Components, Solvers and Fourier Domains – Plane Surface
Abstract

The field-tracing technology in VirtualLab Fusion rests on the philosophy of “connecting field solvers”: using different solvers for different components inside a single system, so that the best-suited option is applied to each part of the system. The choice exists for each solver to be implemented in the space domain or in the spatial-frequency domain. One or the other will be selected depending on the mathematical characteristics of said solver – for many of the most common components, the corresponding solver is going to be much lighter numerically in one domain than in the other, and therefore faster. This results in a simulation sequence that must move back and forth between the Fourier domains.
Modeling Task

etalon configuration
- planar-planar (tilted)
  - center thickness 100 µm
  - tilt of first surface 0.1°

source
- plane wave
- wavelength: 532 nm
- angle: 30°
- truncated by circular aperture (2.5 mm diameter)

how does the simulation of this system with field tracing work behind the scenes?

see the full Application Use Case: “Modeling of Etalon with Planar or Curved Surfaces”
Connecting Solvers!

- Field tracing connects electromagnetic field solvers!
- An optical system is broken up into its different constituent parts.
- Each part is modeled with a specific field solver.
- In general, these solvers can be implemented in the space (x) domain or in the spatial-frequency (k) domain.
- **VirtualLab Fusion connects all the solvers in a seamless, non-sequential way, to provide a fully electromagnetic solution to the system!**

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Domain of Application of the Solvers

For solvers implemented in the space domain, the field-tracing sequence would look like this…

… while for solvers implemented in the k domain, the field-tracing sequence would look like this.
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For solvers implemented in the space domain, the field-tracing sequence would look like this…

While for solvers implemented in the k domain, the field-tracing sequence would look like this.

The free-space propagation operator is just another example of a field solver, but we single it out with its own symbol because of its importance, being present in almost every system!
Some Solvers and Their Domains

- Fresnel matrix
- Free-space propagation
- Fourier Modal Method
- Layer matrix
- Idealized grating function
- Idealized lens functions
- Local Plane Interface Approximation
- Local Linear Grating Approximation
- Runge-Kutta BPM

Hint: click on the logos for additional documentation on the solvers!
Free-Space Propagation

Starting point of propagation

Detector plane

(source field)

Propagation distance $\Delta z$

$F_k$

$F_k^{-1}$

$\times e^{ik_z\Delta z}$

propagated field

propagated spectrum
Free-space propagation (propagation in a homogeneous, isotropic medium) always takes place in the $k$ domain – in other words, we propagate the plane-wave spectrum of the field.
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Free-Space Propagation

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This refers to propagation between elements of an optical system… … as well as to internal propagation between surfaces in some cases, like the Lens System component.
Free-Space Propagation: Why K Domain?

Space domain

Rayleigh-Sommerfeld integral:

$$V_{\ell}^{\text{out}}(\rho, z) \propto \int_{-\infty}^{+\infty} V_{\ell}^{\text{in}}(\rho', z_0) \frac{e^{ik_0nR}}{R} \left( ik_0n - \frac{1}{R} \right) \frac{\Delta z}{R} d^2\rho'$$

with $R = \sqrt{(x-x')^2 + (y-y')^2 + (\Delta z)^2}$

Spatial-frequency domain

Plane-wave propagation operator:

$$\hat{V}_{\ell}^{\text{out}}(\kappa, z) = \hat{V}_{\ell}^{\text{in}}(\kappa, z_0) \times e^{ik_z(\kappa)\Delta z}$$

Number of operations $\sim N^2$

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$N$: number of samples
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Pointwise operator!

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What Solvers Do We Need in This System?

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    - center thickness 100 µm
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- solver for plane surface

- solver for free-space propagation
Possible Field Solvers for Plane Surfaces

- As an infinitely extended ideal plane surface ➔ *Fresnel Matrix*
  - Solver in **k** domain
  - Implemented in *Plane Surface* component

- As a curved surface without curvature ➔ *Local Plane Interface Approximation (LPIA)*
  - Solver in **x** domain
  - Implemented in *Lens System, Curved Surface, Spherical Lens* and *Light Guide* components, among others.
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LPIA

Fresnel matrix

per individual interaction of field with plane surface
In VirtualLab Fusion, including a certain type of component in your system means, in practice, selecting an *electromagnetic field solver* to model that part of the system.
Possible Field Solvers for Plane Surfaces

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*Lens System component (LPIA)*

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\[ \Delta t_{\text{simulation}} \sim 1.5 \text{ min} \ (* \) \]

\[ \Delta t_{\text{simulation}} \sim 10 \text{ s} \ (*) \]

(*) Approximate simulation times on a PC with the following technical specs: processor Intel(R) Core(TM) i7-7700HQ CPU @ 2.80GHz and 32 GB RAM
The Importance of the Fourier Transform

- Etalon configuration: planar-planar (tilted)
  - Center thickness: 100 µm
  - Tilt of first surface: 0.1°

- Source: plane wave
  - Wavelength: 532 nm
  - Angle: 30°
  - Truncated by circular aperture (2.5 mm diameter)

- Simulation times:
  - \( \Delta t_{\text{simulation}} \approx 1.5 \text{ min} (*) \)
  - \( \Delta t_{\text{simulation}} \approx 10 \text{ s} (*) \)

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With FFTs $\Delta t_{\text{simulation}} \sim 1.5 \text{ min}$

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The Importance of the Fourier Transform

Note: Fourier transforms are also performed at the source and detector planes, hence there is also a slight time improvement in the Fresnel Matrix case when the **Pointwise Fourier transform is enforced** across the system.

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With FFTs \( \Delta t_{\text{simulation}} \sim 1.5 \text{ min} \)

With FFTs \( \Delta t_{\text{simulation}} \sim 10 \text{ s} \)

\[ \Delta t_{\text{simulation}} \sim 3 \text{ s (*)} \]

More information about our catalog of Fourier transform algorithms in our use case “Fourier Transform Settings – Discussion at Examples”

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Practical Conclusions: Which Solver Do I Use?

Two possible solvers for plane interfaces in an optical system: the Fresnel Matrix and the Local Plane Interface Approximation (LPIA). Which one is more appropriate for your system depends on the circumstances:

**Fresnel Matrix:**
- Rigorous solver for ideal plane surface
- Works in spatial-frequency (k) domain
- Fewer Fourier transforms to be calculated ➔ potential numerical gain
- Assumes infinite surface

**LPIA:**
- Solver for curved surfaces
- Works in space (x) domain
- Requires computation of additional Fourier transforms
- Considers finite size (aperture) of surface
Practical Hint: Component Substitution

How to modify your Optical Setup if you have imported a lens system into a Lens System component in VirtualLab Fusion, but you would like to use the Fresnel Matrix solver for a plane surface inside that system?

Do not forget to include and configure the Plane Surface component (inclination, material behind surface, etc.)
Peek into VirtualLab Fusion

solver information panel in components

catalog of Fourier transform algorithms
VirtualLab Fusion Technologies

prisms, plates, cubes, ...
lenses & freeforms
apertures & boundaries
gratings
diffractive, Fresnel, meta lenses
HOE, CGH, DOE
micro lens & freeform arrays
SLM & adaptive components
diffusive beam splitters
scatterer
waveguides & fibers
free space
crystals & anisotropic components
nonlinear components
Field Solver
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| further reading | - [Modeling of Etalon with Planar or Curved Surfaces](#)  
  - [Fourier Transform Settings – Discussion at Examples](#)  
  - [The Local Plane Interface Approximation (LPIA)](#)  
  - [The Fresnel Matrix](#)  
  - [Channel Configuration for Surfaces and Grating Regions](#) |