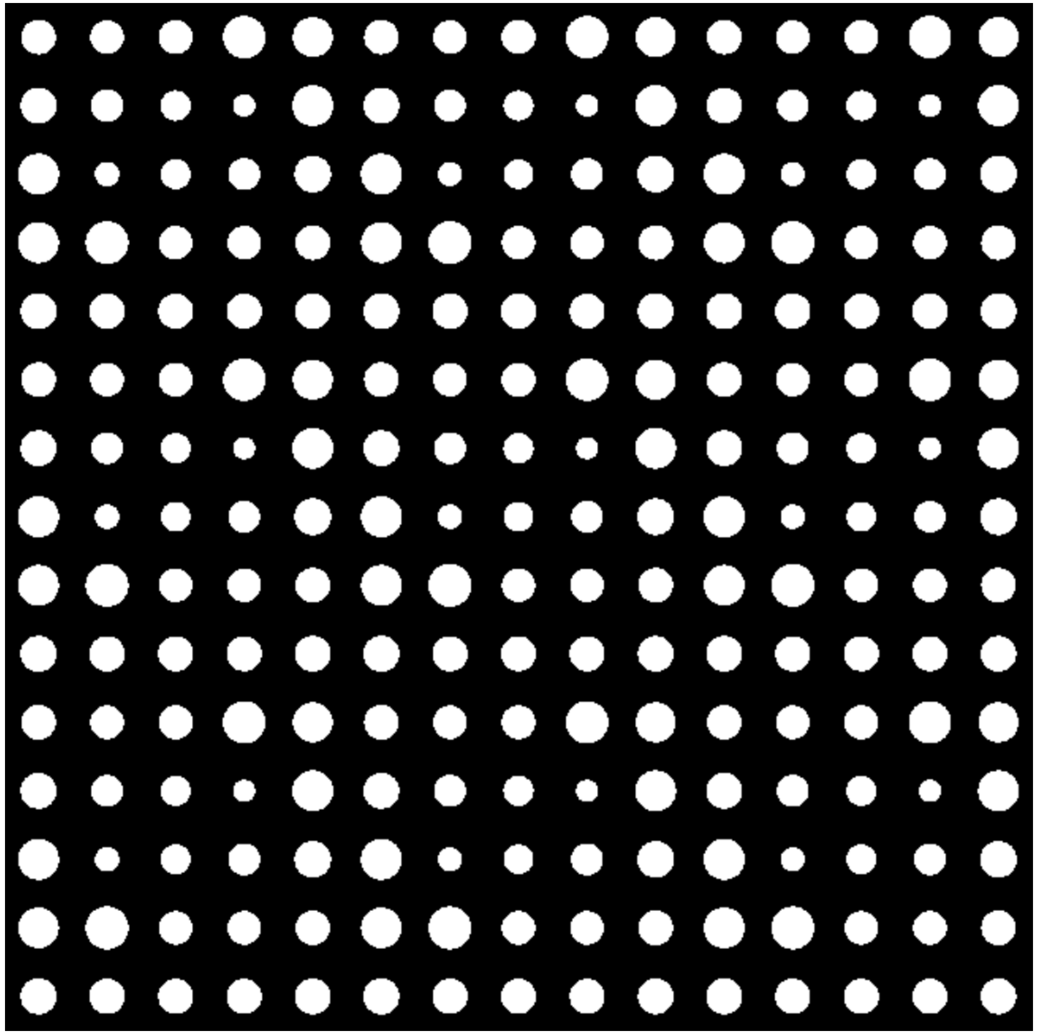
Design of 2D Non-Paraxial Beam-Splitting Metagrating

Abstract

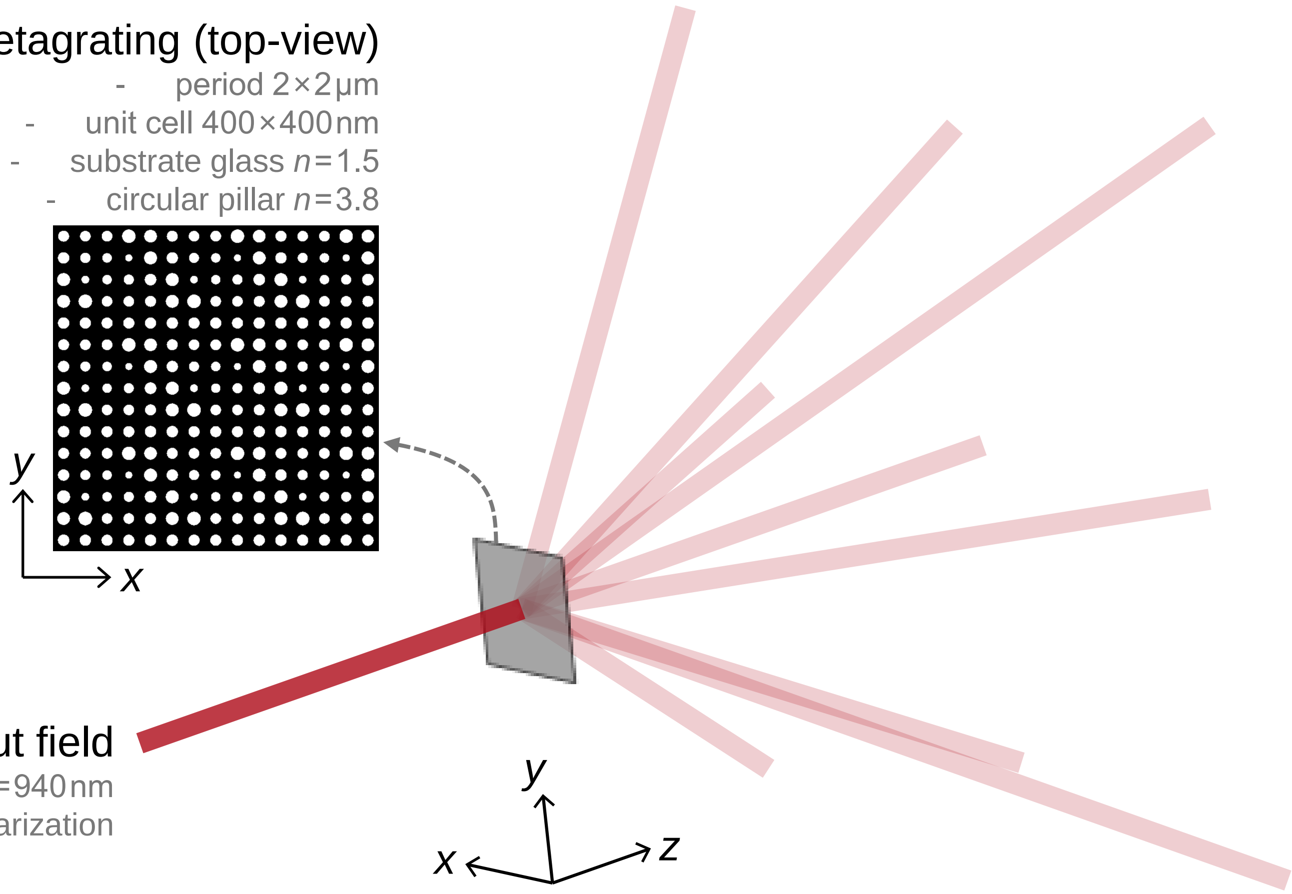


Metagratings are shown to have advantages when compared with traditional gratings, especially in non-paraxial cases. In this example, we design a two-dimensional (2D) metagrating that splits the input into 3x3 beams. The metagrating is constructed with circular nano pillars, and in VirtualLab Fusion, we use FMM/RCWA to evaluate the diffraction efficiency of the metagrating. And, we show how to use the parametric optimization tool to improve the uniformity of the diffraction efficiencies.

Design Task

metagrating (top-view)

- period 2×2 μm
- unit cell 400×400 nm
- substrate glass n=1.5
- circular pillar n=3.8



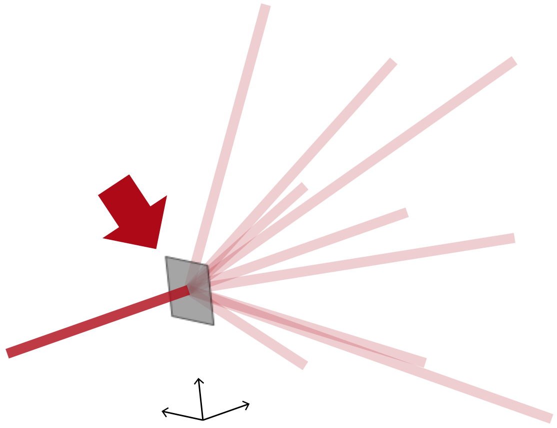
input field

- wavelength λ=940 nm
- x-polarization

How to design a metagrating that splits the input into 3×3 beams, with

- uniform power distribution into the 3×3 beams, and
- high overall transmission power of the 3×3 beams?

Connected Modeling Techniques: Metagrating

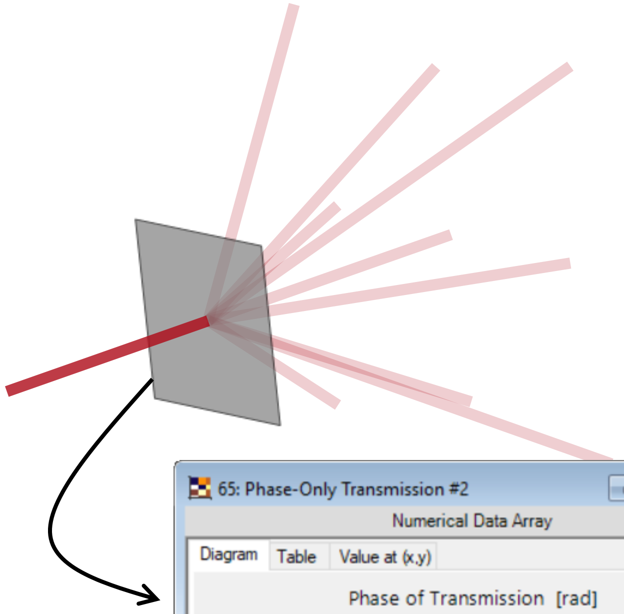


Available modeling techniques for periodic micro and nano structures:

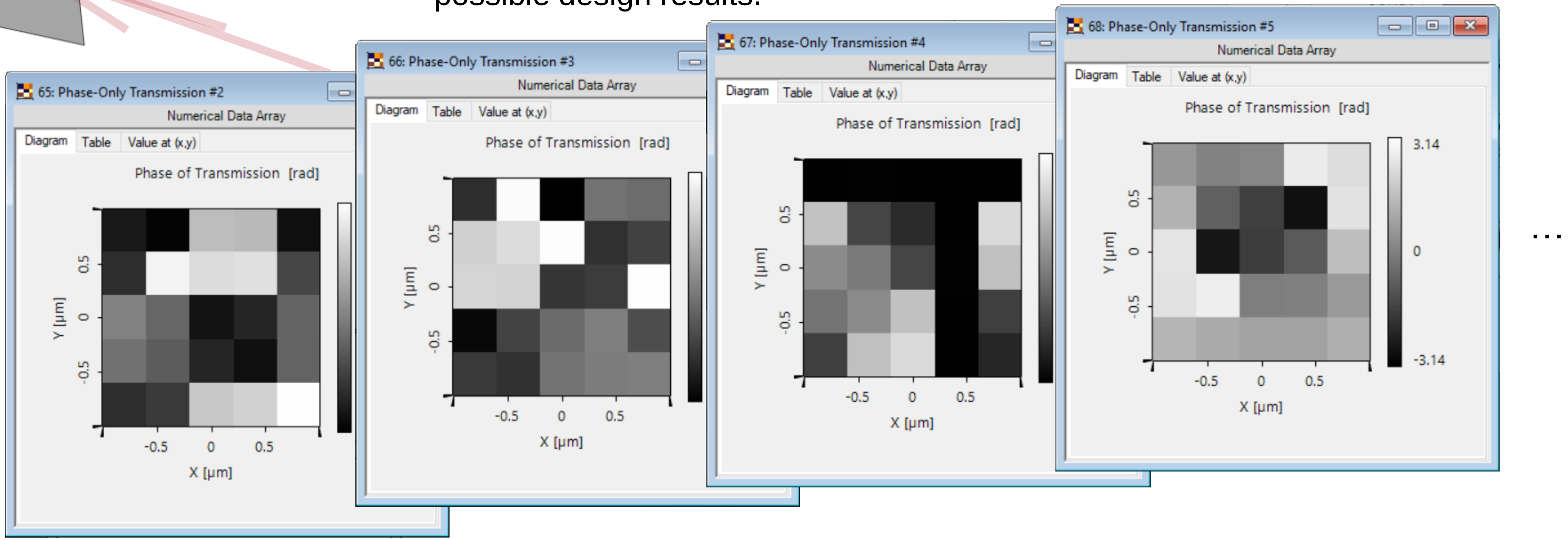
Methods	Preconditions	Accuracy	Speed	Comments
Fourier Modal Method (FMM)	None	High	High	**Small periods**
Thin Element Approximation	**Large periods & features, thin**	High	High	Thickness about wavelength; period & features larger than about ten wavelengths
	Otherwise	Low	High	
FMM in Kogelnik Approximation	**Thick volume gratings; Bragg condition**	High	Very high	Method is electromagnetic formulation of Kogelnik's approach
	No Bragg condition	Low	Very high	

As a rigorous eigenmode solver, the Fourier modal method (also known as rigorous coupled wave analysis, RCWA) provides a very high accuracy. Due to the small periods and distances in this setup, the calculation speed is fast. FMM is then the best compromise of accuracy and speed for the simulation of the beam-splitting metagrating.

Phase-Only Transmission Design (IFTA)



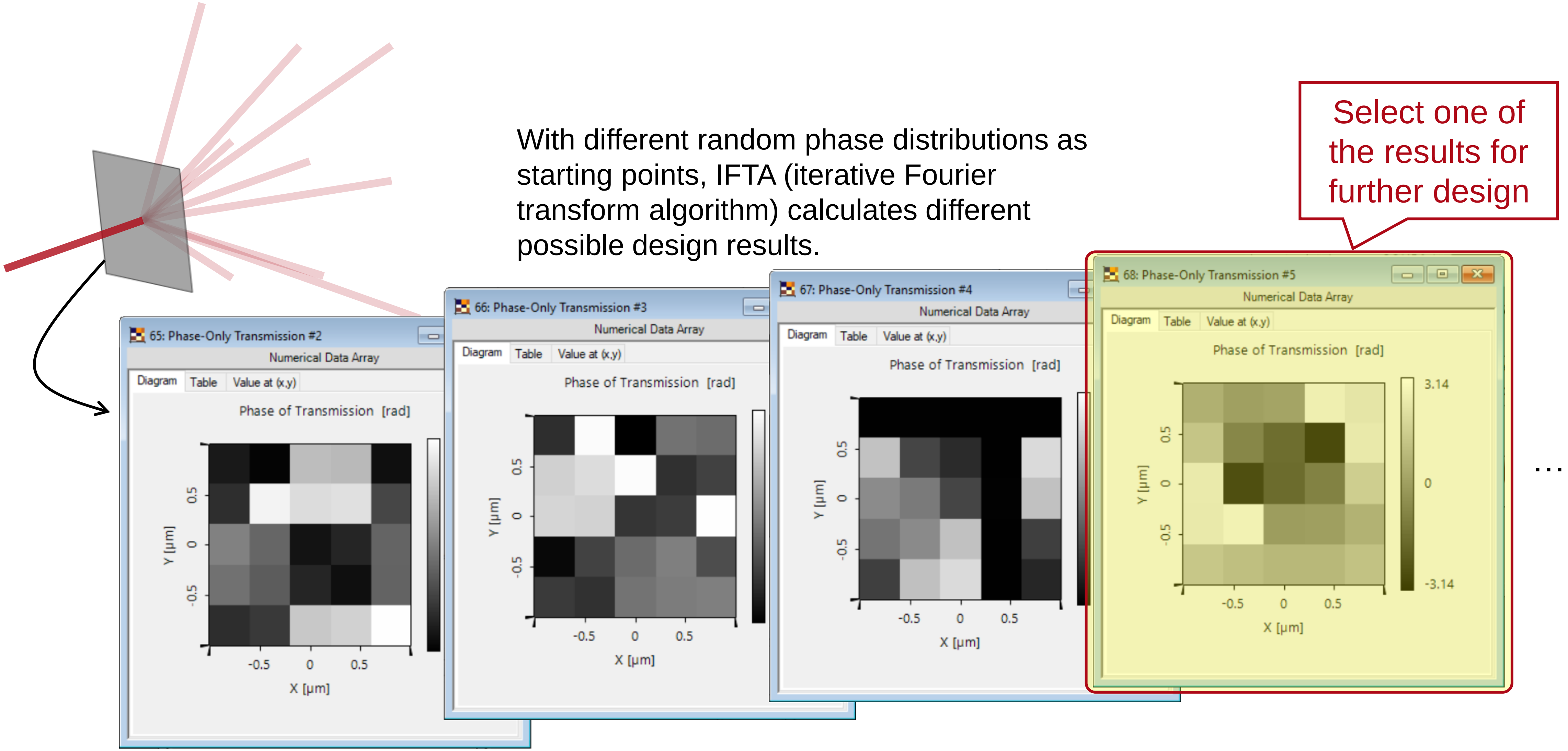
With different random phase distributions as starting points, IFTA (iterative Fourier transform algorithm) calculates different possible design results.



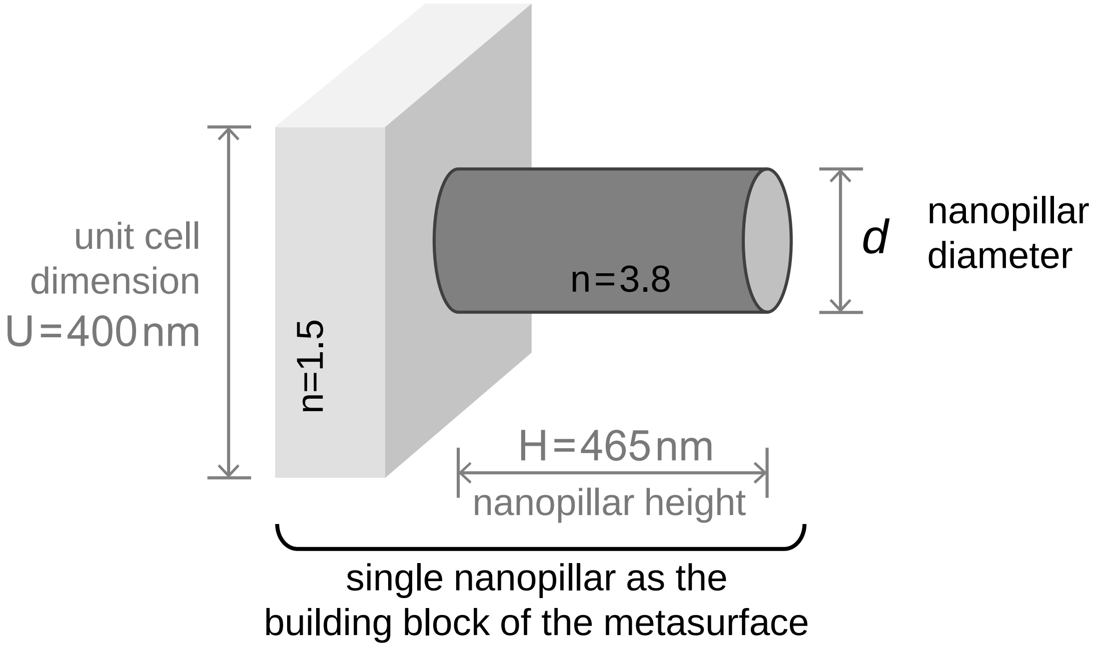
Phase-Only Transmission Design (IFTA)

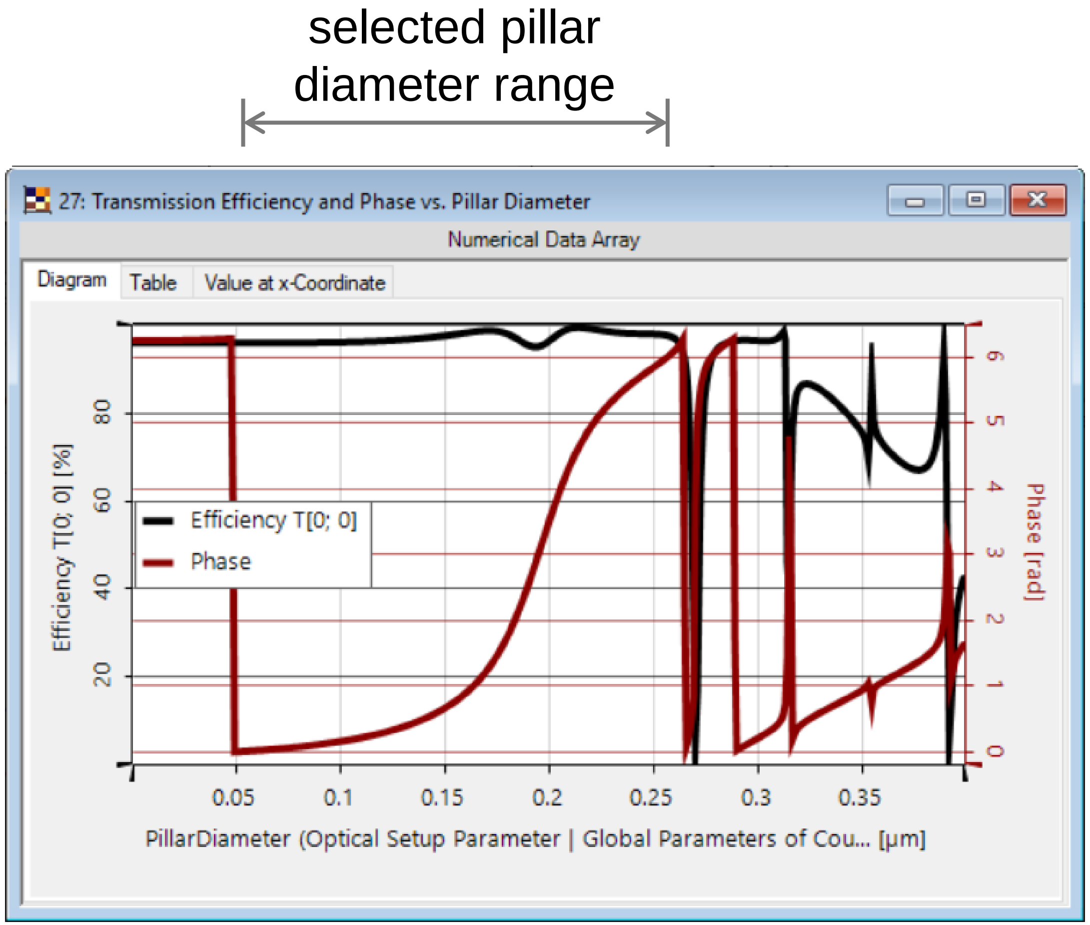
With different random phase distributions as starting points, IFTA (iterative Fourier transform algorithm) calculates different possible design results.

Select one of the results for further design



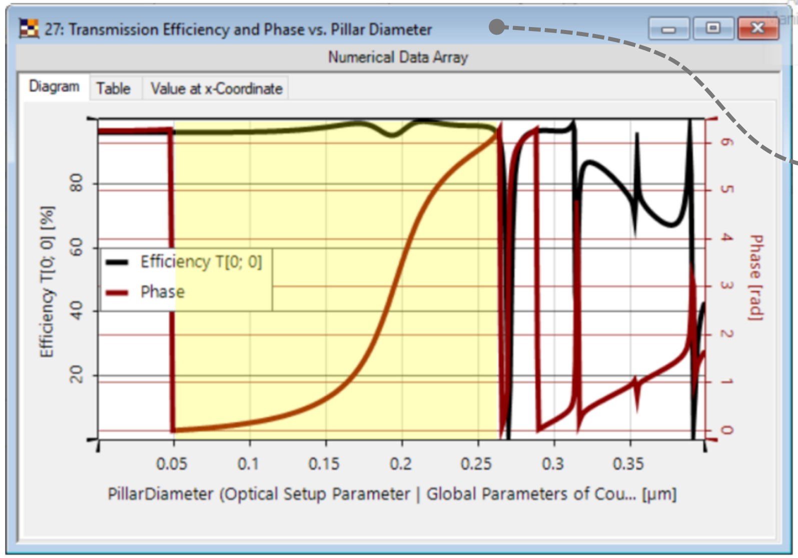
Metasurface Unit Cell Analysis

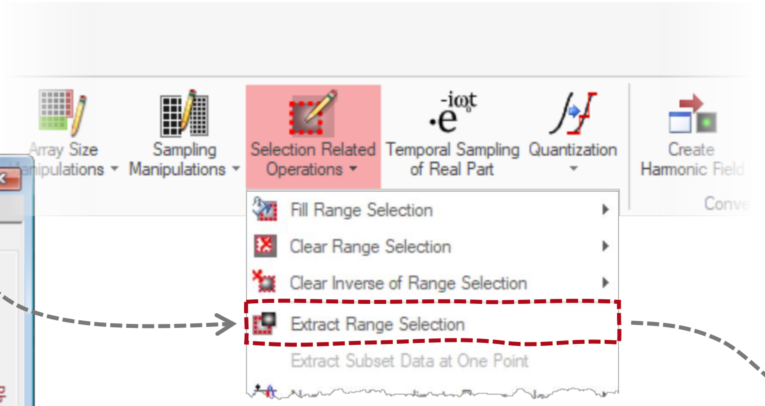


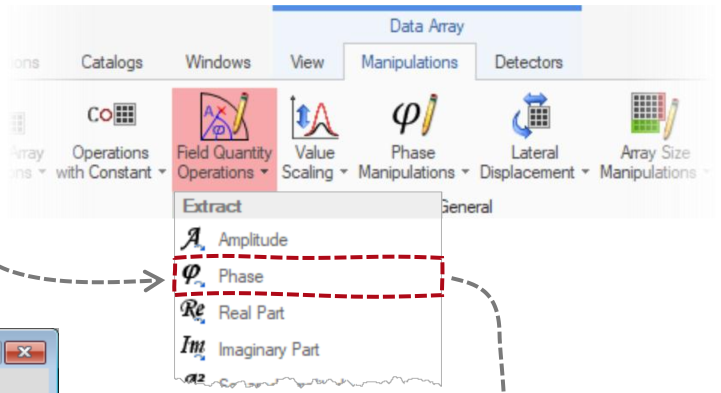


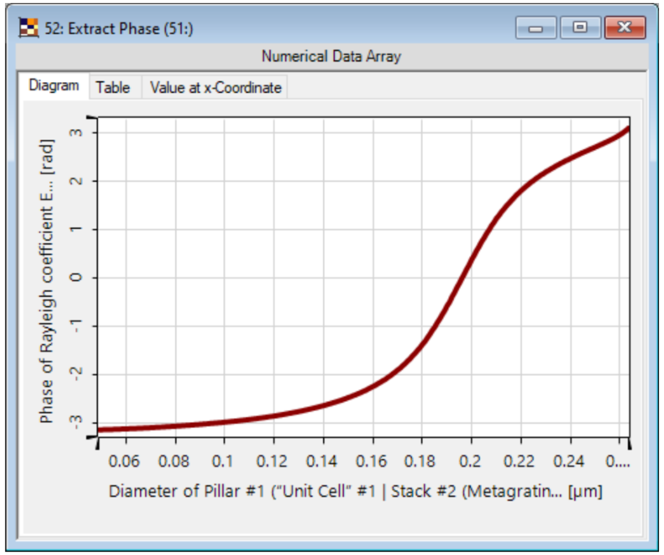
Unit Cell Parameter Range Selection

selected pillar diameter range





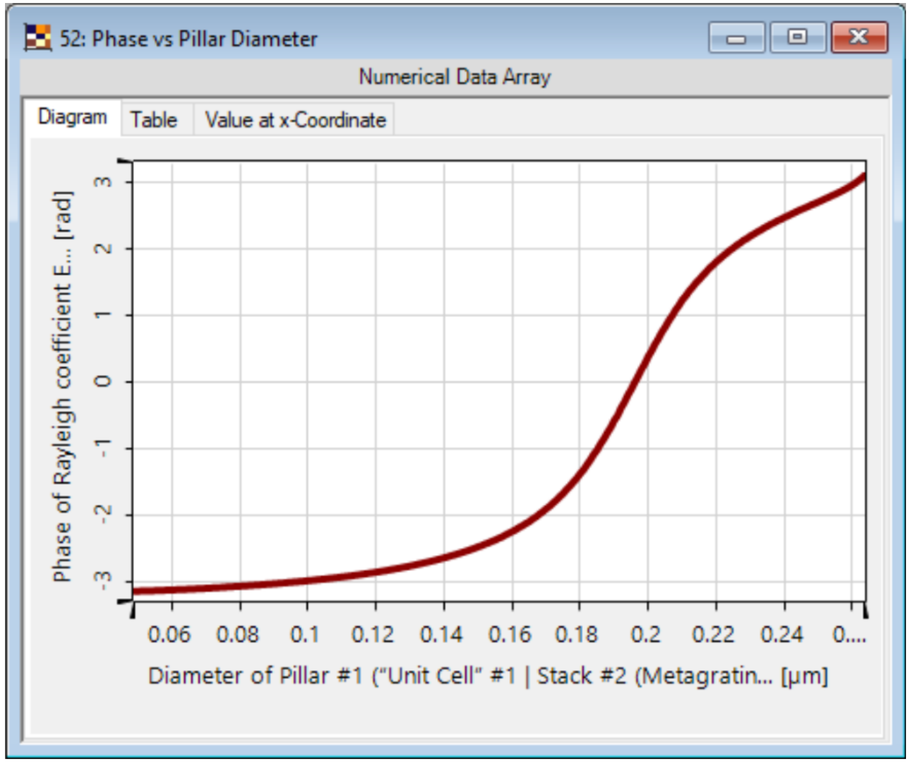




phase vs pillar diameter within the selected parameter range

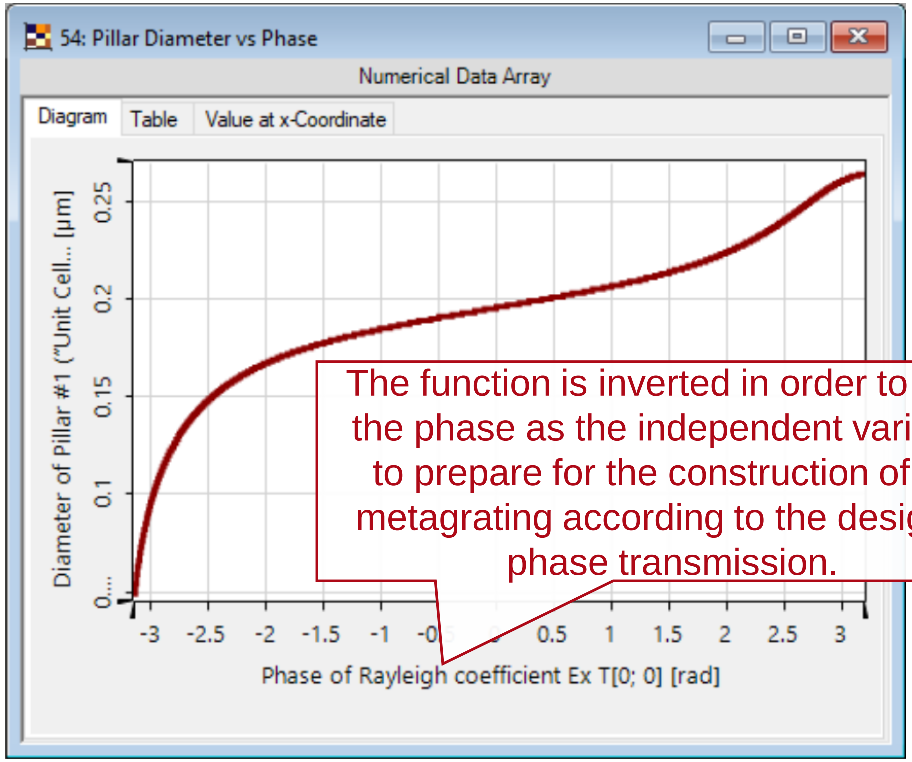
Phase vs Pillar Diameter and Its Inverse

phase value vs pillar diameter
(result from last step)



inverse

pillar diameter vs phase value



The function is inverted in order to have the phase as the independent variable, to prepare for the construction of the metagrating according to the designed phase transmission.

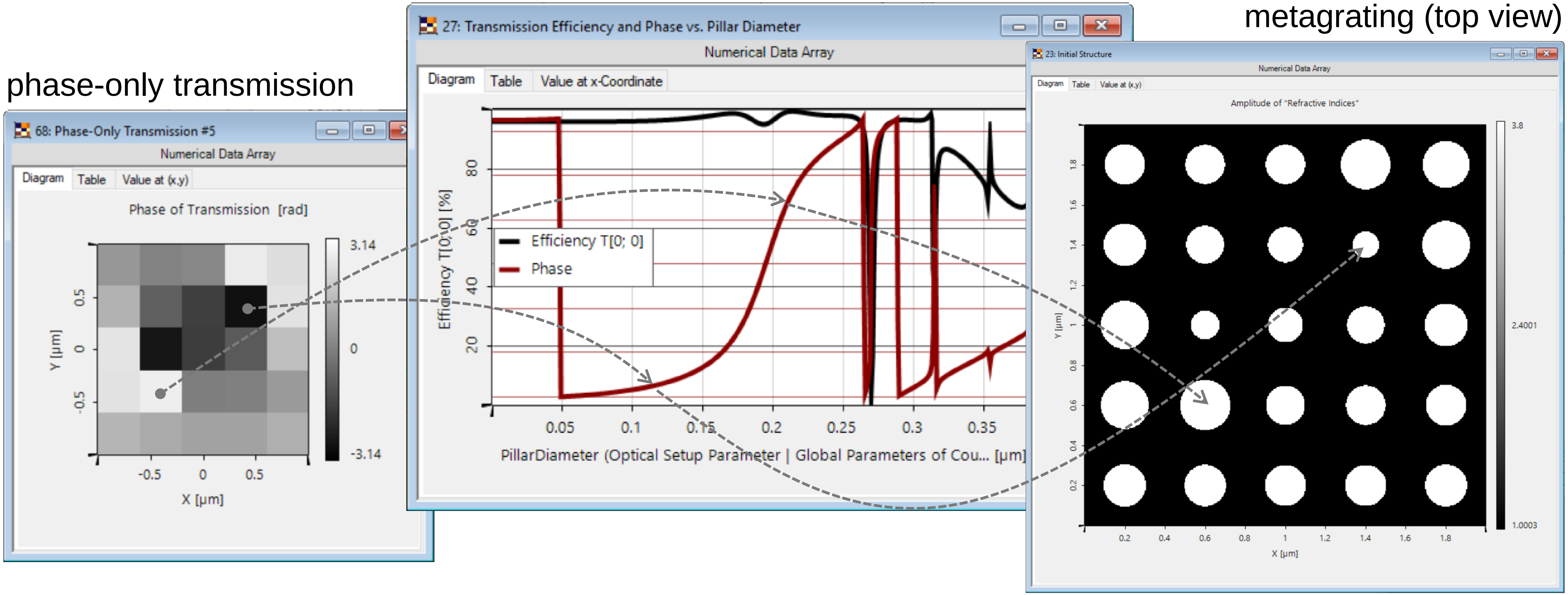
In this example, function inversion can be done with the VirtualLab C# Module: Appx_01_Calculate Inverse of 1D Function.cs

Metagrating Construction

phase-diameter map/library

metagrating (top view)

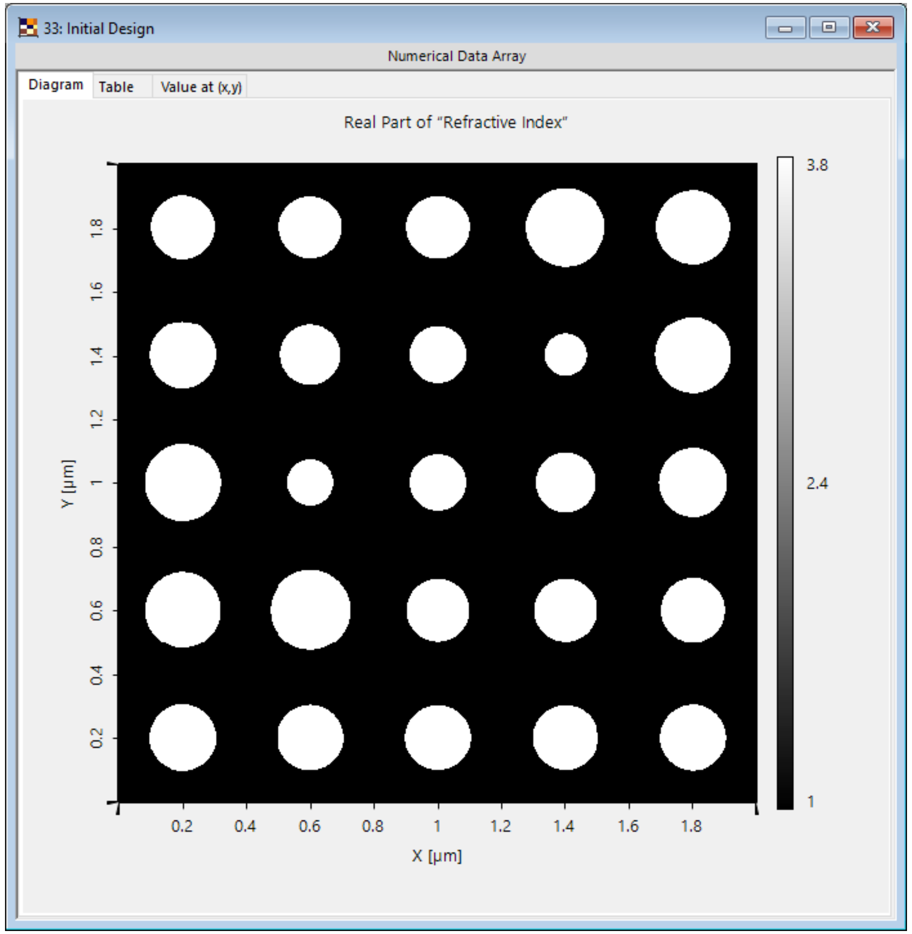
phase-only transmission



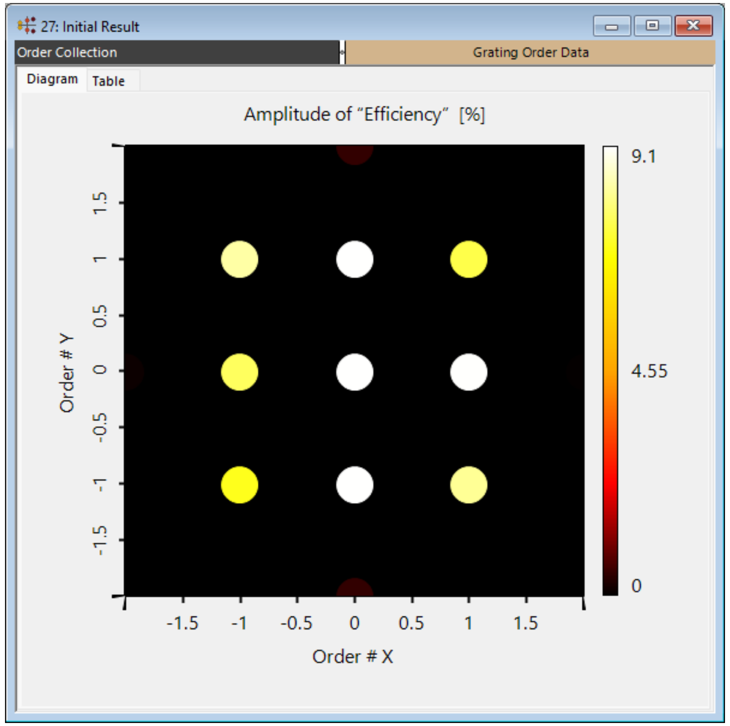
In this example, pillar distribution can be done with the VirtualLab C# Module: Appx_02_Calculate Pillar Diameters from Phase Profile.cs

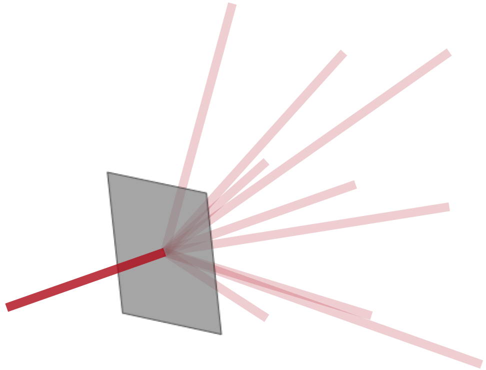
Evaluation of Initial Metasurface Design

initial metagrating (top-view)



diffraction efficiencies

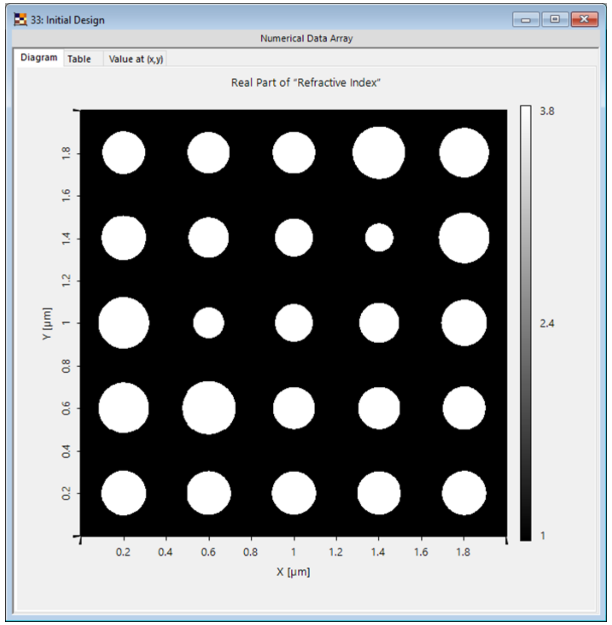




overall efficiency	79.6%
uniformity error (PV)	25.3%
uniformity error (RMS)	16.9%

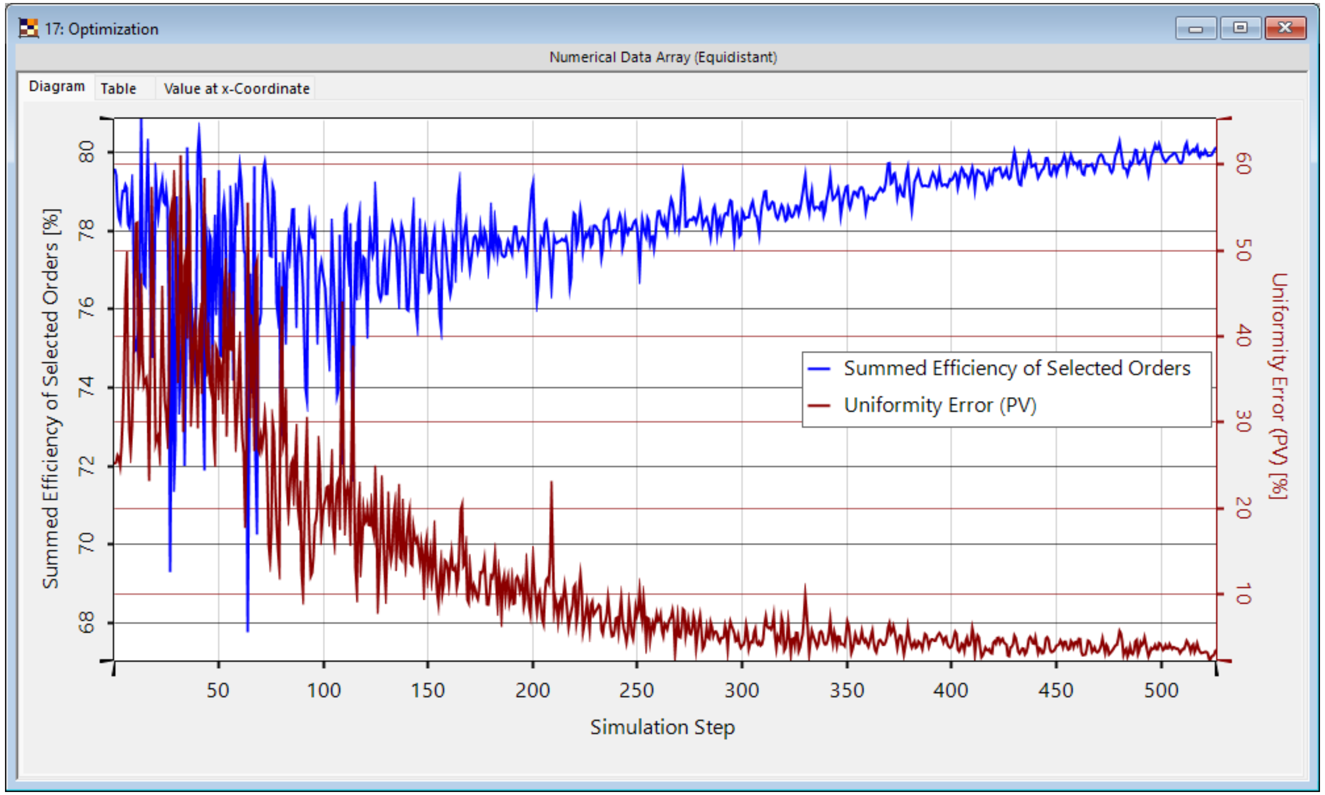
Parametric Optimization

initial metagrating



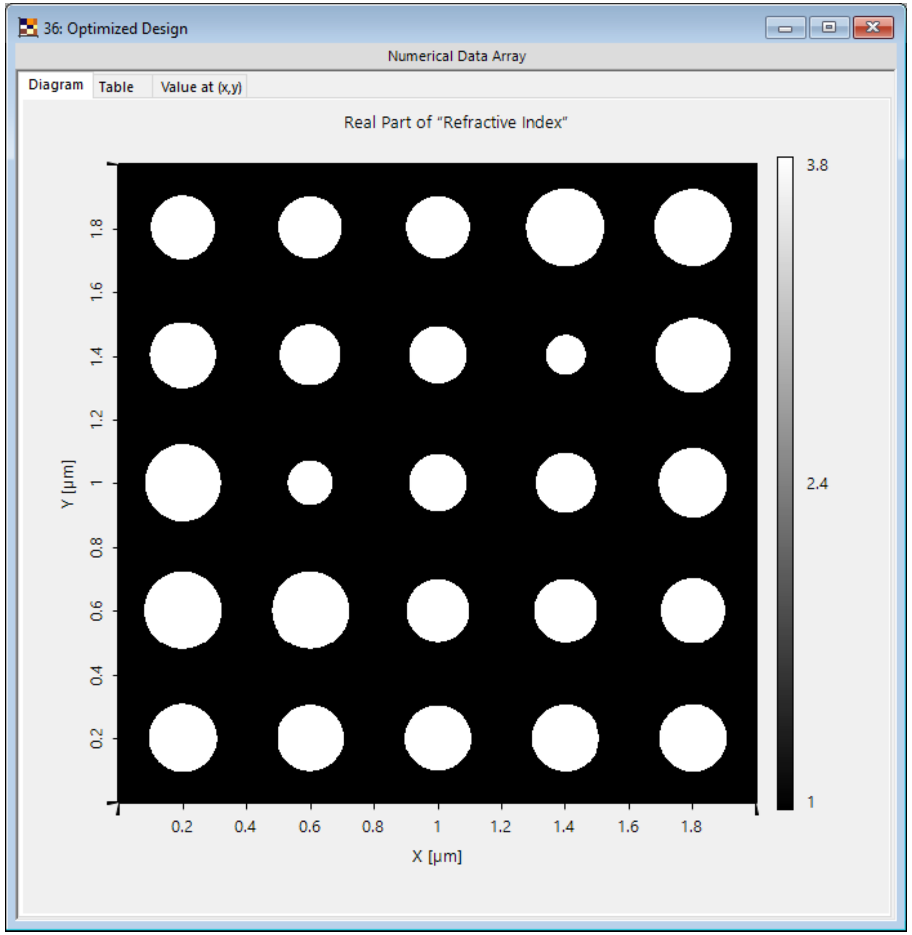
- keep pillar positions
- **vary** pillar diameters (25 variables)

downhill simplex optimization with FMM/RCWA for grating analysis

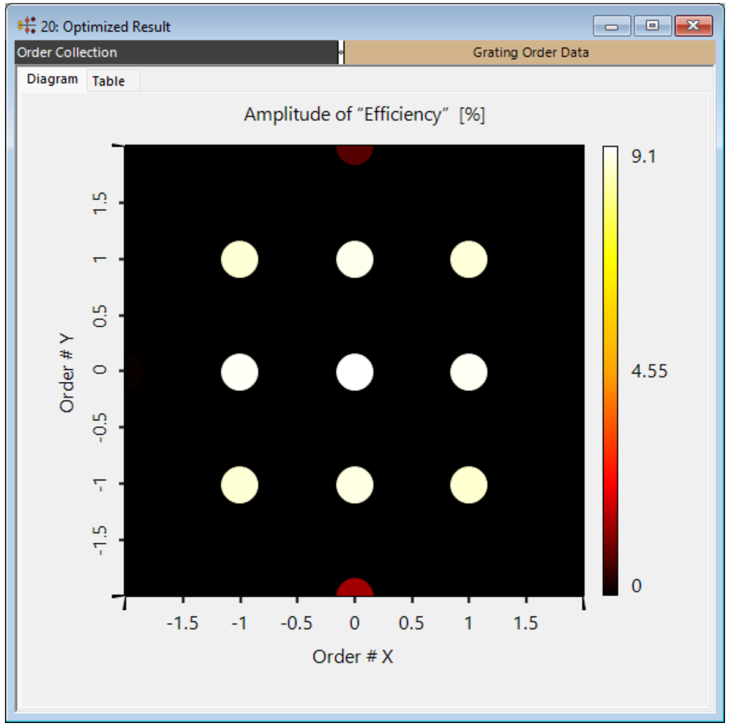


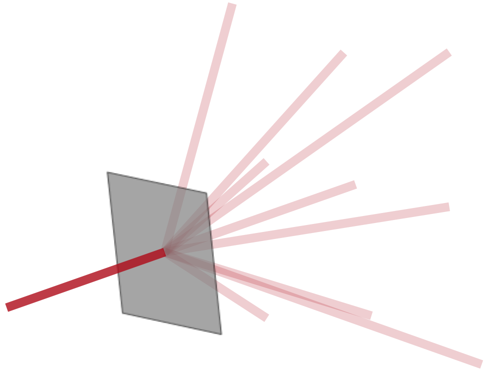
Evaluation of Optimized Metagrating Design

optimized metagrating (top-view)



diffraction efficiencies

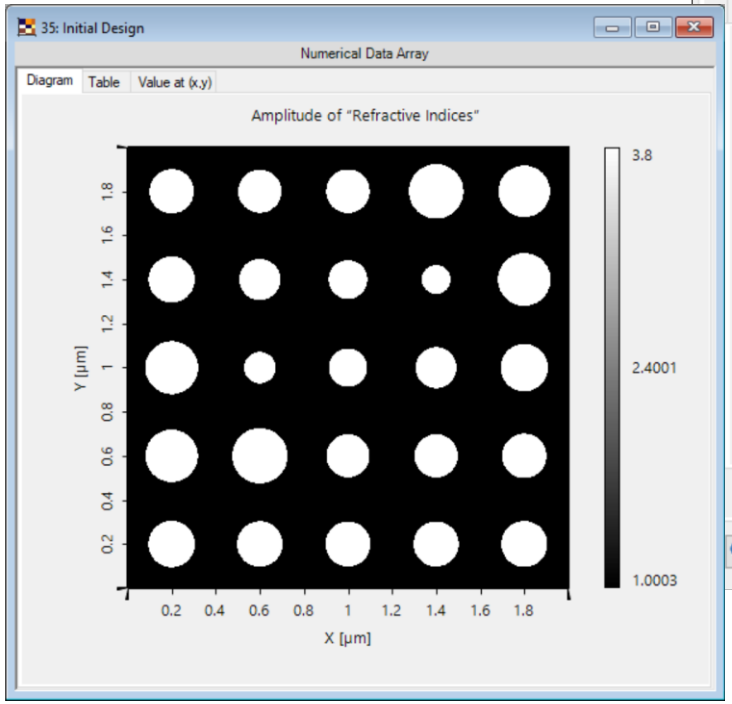


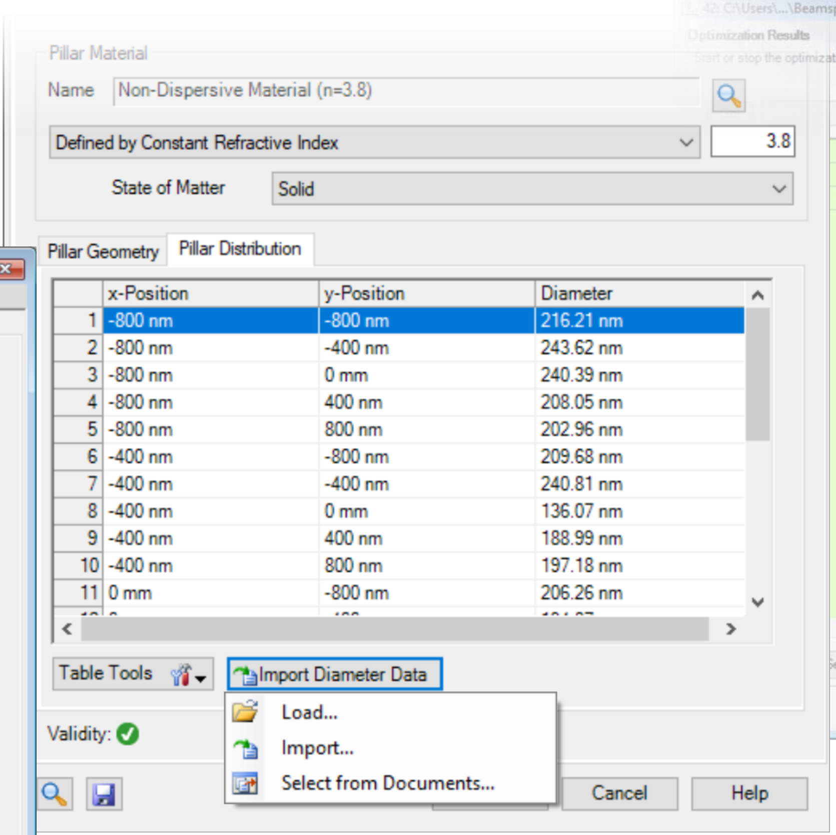


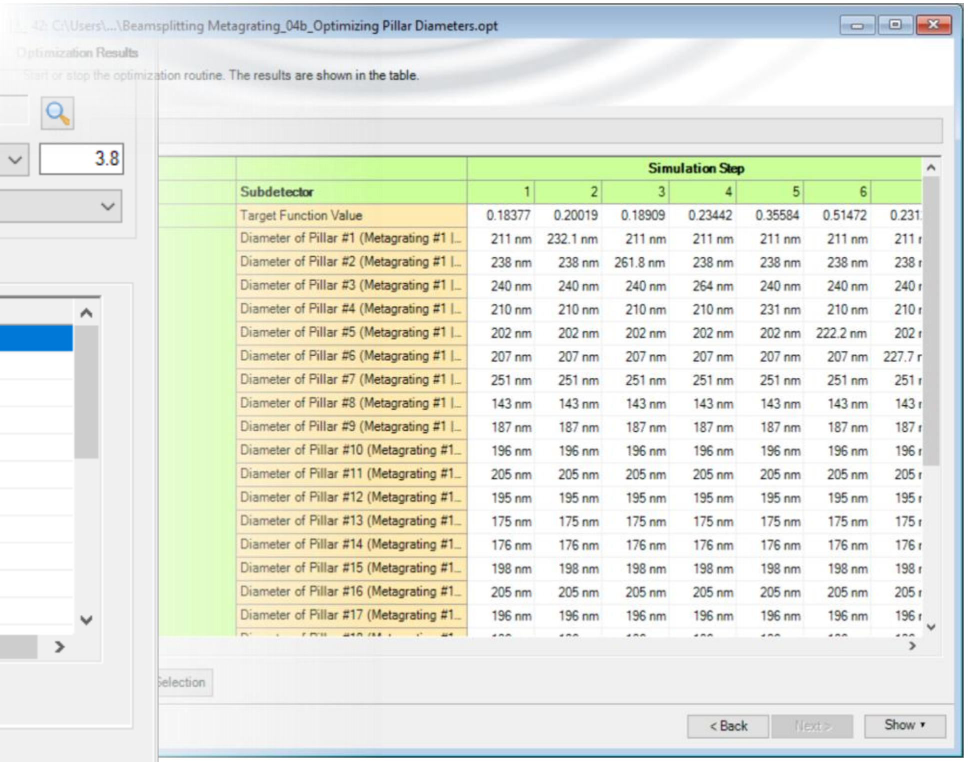
overall efficiency	79.9%
uniformity error (PV)	**2.3%**
uniformity error (RMS)	**1.6%**

Peek into VirtualLab Fusion

flexible definition of 2D metagrating surface



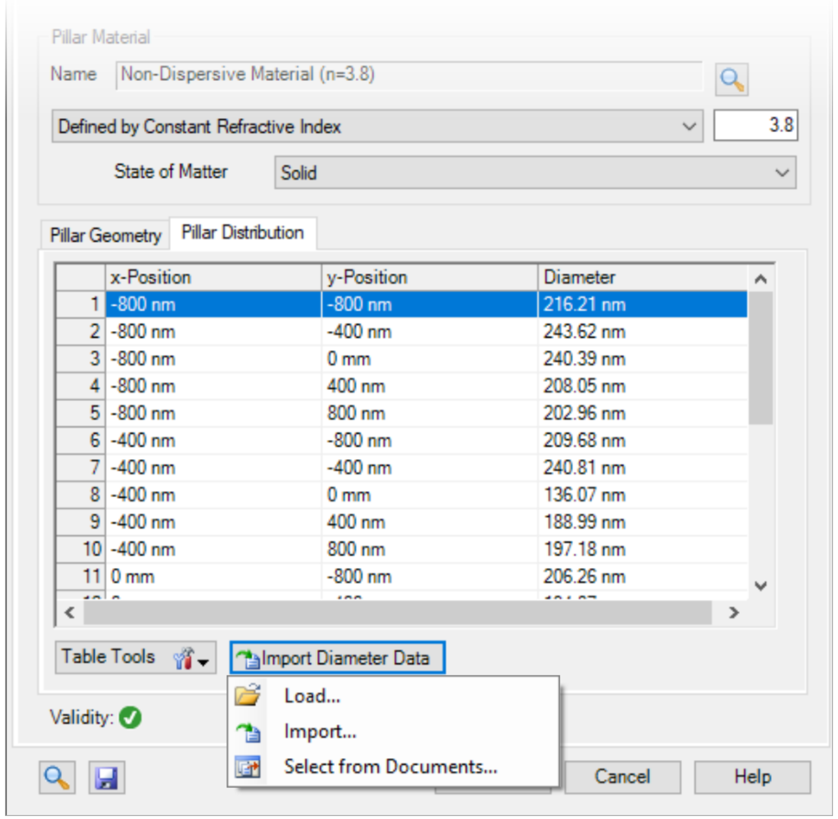




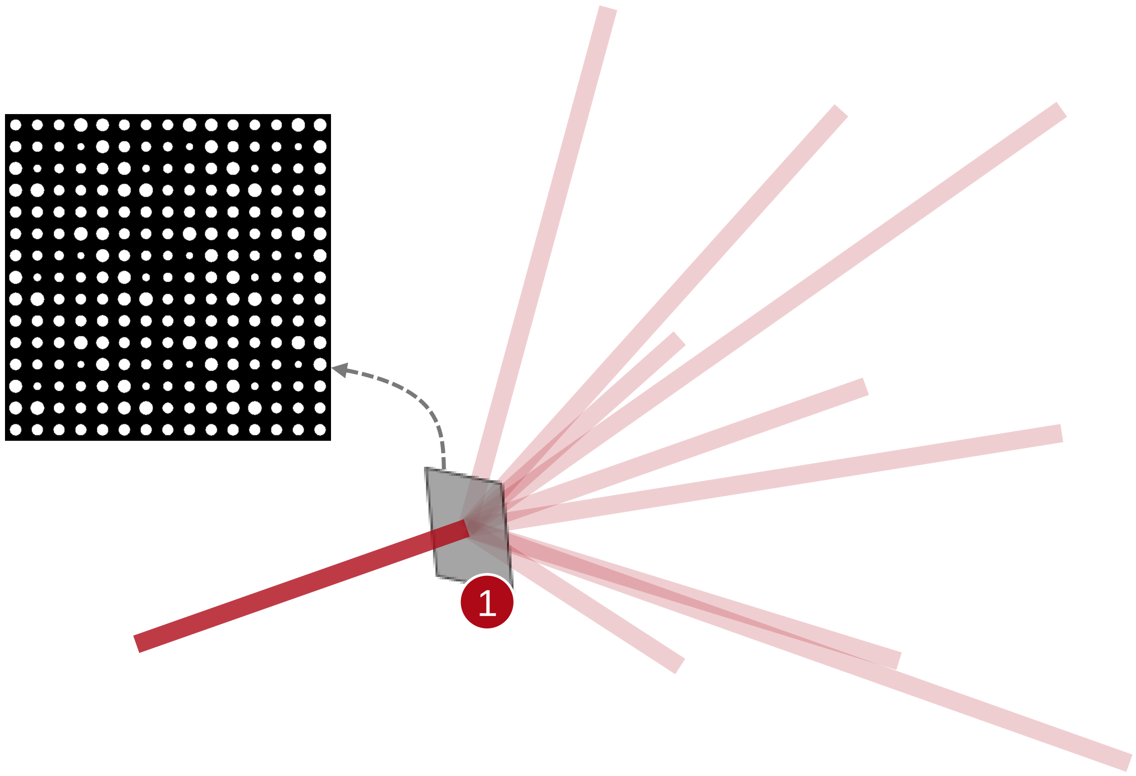
parametric optimization of metagrating structure

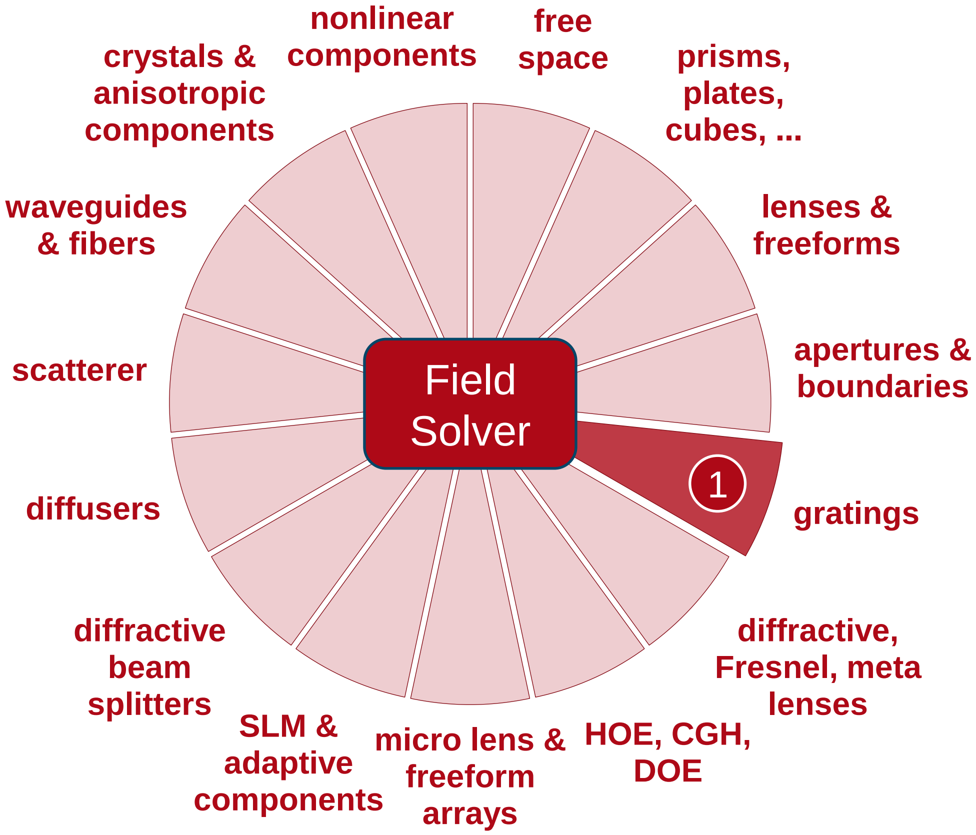
Workflow in VirtualLab Fusion

- Analyze metasurface unit cell
  - Rigorous Analysis of Nanopillar Metasurface Building Block [Use Case]
- Construct metagratings
  - Metagrating Construction - Discussion at Examples [Use Case]
- Analyze grating diffraction efficiency
  - Grating Order Analyzer [Use Case]
- Parametric optimization of grating structure
  - Parametric Optimization [Tutorial Video]



VirtualLab Fusion Technologies





Document Information

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software version	2024.1 (Build 1.132)
category	Application Use Case
further reading	- Rigorous Analysis of Nanopillar Metasurface Building Block - Modeling and Design of Blazed Metagratings