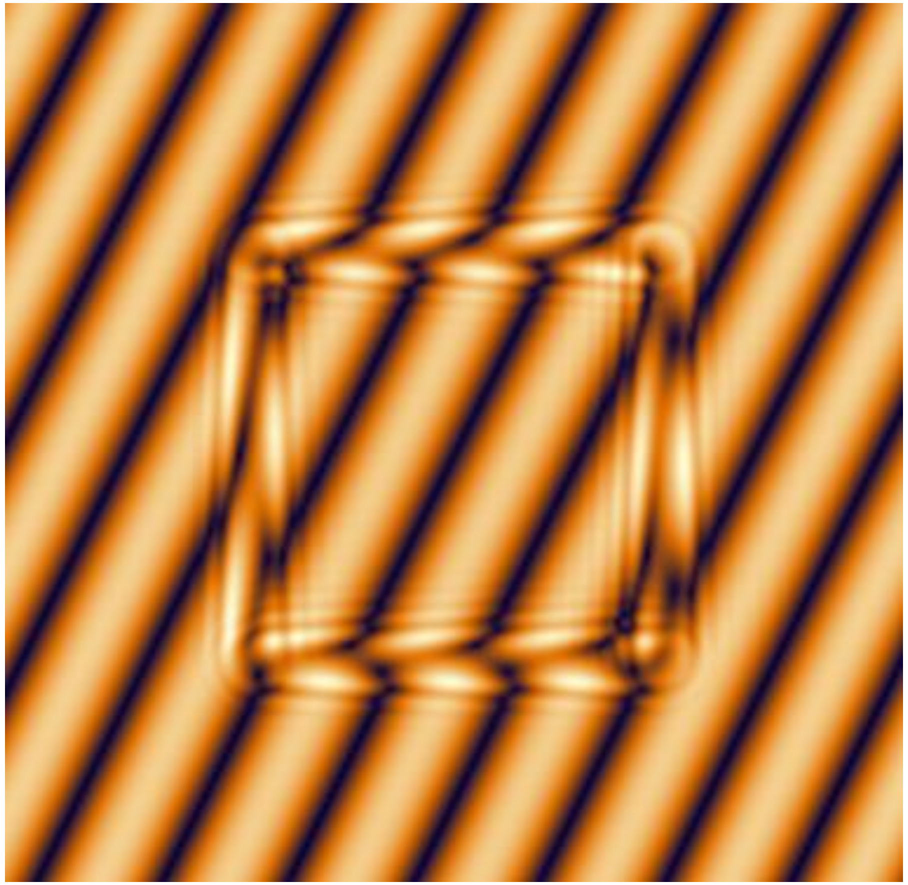
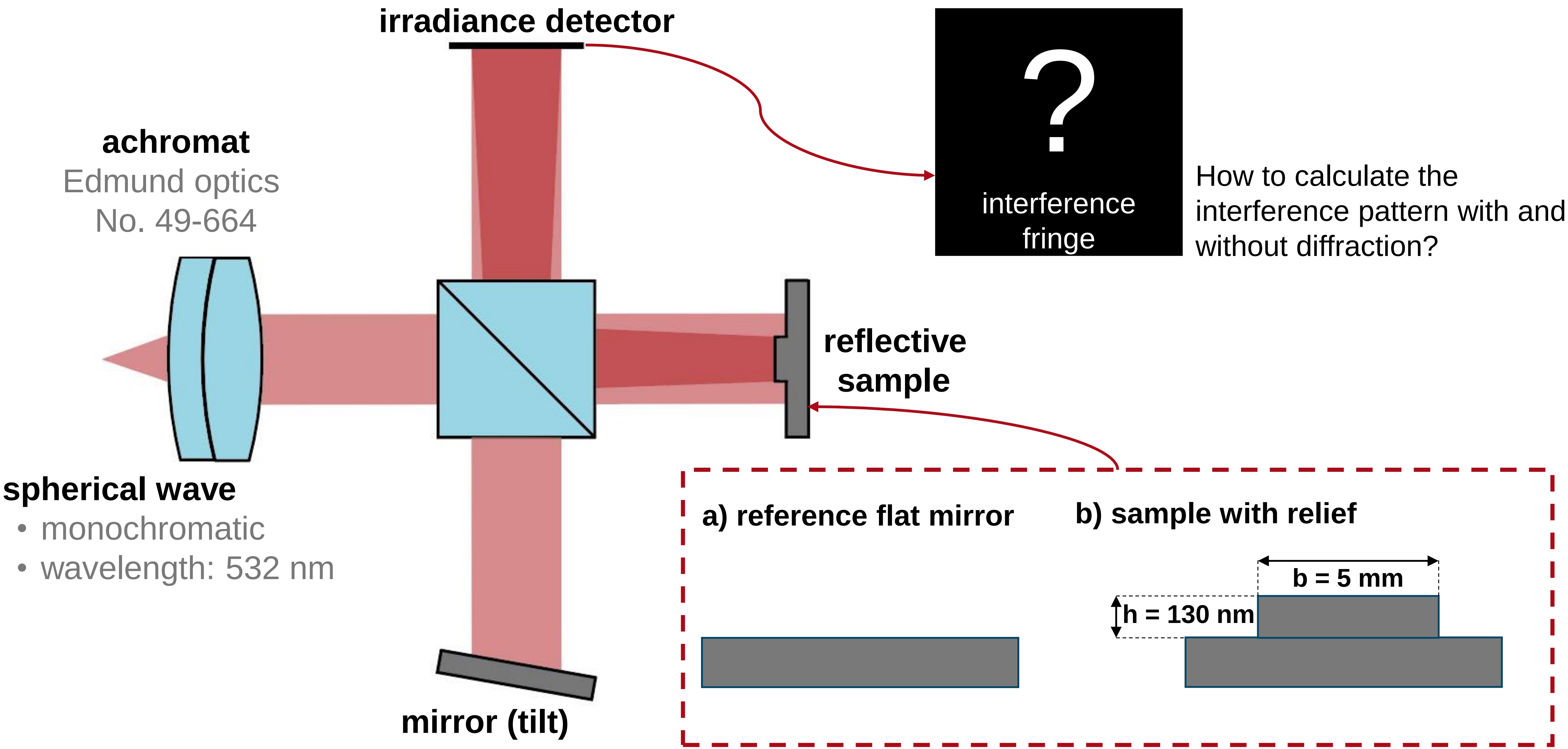
Investigation of Diffraction in Interferometer Caused by Sharp Relief

Abstract



Diffraction effects introduced by apertures and edges can have a strong impact on light propagation in optical systems. VirtualLab Fusion’s platform with a rich catalog of interoperable modeling techniques allows us to include these effects in a very efficient way, but also to neglect them if desired, just with a few clicks. In this application, diffraction effects are showcased in a system with a reflective sample with a rectangular height relief in a Michelson interferometer.

Simulation Task



irradiance detector

achromat
Edmund optics
No. 49-664

spherical wave
- monochromatic
- wavelength: 532 nm

mirror (tilt)

reflective sample

?
interference fringe

How to calculate the interference pattern with and without diffraction?

a) reference flat mirror

b) sample with relief

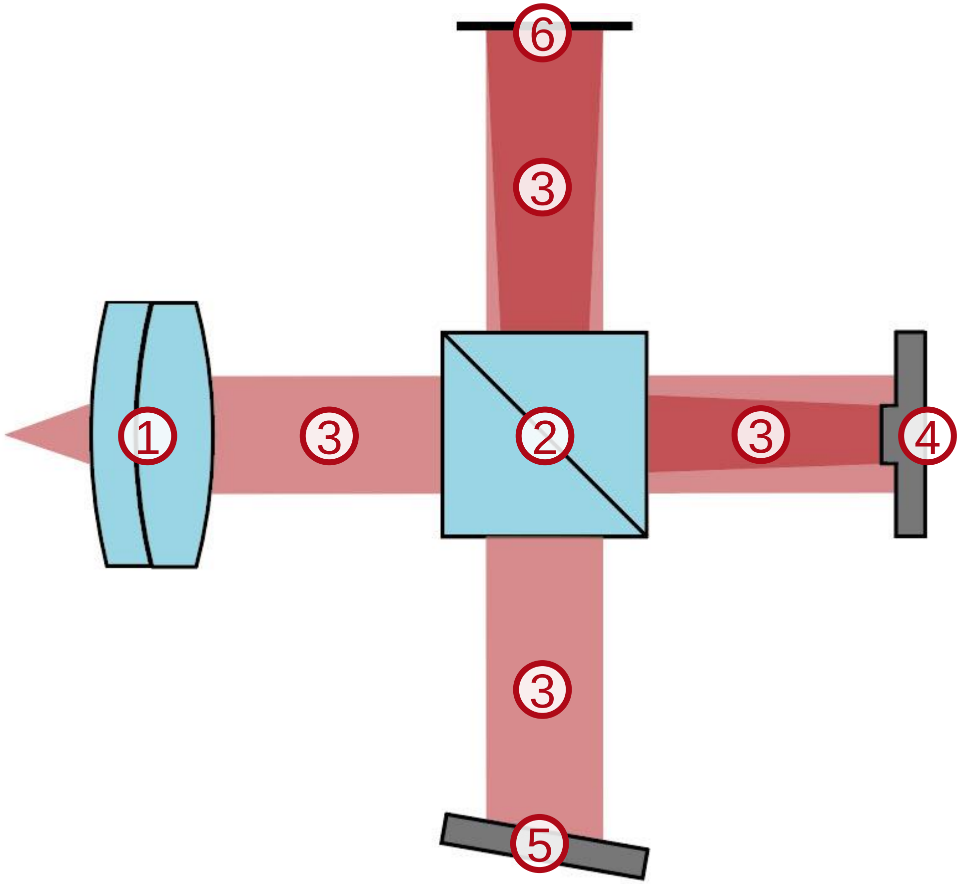
b = 5 mm

h = 130 nm

Single-Platform Interoperability of Modeling Techniques

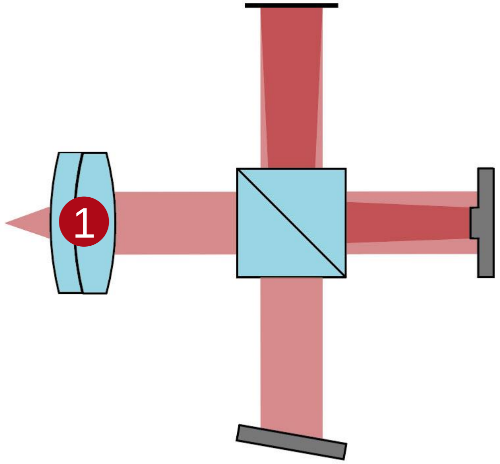
Light will encounter and interact with different components as it propagates through the system. Due to the non-sequential nature of the system, there may be multiple interactions at different points in the propagation. A suitable model that provides a good compromise between accuracy and speed is required for each of these elements of the system:

① achromat
② beam splitter
③ free-space propagation
④ mirror with specimen
⑤ reference mirror
⑥ detector



Connected Modeling Techniques: Achromat

1. achromat
2. beam splitter
3. free-space propagation
4. mirror with specimen
5. reference mirror
6. detector



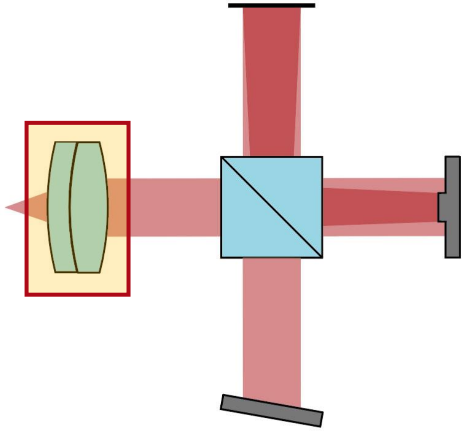
Available modeling techniques interaction with surfaces:

Methods	Preconditions	Accuracy	Speed	Comments
Thin Element Approximation (TEA)	Element not too thick/curvature not to strong	Low	High	Thickness about wavelength
Local Planar Interface Approximation	Surface not in focal region of beam	High	Very High	Local application of S matrix; LPIA; x-domain

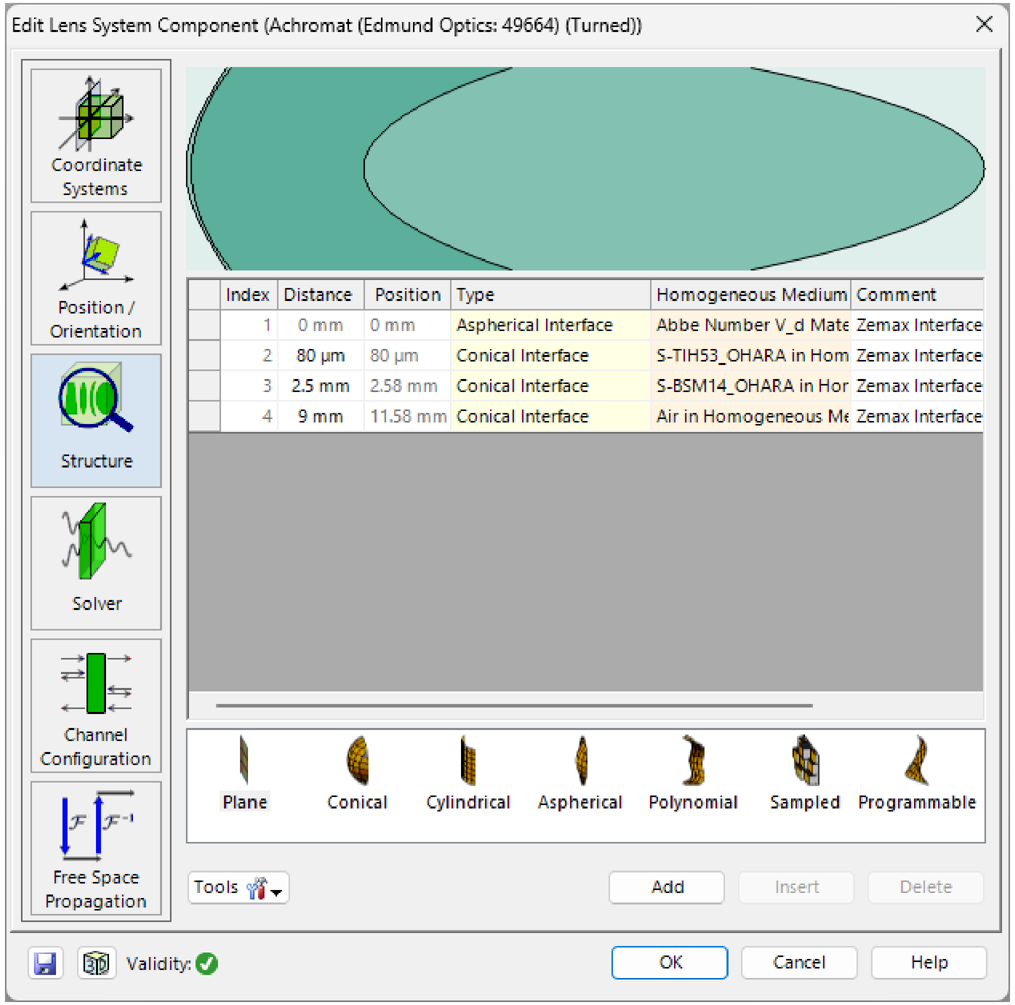
Two modeling techniques are available for calculating the interaction with the surfaces.

As the Thin Element Approximation (TEA) assumes thin components, the **Local Planar Interface Approximation** offers the best compromise between speed and accuracy.

Achromat: Lens System Component



The *Lens System Component* allows the user to easily define a component consisting of an alternating sequence of smooth surfaces and homogeneous, isotropic media. For both interfaces and materials, you can choose ready-made entries from the built-in catalogs or customize your own for maximum flexibility.

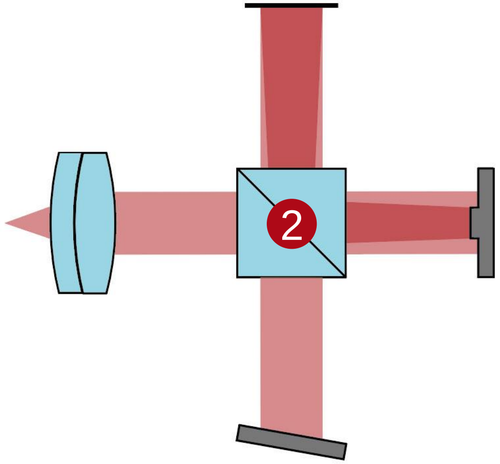


Edit Lens System Component (Achromat (Edmund Optics: 49664) (Turned))

Index	Distance	Position	Type	Homogeneous Medium	Comment
1	0 mm	0 mm	Aspherical Interface	Abbe Number V_d Mate	Zemax Interface
2	80 µm	80 µm	Conical Interface	S-TIH53_OHARA in Hom	Zemax Interface
3	2.5 mm	2.58 mm	Conical Interface	S-BSM14_OHARA in Hor	Zemax Interface
4	9 mm	11.58 mm	Conical Interface	Air in Homogeneous Me	Zemax Interface

Connected Modeling Techniques: Beam Splitter

1. achromat
2. beam splitter
3. free-space propagation
4. mirror with specimen
5. reference mirror
6. detector



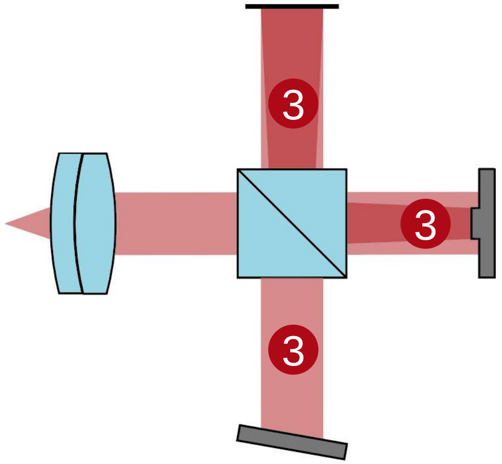
Available modeling techniques for beam splitter:

Methods	Preconditions	Accuracy	Speed	Comments
Functional Approach	No Fresnel losses	Low	Very High	Idealized version of a beam splitter
S matrix	Planar surface	High	High	Rigorous model; includes evanescent waves (for e.g. FTIR effect modeling)
Local Planar Interface Approximation	Surface not in focal region of beam	High	Very High	Local application of S matrix; LPIA; x-domain

The choice of an appropriate modeling technique for a beam splitter heavily depends on which kind of beam splitter is used. In this use case we employ an idealized beam splitter model since we in principle have no interest in investigating e.g. the Fresnel losses that appear in the beam splitter, hence a **Functional Approach** is sufficient.

Connected Modeling Techniques: Free-Space Propagation

- ① achromat
- ② beam splitter
- ❸ free-space propagation
- ④ mirror with specimen
- ⑤ reference mirror
- ⑥ detector



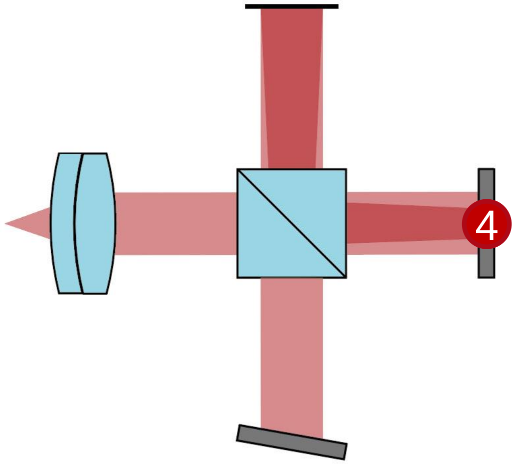
Available modeling techniques for free-space propagation:

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	

In this use case we investigate the influence of diffraction effects on the result. For this purpose, **Geometric Propagation** is used for the simulation when diffraction effects are neglected/not important, and **Fourier Domain Techniques** are applied if/when diffraction effects caused by edges and apertures are of interest.

Connected Modeling Techniques: Mirror with Specimen

① achromat
② beam splitter
③ free-space propagation
④ mirror with specimen
⑤ reference mirror
⑥ detector

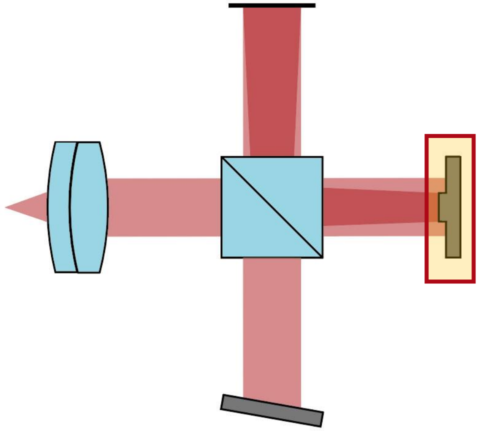


Available modeling techniques interaction with surfaces:

Methods	Preconditions	Accuracy	Speed	Comments
Thin Element Approximation	Thin element, large feature sizes	High	Very High	Thickness about wavelength; period & features larger than about ten wavelengths
Local Planar Interface Approximation	Surface not in focal region of beam	High	Medium	Local application of S matrix; LPIA; x-domain

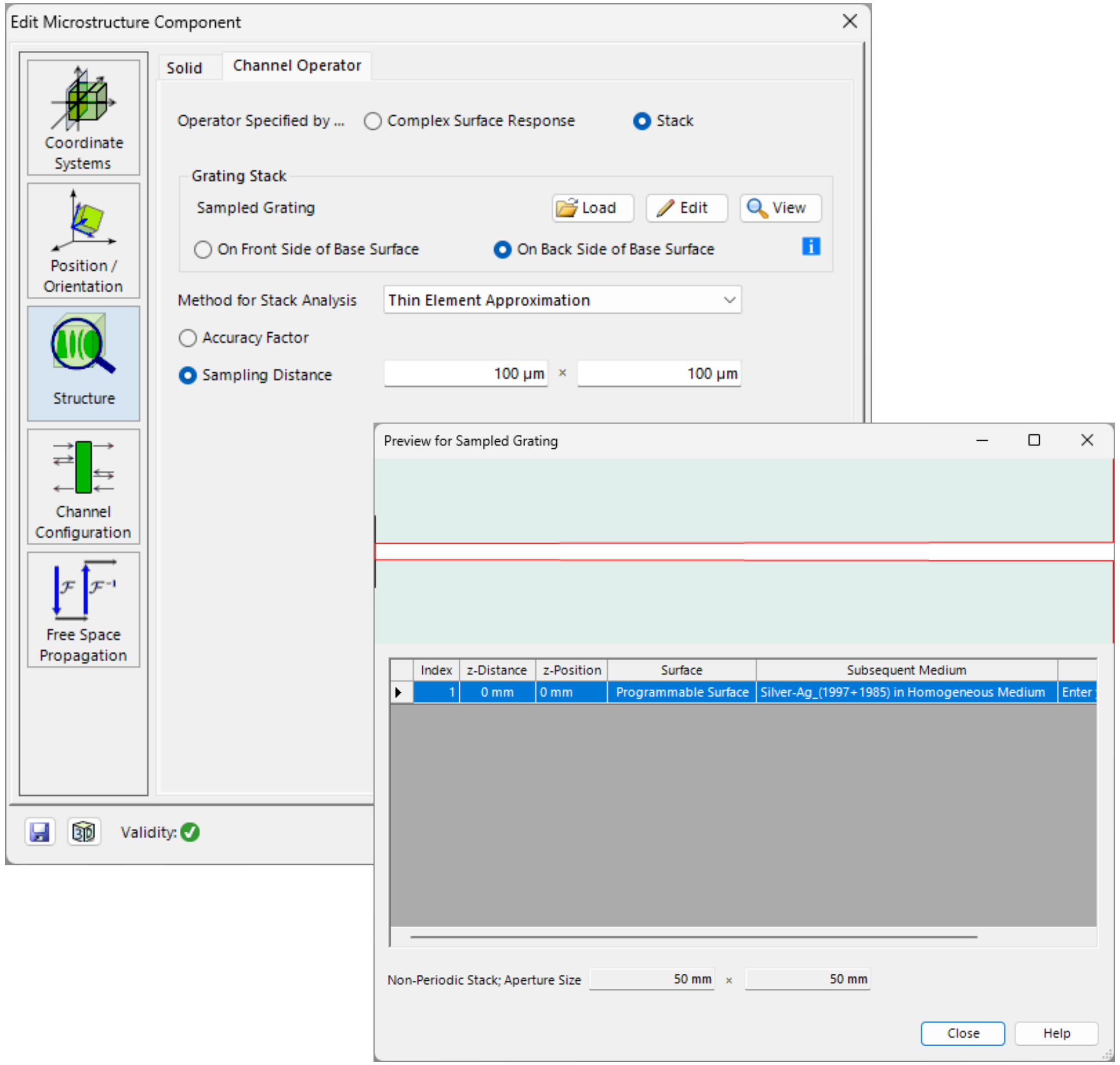
As the relief of the rectangular object is quite shallow, the **Thin Element Approximation** offers the best compromise between accuracy and speed for the calculation.
(comment: The LPIA is also able to provide an accurate result, but requires increased sampling to resolve the sharp relief of the sample).

Sample with Rectangular Object



The reflective sample with the rectangular object is modeled by the *Microstructure* component. It can be found under *Components* > *Single Surface & Stack.* More information on the component can be found under:

[Diffractive Optical Element (DOE) & Microstructure Component]()



Operator Specified by ... ○ Complex Surface Response ● Stack

Grating Stack

Sampled Grating

○ On Front Side of Base Surface ● On Back Side of Base Surface

Method for Stack Analysis: Thin Element Approximation

○ Accuracy Factor

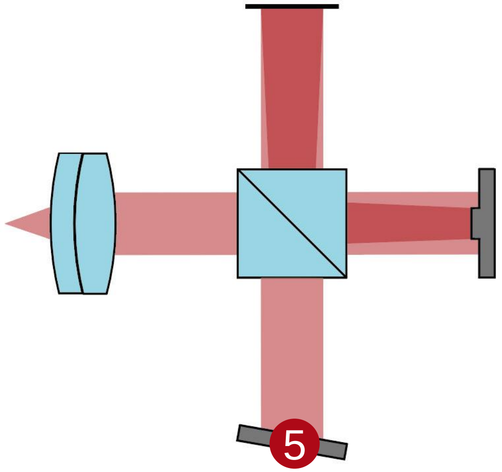
● Sampling Distance: 100 µm × 100 µm

	Index	z-Distance	z-Position	Surface	Subsequent Medium	
▶	1	0 mm	0 mm	Programmable Surface	Silver-Ag_(1997+1985) in Homogeneous Medium	Enter

Non-Periodic Stack; Aperture Size: 50 mm × 50 mm

Connected Modeling Techniques: Reference Mirror

① achromat
② beam splitter
③ free-space propagation
④ mirror with specimen
⑤ reference mirror
⑥ detector



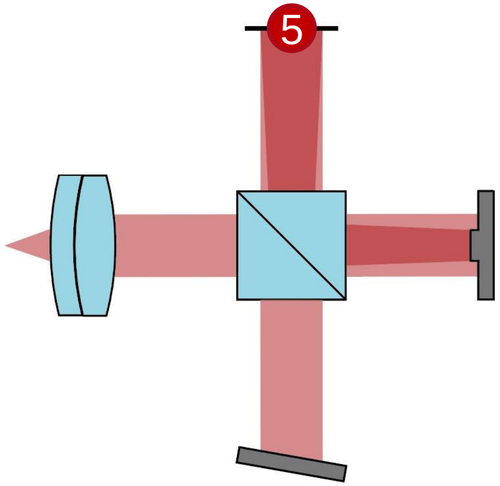
Available modeling techniques for beam splitter:

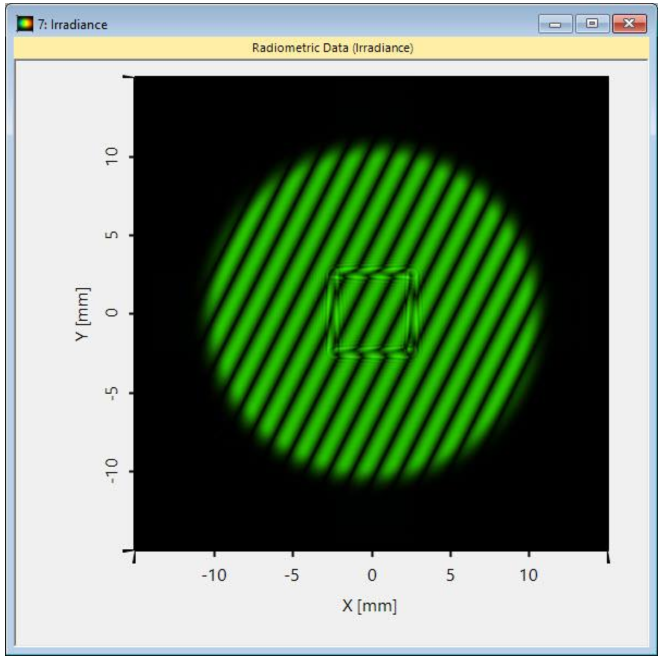
Methods	Preconditions	Accuracy	Speed	Comments
Functional Approach	No Fresnel losses	Low	Very High	Idealized version of a mirror
S matrix	Planar surface	High	High	Rigorous model; includes evanescent waves (for e.g. FTIR effect modeling)
Local Planar Interface Approximation	Surface not in focal region of beam	High	High	Local application of S matrix; LPIA; x-domain

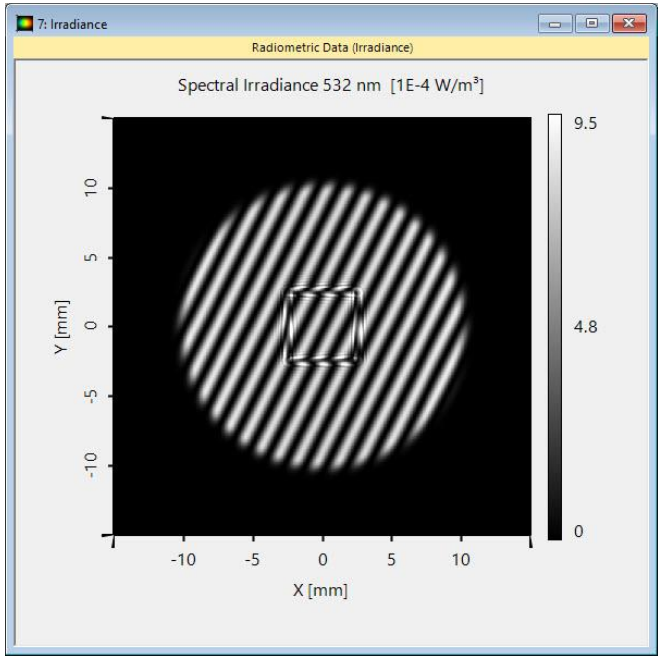
In this use case we investigate the effects of a rectangular object in an interferometer. In the other arm of the interferometer (that provides the reference) we employ an idealized mirror model since we do not want to investigate e.g. the Fresnel losses that appear there. A **Functional Approach** is therefore sufficient.

Connected Modeling Techniques: Detector

① achromat
② beam splitter
③ free-space propagation
④ mirror with specimen
⑤ reference mirror
⑥ detector



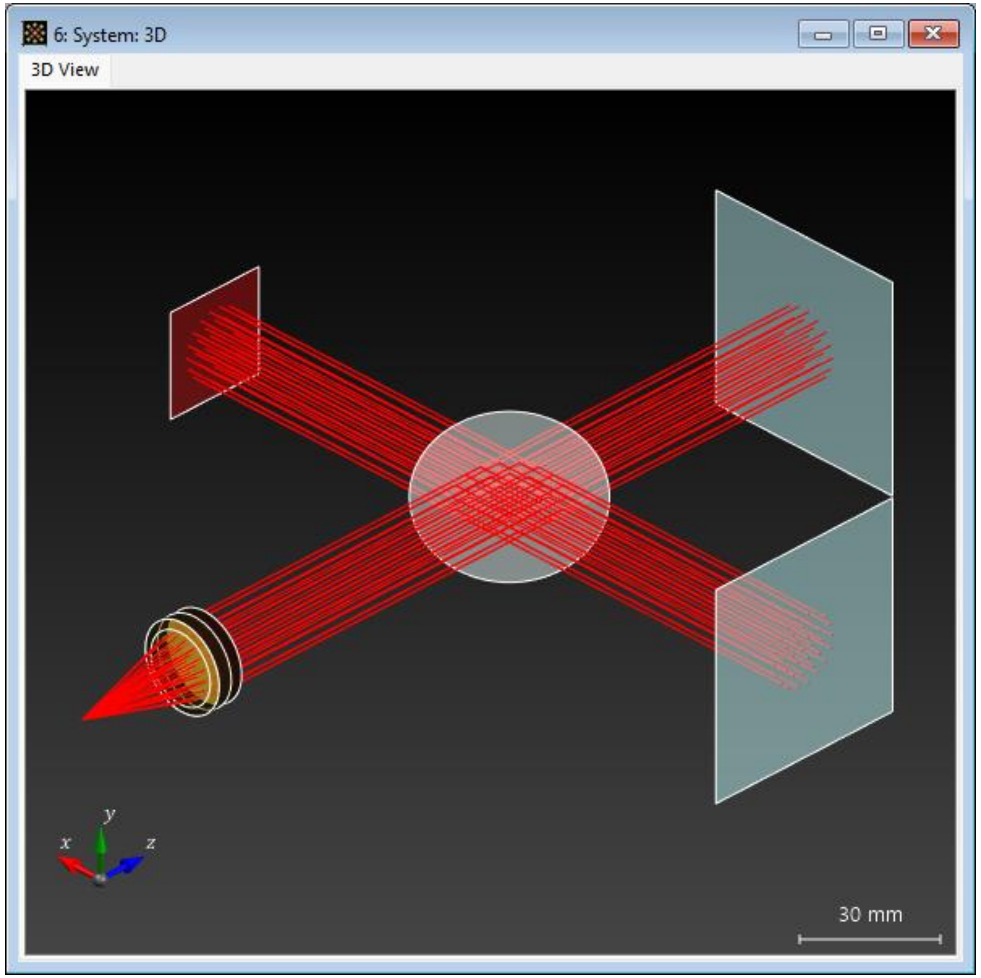


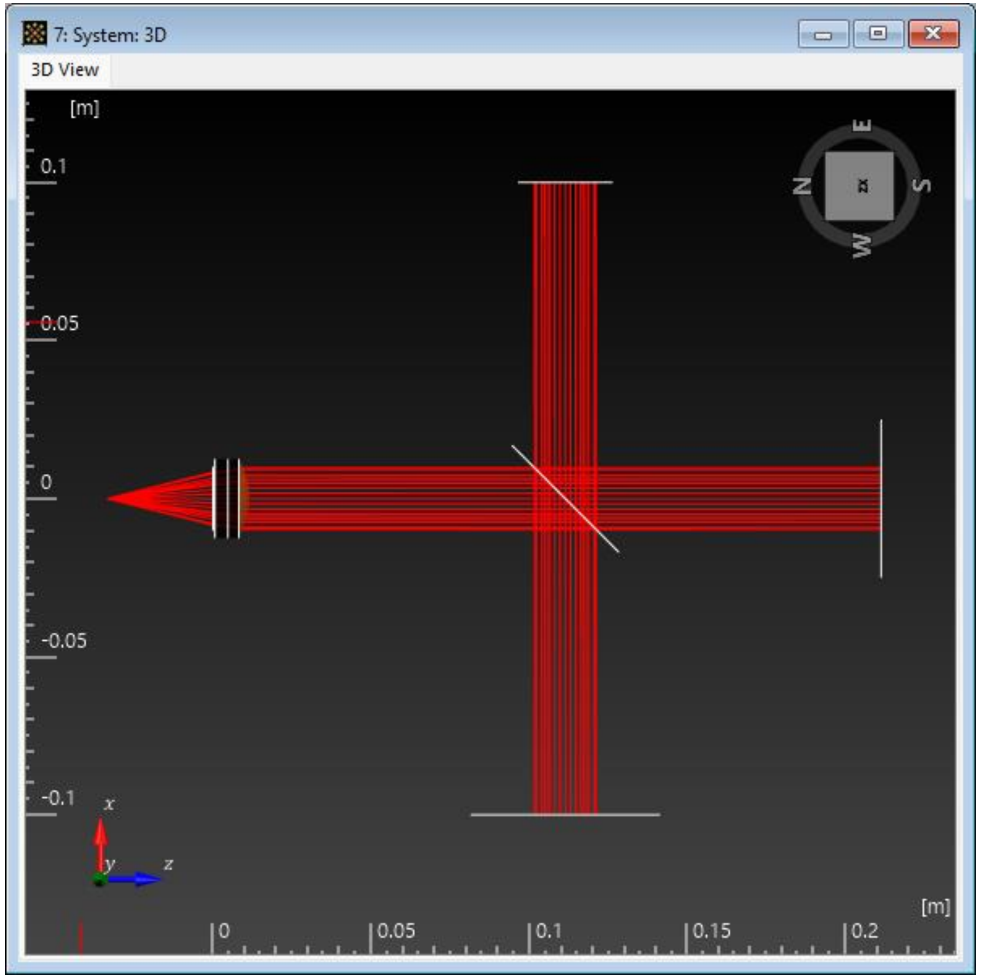


Full flexibility in detector modeling of various physical quantities, including irradiance, which can be displayed in a predefined color-scheme or in the *Real-Color View,* where the wavelengths are summed (including consideration of the sensitivity of the human eye), allowing a realistic color perception.

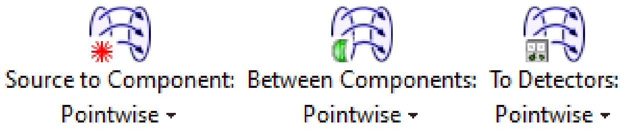
Simulation Results

System Overview (Ray Results Profile: System 3D)





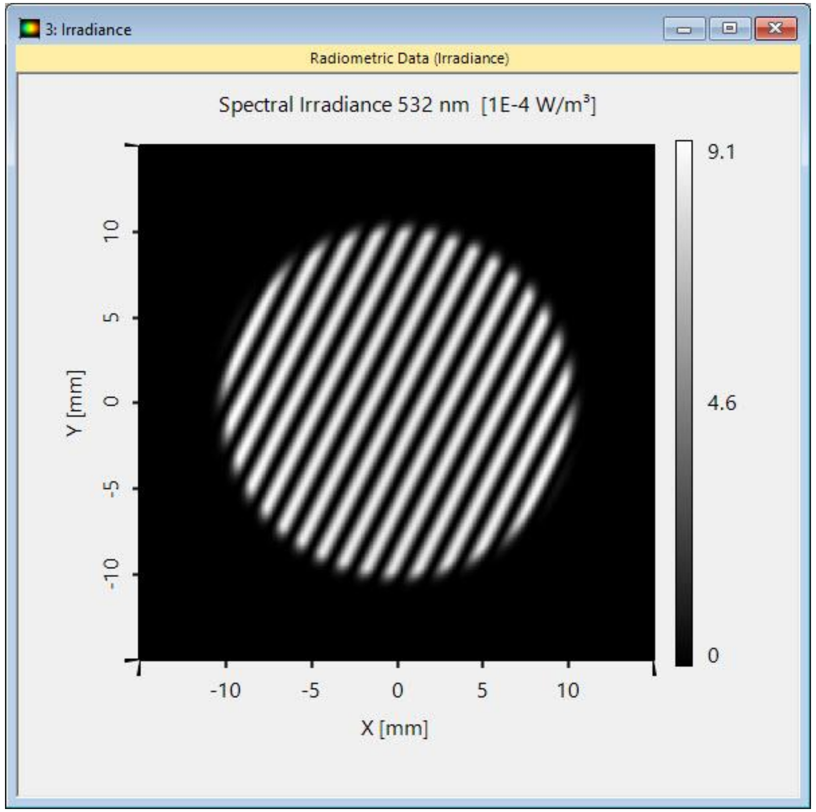
Results without Diffraction Effects



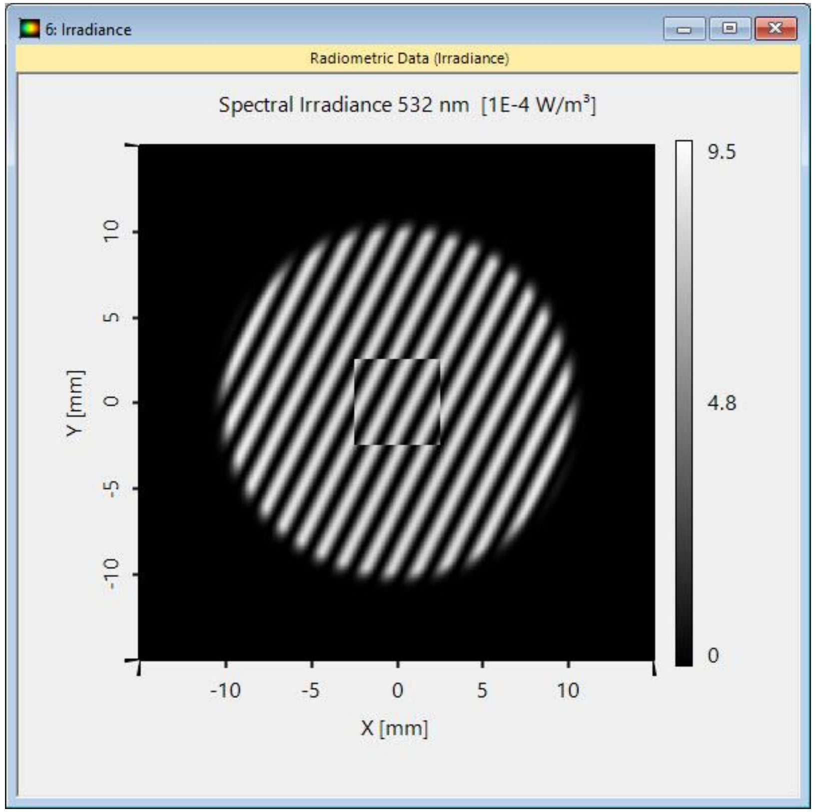
Source to Component: Pointwise
Between Components: Pointwise
To Detectors: Pointwise

To first investigate the resulting effects introduced by the structure of the sample we set up the system to perform the simulation neglecting diffraction effects, by only allowing *Pointwise Fourier Transforms*. In this case the rectangular object can be interpreted as an even plane with a different distance to the beam splitter. Therefore, it creates a local shift in the interference pattern.

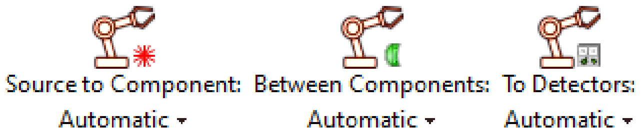
reference (flat mirror)



sample with rectangular object

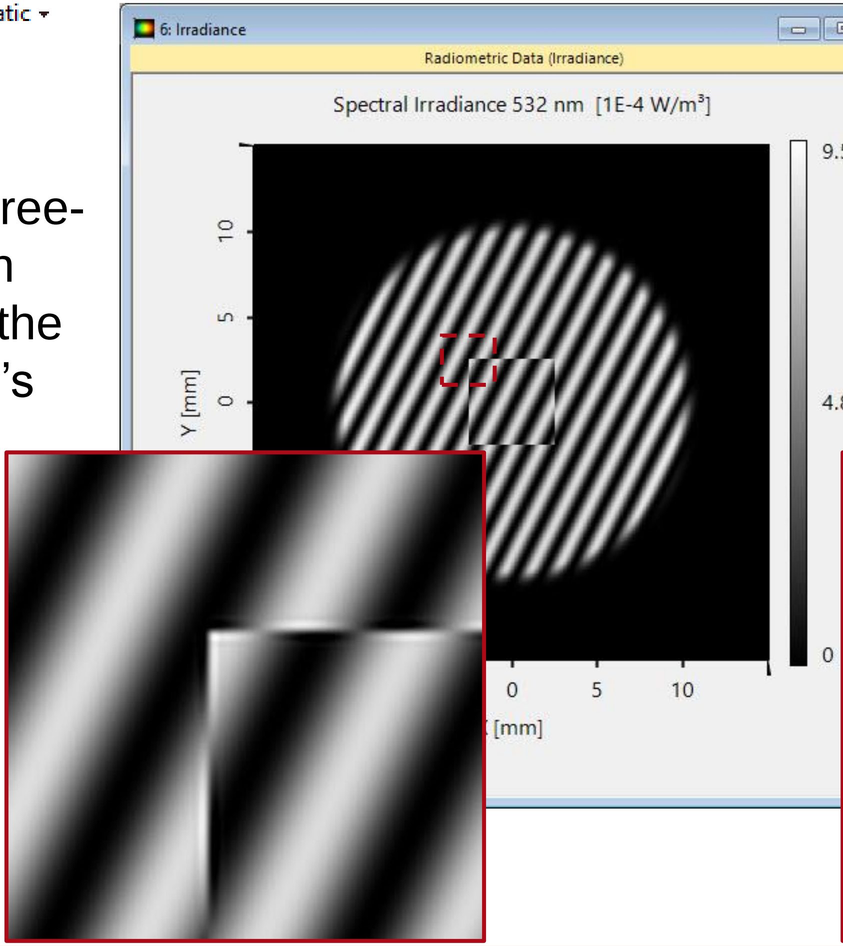


Results Including Diffraction Effects


Source to Component: Automatic
Between Components: Automatic
To Detectors: Automatic

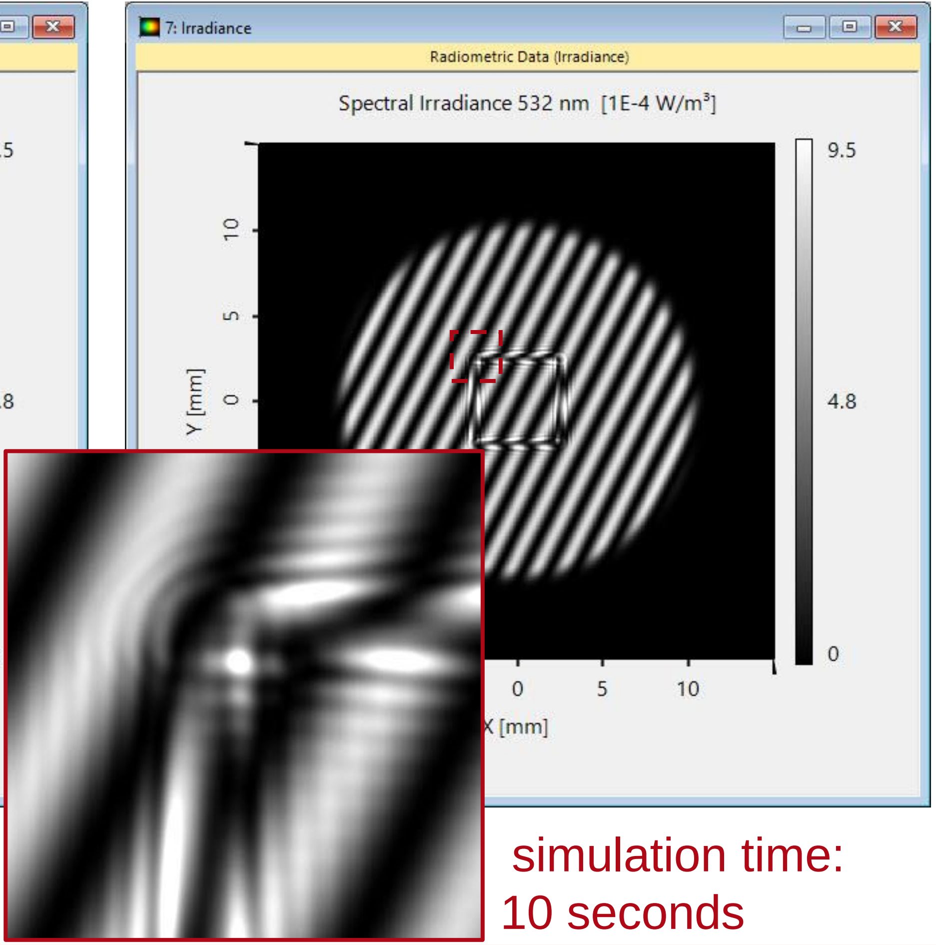
By enabling the automatic selection of the used Fourier transform algorithms for the free-space propagation, diffraction effects can be considered in the simulation. VirtualLab Fusion's Fourier domain techniques allow for a fast modeling even if diffraction effects are included in the simulation. The diffraction results in additional fringes around the edges.

Geometric propagation (just pointwise Fourier transforms)



simulation time:
3 seconds

Fourier domain techniques (automatic selection of pointwise and rigorous Fourier transforms)



simulation time:
10 seconds

Document Information

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software version	2023.1 (Build 1.556)
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