and the rest are various types of mechanical splices.



Splices: fusion on the far left, other types of mechanical splices.

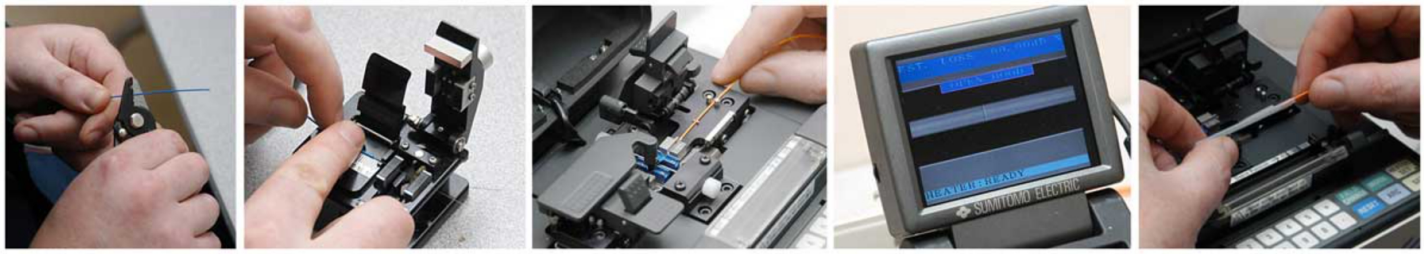


Fusion Splices

Fusion plices are made by "welding" the two fibers together usually by an electric arc. To be safe, you should not do that in an enclosed space like a manhole or an explosive atmosphere, and the equipment is too bulky for most aerial applications, so fusion splicing is usually done above ground in a truck or trailer set up for the purpose. (photo above) Splicing on poles is obviously dangerous too. It's easier to bring extra cable length into a trailer on the ground and work in a clean environment for splicing, placing splices in a closure and testing. The final closure is then placed in location and the extra fiber carefully looped and mounted in an appropriate place.

Today's singlemode fusion splicers are automated and you have a hard time making a bad splice as long as you cleave the fiber properly. The biggest application is singlemode fibers in outside plant installations. Fusion splices are so good today that splice points may not be detectable in OTDR traces. Some splicing machines can do one fiber at a time but Mass Fusion Splicers can do all 12 fibers in a ribbon at once. Fusion splicers cost $15,000 to $40,000, but the splices only cost a few dollars each.

The Fusion Splicing Process



Preparing the Fibers

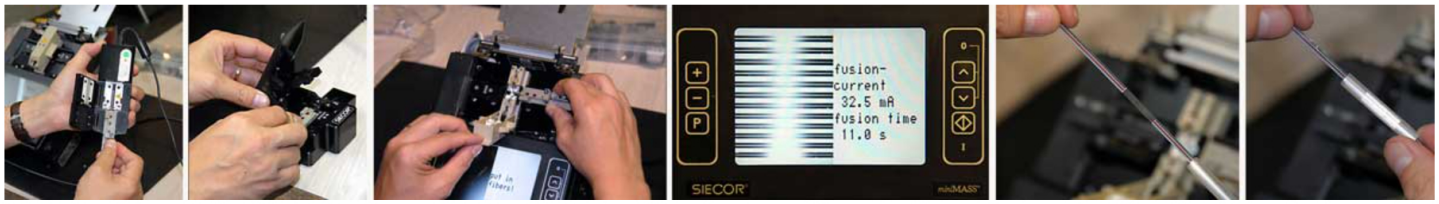
The fusion splicing process is basically the same for all automatic splicing machines. The first step is to strip, clean & cleave the fibers to be spliced. Strip the primary buffer coating to expose the proper length of bare fiber. Clean the fiber with appropriate wipes. Cleave the fiber using the directions appropriate to the cleaver being used. Place each fiber into the guides in the fusion splicing machine and clamp it in place.

Running the splicer program

First choose the proper program for the fiber types being spliced. The splicer will show the fibers being spliced on a video screen. Fiber ends will be inspected for proper cleaves and bad ones will be rejected. That fiber must be cleaved again. The fibers will be moved into position, prefused to remove any dirt on the fiber ends and preheat the fibers for splicing. The fibers will be aligned using the core alignment method used on that splicer. Then the fibers will be fused by an automatic arc cycle that heats them in an electric arc and feeds the fibers together at a controlled rate.

When fusion is completed, the splicing machine will inspect the splice and estimate the optical loss of the splice. It will tell the operator if a splice needs to be remade. The operator removes the fibers from the guides and attach a permanent splice protector by heat-shrinking or clamping clam shell protectors.

Mass (Ribbon) Fusion Splicing



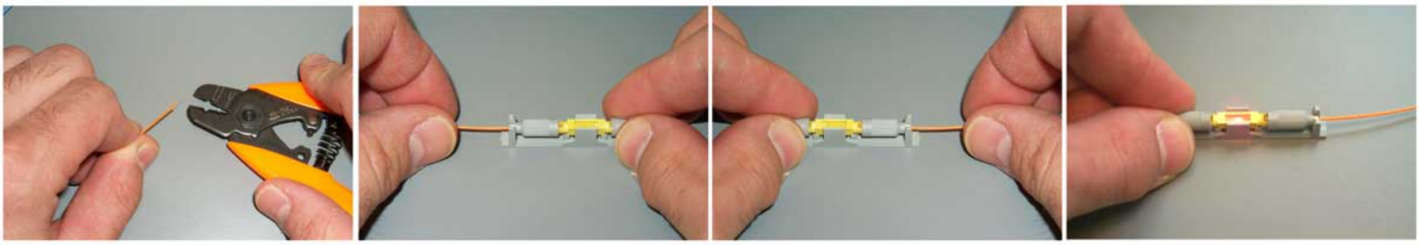
Ribbon cables are fusion spliced one ribbon at a time, rather than one fiber at a time. Thus each ribbon is stripped, cleaved and spliced as a unit. Special tools are needed to strip the fiber ribbon, usually heating it first, then cleave all fibers at once. Many tools place the ribbon in a carrier that supports and aligns it through stripping, cleaving and splicing. Consult both cable and splicer manufacturers to ensure you have the proper directions.

More on fusion splicing.

Mechanical Splicing

Mechanical splices are alignment fixtures that hold the ends of two fibers together with some index matching gel or glue between them. There are a number of types of mechanical splices, like little glass tubes or V-shaped metal clamps. The tools to make mechanical splices are cheap, but the splices themselves are more expensive. Many mechanical splices are used for restoration, but they can work well with both singlemode and multimode fiber, with practice - and using a quality cleaver such as those used for fusion splicing.

Mechanical Splicing Process



Preparing the Fibers

The splicing process is basically the same for all types of mechanical splices. The first step is to strip, clean & cleave the fibers to be spliced. Strip the primary buffer coating to expose the proper length of bare fiber. Clean the fiber with appropriate wipes. Cleave the fiber using the directions appropriate to the cleaver being used. Using a high quality cleaver such as those provided with fusion splicers will yield more consistent and lower loss splices.

Making The Mechanical Splice

Insert the first fiber into the mechanical splice. Most splices are designed to limit the depth of the fiber insertion by the stripped length of buffer coating on the fiber. Clamp the fiber in place if fibers are held separately. Some splices clamp both fibers at once. Repeat these steps for the second fiber.

You can optimize the loss of a mechanical splice visually using a visual fault locator, a visible laser test source if the fiber ends being spliced are visible. Gently withdraw one of the fibers a slight amount, rotating it slightly and reinserting it until the visible light is minimized, indicating lowest loss.

More on mechanical splicing.

Color Codes for Splicing

Individual fibers and buffer tubes in loose tube cables are color coded for identification. When splicing similar cables on long runs, fibers should be spliced straight through according to color codes to continue the same color coding for each joined fiber in the concatenated cables. When connecting large fiber count cables to several smaller cables, fibers should be spliced in order and records kept of the connections made.

Protecting Splices



For protection against the outside plant environment and damage, splices require placement in a protective case. They are generally placed in a splice tray which is then placed inside a splice closure for OSP installations or a patch panel box for premises applications. Indoors, splice trays are often integrated into patch panels to provide for connections to the fibers.
There are probably thousands of different types and options on splice closures. Some are designed for concatenation of long distance cables where two identical cables are spliced together. Some closures are designed for connecting several smaller cables to a larger one for breaking out the larger cable to several destinations. Closures can be used for midspan entry also, where the cable jacket is stripped but most of the buffer tubes are coiled inside without opening, while one or more tubes will be opened and spliced to other cables. Some have cables entering into one end, some have cable entries on both ends.
There are splice closures designed to be buried, mounted on walls, hung from cables or poles. Some are small pedestals themselves. Each type has a particular application and probably every application has a special closure. Even special hardware may be necessary for handling different cable or splice types, so make certain you have the right hardware before using the closure. It is recommended that you work with vendors to find the best closure for your applications then follow their instructions.
Preparing cables for splice closures involves several steps that should be followed in the exact sequence specified by the manufacturer to ensure the cables are properly secured and the closure will seal. For every splice closure, it is important to follow the manufacturer's instructions on stripping the cable to ensure proper lengths of strength members to secure the cable to the closure and proper lengths of buffer tubes to connect to the splice trays. The proper length of fiber is needed to allow splicing and then neatly storing fiber in the splice tray. Inside splice closures and at each end, cables with metallic shielding or strength members must be properly grounded and bonded.
Care should be taken when arranging fibers and splices in splice trays and buffer tubes in the splice closure to prevent stress on the fibers. Arranging fibers inside splice trays may require twisting the fiber but following the closure manufacturer's instructions will minimize the stress on the fiber. Often the fibers are broken as the trays and closure are assembled or re-entered for troubleshooting and repair. Cables must be secured to the splice closure and sealed properly. Generally loose tube cables will have the tubes extending from the entrance of the closure to the tray, where they are secured, then approximately 1 meter of bare fibers are organized in the tray after splicing. Care must be taken to properly bond electrical conductors such as the armor on some cables or center metallic strength members to the closure and at each end.
All closures must be sealed to prevent moisture entry. Closures must be properly secured, with the location being determined by the installation type, and excess cable properly coiled and stored. This may be in a pedestal or vault, on a pole or tower or buried underground.

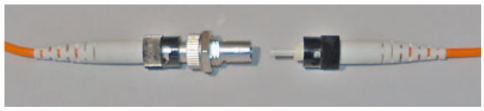
Which Splice ?
If cost is the issue, fusion requires expensive equipment and but makes cheap splices, while mechanical splices require inexpensive equipment and expensive splice hardware. So if you make a lot of splices (like thousands in an big telco or CATV network) use fusion splices. If you need just a few, use mechanical splices.
Fusion splices give very low back reflections and are preferred for singlemode high speed digital or CATV networks. However, they may not work well some multimode fibers, so mechanical splices may be preferred for MM, unless it is an underwater or aerial application, where the greater reliability of the fusion splice is preferred.

Making Good Splices
Making consistently low loss splices depends on proper techniques and keeping equipment in good shape. Cleanliness is a big issue, of course. Fiber strippers should be kept clean and in good condition and be replaced when nicked or worn. Cleavers are most important, as the secret to good splices - either fusion or mechanical - is having good cleaves on both fibers. Keep cleavers clean and have the scribing blades aligned and replaced regularly. Fusion splicers should be properly maintained and fusing parameters set for the fibers being spliced. For mechanical splices, light pressure on the fiber to keep the ends together while crimping is important. Use a visual fault locator (VFL) to optimize the splice before crimping if possible.

Verifying Splice Loss
Splices are permanent joints that cannot be accessed for individual insertion loss testing with a source and power meter as connectors are tested. Fusion splicers generally provide an estimate of connector loss based on an analysis of data from the alignment system used by the splicer, but it is only an estimate. An insertion loss test of the entire finished cable will be done when installation is finished, but that only allows comparison to the overall loss predicted by the loss budget created during the design phase, not verification of any individual splice.
For concatenations of cables, only an OTDR can see the splice and confirm its loss, but for accurate loss measurements it requires testing from both ends and averaging (see Chapter 8 on Testing.) The OTDR test will also confirm that the splice is not reflective, an important issue in many systems. The limited resolution of the OTDR means that it cannot be used to verify the splices used to terminate fibers with pigtails, but a visual fault locator can be used to check these splices near the ends of the cable.

More on splices, including hands-on tutorials

Connectors



Most fiber optic connectors are plugs or so-called male connectors with a protruding ferrule that holds the fibers and aligns two fibers for mating. They use a mating adapter to mate the two connectors that fits the securing mechanism of the connectors (bayonet, screw-on or snap-in.) The ferrule design is also useful as it can be used to connect directly to active devices like LEDs, VCSELs and detectors.

Different connectors and termination procedures are used for singlemode and multimode connectors. Multimode fibers are relatively easy to terminate, so field termination is generally done by installing connectors directly on tight buffered fibers using the procedures outlined below. Most field singlemode terminations are made by splicing a factory-made pigtail onto the installed cable rather than terminating the fiber directly as is commonly done with multimode fiber. Singlemode terminations require extreme care in assembly, especially polishing, to get good performance (low loss and reflectance), so they are usually done in a clean manufacturing facility using heat-cured epoxy and machine polishing.

Choosing a connector type for any installation should consider if the connector is compatible with the systems planned to utilize the fiber optic cable plant, if the termination process is familiar to the installer and if the connector is acceptable to the customer. If the systems are not yet specified, hybrid patchcords with different connectors on each end may be necessary. If the installer is not familiar with connector installation, training may be necessary. And sometimes, the user may have been sold on a connector type that is not ideal for the installation, so the installer should discuss the merits of other types before committing to the project.

Styles of Fiber Optic Connectors



Since fiber optic technology was introduced in the late 70s, numerous connector styles have been developed - probably over 100 designs. Each new design was meant to offer better performance (less light loss and reflectance) and easier, faster and/or more inexpensive termination.

Of course, the marketplace eventually determines which connectors are successful. However several attempts to standardize connectors have been attempted. Some were unique to systems or networks. FDDI, the first fiber LAN, and ESCON, the IBM mainframe peripheral network, required unique connectors. TIA 568 originally called for SC connectors as a standard, but when users continued to use more STs than SCs and a whole new generation of smaller connectors were introduced, TIA-568B was changed to say that any connector standardized by a FOCIS standard document was acceptable.

The four connectors shown at left show how fiber optic connectors have evolved. The bottom connector is a Deutsch 1000, the first commercially-available fiber optic connector. It was really a mechanical splice, where fibers were held inside the connector with a tiny screw-tightened chuck. The nose piece was spring-loaded, allowing exposing the fiber for cleaving and mating with a small plastic lens in a mating adapter. The mating adapter also had index-matching fluid to reduce loss but it was a dirt problem.

The yellow connector is an AT&T Biconic. It was developed by Jack Cook at Bell Labs in the late 1970s. The conical ferrule was molded from glass-filled plastic. The first Biconics had ferrules molded around the fiber, until a die with a tiny 125 micron pin in the exact center was developed. When Biconics were adapted to singlemode fiber, the ferrules were ground on a special grinding machine to center the fiber.

The SC, which was introduced in the mid-1980s, used a new invention, the molded ceramic ferrule, that revolutionized fiber optic termination. Ceramic was an ideal ferrule material. It could be made cheaply by molding, much cheaper than machining metal for example. It was extremely stable with temperature, having similar expansion characteristics to glass which prevented "pistoning" when the ferrule came unglued, a problem with metal or plastic ferrules. It's hardness was similar to glass which made polishing much easier. And it readily adhered to fibers using epoxies or anaerobic adhesives. Today, virtually all connectors use the ceramic ferrule, usually 2.5 mm diameter (SC, ST, FC) or 1.25 mm (LC, MU.)

The LC connector was introduced in the late 1990s to miniaturize connectors for higher density in patch panels or equipment. It uses a smaller ceramic ferrule, 1.25 mm diameter. The LC is the connector of choice for telecom and high speed data (>1 Gb/s) networks.

Guide to Identifying Fiber Optic Connectors

Check out the "spotters guide" below and you will see the most common fiber optic connectors. (All the photos are to the same scale except the MTP, so you can get an idea of the relative size of these connectors.)

ST (an AT&T Trademark) is the one of the most popular connectors for multimode networks, like most buildings and campuses. It has a bayonet mount and a long cylindrical ferrule to hold the fiber. Most ferrules are ceramic, but some are metal or plastic. And because they



ceramic, but some are metal or plastic. And because they are spring-loaded, you have to make sure they are seated properly. If you have high loss, reconnect them to see if it makes a difference.

FC/PC has been one of the most popular singlemode connectors for many years. It screws on firmly, but make sure you have the key aligned in the slot properly before tightening. It's being replaced by SCs and LCs.



SC is a snap-in connector that is widely used in singlemode systems for it's excellent performance and multimode systems because it was the first connector chosen as the standard connector for TIA-568 (now any connector with a FOCIS standard is acceptable.) It's a snap-in connector that latches with a simple push-pull motion. It is also available in a duplex configuration.



The ST/SC/FC/FDDI/ESON connectors have the same ferrule size - 2.5 mm or about 0.1 inch - so they can be mixed and matched to each other using hybrid mating adapters. This makes it convenient to test, since you can have a set of multimode reference test cables with ST or SC connectors and adapt to all these connectors.

From the top:
ST>FC
SC>FC
SC>ST



LC is a new connector that uses a 1.25 mm ferrule, half the size of the ST. Otherwise, it's a standard ceramic ferrule connector, easily terminated with any adhesive. Good performance, highly favored for singlemode and the connector of choice for multimode transceivers for gigabit speeds and above, including multimode Ethernet and Fibre Channel.



MT-RJ is a duplex connector with both fibers in a single polymer ferrule. It uses pins for alignment and has male and female versions. Multimode only, field terminated only by prepolished/splice method.



Opti-Jack is a neat, rugged duplex connector cleverly designed around two ST-type ferrules in a package the size of a RJ-45. It has male and female (plug and jack) versions.



Volition is a simple, inexpensive duplex connector that

uses no ferrule at all. It aligns fibers in a V-groove like a splice. Plug and jack versions, but one can field terminate jacks only.



MU looks a miniature SC with a 1.25 mm ferrule. It's more popular in Japan.



MTP is a 12 fiber connector for ribbon cable. It's main use is for preterminated cable assemblies.



Here is an even more comprehensive guide to fiber optic connectors, including obsolete ones.

The ST/SC/FC/FDDI/ESCON connectors have the same ferrule size - 2.5 mm or about 0.1 inch diameter- so they can be mixed and matched to each other using hybrid mating adapters. This makes it convenient to test, since you can have a set of multimode reference test cables with ST connectors and adapt to all these connectors. Likewise, the LC and MU use the same ferrule (1.25 mm diameter) so mating is possible.

Connector Popularity

The ST is still one of the most popular multimode connectors because it is inexpensive and easy to install. The SC connector was specified as a standard by the old EIA/TIA 568A specification, but its higher cost and difficulty of installation (until recently) limited its popularity in premises applications at first. However, newer SCs are much better in both cost and installation ease, so it has been growing in use, but is now challenged by the LC, which is the connector of choice for transceivers for systems operating at gigabit speeds because of its small size and high performance.
Singlemode networks have used FC or SC connectors in about the same proportion as ST and SC in multimode installations. There are some D4s out there too. But LCs have become the most popular, again for their performance and small size.
EIA/TIA 568 now allows any fiber optic connector as long as it has a FOCIS (Fiber Optic Connector Intermateability Standard) document behind it. This opened the way to the development of several new connectors, which we call the "Small Form Factor" (SFF) connectors, including AT&T LC, the MT-RJ, the Panduit "Opti-Jack," 3M's Volition, the E2000/LX-5 and MU. The LC has been particularly successful in the US.

Specialty Fiber Optic Connectors



There are a number of specialty fiber optic connectors available such as this multifiber military connector, special underwater or aircraft connectors, plastic optical fiber (POF) connectors, etc. Most have been designed for very specific applications and require extremely rigorous qualification testing. Some like the Mil-C-38999, are copper wiring connectors adapted to hold fiber optic ferrules. Many of these connectors require special cable types, termination procedures, cleaning, handling and test procedures. Refer to manufacturer's instructions whenever dealing with these types of connectors.