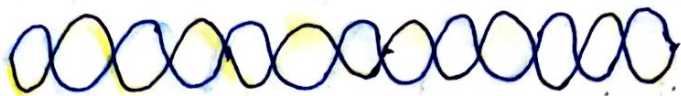


Coherence & Optical Fibers

Coherence :-



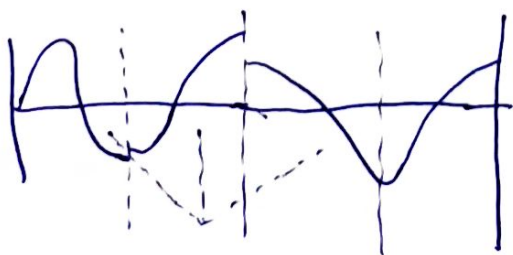
When two or more light waves reach to a point in space with phase difference is about to zero & minimum path difference from source & having same wavelength, frequency & amplitude then these light wave will be coherent to each other & this nature of light waves is known as Coherence.

Types of Coherence

- Temporal
- Spatial

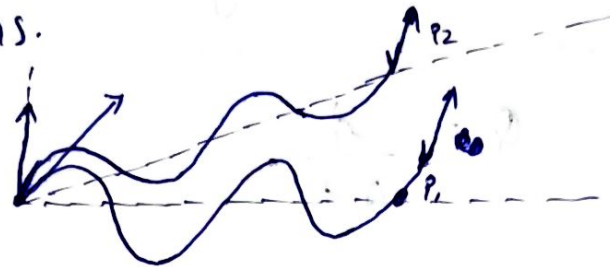
1. Temporal Coherence :-

It is a measure of the correlation b/w the phase of the light wave at different points b/w the direction of propagation. It is the correlation b/w the waves at one place at different times along the path of a beam called 'temporal coherence'.



2. Spatial Coherence:-

It refers to the consistency of the phase b/w waves at different points in space, often observed in interference & diffraction patterns.



Coherence Length and Coherence Time $\Rightarrow$

The average ~~time~~ length of the wavetrains for which the field remains sinusoidal is called 'Coherence Length'.

It is denoted by l_c .

$$l_c = c \times \tau_c$$

where c = speed of light
 τ_c = Coherence time

And the average time interval during which the field remains sinusoidal and the phase of the wavetrain can be predicted reliably. It is denoted by τ_c .

$$\tau_c = \frac{l_c}{c}$$

where l_c = Coherence length
 c = speed of light

Q - Factor for a Spectral line :-

The monochromaticity of a source may be expressed in terms of Q-factor, defined as the ratio of central wavelength to bandwidth of source

$$Q = \frac{\lambda}{\Delta \lambda}$$

for an ideal monochromatic source, since $\Delta \lambda = 0$ so Q-factor for light becomes infinite.

→ A sinusoidal plane wave extends to infinity in space & time. It is perfectly coherent in space & time and its coherence length, coherence time & coherence areas are all infinite.

$$l_c = c \tau_c \quad \text{--- (1)}$$

By Fourier analysis $\Delta \nu = \frac{1}{\tau_c}$

$$l_c = \frac{c}{\Delta \nu} \quad \text{--- (2)}$$

Using relation $\nu = \frac{c}{\lambda} \quad \text{--- (3)}$

Differentiating eqn (3), we have

$$|\Delta \nu| = \left| \frac{-c}{\lambda^2} \right| \Delta \lambda$$

where
 $\Delta \nu$ = bandwidth
 $\Delta \lambda$ = line width

$$\Delta \nu = \frac{c}{\lambda^2} \Delta \lambda$$

$$l_c = \frac{c}{\Delta \nu} = \frac{\lambda^2}{\Delta \lambda} \quad \text{--- (4)}$$

$$l_c = \frac{\lambda^2}{\Delta\lambda} = \left(\frac{\lambda}{\Delta\lambda} \right) \lambda$$

$$Q = \frac{1}{\Delta\lambda}$$

$$\star \quad l_c = \lambda Q$$

Now,

$$\tau_c = \frac{l_c}{c}$$

Now from eqⁿ - (4)

$$\tau_c = \frac{\lambda^2}{c \cdot \Delta\lambda} = \frac{\lambda}{c} \left(\frac{\lambda}{\Delta\lambda} \right)$$

$$\star \quad \tau_c = \left(\frac{\lambda}{c} \right) Q$$

★ Visibility as a Measure of Coherence :-

The visibility of coherent sources can be defined as the ratio of difference b/w maximum intensity & minimum intensity to sum of these intensities i.e.

$$V = \frac{I_{\max} - I_{\min}}{I_{\max} + I_{\min}}$$

→ Let us consider two interfering waves, each of intensity I_0 . Both the waves consists of coherent part I_c & incoherent part I_{inc} if C is degree of coherence, then

$$I_c = C I_0 \text{ --- (1) , } I_{inc} = (1 - C) I_0 \text{ --- (2)}$$

→ When these waves superimposed, the coherent part will interfere by adding their amplitudes whereas for incoherent parts intensities are simply added.

$$a_c + a_c = 2a_c \quad \& \quad (2a_c)^2 = 4a_c^2 = 4I_c \quad \text{Ref}$$

$$a_c^2 + a_c^2$$

$$I_{\max} = 4I_c + 2I_{\text{inc}} \quad \text{--- (3) (constructive interference)}$$

Hence the resultant intensity for constructive interference is sum of $4I_c$ & $2I_{\text{inc}}$.

$$\text{Thus, we get } I_{\max} = 4CI_0 + 2(1-c)I_0 \quad \text{--- (4)}$$

For destructive interference

$$I_{\min} = 0 + 2I_{\text{inc}} \quad \text{--- (5)}$$

$$\text{as } a_c + (-a_c) = 0 \quad (\text{coherent part})$$

$$I_{\text{inc}} + I_{\text{inc}} = 2I_{\text{inc}} \quad (\text{incoherent part})$$

$$I_{\min} = 0 + 2(1-c)I_0 \quad \text{--- (6)}$$

Now fringe visibility

$$V = \frac{I_{\max} - I_{\min}}{I_{\max} + I_{\min}}$$

$$V = \frac{4I_c + 2I_{\text{inc}} - 2I_{\text{inc}}}{4I_c + 2I_{\text{inc}} + 2I_{\text{inc}}}$$

$$V = \frac{4I_c}{4I_c + 4I_{\text{inc}}} = \frac{CI_0}{C(I_0 + (1-c)I_0)}$$

$$V = \frac{CI_0}{CI_0 + I_0 - CI_0} = \frac{C I_0}{I_0}$$

$$\boxed{V = C}$$

Therefore, fringe visibility i.e. the degree of contrast is measure of degree of coherence b/w waves of equal intensities.

Optical Fiber

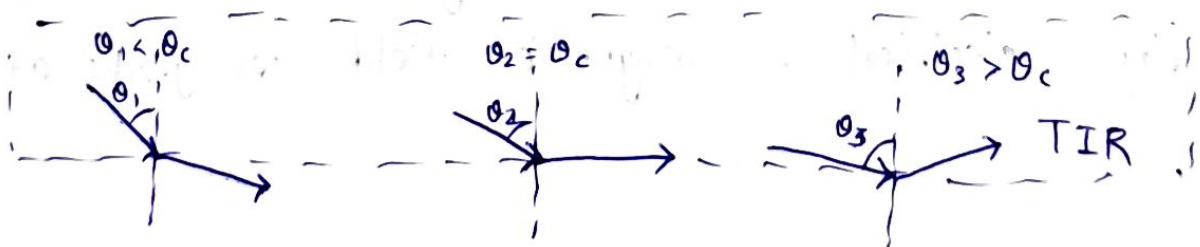
Optical Fiber is a technology that uses glass, plastic, threads or fibers to transmit data. A fiber optic cable consists of a bundle of glass threads which are protected by the outer covering of several jackets.

Optical fiber uses light to carry digital signals & is based on the concept of total internal reflection.

Total Internal Reflection :-



When the light travels from denser medium to rarer medium the reflected ray bends away from normal. When the angle of incidence is greater than critical angle, the reflected ray reflects into same medium. This phenomenon of reflection of light ray from a refractive surface is called as TOTAL INTERNAL REFLECTION.



→ from denser to rarer medium

→ $\theta > \theta_c$

Construction of Optical Fiber:-

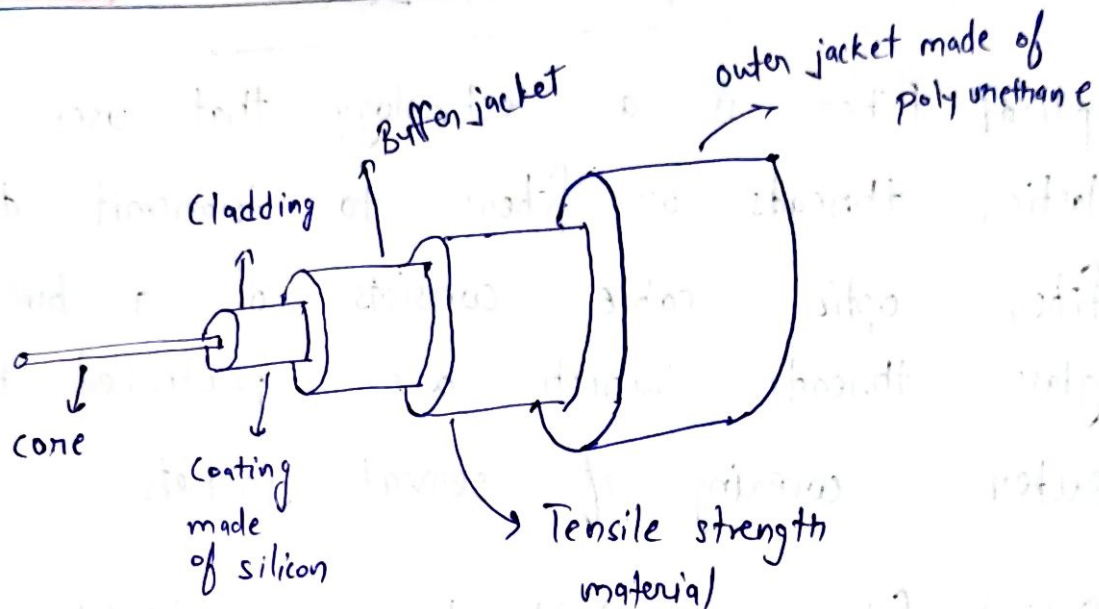


fig:- Optical Fiber

→ It consists of essentially three regions:-

1. Core:- Core is the innermost part of optical fiber basically made of glass or plastic & of diameter of $80\mu\text{m} - 100\mu\text{m}$. Signal transmission is performed in core.



2. Cladding:- It is coaxial cylindrical tube of diameter of $125\mu\text{m} - 150\mu\text{m}$ made of material having lower refractive index than core.

3. JACKET:- The outer cylindrical coaxial tube made of plastic or polymer provided for protection from environmental changes such as temperature, humidity, electrical & magnetic field or jerks etc.

Working:-

When a light ray is incident at one end of the core of the fiber, because of the small radius of fiber light ray going into the core makes an angle greater than the critical ~~ang~~ angle & TIR take place. & light will be reflected back into the core. And so light ray repeated multiple reflections & propagates along the fiber from one end to other end.

In silica glass fibers more than 95% of light is transmitted over a distance of 1 km.

To transmission of signal through optical fiber

- (1) The core material should have higher refractive index (μ_{core}) than of cladding material (μ_{clad}).
- (2) The angle of incidence should be greater than the critical angle.

Classification of Optical Fiber:-

→ Based on Refractive index of core medium

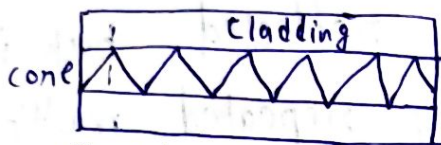
1. Step index Optical fiber
2. Graded index Optical fiber

→ Based on Mode of Transmission

- (i) Mono mode Optical fiber
- (ii) Multimode Optical fiber

1.) Step Index Optical Fiber:-

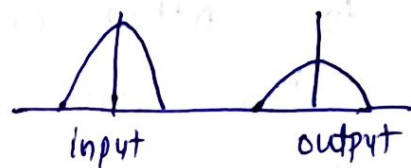
In this, the refractive index of core medium is uniform & undergoes an abrupt change at the interface of core cladding.



Step index Mono Mode Optical fiber

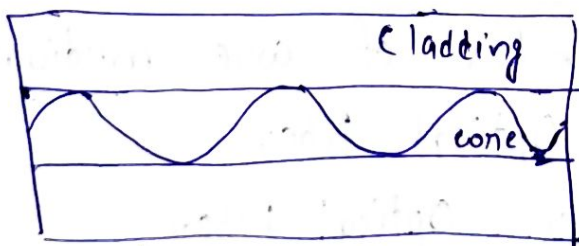


Step Index Multi mode Optical fiber

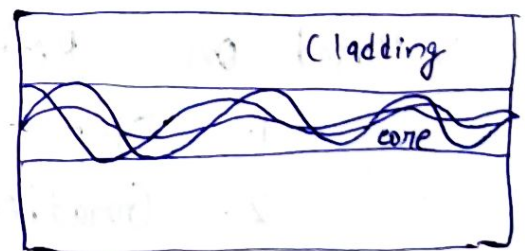


2.) Graded Index Optical Fiber:-

The graded index optical fiber has refractive index of core decreases in a parabolic manner from a maximum value at the center of the core to a constant value of core-cladding interface.

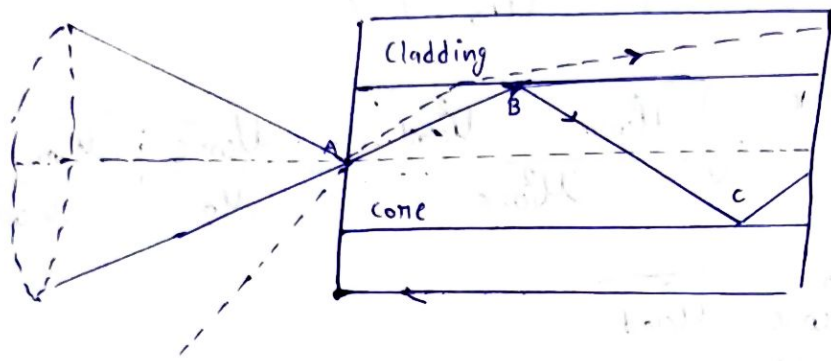


Graded index mono mode optical fiber

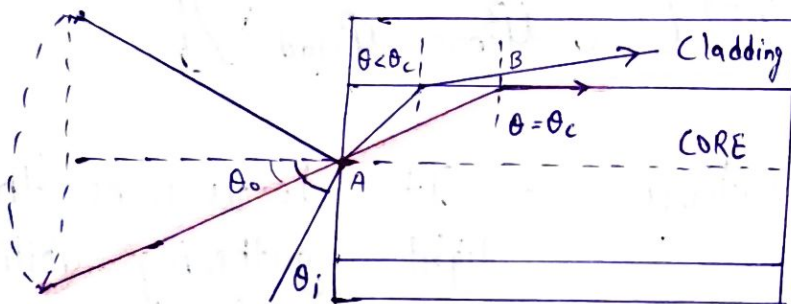


Graded index multi-mode optical fiber

Acceptance Angle & Numerical Aperture

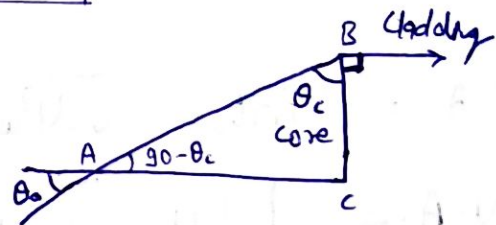


Acceptance angle is the maximum angle that a light ray can have relative to the axis of the fibre & propagate down the fiber.



$$\mu_1 \sin i = \mu_2 \sin r$$

$$\frac{\sin i}{\sin r} = \frac{\mu_2}{\mu_1} \quad (\text{Applying laws of refraction at point A})$$



$$\frac{\sin \theta_0}{\sin(90 - \theta_c)} = \frac{\mu_{\text{core}}}{\mu_0}$$

$$\sin^2 \theta + \cos^2 \theta = 1$$

$$\mu_0 \sin \theta_0 = \mu_{\text{core}} \sin(90 - \theta_c)$$

$$\mu_0 \sin \theta_0 = \mu_{\text{core}} \cos \theta_c \quad \text{--- (1)}$$

$$\mu_0 \sin \theta_0 = \mu_{\text{core}} \sqrt{1 - \sin^2 \theta_c} \quad \text{--- (2)}$$

$$\frac{\sin i}{\sin r} = \frac{\mu_2}{\mu_1} \quad (\text{Applying laws of refraction at point B})$$

$$\frac{\sin \theta_c}{\sin 90^\circ} = \frac{\mu_{\text{clad}}}{\mu_{\text{core}}} = \sin \theta_c = \frac{\mu_{\text{clad}}}{\mu_{\text{core}}} \quad \text{--- (3)}$$

putting this value in eqⁿ - (2)

$$\mu_0 \sin \theta_0 = \mu_{\text{core}} \sqrt{1 - \left(\frac{\mu_{\text{clad}}}{\mu_{\text{core}}} \right)^2}$$

$$\sin \theta_0 = \frac{\mu_{\text{core}}}{\mu_0} \cdot \sqrt{\frac{\mu_{\text{core}}^2 - \mu_{\text{clad}}^2}{\mu_{\text{core}}^2}} = \frac{\mu_{\text{core}}}{\mu_0} \cdot \frac{\sqrt{\mu_{\text{core}}^2 - \mu_{\text{clad}}^2}}{\mu_{\text{core}}}$$

$$\sin \theta_0 = \frac{\sqrt{\mu_{\text{core}}^2 - \mu_{\text{clad}}^2}}{\mu_0}$$

If optical fiber is placed in air $\mu_0 = 1$

$$\sin \theta_0 = \sqrt{\mu_{\text{core}}^2 - \mu_{\text{clad}}^2}$$

$$\star \boxed{\theta_0 = \sin^{-1} \left(\sqrt{\mu_{\text{core}}^2 - \mu_{\text{clad}}^2} \right)} \star$$

Numerical Aperture: — It determines the light gathering ability of the fiber.

$$N.A. = \sin \theta_0 = \sqrt{\mu_{\text{core}}^2 - \mu_{\text{clad}}^2}$$

$$N.A. = \sqrt{(\mu_{\text{core}} + \mu_{\text{clad}})(\mu_{\text{core}} - \mu_{\text{clad}})}$$

$$N.A. = \sqrt{2 \mu_{\text{core}} (\mu_{\text{core}} - \mu_{\text{clad}})} \quad \left[\begin{array}{l} \text{Here} \\ \mu_{\text{core}} + \mu_{\text{clad}} \approx 2 \mu_{\text{core}} \end{array} \right]$$

$$N.A. = \frac{\sqrt{2 \mu_{\text{core}}^2 (\mu_{\text{core}} - \mu_{\text{clad}})}}{\mu_{\text{core}}}$$

$$\star \boxed{N.A. = \mu_{\text{core}} \sqrt{2 \Delta}} \star$$

$$\star \boxed{\Delta = \frac{\mu_{\text{core}} - \mu_{\text{clad}}}{\mu_{\text{core}}}} \star$$

Δ = fractional difference of index