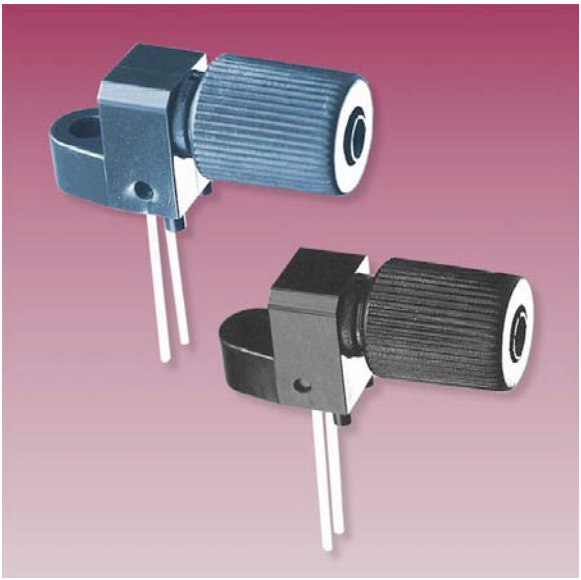
The Duplex Optical Voice Link

Light, Electrical Energy And Sound In Concert

A Project-Oriented Introduction to the Marvels and Science of Fiber Optics Communications

- **For the Classroom**
- **For the Hobbyist**



INDUSTRIAL FIBER OPTICS

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Previous printing 2006, 2003, 2000
Industrial Fiber Optics, Inc.
Revision - B

Printed in the United States of America

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Warranty Information

This kit was carefully inspected before leaving the factory. *Industrial Fiber Optics* products are warranted against missing parts and defects in materials in materials 90 days. Since soldering and incorrect assembly can damage electrical components, no warranty can be made after assembly has begun. If any parts become damaged, replacements may be obtained from most radio/electronics supply shops. Refer to the parts lists on pages 2 and 5 of this manual for identification.

Industrial Fiber Optics recognizes that responsible service to our customers is the basis of our continued operation. We welcome and solicit your feedback about our products and how they might be modified to best suit your needs.

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 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 fiber's 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.

Having passed the millennium, fiber optics will become common in your everyday life. It will enter the office environment. In your home, it will provide services that would have been impractical without it: high-definition TV, secondary education classes in the comfort of your home, a paper-less, environmentally clean "newspaper," high-speed Internet access.

A decade ago, fiber optics was tucked away in the back pages of optics books, and optics courses were options for senior-level physics majors. Even today, few universities have full-fledged optics programs, and even fewer have fiber optics programs alone. Most of today's optics specialists were trained in other fields, typically electronics or physics.

But today, you are not alone in your interest in fiber optics. Interest is increasing as technology advances and begins affecting everyone's life.

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.

OBJECTIVE

The *Duplex Optical Voice Link* 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.

Multiple applications can utilize the *Duplex Optical Voice Link*: Technicians might use it to provide an isolated voice link in a construction crane; salvage divers could use its communication potential as part of their diving gear; an instructor may use it as a short, hands-on fiber optic curriculum or as a module to demonstrate before the class; a student may use the kit for a science project; hobbyists can use it as a project to amaze their friends. Important experience and technical knowledge will be gained during assembly and while working with the electronic microphone, analog fiber optic transmitter and receiver, and the fiber cable interfaces. Upon completion you will have assembled a full duplex fiber optic communications link. You will hear your own voice, for example, after it has been converted into light and then coupled into, through, and out of an optical fiber.

STARTING OUT

The *Duplex Optical Voice Link* is an introduction to the mysteries and science of fiber optics. No prior fiber optics experience is needed to build this kit and bring it to operational level. After completion, it can be used to demonstrate the unique characteristics of fiber optics or in several practical commercial and industrial applications.

This booklet is your guide to understanding the theory of fiber optic communication, and it includes assembly instructions; please read them carefully to avoid mistakes. Several exercises have also been included to help you understand this technology. If, after completing this kit, you would like to acquire more knowledge about fiber optics, check the **List of References** on pages 30 and 31, and the list of other products we offer on pages 32 and 33, or visit our website at ***www.i-fiberoptics.com.***

The kit you have purchased furnishes all the parts required to construct a fully functional, bi-directional fiber optic voice link. Before beginning the actual assembly, check the contents of each component packet against the lists in **Tables 1** and **2** to ensure you have a complete kit. The link can be extended up to 40 meters with additional fiber cable and splices purchased separately.

A portion of the instructions in this manual mentions using an oscilloscope to perform demonstrations and to make some of the measurements. It is helpful but not necessary. You can complete the kit and learn a significant amount about fiber optics without one.

TOOLS AND TEST EQUIPMENT YOU'LL NEED

Wire cutters
Needle-nose pliers
Small adjustable wrench
1 ml water or light oil
Rosin-core solder
Single-edge razor blade or sharp knife
Sizes 0 and 1 Phillips screwdrivers
25-watt soldering iron
18-gauge wire-stripper
Dual-trace oscilloscope (optional)

KIT COMPONENTS

This kit comes packaged along with this manual in the following manner:

- 2 printed wiring boards
- bag of receiver components
- bag of transmitter components
- 2 speakers
- 2 110-VAC-to-12-VDC power adapters
- 3 meters of duplex jacketed 1000 µm core optical fiber
- 2000-grit polishing paper

The components required for assembling both transmitter circuits on the printed wiring boards of the duplex voice link are listed in **Table 1** and will be found together in one bag. The components for completing both receiver circuits are contained in the other bag and are listed in **Table 2**. If any components are missing, see the warranty section at the bottom of page *i*.

Table 1. Transmitter parts list.

D/N	QTY	P/N	Description	Color-code
C1	2		220 ! f electrolytic capacitor	
C2	2		.047 ! f Mylar ® capacitor	
D1	2		Red T 1 - 3/4 LED	
D2	2	IF-E96	Fiber optic infrared LED	Pink Dot
H1	2		2-56 screws	
H2	2		2-56 hex nuts	
MIC1	2		Microphone	
R1	2		2.2 k" 1/4 watt resistor	Red Red Red
R2	2		2.2 k" 1/4 watt resistor	Red Red Red
R3	2		150 " 1/4 watt resistor	Brown Green Brown
SW1	2		Momentary switch	
U1	2	LM386N	Audio amplifier	

ASSEMBLY INSTRUCTIONS

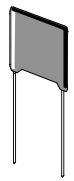
Printed Wiring Boards

This kit contains two identical printed wiring boards, each divided into section. One section contains the transmitter circuit and the other section contains the voltage regulation circuitry and receiver circuitry. To assemble the printed wiring boards, read the introduction and complete the following steps:

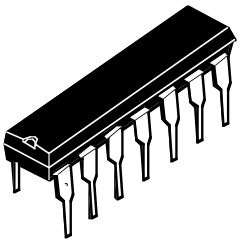
- Mount all components on the side of the printed wiring boards with the white lettering.
- Use the white markings on the printed circuit boards to determine where and how each part is to be placed.
- All soldering is to be completed on the side opposite the components.
- Use a water-soluble or rosin 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 prolonged heat 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 with a wire cutter.



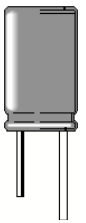
Resistor



Mylar® capacitor



Integrated Circuit (IC)



Electrolytic capacitor

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

Transmitter Preliminary Assembly

Complete the following steps for the transmitter portion of both printed wiring boards. In Steps 2 through 8 install all the components above the groove dividing the board lengthwise into receiver and transmitter portions.

1. Position a printed wiring board directly in front of you. Align the board so the word "TRANSMITTER," printed on the top side of the printed wiring board, is horizontal and reading left to right.
2. Insert resistors **R1** (2.2 k), **R2** (2.2 k) and **R3** (150), one at a time into the printed wiring board and solder them in place on the transmitter portion of the board.
3. The 220 µf (**C1**) capacitor is polarity sensitive to the direction in which it is installed. Insert the longer lead of the capacitor (the positive lead) into the square pad and the short lead (the negative lead) into the round pad within the area identified for this capacitor and solder.
4. There is no positive/negative orientation of the .047 µf capacitor (**C2)**. Identify, insert its leads through the board and solder them in place.
5. Locate the square pad within the area on the printed wiring board designated for placement of **D1** (the red T 1 - 3/4 LED). Insert the LED with the shortest leg of **D1** (the cathode) into the respective square pad on the printed wiring board, and solder it 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.
7. The microphone, **MIC1**, is polarity sensitive. Insert it so the part outline aligns with the white legend on the printed wiring board. Solder in place.
8. Insert switch **SW1** on the board and solder it in place.

Receiver and Regulator Preliminary Assembly

Complete the following steps for the receiver and voltage regulator portion of both printed wiring boards. In Steps 2 through 9 install all the components above the groove dividing the board lengthwise into receiver and transmitter portions.

1. Position a printed wiring board directly in front of you. Align the board so the word "RECEIVER," printed on the top side of the printed wiring board, is horizontal and reading left to right.
2. Insert resistors **R1**(2.2 k) and **R3** (10), one at a time into the receiver printed wiring board and solder them in place.
3. The 220 µf (**C1** and **C3**) capacitors are polarity sensitive, or sensitive to the direction in which they are installed. Insert each capacitor with the longer lead of the capacitor (the positive lead) into the square pad and the short lead (the negative lead) into the round pad within the area identified for these capacitors and solder.

Table 2. Receiver parts list.

D/N	QTY	P/N	Description	Color-code
C1	2		220 ! f electrolytic capacitor	
C2	2		.047 ! f Mylar ® capacitor	
C3	2		220 ! f electrolytic capacitor	
C4	2		.047 ! f Mylar ® capacitor	
D1	2		Green T 1 - 3/4 LED	
H1	2		2-56 screws	
H2	2		2-56 hex nuts	
H3	3		Rubber mounting bumpers	
H4	2		6 inches speaker wire	
H5	2		4-40 x 3/8" machine screw	
H6	2		4-40 hex nut	
J1	2		2.1 mm power jack	
Q1	2	IF-D92	Fiber optic phototransistor	White Dot
R1	2		2.2 k" 1/4 watt resistor	Red Red Red
R2/ SW1	2		5 k" potentiometer with on/off switch	N/A
R3	2		10 " 1/4 watt resistor	Brown Black Black
U1	2	LM386N	Audio amplifier	
SW1	2		3-inch speaker	
U2	2	DB101	Bridge rectifier	
VR1	2	LM7808	Voltage regulator	

4. There is no positive/negative orientation for capacitors **C2** (.047 µf) and **C4** (.047 µf). Identify each, insert their leads through the board and solder in place.

5. Locate the square pad within the area on the printed wiring board designated for placement of **D1** (the green T 1 3/4 LED). Insert the shortest leg of **D1** (the cathode) into the respective square pad on the printed wiring board, and solder 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 square hole. Solder in place.

7. Insert **U2** into the designated spot marked on the printed circuit board, aligning the polarity marks on the bridge rectifier integrated circuit and circuit board. Solder in place.

8. The leads to the voltage regulators (**VR1**) are formed using needle-nose pliers. From the case of the regulator measure 7 mm (.25 inches) and bend both outer leads at 90° degree away from the lettering on the component. Measure 1 cm (.40 inches) from the case and then bend the center lead in the same manner as

the outer leads. Mount the voltage regulators on the printed wiring board using the 4-40 ! 3/8 inch screws and 4-40 hex nuts. Tighten the hex nuts. Solder each lead of the voltage regulator.

9. Separate the two conductors of the speaker wire 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.

10. Locate an area marked "SPKR" on the receiver portion of the printed wiring board. Insert the copper-colored conductor of the speaker wire into the hole marked "**+**", and solder. Insert the other conductor into the hole marked "**–**" and solder it in place.

11. Using the bare wires clipped from the capacitors and a needle-nose pliers, form two jumper wires into the shape of a " ". The bottom of the " " should be about 6 mm (.25 inch) long and the sides of the " " about 3 mm (.125 inch) high. Install one jumper connecting the holes marked "GND" on the printed wiring board together and solder. Install the remaining jumper to connect the holes marked "9 VDC" to each other and solder.

Cleaning and Final Assembly

12. Clean both printed circuit boards 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 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.

13. Identify the two blue fiber optic housings (LEDs) with a pink dot on one side. Insert one in each area marked "**IF-E91A**" on transmitter portions of the printed wiring boards. Fasten in place with a 2-56 screw and hex nut. Solder the leads.

14. Identify the two black fiber optic housings (phototransistors) with a white dot on one side. Insert **Q1** in the area marked "**IF-D92**" on receiver portions of the printed wiring boards. Fasten in place with a 2-56 screw and hex nut. Solder the leads.

15. Insert the potentiometers into the area labeled SW/5k on both boards and solder in place.

16. Install power jacks, **J1**, on both boards and solder into place.

17. Separate the three rubber bumpers from each other, remove the paper backing that protects the adhesive and install on the solder side of the printed wiring board. Place one bumper between the hex nuts of the fiber optic LED and photodetector, and the other two near the edges between the regulator and transmitter/receiver circuitry.

18. Solder the unattached copper-colored wire to the terminal on the speaker marked with a "**+**". Solder the remaining unattached wire to the terminal marked "**–**".

FIBER PREPARATION INSTRUCTIONS

Each end of the optical fiber 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 2**. You may get the best results by supporting the upright fiber against some flat object such as a portion of a printed wiring board or square block.
3. Starting about 15 cm (six inches) from one end of the duplex fiber, carefully cut between the two fibers with a razor blade or sharp knife in the groove of the fiber cable all the way to its end.
4. Turn the fiber cable over and carefully cut on its opposite side, down the middle of the fiber cable groove, for the same 15 cm (6 inches) distance.
5. Starting at one end, separate or pull the two fibers apart for about 15 cm (6 inches).

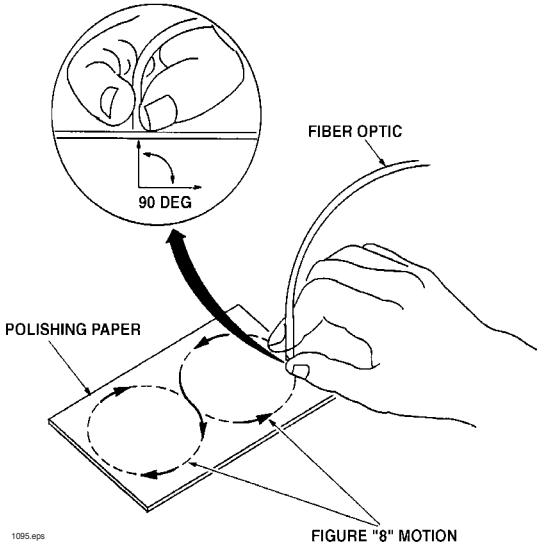


Figure 2. Pattern and orientation of the optical fiber during polishing.

(Don't insert the fiber ends into the fiber optic LED or photodetector until we give you the word, in the next section.)

EXPERIMENTS AND ACTIVITIES

A1. *Grasp the optical fibers near their tips between your thumb and forefinger. Point them toward a light source and observe the other end of the fiber. Note the changes in brightness on both fiber ends 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 both of the fiber tips about .5 mm from this page, move them from left to right across the heading of this section. What changes do you observe in the brightness at the other end of the fibers? Can you (while watching one end of the fibers) observe the black print passing beneath the other ends of the fibers as you move them across the page?*

A3. *Ensure that both receivers are off by turning the receiver switch counterclockwise until it rests in a détente position. Plug the 110-VAC-to-12-VDC power adapters into 110-VAC wall outlets. Plug the 2.1 mm power plug on the end of each power adapter cord into the 2.1 power jack located on each printed wiring board.*

A4. *Turn the receiver switch clockwise 1/4 of a turn on both boards. The green LEDs (**D1**) on both boards should light. If not, check to see if the power adapters are plugged in, that there is power to the wall outlet, and that assembly of the printed wiring board (including installation of **R1** and orientation of **D1**) has been done properly.*

A5. *Push the momentary switch on both boards to energize the transmitter circuitry. The red LED (**D1**) on each board should light. If not, check the assembly of the printed wiring board including installation of **R1** and orientation of **D1**.*

A6. *Determine if both of the transmitter fiber optic LEDs (**IF-E96**) are on by measuring the voltage across them with a multimeter or oscilloscope when the momentary switch is closed. The proper operating voltage for this LED is approximately 1.7 volts. If the LED does not have any voltage across it, double-check the installation of **U1** and **R2**.*

A7. *With an oscilloscope, using AC and DC input coupling, vary the sweep setting and observe the voltage at the output of* ***LM386N*** *(****pin 5****,* ***U1****) on one of the printed wiring boards for the following sounds: talking, crumpling paper, whistling, humming, blowing a whistle, tapping your finger on the microphone, clapping. Describe or draw below the amplitude and frequency of the signals seen on the oscilloscope display.*

A8. *Do you see a periodic signal on the oscilloscope display when humming or whistling? If you change pitch does the period of measured signal on the oscilloscope change?*

A9. *In electronics, multiple circuit designs often will achieve the same design goals. We'd now like you to design an electronic fiber optic LED drive circuit different than the one on the transmitter printed wiring board. A schematic of this transmitter is shown in* ***Figure 11*** *(gain of LM386N as shown is 20). We suggest using an operational amplifier and an NPN transistor. Single or dual voltage power supply is acceptable. Draw that circuit below.*

A10. *Press the momentary switch and measure the voltage across* ***R3*** *with an oscilloscope or multimeter. Calculate the current through the red LED (****D2****).*

A11. *What is the minimum voltage out of LM386N in the circuit shown in* ***Figure 11*** *before the red LED would turn off, or become very non-linear? Assume* V_f *of the LED is 1.7 volts.*

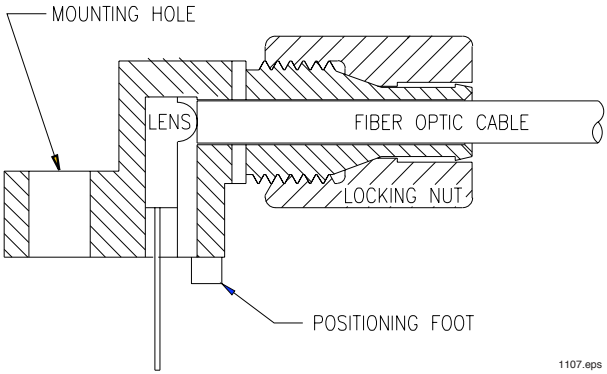
A12. *Assuming a constant 8-volt output from the regulator, what is the maximum current that can flow through the red LED (****D2****) when being driven by* ***U1*** *through* ***R3****?*

A13. *Locate the individual fiber on the duplex fiber pair that has small blue dots on its jacket. Insert one end of this fiber into* ***D2*** *on the transmitter portion of one printed wiring board and the other end into* ***Q1*** *of the other printed wiring board, following the steps in* ***Figure 3****.*

A14. *Identify the optic fiber at the unconnected end of the duplex optical fiber with the red light coming out of it. Insert this fiber into the Phototransistor at the other receiver using the instructions in* ***Figure 3****. Insert the remaining unconnected fiber into the other fiber optic LED.*

A15. *Separate the two printed wiring boards as far as the fiber optic cable allows (about 3 meters or 10 feet). Turn both receivers switches on and turn them clockwise to about the midway position.*

A16. *Press the momentary switch on one of the transmitter circuits and speak into the microphone. You and your partner should hear your voice from the receiver 's speaker at the other end. Adjust the receiver's volume as required.*



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

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

Figure 3. Cross-section of fiber optic LED and cable.

A17. *Locate yourself at one of the assembled printed wiring boards and a partner at the other. Have your partner press the momentary switch on his/her transmitter and speak into the microphone. Describe below their voice sounds when reproduced by the fiber optic receiver, compared to traveling through air.*

A18. *Assuming that this receiver needs 2 ! 10 $^{-6}$ watts of light to reproduce the audio signal, the transmitter launches 50 ! 10 $^{-6}$ watts of power into the fiber, and the fiber has 1 dB (20%) of attenuation per meter, determine the maximum length of cable that can be installed between transmitter and receiver and still function properly.*

A19. *Have your partner hold the microphone located on her/his printed wiring board as close as possible to a mechanical clock while holding down the momentary switch. (If you are completing this project by yourself, you may solder a jumper wire across the switch connections.) Can you hear the gears inside the clock moving, through the receiver speaker? Adjust the volume at your receiver as required. Repeat this experiment with an electric clock. Described the differences below.*

A20. *Disconnect the fiber from the transmitter and receiver of one PWB and place it off to one side. Leave the fiber connected to the other transmitter and receiver. Turn the volume on the receiver switch to maximum. Hold both ends of the unconnected 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. You may choose to connect an oscilloscope probe to pin 5 of U1 and "electrically view" the light being produced by the fluorescent light*

A21. *What is the numerical value for the current through the fiber optic LED in terms of millivolts of input voltage to LM386N? (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 and the gain of LM386N is 20.*

"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 optics changed that by providing an alternate means of sending information over significant distances — using light energy. Although initially a 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, and utilizing electronic technology to a large extent. 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 reality when several technologies came together at once. It was not an immediate process, nor was it easy, but it was most impressive when it occurred. An example of one critical product which emerged from that technological merger was the semiconductor LED, of the type used in the educational kit which you have constructed. 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 basic fiber optic data link 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, such as satellite communications. 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 when through-the-air transmission would encounter interference.

Also contained in fiber optic data links are connectors that provide 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 in this kit are analog. This means the sound waves are converted to an amplitude-modulated light signal which is transmitted 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.

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 4**. The relationship between light's wavelength and frequency can be seen by **Equation 1**:

$$\lambda = \frac{c}{f} \qquad \textbf{Eq. 1}$$

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 those of electrons. 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:

$$E = h \bullet f \qquad \textbf{Eq. 2}$$

where f is frequency in Hz and h is Planck's constant, which is 6.63 ! 10^{-34} joule-seconds.

Light's ability to act sometimes as a wave and sometimes 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.

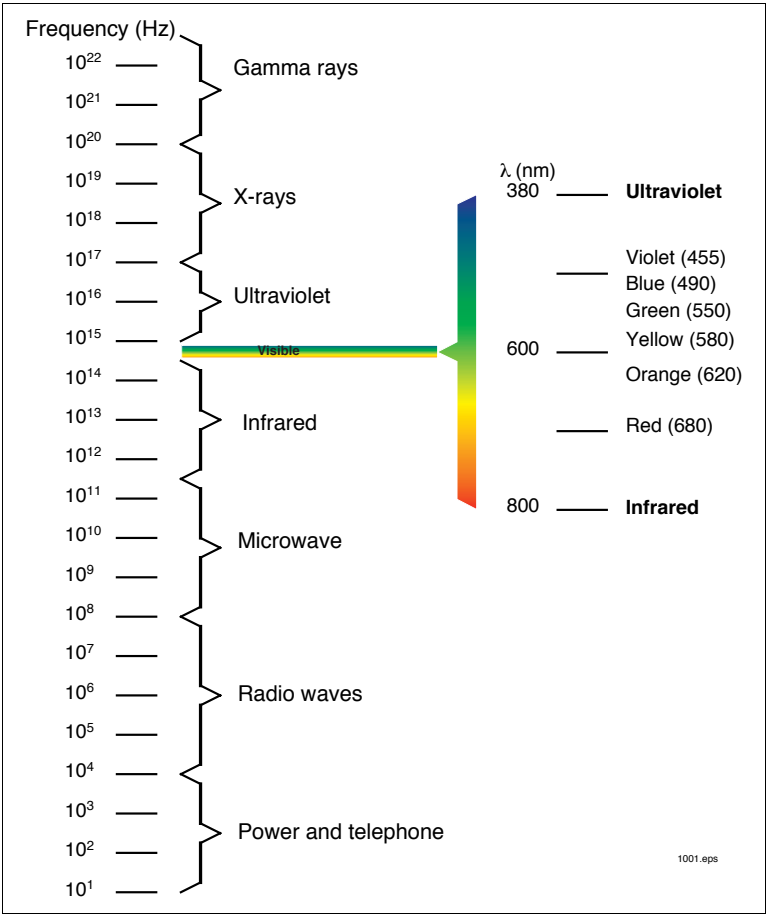


Figure 4. The electromagnetic spectrum.

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.

$$n = \frac{c_{vacuum}}{v_{material}} \qquad \textbf{Eq. 3}$$

The speed of light through any material is always slower than in a vacuum, so the refractive index is always 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 5**. 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**:

$$n_1 \bullet \sin\theta_1 = n_2 \bullet \sin\theta_2 \qquad \textbf{Eq. 4}$$

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.

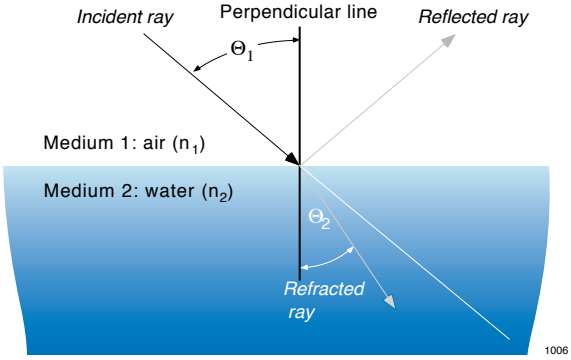


Figure 5. The different portions of a light ray at a material interface.

Snell's equation can be rearranged to determine the refracted angle, θ_2, knowing n_1, n_2, and θ_1.

$$\theta_2 = arc\sin\left(\frac{n_1}{n_2} \bullet \sin\theta_1\right) \qquad \textbf{Eq. 5}$$

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

$$\frac{n_1}{n_2} \bullet \sin\Theta_1 \geq 1 \qquad \textbf{Eq. 6}$$

In this case the incident light ray, θ_1, does not exit and 100 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

$$\Theta_{critical} = arc\sin\left(\frac{n_2}{n_1}\right) \qquad \textbf{Eq. 7}$$

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 this 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. 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 strand is shown in **Figure 6**.

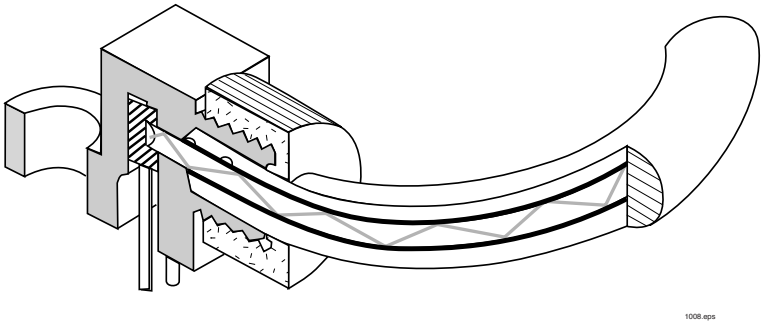


Figure 6. A light ray traveling through, and trapped, by total internal reflection inside an optical fiber.

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

Numerical Aperture

The *critical* angle of an optical fiber, as we have defined and discussed in previous section, is not usually a specified parameter. Acceptance angle and numerical aperture are much more common fiber specifications and are related to the critical angle. Numerical aperture of an optical fiber is be calculated from the core's and cladding's refractive indices by.

$$NA = \sqrt{n_{core}^2 \,!\; n_{cladding}^2} \qquad \textbf{Eq. 8}$$

Acceptance angle, which can

$$\Theta_{acceptance} = 2 \bullet arc \sin \sqrt{n_{core}^2 - n_{cladding}^2} \qquad \textbf{Eq. 9}$$

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 7**. A fiber's numerical apertures or acceptance angles are used to determine collection efficiency of LEDs and photodetectors.

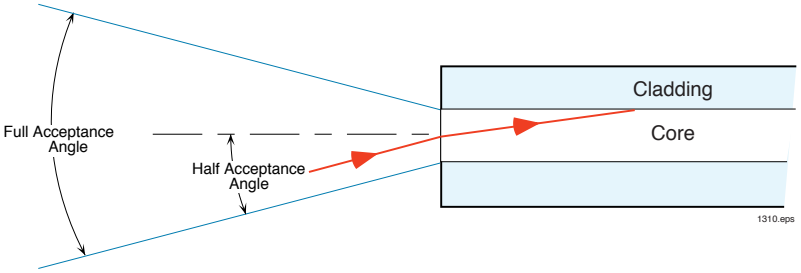


Figure 7. Optical fiber showing the acceptance angle of light.

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.

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 100 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-clad 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
- light leakage from core caused by external environmental factors such as moisture, chemicals and salt

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:

$$Loss = 10 \bullet Log_{10} \frac{P_o}{P_i} \qquad \textbf{Eq. 10}$$

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 fiber attenuation measurements.)

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 8**. 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.

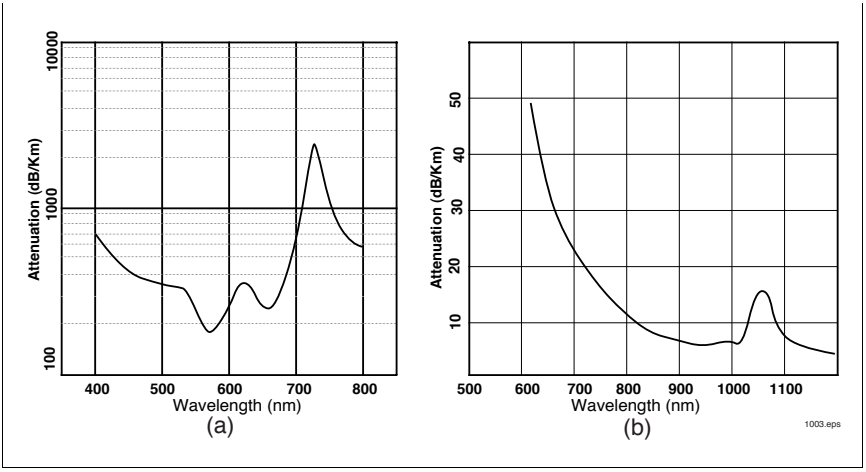


Figure 8. Attenuation of plastic fiber (a), glass fiber (b).

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 as shown in **Figure 9** to protect the core and cladding from environment and mechanical damage or degradation before use, since any damage degrades the optical waveguide. Common additional layers found in a fiber optic cable 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 (.04 inches) in diameter, surrounded by 10 µm of cladding.

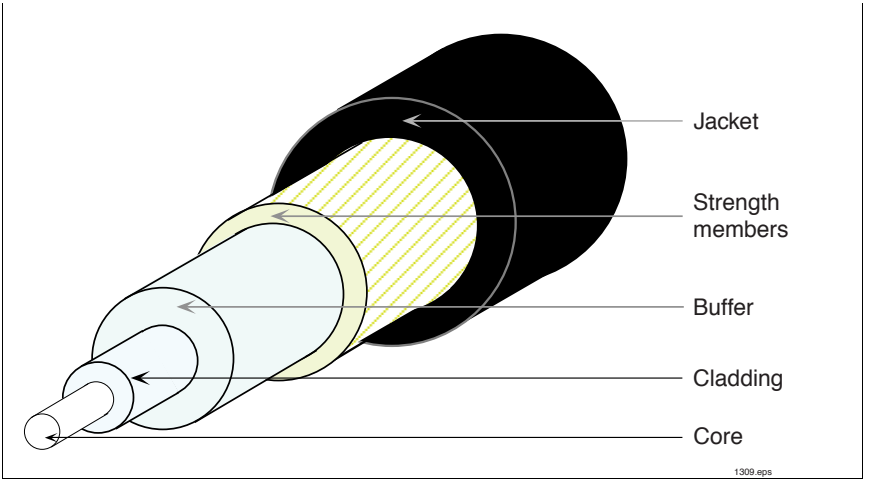


Figure 9. Cross-section of a simple fiber optic cable.

Transmitter

The simplest fiber optic transmitters are typically composed of a buffer, driver, and optical 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 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 to 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.

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, and it receives power from the voltage regulator in the receiver portion of the circuit board. **Figure 11** shows the schematic of the circuit contained on the transmitter printed wiring board of this kit.

Depressing the momentary-close switch, **SW1**, activates the transmitter portion of the optical voice link by applying 8-volt power to the indicator light (LED), microphone, audio circuits and fiber optic LED. The switch must be held closed for the transmitter to operate by generating light to carry audio signals.

Tracing a signal through 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 blocking capacitor (**C2**) to the **LM386N** audio amplifier. The

LM386N amplifies the signal and drives the fiber optic LED (**D2**). The output of the LED is red light with a DC component and AC signal superimposed upon it from LM386N. A typical output signal from LM386N is shown in **Figure 10**.

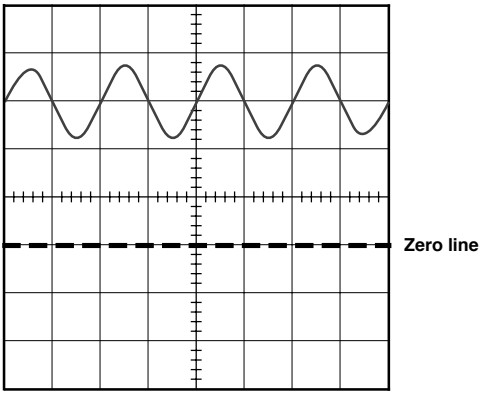


Figure 10. Oscilloscope display showing a typical AC signal superimposed on a DC level from pin 5 of LM386N in the transmitter circuit.

Microphone

Your voice produces acoustic vibrations, which are picked up by a microphone (**MIC1**) containing a sensitive membrane and an **FET** (Field effect transistor). The microphone and **R2** form a voltage divider. With no voice input, the microphone acts as a passive resistor, resulting in a voltage across the microphone of about seven volts. When sound is sensed by the microphone, its resistance (and voltage across it) will vary according to the loudness and the frequency.

Amplifier/Driver

LM386N is a power audio amplifier designed for use in low-voltage consumer applications. It has an input impedance (pin 2) of 50 k ohms. This input impedance combined with the .047 µf capacitor (**C2**) produces a 3 dB high-pass-frequency point of 70 Hz for the microphone signals. The gain of LM386N as shown in the circuit schematic is 20. Inputs to the amplifier are ground-referenced and the output is internally automatically biased at one-half the supply voltage. The output of LM386N, being at one-half supply voltage, causes a DC current to flow through the infrared LED equal to

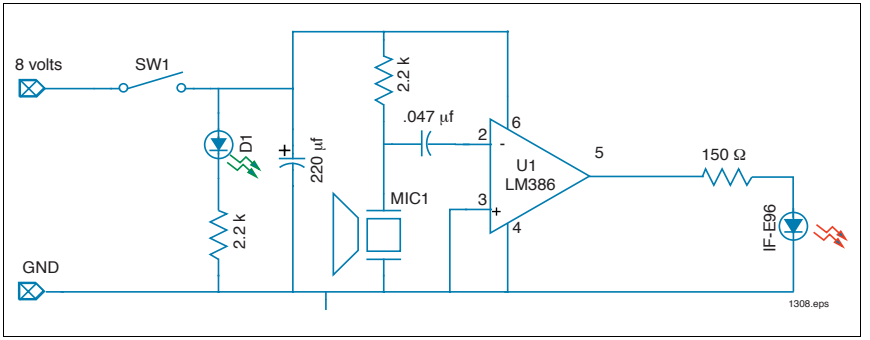


Figure 11. Transmitter circuit schematic.

$$I_{LED} = \frac{\frac{V_{cc}}{2} ! V_{LED}}{R3}$$

$$V_{cc} ! 9 \; volts$$

$$V_{LED} ! 1.5 \; volts$$

Eq. 11

LED

The LED **IF-E96** used in this kit produces red visible light. Its optical output is centered at a wavelength of 660 nanometers (nm). The **fiber optic LED** also has a built-in connector/fiber-termination optimized for the jacketed 1000 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.

Miscellaneous Parts

Power for the transmitter circuit is provided by an 8-volt regulator in the receiver portion of the circuit board. The transmitter is activated when the momentary switch (**SW1**) is pressed and held. When the switch is open, no power is consumed by the transmitter circuit. Typical current consumption for this circuit when the momentary switch is closed is 25 mA.

A red LED (**D1**) and limiting resistor (**R1**) function as a "switch-on" indicator. The LED will light immediately with the momentary switch's closure.

C1 functions as a power supply filter capacitor for the receiver circuit when the LM386N amplifier/driver requires a low impedance source of energy to drive the LED.

Receiver

Once light energy from the fiber optic transmitter reaches the destination (receiver) it must be converted back to a form of electrical energy with the same information pattern that was fed to the transmitter by the person sending the message. Analog fiber optic receivers typically perform these functions using three elements: a photodetector, an amplifier and sometimes a buffer. As with fiber optic transmitters, the optical connector is often integrated into the receiver package. The photodetector converts light energy (optical power) to an electrical current. Any pattern or modulation imparted in the optical power (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. Finally, buffer electronics isolate the photodetector and amplifier from any load the receiver is required to drive.

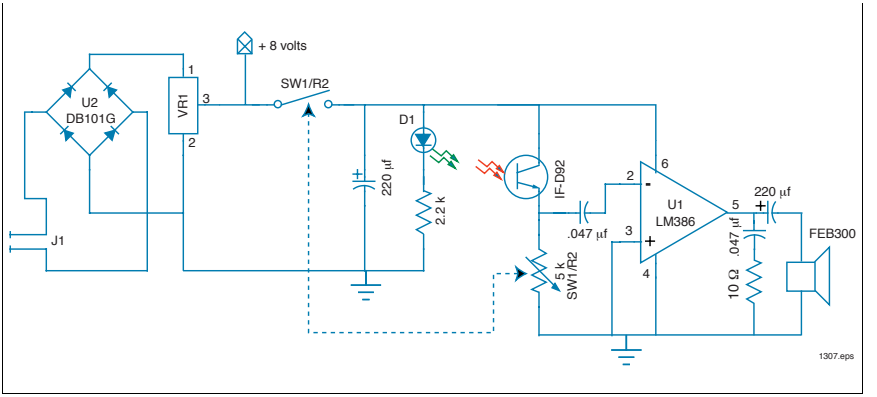


Figure 12. Receiver and voltage regulator circuit schematic.

Circuit Operation

A schematic diagram of this fiber optic receiver is shown in **Figure 12**. In the diagram are the receiver circuit functions: photodetector, amplifier, adjustable volume control and miscellaneous electronics. Following a signal as it exits from the optical fiber, in the form of light: The signal is input to the NPN phototransistor (**IF-D92**) which converts the light photons to a current. The phototransistor current flows through the potentiometer (**R2**) which produces a voltage — with the voltage amplitude dependent upon the position of the potentiometer and the amount of light exiting from the fiber. The voltage across the potentiometer is AC-coupled through **C1** into an amplifier (**U1**) which increases the AC voltage portion of the input signal. The output of the amplifier is AC-coupled to an 8-ohm speaker which converts the electrical signal to acoustic waves capable of being heard by our ears. The printed wiring board also contains an 8-volt regulator which conditions the input voltage, and an indicator LED (**D1**) to monitor operation.

Photodetector and Potentiometer

Q1 is an NPN phototransistor. A phototransistor is similar to a normal transistor, but differs in that it has an optical transparent base area to receive light. This base acts as a photodetector, generating base current when exposed to light. As with a conventional transistor, a small current through the base-emitter junction controls a larger current flowing from the collector to the emitter. The ratio of collector current to base current is the transistor's gain, usually expressed as h_{fe} In a phototransistor the same phenomenon amplifies the base photo-generated current, as in a conventional transistor. The result is conversion from light energy to electric current, and amplification in one device. Phototransistors are often rated by their ability to convert optical energy to electrical energy with a transfer function ***R***. The symbol ***R*** is short for responsivity, and for a phototransistor indicates its sensitivity in units of amps (collector current) per watt of incoming optical power. Typical responsivity for the **IF-D92** is 125 µA/µW.

Current through the phototransistor is converted to a voltage by a potentiometer, **R2**. The audio volume of the *Duplex Optical Voice Link* receiver is set by this variable

resistor. **R2** has an audio taper, allowing a wide operating range to match the human ear's response. The potentiometer is mechanically integrated with the on/off receiver power switch, **SW1**.

Amplifier and Speaker

The amplifier in this circuit is LM386N (**U1**). LM386 is a power audio amplifier designed for use in low-voltage consumer applications. It has an input impedance (pin 2) of 50 k ohms. This input impedance combined with the 0.047 µf capacitor (**C1**) produces a 3 dB high-pass-frequency point of 70 Hz. The gain of LM386N as shown in the circuit schematic is 20. (Options for increasing this gain are discussed in the section "**Extending the Link**".) Inputs to the amplifier are ground-referenced and the output is automatically internally biased at one-half the supply voltage. Components **C4** and **R3** provide capacitive load compensation to the inductive speaker load for LM386N.

The 8-ohm speaker is capacitively coupled through **C3**, a 220 µf electrolytic capacitor. The 3 dB high-pass frequency can be calculated from the equation

$$f_{3\ dB} = \frac{1}{2 \quad R \ C} \qquad \textbf{Eq. 12}$$

Voltage Regulator and Miscellaneous Parts

Power for the voice link receiver and transmitter is provide by a 120-VAC-to-12-VDC power adapter, and applied to the circuit board at receptacle **J1**. Diode bridge **U2** steers the oncoming power so that the correct polarity is applied to the circuit regardless of adapter plug polarity. **VR1** is a three-terminal device that produces a fixed 8-volt output from the unregulated power adapter voltage. The regulator has a 1.25-volt internal band gap voltage reference, an error amplifier and a series pass transistor. An internal voltage divider scales the output voltage and presents it as feedback to an error amplifier, which compares it to the internal 1.25-volt internal reference. Any variation in output voltage due to changes in the load current or input voltages generates an error signal. This is amplified and used to control the drive of the series-pass transistor until the desired output voltage is restored. The idle current for the receiver when it is not generating audio signal is less than 10 mA.

C1 (220 µf) functions as a low impedance power source (reservoir) for the receiver circuit when the LM386N amplifier requires a large amount of energy to drive the speaker. The green LED (**D1**) indicates when power is applied to the receiver circuit.

Final Assembly

This kit when assembled will functionally look like the block diagram shown in **Figure 13**. The transmitter on the left will be optically coupled to the receiver on the right. The transmitter on the right will be optically connected to the receiver on the left. Optically coupling the left and right sides will be a 3-meter length of jacketed duplex optical fiber with a 1000 µm core.

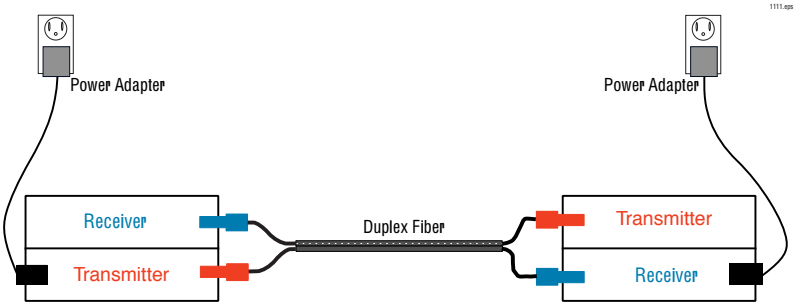


Figure 13. Block diagram of duplex voice link.

EXTENDING THE LINK

The distance between the transmitter and receiver can be extended up to 40 meters by using fiber. To purchase this additional fiber, determine the length desired and contact the distributor from whom you purchased this kit. Industrial Fiber Optics' part number is IF-C-D1000. If you cannot determine who that distributor is, please contact Industrial Fiber Optics for assistance. (See page 32 for contact numbers.)

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

1. Terminate both fiber ends as described on page 7 of this manual.
2. Install one fiber end into the fiber optic LED and the other end into the phototransistor as described in **Figure 3**.
3. Physically separate the transmitter and receiver as far as the fiber length will allow.
4. Turn the receiver switch on and to the position which produces maximum volume. Have an associate remain at the receiver.
5. Press the momentary switch and speak into the microphone while watching your associate.
6. If your associate cannot hear your voice, you will have to further modify the link. Solder a radial 10 µf electrolytic capacitor in the location marked **C5** on the *receiver* printed wiring board. (This will increase the gain of LM386N to 200 V/V.)
7. If the sound at the receiver is still too low, change **R3** in the transmitter circuitry from a 150 resistor to a 47 resistor.

# # #

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 constantly varies. 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 emitter of one transistor is fed into the base of another transistor 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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Fiberoptic Product News Buying Guide, Gordon Publications, Inc., Box 1952, Dover, NJ 07801

Lightwave 2000 Buyer's Guide, PenWell Publishing Co., 1421 S. Sheridan, Tulsa, OK 74112

Organizations

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

Society of Photo-Optical Instrumentation Engineers (SPIE), P. O. Box 10, Bellingham, WA 98227-0010

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

* Buyers guides are updated and published each year.

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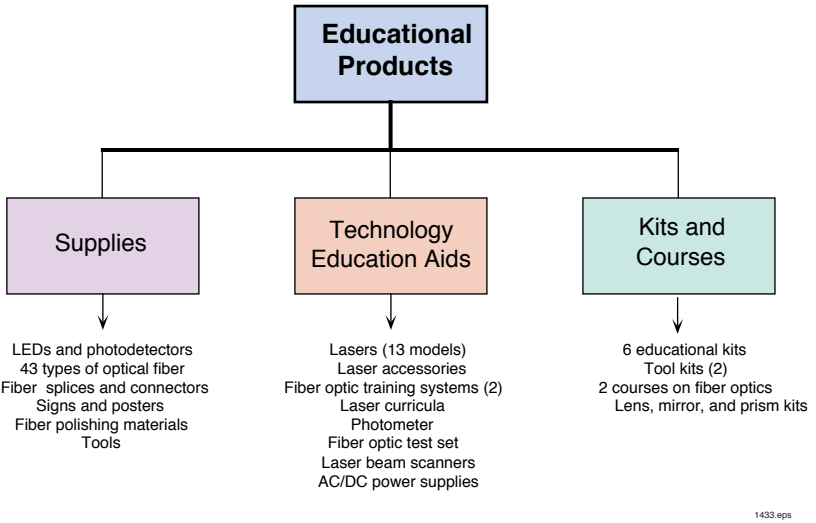
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ADDITIONAL KITS:

ADVENTURES IN FIBER OPTICS KIT



With the Adventures in Fiber Optics kit you can follow the exploits of famous experimenters such as Galileo, Franklin, Gould, begin to explore fiber optics basics and learn more about the fascinating potential of fiber optical technology. The kit is suggest for ages 10 and above. It contains materials and an instruction manual to complete fiber unique projects such as: Bending a Light Guide • Fluorescence • Tyndall's Prestigious Light-in-Water Experiment • Special Fiber Optic Lighting • Art of Polishing Glass • Making Your Own Image Conduit. (Product number **IF E60**)

SPEED OF LIGHT KIT

For centuries, men and women of science tried in fascinating ways to measure the speed of light. The culmination of their efforts is this low-cost ingenious kit that allows the common person to measure the speed of light. Included with the electronic and physical components is an easily understood and often lighthearted manual which traces the steps of the pioneers in optics research as well as step-by-step assembly instructions. (Product number **IF SLK**)

LAB KIT



A kit that contains a 68-page technical manual, and all the fiber optic and electronic components needed to complete nine exciting experiments in fiber optics. Experiments include "Making a Light Guide," "Fiber Optic Cable Transmission," "Connectors and Splices," "Index Matching," "Fiber Terminations," and "Fiber Optic Receivers." Manual also contains a list of references and glossary of fiber optic terms. (Product number **IF LMH**)

PLASTIC FIBER TOOL KIT

A tool kit (Product number **IF TK4**) exclusively for use with the most common types of jacketed and unjacketed plastic fiber. It contains all the tools and instructions in an impact-resistant carrying case to complete the following procedures with plastic fiber:

- Cut jacketed and unjacketed plastic optical fiber
- Use a hot knife to cut fiber
- Remove the jacket from most common jacketed plastic optical fibers
- Polish a fiber end installed in a fiber connector



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ОГРН: 1167746717709