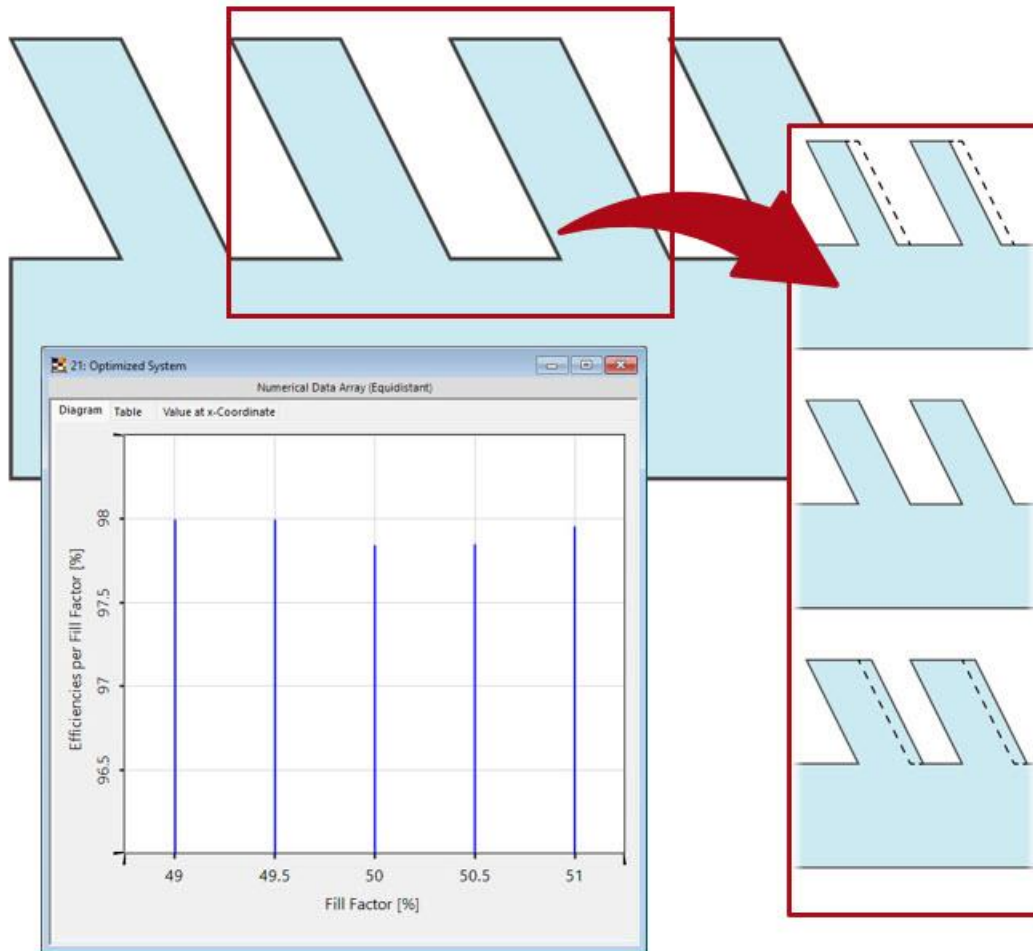


Robustness Optimization of a Slanted Grating

Abstract



Due to potential inaccuracies in the manufacturing process, it is essential for a good grating design to provide robust results in the face of slight variations in the grating parameters. VirtualLab Fusion offers the optical engineer various tools to incorporate this behavior directly in the optimization process, such as the Parameter Variation Analyzer. This tool combines multiple iterations of the same system, enabling the representation and automatic calculation of merit functions, like the mean efficiency, during optimization. In this use case we demonstrate this feature by optimizing a slanted grating with a slightly varying fill factor.

Simulation Task

plane wave

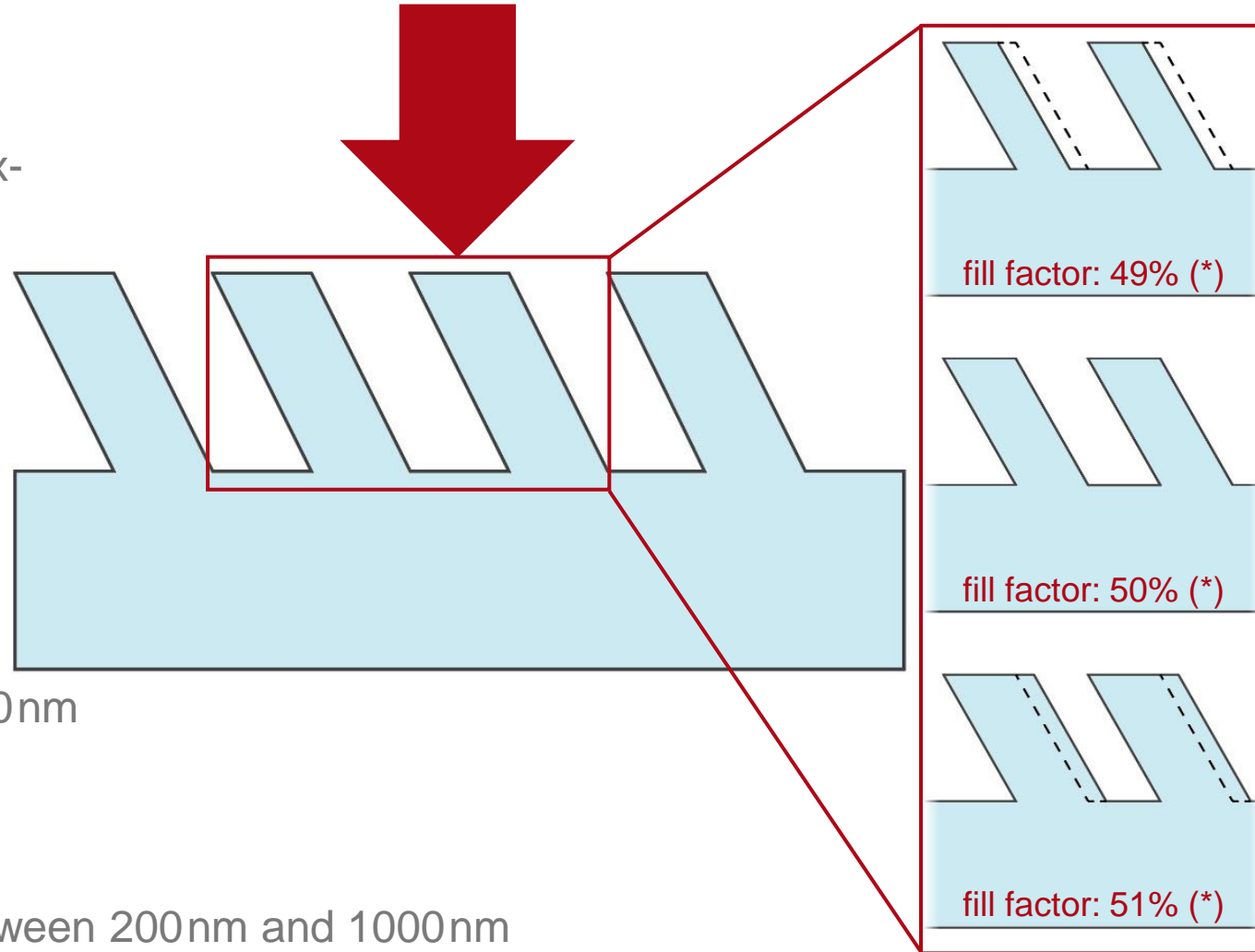
- wavelength: 532 nm
- linearly polarized along x-axis

slanted grating

- operation order: +1st (transmission)
- fill factor: 50% \pm 1%
- medium in front: air
- medium behind: $n=1.6$
- period: 500 nm
- grating height (initial): 250 nm
- slant angle (initial): 40°

optimization parameters

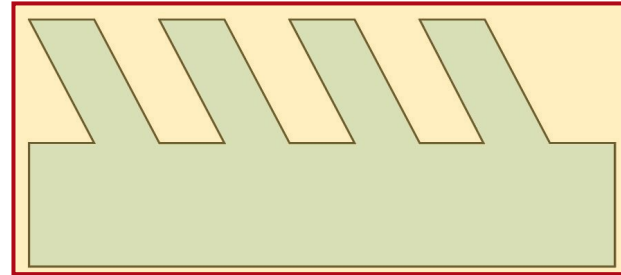
- grating height: varied between 200 nm and 1000 nm
- slant angle: varied between 0° and 60°



To perform a robustness analysis, efficiencies of 5 different fill factors between 49% and 51% will be combined in two merit functions: contrast (of the diffraction efficiencies) & mean efficiency.

(* figures slightly exaggerated for illustration purposes)

Connected Modeling Techniques: Slanted Grating

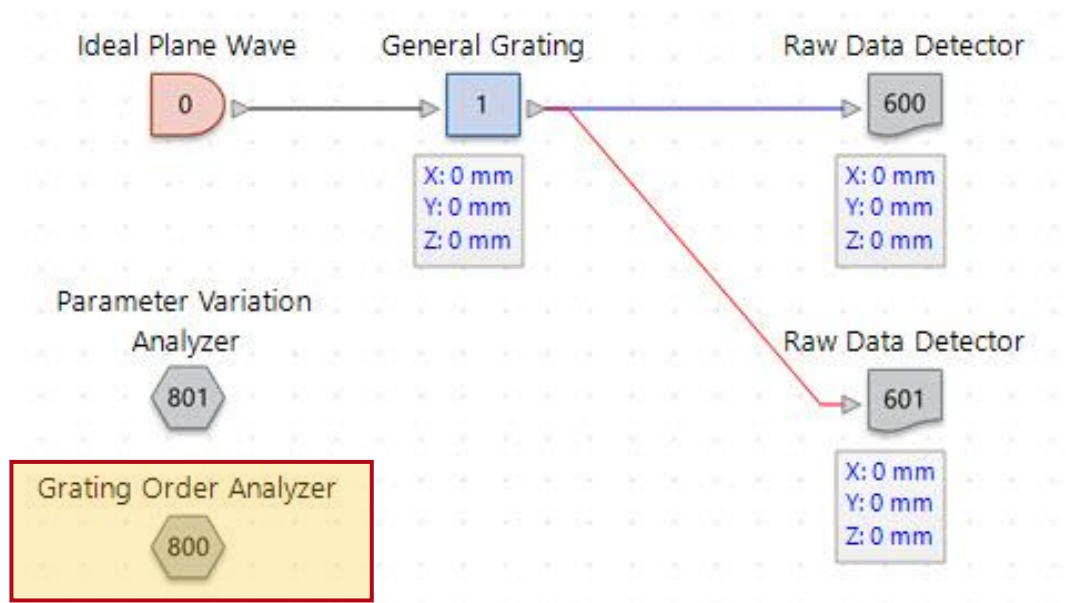


Available modeling techniques for microstructures:

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	

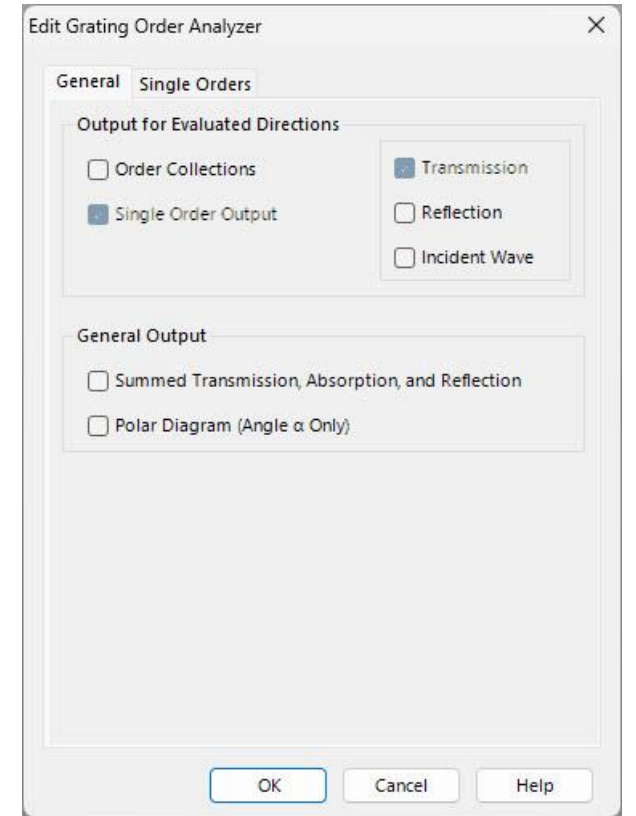
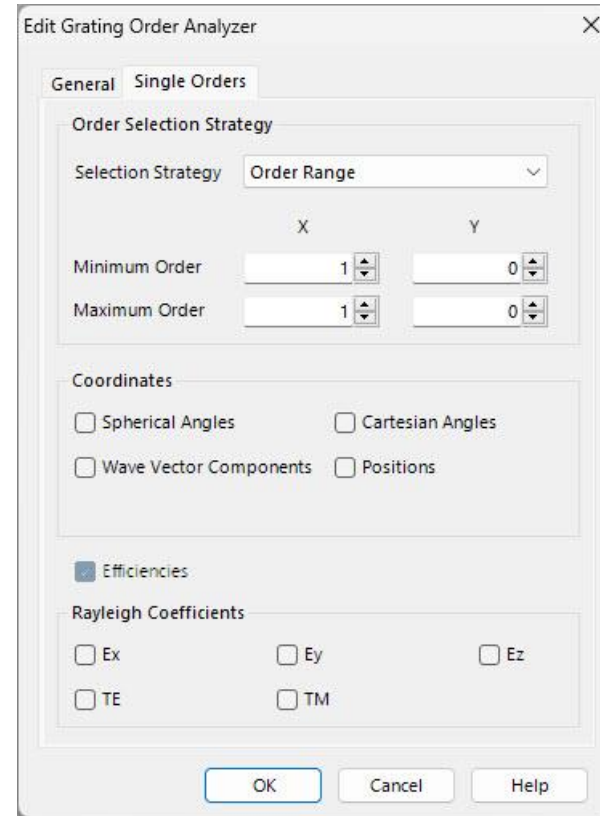
The considerable modulation height and small period make the **Thin Element Approximation (TEA)** solver inaccurate in the given case. Hence, the **Fourier Modal Method (FMM)** is used to provide a rigorous solution.

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:

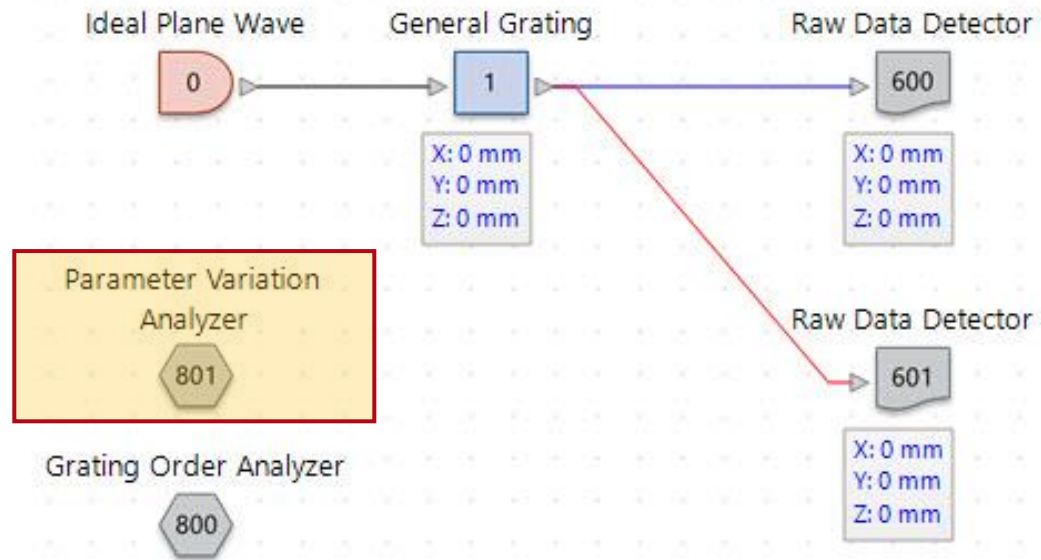
[Grating Order Analyzer](#)



resulting efficiency in the *Detector Results* tab:

Efficiency T[+1; 0] 11.997 %

Parameter Variation Analyzer



```

77 double effMax = Double.MinValue;
78 double meanValue = 0;
79 double meanVa
80
81
82
83 //run through
84 for (int runM
85
86 //extract cu
87 //check i
88 if (currE
89 else {
90 //sum
91 meanVa
92 meanVa
93 //che
94 if (c
95 if (c
96
97
98
                    
```

37: 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: Standard

Filter by...

1	2	*	Object	Category	Parameter	Vary	From	To	Steps	Step Size	Original Val
			Medium #1 (Slanted Gra...		Medium #1 (Slanted Gra...	<input type="checkbox"/>	100 nm	1e+297 km	1	1e+297 km	Infinity nm
			Medium #1 (Slanted Gra...		Medium #1 (Slanted Gra...	<input type="checkbox"/>	0	1e+300	1	1e+300	0
			"General Grating" (#1)	Stack #1 (Incouple Grating (Slanted))	Medium #1 (Slanted Gra...	<input checked="" type="checkbox"/>	49 %	51 %	5	0.5 %	50 %
			Medium #1 (Slanted Gra...		Medium #1 (Slanted Gra...	<input type="checkbox"/>	100 fm	1e+297 km	1	1e+297 km	5 μm

Since results generated with different grating configurations must be considered, the *Parameter Variation Analyzer* is used to calculate the overall merit function. This tool enables the computation of efficiencies for gratings with different fill factor values, automatically determining the resulting mean efficiency and contrast. For more information, see:

[Parameter Variation Analyzer](#)

merit functions:

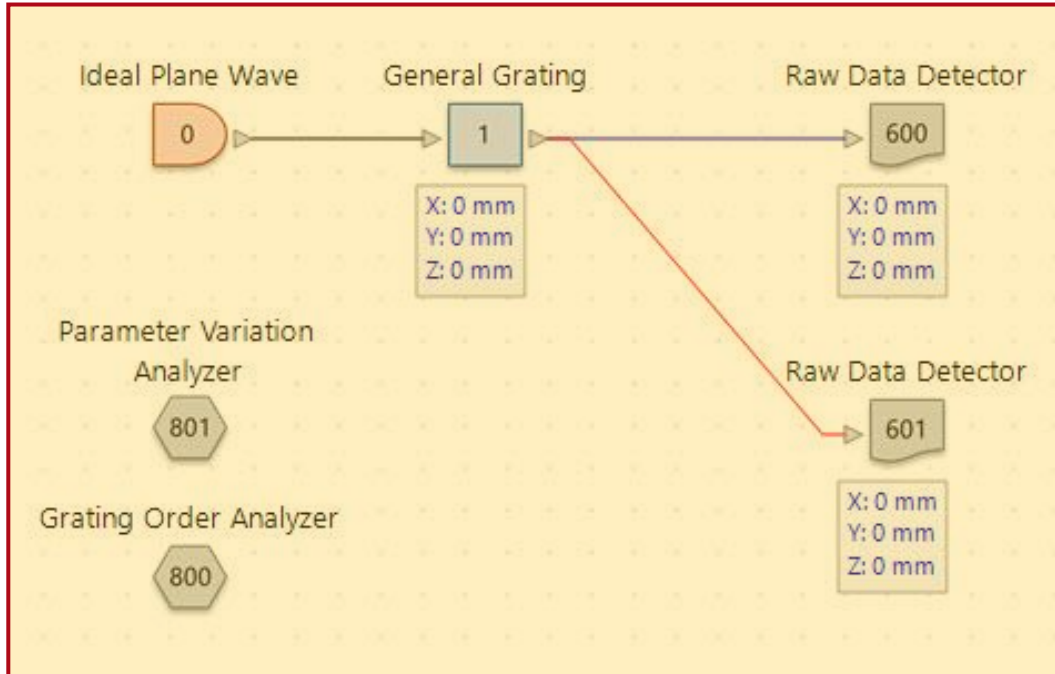
mean efficiency – to be maximized: $\eta_{\text{mean}} = \frac{\sum_i^n \eta_i}{n}$

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 1st order transmission efficiency for the i^{th} value of the fill factor.

Parametric Optimization



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

The top screenshot displays the 'Constraint Specifications' window. It contains a table with the following data:

Constraint Host	Constraint Name	Use	Weight	Constraint Type	Value 1	Value 2	Start Value	Contribution
"General Grating" (# 1)	Stack #1 (Incouple Grating (Slanted))	<input checked="" type="checkbox"/>	1	Range	50 nm	1 μm	250 nm	0 %
	Stack #1 (Incouple Grating (Slanted))	<input checked="" type="checkbox"/>	1	Range	0°	60°	45°	0 %
"Parameter Variation Analyzer" (# 801) (Mean Efficiency & Uniformity)	mean efficiency	<input checked="" type="checkbox"/>	1	Target Value	100 %		6.8003 %	84.234 %
	contrast of diffraction efficiency	<input checked="" type="checkbox"/>	20	Target Value	0 %		9.0159 %	15.766 %

The bottom screenshot displays the 'Optimization Results' window. It shows a table with the following data:

Detector	Subdetector	Combined Output	Simulation Step										
			111	112	113	114	115	116	117	118	1		
Optimizer Logging	Target Function Value	Data Array	94	0.00044288	0.00044285	0.00044278	0.00044271	0.00044264	0.00044262	0.0004456	0.000443		
Parameter Constraints	Slant Angle ("General Grati...	Data Array	35°	29.568°	29.569°	29.572°	29.577°	29.583°	29.588°	29.598°	29.59		
	z-Extension ("General Grati...	Data Array	nm	860.23 nm	860.18 nm	860.06 nm	859.91 nm	859.67 nm	859.5 nm	859.14 nm	859.12 n		
"Parameter Variation Analyzer" (# 801) (Mean Efficiency & Uniformity)	contrast of diffraction effici...	Data Array	%	0.082483 %	0.082194 %	0.081423 %	0.080458 %	0.078954 %	0.077881 %	0.081698 %	0.077076		
	mean efficiency	Data Array	%	97.928 %	97.928 %	97.928 %	97.927 %	97.926 %	97.925 %	97.921 %	97.923		

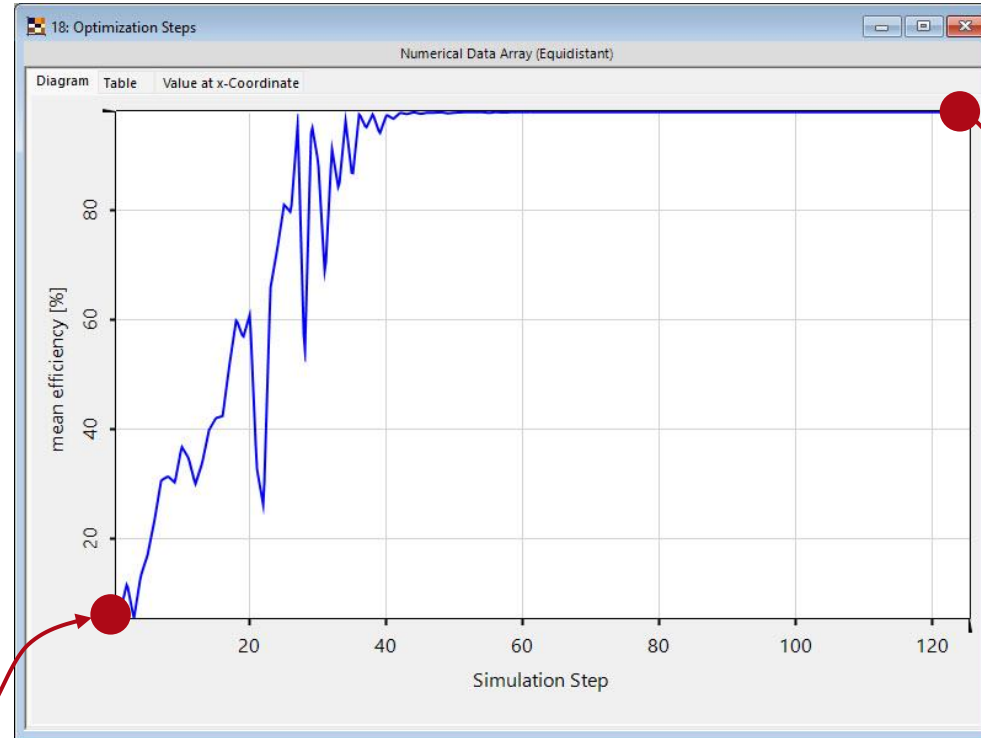
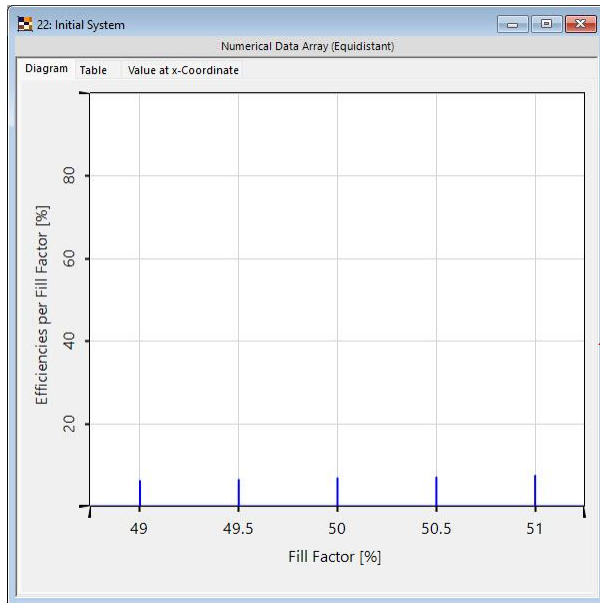
More information under:

[Introduction to the Parametric Optimization Document](#)

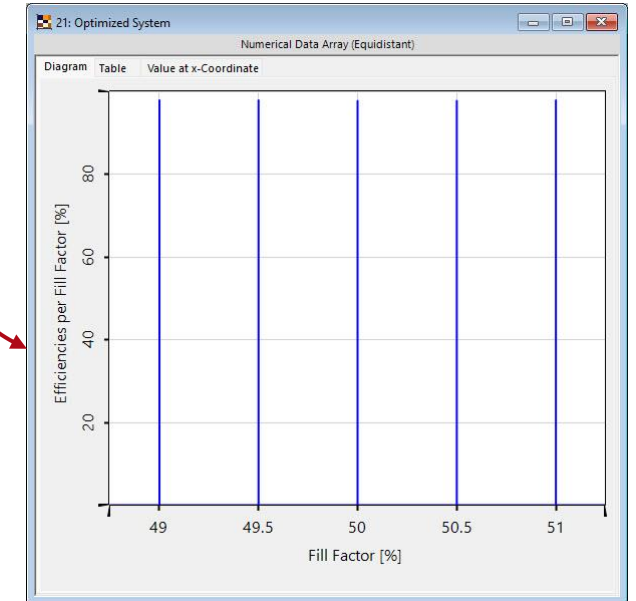
Optimization Result – Mean Efficiency

initial design:

- height: 250 nm
- slant angle: 45°
- mean efficiency: 6.8%
- contrast: 9.0%



The optimization led to a drastic improvement of the mean efficiency, increasing from ~7% to almost 100%.



optimized design:

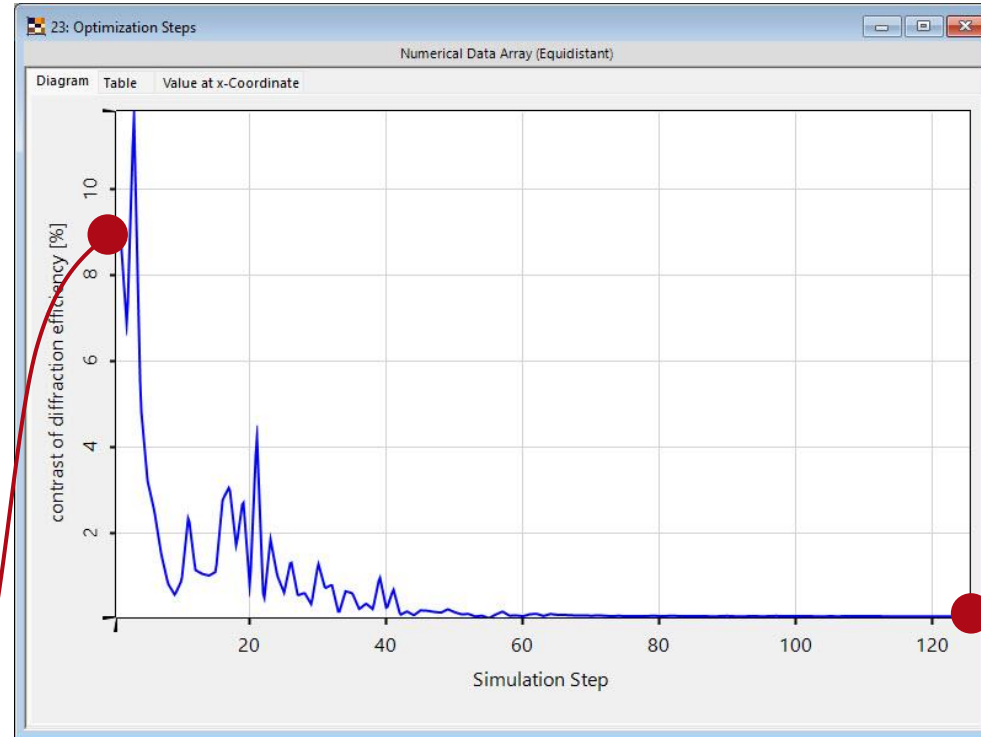
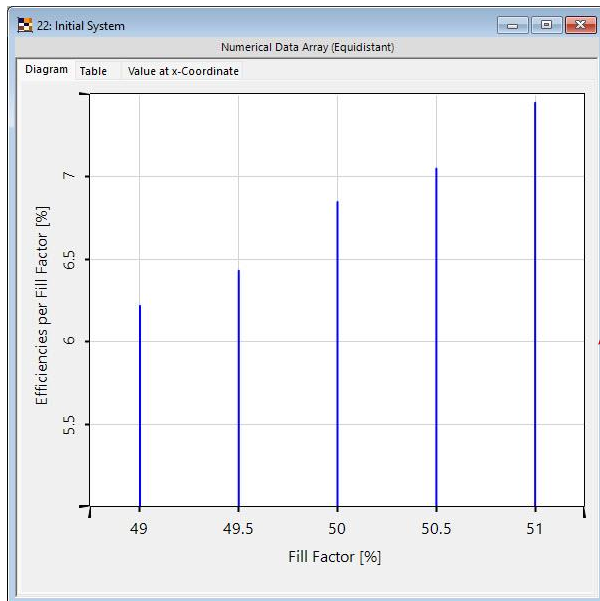
- height: 859.5 nm
- slant angle: 29.6°
- mean efficiency: 97.9%
- contrast: 0.1%

Optimization Result – Contrast

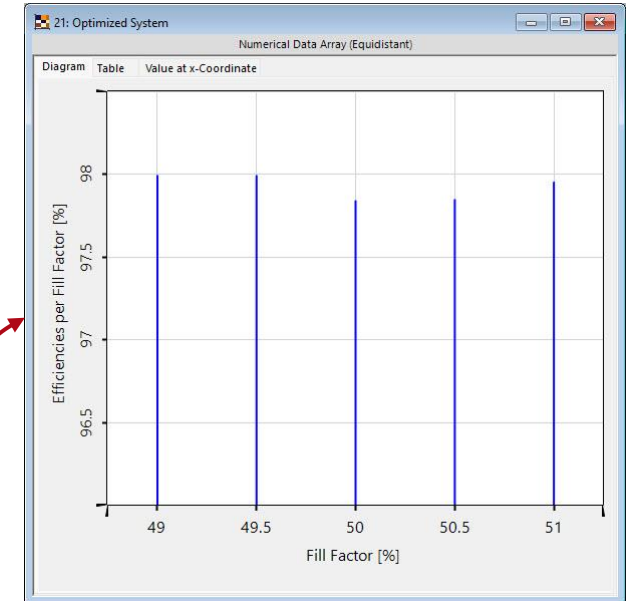
initial design:

- height: 250 nm
- slant angle: 45°

- mean efficiency: 6.8%
- **contrast: 9.0%**



At the same time, the contrast also improved. While in the initial system a linear behavior between efficiency and fill factor was observed, the optimized result is much more even.



optimized design:

- height: 859.5 nm
- slant angle: 29.6°

- mean efficiency: 97.9%
- **contrast: 0.1%**

Document Information

title	Robustness Optimization of a Slanted Grating
document code	GRT.0034
document version	1.0
required packages	<ul style="list-style-type: none">• Grating Package
software version	2023.2 (Build 1.242)
category	Application Use Case
further reading	<ul style="list-style-type: none">• Grating Order Analyzer• Parameter Variation Analyzer• Introduction to the Parametric Optimization Document