Chapter 8

Couplers and connectors

- Connections are normally quite simple in metallic systems. Wires can be spliced very easily by soldering.
- The splice can even be undone, merely by melting the solder.
- The losses in a solder joint are so small that they are not usually considered in the system design.
- Removable connectors for wires are also simple, easy to attach, reliable, economical, and virtually lossless.
- The favorable attributes of wire connectors are not shared by their fiber counterparts.
- We shall see what the problems are in splicing and connecting fibers and how these problems can be overcome with sufficient care.

- **Fiber-to-fiber connections are needed for a variety of reasons.**
- Several fibers must be spliced together for links of more than a few kilometers because only limited continuous lengths of fiber are normally available from manufacturers.
- Moderate lengths of fiber are easier to pull through ducts than very long cables are, and moderate lengths simplify direct burial or aerial installations.
- Coupling of light from a source into a fiber can be very inefficient. We evaluate source-coupling-losses and describe techniques for reducing them.
- At the receiver, light is coupled from the fiber onto the detector surface. This surface can be chosen to be larger than the fiber core, resulting in very efficient coupling.
- A small loss due to **reflections** at the fiber-to-air and air-to-detector interfaces does occur.
- It can be removed by filling the air gap with index-matching material or by antireflection-coating the detector surface. In any case, detector coupling is not difficult and need not be discussed further.

8-1 CONNECTOR PRINCIPLES

- Losses in fiber-to-fiber connections arise in a number of ways.
- Core **misalignments** and **imperfections**, illustrated in Fig. 8-1, are major factors.
- A perfect joint would require:
    - lateral (or axial) **alignment**,
    - **angular** alignment (parallel fiber axes),
    - contacting ends (no gap), and
    - smooth, parallel ends.
- Coupling efficiency may be reduced when fibers that have different numerical apertures or core diameter are connected.
- More loss is present when core having elliptical (rather than circular) cross sections are attached with their major axes aligned.
- If core is not centered in the cladding and if the outside of the cladding is used as the reference for aligning the joint, then more loss occurs.
- With care, these problems can be minimized. Producing splicing with losses of the order of 0.1 dB and reusable connectors with losses less than 1 dB.

The **factors**, which should be in mind about the loss in the system.

- **Lateral Misalignment**
- **Angular misalignment.**
- **End Separation**
- **Smooth and parallel Ends**
- **Connecting different fibers.**

Lateral Misalignment

- A simple model assumes that the power is uniformly distributed over the fiber core. This approximation is most suitable for multimode SI fiber.
- With this assumption, the lateral misalignment loss is simply due to the no overlap of the transmitted and receiving fiber cores.

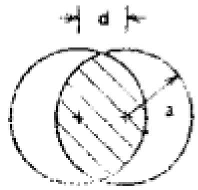


Fig 8.2 Overlap of transmitting and receiving fibers. The cores are offset by distance d.

Angular misalignment.

- The coupling efficiency due to small angular misalignments of the multimode SI fibers.
- The efficiency was found by computing the overlap of the transmitting and receiving cones.

End Separation

- When there is a gap between the fibers being joined, **two** distinct loss phenomena occur.
- **First**, there are two boundaries between the fiber medium and air. In Section 3-5 we computed a reflectance of 4% (0.177 dB) at an air- glass interface, so the two reflecting surfaces together contribute about 0.35 dB loss.
- One way to eliminate this loss is to fill the gap with an **index-matching fluid**, a transparent fluid whose index of refraction equals that of the fiber core.
- This is often (but not always) done in practical splices and connectors. As indicated in Fig. 8.7, the fluid increase the sensitivity of the connection to angular misalignment.

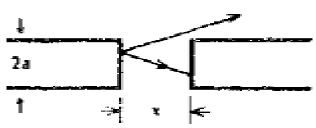


Figure 8-9 A gap allows some of the transmitted rays to escape.

- The **second loss** mechanism is sketched in Fig. 8-9.
- When a gap is present, some of the transmitted rays are not intercepted by the receiving fiber.
- As the gap increases, larger amounts of the transmitted power miss the receiving core because of the beam divergence.
- Fibers with larger NA will have greater separation losses simply because their beams diverge quicker.
- An index-matching fluid will decrease the gap loss. This is in addition to the reduction in reflection loss because of the fluid.
- This behavior can be explained by referring to Section 2-1, where we found that rays traveling from a high-index medium (the fiber core) to a lower-index one (air) will be bent away from the normal (as shown in Fig. 8-11),

- The radiated beam diverges faster on the air region than in the fiber. The fluid keeps this from happening. With less beam divergence more of the transmitted rays are intercepted by the receiving fiber.

Smooth and parallel Ends

- Scattering from **rough end** face would cause appreciable loss.
- **Non parallel ends**, formed by end surface that are not at right angles to the fiber axis also add to the loss of a connection.
- Matching fluid tends to solve these problems by filling in the ragged deviations from flatness and by effectively removing the tilt.

Connecting different fibers.

- Connecting between fibers having different NA or different core diameters are common.
- Eg. pigtailed source may be available with a fiber that is different from the one being used for the information channel.
- Unintended diameter differences between fibers of the same construction are also possible.

8-2 FIBER END PREPARATION

- The **two distinct methods** of fiber end preparation are:
    - *scribe-and-break* and
    - *lap-and-polish*

Scribe-and-break

- **Scribe-and-break** is practical when fibers are to be spliced, while lap and-polish is required when the fiber end is **permanently attached** to the body of a connector. The procedures we will describe first are applicable to **all-glass fibers.**

- In both methods the fiber must **first be bared**. Any plastic jacketing material, Kevlar stranding, and buffering can be removed by using **wire strippers**, razor blades, or some other sharp tool.
- In removing the buffer, great care must be taken to **prevent scratching** the surface of the cladding.
- In place of mechanical stripping, a chemical such as **methylene chloride** can be used to dissolve the coating with care.
- The bared glass fiber should next be **chemically cleaned** (for example, it could be wiped with isopropyl alcohol).
- In the **scribe-and-break** method, the outer edge of the cladding is nicked by a hard tool, such as a diamond-edge blade (or a sapphire or tungsten-carbide blade).
- The blade can be pulled across a stationary fiber, or the fiber can be pulled across a fixed blade.
- In either case, the fiber should be under moderate tension during cutting.
- After nicking, the tension is increased, by pulling until the fiber breaks.
- A force of just over 1.47 N (0.15 kg or 0.33 Ib of force) is typical.
- When performed properly, this technique produces a flat, mirror-finish surface.
- Trained personnel can complete this procedure by hand in just a few minutes, obtaining smooth end faces that are perpendicular to the fiber axis.
- Commercial equipment is also available that perform mechanically.
- Regardless of the method used, the end must be **carefully inspected** to verify that a smooth, clean fracture has been obtained.

- The **scribe-and-break** technique is the quickest and cheapest method of preparing fibers for connection.

- When the fiber is to be part of a demountable connector, however, the **lap-and-polish** procedure may be followed.
- A number of different connectors exist, each with an attachment and polishing procedure peculiar to the particular design.
- A **generalized preparation procedure** can be described that applies to most connectors.
- The bared fiber must be inserted into a **ferrule** (usually metal, ceramic or plastic), which will hold the delicate fiber in place, protect it, and mechanically position and align the fiber to prevent the losses discussed in the preceding section.
- The ferrule is basically a cylindrical tube with a small hole in one end for the fiber and a larger hole in the other end for the cable jacket. Figure 8-18 illustrates the basic concept.
- In a precision design, a **watch jewel** placed inside one end of the ferrule accurately positions the fiber.

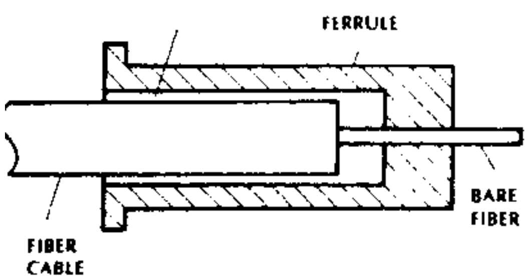


Figure 8-18 Attaching a fiber to a ferrule.

- At this point in the end preparation, the fiber protrudes from the ferrule.
- The bare fiber and its jacketing are epoxied to the ferrule, forming a permanent bond.
- An epoxy head is left around the protruding fiber.
- A removable lapping tool, designed to hold the ferrule securely during polishing, is then attached to the ferrule.
- It guides the fiber as it is moved across abrasive paper, keeping the fiber perpendicular to the flat **grinding** surface.

- The fiber is ground by successively finer abrasive until a polished surface remains. Water is used to lubricate and cool the fiber and to flush residual particles away.
- The lapping tool, ferrule, and fiber should be rinsed before progressing from one abrasive to another.
- The final finishing is done with a **polishing paste** having suspended particles of 0.3- 1 μm diameter.
- After a smooth surface has been obtained, the polishing tool is removed from the assembly.
- The flat end of the fiber is now flush with the end of the ferrule and perpendicular to the fiber axis, completing the lap-and-polish procedure.

- Plastic-cladded silica and all-plastic fibers are usually prepared by polishing because plastic does not fracture smoothly like glass.

8.3 SPLICES

- Splices are generally permanent fiber joints.
- Basic splicing techniques include **fusing** the two fibers or **bonding** them together in an alignment structure.
- The bond may be provided by an adhesive, by mechanical pressure, or by a combination of the two.

Fusion Splicing

- Fusion splices are produced by welding two glass fibers, as sketched in Fig. 8-20.
- Commercial fusion machines use an electric arc to soften the fiber ends.
- The ends are prepared by the scribe-and-break method.
- Alignment is obtained by adjusting **micromanipulators** visually inspecting with a microscope.
- can be checked by monitoring the power transmitted past the joint before the fibers are fused.
- If the transmitter and receiver are far from the splice joint (say, a few hundred meters or more), then this can be a difficult and time-consuming measurement.
- The solution to this problem is the *light injection and detection* (LID) system.
- In the LID arrangement, light is inserted into one of the fibers close to the splice joint (about 10-20 cm) and extracted for detection from the other fiber (again close to the joint).
- In many single-mode fibers the buffer coating is transparent so that it need not be removed for the LID coupling.
- On the other hand, some coatings are covered with a dye (for identification purposes) that may be opaque. If this is the case, the coloring must be removed. A solvent such as acetone will usually work for removal of the dye.

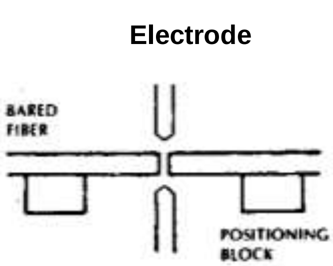
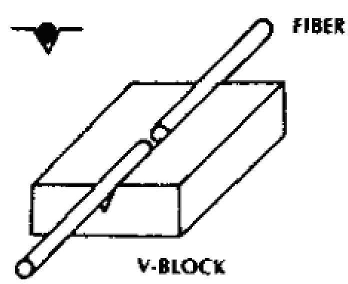


Figure 8-20 Electric-arc fusion.

- Fibers are sometimes packaged in a ribbon containing multiple fibers. Splicing these fibers one at a time is very time consuming.
- To overcome this problem, **fusion splicers** have been developed which fuse all the fibers in the ribbon simultaneously.
- The fibers are aligned mechanically and a single arc is generated that heats all fibers evenly, fusing them all at the same time.
- During fusion, surface tension tends to align the fiber axes, minimizing lateral offset.
- Splices produced by commercial fusion equipment have losses less than 0.25 dB. With care, losses less than 0.05 dB can be obtained.
- The splice area is protected by covering with such materials as RTV, epoxy, and heat-shrinkable tubing.
- Fusion works well with all-glass fibers, both multimode and single mode.

Adhesive Splicing

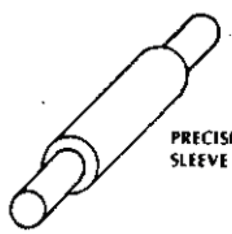
- A number of **alignment configurations** have been suggested for splices by using adhesive bonding.
- Some of them are sketched in Fig. 8-21. Each of these structures mechanically aligns the fibers and provides strength to the joint.
- The fibers are held in place by **epoxy**. Because the epoxy must be cured, these splices cannot be used immediately.
- **Curing times** can be reduced by application of heat or, for some epoxies, exposure to ultraviolet radiation.
- The **V-block** is probably the simplest mechanical splice. The bared fibers to be joined are placed in the groove.
- Angular alignment is particularly well controlled. The two fibers can **slide in** the groove until they touch.



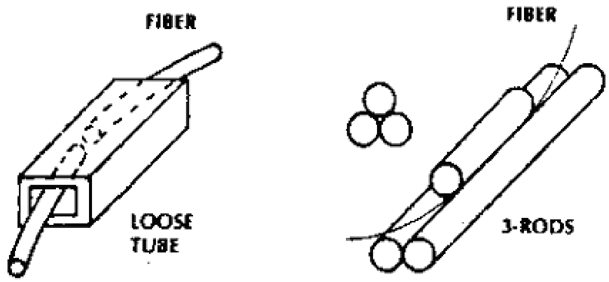
- They are then epoxied permanently into position, so end-separation errors are minimal.

- If the epoxy is **index matched** to the fiber, even small gaps can be **tolerated** with little loss.
- Lateral misalignment would be negligible in the groove if both fibers had the **same core and cladding** diameters and if the cores were centered within the cladding.
- Offset cores can be detected by rotating the output fiber while monitoring the transmitted power.
- Identical, well-constructed fibers would produce the same output power for all orientations.
- None of the splices in Fig. 8-21 can compensate for non-centered cores. A cover plate can be placed over the V-block to protect the splice further.

- The **precision sleeve**, shown in Fig. 8-21, has a central hole just large enough for insertion of the cladded fiber. The ends of the sleeve are tapered to accept the fiber more easily.
- An index-matching epoxy can be applied to the fiber ends before insertion into the sleeve.



- Alternatively, a hole drilled into the side of the sleeve can be used for **observing** the contacting fibers and for **injecting epoxy** or an index-matching fluid.
- Sleeves may be metal or plastic. In one splicing technique, the sleeve material is a compliant plastic.
- When the fibers are inserted into the slightly undersized hole, the resilient material forces both fibers to align along a common central axis.
- Even fibers with unequal cladding diameters will have their axes laterally aligned.



- The **loose-tube splice**, illustrated in Fig. 8-21, is interesting. Two fibers are inserted into the freely suspended tube. Bending the fibers causes the tube to rotate, aligning the fibers in one of the corners. Epoxy secures the aligned fibers.
- **Three precision glass** or metal rods can be positioned as shown in Fig. 8-21 to align fibers.
- Rod diameters are chosen so that the hole formed at the junction is just large enough to accept the fiber.
- Index-matching epoxy is applied to the fibers and they are inserted into the hole until they touch.
- A heat-shrinkable sleeve is placed over the assembly. When heat is applied, it secures the rods and squeezes them against the fiber.

Bend fused-rod splice

- A splice related to those just described is sketched in Fig. 8-22.
- Four glass rods are fused together, forming four V-grooves.
- The spacing between the rods is larger than the fiber. The ends of the bundle are bent so that an entering fiber will be forced into one of the grooves, very much as in the loose-tube arrangement.
- The glass guide can be **pre-filled** with an index-matched, ultraviolet (UV)-curable epoxy.
- Prepared fibers are pushed into the flared openings until they touch. The epoxy is exposed to ultraviolet radiation to secure the bond.

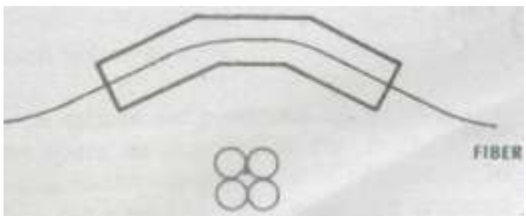


Figure 8-22 Bent, fused-rod splice.

Rotary mechanical splice

- A splicing technique that does not use a precision-machined structure to align the fibers directly is the ***rotary mechanical splice,*** sketched in Fig. 8-23.
- In this splice, three rods in a **bronze alignment clip** secure the **ferrules**.
- The holes in the ferrules are not centered, so that the two fibers can be aligned by **rotating** the ferrules while monitoring the transmitted power.
- Since the ferrules are transparent, they can be fixed in place with an UV-curable epoxy after alignment.
- The rotary splice is suitable for connecting single-mode fibers because of the active alignment. Losses of less than 0.1 dB can be expected.

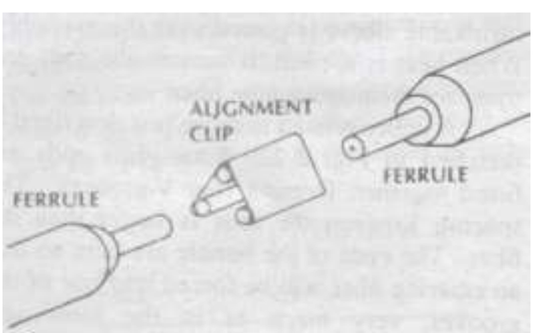


Figure 8-23 Rotary mechanical splice. (From AT&T manufacturer's literature. American Telephone and Telegraph Co., New York, 1985.)

- It should be apparent, from the sampling just presented, that many splicing techniques exist.
- Designers can choose from a variety of methods already developed or can use their ingenuity to develop new and improved versions.
- Good mechanical splices produce losses from less than 0.1 dB to just under 1 dB when identical fibers are connected.
- To obtain the lowest losses, it is imperative that the fiber ends be kept clean.
- It is clear, by comparing the efficiency of actual splices with the misalignment losses enumerated in the preceding section, that mechanical splices provide a high degree of precision positioning.
- After fibers have been attached, any bare fiber remaining should be recoated (e.g., by covering with epoxy, lacquer, or RTV). The coating will protect the fiber from abrasion, which could lead to fracture.

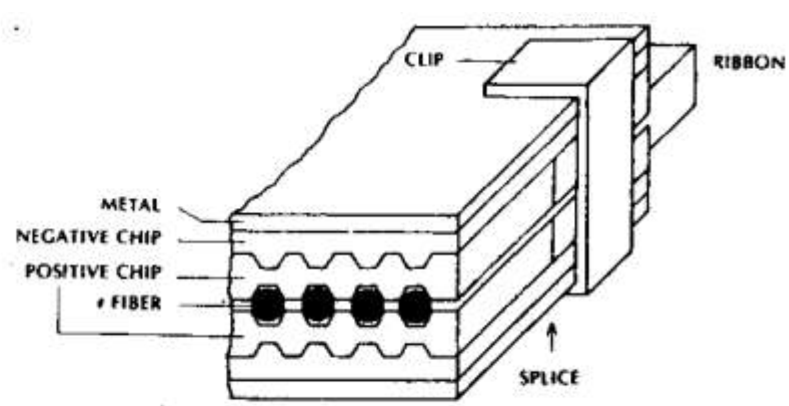


Figure 8-24 Ribbon splice, cutaway view. The position where the fibers meet is marked by the arrow.

8-4 CONNECTORS

Re-matable attachments have tested the ingenuity of connector designers and the pocketbooks of fiber users. The stringent mechanical tolerances required for efficient coupling make quality connectors difficult to design and expensive to build.

Requirements for a good connector include the following:

1. *Low loss.* The connector assembly must ensure that misalignments are minimized automatically when connectors are mated. Unlike the situation in some splicing arrangements, the joint is not available for viewing within a connector, and positioning corrections cannot be made. A system containing several connectors must have efficient ones. For example, if five connectors are used and each has a 2-dB loss, the total loss will be 10.dB, reducing the power available to the receiver by a factor of 10.
2. *Repeatability.* The coupling efficiency should riot change much with repeated matings.
3. *Predictability.* The same efficiency should be obtained if the same combinations of connectors and fibers are used. That is, the loss shoifld be relatively in sensitive to the skill of the assembler.
4. *Long life.* Repeated matings should not degrade the efficiency or strength of the connection. The loss of a mated connector should not change with time.
5. *High strength.* The connection should not degrade owing to forces on the connector body or tension on the fiber cables.
6. *Compatibility with the environment.* The connection may have to withstand large temperature variations, moisture, chemical attack, dirt, high pressures, and vibrations.
7. *Ease of assembly.* Preparing the fiber and attaching it to a ferrule should not be difficult or time consuming.
8. *Ease of use.* Mating and unmating the connection should be simple.
9. *Economy.* Precision connectors are expensive. Cheaper connectors, normally plastic, may not perform as well.

Most connectors are designed to produce a butt joint, placing the fiber ends as close together as possible. Butt designs include the straight-sleeve, tapered-sleeve, and overlap connectors.

A lensed connector is an alternative to the butt configuration.

The connector assemblies for general approaches are discussed:

Butt connectors generally consist of a ferrule for each fiber and a precision sleeve into which the ferrules fit.

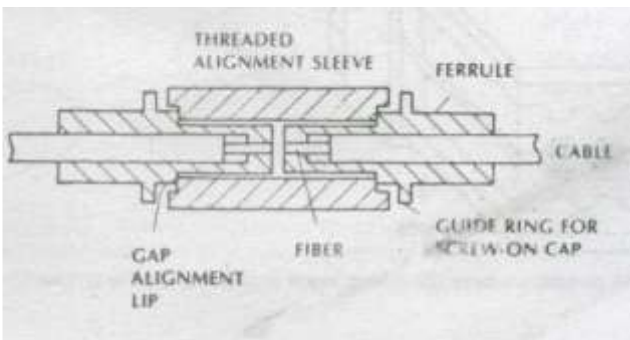
Figure 8-25 illustrates the straight-sleeve concept. Some straight ferrules are designed like SMA coaxial connectors.

Axial and angular alignment are obtained from the smooth fit of the ferrules into the tubular sleeve.

Close tolerances are obviously required. The end separation is determined by the length of the ferrule beyond a gap alignment lip and by the length of the sleeve.

Threaded caps fit against a guide ring and screw onto the sleeve, securing the connection.

The cable in Fig. 8-25 can be epoxied to the tube, crimped to it, or both, to provide strength.



An alternative design permits the Kevlar braid to be crimped to the ferrule, as sketched in Fig, 8-26, for added strength.

Tension on the cable is transferred to the strong Kevlar member, not to the fragile fiber, providing strain relief.

The SMA fiber connector is one of the oldest types, developed in the late 1970s but still in use.

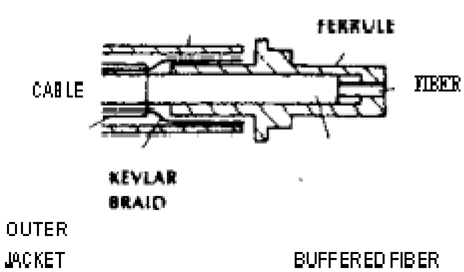


Figure 8-26 The Kevlar-braid strength member can be crimped to the ferrule.

Tapered-sleeve *(biconical)* connectors, illustrated in Fig. 8-27, can have molded plastic parts.

The most popular form of biconical connector was developed by **Bell Laboratories in 1976** and is spring loaded to reduce the force between the two mating fibers.

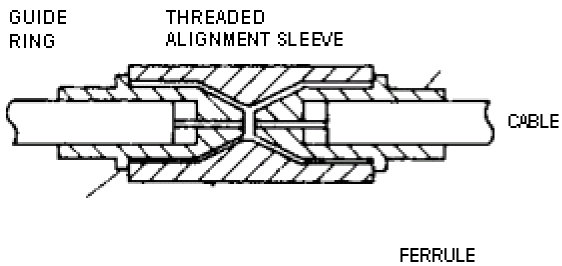


Figure 8-27 Tapered-sleeve connector. Caps fit over the ferrules, rest against the guide rings, and screw onto the threaded sleeve to secure the connection.

Quicker mating and remating are possible with non-screw devices such as the ST connector. This is a keyed and spring-loaded assembly (as illustrated in Fig. 8-28), which attaches to a coupling bushing much like a coaxial BNC connector.

The spring is attached to the ferrule in such a way that the ends of the connector make contact, but the force between the fibers is determined by the spring tension (not by the tightness of the end caps or other securing mechanism).

The key ensures that the fiber will not rotate between multiple matings, yielding a consistent insertion loss. The ST is a physical-contact connector.

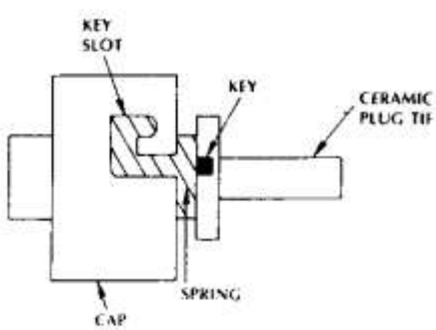


Figure 8-28 The ST type connector is keyed and spring loaded.

A lensed connector is shown schematically in Fig. 8-30. The expanding beam radiating from the transmitting fiber is collimated by a lens. The fiber-to-lens distance is equal to the focal length, as required for collimation. An identical arrangement exists at the receiver.

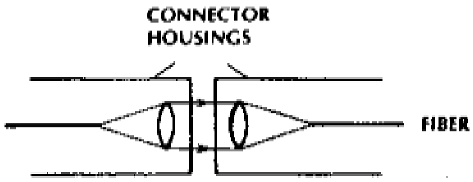


Figure 8-30 Lensed connector.

Lensed connectors have several disadvantages. Losses are more sensitive to angular misalignments than they are in butt joints. Because it is not difficult to obtain good angular alignment, this problem is not too serious. The complexity of lensed connectors makes them costly and difficult to assemble. Finally, because of reflections from the two lenses and the two cover plates (if present), the fixed losses of lensed connectors may exceed those of butt couplers. Antireflection coatings on the boundary surfaces can reduce the reflection losses.

Multi-channel connectors can be constructed. The simplest example is a two-channel connector, which is convenient for duplex systems in which information is carried in one direction in one fiber and in the opposite direction in a second fiber. The overlap design (in Fig. 8-29) can accommodate two fibers if it contains sections with two parallel grooves rather than one. The overlap concept could be extended to more than two channels if there were additional grooves.

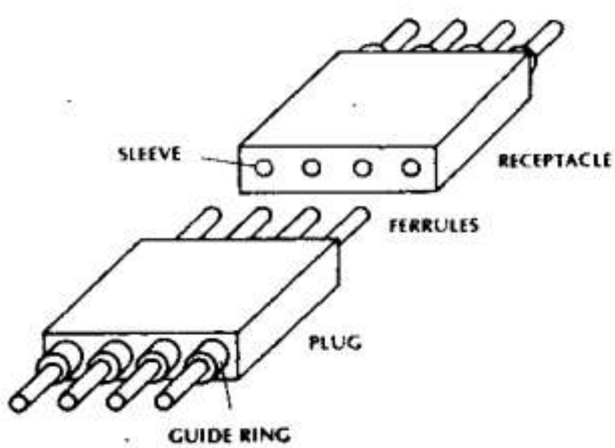


Fig multichannel connector