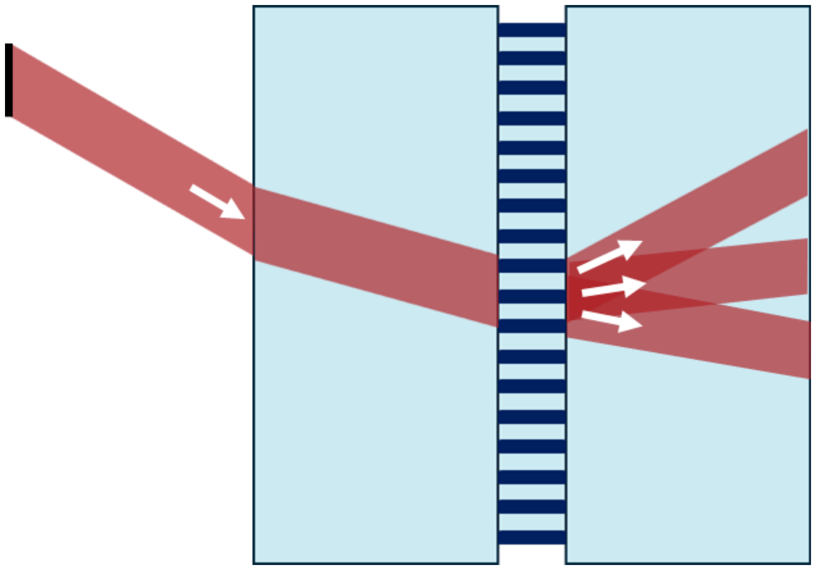
Modeling and Analysis of Volume Holographic Gratings

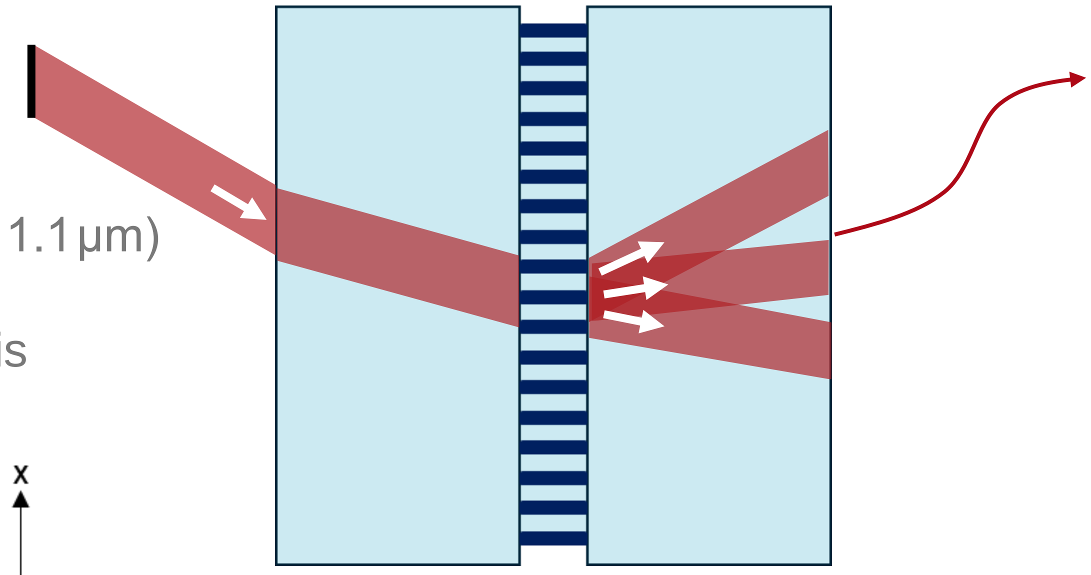
Abstract



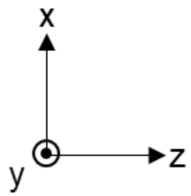
Volume holographic gratings have become powerful devices in the world of optics, offering distinct advantages over traditional surface relief gratings. These elements take advantage of the unique characteristics of volume holography, allowing for efficient and precise control of diffractive elements in a volume.

In this use case, we demonstrate the modeling of such a grating in VirtualLab Fusion, based on the configuration from the publication *Barden, Samuel et al., "Volume-Phase Holographic Gratings and the Efficiency of Three Simple VPH Gratings."(2000).*

Modeling Task – Configuration #1



plane wave
- design wavelength: 1064 nm (to be varied from 300 nm to 1.1 µm)
- incident angle: 9.18°**(*)**
- linearly polarized along x-axis



performance evaluation of the first three transmitted diffraction orders

sinusoidal volume grating
- substrate material: N-BK7
- substrate thickness: 3 mm
- grating thickness: 20 µm
- grating period: 3.33 µm
- grating base material: N-BK7
- ref. index modulation: 0.020

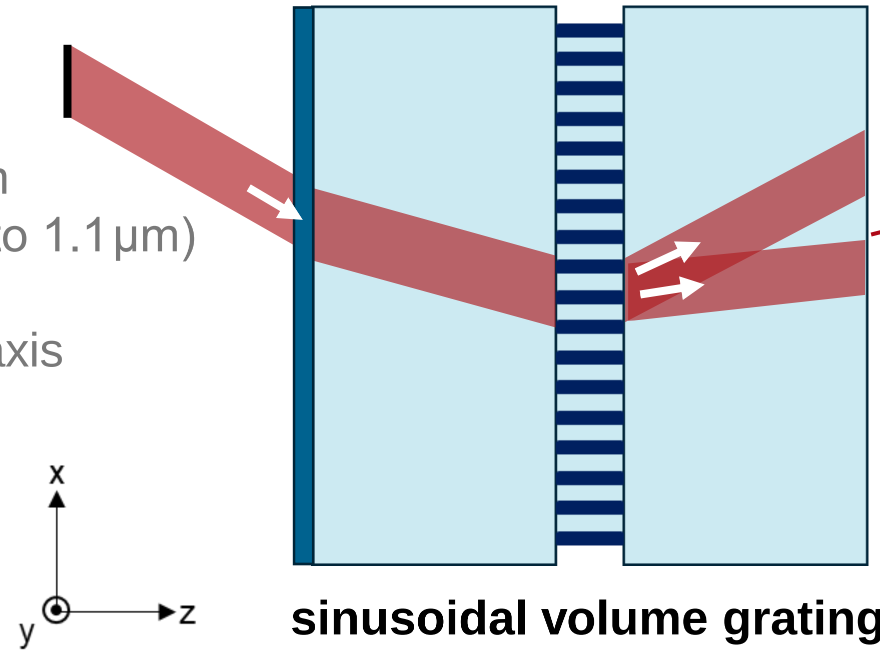
(*) We realize inclined illumination by rotating the volume grating accordingly.

system parameters: *Barden, Samuel et al., "Volume-Phase Holographic Gratings and the Efficiency of Three Simple VPH Gratings.", PUBL ASTRON SOC PAC 112 (2000).*

Modeling Task – Configuration #2

plane wave

- design wavelength: 532 nm
  (to be varied from 320 nm to 1.1 µm)
- incident angle: 18.61°
- linearly polarized along x-axis



performance evaluation of the first two transmitted diffraction orders

sinusoidal volume grating

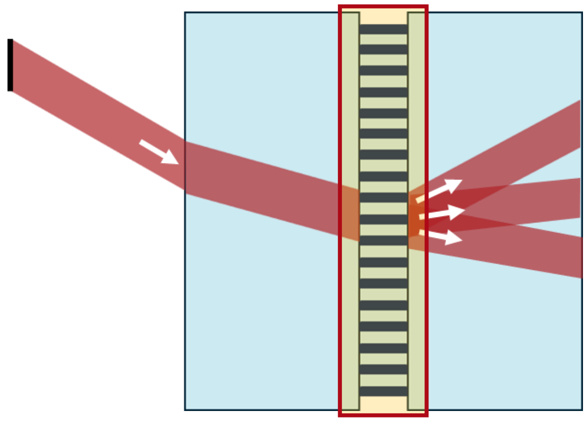
- substrate material: N-BK7
- substrate thickness: 3 mm
- grating thickness: 4 µm
- grating period: 833.33 nm
- grating base material: N-BK7
- ref. index modulation: 0.065
- Coating MgF_2 thickness: 102.6 nm**(*)**

In this example, a layer of anti-reflective (AR) coating is added to the first surface of the substrate according to the paper.

(*) Note: the thickness of the coating layer was not given in the paper. Thus, with the help of the *Parametric Optimization* tool, a reasonable thickness was chosen for the modeling. Find more information under:

Introduction to the Parametric Optimization Document

Connected Modeling Techniques: Volume Grating

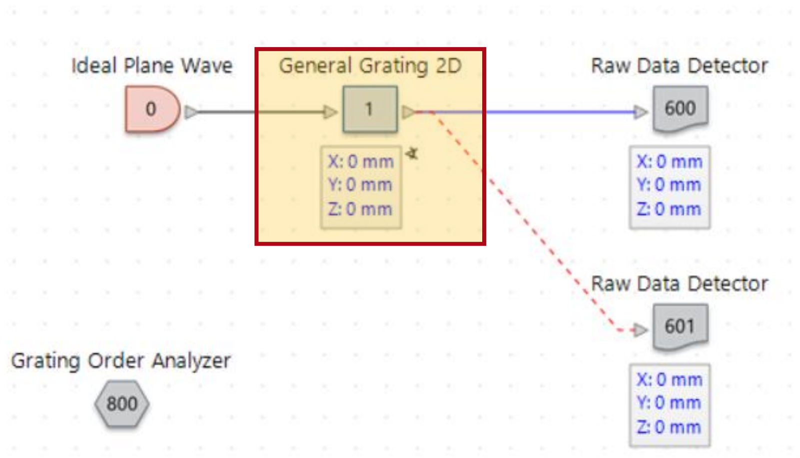


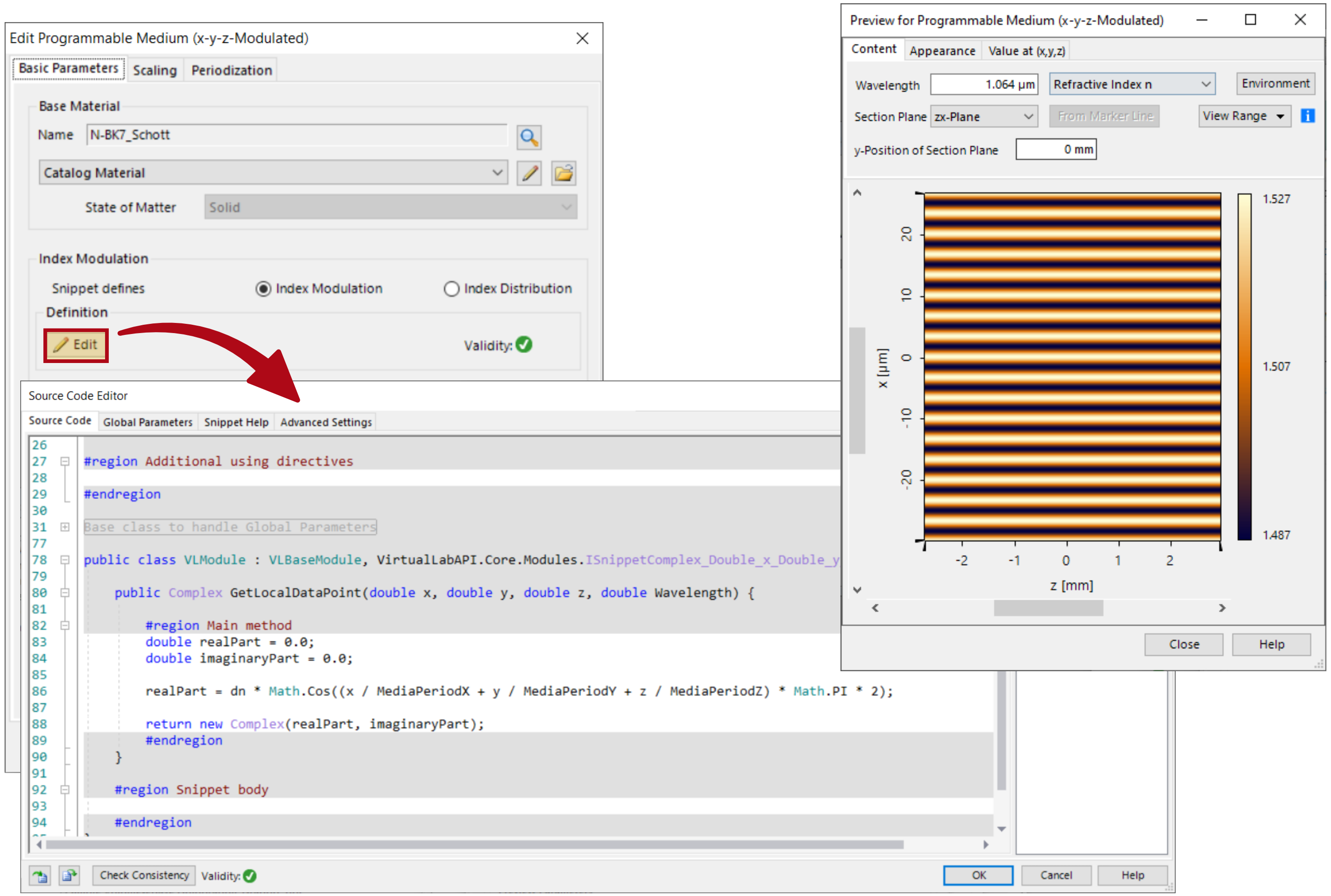
Available modeling techniques for microstructures:

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 < ~ (5$\lambda \times$ 5λ)	very high	high	rigorous solution; fast for structures and periods similar to the wavelength; more demanding for larger periods; k-domain
	period > ~ (15$\lambda \times$ 15λ)	very high	slow	

In this example, the structures are similar in size to the wavelength of light. Thus, 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.

Customized Volume Grating



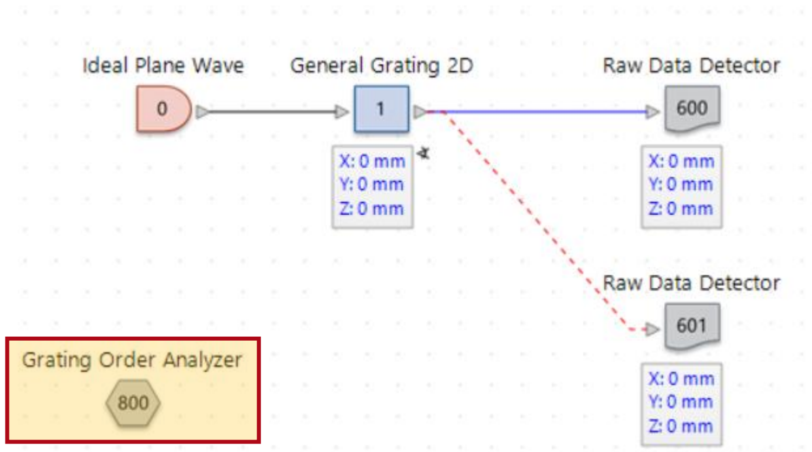


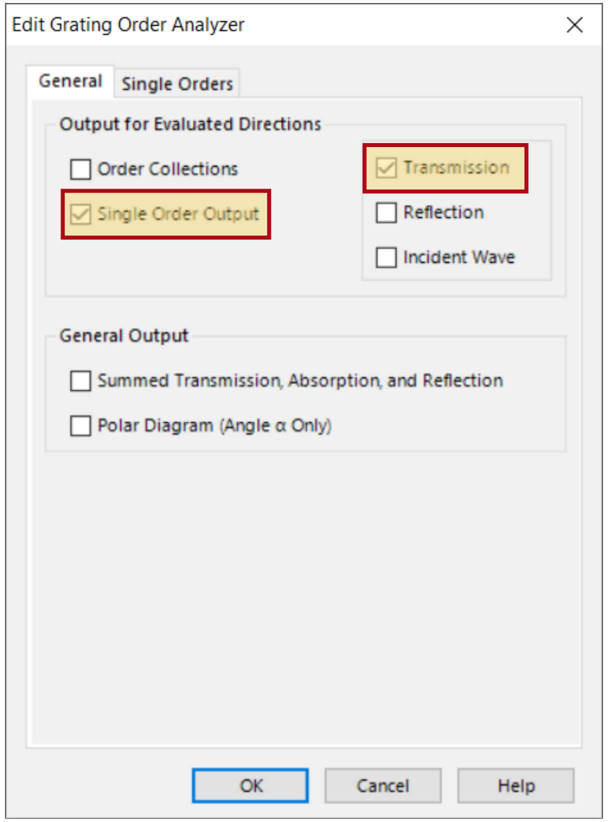
In this use case, we intend to generate a sinusoidally modulated volume grating using the *Programmable Medium*. We define the volume grating based on the following formula:

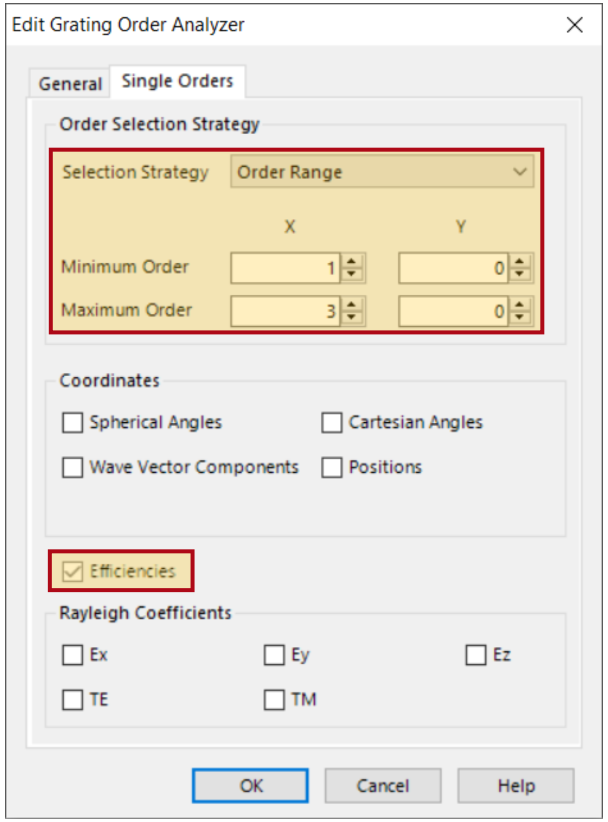
$$n(x,y,z) = dn \cdot \cos\left(2\pi \cdot \left(\frac{x}{\Lambda_x} + \frac{y}{\Lambda_y} + \frac{z}{\Lambda_z}\right)\right)$$

Here, Λ describes the grating period and dn describes the refractive index modulation.

Grating Order Analyzer



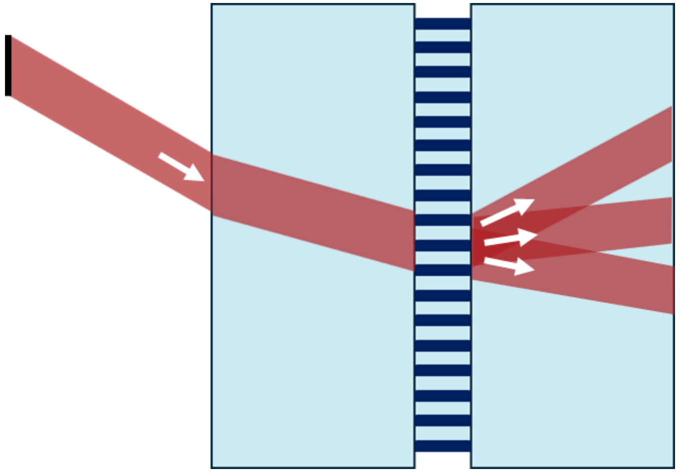


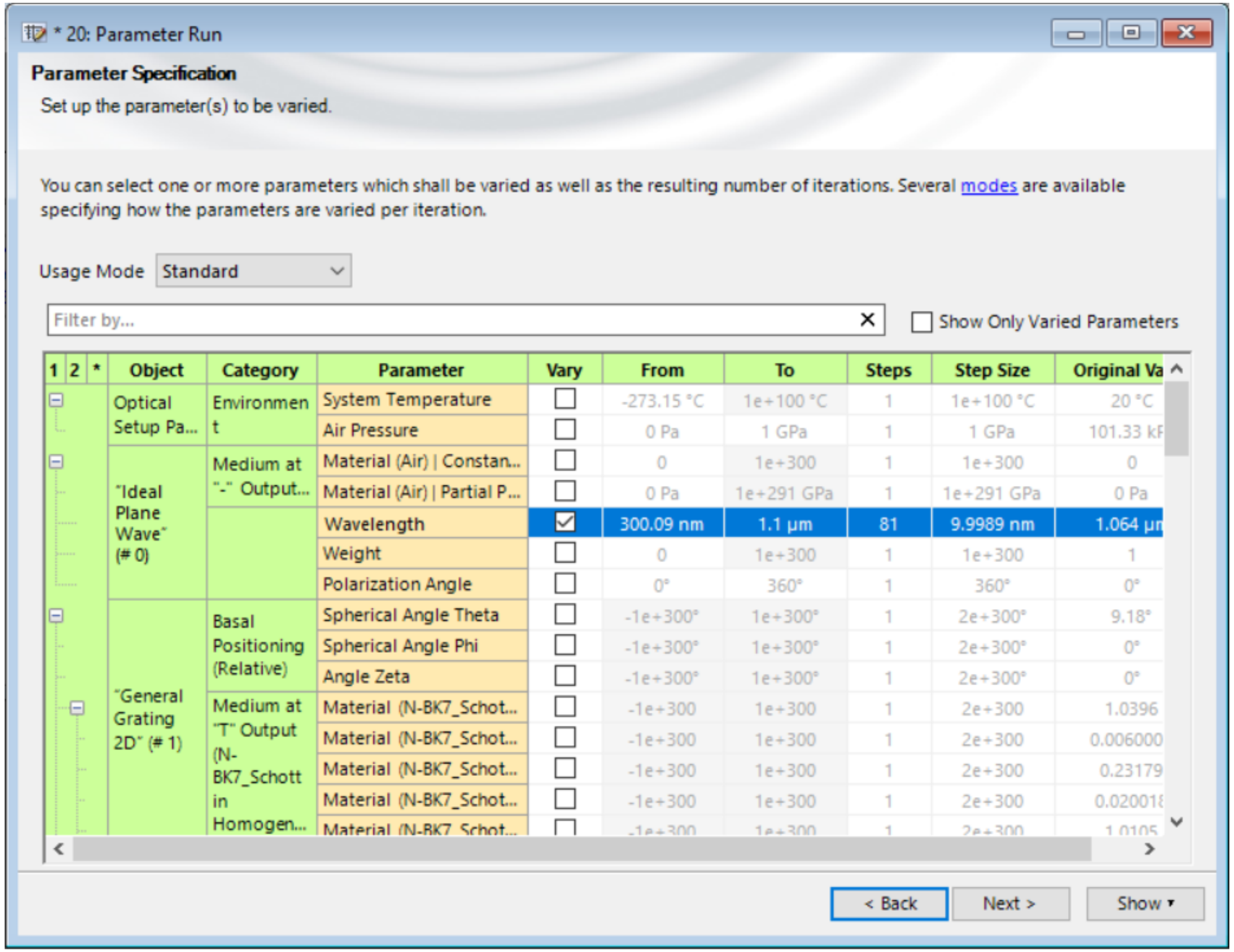


The *Grating Order Analyzer* can be used to investigate the efficiency of the diffraction orders of a given grating. Find more information under:

Grating Order Analyzer

Parameter Run

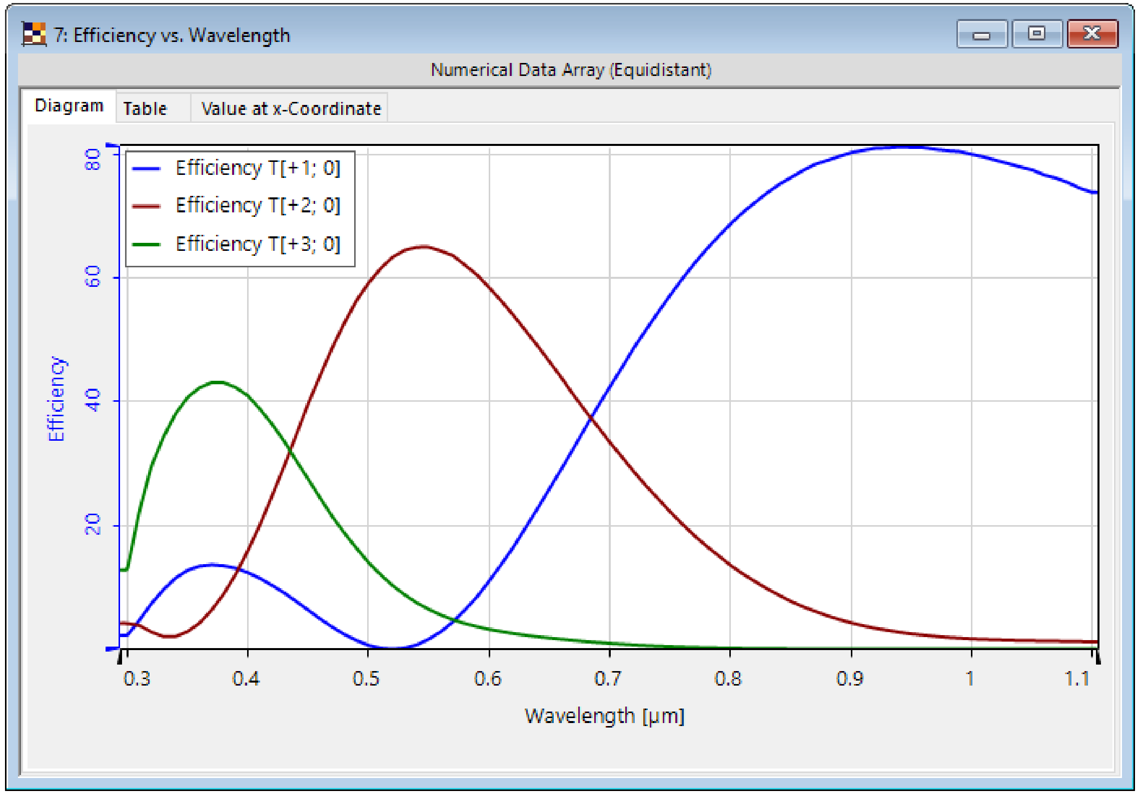




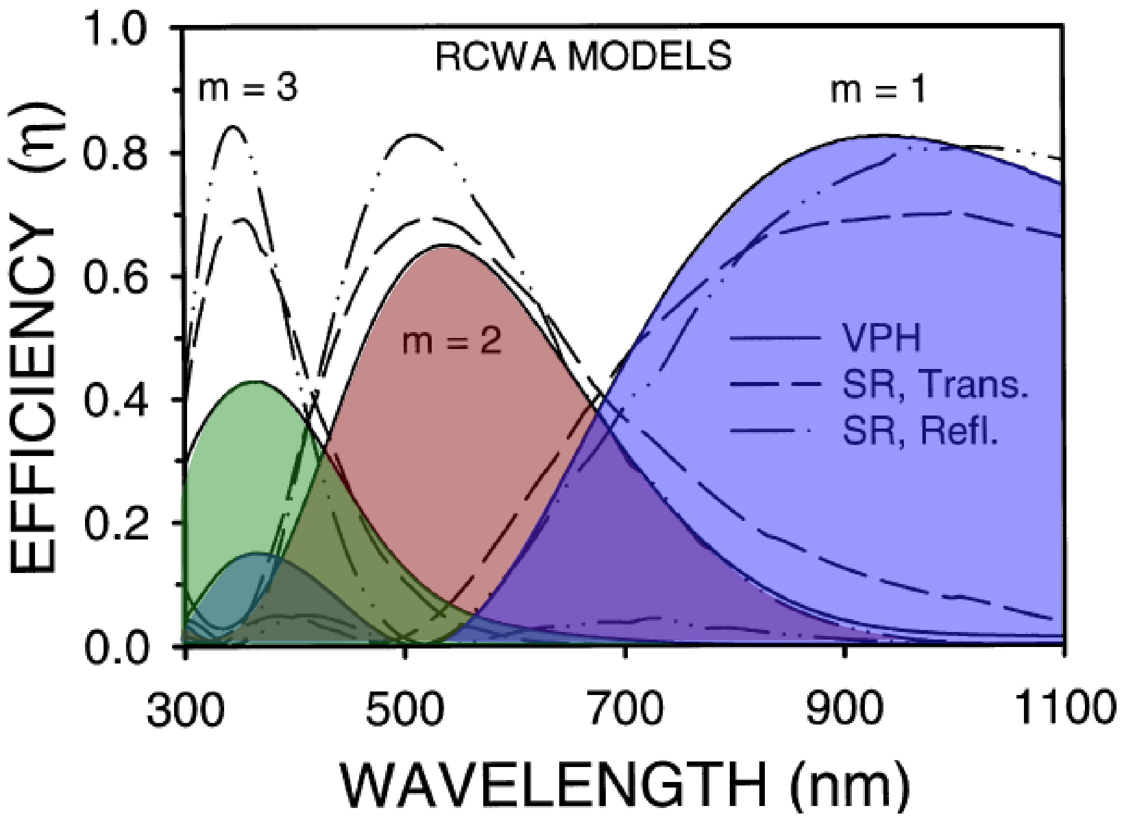
The grating performance is evaluated by varying the wavelength of the impinging light. Such a variation of parameters can be achieved using a *Parameter Run.*

[Usage of the Parameter Run Document](#)

Efficiency vs. Wavelength – Configuration #1



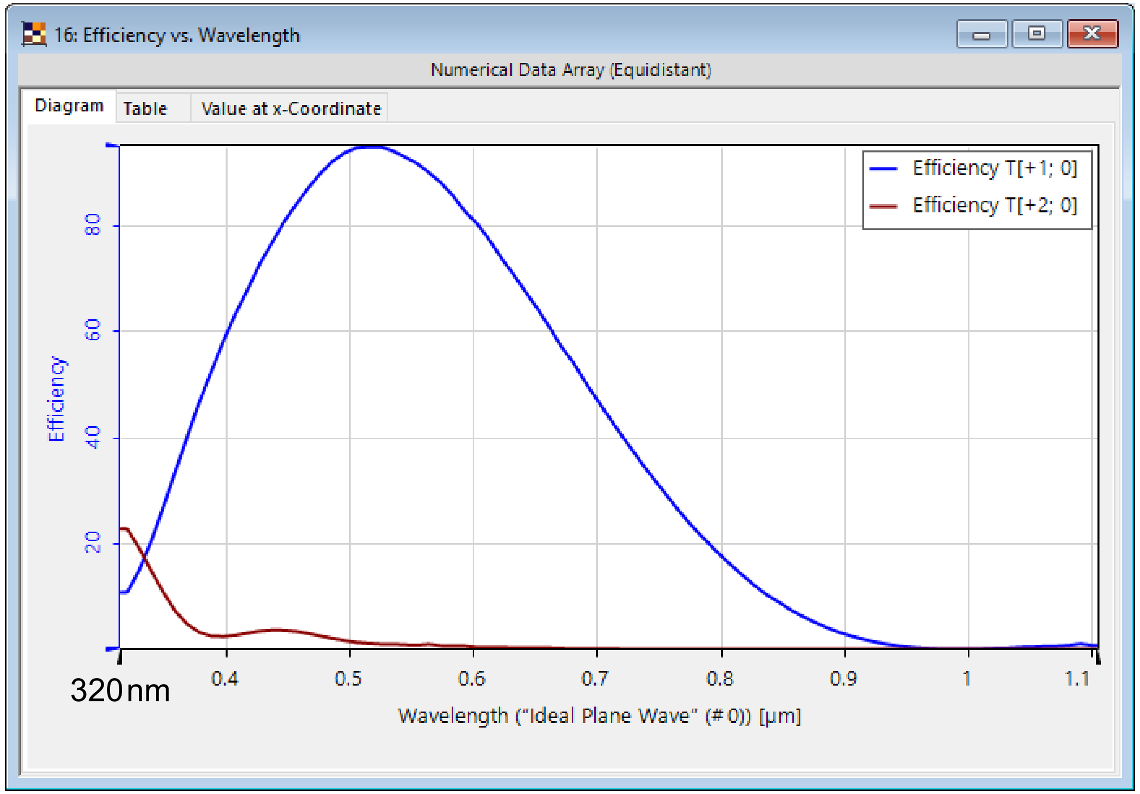
The resulting diffraction efficiencies of the three orders are in perfect agreement with the results of the article.

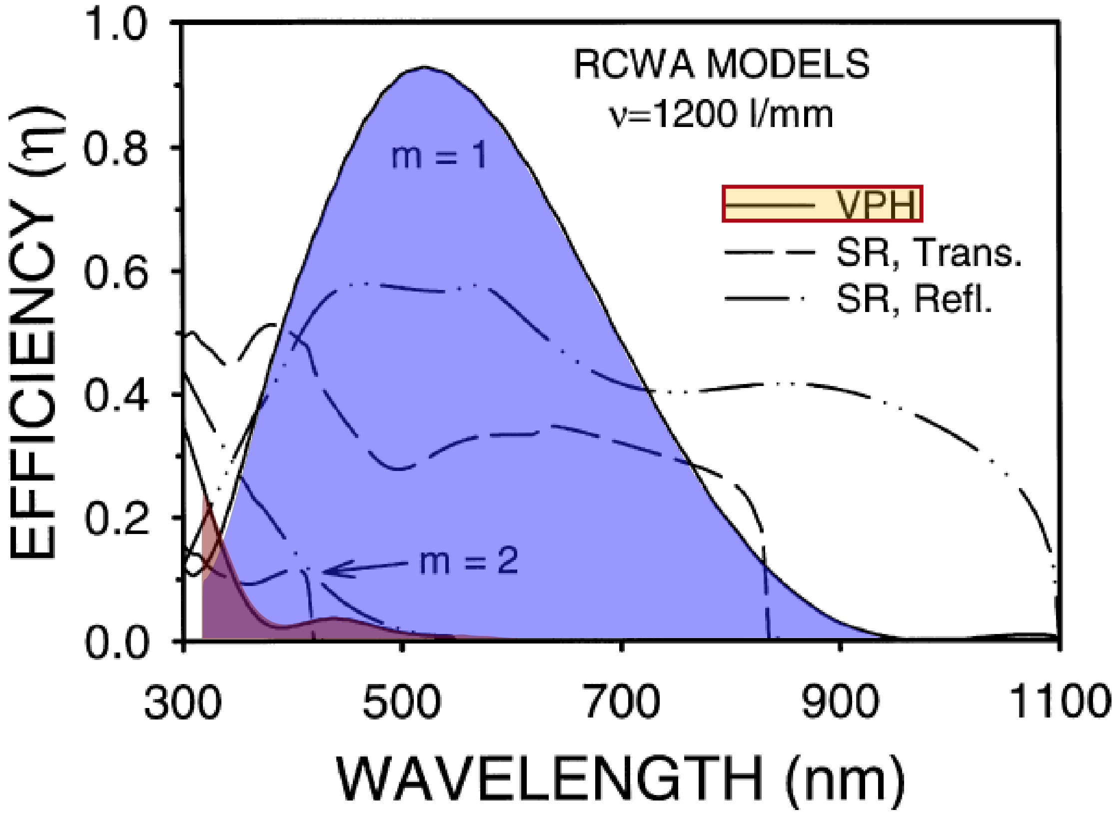


Result from the paper: *Barden, Samuel et al., "Volume-Phase Holographic Gratings and the Efficiency of Three Simple VPH Gratings.", PUBL ASTRON SOC PAC 112 (2000).*

Note: The colored areas were added to highlight the discussed results.

Efficiency vs. Wavelength – Configuration #2





Despite the unspecified thickness of the anti-reflective coating, the results obtained in VirtualLab Fusion are in good agreement with the values given in the publication.

Note: The material data for MgF_2 available in VirtualLab Fusion is only valid for wavelength range from 320nm and upwards.

Result from the paper: *Barden, Samuel et al., "Volume-Phase Holographic Gratings and the Efficiency of Three Simple VPH Gratings.", PUBL ASTRON SOC PAC 112 (2000).*

Note: The colored areas were added to highlight the discussed results.

Document Information

title	Modeling and Analysis of Volume Holographic Gratings
document code	GRT.0037
document version	1.0
required packages	Grating Package
software version	2023.2 (Build 2.30)
category	Application Use Case
further reading	• Grating Order Analyzer • Usage of the Parameter Run Document • Holographically Generated Volume Grating • Angular-Filtering Volume Gratings for Suppressing Higher Diffraction Orders • How to Work with the Programmable Medium