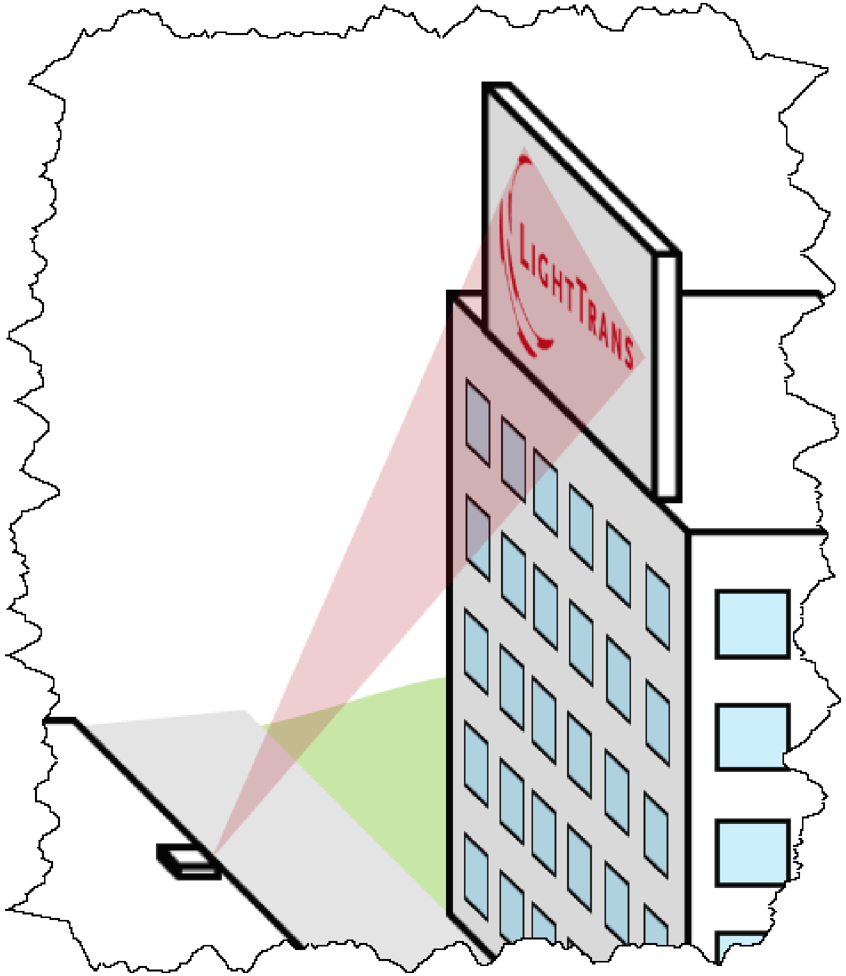
UseCase

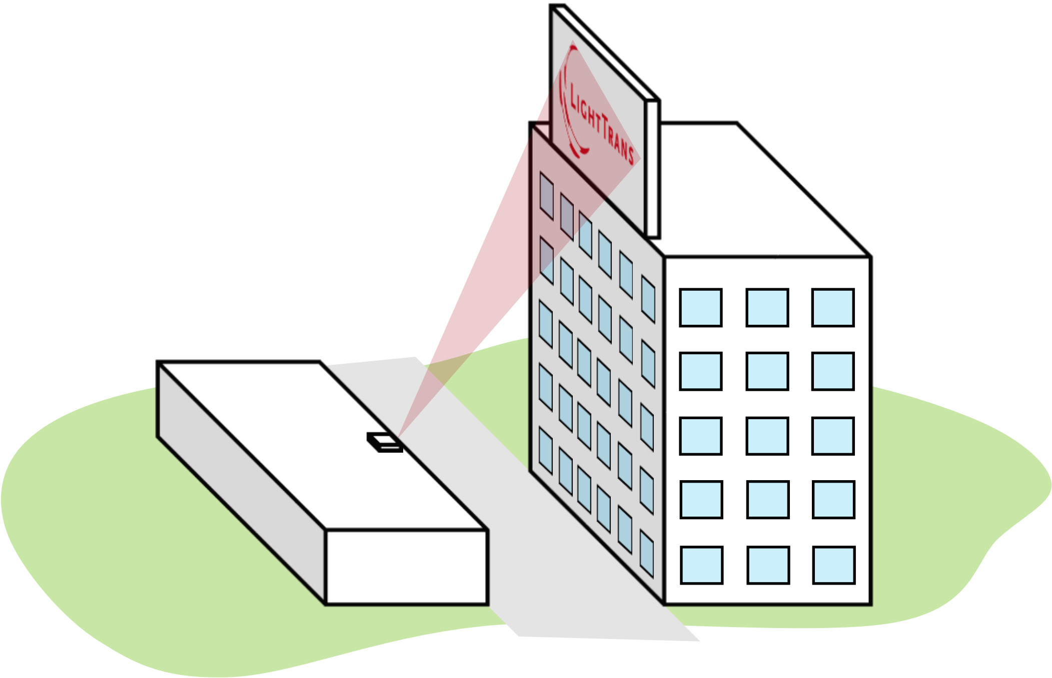
Design & Analysis of System with Diffractive Light Diffuser Generating the LightTrans Logo

Abstract



Diffractive diffusers can be designed to create any pattern. Here we demonstrate some possibilities of VirtualLab Fusion to design, optimize, model and simulate such diffractive optical elements (DOE) and the whole system to project our company's logo high up on a building. There are different approaches for generating light patterns. With a coherent laser light and a diffractive diffuser element, good efficiencies and interesting light textures can be achieved, which will be shown.

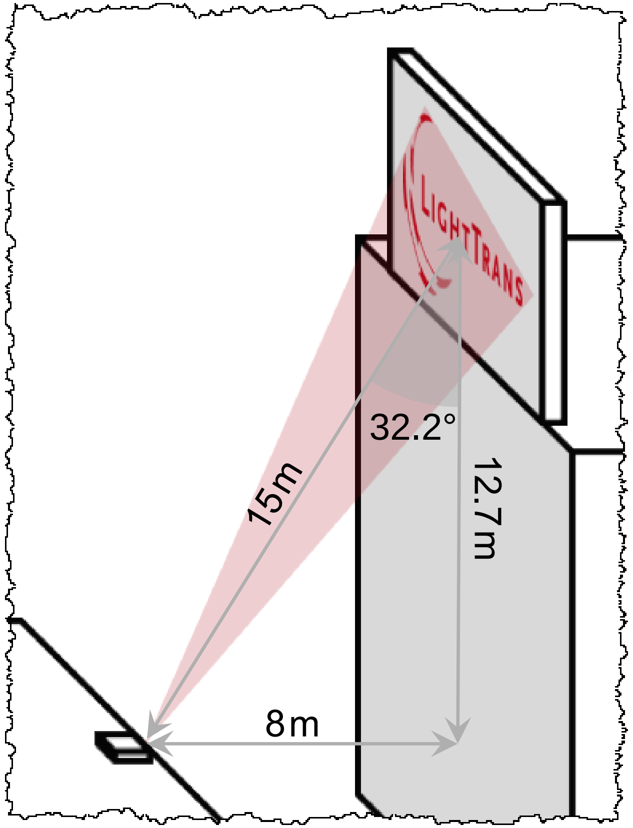
Task

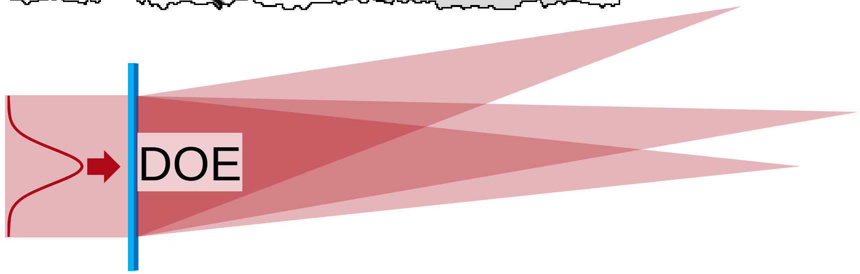


Gaussian laser beam

- wavelength λ: 650 nm
- assumed shape: circular
- 1/e² waist diameter w_{d}:free
- linearly polarized in x

For illustration purpose the LightTrans logo is depicted a bit bigger.





pattern to be generated

- shape: LightTrans logo (given via bitmap file)
- side length L_{pattern}: 4 m
- projection area: 4.6 m × 2.46 m

System Requirements

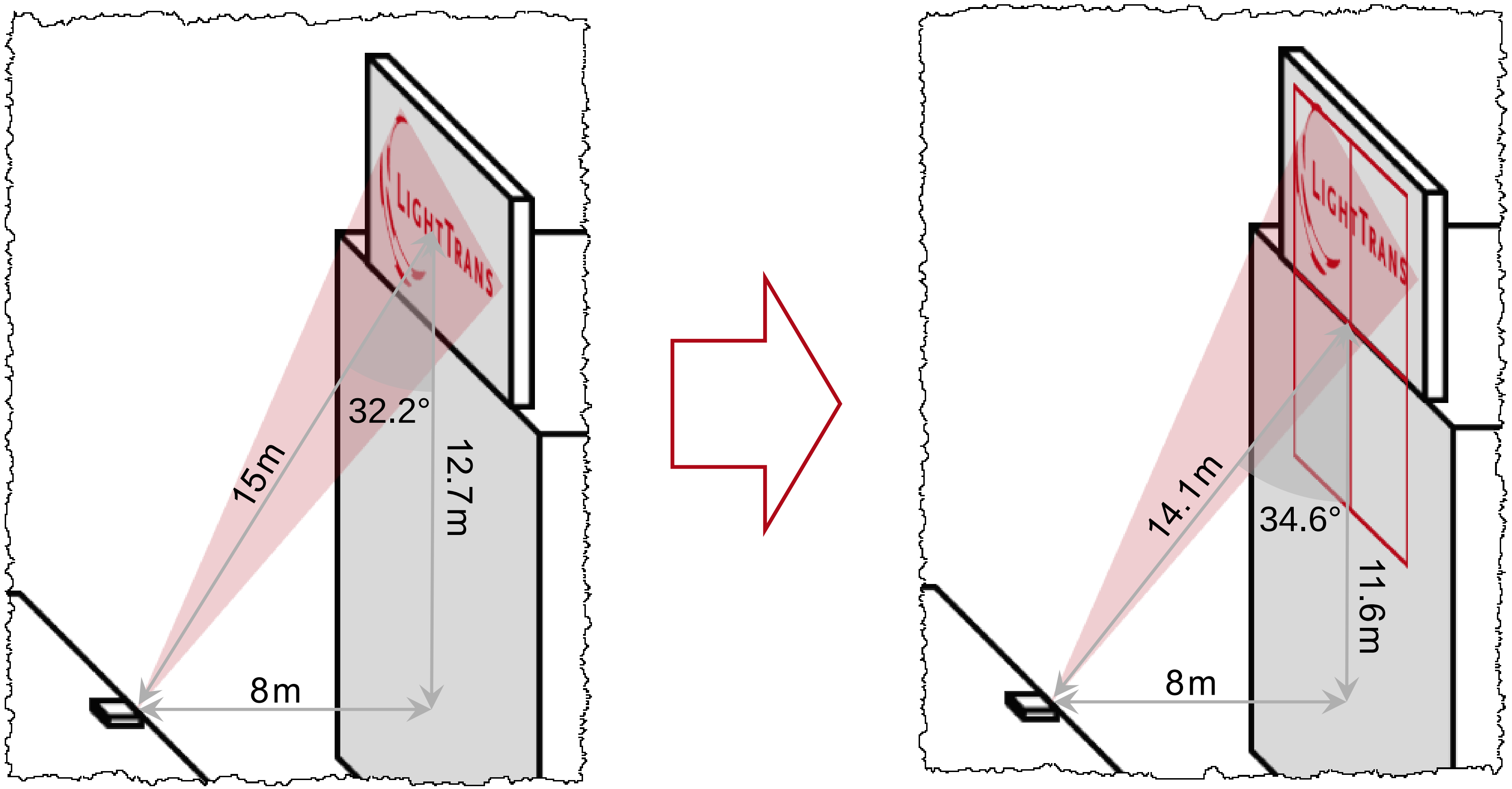
- no stray light outside of projection area

DOE (only optical element for pattern generation)

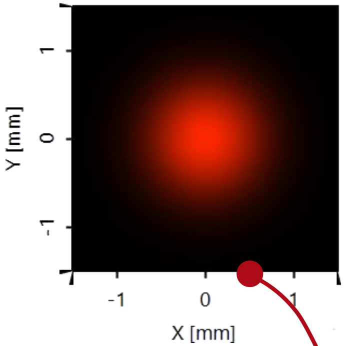
- shape: rectangular
- side length L_{DOE}: free
- material: fused silica
- structure type: required quantization level to be evaluated

Avoiding Possible Problems from 0th Order

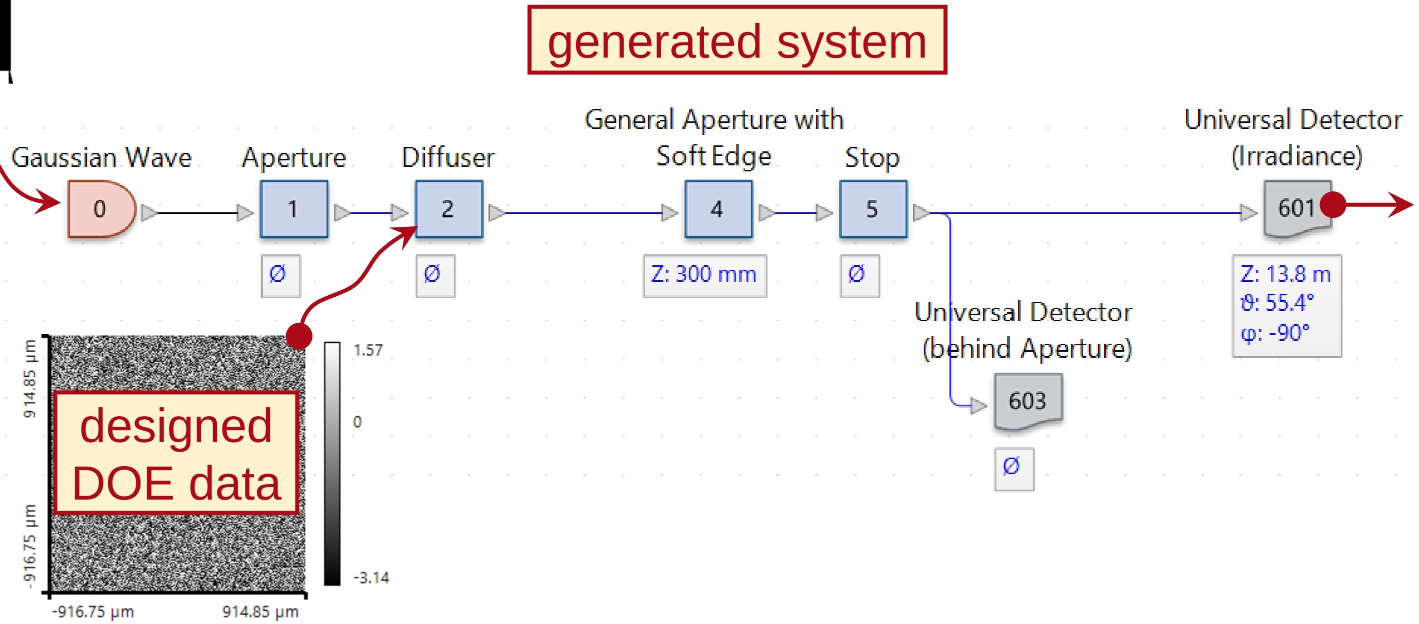
For being able to block the 0th order, the diffractive diffuser will be designed such, that it generates an off-axis LightTrans logo.



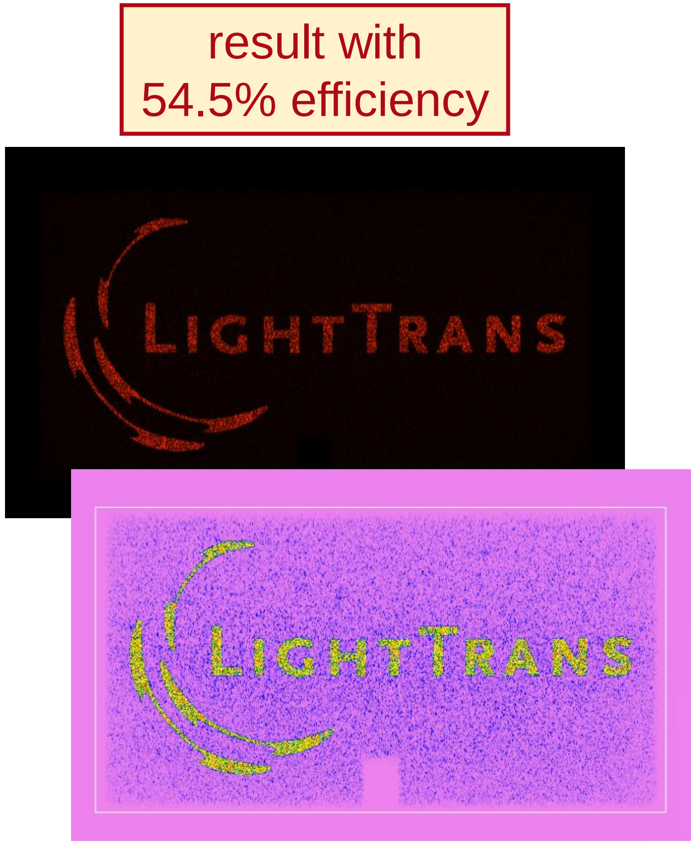
Result Preview



input beam
Gaussian laser



pattern shaping diffuser element
4-level phase function



irradiance result
in real color and
logarithmic reverse rainbow
(with indication of screen size)

Beam & Pattern Conditions→ Design Target Pattern (DTP)

beam: size evaluation

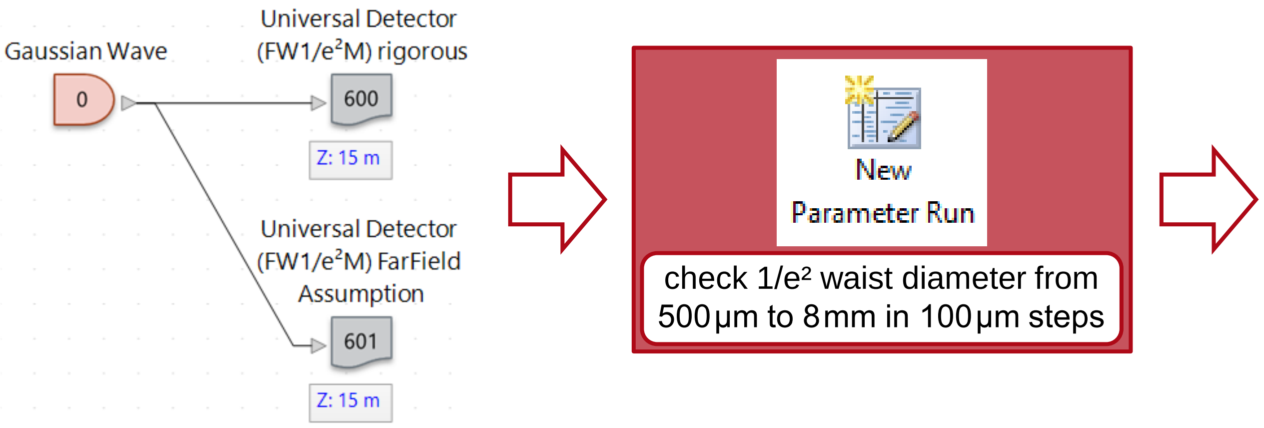
pattern: import, preparations, predistortions, sampling considerations

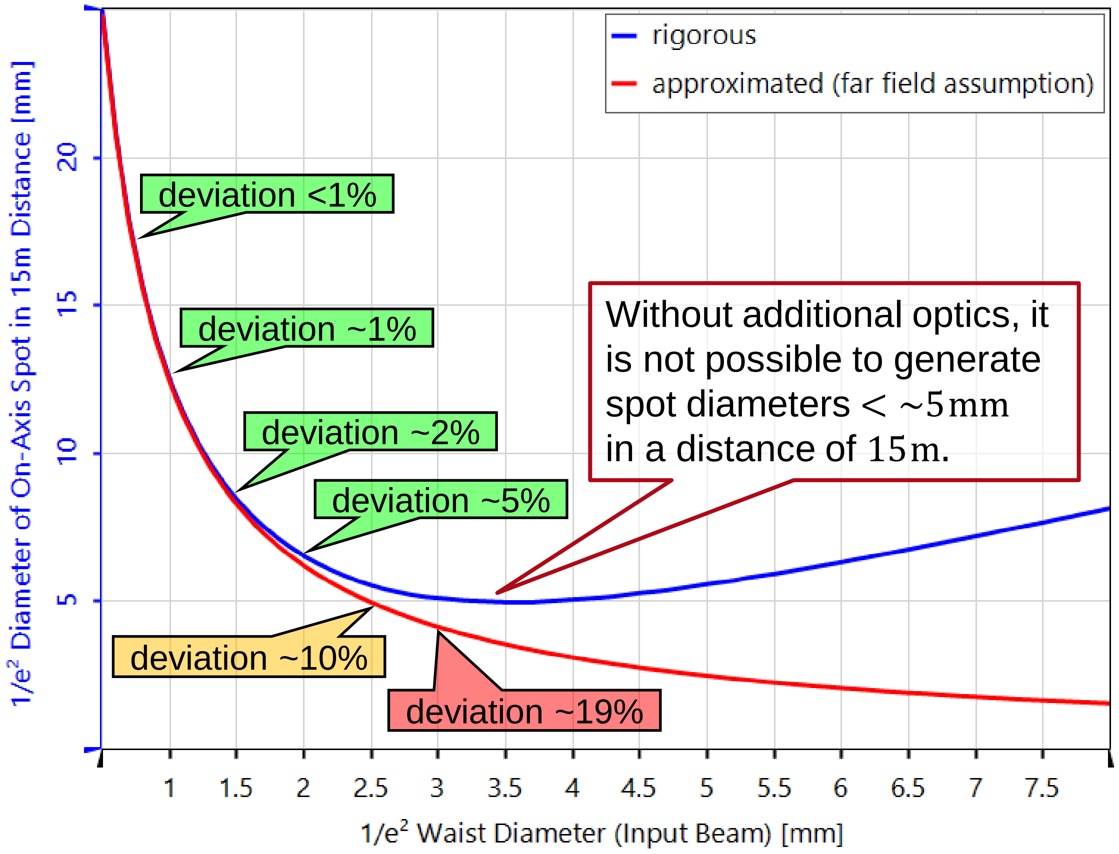
Spot Sizes in 15 m Distance

The diffuser element deflects the incident beam in such a way that the desired pattern is created. The resolution is determined by the size of the individual beam spot.

Via a simple optical setup, we ascertain the achievable spot diameters to be $\geq 5\,\mathrm{mm}$.

At the same time, we can already recognize which beam waists do not yet have the target plane completely in their far field.





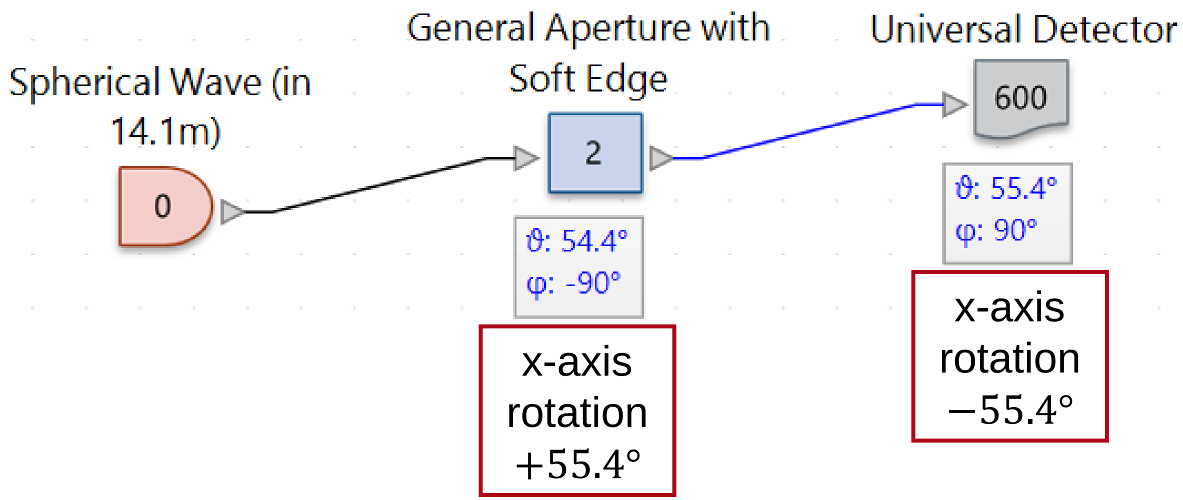
Information about the Design Target Pattern (DTP)

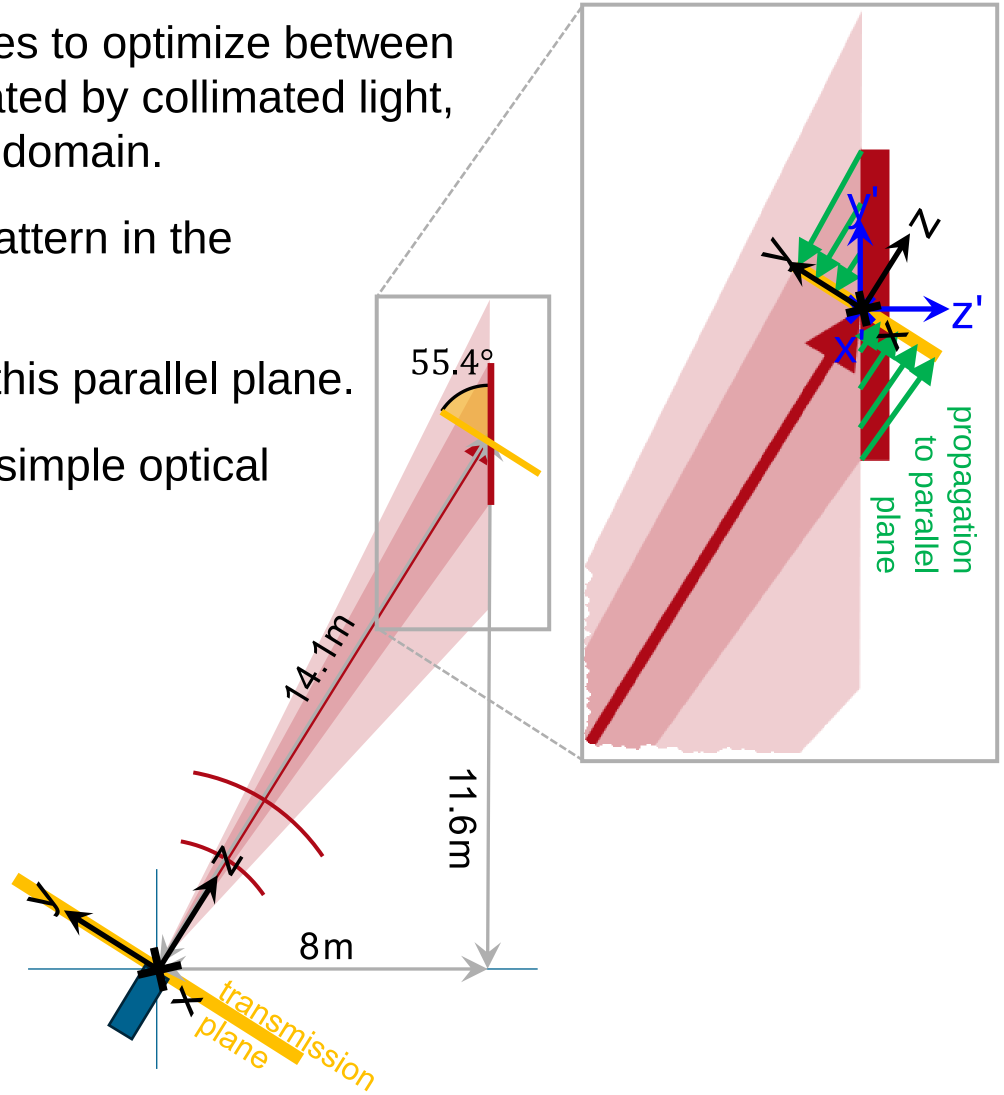
The iterative Fourier transform algorithm (IFTA) used for the design serves to optimize between the plane with the transmission function to be designed, which is illuminated by collimated light, and the associated target values of the deflected light directions in the k-domain.

For paraxial systems, the pattern in the k-domain is proportional to the pattern in the space domain parallel to the plane of the DOE.

For the design presented here, the pattern must therefore be defined in this parallel plane.

This geometrically distorted pattern can be easily created using another simple optical setup.

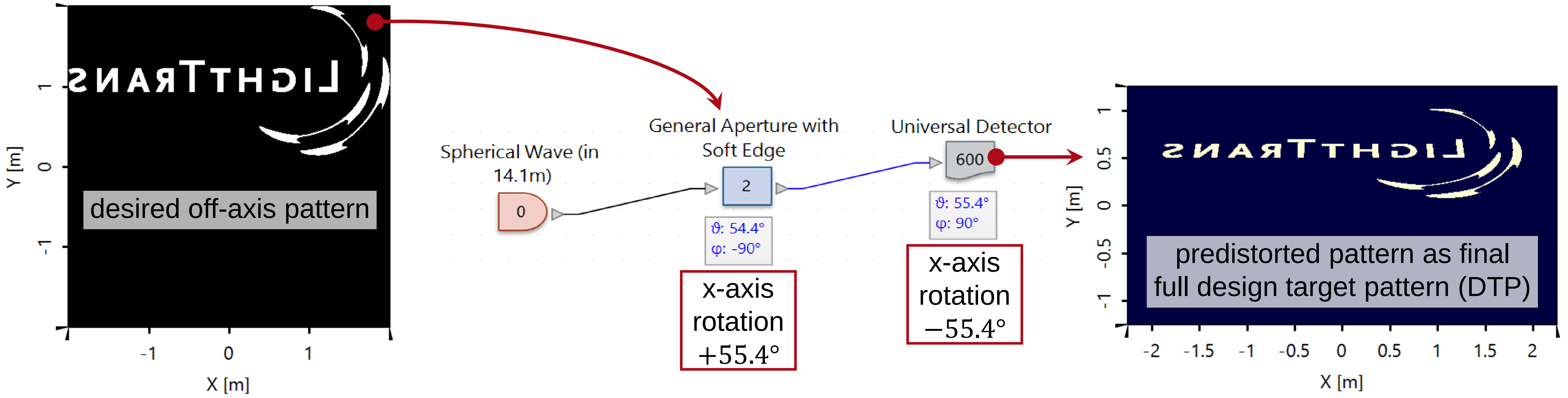




Predistorted Pattern for Design

Via the optical setup below, one can easily calculate how any desired projected light shape on the intended screen will look like on a plane that is tilted parallel to the DOE.

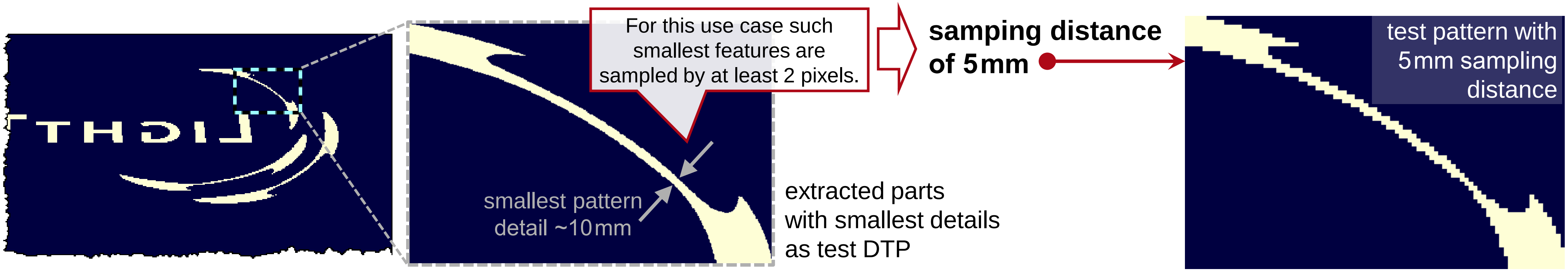
These distorted patterns can be used for the design process.



For more info follow this link into the appendix.

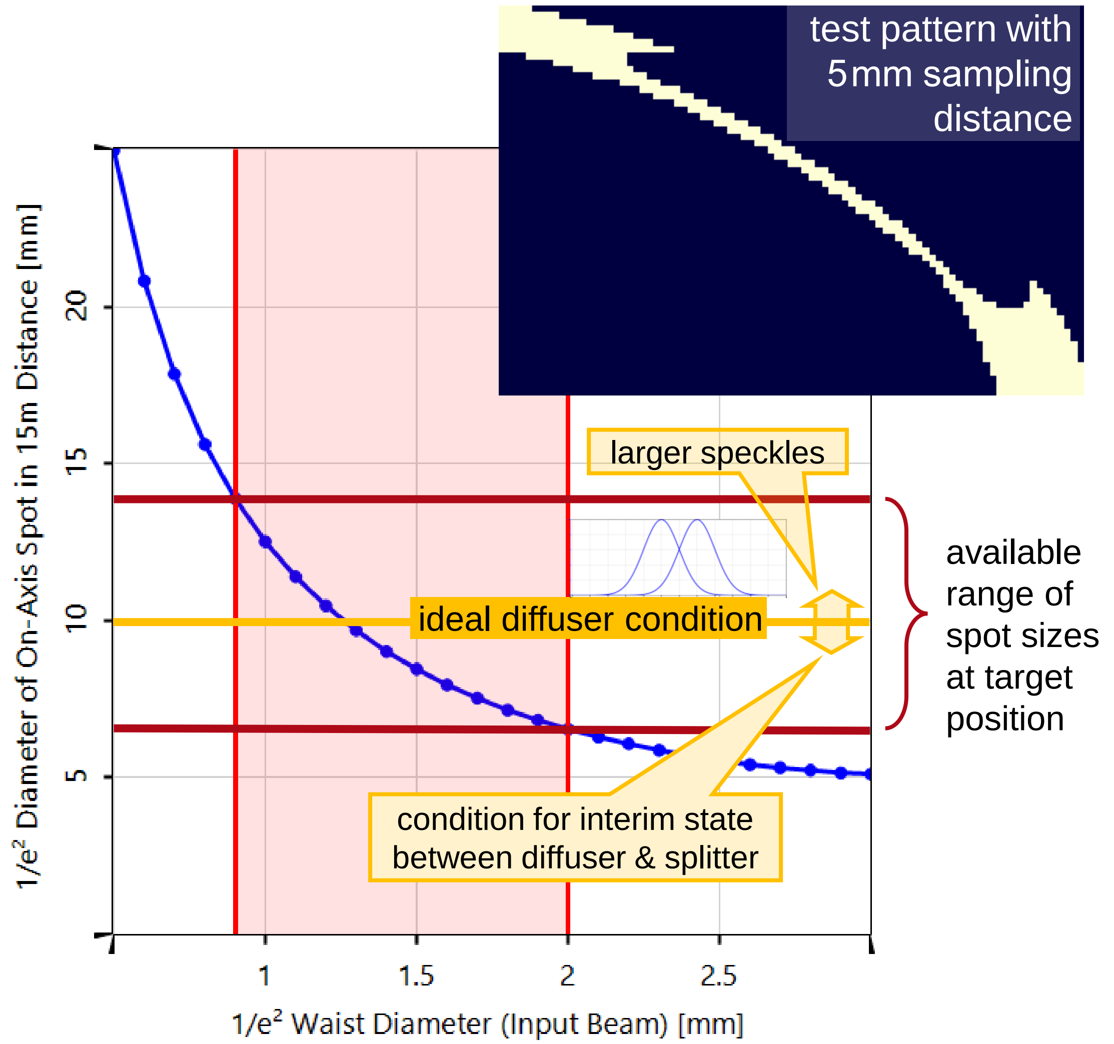
Sampling & Test DTP

- Depending on the desired light impression, a suitable sampling of the pattern must be considered, as each pixel center of the DTP represents a target position of a beam deflected by the diffuser.
- Based on our experience and intentions for this scenario, a sampling distance of 5mm is selected.
- It is also often helpful to create test designs based on smaller parts of the complete sample.



Target Spot Diameter for Pattern with 5 mm Sampling Distance

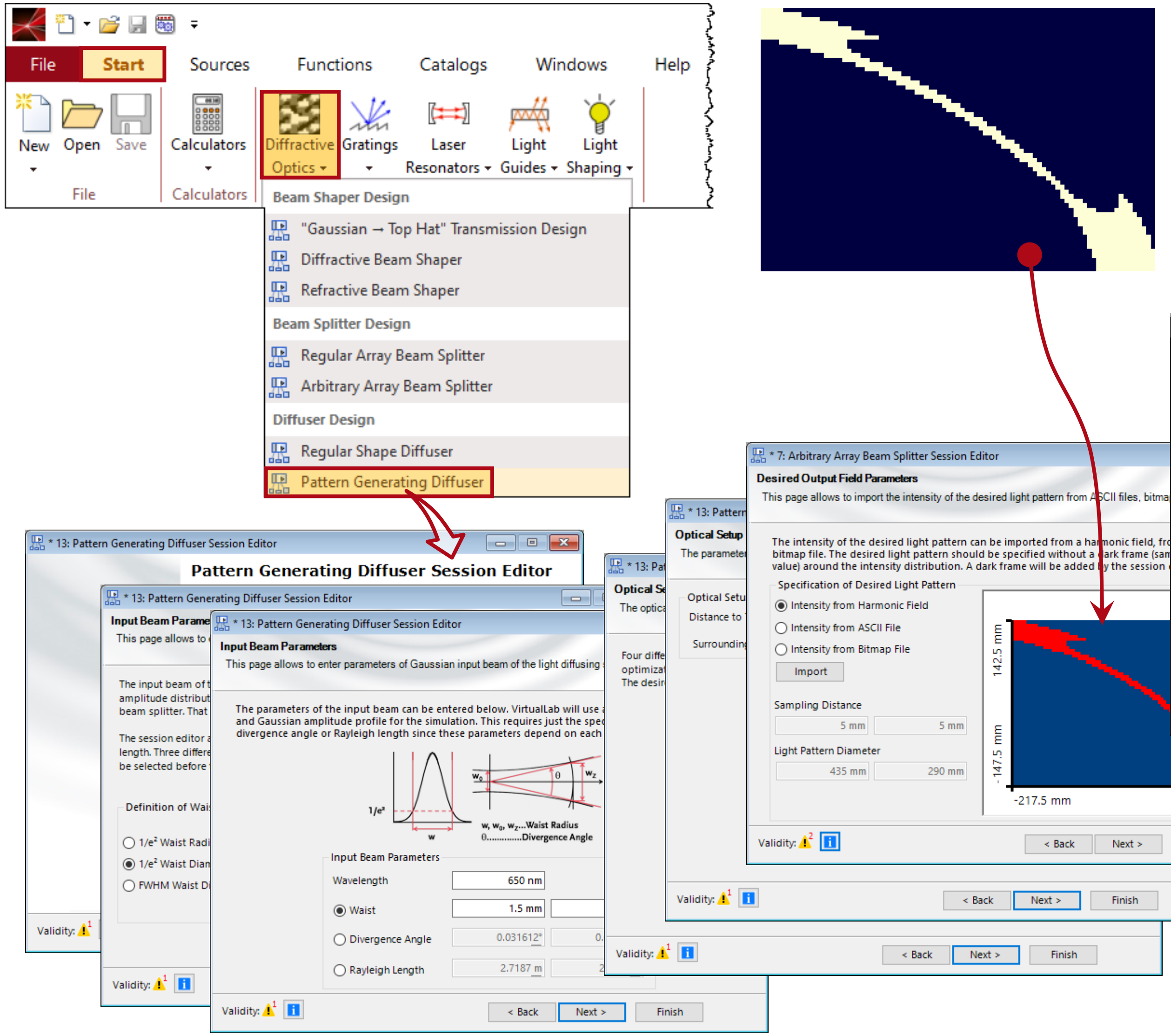
- In order to show different types of speckle patterns, the considered waist diameters will be in the range of $[0.9; 2.0]\,\mathrm{mm}$.
- The associated target spot diameters are in the range of about $[6.5; 13.9]\,\mathrm{mm}$.



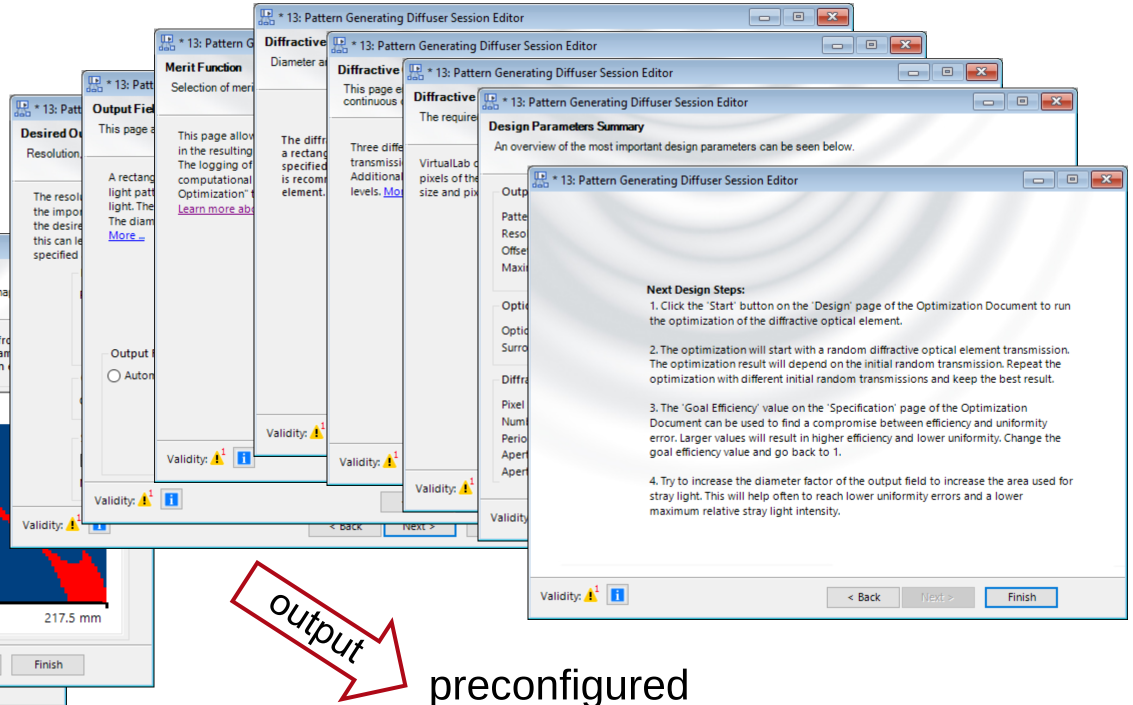
Test Design

comparing of achievable light textures
for decision on input beam diameter

Session Editor



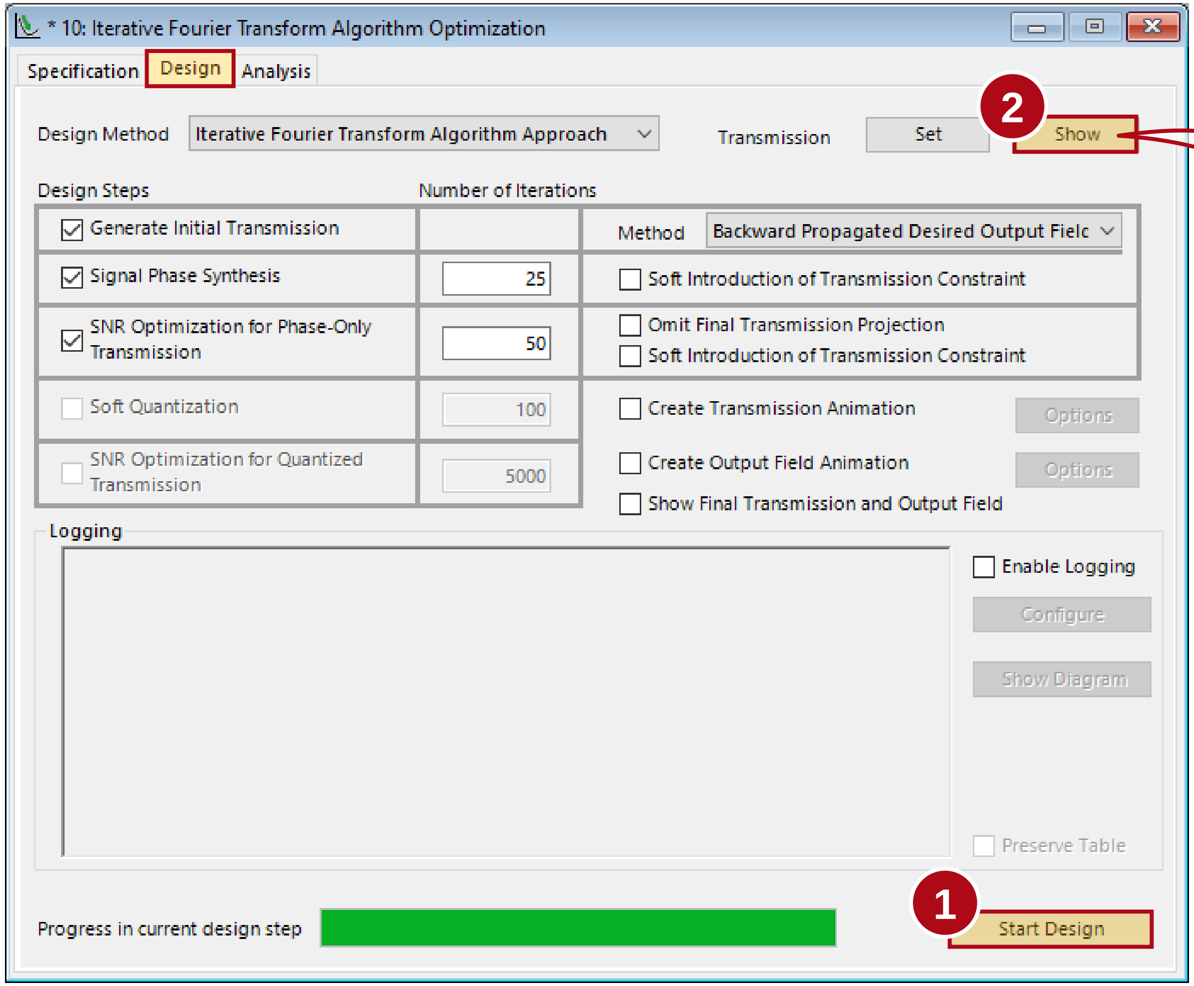
VLF provides assisting wizards, the so-called session editors, which guide you step by step through the different parameter configurations.

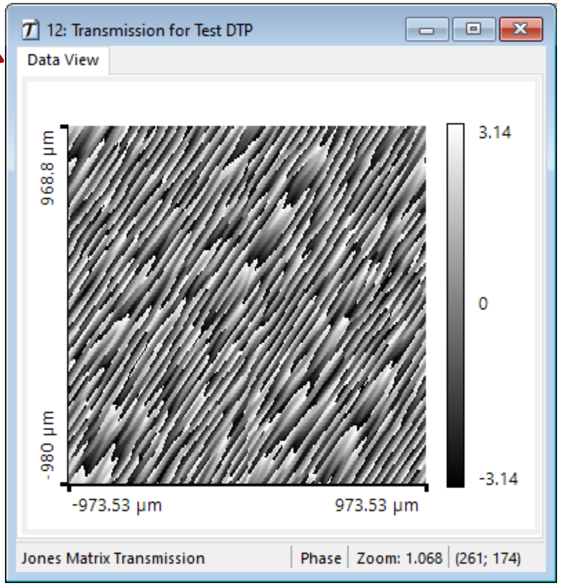


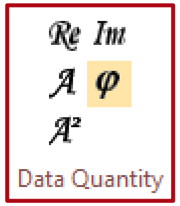
preconfigured

- IFTA design & optimization document
- optical setup document for system simulation

IFTA: Design & Result of Test Pattern

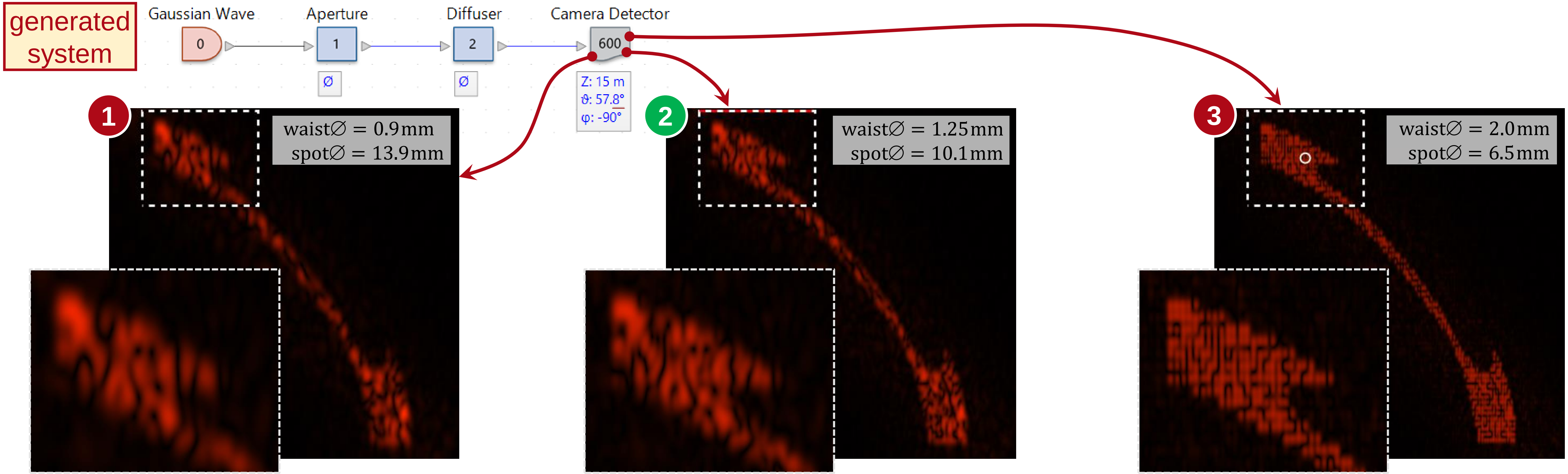






designed continuous phase-only transmission function

Pattern Texture/Impression → Selection of Illuminating Waist



The above results provide three representative impressions for different scenarios of target point overlap: (where a larger overlap leads to larger speckles with higher peaks)

1. standard overlap → smallest speckles
2. less overlap → interim appearance between diffuser and splitter

It is a matter of taste, which is the best solution.

For this use case the standard overlap is chosen, yielding an organic, flamy texture.

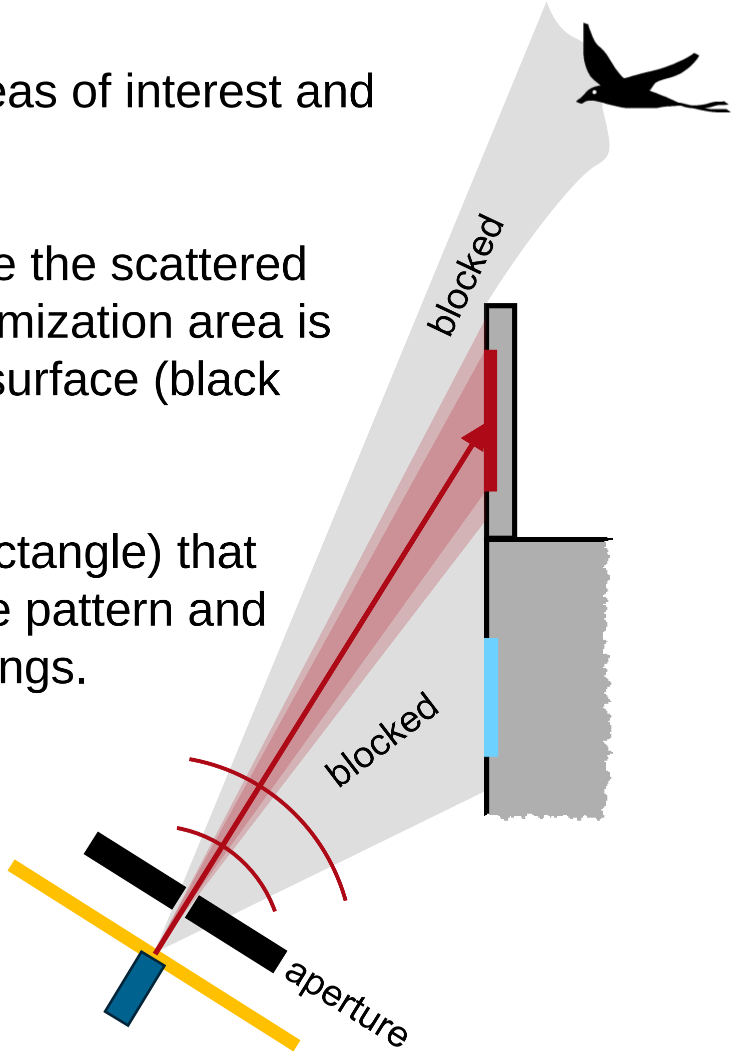
Full Design, Merit Functions & Simulation

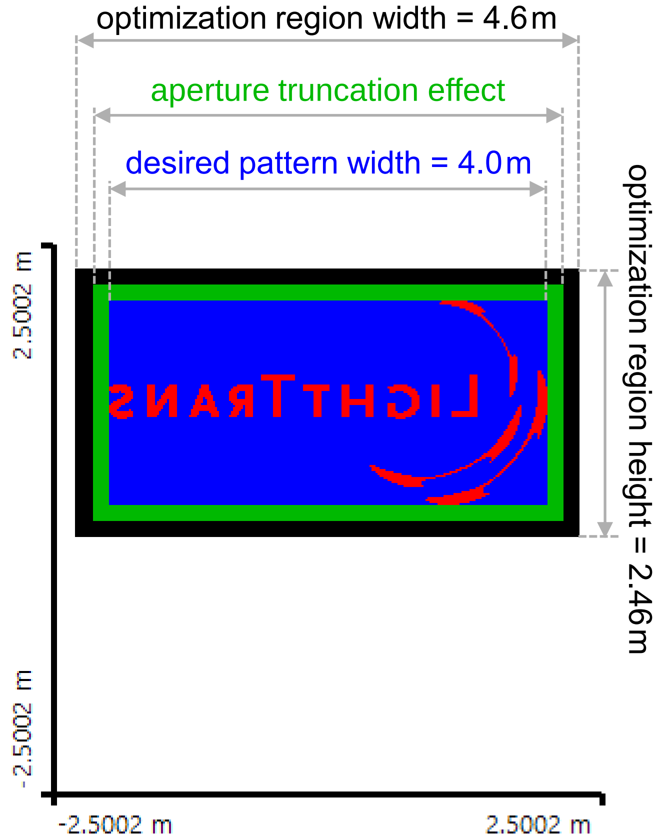
stray light, efficiencies & full output field impressions

Optimization Region

The illustrations opposite show various areas of interest and their purpose.

- To improve the contrast and thus reduce the scattered light around the desired pattern, an optimization area is introduced in the size of the projection surface (black rectangle).
- Later, we will use an aperture (green rectangle) that only transmits the light generated by the pattern and blocks the stray light from the surroundings.

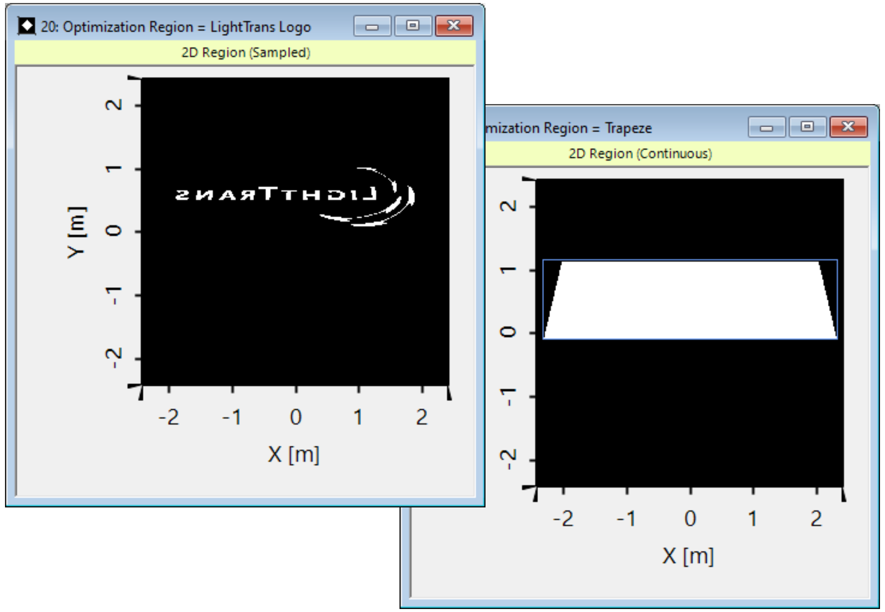


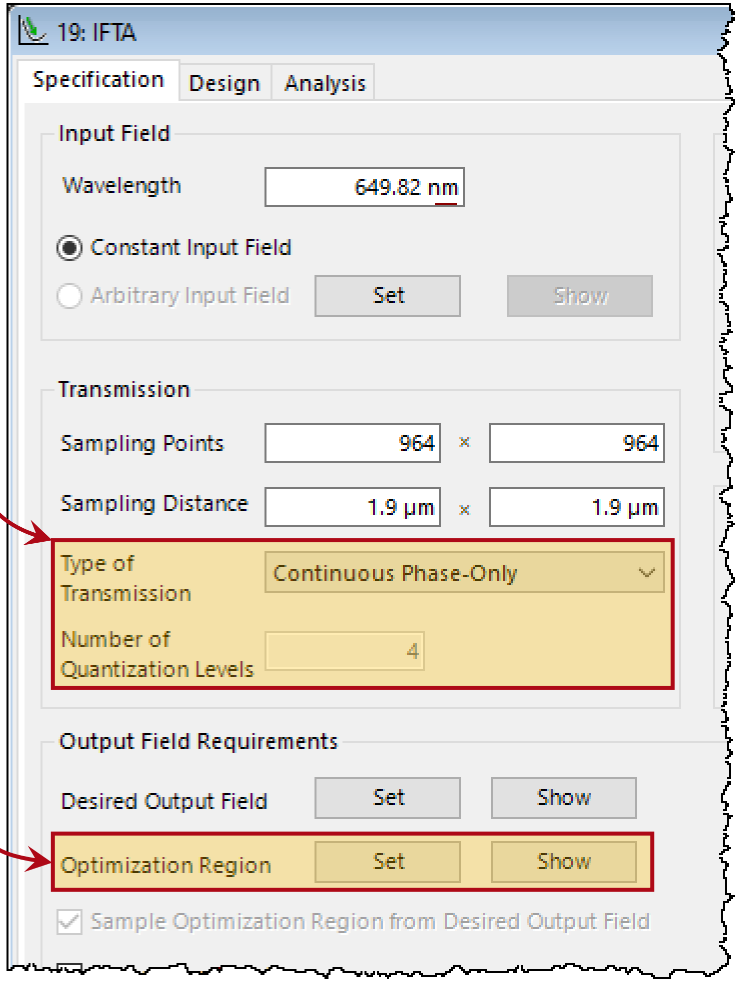


Designs of Different Modes

- For comparison purposes, we carry out designs of elements with continuous phase values, 8 and 4 phase stages.
- As optimization region either the LightTrans logo pattern itself or an expanded area connected with the projection area is used.

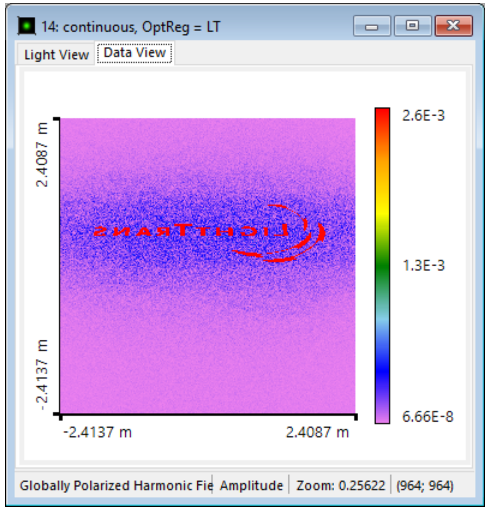
- continuous
- 8 levels
- 4 levels



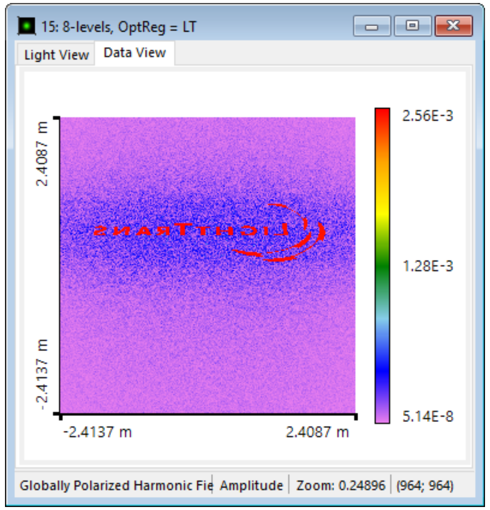


Visual IFTA Design Evaluations (Amplitudes)

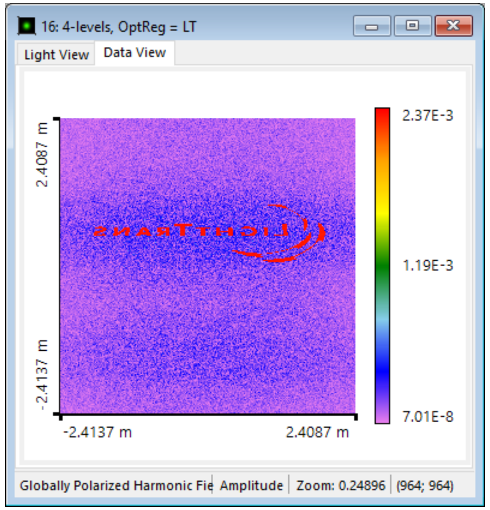
- The adjacent figures show the diffraction orders for the different design modes.
- Each pixel represents one diffraction order.
- Each design could be further optimized. For this comparison, however, all results were generated with the original IFTA default settings.
- For this application, we will stick with the 4-level element type, which should be easier and cheaper to manufacture.
- The trapezoidal area is used as the optimization area, which also ensures improved contrast for the 4-level element.



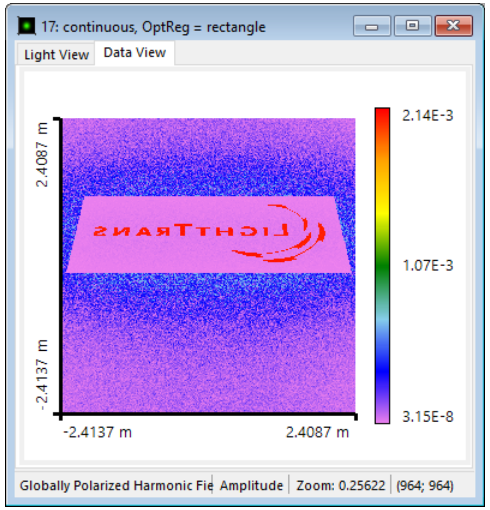
continuous, opt.reg.=DTP



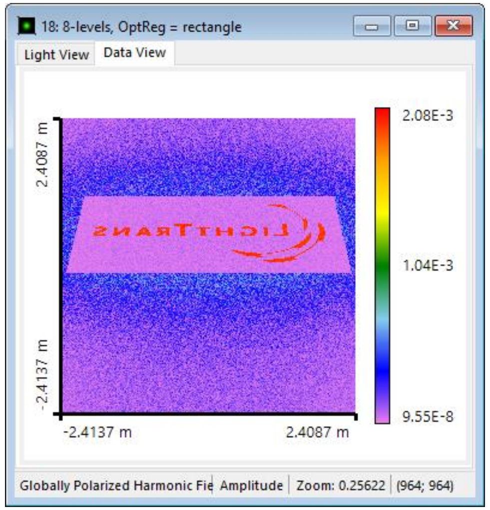
8-level, opt.reg.=DTP



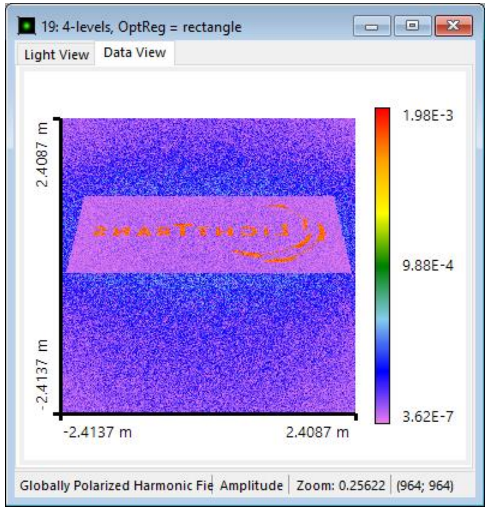
4-level, opt.reg.=DTP



continuous, opt.reg.=rectangle



8-level, opt.reg.=rectangle



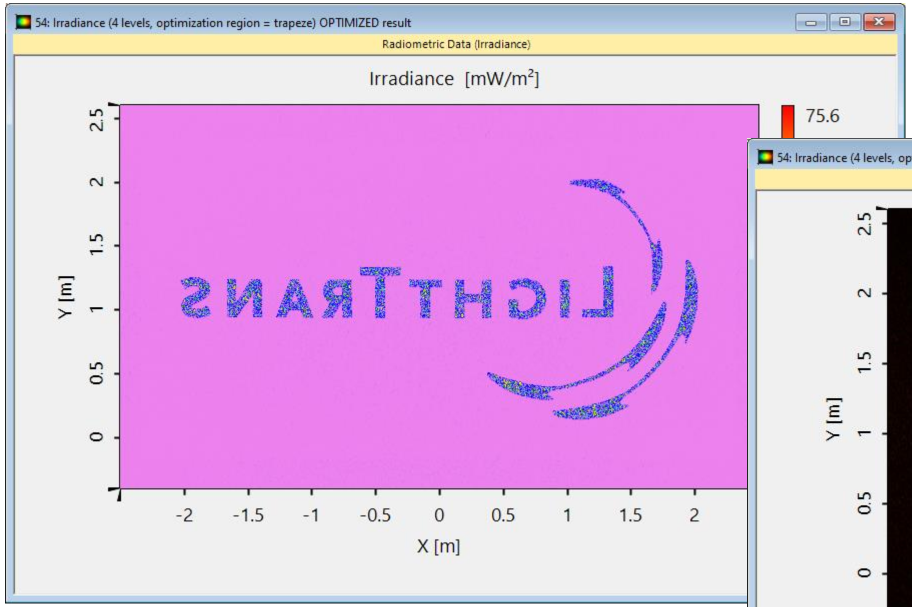
4-level, opt.reg.=rectangle

Results from Optimized 4-level Phase Transmission Function

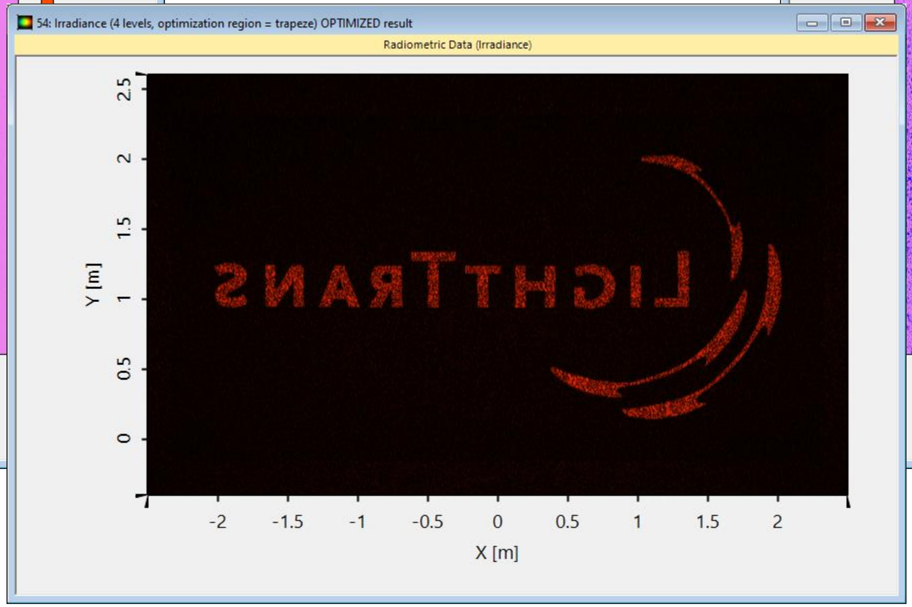
By using the IFTA's tuning options, the 4-level phase design could be optimized significantly.

For more info follow this link into the appendix.

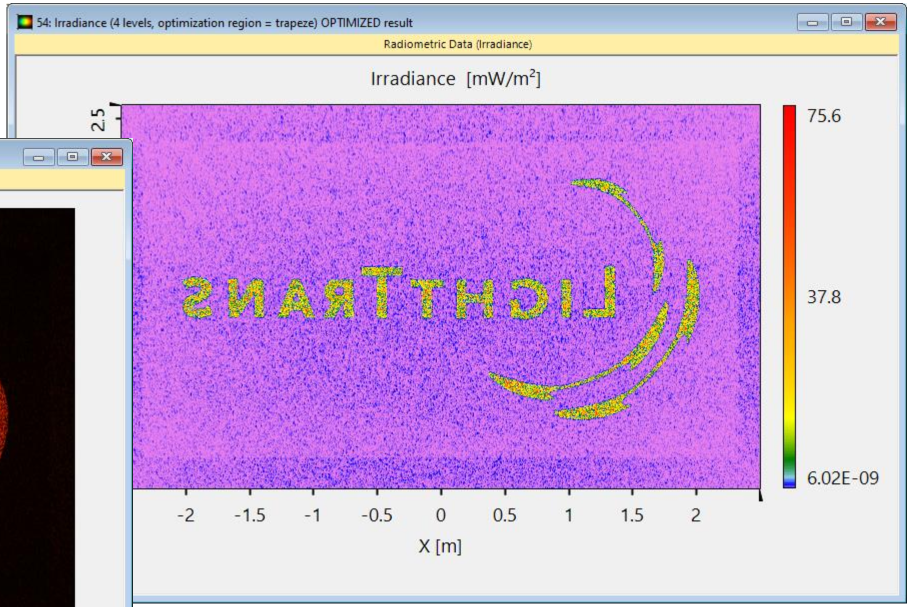
	Conversion Efficiency	Max.Rel.Int. Stray Light
default settings	31.0%	19.0%
optimized	54.5%	8.5%



false color (reverse rainbow)

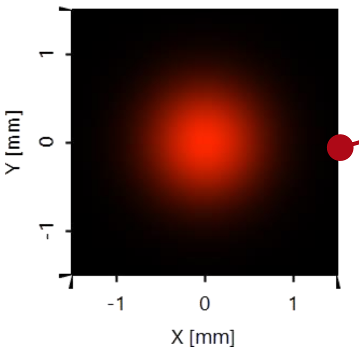


real color (emulated eye perception)

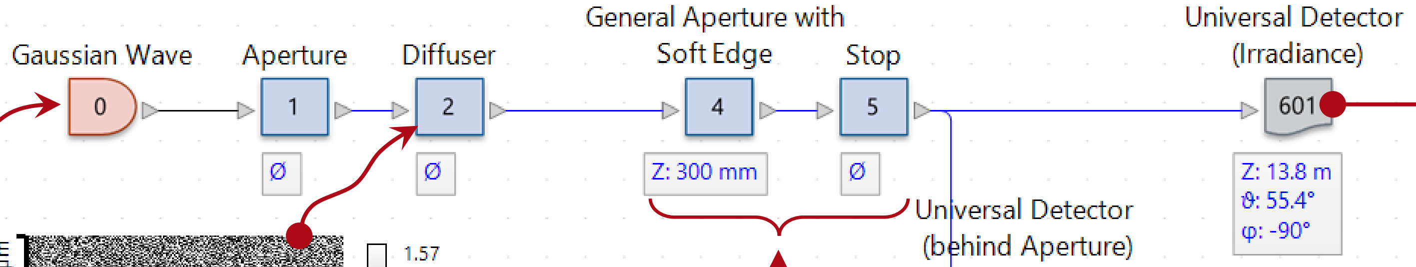


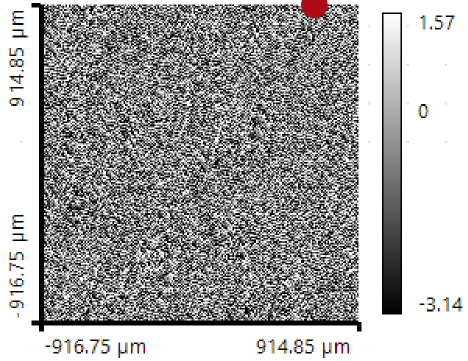
false color (reverse rainbow, logarithmic)

Final System with Aperture Blocking the Stray Light

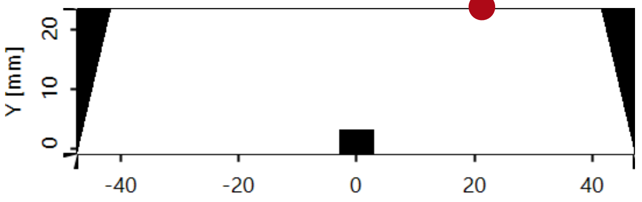


input beam
Gaussian laser

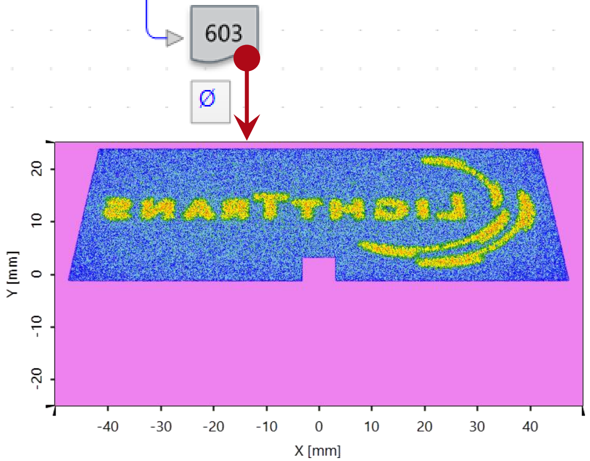




pattern shaping diffuser element
4-level phase function



aperture for blocking the stray light
modelled with 500µm soft edge



E field's amplitude directly behind aperture
false color view: logarithmic reverse rainbow

irradiance result
in real color and
logarithmic reverse rainbow
(with indication of screen size)

This simulation requires more time and RAM. To reduce the effort, we have omitted the pixelation factor in the diffuser element, i.e. neglected the sinc modulation. This effect is irrelevant, as this last simulation only serves to demonstrate the size and effect of the aperture.

Document Information

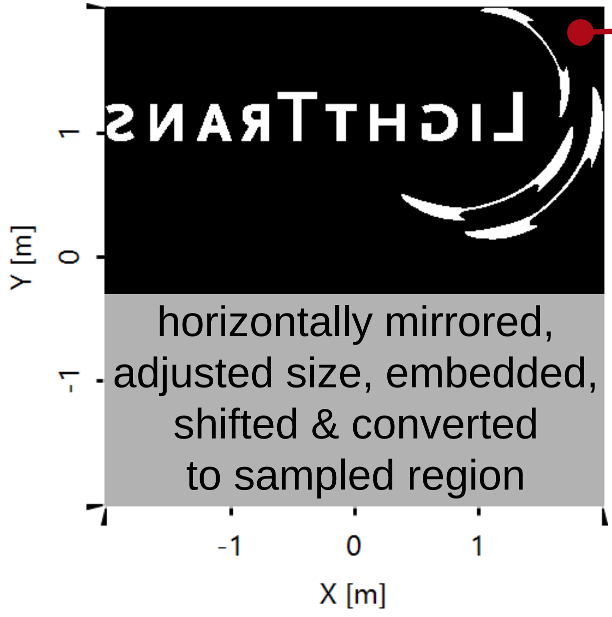
title	Design & Analysis of System with Diffractive Light Diffuser Generating the LightTrans Logo
document code	DOE.0003
document version	3.0
required packages	• Diffractive Optics
software version	2023.2 (2.30)
category	Application Use Case
further reading	

Appendix

Preparation of Distorted Design Pattern

pattern with fine resolution (3543×1655 px)

import

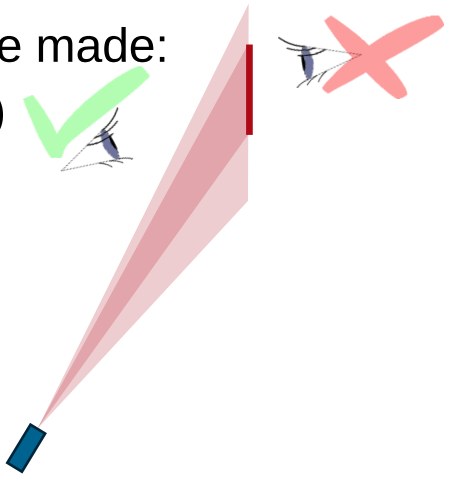


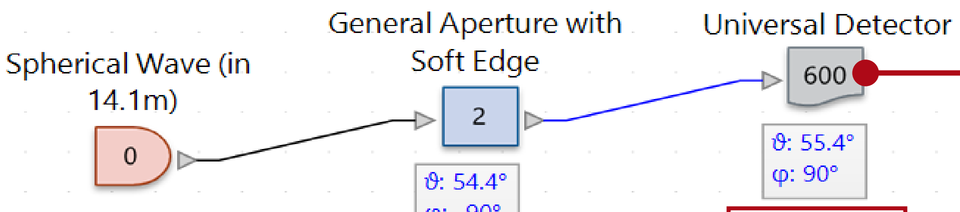
horizontally mirrored, adjusted size, embedded, shifted & converted to sampled region

After importing the desired design, the following adjustments are made:

1. mirroring (as the pattern is intended for reflected perception)
2. pattern size adjustment
3. shifting (for better 0^{th} order handling)
4. conversion to region (for use in special aperture element)

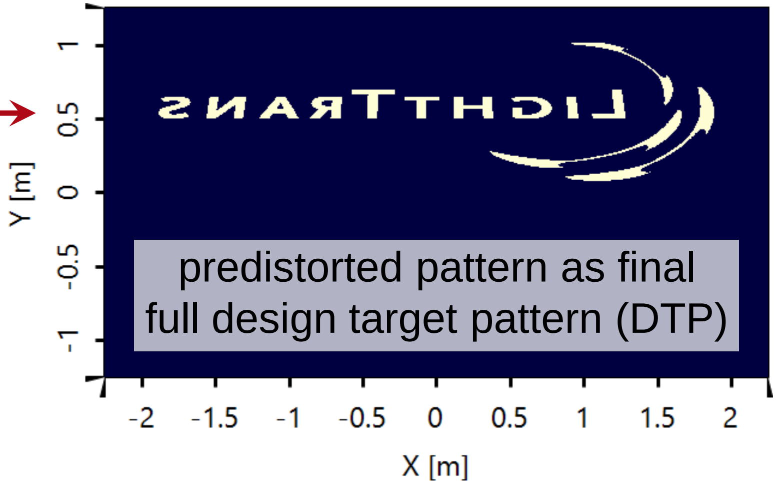
→ generation of predistorted pattern for design





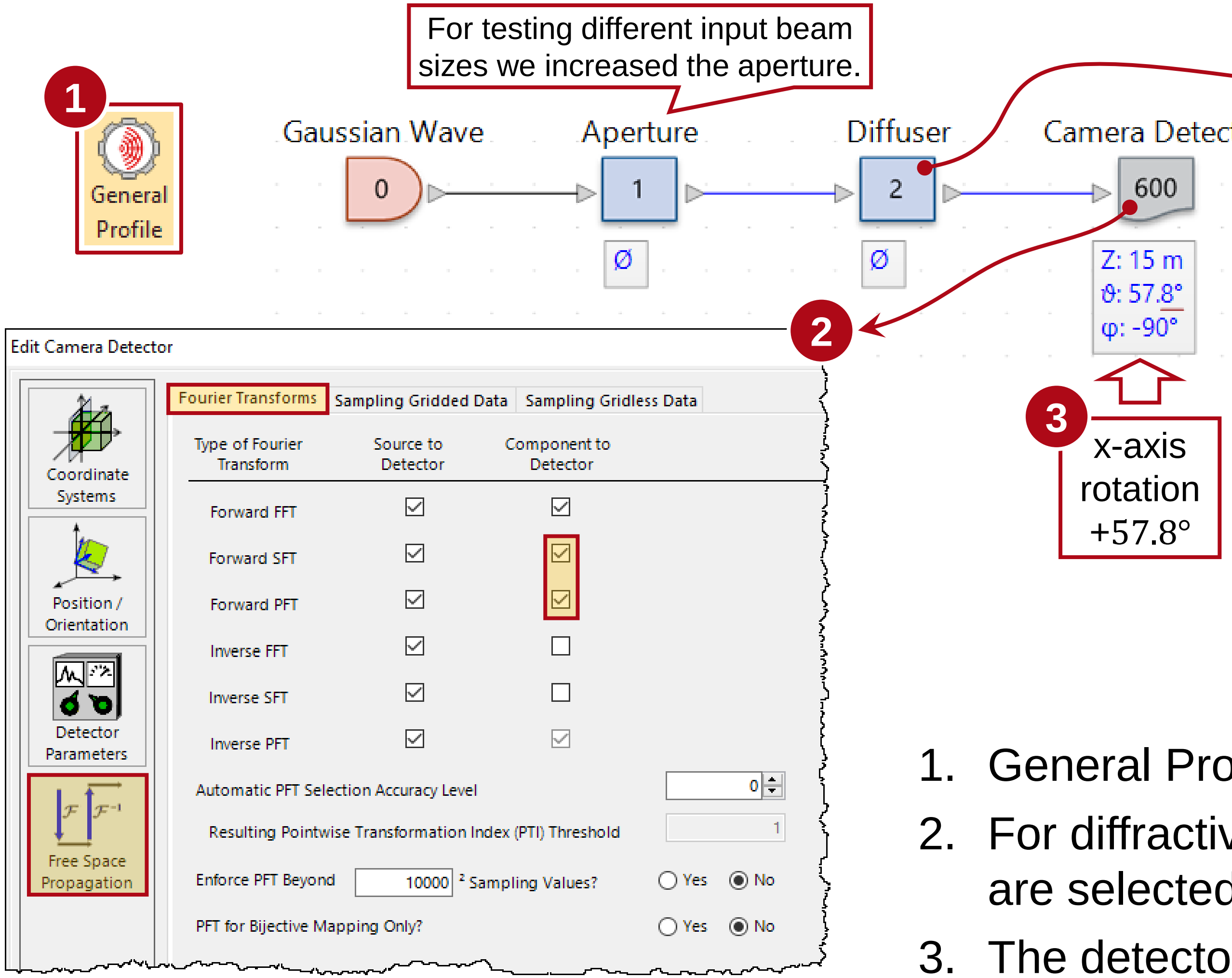
x-axis rotation +55.4°

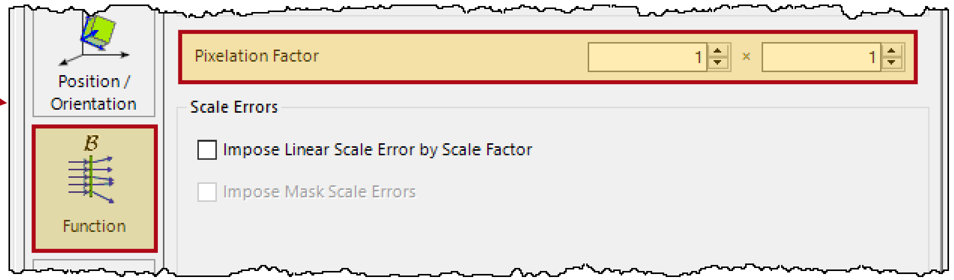
x-axis rotation −55.4°



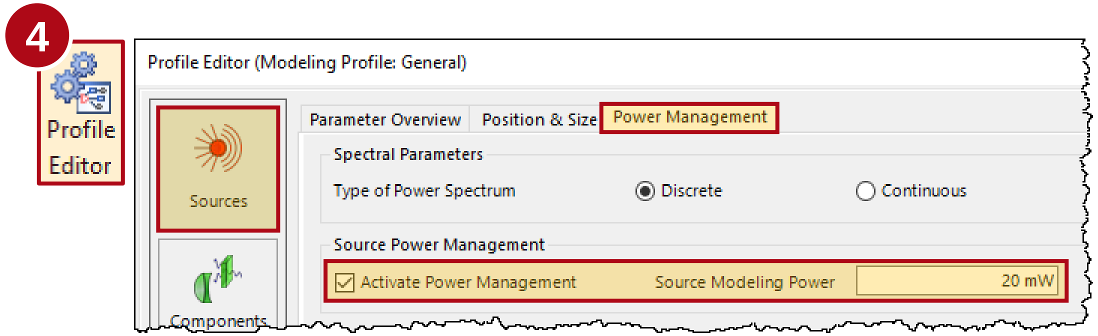
predistorted pattern as final full design target pattern (DTP)

System Adjustments for Test Simulations





We kept the Pixelation Factor at 1×1, for this test, there won't be a relevant sinc modulation.

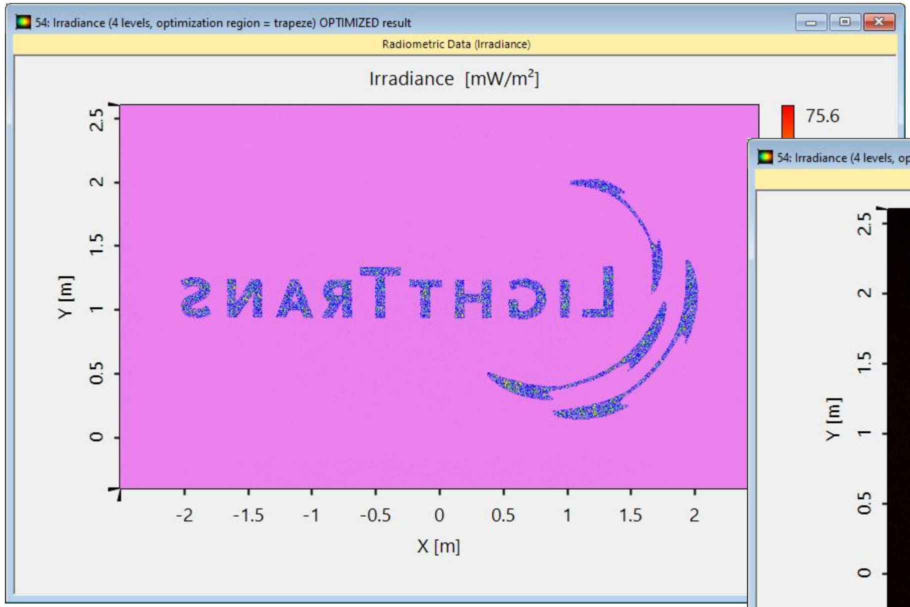


1. General Profile simulation engine is used.
2. For diffractive consideration, integral forward Fourier transforms are selected.
3. The detector is tilted according to the desired orientation.
4. A definite source power was set for comparable results.

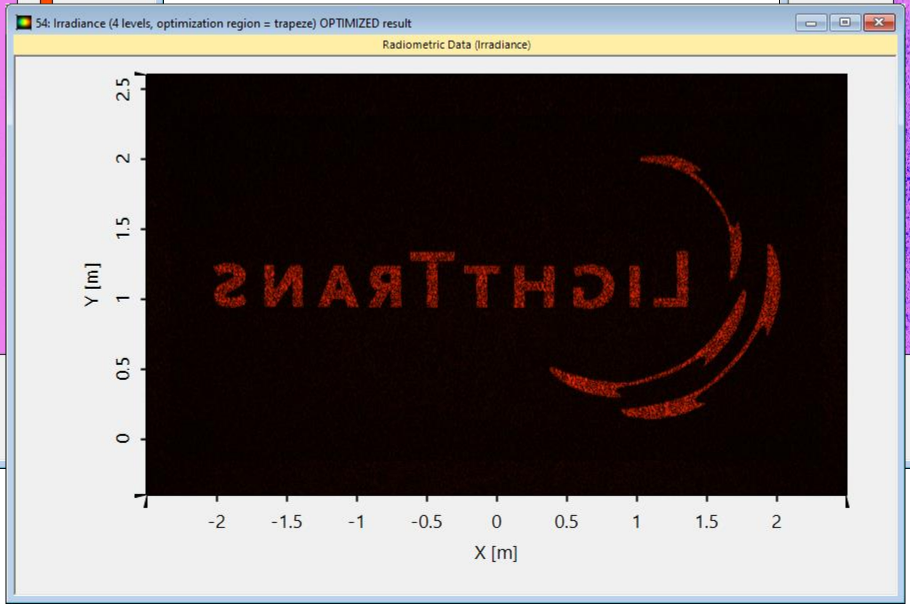
Optimizing 4-level Phase Transmission Function

The design was optimized at the expense of uniformity, but this is negligible, as can be seen from the results below and explained on the next slide.

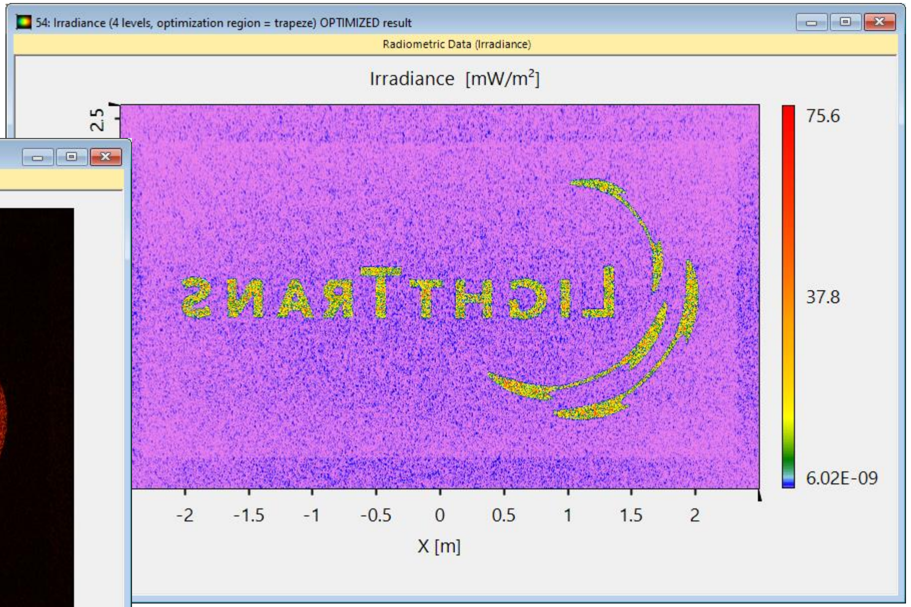
	Conversion Efficiency	Uniformity Error	Max.Rel.Int. Stray Light
default settings	31.0%	21.5%	19.0%
optimized	54.5%	45.7%	8.5%



false color (reverse rainbow)



real color (emulated eye perception)

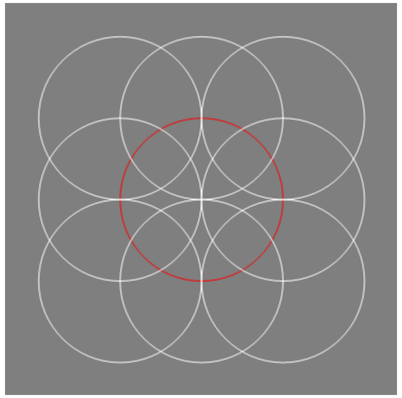


false color (reverse rainbow, logarithmic)

Illustration of Speckle Differences for Different Uniformity Errors

- For the diffractive diffuser elements, the uniformity error is typically not that important. The figures opposite show the simulation results of the IFTA and speckled systems, which illustrate that the less uniform working arrangements do not produce a significantly different speckle pattern.

- The actual resulting intensity impression is represented by values between the theoretical minimum and maximum, which results from the ideal destructive and ideal constructive interference of all overlapping beams involved (with random phase values). The gray figure shows the overlap of a (red) target point with its neighboring points.



The circles correspond to the $1/e^2$ diameter.

Of course, with different quantization settings in the design, leading to the different uniformity errors, the results will vary. But because of the same starting point (initial transmission) in the IFTA's process, the resulting speckle shapes are still nicely comaprable.

So, this comparison gives a representative impression of possible speckle phenomena with different uniformity errors.