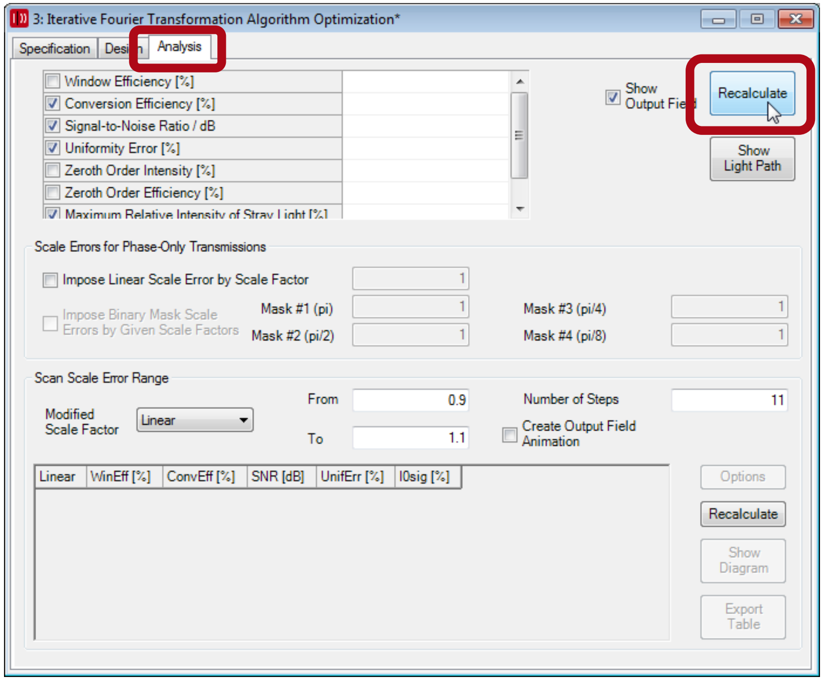
Results in

Geometrically Optimized Transmission 2



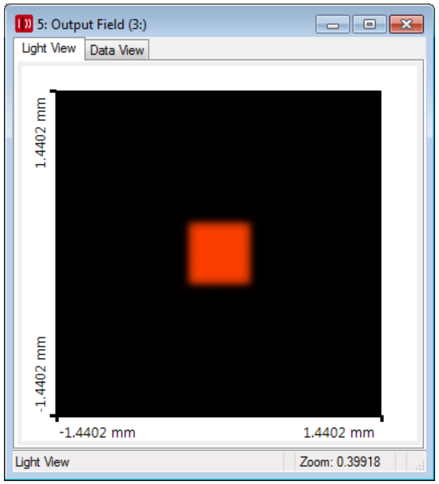
- The phase distribution of the DOE, i.e. the distribution of the DOE's phase modulating property.
- In order to analyze the light propagation through the optical setup switch back to the design document "Iterative Fourier Transformation Algorithm Optimization".

Geometrical Results 1



- Go to the tab "Analysis" and click "Recalculate.

Geometrical Results 2



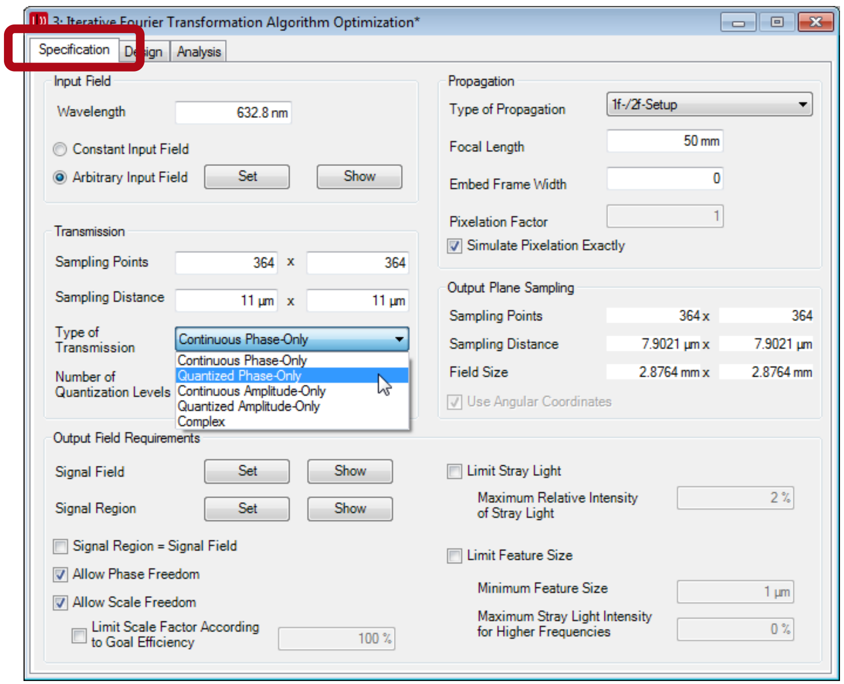
☐ Window Efficiency [%]	
☑ Conversion Efficiency [%]	97.882086297596175
☑ Signal-to-Noise Ratio / dB	29.011091733676729
☑ Uniformity Error [%]	50.379165741753177
☐ Zeroth Order Intensity [%]	
☐ Zeroth Order Efficiency [%]	
☑ Maximum Relative Intensity of Stray Light [%]	2.5263635947899732

- Here you see the result of the geometrical approach.
- The efficiency is almost 98%.
- The Signal-to-Noise Ratio (SNR) is almost 30 dB.
- The requirements are already almost met.

- The SNR is not bad but needs improvement.
- The discrete phase levels (needed due to fabrication constraints) must be introduced.
- Thus for a new optimization go to the tab “Specification”.

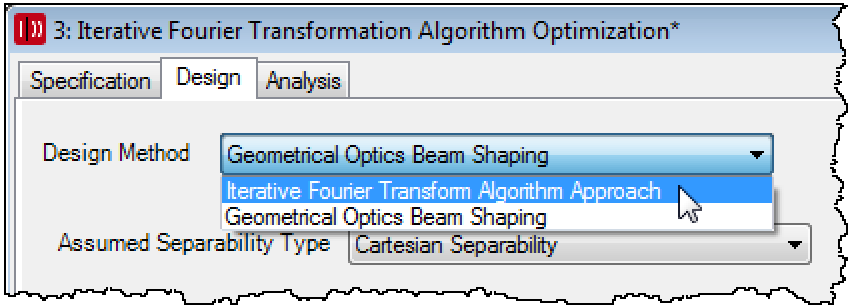
Results in

Geometrically Optimized Transmission 7



- Change the transmission type to "Quantized Phase-Only"
- This means the new optimization of the transmission function will be done for discrete phase levels.
- Leave the number of quantization levels at 16.
- Then go to the tab "Design".

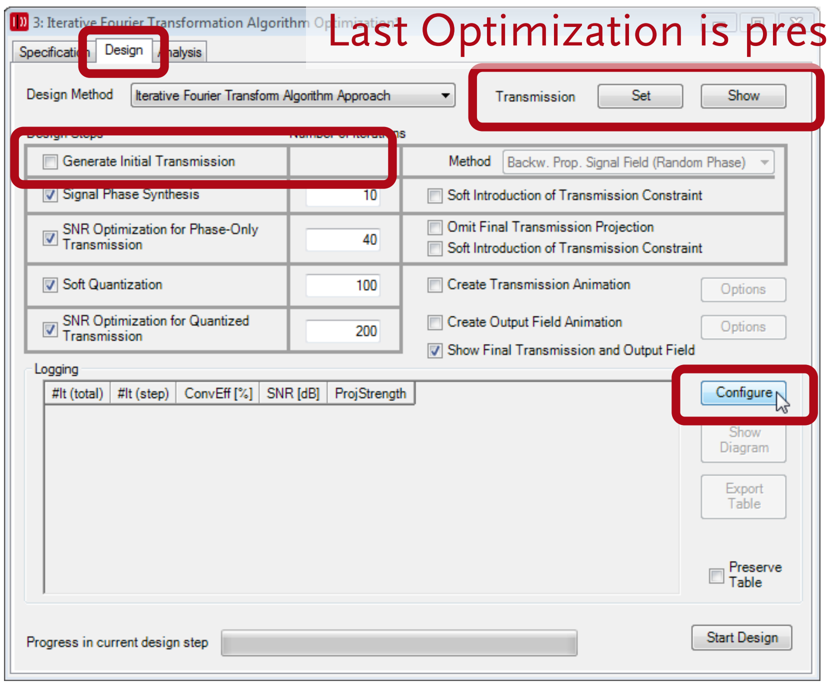
Geometrically Optimized Transmission 8



- Change the design method to “Iterative Fourier Transform Algorithm Approach.

Results in

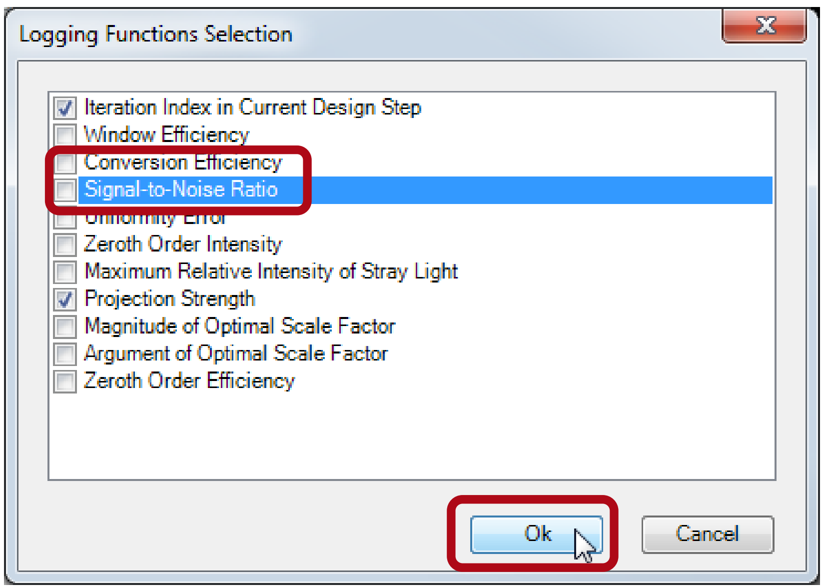
IFTA Optimization 1



- It is important to uncheck the option “Generate Initial Transmission”. For the geometrical approach has already provided a good initial transmission which is preset.
- For speeding up the calculation change the standard settings for logging by clicking “Configure”.

Results in

IFTA Optimization 2



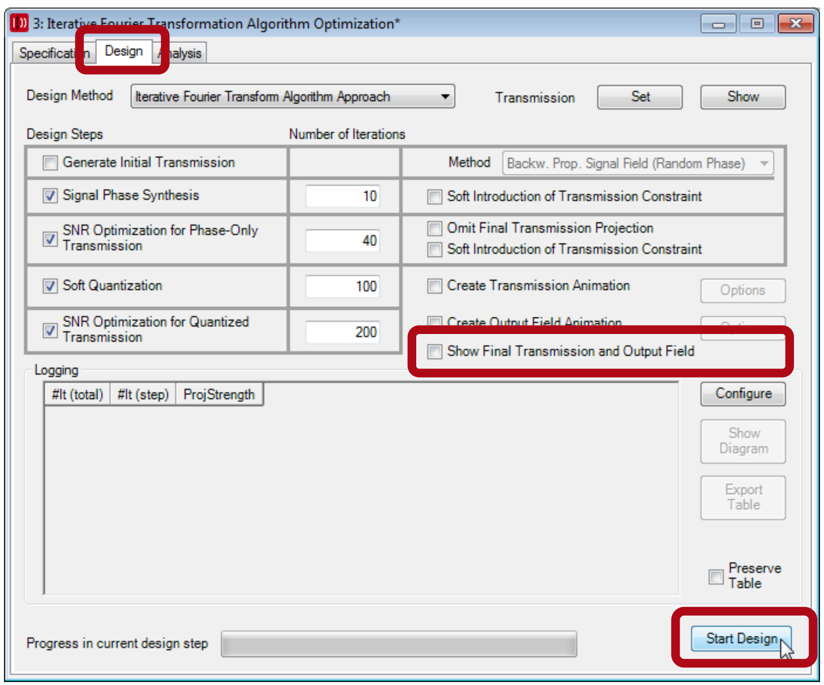
Disable the logging of the following two merit function values:

- Conversion Efficiency
- Signal-to-Noise Ratio

This disabling of some loggings does not affect the optimization.

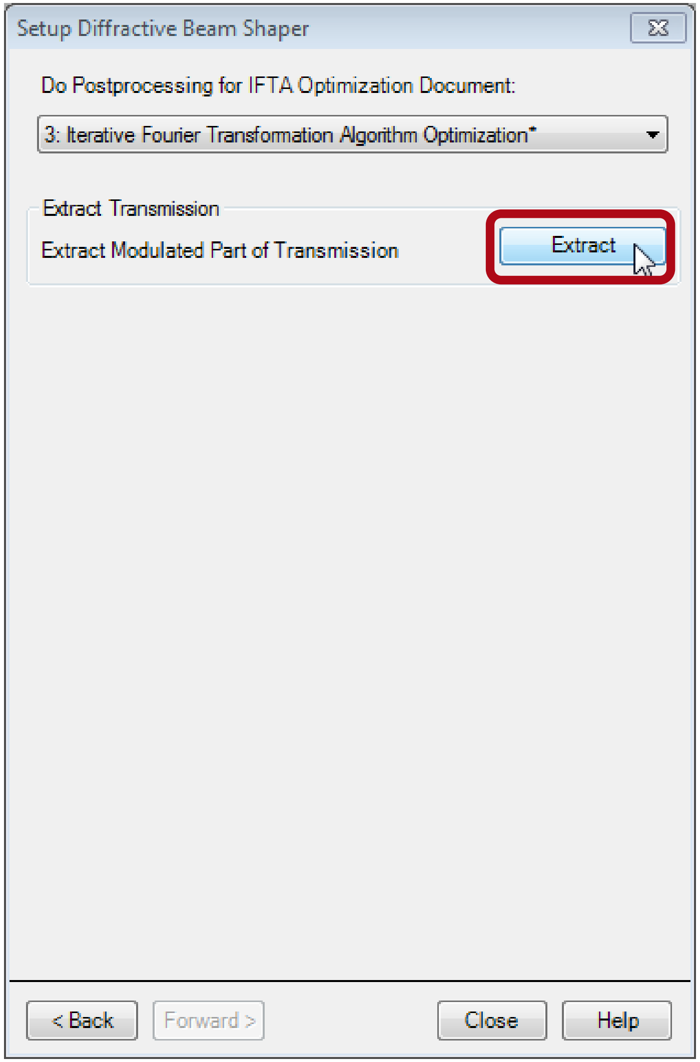
- Confirm with “Ok”.

IFTA Optimization 3

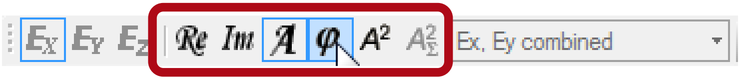


- Uncheck “Show Final Transmission and Output Field” for the relevant data will be extracted using the dialog “Setup Diffractive Beam Shaper”.
- Then click “Start Design.

IFTA Optimization 4

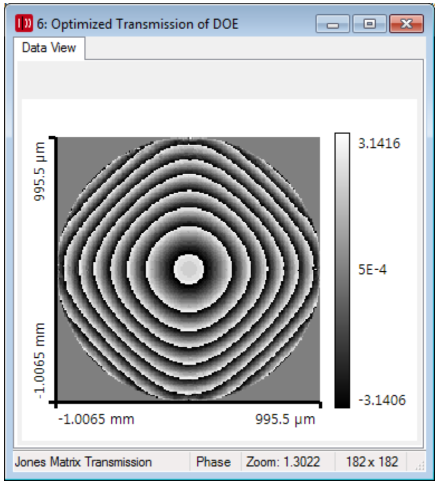


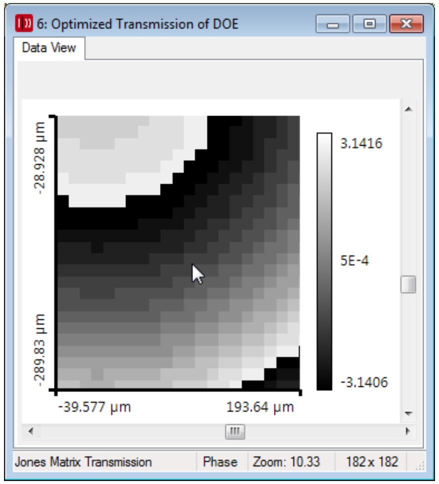
- When the design completed successfully – indicated in the messages panel – switch back to the dialog "Setup Diffractive Beam Shaper" and extract again the data of interest by clicking "Extract".
- Further activate the phase view.



Results in

IFTA Optimized Transmission

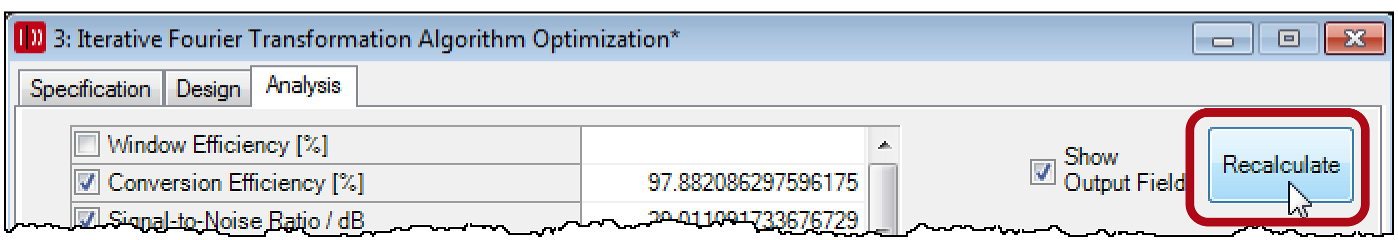




- The result is comparable to the previous one.
- After zooming in (with the mouse wheel) the introduced phase discretization becomes visible.

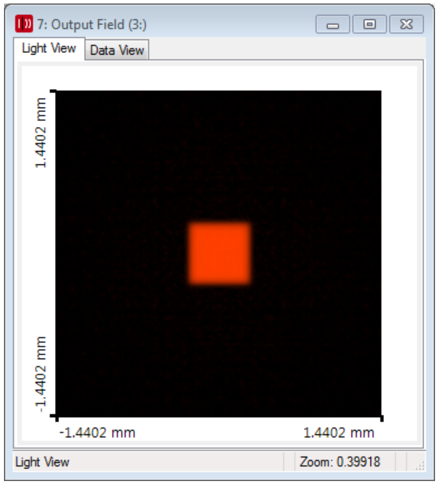
IFTA Results 1

- Again switch back to the Analysis tab of the design document and click “Recalculate”.



Results in

IFTA Results 2



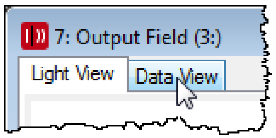
☐ Window Efficiency [%]	
☑ Conversion Efficiency [%]	96.897799114995138
☑ Signal-to-Noise Ratio / dB	48.467698617696094
☑ Uniformity Error [%]	15.433530790091091
☐ Zeroth Order Intensity [%]	
☐ Zeroth Order Efficiency [%]	
☑ Maximum Relative Intensity of Stray Light [%]	1.5324463437275169

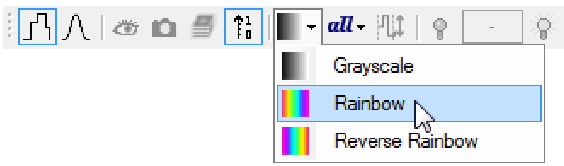
Results from the iterative Fourier transform algorithm approach:

- Efficiency almost 97%
- SNR almost 50%
- Amount of stray light below 2%

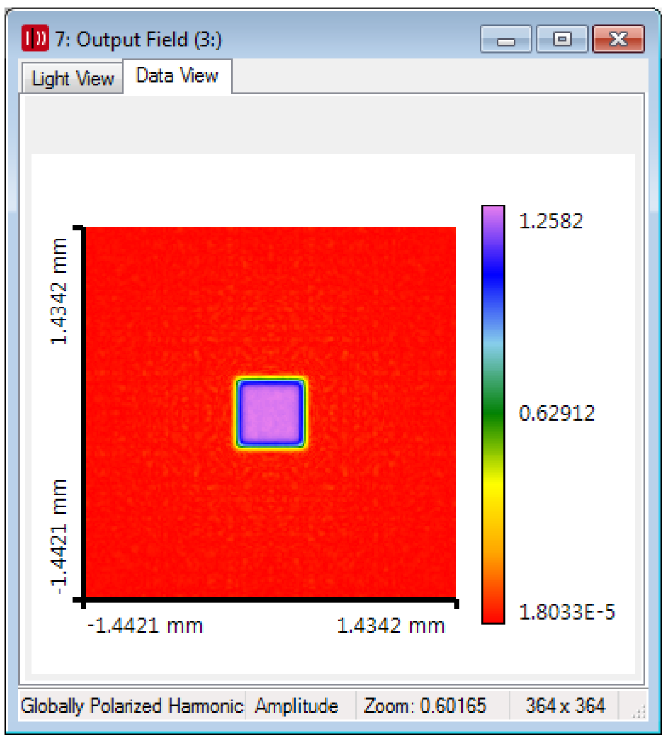
So the specifications are fulfilled.

IFTA Results 3





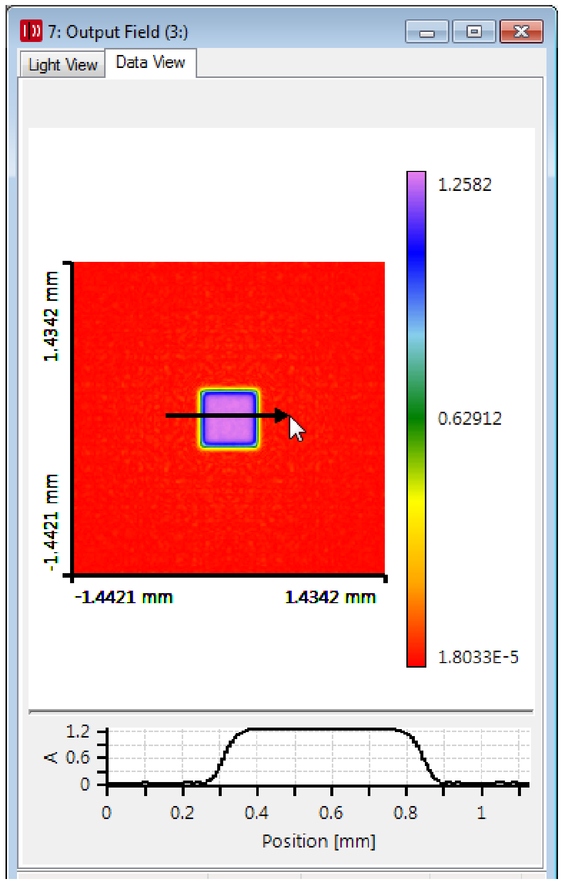
Results in



- To examine the distribution of the light's amplitude in more detail switch to a false color representation.
- Therefore switch first to "Data View" and then click "Rainbow" on the accordant tool bar.

IFTA Results 4

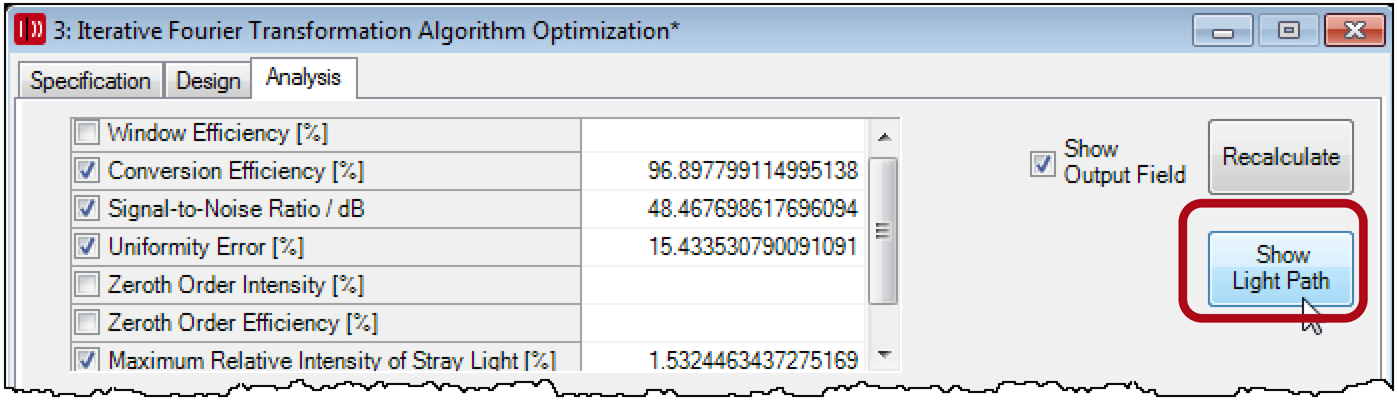
Results in



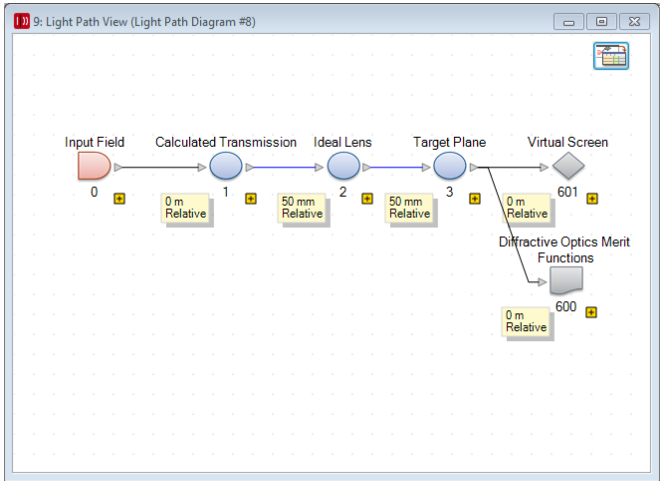
- In order to get the profile of the amplitude distribution select the tool "Profile Line" and draw a line over the area of interest.
- The distribution turns out to be very smooth.

Building of the Light Path Diagram 1

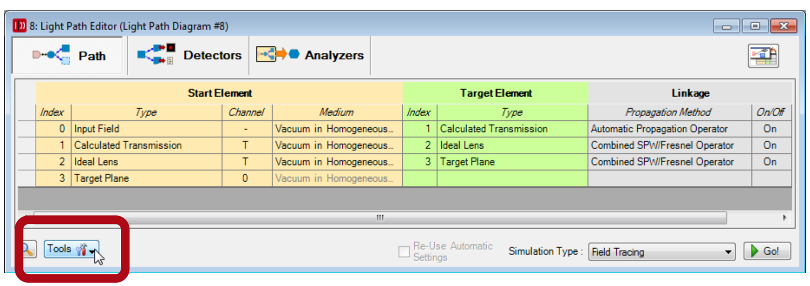
- In order to do further analyzes with this optical setup, such as varying of several parameters with the parameter run (shown in the first step tutorial FS.003_Introduction_to_the_Parameter_Run), one can build a light path diagram that contains the calculated transmission function of the DOE within a so-called stored transmission component by clicking “Show Light Path” on the Analysis tab of the design document.

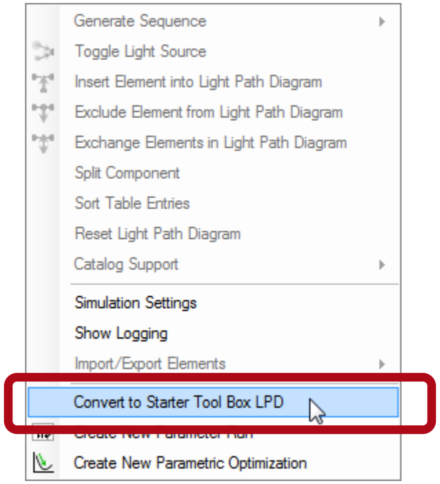


Building of the Light Path Diagram 2

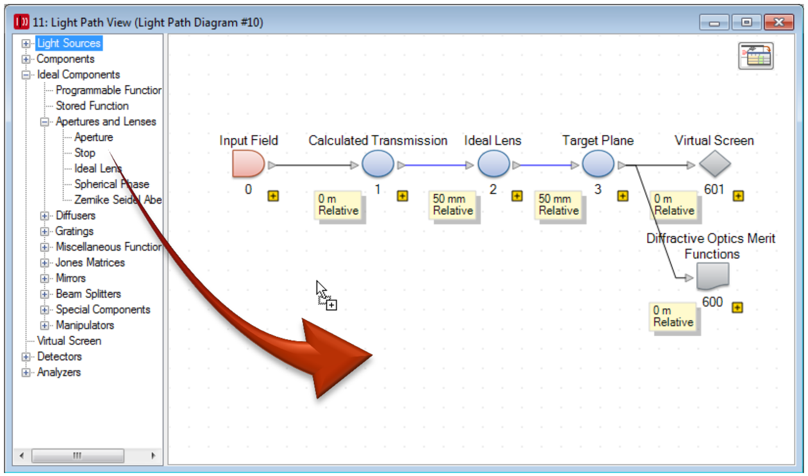


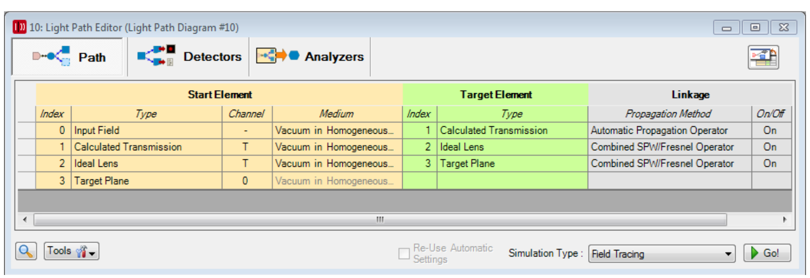
- This preset Light Path Diagram (LPD) has to be adapted a little.
- Note: Only Starter Toolbox LPDs can be changed.
- Thus click "Tools" in the Light Path Editor (LPE) and select "Convert to Starter Tool Box LPD".





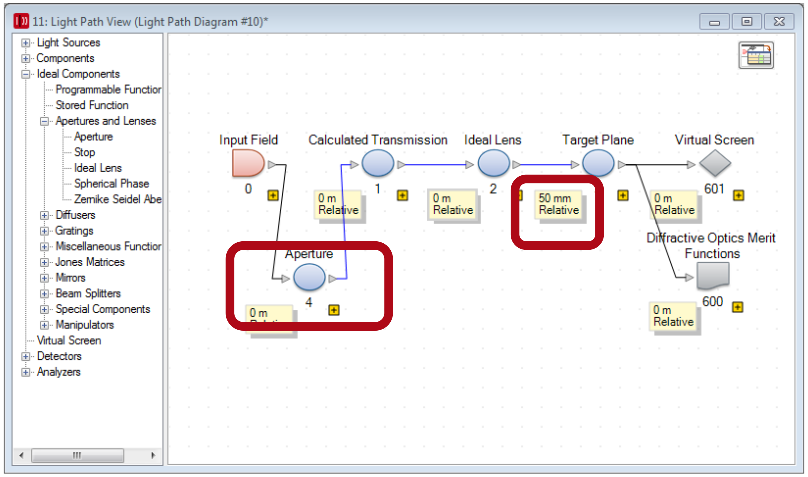
Building of the Light Path Diagram 3



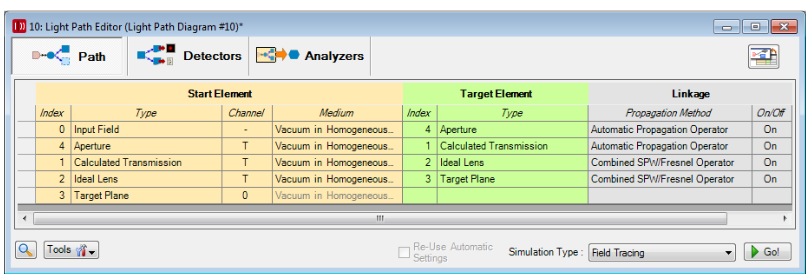


- Add and insert an aperture.
- Set its shape to elliptic and its diameter to 2×2 mm.
- Further change the 2f-setup of the Ideal Lens to a 1f-setup by setting the first distance to 0.

Building of the Light Path Diagram 4

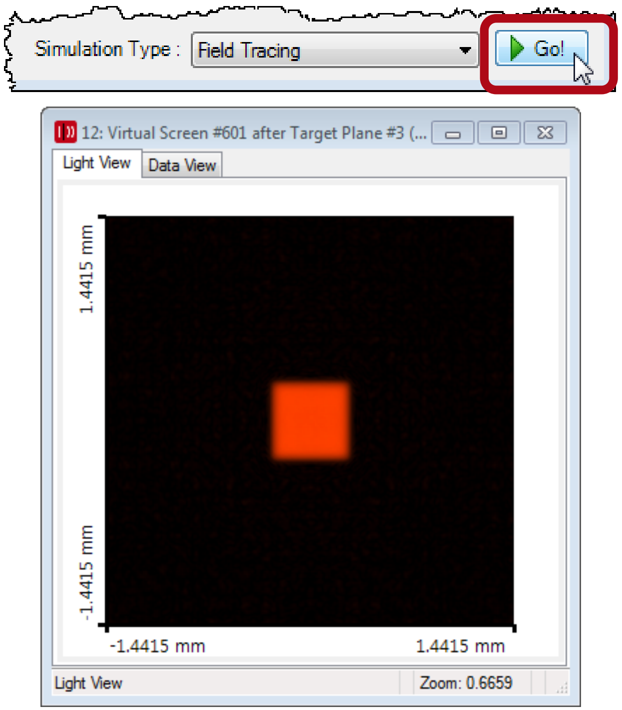


- The first element could be replaced with a Gaussian Wave as by default it is no adjustable light source but a "Stored Field" source that has the generated input field stored inside.



- But for this demonstration the stored complex field is kept as the input field.

Simulation and Results



- Starting the simulation with “Go!” and the light field distribution as well as the results of the diffractive optics merit functions are displayed.
- Results of the output field:
  Efficiency: 98.5%
  SNR: 43.4 dB
  Stray Light: 1.7%

	Date/Time	Detector	Sub - Detector	Result
4	01/09/2012 11:29:24	Diffractive Optics Merit Functions #600 after Target Plane #3 (0)	Conversion Efficiency	98.503 %
3			Signal-to-Noise Ratio	43.362 dB
2			Uniformity Error	10.07 %
1			Maximum Relative Intensity of Stray Light	1.7413 %

Messages | Detector Results

STEP 4

Data Export for manufacturing of the DOE
(just mentioned, details not part of this tutorial)

Data Export for Fabrication

- For fabrication purpose export the data of the transmission function of the DOE.
- How to do this is shown in the “Tutorial_144.01_Structure_Design_and_Fabrication_Export”.

CONCLUSION

Conclusion

- VirtualLab™ allows the design of diffractive beam shapers.
- Arbitrary 2D field distributions can be generated, e.g. top hats or lines.
- Fabrication constraints as for example discrete number of height levels or rectangular pixels can be included in optimization.