20.4.14

Fiber Optic Communication: Fiber Optic Communication is a method of transmitting information from one place to another by sending pulses of light through an optical fiber.

The light forms an electromagnetic carrier wave that is modulated to carry information. Optical fiber is used by many telecommunications companies to transmit telephone signals, internet commonication, and cable television signals.

Comparison with electrical transmission:

1. Depend on applications.
2. Optical fiber is generally chosen for systems requiring higher bandwidth or spanning longer distances than electrical cabling can accommodate.
3. The main benefits of fiber are its exceptionally low loss.
4. Its inherently high data-carrying capacity.
5. Thousands of electrical links would be required to replace a single high bandwidth fiber cable.
6. Fiber cables experience effectively no crosstalk, in contrast to some types of electrical transmission lines.
7. Fiber can be installed in areas with high electromagnetic interference (EMI), such as

alongside utility lines, power lines, and railroad tracks.

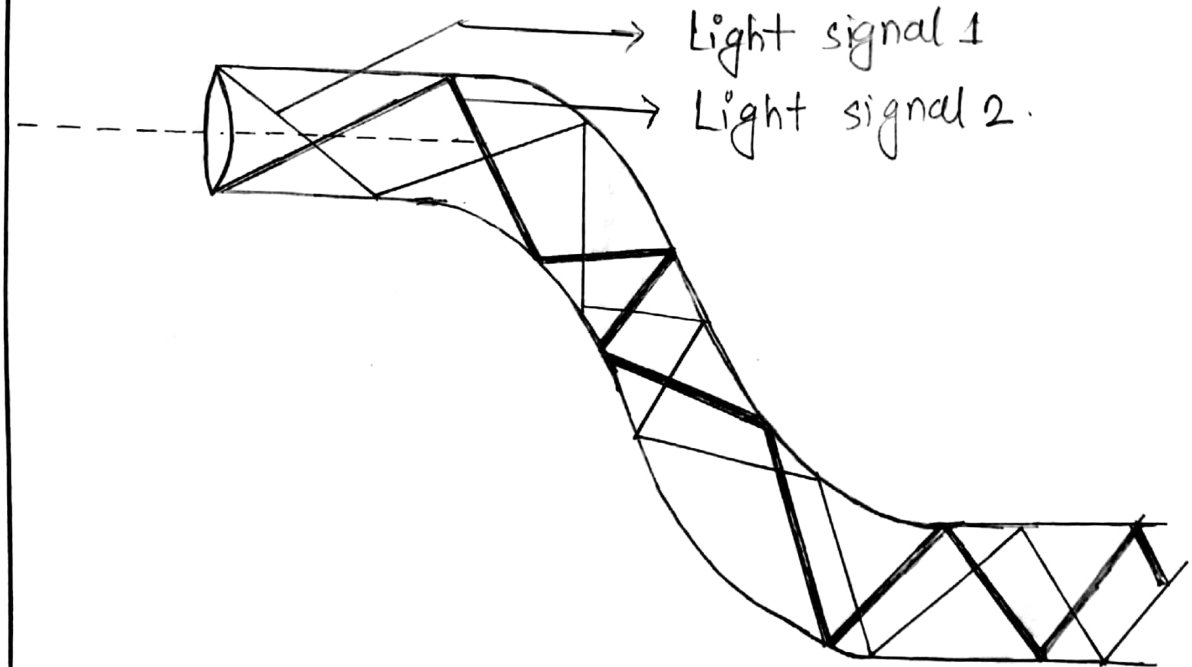
Working Principle

Total internal Reflection:

When a ray of light travels from a denser to a rarer medium such that the angle of incidence is greater than the critical angle, the ray reflects back into the same medium this phenomena is called total internal reflection.

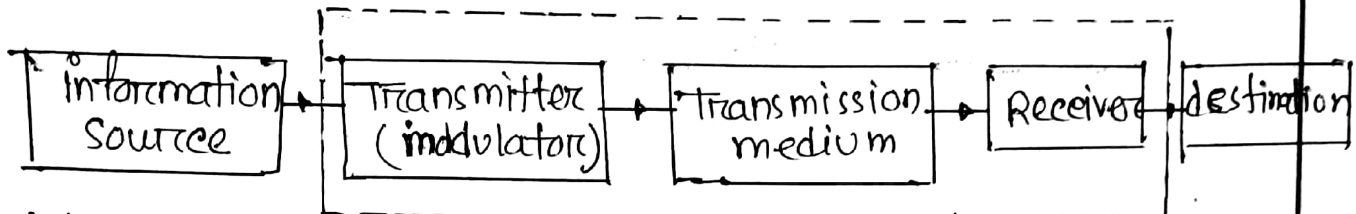
In the optical fiber the rays undergo repeated total number of reflections untill it emerges out of the other end of the fiber, even if the fiber is bent.

Total internal reflection in optical fiber:

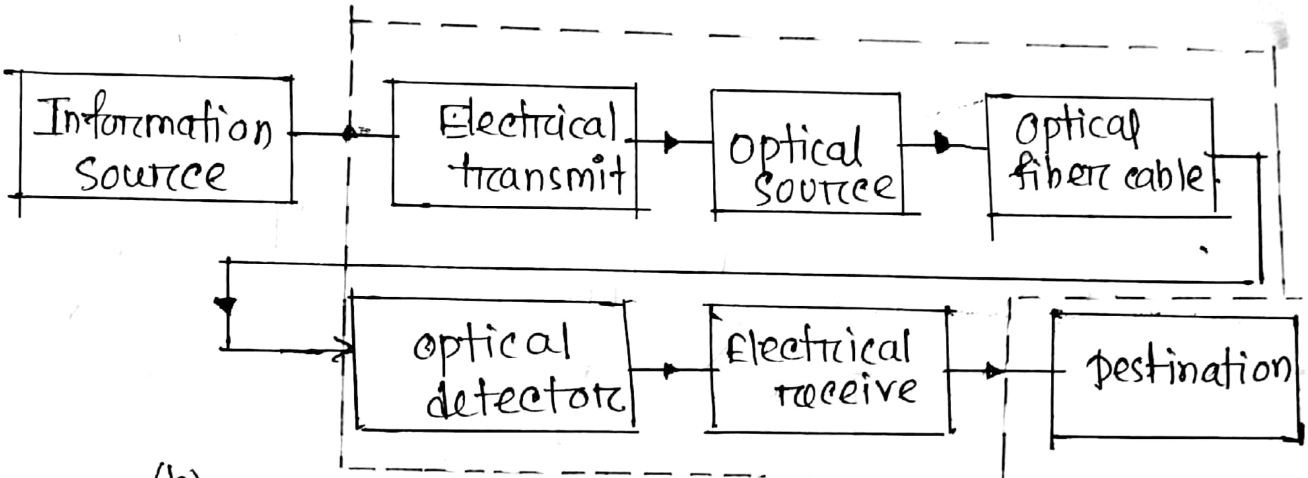


The general system:

An optical fiber communication system is similar in basic concept to any type of communication system. A block schematic of a general communication system is shown in fig 1(a).



(a) Communication system.



(b) Optical fiber communication system. 2017 (3)

Information Source: It provides an electrical signal to a transmitter comprising an electrical stage.

Electrical transmitter: It drives an optical source to give an modulation of the light wave carrier.

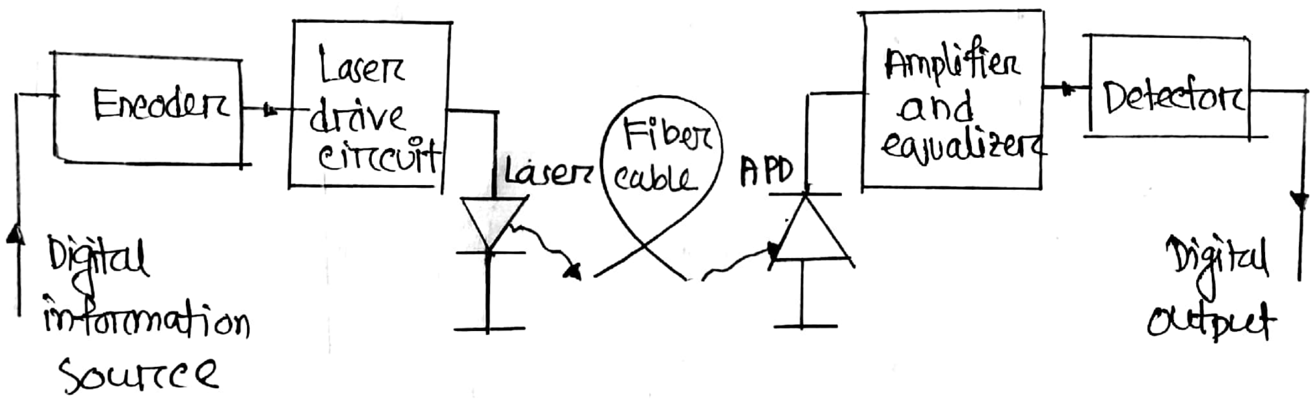
Optical source: It provides the electrical-optical conversion. It may be a semiconductor laser or an LED.

Optical cable: It serves as transmision medium.

optical detector: It is responsible for optical to electrical conversion of data and hence responsible for demodulation of the optical carrier. It may be a photodiodes, phototransistor and photoconductors.

Electrical receiver: It is used for electrical interfacing at the receiver end of the optical link and to perform the signal processing eletrically.

Destination: It is the final point at which we receive the information in the form of electrical signal.



fig(1): A digital optical fiber link using a semiconductor laser source and avalanche photodiode (APD) detector.

(4) Advantages of optical fiber communication:

(a) Enormous potential bandwidth: The optical carrier frequency ~~is~~ in the range 10^{13} to 10^{16} Hz yields :>> metalic cable systems or even millimeter wave radio systems.

(b) Small size and weight: Small diameters < diameter of a human hair.
Therefore it is useful for such as aircraft, satellites and even ships.

(c) Electrical isolation: electrical insulations and therefore, do not exhibit interface problems.
Transmission ideally suited for communication in electrically hazardous environments.

(d) Immunity to interference and crosstalk: optical fibers form a dielectric waveguide and are therefore free from electromagnetic interference (EMI), radio-frequency interference (RFI).
Hence the system is unaffected by transmission through an electrically noisy environment and the fiber cable requires no shielding from EMI.
Moreover there is no optical interference between fibers and hence crosstalk is negligible.

(e) Signal security: The light from optical fibers does not radiate significantly and therefore they provide a high degree of signal security.

(f) Low transmission loss: It exhibits very low attenuation or transmission loss in comparison with the best copper conductors.

Fibers have been fabricated with losses as low as 0.15 dB Km^{-1} and this feature has become a major advantages of optical fiber communications.

(g) Ruggedness and flexibility: The fibers may be bent to quite small radii or twisted without damage.

(h) potential low cost: made from sand, potential for low-cost line communication.
Bulk purchase has become competitive with copper wires.

(i) System reliability and ease of maintenance: the low-loss property of optical fiber cables reduces the requirement for intermediate repeaters or line amplifiers to boost the transmitted signal strength.

Disadvantages: (i) Highly skilled staff would be required for maintenance.

(ii) only point to point working is possible on optical fiber.

(iii) Precise and costly instruments would be required.

(iv) costly if under utilized.

(v) Accepts Unipolar codes only.

(vi) Jointing of fiber and splicing is also time consuming.

Applications:

Optical fiber have wider range of application in almost all field, some are been specified below:

1. In telecommunication field.
2. In space applications.
3. Broadband applications.
4. computer applications industrial applications.
5. mining applications.
6. In medical applications.
7. In military applications etc.

2016 **Ray theory transmission:** 3

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 the medium.

Light travels slowly in dense medium than less dense medium. The angles of incidence ϕ_1 and refraction ϕ_2 are related to each other and to the refractive indices of the dielectrics by Snell's law of refraction, which states that:

$$\eta_1 \sin\phi_1 = \eta_2 \sin\phi_2 \quad \text{or,}$$

$$\frac{\sin\phi_1}{\sin\phi_2} = \frac{\eta_2}{\eta_1} \quad \text{———} \quad (1)$$

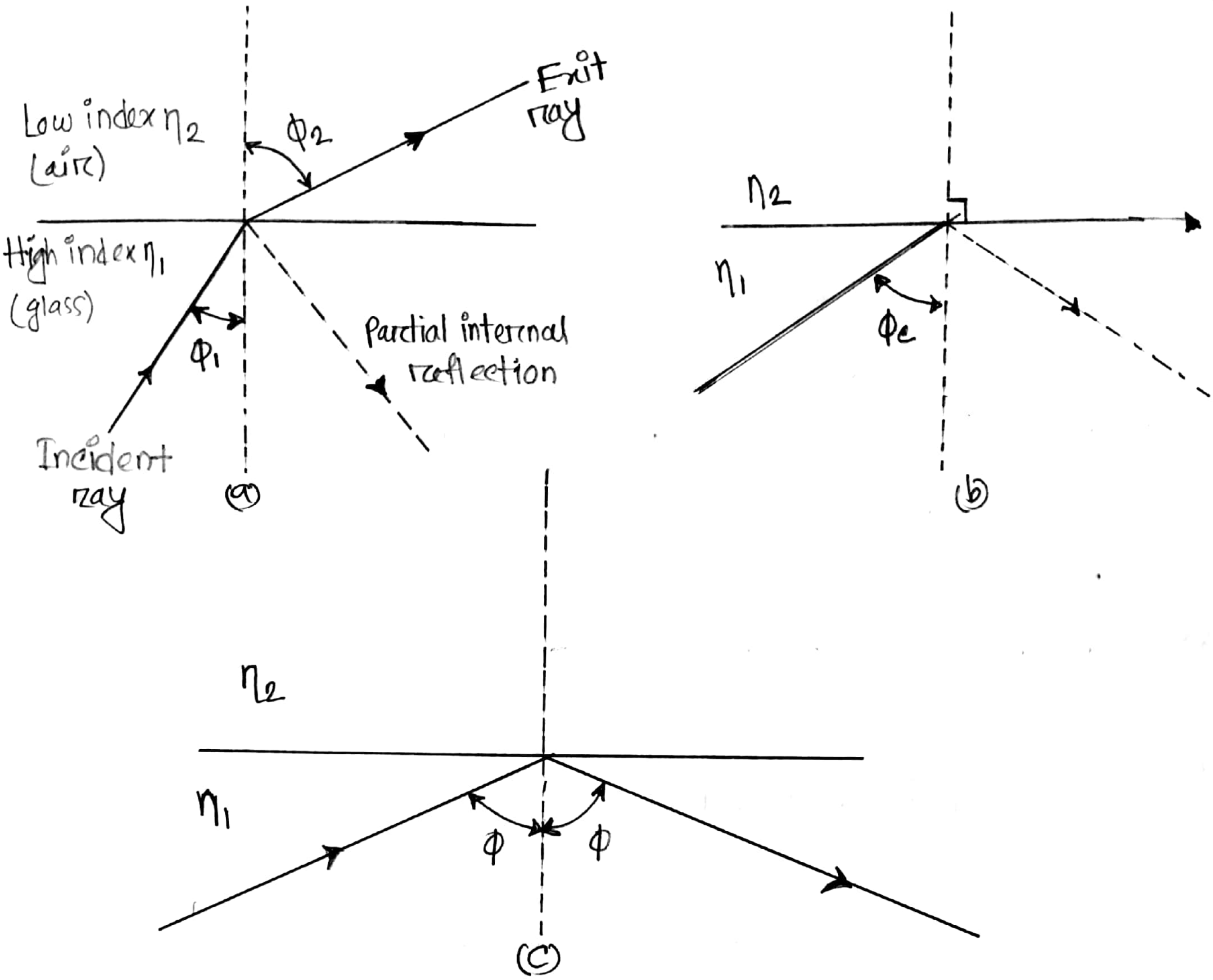


fig 2: Light rays incident on a high to low refractive index interface (e.g glass-air) : (a) refraction (b) the limiting case of refraction showing the critical ray at an angle ϕ_c; (c) Total internal reflection where $\phi > \phi_c$.

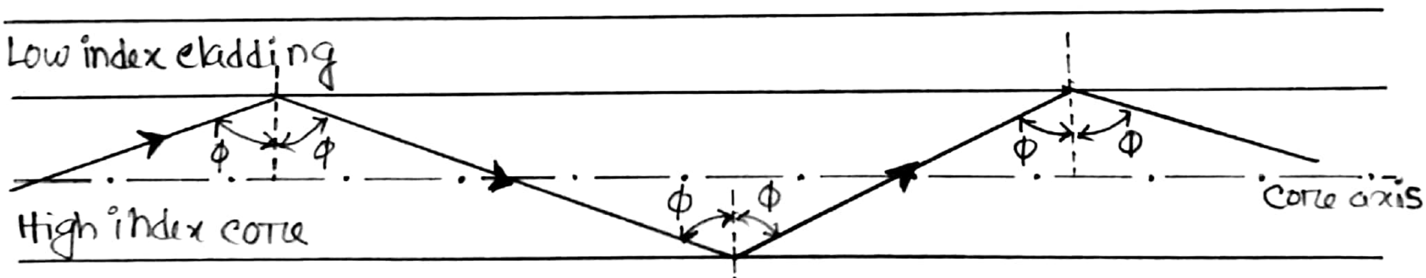
when the angle of refraction is 90° and the refracted ray emerges parallel to the interface between the dielectrics, the angle of incidence must be less than 90°.

The angle of incidence is now known as the critical angle ϕ_c, as shown in fig 2(b). from equation (i) the value of critical angle is given by,

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

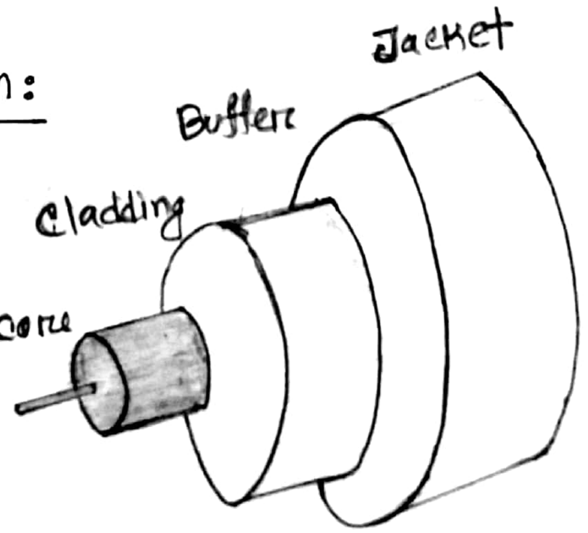
If angles of incidence > than the critical angle, the light is reflected back into the originating dielectric medium. i.e total internal reflection. This is the mechanism of propagating light via an optical fiber with low loss.

Fig (2.3) illustrates the transmission of a light ray in an optical fiber via a series of total internal reflections. The ray has an angle of incidence ϕ at the interface which is greater than the critical angle and is reflected at the same angle to the normal.



fig(2.3): The transmission of a light ray in a perfect optical fiber.

Optical fiber Construction:



Core: Glass or plastic with a higher index of refraction than the cladding.
Carries the signal.

Cladding: Glass or plastic with a lower index of refraction than the core.

Buffer: protects the fiber from damage and moisture.

Jacket: Hold one or more · in a cable.

2015

Acceptance angle:

For transition (অবস্থার পরিবর্তন) of light by total internal reflection within the fiber core, light must be incident on the fiber core within an acceptance cone defined by the conical half angle θ_a.

Hence θ_a is the maximum angle to the axis at which light may enter the fiber in order to be propagated, and is often referred to as the acceptance angle for the fiber.

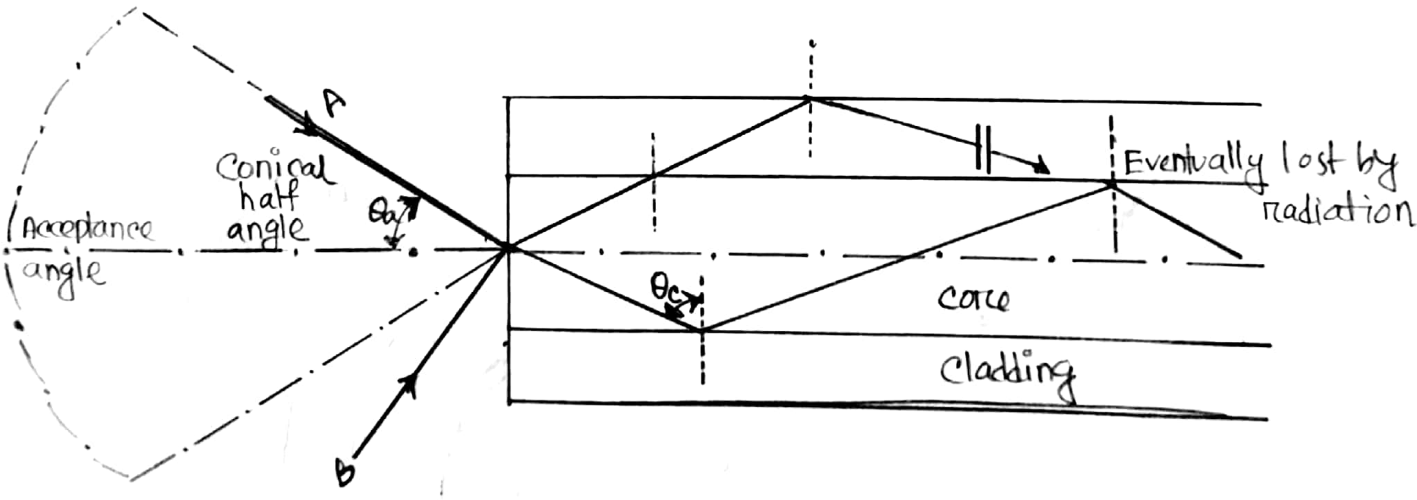


fig: The acceptance angle θ_a when launching light into an optical fiber.

2015 ## Numerical Aperture:

In optics, the numerical aperture (NA) — a dimensionless number. In fiber optics, it describes the range of angles within which light that is incident on the fiber will be transmitted along it.

In most areas of optics, and especially in microscopy, the numerical aperture of an optical system such as an objective lens is defined by,

$$NA = n\sin\theta.$$

where n is the index of refraction of the medium and θ is the maximal half-angle of the cone of light that can enter or exit the lens.

A multi-mode optical fiber will only propagate light that enters the fiber within a certain cone, known as the acceptance cone of the fiber.

The half-angle of this cone is called the acceptance angle, θ_{max}. The NA may also be given in terms of the relative refractive index difference Δ between the core and the cladding which is defined as,

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

$$= \frac{n_1 - n_2}{n_1} \quad \text{for } \Delta \ll 1$$

2015 Ex:2.1 A silical optical fiber with a core diameter large enough to be considered by ray theory analysis has a core refractive index 1.50 and a cladding refractive index 1.47. (a) The critical angle at the core-cladding interface; (b) the NA for the fiber (c) the acceptance angle in air for the fiber.

Soln: (a) The critical angle ϕ_c at the core-cladding interface is given by,

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

$$= \sin^{-1}\frac{1.47}{1.50}$$

$$= 78.5^\circ$$

Here,
$n_1 = 1.50$
$n_2 = 1.47$

(b) We know,

$$NA = n_0 \sin\theta_a$$

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

$$= (1.50^2 - 1.47^2)^{1/2}$$

$$= 0.30.$$

(c) the acceptance angle in air θ_a is given by,

$$\theta_a = \sin^{-1} NA = \sin^{-1} 0.30$$

$$= 17.4^\circ$$

Ex:2.2 A typical relative refractive index difference for an optical fiber designed for long distance transmission is 1%. Estimate the NA and the solid acceptance angle in air for the fiber when the core index is 1.46. Further calculate the critical angle at the core-cladding interface within the fiber.

Captured By Abid Nuri

Sol^n: we know,

$$NA = n_1 (2\Delta)^{1/2} \quad \text{where, } \Delta = 0.01,$$
$$= 1.46 (0.02)^{1/2} \quad n_1 = 1.46.$$
$$= 0.21$$

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

$$\zeta = \pi\theta_a^2 = \pi \sin^2\theta.$$

Hence, $\zeta = \pi (NA)^2$
$= \pi \times 0.04$
$= 0.13 rad.$

The relative ~~refractive~~ index differance is Δ gives:

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

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

~~from~~ ~~eq~~ The critical angle at the core-cladding interface is,

$$\phi_c = \sin^{-1}\frac{n_2}{n_1} = \sin^{-1} 0.99$$
$$= 81.9^\circ$$ (Ans).

problem:2.1 An optical fiber has a numerical aperture of 0.20 and a Cladding refractive index of 1.59. Determine:

(i) the acceptance angle for the fiber in water which has a refractive index of 1.33.

(ii) The critical angle at the core-cladding interface.

~~(iii)~~ comment on any assumptions made about the fiber.

Captured By Abid Nuri

Sol^n: (i) Given that,

$$NA = 0.20$$

refractive index, $n_0 = 1.33$

acceptance angle, $\theta_a = ?$

we know,

$$NA = n_0 \sin\theta_a$$

$$\Rightarrow \sin\theta_a = \frac{NA}{n_0}$$

$$\Rightarrow \theta_a = \sin^{-1}\frac{(0.20)}{(1.33)}$$

$$\Rightarrow \theta_a = 8.6^\circ$$

$\therefore$ The acceptance angle for the fiber in water is 8.6° (Ans)

(ii) Given that,

cladding refractive index, $n_2 = 1.59$

$\phi_c = ?$

we know, $NA = (n_1^2 - n_2^2)^{1/2}$

$$\Rightarrow (NA)^2 = n_1^2 - n_2^2$$

$$\Rightarrow (0.20)^2 + (1.59)^2 = n_1^2$$

$$\Rightarrow n_1^2 = 2.5681$$

$$\therefore n_1 = 1.60$$

Now, The critical angle ϕ_c at the core cladding interface:

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

$$= \sin^{-1}\frac{1.59}{1.60}$$

$$= 83.6^\circ$$

(Ans)

Electromagnetic mode theory:

Electromagnetic waves: Transmission of energy through a vacuum or using no medium is accomplished ~~usin~~ by electromagnetic waves, caused by the oscillation of electric and magnetic fields. The electronic an magnetic fields oscillate in directions perpendicular to each other and to the direction of motion of the wave. Both fields are mutually coupled vector waves and are vector functions of position and time.

In free space, electric and magnetic field satisfy the following partial differential equations, known as maxwell's equations:

$$\nabla \cdot E = 0 \quad \text{———} \ (i)$$

$$\nabla \times E = -\frac{\partial B}{\partial t} \quad \text{———} \ (ii)$$

$$\nabla \cdot B = 0 \quad \text{———} \ (iii)$$

$$\nabla \times B = \mu_0 \epsilon_0 \frac{\partial E}{\partial t} \quad \text{———} \ (iv)$$

Utilizing vector identities, which work for any vector, as follows:

The curl of equation (ii) is,

$$\nabla \times (\nabla \times A) = \nabla(\nabla \cdot A) - \nabla^2 A$$

$$\nabla \times (\nabla \times E) = \nabla \times \left(-\frac{\partial B}{\partial t}\right) \quad \text{———} \ (v)$$

Evaluating the left hand side:

$$\nabla \times (\nabla \times E) = \nabla(\nabla \cdot E) - \nabla^2 E = -\nabla^2 E \quad \text{———} \ (vi)$$

Simplifying the above by using equation (1):

Evaluating the right hand side:

$$\nabla \times \left(-\frac{\partial B}{\partial t}\right) = -\frac{\partial}{\partial t}(\nabla \times B) = -\mu_0 \epsilon_0 \frac{\partial^2 E}{\partial t^2} \quad \text{——} \quad \text{(vii)}$$

equation (vi) and (vii) are equal, so this results in a vector-valued differential equation for the electric field, namely,

$$\nabla^2 E = \mu_0 \epsilon_0 \frac{\partial^2 E}{\partial t^2}$$

Applying a similar pattern results in similar differential equation for the magnetic field:

$$\nabla^2 B = \mu_0 \epsilon_0 \frac{\partial^2 B}{\partial t^2}$$

These differential equations are equivalent to the wave equation:

$$\nabla^2 f = \frac{1}{c_0^2} \cdot \frac{\partial^2 f}{\partial t^2}$$

where c_0 is the speed of the wave in free space and f describes a displacement.

Modes in a planar guide: A transverse mode of electromagnetic radiation is a particular electromagnetic field pattern of radiation measured in a plane perpendicular (i.e transverse) to the propagation direction of the beam.

1. Transverse electric (TE)
2. Transverse magnetic (TM)
3. Transverse electromagnetic (TEM)

when light is described as an electromagnetic wave it consists of a periodically varying electric field E and magnetic field H which are oriented at right angles to each other.