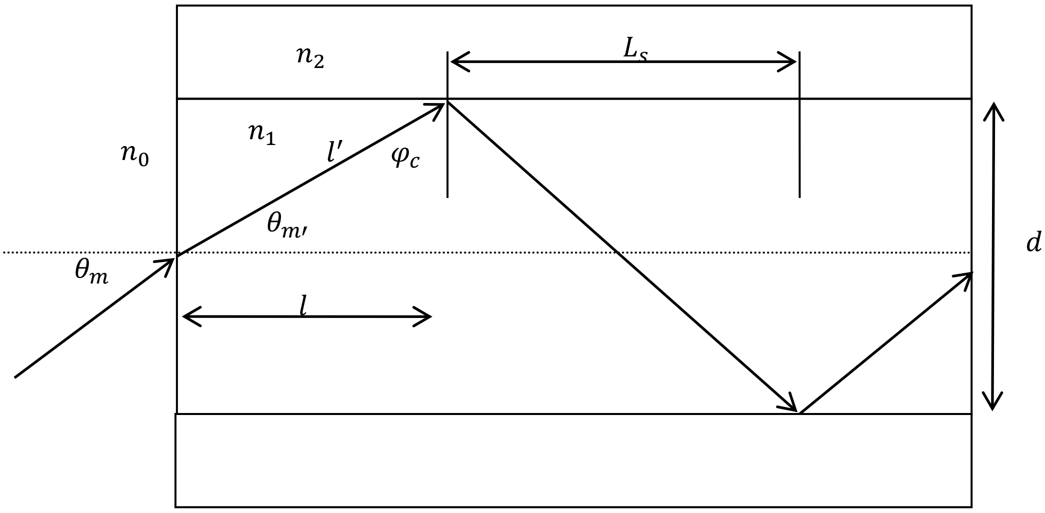
Optical fibers

Numerical Aperture



In the above diagram:
n_0: Refractive index of the surrounding
n_1: Refractive index of the core
n_2: Refractive index of the cladding
d : diameter of the core
φ_c : Critical angle at the core cladding interface
L_s: Skip distance (distance between successive reflections)

Note that there is a maximum value ofθ_i :θ_m, for which the internal ray will impinge at the critical angle φ_c. Rays incident on the face at angles greater than φ_c will strike the interior wall at angles less than φ_c will only be partially reflected and quickly leak out of the fibre

Total internal reflection

The quantity $n_0 \sin(\theta_m)$ is called the numerical aperture. Its square is a measure of the light gathering power of the system.

$$\varphi_c = sin^{-1}\frac{n_2}{n_1}$$

$$n_0 \sin(\theta_m) = n_1 \sin\theta_{m'}$$

$$n_0 \sin(\theta_m) = n_1 \cos\varphi_c = n_1\sqrt{\left(1-\left(\frac{n_2}{n_1}\right)^2\right)} = \sqrt{n_1^2 - n_2^2}$$

Step Index and Graded Index fibers

Step index

Core: Glass Refractive index between 1.5 -1.6 diameter ~10μm, Cladding fused quartz 1.425 or plastic refractive index 1.25 ,diameter ~120μm

Graded Index optical Fiber: Grin Fiber

Core is made with varying refractive index which is a function of radius. The refractive index is greatest at the center and reduces towards periphery but core refractive index remains always *greater* than cladding refractive index.

Modes of propagation

Different rays entering at different angles within the acceptance angle follow different modes of propagation. The situation becomes more complicated with different states of polarizations.

Dispersion

Inter-modal dispersion

There is a difference in time taken for different modes to travel the same distance.

Time taken by an axial ray to travel a distance l

$$t_1 = n_1 \frac{l}{c}$$

Time taken by an oblique ray to travel a distance l

$$t_2 = \frac{n_1 l}{c \cos\theta_{m'}} = \frac{n_1 l}{c \cos(90^\circ - \varphi_c)} = \frac{n_1 l}{c \sin(\varphi_c)} = \frac{n_1^2 l}{n_2 c}$$

(as $\sin(\varphi_c) = \frac{n_2}{n_1}$)

If the two rays are launched together they will be separated on arrival at the other end by dispersion time

$$\Delta T = \frac{n_1 l}{c}\left(\frac{n_1}{n_2} - 1\right)$$

Thus, the dispersion per unit length is given by

$$\frac{\Delta T}{l} = \frac{n_1}{n_2}\frac{\Delta n}{c}$$

In graded index fiber, rays making larger angle during entry to the fiber also travel longer distances but they do so in lower refractive index area and hence they travel with higher speeds of propagations. So there is a self focusing mechanism that leads to a smaller value of pulse dispersion.

Another definition (when practically observing the dispersion)

For an input pulse of width t_1 and output pulse of width $t_2$then the dispersion is defined as $\Delta t = \sqrt{t_2^2 - t_1^2}$

Intra-modal dispersion

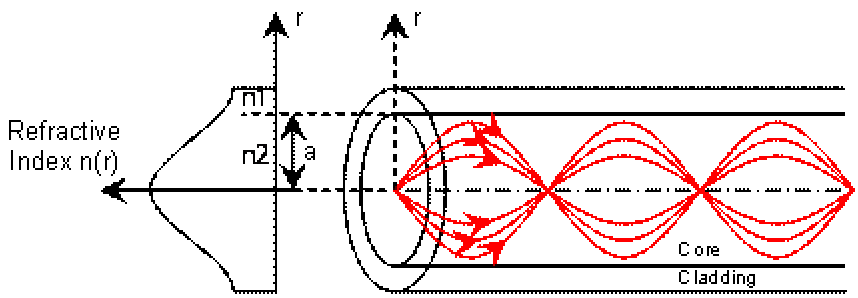
Light waves of different wavelengths travel at different speeds in a medium. The short wavelengths travel slower than long wavelengths. The spectral width of the source decides the extent of this type of dispersion.

Skip Distance: Distance between two successive reflections.

$$L_s = d \cot(\theta_{m'})$$

$$= d\sqrt{\left(\frac{n_1}{n_0 \sin\theta_m}\right)^2 - 1}$$

Graded index optical fiber



Tutorial Questions

Q. Calcualte the number of reflections in a 1m of fiber. Given $n_0 = 1$, $n_1 = 1.60$, $\theta = 30°$ and d= 50μm.

Sln: $L_s = 152\ \mu m$, Thus 1680 reflections.

Optical fiber communication

Microphone → Modulator → Carrier → Detector → Signal Processor → Message Output

Low-loss transmission, high-information carrying capacity, small size and weight, immunity to electro-magnetic interference, better signal security, and the abundant availability of the required raw materials have made ultrapure glass fibers become the premier communication medium.

Attenuation

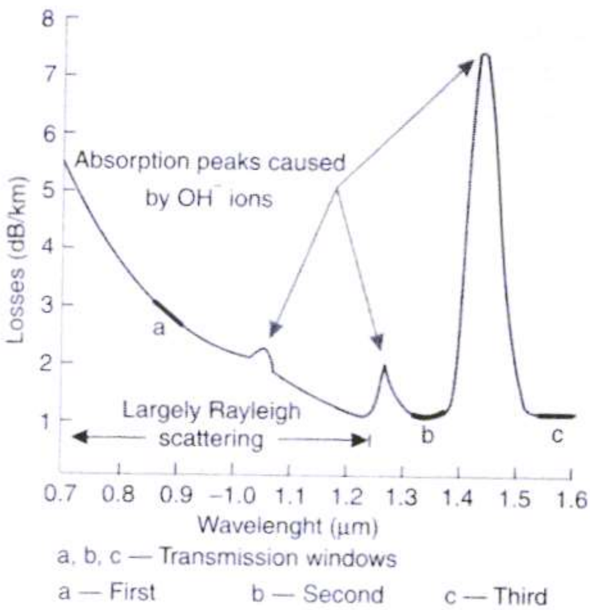
Ratio of the optical output power from a fiber of length L to the input power

$$\alpha = \frac{10}{L} log\left(\frac{P_i}{P_o}\right)$$

Unit db/km(decibel per kilometer)

1. The thermal energy of the material increases and part of the electromagnetic energy is lost. Strong absorption occurs at UV wavelengths. The absorption losses are found to be minimum at 1.3μm.
2. Scattering causes some of the optical energy leave the fiber.
3. Tight bending leads to changes in the angle for total internal reflection. Minute disturbances of the core size.
4. Imperfection in the fiber material. Impurities like OH^- ions, metal ions.
5. Connectors and splices.
6. Rayleigh scattering (local microscopic scattering of light). For glass fiber it sets a lower limit for the wavelength to 0.8μm below which the scattering loss is very high.

λ(nm)	Loss (db/km)
820-880	2.2
1200-1320	0.6
1550-1610	0.2



Fibre losses over the 0.7 to 1.6 μm spectrum.

Q. If an optical fiber has α= 5db/km, Determine the percentage of light reaching the other end after 1 km.

Sln. 32%

Applications

1. Endoscopes for image transmission.
2. Large bandwidth communication.
3. Temperature sensor.
4. Liquid level sensor.
5. Smoke or pollution level detector.
6. To evaporate plaque that is blocking the artery.
7. Fiber guided missiles.
8. Weight of the fiber wire is less for wiring.

Advantages

1. Low loss of intensity.
2. Large bandwidth.
3. High security
4. No fire risk, short circuit problem.
5. Immunity to EMI and RFI (Interference)
6. Low loss per unit length.