UNIT-1

11 MARKS

Overview of Fibre optic communication

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1.1) State the Advantages of Light-wave communication System over EM wave Systems :-

① Long-distance communication :- Light-wave communication System can run long distances (40 km) without having to repeat the signal in-between. It is not possible with EM wave System

② Immune to electro-magnetic interference :- Light wave communication System is not affected by EMI (Electro-magnetic interference) as they carry light, but EM waves are affected by EMI.

③ Bandwidth :- Bandwidth is high in Light wave System. But EM waves have bandwidth limitations.

④ Speed is high

⑤ Low-cost Transmission

⑥ cross-Talk :- Light wave communication System doesn't have any cross-talk problems but EM waves have chances for cross-talk.

⑦ Security :- Light wave communication System is more Secure than EM wave Systems.

→ optical Fibre :-

An optical Fibre is a flexible, transparent fiber made of glass (silica) or plastic to a diameter slightly thicker than that of a human hair.

It is a cable by which light signals can be sent with very little loss.

1.2) Structure of optical Fibre :-

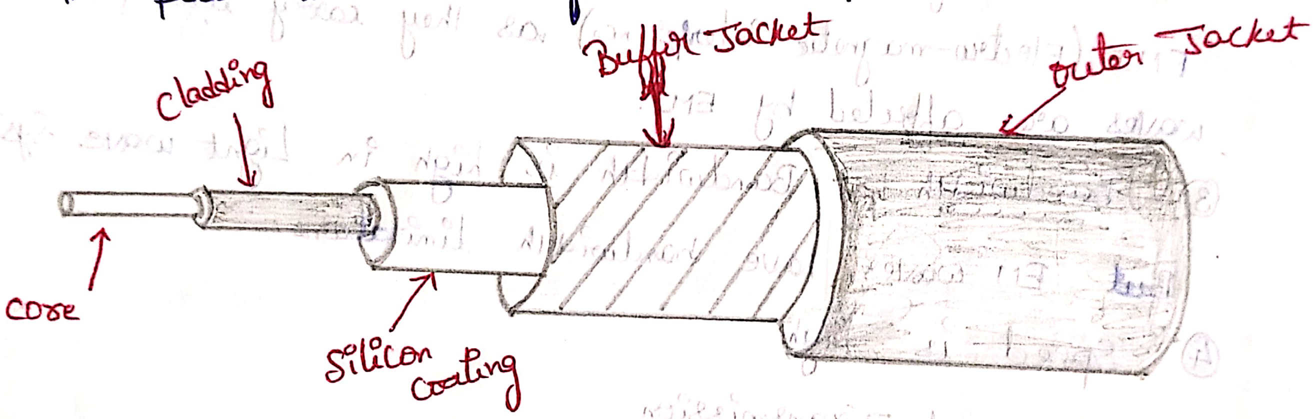
① optical fibers have a very simple structure

② They consist of two main sections :- ① Core and ② cladding

③ Core and cladding have different refractive indices, with the core having a refractive index n_1 which is slightly higher than that of cladding n_2.

$\boxed{n_1 > n_2}$

④ The fiber is also referred as "optical waveguide".



① Core :- → It is the central region made up of Silica
→ It is the main region through which light is transmitted
→ Refractive index of core is taken as n_1
→ The core diameter is 62.5 μm.

② cladding :- → It is the first layer around the core
→ It is also made up silica but not the same composition as the core
→ Refractive index is taken as n_2.
→ The diameter of cladding is 125 μm.

③ coating :- Silicon coating consists of one or more layers of polymer that protect the silica structure against physical or environmental damage.

④ Buffer and outer Jacket :-

→ These two Jackets are used to protect the fiber from breaking during installation and termination

→ These are located outside of the coating.

1.3) classification of optical fibres based on refractive index profile :-

optical Fibers based on refractive index

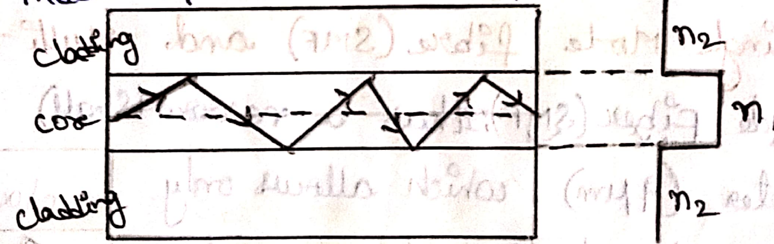
- Step-index fiber
- Graded-index Fiber

① Step-Index Fiber :-

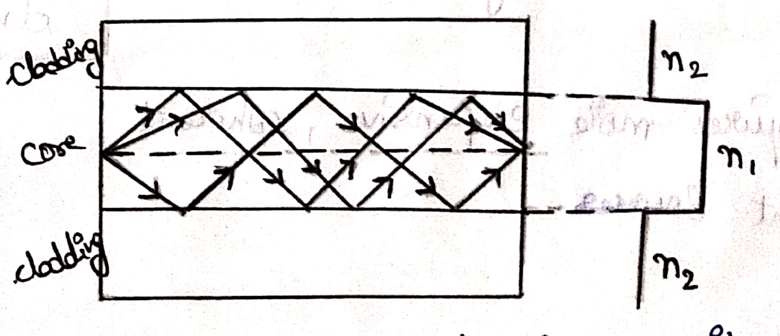
→ The optical Fiber with a core of constant refractive index n_1 and a cladding of slightly lower refractive index n_2 is known as Step-index Fiber.

→ This is because, refractive index profile for this type makes a step change at the core-cladding interface.

→ Refractive index of core is uniform.



(a) single-mode step-index fiber



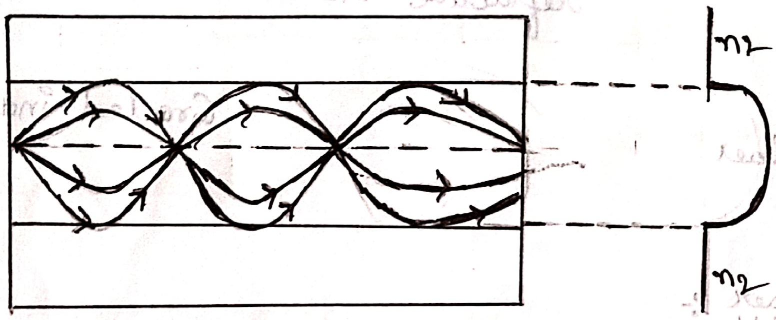
(b) Multi-mode step-index Fiber

② Graded-Index Fiber :-

→ Graded index fibers do not have a constant refractive index.

→ It consists of a pure-glass core surrounded by a number of coaxial layers of glass.

→ The refractive index of each layer is slightly less than refractive index of inner layer.



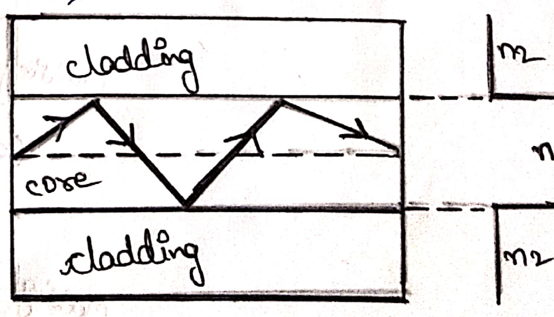
1.4) List the types of fibers based on core diameter :-

optical Fibres based on core diameter

- Single Mode Fiber (SMF)
- Multi-mode fiber (MMF)

1.5) Define Single Mode fibre (SMF) and Multi-mode fibre (MMF)?

→ ① Single Mode Fiber (SMF): It has a narrow (Small) core diameter (9 μm) which allows only a single mode of light to propagate.

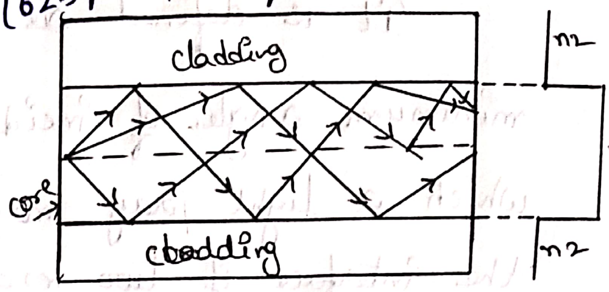


② It is used in long-distance applications

③ It requires more expensive, coherent laser light sources.

② Multi-mode Fiber (MMF) :-

1) It has a large core diameter (62.5 μm to 50 μm) which allows multiple modes of light to propagate.

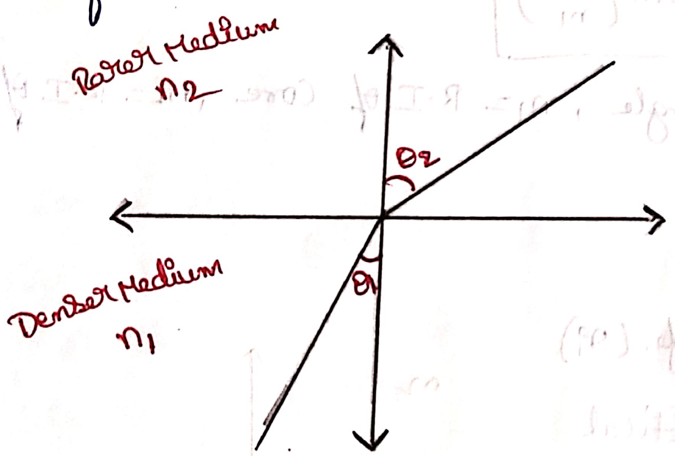


2) It is designed for use with "cheaper" light sources

3) Distance is limited (20-500 meters)

1.6) Define Snell's law in optics ?:-

Snell's Law :- Snell's law is defined as the amount of bending that takes place when a light ray strikes the refractive boundary.



where,

n_1 = Refractive index of Denser Medium

n_2 = Refractive index of Rarer Medium

θ_1 = Angle of incidence

θ_2 = Angle of refraction

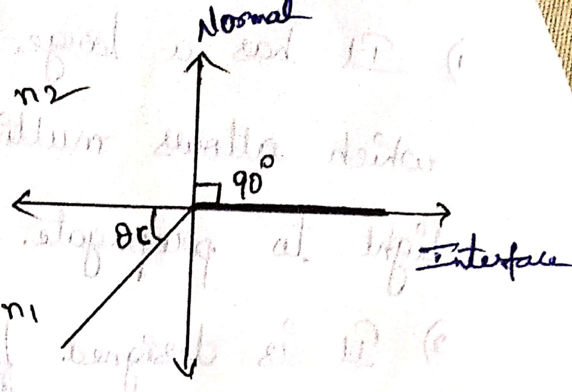
→ Snell's law States that, product of Refractive index of first medium & sine of angle of incidence is equal to product of refractive index of second medium & sine of angle of refraction.

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

$$\Rightarrow \boxed{\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_2}{n_1}}$$

→ Critical Angle :-

It is defined as the minimum angle of incidence at which a light ray may strike the interface of two media and result is an angle of refraction of 90°.



$\theta_1 = \theta_c$

$\theta_2 = 90^\circ$

from Snell's law,

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

$$n_1 \sin\theta_c = n_2 \sin 90^\circ$$

$$n_1 \sin\theta_c = n_2 \cdot 1$$

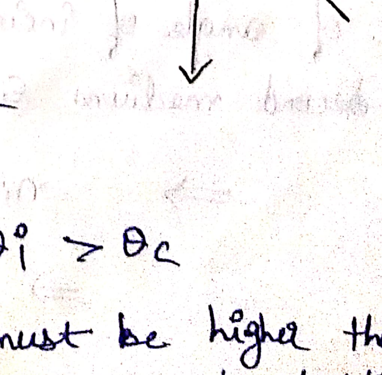
$$\sin\theta_c = \frac{n_2}{n_1}$$

$$\Rightarrow \boxed{\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)}$$

where θ_c = Critical Angle, n_1 = R.I of Core, n_2 = R.I of cladding

→ Total Internal Reflection :-

→ When the incident Angle (θ_i) is made greater than critical Angle (θ_c), then the light reflect to the same medium.

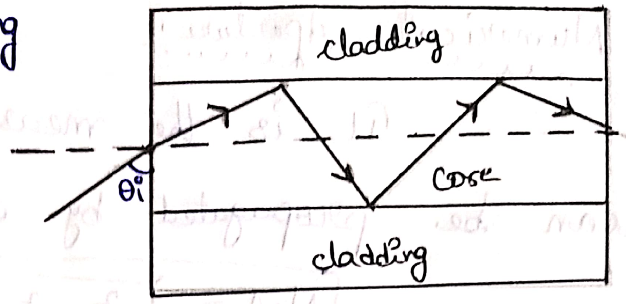


This phenomenon is called Total internal Reflection

2 conditions for TIR is → ① $\theta_i > \theta_c$

② R.I of core must be higher than R.I of Cladding.

Explain Light Wave propagation in OFC :-



→ As Refractive index of cladding is always less than refractive index of core, incident rays gets reflected

→ If Angle of incidence (θ_i) is changed, angle of reflection also changes.

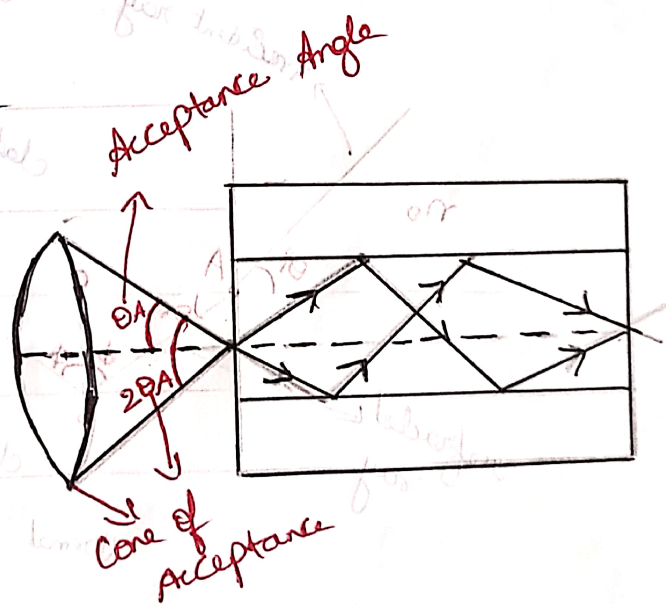
→ Based on θ_i, few waves are captured early and few waves are captured late.

→ Therefore propagation of waves depends on incident angle.

1.8) **Define Acceptance Angle and cone of acceptance?**

① Acceptance angle :-

The Maximum Angle at which a light ray enters the fiber axis in order to get propagated is called as Acceptance Angle (θ_A)



It is given by,

$$\boxed{\theta_A = \sin^{-1}(NA)}$$

→ it is limited by critical Angle.

② Cone of Acceptance :- The Area of gathering the light at input side of the optical fiber having full angle $2\theta_A$ is called as cone of Acceptance ($2\theta_A$).

1.9) Define Numerical Aperture?

Numerical Aperture:-

It is the measure of amount of light that can be propagated by a fiber.

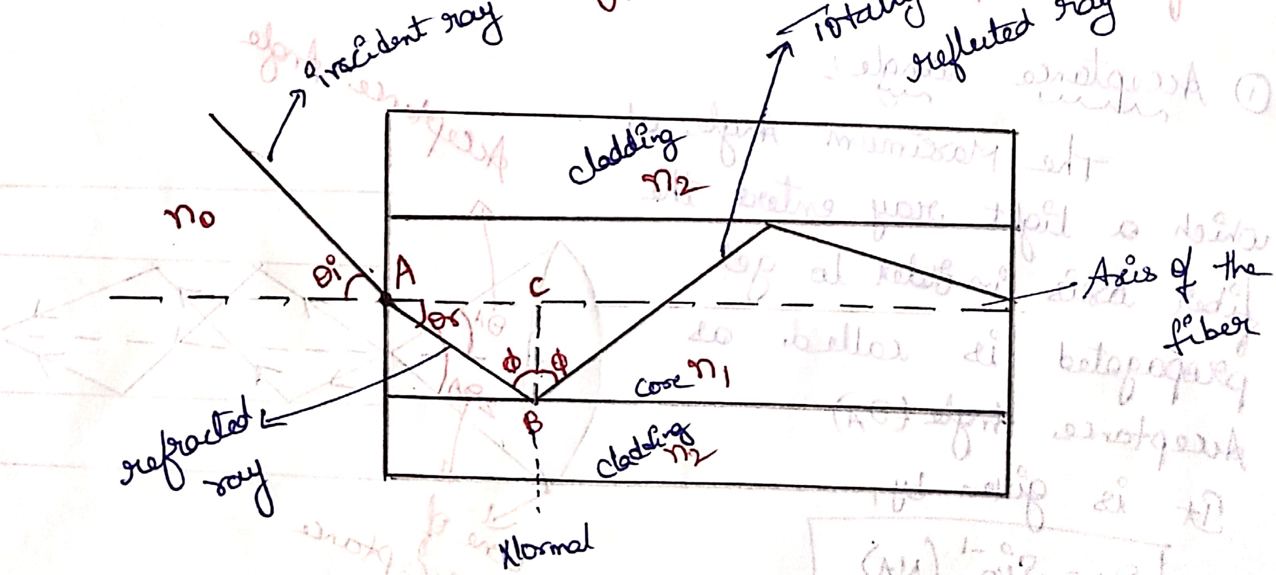
$$\boxed{N.A = \sqrt{n_1^2 - n_2^2}}$$

→ It is defined as the sine of acceptance angle.

$$\boxed{NA = \sin\theta_A} = \frac{\sqrt{n_1^2 - n_2^2}}{n_0}$$ (if, $n_0 = 1$ for air medium)

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

1.10) Derive the Expression for NA in terms of refractive indices of core and cladding?



→ let a light ray enters into the fiber from a medium with refractive index n_0 and angle of incidence θ_i

→ This ray gets refracted from fiber axis with an angle θ_r and strikes core-cladding interface at angle ϕ.

→ Now it gets totally internally reflected and moves in zigzag path along the fiber core.

→ from the diagram,

According to Snell's law,

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

Here ABC is right angled triangle, so $\angle C = 90^\circ$

$$\angle A + \angle B + \angle C = 180^\circ$$

$$\theta_r + \phi + 90^\circ = 180^\circ$$

$$\theta_r + \phi = 90^\circ$$

$$\theta_r = (90^\circ - \phi) \quad \text{——} \ (2)$$

Sub eq (2) in (1),

$$(1) \Rightarrow \ n_0 \sin\theta_i = n_1 \sin(90^\circ - \phi)$$

$$n_0 \sin\theta_i = n_1 \cos\phi \quad \text{——} \ (3)$$

Here the light ray at point B is reflected back only if the angle of incidence is greater than critical Angle.

Hence,
$$\sin\phi = \frac{n_2}{n_1} \quad \text{(from the diagram)}$$

$$\Rightarrow \cos\phi = \sqrt{1 - \sin^2\phi}$$

$$\cos\phi = \sqrt{1 - \frac{n_2^2}{n_1^2}} \quad \text{——} \ (4)$$

Sub eq. ④ in ③,

$$n_0 \sin\theta_i = n_1 \cdot \cos\phi$$

$$= n_1 \cdot \sqrt{1 - \frac{n_2^2}{n_1^2}}$$

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

$$= \frac{\cancel{n_1}}{\cancel{n_1}} \sqrt{n_1^2 - n_2^2}$$

$$n_0 \sin\theta_i = \sqrt{n_1^2 - n_2^2}$$

$$\boxed{\sin\theta_i = \sqrt{n_1^2 - n_2^2}}$$ ($\because n_0 = 1$ for air medium)

Numerical Aperture is defined as sine of acceptance angle ($\theta_i = \theta_A$)

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

Numerical aperture is the measure of amount of light that can be propagated by a fiber.

$$\Rightarrow \boxed{N \cdot A = \sqrt{n_1^2 - n_2^2}}$$