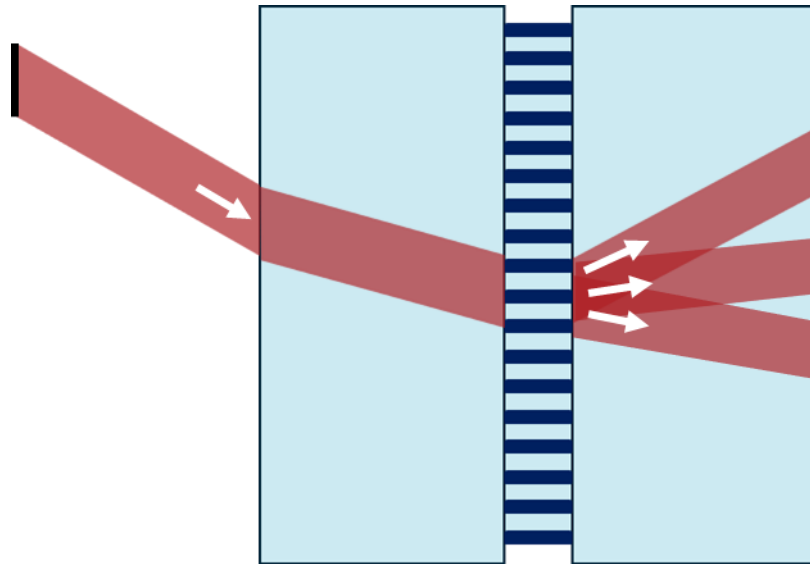


# Modeling and Analysis of Volume Holographic Gratings

# Abstract



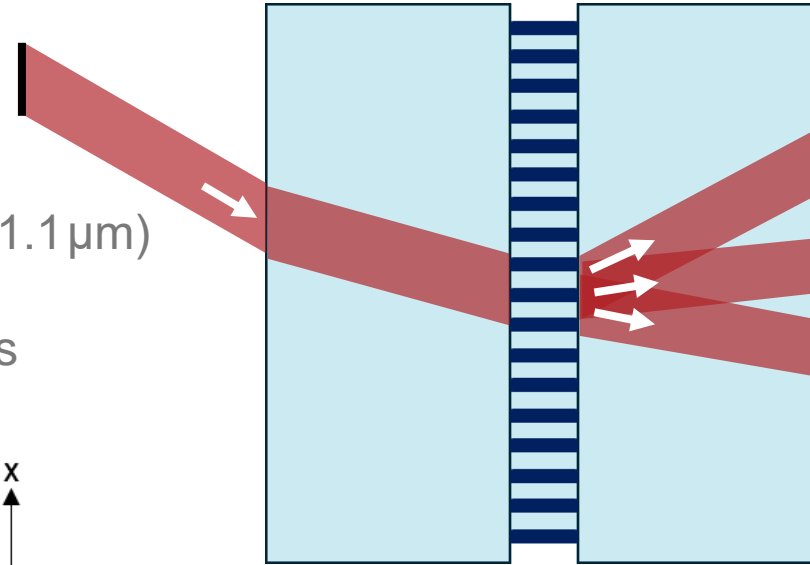
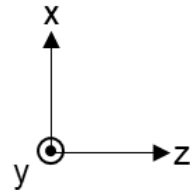
Volume holographic gratings have become powerful devices in the world of optics, offering distinct advantages over traditional surface relief gratings. These elements take advantage of the unique characteristics of volume holography, allowing for efficient and precise control of diffractive elements 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  $\mu\text{m}$ )
- incident angle: 9.18°(\*)
- linearly polarized along x-axis



## sinusoidal volume grating

- substrate material: N-BK7
- substrate thickness: 3 mm
- grating thickness: 20  $\mu\text{m}$
- grating period: 3.33  $\mu\text{m}$
- grating base material: N-BK7
- ref. index modulation: 0.020

performance evaluation of the first three transmitted diffraction orders

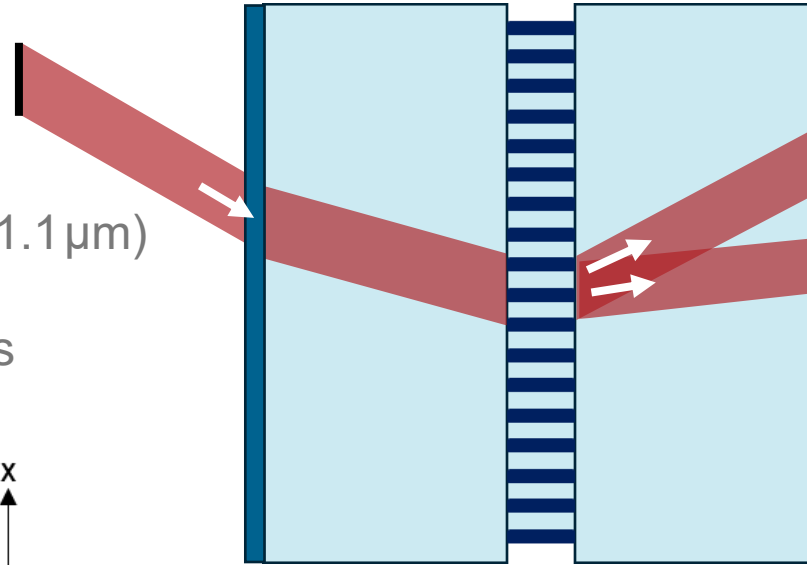
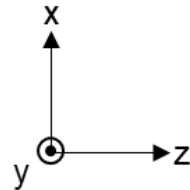
(\*) We realize inclined illumination by rotating the volume grating accordingly.

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: 532nm (to be varied from 320nm to 1.1  $\mu\text{m}$ )
- incident angle:  $18.61^\circ$
- linearly polarized along x-axis



performance evaluation of the first two transmitted diffraction orders

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

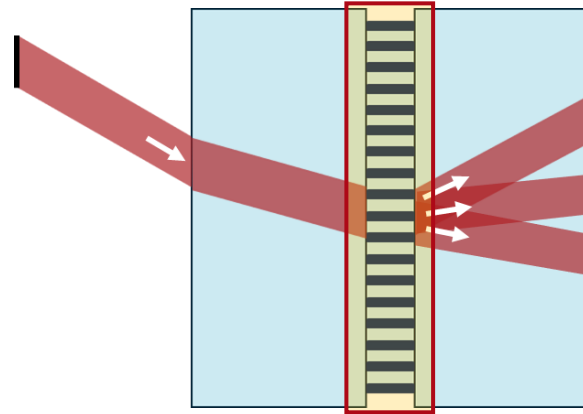
## sinusoidal volume grating

- substrate material: N-BK7
- substrate thickness: 3mm
- grating thickness: 4  $\mu\text{m}$
- grating period: 833.33nm
- grating base material: N-BK7
- ref. index modulation: 0.065
- Coating  $\text{MgF}_2$  thickness: 102.6nm(\*)

(\*) 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



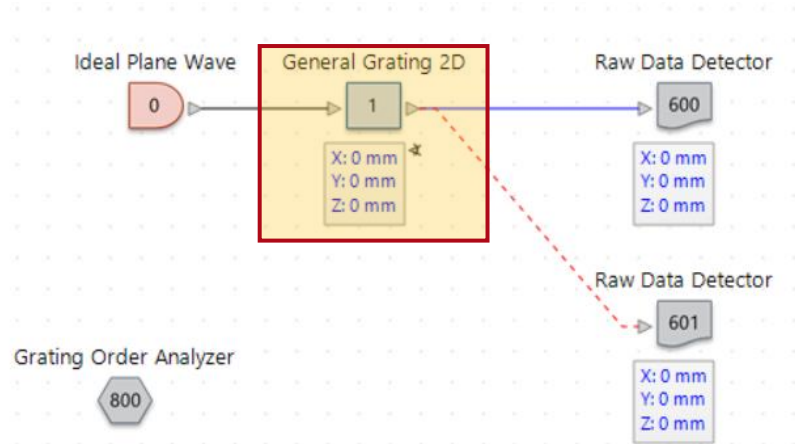
Available modeling techniques for microstructures:

Methods	Preconditions	Accuracy	Speed	Comments
Functional Approach	-	low	very high	diffraction angles acc. to grating equation; manual efficiencies
Thin Element Approximation (TEA)	smallest features $> \sim 10\lambda$	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	

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:

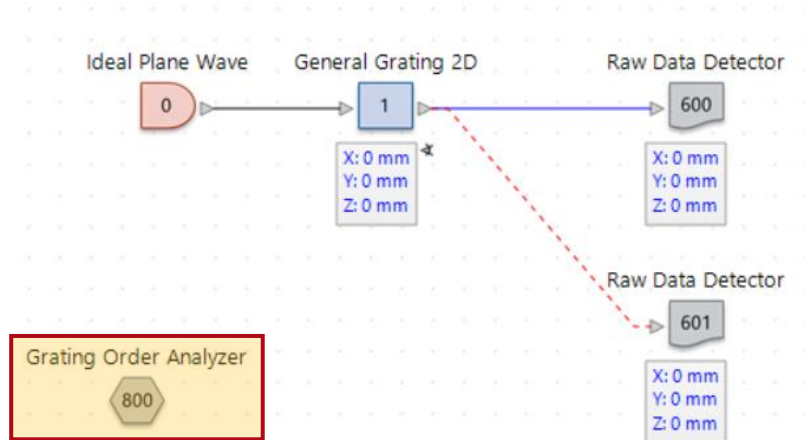
$$n(x, y, z) = dn \cdot \cos\left(2\pi \cdot \left(\frac{x}{\Lambda_x} + \frac{y}{\Lambda_y} + \frac{z}{\Lambda_z}\right)\right)$$

Here,  $\Lambda$  describes the grating period and  $dn$  describes the refractive index modulation.

The screenshot shows the 'Edit Programmable Medium (x-y-z-Modulated)' interface. The 'Basic Parameters' tab is active, showing 'Base Material' as N-BK7\_Schott and 'Index Modulation' selected. The 'Source Code Editor' shows the implementation of the refractive index modulation formula. A 'Preview for Programmable Medium' window shows a 3D visualization of the sinusoidal grating structure.

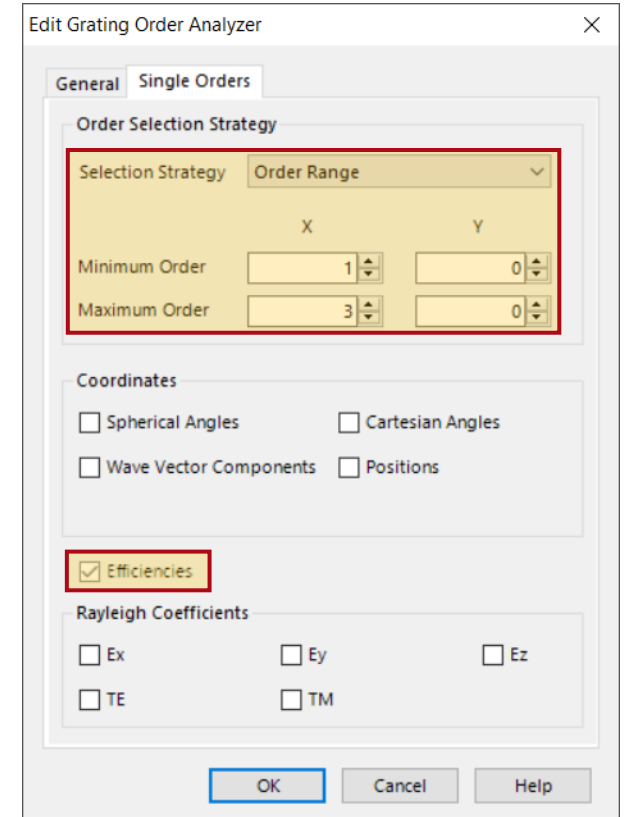
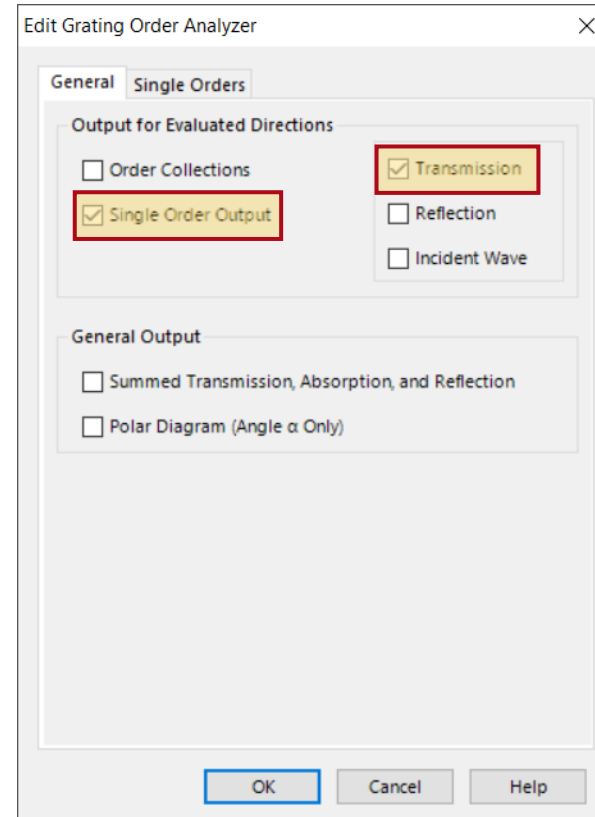
```
26
27 #region Additional using directives
28
29 #endregion
30
31 Base class to handle Global Parameters
77
78 public class VLModule : VLBaseModule, VirtualLabAPI.Core.Modules.ISnippetComplex_Double_x_Double_y
79
80 public Complex GetLocalDataPoint(double x, double y, double z, double Wavelength) {
81
82 #region Main method
83 double realPart = 0.0;
84 double imaginaryPart = 0.0;
85
86 realPart = dn * Math.Cos((x / MediaPeriodX + y / MediaPeriodY + z / MediaPeriodZ) * Math.PI * 2);
87
88 return new Complex(realPart, imaginaryPart);
89 #endregion
90
91 #region Snippet body
92
93 #endregion
94
```

# Grating Order Analyzer

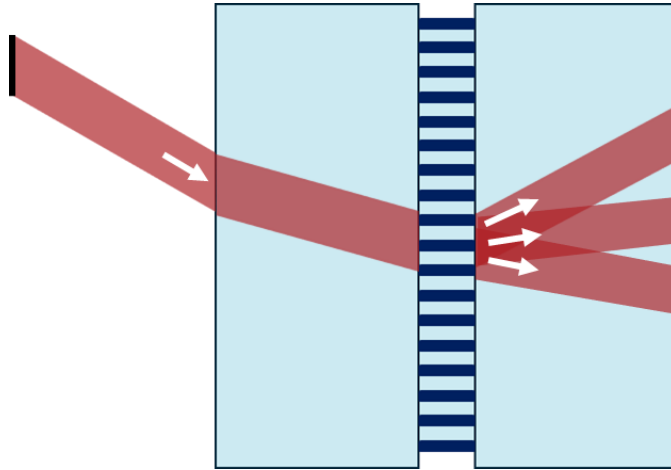


The *Grating Order Analyzer* can be used to investigate the efficiency of the diffraction orders of a given grating. Find more information under:

[Grating Order Analyzer](#)

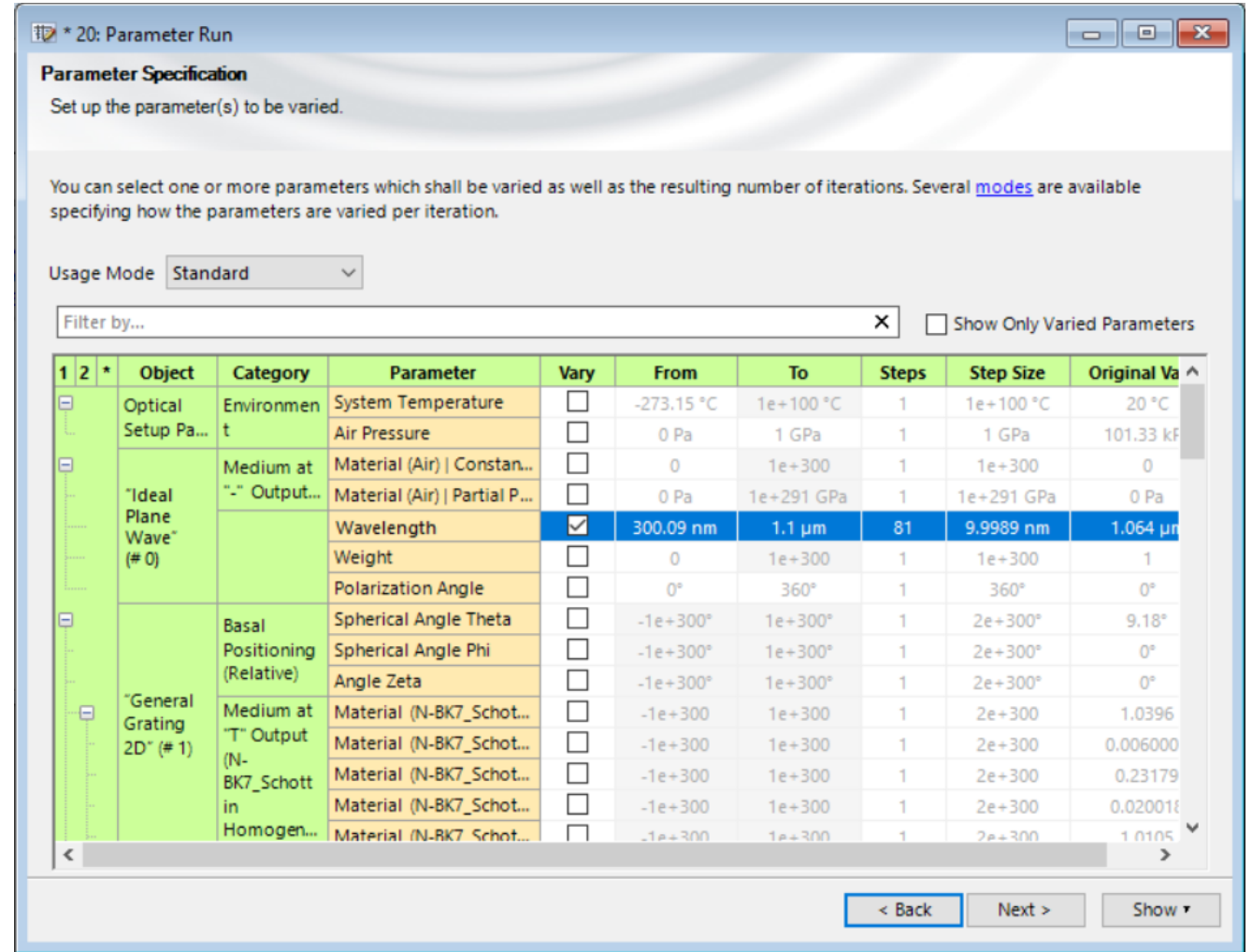


# Parameter Run



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](#)



**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

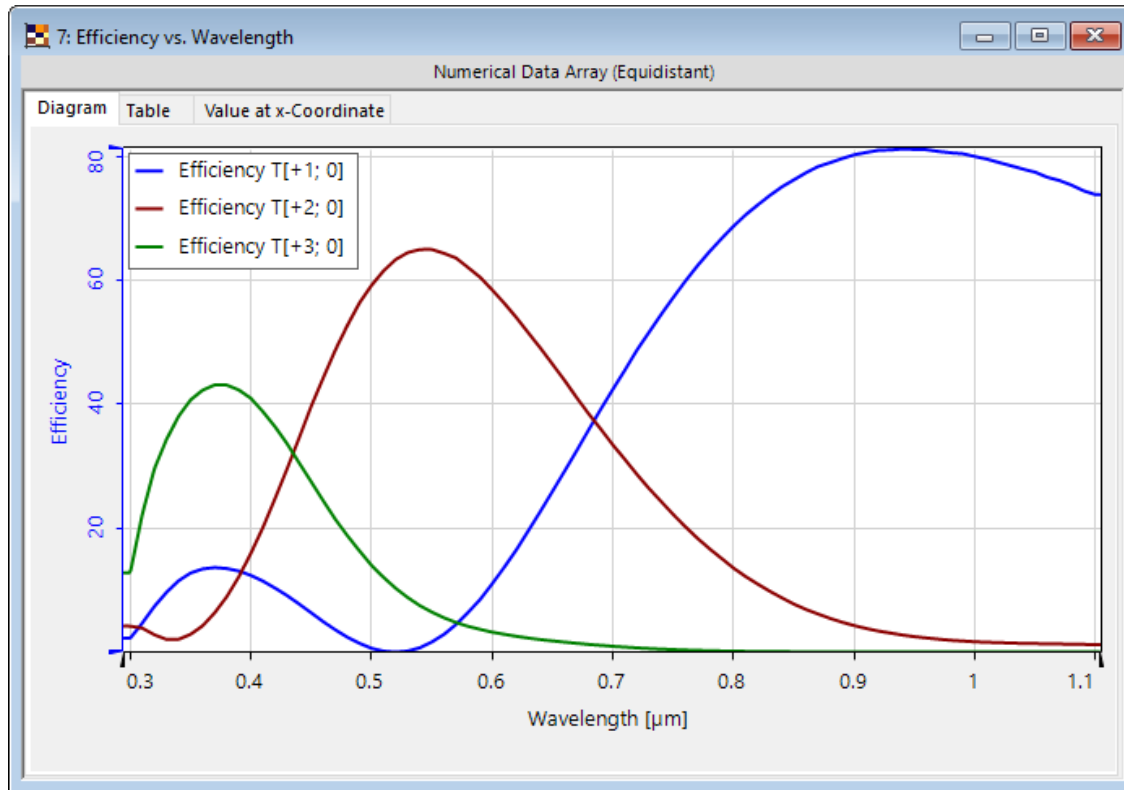
Filter by...  Show Only Varied Parameters

1	2	*	Object	Category	Parameter	Vary	From	To	Steps	Step Size	Original Va
			Optical Setup Pa...	Environment	System Temperature	<input type="checkbox"/>	-273.15 °C	1e+100 °C	1	1e+100 °C	20 °C
					Air Pressure	<input type="checkbox"/>	0 Pa	1 GPa	1	1 GPa	101.33 kPa
			"Ideal Plane Wave" (# 0)	Medium at "..." Output...	Material (Air)   Constan...	<input type="checkbox"/>	0	1e+300	1	1e+300	0
					Material (Air)   Partial P...	<input type="checkbox"/>	0 Pa	1e+291 GPa	1	1e+291 GPa	0 Pa
				Wavelength	<input checked="" type="checkbox"/>	300.09 nm	1.1 µm	81	9.9989 nm	1.064 µm	
				Weight	<input type="checkbox"/>	0	1e+300	1	1e+300	1	
					Polarization Angle	<input type="checkbox"/>	0°	360°	1	360°	0°
			"General Grating 2D" (# 1)	Basal Positioning (Relative)	Spherical Angle Theta	<input type="checkbox"/>	-1e+300°	1e+300°	1	2e+300°	9.18°
					Spherical Angle Phi	<input type="checkbox"/>	-1e+300°	1e+300°	1	2e+300°	0°
					Angle Zeta	<input type="checkbox"/>	-1e+300°	1e+300°	1	2e+300°	0°
				Medium at "T" Output (N-BK7_Schott in Homogen...	Material (N-BK7_Schot...	<input type="checkbox"/>	-1e+300	1e+300	1	2e+300	1.0396
					Material (N-BK7_Schot...	<input type="checkbox"/>	-1e+300	1e+300	1	2e+300	0.006000
				Material (N-BK7_Schot...	<input type="checkbox"/>	-1e+300	1e+300	1	2e+300	0.23179	
				Material (N-BK7_Schot...	<input type="checkbox"/>	-1e+300	1e+300	1	2e+300	0.020010	
				Material (N-BK7_Schot...	<input type="checkbox"/>	-1e+300	1e+300	1	2e+300	1.0105	

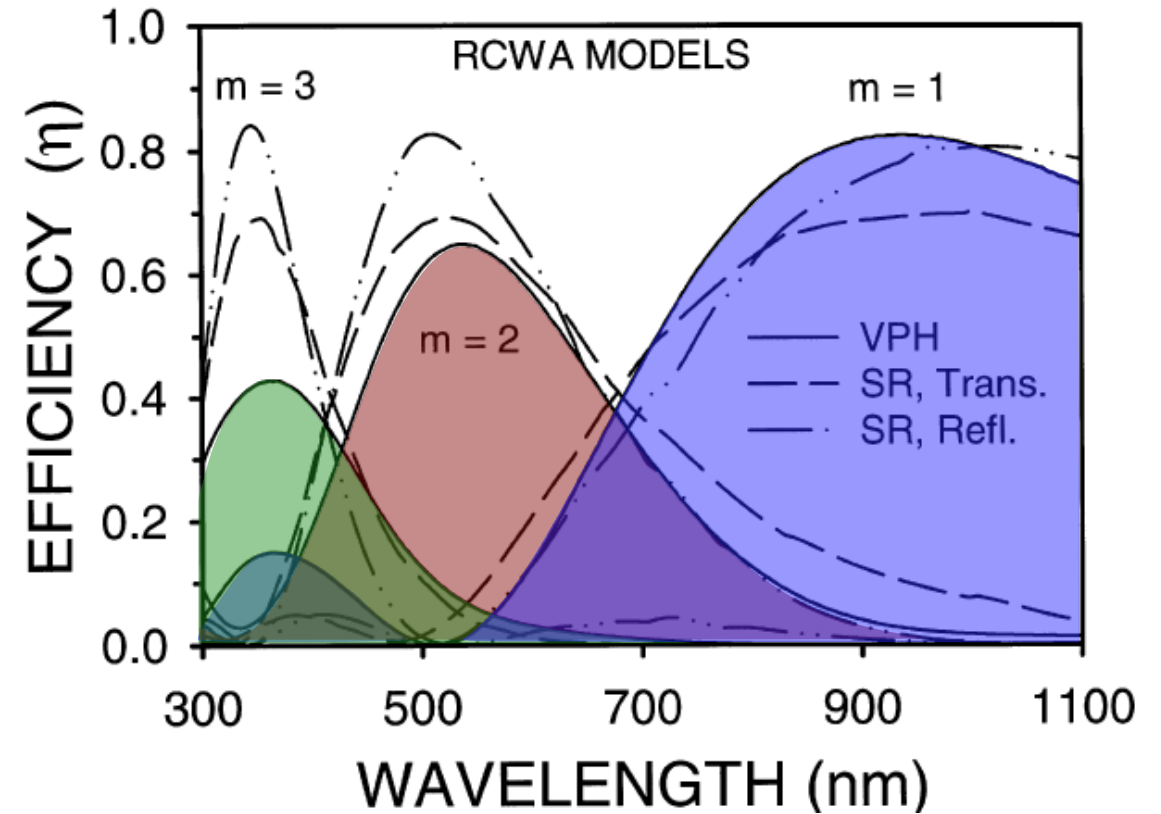
< Back Next > Show ▾



# Efficiency vs. Wavelength – Configuration #1



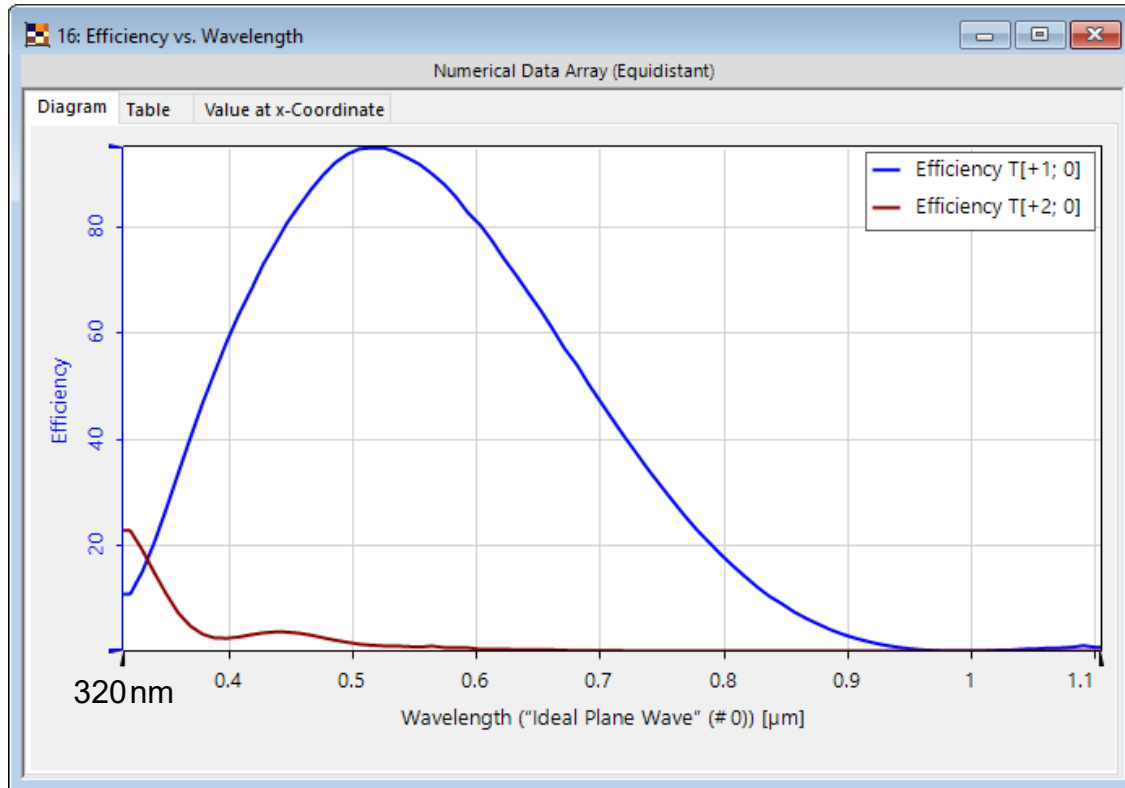
The resulting diffraction efficiencies of the three orders are in perfect agreement with the results of the article.



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).

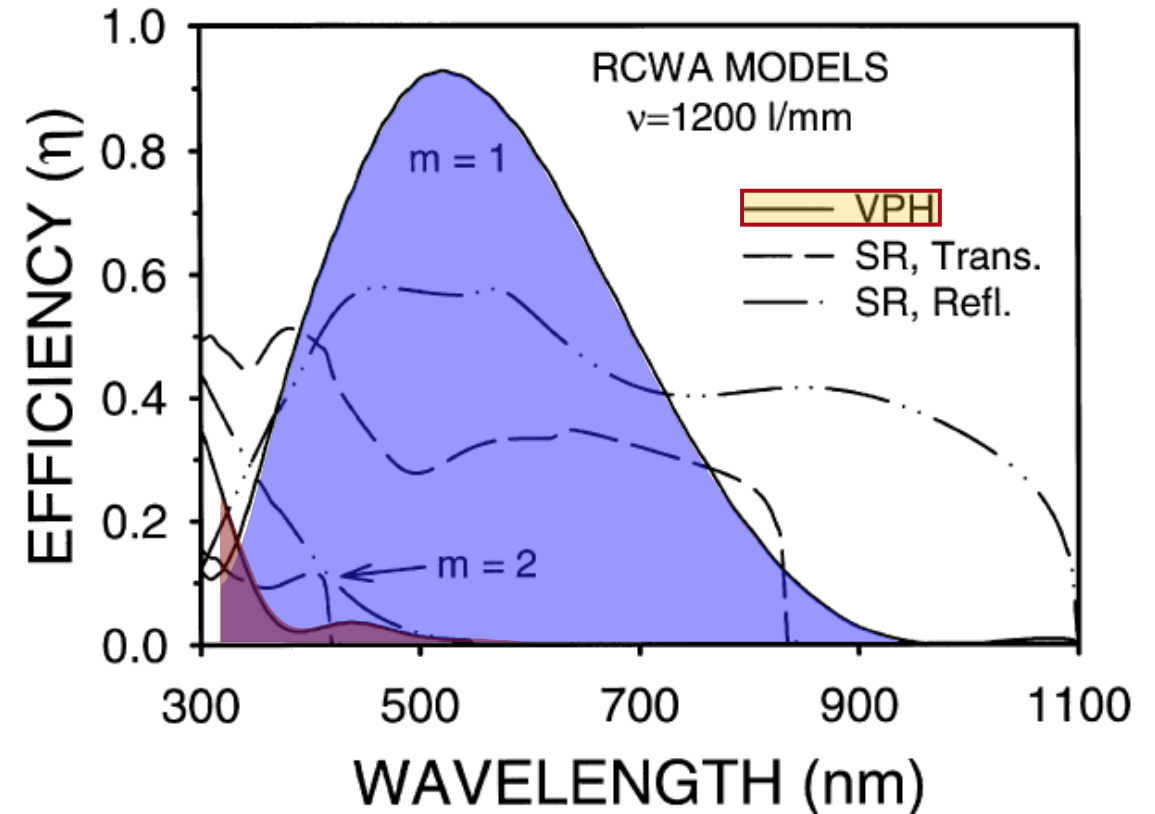
Note: The colored areas were added to highlight the discussed results.

# 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  $\text{MgF}_2$  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	<ul style="list-style-type: none"><li>• <a href="#"><u>Grating Order Analyzer</u></a></li><li>• <a href="#"><u>Usage of the Parameter Run Document</u></a></li><li>• <a href="#"><u>Holographically Generated Volume Grating</u></a></li><li>• <a href="#"><u>Angular-Filtering Volume Gratings for Suppressing Higher Diffraction Orders</u></a></li><li>• <a href="#"><u>How to Work with the Programmable Medium</u></a></li></ul>