Fiber Optic A/D Kit

Instruction Manual

Model Number:
IF 545

INDUSTRIAL FIBER OPTICS

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Revision I

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

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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

Axial Capacitor

Resistor
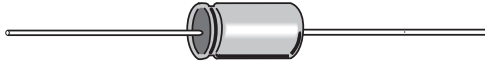
Electrolytic Axial Capacitor

Ceramic Capacitor
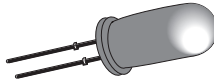
LED
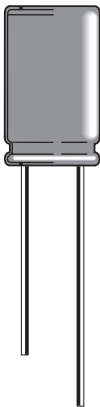
TO92 Transistor
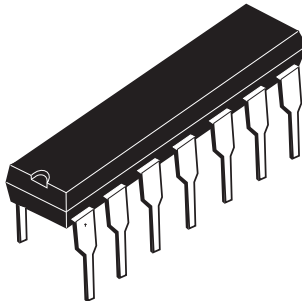
Axial Capacitor

Fiber Optic
LED Housing

Electrolytic
Radial Capacitor
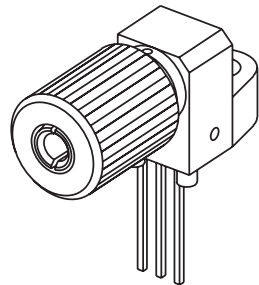
1761

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
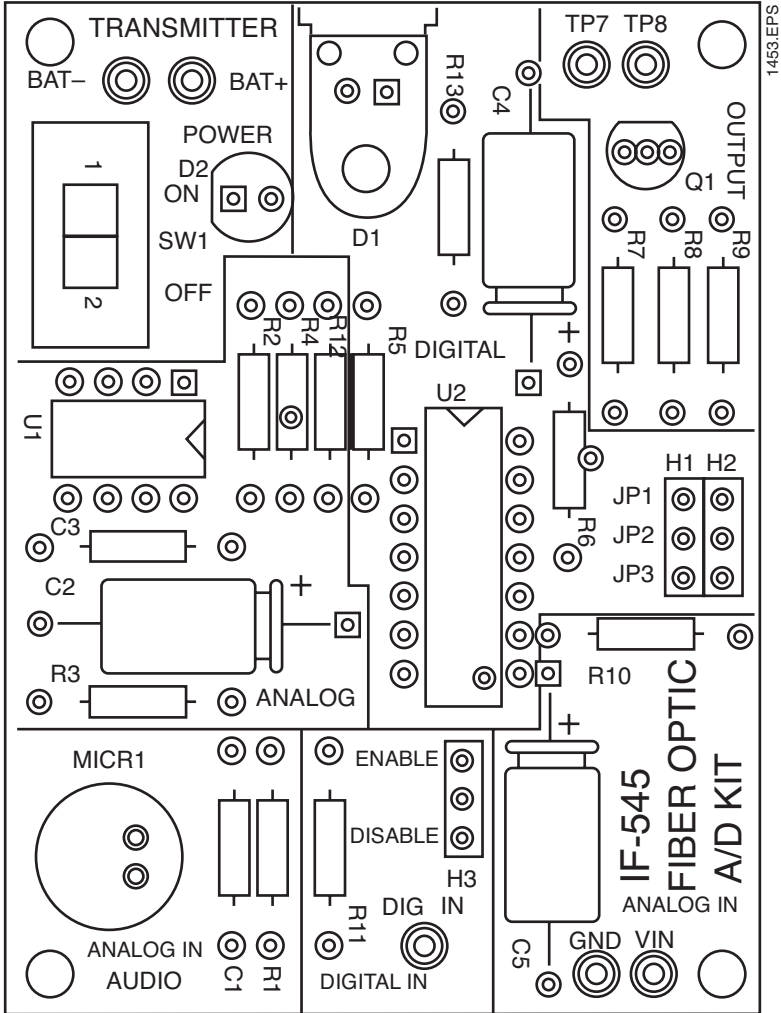
Figure 2. Transmitter parts layout diagram

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-E96E	Fiber optic red LED	Blue housing with orange dot or P/N
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 an orange dot on one side or P/N on top. 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
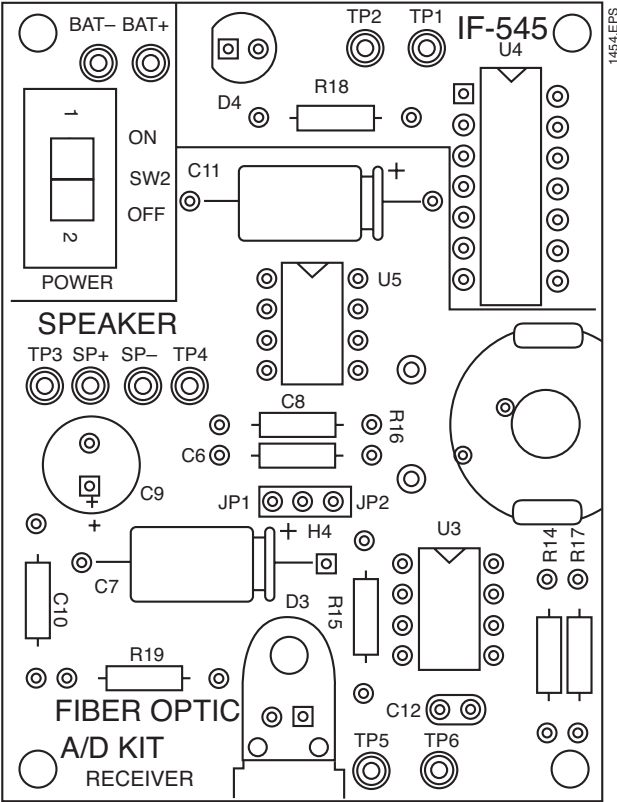
Figure 3. Receiver parts layout diagram

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 or P/N
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 or P/N on top. 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.)
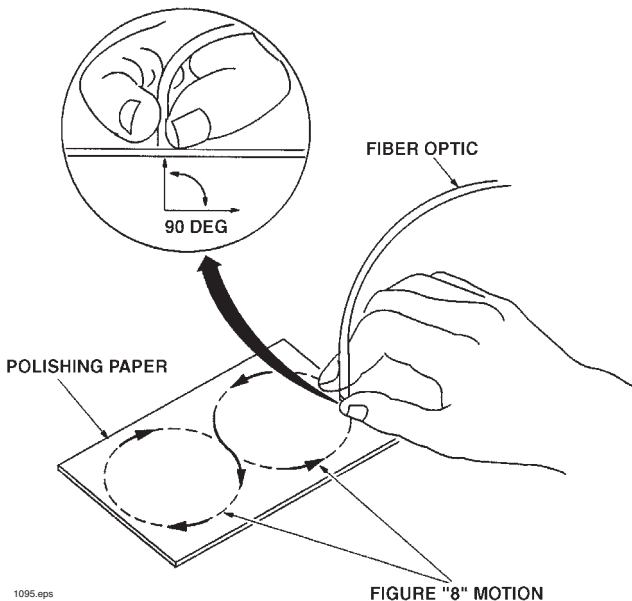

90 DEG

FIBER OPTIC

POLISHING PAPER

FIGURE "8" MOTION

1095.eps

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?

MOUNTING HOLE   LENS

OPTICAL FIBER

LOCKING NUT

PHOTODIODE

POSITIONING FOOT
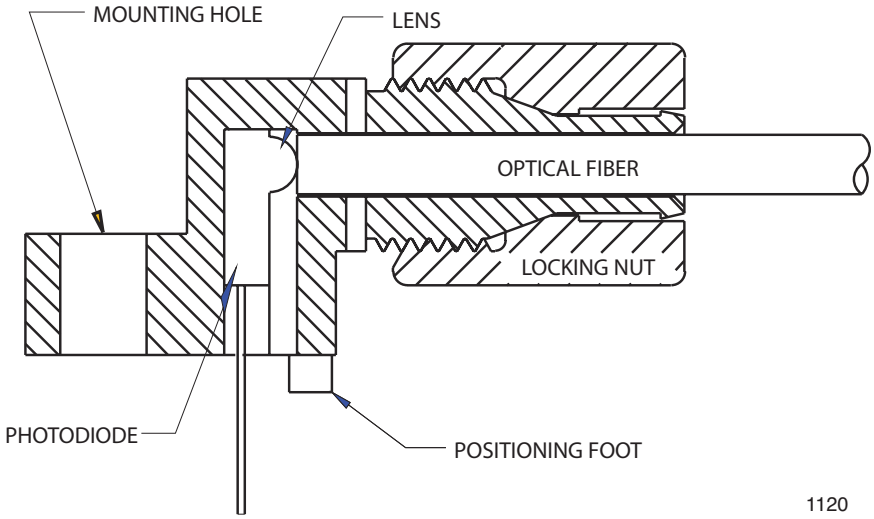
1120

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.)

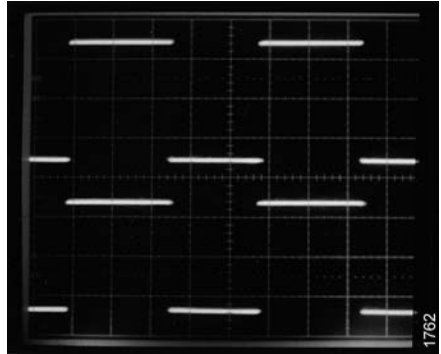**Figure 6. Two oscilloscope traces of: transmitter TP7 (top) and receiver TP1 (bottom) signals**

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?

– 15 –

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.

Frequency (Hz)

10^{22}	Gamma rays
10^{21}	
10^{20}	
10^{19}	X-rays
10^{18}	
10^{17}	
10^{16}	Ultraviolet
10^{15}	
10^{14}	Visible
10^{13}	Infrared
10^{12}	
10^{11}	
10^{10}	Microwave
10^{9}	
10^{8}	
10^{7}	
10^{6}	Radio waves
10^{5}	
10^{4}	
10^{3}	
10^{2}	Power and telephone
10^{1}	

λ (nm)

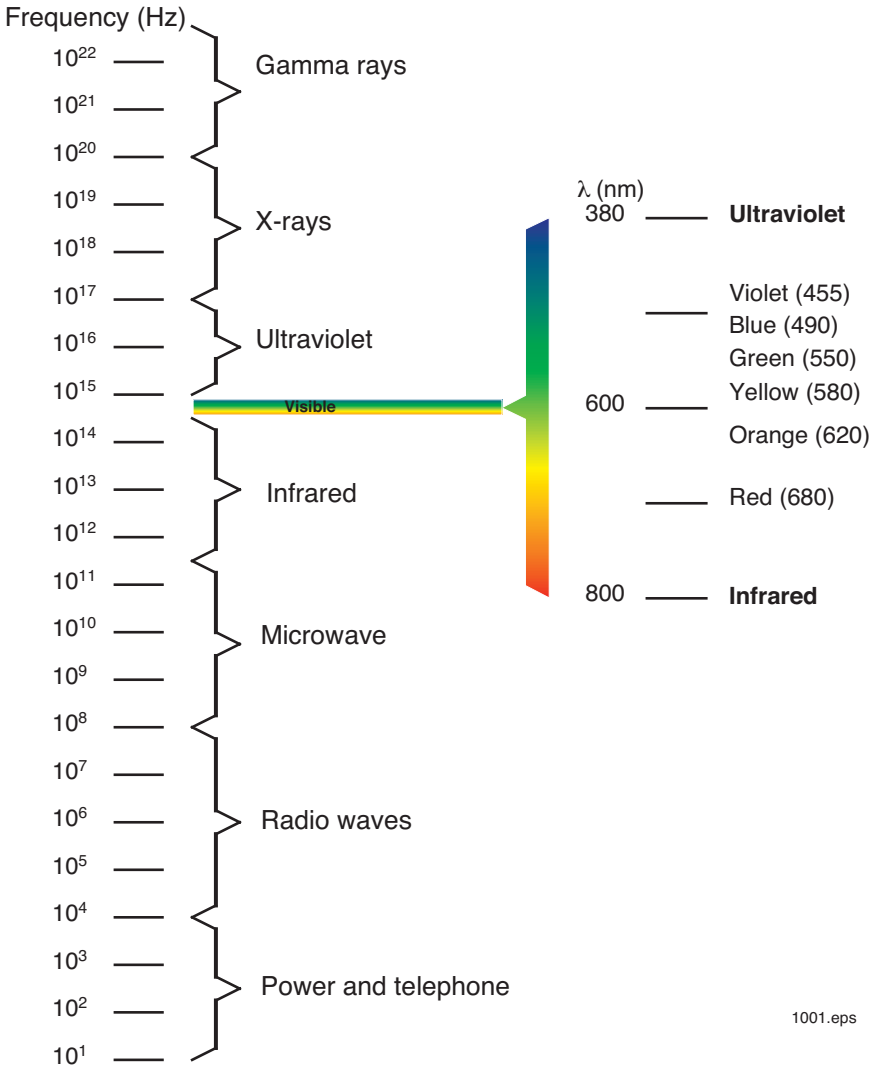|	
380	**Ultraviolet**
	Violet (455)
	Blue (490)
	Green (550)
600	Yellow (580)
	Orange (620)
	Red (680)
800	**Infrared**

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Figure 7. The electromagnetic spectrum

Wavelength and Particles

Many of light's properties are explained by thinking of light as an electromagnetic wave. "Light" is a small part of the electromagnetic spectrum as can be seen in Figure 7. The relationship between light's wavelength and frequency is described by Equation 1:

$$\lambda = \frac{c}{f}$$

Equation 1.

where c is the speed of light and f is frequency.

Light is higher in frequency and shorter in wavelength than the more common AM and FM radio waves. Visible light ranges from 380 nanometers, (nm), as far deep violet, to 750 nm, as far deep red. Infrared radiation has longer waves than visible light. Most fiber optic systems operate using infrared light with wavelengths between 750 and 1500 nm.

Light also has some particle-like properties similar to electrons (atomic). A light particle is called a photon, a discrete unit of energy, but it has no mass. The amount of energy contained by a photon depends on its frequency. The higher the frequency, the higher the energy. The energy, E, in joules, contained by a photon is:

$$E = h \bullet f$$

Equation 2.

where f is frequency in Hz and h is Planck's constant, which is $6.63 \times 10\text{-}34$ joule-seconds.

The ability of light to sometimes act as a wave and sometimes act as a particle prompted the famous "wave-particle duality" theory of modern physics. Using both of light's properties is important in fiber optics. For example, many properties of optical fiber vary with wavelength, so the wave description is used. The responsivity of optical detectors is best explained by light's particle theory.

Refractive Index

The most important optical measurement for any optical material is its refractive index (n). Refractive index is the ratio of the speed of light in a vacuum to the speed of light in a material.

$$n = \frac{c_{vacuum}}{c_{material}}$$

Equation 3.

Table 3. Refractive indices of some common materials.

Material	Refractive Index
Vacuum	1.0
Air	1.00029
Water	1.33
Fused quartz	1.46
Glass	1.45 - 1.6
Silicon	3.4
Diamond	2.0
Gallium arsenide	3.6

The speed of light through any material is always slower than in a vacuum, so all materials' refractive indici are greater than one. In practice, the refractive index is measured by comparing the speed of light in the material to that in air, rather than in a vacuum. This simplifies the measurements and in most cases does not make any practical difference, since the refractive index of air is very close to that of a vacuum. See Table 3.

WHY OPTICAL FIBER WORKS AS IT DOES

Light travels in straight lines through most optical materials, but that's not the case at the junction (interface) of two materials with different refractive indices. Air and water are a case in point, as shown in Figure 8. The light ray traveling through air actually is bent as it enters the water. The amount of bending depends on the refractive indices of the two materials involved, and also on the angle of the incoming (incident) ray of light as it strikes the interface. The angle of the incident ray is measured from a line drawn perpendicular to the surface. The same is true for the angle of the refracted ray of light after it has been bent. The mathematical relationship between the incident ray and the refracted ray is explained by Snell's Law:

$$n_1 \bullet \sin\Theta_1 = n_2 \bullet \sin\Theta_2$$

Equation 4.

in which n_1 and n_2 are the refractive indices of the initial and secondary materials, respectively, and Θ_1 and Θ_2 are the incident and refracted angles.
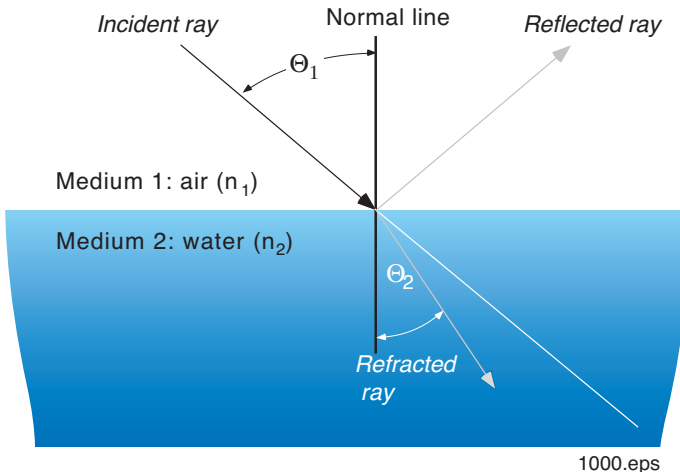

Figure 8. The different portions of a light ray at a material interface.

Snell's equation can be rearranged to determine the refracted angle, Θ_2, knowing n_1, n_2, and Θ_1.

$$\Theta_2 = arc\sin\left(\frac{n_1}{n_2} \bullet \sin\Theta_1\right)$$

Equation 5.

When n_1 is larger than n_2 there are angles of incidence in which

$$\frac{n_1}{n_2} \bullet \sin\Theta_1 \geq 1$$

Equation 6.

In this case, the refracted light ray does not exit. One hundred percent of light is reflected at an angle equal to the angle of incidence as if the boundary of n_1 and n_2 were a mirror. (Recall from trigonometry that the maximum value of the sine of any angle is 1.) The phenomenon just described is called total internal reflection. The angle at which this total internal refection occurs is

$$\Theta_{critical} = arc\sin\frac{n_2}{n_1}$$

Equation 7.

The concept above, which has been discussed in one dimension, can be further expanded into two dimensions which would then have the capability of channeling or directing light from one point to another. The most common two-dimensional structure to achieve is a solid rod of material surrounded by a layer of lower-refractive-index material. This two-dimensional structure is the fundamental construction of all optical fibers as shown in Figure 9. The total internal reflection property (where the outer layer has a lower refractive index than the core) is a critical element of the principal theory for light transmission in all optical fibers. If you'd like to learn more about the mathematics governing fiber optics, we recommend that you consult the books listed in the References section. A diagram of a light ray traveling down an optical fiber strand is shown in **Figure 9**.
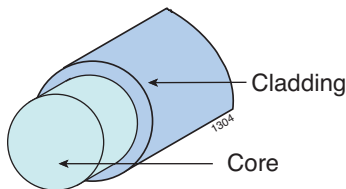

**Figure 9. A light ray traveling through and trapped by
total internal reflection inside an optical fiber.**

Numerical Aperture

The critical angle of an optical fiber although, critical to understanding how a fiber operates, is not normally a specified value. Acceptance angle and numerical aperture are the common specifications and are related to the critical angle. Numerical aperture of an optical fiber can be calculated from the core's and cladding's refractive indices.

$$NA = \sqrt{n_{core}^2 - n_{cladding}^2}$$

Equation 8.

Acceptance angle can be determined by the following equation:

$$\Theta_{acceptance} = 2 \bullet arc\sin\sqrt{n_{core}^2 - n_{cladding}^2}$$

Equation 9.

Acceptance angle of a fiber is the half cone angle of the light that can be launched into an optical fiber and be reflected internally as shown in Figure 10. A fiber's numerical apertures or acceptance angles are used to determine collection efficiency from LEDs and photodetectors.

Fiber Materials

Optical fiber is made from three types of materials:

- Glass
- Plastic
- Other

More than 99 percent of all optical fiber used for data communications in the world is made from glass or plastic. The category "other" includes exotic optical materials such as silicon or gallium arsenide, which are used for special ultraviolet or infrared light applications.
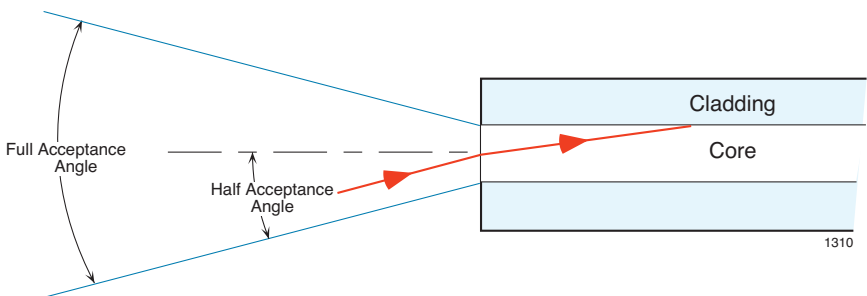

Figure 10. Optical fiber showing the acceptance angle of light.

Glass has superior optical qualities compared to plastic, but is more expensive, harder to cut and requires special end connections. Glass fiber is typically used for high-data-rate/long-distance transmission and for medical applications because it can be autoclaved and is impervious to body fluids. For lower data rates and distances less than 150 meters, plastic fibers are more economical, easy to terminate and do not require special tools. A very small amount of fiber is a hybrid solution — plastic-cladding glass. The fiber core is high quality glass, with an inexpensive plastic cladding.

Attenuation

Throughout this manual we have praised the capabilities of fiber optics. Although fiber has many advantages it is not perfect because a certain amount of light is lost as it travels through the optical fiber. This loss is called attenuation, and it has several causes:

- absorption by the material through which light travels
- scattering of light out of the fiber core by imperfections in the fiber
- leakage of light from the core caused by environmental factors such as moisture

Fiber attenuation is measured by comparing output power with input power. Attenuation of a fiber is most often described in decibels (dB). The decibel is a logarithmic unit, relating the ratio of output power to input power. Loss in decibels is defined as:

$$Loss = 10 \bullet Log_{10} \frac{P_o}{P_i}$$

Equation 10.

If the output power from a fiber is 0.001 of the input power, the signal has experienced a 30 dB loss. (The minus sign has been dropped for convenience and is implied on all attenuation measurements.)
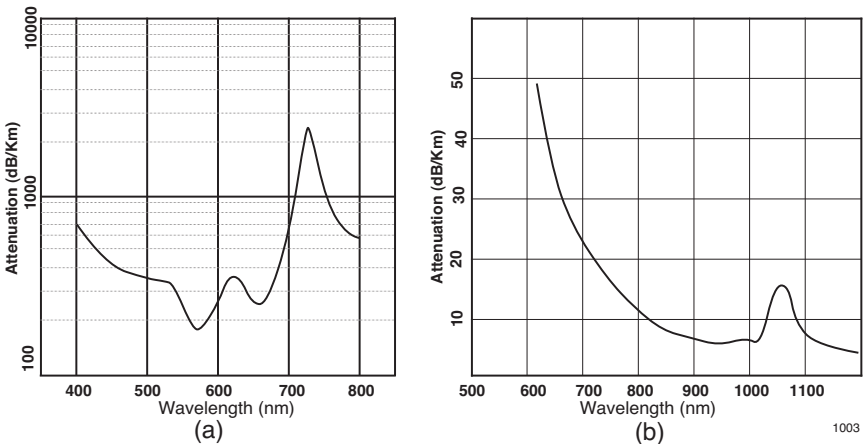

Figure 11. Attenuation of plastic fiber (a), glass fiber (b).

A fiber's attenuation is very dependent upon the composition of its core material and the wavelength of light being transmitted, as can be seen in Figure 11. A fiber's attenuation is normalized for a unit length, usually in kilometers. This normalized definition is called a fiber's characteristic attenuation and is accurate for the measured wavelength only.

Fiber Construction

The simplest optical fiber cable consists of two concentric layers of transparent materials. The inner portion (the core) transports the light. The outer covering (the cladding) must have a lower refractive index than the core, so the two are made of different materials. Most optical fibers are packaged in a cable with additional layers to protect the core and cladding from environmental and mechanical damage or degradation before use, since any damage degrades the optical waveguide. Common additional layers found in a fiber optic cable, as shown in Figure 12, include:

Buffer - A protective layer around the cladding to protect it from damage. It also serves as the load-bearing member for the optical cable.

Strength Member - Material that is added to the cable to increase tensile strength. Common strengthening materials are Kevlar®, steel and fiberglass strands or rods.

Jacket - The outermost coating of the cable, which provides protection from abrasion, acids, oil, water, etc. The choice of jacket depends upon the type of protection desired. The jacket may contain multiple layers.

The fiber optic cable in this kit has a polyethylene jacket to protect the polymethyl methacrylate polymer (PMMA) core and fluorine polymer cladding. The fiber core is 980 µm (0.04 inches) in diameter, surrounded by 10 µm layer of cladding.
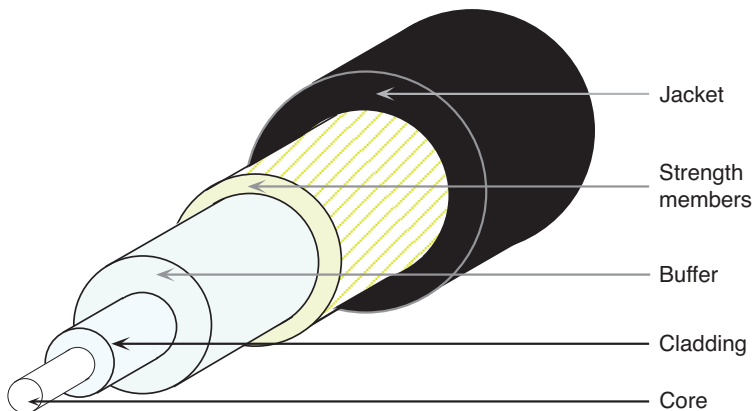
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Figure 12. Cross-section of a simple fiber optic cable.

TRANSMITTER THEORY OF OPERATION

Fiber optic transmitters are typically composed of a buffer, driver and optical light source. Often, optical connectors are also integrated into the final package. The buffer electronics provide both an electrical connection and "isolation" between the driver electronics and the electrical system supplying the data. The driver electronics provide electrical power to the optical light source in a fashion that duplicates the pattern of data being fed to the transmitter. Finally, the optical source (LED in this kit) converts the electrical power into light energy with the same pattern.

The following discussion assumes the reader has a basic knowledge of analog circuit functions (e.g., amplifiers, AC-coupling, DC bias) and vocabulary. It also assumes the reader has a basic knowledge of digital logic functions (e.g., AND, NAND, OR, NOR) and theory of transistor operation.

Circuit Operation

As mentioned previously, most fiber optic transmitters typically have an amplifier or buffer, driver, optical source, and sometimes an optical connector or interface. The transmitter in this kit also has an acoustic microphone for converting sound waves to an electrical signal, analog and digital inputs for external sources, and a digital signal source that produces a 10 Hz square wave. Figure 13 shows the block diagram; and Figure 14 shows the schematic of the transmitter printed wiring board in this kit.

The circuit requires a 9-volt battery to provide electrical power. The ON/OFF switch SW1 must be in the ON position for the transmitter to generate light that will carry audio, analog and digital signals.
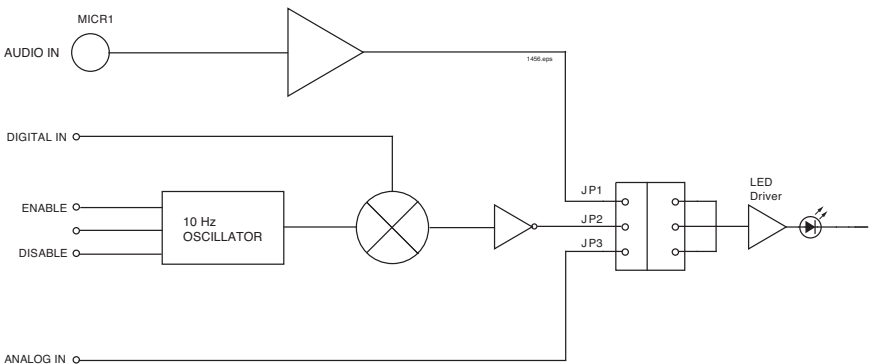

Figure 13. Transmitter block diagram.

Analog

Tracing a signal through the audio portion of the transmitter circuit starts with the microphone. Here any acoustic vibrations near the microphone are sensed and produce an electrical AC signal proportional in strength and frequency to that of the acoustic signal. This AC signal is coupled through the DC blocking capacitor C1 to the LM741 op-amp U1. The LM741 amplifies the signal and drives the base of the NPN transistor Q1. Q1 acts as a current amplifier to produce sufficient current to drive the fiber optic LED D1. The output of the LED is red light with a DC component and AC signal superimposed upon it from the LM741. A typical output signal from the transmitter is shown in Figure 15.

Your voice produces acoustic vibrations, which are picked up by a microphone MICR1 containing a sensitive membrane and an FET (field effect transistor) amplifier. The microphone and R1 form a voltage divider. With no voice input, the microphone acts as a passive resistor, resulting in a voltage across the microphone of about eight volts. When sound is sensed by the microphone, its resistance (and voltage across it) will vary according to the amplitude and the frequency of the signal source.

An external analog signal may be applied through the ANALOG IN terminal on the circuit board. The external signal is coupled through the DC blocking capacitor C5 and then drives Q1 as described above.
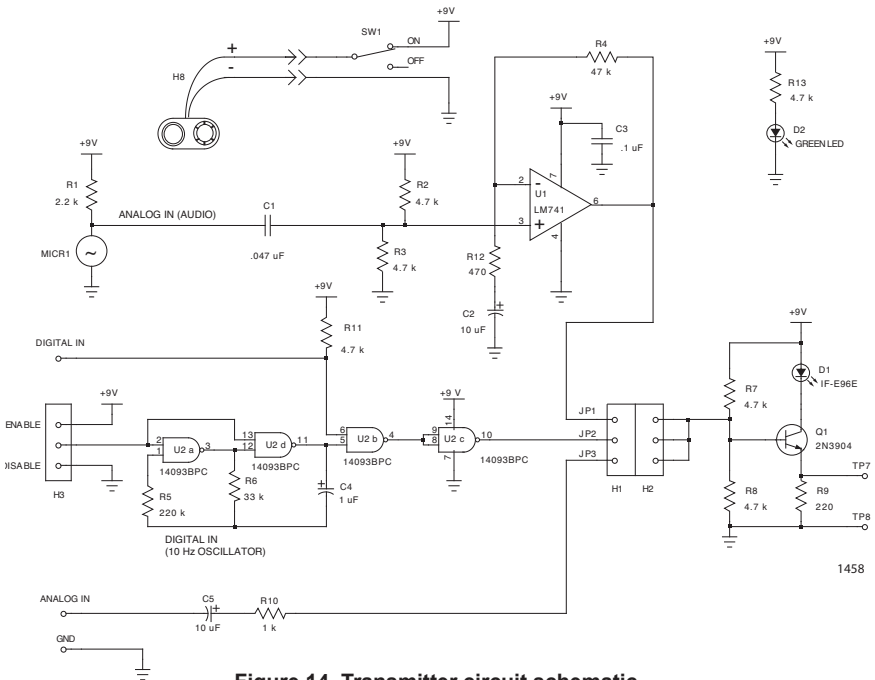

Figure 14. Transmitter circuit schematic.

Amplifier/Driver

The LM741 op-amp U1 is used in the non-inverting configuration as an AC-coupled DC amplifier. After the incoming AC signal passes through the DC blocking capacitor C1, the signal is routed to the op-amp non-inverting input, pin 3. This input is biased to half the supply voltage from the voltage divider created by R2 and R3. This DC bias voltage will appear on the output, pin 6, with the amplified AC signal superimposed on top of it, as shown in Figure 15. The gain of the op-amp is set to 101 by the ratio of R4 and R12. Capacitor C2 provides the return path to ground. Since we are amplifying an AC signal, the gain is "rolled off" at a low-frequency 3 dB point of 34 Hz, the

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**Figure 15.
Oscilloscope display showing a typical AC signal superimposed on a DC level from pin 6 of the LM741 in the transmitter circuit.**

frequency at which the impedance of C2 equals 470 ohms. Capacitor C3 is a DC bypass capacitor used to remove any stray noise or transients that might occur on the 9-volt supply line. After the signal is amplified, it is routed to header H1 via JP1.
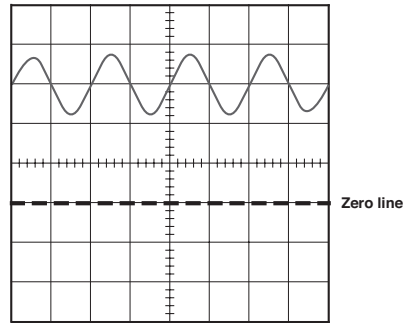
An external analog signal can be connected to the ANALOG IN and GND terminals on the printed wiring board. Capacitor C5 provides DC blocking and resistor R10 sets the input impedance. The external signal is routed to header H1 via JP3.

Digital

The kit you have assembled has a digital portion as well as analog. The digital electronics include an oscillator plus a method to input external digital signals. The oscillator circuit provides a repetitive signal so you can demonstrate the operation of the transmitter without additional equipment.

The Quad 2-input NAND CMOS IC used in the transmitter is a special type called a SCHMITT TRIGGER. The Schmitt device is one in which the input voltage at which the gate switches from logic low to high is higher than that which would cause a logic high-to-low transition (different threshold depending on which direction the input signal is traveling). This characteristic improves the gate's immunity to noise on signals with slow rise and fall times (as will be discussed later), and sharpens the resulting output from these signals.

The digital oscillator uses two gates, a and d, of quad 2-input NAND IC U2 as a relaxation oscillator producing a 10 Hz square wave at pin 11. The oscillator is enabled or disabled depending on the position of the jumper on H3. When the oscillator is ENABLED, pins 2 and 13 are brought high. When enabled, gates a and d act like conventional inverters with pins 1, 11 and 12 responding to the oscillator timing circuitry R5, R6 and C4. Referring to Table 4, as long as one of the inputs of the NAND gate is high, the output will be high. However, when both inputs are high, the output will be low.

When the oscillator is first powered on, assume that pin 11 is low. This will begin charging capacitor C4 through resistor R6 at a rate determined by the time constant RC. Therefore, pins 3 and 12 must be high, and pin 1 must be low. When the charge on C4 reaches one-half the supply voltage, pin 1 of gate a goes high, causing its output to switch low. Gate d now switches from low to high, and C4 begins charging in the opposite direction or polarity. The voltage on pin 1 begins decreasing until a level recognized as low by gate a is reached. The cycle repeats indefinitely and a square wave appears on pin 11.

Gate U2b is used as a mixer to select either the 10 Hz oscillator output or an external digital input. If the oscillator is enabled, U2b will pass the oscillator signal but invert its phase. This is because of the oscillator transitions and pin 6 is pulled high by R11. When the oscillator is DISABLED pins 5 and 11 will be low and U2b will select the transitions from the DIGITAL IN line. U2c is wired as an inverter by shorting pins 8 and 9 together and will restore the proper phase to an external signal or the oscillator. The digital output is routed to header H1 via JP2.

LED Driver

The LED Driver circuit has been designed so that it is compatible with analog or digital circuitry. When an analog signal is fed to the base of transistor Q1, the AC component of the signal will vary the base current of the transistor and subsequently the brightness of LED D1 as the amplitude changes. Q1 controls the amount of current flowing through the LED D1 in response to current changes applied to its base. Resistors R7 and R8 form a voltage divider that biases Q1 to half the supply voltage and sets its operational range. This puts approximately 3.8 volts at the emitter and, with resistor R9, sets the LED current to 17 mA.

A digital signal will turn the transistor on and off as the square wave changes from high to low and back again. As Q1 turns on and off, D1 will also turn on and off. When the digital signal is low, at 0 volts, transistor Q1 is cut off and acts like an open switch. Since no collector current is flowing, D1 is dark. When the input signal goes high, at approximately 9 volts, the transistor saturates and forward biases the base-emitter and base-collector junctions. This allows collector current to flow and D1 to emit light.

LED

The LED, IF-E96E, used in this kit produces red light. Its optical output is centered at 650 nanometers (nm). The IF-E96E fiber optic component also has a built-in connector/fiber-termination optimized for the jacketed 980 µm core plastic fiber. LEDs are useful for fiber optics because they are inexpensive, reliable, easy to operate, have a wide temperature operating range and respond quickly to electrical current.

RECEIVER THEORY OF OPERATION

When the light energy emitted by the fiber optic transmitter reaches the destination (receiver) it must be converted back into electrical energy with the same information pattern that was fed to the transmitter by the originator of the message. Analog fiber optic receivers typically perform this function using three elements: a photodetector, an amplifier and sometimes a buffer. As with fiber optical sources, the optical connector is often integrated into the detector package. The photodetector converts light energy (optical power) into an electrical current. Any pattern or modulation imparted to the optical energy (from, for instance, a fiber optic transmitter) will be reproduced as an electric current with the same pattern. Long lengths of fibers and other distribution losses can reduce the optical power, resulting in a comparatively weak electrical signal from the photodetector. To compensate for this decline in signal strength, the amplifier increases the amplitude of the electrical signal to a usable level. Finally, the buffer electronics isolate the photodetector and amplifier from any load the receiver is required to drive.

Circuit Operation

The fiber optic receiver is composed of a photodiode with optical connector as the photodetector, amplifier with adjustable gain control and user-selectable digital or analog outputs. See the block diagram in Figure 15. After light energy travels through the optical fiber, it is coupled to the photodiode that converts the light photons to a current. The photodiode current is fed to a transimpedance amplifier where it is converted to an output voltage. The user can route the output voltage to a digital circuit where the amplifier output voltage is shaped into digital pulses and made visible by a red LED. Alternately, the user can route the signal to an audio amplifier coupled to a speaker so the signal can be heard instead of seen. A schematic diagram of the receiver circuit is shown in Figure 16.

Like the transmitter, the receiver is powered by a 9-volt battery and is attached to battery clip H8. Power is controlled by ON/OFF switch SW2 and it must be in the ON position for the receiver to function.
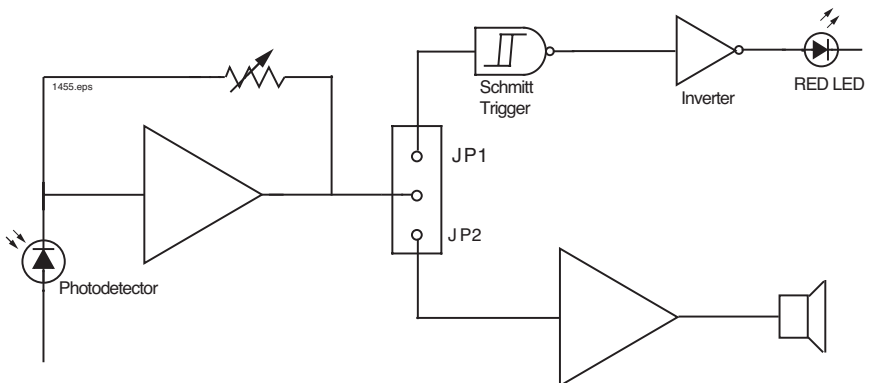

Figure 15. Receiver block diagram.
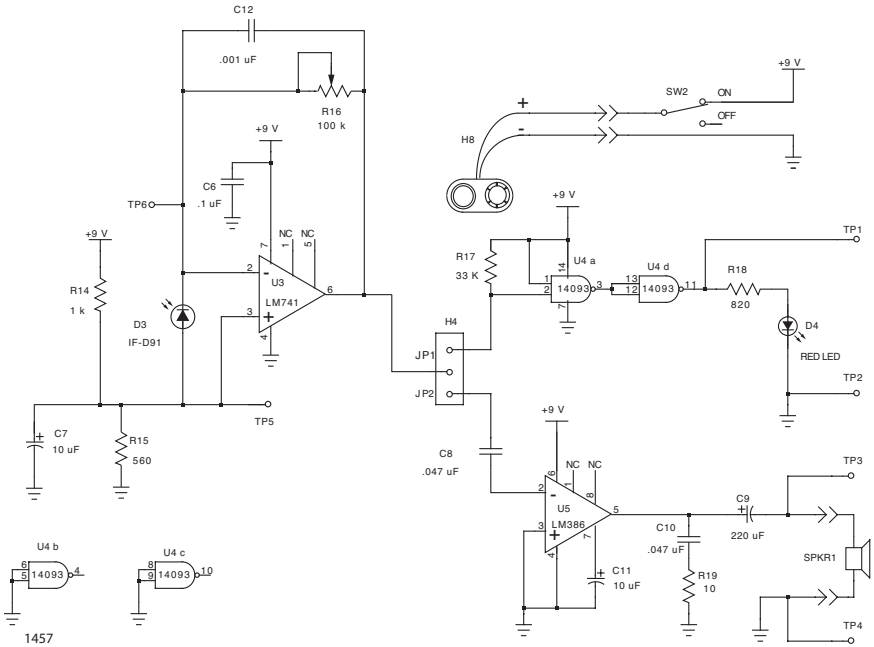
Figure 16. Receiver circuit schematic.

Photodetector and Transimpedance Amplifier

The input fiber cable is coupled into the photodiode D3 that converts the light photons emanating from the cable into a current. Photodiode D3 will behave in one of two ways, depending on whether it is dark or illuminated. When the photodiode is dark, it is an unbiased diode, and no current flows through it. It essentially plays no role in the operation of the circuit. But when photons of light strike the PN junction of the photodiode, electrons will begin to flow across it, from the anode toward the cathode. This makes the photodiode like a current source with a very high impedance and an extremely small (microampere range) current output. This current is very proportional to the amount of light intensity striking the PN junction.

Op-amp U3 is configured to act as a transimpedance amplifier that converts the tiny photodiode current into a usable voltage at its output on Pin 6. To explain how the op-amp performs this "transimpedance function" it is helpful to know a little bit about op-amps. An op-amp is basically a two input amplifier circuit that has three main characteristics.

- Very high gain, typically 10^6 or better,

- Very high input impedance at the inputs, typically 10^6 Ohms or better,

- Low output impedance, typically hundreds of Ohms or less.

– 31 –

This combination of characteristics makes an op-amp an almost "ideal" device, meaning that it will perform almost exactly as approximated in an electronic circuit. As a result, in many cases its behavior in a properly designed circuit can be boiled down to two simple Golden Rules:

1. The output attempts to do whatever is necessary to make the voltage difference between the inputs zero.

2. The inputs draw no current.

Using these two rules we can determine how the op-amp performs the transimpedance.

First, consider the operation of the circuit when D3 is dark. In this state, no current is flowing through it. The voltage on Pin 3 of the op-amp is determined by the voltage divider formed by R14 and R15,

$$V_{pin3} = \frac{R_{15} \bullet (+9V)}{R_{14} + R_{15}}$$

Equation 11.

From Golden Rule number 1, we know that the output wants to force the voltage on Pin 2 to be the same. Since no currents are flowing in that part of the circuit, all the output at Pin 6 has to do is maintain the same voltage that is on Pin 3. All three pins will be at the same voltage.

Now, consider what happens when D3 is illuminated. The photons striking its PN junction cause electrons to flow from its anode to its cathode, towards Pin 2 of the op-amp. This electron current* is extremely tiny as compared to the current flowing through the R14, R15 voltage divider, so the voltage at Pin 3 doesn't change. But look what happens at Pin 2. There is a flow of electrons towards Pin 2, but by Golden Rule number 2, it draws no (electron) current. The accumulation of electrons at Pin 2 quickly causes the voltage there to become more negative (less positive) than at Pin 3. This is in violation of Golden Rule number 1. The output responds by becoming positive enough to draw these excess electrons away from Pin 2, through R16. When the same amount of current is drawn away from Pin 2 (through R16) by the output as is being sourced by the photodiode, the voltages at the inputs equalize, and the both of the Golden Rules are satisfied. The op-amp is once again "happy".

In this part of the discussion, it is more convenient to talk in terms of "electron current," the flow of electrons from negative to positive instead of "conventional current," which is defined to flow from positive to negative.

In this state, the voltage at the output is equal to the voltage at Pin 3, plus the additional voltage required (by Ohm's Law) to draw the photodiode current (ID_3) away from Pin 2;

$$V_{pin6} = \frac{R_{15} \bullet (+9)}{R_{14} + R_{15}} + I_{D3} \bullet R_{16}$$

Equation 12.

Note that the more intense the illumination of D3, the more current it will source and the higher the output must go to keep the inputs balanced. Variations in intensity result in proportional changes in the output voltage. The output voltage will follow, or demodulate a signal modulated onto the light source at the transmitter.

Also, note that changes in the value of R16 cause proportional changes to the amount of voltage the output must produce to keep the inputs balanced. This gives us a variable gain of the circuit by adjusting the value of R16.

Amplifier and Speaker

If the tandem spring shunt is placed between JP2, the output of U3 is routed to the audio amplifier U5, AC-coupled through C8. The audio amplifier increases the AC component of the input signal and boosts the available output current. This output is AC-coupled through C9 to an 8 ohm speaker that converts the current into sound.

The audio amplifier (U5) used in this part of the circuit is an LM386N, an audio power amplifier, used widely in low-voltage consumer applications. Operating at 9 VDC, it can supply over 500 mW of power into an 8 ohm speaker. The output is internally biased at one-half the source voltage, and the current driving the speaker is AC coupled through C9.

Input to the amplifier is ground referenced, and has an input impedance at Pin 2 of 50 k ohms. This input impedance combined with the 0.047 µF capacitance of C8 produces a 3 dB high pass frequency at the input of about 70 Hz as defined by Equation 13.

$$f_{3\ dB} = \frac{1}{2\ \Pi\ R\ C}$$

Equation 13.

Components C10 and R19 provide capacitive load compensation for the inductive component of the speaker coil.

The LM386 is set up in this circuit for its default voltage gain of 20. An option for increasing this gain to as high as 200 is discussed in the section "Extending the Link". C11 has been provided in the circuit as a bypass capacitor that will help keep the LM386 from oscillating as its gain is increased.

Digital Output

If the tandem spring shunt is placed across JP1, the output voltage from U3 drives pin 2 of U4 a. Gate U4 a is wired so pin 2 is pulled high through R17 and pin 1 is pulled high directly to the +9 volt supply. Referring to Table 4, the truth table for 2-input NAND gates, with one input high and the other input toggling high and low, the output on pin 3 will be the same as the input except for being inverted. U4 d is wired as an inverter that restores the phase of the original signal. The output signal goes to TP1 and passes through R18 that limits the current through D4. This digital signal will flash the red LED D4 at the frequency of the received signal, producing a visual representation of the signal. The digital signal can also be observed using an oscilloscope if one is available.

EXTENDING THE LINK

The separation distance between the transmitter and receiver can be extended up to 10 meters by using additional optical cable. To purchase this additional cable, determine the length desired and contact the distributor from whom you purchased this kit. If you do not know who that distributor is, please see our web site for assistance (see page 40 for our address.)

After purchasing a new length of cable, complete the following steps to increase the operating distance of this link:

1. Polish both fiber ends as described on page 10 of this manual.

2. Install one fiber end into the fiber optic LED and the other end into the photodiode as described in Figure 5.

3. Physically separate the transmitter and receiver as far as the fiber length will allow.

4. On the Receiver, set the ON/OFF switch SW2 to the ON position. Rotate the gain control R16 clockwise so that it produces maximum volume. Have an associate remain at the receiver.

5. On the Transmitter, set the ON/OFF switch SW1 to the ON position. Speak into the microphone while watching your associate. Your voice should be audible at the other end of the optical link.

6. The gain of the amplifier U5 in the Receiver may be increased to 200. Solder a 10 μf electrolytic radial capacitor (not supplied) between pins 1 and 8 of U5 on the bottom of the Receiver board. The plus (+) lead of the capacitor goes to pin 1 and the negative (-) lead goes to pin 8. Caution: This modification may not be necessary after increasing the length of the fiber cable. Try the new cable first and then determine if you need more amplification.

GLOSSARY

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 a fiber will accept light for transmission along its core. This angle is measured from the centerline of the core.

Analog: A type of information system in which the information is constantly varying with respect to time. Sound is analog because it varies within a given frequency range. Compare with: Digital.

Attenuation: Loss of optical power (i.e., light pulses losing some of their photons), normally measured in decibels per kilometer.

Cable: A single optical fiber or a bundle of fibers, often including strengthening strands of opaque material and a protective outer jacket.

Cladding: The layer of glass or other transparent material surrounding the light-carrying core of an optical fiber that keeps the light trapped in the core. It has a lower refractive index than the core. Additional coatings, such as jackets, are often applied over the cladding to strengthen and protect it.

Core: The central, light-carrying portion of an optical fiber.

Connector: A device which joins two fiber optic cable ends or one fiber end and a light source or detector.

Coupler: A device which connects three or more fiber ends, dividing one input between two or more outputs, or combining two or more inputs in one output.

Critical Angle: The incident angle at which light undergoes total internal reflection in a fiber.

Darlington: An electronic circuit in which the collectors of two transistors are tied together, and the emitter of the first transistor drives the base of the second and used to amplify current.

Detector: A device that generates an electrical signal when illuminated by light. The most common in fiber optics are photodiodes, photodarlingtons and phototransistors.

Digital: A type of information system in which the information exists in the form of precise numerical values of digital pulses. The fundamental unit of digital information is the bit — short for binary digit. Compare with: Analog.

Diode: An electronic device which usually restricts electric current flow to one direction.

Fiber: The optical waveguide, or light-carrying core or conductor. It may be made of glass or plastic. See also: Core; Cladding.

IC: Integrated circuit. A tiny slice or "chip" of material on which a complete electrical circuit has been etched or imprinted.

Incident ray: An "incoming" ray of light — light which falls upon or strikes a surface. Compare with: Reflected ray.

Infrared: Electromagnetic energy with wavelengths longer than 750 nanometers and shorter than 1 millimeter. Infrared radiation cannot be seen, but it can be felt as heat or measured by instruments.

Jacket: A layer of material surrounding an optical fiber to protect the optical core and cladding but not bonded to it.

LED: Light-emitting diode. A semiconductor diode which converts electrical energy to light.

Light: Strictly speaking, electromagnetic radiation visible to the human eye. Commonly, however, 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. See also: Infrared.

Near-Infrared: Wavelengths of radiation longer than 700 nm and shorter than 1 mm. Infrared radiation cannot be seen but can be felt as heat. Glass fibers transmit radiation best in the region 800 – 1600 nm, and plastic fibers in the 640 nm to 900 nm range.

Numerical Aperture: (NA) The sine of the half angle over which an optical fiber can accept light. Incident light which strikes the end of an optical fiber can be transmitted along that fiber only if the light strikes the fiber within the numerical index. If the incident light strikes the end of the fiber at too oblique an angle, it won't travel down the core of the fiber.

Photodetector: A device which detects and receives light waves (optical energy), then converts them into electrical signals.

Photons: Units of electromagnetic radiation. Light can be explained as either a wave or 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.

Reflected ray: A ray of light which has "bounced off" some surface. When an incident ray strikes a surface and bounces off, it becomes a reflected ray.

Refracted ray: A light ray which has been bent by its passage from one medium into another medium of 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".

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

Responsivity: The ratio of detector output to input, usually specified in Amperes/watt for photodiodes, photodarlingtons and phototransistors.

Scattering: The changes in direction of light travel in an optical fiber occurring due to imperfections in the core and cladding material.

Splice: A permanent junction between two optical fiber ends.

Step-index fiber: An optical fiber in which the refractive index changes abruptly at the boundary between core and cladding.

Transmitter: A device that converts an electrical signal into an optical signal for transmission in a fiber cable. See also: Receiver.

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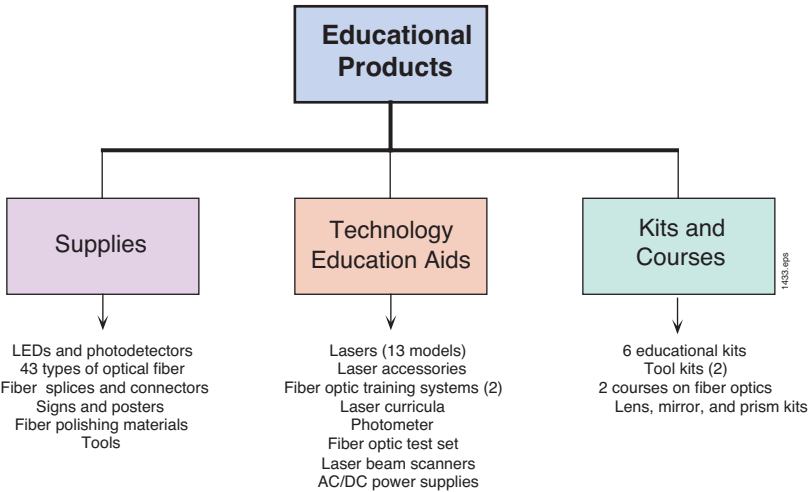*Optical Engineering,* SPIE, P. O. Box 10, Bellingham, WA 98227-0010

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