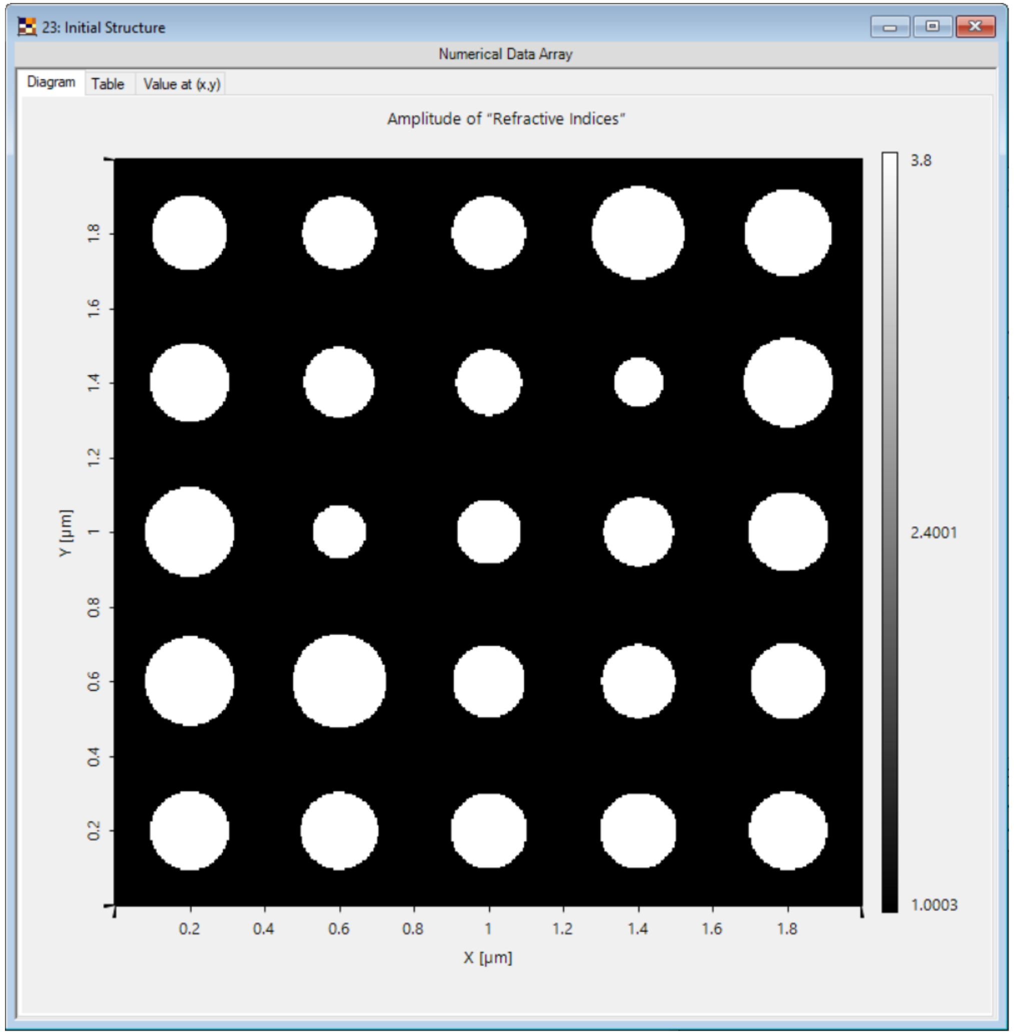
Two-Dimensional Meta-Gratings Modeling and Design

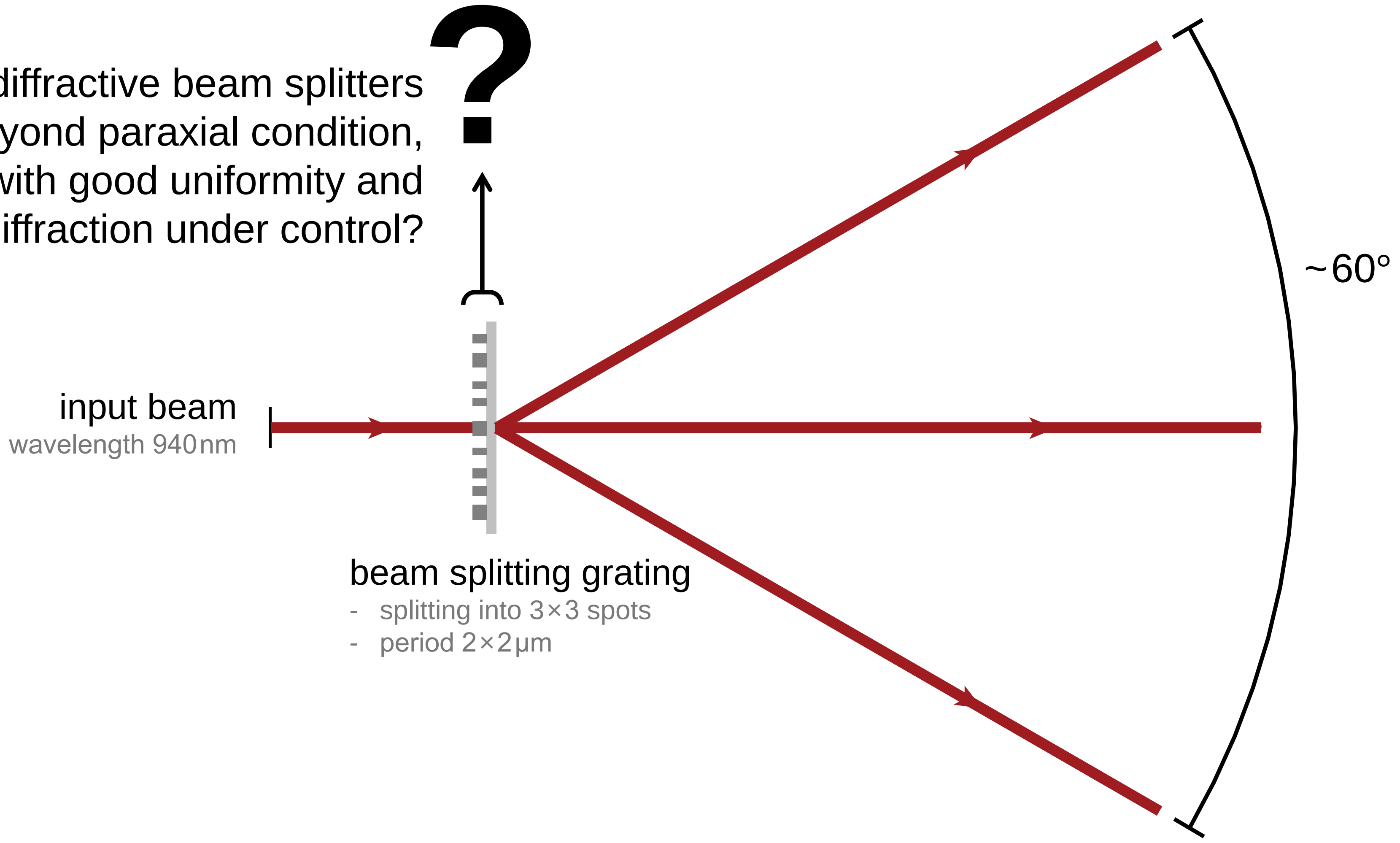
Abstract



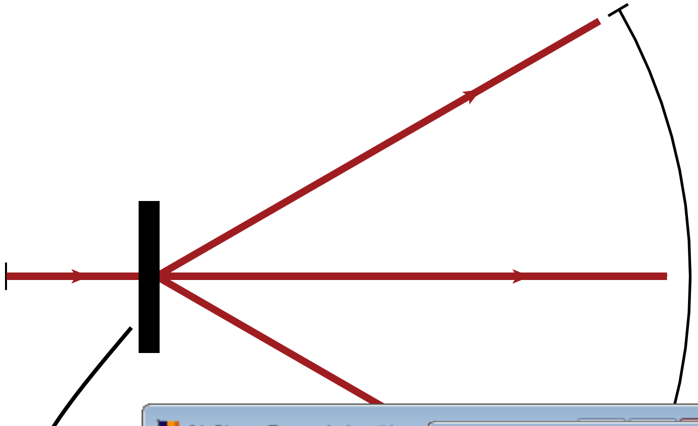
We demonstrate the design of 2D meta-gratings as large-angle beam splitters and how to further optimization with the rigorous Fourier modal method (FMM, also known as RCWA) and parametric optimization algorithm.

Design Task

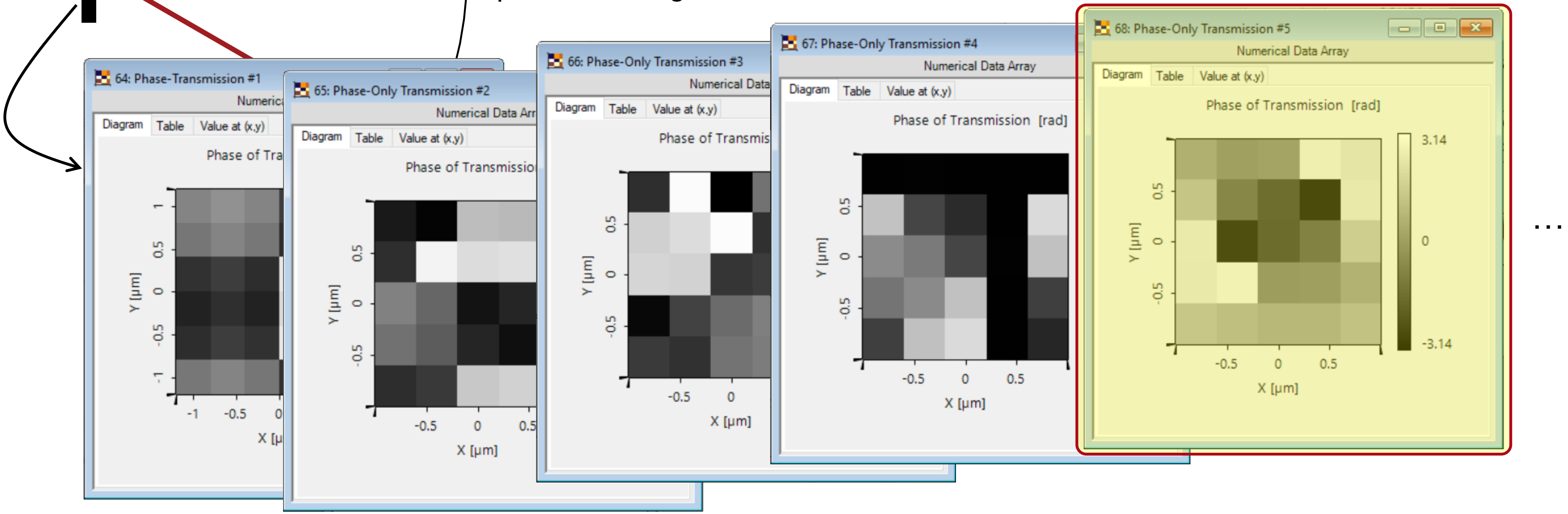
How to design diffractive beam splitters that work beyond paraxial condition, especially with good uniformity and zeroth-order diffraction under control?



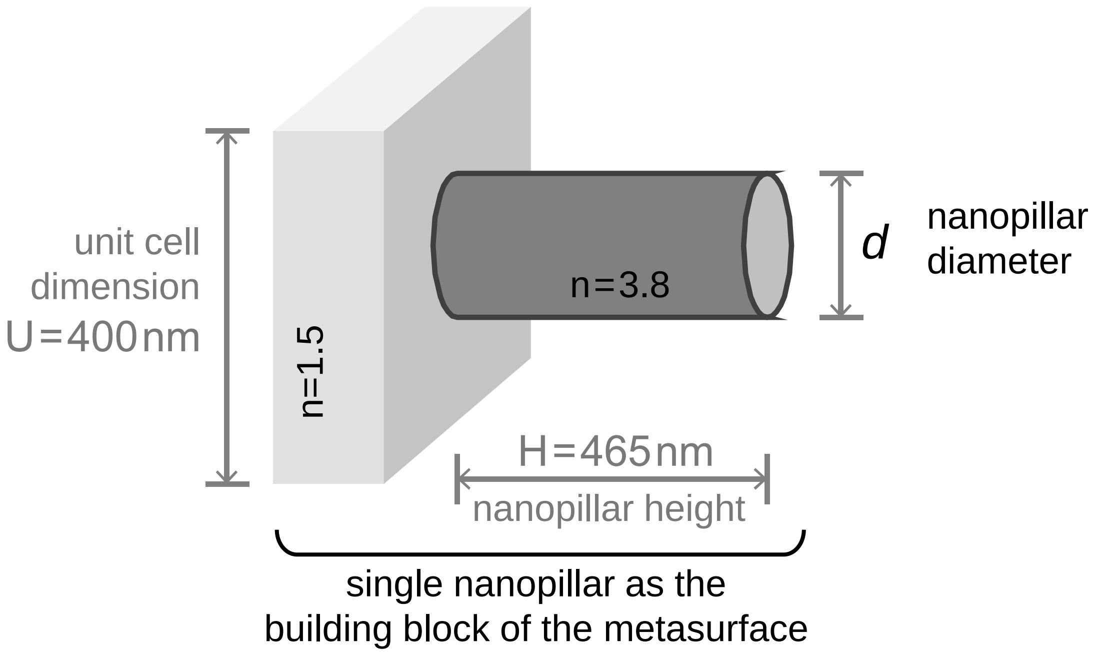
Phase-Only Transmission Design (IFTA)

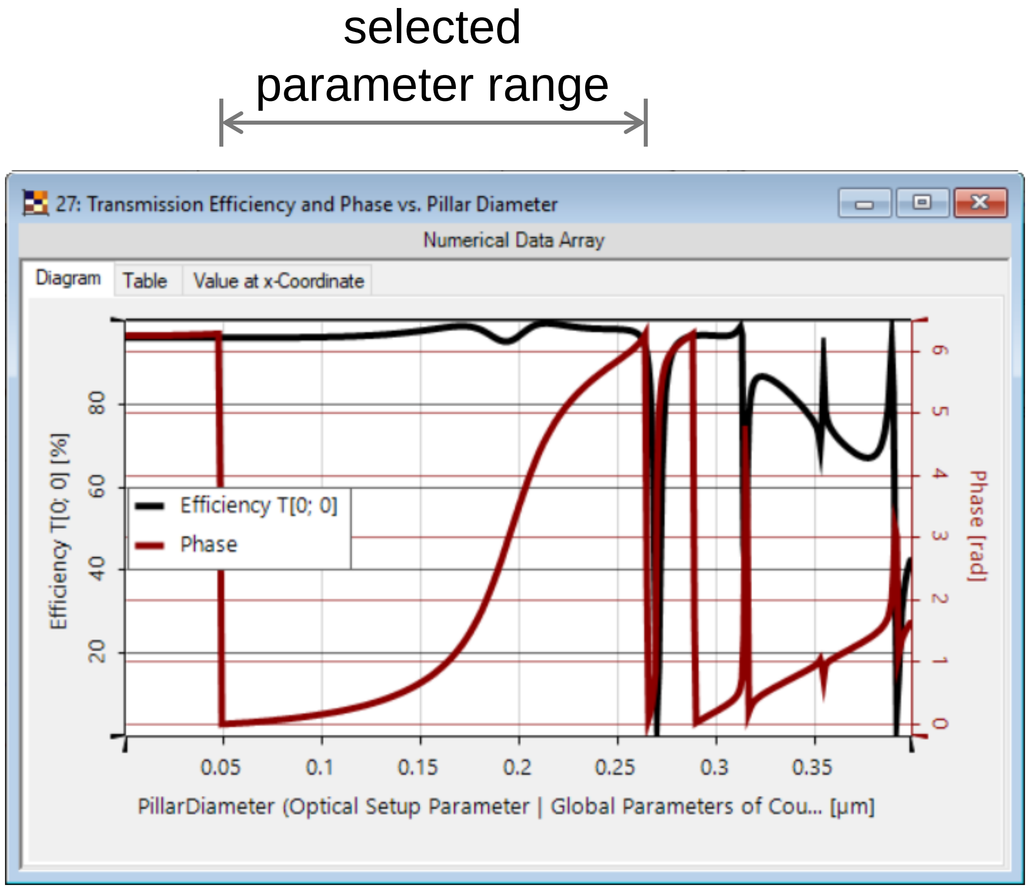


With differently random phase distributions as starting points, IFTA calculates different possible design results.



Metasurface Building Block / Unit Cell



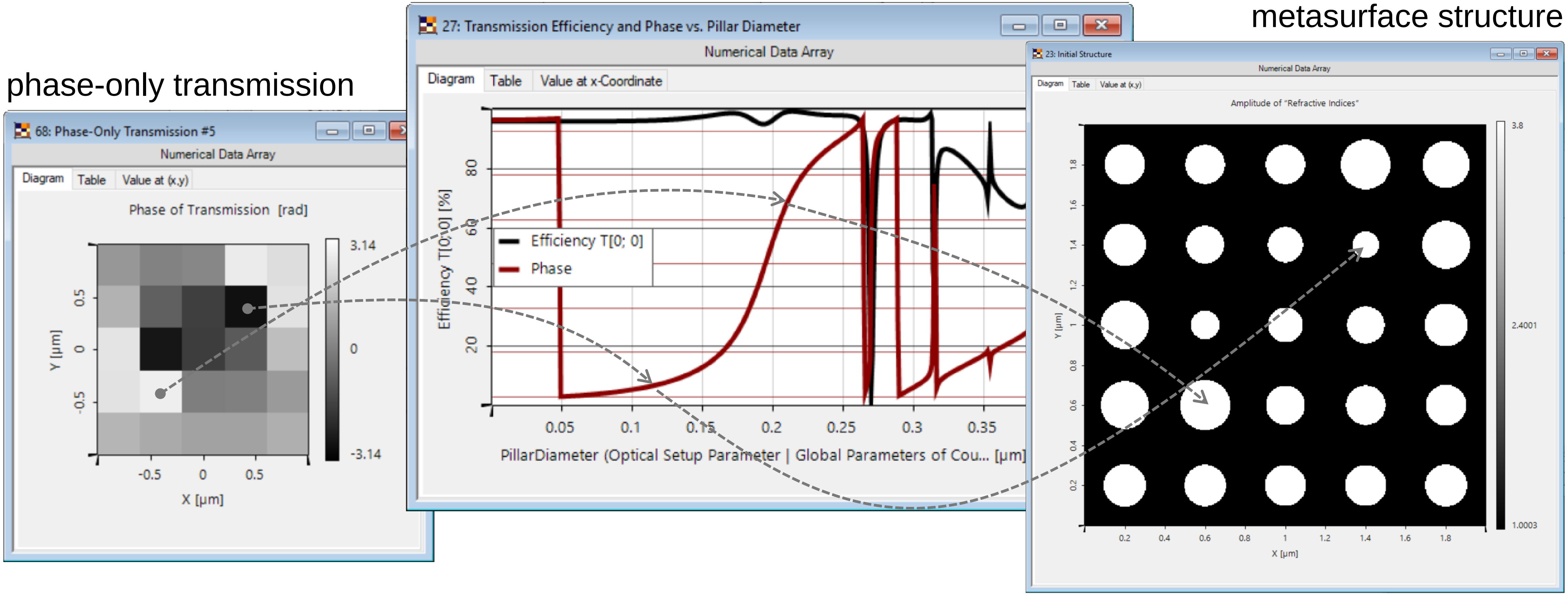


Phase Distribution ➔ Metasurface Structure

phase-diameter map / library

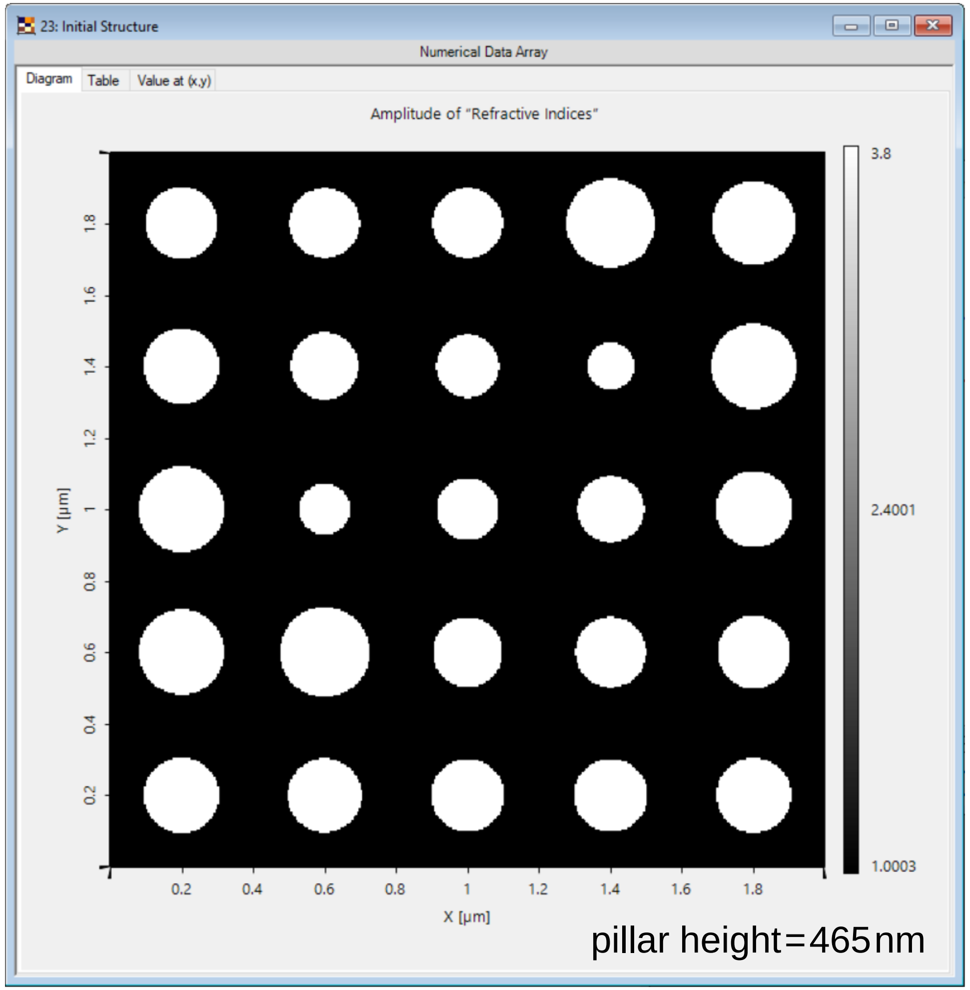
metasurface structure

phase-only transmission



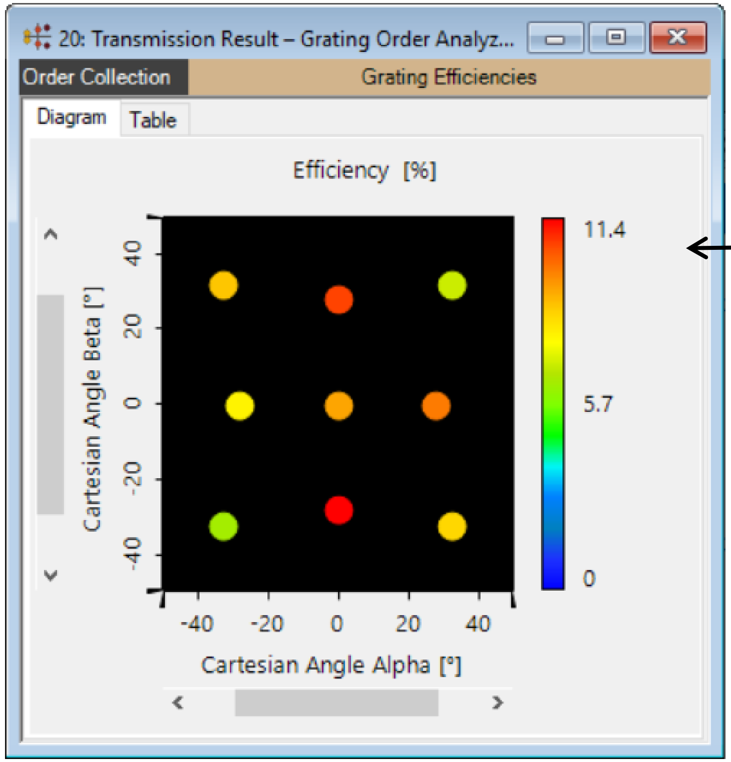
Evaluation of Initial Metasurface Design

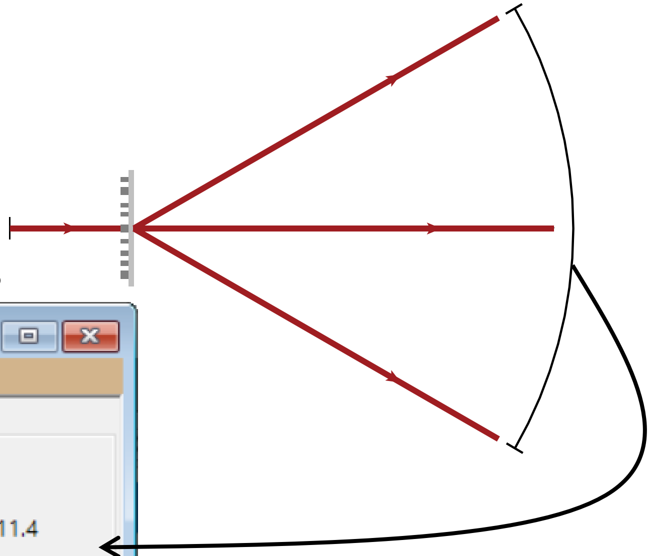
metasurface structure



pillar height=465nm

diffraction efficiencies

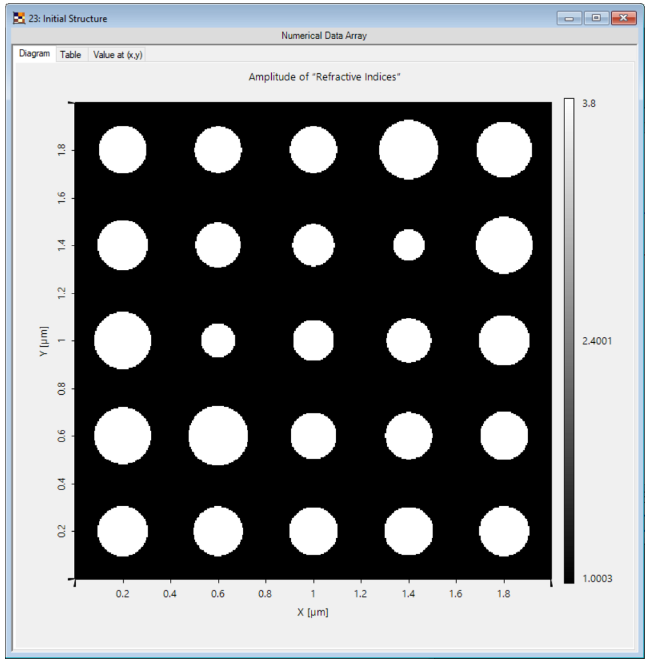




Overall efficiency	79%
Uniformity error (PV)	29%
Uniformity error (RMS)	18%

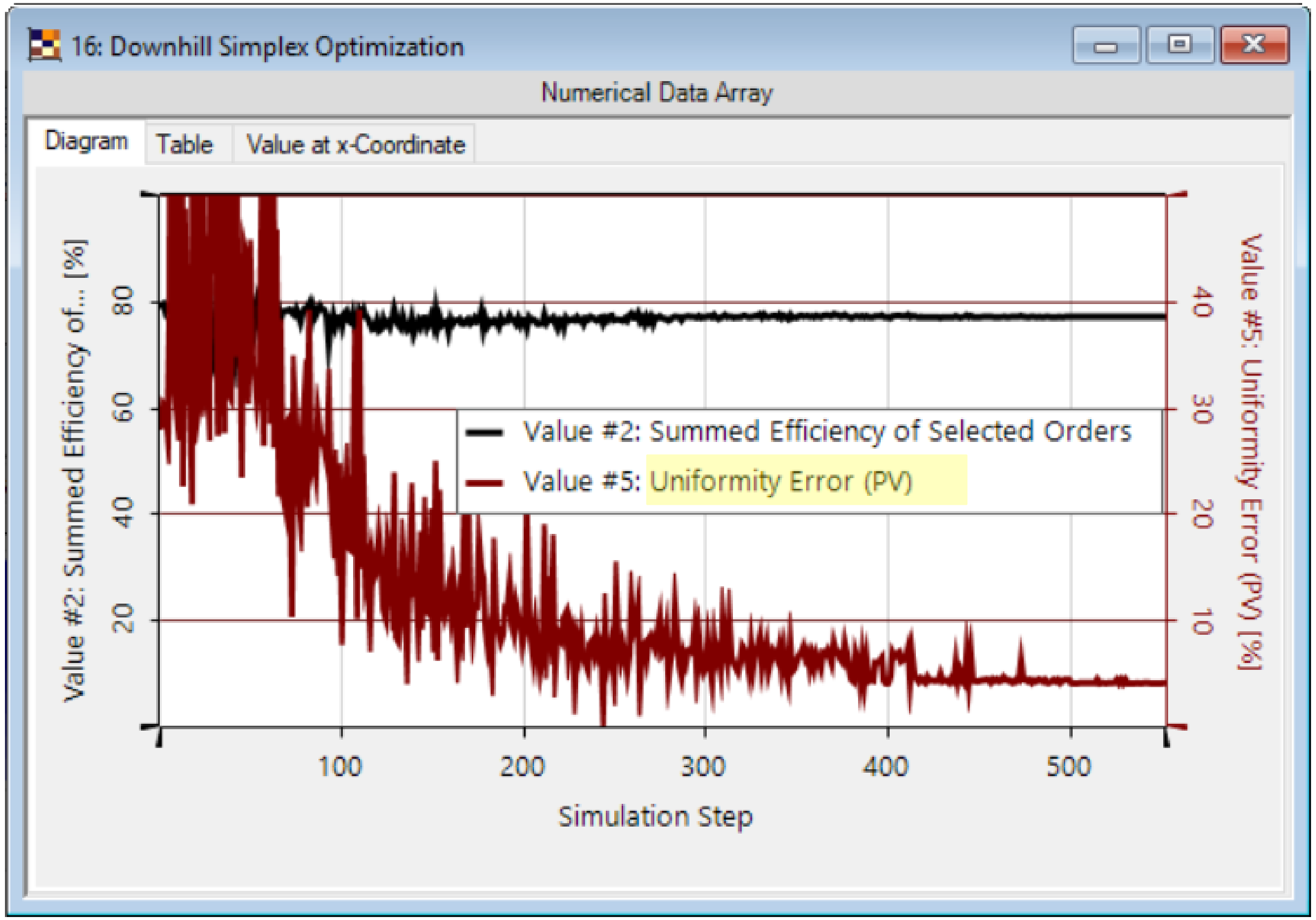
Parametric Optimization

initial structure



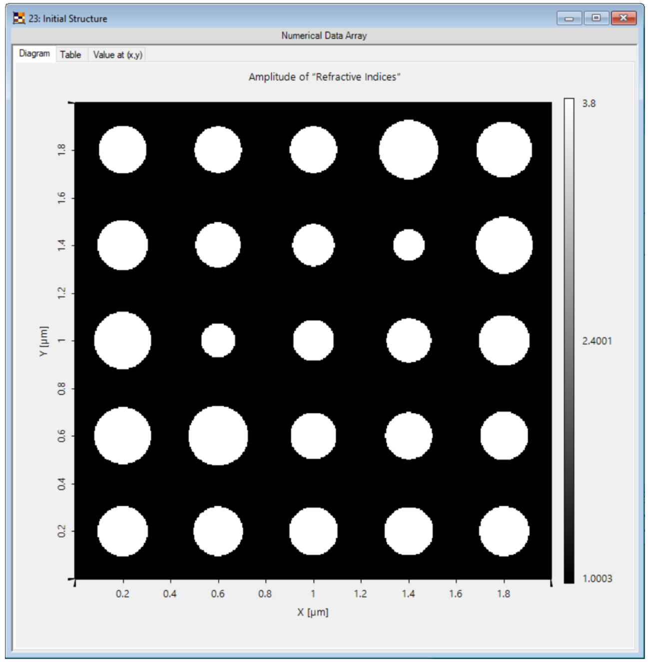
- keep pillar positions
- varying pillar diameters
- vary overall height
- 26 variables in total

downhill simplex optimization with FMM/RCWA for grating analysis



Parametric Optimization

initial structure



- keep pillar positions
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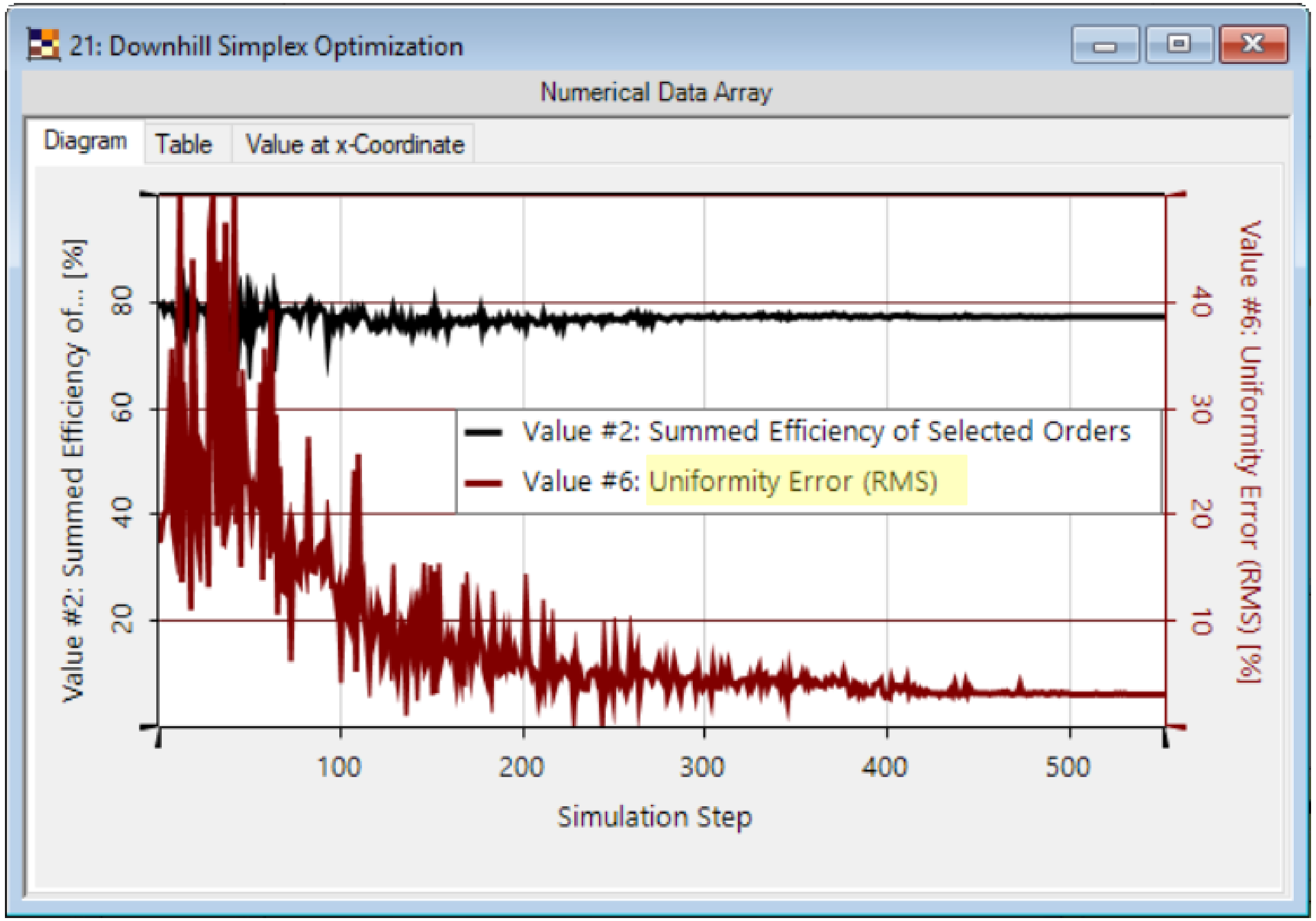
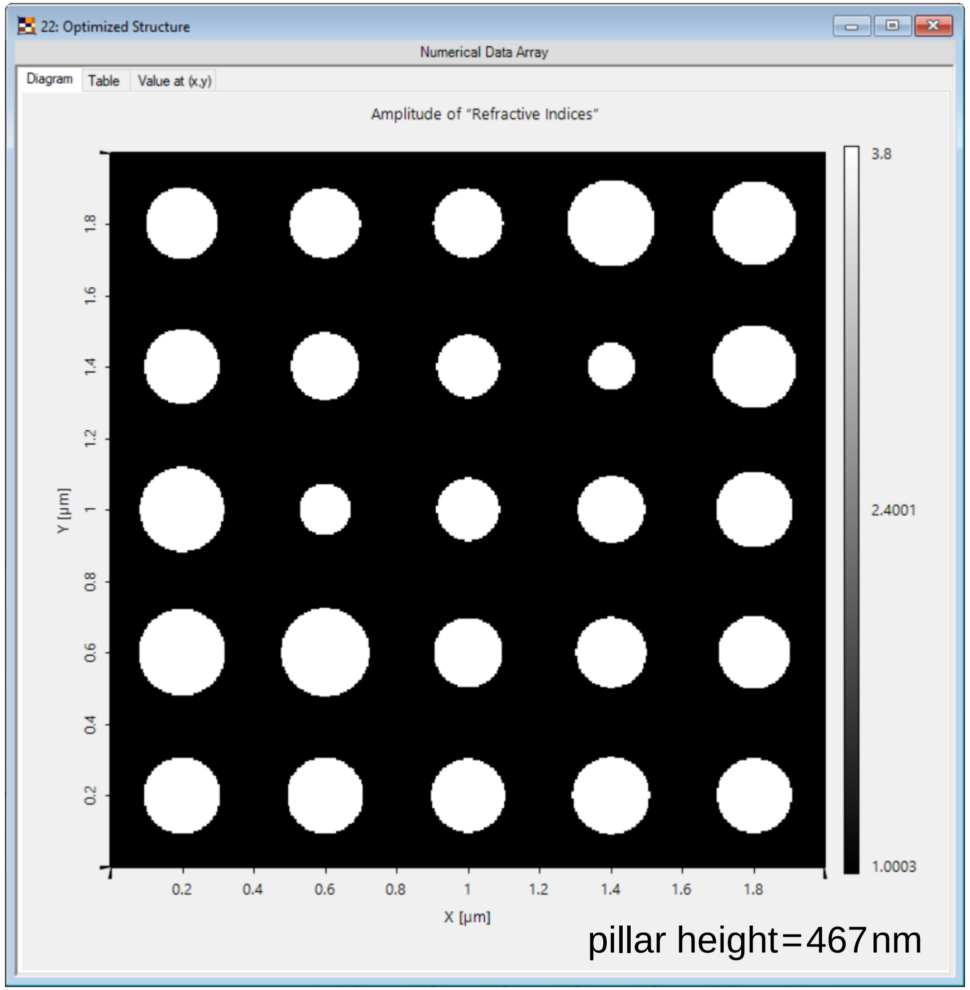
downhill simplex optimization with FMM/RCWA for grating analysis

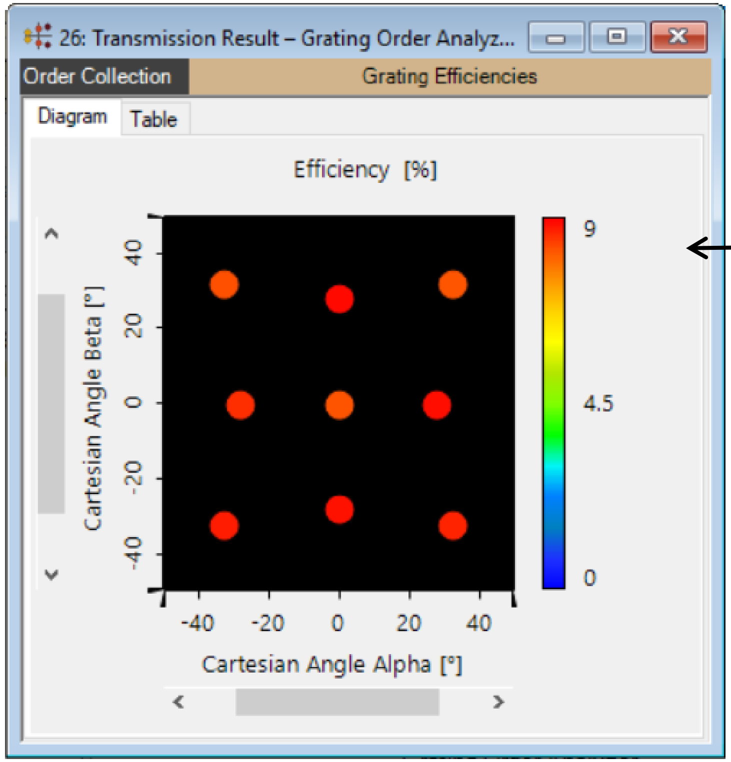


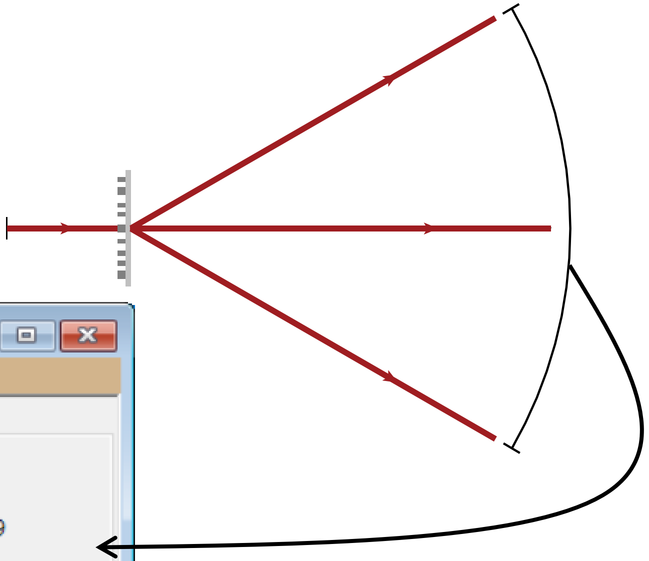
Evaluation of Optimized Metasurface Design

metasurface structure



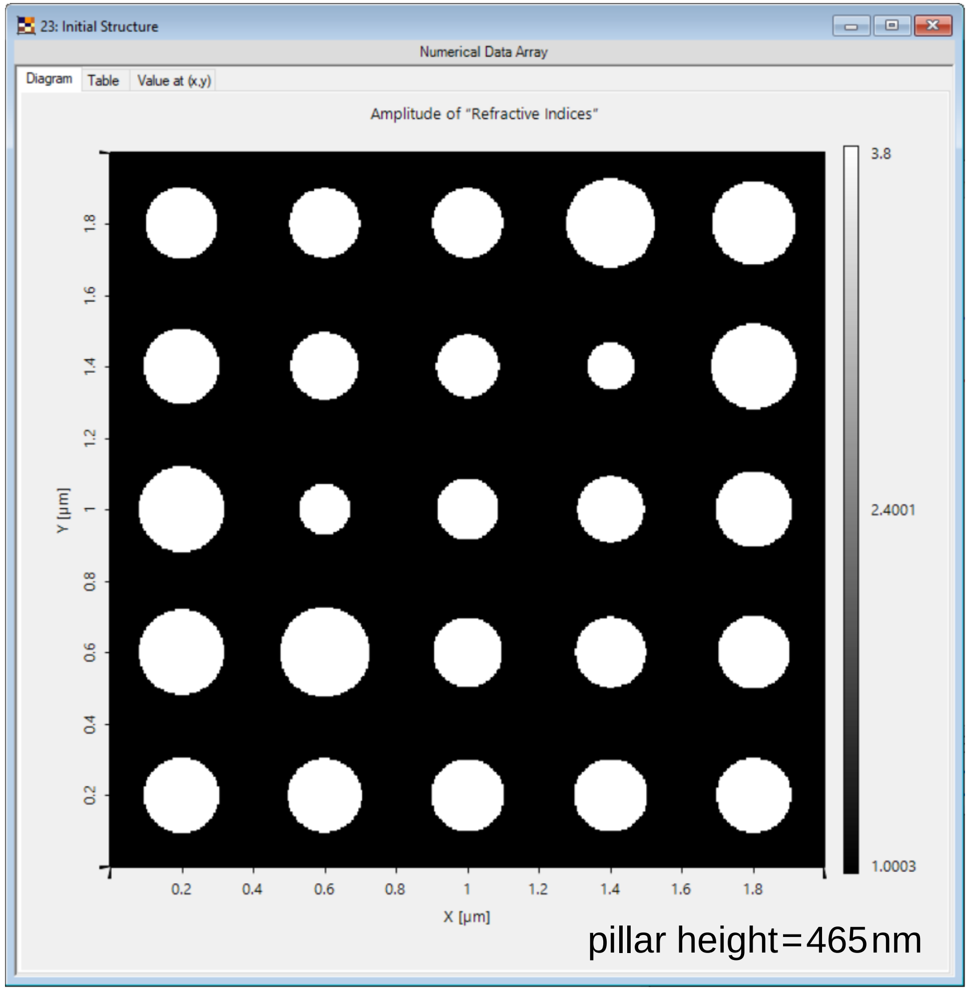
diffraction efficiencies





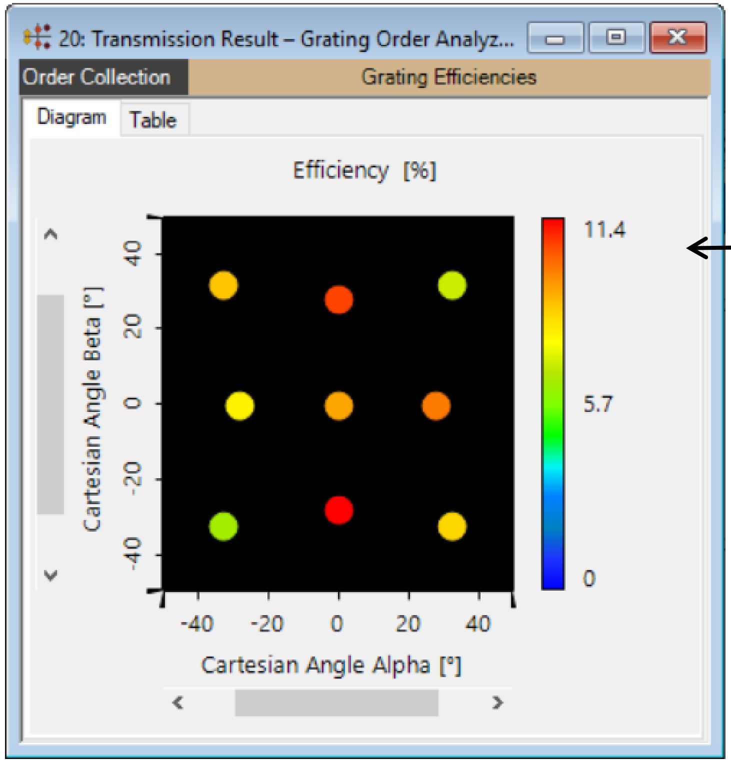
Overall efficiency	77 %
Uniformity error (PV)	**4.1 %**
Uniformity error (RMS)	**3.2 %**

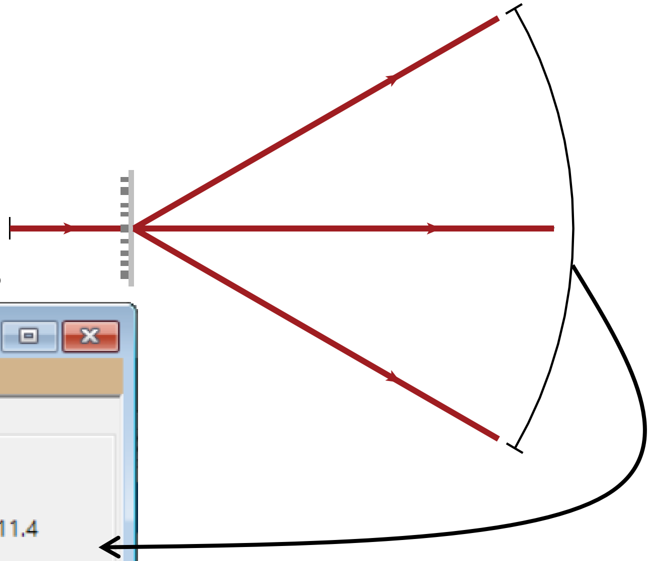
Meta-Grating Design – Initial Structure (for Comparison)



pillar height=465nm

diffraction efficiencies

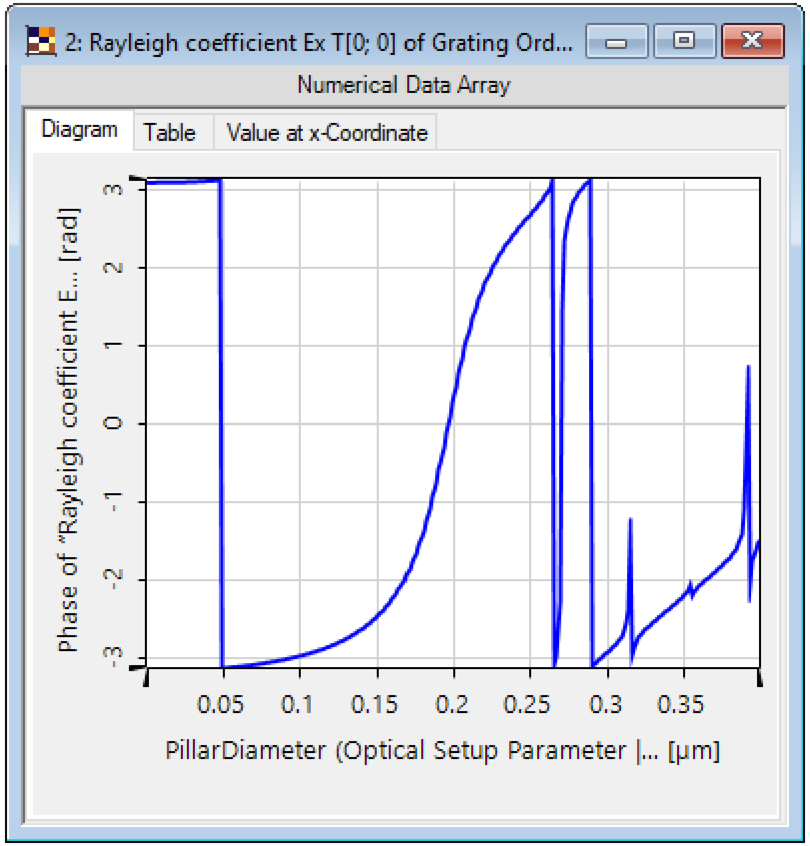




Overall efficiency	79%
Uniformity error (PV)	29%
Uniformity error (RMS)	18%

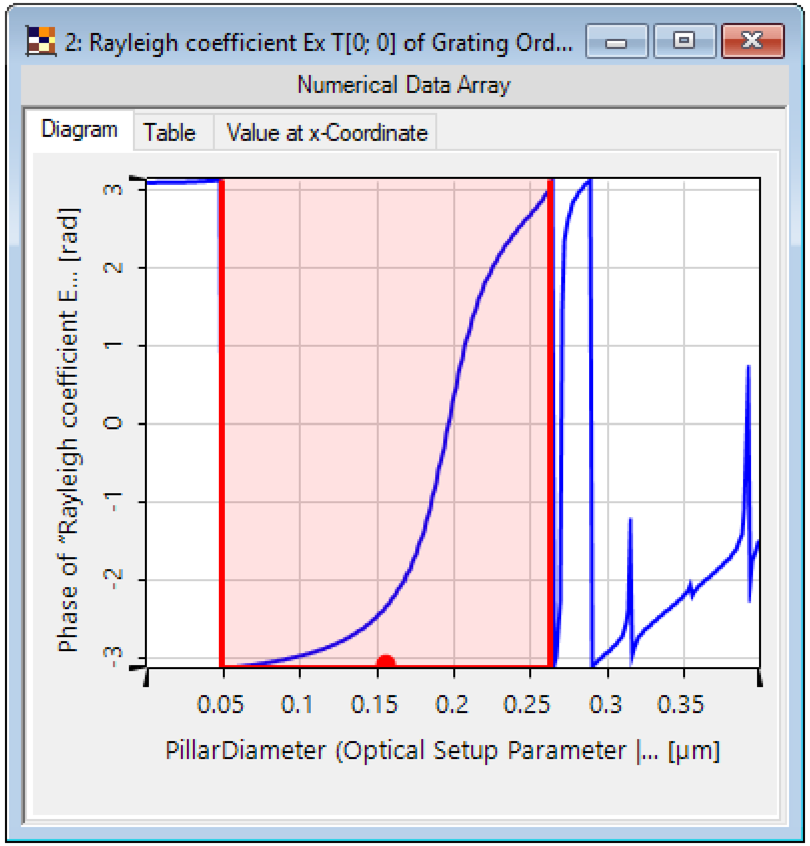
Brief Instruction on Workflow in VirtualLab Fusion

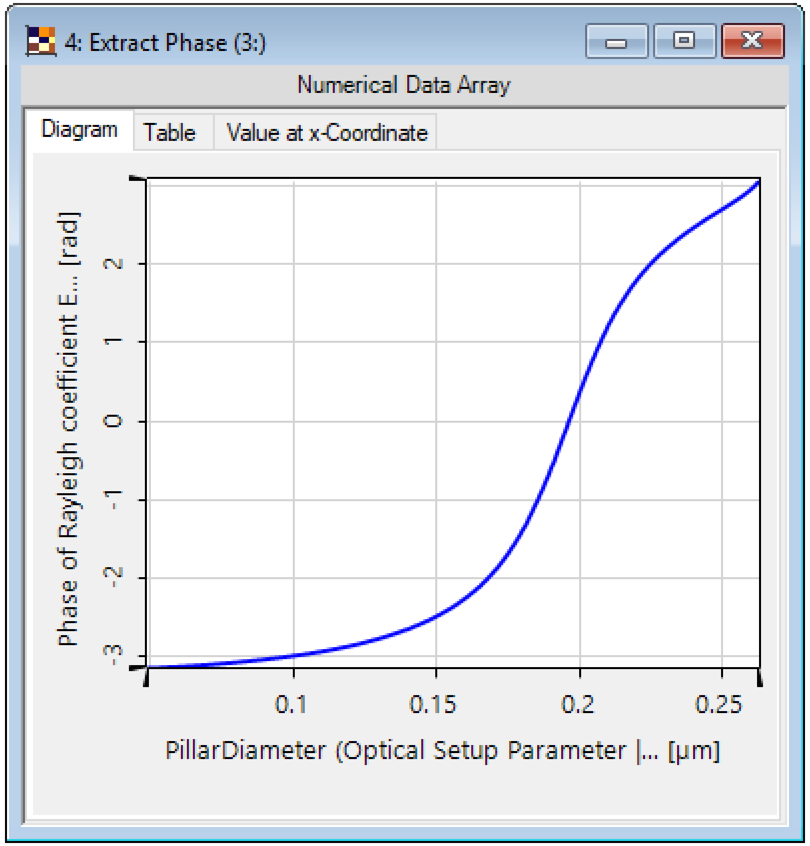
Step 1: Unit Cell Analysis



- Vary the pillar diameter and obtain the phase-diameter characteristic curve.
- Note that the phase value is wrapped within [-pi, +pi], and it may contain certain dips.
- In this case, one can find a smooth phase function that covers 2pi range, and that will be used for constructing the meta-grating.
- In case of irregular phase behavior, one can regularize it as shown in the blazed meta-grating example.

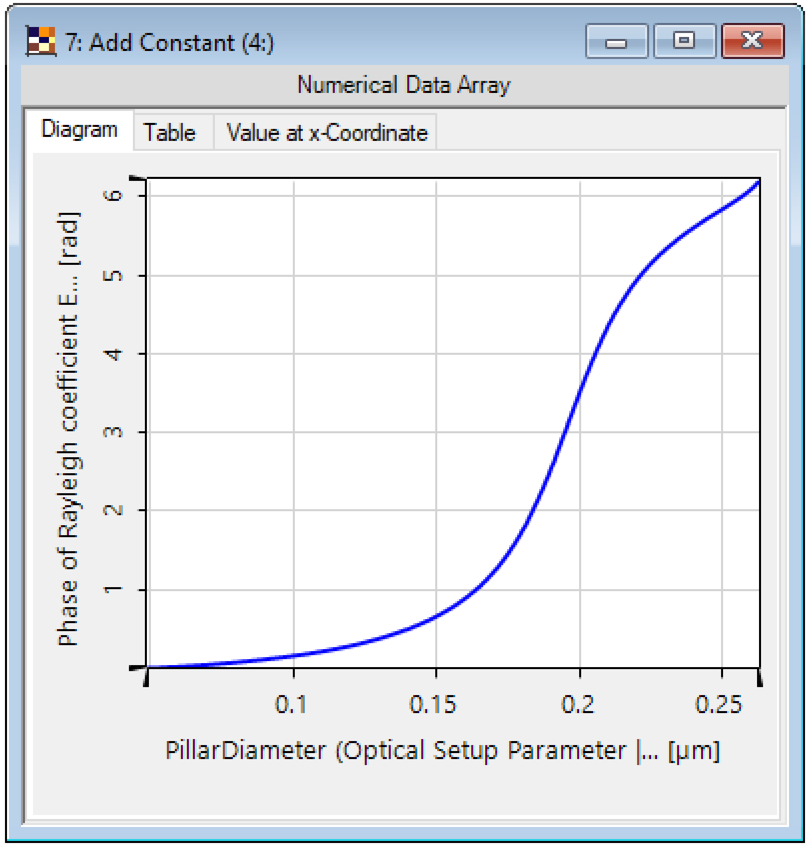
Step 2: Select Valid Pillar Diameter Range

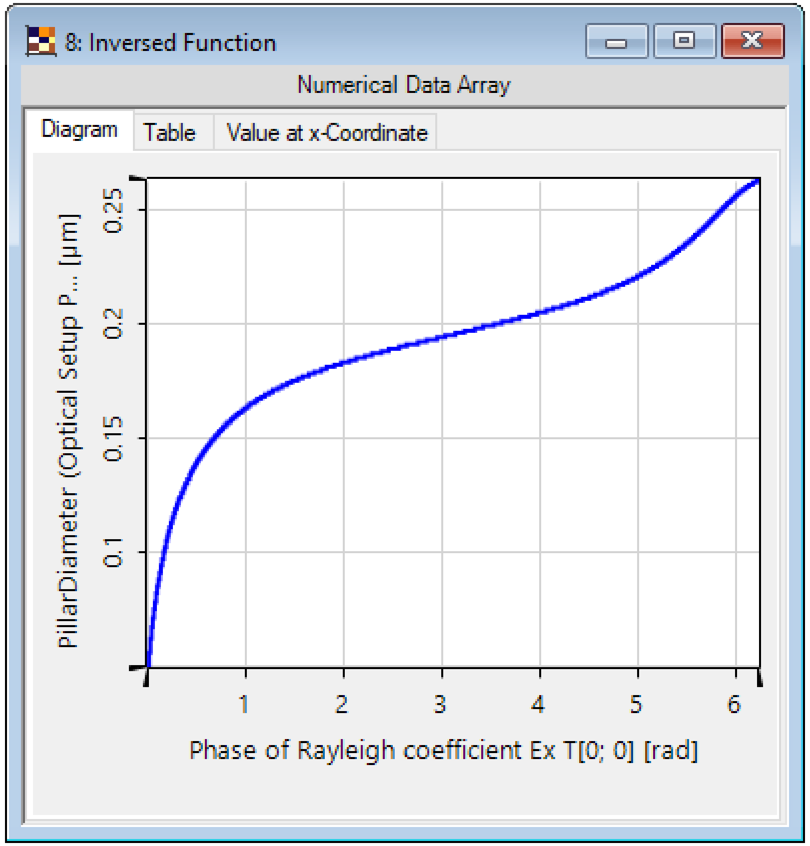




(This step is very similar to the 1D grating case)

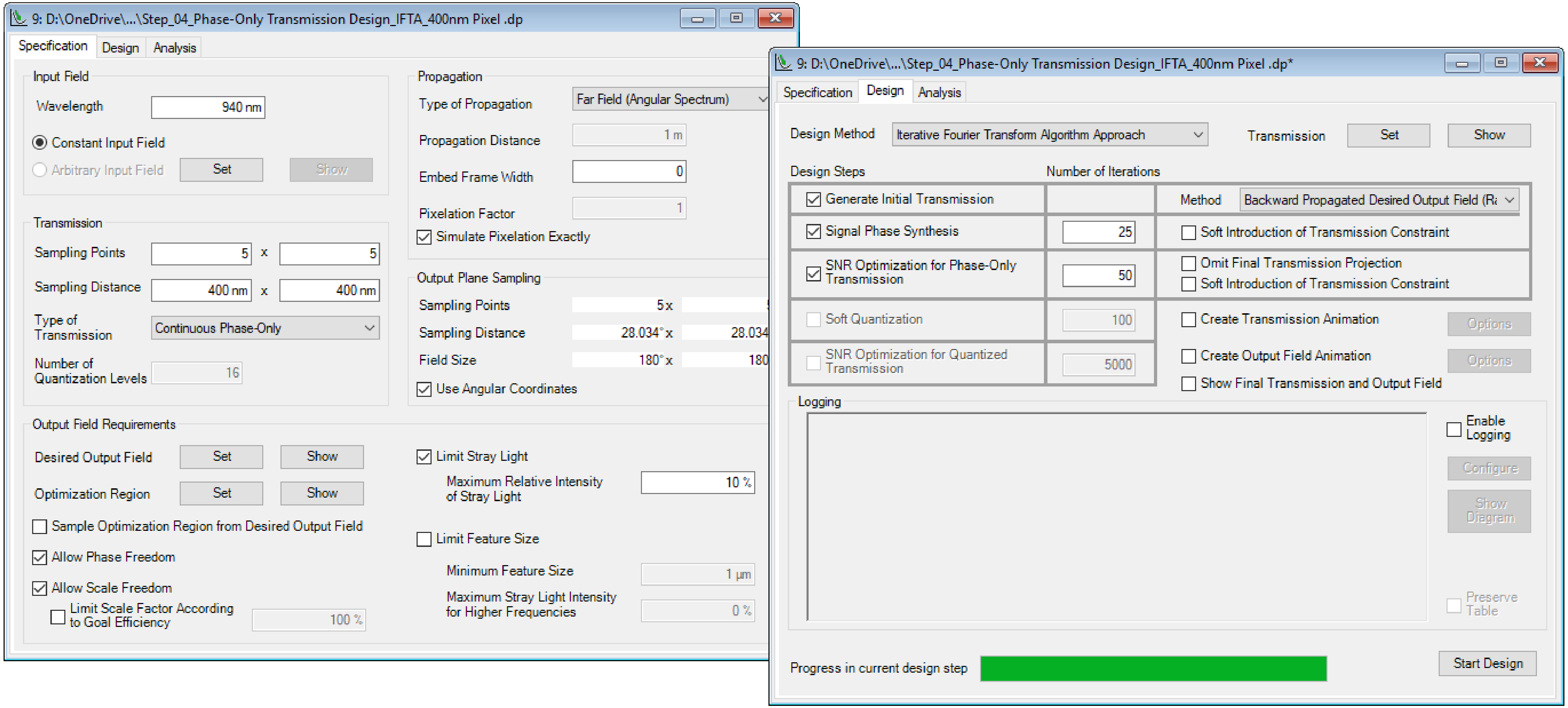
Step 3: Define Diameter – Phase Mapping Relation



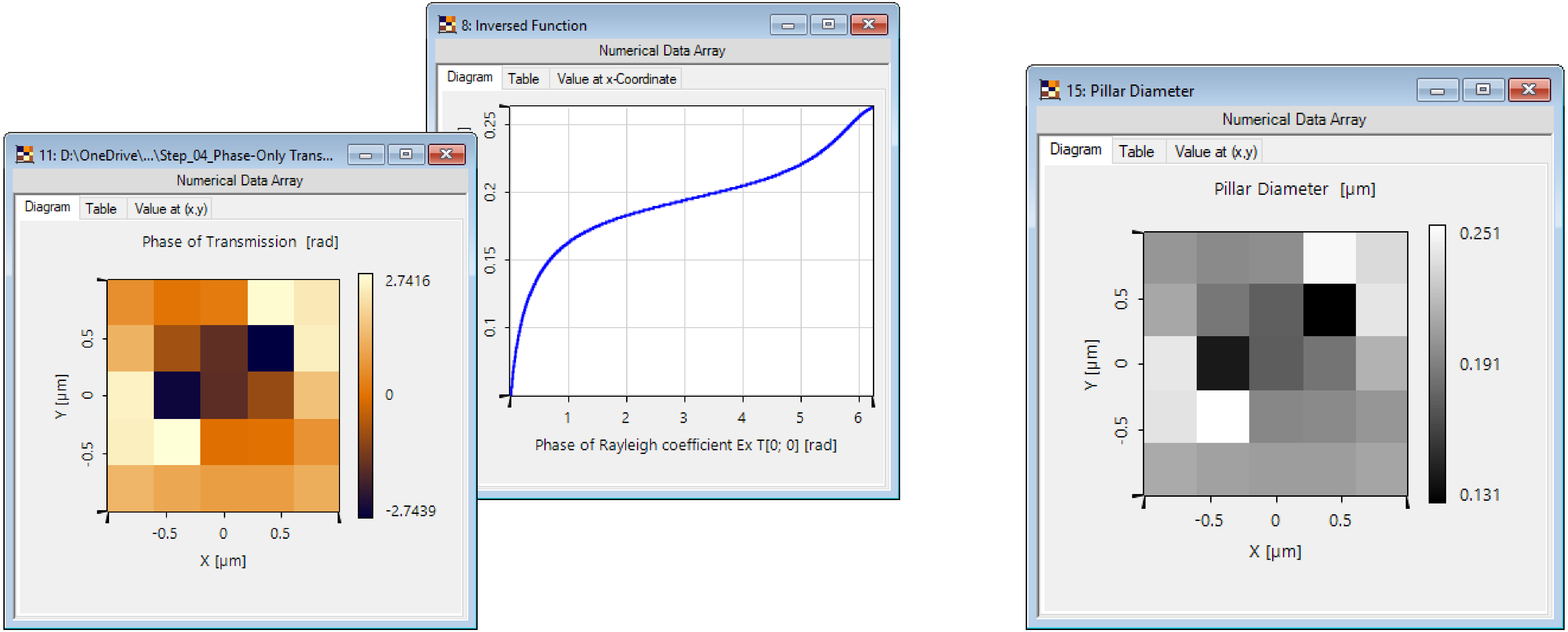


(This step is very similar to the 1D grating case)

Step 4: Calculate Phase-Only Transmission

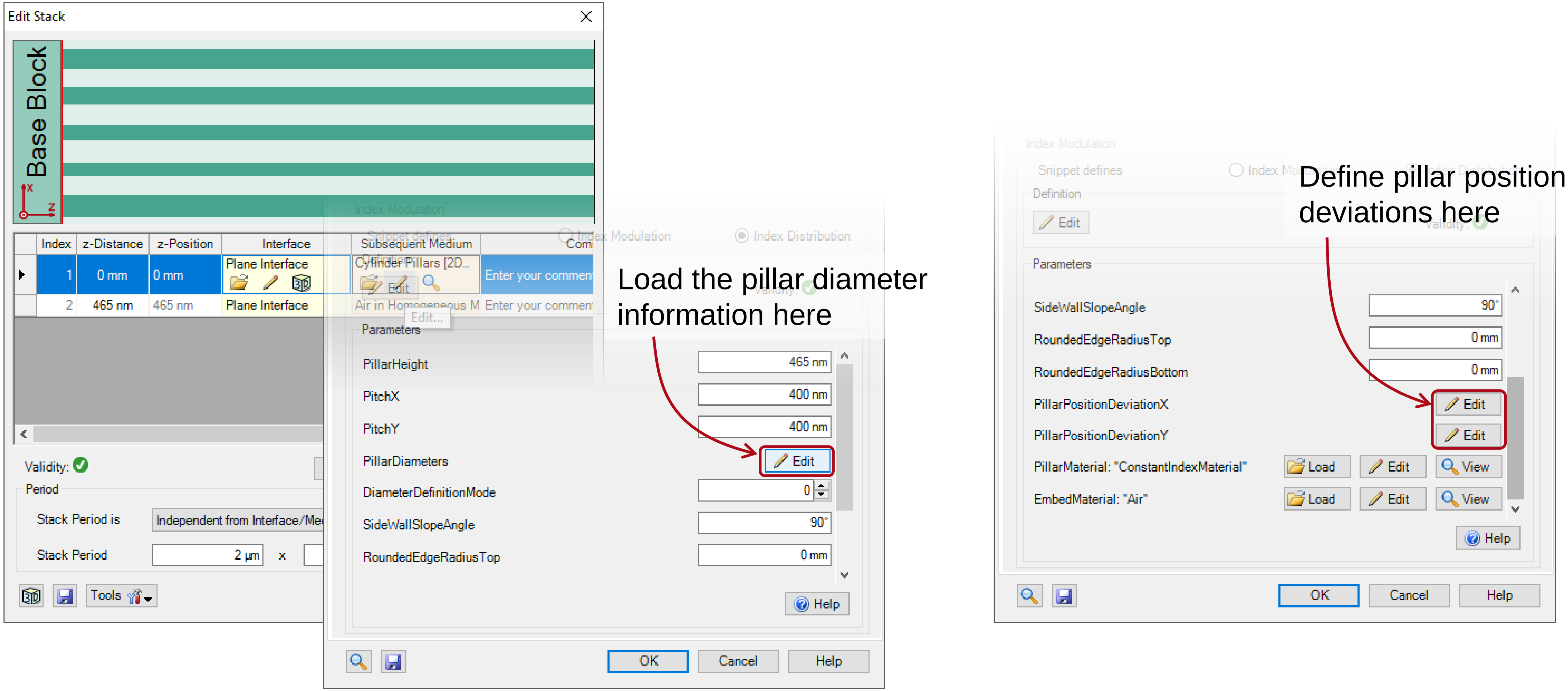


Step 5: From Phase Profile to Structure



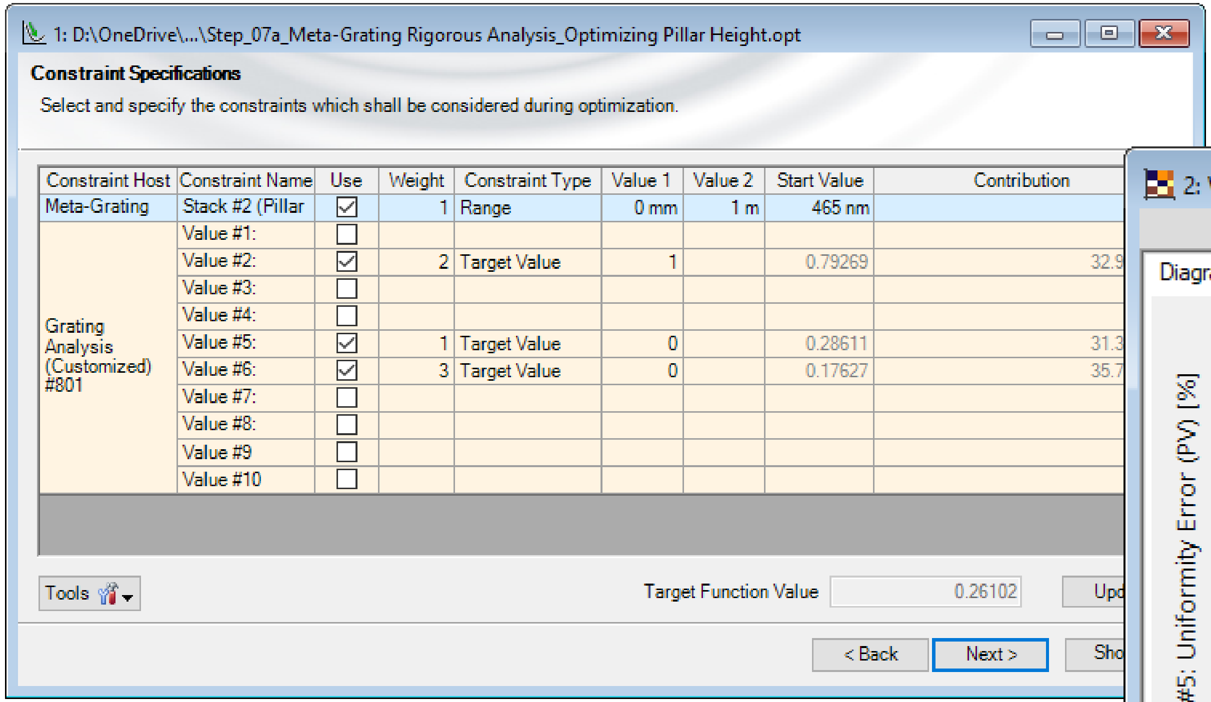
Step_05_Calculate Pillar Diameters from Phase Profile_2D Regular Array.cs

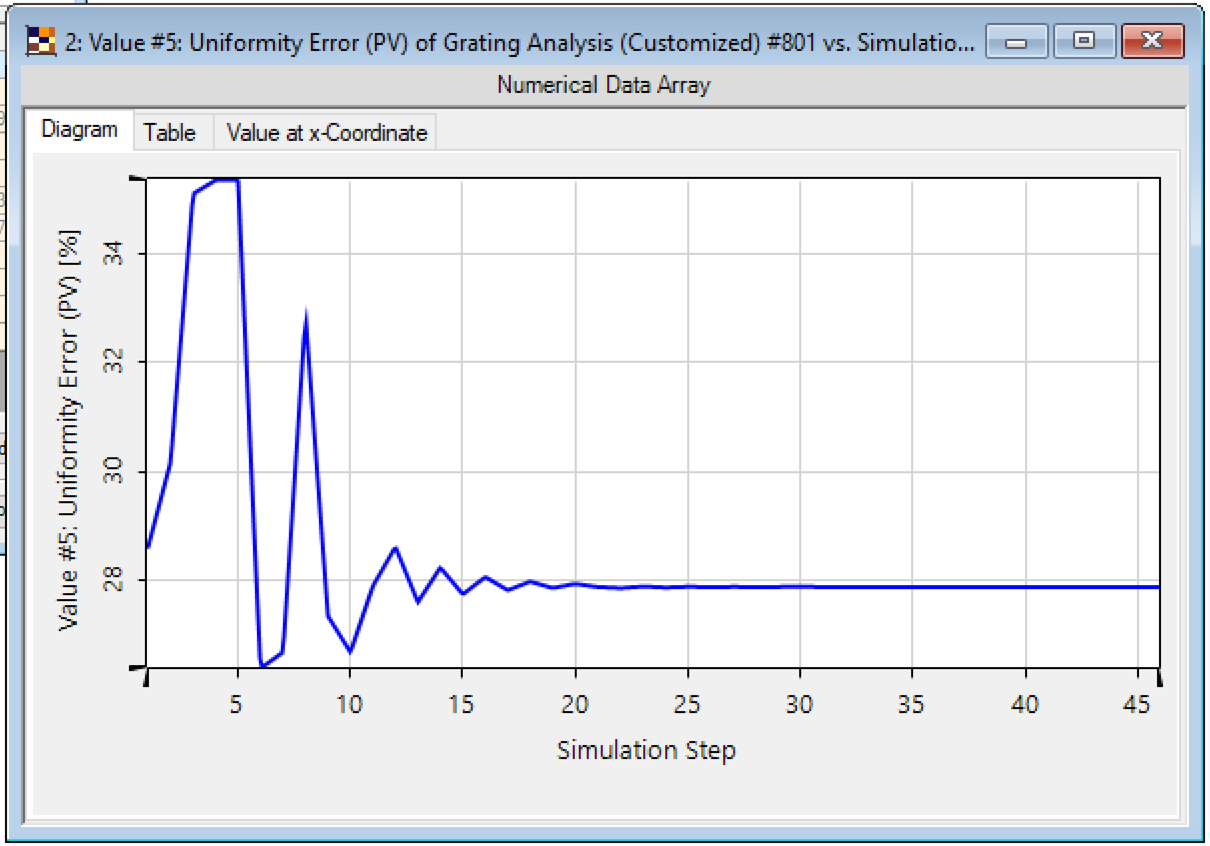
Step 6: Load Meta-Grating Structre in FMM Simulation



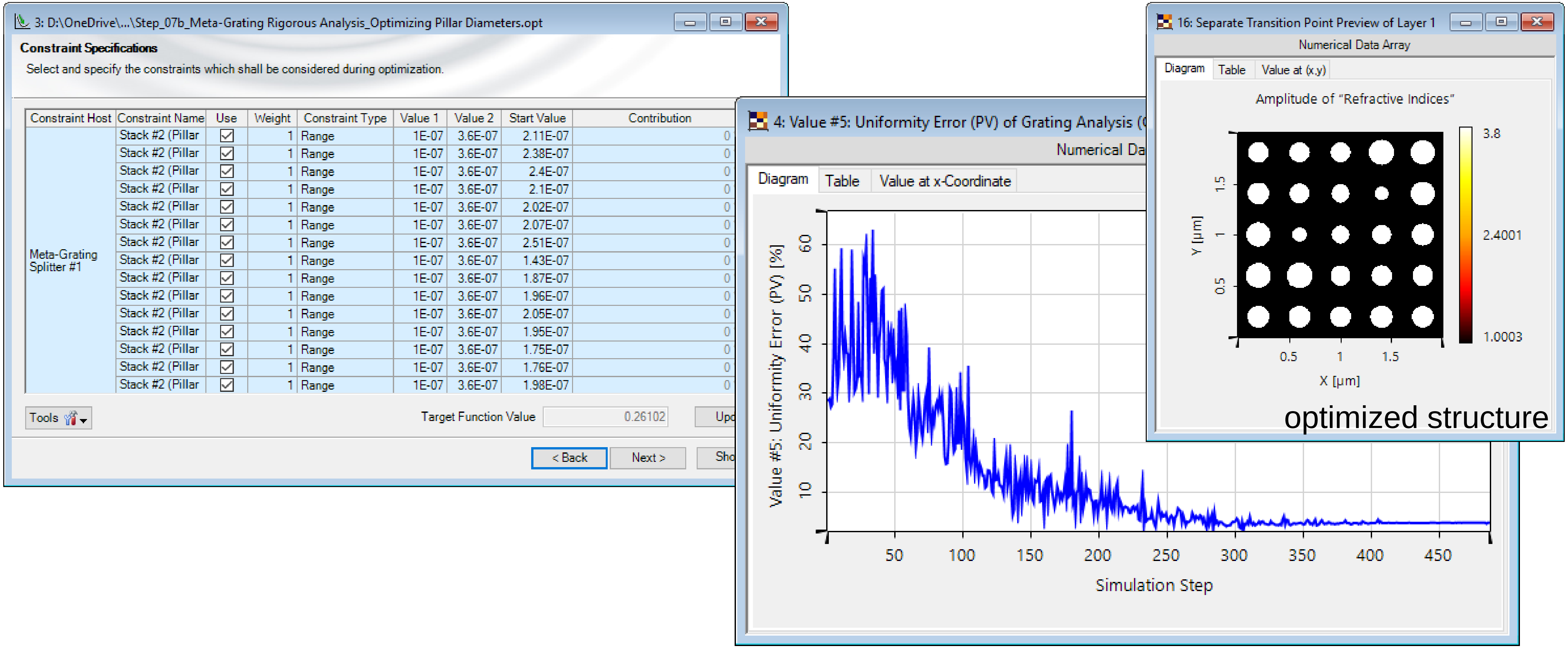
Step 7a: Optimization of Pillar Height

Not very effective on the optimization

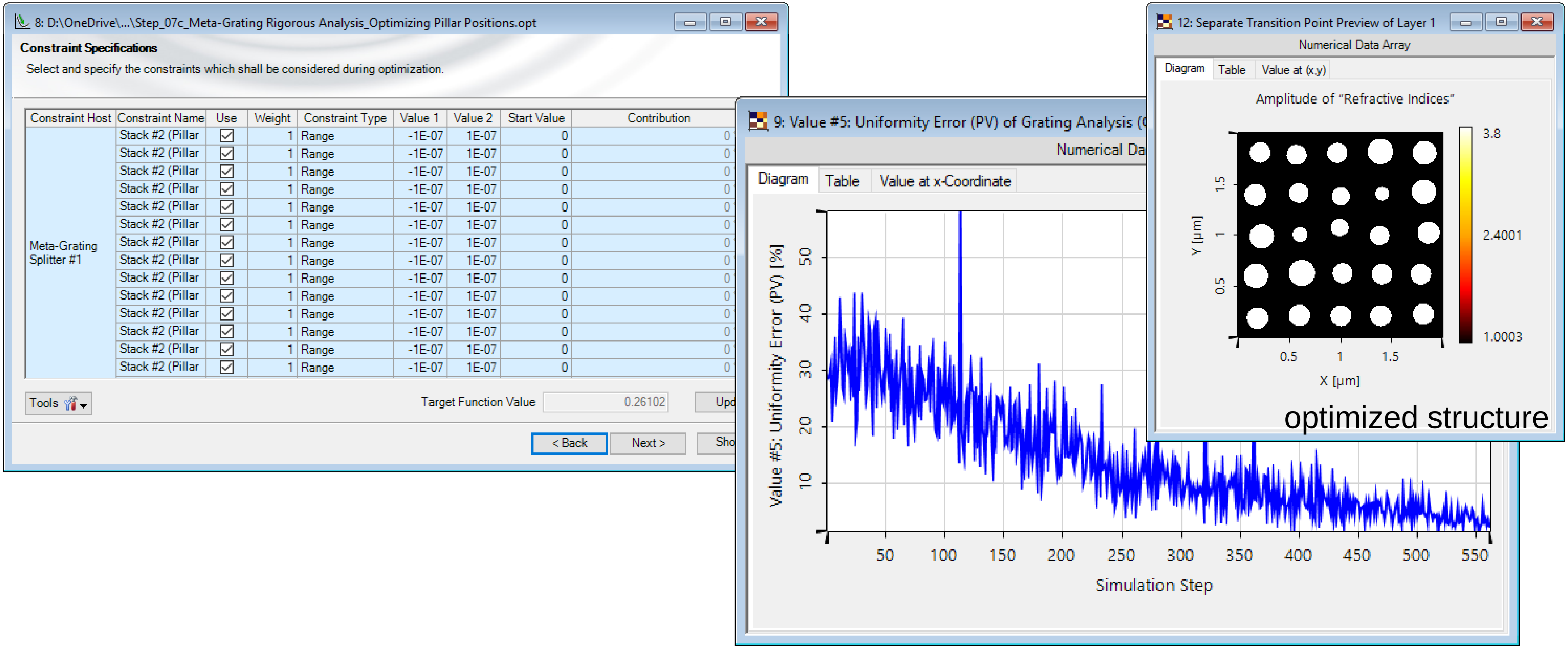




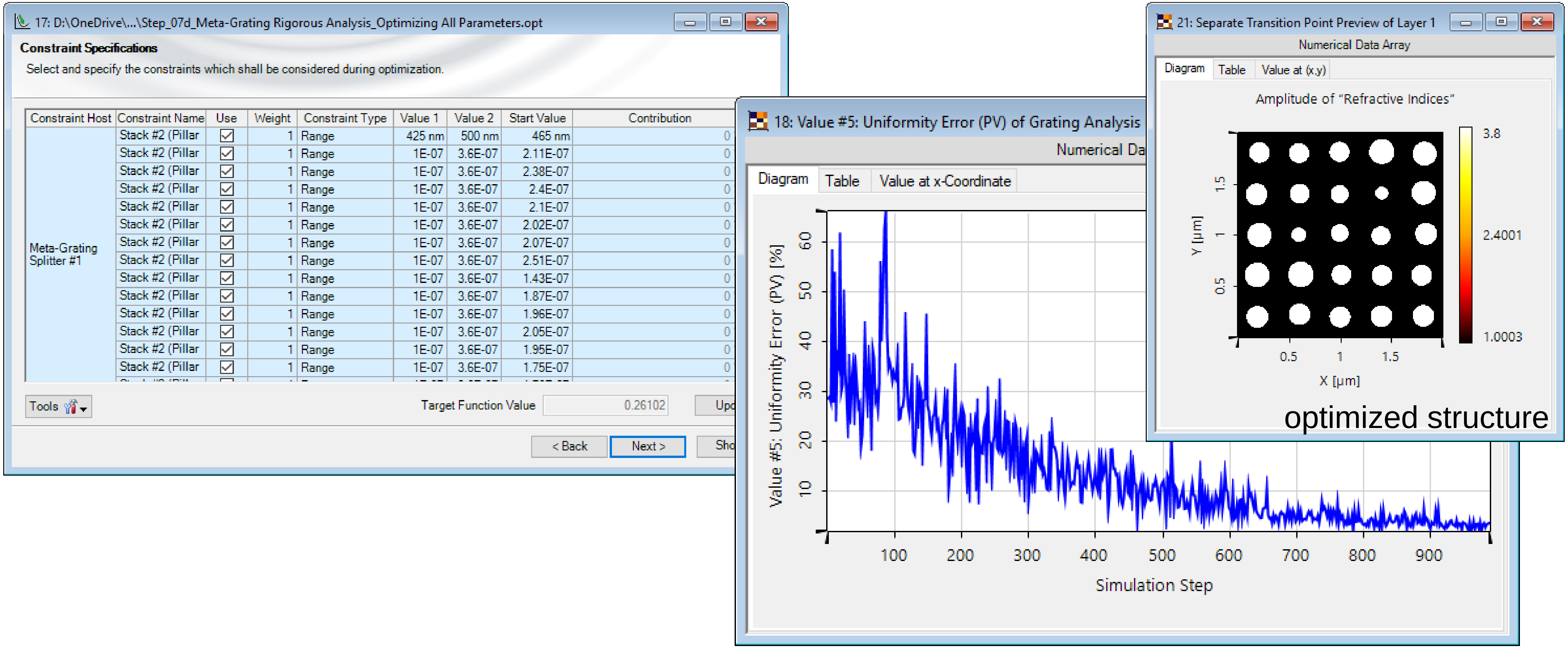
Step 7b: Optimization of Pillar Diameters



Step 7c: Optimization of Pillar Positions



Step 7d: Optimization of All Parameters



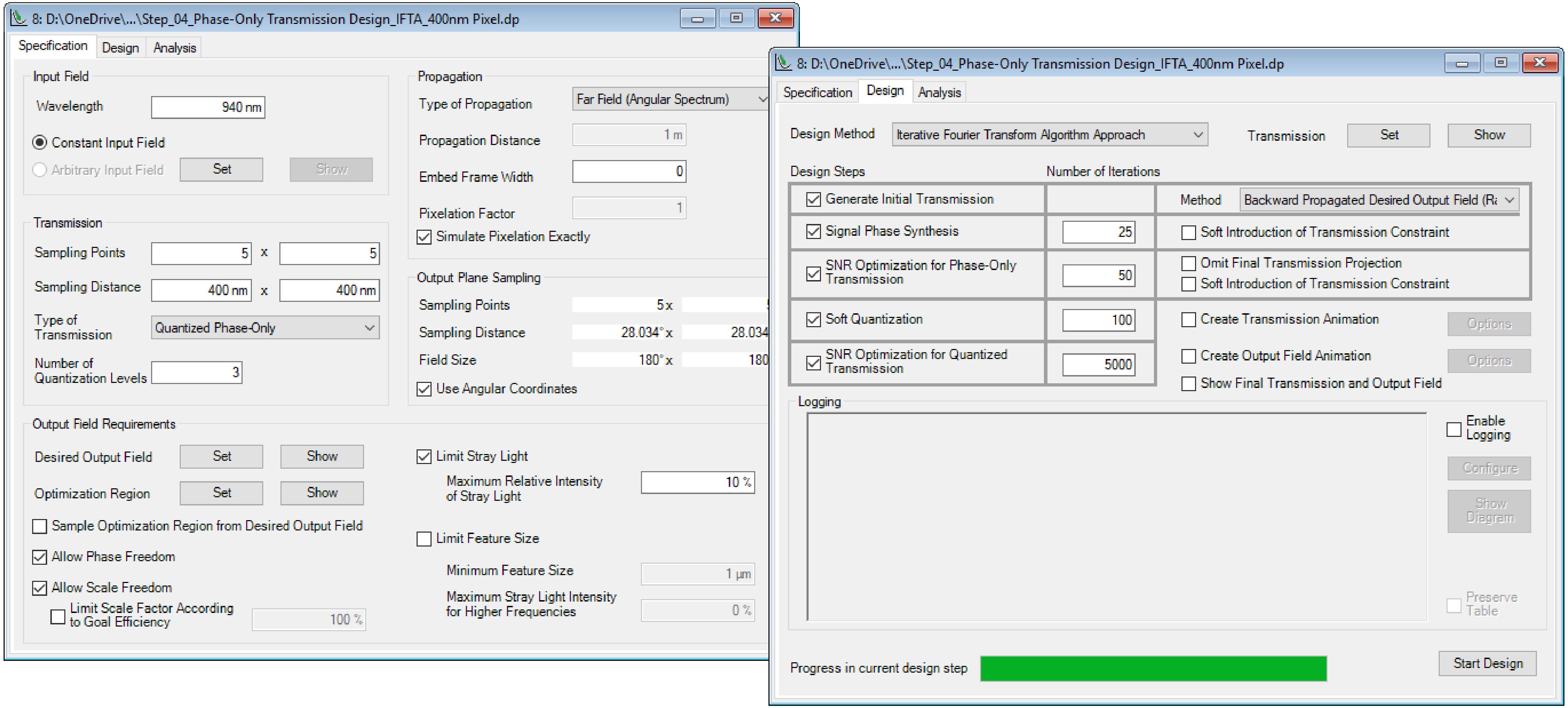
Constraint Host	Constraint Name	Use	Weight	Constraint Type	Value 1	Value 2	Start Value	Contribution
Meta-Grating Splitter #1	Stack #2 (Pillar	☑	1	Range	425 nm	500 nm	465 nm	0
	Stack #2 (Pillar	☑	1	Range	1E-07	3.6E-07	2.11E-07	0
	Stack #2 (Pillar	☑	1	Range	1E-07	3.6E-07	2.38E-07	0
	Stack #2 (Pillar	☑	1	Range	1E-07	3.6E-07	2.4E-07	0
	Stack #2 (Pillar	☑	1	Range	1E-07	3.6E-07	2.1E-07	0
	Stack #2 (Pillar	☑	1	Range	1E-07	3.6E-07	2.02E-07	0
	Stack #2 (Pillar	☑	1	Range	1E-07	3.6E-07	2.07E-07	0
	Stack #2 (Pillar	☑	1	Range	1E-07	3.6E-07	2.51E-07	0
	Stack #2 (Pillar	☑	1	Range	1E-07	3.6E-07	1.43E-07	0
	Stack #2 (Pillar	☑	1	Range	1E-07	3.6E-07	1.87E-07	0
	Stack #2 (Pillar	☑	1	Range	1E-07	3.6E-07	1.96E-07	0
	Stack #2 (Pillar	☑	1	Range	1E-07	3.6E-07	2.05E-07	0
	Stack #2 (Pillar	☑	1	Range	1E-07	3.6E-07	1.95E-07	0
	Stack #2 (Pillar	☑	1	Range	1E-07	3.6E-07	1.75E-07	0

“Binary” Design Example

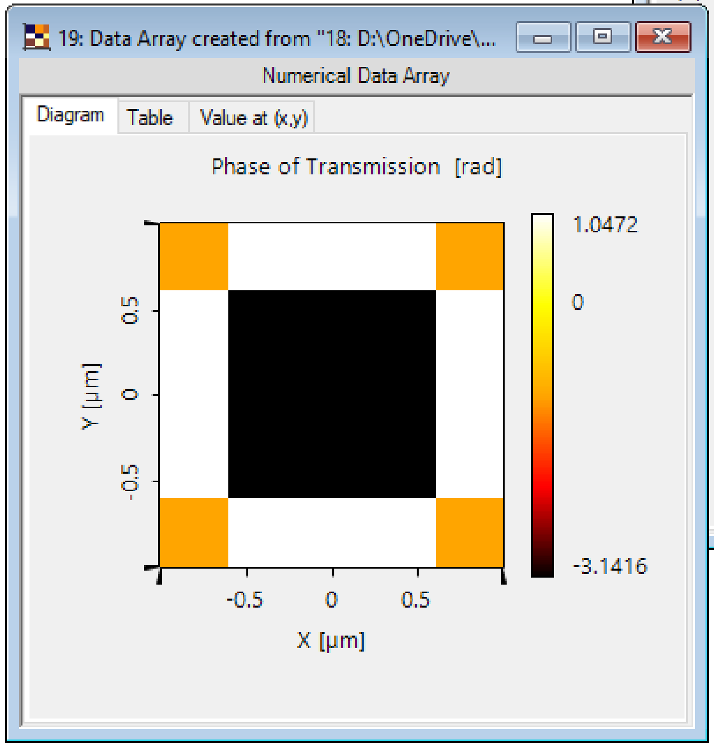
Step 1~3: Analysis of Single Pillar

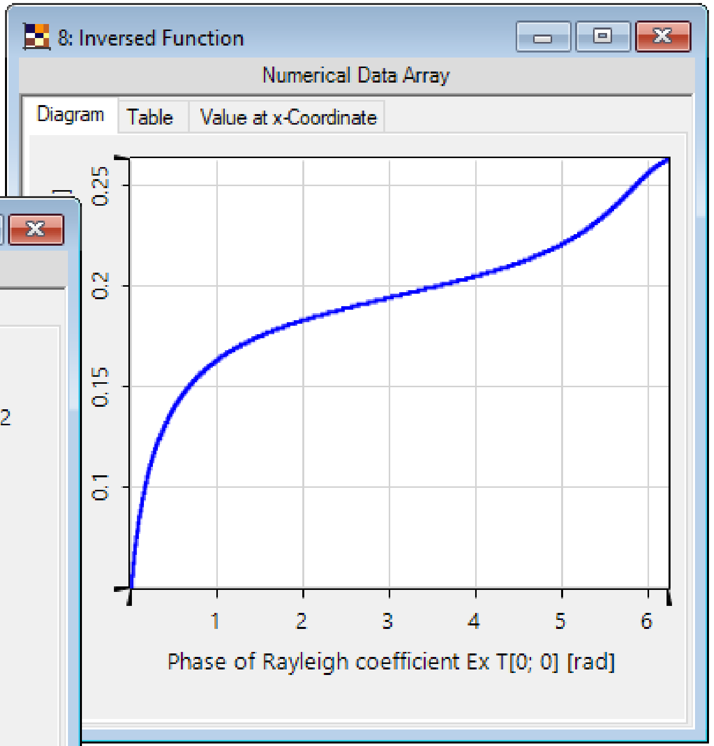
- The procedure on finding proper pillar diameters is the same as in the previous example, and thus will not be repeated here.

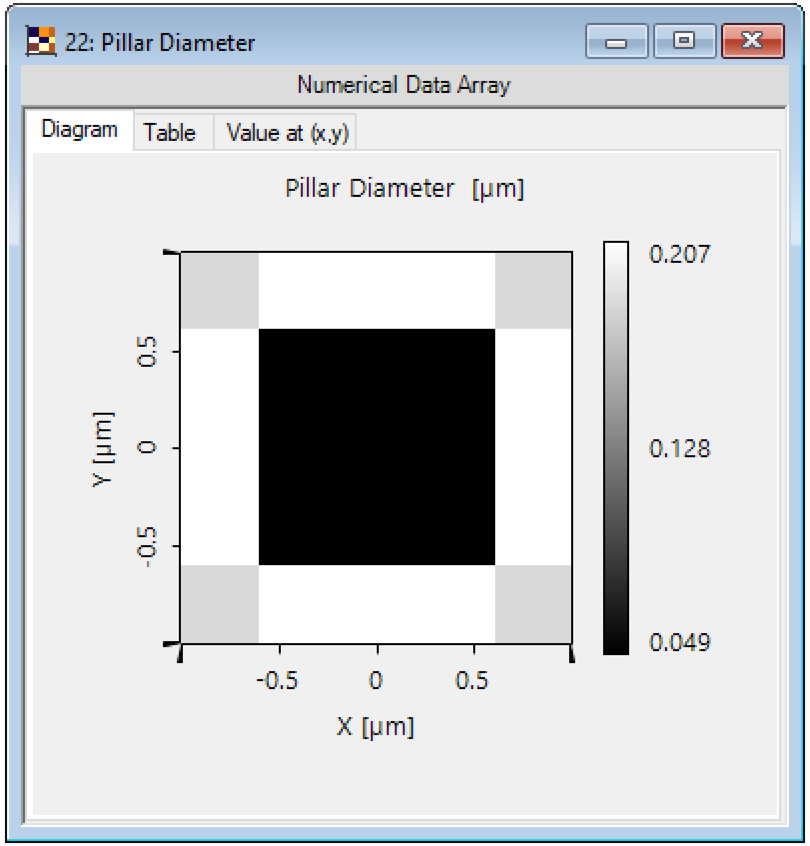
Step 4: Calculate Phase-Only (3-Level) Transmission



Step 5: From Phase Profile to Structure







Step_05_Calculate Pillar Diameters from Phase Profile_2D Regular Array.cs

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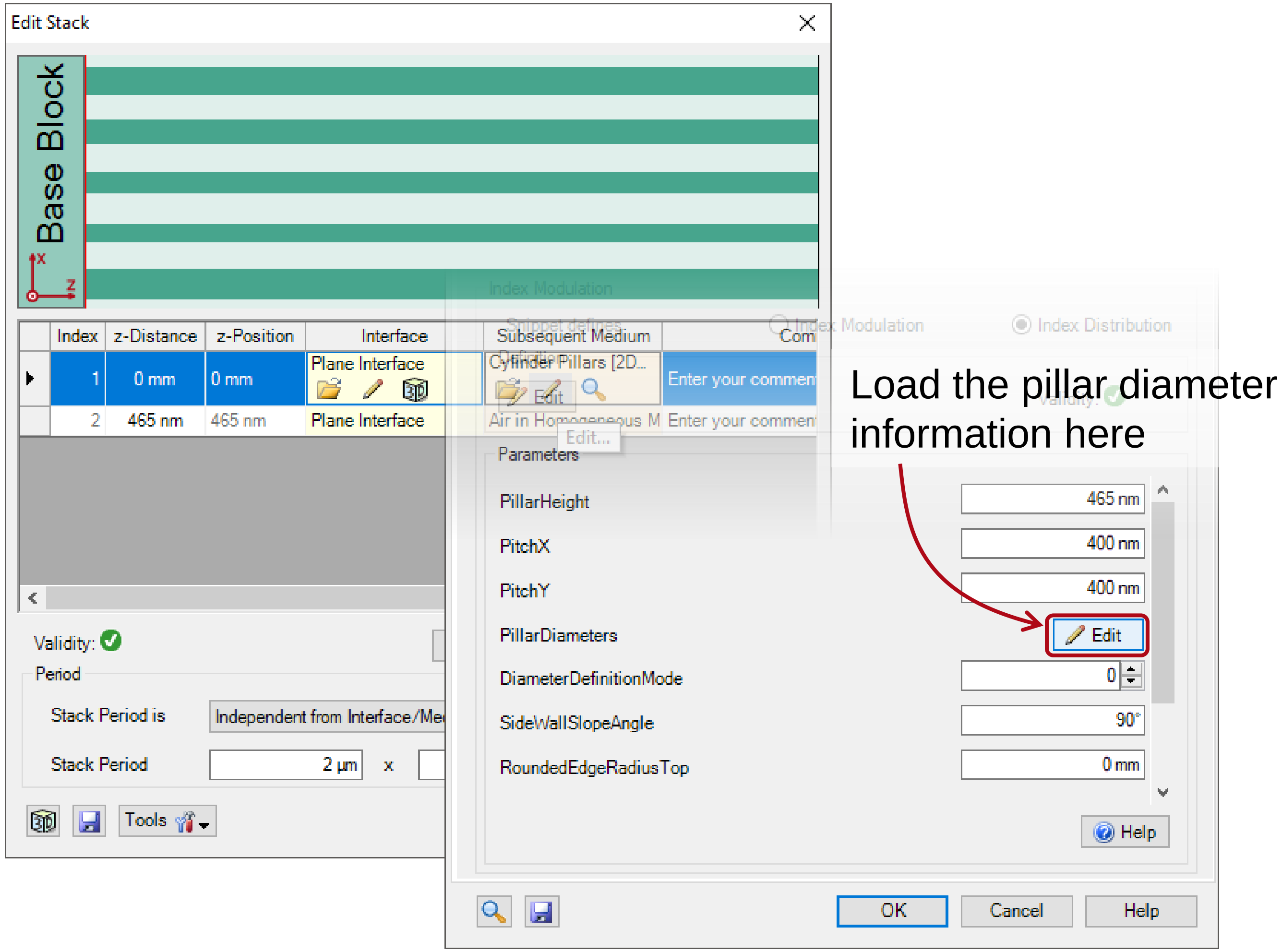
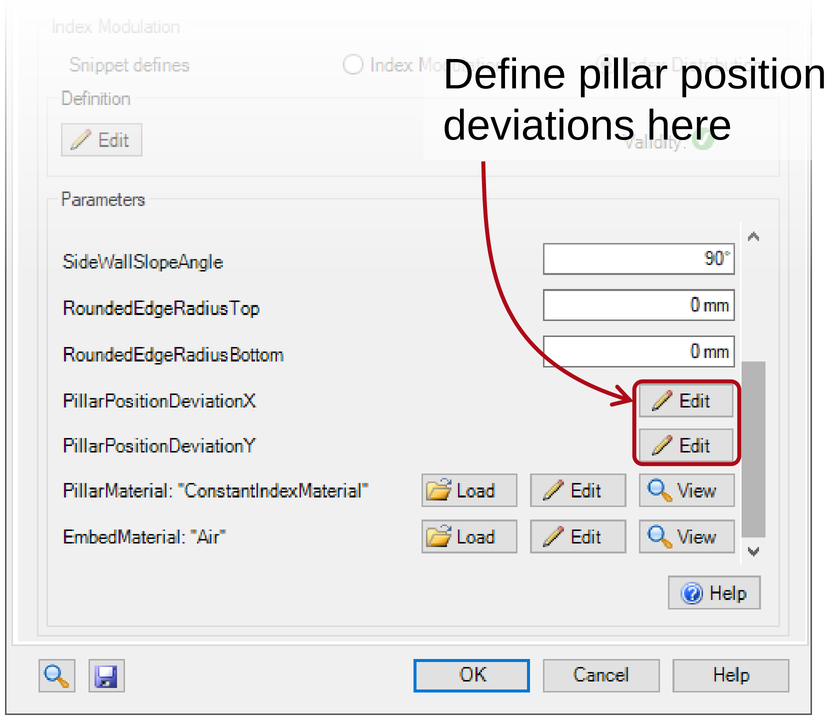
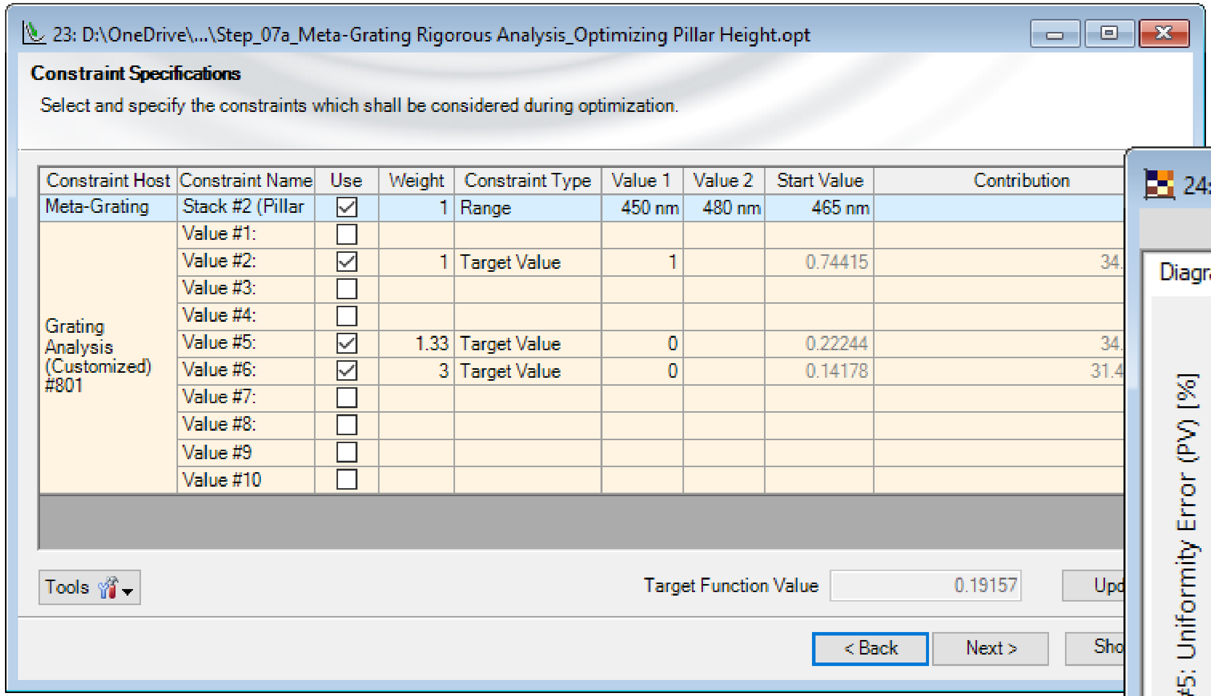
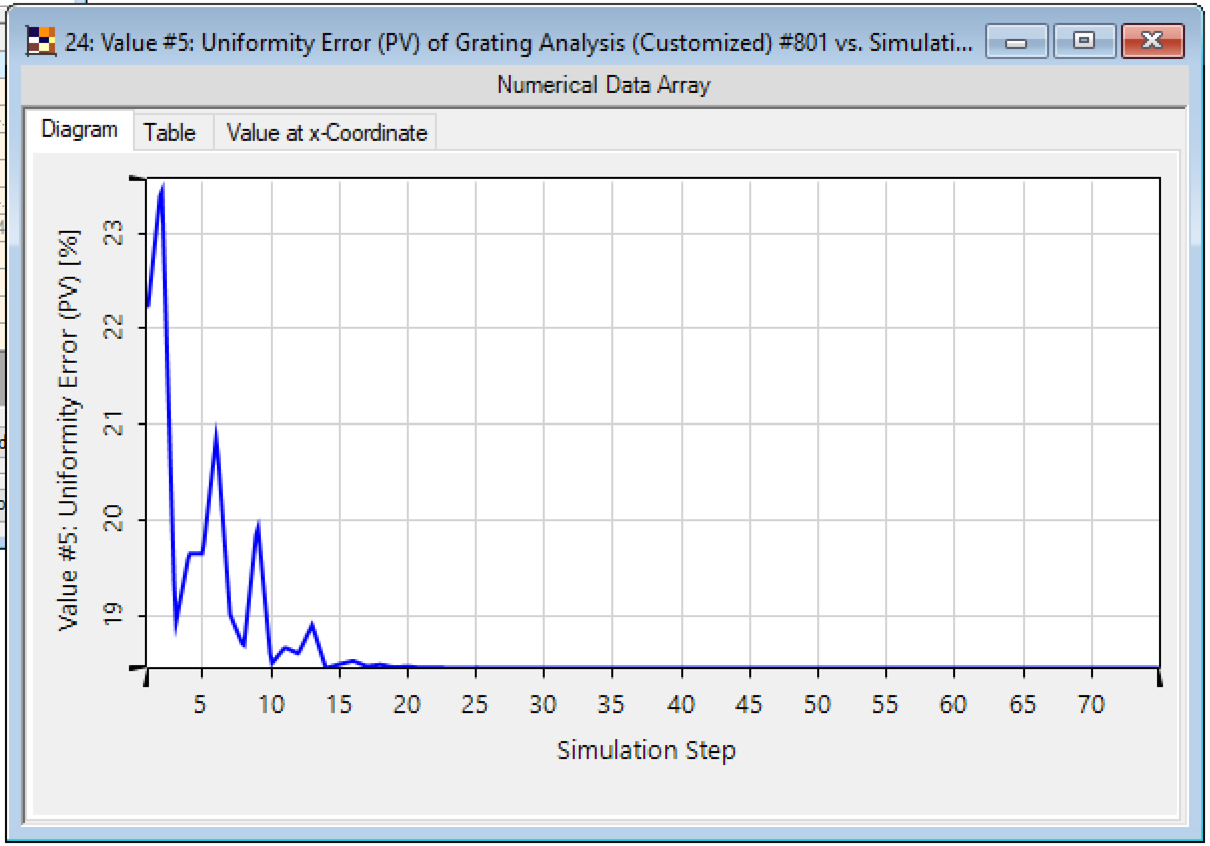




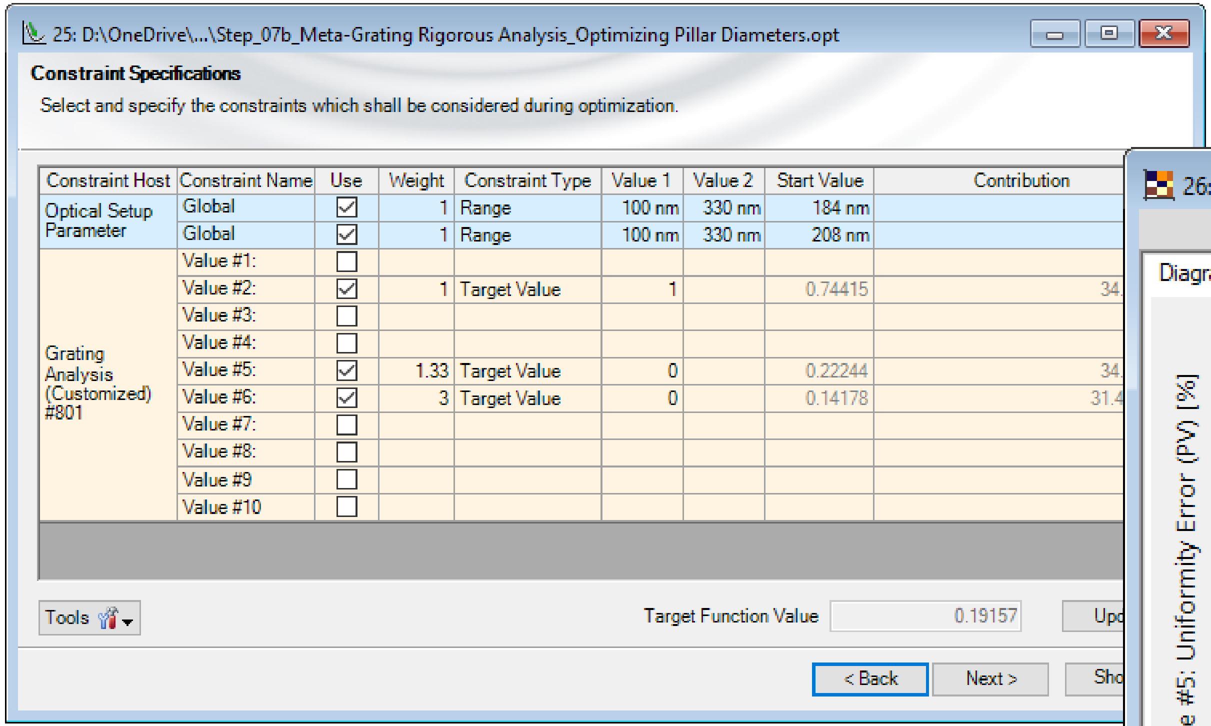
Step 7a: Optimization of Pillar Height



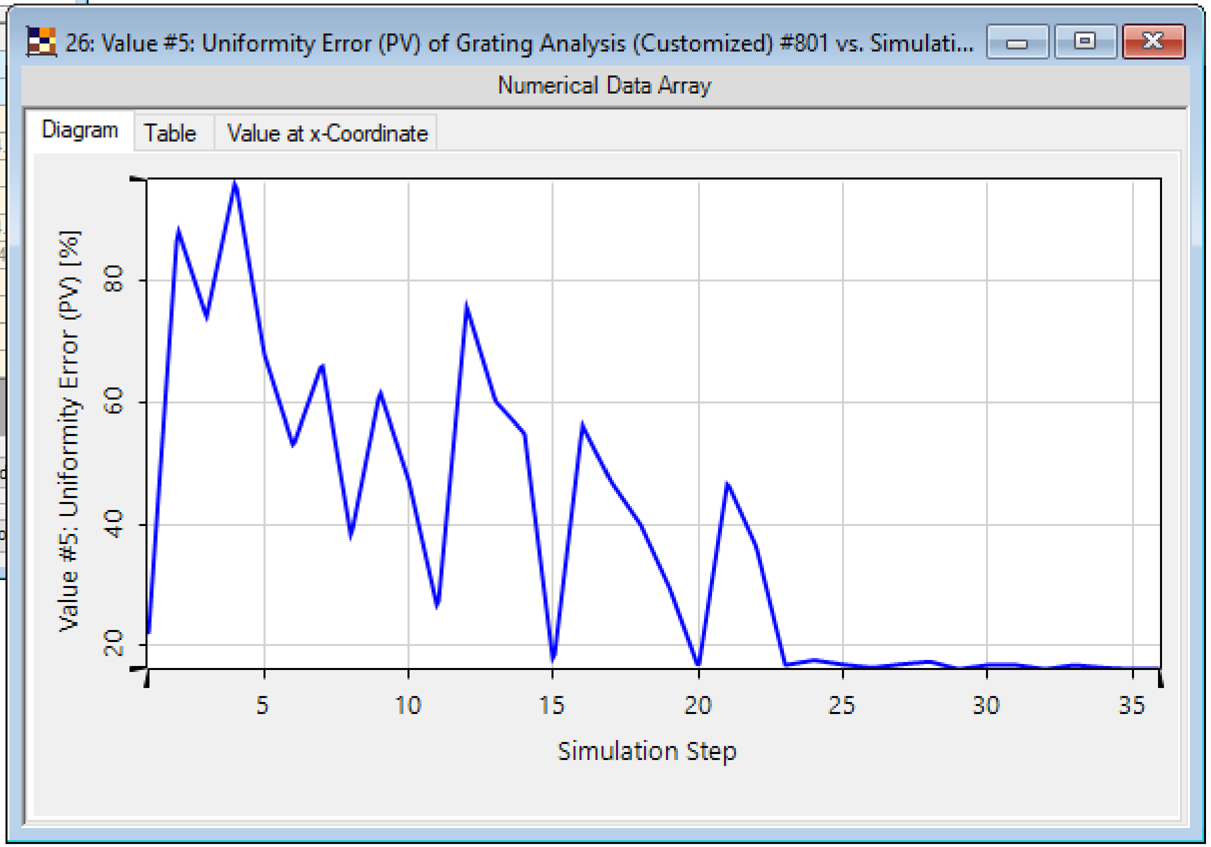
Not very effective on the optimization



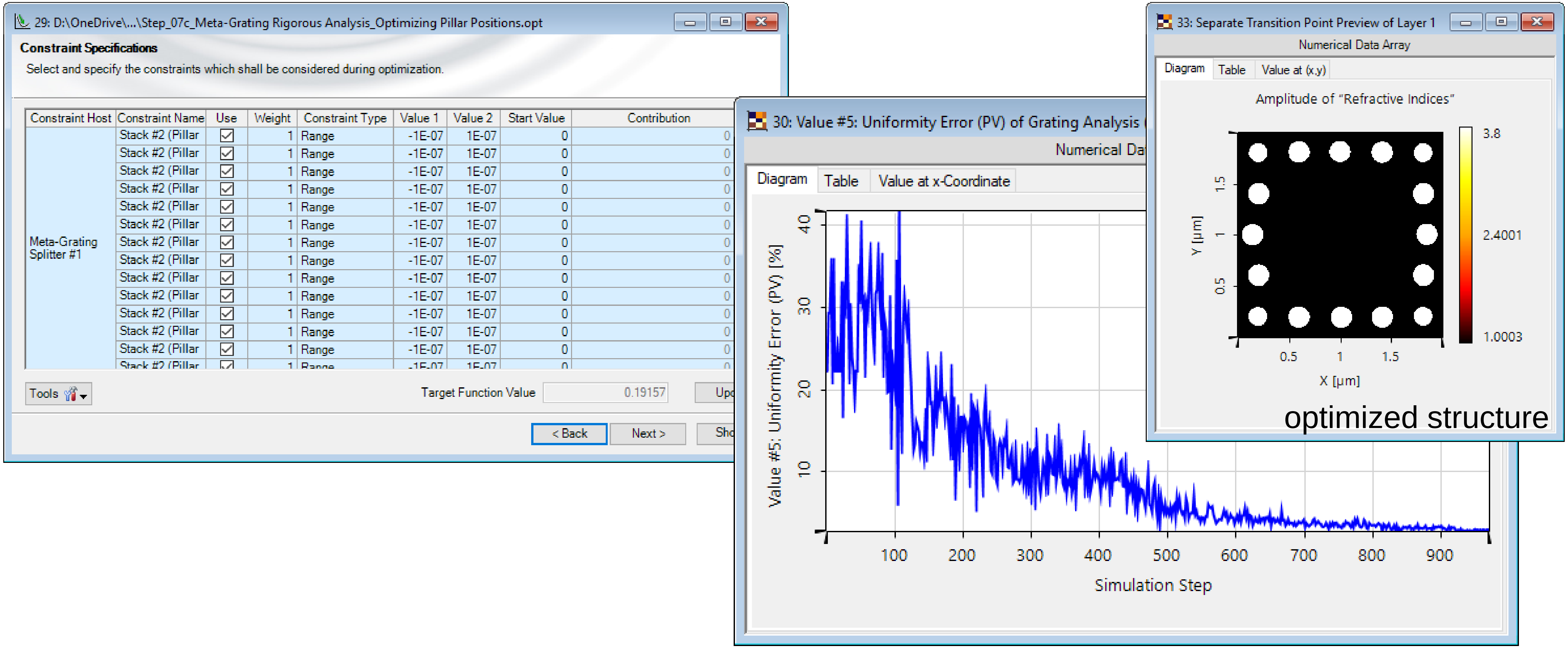
Step 7b: Optimization of Pillar Diameters



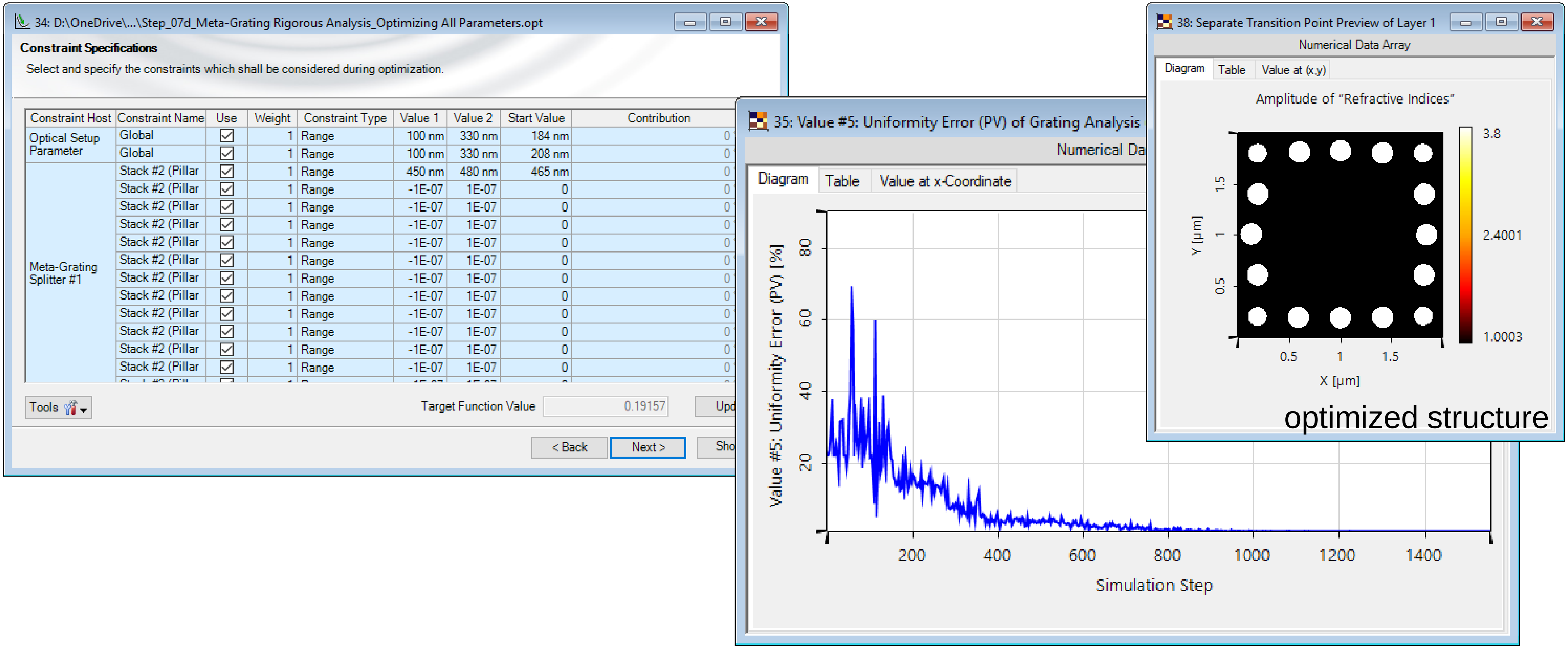
Not very effective on the optimization



Step 7c: Optimization of Pillar Positions



Step 7d: Optimization of All Parameters



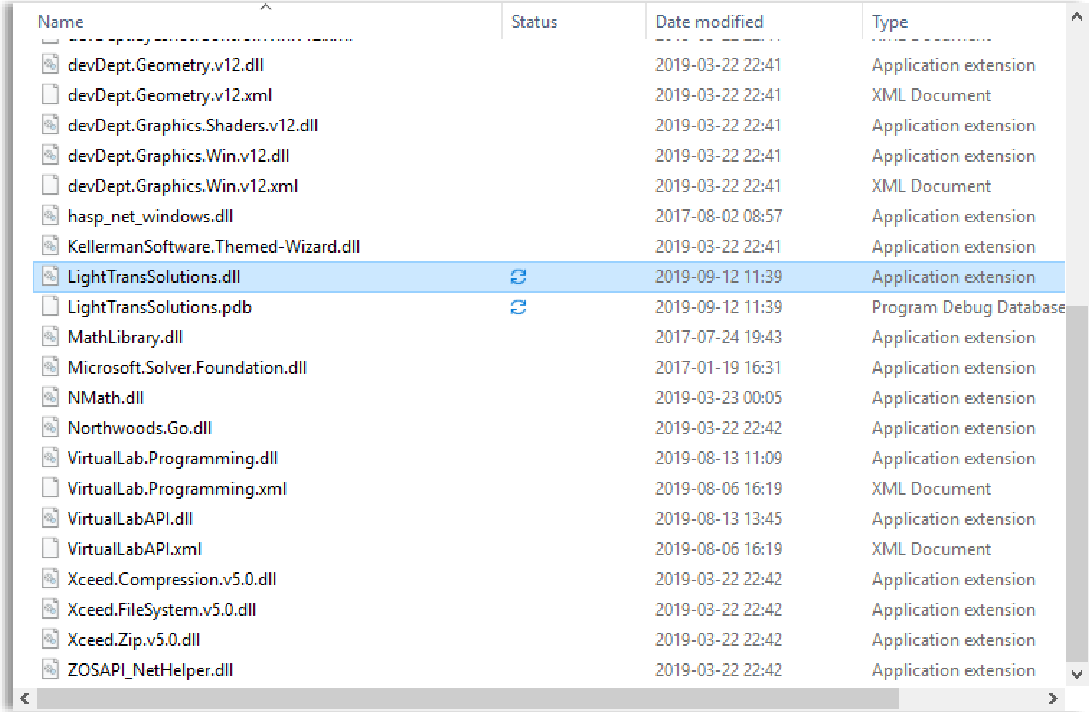
Appendix: How to Use LightTransSolutions.dll?

- Make a copy of

  LightTransSolutions.dll

- Paste it into the installation location of VirtualLab Fusion, e.g.,

  C:\Program Files\Wyrowski Photonics\VirtualLab Fusion (7.5.0)



Document Information

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VL version used for simulations	VirtualLab Fusion Summer Release 2019 (7.6.1.18)
category	Demo
further reading	