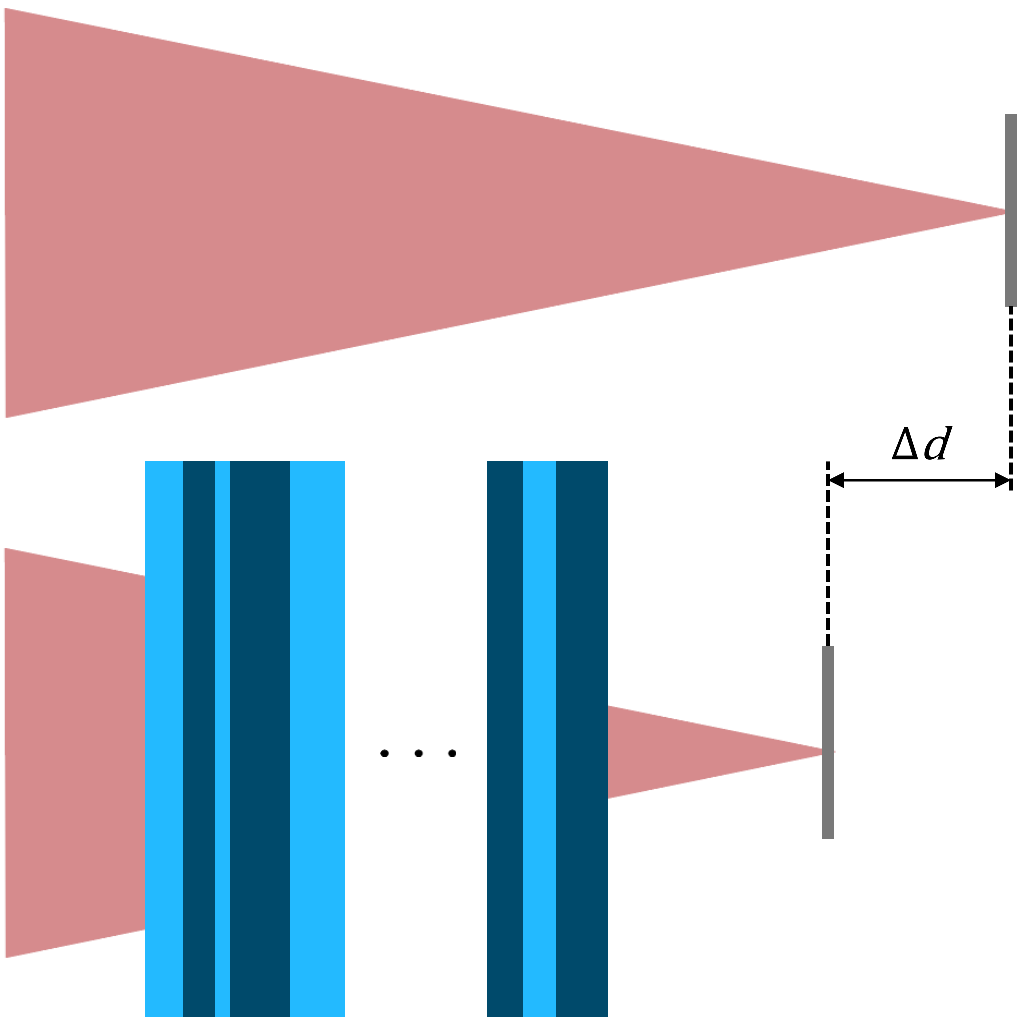
Modeling of a Space Plate by using a Multilayered Metasurface

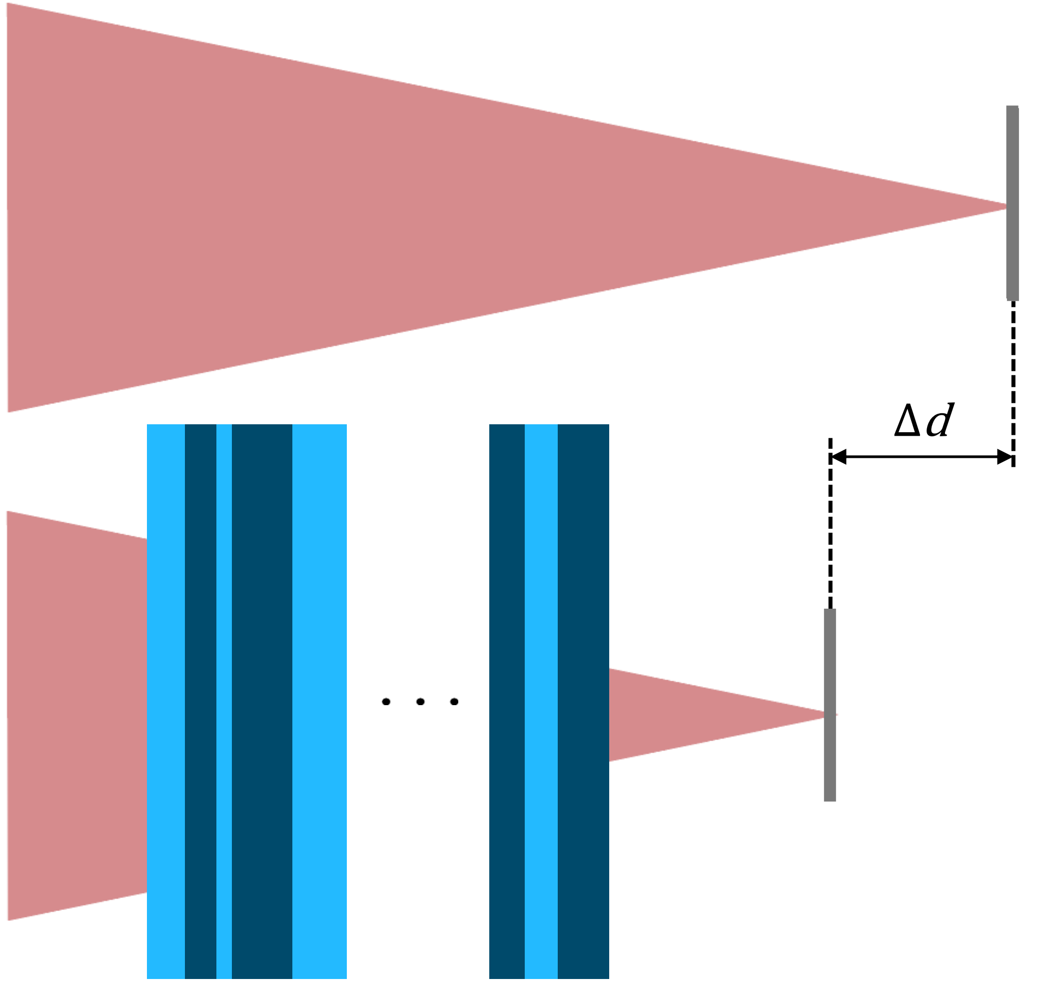
Abstract



In many modern optical applications, achieving the greatest possible compactness is one of the most sought-after optimization goals. There are many reasons for this: portable devices have less installation space for the optical components, and smaller systems tend to have lower weight and material costs. One recently proposed ingenious strategy in this field are “space plates”: Meta-surfaces allow to imitate a propagation in free space much longer than the actual thickness of the plate. For example, such elements allow the distance behind a focusing lens to be shortened to achieve focus (without changing the NA). In this example we showcase the characteristic of a space plate by a multilayered metamaterial proposed by Orad Reshef et al. and study its behavior in the optical modeling and design software VirtualLab Fusion.

Modeling Task

source:
- Gaussian wave
- wavelength: 1550 nm



detector:
Squared amplitude of electric field E^2 along beam axis

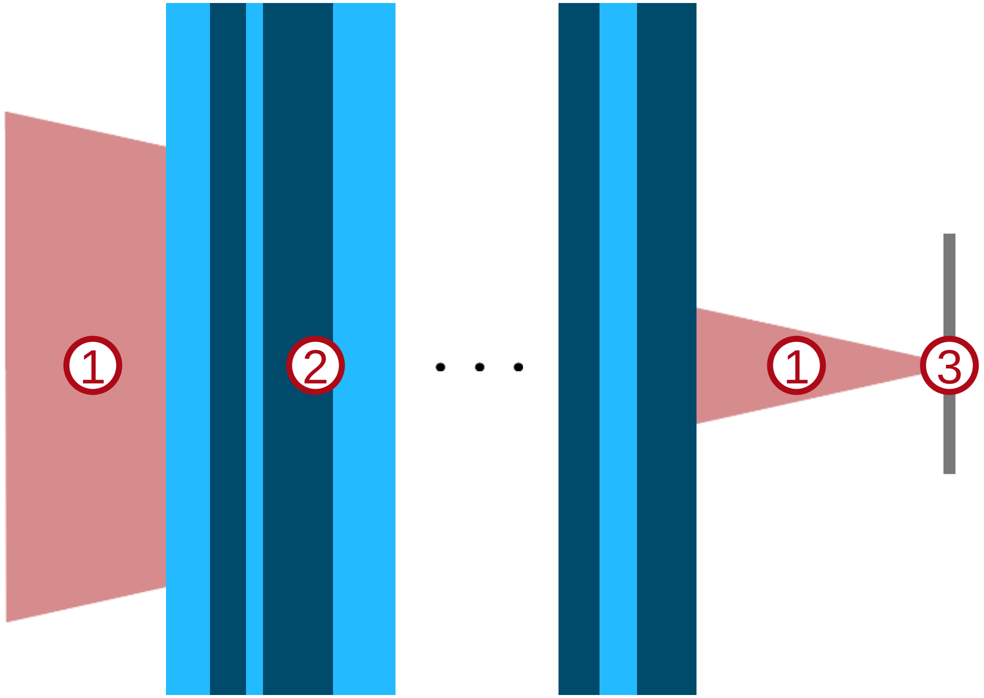
space plate
A multilayer stack composed of alternating layers of silicon and silica with different thicknesses to reduce the propagation length in free space.

System from: *Reshef, O., DelMastro, M.P., Bearne, K.K.M. et al., "An optic to replace space and its application towards ultra-thin imaging systems.", Nat. Commun.* ***12****, 3512 (2021). https://doi.org/10.1038/s41467-021-23358-8*

Single-Platform Interoperability of Modeling Techniques

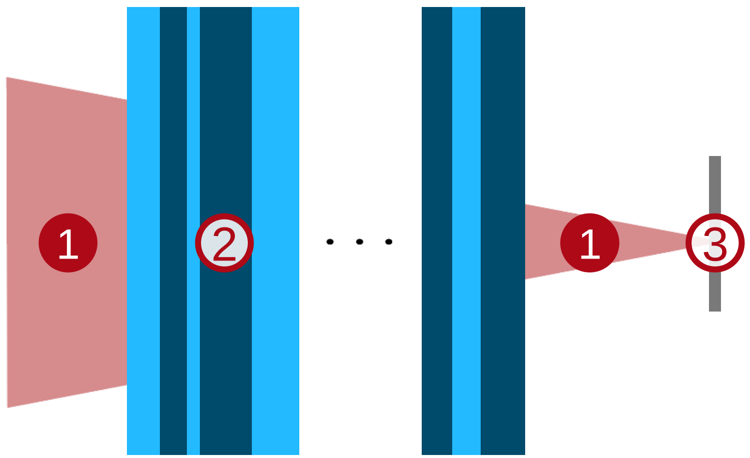
Light will encounter and interact with different components as it propagates through the system. A suitable model that provides a good compromise between accuracy and speed is required for each of these elements of the system:

① free space propagation
② space plate
③ detector



Connected Modeling Techniques: Free Space Propagation

1. free space propagation
2. space plate
3. detector



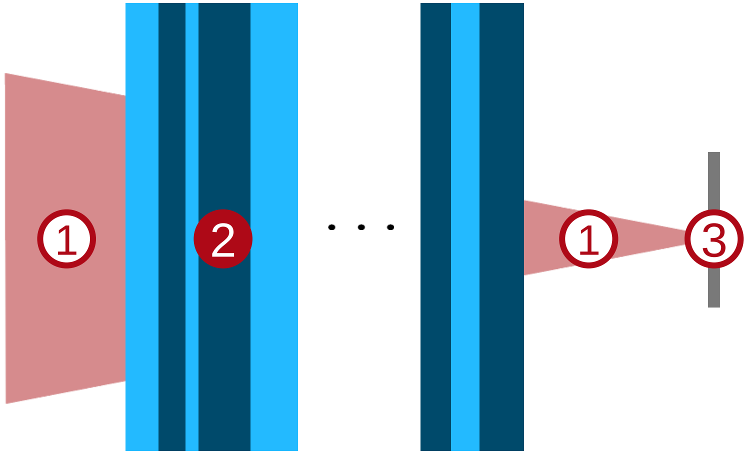
Available modeling techniques for free space propagation:

Methods	Preconditions	Accuracy	Speed	Comments
Rayleigh Sommerfeld Integral	None	High	Low	Rigorous solution
Fourier Domain Techniques	None	High	High	Rigorous mathematical reformulation of RS integral
Fresnel Integral	**Paraxial**	High	High	Assumes paraxial light; moderate speed for very short distances
	Non-paraxial	Low	High	
Geometric Propagation	**Low diffraction**	High	Very high	Neglects diffraction effects
	Otherwise	Low	Very high	

As the propagation to the focus must include diffractive effects in order to achieve an accurate result, the **Fourier Domain Techniques** are chosen as a good compromise between speed and accuracy for the simulation.

Connected Modeling Techniques: Beam Splitter

1 free space propagation
2 space plate
3 detector

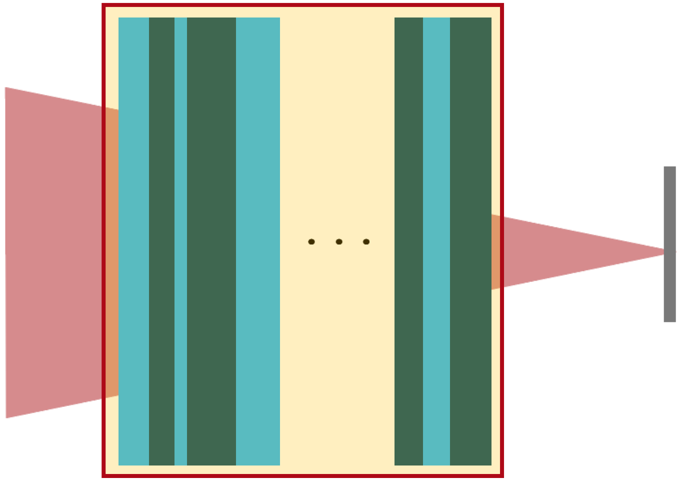


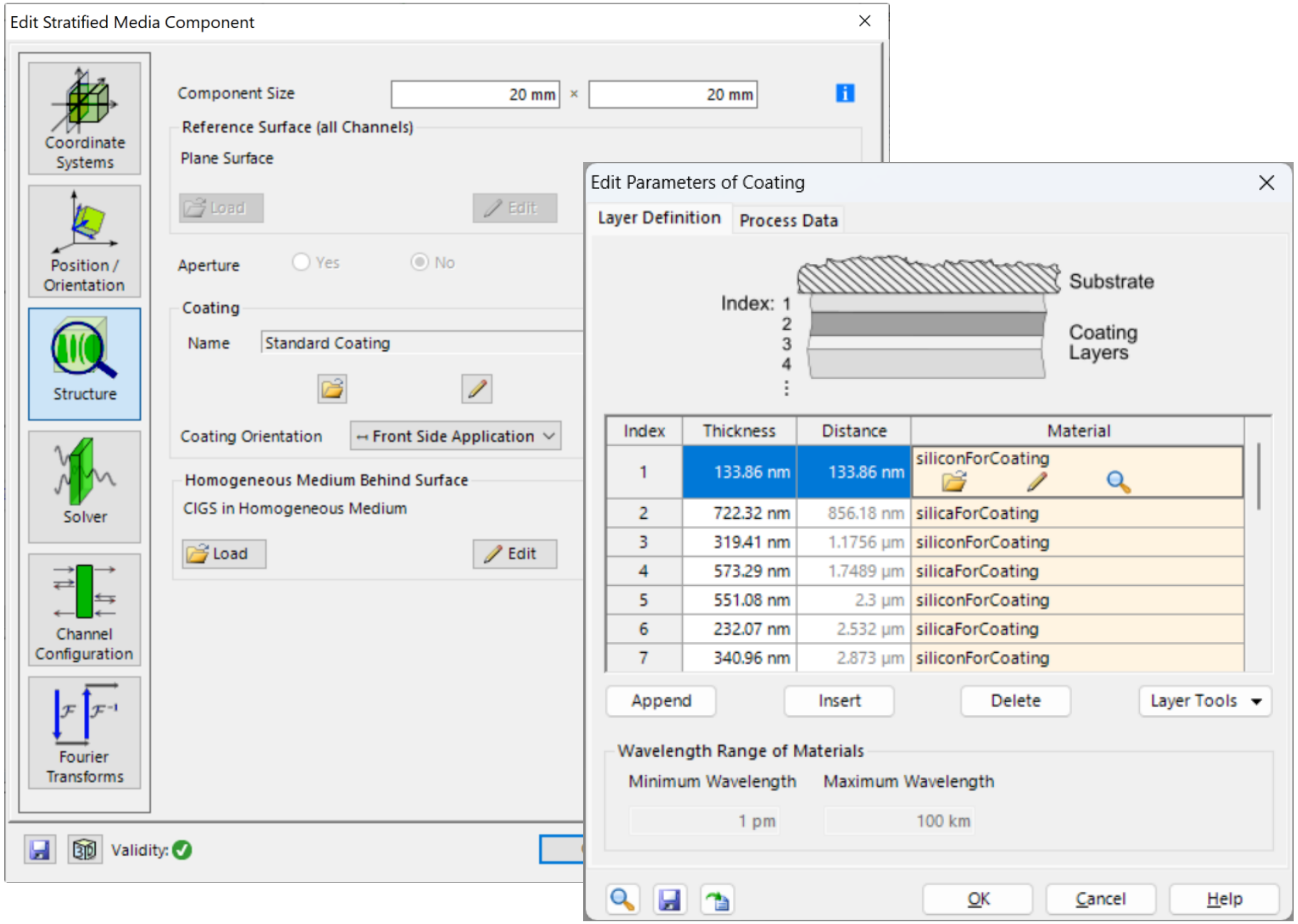
Available modeling techniques for beam splitter:

Methods	Preconditions	Accuracy	Speed	Comments
FMM/RCWA	None	High	High	Rigorous model; includes evanescent waves; k-domain
S matrix	Planar surface	High	Very High	Rigorous model; includes evanescent waves; k-domain
Local Planar Interface Approximation	Surface not in focal region of beam	High	High	Local application of S matrix; LPIA; x-domain

Since the S-matrix solver operates entirely in the k-domain, no additional steps for switching between domains (Fourier transforms) are required for the application of this solver. This allows for the fastest possible simulation speed while maintaining a rigorous model.

Stratified Media Component





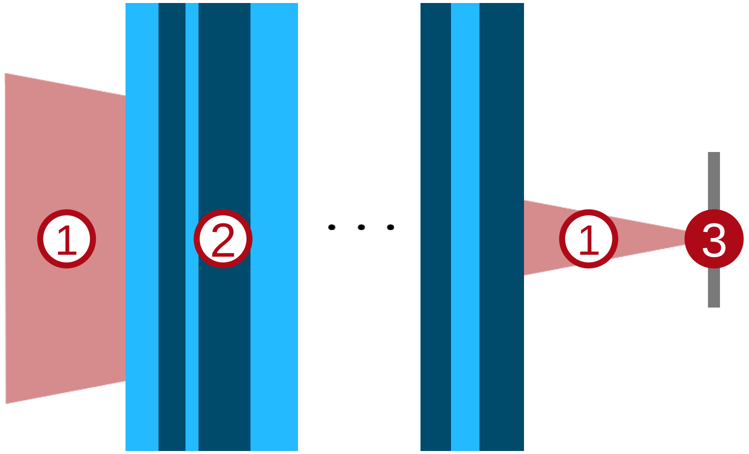
We use the *Stratified Media Component* to model the multi layer structure of the space plate, since it provides a fast and rigorous solution for lateral invariant layer stacks.

For further information:

Stratified Media Component

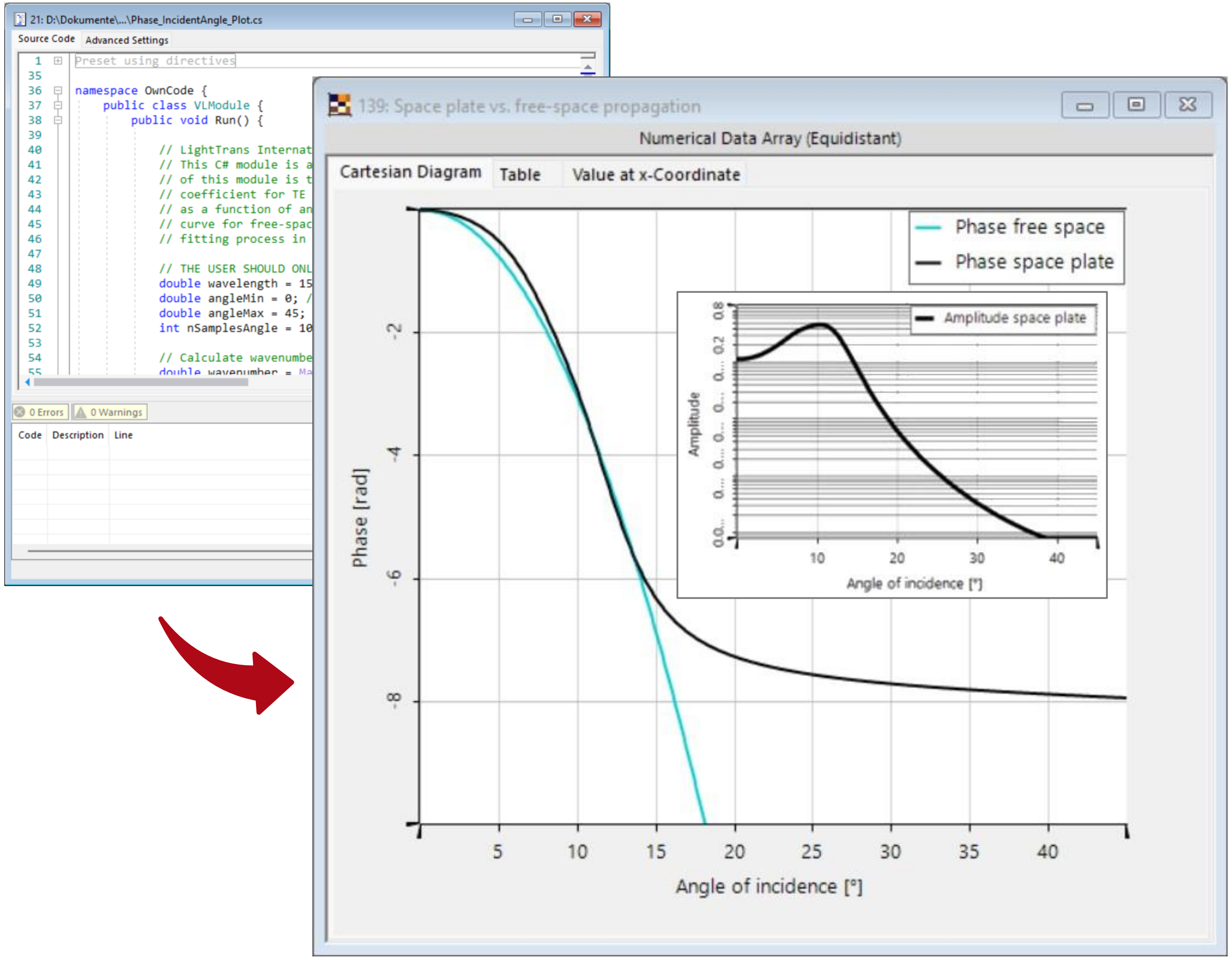
Connected Modeling Techniques: Detector

① free space propagation
② space plate
❸ detector

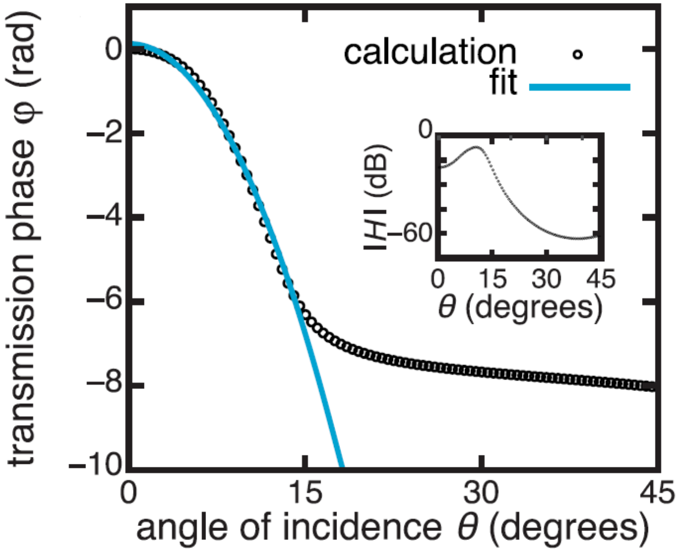


In this case, the universal detector in combination with a customized add-on is used to calculate the squared amplitude of the electric field $\boldsymbol{E}^2$ along the beam axis.

Visualization of Free Space vs. Space Plate



The space plate can reduce the required propagation distance by imitating the phase response of a free-space propagation step for a desired range of incident angles. A C# module was used to compute and visualize this phenomenon in a format similar to the reference. In comparison to the figure below, the result is reproduced in VirtualLab Fusion.



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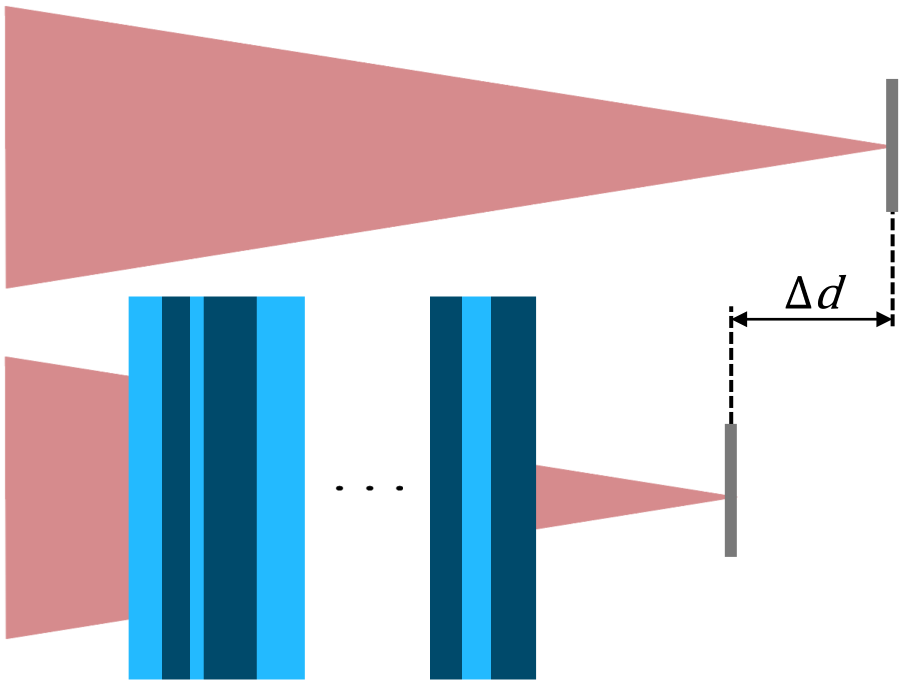
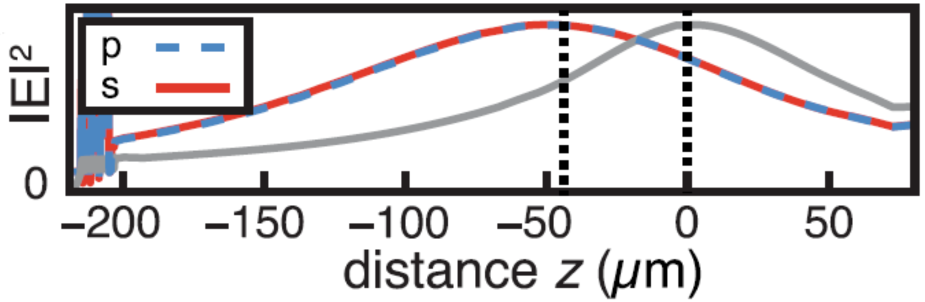
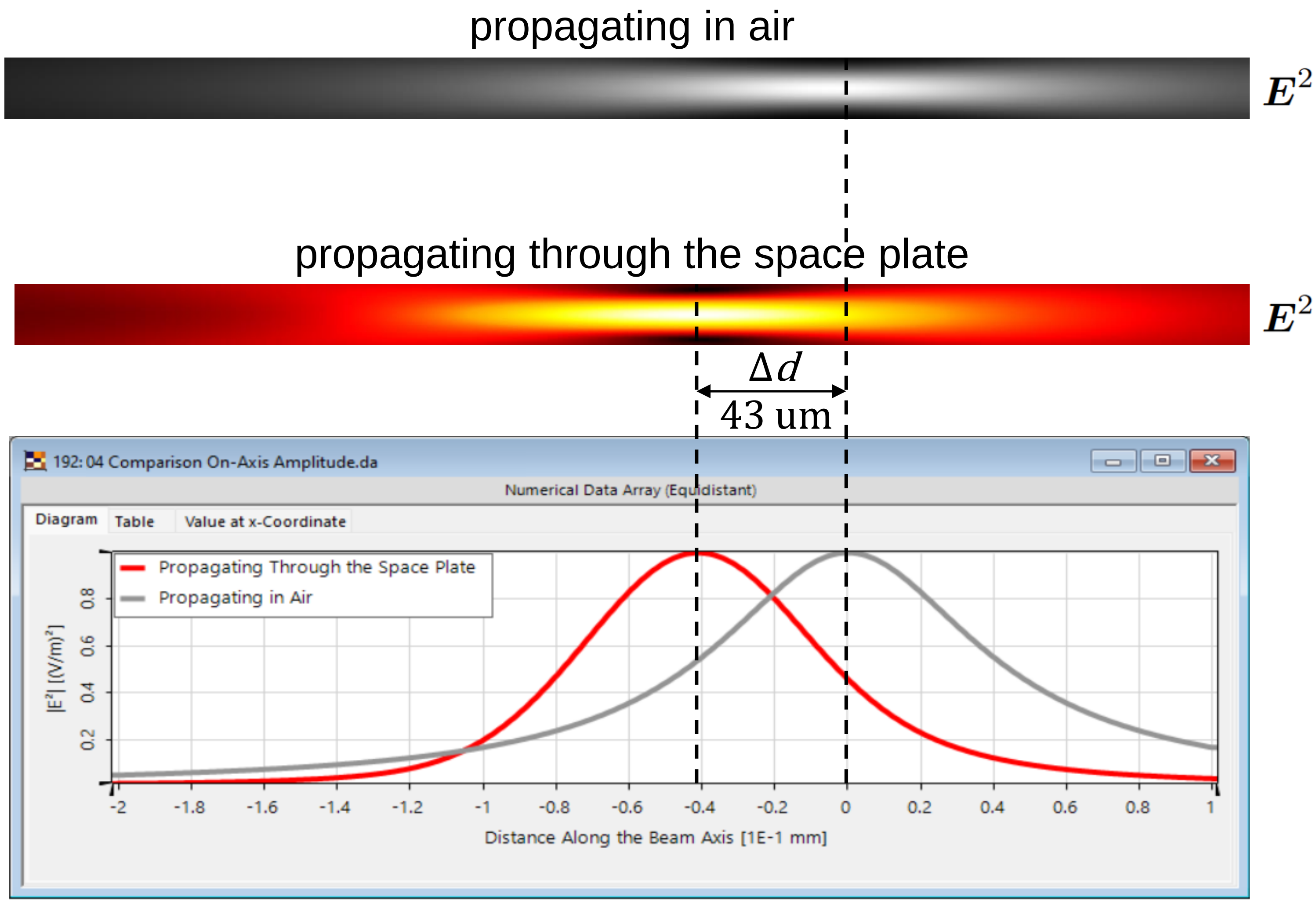
Comparison of Focal Region







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Document Information

title	Space Plate System Made by Multilayer Stack
document code	MISC.0101
document version	1.0
software edition	VirtualLab Fusion Basic
software version	2023.1 (Build 1.556)
category	Application Use Case
further reading	- Stratified Media Component