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Precision Beam Profiling

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Application Note

Laser Mode Analysis with Photon Beam Profilers

How Gaussian is Your Beam?

The Gaussian form $I = e^{-2(r/w)^2}$ gives the intensity at each value of **r.** The parameters are illustrated in Figure 1: **r** is the radius at a particular intensity **I**; **w** is the radius at the $1/e^2$ intensity.

One can measure the beam diameter at two intensity values and obtain their ratio. The ratio can then be compared to that of a perfect Gaussian beam.

If, for example, we select the $1/e^2$ and 53.5% intensity values, the theoretical beam diameter ratio for a Gaussian beam is found by solving the equation for **I = 0.535** (the intensity clip level setting):

$$ln\,(0.535) = ln\,e^{-2(r/w)^2}$$

$$-0.62548 = -2(r/w)^2$$

$$0.3127 = (r/w)^2$$

$$0.5592 = (r/w)$$

$$R = \frac{2r}{2w} = \frac{D(53.5\%)}{D(13.5\%)} = 0.559$$

$$ln\,(\times) = \log \text{ to base } e \text{ of quantity } \times$$

For profiles close to a pillbox shape, the measured ratio will be greater than 0.559; for waveforms close to a triangle shape, the ratio will be less than 0.559. You can calculate any ratio set you choose by solving the more general equation: $I = e^{-a^2}$ at the two clip levels of interest and determining the ratio **r**. For illustration, let's assume we'd like to use the 90% and 10% intensity beam diameters; solve for **a**:

$$ln\,I = -a^2$$

$$a^2 = -ln\,I$$

$$a = \sqrt{-ln\,I}$$

Substituting **I** = 90%

$$a\,(90\%) = \sqrt{-ln(0.90)}$$

$$a\,(90\%) = 0.3245$$

With **I** = 10%:

$$a\,(10\%) = \sqrt{-ln(0.10)}$$

$$a\,(10\%) = 1.5174$$

The ideal Gaussian ratio is then:

$$R = \frac{a\,(90\%)}{a\,(10\%)} = \frac{0.3245}{1.5174} = 0.2138$$

For some applications of lasers, it is very important to know the mode mixture; a Photon beam profiler can be used to detect this mixture. To illustrate, we calculated the ideal profile, and then added increments of $\mathbf{TEM_{01}}$ mode to the $\mathbf{TEM_{00}}$ beam.

Figures 2-5 illustrate profiles with decreasing $\mathbf{TEM_{01}}$ content; the beam diameter decreases and the slopes change; both these changes are detectable with a Photon profiler. Figure 6 illustrates a two-dimensional intensity contour map. Both the pure Gaussian and the Gaussian +5% $\mathbf{TEM_{01}}$ contours are shown. Each contour line represents a 5% change in intensity. Visually, it is easy to see that the beam is elliptic; and practically, that the ellipticity can be measured by a Photon profiler.

Repeatability of beam diameter measurements for a standard BeamScan with a 2.5mW commercial HeNe laser is ±3µm in 680µm, or approximately 1/2% at $1/e^2$ diameter. Many parameters can degrade this performance, but let's assume this repeatability and ask what change in Gaussian ratio, **R**, is significant? Assume the test is made at the 53.5% and $1/e^2$ intensity. The ideal ratio is 0.559; significant ratios are less than 0.551 and greater than 0.567.

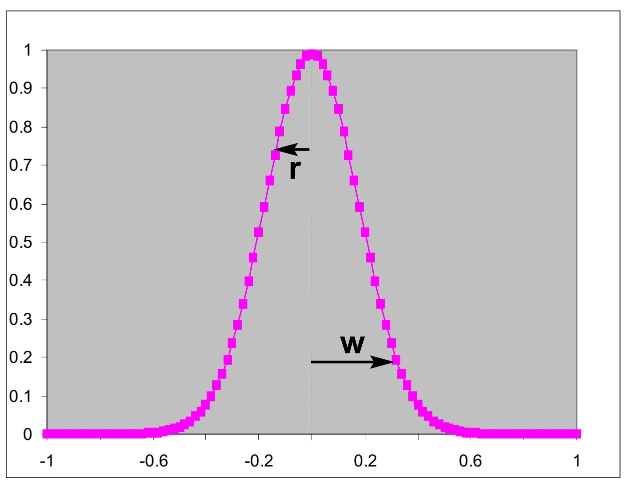

Figure 1
Pure TEM_{00} and 99% TEM_{00}
Plus 1% TEM_{01}

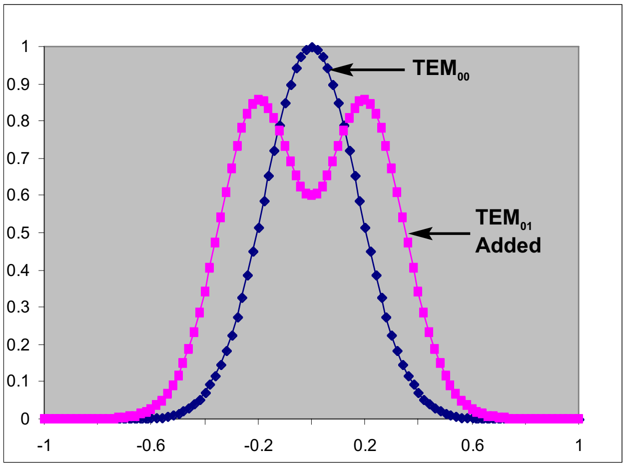

Figure 2
Pure TEM00 and 60% TEM_{00}
Plus 40% TEM_{01}

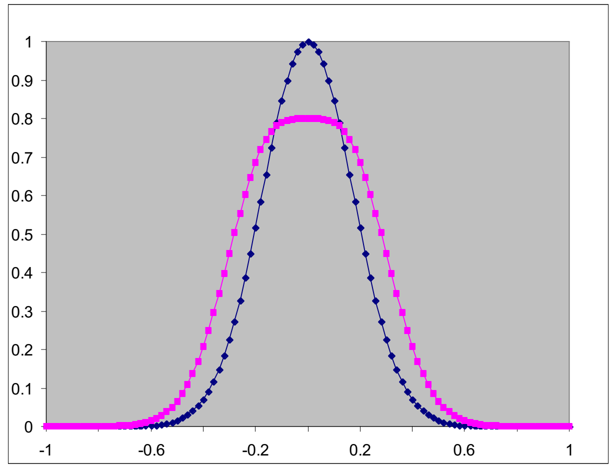

Figure 3
Pure TEM00 and 80% TEM_{00}
Plus 20% TEM_{01}

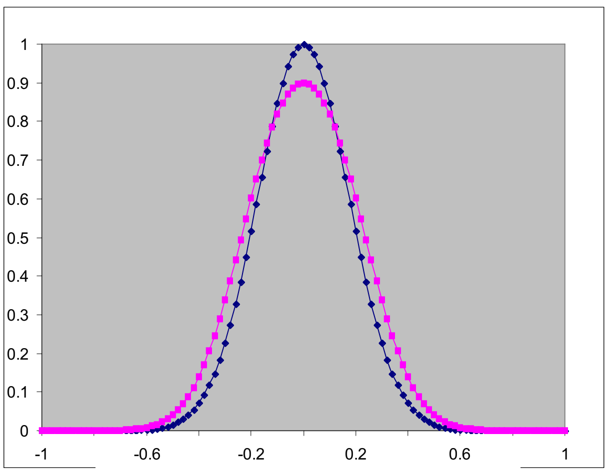

Figure 4
Pure TEM00 and 90% TEM_{00}
Plus 10% TEM_{01}

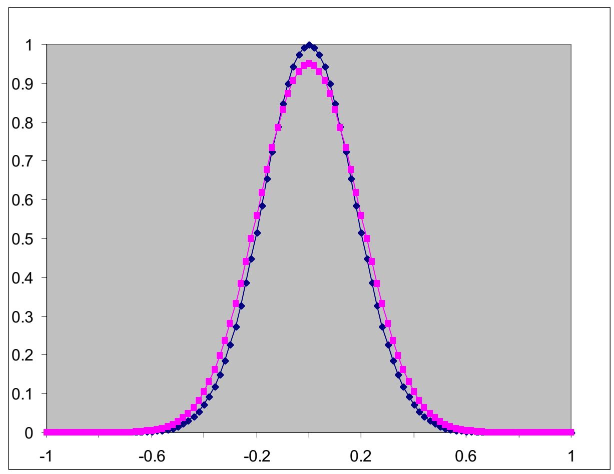

Figure 5
Pure TEM00 and 95% TEM_{00}
Plus 5% TEM_{01}

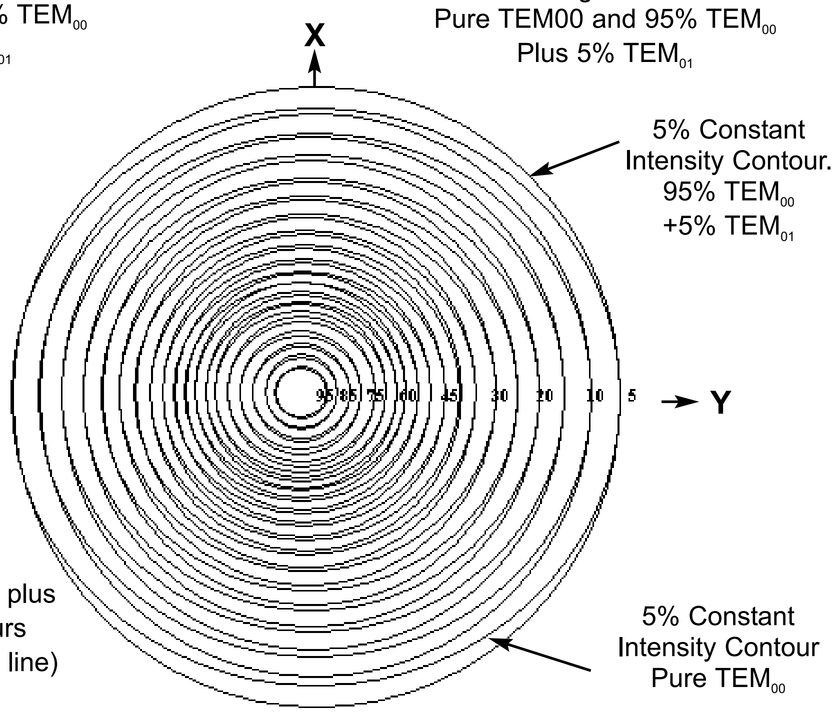

Figure 6
Pure TEM_{00} and 95% TEM00 plus
5% TEM_{01} Intensity Contours
(5% intensity change/contour line)