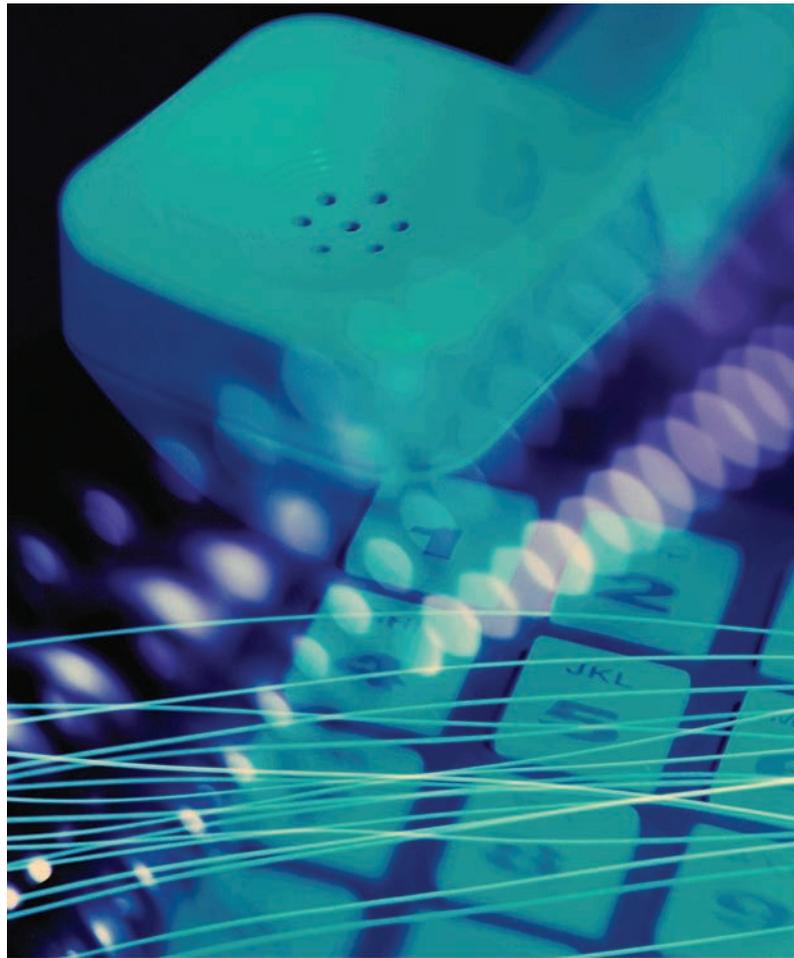


Advanced Communications and Networking Module



INDUSTRIAL FIBER OPTICS



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Before you begin...

The Industrial Fiber Optics IF 527 Fiber Optic Communications and Networking Module is a 10-day curriculum on advanced topics of fiber optics. It is designed for science, physics, industrial technology, secondary education and vocational classrooms at grade levels 11 and above. This module is a complete curriculum – no additional reading material is required except to complete homework assignments, for which a library and Internet access are adequate.

As you complete this module you may be surprised at the composition of fiber optic technology. In fact, you may have learned some of the material in other classes or modules. It is a combination of electronic, laser and optical technology and is currently in an evolving as opposed to a revolutionary stage. Optical fibers are a spin-off from the field of classical optical study. Fiber optic transmitter and receiver circuits are made from the semiconductor devices used in electronics technology. Light emitting diodes (LEDs) and laser diodes are also made from semiconductors, but laser diode operation falls in the category of physics that also describes gas and liquid lasers. The curriculum in this manual will cover how these components are used in communications and networking applications.

Everyone who samples or completes these activities will see how fiber optics is used in everyday applications, and thus be able to better appreciate this new and exciting technology. Please take the time to browse through this manual carefully. It contains a wealth of information when used with the reference materials, vocabulary, advanced courses, etc.

This manual is an integral part of the IF 527 Fiber Optic Communications and Networking Module. It will guide instructors and students through 10 separate activities, each of which has reading assignments with background knowledge and theory, lab exercises that use or apply fiber optics, and worksheets containing questions and homework assignments. At the rear of the manual is an operational and reference guide for the equipment

The Metric System is the primary unit of measure used throughout this product because it was used in the development of fiber optic technology. For those who prefer the English measurement system of inches, feet, etc., it has been listed behind metric terms (in parentheses) in most instances. The English dimensions may not always be an exact conversion.

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 website 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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Section Guide

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Introduction & Inventory

Activity 2
Optical Fiber Characteristics

Activity 3
Fiber Advantages & Cabling

Activity 4
Optical Performance & Characteristics

Activity 5
Fiber Interconnection Devices

Activity 6
Other Passive Devices

Activity 7
Communications & Switches

Activity 8
Expand & Network

Activity 9
Implementation

Activity 10
Wrap-up

Activity #1

Introduction & Inventory

Objectives:

- ❑ Evaluate your current knowledge of fiber optics technology
- ❑ Review safety rules
- ❑ Inventory—familiarize yourself with all the components in this Fiber Optic Communications and Networking Module
- ❑ Inspect the tip of a polished optical fiber under high magnification
- ❑ See light transmitted through an optical fiber
- ❑ Learn the proper technique to clean the tips of optical fibers in connectors
- ❑ Review the history and fundamentals of fiber optics

Equipment you will need to complete this activity:

- (2) Fiber Optic Reference Guides
- All the components that are part of this module. Refer to the parts list in Table 1 or the detailed description of the components beginning on page 10.

To complete this activity you must:

1. Complete the Pre-test on pages 2 through 4.
2. Read the safety instructions on page 5
2. Read the section marked “Forward” in “*Fiber Optic Reference Guide.*”
3. Complete **Fiber Exercise I.**
4. Answer all Questions on **Worksheet #1.**
5. Complete **Homework Assignment #1.**

Homework Assignment #1

Read Chapters 1 and 2 in the “*Fiber Optic Reference Guide.*” Also review Table A-1 in Appendix A of “*Fiber Optic Reference Guide.*” Table A-1 is a table of commonly used prefixes in the scientific community. If you are slightly rusty with your Metric System you might want to review A-2 in the “*Fiber Optic Reference Guide.*” Metric dimensions are used almost exclusively in fiber optics.

Pre-test

Student: _____

1. Kevlar® is a material that is added to optical fiber to increase its strength.
 - a) True
 - b) False

2. The life expectancy of a fiber optic cable after installation is:
 - a) 1 to 5 years
 - b) 5 to 10 years
 - c) 10 to 20 years
 - d) 20 to 40 years
 - e) 40 to 80 years
 - f) None of the above

3. Fiber optics is best known for its application in long-distance telecommunications.
 - a) True
 - b) False

4. Circle the three basic components in a fiber optic communications system.
 - a) Telescope
 - b) Transmitter
 - c) Receiver
 - d) Surveillance satellites
 - e) Maser fiber
 - f) Optical fiber
 - g) Alternator

5. Information (data) is transmitted over optical fiber by means of:
 - a) Light
 - b) Radio waves
 - c) Cosmic rays
 - d) Acoustic waves
 - e) None of the above

6. The first operating window for fiber optics was:
 - a) 1550 nm
 - b) 660 nm
 - c) 1300 nm
 - d) 850 mm
 - e) None of the above

7. What procedures are steps of installing a fiber connector?
- a) Polishing
 - b) Cleaning
 - c) Cleaving
 - d) Stripping jacket
 - e) All of the above
 - f) None of the above
8. Connectors and splices add light loss to a system or link.
- a) True
 - b) False
9. What are the two types of fiber optic splices?
- a) Optical
 - b) Fusion
 - c) Mechanical
 - d) Radical
 - e) A and B
 - f) B and C
10. Silicon is the most commonly used detector material in fiber optic applications for wavelengths between 400 and 1050 nm.
- a) True
 - b) False
11. List two advantages of using optical fiber.
-
-
12. Fiber optic couplers connect one fiber to another.
- a) True
 - b) False
13. WDM allows for multiple totally independent data streams to be transmitted over a single optical fiber.
- a) True
 - b) False
14. The replacement of copper wiring harnesses with fiber optic cabling will increase the weight of an aircraft.
- a) True
 - b) False

- 15.** Light is a small part of the electromagnetic spectrum.
- a) True
 - b) False
- 16.** A dB is the ratio of two numbers to each other.
- a) True
 - b) False
- 17.** One of the most important optical measurements of any optical material is its refractive index.
- a) True
 - b) False
- 18.** Fiber optic components are (complete the sentence that makes it the most accurate):
- a) Increasing in cost every year
 - b) Staying about the same in cost
 - c) Decreasing in cost every year
- 19.** Circle the two most common materials of which optical fibers are made:
- a) Plastic
 - b) Sodium chloride
 - c) Gallium aluminum phosphide
 - d) Glass
 - e) Flint
 - f) Hair
 - g) Diamond
- 20.** The principle called total internal reflection explains why light is not guided in an optical fiber.
- a) True
 - b) False

Safety

The Industrial Fiber Optics equipment included with this curriculum contains UL-certified power adapters and LEDs (light emitting diodes) that produce low-power incoherent radiation for maximum safety. The LEDs are broadband components whose outputs can not be focused to a fine spot like a laser. Since some fiber optic equipment can contain lasers, please review our laser safety suggestions for future thought. Remember: Just because you can not see the beam does not mean it is not dangerous.

Rules Of Lab Safety

- Lasers produce a very intense beam of light. Treat them with respect. Most educational lasers have an output of less than 3 milliwatts, and will not harm the skin.
- Never look into the laser aperture while the laser is turned on! **PERMANENT EYE DAMAGE COULD RESULT.**
- Never stare into the oncoming beam. Never use magnifiers (such as binoculars or telescopes) to look at the beam as it travels — or when it strikes a surface.
- Never point a laser at anyone's eyes or face, no matter how far away they are.
- When using a laser in the classroom or laboratory, always use a beam stop, or project the beam to areas which people won't enter or pass through.
- Never leave a laser unattended while it is turned on — and always unplug it when it's not actually being used.
- Remove all shiny objects from the area in which you will be working. This includes rings, watches, metal bands, tools, and glass. Reflections from the beam can be nearly as intense as the beam itself.
- Never disassemble or try to adjust the laser's internal components. Electric shock could result.

Lab Exercise #1

The first lab exercise in this course requires students to inventory and identify all items furnished with this fiber optic training module and required for the remaining nine activities. This inventory process will introduce you to the terminology used in the manual and also speed completion of the the following two activities. Following this you will conduct some basic exploratory experiments to further familiarize yourself with equipment and procedures.

Experiment A: Inventory

1. Choose a flat, level table approximately 90 × 180 cm (3 × 6 feet) in size as your work area for this activity.
2. At your work area, assemble all materials your instructor provides for you.
3. Locate the item that looks like part of a soldering iron. This is a 25-watt heating element that will be part of the Hot Knife assembly you will use to cut plastic optical 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 knife blade from their 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 bottoms. 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 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 knife blade. 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 3, notify your instructor.

10. Identify the 1 amp Power Adapters for the video transceivers. Do not try to power the video transceivers with the 500 mA Power Adapter.
11. The inspection microscope that you identified above is a specially designed tool for examining the ends of optical fibers. Please read the following paragraphs and familiarize yourself with its 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 has 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 is a slide switch that turns the light bulb on and off. A focus wheel in the center of the microscope has an exposed edge on two sides. Turning this wheel will adjust the focus of the microscope.

There may also be a small sliding adjustment on one face of the microscope (near the end with the clear plastic hood) that sets the angle of the light bulb.

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.

12. Insert the ferrule tip (see Figure 1 for identification) into the adapter on the microscope until the ferrule body is completely seated. Turn on the microscope light and adjust the angle of the light bulb so the ferrule tip is illuminated.
13. 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.
14. When done, turn off the microscope light.

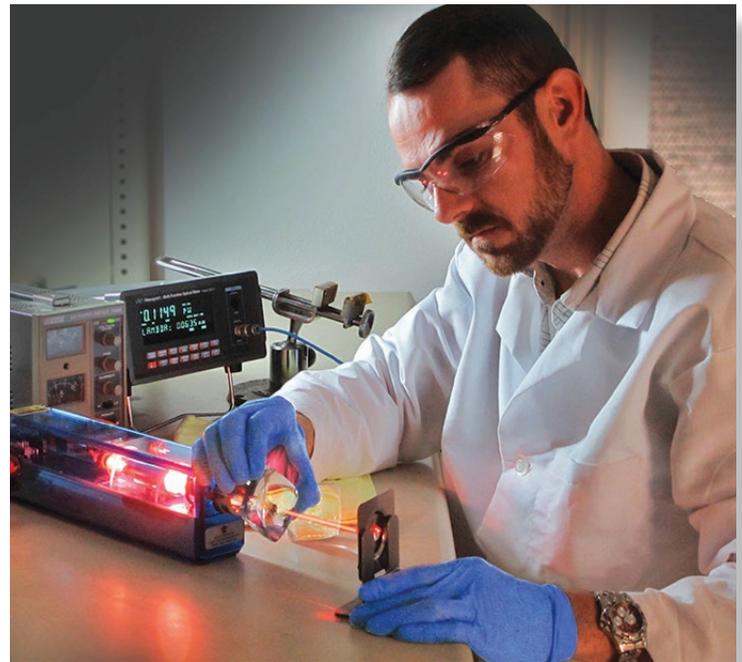


Photo 2. Fiber optic technician working in a lab.

Experiment B: *Fiber Tip Cleaning*

It is important to keep fiber optic tips, or ferrules, clean. Before inserting them into any LED or photodetector receptacle, always inspect each end for cleanliness. To learn the proper steps in cleaning a fiber connector end, go to page 96 of the *Fiber Optic Reference Guide* and read the entire section titled “Care of Fiber Optic Connectors.”

1. Remove the dust cap from a 1-meter fiber cable and clean the fiber end using the procedure that you just read.
2. Throughout the rest of this manual it is expected that you will inspect the fiber ferrules before inserting them into any receptacle and clean as required with Kimwipes® and clean water.



Figure 1. Identification of the dust cap and the ferrule of an ST® fiber connector.

3. Remember to replace the protective dust caps on the fiber ferrules after completing an experiment or procedure.

Experiment C: *Basic light transmission through an optical fiber*

1. Remove the dust caps from the connectors on both ends of the 1-meter fiber cable.
2. Grasp the 1-meter fiber cable near one end with your thumb and forefinger. Point it toward a light source and different colored objects while observing the other end of the fiber. Note the changes in brightness in the end you’re viewing as you move the other end around or cover its tip with a finger.
3. Holding the fiber tip about .5 mm (.020 inches) from this page, move it left to right across the heading of this section.
4. Answer Questions 5 and 6 on **Worksheet #1**.

Experiment D: *ST® Fiber Connections*

The standard fiber optic connector used in this module is called an ST connector. Throughout this module you will be asked to connect various fiber optic cables with ST connections to various devices. Rather than repeat detailed steps each and every time we will walk you through the instructions here once. Learn and use this installation/connection procedure through the rest of the module. To install an ST connector, refer to Figure 2 and complete the following steps.

1. Remove the dust cap from one of the transceiver’s LEDs. Align the key on the connector body with the slot on the ST receptacle, then gently push in.
2. Rotate and push the knurled locking ring until the slots engage the bayonet ears on the ST receptacle
3. Continue twisting against the spring tension until the knurled ring snaps and locks over the bayonet ears.

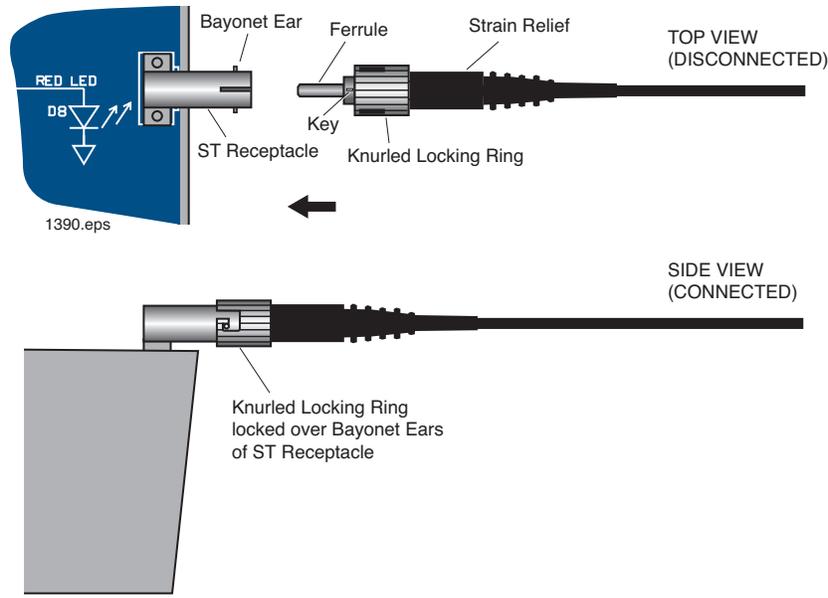


Figure 2. Installing an ST fiber connector onto a receptacle.

Procedure E: *Zeroing the Fiber Optic Test Set*

Throughout this manual you will be using the Fiber Optic Test Set. Each time you use it you will need to zero this instrument. This procedure is found on page 17 of its operating manual.

1. Locate the Fiber Optic Test Set manual and read the zeroing procedure. Follow and repeat the procedure until you are comfortable with the process. If you cannot locate this manual in the module materials, go to this address <http://i-fiberoptics.com/tool-detail.php?id=650> on the Industrial Fiber Optics website and download a copy of the operator's manual.
2. When finished, return all materials to their proper storage containers and locations.

Table 3. Inventory Sheet for Lab Activity 1.

<i>Description</i>	<i>Quantity</i>
Hot Knife with blade attachment and stand	1
Fiber Optic Video Transceiver Modules	3
120-VAC-to-14-VDC 1-Amp power adapters	3
Photonics Wall Chart	1
Infrared Sensing Card	1
Scale	1
1-meter 980/1000 μm plastic core fiber cables with ST/ST connectors on both ends	2
3-meter 980/1000 μm plastic core fiber cables with ST/ST connectors on both ends	1
10-meter 980/1000 μm plastic core fiber cables with ST/ST connectors on both ends	1
Kimwipes [®]	1
Microphones	2
DC motor with mount	1
120-VAC-to-12-VDC 500 mA power adapter	1
Micro-Strip [®] fiber stripper	1
ST polishing puck	1
Fiber optic crimp tool	1
Professional Fiber Cutter	1
ST barrel connectors	1
Tool box	1
Fiber Optics Test Set	1
1 x 2 fiber coupler or splitter	1
2-meter length of 980/1000 μm plastic core unterminated fiber cable	1*
ST fiber connectors	2*
Fiber optic splice	1*
Sheet of 2000 grit sandpaper (gray)	1*
Sheet of 3 μm polishing film (pink)	1*

Table 3. Inventory Sheet for Lab Activity 1 (Continued)

<i>Description</i>	<i>Quantity</i>
Audio patch cord with 3.5 mm mono plugs	2
Glass polishing plate	1
Fiber optic inspection microscope	1
Polishing slurry (130 ml)	1
Vial of index-matching gel	1
AM/FM radio with 3 AA batteries	2
Coaxial cables with Type F connectors	2
10 meters of coaxial cable	1
Optical Demultiplexer	1
Fiber Optic Reference Guides	2
Teacher's Curriculum Manual	1
Student Curriculum Manuals	2

Micro-Strip is a registered trademark of Micro Electronics, Inc.

Kevlar is a registered trademark of du Pont de Nemours and Company.

Kimwipes is a registered trademark of Kimberly-Clark.

** The number indicated is the minimum quantity needed to complete the activities in this manual once. There may be more than the number indicated when this product is new or recently re-supplied.*

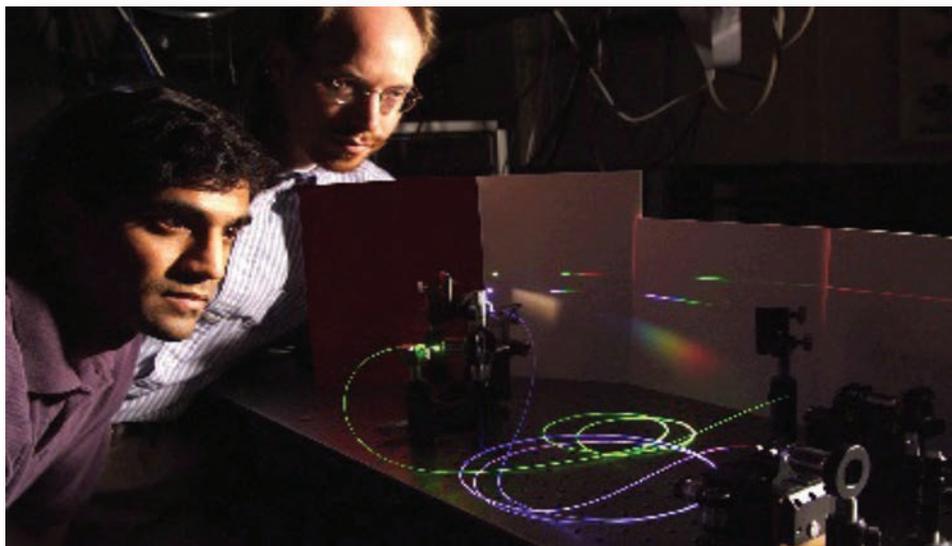


Photo 2. Research scientists continually explore ways to increase optical communications bandwidth and apply fibers to lighting applications to conserve energy.

Worksheet #1

Student: _____

1. One of the reasons fiber optics hasn't been used in more areas has been the improvement in copper cable such as twisted pair.
 - a) True
 - b) False

2. The symbol for refractive index is:
 - a) n
 - b) c
 - c) M
 - d) ∞
 - e) None of the above

3. There are no standards in fiber optics. Every manufacturer does what it wants.
 - a) True
 - b) False

4. Fiber optics has extraordinary opportunities for future applications because of its immense bandwidth.
 - a) True
 - b) False

5. Do any colors of light seem to transmit better through the 1-meter fiber cable than others?

6. What changes do you observe in brightness at the other end of the fiber?

Activity #2

Optical Fiber Characteristics

Objectives:

- Learn about the optical fiber manufacturing process
- Review the principles of optical fiber operation
- Describe the two types of optical fiber by mode structure
- Understand the effects of “attenuation” and “dispersion” in optical fiber
- Describe the different types of absorption in optical fiber
- Compare performance characteristics of various optical fiber types
- Set up fiber optic lab equipment to send voice signals over optical fiber
- Demonstrate optical fiber’s ability to carry different wavelengths of light
- Use a special imaging card to identify near-infrared radiation or light

Equipment you will need to complete this activity:

- 2 Fiber Optic Reference Guides
- 1 Photonics Wall Chart
- 2 120-VAC-to-14-VDC 1-amp power adapters
- 2 Fiber Optic Video Transceivers
- 2 Microphones
- 2 10-meter fiber cables
- 1 Infrared sensing card

To complete this activity you must:

1. Review **Homework Assignment #1** with your instructor to answer any questions that you may have from reading.
2. Read pages 15 through 28 in Chapter 3 of “*Fiber Optic Reference Guide.*”
3. Answer Questions 1 through 11 on **Worksheet #2.**
4. On the “Photonics Wall Chart” identify the four different fiber optic optical windows as described in Chapter 1 of “*Fiber Optic Reference Guide.*”
5. Find the chemical composition of one detector on the Photonics Wall Chart that is capable of detecting the third fiber optic operating window. Write this chemical composition in response to Question 12 of **Worksheet #2.**
6. Complete **Lab Exercise 2.**
7. Complete **Homework Assignment #2.**

Homework Assignment #2:

Once you begin working in industry you may often find yourself in a position where you need to locate sources for products or services. One of the most powerful resources you can use is the Internet. Several websites are dedicated as sources for products and services. Two such sites are <http://www.fiberoptic.com> and <http://www.photonics.com>. Go to these websites and explore. Write 50 to 100 words describing what you found on the sites.

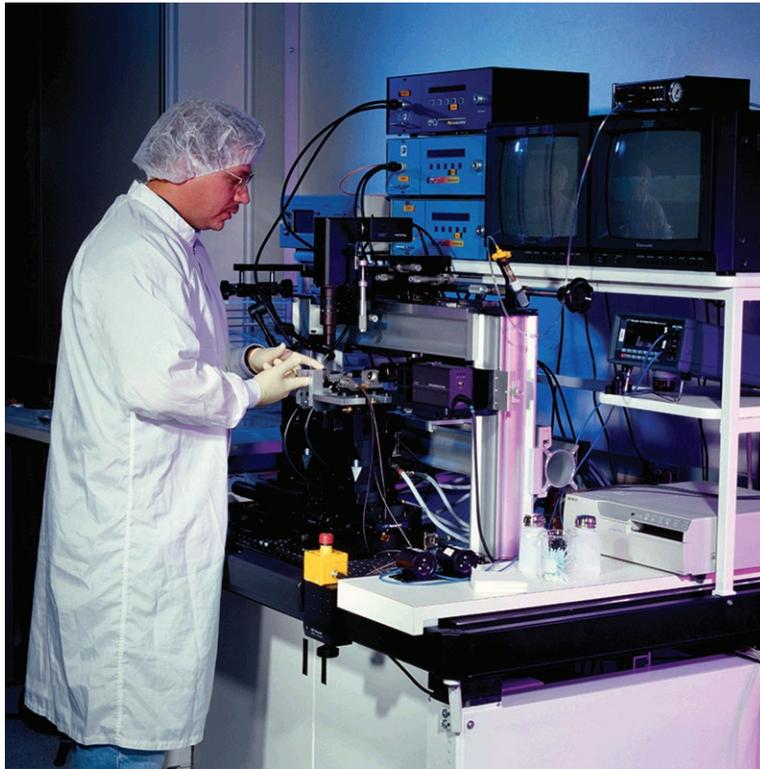


Photo 3 . A technician prepares to align and position a single-mode optical fiber with a laser. The very small dimensions of single-mode optical fiber require very precise positioning equipment.

Lab Exercise #2

In your first experiment you will set up a duplex (bi-directional) voice transmission project with which you and your fellow students can communicate with each other over optical fiber cables using different wavelengths of light. You will then use a special sensing card to convert infrared light (radiation) to visible light. Finally you will familiarize yourself with how to connect/switch various transceiver input jacks to three different LED outputs.

Experiment A: *Voice Transmission*

This experiment will show you how easy it is to make productive use of fiber optics technology building blocks. The equipment that you assemble will transmit voices from one location to another, using light traveling through an optical fiber. You'll learn that, along with your own voice, other sounds can be carried over the optical fiber.

1. Choose two flat, level locations approximately 60 × 90 cm (2 × 3 feet) in size, separated by 6 to 7 m (20 to 23 feet). (This demonstration is most dramatic if a door or other sound barrier is located between the two fiber optic transceivers to impede the direct path of sounds produced in the two areas.)
2. Place both 10-meter fiber cables, one microphone, one power adapter, a transceiver and the infrared sensing card at Location 1. Place one microphone, a transceiver and a power adapter at Location 2.

Set-up Location 1

3. Your equipment set-up should look like Figure 3 when completed. You may wish to refer to this figure as you complete the following steps.
4. Insert the 3.5 mm male plug on the end of the microphone into the AUDIO 1 jack located in the upper left portion of the Transceiver.
5. Locate the RED LED ST receptacle in the upper right portion of the Transceiver's front panel. Remove the LED's and fiber ferrules' dust caps and attach one end of a 10-meter fiber cable to the RED LED receptacle.
6. Locate the OPTICAL INPUT receptacle on the Transceiver's front panel. Remove dust caps and insert one end of the other 10-meter fiber cable into the receptacle.
7. Insert the small end of one 120-Volt Power Adapter cord into the black plastic power input jack on the Transceiver.
8. Plug the two-pronged end of the Power Adapter into a 120-volt wall outlet or extension cord.

9. Located directly to the right of the power jack is the on/off switch for the Transceiver. Push the switch tab to the left to turn the Transceiver on. At this time the green LED above the power jack and switch should light up. If not, make sure both ends of the Power Adapter are firmly plugged in.
10. Set the VOLUME control knob to the 12 o'clock position.
11. Press the middle momentary switch (as indicated in Figure 3) in the center of the TRANSMITTER portion of the Transceiver until the green LED labeled D6 is lit.
12. Press the momentary switch in the RECEIVER portion of the Transceiver until the LED labeled D19 is lit.
13. String both 10-meter fiber cables between the two locations.

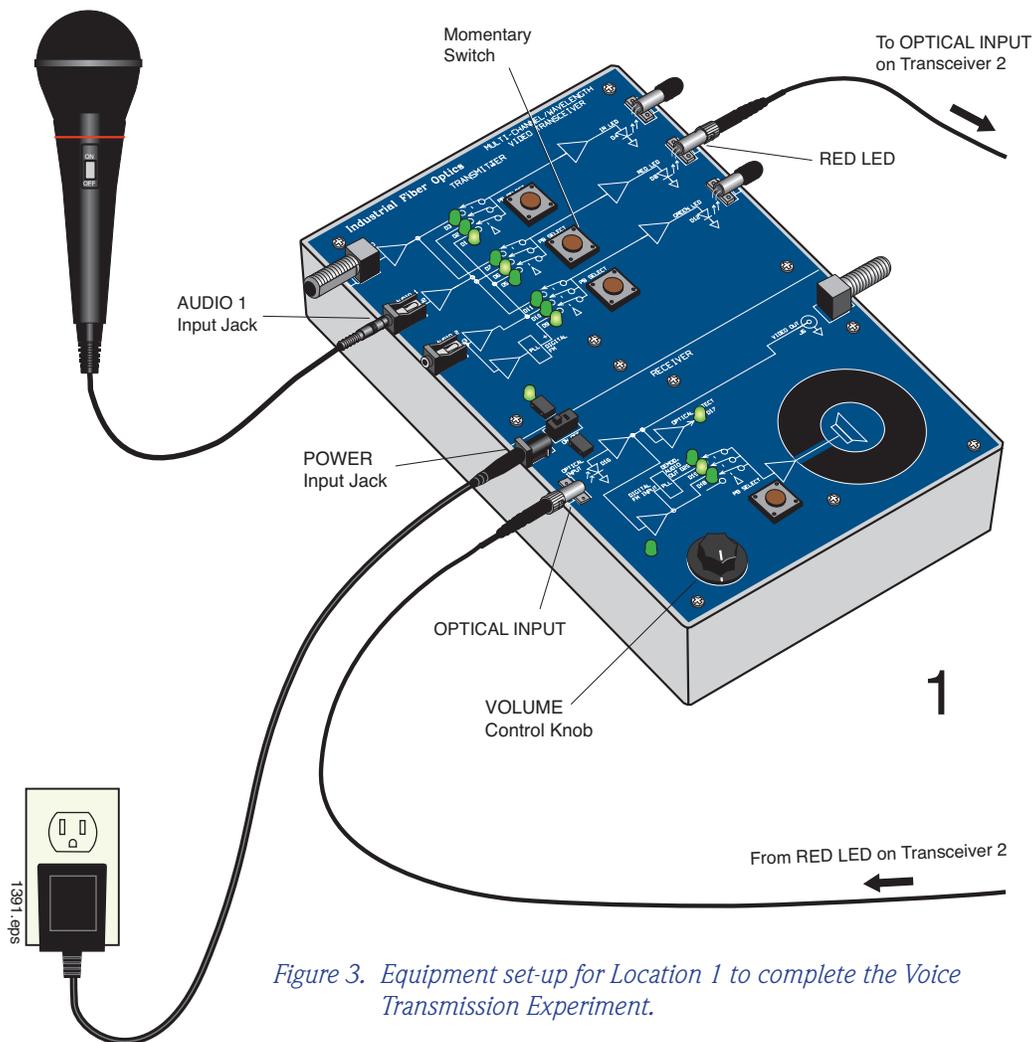


Figure 3. Equipment set-up for Location 1 to complete the Voice Transmission Experiment.

Set-up Location 2

14. Your equipment set-up at this location should look like Figure 4 when completed. You may wish to reference this figure as you complete the following steps.
15. Insert the 3.5 mm plug of the microphone into the AUDIO 1 jack on the Transceiver.
16. Identify the fiber cable that is installed on the RED LED at Location 1 by the red glow being emitted from the end. Attach this fiber end to the OPTICAL INPUT receptacle at Location 2.
17. Attach the remaining fiber end to the RED LED receptacle at Location 2.
18. Insert the small end of one 120-volt power adapter cord into the power jack on the Transceiver.
19. Plug the two-pronged end of the Power Adapter into a 120-volt wall outlet or extension cord.

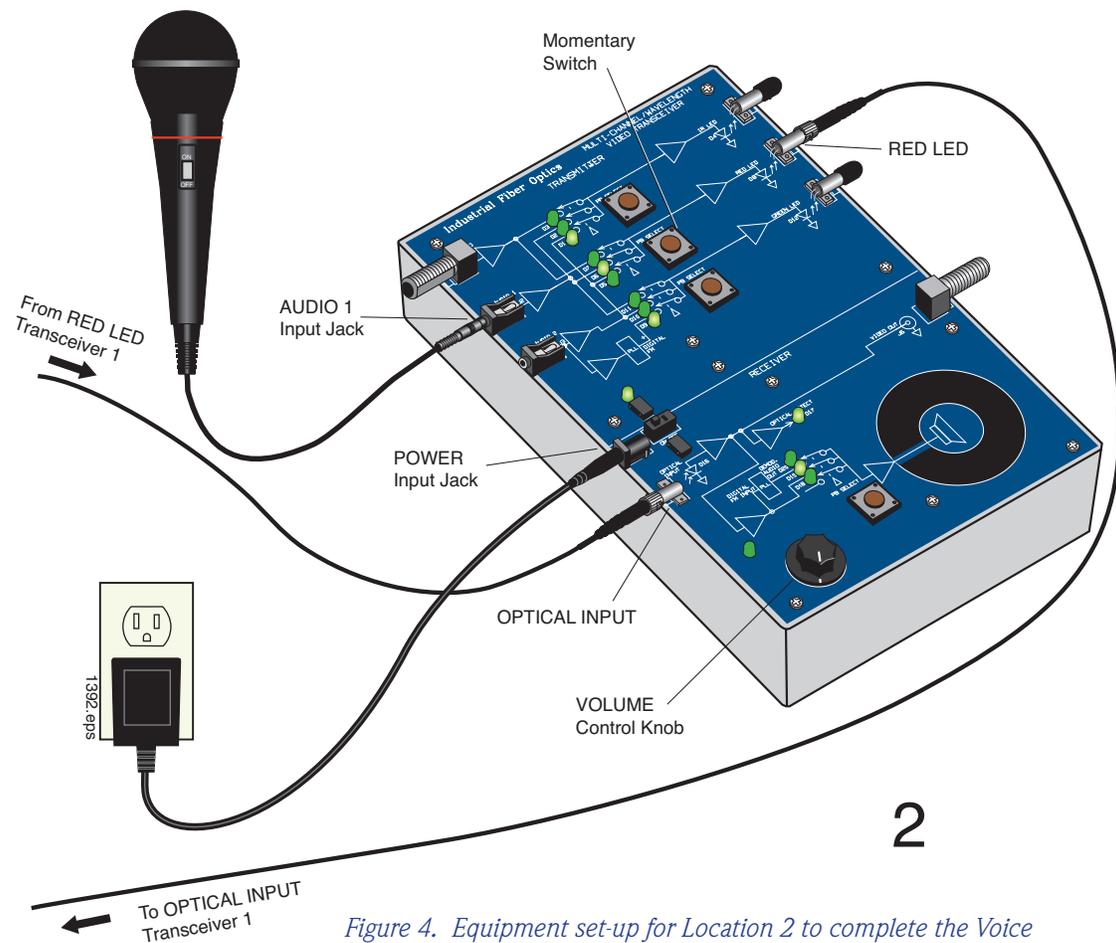


Figure 4. Equipment set-up for Location 2 to complete the Voice Transmission Experiment.

20. Located directly to the right of the power jack is the on/off switch for the Transceiver. Push the switch tab to the left to turn the transceiver on. At this time the green LED above the power jack and switch should light up. If not, make sure both ends of the Power Adapter are firmly plugged in.
22. Set the Transceiver's VOLUME control knob to the 12 o'clock position, just as you did at Location 1.
23. Press the middle momentary switch in the center of the TRANSMITTER portion of the Transceiver until the LED labeled D6 is lit.
24. Press the momentary switch in the RECEIVER portion of the Transceiver until the LED labeled D19 is lit.
25. If a high-pitched squeal begins to sound from either speaker when you connect the power, first move the microphone element as far away from the speaker as possible, then reduce the internal amplification of both transceivers by turning their VOLUME control knobs slowly counter-clockwise until the noise subsides.

At each of your two locations you now have assembled an efficient optical transceiver which can operate as a “sender” and a “receiver” of acoustic (sound) waves. The microphone converts sound waves into an electrical signal, which then is amplified and converted to optical (light) form in the internal circuitry. The optical signal is directed into the optical fiber, which carries it to the opposing Receiver. The Receiver's photodetector “decodes” the optical signal and converts light into an electrical signal which, in turn, drives the Speaker on the Transceiver to create acoustic waves, or sound — in this case, the voices of the people in your class.

Your communication system is now ready for use. Position a person, or half your group, at Location 1 and the other half at Location 2.

26. Verify that each transceiver is operating properly by lightly tapping or blowing across the microphone. If the sounds you hear are very faint, try increasing the volume by slowly turning the Volume Control Knob clockwise.
27. Let each student talk through the system and hear students at the other location talking.
28. Have one group of students create noises close to the microphone and ask the other group to identify the source of the noises. Some examples are crumpling paper, breathing, snapping your fingers briskly above the microphone, moving a finger across the surface of the microphone, plucking a rubber band, etc.
29. Answer Questions 13 and 14 on **Worksheet #2**.

Experiment B: *Green light data transmission*

In this experiment you will re-configure one of the fiber optic transceivers to transmit voices using the green light rather than the red light in the previous experiment.

Location 1

1. Locate the GREEN LED receptacle in the central right portion of the Transceiver's front panel. Detach the 10-meter fiber connected to the RED LED receptacle and attach it to the GREEN LED receptacle.
2. Press the bottom momentary switch as indicated in Figure 5 until the LED labeled D11 is lit.
3. Communicate with your partner or group at Location 2 to determine if the voice transmission system works as before.
4. Answer Question 15 on **Worksheet #2**.
5. Disconnect the fiber cables from the transceivers and install dust caps on all connector ends. Unplug and put away all equipment at Location 2.

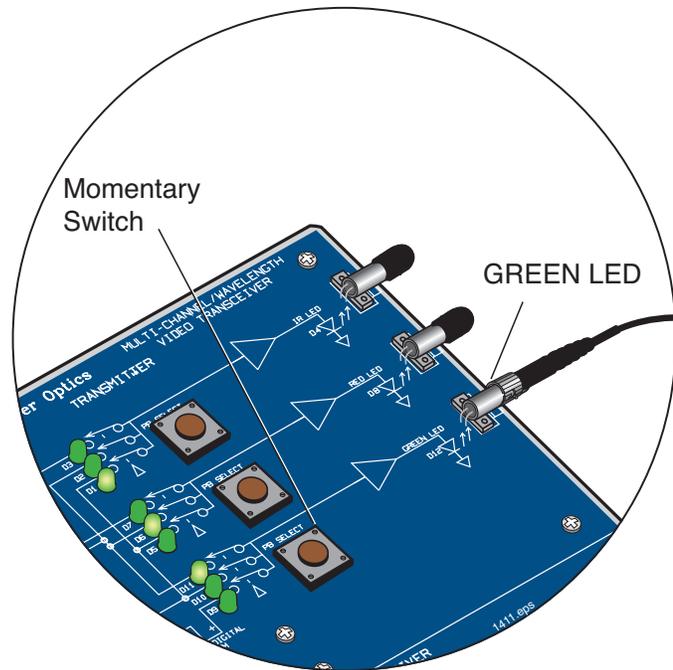


Figure 5. Location of the switch to select the electrical input to the green LED.

Experiment C: *Infrared (IR) light*

Much of the world's high-speed, fiber optic data communication is done with infrared, or IR, radiation. The most common IR wavelengths are 850 nm, 1300 nm and 1550 nm. Very long distance data transmission is almost the exclusive domain of 1550 nm operational wavelengths. In the following steps you will use a special sensing card to convert infrared light (radiation) to visible light.

1. Remove the dust cap from the IR LED receptacle on the Transceiver at Location 1.
2. Charge the pale orange phosphor square on the Infrared Sensor Card by holding it near a light source for about 10 seconds. Either an incandescent or fluorescent light will work, but fluorescent is better.

- Place the pale orange phosphor square on the Infrared Sensor Card right up against the IR LED as shown in Figure 6. You should see a glowing area on the card corresponding to the infrared energy coming out of the IR LED. You may need to dim the room lights to see this. Change the distance between the LED receptacle and sensor card and note how the size of the glowing area changes. Turn the card around and place its back side against the IR LED receptacle and see if you can observe any glow this time.

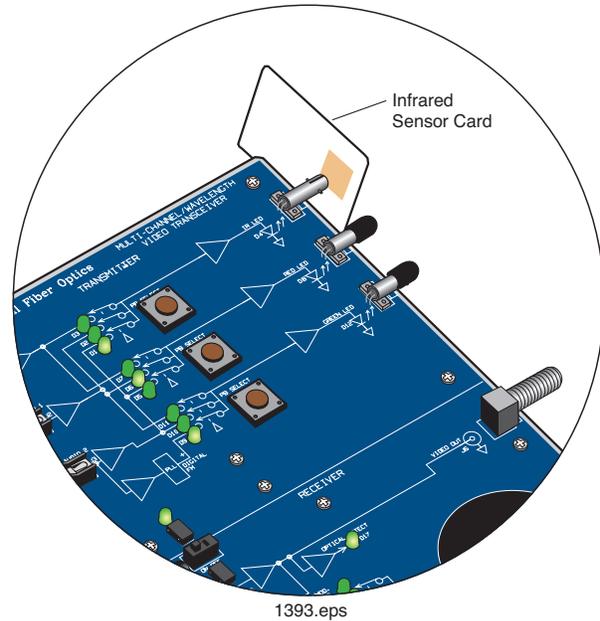


Figure 6. Correct location of the infrared sensing card to view IR Light.

- Answer Questions 16 and 17 on **Worksheet #2**.

Experiment D: *Transceiver Operation*

In the first two experiments you learned to use the momentary switches to direct the signal flow from the AUDIO 1 input jack to the RED output LED, and then the GREEN output LED. Now study the schematic shown by the white lines on the front panel of the Transceiver. Use it to understand how a signal from any one of the three input jacks routes to one of the three fiber optic LEDs using the three momentary switches in Figure 7. You will observe that not every LED has access to every input.

When finished, unplug the power adapters from the 120-volt outlets and the transceivers. Replace dust caps on all ferrule ends. Return all items to their proper storage containers and locations.

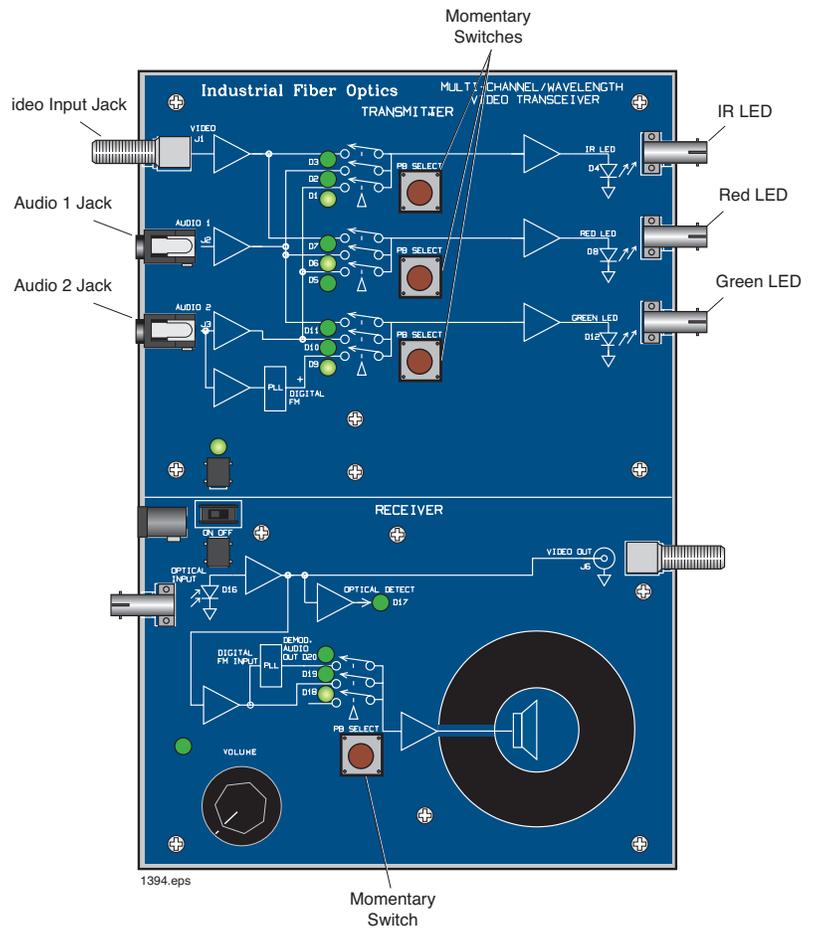


Figure 7. Location of momentary switches used to control the selection of inputs available to the LEDs, and the receiver capabilities.

Worksheet #2

Student: _____

1. Light, in fiber optics vocabulary, means electromagnetic radiation or energy in the wavelength range including infrared, visible and ultraviolet.
 - a) True
 - b) False

2. Dispersion is the technical term for the spreading of light pulses as they travel down an optical fiber.
 - a) True
 - b) False

3. Choose the basic types of optical fiber:
 - a) Single-mode
 - b) X-mode
 - c) Microwave-mode
 - d) Graded-index mode
 - e) Multi-mod
 - f) A and C
 - g) B and D
 - h) A and E

4. Attenuation is a linear relationship between optical output power and input power.
 - a) True
 - b) False

5. Single-mode fiber has the advantage of greater bandwidth capability.
It has the disadvantage of:
 - a) Being harder to bend
 - b) Smaller mechanical tolerances in connectors and splices
 - c) Being difficult to couple light into
 - d) B and C
 - e) None of the above

6. Numerical aperture of a fiber determines its light-gathering capability.
 - a) True
 - b) False

7. The first operating window for fiber optics was:
 - a) 1550 nm
 - b) 660 nm
 - c) 1300 nm
 - d) 850 nm
 - e) None of the above

- 8.** Most modern optical fiber is manufactured with which materials?
- a) Ultra-pure materials
 - b) Vaporized gases
 - c) Preformed silica tubes
 - d) All of the above
 - e) None of the above
- 9.** Silicon is the base material for most of the optical fiber used in communications today.
- a) True
 - a) False
- 10.** High dispersion is a very undesirable characteristic of multimode fiber.
- a) True
 - a) False
- 11.** Operation of optical fiber is based on:
- a) Total internal reflection
 - b) Total internal refraction
 - c) Snell's law
 - d) Einstein's theory of reality
 - e) None of the above
- 12.** Chemical composition of a detector suitable for the third fiber optic operating window would be:
- 13.** Do you find it hard to identify a person's voice at the other location? If so why?
- 14.** Do some sounds or voices transmit better than others? If so, identify them.
- 15.** Do you notice any difference with audio quality or amplitude (volume) using the green LED source instead of the red LED source?
- 16.** What happens to the size of the light pattern on the IR sensor card as it moves further away from the receptacle?

Activity #3

Fiber Cable Splicing

Objectives:

- Understand why optical fiber is cabled before application
- Describe physical differences between loose-tube and tight buffer cable construction
- Identify the various components in fiber optic cable
- Learn about materials used in fiber optic cables
- Understand why Kevlar® is used in fiber cables
- Read about different types of fiber optic cables
- Identify the many advantages of optical fiber technology over copper
- View or hear the effects of electromagnetic interference (EMI) caused by a DC motor on copper cabling technology.
- Observe how optical fiber technology is immune to EMI effects
- Compare the weight of optical fiber to copper coaxial cable

Equipment you will need to complete this activity:

- 2 Fiber Optic Reference Guides
- 3 Fiber Optic Video Transceivers
- 3 120 VAC-to-14 VDC, 1-amp power adapters
- 1 120 VAC-to-12 VDC 500 mA power adapter
- 1 DC motor
- 1 Scale
- 1 10-meter fiber cable
- 1 3-meter fiber cable
- 1 10-meter length of coaxial cable

To complete this activity you must:

1. Review Homework Assignment #2 with your lab partner or group. Discuss any particularly interesting companies or products that you found.
2. Read Chapter 4 of “*Fiber Optic Reference Guide*.”
3. Answer Questions 1 through 9 on **Worksheet #3**.
4. Complete **Lab Exercise #3**.
5. Complete **Homework Assignment #3**.

Homework Assignment #3:

Optional: Read Chapter 5 of “*Fiber Optic Reference Guide*” if this is your first exposure to fiber optic technology and you are not familiar with the light sources used in this technology.

Lab Exercise #3

You have been learning about the many advantages of fiber optics. The experiments in this activity will allow you to experience two of them first-hand. Let's proceed.

Experiment A: *Demonstration of EMI*

1. Choose a flat, level table approximately 60 × 120 cm (2 × 4 feet) in size.
2. Your equipment set-up in this experiment is shown in Figure 8. You may wish to refer to this figure as you complete the following steps.
3. Attach one end of the 3-meter fiber cable to the RED LED receptacle. Attach the other end to the OPTICAL INPUT receptacle.
4. Plug the microphone into the jack on the motor as shown in Figure 8. Insert the plug on the cable end from the motor into the AUDIO 1 jack on the Transceiver.
5. Insert the small end of the 120 VAC-to-14 VDC Power Adapter cord into the power input jack on the Transceiver. **CAUTION: Make sure to use the larger 1-amp power adapter with the Transceiver. The smaller 500 milliamp Power Adapter for the DC motor will not properly power the Transceiver.**
6. Plug the Power Adapter into a 120-volt wall outlet or extension cord.
7. Turn on the Transceiver. Verify that it is powered by seeing some of the LEDs lighting up.
8. Press the middle momentary switch shown in Figure 8 until the LED labeled D6 is lit.
9. Set the VOLUME control knob in the receiver section of the Transceiver to the 12 o'clock position.
10. Press the momentary switch in the RECEIVER portion of the Transceiver until the LED labeled D19 is lit.
11. You or your lab partner can now speak into the microphone. You should hear sound coming from the speaker on the Transceiver. If not, rotate the volume control knob clockwise as you speak into the microphone. Stop increasing volume when the sound coming from the speaker is at a moderate level.
12. Insert the small end of the 120 VAC-to-12 VDC Power Adapter cord into the power input jack on the motor. The 120 VAC-to-12 VDC power adapter is the smallest of the four that came with this module.

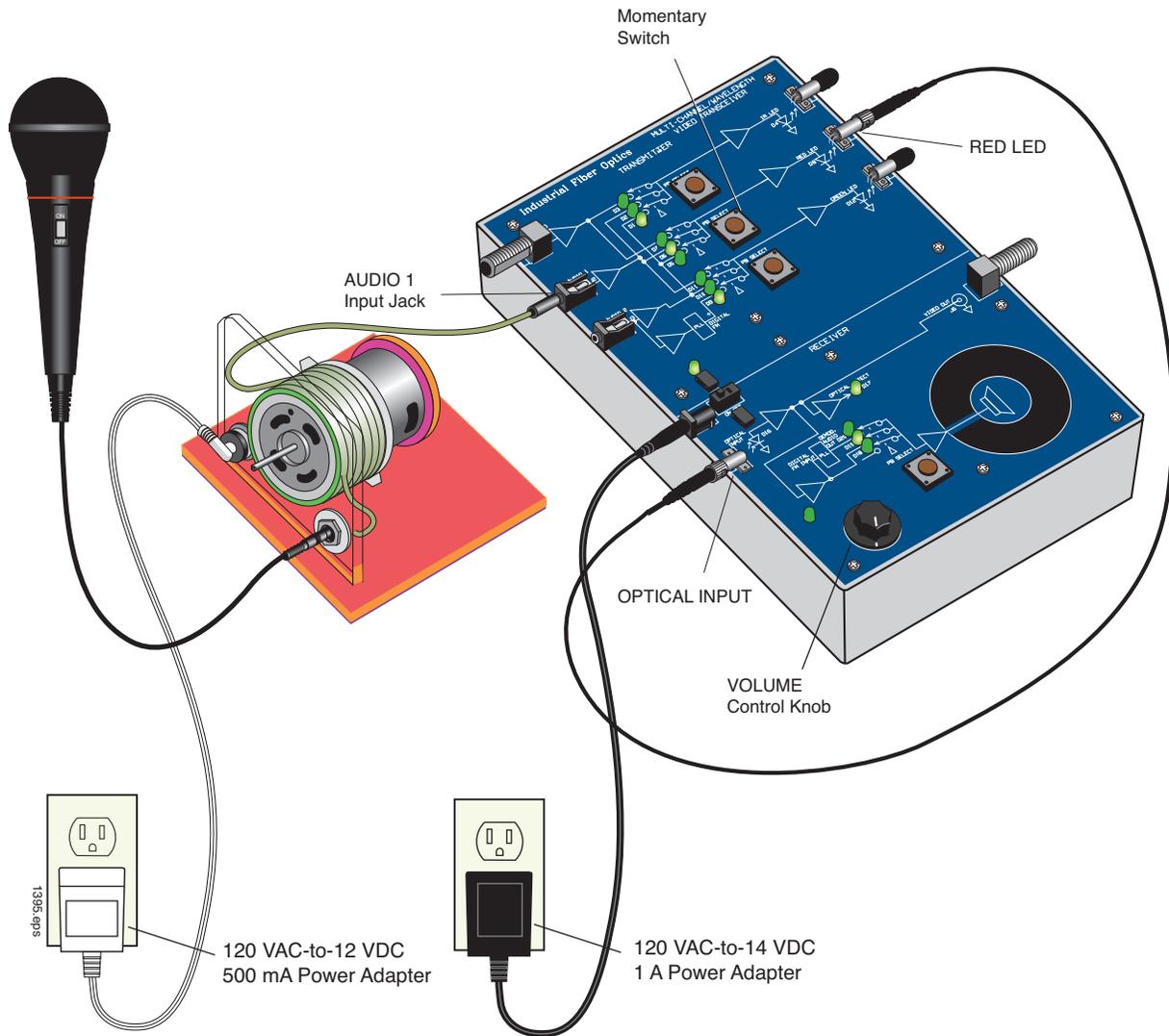


Figure 8. Equipment set-up to demonstrate the effects of EMI on communications systems

13. Plug the Power Adapter into a 120-volt wall outlet or extension cord.
14. When power is applied to the motor you should notice static or noise coming from the speaker.
15. Now have your lab partner or one of your group speak into the microphone. Observe how much harder it is to understand what is being said. Switch roles, with your lab partner listening while you speak into the microphone.
16. Unplug the 12 VDC power adapter jack from the motor.

Experiment B: *EMI immunity of fiber optics*

1. In this experiment you will add two more transceivers and a second microphone to observe the immunity of fiber optic cable to EMI. The original Transceiver you set up in Experiment A will be referred to as Transceiver 1 from now on. Your final equipment set-up to complete this experiment should look like the diagram in Figure 9. You will definitely want to reference this figure as you complete the following steps.
2. Insert the small end of the 120 VAC-to-14 VDC Power Adapter cords into the power input jacks on transceivers 2 and 3.
3. Plug the other ends of both Power Adapters into 120-volt wall outlets or extension cords.
4. Turn on transceivers 2 and 3 with the on/off switch.
5. Set each Transceiver's VOLUME control knob to the 12 o'clock position.
6. Disconnect the fiber cable from the OPTICAL INPUT receptacle on Transceiver 1 and attach it to the OPTICAL INPUT receptacle on Transceiver 2.
7. Insert the plug of the second microphone cord into the AUDIO 2 jack on Transceiver 1.
8. Press the bottom momentary switch in the TRANSMITTER portion of Transceiver 1 until the LED labeled D10 lights up.
9. Attach one end of the 10-meter cable to the GREEN LED on Transceiver 1. Carefully wrap eight loops of this fiber cable around the DC motor. Connect the other end of this fiber to the OPTICAL INPUT receptacle on Transceiver 3.
10. Press the momentary switch in the RECEIVER portion of transceivers 2 and 3 until the LED labeled D19 is lit.
11. Plug the motor's power adapter into the wall outlet again. At this point, noise should be coming from Transceiver 2's speaker as in Experiment A.
12. Have somebody in your group speak into the microphone.
13. You should hear that the sound coming from Transceiver 3 is crystal clear, but the sound from Transceiver 2 has static.
14. Unplug all the power adapters from the transceivers and roll up all fiber cables. Return all items to their proper storage locations.
15. Answer Question 11 on **Worksheet #3**.

Worksheet #3

Student: _____

1. Name the first layer of material that surrounds fiber cladding in a fiber optic cable.

2. Fiber optic cables are classified according to which of the following construction design(s)?
 - a) Tight-buffer
 - b) Loose-tube
 - c) Kevlar®
 - d) Graded-index mode
 - e) Underground
 - f) A and B
 - g) B and D
 - h) A and E

3. AT&T and GTE installed the first fiber optic telephone system in:
 - a) 1977
 - b) 1967
 - c) 1971
 - d) 1871
 - e) 1950
 - f) None of the above

4. Kevlar® is a common material added to a fiber cable as a strength member.
 - a) True
 - b) False

5. Duplex fiber optic cable has only one optical fiber inside it.
 - a) True
 - b) False

6. A hybrid fiber optic cable construction contains copper wire and optical fiber.
 - a) True
 - b) False

7. The life expectancy of a fiber optic cable after installation is:
 - a) 1 to 5 years
 - b) 5 to 10 years
 - c) 10 to 20 years
 - d) 20 to 40 years
 - e) 40 to 80 years
 - f) None of the above

8. There are numerous designs and standards for fiber optic cables ranging from plenum to underground.
 - a) True
 - b) False

9. Fiber optic installations are not practical for distances greater than 100 km.
 - a) True
 - b) False

10. What elements can be found in optical cables?
 - a) Gel
 - b) Jacket
 - c) Buffer
 - d) Strength members
 - e) Optical core and cladding
 - f) All of the above

11. Describe in your own words your observation of EMI and the immunity of optical fiber technology.

Table 1. Measured weights of coaxial cable and fiber cable.

CABLE	WEIGHT
Coaxial	
Fiber Optic	

12. Calculate, as a percentage, the lighter weight of fiber cable compared to coaxial cable.

Activity #4

Optical Performance & Characteristics

Objectives:

- ❑ Learn about other active components used in fiber optic communications
- ❑ Describe a semiconductor optical amplifier
- ❑ Understand why fiber amplifiers are used in fiber optics
- ❑ Develop and understand what problems laser diode “chirp” can cause
- ❑ Learn about applications for external modulators and laser diodes
- ❑ Demonstrate one of the many wide bandwidth applications of optical fiber
- ❑ Learn how to measure or characterize attenuation in optical fiber
- ❑ Observe that attenuation of light in an optical fiber is not the same for all wavelengths

Equipment you will need to complete this activity:

- 2 Fiber Optic Reference Guides
- 2 Video Transceivers
- 2 120 VAC-to-14 VDC, 1-amp power adapters
- 1 10-meter fiber cable
- 1 3-meter fiber cable
- 1 1-meter fiber cable
- 2 coaxial cables with type F connectors on both ends
- 1 Fiber Optic Test Set
- VCR with tape cassette* or digital TV tuner*
- Television*

* Not included with this module

To complete this activity you must:

1. Review **Homework Assignment #3** with your lab group or partner. Would you say the exercise that transmitted video over the optical fiber used very much of the light/fiber bandwidth?
2. Read Chapter 7 in “*Fiber Optic Reference Guide*.”
3. Answer Questions 1 through 8 on **Worksheet #4**.
4. Examine Appendix C of “*Fiber Optic Reference Guide*.” This is a list of the standard symbols used in the cable television industry relating to fiber optic technology.
5. Complete **Lab Exercise #4**.
6. Complete **Homework Assignment #4**.

Homework Assignment #4:

Log onto the Internet and go to website <http://www.uspto.gov>. Once at the site, conduct a search for patents covering fiber optics or optical fibers. Find two patents that interest you and write a paragraph about each regarding their apparent merits or benefits. Be prepared to discuss in your next activity.

Optional: Read Chapter 6 of “*Fiber Optic Reference Guide*” if this is your first exposure to fiber optic technology and you are not familiar with the light detectors used in this technology.

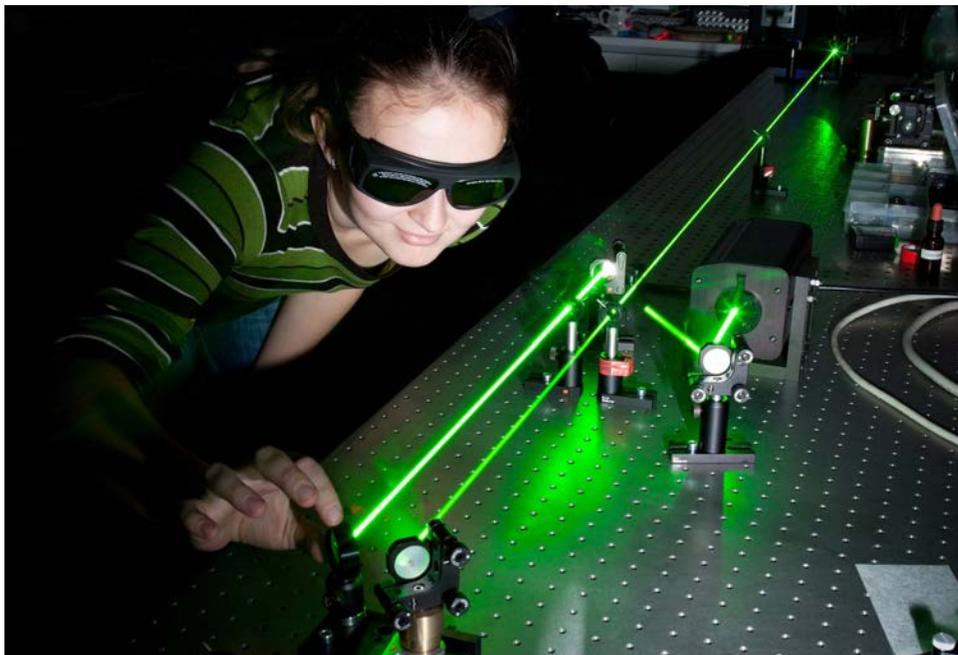


Photo 2. Scientist in an optic lab

Lab Exercise #4

As you have learned in your text, optical fiber has the capacity for many times more bandwidth than conventional coaxial cable. As a first step in exploring the enormous capabilities of optical fiber, you will transmit RF video over a plastic core optical fiber. You will then measure or characterize green, red and infrared light through different optical fiber lengths to learn about attenuation.

Experiment A: *Setting up the TV and video source*

In this procedure we will electrically link a video source to a television and test that connection. Although this initial experiment has nothing to do with fiber optics technology you will use it as a stepping stone toward transmitting video over optical fiber. Because video sources and televisions vary, it is possible the following steps may need to be altered to accommodate your particular situation.

1. Choose a flat, level table approximately 90 × 240 cm (3 × 8 feet) in size as your work area for this exercise.
2. Assemble all items from the Equipment Needed list at your work area.
3. Plug the power cords for the video source and the television into 120-VAC outlets.
4. Find the RF “OUTPUT” jack on the video source and insert the type F end of the first video coaxial cable. (Note: The name varies on video sources, but it’s the jack that sends RF-based video signals to the television tuner). The type “F” connections on the coax cables can be either a press-on or a screw-on type. Connect the other end of the video coax cable to the RF “INPUT” (tuner) jack on the television.
5. Turn on the video source and television. Set the tuner on the television to channel 3 or 4, whichever is unused in your broadcast area. Find the switch on the video source that selects the channel for the RF output, usually located in the rear near the “OUTPUT” connector. Set it to the same channel as the television, either 3 or 4. (Whatever names are used on your particular equipment, the key is to have the television tuned to the same channel as the video source output.)
6. You may also use the tuner to receive broadcasts from a television station, or, if using a VCR, insert a tape and start it playing.
7. Make certain the television set is clearly displaying the video and the audio signal properly before proceeding to the next experiment. If it is not, check the volume control, signal switch positions and cable connections.
8. Leave the signal switch positions on the video source and television exactly as you set them, then stop the playback on the video tape (if used) and turn the video source and television off. Disconnect the coaxial cable from the rear of the television.

Experiment B: *Video over optical fiber*

In this procedure you will transmit a signal from the video source to the television through fiber cables with two video transceivers. The frequency of the video signal will be approximately 50 Megahertz. Although far below the capabilities of a modern state-of-the-art fiber system, this frequency is high enough that significant attenuation can occur when copper-based coaxial cable is used instead of optical fiber.

1. Position the video source, the two transceivers and the television on the table top as shown in Figure 10.

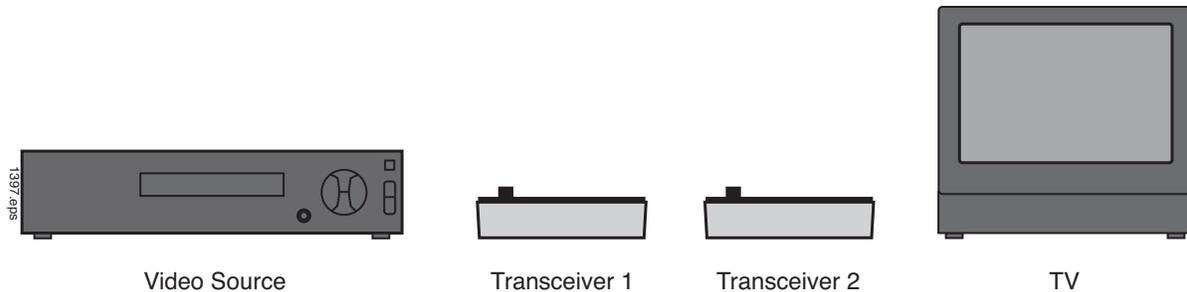


Figure 10. Initial position of equipment for completing video signal transmission over optical fiber.

2. Connect the coaxial cable attached to the video source to the Video input jack on Transceiver 1. See Figure 11.
3. Attach one end of the 3-meter fiber cable to the IR LED receptacle on Transceiver 1.
4. Attach the other end of the fiber cable to the OPTICAL INPUT receptacle on Transceiver 2.
5. Connect one end of the remaining coaxial cable to the television set and the other end to the VIDEO OUT jack of Transceiver 2.
6. Insert the small end of the 120-volt Power Adapter cords into the power input jack on both transceivers.
7. Plug the power adapters into 120-volt wall outlets and slide the On/Off switch of both transceivers to On.
8. Press the top momentary switch in the center of the TRANSMITTER portion of Transceiver 1 until the LED labeled D3 is lit.
9. Turn on the video source and television. You should now see a picture and hear sound from the television.
10. Unplug the power adapter to Transceiver 2 and disconnect the coaxial cables from both transceivers, video source and television.
11. Answer Question 9 on **Worksheet #4**.

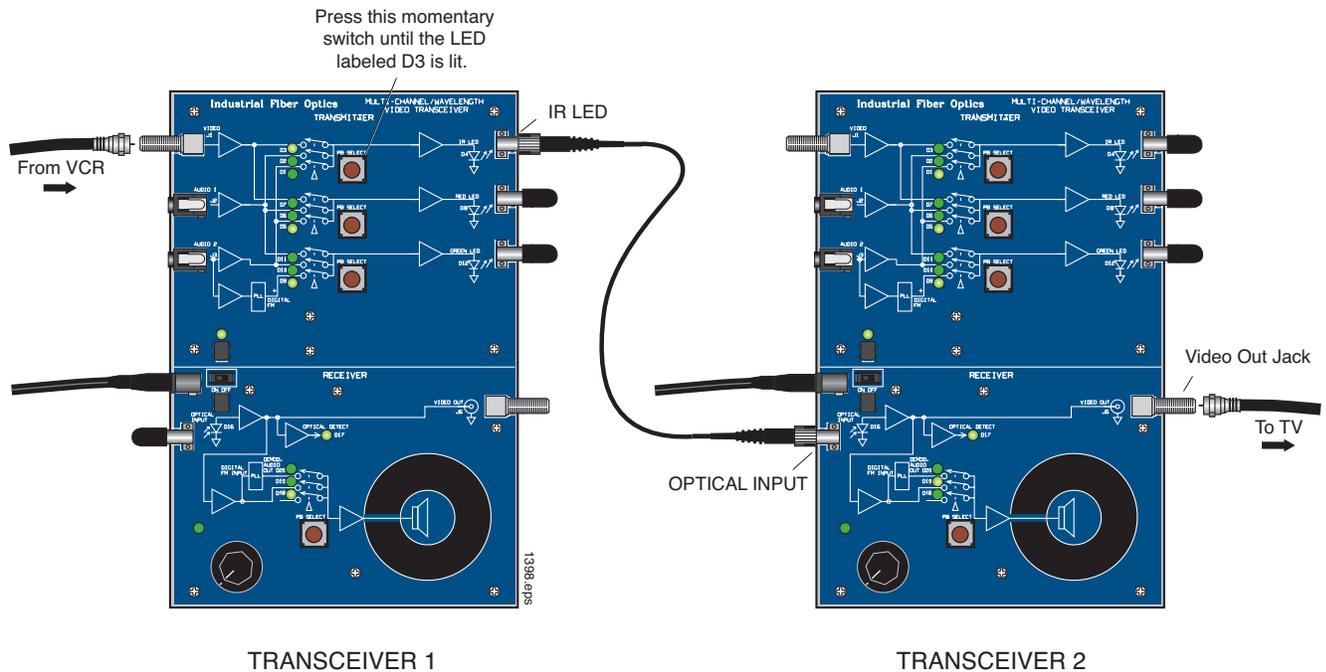


Figure 11. Detailed view of electrical and optical connectors on the two transceivers for demonstrating video transmission over optical fiber.

Experiment C: Measuring Fiber Attenuation

Fiber optic cables offer many advantages over copper cables, including lighter weight, higher information-carrying capacity and lower signal loss. Eventually, though, as light travels through an optical fiber some optical signal loss or attenuation occurs. The two main causes of optical attenuation are scattering and absorption. Scattering is the redistribution of a light beam from a single direction into many or all directions. In an optical fiber scattering is the result of imperfections in density and composition that are natural by-products of manufacturing. Light rays hitting these imperfections are scattered, reducing power in the area where it was wanted. Absorption is a process where impurities in the fiber absorb optical energy and dissipate it as heat. (Impurities occur during the manufacturing process when unwanted chemical ions and other substances are introduced into the fiber.)

Knowing the level of attenuation in optical fibers is important because it allows fiber optic system designers to predict the power which will be lost through a fiber optic cable. For long-distance transmission, multiple optical links are used with repeaters to replace the power lost to attenuation. Repeaters amplify weak signals and restore the power to a level high enough to send the signal down to the next link. By knowing the attenuation and other losses in fiber optic cable links, a designer can budget the correct quantity and location of repeater systems.

In this experiment you will measure the optical power out of the 1-meter, 3-meter and 10-meter fibers for three different operating wavelengths (530, 660 and 850 nm). The three different light sources will be the LEDs that you have been using on the optical transceivers.

1. Switch on the Fiber Optic Test Set, rotate the Display Selector Switch to 200 μW and set the wavelength selector switch to 850 nm. Adjust the LCD Display indicator so it reads “zero,” using the “Zeroing Procedure” found in the Fiber Optic Test Set manual.
2. Remove the dust caps from the test set’s detector.
3. Attach one end of the 1-meter fiber cable to the IR LED receptacle in the TRANSMITTER portion of the transceiver.
4. Attach the other end of the fiber cable to the DETECTOR receptacle on the Fiber Optic Test Set as shown in Figure 12.

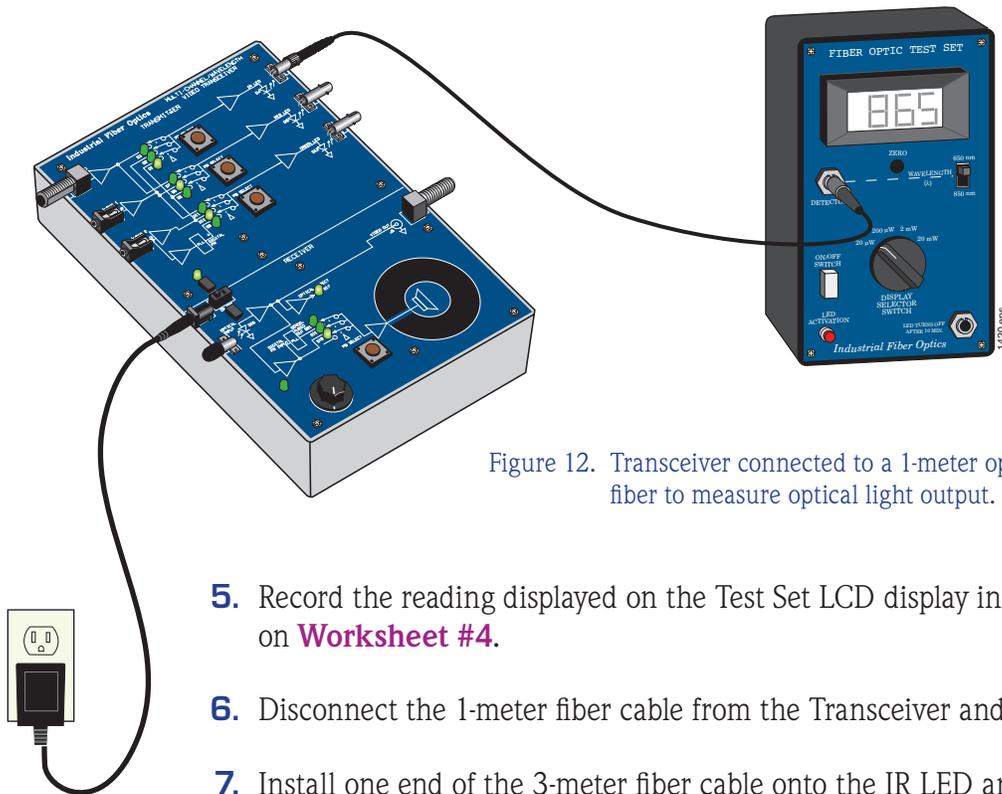


Figure 12. Transceiver connected to a 1-meter optical fiber to measure optical light output.

5. Record the reading displayed on the Test Set LCD display in Table 1 on **Worksheet #4**.
6. Disconnect the 1-meter fiber cable from the Transceiver and Test Set.
7. Install one end of the 3-meter fiber cable onto the IR LED and the other end onto the test set detector. If at any time during this experiment the test set display reads less than 20 μW , switch the meter to the 20 μW scale and rezero the meter before continuing.
8. Record the test set display’s reading in Table 1 of **Worksheet #4**.
9. Repeat Steps 6 through 8 with the 10-meter fiber cable.
10. Move the wavelength selection switch on Fiber Optic Test Set to the 650 nm position.
11. Now repeat Steps 3 through 9 — this time attaching all three fiber cables to the Transceiver’s red LED.

12. Now repeat Steps 3 through 9, but this time attaching all three fiber cables to the transceiver's green LED.
13. Unplug the power adapter from the 120-volt outlets and the Transceiver. Replace all dust caps. Return all items to their proper storage containers and locations.
14. Answer the remaining questions on **Worksheet #4**.

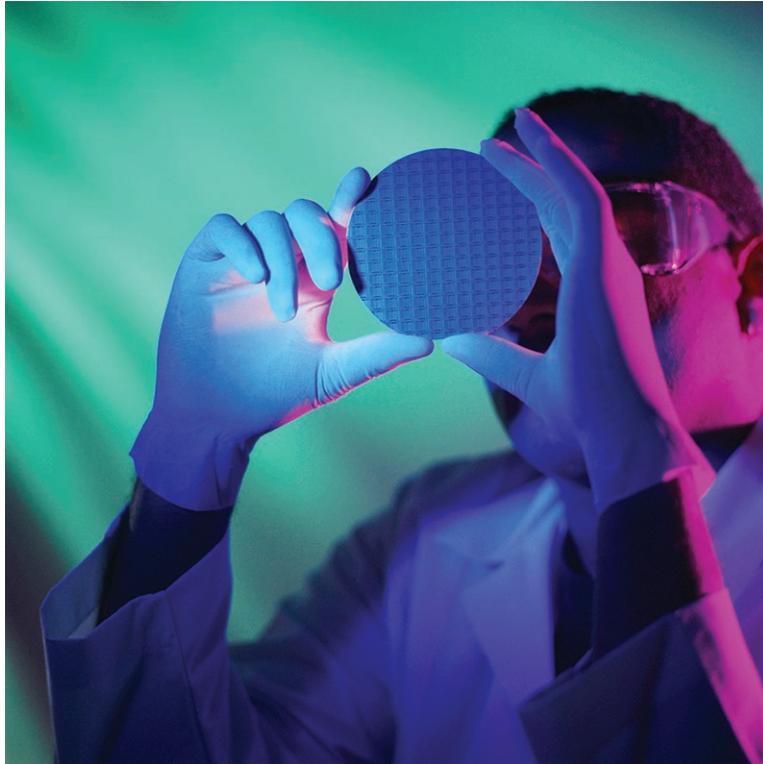


Photo 4. Technician inspecting a semiconductor wafer which is a critical component in fiber optic technology

Worksheet #4

Student: _____

1. Semiconductor optical amplifiers are essentially laser diode chips with fibers attached to both ends that amplify and retransmit any incoming optical signal.
 - a) True
 - b) False

2. With current long-distance fiber optic systems using wavelength-division multiplexing, the use of fiber amplifiers has become almost mandatory.
 - a) True
 - b) False

3. The following is true about erbium-doped fiber amplifiers:
 - a) Amplification is independent of data rate
 - b) Additional wavelengths can be added to the system without upgrading the amplifier
 - c) Used in dense wavelength-division multiplexing systems
 - d) All of the above

4. Optical amplifiers are used in the following fiber optic applications:
 - a) Power
 - b) In-line
 - c) Preamplifier
 - d) All of the above

5. In laser diodes wavelength “chirp” is caused by:
 - a) Turning the laser diode on and off
 - b) Temperature
 - c) Aging
 - d) Component-to-component variation
 - e) Electrical stress applied to the laser diode
 - f) All of the above
 - g) A and B
 - h) B and C

6. External optical modulators are used to eliminate the effects of wavelength “chirp” in laser diodes.
 - a) True
 - b) False

7. External optical modulators and amplifiers change what characteristics of light passing through them?
 - a) Power
 - b) Range
 - c) Single-mode to multi-mode
 - d) Polarization
 - e) All of the above

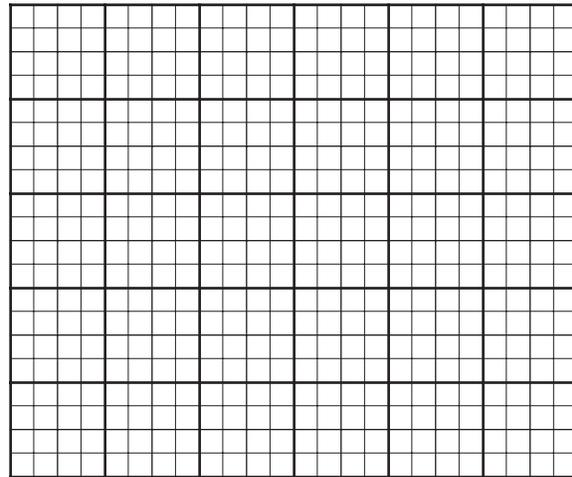
8. The use of external optical modulators is straightforward with digital modulation, compared to analog modulation which can require much more care
 - a) True
 - b) False

9. Describe the quality of the television picture after it had gone through transceivers and optical fiber. Was it better or poorer than through the coaxial cable?

Table 1. Output power measured out of three different cable lengths with all transceiver LEDs.

CABLE	IR (μW)	RED (μW)	GREEN (μW)
1-meter			
3-meter			
10-meter			

10. Plot the optical power versus distance on the grid to the right.



11. Calculate the attenuation of the optical fiber using the equations shown in Table 2.

Table 2. Calculation of plastic core optical fiber attenuation for various wavelengths

CABLE	$\frac{p_{(10 - meter)}}{p_{(1 - meter)}}$	$\log \left[\frac{p_{(10 - meter)}}{p_{(1 - meter)}} \right]$	$\frac{\log \left[\frac{p_{(10 - meter)}}{p_{(1 - meter)}} \right]}{9}$
IR			
Red			
Green			

Activity #5

Fiber Interconnection Devices

Objectives:

- ❑ Be able to define fiber interconnections
- ❑ Learn about the evolution of fiber connectors from initial difficulties to their current designs
- ❑ Identify the four basic components that comprise a fiber optic connector
- ❑ See that there are many different types of fiber optic connectors, and the advantages and disadvantages of each.
- ❑ Study the general procedure for installing fiber optic connectors on fiber optic cables and polishing the ends
- ❑ Learn about mechanical and fusion optical fiber splices
- ❑ Review care of fiber optic connectors
- ❑ Install ST connectors on the end of fiber cable, including crimping and two-step polishing
- ❑ Measure insertion loss of fiber optic cable
- ❑ Observe how index-matching gel can reduce connector-related light loss

Equipment you will need to complete this activity:

- 2 Fiber Optic Reference Guides
- 1 Micro-Strip® fiber stripper
- 1 Fiber optic crimping tool
- 1 Hot Knife with blade attachment and stand
- 1 ST 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 polishing film (pink)
- 1 2-meter length of plastic core fiber optic cable
- 2 ST-style fiber connectors (4-piece sets)
- 1 ST/ST connectors
- 1 ST Barrel connector
- Cotton swabs and clean water

To complete this activity you must:

1. Discuss with your lab partner or group one of the two patents that you researched for **Homework Assignment #4**. If you have any questions, seek clarification from your instructor.
2. Read Chapter 8 in “*Fiber Optic Reference Guide*.”
3. Answer Questions 1 through 9 on **Worksheet # 4**.
4. Complete **Lab Exercise #4**.
5. Complete **Homework Assignment #4**.

Homework Assignment #5:

Research on the Internet several fiber optic connector manufacturers. To start, go to the website <http://www.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. Examples would be telecommunications and local area networks.

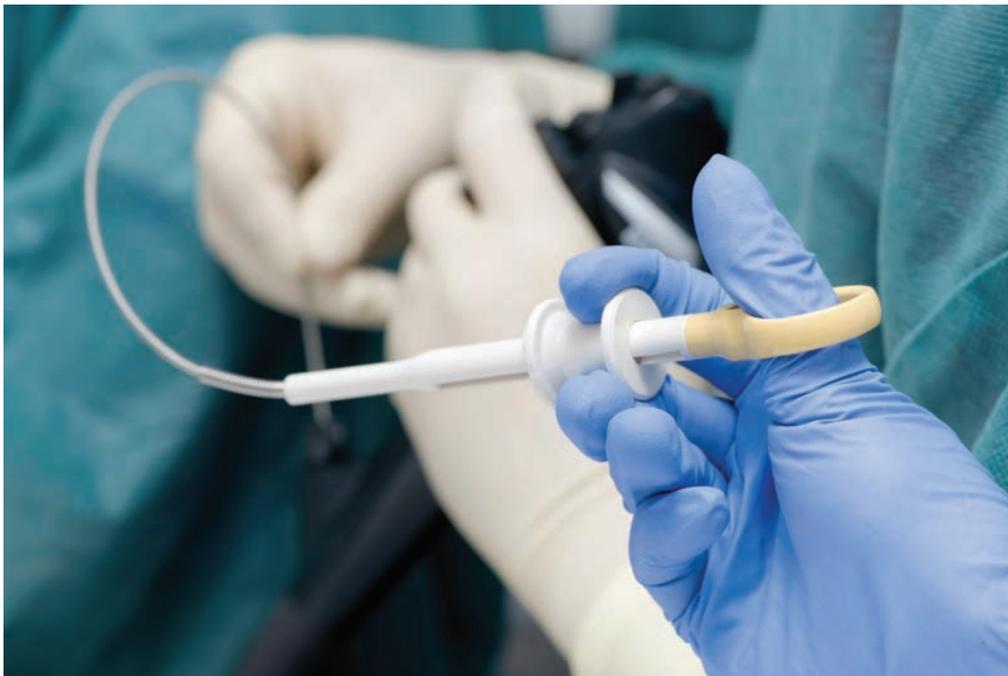


Photo 5. Optical biopsy. Fiber optics has made dramatic advances in physicians' ability to see and evaluate medical conditions inside the human body.

Lab Exercise #5

In this lab exercise you will learn how to install an ST connector on 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 the fiber ends, which is a very important part of the termination procedure. After assembling the connector to the fiber you will measure the attenuation.

Experiment A: *Install ST connectors on plastic core fiber*

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 knife to heat about 15 minutes before use.
3. The ST connector assemblies that you will use in this activity consist of three parts as shown in Figure 13. Each assembly contains a black rubber strain relief boot, stainless 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).

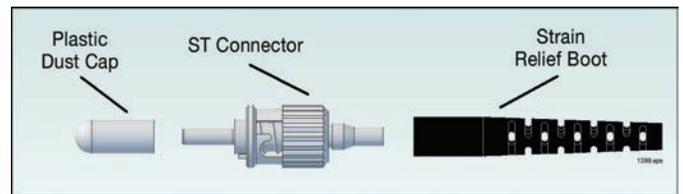


Figure 13. 4 components of the ST® connector.

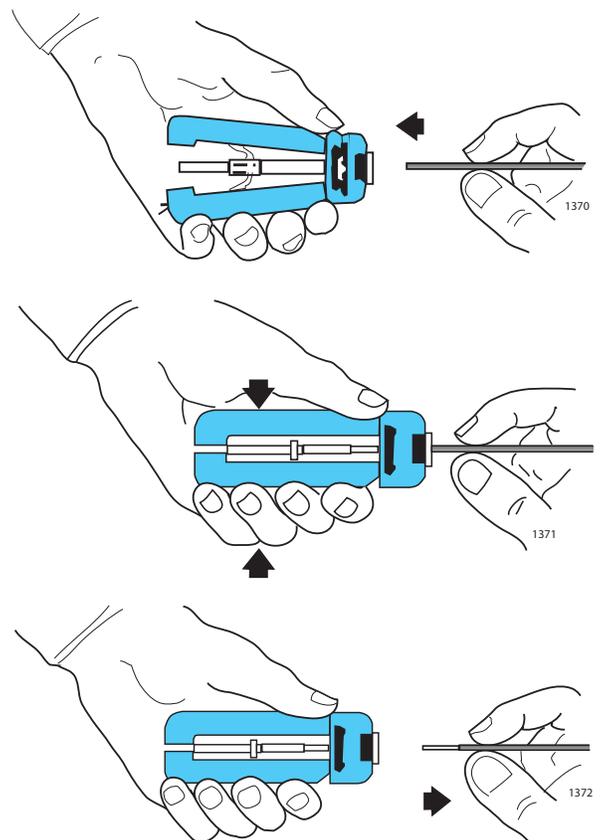
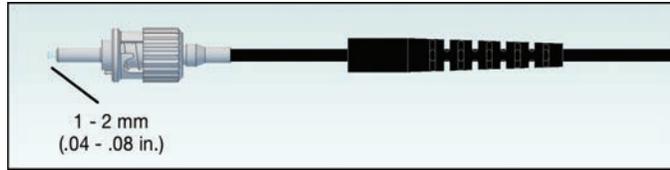


Figure 14. Proper orientation and use of fiber cable and fiber stripper.

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.

Figure 15. ST® connector properly located and crimped onto a fiber cable.

11. Slide the large end of the fiber connector body (ferrule) onto the stripped end of the fiber cable. Push it onto the cable as far as it will go. There should be 1 to 2 millimeters (.04 to .08 inches) of bare fiber protruding from the ferrule tip.
12. You will use the 0.1 inch hex hole in the jaws of the crimping tool to crimp the ferrule onto the fiber cable. 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 as shown in Figure 16.

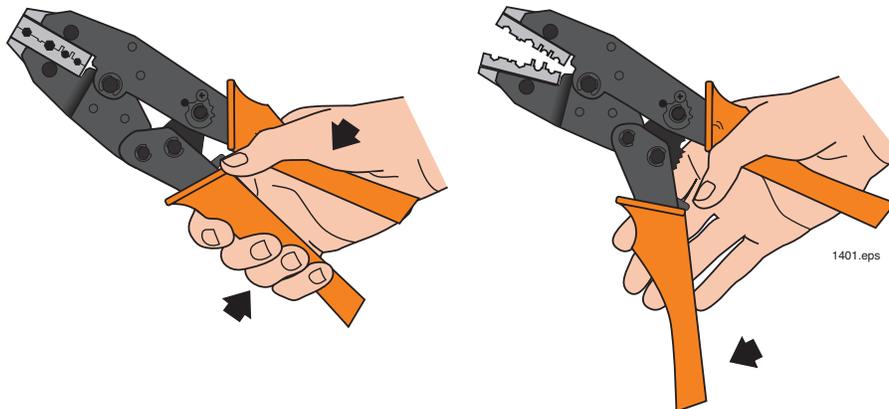


Figure 16. Proper grip of the crimper and tool in its open position.

13. Place the large end of the ferrule in the 0.1 inch hex hole as shown in Figure 17 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 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 ferrule 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 core.

18. CAUTION: Never examine 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.
20. Observe 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 18. 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.

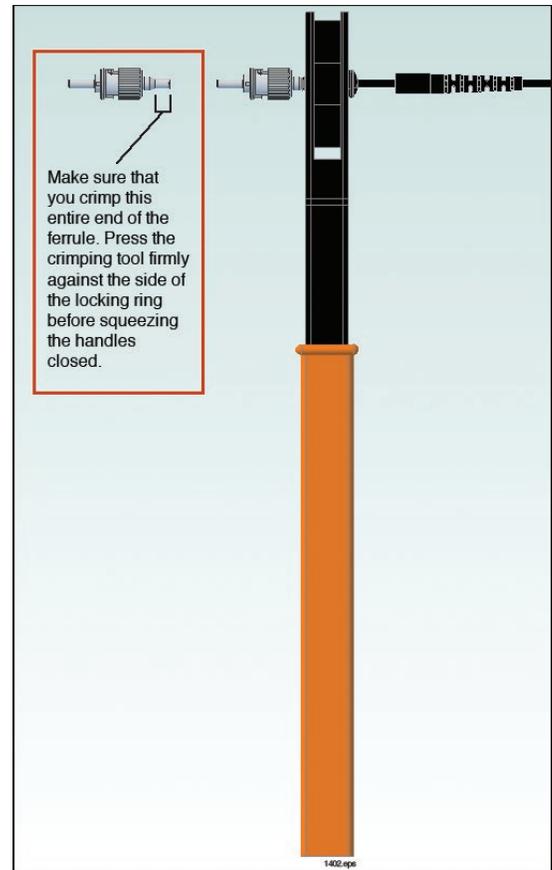


Figure 17. Position of the ST connector in crimper for proper crimp.

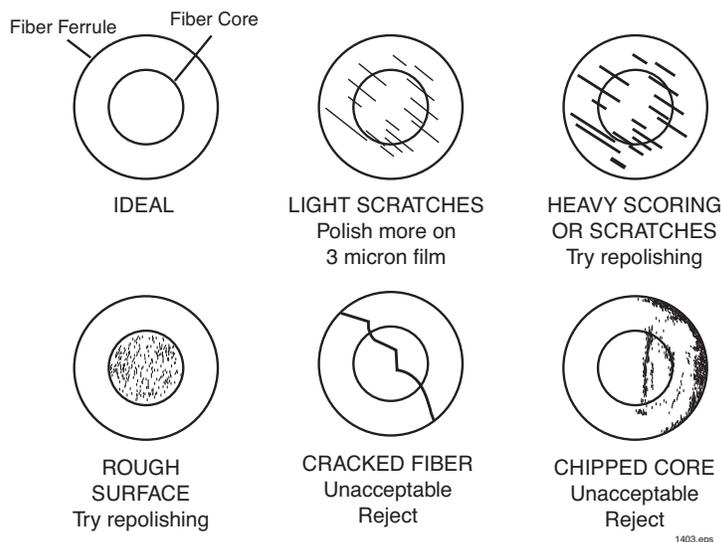


Figure 18. Defects found in fiber ends after polishing.

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 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 the tip of the fiber contacts the sandpaper.

23. Polish the end of the fiber in a “figure 8” pattern as shown in Figure 19. 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 “figure-8” strokes, clean the puck and the connector by wiping them off with a Kimwipe® and water.

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.

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 or polishing 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 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.

29. Answer Question 10 on **Worksheet #2**.

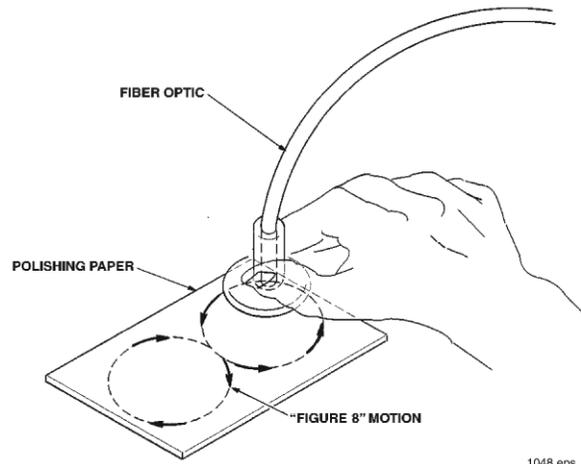


Figure 19. Fiber polishing showing the figure-8 pattern.

Measuring insertion loss

Fiber optic cables are often tested for attenuation once they are completed. This often occurs right after manufacturing, and many times they may be retested before or after installation. You will now measure the attenuation or light loss through the fiber cable that you just assembled.

1. On the Fiber Optic Test Set, turn the Display Selector Switch to 200 μ W and set the wavelength selector switch to 650 nm. With the protective dust caps on, turn the On/Off switch on. Adjust the LCD Display indicator so that it reads “zero,” following the “Zeroing Procedure” in its manual.
2. Remove the dust caps from the LED and photodetector receptacles on the Fiber Optic Test Set and press the LED ACTIVATION button.
3. Locate the LED receptacle in the lower right corner of the front panel. Remove the dust caps from the 3-meter fiber cable and attach one end to the LED receptacle.
4. Attach the other end of the 3-meter fiber cable to the Test Set DETECTOR receptacle.
5. Record the test reading in Table 1 on **Worksheet #5**.
6. Remove the end of the 1-meter fiber cable from the Test Set DETECTOR receptacle and attach it to one side of the ST barrel connector.
7. Attach one end of the 2-meter fiber cable that you just assembled to the other side of the barrel connector.
8. Attach the other end of the 2-meter fiber to the test set detector.
9. Record the results in Table 1 of **Worksheet #5**.

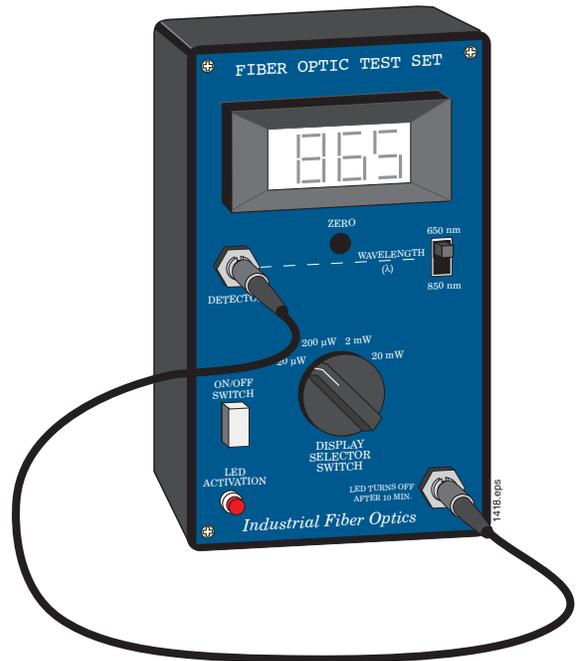


Figure 20. 3-meter fiber cable installed onto the Fiber Optic Test Set to take baseline measurements for characterizing the 2-meter fiber cable.

Procedure C: *Effects of index-matching gel*

In this procedure you will learn how light losses in fiber optic cable connections can be reduced by using index-matching gel. Although in industry applications you will seldom use index-matching gel on fiber connector ferrules, this experiment will demonstrate its effects.

1. Disconnect both fiber connectors attached to the ST barrel connector.
2. One at a time, dip the tips of the fiber ferrules into the index-matching gel and then reattach to the ST barrel connector.
3. Using the Fiber Optic Test Set, measure the optical power and record the results in Table 1 of **Worksheet #5**.
4. Detach all the fiber connectors from other fibers and the test set.
5. With Kimwipes® and water clean the fiber connector ferrules that were dipped in the index-matching gel.
6. Return all items to their proper storage containers and locations.
7. Answer the remaining Questions on **Worksheet #5**.

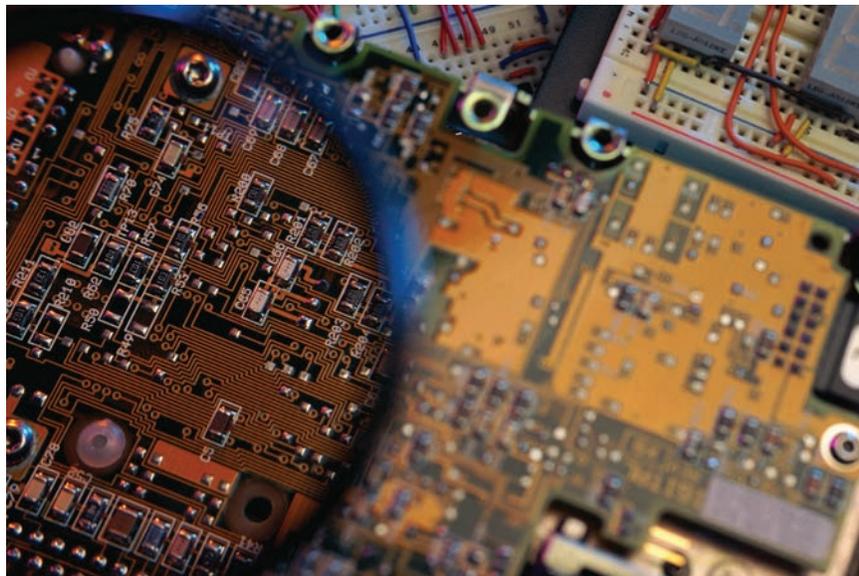


Photo 6. Critical to obtaining high communication bandwidth with optical fiber is the minaturization of the electronic components.

Worksheet #5

Student: _____

1. Connectors and splices add loss to a system or link.
 - a) True
 - b) False

2. What are the two types of fiber optic splices?
 - a) Optical
 - b) Fusion
 - c) Mechanical
 - d) Radical
 - e) A and B
 - f) B and C

3. What procedures are part of installing a fiber connector?
 - a) Polishing
 - b) Cleaning
 - c) Cleaving
 - d) Stripping jacket
 - e) All of the above
 - f) None of the above

4. Splices (complete the sentence that makes it the most accurate):
 - a) are permanent connections between fibers.
 - b) are temporary connections between fibers.
 - c) have higher insertion loss than connectors.
 - d) None of the above apply.

5. The procedure for installing a connector onto a fiber does not vary among connector types.
 - a) True
 - b) False

6. A fiber optic interconnection refers to any mechanism or technique used to join an optical fiber to another fiber or fiber optic component such as a connector or splice.
 - a) True
 - b) False

7. Today's third generation fiber optic connectors are push-pull devices.
 - a) True
 - b) False

8. A fiber optic connector contains which components?
- Cable
 - Ferrule
 - Connector body
 - Coupling device
 - All of the above
9. A fiber optic connector is one of the most complex aspects of fiber optics today.
- True
 - False
10. Describe the differences you observed with the fiber microscope when the fiber end was polished with 2000 grit, then with 3 μm polishing film.

Table 1. Output power measured out of different cable lengths.

Cable	Optical Power μW	With Index-Matching Gel μW
3-meter		
3-meter + 2-meter		

11. Calculate the loss in the 2-meter fiber cable that you just constructed with and without the index-matching gel between fiber connections. Use the data from Table 1 above and perform the calculations shown in the first line.

Table 2. Calculation of loss for a 2-meter fiber cable.

CABLE	$\frac{P_{(3+2)}}{P_{(2)}}$	$\log \left[\frac{P_{(3+2)}}{P_{(3)}} \right]$
Attenuation		
Attenuation with gel		

Activity #6

Other Passive Devices

Objectives:

- ❑ Learn about passive fiber optic devices such as splitters, taps and WDMs
- ❑ Understand that fiber optic couplers are available in many physical configurations and splitting ratios
- ❑ Describe how a fused-junction fiber optic coupler is manufactured
- ❑ Define what WDM means in fiber optics
- ❑ Explain the application of fiber switches
- ❑ Test the transmission characteristics of a 1 × 2 fiber optic coupler
- ❑ Observe the distribution of information with a fused-junction fiber optic coupler

Equipment you will need to complete this activity:

- 2 Fiber Optic Reference Guides
- 1 Fiber Optic Test Set
- 1 1 × 2 Fiber Optic Coupler with ST connectors on all ends
- 1 ST Barrel Connector
- 3 Video Transceivers
- 3 120 VAC-to-14 VDC, 1-amp power adapters
- 1 1-meter fiber cable
- 1 3-meter fiber cable
- 1 Audio patch cord with 3.5 mm mono plugs on both ends
- 1 AM/FM radio with batteries

To complete this activity you must:

1. Review **Homework Assignment #6**.
2. Read Chapter 9 in “*Fiber Optic Reference Guide*.”
3. Answer Questions 1 through 8 on **Worksheet #6**.
4. Complete **Lab Exercise #6**.
5. Complete **Homework Assignment #6**.

Homework Assignment #6:

On the Photonics Wall Chart determine the wavelengths of light that make up the near-infrared, mid-infrared and far-infrared bands.

Lab Exercise #6

Have you ever considered how you might split a light beam into two equal parts? Now think of how hard it would be to split a bundle of light rays in an optical fiber — because they are all now traveling in different directions. It is not as simple as twisting two wires together, as in electronics. To split optical signals we use a special device that is often called a fused junction coupler. You will now test an optical splitter or coupler and observe it in application.

Experiment A: *Measuring and characterizing a 1 × 2 fiber splitter*

1. Choose a flat, level table approximately 90 × 120 cm (3 × 4 feet) in size as your work area for this experiment.
2. On the Fiber Optic Test Set, turn the Display Selector Switch to 200 μ W and set the wavelength selector switch to 650 nm. With the protective dust caps on, turn the On/Off switch on. Adjust the LCD Display indicator so it reads “zero,” following the “Zeroing Procedure” in its manual.
3. Remove the dust caps from the LED and photodetector receptacles on the Fiber Optic Test Set and press the LED ACTIVATION button.
4. Locate the LED receptacle in the lower right corner of the front panel. Remove the dust caps from the 1-meter fiber cable and attach one end to the LED receptacle.
5. Attach the other end of the fiber to the Test Set DETECTOR receptacle. Equipment should now look like Figure 21.
6. Record the test reading in Table 1 on **Worksheet #6**.
7. Remove the end of the 1-meter fiber cable from the Test Set DETECTOR receptacle and attach it to one side of the barrel connector.
8. The 1 × 2 fiber splitter comes with one input and two outputs, all three of which have ST®-style connectors. Attach the single input into the other side of the barrel connector.
9. Attach one of the two coupler fiber outputs to the Test Set DETECTOR receptacle as shown in Figure 22.
10. Record the power indicated by the Fiber Optic Test Set in Table 1 on **Worksheet #6**.

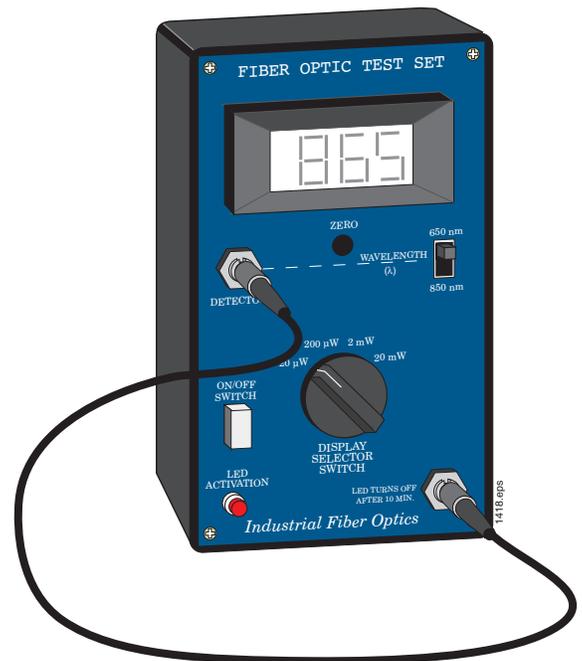


Figure 21. 1-meter fiber cable installed onto the Fiber Optic Test Set to take baseline measurements for characterizing an optical fiber coupler.

11. Now disconnect Output 1 and attach Output 2 to the DETECTOR receptacle. Record the power out of the 1-meter fiber in Table 1 on **Worksheet #6**.
12. Disconnect all the fibers from the Test Set and barrel connector. Turn the Test Set off.

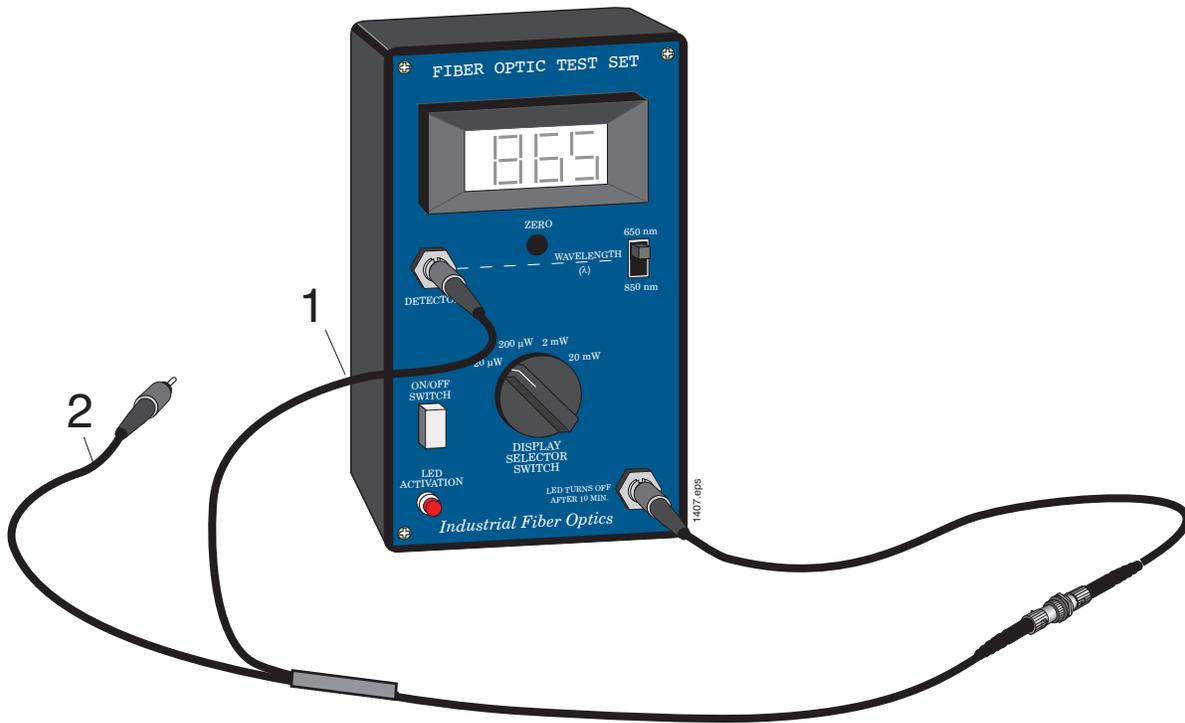


Figure 22. 1 × 2 fiber coupler connected to 1-meter fiber cable for characterizing.

Experiment B: A fiber coupler in action

In this experiment you will use an AM/FM radio and three fiber optic transceivers to demonstrate the fiber splitter in action. Although the signal source is an AM/FM radio in this experiment, it is very easy to see how the source could be cable television and each receiver could be a home destination.

1. Choose two flat, level locations, the first location approximately 90 × 240 cm (3 × 8 feet), the second location approximately 90 × 120 cm (3 × 4 feet) in size, separated by 2 m (7 feet).
2. Place two transceivers with their power adapters, the 1 × 2 fiber splitter, the AM/FM radio, fiber cables and the barrel connector at Location 1. Place one Transceiver and power adapter at Location 2.
3. Your equipment set-up in this experiment once assembled will look like the diagram in Figure 23. You may wish to refer to this figure as you complete the following steps.
4. Turn on the radio, tune it to a static-free station and adjust the volume to a comfortable listening level.

Location 1 Transceivers 1 and 2

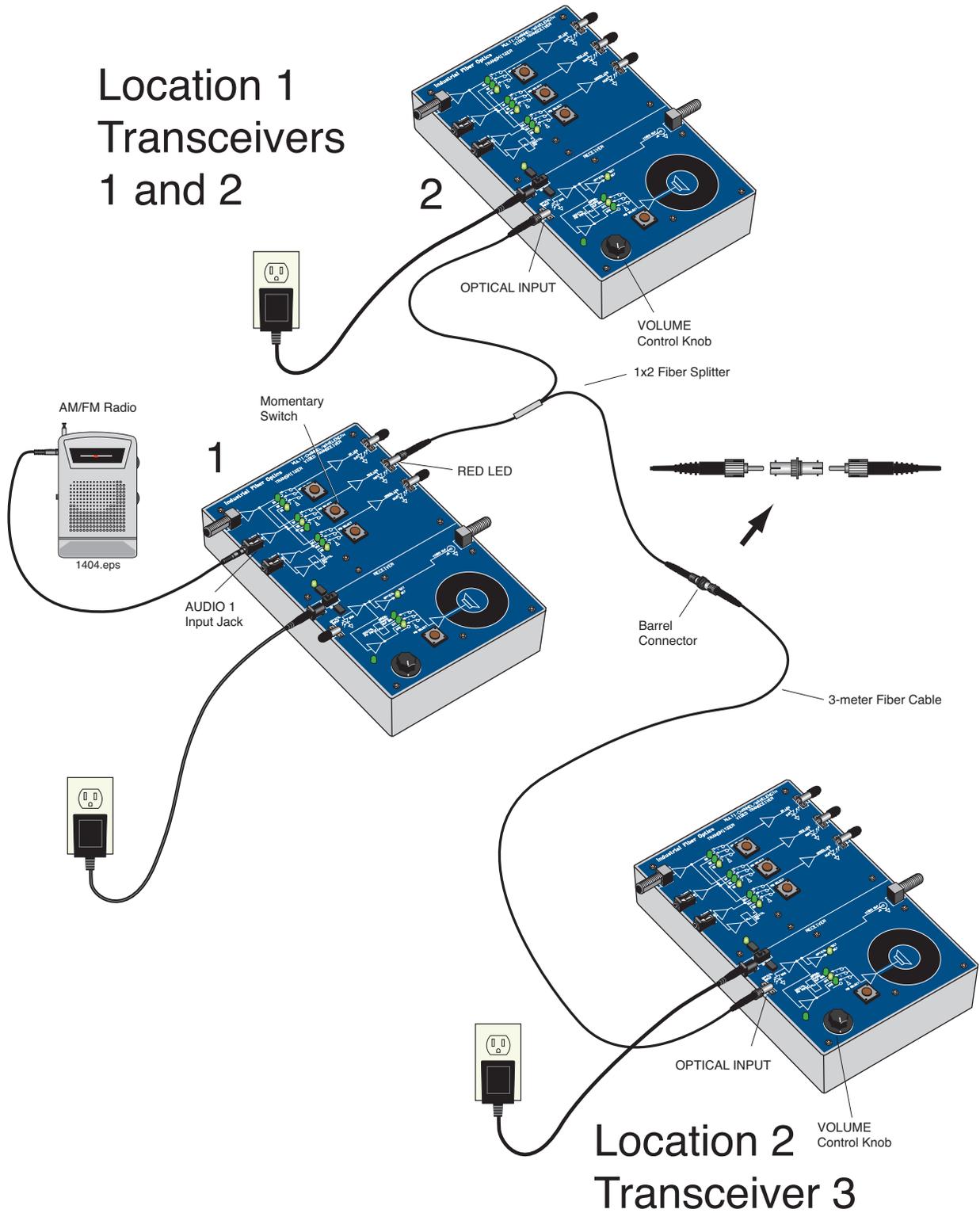


Figure 23. Equipment setup for demonstrating a fiber coupler in action.

Location 1 (Transceivers 1 and 2)

5. Insert the small end of the 120-volt Power Adapter cords in the power input jacks on both transceivers.
6. Plug the 2-pronged end of the Power Adapters into 120-volt wall outlets and switch the transceivers on.
7. Plug one end of the audio patch cord into the radio and the other end into the AUDIO 1 jack in the TRANSMITTER portion of Transceiver 1.
8. Attach the ST connector of the single fiber side of the 1 × 2 fiber splitter to the RED LED receptacle in the TRANSMITTER portion of Transceiver 1.
9. Attach one of the two unattached fibers from the 1 × 2 fiber splitter to the OPTICAL INPUT receptacle in the RECEIVER portion of Transceiver 2.
10. Turn both transceivers on by sliding their on/off switches to the left.
11. Press the middle momentary switch in the TRANSMITTER portion of Transceiver 1 until the LED labeled D6 is lit.
12. Press the momentary switch in the RECEIVER portion of Transceiver 2 until D19 is lit.
13. Sound should now be coming from the speaker of Transceiver 2.
14. Attach the remaining fiber from the 1× 2 fiber splitter to one side of the barrel connector.
15. Attach one end of the 3-meter fiber cable to the other side of the barrel connector.

Location 2 (Transceiver 3)

16. Insert the small end of the 120-volt Power Adapter cord in the power input jack on Transceiver 3.
17. Plug the 2-pronged end of the Power Adapter into a 120-volt wall outlet and turn on transceivers.
18. Attach the other end of the 3-meter fiber to the OPTICAL INPUT of Transceiver 3.
19. Press the momentary switch in the RECEIVER portion of Transceiver 3 until D19 is lit.
20. At this time you should hear sound coming from Transceivers 2 and 3.
21. Unplug the power adapters from the 120-volt outlets and the transceivers. Replace dust caps on all connector ends. Return all items to their proper storage containers and locations.
22. Answer Questions 10 through 13 on **Worksheet #6**.

Worksheet #6

Student: _____

1. Fiber optic couplers connect one fiber to another.
 - a) True
 - b) False

2. Cross-talk is an important consideration in fiber optic WDM because it refers to how well separated demultiplexed channels are.
 - a) True
 - b) False

3. WDM allows for multiple totally independent data streams to be transmitted over a single optical fiber.
 - a) True
 - b) False

4. WDM is an abbreviation for what in fiber optics?
 - a) Water dependent material
 - b) Wavelength dispersion multiplexer
 - c) Wide-division mode
 - d) Wavelength-division multiplexer

5. A fiber coupler's operation is described by:
 - a) Input and output parts ($n \times m$)
 - b) Splitting radius (50-50, 90-10)
 - c) Even numbers of input and output parts
 - d) A and B
 - e) B and C
 - f) All of the above

6. Fiber optic switches are available in which of the following technologies?
 - a) Phenolic
 - b) Electro-optical
 - c) Opto-mechanical
 - d) B and C
 - e) A and B

7. Types of passive fiber optic devices include:
 - a) Wavelength division multiplexers
 - b) Circulators
 - c) Splitters
 - d) Couplers
 - e) All of the above
 - f) None of the above

8. WDMs are available for multi-mode fiber.
 a) True
 b) False

Table 1. Output power measurements from Experiment B.

INPUT	OUTPUT POWER- μW
1-meter fiber	
PORT 1	
PORT 2	

9. Add the output powers of Port 1 and 2 and record the sum in the chart.

10. Assuming that fiber attenuation can be neglected, compute the excess loss of a fiber coupler by dividing the sum of the optical power measured from Ports 1 and 2 by the output power from the 1-meter fiber by itself. Perform this calculation using the sum of the output powers and write your answer below.

11. Fiber couplers are manufactured in standard splitting ratios as listed below. Determine the splitting ratio of this coupler by dividing the output power from Port 1 by the sum of the power from Ports 1 and 2. (The numbers below are listed in percentages.)
 a) 90:10
 b) 80:20
 c) 50:50
 d) 70:30
 e) None of the above

Table 2. 1×2 fiber coupler's ports' excess loss calculations.

PORT	$10 \cdot \log \left[\frac{P_{(port1)}}{P_{(1-meter)}} \right]$
1	
2	

12. Calculate the insertion loss of each fiber coupler port by multiplying 10 times the log of the port's output power divided by the power output from the 1-meter fiber.

13. After completing this procedure can you visualize how fiber optic couplers are used in real-insworld applications ? Explain below.

Activity #7

Communication & Switches

Objectives:

- Understand that careful decisions must be made when designing a fiber optic link
- Define the term decibel and its use
- Be able to convert 1 dBm to optical power in mW
- Learn that optical power, losses and receiver noise in a fiber optic link can all be mathematically described or modeled
- Be aware that optical power and electrical bandwidth budgets are both considered during design or specification of a fiber optic link
- Learn the difference between analog and digital signals
- Learn that information can be transmitted with many different modulation schemes
- Understand why FM radio sounds better than AM radio
- Understand the differences between AM and FM
- Learn about cost versus performance issues in link design
- Set up and operate an AM and FM fiber transmission system
- Compare the functional differences between an operational AM and FM fiber link

Equipment you will need to complete this activity:

- 2 Fiber Optic Reference Guides
- 2 Video transceivers
- 2 120-VAC-to-14 VDC, 1-amp power adapters
- 1 3-meter fiber cable
- 1 10-meter fiber cable
- 1 ST Barrel Connector
- 1 AM/FM radio with batteries
- 1 Audio patch cord with 3.5 mm mono plugs on both ends

To complete this activity you must:

1. Review **Homework Assignment #6** with your lab group or partner and compare answers.
2. Read Chapter 10 in “*Fiber Optic Reference Guide*.”
3. Answer Questions 1 through 7 on **Worksheet #7**.
4. Complete **Lab Exercise #7**.
5. Complete **Homework Assignment #7**.

Homework Assignment #7:

Appendix E at the back of the *Fiber Optic Reference Guide* contains a list of fiber optic societies, conference sponsors and trade magazines. Review this list to familiarize yourself with the many industrial resources. Locate at least one magazine online and one future trade show or conference.

Go to a search engine on the web and locate at least one company that installs fiber optic cable in businesses or homes.



Photo 7. Installing fiber optic cable

Lab Exercise #7

In this lab you will observe one of the few weaknesses of optical fiber communications and learn how a digital transmission mode is used to overcome this weakness. You will start by sending an AM radio station signal from one transceiver to another through a 3-meter fiber cable. You will add a 10-meter fiber cable to the 3-meter length and observe (hear) the change in the audio signal at the other end. You will then replace the AM optical signal transmitted through fiber cable with an FM digital optical signal and observe how the signal at the receiver is independent of fiber length.

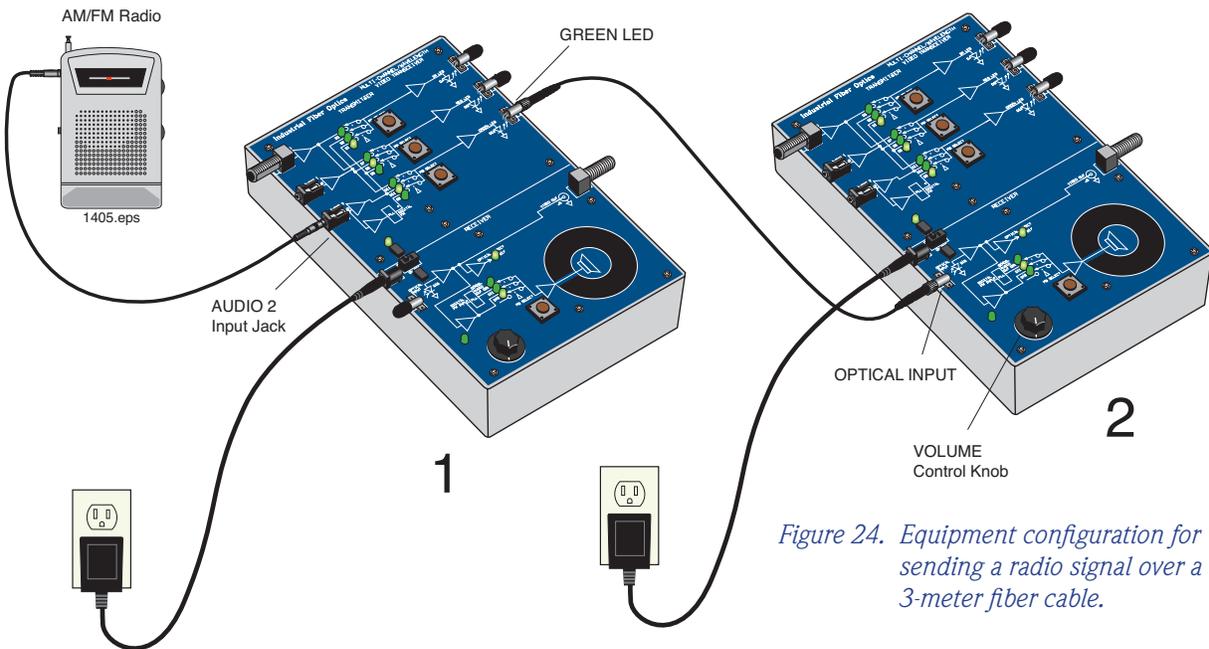


Figure 24. Equipment configuration for sending a radio signal over a 3-meter fiber cable.

Experiment A: AM signal transmission

1. Choose a flat, level location approximately 60 × 240 cm (2 × 8 feet) in size.
2. Your equipment set-up in this experiment should look like the diagram in Figure 24. You may wish to refer to this figure as you complete the following steps.

Transceiver 1

3. Insert the small end of the 120-volt Power Adapter cord into the power input jack on Transceiver 1.
4. Plug the 2-pronged end of the Power Adapter into a 120-volt wall outlet. Slide the On/Off switch to turn the Transceiver On.
5. Turn on the radio and tune it to a clear, static-free station (preferably an FM station).
6. Plug one end of the audio patch cord into the radio jack. Plug the other end of the patch cord into the AUDIO 2 jack on Transceiver 1.

7. Press the bottom momentary switch in the TRANSMITTER portion of Transceiver 1 until the LED labeled D10 is lit.
8. Attach one end of the 3-meter fiber cable to the GREEN LED on Transceiver 1.

Transceiver 1

9. Insert the small end of the 120-volt Power Adapter cord into the power input jack on Transceiver 2.
10. Plug the 2-pronged end of the Power Adapter into a 120-volt wall outlet. Slide the On/Off switch to turn the Transceiver On.
11. Attach the other end of the 3-meter fiber cable to the OPTICAL INPUT receptacle in the RECEIVER portion of Transceiver 2.
12. Press the momentary switch in the RECEIVER portion of the Transceiver until D19 is lit.
13. Adjust the VOLUME control on Transceiver 2 as required. The sounds from the radio station that you selected a few minutes ago should be coming from the speaker on Transceiver 2.

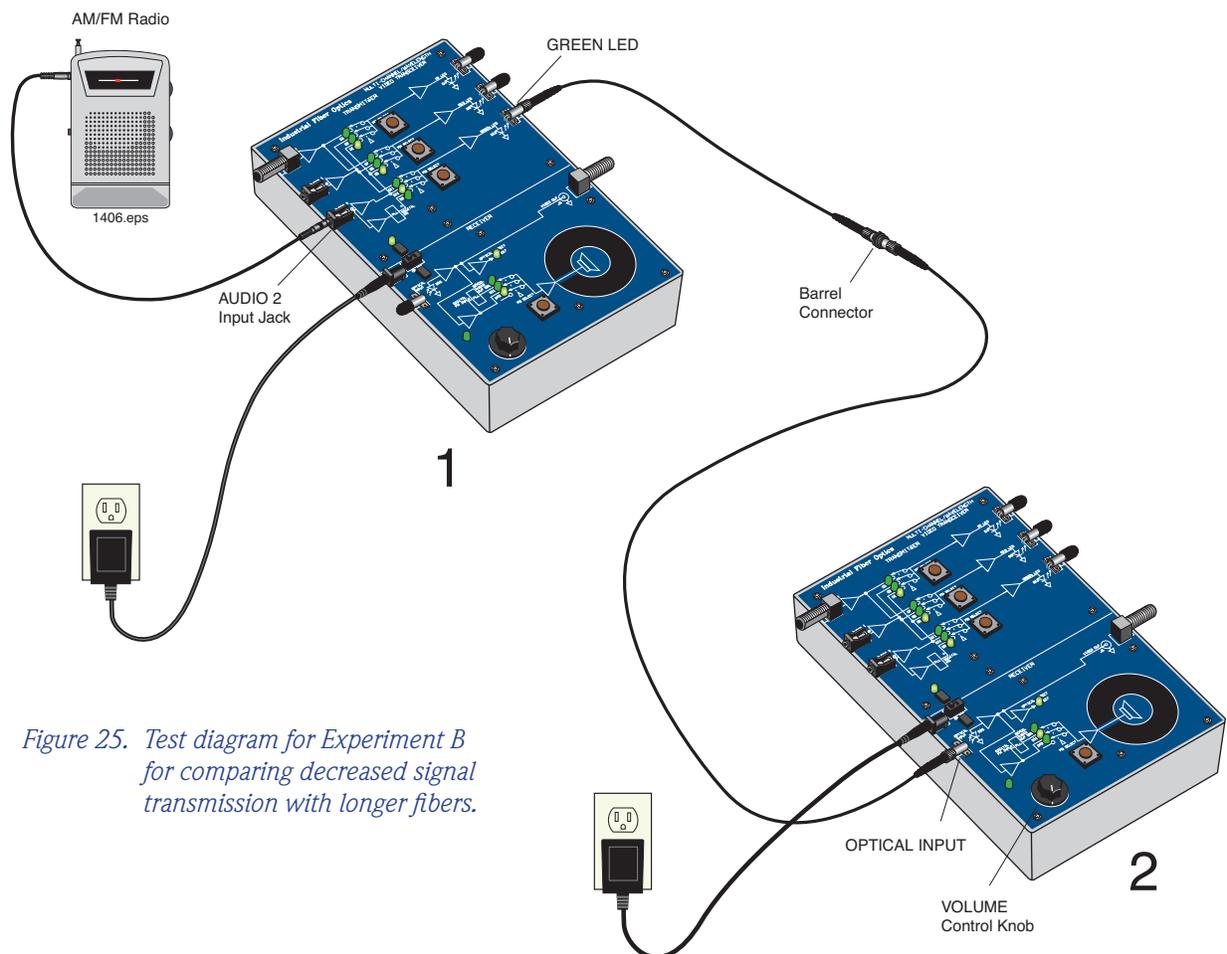
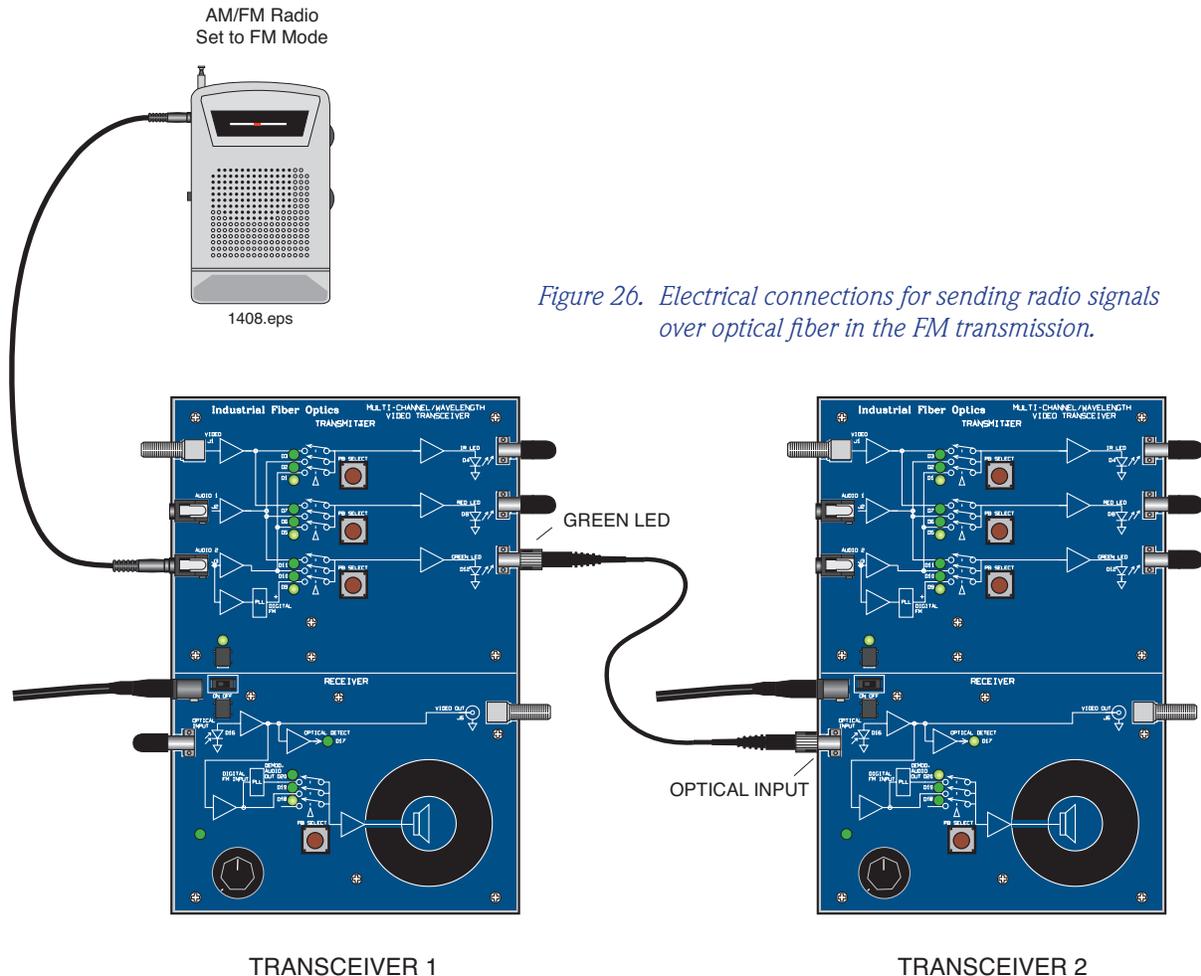


Figure 25. Test diagram for Experiment B for comparing decreased signal transmission with longer fibers.

Experiment B: *Extending the distance*

1. Do not change the volume or the station settings on the radio or adjust the VOLUME control knob on Transceiver 2. Doing so will negate the intent and results of this experiment.
2. Disconnect the 3-meter fiber cable from Transceiver 2 and connect the unattached end of the 3-meter cable to one side of the ST barrel connector.
3. Attach one end of the 10-meter fiber cable to the other side of the barrel connector.
4. Attach the remaining end of the 10-meter fiber cable to Transceiver 2's OPTICAL INPUT.
5. Your equipment set-up in this experiment should not look like the diagram in Figure 25.
6. You should notice that the audio sound originating from the AM radio being reproduced at Transceiver 2 is now much lower in volume. The reason for the reduced volume is attenuation through the optical fiber and the losses through the ST[®] barrel connector.



Experiment C: *Converting to FM/Digital*

In this experiment you will convert the optical signal transmission mode from simple AM to FM digital mode. To start you will establish a base line as you did in Experiment A with a 3-meter fiber cable. Then you will extend the distance by adding a 10-meter fiber cable and listen for change (if any) in the audio signal.

1. Disconnect the 3-meter fiber cable from the barrel connector and disconnect the 10-meter fiber cable from Transceiver 2. (Leave the barrel connector connected to the 10-meter fiber cable and set the 10-meter fiber cable aside.)
2. Connect the unattached end of the 3-meter fiber cable to the OPTICAL INPUT receptacle in the RECEIVER portion of Transceiver 2.
3. Press the bottom momentary switch receptacle in the TRANSMITTER portion of Transceiver 1 until the LED labeled D9 is lit.
4. Press the momentary switch in the RECEIVER portion of Transceiver 2 until D20 is lit.
5. Exiting the speaker on Transceiver 2 should be the sounds from the same radio station that you selected a few minutes ago. Adjust the VOLUME control on Transceiver 2 as required to produce a moderate sound level.

Experiment D: *Extending fiber length with digital signals*

1. Do not change the volume or the station settings on the radio or adjust the VOLUME control knob on Transceiver 2. Doing so will affect the accuracy of this experiment.
2. Disconnect the 3-meter fiber cable from Transceiver 2 and connect the unattached end of the 3-meter fiber cable to one side of the barrel connector, which is still connected to the 10-meter fiber.
3. Connect the remaining end of the 10-meter fiber to the OPTICAL INPUT receptacle on Transceiver 2.
4. You should notice very little change in sound from the speaker at Transceiver 2.
5. Unplug all electrical items and return all materials to their proper storage containers and locations.
6. Answer Question 11 on **Worksheet #7**.

Worksheet #7

Student: _____

1. A decibel is proportional to the ratio of two numbers to each other.
 - a) True
 - b) False

2. The basic unit of digital modulation is:
 - a) Zero
 - c) Two
 - d) A and B
 - e) None of the above

3. Key factors in designing a fiber optic link are:
 - a) Transmitter output power
 - b) Receiver optical sensitivity
 - c) Fiber attenuation
 - d) Operating wavelength
 - e) Fiber bandwidth
 - f) All of the above

4. Adding two numbers that have dimensions in dBs is analogous to:
 - a) Multiplying
 - b) Adding
 - c) Subtracting
 - d) The natural log of their division

5. A fiber optic link bandwidth cannot be estimated with mathematical equations and can be only determined empirically.
 - a) True
 - b) False

6. Many different factors such as bit error rate, bandwidth and linearity go into a fiber optic link.
 - a) True
 - b) False

7. Amplitude modulation (AM) schemes are the simplest modulation method to implement.
 - a) True
 - b) False

- 8.** 10 dB loss is equivalent to what percentage of power lost?
- a) 21%
 - b) 90%
 - c) 990%
 - d) 99%
- 9.** FM stands for what, as it applies to communications?
- a) Frequency modulation
 - b) Frequency multiplication
 - c) Faulty multiplexer
 - d) Federal Department of Memory
 - e) None of the above
- 10.** Frequency modulation schemes are ideally suited to fiber optic communications.
- a) True
 - b) False
- 11.** Write a paragraph about what you learned about AM transmission versus FM digital, including the advantages and disadvantages of each.

Activity #8

Expand & Network

Objectives:

- ❑ Review advantages of fiber optic systems
- ❑ Learn what issues are driving applications toward fiber optics
- ❑ List at least three major applications for fiber optic systems
- ❑ Be aware of critical issues such as cost that limit fiber optics in certain applications
- ❑ Be aware that telecommunications is the heaviest user of fiber optics to-date
- ❑ Observe that major applications of fiber optics have within them numerous smaller market subdivisions
- ❑ Complete the process of installing a fiber optic cable splice
- ❑ Measure the attenuation caused by a fiber splice

Equipment you will need to complete this activity:

- 2 Fiber Optic Reference Guides
- 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 3-meter fiber cable
- 1 2-meter fiber cable with ST connectors on both ends (one assembled in previous activity)
- 1 ST barrel connector
- 1 Fiber Optic Test Set

To complete this activity you must:

1. Review **Homework Assignment #7** with your lab group or partner.
2. Read Chapter 11 in “*Fiber Optic Reference Guide.*”
3. Answer Questions 1 through 6 on **Worksheet #8.**
4. Complete **Lab Exercise #7.**
5. Complete **Homework Assignment #8.**

Homework Assignment #8:

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 and electronics.

Estimate how many layers you would recommend to protect a splice for a transoceanic cable.



Photo 8. Fiber optics is often used to transmit data between microwave receivers and control stations to minimize the effects of EMI.

Lab Exercise #8

In this exercise we will join two fiber cable ends using a mechanical splice fastened by crimping. You will also manually apply index-matching gel to the fiber ends to reduce light losses in the fiber splice. After splicing you will test your fiber cable for losses.

Experiment A: *Baseline measurements*

1. Choose a flat, level table approximately 90 × 120 cm (3 × 4 feet) in size as your work area for this demonstration.
2. Turn on the Fiber Optic Test Set, rotate the Display Selector Switch to 200 μW and set the wavelength to 650 nm. With the protective caps on, turn the On/Off switch on. Adjust the LCD Display indicator so it reads “zero,” following the “Zeroing Procedure” in the Fiber Optic Test Set manual. You may not get it down to zero, in which case just make sure to subtract this offset number from the readings you get.
3. Remove the protective caps and press the LED ACTIVATION button.
4. Attach one end of the 3-meter fiber cable to the LED receptacle. Attach the other end of this fiber to one side of the ST barrel connector.
5. Attach one end of the 2-meter fiber cable you made in Lab Exercise #5 to the LED receptacle. Attach the other end of this fiber to the ST barrel connector.
6. Attach the other end of the fiber to the DETECTOR receptacle.
7. Record the reading from the Fiber Optic Test Set Table 1 of **Worksheet #8**.
8. Disconnect the fiber cable and turn the Fiber Optic Test Set off.

Experiment B: *Splicing a fiber cable*

1. 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 knife to heat about 15 minutes before use.
2. After the knife is warmed up, use it to cut the fiber cable on which you installed the ST connectors in Lab Exercise # 5. Cut the fiber about 1 meter (39 inches) from either end (this is about the midpoint of the fiber cable assembly).



Photo 9. Fiber optic cable installed in the fiber cutter for proper cutting.

3. Insert one of the cut fiber ends into the Professional Fiber Cutter through one of the center-most holes on the side farthest from the cutting blade as shown in Photo 9. Slide the fiber into either hole until 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.

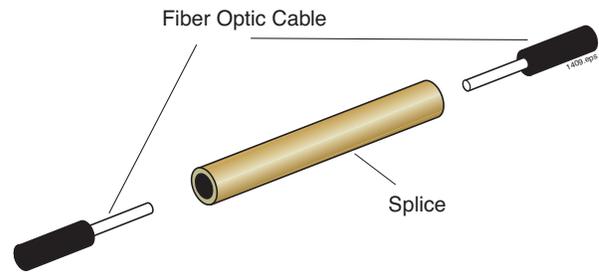
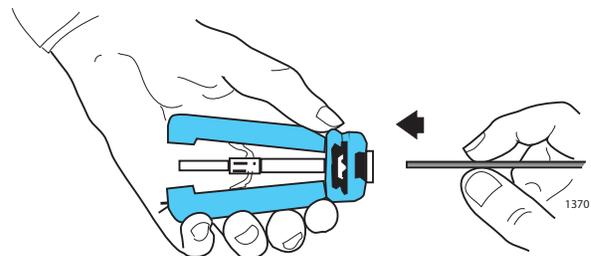


Figure 27. Capillary splice used in this activity with plastic optical fibers.

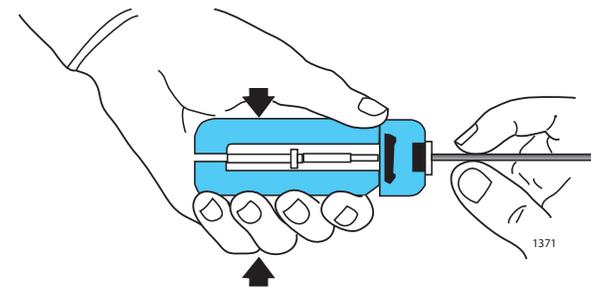
4. Unplug the Hot Knife.
5. The Fiber Optic Splice you will use in this activity is a capillary type. It is an aluminum cylinder with two precision holes drilled through the center axis. The smaller hole is drilled completely through, and is slightly larger than the cladding diameter of the 1000 μm optical 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.

6. 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.

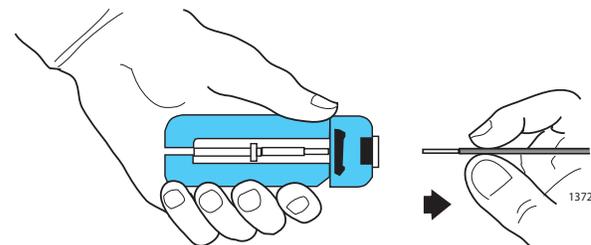
7. Insert the fiber cable through the hole (fiber guide) in the fiber stripper until the fiber end aligns with the ruler markings for 6.3 mm (1/4 inch) on one of the handles. **Note: This may be the shortest marked length on the stripper.**



8. Squeeze the handles of the fiber stripper fully closed for five seconds and then slightly release pressure on the handles.



9. 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).



10. 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.

Figure 28. Proper orientation and use of fiber cable and fiber stripper.

11. 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 aluminum Fiber Optic Splice until the fiber jacket seats.
12. You will use the 0.128 inch hex hole in the jaws of the crimping tool to crimp the splice onto the fiber cable. 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.
13. Make sure the fiber cable is still pushed completely into the splice as shown in Figure 29. 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.
14. 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 12 through 13.

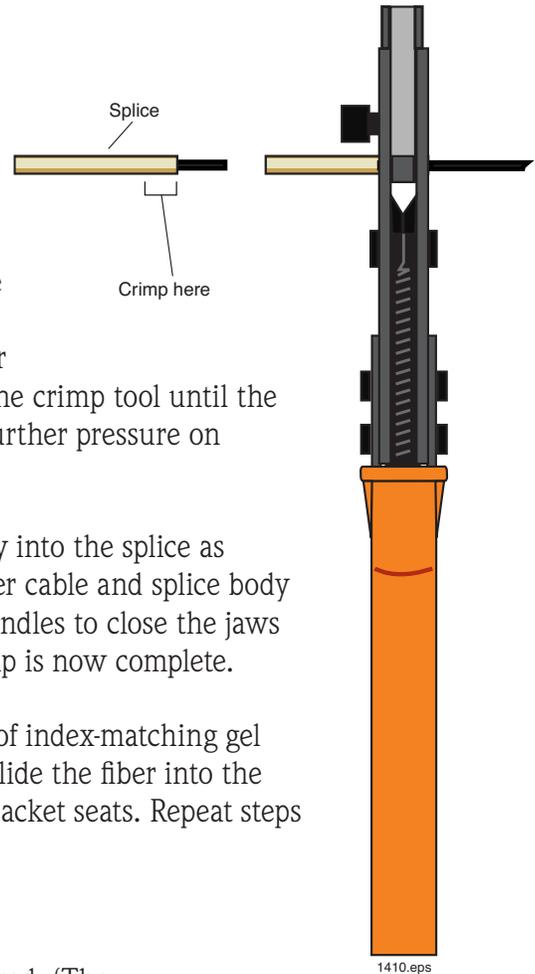


Figure 29
Alignment of the fiber capillary fiber splice with the fiber crimper for correct installation.

Experiment C: *Measuring loss in splice*

1. Turn on the Fiber Optic Test Set and zero as required. (The 3-meter fiber cable should still be attached to the Test Set's receptacle.)
2. Attach one end of the spliced fiber to the ST barrel connector. Attach the other end of the fiber to the DETECTOR receptacle.
3. Record the reading from the Test Set in Table 1 on **Worksheet #8**.
4. Disconnect the fiber cables from the Test Set and barrel connector. Replace all protective caps. Return all items to their proper storage locations.
5. Using the information in Table 1 of Worksheet #8, calculate the increase in loss of the two fibers after the splice was installed.
6. Unplug all electrical items and return all materials to their proper storage containers and locations.

Worksheet #8

Student: _____

1. List three advantages of fiber optics as compared to copper cabling.

2. The longer the operating wavelength in a fiber optic system:

- a) The greater the optical loss
- b) The less expensive it is to build
- c) The more taxes are paid
- d) The less the optical loss
- e) All of the above
- f) None of the above

3. CATV, which once was dominated by copper cabling, is now using some fiber optic technology.

- a) True
- b) False

4. LAN fiber optics systems may use fiber couplers to distribute signals.

- a) True
- b) False

5. List at least two applications of fiber optics in sensing and control.

Table 1. Output power measured from the optical fibers and calculation of loss in the splice.

CABLE	OPTICAL POWER μW	$\frac{P^{(3+2\text{splice})}}{P^{(3+2)}}$ $10 \cdot \log \left[\frac{P^{(3+2\text{splice})}}{P^{(3+2)}} \right]$
3-meter + 2-meter		
3-meter + 2-meter + splice		

Activity #9

Implementation

Objectives:

- ❑ Examine the major trends in optical fiber technology
- ❑ Realize how the Internet has affected communications networks and the future opportunity that fiber optics may provide
- ❑ See how the “chicken and the egg” concept has applied to fiber optics
- ❑ Review competing technologies and improving nature
- ❑ Examine the role that standards have played in fiber technology
- ❑ Understand that new technology is widely accepted only when it offers better performance and lower cost than existing products — rather than simply being a novelty
- ❑ Briefly describe some of the failures in optical fiber technology and the reasons for them
- ❑ Create a fiber optic wavelength division multiplexed system and demonstrate its application
- ❑ Measure the optical crosstalk of a wavelength division multiplexer

Equipment you will need to complete this activity:

- 2 Fiber Optic Reference Guides
- 3 Fiber Optic Video Transceivers
- 3 120-VAC-to-14-VDC, 1 Amp power adapters
- 2 1-meter fiber cables
- 1 1 × 2 Fiber Optic Coupler
- 2 AM/FM radios
- 2 Audio patch cords with 3.5 mm jacks on both ends
- 1 Fiber optic optical demultiplexer
- 1 Fiber Optic Test Set

To complete this activity you must:

1. Discuss **Homework Assignment #8** with your lab part or group.
2. Read Chapter 15 in “*Fiber Optic Reference Guide*”.
3. Answer Questions 1 through 7 on **Worksheet #9**.
4. Complete **Lab Exercise #9**.
5. Complete **Homework Assignment #9**.

Homework Assignment #9:

Consider applications for fiber optics that were not described in your readings or lab exercises. Think of at least three applications and be prepared to discuss them with your lab group the next time you get together

Review the **Pre-test** that you took at the beginning of this module, the summary at the end of each chapter that you read, and all of your worksheets.

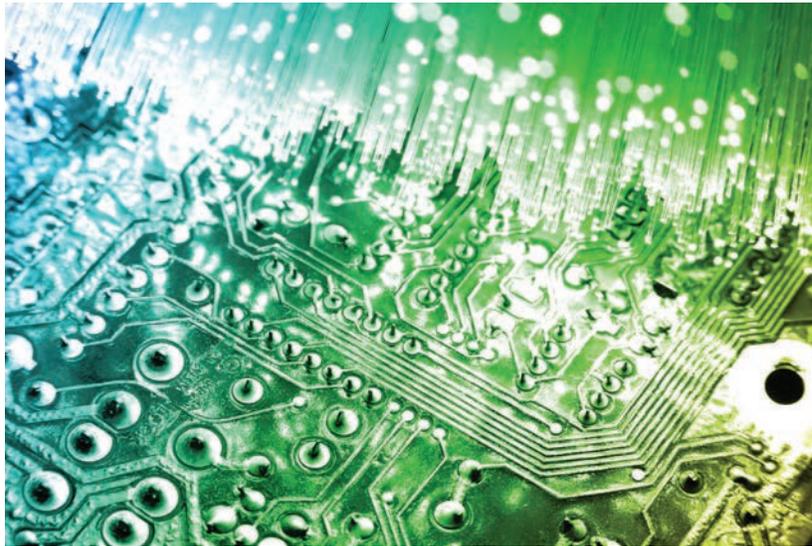


Photo 9. Optical circuits are integral to quantum computing.

Lab Exercise #9

In this activity you will set up fiber optic transceivers and a fiber optic coupler to transmit more than one wavelength of light down an optical fiber. On the other end of the fiber you will install an optical demultiplexer to split the two wavelengths of light apart. By special design we have a wavelength division multiplexer that demonstrates what is known as crosstalk in the optical wavelength bands. Crosstalk in an optical multiplexed network is a very critical design parameter. In one of the experiments you will hear and measure the effects of crosstalk.

Experiment A: *Transmitting two signals*

1. Choose a flat, level location approximately 90 × 240 cm (3 × 8 feet) in size as your work area for this experiment.
2. Your equipment set-up should look like Figure 30 when completed. You may wish to reference this figure as you complete the following steps.
3. On all three transceivers, insert the small end of a 120-Volt Power Adapter cord into the power input jack. Plug the 2-prong end of each Power Adapter into a 120-volt wall outlet or extension cord.

Transceiver 1

4. Turn one radio on and select an FM radio station. Set volume to a moderate level.
5. Turn the other radio on and set to another FM radio station. Do not set both radios to the same station. This experiment will not be successful if the radios are tuned to the same station.
6. Plug one end of an audio patch cord into the microphone jack of one radio. Plug the other end of the audio patch cord into the AUDIO 1 jack.
7. Plug one end of the remaining audio patch cord into the microphone jack of one radio. Plug the other end of the audio patch cord into the AUDIO 2 jack.
8. Remove the dust caps from both ends of a 1-meter fiber cable and attach one end to the RED LED receptacle on Transceiver 1's front panel.
9. Remove the dust caps from both ends of the other 1-meter fiber and attach one end to the GREEN LED receptacle.
10. Turn Transceiver 1 on by sliding the on/off switch to the left.
11. Press the middle momentary switch in the TRANSMITTER portion of Transceiver 1 until the LED labeled D6 is lit.
12. Press the bottom momentary switch in the TRANSMITTER portion of Transceiver 1 until the LED labeled D10 is lit.

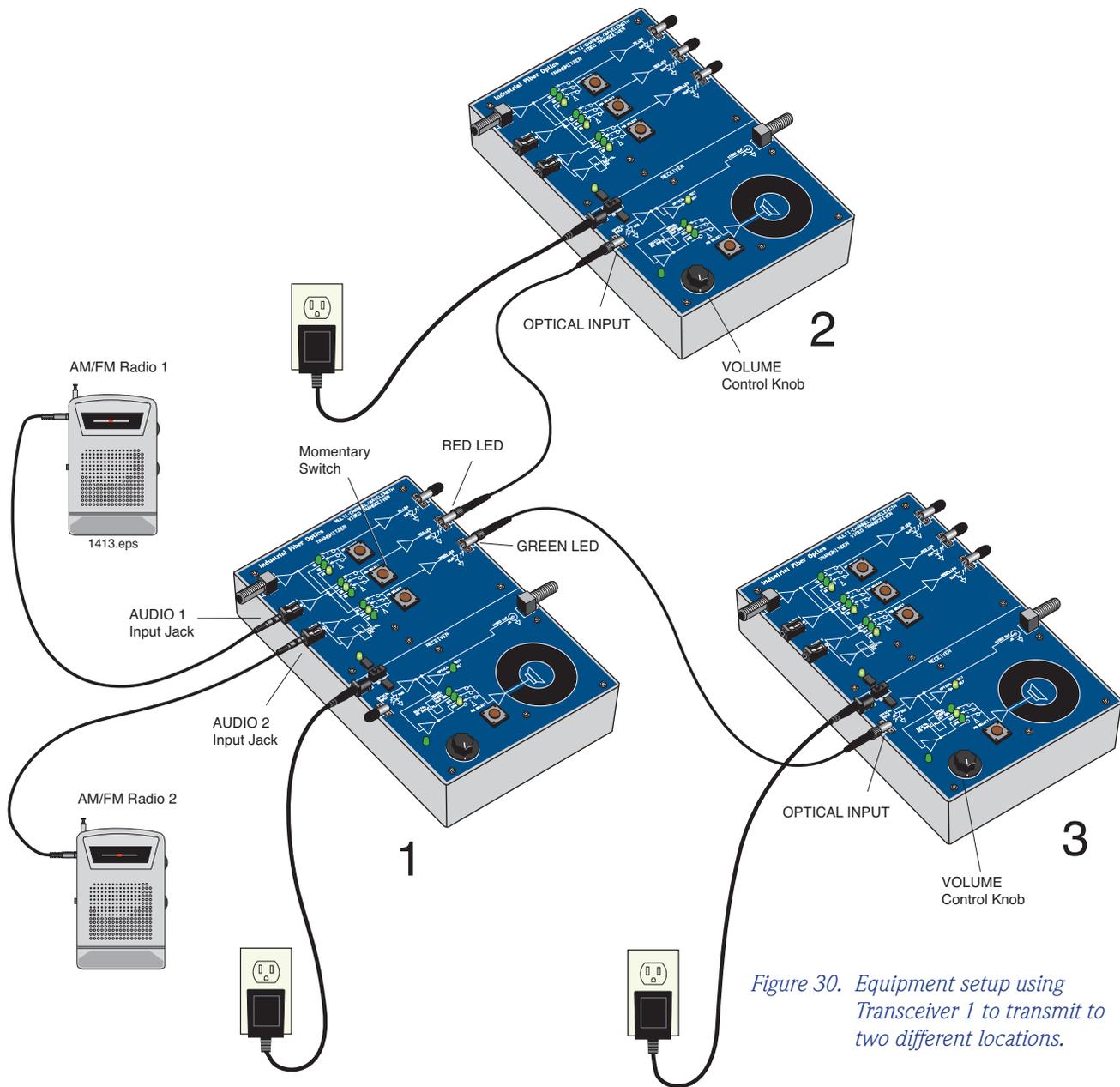


Figure 30. Equipment setup using Transceiver 1 to transmit to two different locations.

Transceiver 2

13. Remove the dust cap from the OPTICAL INPUT receptacle and attach the end of the 1-meter fiber cable originating from the RED LED receptacle on Transceiver 1.
14. Turn Transceiver 2 on by sliding the on/off switch to the left.
15. Press the momentary switch in the RECEIVER portion of Transceiver 2 until the LED labeled D19 is lit.
16. Turn the VOLUME control knob as required to produce a moderate sound level starting at the 12 o'clock position. From the speaker of Transceiver 2 you should now hear one of the radio stations.

Transceiver 3

17. Remove the dust cap from the OPTICAL INPUT receptacle of Transceiver 3 and attach the end of the 1-meter fiber cable originating from the Green LED receptacle.
18. Turn Transceiver 3 on.
19. Press the momentary switch in the RECEIVER portion of Transceiver 3 until the LED labeled D19 is lit.
20. Turn the VOLUME control knob to the 12 o'clock position. You should hear the second radio station's sounds from the speaker of Transceiver 3.

Experiment B: *Mixing the data and optical signals*

1. In this experiment you will combine the optical signals from the red and green LEDs with a fiber coupler. You will then listen at one of the transceivers for the combined signals. Your equipment set-up should look like Figure 31 when assembled properly.
2. Disconnect both 1-meter fiber cables from the transceivers and set them aside for the time being.
3. Take the end of the 1 × 2 fiber coupler that has only a single fiber and attach its ST[®] connector to the OPTICAL INPUT receptacle on Transceiver 3.
4. Take the remaining fibers from the 1 × 2 fiber coupler and attach to the red and green LED receptacles on Transceiver 1 as shown in Figure 31.
5. Listen to the sounds coming from the speaker of Transceiver 2. You should hear the combination of the two radio stations from Experiment A. As you can hear, the photodetector at Transceiver 3 has no way of separating the two wavelengths coming from Transceiver 1. This lack of selectivity has little practical application in a real fiber optic network.

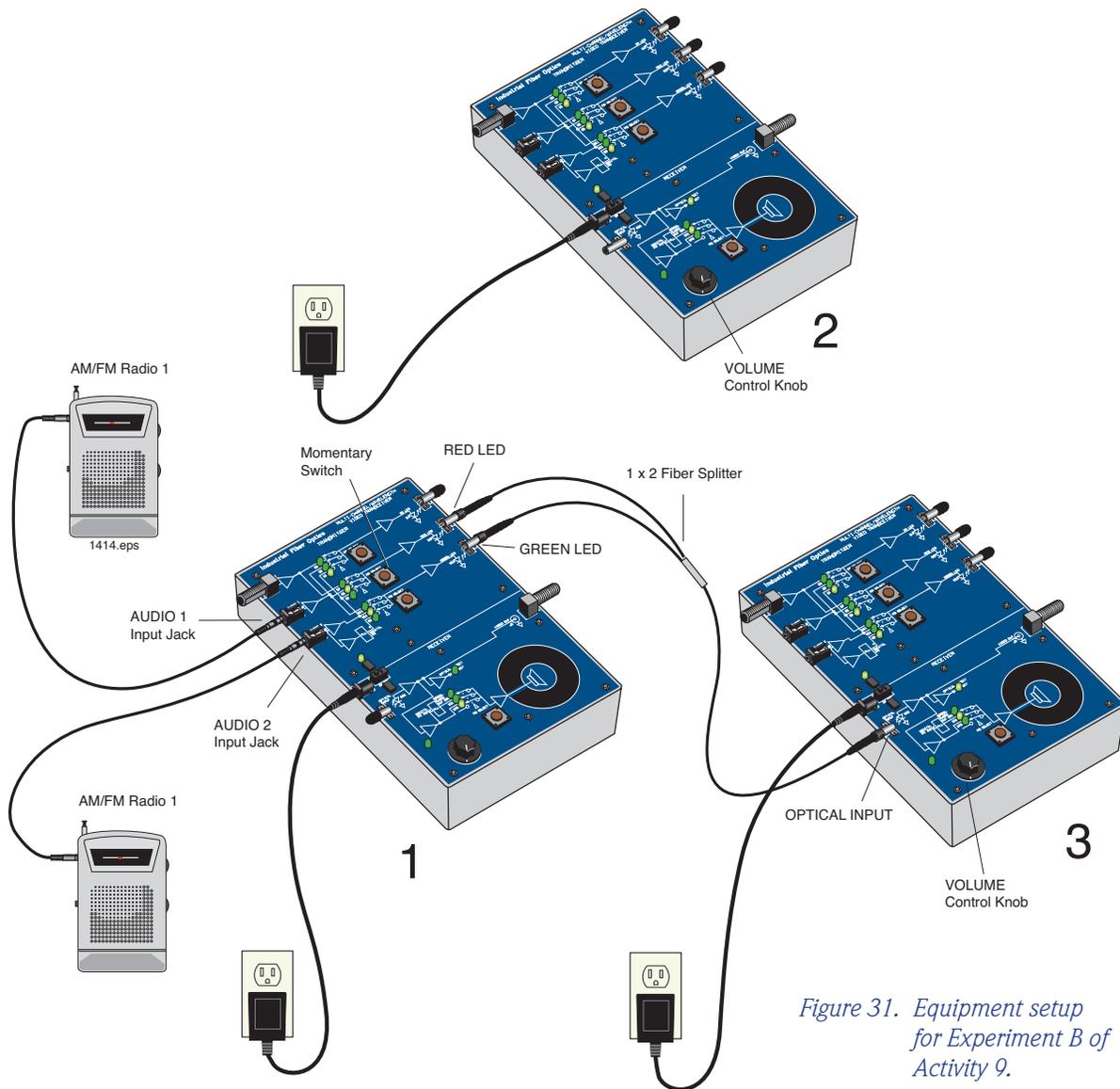


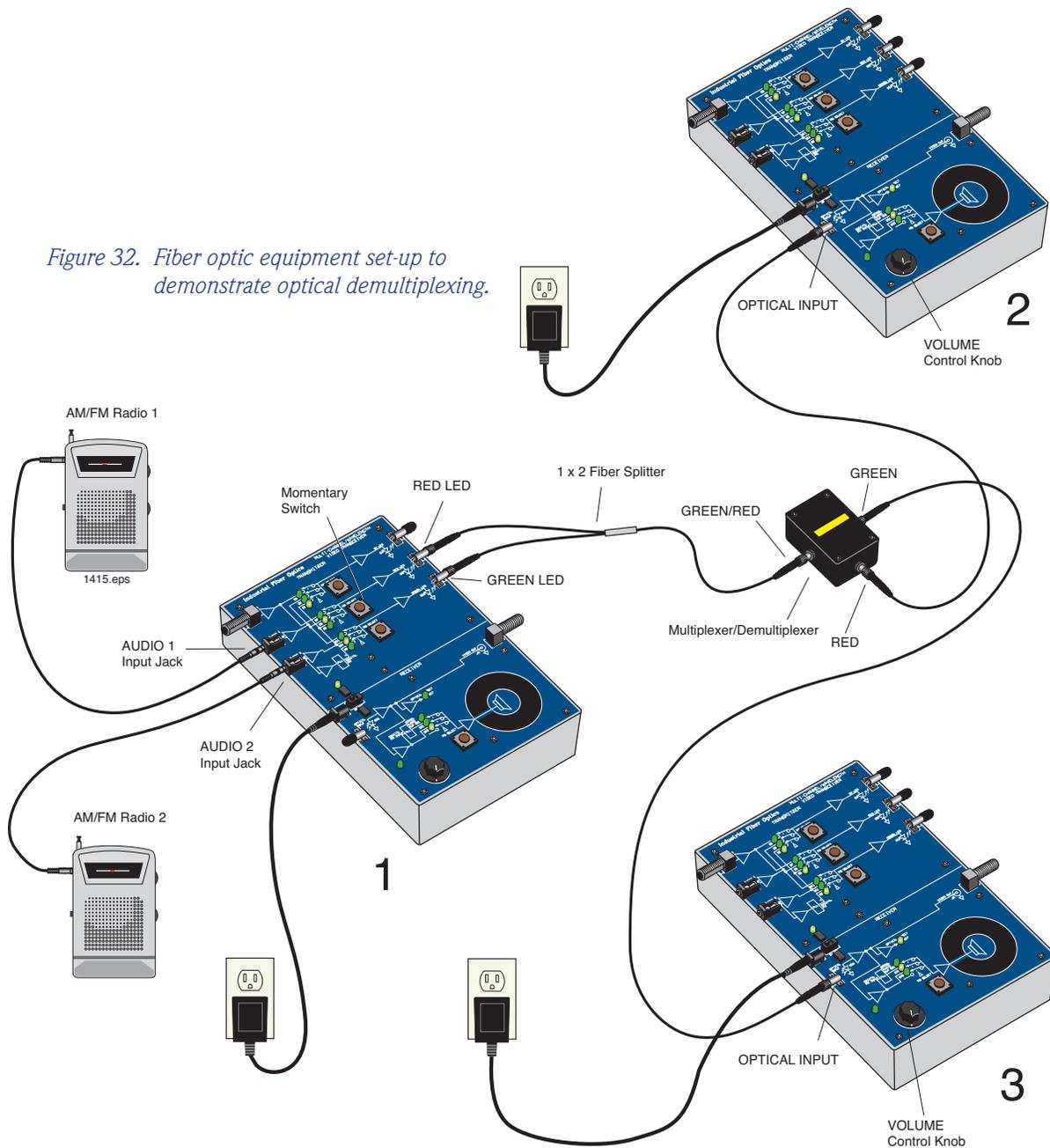
Figure 31. Equipment setup for Experiment B of Activity 9.

Experiment C: Demultiplexing the optical signals

In this experiment you will install an optical multiplexer/demultiplexer and see how it separates the RED and GREEN wavelengths from those mixed in the 1×2 fiber coupler.

1. Your equipment set-up should look like Figure 32 when completed. You may wish to reference this figure as you complete the following steps.
2. Disconnect the fiber attached to receiver input of Transceiver 3. Attach it to the ST[®] receptacle on the multiplexer/demultiplexer marked GREEN/RED.
3. Connect one end of the 1-meter fiber cable set aside from Experiment A to the ST[®] receptacle labeled “RED” on the demultiplexer. Connect the other end to the OPTICAL INPUT receptacle of Transceiver 2.

Figure 32. Fiber optic equipment set-up to demonstrate optical demultiplexing.



4. Connect one end of the remaining 1-meter fiber cable to the ST receptacle labeled “GREEN” on the demultiplexer and the other end to the OPTICAL INPUT receptacle of Transceiver 3.
5. Because of losses in the connections, the sounds from the speakers will be lower and you will need to increase the speaker volume at both transceivers. It should not be necessary to adjust the volume of either radio. The station you selected on the radio connected to AUDIO 1 should now be playing on Transceiver 2. The station you selected on the radio connected to AUDIO 2 should be playing on Transceiver 3. If you do not hear a different radio station at Transceiver 2 and 3, compare your equipment set-up to Figure 32 for errors.

Experiment D: *Measuring the optical crosstalk*

1. Disconnect the fiber attached to the red LED of Transceiver 1.
2. Increase the volume of Transceiver 2. At a very low level you should hear the same radio station that is present at Transceiver 3. This is caused by green LED light that is “leaking” over to the RED side on the optical demultiplexer. This leakage is called crosstalk. This is a very important parameter in fiber optic systems. In a very high-quality audio system this crosstalk would be not just an oddity, but could cause degradation of a desired signal. Think of how this might affect music with quiet passages that could be overwhelmed by louder music from another station.
3. Look into the port on the demultiplexer labeled RED.
4. Answer Question 7 on **Worksheet #7**.
5. Disconnect the fibers from Transceivers 2 and 3. Turn off both radios and remove the audio patch cords from the transceivers and radios.
6. Turn on the Fiber Optic Test Set, rotate the Display Selector Switch to 20 μW and set the wavelength selection switch to 650 nm. With the protective caps on, turn the On/Off switch on. Adjust the LCD Display indicator so that it reads “zero,” following the “Zeroing Procedure” in the Fiber Optic Test Set manual. You may not get it down to zero, in which case just make sure to subtract this offset number from the readings you get.
7. Attach the 1-meter fiber attached to the ST port on the demultiplexer labeled “RED” to the Test Set photodetector as shown in Figure 33.
8. Record the reading from the Fiber Optic Test Set display in Table 1 of **Worksheet #9**.
9. Detach the fiber cable originating from the demultiplexer red port from the test set photodetector. Attach the fiber from the ST[®] port labeled “Green” to the test photodetector.
10. Record the reading from the Fiber Optic Test Set display in Table 1 of **Worksheet #9**.
11. Disconnect all fibers and replace their dust caps. Replace all dust caps on the Fiber Optic Test Set, the demultiplexer and the Transceivers. Unplug all the power adapters and return all items to their proper storage location.
12. Answer Questions 8 through 9 on **Worksheet #9**.

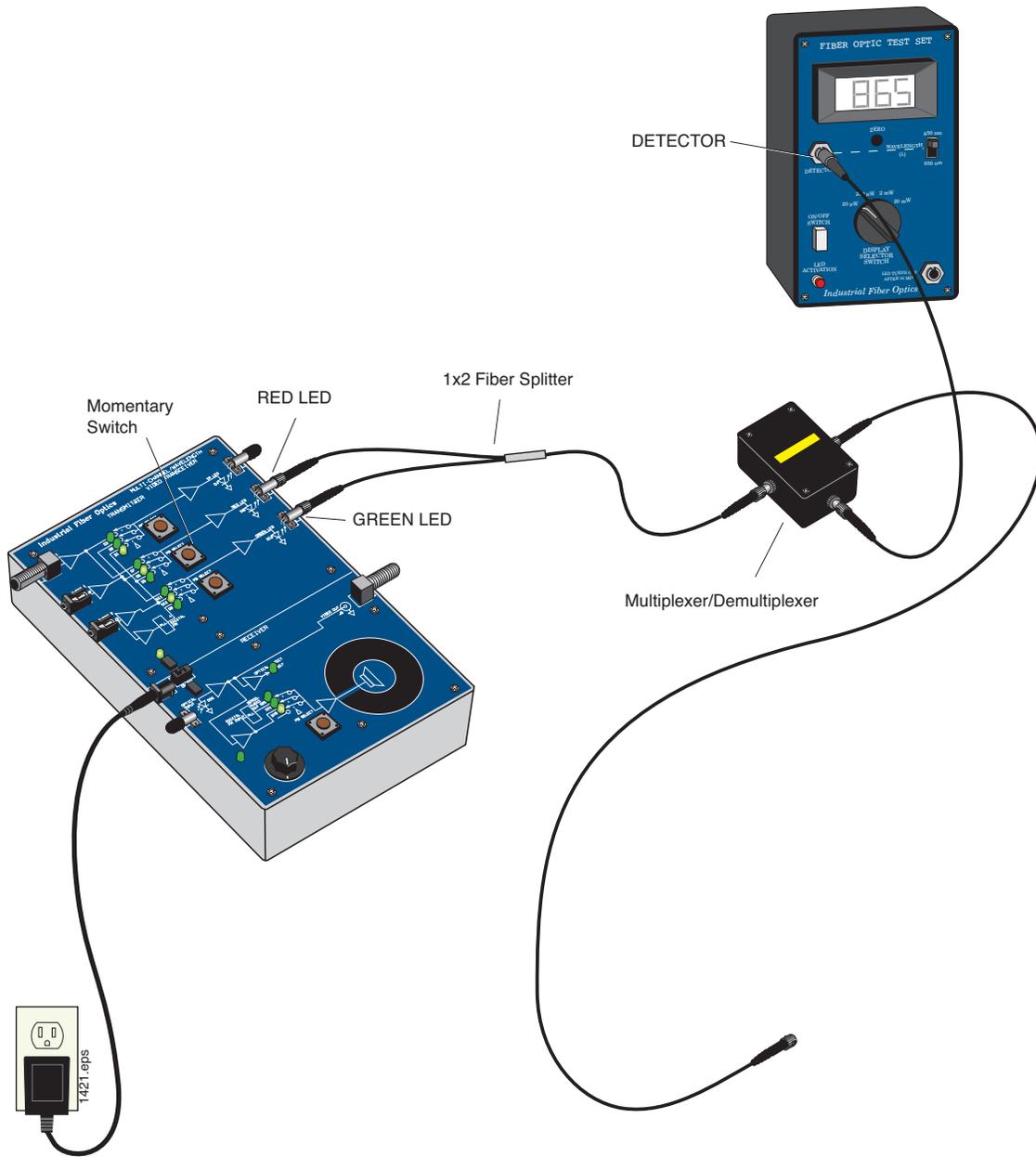


Figure 33. Measuring the optical power leaking through the optical demultiplexer.

Worksheet #9

Student: _____

1. List at least three trends in fiber optics

2. Wavelength division multiplexing is used only by the military.
 - a) True
 - b) False

3. In the CATV industry fiber optics was chosen because it provided:
 - a) Lowest cost
 - b) Best solution
 - c) Longest distance
 - d) Tax credits offered by the government
 - e) A and C
 - f) A and B
 - g) All of the above
 - h) None of the above

4. Fiber optic components are (choose the answer that best completes this sentence):
 - a) Increasing in cost every year
 - b) Staying about the same in cost
 - c) Decreasing in cost each year

5. Fiber optics technology is in the evolutionary stage rather than revolutionary.
 - a) True
 - b) False

6. Integrated optics will have no role in future fiber optic applications.
 - a) True
 - b) False

7. What color of light do you see when you look into the port on the demultiplexer labeled RED? Why?

Table 1. Output power measured from the optical fibers and calculation of loss in the splice.

PORT	OPTICAL POWER μW	$\frac{p^{(red)}}{p^{(green)} + P^{(red)}}$ $10 \cdot \log \left[\frac{p^{(red)}}{p^{(green)} + p^{(red)}} \right]$
Red		
Green		
Crosstalk		

8. What have you learned about optical mutliplexers?

9. Does it surprise you that this small amount of crosstalk resulted in the audio signal being as loud as it was? Why?

Activity #10

Wrap Up

Objectives:

- ❑ Discuss with your lab group future fiber optic applications
- ❑ Review unanswered questions to prepare you for the final test
- ❑ Final inventory or accounting of all the items in this module.
- ❑ Evaluate the knowledge you have gained through reading assignments, special project and lab exercises

Equipment you will need to complete this activity:

- All the components that are part of this Advanced Communications and Networking Module.

To complete this activity you must:

1. Discuss with your lab partner or group your new knowledge of fiber optic applications.
2. Review any unresolved questions that you have as a result of reviewing the **Pre-test** and **Worksheets 1 through 9** with your instructor.
3. Inventory all items in this module by going to the following page, where you will complete column 3 in **Table 2**.
4. Complete the **Final Test** furnished by your Instructor.
5. Turn in your complete **Final Test** for grading.

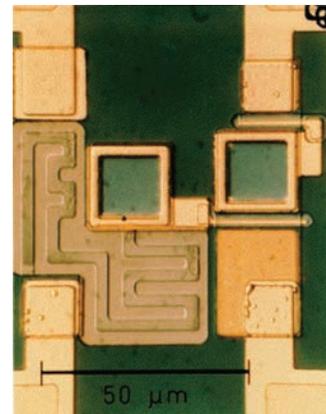


Photo 10. High-magnification view of microelectronics circuits used in fiber optic receiver circuits.

Lab Exercise #10

Table 2. Inventory Sheet for Lab Exercise 10.

<i>Description</i>	<i>Quantity</i>
Fiber Optic Video Transceiver Modules	3
120-VAC-to-14-VDC 1-Amp power adapters	3
Photonics Wall Chart	1
Infrared Sensing Card	1
Scale	1
1-meter 980/1000 μm plastic core fiber cables with ST/ST connectors on both ends	2
3-meter 980/1000 μm plastic core fiber cables with ST/ST connectors on both ends	1
10-meter 980/1000 μm plastic core fiber cables with ST/ST connectors on both ends	1
Kimwipes [®]	1
Microphones	2
DC motor with mount	1
120-VAC-to-12-VDC 500 mA power adapter	1
Micro-Strip [®] fiber stripper	1
ST polishing puck	1
Fiber optic crimp tool	1
Professional Fiber Cutter	1
ST Barrel Connectors	1
Tool Box	1
Fiber Optics Test Set	1
1 x 2 fiber coupler or splitter	1
2-meter fiber cable with ST connectors on both ends, and splice in the middle	1
Sheet of 2000 grit sandpaper (gray)	1*
Sheet of 3 μm polishing film (pink)	1*
Audio patch cord with 3.5 mm mono plugs	2
Hot Knife with blade attachment and stand	1

Table 2. Inventory Sheet for Lab Exercise 10 Continued

<i>Description</i>	<i>Quantity</i>
Glass polishing plate	1
Fiber optic inspection microscope	1
Polishing slurry (130 ml)	1
Vial of index-matching gel	1
AM/FM radio with 3 AA batteries	2
Coaxial cables with Type F connectors	2
10 meters of coax	1
Optical Demultiplexer	1
Fiber Optic Reference Guides	2
Teachers Curriculum Manual	1
Student Curriculum Manuals	2

** The number indicated is the minimum quantity needed to complete the activities in this module. There may be more or less than the number indicated when this product is new or re-supplied.*

