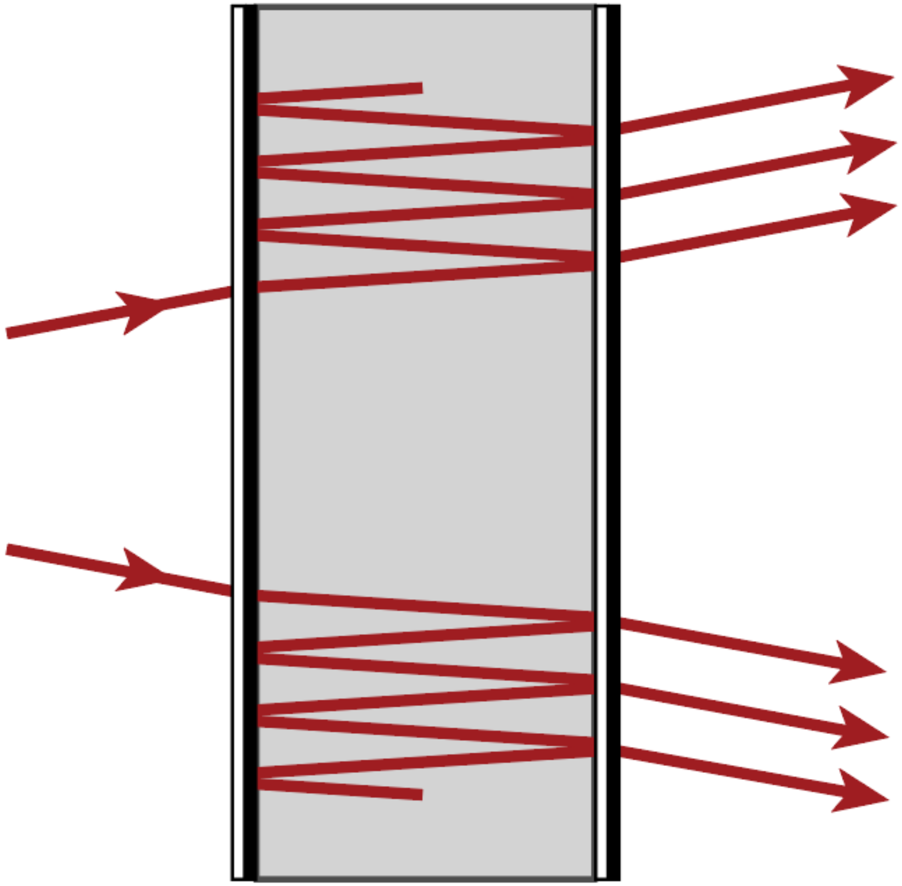
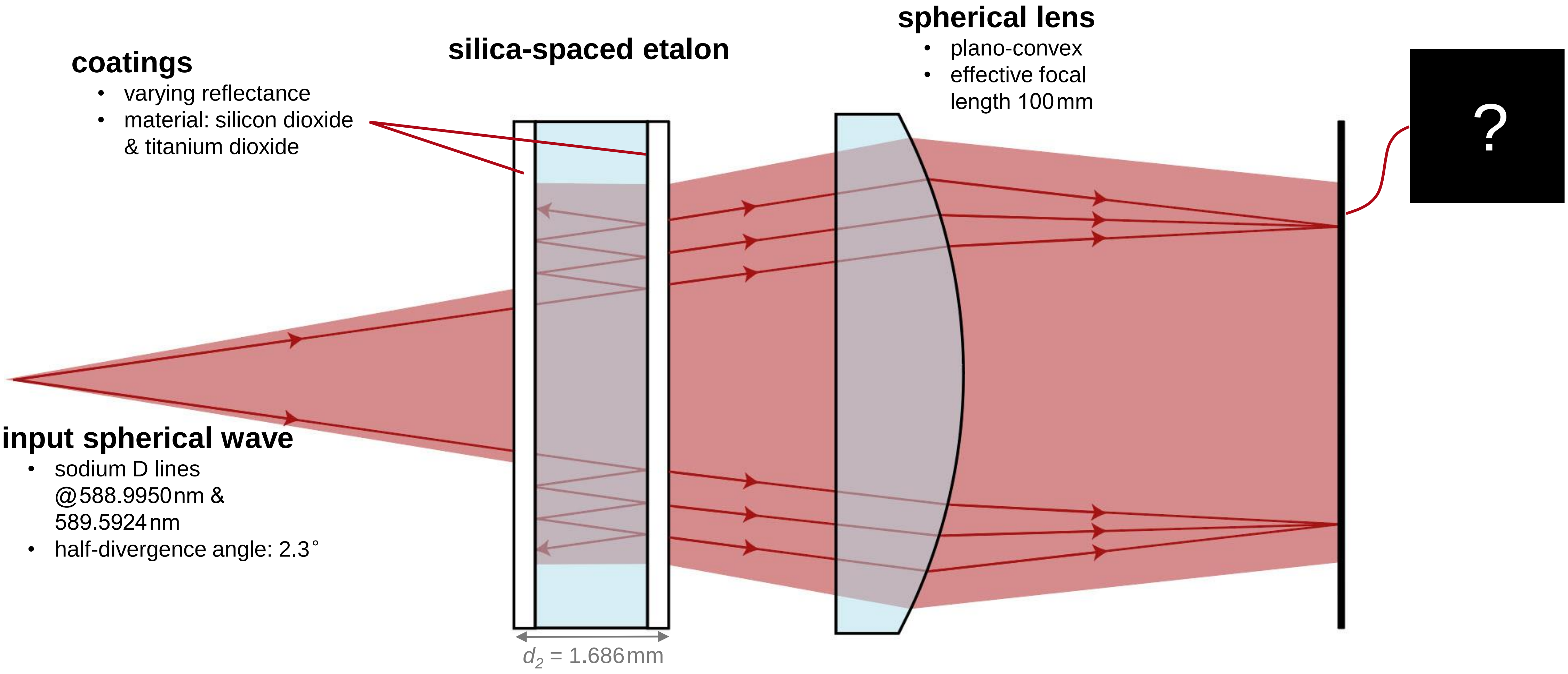
Investigation of Sodium D Lines with a Fabry-Pérot Etalon

Abstract



Fabry-Pérot etalons are widely used in laser resonators and spectroscopy for sensitive wavelength filtering. Typically, they are composed of two high-reflective (HR) coated surfaces with air or glass in between. In this example, an optical metrology system with a silica spaced etalon is set up to measure the sodium D lines in VirtualLab Fusion. With our seamless non-sequential single-platform interoperability of modeling techniques, the interference due to multiple reflections in the etalon is fully considered, and the influence from the reflectance of the applied coatings on the fringe contrast is investigated.

Modeling Task

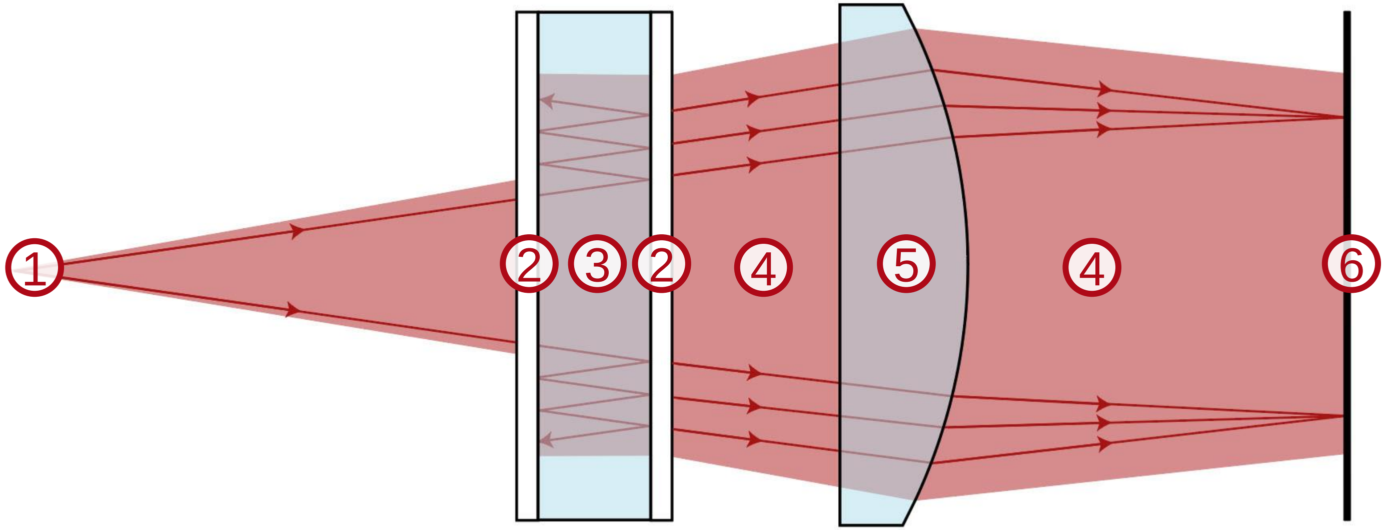


Simulation & Setup: Single-Platform Interoperability

Single-Platform Interoperability of Modeling Techniques

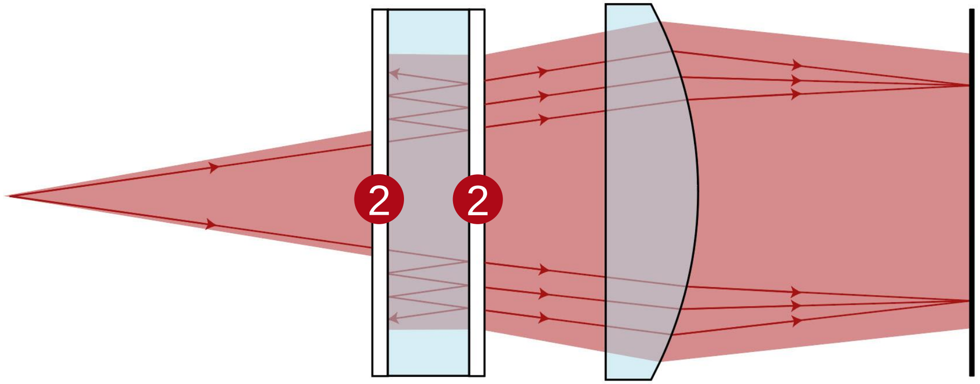
Light will encounter and interact with different components as it propagates through the system and there may be multiple interactions at different points in the propagation. A suitable model that provides a good compromise between accuracy and speed is required for each of the following elements:

1. source (sodium-D lines)
2. high-reflective coatings
3. etalon
4. free-space propagation
5. spherical lens
6. detector



Connected Modeling Techniques: Coatings

1. source (sodium-D lines)
2. high-reflective coatings
3. etalon
4. free-space propagation
5. spherical lens
6. detector

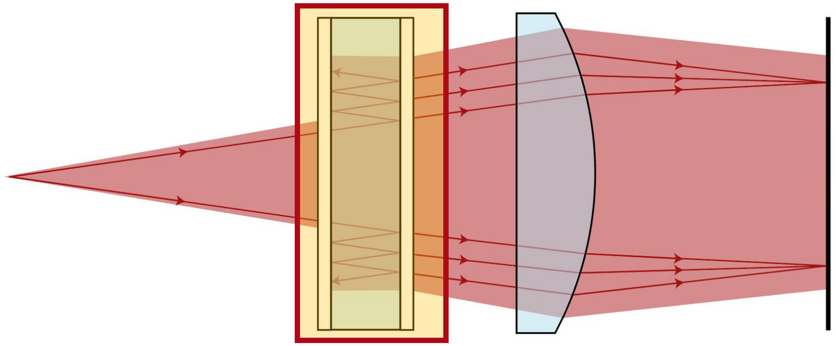


Available modeling techniques for coatings/multilayer systems:

Methods	Preconditions	Accuracy	Speed	Comments
FMM/RCWA	None	High	Low	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

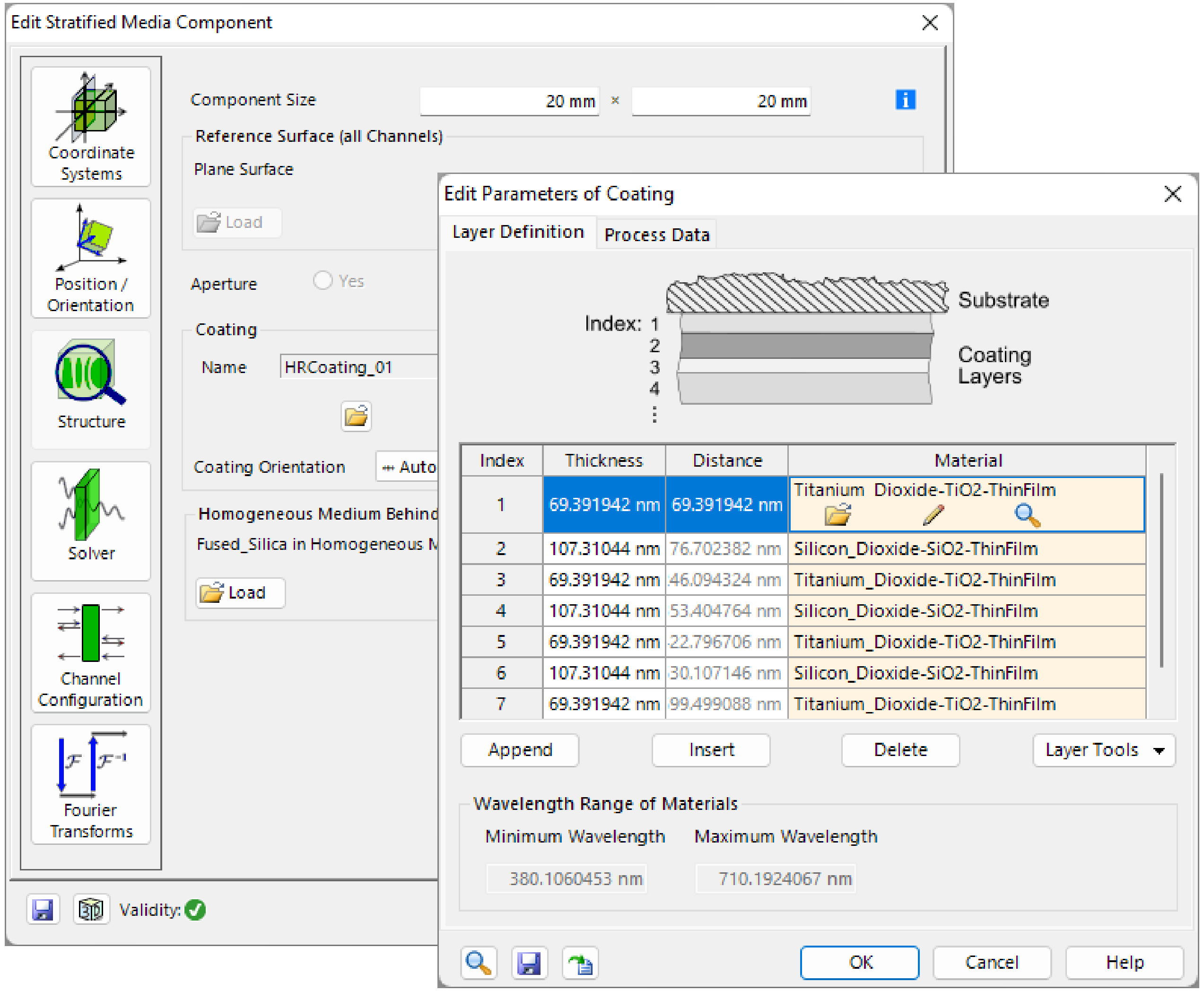
Since the S-matrix solver operates entirely in the k-domain, no additional steps for switching between domains (Fourier transforms) are required for the application of this solver. This allows for the fastest possible simulation speed while maintaining a rigorous model.

Etalon with High-Reflective (HR) Coatings



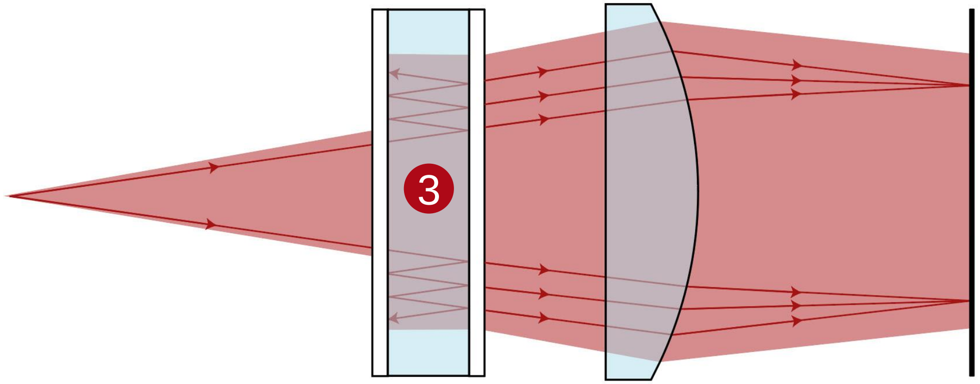
For the coated etalon surfaces we employ the *Stratified Media Component*, since it provides a fast and rigorous solution for x, y-invariant layer stacks. The coating itself is defined by alternating titanium and silicon dioxide films, where the reflectivity increases with the number of iterations. More information about the *Stratified Media Component* under:

[Stratified Media Component]



Connected Modeling Techniques: Etalon

1. source (sodium-D lines)
2. high-reflective coatings
3. etalon
4. free-space propagation
5. spherical lens
6. detector



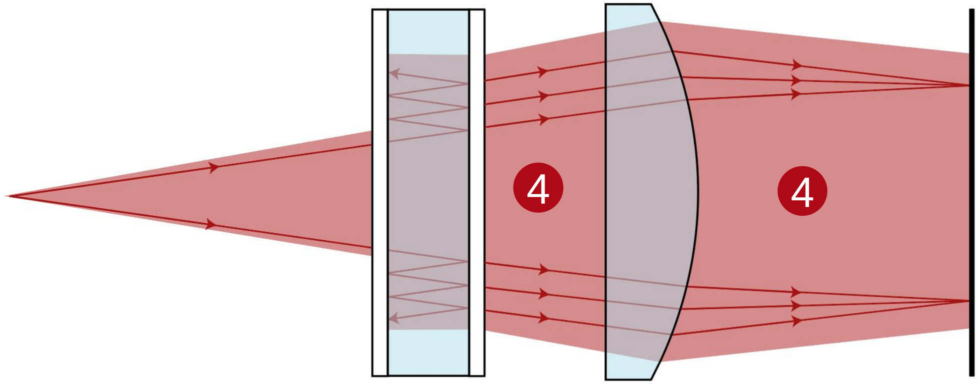
Available modeling techniques for free space propagation:

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	

As the interaction with the surfaces are already handled with the coating solver, all that remains from the etalon is a free-space propagation step.
As we do not expect diffraction effects to play a major role **Geometric Propagation** is chosen for maximum speed.

Connected Modeling Techniques: Free-Space Propagation

1 source (sodium-D lines)
2 high-reflective coatings
3 etalon
4 free-space propagation
5 spherical lens
6 detector



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	Non-paraxial	Low	High	
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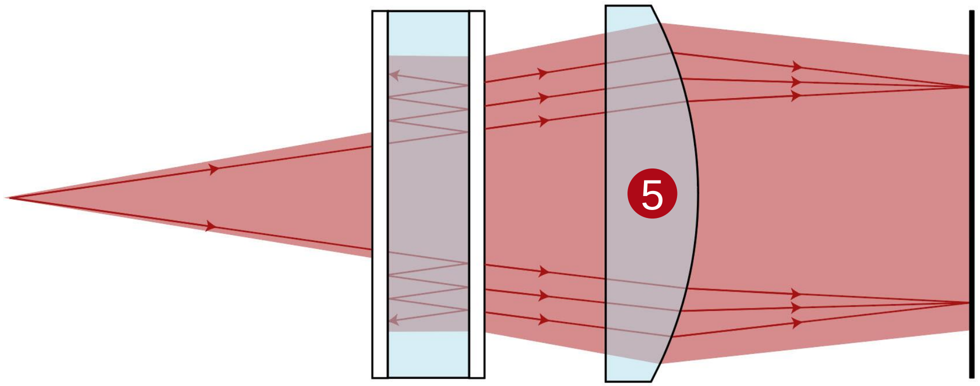
	Otherwise	Low	Very high	

The same principle applies to the other free-space propagation steps.

Connected Modeling Techniques: Spherical Lens

1. source (sodium-D lines)
2. high-reflective coatings
3. etalon
4. free-space propagation
5. **spherical lens**
6. detector



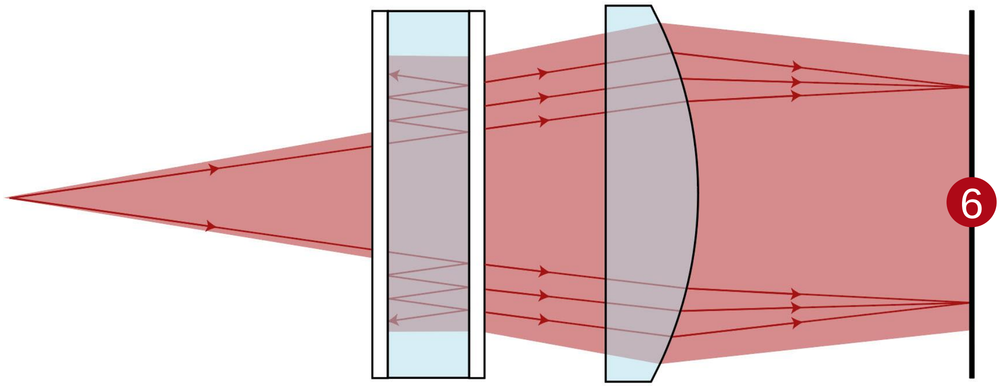
Available modeling techniques interaction with surfaces:

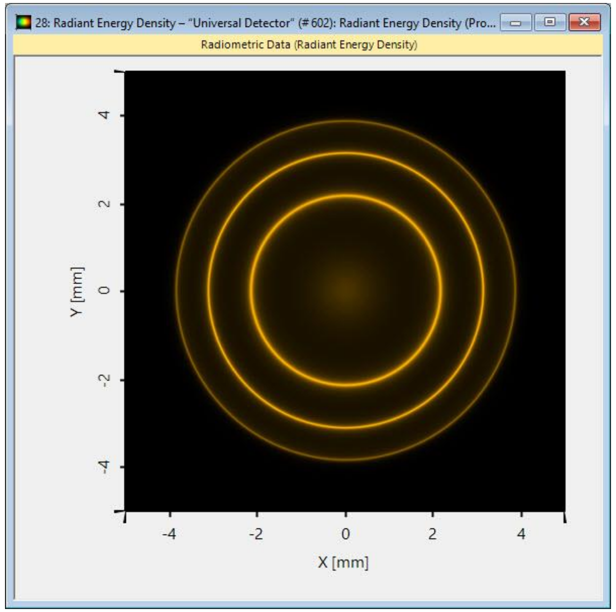
Methods	Preconditions	Accuracy	Speed	Comments
Functional Approach	No Fresnel losses	Low	Very High	transmission function
Thin-Element Approximation (TEA)	Shallow height modulation	Low	High	-
Local Planar Interface Approximation (LPIA)	Surface not in focal region of beam	High	High	Local application of S matrix; LPIA; x-domain

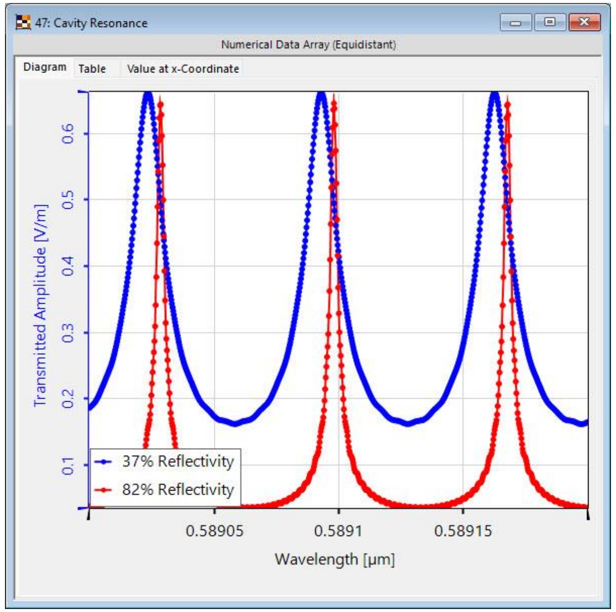
As the Thin Element Approximation (TEA) assumes thin components and a functional approach does not include Fresnel losses, the **Local Planar Interface Approximation (LPIA)** offers the best compromise between speed and accuracy.

Connected Modeling Techniques: Spherical Lens

1. source (sodium-D lines)
2. high-reflective coatings
3. etalon
4. free-space propagation
5. spherical lens
6. detector



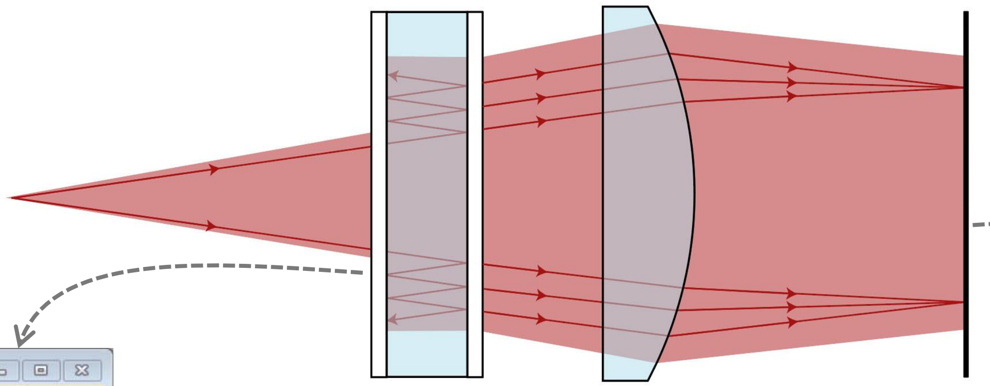


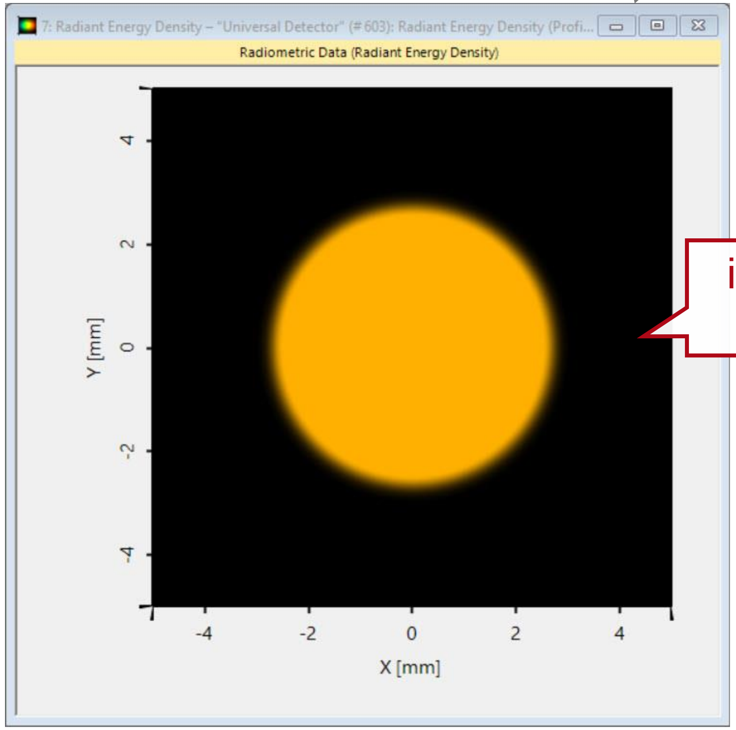


VirtualLab Fusion's flexible *Universal Detector* as well as various parameter variation tools allow for the in-depth investigation of any optical system. In this case we want to measure the *Radiant Energy Density* at the detector and investigate its behavior depending on the wavelength and reflectance of the coatings.

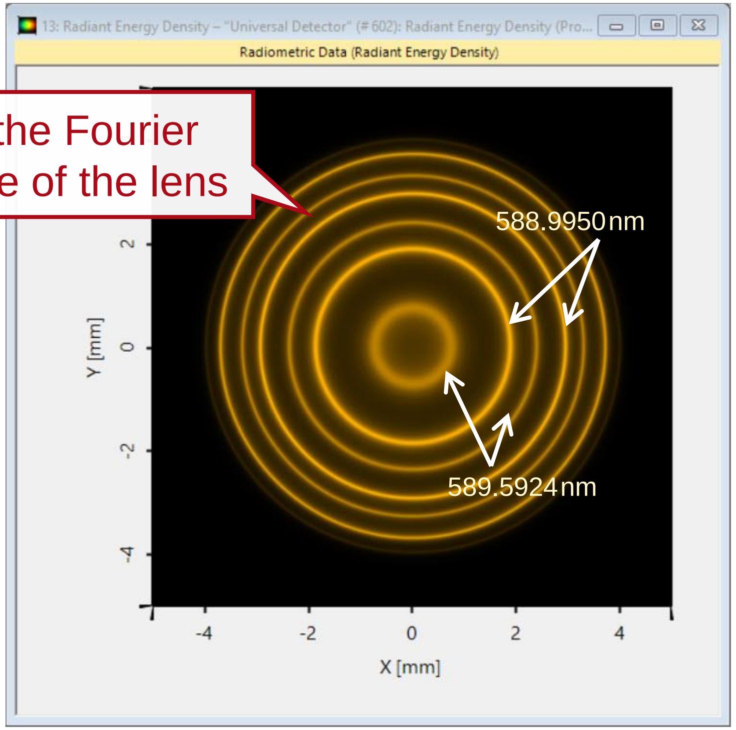
Simulation Results

Visualization of Both Spectrum Lines



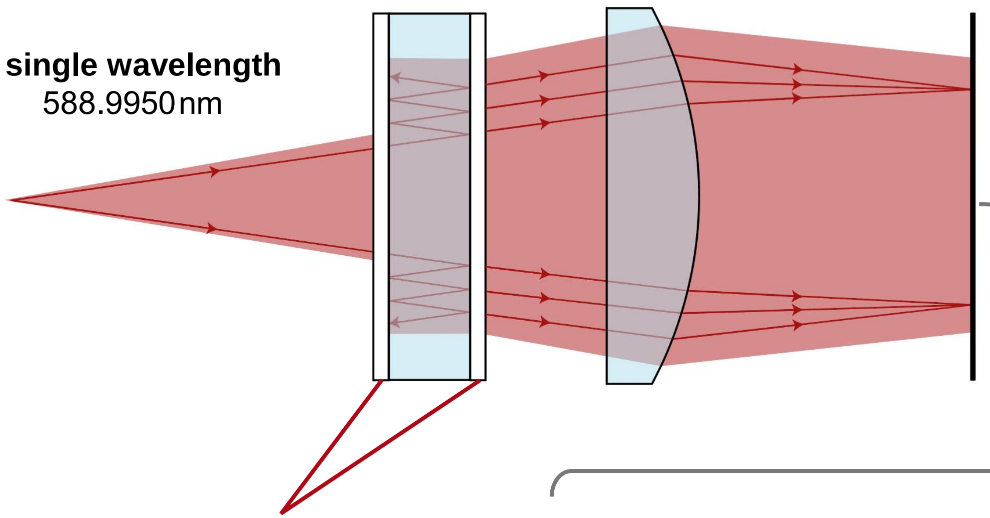


impinging light



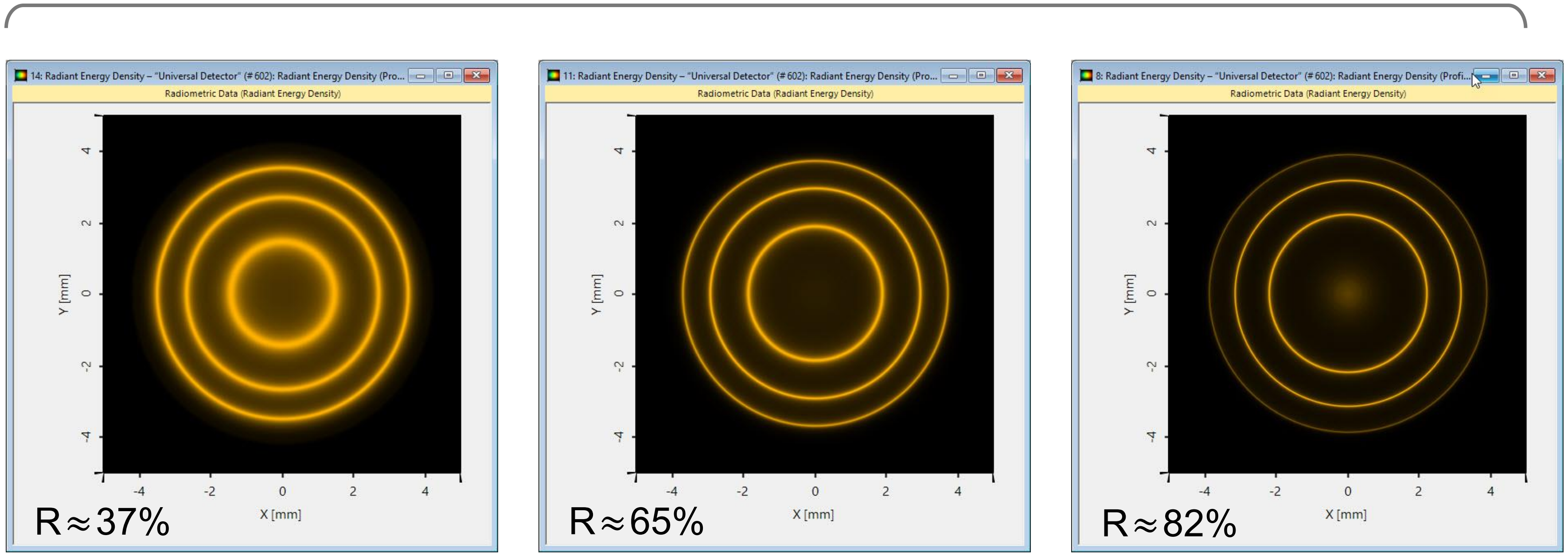
at the Fourier plane of the lens

Finesse vs. Coating Reflectance



coatings
varying reflectance:
82%, 65%, 37%

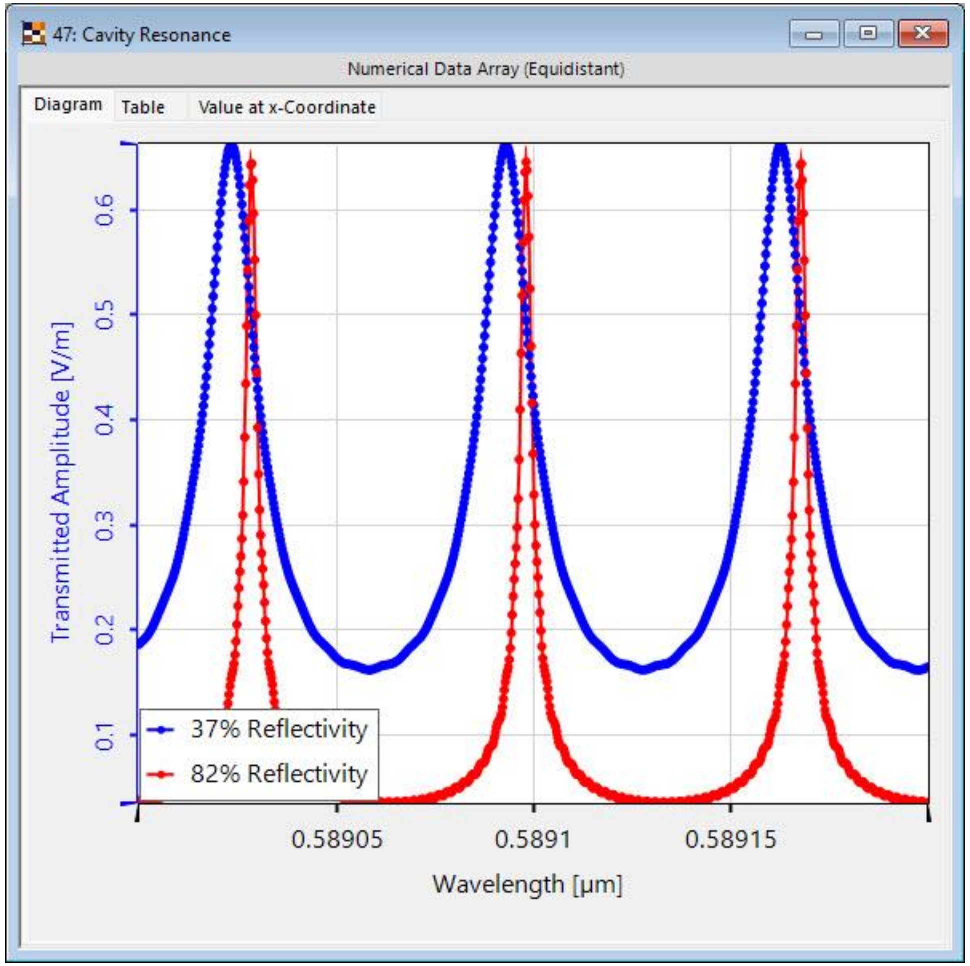
Sharpness of the interference fringes depends on the reflectance of the coatings on the etalon.

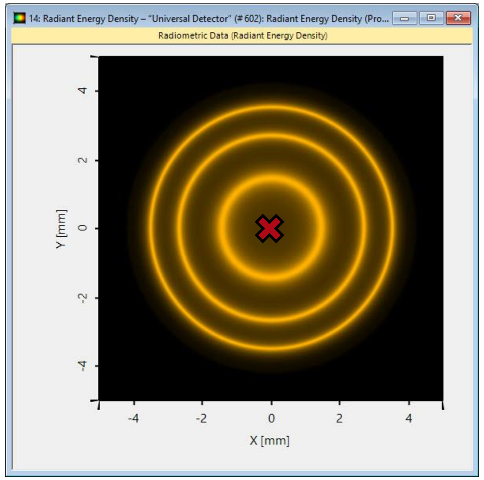


Internal Resonance Enhancement

The overall transmission will peak at multiples of the resonance wavelength. The exact shape of these curves are also dependent on the reflectivity of the coatings applied on the etalon surfaces.

Please note that, in our example, real coatings are used. By design, coatings with a higher reflectance have more layers and are hence thicker, which effectively changes the distance between the surfaces of the etalon. This leads to a slight shift of the resonance peaks.





Note: Transmission values have been taken from the center of the airy pattern.

Document Information

title	Examination of Sodium D Lines with Etalon
document code	IFO.0012
document version	2.2
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software version	2023.1 (Build 1.556)
category	Application Use Case
further reading	- Modeling of Etalon with Planar or Curved Surfaces - Coherence Measurement Using Michelson Interferometer and Fourier Transform Spectroscopy - Stratified Media Component