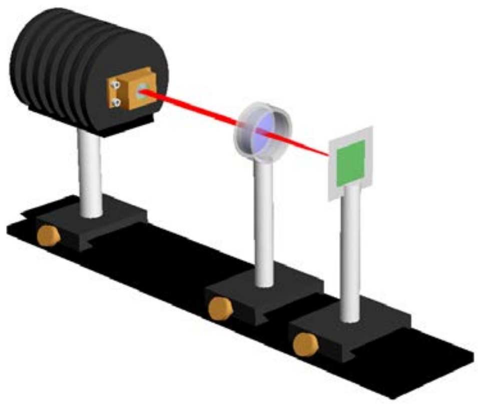
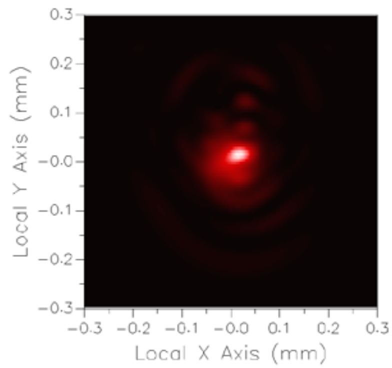
Laser Diode Application Note





Introduction

FRED software has great flexibility when it comes to modeling laser diodes. In this application note, laser source models from simple to detailed will be described. The most basic model is a Gaussian $TEM_{0,0}$ mode. More advanced models include astigmatism in beam waist displacement and divergence. The laser can also be specified using its M^2 factor. Finally, an arbitrary mixed-mode laser can be created. This model coherently combines a chosen distribution of Gaussian TEM modes (Hermite, Laguerre, Laguerre Cosine, and Laguerre Sine).

Modeling Methods

Example 1: Gaussian 00 Mode

The *Laser Beam (Gaussian 00 Mode)* source consists of a collimated grid of rays which are apodized to have a Gaussian 00 irradiance profile at the beam waist. This source is sufficient for very low divergence beams. Note that if the Grid Size is chosen to be less than the Beam Size, the beam will be truncated and undergo diffraction as if it were blocked by a circular aperture.

Type: Laser Beam (Gaussian 00 mode)

	Value	Description
Beam Size	0.5	Waist semi-aperture
Grid Size	1	Semi-aperture of the sample plane at the waist
Sample Pts	21	Number of sample points across the sample plane

Figure 1. Simplified *Laser Beam (Gaussian 00 mode)* specifications.

Example 2: Astigmatic Gaussian Beam

The *Astigmatic Laser Diode* source provides a more realistic model. Most diode lasers suffer from astigmatism: x- and y-components of the beam waist are displaced along the axis. In index-guided lasers, displacement is 2-8 µm. In gain-guided lasers, displacement is typically ≈40 µm. Astigmatism can be modeled by specifying x- and y- divergence angle and separation of foci. The *Astigmatic Laser Diode* also allows ray generation at some distance from the beam waist for greater accuracy.

Type: Astigmatic Gaussian Beam

	Note: use Diode Laser source if angles > 5 degrees	
	Value	**Description**
Ang X	5	X divergence angle of full cone (degrees)
Ang Y	15	Y divergence angle of full cone (degrees)
Focii	0.1	Axial separation of the astigmatic focii (in system units)
Create	0.2	Z-axis location for ray creation
Wavelength	0.6328	Wavelength (micron) for computing Gaussian Beam para
X samp Pts	11	# of beam sample points in X direction
Y samp Pts	11	# of beam sample points in Y direction
Note:	set ray creation Z-axis location approx same as your analysis distance	

Figure 2. Simplified *Astigmatic Gaussian Beam* specifications.

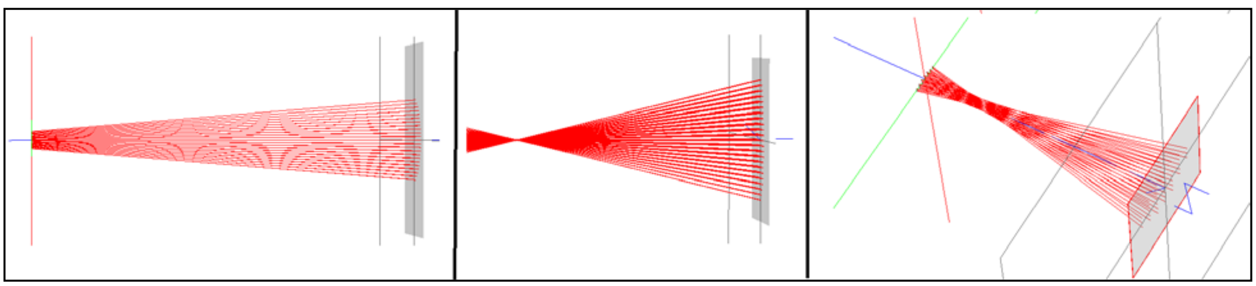


Figure 3. Schematic raytrace of a divergent astigmatic laser source along the: x-z axis (left), y-z axis (center), and perspective view (right). Divergence angles are 5° in the x-direction and 15° in the y-direction. Foci are separated by 0.5 units.

Example 3: Laser Diode Beam

The *Laser Diode Beam* is a newer and more accurate model of an astigmatic divergent laser source. The laser is specified in terms of x- and y- divergence angles and foci positions. In addition, the exact meaning of divergence angle can be specified in terms of various half- and full-widths. This laser model also performs Gabor Synthesis for more accurate modeling of coherent light propagation.

Type: Laser Diode Beam

	Value	**Description**
X ang	5	X divergence angle (degrees)
Y ang	15	Y divergence angle (degrees)
Angle Type	Half width at 1/e amplitud	Meaning of divergence angle
X samps	8	Num samples across full X width
Y samps	8	Num samples across full Y width
X focus	-0.2	X focal point offset (in system units)
Y focus	0.3	Y focal point offset (in system units)

Figure 4. Simplified *Laser Diode Beam* specifications.

Example 4: M squared Laser Beam

The *M squared Laser Beam* models a laser based on its M^2 factor, also known as beam quality or beam propagation factor. The smallest possible value of M^2 is 1, and this specifies a Gaussian TEM 00 beam. Larger values of M^2 indicate a mix of higher order modes in the beam. To determine the mode composition of an M^2 beam created in FRED, right-click the Source category on the tree and select *Detailed Analysis*.

Type: M squared Laser Beam

	Value	Description
X ang	1	X divergence angle (degrees)
Y ang	2	Y divergence angle (degrees)
Angle Type	Half width at 1/e amplitud	Meaning of divergence angle
X samps	64	X relative ray sampling density
Y samps	64	Y relative ray sampling density
M^2 X	2.1	M squared value in X direction
M^2 Y	2.6	M squared value in Y direction

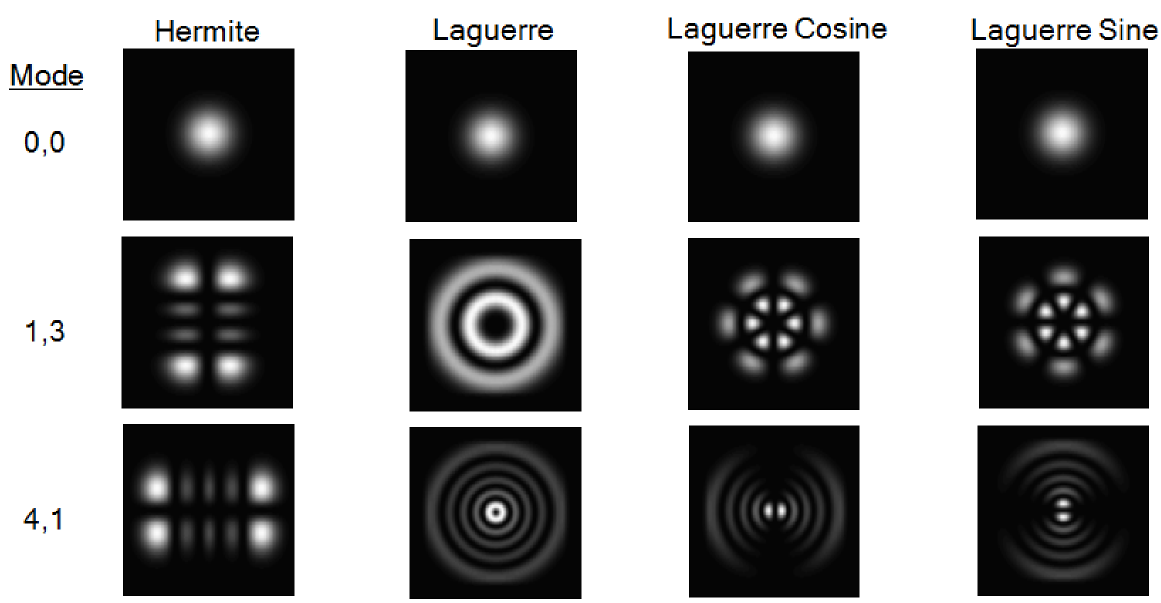
TEMmn mode composition:

m	n	amplitude
0	0	0.747041
1	0	0.364461
2	0	0.253522
0	1	0.374521
0	2	0.317756
2	1	0.035630
1	2	0.048145

Figure 5. Left: Simplified *M squared Laser Beam* specifications. Right: Distribution of modes in this M^2 laser source.

Mixed Mode, Higher Order Modes

A multimode beam occurs if a laser does not have sufficient spatial filtering (the limiting aperture is larger than the lowest order mode radius). As a result, multiple modes exist in the laser cavity. To model a laser with a specific mode distribution, multiple light sources can be assigned to each TEM mode. To create a mode, add a coherent *Detailed Optical Source*. Choose a hexagonal or grid plane of ray positions. The TEM mode is created by enabling Position Apodization under the Power tab of the source. Choose the *Gaussian Apodization* type. Specify x and y semi-width, lateral offset, mode number (m, n), and mode type (Hermite, Laguerre, Laguerre Cosine, Laguerre Sine). Irradiance profiles of several TEM modes are shown in Figure 6. A mixed-mode example is shown in Figure 7.



$$H_n\left(\frac{\sqrt{2}r}{w(z)}\right) \qquad L_n\left(\frac{2r^2}{w^2(z)}\right)e^{im\phi} \qquad L_n\left(\frac{2r^2}{w^2(z)}\right)\cos(m\phi) \qquad L_n\left(\frac{2r^2}{w^2(z)}\right)\sin(m\phi)$$

Figure 6. Irradiance profile of various Gaussian TEM modes as modeled in FRED.

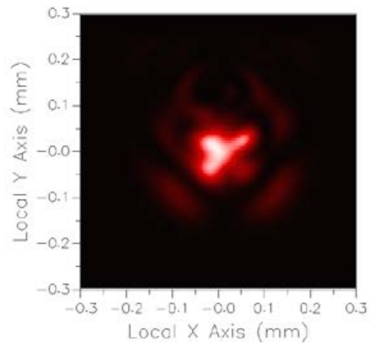


Figure 6. Mixed-mode irradiance profile consisting of [1 : 0.5 : 0.25] power distribution of $TEM_{0,0}$, $TEM_{2,1}$, and $TEM_{2,3}$ modes. The $TEM_{2,1}$ and $TEM_{2,3}$ modes are also slightly displaced from the axis.

References:

1. Paschotta, R. "M^2 Factor." Accessed 1/28/16. <https://www.rp-photonics.com/m2_factor.html>.
2. Ready, J. F. *Industrial applications of lasers*. Academic press, 1997.
3. "Correcting Astigmatism in Diode Lasers." Accessed 1/28/16. <http://uotechnology.edu.iq/eretc/books/corast.pdf>.

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