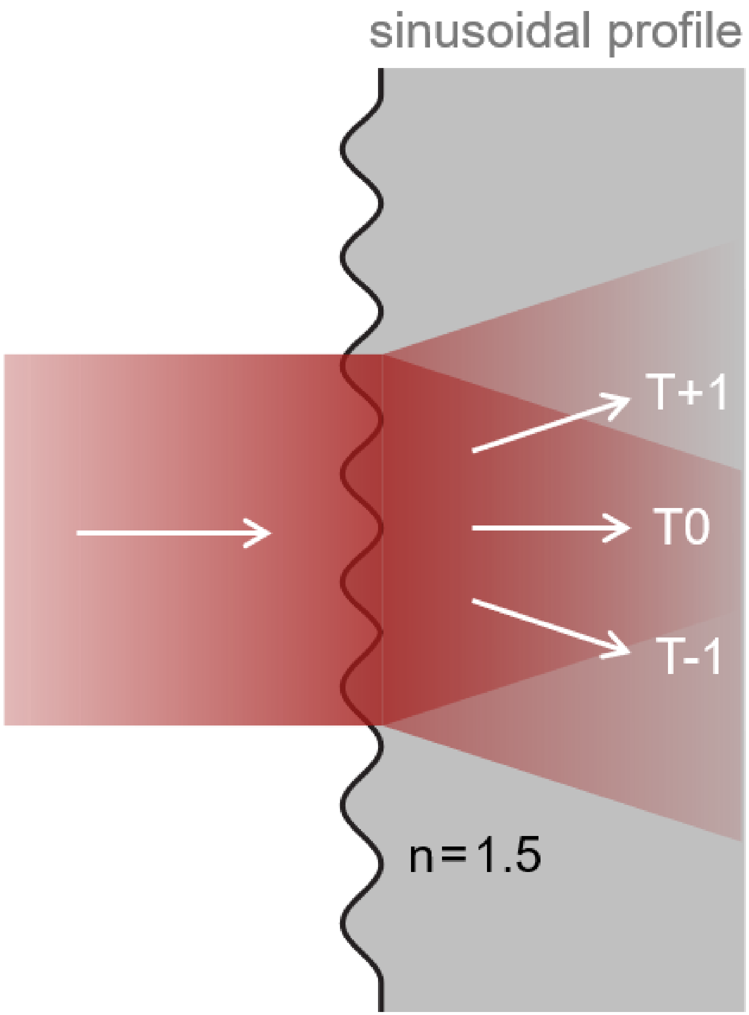
Thin Element Approximation (TEA) vs. Fourier Modal Method (FMM) for Grating Modeling

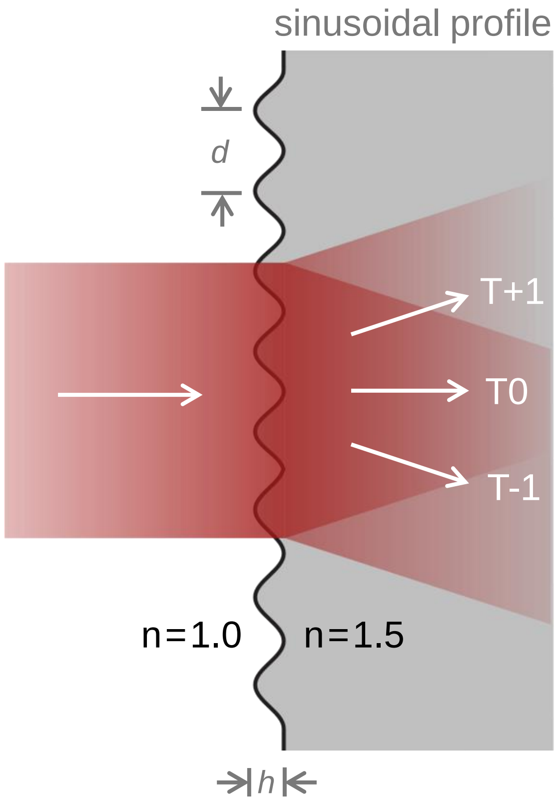
Abstract

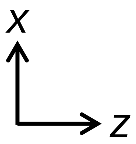


The Thin Element Approximation (TEA) is a widely-used method in Fourier optics to calculate the diffraction efficiency of gratings. However, it is also known that the approximation becomes inaccurate for smaller grating periods, means closer to the wavelength of light. In this example, two types of transmission gratings are selected to showcase this effect: sinusoidal and blazed. We use both TEA and FMM (also known as RWCA, which is rigorous) to analyze such gratings with varying period, and by comparing the results, we investigate the behavior of the two methods.

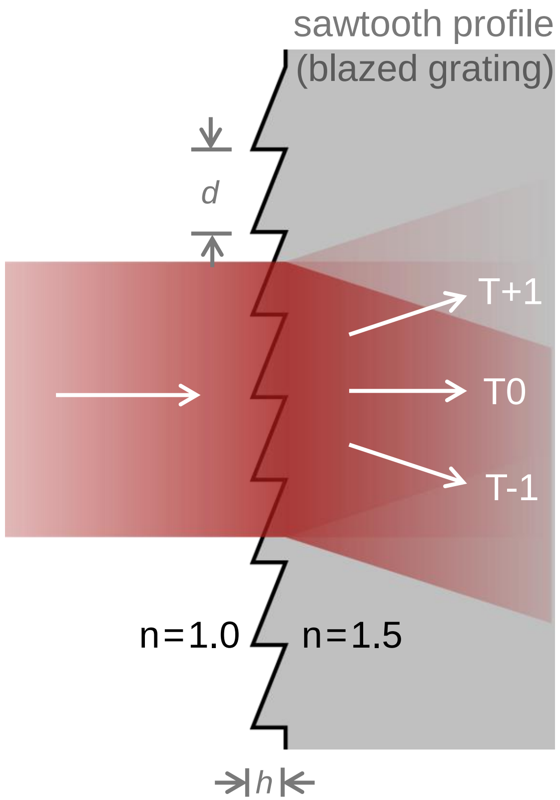
Modeling Task

input plane wave
- wavelength λ=532 nm
- polarization in TE



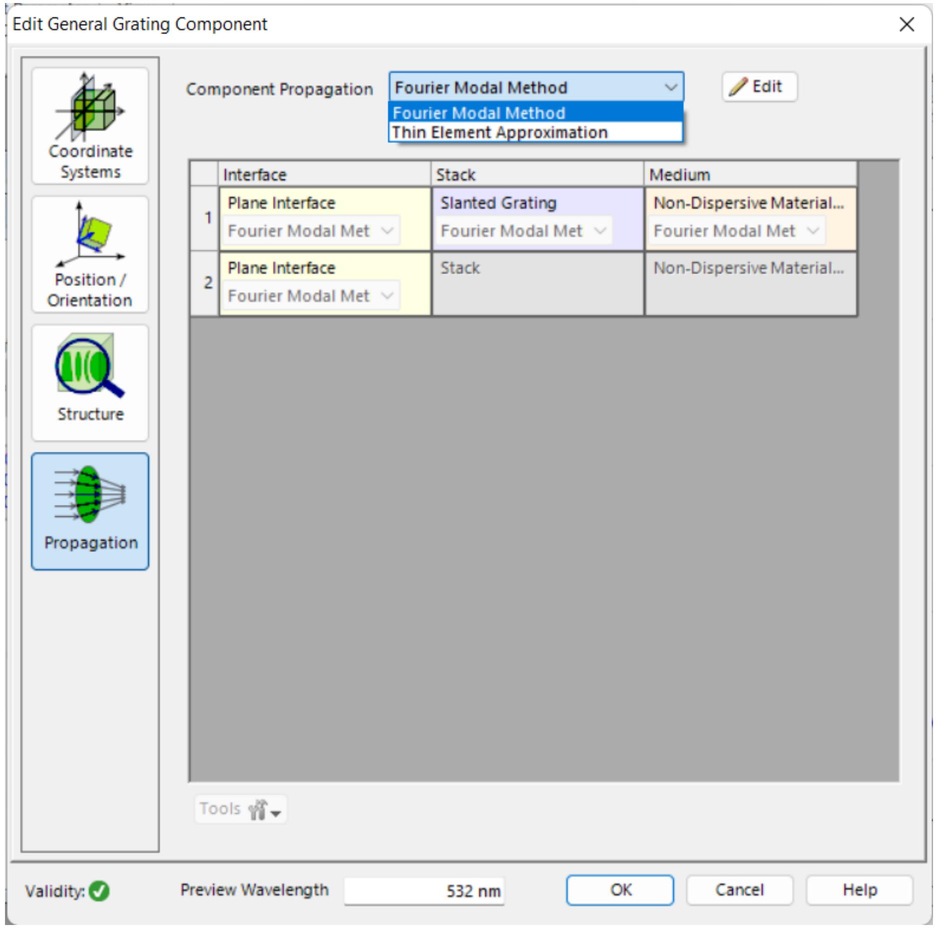


grating parameters
- grating period *d*
- grating height *h*



For both the sinusoidal and the blazed gratings, the diffraction efficiency is analyzed by applying TEA and FMM.

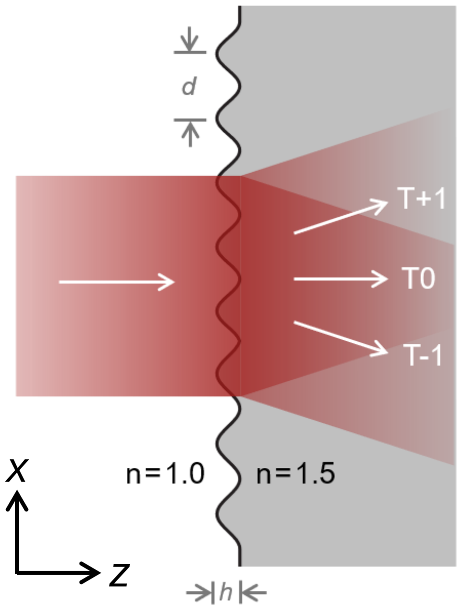
Grating Component



The *General Grating Component* allows the user to choose different solver algorithm in the simulation. The user can choose between the rigorous *Fourier Modal Method* (FMM) and the approximated, but faster *Thin Element Approximation* (TEA). More information about the solvers can be found here:

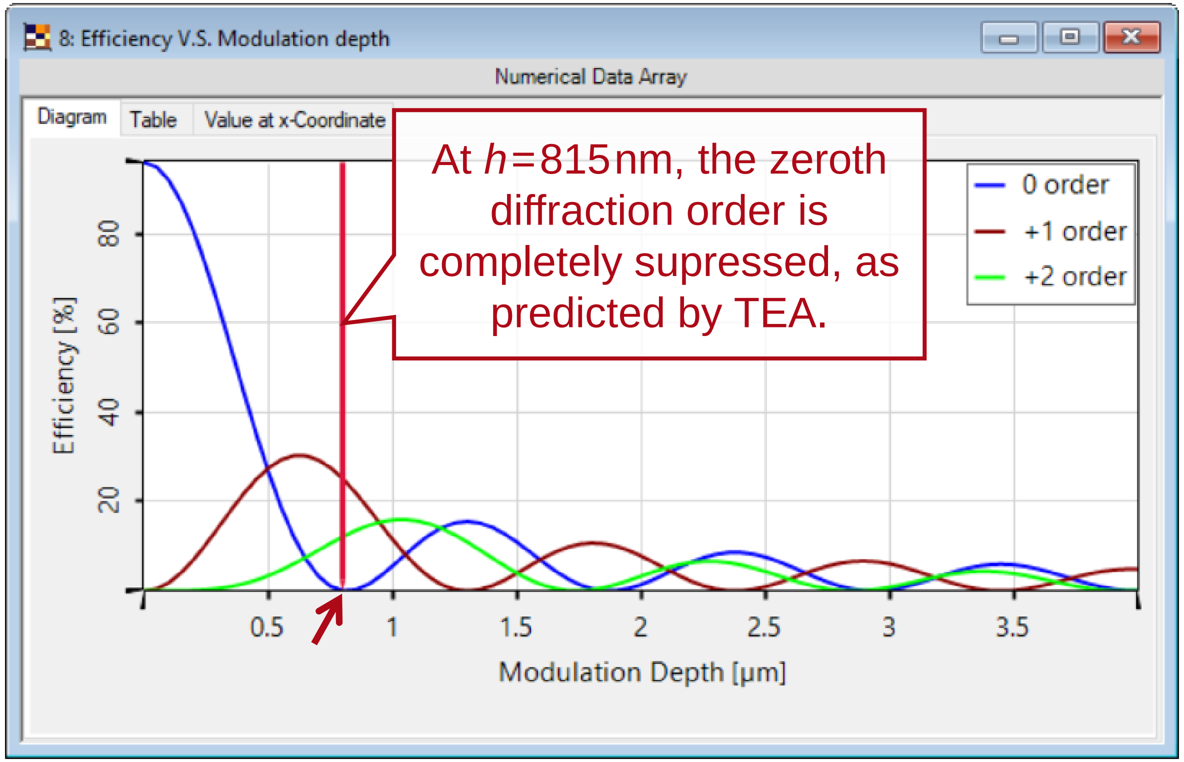
- FMM/RCWA
- Diffractive Lens Component

Sinusoidal Grating – Efficiency vs. Height (TEA Only)



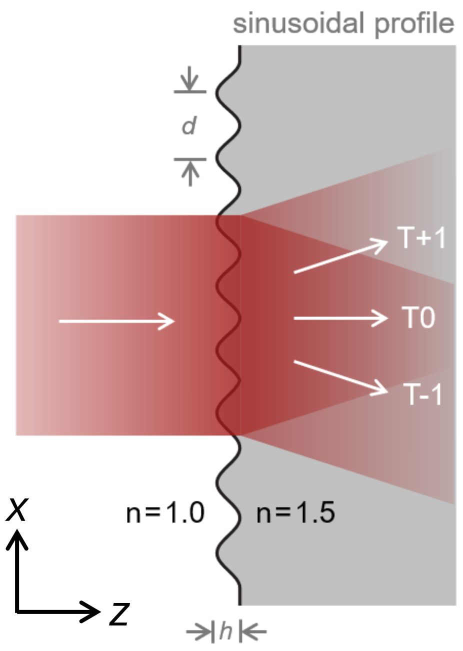
fixed period d=1µm
fixed TE polarization
varying height *h*

It is often efficient to use TEA as a fast design tool for searching proper grating parameters. However, the limitation of the method shall be noticed.



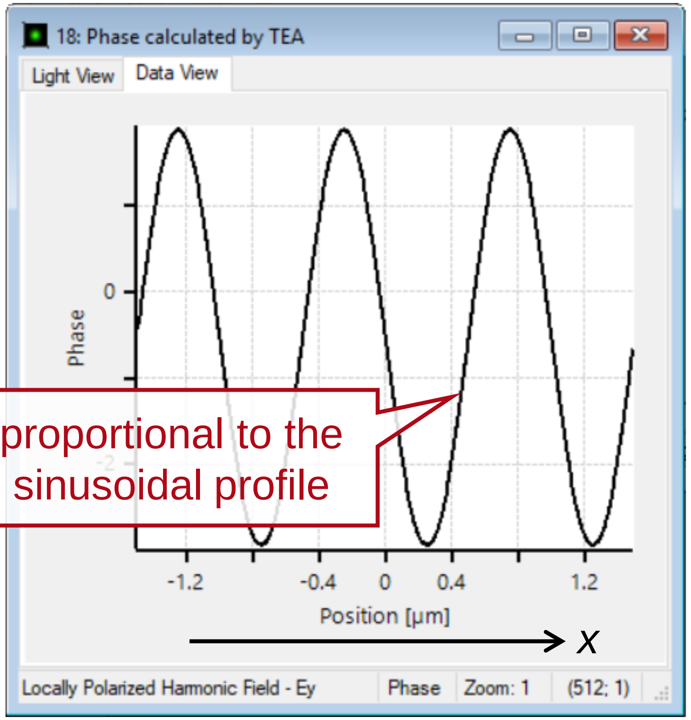
To have symmetric diffraction effect without zeroth order, we pick up h=815nm as the grating height.

Sinusoidal Grating – Transmitted Phase Profiles



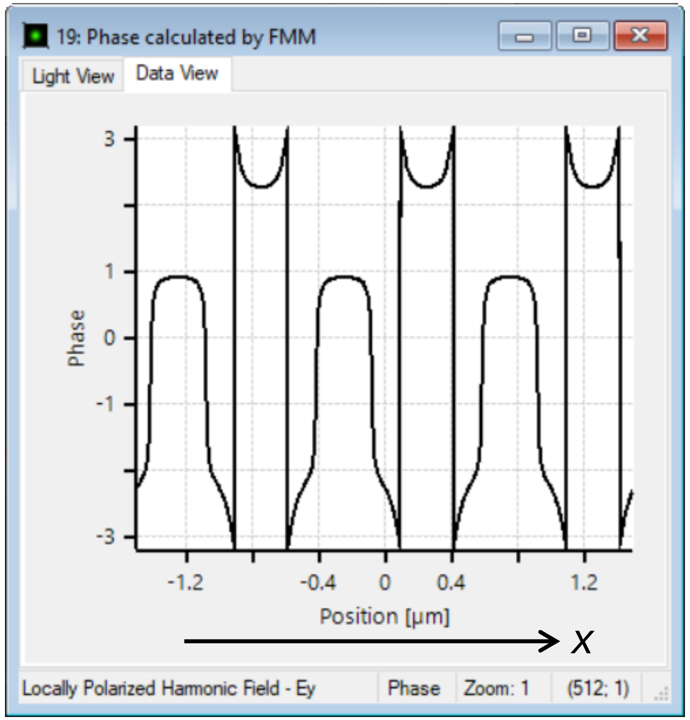
fixed period $d=1\,\mu m$
fixed TE polarization
fixed height $h=815\,nm$

phase behind grating (TEA)

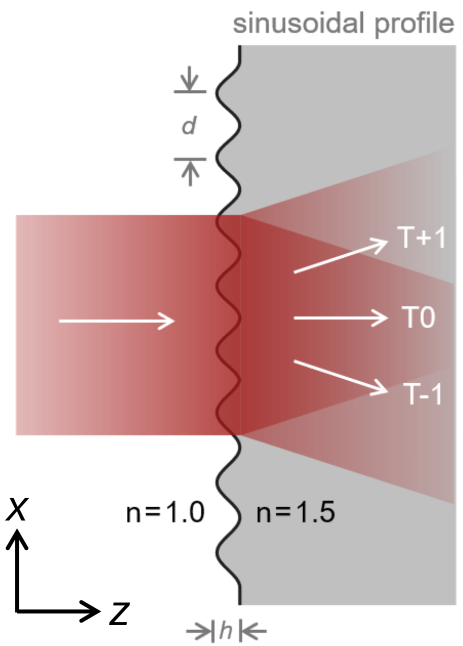


proportional to the sinusoidal profile

phase behind grating (FMM)

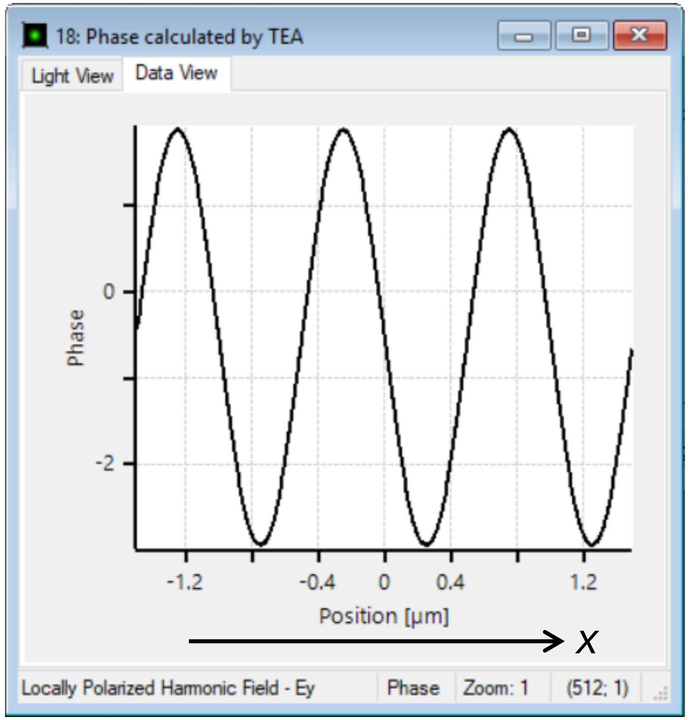


Sinusoidal Grating – Transmitted Phase Profiles



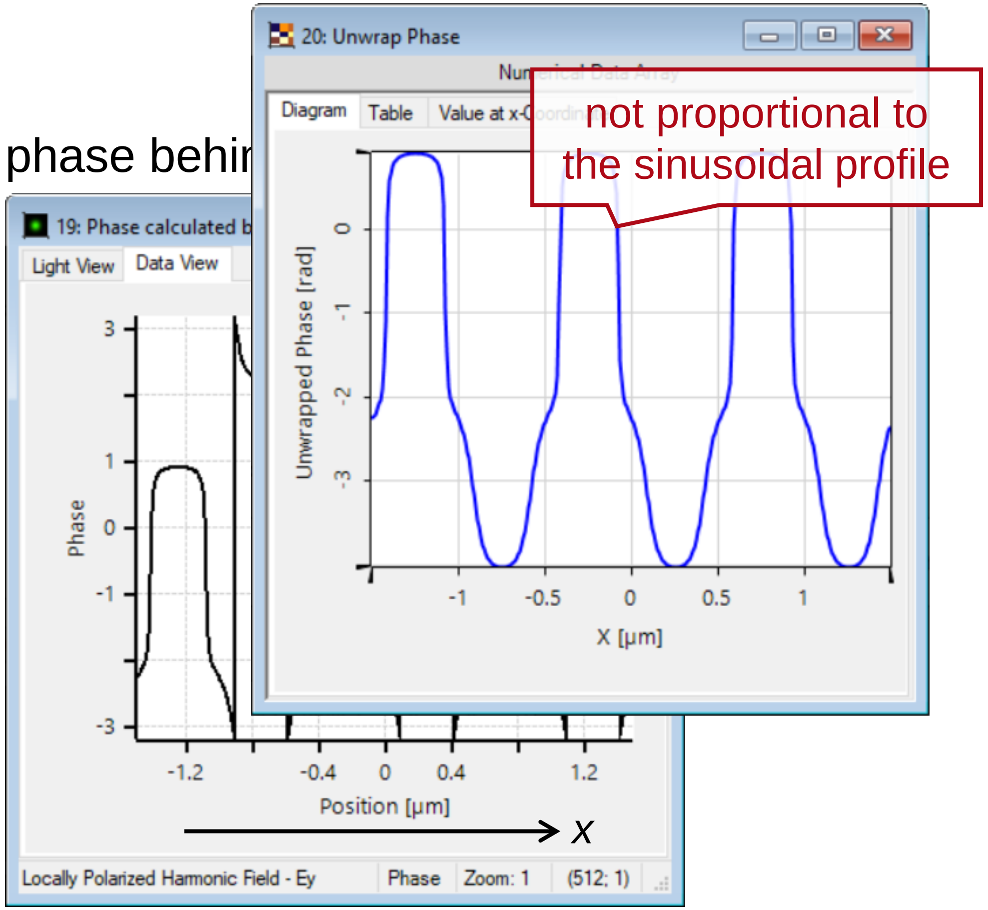
fixed period d=1 µm
fixed TE polarization
fixed height h=815 nm

phase behind grating (TEA)

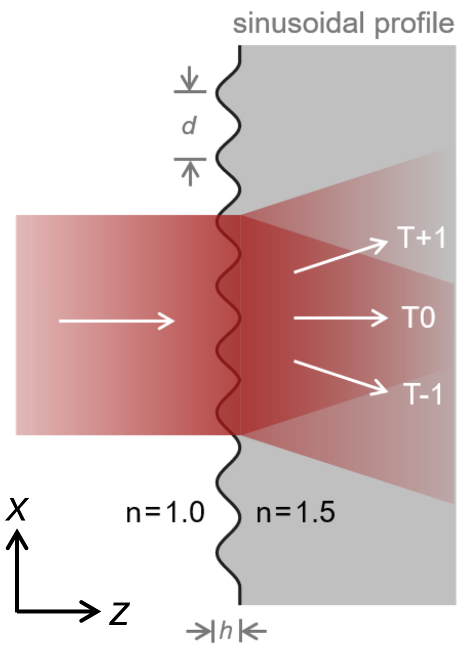


phase behin

unwrapped phase (FMM)

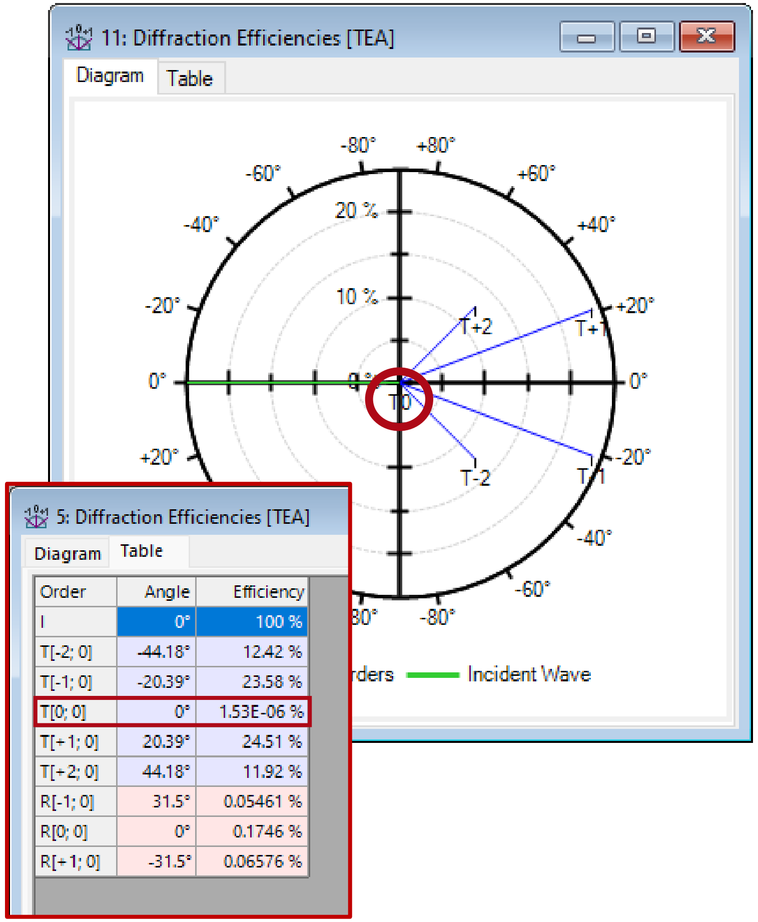


Sinusoidal Grating – Diffraction Efficiencies



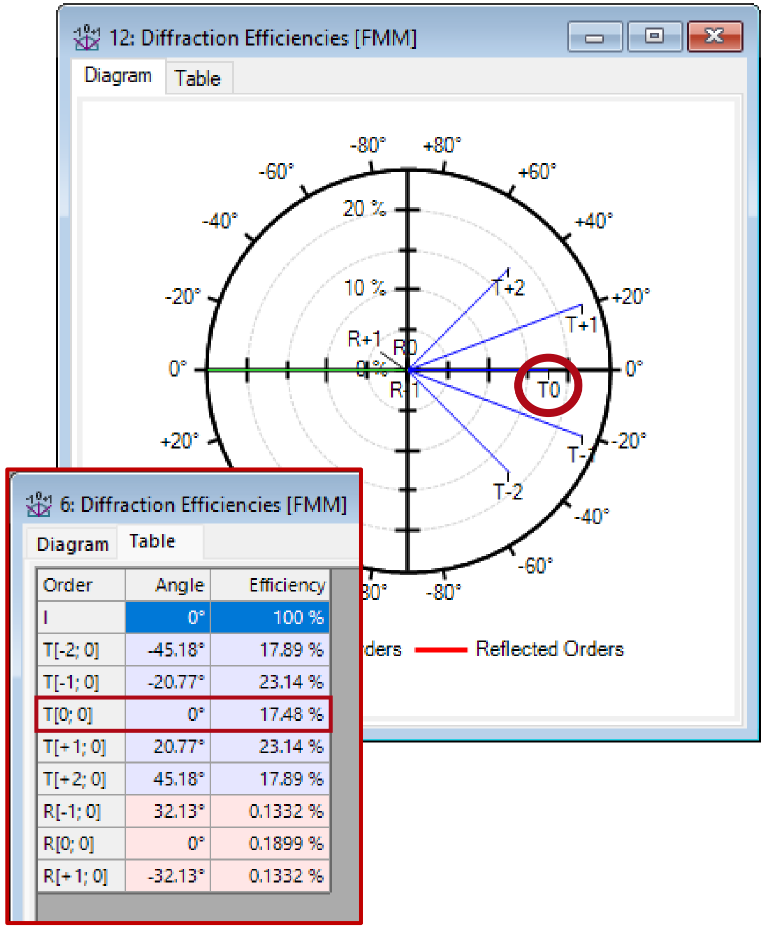
fixed period d=1µm
fixed TE polarization
fixed height h=815nm

diffraction efficiencies (TEA)



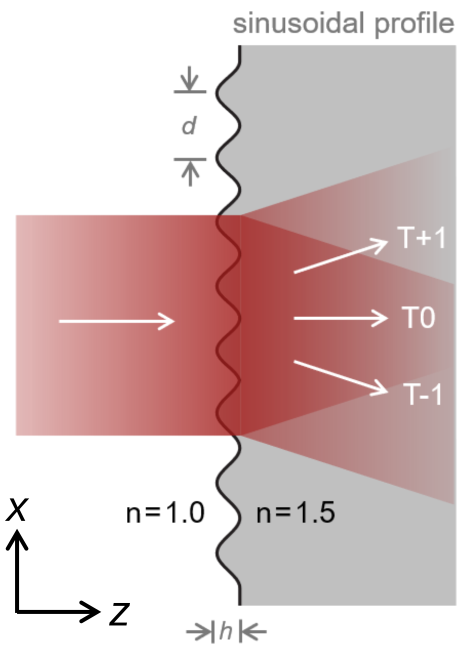
Order	Angle	Efficiency
I	0°	100 %
T[-2; 0]	-44.18°	12.42 %
T[-1; 0]	-20.39°	23.58 %
T[0; 0]	0°	1.53E-06 %
T[+1; 0]	20.39°	24.51 %
T[+2; 0]	44.18°	11.92 %
R[-1; 0]	31.5°	0.05461 %
R[0; 0]	0°	0.1746 %
R[+1; 0]	-31.5°	0.06576 %

diffraction efficiencies (FMM)



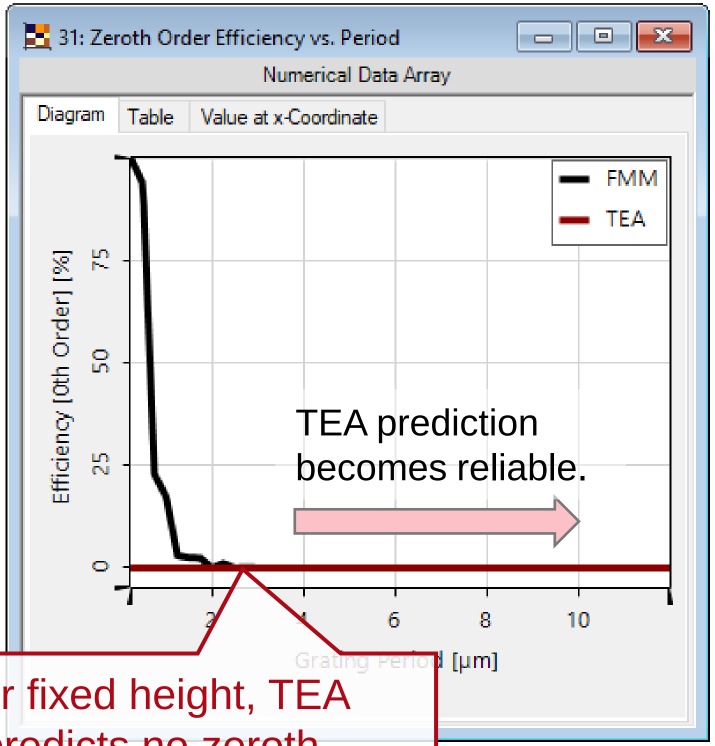
Order	Angle	Efficiency
I	0°	100 %
T[-2; 0]	-45.18°	17.89 %
T[-1; 0]	-20.77°	23.14 %
T[0; 0]	0°	17.48 %
T[+1; 0]	20.77°	23.14 %
T[+2; 0]	45.18°	17.89 %
R[-1; 0]	32.13°	0.1332 %
R[0; 0]	0°	0.1899 %
R[+1; 0]	-32.13°	0.1332 %

Sinusoidal Grating – Efficiencies vs. Period



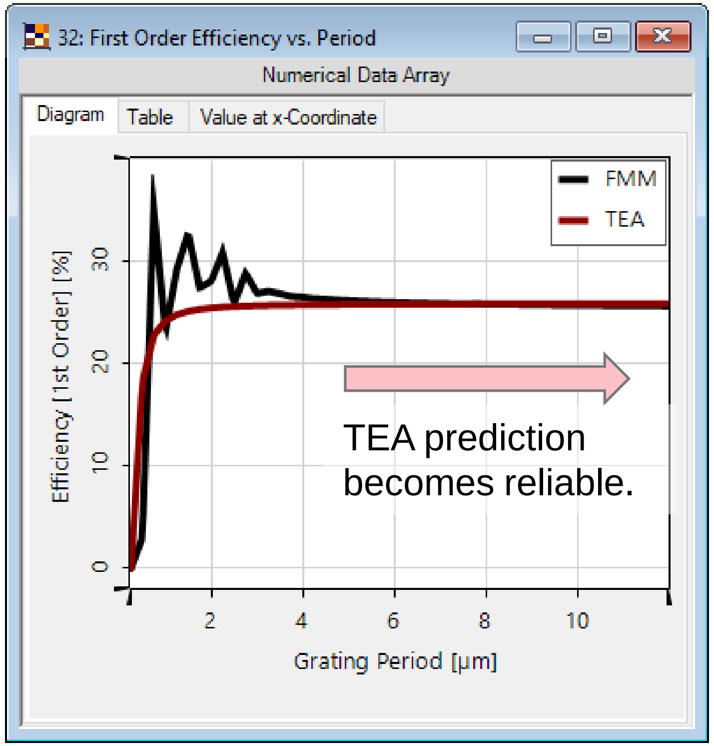
varying period *d*
fixed TE polarization
fixed height h=815nm

diffraction efficiencies – 0^{th} order

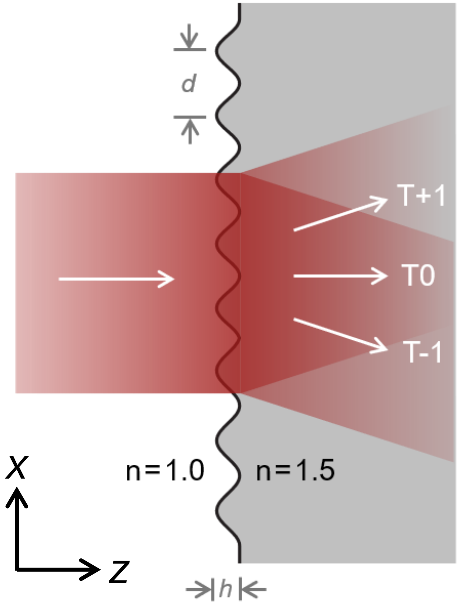


For fixed height, TEA predicts no zeroth diffraction order regardless of the grating period.

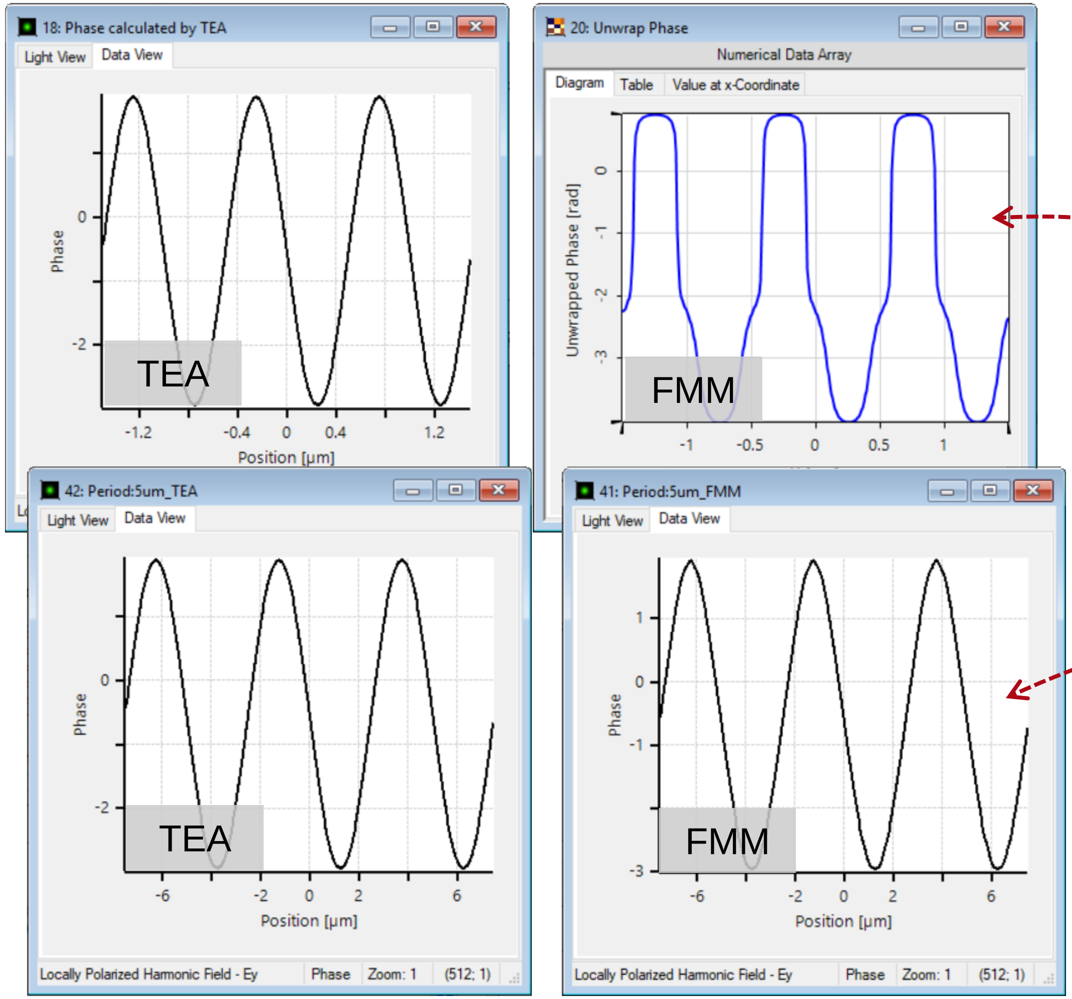
diffraction efficiencies – 1^{st} order



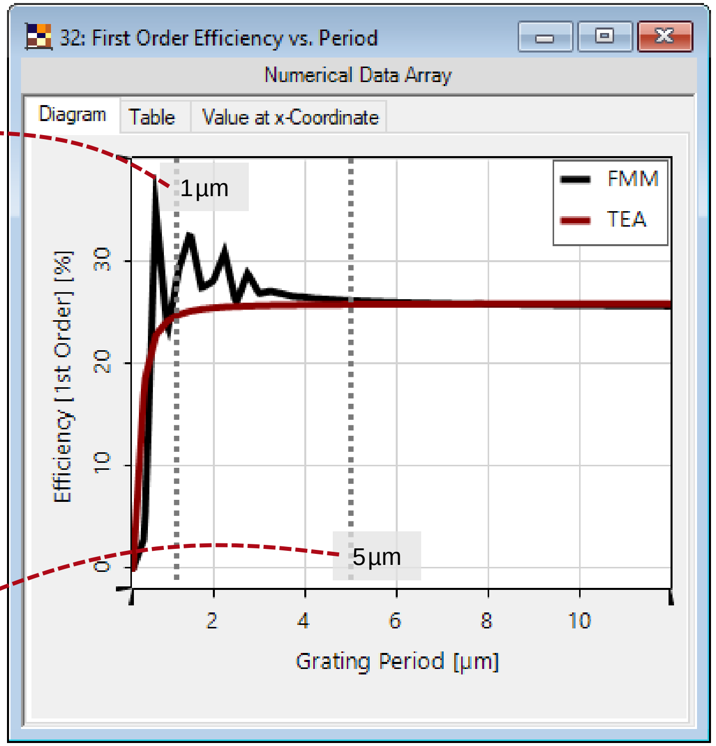
Sinusoidal Grating – Phase Profiles at Selected Periods



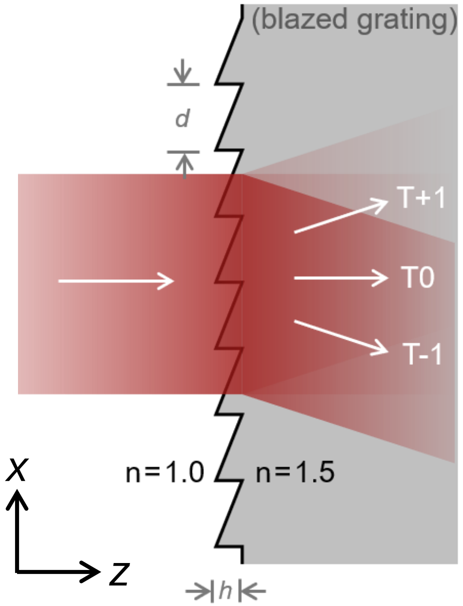
period *d* = 1µm or 5µm
fixed TE polarization
fixed height *h* = 815nm



diffraction efficiencies – 1st order

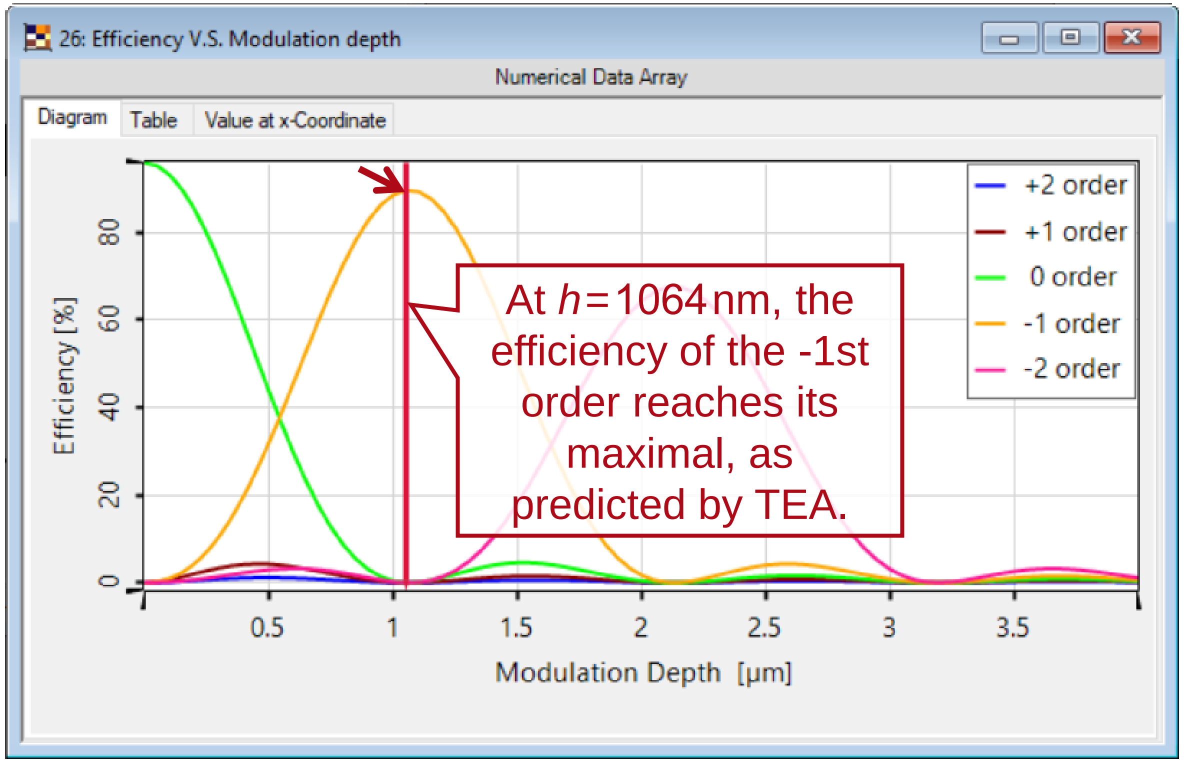


Blazed Grating – Efficiency vs. Height (TEA Only)



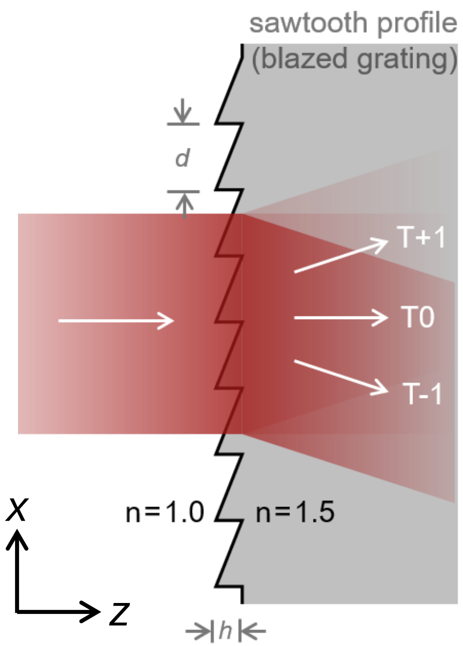
fixed period d=1µm
fixed TE polarization
varying height *h*

It is often efficient to use TEA as a fast design tool for searching proper grating parameters. However, the limitation of the method shall be noticed.



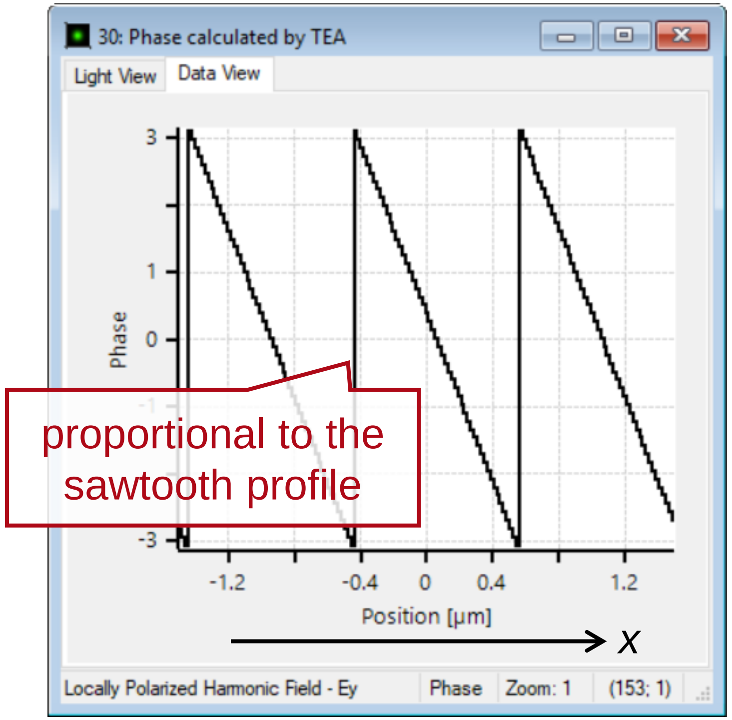
To maximize the diffraction efficiency of the -1st order, we pick up h=1064 nm as the grating height.

Blazed Grating – Transmitted Phase Profiles

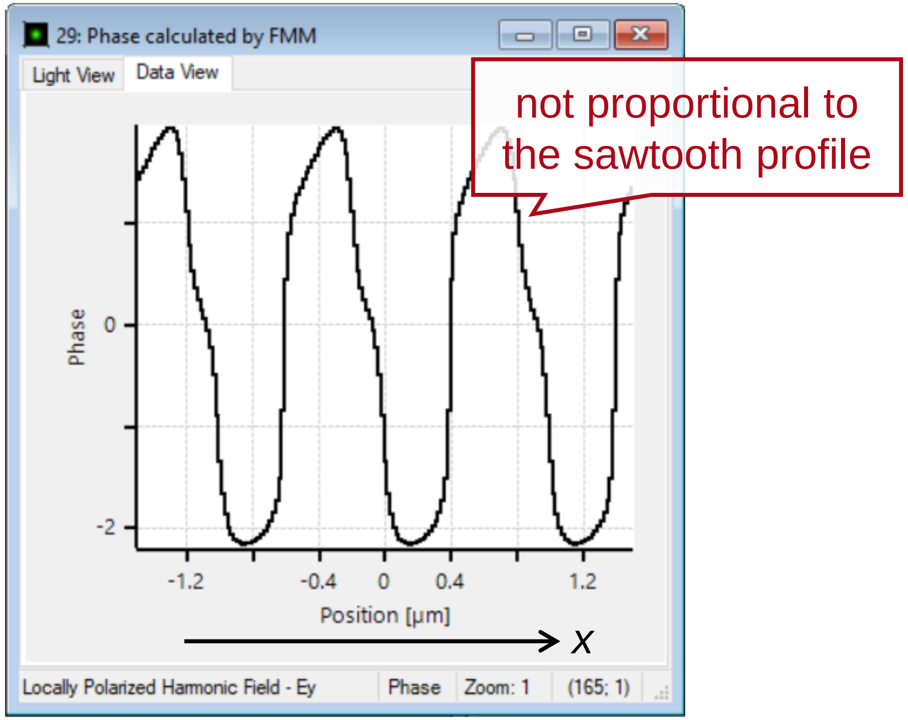


fixed period d=1µm
fixed TE polarization
fixed height h=1064nm

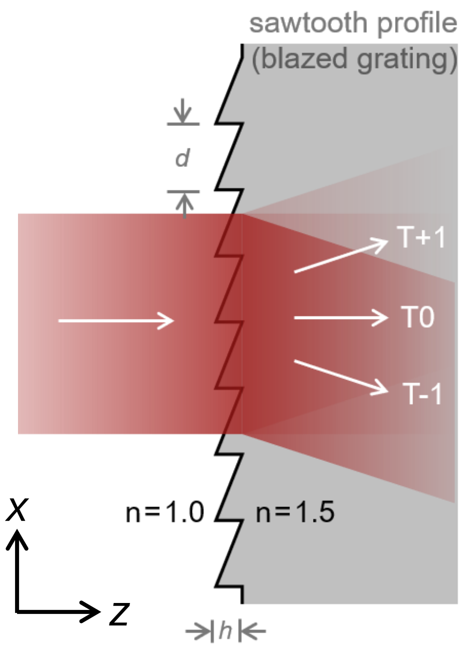
phase behind grating (TEA)



phase behind grating (FMM)

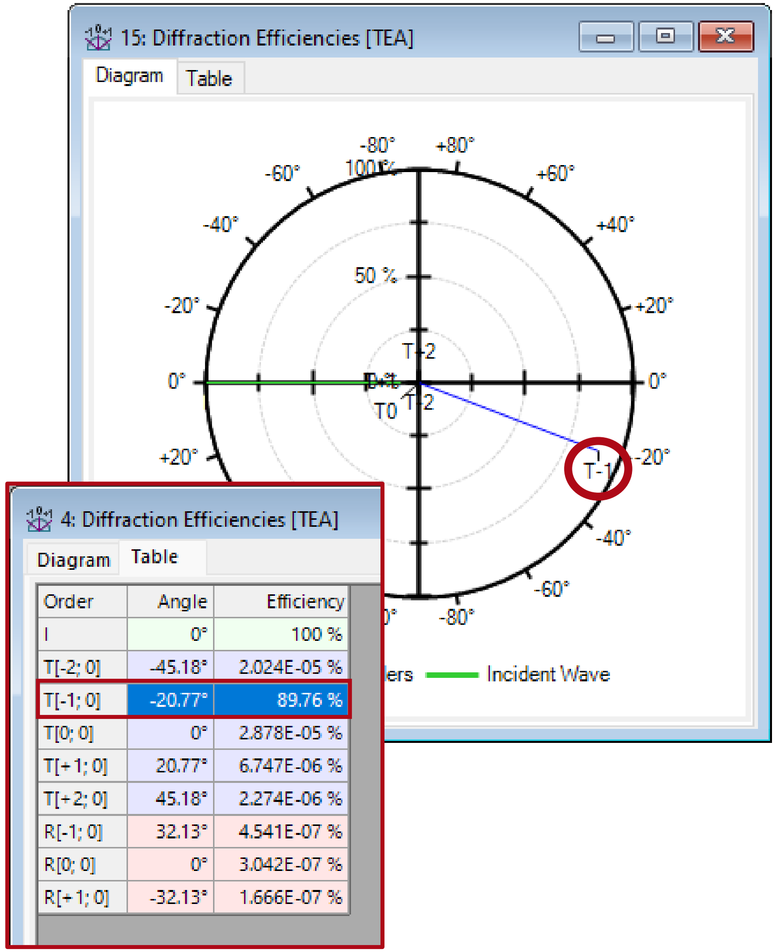


Blazed Grating – Diffraction Efficiencies



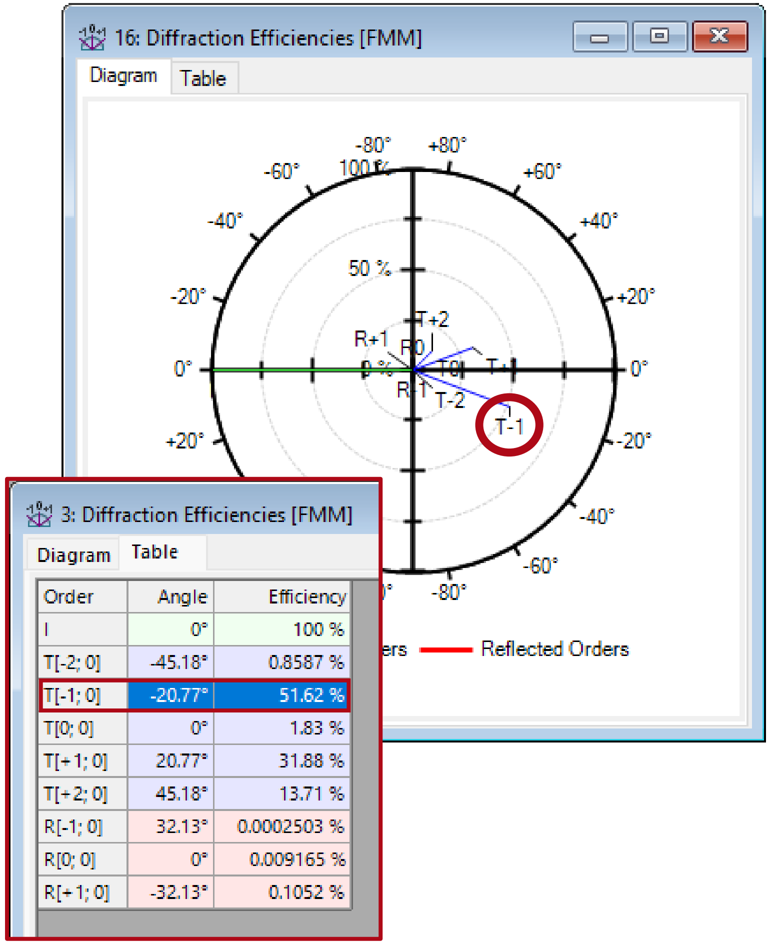
fixed period $d=1\,\mu m$
fixed TE polarization
fixed height $h=1064\,nm$

diffraction efficiencies (TEA)



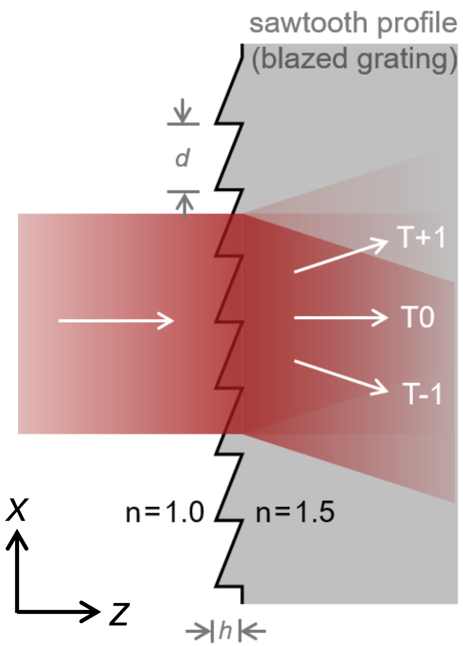
Order	Angle	Efficiency
I	0°	100 %
T[-2; 0]	-45.18°	2.024E-05 %
T[-1; 0]	-20.77°	89.76 %
T[0; 0]	0°	2.878E-05 %
T[+1; 0]	20.77°	6.747E-06 %
T[+2; 0]	45.18°	2.274E-06 %
R[-1; 0]	32.13°	4.541E-07 %
R[0; 0]	0°	3.042E-07 %
R[+1; 0]	-32.13°	1.666E-07 %

diffraction efficiencies (FMM)



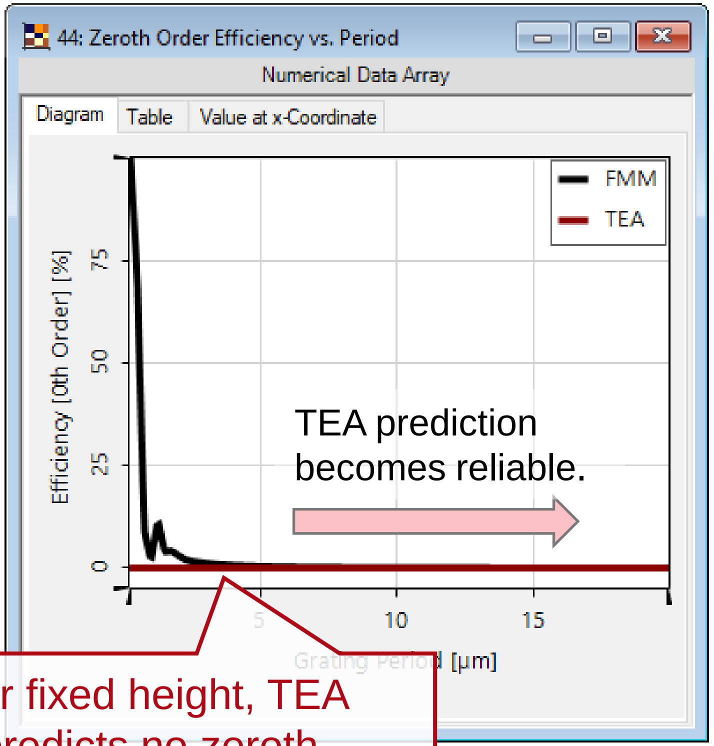
Order	Angle	Efficiency
I	0°	100 %
T[-2; 0]	-45.18°	0.8587 %
T[-1; 0]	-20.77°	51.62 %
T[0; 0]	0°	1.83 %
T[+1; 0]	20.77°	31.88 %
T[+2; 0]	45.18°	13.71 %
R[-1; 0]	32.13°	0.0002503 %
R[0; 0]	0°	0.009165 %
R[+1; 0]	-32.13°	0.1052 %

Blazed Grating – Efficiencies vs. Period



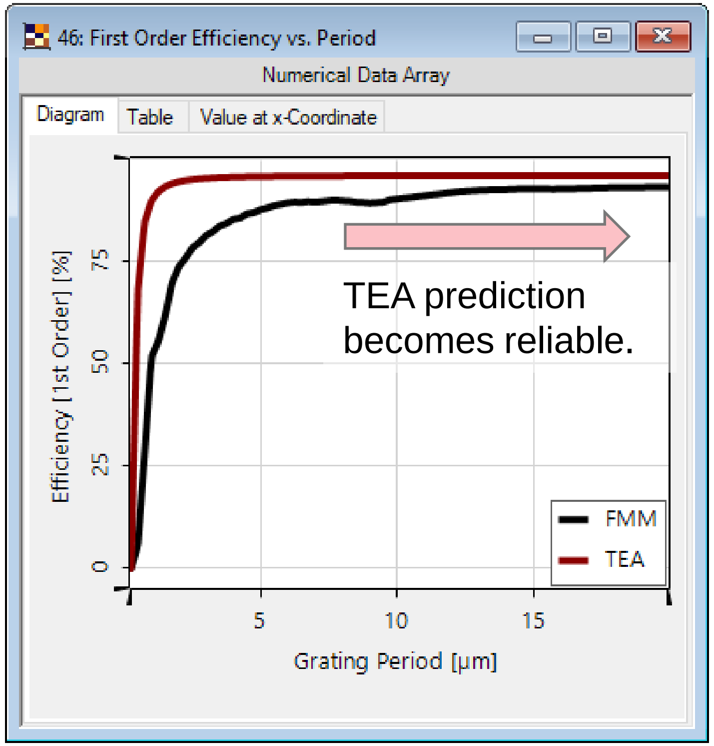
varying period *d*
fixed TE polarization
fixed height h=1064nm

diffraction efficiencies – 0^{th} order

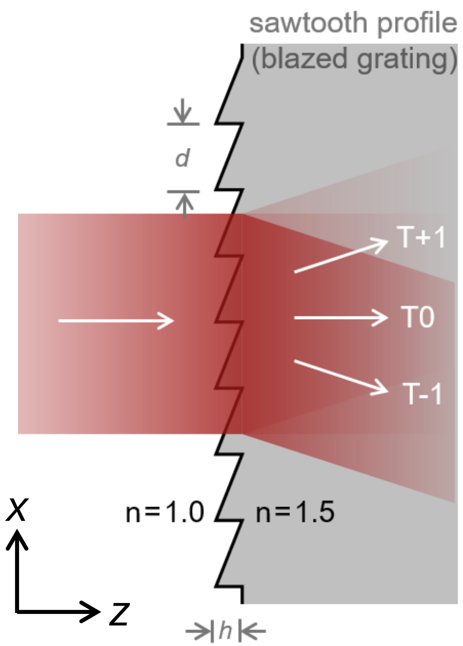


For fixed height, TEA predicts no zeroth diffraction order regardless of the grating period.

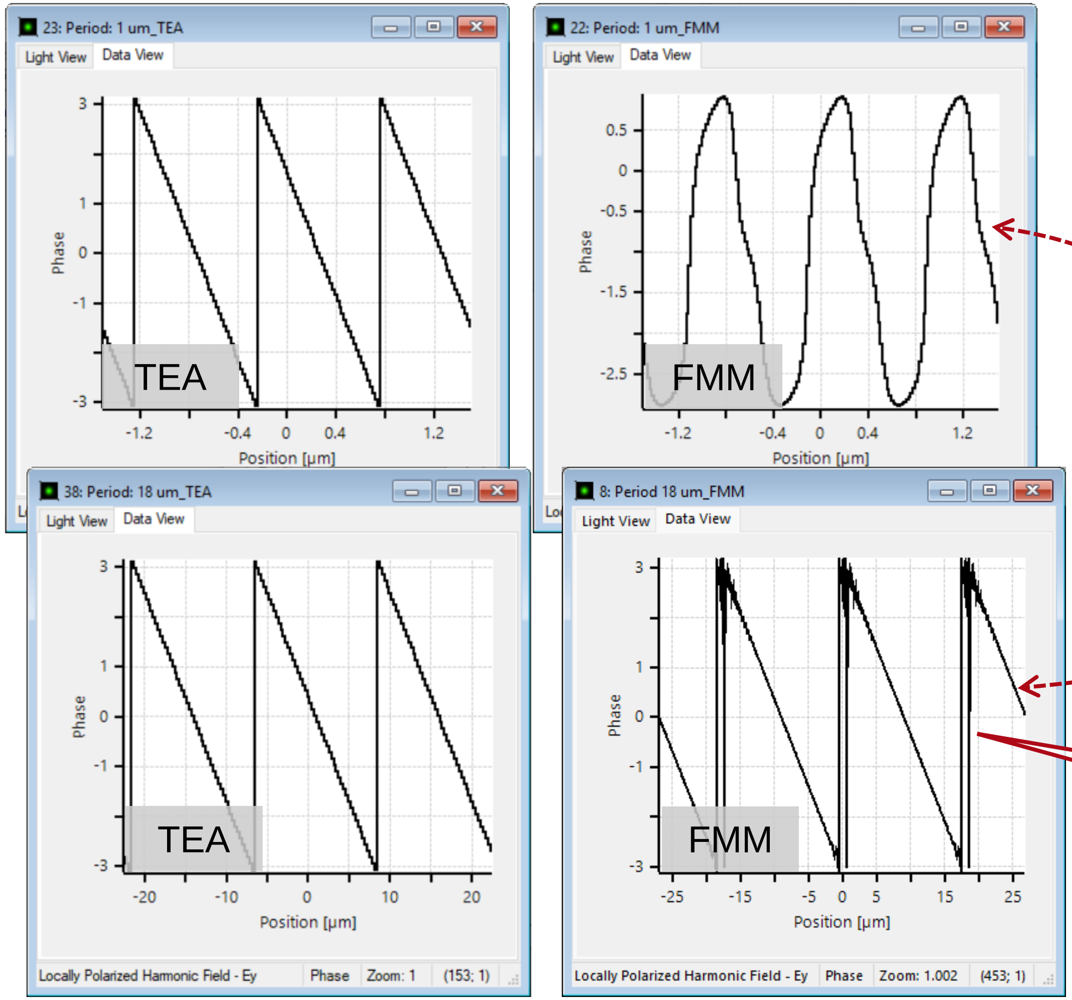
diffraction efficiencies – 1^{st} order



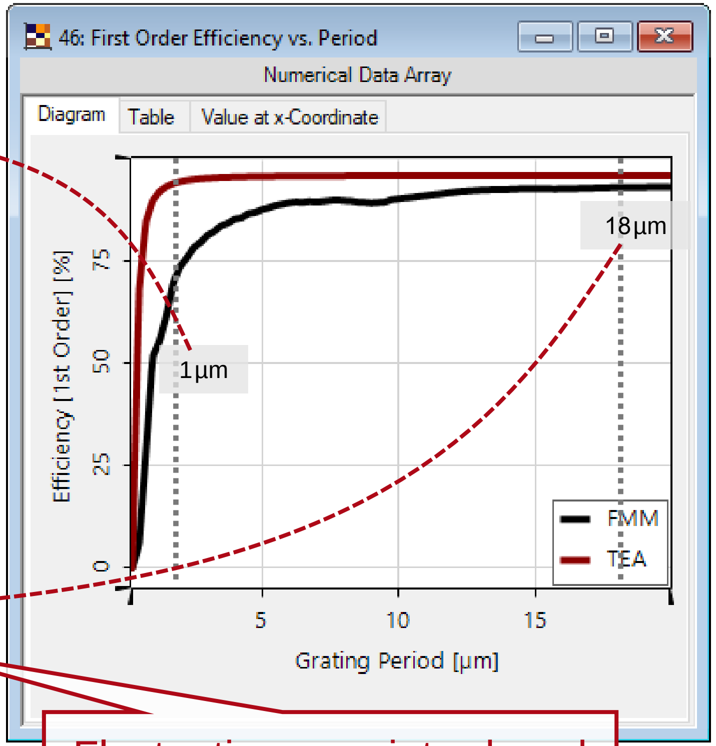
Blazed Grating – Phase Profiles at Selected Periods



period *d* = 1 µm or 18 µm
fixed TE polarization
fixed height *h* = 1064 nm

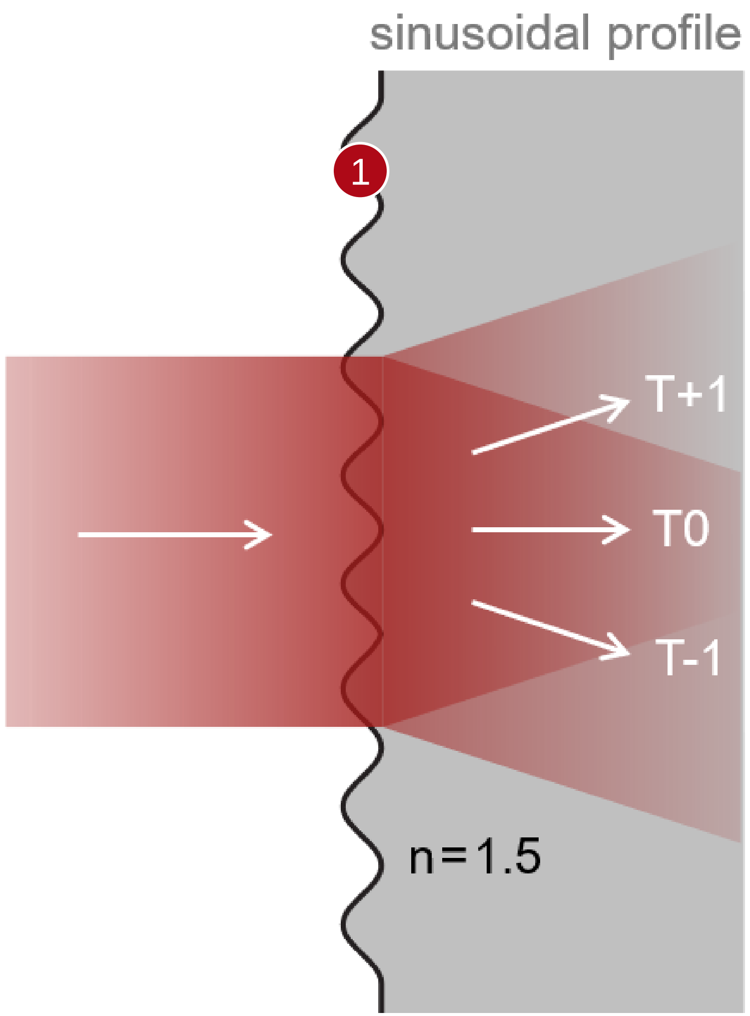


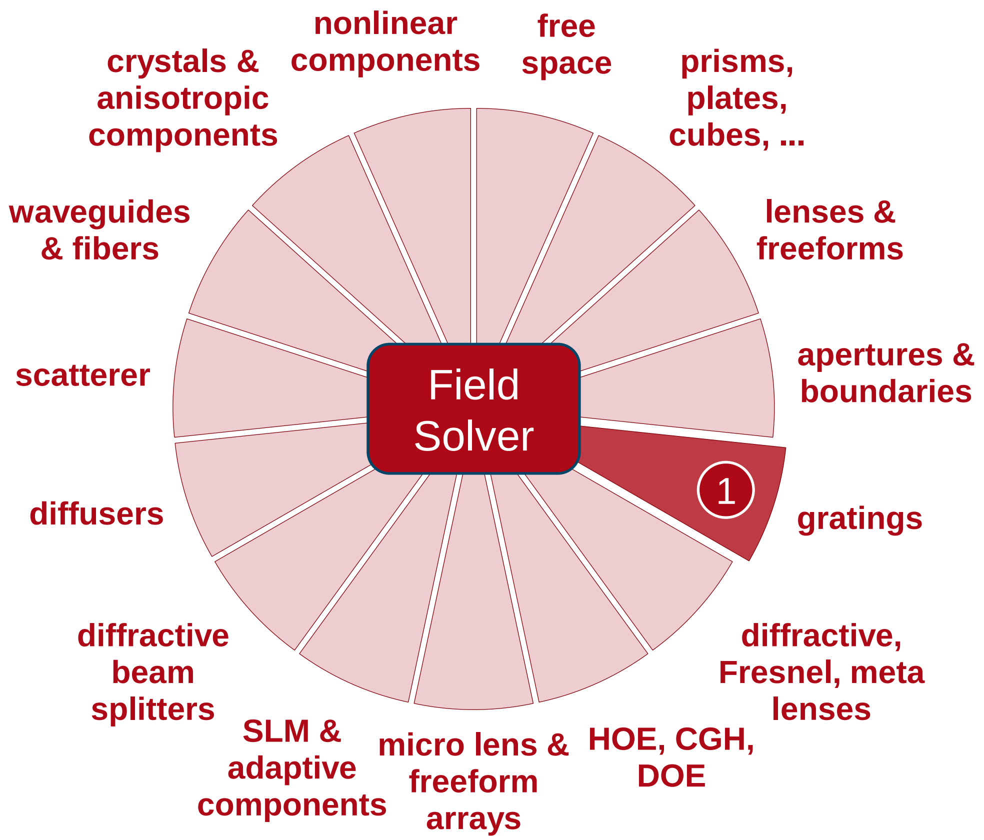
diffraction efficiencies – 1st order



Fluctuations are introduced by the sharp tip of the grating structure.

VirtualLab Fusion Technologies





Document Information

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software edition	VirtualLab Fusion Advanced
software version	2021.1 (Build 1.180)
category	Application Use Case
further reading	• Analysis of Slanted Gratings for Lightguide Coupling • Grating Order Analyzer • Configuration of Grating Structures by Using Interfaces