OPTICAL FIBER COMMUNICATION
6th Sem. MID SEMESTER 2019 B.Tech. (ECE)

Q.N. 1

Ans:- (i) (c) Step Index.

(ii) (b) Skew Rays

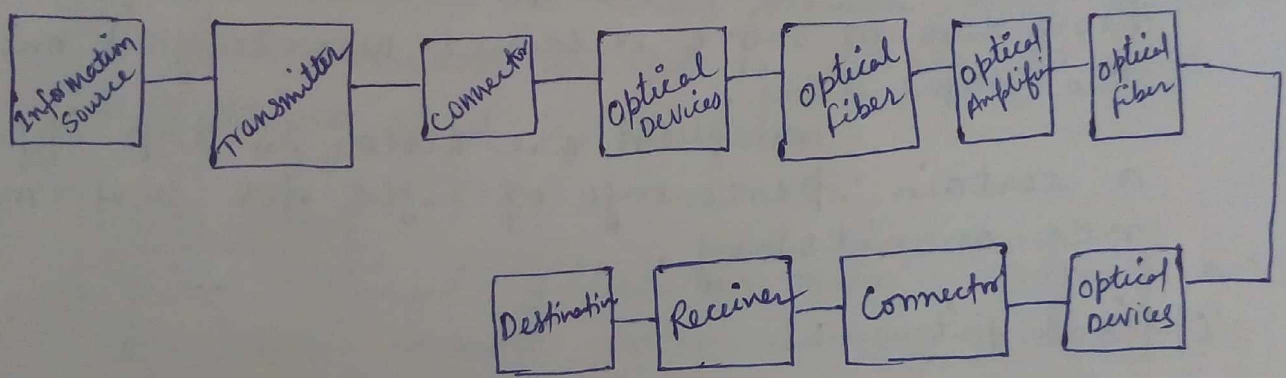
(iii) (a) Step Index Multimode fiber

(iv) (c) Total Internal reflection at the core-cladding Interface.

(v) (a) P_2O_5

Q.N. 2

Ans:-



Block diagram of optical fiber communication system

Information source:-

↳ It provides the information which is to be transmitted to the destination.

↳ Original message (information) is being transformed into electrical signal with the help of transducers.

Optical transmitter:-

↳ It consists of light source and its associated drive circuitry.

↳ Light source (LED | LASER) provides the carrier signal.

↳ The drive circuit provides the modulation of the carrier signal with the help of electrical signal received from the information source.

Optical Connectors :-

↳ optical connectors are required for making connection between fiber to fiber or fiber to optical components.

Optical Devices :-

↳ optical devices such as optical multiplexer and couplers are used.

↳ Multiplexers are used to combine signals from two or more distinct wavelengths onto the same fiber.

couplers are used to tap off a certain percentage of light for performance monitoring.

optical fiber :-

↳ It is the transmission medium and is used to transmit the optical signal received from transmitter to the receiver end.

optical Amplifier :-

↳ optical amplifier is used to boost the optical power level of weakend signal after travelling a certain length over optical fiber.

optical Receiver :-

↳ It consists of photodetector (APD or PIN photodiode) & amplification and signal restoring circuitry.

Advantages of optical fiber communication system

1. **Wide Bandwidth :-**

↳ Optical carrier freq. (10^{13} – 10^{16} Hz) range provide wide bandwidth.

2. **Low transmission Loss :-**

↳ Optical fiber provides very low transmission loss of the order of 0.15 dB/Km.

3. **Small Size & low weight :-**

↳ As the diameter of optical fiber is of um scale, hence it has small size & low weight which helps in easy storage, handling and installation.

4. **Low Cost :-**

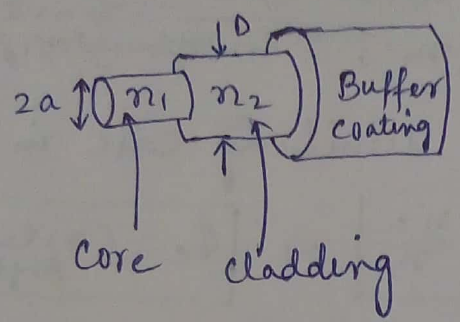
↳ The optical fiber is made from glass which is made from sand. Which is easily available & low cost material.

5. **Signal Security :-**

↳ Since the optical signal is well confined within the fiber (and does not radiate significantly) which provide high degree of data security.

Q.N.3

Ans:: <u>Optical Fiber</u>:-



where,

a = Radius of core

D = Diameter of cladding

n_1 = Refractive Index (R.I.) of core

n_2 = R.I of cladding

↳ Optical fiber is a dielectric cylindrical wave-guide. It consists of core, cladding and coating layers.

↳ The R.I. of the core region is higher than that of the cladding region. Due to which light propagate inside the core region by mainting total internal reflection.

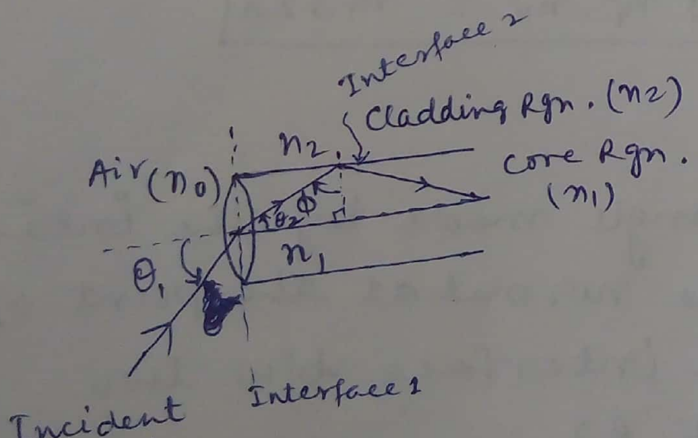


Fig. 1

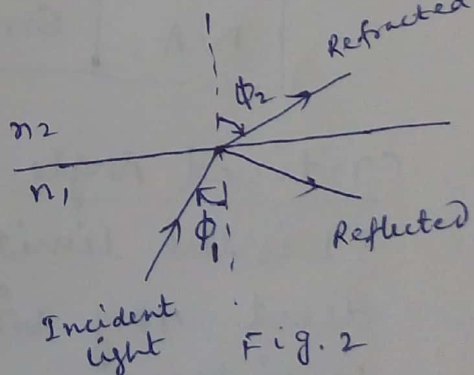


Fig. 2

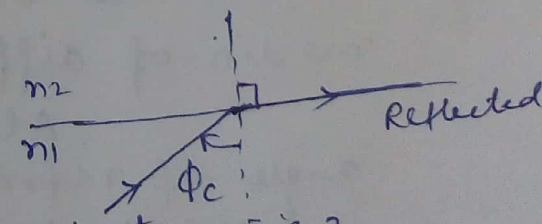


Fig. 3

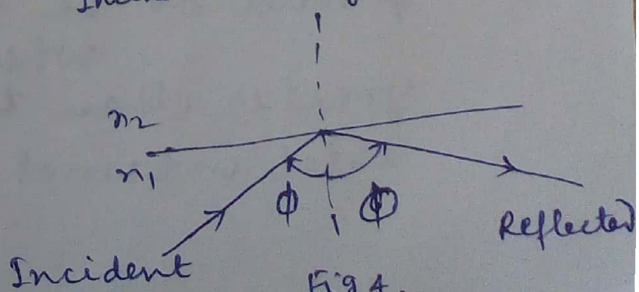


Fig 4.

From Snell's law at interface 1

$$n_0 \sin\theta_1 = n_1 \sin\theta_2$$
$$= n_1 \sin(90^\circ - \phi)$$
$$= n_1 \cos\phi$$
$$= n_1 \sqrt{1-\sin^2\phi}$$

Considering the limiting case in fig. 3 at Interface 2:

$$\boxed{\sin\phi = \sin\phi_c = \frac{n_2}{n_1}} \Rightarrow \boxed{\phi_c = \text{Critical Angle} = \sin^{-1}\left(\frac{n_2}{n_1}\right)}$$

$$n_0 \sin\theta_1 = n_1 \sqrt{1-\left(\frac{n_2}{n_1}\right)^2}$$

$$\boxed{n_0 \sin\theta_1 = \sqrt{n_1^2 - n_2^2}}$$

AS $\Delta = \dfrac{n_1^2 - n_2^2}{2n_1^2} \Rightarrow \boxed{n_1^2 - n_2^2 = 2n_1^2\Delta}$

$$n_0 \sin\theta_1 = \sqrt{2n_1^2\Delta}$$

$$\boxed{n_0 \sin\theta_1 = n_1\sqrt{2\Delta}}$$

For $n_0 = 1$ (Air)

$$\boxed{NA = \sin\theta_1 = \sqrt{n_1^2 - n_2^2} = n_1\sqrt{2\Delta}}$$

Critical Angle:-

It is the limiting angle made by the incident ray with the normal at the point of incidence on the interface b/w two media of different R.I.

At this angle of incidence the angle of refraction is 90° & the ray emerges parallel to the interface.

When the angle of incidence is greater than this critical angle then the total internal reflection occurs.

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Acceptance Angle (θ_1).

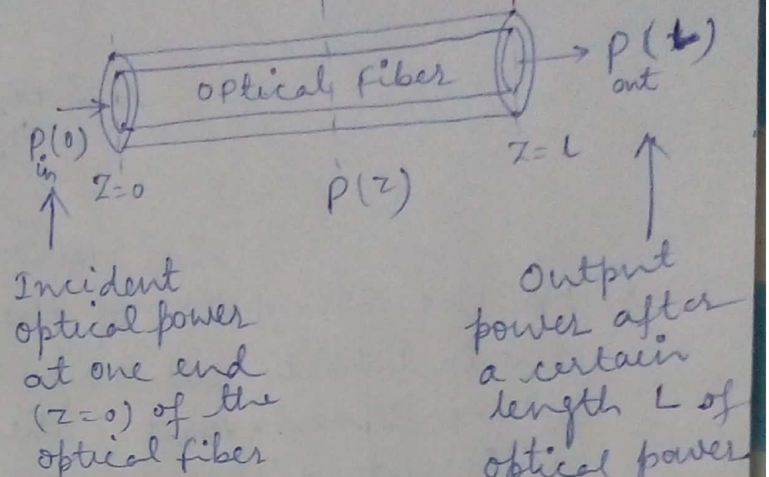
↳ It is the maximum angle made b/w the incident ray and the axis of the fiber at the fiber - air interface, at which if any ray is incident, then it maintain total internal reflection.

Q.N. 4:-

Ans:-

Signal Attenuation:-

↳ It is the measure of amount of optical power which is reduced after travelling a certain length of optical fiber.



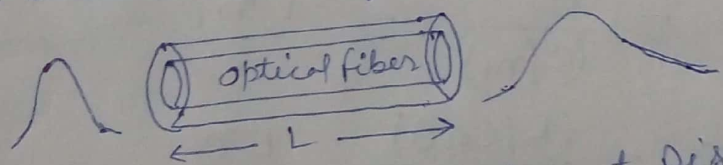
↳ It is used to determine the maximum unamplified or repeaterless seperation between a transmitter and receiver.

$$\text{Attenuation (dB)} = 10 \log_{10}\left(\frac{P(0)}{P(z)}\right)$$

Dispersion:-

↳ It is a pulse broadening phenomenon.

↳ optical signal in the form of pulse at the Input end of fiber gets broadened after travelling a certain distance (length) over optical fiber.



Different Attenuation mechanisms:-

1. Absorption Losses
   - Intrinsic
   - Extrinsic
2. Scattering losses
   - Linear Scattering
     - Rayleigh
     - Mie
   - Nonlinear Scattering
     - Stimulated Raman scattering (SRS)
     - Stimulated Brillouin Scattering (SBS)
3. Bending losses:-

Different Dispersion Mechanism:-

Dispersion

- Intramodal Dispersion
  ⇓ Type of dispersion which occurs within a single mode
  ⇓ occurs in SMF & MMF Both
- Intermodal Dispersion
  ⇓ Types of dispersion which occur between two modes.
  ⇓ occurs only in MMF

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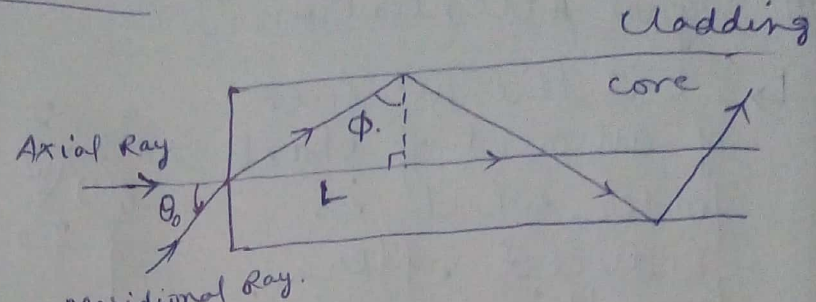
Expression of delay difference in multimode step index fiber (MM-SIF) :-



↳ In the SIF, R.I. of the core region is constant. due to which all rays (guided) propagate with same speed. But, the different rays travel different distance while propagating through core region. Therefore, the fastest moving ray will reach at the other end of the fiber earlier while the slowest ~~most~~ moving ray takes more time in reaching the same distance. Thus, this cause delay in time.

Axial ray → Fastest moving ray.

Extreme meridional ray → slowest moving ray.

Speed of propagation of both ray $= \frac{c}{n_1}$

$$T_{min} = \frac{L}{(c/n_1)} = \frac{L n_1}{c} \quad \text{--- (1)}$$

$$T_{max} = \frac{(L/\cos\theta)}{(c/n_1)} = \frac{L n_1}{c \cos\theta} \quad \text{--- (2)}$$

As, $\sin\phi_c = \frac{n_2}{n_1} \Rightarrow \sin(90^\circ - \theta) = \frac{n_2}{n_1}$

$$\Rightarrow \cos\theta = \frac{n_2}{n_1} \quad \text{--- (3)}$$

putting the value of $\cos\theta$ in eqn (2)

$$T_{max} = \frac{L n_1}{c \times \frac{n_2}{n_1}} = \frac{L n_1^2}{c n_2} \quad \text{--- (4)}$$

$$\Delta T = T_{max} - T_{min} = \frac{L n_1^2}{c n_2} - \frac{L n_1}{c} \Rightarrow \frac{L n_1}{c}\left[\frac{n_1}{n_2} - 1\right]$$

$$\Delta T = \frac{L n_1}{c}\left[\frac{n_1 - n_2}{n_2}\right] = \frac{L n_1^2}{c n_2}\left[\frac{n_1 - n_2}{n_1}\right]$$

$$\Delta T \simeq \frac{L n_1^2}{c n_2} \Delta \left[\frac{n_1 - n_2}{n_1}\right]$$

$$\simeq \frac{L n_1^2}{c n_1} \left[\frac{n_1 - n_2}{n_2}\right] \qquad (\because n_1 \simeq n_2)$$

$$\simeq \frac{L n_1}{c} \left[\frac{n_1 - n_2}{n}\right]$$

$$\simeq \frac{L n_1}{c} \Delta$$

$$\boxed{\Delta T = \frac{L n_1^2 \Delta}{c n_2} \simeq \frac{L n_1}{c} \Delta \simeq \frac{L (NA)^2}{2 n_1 c}}$$

Q.N. 5 (a)

Solⁿ:- Given: θ_m = Acceptance angle = 22°

Δ = Relative refractive Index difference

= 3%

NA = Numerical Aperture = $\sqrt{n_1^2 - n_2^2} = n_1\sqrt{2\Delta}$

$$\boxed{NA = n_1\sqrt{2\Delta}} \quad \text{——— (1)}$$

$$NA = \sin\theta_m = \sin(22^\circ) = 0.375 \quad \text{— (2)}$$

from Eqⁿ (1) & (2)

$$n_1 = \frac{NA}{\sqrt{2\Delta}} = \frac{0.375}{\sqrt{2\times0.03}} = 1.5306$$

$$\phi_c = \text{Critical Angle} = \sin^{-1}\left(\frac{n_2}{n_1}\right) = \sin^{-1}\left(\frac{n_1(1-\Delta)}{n_1}\right)$$

$$= \sin^{-1}(1-\Delta) = \sin^{-1}(1-0.03) = \sin^{-1}(0.97)$$

$$\boxed{\phi_c = 75.93}$$

Hence, NA = 0.375 and $\phi_c = 75.93$

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Q.N. 5 (b)

Solⁿ:- Given.

Length of fiber = 8 Km

Mean optical power launched = 120 μW

Mean optical power at the fiber output = 3 μW

(i) Loss (overall signal attenuation)

$$= 10 \log_{10}\left(\frac{120}{3}\right)$$

$$= 10 \log_{10} 40$$

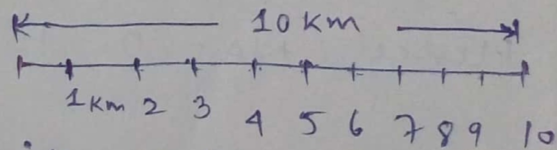
$$= 16 \text{ dB}$$

(ii) Attenuation per Km $= \dfrac{\text{Total loss}}{\text{Length of fiber}}$

$$= \frac{16}{8} \text{ dB/Km}$$

$$= 2 \text{ dB/Km.}$$

(iii)



For a 10 Km long fiber with splices at each 1 km, there will be total 9 splices.

Overall signal attenuation = (Attenuation in 10 km fiber) + (Attenuation due to splices)

$$= (10 \times 2) \text{ dB} + (9 \times 1) \text{ dB}$$

$$= 29 \text{ dB}$$

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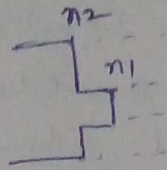
Q.N.6

Ans:-

Single mode Fiber (SMF):-

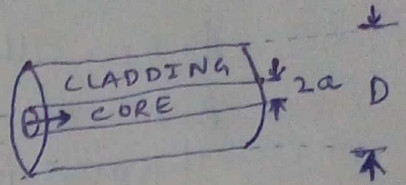
- It is the type of optical fiber which supports single mode to propagate inside the core of fiber.
- This single mode propagates along the axis of fiber.
- Generally, the preferred R.I profile of the SMF is of <u>Step Index</u> type in which the R.I. of the core rgn. is uniform & has higher value than that of the cladding rgn.



R.I. profile

Step Index profile

Fig. 2



SMF Design

Fig. 1

where,
a = Core Radius
D = cladding diameter
n_1 = R.I. of core Region.
n_2 = R.I of cladding Rgn.

Step Index fiber (SIF):-

- Based on the R.I. profile of the fiber, it is classified as
  - Step Index fiber (SIF) &
  - Graded Index fiber
- The R.I. profile of a SIF is shown in fig. 2 above.
- In the SIF, the R.I. of the core rgn. is ~~const.~~ constant over the entire core rgn. and has higher value than cladding rgn.

$$n(r) = n_1 \; ; \quad r < a \quad \text{(In the core Rgn.)}$$
$$\quad\;\; = n_2 \; ; \quad r \geq a \quad \text{(In the cladding Rgn.)}$$

Graded Index fiber (GIF)

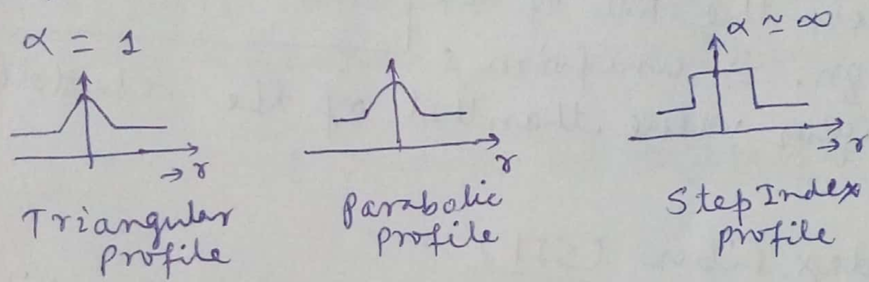
↳ The R.I. of the core region is made to vary as a function of the radial distance from the center of the core, while the R.I. of the cladding region is constant throughout cladding region.

$$n(r) = n_1\left(1 - 2\Delta\left(\frac{r}{a}\right)^{\alpha}\right)^{1/2} \; ; \; r < a \quad (\text{In the core rgn.})$$

$$= n_2 \; ; \; r \geq a \quad (\text{In the claddig Rgn.})$$

α = Refractive Index profile parameter

For



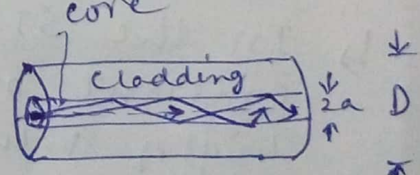
r = Radial distance from the center of the core.

a = core Radius

n_1 = R.I. at the axis of the core.

Δ = Relative R.I. difference.

Multimode Fiber (MMF):-



↳ Multimode fiber supports many modes to propagate inside the core region.

↳ The core diameter of the MMF is larger than that of the single mode fiber

$2a \simeq 50-200\ \mu m$

$D \simeq 125\ \mu m$

↳ The R.I profile of MMF may be of either Step index or Graded Index type.

Optical fiber cable :-

1) ↳ Need of Cabling :-

Bare fiber (core + cladding) is sufficient for the transmission of optical signal, but ~~In actual environment~~ it is brittle and have small cross sectional area which make it very susceptible to damage.

In practical environment, installation of fiber in different ~~envir~~ environments & require protection from external influences (strain & stress, contaminants etc). Therefore a series of protective layers are used.

↳ The optical cable (Different Layers) provide protection against damage & breakage while installation & also strength member.

~~↳ The cabled fiber~~

↳ Suitable strength member is used to ~~impro~~ provide improved strength against tension, bending, vibration etc.

FIBER Buffering :-

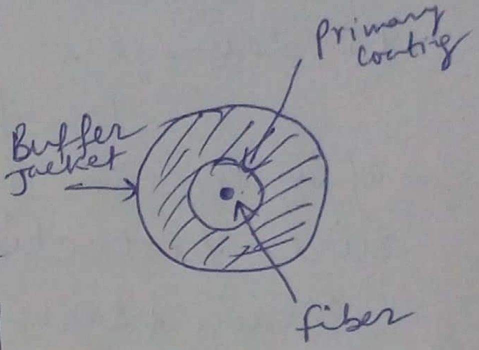
↳ Primary coating is used to prevent abrasion of glass surface.

↳ The primary coated fiber is given a secondary or buffer coating (Jacket) to provide protection against external mechanical and environmental influences. This buffer Jacket protect the fiber from microbending losses.

↳ Based on buffering arrangement there are three different jacketing (Buffering)

1. Tight buffer Jacket
2. Loose tube Buffer Jacket] Loose tube buffer Jacket.
3. Filled loose tube buffer Jacket]

1. Tight buffer Jacket :-



↳ It consist of a hard plastic buffer jacket which is in direct contact with the primary coated fiber which has a dia 250 um.

↳ This thick buffer coating (usually 900 um in diameter) provides stiffening for the fiber against outside microbending influences.

2. Loose tube buffer Jacket

↳ It uses oversized tube in which fiber is placed & which mechanically isolates the fibers from external forces.

↳ The tube is hard outside & smooth inside which exhibits low resistance to movement of the fiber.

↳ Polyester ~~or~~ polyamide materials are generally used for tube.

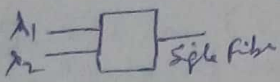
Indoor Cables (Tight Buffered Cables)

↳ patch Cord (Jumper cables)

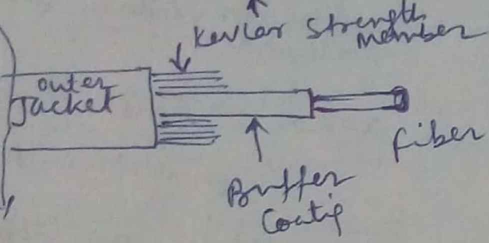
- (~ < 2m)
- Simplex / duplex type (B)

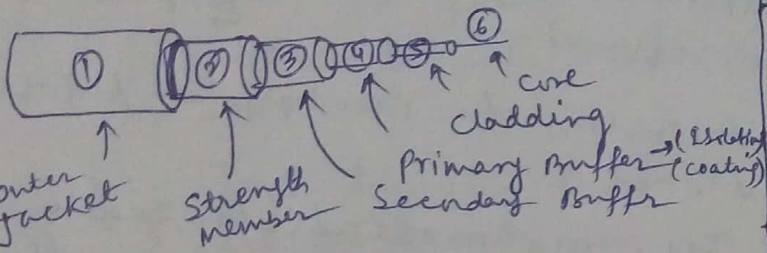
(A) Simplex ↓ For Interconnection (of equipment to equipment) ↓ LAN connection

Duplex ↳ used in WDM module



↳





Role of each layers :-

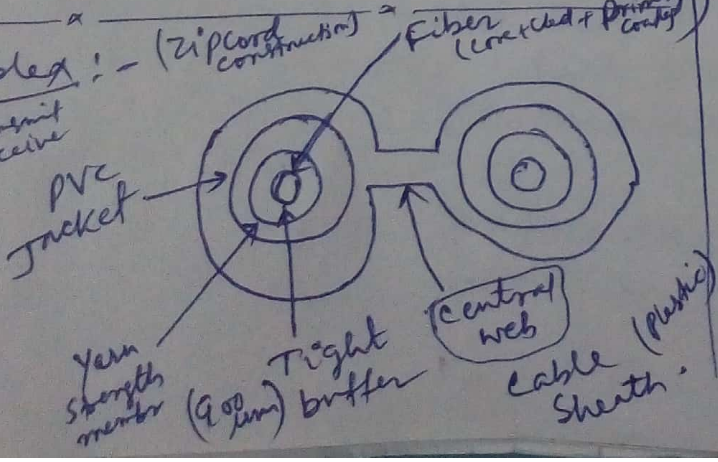
1. primary Coating (Buffer) | Secondary Buffer

2. Strength member :-

3. Outer Jacket :-

(B) Duplex :- (Zipcord construction)

→ Transmit
← Receive

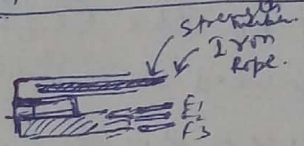


Outdoor cables (Loose - tube Buffered)

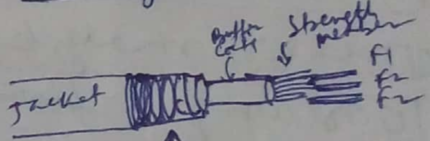
↳ 1. Aerial Cable :-

↳ mounted on poles

↳ Two popular aerial cable designs.

Self supporting cable	facility supporting Cable
Contains an Internal strength member that permit the cable to be strung b/w poles without using any additional support mechanism for the cable.	↳ It is clipped to a seperate strength member which is strung b/w the poles.
 To avoid bend. ↳ Affect TIR	

2. Underground (Armored cable)



Steel capping.

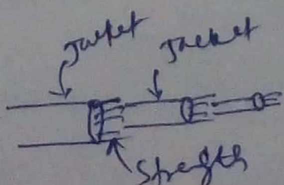
↳ To protect from chewing the cable by Rats, Rodents.

↳ It provides additional Strength & protection from

3. ~~Undergr~~ Under Sea Cable

↳ Double proof

↳ To avoid from drop of water to come in contact with fiber to avoid absorptive loss.



Also protection from rodent So steel armoring is reqd.

Indoor cable Design :- "Tight-buffered construction"

↳ Indoor applications :- ↳ Interconnecting Instruments
↳ Short patch cords in telecomm. equipment racks.

1. Interconnect cable :-

↳ tight-buffered ~~com~~ construction of cable.

↳ Fiber optic patch cord (Jumper cables) are short length (< 2 m) of simplex or duplex cable design with connectors on both ends.

Outdoor cables :-

↳ Outdoor application : Involves installation in aerial, duct, direct-burial, and underwater applications

1. Aerial cable :-

↳ Mounted on poles

↳ Two popular aerial cable designs

Self supporting cable	facility supporting cable
↳ contains an internal strength member that permits the cable to be strung b/w poles without using any additional support mechanism for the cable.	↳ facility - supporting cable is clipped to a seperate wire or strength member strung b/w the poles.