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Real Beam Propagation

Incorporating M^2 Into the Propagation Equations

In the previous section we defined the propagation constant M^2

$$M^2 = \frac{w_{0R} \cdot \theta_R}{w_0 \cdot \theta}$$

where w_{0R} and θ_R are the beam waist and far-field divergence of the real beam, respectively. For a pure Gaussian beam, $M^2 = 1$, and the beam-waist beam-divergence product is given by

$$w_0 \theta = \lambda / \pi$$

For a real laser beam, we have

$$w_{0M} \theta_M = \frac{M^2 \lambda}{\pi} > \frac{\lambda}{\pi}$$

where w_{0R} θ_R are the 1/2 intensity waist radius and the far-field half-divergence angle of the real laser beam, respectively.

The propagation equations for a real laser beam are now written as

$$w_R(z) = w_{0R} \left[1 + \left(\frac{z \lambda M^2}{\pi w_{0R}^2} \right)^2 \right]^{1/2}$$

and

$$R_R(z) = z \left[1 + \left(\frac{\pi w_{0R}^2}{z \lambda M^2} \right)^2 \right]$$

where $w_R(z)$ and $R_R(z)$ are the $1/e^2$ intensity radius of the beam and the beam wavefront radius at z , respectively.

The definition for the Rayleigh range remains the same for a real laser beam and becomes

$$z_R = \frac{\pi w_{0R}^2}{\lambda}$$

For $M^2 = 1$, these equations reduce to the Gaussian beam propagation equations

$$R(z) = z \left[1 + \left(\frac{\pi w_0^2}{\lambda z} \right)^2 \right]$$

and

$$w(z) = w_0 \left[1 + \left(\frac{\lambda z}{\pi w_0^2} \right)^2 \right]^{1/4}$$

In a like manner, the lens equation can be modified to incorporate M^2 . The standard equation becomes

$$\frac{1}{s + (z_R / M^2)^2 / (s - f)} + \frac{1}{s''} = \frac{1}{f},$$

and the normalized equation transforms to

$$\frac{1}{(s/f) + (z_R / M^2 f)^2 / (s/f - 1)} + \frac{1}{(s''/f)} = 1.$$

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