Transmission Characteristics
of Optical Fiber II

Intermodal dispersion

- Dispersion caused by multipath propagation of light energy is referred to as intermodal dispersion.

- Signal degradation occurs due to different values of group delay for each individual mode at a single frequency.

- In digital transmission, we use light pulse to transmit bit 1 and no pulse for bit 0. When the light pulse enters fiber it is breakdown into small pulses carried by individual modes. At the output individual pulses are recombined and since they are overlapped receiver sees a long pulse causing pulse broadening.

Dispersion affect the transmission bandwidth:

For no overlapping of light pulse down on an optical fiber link,
the Digital bit rate (B_T)

$B_T = 1/2ｒ$ where $2ｒ$ is the pulse duration

Maximum bit rate $B_{Tmax}=0.2/\sigma$ bits

where δ represents the rms impulse response for the channel

Multimode step index fiber

Using the ray theory model, the fastest and slowest modes propagating in the step index fiber may be represented by the axial ray and the extreme meridional ray (which is incident at the core–cladding interface at the critical angle φ_c) respectively.. The delay difference between these two rays when traveling in the fiber core allows estimation of the pulse broadening resulting from intermodal dispersion within the fiber. As both rays are traveling at the same velocity within the constant refractive index fiber core, then the delay difference is directly related to their respective path lengths within the fiber. Hence the time taken for the axial ray to travel along a fiber of length L gives the minimum delay time T_{Min} :

$$T_{\mathrm{Min}} = \frac{\text{distance}}{\text{velocity}} = \frac{L}{(c/n_1)} = \frac{Ln_1}{c}$$

where n_1 is the refractive index of the core and c is the velocity of light in a vacuum.

The extreme meridional ray exhibits the maximum delay time T_{Max}

$$T_{\mathrm{Max}} = \frac{L/\cos\theta}{c/n_1} = \frac{Ln_1}{c\cos\theta}$$

Using Snell's law of refraction at the core–cladding interface following

$$\sin\phi_c = \frac{n_2}{n_1} = \cos\theta$$

where n_2 is the refractive index of the cladding. Furthermore, substituting into Eq. (2.21) for cosθ gives:

$$T_{\mathrm{Max}} = \frac{L n_1^2}{c n_2} \tag{2.23}$$

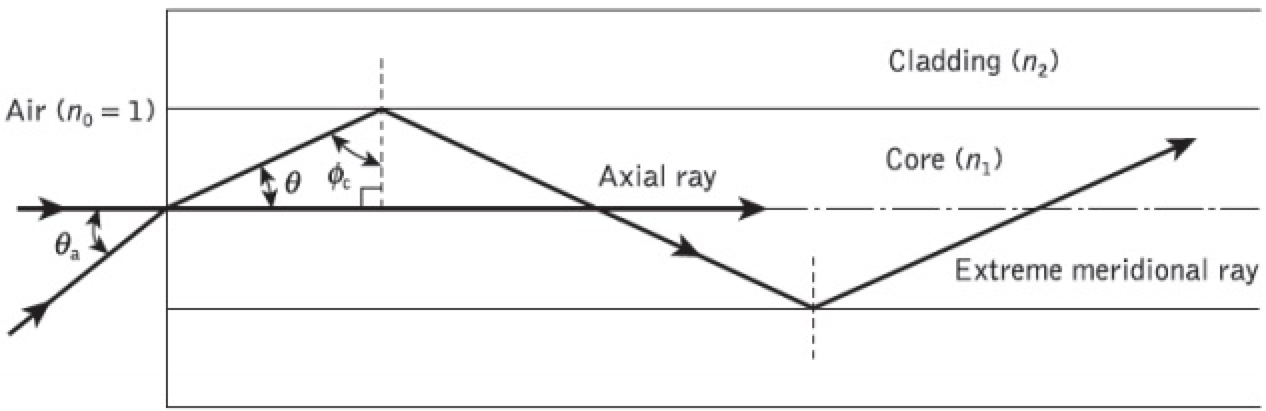

Figure 2.9 The paths taken by the axial and an extreme meridional ray in a perfect multimode step index fiber

The delay difference δ*T*s between the extreme meridional ray and the axial ray may be obtained by:

$$\delta T_s = T_{Max} - T_{Min} = \frac{Ln_1^2}{cn_2} - \frac{Ln_1}{c}$$

$$= \frac{Ln_1^2}{cn_2}\left(\frac{n_1 - n_2}{n_1}\right) \tag{2.24}$$

$$\simeq \frac{Ln_1^2\Delta}{cn_2} \quad \text{when } \Delta \ll 1 \tag{2.25}$$

where Δ is the relative refractive index difference. However, when Δ<< 1, then from the definition given by Eq. (2.9), the relative refractive index difference may also be given approximately by:

$$\Delta \simeq \frac{n_1 - n_2}{n_2} \tag{2.26}$$

Hence rearranging Eq. (3.24):

$$\delta T_s = \frac{Ln_1}{c}\left(\frac{n_1 - n_2}{n_2}\right) \simeq \frac{Ln_1\Delta}{c} \tag{2.27}$$

Also substituting for Δ from Eq. (2.10) gives:

$$\delta T_s \simeq \frac{L(NA)^2}{2n_1 c} \tag{2.28}$$

where *NA* is the numerical aperture for the fiber. The approximate expressions for the delay difference given in Eqs (2.27) and (2.28) are usually employed to estimate the maximum pulse broadening in time due to intermodal dispersion in multimode step index fibers. Again considering the perfect step index fiber, another useful quantity with regard to intermodal dispersion on an optical fiber link is the rms pulse broadening resulting from this dispersion mechanism along the fiber. When the optical input to the fiber is a pulse $p_i(t)$ of unit area, as illustrated in Figure 2.10, then

$$\int_{-\infty}^{\infty} p_i(t)\, \mathrm{d}t = 1 \tag{2.29}$$

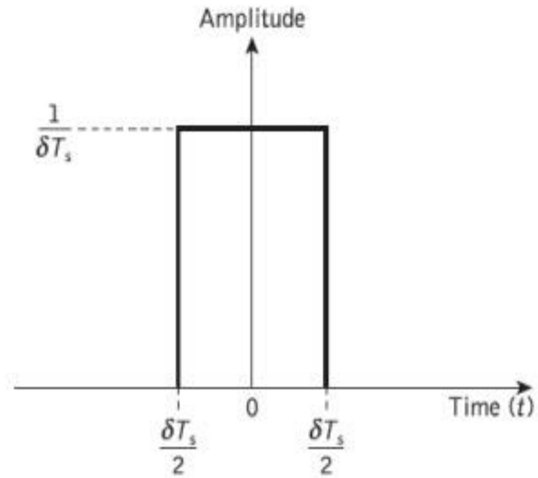

Figure 2.10 An illustration of the light input to the multimode step index fiber consisting of an ideal pulse or rectangular function with unit area

It may be noted that pi(t) has a constant amplitude of 1/δTs over the range:

$$\frac{-\delta T_s}{2} \le p(t) \le \frac{\delta T_s}{2}$$

The rms pulse broadening at the fiber output due to intermodal dispersion for the multimode step index fiber σ_s (i.e. the standard deviation) may be given in terms of the variance σ_s^2:

$$\sigma_s^2 = M_2 - M_1^2 \tag{2.30}$$

where M_1 is the first temporal moment which is equivalent to the mean value of the pulse and M_2, the second temporal moment, is equivalent to the mean square value of the pulse.
Hence:

$$M_1 = \int_{-\infty}^{\infty} t p_1(t)\, dt \tag{2.31}$$

And:

$$M_2 = \int_{-\infty}^{\infty} t^2 p_1(t)\, dt \tag{2.32}$$

The mean value $M1$ for the unit input pulse of Figure 2.10 is zero, and assuming this is maintained for the output pulse, then from Eqs (2.30) and (2.32):

$$\sigma_s^2 = M_2 = \int_{-\infty}^{\infty} t^2 p_i(t)\, dt \tag{2.33}$$

Integrating over the limits of the input pulse (Figure 3.12) and substituting for $pi(t)$ in Eq. (2.33) over this range gives:

$$\begin{aligned}\sigma_s^2 &= \int_{-\delta T_s/2}^{\delta T_s/2} \frac{1}{\delta T_s} t^2\, dt \\ &= \frac{1}{\delta T_s}\left[\frac{t^3}{3}\right]_{-\delta T_s/2}^{\delta T_s/2} = \frac{1}{3}\left(\frac{\delta T_s}{2}\right)^2\end{aligned} \tag{2.34}$$

Hence substituting from Eq. (2.27) for δTs gives:

$$\sigma_s \simeq \frac{L n_1 \Delta}{2\sqrt{3}c} \simeq \frac{L(NA)^2}{4\sqrt{3}n_1 c} \tag{2.35}$$

The pulse broadening is directly proportional to the relative refractive index difference Δ and the length of the fiber L. The latter emphasizes the bandwidth–length trade-off that exists, especially with multimode step index fiber, and which inhibits their use for wideband long-haul (between repeaters) systems. Furthermore, the pulse broadening is reduced by reduction of the relative refractive index difference Δ for the fiber.