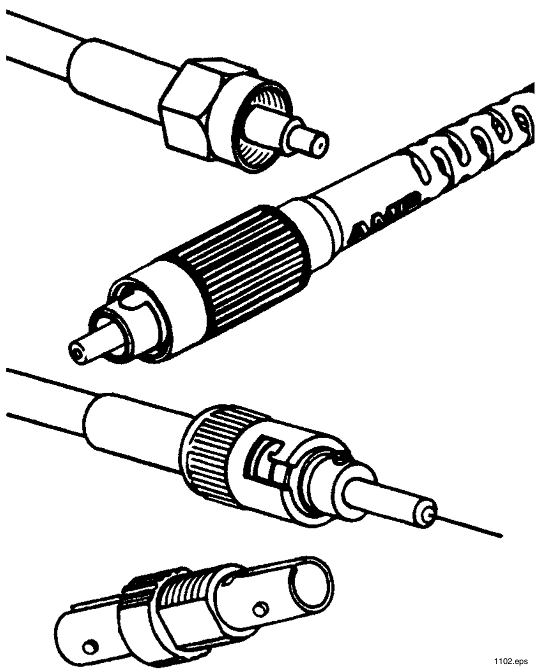
Fiber Optic Lab Manual

Fifth Edition



INDUSTRIAL FIBER OPTICS

*

* * *

* * * * *

TABLE OF CONTENTS

Introduction

This manual is an action-filled guide for completing nine stimulating activities related to fiber optic communications. The manual is compatible with most classroom texts and is ideal for creating a lab to go with almost any vocational or secondary-education fiber optics course.

For best results we suggest using the "Hardware Kit" from Industrial Fiber Optics that contains all the necessary fiber optic, opto-electronic and electronic components required to complete these nine activities. To achieve the best results and understand the electronics terminology here, we suggest that you have a minimum of one year of electronics experience. Please read the manual carefully when completing these activities.

Upon completing the activities, you will have gained a better understanding of fiber optics from having worked with real fiber optics hardware and learning techniques, and from gaining hands-on experience. In "real-life" practice, the components may change, but the principles remain the same.

As soon as you receive this product, inspect it and the shipping container for damage. If any damage is found, immediately refer to the section of this manual entitled Shipment Damage or Missing Parts Claims.

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 and products refer to ***http//www.i-fiberoptics.com*** *on the worldwide web.*

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

Sincerely,

Industrial Fiber Optics

ACTIVITY I: COMPONENT IDENTIFICATION

In this activity you will identify the components in the IF-LMH kit. **Table 1.1** is a list of components. Part numbers have been included where necessary.

Table 1.1 IF-LMH Parts list.

General Description	Industry Standard P/N	IFO Reorder P/N	Quantity in kit
Red LED (T 1 3/4 pkg.)		750050	1
Red LED (Blue w/pink dot)		IF-E96E	1
Green LED (Blue w/white dot)		IF-E93A	1
Infrared LED (Blue w/copper dot)		IF-E91A	1
Sidelooker Device Housing (black)		410509	1
Cinch Nut (black)		410512	1
Penlight, 2-volt 60 mA		790005	1
Photodiode (Sidelooker package)	OP950	770065	1
Phototransistor (Sidelooker package)	LPT80A or PT1928	770025	1
Phototransistor (T 1 3/4 pkg.)	SHF300	770100	1
Photodarlington (Sidelooker package)	OP560	770050	1
TTL open-collector hex inverter	74LS05	730055	1
CMOS hex inverter	4069	730035	1
Operational amplifier	LM741	720075	1
General-purpose NPN transistor	2N3904	710040	2
General-purpose NPN transistor	PN2222	710025	1
High-speed PNP transistor	2N4403	710057	1
Switching diode	1N914	710010	3
0.01 µf Mylar® capacitor		640035	1
0.001 µf ceramic capacitor		640030	1
Fiber optic splice	228051-1	2280511	1
Fiber optic retention clip	228046-1	2280461	2
Fiber optic simplex receptacle	228042-1	2280421	1
Fiber optic simplex assembly	228087-1	2280871	2
1000 µm core plastic optical fiber		IFCE1000	3 meters
Vinyl tubing 3/16 inch I.D.		310005	15 cm
1/4-watt carbon film resistors	See Table 1.2		50
2000-grit polishing paper		290010	1
3 mm polishing film		290024	1
Eye dropper		860010	1

Procedure

1. Place all the electrical and fiber optic components contained in the kit on the left side of a work space with a flat surface such as a table approximately 60 x 90 cm (2 x 3 feet) in size. (The left side will contain unidentified components; on the right side will be the identified components.)

2. Locate the 3-meter length of 1000 µm core plastic optical fiber and move it to the right side of your work space.

3. Identify the 15 cm (6 inches) length of vinyl tubing. It has an outside diameter of 7.5 mm (5/16 inch) and an inside diameter of 4.8 mm (3/16 inch). Move it to the right side of your workspace.

4. Identify the 2000-grit polishing paper. It is approximately 50 x 50 mm (2 x 2 inches) in size, shiny black on the front side and medium-gray on the back. Identify the 3 µm polishing paper. It will be light pink in color and approximately 50 x 50 mm (2 x 2 inches) in size also. Set both items to the right.

5. Select the red LED using **Figure 1.1** to aid in its identification. The red LED will emit red light when electrical current flows through it. Place the LED to the right side of your workspace.

6. Identify the 3 fiber optic LEDs in the kit, which are the devices in a blue device housing. They are red, green and infrared light-producing. An electrical pin diagram of these devices can be seen on page 49. The red LED has a pink dot on the device housing, the green has a white dot, and the infrared has a copper dot.

7. Identify the 2-volt penlight. It looks like a small incandescent bulb and is approximately the same size as the LEDs. A diagram of the penlight is shown in **Figure 1.2**.

8. Identify the 3 sidelooker style photodetectors in the kit. They are a photodiode, phototransistor and photodarlington. A diagram of these devices can be seen on page 49. The photodiode has a blue stripe on the back, the phototransistor has a black stripe on the back and the photodarlington has no marking.

9. Identify the SFH300 phototransistor which is in a T 1 3/4 package. See page 49 for diagram of this part.

10. The three integrated circuits (ICs) contained in this kit are shipped in a plastic tube for protection. A 14-pin DIP IC is shown in **Figure 1.3**. Part numbers are found on the topside of the ICs. Identify each of the generic parts numbers LM741, 4069, and 74LS05. Return the ICs to their protective tube and set them to the right.

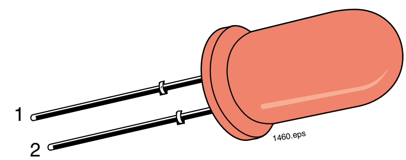


Figure 1.1 Red LED.

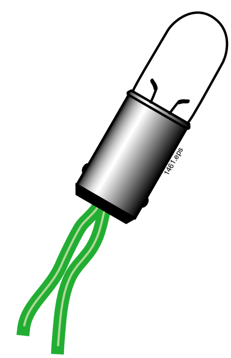


Figure 1.2 The 2-volt penlight.

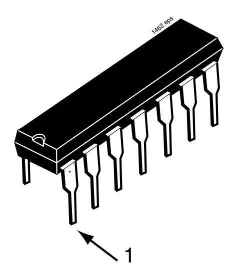


Figure 1.3 A 14-pin integrated circuit (IC) in a dual-in-line-package (DIP).

11. Identify the three different transistors in the kit. All three transistors are packaged in what is commonly called a TO-92 case. A TO-92 package is shown in **Figure 1.4**. On the flat side will be markings or lettering. Read the markings on each device and identify their part numbers in **Table 1.1**. When all three transistors have been identified, set them to the right side of your work space.

12. Find the three 1N914 silicon switching diodes. They are axial two-leaded devices, slightly smaller than a resistor and have a copper base color with black band. The lead closest to the black band is the device's cathode.

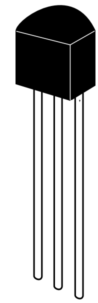


Figure 1.4 A TO-92 case.

13. Locate the fiber optics splice (P/N 228051-1), simplex receptacle (P/N 228042-1), two retention clips (P/N 228046-1), black sidelooker device housing (410510), black cinch nut (410509) and two simplex assemblies (P/N 228087-1). Use the component diagrams shown in **Figure 1.5** to aid in identification.

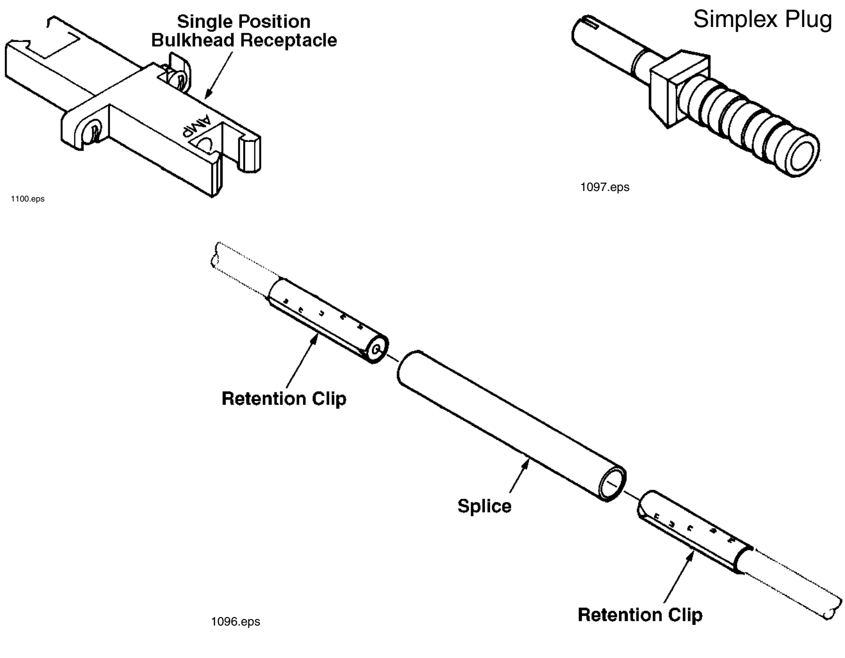


Figure 1.5 Simplex plug assemblies, splices and fiber retention clips found in the IF-LMH kit.

13. Identify the 100 pf ceramic disk capacitor (light brown in color) and the .01 Mylar® capacitor, which has a green body. The Mylar® capacitor is shown in **Figure 1.6**.

14. The resistors listed in **Table 1.2** are contained in a 2 **x** 4 inch reclosable plastic bag. Identify each by color and quantity.

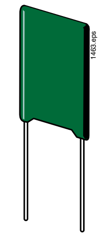


Figure 1.6 .01 μf Mylar® capacitor.

Table 1.2 Color code bands for resistors in kit.

Description	Quantity	Color Code
47 Ω	2	Yellow Purple Black
100 Ω	4	Brown Black Brown
150 Ω	2	Brown Green Brown
220 Ω	2	Red Red Brown
390 Ω	2	Orange White Brown
470 Ω	2	Yellow Purple Brown
560 Ω	2	Green Blue Brown
820 Ω	2	Gray Red Brown
1 k Ω	4	Brown Black Red
2.2 k Ω	2	Red Red Red
3.9 k Ω	2	Orange White Red
4.7 k Ω	2	Yellow Purple Red
5.6 k Ω	2	Green Blue Red
8.2 k Ω	2	Gray Red Red
10 k Ω	4	Brown Black Orange
22 k Ω	2	Red Red Orange
39 k Ω	2	Orange White Orange
47 k Ω	2	Yellow Purple Orange
56 k Ω	2	Green Blue Orange
82 k Ω	2	Gray Red Orange
100 k Ω	4	Brown Black Yellow

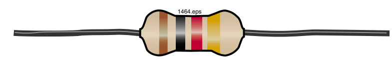


Figure 1.7 Illustration of a typical resistor.

ACTIVITY II: MAKING A LIGHT GUIDE

Overview

In this activity you will construct a simple light guide using water and a length of vinyl tubing. The water and vinyl tubing will act as the core, while air will act as the cladding or boundary layer. The experiment will demonstrate how effective even a simple light guide is for coupling energy from a light source to a detector. You will also observe how the light guide can carry light “around a corner” with relatively little loss compared to when light travels in a straight line.

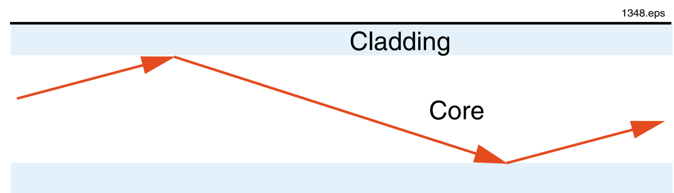


Figure 2.1 Cross section of an optical fiber with a light ray traveling down the core.

Materials Required

Red LED	**Paper towels***
Phototransistor (T 1 ^{3}/4 package)	**Small, shallow, water-tight pan***
Vinyl tubing, 15 cm	**Miscellaneous electrical test leads***
150 Ω resistor	**Multimeter***
Eye dropper	**Distilled Water***
	Solderless breadboard*
Single-edge razor blade or sharp knife*	**Variable voltage power supply***

* Not included in the IF-LMH kit. For suggestions on recommended test equipment see **APPENDIX**.

Procedure

1. Using a single-edge razor or sharp knife trim a small amount from the ends of the vinyl tubing so that they are clean and square (90 degrees).
2. Insert the red flat-topped LED into one end of the vinyl tube. Be sure to insert the LED all the way into the tubing to ensure a tight fit.
3. Insert the phototransistor (T 1 ^{3}/4 package) into the other end of the vinyl tubing. Push the phototransistor in completely for a tight fit.
4. Turn on the variable voltage power supply and adjust the output to + 5 volts DC.
5. Set the function of the multimeter to read "Current" on the 2 mA scale.
6. On your solderless breadboard connect the electrical circuits as shown in **Figure 2.2**. Use the device diagrams found in the **APPENDIX** to identify anode and cathode on the LED, and collector and emitter on the

phototransistor. (The phototransistor and multimeter circuit will function as an inexpensive radiometer to evaluate the light guide. This type of circuit photodetector/multimeter) will be used as a radiometer throughout this manual.)

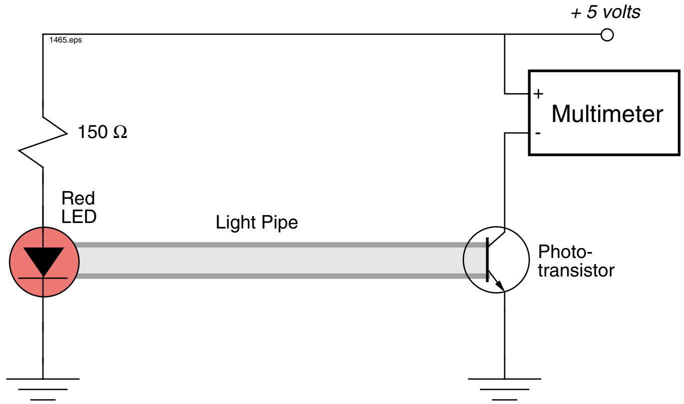


Figure 2.2 Test circuits for evaluating light guide.

7. Light should be visible from the red LED at this point. If not, check the electrical connections to the LED.

8. The multimeter should indicate current flow through the phototransistor. If not, check the electrical connections and correct polarity for the phototransistor.

To obtain best results in this activity, you may need to dim the room lights or cover the light guide with a dark cloth or box. This will minimize the chance of ambient light being captured by the phototransistor, and improve the accuracy of your measurements.

9. In **Table 2.1** record the current measured by the multimeter (LED ON).

10. Disconnect the 150 Ω resistor from the + 5 volt power supply, which will turn the LED off.

11. In **Table 2.1** record the current measured by the multimeter through the phototransistor with the LED off.

Table 2.1 Empirical data for 15 cm (6-inch) light guide with air core.

LEDs	LED OFF	LED ON
Red		

12. Remove the vinyl tubing, red LED and phototransistor as an assembly from the solderless breadboard. Pull the red LED from the vinyl tubing (leaving the phototransistor in), and slowly fill the vinyl tubing with distilled water using the eyedropper. Do not hurry when filling the tubing; try to put in a drop at a time to avoid leaving any air bubbles in the tubing. Bubbles will scatter some of the light being transmitted through the water.

13. Re-insert the red LED in the vinyl tubing and push in completely for a tight fit to prevent water from leaking out. Make certain there are no air bubbles inside the tubing between the red LED and phototransistor. Refill as necessary during the experiment if any water leaks out.

14. Re-connect the red LED and phototransistor to the circuit on the solderless breadboard. Re-connect the 150 Ω resistor to the +5 volt power supply. In **Table 2.2** record the current measured by the multimeter (LED ON).

15. Disconnect the 150 Ω resistor from the + 5 volt power supply, which will turn the LED off. In **Table 2.2** record the current measured by the multimeter through the phototransistor with the LED off.

16. Gently make a 90-degree bend in the light guide and repeat steps 14 and 15. Be careful to not let any water leak out from the light guide — refill if necessary. Record the data in **Table 2.3**.

17. Dip the light guide into a pan of water. Describe below what happens to current measured by the multimeter, and what happens to the red LED light. (It may help to dim the room lights to view the LED light better.)

18. Turn off the power supply and return all items to their proper storage containers and locations.

Table 2.2 Empirical data for 15 cm light guide with water core.

Source	LED OFF	LED ON
Red		

Table 2.3 Empirical data for light guide with 90-degree bend.

Source	LED OFF	LED ON
Red		

Analysis & Questions

What is the amount of light in milliwatts (mW) that falls on the phototransistor when using the red LED with the light guide and water core [assuming the responsivity of the phototransistor to be 50 milliamperes/milliwatt (mA/mW)]? What is it with no water in the core?

Does the light guide send more or less light onto the phototransistor with water in the core? Why?

Did the 90-degree bend significantly change the amount of light hitting the phototransistor? Why or Why not?

Calculate the critical angle of the light guide with the core. Assume canola water has a refractive index of 1.33 and the cladding has a refractive index of 1.0.

$$\theta = \sin^{-1}\frac{n_1}{n_2}$$

$$n_1 \; - \; \textit{refractive index of the cladding}, \; 1.0$$

$$n_2 \; - \; \textit{refractive index of the core}, \; 1.45$$

Do you know of any other liquids which may trap more light inside the vinyl tubing than the water used in this experiment?

HOMEWORK PROJECT

Find at least two common diameters of core and cladding used in communication-grade optical fibers. Be sure to include units of size (meters, inches, centimeters, etc.) The periodicals in the **List of References** are a good place to look for such information.

ACTIVITY III: FIBER OPTIC CABLE TRANSMISSION

Overview

In the preceding activity you constructed basic light guides using simple materials. In practice, few people make their own optical fiber. Commercially available optical fiber has much superior "performance" and is much more convenient to obtain. Optical fibers are composed of one of the following materials:

- Glass
- Plastic
- Other

More than 99 percent of all fiber optics cable used in the world is made from glass or plastic. The category "other" includes exotic optical materials such as silicon or gallium arsenide, which is used for ultraviolet or infrared light applications. The remaining activities in this manual will utilize a commercially available plastic core optical fiber. It is inexpensive, easy to use, safe and in most cases handled very much like the copper wire or cable that it replaces.

In each field "performance" has its own meaning. In fiber optics one of the terms that defines optical fiber performance is attenuation, or light loss per unit of travel. In this activity you will measure the light transmitted through several lengths of optical fiber and use the measured results to determine what is known as the attenuation coefficient, α, of the fiber.

Materials Required

Green LED (IF-E93A-blue w/white dot)	**Miscellaneous electrical test leads***
Red LED (IF-E96E-blue w/pink dot)	**Small flat bladed screwdriver***
Phototransistor LPT80A	**Multimeter***
Sidelooker device housing (black)	**1-meter measuring device***
Infrared LED (IF-E91A-blue w/copper dot)	**Single-edge razor blade or sharp knife***
390 Ω resistor	**Solderless breadboard***
Cinch Nut (black)	**Variable voltage power supply***

* Not included in the IF-LMH kit.

Procedure

1. Cut 2 mm (.1 inch) off the ends of the 3 meter optical fiber with a single-edge razor blade or sharp knife. Try to obtain a precise 90-degree angle (square).

2. While observing one end of the optical fiber, aim the other end toward a sunlit window or other strong light source. As the "aimed" end faces the light source, the "viewing " end should brighten with the transmitted light.

3. **Figure 3.1** shows a cross-sectional view of a sidelooker device housing with a component inserted. The component can either be an LED or photodetector, like the ones in the kit provided with this manual. With the phototransistor in hand, look at the pictorial of the device on page 49 of the manual, and notice the raised section of the body. This dome shaped protrusion acts as a micro-lens. Note in **Figure 3.1** that the micro-lens

lines up with the fiber entry point in the device housing. When a fiber is installed flush to the micro-lens, it captures the light and helps focus it on the photodetector. The same principle applies in reverse for the case of an LED component.

4. Identify and set aside the red, green, and infrared LEDs in the blue fiber optic device housings.

5. Using a small flat bladed screwdriver, gently insert the phototransistor (LPT80A) into the black sidelooker device housing.

6. Thread the black cinch nut onto the sidelooker housing containing the phototransistor. Insert the ends of the 3-meter optical fiber into the red LED and phototransistor sidelooker device housings. Push in the fiber until the end seats against the red LED and phototransistor micro lens. Tighten the cinch nut for a snug fit to lock the fiber in place.

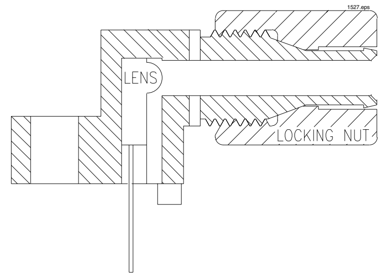


Figure 3.1 Cross-sectional view of fiber optic housing with photodetector installed.

7. Using a solderless breadboard, electrically connect the red LED and phototransistor as shown in the circuit diagram in **Figure 3.2.** Use the device diagrams found in the **Appendix** to identify anode and cathode on the LED, and collector and emitter on the phototransistor. (A radiometer or optical power meter can be used instead of the phototransistor, device mount and multimeter if your lab has this equipment available.)

8. Set the function of the multimeter to read "Current" on the 2 mA scale.

9. Turn on the variable voltage power supply and adjust the output voltage to + 5 volts DC. From the bottom of the device housing red light should now be visible from the LED. If not, check your power supply, electrical connections and components.

10. Record the current measured by the multimeter in **Table 3.1.**

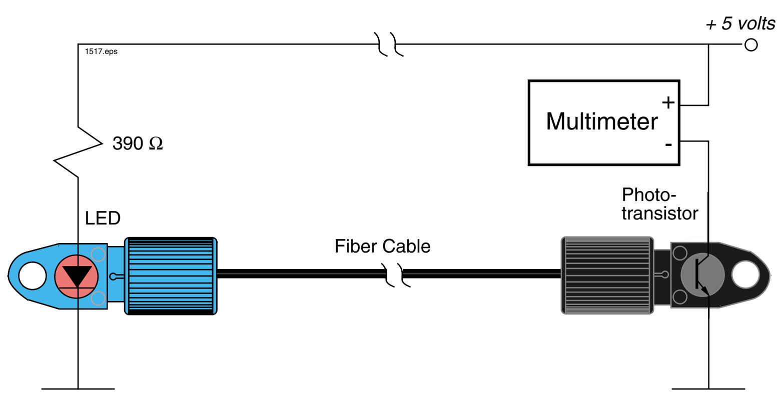


Figure 3.2 Test circuits for measuring cable transmission.

11. Replace the red LED with the green LED. Be sure to re-insert the fiber and tighten the cinch nut snugly.

12. Record the phototransistor current measured by the multimeter in **Table 3.1.**

13. Replace the green LED with the infrared LED, then repeat **Step 13**.

14. Remove the 3-meter optical fiber assembly from both sidelooker device housings.

15. Measure a distance of one meter from one end of the 3-meter fiber assembly.

16. Cut the cable with a single-edge razor blade or sharp knife at the 1-meter point. Try to obtain a precise 90-degree angle (square).

17. Insert the 1-meter optical fiber cable into the sidelooker device housings containing the infrared LED and phototransistor, then push in place until the ends seat against the micro lens. Tighten the cinch nuts snugly.

18. Record the current measured by the multimeter in **Table 3.1**.

19. Complete the remainder of Column 3 in **Table 3.1** using the red and green LEDs.

20. Turn off the variable voltage power supply, then unhook and return all the components to their proper storage container and locations.

Table 3.1 Measured phototransistor current with 3- and 1-meter lengths of 1000 μm core plastic fiber.

LED	$i_{3-meter}$	$i_{1-meter}$
Red		
Green		
Infrared		

Analysis & Questions

In general, the output power from a fiber cable at a given length is defined by the equation:

$$P_l = P_o \cdot e^{-\alpha l}$$

$$Po - launch\ \ power$$

$$L - length\ \ of\ \ fiber$$

$$\alpha - attenuation\ \ coefficient$$

From the equation above, another equation can be derived to determine the attenuation coefficient, α, from having measured the optical power output at two different optical fiber lengths. That equation is:

$$\alpha = \frac{\ln(P_1 / P_2)}{L_2 - L_1}$$

$$P_2 - power\ \ output\ \ of\ \ fiber\ \ length\ \ 2$$

$$P_1 - power\ \ ouput\ \ of\ \ fiber\ \ length\ \ 1$$

$$L_2 - length\ \ of\ \ fiber\ \ 2$$

$$L_1 - length\ \ of\ \ fiber\ \ 1$$

$$\ln -\ \ natural\ \ logrithum\ \ of\ \ x$$

In this activity we did not measure optical power, but rather phototransistor current, which is linearly proportional to the optical power. Substituting the phototransistor current for optical power and rewriting the equation above for the 1- and 3-meter optical fiber lengths used in this activity the equation becomes:

$$\alpha = \frac{\ln(I_1 / I_2)}{L_2 - L_1}$$

$$I_2 - measured\ \ current\ \ for\ 1 - meter\ \ fiber$$

$$I_1 - measured\ \ current\ \ for\ \ 3 - meter\ \ fiber$$

$$L_2 - length\ \ of\ \ 1 - meter\ \ fiber$$

$$L_1 - length\ \ of\ \ 3 - meter\ \ fiber$$

*Complete **Table 3.2** to calculate the fiber attenuation coefficients for each of the LEDs from the data recorded in **Table 3.1**.*

Are the attenuation coefficient values the same for the different LEDs? Why or why not?

Table 3.2 Table for calculating attenuation coefficients.

LED	$\frac{i_{(3-meter)}}{i_{(1-meter)}}$	$\ln\frac{i_{(3-meter)}}{i_{(1-meter)}}$	$\alpha = \frac{\ln\frac{i_{(3-meter)}}{i_{(1-meter)}}}{-2}$
Red			
Green			
Infrared			

The launch power (current) into a fiber can be calculated by rearranging the first equation described in this activity. The rearranged equation for calculating launch power (when the attenuation is known) is shown below:

$$P_o = P_l \cdot e^{\alpha l}$$

P_o – launch power

l – length of fiber

α – attenuation coefficient

P_l – power at given length

*Calculate the launch power for each LED using **Table 3.3**. (Substitute the phototransistor current for power in this equation because the phototransistor current is linearly proportional to the optical power.)*

Table 3.3 Calculation of launch power (equivalent current) for each LED.

LED	$P_{1-meter}$	α	$e^{\alpha(1)}$	$P_o = P_{1-meter} \cdot e^{\alpha(1)}$
Red				
Green				
Infrared				

*Calculate the phototransistor current produced by the light from the three LEDs having traveled down a 5-meter plastic optical fiber. Use **Table 3.4** as a guide. (Obtain α from **Table 3.2** and P_0 from **Table 3.3**.)*

*Calculate the phototransistor current produced by light from the three LEDs traveling down a 10-meter plastic optical fiber, using **Table 3.5** as a guide. (Obtain a from **Table 3.2** and P_0 from **Table 3.3**.)*

Table 3.4 Calculation of phototransistor current for a 5-meter fiber length.

LED	P_o	α	l	$e^{-\alpha(5)}$	$P_{5-meter} = P_o \cdot e^{-\alpha(5)}$
Red			5		
Green			5		
Infrared			5		

Table 3.5 Calculation of phototransistor current for a 10-meter fiber length.

LED	P_o	α	l	$e^{-\alpha(10)}$	$P_{10-meter} = P_0 \cdot e^{-\alpha(10)}$
Red			10		
Green			10		
Infrared			10		

Plot measured phototransistor currents for the 1-meter and 3-meter lengths, and the calculated phototransistor currents for 5- and 10-meter fiber lengths for all three LEDs in ***Figure 3.3****.*

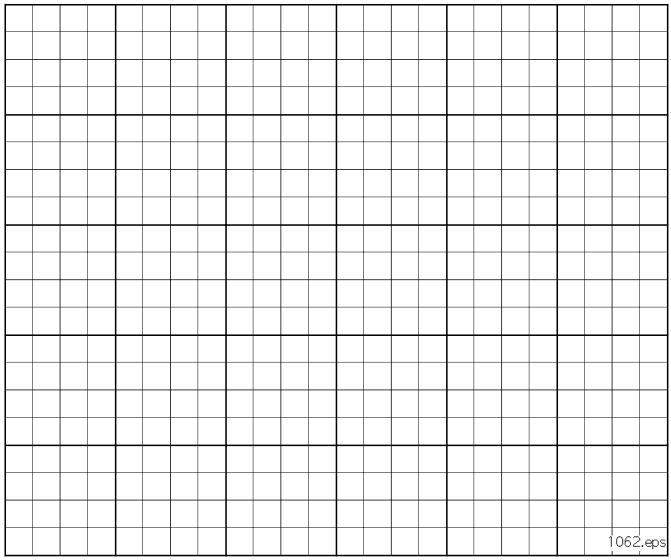


Figure 3.3 Phototransistor current created at the end of various fiber lengths for three different LED light sources.

HOMEWORK PROJECT

Find the optical wavelength, in nanometers, of the colors red and green. An excellent source for such information would be a good encyclopedia or physics book.

ACTIVITY IV: CONNECTORS AND SPLICES

Overview

In the previous experiment you learned that while having many advantages, fiber optics technology is not "perfect" because some light is lost as it travels down the optical core. Light loss inside the fiber, or attenuation, is called "intrinsic" loss. This intrinsic loss can be categorized as either *scattering* or *absorption*. With high-quality raw materials, super-quality clean rooms and modern manufacturing methods, intrinsic fiber loss can be reduced almost to zero. The clarity of today's premium quality optical glass fiber is comparable to a slab of window glass one mile thick losing only 50 percent of the light intensity passing through.

Fiber optics systems cannot always be installed with a single uninterrupted length of optical fiber. Often, two or more fiber lengths must be joined in order to obtain a necessary length, or route through buildings and enclosures. Losses from these connections are called "extrinsic" losses because they occur outside the optical fiber core and cladding boundary.

The two most common extrinsic losses due to joining or connecting optical fibers occur at:

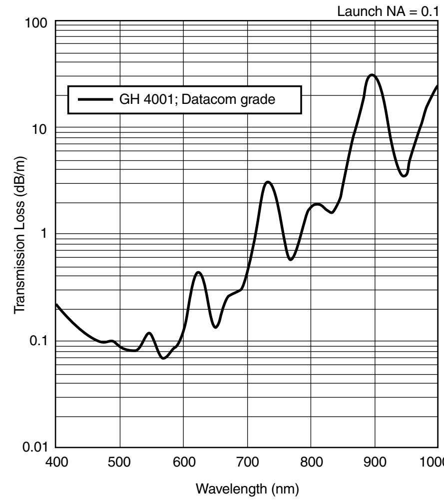


Figure 4.1 Attenuation of 1000 μm core plastic fiber versus wavelength.

Splices - Permanent connections of two optical fiber lengths that may be thermally fused or mechanically applied.

Connectors - Junctions that allow an optical fiber to readily be attached or detached from a light source, detector or another fiber.

In this activity you will work with and measure the attenuation in a fiber optic connector and splice.

Materials required

Phototransistor LPT80A from activity III	**1-meter fiber from activity III**
2-meter fiber from activity III	**Multimeter***
Red LED (IF-E96E-blue housing pink dot)	Variable voltage power supply*
Simplex assembly 228087-1	**Needle-nose pliers***
Retention clips 228046-1 (2)	**Single-edge razor blade or sharp knife***
Splice 228051-1	**Miscellaneous electrical test leads***
Infrared LED (IF-E91A-blue housing-copper dot)	**Solderless breadboard***
Simplex receptacle 228042-1	**18-gauge wire stripper***
390 Ω resistor	

* Not included in the IF-LMH kit.

Procedure #1: Fiber Connectors

1. Take the 1-meter optical fiber cable from the previous activity and use an 18 gauge wire stripper to remove 5mm (3/16 inch) of the fiber jacket from one end. Be careful not to knick the fiber while stripping or you'll lose light later in the experiment.

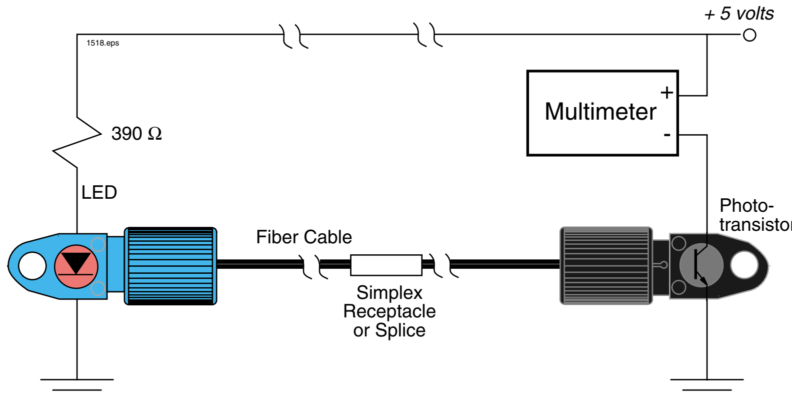


Figure 4.2 Test circuits for measuring cable transmission with bulkhead connectors and splices.

2. Use the needle nose pliers to push the stripped cable end into the large opening in the simplex assembly. Continue pushing the cable until the fiber tip is flush with the end of the simplex assembly body. Repeat Steps 1 and 2 above for one end of the 2-meter optical fiber cable.

3. Assemble the electrical circuit shown in **Figure 4.2** on the solderless breadboard. Use the red LED device housing as the light source to start this activity.

4. Set the function of the multimeter to measure "Current", on the 20 mA scale.

5. Insert the bare end of the 2-meter optical fiber cable into the red LED/device housing and push until it seats against the microlens. Tighten the cinch nut snugly to lock the fiber in place.

6. Insert the simplex assembly end of the 2-meter optical fiber into one port of the simplex receptacle (part number 228042-1). Push until the fingers on the simplex receptacle fully capture the flanges on the simplex assembly.

7. Insert the simplex assembly end of the 1-meter optical fiber cable into the remaining port of the simplex receptacle. Push until the fingers on the simplex receptacle fully capture the flanges on the simplex assembly.

8. Insert the bare end of the 1-meter optical fiber into the phototransistor device housing and push until it seats against the micro lens. Tighten the cinch nut snugly to lock the fiber in place.

9. Turn on the variable voltage power supply and adjust the output voltage to + 5 volts DC. From the bottom of the device housing red light should now be visible from the LED. If not, check your power supply, electrical connections and components.

10. Record the current measured by the multimeter in Row 2, Column 3 of **Table 4.1**.

11. Turn off the power supply.

12. Remove the fiber end from the red LED device housing.

13. Replace the red LED with the infrared LED on the solderless breadboard. Insert the end of the 2-meter fiber into the infrared LED device housing, until it seats against the micro lens, and then securely tighten the cinch nut.

14. Turn on the power supply.

15. Record the current measured by the multimeter in Row 3, column 3 of **Table 4.1.** (If the current measured is zero, check to determine if the LED is installed correctly.)

16. Remove the 1-meter fiber from the simplex receptacle and rotate the simplex assembly, including fiber, clockwise 90 degrees. Re-insert the simplex assembly in the simplex receptacle and press it into place until the fingers on the simplex receptacle fully capture the flanges on the simplex assembly.

Table 4.1 Measured phototransistor current with 2- and 1-meter fibers joined with a simplex receptacle.

LED	Position	$i_{simplex}$
Red		
Infrared	#1	
	#2	
	#3	
	#4	

17. Re-measure the phototransistor current with the multimeter and record the current in Row 4, Column 3 of **Table 4.1**.

18. Repeat **Steps 16** and **17** two more times and record the measured results in rows 5 and 6 of **Table 4.1** respectively.

19. Turn off the power supply.

Procedure #2: Fiber Splices

1. Remove the 2-meter and 1-meter fibers from the simplex receptacle. Leave the other end of the fiber cables attached to the LED and phototransistor device housings. Be careful in the next few steps to not pull on these components.

2. Using a sharp knife or single edge razor, cut off the simplex assemblies from the free ends of the 1- and 2-meter fiber scables. To preserve length, cut close to the shoulder of the simplex assembly where the fiber cables enter.

3. Trim the 1-meter cable further by laying it on a flat surface and cutting an additional 1 mm (0.04 inch) off the end with a sharp knife or single-edge razor blade. Try to obtain a precise square cut, at a 90-degree angle to the length of the cable.

4. Pick up the retention clip (part number 228046-1) and look at it closely. Identify the end of the retention clip opposite the triangular cutout or “V” groove. Insert the free end of the 1-meter fiber cable into this side of the retention clip.

5. Place the tip of the retention clip end on a hard, flat surface and press down on the cable until the end is flush with the end of the retention clip. Repeat Steps 3 through 5 for the 2-meter fiber cable.

6. Using needle-nose pliers gently grip the 1-meter fiber cable just behind the retention clip. Push the retention clip and fiber into the fiber splice (part number 228051-1) until the back end of the retention clip is flush with the rear of the splice.

7. Repeat steps 6 above for the 2-meter cable and retention clip. Continue pushing the 2-meter cable until both fibers make physical contact inside the splice. The fiber cores should touch when the backs of both retention clips are even with the rear of the splice. (Both clips will be fully inside the splice).

8. Turn on the power supply.

9. Record the current measured by the multimeter in Row 3, column 2 of **Table 4.2.**

10. Turn off the power supply.

11. Replace the infrared LED with the red LED, tighten the cinch nut and turn on the power supply.

12. Record the current measured by the multimeter in Row 2, Column 2 of **Table 4.2**.

Table 4.2 Measured phototransistor current with 2-meter and 1-meter optical fibers spliced together.

LED	i_{splice}
Red	
Infrared	

13. Turn off the power supply and multimeter.

14. Disconnect all the electrical connections from the multimeter and power supply that are attached to the breadboard. Remove the fiber from the LED and phototransistor device mounts. You can leave the electrical circuit intact on the solderless breadboard and the 1- and 2-meter fibers spliced together, because you will be using them in the next activity.

15. Return all remaining items to their proper storage containers and locations.

Analysis & Questions

*From **Activity III, Table 3.1,** Column 2, copy the measured phototransistor currents for the red and infrared LEDs and record them in Rows 2 and 3, Column 3 of **Table 4.3**. For rows 4 through 6 (infrared LED) write in the same numbers as those in Row 3.*

*Copy the measured data from Column 3 of **Table 4.1** and record it in Column 4 of **Table 4.3**.*

*Divide Column 4 by Column 3 and multiply by 100 for rows 2 through 6 in **Table 4.3**. Record your results in Column 5.*

Is the fiber's transmission more or less after the fiber connector is installed in the 3-meter fiber? Why?

What happens to the measured phototransistor current when the simplex assembly and 1-meter fiber are rotated to different positions within the simplex receptacle? Describe below the physical conditions that are occurring and why. (Drawing a picture might be helpful.)

*From Rows 2 and 3, Column 3 in **Table 4.3**, copy the measured phototransistor current for the 3-meter continuous fiber and record it in Column 2 of **Table 4.4**. Copy the data from Column 2 of **Table 4.2** to Column 3 in **Table 4.4**.*

*Divide Column 3 by Column 2, multiply by 100 for Rows 2 and 3 in **Table 4.4** and write the results in Column 4 of **Table 4.4**.*

Is the transmission greater for the 3-meter fiber with the splice installed or with the simplex receptacle? Is this what you expected? Why or why not?

Table 4.3 Comparison of transmission characteristics of a continuous 3-meter fiber optic cable to those of a 3-meter fiber length with fiber optic connector installed.

LED	Rotation	$i_{Activity\ III}$	$i_{simplex}$	% Transmission
Red				
Infrared	#1			
	#2			
	#3			
	#4			

In your own words, state at least two advantages and disadvantages of fiber connectors versus fiber splices. List at least two for each.

Table 4.4 Comparison of the transmission characteristics of a continuous 3-meter fiber optic cable and those of a length with a splice in it.

LED	$i_{Activity\ III}$	i_{splice}	% Transmission
Red			
Infrared			

HOMEWORK PROJECT

In a large metropolitan phone book find the names, addresses and phone numbers of two fiber optics companies. Ask them to send you information about their products or services.

ACTIVITY V: INDEX MATCHING

Overview

Extrinsic losses, as we noted in the previous activity, occur outside the optical fiber. As demonstrated by the rotation of the simplex assembly, physical alignment of two optical fibers has a great deal of effect on the integrity of optical coupling between them. The most commonly used method to minimize loss caused by alignment mismatch is to maintain very close tolerances on the diameters and concentricity of the optical fiber and fiber terminations.

Another common extrinsic loss is caused by Fresnel reflections (sometimes called Fresnel losses). These reflections are analogous to voltage standing waves (measured as ratios or VSWR) that reduce power transfer in radio frequency (RF) applications. The greater the electrical mismatch (higher VSWR), the more power is reflected back. Fresnel reflections demonstrate this same effect in a different part of the electromagnetic spectrum. See **Figure 5.1**. The greater the mismatch of refractive indexes as light travels from one medium to the other, the greater the amount of optical energy that is reflected back. For a uniformly polarized light beam at near perpendicular angles the generalized equation for Fresnel reflections is:

$$\phi_{\%} = \left[\frac{n_2 - n_1}{n_2 + n_1}\right]^2$$

n_1 – *refractive index of material* 1

n_2 – *refractive index of material* 2

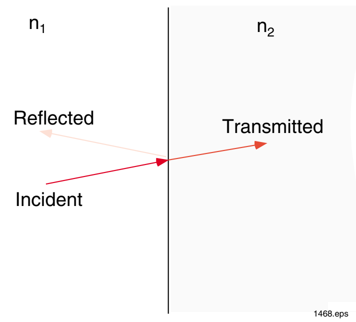


Figure 5.1 Diagram of incident light ray being split into two components at the boundary between optical materials with different refractive indices.

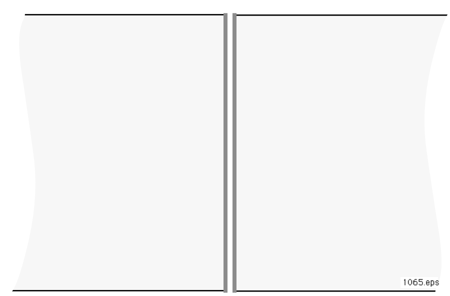


Figure 5.2 Magnified view of air gap between two optical fiber cores in a splice that causes Fresnel reflections.

Fresnel losses in an optical fiber connection/splice can be reduced by a method known as index matching. This involves filling the microscopic air gap between the two optical cores with a material that has a refractive index very close to that of the core materials. In this activity you will demonstrate how index matching can reduce Fresnel losses in a fiber optic splice.

Materials Required

Phototransistor, LPT80A in black sidelooker housing	**Needle-nose pliers***
Red LED (IF-E96E-blue housing-pink dot)	**Variable voltage power supply***
1 & 2-meter optical fibers joined together in a splice	**Multimeter***
Infrared LED (IF-E91A-blue housing-copper dot)	**Solderless breadboard***
Eyedropper	**Miscellaneous electrical leads***
390 Ω resistor	

* Not included in the IF-LMH kit.

Procedure #1: Index matching

1. Begin this activity by using the red LED housing as the light source.
2. Assemble the electrical circuits shown in **Figure 5.3** on your solderless breadboard.
3. Set the function of the multimeter to measure "Current" on the 2 mA scale.

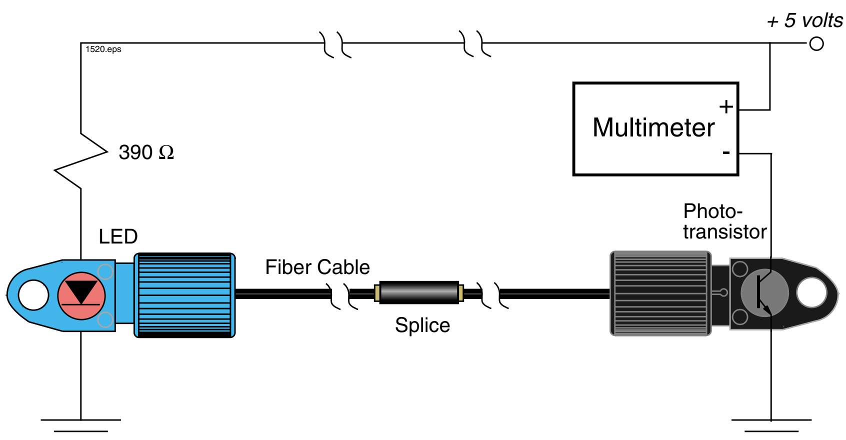


***Figure 5.3** Test diagram for measuring photodiode current with a fiber splice installed.*

4. Insert the unattached end of the 2-meter optical fiber into the red LED device housing and push until it seats against the micro lens. (The other end should still be installed in the splice from Activity IV along with the 1-meter fiber. If there is no splice joining the 1-meter and 2-meter fibers, go back to Activity IV for instructions on doing so.)
5. Insert the free end of the 1-meter optical fiber in the phototransistor housing. Tighten the cinch nuts to lock the fiber ends in place.
6. Turn on the power supply and set the output voltage to + 5 volts DC. Red light from the red LED should be visible from the bottom of the device housing. If not, check the power supply, electrical connections and components.
7. Record the current measured by the multimeter in Row 2, Column 2 of **Table 5.1**.
8. Turn off the power supply and remove the fiber end from the red LED device housing.

9. Replace the red LED with the infrared LED on the solderless breadboard. Insert the end of the 2-meter fiber into the infrared LED housing until it seats against the micro lens, and then securely tighten the cinch nut.
10. Turn on the power supply.
11. Record the current measured by the multimeter in **Table 5.1**, Row 3, Column 2.

Table 5.1 Measurements of phototransistor current when 2-meter and 1-meter fibers are spliced together with and without index-matching.

LED	i_{splice}	$i_{index-matched}$
Red		
Infrared		

12. Remove the 1-meter fiber from the splice — there should be a retention clip attached.
13. Using the eyedropper place one drop of glycerin on the core (the clear center portion) of the 1-meter fiber.
14. Firmly hold the 2-meter fiber where it enters the splice (behind the retention clip). Insert the 1-meter fiber and retention clip into the fiber splice.
15. Using needle-nose pliers, gently grip the 1-meter optical fiber behind the retention clip and push it into the splice until the fiber cores touch. The fiber cores should touch when the back of both retention clips are approximately even with the rear of the splice.
16. Record the current measured by the multimeter in Row 3, Column 3 of **Table 5.1**.
17. Turn off the power supply and remove the fiber end from the infrared LED housing.
18. Replace the infrared LED the red LED. Re-insert and seat the fiber, then securely tighten the cinch nut.
19. Turn on the power supply.
20. Record the current measured by the multimeter in Row 2, Column 3 of **Table 5.1**.
21. Turn off the power supply and multimeter.
22. Remove the 2-meter and 1-meter fibers from the splice.
23. Remove the fibers from the LED and phototransistor device housings.
24. Turn off the variable voltage power supply, then unhook and return all the components to their proper storage container and locations.

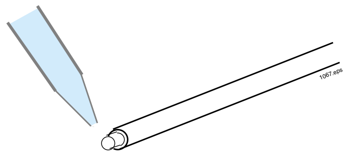


Figure 5.4 Correct position for placing a drop of glycerin on the 1-meter fiber end.

Analysis & Questions

*Copy the data from **Table 5.1** into **Table 5.2**.*

*For Rows 2 and 3 in **Table 5.2**, divide Column 3 by Column 2, subtract one, and multiply the result by 100. Write the results in Column 4.*

*Explain the change in transmission indicated by Column 4 in **Table 5.2**.*

Explain in your own words what "index-matching" means.

Table 5.2 Comparison of the transmission characteristics of a fiber splice with and without index-matching.

LED	i_{splice}	$i_{index-matched}$	% Improvement
Red			
Infrared			

Calculate the magnitude of a Fresnel reflection using the equation at the introduction to this activity. Assume the refractive index of Medium #1, the fiber core, to be 1.49 and Medium #2, air, to be 1.0.

*By the boundary conditions shown in **Figure 5.2**, how many Fresnel reflections are there for an optical ray passing from one fiber into the other? Calculate the increase in fiber transmission if a perfectly index-matched gel filled the gap between the fibers.*

HOMEWORK PROJECT

In an optics or physics books look up the detailed equations for Fresnel reflections that include effects of polarization and incident angles.

ACTIVITY VI: FIBER TERMINATIONS

Overview

In the preceding activity we learned about Fresnel losses and how to reduce them. As you may already know, the preparation of the fiber optic "end", or core/cladding, is very important in determining the coupling between two fibers. At the top of **Figure 6.1** is an illustration of an ideal fiber termination. It has a completely flat surface with no irregularities or imperfections to scatter light outside the expected light cone. The bottom half of **Figure 6.1** depicts a fiber end with a rough end surface which causes light rays to scatter over a much greater angle. When the light rays are scattered over a greater angle, the adjoining detector or fiber does not capture as much of the exiting light.

In this activity we will go through the various steps of terminating an optical fiber and measure improvements in coupling with each step. The baseline measurement will be an optical fiber cut with a wire cutter. (Using a fiber with such a poor termination would never be acceptable in real applications. We do so here only for educational purposes.) The fiber will then be cut and polished in successive steps to create a proper fiber end termination.

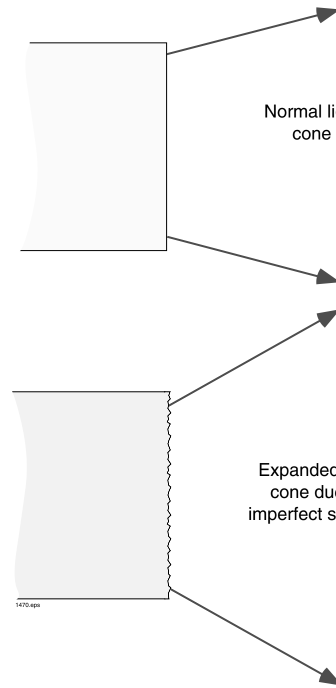


***Figure 6.1** (Top) Fiber with a perfectly flat termination, arrows depicting the cone of light exiting the fiber core. (Bottom) A poor fiber polish/termination showing the resultant increased divergence of exiting light rays.*

Materials Required

Phototransistor, LPT80A in black sidelooker housing	**Solderless breadboard***
2-meter optical fiber	**Paper Towels***
Red LED (IF-E96E-blue housing-pink dot)	**Single-edge razor blade or sharp knife***
2000 grit polishing paper (dark gray color)	**Diagonal-cutting pliers***
3 µm polishing film (pink color)	**Water, light oil or glycerin***
390 Ω resistor	**18-gauge wire stripper***
1-meter optical fiber	**Variable voltage power supply***
Infrared LED (IF-E91A-blue housing-copper dot)	**Multimeter***

* Not included in the IF-LMH kit

Procedure #1: Fiber Polishing

1. Using the diagonal-cutting pliers, cut 19 mm (3/4 inch) off the 1-meter fiber cable end removed from the splice in the previous activity. This removes the retention clip and a small amount of fiber from the cable.
2. Assemble the circuit diagram shown in **Figure 6.2** on the solderless breadboard.
3. Insert the fiber end cut with the diagonal-cutting pliers into the infrared LED device housing, then push in place until it seats against the micro lens. Tighten the cinch nut to lock the fiber in place.
4. Insert the other end of the 1-meter fiber assembly into the phototransistor device housing and push it into place, then tighten the cinch nut.
5. Set the function of the multimeter to measure "Current", on the 2 mA scale.
6. Turn on the power supply and set the output voltage to + 5 volts DC.
7. Measure the current through the phototransistor with the multimeter and record the results in Row 2, Column 2 of **Table 6.1**.

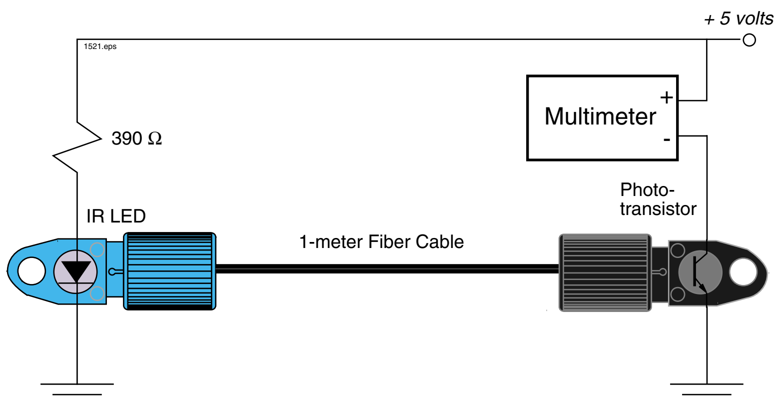


Figure 6.2 Test diagram for measuring the effects of various fiber terminations.

8. Remove the optical fiber end from the infrared LED device housing.
9. Cut 1 mm (.040 inch) off the end of the 1-meter fiber with a single-edge razor blade or sharp knife, trying to achieve a square (90 degree) edge.
10. Insert the newly cut fiber end into the infrared LED housing and push into place. Tighten the cinch nut to secure the fiber.
11. Measure the phototransistor current and record it in Row 3, Column 2 of **Table 6.1**.
12. Remove the 1-meter fiber end from the infrared LED housing.
13. Place the dark gray, gritty side of the 2000-grit polishing paper gritty-side-up on a hard, flat surface.
14. Wet the center of the 2000-grit polishing paper with water, light oil or glycerin.

15. Hold the 1-meter fiber upright, at right angles to the polishing paper, and polish the fiber tip with a gentle "figure-8" motion as shown in **Figure 6.3**. You may get the best results by supporting the upright fiber against some flat object such as a small piece of wood. Complete about 20 "figure-8" strokes. It isn't necessary to press down on the fiber — just make gentle contact between the fiber and paper.

16. Repeat Steps 14 and 15 using the 2-meter fiber end.

17. Place the smooth side of the 3 µm polishing film down on a hard, flat surface and wet the center of the film with water, light oil or glycerin.

18. Take the 2-meter fiber end just polished on the 2000-grit paper and polish it using the 3 µm polishing film. Use 20 of the same "figure-8" strokes depicted in **Figure 6.3**.

19. Visually compare the end of the 1-meter fiber polished with 2000-grit paper to the 2-meter fiber end polished with 3 µm film. (Good lighting and/or a magnifying lens or microscope may be helpful.)

20. Polish the free end of the 1-meter fiber, using 20 of the same "figure-8" strokes, on the 3 µm polishing film.

21. Insert the 1-meter optical fiber end just polished into the infrared LED device housing. Push into place and tighten the cinch nut.

22. Measure the phototransistor current and record it in Row 4, Column 2 of **Table 6.1**.

23. Turn off the multimeter and power supply.

24. Rinse off the 3 µm polishing film and the 2000-grit polishing paper in water. Use dishwashing soap as needed. Dry each with a paper towel.

25. Return all items to their proper storage containers and locations.

Table 6.1 Transmission data measured for a 1-meter optical fiber with three different end preparations.

Fiber Termination	Phototransistor current
Wire cutter	
Sharp knife	
Polished	

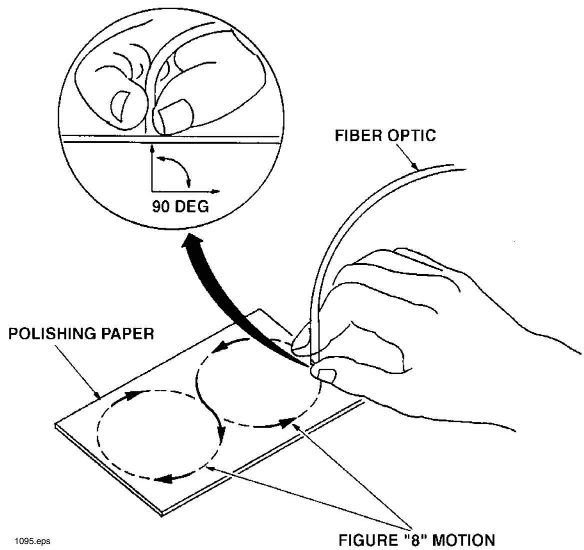


Figure 6.3 Position and pattern of the optical fiber during polishing.

Analysis & Questions

In the space below, draw pictures to show the differences between the fiber end polished with 2000 grit paper and the end polished with the 3 μm polishing film.

*Copy the data from **Table 6.1** into **Table 6.2**.*

*In Row 2, Column 3 of **Table 6.2** write the number resulting from dividing the number in Row 2, Column 2 by the number in Row 4, Column 2.*

*In Row 3, Column 3 of **Table 6.2** write the number resulting from dividing the number in Row 3, Column 2 by the number in Row 4, Column 2.*

Table 6.2 Calculations for determining losses due to fiber end preparation.

Fiber Termination	Phototransistor current	Column #3	Losses %
Wire cutter			
Sharp knife			
Polished			

In Column 4, record the numbers resulting from subtracting the numbers in Column 3 from 1 and multiplying by 100 percent.

Are the increased losses with poorer fiber termination what you expected? Why or why not?

Describe how the surface texture caused low phototransistor current with poorer terminations in this activity. Relate your answer to critical angle and fiber end termination. Drawing an illustration may be helpful.

Describe how poor fiber terminations on both ends of a fiber, along with light exiting and entering, causes reduced optical power at the photodetector.

HOMEWORK PROJECT

Find at least one company that manufactures fiber optic splices or connectors. (AMP, the supplier of fibers used in this kit, does not count.) Try looking in the buyers guides or the periodicals found in the **List of References**.

ACTIVITY VII: SPEED OF OPTO-ELECTRONIC DEVICES

Overview

Where optical fiber is used for data communications, semiconductor technology produces the most suitable light sources and photodetectors. Components manufactured using semiconductor technology are:

- Fast
- Small
- The most cost-effective devices on the market
- Easily interfaced with electronic circuits

In this activity you will broaden your experience to include the most common types of photodetectors — photodiodes, phototransistors, and photodarlingtons. Avalanche photodiodes have been omitted here because of their high cost — $50 each or more, even in quantities of 1,000 pieces. You will also focus your attention on the key characteristic of LEDs and photodetectors that is important for data communications — speed or bandwidth. Bandwidth is a measure of data transfer rate that can be defined by numerous terms including rise and fall times, 3 dB bandwidth frequency, and baud rate. Rise and fall times will be used as a relative measure of speed in this manual. The faster the rise and fall times, the greater the data transfer capability of an LED or photodetector.

Following, you will set up some basic equipment and electrical circuits to make rise and fall time measurements of several LEDs and photodetectors. From those measurements you will observe that each light source and photodetector has its own characteristics. Some devices have high light output and slow rise/fall times, while others have high rise/fall times and low light output. In fiber optic applications you will find that there are no "best" light sources or detectors. (In the real world the performance of a device is linked to its cost — somewhat like sports cars.) The best choice for an LED or photodetector is entirely dependent upon the specific size, load, environment, available voltage, and other factors. In fact, you may find applications where there is no suitable LED or photodetector available. In those situations, the skills/knowledge you acquire from this manual will help you determine a compromise among various requirements to arrive at an acceptable solution.

Materials Required

2-volt penlight	**Photodarlington – OP560 sidelooker – no stripe on back**
Phototransistor LPT80A in black sidelooker housing	**1-meter 1000 μm fiber**
74LS05, TTL open collector inverter	**150 Ω resistors (2)**
47 Ω resistors (2)	**10 k Ω resistor**
1 k Ω resistor	**Dual trace 40 MHz oscilloscope with probes***
Infrared LED (IF-E91A-blue housing-copper dot)	**Solderless breadboard***
Device Housing w/Green	**40 MHz square wave signal generator***
Red LED (IF E96E-blue housing-pink dot)	**Variable voltage power supply***
Photodiode – OP950 sidelooker style – blue stripe	**Needle-nose pliers***

* Not contained in the IF-LMH kit.

Procedure #1: Photodetectors

1. On your solderless breadboard assemble the circuit diagram shown in **Figure 7.1**. The multiple pin numbers on the input and output of the IC shown in **Figure 7.1** are five gates in parallel, drawn as one. Use the data sheet provided in the Appendix to identify the input and output pins on the 74LS05. Do not connect the signal generator to pin 1 of the 74LS05 IC yet.

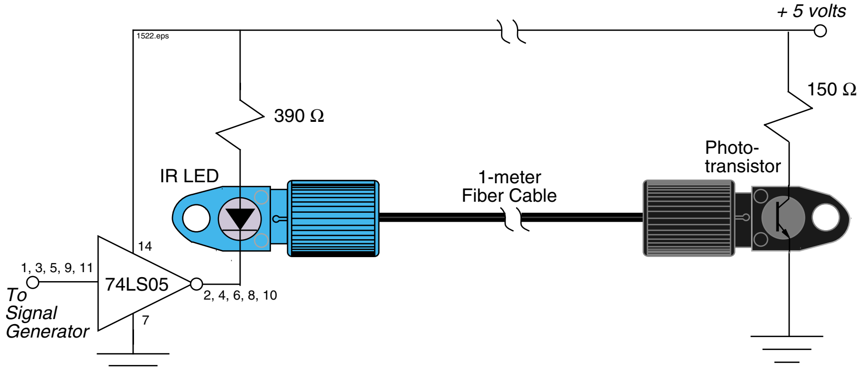


Figure 7.1 Test circuit for measuring rise and fall times of various light sources and photodetectors in Activity VII.

2. Begin this activity by using the infrared LED housing as the light source in **Figure 7.1**. (The photo transistor is already in a device housing so we will characterize that photodetector first.)

3. Insert one end of the 1-meter optical fiber cable into the infrared LED housing and the other end into the phototransistor housing. Push the cable into each device housing until it seats against the micro lens, then tighten the cinch nut snugly to lock the fiber in place.

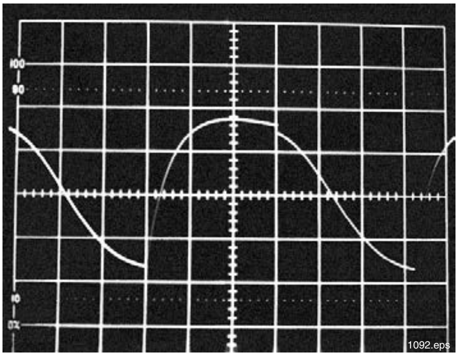


Figure 7.2 Oscilloscope screen showing the output of the signal generator and hex inverter (pins 2, 4, 6, 8 and 10 of 74LS05).

4. Turn the signal generator and oscilloscope on. Adjust the time base and amplitude settings on the oscilloscope so you can observe the signal generator's output amplitude and frequency.

5. Set the frequency of the signal generator for a 10 kHz (10,000 Hz), symmetrical square wave. Verify the frequency with the oscilloscope. Check the rise and fall times of the signal generator. Rise and fall times for the output of the generator should be faster than 10 nanoseconds. If that is not the case, the conclusions you make from the data may be inconclusive.

6. Set the amplitude out of the signal generator to produce a TTL level signal (3.4 volts < V_{high} < 5.0 volts and 0 volts < V_{low} < .7 volts). Verify amplitudes with the oscilloscope.

7. Turn the variable voltage power supply on and adjust the output voltage to + 5 volts DC.

8. Connect the signal generator output to pins 1, 3, 5, 9 and 11 of the 74LS05 IC.

9. Verify that the 74LS05 gate is driving the LED properly by observing the electrical signal present at pin 2 of the 74LS05 hex inverter with the oscilloscope. The observed signal should be similar to that shown in **Figure 7.2**.

10. Connect the other oscilloscope probe to the junction of the phototransistor collector and the 150 Ω resistor. The observed voltage on the oscilloscope will be in phase with that on pin 2 of the inverter, and inverted from the signal generator output.

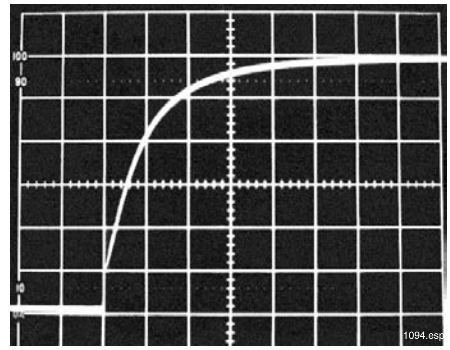


Figure 7.3 Proper oscilloscope display for measuring the rise time of the phototransistor.

11. Expand the sweeptime/timebase and the vertical amplitude settings on the oscilloscope to measure the rise time at the phototransistor collector. (If you are uncertain about the definitions of rise and fall times see the **Glossary** at the rear of this manual.) See **Figure 7.3** for a typical oscilloscope display for measuring rise time. Record the rise time in **Table 7.1**.

12. Adjusting the oscilloscope as required, measure the fall time of the phototransistor, then record the time in **Table 7.1**.

13. Turn the power supply and signal generator off.

14. Using a pair of needle nose pliers carefully remove the phototransistor from the device housing and replace it with the photodarlington, part number OP560. Replace the 150 Ω resistor connected to the collector of the phototransistor with a 47 Ω resistor. (Check the photodarlington pin connection in the **Appendix** of this manual.)

15. Turn the power supply and signal generator on.

16. Reduce the signal generator frequency to 1 kHz.

17. Adjust the sweeptime/timebase and vertical amplitude settings of the oscilloscope and measure the rise and fall times present at the collector of the photodarlington. Record your measured results in **Table 7.1**.

18. Turn the power supply and signal generator off.

Table 7.1 Measured values of photodetector rise and fall times, with an infrared LED as the optical source.

Detector	Rise time	Fall time
Phototransistor		
Photodarlington		
Photodiode		

19. Remove the 47 Ω resistor and connect a 10 k Ω resistor to circuit ground. Replace the photodarlington with the photodiode (part number OP950-blue stripe on back) in the device housing. Electrically connect the photodiode's cathode to + 5 volts and its anode to the 10 k Ω resistor on the solderless breadboard.
20. Turn on the power supply and signal generator.
21. Increase the operating frequency of the signal generator to 100 kHz.
22. With the oscilloscope, measure the rise and fall times at the junction of the 10 k resistor and the photodiode anode. Record the results in **Table 7.1**.
23. Turn off the power supply and signal generator.

Procedure #2: LEDs

1. Copy your measurements from Row 4, **Table 7.1**, in Row 2 of **Table 7.2**.
2. Replace the infrared LED with the red LED on the solderless breadboard. Be sure to re-insert the fiber and tighten the cinch nut snugly.
3. Turn on the power supply and signal generator.
4. Adjust the oscilloscope sweeptime/timebase and vertical amplitude as required to measure the rise and fall time of the red LED using the photodiode as the detector. Record your results in Row 3 of **Table 7.2**.
5. Turn off the power supply and signal generator.
6. Remove the red LED from the breadboard.
7. Remove the 1-meter fiber from the photodiode and red LED housings and place the fiber to one side.
8. Remove the photodiode from its housing and reinstall it on the breadboard.
9. Using needle-nose pliers carefully remove the green LED from its device mount and install it onto the breadboard facing directly into the photodiode. Place the LED so the distance between it and the phototransistor face is less than .5 mm (.020 inch).

Table 7.2 Measured values of rise and fall times of four optical sources using the photodiode as the optical detector.

LED	Rise time	Fall time
Infrared		
Red		
Green		
Penlight		

10. Replace the 150 Ω resistor (in series with the + 5 volt power supply and the green LED) with a 47 Ω resistor.
11. Turn on the power supply and signal generator.
12. Set the frequency of the signal generator to 1 k Hz.
13. Press the green LED directly against the photodiode and measure the rise and fall times at the anode of the photodiode, using the oscilloscope. Record your results in Row 4 of **Table 7.2**.

14. Turn off the power supply and signal generator.

15. Remove the green LED and the 47 Ω resistor from the breadboard. Connect the penlight between the +5 volt power supply and the outputs of the 74LS05 IC. (The penlight has no polarity.)

16. Turn on the power supply and signal generator.

17. Slow the signal generator frequency down to 20 Hz. See **Figure 7.4**

18. Measure the rise and fall times of the penlight and record the results in **Table 7.2**

19. Turn off the power supply and signal generator.

20. Return all items to their proper storage containers and locations.

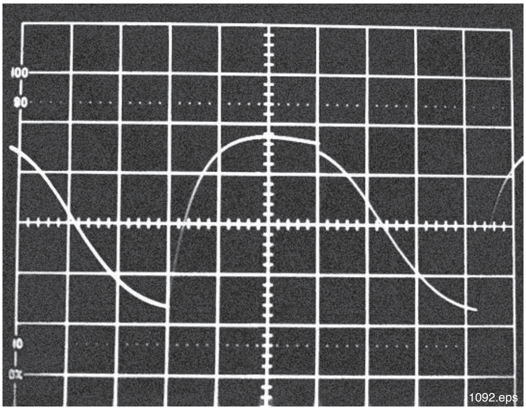


Figure 7.4 Oscilloscope trace showing rise and fall times when a photodiode is used as the detector and penlight as an optical source.

Analysis & Questions

Which of the photodetectors tested in Table 7.1 had the fastest rise and fall times?

*Are there any detectors tested in **Table 7.1** for which the rise and fall times are significantly different? If so, which ones?*

The upper 3 dB frequency bandwidth of a device can be determined from the rise time, or the fall time, by using the equation below:

$$f_{3dB} = \frac{.35}{\tau_r}$$

$$\tau_r - rise\ time,\ 10\ to\ 90\%$$

$$f_{3dB} - 3\ dB\ bandwidth\ in\ Hz$$

*Copy the photodetector rise and fall time data recorded in **Table 7.1** to **Table 7.3**.*
*Taking the longer of the rise times and fall times for each detector, calculate the 3 dB frequency bandwidth and record it in Column 4 of **Table 7.3**.*

Table 7.3 Calculation of detector upper frequency 3 dB bandwidth using an infrared LED as the optical source.

Detector	Rise time	Fall time	f_{3dB}
Phototransistor			
Photodarlington			
Photodiode			

Which photodetector has the largest bandwidth?

*Copy the light source rise and fall time data from **Table 7.2** to **Table 7.4**.*

*Taking the longer of the rise times and fall times for each light source, calculate the 3 dB frequency bandwidth and record it in Column 4 of **Table 7.4**.*

*Which LED is the fastest in **Table 7.4**? Is this what you expected? Why?*

Why are incandescent bulbs not used as fiber optics light sources? (Use the data in this activity to formulate your answer.)

*Using information as required from **Activity III**, determine if a particular LED emits the greatest amount of optical power, has the best optical fiber transmission and the fastest rise/fall times. Which one? If one does not meet all the criteria, pick the best LED in each category and list it below.*

Table 7.4 Calculations of light source upper frequency 3dB bandwidth using a photodiode as the optical detector.

LED	Rise time	Fall time	f_{3dB}
Infrared			
Red			
Green			
Penlight			

HOMEWORK PROJECT

Determine if the rise and fall times measured in this activity are typical of these devices by researching the speed of comparable LEDs and photodetectors. Try looking in manufacturers' data books. Device data books are normally available in most vocational, trade and engineering libraries or can be obtained from manufacturers themselves such as: America Bright, Agilent, Honeywell, Fairchild, Optek, Seimens, Toshiba, Stanley and arp.

ACTIVITY VIII: FIBER OPTIC TRANSMITTERS

Overview

As you learned in your main course, all fiber optic systems have three major elements:

- Transmitter
- Receiver
- Optical fiber

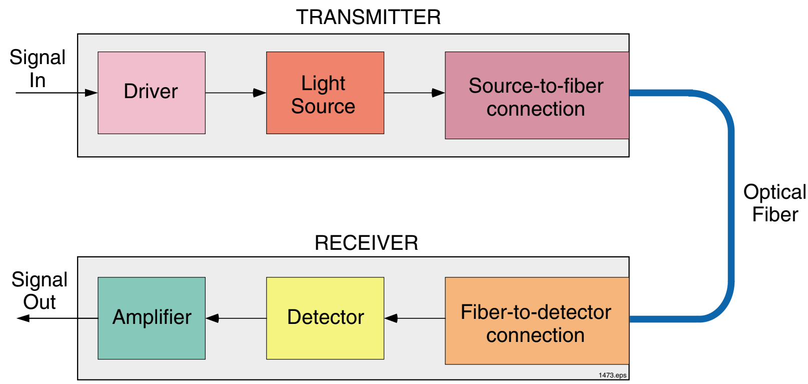


Figure 8.1 Basic elements in fiber optic links.

Figure 8.1 depicts these major elements. The transmitter and receiver contain smaller elements or building blocks, some of which you should recognize from previous activities. So far with the instructions in this manual we have made a light guide, characterized and terminated optical fibers, and evaluated LEDs and detectors. In this activity we shall investigate one of the last two elements in a fiber optic system the driver for the light source. As you have studied, there are two commonly used light sources in fiber optics, LEDs and laser diodes. The drivers covered in this activity are for visible and infrared LEDs. We will not discuss drivers for laser diodes because they are outside the scope of this manual. They can be very sophisticated, complex, and cost thousands of dollars. There are also optical safety considerations when using laser diodes. In more advanced fiber optics classes, or in your job, you will find the information you learned here about driving LEDs is a good primer for laser diode driver design.

Materials Required

Red LED (IF-E96E-blue housing-pink dot)	**2N3904**
PN2222	**74LS05 TTL Hex inverter**
2N4403	**220 Ω resistor**
47 Ω resistor	**40 MHz signal generator***
470 Ω resistors (2)	**Multimeter***
Assorted resistors	**Oscilloscope***
0.01 µf capacitor	**Solderless breadboard***
1 k Ω resistors (2)	**Variable voltage power supply***
100 pf capacitor	**Miscellaneous electrical leads***
1N914 (3)	

* Not contained in the IF-LMH kit

Procedure #1: Digital Circuits

The word "digital" in fiber optics means much the same as it does in electronics. Digital gates, circuits or systems are those in which there are two defined states — a "high" or digital 1, and "low", a digital 0. See **Figure 8.2** for an illustration. In all digital systems a "low" or digital 0 does not necessarily mean zero voltage or zero optical signal. A digital 0 means a lower state than the digital 1 state. In the electronics industry, the definitions of a digital 1 and 0 are defined within a logic family. For example, the established limits for the electronic TTL logic family are that V_{high} must be between 2.0 and 5.0 volts and V_{low} between 0 and 0.8 volts.

A very simple electronic circuit that can be connected to the output of any TTL or CMOS logic gate for driving a LED is shown in **Figure 8.3**. It will drive an LED with up to 50 mA of current, and a frequency of several megahertz.

1. Calculate the resistor value, R_c, needed to permit a current of 20 mA through the LED in **Figure 8.3** when the transistor is saturated. Assume the $V_{ce(sat)}$=.2 volts and the V_f for the LED to be 1.8 volts.

$$R_c = \frac{5 - V_f - V_{ce(sat)}}{I_c}$$

2. Calculate the maximum value of the base resistor, R_b, needed to drive the transistor into saturation if V_i was connected to + 5 volts. Assume V_{be}=.7 volts and $h_{fe(min)}$= 50.

$$R_b = \frac{5 - V_{be(sat)}}{\frac{I_c}{h_{fe}}}$$

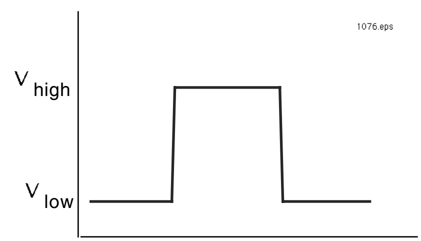


Figure 8.2 The two states of digital and fiber optic systems.

3. Choose resistors from the kit that are closest to the calculated R_c and one-half the calculated R_b. See **Table 1.2** for choices.

4. Assemble the circuit shown in **Figure 8.3** on your solderless breadboard. Use the pin diagrams found in the **APPENDIX** to identify device connections.

5. Turn on the variable voltage power supply and adjust the output voltage to + 5 volts DC.

6. Connect the end of R_b marked V_i to + 5 volts. The red LED should now be on. If not, check the power supply and electrical connections.

7. With the multimeter measure the transistor collector-to-emitter voltage and the voltage across the LED, then record the results in **Table 8.1**.

8. Change V_i from the + 5 volts to ground. The red LED should now be off.

9. With the multimeter, measure the collector-to-emitter voltage across the transistor and record the result in **Table 8.1**.

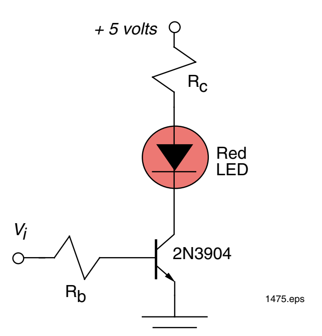


Figure 8.3 Single NPN transistor switching circuit for driving a fiber optic LED.

10. Turn on the signal generator and set it for a symmetrical square wave with a frequency of 100 kHz and a V_{high} between 3.4 volts and 5 volts, and V_{low} greater than 0 volts and less than 0.7 volts. Check the frequency and amplitude with an oscilloscope.

11. Disconnect V_i from ground and connect it to the signal generator output.

12. Using the oscilloscope measure the rise and fall times of the LED drive circuit at the collector of the 2N3904 transistor. Record your results in **Table 8.1**.

13. Increase the frequency of the signal generator until the digital signal on the collector of the transistor reduces to 70 percent of its peak value. Measure the period of the frequency and record it in **Table 8.1**.

14. Turn off the power supply and signal generator.

Table 8.1 Measured data taken from the circuit shown in Figure 8.3.

Measurement	Data
V_{ce} (LED on)	
V_f (LED)	
V_{ce} (LED off)	
Rise time	
Fall time	
$Period_{3\ dB}$	

Fiber optic communication systems are often duplex in configuration, and have transmitters and receivers adjacent on a printed circuit board. The on/off current of the LED driver may cause power supply ripples or generate noise that could affect the adjacent receiver. Driving the LED in a push/pull arrangement that shunts the current when the LED is not on can reduce power supply ripple. (This provides a more constant current drain from the power supply.) **Figure 8.4** is a modification of the circuit in **Figure 8.3** that does exactly that.

15. Reconfigure the electrical components on the breadboard to match those with the circuit shown in **Figure 8.4**.

16. Turn on the power supply. Connect the unattached end of R_b marked V_i to + 5 volts.

17. With the multimeter measure the voltage across the transistor and record your results in **Table 8.2**.

18. Change V_i from the + 5 volts to ground. The red LED should now be lit.

19. Measure the voltage across the LED with the multimeter and record your results in **Table 8.2**.

20. Turn on the signal generator and set it for a symmetrical square-wave with a frequency of 100 kHz, with the same voltage amplitudes as in **Step 18**.

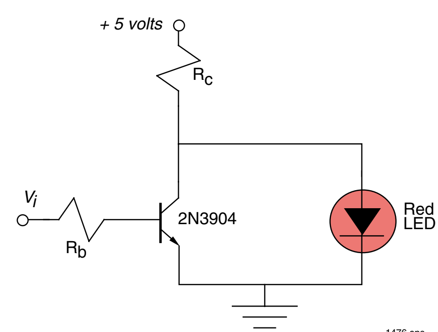


Figure 8.4 Transistor shunt circuit for driving a fiber optic LED that would reduce power supply current ripple.

21. Disconnect V_i from ground and connect it to the signal generator output.

22. Using the oscilloscope measure the rise and fall time of the LED drive circuit at the collector of the 2N3904 transistor. Record the results in **Table 8.2**.

23. Increase the frequency of the signal generator until the digital signal on the collector of the transistor reduces to 70 percent of its peak value. Measure the period of the frequency and record it in **Table 8.2**.

24. Turn off the power supply and signal generator. Disconnect the signal generator from R_b.

Table 8.2 Measured data on the LED drive circuit shown in Figure 8.4.

Measurement	Data
V_{ce}	
V_f	
Rise time	
Fall time	
$Period_{3\ dB}$	

Procedure #2: Digital Circuits II (Optional)

1. Remove the LED drive circuit from the breadboard and replace it with the circuit shown in **Figure 8.5**. Use the same value for R_c as used in **Procedure #1**.

2. Perform all the necessary steps needed to measure the data required to complete **Table 8.3**.

Table 8.3 Measured data for the high-speed LED drive circuit shown in Figure 8.5.

Measurement	Data
V_{ce} (LED on)	
V_{ce} (LED off)	
Rise time	
Fall time	
$Period_{3dB}$	

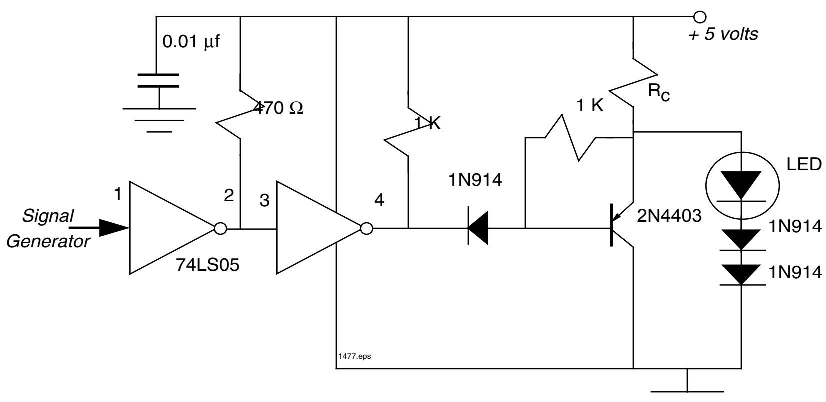


Figure 8.5 Ten-megabit push-pull LED drive circuit.

Procedure #3: Analog Circuits

Although most fiber optics systems are digital in format, there are a few analog applications. Designing an LED driver for an analog fiber optics system is comparable to designing an electronic Class A amplifier. It must have adequate bandwidth, good linearity and not clip for the range of input signals. A circuit suitable for driving an LED in a color video application is shown in **Figure 8.6**. (Color video requires about 8 MHz of bandwidth and has a standard 1-volt peak-to-peak signal level.)

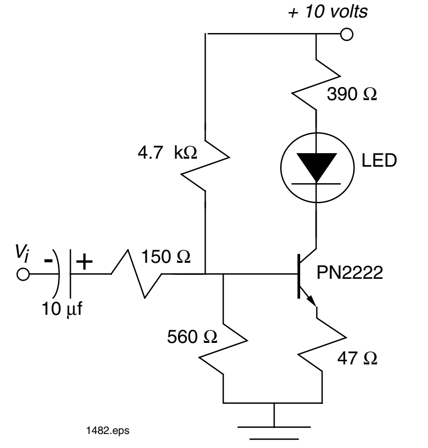


Figure 8.6 Analog fiber optic transmitter.

1. Replace the LED drive circuit on your breadboard with the one shown in **Figure 8.6**.
2. Turn on the variable voltage power supply and adjust the output voltage to + 10 volts DC.
3. With V_i open, measure the current through the LED with the multimeter and record the results in **Table 8.4**.
4. Turn on the signal generator. Set it to produce a 10 kHz sine wave with an amplitude of 0.5 volt peak-to-peak. Check the frequency and amplitude with the oscilloscope.
5. Connect the signal generator output to V_i, and readjust amplitude if necessary.
6. Observe the sine wave with the oscilloscope on the collector connection of the PN2222 transistor. Record the peak-to-peak amplitude (volts) in **Table 8.4**.
7. While observing the waveform on the transistor collector, increase the amplitude of the signal generator output until the sine wave becomes barely distorted. Record this peak-to-peak voltage in **Table 8.4**.
8. With the oscilloscope measure the peak-to-peak voltage at the signal generator output that caused distortion in **Step 7**. Record this voltage in **Table 8.4**.
9. Return the amplitude of the signal generator output to 0.5 volts peak-to-peak.
10. While monitoring the peak-to-peak voltage at the collector of the transistor, increase the frequency of the signal generator until the amplitude has decreased to 70 percent of the original value. Record the period of the frequency in **Table 8.4**.
11. Turn off the power supply, oscilloscope and signal generator.
12. Return all items and test equipment to their proper storage containers and locations.

Table 8.4 Measured data for the analog LED drive circuit shown in Figure 8.6.

Measurement	Data
I_C	
V_C (0.5-volt input)	
V_C (distorted)	
V_i (distorted)	
$\text{Period}_{3\ dB}$	

Analysis & Questions

*Is the measured voltage across the collector of 2N3904 transistor in **Figure 8.3** for the LED "on" and "off" compare to what you expected? Why or why not?*

*With the LED "on" in **Figure 8.3** calculate the "on" current using the measured data in this activity for $V_{ce\ (sat)}$ and V_f.*

*Using the measured rise time from **Table 8.1,** calculate the 3 dB bandwidth for the circuit shown in **Figure 8.3**.*

$$f_{3\ dB} = \frac{.35}{\tau_r}$$

$$\tau_r - rise\ \ time,\ 10\ \ to\ \ 90\%$$

$$f_{3\ dB} - 3\ \ dB\ \ bandwidth\ \ in\ \ Hz$$

How does the calculated bandwidth compare to the measured bandwidth?

*Calculate the average current used by the LED driver in **Figure 8.3,** assuming it is being driven at a 50 percent duty cycle.*

*Using the measured value for V_f, calculate the current through the LED in **Figure 8.4**.*

*Calculate the current through the 2N3904 in **Figure 8.4** when it is on and the LED is off.*

*What is the average current though the circuit shown in **Figure 8.4,** assuming that it is being driven at a 50 percent duty cycle?*

*Comparing the peak current and average current for the circuits in **Figures 8.3** and **8.4,** which would cause the greatest power supply ripple? By how much?*

*What is the difference between the circuits in **Figure 8.3** and **8.4**? (HINT: Consider inverted and non-inverted functions.)*

*Assuming h_{fe} is 100 for the PN2222, calculate the DC LED current drawn for the circuit shown in **Figure 8.6** with no input signal.*

*What is the maximum linear voltage swing of the circuit shown in **Figure 8.6**? (HINT: Determine the answer from empirical data.)*

*What is the 3 dB bandwidth of the circuit shown in **Figure 8.6**?*

HOMEWORK PROJECT

Design a digital LED drive circuit using an N-channel enhancement-mode MOSFET that will drive the LED with a current of 100 mA and a frequency of 5 MHz. The circuit must be powered from + 8 volts and the input must be electrically compatible with CMOS logic devices operating from the same + 8 volt power supply.

ACTIVITY IX: RECEIVER AMPLIFIER DESIGN

Overview

Photodiode, phototransistor and photodarlington photodetectors are all photon detectors. When light photons are absorbed in the detectors' “active area”, free "electrons" and "holes" are produced. These electrons and holes cause current flow if the device has a bias voltage applied across it.

As you may already know, most electronic signals are developed using voltages rather than current. Since voltage signals are more commonly used in electronics, the amplifier shown in **Figure 9.1** needs to convert photodetector current to a voltage. Amplifiers with this type of transfer function are called "transimpedance" amplifiers and have the dimensional units of volts/ampere (V/A).

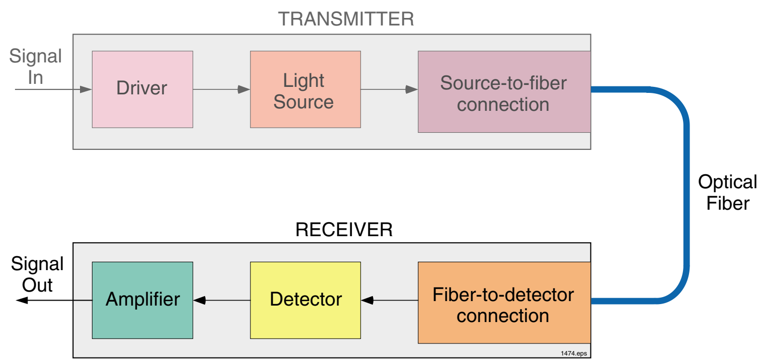


***Figure 9.1** Basic elements found in a fiber optic link with the receiver amplifier portions highlighted.*

The transimpedance amplifier is probably the most sensitive element in the entire fiber optics system. Because the transimpedance amplifier magnifies very small signal currents, it must be shielded from electromagnetic interference (EMI). Without shielding, EMI may induce current into the electronic circuitry that will be amplified along with the photodetector current. The result would be a noisy fiber link. Electrical leads from the photodetector to the transimpedance amplifier should also be kept as short as possible to reduce capacitance and to minimize EMI pickup.

In this activity you will construct and characterize some basic transimpedance circuits. The first circuits will be very simple, and then progress to more sophisticated ones. In addition you will learn about parasitic effects on the transimpedance amplifier's performance.

Materials required

Device housing w/Infrared LED	**10 kΩ resistor**
74LS05	**100 kΩ resistor**
100 Ω resistor	**2N3904 (2)**
10 Ω resistor	**.01 µf capacitor**
47 Ω resistor	**Multimeter***
PN2222	**Oscilloscope***
LM741	**Signal generator***
1000 µm optical fiber, 1-meter length	**Solderless breadboard***
560 Ω resistor	**Dual voltage variable power supply***
Device housing w/Photodiode (assemble if necessary)	

* Not contained in the IF-LMH kit.

Procedure #1: Basic Transimpedance Function

The simplest transimpedance device is just a resistor. Its output is measured in volts per ampere. A photodiode and resistor termination is shown in **Figure 9.2**. The transfer function of this receiver circuit is:

$$V_o = P_i \bullet \Re \bullet R_x$$

P_i – *Optical power incident upon photodiode*

$\Re$ – *responsivity of photodetector*

R_x – *value of resistor, ohms*

1. Assemble the circuit shown in **Figure 9.2** on the solderless breadboard. Start with the resistor R_x at a value of 100 kΩ.
2. Turn on the power supply and adjust the output voltage to + 5 volts DC.
3. Turn on the signal generator and oscilloscope.
4. Adjust the signal generator to produce an output with a symmetrical 10 kHz square wave frequency, and a TTL amplitude as follows (3.4 volts < V_{high} < 5.0 volts and 0 volts < V_{low} < .7 volts). Check the frequency and amplitude with your oscilloscope.
5. Connect the signal generator output to pin 1 of the 74LS05 IC on the breadboard.
6. On the oscilloscope observe the signal at the node marked V_o (between the photodiode and the resistor, R_x).

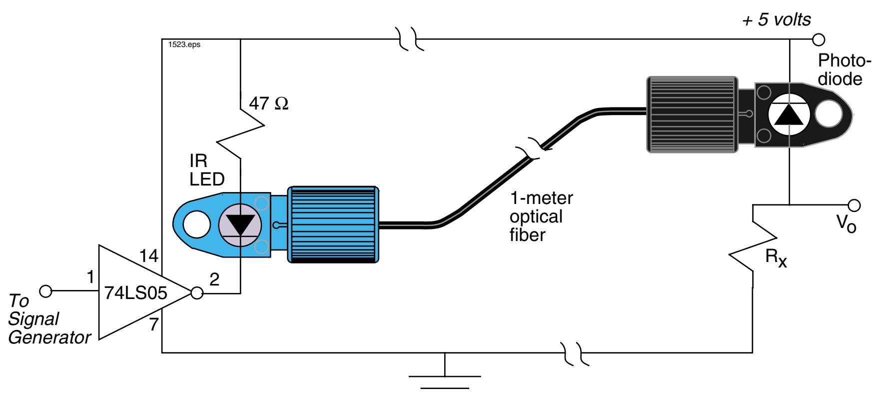


Figure 9.2 Photodiode terminated with a resistor.

7. Adjust the oscilloscope settings to measure the peak-to-peak voltage, and the rise time and fall time at V_o. Record the measurements in **Table 9.1**.
8. Turn off the signal generator and power supply.
9. Replace the 100 kΩ resistor with a 47 kΩ resistor.
10. Turn on the power supply and signal generator, measure $V_{p\text{-}p}$, t_r and t_f at V_o with the oscilloscope and record the results in **Table 9.1**.
11. Repeat **Steps 8** through **10**, replacing the 47 kΩ resistor with a 10 kΩ resistor.
12. Place a .001 µf capacitor in parallel with the 10 kΩ resistor.

13. Adjust the oscilloscope and signal generator to measure $V_{p\text{-}p}$, t_r and t_f at V_o. Record these measurements in **Table 9.1**.

14. Turn off the signal generator and power supply.

Table 9.1 Measured data for various termination resistors, R_x, in the circuit shown in *Figure 9.2.*

R_X	$V_{p\text{-}p}$	t_r	t_f
100 kΩ			
47 kΩ			
10 kΩ			
10 kΩ ‖.001 µf			

The transimpedance resistor used as a fiber optic receiver has two major drawbacks. The first is that the impedance of the load must be high, as compared to R_X , or the gain of the receiver goes down. The second is that the capacitance of the load can greatly affect the bandwidth of the circuit, as can be seen by the equation:

$$f_{3dB} = \frac{1}{2\pi R_x (C_d + C_r + C_l)}$$

R_x – resistance value

C_d – capacitance of photodetector

C_r – capacitance of resistor, R_x

C_l – capacitance of load

Procedure #2: Operational Amplifiers

Fortunately there are much better fiber optic receivers than the photodiode and single resistor. One example, an operational amplifier design, is shown in **Figure 9.4**. Its main advantage over the previous circuit is that the operational amplifier buffers the load impedance from the transimpedance gain resistor, R_X. The receiver gain is still determined by the feedback resistor, and the 3 dB frequency by the circuit capacitances at the operational amplifier inverting terminal.

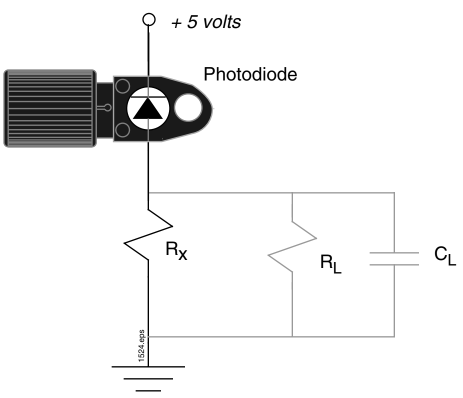


Figure 9.3 Receiver showing a parasitic load resistor and capacitor.

1. Replace the simple resistor located on the breadboard with the circuit shown in **Figure 9.4**. (Ignore C_1 for now.)
2. Turn on the power supply and adjust its output to provide a voltage of +/- 5 volts DC.
3. Turn on the signal generator.
4. For the three values of R_f listed in **Table 9.2**, measure $V_{p\text{-}p}$, t_r and t_f with an oscilloscope. Record the measured results in **Table 9.2**.
5. Place one end of the .001 µf capacitor (C1) at the output of the operational amplifier and the other end to ground as shown in the dashed outline in **Figure 9.4**.

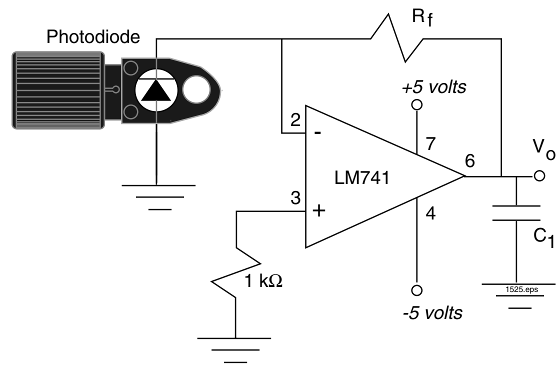


Figure 9.4 Non-inverting fiber optic receiver using an operational amplifier.

6. Record in the last row of **Table 9.2** $V_{p\text{-}p}$, t_r and t_f of this receiver circuit with the added load capacitance.
7. Turn off the signal generator and power supply.

Table 9.2 Measured data for various termination resistors, R_f, in the circuit shown in *Figure 9.4*.

R_f	$V_{p\text{-}p}$	t_r	t_f
100 kΩ			
47 kΩ			
10 kΩ			
10 kΩ ||.001 µf			

Procedure #3: Discrete Designs

Although operational amplifiers are readily available and easy to use, they sometimes lack the required frequency bandwidth for some applications. For these applications, discrete transistor amplifiers are often the answer. Examples of two discrete bipolar-transistor amplifier circuits are shown in **Figure 9.5**.

1. Replace the operational amplifier and associated circuitry on the breadboard with the circuit shown in **Figure 9.5 (a)**. Reposition the photodiode and device mount as needed.
2. Turn on the power supply and adjust the output connected to the discrete transistor receiver to + 5 volts DC.
3. Turn on the signal generator.
4. Measure the $V_{p\text{-}p}$, t_r and t_f with an oscilloscope for the values of R_f listed in **Table 9.3**. Record the results. (It will be helpful if you set your oscilloscope input for AC coupling.)
5. Turn off the signal generator and power supply.

To achieve high frequency bandwidth and low electrical noise, discrete designs use state-of-the-art transistors and circuit miniaturization techniques to reduce the package size as much as possible. Very often these circuits are built using the bare transistor chip (no package, just the semiconductor die), chip resistors and chip capacitors.

Most discrete designs are obsolete these days (except for the very highest frequency bandwidth applications) because special integrated circuits optimized for the transimpedance function are available. One such integrated circuit available from Signetics is part number NE5212. It has an impressive 3 dB frequency bandwidth of 125 MHz and a transimpedance gain of 7000 V/A. This device is also inexpensive and very easy to use.

Table 9.3 Measured data for various termination resistors, R_f, in the circuit shown in *Figure 9.5.*

R_f	$V_{p\text{-}p}$	t_r	t_f
100 kΩ			
47 kΩ			
10 kΩ			
10 kΩ ‖.001 µf			

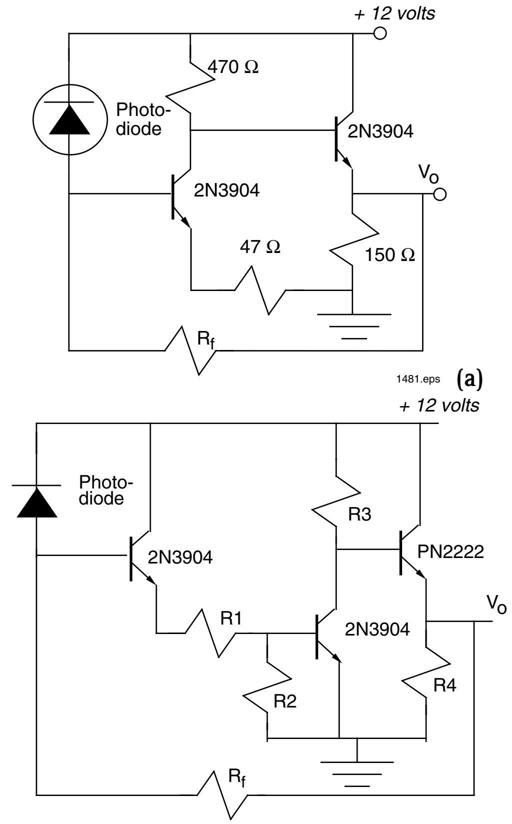


Figure 9.5 Fiber optic receivers using a discrete bipolar transistor.

Procedure #4: Phototransistor and Photodarlington Receivers

All the discussions in this activity have involved amplifiers with high-frequency bandwidth capabilities. Phototransistor and photodarlington devices, although much slower, do not require a high-speed amplifier attached to them. All of the circuits shown so far in this activity will work by substituting the phototransistor or photodarlington for the photodiode.

Phototransistors and photodarlingtons are great detectors for low-speed applications, and their receivers are often designed for simplicity. Examples of amplifiers for a phototransistor or photodarlington type photodetector are shown in **Figures 9.6 (a)** and **(b)**. Typical applications of such receivers include appliances, games and motor controls.

1. Replace the photodiode in the device housing with the phototransistor. Replace the 47 Ω resistor in **Figure 9.2** with a 100 Ω resistor.

2. Remove the receiver circuitry on the breadboard and replace it with the circuitry shown in **Figure 9.6 (a)**. (Ignore the dashed resistor in parallel with the 390 Ω resistor.)

3. Turn on the power supply and adjust the output voltage to + 5 volts DC.

4. Turn on the signal generator.

5. Observe the signal at the emitter of the phototransistor with an oscilloscope. Record $V_{p\text{-}p}$, t_r and t_f in **Table 9.4**.

6. Measure $V_{p\text{-}p}$, t_r and t_f at pin 2 of the 4069 logic gate and record in **Table 9.4**.

7. Place successively smaller value resistors in parallel with the 390 Ω resistor shown in **Figure 9.6 (a)** until the output of 4069 no longer is a periodic signal. Record below the value of the equivalent resistor that just removes the periodic signal at pin 2 on the 4069 IC.

   R=

8. Turn off the power supply and signal generator.

9. Replace the phototransistor in the device housing with the photodarlington.

10. Turn on the power supply and signal generator.

11. Again place successively smaller value resistors in parallel with the 390 Ω resistor until a periodic signal is no longer present at the output of 4069. Record below the value of the equivalent resistor that just removes the periodic signal at pin 2 on the 4069 IC.

    R=

12. Turn off the power supply and signal generator.

13. Return all items to their proper storage containers and locations.

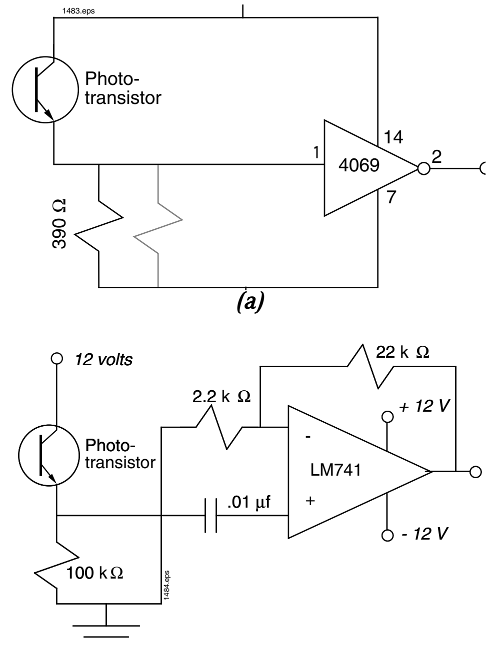


Figure 9.6 (a)Inverting phototransistor CMOS receiver; (b)non-inverting receiver with AC-coupled buffer amplifier.

Table 9.4 Measured data for various termination resistors, R_f, in the circuit shown in *Figure 9.6 (a).*

Location	$V_{p\text{-}p}$	t_r	t_f
$V_{emitter}$			
V_{4069}			

Analysis & Questions

*What happens to the rise and fall times at the receiver as the resistor value is reduced in **Figure 9.2**? What happens to the peak-to-peak voltage?*

*What happens to the rise and fall times across the termination resistor (R_X) when capacitance is added in the circuit shown in **Figure 9.2**?*

*What are the advantages and disadvantages of the receiver circuit shown in **Figure 9.4** compared to the circuit shown in **Figure 9.2**?*

*How does the addition of the load capacitance affect the rise and fall times in the circuit shown in **Figure 9.4** as compared to **Figure 9.2**? Why?*

*Calculate the bandwidth of the receiver shown in **Figure 9.4** with the 10 k gain resistor installed using the equation:*

$$f_{3\ dB} = \frac{.35}{\tau_r}$$

$$\tau_r - \ rise\ \ time,\ 10\ \ to\ \ 90\%$$

$$f_{3\ dB} - \ 3\ \ dB\ \ bandwidth\ \ in\ \ Hz$$

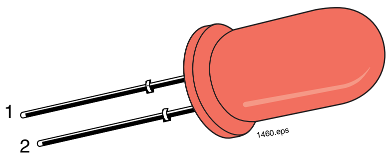
*Calculate the bandwidth of the bipolar transistor receiver in **Figure 9.5** using the 10 k feedback resistor installed.*

*How much more gain does the photodarlington have than the phototransistor in the circuit in **Figure 9.6 (a)**? (Hint: Use the ratio of the equivalent resistances which just removed the periodic signal at the output of 4069.)*

HOMEWORK PROJECT

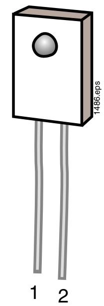
From the information received from the fiber optic vendors in **Activity IV**, write a paragraph describing a product or service that each company provides.

DEVICE PIN DIAGRAMS



Red LED

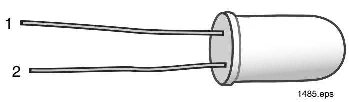
1. Anode
2. Cathode



Photodiode (Blue stripe on back)
1. Anode
2. Cathode

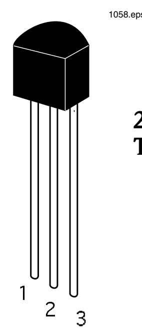
Phototransistor (Black stripe on back)
1. Emitter
2. Collector

Photodarlington (No stripe on back)
1. Emitter
2. Collector



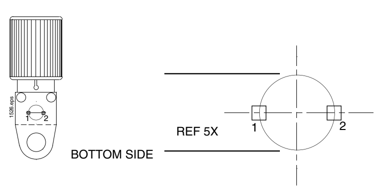
SFH300: Phototransistor in T 1 3/4 package

1. Emitter
2. Collector

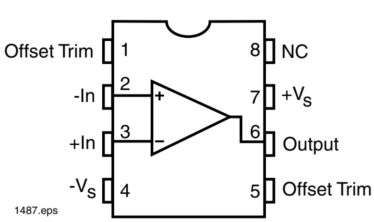


2N3904, PN2222, 2N4403 Transistors

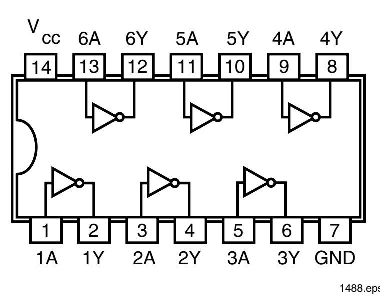
1. Emitter
2. Base
3. Collector



Fiber Optic LEDs: IF-E91C, IF-E93A and IF-E96
1. Cathode
2. Anode



LM741 Operational Amplifier



74LS05 and 4069 Hex inverters

RECOMMENDED TEST EQUIPMENT

The activities in this manual include lists of recommended parts and equipment. Following is a general description of each item to help you in proper selection.

18-gauge wire stripper

The 18-gauge wire stripper can be a tool sized for stripping *only 18* gauge wire; a stripper sized for multiple gauges; or an adjustable wire stripper. When using an adjustable wire stripper, be sure it is not sized too small or the optical fiber cladding can be nicked, which could cause you to make inaccurate determinations from the results.

Miscellaneous electrical test leads

A generic description for all the electrical (test) leads required to electrically connect the power supply, signal generators, multimeter and oscilloscope to the circuits on the solderless breadboard used in this manual. It is recommended that oscilloscope probes be attached to the oscilloscope inputs when monitoring circuit activity for best measurement accuracy.

Multimeter

We suggest using a Fluke 73 digital multimeter or equivalent. An analog multimeter is also suitable if it can accurately measure DC current to at least .01 mA. (DC current is the most critical measurement made by the multimeter)

Oscilloscope

This instrument and its input measurement probes are critical to making measurements of circuit performance in **ACTIVITIES VII** through **IX**. It is suggested that you use an oscilloscope with dual trace capabilities and an electrical bandwidth of at least 40 MHz. If you are using a digital sampling oscilloscope, we suggest one with a bandwidth rating of 80 MHz or more. All oscilloscope probes should have a bandwidth in excess of 40 MHz; have been recently calibrated; and be in good working condition. Very often a good oscilloscope can produce inaccurate results due to poor or damaged probes.

Signal generator

The signal generator is used to produce two waveforms. One is a square-wave, TTL- compatible signal at a frequency from 10 Hz to 40 MHz. The other is an analog sine wave with variable amplitude from 10 millivolts to 2 volts peak-to-peak and a frequency from 2 kHz to 20 MHz. You may choose to use separate signal generators for the analog and digital functions.

Solderless breadboard

"Solderless breadboard" is a generic term used to describe a piece of equipment that allows electric circuits to be assembled and tested without soldering. Suggested board capacity for completing the activities in this manual is 1360 total contacts and a size of 16.5 x 8 cm (6.5 x 3.125 inches). A solderless breadboard with electrical binding posts for electrical input power is optional.

Variable voltage power supply

In this manual the variable voltage power supply should have two independent and isolated sources capable of delivering from 0 to 12 volts. Current rating for both supplies should exceed 100 mA. A chassis ground isolated from the negative terminal is necessary for the negative 12 volt output.

SHIPMENT DAMAGE OR MISSING PARTS CLAIMS

Shipment Damage Claims

If damage to an *Industrial Fiber Optics* product should occur during shipping, it is imperative that it be reported immediately, both to the carrier and the distributor or salesperson from whom the item was purchased. DO NOT CONTACT *INDUSTRIAL FIBER OPTICS*.

Time is of the essence because damage claims submitted more than five days after delivery may not be honored. If damage has occurred during shipment, please do the following:

- Make a note of the carrier company; the name of the carrier employee; the date; and the time of the delivery.
- Keep all packing material.
- In writing, describe the nature of damage to the product.
- In the event of severe damage, do not attempt to use the product (including attaching it to a power source).
- Notify the carrier immediately of any damaged product.
- Notify the distributor from whom the purchase was made.

Missing Parts Claims

Industrial Fiber Optics products are warranted against missing parts and defects in materials and workmanship for 90 days. Since soldering and incorrect assembly can damage electrical components, no warranty can be made after assembly has begun. If any parts become damaged, replacements may be obtained from most radio/electronics supply shops. Refer to the parts list in **Table 1.1** of this manual for identification.

LIST OF REFERENCES

Following is a list of books, magazines, and other items that may be useful in the study of fiber optics. If the title does not mention fiber optics, you still may consider it a worthwhile source of information, since fiber optic technology spans multiple disciplines.

BOOKS

Introductory

Fiber Optics: A Bright New Way to Communicate, Billings, Dodd, Mead & Company, New York, NY 1986

The Rewiring of America: The Fiber Revolution, David Chaffee, Academic Press, Inc., Orlando, FL 32887, 1988

Understanding Fiber Optics, Second Edition, Hecht, Howard W. Sams, 201 West 103rd Street, Indianapolis, IN 46290, 1993

Fiber Optics Communications, Experiments & Projects, Boyd, Howard W. Sams, 4300 West 62nd Street, Indianapolis, IN 1982

Technicians Guide to Fiber Optics, Sterling, AMP Incorporated, Harrisburg, PA 17105, 1987 (Paperback), Delmar Publishers, 2 Computer Drive West, Box 15-015, Albany, New York 12212-9985 (Hardbound version)

Fiber Optics Handbook, Second Edition, Hentschel, Hewlett Packard, 1988

Advanced

Fiber Optic Communications, Third Edition, Palais, Prentice-Hall Publishing, 1987

Optical Fiber Transmission, Basch, Howard W. Sams, 201 West 103rd Street, Indianapolis, IN 46290, 1986

College Level

An Introduction to Optical Fibers, Cherin, McGraw-Hill Book Company, 1983

Fiber Optic Handbook for Engineers and Scientists, Allard, McGraw-Hill Publishing, New York, NY 1990

Fiber Optics, Daly, CRC Press, 1986

Fiber Optics in Communication Systems, Elion and Elion, Marcel Dekker, Inc. 1978

Pulse Code Formats for Fiber Optic Communications, Morris, Marcel Dekker, Inc. 1983

Optical Fibre Sensing and Signal Processing, Culshaw, Peter Peregrinus LTD., 1984

Principles of Optical Fiber Measurements, Marcuse, Academic Press, 1974

Semiconductor Devices for Optical Communications, Kressel, Springer-Verlag, Inc., 1980

Semiconductor Laser and Heterojunction LEDs, Butler and Kressel, Academic Press, Inc., 1977

Other

Laser Receivers, Ross, John Wiley & Sons, Inc., 1966

Noise in Electronic Circuits, Ott, John Wiley & Sons, 1976

Safety

Safety with Lasers and Other Optical Sources, Stiney and Wolbarsht, Plenum Press, 1980

Safe Use of Lasers, ANSI Standard Z136.1, LIA, 12424 Research Parkway, Suite 130, Orlando, FL 32826

Safe Use of Optical Fiber Communications Systems Utilizing Laser Diodes & LED Sources, ANSI Standard Z136.2, LIA, 12424 Research Parkway, Suite 130, Orlando, FL 32826

A User's Manual for Optical Waveguide Communications, Gallawa, U.S. Department of Commerce

Fiber Optics, Lacy, Prentice-Hall, Inc., 1982

MONTHLY PUBLICATIONS

The first two listings are journals available to members of the respective professional societies. The last four are trade magazines often available free of charge.

Applied Optics, Optical Society of America, 1816 Jefferson Place, NW, Washington, DC 20036

Optical Engineering, SPIE, P. O. Box 10, Bellingham, WA 98227

Fiberoptic Product News, Gordon Publications, Inc., Box 1952, Dover, NJ 07801

Laser Focus World, PenWell Publishing Co., 1421 S. Sheridan, Tulsa, OK 74112

Lightwave Magazine, PenWell Publishing Co., 1421 S. Sheridan, Tulsa, OK 74112

Photonics Spectra, Laurin Publishing Co., Berkshire Common, P.O. Box 4949, Pittsfield, MA 01202-4949

BUYER'S GUIDES

Fiberoptic Product News Buying Guide, Gordon Publications, Inc., Box 1952, Dover, NJ 07801

Lightwave 2003 Buyer's Guide, PenWell Publishing Co., 1421 S. Sheridan, Tulsa, OK 74112

ORGANIZATIONS

Optical Society of America, 1816 Jefferson Place, NW., Washington, DC 20036

Society of Photo-Optical Instrumentation Engineers (SPIE), P. O. Box 10, Bellingham, WA 98227

Laser Institute of America, 12424 Research Parkway, Suite 130, Orlando, FL 32826

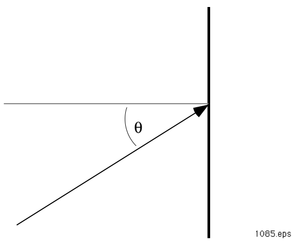
GLOSSARY

This glossary contains definitions to help readers understand the meanings of technical terms as they are used in this manual, and as they relate to electronics, fiber optics, and lasers. Some words have different meanings when used in other contexts.

A

Absorption - In an optical fiber, the loss of optical power resulting from conversion of that power into heat. See also: **Scattering**.

Acceptance angle - The angle within which an optical fiber will accept light for transmission along its core. This angle is measured from the centerline of the core.



Acousto-optic modulator - A device that varies the amplitude and phase of a light beam (for example, from a laser) by sound waves.

Active port diameter - In a light source or detector, the diameter of the area in which light can be guided into or from an optical fiber.

Analog - A signal that varies continuously (sound or water waves, for example). Analog signals have a frequency and bandwidth measured in Hertz (Hz).

Angle of incidence - The angle formed between a ray of light striking a surface and a line drawn perpendicular to that surface at the point of incidence (the point at which the light ray strikes the surface).

Angstrom (Å) - A unit of length often used to characterize light. An Angstrom is equal to 0.1 nm or 10^{-10} meters. The word is often spelled out as Angstrom(s) because the special symbol is not available on typewriters and older printers.

Angular misalignment loss - The optical power loss caused by angular deviation from the optimum alignment of a source to an optical fiber, fiber-to-fiber, or fiber-to-detector. See also: **Extrinsic joint loss**; **Intrinsic joint loss**; **Lateral offset loss**.

Anode - The positive electric terminal in a laser, semiconductor or other electronic component. The electron stream normally flows toward this terminal. See also: **Cathode**.

Anti-Reflection (AR) coating - A thin layer of material, or a composite of materials, applied to an optical surface to reduce reflectance and increase transmittance of light.

Attenuation - Loss of optical power.

Attenuation coefficient - The rate of diminution of average optical power — the sum of the scattering and absorption coefficients.

Attenuation-limited operation - The condition prevailing when the received signal amplitude (rather than distortion) limits a fiber optic system's performance. See also: **Bandwidth-limited operation**; **Distortion-limited operation**.

Avalanche photodiode (APD) - A semiconductor photodetector that includes detection and amplification stages. Electrons and hole pairs generated between the *p* and *n* junctions are accelerated in a high electronic field region where they collide with ions to create other electron hole pairs, or current amplification. APDs can detect faint signals, but require higher operating voltages than other semiconductor photodetectors.

Axis - A straight line, real or imaginary, passing through a body and indicating its center.

Axial ray - A light ray that travels along an optical fiber's axis. See also: **Meridional ray**; **Skew ray**.

B

Backscattering - The portion of scattered light which returns in a direction generally opposite the direction of propagation. See also: **Rayleigh scattering**.

Bandwidth - The range of frequencies which can be handled by a device or system within specific limits. See also: **Fiber bandwidth**.

Bandwidth-limited operation - The condition prevailing when the system's frequency bandwidth, rather than the amplitude (or power) of the signal limits, performance. This condition can be reached when the fiber optic cable's material and modal dispersion distort the shape of the waveform beyond specified limits. See also: **Attenuation-limited operation**; **Distortion-limited operation**.

Beam divergence - The increase in beam diameter as distance from the source increases.

Beamsplitter - A device for dividing an optical beam into two or more separate beams; often a partially reflecting mirror. See also: **Coupler**; **Splitter**.

Birefringence - The separation of a light beam (as it penetrates a doubly refracting object) into two diverging beams, commonly known as ordinary and extraordinary beams.

Bit Error Rate (BER) - In digital applications, the ratio of bits received in error to total number of bits sent. BERs of 10^{-9} (one error bit in one billion sent) are typical.

Boltzman Constant - A constant which is equal to 1.38×10^{-23} joules per Kelvin. Commonly expressed by the symbol K.

Buffer - See: **Fiber buffer**.

C

Cable - A single fiber or a bundle, sometimes including strengthening strands of opaque material covered by a protective jacket.

Cathode - Also known as the negative electric terminal, in a laser, semiconductor or other electronic component. The electron stream normally flows from the cathode to the anode. See also: **Anode**.

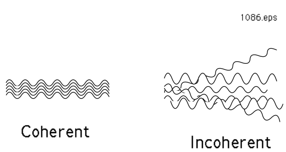
Characteristic angle - The angle at which a given mode travels down an optical fiber. See also: **Mode**.

Cladding - A layer of glass or other transparent material surrounding the light-carrying core of an optical fiber. It has a lower refractive index than the core. Coatings may be applied over the cladding.

Cladding mode - A mode that is confined in the cladding of an optical fiber by virtue of the material surrounding the cladding having a lower refractive index. See also: **Mode**.

Coaxial - Having the same centerline. A cross-section of coaxial cable reveals concentric circles.

Coherent - Light, as in a laser beam, whose waves have identical frequencies and are in phase with each other. Only lasers produce coherent light.



Collimated - Light rays, within a light beam, that are parallel to each other, as within a laser beam.

Combiner - A passive device in which optical power from several input fibers is collected at a common point in a single fiber. See also: **Coupler**.

Connector - A device mounted at the end of a fiber optic cable, light source, receiver or housing that mates to a similar device to couple light optically into and out of optical fibers. A connector joins two fiber ends or one fiber end and a light source or detector.

Core - The central portion of an optical fiber that carries light.

Coupler - A device which connects three or more fiber ends, dividing one input among two or more outputs or combining two or more inputs into one output. See also: **Beam splitter**

Coupling efficiency - The fraction of available output from a radiant source which is captured and transmitted by an optical fiber. The coupling efficiency of a Lambertian radiator is usually equal to the $\sin^2 \Theta_{maximum}$ for the optical fiber being used.

Coupling loss - The amount of power in a fiber optic link lost at discrete junctions such as source-to-fiber, fiber-to-fiber, or fiber-to-detector.

Critical angle - The smallest angle of incidence at which light will undergo total internal reflection.

Cutback technique - A technique for measuring fiber attenuation or distortion by performing two transmission measurements. One measurement is taken at the full length of the fiber; the other when a portion has been cut from the full length.

D

Dark current - A parasitic output current that a photodetector produces in the absence of light and operational voltages.

Decibel (dB) - A logarithmic unit of measure used to express gain or loss and relative power levels. Ten times the base-ten logarithm of that ratio:

$$dB = 10 \bullet \log_{10}(P_2 / P_1)$$

Demodulator - A circuit that separates an information signal from its carrier.

Detector - A device that generates an electrical signal when illuminated by light or infrared radiation. The most common detectors in fiber optics are APDs, photodiodes, photodarlingtons and phototransistors.

Diffuse reflection - Reflection from a surface that makes its texture appear matte or dull. Opposite of the spectral reflection occurring from a mirror.

Digital - A signal format in which the information being conveyed is contained in the presence or absence of signal in sequential time periods, resulting in "zero bits" and "one bits" represented in varying sequences.

Diode - An electronic device that allows current to flow in only one direction.

Diode laser - See: **Injection Laser Diode**

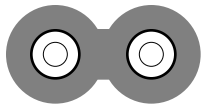
Discrete - Referring to an individual component that is complete in itself. Examples of such are resistors, printed circuit boards, transistors and LEDs.

Dispersion - Distortion of an electromagnetic signal caused by the varying propagation characteristics (speed) of different wavelengths. In an optical fiber the optical pulses spread out.

Distortion - Change in a signal's wave shape. Examples of distortion include dispersion and clipping in an amplifier circuit.

Distortion-limited operation - The condition prevailing when distortion of a received signal, rather than its amplitude (or power), limits performance. The condition reached when a system distorts the shape of the wave form beyond specified limits. In a fiber-optic system, it usually results from dispersion. See also: **Attenuation-limited operation**; **Bandwidth-limited operation**.

Duplex - Dual. A fiber-optic cable that contains two optical fibers.



1088.eps

E

Electron - A particle which orbits the atomic nucleus. It possesses a unit negative electrical charge of 1.6×10^{-19} coulombs.

Electro-optic effect - The change of a material's refractive index or the change of its birefringence under the influence of an electric field. One material that exhibits this effect is lithium-niobate.

End finish - Quality of the surface at an optical-fiber's end, commonly described as mirror, mist, hackle, chipped, cracked, or specified by final grit size of the polishing medium (1 μm, 0.3 μm, etc.).

Endoscope - A medical-optical fiber bundle used to examine the inside of the human body.

End separation loss - The optical power loss caused by increasing the longitudinal distance between the end of an optical fiber and a source, detector, or fiber. See also: **Extrinsic joint loss**.

Equilibrium length - For a specific excitation condition, the length of a multimode optical wave guide necessary to attain stable distribution of optical power among the propagating modes.

Equilibrium mode distribution (EMD*)* - The condition in a multimode optical fiber in which the relative power distribution among the propagating modes is independent of length. Synonym: Steady-state condition. See also: **Equilibrium length**; **Mode**; **Mode coupling**.

Extraordinary ray - A ray that has a non-isotropic speed in a doubly refracting crystal. It does not necessarily obey Snell's law upon refraction at the crystal interface. See also: **Birefringence**; **Ordinary ray**.

Extrinsic joint loss - Light loss caused by imperfect alignment of fibers in a connector or splice. Contributors include angular misalignment, lateral offset, end separation and end finish. Generally synonymous with **Insertion loss**. See also: **Angular misalignment loss**; **End separation loss**; **Intrinsic joint loss**; **Lateral offset loss**.

F

Fall time - Typically specified as the time required for a signal to fall from 90 percent to 10 percent of its original negative or positive amplitude. See also: **Rise time**

Ferrule - A component of a fiber-optic connection that holds a fiber in place and aids in its alignment.

Fiber - The optical wave guide, or light-carrying core or conductor. Generally refers to the combination of optical core and cladding.

Fiber amplifier - A special length of fiber that will amplify optical signals entering its active area. Very similar in operation to a laser amplifier.

Fiber bandwidth - The frequency at which the magnitude of the fiber transfer function decreases to a specified fraction of the zero frequency (DC) value. Often, the specified value is one-half the optical power at zero frequency.

Fiber buffer - A material protecting optical fibers from physical damage by providing mechanical isolation between them and external influences.

Fiber bundle - An assembly of unbuffered fibers. These are usually used as a single transmission channel to transmit light or images which may be either coherent or incoherent.

Fiber-optic link - Any optical transmission channel designed to connect two end terminals.

Fiber optics - A branch of optical technology that deals with the transmission of radiant energy through optical wave guides generally made of glass or plastic.

Fresnel reflection - Reflection losses that occur at the input and output faces of any optical material due to the differences in refractive indexes between them. Similar to "standing wave ratio" in electronics.

G

Graded-index fiber - An optical fiber which has a gradual refractive index change from the center to the edge. This type of fiber has much less dispersion than step-index fiber.

H

Hertz (Hz) - A unit of frequency equivalent to one cycle per second.

I

Inclusion - The presence of an impurity within a body of glass.

Incoherent light - Light that is made up of rays which lack a fixed phase relationship. Most light is incoherent. LEDs produce this type of radiation. See Also: **Coherent**.

Index-matching material - A liquid or cement whose refractive index is nearly equal to that of a fiber's core index; used to reduce Fresnel reflections from an optical fiber's end face. See Also: **Fresnel reflection**; **Refractive index**.

Index of refraction - See: **Refractive index**.

Infrared - Wavelengths longer than 700 nm and shorter than 1 mm. Infrared radiation cannot be seen, but it can be felt as heat.

Infrared light-emitting diode (ILED) - A semiconductor diode very similar to LEDs, but which emits infrared radiation rather than visible light. The manufacturing methods for both LEDs are similar, but they are composed of different semiconductor materials.

Injection laser diode - A solid state semiconductor device consisting of at least one *p-n* junction capable of emitting coherent, stimulated radiation under specified conditions.

Insertion loss - The optical power loss caused by insertion of an optical component such as a connector, splice, or coupler into a previously continuous light path.

Interference - 1. The additive process whereby the amplitudes of two or more waves are systematically attenuated and reinforced. 2. The process whereby a given wave is split into two or more waves by, for example, reflection and refraction of beam splitters, and then reunited to form a single wave.

Intrinsic joint loss - Loss caused by fiber-parameter (e.g., core dimensions, profile parameter) mismatches when two non-identical fibers are joined. See also: **Extrinsic joint loss**; **Lateral offset loss**; **Angular misalignment loss**.

J

Jacket - A layer of material surrounding a fiber but not bonded to it.

Joule - One unit of measure for energy (usually for small amounts).

K

Kilo - A prefix in the SI system meaning one thousand (1×10^3). Abbreviation k.

L

Laser - 1. An acronym for "Light Amplification by Stimulated Emission of Radiation." Laser light is highly directional, occupies a very narrow band of wavelengths and is more coherent than ordinary light. 2. "Laser" also refers to the apparatus which creates laser light.

Lateral offset loss - Optical power loss caused by transverse or lateral deviation from optimum alignment of source-to-optical-fiber, fiber-to-fiber, or fiber-to-detector. See also: **Angular misalignment loss**.

Launch angle - The angle between a light ray and the optical axis of an optical fiber or bundle.

LED - See: **Light Emitting Diode**.

Light - 1. Electromagnetic radiation visible to the human eye. 2. Commonly, the term is applied to electromagnetic radiation with properties similar to those of visible light, including the invisible near-infrared radiation used in fiber optic systems.

Light emitting diode (LED) - A *p-n* junction semiconductor device that emits incoherent optical radiation when biased in the forward direction.

Loss - See: **Absorption**; **Angular misalignment loss**; **Insertion loss**; **Intrinsic joint loss**; **Lateral offset loss**; **Rayleigh scattering**.

M

Macrobending loss - Light losses caused by light rays exiting a wave guide because the incident angle is less than the critical angle, due to fiber bends greater than the fiber's diameter. Does not cause radiation losses.

Mega - A prefix in the SI system meaning one million (1×10^6). Abbreviation, M.

Meridional ray - A ray that passes through the optical axis of an optical fiber (in contrast to a skew ray, which does not). See also: **Axial ray**; **Numerical aperture**; **Skew ray**.

Microbending loss - In an optical fiber, light loss caused by sharp curvatures involving local axial displacements of a few micrometers and spatial wavelengths of a few millimeters. Such bends may result from fiber coating, cabling, packaging and installation. Note: Microbending can cause significant radiation losses and mode coupling.

Micro - A prefix in the SI system meaning one millionth (1×10^{-6}). Abbreviation, µ.

Micrometer - A unit of length in the SI system equal to 1×10^{-6} meters. Abbreviation, µm.

Milli - A prefix in the SI system meaning one thousandth (1×10^{-3}). Abbreviation, m.

Modal noise - The noise generated at the exit aperture of a wave guide when a coherent light source is used. The effect is caused by interference between modes in the wave guide. See also: **Mode**; **Interference**.

Mode - In any cavity or transmission line, one of the electromagnetic field distributions that satisfies Maxwell's equations and boundary conditions. The field pattern of a mode depends on the wavelength, refractive index, and cavity or wave guide geometry. See also: **Equilibrium mode distribution**.

Mode coupling - In an optical fiber, the exchange of power among modes. The exchange will reach statistical equilibrium after propagation over a finite distance that is designated the equilibrium length. See also: **Equilibrium mode distribution**.

Modulate - To modify a single-frequency carrier frequency with a superimposed signal containing information, e.g., amplitude modulation, frequency modulation, phase modulation, pulse modulation. Used whether the carrier is a light-frequency signal or a radio-frequency (RF) signal.

Multifiber cable - An optical cable that contains two or more fibers, each of which provides a separate information channel. See also: **Fiber bundle**; **Cable**.

Multimode fiber - A fiber that permits propagation of more than one mode. The number of modes in a fiber is defined by boundary conditions and Maxwell's equations. The core diameter of multimode fibers can range from 25 - 2,000 microns. See also: **Mode**.

N

n - A symbol used to represent refractive index.

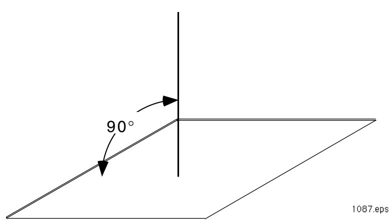
Nanometer - One trillionth of a meter, one millionth of a millimeter. A common unit of measure for wavelengths of high-frequency energy such as light. Abbreviation, nm.

Near-infrared - The shortest wavelengths in the infrared region (700 to 2,000 nm), just slightly longer than those of visible light. Often called near-IR.

Noise currents - Any noise voltage or current that prevents precise measurements. Dark current and thermal noise (from amplifiers and resistors) contribute to noise in fiber optic systems.

Noise equivalent power (NEP) - The rms value of optical power which is required to produce an rms signal-to-noise ratio of 1/1. NEP is an indication of noise level which defines the minimum detectable signal level

Normal - Also referred to as *line normal*. An imaginary line that forms a right angle with a surface or with other lines. The word "normal" is often used rather than "perpendicular" when measuring/describing incident, reflected and refractive angles.



Numerical aperture (NA) - The numerical aperture of an optical fiber defines the characteristic of a fiber in terms of its acceptance of impinging light. The larger the numerical aperture the greater the ability of a fiber to accept light. See also: **Acceptance angle**; **Critical angle**.

O

Optical spectrum - Generally, the portion of electromagnetic spectrum within the wavelength region extending from the ultraviolet at 20 nm to the far-infrared at 100 µm.

Optical time domain reflectometry - A method for characterizing a fiber whereby an optical pulse is transmitted through the fiber and the resulting backscatter and reflections are measured as a function of time. Useful in estimating attenuation coefficient as a function of distance and identifying defects and other localized losses. See also: **Back-scattering**; **Rayleigh scattering**; **Scattering**.

Optical wave guide - Any structure having the ability to guide a flow of radiant energy along a path parallel to its axis and, at the same time, to contain that energy within or adjacent to its surface.

Optoelectronics - The field of electronics that deals with LEDs, lasers, and photodetectors, or any other electronic devices that produce, respond to or utilize optical radiation.

Ordinary ray - A ray that has isotopic speed in a doubly refracting crystal. It obeys Snell's law upon refraction at the crystal surface. See also: **Birefringence**; **Extraordinary ray**.

P

Photoconductivity - A conductivity increase exhibited by some nonmetallic materials, resulting from free carriers generated when photon energy is absorbed in electronic transitions. An example of a photoconductive material is cadmium sulfide (CdS).

Photocurrent - The current that flows through a photosensitive device (such as a photodiode) as the result of exposure to radiant power. See also: **Dark current**; **Photodetector**.

Photodarlington - A light detector in which a phototransistor is combined in a device with a second transistor to amplify its output current.

Photodetector - A detector that responds to incident light upon its surface. See Also: **Photodarlington**; **Phototransistor**; **Photodiode**.

Photon - In the quantum theory of physics, the fixed, elemental unit of light energy. Light can be viewed either as a wave of electromagnetic energy or as a series of photons.

Phototransistor - A transistor that detects light and amplifies the resulting electrical signal. Light falling on the base-emitter junction generates a current, which is amplified internally.

Photovoltaic effect - Production of a voltage difference across a *p-n* junction resulting from the absorption of photon energy. The voltage difference is caused by internal drift of holes and electrons. See also: **Photon**.

Photodiode - A two-electrode, radiation-sensitive junction formed in a semiconductor material in which the reverse current varies with illumination. Photodiodes are used for the detection of optical power and for the conversion of optical power to electrical power. See also: **Avalanche photodiode**.

Planck's Constant - A universal constant (h) which describes the ratio of a quantum of radiant energy (E) to the frequency (ν) of its source. It is expressed:

Plastic clad silica (PCS) fiber - A fiber with a glass core and plastic cladding. This fiber has very high numerical aperture and high light transmission.

Polarization - The electric field vector motion in an electromagnetic wave. Different types of polarization describe different types of sources.

Propagating - Transmitting or moving energy along a path.

Pulse dispersion - The widening of an optical pulse as it travels the length of a fiber. This property — which limits the useful bandwidth of the fiber — is usually expressed in nanoseconds of widening per kilometer. The principal mechanisms are material dispersion and multimode distortion effect.

Q

Quantum efficiency - The conversion of photons/second to electrons/second for detectors and electrons/second to photons/second for light sources.

R

Ray - A geometric representation of a light path through an optical medium: a line normal (perpendicular) to the wave front indicating the direction of radiant energy flow. Compare: **Mode**.

Rayleigh scattering - Scattering by refractive index fluctuations (inhomogeneities in material density or composition) that are small with respect to wavelength. The scattered field is inversely proportional to the fourth power of the wavelength. See also: **Scattering**; **Backscattering**.

Receiver - A device that detects an optical signal and converts it into an electrical form usable by other electronic devices. See also: **Transmitter**.

Refraction - The bending of oblique incident rays as they pass from a medium having one refractive index into a medium with a different refractive index.

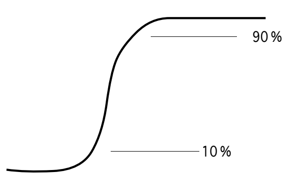
Refractive index - The ratio of the speed of light in a vacuum to the speed of light in a material. Abbreviated n.

Refractive index profile - The description of refractive index as a function of radius in a fiber. See also: **Graded-index fiber**; **Step-index fiber**.

Repeater - In an optical fiber communication system, an optoelectronic device or module that receives an optical signal, converts it to electrical form, amplifies it (or in the case of a digital signal, reshapes, retimes, or otherwise reconstructs it) and re-transmits it in optical form.

Responsivity - The ratio of detector output to input, usually measured in units of amperes per watt (or microamperes per microwatt).

Rise time - The time required for an output to rise from a low level to peak value. Typically specified as the time to rise from 10 percent to 90 percent of its final steady state value. See also: **Fall time**.



S

Scattering - The changes in direction of light confined within an optical fiber, occurring due to imperfections in the core and cladding. Scattering causes no changes in the wavelengths of radiation. See also: **Absorption**.

Sensitivity - 1. Minimum optical power at receiver input required for proper system operation. 2. Sometimes incorrectly used as a synonym for responsivity.

Shot noise - Noise generated by the statistical process of single electrons crossing a *p-n* junction. The mean square shot noise current is directly related to the diode's average current and bandwidth:

$$i^2_{shot} = 2 \bullet e \bullet I \bullet \beta$$

Signal-to-noise ratio (SNR) - The ratio of signal level to noise level, related to bit error rate performance, most often stated in power. See also: **Bit error rate**.

Single-mode fiber - A fiber through which light can travel in only one path, because of the fiber's very small core diameter — less than 10 microns. See also: **Multimode fiber**.

Skew ray - A ray that does not intersect the optical axis of a fiber (in contrast to a meridional ray). See also: **Axial ray**; **Meridional ray**.

Spectrum - See: **Optical Spectrum**.

Splice - A permanent junction between optical fibers. Splices may be thermally fused or mechanically applied. **Splitter** - A passive optical device which divides optical power among several output fibers from a common input. See also: **Combiner**; **Coupler**; **Star coupler**; **Beam splitter**.

Spontaneous emission - Radiation emitted when the internal energy of a quantum mechanical system in an atom drops from an excited level to a lower level without regard to the simultaneous presence of similar radiation. Examples of spontaneous emission include: 1) radiation from an LED, and 2) radiation from the sun. See also: **Injection laser diode**; **Light emitting diode**; **Stimulated emission**.

Star coupler - A passive device in which power from one or more input optical fibers is distributed among a larger number of output fibers. See also: **Combiner**; **Coupler**; **Splitter**.

Step-index fiber - A fiber in which the core has a uniform-refractive index profile which abruptly changes at the boundary between core and cladding.

Steradian (sr) - The unit of solid angular measure, being the subtended surface angle of a sphere divided by the square of the sphere's radius. There are 4 π steradians in a sphere. The solid angle subtended by a cone of half-angle Θ is 2 π (1-cos Θ).

Stimulated emission - Radiation emitted when the internal energy of a quantum mechanical system drops from an excited level to a lower level when induced by the presence of radiant energy at the same frequency. An example is the radiation from an injection laser diode above lasing threshold. See also: **Spontaneous emission**; **Injection Laser Diode.**

T

Total internal reflection - The total reflection of light back into a material when it strikes a boundary at an angle exceeding the critical angle. This is the property that keeps light confined within an optical fiber. See also: **Critical Angle**.

Transducer - A device designed to convert one form of energy into another. Audio speakers for radio, TV and tape decks, convert audio-frequency electrical energy into audible sound. A phonograph cartridge converts mechanical movement of the needle into an electrical signal that activates the speakers.

Transmittance - The ratio of the radiant power transmitted by an object to the incident radiant power. Thus, sunglasses may transmit to your eyes only 10 percent of the light being radiated by the sun.

Transmitter - A device such as a transducer which converts an electrical signal into an optical wave for transmission over a fiber cable. See also: **Receiver**.

U

Ultraviolet - An invisible portion of the optical spectrum whose wavelengths begin immediately beyond the violet end of the visible spectrum. Ultraviolet wavelengths range from approximately 20 to 380 nm. These are the most damaging of the sun's rays to human skin and eyes.

V

Velocity of light - The speed of light in a vacuum, in round numbers, is 300,000 kilometers per second, or 186,000 miles per second. It is less than .01 % slower in air.

W

Wavelength - The distance an electromagnetic wave travels in the time it oscillates through a complete cycle. Wavelengths of light are most often measured in nanometers (nm) or micrometers (mm).

X

Y

Z

Table 3. Metric Prefixes and Their Meanings.

Prefix	Symbol	Multiple
tera	T	10^{12} (trillion)
giga	G	10^{9} (billion)
mega	M	10^{6} (million)
kilo	k	10^{3} (thousand
hecto	h	10^{2} (hundred
deca	da	10^{1} (ten)
deci	d	10^{-1} (tenth)
centi	c	10^{-2} (hundredth)
milli	m	10^{-3} (thousandth)
micro	µ	10^{-6} (millionth)
nano	n	10^{-9} (billionth)
pico	p	10^{-12}(trillionth)
femto	f	10^{-15} (quadrillionth)