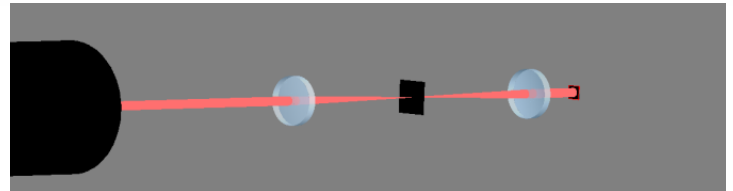
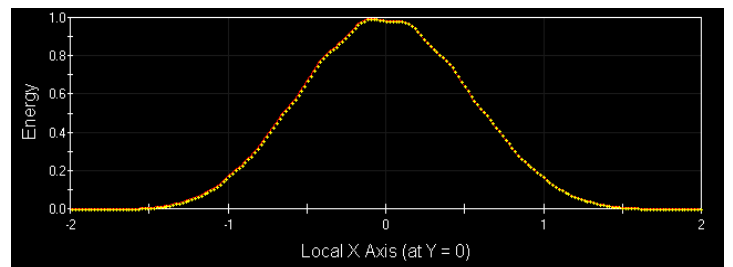
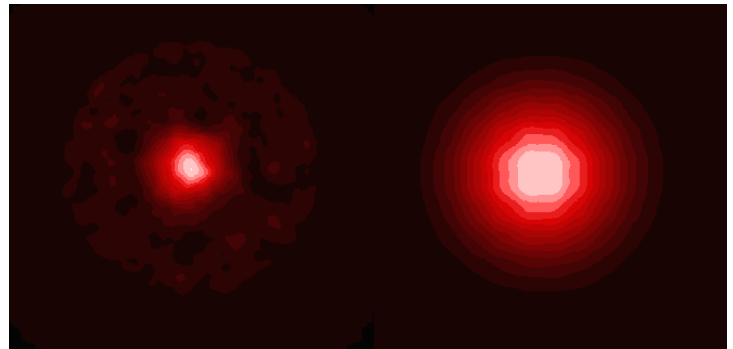


This Application Note describes how to model a spatial filter in **FRED**. The discussion is relevant to any situation where a coherent beam passes through a small aperture.



FRED Tools for Spatial Filtering

- ✓ **Source Power Apodizations**
Built-in and custom source power apodization functions for easy and precise definitions of beam profiles.
- ✓ **Best Geometric Focus**
Find the best focus position in the coordinate system of any surface, using any subset of rays.
- ✓ **Advanced Raytrace**
Flexible and precise raytrace control capability with options for sequential and non-sequential propagation, specific number of intersections, and ray starting and stopping surfaces.
- ✓ **Coherent Scalar Field Analysis**
The coherent field computation allows for computation and display of amplitude, energy, phase, or wavefront.
- ✓ **Coherent Field Clipping**
Clip a coherent field to accurately simulate a small aperture.
- ✓ **Coherent Field Synthesis**
Synthesize a new coherent rayset from a calculated or user-specified complex field.



Contents

Introduction.....	2
Practical Example in FRED: Spatially Filtering a Noisy Laser Beam.....	2
For More Information.....	9

Introduction

Many laser systems include a spatial filter to “clean up” high frequency noise caused by scattering or unwanted higher order modes in order to produce a collimated, single mode Gaussian beam. Typically, a lens brings the beam to a focus on a small pinhole and it is recollimated by a second lens. Because of the Fourier transforming property of a lens, the beam profile at the pinhole plane is the Fourier transform of the original beam. The pinhole rejects the high frequency noise on the outer edges while letting through a high percentage (98-99%) of the low frequency Gaussian. Simulating this process in **FRED** involves a few techniques relating to the modeling and propagation of coherent beams using complex raytracing. This Application Note details the steps to properly model a spatial filter in **FRED** and highlights some useful features and tips along the way. Note that this information is relevant to the modeling of any situation in which a coherent beam is passed through a small aperture.

Practical Example in **FRED**: Spatially Filtering a Noisy Laser Beam

The beam profile of a source can be specified in **FRED** by a positional power apodization function. The *Power* tab of the *Detailed Source* dialog contains the positional apodization choices shown in Figure 1. The Gaussian and amplitude/phase mask apodizations will be used in this example. “Amplitude/Phase Mask on Rectilinear Grid” allows for custom input of amplitude and phase for each pixel and supports import of a text file or bitmap image. This provides flexibility when modeling complex beam profiles. There is also a level of customization within the pre-defined apodizations; “Gaussian Apodization” lets the user specify x and y semi-widths (at the $1/e^2$ point), x and y coordinates of the Gaussian beam center offset, as well as higher order mode definitions (Hermite and Laguerre).

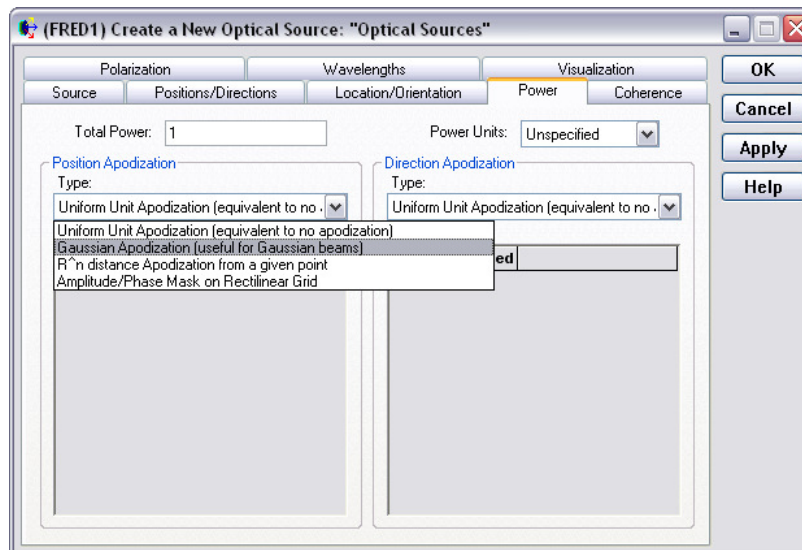


Figure 1. Source Power tab showing different Power Apodization functions available.

Consider a HeNe laser with a noisy Gaussian beam profile. One method of modeling this in **FRED** is by first creating a coherent source with the desired parameters (beam size, number of rays, wavelength, etc.) and a Gaussian apodization function. Then a simple **FRED** script is written that calculates the irradiance distribution of the source (perfect Gaussian), adds random variations, and assigns the new irradiance values as the apodization using “Amplitude/Phase Mask on Rectilinear Grid” (amplitude). Figure 2 shows the coherent scalar field energy of the resulting noisy HeNe beam. **FRED** has a number of plot options that allow the user to control parameters such as the color scheme, number of color levels, plot scaling, 3D perspective view, FFT, smoothing data, range, and more.

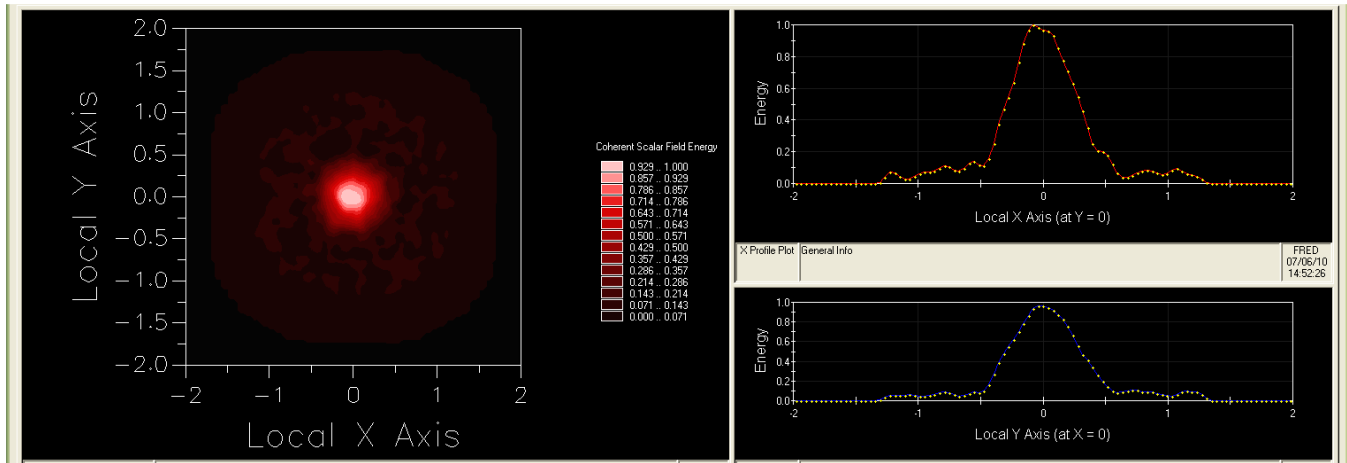


Figure 2. Energy plot of a noisy Gaussian laser beam modeled in FRED.

Next, a spatial filter is set up using two identical plano-convex lenses, as shown in Figure 3. Before placing the second lens in the model, **FRED's Best Geometric Focus** feature can be used to determine the appropriate location for the pinhole. This location can also be used as a guideline for placing the second plano-convex lens such that the exiting beam is perfectly collimated. Strictly speaking, the optimal location of the pinhole is where the field energy density is maximum and not at the geometric focus, but in this high F/# system the aberrations are low and the two locations are practically coincident (displaced by about 78 μm). To determine the location of maximum energy density, an *Analysis Surface* is placed in the vicinity of the focus and rotated by 90° so it cuts the beam laterally. The *Coherent Scalar Field Energy* calculation is performed and the location of maximum energy density is displayed in the Output Window.

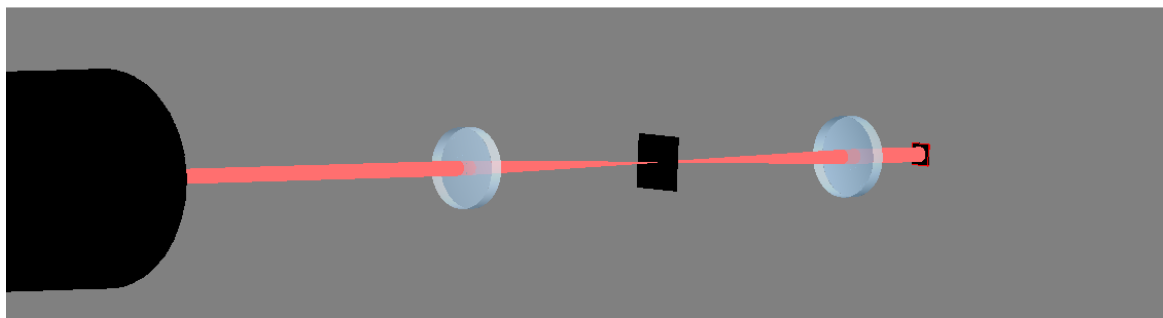


Figure 3. Spatial filter consisting of two plano-convex lenses and a pinhole.

Modeling the pinhole is more complicated than inserting an absorbing plane surface with a small hole in the center. Because of how **FRED** models and propagates coherent beams, doing so will yield the same irradiance on the output plane as not having included the filter at all. **FRED** uses a generalized form of Gaussian Beam Decomposition (GBD) to propagate coherent fields, also known as complex raytracing. For a detailed discussion of coherence in **FRED**, please refer to the **FRED** Application Note on Modeling Coherence. The coherent field is represented by a sum of Gaussian beamlets, each of which is described by multiple rays: a base ray, secondary waist rays (typically 4) representing the beamlet's waist, and secondary divergence rays (typically 4) representing the beamlet's divergence. The rays and the Gaussian beamlet they represent are shown in Figure 4. One of the fundamental rules of complex raytracing is: *If the base ray intersects a surface, then all of its secondary rays must intersect the same surface.* In the spatial filter example, the base rays come to a very tight focus, most likely within the pinhole aperture. Therefore, even with a very small pinhole in place, most if not all of the beam will pass through the pinhole at the lens focus. **FRED** has a way to properly model diffraction effects from small apertures: *Field Clipping* and *Coherent Field Synthesis*.

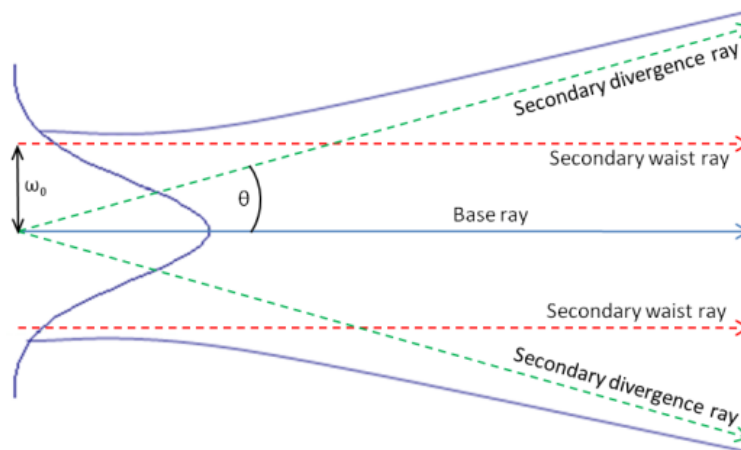


Figure 4. Gaussian beamlet profile and propagation showing the corresponding base and secondary rays.

The following steps describe the procedure for properly modeling the effect of the spatial filter:

1. A transmitting dummy plane is placed at the pinhole location. The plane should not have a hole in the center; otherwise, the rays in Step 3 will not stop on this surface.
2. A circular curve of the desired pinhole size is created (also at the pinhole location) and defined as an *aperture curve*. Tip: typically a pinhole twice the $1/e^2$ beam size at the focus is recommended. In this example a 44 μm -diameter pinhole is used.
3. The source rays are propagated to the pinhole plane by using the *Advanced Raytrace* feature, which allows control over raytrace aspects such as sequential or non-sequential, number of intersections, and starting and stopping surfaces. The *Advanced Raytrace* dialog is shown in Figure 5; the pinhole plane is selected as the *Ray Stop Surface*.

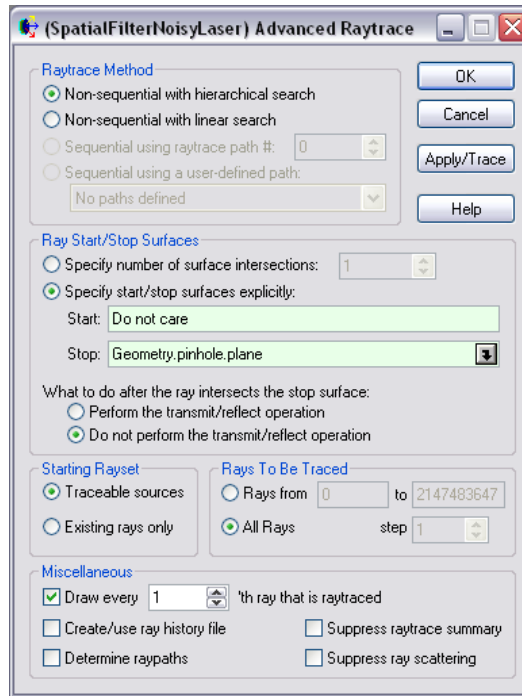


Figure 5. Advanced Raytrace dialog showing various available options, with the pinhole plane set as the stop surface.

4. The field at the pinhole plane is computed using the *Scalar Coherent Field* calculation. Figure 6 shows the field energy in log scale to emphasize the low power, high frequency noise present on the edges of the spot.
5. To simulate the pinhole, the field computed in the previous step is clipped using the *Coherent Field Clipping* feature. The circular aperture defined in Step 2 specifies the region to be clipped. This is done by right clicking on the field plot shown in Figure 6, selecting *Coherent Field Operations > Apply Clipping to Field...*, and choosing the circular aperture curve from the drop down menu, *Select Clipping Curve*. Figure 7 shows the clipped field energy in log scale.
6. A new rayset is defined based on the clipped field using the *Coherent Field Synthesis* feature (which is accessed by right clicking on the field plot shown in Figure 7 and selecting *Coherent Field Operations > Synthesize Field...*). The general approach behind *Coherent Field Synthesis* is to create a rayset that, when coherently summed, yields the desired field. The rayset consists of coherent Gaussian beamlets of equal size, but at different locations and propagating in different directions. The details of the synthesis are beyond the scope of this Application Note and the reader is referred to the **FRED** Help topic *Coherent Field Synthesis* for an in-depth discussion of the methodology and options. The *Synthesize Field* dialog is shown in Figure 8. One important option is worth mentioning: *Max Ray Angle (deg)* (outlined in red in Figure 8). This setting defines the maximum angular extent of the rays to be created. It is important to calculate and enter the angular extent of the optical element following the pinhole to ensure that it is not under or overfilled.

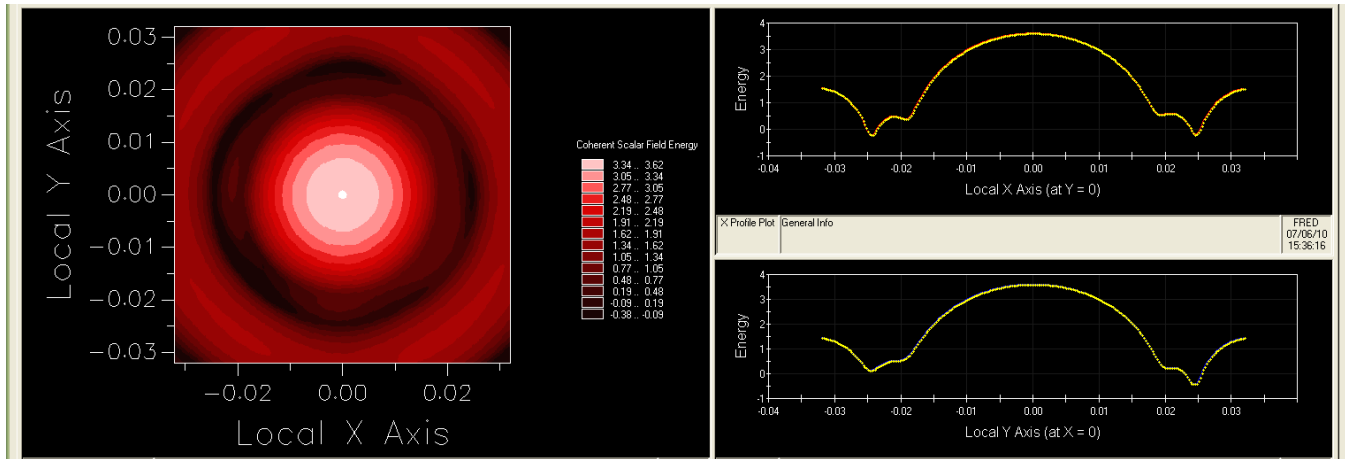


Figure 6. Coherent Scalar Field Energy at the pinhole plane, shown in log scale.

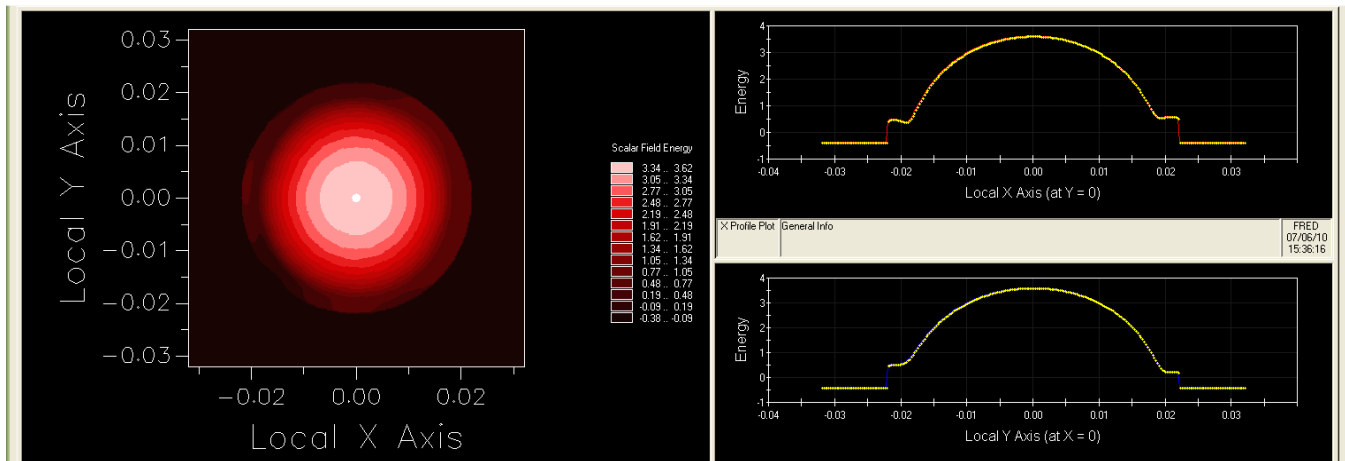


Figure 7. Coherent Scalar Field Energy at the pinhole plane in log scale after the field has been clipped to simulate propagation through the pinhole.

- The newly created rays are then propagated through the rest of the system and the output can be analyzed. Figure 9 shows the beam after passing through both lenses without the pinhole, and Figure 10 shows the spatially filtered beam after going through the correctly modeled pinhole.

The technique outlined above should be used in situations where a coherent beam passes through a small aperture. In short, it consists of propagating the field to the aperture plane, clipping the field according to the aperture, synthesizing a new field, and propagating it through the remainder of the model.

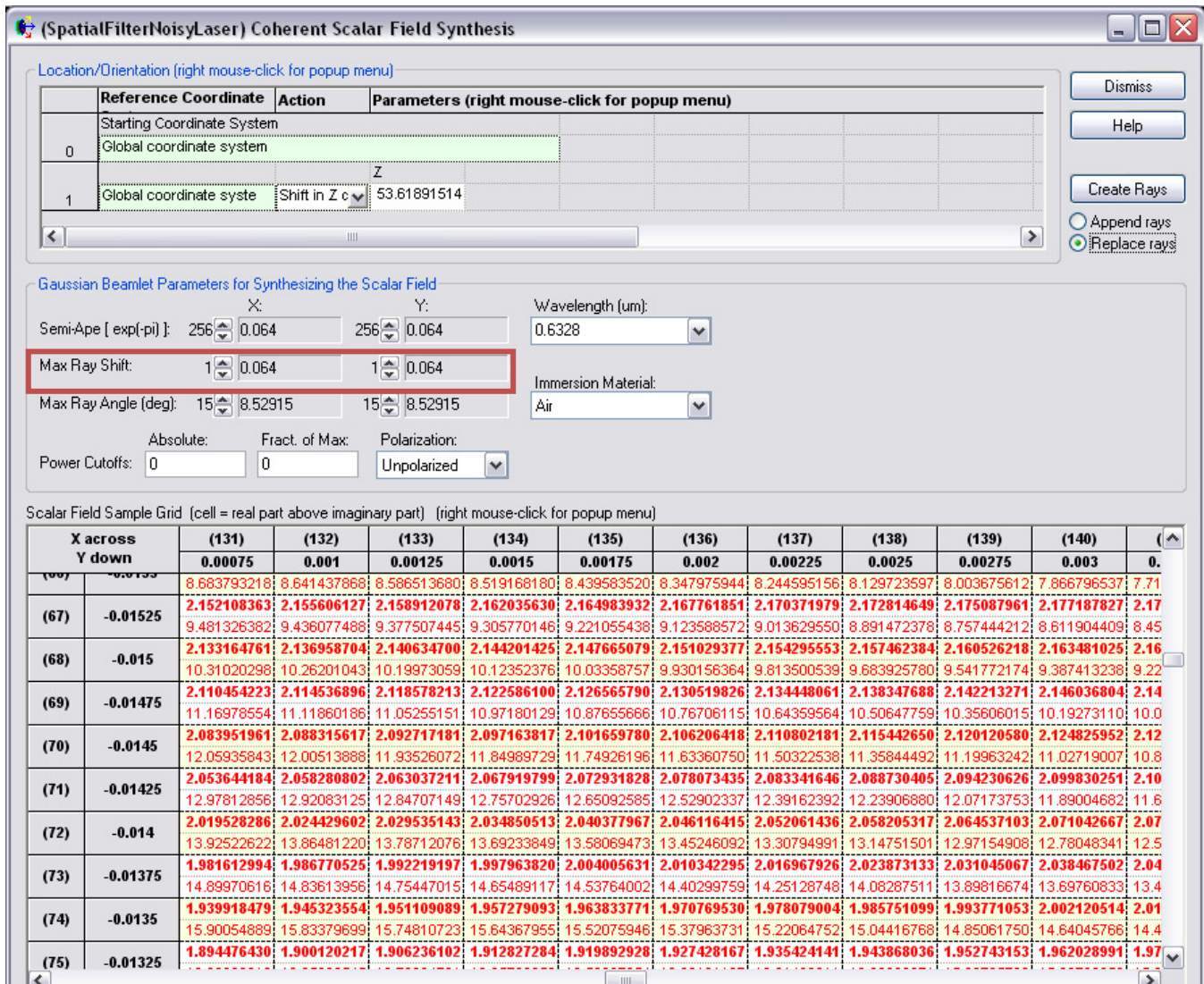


Figure 8. Coherent Field Synthesis dialog box showing various options along with a grid of scalar field samples. The maximum ray angle option is outlined in red.

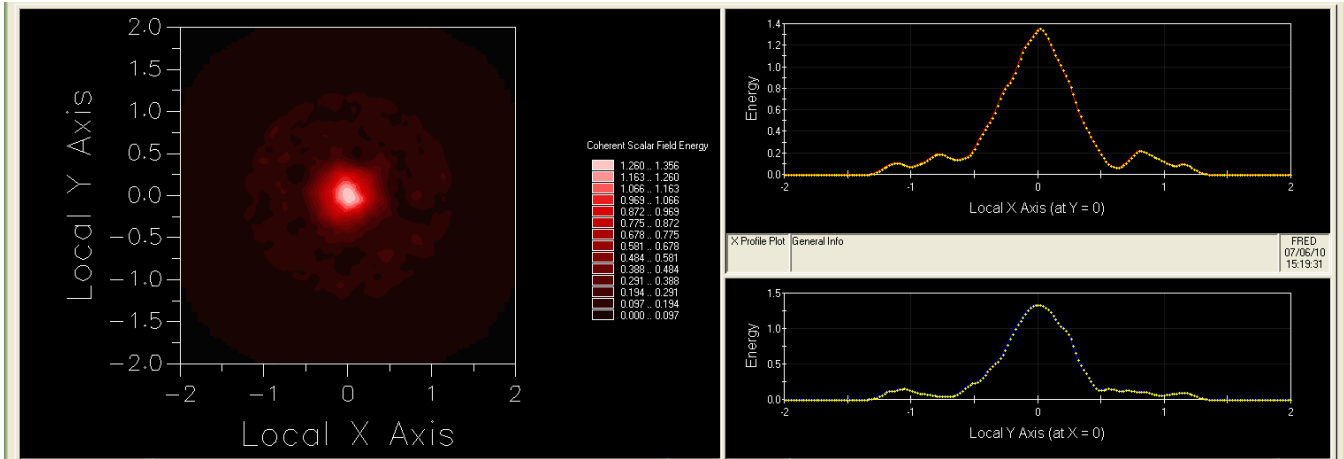


Figure 9. Noisy laser beam after having travelled through the two lenses without the pinhole filter.

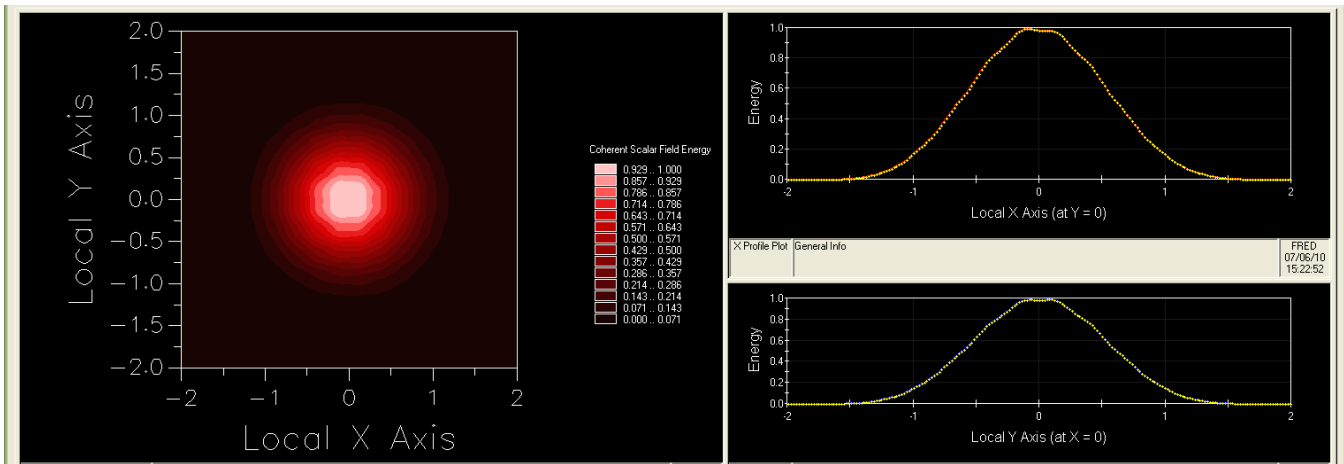


Figure 10. Noisy laser beam after having travelled through the spatial filter with the pinhole properly modeled.

For More Information...

On this Application Note and others

Visit our website at <http://www.photonengr.com>

Email us at support@photonengr.com

On purchasing a copy of **FRED or getting a free Demo version**

Email us at sales@photonengr.com

On our many tutorials and short courses

Visit our website at <http://www.photonengr.com>

Email us at tutorials@photonengr.com



Photon Engineering, LLC

440 South Williams Blvd., Suite # 106

Tucson, Arizona 85711

Tel: +1-520-733-9557

Fax +1-520-733-9609

<http://www.photonengr.com>