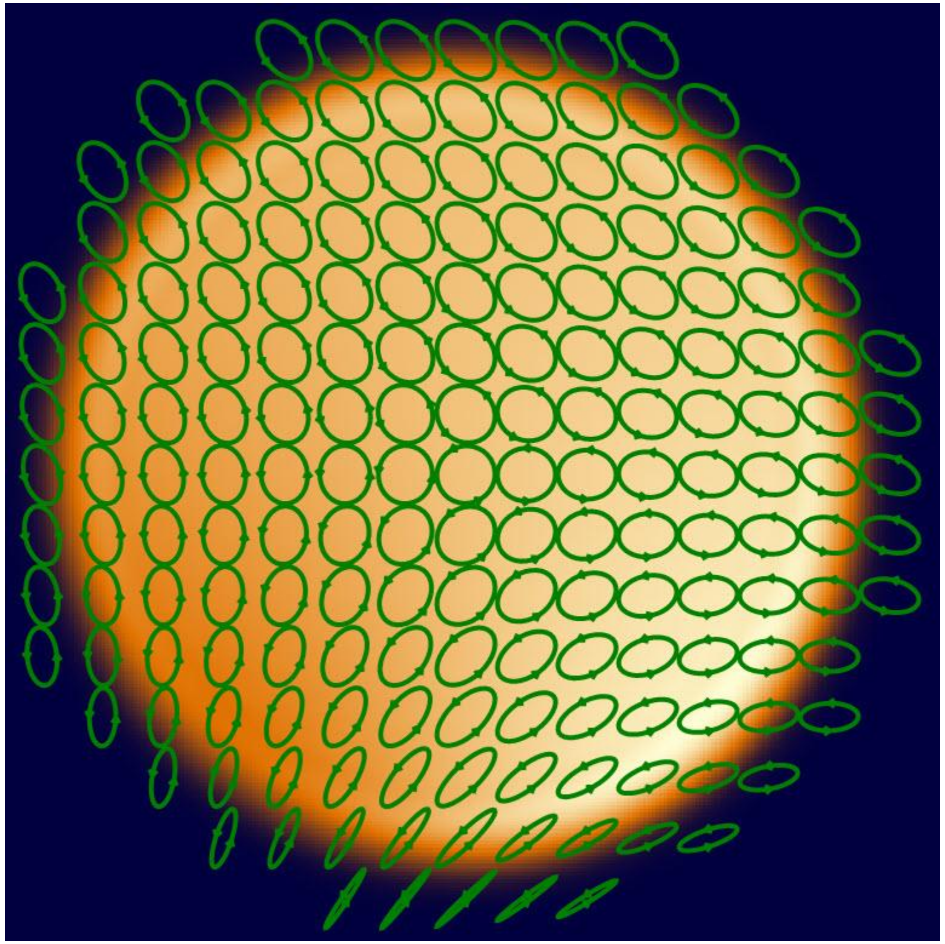
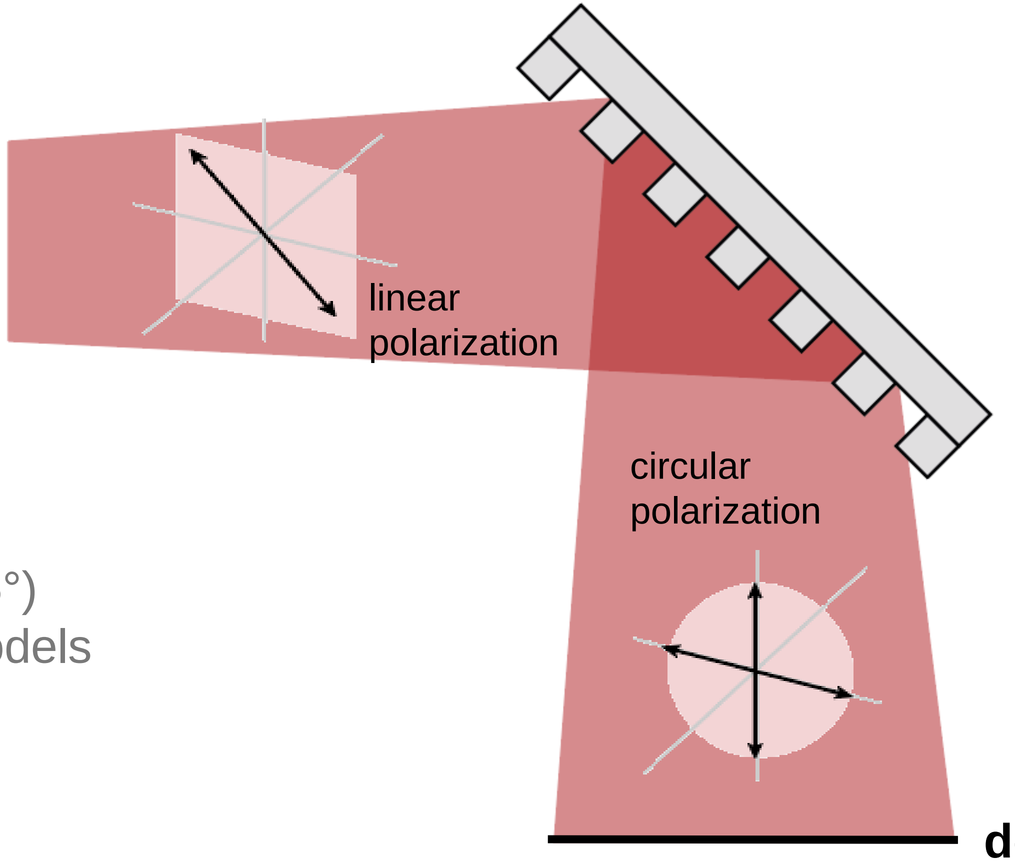
Meta-Structured Phase Retarder

Abstract



Quarter-wave plates – optical elements that can shift polarization states from linear to circular and vice versa – are quite versatile tools used in many different applications, from laser resonators to petrographic microscopes. In particular, diffractive waveplates are a variant of this type of element that is currently increasing in popularity. Diffractive waveplates use subwavelength periodic structures to produce the polarization shift, while maintaining high reflectance over a wide wavelength range. In this use case, we will demonstrate and analyze one such structure that has been optimized to work with a C02 laser beam.

Scenario



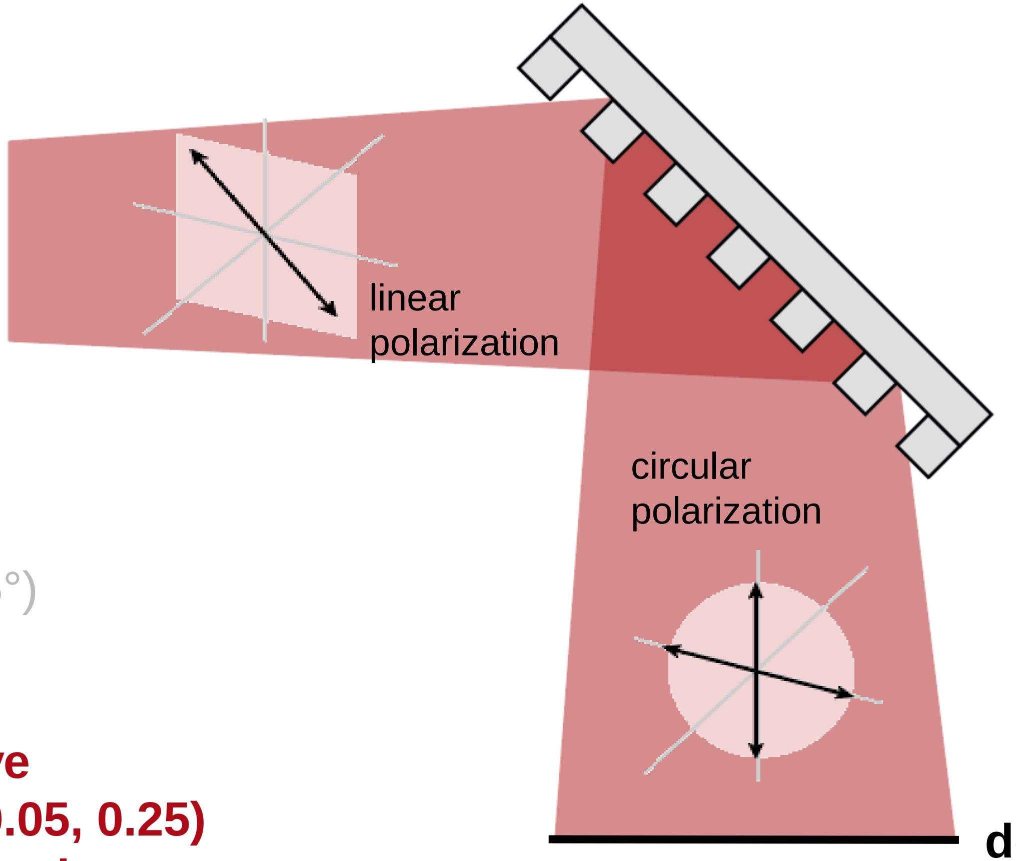
binary grating

- working order: 0th (reflection)
- surrounding material: air
- grating material: copper
- grating period: 8 μm
- grating height: 5.31μm
- fill factor: 41%

CO_2 laser

- wavelength: 10.6 μm
- linearly polarized (45°)
- 6 different spatial models

Task Description



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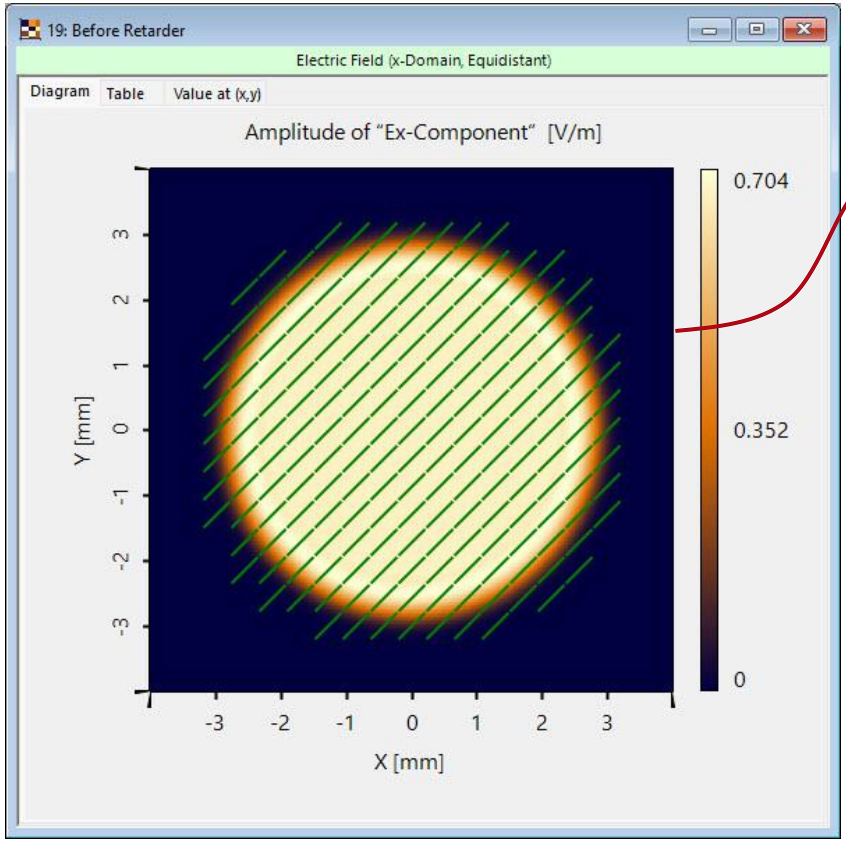
source modelled by:

a) **spherical wave (NA: 0.0018, 0.05, 0.25)**

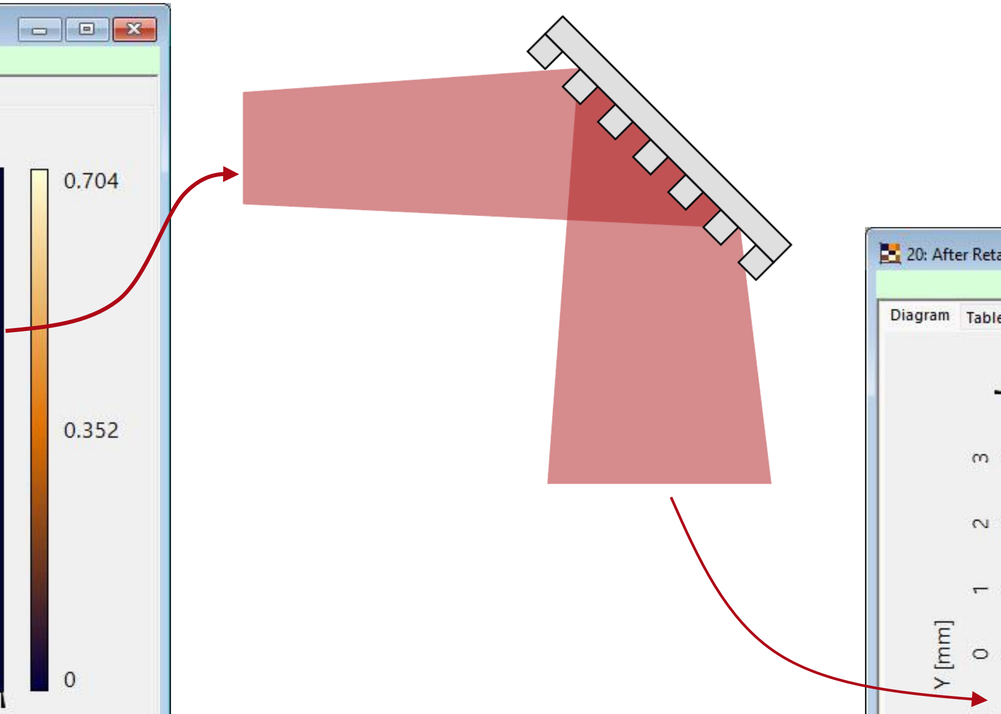
b) **Laguerre-Gaussian wave (mode: 0,0; 1,1; 2,2)**

detector
- **electromagnetic field**
- **polarization ellipses**

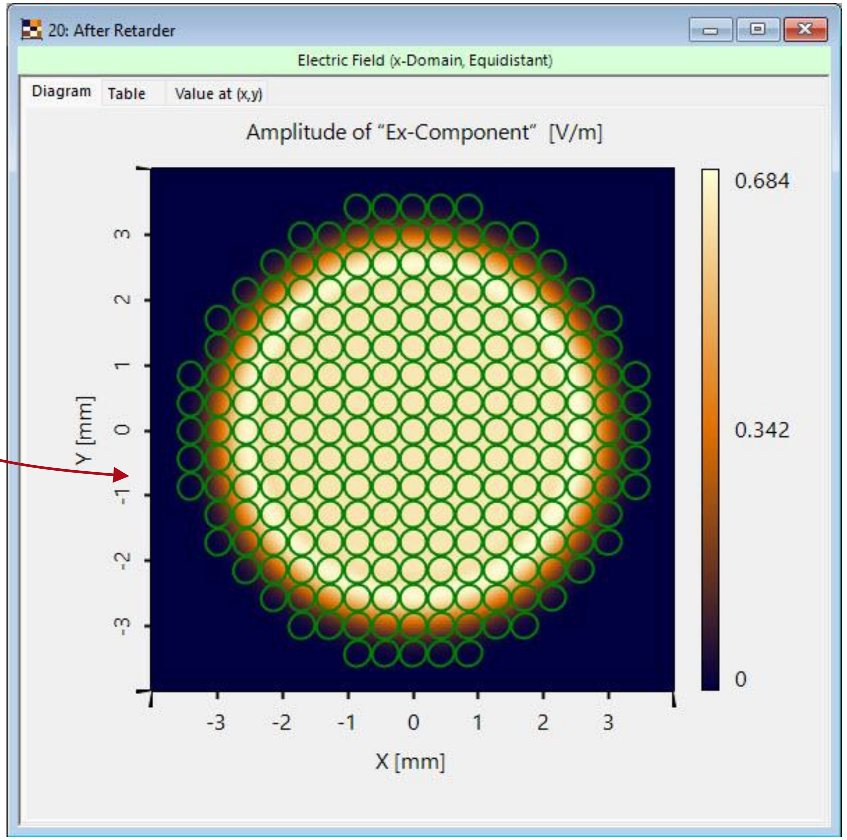
Result



input field (spherical wave, 0.0018 NA)



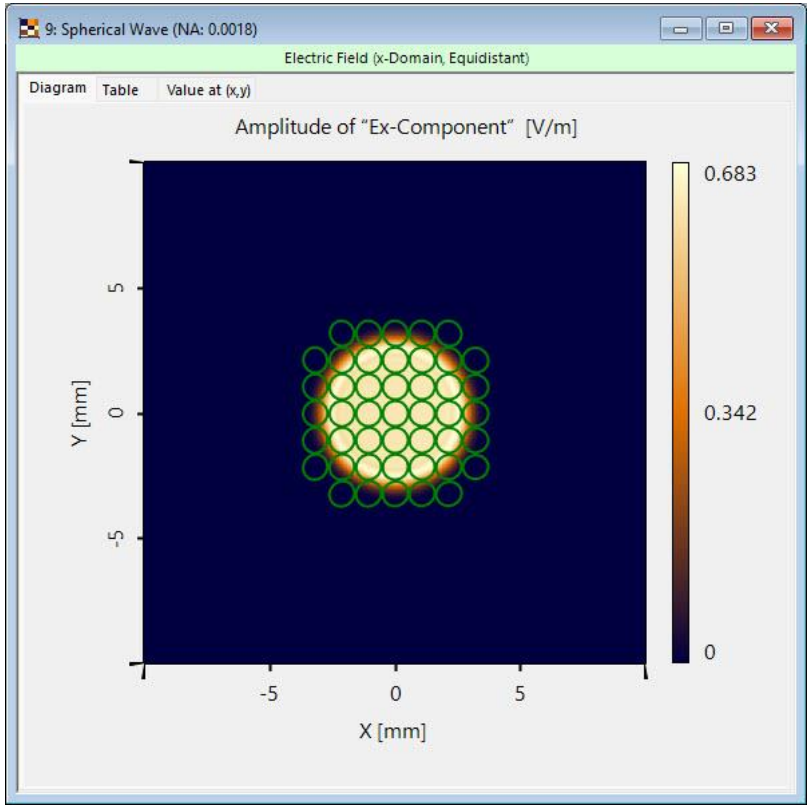
output field



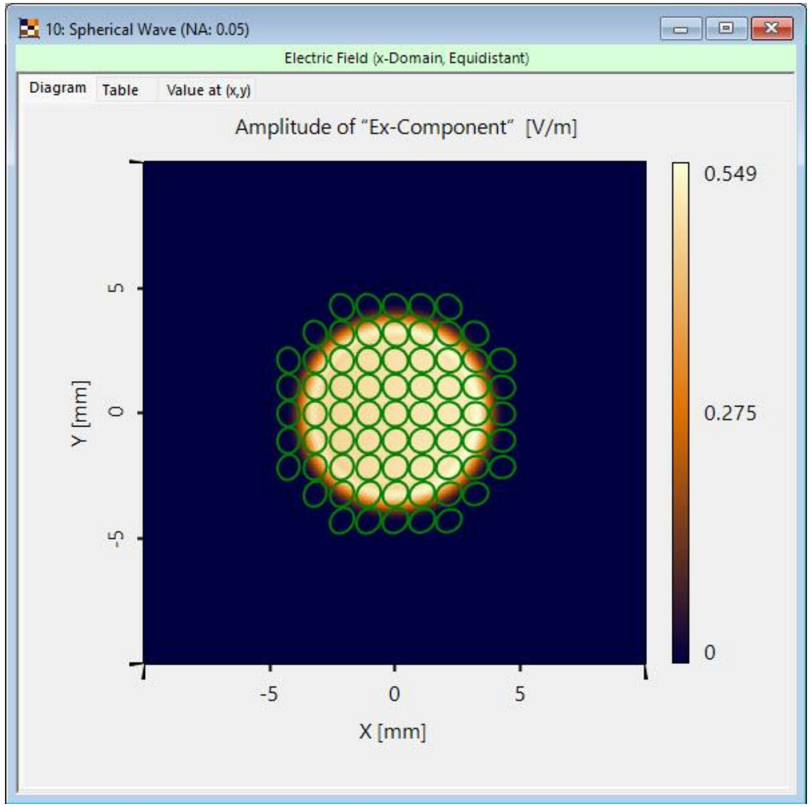
(Note: Polarization ellipses are calculated per pixel, but for clarity we show the average of 20x20 pixels in these illustrations.)

Polarization Uniformity for Different Spherical Waves

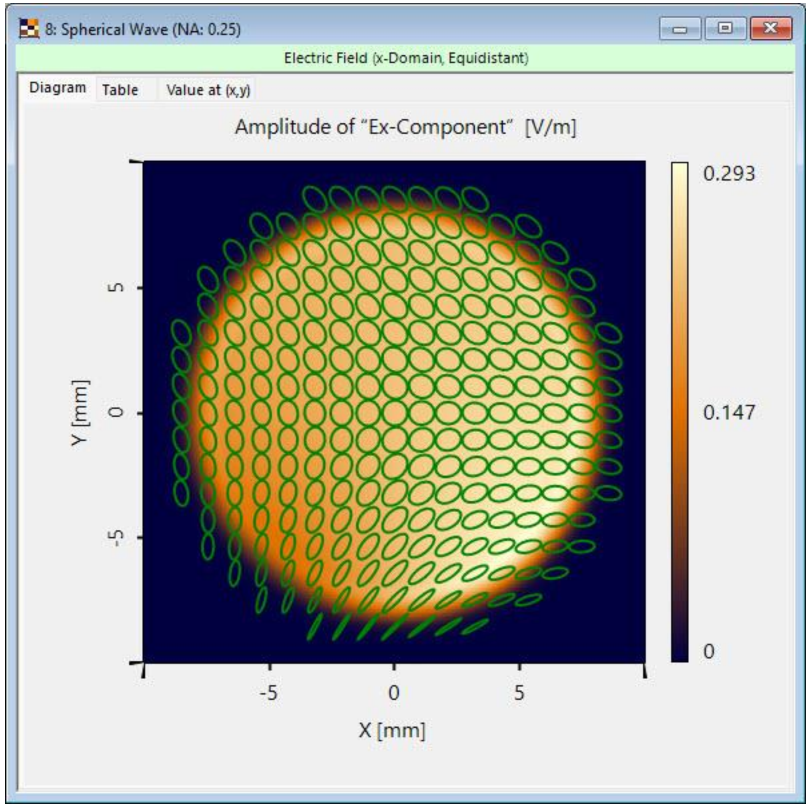
As the grating structure was optimized for illumination from a single direction, using higher NA (and therefore a more divergent field), leads to a local deformation of the polarization ellipses.



NA: 0.0018



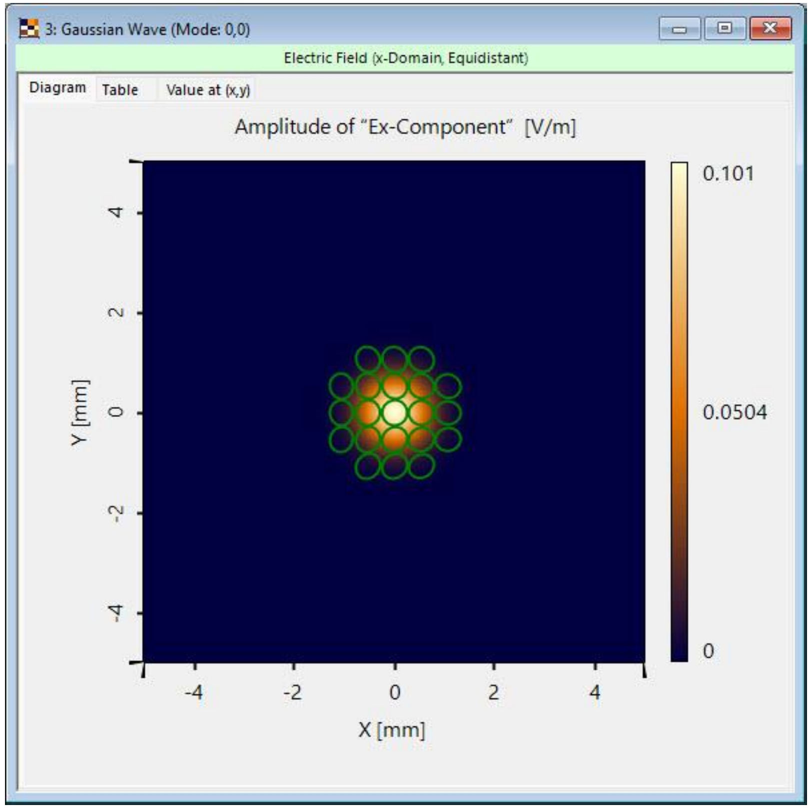
NA: 0.05



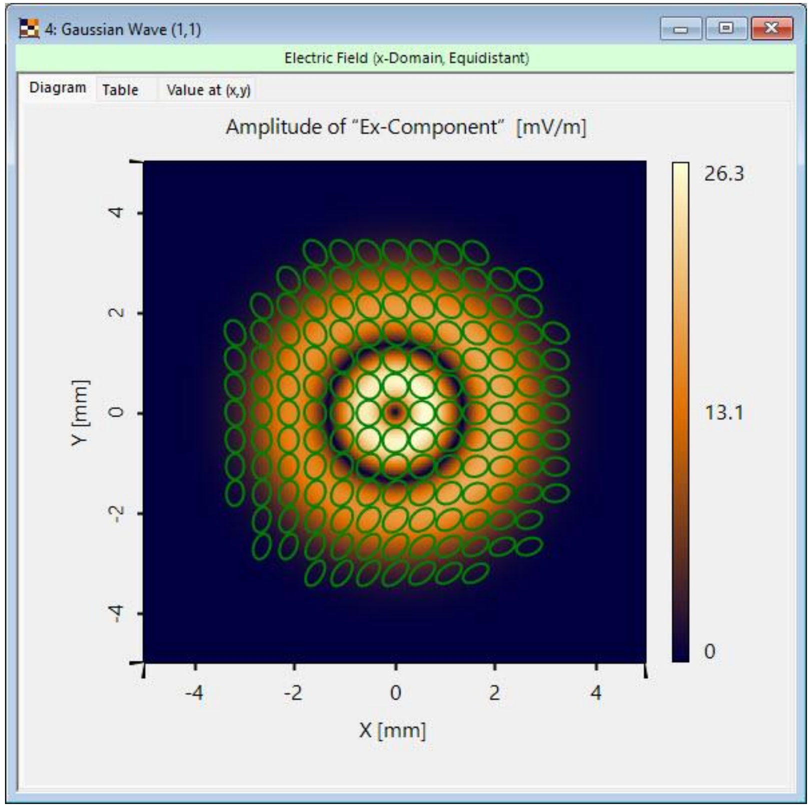
NA: 0.25

Polarization Uniformity for Different Gaussian Modes

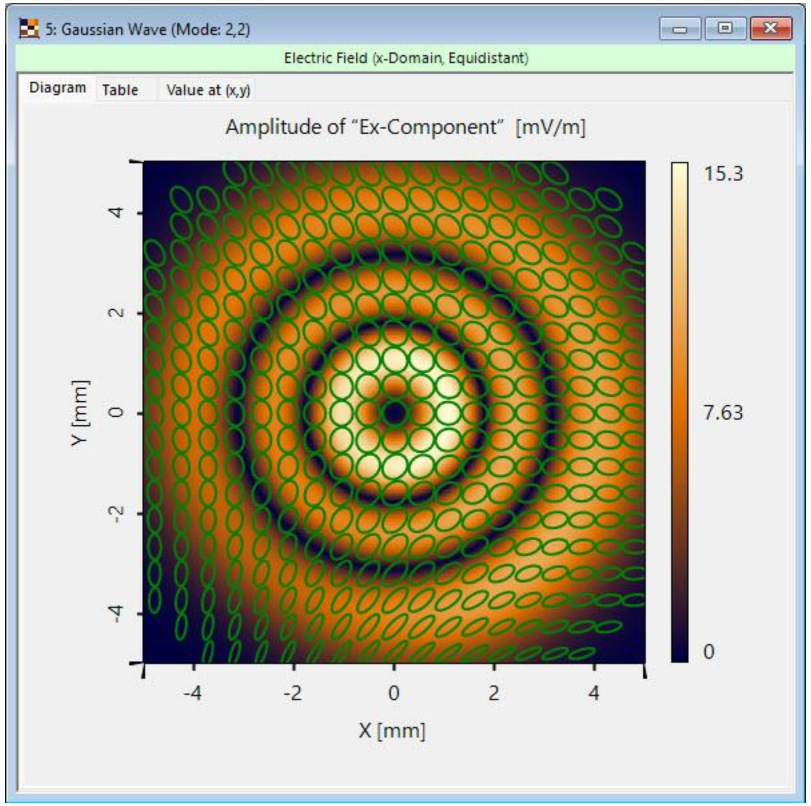
The same effect can be seen for higher order Gaussian Modes, as they are, also, higher divergent fields.



(0,0) mode



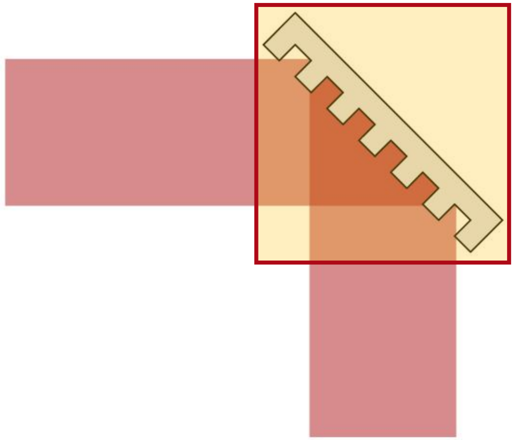
(1,1) mode



(2,2) mode

Workflows

Connected Modeling Techniques: Meta-Structured Grating

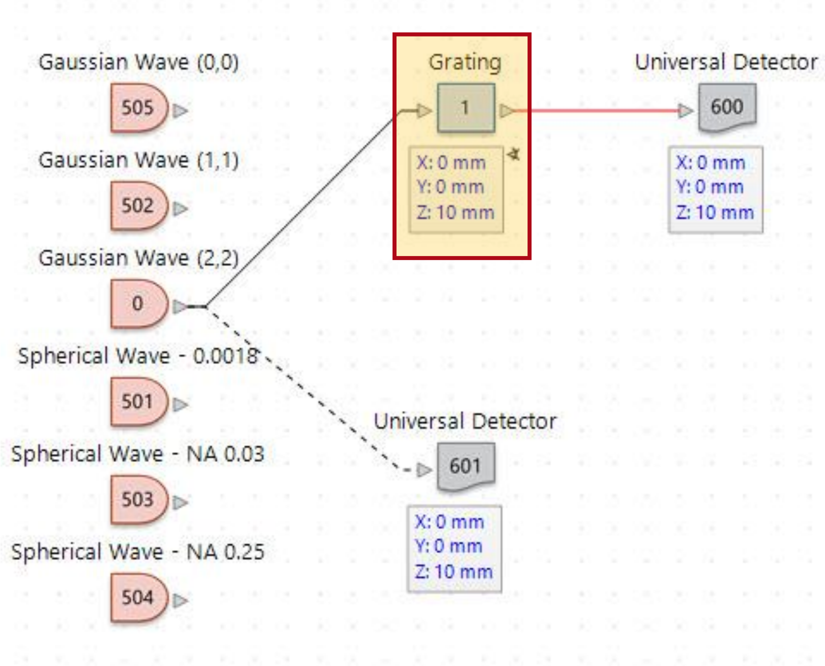


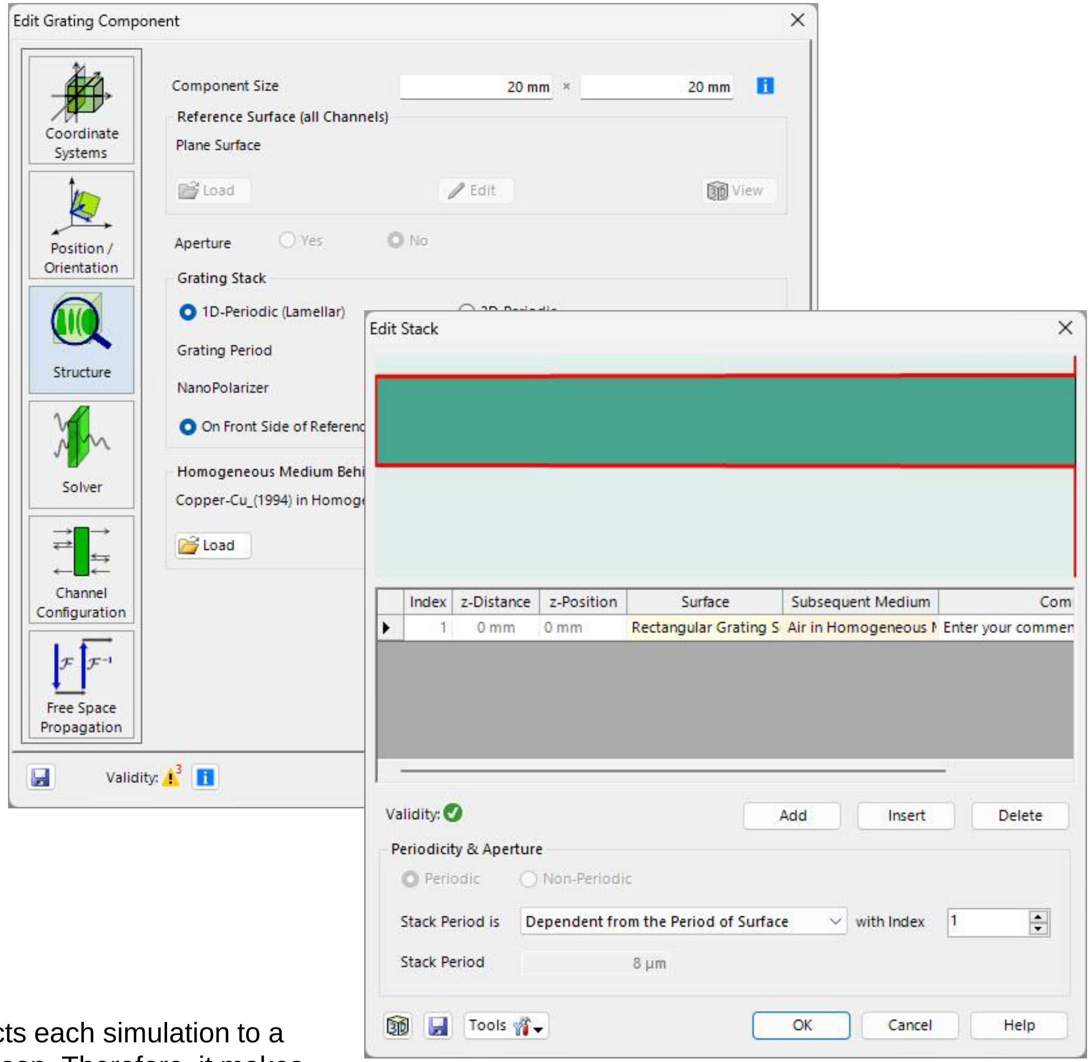
Available modeling techniques for microstructures:

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 < ~ (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	

While the period might seem large at first sight it is still small in comparison to the long wavelength of the CO_2 laser. Hence, the **Fourier Modal Method (FMM)** can be used to provide a rigorous solution.

Simulation of the Structure: Stacks & Grating Component





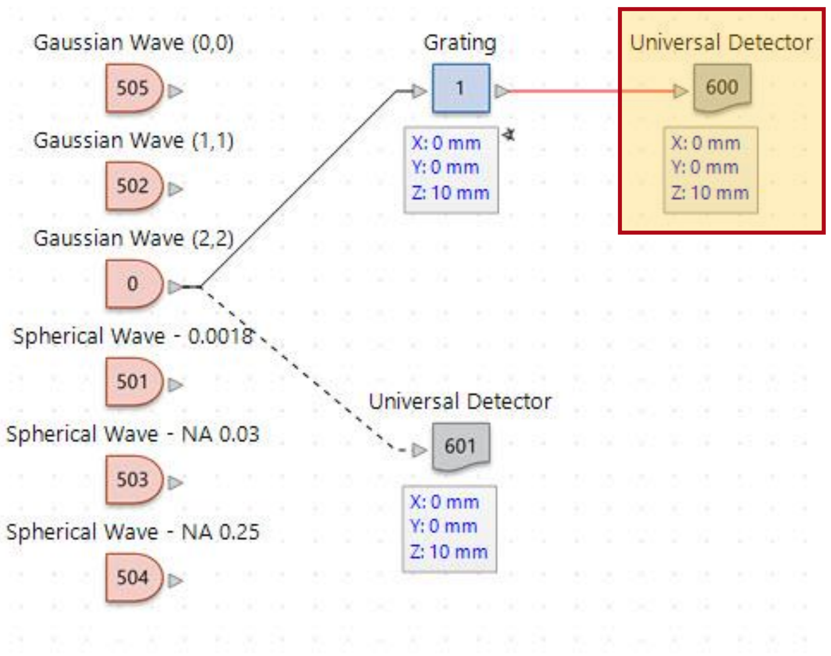
The meta-structured grating can be included as a *Stack* into a *Grating Component* in the *General Optical Setup**, to combine it with the various different source models required for the example.

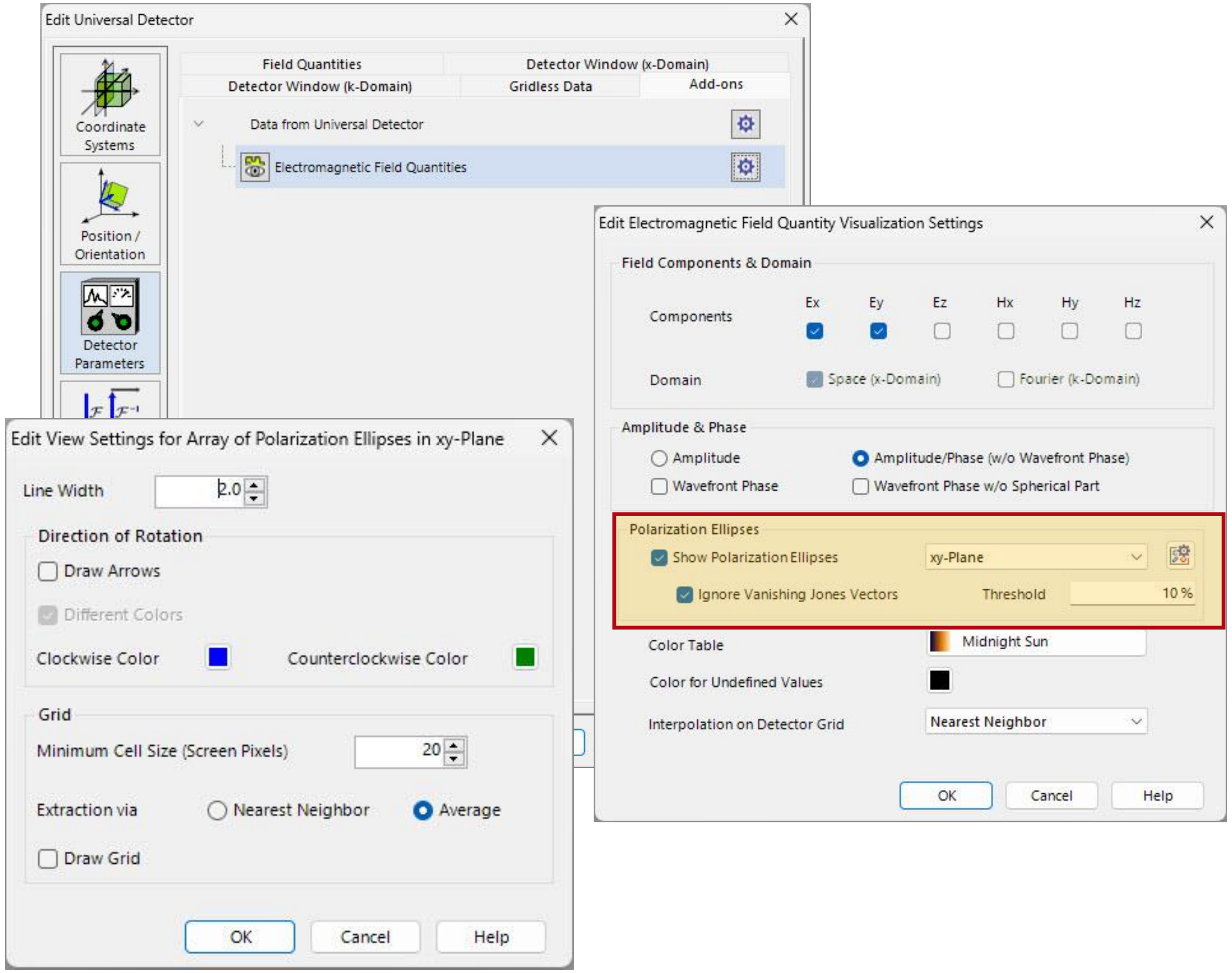
*The *Grating Optical Setup*, which might at first appear to be the obvious choice for this example, restricts each simulation to a single pass of the FMM algorithm. Only the *Ideal Plane Wave* source is then available there, for this reason. Therefore, it makes sense here to work with the *General Optical Setup.*

Document Information

title	Meta-Structured Phase Retarder
document code	GRT.0035
document version	1.0
required packages	-
software version	2024.1 (Build 1.132)
category	Application Use Case
further reading	• Grating Order Analyzer • Parameter Variation Analyzer • Introduction to the Parametric Optimization Document

Visualization of the Result: Universal Detector





The flexible *Universal Detector* provides access to the electromagnetic field at the detector plane and can be used to calculate additional magnitudes from this information. In this particular case we want to calculate the local polarization ellipses on the x, y plane.