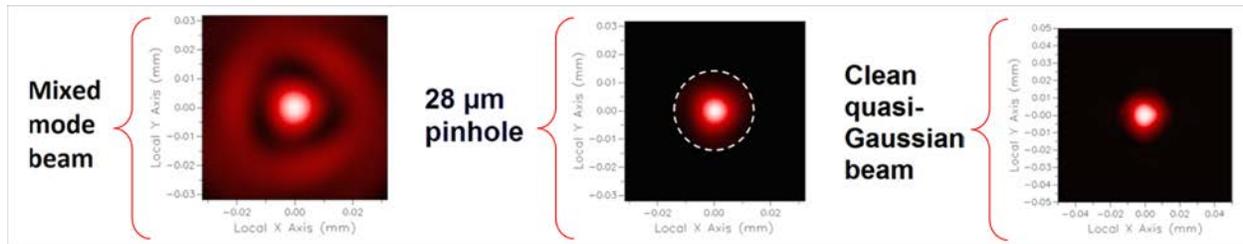


FRED Spatial Filter Application Note



Introduction

Laser systems often use a pinhole aperture called a *spatial filter*. Spatial filtering is a technique used to improve laser quality by removing higher-order modes and noise in the beam. To accurately model laser propagation through a spatial filter in **FRED**, it is important to re-synthesize the light field just after the filter. Doing so will accurately model clipping at the aperture. In this note, a light synthesis technique called Gabor decomposition will be described.

Gaussian Beamlet Model of Coherent Light

Modeling coherent light in **FRED** is accomplished using a technique called Gaussian Beam Decomposition (GBD). The light field is divided into individual Gaussian beamlets that propagate coherently with respect to each other. Each beamlet is represented as a set of rays (Figure 1). The *base ray* is traced along the axis of the beamlet. Eight secondary rays are included: four orthogonal *secondary waist rays* representing the beam waist, and four orthogonal *secondary divergence rays* representing beam divergence. During a raytrace, the base ray determines the fate of all secondary rays: if the base ray passes through an aperture, for example, all secondary rays must also pass through the aperture. This technique of representing Gaussian beamlets using rays is called *complex ray tracing*.

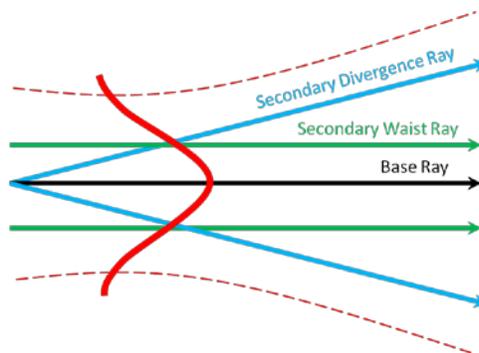


Figure 1. Complex ray representation of a Gaussian beamlet.

If laser light is brought to a focus at a spatial filter, most base rays in the coherent ray trace will pass through the aperture. This neglects the effect of clipping. To properly model clipping, the light field at the spatial filter plane should be re-sampled within the aperture. A new set of rays is generated for further propagation through the system.

Gabor Decomposition within 14 μm Spatial Filter

A spatial filtering system is modeled in **FRED** (Figure 2). Coherent collimated HeNe laser light is created. The source consists of 21 x 21 rays in an elliptical aperture with diameter of 6 mm. The light passes through a plano-convex lens with focal length of 52 mm. A spatial filter is placed at the focal point. Spatial filter diameter (14 μm) is calculated based on lens focal length and beam diameter:

$$D_{pinhole} = \frac{8}{\pi} \cdot \frac{\lambda \cdot f}{D_{input\ beam}}$$

The spatial filter pinhole is created by adding a custom element. Add a curve to the custom element of the type *Circular Arc* with radius of 0.007 mm. Add another curve to the custom element of the type *Aperture curve collection*. For *Usage*, select “Clear Aperture”. For *Curve*, select the *Circular Arc* curve. Create a 1x1 mm absorbing plane at the spatial filter position. Apply an analysis surface (64 x 64 μm width, 257 x 257 pixels) to this plane to collect the light field. After plotting the light field, right-click and select *Coherent Field Operations* → *Apply Clipping to Field*. Select the clipping curve, which is the *Aperture curve collection* curve. The field is now appropriately clipped (Figure 3).

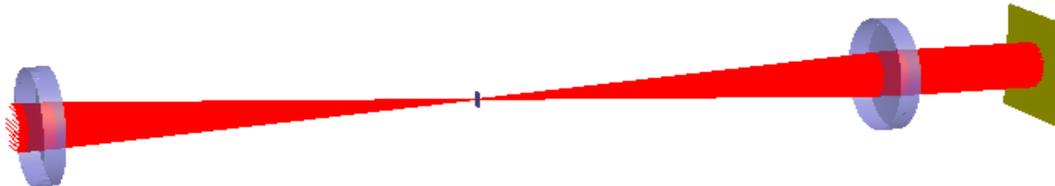


Figure 2. Spatial filtering of HeNe laser light.

Field at pinhole aperture plane

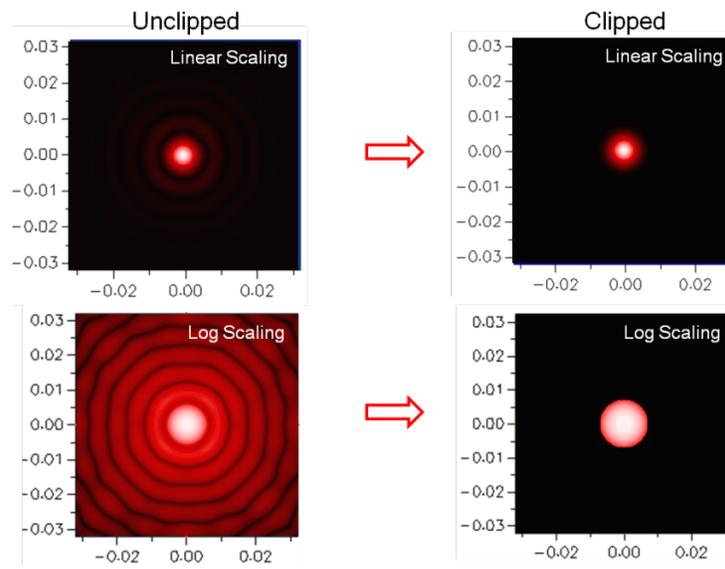


Figure 3. The result of clipping the light field within the spatial filter aperture.

Finally, a new set of complex rays should be generated within the clipped region. This is accomplished using Gabor decomposition. In the graph, right-click and select *Coherent Field Operations* → *Synthesize Field*. Check the output window to ensure that new rays have been created. Coherent field synthesis parameters are shown in Figure 4. Finally, select “Trace Existing” to model light propagation beyond the spatial filter. Figure 5 shows irradiance distribution beyond the collimating lens with field synthesis compared to a distribution that neglects spatial filter clipping. It is clear that field synthesis accurately models the reduced beam diameter and expected diffraction characteristics.

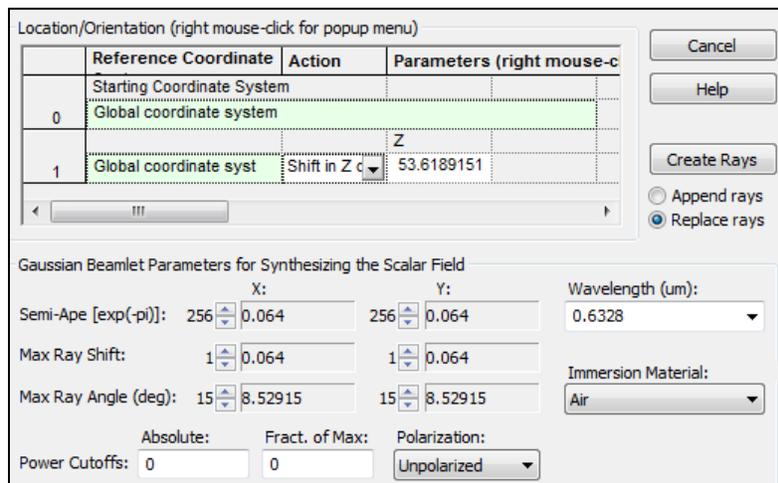


Figure 4. Coherent field synthesis parameters. Gabor decomposition is a directional synthesis which requires maximum beamlet semi-aperture. Maximum ray shift is set to 1 to ensure beam overlap. Maximum ray angle is determined by the diameter of the next optic. In this case, the collimating lens requires a maximum angle of at least 8°. For more information on Gabor decomposition, Photon Engineering’s Physical Optics Modeling short course is recommended.

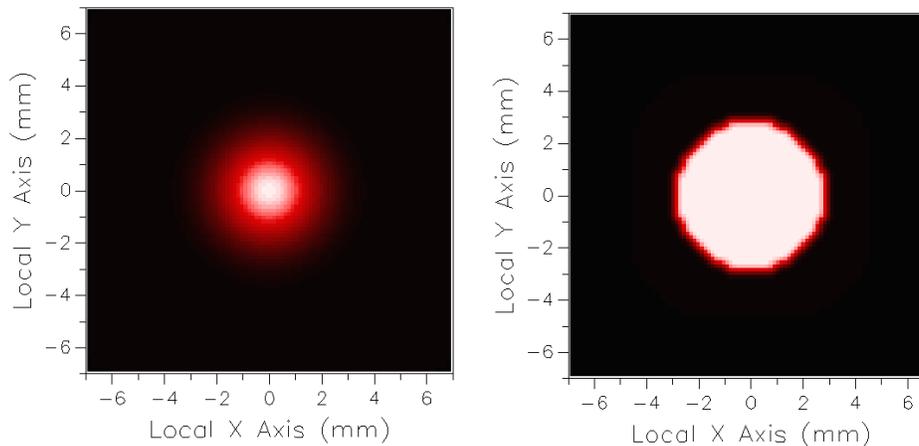


Figure 5. Irradiance distribution beyond the collimating lens. Left: The light field has been properly resynthesized within the spatial filter. Right: without field synthesis, all complex rays pass through the spatial filter unobstructed and clipping is ignored.

Conclusions

FRED has the capability to model coherent wave propagation using Gaussian beamlet propagation. While this approach is appropriate for free-space propagation of light, optical components that clip the beam should be treated with care. Very small apertures such as spatial filters require a resynthesis of the light field to accurately model clipping of the beam. Using a simple example, Gabor decomposition has been demonstrated to properly model the effect of using a spatial filter in a laser system. Additional applications for Gabor decomposition include the use of a spatial filter with a mixed-mode beam, monochromator slit apertures, and Young's slit/pinhole interferometers.

References:

1. Herloski, R. et al "Gaussian Beam Ray-Equivalent Modeling and Optical Design", Applied Optics, Vol. 22, No. 8, p. 1168-1174, April 1983 (Erratum, Applied Optics, Vol 22, No. 20, p 3151).
2. P. D. Einzinger, S. Raz and M. Shapiro, "Gabor Representation and Aperture Theory", J. Opt. Soc. Am. A, 3 (4) (April 1986).



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