Learning Objectives

After studying this chapter, the student will be able to:

- ➡ Describe the term fibre optic system
- ➡ Understand and explain the physical principle of how an optical fibre guides light
- ➡ Explain the fibre cable construction
- ➡ Compare and contrast the features, functions and benefits of different optical fibres
- ➡ Explain the propagation of information in a fibre optic communication link and its application

.1 INTRODUCTION

The term communication may be defined as the transfer of information from one point (source) to another (destination). For the information to be transmitted over a distance, a communication system is usually required.

Within a communication system the information transfer is made possible by modulating or superimposing the information on to an electromagnetic wave which acts as a carrier for the information signal. This modulated carrier is then transmitted to the required destination where it is received and the original information signal is obtained by demodulation.

Electromagnetic waves operating at radio frequencies, as well as microwave frequencies are being used for communication. However, it was also discovered that communication may also be made possible using an electromagnetic wave which is selected from the optical range of frequencies.

.2 FIBRE-OPTIC SYSTEM

Communication systems that uses light as the carrier of information from a source to a destination through a guided fibre cable (glass or plastic) are called fibre-optic systems.

The information carrying capacity of a communication system is directly proportional to its bandwidth, i.e., the wider the bandwidth, the greater is its information carrying capacity. Light frequencies used in fibre optic system are between 10^4 and 4×10^{14} Hz (10,000 to 400,000 GHz), as a result they have higher information carrying capacity.

In addition to the capability of carrying a tremendous amount of information, fibres have extremely low loss of about 0.2 dB/km i.e., 0.5% of power loss over a distance of 1 km. Whereas, a coaxial cable for TV distribution has a loss of the order of 20 dB/km at 50 MHz, 50 dB/km at 250 MHz, etc.

Because of high information carrying capacity and low attenuation, now-a-days fibres are finding wide applications in telecommunications, local area networks, sensors, computer networks, etc.

3 THE PRIMARY ADVANTAGES OF FIBRE-OPTIC COMMUNICATION COMPARED TO METALLIC CABLE (ELECTRICAL) COMMUNICATION

3.1 Extremely Wide (Large) Bandwidth

The bandwidth available with a single glass fibre is more than 100 GHz. With such a large bandwidth, it is possible to transmit thousands of voice conversations or dozens of video signals over the same fibre simultaneously. Irrespective of whether the information is voice, data or video or a combination of these, it can be transmitted easily over the optical fibres. Whereas, only a very less number (40–50) of independent signals alone can be sent through metallic cables.

3.2 Immunity to Electrostatic Interference

As optical fibres are being made of either glass or plastic (non conductors of electricity) external electrical noise and lightning do not affect the energy in a fibre cable. The result is noise free transmission. However, this is not true for metallic cables made of metals, as they are good conductors of electricity.

3.3 Elimination of Cross Talk

Fibre systems are immune to cross talk between cables caused by magnetic induction. Whereas, in a metallic cable cross talk results from the electromagnetic coupling between two adjacent wires.

3.4 Lighter Weight and Smaller Size

Fibres are very smaller in size. This size reduction makes fibres the ideal transmission medium for ships, aircraft and high rise buildings where bulky copper cables occupy too much space. Reduction in size results in reduction of weight also.

6.3.5 Lower Cost

The material used in fibres is silica glass or silicondioxide which is one of the most abundant material on earth, resulting in lower cost. Optical-fibre costs are continuing to decline. The costs of many systems are declining with the use of fibre and that trend is accelerating.

6.3.6 Security

Fibre cables are more secure than metallic cables. Due to its immunity to electromagnetic coupling and radiation, optical fibre can be used in most secure environments. Although it can be intercepted or tapped, it is very difficult to do so because, at the receiving user's end an alarm would be sounded.

6.3.7 Greater Safety

In many wired systems, (metallic cables) the potential hazard of short circuits requires precautionary designs. Whereas, the dielectric nature of optical fibres eliminates the spark hazard.

6.3.8 Corrosion

Fibre cables are more resistive to environmental extremes. They operate over large temperature variation than their metallic counter parts, and are less affected by corrosive liquids and gases.

6.3.9 Longer Life Span and Ease of Maintenance

A longer life span of 20 to 30 years is predicted for the fibre optic cables as compared to 12 to 15 years for the conventional cables.

6.4 FIBRE CABLE CONSTRUCTION

There are many different cable designs available today. Depending on the configuration, the cable may include a core, a cladding, a protective tube, a polyurethane compound and one or more protective jackets.

The fibre cable consists of a core at the centre and a cladding outside the core. The core is generally a cylindrical dielectric glass with a refractive index n_1 and the cladding is the second sheath or cover made of glass with a lower refractive index n_2 than the core refractive index, Figure ' 1. The cladding in turn is covered by a buffer jacket. This buffer jacket provides protection for the fibre from external mechanical influences that could cause fibre breakage or excessive optical attenuation.

Surrounding the buffer jacket there is a layer of strength memebrs called Kevlar (a yarn-type material) which increases the tensile strength of the cable. Again, an outer protective tube is filled with polyurethane, which prevents moisture from coming into contact with the fibre.

When light propagate through the fibre, the light is transmitted within the core. The cladding keeps the light waves within the core because, the refractive index of the cladding material is less than that of the core.

The type of cable construction used depends on the performance requirements of the system and both the economic and environmental constraints.

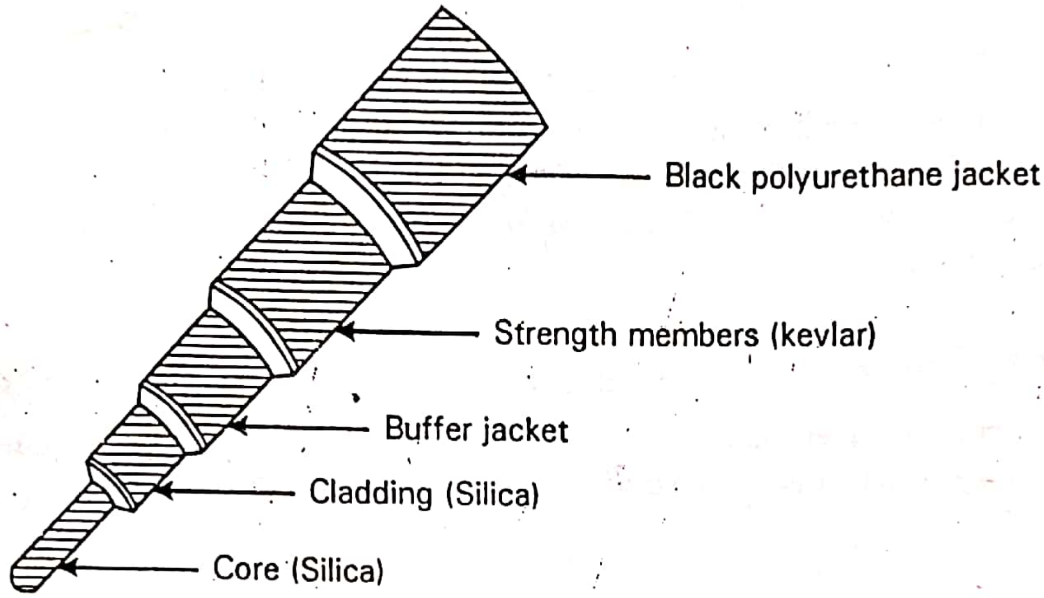

Figure 1: Fibre optic cable

5 BASIC PRINCIPLE – TOTAL INTERNAL REFLECTION

The transmission of light in an optical fibre involves the phenomena of total internal reflection at the interface between the core and cladding. Let us consider it in detail.

When light enters one end of a glass fibre under the right conditions, most of the light will propagate or move down the length of the fibre and exit from the far end.

A small part of the light will escape through the side walls of the fibre, and some will also be lost due to internal absorption. But, a portion of the light will be contained and guided to the far end. *Such a fibre is called a "light pipe" or "light guide".*

Total internal reflection within fibre wall can occur only if two conditions are satisfied.

1. *The refractive index n_1 of the core must always be greater than the refractive index n_2 of the cladding.*
2. *The light must approach the wall with an angle of incidence ϕ that is greater than the critical angle ϕ_c given by*

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

[When $\phi = \phi_c$, then by Snell's Law, $n_1 \sin \phi_c = n_2 \sin 90°$ or $\sin \phi_c = \frac{n_2}{n_1}$]

Critical angle ϕ_c is defined as the value of the incident angle at which the angle of refraction is 90°.

Figure 6.2 shows a comparison of the angle of refraction and the angle of reflection, when the angle of incidence is less than or more than the critical angle.

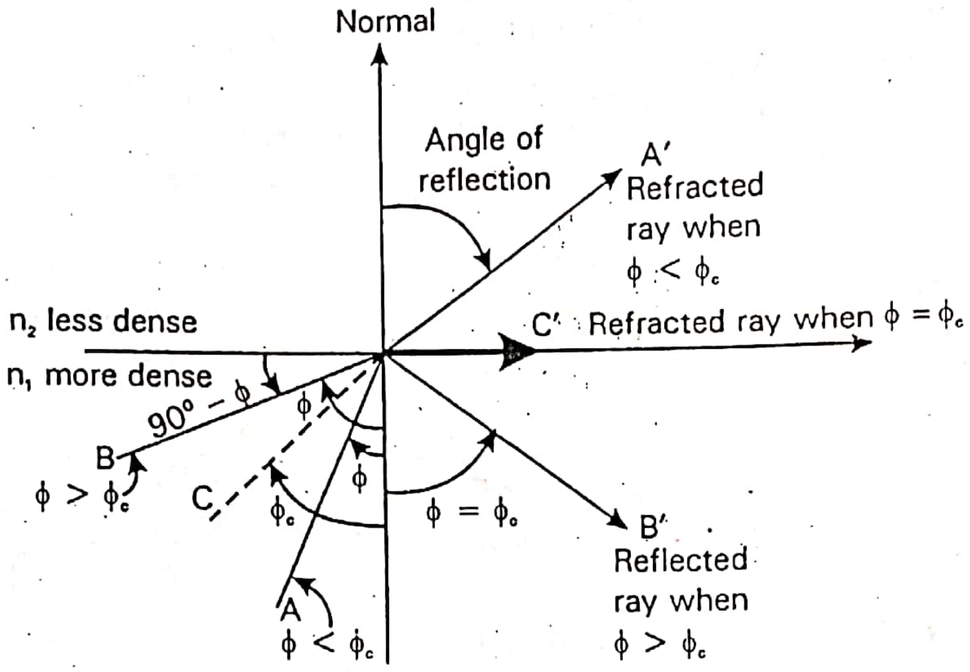

Figure 6.2: Comparison of angle of refraction and angle of reflection

1. When the angle of incidence ϕ is less than the critical angle ϕ_c, refraction occurs rather than total internal reflection, with the subsequent loss of the light ray into the cladding (Ray AA').
2. When the angle of incidence ϕ is greater than the critical angle ϕ_c, total internal reflection occurs and is reflected at the same angle to the normal (Ray BB').
3. When the angle of incidence ϕ is equal to the critical angle ϕ_c the refracted ray emerges parallel to the interface between the core and the cladding, i.e., the angle of refraction is 90° (Ray CC').

6 ACCEPTANCE ANGLE AND NUMERICAL APERTURE

6.1 Definition – Acceptance Angle

Acceptance angle of the fibre ϕ_{max} is defined as the maximum value of the angle of incidence at the entrance (air/fibre interface) end of the fibre, at which the angle of incidence at the core-cladding interface is equal to critical angle of the core medium.

Mathematically given as

$$\sin \phi_{max} = \sqrt{n_1^2 - n_2^2}$$

where n_1 and n_2 are the refractive index of the core and the cladding respectively.

6.2 Derivation

The above mathematical relation can be obtained as follows. The Figure 3 shows the longitudinal cross section of the launch end of a fibre with a ray entering it.

The core of the fibre has a refractive index n_1 and is surrounded by a cladding of material with a lower refractive index n_2.

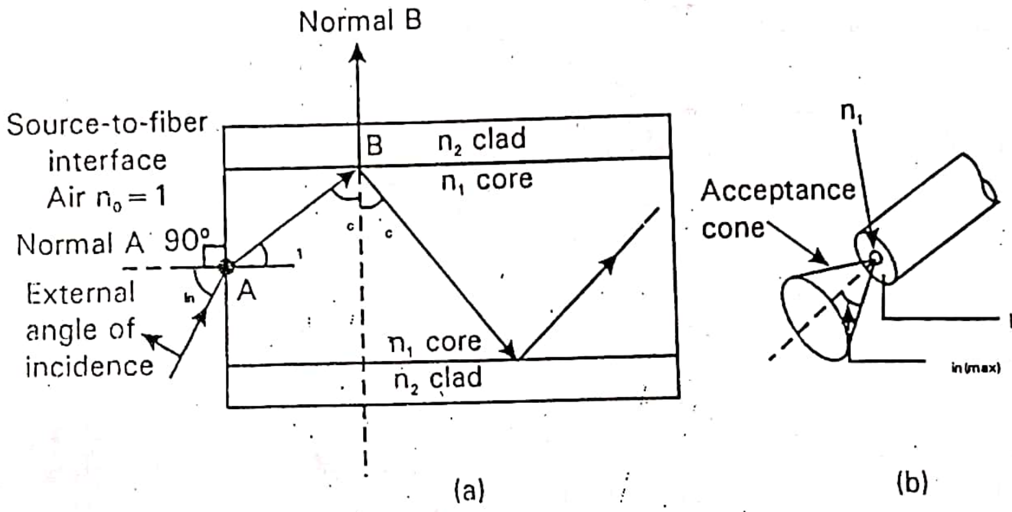

Figure 3: (a) Ray Propagation into and down an optical fibre (b) Acceptance cone

Light is launched into the end of the fibre from a launch region with a refractive index n_0. If the launch region is air then $n_0 = 1$. When light rays enter the fibre, they strike the air/glass interface at its axis point A, with an angle of incidence ϕ_{in}. Consequently, the light entering the air/glass interface propagates from a less dense medium into a more dense medium. Under these conditions and according to Snell's law, the light rays will refract towards the normal (i.e., normal B). The angle of refraction is denoted as ϕ_1. It is then reflected from the core/cladding interface at point B with an internal incidence angle ϕ_c. [This is different from the external angle of incidence at the air/glass interface ϕ_{in}.]

In order for a ray of light to propagate down the cable (i.e, for total internal reflection to take place), it must strike the internal core/cladding interface at an angle that is greater than the critical angle ϕ_c.

Applying Snell's law to the external angle of incidence yields, the following relation

$$n_0 \sin \phi_{in} = n_1 \sin \phi_1 \quad \text{...(1)}$$

But,

$$\phi_1 = 90° - \phi_c \quad \text{...(2)}$$

Therefore, substituting equation (2) in (1) we get,

$$n_0 \sin \phi_{in} = n_1 \sin (90° - \phi_c)$$

$$n_0 \sin \phi_{in} = n_1 \cos \phi_c \qquad [\because \sin (90° - \phi_c) = \cos \phi_c] \quad \text{...(3)}$$

If we consider the point B in Figure 6.3a, the critical angle value for ϕ_c is

$$\sin \phi_c = \frac{n_2}{n_1} \quad \text{[from Snell's law, refer section 5]} \quad \text{...(4)}$$

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Expressing the term $\cos\phi_c$, in equation (3), in terms of $\sin\phi_c$, then equation (3) modifies to the form,

$$n_0 \sin\phi_{in} = n_1 (1 - \sin^2\phi_c)^{1/2} \quad [\text{using } \cos^2\theta = 1 - \sin^2\theta] \qquad ...(5)$$

Substituting for $\sin\phi_c$ from equation (4)

$$n_0 \sin\phi_{in} = n_1 \left[1 - \left(\frac{n_2}{n_1}\right)^2\right]^{1/2}$$

$$n_0 \sin\phi_{in} = n_1 \left(\frac{n_1^2 - n_2^2}{n_1^2}\right)^{1/2}$$

or

$$n_0 \sin\phi_{in} = \frac{n_1}{n_1}\sqrt{n_1^2 - n_2^2} \qquad ...(6)$$

Because light rays generally enter the fibre from an air medium, $n_0 = 1$. Therefore, the maximum value of $\sin\phi_{in}$ is given as

$$\sin\phi_{in\,(max)} = \sqrt{n_1^2 - n_2^2}$$

or

$$\phi_{in\,(max)} = \sin^{-1}\sqrt{n_1^2 - n_2^2} \qquad ...(7)$$

Thus, ϕ_{in} is called the acceptance angle or acceptance cone half-angle.

Thus,

(a) Acceptance angle of the fibre is the maximum angle with which a light ray can enter into the fibre and still be totally internally reflected.

(b) A cone of light incident at the entrance end of the fibre will be guided through the fibre, provided, the semi-vertical angle of the core is less than or equal to $\phi_{in\,(max)}$ Figure 3(b).

Note :

- The angle $\phi_{in\,(max)}$ is unique only for a particular fibre. It differs from fibre to fibre and depends on the material and the core diameter.

6.3 Numerical Aperture

Numerical aperture (NA) is a Figure of merit that is used to describe the light-gathering or light collecting ability of an optical fibre. The larger the magnitude of NA, the greater the amount of light accepted by the fibre from the external light source.

Numerical aperture is mathematically defined as the sine of the acceptance cone half-angle.

Thus,

$$NA = \sin\phi_{in(max)}$$

or

$$NA = \sqrt{n_1^2 - n_2^2} \qquad ...(8)$$

The NA can also be expressed in terms of normalized refractive index difference or relative refractive index (Δ). *It is defined as the ratio of refractive index difference between core and cladding to the refractive index of core.*

i.e.,
$$\Delta = \frac{n_1^2 - n_2^2}{2n_1^2} = \frac{n_1 - n_2}{n_1} \text{ for all practical purposes.}$$

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

Solution:

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

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

$$= \sqrt{2n_1^2 \Delta} \qquad \text{if } n_1 = n_2$$

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

It can be noted that, the NA is effectively dependent only on the refractive indices of the core and cladding materials and is not a function of the fibre dimension.

Example . 1

An optical fibre core and its cladding have refractive indexes of 1.545 and 1.495 respectively. Calculate the critical angle ϕ_c acceptance angle $\phi_{in(max)}$ and Numerical aperture.

Solution:

Given,

$$n_1 = 1.545 \qquad \phi_c = ? ; NA = ?$$
$$n_2 = 1.495 \qquad \phi_{in(max)} = ?$$

1. Critical angle ϕ_c $= \sin^{-1}\left(\frac{n_2}{n_1}\right)$

$$\phi_c = \sin^{-1}\left(\frac{1.495}{1.545}\right)$$

$$\phi_c = \sin^{-1}(0.9676)$$

$$\therefore \quad \phi_c = 75° \, 23'.$$

2. Acceptance angle $\phi_{in(max)}$ $= \sin^{-1}\sqrt{n_1^2 - n_2^2}$

$$\therefore \quad \phi_{in(max)} = \sin^{-1}\sqrt{1.545^2 - 1.495^2}$$

$$= \sin^{-1}\sqrt{0.152}$$

$$= \sin^{-1}(0.3898)$$

$$\phi_{in(max)} = 22° \, 56'.$$

3. Numerical aperture $NA = \sin \phi_{in\,(max)} = \sin (22° 56')$

$\therefore$ $NA = 0.3896.$

Example : 2

The refractive index of the core and cladding materials of an optical fibre are 1.54 and 1.5 respectively. Calculate the numerical aperture of the optical fibre.

Solution:

Given, $n_1 = 1.54$; $n_2 = 1.50$; NA = ?

Formula:

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

$$= \sqrt{(1.54)^2 - (1.5)^2} = \sqrt{0.1216}$$

$\therefore$ $NA = 0.3487.$

Example . 3

A silica optical fibre has a core of refractive index 1.55 and a cladding of refractive index of 1.47. Determine (a) the critical angle at the core cladding interface (b) the numerical aperture for the fibre and (c) the acceptance angle in air for the fibre.

Solution:

Given, $n_1 = 1.55$; $n_2 = 1.47$; $\phi_c = ?$; NA = ? ; $\phi_{in(max)} = ?$

Formula:

(a) The critical angle is $\phi_c = \sin^{-1}\left(\frac{n_2}{n_1}\right) = \sin^{-1}\left(\frac{1.47}{1.55}\right)$

$$\phi_c = \sin^{-1} (0.94838)$$

$\therefore$ $\phi_c = 71° 30'.$

(b) The numerical aperture for the fibre is

$$NA = \sqrt{n_1^2 - n_2^2} = \sqrt{1.55^2 - 1.47^2} = \sqrt{0.2416}$$

$\therefore$ $NA = 0.4915.$

(c) The acceptance angle in air for the fibre is

$$\phi_{in(max)} = \sin^{-1} (NA) = \sin^{-1} (0.4915)$$

$\therefore$ $\phi_{in(max)} = 29° 26'.$

Example : 4

An optical fibre has a numerical aperture of 0.20 and a cladding refractive index of 1.55. Determine the acceptance angle for the fibre in water which has a refractive index 1.33.

Solution:

Given,

$n_2 = 1.55$, $NA = 0.20$, $n_0 = 1.33$

$n_1 = ?$; NA in water = ? and $\phi_{in(max)} = ?$

When fibre is in air $n_0 = 1$

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

$$\text{or} \qquad NA^2 = n_1^2 - n_2^2$$

$$\therefore \qquad n_1^2 = n_2^2 + NA^2$$

$$\text{or} \qquad n_1 = \sqrt{n_2^2 + NA^2}$$

$$= \sqrt{1.55^2 + 0.20^2}$$

$$n_1 = \mathbf{1.5628.}$$

when fibre is in water $n_0 = 1.33$

Therefore, numerical aperture when fibre is in water is

$$NA = \frac{\sqrt{n_1^2 - n_2^2}}{n_0} = \frac{\sqrt{0.03984}}{1.33} = \frac{0.19960}{1.33}$$

$$\therefore \qquad NA = \mathbf{0.1500.}$$

Hence acceptance angle is

$$\phi_{in(max)} = \sin^{-1}(NA)$$

$$= \sin^{-1}(0.1500)$$

$$\therefore \qquad \phi_{in(max)} = \mathbf{8^\circ\ 37'.}$$

Example 5

Calculate the refractive indices of the core and cladding material of a fibre. [Given, NA = 0.22 and relative refractive index difference $\Delta = 0.012$]

Solution:

Numerical aperture in terms of relative refractive index difference is

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

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

$$= \frac{0.22}{0.1549} = 1.420$$

To find n_2:

Formula - 1

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

$$NA^2 = n_1^2 - n_2^2$$

$$\therefore \quad n_2^2 = n_1^2 - NA^2$$

$$\text{or} \quad n_2 = \sqrt{n_1^2 - NA^2}$$

$$= \sqrt{1.968}$$

$$n_2 = 1.402.$$

The refractive index of the cladding is **1.402.**

Formula - 2

$$\frac{n_1 - n_2}{n_1} = \Delta$$

$$\therefore \quad n_2 = n_1 (1 - \Delta)$$

$$= 1.42\ (1-0.012)$$

$$= 1.42 \times 0.988$$

$$\therefore \quad n_2 = \mathbf{1.402.}$$

7 TYPES OF OPTICAL FIBRES

The optical fibres can be classified into different types based on:

(a) Materials of which the fibres are made

(b) The mode of propagation and (c) the refractive index (index profile).

7.1 Fibre materials

The fibre materials normally used in the manufacture of fibres are:

1. High content silica glass.
2. Multicomponent silica glass.
3. Plastic.

In the latest trend heavier atoms like halide materials are also used because of low Rayleigh scattering and UV absorption.

Basic requirements to be satisfied by a material to obtain highest quality of optical fibres.

1. It must be possible to make long, thin flexible fibres from the material.
2. Physically compatible materials having slightly different refractive indices for the core and cladding must be available.
3. The material must be transparent at a particular optical wavelength to guide the light efficiently.

To establish a difference in the refractive index between the core and cladding dopants usually oxides such as TiO_2, Al_2O_3, GeO_2, P_2O_5, etc. will be mixed with silica system consisting of silicondioxide.

The physical properties such as thermal expansion, viscosity, low material scattering, low melting temperatures and long term chemical stability of the glasses used for core and cladding must be similar.

Attenuation and dispersion are very high in the case of multicomponent glass and plastic fibres. Hence, they cannot be used for mass communication. But, a high content silica glass fibre is found to be more suitable for mass communication.

8 TYPES OF OPTICAL FIBRES BASED ON MATERIAL

There are three major types of optical fibres based on the material type of make. In all the three types, the core as well as the cladding can be made of either glass or plastic. The three types are:

1. Plastic core with plastic cladding.
2. Glass core with plastic cladding (Also called PCS fibre, plastic-clad-silica).
3. Glass core with Glass cladding (Also called SCS fibre, silica-clad-silica).

8.1 Plastic Core with Plastic Cladding

This type of fibres are commonly used because, in this both the core and the cladding being made up of same material simplifies the production process.

The advantage of this fibre are, they are more flexible, easy to install can better withstand stress, less expensive and weigh approximately 60% less than glass fibres. The major disadvantage is that, the attenuation characteristic of this plastic fibres are high. But, even then they are frequently used for short distance computer applications with information capabilities of about 6 Mbps over a distance of 50–200 meters.

Example:

1. A polystyrene core and a methyl methacrylate cladding.
2. A polymethyl methacrylate core and a cladding of its co-polymer.

8.2 Glass Core with Plastic Cladding (PCS)

fibres with glass cores exhibit low attenuation characteristics. The PCS fibres are less affected by radiation and hence more suitable for military applications.

8.3 Glass Core with Glass Cladding (SCS)

The attenuation characteristics of this SCS fibre are slightly better than PCS fibres. These fibres have best propagation characteristics and can also be easily terminated. SCS fibres are least rugged and they are more susceptible to increase in attenuation in radiation areas.

Example:

1. SiO_2 core, P_2O_5-SiO_2 cladding.
2. P_2O_5-SiO_2 core, SiO_2 cladding.

9 PROPAGATION (TRANSMISSION) OF LIGHT THROUGH AN OPTICAL FIBRE

Light can be propagated down an optical fibre by either reflection or refraction.

In reflective type light rays travel in a zigzag fashion (in step-index fibre), whereas in refractive type light rays travel in a continuous wave from, i.e., the path of travel will appear almost sinusoidal (in graded-index fibre).

How the light is propagated depends on the mode of propagation and the index profile of the fibre.

9.1 Mode of Propagation

In fibre optics terminology, the word mode simply means path. That is, it defines the number of paths being taken by the light to propagate down the cable. There are only two modes of propagation.

1. Singlemode fibre (also known as monomode or Fundamental fibre).
2. Multimode fibre.

Singlemode Fibre

If there is only one path for the light to propagate down the cable, it is called a single mode fibre, Figure 6.4a. Inorder for the light to take a single path the diameter of the core must be very small (about 7 to 10 μm).

Singlemode fibres are capable of wide bandwidths (up to 40 GHz) and are ideally suited for long haul communication. Low cost and high capacity circuits for the transmission of telephone and cable television etc., are the additional features of this fibre.

Multimode Fibre

If the light takes more than one path to propagate down the cable it is called a multimode fibre, Figure 6.4b.

Fibres with cores of about 20 to 100 μm diameter, support many waveguide modes (i.e., light can take many paths). These fibres are ideally suited for high bandwidth (a few GHz) medium haul applications. The upper limit of the mode is determined by the core diameter and numerical aperture.

Note:

- Long-Haul is a term used to describe the transmission of data over hundreds or thousands of miles.

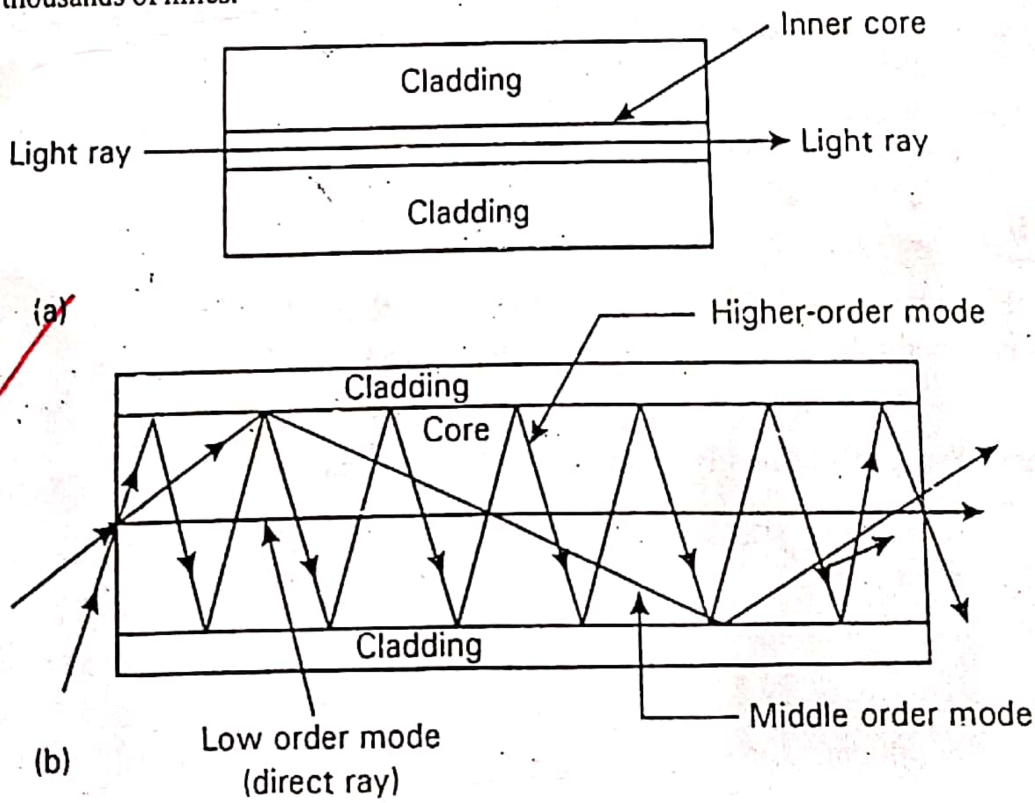

Figure 6.4: Modes of Propagation-(a) Singlemode fibre (b) Multimode fibre

Note:

- *V-number:* The number of modes supported for propagation in the fibre is determined by a parameter called V-number. It is given by $V = \frac{2\pi a}{\lambda}\sqrt{n_1^2 - n_2^2}$ where a is the radius of the core and λ is the free space wavelength. In terms of NA, $V = \frac{2\pi a}{\lambda}(NA)$.

  The maximum number of modes for a SI fibre is given by $N_m = \frac{V^2}{2}$. For GRIN fibre $N_m = \frac{V^2}{4}$. For SMF $V < 2.405$ and for MMF $V > 2.405$.

10 INDEX PROFILE

In any optical fibre, the whole material of the cladding has a uniform refractive index value. But, the refractive index of the core material may either remain constant or subjected to variation in a particular way.

The curve which represents the variation of refractive index (along the vertical axis) with respect to the radial distance (along the horizontal axis) from the axis of the fibre is called the refractive index profile.

There are two basic types of index profiles:

1. Step-index fibre.
2. Graded-index-fibre.

10.1 Step-Index Fibre

A step index fibre has a central core with a uniform refractive index. The core is surrounded by an outside cladding with a uniform refractive index less than that of the central core. Figure 6.5(a) shows the index profile for a step-index fibre. From the Figure it is seen that, there is an abrupt change in the refractive index at the core/cladding interface and hence the refractive index profile takes the shape of a step. Hence, the name step-index fibre.

10.2 Graded Index Fibre (GRIN Fibre)

In a graded index fibre the refractive index of the core is non-uniform, it is highest (maximum) at the center and decreases gradually with distance towards the outer edge, Figure 6.5(b).

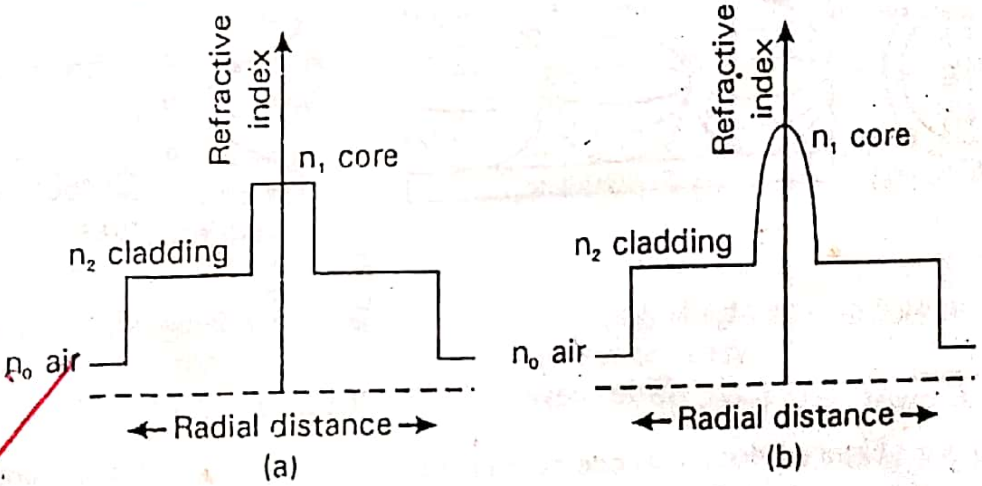

Figure 5: (a) Step index fibre (b) Graded index fibre

11 FIBRE CONFIGURATIONS

Essentially, there are three types of optical fibre configurations (combining the mode and index profile):

1. Singlemode step-index fibre.
2. Multimode step-index fibre.
3. Multimode graded index fibre.

11.1 Singlemode Step-Index Fibre (SMSI Fibre)

A single mode step index fibre has a central core material of uniform refractive index value. The diameter of the core is (8–10 μm) sufficiently small so that, there is essentially only one path that light may take as it propagates down the cable.

Similarly, the cladding also has a material of uniform refractive index of lesser value. The diameter of the cladding is 60–70 μm, Figure 6.6.

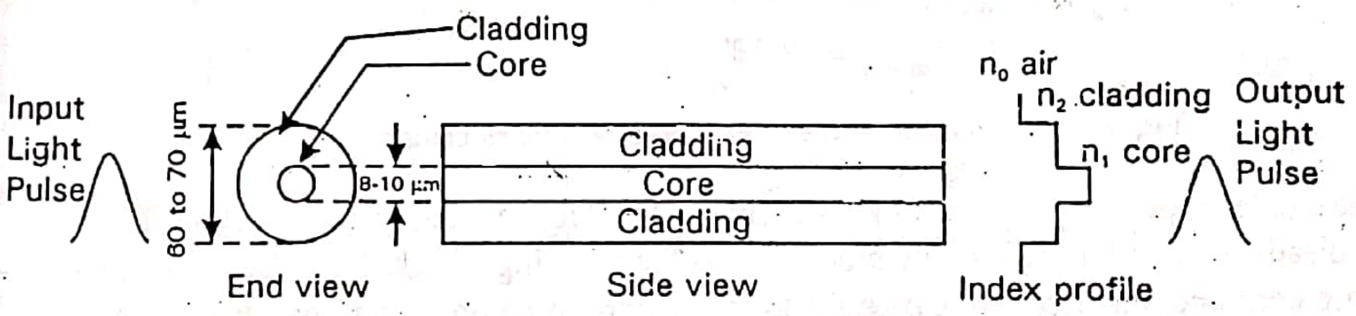

Figure ...6: Singlemode step index fibre
(Including Typical Dimensions, Index profile and Pulse Dispersion Effects)

The simplest form of single mode step index fibre has glass core and air cladding Figure 6.7. Eventhough it is relatively easy to couple light from a source into the cable, this type of fibre is very weak and of limited practical use.

A more practical type of single mode step index fibre is one, that has a cladding other than air. This type of cable is physically stronger than air-clad fibre and the critical angle is also much higher ≃ 77°. This results in a small acceptance angle and a narrow source to fibre aperture Figure 6.8 making it much more difficult to couple light into the fibre from a light source. With both types of single mode step index fibres light is propagated down the fibre through reflection. Light rays that enter the fibre propagates straight down the core or perhaps are reflected once. Consequently all light rays follows approximately the same path down the cable and take approximately the same amount of time to travel the length of the cable.

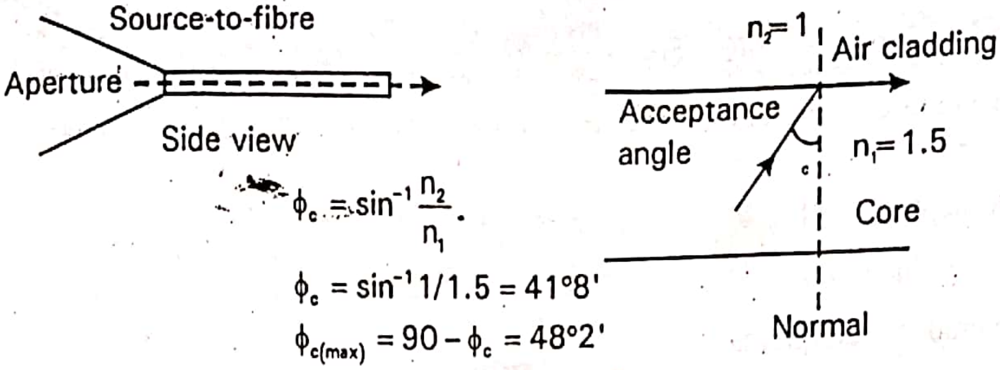

Figure 6.7: Singlemode Step index fibre with air cladding

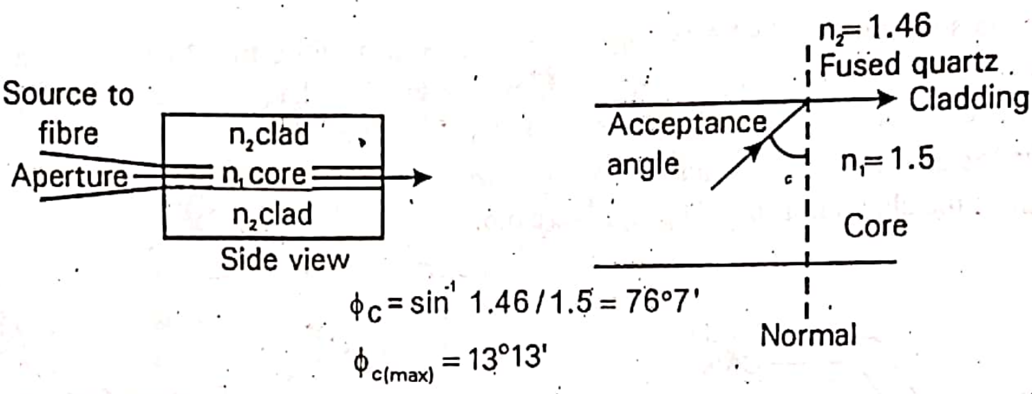

Figure 6.8: Singlemode Step index fibre with glass cladding

The single mode step index fibres are widely used in long-haul telecommunication. The major disadvantage of using a single mode fibre is the coupling of light from the source to the fibre core and again coupling of light from the core to an optoelectronic detector or when trying to splice it to another length of fibre.

11.2 Multimode Step-Index Fibre (MMSI Fibre)

In comparison to the single-mode fibre, multimode fibre has a relatively large core of diameter 50–100 µm and a high numerical aperture. The diameter of the cladding usually lie between 100–250 µm, Figure 6.9. These fibres support many waveguide modes.

As there are many paths for the light to propagate, all light rays do not follow the same path, and consequently, do not take the same amount of time to travel the length of the fibre.

For example, the lowest order mode is seen travelling along the axis of the fibre, and the middle-order mode is reflected twice at the interface. The highest-order mode is reflected many times and makes many trips across the fibre, Figure 6.9. As a result of these variable path lengths, the light entering the fibre takes a variable length of time to reach the detector. This results in a pulse broadening or dispersion characteristic as shown in Figure 6.9. This effect is termed pulse dispersion, and limits the maximum distance and rate at which data (pulses of light) can be practically transmitted.

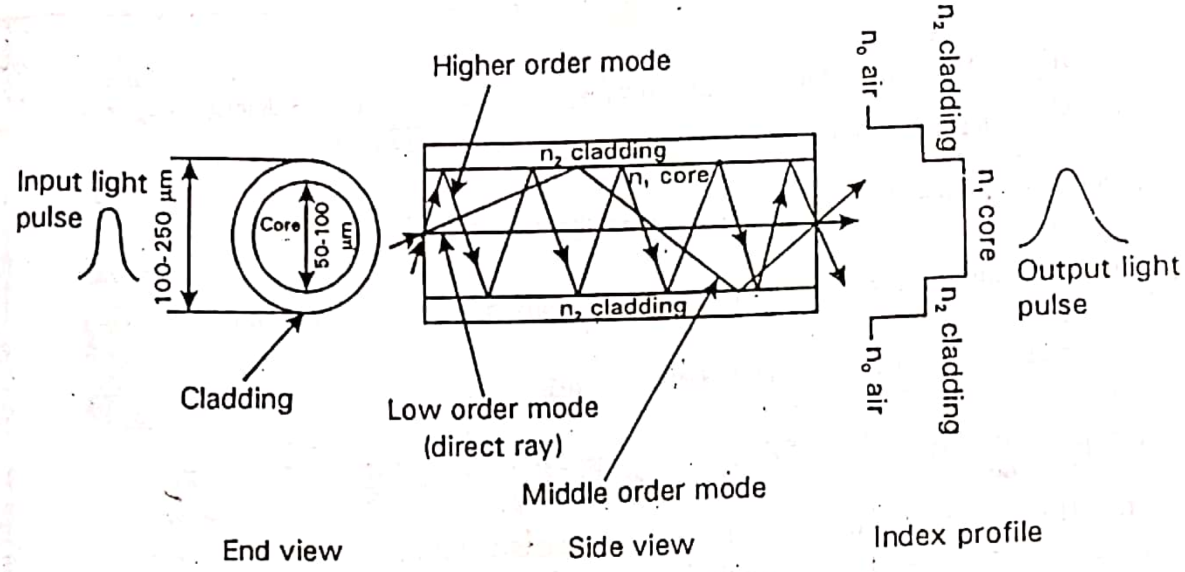

Figure [illegible].9: Multimode Step index fibre

· From the Figure it is also seen that, the output pulse has reduced amplitude as well as increased width. The greater the fibre length, the worse this effect will be, as a result step-index multimode fibres are rarely used in telecommunications.

Note:

- Pulse dispersion means the stretching of received pulse width because of the multiple paths taken by the light.

11.3 Multimode Graded Index Fibre

In an effort to reduce the pulse dispersion, multimode graded index fibre was developed. A multimode graded index fibre is characterised by a central core that has a refractive index which is not uniform. It is maximum at the centre and (minimum) decreases gradually towards the outer edge as shown in Figure 6.10.

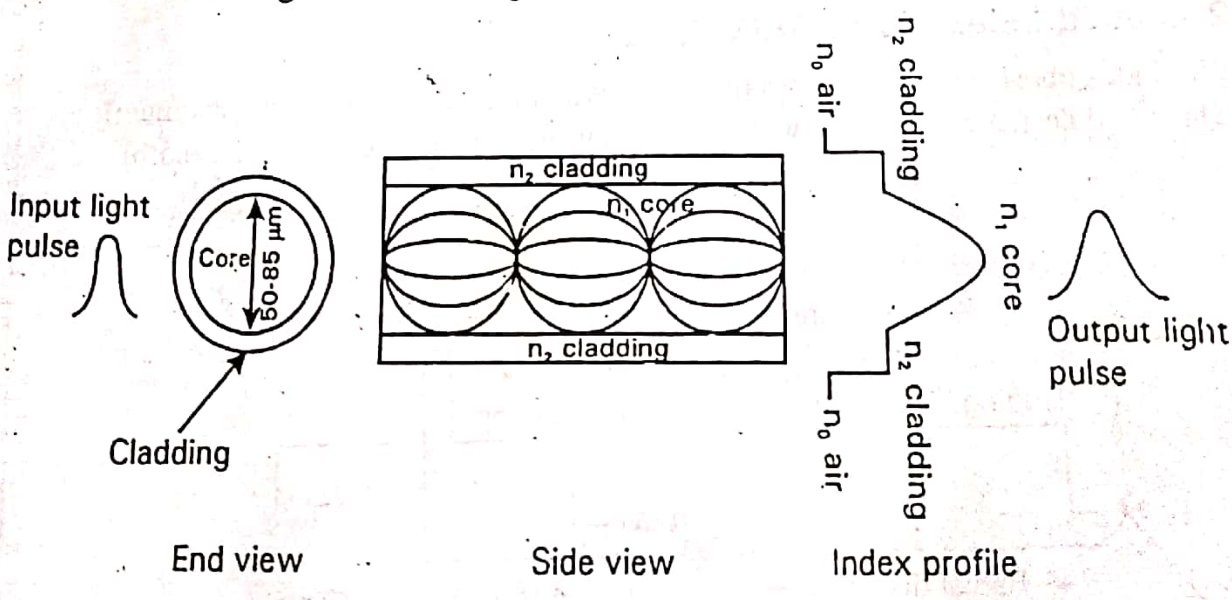

Figure [illegible].10: Multimode graded index fibre

This results in lower order modes travelling through the constant density material in the center, Figure 6.10. High-order modes see lower index of refraction material further from the core axis, and thus the velocity of propagation increases away from the centre (since velocity is inversely proportional to the refractive index). Therefore all modes, even though they take various paths and travel different distances, tend to travel the fibre length in about the same amount of time. These fibres can therefore handle higher bandwidths and provide longer lengths of transmission before pulse dispersion effect destroy the transmitted pulse.

Light is propagated down this fibre through refraction. As a light ray propagates diagonally across the core towards the centre it is continuously intersecting a more-dense interface. Consequently, the light rays are constantly being refracted, resulting in a continuous bending of light rays. Thus, the path of travel therefore appears almost sinusoidal Figure 6.11.

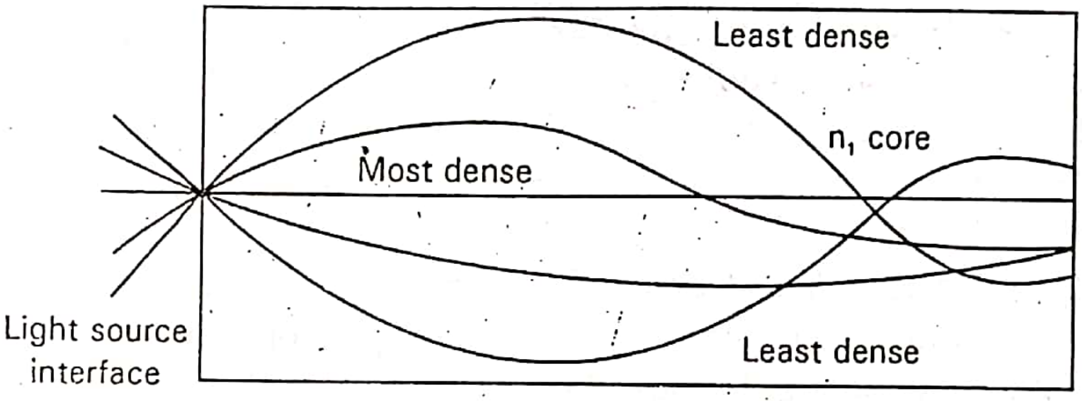

Figure 6.11:

Multimode graded index fibre has a bandwidth of upto 1600 MHz/km and is generally used in data communications (LAN's).

12 DIFFERENCE BETWEEN SINGLEMODE FIBRE AND MULTIMODE FIBRE

S.No.	*Singlemode fibre*	*Multimode fibre*
1.	Light can propagate through the fibre in only one mode.	Light can propagate through the fibre with a large number of modes.
2.	The fibre core diameter is very small (~10 μm) and also, the difference between and the refractive indices of the core and cladding is very small.	The fibre core diameter is large and also, the difference in refractive indices of the core cladding is also large.
3.	Since light propagates in singlemode, no dispersion occurs (i.e., no degradation of light signal takes place during propagation through the fibre).	Due to multimode propagation and material scattering, there is signal degradation.
4.	Launching of light into the fibre and coupling process is not easy.	Launching of light into the fibre and coupling process are easy.
5.	Used in long haul communication.	Used in LAN (local Area Network).
6.	Since, the fabrication is difficult, the production cost is high.	Since, the fabrication is easy, the production cost is low.

13 DIFFERENCE BETWEEN STEP INDEX FIBRE AND GRADED INDEX FIBRE

S.No.	Step index fibre	Graded index fibre
1.	Refractive index of the core cladding is uniform.	Refractive index of the core is not uniform. But, the refractive index of the cladding is uniform.
2.	Since there is an abrupt change in the refractive index at the core and cladding interface, the refractive index profile takes the shape of a step. Hence, called step index fibre.	In this fibre, the refractive index of the core is maximum at the centre and decreases gradually (parabolic manner) with distance towards the outer edge. Hence, called graded index fibre.
3.	Pulse dispersion is more in single mode step index fibre.	Pulse dispersion is reduced by a factor of 200 in comparison to step index.
4.	Attenuation is less for single mode step index fibre and more for multimode step index fibre.	Attenuation is less.
5.	Number of modes of propagation for a multimode step index fibre is given by $N_{step} = 4.9\left(\frac{d \times NA}{\lambda}\right)^2$ where d is diameter of the core, λ is optical wavelength and NA is Numerical aperture.	Number of modes of propagation for a multimode graded index fibre is given by $N_{graded} = \frac{4.9 \times \left(\frac{d \times NA}{\lambda}\right)^2}{2}$ i.e., $N_{graded} = \frac{N_{step}}{2}$ Thus, the number of modes is half the number supported by a MMSI fibre.
6.	The light rays propagate through the fibre in the form of meridional rays. i.e., the rays follow a zig zag path when they travel through fibre and, for every reflection it will cross the fibre axes.	The light ray propagate through the fibre in the form of skew rays. i.e., The rays follow a helical path around the fibre axis, and they would not cross the fibre axis at any time during their propagation.
7.	SMSI fibre are expensive and difficult to manufacture. But, MMSI are inexpensive and simple to manufacture.	Graded index fibres are easy to manufacture.
8.	The bandwidth for singlemode step index fibre is more than multimode step index fibre.	Multimode graded index fibre has a higher band width.
9.	Numerical aperture is very less for singlemode step index fibre but is more for MMSI fibre.	Numerical aperture is high.

Applications of Fiber optic cables

Fiber optic cables find many uses in a wide variety of industries and applications. Some uses of fiber optic cables include:

Data Transmission

Fiber optic cables can be laid and used for data transmission and receiving. It increases the speed and accuracy.
Light travels through the fiber with minimal attenuation, which dramatically reduces data loss.

Networking

The increased accuracy, bandwidth, flexibility, and speed of fiber optic cables make them perfect candidates for computer networking. Fiber optics can be used in trunk cables, distribution cables, high-density interconnect cables, and standard patch cords.

Medical

Medical environments have used fiber optic cables as light guides and in imaging tools. This is because they can shine a bright light on a target without requiring a straight path. A coherent bundle of fibers is used, some times along with lenses, for a long, thin imaging device called an endoscope, which is used to view objects through a small hole. Medical endoscopes are used for minimally invasive exploratory or surgical procedures (endoscopy).

Wiring

Complex or difficult wiring jobs have been simplified through the use of fiber optic cables. They have been used to wire aircraft, submarines and other challenging machines.

Sensors

Fiber optic cables can also be used as sensory devices that detect temperature, pressure, vibration, torque, or other measurable perceptions. Sensors that vary the intensity of light are the simplest, since only a simple source and detector are required. A particularly useful feature of such fiber optic sensors is that they can, if required, provide distributed sensing over distances of up to one meter.

Spectroscopy

In spectroscopy, optical fiber bundles are used to transmit light from a spectrometer to a substance which cannot be placed inside the spectrometer itself, in order to analyze its composition. A spectrometer analyzes substances by bouncing light off of and through them. By using fibers, a spectrometer can be used to study objects that are too large to fit inside, or gasses, or reactions which occur in pressure vessels.