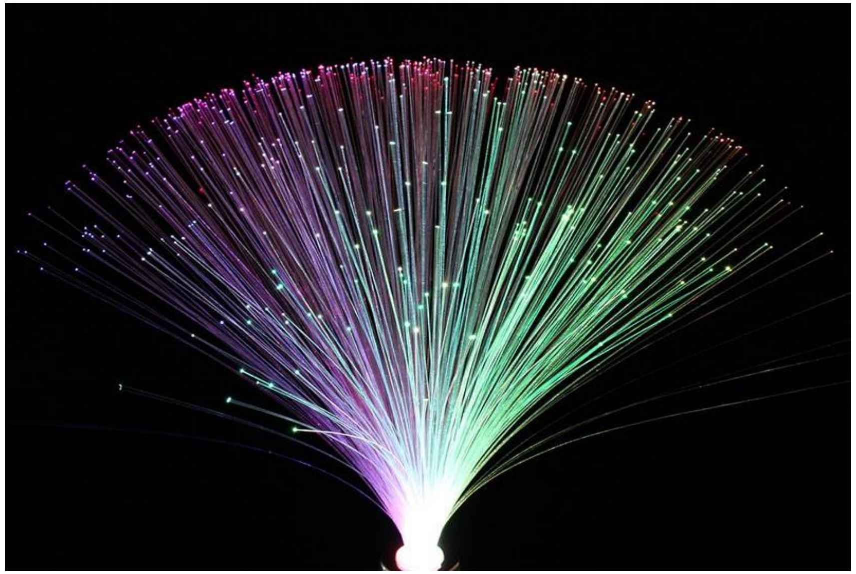
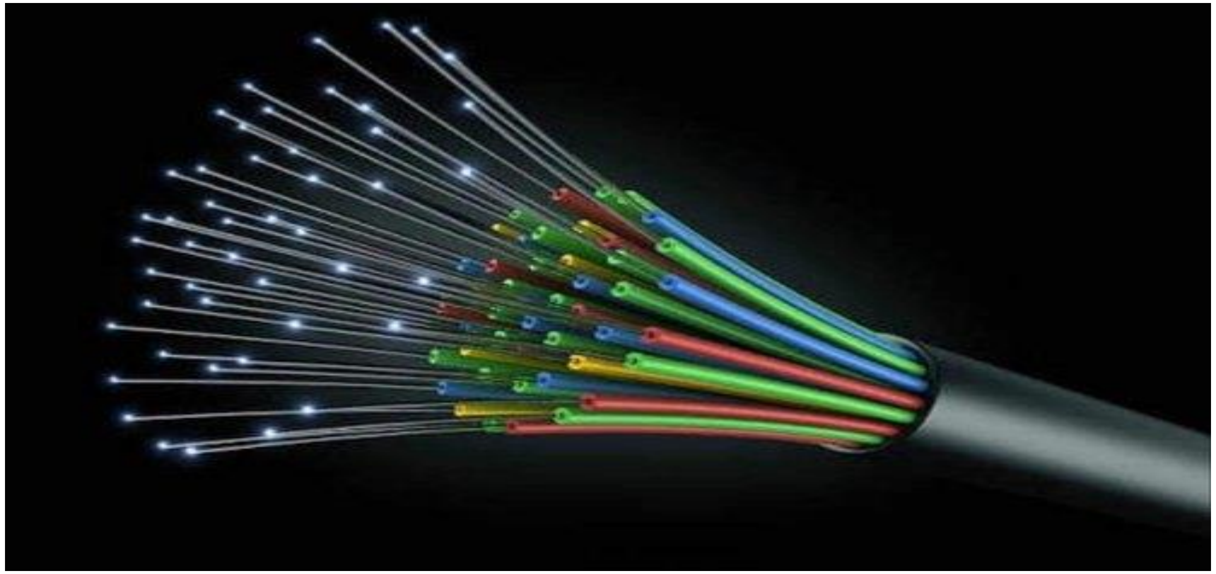
Module-2

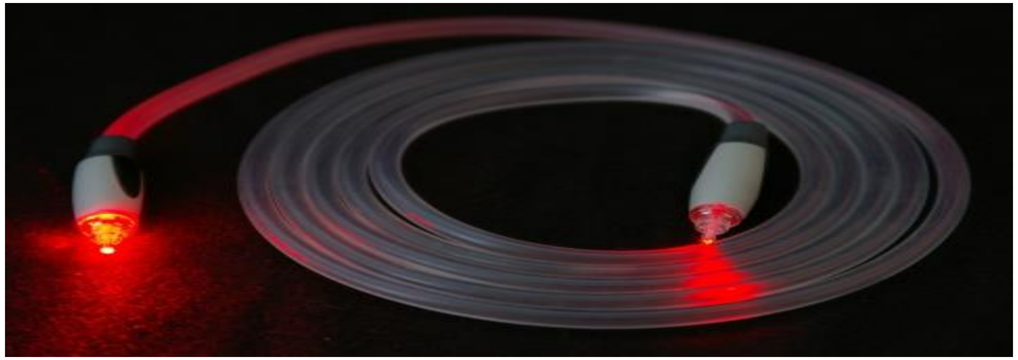
Diffraction (Laser and Optical fiber)

Optical fibre

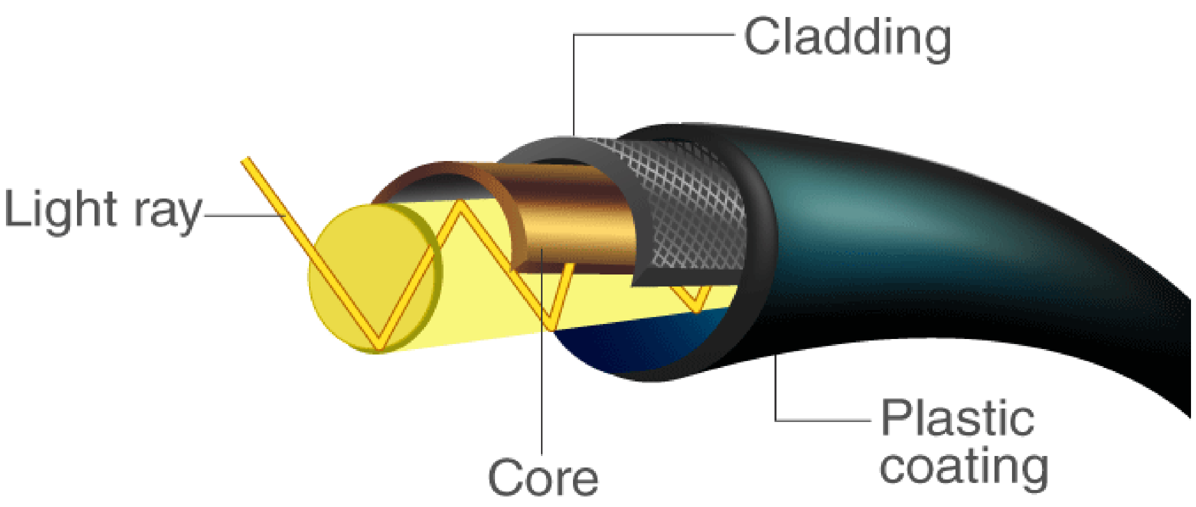




Optical fibre wire is very thin and flexible wire made of glass or plastic which carry information in the form of light from place to another place



Structure of Optical Fibre Cable



n_1 = Refractive index of core

n_2 = Refractive index of cladding

$n_1 > n_2$ The core medium refractive is always greater than the cladding refractive index.

Optical Fibre Cable it consist of three parts

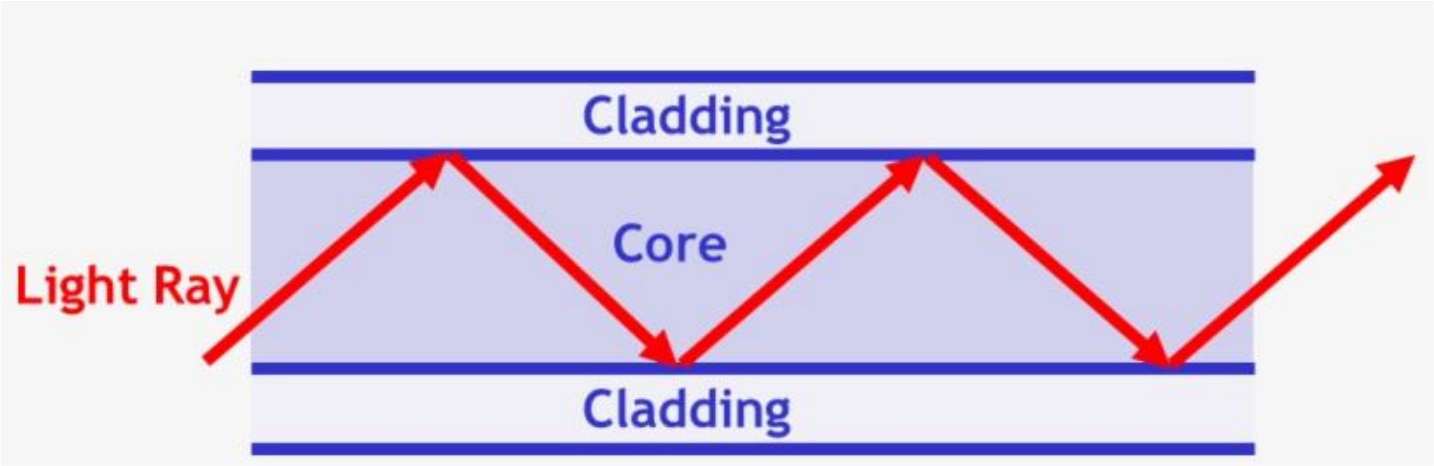
Core : Central part of OFC made up of glass or plastic where light travels.

Cladding : Cladding refractive index is lesser than the cores refractive index.

Plastic Jacket (Buffer Coating): plastic coating that protects the fiber.

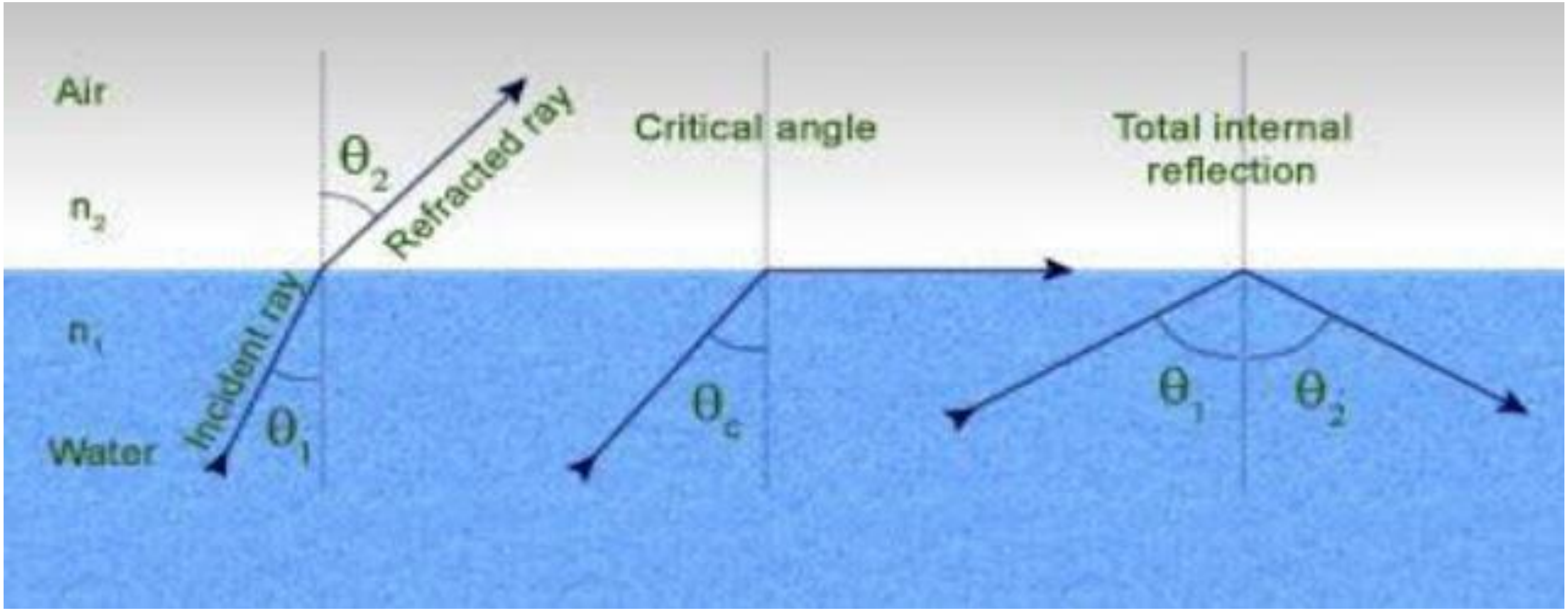
Optical fiber is used to transmit data from one place to another.

What is the mechanism used to ensure that data can be transmitted even after the bending of optical fibres?



Total internal reflection (TIR)

Total Internal Reflection (TIR)

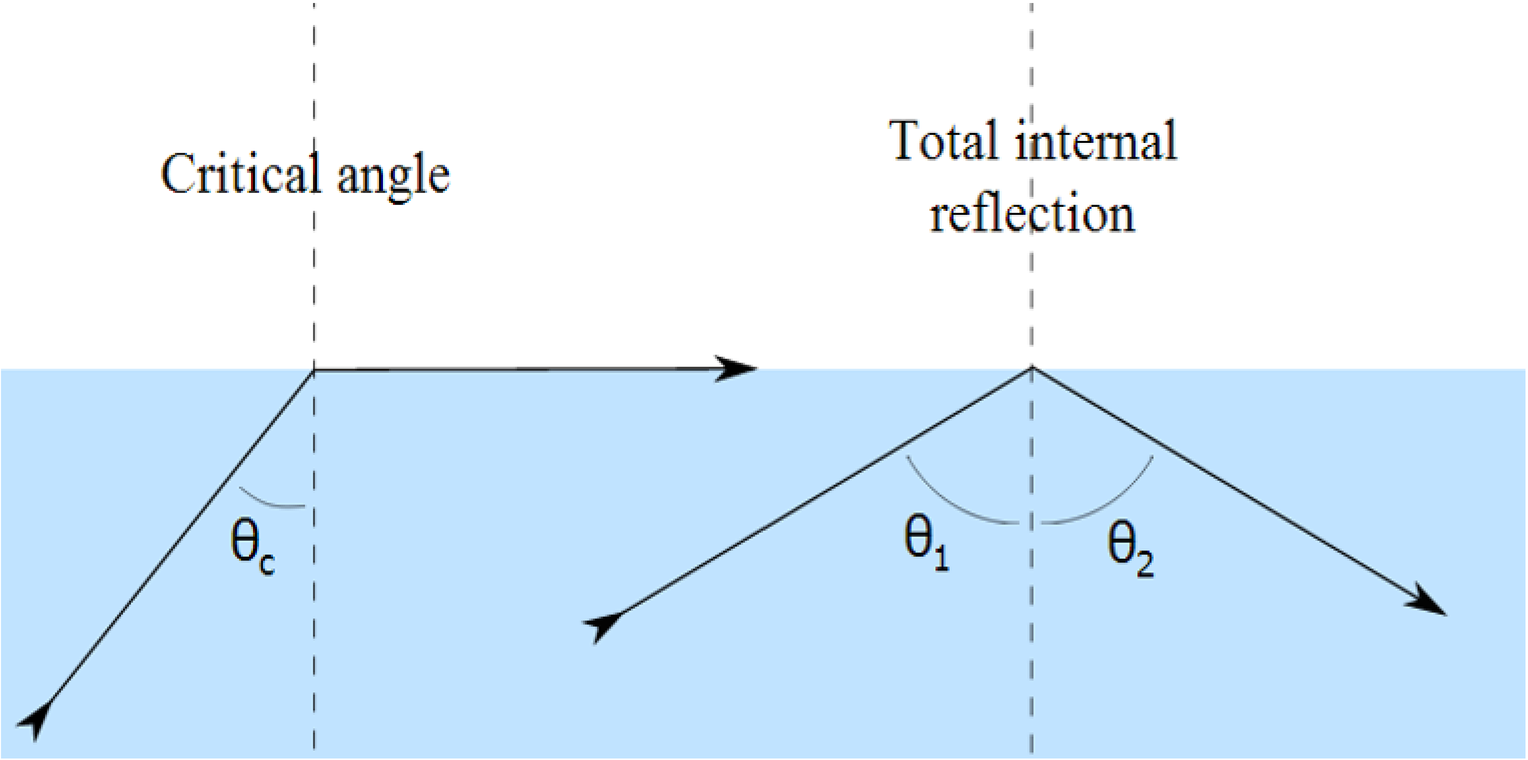


➢ Ray having small angle of incidence is **refracted**.

➢Angle of incidence at which the angle of refraction is **90 degree** is called as **critical angle for the given pair of mediums**.

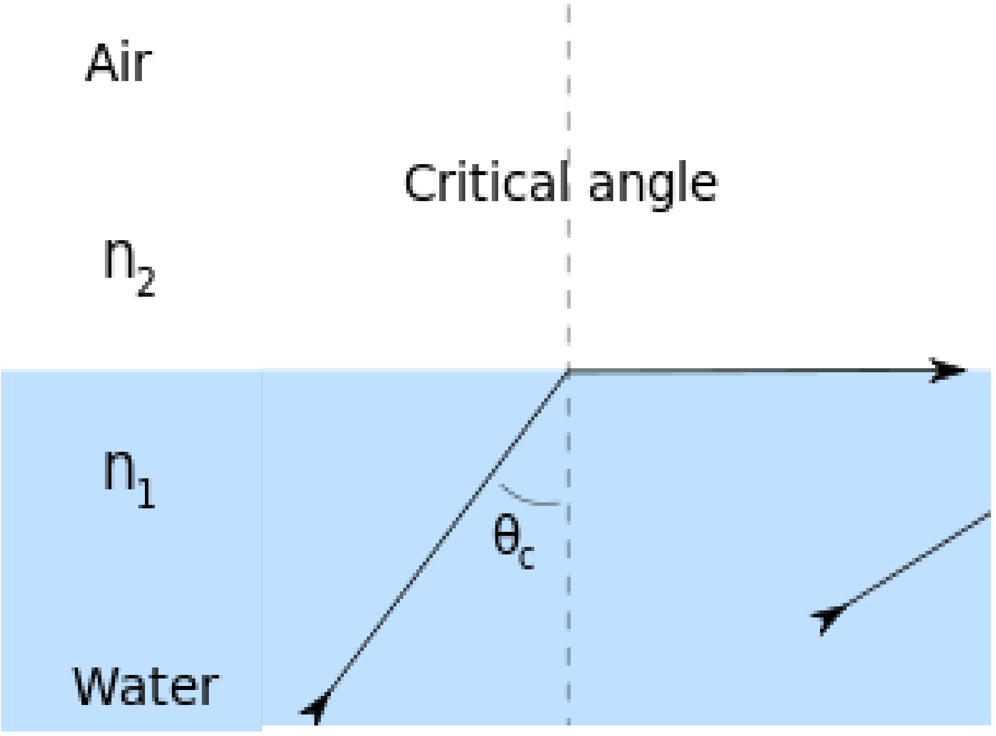
Further increase in angle of incidence makes **reflection instead of refraction.** This phenomena is known as **Total Internal Reflection (TIR).**

Total internal reflection:-



Definition: When the angle of incidence is greater than the critical angle, the refracted ray again reflects into the same medium. This phenomenon is called total internal reflection.

Critical Angle θ_c



By Snells law

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

Sin θ_c = $\frac{n_2}{n_1}$ sin r

For critical angle r= 90^0

Sin θ_c= $\frac{n_2}{n_1}$ sin 90

Sin θ_c= $\frac{n_2}{n_1}$

$$\theta_c = \sin^{-1}\frac{n_2}{n_1}$$

Classification of fibres

Based on the refractive index of core medium, optical fibres are classified into two categories.

- Step index fibre
- Graded index fibre

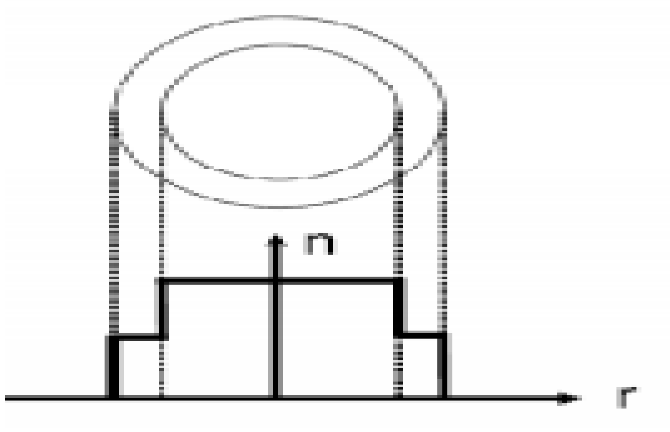
Based on the number of modes of transmission, optical fibres are classified into two categories

- Single mode fibre
- Multi-mode fibre

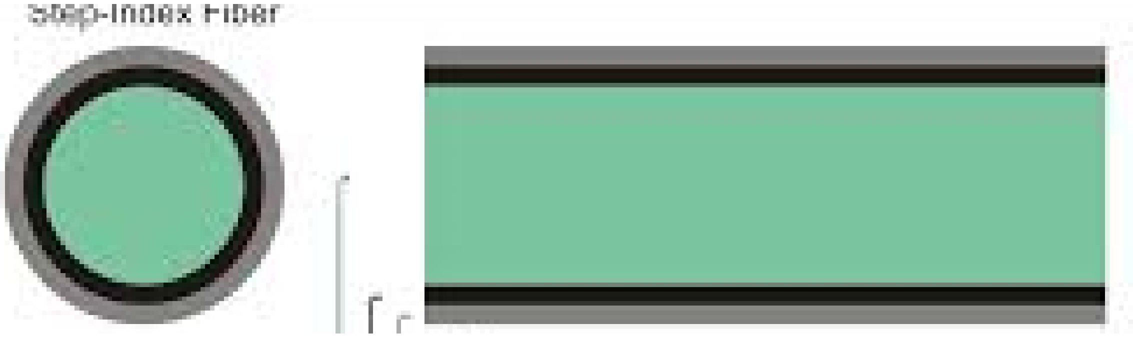
Based on the material used, optical fibres are may broadly classified into four categories

- All glass fibre
- All plastic fibre
- Glass core with plastic cladding fibre
- Polymer clad silica fibre.

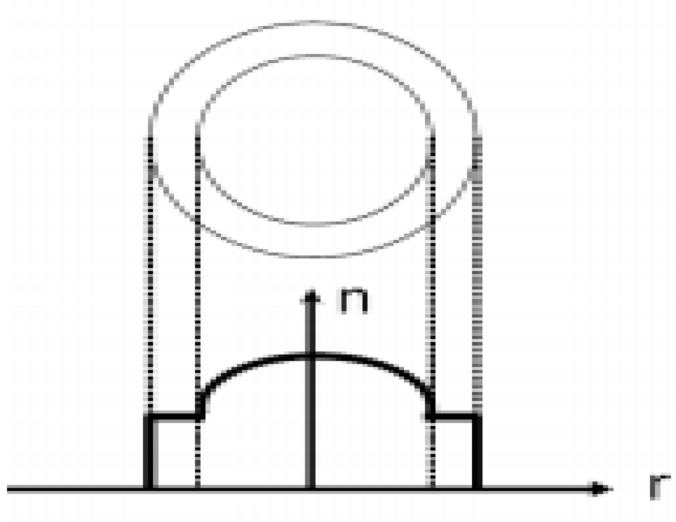
Step index fibre- refractive index profile



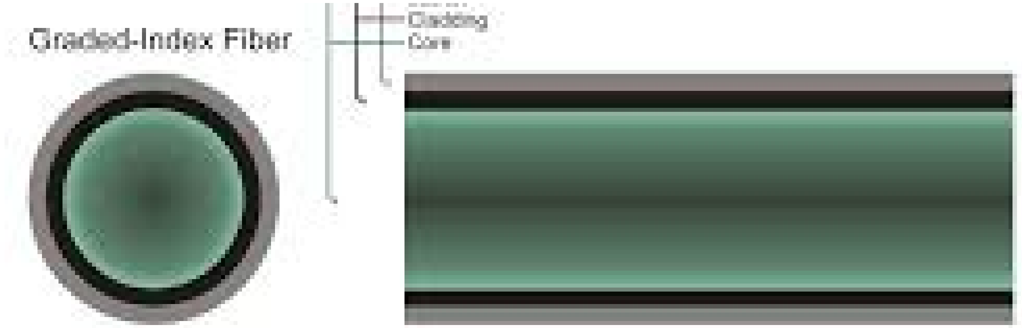
In step index fibre the refractive index of the core medium is uniform and undergoes an abrupt change at the interface of core and cladding

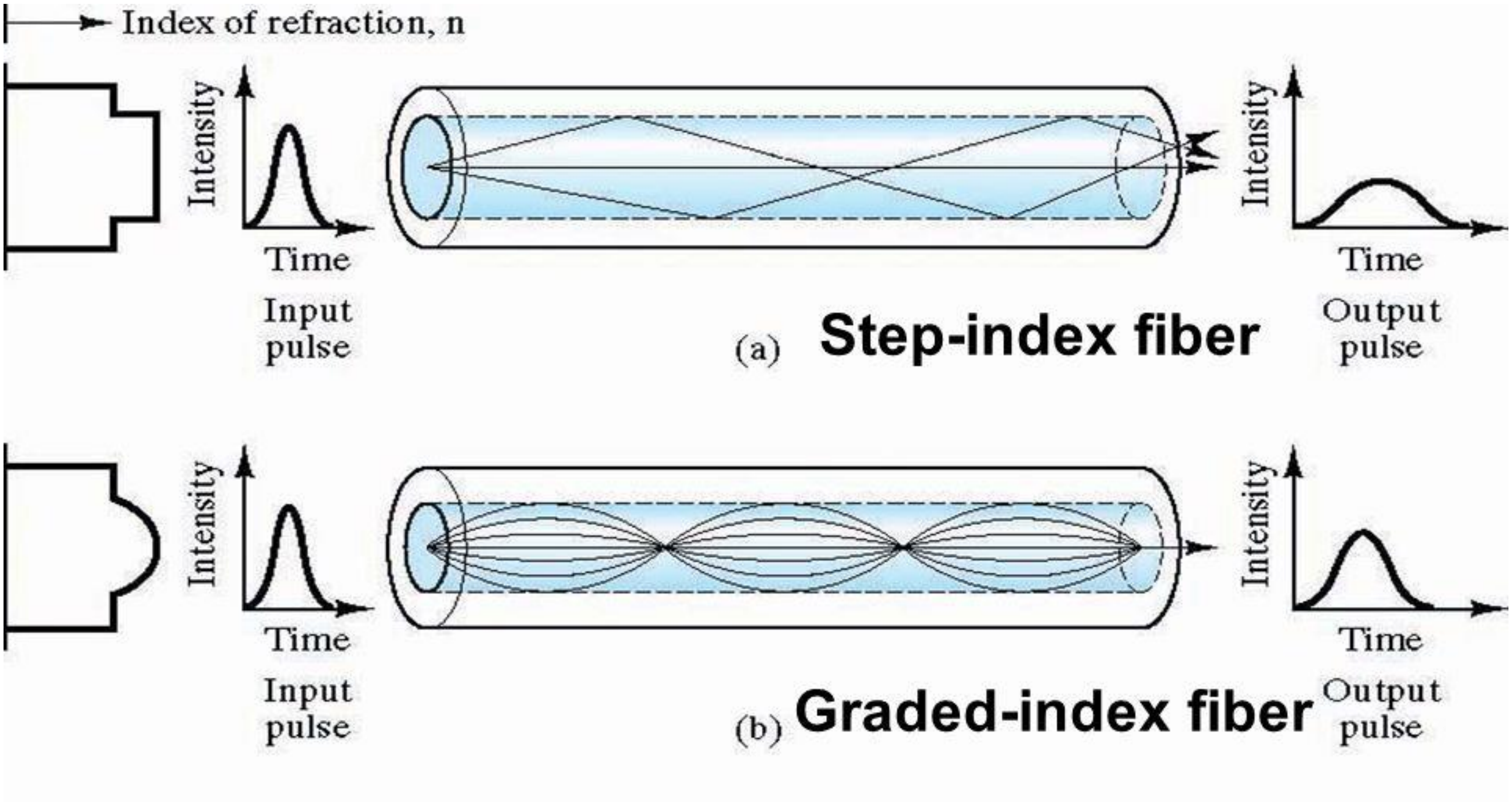


Graded index fibre - refractive index profile



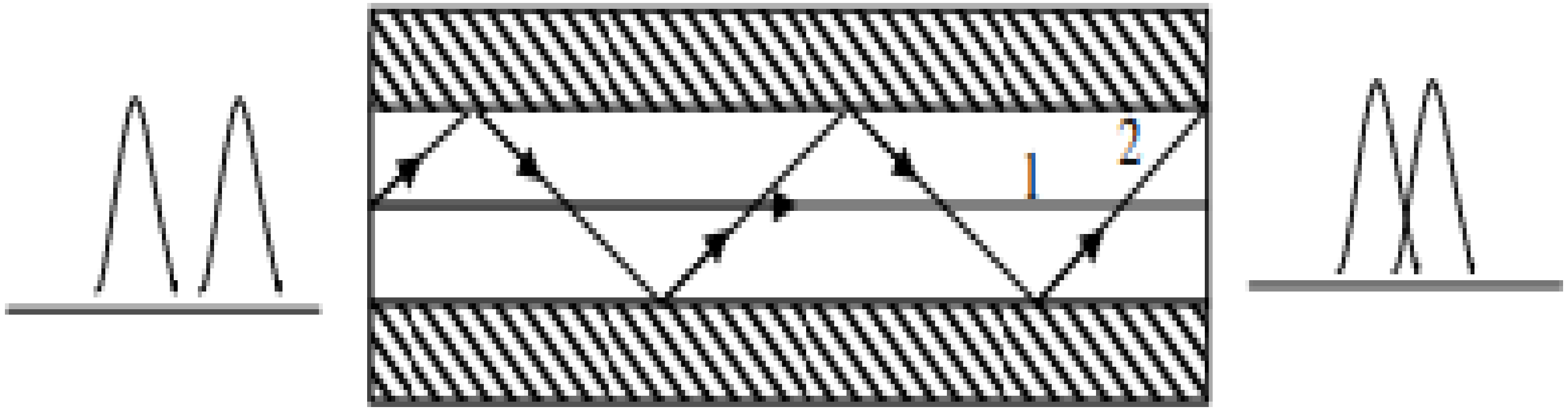
In graded index fibres, the refractive index of the core medium is varying in the parabolic manner such that the maximum refractive index is present at the center of the core.




Index of refraction, n
Intensity
Time
Input pulse
Intensity
Time
Output pulse
(a) Step-index fiber
Intensity
Time
Input pulse
Intensity
Time
Output pulse
(b) Graded-index fiber

Transmission of signal in step index fibre

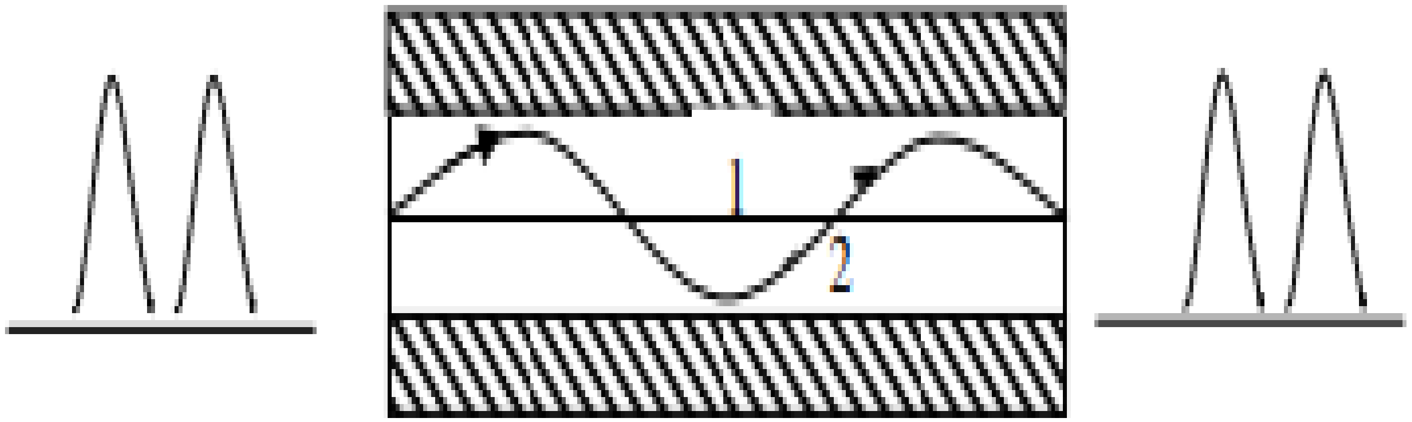
Generally, the optical signal is transmitted through the fibre in the digital form i.e., in the form of 1’s and 0’s. the propagation of signals through the multi-mode fibre is shown in fibre. The transmitted optical signal will cross the fibre axis during every reflection at the core cladding boundary. The shape of propagation of the optical signal is in zigzag manner. Generally the signal through the fibre is in digital form i.e. in the form of pulses representing 0s and 1s.



From figure the ray 1 follows shortest path (i.e. travels along the axis of fibre) and the ray 2 follows longer path than ray 1. Hence the two rays reach the received end at different times. Therefore, the pulsed signal received at other end gets broadened. This is called intermodal dispersion. This difficulty is over come in **graded index fibres**.

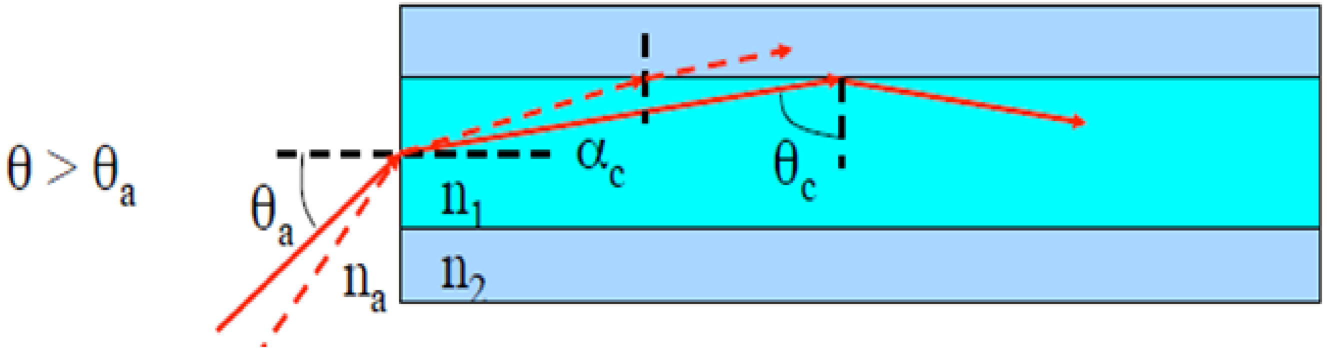
Transmission of signal in graded index fibre:-

The shape of propagation of the optical is in helical or spiral manner. The transmitted optical signal will never cross the fibre axis during every reflection at the core cladding boundary.

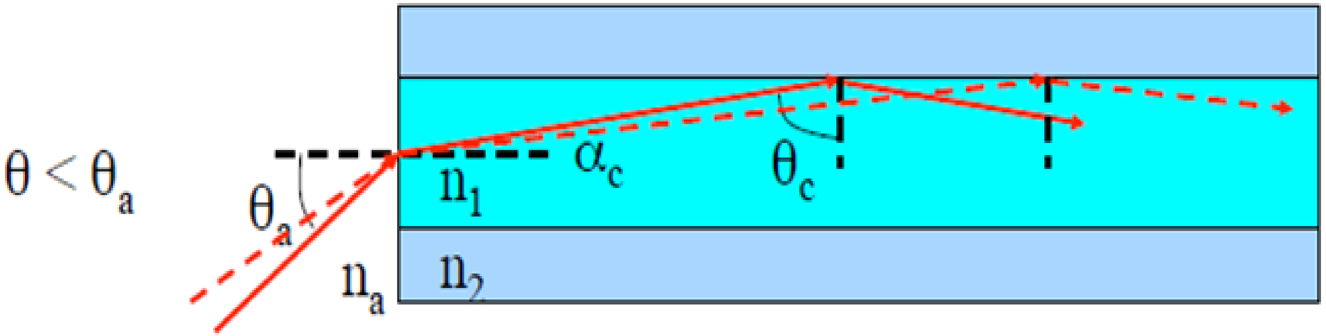


To discuss intermodal dispersion, we consider two rays as shown in figure, the ray 1 is traveling along the axis of the core and the other ray 2 traveling away from the axis undergoes refraction and bent. Since, ray 2 is traveling in the lesser refractive index medium, so ray 2 moves slightly faster than ray 1. Hence the two rays reach the other end simultaneously. Thus the problem of intermodal dispersion can be overcome by using graded index fibre.

Acceptance Angle



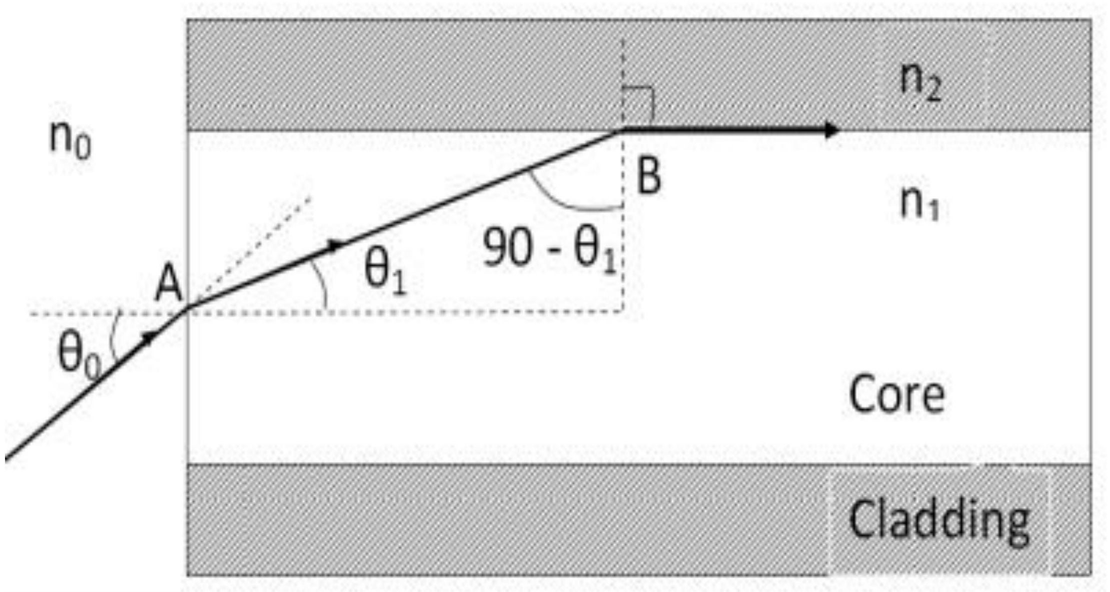
When angle of incidence θ is greater than θ_c then it will not be reflected at core-cladding interface



When angle of θ incidence is less than θ_c then it will be reflected at core-cladding interface and transmitted

Definition:- Acceptance angle is defined as the maximum angle of incidence at the interface of air medium and core medium for which the light ray enters into the core and travels along the interface of core and cladding.

Let, find the formula of acceptance angle in term of refractive index of core n_1 and cladding n_2



According to Snell's law at point A

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

$$\sin\theta_0 = \frac{n_1}{n_0}\sin\theta_1$$

According to Snell's law at point B

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

$$n_1 \cos\theta_1 = n_2$$

$$\cos\theta_1 = \frac{n_2}{n_1}$$

$$\sin\theta_1 = \sqrt{(1 - \cos^2\theta_1)}$$

$$\sin\theta_1 = \sqrt{\left(1 - \frac{{n_2}^2}{{n_1}^2}\right)} = \frac{\sqrt{({n_1}^2 - {n_2}^2)}}{n_1}$$

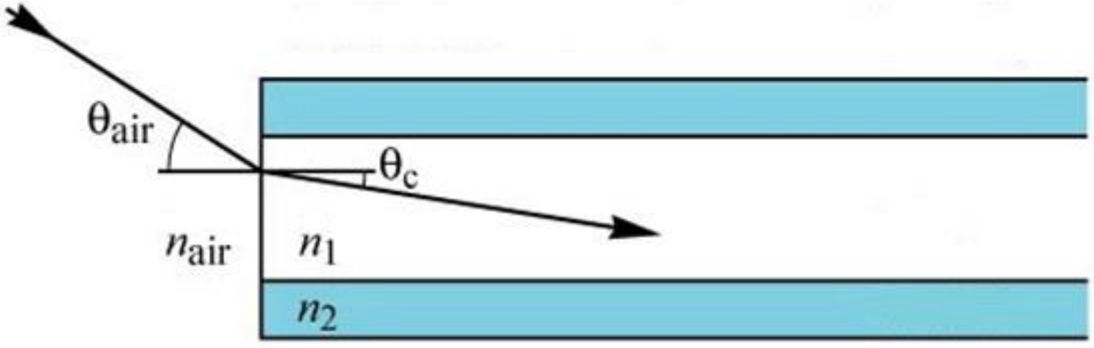
$$\sin\theta_0 = \frac{n_1}{n_0}\sin\theta_1 = \frac{n_1}{n_0}\frac{\sqrt{({n_1}^2 - {n_2}^2)}}{n_1} = \frac{\sqrt{({n_1}^2 - {n_2}^2)}}{n_0}$$

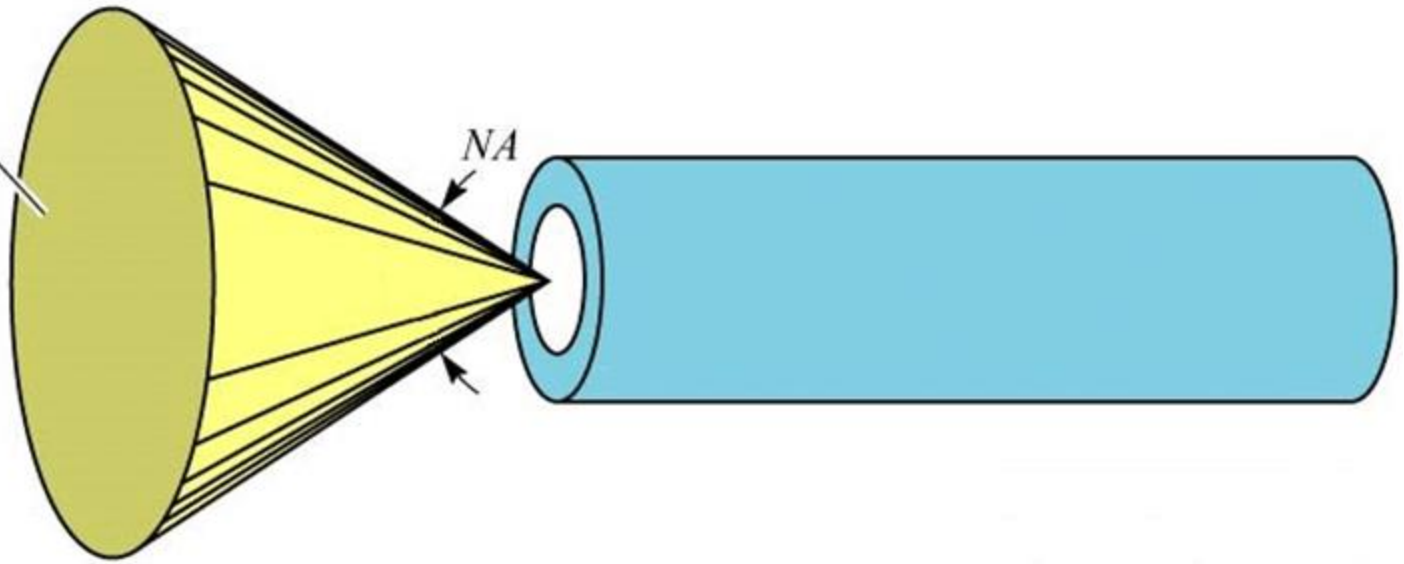
$$\sin\theta_0 = \frac{\sqrt{({n_1}^2 - {n_2}^2)}}{n_0}$$

$$\sin \theta_0 = \frac{\sqrt{(n_1{}^2 - n_2{}^2)}}{n_0}$$

$$\theta_0 = \sin^{-1}\left(\frac{\sqrt{(n_1{}^2 - n_2{}^2)}}{n_0}\right)$$

$$\text{Acceptance angle } \theta_0 = \sin^{-1}\left(\frac{\sqrt{(n_1{}^2 - n_2{}^2)}}{n_0}\right)$$





Acceptance cone

Definition:-

when acceptance angle is rotated along the axis of core, then cone is formed known as acceptance cone.

Numerical aperture (NA)

Definition: -

Numerical aperture is defined as the light gathering capacity of an optical fibre and it is directly proportional to the acceptance angle.

Numerically it is equal to the sin of the acceptance angle.

1

NA = sin (acceptance angle)

NA= sin θ_A

$$\text{Acceptance angle } \theta_0 = \sin^{-1}\left(\frac{\sqrt{(n_1{}^2 - n_2{}^2)}}{n_0}\right)$$

2

$$NA = Sin\left(Sin^{-1}\left(\frac{\sqrt{(n_1^2 - n_2^2)}}{n_0}\right)\right)$$

$$NA = \frac{\sqrt{(n_1^2 - n_2^2)}}{n_0}$$

If the refractive index of the air medium is equal to unity then

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

Fractional change in refractive index

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

$$n_1 \Delta = (n_1 - n_2)$$

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

$$NA = \sqrt{(n_1 - n_2)(n_1 + n_2)}$$

$$NA = \sqrt{(n_1 - n_2)(n_1 + n_2)}$$

$$NA = \sqrt{n_1 \Delta (n_1 + n_2)} \qquad \because n_1 \Delta = (n_1 - n_2)$$

$$NA = \sqrt{n_1 \Delta 2 n_1} \qquad \because n_1 \approx n_2 ; \quad n_1 + n_2 = 2n_1$$

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

The above equation gives a relationship between numerical aperture and fractional change in relative refractive index.

An optical fibre has a core material of reflective index 1.55 and cladding material of refractive index 1.50. The light is launched into it in air. Calculate its numerical aperture.

Given : Refractive index of core = n_1 = 1.55

Refractive index of cladding = n_2 = 1.50

Solution : Formula : N.A. $= \sqrt{n_1^2 - n_2^2}$

$$\therefore \quad \text{N.A.} = \sqrt{(1.55)^2 - (1.50)^2}$$

$$\textbf{N.A.} = \mathbf{0.3905}$$

Calculate the angle of acceptance of a given optical fibre if the refractive indices of the core and cladding are 1.563 and 1.498 respectively.

Given : $n_1 = 1.563, \quad n_2 = 1.498$

Solution : Formula : N.A. $= \sqrt{n_1^2 - n_2^2} = \sin \theta_{0\,(max)}$

$$\theta_{0\,(max)} = \sin^{-1}(NA)$$
$$= \sin^{-1}\sqrt{(1.563)^2 - (1.498)^2}$$
$$= \sin^{-1}(0.446)$$
$$= 26°30'$$

Acceptance angle = 26°30′

Calculate the fractional index change for a given optical fibre, if the refractive indices of the core and cladding are 1.563 and 1.498 respectively.

Given : $n_1 = 1.563, \quad n_2 = 1.498$

Solution : Formula : Fractional refractive index $= \Delta = \dfrac{n_1 - n_2}{n_1}$

Given : $n_1 = 1.563, \quad n_2 = 1.498$

$$\Delta = \frac{1.563 - 1.498}{1.563}$$

$$\Delta = \mathbf{0.0416}$$

The refractive indices of core and cladding materials of a step index fibre are 1.48 and 1.45 respectively. Calculate (1) Numerical aperture, (2) acceptance angle, (3) the critical angle at the core-cladding interface, (4) fractional refractive indices change.

Solution : Given : $n_1 = 1.48, \quad n_2 = 1.45$

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

$= \sqrt{(1.48)^2 - (1.45)^2}$

$= \mathbf{0.2965}$

(2) Let θ_0 be the acceptance angle.

Then, $\sin \theta_0 = \text{N.A.} = \sqrt{n_1^2 - n_2^2}$

$\theta_0 = \sin^{-1} \sqrt{n_1^2 - n_2^2}$

$= \sin^{-1} (0.2965)$

$= \mathbf{17°15'}$

(3) $\sin \theta_C = \dfrac{n_2}{n_1}$

$\theta_C = \sin^{-1}\left(\dfrac{n_2}{n_1}\right) = \sin^{-1}\left(\dfrac{1.45}{1.48}\right)$

$\theta_C = \mathbf{78°26'}$

(4) The fractional refractive index change $= \Delta = \dfrac{n_1 - n_2}{n_1}$

$\Delta = \dfrac{1.48 - 1.45}{1.48}$

$\Delta = \mathbf{0.02}$

Calculate the refractive index of core and cladding of an optical fibre with a numerical aperture of 0.33 and their fractional difference of refractive indices 0.02.

Solution : Given : $n_1 = ?$, $n_2 = ?$

$$N.A. = 0.33$$

$$\Delta = 0.02$$

$$\Delta = \frac{n_1 - n_2}{n_1} = 0.02$$

$$n_2 = (1 - 0.02)\, n_1$$

$$n_2 = 0.98\, n_1$$

$$N.A. = \sqrt{n_1^2 - n_2^2}$$

$$0.33 = \sqrt{n_1^2 - (0.98\, n_1)^2}$$

$$(0.33)^2 = n_1^2 - (0.98\, n_1)^2$$

$$\therefore \mathbf{n_1 = 1.6583}$$

$$\mathbf{n_2 = 0.98 \times 1.6583 = 1.625}$$

“V” Number or Normalized Frequency

According to wave guide theory transmission of signal in fibre each mode has a cut off frequency below which it is not sustained and the entire power leaks out into the cladding.

The cut off frequency is given by

$$V = \frac{2\pi a}{\lambda}\sqrt{{n_1}^2 - {n_2}^2} \quad = \frac{2\pi a}{\lambda}\mathrm{NA},$$

Where a =Radius of core,

λ =wavelength of light

When V<2.405 then fibre supports **only one mode**

V>2.405 then fibre supports **multimode**

Number of modes for the given fibre can be calculated with

$$N = \frac{V^2}{2}$$ For Step index fibre

$$N = \frac{V^2}{4}$$ For Graded index fibre

A step index fibre in air has N.A. of 0.16, a core refractive index 1.45 and a core diameter of 60 μm. Determine the normalized frequency for the fibre when light of wavelength of 0.9 μm is transmitted.

Solution : Given : N.A. = 0.16, $n_1 = 1.45$, $d = 60\ \mu m = 60 \times 10^{-6}$ m

$\lambda = 0.9\ \mu m = 0.9 \times 10^{-6}$ m

Formula :

$$V = \frac{\pi d}{\lambda}\ \text{N.A.}$$

$$= \frac{3.14 \times 6 \times 10^{-5}}{0.9 \times 10^{-6}} \times 0.16$$

$$= 33.49$$

$$\boxed{V = 33.49}$$

A graded index fibre has a core diameter of 0.05 mm and numerical aperture of 0.22 at a wavelength of 8500Å. What is the normalized frequency and the number of modes guided in the core?

Solution : Given : N.A. = 0.22, λ = 8500Å, d = 0.05 mm

Formula :

$$V = \frac{\pi d}{\lambda} \text{ N.A.} \qquad N_m = \frac{V^2}{2}$$

$$V = \frac{3.14 \times 5 \times 10^{-3}}{8500 \times 10^{-10}} \times 0.22 = 0.04063 \times 10^5$$

$$V = 40.63$$

$$N_m = \frac{(40.63)^2}{2} = 412.5 \approx 412$$

$$\boxed{V = 40.63, \quad N_m = 412}$$

The core diameter of a multimode step index fibre is 50 μm. The numerical aperture is 0.25. Calculate the number of guided modes at an operating wavelength of 0.75 μm.

Solution : Given : $d = 50\ \mu m = 50 \times 10^{-6}\ m$, N.A. = 0.25

$\lambda = 0.75\ \mu m = 75 \times 10^{-8}\ m$

Formula :

$$N_m = \frac{V^2}{2}, \quad V = \frac{\pi d}{\lambda} \text{ N.A.}$$

$$V = \frac{3.14 \times 50 \times 10^{-6}}{75 \times 10^{-8}} \times 0.25 = 52.36$$

$$N_m = \frac{(52.36)^2}{2} = 1370$$

$$\therefore \boxed{N_m = 1370}$$

A step index fibre in air has N.A. of 0.16; a core refractive index 1.45 and a core diameter of 60 μm. Determine the normalized frequency for the fibre when light of wavelength of 0.9 μm is transmitted.

Solution : Given : N.A. = 0.16, $n_1 = 1.45$, $d = 60 \times 10^{-6}$ m

$\lambda = 0.9\ \mu m = .9 \times 10^{-6}$ m

Formula :

$$V = \frac{\pi d}{\lambda} \text{ N.A.}$$

$$V = \frac{3.14 \times 6 \times 10^{-5}}{0.9 \times 10^{-6}} \times 0.16$$

$$V = 33.49$$

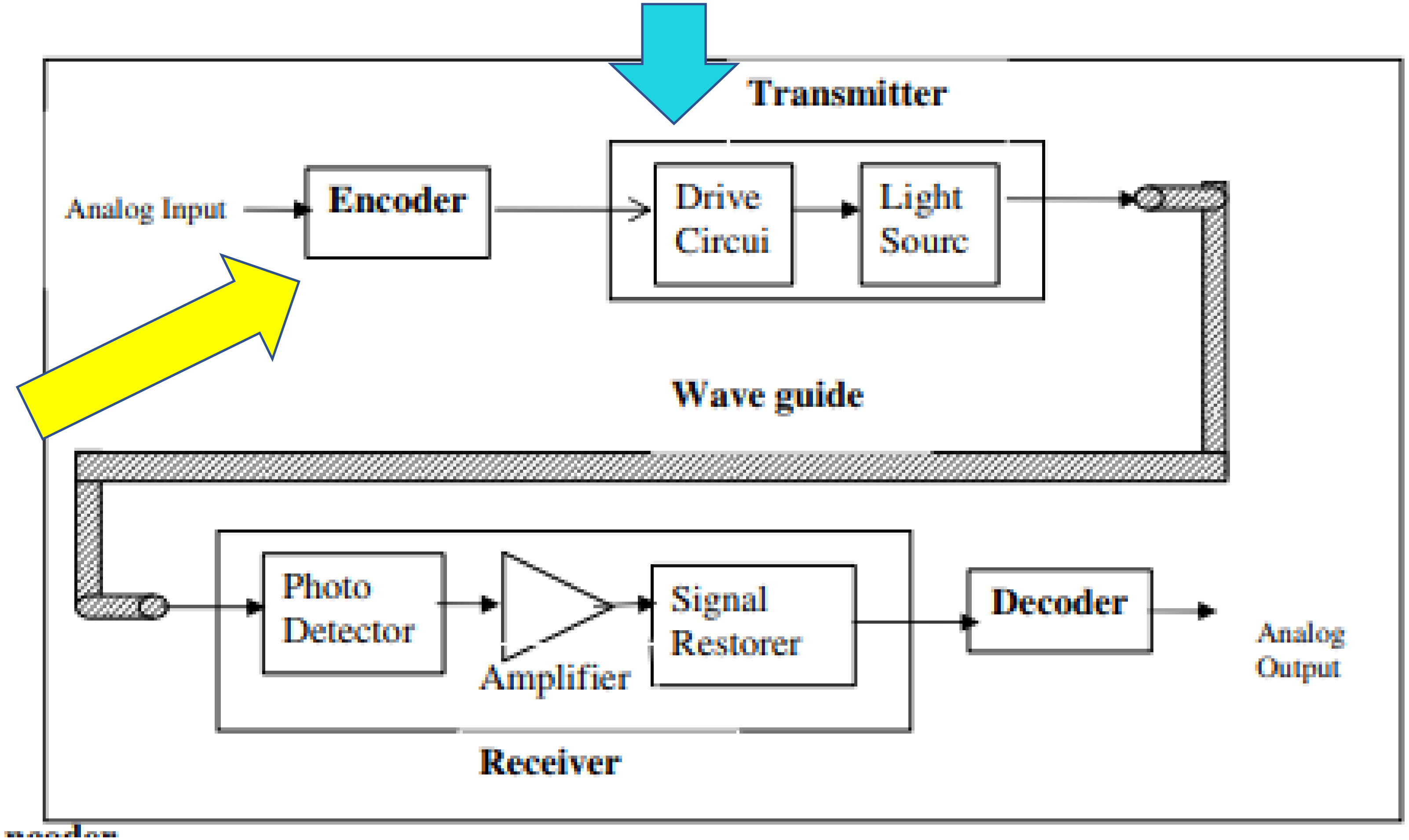
$\therefore$ $\boxed{\textbf{Normalized frequency = 33.49}}$

Optical fibre communication system

An efficient optical fibre communication system requires high information carrying capacity, fast operating speed over long distances with a minimum number of repeaters.

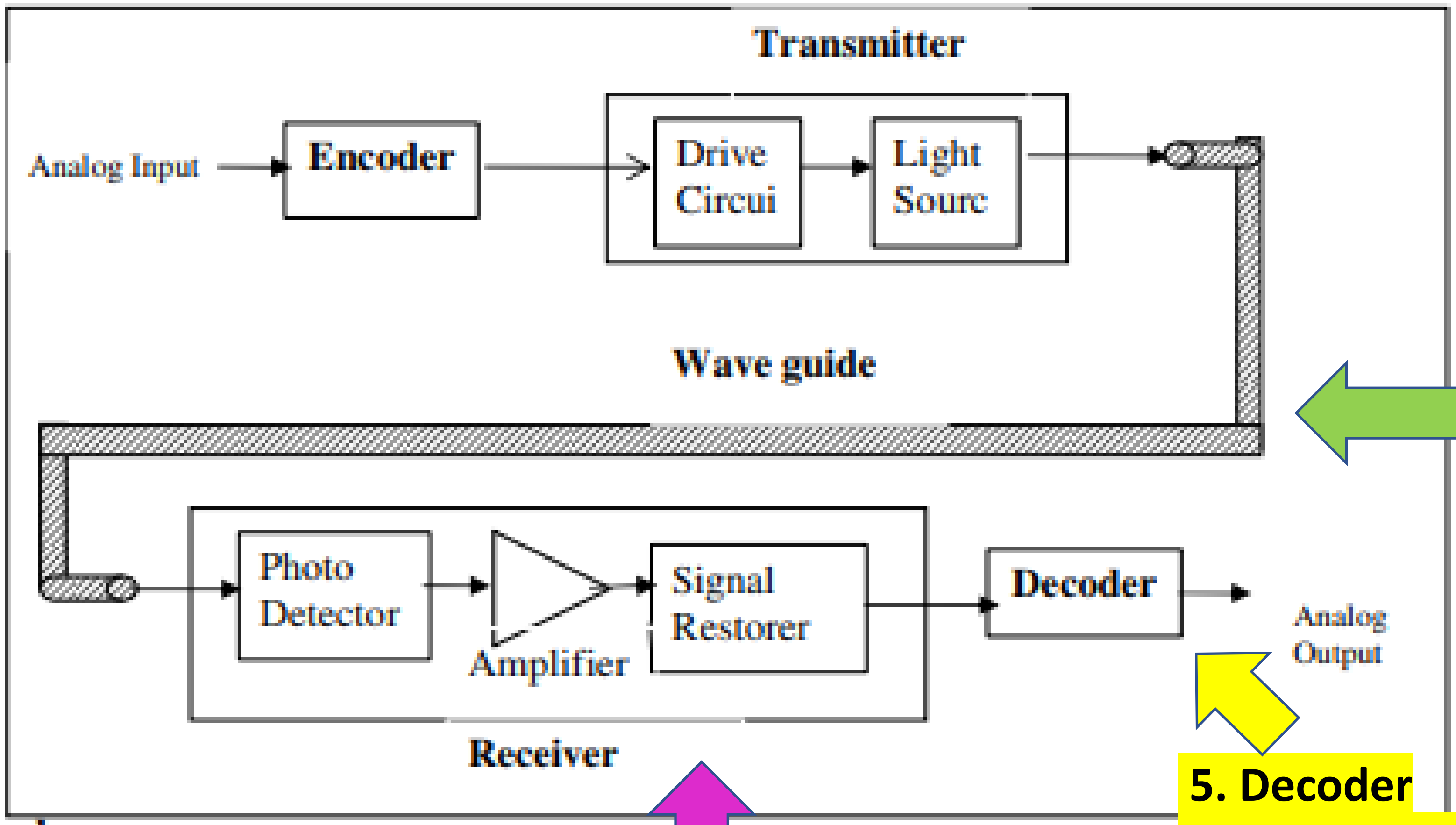
2. Transmitter

It contain two parts, they are drive circuit and light source. Drive circuit supplies the electric signals to the light source from the encoder in the required form. The light source converts the electrical signals into optical form. With the help of specially made connector optical signals will be injected into wave guide from the transmitter.



1. Encoder

Encoder is an electronic system that converts the analog information like voice, figures, objects etc., into binary data.



3. Wave guide.

It is an optical fibre which carriers information in the form of optical signals over distances with the help of repeaters. With the help of specially made connector optical signals will be received by the receiver from the wave guide.

5. Decoder

It converts electric signals into the analog information.

4. Receiver.

It consists of three parts; they are photo detector, amplifier and signal restorer. The photo detector converts the optical signal into the equivalent electric signals and supply to them to amplifier. The amplifier amplifies the electric signals as they become weak during the long journey through the wave guide over longer distance. The signal restorer deeps the electric signals in a sequential form and supplies to the decoder in the suitable way.

Advantages of fibre optic communication

The optical fibre communication has more advantages than convectional communication.

1. Enormous bandwidth
2. low transmission loss
3. electric isolation
4. signal security
5. small size and less weight
6. low cost
7. immunity cross talk

1. **Enormous bandwidth**

The information carrying capacity of a transmission system is directly proportional to the frequency of the transmitted signals. In the coaxial cable (or convectional communication system) transmission the bandwidth range is up to around500MHZ. only. Where as in optical fibre communication, the bandwidth range is large as 105 GHZ.

2. **Low transmission loss:-**

The transmission loss is very low in optical fibres (i.e. 1 2.0 − Km) than compare with the convectional communication system. Hence for long distance communication fibres are preferred.

3. **Electric isolation**

Since fibre optic materials are insulators, they do not exhibit earth and interface problems. Hence communicate through fibre even in electrically danger environment.

4. **Signal security**

The transmitted signal through the fibre does not radiate, unlike the copper cables, a transmitted signal cannot be drawn from fibre without tampering it. Thus the optical fibre communication provides 100% signal security.

5. Small size and less weight

The size of the fibre ranges from 10μm to50μm , which is very small. The space occupied by the fibre cable is negligibly small compared to conventional electrical cables. Optical fibres are light in weight.

6. Low cost

Since optical fibres made up of silica which is available in abundance, optical fibres are less expensive.

7. Immunity cross talk

Since the optical fibres are dielectric wave guides, they are free from any electromagnetic interference and radio frequency interference. Since optical interference among different fibres is not possible, cross talk is negligible even many fibres are cabled together.