Unit 2b: <u>LASER AND FIBRE OPTICS</u>

Q2b.1. Explain the phenomenon of Total internal reflection.

(M.U. May 2009; Dec. 2013, 14, 15) (3 m)

When a ray of light suffers refraction at a boundary while travelling from a rarer medium to a denser medium, it bends towards the normal as shown in *Figure 2b.1.1a*. Similarly, if a ray of light travels from a denser medium to a rarer medium, it bends away from the normal as shown in *Figure 2b.1.1b*

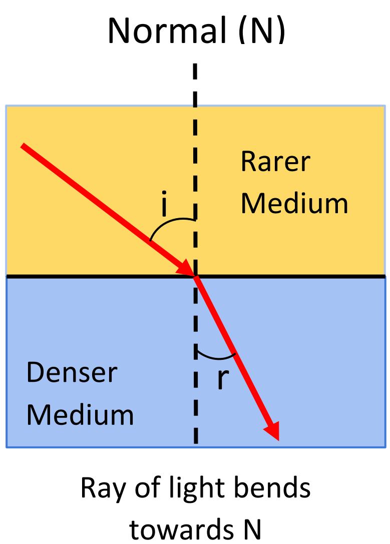


Figure 2b.1.1a: Reflection at the boundary of a denser medium

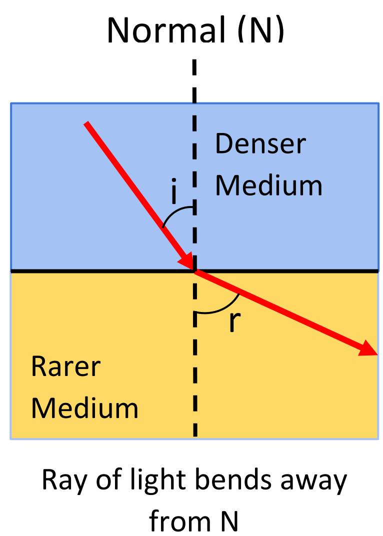


Figure 2b.1.1b: Reflection at the boundary of a rarer medium

In both the cases angle of refraction (r) increases with increase in the angle of incidence (i). When the ray of light is travelling from denser medium towards the rarer medium similar to the case as shown in *Figure 2b.1.1b*, then the angle of incidence for which the angle of refraction

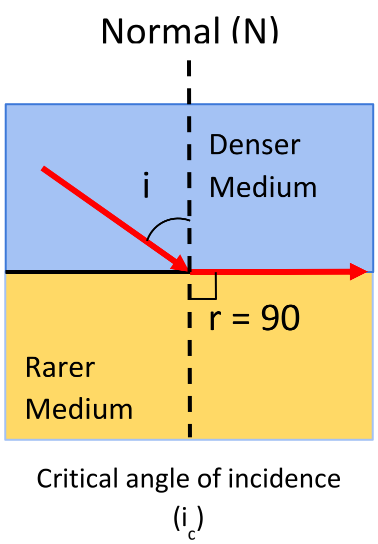


Figure 2b.1.2a: Critical angle of incidence (ic)

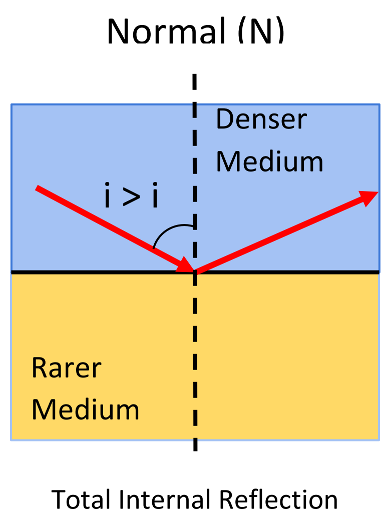


Figure 2b.1.2b: Total Internal Reflection

becomes 90° is called the critical angle of incidence (i_c) as shown in *Figure 2b.1.2a*.

When the angle of incidence increases further ($i > i_c$) the refracted ray does not enter the rarer medium and is reflected back to the denser medium .

Thus, when a ray of light is travelling from the denser medium towards the rarer medium is incident at the boundary with an angle greater than the critical angle ($i > i_c$), the ray of light instead of getting refracted to the rarer medium gets reflected back to the denser medium.

This phenomenon where light is reflected back into the denser medium, is called **Total Internal Reflection** as shown in *Figure 2b.1.2b*.

Q2b.2. Write a note on optical fibres.

Optical fibres are long thin hair like cables made of plastic or glass to electric light along their length.

An Optical fibre generally has three co-axial regions as shown in *Figure 2b.2.1*.

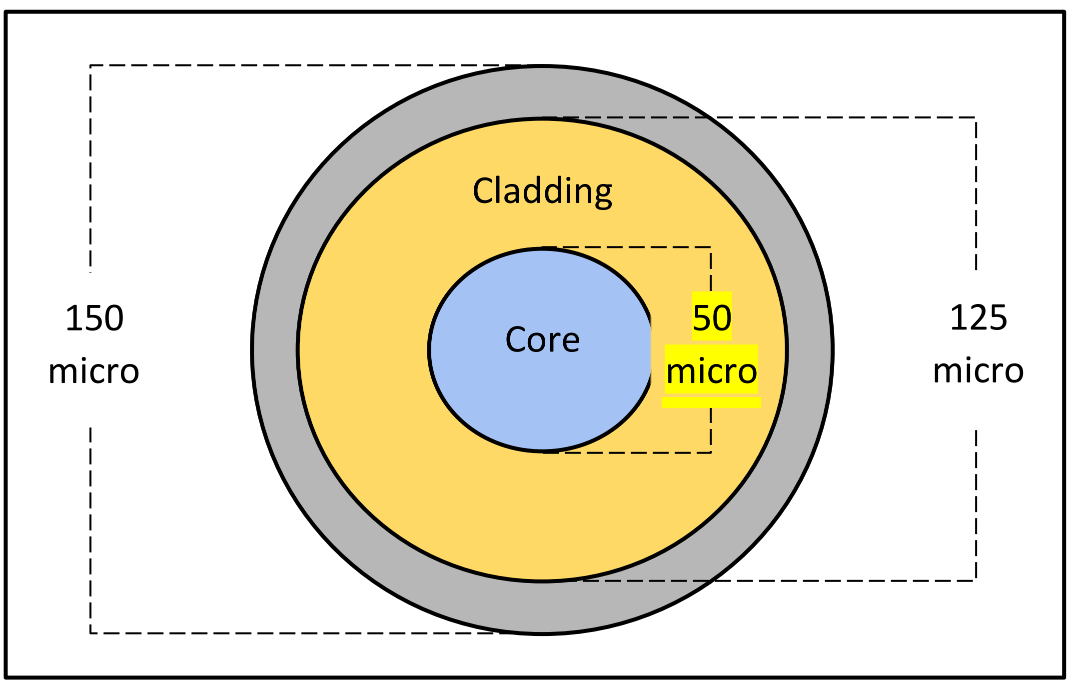


Figure 2b.2.1: Dimensions of Fibre optic cable

1. **Core:** The innermost region of nearly 50μm in diameter which is optically dense as compared to cladding is called core.
2. **Cladding:** The region surrounding the core with 125 μm diameters which is rarer as compared to core is called cladding.
3. **Sheath:** The outermost skin of optical fire to protect it from external damage is called sheath.

Q2b.3. Why is cladding required when light travels through core only?

Cladding is required as:

1. It enhances the mechanical strength of fiber.
2. Protects core from surface contamination.
3. Reduces scattering loss at the core.

Q2b.4. Derive expression for acceptance angle of an optical fibre.

(M.U. Dec. 2002, 05,07,08,11,12,15, 16: May 2013, 15) (5 m)

The maximum angle of incidence for which the light incident on the core propagates successfully through the fibre is called acceptance angle (θ_0).

Consider a step index optical fibre with core of refractive index μ_1 and cladding of refractive index μ_2 placed in air which has refractive index μ_0 as shown in *Figure 2b.4.1*.

For a ray of light that is travelling from air to core the relative refractive index can be written as:

$$\mu_1^0 = \frac{\mu_1}{\mu_0} \text{-------------------------} \textbf{(1a)}$$

For a ray of light that is travelling from core to cladding the relative refractive index can be written as :

$$\mu_2^1 = \frac{\mu_2}{\mu_1} \text{-------------------------} \textbf{(1b)}$$

Applying Snell's law of refraction at the air – core interface:

$$\mu_1^0 = \frac{\sin \theta_0}{\sin r}\text{-------------------------}\mathbf{(2)}$$

Critical angle (i_c) and angle of refraction (r) are complementary angles (i_c + r =90), hence

$$\mu_1^0 = \frac{\sin \theta_0}{\sin r} = \frac{\sin \theta_0}{\sin (90 - i_c)} = \frac{\sin \theta_0}{\cos i_c}\text{-------}\mathbf{(3)}$$

Using (1a) , (3) and $\mu_0 = 1$ for air we get:

$$\frac{\sin \theta_0}{\cos i_c} = \frac{\mu_1}{\mu_0} = \mu_1\text{-------}\mathbf{(4)}$$

Applying Snell's law of refraction at the core-cladding interface:

$$\mu_2^1 = \frac{\sin i_c}{\sin 90}\text{-------}\mathbf{(5)}$$

Using (1b) , (5) and $\sin \sin 90 = 1$ we get:

$$\frac{\mu_2}{\mu_1} = \sin i_c \text{-------}\mathbf{(6)}$$

Using $(sinx)^2 + (\cos x)^2 = 1$, (4) and (6) we get:

$$(\sin i_c)^2 + (\cos i_c)^2 = \frac{{\mu_2}^2}{{\mu_1}^2} + \frac{(\sin \theta_0)^2}{{\mu_1}^2}\mathbf{=1}$$

$$\frac{(\sin \theta_0)^2}{{\mu_1}^2} = 1 - \frac{{\mu_2}^2}{{\mu_1}^2}$$

$$(\sin \theta_0)^2 = {\mu_1}^2 - {\mu_2}^2$$

Numerical Aperture: Sine of acceptance angle is called Numerical Aperture.

$$sin\theta_0 = \sqrt{{\mu_1}^2 - {\mu_2}^2}$$

Thus the expression for acceptance angle is :

$$\theta_0 = sin^{-1}(\sqrt{\mu_1{}^2 - \mu_2{}^2})$$

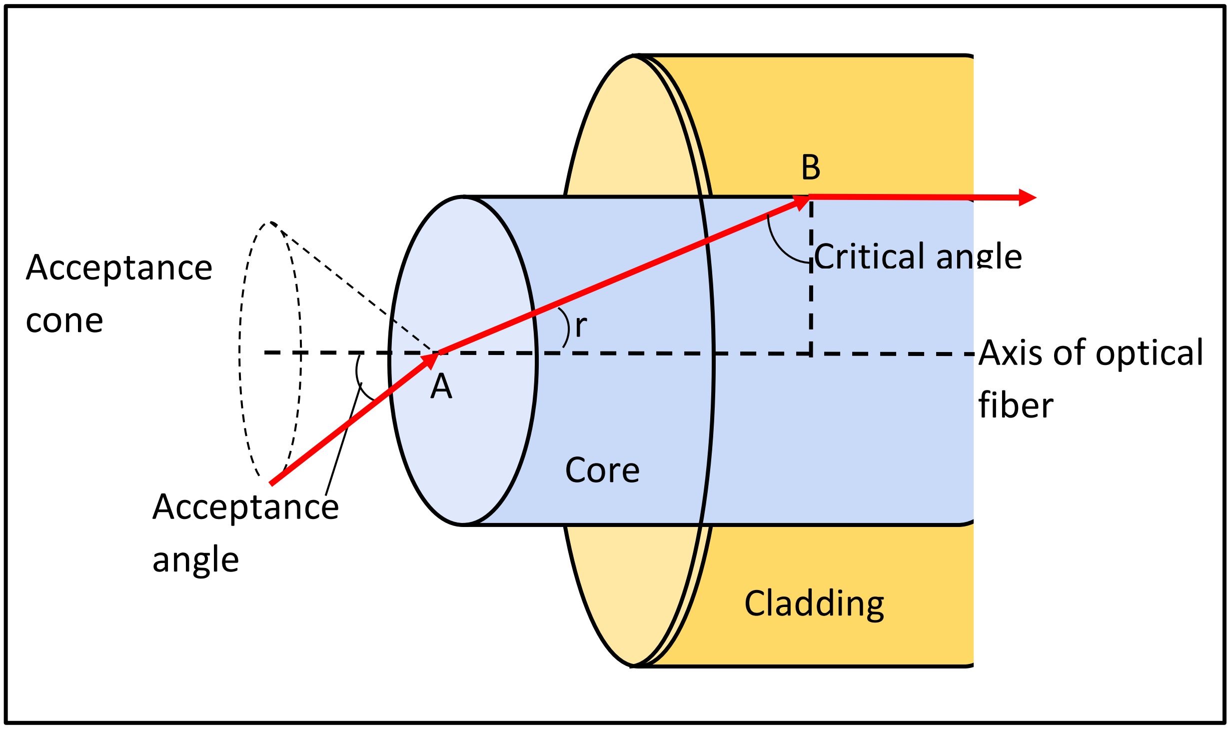


Figure 2b.4.1: Acceptance angle for fibre optic cable

Acceptance Cone: The solid angle made by the acceptance angle in all directions is called acceptance cone all light incident in this cone propagates through the fibre successfully.

Q2b.5. Distinguish between single mode and multimode fibres.

(M.U. Dec 2009; May 2013) (3 m)

Single / Mono mode fibre (SMF)	Multi-mode fibre (MMF)
Support only one mode of propagation	Support more than one mode
Core diameter is small	Core diameter is large

Usually step index type	Further divided as step index and graded index

Q2b.6. Differentiate between SI fibre and GRIN fibre.

(M.U. Dec 2003, 05, 10, 16; May 2013, 15) (5m)

Step index optical fibre	**Graded Index optical fibre**
Discontinuity of index profile at core cladding junction.	R.I. of core decreases gradually to attain R.I. of cladding at core-cladding.
R.I. of core is constant.	R.I. of core decreases nearly in parabolic manner.
High attenuation.	Low attenuation.
For a given diameter the Numerical Aperture (N.A.) is greater.	For a given diameter the Numerical Aperture (N.A.) is lesser compared to SI.

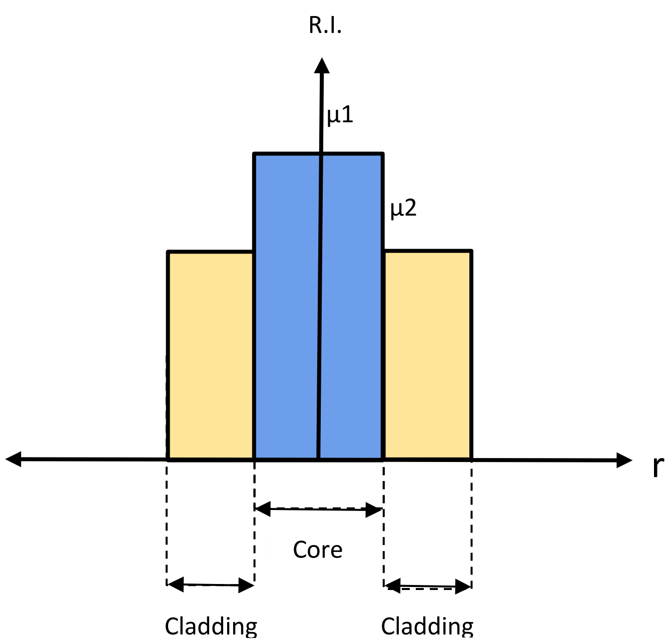


Figure 2b.6.1: Step Index fibre

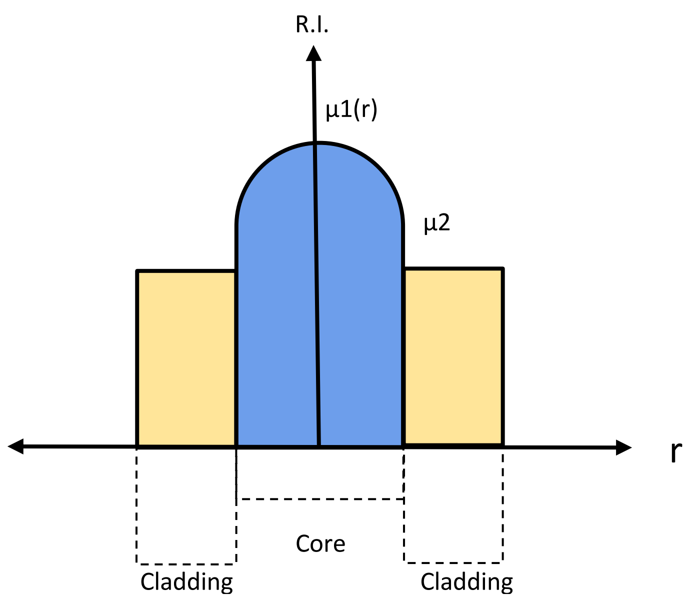


Figure 2b.6.2: Graded Index fibre

Q2b.7. Describe fibre optic communication system.

(M.U. Nov. 2018) (5m)

Transfer of information from one place to another is called communication. For communication to occur a system should consist following three main parts as shown in *Figure 2b.7.1*:

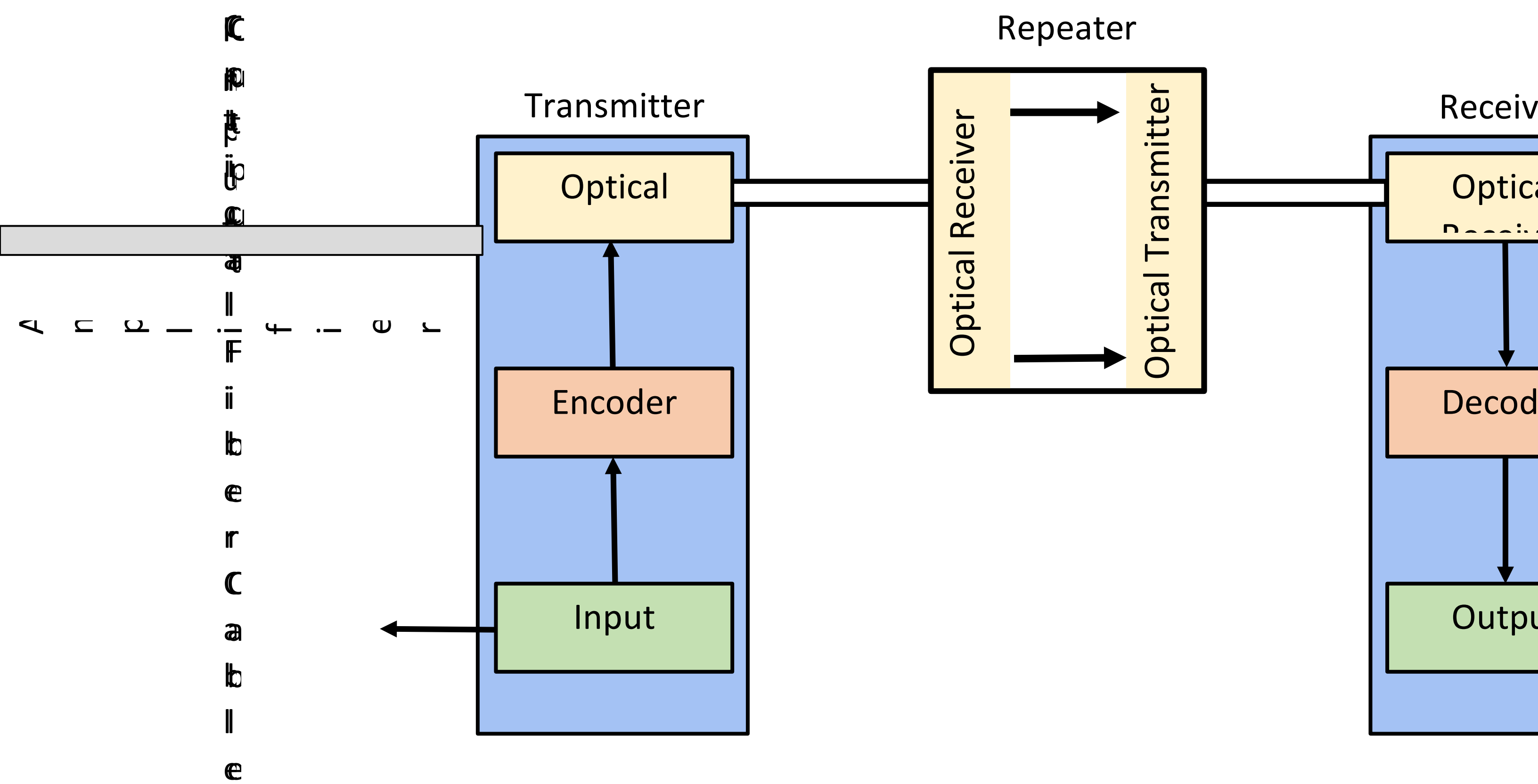
A. Transmitter (T)
B. Receiver (R)
C. Channel for propagation of information from (T) to (R)

Fibre optic communication system is specialized in a sense that the information propagates in the form of light and hence the transmitter and receiver in this type of system has additional components to support this modification. A block diagram for a typical optical fibre communication system is shown in the figure below.

Principle Elements of typical Fibre optical communication system are:

1. **Input Device:** A typical input device would be a Telephone or mike in case of a voice input to be transmitted across the channel to the receiver
2. **Encoder:** This block collects the input signal from the Input device, mixes it with a high frequency carrier as and when required and converts it to an electrical signal which is sent to the optical transmitter.
3. **Optical transmitter:** This is the special device in the transmitter that converts electrical signal to light and launches it appropriately to propagate through the optical fiber. Eg. LED.
4. **Optical fibre:** This is the three layered fibre consisting of a core-cladding interface covered in a sheath. The information propagates through the core in the form of light due to the phenomenon of total internal reflection in a zig – zag manner.

5. **Optical receiver:** This is the special device in the Receiver that converts light from the optical fiber to electrical signal. Eg. Photodiode.
6. **Decoder:** This block collects the signal from the Optical receiver, removes the high frequency carrier as and when required and converts electrical signal from the optical receiver into a user understandable output (Audio).
7. **Output Device:** A typical output device would be a Telephone or speaker in case a voice output is expected at the receiver end.
8. **Repeater:** A typical amplification device suitable for long distance communication through optical fibres.



Q2b.8. What are the advantages of using fibre optic communication systems?

(M.U. May 2008, 16, 17; Dec. 2012) (3m)

The advantages of using a fiber optic communication system are:

1. **Greater Bandwidth:** Fiber optic cables provide more bandwidth than copper cables of the same diameter, in carrying more data.
2. **Faster Speeds:** Fiber optic cables have a center that carries light to transmit data. This allows fiber optic cables to carry signals at a faster pace.
3. **Better Reliability:** Fiber optic cable is immune to temperature changes, severe weather and moisture, all of which can hamper the connectivity of copper cable. Plus, fiber doesn't carry current , so it's not bothered by electromagnetic interference (EMI) which will interrupt data transmission.

4. **Thinner and Sturdier:** In comparison to copper cables, fibre optic cables are lighter and thinner. They are also less susceptible to breakage and can also withstand a higher amount of pull and pressure.

5. **Lower Total Cost of Ownership:** Although some fiber optic cables may have a better initial cost than copper, the sturdiness and reliability of fiber can make the entire cost of ownership (TCO) lower. Day by day costs continue to decrease for fiber optic cables as technology advances.