BUDDHA SERIES

(Unit Wise Solved Question & Answers)

Course – B. Tech (ECE)

College – Buddha Institute of Technology

(AKTU CODE-525)

Department: Electronics and Communication Engineering

Subject: Optical Communication (BEC-057)

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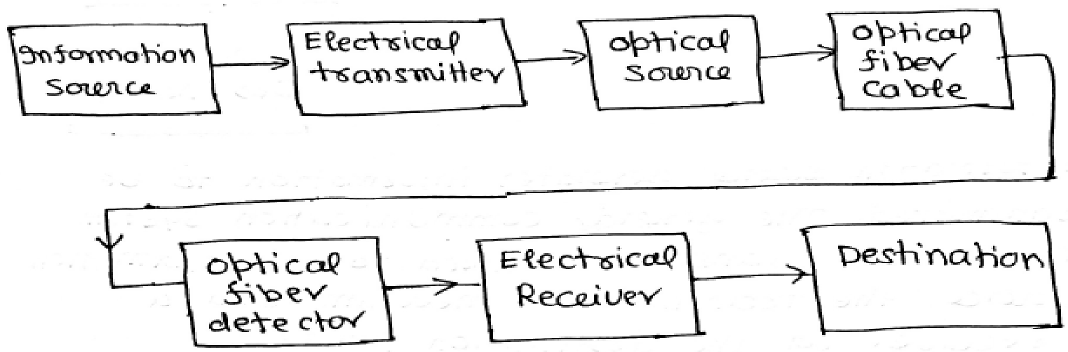
Unit – 1

Q1. Draw the block diagram of fiber optical communication system and describe the function of each component. **[AKTU: 2020-21]**

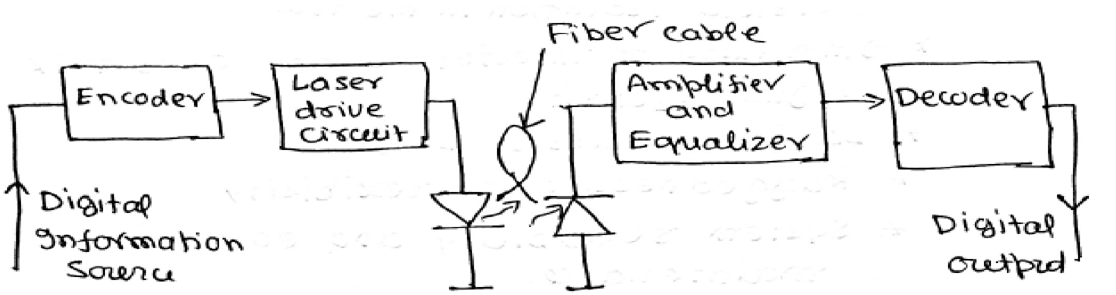
ANS:

Optical Fiber Communication system-



* Information source provides an electrical signal to a transmitter. Transmitter has electronic circuit which drives an optical source to give modulation of the lightwave carrier.
* The optical source which provides electrical-optical conversion may be either a semiconductor laser or LED.
* The transmission medium consists of an optical fiber cable and the receiver consists of an optical detector.

* optical detector provides the demodulation of optical carrier. Photodiodes, phototransistors or photoconductors are used for detection of optical signal and optical-electrical conversion.



A digital optical fiber link

* The optical carrier may be modulated using either an analog or digital information signal. In analog modulation, the variation of light emitted from optical source in a continuous manner. with digital modulation, descrete change in light intensity are obtained (i.e. on-off pulses).
* In digital optical communication system, the input digital signal from the information source is suitably encoded. The Laser drive circuit directly modulates the intensity of the Laser with the encoded digital signal. Hence digital optical signal is launched into the optical cable. Finally the signal obtained is decoded to give the original digital information.

Q2. Writ the advantages of fiber optical communication.

Advantages of optical fiber communication

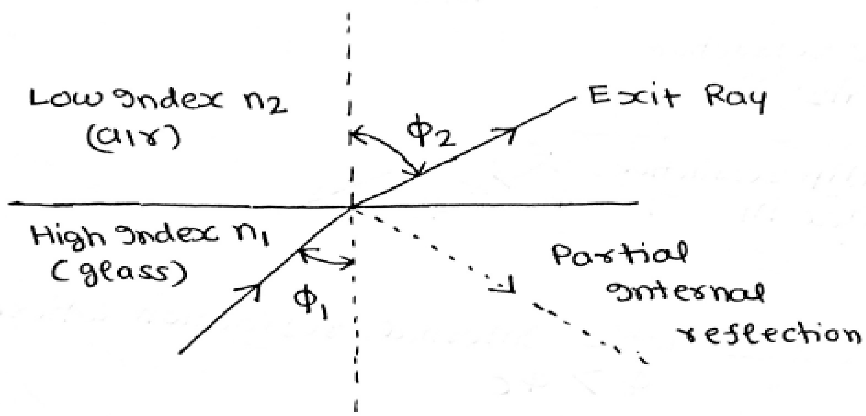
* Enormous potential bandwidth (10^{13} Hz to 10^{16} Hz)
* Small size and weight.
* Electrical isolation in the transmission medium.
* Immunity to interference and cross talk
* signal security
* Low transmission Loss
* Ruggedness and flexibility
* System reliability and ease of maintenance.
* Potential low cost

Q3. Draw and explain ray theory transmission in an optical communication. [AKTU: 2020-21]

Ray Theory Transmission

Total Internal Reflection

* The refractive index of a medium is defined as the ratio of the velocity of light in a vacuum to the velocity of light in a medium.



(Fig - a)

n_1 = Refractive index of medium (1) a -

n_2 = Refractive index of medium (2) air

$n_1 > n_2$

According to Snell's Law,

$$n_1 \sin \phi_1 = n_2 \sin \phi_2$$

or

$$\frac{\sin \phi_1}{\sin \phi_2} = \frac{n_2}{n_1}$$

* since n_1 is greater than n_2 hence angle of refraction is always greater than the angle of incidence.

* when the angle of refraction is 90° and the refracted ray emerges parallel to the interface between the dielectrics, then the angle of incidence is called critical angle ϕ_c. The value of critical angle is given by

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

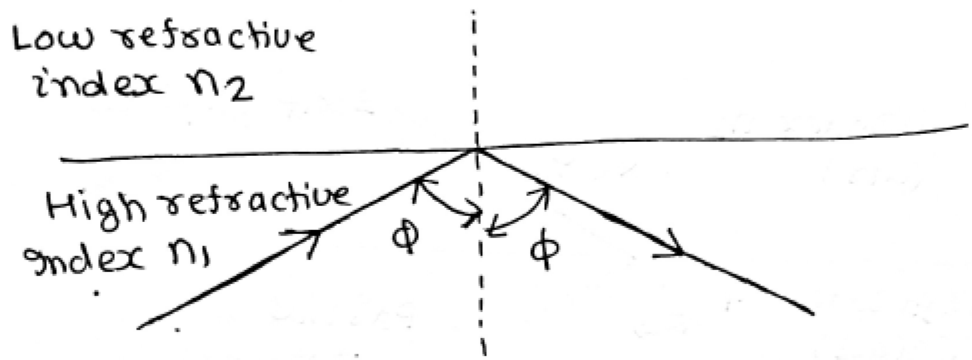


Fig-b Total internal reflection where $\phi > \phi_c$

* The total internal reflection occurs at the interface between two dielectrics of different refractive indices when light is incident on the dielectric of lower index from the dielectric of higher index, and the angle of incidence of ray is greater than critical angle. In this case light is reflected back into the originating dielectric medium with high efficiency (around 99.9 %)

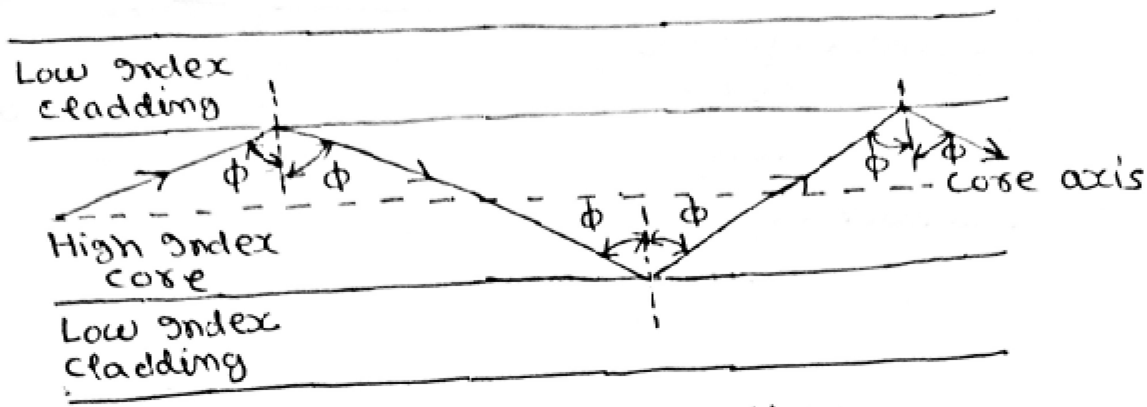
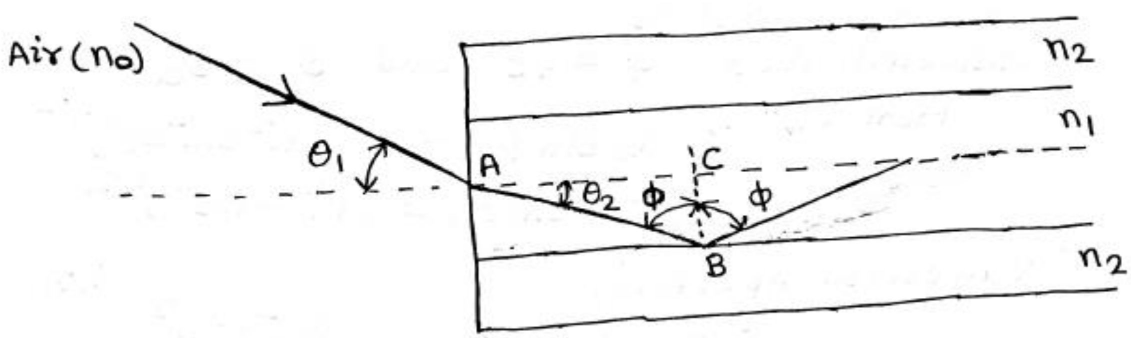


Fig-3 Transmission of a light ray in a perfect optical fiber.

Q4. Find out the relationship between acceptance angle and refractive indices of core, cladding and medium for a light ray incident on the fiber core. **[AKTU: 2021-22]**

ANS:



The sign of acceptance angle of the optical fiber is known as the numerical aperture of optical fiber. It is a measure of light gathering ability of the fiber.

It is given by,

$$NA = n_0 \sin \theta_a = (n_1^2 - n_2^2)^{\frac{1}{2}}$$

Fig shows a light ray incident on the fiber core at an angle θ_1 to the fiber axis, which is less than acceptance angle for the fiber θ_a. The ray enters the fiber from a medium (air) of refractive index n_0 and the fiber core has a refractive index n_1 which is slightley greater than the cladding refractive index n_2.

using Snell's Law,

$$n_0 \sin \theta_1 = n_1 \sin \theta_2$$

$$\phi = 90 - \theta_2$$

where ϕ is greater than the critical angle at the core-cladding interface. hence

$$n_0 \sin \theta_1 = n_1 \sin (90 - \phi)$$

$$= n_1 \cos \phi$$

$$n_0 \sin \theta_1 = n_1 (1 - \sin^2 \phi)^{\frac{1}{2}} \quad \text{— (1)}$$

when limiting case of total internal reflection is considered, then $\phi = \phi_c$ and $\theta_1 = \theta_a$

From eq^n 1,

$$n_0 \sin \theta_a = (n_1^2 - n_1^2 \sin^2 \phi_c)^{1/2}$$

$$n_0 \sin \theta_a = (n_1^2 - n_2^2)^{1/2}$$

Numerical Aperture,

$$NA = n_0 \sin \theta_a = (n_1^2 - n_2^2)^{1/2}$$

$$NA = n_1 (2\Delta)^{1/2}$$

where Δ = Relative refractive index difference

$$\Delta = \frac{n_1^2 - n_2^2}{2n_1^2} \simeq \frac{n_1 - n_2}{n_1} \quad \text{for } \Delta << 1$$

Q5.A silica optical fiber with a core diameter large enough to be considered by ray theory analysis has a core refractive index of 1.50 and a cladding refractive index of 1.47. Determine the critical angle at the core–cladding interface. [AKTU: 2022-23]

ANS:

Numerical aperture $NA = (n_1^2 - n_2^2)^{1/2}$

$= [(1.5)^2 - (1.47)^2]^{1/2}$

$= [2.25 - 2.16]^{1/2}$

$NA = 0.30$

For meridional rays,

$NA = n_0 \sin\theta_a$

n_0 = refractive index of air $= 1$

$NA = \sin\theta_a$

$\theta_a = \sin^{-1}(NA)$

$= \sin^{-1}(0.30)$

$= 17.4^\circ$

Acceptance angle $\theta_a = 17.4^\circ$

Q6. A typical relative refractive index difference for an optical fibre designed for long distance transmission is 1%. Estimate the *NA* and the solid acceptance angle in air for the fibre when the core index is 1.46. Further, compute the critical angle at the core– cladding interface within the fibre. It may be assumed that the concepts of geometric optics hold for the Fiber. [AKTU:2023-24]

n_1 = refractive index of core $= 1.46$

Relative refractive index difference $= 1\% = 0.01$

$\Delta = 0.01$

Numerical aperture $NA = n_1 (2\Delta)^{1/2}$

$= 1.46 [2 \times 0.01]^{1/2}$

$= 0.21$

For small angles the solid acceptance angle in air ς is given by

$$\varsigma = \pi \theta_a^2$$

Solid acceptance angle $\varsigma = \pi \theta_a^2 = \pi \sin^2 \theta_a$

$$= \pi (NA)^2 = \pi \times (0.21)^2$$

$$= 0.13 \text{ rad}$$

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

or $\frac{n_2}{n_1} = 1 - \Delta = 1 - 0.01 = 0.99$

critical angle $\phi_c = \sin^{-1} \frac{n_2}{n_1}$

$$= \sin^{-1}(0.99) = 81.9\%$$

Q7. Differentiate between step index and graded index fiber. How do the rays propagate in graded index fiber? **[AKTU: 2020-21]**

Difference between Step index and graded index fiber –

Step index fiber	Graded index fiber
1. The refractive index of the core is uniform throughout and undergoes an abrupt change at the core cladding boundary.	1. The refractive index of core is made to vary gradually such that it is maximum at the center of core.
2. The diameter of the core is about 50 μm to 1000 μm case of multi-mode fiber and 2 μm to 10 μm in case of single mode fiber.	2. The diameter of core is about 50 μm in case of multimode fiber

3. Attenuation is more in case of multimode step index but it is very less in case of single mode.	3. Attenuation is less
4. The path of light propagation is zig-zag in manner.	4. The path of light is helical in manner.
5. This fiber has lower bandwidth	5. This fiber has higher bandwidth.
6. The light ray propagation is in the form of meridional ray and it pass through the fiber axis	6. The light propagation is in the form of skew ray and it will not cross fiber axis

Q8.What is graded index fibers in optical fiber communication? A graded index fiber has a core with a parabolic refractive index profile which has a diameter of 50 µm. The fiber has a numerical aperture of 0.2. Estimate the total number of guided modes propagating in the fiber when it is operating at a wavelength of 1µm. [AKTU:2022-23]

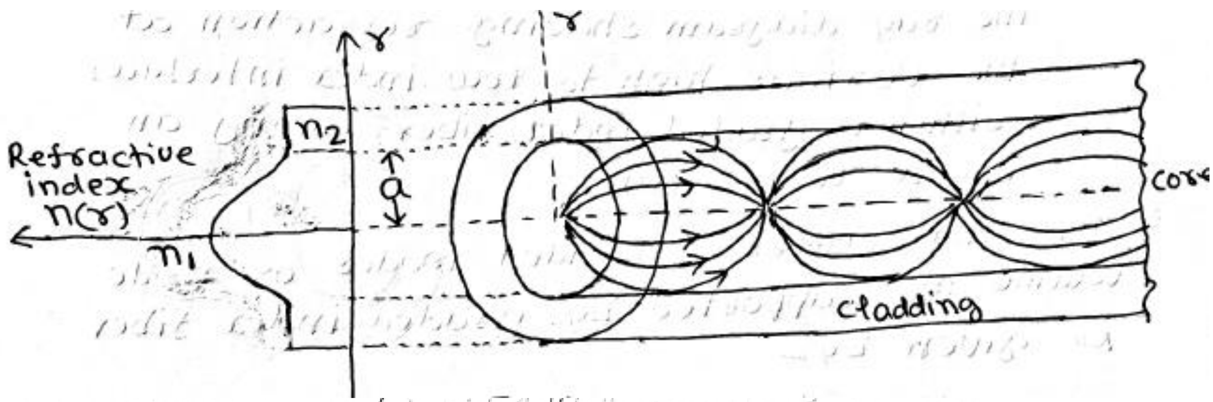
ANS:

Graded Index Fiber - Graded index fiber do not have a constant refractive index in the core. It has a decreasing core index $n(r)$ with radial distance from a maximum value of n_1 at the axis to a constant value n_2 beyond the core radius a in the cladding. The index variation may be represented as-

$$n(r) = \begin{cases} n_1 (1 - 2\Delta (r/a)^{\alpha})^{\frac{1}{2}} & r < a \text{ (core)} \\ n_1 (1 - 2\Delta)^{1/2} & r \geq a \text{ (cladding)} \end{cases}$$

where Δ = Relative refractive index difference

α = Profile parameter



The refractive index profile and ray transmission in a multimode graded index fiber

Diameter $a = 50\,\mu m$

$NA = 0.2$

$\lambda = 1\,\mu m$

Normalized frequency or V number or V value,

$$V = \frac{2\pi}{\lambda} a\,(NA)$$

$$= \frac{2\pi}{1\times10^{-6}} \times 50\times10^{-6} \times 0.2$$

$$= 31.4$$

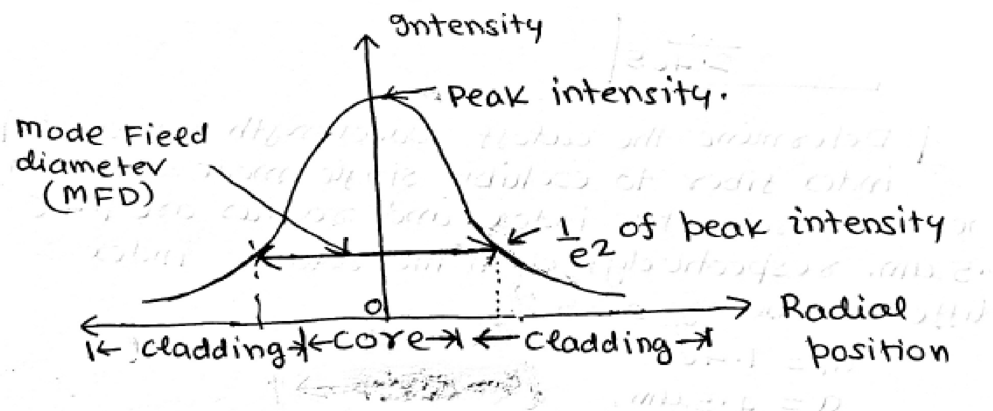
The mode value or total number of guided wave

$$m_g \simeq \frac{V^2}{4} = \frac{(31.4)^2}{4} = 247$$

Q9. Discuss Mode field diameter. **[AKTU:2023-24]**

Mode-Field Diameter (MFD)

* The mode field diameter (MFD) of a single mode fiber is the width of its intensity profile, which is a measure of the size of optical field.
* The MFD is the radial position where the intensity drops to $\frac{1}{e^2}$ of the peak intensity. It is a measure of the diameter of optical power density distribution, which is the diameter in which 95% of the power resides.



* MFD is determined by Numerical aperture (NA) and cutoff wavelength (λ_c) of the fiber and is related to the diameter of the fiber core.
In general, MFD is greater than physical diameter of the fiber core, which means that some optical power is always guided by the fiber cladding.

Q10.Explain Phase and Group Velocity with proper derivation. **[AKTU:2023-24]**

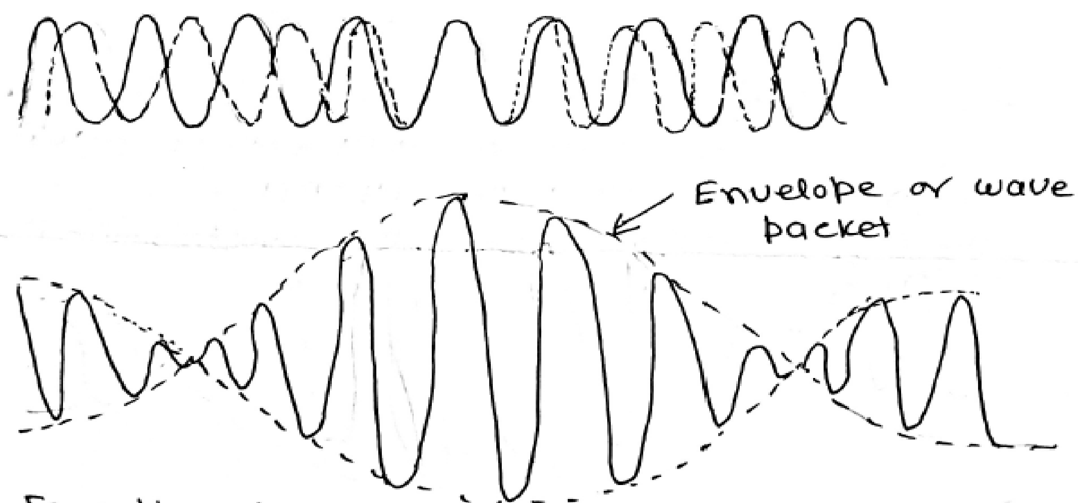
Phase Velocity - The rate at which the phase of a wave propagates along a waveguid is known as its phase velocity.

* Phase velocity is defined as the rate at which the wave changes its phase in terms of the guide wavelength. The phase velocity v_p is given by

$$v_p = \frac{\omega}{\beta}$$

where ω = angular frequency of the wave
β = Phase propagation constant
$= \frac{2\pi}{\lambda}$

If propagation in an infinite medium of refractive index n_1 is considered, then β may be written as $\beta = n_1 \frac{2\pi}{\lambda} = n_1 \frac{\omega}{c}$



Formation of wave packet from the combination of two waves with nearly equal frequencies

Group velocity – The velocity with which the envelope or wave packet travels is called group velocity. When a group of waves with closely similar frequencies propagates so that their resultant forms a packet of waves. The formation of such a wave packet resulting from the combination of two waves of slightly different frequency propagating together as shown in figure. The wave packet does not travel at the phase velocity of individual packets but it moves at a group velocity v_g given by

$$v_g = \frac{\delta \omega}{\delta \beta}$$

Therefore group velocity is the ratio of the apparent change in frequency ω to the change in the phase propagation constant β.