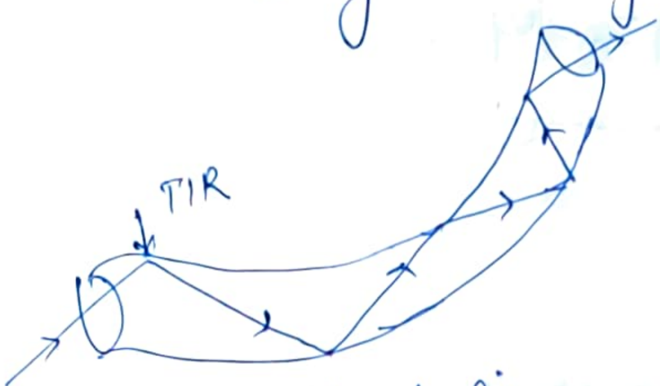
Module No 2: Fibre optics:

* Fibre Optics is a branch of physics that deals with a technology in which signals are converted from electrical signal to optical signal, transmitted through thin glass fibre and reconverted into electrical signal.

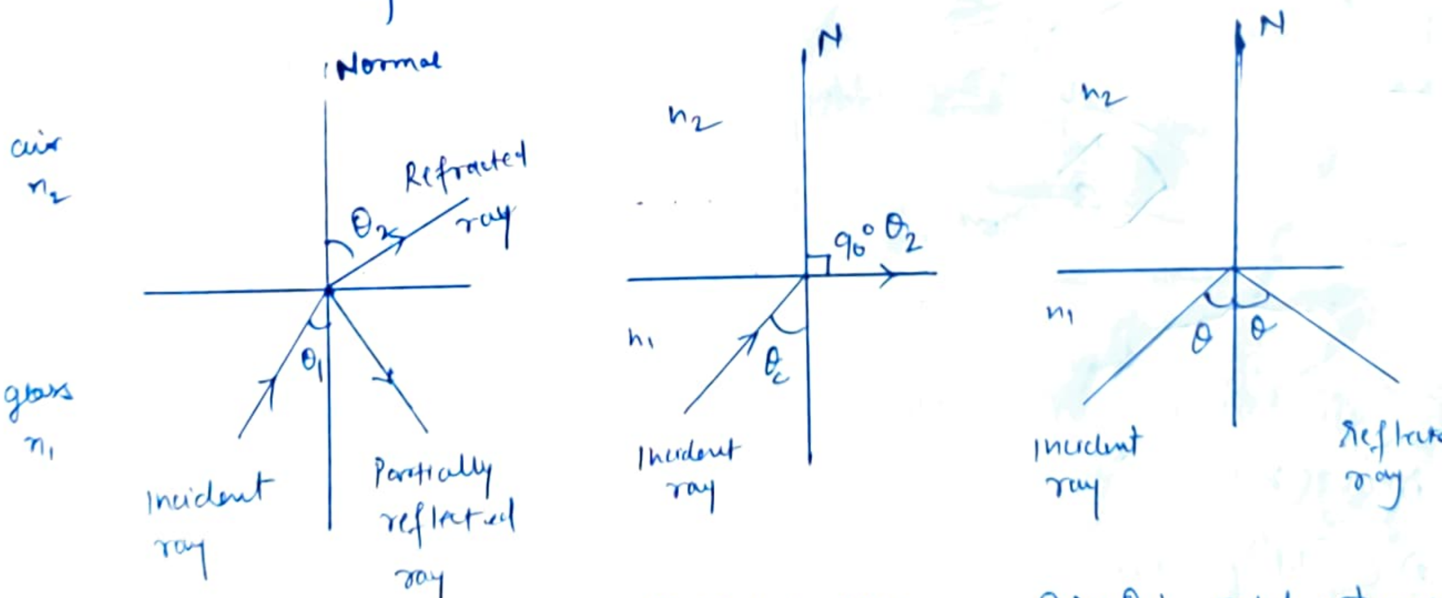
* Optical fibre:

An optical fibre is a cylindrical ~~glass~~ wave guide made of transparent dielectric (glass / plastic), which guides light waves along its length by total internal reflection



optical fibre

* Total internal reflection



$\theta_1 < \theta_c$: refracts into rarer medium

$\theta_1 = \theta_c$: grazes the interface

$\theta_1 > \theta_c$: Total internal reflection.

Using Snell's Law we can write

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

when $\theta_1 = \theta_c$ $\theta_2 = 90^\circ$, $\therefore$ $n_1 \sin\theta_c = n_2 \sin 90^\circ$

$$\therefore \sin\theta_c = \left(\frac{n_2}{n_1}\right)$$

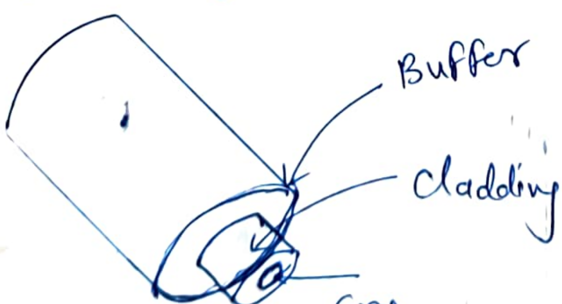
when the rarer medium is air $n_2 = 1$ and $n_1 = n$

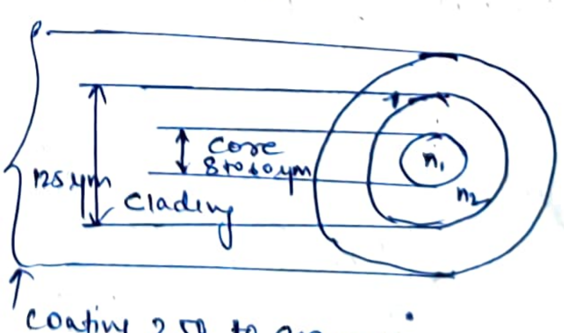
$$\boxed{\theta_c = \sin^{-1}\left(\frac{1}{n}\right)}$$

$n = \mu$
Refractive Index of the medium

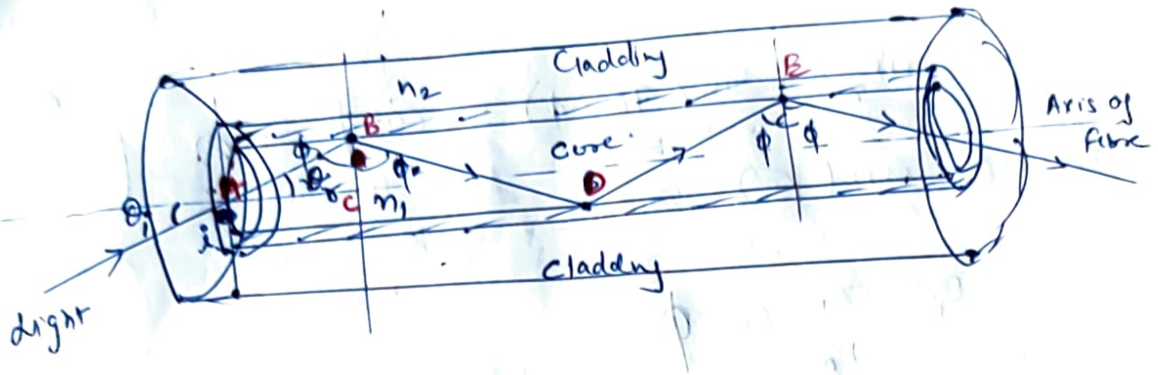
θ_c = Critical angle

*Light propogation through optical fibre





Cylindrical in shape and has 3 co-axial regions
1) Core: The innermost cylindrical region use for guiding light
2) Cladding: The middle co-axial region having refractive index lower than core.
3) The outermost region is called sheath or protective buffer coating



Acceptance angle:

Let the refractive index of core be n_1 and cladding be n_2, n_0 be the refractive index from which the light is launched.

3) Assume θ_i = angle at which light enters the fibre w.r.t axis

θ_r = angle of refraction into the core w.r.t fibre axis

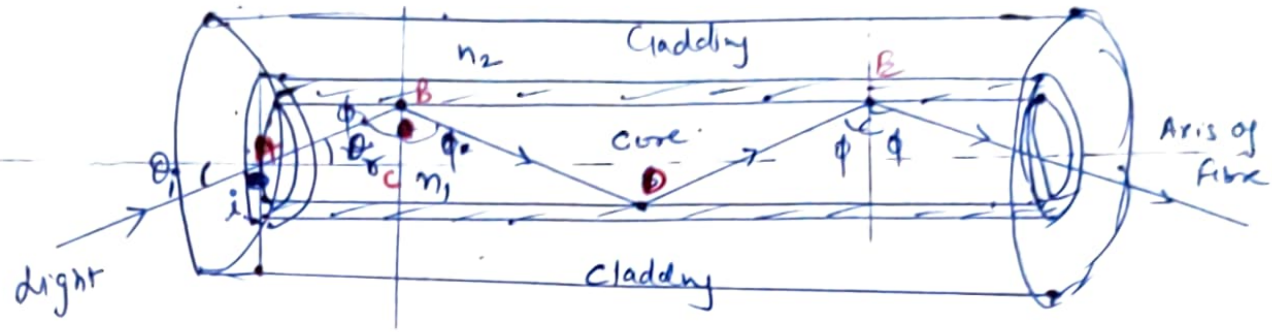
ϕ = the angle at which ~~refracted~~ refracted ray strikes the core-cladding interface

4) ~~~~ If ϕ is greater than critical angle ϕ_c the incident ray undergoes Total internal reflection, since $n_1 > n_2$. As long as $\phi > \phi_c$ the light will stay within the fibre

5) Using Snells law to the launching face of fibre, we get

$$n_0 \sin\theta_i = n_1 \sin\theta_r \quad \text{--- (1)}$$

$$\Rightarrow \sin\theta_i = \frac{n_1}{n_0} \sin\theta_r$$



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From Δ^{le} ABC

$$\sin\theta_r = \sin(90-\phi) = \cos\phi \quad -②$$

$\{ \theta_r + \phi + 90 = \ldots$

$\theta_r = 90 - \phi$

from ① and ②

$$\sin\theta_i = \frac{n_1}{n_0} \cos\phi$$

when $\phi = \phi_c$ then $\sin(\theta_i)_{max} = \frac{n_1}{n_0} \cos\phi_c \quad - ③$

for TIR formulae $\sin\phi_c = \frac{n_2}{n_1}$

$$\cos\phi_c = \frac{\sqrt{n_1^2 - n_2^2}}{n_1} \quad — ④$$

from ③ and ④

$$\sin(\theta_i)_{max} = \frac{n_1}{n_0}\left(\frac{\sqrt{n_1^2 - n_2^2}}{n_1}\right) = \frac{\sqrt{n_1^2 - n_2^2}}{n_0}$$

most of the time the incident ray is launched from air therefore $n_0 = 1$ and $\theta_i(max) = \theta_0$

$$\therefore \sin\theta_0 = \sqrt{n_1^2 - n_2^2}$$

$$\boxed{\theta_0 = \sin^{-1}\sqrt{n_1^2 - n_2^2}}$$

Acceptance angle of the fibre

Acceptance angle is the maximum angle that a light ray can have relative to the axis of fibre and propogate down the fibre.

Fractional Refractive Index Change

The fractional difference between the refractive indices of the core and cladding is known as fractional refractive index change.

i.e. $$\boxed{\Delta = \frac{n_1 - n_2}{n_1}}$$

Δ is always positive as $n_1 > n_2$ for TIR.

For guiding the light rays effectively $\Delta \ll 1$

$\Delta \approx 0.01$.

* Numerical Aperture:

The numerical Aperture (NA) is defined as the sine of the acceptance angle.

i.e. $NA = \sin\theta_0 = \sqrt{n_1^2 - n_2^2}$

n_1 : RI of core
n_2 : RI of cladding

$$\therefore \boxed{NA = \sqrt{n_1^2 - n_2^2}}$$

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

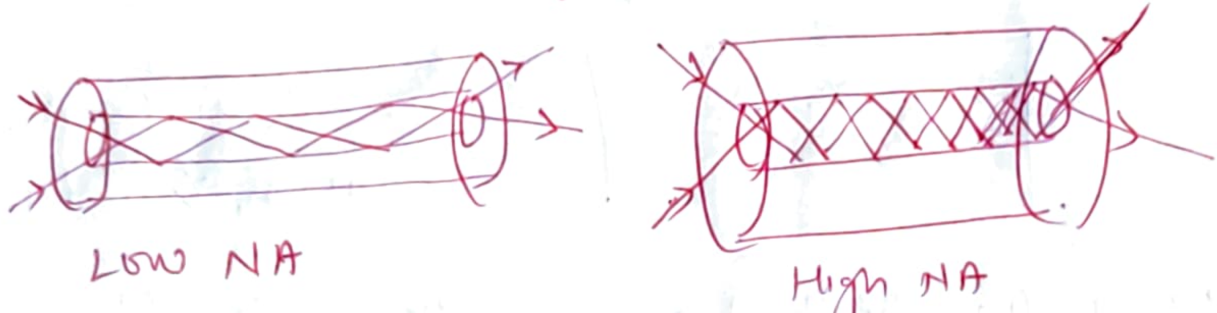
$\frac{n_1 - n_2}{n_1} = \Delta$ and Approximate $\frac{n_1 + n_2}{2} \approx n_1$

$$\therefore NA = \sqrt{n_1 \Delta 2n_1} = n_1\sqrt{2\Delta}$$

$$\therefore \boxed{NA = \sqrt{n_1^2 - n_2^2} = n_1\sqrt{\Delta}}$$

Physical meaning of NA:

1) It is a measure of the amount of light that can be accepted by a fibre



2) NA depends on n_1 and n_2 ie R.I. of core and cladding and does not depend on the physical dimension of the fibre

3) A large NA means the fibre will accept large amount of light from source.

4) Values of NA $0.13 < NA < 0.5$

Fibre optics:

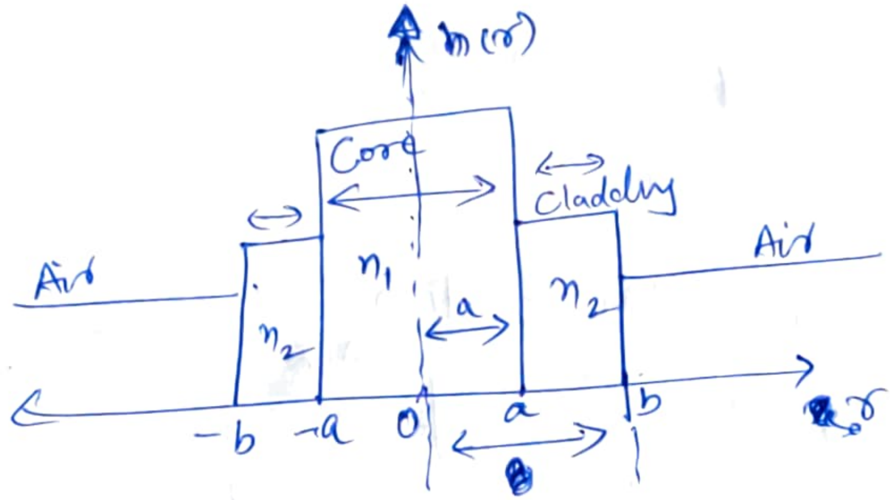
Course objective: To explain the basic principle of optical fibre and its use in Communication Technology.

Course outcome: To apply the foundation of fibre optics in the development of modern Communication Technology.

The fibres used for communications are classified into 2 types

1) Step Index optical fibre:

The core and cladding has a uniform refractive index



$n(r) = n_1 \quad \forall \; 0 < r < a$ for Core

$= n_2 \quad r > a$

Core diameter: 50 - 200 μm

Cladding diameter: 100 - 200 μm

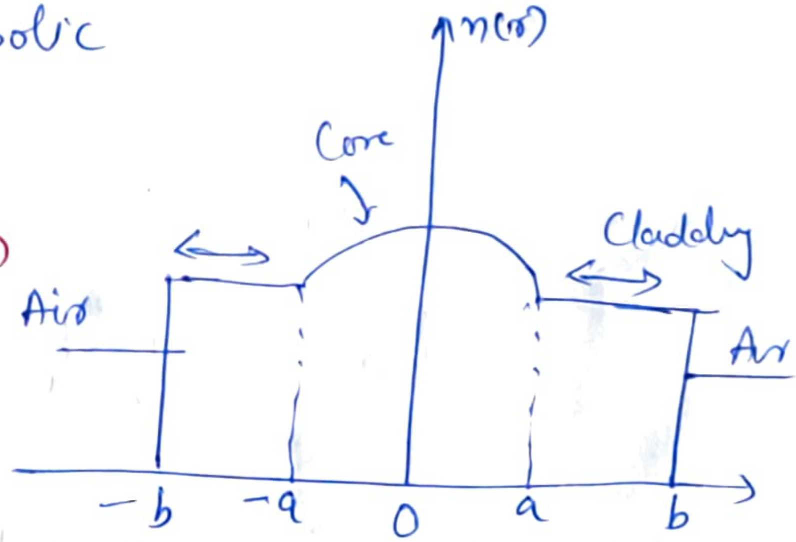
$\boxed{\text{Pulse dispersion} = 50\,ns/Km}$

Used in data links which have lower bandwidth requirements

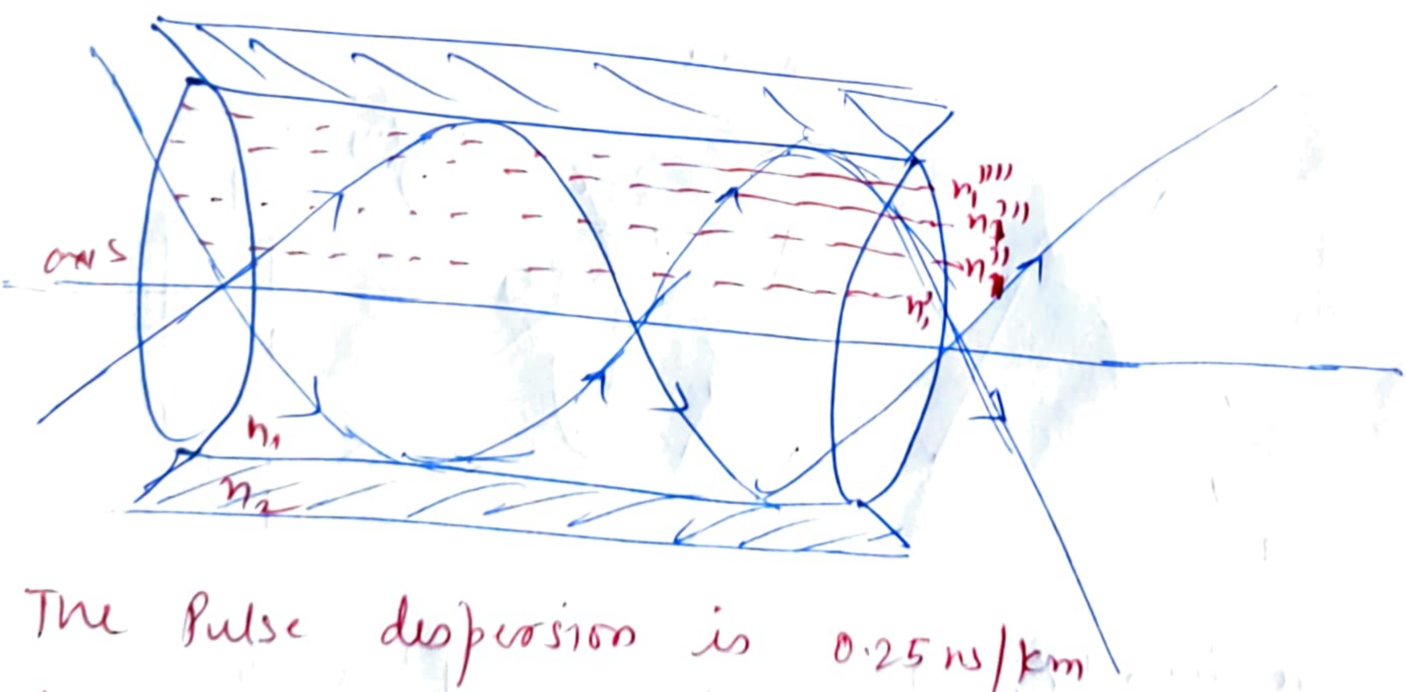
2) Graded Index: (Parabolic Index fibre)

The core has non-uniform refractive index. It decreases as we move away from the fibre axis and move towards core-cladding interface. The cladding has uniform refractive index.

The variation is parabolic i.e.



Because of the variation the capacity of carrying information increases.

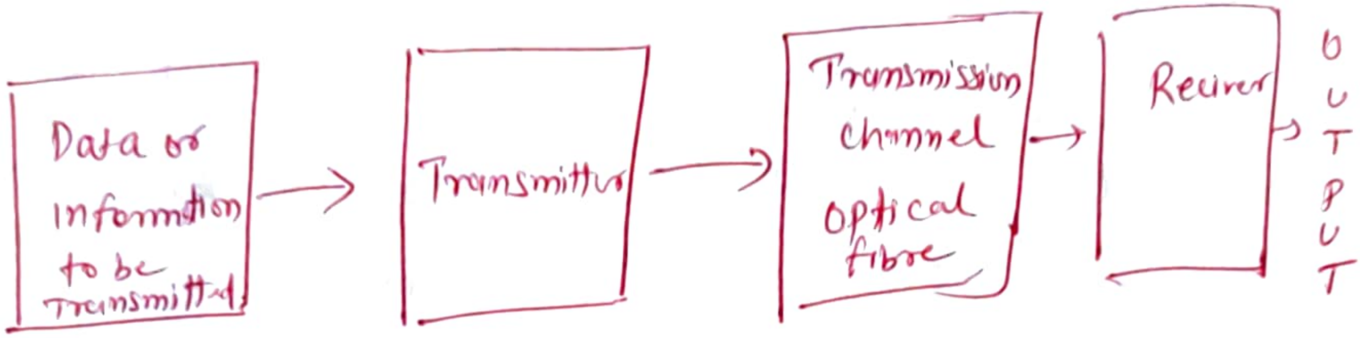


The Pulse dispersion is 0.25 ns/km

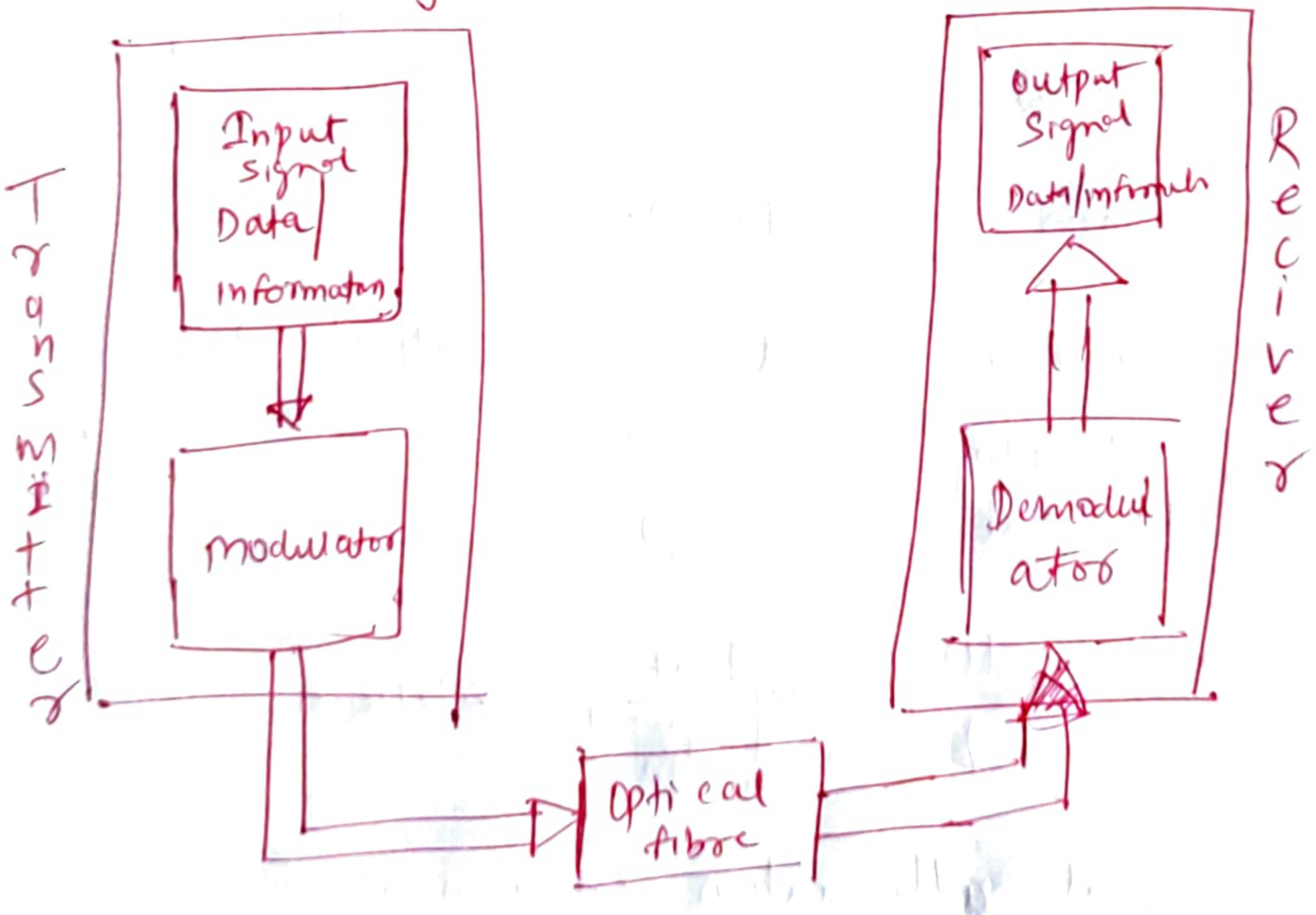
Higher capacity than step Index fibre

mostly used in communication

Fibre optics Communication :



Typical Communication System



Point to point Communication link using optical fibre.

* Losses in fibre :

1) ~~Attenuation~~

When a light propagates through an optical fibre a small percentage of a light is ~~lost~~ lost through different mechanisms.

* The loss of optical power is measured in terms of decibels/km for attenuation loss.

Attenuation Coefficient (α):

The ratio of optical power output (P_{out}) from a fibre of length 'L' to the power in to the fibre (P_{in})

$$\alpha = -\frac{10}{L} \log_{10}\left(\frac{P_{out}}{P_{in}}\right) \quad dB/km$$

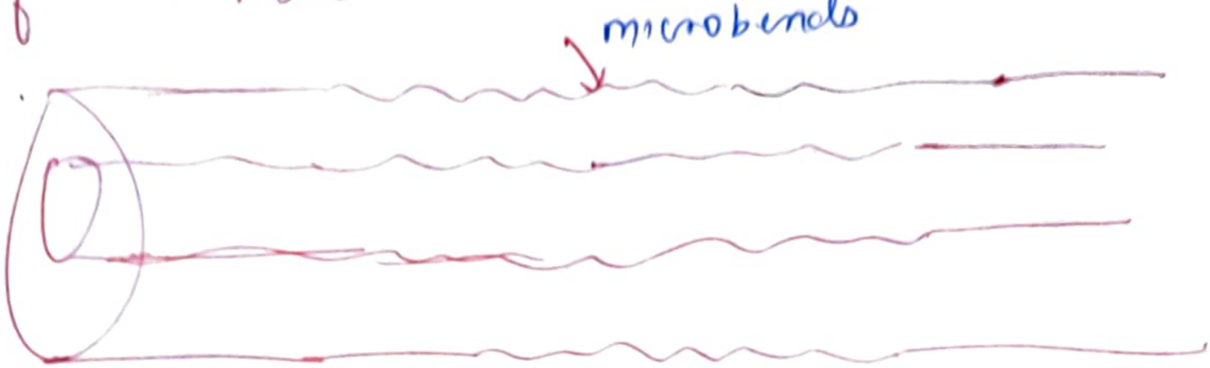
The signal attenuation in optical fibre is due to following mechanism

1) Intrinsic loss in fibre material
2) Scattering due to micro-irregularities inside the fibre

~~material~~

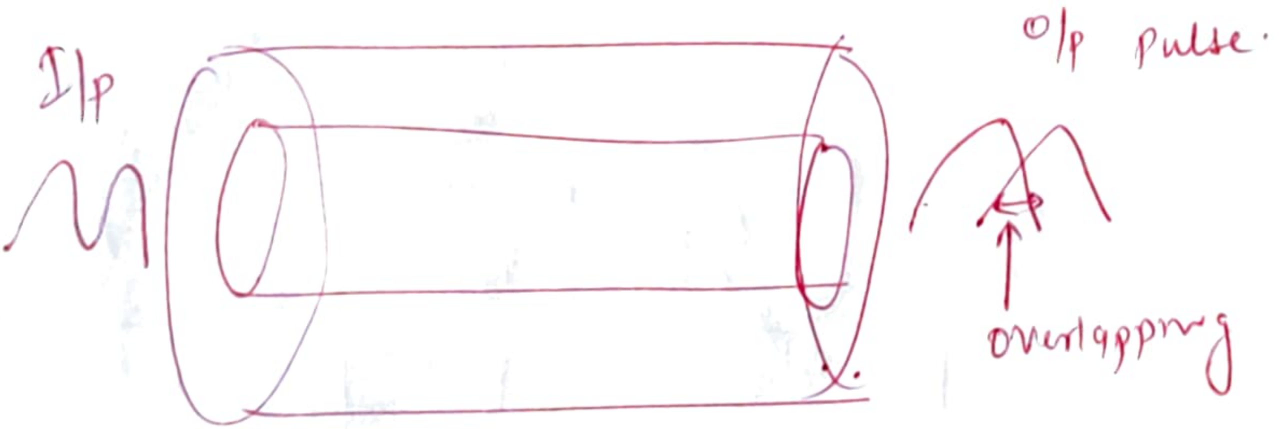
Due to manufacturing

3) Micro bending loss due to micro deformation of the fibre



4) Bending / radiation losses

5) Dispersion of signal in fibre.



H.W Factors affecting attenuation losses

1) Numericals on 1) Critical angle
2) Numerical Aperture
3) Acceptance Angle
4) Attenuation Coefficient