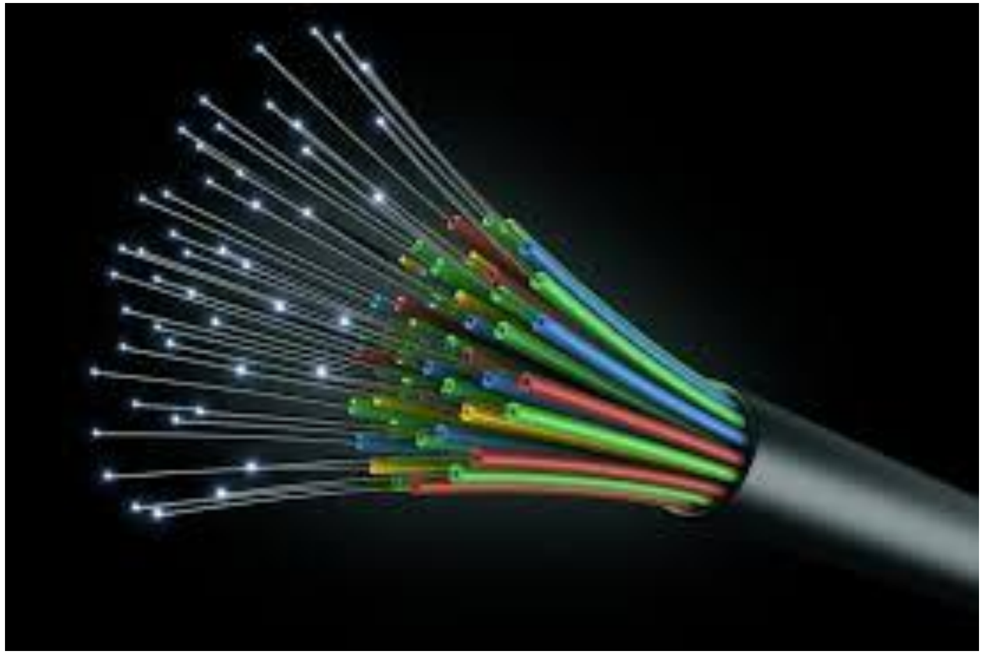
Unit-V

FIBRE OPTICS

An Introduction and Applications

By: Dr. Vanita Thakur

Optical fibre cables



Fibre Optics

It is a technology in which signals are converted from electrical form into optical signals, transmitted through a thin glass fibre and reconverted into electrical signals.

Optical fibre is a cylindrical waveguide made of a transparent dielectric (glass or plastic), in which light waves are guided along its length along its length by *total Internal reflection.*

Its thickness is around ~70 μm.

So, Fiber Optics is a technology related to transportation of optical energy (light energy) in guiding medium specifically.

Optical fibre

- An optical fiber is essentially a waveguide for light.

- An Optical Fiber, is a flexible transparent fiber made by glass(silica) or plastic to a diameter slightly thicker than that a human hair.

- It consists of a **core** and **cladding** that surrounds the core.

- The **index of refraction** of the cladding is less than that of the core, causing rays of light leaving the core to be refracted back into the core

- A light-emitting diode (LED) or **laser diode** (LD) can be used for the source.
- It Carries EM waves of visible and IR frequencies from one end to the other end of the fiber by means of TIR.

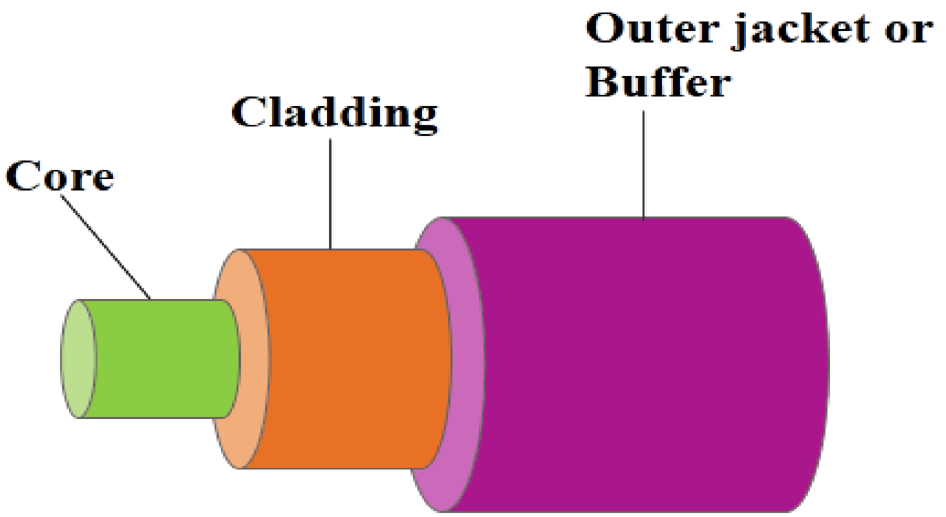
Structure of Optical fibres

Optical fibre cable consists of 3-main parts:

1. **Core- Innermost part**
(diameter $\approx 8.5\ to\ 62.5\ \mu m$)

2. **Cladding- Middle region**
(diameter $\approx$ 125 µm)

3. **Outer jacket or Buffer Coating- Outermost region**
$(diameter\ 250\ to\ 900\ \mu m)$



Structure of Optical Fibre

➢ Core:

- This is the physical medium that transports optical signals from an attached light source to a receiving device.
- The larger the core, the more light the cable can carry, which correlates to a higher data transfer rate.
- The refractive index of core is higher than cladding.

➢ Cladding:

- This is a thin layer that is extended over the core and serves as the boundary that contains the light waves, enabling data to travel through the length of the fiber.
- It prevents the light from escaping from core i.e. it confines the light to the core.
- The refractive index of cladding is lower than core.

➢ Outer jacket or Buffer Coating:

- This is the outer layer, or sheathing, of the cable. Its purpose is to protect the cable from environmental hazards, moisture, radiation, contaminations, etc.

Necessity for Cladding

The cladding performs the following important functions:

- Keeps the size of the fibre constant and reduces loss of light from the core into the surrounding air.
- Protects the fibre from physical damage and absorbing surface contaminants
- Prevents leakage of light energy from the fibre through evanescent waves.

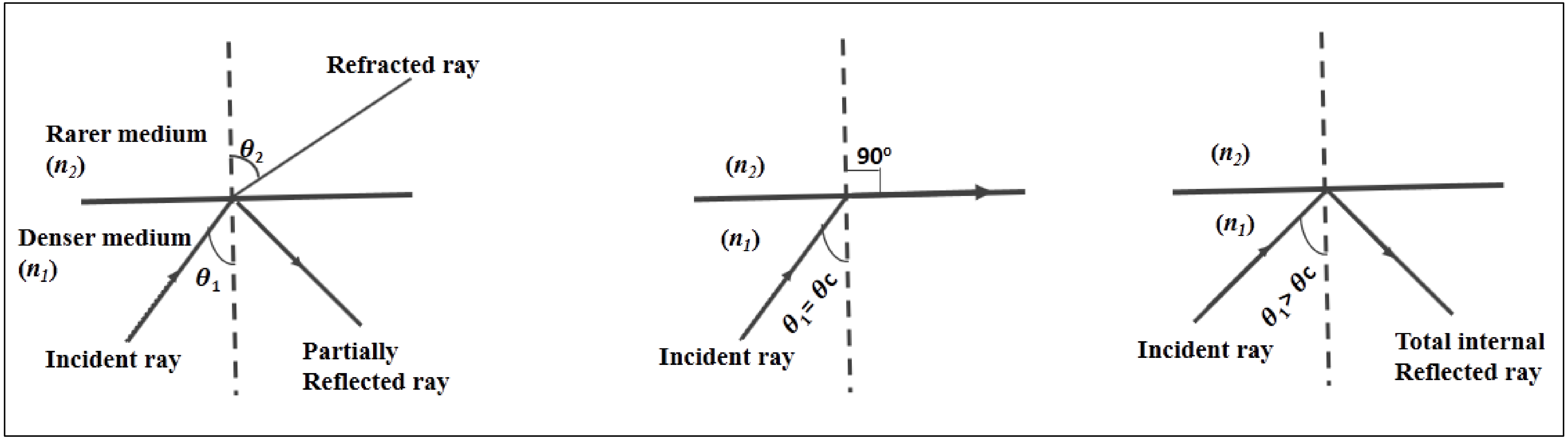
- Prevents leakage of light energy from the core through frustrated total internal reflection.
- Reduces the core of acceptance and increases the rate of transmission of data.
- A solid cladding, instead of air, also makes it easier to add other protective layers over the fibre.

Basic Principle of Optical fibres

- The propagation of light signal in optical fibre is based on the principle of **Total Internal Reflection.**

When a light ray is incident on a medium, three possibilities are there:

- If $\theta_1 < \theta c$, the ray refracts into the rarer medium.
- If $\theta_1 = \theta c$, the ray travels along the interface of denser -to- rarer media.
- If $\theta_1 > \theta c$, the ray is reflected back into the denser medium.



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The critical angle can be calculated from Snell's law:

$$\frac{\sin\theta_2}{\sin\theta_1} = \frac{n_1}{n_2} \qquad \text{------- (1)}$$

where n_1- refractive index of denser medium

n_2- refractive index of rarer medium.

clearly, $n_1 > n_2$

when, $\theta_1 = \theta c$, $\theta_2 = 90^o$

From *eqn*. (1),

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

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

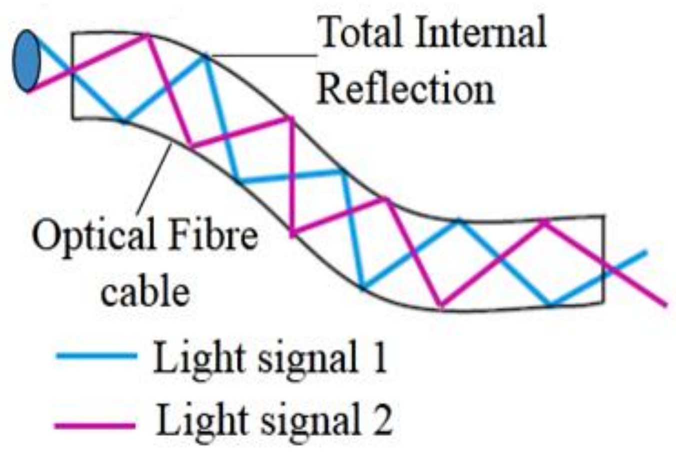
If the rarer medium is air, $n_2 = 1$, and let $n_1 = n$, we get

$$\sin\theta_c = \frac{1}{n}$$

$$n = \frac{\text{Speed of Light in Free Space}}{\text{Speed of Light in the Medium}}$$

PROPAGATION OF LIGHT THROUGH AN OPTICAL FIBER

- LED and laser diodes are the light sources used for this purpose alongwith the focusing lens.
- In the optical fibre, light propagates as an electromagnetic (EM) wave.
- Propagation of light through an optical fiber can be understood on the basis of ray model.
- According to which, the light rays entering the fibre hit the core-cladding interface at different angles and since the refractive index of cladding is less than that of core, therefore the rays undergo total internal reflections (TIR).
- Thus, the rays travel down the optical fibre via multiple total internal reflections and emerge out at the other end of fibre, where the light signal is detected by the photodetector.



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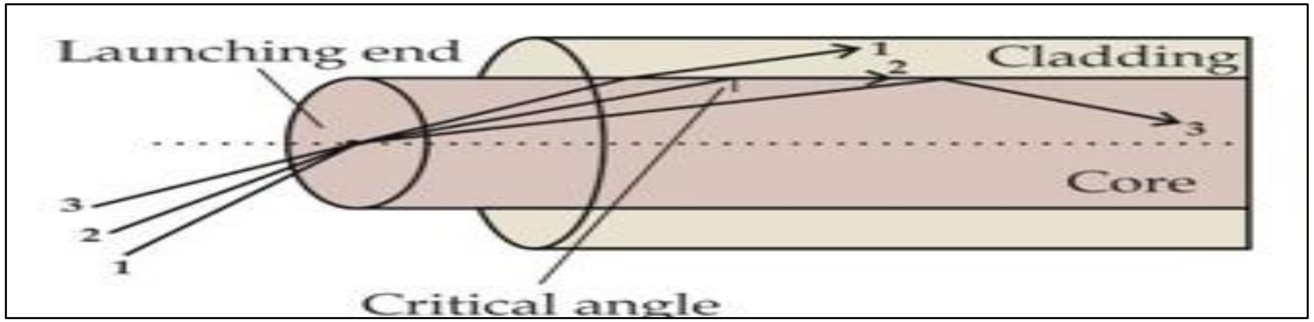
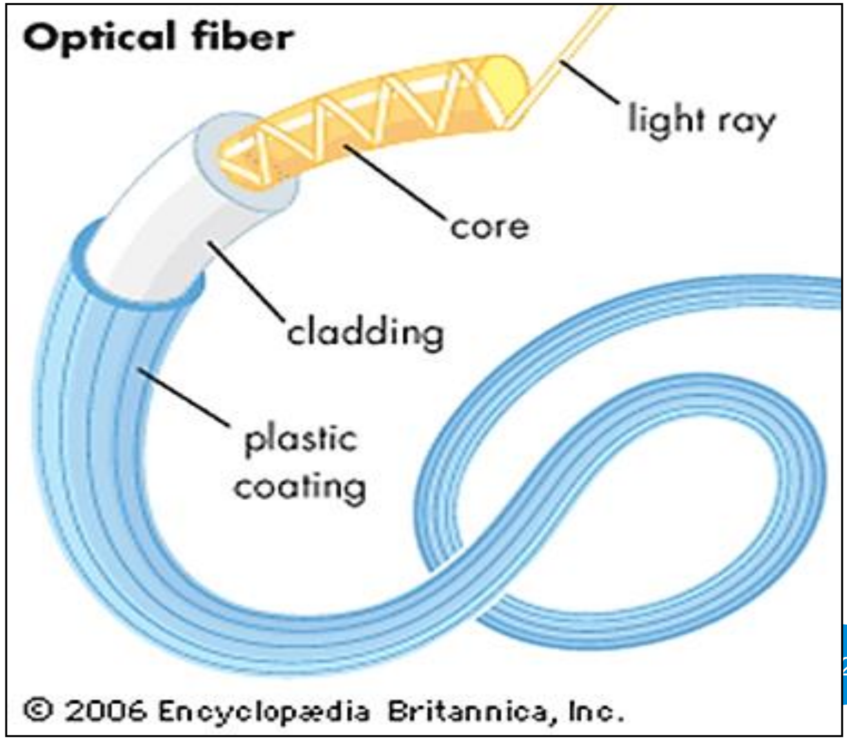
The total internal reflection (TIR) will take place in the fibre only if the following two conditions will be met:

i. Refractive index of core should be made greater than the refractive index of cladding.

$$n_{core} > n_{clad}.$$

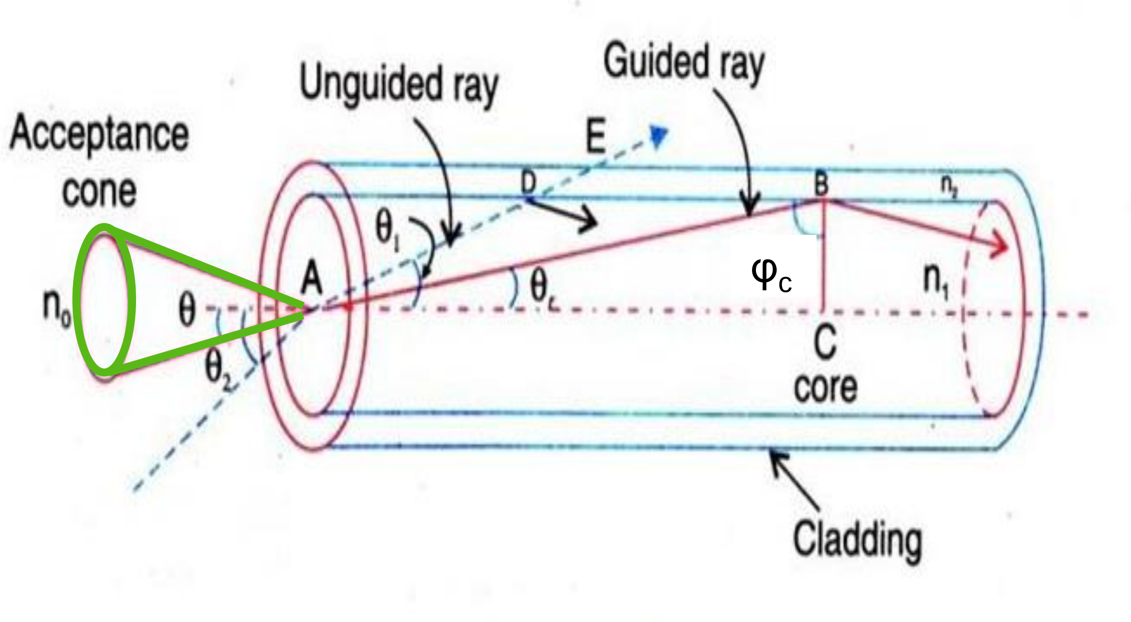
ii. At the core-cladding interface, angle of incidence must be greater than the critical angle (ϕ_c).





Critical angle of Propagation

- A ray incident with an angle larger than θ_c will be confined to the fibre and propagate in the fibre.
- A ray incident , at the core-cladding boundary, at the critical angle is called **critical ray.**
- The critical ray makes an angle θ_c with axis of the fibre.
- It is obvious that rays with propagation angles larger than θ_c will not propagate in the fibre.
- Therefore, the angle θ_c is called the **critical propagation angle.**



$$\frac{AC}{AB} = \sin \phi_c$$

$$also, \frac{AC}{AB} = \cos \theta_c$$

$$\sin \phi_c = n_2/n_1$$

$$\cos \theta_c = n_2/n_1$$

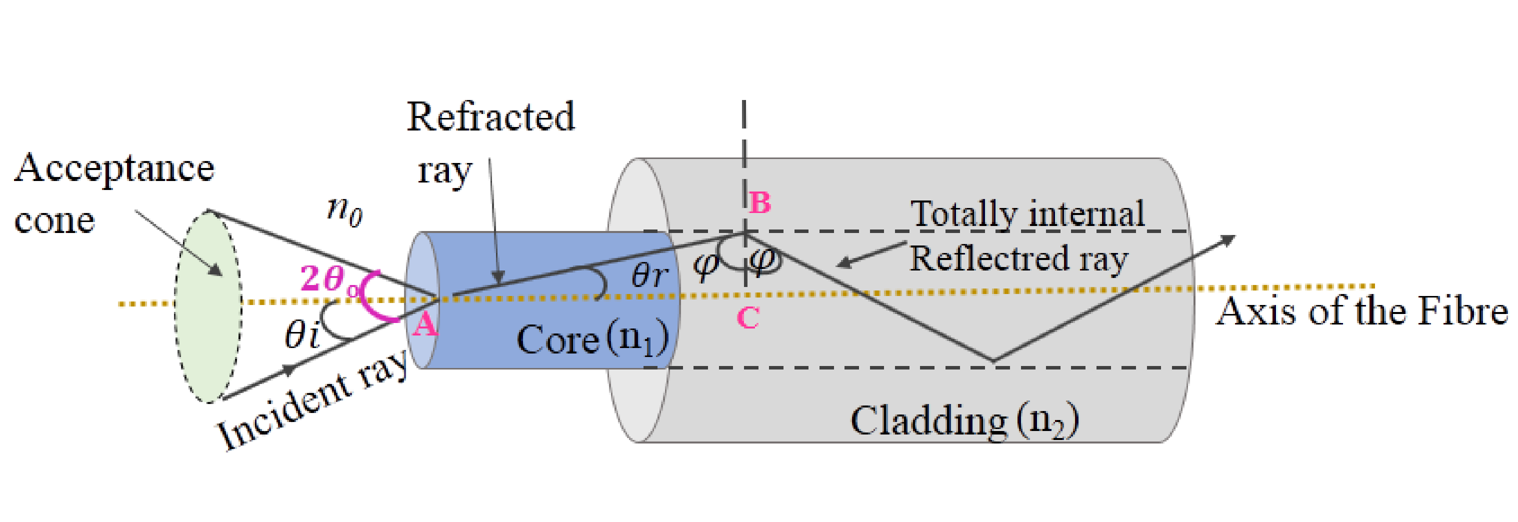
$$\theta_c = \cos^{-1} \frac{n_2}{n_1}$$

Thus, only those rays which are refracted into the the cable at angles $\theta_r < \theta_c$ will propagate in the optical fibre.

ACCEPTANCE ANGLE

Acceptance angle is the maximum angle of incidence at which a light ray may enter the fibre in order to be guided along the core.

- Assume the light ray enters the fiber at an angle θi to the axis of fibre and refracts at an angle θ_r and strikes the core -cladding interface at an angle **φ.**
- If $\varphi > \varphi_c$, the ray will undergo total internal reflection as $n_2 > n_1$.
- As long as $\varphi > \varphi_c$, the light ray will remain within the fibre.



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Applying Snell`s law to launching end,

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

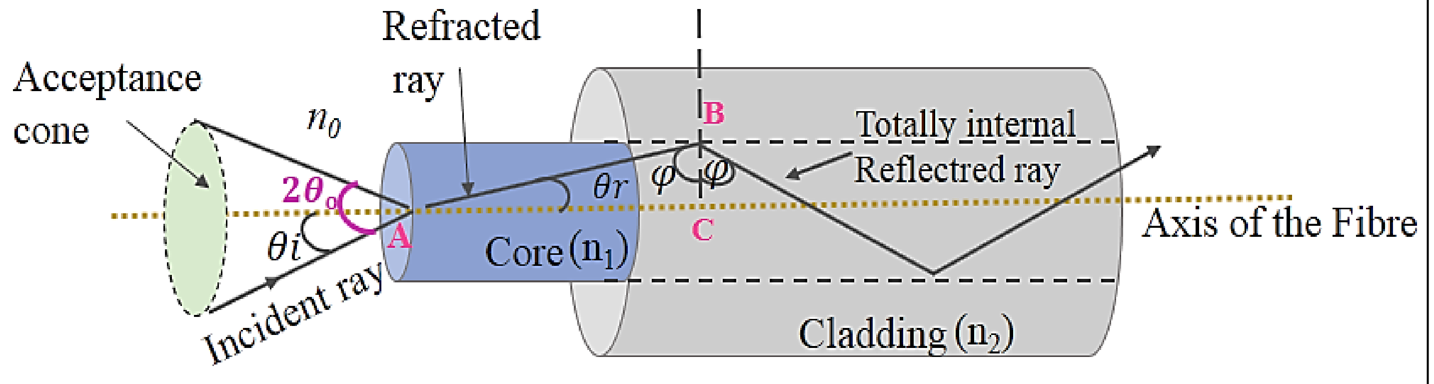
The maximum value of θi occurs when $\varphi = \varphi_c$.

From ΔABC,

$$\sin\theta_r = \sin(90^0 - \varphi) = \cos\varphi \quad \text{----------- (2)}$$

Using eqn. (2) in (1), we get

$$\sin\theta_i = \frac{n_1}{n_0}\cos\varphi$$



when, $\varphi = \varphi_c$

$$\sin[\theta_i]_{max.} = \frac{n_1}{n_0}\cos\varphi_c \quad \text{---------- (3)}$$

$$But,\ \sin\varphi_c = \frac{n_2}{n_1}$$

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

$$\cos^2\varphi_c = 1 - \sin^2\varphi_c$$

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

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

$$\cos\varphi_c = \frac{1}{n_1}\sqrt{n_1^2-n_2^2} \qquad \text{--------}(4)$$

Substituting eqn. (4) in (3), we get

$$\sin[\theta_i]_{max} = \frac{1}{n_0}\sqrt{n_1^2-n_2^2} \qquad \text{-----------}(5)$$

In most of the cases, light is incident from air, so, in that case $n_o = 1$

also putting, $\theta_{i\,max} = \theta_0$, eqn. (5) becomes,

$$\sin\theta_0 = \sqrt{n_1^2-n_2^2}$$

$$\boldsymbol{\theta_0 = \sin^{-1}\left[\sqrt{n_1^2-n_2^2}\right]}$$

θ_o is the acceptance angle of the fibre.

Thus, of all the light rays' incident on the face of fibre, only those light rays will enter the fibre and undergo multiple total internal reflections, which fall at an angle less than θ_o.

All other rays with $\theta_o > \theta$, will refract through cladding and will escape the fibre.

In 3-dimensions, the light rays that fall within the cone having angle $2\theta_o$ are accepted and travel along the fibre. This cone is called acceptance cone.

Fractional Refractive Index Change (Δ)

- The fractional difference (Δ) between the refractive indices of the core and the cladding is known as fractional refractive index change. It is calculated as:

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

- Δ is always positive as $n_1 > n_2$, for total internal reflection condition.
- Δ << 1, for light rays to be guided effectively.
- Typically, $\Delta \approx 0.01$

NUMERICAL APERTURE (NA)

- *Numerical Aperture determines the light gathering capability of an optical fiber. It is the measure of the fraction of light that can be accepted by an optical fiber.*

Numerical Aperture is defined as the sine of the acceptance angle. Thus,

$$NA = \sin\theta_o \qquad \text{---------}(1)$$

where, θ_o is the acceptance angle.

Also, $\sin\theta_0 = \sqrt{n_1^2 - n_2^2}$

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

$$n_1^2 - n_2^2 = (n_1 + n_2)\,(n_1 - n_2) = \left(\frac{n_1 + n_2}{2}\right)\left(\frac{n_1 - n_2}{n_1}\right)2n_1$$

But, $\frac{n_1 + n_2}{2} \approx n_1$,

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

Therefore, $(n_1^2 - n_2^2) = 2\, n_1^2\Delta$

Using above value in eqn. (2), we get $NA = \sqrt{2n_1^2\Delta}$

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

The above expression gives the ***relation between NA and fractional refractive index change***.

Modes of propagation

- When light is launched into an optical fibre only certain ray directions are allowed to propagate. These allowed directions correspond to the **modes of the fibre**.

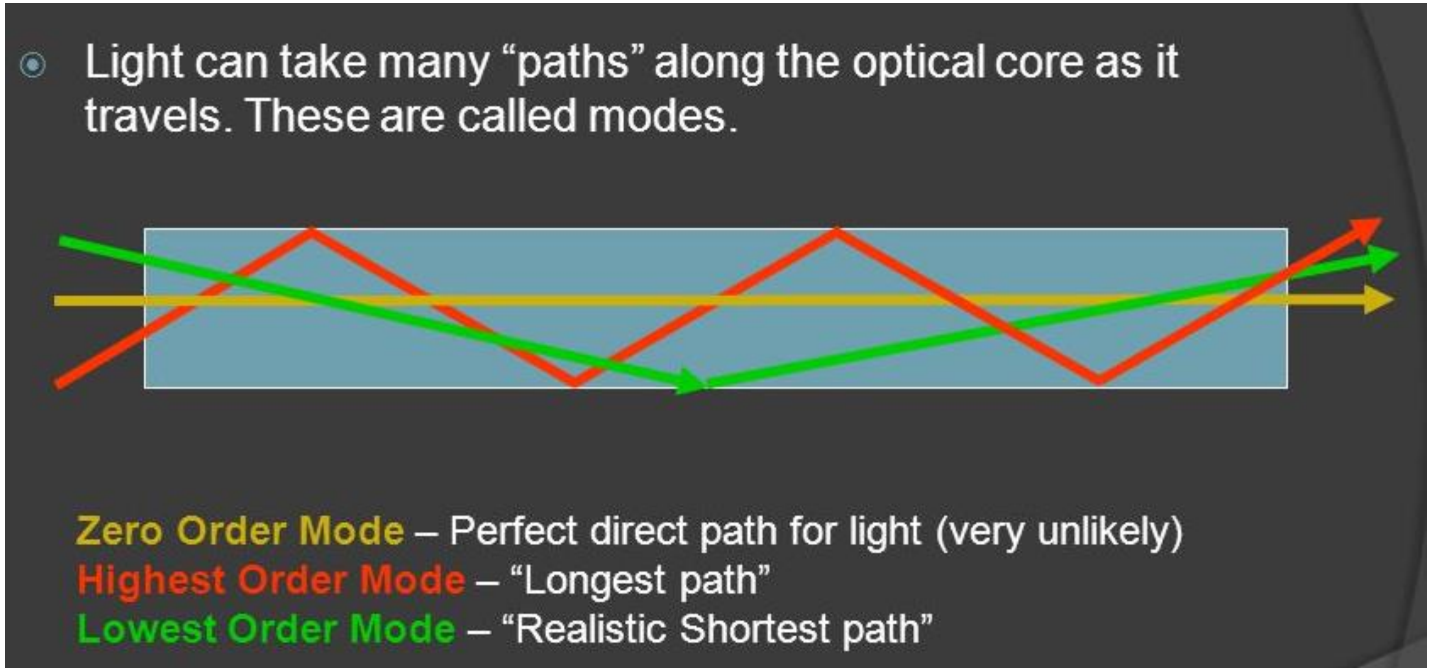
In simple terms, **modes can be visualized as the possible number of paths of light in an optical fibre.**

- The paths are all zig zag excepting the axial direction.
- The light ray paths along which the waves are in phase inside the fibre are known as modes.
- The number of modes propagating in a fibre increases as critical agle or Δ increases.
- Increasing the core refractive index also increases number of propagating modes.
- On the other hand, Increasing the clad refractive index decreases the number of propagating modes.
- The number of modes that a fibre will support depends on the ratio d/λ

where d is the diameter of the core and λ is the wavelength of the wave being transmitted.

The zero order ray travels along the axis is known as *axial ray*.

In a fibre of fixed thickness, the modes that propagate at angles close to the critical angle are higher order modes.
The modes that propagate with angles larger than the critical angle are lower order modes.



When a light ray is guided through an optical fibre, it propagates I different types of modes. Each of theses guided modes consists of a variety of EM field configurations, such as Transverse electric (TE), transverse Magnetic (TM) and hybrid modes.

- In case of lower order modes , the fields are concentrated near the centre of the fibre.
- In case of higher order modes, the fields are distributed more towards the edge of the wave-guide
- This mode of tend to send light energy into the cladding.
- This energy is lost ultimately.
- The higher order modes have to traverse longer paths and hence take larger time than the lower order modes to cover a given length of the fibre.
- Thus, the higher order modes arrive at the output end of the fibre later than the lower order modes.

Evanescent Field

- For light reflecting at angles near the critical angle, a significant portion of the power extends into the cladding i.e. the medium which surrounds the core. These are known as known as the evanescent waves. The field created is called Evanescent field.
- These waves extends only to a short distance from the interface, with power dropping exponentially with distance.

Normal frequency or V-number

- An optical fibre is also characterized by one more parameter known as normalized frequency or V-number of optical fibre.
- **The V-number of any optical fibre is helpful to decide about the number of modes that it can support.**
- A mode is a path that a light wave can follow as it travel down the core of the fibre. A step index optical fibre can support number of modes ranging from 1 to 10,000.
- The V number of any optical is fibre is given by

$$V = \frac{2\pi a}{\lambda}\sqrt{n_1^2 - n_2^2}$$

where 'a' is the radius of core and λ is the wavelength of optical signal. In term of numerical aperture.

$$\mathbf{V = \frac{2\pi a}{\lambda} N.A.}$$

For optical fibres with large V-number, the possible number of supported modes is approximately given by

$$N \approx \frac{1}{2}V^2$$

Note : This is a approximate formula and should not be used for fibre carrying only a few modes i.e. small V-number. When

(i) **$V < 2.405$**, the optical fibre can support only one mode.

(ii) **$V > 2.405$**, the optical fibre can support more than one mode and known as multi mode optical fibre.

(iii) **$V = 2.405$**, the wavelength corresponding to $V = 2.405$ is known as cut off wavelength λ_c.

In case of GRIN fibres, for larger values of V

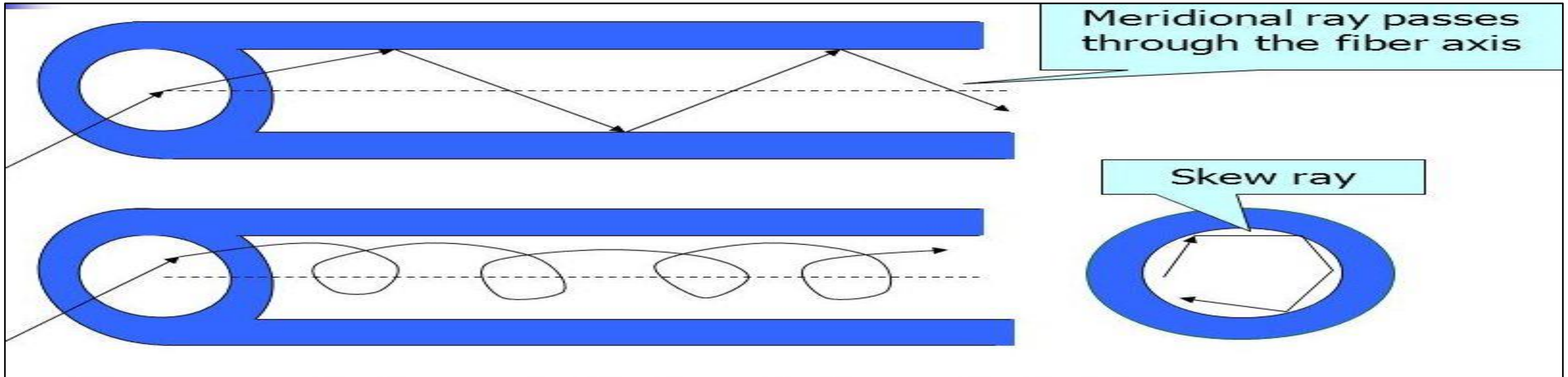
$$N \approx \frac{1}{4}V^2 \ .$$

Types of Rays

- The rays that propagate in optical fibres can be classified into two types:

1. **Meridional Rays:** A **meridional ray** is a **ray** that passes through the longitudinal axis of an optical fiber. The propagation of these rays is possible only in TE or TM modes.

2. **Skew rays**: A **skew ray** is a **ray** that travels in a non-planar zig-zag path and never crosses the axis of an optical fiber. Skew rays are also known as helical rays as they move on helical path inside the optical fiber. These rays propagate only in annular region near the outer surface of core.



Skew ray follows helical path in optical fiber

Optical Light Sources

- Light emitters and detectors are the key elements in optical fiber technology.
- **Light emitters** convert the electrical signal into corresponding optical signals that can be injected into fibers and detectors convert the light signal in to suitable electrical signal at the receiver.

Generally use light emitters are

1. LED
2. Laser diode

Generally use light detectors are

1. Photo diode
2. p-i-n diode
3. APD

LED's and Laser Diodes acts as signal emitters and must meet certain requirements:

1. Light emitted must be monochromatic, to minimize chromatic dispersion and hence to increase transmission bandwidth.
2. Light emitted must be intense enough so that transmission over relatively long distances is possible inspite of intrinsic losses.
3. Light sources must be capable of being easily modulated.
4. Light sources must be smll and compact so that the output can be easily and effectively coupled to fibres.
5. Light sources must be durable and inexpensive.

Photodetectors

1. High quantum efficiency (i,.e. photon to electron conversion)
2. Adequate frequency response
3. Low dark current
4. Low signal dependent noise

TYPES OF OPTICAL FIBRES

R.I

Based on
Refractive index

- **Step-index fibres**
- **GRIN (Graded index)**

MODES

Based on
Modes of Propagation

- **Step index single mode fibre**
- **Step index Multimode fibre**
- **GRIN Multimode fibre**

Material

Based on
Materials

- **Glass/Glass**
- **Plastic/Plastic**
- **PCS (Plastic clad silica)**

Classification Based on Refractive Index:

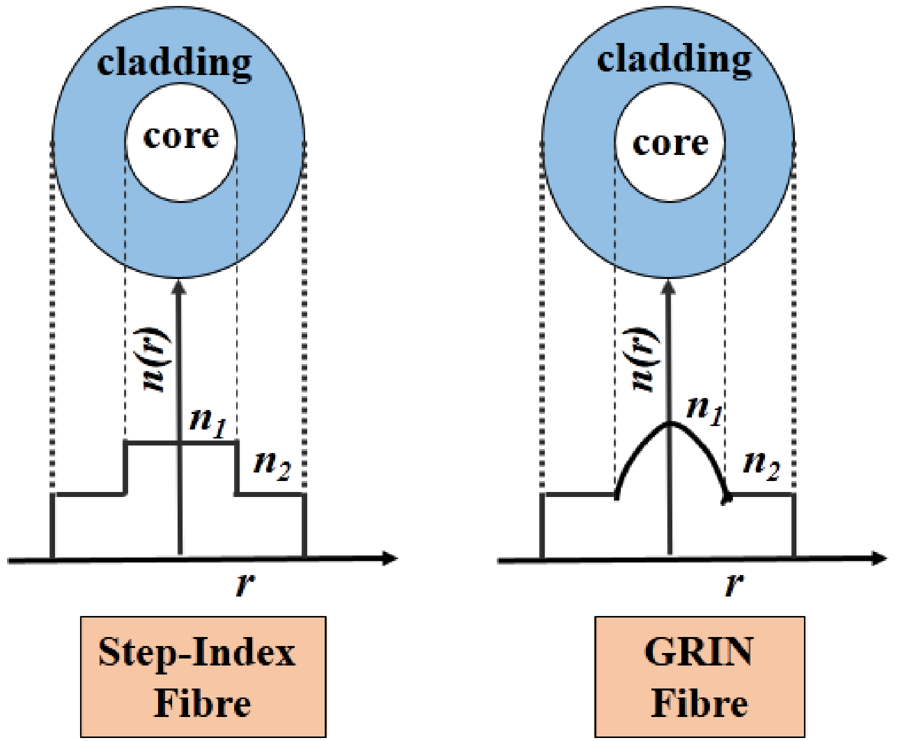
1. Step-index Fibres

In such type of fibres there is uniform refractive index within the core and a sharp decrease in refractive index at the core-cladding interface so that the cladding is of a lower refractive index.

Step index fiber is found in two types, that is **mono mode fiber and multi mode fiber.**

2. Graded Index Fibres:

The refractive index of the core in graded-index fibers is not constant but decreases gradually from its maximum value n_1 at the core center to its minimum value n_2 at the core-cladding interface.



Comparison of SI and GRIN Fibres

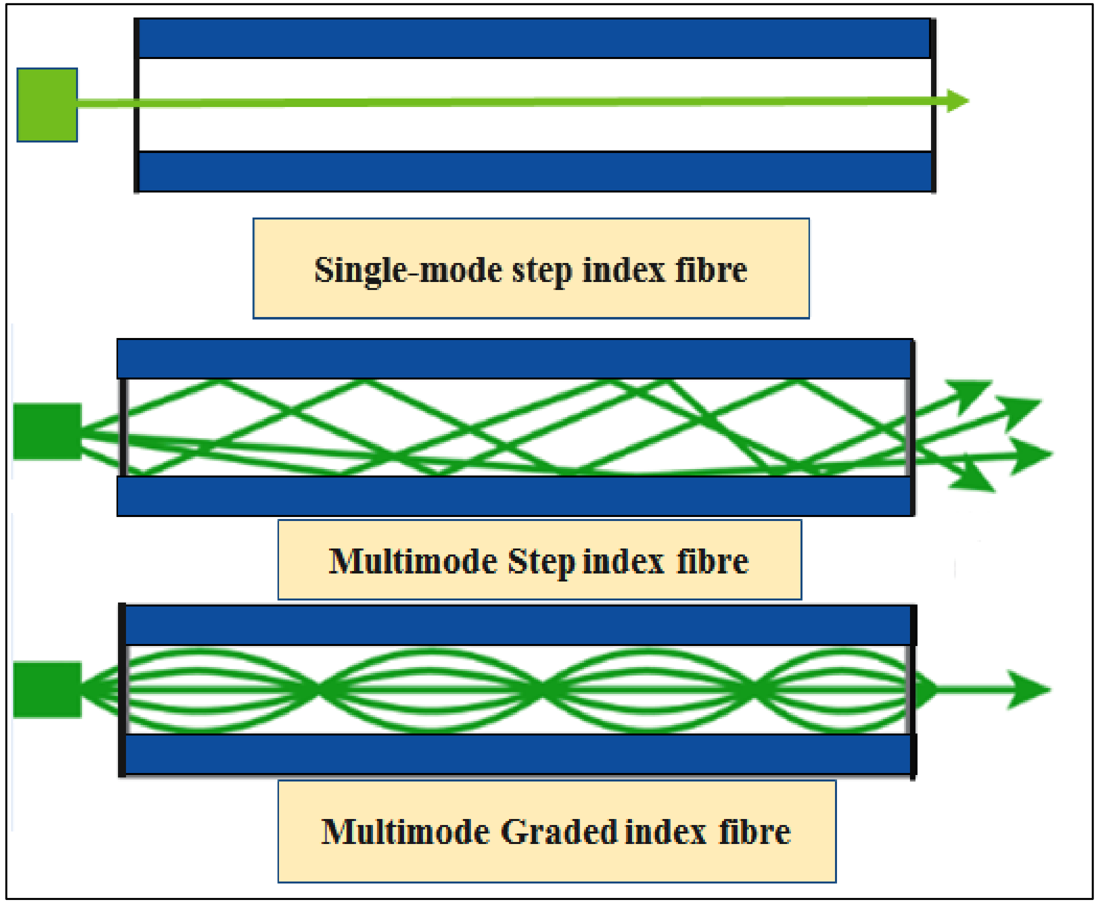
Sr. No.	Step-index Fibres	Graded index Fibres
1.	Refractive index of core is constant throughout and falls abruptly to a lower value at the core-cladding interface.	Refractive index of core is not constant but varies gradually over the diameter of core.
2.	Both single & multimode propagations exist.	Only multimode propagations exist.
3.	Used for short distance applications	Used for long distance applications
4.	The attenuation losses are more approx. of the order 100 dB/km for multimode fibre. However, for single mode fibres attenuation is less.	Attenuation losses are less i.e of the order 10dB/km.
5.	They are Easy to manufacture	These fibres are difficult to manufacture

Classification Based on Modes of Light Propagation:

On the basis of modes the Optical fibres are classified into 2-categories:

1. Single mode fibres (SMF) :
Also known as Single mode step index fibers.

2. Multimode fibres (MMF)
- Multimode Step index Fibers
- Graded index multimode Fibers



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Thus, on the whole there are three types of Optical fibres:

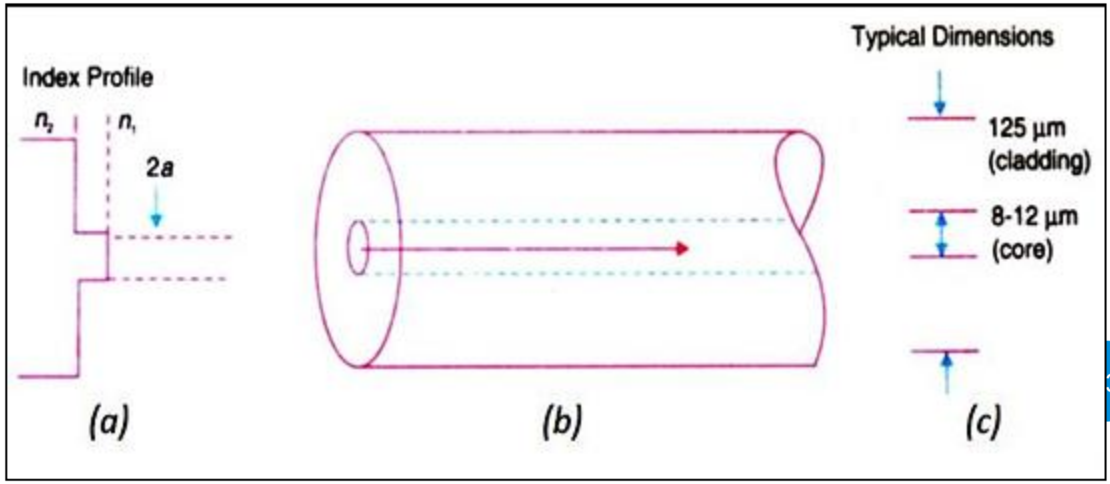
1. Single mode step index fibers
2. Multimode Step index Fibers
3. Graded index multimode Fibers

1. Single mode Step Index Fibre (SMF)

- These type of fibres have a smaller core diameter and can support only one mode of propagation.
- In these fibres, light propagates along straight path.
- Single mode fibres usually have a low signal losses and high information carrying capacity. Therefore, SMF are generally used for long distance transmission and large bandwidth applications such as telephone and cable television networks.

The variation of the refractive index of a step index fibre as a function of radial distance be mathematically represented as

$$n(r) = n_1 \; [r < a \;\; in \;\; core]$$
$$= n_2 \; [r > a \;\; in\, cladding]$$

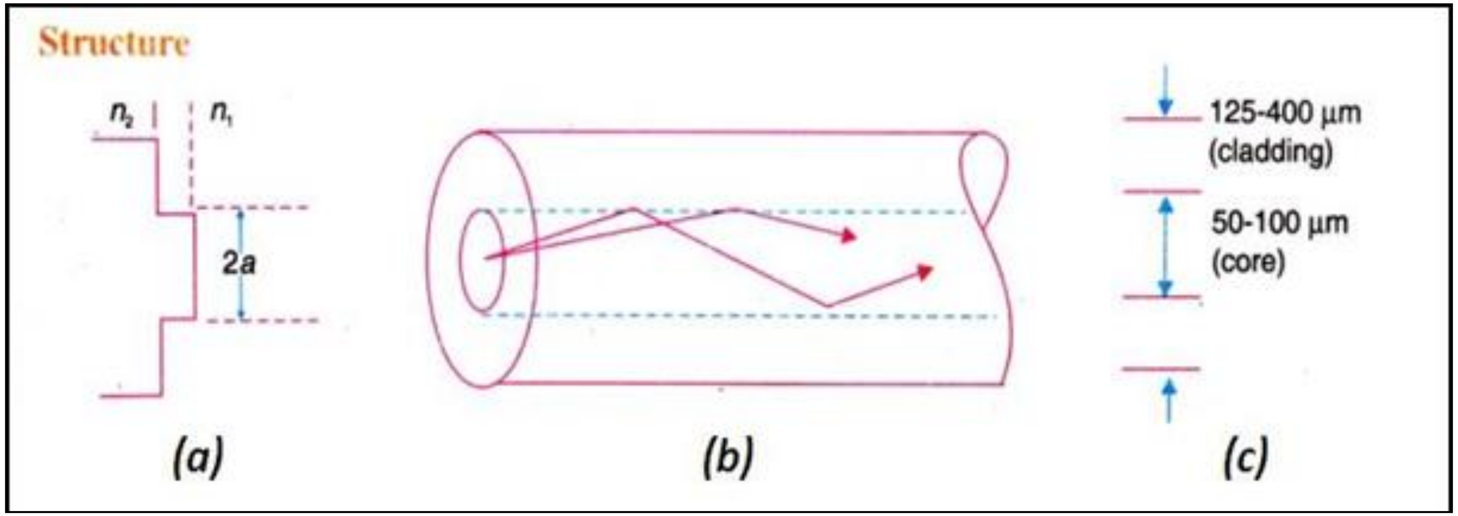


Propagation of light in SMF

- Light travels in SMF along a single path that is along the axis as shown in figure
- It is the zero order mode that is supported by a SMF
- Both Δ and N A are very small for single mode fibres.
- This small value is obtained by reducing the fibre radius and by making Δ to be small.
- The low N A means low acceptance angle.
- Therefore, light coupling into the fibre becomes difficult.
- Costly laser diodes are needed to launch light into SMDF.

2. Multimode Step Index Fibre (MMF)

- A multimode step-index fibre is quite similar to the single mode step-index fibre except for that it has larger core diameter.
- A multimode step-index fibre supports a finite number of modes of propagation of light.
- Different light rays will travel along different paths (zig-zag paths).



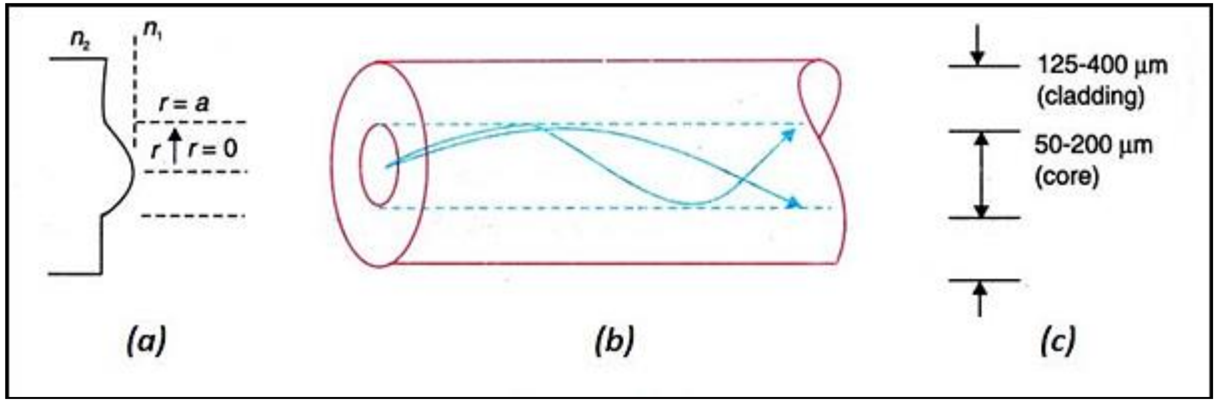
Propagation of light in MMF

- Multimode step index fibre allows finite number of guided modes.
- The direction of polarization, alignment of electric and magnetic fields will be different in rays of different modes.
- Many zigzag paths of propagation are permitted in a MMF.
- The path length along the axis of the fibre is shorter while the other zigzag paths are longer.
- The lower order modes reach the end of the fibre earlier while the high order modes reach after some time delay

3. Graded Index (Multimode) Fibre (GRIN)

- It is a multimode fibre in which refractive index of core is non-uniform.
- Since, in these fibres light rays propagates from a region of higher refractive index to a region of lower refractive index, it experiences refraction, thus, it gets bent towards the core.
- In these fibres, the incident light rays do not travel by following a straight line path, however, they follow parabolic path because of the non-uniformity in the refractive index of the core.

$$n(r) = \begin{cases} n_1 \sqrt{1 - \left[2\Delta\left(\frac{r}{a}\right)^{\alpha}\right]}, & r < a \text{ inside core} \\ n_2, & r > a \text{ in cladding} \end{cases}$$



Classification Based on Modes of Light Propagation:

Sr. no.	Single mode Fibres	Multimode Fibres
1.	Core diameter is small (8 μm to 12 μm)	Core diameter is large (50-100 μm)
2.	Signal entry is difficult because of small core diameter.	Signal entry is easy.
3.	Single mode fibres are more expensive because of the use of laser diodes.	Multimode fibres are less expensive.
4.	Single mode fibres are preferred for long distance communication	Multimode mode fibres are used for short distance communication
5.	Single mode fibres have high information carrying capacity.	Multimode mode fibres have low information carrying capacity.

Classification Based on Materials Used

1. All Glass Fibres: In these type of fibres both core and cladding are fabricated from glasses.

- The optical fibres made from glass have low losses and therefore, they are used in long distance communications.

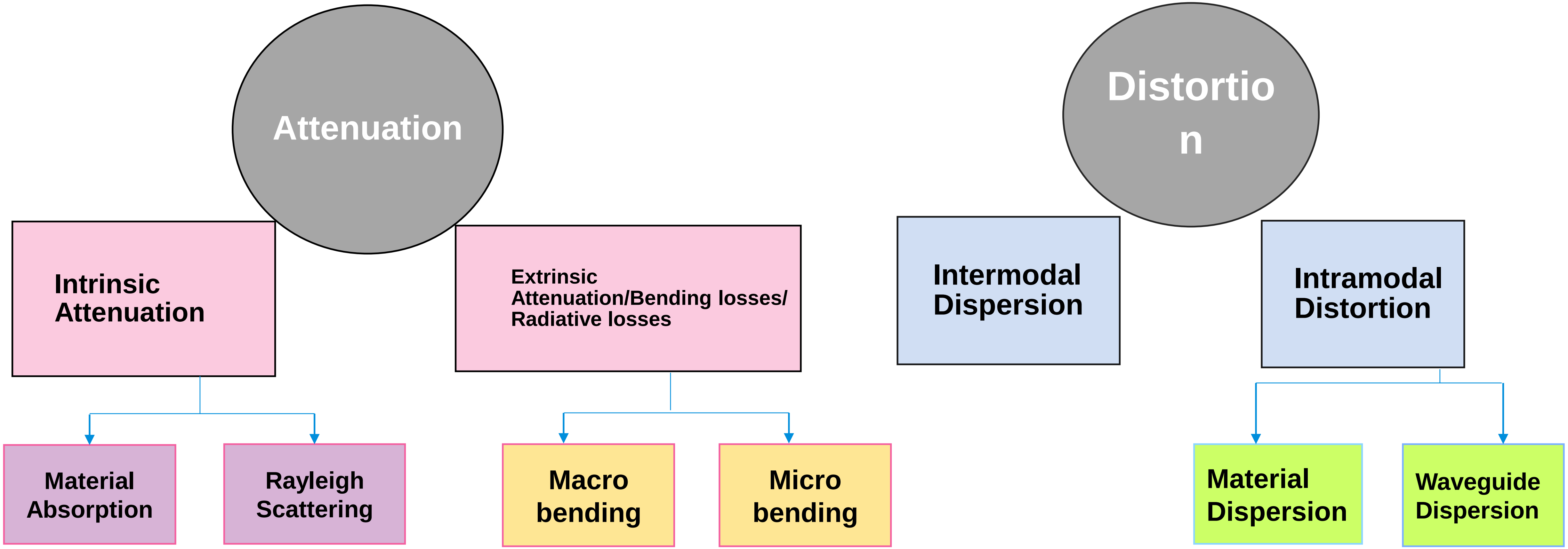
2. All plastic Fibres: In these type of fibres both core and cladding are made from plastic.

- The main ***advantages*** of plastic fibres are low cost and high mechanical flexibility.
- ***Disadvantages:*** They exhibit high loss and are temperature sensitive.
- Therefore, these fibres are used for low cost applications and at normal temperatures, usually below $80^{o}C$.

3. PCS Fibres: Plastic clad silica (PCS) fibres are the one in which core is fabricated using silica (high quality quartz) and cladding is formed using transparent polymer.

- PCS fibres are cheap and exhibit high losses, therefore, they are used in ***short distance communications***.

VARIOUS SIGNAL LOSSES IN OPTICAL FIBRES



1. Attenuation (loss of amplitude)

- **Attenuation:** When a light signal propagates through an optical fibre, a small percentage of the signal is lost with increasing distance. This loss of optical power as the light signal travels down the fibre, is known as attenuation.
- *It is defined as the ratio of the optical output power (P_o) from a fibre of length L to the input power (Pi).*

$$P_o = Pi\ e^{-\alpha L}$$

where *α* is the *fibre attenuation coefficient* and it is measured in units: *dB/km.*

Taking log on both sides of above equation, we get

$$\log P_o = \log Pi\ (-\alpha L)$$

$$\alpha = \frac{1}{L}\ ln\ \frac{P_i}{P_o}$$

In units of dB/km, α is defined as

$$\alpha = \frac{10}{L}\ log\ \frac{P_i}{P_o}$$

In case of an ideal fibre, Po = Pi and attenuation (α) is zero.

Two main mechanisms of Attenuation

1. **Intrinsic Attenuation**

i. Material Absorption

ii. Rayleigh Scattering

2. **Extrinsic Attenuation**

i. Macrobend losses

ii. Microbend losses

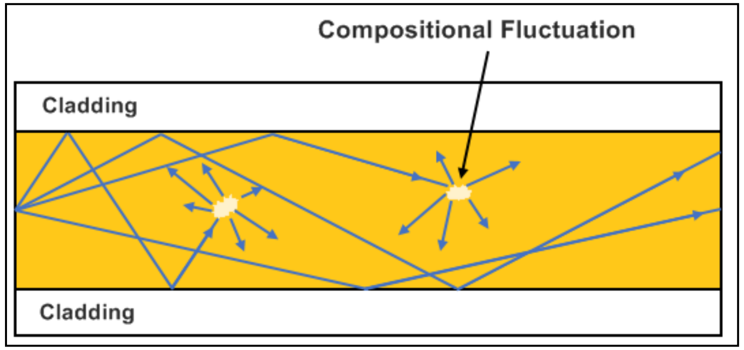
1. Intrinsic Attenuation:

i. Material Absorption: Material Absorption results from the impurities and imperfections in the fibre.

- It accounts for 3 to 5% of attenuation.
- The most common impurity is the OH- molecule

Remedy: The absorption losses can be reduced by controlling the amount of impurities during manufacturing process.

ii. Rayleigh Scattering: The major cause of attenuation (~96%) is Rayleigh scattering.



- The local microscopic variations in the density of glass,

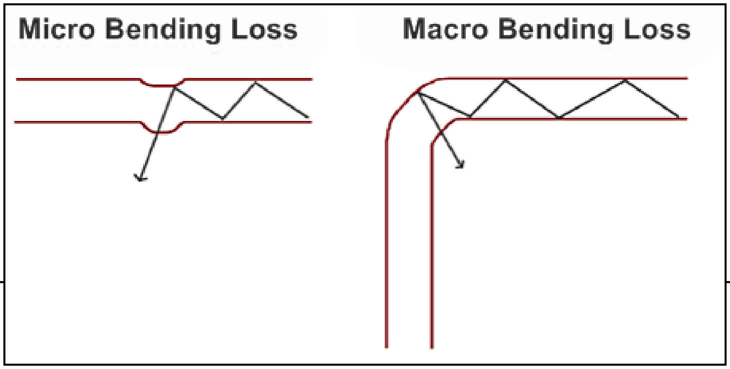
act as obstructions to light.

- The Rayleigh scattering loss is function of wavelength and varies as $1/\lambda^4$.

Any wavelength that is below 800nm is unusable for optical communication because attenuation losses due to Rayleigh scattering are high. At the same time propagation above 1700nm is not possible due to high losses resulting from absorption.

Remedy: That is why, for long distance transmission, it is beneficial to use the longer wavelengths for minimum attenuation.

2. Extrinsic attenuation



i. Macrobend losses:

A macrobend is a large bent with more than 2mm radius, which causes bending strain. This bending strain affects the **refractive index and critical angle** in that particular area, as a result the light in the core will refract out and that signal will be lost.

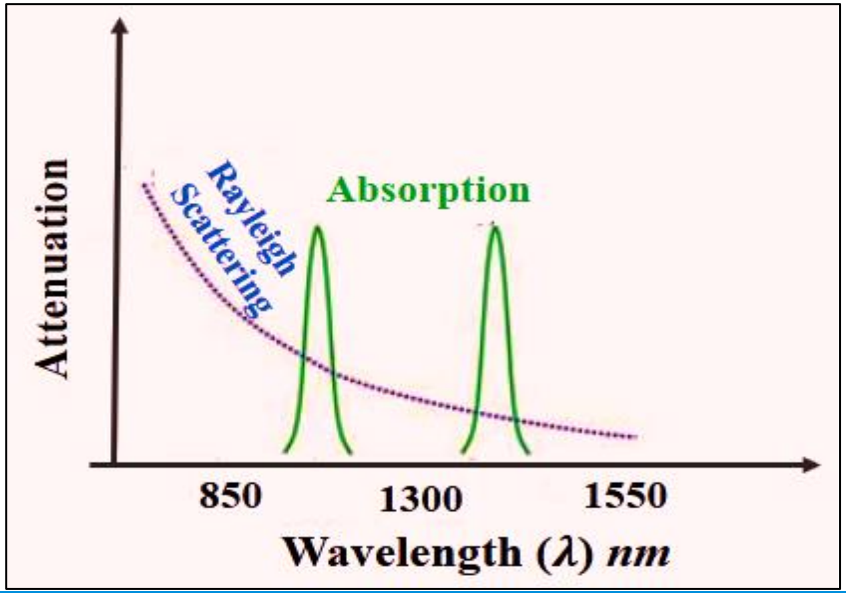
- **Remedy:** The optical fibres come with minimum bend radius specification and that should not be exceeded in order to prevent macrobends.

ii. Microbend losses:

It is a small scale and localized bend in the fibre cable. It might occur due to temperature or tensile stress or crushing force.

It can also be caused by imperfections in the cylindrical geometry of fibre during manufacturing or installation.

- **Remedy:** Micro-bend losses can be reduced by covering the fibre cable with a compressible jacket.



Attenuation *vs.* wavelength curve for a typical glass optical fiber.

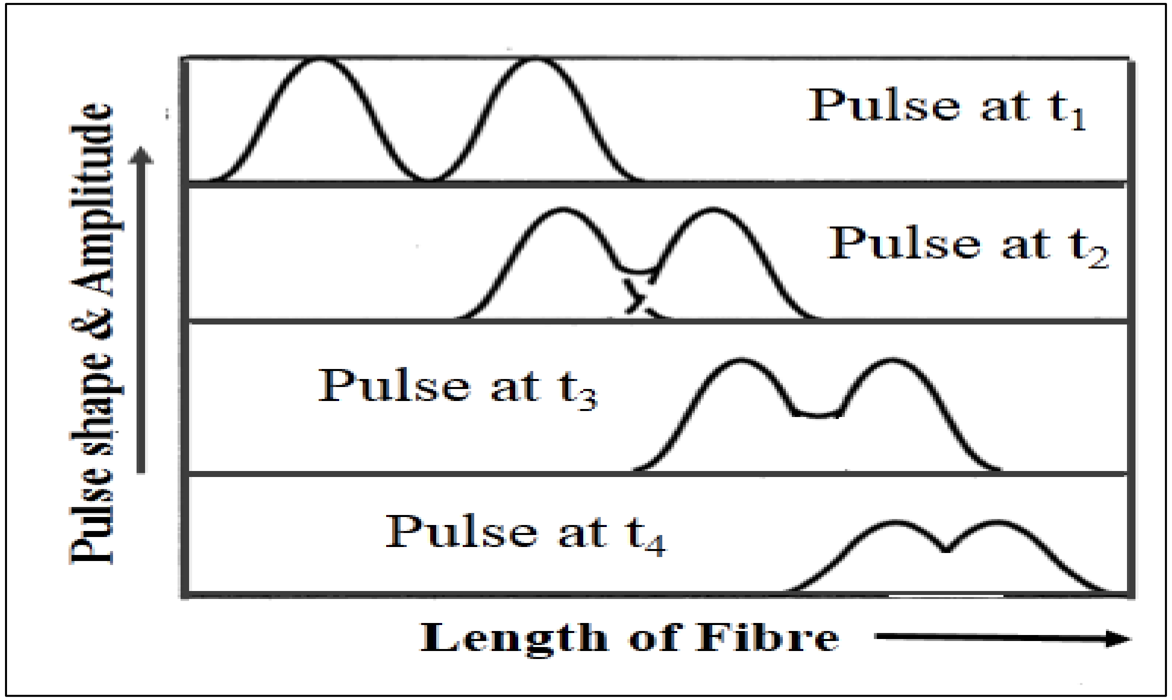
λ (nm)	**Approx. loss (dB/km)**
820-880	2.2
1200-1320	0.6
1550-1610	0.2

The band of wavelengths at which the attenuation is minimum is called optical window or transmission window or low-loss window. There are 3 principal windows mentioned above.

2. Distortion (change in shape of signal)

The pulse broadening depends on the length of the travel of the pulse through the fibre.

- **Units of dispersion:** ***ns/km***



Distortion in optical fibres is of two types:

1. **Intermodal dispersion:** Inter modal dispersion occurs in the optical fibre when a number of modes are propagating through the fiber. It occurs as aresult of difference in group velocities of the modes. Different modes will have different wavelengths and hence, will take different time to reach the end of the fiber. This leads to the intermodal dispersion.

2. **Intramodal dispersion**: It is the spreading of light pulse within a single mode. The two main causes of intramodal dispersion are:

i. **Material dispersion: (Chromatic dispersion)**It occurs due to different wavelength travelling at different speed inside the fibers. The short wavelength components travel slower than long wavelength components, causing the light pulse to broaden.

Remedy: can be reduced by using monochromatic light or narrow spectral range.

ii. Waveguide dispersion: Waveguide dispersion is due to the distribution of light between core (80%) and cladding (20%). This type of dispersion is more prominent in Single mode fibres (SMF).

Remedy: Intermodal dispersion can be reduced by using GRIN fibres.

ALIGNMENT LOSSES

- The principal source of loss in both connectors and splices is fiber-to-fiber end face misalignment.
- There are three types of misalignment loss which may occur individually or in combination. These are

1. lateral misalignment: It is the largest contributor to the total loss in a fiber connection. It arises due to the failure of the cross sections of the two fiber cores to perfectly overlap
2. axial separation: Axial separation contributes to the connection loss when the end surfaces of the two fibers do not come into contact with each other.
3. angular misalignment: The third loss mechanism, angular misalignment generally does not contribute significantly to connection losses. Manufacturing tolerances virtually eliminate this misalignment in connectors and splices

Characteristics of Fibres

- **Step index single mode fibre:**
- It has a very small core diameter, typically of about 10μm.
- Its numerical apertures is very small
- It supports only one mode in which the entire light energy is concentrated.
- A single mode step index fibre is designed to have a V number between 0 and 2.4.
- Because of a single mode of propagation, loss due to intermodal dispersion does not exist.

- With careful choice of material, dimensions, and wavelength, the total dispersion can be made extremely small.
- The attenuation is least.
- The single mode fibres carry higher bandwidth than multimode fibres.
- It requires a monochromatic and coherent light source. Therefore, laser diodes are used along with single mode fibres.

- **Advantages:**
- No degradation of signal
- Low dispersion makes the fibre suitable for use with high data rates.
- Single-mode fiber gives higher transmission rate and up to 50 times more distance than multimode.
- Highly suited for communications.

Disadvantages:

- Manufacturing and handling of SMF are more difficult.
- The fibre is costlier.
- Launching of light into fibre is difficult.
- Coupling is difficult.

Applications:

- Used as under water cables

- **Step-index multi-mode fibre:**
- It has larger core diameter, typically ranging between 50-100μm.
- The numerical aperture is larger and it is of the order of 0.3
- Larger numerical aperture allows more number of modes, which causes larger dispersion.
- The dispersion is mostly intermodal.
- Attenuation is high.
- Incoherent sources like LEDs can be used as high sources with multimode fibres.

- **Advantages:**
- The multimode step index fibre is relatively easy to manufacture and is less expensive
- LED or laser source can be used.
- Launching of light into fibre is easier.
- It is easier to couple multi-mode fibres with other fibres.
- **Disadvantages:**
- It has smaller bandwidth.
- Due to higher dispersion data rate is lower and transmission is less efficient.
- It is less suitable for long distance communications.
- **Applications:**
- Used in data links.

- **Graded-index multi-mode fibre:**
- Core diameter is in the range of 50-100μm.
- Numerical aperture is smaller than that of step-index multimode fibre.
- The number of modes in a graded index fibre is about half that in a similar multimode step-index fibre.
- It has minimum attenuation.
- Intermodal dispersion is zero, but material dispersion is present.
- It has better bandwidth than multimode step-index fibre.

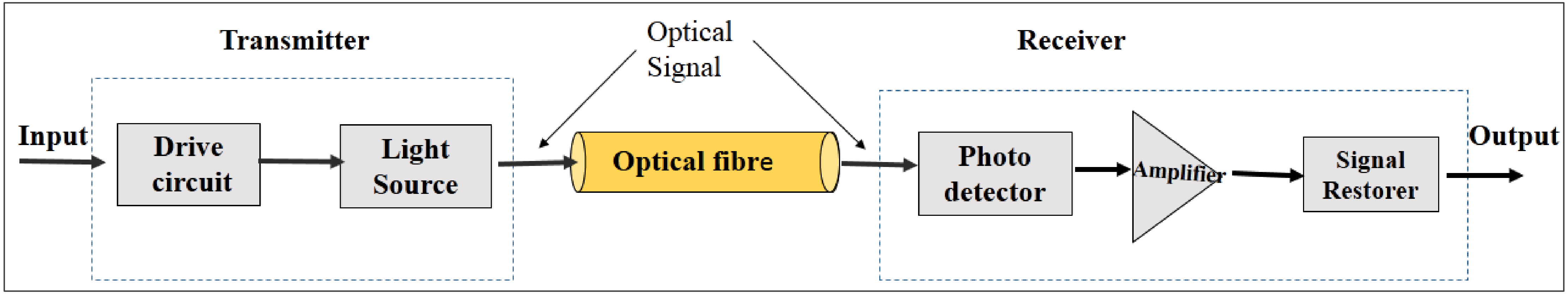
- **Advantages:**
- Either an LED or a laser can be used as the source of light with GRIN fibres.
- **Disadvantages:**
- The manufacture of graded index fibre is more complex. Hence, it is the most expensive fibre.
- Coupling fibre to the light source is difficult.
- **Applications:**
- Used in telephone links.

Table 1: Comparison of Different Types of Fibres

S.No.	Feature	SMF	MMF	GRIN
1.	Typical core diametre	10 μm	50 to 100 μm	50 to 100 μm
2.	Δn	Very small	Large	
3.	Numerical Aperture	Small	Large	Smaller than that of MMF
4.	Number of modes	Only one	Many	Many
5.	Attenuation	Least	High	Lower
6.	Dispersion	Zero Intermodal dispersion	Large	Intermodal dispersion is zero. Material dispersion is present
7.	Bandwidth	>3 GHz-km	<200 MHz-km	200 MHz-km to 3 GHz-km
8.	Advantages	No degradation of signal, High data transfer rate, Highly suitable for communications	Less expensive, LED or laser source can be used, Launching of light is easier, Coupling of fibres is easier.	LED or Laser light source can be used
9.	Drawbacks	Costly, Requires a laser source, Coupling is difficult, Launching of light into fibre difficult, Intensity gets reduced.	Degrades signal, less suitable for communications.	
10.	Applications	Under water cables	Data Links	Telephone Lines

BLOCK DIAGRAM OF OPTICAL COMMUNICATION SYSTEM

1. **A transmitter:** It converts electrical signal into optical signals.
2. **An optical fibre:** It transmits (carries) the optical signal.
3. **A receiver:** It receives the optical signal at the other end of fibre and converts it into electrical form.



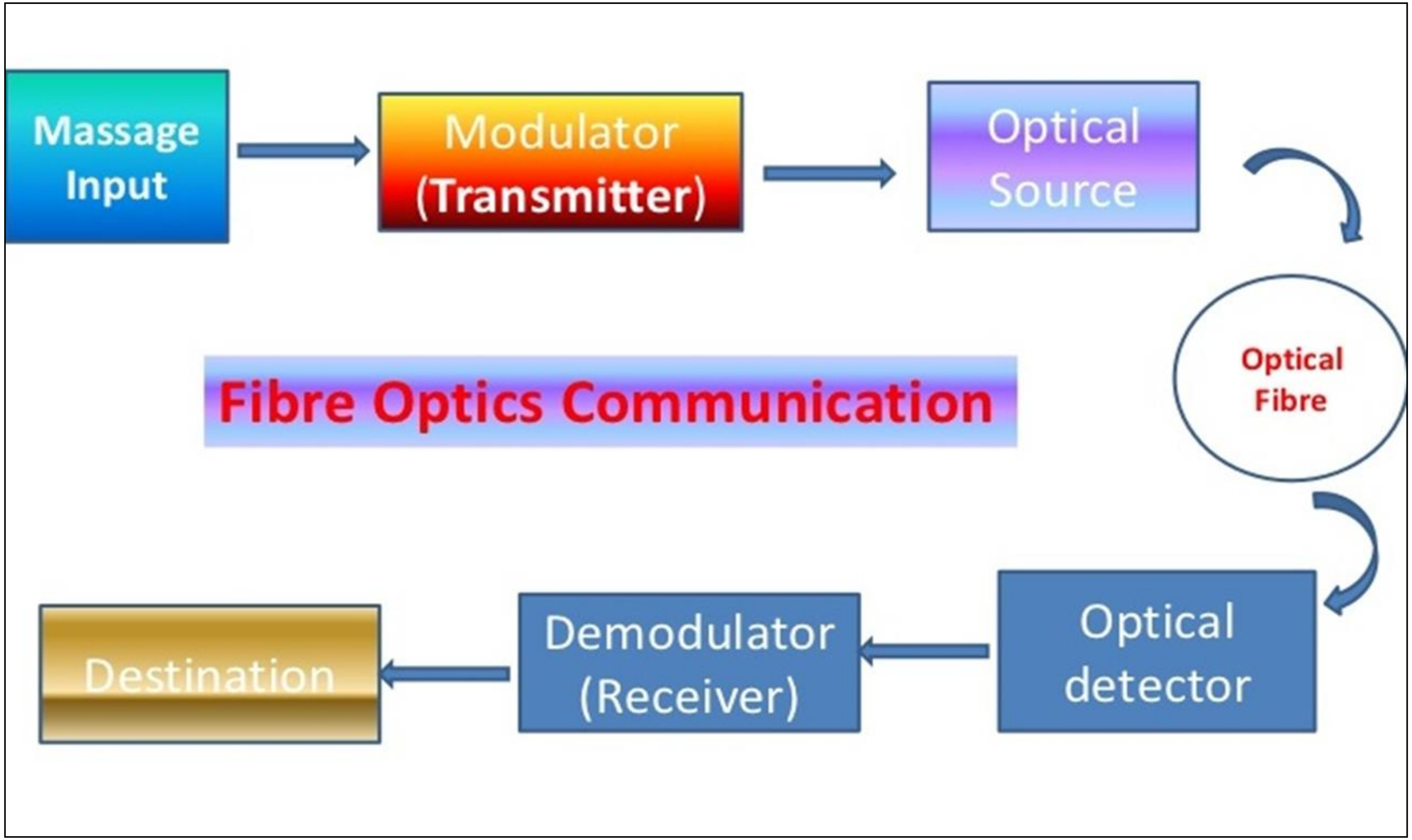
Transmitter: It consists of a driver circuit and light source.
A transducer converts the analog signals into electrical form. This electrical signal is then fed to the light source.
The light source can be a LED or semiconductor laser, which converts the electrical signal into optical signal in IR range 850nm, 1300nm, 1550nm .

Source to Fiber Connector: It is used for transmitting the light signal from source to the optical fiber. This connector acts as a joint between the fiber and light source.

Optical Fibre: The only purpose of optical fibre is to transmit the optical signal from the transmitter to the detector, by multiple total internal reflections. While travelling through optical fibres the signal gets attenuated and distorted. Therefore, repeaters are used at specific intervals to regenerate signal.

Fiber to Detector Connector: It is used for collecting the light signal from the fibre.

Receiver: The receiver comprises of a photo detector, an amplifier and a signal restorer.
Photo detector, usually PIN diode, converts optical signal back into an electric signal, which is then amplifies and decoded to retrieve the message.
This output is fed to a transducer to convert it into the original form audio or video.


Massage Input
Modulator (Transmitter)
Optical Source
Optical Fibre
Fibre Optics Communication
Optical detector
Demodulator (Receiver)
Destination

ADVANTAGES OF FIBRE COMMUNICATION SYSTEM

1. *Small size, light weight, flexible yet strong*
2. *Wider Bandwidth*
3. *No cross talk*
4. *Immune to EM and RF interference*
5. *Not Hazardous*
6. *Longer life span*
7. *Low cost, easy maintenance*:

By: Dr. Vanita Thakur

Advantages.....

✓ Extremely High Bandwidth :

- Fibre optic cables have a much greater bandwidth than metal cables.
- The amount of information that can be transmitted per unit of optical fibre cable is its most significant advantage.

✓ Size

- In comparison to copper, a fibre optic cable has nearly 4.5 times as much capacity and - cross sectional area is 30 times less.

✓ Weight

- Fibre optic cables are much thinner and lighter than metal wires. They also occupy less space with cables of the same information capacity.

✓ Flexibility :

An optical fibre has greater tensile strength than copper or steel fibres of the same diameter. It is flexible, bends easily and resists most corrosive elements that attack copper cable.

✓ Cost:

The raw materials for glass are plentiful, unlike copper. This means glass can be made more cheaply than copper.

Cont..

✓Low Power Loss

- An optical Fibre offers low power loss.
- This allows for longer transmission distances.
- In comparison to copper; in a network, the longest recommended copper distance is 100m while with fibre, it is 2000m.
- In order to increase the transmission distance, a repeater must be installed in the middle of the path to re-generate the signal
- Optical fibre cable allows data to be sent far without as many repeater devices that are required by other types of cabling

✓Interference :

- Fibre optic cables are immune to em interference.
- It can also be run in electrically noisy environments without concern as electrical noise will not affect fibre.
- Optical fibre transmits light (photons) rather than electrons, it does not radiate electromagnetic fields, nor is it susceptible to electromagnetic fields

Cont..

✓ Secure Transmissions :

- Optical fibre cabling provides an extremely secure transmission medium.
- Optical fibre is a dielectric, it does not present a spark hazard.
- Fibre optic cabling does not radiate magnetic fields.
- The light (photons) is confined within the fibre which makes it impossible to tap the signal without cutting into the fibre.
- Fibre is the most secure medium available for carrying sensitive data.

APPLICATIONS OF FIBRE COMMUNICATION SYSTEM

- ***Internet***: Optical fibres are used for high speed data transmission.
- ***Telephone industry:*** Optical fibre cables have a major role in telecommunication for transmitting and receiving data at high speed and no noise.
- ***Military Applications:*** Optical fibres are used for data transmission in high level data security fields of military and for satellite communications.
- ***Medical field:*** Being very thin and quite flexible, optical fibres are used in various instruments to view internal body parts by inserting into hollow spaces in the body.
- ***For Broadcasting:*** O.F. cables are used to transmit high definition television signals in the cable-television industry. (one optical line is sufficient for around 500 households).
- ***Computer networking:*** With the help of optical fibre cables the data transformation between computers in nearby places has become easier and faster.

Disadvantages of Optical Fibre

- **Limited Application**—Fibre optic cable can only be used on ground, and it cannot leave the ground or work with the mobile communication.
- **Low Power**— Light emitting sources are limited to low power. Although high power emitters are available to improve power supply, it would add extra cost.
- **Fragility**— Optical fibre is rather fragile and more easy to damage compared to copper wires.
- Need more expensive optical transmitters and receivers
- More difficult and expensive to splice than wires

Thank you!