Mode Field Diameter and Effective Area
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Mode Field Diameter

The mode field diameter (MFD) represents a "measure of the transverse extent of the electromagnetic field intensity of a mode of light in a fiber cross section"[1]. In optical fiber, this typically is larger than the fiber core, since a portion of the light propagates through the cladding. MFD traditionally has been determined using a Gaussian approximation of the intensity distribution with the MFD defined as the width of the curve at the $1/e^2$ power level. As fiber refractive index profiles have evolved, however, their complexity has rendered the Gaussian approximation invalid. The current international standard measurement is the "Petermann II" method, a rigorous approach that calculates MFD by integrating the actual intensity distribution over the range of far field angles. Thus, it does not rely on the shape of the fiber's transmitted intensity curve; rather, it integrates the continuous intensity function, regardless of shape. The Petermann II mode field diameter definition is as follows:

$$MFD = 2\omega_o = \left(\frac{\lambda}{\pi}\right)\left[\frac{2\int_0^{\pi/2} I(\theta)\sin(\theta)\cos(\theta)d\theta}{\int_0^{\pi/2} I(\theta)\sin^3(\theta)\cos(\theta)d\theta}\right]^{1/2}$$

where:
$I(\theta)$ is the intensity distribution at all angles

Effective Area

Effective area is not just the geometric transform of the MFD (the old πr^2 – sometimes called the mode field area [MFA]). Rather, it is a mathematical representation of the light transmitting area calculated with respect to a fiber's response to nonlinear effects, primarily self phase modulation (SPM) and four wave mixing (FWM). Thus, the effective area is different for each type of fiber, based primarily on that fiber's refractive index profile and the input wavelength. The effective area has been empirically determined to be typically in the range of 95-104% of the MFA, though it has been shown to be as much as 111% of the MFA[2]. We calculate the effective area by using a nonlinear solution to the Schrodinger's equation, which accounts for the fiber's response to non-linear effects:

$$A_{eff} = \left\{\frac{2\pi\left[\int_0^\infty E(r)^2\, r\, dr\right]^2}{\int_0^\infty E(r)^4\, r\, dr}\right\}$$

where:

$$E(r) = E_o\int_0^\infty \left[Pm(\theta)\right]^{1/2} J_o(r)\beta\sin(\theta)\sin 2\theta\, d\theta,$$

the near field Hankel Transform of the far field scan[3]

It is possible to empirically determine a mapping relationship between the MFD and the effective area, but this relation is wavelength dependent. The general relation is as follows:

$$A_{eff} = k(\lambda)\left(\frac{\pi}{4}\right)MFD^2$$

where:
k (λ) is the mapping value and MFD is determined by the Petermann II method[4].

In summary, the effective area and MFD are not directly related. The effective area is the more appropriate representation of the light-carrying region in fibers used in applications in which nonlinear effects can be a significant restriction to system performance.

References

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Additional References

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