# OPTICAL FIBRES

**Notes as per Somaiya Vidyavihar University syllabus**

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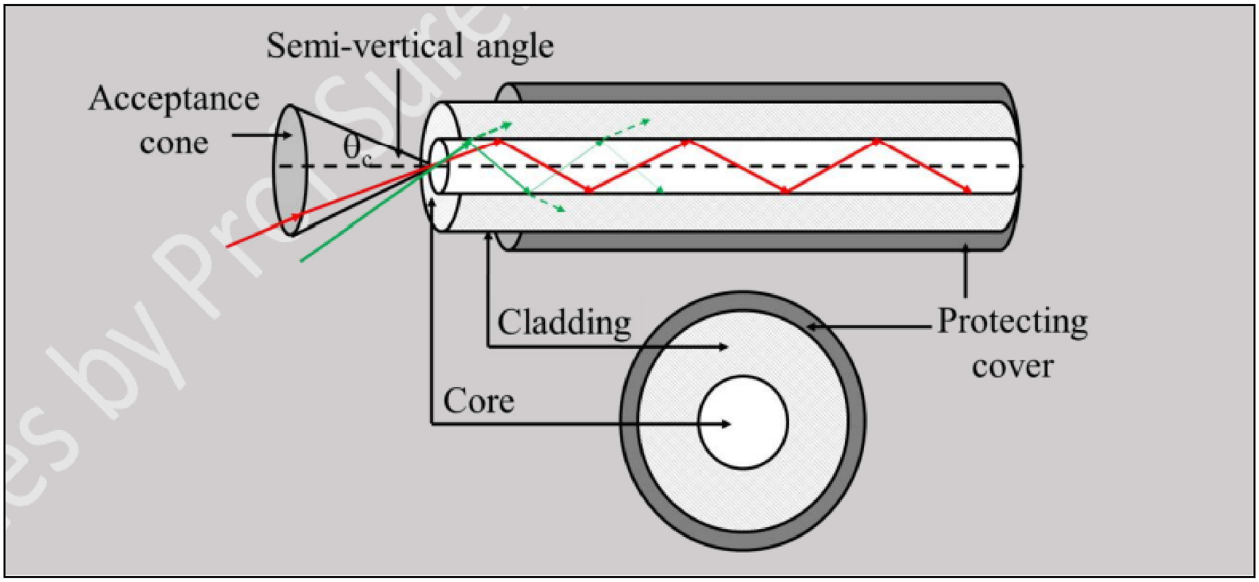
## BASICS:

- Fibre-optic lines are strands of optically pure glass as thin as a human hair that carry digital information over long distances.
- Optical fibres work as Wave-guiders 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 fibre.
- They are also used in medical imaging and mechanical engineering inspection.

- ## STRUCTURE OF AN OPTICAL FIBRE:
    - An optical fibre basically consists of two coaxial regions called the (inner) "core" and the (outer) "cladding".
    - Usually these regions cannot be visually distinguished from each other since the only difference between them being that of refractive index and that is too, very small (on the order of 0.01 to 0.1).
    - The core diameter varies from 5 to 125 µm while the cladding diameter is usually 25 to 500 µm.
    - The Cladding is enclosed by a protective jacket made of polyurethane, which the fibre from surroundings. Diameter: 100-400 µm.
    - An optical fibre possesses an "acceptance cone", which is a measure of its light gathering capacity. It basically indicates that if rays of light from a source fall within this cone, then only they would undergo total internal reflection.
    - Optical fibres are characterised by two important parameters called the "**numerical aperture**" and the "**normalised frequency**" or "**V-number**".

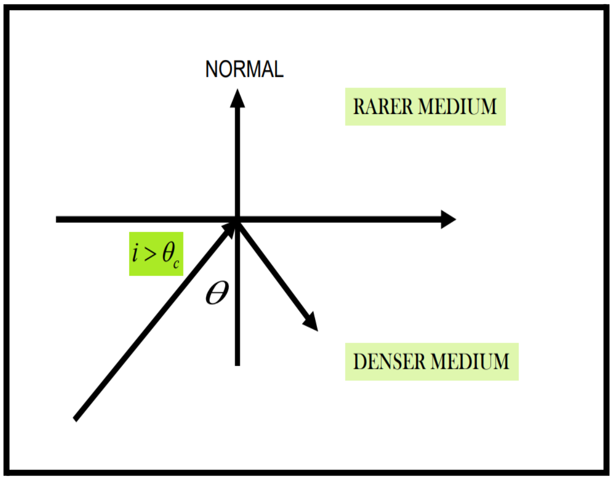

Semi-vertical angle
Acceptance
cone
$\theta_c$
Cladding
Protecting
cover
Core

## ADVANTAGES OF OPTICAL FIBRES:

- Cheaper, smaller, lighter, durable, chemically stable and mechanically flexible.
- Safer, immune to stray EM signals, reduced cross-links, noise-free.
- High bandwidth, very high data speeds.
- Lower losses.

## PRINCIPLE OF OPERATION OF FIBRE OPTICS:

- The Fibre Optics work on the simple principle of Total Internal Reflection.




### To calculate critical angle

*According to law of refraction*

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

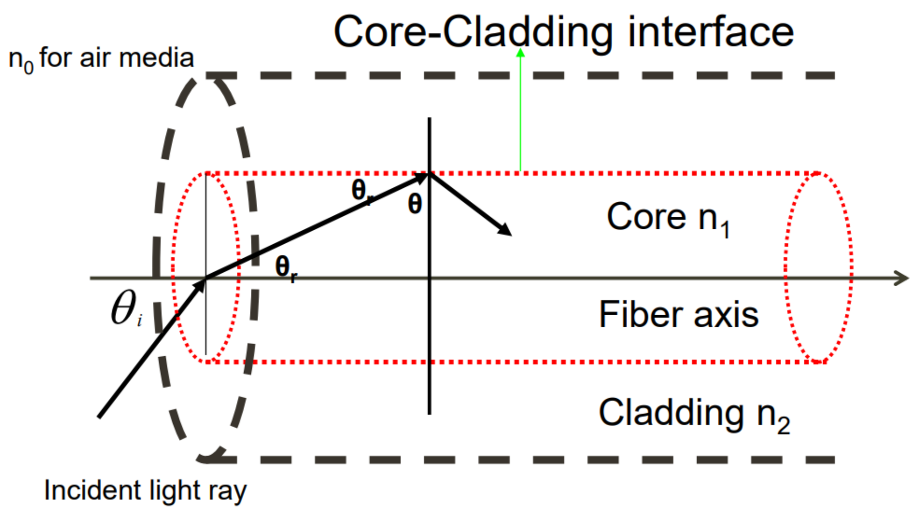
$$i = \theta_c \rightarrow r = 90^0$$

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

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

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

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




## NUMERICAL APERTURE

- The light gathering capacity of an optical fibre is defined as Numerical aperture.
- It is 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 the cladding of the optical fibre, it can also be represented as:

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

  Where, n1 is the refractive index of the core and n2 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)

## IMPORTANT PARAMETERS:

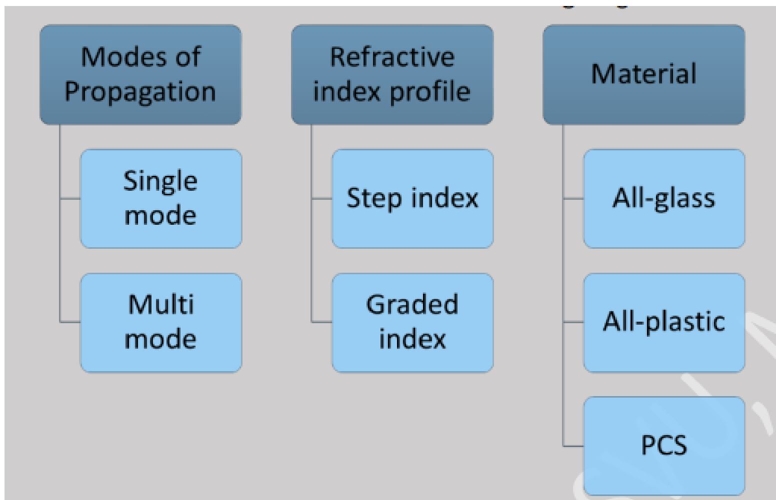
- The light gathering capacity of an optical fibre is known as **Numerical Aperture** and it is proportional to **Acceptance Angle**.
- It is numerically equal to the **sine of Acceptance Angle**.
- The ratio between the difference in Refractive Indices of Core and Cladding to that of RI of core is called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

**IMPORTANT FORMULAE:**

| | |
|---|---|
| $NA = \sin\theta_{\max}$ <br> $\sin\theta_{\max} = \dfrac{\sqrt{n_1^{\,2} - n_2^{\,2}}}{n_0}$ <br> $NA = \sqrt{n_1^{\,2} - n_2^{\,2}}$ <br> $\Delta = \dfrac{n_1 - n_2}{n_1}$ <br> $NA = n_1\sqrt{2\Delta}$ <br> $V = \dfrac{2\pi a}{\lambda}\sqrt{(n_1^2 - n_2^2)}$ <br> $N_{\max} = \dfrac{V^2}{2}(Step\ index\ fiber)$ <br> $N_{\max} = \dfrac{V^2}{4}(Graded\ index\ Fiber)$ | *NA: Numerical Aperture* <br> $\theta_{max:}$ *Acceptance angle* <br> $n_1$: *RI of core* <br> $n_2$: *RI of cladding* <br> $n_0$: *RI of the medium* <br> $\Delta$: *Fractional change in RI* <br> *V: V-number* <br> *a: radius of the core* <br> $N_{max}$: *No. of allowed modes* |

# CLASSIFICATION OF OPTICAL FIBRES:

- Depending upon applications, optical fibres are classified into single mode (SM) and multimode (MM) fibres.
- In simple context, modes refer to the total number of allowed paths inside the core.
- Multimode fibres are further classified into step index (SI) and grade index (GRIN) fibres.
- In Step Index fibre, the Reflective Index of core is uniform and changes abruptly at the core-cladding interface while in Graded Index fibre, Reflective Index varies gradually within the core region from axis of fibre towards core-cladding interface. The graded index fibre can be graded in a linear, parabolic or in a staircase manner.
- Another classification is based on material used for fibre.




- **Single mode v/s. multimode**

| Single mode | Multimode |
|---|---|
| Supports only axial modes | Supports axial and non-axial modes |
| Core diameter is small (5-10 μm) | Core diameter is larger (50-100 μm) |
| It works with only laser diode sources | It works with LED as well as laser diode sources |
| It offers lowest attenuation losses | It has higher attenuation than single mode fibres |
| Waveguide dispersion is limiting parameter | Waveguide dispersion is insignificant |
| Used for very long distance applications | Used for short to medium distance applications |
| It has only step index profile | It can have step and graded index profile |
| It is made from glass | It is made from glass or plastic |

- **Step index v/s. graded index (Multimode)**

| Step index (Multimode) | Graded index (Multimode) |
|---|---|
| RI of core is uniform | RI of core is gradually lowered |
| Suffers from pulse distortion | Pulse distortion effect is overcome by RI grading |
| Offers lower bandwidth | Offers higher bandwidth |
| Numerical aperture is higher | Numerical aperture is lower |
| Reflection losses are present | Reflection losses are minimal |
| Attenuation is higher | Attenuation is lower |
| They can be single mode or multimode | They are only multimode |
| Easier manufacturing process | Complex manufacturing process |

# BASED ON THE REFRACTIVE INDEX OF THE CORE AND CLADDING

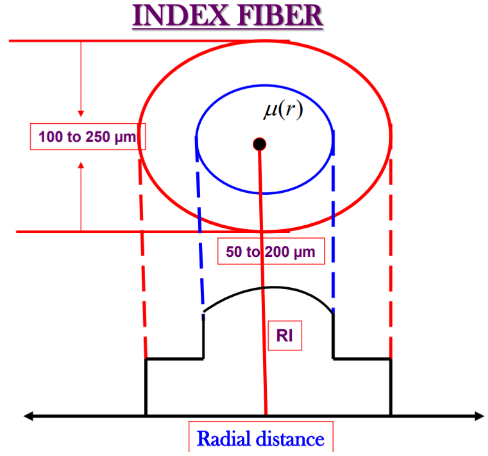
## STEP INDEX FIBRE

- The Reflective Index is constant for the core in this fibre. As we go radically from the centre of the core, the Reflective Index undergoes a step change at the core-cladding interface .
- The core diameter of this fibre is about 8 to 10µm and the outer diameter of cladding is 60 to 70µm.
- It is a reflective fibre since light is transmitted from one end to the other end of a fibre by Total Internal Reflection.
- These are extensively used because distortion and transmission losses are very less.

## GRADED INDEX FIBRE

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

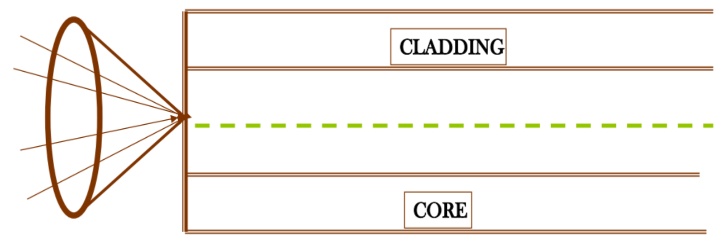
REFRACTIVE INDEX PROFILE OF GRADED INDEX FIBER



# BASED ON THE MODES OF PROPAGATION

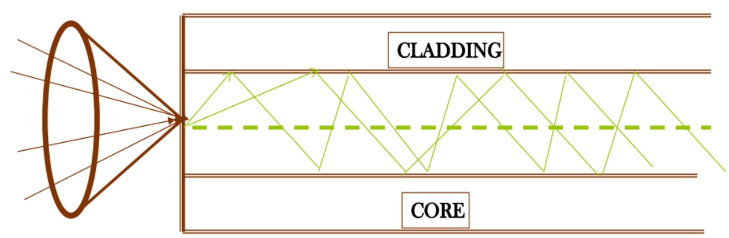
## SINGLE MODE STEP INDEX FIBRE

- 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.



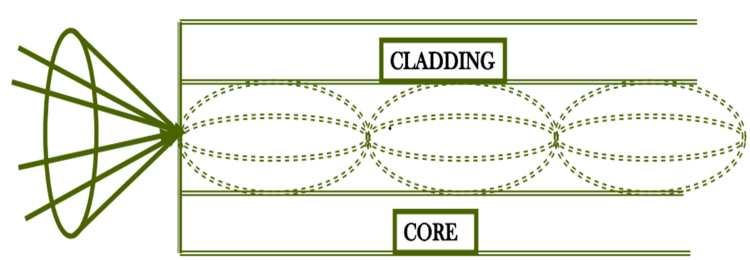

## MULTIMODE STEP INDEX FIBRE

- MMSIF permits large no. of signals to propagate through it.
- Different modes of rays have different angles of incidence at the core cladding interface.
- Different signals arrive at different times.
- They are best suited for short distance signal transmission.




## MUTI-MODE GRADED INDEX FIBRE

- 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

## SILICA FIBRE:

- 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 FIBRE

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

## PLASTIC CLAD FIBRE

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

# LOSSES IN OPTICAL FIBRES

## 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.

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

***α is the attenuation constant**, **L is the length of the fibre**, **$P_o$ is the output power and $P_i$ is the input power**.*

- Attenuation is found to be a function of fibre material, wavelength of light and length of the fibre and it is measured in terms of the decibel.
- Attenuation is mainly of Four types:

### I. ABSORPTION:

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

### II. GEOMETRIC EFFECTS:

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

### III. SCATTERING:

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

### IV. BENDING LOSS:

- Bending of Optical Fibre 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 Fibre. It is expressed in ns/km. The two types of Distortion are:

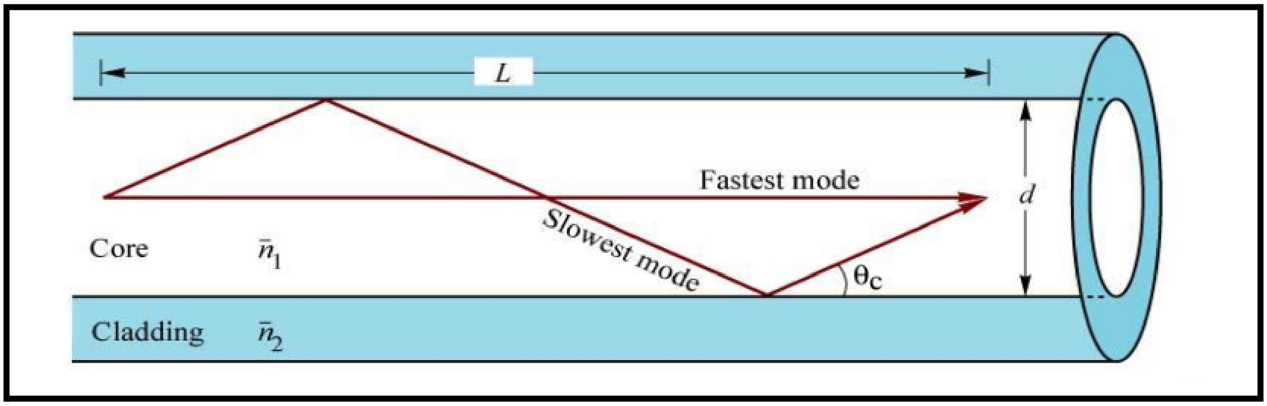
### I. INTERMODAL DISTORTION

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

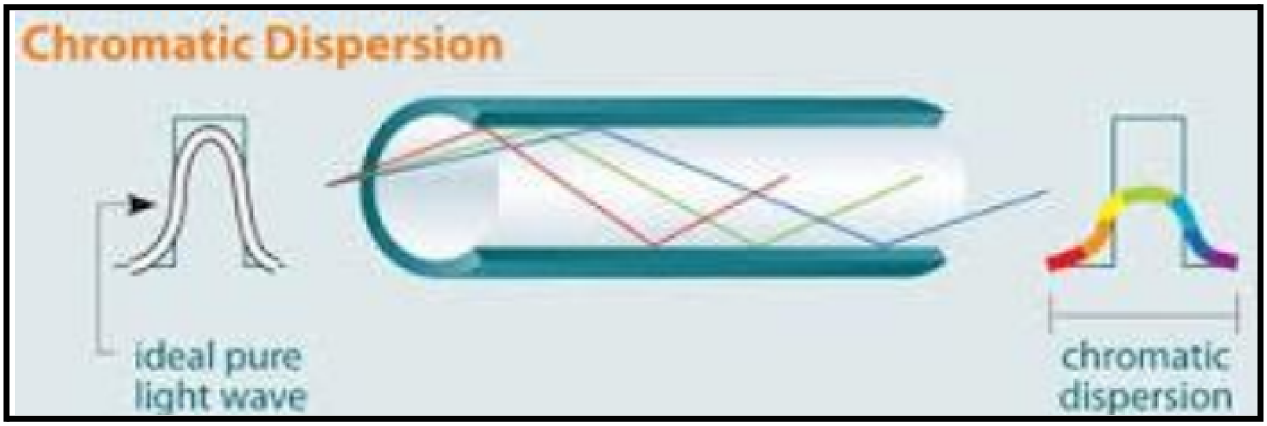
### II. INTRAMODAL DISPERSION

Intramodal Dispersion is of 2 types:

a. **Waveguide dispersion:**




b. **Material dispersion:**



## 3. OPTICAL WINDOW

- For better performance choice of wavelength is must in order to minimise 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 it is the most preferable wavelength for transmission.

## BIT RATE

- It is a measure of optical Fibre performance or traffic capacity at which the full-wave half-power point occurs at the receiving end of a given length of the Fibre.

- For an optical Fibre, the product of a given length of the Fibre and the bit rate, i.e., the data signalling rate (DSR), the Fibre 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 · kilometres per second.

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

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

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

## OPTICAL FIBRE COMMUNICATION SYSTEM

An efficient optical fibre 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