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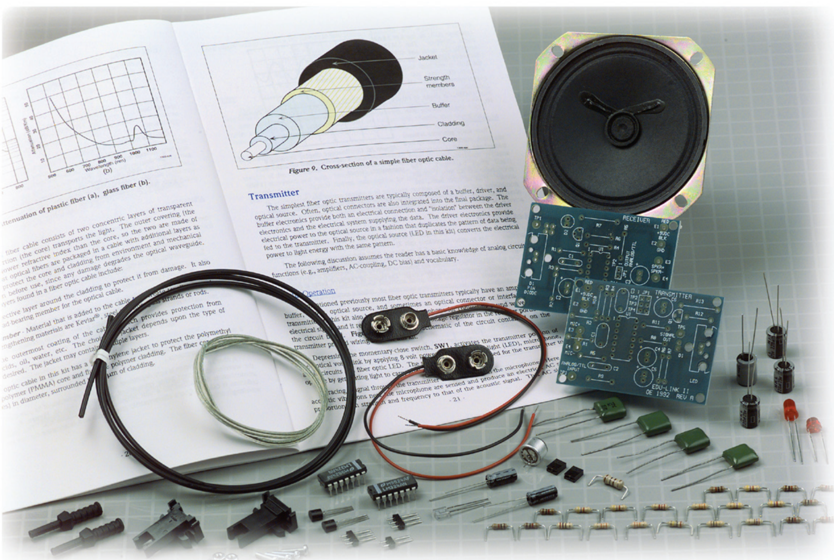
Fiber Optic A/D Kit

Instruction Manual



Model Number:
IF 545

INDUSTRIAL FIBER OPTICS

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Printed in the United States of America

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INTRODUCTION

The Fiber Optic A/D Kit *is an ideal vehicle for instructors, students or hobbyists to explore the fascinating world of fiber optic communications. Instructors will find this kit useful as a self-contained hands-on fiber optics course. Students may use the kit for a science project, while hobbyists can use it as a home or industrial project to amaze their friends. Electronic assembly experience will be gained during construction of the kit. Performing the Experiments and Activities found in this manual will demonstrate analog and digital communication techniques using the electronic microphone or digital oscillator with the fiber optic transmitter, receiver and the fiber cable interfaces. You will hear your own voice, for example, after it has been converted into light and then coupled into, sent through and out of an optical fiber. You will also learn the basics of digital communications technology while working with the digital oscillator and receiver portions of the circuits*

Sincerely,

The Industrial Fiber Optics Team

TABLE OF CONTENTS

PREFACE

You have undoubtedly heard about the wonders of fiber optics. AT&T, Sprint and other large telecommunication companies have saturated the airwaves and print media with advertisements heralding this bright new technology. Futurists talk about the marvels of lightwave communications and photonic technology. Omni magazine writes about “Fiberopolis”. Long-distance telephone calls travel through optical fiber crossing the United States and spanning the oceans to connect the continents.

The enthusiasm is not mere hype; fiber optic technology is real and important. From coast to coast, phone companies are laying fiber in the ground, pulling cable through manholes and stringing it between poles. The military is buying fiber for portable battlefield communications systems, due to its superior performance. Medical fiber optic systems allow physicians to peer inside the human body without surgery. Very few technologies ever realize the fantastic growth rates predicted for them by market analysts. Fiber optics, however, has exceeded predictions.

With the passage of Y2k, fiber optics is becoming more common in your everyday life. It has entered the office environment linking computer networks. In your home, you can now enjoy the pristine clarity of high-definition TV and CD audio. Soon it will provide services that would have been impractical without it: secondary education classes in the comfort of your home, a paper-less, environmentally clean “newspaper”, even faster computer communications, and remote utility meter reading.

Twenty years ago, fiber optics was tucked away in the back pages of optics books, and optics courses were options for senior-level physics majors. Today, most universities have some optics programs, and a few have fiber optics programs. Most of today’s optics experts were trained in other fields, typically electronics or physics. In the years to come this will change.

But today, you are not alone in your interest in fiber optics. Interest has increased substantially as technology advances and begins affecting everyone’s life.

The Fiber Optic A/D Kit is a project-oriented introduction to optical fiber communications. This booklet contains all the information needed to construct this project including component lists, a section on theory of design and operation, assembly instructions and simple exercises to increase your knowledge. A list of references, fiber optics glossary and additional projects complement the instruction.

Welcome to the fascinating and expanding world of fiber optics. We hope that you will find the field an exciting and interesting one in which to work and play.

STARTING OUT

The Fiber Optic A/D Kit is the ideal starting place to begin exploring the mysteries and science of fiber optics. No prior fiber optics experience is needed to build this kit and make it operational. After you've completed assembling the kit, you can use it to demonstrate the unique characteristics of fiber optics just as they are used in a variety of commercial and industrial applications.

This booklet is your guide to understanding the theory of fiber optic communication and it includes complete assembly instructions. Please read those instructions carefully to avoid wiring errors. Several exercises are also included to help you understand this emerging technology. If, after completing this kit you would like to further explore the amazing world of fiber optics, we have included a List of References on pages 38 and 39. You will also find a list of related products we offer on page 40.

The kit you have purchased includes all the parts required to construct a fully functional fiber optic analog or digital link. Before beginning the actual assembly, check the contents of each component packet against the parts lists in Tables 1 and 2 to ensure you have a complete kit. Alkaline batteries are required, but not included (the link may not work properly if you do not use alkaline batteries). The link can be extended up to 10 meters with additional fiber cable purchased separately.

A portion of the instructions suggests the use of an oscilloscope to perform demonstrations and to make some of the measurements. While helpful, an oscilloscope is not necessary. You can complete the kit and learn a significant amount about fiber optics without one.

MATERIALS NEEDED

- Wire cutters
- Small Phillips screwdriver
- 1 ml water or light oil
- 25-watt soldering iron
- Two 9-volt alkaline batteries
- Single-edge razor blade or sharp knife
- Needle-nose pliers
- Small adjustable wrench
- Rosin-core solder
- 18-gauge wire-stripper
- Dual-trace oscilloscope (optional)

ASSEMBLY INSTRUCTIONS

Follow the guidelines below when assembling printed wiring boards:

- Mount all components on the side of the printed wiring boards with the white lettering (Component Side).
- Use the white markings on the printed circuit boards to determine where each part is to be placed.
- All soldering is to be completed on the side opposite components Solder side).
- Use a water-soluble or rosin core solder such as Radio Shack P/N 64-001. Do not use an acid or caustic flux solder such as used in industrial applications.
- Avoid applying prolonged heat (no more than five seconds) to any part of the board or component, to prevent damage.
- After soldering each component, trim its lead length flush with the surface of the solder.

PARTS IDENTIFICATION GUIDE

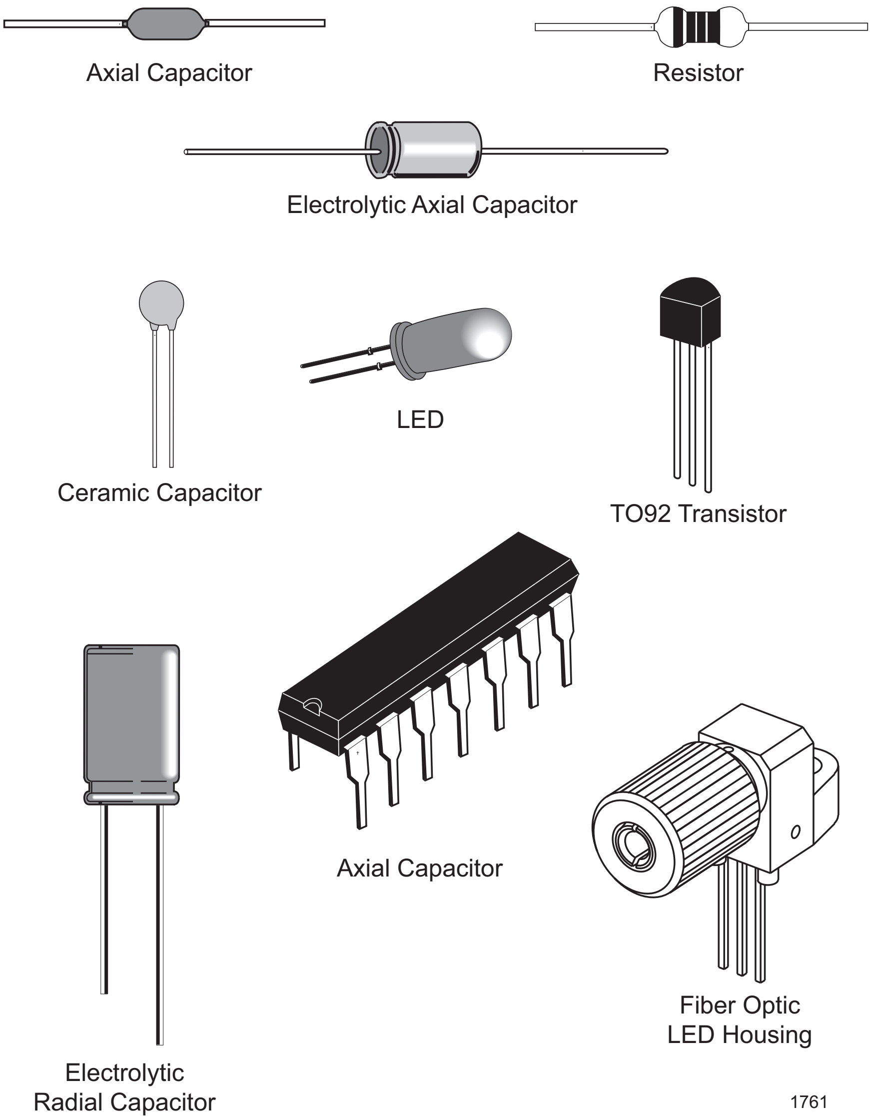


Figure 1. Component identification: resistors, capacitors, ICs, transistor, LED

KIT COMPONENTS

This kit when completed features a transmitter assembly, an inter-connecting fiber optic cable and a receiver assembly. Table 1 contains the component list for the Transmitter, and Figure 2 is the Transmitter Parts Layout Diagram. Table 2 contains the component list for the Receiver, and Figure 3 is the Receiver Parts Layout Diagram. Figure 4 shows the pattern and orientation of the fiber optic cable during polishing.

Transmitter Printed Wiring Board Diagram and Parts

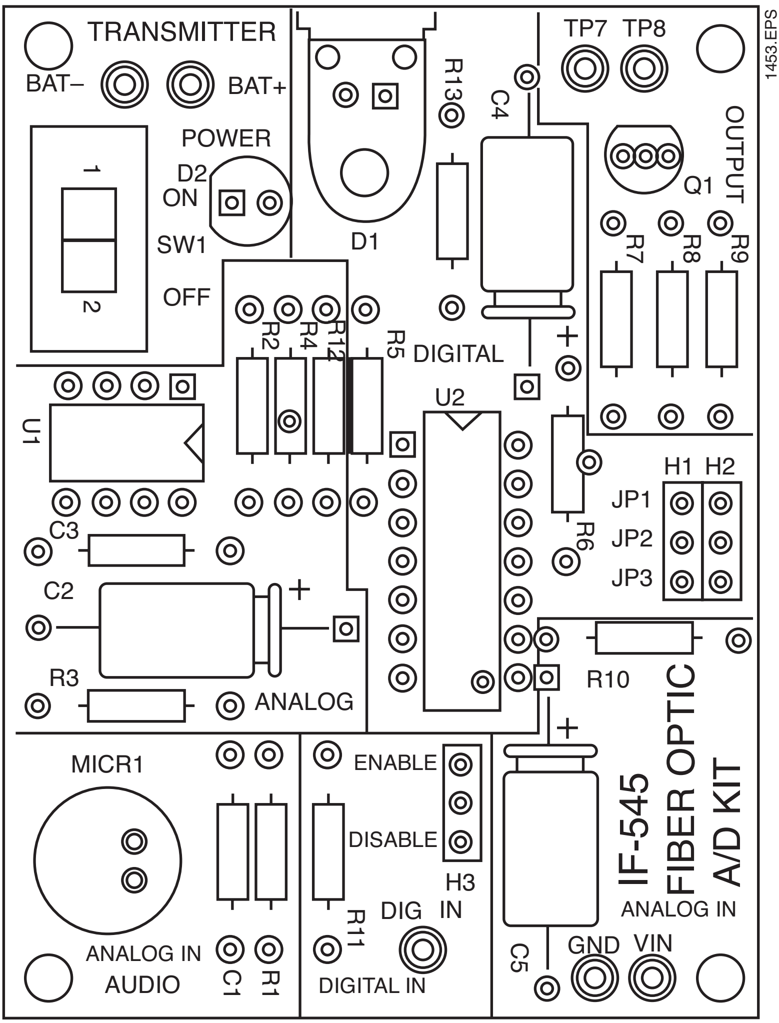


Figure 2. Transmitter parts layout diagram

Table 1. Transmitter printed wiring board parts list.

D/N	P/N	Description	Color-code
C1		.047 µF ceramic axial capacitor	Yellow Violet Orange or 473
C2		10 µF electrolytic axial capacitor	
C3		.1 µF ceramic axial capacitor	Brown Black Yellow or 104
C4		1 µF electrolytic axial capacitor	
C5		10 µF electrolytic axial capacitor	
D1	IF-E96	Fiber optic red LED	Blue housing with pink dot
D2		Green LED, 5 mm package	
H1		3 pin interconnect strip	
H2		3 pin interconnect strip	
H3		3 pin interconnect strip	
H5		2-56 x 3/8 inch long screw	
H6		2-56 nut	
H7		Tandem spring shunt (2)	
H8		Battery clip	
MICR1		Microphone	
PWB1		Transmitter printed wiring board	
Q1	2N3904	General purpose NPN transistor	
R1		2.2 kΩ 1/4 watt resistor	Red Red Red
R2		4.7 kΩ 1/4 watt resistor	Yellow Violet Red
R3		4.7 kΩ 1/4 watt resistor	Yellow Violet Red
R4		47 kΩ 1/4 watt resistor	Yellow Violet Orange
R5		220 kΩ 1/4 watt resistor	Red Red Yellow
R6		33 kΩ 1/4 watt resistor	Orange Orange Orange
R7		4.7 kΩ 1/4 watt resistor	Yellow Violet Red
R8		4.7 kΩ 1/4 watt resistor	Yellow Violet Red
R9		220 Ω 1/4 watt resistor	Red Red Brown
R10		1 kΩ 1/4 watt resistor	Brown Black Red
R11		4.7 kΩ 1/4 watt resistor	Yellow Violet Red
R12		470 Ω 1/4 watt resistor	Yellow Violet Brown
R13		4.7 kΩ 1/4 watt resistor	Yellow Violet Red
SW1		SPDT ON/OFF slide switch	
U1	LM741	General purpose op-amp	
U2	4093	Quad Schmitt trigger NAND Gate	

Transmitter Printed Wiring Board Assembly

1. If the transmitter and receiver printed wiring boards are connected, break them apart along the groove running between them. Set the receiver board aside until you reach the Receiver Printed Wiring Board Assembly section.

2. Insert resistors R1 through R13, one at a time into the printed wiring board (PWB1) and solder them in place.

3. Locate the square pad within the area on the printed wiring board designated for placement of D2 (the green LED). Insert the shortest leg of D2 (the cathode) into the respective square pad on the printed wiring board, and solder into place.

4. There is no positive/negative orientation of capacitors C1 or C3. Identify them, insert their leads through the board and solder them in place. Do not allow solder to touch the body of the component.

5. C2, C4 and C5 are sensitive to the direction in which they are installed. For each one, identify the wire marked with minuses (- - -), then the round pad on the printed wiring board within the area corresponding to that capacitor. Match up the two, insert the leads properly into the board, and solder the capacitor into place.

6. Identify pin 1 of U1 (the lower left pin of the integrated circuit [IC] when viewed from above). Insert the IC into the designated spot marked on the printed circuit board, with pin 1 to your lower left, into the hole with the square pad. Solder in place. Repeat the process with U2.

7. Insert the 3-pin interconnect strips H1, H2 and H3 into the board and solder them in place.

8. Slip one of the tandem spring shunts H7 onto the pair of interconnects labeled JP1. Slip the other one onto H3, between the pin labeled DISABLE and the center pin.

9. Insert Q1 into the board so its shape aligns with the white legend on the printed wiring board. Solder it in place.

10. The battery clip H8 is polarity sensitive also. Insert its red wire into its "+" pad on the board and solder in place. Insert its black lead into its "-" pad on the board and solder in place.

11. Clean the printed circuit board with soap and warm water to remove solder residue. Soapy water will not harm the components as long as electrical power is not being applied — in which case you don't want to get anywhere near water anyway, for safety's sake. If you used a rosin core solder, clean

the board with the flux remover before washing in soap and water. Rinse thoroughly. Shake the board to remove water from under the ICs. Wipe everything dry with paper towels and let air-dry for 30 minutes.

12. The microphone, MICR1, is polarity-sensitive. Insert it so the part outline aligns with the white legend on the printed wiring board. Solder in place

13. Identify D1 as the blue fiber optic housing with a pink dot on one side. Insert D1 in the designated area on the printed wiring board. Fasten in place with a 2/56 × 3/8 inch screw (H5) and nut (H6). Solder the leads.

14. Insert the ON/OFF switch SW1 into the board and solder it in place. The switch is not polarity sensitive, but make sure to turn it to the OFF position after installing it.

15. Insert a 9-volt alkaline battery (user provided) into the battery holder.

Receiver Printed Wiring Board Diagram and Parts

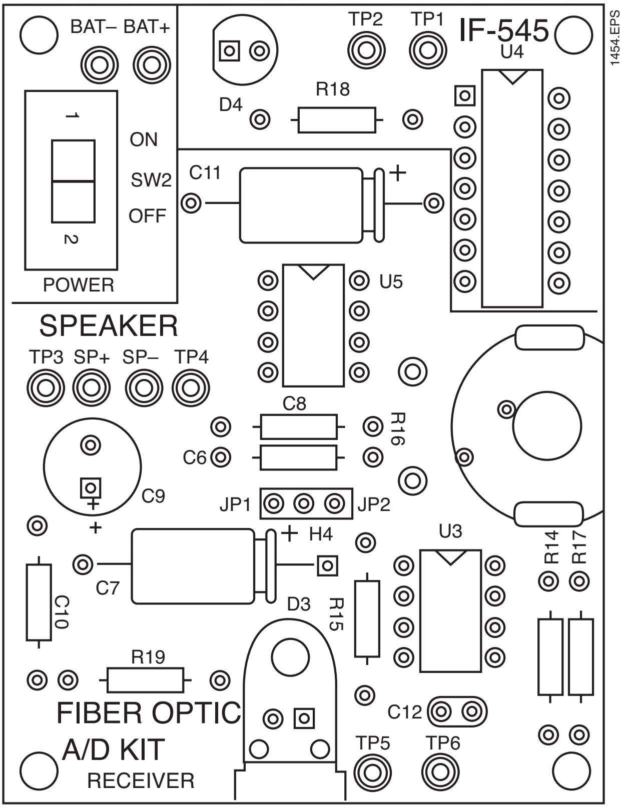


Figure 3. Receiver parts layout diagram

Table 2. Receiver printed wiring board parts list

D/N	P/N	Description	Color-code
C6		.1 µF ceramic axial capacitor	Brown Black Yellow or 104
C7		10 µF electrolytic axial capacitor	
C8		.047 µF ceramic axial capacitor	Yellow Violet Orange or 473
C9		220 µf electrolytic radial capacitor	
C10		.047 µF ceramic axial capacitor	Yellow Violet Orange or 473
C11		10 µF electrolytic axial capacitor	
C12		.001 µF ceramic capacitor	
D3	IF-D91	Fiber optic photodiode	Black housing w orange dot
D4		Red LED, 5 mm dome	
H4		3 pin interconnect strip	
H5		2-56 x 3/8 inch long screw	
H6		2-56 nut	
H7		Tandem spring shunt	
H8		Battery clip	
H9		6 inches speaker wire	
PWB2		Rec. printed wiring board	
R14		1 kΩ 1/4 watt resistor	Brown Black Red
R15		470 Ω 1/4 watt resistor	Yellow Violet Brown
R16		100 kΩ potentiometer	N/A
R17		33 kΩ 1/4 watt resistor	Orange Orange Orange
R18		820 Ω 1/4 watt resistor	Grey Red Brown
R19		10 Ω 1/4 watt resistor	Brown Black Black
SW2		SPDT ON/OFF slide switch	
U3	LM741	General purpose op-amp	
U4	4093	Quad Schmitt trigger NAND Gate	
U5	LM386N	Audio amplifier	
SPKR1		3-inch speaker	
F1		3 meters 1000 µm plastic fiber	
		2000 grit polishing paper	

Receiver Printed Wiring Board Assembly

1. Insert resistors R14 through R19, one at a time into the receiver printed wiring board (PWB2) and solder.
2. C7, C9 and C11 are sensitive to the direction in which they are installed. Identify the wire marked with minuses (- - -), the shortest lead, then the round pad on the printed wiring board within the area corresponding to that capacitor. Match up the two, insert the leads properly into the board, and solder the capacitor into place.
3. There is no positive/negative orientation of capacitors C6, C8, C10 and C12. Identify each, insert their leads through the board and solder in place.
4. Locate the square pad within the area on the printed wiring board designated for placement of D4 (the red LED). Insert the shortest leg of D4 (the cathode) into the respective square pad on the printed wiring board, and solder into place.
5. dentify pin 1 of U3 (the lower left pin of the integrated circuit [IC] when viewed from above). Insert the IC into the designated spot marked on the printed circuit board, with pin 1 to your lower left, into the square hole. Solder in place. Repeat this process for U4 and U5.
6. Solder the leads of the battery clip (H8) into place, red to "+" and black to "-".
7. Separate the two conductors of the speaker wire (H9) about 12 mm (.5 inch) on one end and about 25 mm (1 inch) on the other end. Remove 6 mm (.25 inch) of insulation from both ends of both conductors.
8. Locate an area marked SPEAKER on the receiver printed wiring board. Insert the copper-colored conductor of the speaker wire into the hole marked with a "+" and solder. Insert the other conductor into the other hole and solder it in place.
9. Insert the 3-pin interconnect strip H4 into the board and solder it in place.
10. Slip the tandem spring shunt H7 onto the 3-pin interconnect between the pins labeled JP2.
11. Clean the printed circuit board with soap and warm water to remove solder residue. Soapy water will not harm the components as long as electrical power is not being applied. If you used a rosin core solder, clean the board with the flux remover before washing in soap and water. Rinse thoroughly. Shake the board to remove water from under the ICs. Wipe everything dry with paper towels and let air-dry for 30 minutes.
12. Identify D3 as the black fiber optic housing with an orange dot on one side. Insert D3 in the designated area on the printed wiring board. Fasten it in place with a 2-56 inch × 3/8 screw (H5) and nut (H6). Solder the leads.

13. Insert the potentiometer, R16, into the board and solder in place.

14. Solder the unattached copper-colored wire to the terminal on the speaker (SPKR1) marked with a "+". Solder the remaining unattached wire to the other speaker terminal.

15. Insert the ON/OFF switch SW2 into the board and solder it in place. The switch is not polarity sensitive, but make sure to turn it to the OFF position after installing it.

16. Insert a 9-volt alkaline battery into the battery holder.

Fiber Preparation Instructions

Each end of the optical fiber (F1) must be carefully prepared so it transmits light effectively.

1. Cut off the ends of the cable with a single-edge razor blade or sharp knife. Try to obtain a precise 90-degree angle (square).

2. Wet the 2000 grit polishing paper with water or light oil and place it on a flat, firm surface. Hold the optical fiber upright, at right angles to the paper, and polish the fiber tip with a gentle "figure-8" motion as shown in Figure 4. You may get the best results by supporting the upright fiber against some flat object such as a portion of a printed wiring board.

(Do not insert the fiber ends into the fiber optic LED or photodetector until instructed to do so in a later section.)

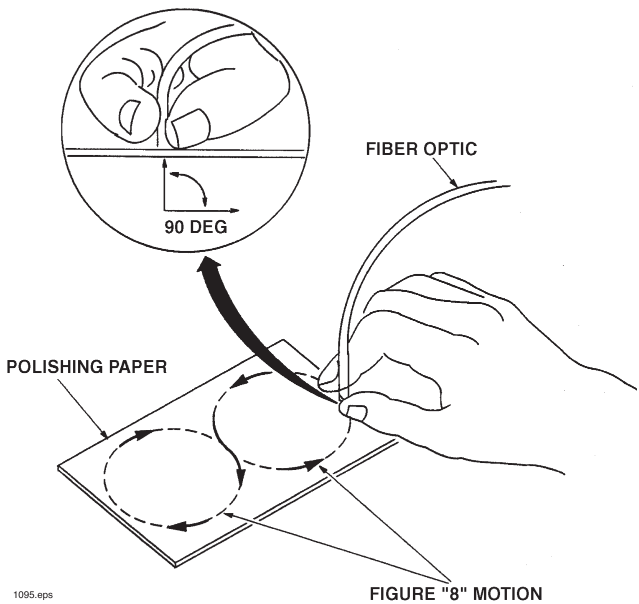


Figure 4. Pattern and orientation of the optical fiber during polishing

EXPERIMENTS AND ACTIVITIES

Record your answers in the space provided after each question.

A1. Grasp an optical fiber near its tip between your thumb and forefinger. Point it toward a light source and observe the other end of the fiber. Note the changes in brightness in that end as you move the other end around, or cover its tip with a finger. Do any colors seem to transmit better than others?

A2. Holding the fiber about .5 mm (.02 inches) from this page, move it left to right across the heading of this section. What changes do you observe in the brightness at the other end of the fiber?

A3. Insert a 9-volt battery into the battery clip attached to the transmitter board and place switch SW1 to the ON position to energize this assembly. The fiber optic LED D1 should glow red light. If not, check battery condition and assembly of the printed wiring board including installation of R7 through R9 and Q1.

A4. On the transmitter board slip a tandem spring shunt onto the pair of interconnect squares labeled JP1. Slip another one onto H3 between the center pin and the pin labeled DISABLE. With an oscilloscope, first using AC and then the DC input coupling, vary the sweep setting and observe the voltage at the output TP7. While talking, crumpling paper, whistling, humming, blowing a whistle, tapping your finger on the microphone, or clapping your hands, observe the different waveforms produced on the oscilloscope display. Describe or draw below the amplitude and duration of the signals seen on the oscilloscope.

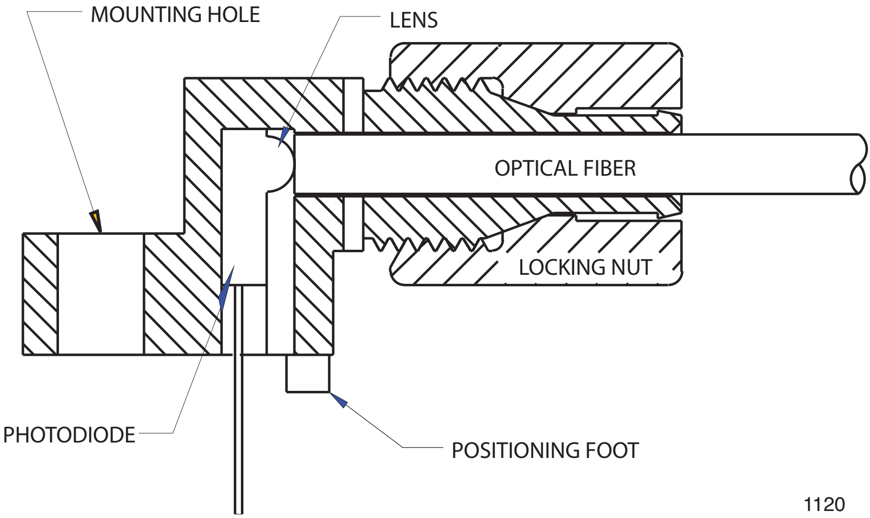
A5. Do you see a periodic signal on the oscilloscope display when humming or whistling? If you change pitch does the period of the measured signal on the oscilloscope change?

A6. In electronic design, multiple circuits often will achieve the same design goals. We'd now like you to design an alternate electronic LED drive circuit that will accept an external oscillator input signal. Draw that circuit below. You may use Figure 14 as a reference.

A7. On the transmitter board, measure the voltage across R9 with an oscilloscope or multimeter. Calculate the current through the red fiber optic LED D1.

A8. What is the minimum voltage out of LM741 in the circuit shown in Figure 14 before the red fiber optic LED would turn off, or become very non-linear? Assume Vf of the LED is 1.6 volts.

A9. Assuming that the maximum voltage output from the 9-volt battery is 8.5 volts under load, what is the maximum current that can flow through the red fiber optic LED D1 when being driven by U1 through Q1 and R9?



1. Insert the prepared fiber end through the cinch nut and into the connector until the core tip seats against the molded lens inside the device package.

2 Screw the connector cinch nut down to a snug fit, locking the fiber in place.

Figure 5. Cross-section of fiber optic LED and cable

A10. Slip a tandem spring shunt onto the 3-pin interconnect H4, between the center pin and JP2. Connect the transmitter and receiver assemblies with the optical fiber, following the steps in Figure 5. Move the transmitter and receiver printed wiring boards as far apart as the fiber length will allow.

A11. Turn the receiver switch ON and turn R16 clockwise to about the midway position. Speak into the microphone. You should hear your voice from the speaker at the receiver end. (If a high-pitched sound is produced by the receiver reduce the volume by adjusting R16 counterclockwise.) In the space below describe the quality of your voice reproduction at the receiver.

A12. Using both channels of a dual-trace oscilloscope, look at the signals at the output of U1 (pin 6) on the transmitter and U3 (pin 6) on the receiver. Observe the signals at both points while whistling softly. Describe the signals. Are the two signals in phase? Move closer to the microphone or whistle louder. Can you see signals on the oscilloscope beginning to get distorted? When distortion is visible on the oscilloscope display, what is the quality of sound coming from the receiver?

A13. Assuming that this receiver needs 10×10 -6 watts of light to reproduce the audio signal, the transmitter launches 200×10 -6 watts of power into the fiber and the fiber has .2 dB of attenuation per meter, determine the maximum length of cable that can be installed between transmitter and receiver and still function properly.

A14. With the transmitter and receiver assemblies as far apart as possible, adjust the gain of the receiver to as high as possible without the receiver producing a high-pitched squeal. Have somebody touch the transmitter microphone to a mechanical clock. Can you hear the gears inside the clock moving, through the receiver speaker? Repeat this experiment with an electric clock.

A15. Disconnect the fiber from the transmitter, leaving the fiber connected to the receiver. Turn R16 on the receiver board clockwise to maximum. Hold the free end of the fiber up to a fluorescent light. What do you hear? The noise you hear is 120 Hz, twice the frequency of the 110-volt, 60 Hz AC input. The fluorescent light is pulsing; it is not actually “on” all the time. Repeat this procedure, holding the fiber close to an incandescent light bulb. What do you hear now? Describe the difference.

A16. Assuming the shunt is across JP1, what is the numerical value for the current through the fiber optic LED in terms of millivolts of input voltage to U3, the LM741 op-amp ? (Answer is in mA/mV.) What is the numerical value of the voltage output to the speaker in terms of milliwatts of optical power on the base of Q1? Assume the responsivity of Q1 to be 100 mA/mW.

On the transmitter board, move the tandem spring shunt that is in the JP1 position to the JP2 position. Move the shunt that is in the DISABLE position to the ENABLE position. On the receiver board, move the tandem spring shunt to the JP1 position. Turn power on to the oscilloscope and set the horizontal time scale to .2 milliseconds per division and the vertical scales to 2 volts/division for both channels. Hook up one probe of a dual-trace oscilloscope to TP7 on the transmitter circuit and the other to TP1 on the receiver circuit. (You should see two square wave signals similar to those shown in Figure 6.)

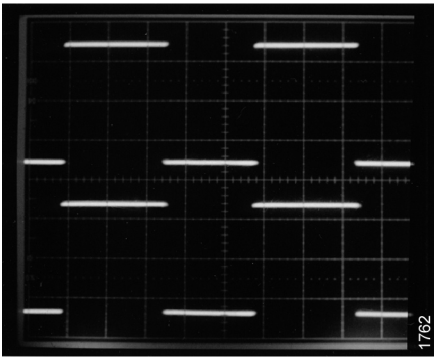


Figure 6. Two oscilloscope traces of: transmitter TP7 (top) and receiver TP1 (bottom) signals

A17. Measure the transmitter board's oscillator period with the oscilloscope and calculate the oscillating frequency.

_________________________ Hz

A18. Compare the signal on the transmitter from TP7 (emitter of transistor Q1) to TP1 on the receiver and observe the received signal as depicted in Figure 6. Is the frequency the same?

A19. Measure the rise and fall time at TP1. Estimate or determine the maximum data rate this data link could transmit. (Hint: The answer can be empirically determined using an external function generator connected to the Vin input, or analytically determined, from the measured rise and fall times.)

A20. How would you change the sensitivity or gain of this receiver?

A21. Remove the tandem spring shunt from the interconnect on H4. Measure and record the voltage at pin 6 of U3. Determine the minimum power input to the photodiode from the fiber (assuming its responsivity is 0.2 µA/µW) necessary to create this voltage.

A22. If an optical radiometer or fiber optic power meter is available to you, disconnect the optic fiber from the receiver photodiode and measure the optical power coming out of the fiber. Recalculate the maximum distance for which this data link can be used, based on the actual measured power out of the fiber.

A23. Design a fiber optic transmitter and receiver circuit using PNP transistors and a negative 5-volt power supply. Draw your design below.

“NUTS AND BOLTS” OF FIBER OPTICS

Before fiber optics came along, the primary means of real-time, reliable data communication was electrical in nature. It was accomplished using copper wire or by transmitting electromagnetic (radio) waves through free space. Fiber optic technology changed that by providing an alternate means of sending information over significant distances using light energy. Although initially a very controversial technology, fiber optics has today been shown to be very reliable and cost-effective.

Light, as utilized for communications, has a major advantage because it can be manipulated (modulated) at significantly higher frequencies than electrical signals. For example, a fiber optic cable can carry up to 100 million times more information than a telephone line! The fiber optic cable has lower energy loss and wider bandwidth capabilities than copper wire.

As you will learn, fiber optic communication is a quite simple technology, closely related to electronics. In fact, it was research in electronics that established the groundwork for fiber optics to develop into the communications giant that it is today. Fiber optics became a reality when several technologies came together simultaneously. It was not an immediate process, nor was it easy, but it was most impressive when it occurred. The type of LED used in this educational kit is one example of a critical product that emerged from that technological merger. The following sections provide more detail about the electronics nature of a basic fiber optic data link, and the theory of operation for your Industrial Fiber Optics kit.

Advantages of Fiber Optics

Fiber optics has at least eight advantages over conventional copper cables:

- Greater information carrying capabilities
- Smaller cable diameter
- Lighter weight per cable length
- Greater transmission distance
- Immunity to electrical interference
- Cables do not radiate energy
- Greater reliability
- Lower overall cost

Elements of a Fiber Optic Data Link

A fiber optic data link basically contains three main elements: a transmitter, an optical fiber and a receiver. The transmitter takes data previously in electrical form and transforms it into optical (light) energy containing the same information. The optical fiber is the medium which carries the energy to the destination (receiver). At the receiver, light is converted back into electrical form with the same pattern as originally fed to the transmitter by the person who sent the message.

It is important to note that optical energy can be beamed through the air or free space (like a flashlight beam). In fact, there are applications in which communication through air is used when installing optical fiber would be too costly or impractical. The advantages of optical fiber are that it allows light to be routed around corners and transported through obstructions (such as walls in buildings), just as household electrical and telephone wiring do, but with much greater signal-carrying capacity, plus being able to operate at greater distances and on foggy and rainy days.

Also contained in fiber optic data links are connectors that provide the connections among transmitter and receiver modules and optical fiber. These allow quick addition or removal of modules, and the ability to offer communication capabilities at multiple locations using various “coupling” and “splitting” devices.

The educational kit you have constructed contains all the elements described above with the exception of multiple distribution devices, since it links a single receiver and transmitter. The transmitter and receiver circuits in this kit are analog. This means the sound waves are converted into light to transmit through the fiber and then converted back into electrical and acoustic waves at the receiver. We will not digitize the audio sounds and recreate them at the receiver as is done in telephone fiber optic networks.

LIGHT: A REVIEW

The operation of an optical fiber depends on the basic principles of optics and the interaction of light with matter. The first step in understanding fiber optics is to review some of the properties of light.

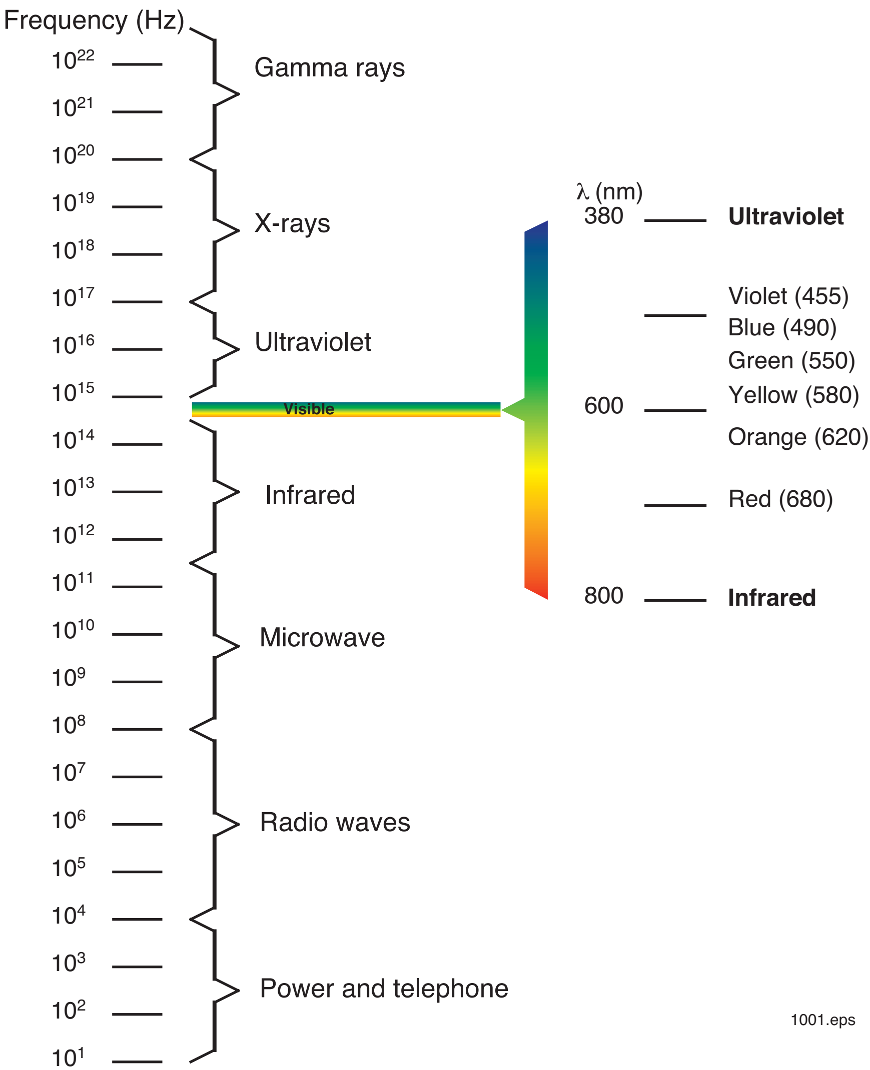


Figure 7. The electromagnetic spectrum