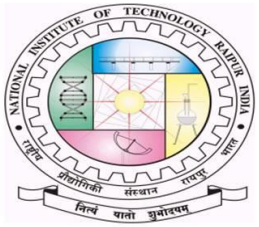
FIBRE OPTICS



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Keywords

- Introduction
- Principle
- Construction
- Classification
- Acceptance angle
- Numerical Aperture
- Advantages
- Application

Introduction

- Fiber Optics is a Technology which plays an important role in communication system.
- Optical fiber is a transmission channel which deals with the light propagation through thin glass fibre (like human hair).
- This technology was firstly demonstrated by John Tyndall in 1870.
- It is tried only from 1927.

Principle of Fibre

The basic principle of fibre in the transmission of optical signal is

Total Internal Reflection.

- When the light ray travels from denser medium to rarer medium the refracted ray bends away from the normal. When the angle of incidence is greater than the critical angle, the refracted ray again reflects into the same medium. This phenomenon is called total internal reflection.
- When a light signal is directed at one end of the fiber at a suitable angle, it undergoes repeated total internal reflection along the length of the fiber and finally comes out at the other end.

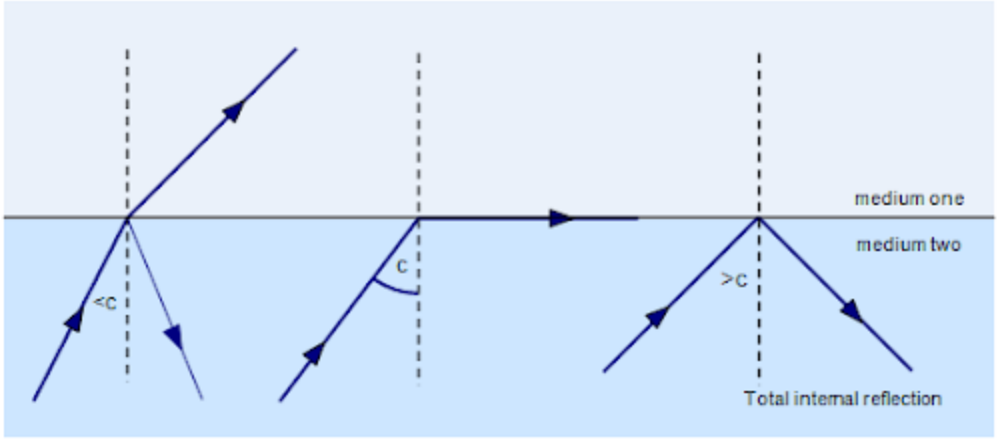
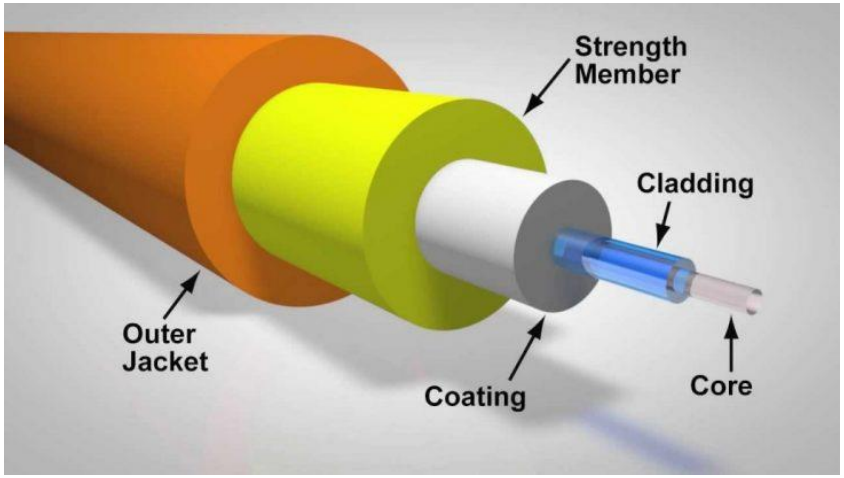


Figure 1

Construction of Optical Fibre



- **Core** – Glass or plastic with a higher index of refraction than the cladding.
- **Cladding** – Glass or plastic with a lower index of refraction than the core
- **Buffer** – Protects the fiber from damage and moisture
- **Jacket** – Holds one or more fibers in a cable

Classification of Fibre

1. On the basis of refractive index of core

   (i) Step index fibre

   (ii) Graded index fibre

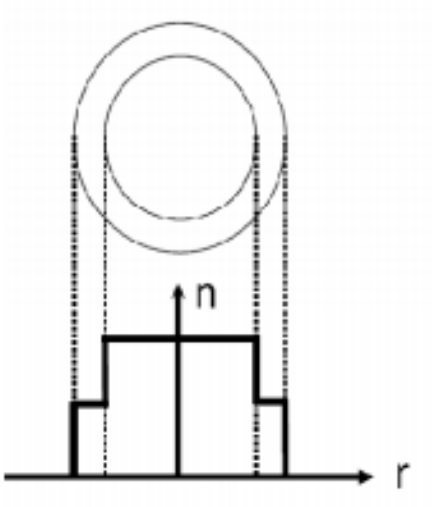
2. On the basis of no. of modes of transmission

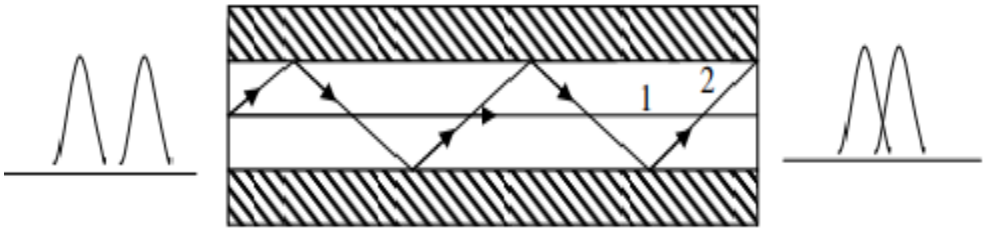
   (i) Single mode fibre

   (ii) Multimode fibre

Step Index Fibre

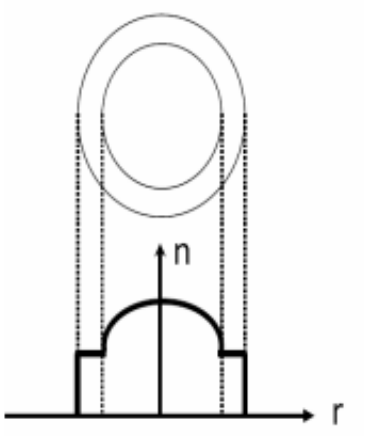
- In step index fibre the refractive index of the core medium is uniform and undergoes an abrupt change at the interface of core and cladding as shown in figure.
- The diameter of core is about 50 to 200 micrometers in case of multi mode and 10 micrometers in single mode fibre.
- Attenuation is more for step index multi mode fibres but less in step index single mode fibres Numerical aperture is more for step index multi mode fibres but it is less in step index single mode fibres. This fibre is called reflective type fibre.

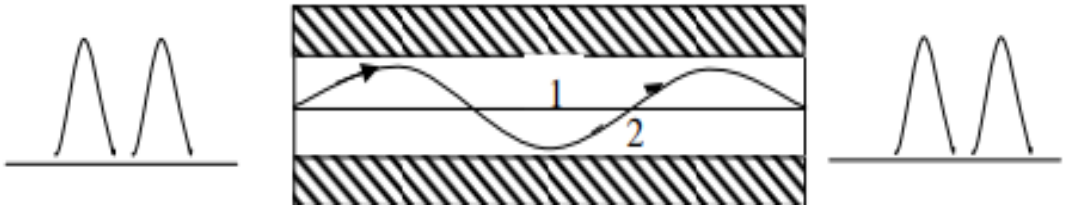




Graded Index Fibre

- In graded index fibres, the refractive index of the core medium is varying in the parabolic manner such that the maximum refractive index is present at the center of the core.
- The diameter of the core is about 50 micro meters. Attenuation is very less in graded index fibres Numerical aperture is less in graded index fibres This fibre is called reflective type fibre
- The shape of propagation of the optical is in helical or spiral manner. The transmitted optical signal will never cross the fibre axis during every reflection at the core cladding boundary..





Difference between Step Index and Graded Index Fibre

Step index fiber	Graded index fiber
1. In step index fibers the refractive index of the core medium is uniform through and undergoes an abrupt change at the interface of core and cladding.	1. In graded index fibers, the refractive index of the core medium is varying in the parabolic manner such that the maximum refractive index is present at the center of the core.
2. The diameter of core is about 10micrometers in case of single mode fiber and 50 to 200 micrometers in multi mode fiber.	2. The diameter of the core is about 50 micro meters.
3. The transmitted optical signal will cross the fiber axis during every reflection at the core cladding boundary.	3. The transmitted optical signal will never cross the fiber axis at any time.
4. The shape of propagation of the optical signal is in zigzag manner.	4. The shape of propagation of the optical signal appears in the helical or spiral manner
5. Attenuation is more for multi mode step index fibers but Attenuation is less in single mode step index fibers	5. Attenuation is very less in graded index fibers
6. Numerical aperture is more for multi mode step index fibers but it is less in single mode step index fibers	6. Numerical aperture is less in graded index fibers

Single Mode Optical Fibre

- In single mode optical fibers only one mode of propagation is possible.
- In case of single mode fiber the diameter of core is about 10micrometers
- The difference between the refractive indices of core and cladding is very small.
- In single mode fibers there is no dispersion, so these are more suitable for communication.
- The single mode optical fibers are costly, because the fabrication is difficult.
- The process of launching of light into single mode fibers is very difficult.
- The condition for single mode operation is

$$V = \frac{2\pi}{\lambda} a\, NA$$

$$V = \frac{2\pi}{\lambda} a\, n_1 \sqrt{2\Delta}$$

Where a is the radius of the core of the fiber,

n_1 is the refractive of the core,

NA is the numerical aperture and

λ is the wave length of light traveling through the fiber

Multi Mode Optical Fibre

- In multi mode optical fibers many mummer of modes of propagation are possible.
- In case of in multi mode fiber the diameter of core is 50 to 200 micrometers.
- The difference between the refractive indices of core and cladding is also large compared to the single mode fibers.
- Due to multi mode transmission, the dispersion is large, so these fibers are not used for communication purposes.
- The multi mode optical fibers are cheap than single mode fibers, because the fabrication is easy.
- The process of launching of light into single mode fibers is very easy.
- The condition for multi mode propagation is

$$N = 4.9\left(\frac{d \bullet NA}{\pi}\right)^2$$

Where d the radius of the core of the fiber and NA is is the numerical aperture.

Difference between Single Mode And Multi Mode Fibre

Single mode fiber	Multi mode fiber
1. 1. In single mode optical fibers only one mode of propagation is possible	1. In multi mode optical fibers many mummer of modes of propagation are possible.
2. In case of single mode fiber the diameter of core is about 10micrometers	case of in multi mode fiber the diameter of core is 50 to 200 micrometers.
3. The difference between the refractive indices of core and cladding is very small.	2. The difference between the refractive indices of core and cladding is also large compared to the single mode fibers.
4. 3. In single mode fibers there is no dispersion, so these are more suitable for communication.	3. Due to multi mode transmission, the dispersion is large, so these fibers are not used for communication purposes.
5. 4. The process of launching of light into single mode fibers is very difficult	4. The process of launching of light into single mode fibers is very easy.
6. The condition for single mode operation is $V = \frac{2\pi}{\lambda} a\, NA$	5. The condition for multi mode propagation is $N = 4.9\left(\frac{d \bullet NA}{\pi}\right)^2$
7. 6. Fabrication is very difficult and the fiber is costly.	6. Fabrication is very easy and the fiber is cheaper.

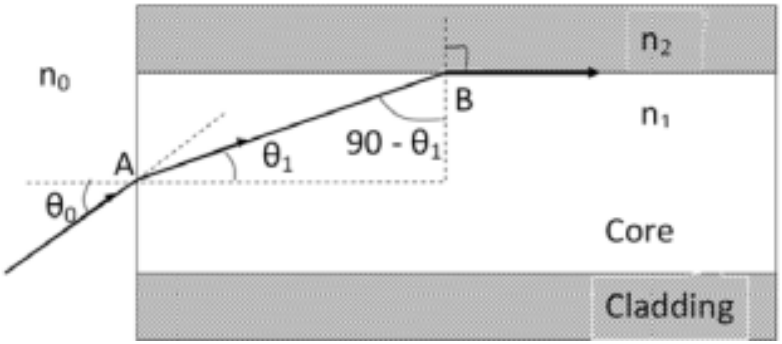
Acceptance Angle

Definition:-

Acceptance angle is defined as the maximum angle of incidence at the interface of air medium and core medium for which the light ray enters into the core and travels along the interface of core and cladding.

Let n_0, n_1 and n_2 be the refractive indices of air, core and cladding media. Let a light ray OA is incident on the interface of air medium and core medium with an angle of incidence θ_0 then the light ray refracts into the core medium with an angle of refraction θ_1, and the refracted ray AB is again incidenting on the interface of core and cladding with an angle of incident $(90^0 - \theta_1)$.

If $(90^0 - \theta_1)$ is equal to the critical angle of core and cladding media then the ray travels along the interface of core and cladding along the path BC. If the angle of incident at the interface of air and core $\theta_1 < \theta_0$, then $(90^0 - \theta_1)$ will be greater than the critical angle. Therefore, the total internal reflection takes place.



Acceptance Angle

According to Snell's law at point A

$$n_0 \sin\theta_0 = n_1 \sin\theta_1$$

$$\sin\theta_0 = \frac{n_1}{n_0}\sin\theta_1$$

According to Snell's law at point B

$$n_1 \sin(90 - \theta_1) = n_2 \sin 90$$

$$n_1 \cos\theta_1 = n_2$$

$$\cos\theta_1 = \frac{n_2}{n_1}$$

$$\sin\theta_1 = \sqrt{(1 - \cos^2\theta_1)}$$

$$\sin\theta_1 = \sqrt{\left(1 - \frac{{n_2}^2}{{n_1}^2}\right)} = \frac{\sqrt{({n_1}^2 - {n_2}^2)}}{n_1}$$

$$\sin\theta_0 = \frac{n_1}{n_0}\sin\theta_1 = \frac{n_1}{n_0}\frac{\sqrt{({n_1}^2 - {n_2}^2)}}{n_1} = \frac{\sqrt{({n_1}^2 - {n_2}^2)}}{n_0}$$

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

$$\theta_0 = \sin^{-1}\left(\frac{\sqrt{({n_1}^2 - {n_2}^2)}}{n_0}\right)$$

Acceptance angle $\theta_0 = \sin^{-1}\left(\frac{\sqrt{({n_1}^2 - {n_2}^2)}}{n_0}\right)$

Numerical Aperture

Definition: -

Numerical aperture is defined as the light gathering capacity of an optical fiber and it is directly proportional to the acceptance angle.

Numerically it is equal to the sin of the acceptance angle.

$$NA = \sin(acceptance\ angle)$$

$$NA = Sin\left(Sin^{-1}\left(\frac{\sqrt{\left(n_1^2 - n_2^2\right)}}{n_0} \right) \right)$$

$$NA = \frac{\sqrt{\left(n_1^2 - n_2^2\right)}}{n_0}$$

If the refractive index of the air medium is equal to unity then

$$NA = \sqrt{\left(n_1^2 - n_2^2\right)}$$

Fractional change in refractive index

$$\Delta = \frac{\left(n_1 - n_2\right)}{n_1}$$

$$n_1 \Delta = \left(n_1 - n_2\right)$$

$$NA = \sqrt{\left(n_1 - n_2\right)\left(n_1 + n_2\right)}$$

$$NA = \sqrt{n_1 \Delta \left(n_1 + n_2\right)} \qquad \because n_1 \Delta = \left(n_1 - n_2\right)$$

$$NA = \sqrt{n_1 \Delta 2n_1} \qquad \because n_1 \approx n_2 \ ; \quad n_1 + n_2 = 2n_1$$

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

The above equation gives a relationship between numerical aperture and fractional change in relative refractive index.

Advantages of Optical fibre

The optical fiber communication has more advantages than convectional communication.

1. Enormous bandwidth
2. low transmission loss
3. electric isolation
4. signal security
5. small size and less weight
6. low cost
7. immunity cross talk

1. Enormous bandwidth

The information carrying capacity of a transmission system is directly proportional to the frequency of the transmitted signals. In the coaxial cable (or convectional communication system) transmission the bandwidth range is up to around500MHZ. only. Where as in optical fiber communication, the bandwidth range is large as 10^5 GHZ.

Advantages of Optical fibre

2. **Low transmission loss:-**

The transmission loss is very low in optical fibers (i.e. $0.2\ dB/Km$) than compare with the convectional communication system. Hence for long distance communication fibers are preferred.

3. **Electric isolation**

Since fiber optic materials are insulators, they do not exhibit earth and interface problems. Hence communicate through fiber even in electrically danger environment.

4. **Signal security**

The transmitted signal through the fiber does not radiate, unlike the copper cables, a transmitted signal cannot be drawn from fiber without tampering it. Thus the optical fiber communication provides 100% signal security.

5. **Small size and less weight**

The size of the fiber ranges from $10\mu m$ to $50\mu m$, which is very small. The space occupied by the fiber cable is negligibly small compared to convectional electrical cables. Optical fibers are light in weight.

6. **Low cost**

Since optical fibers made up of silica which is available in abundance, optical fibers are less expensive.

7. **Immunity cross talk**

Since the optical fibers are dielectric wave guides, they are free from any electromagnetic interference and radio frequency interference. Since optical interference among different fibers is not possible, cross talk is negligible even many fibers are cabled together.

Application of optical fibre

1. Optical fibers are extensively used in communication system.
2. Optical fibers are in exchange of information between different computers
3. Optical fibers are used for exchange of information in cable televisions, space vehicles, submarines etc.
4. Optical fibers are used in industry in security alarm systems, process control and industrial auto machine.
5. Optical fibers are used in pressure sensors in biomedical and engine control.
6. Optical fibers are used in medicine, in the fabrication in endoscopy for the visualization of internal parts of the human body.
7. Sensing applications of optical fibers are
   Displacement sensor
   Fluid level detector
   Liquid level sensor
   Temperature and pressure sensor
   Chemical sensors
8. Medical applications of optical fibers are
   Gastroscope
   Orthoscope
   Couldoscope
   Peritonescope
   Fiberscope

THANK YOU