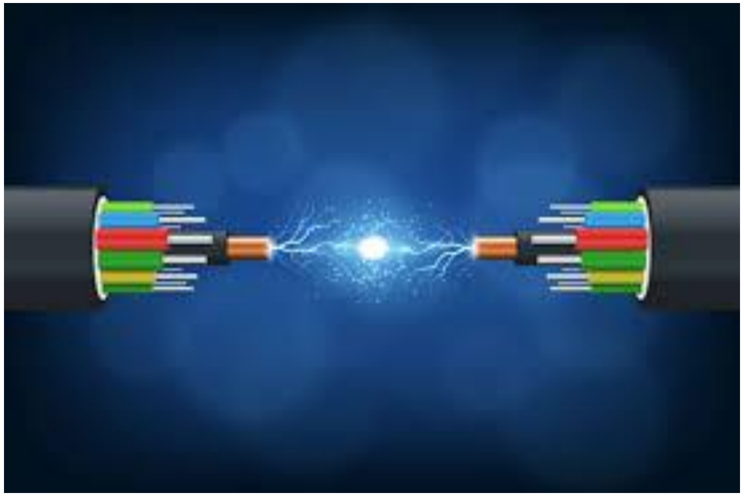
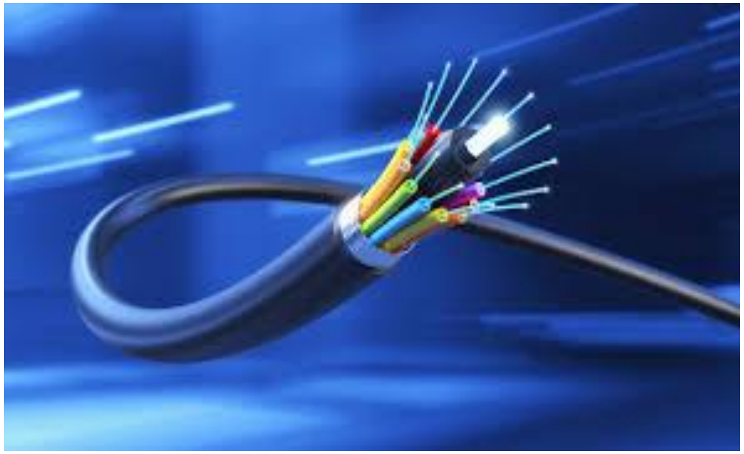
INTRODUCTION

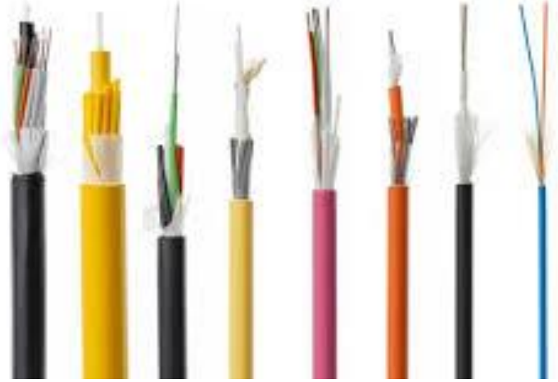
- Whenever people talk about the telephonic system, the cable TV system or the Internet, we hear about fiber-optic cables

- Fiber-optic lines are strands of optically pure glass/plastic as thin as a human hair that carry digital information over long distances.

- They works as wave guides in optical television signals, digital data to transmit voice television signals, digital data to any desired distance from one end to the other end.

- They are also used in medical imaging and mechanical engineering inspection.

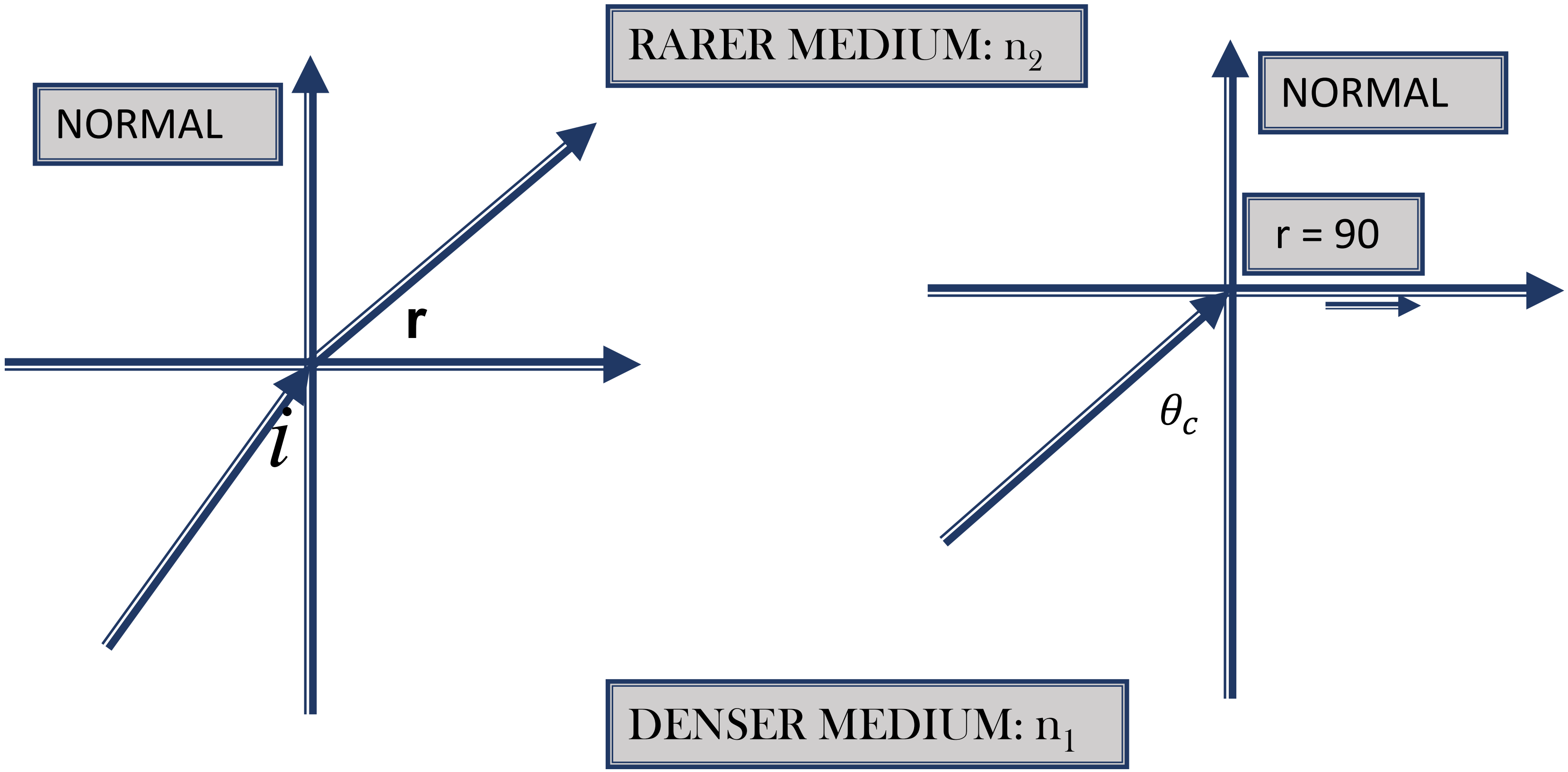




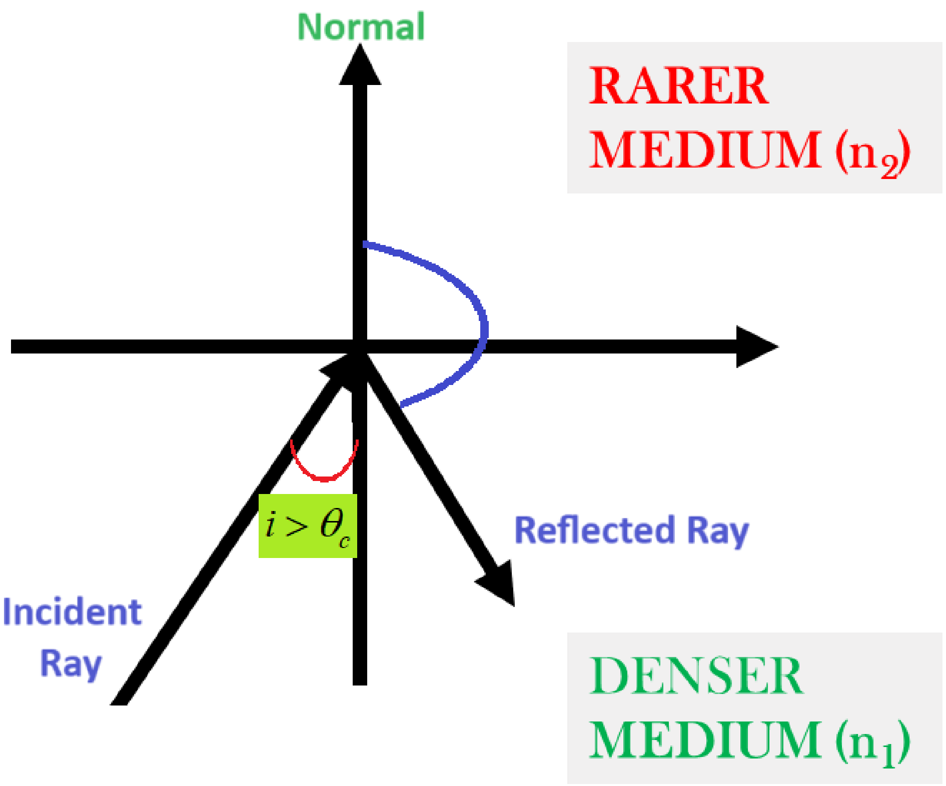
Major Advantages of Optical Fibre Cable

- High bandwidth
- Very high data speed
- Immune to interference
- High signal quality
- Long Distance transmissions
- Low Cost
- Lighter

TOTAL INTERNAL REFLECTION



TOTAL INTERNAL REFLECTION



According to Snell's law of Refraction

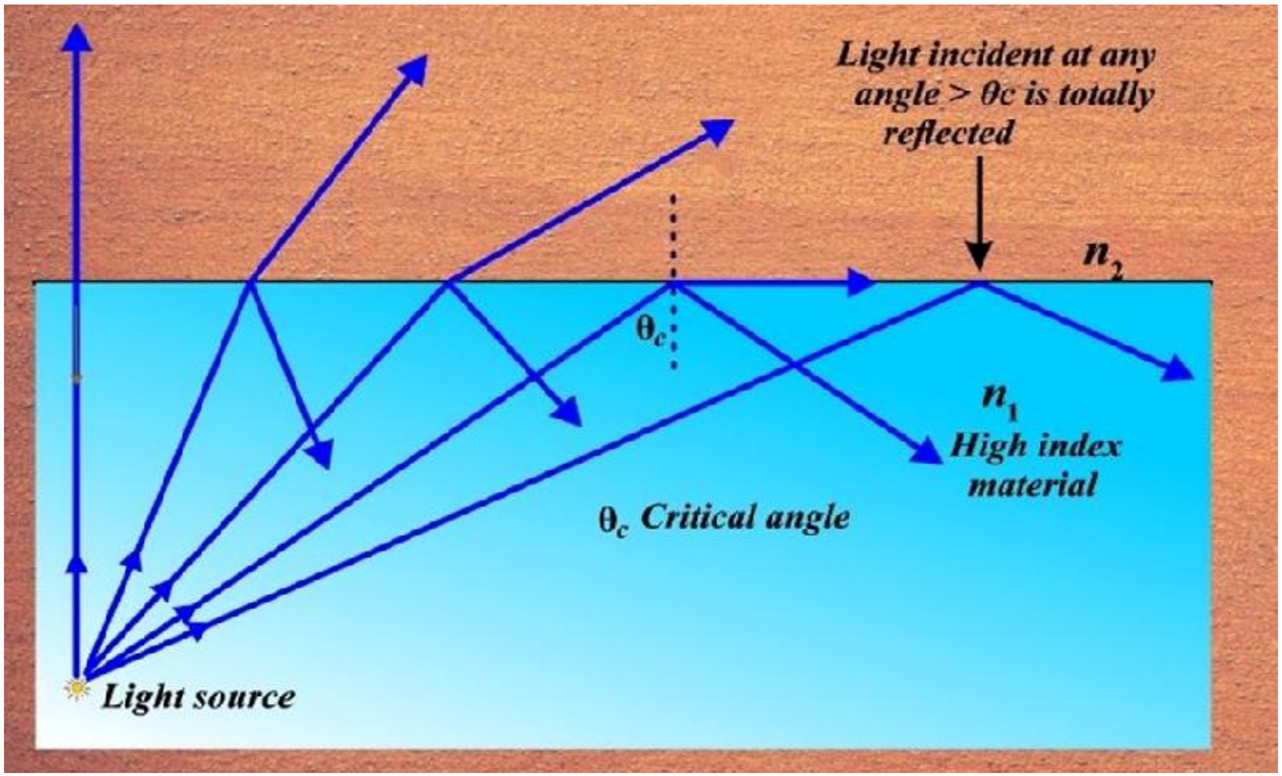
$$n_1 \sin i = n_2 \sin r$$

$$i = \theta_c \rightarrow r = 90^0$$

$$\sin \theta_c = \frac{n_2}{n_1} \sin 90^0$$

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

Total Internal Reflection



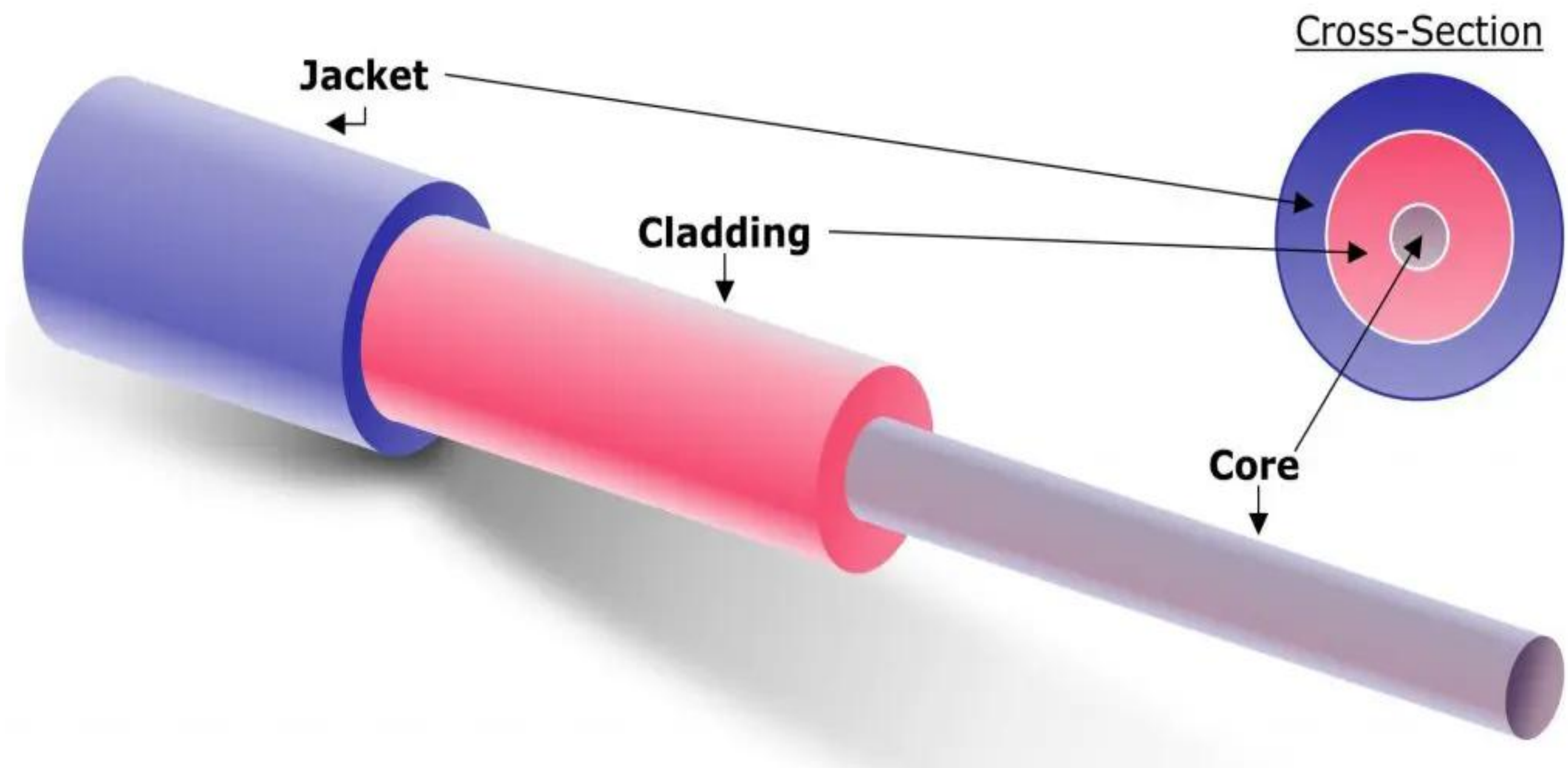
$$\frac{n_1}{n_2} = \frac{\sin r}{\sin i}$$

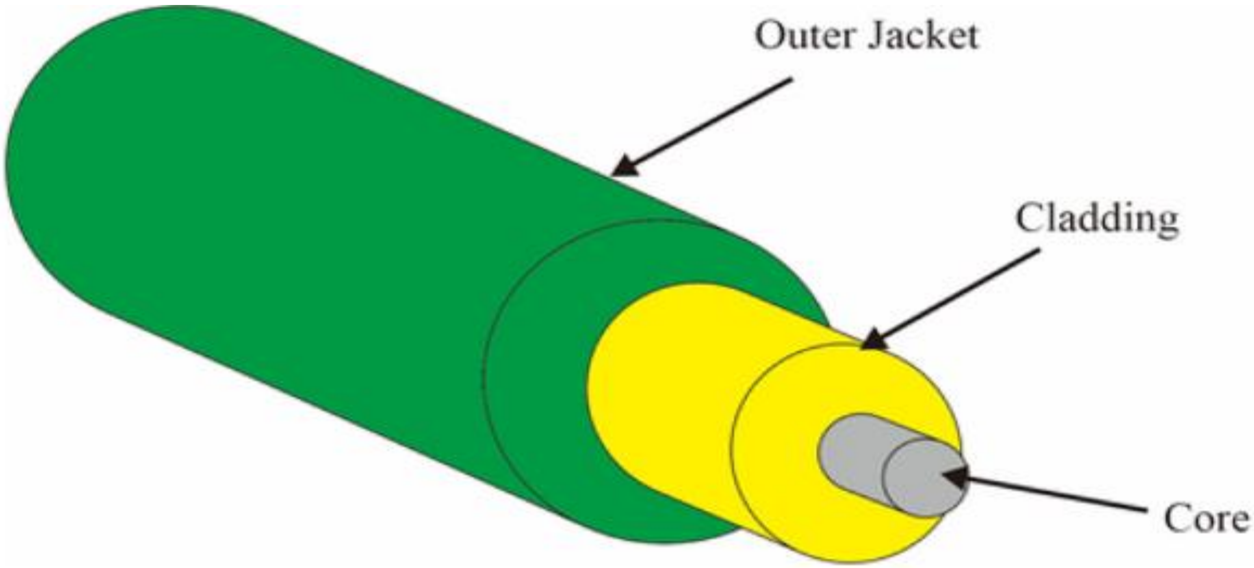
$$\sin\theta_c = \frac{n_2}{n_1}$$

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

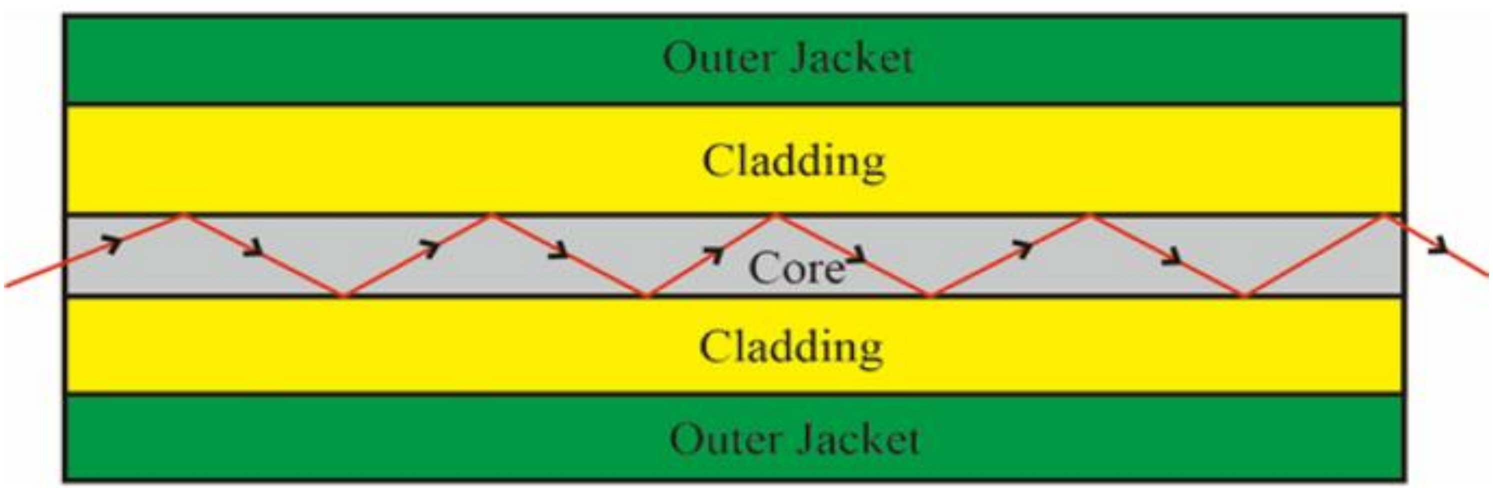
Optical fiber

Optical fiber is a thin, flexible strand of glass or plastic that transmits light signals over long distances.
It's also known as fiber optics.




Outer Jacket
Cladding
Core

(a)

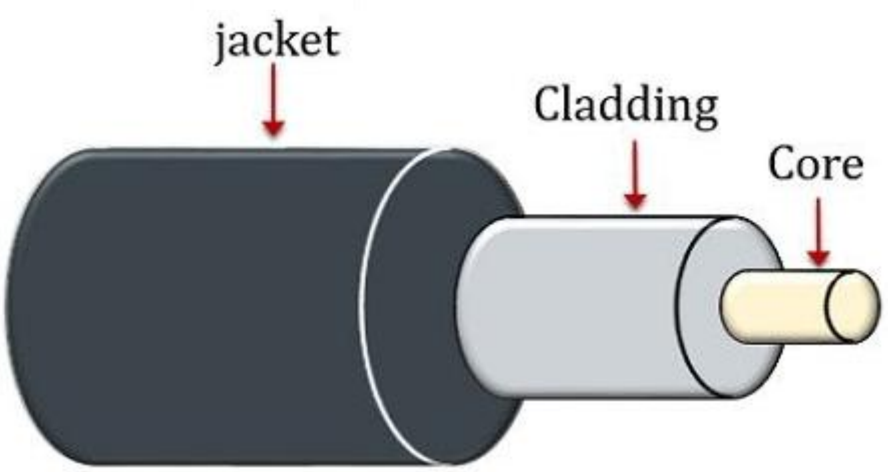

Outer Jacket
Cladding
Core
Cladding
Outer Jacket

(b)

Structure of an Optical Fiber

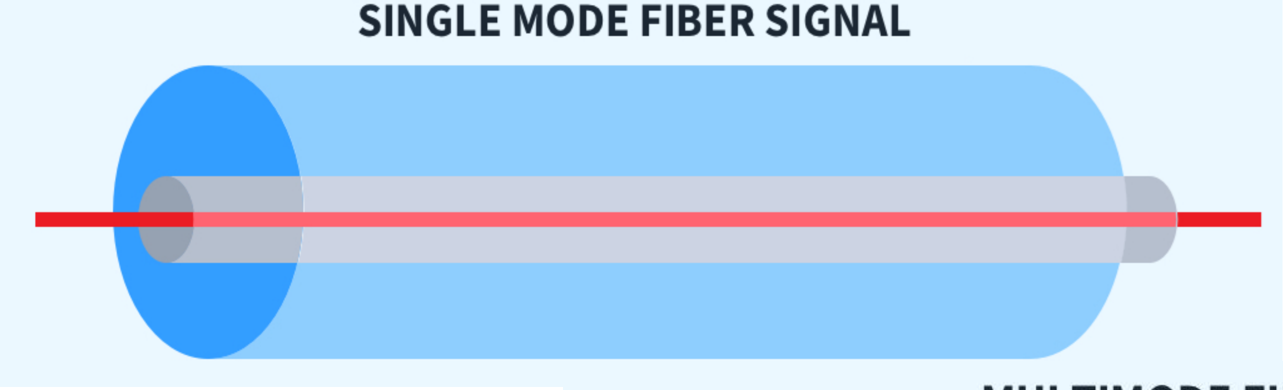
- **Core:** It is an inner cylindrical material made up of **glass** or **plastic**. It has diameter of 8 to100 μm.
- **Cladding:** It is a cylindrical shell of glass or plastic material in which core is inserted. It has diameter of 50 to 200 μm.
- **Protective Jacket:**

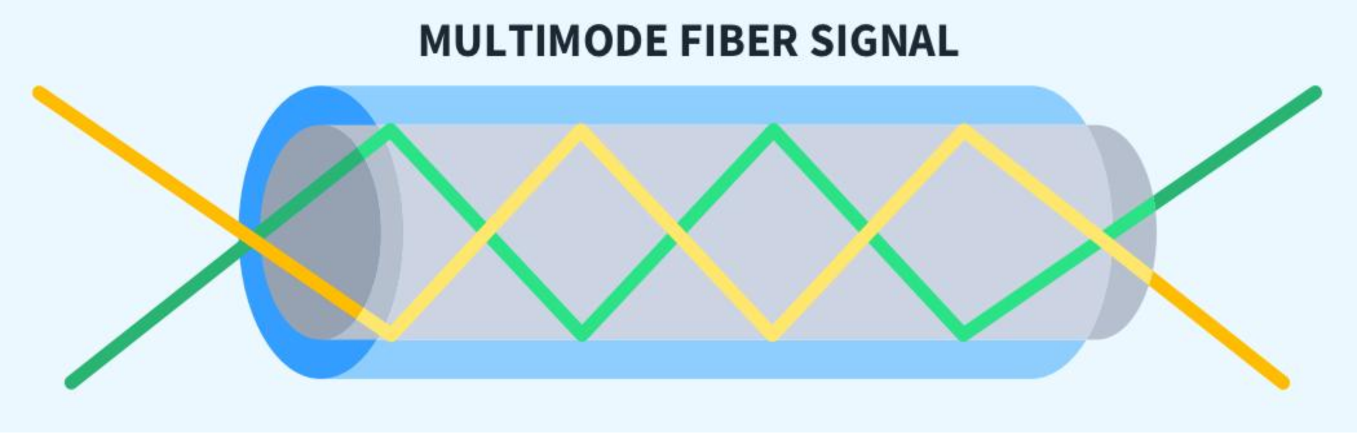
The Cladding is enclosed in **polyurethane** jacket, and it protects the fiber from surroundings. It has diameter of 100 to 400 μm.

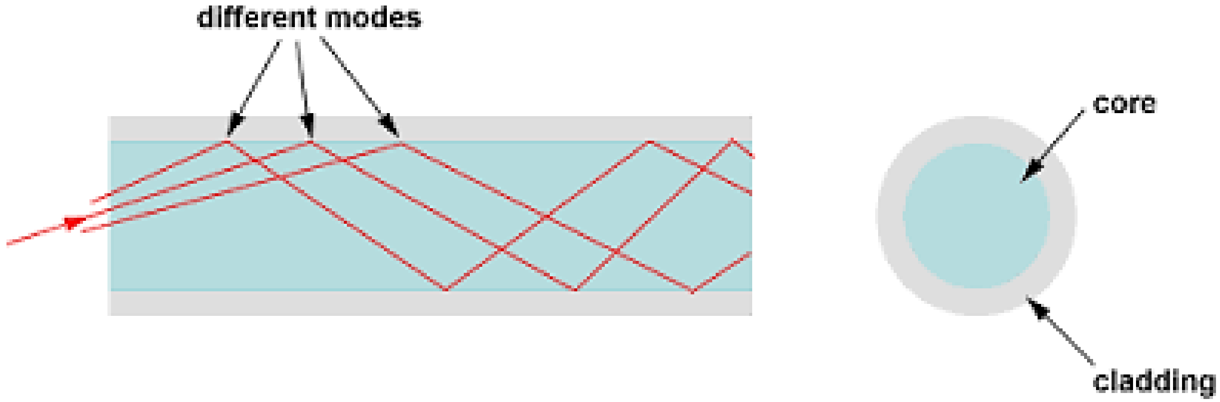


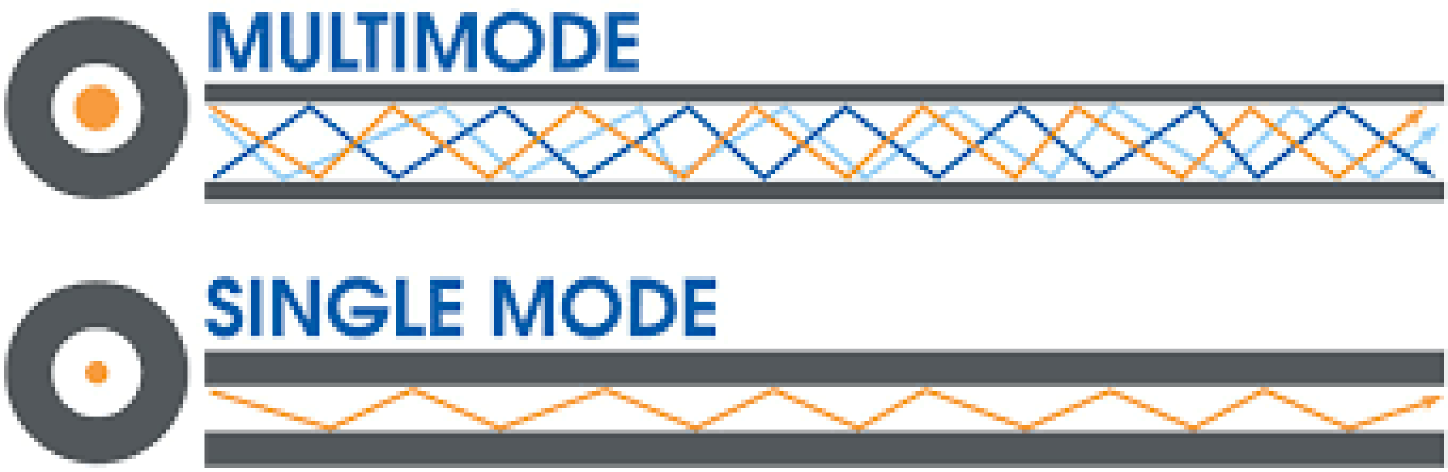
Modes of Propagation

- When light travels along the fiber then it will transmit down the core by taking either single or multiple paths.
- The number of paths a light ray takes during propagation along the fiber is called modes of propagation.

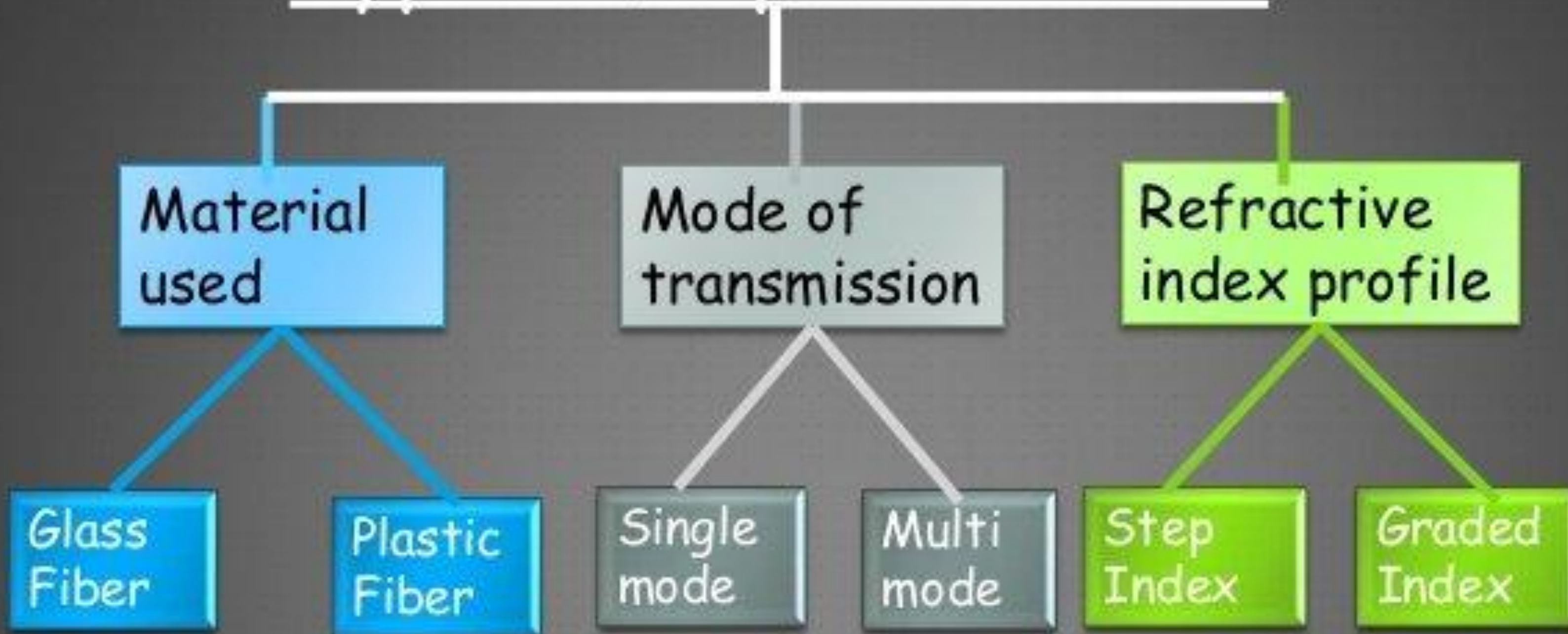





different modes
core
cladding


MULTIMODE
SINGLE MODE

Types of Optical Fibers:



CLASSIFICATION OF OPTICAL FIBER

- **Based on Refractive Index**
  - Step Index (SI)
  - Graded Index (GI)
- **Modes of Propagation**
  - Single Mode (SM)
  - Multimode (MM)
- **Based on material**
  - All Glass
  - All Plastic
  - Plastic clad Fiber

BASED ON THE MATERIAL OF THE CORE AND CLADDING

TYPES OF FIBER BASED ON MATERIALS

ALL GLASS FIBER

- Core and cladding made up of fused silica or fused quartz.
- Adding Ge or P in fused Silica: RI increases
- Adding B or F: RI decreases.
- Adding impurities can cause attenuation or scattering of the signal.

ALL PLASTIC FIBER

- Core and cladding made of plastic
- Light and flexible
- Used for short distance applications

PLASTIC CLAD FIBER

- Core is made of glass and cladding is made of polymer.
- Light, flexible and cheap.
- losses are more.
- Suitable for short distances.

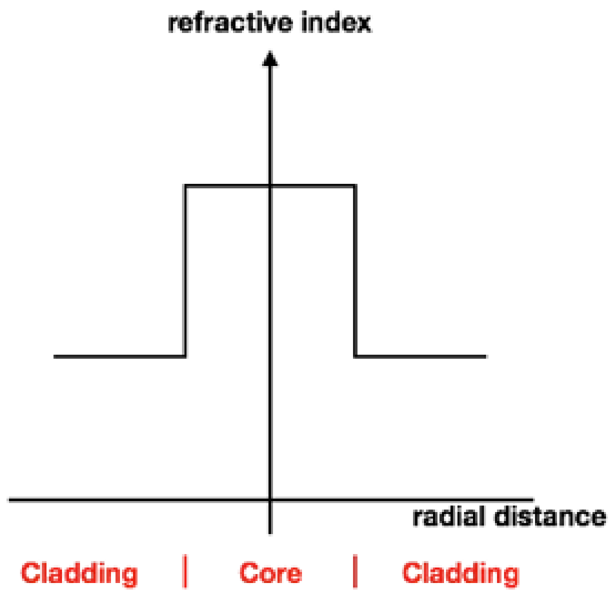
BASED ON THE REFRACTIVE INDEX OF THE CORE AND CLADDING

STEP INDEX FIBER

❖ The RI of core is constant inside the fiber.

❖ As we go radically from center of the core, the RI undergoes a step change at core-cladding interface.

❖ The core diameter of this fiber is about 8 to 10μm and the outer diameter of cladding is 60 to 70μm.

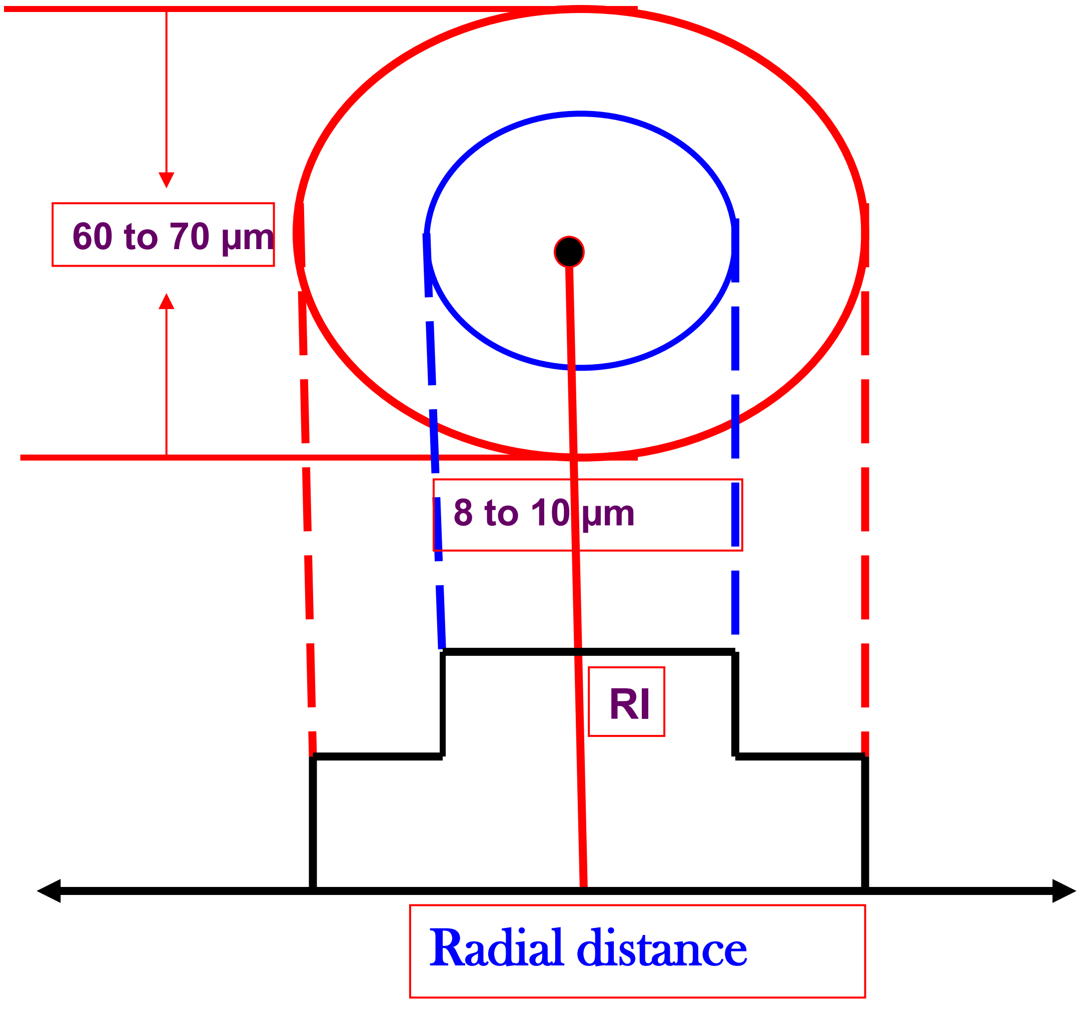


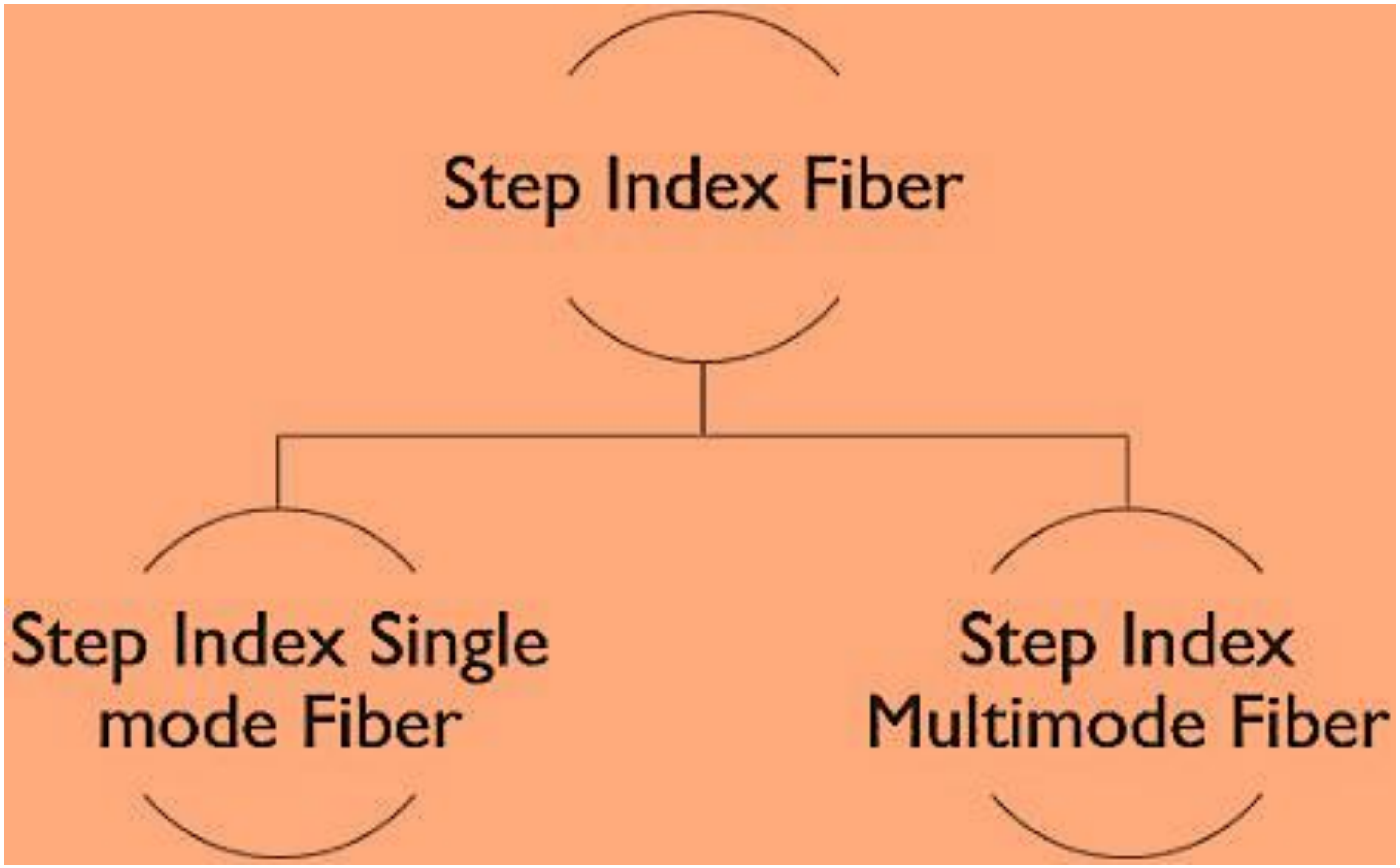
Step-Index

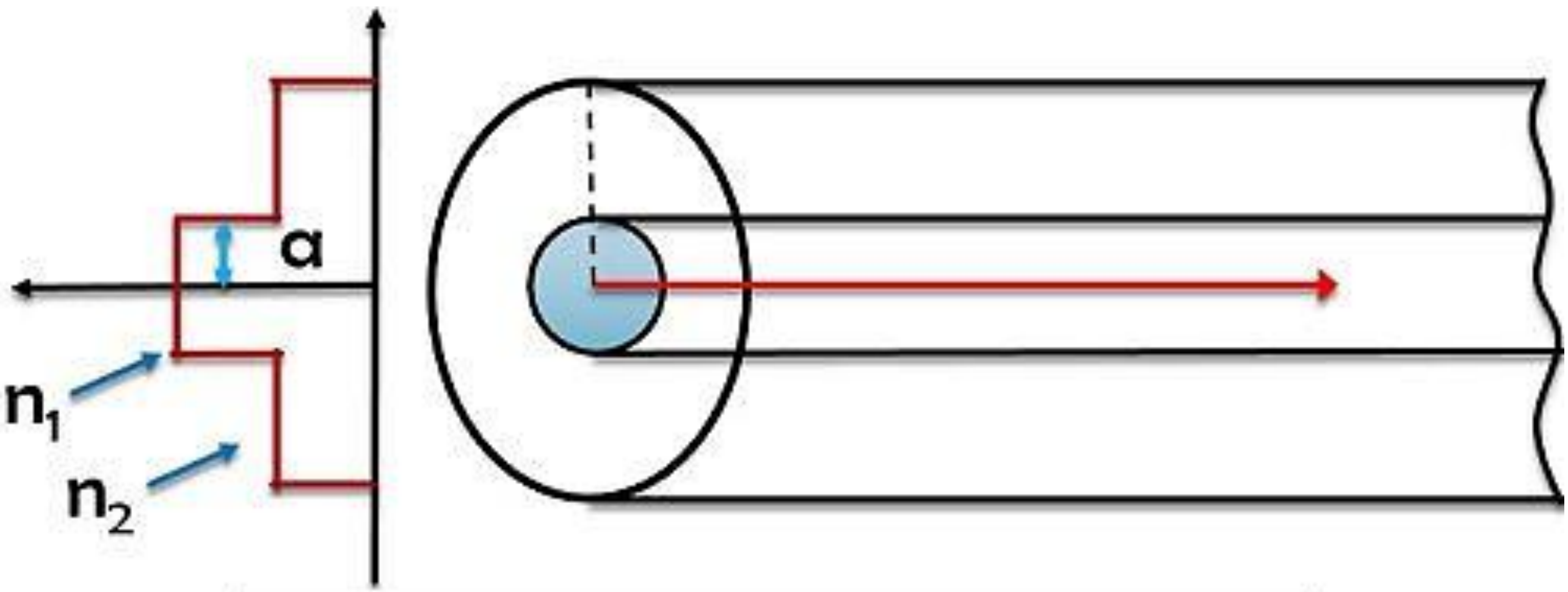
❖ It is a reflective fiber since light is transmitted from one end to the other end of a fiber by TIR.

❖ These are extensively used because distortion and transmission losses are very less.

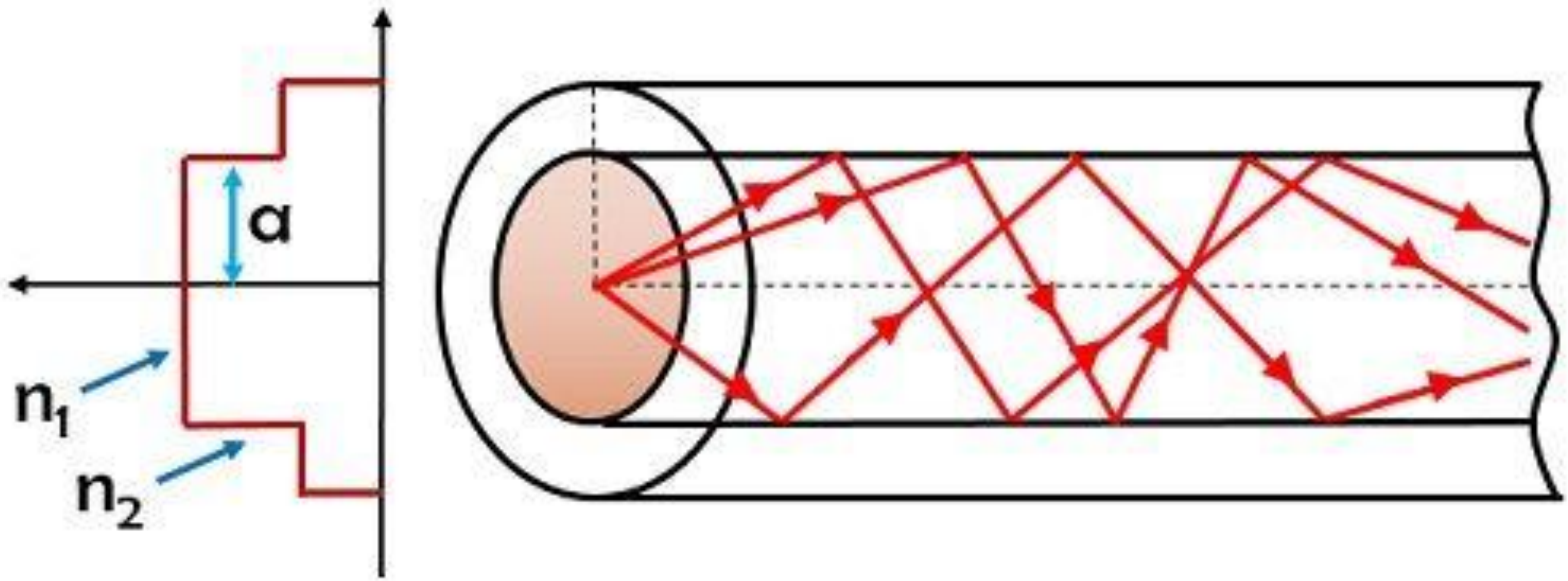
REFRACTIVE INDEX PROFILE OF STEP INDEX FIBER



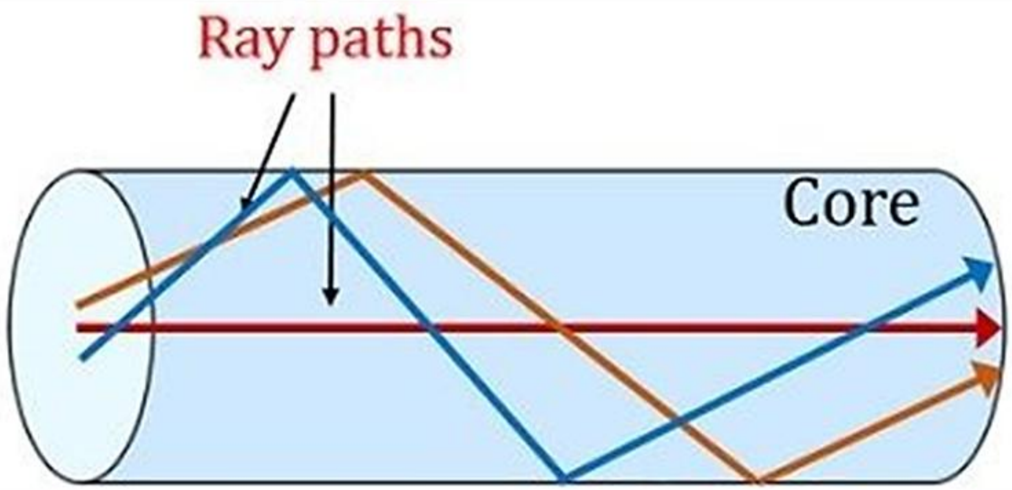

Step Index Fiber
Step Index Single mode Fiber
Step Index Multimode Fiber

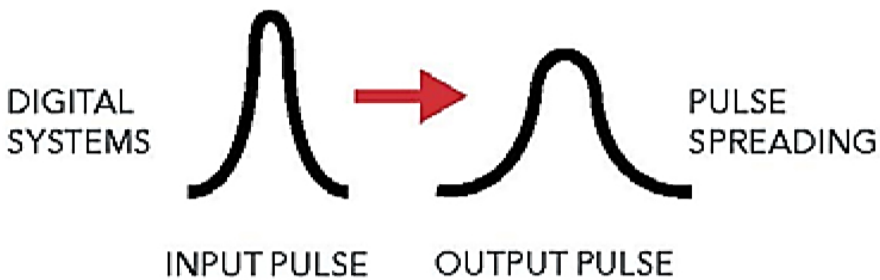


Step Index single mode fiber



Step Index multimode fiber



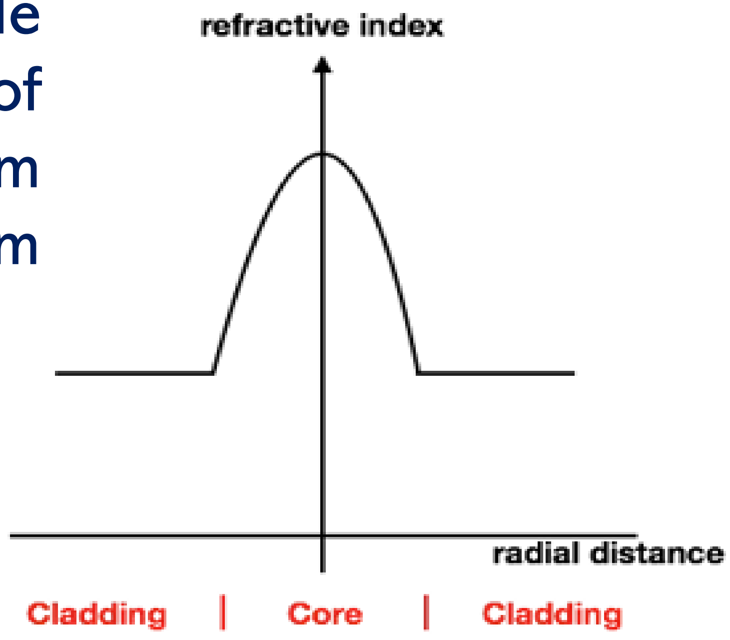


This is called internal modal dispersion

Intermodal dispersion where light rays propagate through different paths hence their reaching time at the destination is different.

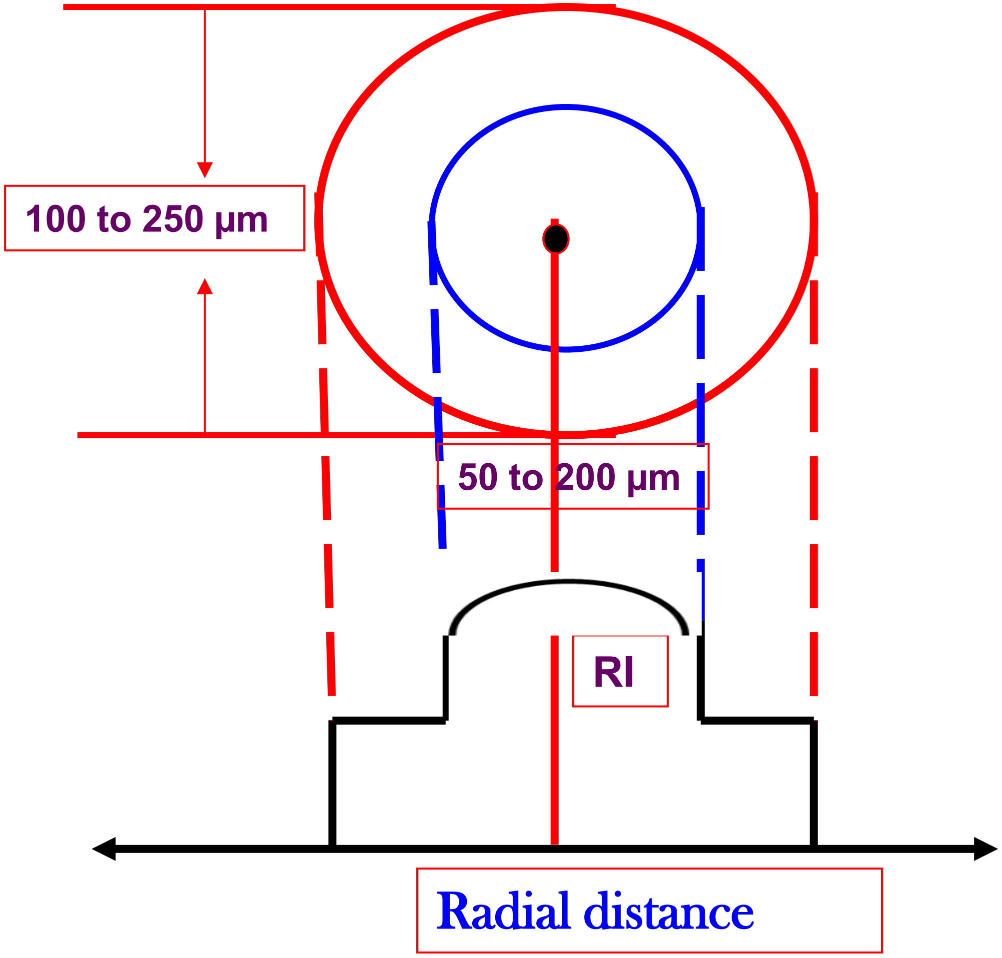
GRADED INDEX FIBRE

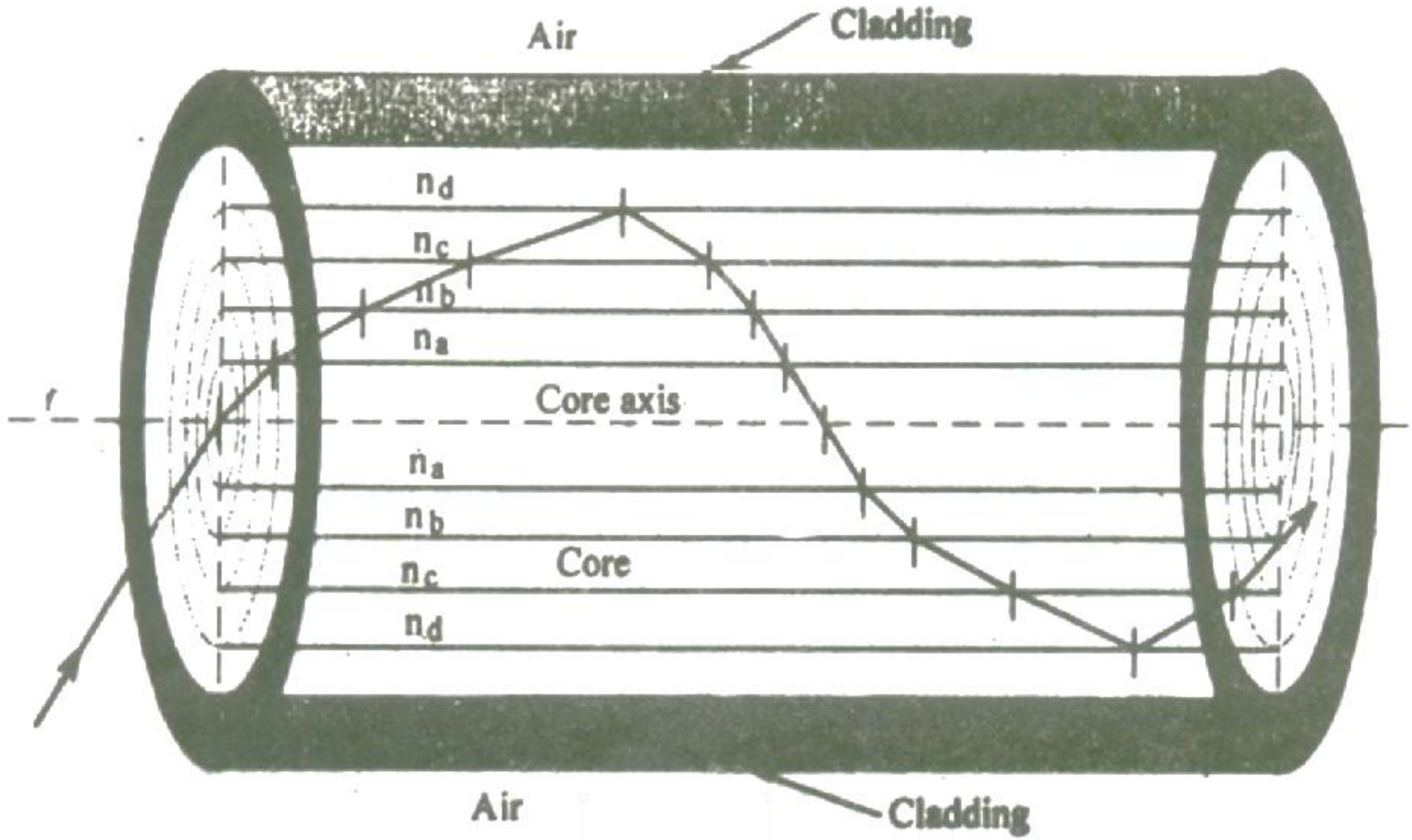
- In this fibre, the RI of core continuously decreases from center to the surface.
- The RI is maximum at the center of core and minimum at the surface.
- This fiber can be a single mode or Multimode, the diameters of core and cladding varies from 50-200μm and 100-250 μm respectively.
- Light propagation takes place in a parabolic path.



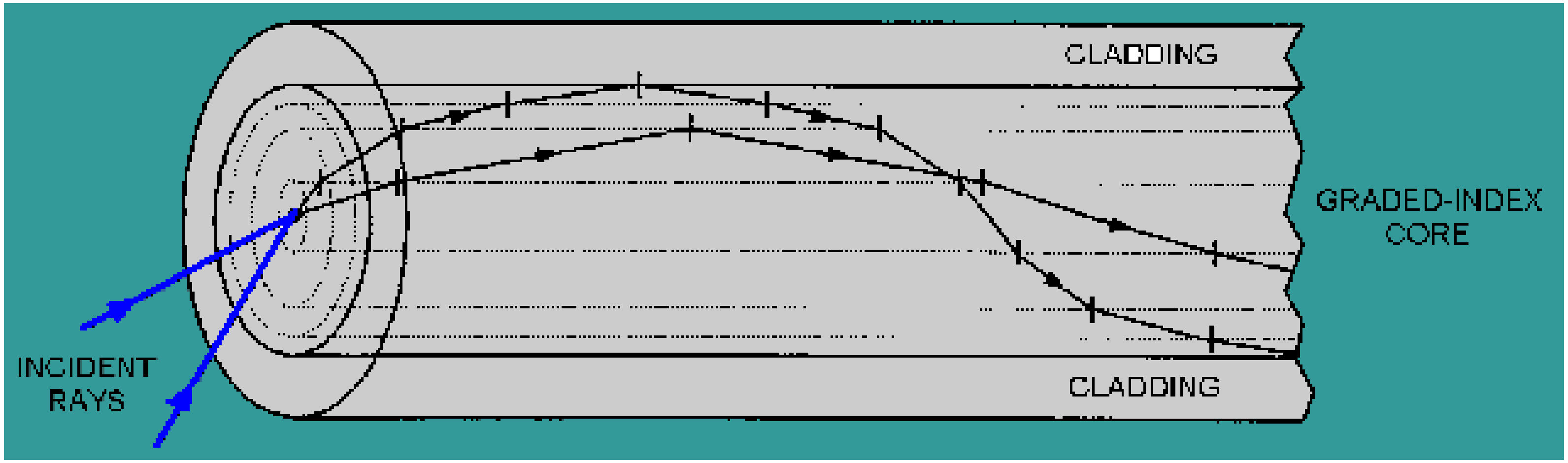
Graded-Index

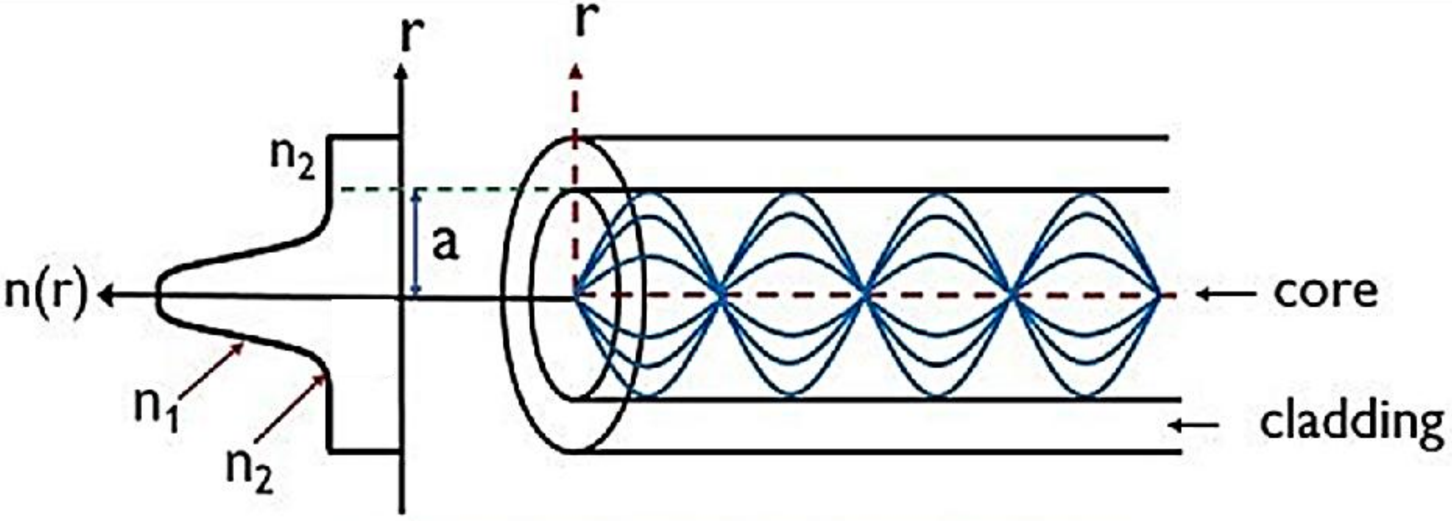
REFRACTIVE INDEX PROFILE OF GRADED INDEX FIBER



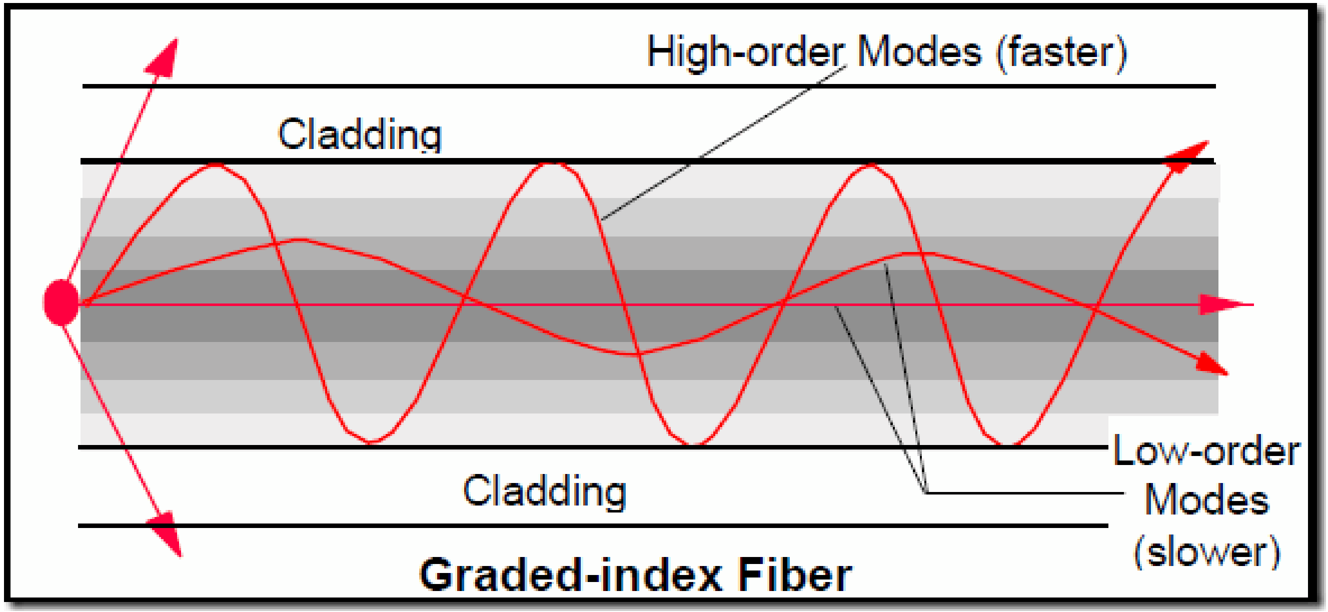


Air
Cladding
n_d
n_c
n_b
n_a
Core axis
n_a
n_b
Core
n_c
n_d
Air
Cladding





Ray Transmission in Multimode Graded Index Fiber



- Intermodal dispersion in graded index fiber is lower than multi mode step index fiber
- It is due to the different velocities of different modes in multi mode fiber

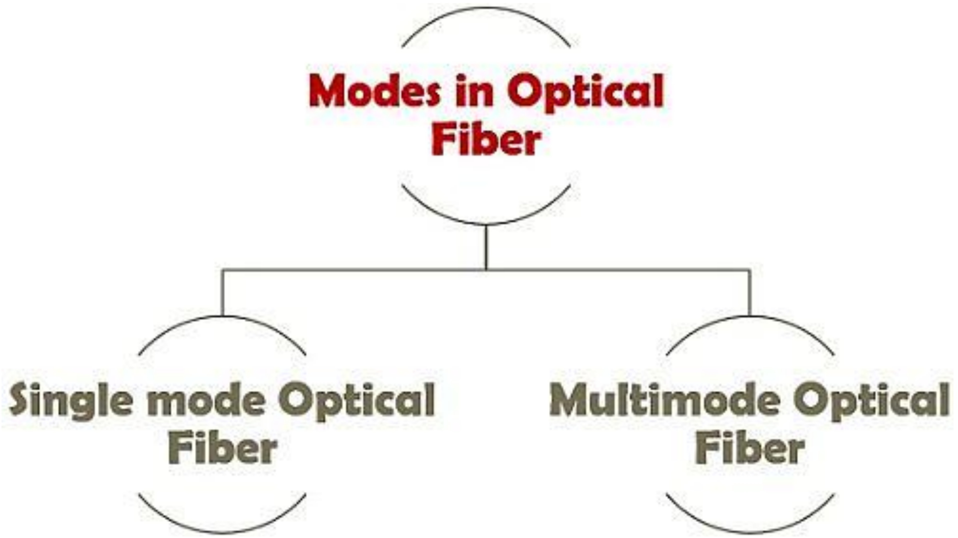
S. NO	STEP INDEX FIBER	GRADED INDEX FIBER
1.	The refractive index of the core is uniform throughout and undergoes on abrupt change at the core cladding boundary	The refractive index of the core is made to vary gradually such that it is maximum at the center of the core.
2.	The diameter of the core is about 50-200μm in the case of multimode fiber and 10μm in the case of single mode fiber	The diameter of the core is about 50μm in the case of multimode fiber
3.	The path of light propagation is *zig- zag* in manner	The path of light is *helical* in manner
3.	*Attenuation is more* for multimode step index fiber but for single mode it is very less. *Explanation:* When a ray travels through the longer distances there will be some difference in reflected angles. Hence high angle rays arrive later than low angle rays causing dispersion resulting in distorted output.	*Attenuation is less.* *Explanation:* Here the light rays travel with different velocity inn different paths because of their variation in their refractive indices. At the outer edge it travels faster than near the center. But almost all the rays reach the exit at the same time due to helical path. Thus, there is no dispersion.

BASED ON THE MODES OF PROPAGATION

Modes of Propagation

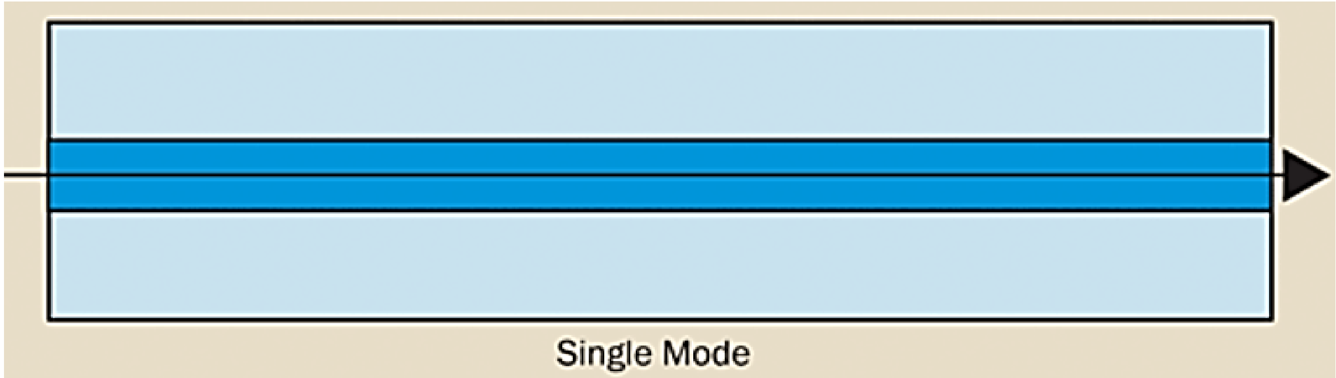
As we discussed earlier

The number of paths a light ray takes during propagation along the fiber is called modes of propagation.



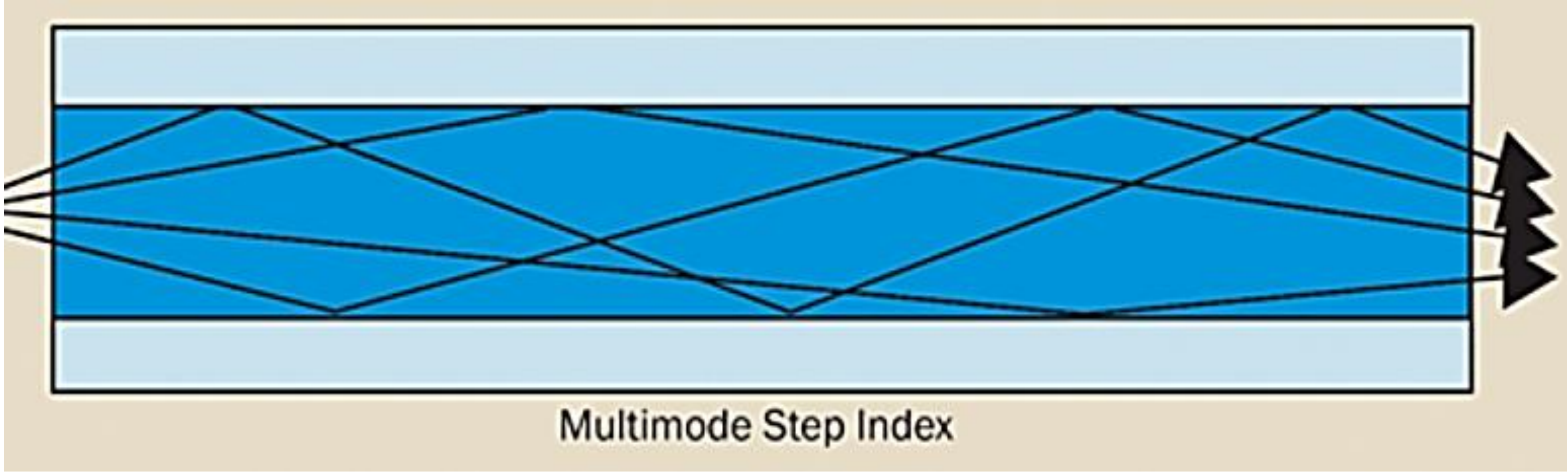
SINGLE MODE STEP INDEX FIBER

- Core diameter is very small of the order of 8 -10 μm
- Signal propagates in only one mode.
- Light travels parallel to the axis of the core.
- Transmission loss of the signal is very small.
- They are best suited for long distance signal transmission.



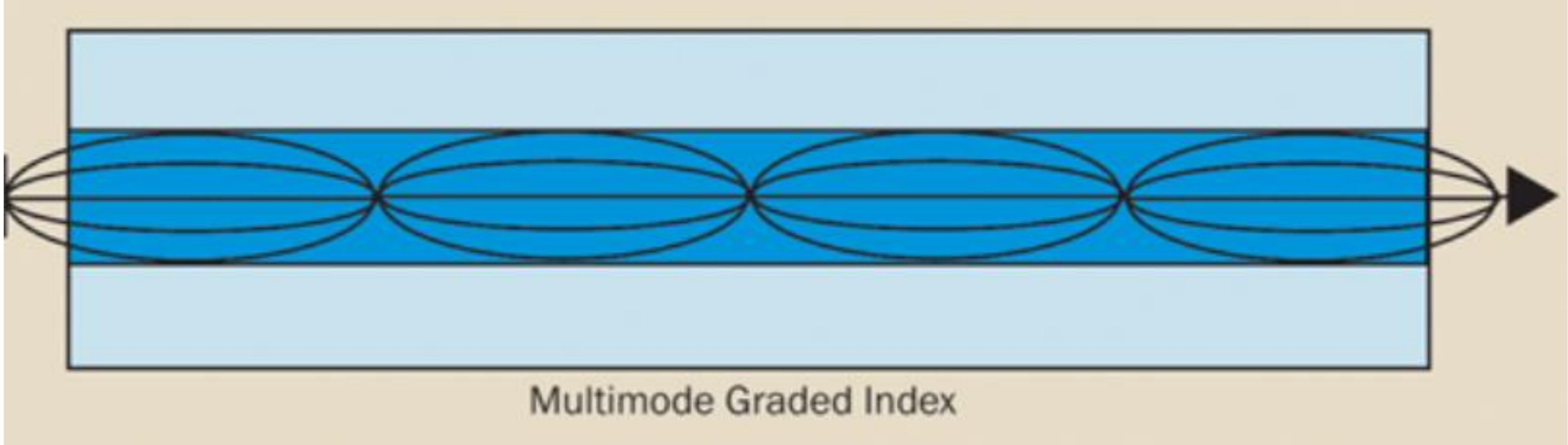
MULTIMODE STEP INDEX FIBER

- Core diameter is large of the order of 50 -125 μm.
- MMSIF permits large number of signal to propagate through it.
- Different modes of rays have different angle of incidence at the core cladding interface.
- Different signal arrive at different time.
- They are best suited for short distance signal transmission.



MUTIMODE GRADED INDEX FIBER

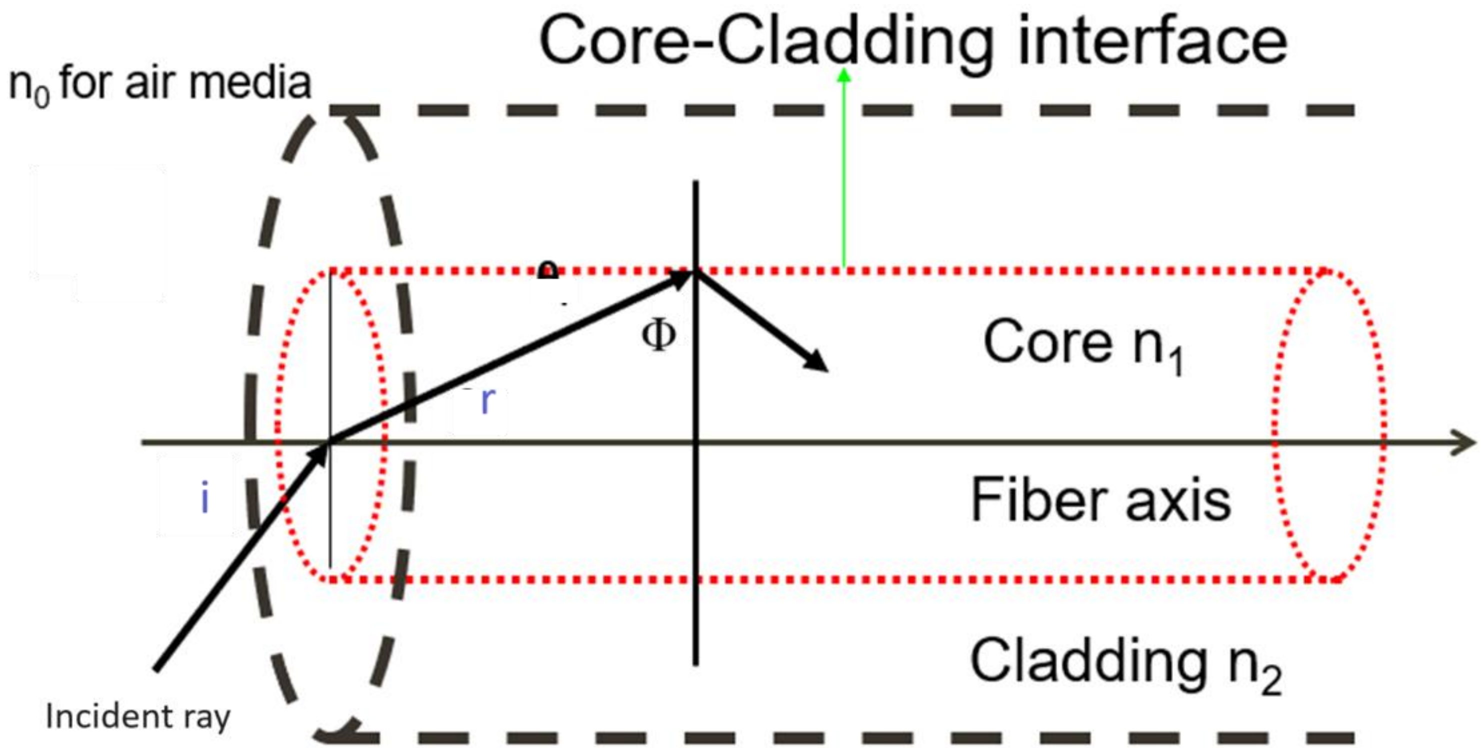
- Core diameter is large of the order of 50 -125 μm.
- Allows large number of signals to propagate.
- Angle of incidence of the signal in the region of high RI to the region of low RI continuously bends.
- The rays propagates in the form of skew rays or helical manner.

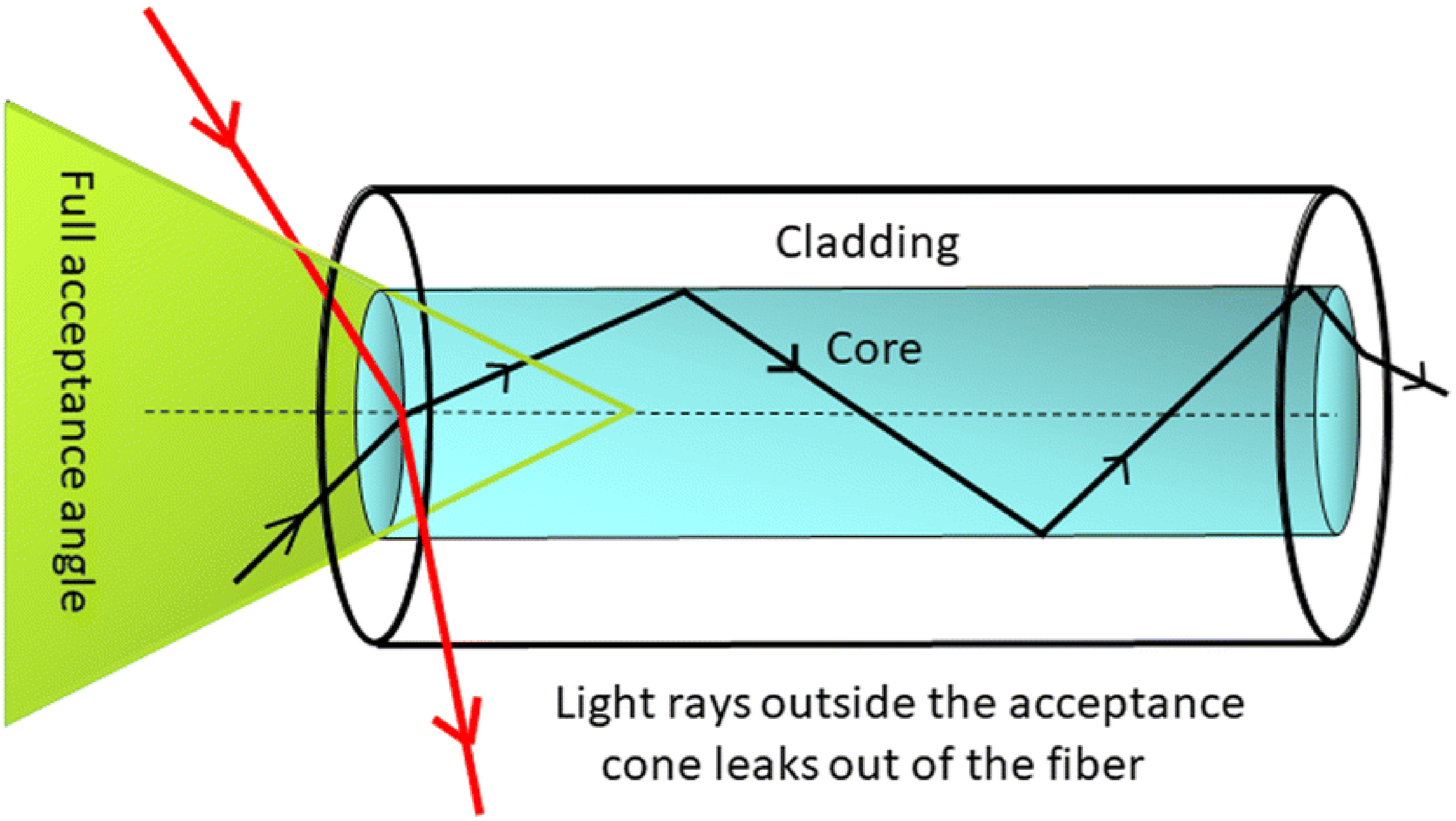


S.NO	SINGLE MODE FIBER	MULTIMODE FIBER
1.	In single mode fiber only one mode can propagate through the fiber	In multimode it allows a large number of paths or modes for the light rays travelling through it.
2.	It has smaller core diameter and the difference between the refractive index of the core and cladding is very small.	It has larger core diameter and refractive index difference is larger than the single mode fiber.
3.	**Advantages:** No dispersion(i.e. there is no degradation of signal during propagation)	**Disadvantages:** Dispersion is more due to degradation of signal owing to multimode.
4.	Since the information transmission capacity is inversely proportional to dispersion $\left(T \propto \frac{1}{D}\right)$ the fiber can carry information to longer distances.	Information can be carried to shorter distances only.
5.	**Disadvantages:** Launching of light and connecting of two fibers difficult.	**Advantages:** Launching of light and also connecting of two fibers is easy.
6.	Installation (fabrication) is difficult as it is more costly	Fabrication is easy and the installation cost is low.

ACCEPTANCE ANGLE

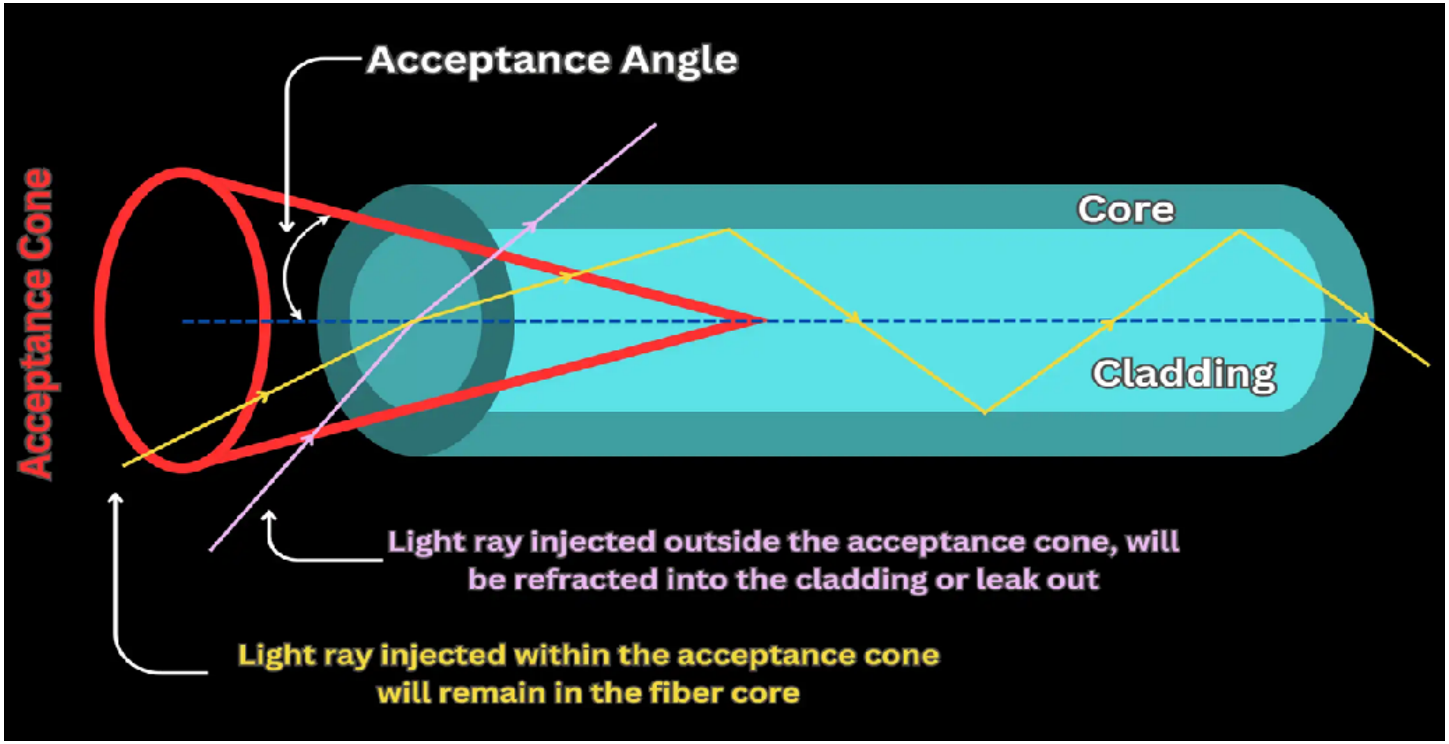
The maximum angle of incidence at the end face of an Optical fiber for which the light ray can be propagated along Core-Cladding interface is known as maximum Acceptance angle.




Full acceptance angle
Cladding
Core
Light rays outside the acceptance
cone leaks out of the fiber

ACCEPTANCE CONE

- Rotating the Acceptance angle about the fiber axis describes the Acceptance Cone of the fiber.
- Light launched at the fiber end within this Acceptance Cone alone will be accepted and propagated to the other end of the fiber by Total internal reflection.



NUMERICAL APERTURE

- The light gathering capacity of an optical fibre is defined as Numerical aperture.

- It is also defined as the sin of the angle of acceptance.
- $NA = \sin i_{max}$
- As, Numerical aperture also depends on the refractive indices of the core and cladding of the optical fibre, it can be represented as

- $NA = \sqrt{{n_1}^2 - {n_2}^2}$, where, n_1 is the refractive index of the core and n_2 is the refractive index of the cladding.
- If the light goes beyond the acceptance cone, it does not contributes to the light propagation (as the angle of incidence will be more than the acceptance angle and hence, no total internal reflection will occur)

Derivation of the formula for Numerical Aperture

Refer Class Notes

The number of guided modes inside optical fiber depends on

1. Numerical Aperture
2. Diameter (of circumference) of core
3. Wavelength of light

The quantity which determines the number of guided modes inside the optical fiber is called **V number or normalized frequency**

It is given by $$V = \frac{(2\pi\, a)\,(NA)}{\lambda}$$

where "a" is the fiber core radius and "λ" is wavelength of light

Number of Modes

- The number of modes can be characterized by the normalized frequency

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

- Most standard optical fibers are characterized by their numerical aperture

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

- Normalized frequency is related to numerical aperture

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

- The optical fiber is single mode if **V< 2.405**

The maximum number of modes for step index fiber $(N_{max}) = \frac{V^2}{2}$

The maximum number of modes for graded index fiber $(N_{max}) = \frac{V^2}{4}$

IMPORTANT PARAMETERS

- The ratio between the difference in RI's of Core and Cladding to that of RI of core is called the **Fractional change Δ**.

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

- **V- number**: Normalized frequency of the fiber.

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

- **N_{max}**: Maximum number of modes allowed by the optical fiber.

$$N_{\max} = \frac{V^2}{2} (Step \quad index \quad fiber)$$

$$N_{\max} = \frac{V^2}{4} (Graded \quad index \quad Fiber)$$

LOSSES IN OPTICAL FIBERS

1. ATTENUATION

The power of the light at the output end is found to be always less than the power launched at the input end. Power decreases exponentially with distance.

$$\alpha = \frac{10}{L} log_{10} \frac{P_i}{P_o} \quad \text{(dB/km)}$$

α is the attenuation constant, L is the length of the fibre
Po is the output power and Pi is the input power.

Attenuation is found to be a function of fiber material wavelength of light and length of the fiber, and it is measured in terms of the decibel.

Attenuation are mainly of four types….

1. Absorption
2. Geometric effects
3. Scattering
4. Bending losses

ABSORPTION:

- Impurities present in the material
- Absorbs light of some specific wavelength region.

GEOMETRIC EFFECTS:

- Non uniformity of the core cladding interface results in the escape of light
- as the condition of TIR is not satisfied.

SCATTERING:

- Glass has disordered structure.
- Variation in density leads to change in RI
- Light scatters and hence suffers loss given by $1/\lambda^4$

BENDING LOSS:

- Bending of Optical Fiber causes strain
- RI of the core and critical angle of the cladding gets affected.
- Transmitted light suffers reflection and refraction at both at the bending.

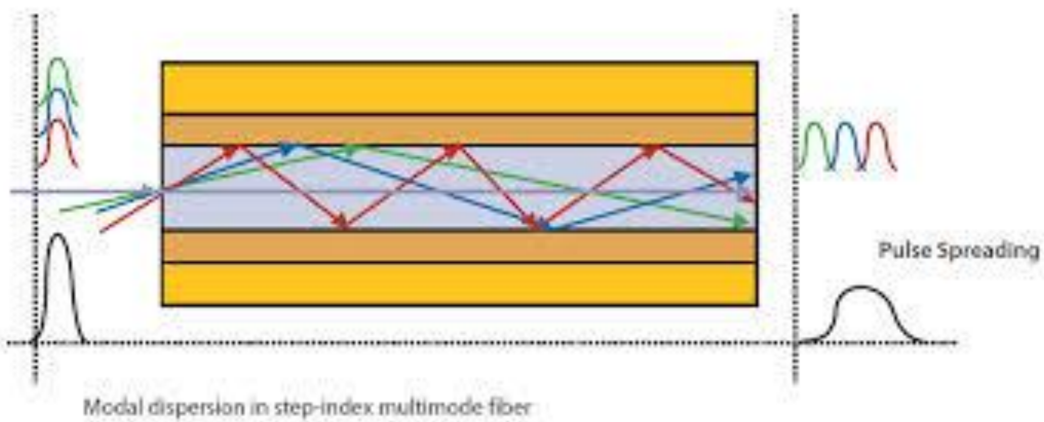
2. DISTORTION

Broadening of the light pulse while transmitting through the optical fiber.
It is expressed in ns/km.

Types of Distortion

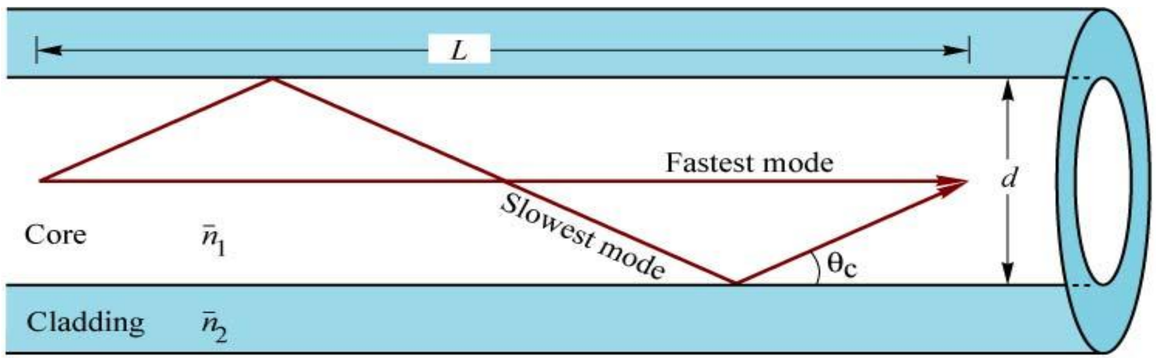
1. Intermodal distortion

Different modes have different velocities. Time for reaching the output end is different thus, leading to the pulse broadening.

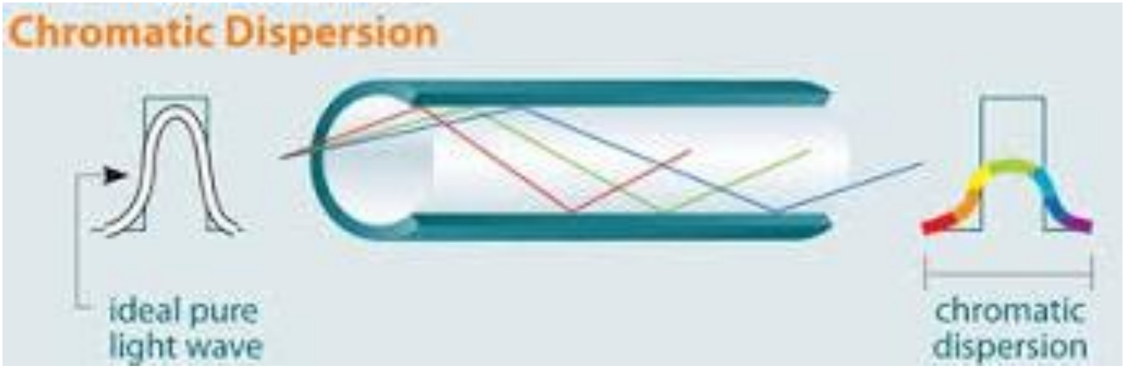


2. Intramodal dispersion

(a) Waveguide dispersion:

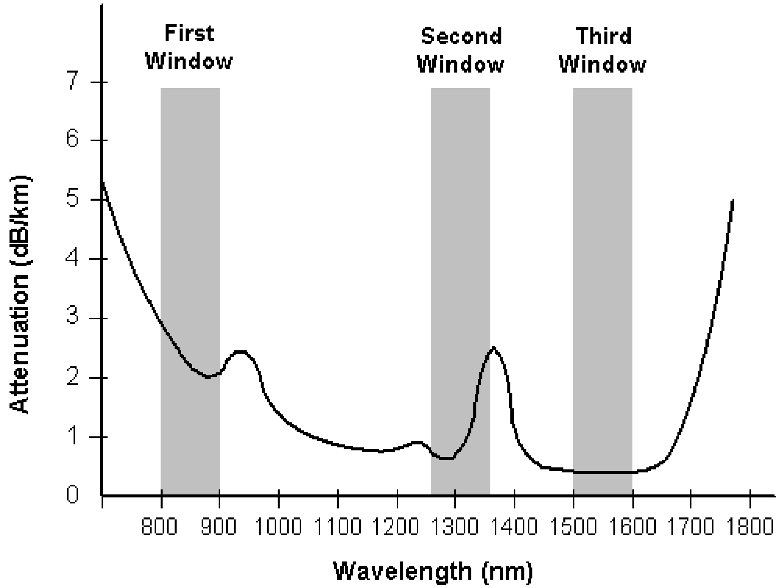


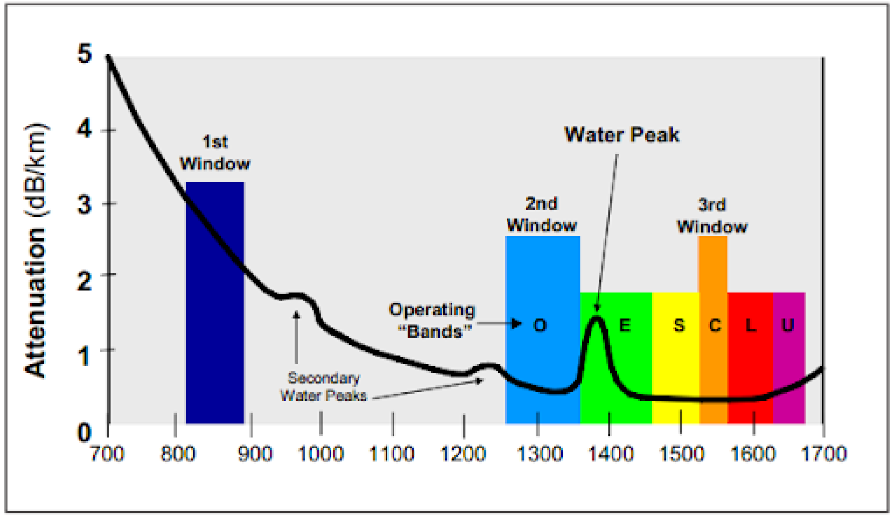
(b) Material dispersion



Optical window

For better performance choice of wavelength is must to minimize loss and dispersion.

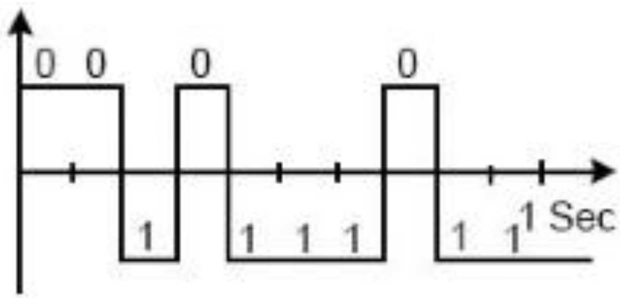




- ❖ The band of wavelengths at which the attenuation is a minimum is called optical window or transmission window or low loss window.
- ❖ The minimum attenuation is in the range of 1500-1600 nm, hence is most preferable wavelength for transmission.

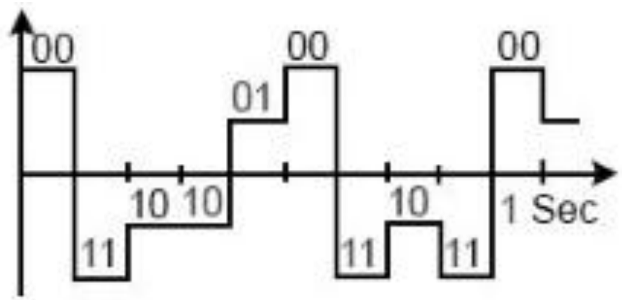
Bit rate

- It is defined as number of bits transmitted per second over an optical fiber link.
- **It is data-carrying capacity and speed of data transmission**
- While **baud rate** relates to the number of signal changes per second in optical fiber communication.
- It quantifies the volume of data that can be transferred through the fiber optic channel within a given time frame.
- The unit is bits per second (bps), where 1 bps represents one bit transmitted in one second.



Boud = 10

Bit rate = 10 bps



Boud = 10

Bit rate = 20 bps

The maximum data speed or "bit rate" is theoretically given by

$B \approx \frac{0.7}{\tau}$ bits/sec.

Usually, the bit rate inexpresed in MBPS (Mega Bits Per Second)

The total dispersion (neglecting waveguide dispersion) is given by

$\tau = \sqrt{\tau_i^2 + \tau_m^2}$, where τ_m is material dispersion.

Dispersion in fibres is usually expressed in ns/km or ps/km. The intermodal dispersion is given by

$\tau_i = \frac{n_1 L}{c} \Delta$ for SI fibre and

$\tau_i = \frac{n_2 L}{2c} \Delta^2$ for GRIN fibre (parabolic profile)

Here, L is length of fibre and c is speed of light