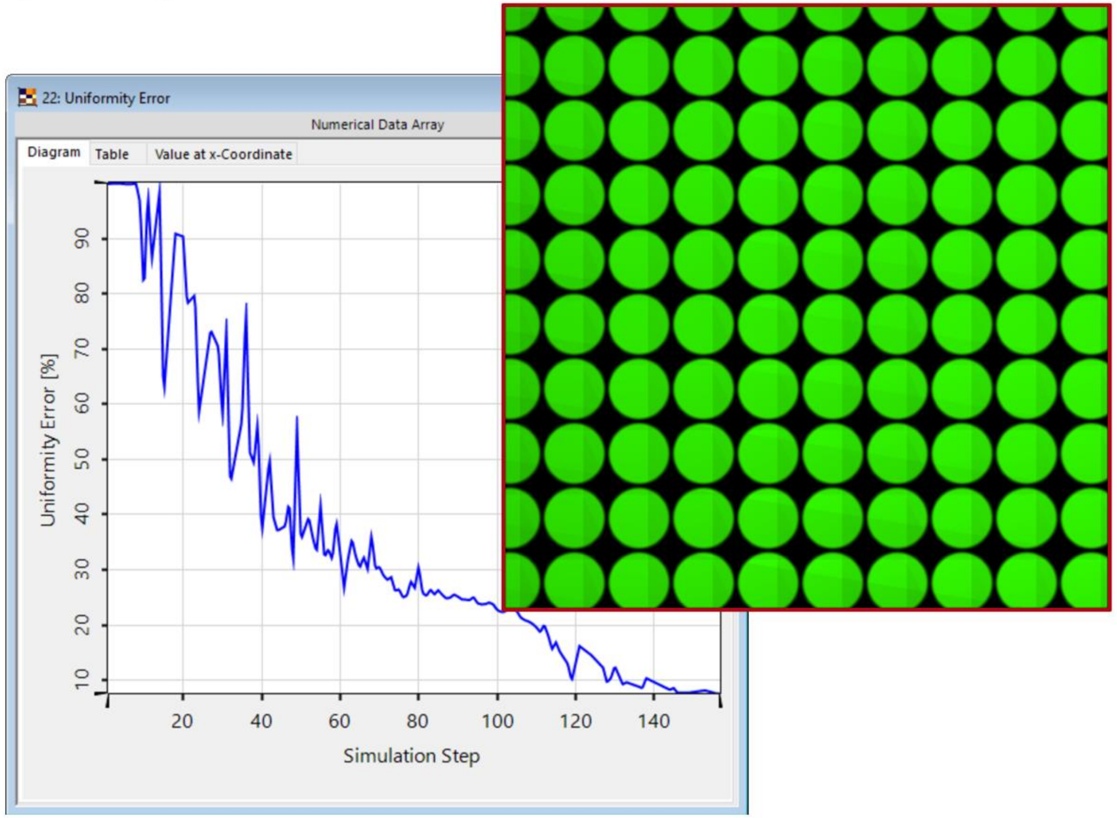
Optimization of Lightguide with Continuously Modulated Grating Regions

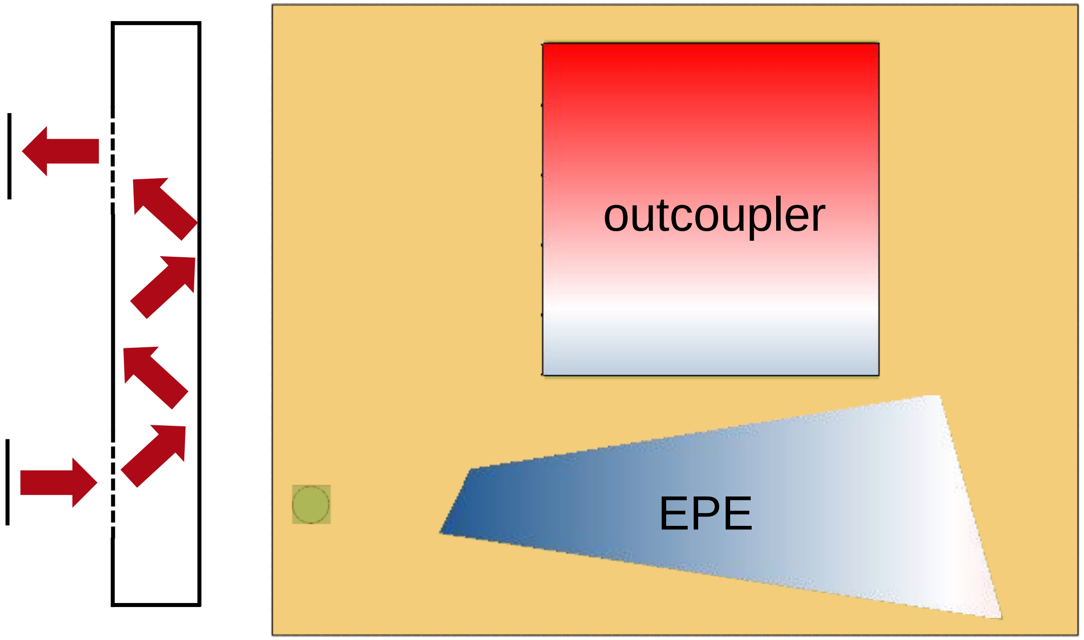
Abstract



In the design process of lightguide devices in the field of augmented and mixed reality applications (AR & MR), lateral uniformity (per field of view mode) and overall efficiency are two of the most important merit functions. In order to achieve appropriate values for the uniformity and efficiency in a lightguide system, it is necessary to allow for a variation of the grating parameters, particularly in the expander and/or outcoupling region. For this purpose, VirtualLab Fusion enables the introduction of smoothly varying grating parameters in a grating region along with the necessary tools to run an optimization according to a defined merit function. This use case demonstrates the optimization of a lightguide with continuously varied values of the fill factor in order to obtain an adequate uniformity.

Task Description

Task: How to optimize the continuously varied fill factor of the grating regions to achieve adequate lateral uniformity in the eyebox (for a single FOV mode)?



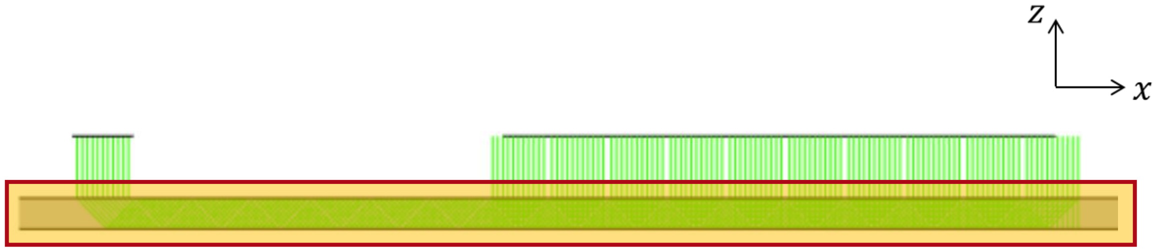
Source
- Plane Wave
- 532 nm wavelength
- 1 mm × 1 mm diameter

Outcoupler
- binary grating
- 380 nm period
- height 165 nm
- linearly varying fill factor

Eye Pupil Expander
- binary grating
- 268.7 nm period
- height 150 nm
- linearly varying fill factor

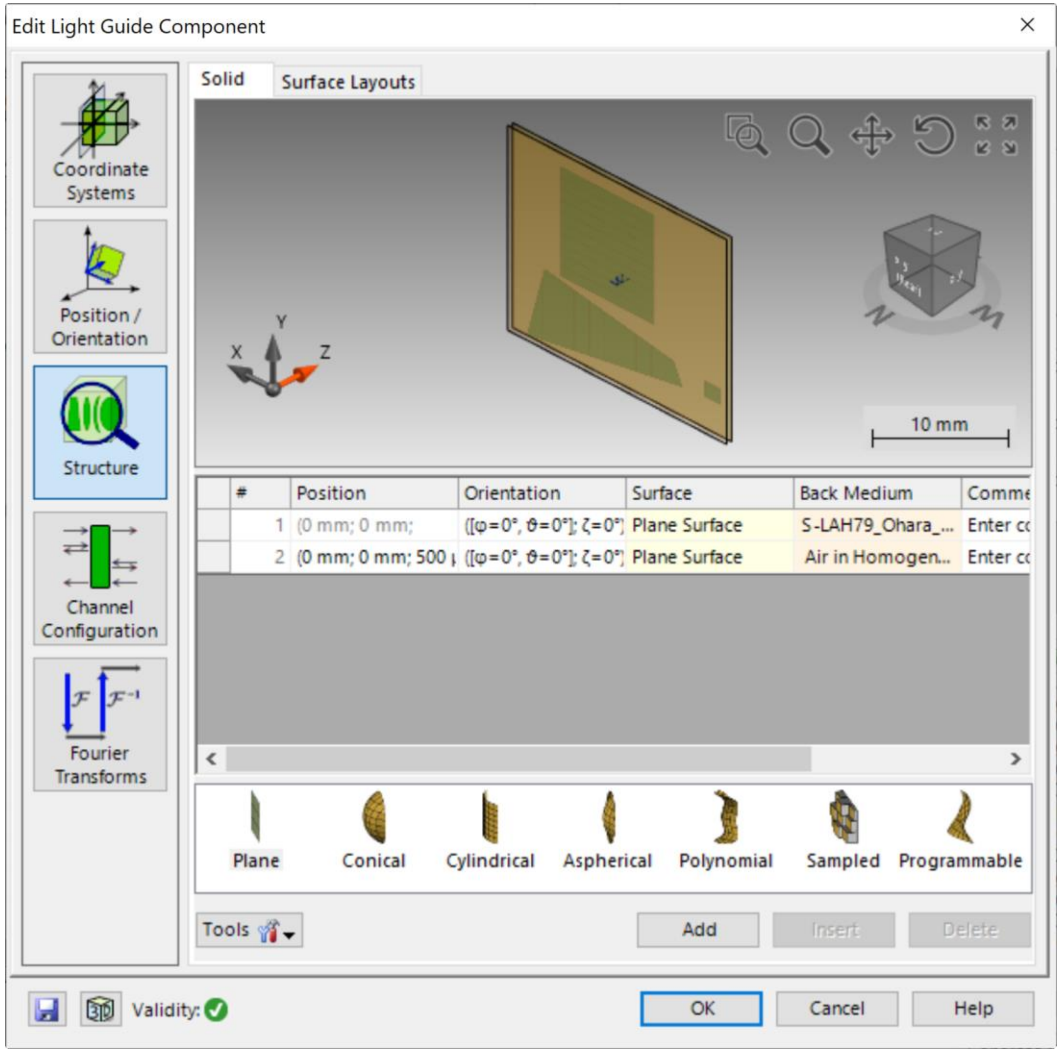
Incoupler
- slanted grating
- 380 nm period
- fill factor 50%
- height 300 nm
- angle 45°

Light Guide Component

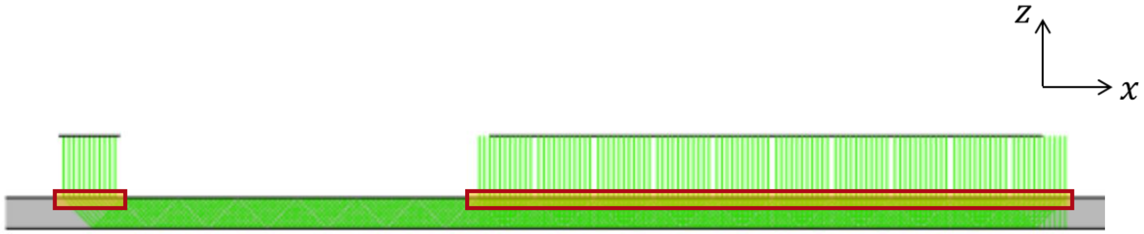


With the *Light Guide Component*, lightguide systems with complex-shaped regions can easily be defined. Furthermore, these regions can be equipped with idealized or real grating structures to act as incoupler, outcoupler or exit pupil expanders. More information under:

Construction of a Light Guide

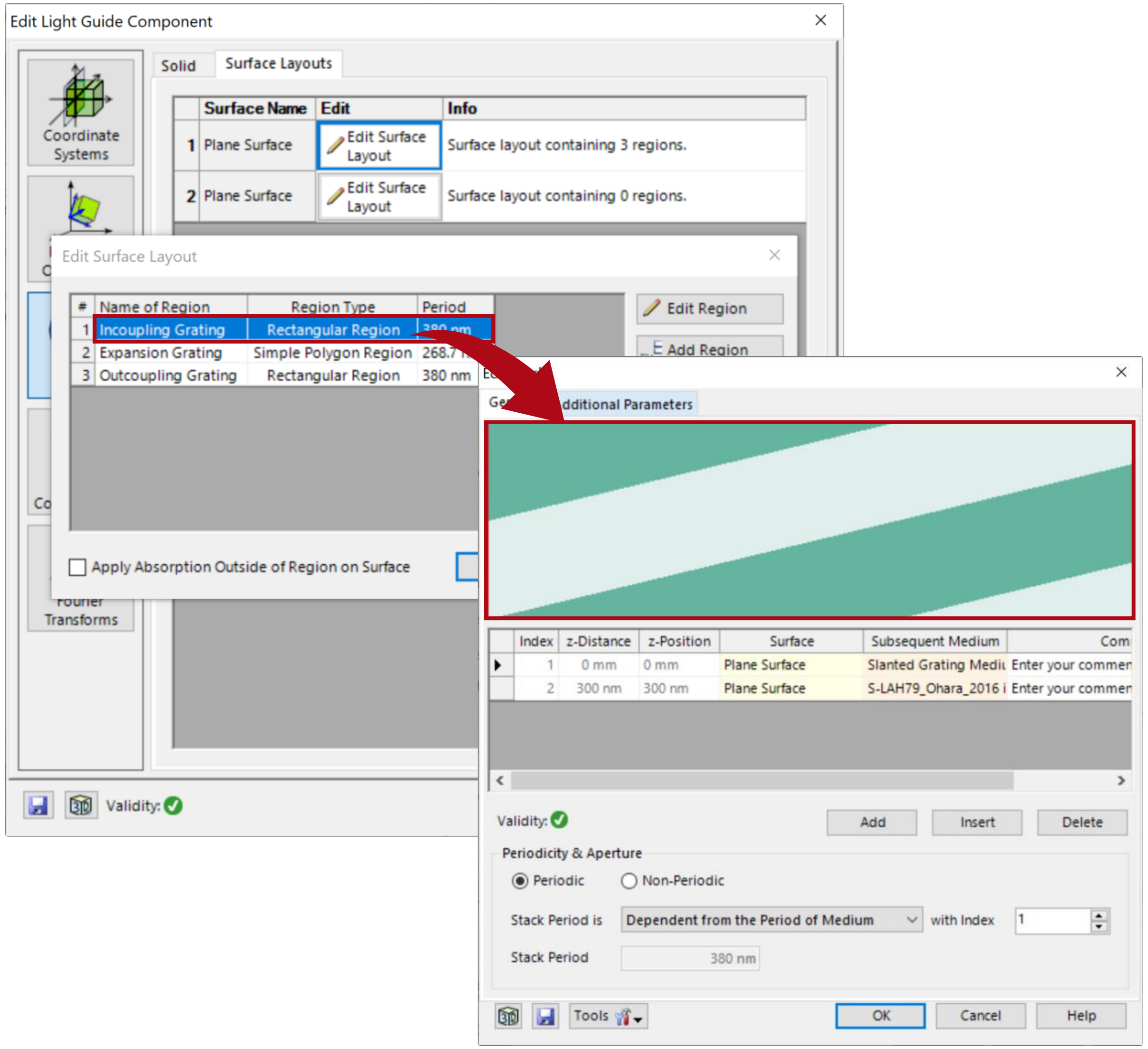


Grating Regions

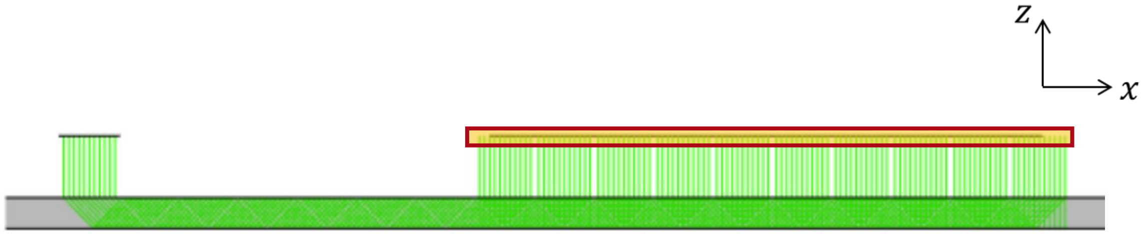


For the incoupler, outcoupler and eye pupil expander (EPE) real gratings were used. Their Rayleigh matrices and the corresponding efficiencies are calculated rigorously with FMM (RCWA). You can find more information on how to set this up under:

[How to Set Up a Lightguide with Real Grating Structures]



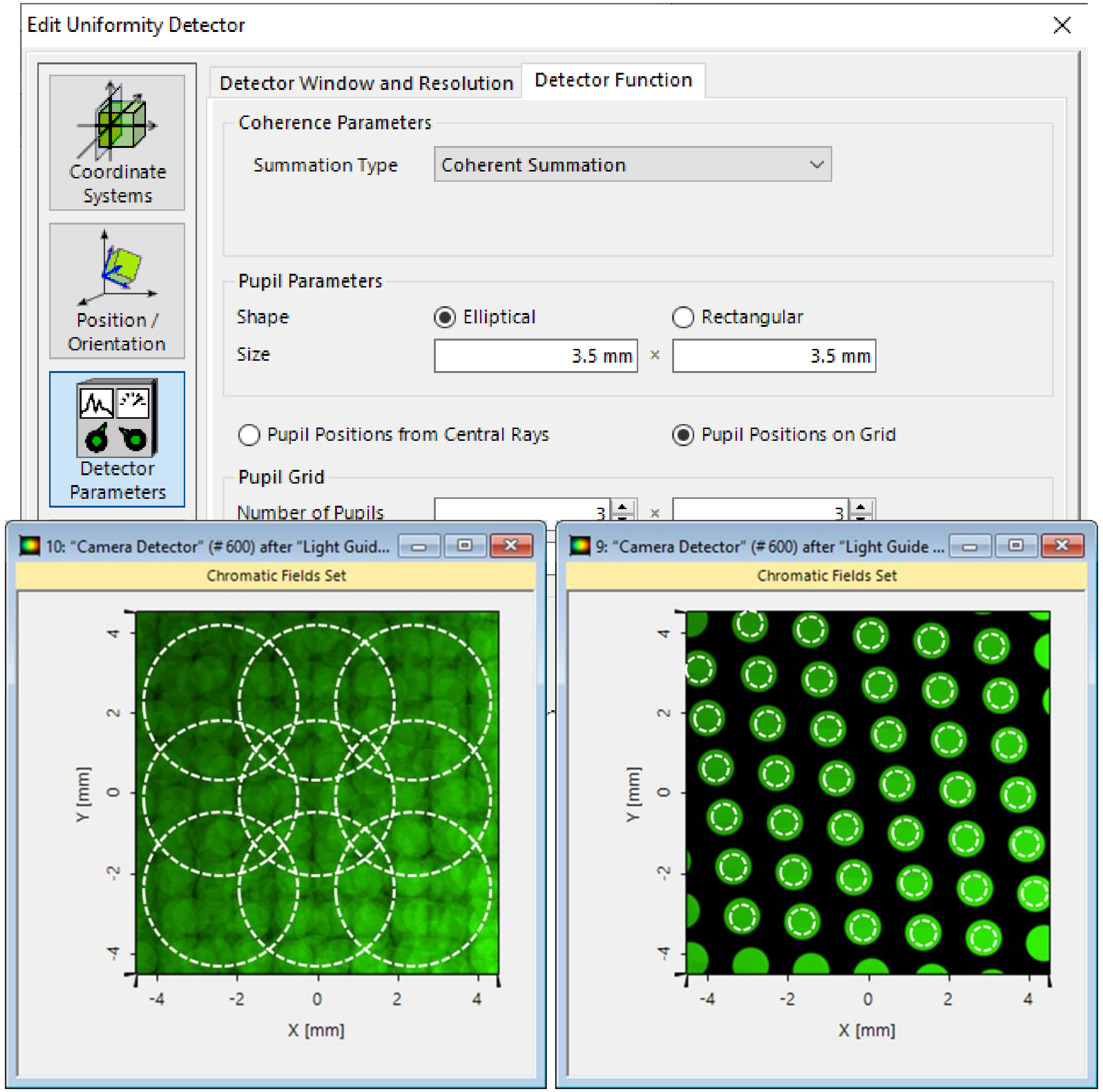
Uniformity Detector



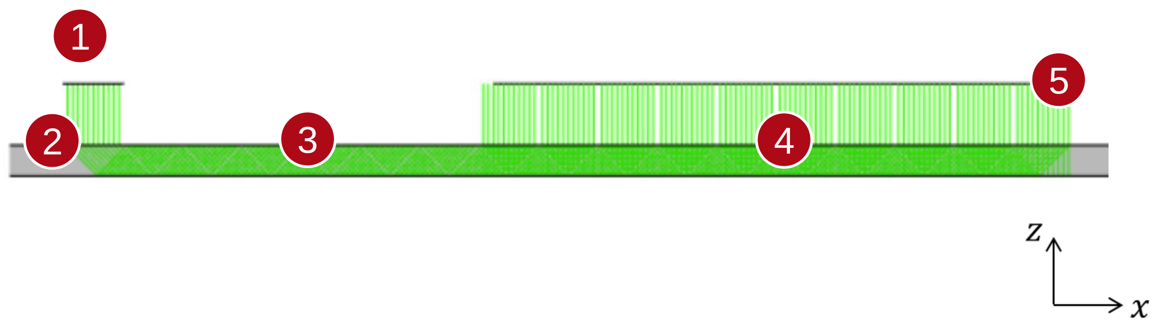
The *Uniformity Detector* evaluates the impinging intensity in configured local areas, which are called pupils. Each pupil is defined by its size ($dx \times dy$) and shape, which can be set either elliptical or rectangular.

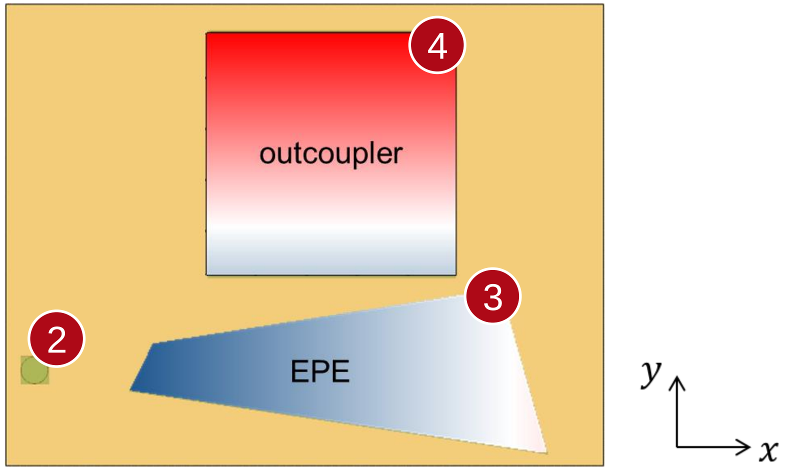
You can find more information on how to set this up under:

[Uniformity Detector for Lightguide Systems]



Summary – Components...





… of Optical System	… in VirtualLab Fusion	Model/Solver/Detected Value
1. Source	*Plane Wave* source	Truncated Ideal Plane Wave
2. Incoupler	Slanted grating in *Rectangular Region*	Fourier Modal Method (FMM)/RCWA
3. Eye Pupil Expansion	Binary grating in *Polygonal Region*	Fourier Modal Method (FMM)/RCWA
4. Outcoupler	Binary grating in *Rectangular Region*	Fourier Modal Method (FMM)/RCWA
5. Detector	*Camera Detector, Uniformity Detector*	Energy density measurement

General Workflow with Additional Guidance

1. Configuration of basic optical lightguide setup (not part of this use case)
2. Application of the *Footprint and Grating Analysis* tool including the generation of the optical setup equipped with all requirements for the parameter modulation
3. Definition of desired modulation of grating parameters
4. Select variables and define merit functions to optimize the modulated grating parameters.

The starting point is an existing, executable lightguide system, where the basic geometries (desired distances and positioned grating regions) and grating specifications (orientation, period, orders) are already included. This example is taken from:

- Construction of a Light Guide [Use Case]
- Light Guide Layout Design Tool [Use Case]

The real grating structures of the grating regions are configured, a necessary step before applying a continuous or smooth variation of the grating parameters:

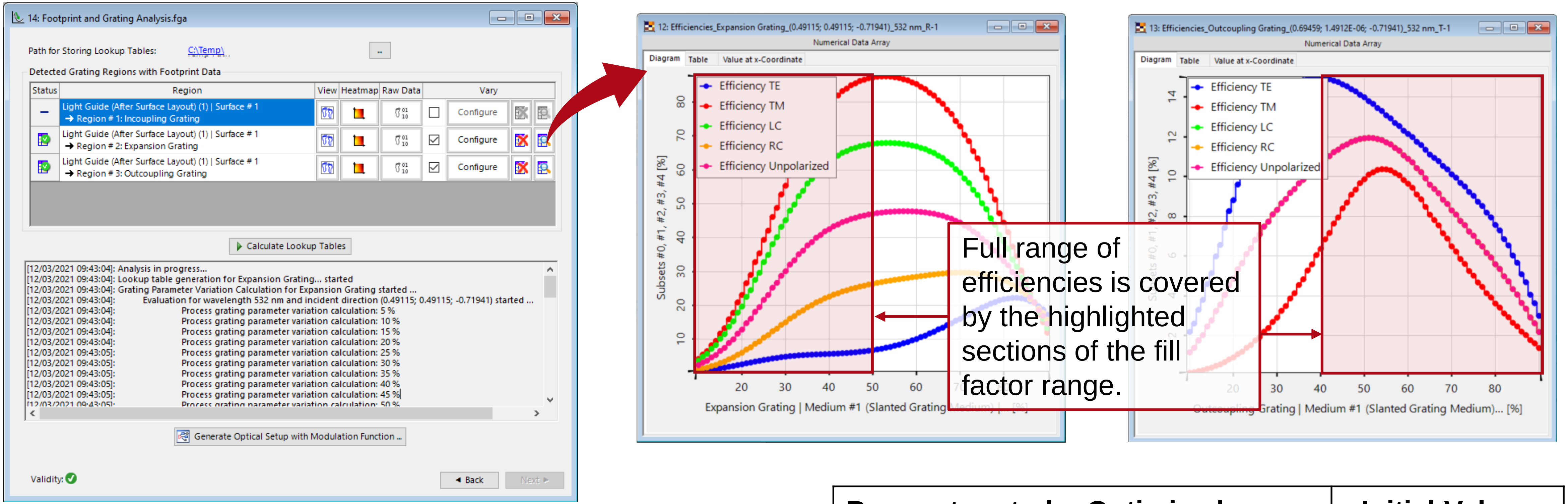
- How to Set Up a Lightguide with Real Grating Structures [Use Case]
- Simulation of 1D-1D Pupil Expander with Real Gratings [Use Case]

The *Footprint and Grating Analysis* tool is used to specify the desired range for the variation of the grating parameters and to pre-calculate the according Rayleigh coefficients for the specific conditions (wavelength and directions). As a next step, an optical setup is generated, where the smooth parameter variation can be defined:

- Footprint Analysis of Lightguides for AR/MR Applications [Use Case]
- Grating Analysis and Smoothly Modulated Grating Parameters on Lightguides [Use Case]

Note:
The grating modulation is defined for individual grating regions.

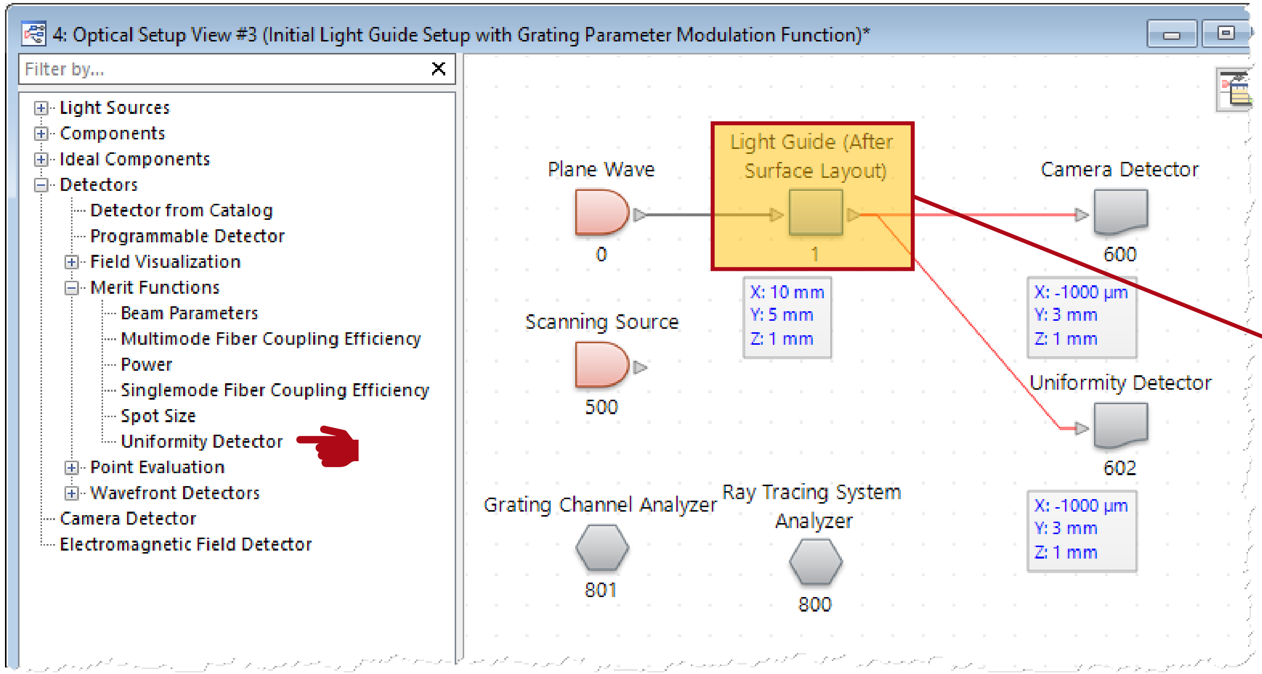
Footprint & Grating Analysis



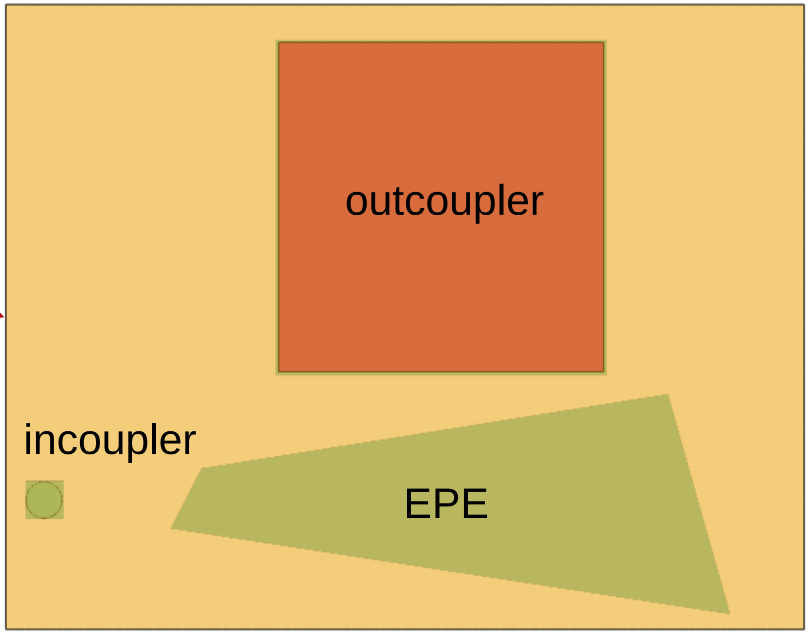
With the help of the *Footprint & Grating Analysis Tool*, the grating characteristics (complex valued) are pre-calculated and stored in lookup tables for a specified range of the chosen parameter (e.g. fill factor). The initial range of the fill factor is chosen according to the range of available efficiency modulation. More information can be found in: [Grating Analysis and Smoothly Modulated Grating Parameters on Lightguides]

Parameters to be Optimized	Initial Values
varied range of fill factor (EPE)	10% – 50%
varied range of fill factor (outcoupler)	40% – 90%

Generation of the Initial System

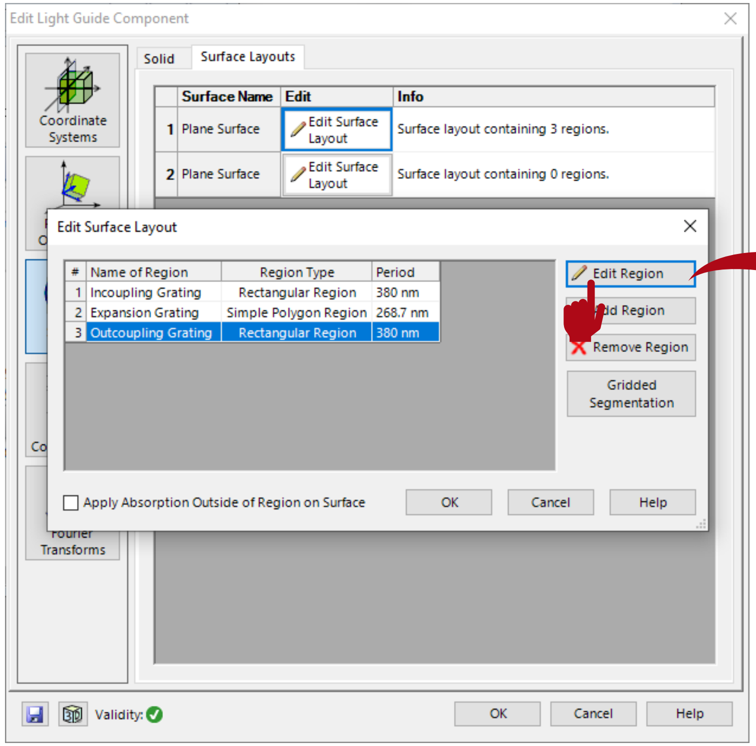


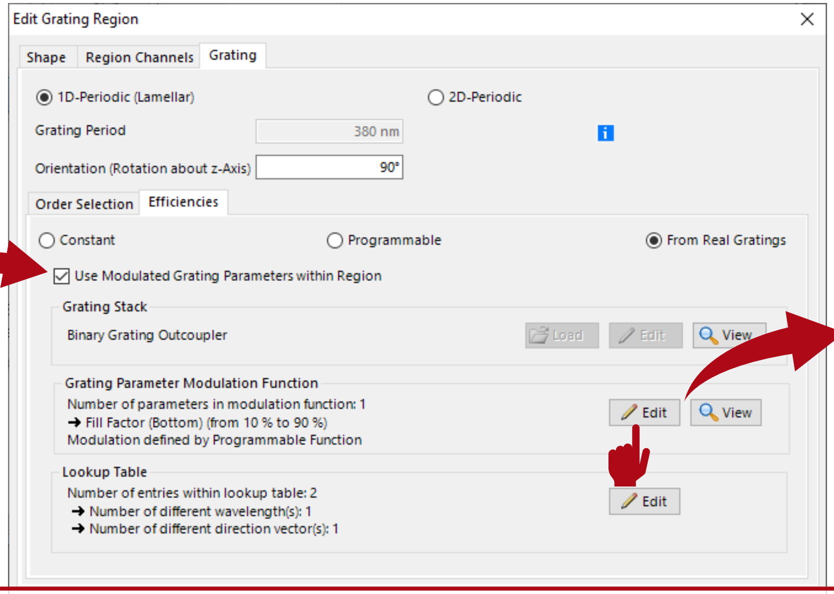
grating regions without smooth modulation



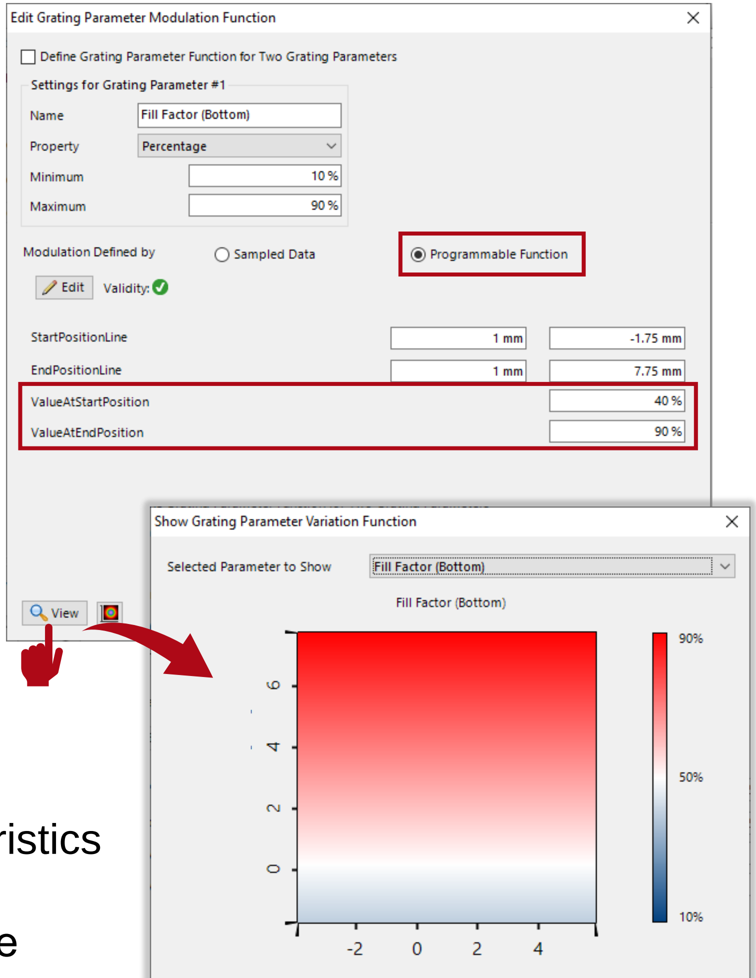
- A lightguide setup with a so-called grating parameter modulation function is generated from the *Footprint & Grating Analysis Tool* (including the grating characteristics).
- The *Uniformity Detector* is used to define the merit function for the optimization.

Define Modulation Function of the Grating Region





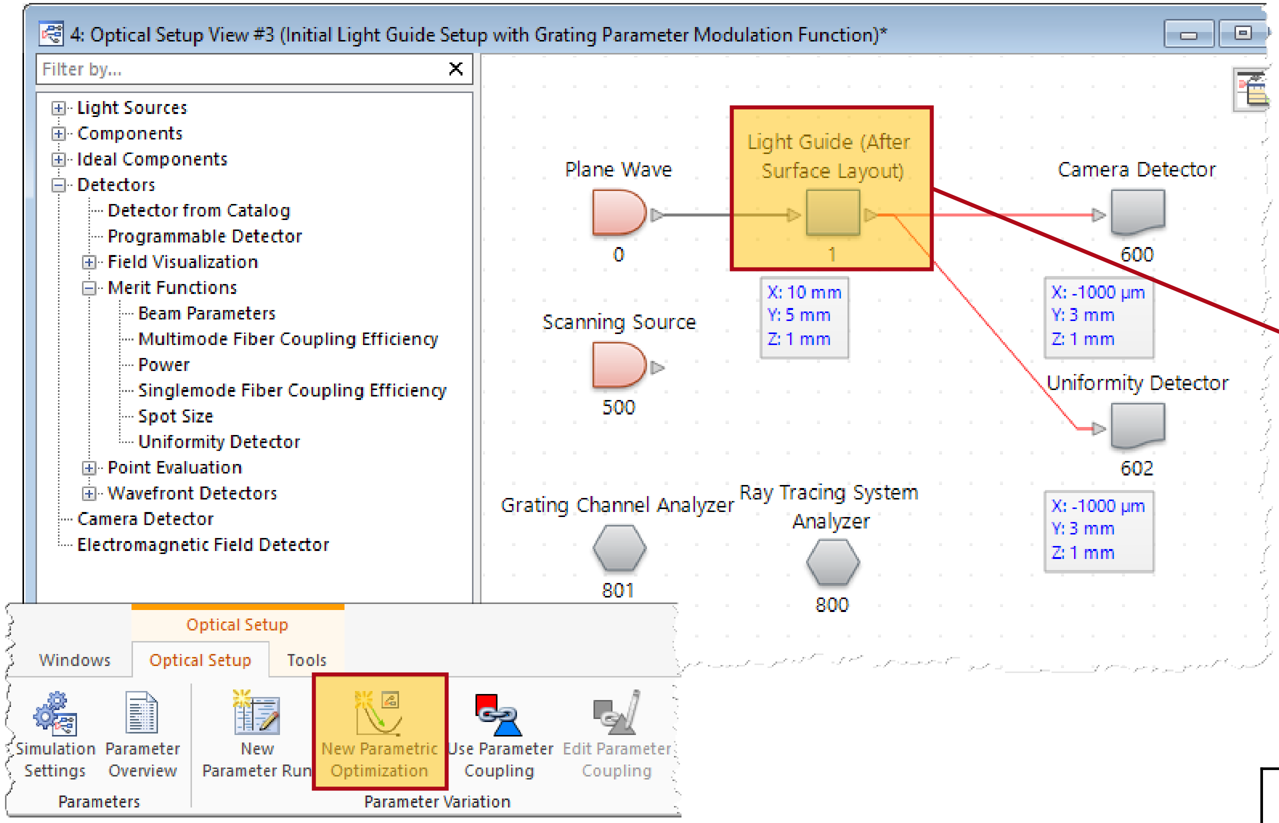
See the full use case for setting up a smooth modulation based on mathematical function: Grating Analysis and Smoothly Modulated Grating Parameters on Lightguides



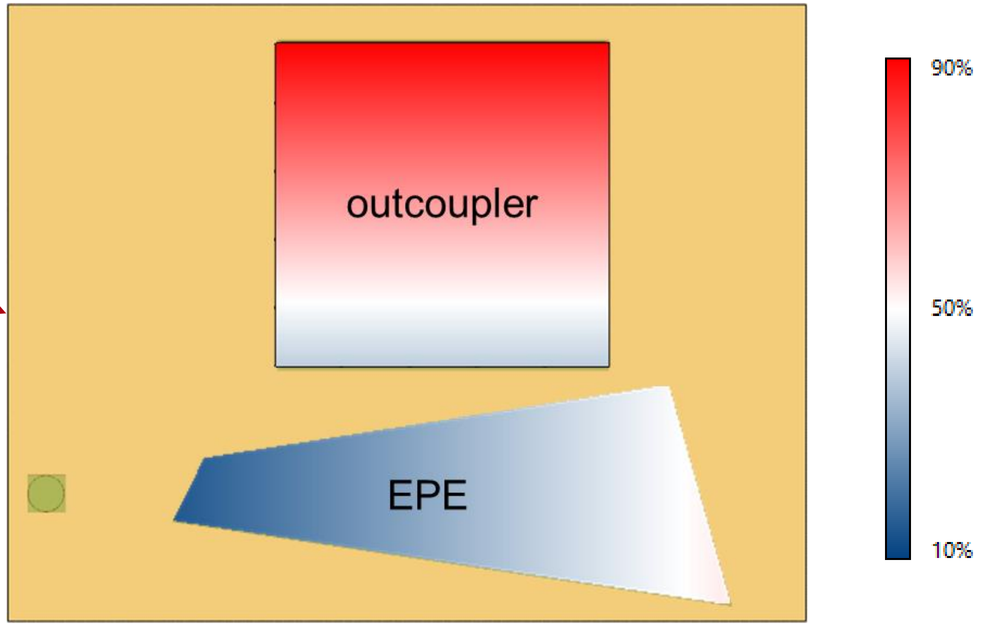
linear modulation for outcoupler

- Open the edit dialogue of the region in the lightguide component; the grating characteristics and the lookup tables are stored in the grating regions.
- Edit the *Grating Parameter Modulation Function* so that it's defined as a programmable function, the intended linear modulation of the grating parameters is defined by the value at the start and end position (left to right border for EPE & top to bottom for the outcoupler).

Generation of the Initial System



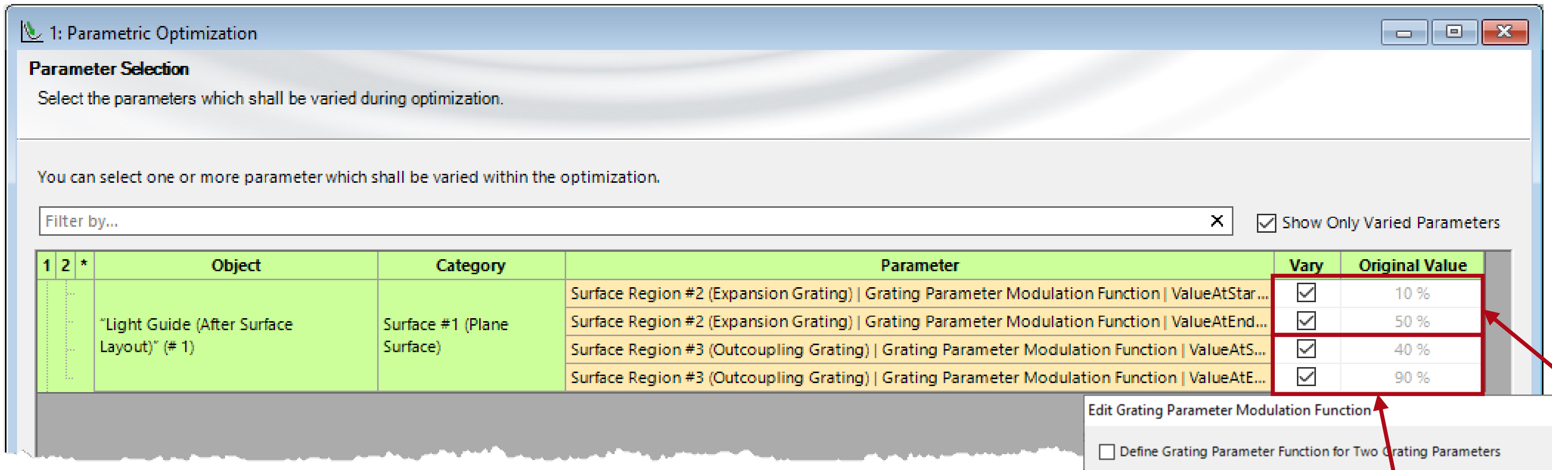
grating regions after smoothly modulation



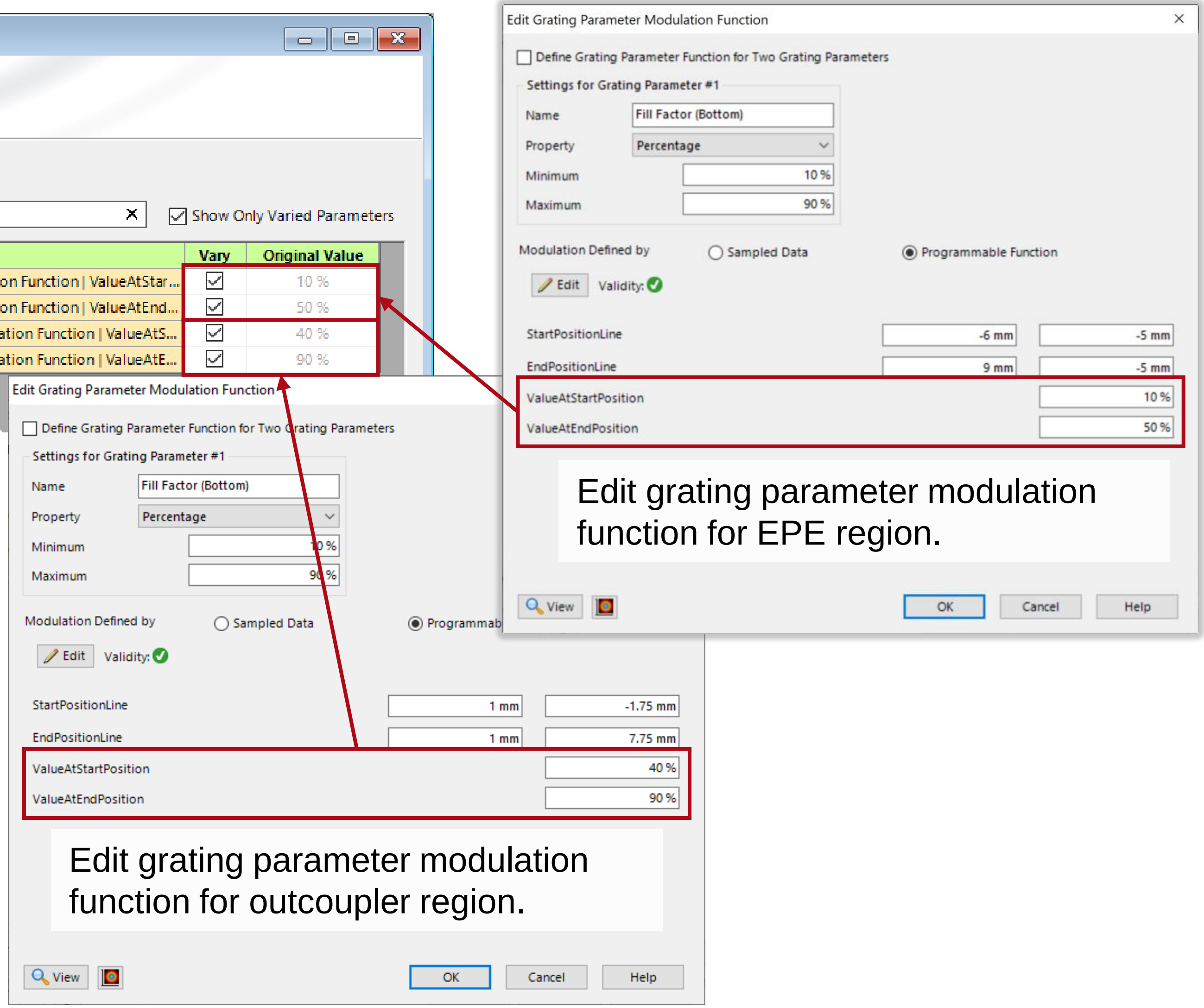
After defining the modulation for the EPE and outcoupler respectively, the *Parametric Optimization* document can be started via *Optical Setup > New Parameter Optimization.*

Parameters to be Optimized	Initial Values
varied range of fill factor (EPE)	10% – 50%
varied range of fill factor (outcoupler)	40% – 90%

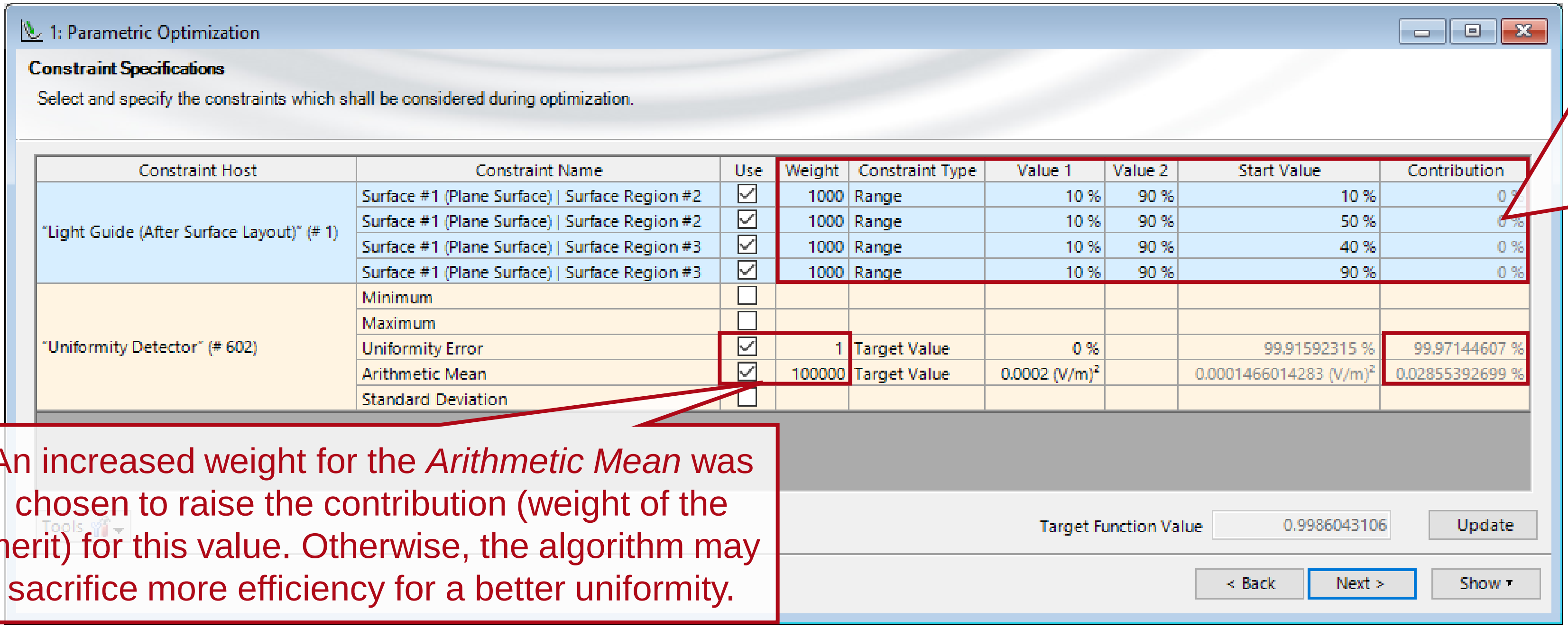
Optimization Settings – Select Parameters



- Select the value of the fill factor at the start and end positions of the modulation for the EPE and outcouple gratings, respectively.
- The initial values are automatically filled in according to the settings in the modulation function editor.



Optimization Settings – Specify Constraints



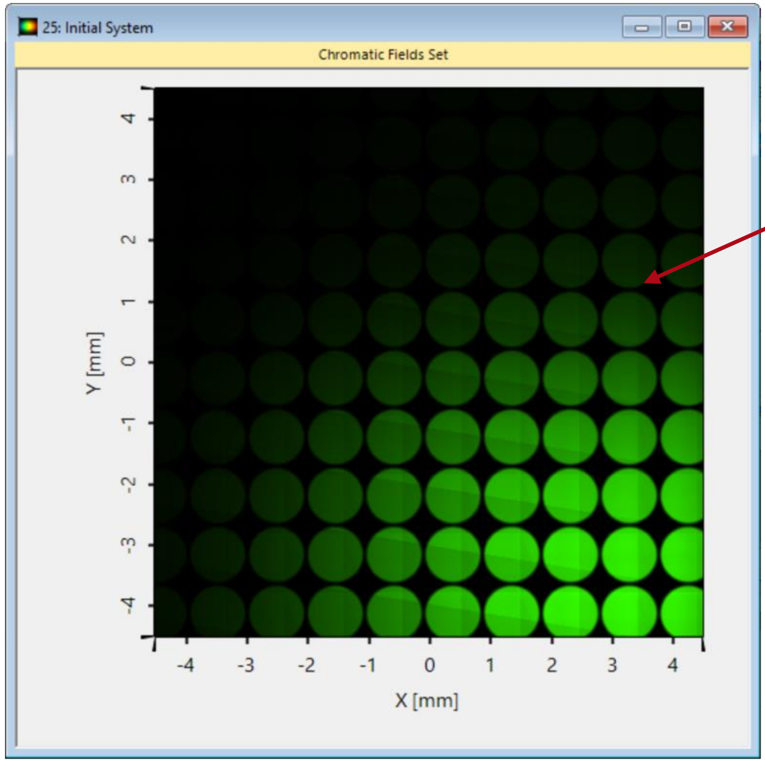
In this optimization, the initial values are quite close to the limits of the available range. Hence, the weights for the *Range* constraints are increased, in order to ensure that the values in the optimization stay inside the given range (the downhill-simplex does not provide hard boundaries for the parameter ranges). And because the *Start Values* are inside the allowed value range, the associated *Contribution* is regarded as 0%.

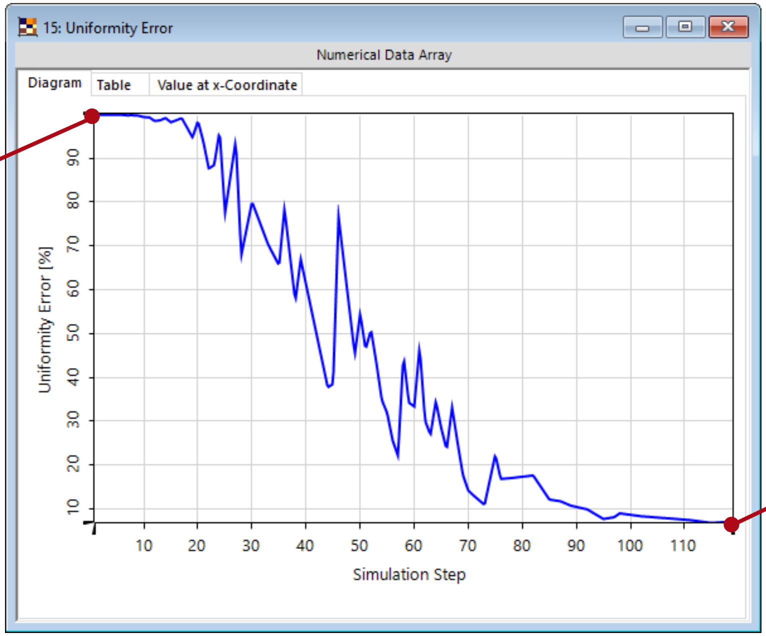
An increased weight for the *Arithmetic Mean* was chosen to raise the contribution (weight of the merit) for this value. Otherwise, the algorithm may sacrifice more efficiency for a better uniformity.

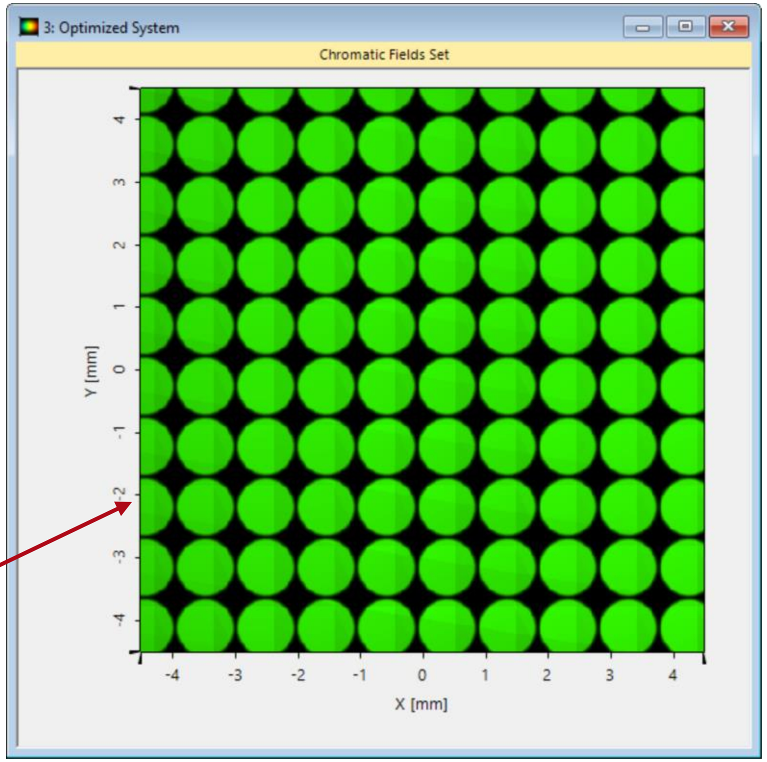
merit function	Values
Uniformity Error	0%
Arithmetic Mean	0.0002(V/m)²

- Define available range of the variables (here: fill factors of EPE and outcoupler).
- In order to achieve a low uniformity error with acceptable intensity distribution, the target value for the uniformity error is set to 0%, and a target value of the arithmetic mean is specified.
- By defining the weight value for the merit functions, the contribution (relevance or priority) for the optimization can be adapted.

Optimization Result







initial system

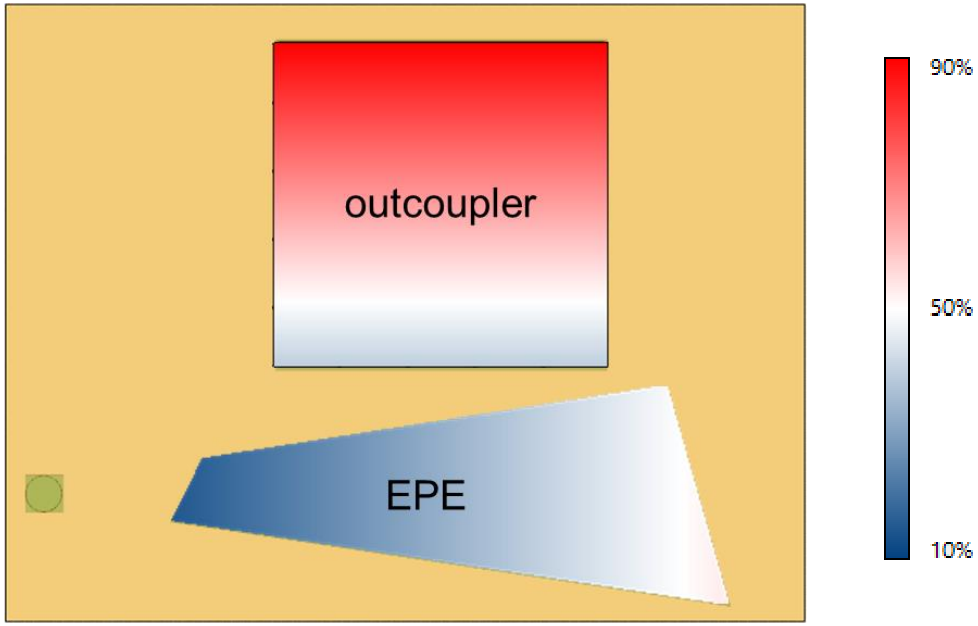
merit function	Values
Uniformity Error	99.92%
Arithmetic Mean	1.47E-04 (V/m)²

optimized system

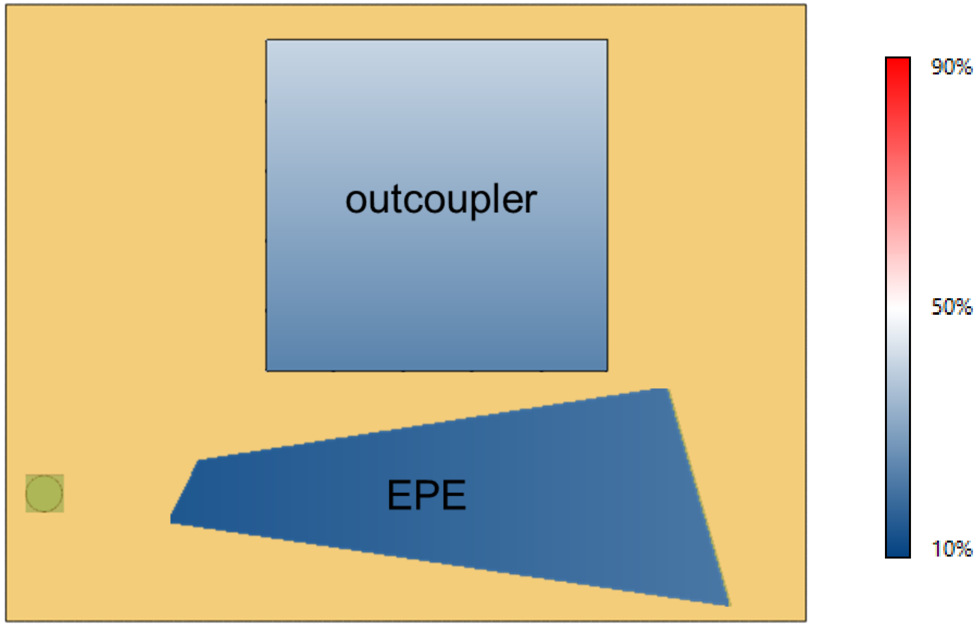
merit function	Values
Uniformity Error	6.84%
Arithmetic Mean	1.40E-04 (V/m)²

Optimization Result

Initial System

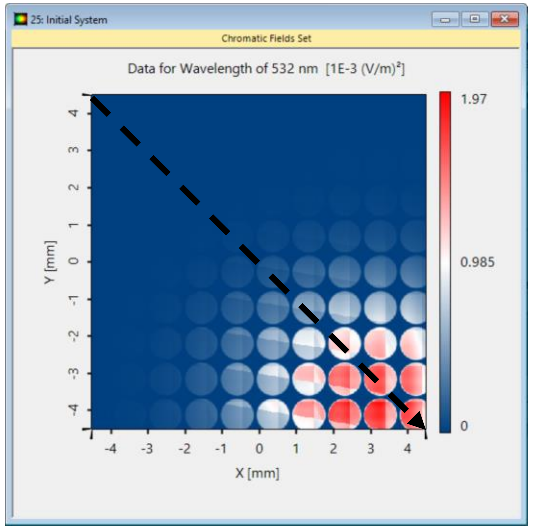


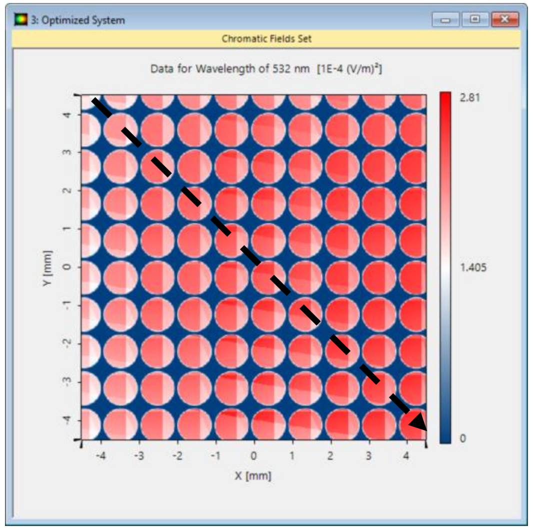
Opt. System



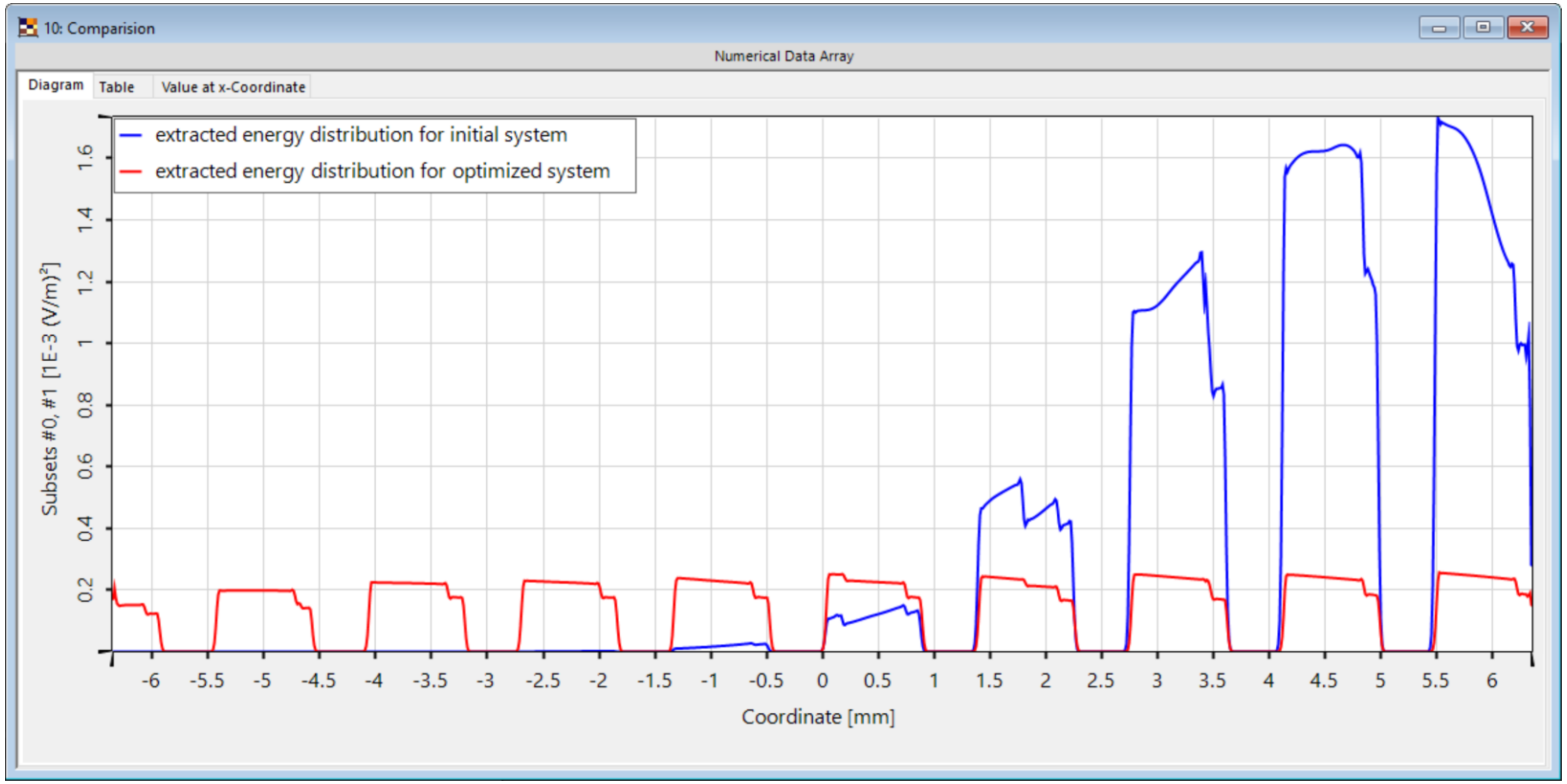
Parameters	Initial Values	Optimized Values
varied range of fill factor (EPE)	10% – 50%	10.0% – 17.1%
varied range of fill factor (Outcoupler)	40% – 90%	24.1% – 41.4%

Optimization Uniformity vs. Energy Density

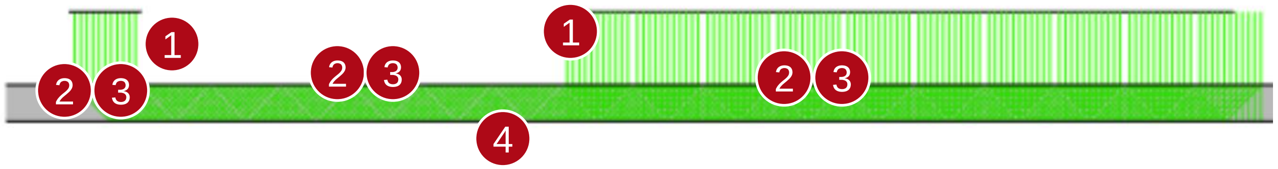


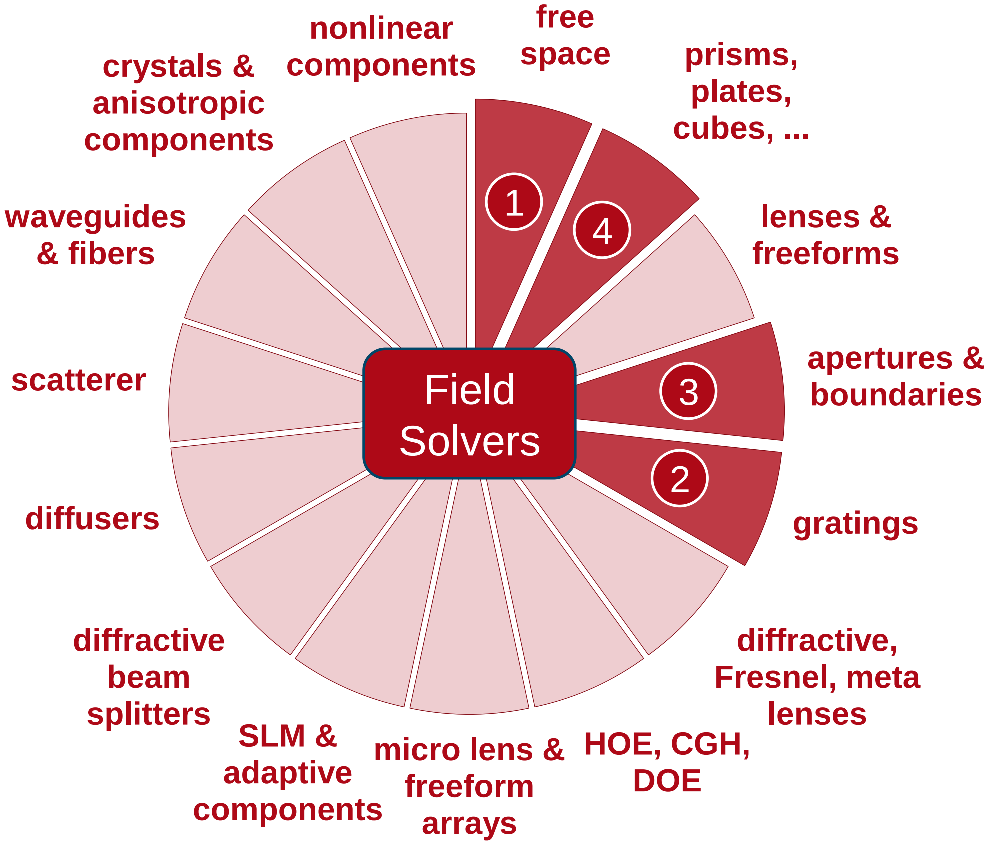


The line scan through the eyebox for the initial and optimized systems reveals the difference in uniformity and local energy density.



VirtualLab Fusion Technologies





Document Information

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category	Application Use Case
further reading	• Grating Analysis and Smoothly Modulated Grating Parameters on Lightguides • Uniformity Detector for Lightguide Systems • Light Guide Layout Design Tool • Flexible Region Configuration • How to Set Up a Lightguide with Real Grating Structures