Fiber Optic Connector & Splicing Module

Supplemental Curriculum for the Fiber Optic Demonstration System

Industrial Fiber Optics

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IF 120231 Teacher's Manual Revision A

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INDUSTRIAL FIBER OPTICS, INC.
1725 West 1st Street
Tempe, AZ 85281-7622 USA

BEFORE YOU BEGIN . . .

The Industrial Fiber Optics' *Fiber Optic Connector and Splicing Module* contains three learning activities that cover the basics of attaching connectors and splices to fiber optic cables. These technical and highly sought-after skills in the fiber optics industry are taught using a hands-on approach. Each activity will take roughly 50 minutes to complete. This module is suitable for science, physics, industrial technology and vocational education classes at grades 11 and above. This module is a complete curriculum package — no additional materials are required except to complete some homework assignments using a library or the Internet.

The *Fiber Optic Connector and Splicing Module* was designed to be used as a supplement for the Industrial Fiber Optics Fiber Optic Demonstration System, although it can be used separately. The Fiber Optic Demonstration System has been sold in glass and plastic versions by Industrial Fiber Optics (IF-DS100G & IF-DS100P) and in a plastic version by Scientific Laser Connection. This product is compatible with all versions of the Fiber Optic Demonstration System.

This manual will guide instructors and students through the three separate activities. Each activity has assignments containing reading assignments, lab exercises which involve working with fiber optics, worksheets containing questions and homework assignments.

Industrial Fiber Optics makes every effort to incorporate state-of-the-art technology, highest quality and dependability in its products. We constantly explore new ideas and products to best serve the rapidly expanding needs of industry and education. We encourage comments that you may have about our products, and we welcome the opportunity to discuss new ideas that may better serve your needs. For more information about our company or any new products that we have to offer, refer to our web site listed below on the Worldwide Web at:

http//www.i-fiberoptics.com

Thank you for selecting this Industrial Fiber Optics product. We hope it meets your expectations and provides many hours of productive activity.

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Teacher's Manual Only

Section Guide

INVENTORY
ACTIVITY #1:

This activity is intended to acquaint you with Industrial Fiber Optics' *Fiber Optic Connector and Splice* modular training curriculum. You will set up equipment, identify each item that you will be using in the next two activities and familiarize yourself with a specialized microscope.

Equipment Needed:

- All the components that are part of this module. Please refer to the parts list on page 4.

To complete this activity you must:

1. Complete Lab Exercise #1 - Equipment Familiarization on page 2 and take inventory of all the equipment in this module. If you are missing any equipment or parts, let your instructor know before continuing. You may refer to the parts list on page 4 to help describe the components.
2. Answer all Questions on **Worksheet #1**.
3. Complete **Homework Assignment #1**.

Homework Assignment #1:

At a library or on the Internet, find a company that sells or manufactures tool kits for putting connectors or splices on fiber cables. Compare the items in these tool kits to those contained in this module and describe the similarities.

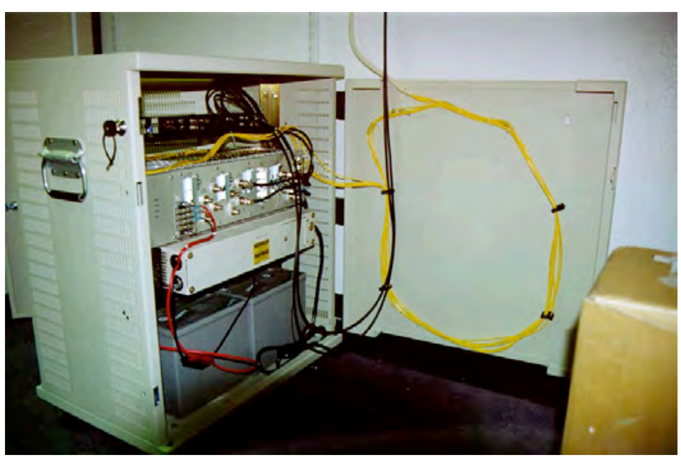

Photo 1. Installed fiber optic cables appear similar to copper cabling, but carry much more communications bandwidth.

EQUIPMENT FAMILIARIZATION
Lab Exercise #1

In the first Lab Exercise students identify and inventory all items furnished with this fiber optic training module. This inventory process is required since it will introduce you to the technical terms used in this manual and speed completion of the following two activities.

Procedure

1. Choose a flat, level table approximately 90 × 120 cm (3 × 4 feet) in size as your work area for this exercise.

2. At your work area, assemble all materials your instructor provides for you.

3. Locate the only item with an electrical cord attached. This is a 25-watt heating element that is part of the Hot Knife assembly you will use to cut plastic fiber.

4. Determine if the heating element has a knife tip attached. If not, locate a clear plastic bottle that contains a knurled brass collar and a threaded chuck about 7.5 mm (.3 inches) in diameter and 32 mm (1.25 inches)long. Remove the collar, chuck and Exacto® knife blade from the enclosure.

5. Slide the threaded end of the slotted brass chuck through the large opening of the knurled cinch nut. Push the chuck through the cinch nut until the thread comes out the small opening in the cinch nut.

6. Thread the brass chuck/cinch nut assembly into the threaded end of the heating element until it lightly touches bottom. Use your fingers to turn the slotted end of the brass chuck for this purpose. Do not tighten any further at this time

7. Insert the square (non-cutting) end of the Exacto® knife blade into the slot in the chuck. Make certain the square end of the blade slides past the large opening in the knurled cinch nut. CAUTION: DO NOT TOUCH OR PRESS THE CUTTING END OF THE BLADE WITH YOUR FINGERS OR INJURY MAY RESULT. GRASP THE BLADE ONLY ON THE FLAT PORTIONS.

8. Tighten the cinch nut so that the chuck firmly clamps the Exacto® knife. Finger tighten only — you must allow some room for thermal expansion when the heating element is powered.

9. Identify the remaining components in **Table 1**. Write in the column marked **ACTIVITY 1** the number of components you found. If the number that you identify does not match the numbers in Column 2, notify your instructor.

10. Reference the parts list in **Table 3** for part numbers for each of these items, for future reordering.

11. The inspection microscope that you identified above is a specially designed tool for examining the ends of optical fibers. Please read the following paragraph and familiarize yourself with microscope operation to save steps in the next activities.

Fiber inspection microscope - A specialized tool for viewing the tip or termination of fiber optic connectors. One end of the microscope has a clear plastic hood with an adapter into which an ST® fiber connector tip is inserted. A swiveling light bulb illuminates the fiber end. The other end of the microscope contains the eyepiece through which the fiber is viewed.

On one narrow side of the microscope there may be a sliding adjustment (ZOOM) that moves the eyepiece. This varies the magnification of the microscope. On the opposite side there is a slide switch that turns the light bulb on and off. There is a focus wheel in the center of the microscope with an exposed edge on two sides. Turning this wheel will adjust the focus of the microscope.

A small sliding adjustment on one face of the microscope (near the end with the clear plastic hood) sets the angle of the light bulb. The ST® adapter has a slot that allows light from the bulb to shine on the fiber end. Changing the position of this slot will adjust the amount of light that falls on the fiber termination. These two adjustments can be used to vary the lighting conditions under which the termination is viewed.

12. Locate an ST® style connector from the parts kit. The connector body has a knurled locking ring with bayonet style slots. This is attached to a metal cylinder which has a large diameter hole on one end and a small one on the other. The cylinder end with the small hole is the fiber ferrule.

13. Insert the ferrule tip into the adapter on the microscope until the ferrule body is completely seated. Turn on the microscope light and as required adjust the angle of the light bulb so the ferrule tip is illuminated.

14. While looking through the eyepiece adjust the focus wheel until the ferrule tip comes into focus. Make certain you apply light pressure to the ST connector to keep the ferrule seated in the microscope adapter. Try different ZOOM settings if your inspection scope has that feature.

15. When done, turn off the microscope light and return it and other materials to their proper storage containers and locations.

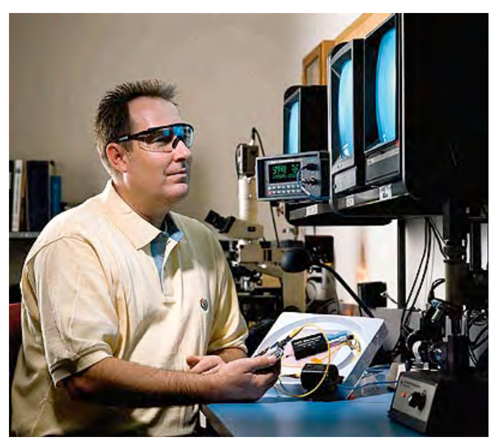

Photo 2. Fiber optic technician testing a prototype fiber optic component.

# # #

Table 1. Inventory sheet for Lab Demonstration 1.

DESCRIPTION	QUANTITY ACTIVITY 1
Hot knife with blade attachment and stand	1
Fiber optic crimp tool	1
Micro-Strip fiber stripper	1
Stainless steel polishing puck	1
Glass polishing plate	1
Fiber optic inspection microscope	1
Professional Fiber Cutter	1
Polishing slurry (4 oz)	1
Vial of index-matching gel	1
Isopropyl alcohol	1
2 m length of plastic core optical cable	1*
ST® style fiber connectors (4 piece sets)	2*
Fiber splice	1*
Kimwipes®	2
Sheet of 2000 grit sandpaper (gray)	1
Sheet of 3 μm polishing film (pink)	1
1 meter 1000 μm plastic core fiber cables with ST® Connectors on one end	2†
ST® Barrel Connectors	2†

® ST is a registered trademark of AT&T. Kimwipes is a registered trademark of Kimberly-Clark.

* The number indicated is the minimum quantity needed to complete Activities 2 and 3 once. There may be more or less than the number indicated when this product is new or recently re-supplied.

† These items are needed only when this module is used with the plastic version of the Fiber Optic Demonstration System (part number IF-DS100P). They are not needed for the glass version of the Fiber Optic Demonstration System because that product comes with ST® connectors as an integral part of the design.

Worksheet #1 Student: ___________________________

1. Describe how the fiber ferrule end of the ST® connector looks with the naked eye compared to what you see under the microscope at different magnifications.

2. Why might the hot knife be a better way to cut plastic fiber optic cable than some other method?

3. What purpose does the polishing slurry (fiber optic extender) serve?

NOTES

INSTALLING A FIBER CONNECTOR
ACTIVITY #2:

In this activity you will first learn about the various types of fiber connectors such as the first generation SMA and second generation ST®. You will understand why technical performance has driven engineers and manufacturers to the latest generation of fiber connectors which include the LC, MT and MT-RJ. A Lab Exercise will provide you hands-on experience with installing a connector to a fiber optic cable.

Equipment Needed:

- 1 Micro-Strip fiber stripper
- 1 Fiber optic crimping tool
- 1 Hot knife with blade attachment and stand
- 1 Stainless steel polishing puck
- 1 Glass polishing plate
- 1 Fiber optic inspection microscope
- 1 4 oz. bottle of polishing extender
- 1 Sheet of 2000 grit sandpaper (gray)
- 1 Sheet of 3 µm diamond polishing film (pink)
- 2 Kimwipes® and isopropyl alcohol
- 1 2 m length of plastic core optical cable
- 2 ST® style fiber connectors (4 piece sets)
- 2 One meter 1000 µm plastic core fiber cables with ST® Connectors on one end (Sensor Fibers)
- 2 ST® Barrel connectors
- 1 Fiber Optic Demonstration System (Plastic or Glass model)*

* Not included in this module

To complete this activity you must:

1. Complete Reading Assignment #2 - FIBER OPTIC CONNECTORS.
2. Answer Questions 1 through 5 on **Worksheet #2**.
3. Complete **Lab Demonstration #2 - INSTALLATION**.
4. Complete **Homework Assignment #2**.

Homework Assignment #2:

Research on the Internet several fiber optic connector manufacturers. To start, go to the web site http//fiberoptic.com to find some fiber optic connector companies. Pick a specific connector type they produce and describe where it is used in the fiber optics industry (for example, telecommunications, local area networks).

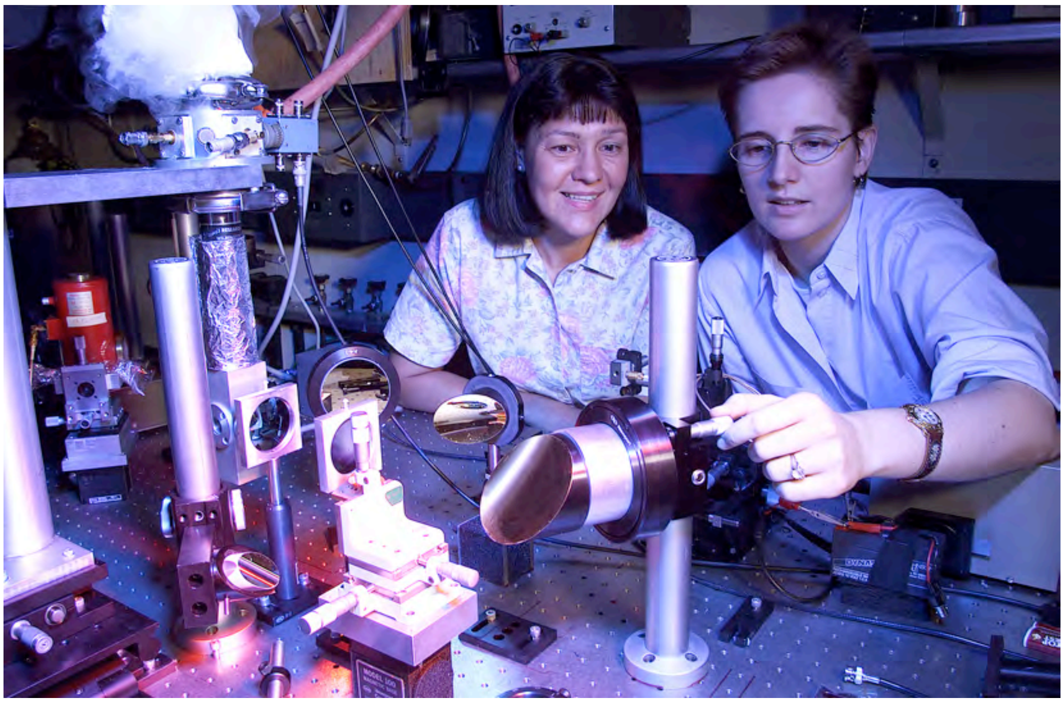

Photo 3. Two Bell Labs scientists test a bidirectional laser that may one day be used in fiber optic systems or advanced sensor technology.

FIBER OPTIC CONNECTORS
Reading assignment #2

Electronic devices are often interconnected, either to form a larger system or to exchange information or data. An example of this is the local telephone system, which has electronic devices (such as a telephone) connected with copper wires to large switching networks. The wire carries power and signals from the phone to the switching office, and electrical connectors are used to link the wire to various devices in the system.

In the previous module, we mentioned optical fiber, networks, transmitters and receivers, but we have not described in detail how these elements are connected to each other. Fiber optic cable performs a function similar to that of copper wire, and connectors are similarly used to attach fiber to the many devices in a fiber optic system. Fiber optic cables need to be connected and disconnected just like their copper counterparts. In this section we will discuss several connection methods and tools used with optical fiber components.

Linking Optical Fibers and Devices

In electronic systems, electrical current or energy is used either to transfer power or carry information among components and subsystems. Fiber optic systems use optical energy primarily to carry information or data. Regardless of the data format or transmission rate within a fiber optic system, three fundamental actions are performed among the various components and subsystems. A component is either emitting optical energy (LEDs and lasers), transferring optical energy (fiber optic cables and couplers), or receiving optical energy (phototransistors and photodiodes).

To link these fiber optic components so optical energy can be transferred within the system, two primary methods are used:

- Connectors
- Splices

Table 2. Comparison of fiber optic connectors and splices.

CONNECTORS	SPLICES
Removable	Permanent
Can be factory-installed	Can be field-installed
Can be field-installed	Lower attenuation/reflection than connectors
Easy to reconfigure	Strong, compact junction
Provide standard interface	Lower cost per connection
	Easier to fit inside conduit

Connectors most often are used to link fiber optic cable to photodetectors or LEDs. The devices are packaged in a housing which accepts a connectorized fiber optic cable, permitting efficient transfer of optical energy between the cable and optoelectronic component. Splices most often are used to permanently connect two fiber optic cables. While connectors can also be used to attach two fibers, splices generally offer less light loss and are more permanent. Connectors are removable and therefore more flexible when interchanging components within a system. **Table 2** shows a comparison between connectors and splices. More detail on splices will be presented in the next reading assignment.

Connectors and Their Uses

In many electronic systems, the ability to add, change, or remove components or subsystems is a necessity. The reasons may include equipment expansion, repairs, or upgrades. Electrical connectors are crucial in performing these activities with a minimum of labor and time, permitting rapid exchange of components which have the same connector type. An everyday example of an electrical connector is the power line cord on many common appliances. Imagine the inconvenience of having to permanently wire an appliance to the power grid in your home and you can appreciate the convenience an electrical connector can provide. There is a strong need for connectors in fiber optic systems for the same reasons.

Connector Components

Photo 4. Sampling of the various fiber optic connectors that are currently being used in the world today.

Just as there are many different electrical connectors, a variety of fiber optic connectors exist, including SMA, SC, ST, FDDI, Biconic and DNP simplex. Each connector style has unique characteristics with particular advantages, depending on the application. Regardless of type, all connectors share common design characteristics. They provide a strain relief to isolate the fiber cable from mechanical stress, a ferrule to capture and align the fiber, and a body to contain the ferrule so it can be attached to mating receptacles.

Fiber cable is attached to a connector body or housing by bonding or crimping, often with a strain relief boot where the cable outer jacket meets the connector body. The ferrule is typically a long, thin precision cylinder bored through the center with a hole diameter slightly larger than the fiber cladding. Held within the connector body the ferrule acts as an alignment mechanism so the fiber end can be precisely positioned when the connector is mated. When fiber cables are connected together a coupling device is usually employed in the form of a dual female bulkhead adapter.

Early Connector Designs

As with many other technologies, connectors have gone through several generations of design evolution. Many early fiber optic connectors were modifications of existing electrical connectors. An example of this is the SMA style which had a body threaded the same as its electrical counterpart used in radio frequency applications. While rugged, it had drawbacks. There was large variability in the optical connector loss because it allowed the fiber ferrule to rotate within the connector body when it was attached or removed. Early fibers had significant variations in cladding diameter and the cores were not precisely concentric with the cladding. Any rotation between mating fibers would vary the amount of overlap and the optical coupling achieved, and possibly scratch the fiber ends.

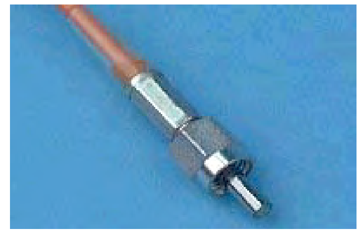

Photo 5. SMA fiber optic connector with glass fiber installed.

Another drawback was that a spring alignment sleeve was required between the ferrules of mating connectors. If omitted, the fiber ends might be misaligned sufficiently to render the connector unusable. The threaded design was also time consuming to engage and permitted too much operator variation in the amount of torque used when tightened.

Improved Connector Designs

Second generation connector designs solved many of the early application problems. A ST® connector, as used in this curriculum, is built around a cylindrical ferrule that mates with a coupling receptacle. The outer connector body is a spring-loaded bayonet socket that allows quick engagement with the coupling receptacle. The loose alignment sleeve of the SMA is now integrated within the receptacle or bulkhead adapter. The ferrule is also keyed to prevent rotation of the fiber when the connector is attached.

The result is a consistent connection independent of operator assembly skill. ST® connectors have better repeatability and the average optical loss is less than the optics loss of SMA connectors. They are popular in data communications and medium-distance applications.

Recent Connector Technology

The increasing demand for data communication links has pushed fiber optic technology to new levels of performance. Modern connectors are smaller, have lower overall loss and often link fiber cable arrays used in multi-channel data links.

Photo 6. ST® fiber optic connector.

Examples include the LC connector developed by Lucent Technologies for residential/business applications. The 1.25 mm diameter ferrule is half the size of many other connectors and is housed in a body similar to the RJ-45 telephone style connector. Another example is the MT array style connector which is used with ribbon fiber containing up to 12 individual fibers. The high packing density gives a significant advantage in tightly spaced applications that require many data channels.

Connector Installation Overview

The installation of a connector onto a fiber optic cable is similar in concept to attaching an electrical connector; however, the process requires more care, precision and time. Special tools often are required, and each connector type (and often manufacturer) has a unique procedure, although many steps are common to all. The following describes a typical installation sequence:

Photo 7. Duplex LC® fiber optic connector with glass fiber installed.

1. Cut fiber optic cable to desired length.
2. Slip strain relief over jacket.
3. Remove layers to expose optical fiber.
4. Pre-trim fiber end to length.
5. Insert fiber into ferrule.
6. Epoxy or crimp fiber cable into connector.
7. Polish fiber end and inspect with microscope.

The goals of any connector installation procedure are to anchor the fiber in a protective mechanical housing, ensure it is properly aligned, and provide a smooth fiber tip finish to maximize transmission.

Some connectors are designed to reduce the installation steps needed for a good assembly. An example of this is the plastic DNP (dry, no-polish) simplex connector. It is a low-cost connector for plastic optical fiber links under 30 meters in length, and uses no epoxy or crimp to hold the fiber to the connector plug. The fiber jacket is stripped, the fiber end is cut with a knife or razor blade then inserted and held in the connector plug containing a barbed retention clip. The whole process takes less than a minute.

Other techniques for linking fiber optic cables and system components use no connectors whatsoever. An example of this includes the fiber optic LEDs and photodetectors manufactured by Industrial Fiber Optics. These devices are contained in housings which accept the 1 mm core/clading plastic fiber cable directly. The fiber end is cut with a razor blade, inserted carefully into the component housing, then held in place with a cinch nut. The internal construction of the housing accurately aligns the fiber with the photodetector or LED for maximum transfer of optical energy. This connector-less termination type is used only with plastic fiber. To view these types of components please go to our web site *www.i-fiberoptics.com*.

When installed, all connectors have attenuation, or loss of optical energy within the connector. There are several causes for this, including mechanical misalignment of the fiber, and the quality of the end finish. As an example, assume two fiber cables with connectors are attached to each other. If the fiber ends are not aligned so that the area of one fiber core completely overlaps the other, some light will be lost where there is no overlap. Any tilt in the axis of the fiber ends may cause light to leave the confines of the collection angle of the fibers. Also, a gap between the fiber ends may cause light exiting one fiber to spread outside the collection diameter of the other.

In fibers with poor end finish, light will be absorbed, reflected, or scattered by the irregularities on the fiber ends. Finally, any gap between fiber ends will cause the index of refraction from the discontinuity in refractive indices (glass to air to glass). This can be significantly reduced by the use of index-matching gel.

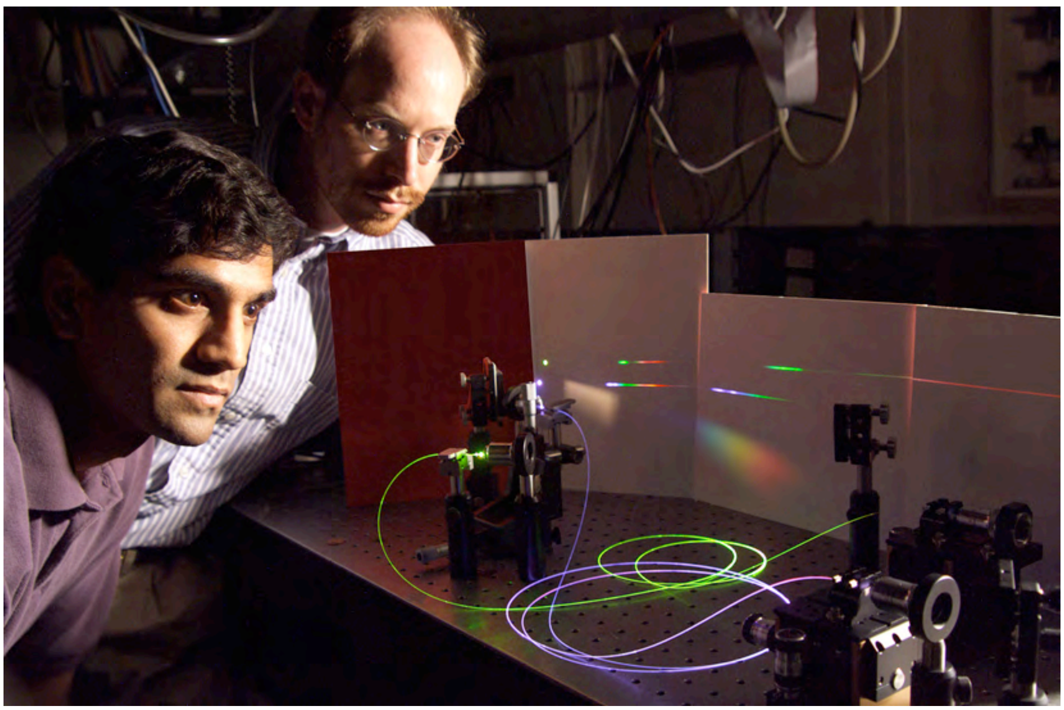

Photo 8. Research scientists continually explore ways to increase optical communications bandwidth, and apply fibers to lighting applications to conserve energy.

INSTALLATION
Lab Exercise #2

In this demonstration you will learn how to install an ST® connector onto a fiber optic cable. Each step of the procedure will be carried out as it would be performed in a real world application. One of the steps you will complete is polishing of the fiber core/cladding ends, which is a very important part of the termination procedure. After assembling the connector to the fiber cable you will test it to show that it works.

Procedure A

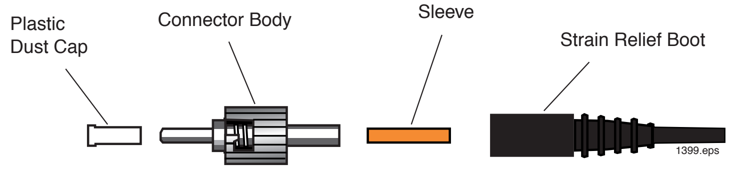

Figure 1. 4 components of the ST® connector.

1. Choose a flat, level table approximately 90 × 120 cm (3 × 4 feet) in size as your work area for this exercise.
2. If the blade of the hot knife is not attached, carry out steps 4 through 8 of Lab Exercise #1. Place the blade end of the hot knife in its stand on a non-flammable surface and plug it in. Allow the hot knife to heat about 15 minutes before use.
3. The ST® connector assemblies that you will use in this activity consist of four parts as shown in Figure 1. Each assembly contains a black rubber strain relief boot, orange sleeve, plated steel connector body and a plastic dust cap. The connector body is an assembly with a long cylindrical tube (the ferrule), and a spring-loaded locking ring held in place by a C-ring.
4. Hold the Micro-Strip fiber stripper in one hand and one length of fiber cable in the other. Do not compress the handles of the strippers.
5. Insert the fiber cable through the hole in the fiber stripper (fiber guide) until the fiber end aligns with the ruler markings for 22 mm (7/8 inch) on one of the handles.
6. Squeeze the handles of the fiber stripper fully closed and then slightly release pressure on the handles.
7. While maintaining a slight constant pressure on the fiber stripper handles pull the fiber cable away from the tool (a strong tug may be required).

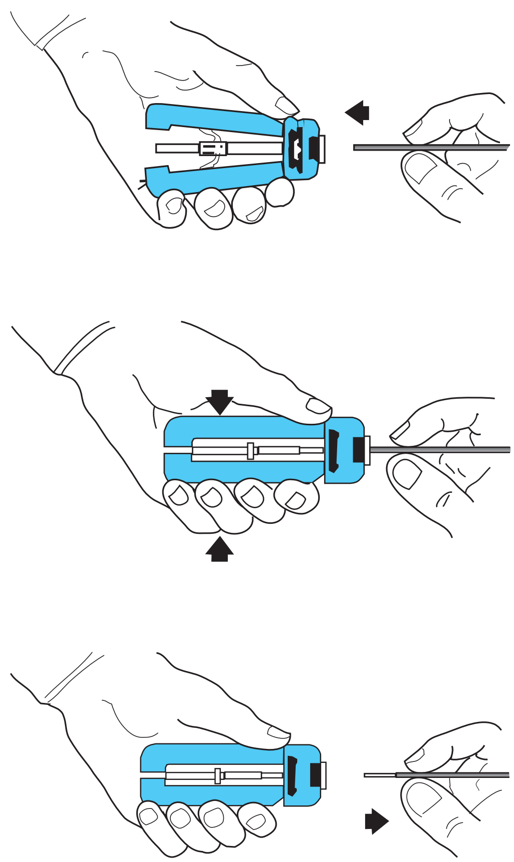

Figure 2. Proper orientation of fiber cable and fiber stripper.

8. You should now have a fiber cable that has its bare core and cladding exposed for about 22 mm (7/8 inch).
9. Slide the small end of a black strain relief boot onto the end of the fiber cable you just stripped.
10. Slide an orange sleeve over the exposed optical fiber onto the jacket of the fiber cable. Push the sleeve until the end closest to the exposed fiber is flush with the end of the jacket.
11. Slide the large end of the fiber connector body (ferrule) onto the stripped end of the fiber cable and up over the orange sleeve. Push it onto the cable as far as it will go. There should be 3 to 10 millimeters (.12 to .39 inches) of the orange sleeve protruding from the large end of the ferrule, and 1 to 2 millimeters (.04 to. 08 inches) of bare fiber protruding from the small end.
12. You will use the 0.128 inch hex hole in the jaws of the crimping tool to crimp the ferrule onto the fiber cable. It is the smallest of the holes in the jaws that have six sides. If the crimping tool jaws are not fully open, slowly squeeze the handles until the jaws fully close. Continue squeezing until the latch mechanism releases, allowing the jaws to open completely.

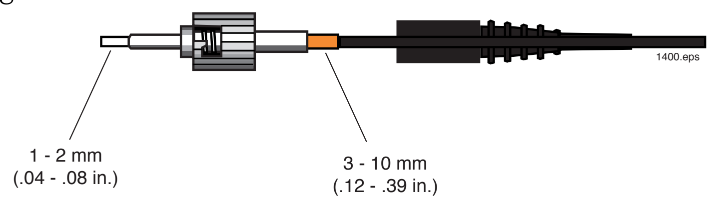

Figure 3. ST connector properly located and crimped onto a fiber cable.

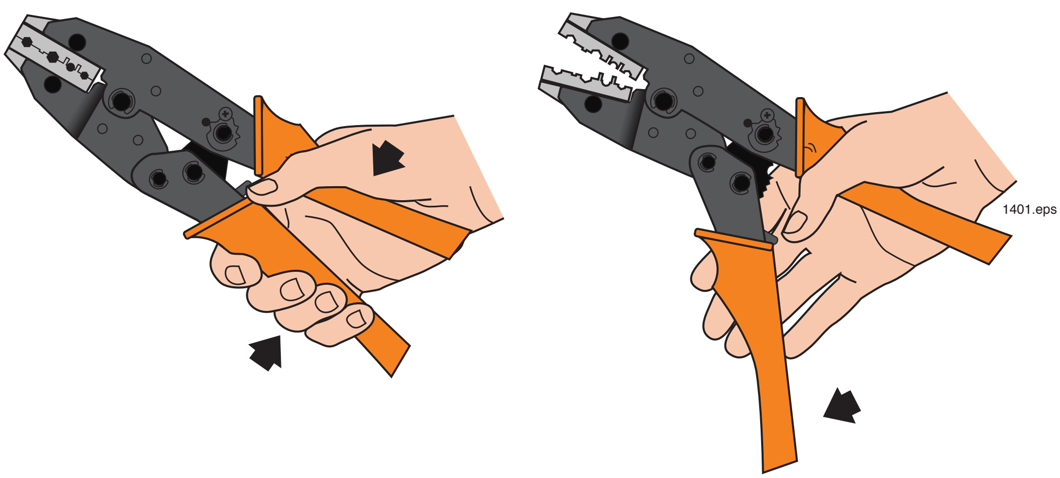

Figure 4. Proper grip of the crimper and tool in its open position.

13. Place the large end of the ferrule in the 0.128 inch hex hole as shown in Figure 5 and slowly squeeze the handles of the crimp tool until the jaws just make contact with it. Do not apply any further pressure on the handles.
14. At this point, make sure the sides of the jaws are pressed firmly against the locking ring of the connector. This will insure that the entire end of the ferrule will be crimped. Also, make sure that the fiber cable is still pushed firmly into the connector.

15. While making sure that the fiber cable and connector do not move out of position, slowly squeeze the handles to close the jaws until the tool bottoms and springs open. The crimp is now complete.

16. Slide the strain relief boot toward the end of the connector.

17. Position the hot knife blade against the side of the protruding fiber, just beyond the tip of the connector, and cut off all but about a half a millimeter (.02 inch) of the excess fiber.

18. CAUTION: Never inspect optical fiber with an inspection microscope when a high intensity light source such as an LED or laser diode is on the opposite end of the fiber. The microscope will focus the light energy to a very small spot on your eye's retina. Permanent eye damage could result.

19. Insert the fiber ferrule on the end of the connector you just assembled into the ST® adapter of the inspection microscope. Look through the eyepiece and adjust the focus and lighting of the microscope until you can clearly see the tip end of the fiber. The end of the fiber you are inspecting can also be back-lighted by pointing the opposite end at a light fixture or open window if the sun is out.

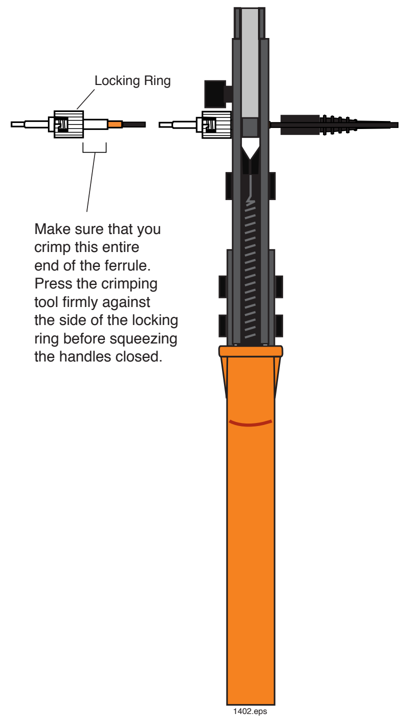

Figure 5. Position of the ST connector in crimper for proper crimp.

20. Look at the fiber end and vary the magnification if your microscope has that option.

21. Visually compare the end of the fiber to the diagram in Figure 6. You should see a rough surface similar to the one in the diagram. These defects reduce the transmission of light into the fiber (insertion loss) and out of the fiber (reflection loss). These defects can be greatly reduced, if not completely eliminated, by polishing the fiber.

22. Place the 2000 grit sandpaper face up in the center of the glass polishing plate (the dark gray rough side is up). Shake the bottle of polishing slurry well. Wet the sandpaper with two or three drops of polish slurry in the center of the sheet. Insert the ferrule of the fiber

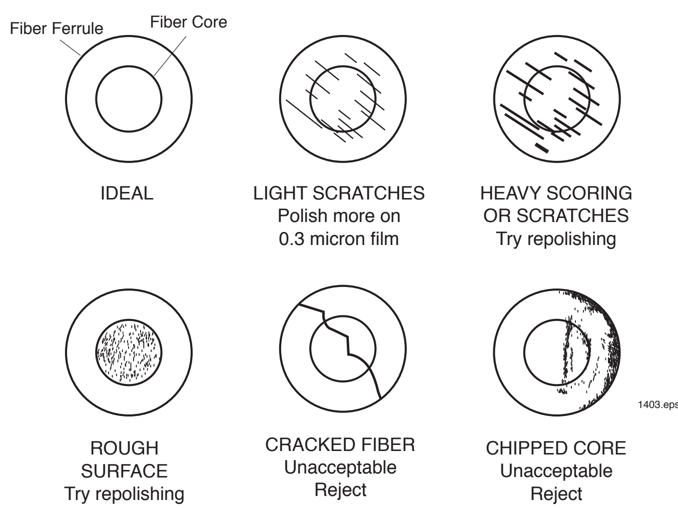

Figure 6. Defects found in the fiber ends after polishing.

connector into the top of the polishing puck. This is the raised side opposite the pattern machined into the bottom of the puck. Place the puck bottom side down on the polishing extender so that the tip of the fiber contacts the sandpaper.

23. Polish the end of the fiber in a "figure 8" pattern as shown in Figure 7. Repeat the pattern while lightly pressing the tip of the fiber against the sandpaper. Use the polishing puck to hold the ferrule at a 90° angle (perpendicular) to the polishing surface to create the ideal polishing angle.

24. After 20 strokes, clean the puck and the connector by wiping them off with a Kimwipe and alcohol.

25. Look at the end of the fiber again with the microscope. The end of the fiber should now be flush with the end of the ferrule. Also, the roughness you saw in the end of the fiber in Step 21 should be gone, replaced by light, parallel scratches. If the roughness is still there, polish the fiber again for 20 more strokes. If necessary, repeat this process until the tip of the fiber is flush with the end of the ferrule and the scratches are the only imperfections you see in the end of the fiber.

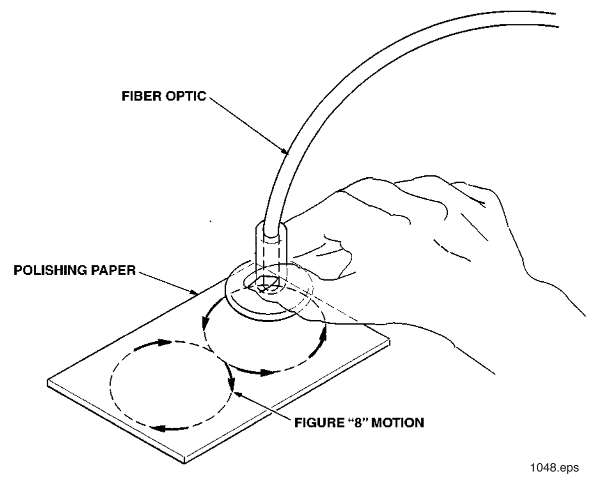

Figure 7. Fiber polishing showing the figure-8 pattern.

26. Visually compare the two sides of the pink 3 µm polishing film. One side is glossy and smooth, the other dull and slightly rough. The dull, rough side is the top side of the film. Wet the polishing film with two or three drops of polish slurry in the center of the sheet. Repeat steps 22 through 24, replacing the 2000 grit sandpaper with the 3 µm polishing film.

27. Observe the end of the fiber ferrule with the microscope. At this point you should not be able to see the scratches left by the polishing film, except by careful examination under the microscope.

28. Repeat steps 4 through 27 to terminate the other end of the fiber, allowing another student to participate if possible. When complete, turn off the Hot Knife and put away unused materials.

29. Answer Question 6 on Worksheet #2.

Procedure B

You will now test the fiber cable that you have just assembled.

1. Choose a flat, level table approximately 90 × 120 cm (3 × 4 feet) in size as your work area for this demonstration.
2. Place the Fiber Optic Demonstration System module on the work area and remove the following:

   Fiber Optic Lab Module

   120-VAC-to-12-VDC power adapters with cords

   Orange banana-to-yellow banana wire test lead
3. Insert the yellow plug of the orange-yellow test lead into the yellow jack of the Signal Generator with the word "Digital" below it. Insert the other end into the orange Transmitter jack.
4. Insert the small end of the 120-VAC Power Adapter cord into the black plastic jack at the center left portion of the Lab Module (just above and to the left of the Speaker).
5. Insert the two-pronged end of the Power Adapter into a 120-volt wall outlet. The yellow LED labeled "On" (located just above the black power input jack) should light up. If not make sure both ends of the Power Adapter are firmly plugged in.
6. If you have a glass version of the Fiber Optic Lab Module (from IF-DS100G) proceed to step 7. If you have the plastic version (from IF-DS100P) proceed to step 8.
7. Insert an ST® connector from the 2-meter fiber optic cable you just assembled into the fiber optic LED (FO LED) as follows: Align the key on the connector body with the slot on the ST® receptacle, then gently push in. Rotate and push the knurled locking ring until the slots engage the bayonet ears on the ST® receptacle. Twist against the spring tension until the knurled ring snaps and locks over the bayonet ears. Insert the remaining ST® connector into the fiber optic photodetector (FO DET). Proceed to step 9.
8. Attach an ST® Barrel connector to each end of the 1-meter fiber optic cable you just assembled as follows: Align the key on the connector body with the slot on the ST® Barrel receptacle, then gently push in. Rotate and push the knurled locking ring until the slots engage the bayonet ears on the ST® Barrel receptacle. Twist against the spring tension until the knurled ring snaps and locks over the bayonet ears. Insert the bare end of a 1-meter Sensor Fiber into the fiber optic LED (FO LED)and tighten the cinch nut. Insert the bare end of the other Sensor Fiber into the fiber optic photodetector (FO DET) and tighten the cinch nut. Attach the ST® connectors from both Sensor Fibers to the ST® Barrels on each end of the 2-meter cable you assembled.
9. Turn the Signal Generator Frequency knob counter-clockwise completely to <u>minimum scale</u> (lowest frequency). Turn the Receiver Gain knob clockwise and observe the green ("High") and red ("Low") LEDs. They should be blinking

alternately. Disconnect one end of the cable you assembled — the LEDs should stop blinking.

10. Disconnect the Power Adapter, remove all fiber and electrical cables and place them in their proper storage locations.

# # #

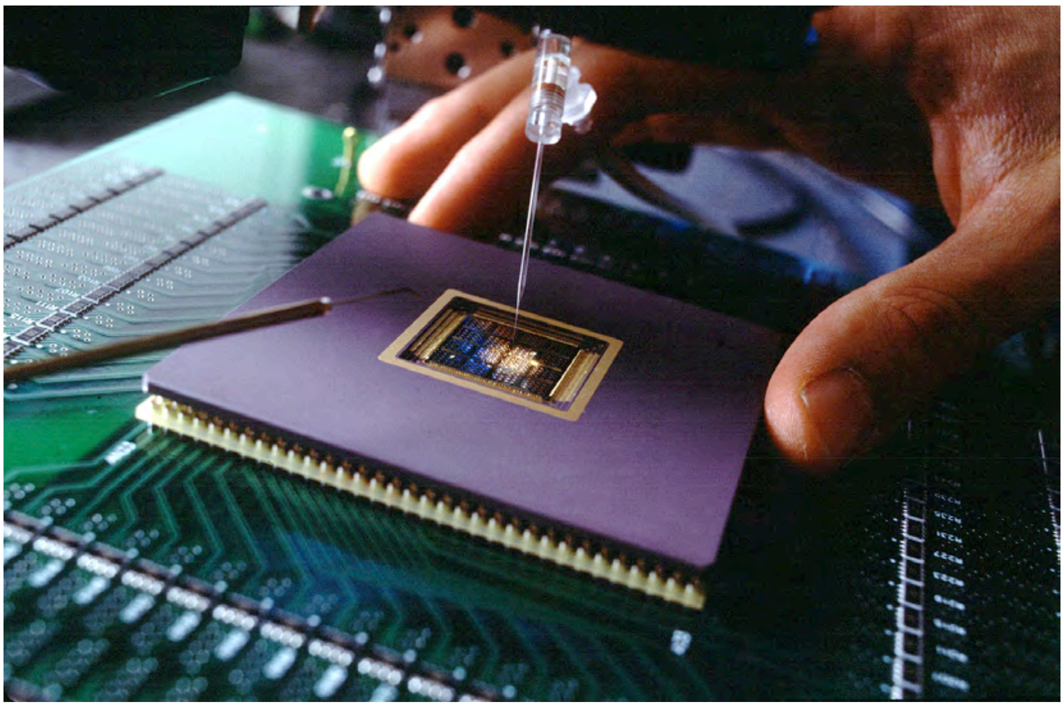

Photo 9. Technician probing a high speed optical and electrical switching circuit.

Worksheet #2 Student: ___________________________

1. Connectors are used to:
   a) Decode data transmitted via fiber optic cable.
   b) Generate light in a fiber optic system.
   c) Attach fiber cables to components or subsystems interconnected with fiber optic cable.

2. An advantage provided by connectors is:
   a) They allow fiber optic components or subsystems to be easily interchanged or upgraded.
   b) They amplify light, causing it to travel farther down a fiber cable.
   c) They are a permanent method of attaching fiber cable to optical components.

3. The main elements of a fiber optic connector are:
   a) Fiber cable, LED and photodiode.
   b) Connector body, ferrule and strain relief.
   c) Laser diode and bulkhead adapter.
   d) Crimper
   e) None of the above
   f) All of the above

4. Early fiber optic connectors:
   a) Had problems with alignment and repeatability.
   b) Were occasionally modifications of existing electrical connectors.
   c) Could be time consuming to install.
   d) All of the above.

5. Recently designed fiber optic connectors:
   a) Require high technical skill to install.
   b) Are smaller with less optical loss.
   c) Can often carry several fibers in a multi-channel system.
   d) b & c above.

6. Describe the differences you observed with the fiber microscope when the fiber end was polished with 2000 grit, then with 3 µm polishing film.

FIBER CABLE SPLICING
ACTIVITY #3:

In this activity you will learn how fiber optic cables are often joined with splices. The discussion will include the advantages of splices, a description of several types, along with the methods used to apply them to cables. In a lab exercise you will attach a mechanical splice to the cable connectorized in Activity #2.

Equipment Needed:

- 1 Hot knife with blade attachment and stand
- 1 Professional Fiber Cutter
- 1 Micro-Strip fiber stripper
- 1 Fiber optic crimping tool
- 1 Fiber optic inspection microscope
- 1 Vial of index-matching gel
- 1 Fiber optic splice
- 1 2-meter fiber cable with ST® connectors on both ends (one assembled in previous activity.)
- 1 Fiber Optic Demonstration System (plastic or glass model)

To complete this activity you must:

1. Complete Reading Assignment #3.
2. Answer Questions 1 through 5 on **Worksheet #3**.
3. Discuss your previous homework assignment with your lab partner or group. Review what the main topic of the article was and what you learned.
4. Complete **Lab Exercise #3 - FIBER SPLICING**.
5. Complete **Homework Assignment #3**.

Homework Assignment #3:

Write a paragraph with examples of how fiber optic splices might be used in other parts of everyday life. For example, think of how they could be used in home construction, automobiles, or electronics.

SPLICES
Reading Assignment #3

Splices

When a low-loss and permanent fiber connection is needed, the preferred joining method is a splice. The goal of a splice is to accurately join two fiber ends while providing negligible interruption to the flow of optical energy. Splices have low loss, typically 0.05 to 0.2 dB, versus 0.2 to 0.7 dB for connectors. In a system with many interconnections this advantage can be significant. The two primary methods of splicing fibers are fusion and mechanical. Fusion splicing joins fibers by melting them together with heat. In a mechanical splice the fiber ends are carefully finished and held together in a structure with adhesive or a clamping device.

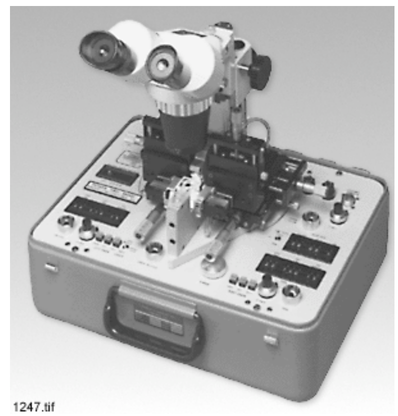

Photo 10. Fusion splicer for glass optical fiber.

Fusion splices achieve the lowest optical losses and are the least costly per splice. The equipment needed, however, is bulky and expensive.

Mechanical splices cost more than fusion splices, but don't require expensive equipment. They generally have higher loss but may make more sense where fewer interconnections are needed.

End Preparation

As with connectors, a crucial aspect of these splices is fiber end preparation. A clean, perpendicular end-face is essential to minimize the loss between fibers. Two methods used for glass fiber end preparation are scribing and breaking (cleaving), and polishing. Cleaving is generally used with splices, while end polishing is most often used for connectors.

Cleaving involves placing a fiber under light tension while a sharp cutting tool scribes a small nick across the cladding. After the fiber is nicked the tension is increased by pulling. The flaw created by the nick spreads across the face of the fiber. The principle is similar to that used for cutting window glass. If done properly the cleave results in a fiber end face with a perpendicular mirror-like finish.

The cleaving process can be done by hand using inexpensive tools or by elaborate automated bench equipment. Manual techniques using hand tools are less costly but depend more on operator skill to achieve consistent end finishes.

Once the fiber ends have been prepared by stripping and cleaving, they are inserted into the splice housing or the fusion equipment. Certain mechanical splice types, such as the rotary ferrule or elastomeric, allow adjustment of the fibers while monitoring with a power meter to minimize loss. In fusion equipment fiber alignment mechanisms are often used before welding. Once the fibers are in optimum position, they are fused or, in the case of mechanical splices, retained by compression, friction or an ultraviolet-cured epoxy.

Fusion Splicing

Fusion splicing requires special (and expensive) equipment containing an electric welder and a precision mechanism for aligning fibers. They often include a video camera or microscope so the operator can observe fibers during the alignment process, and instruments to measure optical power before and after splicing. Many of them are automated to assist the operator.

Fusion splicing two fibers involves several steps. First, the fiber ends are exposed by stripping back any protective buffer or jacket. Then the ends are cleaved to provide clean perpendicular faces and aligned so they butt together accurately. First-generation fusion splicing equipment relied on technicians to manually align the fiber ends. In the latest generation of equipment this process is computer-automated with motorized positioning equipment. The computer aligns the fiber ends until the best optical transmission is achieved before welding.

Finally, an electric arc is established to weld or fuse the two ends together with heat. The resulting joint is re-measured optically to ensure minimal light loss, then protected mechanically and environmentally with either a coating or enclosure. The cost of a fusion splice is low compared to that of a typical connector because less mechanical hardware is required.

Mechanical Splicing

Mechanical splices come in a variety of forms, similar to connectors. Two popular types are capillary and elastomeric.

A capillary splice as provided with this curriculum is the most basic form of mechanical splicing. Two fiber ends are inserted into a thin capillary tube as shown in Figure 8. Often an index-matching gel is applied to each fiber end to keep the Fresnel (optical) loss to a minimum. The fibers are held in place using epoxy or a compression technique such as a heat shrink sleeve or a mechanical crimp.

An elastomeric splice contains two elastomeric (rubber like) inserts inside a glass sleeve as shown in Figure 9. A V-groove is molded into one insert, while the other has a flat surface. The triangular-

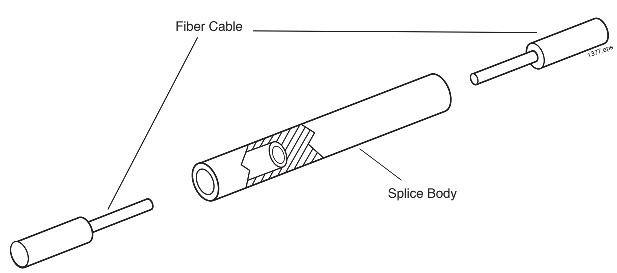

Figure 8 Line drawing of the capillary splice used in this module.

shaped space formed where the two insert halves mate is slightly smaller in dimension than the diameter of the fibers being joined. When the fiber ends are pushed into the inserts the elastomer compresses equally on each side in contact with the fiber. As a result, the fibers are aligned on their center axes. Even fibers with different diameters are centered along their respective axes, maximizing the overlap of their end faces. The fibers are usually held in place using an adhesive cured with ultraviolet(UV) light. As in the capillary splice an index matching gel is often applied to minimize Fresnel losses. Many manufacturers include the gel within the splice body, which reduces this assembly step for the technician.

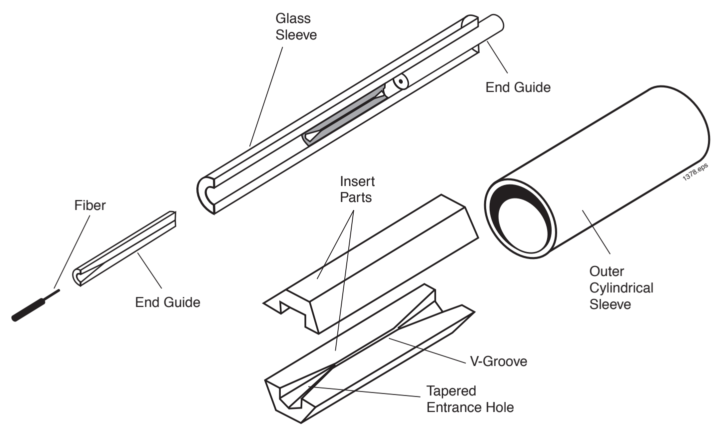

Figure 9. Line drawing of a basic elastomeric splice.

SPLICING A FIBER CABLE
Lab Exercise #3

In this exercise we will join two fiber cable ends using a mechanical splice. You will also manually apply index-matching gel to the fiber ends to reduce losses in the fiber splice. After splicing you will test your cable on either a plastic or glass version of the Fiber Optic Demonstration System.

Procedure A

1. Choose a flat, level table approximately 90 × 120 cm (3 × 4 feet) in size as your work area for this demonstration.
2. If the blade of the hot knife is not attached, carry out steps 4 through 8 of Lab Exercise #1. Place the blade end of the hot knife in its stand on a non-flammable surface and plug it in. Allow the hot knife to heat about 15 minutes before use.
3. After the hot knife is warmed up, use it to cut the fiber cable on which you installed the ST® connectors in Lab Exercise # 2. Cut the fiber about 1 meter (39 inches) from either end (this is about the midpoint of the fiber cable assembly).
4. Insert one of the cut fiber ends into the Professional Fiber Cutter through one of the center-most holes farthest from the cutting blade. Make certain the fiber end extends slightly past the opposite end of the cutter body. Trim the fiber by applying pressure to the cutter razor blade. Repeat with the remaining fiber end.
5. Unplug the hot knife.
6. The Fiber Optic Splice you will use in this activity is a capillary type. It is a brass cylinder with two precision holes drilled through the center axis. The smaller hole is drilled completely through, and is slightly larger than the cladding diameter of the 1000 µm optical core/cladding fiber supplied with this kit. The larger hole is slightly larger than the fiber jacket diameter and is only partially drilled into each end.
7. Hold the Micro-Strip fiber stripper in one hand and one length of fiber cable in the other. Do not compress the handles of the strippers.
8. Insert the fiber cable through the hole (fiber guide) in the fiber stripper until the fiber end aligns with the ruler markings for 6.3 mm (1/4 inch) on one of the handles. Note: This may be the shortest marked length on the stripper.
9. Squeeze the handles of the fiber stripper fully closed for five seconds and then slightly release pressure on the handles.
10. While maintaining a slight constant pressure on the fiber stripper handles pull the fiber cable away from the tool (a strong tug may be required).
11. You should now have a fiber cable that has its bare core and cladding exposed for about 6.3 mm (1/4 inch). Repeat steps 7 through 10 for the other cable fiber end.
12. Dip one of the stripped fiber ends into the vial of index-matching gel to place a small bead of gel on the fiber end face. Slide the fiber end into the brass Fiber Optic Splice until the fiber jacket seats.

13. You will use the 0.128 inch hex hole in the jaws of the crimping tool to crimp the splice onto the fiber cable. It is the smallest of the holes in the jaws that have six sides. If the crimping tool jaws are not fully open, slowly squeeze the handles until the jaws fully close. Continue squeezing until the latch mechanism releases. Make certain the end of the splice body with the fiber is lined up with one side of the hex hole. The hex hole in the crimp tool should overlap the splice body only where the fiber jacket is inserted. Slowly squeeze the handles of the crimp tool until the jaws just make contact with it. Do not apply any further pressure on the handles.
14. Make sure the fiber cable is still pushed completely into the splice. While making certain the fiber cable and splice body do not move out of position, slowly squeeze the handles to close the jaws until the tool bottoms and springs open. The crimp is now complete.
15. Dip the remaining stripped fiber end into the vial of index-matching gel to place a small bead of gel on the fiber end face. Slide the fiber into the other end of the brass Fiber Optic Splice until the jacket seats. Repeat steps 14 through 15.

Procedure B

You will now test the fiber cable on which you just installed a fiber splice.

1. To test the fiber splice you just assembled perform Procedure B of Lab Exercise #2 in Activity #2.
2. Put away all unused materials in their proper storage locations.

# # #

Worksheet #3 Student: ___________________________

1. Splices are used when:
   a) A low-loss permanent connection is needed between fibers.
   b) An easily removable connection is needed between fibers.
   c) Connectors are in short supply.

2. A fusion splice has the advantage of:
   a) Easy installation with ordinary hand tools.
   b) Extremely low insertion loss and low cost per splice.
   c) Both of the above.

3. Mechanical splices:
   a) Require expensive equipment to install.
   b) Have extremely low insertion loss and cost per splice.
   c) Can be installed using simple hand tools.
   d) None of the above

4. End preparation of a fiber prior to splicing:
   a) Is not critical for good optical performance.
   b) Is usually done by cleaving for splice applications.
   c) Can be done with inexpensive hand tools or automated equipment.
   d) b & c above.

5. An elastomeric splice has the following advantage(s) over a capillary splice:
   a) Fibers with slightly different diameters are aligned for best overlap.
   b) It is lower cost and easier to install.
   c) Index-matching gel is often contained in the splice.
   d) a & c above.

NOTES

TO THE INSTRUCTOR

The Industrial Fiber Optics *Fiber Optic Connector and Splicing Module* contains several consumable items among those on the parts list. Items with an asterisk (*) are completely expended each time a student finishes the related Lab Exercises. The quantities listed are minimum for a one-time completion of Activities 2 and 3. Please order an appropriate quantity of these items to ensure your classroom activities are not interrupted.

Several other items are consumed or worn down in use during the lab exercises, but are supplied in sufficient quantity for completion of several activities. These include:

- Xacto® blade (supplied with the hot knife)
- Ultra-Keen razor blades (used with the fiber cutter)
- Polishing slurry (polish extender)
- Index-matching gel
- 2000 grit sandpaper
- 3 µm polishing paper (purchase with the 2000 Grit as IF-C-PK)

All items above items may be identified on Industrial Fiber Optics' website *http://www.i-fiberoptics.com* and purchased from a distributor.

It is recommended that instructors periodically check the blades on the Hot Knife and the fiber cutter for sharpness and, as required, replace the blades.

As always, please follow the safety measures detailed in the manual and required in your classroom environment. If you have any questions regarding appropriate use of the materials contained in the *Fiber Optic Connector and Splicing Module* please contact Industrial Fiber Optics at 480-804-1227 or indfo@i-fiberoptics.com.

REPLACEMENT PARTS LIST:

Following is a list of all the items in Industrial Fiber Optics' Fiber Optic Connector and Splicing module with replacement part numbers. Please contact the company that sold this equipment for replacement items, or go to our Web site for contact information about our distributors. Some of the items listed below do not have part numbers because it is most economical to purchase them from a local drug store or lab supply.

Table 3. Parts list and replacement part numbers.

DESCRIPTION	QUANTITY	Replacement part numbers
Hot knife with blade attachment and stand	1	IF-TK1-RP1
Fiber optic crimp tool	1	IF-370042
Micro-Strip fiber stripper	1	IF-370075
Stainless steel polishing puck	1	IF-370045
Glass polishing plate	1	IF-830090
Fiber optic inspection microscope	1	IF-370050
Professional Fiber Cutter	1	IF-FC1
Polishing slurry (4 oz)	1	IF-370060
Vial of index-matching gel	1	IF-400010
Kimwipes® and Isopropyl alcohol	1	*
2 m length of plastic core optical cable	1*	IF-C-E1000
ST® style fiber connectors (4 piece sets)	2*	IF-C-ST
Fiber splice	1*	420090
Sheet of 2000 grit sandpaper (gray)	1	IF-C-PK**
Sheet of 3 μm polishing film (pink)	1	IF-C-PK**
1 meter 1000 μm plastic core fiber cable with ST® Connectors on one end	2	IF-DSOOG-RP7
ST® barrel connectors	2	IF-820063

® ST is a registered trademark of AT&T. Kimwipes is a registeredtrademark of Kimberly-Clark.

* Obtain these items from your local drug store or lab supply.

** Order one and you will receive two pieces of the 2000 grit and 3 µm film.

Worksheet #1 Answer Sheet

1. Describe how the fiber ferrule end of the ST® connector looks with the naked eye compared to what you see under the microscope at different magnifications.

   With the naked eye the ferrule end appears smooth and precise. Under the microscope you can see small imperfections in the ferrule such as surface roughness and small metal burrs around the hole edge.

2. Why might the hot knife be a better way to cut plastic fiber optic cable than some other method.

   If you use wire cutters or an ordinary knife to cut the plastic fiber the compression pressure may cause cracks to develop in the fiber core. These may stretch far enough into the core to cause optical loss. A hot knife cuts the fiber by melting so the damage stays close to the fiber end. This can be polished to give a superior end finish.

3. What purpose does the polishing slurry (fiber optic extender) serve?

   The slurry is both a very fine abrasive and a lubricant that helps grind the fiber end to a smooth finish during polishing.

Worksheet #2 Answer Sheet

1. Connectors are used to:
   a) Decode data transmitted via fiber optic cable.
   b) Generate light in a fiber optic system.
   c) **Attach fiber cables to components or subsystems interconnected with fiber optic cable.**

2. An advantage provided by connectors is:
   a) **They allow fiber optic components or subsystems to be easily interchanged or upgraded.**
   b) They amplify light, causing it to travel farther down a fiber cable.
   c) They are a permanent method of attaching fiber cable to optical components.

3. The main elements of a fiber optic connector are:
   a) Fiber cable, LED and Photodiode.
   b) **Connector body, ferrule and strain relief.**
   c) Laser diode and bulkhead adapter.
   d) Crimper
   e) None of the above
   f) All of the above

4. Early fiber optic connectors:
   a) Had problems with alignment and repeatability.
   b) Were occasionally modifications of existing electrical connectors.
   c) Could be time consuming to install.
   d) **All of the above.**

5. Recently designed fiber optic connectors:
   a) Require high technical skill to install.
   b) Are smaller with less optical loss.
   c) Can often carry several fibers in a multi-channel system.
   d) **b & c above.**

6. Describe the differences you observed with the fiber microscope when the fiber end was polished with 2000 grit, then with 3 µm polishing film.

   The surface finish with 2000 grit film had coarse scratches and a rough appearance. The finish with 3 µm film was much smoother with few visible imperfections.

Worksheet #3 Answer Sheet

1. Splices are used when:
   a) **A low-loss permanent connection is needed between fibers.**
   b) An easily removable connection is needed between fibers.
   c) Connectors are in short supply.

2. A fusion splice has the advantage of:
   a) Easy installation with ordinary hand tools.
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3. Mechanical splices:
   a) Require expensive equipment to install.
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   b) It is lower cost and easier to install.
   c) Index-matching gel is often contained in the splice.
   d) **a & c above.**