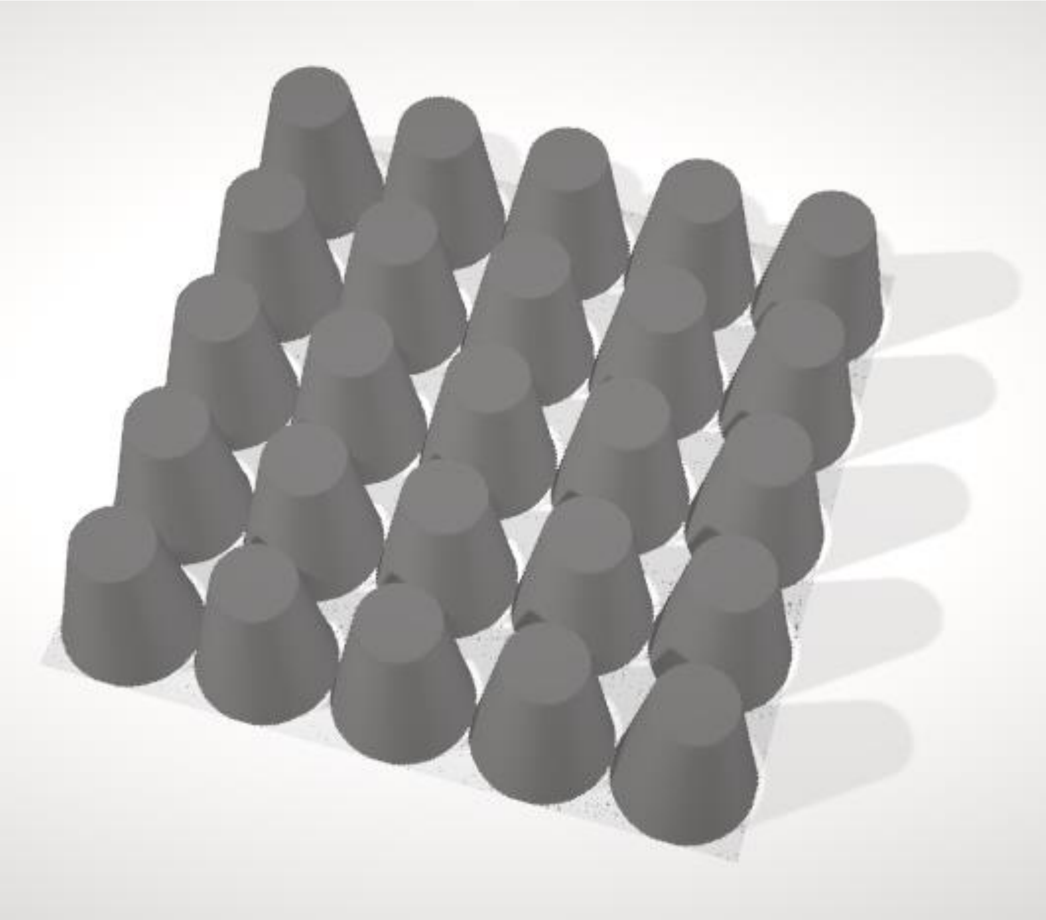
Rigorous Analysis and Design of Anti-Reflective Moth-Eye Structures

Abstract

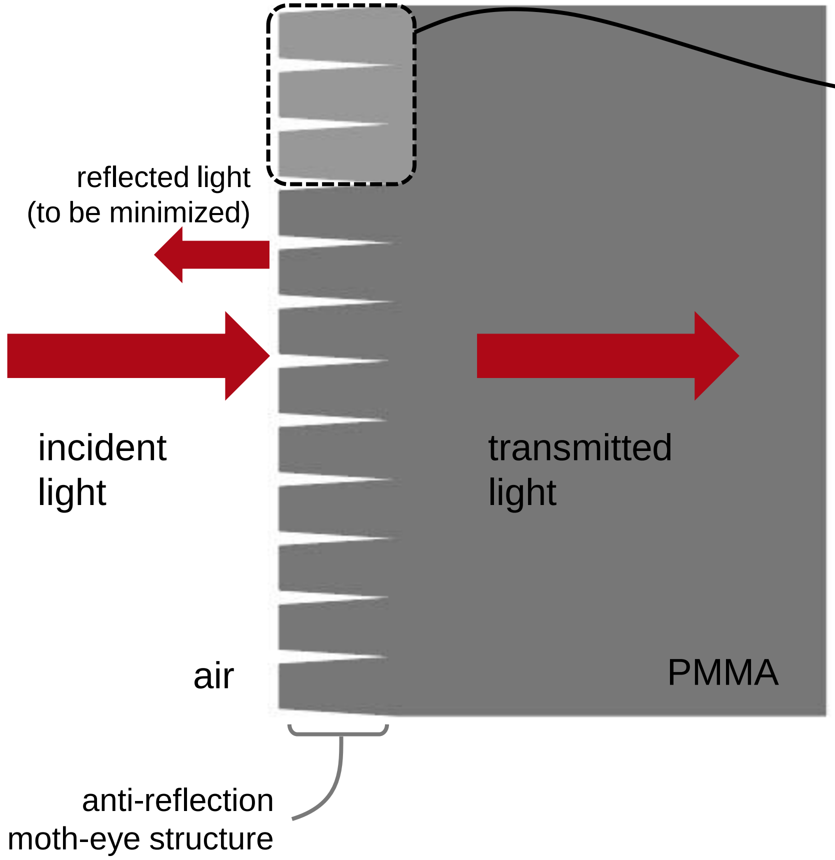


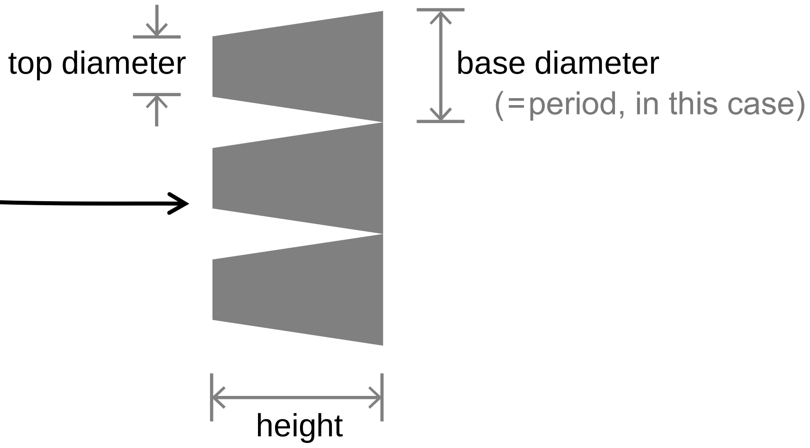
The suppression of reflection at surfaces of components is of interest for numerous optical applications. One very interesting approach to controlling the reflection at surfaces is the use of anti-reflective nano- and microstructures, which are motivated by nature (moth-eye). These structures with feature sizes in the sub-wavelength domain exhibit unique properties concerning wavelength and angular dependency. In this document, the analysis and design of deterministic anti-reflective structures in VirtualLab Fusion is presented.

Design Task

input plane wave

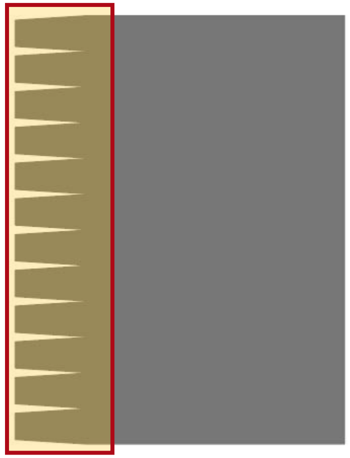
- wavelength 532 nm
- normal & oblique incidence





How to optimize the parameters of the structure to minimize the reflection at the interface?

Connected Modeling Techniques: Moth-Eye Structure

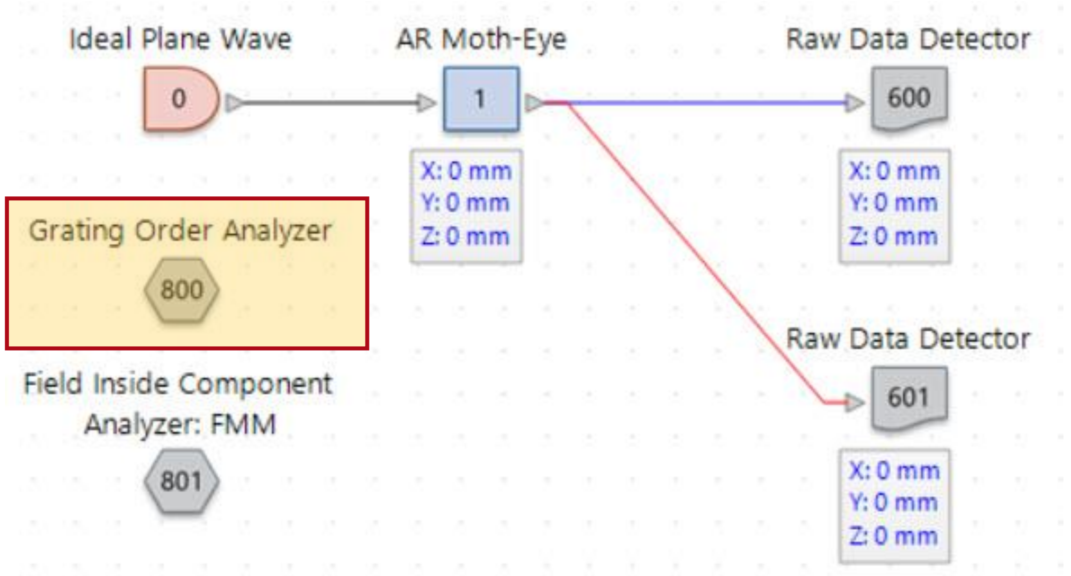


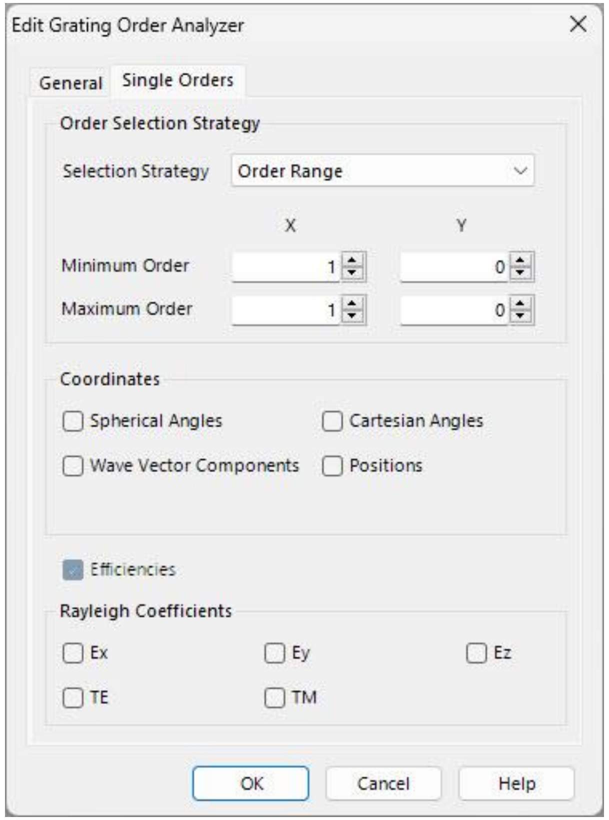
Available modeling techniques for microstructures:

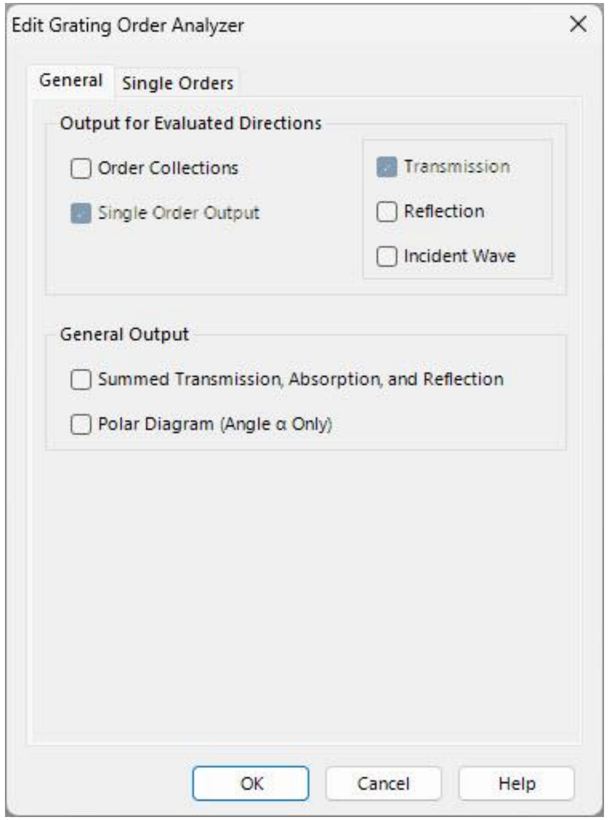
Methods	Preconditions	Accuracy	Speed	Comments
Functional Approach	-	low	very high	diffraction angles acc. to grating equation; manual efficiencies
Thin Element Approximation (TEA)	smallest features > ~10λ	high	very high	inaccurate for larger NA and thick elements; x-domain
	smallest features < ~2λ	low	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 small feature sizes (in the order of magnitude of the wavelength), the **Fourier Modal Method (FMM)** provides a very accurate and fast solution and hence is used for the analysis.

Grating Order Analyzer



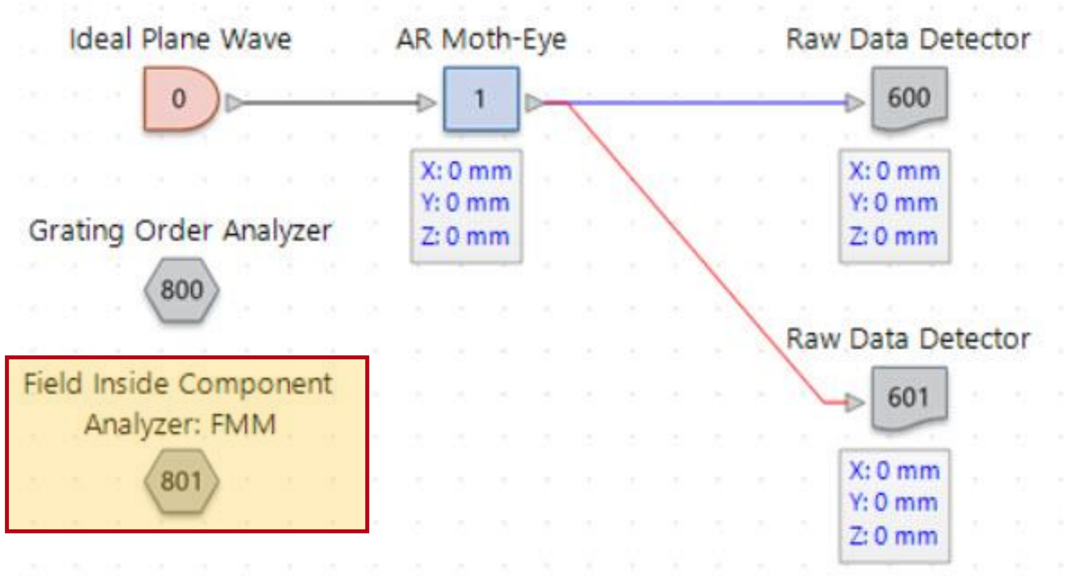


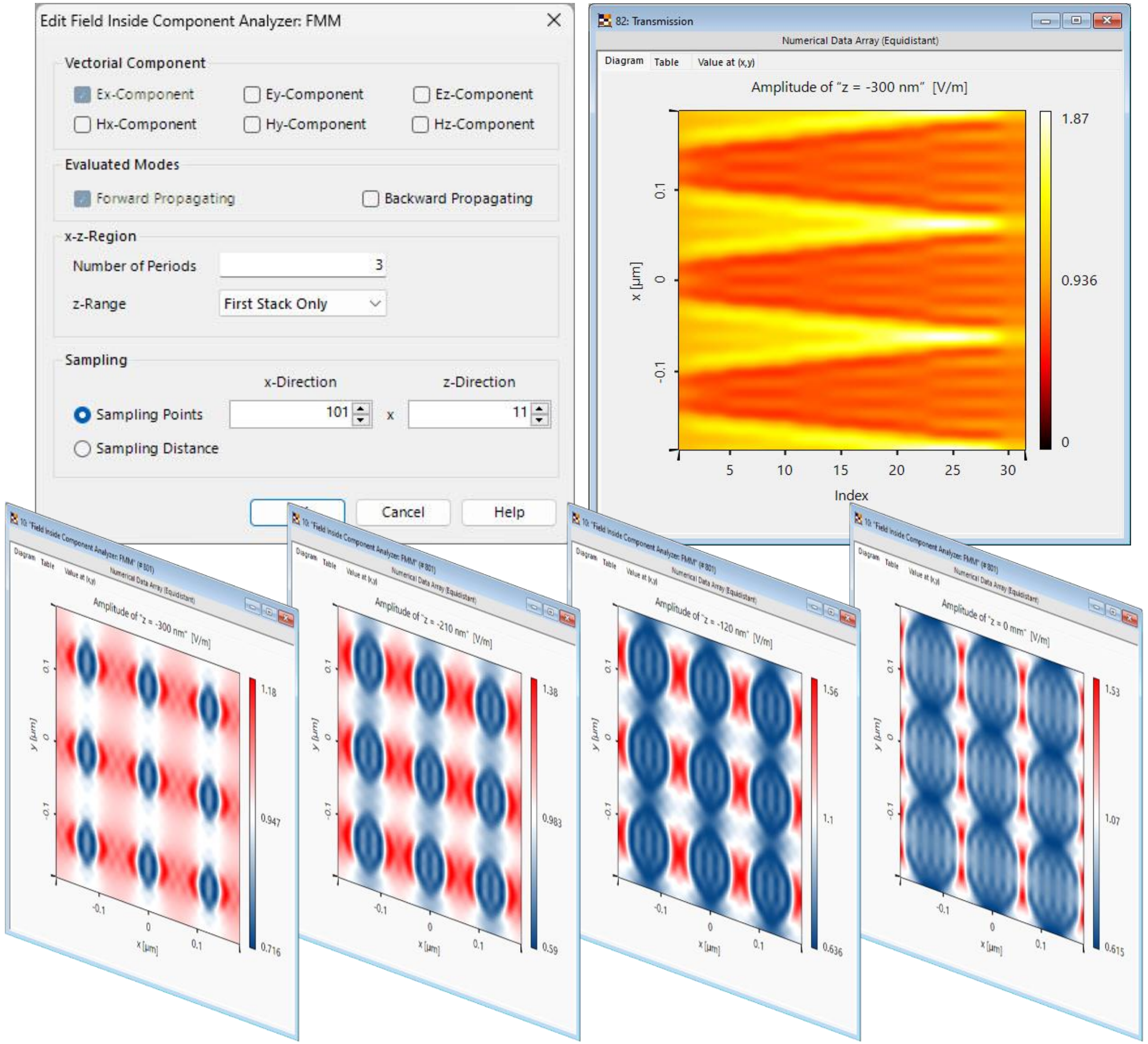


The *Grating Order Analyzer* can be used to investigate the order efficiencies of any given grating. Find more information under:

Grating Order Analyzer

Field Inside Component Analyzer: FMM

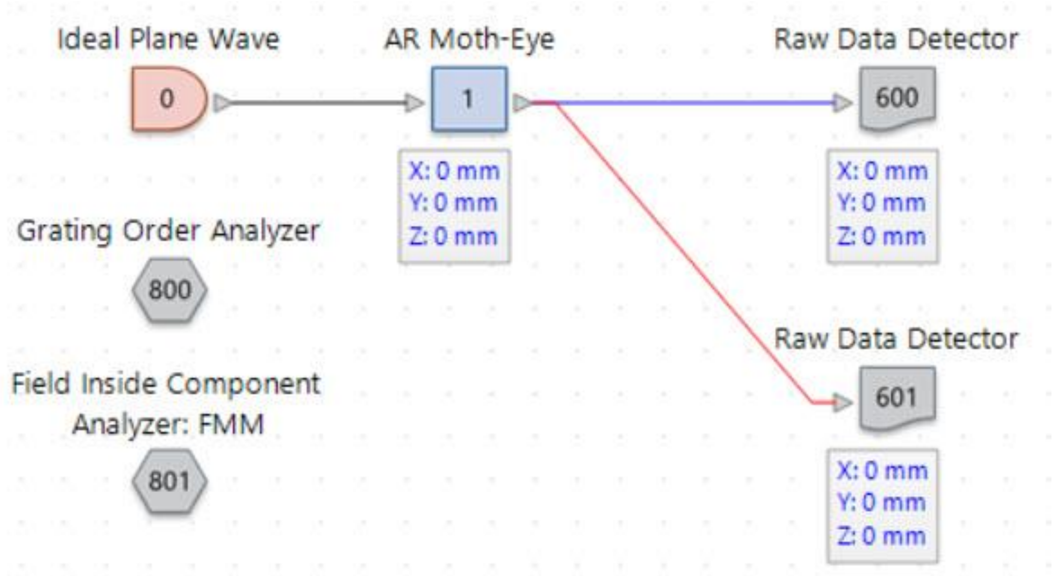


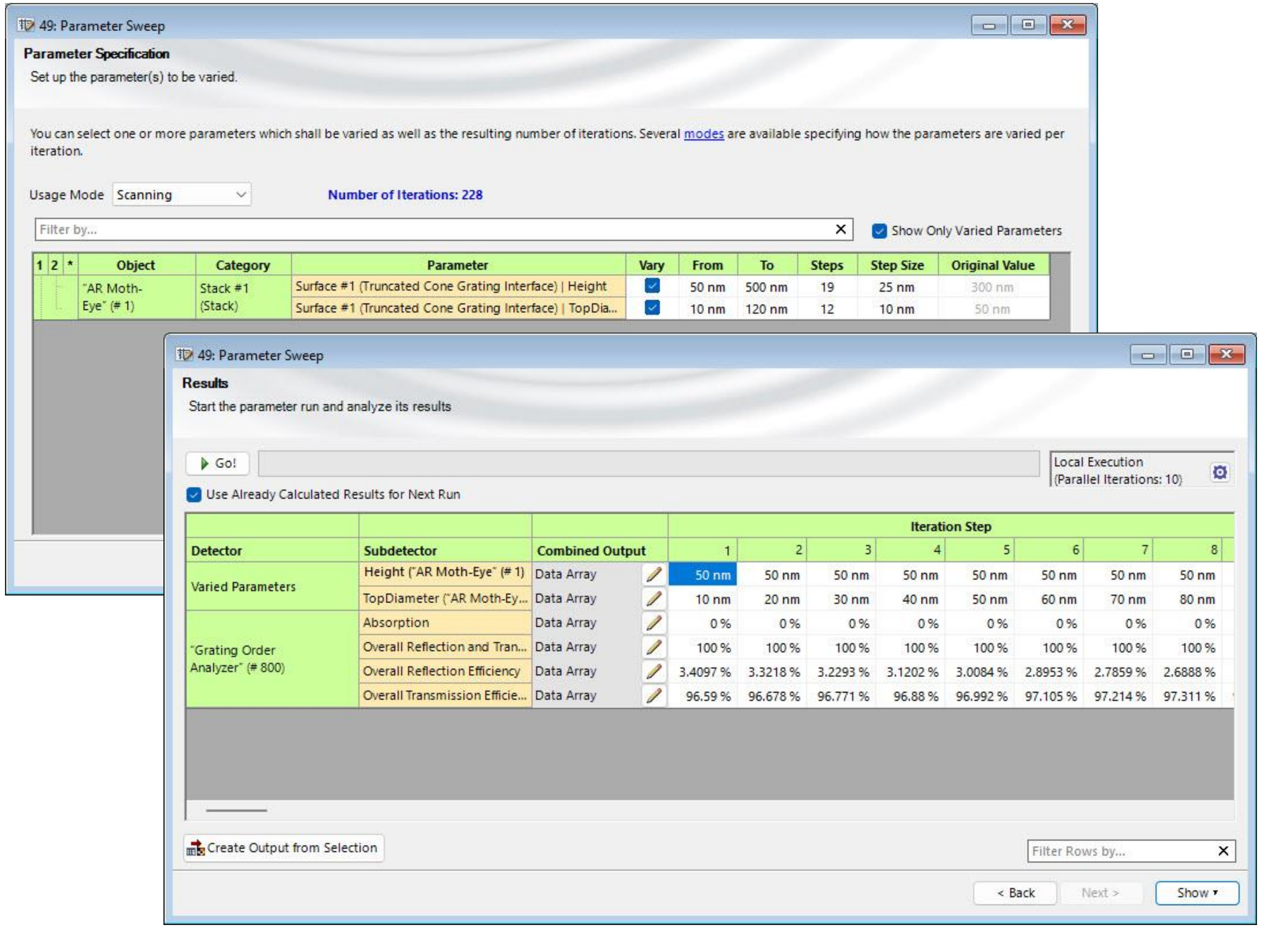


With the *Field Inside Component Analyzer: FMM*, the propagated field can be displayed in various planes inside the moth-eye structure. Find more information under:

[Field Inside Component Analyzer: FMM]

Parameter Run

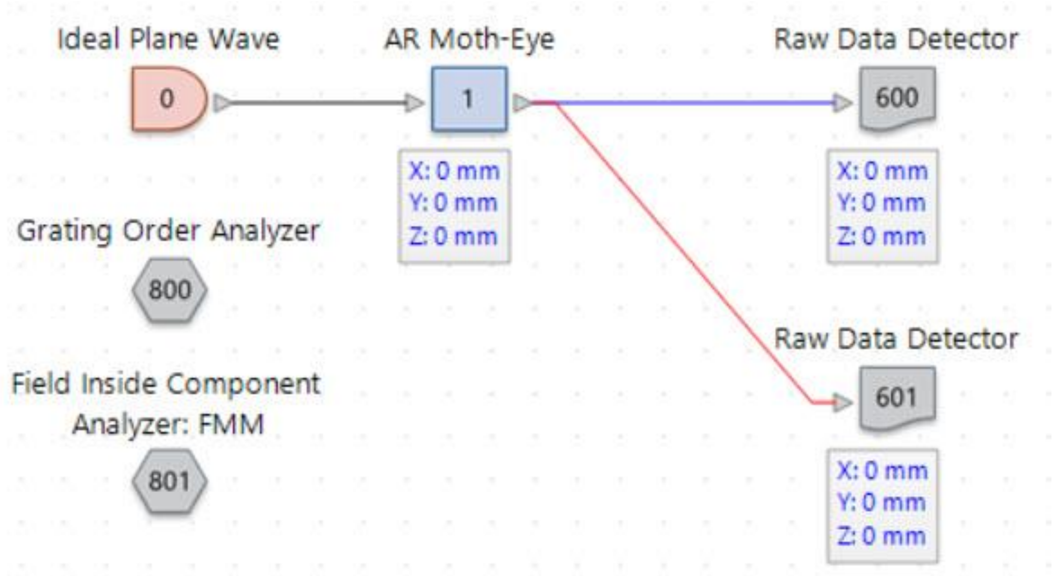


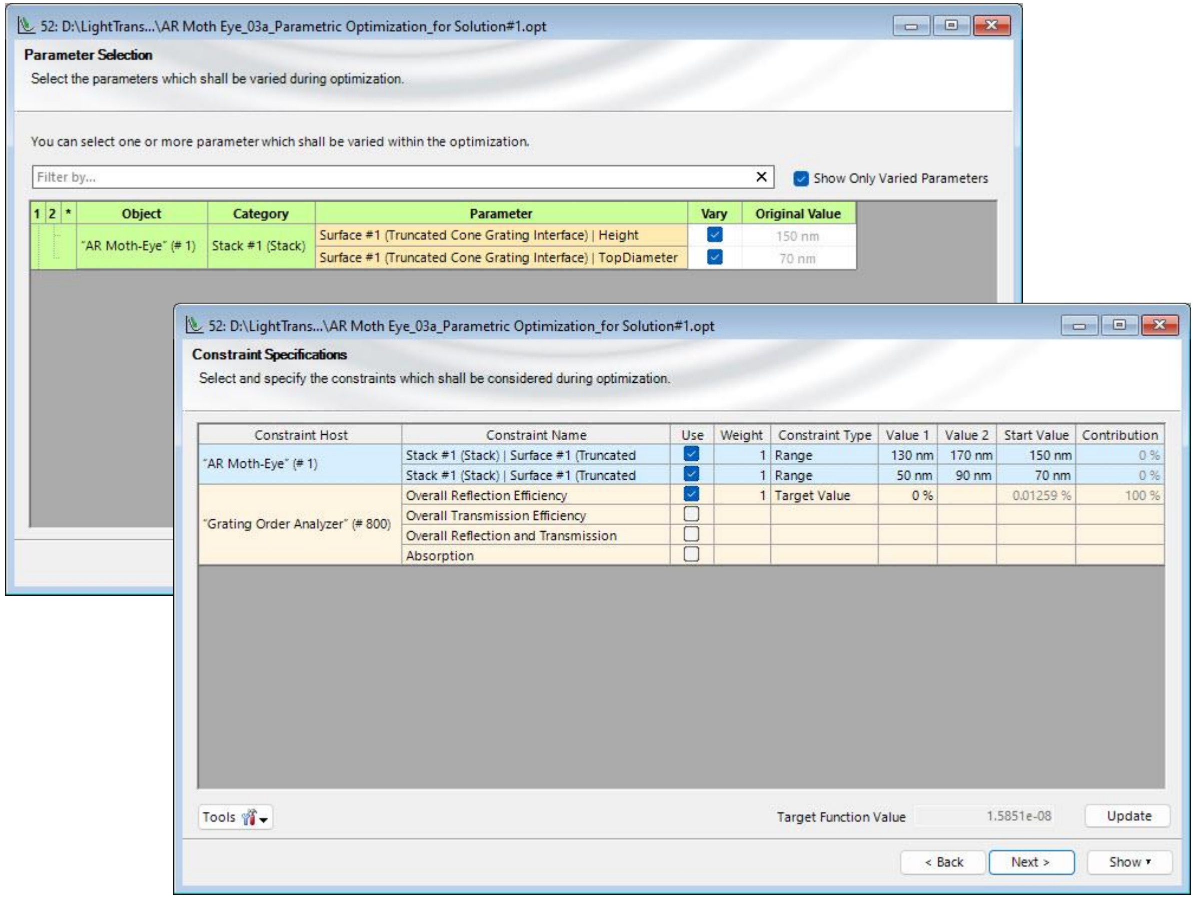


To analyze the behavior in the tolerance range envisaged for the device, a parameter sweep is performed with the Parameter Run document.

More information under:
[Usage of the Parameter Run Document]

Parametric Optimization





Then, the grating structure can be optimized using the in-built *Parametric Optimization*. A reflection efficiency of 0 (to minimize this value) is used as target for the optimization.

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

Simulation Results

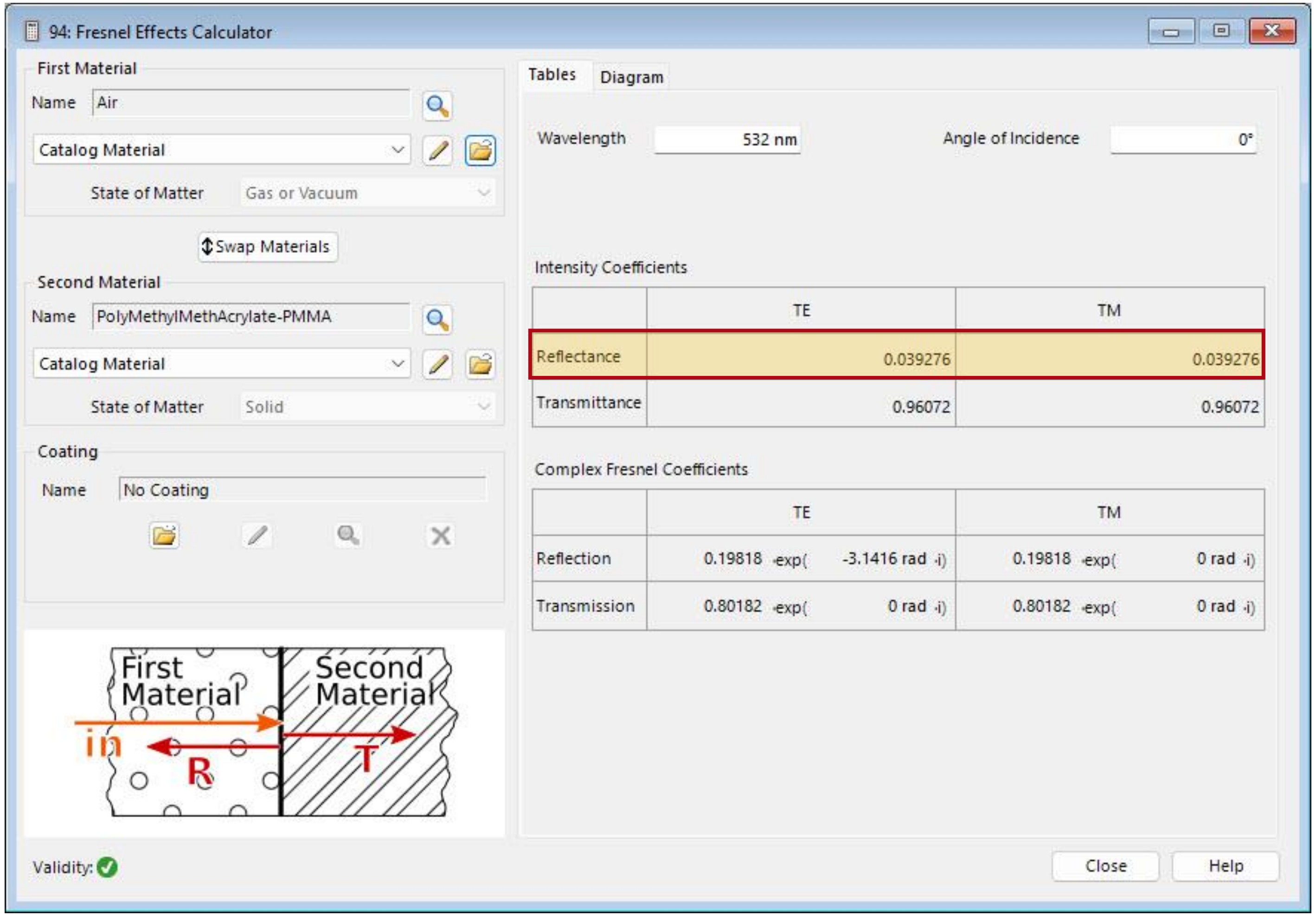
Reference Measurement by Calculator

In this example, we want to minimize the reflection at the surface of a substrate, which consists of PMMA (polymethyl-methacrylate).

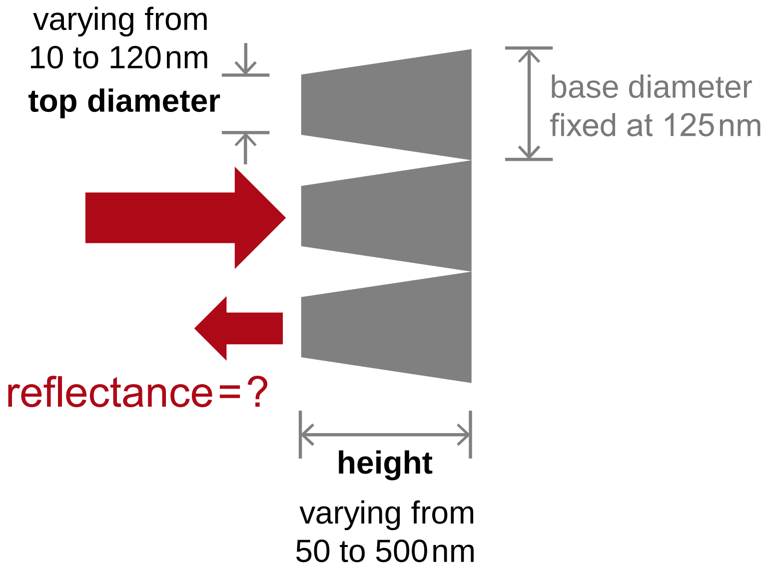
The *Fresnel Effects Calculator* can be used to get information about the reflectance and transmittance at an interface between air and PMM (3.93% without any anti-reflection).

Learn more about the *Fresnel Effects Calculator* under:

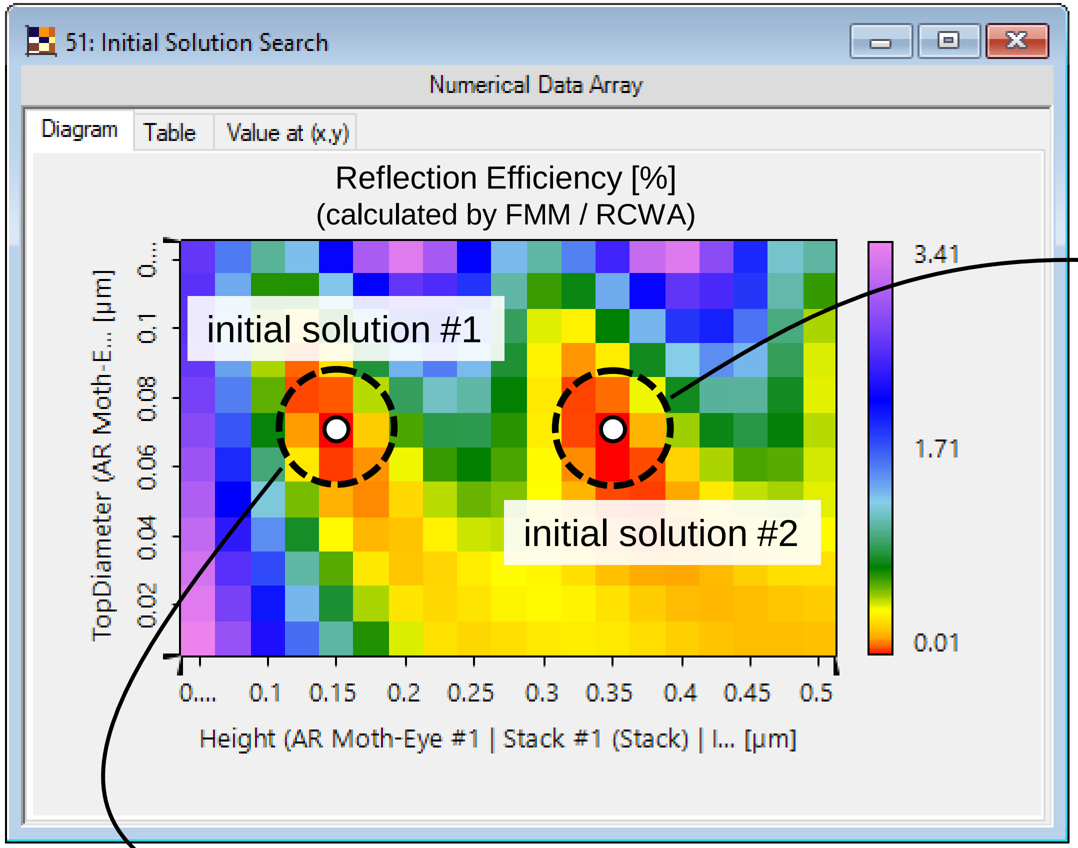
[Fresnel Curves on a Plane Surface]()



Scanning over Parameter Space for Initial Solutions



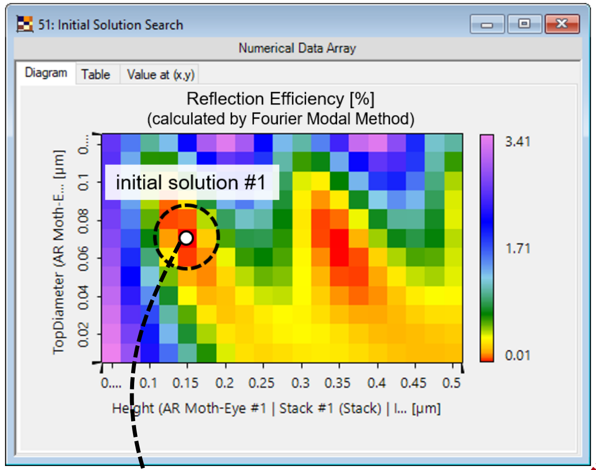
A parameter sweep is performed in order to find an adequate initial solution for the optimization.

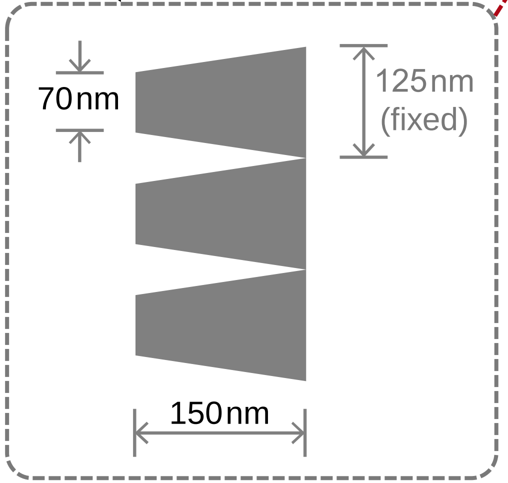


higher aspect ratio and maybe not the first choice for fabrication, but could be more robust

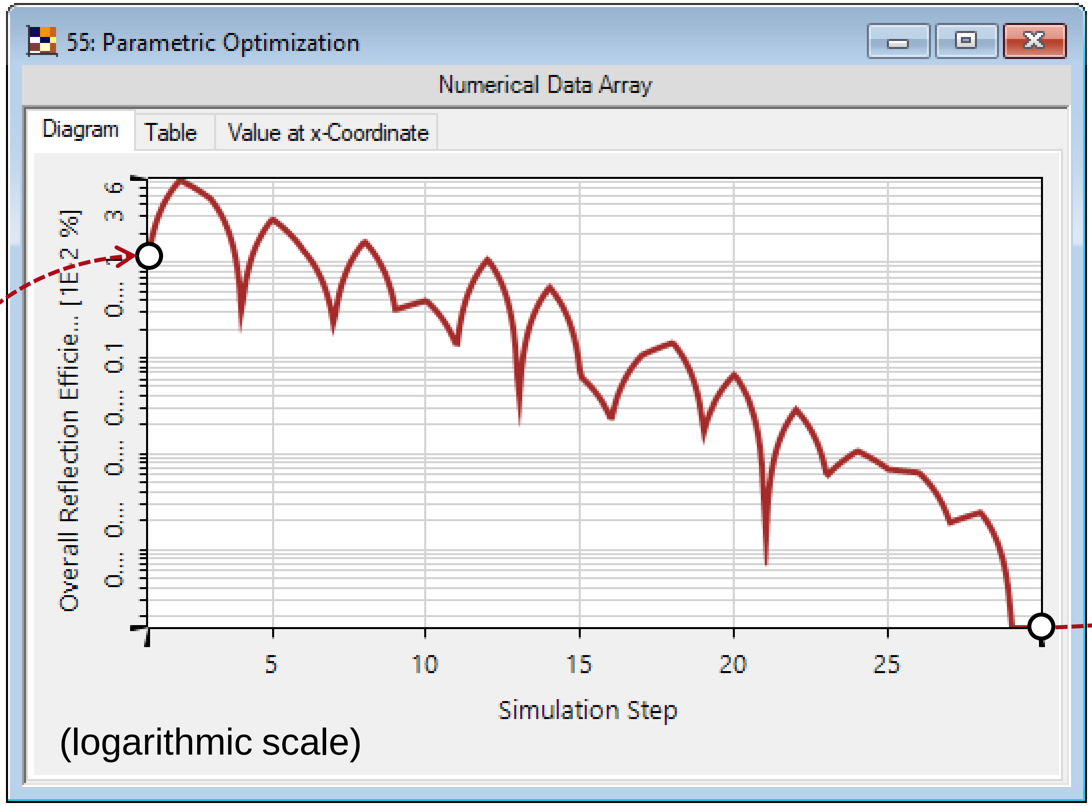
smaller aspect ratio and therefore preferable for fabrication

Parametric Optimization for Initial Solution #1

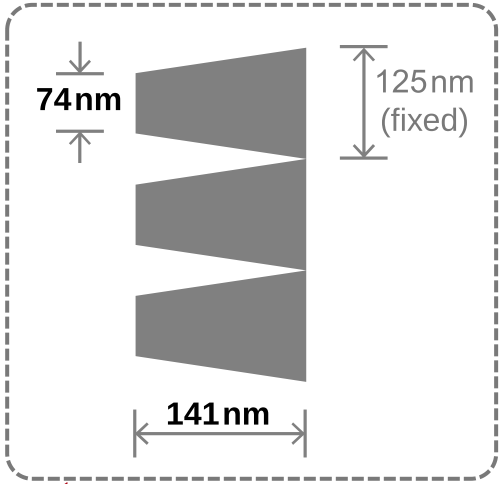




parametric optimization by downhill simplex method
(each iteration calculated by FMM / RCWA)

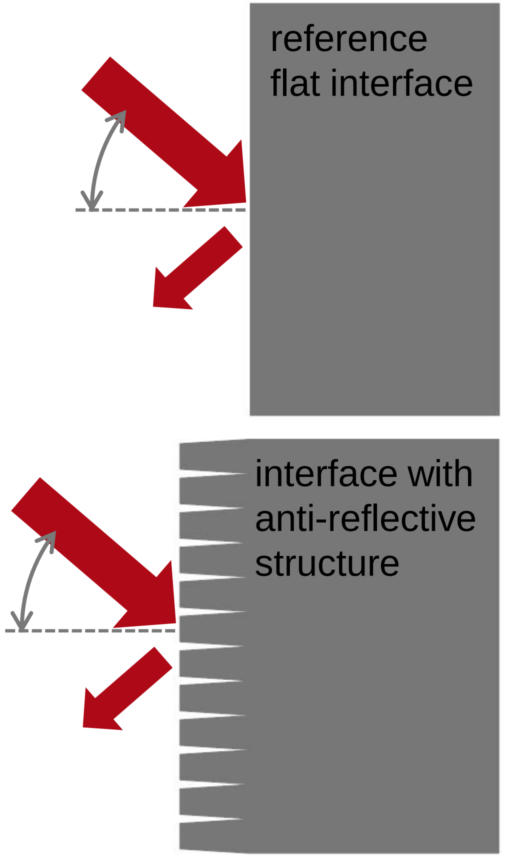


final design #1



optimized reflectance:
1.5E-6%

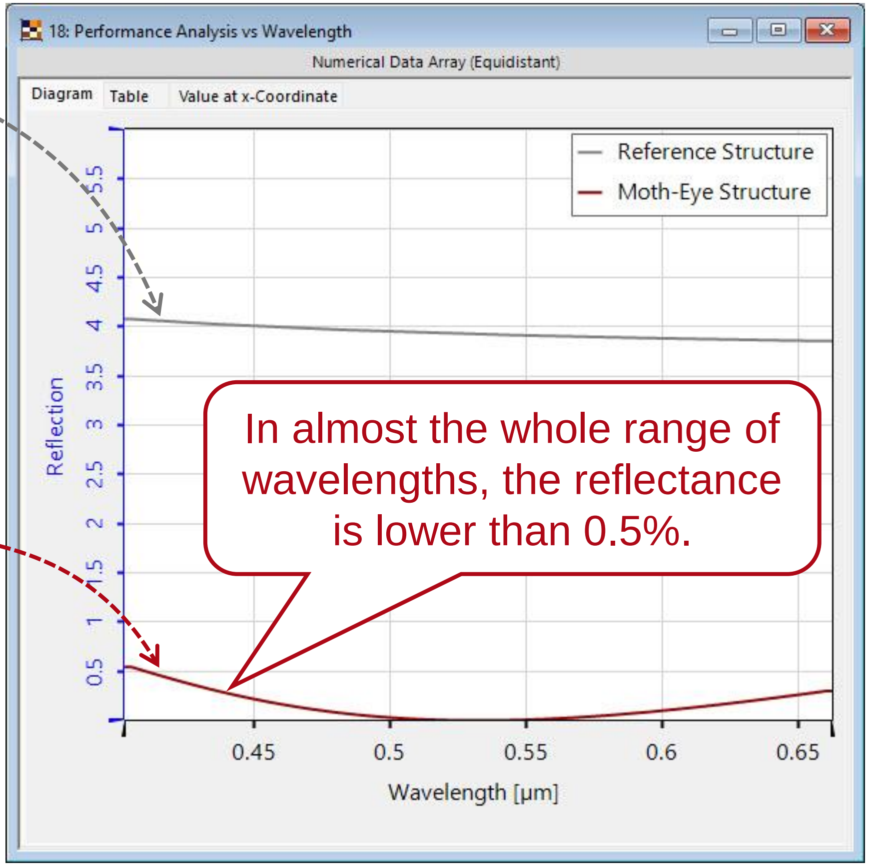
Performance Analysis of Final Design #1



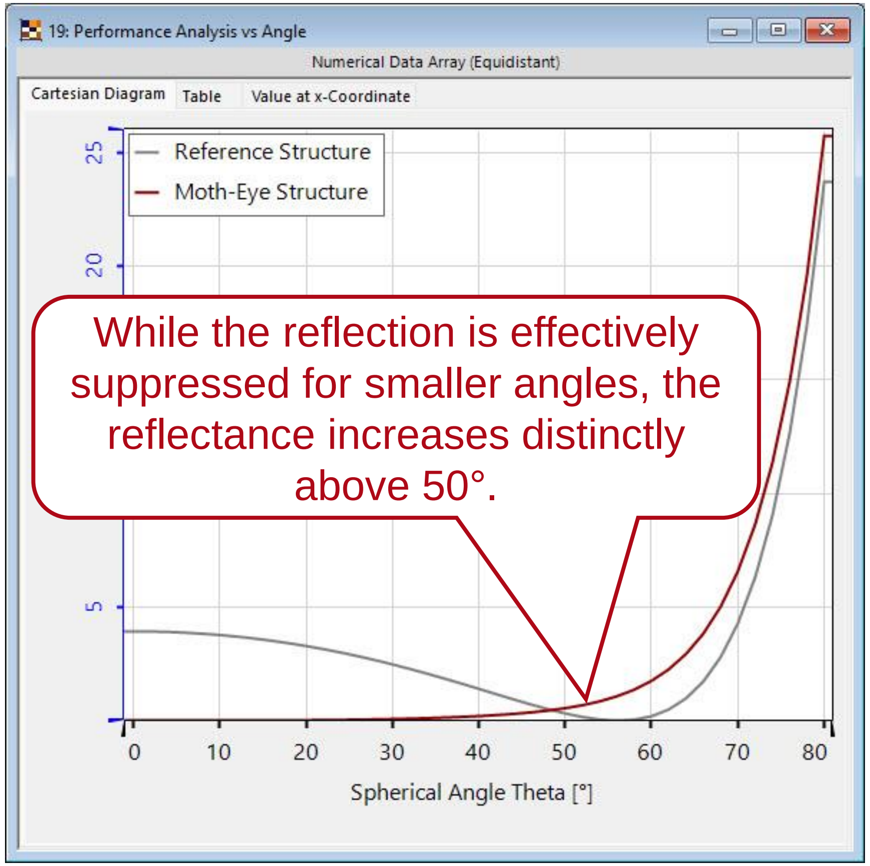
varying parameter:

- wavelength (405 to 660 nm)
- incident angle (0° to 80°)

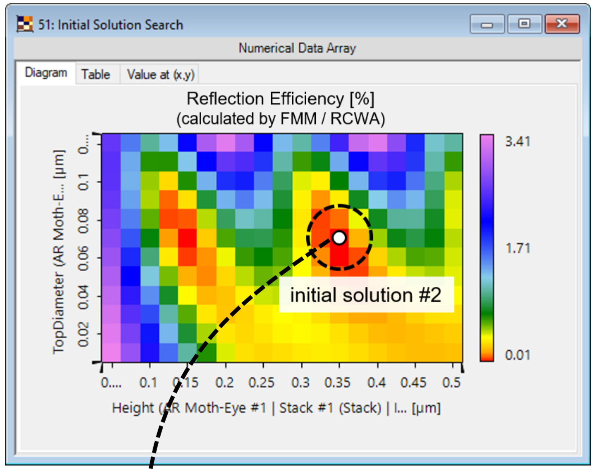
reflection efficiency vs. wavelength
(at normal incidence)

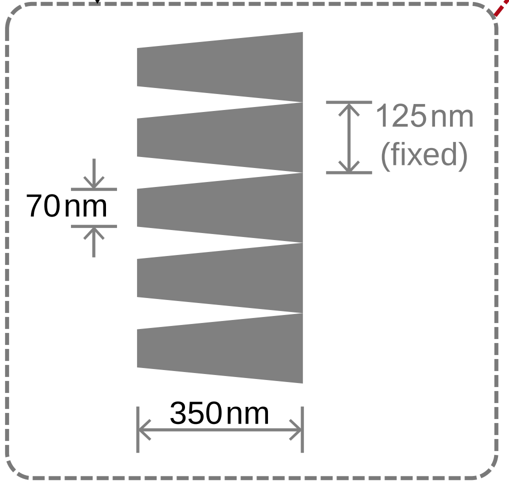


reflection efficiency vs. angle of incidence
(at 532 nm wavelength)

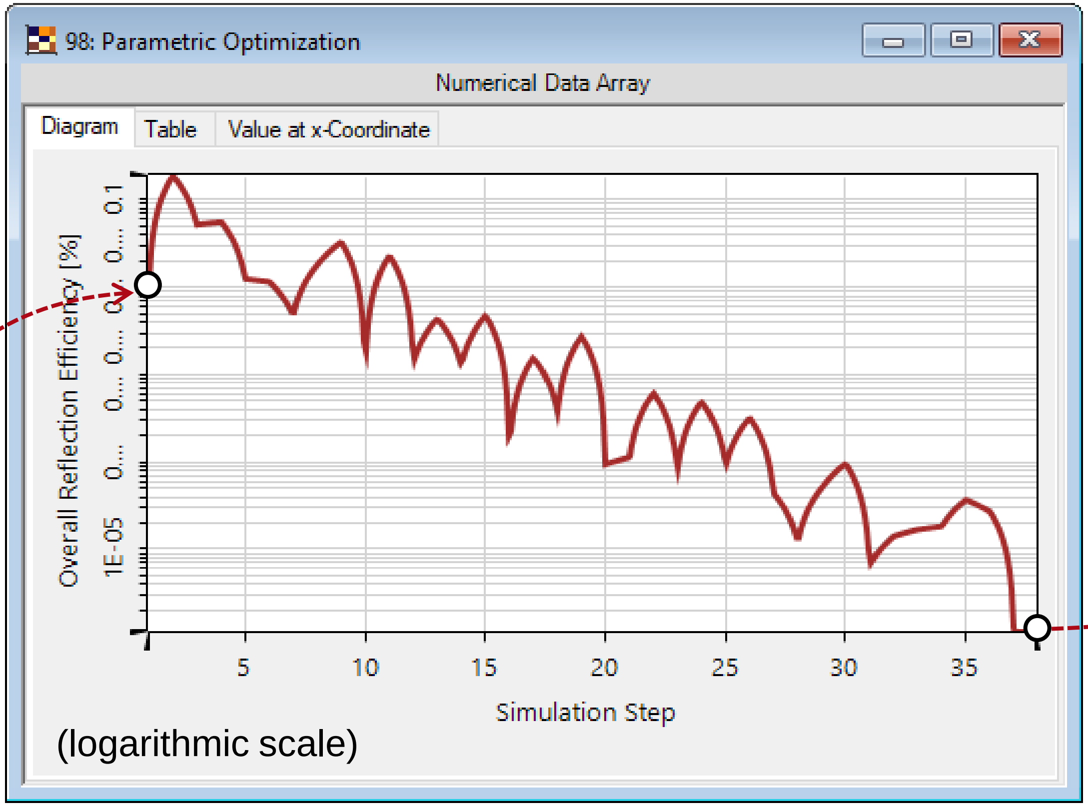


Parametric Optimization for Initial Solution #2

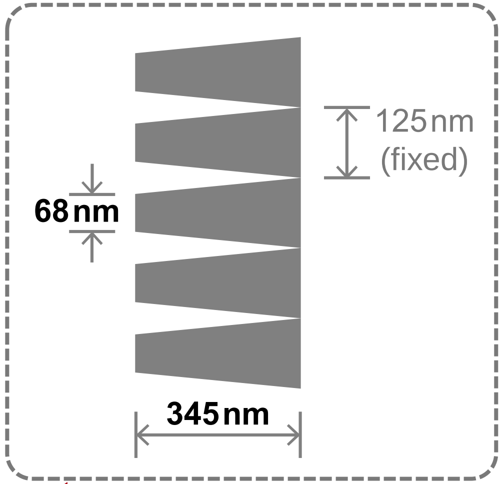




parametric optimization by downhill simplex method
(each iteration calculated by FMM / RCWA)

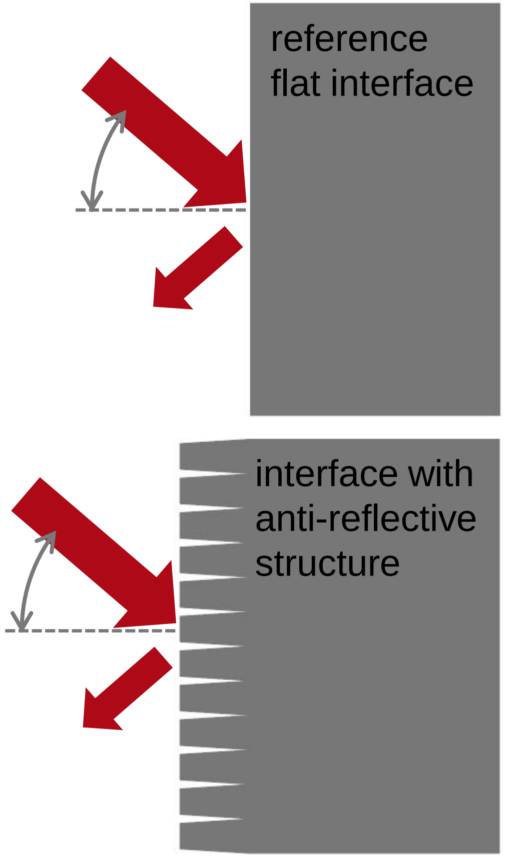


final design #2

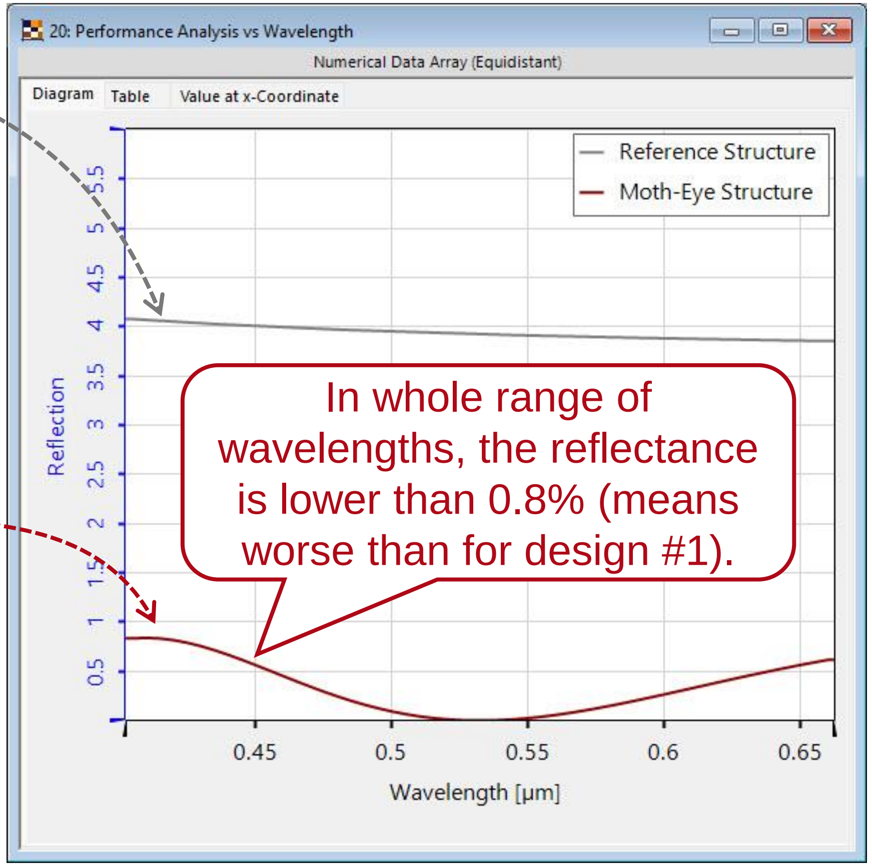


optimized reflectance:
1.1E-6%

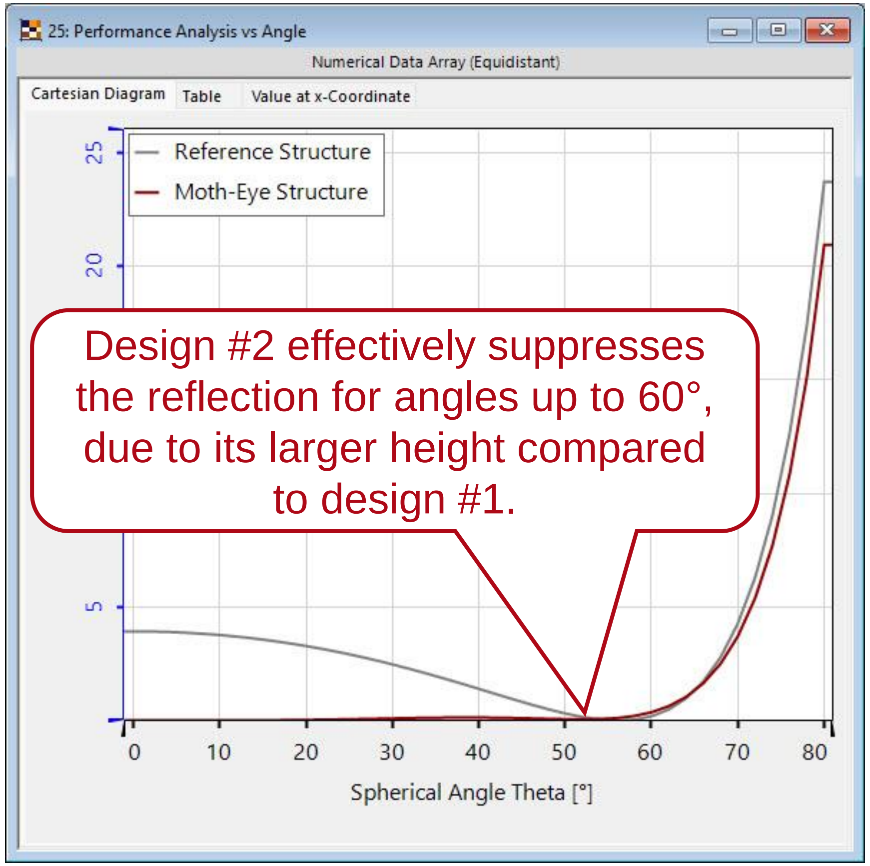
Performance Analysis of Final Design #1



reflection efficiency vs. wavelength
(at normal incidence)



reflection efficiency vs. angle of incidence
(at 532 nm wavelength)



varying parameter:

- wavelength (405 to 660 nm)
- incident angle (0° to 80°)

Document Information

title	Rigorous Analysis and Design of Anti-Reflective Moth-Eye Structures
document code	GRT.0011
document version	2.0
software edition	• VirtualLab Fusion Standard • Grating Package
software version	2023.2 (Build 1.242)
category	Feature Use Case
further reading	• Thin Element Approximation (TEA) vs. Fourier Modal Method (FMM) for Grating Modeling • Parametric Optimization and Tolerance Analysis of Slanted Gratings • Field Inside Component Analyzer: FMM • Fresnel Curves on a Plane Surface