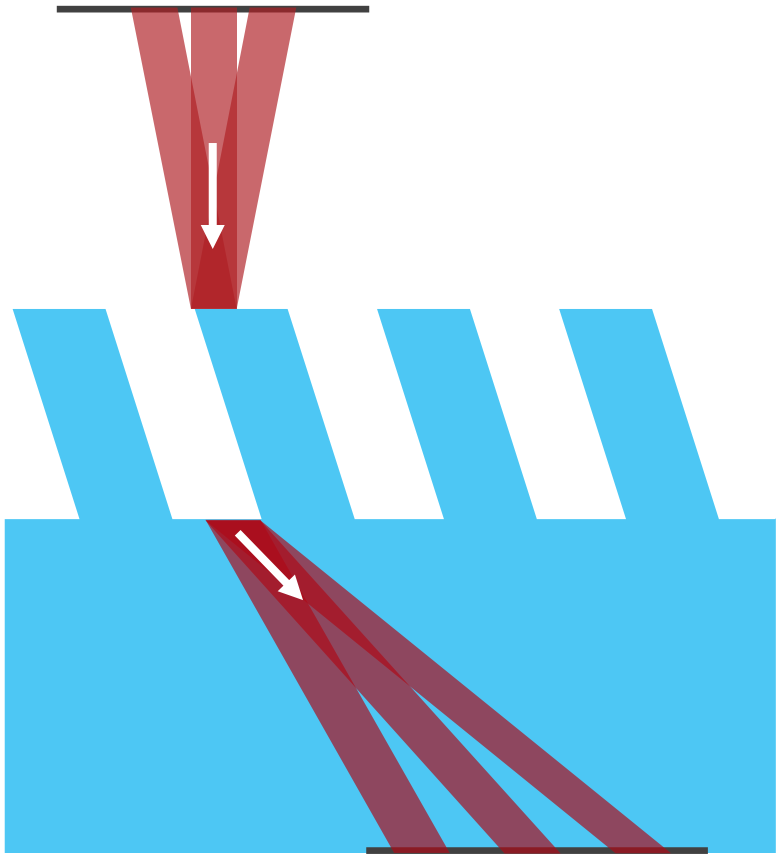
Optimization of Grating Incoupler for Lightguides/Waveguides

Abstract



Lightguide or waveguide-based systems have proven to be a good approach for many AR/VR applications. To achieve high performance for these types of applications, it is necessary that the gratings involved exhibit a high degree of uniformity with respect to different angles of incidence while simultaneously maximizing the overall efficiency across the entire field of view (FOV). The Parameter Variation Analyzer in VirtualLab Fusion allows the user to analyze system performance for a given field of view, automatically calculating the corresponding merit functions. In addition, the integrated Parametric Optimization facilitates the determination of the optimal grating structure by adjusting parameters such as fill factor, modulation depth and tilt angle.

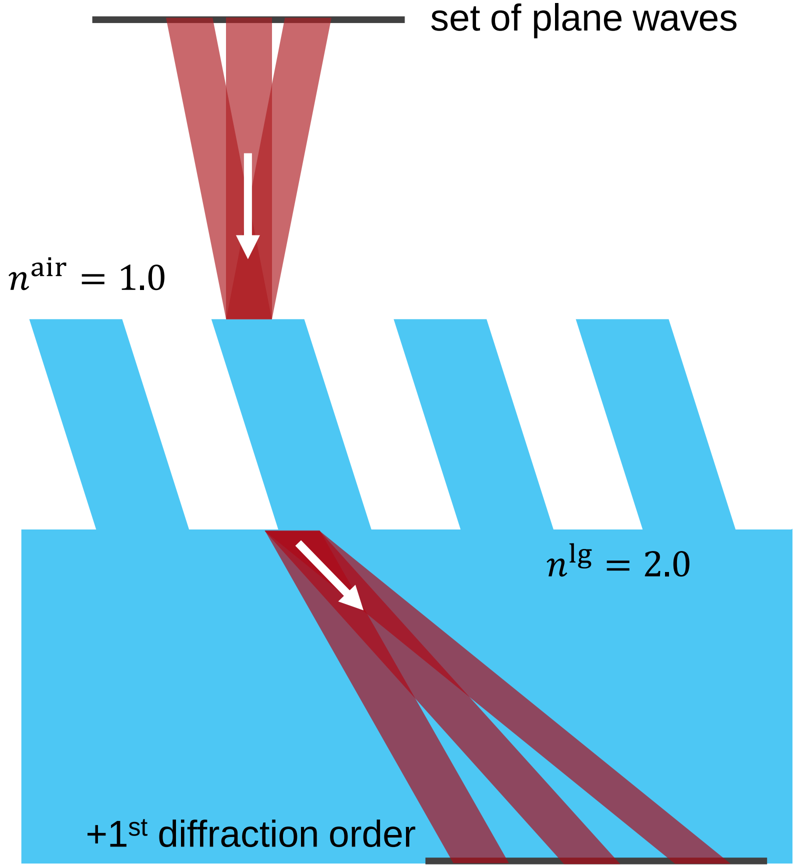
Simulation Task: Slanted Grating

set of plane waves

- field of view (-15°...15° along x and y axis) **(*)**
- wavelength 532 nm
- linearly polarized along x-axis

incoupling grating

- slanted grating
- period: 400 nm
- operation order: +1
- transmission grating
- surrounding medium: $n^{\mathrm{air}} = 1.0$
- refractive index glass: $n^{\mathrm{lg}} = 2.0$



optimization parameters

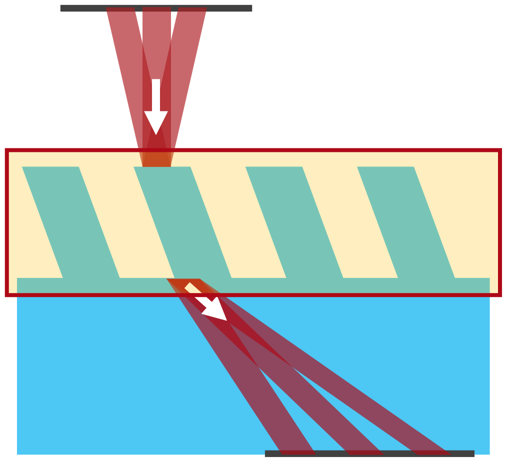
- fill factor: 10% – 90%
- modulation depth: 50 nm – 600 nm
- slant angle: 0° – 60°

merit function (*Parameter Variation Analyzer*):

- mean efficiency (to be maximized)
- uniformity error (to be minimized)

(*) internally the different angles of the FOV (“modes”) are modeled by tilting the grating accordingly

Connected Modeling Techniques: Incoupling Grating

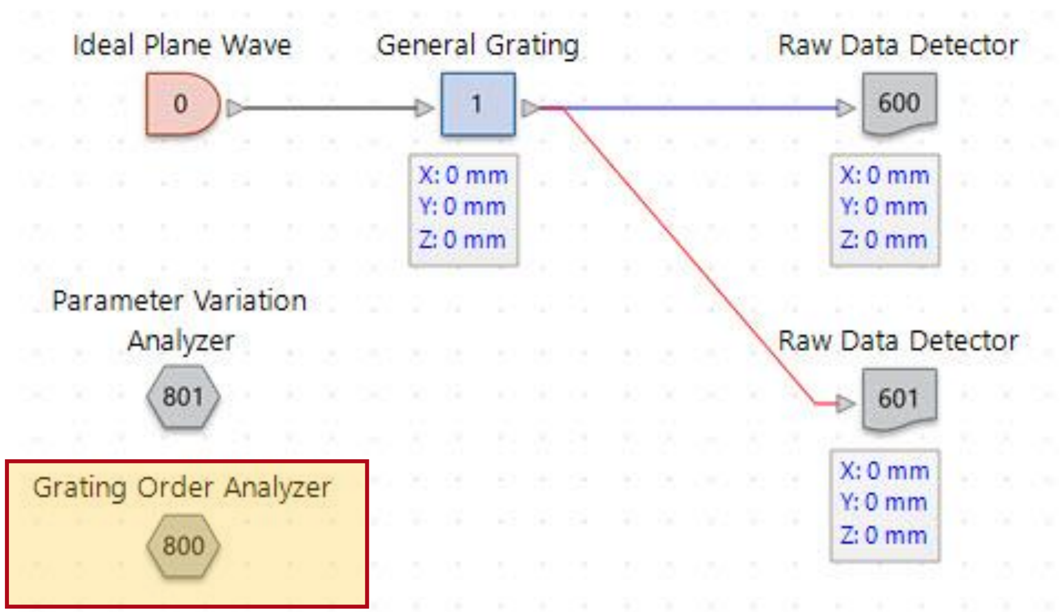


Available modeling techniques for microstructures:

Methods	Preconditions	Accuracy	Speed	Comments
Functional Approach	-	low	very high	diffraction angles acc. to grating equation; manual efficiencies
Thin Element Approximation (TEA)	smallest features > ~10λ	high	very high	inaccurate for larger NA and thick elements; x-domain
	smallest features < ~2λ	low	very high	
Fourier Modal Method (FMM)	period < ~ (5λ × 5λ)	very high	high	rigorous solution; fast for structures and periods similar to the wavelength; more demanding for larger periods; k-domain
	period > ~ (15λ × 15λ)	very high	slow	

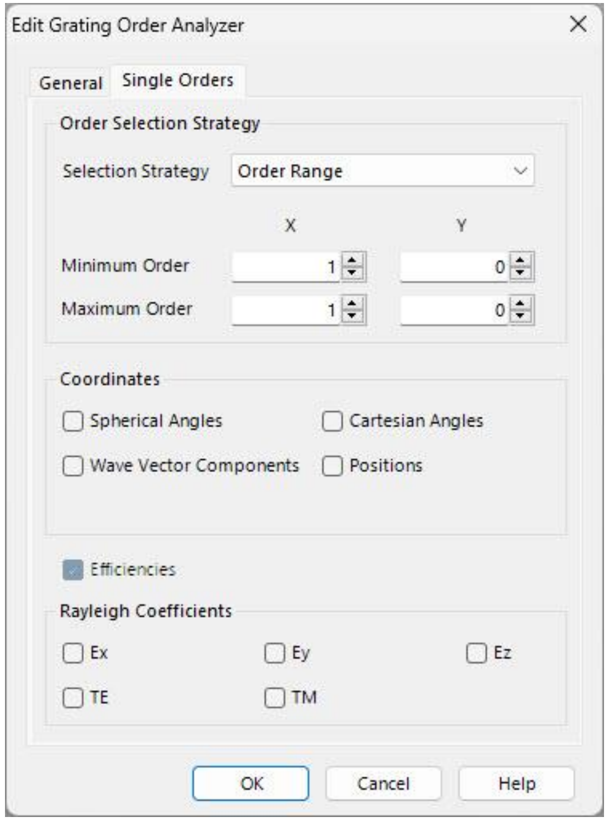
Due to the grating period is smaller than the wavelength of light a rigorous treatment of the grating is inevitable, as other solvers like **Thin Element Approximation (TEA)** become inaccurate. Hence, the **Fourier Modal Method (FMM)** is used to calculate the diffraction efficiency rigorously.

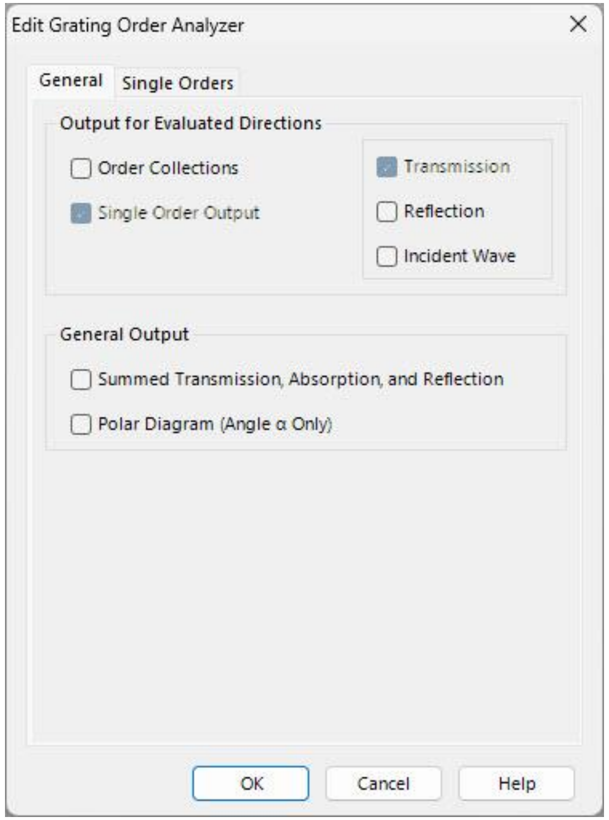
Grating Order Analyzer



The *Grating Order Analyzer* can be used to investigate the efficiency of the diffraction orders of a given grating. Find more information under:

[Grating Order Analyzer]

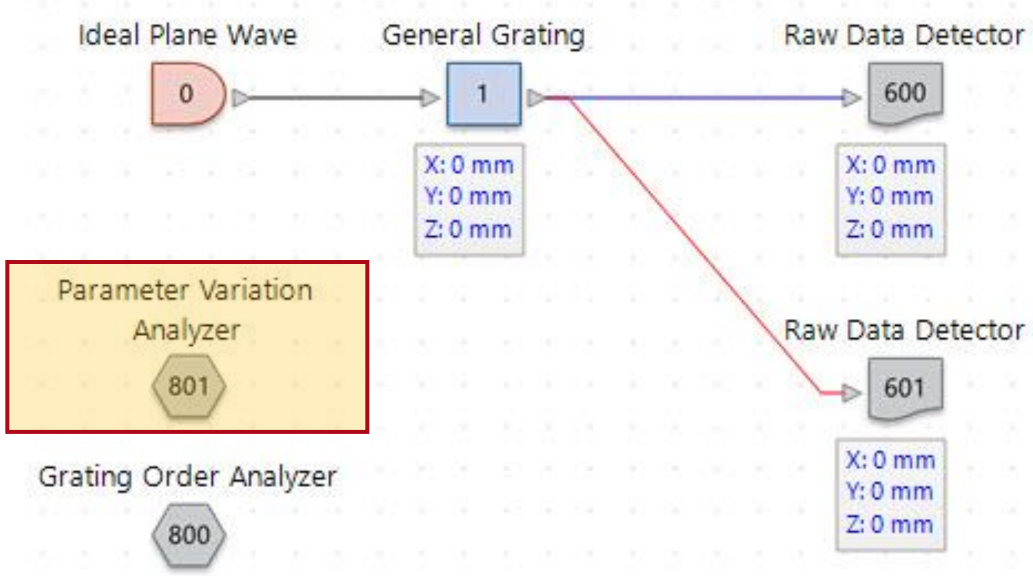


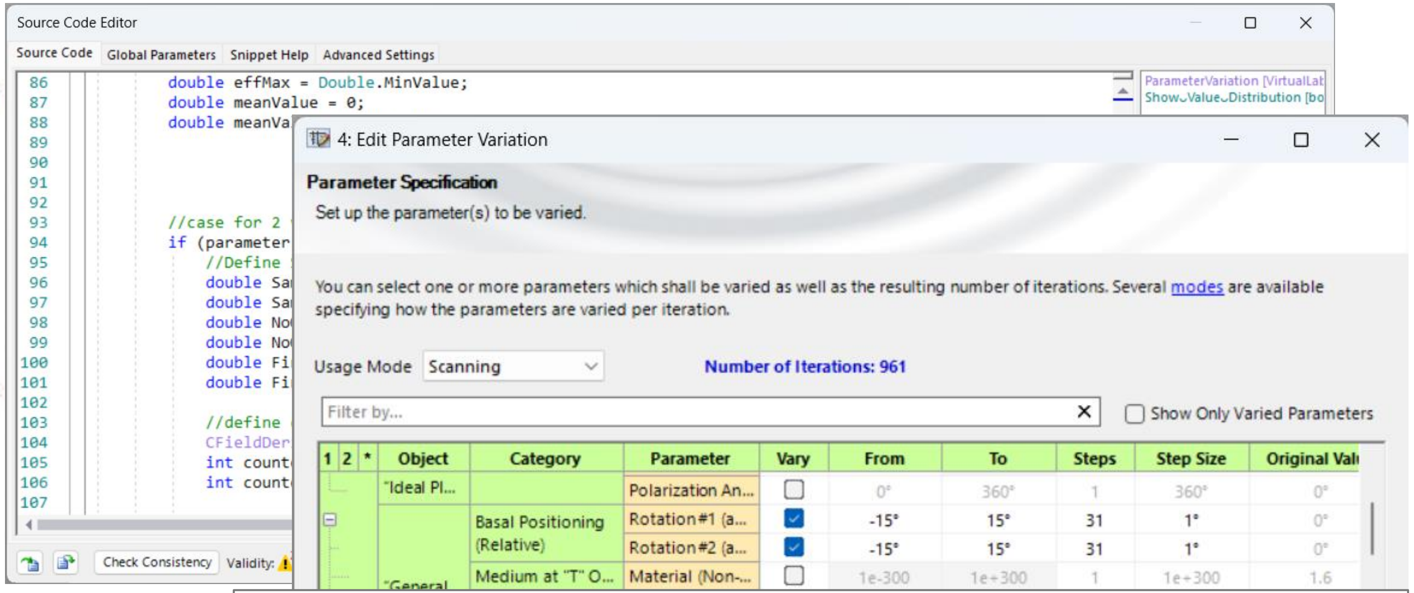


resulting efficiency provided in the *Detector Results* tab:

Efficiency T[+1; 0]	85.98 %

Parameter Variation Analyzer





Since diffraction efficiencies for a range of angles (FOV) of incidence have to be evaluated for each set of grating parameters, the *Parameter Variation Analyzer* is used to calculate the overall merit functions which are later used in the parametric optimization.

For more information, see: Parameter Variation Analyzer

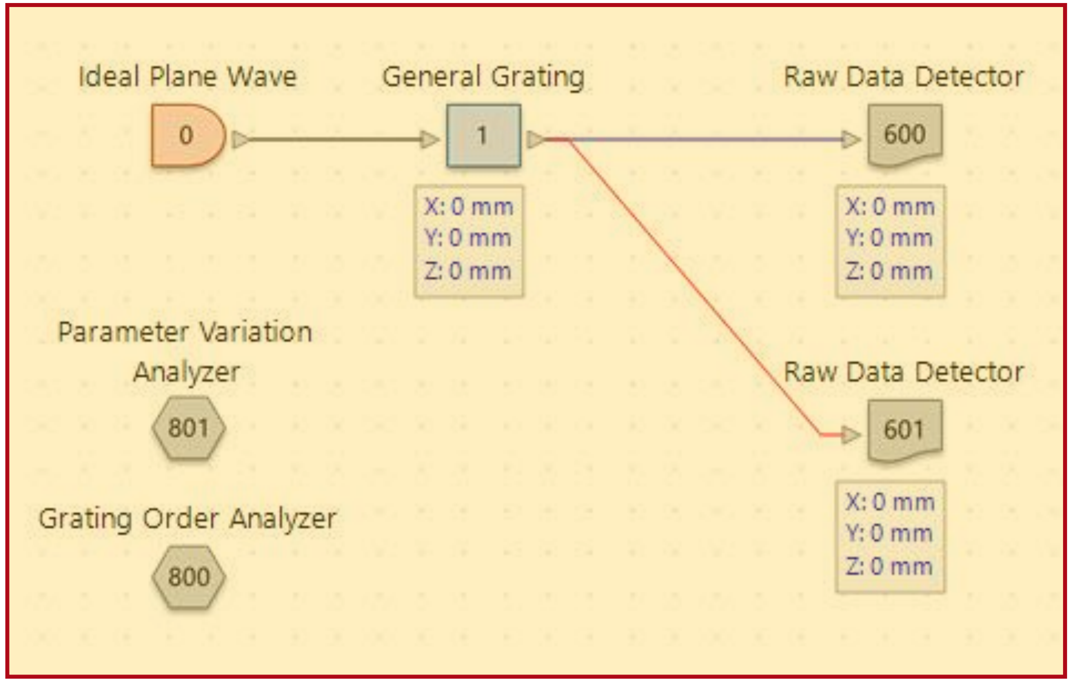
merit functions:

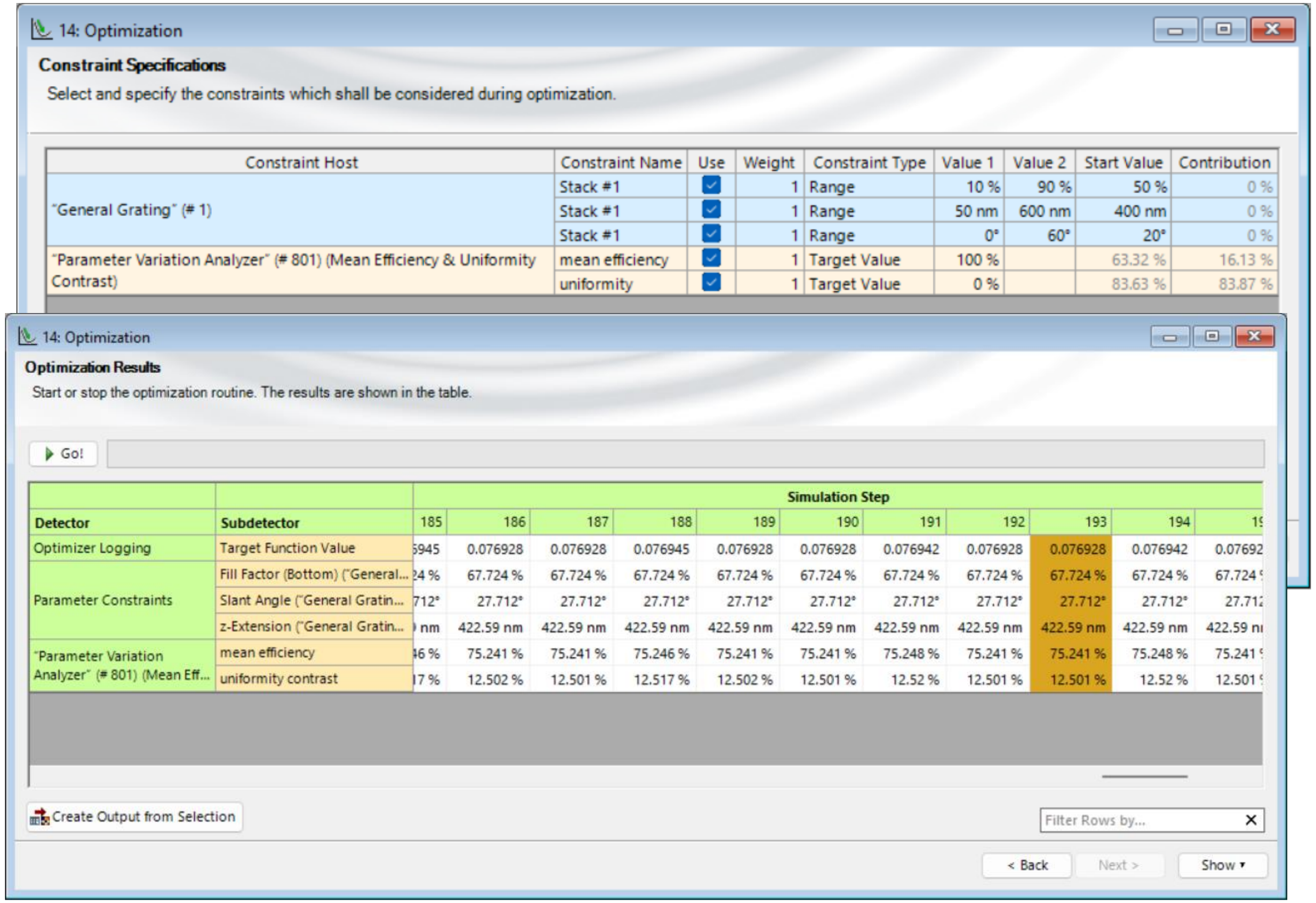
mean efficiency – to be maximized: $\eta_{\mathrm{mean}} = \frac{\sum_i^n \eta_i}{n}$

uniformity contrast (of diffraction efficiency) – to be minimized: $u = \frac{\eta_{\max} - \eta_{\min}}{\eta_{\max} + \eta_{\min}}$,

with η_i the transmission efficiency of diffraction order +1 for a single angle of the field of view (α_i, β_i).

Parametric Optimization





Now, the grating can be optimized using the in-built *Parametric Optimization*. A mean efficiency of 100% (to maximize this value) und contrast of 0% (to minimize this value) are used as target values for the merit function.

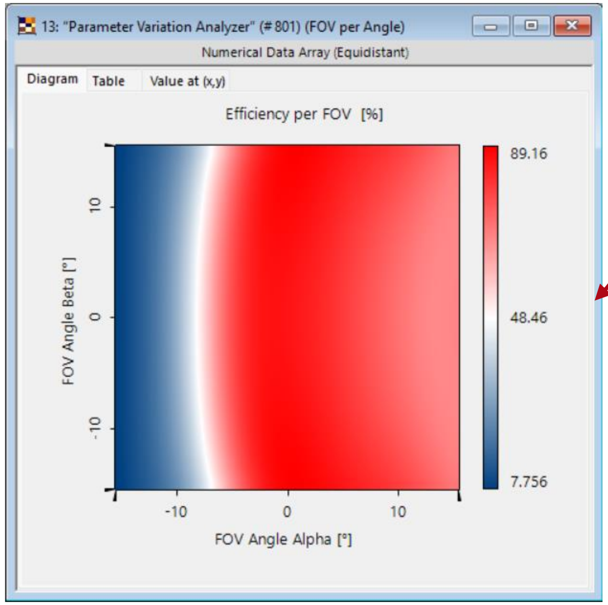
More information under:
[Introduction to the Parametric Optimization Document]

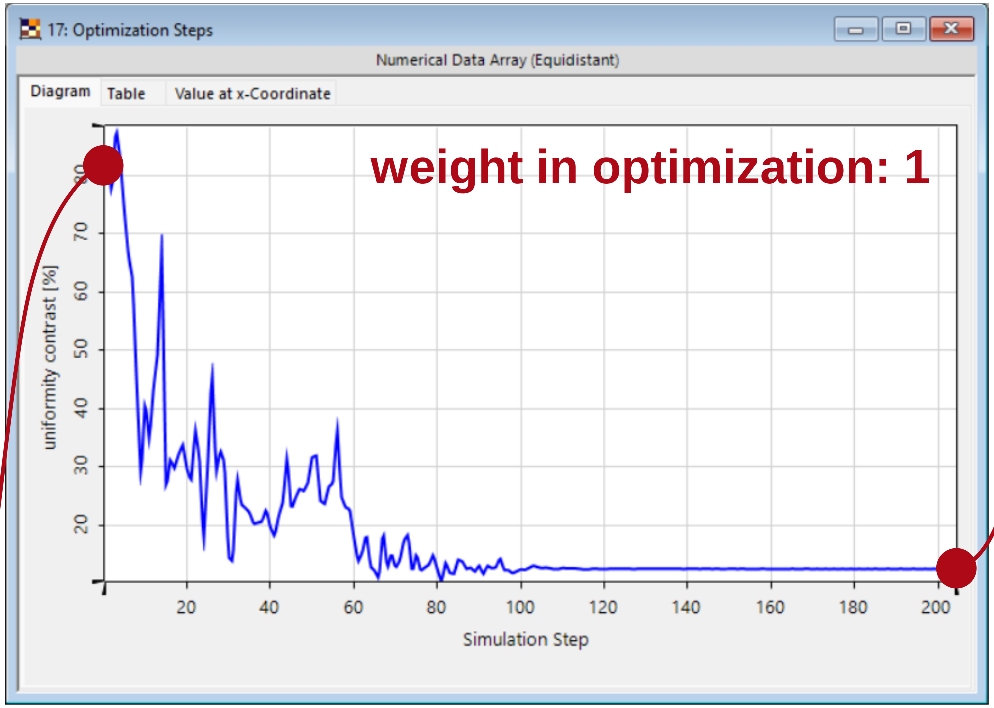
Optimization Result 1 – Uniformity Contrast for Weights of 1

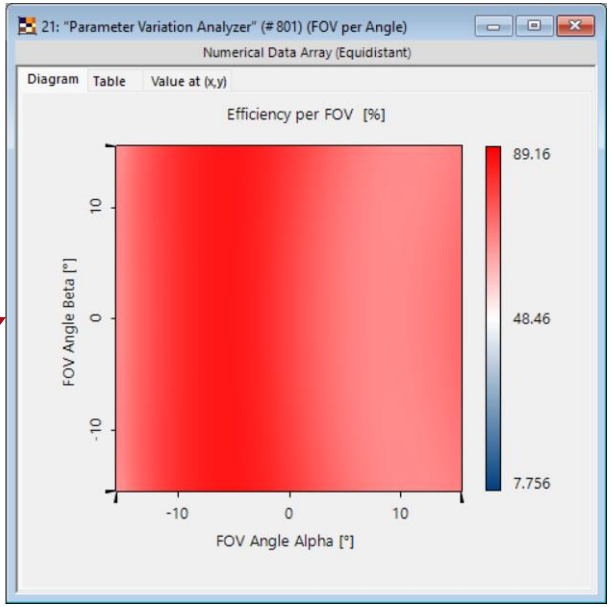
initial design:

- modulation depth: 400.00 nm
- fill factor: 50.00%
- slant angle: 20.00°

- mean efficiency: 63.32%
- uniformity contrast: 83.63%







For the optimized grating structure, the distinct contrast between the left and right part of the FOV is flattened.

optimized design:

- modulation depth: 422.59 nm
- fill factor: 67.72%
- slant angle: 27.71°

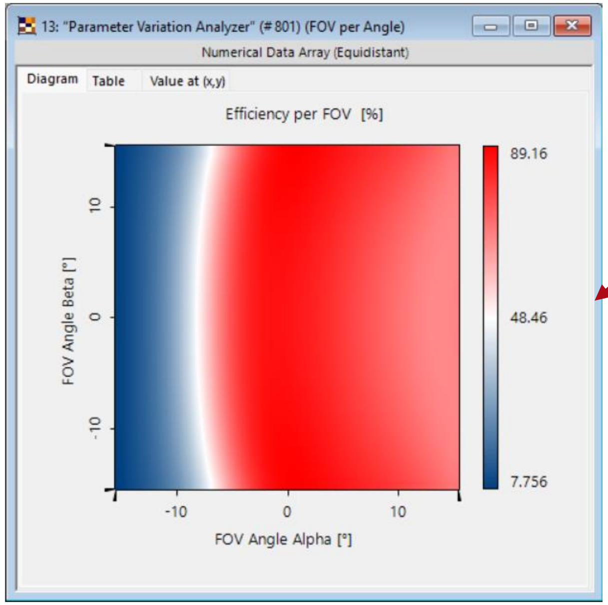
- mean efficiency: 75.24%
- uniformity contrast: 12.50%

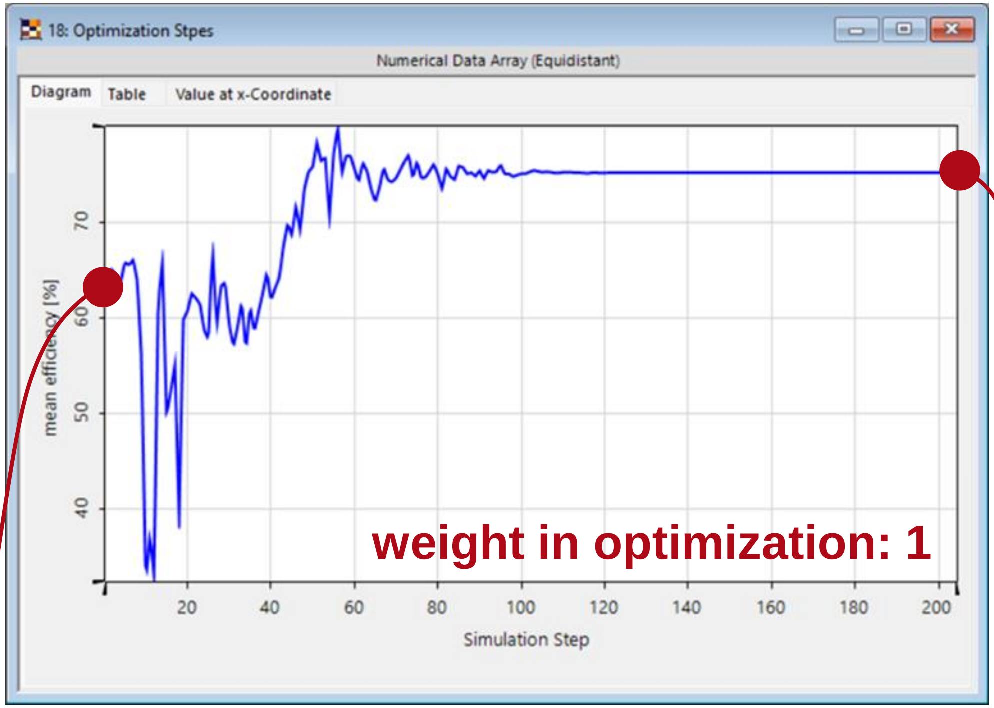
Optimization Result 1 – Mean Efficiency for Weights of 1

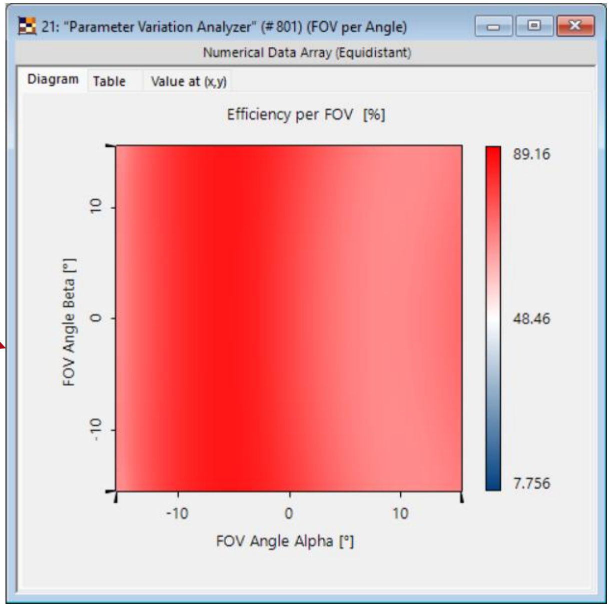
initial design:

- modulation depth: 400.00 nm
- fill factor: 50.00%
- slant angle: 20.00°

- mean efficiency: 63.32%
- uniformity contrast: 83.63%







This particular optimization not only improves the uniformity, but also increases overall efficiency.

optimized design:

- modulation depth: 422.59 nm
- fill factor: 67.72%
- slant angle: 27.71°

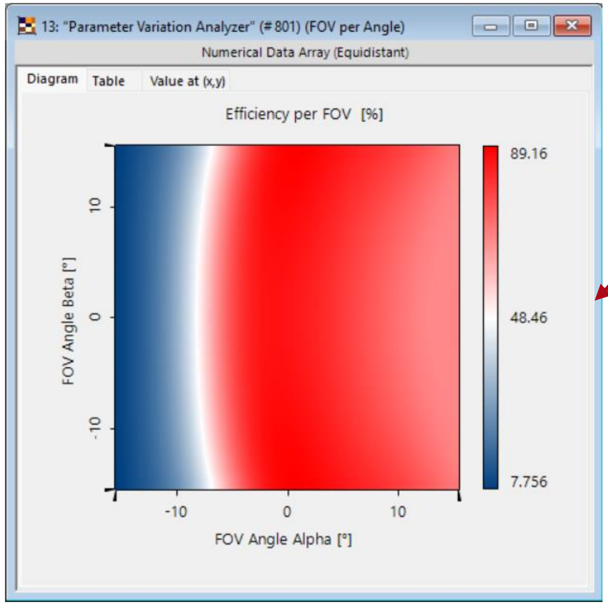
- mean efficiency: 75.24%
- uniformity contrast: 12.50%

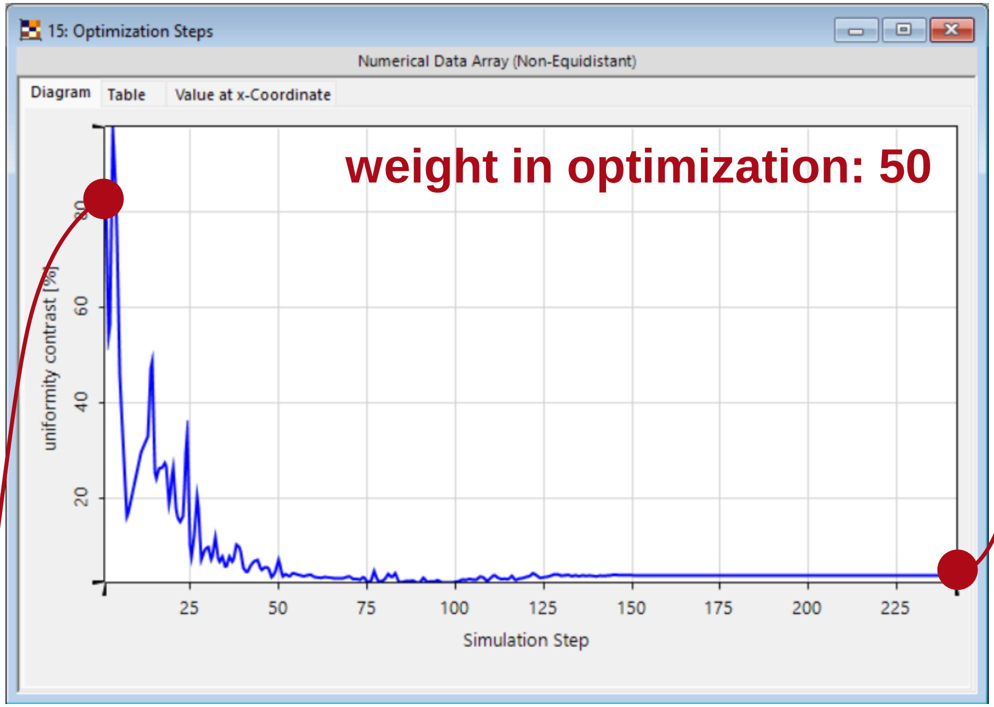
Optimization Result 2 – Uniformity Contrast – Increased Weight

initial design:

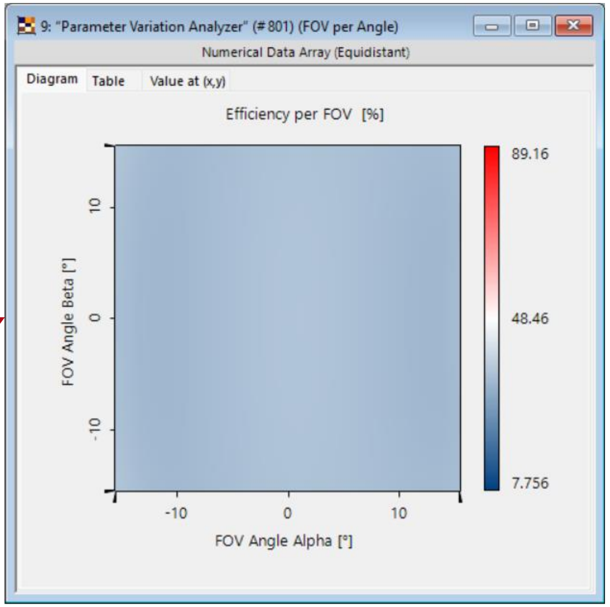
- modulation depth: 400.00 nm
- fill factor: 50.00%
- slant angle: 20.00°

- mean efficiency: 63.32%
- contrast: 83.63%





The weight of constraints can be adjusted based on specific requirements. In this example, achieving optimal uniformity is prioritized at the detriment of attaining maximum efficiency.



optimized design:

- modulation depth: 274.13 nm
- fill factor: 73.79%
- slant angle: 20.91°

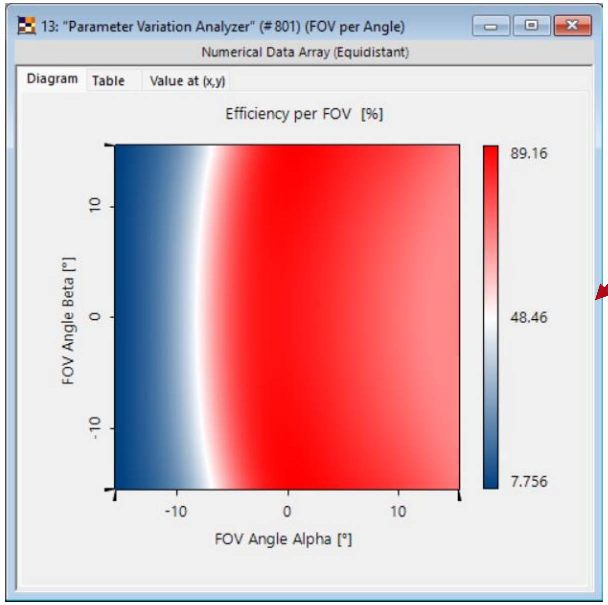
- mean efficiency: 34.61%
- contrast: 3.98%

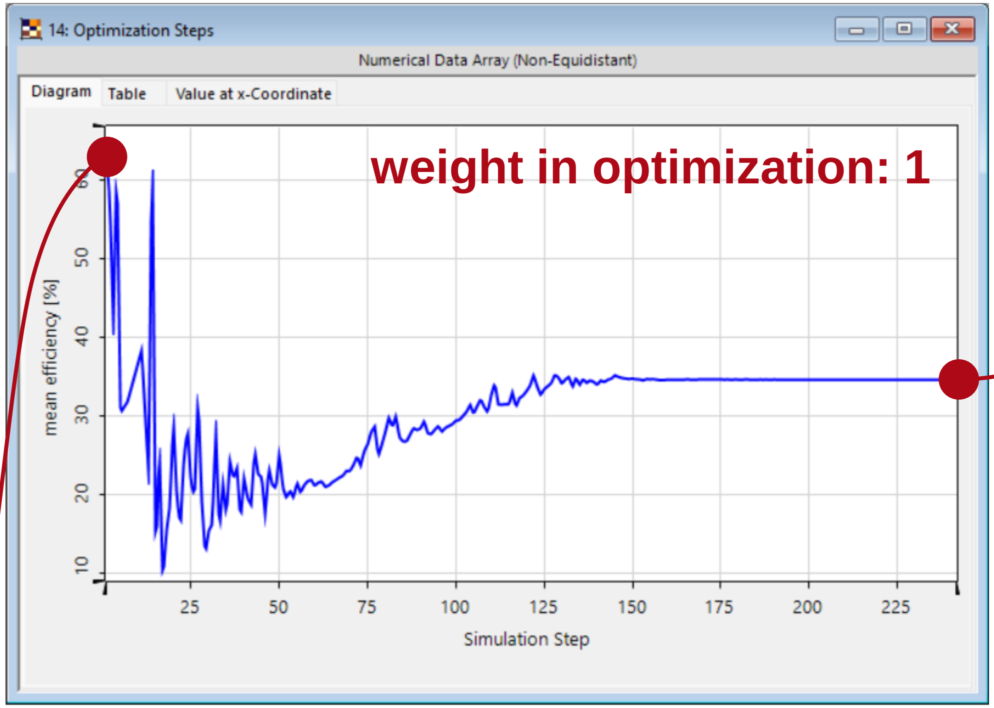
Optimization Result 2 – Mean Efficiency

initial design:

- modulation depth: 400.00 nm
- fill factor: 50.00%
- slant angle: 20.00°

- mean efficiency: 63.32%
- uniformity contrast: 83.63%



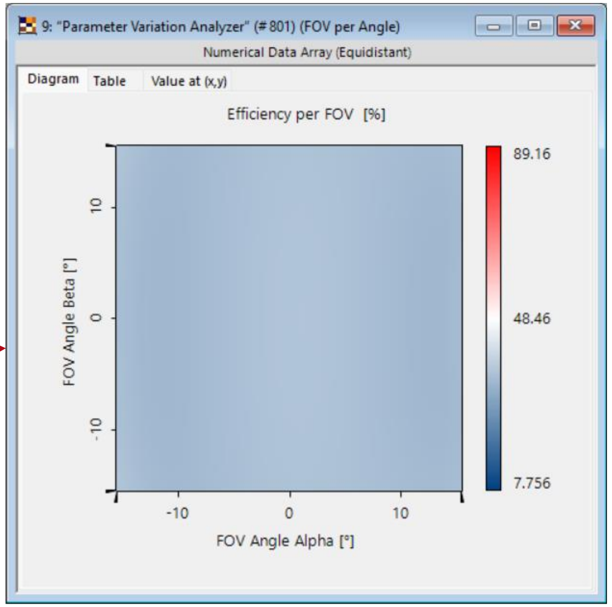


The distinct improvement in uniformity comes with a sacrificed mean efficiency.

optimized design:

- modulation depth: 274.13 nm
- fill factor: 73.79%
- slant angle: 20.91°

- mean efficiency: 34.61%
- uniformity contrast: 3.98%



Document Information

title	Optimization of Grating Incoupler for Lightguides/Waveguides
document code	LGC.0003
document version	2.0
required packages	• Grating Package
software version	2023.2 (Build 2.30)
category	Application Use Case
further reading	• Grating Order Analyzer • Parameter Variation Analyzer • Introduction to the Parametric Optimization Document