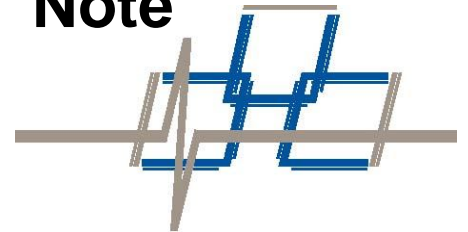


# Fiber Optics

## Application Note



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## Contents

1. Introduction .....	4
2. Types of fiber .....	4
3. Types of connectors.....	7
4. Installing connectors .....	10
5. Fusion splicing .....	17
6. Cleaning fiber optics .....	27
7. Testing.....	30
8. Sensing with optical fibers.....	35

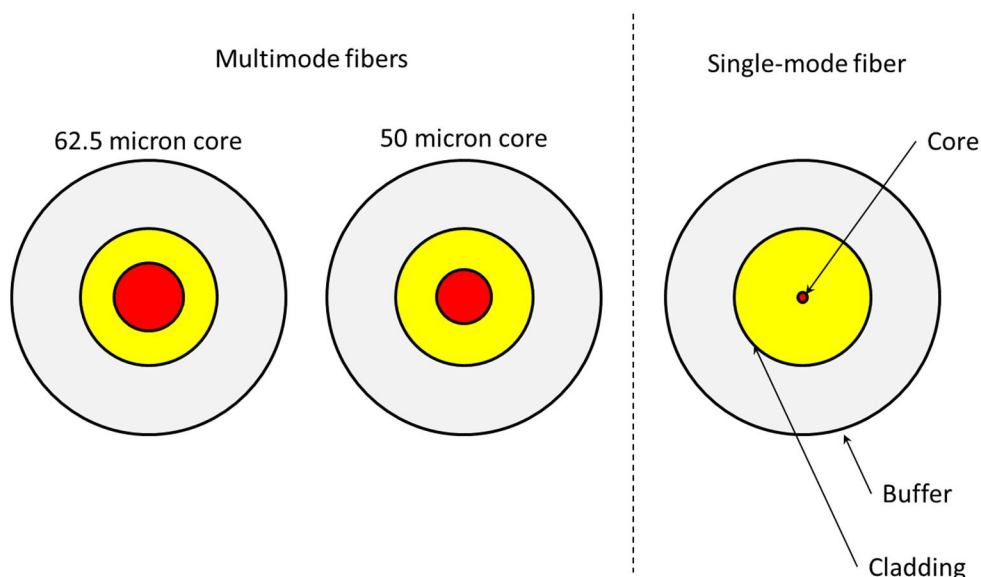
## 1. Introduction

This application note provides some practical information about basic fiber optics, including tips on cleaning, installing optical connectors, fusion splicing, and testing.

## 2. Types of fiber

Optical fibers consist of a core surrounded by a cladding, and covered by a protective acrylate coating. For standard telecommunications fibers, the diameter of the protective acrylate coating is 250 microns and the diameter of the claddings is 125 microns.

There are two basic types of optical fibers, multimode and single-mode, and the distinguishing factor between these two types is the diameter of their core regions. For single-mode fibers the core diameter is approximately 9 microns, and for multimode fibers the core diameter is either 50 microns (the standard in Europe) or 62.5 microns (common in the US).



The core and cladding are distinguishable by their index of refraction, which defines the speed of light in the fiber. Single-mode fibers often have a simple, sharp (step), change in index between the core and the cladding, but in multimode fibers the index of the core changes gradually between the axis (highest index) and the cladding (lowest index)<sup>1</sup>. These are called “graded index” fibers.

<sup>1</sup> Some single-mode fibers have more complicated index profiles in order to modify the dispersion characteristics of the fiber. Virtually all multimode fibers have a “graded index” for minimizing modal dispersion, although there are some specialty “step-index” multimode fibers available.

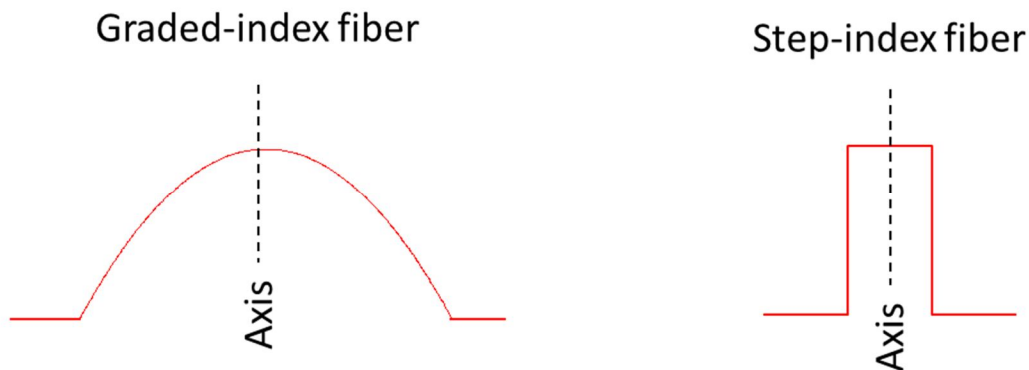


Figure 2-1. Cross-sectional view of the index profile of a graded-index and a step-index fiber.

The most important specifications that define a fiber's performance and uses are:

- Whether the fiber is single-mode or multimode
  - Single-mode fibers are used with lasers, and typically operate at wavelengths of 1310 nm and 1550 nm.
  - Multimode fibers are typically used with LEDs (though they can be used with lasers) and typically operate at wavelengths of 850 nm and 1310 nm.
  - Single-mode fibers can support bit rates well in excess of 10 GB/sec, while multimode fibers (except for short lengths) are used for sub-GB/sec applications.
- Optical loss (attenuation)
  - Loss is measured in dB/km.
  - Loss is higher at short wavelengths, lower at longer wavelengths (until the wavelength reaches about 1550 nm, at which point the loss begins to increase with wavelength).
  - Loss is higher with multimode fibers, lower with single-mode fibers.
- Dispersion
  - Optical dispersion limits the data bandwidth on the fiber, and results in pulses of light spreading out (dispersing) as they travel along the fiber.

Optical cables are structures consisting of optical fiber. There are many different types of cables, distinguishable by the number and type of fibers in them, whether they are tight buffered or loose tube, and the type of strength members, armor, etc. used in their construction.

- Simplex cables
  - A single tight-buffered fiber (covered with a 900-micron coating) protected with Kevlar, and covered with a jacket that is usually 3 mm in diameter.

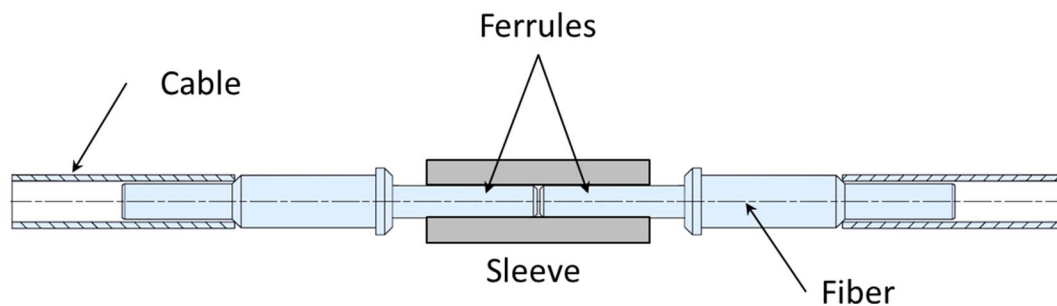
- Distribution Cables
  - Contain several tight-buffered fibers bundled within the same jacket, with Kevlar strength members and sometimes a fiberglass rod to stiffen the cable and prevent kinking.
- Breakout Cables
  - Made of several simplex cables bundled together.
- Loose Tube Cables:
  - Composed of several fibers together inside a small plastic tube, which are in turn wound around a central strength member and jacketed, providing a small, high fiber count cable.
- Ribbon Cable
  - Ribbon with all the fibers are laid out in rows.
- Armored Cable
  - Usually designed with metal armoring between two jackets to prevent rodent penetration.
- Aerial Cable
  - Used for outside installation on poles.



Figure 2-2. Two examples of fiber-optic cables (the example on the left is a break-out cable, and the one on the right is a loose-tube cable).

### 3. Types of connectors

Optical fibers can be connected by either fusion splicing (melting the fibers together) or with fiber-optic connectors. Over a dozen types of fiber optic connectors have been developed by various manufacturers since the 1980s. Although the outer mechanical design varies from one type to the next, most connectors have several parts in common, namely a sleeve that is used to align two ferrules, each containing the optical fiber. Two standard ferrule diameters are in common use today; 2.5 mm and 1.25 mm.



**Figure 3-1.** Cutaway diagram showing the ferrules in a connector, held in juxtaposition by the alignment sleeve.

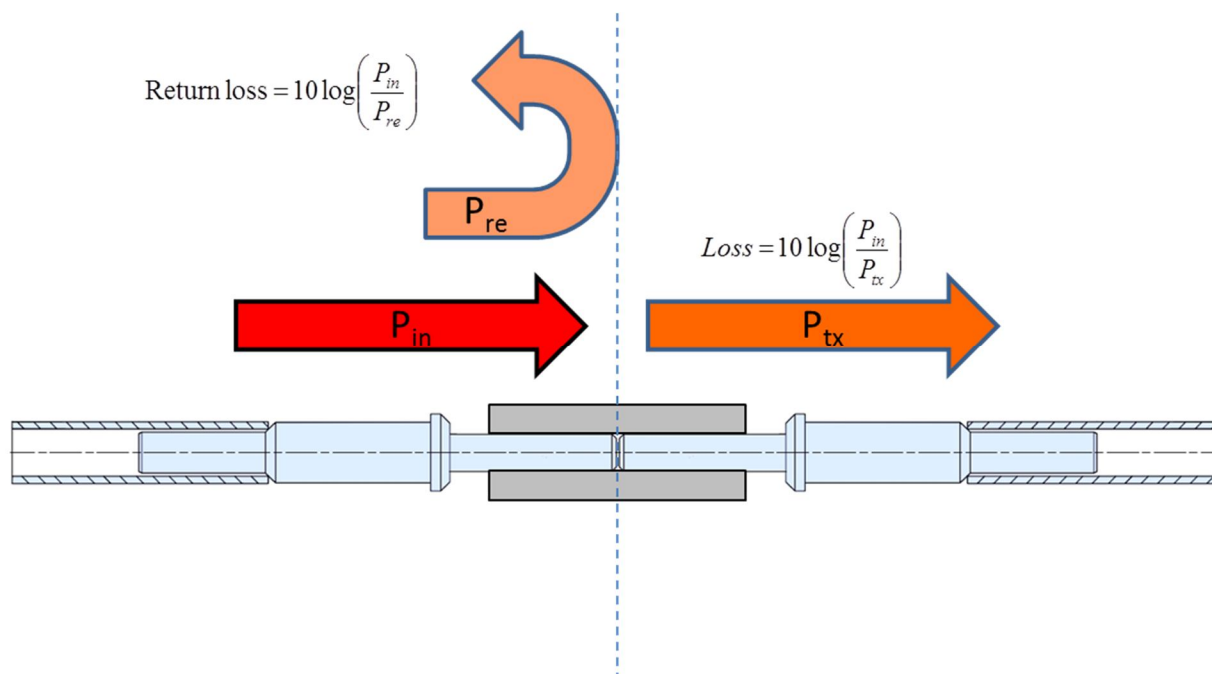
The ferrules are contained within the connector, and the sleeve is contained within the connector housing, or feed-through. In addition to the ferrule, each connector typically contains a spring that pushes the ferrules together (so they touch) and some sort of threaded or snapping mechanism to physically hold the connector in the housing.



**Figure 3-2.** Two FC connectors and the feed-through, or housing, used to connect them together.

The two most important optical specifications for connectors are the transmission loss and the reflection loss. Transmission loss is important because it limits the range over which a fiber-

optic network can operate. Reflection loss is important because it defines how much light reflects off the connector, and goes back to the transmitter. Many transmitters are highly sensitive to connectors that are highly reflective (have low return loss).



**Figure 3-3. Definitions of loss and return loss.**  $P_{in}$  is the input power,  $P_{tx}$  is the output power, and  $P_{re}$  is the reflected power.

Transmission and reflection loss both occur at the interface between the two fibers, and the amount of loss depends on the way this interface is designed, especially the way the fibers are polished. A simple flat polish on the ferrules, with a slight gap between them, results in the lowest return loss (most light reflected). This design is improved upon by removing the air gap. Even when the ferrules are pushed solidly together, however, microscopic fluctuations in flatness mean there is still a slight gap, so the return loss is still relatively low. A hemispherical polish means there is less surface area for contact, and better contact over the parts of the ferrule that touch – greatly improving the connector's return loss characteristics. The highest (best) return loss is achieved with an angled hemispherical polish, or APC.

Type of connector	Typical return loss
Un-terminated connector	14
Flat PC	35
UPC	55
APC	65

Multimode connectors have typical losses of 0.2-0.5 dB, while the typical loss for single-mode connectors, that are factory made, and fusion spliced onto a fiber, is 0.1 -0.2 dB. Field terminated single-mode connectors may have losses as high as 0.5-1.0 dB.

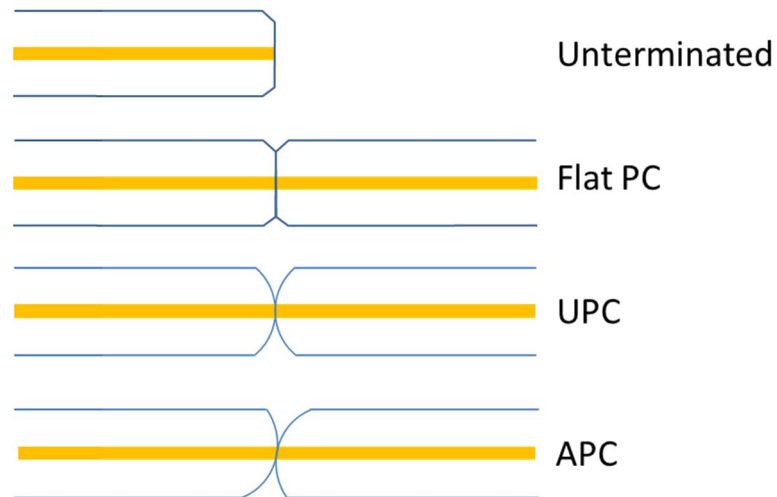






Figure 3-4. Exaggerated view of the different ferrule geometries for different grades of connectors.

Name	Description	Picture
FC	Metal connector with a threaded coupling, 2.5 mm ferrule.	
SC	Plastic-bodied connector with a push-pull design, 2.5 mm ferrule.	
ST	Metal connector with a bayonet coupling, 2.5 mm ferrule.	
LC	Plastic bodied connector featuring a snap-in mechanism, 1.25 mm ferrule.	



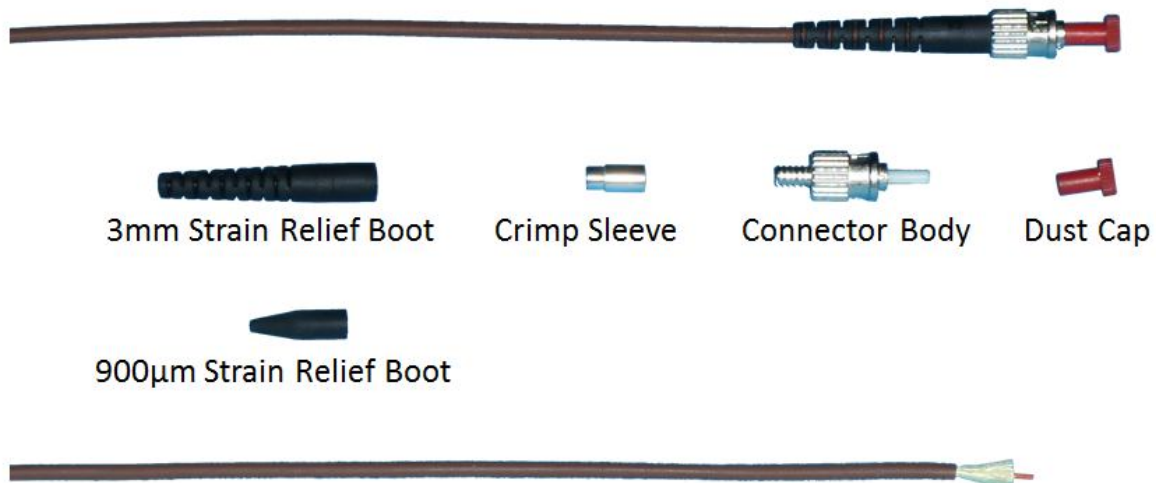
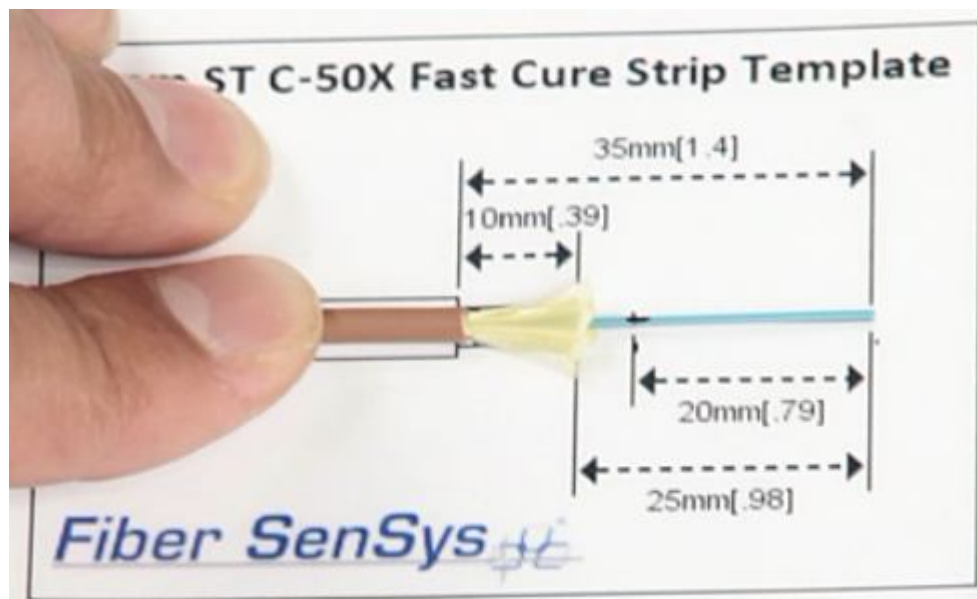


Figure 4-2. Parts to be assembled when building the connector termination.

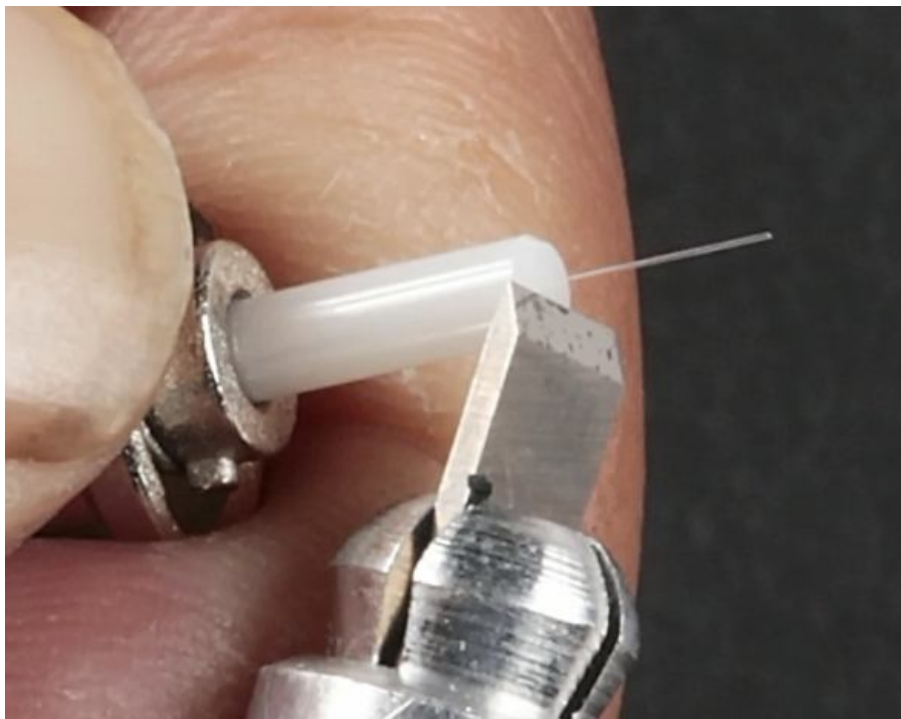
The detailed procedure follows:

- ✓ Slide the strain relief boot onto the cable, small end first.
- ✓ Slide the crimping sleeve over the fiber (again, small end first).
- ✓ Mark the fiber jacket 35 mm from the end.
- ✓ Using a fiber stripping tool, remove the outer jacket layer.
- ✓ Twist the Kevlar and mark it 10 mm from the cut end of the jacket – then cut the Kevlar at the mark.



- ✓ Mark the fiber buffer 15 mm from cut end of the jacket.

- ✓ Strip the buffer from the fiber, cutting at the mark. To avoid breaking the fiber, remove the buffer/coating in two or three sections (not all at once) with the final cut removing the buffer back to within 15 mm of the cut end of the jacket.
- ✓ Carefully wipe the fiber with a moistened lint-free cloth
- ✓ Prepare the adhesive in the plunger. Push the plunger up, to remove the air.
- ✓ Insert the plunger into the ferrule, and push down on the plunger, forcing the adhesive into the ferrule. Continue to press down on the plunger until a small bead of adhesive can be seen at the plunger tip.
- ✓ Apply the primer to the bare fiber
- ✓ Push the fiber into the ferrule, all the way, until the buffer reaches the back of the connector. Do this quickly, and smoothly, to avoid having the adhesive cure before the operation is complete.
- ✓ Hold the fiber in position for at least 30 seconds, to allow the compound to cure.
- ✓ Hold the beveled edge of the scribe tool flat against the end of the ferrule and gently score the fiber close to the point where it emerges from the ferrule.



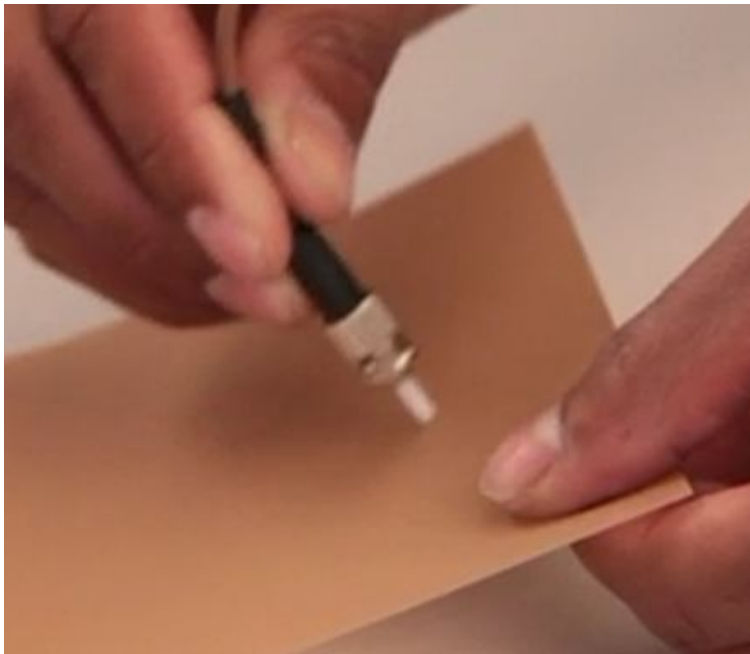
- ✓ Don't attempt to cut the fiber off, at this stage, as this might cause cracking that will extend down inside the ferrule.
- ✓ Grab the fiber in your fingers, and using a straight pull, remove it from the end of the ferrule and deposit it in a safe place.
- ✓ Slide the crimping sleeve up the fiber and over the Kevlar, and push up against the shoulder of the connector housing.



- ✓ Crimp the sleeve using the crimping tool, first crimping the large part of the sleeve, and then the smaller portion. Be sure to use the appropriate crimping hole for the large and the small end of the crimping sleeve.



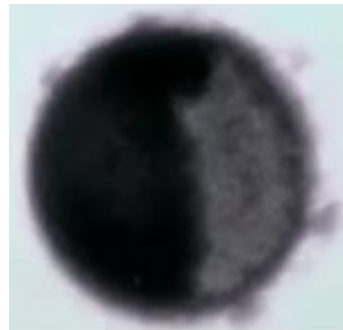
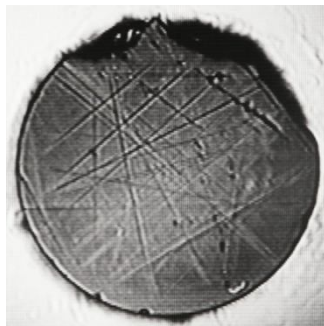
- ✓ Slide the boot back up the cable, and over the crimp sleeve.
- ✓ Take a sheet of the coarsest polishing film and hold it in the air, then rub it against the end of the ferrule in a circular motion. This “air polish” rounds off the fiber stub so that it doesn’t shatter during the rest of the polishing process.



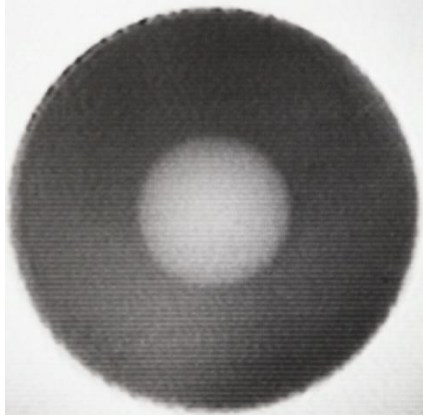
- ✓ Prepare to polish the ferrule by placing the glass plate on the table, and the rubber polishing pad on top (dull surface up).
- ✓ Place a drop of water on the rubber polishing pad, and place the medium polishing film on top (the drop of water helps to hold the polishing film in place).
- ✓ Add another drop of deionized water to the top of the polishing film.
- ✓ Clean the end of the polishing puck, and then fit the connector ferrule into the hole of the puck.
- ✓ Holding the connector, polish the connector on the polishing pad using a figure-eight polishing motion.



- ✓ Polish the ferrule for 20-30 rotations.
- ✓ Remove the ferrule from the polishing puck and clean the ferrule end
- ✓ Check the ferrule end, using a fiber-optic microscope
- ✓ If there are fine scratches (figure below, left), do some additional polishing. But if the fiber is cracked (figure below, right) there is no point continuing; the connector should be cut off, and a new one fitted and polished.



- ✓ If the fiber is not cracked, remove the medium polishing film and replace it with the fine polishing film. Then replace the ferrule in the puck and polish again.
- ✓ Clean the ferrule end, and inspect again, using the microscope. The ferrule end should look like the figure below:



## 5. Fusion splicing

Optical connectors have the advantage of allowing the optical fiber to be repeatedly connected and disconnected. Their convenience is countered by relatively high loss and reflectivity. If it is desired to permanently connect two optical fibers, with low transmission loss and high return loss, the most effective way is to fuse the two fibers together.

Fusion splicing involves precision melting of the two optical fibers into a single un-broken piece of fiber. To accomplish this, one uses a fusion splicing machine like the one illustrated in figure 5-1.

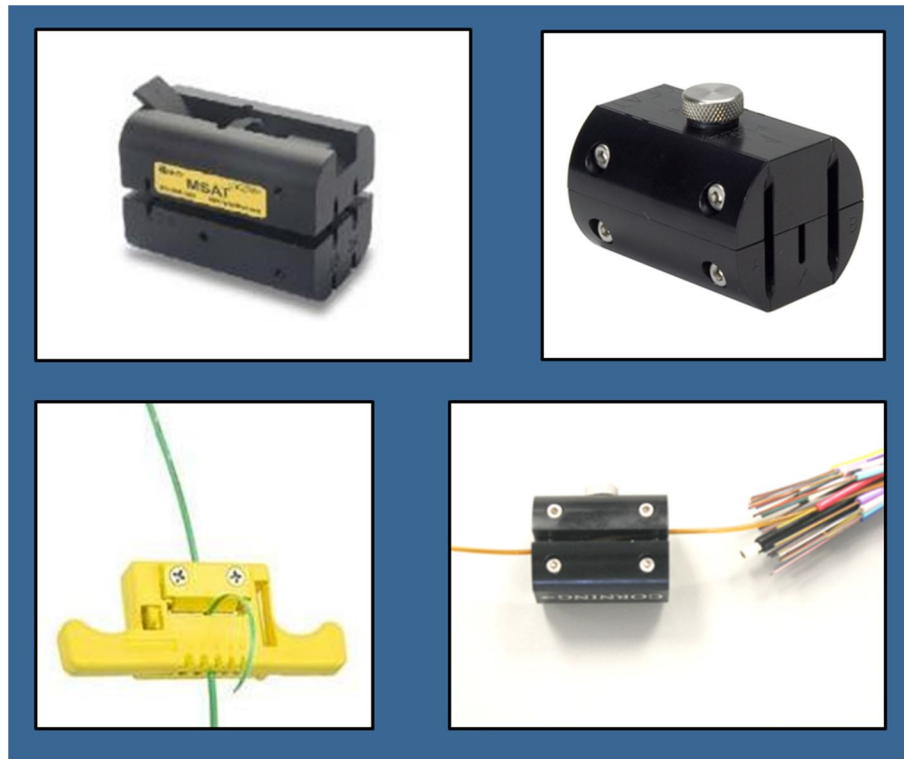


**Figure 5-1. Typical fusion splicing machine.**

To successfully splice two optical fibers one must:

1. Expose the bare fiber
2. Clean and cleave the bare fiber
3. Fuse the fiber
4. Protect the fusion splice

In most applications, exposing the bare fiber begins with removal of the outer layers of the cable. Sometimes the application calls for splicing a fiber-optic component to one of the fibers in a cable, and so the fibers must be accessed mid-cable, and not from the end. Such mid-span entry is accomplished with specialized access tools (see figure 5-2) which are used to carefully remove buffer tubes from 250um loose tube fiber without disrupting active signals or damaging fibers.



**Figure 5-2. Mid-entry (also called Mid-span or Mid-access) tools. Top left: Ripley MSAT (80785)<sup>2</sup>. Top right: Corning OFT-000<sup>3</sup>. Bottom left: RIPLEY MSAT-5 (80930)<sup>4</sup>. Bottom right: MSAT-302<sup>5</sup>.**

Once the desired fiber is isolated, and all the loose cable structure, moisture block, and loose tubing removed, the next step is to strip the fiber of any tight-buffered coatings. Sometimes the fiber has a 900-micron tight-buffered coating, which must be removed; in addition, the 250-micron buffer must be taken off. Stripping and preparing the fiber can only be efficiently and properly accomplished with tools that are specifically designed for the job – this is because the tools must not nick the fiber, as any nicks will seriously weaken it and probably result in future failure. There are many different brands and styles of these tools, and a little experimentation will help in the selection of fiber stripping tools that works best for you.

<sup>2</sup> For accessing fibers in 2, 2.5 and 3mm buffer tubes in mid-span locations.

<sup>3</sup> For mid-span fiber access in standard Corning Cable Systems ALTOS® Cables.

<sup>4</sup> For mid-span access to optical fibers in loose buffer tubes (1.9mm to 3.0mm).

<sup>5</sup> For mid-span access entry to buffer tubing between 2.4 and 3.0 MM diameters.



**Figure 5-3. Examples of stripping tools.**

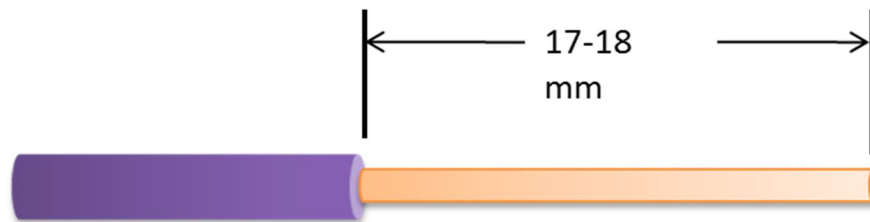
Before you begin the final process of stripping the 250 micron buffer, be sure to place the splice protector on first. It's easier to thread the fiber through the splice protector, this way. Additionally, the act of sliding the stripped/cleaved fiber through the splice protector results in contamination which can release volatile compounds during the fusion process, weakening the splice and causing it to fail.



**Figure 5-4. Using a stripping tool to remove the 250 micron Acrylate buffer from the fiber.**

When removing the 250 micron Acrylate coating from the fiber, remove enough to expose approximately 1 ¼" (32mm) of bare fiber; after the fiber is cleaved, the length of the exposed

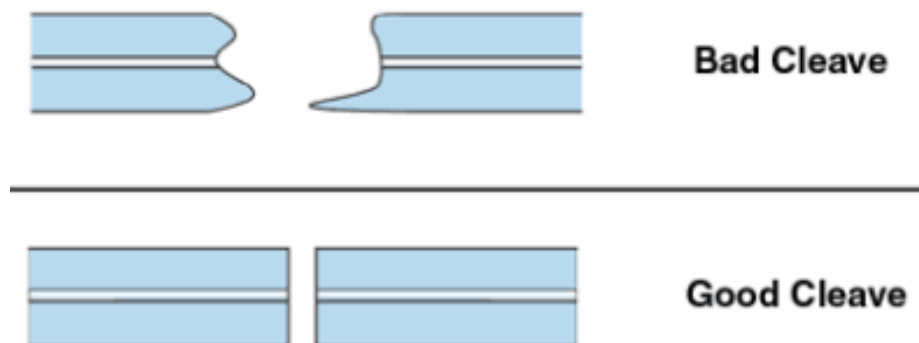
fiber should be 17-18 mm (this will depend somewhat on the fusion splicer that you are using – so see the manufacturer's recommendations).



**Figure 5-5. Proper amount of buffer to remove from the fiber when preparing it for fusion splicing.**

The fusion process involves a high-temperature electric arc that melts the optical fiber. Any contaminants on the fiber, especially volatile compounds, will vaporize in the arc and this will often cause contamination and failure in the splice. Additionally, the fibers are aligned in precision V-grooves and dirt on the fiber causes misalignment in the V-groove and subsequent poor alignment between the fibers, resulting in higher-loss fusion splices. Thus it is essential to carefully clean the fiber with a lint-free, wipe that is impregnated with reagent-grade isopropyl alcohol.

Thorough cleaning is one of the most essential steps for a successful fusion splice. Another critical step is to prepare the ends of the fibers with a high-quality cleave that is perpendicular to the axis of the fiber, and free of any hackles.



**Figure 5-6. One of the most important steps in preparing the fiber is to have a high-quality cleave.**

Modern fiber-optic cleavers will (when properly used and maintained) yield thousands of high-quality cleaves. The discarded fiber ends, from the cleaving process, should be considered hazardous because they can accidentally become embedded in the skin or eyes. Consequently, you should exercise prudent safety procedures and you should use a cleaver that has a built-in scrap collector for storing fiber shards for safe disposal.



Figure 5-7. Fiber-optic cleaver equipped with holder for the cleaved fiber ends.

The objective of cleaving is to create an end face that is cut perpendicular to the length of the fiber and is free of defects. Modern fusion splicers automatically measure the angle of the cleaved fiber end and, if the end is not properly cleaved, may give a warning that the fiber should be re-cleaved. If this warning occurs repeatedly there is a good chance that either the cleaver or the fusion splicer needs maintenance or repair.

There are two types of fiber-alignment processes used in modern fusion splicers. The simplest, least expensive, and least accurate method uses profile alignment and fixed V-grooves to align the fibers using their outer diameters. This method is subject to errors if the cores are not concentric. A more accurate method uses optical imaging to align the two cores directly, thus removing errors that would otherwise result from a lack of core concentricity. Core alignment is preferred for splicing two single-mode fibers together, while profile alignment is suitable for splicing multimode fibers together, or when splicing a single-mode fiber to a multimode fiber.

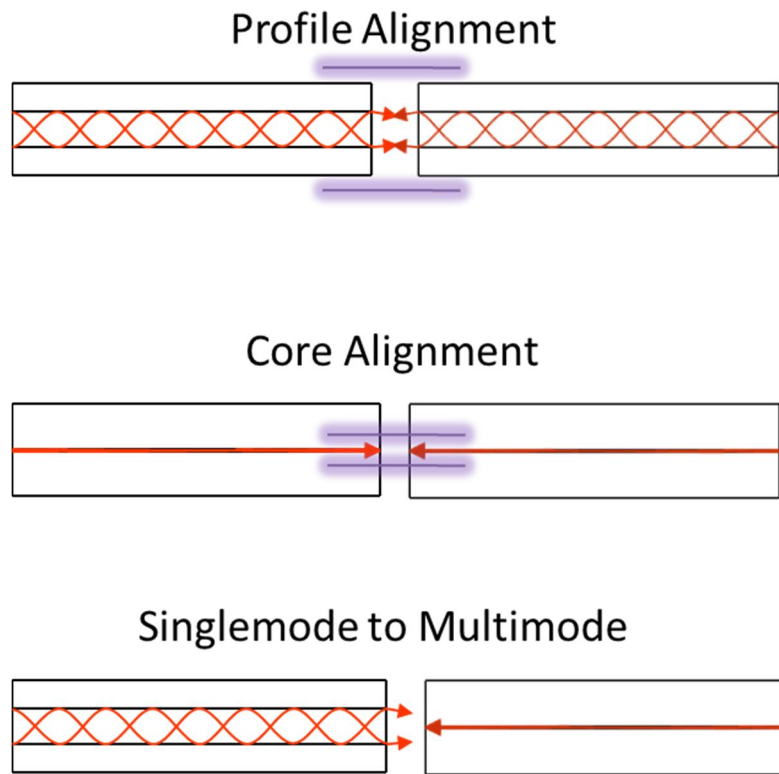


Figure 5-8. Profile and core alignment methods.

Whether using a core alignment or fixed-V groove fusion splicer, it is important to make sure the outer surface of the fiber is clean (this must be done prior to cleaving) and properly aligned inside the V-groove. Otherwise, dirt/contamination on the fiber can cause misalignment of the fibers, resulting in a poor splice.

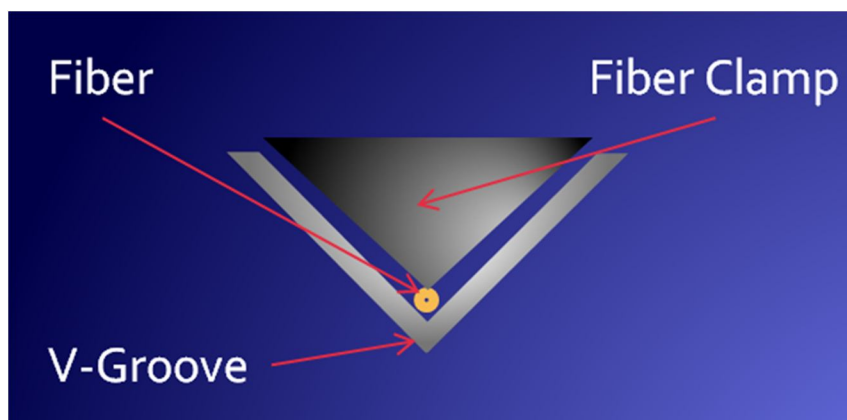


Figure 5-9. Make sure the fiber is placed in the bottom of the V-groove and that the fiber is clean.

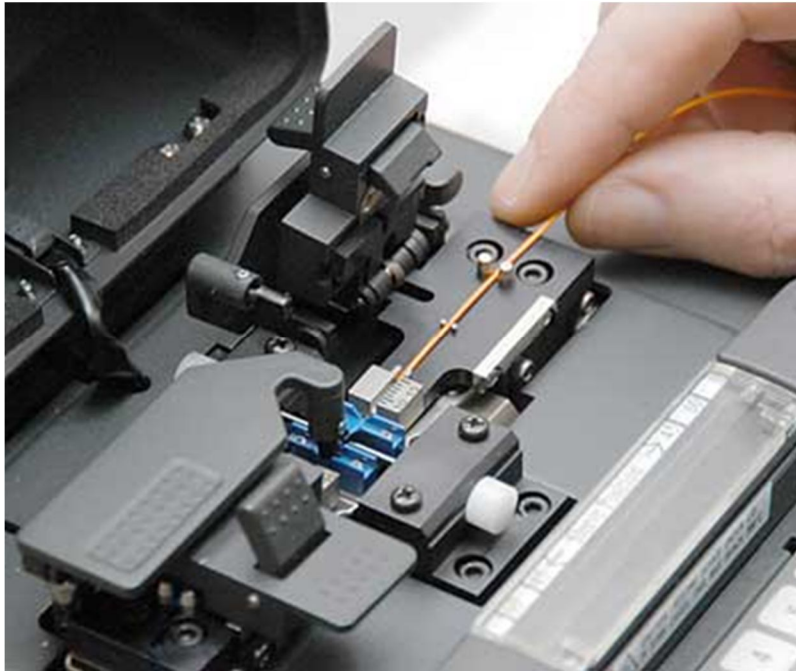


Figure 5-10. Placing the fiber in the V-groove.

Modern fusion splicers use video microscopes to monitor the orientation/placement of the fibers and the alignment during the splicing process. This also allows the splicing technician to monitor the splice in real time.

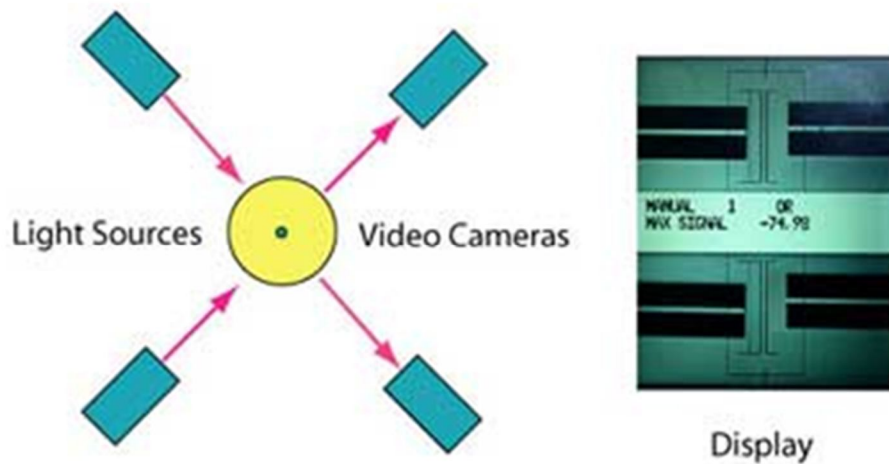


Figure 5-11. Video cameras and microscopic imaging show the fiber alignment in real time.

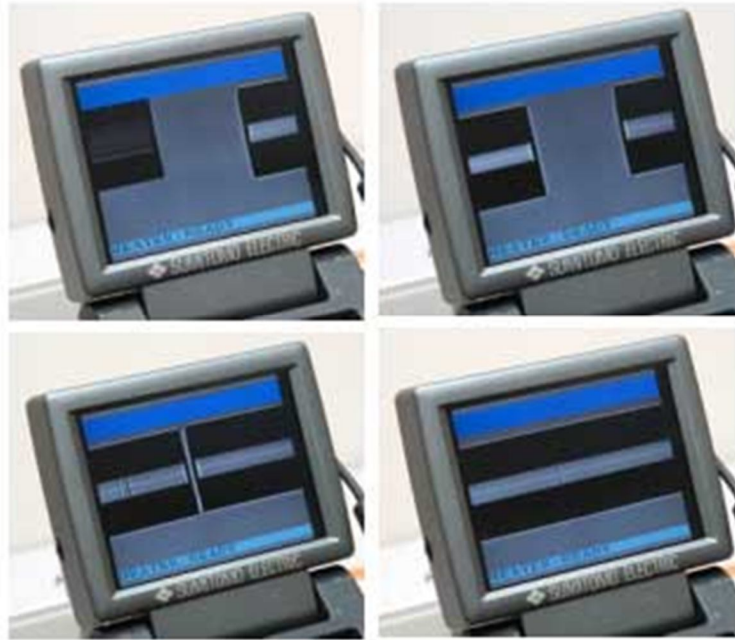


Figure 5-12. This series of images shows the fiber as initially inserted into the V-grooves (top left), after initial alignment (top right), just before splicing (bottom left) and after the splice is completed (bottom right).

Fusion splicing optical fibers is similar to welding; after aligning the two fibers and spacing them correctly, the fusion splicer establishes a high-powered electrical arc between two electrodes. The fiber is placed between these two electrodes so that the fiber is heated by the electric arc. As the arc heats the optical fiber, precision actuators in the fusion splicer push the two fibers toward each other, slightly, thus merging the melted glass into one continuous optical fiber.

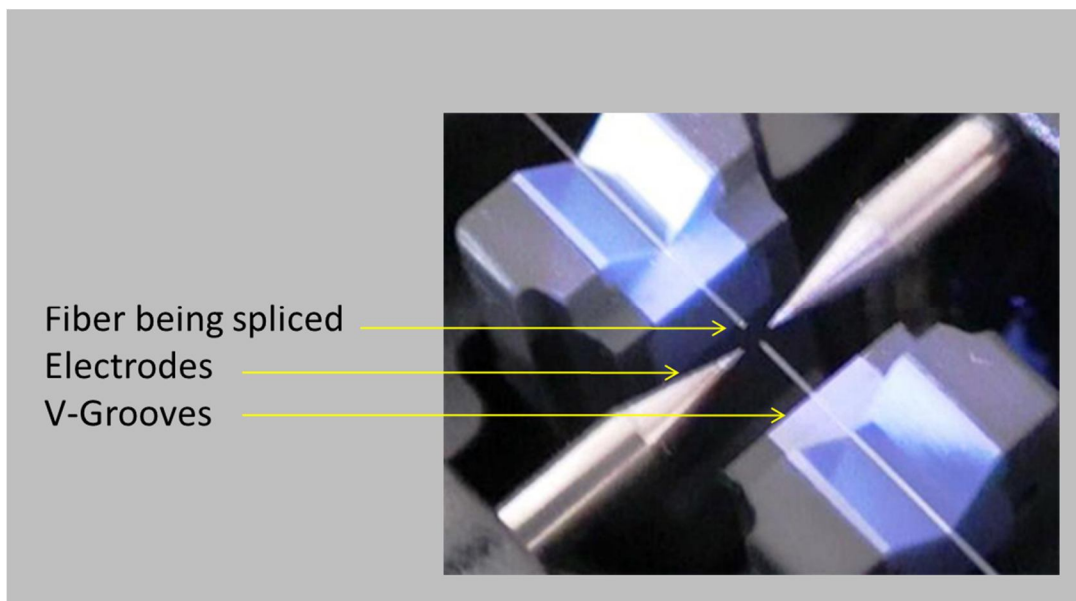


Figure 5-13. Close-up view showing the two fibers that will be spliced, supported by the V-grooves, with the electrodes on either side of the fiber joint.

Fusion splicers have built-in visual diagnostics so they can tell if a splice is good or bad. If the fiber has been properly cleaned, cleaved, and placed in the V-grooves the result is almost always a good splice, but if one of these steps is not performed properly, the result can often be a defective splice that needs to be redone. In addition to following any instructions the fusion splicer may give about the viability of the fusion splice, it's a good idea to do a visual inspection of your own, by examining the splice's appearance on the splicing screen.

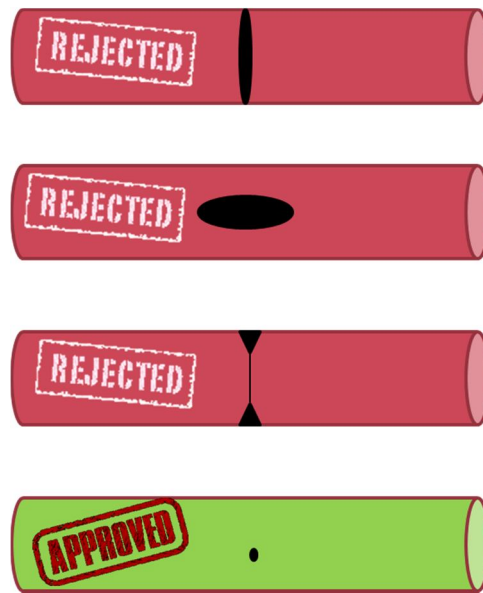
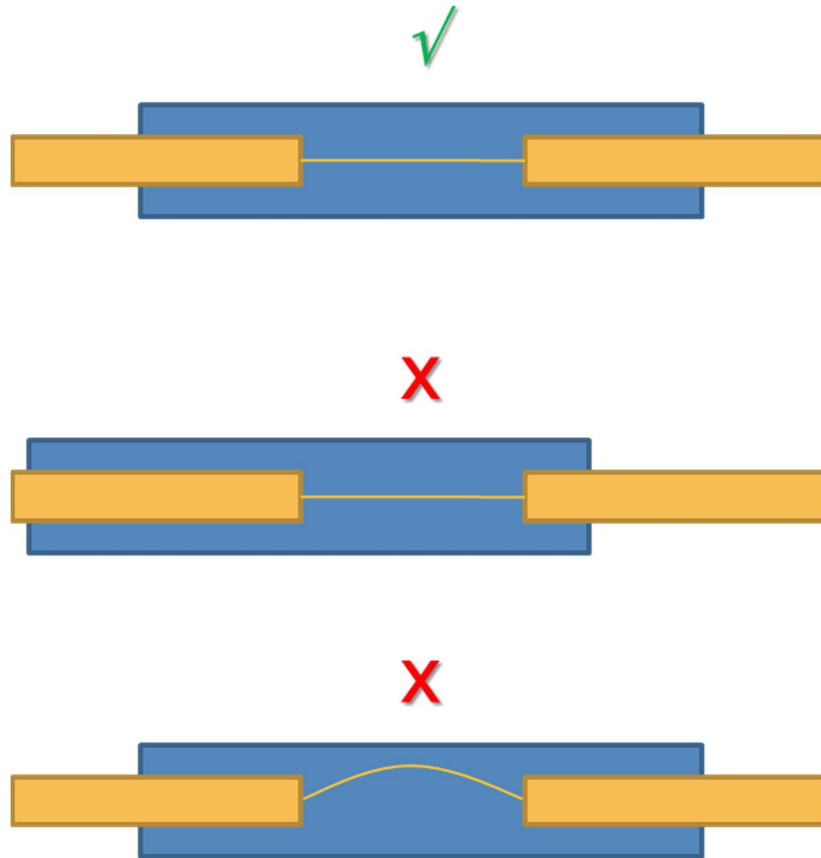


Figure 5-14. A good splice will be free of large distinguishing features like bubbles.

Bare fiber-optic glass is very fragile, and easily broken if exposed to excessive bending or tensile stress. Before the splice can be normally handled, it must be secured within a splice-protecting sleeve. When inserting the splice into the splice-protection sleeve, make sure the splice is centered inside the sleeve, and that the sleeve has a sufficient (at least several mm) length of buffer inside. Also, be careful not to allow the fiber, inside the splice-protection sleeve, to be bent.



**Figure 5-15. Make certain to properly place the splice-protection sleeve over the fusion splice.**

The splice protector is firmly attached to the fiber/buffer by heating it – typically in a small oven on top of the fusion splicer designed to heat-shrink the protector onto the buffer. When removing the finished fusion splice, be careful not to burn yourself, as the splice protection sleeve will remain hot for several minutes after the heating process is completed.

## 6. Cleaning fiber optics

There are several reasons why it's very important to keep fiber optic connectors clean. First, the tolerances in fiber-optic connectors are very small, often less than a millionth of a millimeter. Because these tolerances are so small, even microscopic bits of dust can cause the fibers to be misaligned. When the fibers in an optical connector are misaligned, the loss and the reflectivity (return loss) can be out of specification. The second reason to keep optical connectors clean is that tiny bits of dirt, when ground between the ends of the connectors, can cause permanent damage, resulting in connectors with high reflectivity and/or high loss.

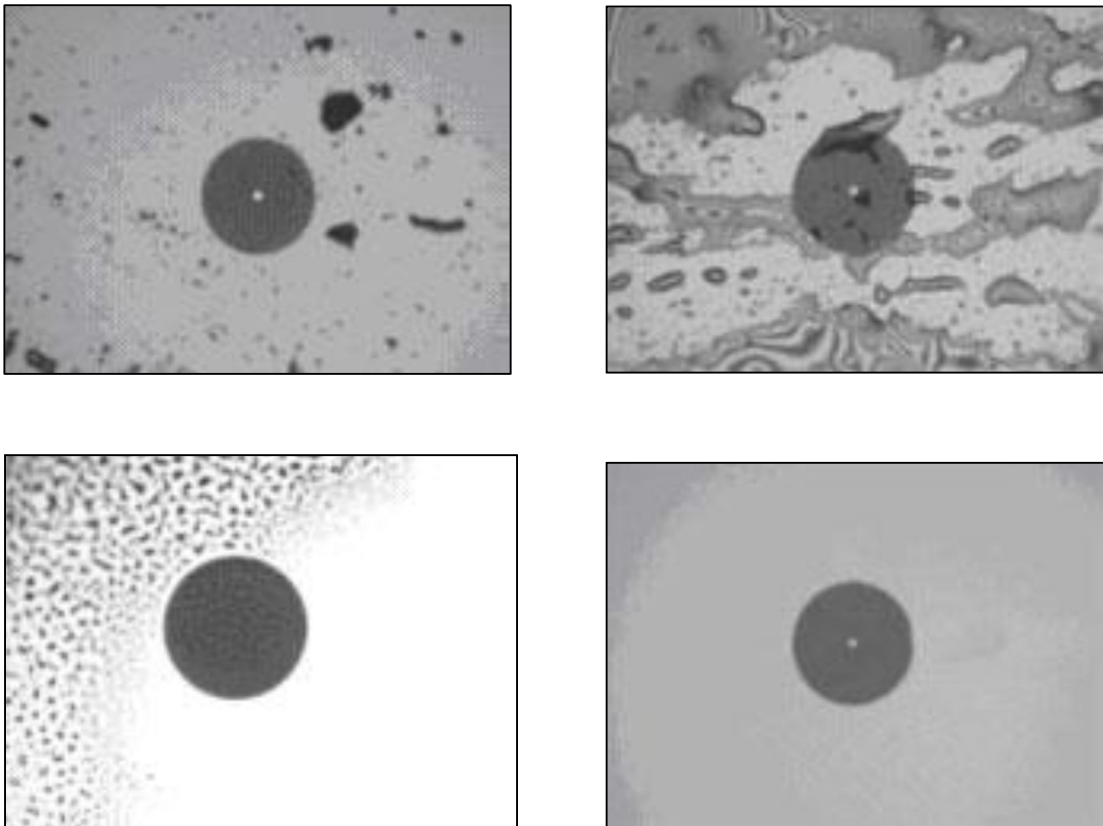
Because of these reasons, it is important that all the surfaces of a fiber-optic connector be very clean. Proper cleaning and maintenance techniques will greatly extend the life of connectors, and improve the overall performance of the optical systems in which the connectors are used.



**Figure 6-1.** An example of a mechanical cleaner (left), used for cleaning the ends of the ferrules on connectors. Also, an example of swabs (right) used to clean the insides of feed-through couplers.

A wide variety of cleaning tools are commercially available for cleaning optical connectors. Wipes, sometimes pre-moistened in a solvent like isopropyl alcohol, can be used, as well as lint-free textile materials. Swabs are used for cleaning the inside of feed-through couplers and are available in different sizes and shapes for various applications. Mechanical cleaners are available in two different styles: the first for cleaning the connector faces; the second for cleaning the inside of feed-through couplers. Both styles typically contain a long roll of dry lint-free textile which auto-advances to provide a fresh cleaning area for each use. Many have replaceable cleaning rolls, some are disposable.

Whenever you clean optical fibers, always use a new applicator with each cleaning, to avoid introducing contamination. When using mechanical cleaners, be sure to advance the cleaning surface for each connector you clean. When using moistened cleaners, use a new wipe for each application. If you are moistening the wipe by dipping it into a reagent grade solvent, never “double dip,” as this will transfer contamination to the solvent. Whether implementing a dry or wet cleaning, wipe the cleaning surface across the tip of the ferrule with light pressure. Do this multiple times, using a new part of the cleaning surface (or a new applicator) each time. After cleaning the connector, inspect the end face using an optical connector scope to verify that the face is clean and free of debris and residue. Repeat the cleaning procedure if necessary. After cleaning, the connector should be promptly inserted into its receptacle; bare fibers left on a table can be easily contaminated, and common dust caps, which are designed to protect the connector from physical damage, are often dirty and a source of contamination themselves.



**Figure 6-2. Examples of dirty connectors. Top left: particulate contamination (dust, grit). Top right: oily residue. Bottom left: watery residue, left over after cleaning with alcohol. Bottom right: clean connector.**

The best way to clean a feed-through coupler is to unplug any connectors and then moisten a clean optical swab with reagent-grade isopropyl alcohol. Gently twist the swab as you insert it into the barrel. If possible pass the swab all the way through the coupler, and out the other side. Inspect the inside of the feed-through coupler to verify cleanliness, and repeat the cleaning

process as necessary. After cleaning, promptly insert clean optical connectors or cover both sides with clean protective caps.

The optical receptacles on the Fiber SenSys Alarm Processing Unit are feed-through couplers with an optical connector mated to the coupler, on the inside of the APU. If the optical receptacle is mated/de-mated often, and attention to cleanliness is not maintained, then the receptacle may require cleaning. A dirty receptacle may result in cases where the internal connector ferrule becomes damaged. If this happens, the APU can only be repaired by the factory, and the repair is not covered under warranty. Thus, it is extremely important that every connector that is mated to the APU receptacles be clean. Also, protective caps should always be in place on the optical receptacles when not in use.

Warning! In order to avoid injury, verify that the Alarm Processing Unit is powered off prior to inspection. Laser energy can be damaging to eye sight.



## 7. Testing

The most common types of testing associated with fiber optics are measurements of optical loss and measurements of optical return loss. When measuring optical loss the two most common tools/methods are:

1. Continuity test
2. Optical time-domain reflectometry

The continuity test involves using a stable light source (usually a laser or LED) to inject a known amount of light into one end of the fiber-optic cable, and then using an optical power meter to measure the amount of light that comes out the other end. The advantages of this approach are its simplicity and relatively low cost. The disadvantages are the required access to both ends of the optical fiber, and the lack of information about the location of loss-inducing fiber damage.

Unlike continuity tests using light sources and power meters, tests with optical time-domain reflectometers (OTDRs) are performed from one end of the optical fiber. In addition, the OTDR provides diagnostic information not available with the continuity test, such as the location of a break, or the return loss of a connector. The disadvantage of OTDRs is they're more expensive and more complicated to use. OTDRs are better suited for use on long fiber, and not very practical when testing short lengths of fiber, such as patch cords.

Figure 7.1 shows the continuity method for measuring the loss of a fiber-optic cable. Two pieces of equipment are required: a stable light source and an optical power meter. In addition, the test setup requires a launch reference cable and a reference receiver cable. The launch reference cable uses single-mode fiber, and the reference receiver cable uses multimode fiber.

The first step in this process is to calibrate the system. This is done by turning on the light source and optical power meter and allowing them to stabilize per the manufacturer's recommendations. Once the laser and power meter are stabilized, connect the launch reference cable to the light source and the receive reference cable to the optical power meter. Make certain to clean all four connectors on these two cables per the instructions in section 6 before making these connections.

Next, connect the launch reference cable to the cable under test, and connect the opposite end of the cable under test to the receive reference cable. Set the power meter to read loss in dB, and set the reference power so that the display reads 0 dB. Then disconnect the launch reference cable from the receive reference cable and insert the test cable (see figure 7-1). The loss of the test cable is now displayed on the optical power meter, in dB.

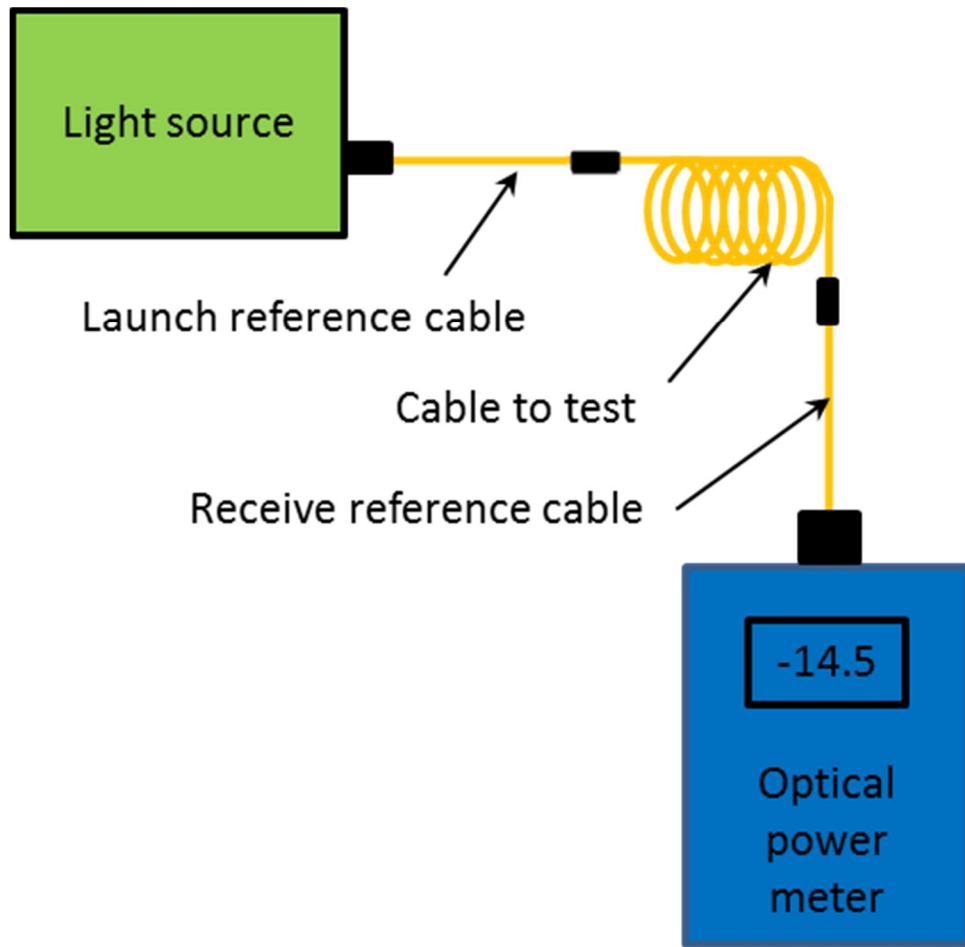


Figure 7-1. Continuity method for measuring the loss in a fiber-optic cable.

The principal source of error in the continuity test results from the unknown loss of the connector between the launch reference cable and the cable under test. This loss might typically be just 0.1-0.5 dB, though in damaged connectors it could be much higher.

Figure 7-2 shows the fiber configuration for measuring loss with an OTDR. Like the continuity test, the OTDR test uses a launch and a receive fiber. The purpose of the launch/receive fibers is to provide a backscatter signature for use in measuring loss<sup>6</sup>. The length of the receive fiber depends on the operational characteristics of the OTDR, but usually 250 meters of fiber is sufficient to ensure a good measurement.

OTDRs work by sending pulses of laser light into the fiber. As these pulses of light travel along the fiber, some of the light is scattered back, toward the OTDR, by a process called Rayleigh scattering (the same physical process responsible for the sky being blue and for red sunsets). Connectors also reflect light back to the OTDR. Within the OTDR is a very sensitive receiver that measures the power in this reflected light, and displays that power as a function of time

<sup>6</sup> The launch fiber provides a backscatter signature for measuring the loss of the launch-end connector, and the receive fiber provides a backscatter signature for measuring the loss of the receive-end connector. If these connectors are known to be good, and only the fiber is being tested, then the launch-end and receive-end fibers can be left out of the test setup.

(distance), where the distance is calculated from the known time delay of the reflections and the speed of light inside the fiber.

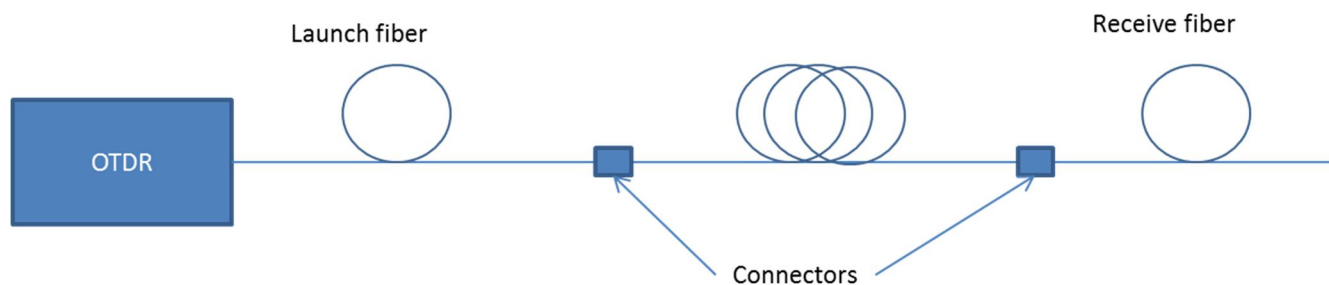


Figure 7-2. Test setup for measuring fiber loss with an OTDR.

Figure 7-3 shows a typical OTDR trace. The relatively flat, horizontal parts of the trace represent Rayleigh backscatter from the fiber, and the spikes represent discrete reflections from connectors and the un-terminated end of the fiber, while the signal beyond the end of the fiber consists only of noise.

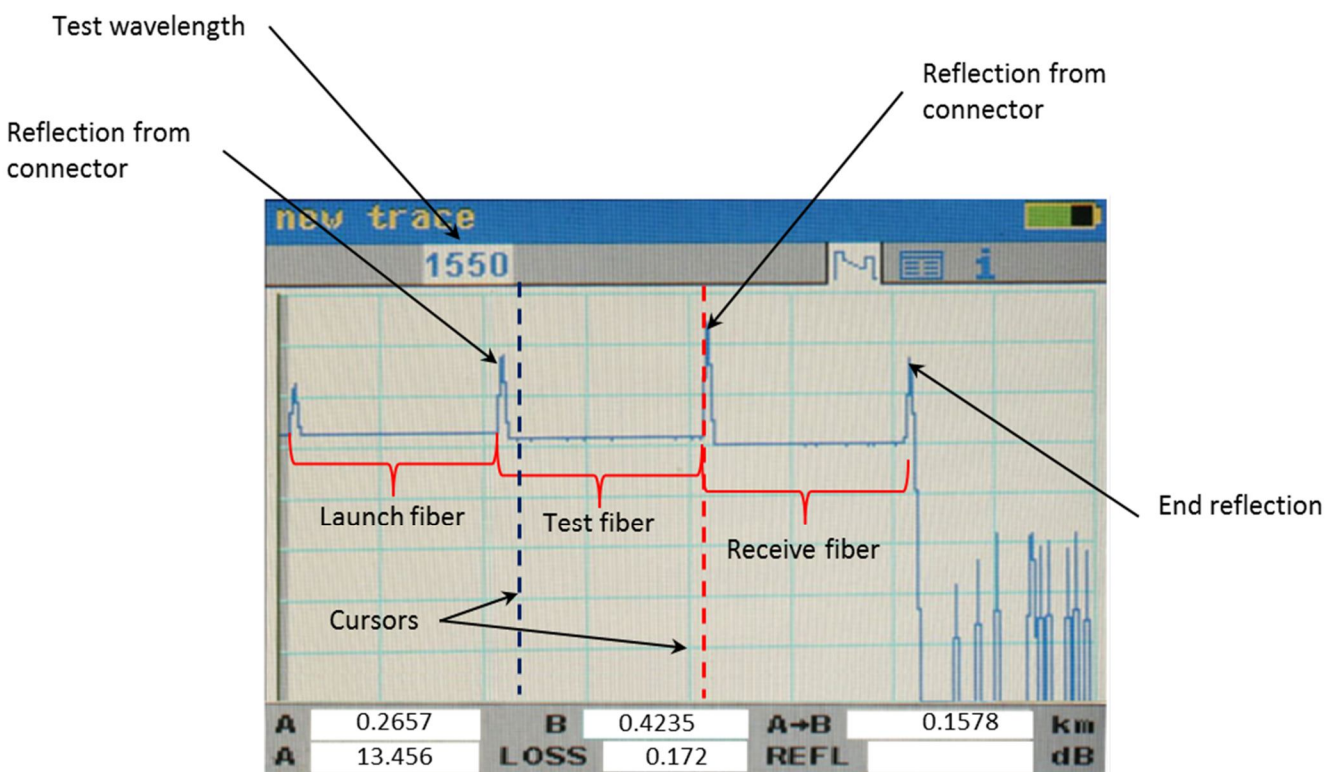


Figure 7-3. Typical OTDR trace, used to measure the loss of the optical fiber.

Loss measurements can be made automatically and/or with manually controlled cursors, depending on the manufacturer. In the example shown in figure 7-3, the loss of the test fiber is 0.172 dB, and the test fiber is 158 meters long.

The OTDR is extremely versatile because, in addition to measuring fiber loss, you can measure the loss of individual connectors and splices, as well as the return loss of connectors (see figure 7-4). Return loss is of primary interest in systems with distributed feedback (DFB) lasers and coherent systems. In such systems it may be necessary to check the reflectivity of any connectors (usually APC) to verify that they are within specifications.

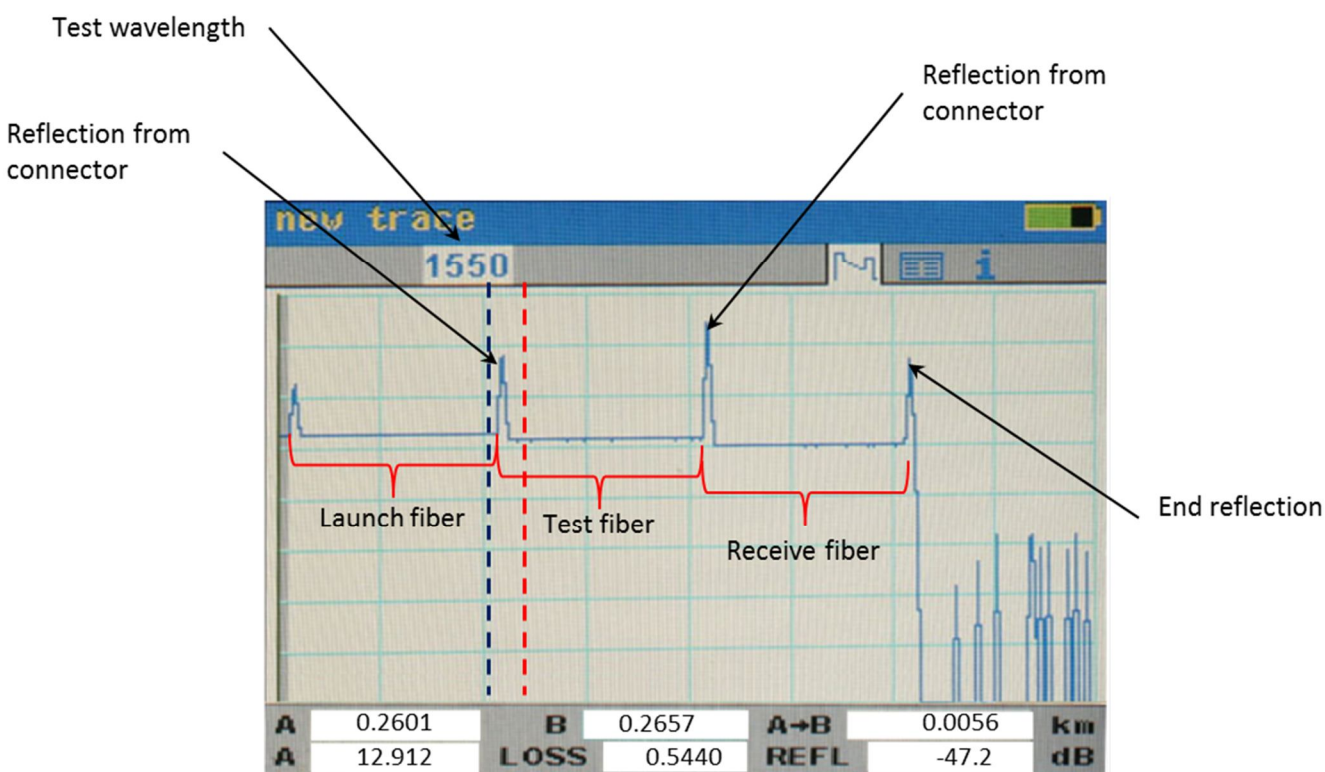
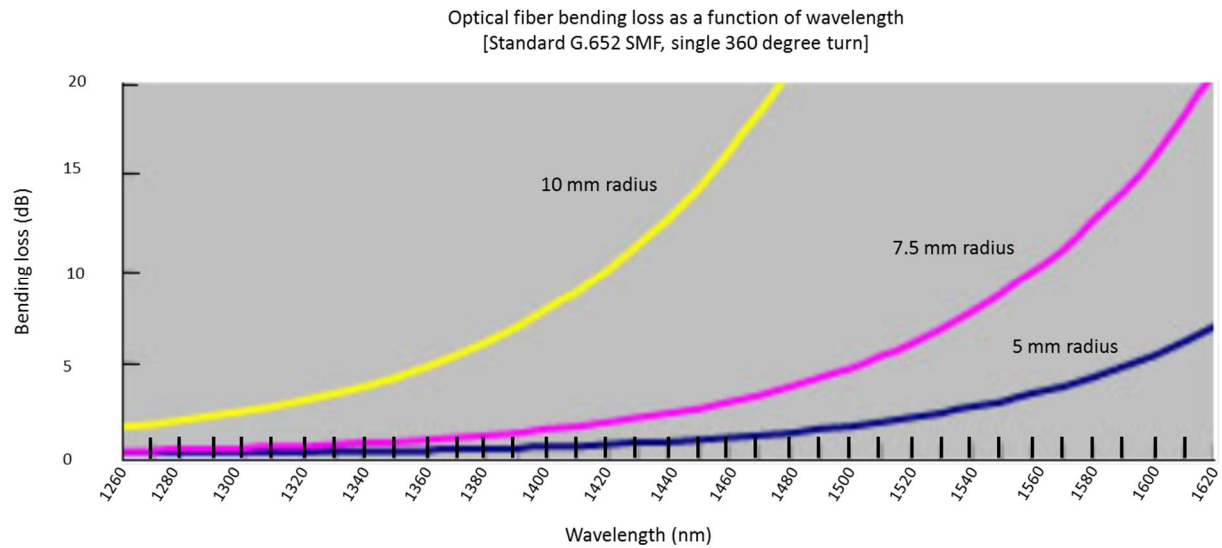


Figure 7-4. OTDR used to measure the loss and reflectivity of a connector. In this case, the connector loss is 0.544 dB, and the return loss is 47.2 dB.<sup>7</sup>

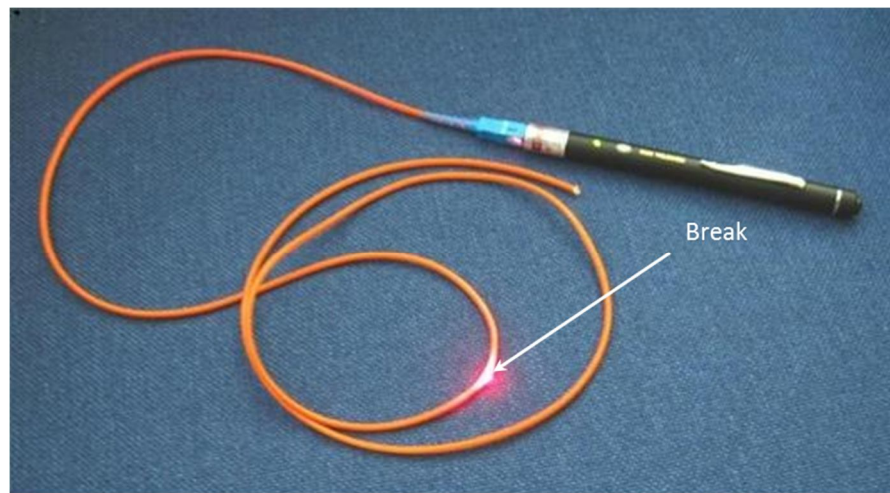
Whether measuring loss with an optical power meter and light source, or with an OTDR, remember that loss on a fiber-optic cable is wavelength dependent, so it is essential that the light source used in the test be the same wavelength as the wavelength that will be used operationally on the fiber. This is particularly important when testing single mode fibers, as the loss on single mode fiber is especially sensitive to wavelength. It is, for example, possible to have comparatively little loss on a bent single mode fiber, at a wavelength of 1310 nm, while experiencing tens of dBs of loss at 1550 nm (see figure 7-5).

<sup>7</sup> Return loss is correctly expressed as a positive number, though this convention is not universally adhered to. Whether the number is expressed as a positive or negative number, the measurement is usually apparent from context.



**Figure 7-5. Bending loss as a function of wavelength.**

If a connector seems to have high loss or high reflectivity there are two tools that can be used effectively to diagnose the problem, the visible fault locator and the fiber-optic microscope. The visible fault locator injects visible red light into the connector, and if the fiber or connector is broken, a glow of red light can be seen at the damaged point (see figure 7-6).



**Figure 7-6. Visible fault locator used to identify the point where a fiber is damaged or broken.**

Fiber-optic microscopes allow you to look at a magnified image of the end of the connector ferrule, thus spotting dirt, oil, or physical damage like chips or cracks (see figure 7-7). Before inspecting the end of a connector, however, always verify that there is no laser or LED light being emitted from the end of the fiber, as this light can cause serious and permanent eye damage.



Figure 7-7. Fiber-optic inspection microscope.

## 8. Sensing with optical fibers

Fiber optic sensors work by monitoring different characteristics of light, and how those characteristics are affected by physical disturbances of the fiber. Modalmetric sensors, for example, work on the principle of coherent interference between the different modes in a multimode fiber. When these modes interfere with each other, they create a speckle pattern. If you connect a short fiber-optic jumper to a visible light source, and project the light from the end of the fiber onto a wall, you can see this speckle pattern (see figure 8-1).

When the fiber is slightly disturbed, the disturbances produce tiny amounts of strain in the fiber that affect the modes differently and, as a result, cause the speckle pattern to fluctuate. This fluctuating speckle pattern can then be analyzed by optical detectors and digital signal processors in order to make inferences about the presence of an intruder.

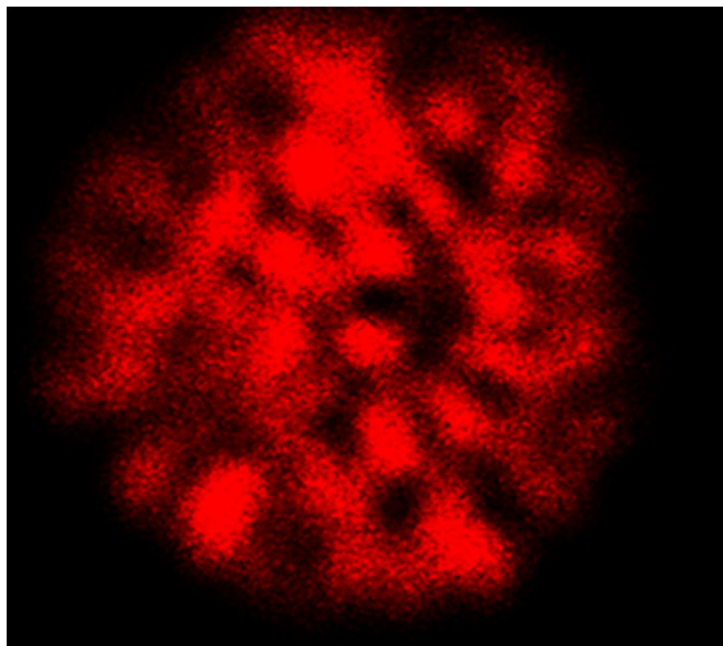
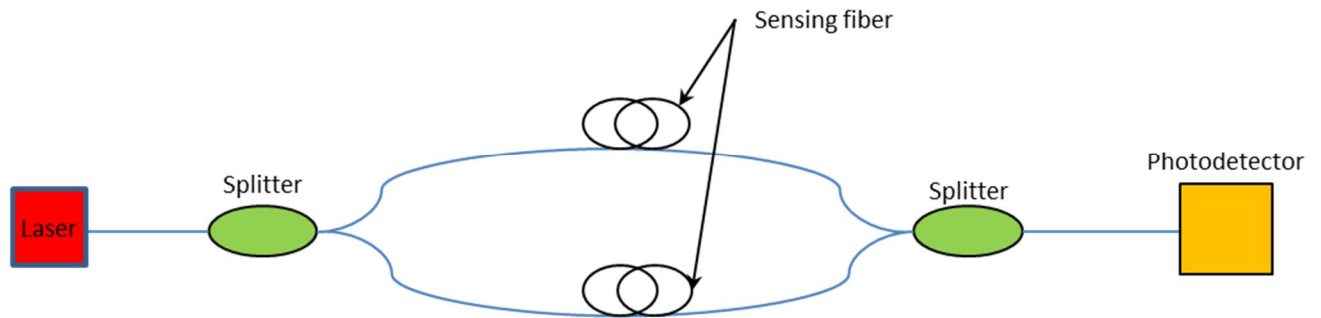


Figure 8-1. Speckle pattern from a typical multimode optical fiber.

Another type of sensor can be made from a fiber-optic interferometer. There are many different types of interferometers, figure 8-2 shows a fiber-optic sensor that uses a Mach Zehnder interferometer configuration.



**Figure 8-2. Sensor using a fiber-optic Mach Zehnder interferometer.**

There are many other types of fiber-optic sensors, as well. Some measure temperature, some measure stress and strain, and some are even used in inertial guidance systems, as gyroscopes, to measure the rate of rotation.

## Index

- Cleaning optical fibers, 27
- Cleaving tools, 21
- Connector
  - APC, 8
  - FC, 9
  - Feed-through, 7
  - Flat PC, 8
  - Installing in the field, 10
  - LC, 9
  - Polishing, 15
  - SC, 9
  - Sleeve, 7
  - ST, 9
  - Unterminated, 8
  - UPC, 8
- Connectors, 7
- Fiber
  - Cables, 6
  - Graded index, 5
  - Multimode, 4
  - Single mode, 4
  - Types, 4
- Fusion splicing, 17
  - Machine, 17
- Loss, 8
- Mid span access tools, 18
- Return loss, 8
- Sensing
  - Interferometric, 36
- Splice quality, 25
- Stripping tools, 19
- Testing, 30
  - Continuity, 31
  - Inspection microscope, 35
  - OTDR, 32
  - Visible fault locator, 34