(NA)

2. Show that, numerical aperture is effectively dependent only on the refractive indexes of the core and cladding material and is no a function of the fiber dimensions. 5

Light stays inside the fiber because it is totally reflected by the inside surface of the fiber. Total internal reflection at the fiber wall can occur only if two conditions are met. The first is that the core index of reflection (n_1) must be higher than the cladding index of reflection (n_2). The second one is the angle of incidence, ϕ must be greater than the critical angle ϕ_c. Which is defined as.

$$\sin \phi_c = \frac{n_2}{n_1} \quad \text{-----} \quad (1)$$

Refraction occurs when the angle of incidence is less then the critical angle. Snell's law says that the incident angle θ_0 is related to the refraction angle θ_1 by the relation -

$$n_0 \sin \theta_0 = n_1 \sin \theta_1 \quad \text{-----} \quad (11)$$

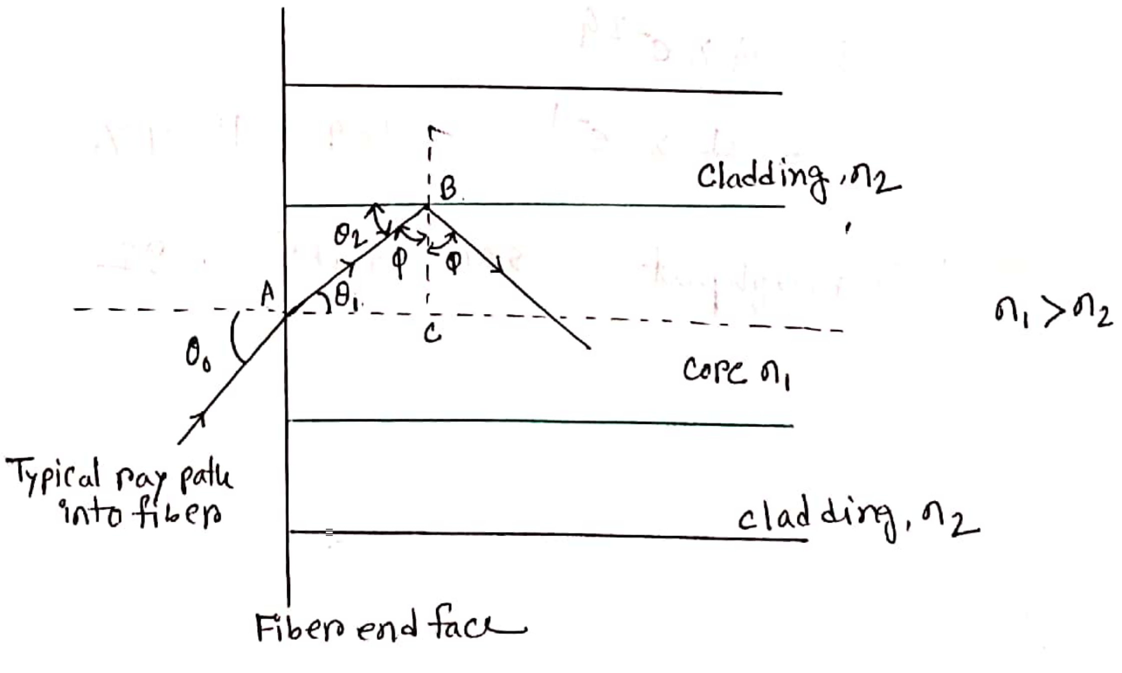


Fig. 1 shows a longitudinal cross section of the lunch end of a fiber with a ray entering it. The core of the fiber has a refractive index n_1 and is surrounded by a cladding of material with a lower refractive index n_2.

The entry incidence angle θ_1 can be related to the internal reflection angle ϕ by the right angle ABC and snell's law as follows, first from the traingle ABC.

$$\theta_1 = 90^\circ - \phi \quad ---- \text{(iii)}$$

From equation (ii),

$$n_0 \sin\theta_0 = n_1 \sin(90^\circ - \phi)$$

or, $$\sin\theta_0 = \frac{n_1}{n_0}\cos\phi \quad ---- \text{(iv)}$$

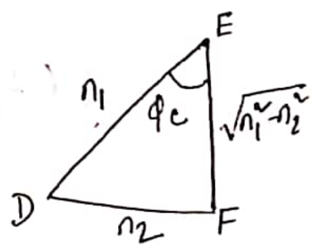
If the internal reflection angle ϕ is less than the critical angle ϕ_c, the light will be refracted into the cladding and lost.

Applying pythogons theorom and the cosine definition gives,

$$\cos\phi = \frac{\sqrt{n_1^2 - n_2^2}}{n_1} \quad ---- \text{(v)}$$

Substituting equation (v) into equation (iv) gives the maximum value of the external incidence angle for which light will ~~light will~~ propagate in the fiber as.

$$\theta_0\,(max) = \sin^{-1}\frac{\sqrt{n_1^2 - n_2^2}}{n_0} \quad ---- \text{(vi)}$$



x. The maximum angle is called acceptance angle or the acceptance cone half angle. Larger acceptance angle makes easier launching.

The numerical aperture (NA) of the fiber is used as a figure of merit and is defined as the sine of the maximum acceptance angle, or

$$NA = \sin\theta_0(max) = \frac{\sqrt{n_1^2 - n_2^2}}{n_0} \quad \text{------ (VII)}$$

If the light in the fiber is launched from air as is often the case, $n_0 = 1$ and the numerical aperture becomes,

$$NA \approx \sqrt{n_1^2 - n_2^2} \quad \text{------ (VIII)}$$

The normalized difference Δ between the indexes of the core and cladding is.

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

Substituting this in eqn (VII) and noting that $n_1 \approx n_2$ for all practical fibers, the numerical aperture becomes,

$$NA = \frac{n_1\sqrt{2\Delta}}{n_0}$$

If, $n_0 = 1$, $NA = n_1\sqrt{2\Delta}$

It should be noted that the numerical aperture is effectively dependent only on the refractive indexes of the core and cladding materials and is not a function of the fiber dimensions.

3. Given that,

Core Refractive index, $n_1 = 1.55$

Clad refractive index, $n_2 = 1.51$

(a) What numerical aperture does the fibre have ?

We know, the normalized difference between the indexes is

$$\Delta = \frac{n_1 - n_2}{n_1} = \frac{1.55 - 1.51}{1.55} = 0.0258$$

$\therefore$ The numerical aperture is,

$$NA \approx n_1 \sqrt{2\Delta} = 1.55\sqrt{2 \times 0.0258}$$

$$= 0.352$$

(b) What is the acceptance angle :

Acceptance angle, $\theta_0 \, (max) = \sin^{-1} NA$

$$= \sin^{-1} 0.352$$

$$= 20.6^{\circ}$$

Given that, core diameter, $d = 50 \, \mu m$

light wavelength, $\lambda = 0.8 \, \mu m$

The diameter/wavelength ratio $= \frac{d}{\lambda} = \frac{50}{0.8} = 62.5$

The V number is, $V = \pi \frac{d}{\lambda} NA$

$$= \pi \times 62.5 \times 0.352 = 69.1152$$

The number of modes :

$$N \, (modes) \approx \frac{V^2}{2} = \frac{69.1^2}{2} = 2387.405$$

This is truly a multimode fiber.

5

6.006

4. Define optical communication system. What are the advantages of optical fiber lines over wire lines. (2)

Optical communication system: optical communication is a type of communication in which light is used to carry the signal to the remote end, instead of electrical current. Optical communication relies on optical fibers to carry signals to their destinations.

Advantages:

1. Bandwidth is higher than wire lines
2. Less power loss and allows data transmission for long distance
3. The optical cable is resistance for electromagnetic interference
4. The size of the fiber cable is 4.5 times batter than copper wires.
5. These cables are lighter, thinner and occupy less area compare with metal wires.
6. Installation is very easy due to less weight.
7. The optical fiber cable is very hard to tap because they don't produce electromagnetic energy.
8. These cables are very secure while carrying or transmitting data
9. A fiber optic cable is very flexible, easily bends and opposes the most acidic elements that hit the copper wire.

5. Plot the core index profiles of different fibers and briefly discuss about them.

There are three types of step index fibers result depending on the material used to surround the core. There are -

(i) Unclad fiber :

→ core surrounded by air with an index of refraction n_0 of unity.

→ small diameter cores make mechanically weak fiber. Core diameter is 200 μm.

→ Large acceptance angle.

An index profile for a fiber is produced by plotting the index of refraction on the horizontal axis against the radial distance from the core axis on the vertical.

The index profile of an unclad core is shown in fig-(a)

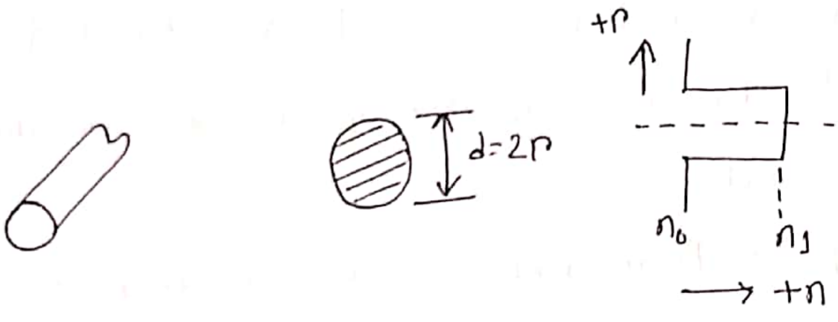


Fig-(a) : The index profile of an unclad core

(ii) Glass-clad core :

The core glass is surrounded by a concentric layer of cladding glass. ~~The clad core may be used bare~~ with a uniform index of refraction n_2 that is only slightly less than that of the core. The clad core may be used bare, or it may be enclosed in an opaque protective sheath. A glass clad core is shown in fig (b).

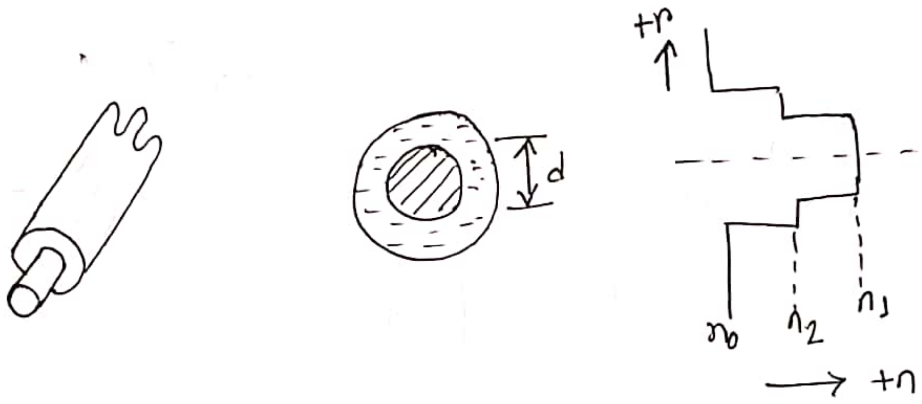
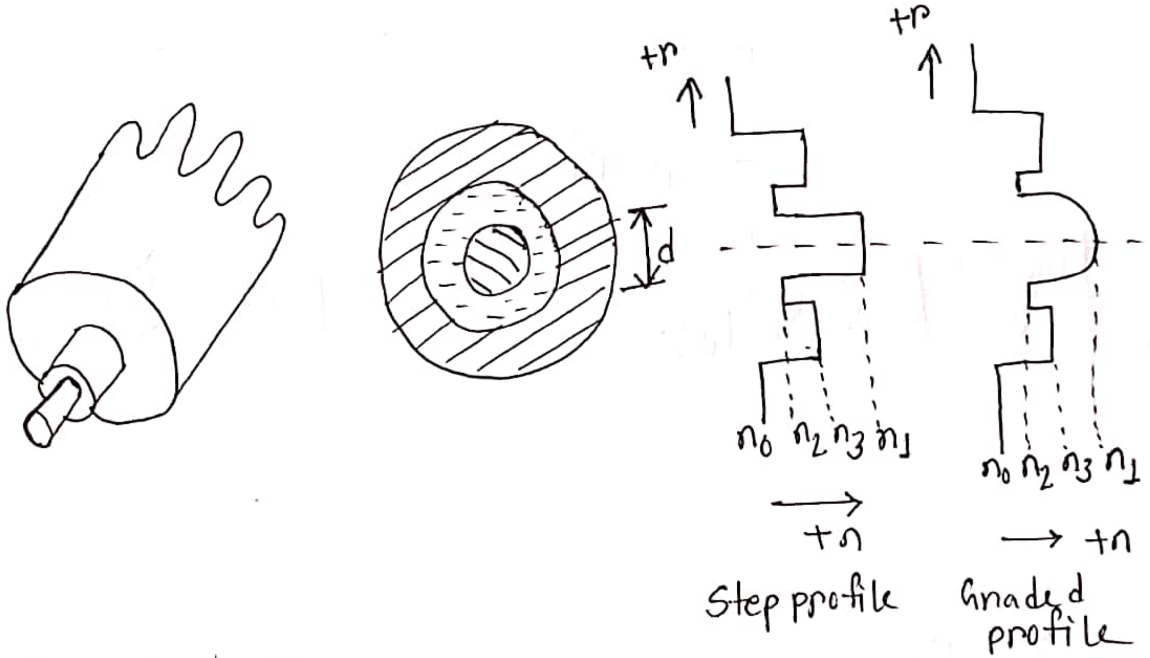


fig-(b) : core profile index for an uncla

The w profile fiber is a variation of the glass-clad fiber. Shown in figure (c).



fig(c)

(iii) Plastic-clad core :

The shape of this profile is same as the glass-clad fiber but the plastic clad ~~co-fiber~~ cable has higher losses than its glass-clad counterpart. It is less expensive to manufacture Use plant instrument.

Graded index fiber : The profile of a graded index fiber is shown in fig (c). The fiber is double clad to give an overall W-profile shape. Index of refraction is not uniform.

6. Explain several types of propagation modes of transverse electromagnetic waves that are confined in a guide.

When transverse electromagnetic waves are confined in a guide they can propagate in several types of mode -

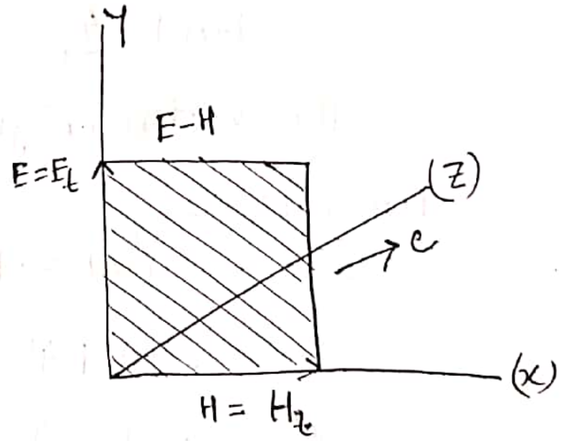
(i) TEM mode :

→ Occurs through free space/ parallel wire / co-axial cable

→ $E_z = 0$, $H_z = 0$

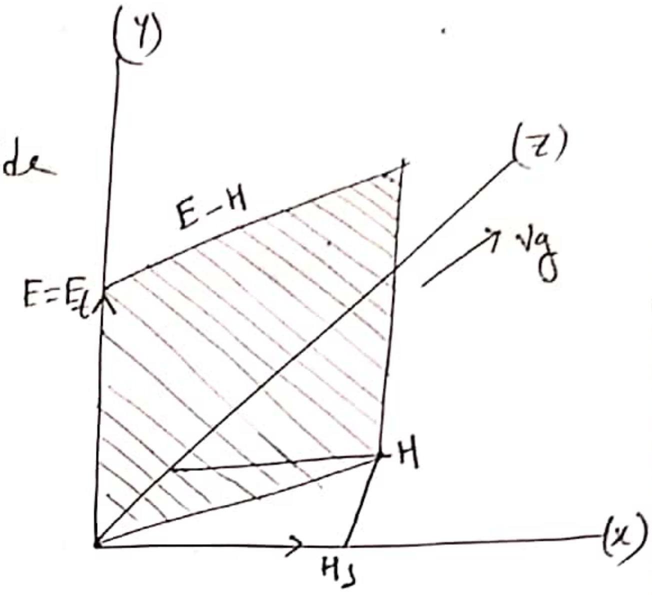
→ E_t, H_t are perpendicular to each other and to direction of propagation.

→ There are no electric or magnetic field component to the direction of propagation.



(a) TEM ($E_z = 0$, $E_H = 0$)

(ii) TE mode :



(b) TE ($E_z = 0$, H_z = finite)

→ Occurs through metallic waveguide

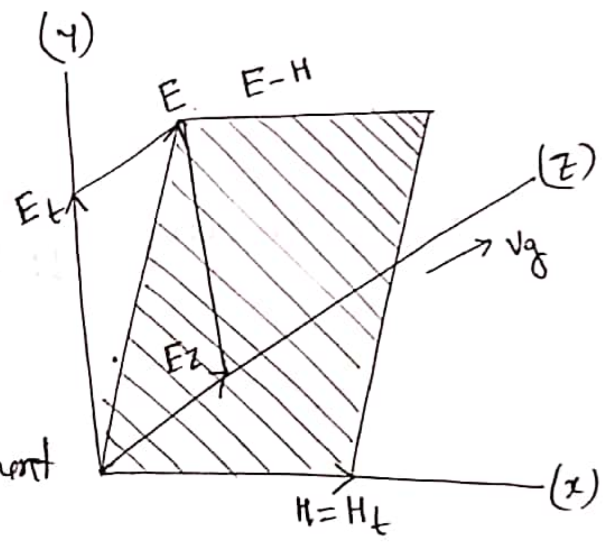
→ $E_z = 0$, H_z = finite.

→ Propagation in z direction takes place with group velocity v_g.

→ Electric field lies entirely in transverse plane.

→ magnetic field vector has component in the direction of z as well as transverse.

(iii) TM mode :



(c) TM (E_z finite, $H_z = 0$)

→ $H_z = 0$, E_z = finite.

→ Propagation in z direction takes place with group velocity

→ The magnetic vector $H = H_t$ lies entirely in the transverse plane

→ Electric field vector has component in the direction of z as well as transverse.

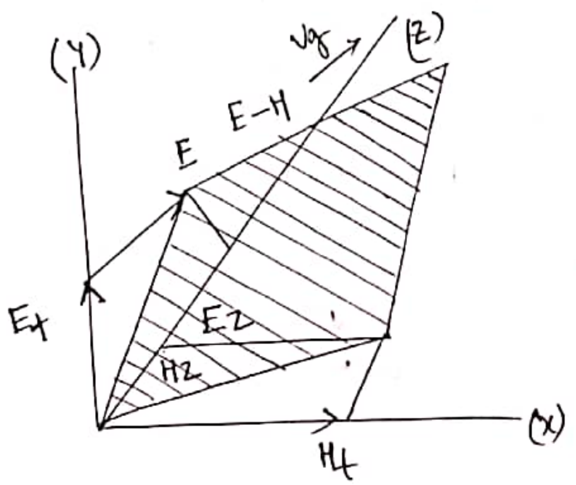
(iv) Hybrid mode:

→ H_z = finite, E_z = finite

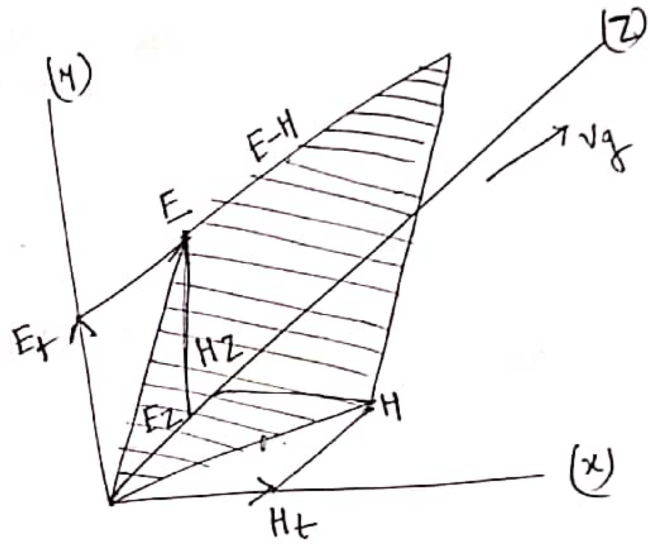
→ Both magnetic field and electric field vector have components in direction of z as well as transverse.

→ $E_t > H_t$ ---- EH mode

→ $H_t > E_t$ ---- HE mode



(d) HE (E_z H_z finite, $H_t > E_t$)



(e) E.H (E_z, H_z finite, $E_t > H_t$)

7. How does fiber-optic communication differ from other forms of communication system? (2)

The main difference is the communication speed and its accuracy.

An optical fiber cable provides a high transmission speed and enable the signal transmission to longer distance as compared to the other forms of communication system.

2019- 2(a)

1. Explain how energy is lost at a sharp bend in a fiber. (5)

Two types of bending can affect a fiber. These are -

1. Microbending
2. large radius bending.

Microbending : Microbending is a microscopic bending of the core of the fiber that may result from different thermal ~~con~~ ~~dit~~ contraction between the core and cladding or because of kinking during handling. These microbends acts as scattering facts within the fiber and cause energy from fully propagate modes to be cross coupled into leaky modes and subsequently lost.

Since microbending are randomly distributed over the length of the fiber, losses are uniformly distributed and total ~~fiber of~~ figure of fiber can be obtained. Manufacturing and handling will minimize microbanding losses.

large radius bending : Large radius bending is caused by several things. Fibers are generally combined in multifiber cables. When they are spiraled about a central cable core. The spiral creates a constant radius bend that extend the length of cable. Aerial cable are hung from poles and each pole hanger introduces a short, sharp bend in fiber. The large radius bending also introduce loss by mode coupling into leaky modes.

Illustrate your concept about ray propagation in bent fiber.

Modes that are fully guided in straight section of fiber are either only partially guided or not guided all over the curved portion of fiber.

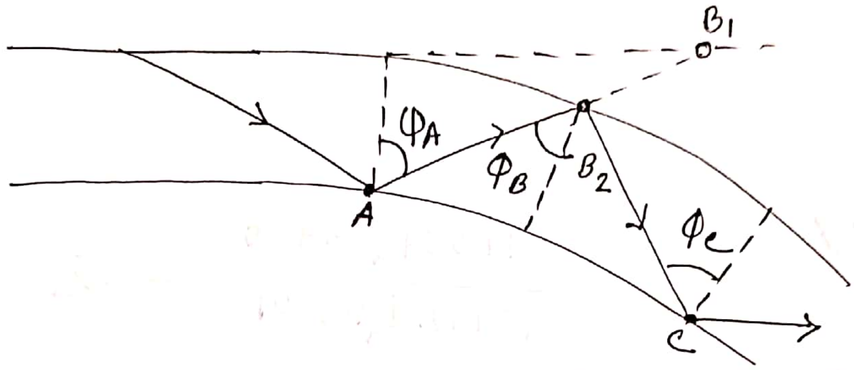


Fig-1 : Ray propagation in a bent fiber.

In fig-1 show the ray propagation of bend in a fiber core. It is fully guided before it reaches point A in straight section. It is reflected from point A at a ~~axis~~ axial angle ϕ_A. If the core were not bent, It arrive the next reflection at point B_1. The ray encounter the fiber wall early at the outer edge of the bend at smaller angle of incidence ϕ_B.

If ϕ_B is less than critical, a portion of energy from the mode will be lost into the cladding. Sharper bends causes more lower order modes to be lost. and core must be taken during installation bends don't have radii less than to be sure that the some minimum.

fiber

2019 - 2 (b)

2. Deduce the equation for the difference in delay times between the maximum and minimum propagation delay times for the step- index fiber.

CI

Let the total fiber length be z. let z be 1 km.

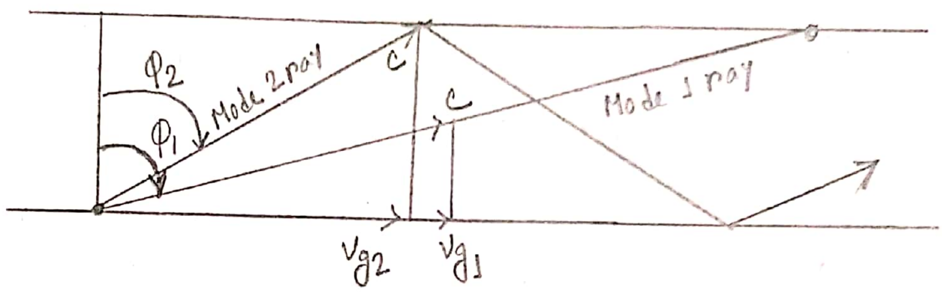


Figure 1: Group velocities for two modes.

Figure 1 shows two meridional rays of different modes following their zigzag paths down at incident angles ϕ.

The total zigzag path length for each ray is,

$$Z_t = \frac{Z}{\sin\phi} \quad ----(I)$$

In the lowest order mode, the maximum angle of incidence is $90°$ and in the highest order mode it is almost critical.

From figure 2(a)

$$\phi_c(max) = \sin^{-1}\frac{n_2}{n_1} \quad ----(II)$$

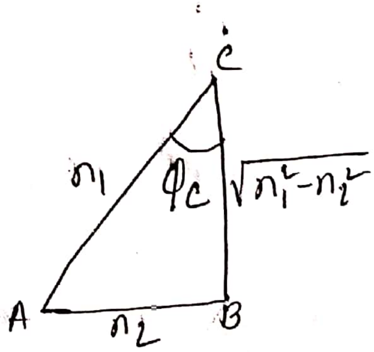


fig - 2(a)

Now, the shortest path is

$$Z_t(min) = \frac{Z}{\sin\phi(max)} = \frac{Z}{\sin 90°}$$

$$= Z \quad ---(III)$$

and the longest path is,

$$Z_t\,(max) = \frac{Z}{\sin\phi\,(min)} = \frac{Z}{\frac{n_2}{n_1}} = Z.\frac{n_1}{n_2} \quad \text{---} \quad (IV)$$

The maximum time dispersion,

$$\Delta Z = Z_t\,(max) - Z_t\,(min) = Z\left(\frac{n_1}{n_2} - 1\right) \quad \text{---} \quad (V)$$

Substituting from $\Delta = \frac{n_1 - n_2}{n_1}$. eqn (5) becomes.

$$\Delta Z = Z.\frac{\Delta}{1 - \Delta} \quad \text{----} \quad (VI)$$

Equation (vi) gives the dispersion of the normalized index of refraction difference.

We know,
the phase velocity in the dielectric is

$$v_p = \frac{c}{\sqrt{\mu\epsilon}} = \frac{1}{\sqrt{\mu_0\epsilon_0}\,\sqrt{\mu_r\epsilon_r}} \quad \text{----} \quad (VII)$$

The speed of light is found when $\epsilon_r = 1$ and $\mu_r = 1$ to be

$$c = \frac{1}{\sqrt{\mu_0\epsilon_0}} \quad \text{----} \quad (VIII)$$

substituting c and

From eqⁿ (VII), ~~where~~ $\mu_r = 1$, eqn (VII) gives the phase velocity In the dielectric as

$$v_p = \frac{c}{\sqrt{\epsilon_r}}$$

~~It can be shown that the dielectric constant is related to the refractive index, as~~,

Again ~~$\epsilon_r =$~~

$$\epsilon = n^2 \quad \& \quad v_p\,(\text{glass}) = \frac{c}{n_1}$$

where, n_1 = Refractive index.

Finally the dispersion in a step index fiber is the maximum, difference of delay between the lowest and heighest order modes, found by deviding the path length difference by the phase velocity in the glass core as.

$$\Delta t = \frac{\Delta Z}{v_p(\text{glass})} = \frac{n_1 Z}{c} \cdot \frac{\Delta}{1-\Delta}$$

which is expressed in units of ns/km.

2015 3(a) Intermodal dispersion: Intermodal dispersion is the phenomenon that the group velocity of light propagating in a multimode fiber depends not noly on the optical frequency but also on the propagation mode involved.

2017 2(a)

3. Explain your idea on different mechanisms contribute to absorption losses in glass fibers. (3)

There are three different mechanisms contribute to absorption losses in glass fiber. These are –

1. Ultraviolet absorption
2. Infrared absorption
3. ion resonance absorption.

Ultraviolet absorption:

Ultraviolet absorption takes place because for pure fused silica, valence electrons can be ionized into conduction by light with a center wavelength of about 0.14 μm, corresponding to an energy level of about 8.9 ev.

Infrared absorption: This absorption takes place because photons of light energy are absorbed by the atoms within the glass molecules and converted to the random mechanical vibrations typical of heating. This IR absorption also exhibits a main spectral peak that for silicon occurs at 8 μm, with minor peakes at 3.2, 3.8 and 4.4 μm. Losses at 1.5 μm are typically less than 0.5 dB/Km.

(iii) ion resonance absorption:

The presence of other impurities in the glass may also create unacceptable losses within the usable portion of the spectrum. Iron, copper and chromium must especially be avoided.

2017 2(b)

4. Drive the equation for the difference in delay times Δt between the maximum and minimum propagation delay times for the multimode graded-index fiber.

2018 3(a)

What is bandwidth distance product (BDP) for fiber ?

BDP is usually defined as the product of the length of a fiber optic ~~lind~~ link and its maximum signal bandwidth.

Deduce an equation of it relating bit rate bandwidth and the length of the total fiber.

When a bit stream is transmitted on a fiber at bit rate B, the maximum sinusoidal frequency) component transmitted is determined as.

$$f_{max} = \frac{B}{2}$$

If the transmitted pulse width is reduced to a very short pulse width, then the received pulse width approaches a minimum width $t_p = \Delta_t$ (tot) or the total dispersion, Which sets a limit on the maximum bit rate B (max) of

$$B\,(max) = \frac{1}{2t_p\,(min)} \approx \frac{1}{2\,\Delta_t\,(tot)}$$

The effective bandwidth,

$$BW = f_{max}\;(max) = \frac{B_{max}}{2} = \frac{1}{4\,\Delta_t\,(tot)}$$

This bandwidth is stated in terms of a sinusoidal signal.

Multiplying the bit rate bandwidth of the total fiber by its length gives a quality factor for the fiber called bandwidth distance product (BDP). This is equivalent to finding the bit rate bandwidth for a 1-km unit length of fiber.

CamScanner

$$\therefore \ BDP = B_{max} \times Z = \frac{1}{2 \ \Delta_t \ (\text{tot per km})}$$

The dispersion-limited length.

$$Z_{max} \ (disp) = \frac{BDP}{B}$$

Why multimode graded index fibers have a much lower inter-modal dispersion than step index fiber?

~~11 (a) Draw the single line diagram of a 132/33 KV substation showing metering and protection schemes.~~

2015 2 (b)

9. Define alpha profile function. Plot index profile for graded index fiber with grading profile index number and also comment about it.

Graded index fiber maybe made with a verity of different index grading profiles.

The alpha profile functions is in which the index of refraction within the core is made to vary radially by the function,

$$n(r) = n_1 \sqrt{1 - 2\Delta\left(\frac{2r}{d}\right)^{\alpha}}$$

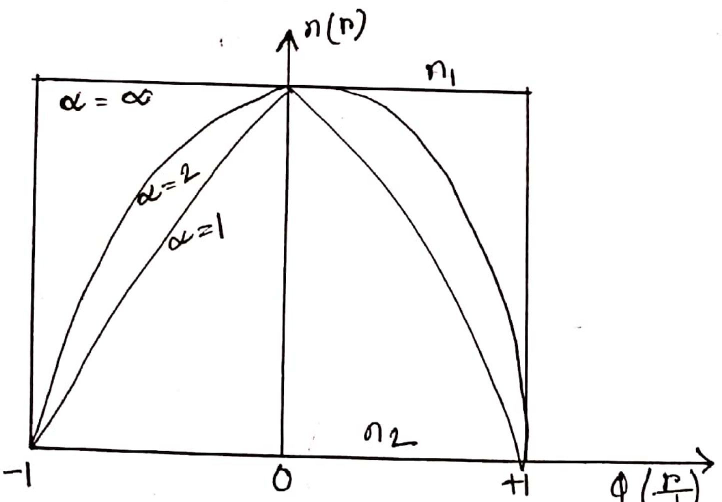
Where, $n(r)$ = is the core index at radius r from core axis.

n_1 = is the index at the core axis

Δ = is the normalized diffenence between the core and cladding indexes.

d = is the core diameter.

α = is the grading profile index number.



for graded index fiber

Fig: Normalized variation of index of refraction with radius

Fig.1 shows the index profile platted for graded index fiber with $\alpha = 1, 2, \infty$ while any value of α between 1 and ∞ maybe used. $\alpha = 2$ which produces a parabolic profile, is most often used for graded index fiber. The profile is easy to manufacture. $\alpha = 2$ simplifies several ~~exper~~ expression involves in analysing such a fiber and $\alpha = \infty$ reponds for ~~det~~ slep index fiber.

8. Math

2016 - 2(c)

$\Delta_t\,(imd) = 0, \quad \Delta_t\,(md) = 2.81\ ns, \quad \Delta_t\,(wgd) = 0.495\ ns$

The total dispersion is,

$$\Delta_t\,(tot) = \sqrt{\Delta_t^2\,(imd) + \Delta_t^2\,(md) + \Delta_t^2\,(wg)}$$

$$= \sqrt{0 + 2.81^2 + 0.495^2} = 2.85\ ns$$

The received pulse width is.

$$t_r = \sqrt{t_w^2 + \Delta_t(tot)^2} = \sqrt{2.5^2 + 2.85^2} = 3.79\ ns$$

So the maximum allowed bit rate becomes,

$$B \le \frac{1}{2t_r} = \frac{1}{2 \times 0.00379\ \mu s} = 131.9\ Mbits/s.$$

Math

2015- 4(c)

(a) At 0.9 μm wavelength, repeater distance Z is

$$Z = \frac{A_{max}}{A} = \frac{25 \text{ dB}}{2 \text{ dB/Km}} = 12.5 \text{ Km}$$

(b) At 1.5 μm wavelength,

$$Z = \frac{A_{max}}{A} = \frac{25 \text{ dB}}{0.3 \text{ dB/Km}} = 83 \text{ Km}.$$

2018 - 3(c)

(i) At 0.9 μm wavelength, repeater distance Z is

$$Z = \frac{A_{max}}{A} = \frac{35 \text{ dB}}{3.5 \text{ dB/Km}} = 10 \text{ Km}$$

(ii) At 1.44 μm wavelength,

$$Z = \frac{A_{max}}{A} = \frac{35 \text{ dB}}{0.3 \text{ dB/Km}} = 116.67 \text{ km}$$

2017 - 2(c)

(i) $$BDP = \frac{1}{2\Delta_t (\text{tot per km})} = \frac{1}{2 \times \cancel{0}4 \times 10^{-6} \mu s/Km} =$$

$$= \frac{1}{2 \times 0.004 \mu s/Km} = 125 \text{ Mbps-Km}$$

(ii) $$Z_{max}(\text{disp}) = \frac{125 \text{ Mbps-Km}}{10 \text{ Mbps}} = 12.5 \text{ Km}$$

$$= \frac{BDP}{B}$$

$B \rightarrow$ Bit rate

2016-3(c), 2015-4(b)

Draw and explain the total loss spectrum for a typical multimode fiber.

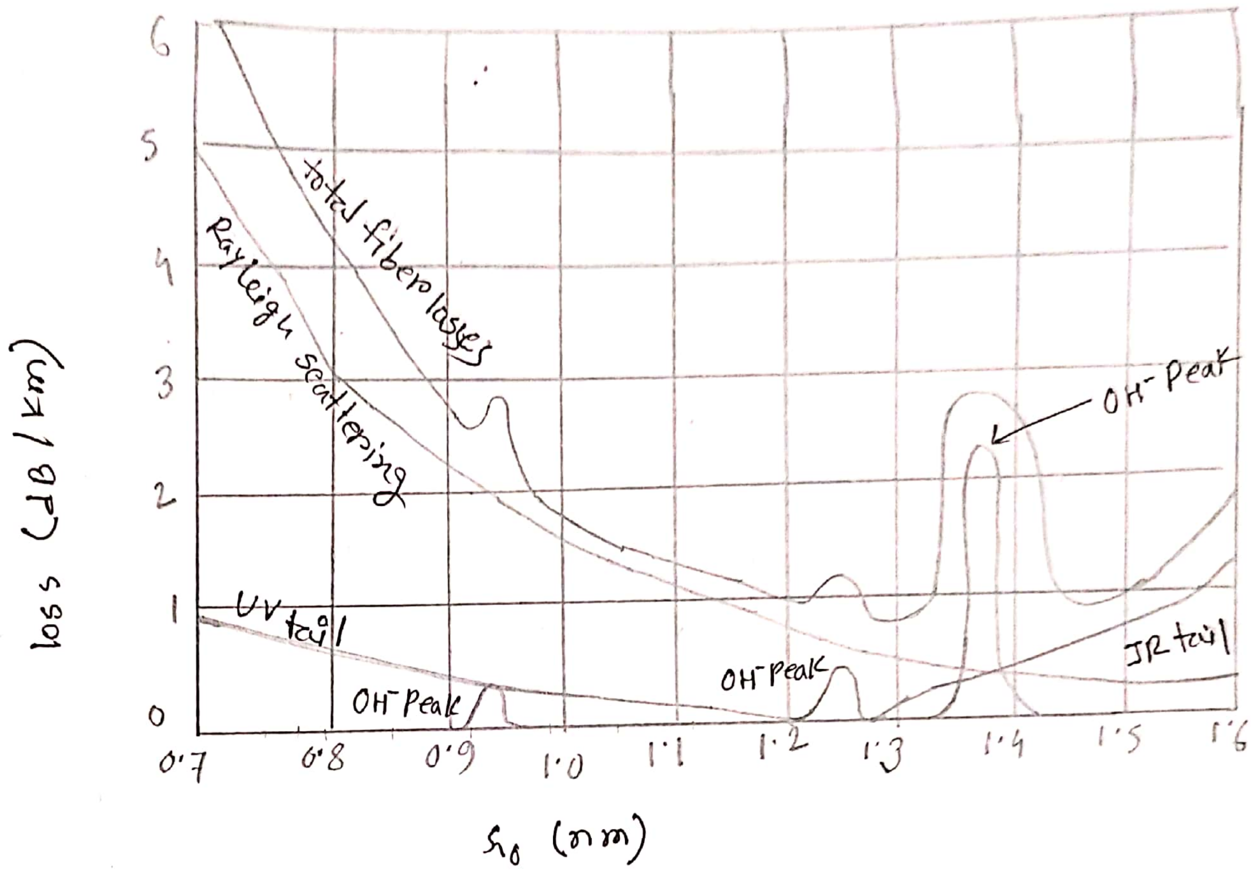


Fig : Total loss spectrum for an optical fiber.

In this figure shows the losses in a typical multimode fiber as a function of wavelength. All fiber are characterized by a loss spectrum curve of this general shape, ~~altho~~ although the actual loss value and peaking wavelength will very depending on the type of fiber. In the region between 0.8 and 1.3 µm the losses are dominated by the Rayleigh scattering effect. Above 1.2 µm the UV become negligible and above 1.3 µm the IR tail become significant. OH⁻ peak reduce in amplitude and width