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.

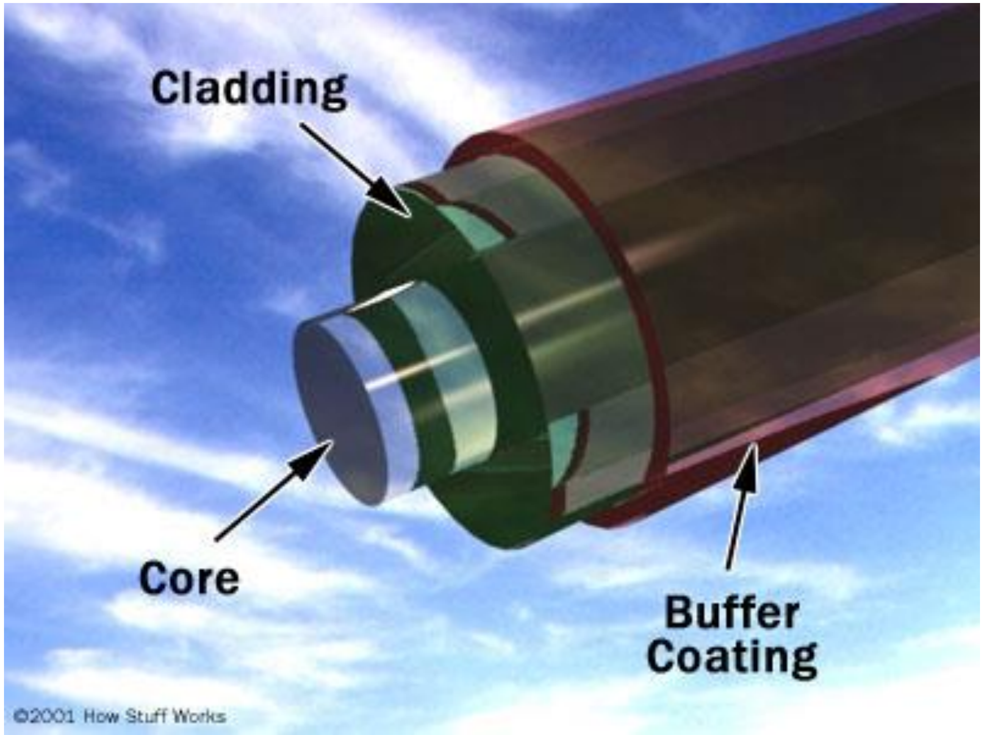
STRUCTURE OF AN OPTICAL FIBER

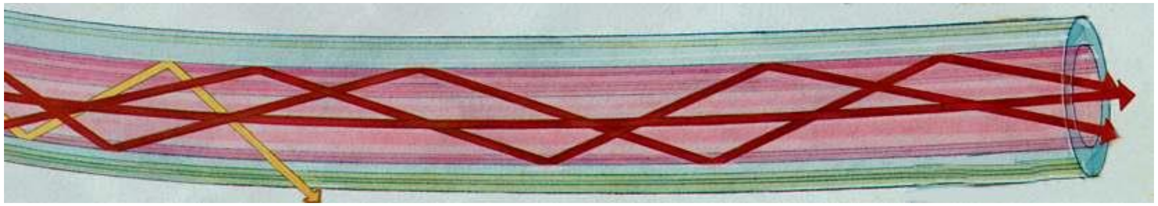
Core: It is an inner cylindrical material made up of **glass** or **plastic**. Diameter: 8-100 μm.

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

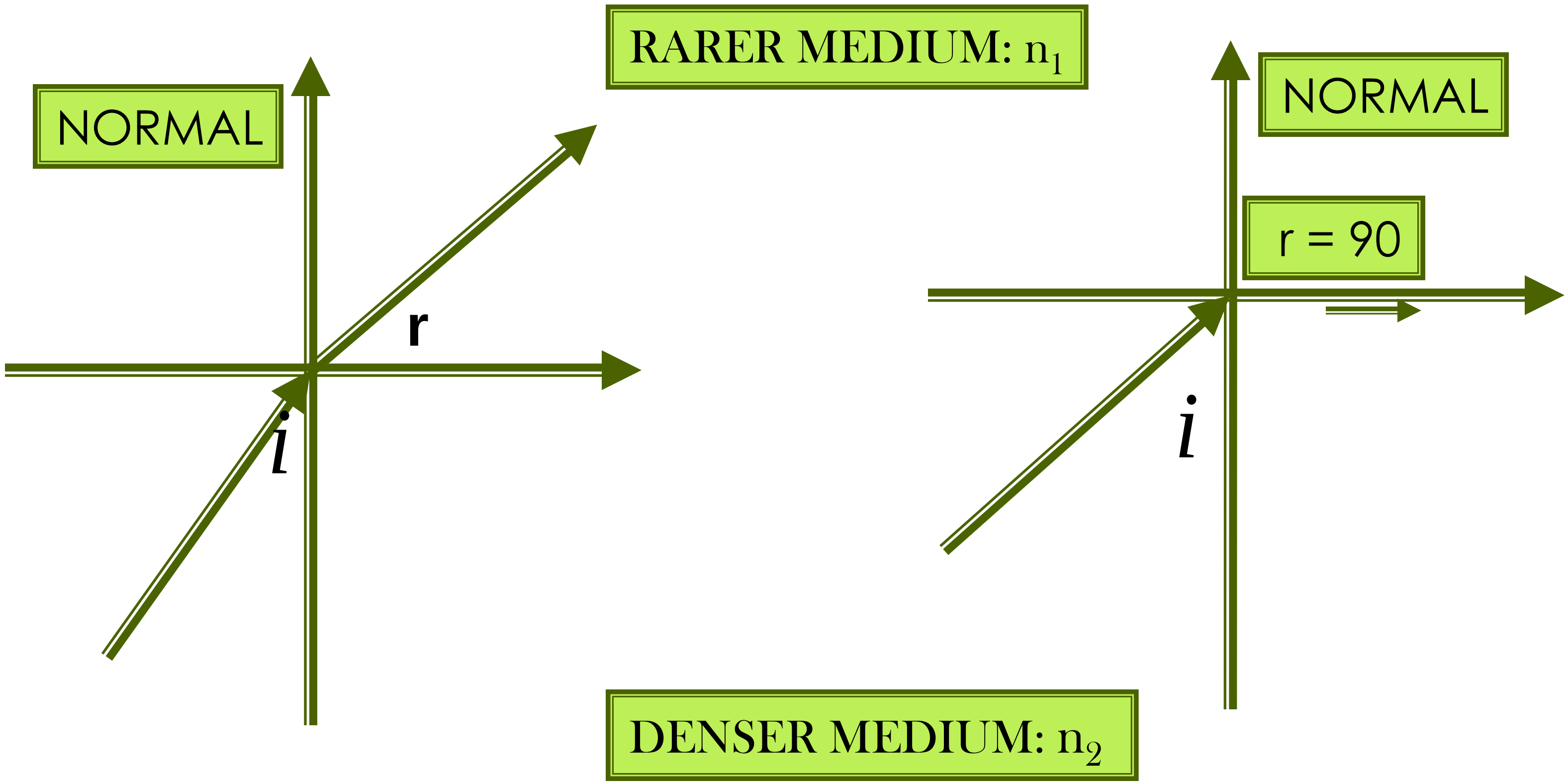
Protective Jacket: The Cladding is enclosed in **polyurethane** jacket and it protects the fiber from surroundings. Diameter: 100-400 μm.

STRUCTURE OF AN OPTICAL FIBER

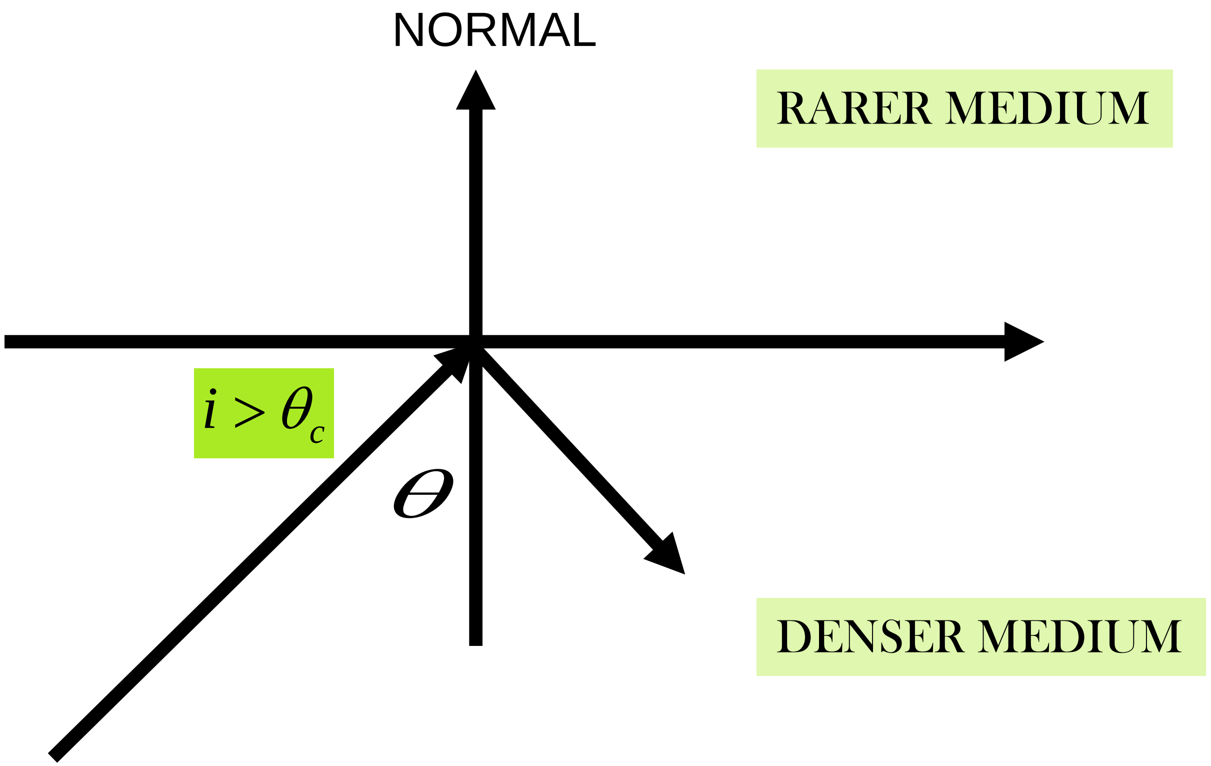




PRINCIPLE OF LIGHT PROPAGATION IN FIBER OPTICS



TOTAL INTERNAL REFLECTION



To calculate critical angle

According to law of refraction

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

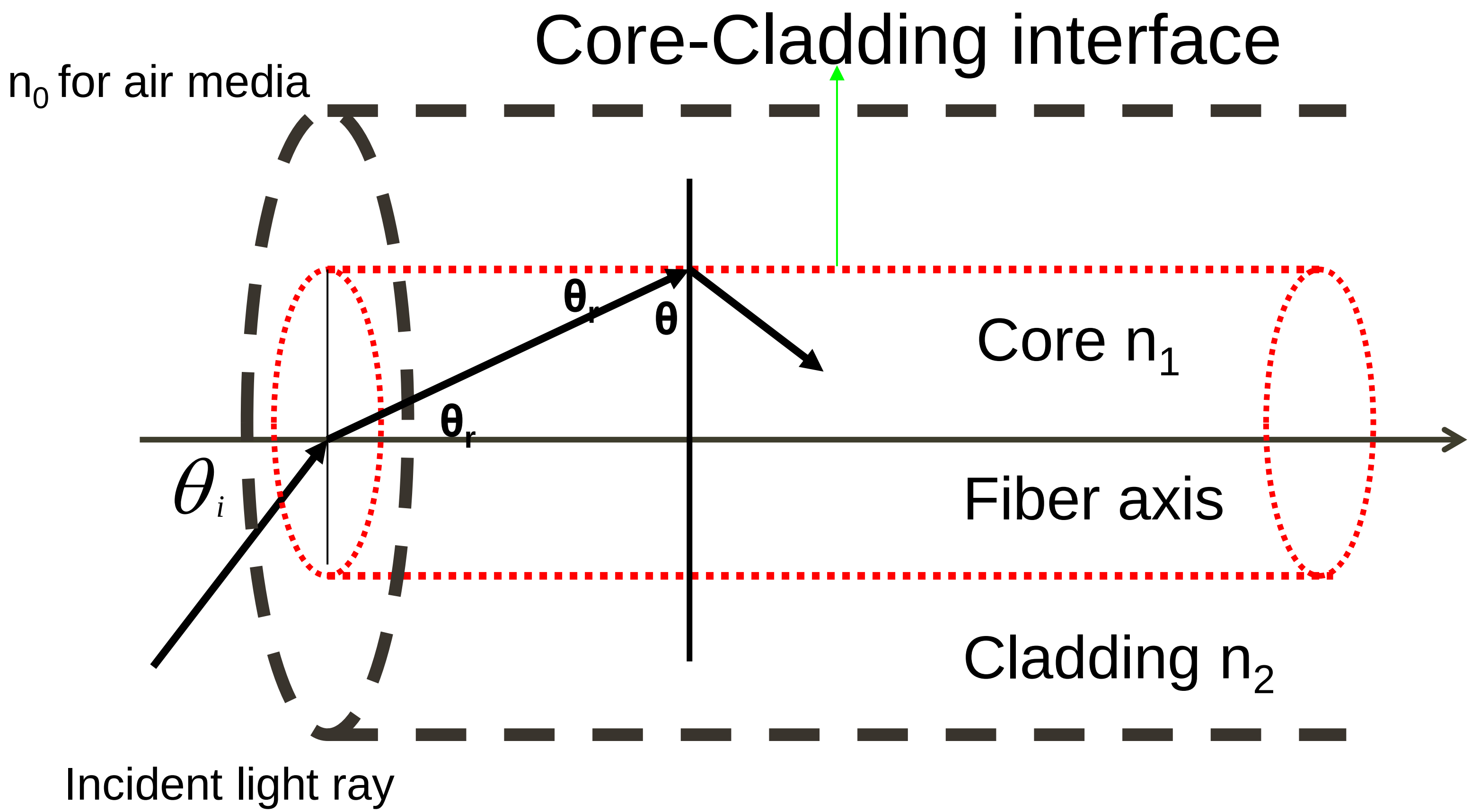
$$i = \theta_c \rightarrow r = 90^0$$

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

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

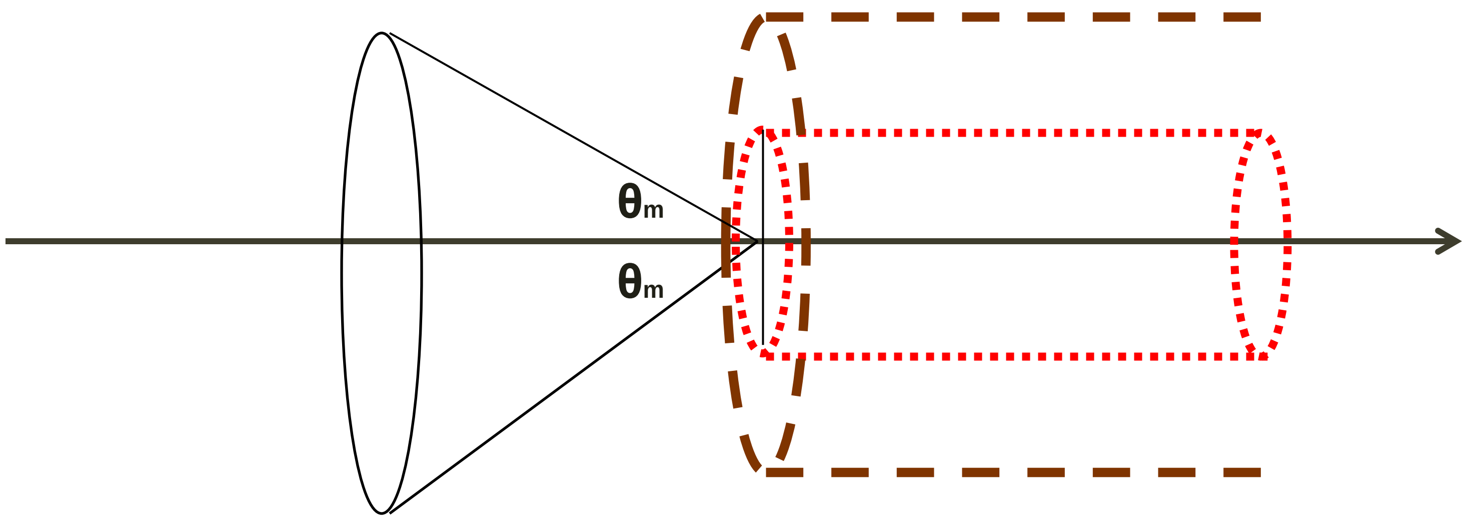
ACCEPTANCE ANGLE

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

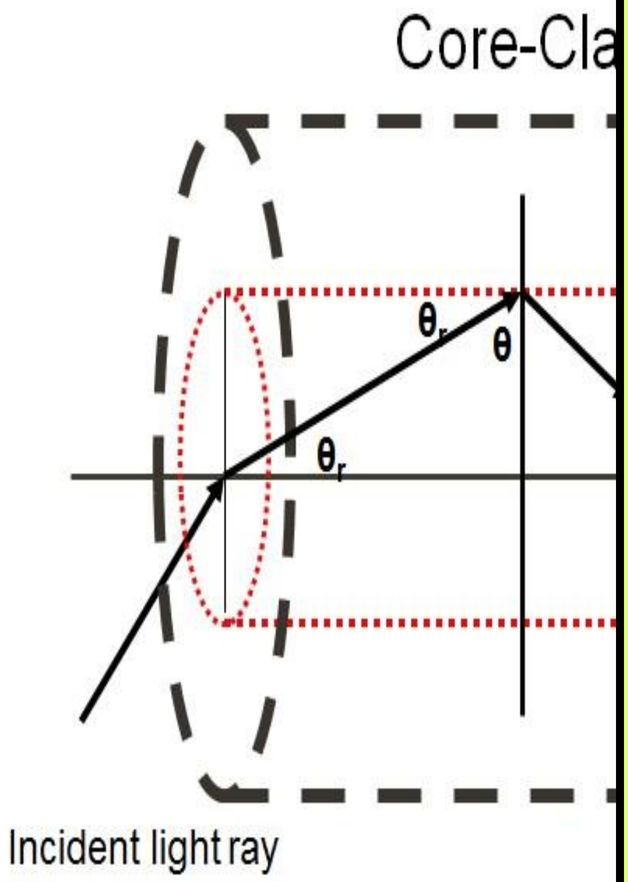
- The light gathering capacity of an optical fibre is defined as Numerical aperture.

- 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

Applying Snell' s law for Air-Core media



$$n_0 \sin\theta_i = n_1 \sin\theta_r \ldots\ldots\ldots\ldots(1)$$

from the right angle triangle ABC

$$\theta_r + \theta = 90^0$$

$$\theta_r = 90^0 - \theta$$

$$n_0 \sin\theta_i = n_1 \sin(90^0 - \theta)$$

$$n_0 \sin\theta_i = n_1 \cos\theta$$

$$\sin\theta_i = \frac{n_1}{n_0}\cos\theta \ldots\ldots\ldots(2)$$

$$when\ \theta = critical\ angle(\theta_c) \longrightarrow \theta_i = \theta_m$$

$$\sin\theta_m = \frac{n_1}{n_0}\cos\theta_c \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

according to law of refraction

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

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

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

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

$$\cos\theta_c = \sqrt{1-\sin^2\theta_c} = \sqrt{1-(\frac{n_2}{n_1})^2}$$

$$\cos\theta_c = \frac{\sqrt{n_1{}^2 - n_2{}^2}}{n_1} \ldots\ldots\ldots\ldots(4)$$

$$substitute\ equation\ (4)\ in\ (3)$$

$$\sin\theta_m = \frac{n_1}{n_0}\frac{\sqrt{n_1^{\,2}-n_2^{\,2}}}{n_1}$$

$$if\ the\ medium\ surrounding\ the\ fiber\ is\ air, then\ n_0 = 1$$

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

$$\theta_{\max} = \sin^{-1}\sqrt{n_1^{\,2}-n_2^{\,2}}$$

This is the required expression for Maximum Acceptance Angle in optical fibers.

IMPORTANT PARAMETERS

- The light gathering capacity of an optical fiber is known as **Numerical Aperture** and it is proportional to **Acceptance Angle**.
- It is numerically equal to **sine of Acceptance Angle**.
- The ratio between the difference in RI's of Core and Cladding to that of RI of core is called the **Fractional change Δ**.
- **V- number**: Normalized frequency of the fiber.
- **N_{max}**: Maximum no. of modes allowed by the optical fiber.

IMPORTANT FORMULAE

$$NA = \sin\theta_{max}$$

$$\sin\theta_{max} = \frac{\sqrt{n_1^2 - n_2^2}}{n_0}$$

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

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

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

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

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

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

NA: Numerical Aperture
$\theta_{max:}$ Acceptance angle
n_1: RI of core
n_2: RI of cladding
n_0: RI of the medium
Δ: Fractional change in RI
V: V-number
a: radius of the core
N_{max}: No. of allowed modes

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 REFRACTIVE INDEX OF THE CORE AND CLADDING

STEP INDEX FIBER

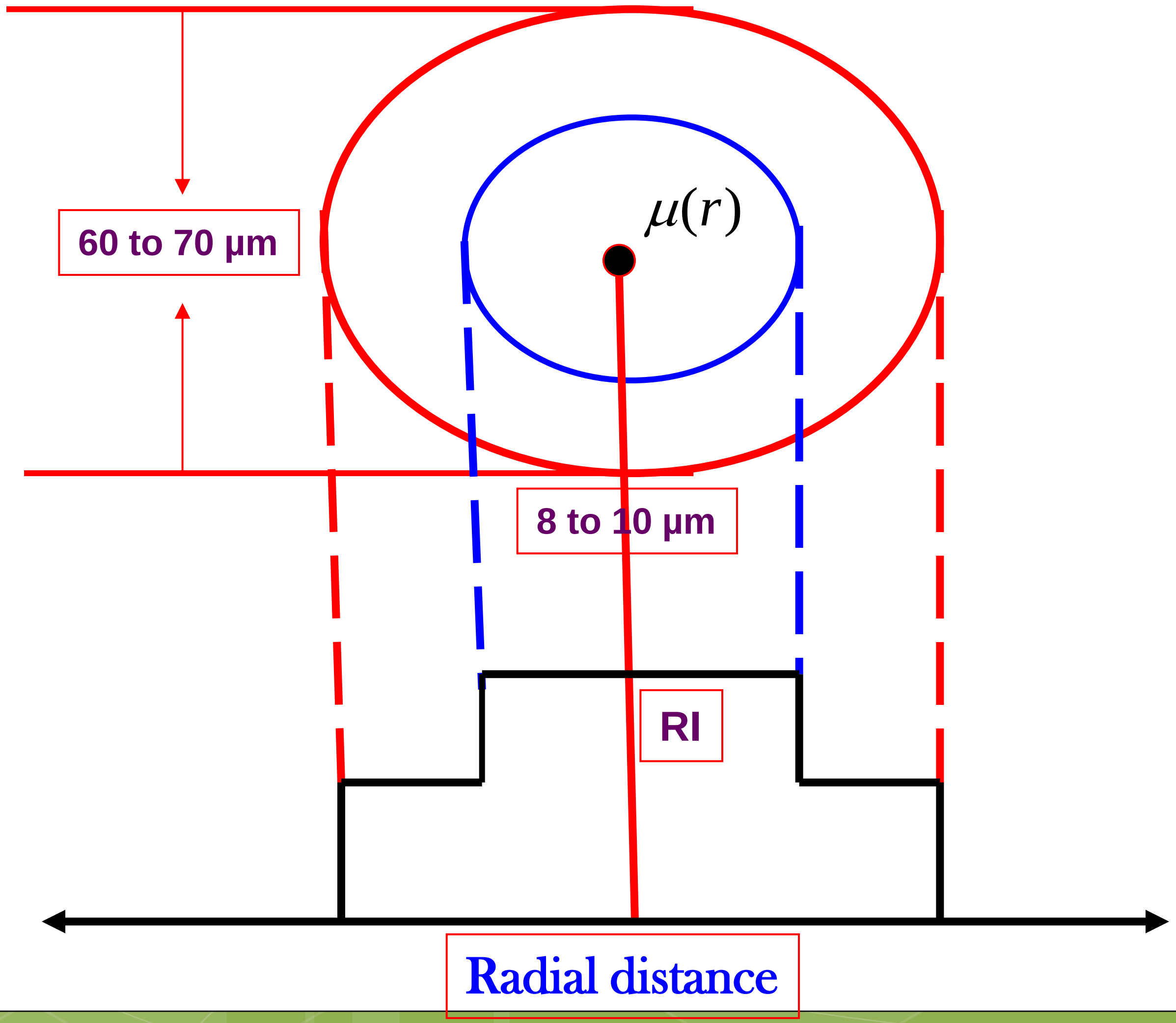
- The RI is constant for the core in this fiber. As we go radically from center of the core, the RI undergoes a step change at core-cladding interface .

- 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.

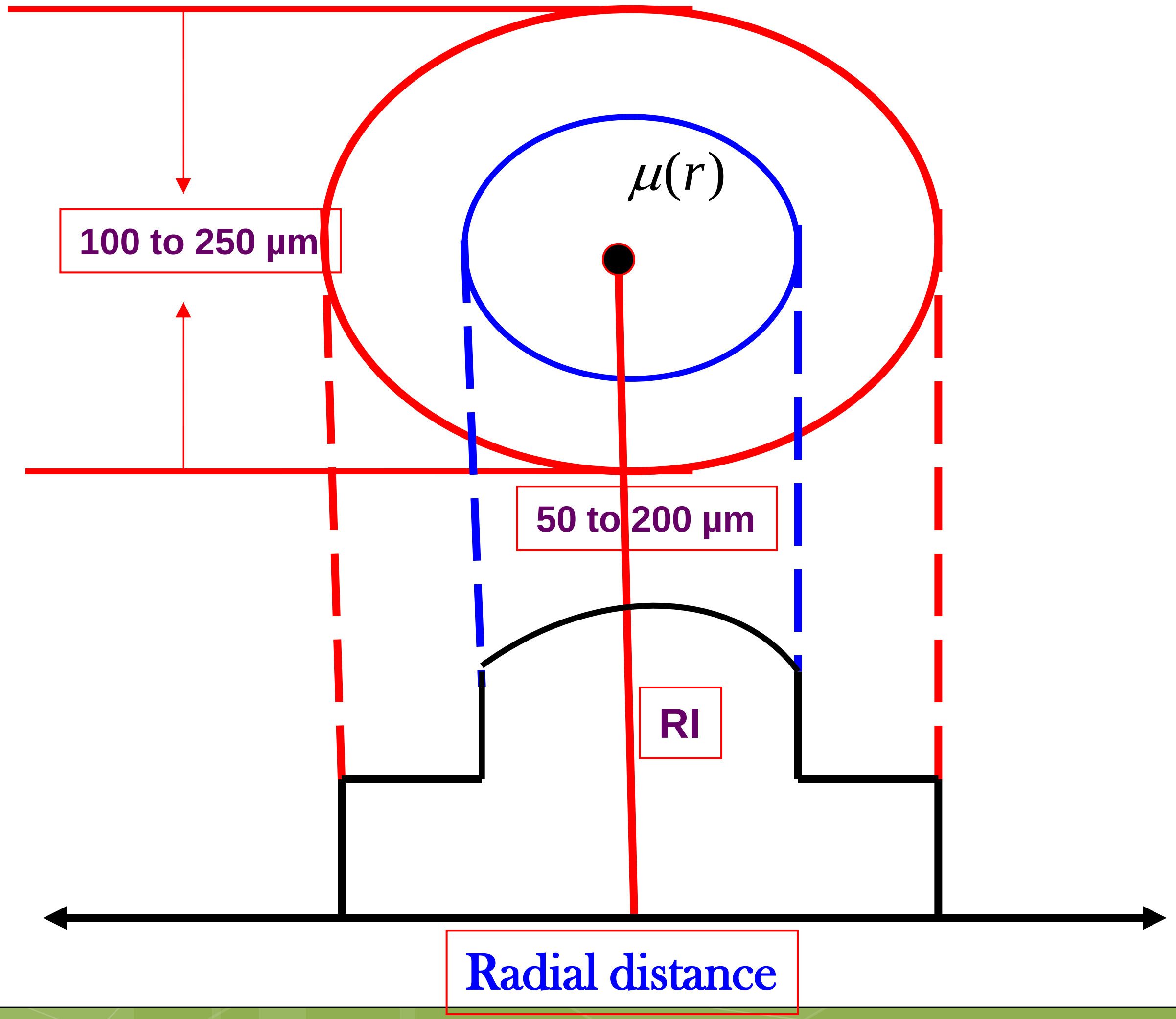
REFRACTIVE INDEX PROFILE OF STEP INDEX FIBER



GRADED INDEX FIBRE

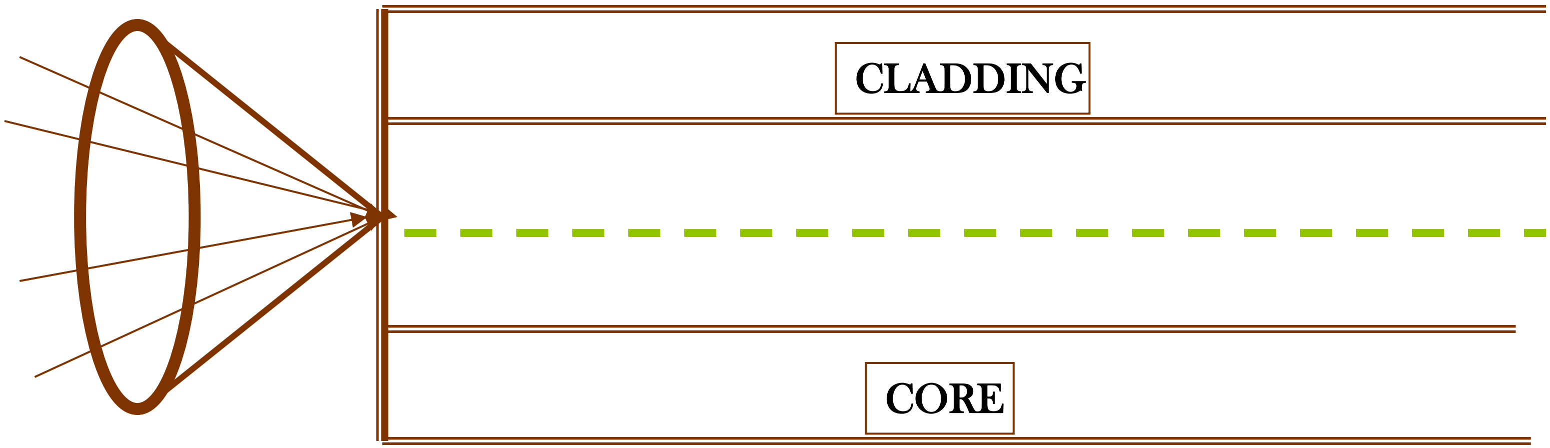
- In this fiber , the RI of Core continuously decreases from center to the surface.
- The RI is maximum at the center of Core and minimum at the Surface.
- This fiber can be a single mode or Multimode ,the diameters of core and cladding varies from 50-200µm and 100-250µm respectively.
- Light propagation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

REFRACTIVE INDEX PROFILE OF GRADED INDEX FIBER



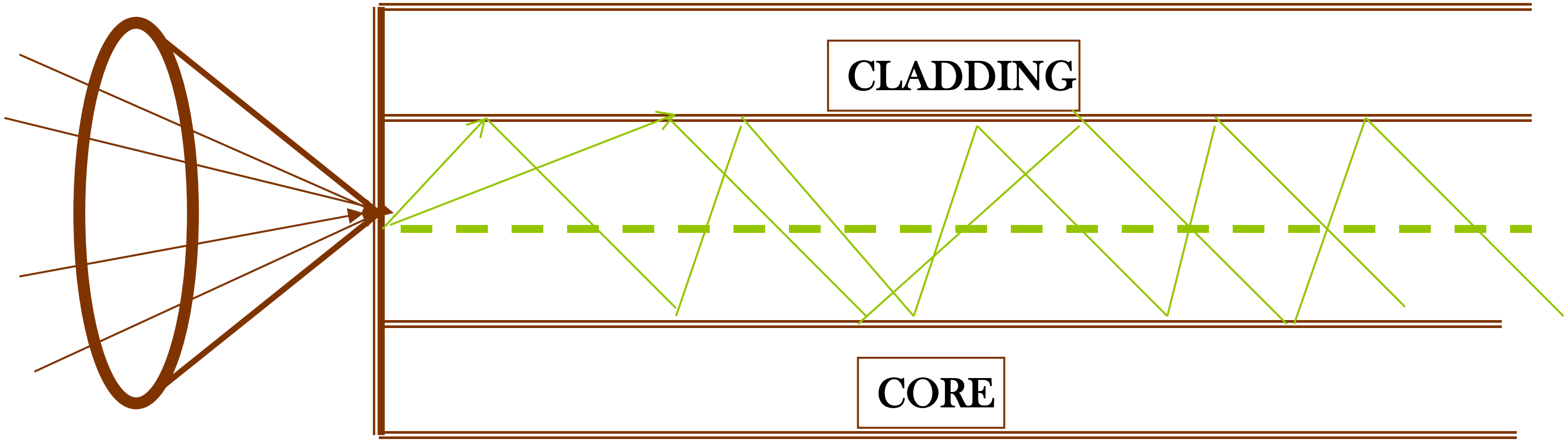
BASED ON THE MODES OF PROPAGATION

SINGLE MODE STEP INDEX FIBER



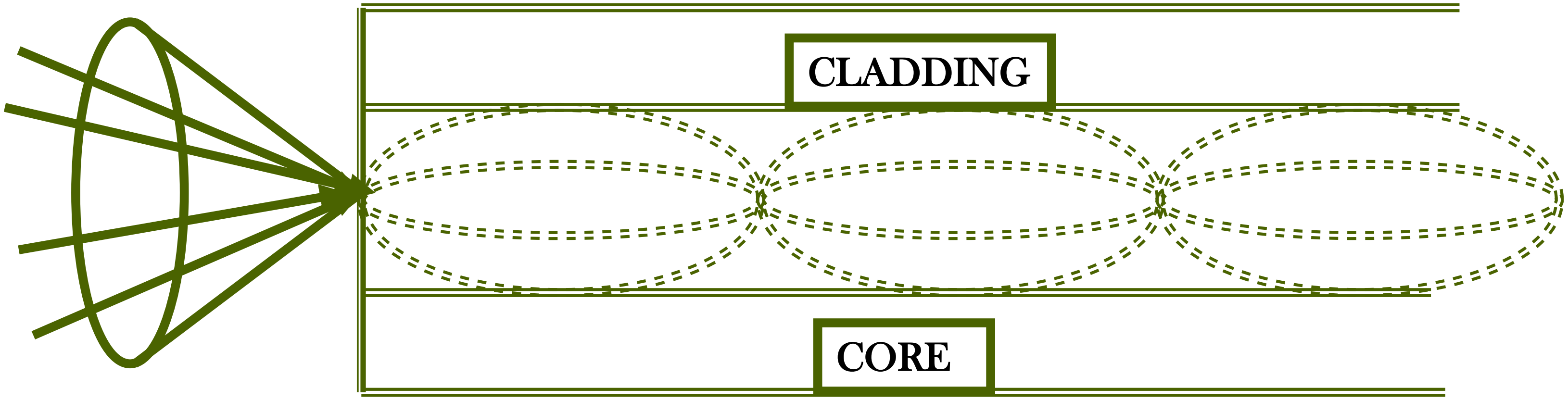
- Signal propagates in only one mode.
- Core diameter is very small of the order of 8-10 µm
- Light travels parallel to the axis of the core.
- Transmission loss of the signal is very small.

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.

MUTI-MODE 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.

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.

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.
- $\alpha = \frac{10}{L} log_{10} \frac{P_i}{P_o}$ (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 three types….

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

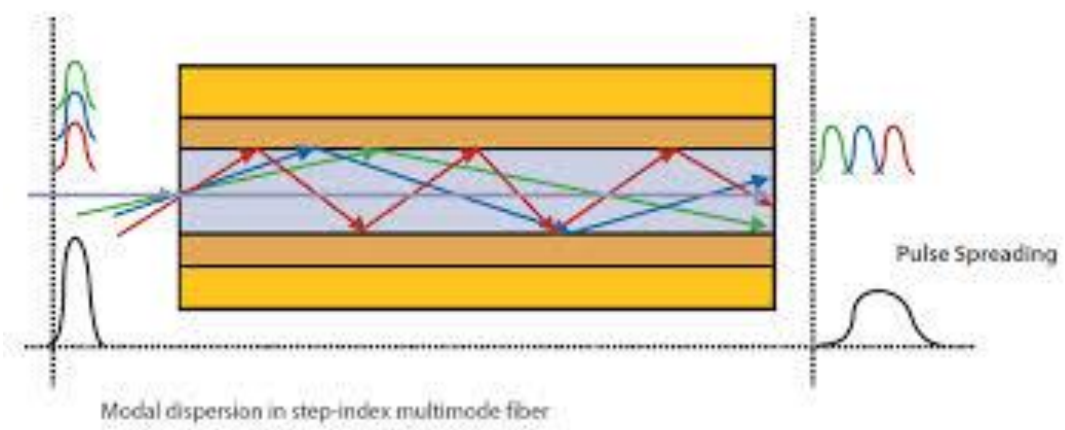
2. DISTORTION

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

Types of Distortion

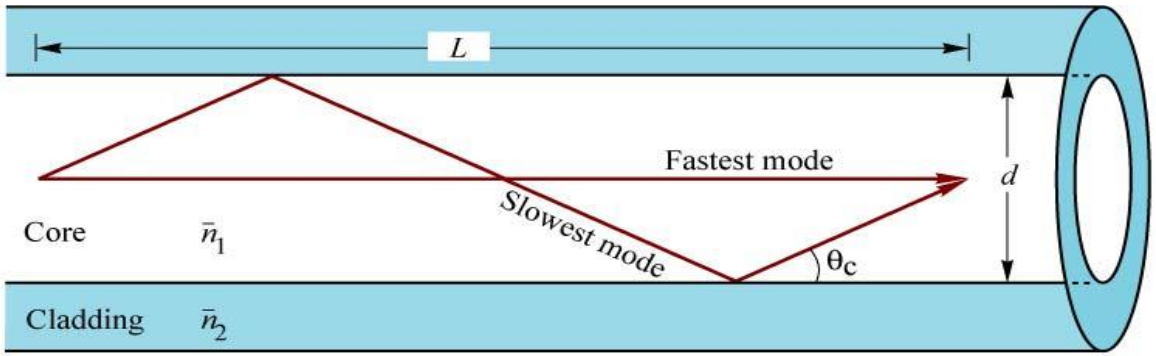
1. INTERMODAL DISTORTION

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

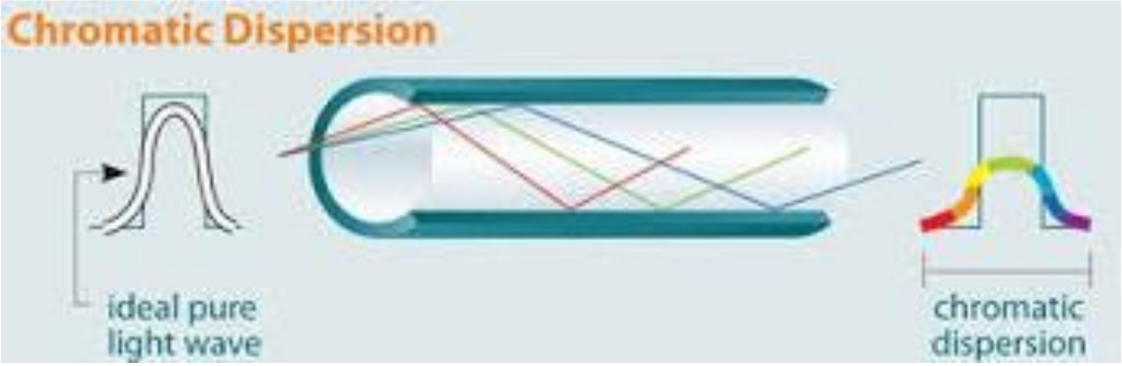


2. INTRAMODAL DISPERSION

(a) Waveguide dispersion:

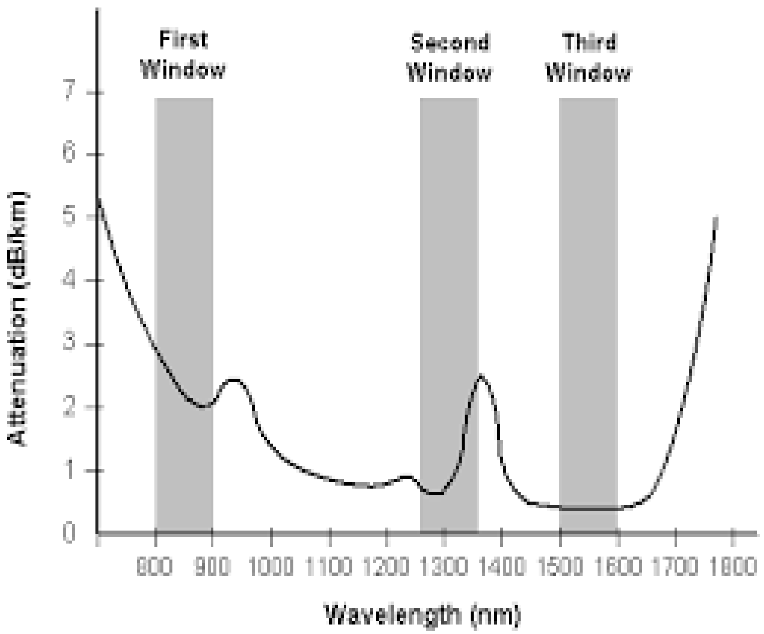


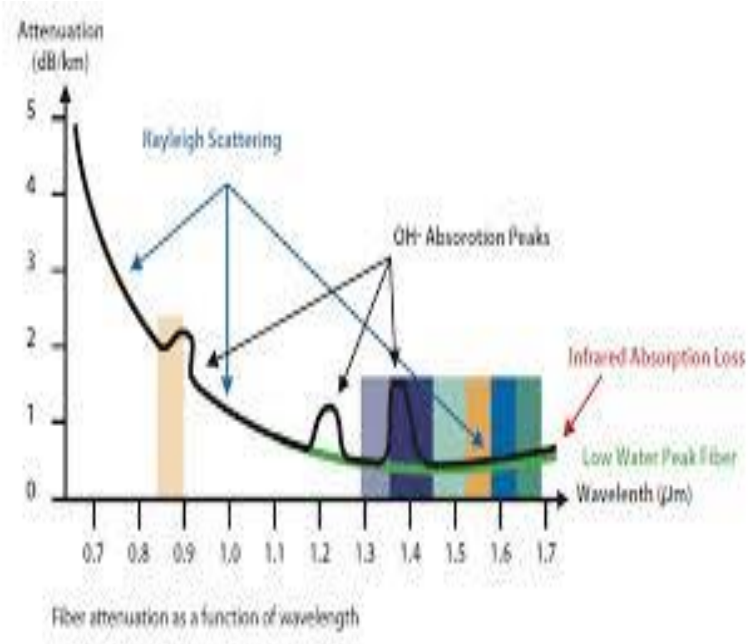
(b) Material dispersion



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.

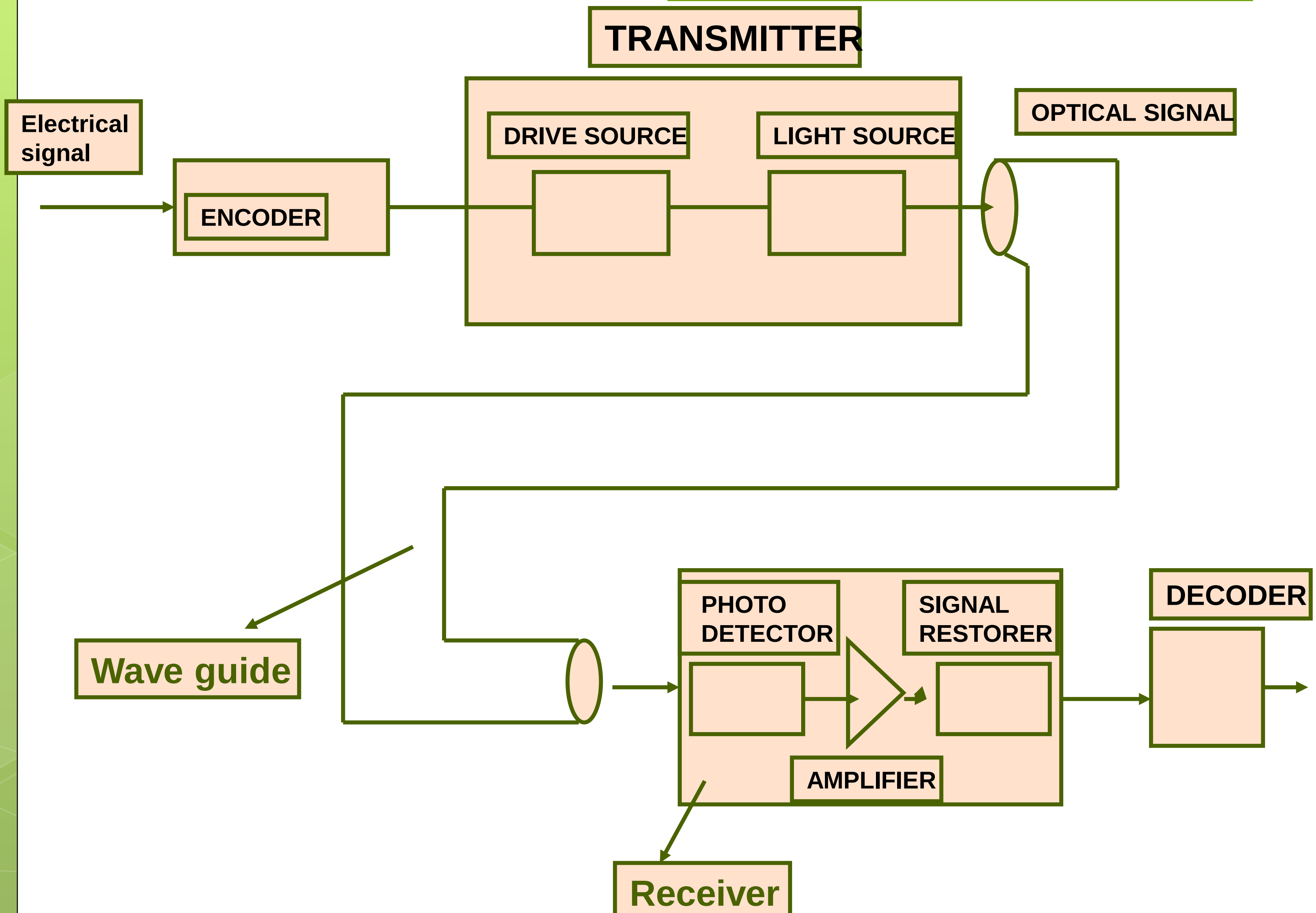
Bit rate

- **It is measure of optical fiber performance or traffic capacity at which the full-wave half-power point occurs at the receiving end of a given length of the fiber.**
- For an optical fiber or fiber optic cable, the product of) a given length of the fiber or the cable and 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). *Common abbreviation* BRLP.
- 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
DECODER
AMPLIFIER
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.