Optical Fibers

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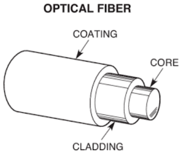
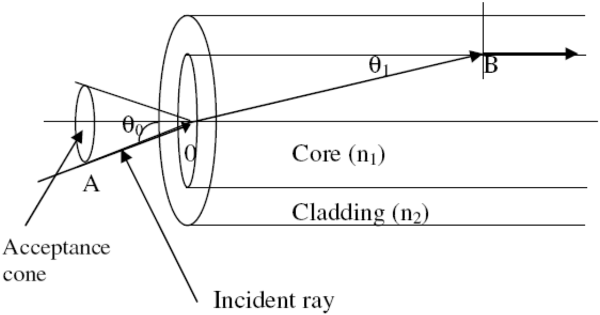
Outline

Introduction

- They are the light guides/wave-guides used in optical communications.
- They are thin, cylindrical, transparent flexible dielectric fibres.
- It can guide optical and IR rays.
- It consists of three layers:
  - Core: inner cylindrical layer made of glass or plastic
  - Cladding: which envelops the inner core and has *less refractive index* than the core
  - Sheath: polyurethane jacket which safeguards the cladding against chemical reactions and mechanical abrasion



Numerical Aperture



Refractive index of surrounding = n_0

Refractive index of core = n_1

Refractive index of cladding = n_2

$$n_0 < n_2 < n_1$$

$90^\circ - \theta_1$ is the critical angle of incidence for *total internal reflection (TIR)* to happen. Hence, OB further grazes along core and cladding interface. Incident angles $< \theta_0$ will further undergo TIR but $> \theta_0$ will simply refract into the cladding. Rotating OA forms a cone called *acceptance cone*. Only rays entering this cone will undergo TIR others refract into the cladding.

θ_0 is called the waveguide acceptance angle or the acceptance cone half angle which is the maximum angle from the axis of optical fibre at which light ray may enter the fibre and propagates in core by TIR.

$\sin\theta_0$ is called the numerical aperture (NA). It determines the light gathering aability of the fibre and purely depends on the refractive index of core, cladding and the surrounding.

$$\theta_0 = \theta_0(n_0, n_1, n_2)$$

By applying Snell's law at O,

$$n_0 \sin\theta_0 = n_1 \sin\theta_1$$

$$\therefore \quad \sin\theta_0 = \frac{n_1}{n_0}\sin\theta_1 \tag{1}$$

By applying Snell's law at B,

$$n_1 \sin(90^\circ - \theta_1) = n_2 \sin 90^\circ$$

$$\therefore \quad \cos\theta_1 = \frac{n_2}{n_1} \tag{2}$$

Using $\sin\theta_1 = \sqrt{1-\cos^2\theta_1}$ and eqn. (2) in (1),

$$\sin\theta_0 = \frac{n_1}{n_0}\sqrt{1-\cos^2\theta_1} = \frac{n_1}{n_0}\sqrt{1-\frac{n_2^2}{n_1^2}}$$

$$\therefore \quad \sin\theta_0 = \frac{1}{n_0}\sqrt{n_1^2 - n_2^2}$$

If the surrounding medium is air, then $n_0 \approx 1$. Therefore numerical aperture (NA) is,

$$\therefore \quad \text{NA} = \sin\theta_0 = \sqrt{n_1^2 - n_2^2}$$

The condition for incident rays to be propagated in the fibre is,

$$\begin{aligned} & \theta_i < \theta_0 \\ \text{or} \quad & \sin\theta_i < \sin\theta_0 \\ \text{or} \quad & \sin\theta_i < \text{NA} \end{aligned}$$

Fraction index change (Δ)

Fraction index change (Δ) is defined as, the ratio of difference in refractive indices of the core and the cladding to the refractive index of the core.

$$\Delta = \frac{\text{Refractive index of core} - \text{Refractive index of cladding}}{\text{Refractive index of core}} = \frac{n_1 - n_2}{n_1}$$

It is also known as relative core clad index difference. That is,

$$\Delta = 1 - \frac{n_2}{n_1}$$

Types of Optical fibres

1. Step index Single Mode Fibre (SMF)
2. Step index Multi Mode Fibre (MMF)
3. Graded Index Multi Mode Fibre (GRIN)

Refractive Index Profile

This variation of *refractive index of core and cladding materials* with respect to the *radial distance* from the axis of the optical fibre is called refractive index profile.

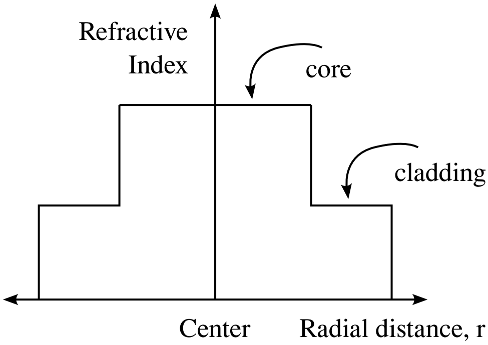


Figure: Graph of RI versus radial distance.

a) Step index Single Mode Fibre (SMF)

- Core and cladding has materials of uniform refractive index.
- Narrow core - guides only single mode.
- Uses laser as light source.
- Difficult to splice them (joining of optical fibres).
- Because of single mode propagation, intermodal dispersion is minimum.
- Extensively used - 80% of world's production.
- Used for long distance communications like submarine cable system.

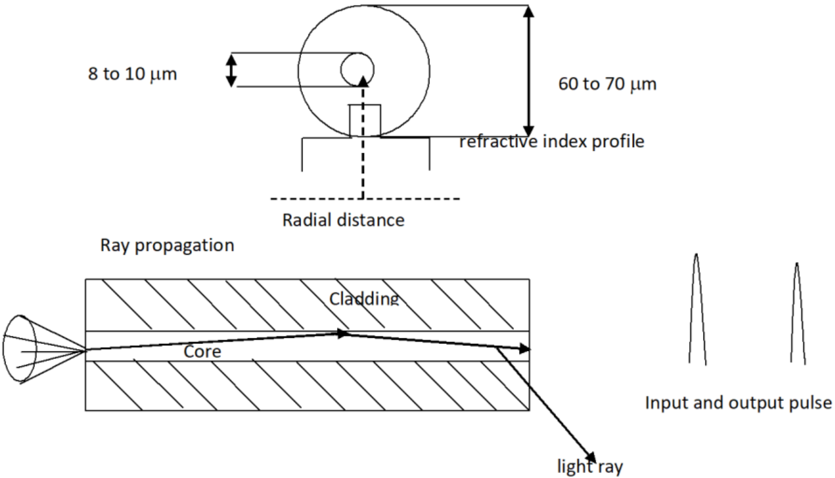


Fig: Step Index Single Mode Fibre

b) Step index Multi Mode Fibre (MMF)

- Core has comparatively larger diameter than that used in single mode fibre.
- Large number of modes propagate through it.
- Refractive index profile has larger plane region for the core.
- Either diode laser or LED can be used as light source.
- Least expensive??
- Joining the optical fibres is relatively easy.
- Because of multi mode propagation, intermodal dispersion is large.
- Used in data links which has lower bandwidth requirements.

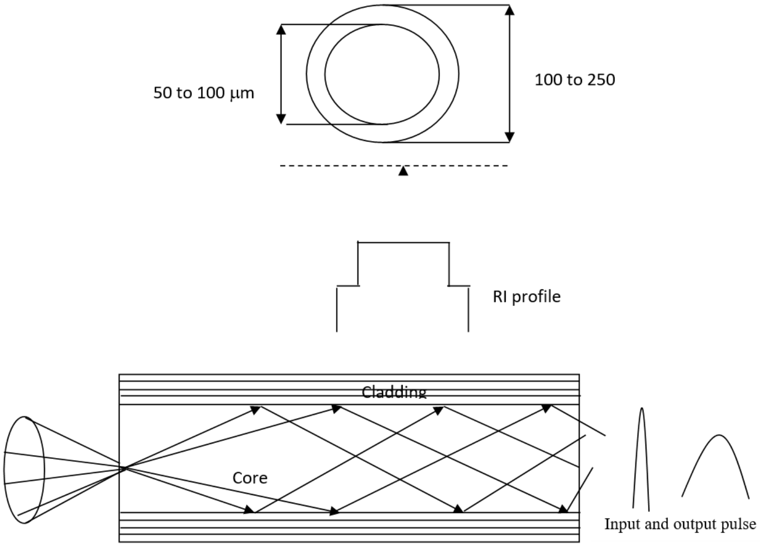


Fig. Step index multimode fibre

c) Graded Index Multi Mode Fibre (GRIN)

- Refractive index of the core varies across the core diameter (radially graded) as shown in figure, while the refractive index of the cladding is fixed.
- Many modes can be transmitted without intermodal dispersion.
- The rays move in a curved path through the core.
- Light travels at lower speed in the high-index region – fastest components of the ray take the longer path and the slower components take the shorter path in the core.
- Hence the travel time of the different modes will be almost same.
- Losses are minimum. Very little pulse broadening.
- Suitable for large bandwidth, medium distance and medium bit rate communication systems.
- Either a laser or LED source can be used.
- Joining the optical fibres is relatively easy.

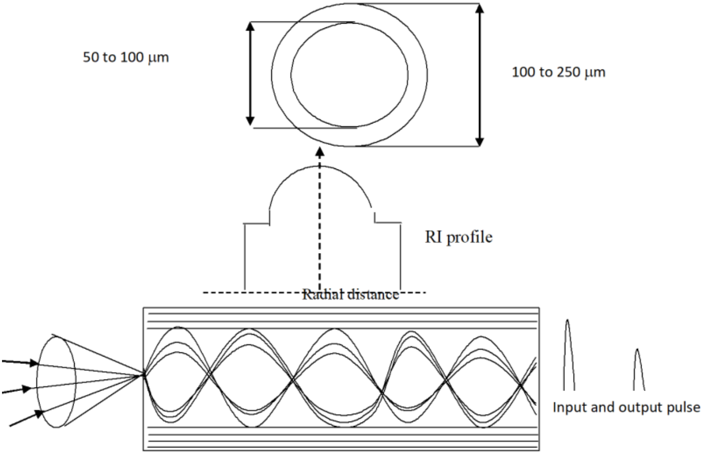


Fig. Graded index multimode fibre

Differences between single and multimode fibres

Single mode fibre	Multi mode fibre
➪ Only one mode can be propagated	➪ Allows large number of modes for light to pass through it
➪ Smaller core diameter	➪ Larger core diameter
➪ Low dispersion of signal	➪ More dispersion of signal
➪ Can carry information to longer distances	➪ Information can be carried to shorter distances only
➪ Launching of light and connecting two fibres are difficult	➪ Launching of light and connecting of fibres is easy

Differences between step and graded index fibres

Step index fibre	Graded index fibre
➪ Refractive index of core is uniform	➪ Refractive index of core is not uniform
➪ Propagation of light is in the form of meridional rays	➪ Propagation of light is in the form of skew rays
➪ Step index fibres has lower bandwidth	➪ Graded index fibres has higher bandwidth
➪ Distortion is more (in multimode)	➪ Distortion is less
➪ Number of modes for propagation $= V^2/2$	➪ Number of modes for propagation $= V^2/4$

Attenuation in optical fibres

The *total energy loss suffered* by the signal due to the transmission of light in the fibre is called attenuation.

The important factors contributing to the attenuation in optical fibre are:

1. Absorption loss
2. Scattering loss
3. Bending loss
4. Intermodal dispersion loss
5. coupling loss

Attenuation coefficient is given by: (1 bel = 10 db)

$$\alpha = -\frac{10}{L}\log\left(\frac{P_{\text{out}}}{P_{\text{in}}}\right) \qquad \text{(in dB/km)}$$

Where P_{out} and P_{in} are the power output and power inputs respectively, L is the length of the fibre in km. Therefore, Loss in the optical fibre = αL.

Point to Point Communication

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Further Reading

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