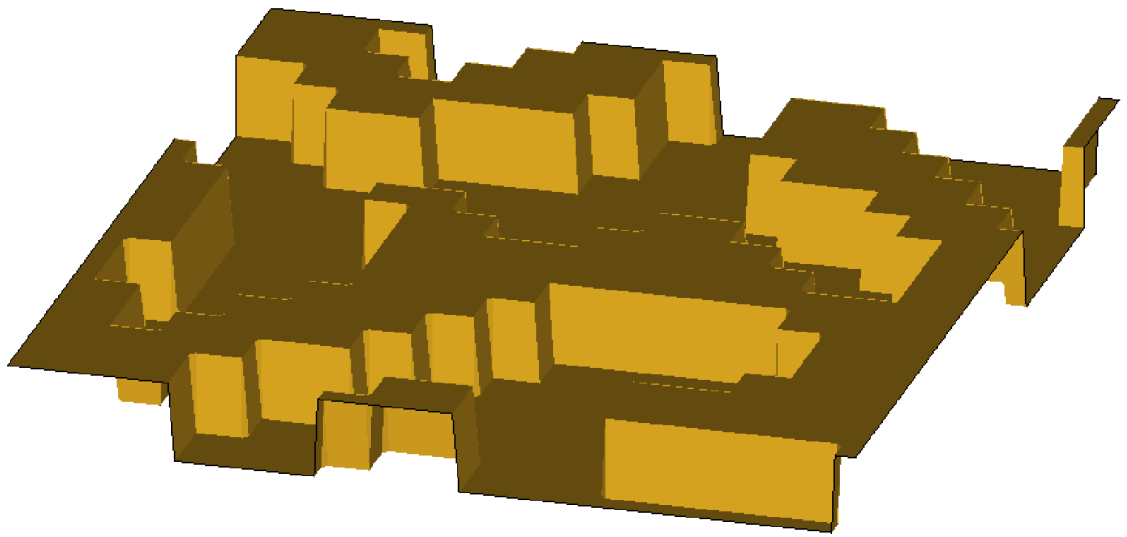
Design and Rigorous Analysis of Non-Paraxial Diffractive Beam Splitter

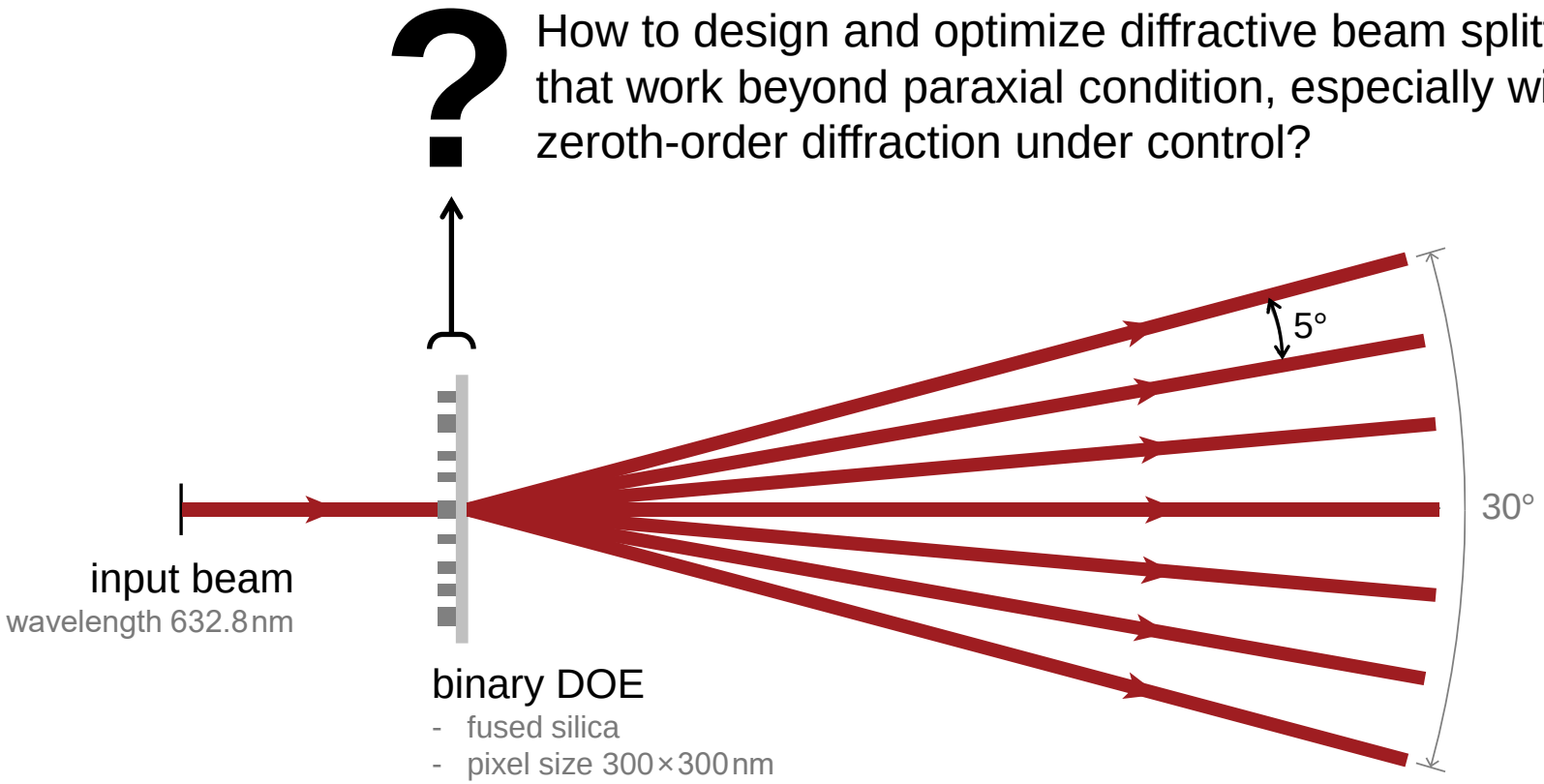
Abstract



Direct design of a non-paraxial diffractive beam splitters is still challenging. Due to the relatively large splitting angle, the feature size of the element is equivalent to or smaller than the working wavelength. Thus, it is often beyond the paraxial modeling approaches. In this example, the iterative Fourier transform algorithm (IFTA) and thin-element approximation (TEA) are used for the initial design of the diffractive element structures, and Fourier modal method (FMM) is then applied for the rigorous performance evaluation.

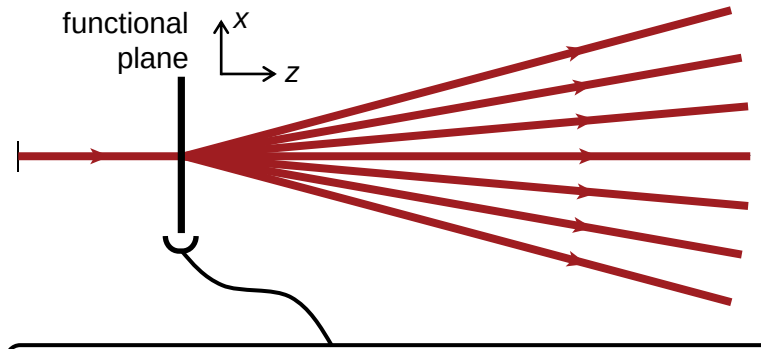
Design Task

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

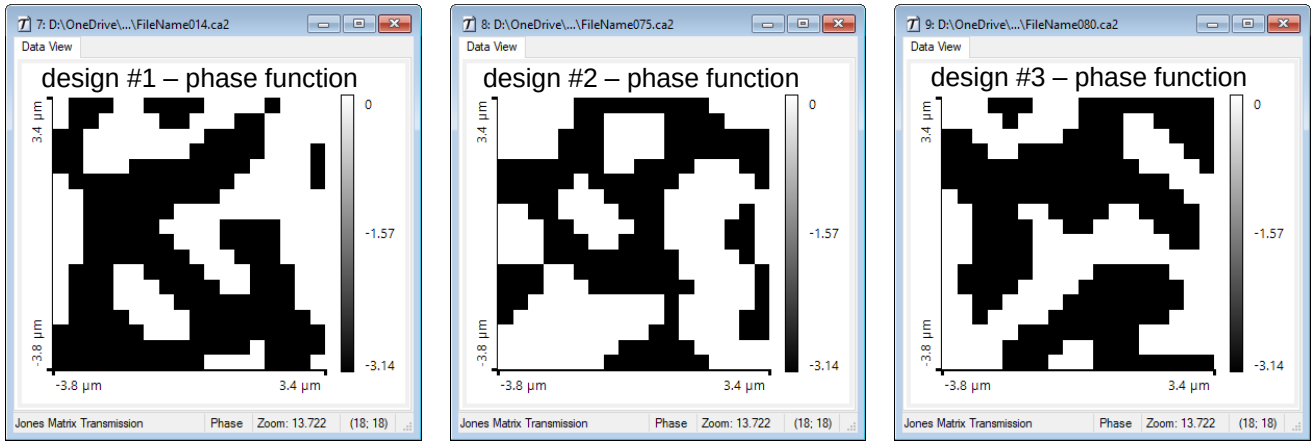


Phase-Only Transmission Design

using the iterative Fourier transform algorithm (IFTA) for phase-only transmission design



With differently random phase distributions as starting points, IFTA calculates different possible design results. 3 designs are selected out of 100 according to customized criteria.



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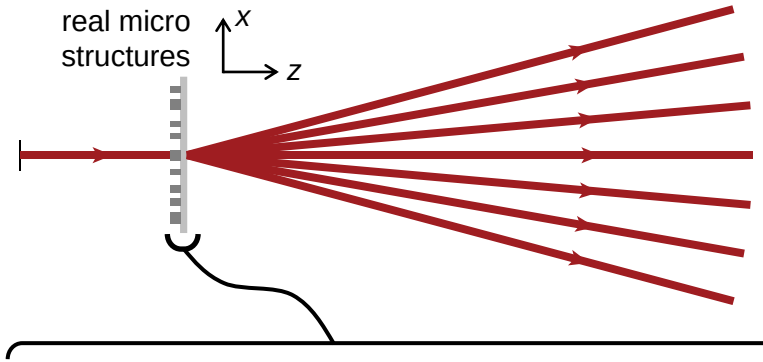
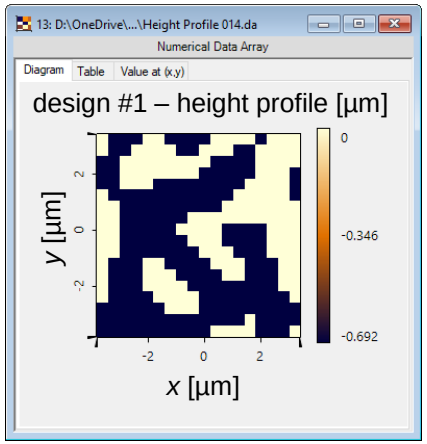
delivery of 100 designs within 20 seconds!

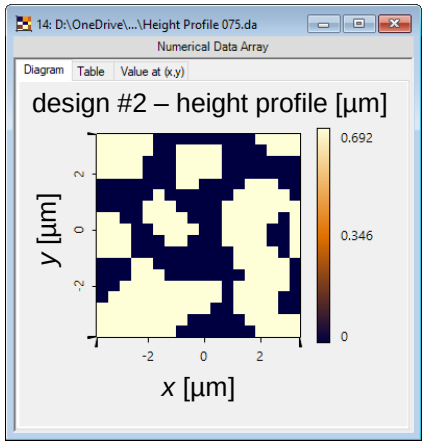
Structure Design

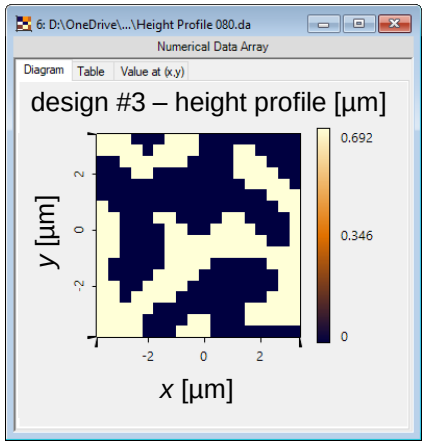
using the thin-element approximation (TEA) for the structure design, under paraxial assumption



Automatic conversion from phase-only transmission to structure height profile, according to given wavelength and material.

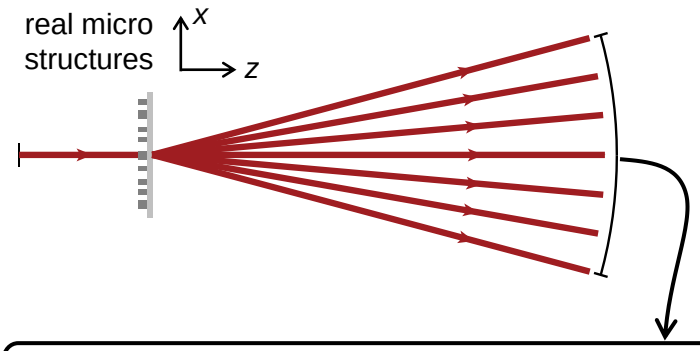




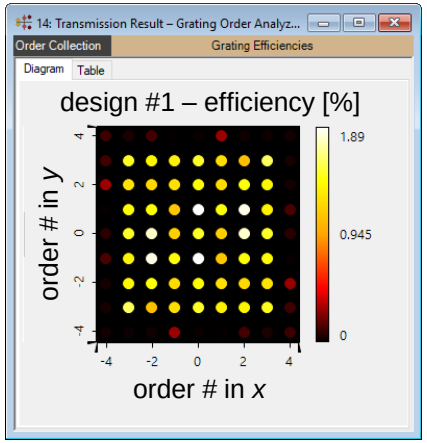


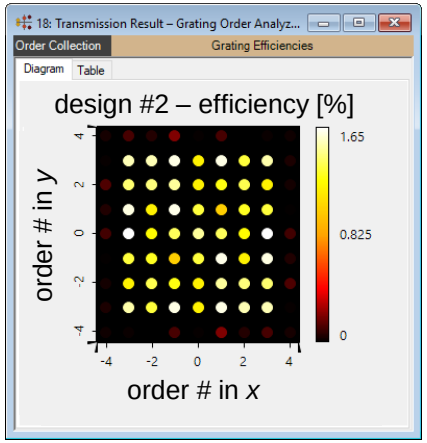
Performance Evaluation with TEA

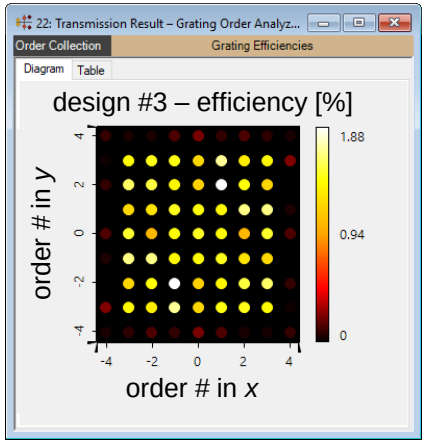
evaluation with TEA, i.e., the same as design method, under paraxial assumption



Merit functions	Design #1	Design #2	Design #3
total efficiency	69.057%	68.068%	69.613%
average efficiency	1.4093%	1.3892%	1.4207%
zeroth efficiency (zeroth order error)	1.4888% (5.6374%)	1.4888% (7.1723%)	1.4704% (3.5%)
uniformity error (RMS)	14.422%	**12.266%**	12.989%



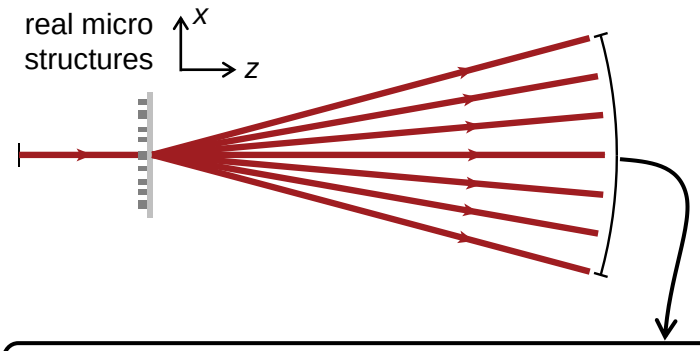




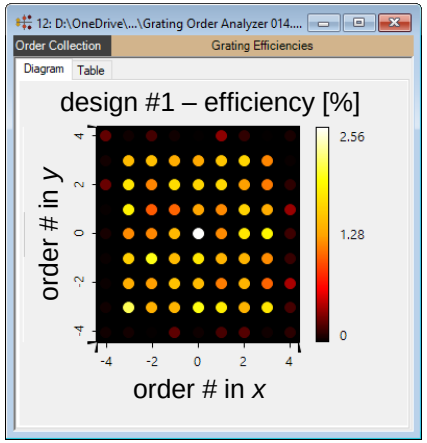
Design #2 seems to give the best uniformity, based on the evaluation results from thin-element approximation. But, is it still true for the non-paraxial situation?

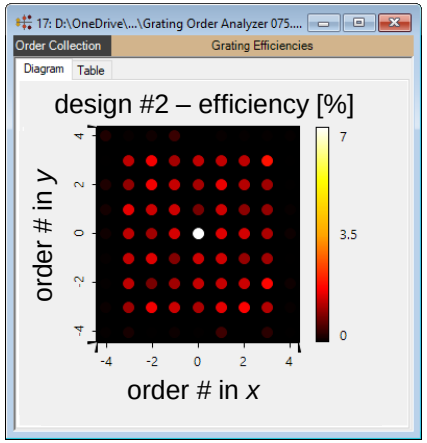
Performance Evaluation with Fourier Modal Method

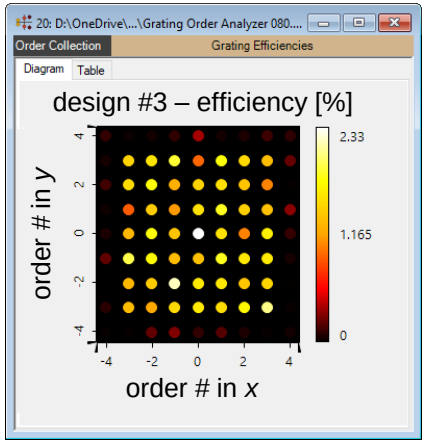
evaluation with the rigorous FMM to check the actual performance in non-paraxial situation



Merit functions	Design #1	Design #2	Design #3
total efficiency	72.122%	70.619%	74.311%
average efficiency	1.4719%	1.4412%	1.5165%
zeroth efficiency (zeroth order error)	2.5574% (73.753%)	7.011% (386.47%)	2.3324% (53.799%)
uniformity error (RMS)	21.064%	**58.431%**	18.946%



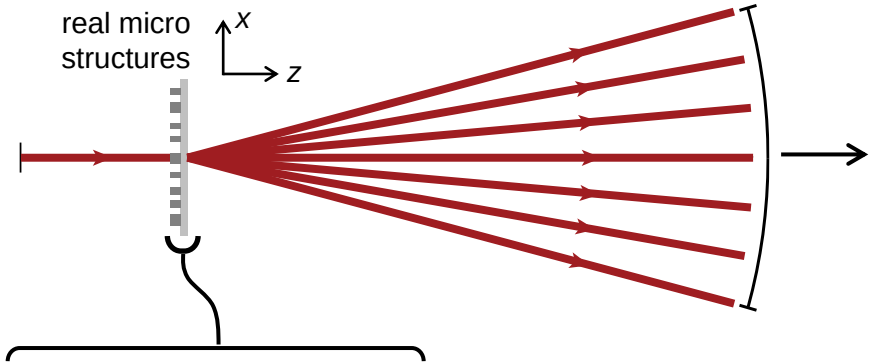


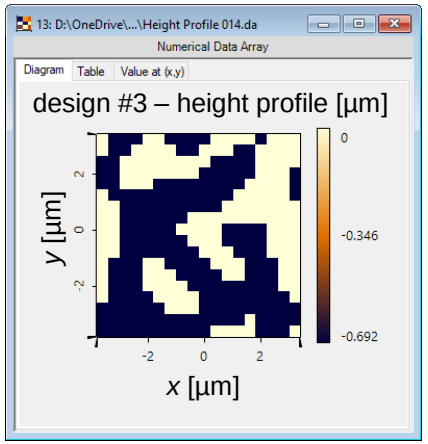


With the rigorous Fourier modal method (FMM), it turns out that design #2 produces strong zeroth diffraction order, resulting in very poor uniformity in fact.

Further Optimization – Zeroth Order Tuning

direct structural optimization with FMM, without any assumption



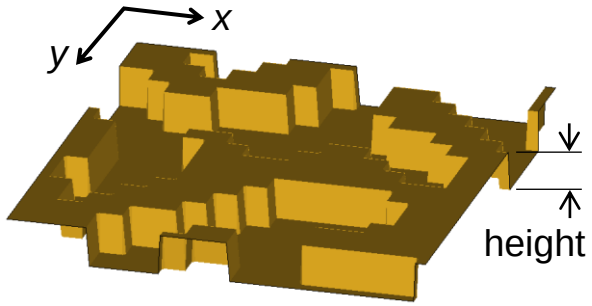


FMM evaluation results

Merit functions	Design #3
total efficiency	74.311%
average efficiency	1.5165%
zeroth efficiency (zeroth order error*)	**2.3324% (53.799%)**
uniformity error (RMS)	18.946%

$$*\text{zeroth order error} = \frac{\text{zeroth efficiency} - \text{average efficiency}}{\text{average efficiency}}$$

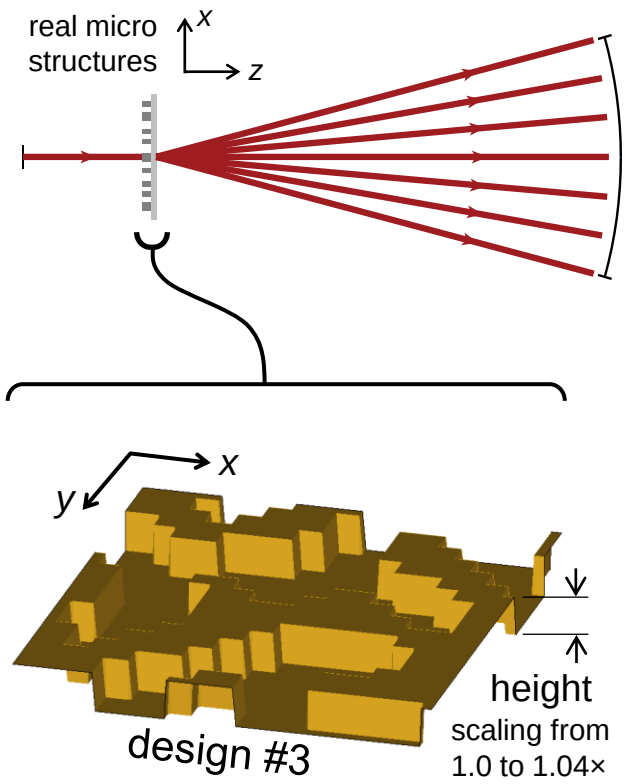
Design #3 gives good overall performance but still produces undesired zeroth order error.

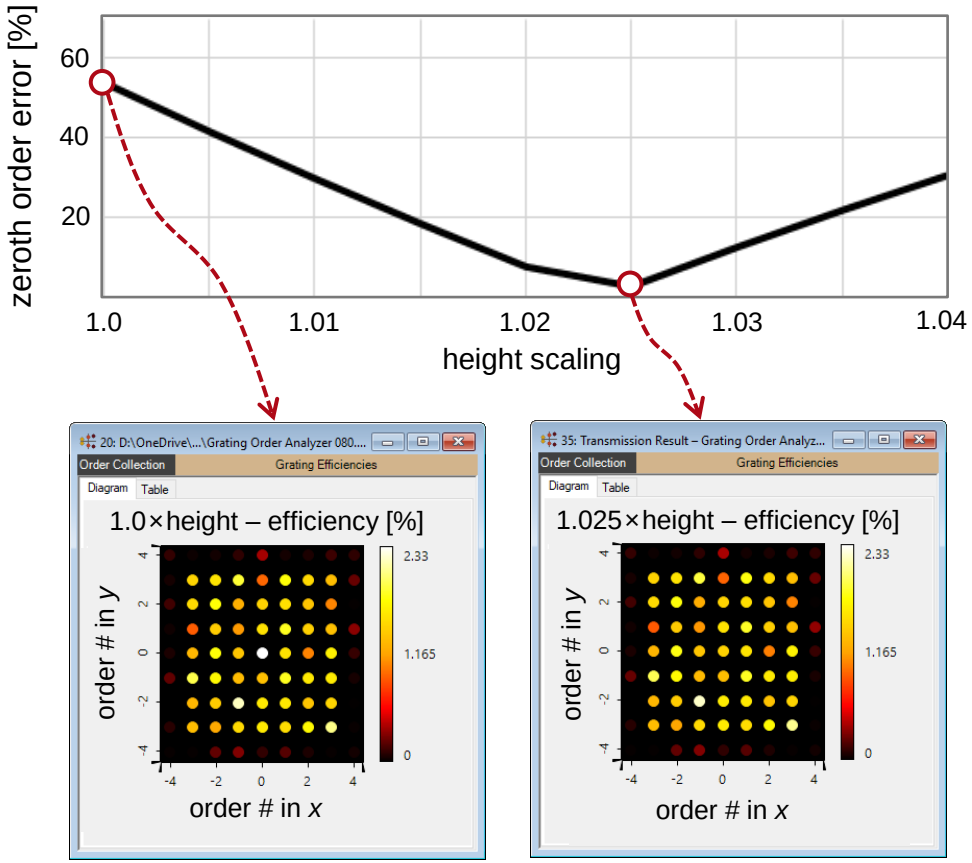


Sometimes, the zeroth order error can be reduced by tuning the height of the binary structure.

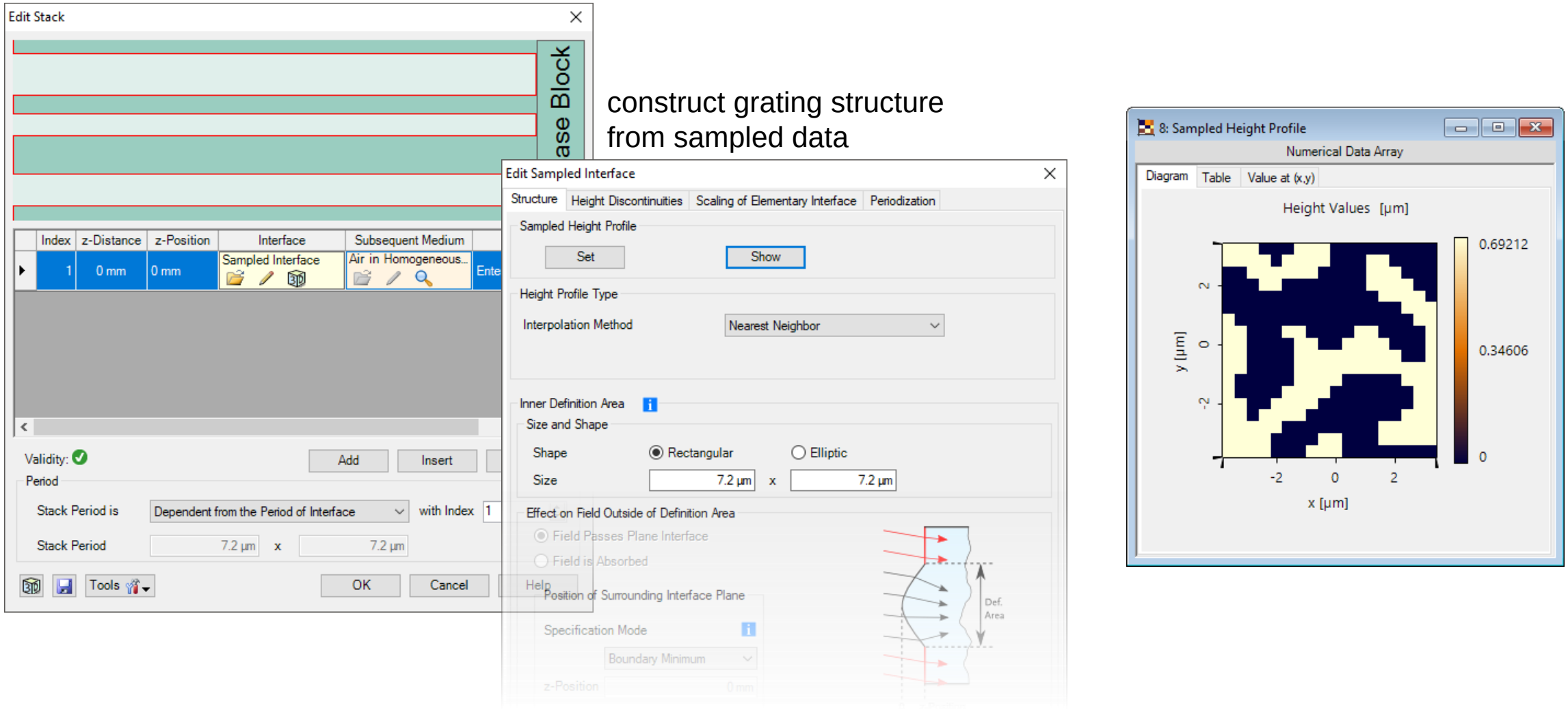
Further Optimization – Zeroth Order Tuning

direct structural optimization with FMM, without any assumption





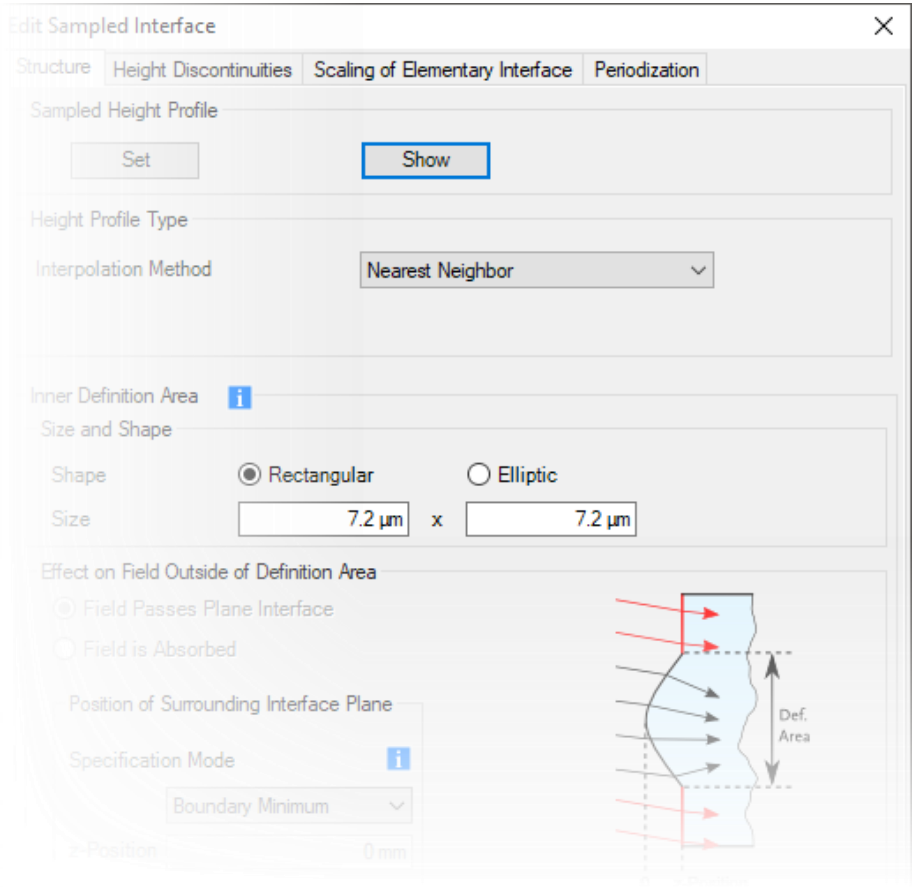
Peek into VirtualLab Fusion



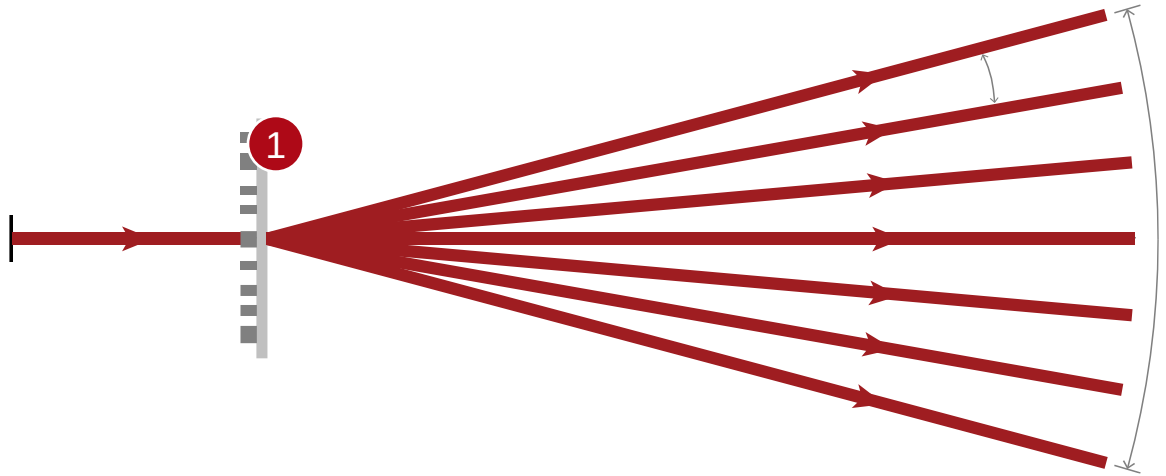
construct grating structure from sampled data

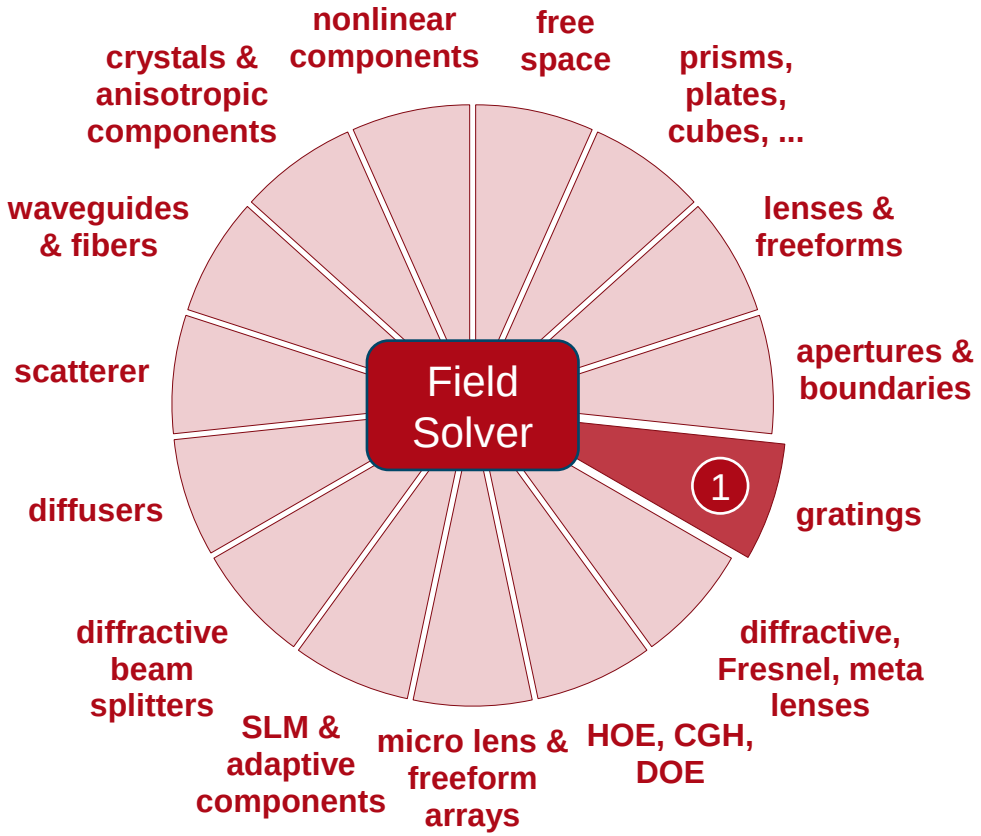
Workflow in VirtualLab Fusion

- Using IFTA to design phase-only transmission
- Execute IFTA in Multi Runs mode
- Design DOE structure from transmission
  - Structure Design [Use Case]
- Define grating using sampled surface
  - Configuration of Grating Structures by Using Interfaces [Use Case]
- Configuration of Parameter Run
  - Usage of the Parameter Run Document [Use Case]



VirtualLab Fusion Technologies





Document Information

title	Design and Rigorous Analysis of Non-Paraxial Diffractive Beam Splitter
document code	DOE.0004
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toolbox(es)	Diffractive Optics Toolbox Silver
software version	2020.1 (Build 1.200)
category	Application Use Case
further reading	- Grating Order Analyzer - Configuration of Grating Structures by Using Interfaces - Design of a High-NA Beam Splitter with 24000 Dots Random Pattern - Design of Diffractive Beam Splitters for Generating a 2D Light Mark