1.2	Optical Fibres: Total internal reflection, numerical aperture, type of optical fibres, modes of propagation, V-number, attenuation and dispersion, bit rate, optical window

INTRODUCTION

- You hear about fiber-optic cables whenever people talk about the telephonic system, the cable TV system or the Internet.
- Fiber-optic lines are strands of optically pure **glass** as thin as a human hair that carry digital information over long distances.
- Optical fibers 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 of the fiber.
- They are also used in medical imaging and mechanical engineering inspection.

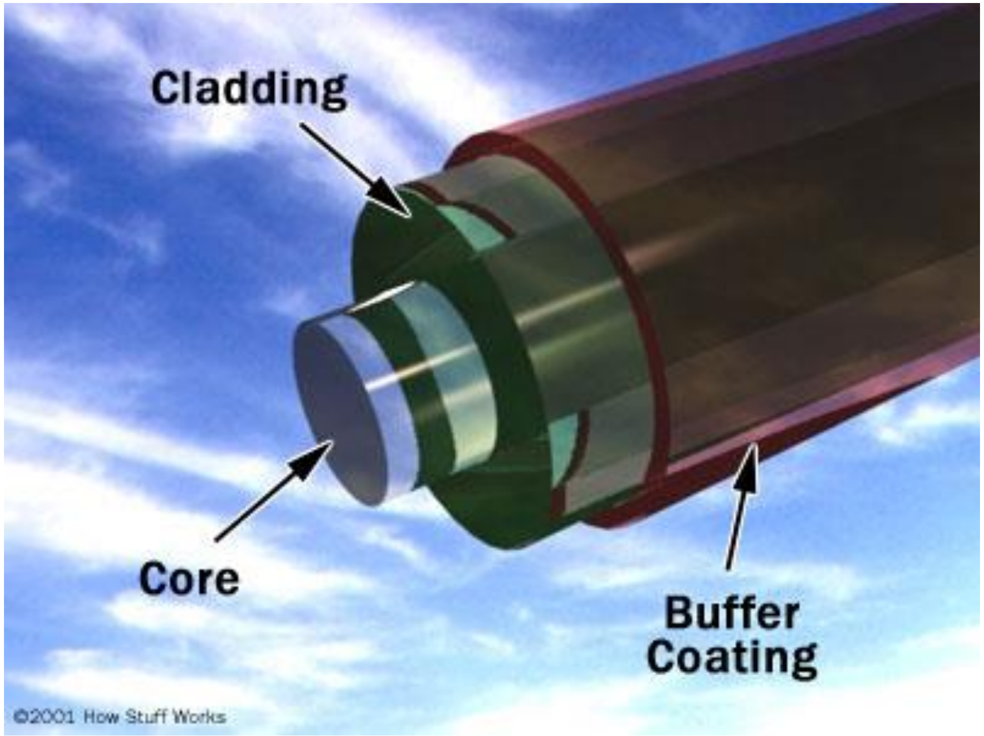
STRUCTURE OF AN OPTICAL FIBER

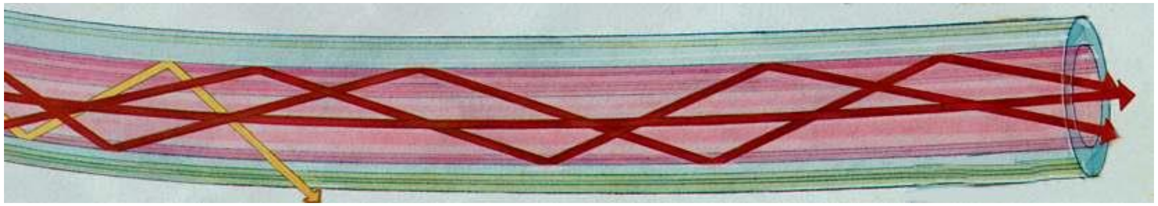
Core: It is an inner cylindrical material made up of **glass** or **plastic**. Diameter: 8-100 μm.

Cladding: It is a cylindrical shell of glass or plastic material in which Core is inserted. Diameter: 50-200 μm.

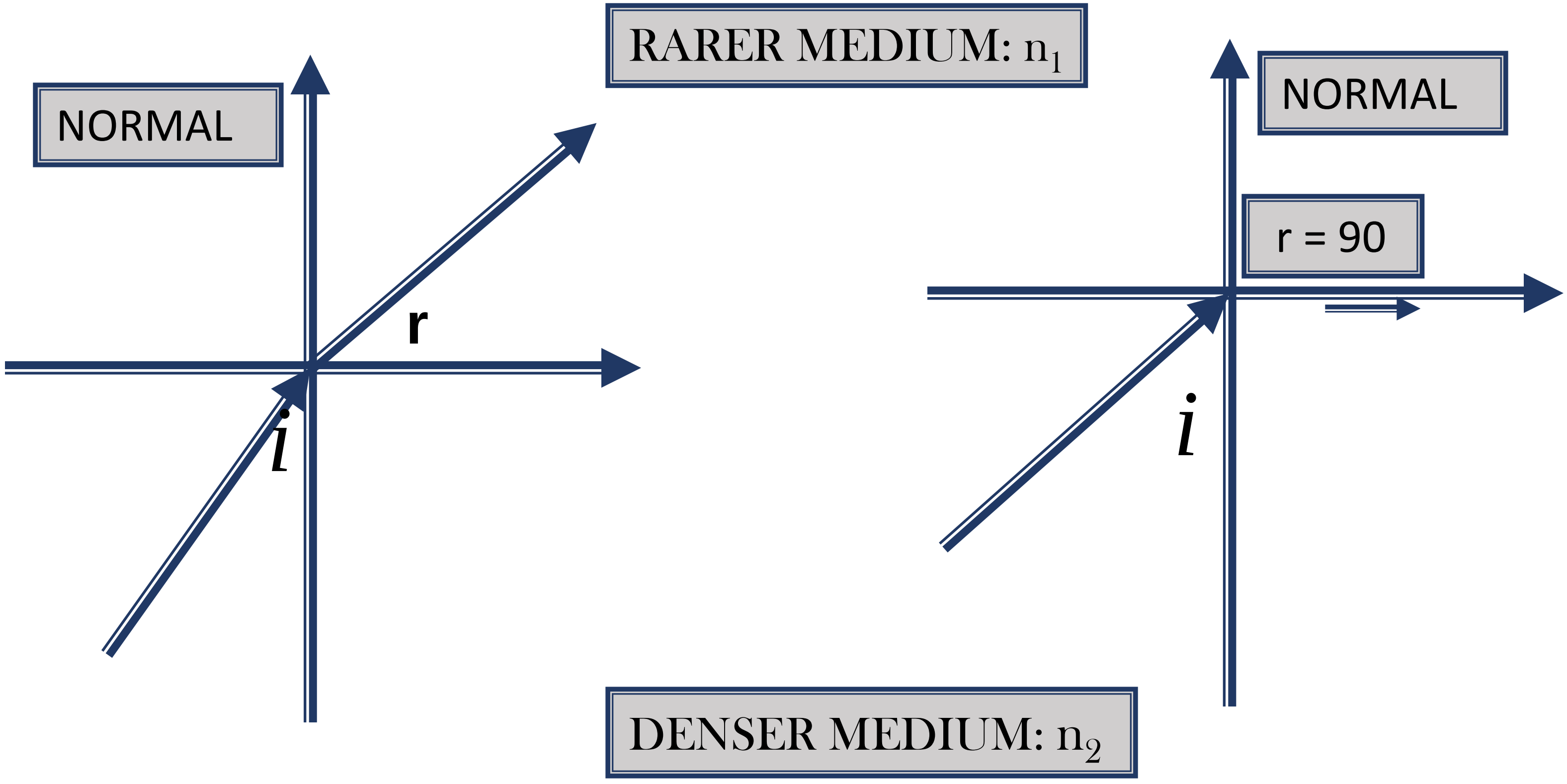
Protective Jacket: The Cladding is enclosed in **polyurethane** jacket and it protects the fiber from surroundings. Diameter: 100-400 μm.

STRUCTURE OF AN OPTICAL FIBER

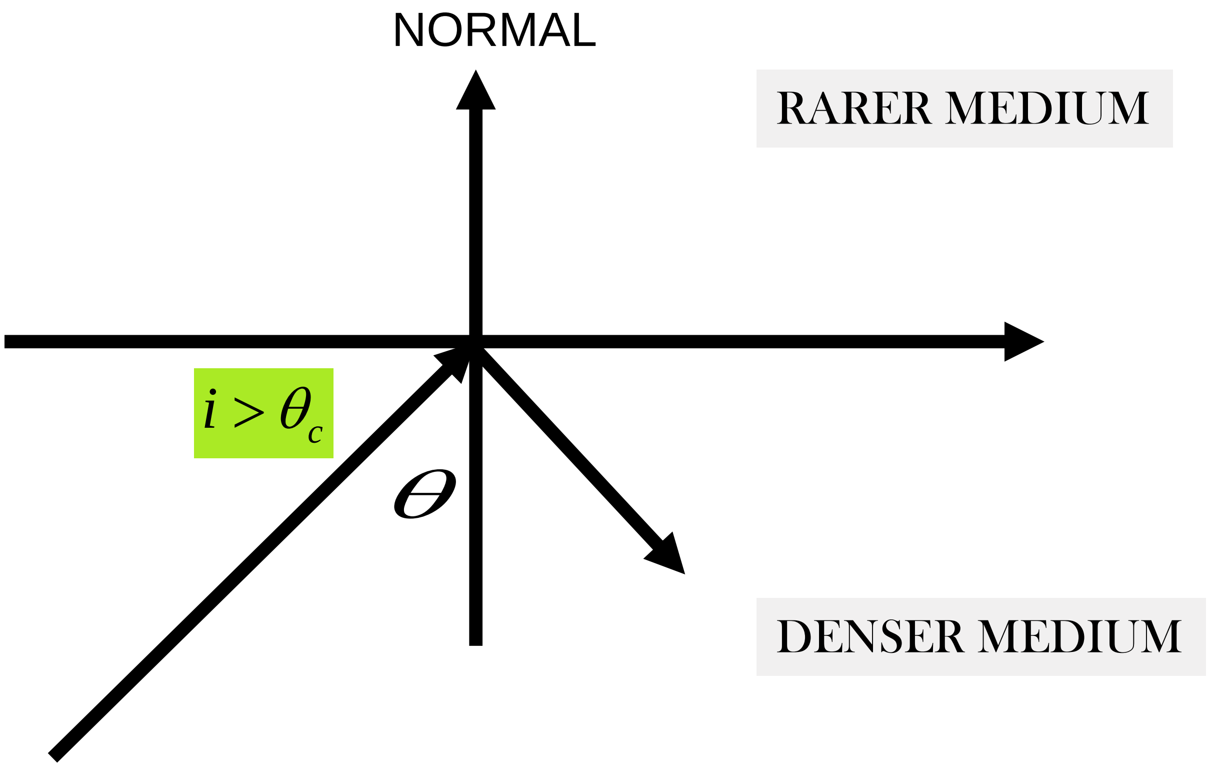




PRINCIPLE OF LIGHT PROPAGATION IN FIBER OPTICS



TOTAL INTERNAL REFLECTION



To calculate critical angle

According to law of refraction

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

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

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

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

CLASSIFICATION OF OPTICAL FIBER

- Based on Refractive Index
  - Step Index Fiber
  - Graded Index Fiber
- Modes of Propagation
  - Single Mode
  - Multimode
- Based on material used
  - Silica Fiber
  - Plastic fiber
  - Plastic clad fiber

BASED ON THE MATERIAL OF THE CORE AND CLADDING

TYPES OF FIBER BASED ON MATERIALS

SILICA 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.

PLASTIC FIBER

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

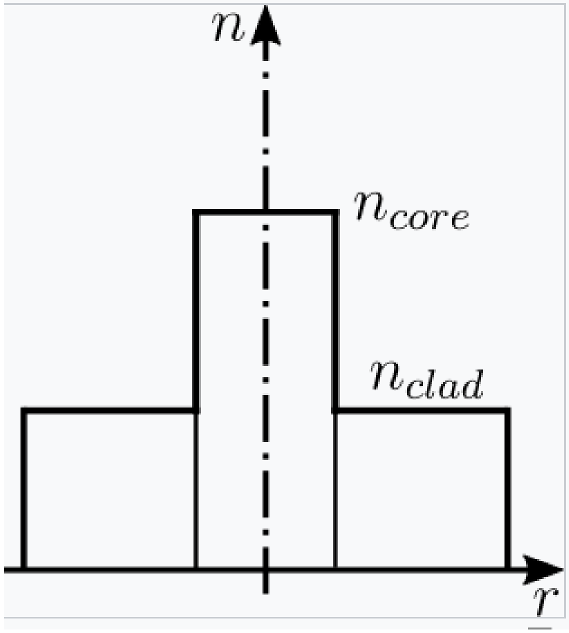
PLASTIC CLAD FIBER

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

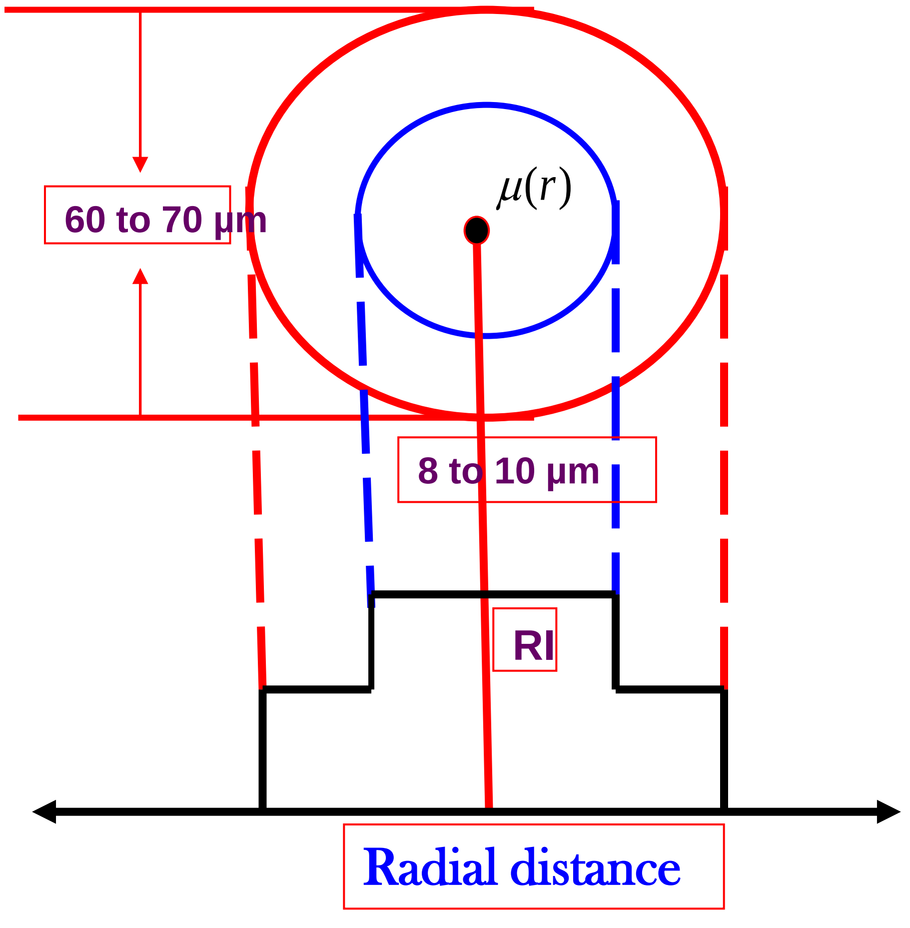
BASED ON THE REFRACTIVE INDEX OF THE CORE AND CLADDING

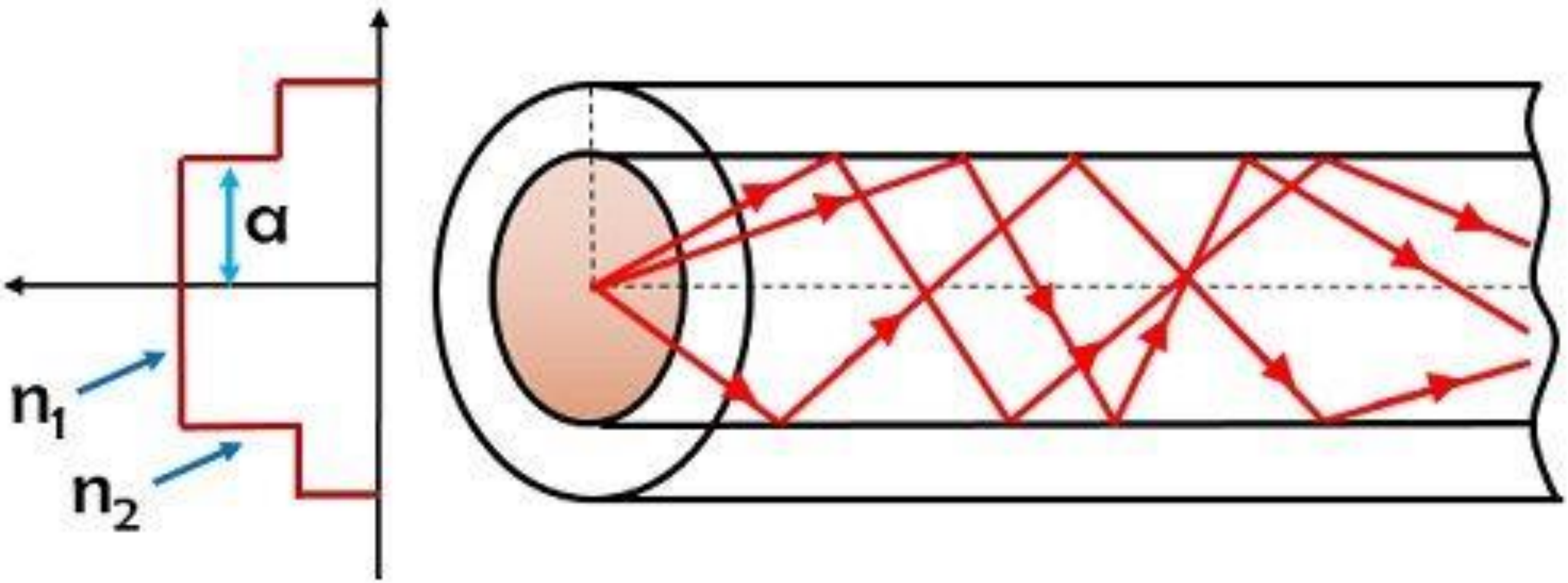
STEP INDEX FIBER

- 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.
- 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

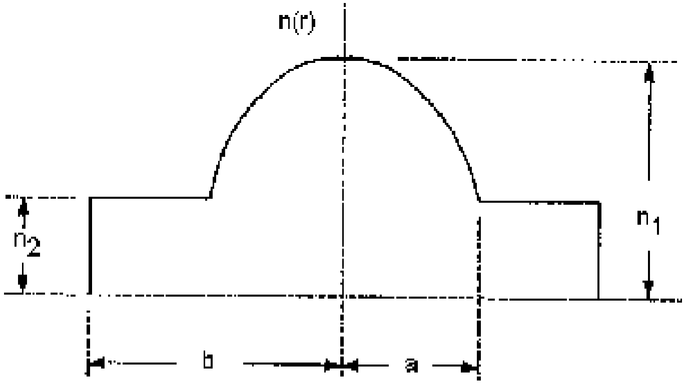




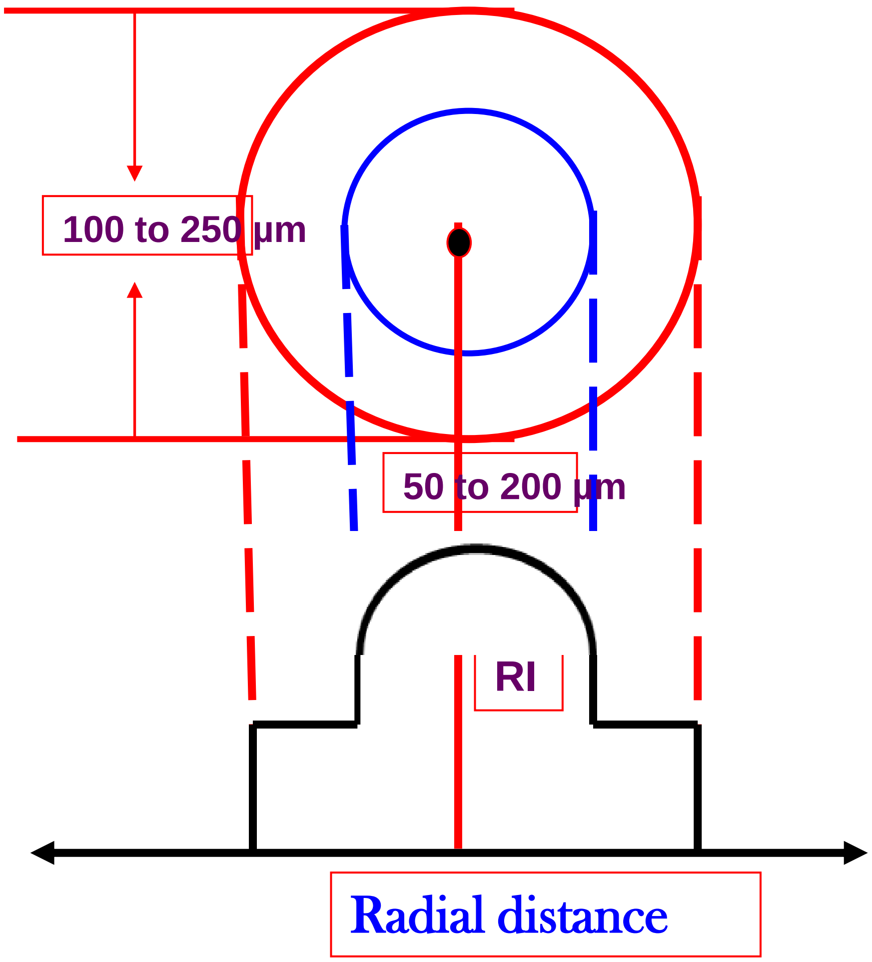
Step Index multimode fiber

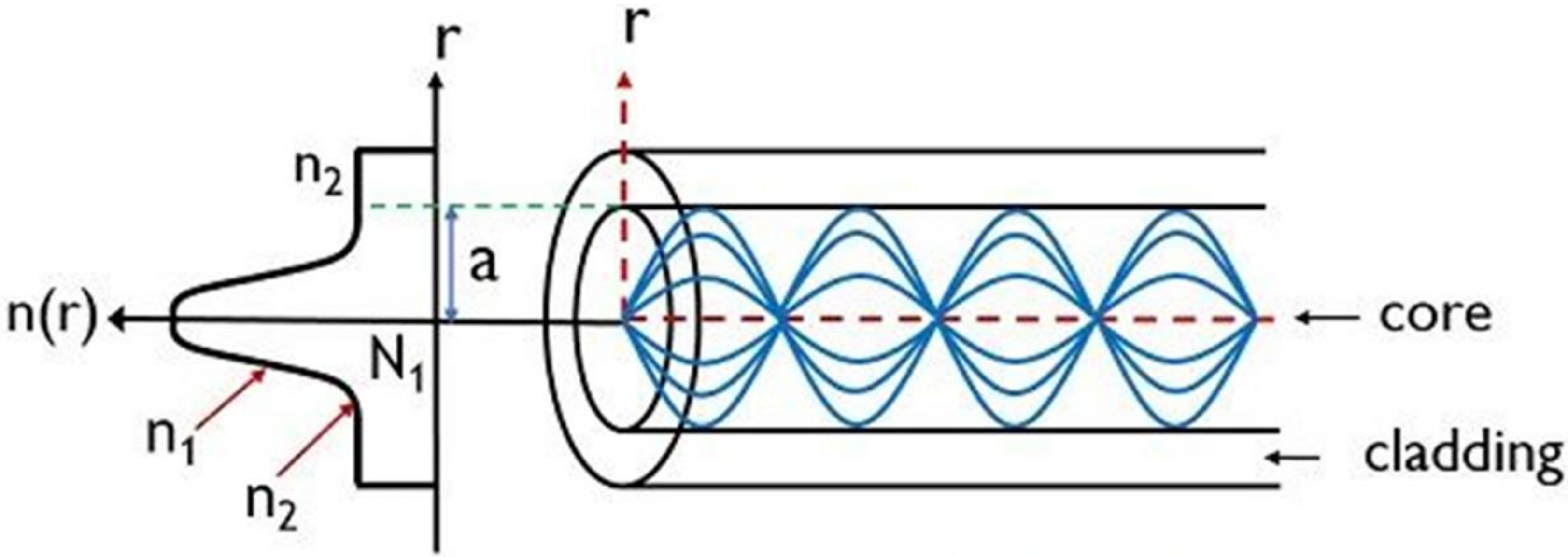
GRADED INDEX FIBRE

- In this fiber , 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.



REFRACTIVE INDEX PROFILE OF GRADED INDEX FIBER





Ray Transmission in Multimode Graded Index Fiber

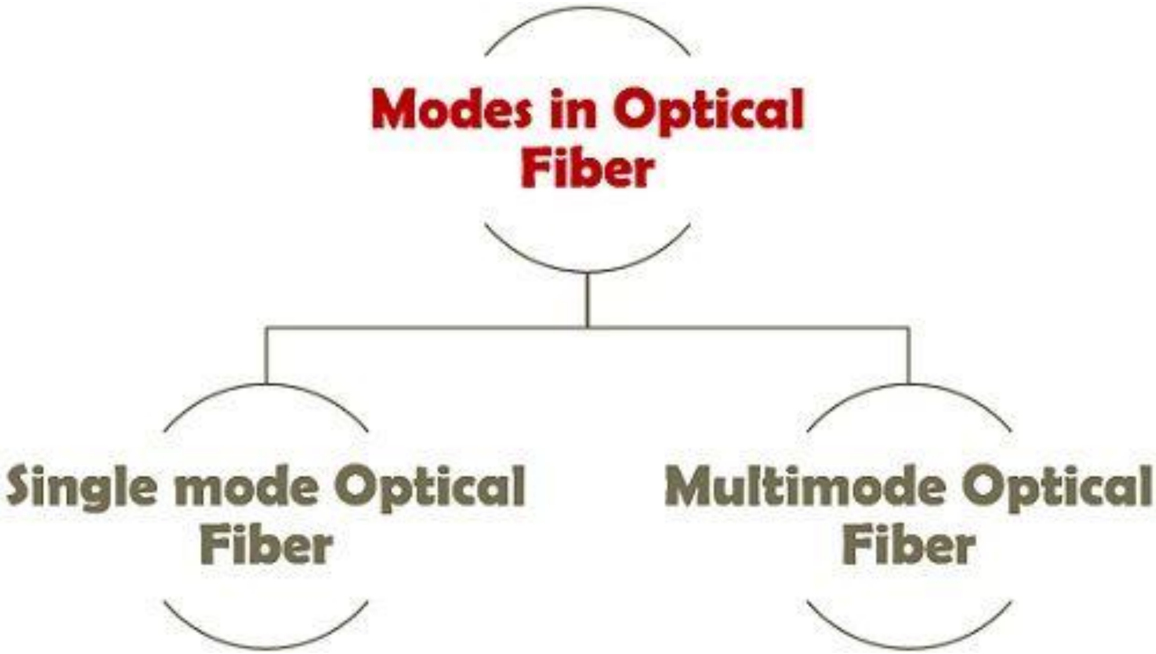
S. NO	STEP INDEX FIBER	GRADED INDEX FIBER
1.	The refractive index of the core is uniform throughout and undergoes on abrupt change at the core cladding boundary	The refractive index of the core is made to vary gradually such that it is maximum at the center of the core.
2.	The diameter of the core is 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

- 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.

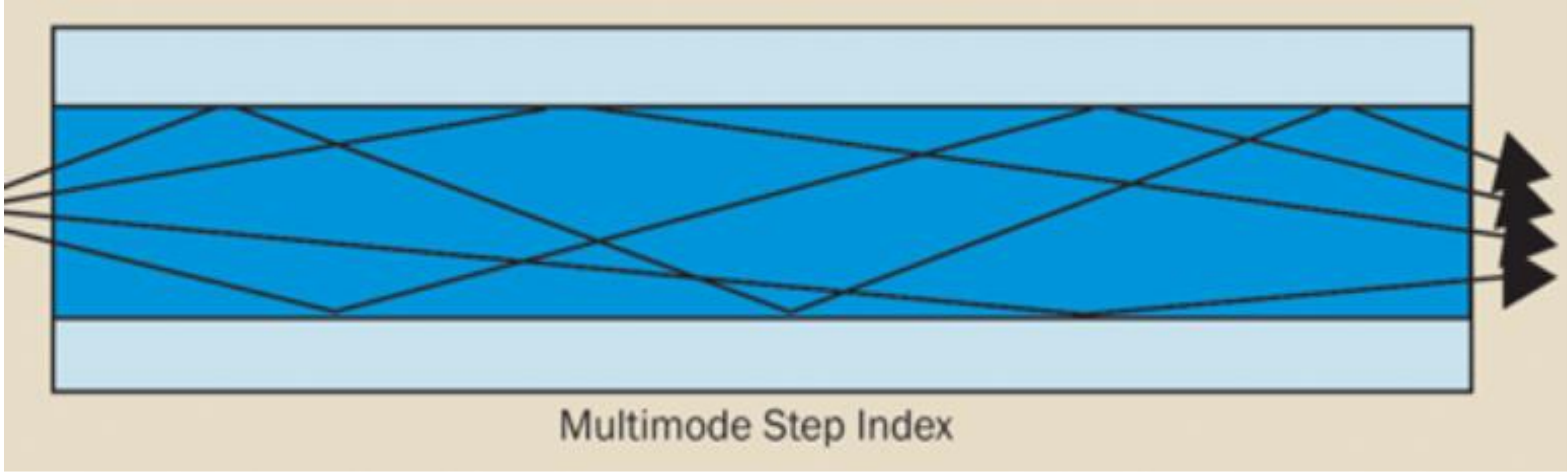


SINGLE MODE STEP INDEX FIBER

- Signal propagates in only one mode.
- Core diameter is very small of the order of 8-10 μm
- Light travels parallel to the axis of the core.
- Transmission loss of the signal is very small.

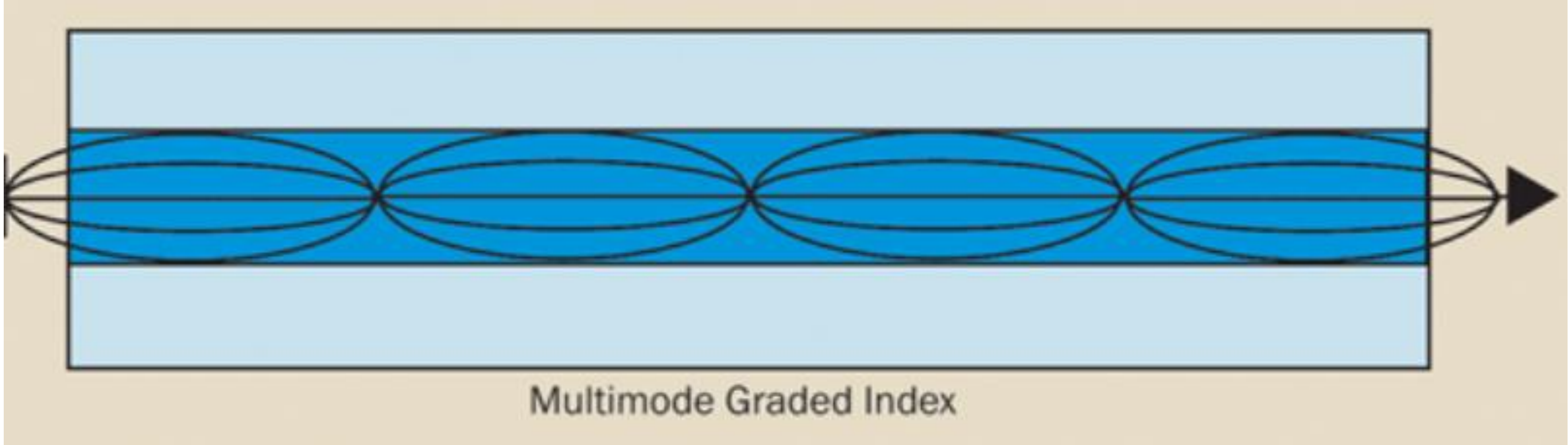
MULTIMODE STEP INDEX FIBER

- MMSIF permits large no. 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

- Allows a 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.

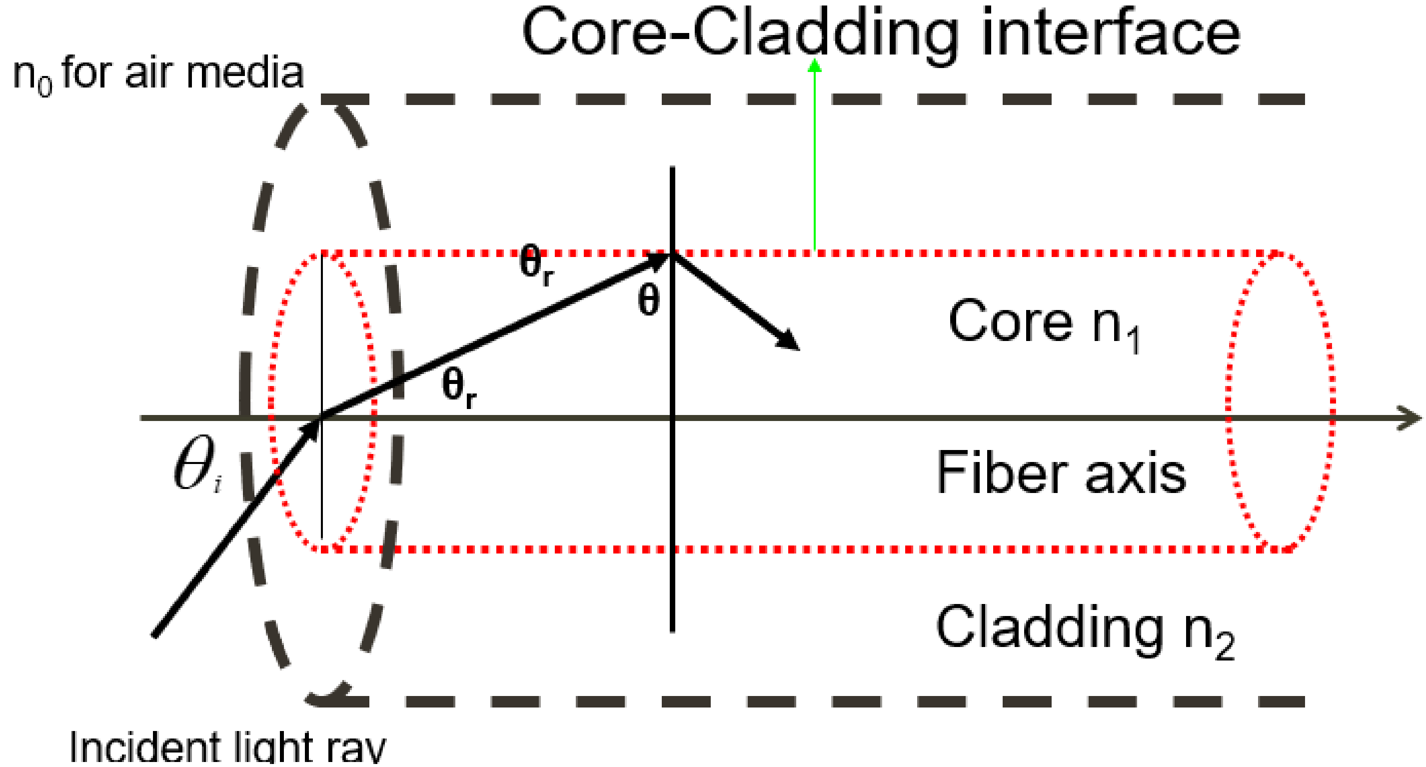


S.NO	SINGLE MODE FIBER	MULTIMODE FIBER
1.	In single mode fiber only one mode can propagate through the fiber	In multimode it allows a large number of paths or modes for the light rays travelling through it.
2.	It has smaller core diameter and the difference between the refractive index of the core and 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.

Discussion on Multimode step index fibre

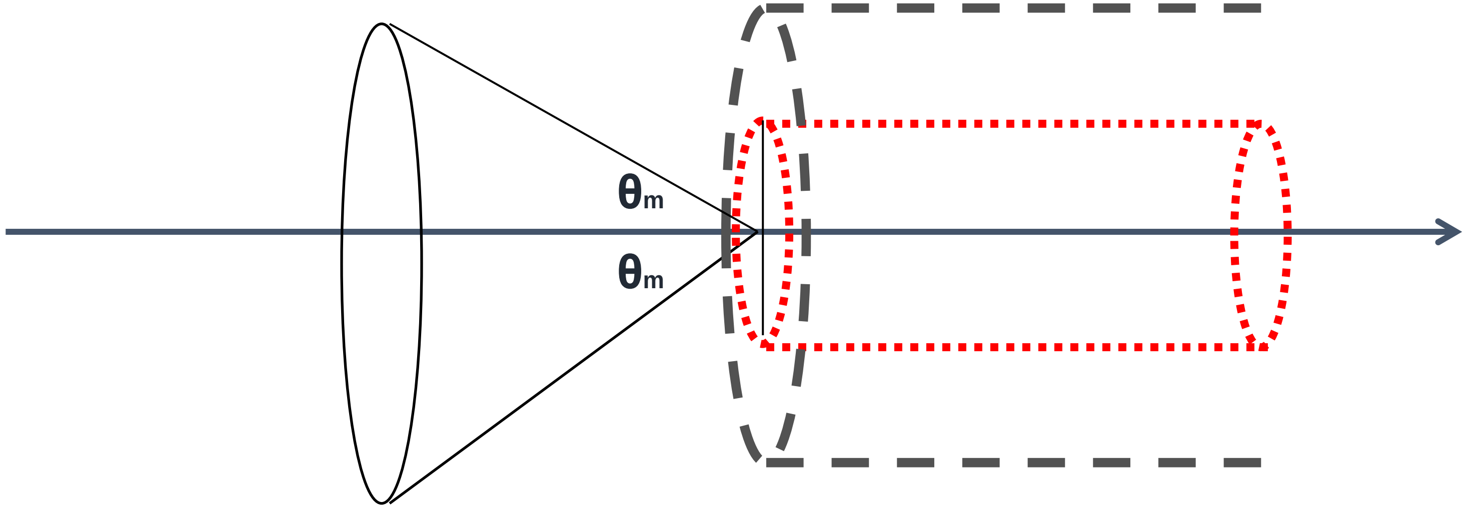
ACCEPTANCE ANGLE

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.



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.



Acceptance Cone

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

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 out put end is found to be always less than the power launched at the input end. Power decreases exponentially with distance.

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

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.

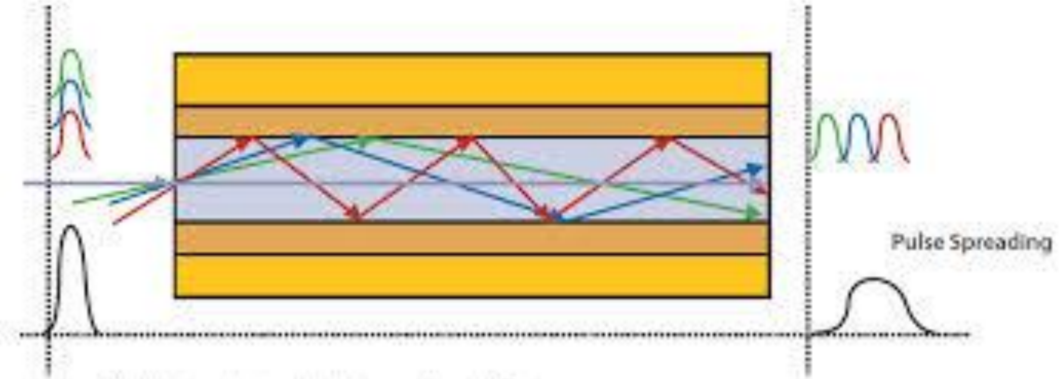
2. DISTORTION

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

Types of Distortion

1. INTERMODAL DISTORTION

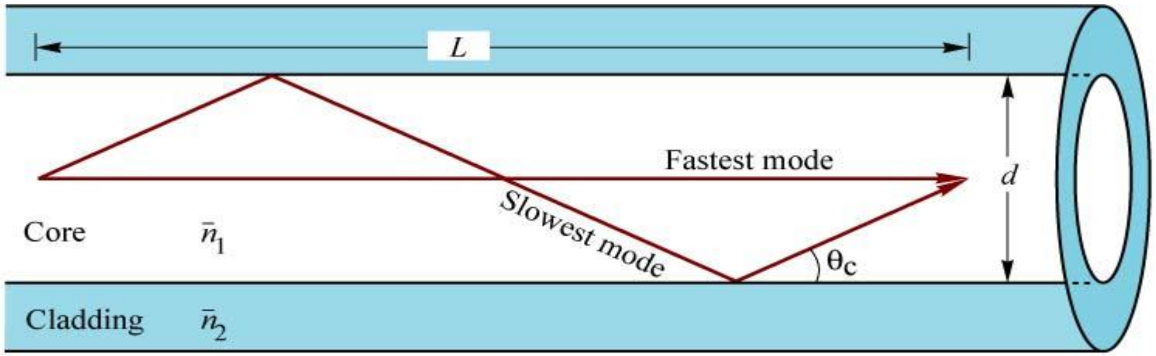
Different modes have different velocities. Time for reaching the output end is different thus, leading to the pulse broadening.



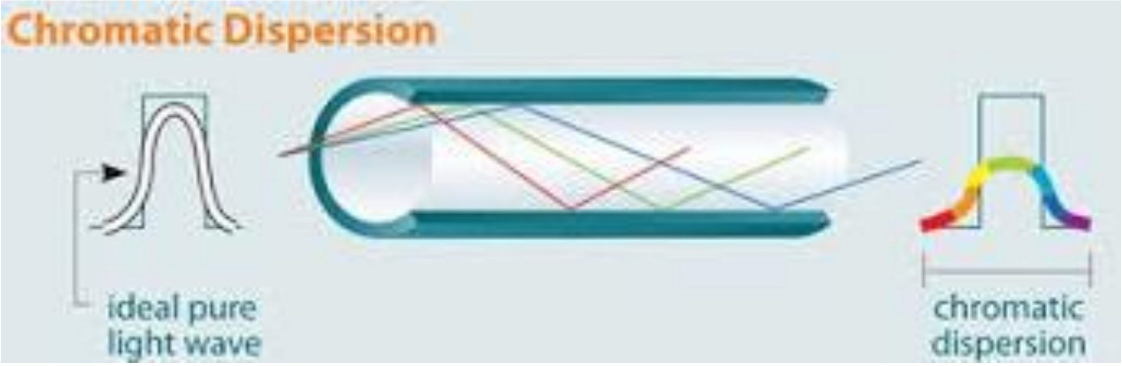
Modal dispersion in step-index multimode fiber

2. INTRAMODAL DISPERSION

(a) Waveguide dispersion:



(b) Material dispersion



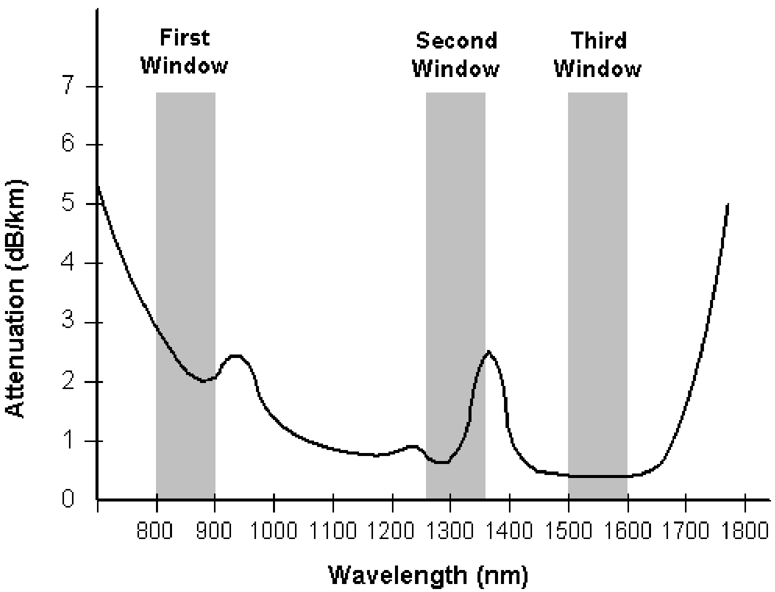
Intermodal dispersion

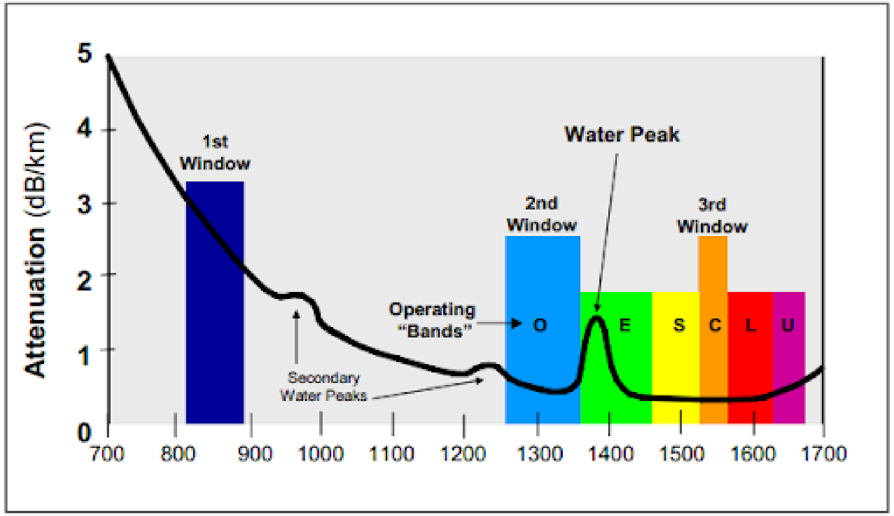
For step index $= \dfrac{(n_{1})(L)(\Delta)}{c}$

For graded index $= \dfrac{(n_{2})(L)(\Delta^{2})}{c}$

Optical window

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

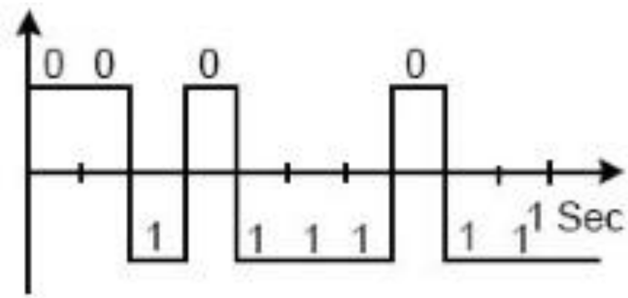




- The band of wavelengths at which the attenuation is a minimum is called optical window or transmission window or low loss window.
- The minimum attenuation is in the range of 1500-1600 nm, hence is most preferable wavelength for transmission.

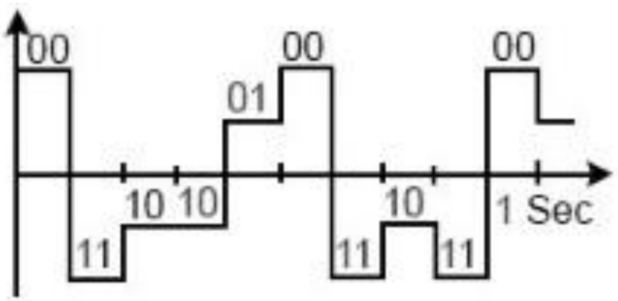
Bit rate

- 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 timeframe.
- 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

- **It is measure of optical fiber performance or traffic capacity at the receiving end of a given length of the fiber.**

- For an optical fiber, the product of (a) a given length of the (b) the bit rate, i.e., the data signaling rate (DSR), the fiber or cable can handle for specified input conditions, tolerable dispersion, acceptable attenuation, and given bit error ratio (BER)

- The bit-rate length product (BRLP) usually is stated in units of megabit· kilometers per second.

- A typical BLRP value for graded-index optical fibers with a numerical aperture (NA) of 0.2 is 1,000 Mb · km · s^{-1}.

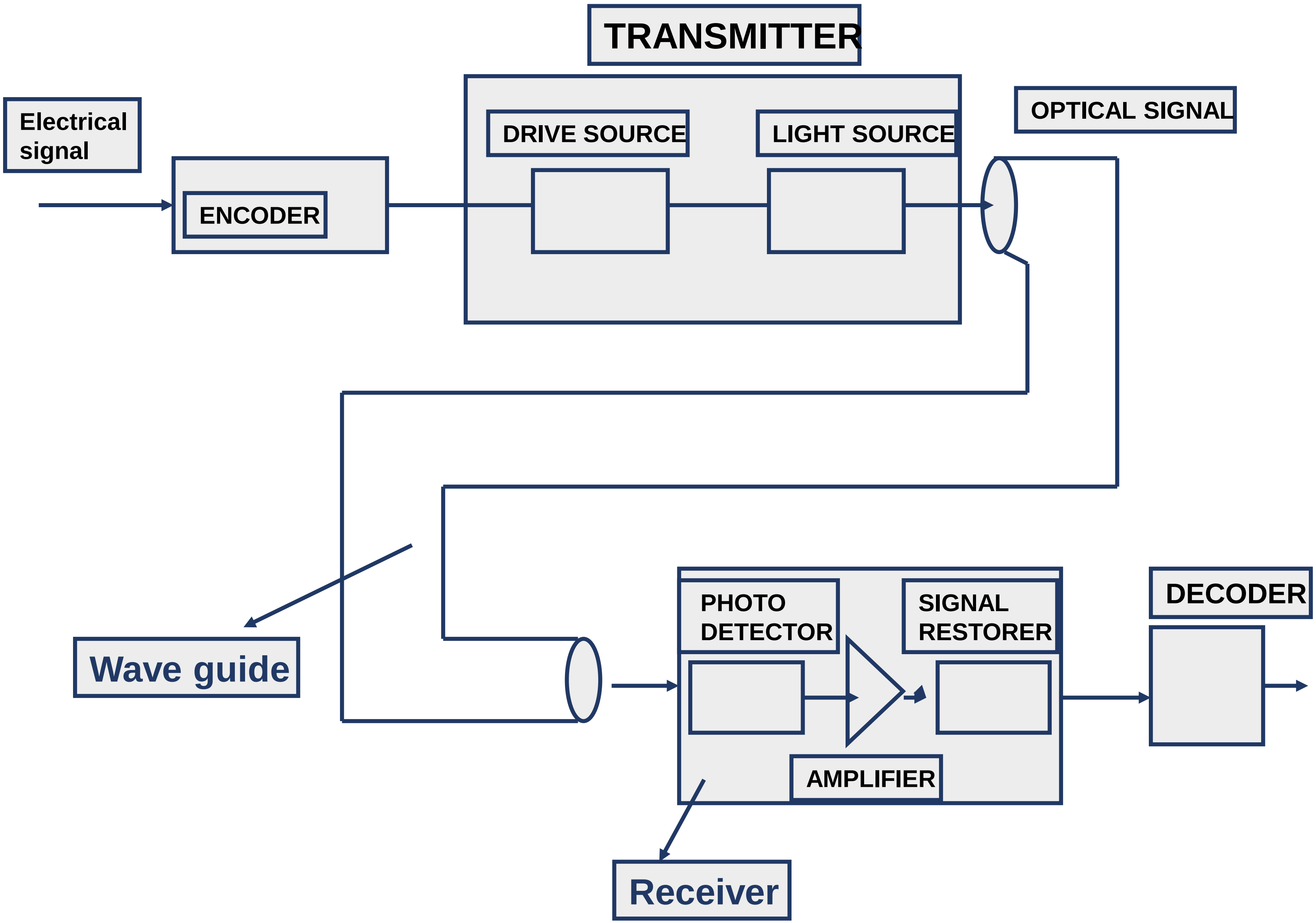
- High-performance optical fibers have a higher BRLP. Higher values are expected in the future.

- The value of the BRLP is a good indicator of fiber performance in terms of transmission capability.

OPTICAL FIBER COMMUNICATION SYSTEM

- An efficient optical fiber communication system requires high information carrying capacity such as voice signals, video signals over long distances with a minimum number of repeaters. It essentially consists of following parts.

1. **Encoder**
2. **Transmitter**
3. **Wave guide**
4. **Receiver**
5. **Decoder**


TRANSMITTER
Electrical signal
ENCODER
DRIVE SOURCE
LIGHT SOURCE
OPTICAL SIGNAL
Wave guide
PHOTO DETECTOR
SIGNAL RESTORER
AMPLIFIER
DECODER
Receiver

1. ENCODER:

It converts electric signal corresponding to analog information such as voice, figures, objects etc. into a binary data. This binary data comes out in the form of stream of electrical pulses.

2. TRANSMITTER:

It mainly consists of driver circuit and a light source. Digital modulation is commonly used in optical fiber communication where the signal is coded using discrete bits. Driver circuit converts the coded electrical signal into optical form. An LED or a Laser diode is used as the converter.

3. RECIEVER:

The data in the form of light is connected to a photo detector. A small current is generated when the light is incident on it. The pulse often requires amplification as the value is very small. A wave-shaper circuit may be required to retain the form of original signal.