Introduction

Fibre optics deals with the light propagation through thin glass fibres. Fibre optics plays an important role in the field of communication to transmit voice, television and digital data signals from one place to another. The transmission of light along the thin cylindrical glass fibre by total internal reflection was first demonstrated by John Tyndall in 1870 and the application of this phenomenon in the field of communication is tried only from 1927. Today the applications of fibre optics are also extended to medical field in the form of endoscopes and to instrumentation engineering in the form of optical sensors.

Generally, communication is transferred through carrier waves in any communication system. When the frequencies of the carrier waves are high then the information carrying capacity also enhances. As the propagation of light takes place in the form of high frequency waves, these light waves can be used to carry information, i.e., as carrier waves. For the proper guiding of information carrying light waves, we need a proper guiding medium or material. That material is the optical fibre.

1. Optical fibre

Optical fibre is a guiding medium or material which guides the information carrying light waves. To guide the light waves, optical fibre should be transparent. To minimize the transmission losses through the optical fibre it is made thin.

Thus **Optical fibre is a thin transparent guiding medium or material which guides the information carrying light waves**

2. The Basic principle of optical fibre (Or) Working principle of optical fibre (or) Total internal reflection

The transmission of light in an optical fibre is based on the phenomenon of total internal reflection. Optical fibre consists of inner most layer known as core, a denser medium and next layer is known as cladding a rarer medium.

**Total internal reflection:-**

**Definition:** *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.*

Let us consider $n_1$ and $n_2$ are refractive indices of core and cladding mediums. Let, a light ray traveling from core medium to cladding medium, then the refracted ray bends away from the normal with $i$ is the angle of incidence and $r$ is the angle of refraction.

In this we get three cases

**Case I:**
When $i < \theta_c$, the light ray refracts into cladding medium. [Figure 1]

![Figure 1](image1.png)

**Case II:**
When $i < \theta_c$, the light ray travels along the interface of core and cladding, $\theta_c$ is known as critical angle. [Figure 2]

![Figure 2](image2.png)
When the angle of incidence is increased angle of reflection also increases and for a particular angle of incidence \( i = \theta_c \) the refracted ray travels along the interface of two mediums. This angle of incidence is known as **critical angle** \( \theta_c \).

\[
\frac{n_1 \sin \theta_c}{\sin \theta} = n_2 \sin 90
\]

\[
n_1 \sin \theta_c = n_2 \Rightarrow \sin \theta_c = \frac{n_2}{n_1}
\]

\[
\theta_c = \sin^{-1} \left( \frac{n_2}{n_1} \right)
\]

**Case III:-**
When \( i > \theta_c \), then the light ray will be reflected back into the core medium and undergoes total internal reflection. [Figure 3]

When the angle of incidence is greater than the critical angle \( i > \theta_c \), the refracted ray again reflects into the same medium. This phenomenon is called total internal reflection.

3. **Construction of optical fibre**

The optical fibre mainly consists the following six parts as shown in figure

1. Core
2. Cladding
3. Silicon coating
4. Buffer jacket
5. Strength member
6. Outer jacket
Core:
A typical glass fibre consists of a central core material. Generally core diameter is ranges from 5 to 600 μm. The core is surrounded by cladding. The core medium refractive is always greater than the cladding refractive index.

Cladding
Cladding refractive index is lesser than the cores refractive index. The overall diameter of cladding is 125 μm to 750 μm.

Silicon Coating
Silicon coating is provided between buffer jacket and cladding. It improves the quality of transmission of light.

Buffer Jacket
Silicon coating is surrounded by buffer jacket. Buffer jacket is made of plastic and protects the fibre cable from moisture.

Strength Member
Silicon coating is surrounded by strength member. It provides strength to the fibre cable.

Outer Jacket
Finally the fibre cable is covered by polyurethane outer jacket. Because of this arrangement fibre cable will not be damaged during pulling, bending, stretching and rolling through the fibre cable is made up of glasses.

4. Dimensions of optical fibre
Optical fibres are made in lengths of 1km. optical fibres can be connected with suitable connectors. Generally its outer diameter ranges from 0.1 to 0.15 mm. Naturally the diameter of core and cladding ranges from 5 to 600 μm and 125 to 750 μm respectively. Due the outer jacket 100 μm may add to diameter of the total optical fibre. The optical signal passes through the core medium of the optical fibre. The propagation of optical signal in the optical fibre in the form of multiple total internal reflection is shown in figure.

5. Classification of fibres
Based on the refractive index of core medium, optical fibres are classified into two categories.
   i. Step index fibre
   ii. Graded index fibre
Based on the number of modes of transmission, optical fibres are classified into two categories
   i. Single mode fibre
   ii. Multi mode fibre
Based on the material used, optical fibres are may broadly classified into four categories
   i. All glass fibre
   ii. All plastic fibre
   iii. Glass core with plastic cladding fibre
   iv. Polymer clad silica fibre.
6. **Step index fibre- refractive index profile**

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.

![Step index fibre diagram](image)

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.

**Transmission of signal in step index fibre**

Generally, the optical signal is transmitted through the fibre in the digital form i.e., in the form of 1's and 0's. The propagation of signals through the multi mode fibre is shown in the figure. The transmitted optical signal will cross the fibre axis during every reflection at the core cladding boundary. The shape of propagation of the optical signal is in zigzag manner. Generally the signal through the fibre is in digital form i.e. in the form of pulses representing 0s and 1s.

From figure the ray 1 follows shortest path (i.e. travels along the axis of fibre) and the ray 2 follows longer path than ray 1. Hence the two rays reach the received end at different times. Therefore, the pulsed signal received at other end gets broadened. This is called intermodal dispersion. This difficulty is over come in graded index fibres.
7. Graded index fibre - refractive index profile:-

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.

![Graded Index Fibre Diagram]

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.

Transmission of signal in graded index 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.

![Transmission Diagram]

To discuss intermodal dispersion, we consider two rays as shown in figure, the ray 1 is traveling along the axis of the core and the other ray 2 traveling away from the axis undergoes refraction and bent. Since, ray 2 is traveling in the lesser refractive index medium, so ray 2 moves slightly faster than ray 1. Hence the two rays reach the other end simultaneously. Thus the problem of intermodal dispersion can be overcome by using graded index fibre.

8. Single mode optical fibre:-

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

\[ V = \frac{2\pi}{\lambda} a \text{ NA} \]

Where \( a \) is the radius of the core of the fibre, \( n_1 \) is the refractive of the core, NA is the numerical aperture and \( \lambda \) is the wave length of light traveling through the fibre.
9. **Multi mode optical fibre:-**

- In multi mode optical fibres many number of modes of propagation are possible.
- These fibres have large core diameter and the difference between the refractive indices of core and cladding is also large compared to the single mode fibres.
- Due to multi mode transmission, the dispersion is large, so these fibres are not used for communication purposes.
- The multi mode optical fibres are cheap than single mode fibres, because the fabrication is difficult.
- The process of launching of light into single mode fibres is very easy.
- Fabrication is very easy and the fibre is cheaper.
- The condition for multi mode propagation is
  \[
  N = 4.9 \left( \frac{d \cdot NA}{\pi} \right)^2
  \]
  Where \( d \) the radius of the core of the fibre and NA is is the numerical aperture.

10. **Glass fibre**

    *If the optical fibres are made by fusing mixtures of metal oxides and silica glasses, thin it is known as glass fibre.* The most common material used in glass fibre is silica (oxide glasses). It has a refractive index of 1.458 at 850 nm. To vary the refractive indices of core and cladding either fluorine or various of oxides such as \( B_2O_3 \), \( GeO_2 \) or \( P_2O_5 \) are added to silica.

    Example of glass fibre compositions are
    
    - \( \text{GeO}_2 – \text{SiO}_2 \) core \( \text{SiO}_2 \) cladding.
    - \( \text{P}_2\text{O}_5 – \text{SiO}_2 \) core \( \text{SiO}_2 \) cladding.
    - \( \text{SiO}_2 \) core, \( \text{P}_2\text{O}_5 – \text{SiO}_2 \) cladding.

11. **Plastic fibre**

    *If the optical fibres are made by plastic, thin it is known as Plastic fibre.* The plastic fibres are low cost and can be handled without special care due to their toughness and boron durability.

    Example of glass fibre compositions are
    
    - a polystyrene core (\( n=1.60 \)) and methylmethacrylate cladding (1.49).
    - a poly methylmethacrylate core (1.49) and cladding made of its co-polymer (\( n=1.40 \)).

12. **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 \( n_a, n_1 \) 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 \( \theta_i \), then the light ray refracts into the core medium with an angle of refraction \( \theta_r \), and the refracted ray AB is again incident on the interface of core and cladding with an angle of incident \( (90^\circ - \theta_t) \).

    If \( (90^\circ - \theta_t) \) 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 \( \theta_i < \theta_t \), then \( (90^\circ - \theta_t) \) will be greater than the critical angle. Therefore, the total internal reflection takes place.
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
\[ n_1 \sin(90 - \theta_1) = n_2 \sin 90 \]
\[ n_1 \cos \theta_1 = n_2 \]
\[ \cos \theta_1 = \frac{n_2}{n_1} \]
\[ \sin \theta_1 = \sqrt{1 - \cos^2 \theta_1} \]
\[ \sin \theta_1 = \sqrt{1 - \frac{n_2^2}{n_1^2}} = \frac{\sqrt{(n_1^2 - n_2^2)}}{n_1} \]
\[ \sin \theta_0 = \frac{n_1}{n_0} \sin \theta_1 = \frac{n_1}{n_0} \sqrt{\frac{n_1^2 - n_2^2}{n_1}} = \frac{\sqrt{(n_1^2 - n_2^2)}}{n_0} \]
\[ \sin \theta_0 = \frac{n_0}{n_0} \]
\[ \theta_0 = \sin^{-1} \left( \frac{\sqrt{(n_1^2 - n_2^2)}}{n_0} \right) \]

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

13. Acceptance cone

**Definition:**
A cone obtained by rotating a ray at the end face of an optical fibre, around the fibre axis with acceptance angle is known as acceptance cone.

14. Numerical aperture

**Definition:**

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

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

\[ NA = \sin(\text{acceptance angle}) \]
If the refractive index of the air medium is equal to unity then

\[ NA = \sqrt{n_1^2 - n_2^2} \]

Fractional change in refractive index

\[ \Delta = \frac{n_1 - n_2}{n_1} \]

\[ n_1 \Delta = (n_1 - n_2) \]

\[ NA = \sqrt{n_1 \Delta (n_1 + n_2)} \quad \therefore n_1 \Delta = (n_1 - n_2) \]

\[ NA = \frac{n_1 \Delta 2n_1}{n_1} \quad \therefore n_1 \approx n_2 ; \quad n_1 + n_2 = 2n_1 \]

\[ NA = n_1 \sqrt{2 \Delta} \]

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

15. Optical fibre communication system

An efficient optical fibre communication system requires high information carrying capacity, fast operating speed over long distances with a minimum number of repeaters. An optical fibre communication system mainly consists of the following parts as shown in figure.

1. **Encoder**

   Encoder is an electronic system that converts the analog information like voice, figures, objects etc., into binary data.

2. **Transmitter**

   It contain two parts, they are drive circuit and light source. Drive circuit supplies the electric signals to the light source from the encoder in the required form. The light source converts the electrical signals into optical form.

   With the help of specially made connector optical signals will be injected into wave guide from the transmitter.
3. Wave guide.
   It is an optical fibre which carries information in the form of optical signals over distances with the help of repeaters. With the help of specially made connector optical signals will be received by the receiver from the wave guide.

4. Receiver.
   It consists of three parts; they are photo detector, amplifier and signal restorer. The photo detector converts the optical signal into the equivalent electric signals and supply to hem to amplifier. The amplifier amplifies the electric signals as they become weak during the long journey through the wave guide over longer distance. The signal restorer deeps the electric signals in a sequential form and supplies to the decoder in the suitable way.

5. Decoder
   It converts electric signals into the analog information.

16. Advantages of fibre optic communication

   The optical fibre 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 around 500MHZ. only. Where as in optical fibre communication, the bandwidth range is large as $10^5$GHZ.

2. Low transmission loss:-
   The transmission loss is very low in optical fibres (i.e. 0.2Km$^{-1}$) than compare with the convectional communication system. Hence for long distance communication fibres are preferred.

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

4. Signal security
   The transmitted signal through the fibre does not radiate, unlike the copper cables, a transmitted signal cannot be drawn from fibre with out tampering it. Thus the optical fibre communication provides 100% signal security.

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

6. Low cost
   Since optical fibres made up of silica which is available in abundance, optical fibres are less expensive.

7. Immunity cross talk
   Since the optical fibres are dielectric wave guides, they are free from any electromagnetic interference and radio frequency interference. Since optical interference among different fibres is not possible, cross talk is negligible even many fibres are cabled together.
17. **Differences between step index fibres and graded index fibres:**

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18. **Differences between single mode and multi mode fibres:**

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