FIBER OPTIC CONNECTORS, SPLICES, AND TOOLS

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FIBER JOINTS (CONNECTIONS)

For the purposes of this chapter we define a fiber joint as the point where two fibers are joined together to allow a light signal to propagate from one fiber into the next continuing fiber with as little loss as possible. Also, to keep from complicating procedures too greatly, all references are to glass fiber unless plastic fiber is specifically mentioned.

Although there are many reasons for fiber joints, the four most common are:

1. Fibers and cables are not endless and therefore must eventually be joined.
2. Fiber may also be joined to distribution cables and splitters.
3. At both transmit and receive termination points, fibers must be joined to that equipment.
4. The last and scariest reason is cable cuts and their subsequent restoration.

Since we have established a need for fiber joints, we should now make that task worthwhile. To that end, all fiber joints must be mechanically strong and optically sound with low loss. Fiber joints must be capable of withstanding moderate to severe pulling and bending tests. And, since the purpose of fiber is to
transmit light, the fiber joint must transmit as much light power as possible with
as little loss and back reflection as can be designed into the joint.

Fiber joints fall generally into two categories: the permanent or fixed joint
that uses a fiber splice, and the terminating (nonfixed) joint that uses a fiber optic
connector. Let us examine these individual types of joints.

Splices are used as permanent fixtures on outside and inside plant cables.
Typical uses include reel ends, pigtail vault splices, and distribution breakouts. In
addition to the benefits of low loss and high mechanical strength, additional con-
siderations are expense per splice and possible reusability of the splice itself.

Fiber optic connectors are used as terminating fixtures for inside plant cables,
outside plant cables as they terminate in a central office, interfaces between ter-
minals on LANs, patch panels, and terminations into transmitters and receivers.

Whether one joins fibers using splices or connectors, one negative aspect is
always common to both methods—signal loss. This loss of light power at fiber
joints is called attenuation.

**ATTENUATION**

Attenuation is the loss of signal or light intensity as it travels through an optical
fiber transmission system. Sometimes the losses occur in the fiber itself and other
times at fiber joints. Measurement of attenuation loss is made in decibels (dB).
The decibel is a mathematical logarithmic unit describing the ratio of output
power to input power in any system (fiber or copper).

Attenuation in the optical fiber itself usually occurs as a result of absorption,
reflection, diffusion, scattering, or dispersion of the photon packets within the
fiber. However, losses also occur at splices and connections. The factors that
cause attenuation in connectors or splices (Figure 6-1) fall into two categories:
intrinsic and extrinsic losses.

Intrinsic losses occur from factors over which the craftsperson has very little
control and are generally caused by engineering design or manufacturing flaws in
the fiber itself. The more prominent intrinsic losses include:

1. Core eccentricity
2. Core ellipticity
3. Numerical aperture (NA) mismatch
4. Core diameter mismatch

Core eccentricity means that the exact center of the core center and the exact
center of the cladding are not precisely the same, causing an overlap or underlap
of fiber cores at a splice point. Core ellipticity (or ovality) is a departure from cir-
cularity. A very small variation in the roundness of a fiber core can affect the
total system loss. Intrinsic loss through mismatch of NAs is not the fault of the
craftsperson; however, care must be taken to butt the fibers as closely as possible
to counteract this mismatch. When splicing fibers having cores of different diameters, testing will show a significant loss when testing from the large core into the small core, and will show a supposed gain when testing from the small core into the large core.

Extrinsic losses, on the other hand, are caused by the mechanics of the joint itself. Frequent causes of extrinsic loss attenuation at splicing points include:

1. Misalignment of fiber ends caused by improper insertion techniques into splices and connectors.
2. Bad cleaves and poor polishing techniques resulting in poor end face quality.
3. Inadvertent air spaces between fibers at a splice or connection that have not been corrected with index-matching gel or liquid.
4. Contamination caused by dirt, wiping tissue, cotton swabs, shirt sleeves, or airborne dust particles. REMEMBER, IF YOU CAN SEE THE CONTAMINATION, IT’S TOO BIG FOR THE CORE TO PASS LIGHT THROUGH. See the section on cleaning connectors later in this chapter.
5. Another loss mechanism is back reflection or reflectance and is measured as optical return loss (Figure 6-2). As the light travels through the fiber, passing through splices and connections, finally arriving at the end point, some of that light is reflected back by fiber end faces at those man-made points. Optical return loss is generally only an issue with high-performance singlemode networks but is now also an issue with multimode networks used for gigabit networks.
Typical allowable splice losses for singlemode fiber are 0 to 0.15 dB and with a return loss of better than 50 dB. In multimode fiber, typical splice losses are 0.0 to 0.25 dB, with an average of 0.20 dB and return loss of less than –50 dB. In the case of fiber connectors, singlemode allowable connector losses range from 0.1 to 1.0 dB per mated pair and return loss typically is less than –30 dB. Multimode connectors have a nominal connector loss of less than 0.75 dB per mated pair with a typical return loss better than 25 dB.

CONNECTORS

Remember that connectors are used as terminating fixtures for temporary non-fixed joints. As such, they are made to be plugged in and disconnected hundreds and possibly thousands of times. Since no one connector is ideal for every possible situation, a wide variety of connector styles and types have been developed over the short life of fiber communications. We can classify connectors by assigning them into five major categories:

1. Resilient ferrule
2. Rigid ferrule
3. Grooved plate hybrids
4. Expanded beam
5. Rotary

Of these types the rigid ferrule is by far the most common. Rigid ferrule types include the popular ST (compatible), FC, and SC, which use a single 2.5-millimeter cylindrical ferrule for fiber alignment. Other simplex connectors housing a single fiber, but no longer in common use today, include the SMA (905 and 906), D4, and the Biconic.

Duplex connectors contain two fibers allowing for a single connector body for both transmit and receive fibers. These connectors have come to the fore in recent years and are expected to gain popularity in the LAN arena. LAN hard-
ware manufacturers have already adopted these connectors since they offer a much smaller size, allowing more links per panel space on network equipment. Early examples of duplex connectors include the FDDI and ESCON. These connectors are rather large and cumbersome. Newer duplex connectors are designed to fit in the same work area outlet space as a standard RJ45 telephone jack and include the MT-RJ, Opti-Jack, and Volition connectors. These are commonly referred to as small form factor (SFF) connectors.

Although some SFF connectors are duplex designs, several others are miniature simplex connectors that are similar in design to the SC. The LC, LX-5, and MU connectors use smaller 1.25-millimeter ferrules and miniature bodies to allow twice the panel density of the earlier simplex connector designs. Examples of typical connector designs are shown in figure 6-3.

The end of an optical connector (Figure 6-4) can be either polished flat or with a PC finish, a slightly rounded, domed end to create a “physical contact,” hence the PC designation. Physical contact of the fibers reduces the back reflection caused by air between the fiber ends. Some singlemode connectors may also have an “angled PC” (APC) finish. The ends are angled at 8 degrees to minimize back reflections at the point of connection. These connectors cannot be mated with the normal flat or domed polish types (Figure 6-4).

Although few, if any, of the original designs were compatible, nowadays compatibility exists between the same types from different manufacturers (i.e., ST or SC designs), thanks to marketplace pressures and standards committees. Although not compatible with all other connector styles, most ferrules are 2.5 millimeters and will loose fit for temporary testing purposes. For example, by lightly inserting the ferrule of an ST into an FC coupler, a “quick-and-dirty” test can be made for continuity. Hybrid adapters to allow coupling of different types of connectors are generally available as either sleeve connectors or patch cords. Although no single connector is best for every application, Table 6-1 lists the currently popular connectors found in many different types for various applications.

**Choosing a Fiber Connector**

With all of the myriad selections of connector types, styles, and physical characteristics available on the market, choosing the specific connector for your job is often a mystifying task. One important criterion is connector performance. When selecting a connector, comparisons of performance are generally based on:

- Insertion loss, usually 0.10 to 1.0 dB per connection
- Return loss (back reflection) varies from −20 (air gap like a SMA) to −60 dB (the best APC angle polished connectors)
- Repeatability of connection, usually specified at thousands of times

Your choice of fiber connector also may depend on whether you are mounting it onto singlemode or multimode fiber. Since singlemode connectors have a
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Figure 6-3  Connector styles.
much tighter tolerance than multimode connectors, they may be used on either type of fiber. However the reverse is not true, that is, one may not use multimode connectors on single mode fiber because the loose tolerance will cause high loss with the very small singlemode core size. Generally multimode connectors are fitted onto multimode fibers because they are less precise and cost about one-half to one-third the cost of single mode connectors.

The accessibility of the fiber to casual users may cause you to anticipate rough handling. In this case, gripping strength of the connector on the cable becomes

<table>
<thead>
<tr>
<th>Data communications (Mostly multimode)</th>
<th>Telecommunications (Mostly singlemode)</th>
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<tbody>
<tr>
<td>SMA (obsolete)</td>
<td>Biconic (obsolete)</td>
</tr>
<tr>
<td>ST (most widely used)</td>
<td>D4 (fading)</td>
</tr>
<tr>
<td>SC (for newer systems)</td>
<td>FC/PC (widely used)</td>
</tr>
<tr>
<td>FDDI (duplex)</td>
<td>SC (growing)</td>
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<tr>
<td>ESCON (duplex)</td>
<td>ST (singlemode version)</td>
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<tr>
<td>MT-RJ (new SFF duplex style)</td>
<td>LC (new SFF)</td>
</tr>
<tr>
<td>Volition (new SFF duplex style)</td>
<td>MU (SFF, outside United States)</td>
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<tr>
<td>Opti-Jack (new SFF duplex style)</td>
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important to avoid pullouts by users. Gripping points of the connector may include the fiber itself, the primary plastic buffer coating (tight buffer), the loose-tube buffer, the cable strength members (Kevlar), and/or the cable jacket itself.

Another reason for choosing a particular type of connector is the type of equipment already purchased or currently in use. If, for instance, you are adding to an existing system already equipped with ST connectors, you should continue to use ST connectors to ensure compatibility systemwide. If you are using previously purchased electronics with Biconic connectors installed, then that will be your choice, unless, of course, you want to change all of the connections on the patch panels and electronics!

Finally, your choice may be influenced by industry standards or new developments in the marketplace. The Electronic Industries Alliance/Telecommunications Industry Association (EIA/TIA) standards for premises cabling calls for the SC connector, although they are considering the new SFF connectors. Many of the newer connectors offer the promise of lower cost or higher performance, which can also influence the decision.

**Cable Termination and Connector Installation**

Fiber optic connectors can be installed directly on most fiber optic cables, as long as the fiber has a tight buffer or jacket to protect it. Before the installation of connectors onto a loose-tube or ribbon fiber optic cable, a breakout kit may have to be installed. This procedure is not necessary on breakout cables having 3-millimeter jacketed fibers, but will be required on 250-, 500-, and some 900-micron tight-buffer cables. The breakout kit consists of plastic tubing into which the bare fibers are inserted to provide handling protection and strength when mounted onto connectors.

Installing a fiber connector onto a fiber is a widely varied process. The most common mounting methods are:

- Adhesives to hold the fiber in the connector and polished ferrules
  - Epoxy glue with room temperature or oven cure
  - Quick curing adhesives
  - Hot Melt, preloaded adhesive (Hot Melt is a 3M trademark)
- Crimping to hold the fiber, with or without requiring polishing of the ferrule end
- Prepolished ferrules with fiber stub; connector is spliced onto the fiber.

The epoxy/polish method (Figure 6-5) is the oldest of all methods and is used today in all manufacturing plants and many field installations. This process involves filling the connector with a premixed two-part epoxy. The prepared and cleaned fiber is then inserted into the connector, which is crimped onto the cable. After curing the epoxy in an oven for the proper time (5 to 40 minutes) or overnight at room temperature, the end of the fiber is polished. The fiber must be
scribed and cleaved nearly flush with the end of the connector and polished with a two or three fine lapping papers (Figure 6-6). The cleaved fiber is usually removed gently with hand-held film of about 12-micron finish in a process called “air polishing.” Final polish papers start at 3 microns and go as fine as 0.3-micron grit. High volume terminations are usually lapped on polishing machines (Figure 6-7) that can handle anywhere from one to a dozen connectors simultaneously.

The Hot Melt (trademark of 3M) uses an adhesive preloaded into the connector. The connector is placed into an oven to soften the glue and allow insertion of the prepared fiber. After cooling, the scribe and polish process is the same as previously described.

Quick-cure adhesives include one- and two-part adhesives that cure in less than one minute. Many different adhesives are used for fiber termination, but it is important to not just use any quick-curing adhesive. The adhesive must meet stringent requirements for adhesion to the fiber and resistance to moisture or temperature extremes.

Some connectors, such as the 3M “CrimpLok” connector use no adhesive to capture the fiber. Instead, an internal malleable metal V-groove plate is locked on to the fiber holding it in place in the ferrule. The fiber cable is then affixed to the backbone of the connector by crimping. The connector requires a special fiber optic cleaver to prepare the fiber and a special polishing procedure.

Figure 6-5 The fiber is epoxied into the connector body, then scribed and broken off just above the connector face before polishing.
Impact mounting, as used by the Valdor connector, is another termination method that requires no adhesive. This connector uses a special metal ferrule rather than ceramic. After the fiber is stripped and cleaned, it is inserted into the

Figure 6-6  A polishing puck holds the connector properly for polishing.

Impact mounting, as used by the Valdor connector, is another termination method that requires no adhesive. This connector uses a special metal ferrule rather than ceramic. After the fiber is stripped and cleaned, it is inserted into the

Figure 6-7  Automatic polishers can polish large quantities of connectors quickly. Courtesy Buehler LTD
connector and a hollow tool impacts the end face of the ferrule, swaging connector onto the fiber. The fiber stub is then scribed off and the end face is polished on a glass plate to provide a flat finish.

Another type of connector crimps the fiber to hold it in place, and then uses a special tool to cleave the fiber flush with the end face of the ferrule. These connectors require no polishing, so they are quickly terminated, but they typically have higher loss than polished connectors.

Cleave and crimp connectors, on the other hand, do not require any type of polish procedure and can be terminated very quickly (Figure 6-8). They already have a polished ferrule tip and are spliced to the fiber. They require only the insertion of a properly cleaved fiber to butt against the internal fiber stub. Once in place, the fiber connector is crimped to hold the fiber. These connectors often have higher loss than polished connectors, since they include both a connection and a splice and require more expensive tools for termination.

Each mounting method has its advantages and disadvantages, varying from ease of installation to cost per connector to performance qualities. See the section at the end of this chapter that compares actual termination procedures for several types of connectors.

**Strip, Clean, and Cleave**

The three basic steps for any fiber joint, whether splicing or connectorizing, are *strip, clean, and cleave*. Stripping involves the removal of the 250-micron primary coating and any other layers of protection on the individual fiber. Sometimes this protection takes the form of a 900-micron tight-buffer coating such as is found in indoor riser cables. The strip process must be accomplished using the correct stripping tool of the correct size. When stripping 250-micron coated loose-tube fiber, the entire length of fiber (usually no more than 3 inches) may be stripped in one pass with the tool. However, stripping 900-micron tight buffer will require that no more than 1/4 inch of tight buffer be removed at a time to prevent breaking the fiber. To avoid microbends and fiber stress, always use the tool at a near right angle and never wrap the fiber around your fingers to “get a better grip.”

![Figure 6-8](image) Cleave and crimp connectors have a short fiber already glued in the ferrule and polished.
The cleaning process is also an inspection and testing process. Once the fiber is stripped it must be cleaned using a lint-free wipe and reagent-grade isopropyl alcohol. The wipe is moistened and the fiber is pinched tightly and wiped using a curling motion. This will cause a fiber that has been scratched or cracked by the stripping process to break. Better now than later! Cleaning should be done in one pass if possible to minimize fiber handling. Make that wiping pad squeak to be sure that all stripped plastic residue is removed!

Cleaving (Figure 6-5) will take place using either a cleaver or a scribe and break process. In either case the fiber should end up with a cleave as near to 90 degrees as possible. When splicing using a cleaver, do not be tempted to clean the fiber again using a wipe as this will draw small glass particles and dirt to the end face. Instead, use a small piece of plastic tape to remove any remaining end-face contamination by performing the “tape-tap” procedure.

Fiber Optic Adhesives

Adhesives have been used since the onset of fiber optics to affix most connectors. The primary purpose is to hold the fiber in place and prevent any movement (pistoning). The adhesives can also supply support and strength to the fiber, specifically at the connector end. Adhesives are also being used to hold protective boots to the fiber jacket. Similar materials are also being used for laser applications. This discussion focuses on the traditional application of attaching fiber into a connector.

Enormous strides have been made in the past 15 years to keep pace with the high performance demands of the latest fiber connectors. New increasingly rigorous aging tests require formulated adhesives that allow little or no dimensional movement of the fiber in the ferrule over strenuous conditions. These systems must be rigid enough for polishing and yet flexible enough to withstand differences in expansion rates from the wide variety of substrates used in fiber optic connectors and cables. Of course, they also must maintain a good bond to all of these substrates.

Application techniques of epoxies vary depending on the type of connector and the production requirements. Most common is the injection of adhesive into the connector using a syringe or automated cartridge. Applying the adhesive directly to the fiber is also used. However, to provide the best bond strength, the adhesive must wet out the surfaces of the fiber and the connector ferrule sufficiently. It is more difficult to achieve the maximum physical properties using the latter method.

There is a misconception concerning the use of epoxies with plastic fibers. Epoxies work well with both plastic and glass fibers. Formulations currently available will not “attack” or contaminate plastic fibers. Room temperature-curing

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This section was contributed by Barry Siroka, formerly Photonics Business Manager, Tracon.
Epoxies are usually used for plastic fibers, although heat-curing and fast-gelling epoxies have been used successfully.

Three basic types of epoxies are currently available for fiber optic connectors. Heat-curing, room temperature-curing, and fast-gelling epoxies can all be used in most connectors with any type of fiber.

Heat-curing epoxies have the highest temperature capabilities of all epoxy systems. These systems are primarily used in connectors where fast cure is desired. It is usually recommended that these systems reach a temperature of 90–100°C in order for the chemical reaction between the epoxy and the hardener to take place. Some heat-curing epoxies can cure in as quickly as one minute at 150°C. An added benefit to this high temperature curing requirement is that these systems usually have the longest working life. They can also be color coded to ensure a proper mix, and some will change color upon cure.

The second type of epoxy used in fiber optic connectors are the room temperature-curing (RT) systems. These are the most popular and can be used in singlemode and multimode connectors. These systems will cure with no heat overnight to a tack-free surface. Many fabricators will speed up the cure by heating the connectors up to 65°C. Full cure is in 1 hour with sufficient cure occurring in 15 minutes for polishing. Some systems can be completely cured at 90°C in 10 minutes. RT-curing systems have a working life of 15 to 60 minutes.

Fast-gelling epoxies are used primarily in field installations where no power is available for ovens and/or speed is essential. These systems have a dual cure mechanism that allows for the fast gel (and therefore can be polished in as little as 10 minutes). After gelling, they will complete their cure overnight at room temperature. Properly applied formulations have been shown not to piston after curing.

Fast-gelling epoxies traditionally have an approximate working time of 5 minutes. New variations can offer a 10-minute working time. These new variations allow for less waste as there is more time to use all the material from one mix. These versions can be polished in as quickly as 20 minutes and will also complete their cure in 12 to 18 hours.

In dealing with epoxies, do not overlook safety issues. Many chemicals can cause dermatitis or respiratory ailments. Therefore, when handling any adhesive product, it is always recommended that care be taken to prevent contact with the skin and adequate ventilation should be employed. The hardeners are usually the most offensive. Again, prepackaged epoxies help limit exposure to chemicals and fumes.

**Fiber End-Face Polish Techniques**

The polishing technique used on fiber optic connectors depends on the connector ferrule. The fiber end face at the ferrule end may be finished in one of three ways: flat, PC-domed, or Angled-PC (Figure 6-4). The flat finish is accomplished by
polishing the connector ferrule end on a glass (or hard plastic) surface. This finish produces a somewhat higher back reflection than other methods but is nonetheless acceptable for most multimode applications.

The most common of all finishes is the domed or PC type. In this case the polishing takes place on a rubber pad. This allows the fiber end face to become slightly rounded providing for contact of the cores only when the fibers are mated together in a mating sleeve.

Angled PC singlemode connectors are relatively new to the fiber market and use an 8-degree chamfer on the end face of the connector ferrule. These connectors produce the least loss and lowest back reflection of the three finish methods. They are, however, difficult to field terminate and cannot be mixed with either of the other two finish types.

Cleaning Fiber Optic Connectors

With fiber optics, tolerance to dirt is near zero. Airborne particles are about the size of the core of SM fiber and are usually silica based. They may scratch PC connectors if not removed! With most network cable plants, every connection should be cleaned during installation and not removed except for testing. Test equipment that has fiber-bulkhead outputs and test cables needs periodic cleaning, since there may be hundreds of insertions in a short timeframe. Here’s a summary of what we have learned about cleaning fiber optic connectors.

1. Always keep dust caps on connectors, bulkhead splices, patch panels, or anything else that is going to have a connection made with it.
2. Use lint-free pads and isopropyl alcohol to clean the connectors. Some solvents might attack epoxy, so only alcohol should be used. Cotton swabs and cloth leave threads behind. Some optical cleaners leave residues. Residues usually attract dirt and make it stick. For over 10 years we have been supplying “Alco Pads” with every Fotec Test Kit with no problems.
3. All “canned air” now has a liquid propellant. Years ago, you could buy a can of plain dry nitrogen to blow things out with, but no longer. Today’s aerosol cleaners use non-CFC propellant and will leave a residue unless you hold them perfectly level when spraying, and spray for three to five seconds before using to insure that any liquid propellant is expelled from the nozzle. These cans can be used to blow dust out of bulkheads with a connector in the other side or an active device mount (xmit/rcvr). NEVER use compressed air from a hose (This emits a fine spray of oil from the compressor!) or blow on connectors (Your breath is full of moisture, not to mention all those yucky germs!).
4. A better way to clean these bulkheads is to remove both connectors and clean with Alco Pads, then use a swab made of the same material with alcohol on it to clean out the bulkhead.
5. Detectors on fiber optics power meters should also be cleaned with the Alco Pads occasionally to remove dirt. Take the connector adapter off and wipe the surface, then air dry.

6. Ferrules on the connectors/cables used for testing will get dirty because they scrape off the material of the alignment sleeve in the splice bushing. Some of these sleeves are molded glass-filled thermoplastic and sold for multimode applications. These will give you a dirty connector ferrule in 10 insertions. You can see the front edge of the connector ferrule getting black. The alignment sleeve will build up an internal ledge and create a gap between the mating ferrules—Voila! A 1–2 dB attenuator! Use the metal or ceramic alignment sleeve bulkheads only if you are expecting repeated insertions. Cleaning the above requires aggressive scrubbing on the ferrules with the Alco Pad and tossing the bulkhead away.

7. Some companies sell a cleaning kit for fiber optics. These are good solutions but perhaps not as cost-effective as making your own to meet your needs.

**SPLICES**

Splices normally are a permanent joint between two fibers. The two basic categories of splices are fusion and mechanical. Generally speaking, splices offer a lower return loss, lower attenuation, and greater physical strength than connectors. Also, splices are usually less expensive per splice (or per joint) than connectors, require less labor, constitute a smaller joint for inclusion into splice closures, offer a better hermetic seal, and allow either individual or mass splicing.

**Fusion Splicing**

Fusion splicing (Figure 6-9) works on the principle of an electric arc ionizing the space between the prepared fibers to eliminate air and to heat the fibers to proper temperature (2,000°F). The fiber is then fed in as a semiliquid and melds into its mate. The previously removed plastic coating is replaced with a plastic sleeve or other protective device. The perfect fusion splice results in a single fiber rather than two fibers having been joined. One drawback to fusion splicing is that it most generally must be performed in a controlled environment, that is, a splicing van or trailer, and should not be done in open spaces because of dust and other contamination. Fusion splicing in manholes is prohibited because the electric arc generated during this process may cause explosions if gas is present. Due to the welding process, it is sometimes necessary to modify the fusion parameters to suit particular types of fibers, especially if it is necessary to fuse two different fibers (from two different manufacturers or fibers with different core/cladding structures).

Fusion splicers can be purchased rather plain, such as the fixed V-groove type, for as little as $10,000, or completely automated and capable of fusing 12 fibers in a ribbon simultaneously. To assure consistent low-loss splices, an automated
splicer costing $25,000–40,000 can be acquired with features such as self-alignment and automatic loss testing.

**Mechanical Splicing**

Mechanical splicing, on the other hand, is quick and easy for restoration, its major use, and is also used for new construction, especially with multimode fiber. It does not require a controlled environment other than common sense dust control. The strength of a mechanical splice is better than most connectors; however, fusion remains the strongest method of splicing. Back reflection and loss vary dramatically from one type of splice to another. Equipment investment for specific splicing kits need not exceed $5,000.

Mechanical splices (Figure 6-10) employ either a V-groove or tube-type design to obtain fiber alignment. The V-groove is probably the oldest and is still the most popular method, especially for multifiber splicing of ribbon cable. Examples of this type include the 3M Fibrlok, Siecor CamSplice, AMP CoreLink, and the Lucent CSL splice.
Tubular splices, on the other hand, require that the fibers be inserted into a small tube, which provides alignment. The splice is then glued or crimped to hold the fibers together. Examples of this type of splice include the Fastomeric, Elastomeric, the AMP Optimize, and the Norland Optical Splice.

Splices originally were either glued (GTE Elastomeric) or polished (AT&T Rotary). However, splices using adhesives have been phased out of common use because of the reusability of the more modern “no-glue” type. Polished splices are very much like miniaturized connectors using ferrules and a polishing process. Because of the extensive time required, polish type splices are also extinct.

In nearly all of today’s splices, the fibers are crimped or locked to achieve fiber alignment and attachment. Most of them may be reopened for fine-tuning and possible reuse. These mechanical splices must all use some type of index-matching gel inside to eliminate back reflection and reduce splice loss. This gel is subject to contamination, so care is required when handling the splice, particularly if it is going to be reused later.

To prepare for mechanical splicing, the fibers are first stripped of all primary coating material, cleaned with alcohol, and then cleaved as previously described. Completed splices, whether fusion or mechanical, are then placed into splicing trays designed to accommodate the particular type of splice in use. Splicing trays then fit into splice organizers and in turn into a splice closure.

Choosing a Splice Type

The type of splice chosen is usually determined by the following criteria:

1. Type of fiber: Most singlemode fiber is fusion spliced because this results in lower loss and better return loss performance. Multimode fiber, with its complicated core structure, does not always fusion splice easily, so mechanical splices can give equal performance at a lower amortized cost.

Figure 6-10  Typical mechanical splices and a fusion splice on the far left.
2. **Attenuation, including return loss:** Today’s automated fusion splicers can produce incredibly low-loss splices (typically 0.0 to 0.15 dB). Although a properly installed mechanical splice may also achieve a near-zero loss, the consistency of the fusion splice is hard to beat. The main difference between the two is the back reflection caused by the nature of mechanical splices.

3. **Physical durability:** The welding process used in the fusion splice gives higher strength and greater durability. Fusion splicing retains the original mechanical tensile strength of the fiber, that is 50,000 to 75,000 psi. Most mechanical splices are rated at a pullout strength of no more than 1 to 2 pounds.

4. **Ease of installation:** A fully automated fusion splicer is very expensive but makes the splicing a one-button process. Mechanical splicing types vary but usually are less expensive to purchase and use for low-count fiber jobs.

5. **Cost per splice:** In the case of fusion splicing, which is the most common type of splicing being performed on singlemode fiber for new construction, the initial capital investment is much greater than the cost for mechanical splicing. A fusion splicing machine is a very large investment. Also, fusion splicing must be performed in a controlled environment, necessitating a splicing trailer or van. Mechanical splicing, on the other hand, requires no controlled environment, has a very low initial capital outlay, and the splices themselves vary from $7 to $20 each.

### Terminating Singlemode Fibers with Pigtails

Singlemode cables are generally terminated using a combination of connector installation and splicing. Since singlemode connectors have such critical dimensions and mating surface requirements, they are generally terminated in a manufacturing lab. There the proper fiber insertion and physical contact polishing can be controlled precisely. Complete cable assemblies with connectors on both ends are made and tested, since testing a cable with two ends is easier than with bare fiber on one end. In the field, the assemblies are cut in half and spliced onto the installed backbone cables. Although the splice contributes some additional loss and cost, the overall method provides a higher yield and better connection at lower cost than trying to control the termination process in the field.

### TOOLS

No job can be completed without the correct tools, and fiber splicing/connectorization is no exception. Following is a summary of the tools and test equipment needed.
Handtools

Handtools can be purchased in a prepackaged tool kit or on an individual basis as needed. At a minimum the following will be needed to complete most fiber optic operations.

1. Cleaning fluid and lint-free wipes (approved cable cleaner)
2. Buffer tube cutter
3. Reagent grade isopropyl alcohol (99%) in nonspill bottle or presoaked pads
4. Canned “air”
5. Tape; masking and Scotch invisible
6. Coating stripper
7. Cleaver or scribe
8. Microscope or cleave checker
9. Splicing method—fusion or mechanical—determines specific tooling needs
10. Connectorization method determines specific tool kit (if required)

The total cost of these tools can vary from as little as $750 to as much as $5,000 depending on the quality and quantity of tools purchased.

Major Equipment

1. Fusion splicer (optional)
2. Optical time domain reflectometer (OTDR) (optional, rentable)
3. Splicing van or trailer (nice to have an organized workplace, especially for outside plant work)
4. Power meter (for measuring optical power or loss)
5. LED or laser light source (to inject a test signal for loss)
6. Visible light source (for tracing cables, absolutely mandatory!)
7. Fiber optic talkset (to communicate over the fiber; alternatives are walkie-talkies and cellular phones)
8. Termination kits (these may be made by purchasing tools individually rather than in a kit form. Sometimes the splicing or connectorization kits will contain too many small insignificant tools that you may already own. Once you determine the needed tools, you can purchase only those tools.)

Since the major tools and test equipment represent a large capital investment, you should consider leasing the more expensive of these to determine which will fit your intended purposes. After a period of use, a purchase might be considered.
REVIEW QUESTIONS

1. Fiber optic joints should have ________________
   a. back reflection.
   b. an index matching gel.
   c. high mechanical strength and low loss.
   d. attenuation.

2. Loss of light power is called ________________
   a. dBm.
   b. attenuation.
   c. absorption.
   d. diffusion.

3. Identify the following as either an
   a. intrinsic loss.
   b. extrinsic loss.
   ___ core eccentricity    ___ NA mismatch
   ___ misalignment         ___ contamination
   ___ poor cleave          ___ core diameter mismatch
   ___ core ellipticity     ___ air gap between fiber ends

4. ________________ connectors do not need to be polished.
   a. Epoxy glue
   b. “Hot Melt”
   c. Anaerobic
   d. Cleave and crimp

5. Match the terms right column with appropriate terms in left column.
   ___ Mechanical splicing   a. nonpermanent connections
   ___ Fusion splicing       b. permanent singlemode connection
   ___ Connector            c. restoration