18PYB101J MODULE-5

LECTURE 13

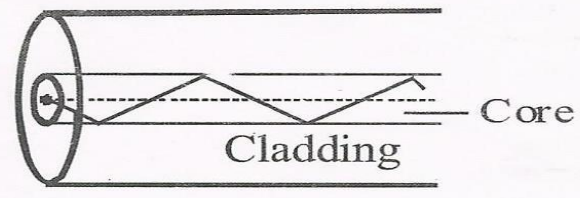
- Propagation characteristics of optical fibre
- Derivation - Numerical aperture and acceptance angle

Propagation characteristics of optical fiber

Meridinal rays and Skew rays

- The light rays, during the journey inside the optical fiber through the core, cross the core axis. Such light rays are known as **meridinal rays.**
- The passage of such rays in a step index fiber is shown in Fig.

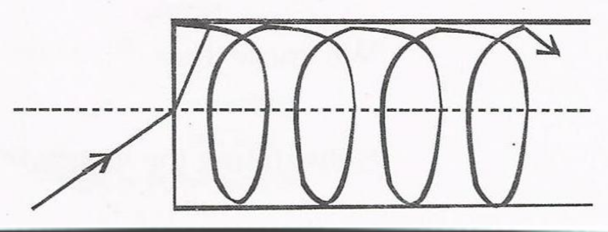
Meridinal rays



(a)

- Similarly, the rays which never cross the axis of the core are known as the **skew rays.**
- Skew rays describe angular 'helices' as they progress along the fiber.
- They follow helical path around the axis of fiber.
- A typical passage of skew rays in a graded index fiber is shown in Fig.
- The skew rays will not utilize the full area of the core and they travel farther than meridinal rays and undergo higher attenuation.

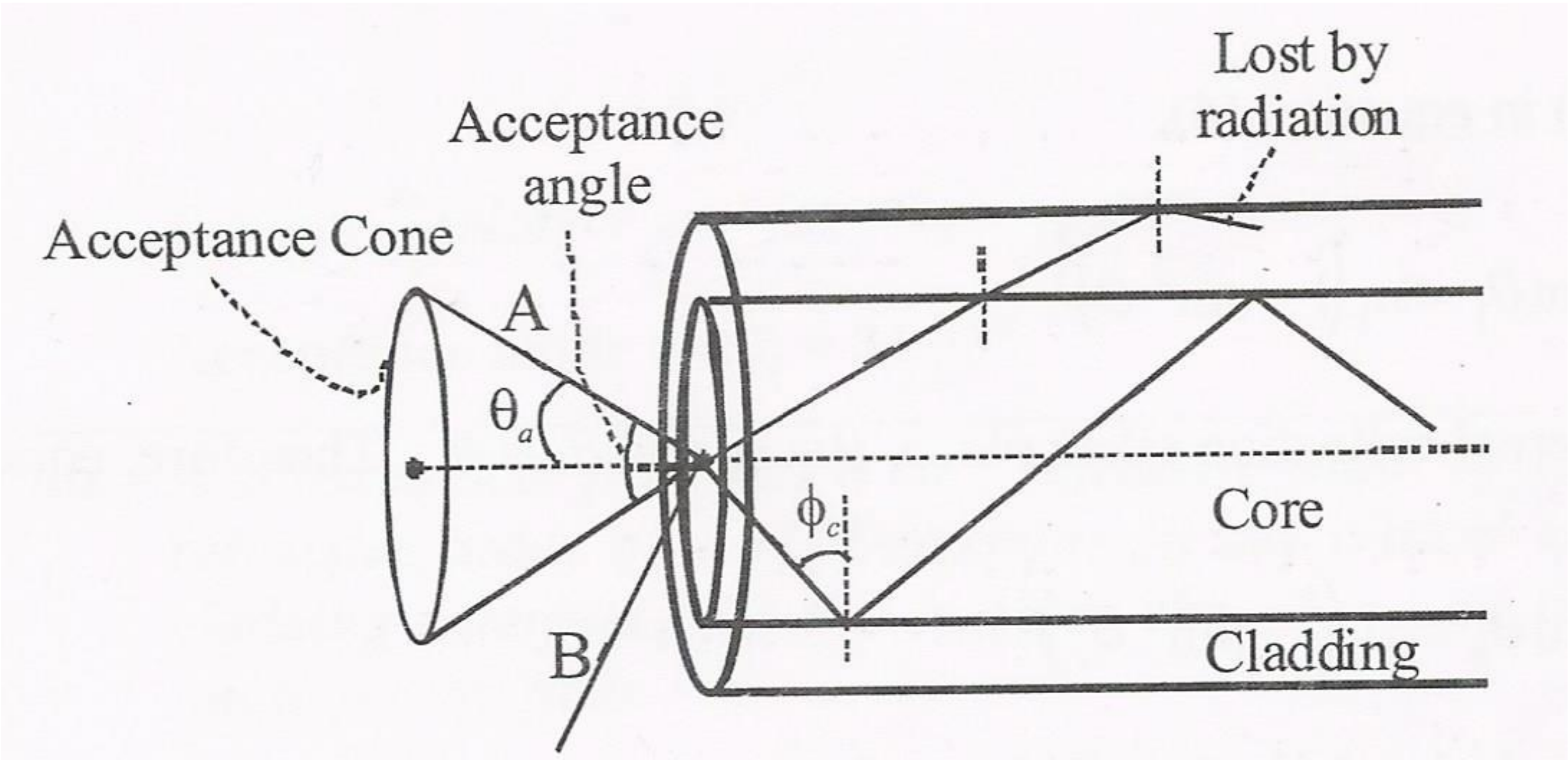
Skew rays



Acceptance Angle

It should be noted that the fiber core will propagate the incident light rays only when it is incident at an angle greater than the critical angle θ_c. The geometry of the launching of the light rays into an optical fiber is shown in Fig.

Acceptance angle



- A meridinal ray A is to be incident at an angle θ_a in the core – cladding interface of the fiber.
- The ray enters the fiber core at an angle θ_a to the fiber axis.
- The ray gets refracted at the air – core interface at angle θ_c and enters into the core – cladding interface for transmission
- Therefore, any ray which is incident at an angle greater than θ_a will be transmitted into the core – cladding interface at an angle less than θ_c and hence will not undergo total internal reflection.

- The ray B entered at an angle greater than θ_a and eventually lost propagation by radiation.
- It is clear that the incident rays which are incident on fiber core within conical half angle θ_c will be refracted into fiber core, propagate into the core by total internal reflection.
- This angle θ_a is called as acceptance angle, defined as the maximum value of the angle of incidence at the entrance end of the fiber, at which the angle of incidence at the core – cladding surface is equal to the critical angle of the core medium.

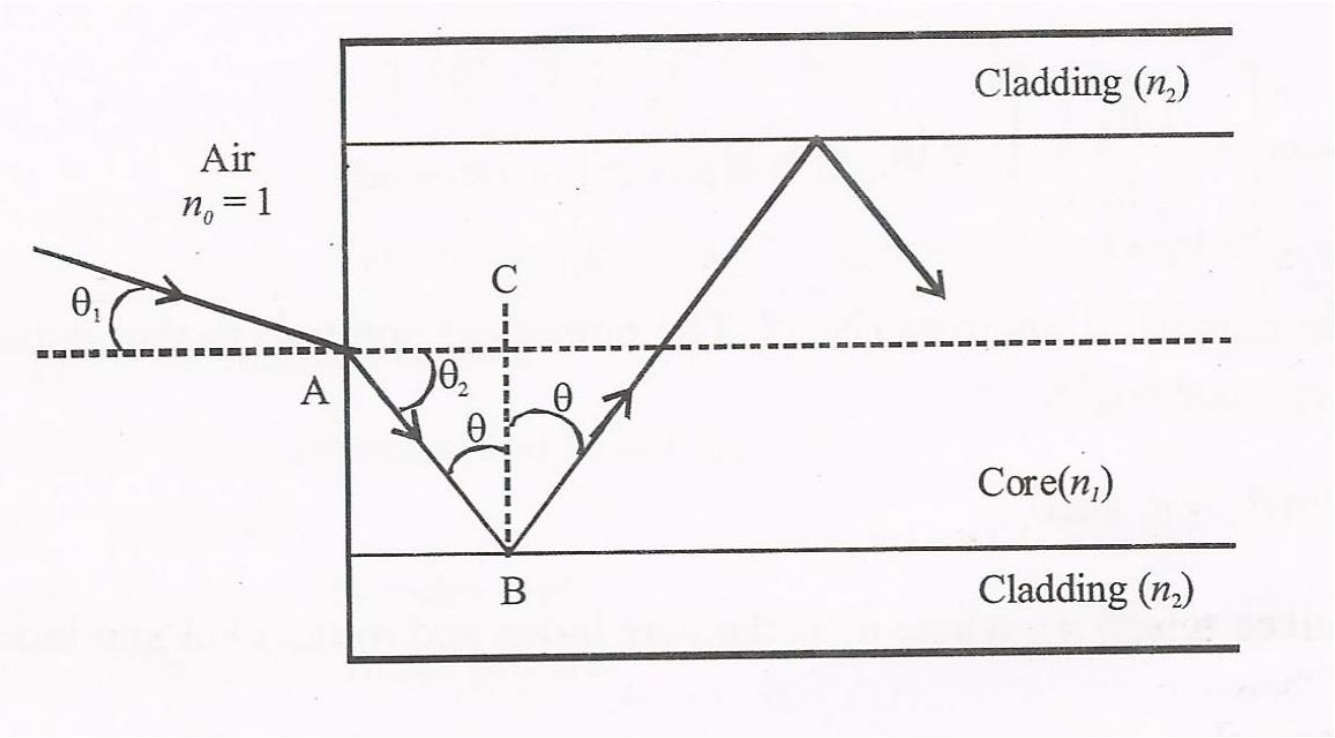
Acceptance cone

The imaginary light cone with twice the acceptance angle as the vertex angle, is known as the acceptance cone.

Numerical Aperture (NA)

Numerical aperture (NA) of the fiber is the light collecting efficiency of the fiber and is a measure of the amount of light rays can be accepted by the fiber.

Numerical aperture



A ray of light is launched into the fiber at an angle θ_1 is less than the acceptance angle θ_a for the fiber as shown.

This ray enters from a medium namely air of refractive index n_0 to the fiber with a core of refractive index n_1 which is slightly greater than that of the cladding n_2 . Assume that the light is undergoing total internal reflection within the core.

Applying Snell's law of refraction at A,

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_1}{n_0} = n_1 \qquad \sin\theta_1 = n_1 \sin\theta_2$$

In the triangle ABC,

$$\theta = \frac{\pi}{2} - \theta_2 \qquad \text{or} \qquad \theta_2 = \frac{\pi}{2} - \theta$$

$$\sin\theta_1 = n_1 \sin\left(\frac{\pi}{2} - \theta\right) = n_1 \cos\theta$$

$$\cos\theta = \left(1 - \sin^2\theta\right)^{\frac{1}{2}}$$

From the above two equations,

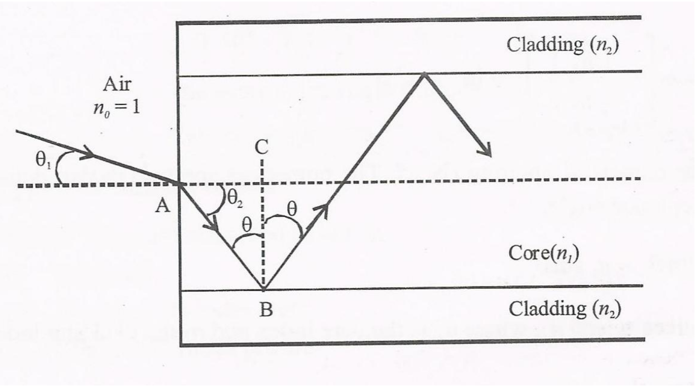
$$\sin\theta_1 = n_1\left(1 - \sin^2\theta\right)^{\frac{1}{2}}$$

When the total internal reflection takes place, $\theta = \theta_c$ and $\theta_1 = \theta_a$. Therefore,

$$\sin\theta_a = n_1\left(1 - \sin^2\theta_c\right)^{\frac{1}{2}}$$

Also, at B, applying the Snell's law of refraction, we get

$$\frac{\sin\theta_c}{\sin 90} = \frac{n_2}{n_1} \text{ (or) } \sin\theta_c = \frac{n_2}{n_1}$$



From the above equation, we get

$$\sin\theta_a = n_1\left[1-\left(\frac{n_2}{n_1}\right)^2\right]^{\frac{1}{2}} = \left(n_1^2 - n_2^2\right)^{\frac{1}{2}}$$

This is called the numerical aperture (N.A). The numerical aperture is also defined as the sine of the half of the acceptance angle.

$$N.A = \sin\theta_a = \left(n_1^2 - n_2^2\right)^{\frac{1}{2}}$$

In terms of refractive indices n_1 and n_2, where n_1 is the core index and n_2 the cladding index

$$N.A = (n_1^2 - n_2^2)^{1/2}$$

The half acceptance angle θ_a is given by

$$\theta_a = \sin^{-1}(N.A)$$

$$= \sin^{-1}(n_1^2 - n_2^2)^{1/2}$$

The N.A can be expressed in terms of the relative refractive index difference Δ as

$$\Delta = \frac{n_1^{\,2} - n_2^{\,2}}{2n_1^{\,2}}$$

$$= \frac{(N.A)^2}{2n_1^{\,2}}$$

From the above eqns, we get

$$\text{N.A} = n_1 \times (2\Delta)^{1/2}$$