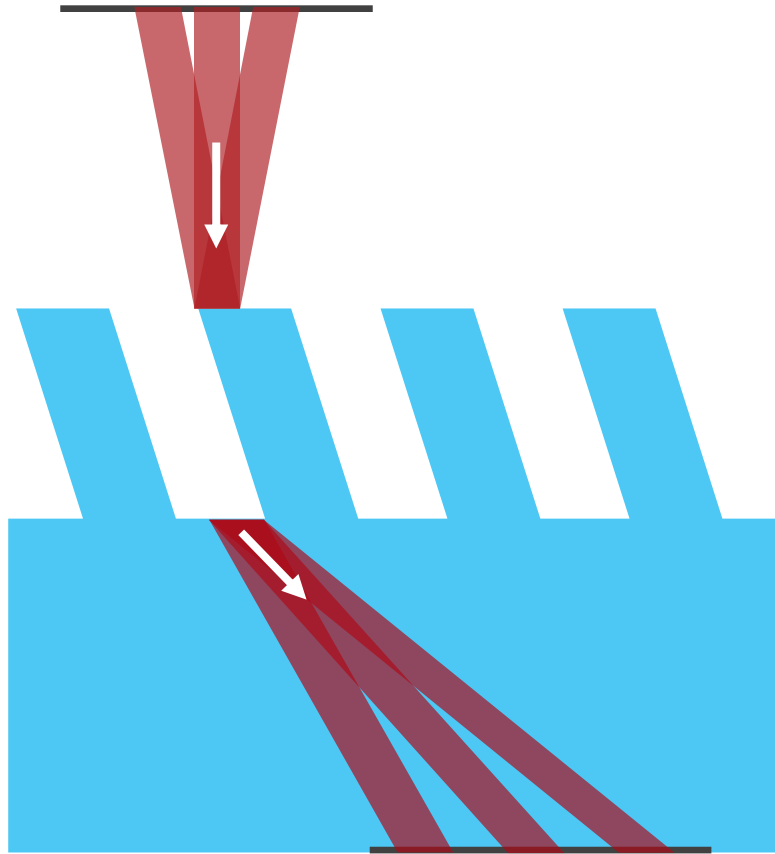


Optimization of Grating Incoupler for Lightguides/Waveguides

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

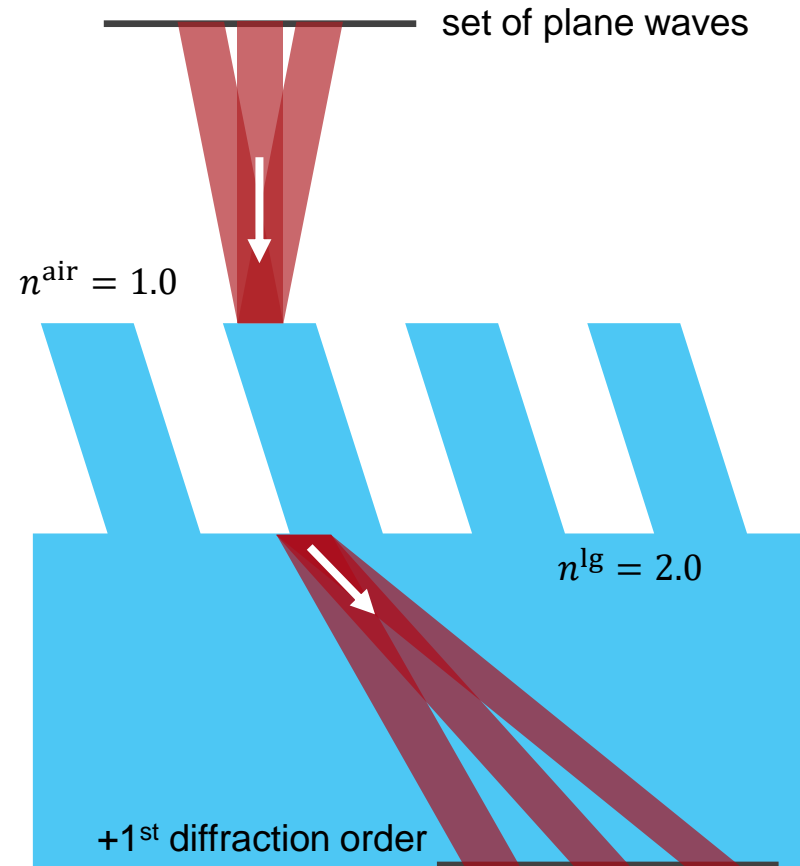
set of plane waves

- field of view ($-15^\circ \dots 15^\circ$ along x and y axis) (*)
- wavelength 532nm
- linearly polarized along x-axis

incoupling grating

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

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



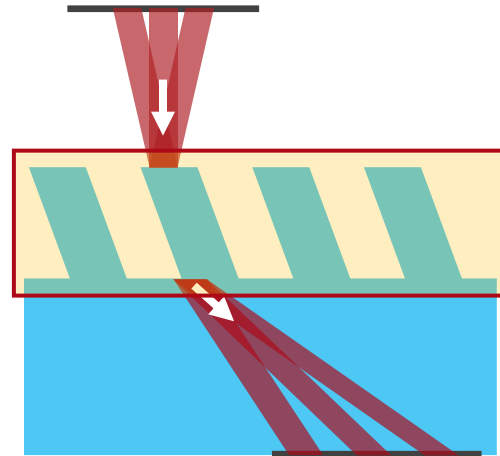
optimization parameters

- fill factor: 10% – 90%
- modulation depth: 50nm – 600nm
- slant angle: $0^\circ - 60^\circ$

merit function (*Parameter Variation Analyzer*):

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

Connected Modeling Techniques: Incoupling Grating



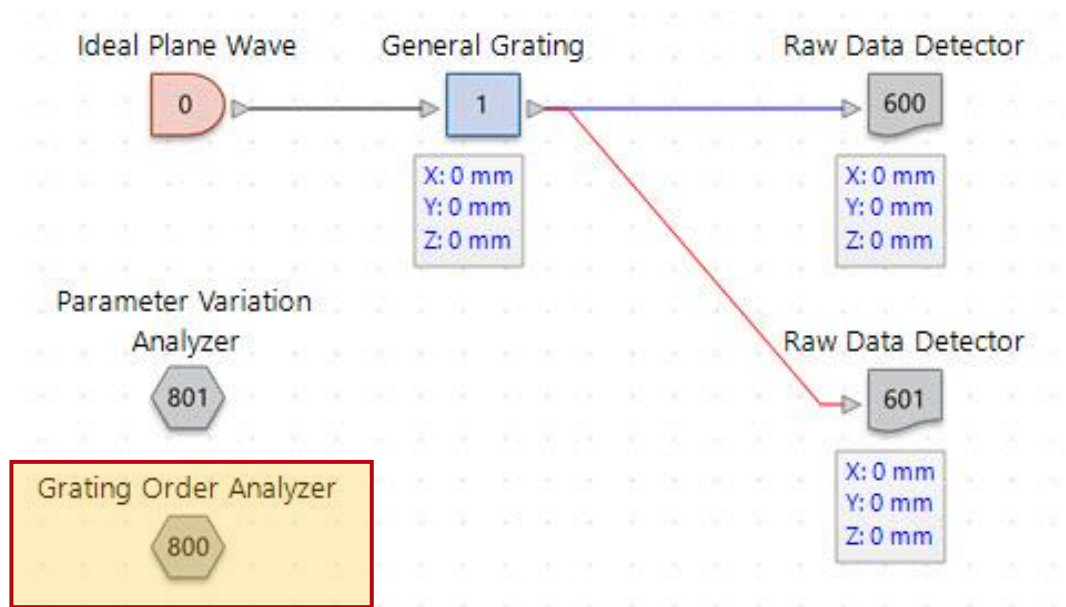
Available modeling techniques for microstructures:

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

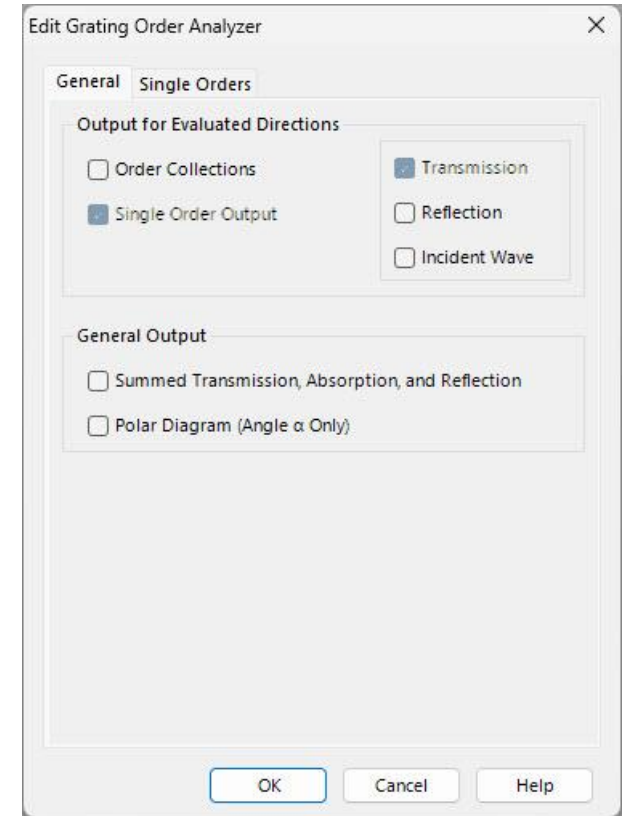
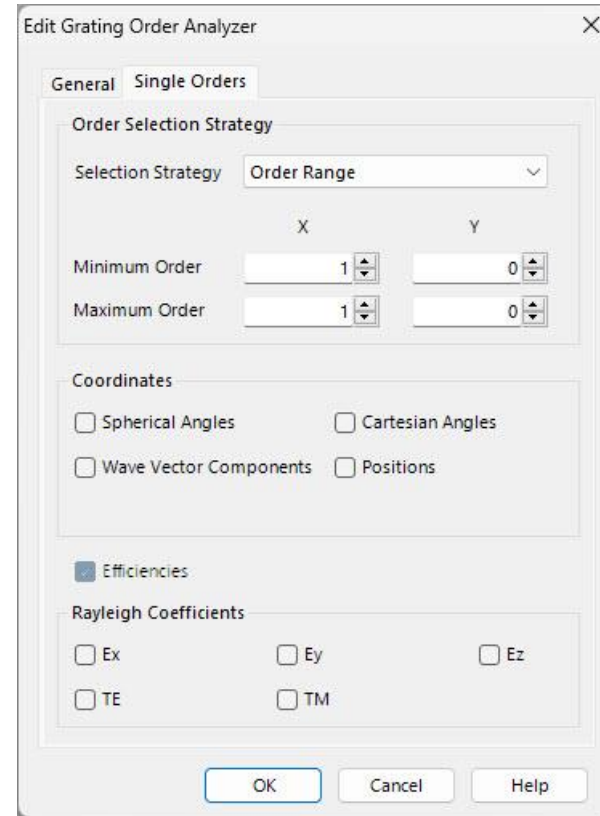


Grating Order Analyzer



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

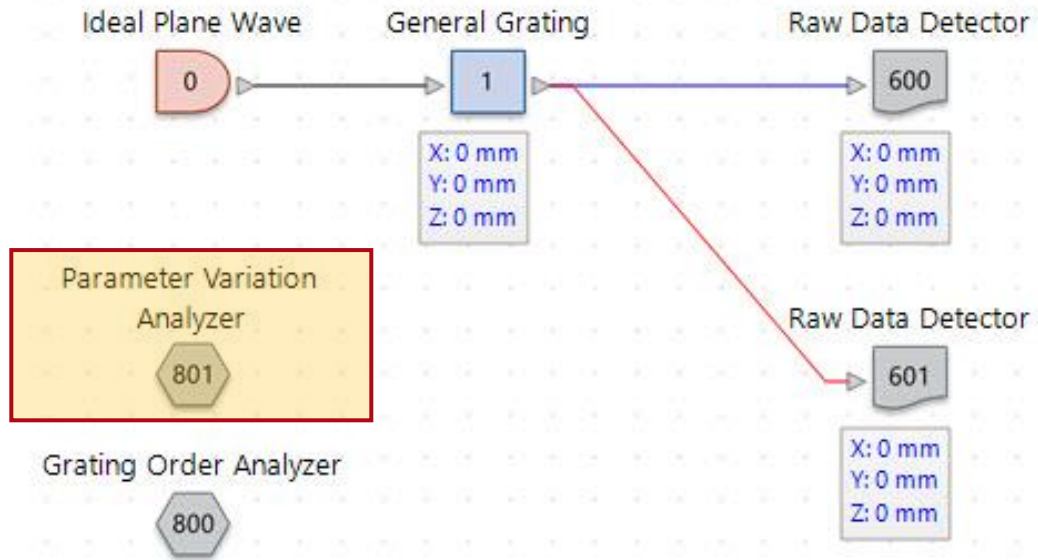
[Grating Order Analyzer](#)



resulting efficiency provided in the *Detector Results* tab:

Efficiency T[+1; 0] 85.98 %

Parameter Variation Analyzer



Source Code Editor

```

86 double effMax = Double.MinValue;
87 double meanValue = 0;
88 double meanVa
89
90
91
92
93
94 //case for 2
95 if (parameter
96 //Define
97 double Sa
98 double Sa
99 double No
100 double No
101 double Fi
102 double Fi
103
104 //define
105 CFieldDer
106 int count
107 int count
            
```

4: Edit Parameter Variation

Parameter Specification
Set up the parameter(s) to be varied.

You can select one or more parameters which shall be varied as well as the resulting number of iterations. Several [modes](#) are available specifying how the parameters are varied per iteration.

Usage Mode: Scanning Number of Iterations: 961

Filter by... Show Only Varied Parameters

1	2	*	Object	Category	Parameter	Vary	From	To	Steps	Step Size	Original Val
			"Ideal Pl...		Polarization An...	<input type="checkbox"/>	0°	360°	1	360°	0°
				Basal Positioning (Relative)	Rotation#1 (a...	<input checked="" type="checkbox"/>	-15°	15°	31	1°	0°
					Rotation#2 (a...	<input checked="" type="checkbox"/>	-15°	15°	31	1°	0°
			"General	Medium at "T" O...	Material (Non...	<input type="checkbox"/>	1e-300	1e+300	1	1e+300	1.6

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.

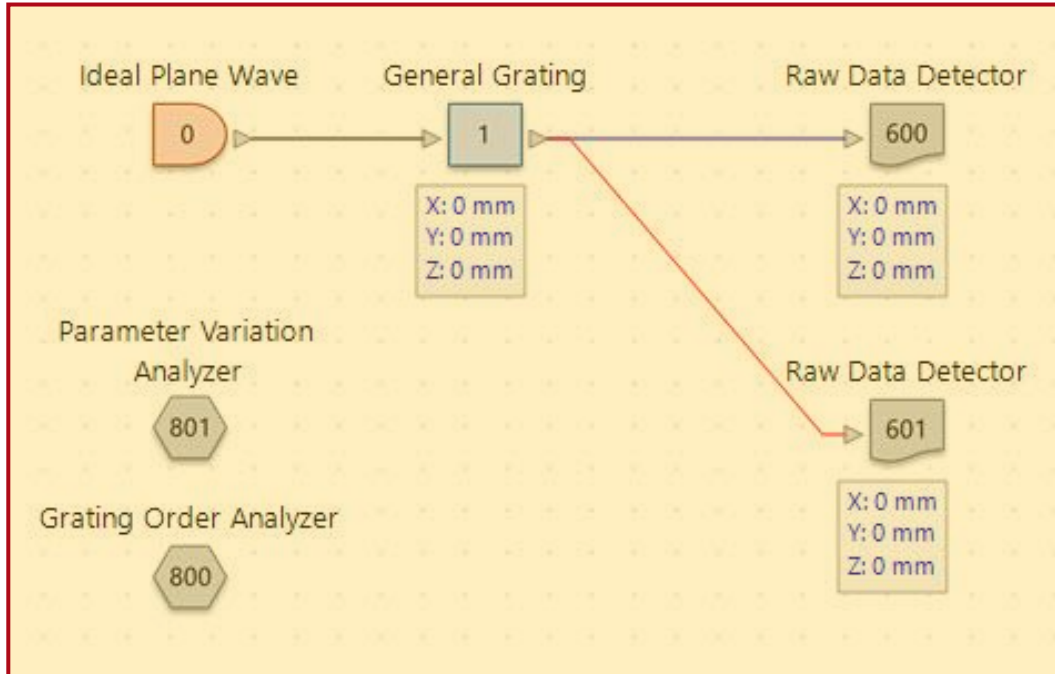
For more information, see: [Parameter Variation Analyzer](#)

merit functions:

mean efficiency – to be maximized: $\eta_{\text{mean}} = \frac{\sum_i^n \eta_i}{n}$
 uniformity contrast (of diffraction efficiency) – to be minimized: $u = \frac{\eta_{\text{max}} - \eta_{\text{min}}}{\eta_{\text{max}} + \eta_{\text{min}}}$,

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) and contrast of 0% (to minimize this value) are used as target values for the merit function.

14: Optimization
Constraint Specifications
 Select and specify the constraints which shall be considered during optimization.

Constraint Host	Constraint Name	Use	Weight	Constraint Type	Value 1	Value 2	Start Value	Contribution
"General Grating" (# 1)	Stack #1	<input checked="" type="checkbox"/>	1	Range	10 %	90 %	50 %	0 %
	Stack #1	<input checked="" type="checkbox"/>	1	Range	50 nm	600 nm	400 nm	0 %
	Stack #1	<input checked="" type="checkbox"/>	1	Range	0°	60°	20°	0 %
"Parameter Variation Analyzer" (# 801) (Mean Efficiency & Uniformity Contrast)	mean efficiency	<input checked="" type="checkbox"/>	1	Target Value	100 %		63.32 %	16.13 %
	uniformity contrast	<input checked="" type="checkbox"/>	1	Target Value	0 %		83.63 %	83.87 %

14: Optimization
Optimization Results
 Start or stop the optimization routine. The results are shown in the table.

Go!

Detector	Subdetector	Simulation Step											
		185	186	187	188	189	190	191	192	193	194	195	
Optimizer Logging	Target Function Value	3945	0.076928	0.076928	0.076945	0.076928	0.076928	0.076942	0.076928	0.076928	0.076942	0.076928	0.076928
Parameter Constraints	Fill Factor (Bottom) ("General...	24 %	67.724 %	67.724 %	67.724 %	67.724 %	67.724 %	67.724 %	67.724 %	67.724 %	67.724 %	67.724 %	67.724 %
	Slant Angle ("General Gratin...	712°	27.712°	27.712°	27.712°	27.712°	27.712°	27.712°	27.712°	27.712°	27.712°	27.712°	
	z-Extension ("General Gratin...	nm	422.59 nm	422.59 nm	422.59 nm	422.59 nm	422.59 nm	422.59 nm	422.59 nm	422.59 nm	422.59 nm	422.59 nm	
"Parameter Variation Analyzer" (# 801) (Mean Eff...	mean efficiency	6 %	75.241 %	75.241 %	75.246 %	75.241 %	75.241 %	75.248 %	75.241 %	75.241 %	75.248 %	75.241 %	
	uniformity contrast	7 %	12.502 %	12.501 %	12.517 %	12.502 %	12.501 %	12.52 %	12.501 %	12.501 %	12.52 %	12.501 %	

Create Output from Selection

< Back Next > Show ▾

More information under:

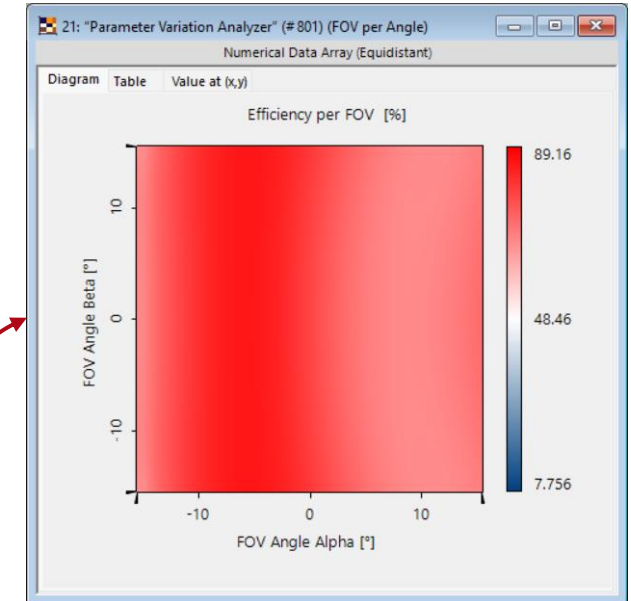
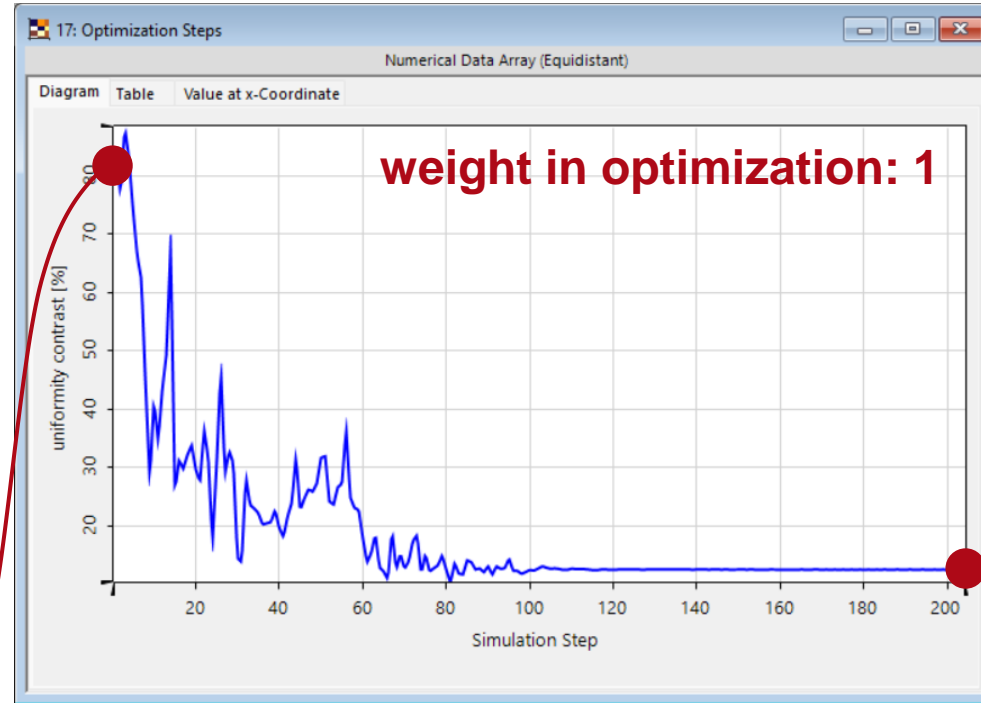
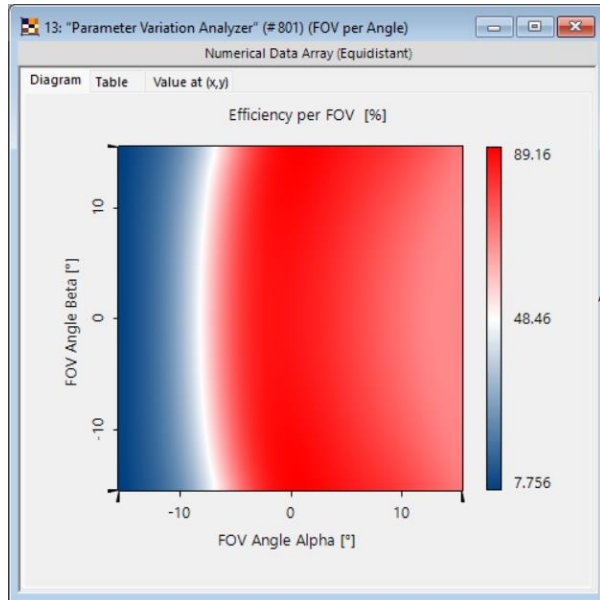
[Introduction to the Parametric Optimization Document](#)

Optimization Result 1 – Uniformity Contrast for Weights of 1

initial design:

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

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



optimized design:

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

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

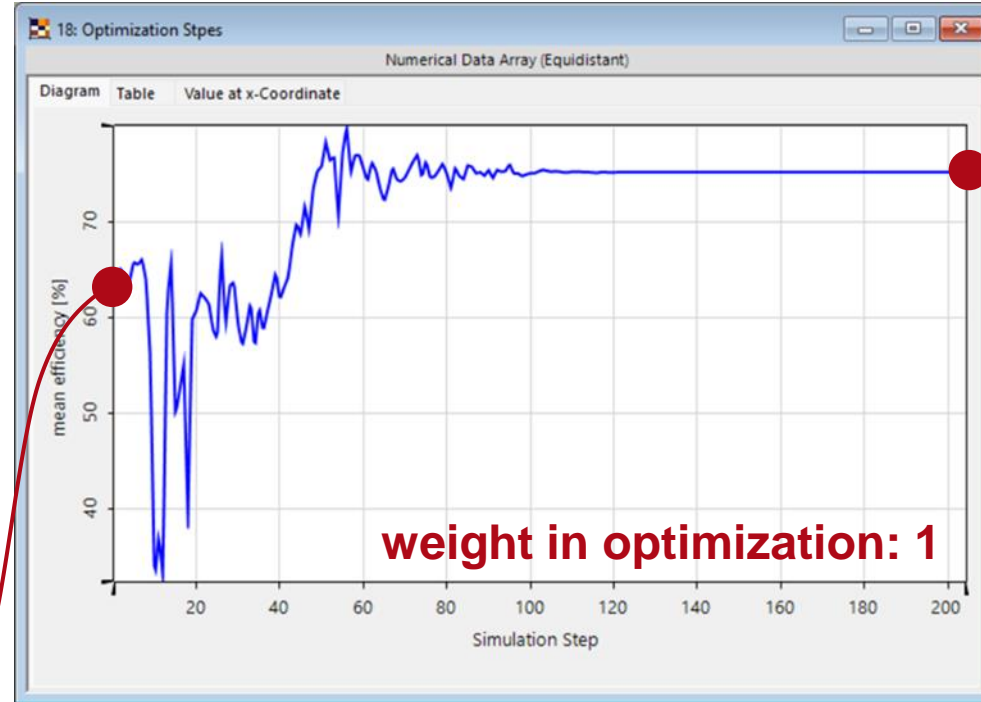
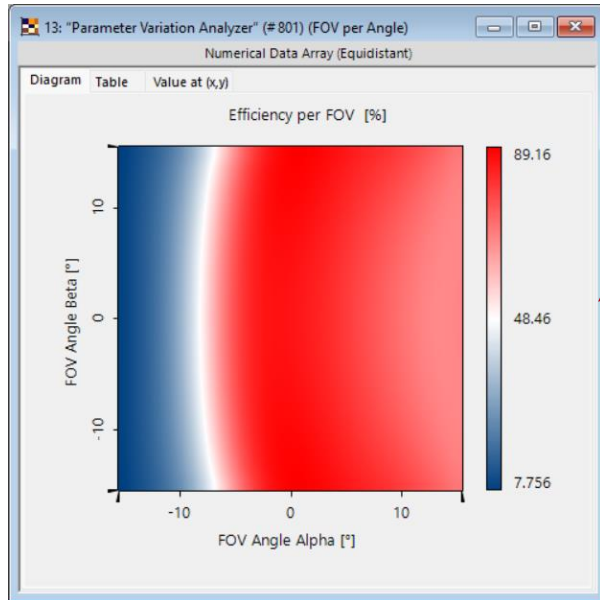
For the optimized grating structure, the distinct contrast between the left and right part of the FOV is flattened.

Optimization Result 1 – Mean Efficiency for Weights of 1

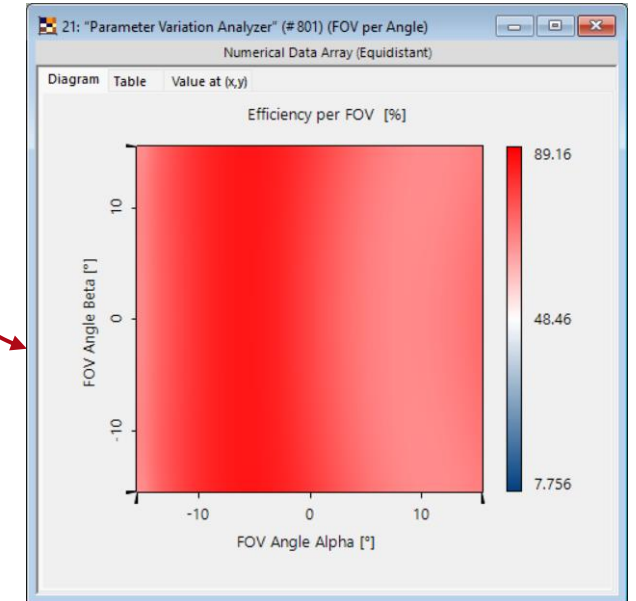
initial design:

- modulation depth: 400.00nm
- 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: 422.59nm
- fill factor: 67.72%
- slant angle: 27.71°

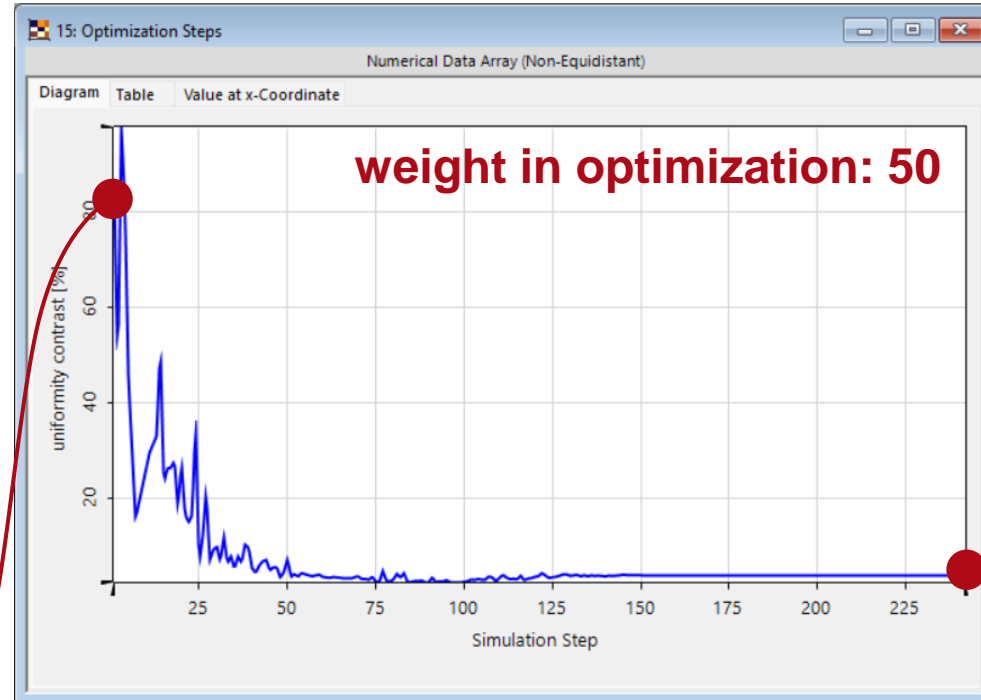
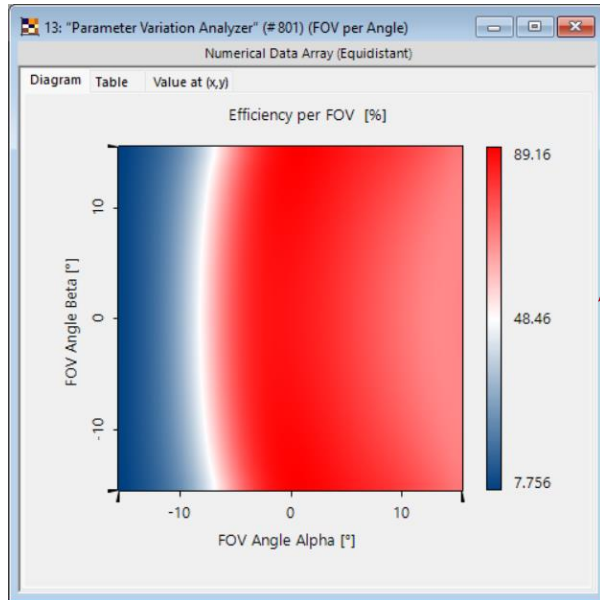
- **mean efficiency: 75.24%**
- **uniformity contrast: 12.50%**

Optimization Result 2 – Uniformity Contrast – Increased Weight

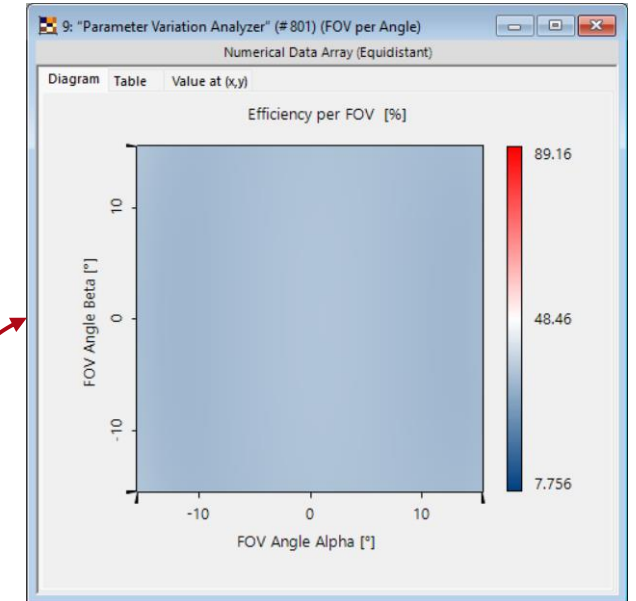
initial design:

- modulation depth: 400.00nm
- 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: 274.13nm
- fill factor: 73.79%
- slant angle: 20.91°

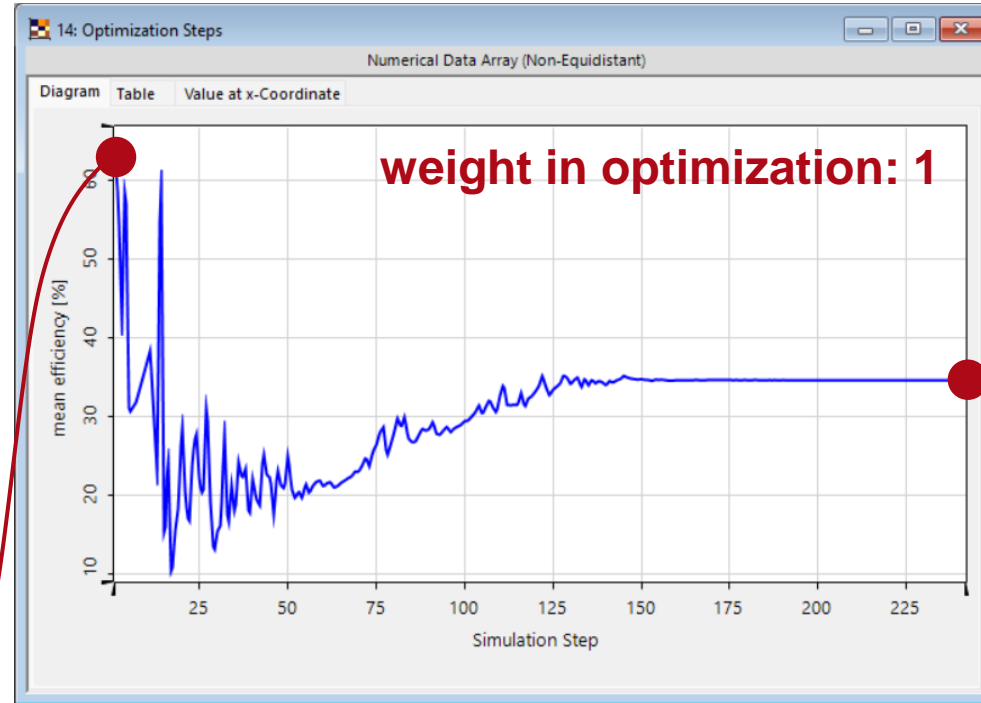
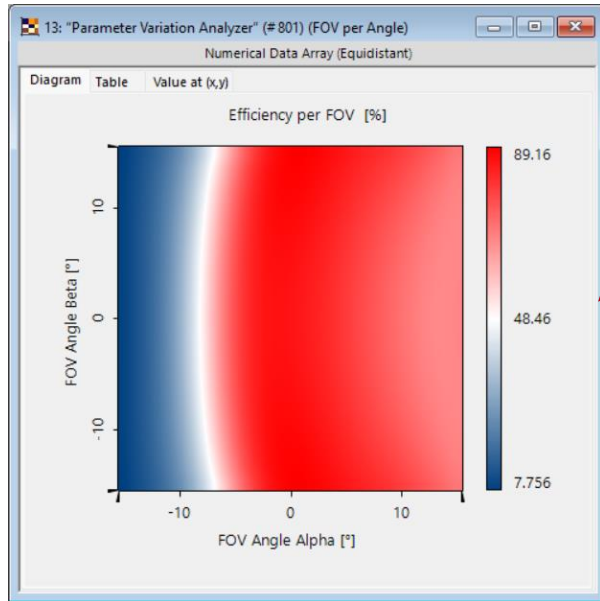
- mean efficiency: 34.61%
- **contrast: 3.98%**

Optimization Result 2 – Mean Efficiency

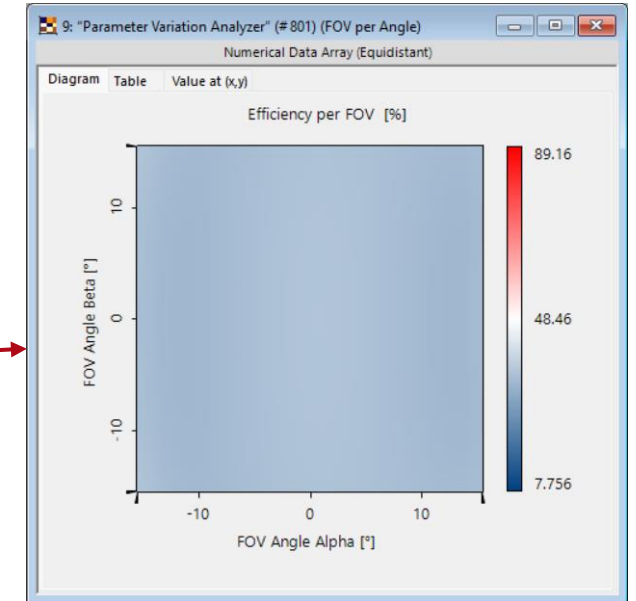
initial design:

- modulation depth: 400.00nm
- 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: 274.13nm
- 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	<ul style="list-style-type: none">• Grating Package
software version	2023.2 (Build 2.30)
category	Application Use Case
further reading	<ul style="list-style-type: none">• Grating Order Analyzer• Parameter Variation Analyzer• Introduction to the Parametric Optimization Document