Unit 3
Optical Fiber Connectors

Optical fiber Connectors:

The optical fiber cables have been laid over too several 1000's of kilometers on earth surface. Hence it is often required to joint to two optical fibers together, to form a continuous optical wave guide. The method and technique for connecting the fibers depends on where whether a perminant joint required & easily disconnected joint is required.

The perminant joint bonding technique is called "Slice Technique" and easily disconnected joint techniques are called "connectors".

Slicing is similar to soldering in metal wires. Some of the main requirements of a good connector design are as follows:

1. Low Coupling loss: Inorder to minimizing the coupling loss, Appropriate connector is to be selected. These losses must not change significantly during operation or after numerous connects and disconnects.
2. Interchange Ability: Connectors of the same time must be compatable from one manufacture to another.
3. Easy of Assembly: A service technician should be able to readily install the connectors in a field environment i.e in a location otherthan the connector factory
4. Low environment sensitivity: conditions such as temperature, dust and moisture should have a small effect on connector loss variations.
5. Low cost & reliable constructions: The connector must have a precession suitable to the application, but its cost must not be the major factor in the fiber system

6. **Ease of connection**: Generally one should be able to connect and disconnect the connector simply by hand.

Single mode fiber Connectors: Based on the Gaussian beam model of single mode fiber fields, the following equation gives the coupling loss (in dB) between the single mode fibers that have unequal modes in diameters and other parameters.

$$L_{SM} = -10 \log \left\{ \frac{16\, n_1^2 n_3^2}{(n_1+n_3)^4} \frac{4\sigma}{q} \exp\left(\frac{-p\mu}{q}\right) \right\}$$

where $p = (k \cdot w_1)^2$; $q = G^2 + (\sigma+1)^2$,

$$\mu = (\sigma+1)F^2 + 2\sigma F G \sin\theta + \sigma(G^2 + \sigma + 1)\sin\theta \; ; \; F = \frac{d}{k w_1^2}$$

$$G = \frac{s}{k w_1^2} \; ; \; \sigma = \left(\frac{w_2}{w_1}\right)^2 ; \; k = \frac{2\pi n_3}{n_1}$$

n_1 is refractive index of the core

n_3 is refractive index of medium between fibers

λ is wavelength of light

d is lateral offset

s is longitudinal offset

θ_i is Angular Misalignment

w_1 is $\frac{1}{e}$ {mode field radius of tx fiber}

w_2 is $\frac{1}{e}$ {mode field radius of Rx fiber}

Extrinsic Coupling losses:

Coupling losses are caused by imperfect physical connections. In fiber cables coupling losses can occur at any of following 4 types of optical junctions:

1. Light source to fiber connections, fiber to fiber connections; fiber to photo detector connection & other different connections

Junction losses are caused by one of the following alignment problems.

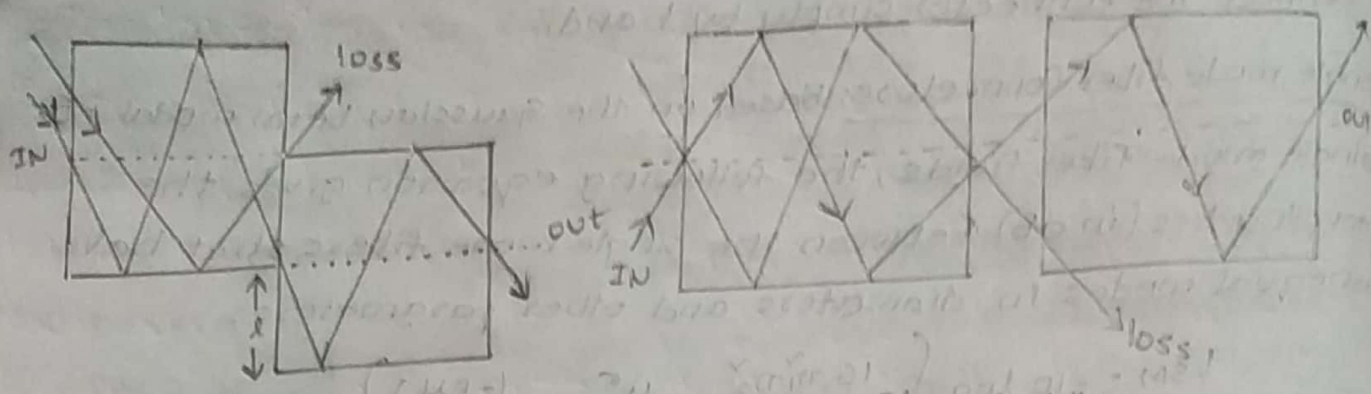


Figure 1(a)

Figure 1(b)

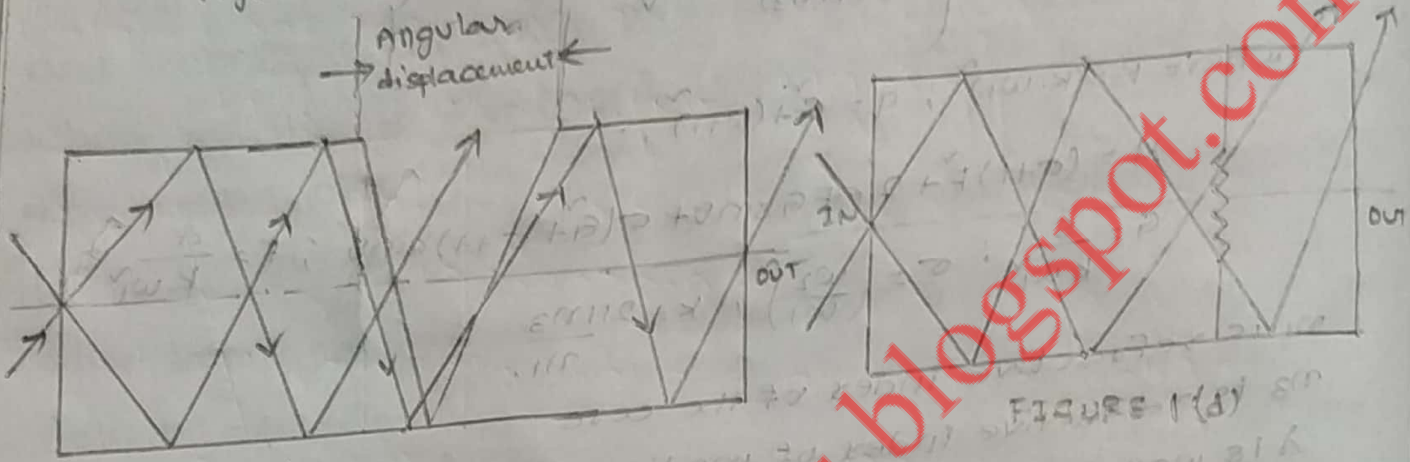


FIGURE 1(C)

FIGURE 1(d)

FIGURE-(1)

Lateral displacement: It is lateral or axial displacement between two pieces of adjoining fiber cabels.

Grap displacement: It is sometimes called end separation, the further apart the fibers the greater the loss of fiber.

Angular displacement:

This is shown in figure 1c. If angular displacement less than 2%. the loss will be less than 0.5dB.

Interfact surface finish: Ends of the two adjoining fibers should be highly polished and file together squarely.

Connector or Return loss:

If an air gap exists between the emitting surface and the fiber then power is reflected at the boundary this is shown in figure 2.

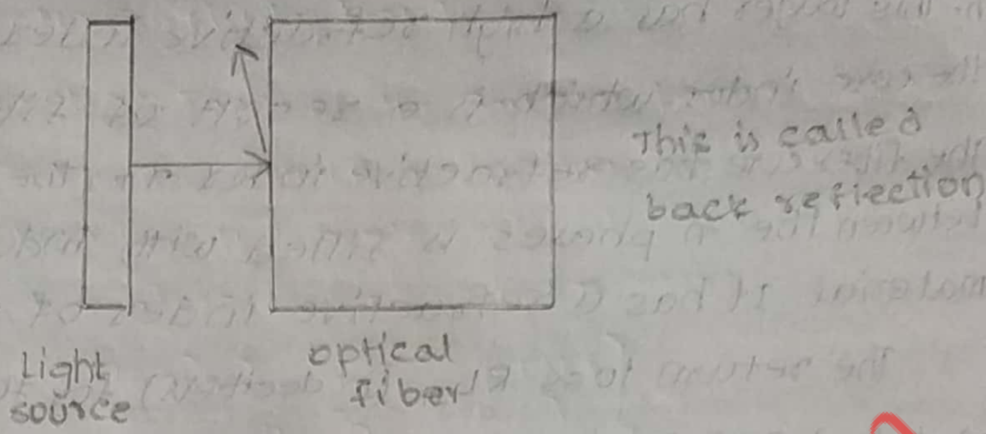
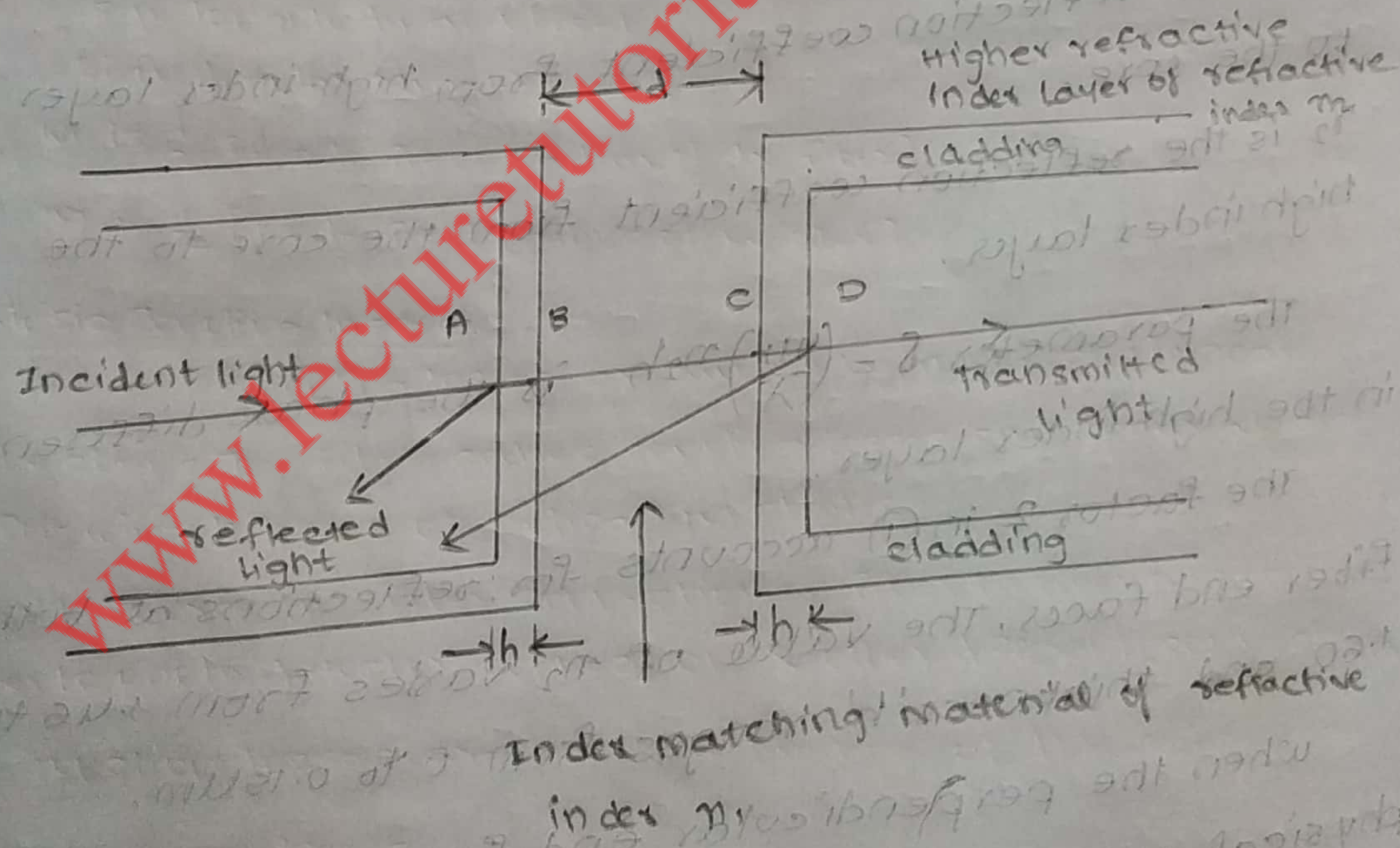


Figure 2

This is known as back reflection or return loss.

Figure (3) shows the modal of an index matched connections with perpendicular fiber end cabels.



The fiber end faces have thin surface layer of thickness h. This layer has a high refractive index n_2 relative to the core index which is a result of fiber polysterene. The fiber core has refractive index n_0, the gap width(d) between the n phases is filled with index-matching material. It has a refractive index of n_1.

The return loss RL_{IN} (in decibels) for the indexe-matched gap region is given by

$$RL_{IN} = -10\log\left\{2R_1\left[1-\cos\left(\frac{4\pi n_1 d}{\lambda}\right)\right]\right\} \quad \text{—(1)}$$

where $R_1 = \dfrac{r_1^2+r_2^2+2r_1r_2\cos\delta}{1+r_1^2r_2^2+2r_1r_2\cos\delta}$ —(2)

R_1 is the reflectivity at a single-material coated end face

$$r_1 = \frac{n_0-n_2}{n_0+n_2} \quad \text{and} \quad r_2 = \frac{n_2-n_1}{n_2+n_1} \quad \text{—(3)}$$

r_1 is the reflection coefficient from high-index layer to the core.

r_2 is the reflection coefficient from the core to the high index layer.

The parameter $\delta = \left(\frac{4\pi}{\lambda}\right)n_2 h$ is the phase difference in the high index layer.

The factor 2 in (1) accounts for reflections at both fiber end faces. The value of n_2 varies from 1.46 to 1.60 and thickness 'h' ranges from 0 to 0.15µm.

When the perpendicular end faces are indirect physical contact, the return loss RL_{PC} (in decibels) is given by $RL_{PC} = -10\log\left\{2R_2\left[1-\cos\left(\frac{4\pi n_2 2h}{\lambda}\right)\right]\right\}$

where $R_2 = \left[\frac{n_0 - n_2}{n_0 + n_2}\right]^2$

R_2 is the reflectivity and discontinuity between refractive indices of the fiber code and high index surface layer.

Fibersplicing:

The optical fiber cables have been laid over several 10,000's of kilometers on earth's surface. Hence it is often required to join two optical fibers together to form a continuous optical waveguide. The method and technique for connecting the fibers depends on whether a permenant joint is required (or) easily disconnected joint is required. The permenant bonding technique is called splice technique. splicing is similar to soldering in metal wires. splicing techniques are classified into two types

1. Fusion Splicing
2. Mechanical splicing.

Mechanical splicing is again classified into two types

(a). V-groove splicing

(b). Elastic-tube splicing

Fusion splicing: Fusion splicing is the process of joining two optical fibers end-to-end using heat

The below figure represents fusion splicing of two optical fibers.

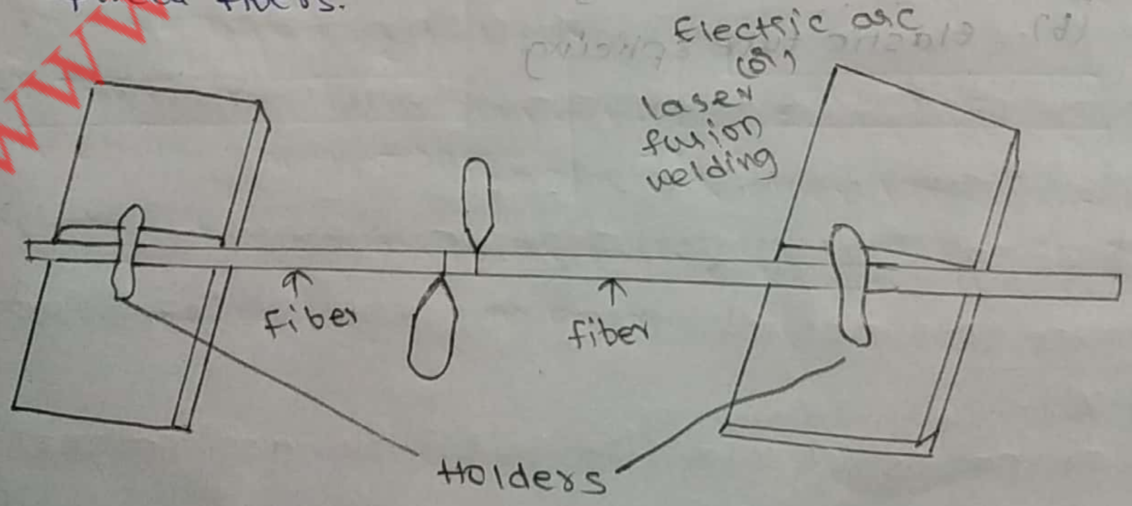


Figure 4

The fiber ends are cleaved(cut) with a precision cleaver. Inorder Not to have light scattered at the joint, the fiber ends must be flat, perpendicular to the fiber axis, and smooth. conventional griding and polishing techniques can produce a very smooth surface i.e perpendicular to fiber axis. The fibers are placed into special holders. The butt joint is then heated with an electric arc (or) a laser pulse so that the fiber ends are melted momentarily and hence bounded together. The fiber ends are inspected using a magnifying viewer

Fiber splices offer a low level of loss and a high degree of performance. Fusion splicing is used for high data rate lines.

Mechanical splicing:

For quicker fastening jobs, a mechanical splice is used ~~to~~. The mechanical splices are normally used when splices need to be made quickly and easily.

Mechanical splices are classified into

(a) V groove splicing

(b) Elastic tube splicing

(a) V groove splicing:

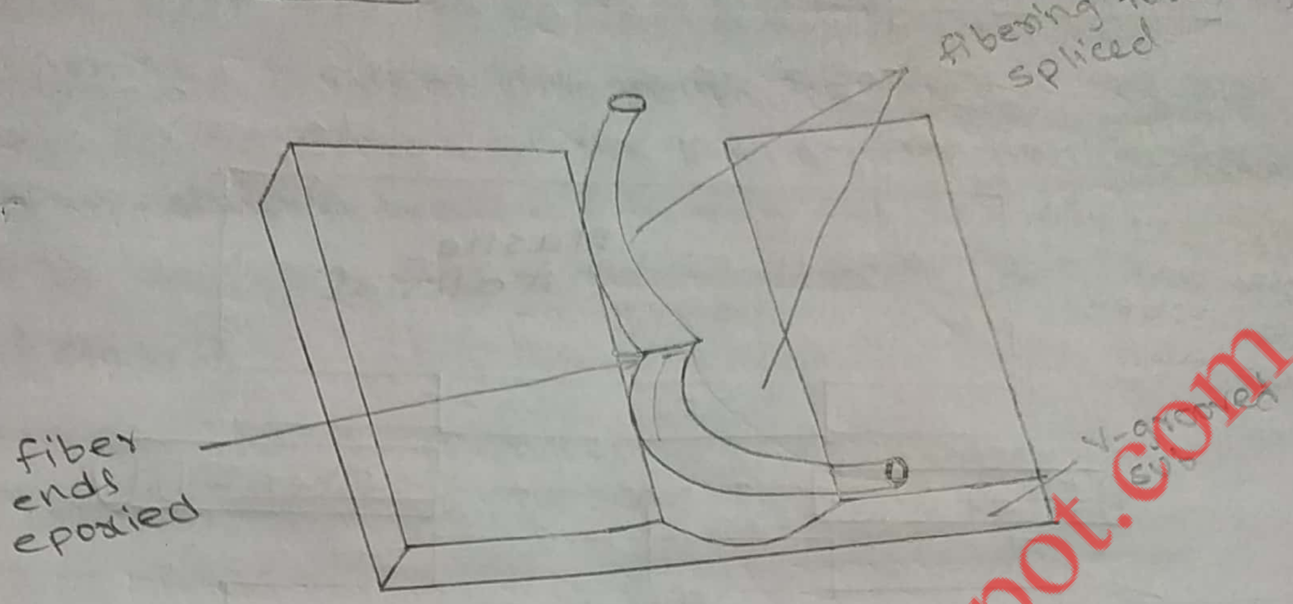


Figure 5

It is the simplest mechanical splice. The separate fibers to be join are placed in the groove. The two fibers can slide through the groove until they touch. They are then epoxied permenantly into position. If the epoxy is index matched through the fiber, even small gaps can be tolerated with little loss. They cover plate can be placed over the V-block to protect the splice further

(b) Elastic tube splicing:

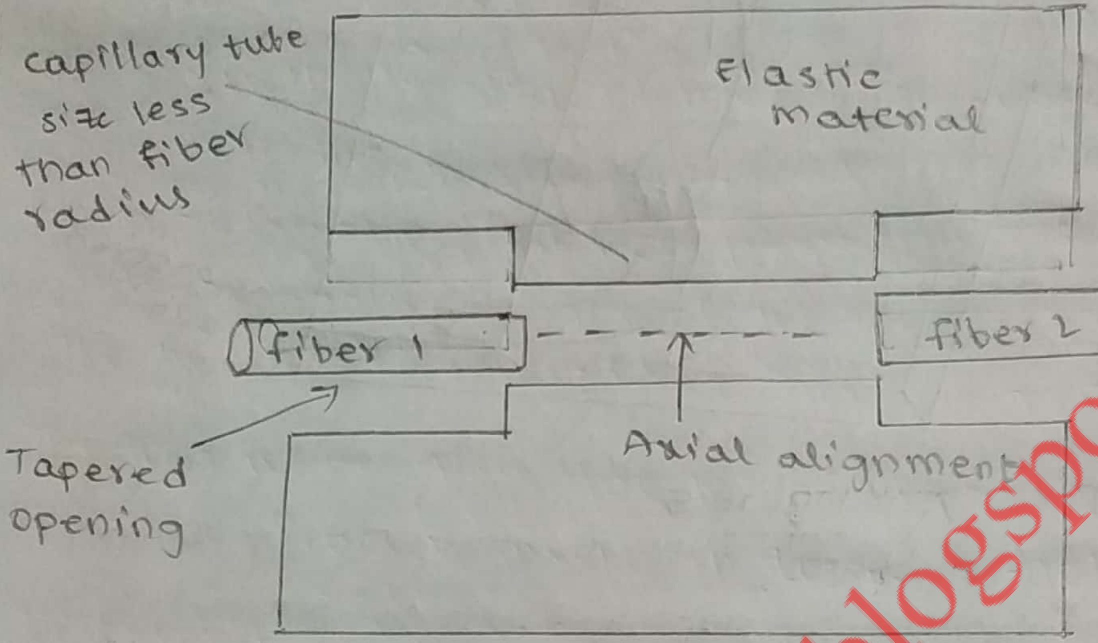


Figure 6

It consists of tube made of elastic material. The centre core diameter is slightly smaller than that of the fiber to be spliced and is tapered on each end for easy fiber insertion. when a fiber is inserted, it expands the core diameter. so that the elastic material exerts a symmetrical force on the fiber. This symmetry feature allows an accurate & automatic alignment of the axes of the two fibers to be joined. A wide range of fiber diameters can be inserted into the elastic tube.

Mechanical fiber optic slices can take as little as five minutes to make although the level of light loss is around 10%.

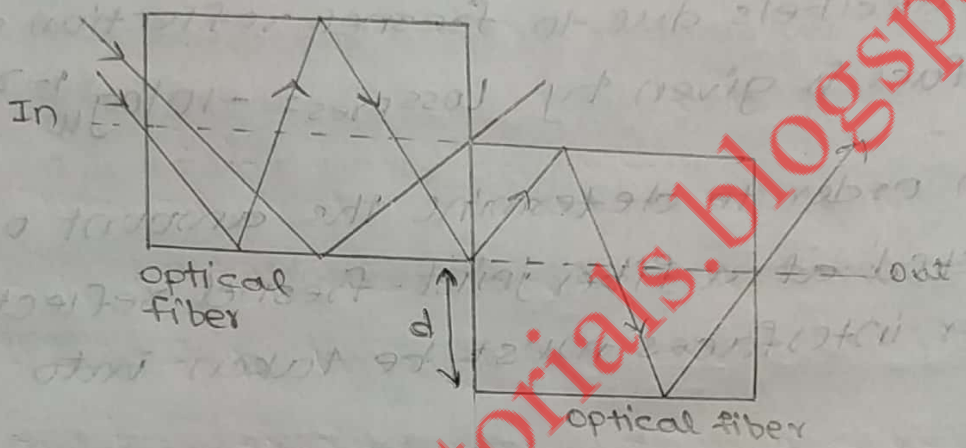
Mechanical splice may be used in applications where the splice may be permenaut

Splicing single mode Fibers:

In single mode fibers the lateral (or) axial misalignment presents the most serious loss. this loss depends on the shape of the propagating mode. for gaussian-shaped beams the loss between identical fibers is

$$L_{SM;\,Lat} = -10 \log \left[\exp\left[-\left(\frac{d}{w}\right)^2\right]\right]$$

where w is mode field radius {also called spot size}
d is lateral displacement



Lateral (or) axial misalignment
Figure

Fiber Alignment and joint loss: A major consideration with all types of fiber-fiber connection is the optical loss encountered at the interface even at the two jointed fiber ends (or) smooth and perpendicular to fiber axis, and the two fiber axis are perfectly aligned, a small portion of the light may be reflected back into the transmitting fiber giving attenuation at the joint. This phenomenon is known as Fresnel reflection. It is associated with the step changes in the refractive index at the jointed interface. {i.e glass-air-glass}

The magnitude of this partial reflection of the light transmitted through the interface may be estimated using the classical fresnel formula.

- for light of normal incidence, $r = \left(\frac{n_1 - n}{n_1 + n}\right)^2$

where r is the fraction of light reflected at a single interface.

n_1 is refractive index of the fiber core.

n is refractive index of the medium between the two connected fibers. {for air $n=1$}

- The loss in decibels due to fresnel reflection at a single interface is given by $Loss_{Fres} = -10 \log_{10}^{1-r}$

However, in order to determine the amount of light reflected at a fiber joint. fresnel reflection at both fiber interfaces must be taken into account.

There are also inherent connection problems when connecting fibers is given below.

a. Different core and cladding diameters.

b. Different numerical Apertures.

c. Different relative refractive index differences.

d. fiber faults.

- The losses caused by the above factor together with fresnel reflection loss are called <u>intrinsic joint losses</u>

Multimode fiber joints:

we consider here some of the expressions used to caluclate losses due to lateral and angular misalignment of optical fiber joints.

Lateral misalignment reduces the overlapped region between two fiber cores the lateral coupling effeciency per the two similar step index fiber is

$$\eta_{lat} = \frac{16(n_1/n)^2}{[1+(n_1/n)]^4} * \frac{1}{\pi}\left\{2\cos^{-1}\left(\frac{y}{2a}\right) - \left(\frac{y}{a}\right)\left[1-\left(\frac{y}{2a}\right)^2\right]^{1/2}\right\}$$

where n_1 is the refractive index of the core

n is refractive index of medium between fibers

y is lateral offset of fiber core axes

a is radius of the core.

The lateral misalignment loss in decibels is

$$loss_{lat} = -10\log_{10}\eta_{lat} \text{ dB}$$

The angular coupling effeciency for the two step index fibers are similar and it is given by

$$\eta_{avg} = \frac{16(n_1/n)^2}{[1+(n_1/n)]^4}\left[1 - \frac{n\theta}{\pi\, n_1(2\Delta)^{1/2}}\right]^4$$

where θ = Angular displacement in radius

Δ = relative refractive index difference for fiber

The angular missalignment loss in dB is

$$loss_{avg} = -10\log_{10}\eta_{avg} \text{ dB}$$

Single Mode fiber Joints:

Misalignment losses at connections in single mode fibers have been theoretically considered by Marcuse

loss due to lateral misalignment {also called offset} is $T_l = 2.17\left(\frac{y}{w}\right)^2$ dB

where y is lateral misalignment

w is mode field radius (or) spot size

$$w = \frac{a\left[0.65 + 1.62V^{-3/2} + 2.88V^{-6}\right]}{2^{1/2}}$$

where w is mode field radius (or) spot size in μm

a is radius of fiber core and

V is normalised frequency

loss due to Angular misalignment is

$$T_a = 2.17\left(\frac{\theta w n_1 V}{a(NA)}\right)^2 \text{ dB}$$

where n_1 is refractive index of core

NA is Numerical Aperture

loss due to mode field diameter mismatch {also called intrinsic coupling} is given by

$$\text{loss}_{int} = -10\log\left\{4\left[\frac{w_{02}}{w_{01}} + \frac{w_{01}}{w_{02}}\right]^{-2}\right\} \text{ dB}$$

where w_{01} is spot size of transmitted fiber

w_{02} is spot size of receiver fiber

1. Explain about the losses in end separation when two fibers are connected.

When two fibers are connected, the losses that occur in end separation are

i. Intrinsic losses
ii. Extrinsic losses
iii. Reflection losses

Intrinsic losses: Intrinsic losses occur due to following reasons

a. Core diameter Mismatch:

If the two fibers have different core diameters, there is optical power loss. 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 multimode fiber, the loss due to core diameter instant is given by $$\text{Loss}_{core} = -10 \log (a_2/a_1)^2$$

a_1 is core radius of transmitting fiber
a_2 is core radius of receiving fiber

b. Numerical Aperture Mismatch:

The receiving fiber has to access all the optical power emitted by the transmitting fiber. If the two fibers have different NA values, there is optical power loss. It is given by $$\text{Loss}_{NA} = -10 \log (NA_2/NA_1)^2$$

where NA_2 is Numerical Aperture of receiving fiber.
NA_1 is Numerical Aperture of Transmitting fiber.

c. Mode field Diameter (MFD) mismatch:

The loss due to MFD mismatch is given by

$$\text{Loss}_{MFD} = -10 \log \left[4 \left(\frac{w_{02}}{w_{01}} + \frac{w_{01}}{w_{02}} \right)^{-2} \right] \text{dB}$$

where w_{01} is mode field radius (spot size) of transmitting fiber
w_{02} is mode field radius of receiving fiber.

(1) An optical fiber has a core refractive index of 1.5. Two lengths of the fiber with smooth and perpendicular end faces are joined together. Assume the fiber axis are perfectly aligned, caluclate the optical loss in decibels at the joint (due to fresnel reflection) when there is a small air gap between the fiber end faces.

Sol: Magnitude of fresnel reflection at the fiber-air interface is given by

$$\gamma = \left[\frac{n_1 - n}{n_1 + n}\right]^2$$

where n_1 is refractive index of core = 1.5

n is refractive index of medium b/w two fibers, i.e for air $n = 1$.

$$\therefore \quad \gamma = \left(\frac{1.5-1}{1.5+1}\right)^2 = 0.04$$

The optical loss in decibels at the single interface is

$$Loss_{fres} = -10 \log_{10} 1-\gamma$$

$$= -10 \log_{10}(0.96)$$

$$= 0.177 \text{ dB}$$

A similar calculation can be performed for the other interface (air-fiber) The optical loss at the second interface is also 0.18 dB. Hence the total loss due to fresnel reflection at the fiber joint is 0.36 dB

(1) A step index fiber has a core refractive index of 1.5 & a core diameter of 50 μm. The fiber is jointed with a lateral misalignment ~~(at the joint)~~ b/w the core axes of 5 μm. Estimate the insertion loss at the joint due to lateral misalignment, assuming a uniform distribution of power b/w all guided modes when

a. There is a small air gap at the joint.

b. The joint is considered indexed matched

sol: refractive index of core, $n_1 = 1.5$

core diameter $2a = 50\,\mu m \Rightarrow a = 25\,\mu m$

Lateral misalignment of two fiber axes, $y = 5\,\mu m$

The coupling effeciency for a multimode step index fiber in case of lateral misalignment is

$$\eta_{lat} = \frac{16(n_1/n)^2}{[1+(n_1/n)]^4}\left\{2\cos^{-1}\left(\frac{y}{2a}\right) - \left(\frac{y}{a}\right)\left[1-\left(\frac{y}{2a}\right)^2\right]^{1/2}\right\} \cdot \frac{1}{\pi}$$

for air gap $n = 1$

(a)
$$\eta_{lat} = \frac{16(1.5/1)^2}{[1+(1.5/1)]^4}\left\{2\cos^{-1}\left(\frac{5\times10^{-6}}{50\times10^{-6}}\right) - \left(\frac{5\times10^{-6}}{25\times10^{-6}}\right)\left[1-\left(\frac{5\times10^{-6}}{50\times10^{-6}}\right)^2\right]^{1/2}\right\}\frac{1}{\pi}$$

$$= \frac{36}{39.06}\{2.94 - 0.1989\} * \frac{1}{\pi}$$

$$= 2.525 * \frac{1}{3.14}$$

$$= 0.803$$

The insertion loss due to lateral misalignment is

$$loss_{lat} = -10\log_{10}\eta_{lat}$$

$$= 0.94\,dB$$

(b)
$$\eta_{lat} = \frac{1}{\pi}\left[2\cos^{-1}\left(\frac{y}{2a}\right) - \left(\frac{y}{a}\right)\left[1-\left(\frac{y}{2a}\right)^2\right]^{1/2}\right]$$

$$= \frac{1}{3.14}\left[2\cos^{-1}\left(\frac{5\times10^{-6}}{50\times10^{-6}}\right) - \left(\frac{5\times10^{-6}}{25\times10^{-6}}\right)\left(1-\left(\frac{5\times10^{-6}}{50\times10^{-6}}\right)^2\right)^{1/2}\right]$$

$$= 0.3\{2.94 - 0.1989\} = 0.872 = 0.9$$

$$loss = -10\log_{10}(0.9)$$
$$= 0.59\,dB$$

③ Two single mode fibers with mode field diameter are 9.2μm, 8.4μm are to be connected together. Assuming no extrinsic losses. Determine the loss at the connection due to mode field diameter mismatch.

Sol: mode field diameter of transmitting fiber = 9.2μm

Mode field diameter of receiver fiber = 8.4μm

loss due to mode field diameter mismatch

$$loss_{int} = -10\log\left[4\left(\frac{\omega_{02}}{\omega_{01}} + \frac{\omega_{01}}{\omega_{02}}\right)^{-2}\right] dB$$

$$= -10\log\left\{4\left(\frac{9.2/2}{\left(\frac{8.4}{2}\right)} + \frac{8.4/2}{\left(\frac{9.2}{2}\right)}\right)^{-2}\right\}$$

$$= -10\log\left\{4\left(\frac{4.6}{4.2} + \frac{4.2}{4.6}\right)^{-2}\right\}$$

$$= -10\log(0.99)$$

$$loss_{int} = 0.035\,dB$$

1. Distinguish between Mechanical splicing and Fusion splicing

Mechanical splicing	Fusion splicing
1. Low initial investment	High initial investment
2. Costs more per slice	Costs less per slice
3. Produce higher splice loss	produce Lower splice loss
4. More reflectance	less reflectance
5. works with both single mode & multimode fibers.	works with single mode fibers
6. Takes less time	Takes more time
7. less Expensive	More Expensive
8. For indoor transmission cabels	for outdoor, long distance applications and in factories

2. write the difference between single mode fiber joints and multi mode fiber joints

single mode Fiber Joints	Multimode fiber Joints
1. The diameter of the core to which light is propagated is 8microns to 10 microns.	The diameter of the core through which light is propagated is upto 62.5 microns & more
2. The core to cladding diameter ratio is 9microns to 125microns.	The core to cladding diameter ratio is 62.5 microns to 125microns
3. The value of Δ is less	The value of Δ is more compared to single mode fiber joint
4. The feeding connectors used are FC field mountable connector SC space connector LC little connector	The connectors used are straight ST- strip Tip Connectors
5. The Intrinsic factor in this case is mode field diameter (MFD)	The Intrinsic factors are core diameter and NA

4) Two multimode step index fibers have numerical apertures of 0.2 and 0.4 respectively and both have the same core refractive index of 1.48. Estimate the insertion loss at a joint in each fiber caused by a 5° Angular misalignment of the fiber core axes. It may be assumed that the medium between fibers is air.

A: Numerical Aperture, NA = 0.2 and 0.4

refractive index of core $n_1 = 1.48$

Angular misalignment, $\theta = 5°$

Angular coupling effeciency for two similar step index fibers is

$$\eta_{ang} = \frac{16(n_1/n)^2}{[1+(n_1/n)]^4}\left[1 - \frac{n\theta}{\pi n_1 (2\Delta)^{1/2}}\right]^4$$

since the medium between the fibers is air, $n = 1$

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

$$\eta_{ang} = \frac{16(n_1/n)^2}{[1+(n_1/n)]^4}\left[1 - \frac{n\theta}{\pi (NA)}\right]^4$$

$1° \rightarrow 60$ radians

$\frac{\pi}{180} \times 5 = \frac{\pi}{36}$

$$= \frac{16(1.48/1)^2}{(1+1.48)^4}\left[1 - \frac{(1)\left(\frac{\pi}{36}\right)}{\pi(0.2)}\right]$$

$\eta_{ang} = 0.83$

The insertion loss due to Angular misalignment is

$$= -10\log_{10}\eta_{ang}$$

$$= -10\log_{10}(0.83)$$

$loss_{ang} = 0.96 dB$

for NA = 0.4 $\eta_{ang} = \frac{16(1.48)^2}{(2.48)^4}\left[1 - \frac{1}{36 \times 0.4}\right]^4$

$= 0.926 \times 0.74 = 0.69$

$loss_{ang} = 1.61 dB$

5. A single mode fiber has the following parameters
Normalised frequency $(V) = 2.40$; Numerical Aperture $(NA) = 0.1$
core diameter $(2a) = 8\mu m$; core refractive index $(n_1) = 1.46$
Estimate the total insertion loss of a fiber joint with a lateral misalignment of $1\mu m$ and an angular misalignment of 1°.

Sol: Given normalised frequency, $V = 2.40$ $\quad y = 1\mu m$

Numerical Aperture $(NA) = 0.1$

core refractive index $(n_1) = 1.46$

core diameter $(2a) = 8\mu m \Rightarrow a = 4\mu m$

$$T_l = 2.17\left(\frac{y}{\omega}\right)^2 \text{ dB}$$

$$\omega = \frac{a\left(0.65 + 1.62V^{-3/2} + 2.88V^{-6}\right)}{2^{1/2}}$$

$$= \frac{4\times10^{-6}}{\sqrt{2}}\left\{0.65 + 1.62(2.40)^{-3/2} + 2.88(2.40)^{-6}\right\}$$

$$= 3.11\times10^{-6}$$

$\omega = 3.11\mu m$

$$T_l = 2.17\left(\frac{1}{3.11}\right)^2$$

$$T_l = 0.224 \text{ dB}$$

The loss due to Angular misalignment $\quad T_a = 2.17\left[\frac{\theta \omega n_1 V}{a(NA)}\right]^2 \text{ dB}$

$$T_a = 2.17\left[\frac{\frac{\pi}{180} * 3.11 * 1.46 * 2.40}{4 * 0.1}\right]^2$$

$$T_a = 0.49 \text{ dB}$$

Hence the total Insertion loss $T_t = T_l + T_a$

$$= 0.224 + 0.49$$

$$T_t = 0.71 \text{ dB}$$

Optical Fiber 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 choosen as per the requirement and cost.

- Various fiber optic connectors from different manufacturer are available SMA 906, ST, Biconic, FC, D4, HMS-10, SC, FDDI, ESCON, EC|RACE, LC, MT.

Principles of good connector design:

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

Connector Types:

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

Butt Joint Connectors

Fiber is epoxied into precision hole and ferrules are 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| Biconical

- In straight sleeve mechanism, the length of sleeve and guided ferrules determines the end separation of two fibers.

The below figure shows the straight sleeve alignment mechanism of fiber optic connectors.

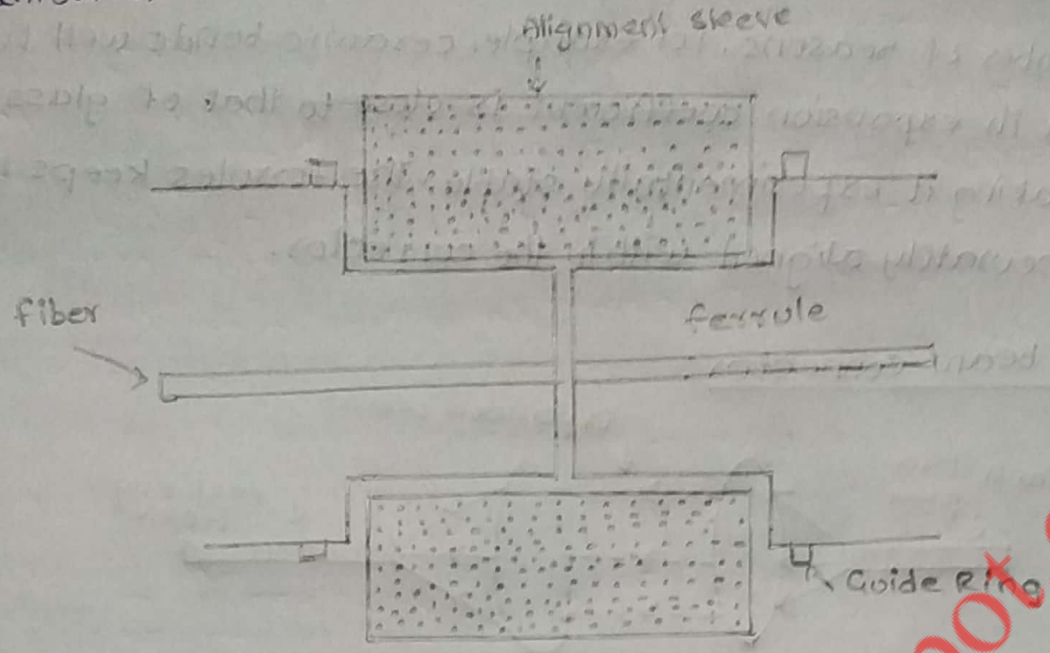


FIGURE: straight sleeve connector

- In tapered sleeve & biconical connector mechanism, a tapered sleeve is used to accomodate tapered ferrules. The fiber end separations are determined by sleeve length and guide rings.

→ The below figure shows the tapered sleeve connector

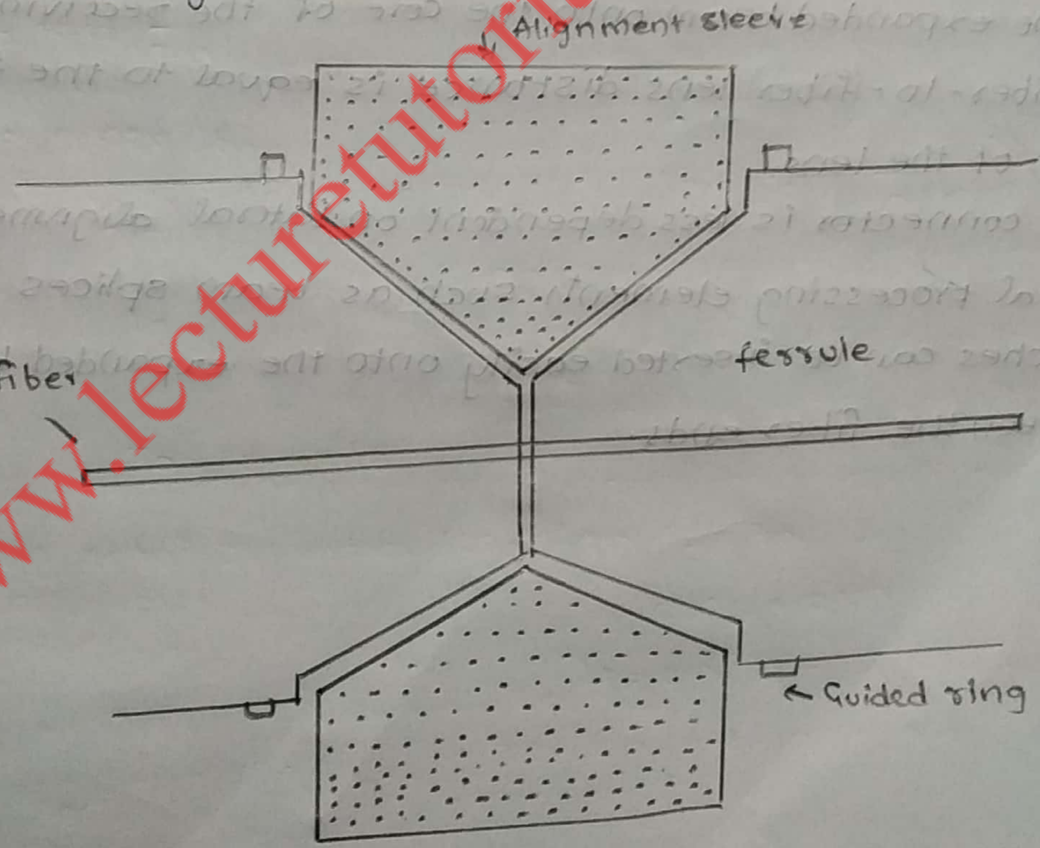
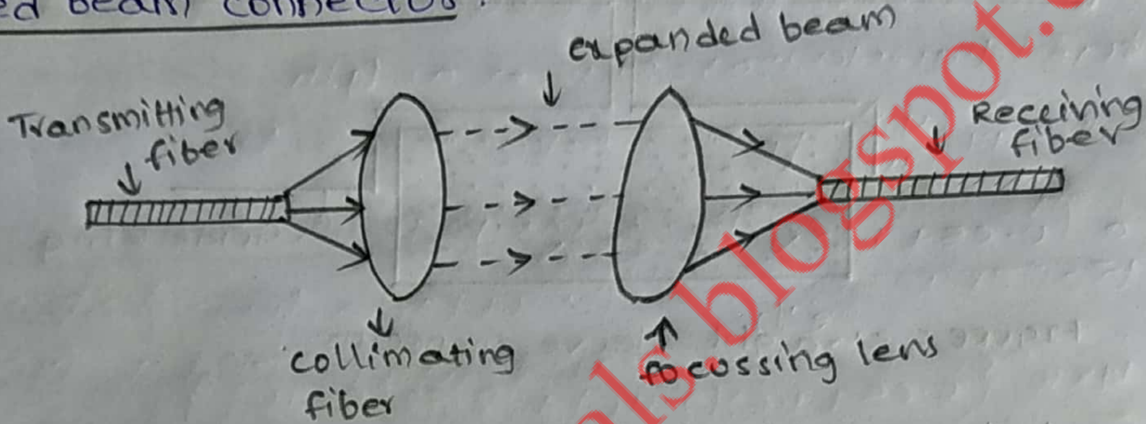


Figure: Tapered sleeve Connector

• Ferrules can be made of glass, plastic, metal or ceramic material. Ceramic is currently considered the best material for a number of reasons. For example, ceramic bonds well to glass and its expansion coefficient is close to that of glass fibers, making it experimentally stable. The ferrules keeps the fibers accurately aligned with in the connector.

Expanded beam connector:



Above figure represents an expanded beam connector. It uses lenses on the ends of the fibers. These lenses either collimate the light emerging from the fiber transmitting or focus the expanded beam onto the core of the receiving fiber.

• The fiber-to-~~fiber~~ lens distance is equal to the focal length of the lens.

→ The connector is less dependent on lateral alignments.

Optical processing elements such as beam splices and switches can be inserted easily onto the expanded beam between the fiber ends.