UNIT 3

1. Write notes on broadening of pulse in the fiber dispersion?

Ans: The dispersion of the transmitted optical signal causes distortion for both digital and analog transmission along optical fibers. If we consider the major implementation of optical fiber transmission which involves some form of digital modulation, then the dispersion technique within the fiber causes broadening of the transmitted light pulses as they travel along the channel. This phenomenon is depicted in figure (a), where it may be observed that each pulse broadens and coincides with its neighbors, eventually becoming indistinguishable at the receiver input

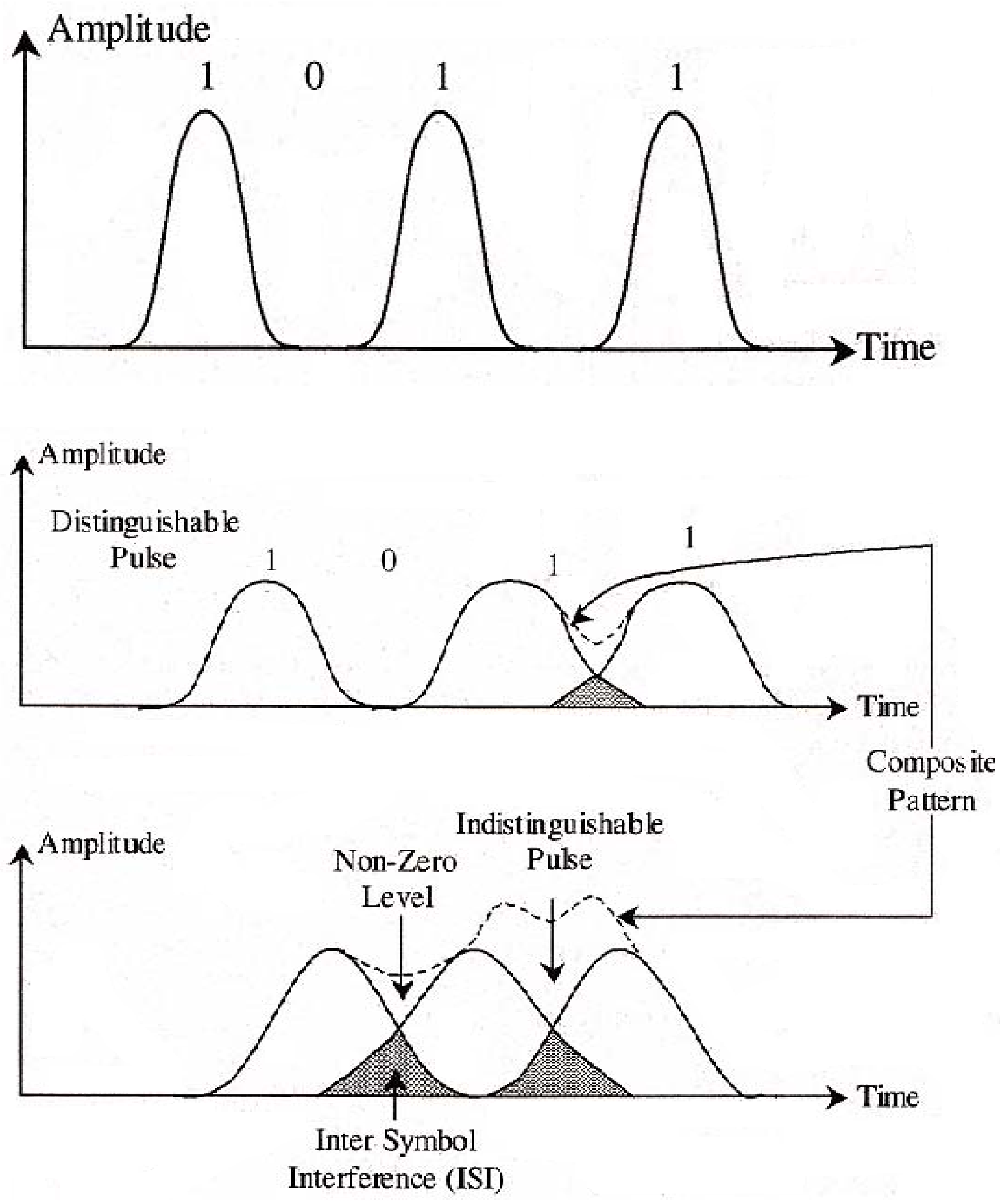


Illustration Of pulse Broading using Digital Bit Pattern 1011

The effect of overlapping of pulses shown in figure (a)' is called Inter Symbol Interference (ISI). Thus, ISI becomes more pronounced when increasing numbers of errors are encountered on the digital optical channel

For no overlapping of pulses down on an optical fiber link, the digital bit rate B_T must be less than the reciprocal of the broadened pulse duration through dispersion (2τ) and hence,

$$B_T \leq 1/2\tau \ldots\ldots\ldots\ldots\ldots\ (1)$$

Equation (1) assumes that the pulse broadening due to dispersion on the channel is **T** which follows the input pulse duration which is also τ.

Another more accurate estimate of the maximum bit rate for an optical channel with dispersion may be obtained by considering the light pulses at the output to have a Gaussian shape with an r.m.s. width of τ.

2. Explain group delay or time delay in fiber optics?

Ans: Modulating signal of an optical source enhances all the modes of fiber equally. This results in carrying of equal amount of energy by each and every mode of fiber. Since each mode contains all the spectral components in the wavelength band over which the source emits, hence the modulating signal modulates every spectral component equally. The signals propagating through these spectral components experience a time delay or group delay per unit length in the direction of propagation and it is given as,

$$\frac{\tau_g}{D} = \frac{1}{V_g} = \frac{1}{C}\frac{d\beta}{dk} = \frac{-\lambda^2}{2\Pi C}\frac{d\beta}{d\lambda}$$

Here D = Distance travelled by the pulse

β = Propagation constant along fiber axis

k = 2Π/λ

V_g= Velocity with which the energy in a pulse travels along a fiber

$$V_g = C\left(\frac{d\beta}{dk}\right)^{-1} = \left(\frac{d\beta}{d\omega}\right)^{-1}$$

From equation (2) we can say that group delay is a function of wavelength 'λ', therefore each spectral component of any particular mode takes different time to travel a particular distance.

This causes difference in time delays and spreading of pulse with time as it travels along the fiber.

The variations in group delay causes pulse spreading. If the spectral width of the optical source is quite wide, then the delay difference per unit wavelength over the propagation path is given as $\frac{d\tau_g}{d\lambda}$ The total delay 8x over a distance 'D' for the spectral components which are δλ apart and δλ/2 above and below a central wavelength 'λ_c' is,

$$\delta\tau = \frac{d\tau_g}{d\lambda}\,d\lambda = \frac{-D}{2\Pi C}\left(2\lambda\frac{d\beta}{d\lambda} + \lambda^2\frac{d^2\beta}{d\lambda^2}\right)\delta\lambda$$

3. Explain about fiber optic connectors and types of connectors in detail?

Ans: Fiber Optic Connectors:

Connectors are mechanisms or techniques used to join an optical fiber to another fiber or to a fiber optic component.

Different connectors with different characteristics, advantages and disadvantages and performance parameters are available. Suitable connector is chosen as per the requirement and cost.

Various fiber optic connectors from different manufacturers are available SMA 906, ST, Biconic, FC, D4, HMS-10, SC, FDDI, ESCON, EC/RACE,

Principles of good connector design

1. Low coupling loss.
2. Inter-changeability.
3. Ease of assembly.
4. Low environmental sensitivity.
5. Low cost.
6. Reliable operation.
7. Ease of connection.

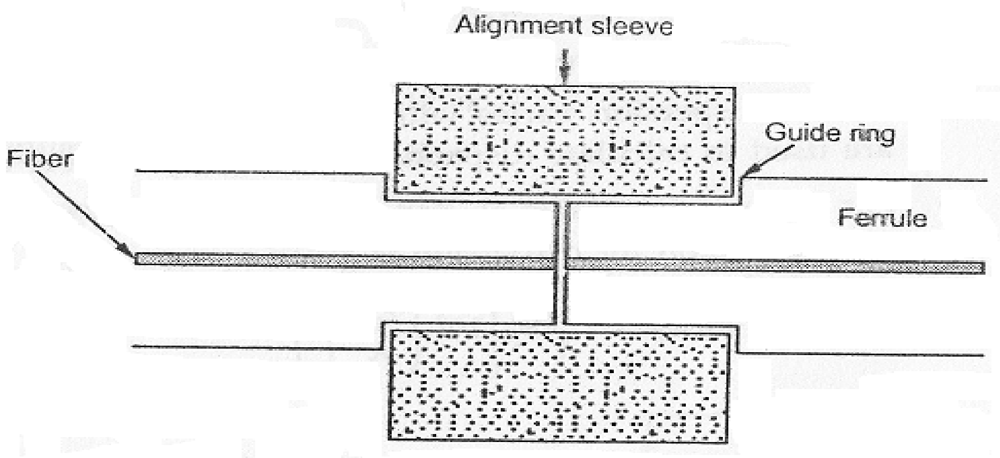
Connector Types Connectors use variety of techniques for coupling such as screw on, bayonet-mount, push-pull configurations, butt joint and expanded beam fiber connectors.

Butt Joint Connectors

Fiber is epoxies into precision hole and ferrules arc used for each fiber. The fibers are secured in a precision alignment sleeve. Butt joints are used for single mode as well as for multimode fiber systems. Two commonly used butt-joint alignment designs are:

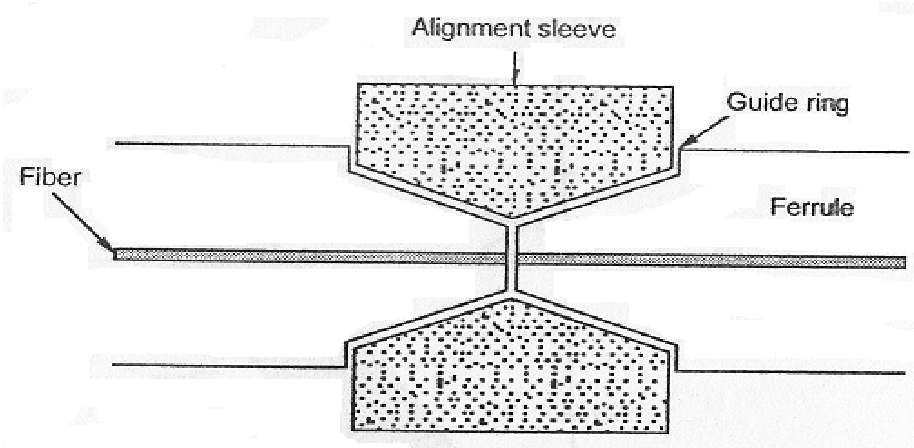
1. Straight-Sleeve.
2. Tapered-Sleeve/Bi conical.

In straight sleeve mechanism, the length of the sleeve and guided ferrules determines the end separation of two fibers. Below Fig. shows straight sleeve alignment mechanism of fiber optic connectors



Straight sleeve connector

In tapered sleeve or bi conical connector mechanism, a tapered sleeve is used to accommodate tapered ferrules. The fiber end separations are determined by sleeve length and guide rings. The below figure shows tapered sleeve fiber connectors



Tapered sleeve connector

4. A multi mode graded index fiber exhibits the pulse broadening of 0.2µs over a distance of 15Km.Estimate,

(i) Optimum bandwidth of the fiber

(ii) Dispersion per unit length

(iii)Band width length product

Ans:

Given that,

For a multimode graded index fiber,

Total pulse boarding, $\tau = 0.2\mu s$

Distance, L =15km

(i) The maximum possible optical bandwidth is equivalent to the maximum possible bit rate assuming no inter symbol interference (ISI) and is given by

$$B_{opt} = B_T = 1/2\tau$$

$$= 1/(2*0.2*10^{-6})$$

$$= 2.5 \text{ MHz}$$

Therefore Bopt = 2.5MHz

(ii) The dispersion per unit length may be acquired by dividing the total dispersion by total length of the fiber i.e,

Dispersion per unit length = Total dispersion / Total length of fiber

= τ/L

= $(0.2*10^{-6})/15$

= $13.33ns\ Km^{-1}$

Therefore Dispersion per unit length = $13.33ns\ Km^{-1}$

(iii) The band width length product may be obtained by simple multiplying the maximum band width for the link by its length as,

Bopt .L= $2.5 *10^6 *15$

= 37.5 MHz Km

Alternately, the band width product may be obtained from the dispersion per unit length as,

Bopt .L = 1/ (2*Dispersion per unit length

= $1/ (2*1.33*10^{-9})$

= 37.5MHz.Km

5. Compare the optical parameters of free space with dispersive and non dispersive mediums?

Ans: The basic optical properties of light are,

(i) Propagation: Light travels along a straight line in a uniform median.
(ii) Reflection: It occurs at the surface or boundary of a medium.
(iii) Refraction (or bending): It may occur where a change of speed is experienced.
(iv) Interference: It is found where two waves are superposed.
(v) Diffraction: It happens around a corner when a wave passes the edge of one obstacle.

Dispersive Medium

Glass is an example of dispersive medium. Non uniform bending of different wavelength of light when it travels along the medium is called dispersion. And the medium in which dispersion takes place is called dispersive medium.

For a uniform dispersive medium the light wave travels along a straight line. If the medium is non-uniform and if its density increases as the light wave travels, then the light waves tends to bend itself towards the normal and vice-versa. Hence, refraction of light waves takes place in dispersive non uniform medium. Also, in dispersive medium the group velocity and phase velocity is not constant as a result of interference of different wave fronts travelling at an angle to each other. Hence refraction takes place. If a plane wave hits an obstacle placed perpendicular to the direction of its propagation with a pin hole in the centre then the plane wave front is changed into spherical wave front due to diffractions of light wave through the pin hole

Non-dispersive Medium

Vacuum is an example of non-dispersive medium. In vacuum the light wave travels in straight line. The group velocity as well as phase velocity of the light wave ii constant. Hence no refraction takes place in phase vacuum. As the waves travel in straight lines and are parallel to each other no interference takes place vacuum is free of obstacles. Hence, no diffraction of light wave takes place.

6. Derive the expression for the phase velocity, group velocity using electric field distribution along the fiber?

Ans:

Phase velocity: All electromagnetic waves which travel along a waveguide have points of constant phase. As a monochromatic light wave propagates along a waveguide in z-direction, this point of constant phase travel at particular velocity termed as phase velocity. It is denoted by V_P

Therefore $V_P = \frac{\omega}{\beta}$

Where ω = angular frequency of the wave and

β = Phase propagation constant

Group Velocity:

Group of waves with closely similar frequencies propagate along the waveguide so that there exists a resultant in the form of packet of waves. This wave packet moves at a velocity termed as group velocity V_g

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

The formation of wave packets from combination of waves of nearly equal frequencies is,

Propagation constant can be given as,

$\beta = n_1 (2\Pi/\lambda) = (n_1 \omega)/c$

where n_1= Refractive index of medium

Phase velocity V_P can be given as

$$V_P = \frac{c}{n1}$$

8. Write a short notes on dispersion shifted fiber and dispersion compensating fiber?

Ans: Dispersion Shifted Fiber

Single mode fibers which are designed to offer simultaneously zero dispersion and minimum attenuation at λ = 1.55μm is called dispersion shifted fibers. The dispersion classifications of various fibers are shown in figure 8.1, which depicts the shifting of zero dispersion wavelength from λ = 1.33 um to λ= 155 mm. This can be achieved by changing the fiber parameters, namely, the refractive index dispersion shifted fiber.

For example, by reducing the fiber core diameter from 8-10μm to 4.5μm and increasing the refractive index difference between core and cladding from 0.003 to greater than 0.01 yields zero dispersion wavelength shifted from 1.33μm to 1.55μm. This may lead to substantial excess loss. Triangular core profile also yields dispersion shifted fibers and moreover it solves the above excess loss problem. So, for better results we have to modify the triangular profile. These Profiles are shown in below figure

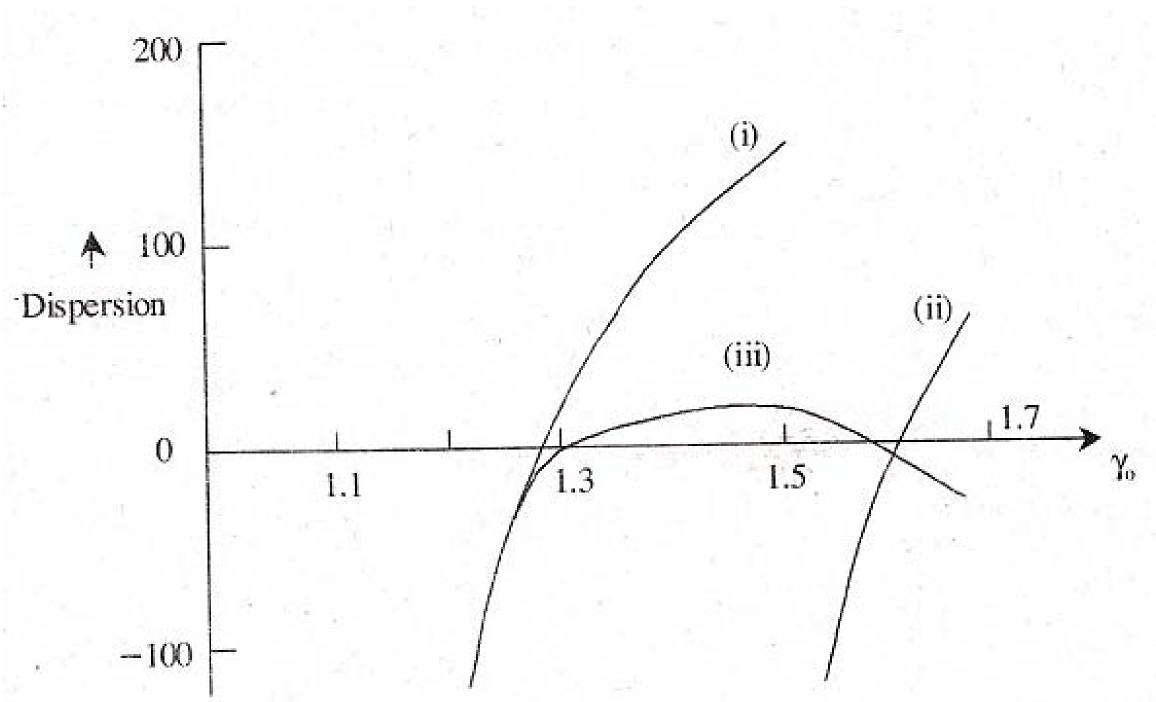


Fig 8.1 (i) Standard fiber (ii) Dispersion shifted fiber (iii)Dispersion Flatted fiber

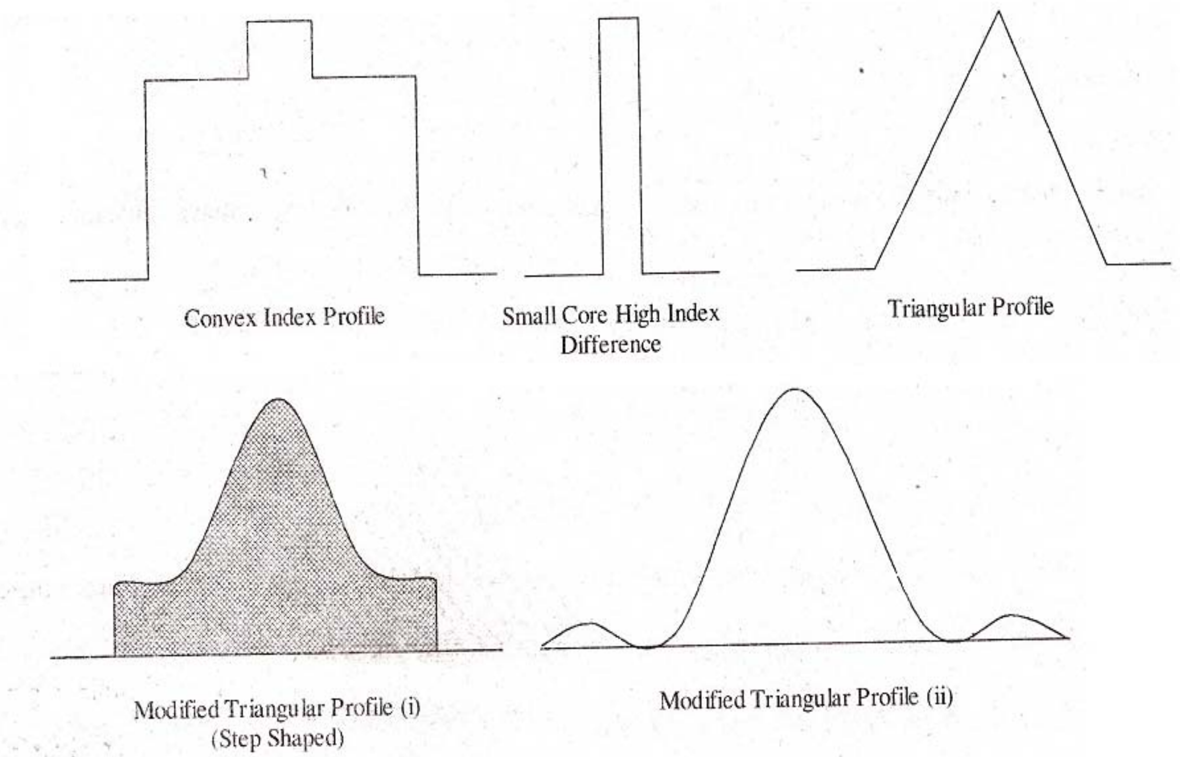


fig 8.2 To achieve dispersion shifted fiber from refractive index profile

The above figure shows that the convex index profile also gives the dispersion shifted fiber.

Dispersion shifted fibers have the advantage of increased guiding strength, increase in the cut-off wavelength of second order mode and better resistance to bending losses.

Such dispersion shifted fibers have been produced by BTRL and others and are now commercially available from any glass company.

Table (1) compares the characteristics of triangular refractive index profile dispersion shifted fiber with that of simple step index fiber.

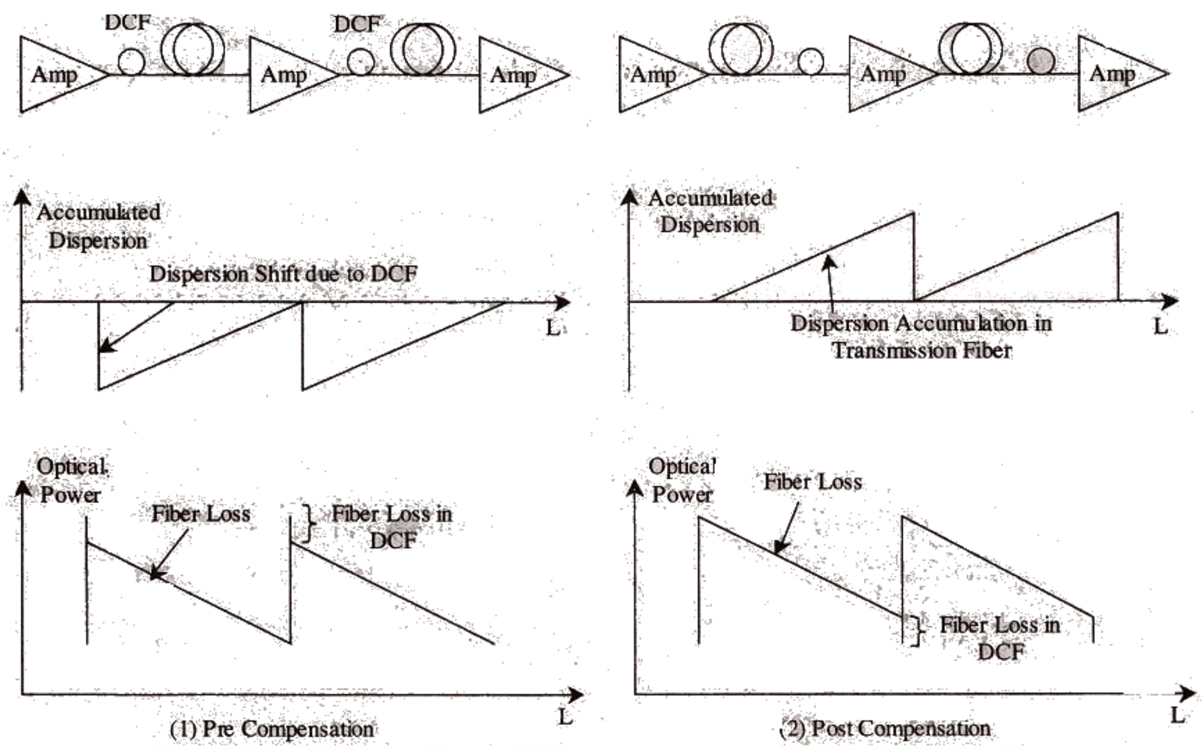
Step-index Fiber	Dispersion shifted fiber(Triangle RI)
Attenuation Dispersion	0.200-0.22 (dB/Km) 17 -180.1 ps(km-nm)

Table (1): Fiber parameters at 1.55 mm

Dispersion Compensating Fiber

The process of dispersion compensation and the fiber loop is referred as dispersion compensating fiber. A large base of dispersion shifted fiber has been installed throughout the world for use in the single wavelength transmission systems. For these kinds of links the complexity arises from Four Wave Mixing (FWM), when one attempt to upgrade them with high speed dense WDM technology in which the channel spacing is less than 100 GHz and the bit rates are in excess of 2.5 Gb/s. By using the passive dispersion compensation technique we can reduce the effect of FWM (four wave mixing). This consists of inserting into the link a loop of fiber having a dispersion characteristic that negates the accumulated dispersion of the transmission fiber. This process is known as dispersion compensation. If the transmission fiber has a low positive dispersion, the dispersion compensating fiber will have a large negative dispersion. By using this technique, the total accumulated dispersion will become zero after some distance, but the absolute dispersion per length is non-zero at all points along the fiber.

Figure depicts the Dispersion Compensating Fiber (DCF) which can be inserted at either the starting (or) the end of an installed fiber span between two optical amplifiers. A third option is to have DCF (Dispersion Compensating Fiber) at both ends.



Dispersion and Power Maps

In pre-compensation schemes, the DCF is located just after the optical amplifier and just before the transmission fiber. Where as in post compensation schemes, the DCF is located just after the transmission fiber and just before the optical amplifier. Above Figure also depicts the plots of accumulated dispersion and optical power level as functions of distance along the fiber. This figure is known as dispersion and power maps respectively.

9. How to connect two fibers in a low manner? Explain?

Ans: Interconnection of Two Fibers in a Low Loss Manner

The major factor in any fiber optic system is the requirement to interconnect fibers in a low loss manner. These interconnections occur in three stages namely.

1. At the optical source
2. At the photo detector
3. At intermediate points.

1. Optical Sources

The optical sources such as Light Emitting Diodes (LEDs), Solid state lasers and semiconductor injection lasers are used because of their efficiency, low cost, longer life, sufficient power output, compatibility and ability to give desired modulations.

2. Photo Detectors

Photo detectors such as semiconductor photodiodes are used because of their high quantum efficiency, adequate frequency response, low dark current and low signal impedance.

3. Intermediate Points

The two fibers are joined at intermediate points with two cables within a cable.

The two major methods for the interconnection of fibers in a low loss manner are as follows,

(i) Fiber Splices

(ii) Simple Connectors.

(i) Fiber splices

In this, the fiber splices are the semi permanent (or) permanent joints which are mostly used for interconnection in optic-telecommunication system.

(ii) Simple Connectors

Simple connectors are the removable joints which allow easy, fast manual coupling of fibers.

We can say that losses in interconnection of two fibers depend on factors like input power distribution to joints, length of fiber between optical source and joint, wave characteristics of two fibers at joint and fiber end face qualities.

If these factors are satisfied low-loss in the interconnection of two fibers is achieved.

10. Explain about losses in end separation, connecting different fibers when joining two fibers?

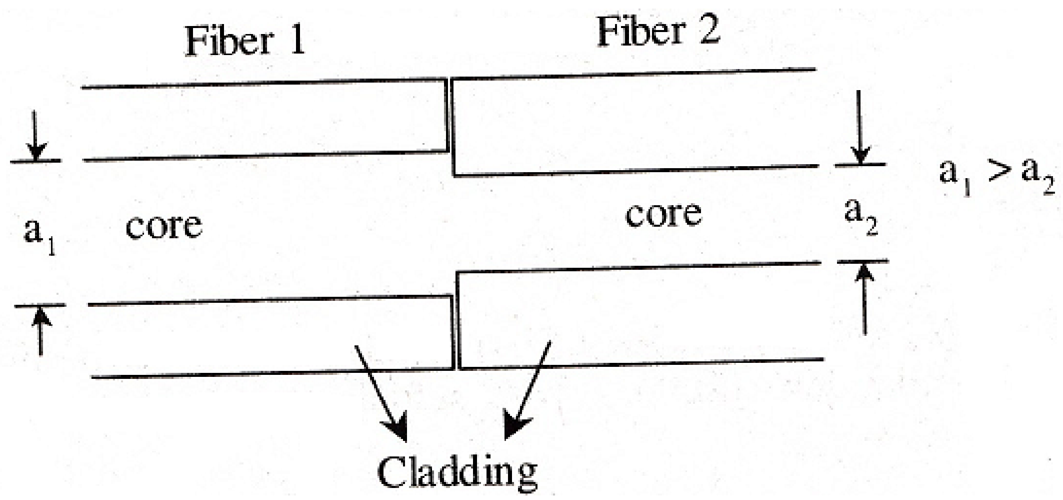
Ans: When an optical fiber communication link is established, interconnections occur at the optical source, at the photo detector, at intermediate points within a cable where two fibers are joined and at intermediate points in a link where two cables are connected. If the interconnection is permanent bound then it is generally referred to as splicing whereas a demountable joint is known as connector. At every joint optical power loss takes place depending on input power distribution to the joint, the length of the fiber between the optical source and the joint, the geometrical and waveguide characteristics of the two fiber ends at the joint and the fiber end face qualities. These losses are classified into (i) Intrinsic losses (ii) Extrinsic losses and (iii) Reflection loss.

(i) Intrinsic Losses

Intrinsic losses occur when a mismatch occurs between two connecting fibers. Mismatch occurs when fiber's mechanical dimensions are out of tolerance limit. The mismatch can occur due to the following.

(a) Core-Diameter Mismatch

If the core of two joining, fibers has different diameter then core-diameter mismatch occurs. The loss will be more if the light is travelling from larger core into a smaller core than if it is in reverse direction.

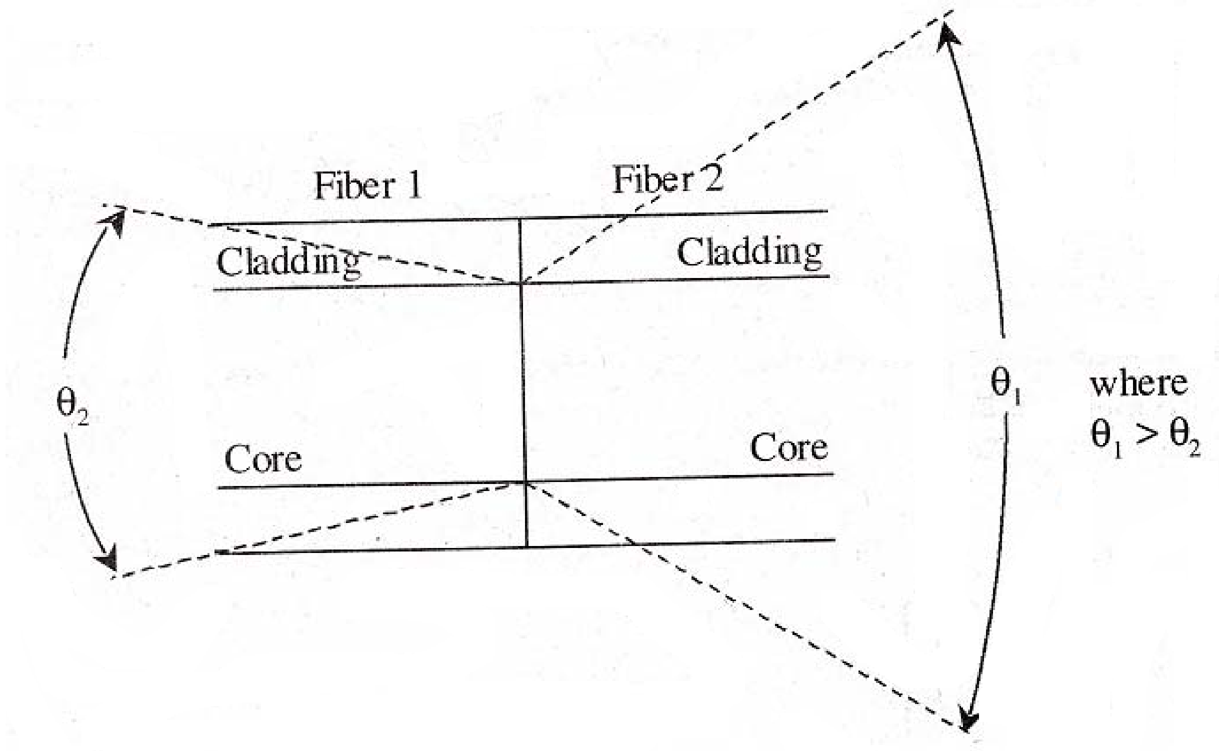


For a gradient multi mode fiber the loss due to core-diameter mismatch is given by,

LOSS (core) =-10log $[\left(\frac{a_2}{a_1}\right)^2]$

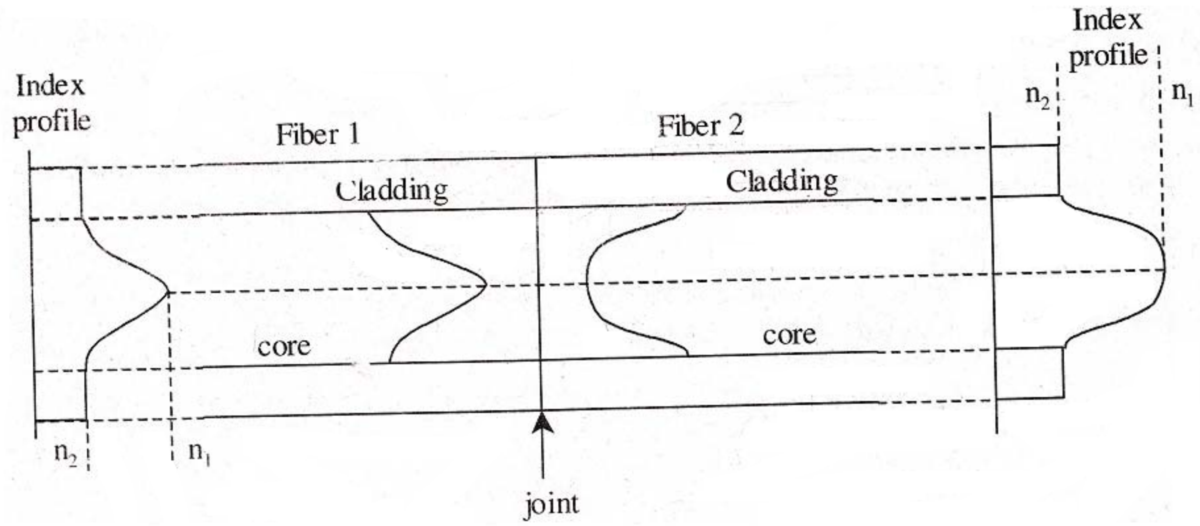
(b) Numerical Aperture Mismatch

The light beam from emitting fiber fills the entire exit aperture of the emitting fiber. The receiving fiber has to accept all the optical power emitted by the first fiber. If there is a mismatch in waveguide characteristics of the two fibers resulting in smaller NA per second fiber, then it results in optical power loss. This loss is called numerical aperture mismatch loss given by,



Numerical Aperature Mismatch

(c) Mode-Field-Diameter (MFD) Mismatch or Refractive Index Profile (α) Mismatch: This loss takes place only in graded-index fiber where the index profile emitting fiber is different from the index profile of receiving fiber.



Mode Field Diameter Mismatch

$$\text{LOSS}_{NA} = -10\log\left[\left(\frac{NA_2}{NA_1}\right)^2\right]$$

The loss due to MFD is given by

$$\text{LOSS}_{MFD} = -10\log\left[\frac{\alpha_1(\alpha_1+\alpha)}{\alpha_2(\alpha_2+\alpha)}\right]$$

Where α_1 = index profile of fiber 1

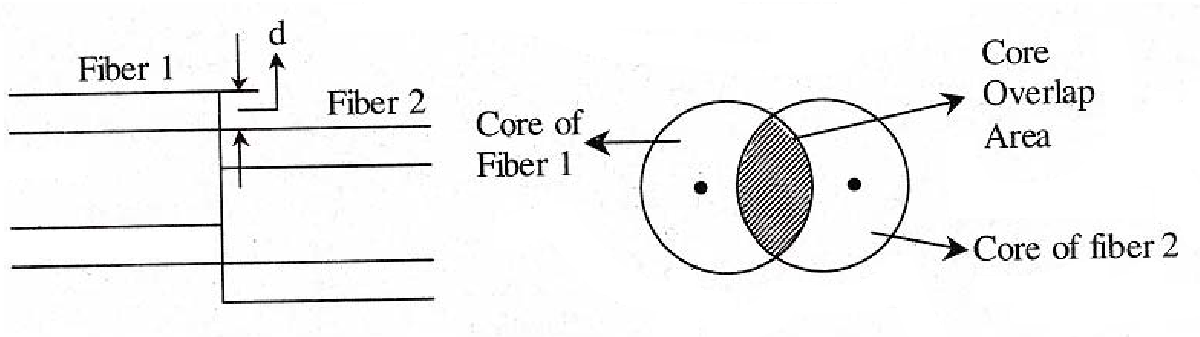
α_2 = index profile of fiber 2

(ii) Extrinsic Losses

Extrinsic losses occur due to mechanical misalignment at point of joints. They are,

(a) Lateral Misalignment

This misalignment occurs when the, fibers are displaced along the face of fiber and hence the core overlapping area is reduced from circular to elliptical form hence power loss from emitting fiber to the receiving is given below,



Lateral MisAlignment

MMGI Fiber

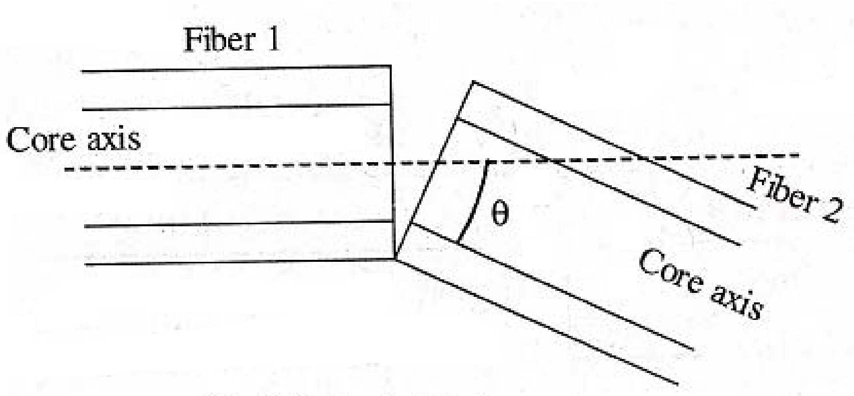
$Loss_{lat} = -10\log\left[1 - \frac{8d}{3\Pi a}\right]$

SM Fiber

$Loss_{lat} = -10\log\left[exp\left(\frac{-d}{\alpha_0}\right)^2\right]$

b) Angular Misalignment

For a perfectly matched fiber, if point of joint at which core axis of fiber 1 is at an angle with the core axis of fiber 2 then angular misalignment occurs and the result is same as due to numerical aperture mismatch.



Angular Misalignment

For MMG1 Fiber,

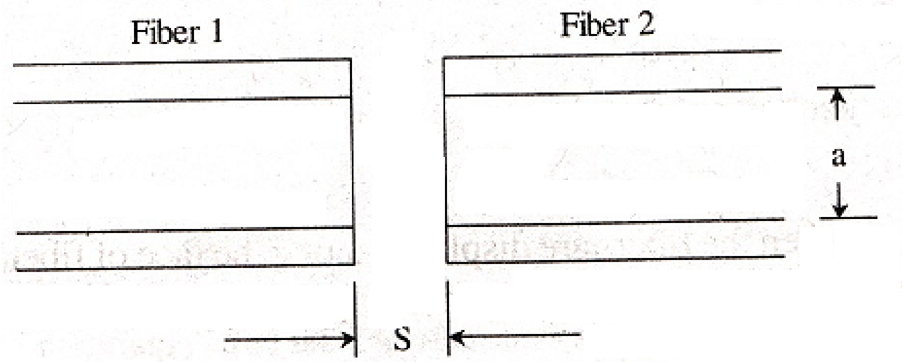
$LOSS_{ang} = -10\log\left[1 - \frac{8n\sin\theta}{3\Pi Na}\right]$

$LOSS_{ang} = -\log e^{-t^2}$

Where $t = n\Pi\alpha_0 SM(\theta)/\lambda$

(c)End separation Misalignment

When two fibers are separated longitudinally by a gap of 'S' between them ,then longitudinal end separation misalignment occurs.



End separation mis alignment

The loss for MGG1 is given by,

Loss(end) = $-\log\left[1 - \frac{S(NA)}{2an}\right]$

And for SM fiber is, Loss(end) = $-10\log[\frac{1}{s^2+1}]$ Where $S = \frac{s\lambda}{(2\Pi n\alpha^2)}$

(iii) Reflection Loss

At the surface of contact some light will be reflected back. This is called Fresnel reflection. This reflection changes the amount of power transmitted towards a receiver. The loss caused by reflection is called Fresnel loss. If the transmitted power is P_{tran} and input power at the source is P_{in} and reflected power is P_{ref} then they are related by,

Hence reflection loss is given by,

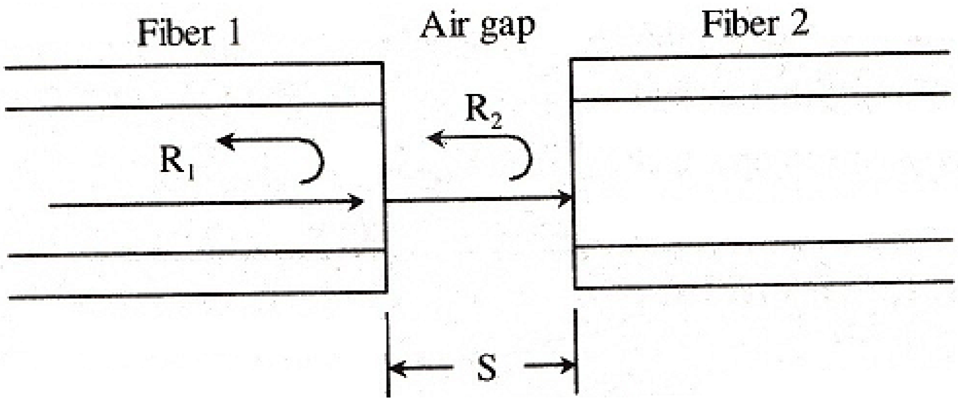
$$P_{trans} = P_{in} - P_{ref}$$

Hence reflection loss is given by,

$$LOSS_{(Fresnel)} = -10\log\left[\frac{4n_1n_2}{(n_1+n_2)^2}\right]$$

or for 2 interface reflections, $LOSS_{(Fresnel)} = -10\log(1-R)$

Where $R = R_1 + R_2 - 2\sqrt{R_1R_2}\cos(4\Pi/\lambda)$ S = The separation between two fiber. R = Total reflection. R_1 and R_2 are reflections at two interfaces



Reflection Losses