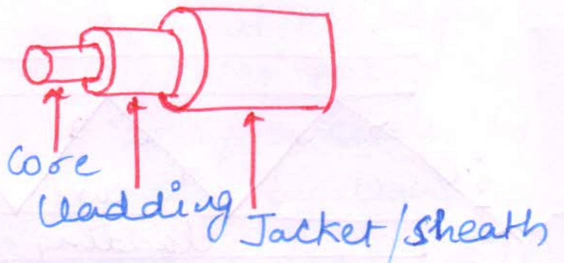
Optical Fibres: Optical fibres serve as cables to carry huge ammount of information in the form of optical signals from one place to another with negligible loss. It is hair thin flexible, transparent medium of cylindrical shape made up of glass through which light can be propagated. It has three principal sections -

1. Core
2. Cladding
3. Jacket or sheath

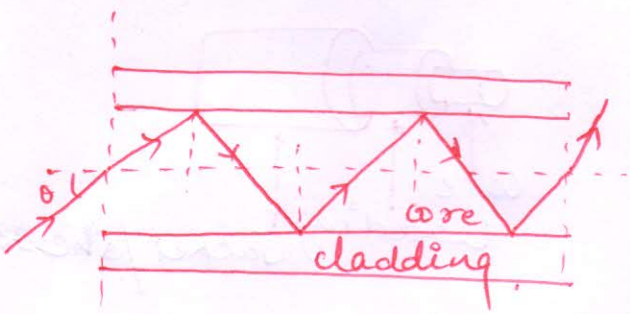


Core: It is the innermost region of the fibre which has specific property of conducting an optical beam. Core is usually made of glass or plastic. The core is actual working structure of the fibre, which is covered with another layer of glass or plastic having sligntly different chemical composition known as cladding.

Cladding: It is the region just above the core region of the fibre. Usually, it has less refractive index than the core region. i.e. $\mu_{cladding} < \mu_{core}$. The cladding has optical properties very different from those of the core. ~~The~~

Jacket/Sheath: The outermost section of optical fibre is known as Jacket or sheath. It is made up of plastic or special kind of polymer or other material. It protects the core from abrasion, interaction with environment, moisture, absorption, crushing and other activities of the terrestial atmosphere and thus enhances its tensile strength.

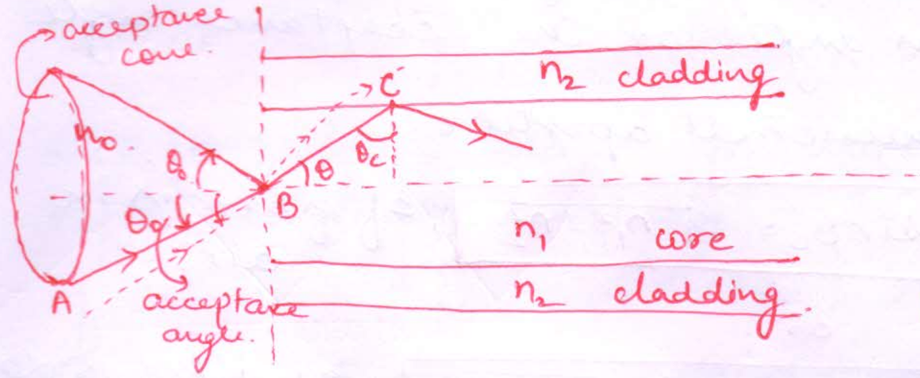
PRINCIPLE OF TRANSMISSION THROUGH OPTICAL FIBRE :



Optical fibre communication is based on the principle of total internal reflection. According to this principle when a light ray goes from denser to rarer medium then at the interface if the angle of incidence is greater than certain critical angle then the ray gets back into the denser medium. As the cladding has a lower refractive index than core, hence a light ray which is incident at the core cladding interface at an angle greater than critical angle, gets total internally reflected and the process continues till the end of fibre. Also, if it strikes core cladding interface at an angle lesser than the critical angle, then ~~it~~ it will travel into the cladding and if it strikes cladding and jacket interface at an angle greater than critical angle then it gets reflected back in cladding and it reenters core.

ACCEPTANCE ANGLE AND CONE:

Acceptance angle is the maximum angle which a light ray makes with the axis of core while entering into the core so that it can propagate along the fibre by the phenomenon of total internal reflection.



"If a light ray enters into the core at an angle greater than acceptance angle, (shown by dashed line in fig) it will not get total internally reflected."

Acceptance cone is the cone of light described at entry end of the fibre with semi angle less than or equal to the acceptance angle of the fibre.

Applying Snell's law for rays AB and BC we have,

$$n_0 \sin\theta_0 = n_1 \sin\theta$$

from fig, $\theta = \pi/2 - \theta_c$

$$n_0 \sin\theta_0 = n_1 \sin(\pi/2 - \theta_c)$$
$$= n_1 \cos\theta_c$$
$$= n_1 \sqrt{1-\sin^2\theta_c}$$
$$= n_1 \sqrt{1-\frac{n_2^2}{n_1^2}} \qquad \left\{\because \sin\theta_c = \frac{n_2}{n_1}\right\}.$$

$$n_0 \sin\theta_0 = \sqrt{n_1^2 - n_2^2} \qquad (1).$$

for external medium being air, $n_0 = 1$.

$\Rightarrow$ $\boxed{\sin\theta_0 = \sqrt{n_1^2 - n_2^2}}$; θ_0 is the acceptance angle.

NUMERICAL APERTURE: It is a number which defines the light acceptance or gathering capacity of an optical fibre. There is a maximum angle from the fibre axis at which light may enter the fibre so that it propagates in the core by several internal reflections. The sine of this maximum angle or the acceptance angle is called the numerical aperture.

$$\boxed{N.A. = \sin\theta_0 = \sqrt{n_1^2 - n_2^2}}$$; If fibre is in air.

or.

$$\boxed{N.A. = \sin\theta_0 = \frac{1}{n_0}\sqrt{n_1^2 - n_2^2}}$$; If fibre is placed in medium of R.I. n_0.

It may also be written in terms of Δ, which is the fractional refractive index and is given as,

$$\Delta = \frac{n_1 - n_2}{n_1}$$

$$= \frac{n_1 - n_2}{n_1} \times \frac{n_1 + n_2}{n_1 + n_2}$$

$$= \frac{n_1^2 - n_2^2}{n_1(n_1 + n_2)}$$

$$= \frac{n_1^2 - n_2^2}{2n_1 \times \frac{(n_1 + n_2)}{2}}$$

Approximating, $\frac{n_1 + n_2}{2} \approx n_1$

$$\Delta = \frac{n_1^2 - n_2^2}{2n_1^2}$$

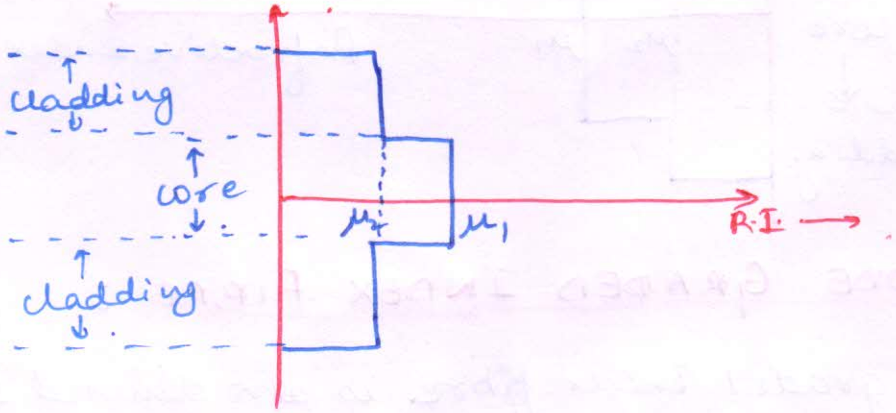
$$\Rightarrow \Delta = \frac{N.A.}{2n_1^2} \Rightarrow \boxed{N.A. = n_1\sqrt{2\Delta}}$$

TYPES OF OPTICAL FIBRE :

In practice, there are three commonly used types of fibre optic cable -

1. Single mode Step Index Fibre.
2. Multimode Step Index Fibre.
3. Multimode Graded Index Fibre.

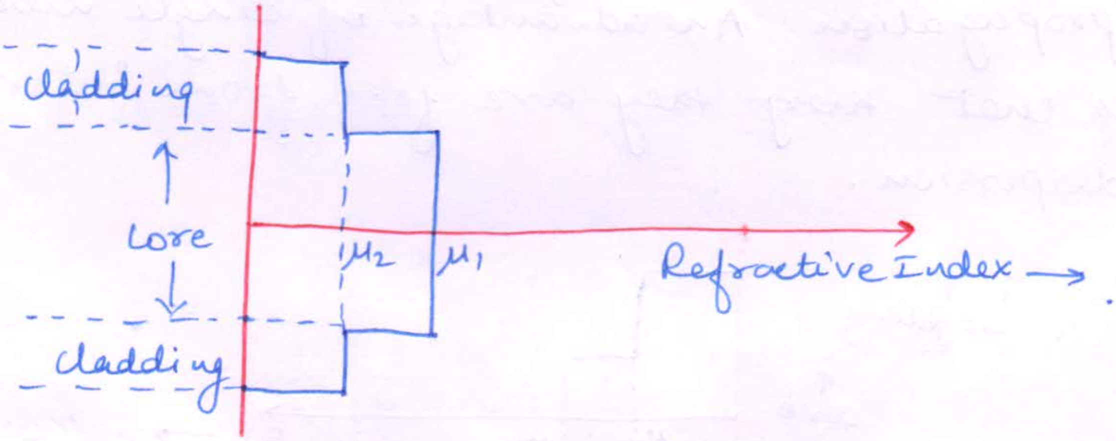
SINGLE MODE STEP INDEX FIBRE : A single mode step index fibre has a core material of uniform refractive index. Similarly, cladding also has a material of uniform refractive index but of lesser value. The typical size of core diameter of single mode fibres are 8-12 μm and thickness of cladding varies from 125 μm to 200 μm. Because, of its narrow core, it can guide just a single mode of propagation. An advantage of single mode fibres is that ~~they~~ they are free from intermodal dispersion.



Refractive Index Profile.

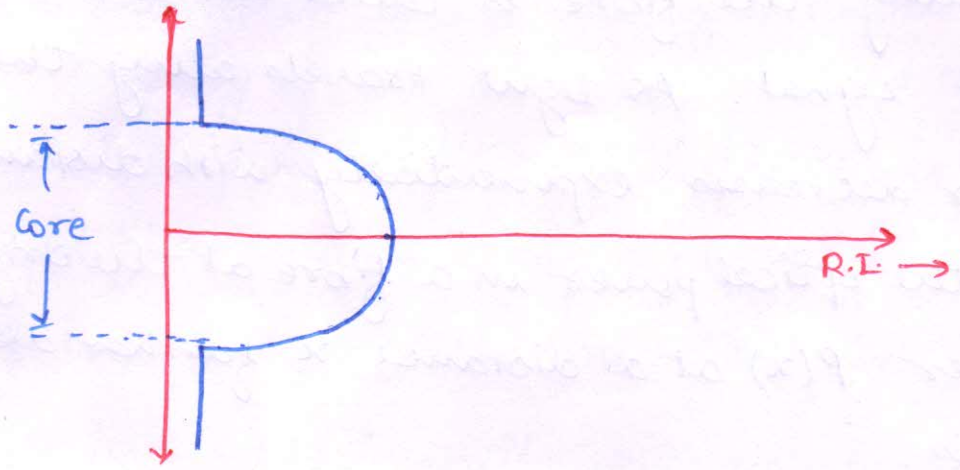
MULTIMODE STEP INDEX FIBRE :

A multimode fibre is that fibre which contains many hundreds of modes of propagation. Core size varies from 50μm to 200μm and thickness of cladding varies from 125μm to 400μm. By virtue of ~~which~~ its larger core diameter it is able to support propagation of large number of modes. Its refractive index profile is similar to that of a single mode fibre. The Multimode step index fibre can accept LED as source of light. Its typical application is in data links, which has lower bandwidth requirements.

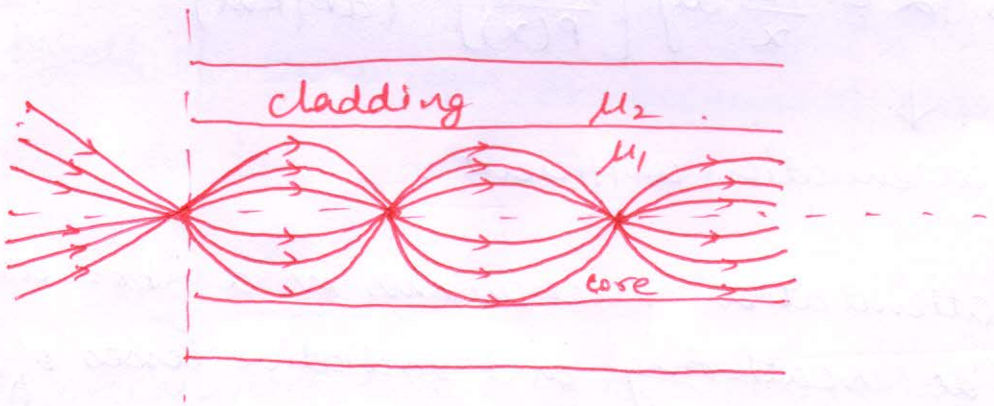


MULTIMODE GRADED INDEX FIBRE :

Multimode graded index fibre is also denoted as GRIN. Its geometry is same as that of multimode fibre, except that the refractive index of core decreases continuously with increasing radiad distance r from the axis of the core but is generally constant in cladding. Either a LASER or LED can be the source of GRIN fibre. It is the expensive one of all fibres.



Refractive Index profile



ATTENUATION : (Losses in Optical fibre)

Decrease in power level of optical signal as light travels along the fibre is called the attenuation of light signal. As light travels along the fibre, its power decreases exponentially with distance. If $P(0)$ is the optical power in a fibre at the origin, then the power $P(x)$ at a distance x further down the fibre is

$$P(x) = P(0)\, e^{-\alpha x}$$

$$\text{where, } \underbrace{\alpha}_{\text{attenuation coefficient}} = \frac{10}{x} \log \left[\frac{P(0)}{P(x)} \right] \quad (dB|Km).$$

The basis attenuation mechanisms in a fibre are absorption, ~~at~~ scattering and radiative losses of optical energy.

ABSORPTION : Absorption is caused by three different mechanisms :

a) Absorption by atomic defects in the glass composition.

b) Extrinsic absorption by impurity atoms is glass material.

c). Intrinsic absorption by the basic constituent atoms of the fibre material.

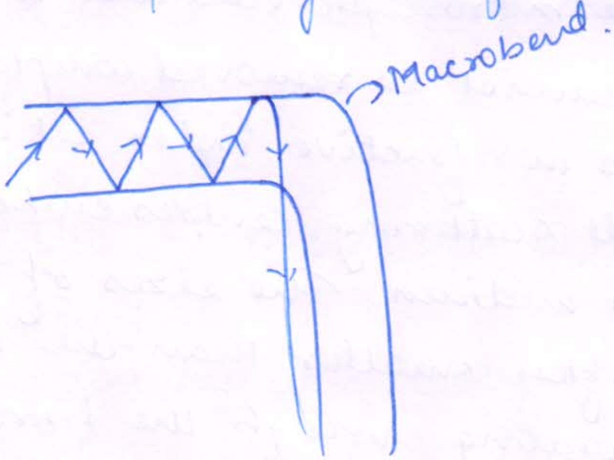
Absorption of light by glass and the impurities present are the major causes of loss, which is also known as material loss, in optical fibres. Even the purest glass absorbs radiation in certain wavelength ranges. This natural property of the substance is called the intrinsic absorption. Impurities are the major source of absorption in optical fibre. This is extrinsic absorption. Two important types of impurities are : the transition metal ions and hydroxyl ions (OH). Impurity absorption occurs either because of electronic transitions between the energy levels associated with the incompletely filled inner subshell of these ions or because of charge transitions from one ion to another.

SCATTERING LOSSES : During fibre manufacture, despite all precautions, localize microscopic variation in density and doping impurities cannot be removed completely due to which local variations in refractive index set in. These variations act as small scattering centres embedded in otherwise homogeneous medium. The sizes of the scatt-ering centres are often smaller than the wavelength. A beam of light propagating through the fibre suffers losses due to Rayleigh scattering. Since, for Rayleigh scattering $\propto \frac{1}{\lambda^4}$, Rayleigh scattering sets a lower limit on wavelengths that can be transmitted through a glass fibre to nearly 0.8 µm. Below this wavelength, scattering loss is appreciably high.

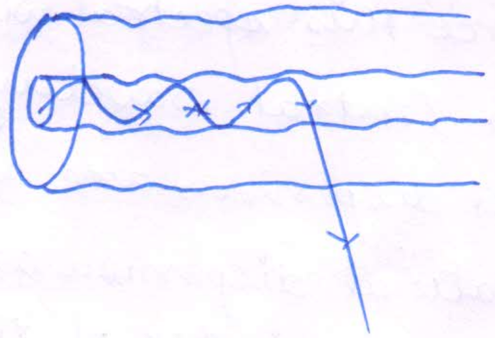
LOSSES DUE TO BENDING: Bending losses occur whenever an optical fibre undergoes a bend of finite radius of curvature. There are mainly two types of bends –

1) Macrobending
2) Microbending.

MACROBENDING LOSSES: Excessive bending of cable or fibre may result in loss known as macrobend losses. The fibre is sharply bent so that the light travelling down the fibre cant make the turn and is lost inside the cladding. The loss may occur when wrapping the fibre on a spool or pulling the fibre around a corner.



MICROBENDING LOSSES : Microbends are repetitive small scale fluctuations in the radius of curvature of the fibre axis as illustrated in fig. They are caused either by nonuniformity in the manufacturing of the fibre or by non uniform lateral pressures created during the cabling of the fibre. One method of minimizing microbending losses is by extruding a compressible jacket over the fibre.



DISPERSION

Whenever optical energy or signal travels along a fibre in the form of pulses, there exists various causes which results into the broadening or spreading of these pulses as they travel along the fibre. Thus the spreading or broadening of light pulses as they travel along the fibre is called dispersion. These dispersive effects determine the limit of the information capacity of the fibre.

TYPES OF DISPERSION: There are two types of pulse dispersion –

a). Intramodal Dispersion.

b). Intermodal dispersion.

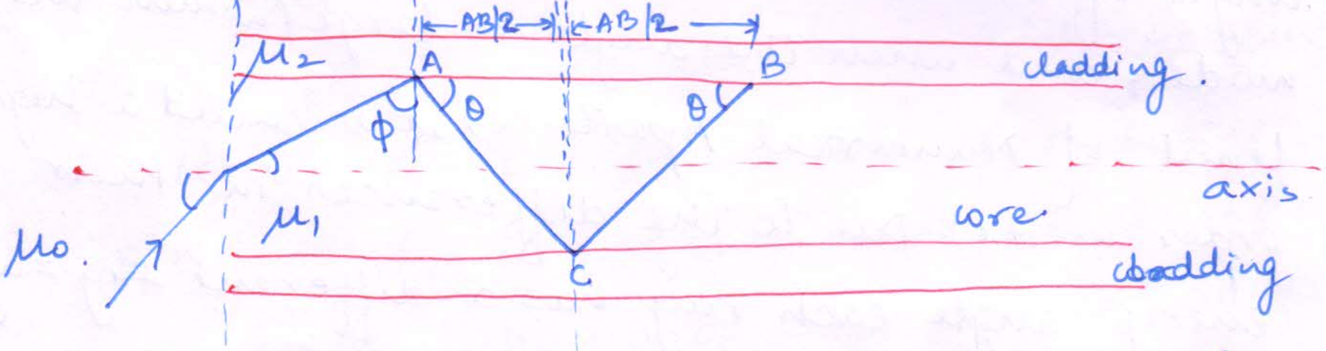
INTRAMODAL DISPERSION: Intramodal dispersion is also called chromatic dispersion and it occurs within a single mode. The spreading of light pulse arises from the finite spectral emission width of an optical source. This spectral width is the range of wavelengths over which the source emits light. For LED source this spectral width is approximately 5% of a central wavelength. ~~For~~ Two main intramodal dispersions are as follows-

i) **Material Dispersion:** Material dispersion arises from the variation of refractive index of the core material as a function of wavelength. Pulse sp-reading occurs even when different wavelengths follow the same path because the material of core offers different speeds to different wavelengths and hence a delay occurs at the reciever end.

ii) **Waveguide Dispersion:** This type of dispersion occurs because a single mode fibre confines only about 80% of the optical power to the core. Disper-sion thus arises, since the 20 percent of the light propagating in the cladding travels faster than the light confined to core.

INTERMODAL DISPERSION: Pulse broadening due to intermodal dispersion is caused by differences in path lengths of different rays of light in a fibre. When a pulse is launched into the fibre core, it is in effect of a collection of thousands of rays of light each being within the limit of shallow angle required for total internal reflection. Each ray is called a mode. When angle of incidence is shallow, it is called a lower mode, and when the angle is large (within the limit of Numerical Aperture) it is called a higher order mode. Due to the differences in their entry angle each ray has a different zigzag pattern. Over a distance, rays that enter a fibre core, simultaneously are unable to travel in unison, because each one is travelling a different path length. The receiving pulse is the summation of pulses each delayed by a different time. This causes the pulse to spread out. Pulse width depends on the transmission times of the fastest and slowest mode.

PULSE WIDTH :- Pulse width at output is the difference between transmission times of the slowest and fastest mode. Fastest mode is the mode having shortest delay i.e. the axial ray. Slowest mode is the mode having the maximum delay and it is the higher mode for which the angle of incidence is just slightly higher than critical angle.



For a ray making an angle θ with the axis the distance AB will be travelled in time,

$$t = \frac{(AC + CB)}{c/\mu_1} \quad \text{------} \quad (1)$$

(AC+CB) is the path followed by ray and c is the speed of light,

From the fig.,

$$\cos\theta = \frac{AB/2}{AC}.$$

$$\Rightarrow AC = \frac{AB}{2\cos\theta}.$$

Similarly, $CB = \dfrac{AB}{2\cos\theta}.$

$$\Rightarrow \boxed{t = \frac{AB \times \mu_1}{c \cos\theta}}$$

Therefore the time in travelling a distance L will be,

$$\boxed{t = \frac{\mu_1 L}{c \cos\theta}}$$

Now, at $\phi = 90°$ i.e. at an angle of 90° at the core cladding interface,

$$t_1 = \frac{\mu_1 L}{c} \quad \text{[time taken by lower mode]}$$

further, time taken by higher order mode,

$$t_2 = \frac{\mu_1 L}{c \cos\theta} = \frac{\mu_1 L}{c \cos(90° - \phi)} = \frac{\mu_1 L}{c \sin\phi}$$

But, by Snell's law,

$$\frac{\sin\phi}{\sin 90°} = \frac{\mu_2}{\mu_1}$$

Hence,

$$t_2 = \frac{\mu_1 L}{c \cdot \mu_2/\mu_1}$$

$$= \frac{\mu_1^2 L}{\mu_2 c}$$

Therefore pulse width,

$$\Delta T = t_2 - t_1$$

$$= \frac{\mu_1 L}{c}\left[\frac{\mu_1 - \mu_2}{\mu_1}\right]$$

$$\boxed{\Delta T = \frac{\mu_1 L}{c} \times \Delta}$$