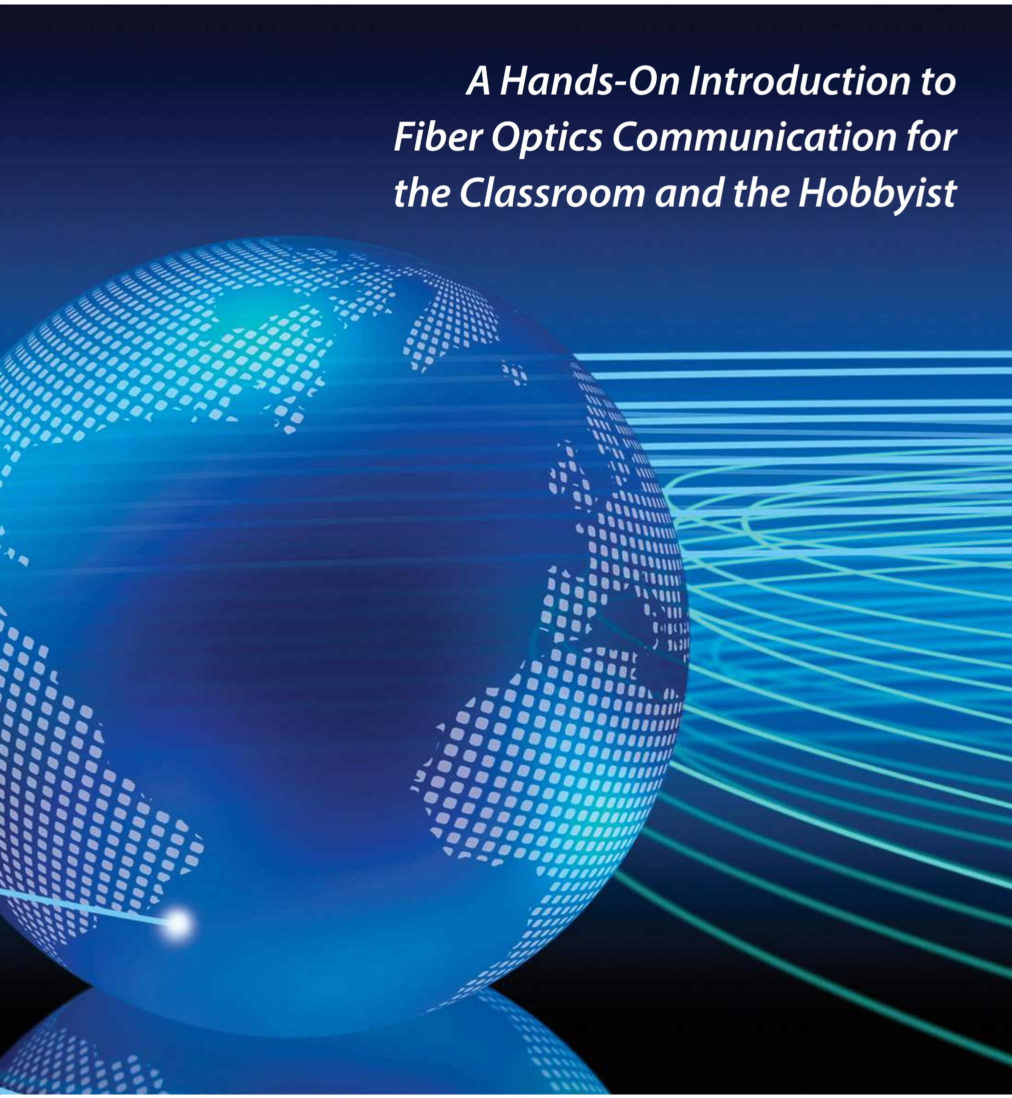
Educational Communication Kit

Radiant Energy in Action



INDUSTRIAL FIBER OPTICS

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Revision B

Printed in the United States of America

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Preface

Fiber optics has become a technology that has become an indispensable part of American life as well as many others on the globe. In many cases this technology is buried underground or behind the scenes and provide benefits that most people do not have a clue about as we go about our daily lives. Telecommunication companies can't say enough good things about this bold technology that has revolutionized systems across the globe. These innovations have cut the costs of many of these systems by about two orders magnitude.

The current expansion in fiber optic technology is now coming closer and closer to the actual point of use. More and more businesses have this technology integrated into their buildings, and residences have it to their local neighborhoods. In the "last mile" of transmission to homes and businesses, wireless and copper have become the most economical solution for the last point of use connection, but all these networks are supported by optical fiber technology.

Today, medical fiber optic systems combined with cell phone camera technology, allow physicians to peer inside the human body without significant surgery. Lasers delivery surgical precision through small apertures which greatly reduce surrounding tissue damage and shorten recovery times. Military command is enabled by portable battlefield communications systems with superior fiber optic and microwave transmission systems.

Massive bundles of copper wiring which once carried telephone conversations across continents and beneath the oceans, are being replaced with much smaller optical fibers that have much higher bandwidth and thousands of channels per fiber. Fiber optic amplifiers with higher bandwidth and greater reliability are replacing electronic repeater stations. To expand this further, each optical fiber is capable of transmitting multiple optical wavelengths increasing capability even further.

The next decade promises even more wonders. The influence of light, lasers and fiber optics will come ever closer to all aspects of our lives. Your television reception has taken on startling clarity and increased resolution, and there is now some programing available in the new 4K2 TV screen format. Japan has committed to broadcasting the 2020 Olympics live in this TV resolution. Paper news media is largely becoming a thing of the past, as it covers stories that are already outdated by the time they are delivered. Environmentally friendly and custom "electronic newspapers" are delivered in real time with new articles being added throughout the day.

Today, anyone who takes an interest in fiber optics to pursue a career in the field will find many years of opportunity and exploration ahead of them. The technology has grown sufficiently that there are many different types of experts within this field. No one skill or training is enough to master all the aspects of optical fiber technology. Most all of the accredited universities have some training in optical fiber or fiber optics in either their engineering or physics departments, offering a rich variation of different curriculums. The future still beckons enticingly with the prospect of making new discoveries.

Objective

The purpose of this kit is to provide you hands-on experience with constructing basic fiber optic receivers, transmitters and cable interfaces, not unlike those used by telephone companies. This booklet contains a parts list; complete assembly instructions; some technical discussions about why everything here works as it does; and a glossary of terms used. You will learn how and why light can be "captured" and transmitted by lengths of optical fiber. With the basic information you gain, you can go on to more sophisticated discussions and demonstrations of fiber optics in action.

Starting Out

In preparing this manual, we assumed you have a basic grasp of digital and transistor electronic circuits. If these topics aren't your strong points, you may choose to skip some of the theory and exercises. You'll still be able to construct the kit and learn the most important fundamentals of fiber optics. Consult the **Glossary** in the rear of the manual if you're uncertain about the meanings of technical terms.

When you have completed this kit and demonstrations, we hope you'll want to move up to more advanced material. See **Page 25** in this manual for a list of other exciting fiber optics products available to you.

Portions of this kit call for the use of an oscilloscope to perform demonstrations and to make some of the measurements. If you don't have, or want to use an oscilloscope, you can make two changes which will still permit you to conduct the demonstrations. First, solder a 10 µf axial-leaded electrolytic capacitor to the transmitter printed wiring board, at the location marked "optional". Second, solder an LED across the output pins on the receiver marked "Data" and "Data Bar" (polarity is not important). During operation, the LED will blink on and off with the transmitter circuit. The visual blinking of the LED is comparable to the waveform as would be seen on an oscilloscope.

Tools and Test Equipment Needed

- Wire cutters
- Needle-nose pliers
- Small Phillips screwdriver
- Small adjustable wrench
- 1 ml water or light oil
- Rosin-core solder
- 25-watt soldering iron
- 18-gauge wire-stripper
- 5-volt DC power supply
- Dual-trace oscilloscope
- Four electrical clip-leads
- Single-edge razor blade or sharp knife

Parts List

Your kit should contain all the components listed in the table below.

Table 1. Parts list.

	P/N	Description	Color-code
C1		.01 μf Mylar® capacitor	
D1	IF-E96A	Fiber optic red LED	Laser marked
H1		Two 2/56 screws	
H2		Two 2/56 hex nuts	
F1		1-meter 1000 μm plastic fiber	
H3		600 grit polishing paper	
Q1	2N3904	NPN transistor	
Q2	IF-D92	Fiber optic phototransistor	Laser marked
Q3	2N3904	NPN transistor	
R1	220 K	1/4 watt resistor	Red Red Yellow
R2	33 K	1/4 watt resistor	Orange Orange Orange
R3	3.9 K	1/4 watt resistor	Orange White Red
R4	33 K	1/4 watt resistor	Orange Orange Orange
R5	100 W	1/4 watt resistor	Brown Black Brown
R6	33 K	1/4 watt resistor	Orange Orange Orange
R7	1 K	1/4 watt resistor	Brown Black Red
U1	4093	Quad CMOS Schmitt	
U2	4093	Quad CMOS Schmitt	

Assembly Instructions

Printed Wiring Board

Follow the guidelines below when assembling your kit:

- Mount all components on the side of the printed wiring board with the white lettering.
- Use the white markings on the printed circuit board to determine the location and orientation of each part. (Component Side.)
- All soldering is to be completed on the opposite side.
- Use a water soluble or rosin core solder such as Digi-Key RASWLF.0311OZ-ND. Do not use an acid or caustic flux solder such as used in industrial or plumbing applications.
- Avoid applying prolonged heat to any part of the board or component, to prevent damage. 5 Seconds maximum.
- After soldering each component, trim its lead length flush with the solder.

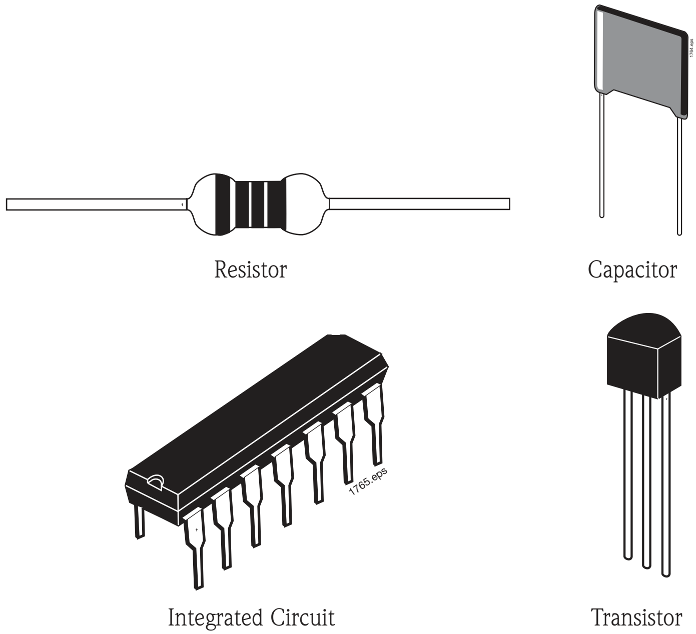


Figure 1. Component identification: resistors, capacitors, ICs.

Board Assembly Steps

1. Insert resistors **R1** through **R**7, one at a time, into the printed wiring board and solder them in place.
2. There is no positive/negative orientation of capacitor **C1**. Identify, insert leads through the board and solder in place.
3. Identify pin 1 of **U1** and **U2** (the lower left pin of the integrated circuit [IC], when viewed from above). Insert the ICs into designed spots marked on the printed circuit board, with pin 1 to your lower left. The lettering on the ICs will face the same direction as the markings on the board. Solder in place.
4. Identify **Q1** and align the package design with the detail on the printed wiring board. Insert and solder.
5. 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 denatured alcohol 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.

6. Identify **D1** as the blue fiber optic housing. Insert **D1** in the designated area on the printed wiring board. Fasten in place with 2/56 screw and nut. Solder the leads.
7. Identify **Q2** as the black fiber optic housing. Insert **Q2** in the designated area on the printed wiring board. Fasten in place with 2/56 screw and nut. Solder the leads.
8. If you are going to operate this kit from one power supply, solder jumper wires from solder pads **GND** to **GND**, and **+5V** to **+5V** on the center left portion of the printed wiring board. If you want to use separate transmitter and receiver power supplies, break the two boards apart at the scribed junction.
9. Solder 24-gauge wires to the connections labeled **+5V**, **GND**, **EN**, **EXT**, **DATA** on the edge of each board. (If you have chosen to keep the boards together you will need to attach wires to only one of the two **+5V** and **GND** connections.)

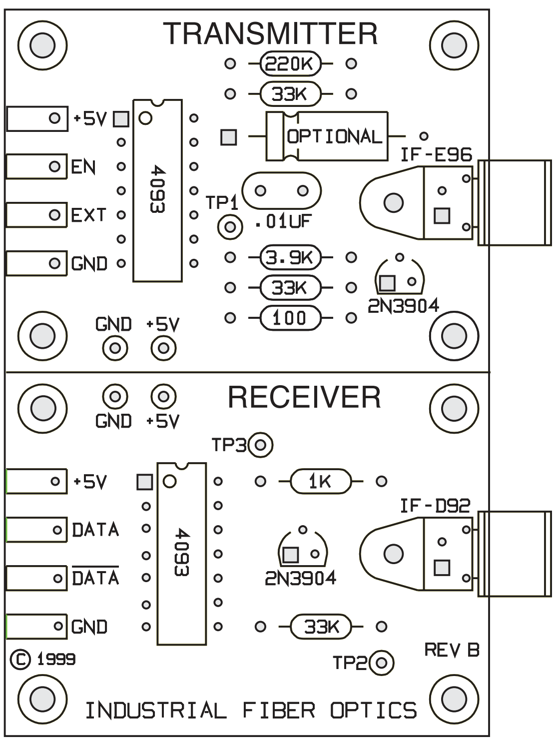


Figure 2. Board details on the printed wiring boards.

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 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 3**. You may get the best results by supporting the upright fiber against some flat object such as a portion of the printed wiring board.

(Don’t insert the fiber ends into their connectors until we give you the word, in the next section.)

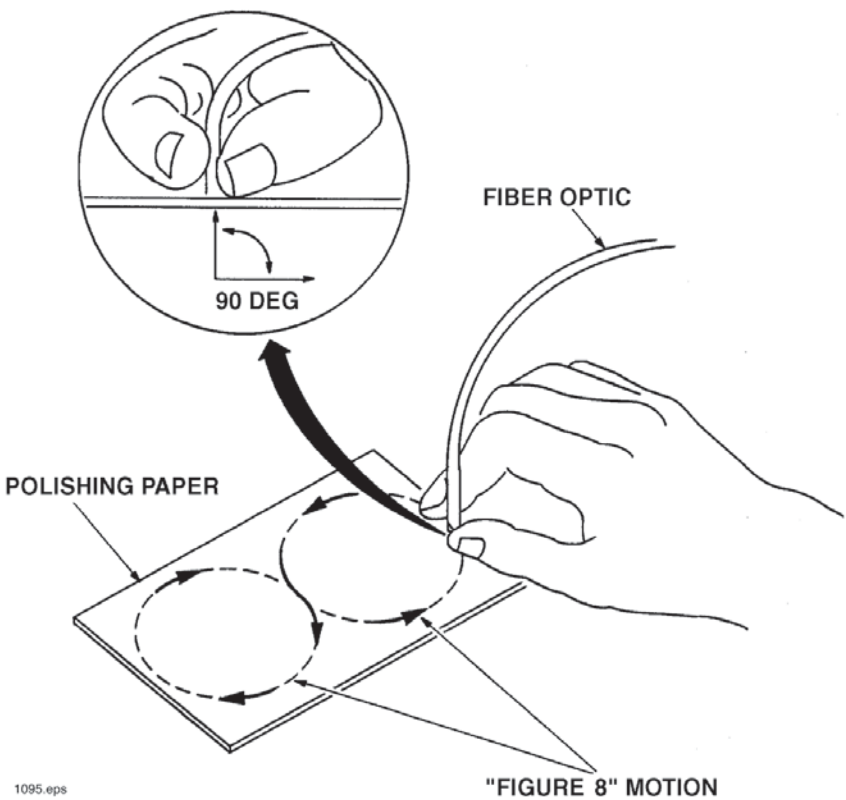


Figure 3. Pattern and orientation of the optical fiber during polishing.

Experiments and Activities

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

A2. Holding the fiber about .5 mm (.020 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?

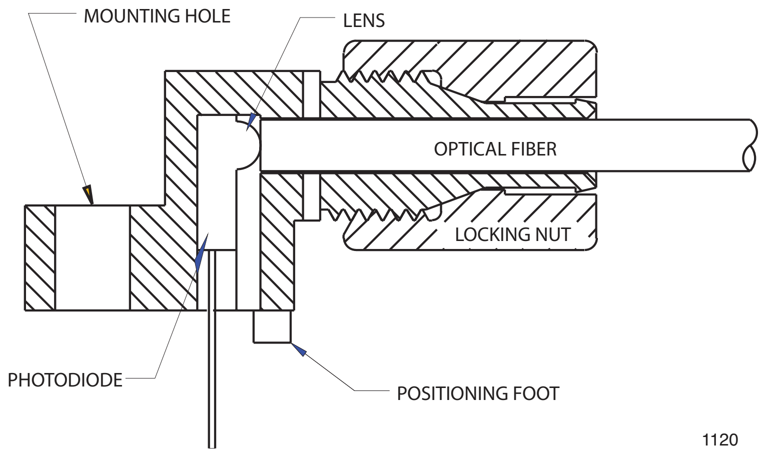
With your power supply turned off, make the following connections with the electrical clip leads to the printed wiring board(s).

- +5 volts to the positive terminal on the power supply
- **GND** to the negative terminal on the power supply
- **EN** to the negative terminal
- **EXT** to positive terminal

If you are using a variable voltage power supply, turn the voltage down to the minimum. Then turn the power supply on, and adjust the power supply to 5 volts.

A3. Determine if the Transmitter LED (**IF-E96A**) is on by measuring the voltage across **R5**. It should measure approximately 3 volts. If the LED does not have any current flowing through it, double-check the power supply, electrical connections, and assembly sequence. (You will be able to see the light being emitted from the LED if you look through the hole that the fiber would be inserted.)

A4. Insert one end of the optical fiber into the fiber optic LED, following the instructions in **Figure 4**.



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.

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

Figure 4. Cross-section of fiber optic LED and cable.

A5. In electronic design, multiple circuits often will achieve the same design goals. We'd now like you to design an alternative electronic LED drive circuit that will accept an external and oscillator input signal. Draw that circuit below. You may use **Figure 9** as a reference.

A6. What is the minimum output voltage at Gate **d** in **Figure 9** necessary to ensure saturation of the LED drive NPN transistor? (Assume h_{fe}= 50; V_{ce}=0.2 volts; V_{cc}=5 volts; and V_{LED}=1.5 volts.)

Insert the unattached fiber end into the fiber optic phototransistor, following the same steps in **Figure 4**.

Connect the EXT and the EN inputs to +5 volts. **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 **TP1** on the transmitter circuit and the other to **TP3** on the receiver circuit. (You should see two square wave signals similar to those shown in **Figure 5a**.)

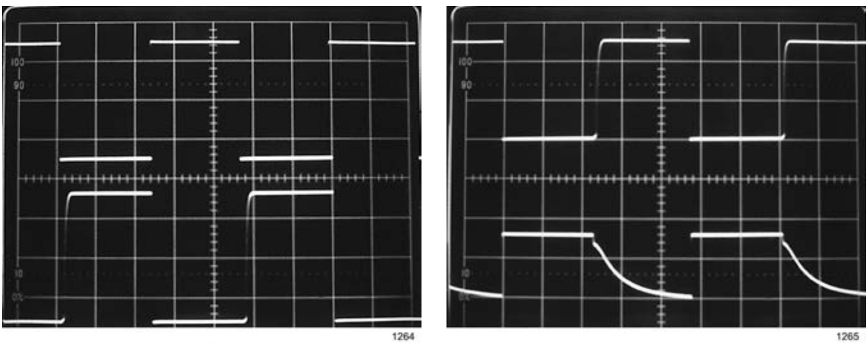


Figure 5. Two oscilloscope traces of: a) transmitter TP1 (top) and receiver TP3 (bottom) signals; and b) receiver TP3 (top) and TP2 (bottom) signals.

A7. Measure the transmitter board's oscillator period with the oscilloscope and calculate the oscillating frequency.

____________________ Hz

A8. Move **Probe 1** located on the transmitter to **TP2** (emitter of the phototransistor **Q2**) and observe the received signal as depicted in **Figure 5b**. Is the frequency the same? What does the signal at **TP2** look like compared to **TP3**?

A9. Measure the rise and fall time at **TP2**. 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 **EXT** input, or analytically determined, from the measured rise and fall times.)*

A10. How would you change the sensitivity or gain of this receiver?

A11. Connect the **EXT** input to + 5 volts and **EN** to ground. Measure and record the emitter voltage at **Q2** of the receiver. Determine the minimum power input to the phototransistor base from the fiber (assuming its responsivity is 125 µA/µW) necessary to create this voltage.

A12. What is the sensitivity of the phototransistor and common-emitter amplifier? (Assume the responsivity of **Q2** is 125 µA/µW, and the h_{fe} of **Q3** is 50.) What are the dimensions (ft/sec, amps/volt) of this sensitivity?

A13. Assuming that this transmitter launches 15 µwatts of energy into the fiber, a receiver sensitivity of 1.25 x 10^{-1} µwatts, and fiber attenuation 1 dB per meter, determine the maximum cable length this system can use.

A14. If an optical radiometer or fiber optic power meter is available to you, disconnect the optic fiber from the receiver phototransistor and measure the optical power existing from the fiber. Recalculate the maximum distance for which this data link can be used based on the actual measured power out of the 1-meter fiber.

A15. 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 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 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 copper residential telephone cable! 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 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 Advantages of Fiber Optics 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

Basically, a fiber optic data link contains three main elements: a transmitter, an optical fiber or cable, and a receiver. The transmitter takes data previously converted to 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 wanted to send 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 advantage of optical fiber is 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 on foggy and rainy days.

Also contained in fiber optic data links are connectors that provide the connections between 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.

Why Optical Fiber Works As It Does

The behavior of light which you saw demonstrated in the preceding activities has a precise scientific explanation. (Remember to consult the **Glossary** in this manual if the meaning of a term isn't clear to you.)

Light travels in straight lines through most optical materials, but that's not necessarily 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 6**. 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 outgoing (transmitted) ray of light after it has been bent.

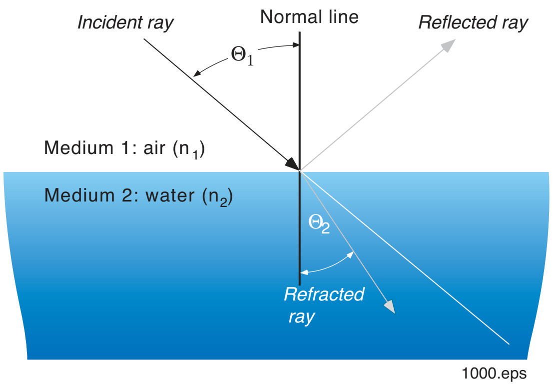


Figure 6. Different portions of a light ray at a material interrace.

The mathematical relationship between the incident ray and the refracted ray is explained by Snell's Law:

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

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 transmitted angles. If n_1 is larger than n_2, Snell's Law says that refraction (bending) of light cannot take place when the angle of incidence is too large.

If the angle of incidence exceeds a certain critical value (in which the product of n_1 and the sine of the angle, Θ, equals or exceeds one) light cannot exit. (Recall from trigonometry that the maximum value of the sine of 90 degrees is 1.)

If mathematically light can not exit the material, 100 percent is reflected. The angle that it is reflected is equal to the angle of incidence. The phenomenon just described is called *total internal reflection*, and it is what keeps light contained inside an optical fiber and is without any loss. An example of a light ray traveling down an optical strand is shown in **Figure 7**.

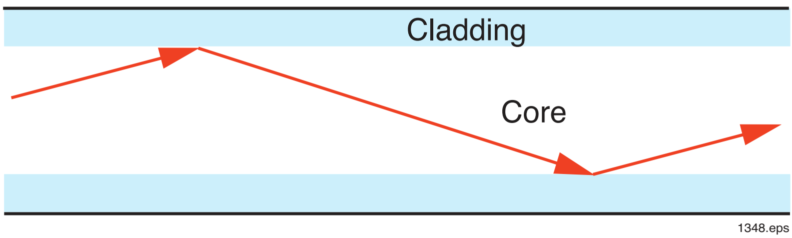


Figure 7. A light ray trapped by total internal reflection inside an optical fiber.

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. The most common two-dimensional model to achieve is a solid rod of material surrounded by a layer of lower-refractive-index material. This two dimensional light confinement construction demonstrates the fundamental mode whereby light travels through 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.

About the Optical Fiber We're Using

The simplest fiber optic cable consists of two concentric layers of optically 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. The cable used in this kit also has a jacket to protect the optical properties of the core and cladding. Cables can contain more layers as the application requires.

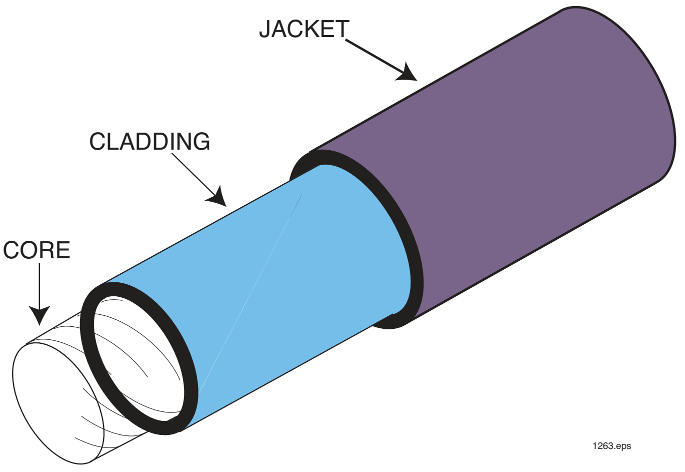


Figure 8. Cross-section of a simple fiber optic cable.

Optical fiber is generally made from either plastic, glass or other specialty materials. This kit uses plastic fiber, which is very easy to terminate and does not require special tools. Plastic is generally limited to uses involving distances of less than 150 meters. Glass fiber, on the other hand, has very, very low attenuation (light loss), is harder to cut, requires special end connections and is more expensive, but can be used in very long distance applications.

The plastic fiber in this kit has a polyethylene jacket, a fluorine polymer cladding and a polymethyl methacrylate polymer (PMMA) core. The core is 980 μm (0.04 inches) in diameter, surrounded by 10 μm of cladding.

Transmitter

Systems which send data, whether it is voice or digital information, almost never power the optical sources directly. This role is handled by transmitter electronics. 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/optical source 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 current to light energy with the same pattern.

The LED, **IF-E96A**, supplied with this kit produces red light. Its optical output is centered at a wavelength of 660 nanometers (nm). 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.

Modern telecommunications network use ultra fast lasers, but that is another topic of in itself. The kit you have assembled has additional electronics in the form of an oscillator. This circuit provides a repetitive signal so you can demonstrate the operation of the transmitter without additional equipment. Note that the kit handles only digital data, produced with an electrical signal which is either On or Off (also known as "high" or "low").

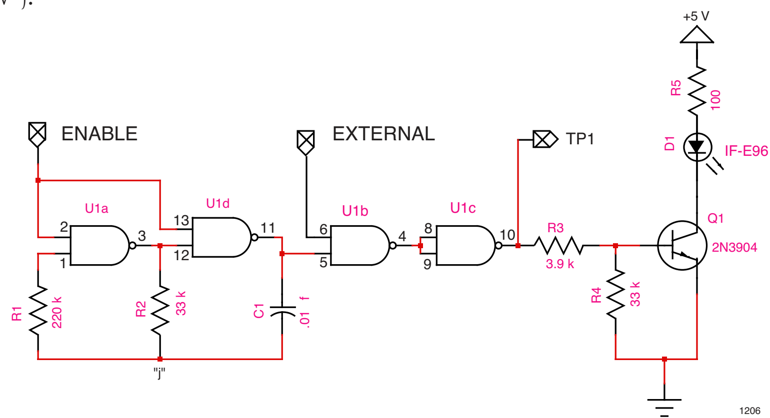


Figure 9. Transmitter board schematic.

The following discussion assumes the reader has a basic knowledge of digital logic functions (e.g., AND, NAND, OR, NOR) and theory of transistor operation.

Table 2. Truth table for 2-input NAND Gate.

Input 1	Input 2	Output
0	0	1
0	1	1
1	0	1
1	1	0

The Quad 2-input NAND CMOS IC used in the transmitter is a special type called a **SCHMITT**. 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.

Circuit Operation

The transmitter uses two gates of quad 2-input NAND IC (**c** and **d**) for the buffer circuit, and two gates (**a** and **b**) as a relaxation oscillator. The transistor (**Q1**) is used as a driver to switch power on and off to the LED. The entire circuit operates at a nominal 5 volts – standard voltage for digital logic used in computers and other data processing equipment. Logical highs and lows (digital "1"s and "O"s), can be created by electrically connecting that input to +5 volts or ground (O volts), respectively.

Buffer and LED Driver

Assume the on-board oscillator is disabled, and the **EN** (enable) input is at logic low, forcing the output of NAND gate "**d**" (**pin 11**) to logic high (5 volts). Gate "**b**" in the buffer circuit now has one input (**pin 5**) above logic high so its output will be determined by the logic level at the **EXT** (External) input (**pin 6**).

When digital data is fed to the **EXT** input, operation is as follows: A logic high forces the output of gate "**b**" (**pin 6**) to logic low. Gate "c" now has both inputs (**pins 8** and **9**) at logic low, forcing its output (**pin 10**) high. The resulting current through **R3** turns **Q1** on, completely energizing the LED. A logic low at the **EXT** input forces the output of gate "b" high. Gate "**c**" now has both inputs at logic high, forcing its output low. There is no current through **R3**, so **Q1** turns off, de-energizing the LED.

R3 limits **Q1**'s base emitter current to a safe level while still providing enough current for complete turn-on or saturation. **R4** bleeds off stored charges in the base-emitter junction, allowing faster operation for **Q1**. **R5** sets the maximum LED current when **Q**1 is saturated.

Oscillator

Gates "**a**" and "**d**" are configured as an RC-controlled relaxation oscillator. Assume the transmitter is powered up and the oscillator is initially disabled (the **EN** input [**pins 2** and **13**] is at logic low). The outputs of gates "**a**" and "**b**" will both be high, and capacitor **C1** will be uncharged because the net voltage across it is zero (**pins 3** and **11** are both at 5 volts).

Upon enabling the oscillator (logic high applied to **EN** input) the output of gate "**d**" switches low, while that of gate "**a**" remains high as capacitor **C1** begins charging through **R2**. If **EN** input is a logical one, the NAND gates behave as inverters (outputs are complements of the inputs), responding only to conditions present on **pins 12** and **1**. Remember that the net voltage across a capacitor cannot change instantaneously, so when gate "**d**" switches low, node "**j**" is instantaneously brought low to satisfy capacitor operation. **Pin 1** of gate "**a**" senses the same input combination present prior to enabling the oscillator, causing its output to remain high.

As **C1** charges, the voltage at node “**j**” increases to a level recognized as a logic high by gate “**a**”, causing its output to switch low. Gate “**d**” now switches from low to high, and capacitor **C1** begins charging in the opposite direction or polarity. The voltage at node “**j**” starts decreasing until a level recognized as logic low by gate “**a**” is reached. The output of gate “**a**” goes high, input to gate “**d**” goes low and the cycle repeats.

The transmitter and oscillator have four possible operational modes resulting from logic levels present on the **EN** and **EXT** inputs. These are summarized in **Table 3**.

Table 3. Transmitter oscillator truth table.

Mode	EN	EXT	LED State
1	0	1	ON
2	0	0	OFF
3	1	1	OSCILLATING
4	1	0	OFF

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. Fiber optic receivers typically perform this function using three elements: a photodetector, an amplifier and a digitizer. As with fiber optic transmitters, the optical connector is often integrated into the total package as is the case in this kit. 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 small electrical current from the photodetector. To compensate for this decline in signal strength the amplifier increases the amplitude of the electrical signal. Finally, a digitizer converts the amplified signal to digital levels and provides the correct voltage levels for the external logic.

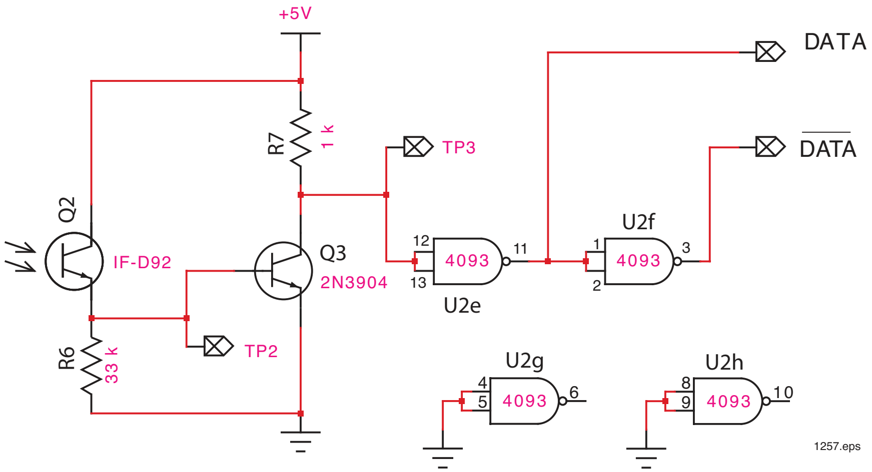


Figure 10. Circuit diagram of receiver.

Circuit Operation

The receiver uses an NPN phototransistor, an NPN transistor amplifier and a quad 2-input NAND CMOS IC to perform all electrical functions mentioned previously. The phototransistor converts incoming light energy to electric current, and provides some preamplification gain. The NPN transistor (**Q3**) further amplifies the electric signal to raise its amplitude to a level suitable for the NAND IC. The NAND gates are configured as inverters, two of which are used to convert the received signal to digital levels, in both non-inverted (DATA) and inverted formats (DATA BAR). The remaining two gates in the quad package are unused. Power for the circuit is a nominal +5 volts. The following discussion about the receiver operation assumes the reader has a basic understanding of digital logic and transistor operation.

Photodetector and Amplifier

Q2 is an NPN phototransistor. A phototransistor is similar to a normal transistor, but different in that it has an exposed base to receive light. This base acts as a photodetector, generating base current when exposed to light. Like 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 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. This response is wavelength dependent for semiconductor devices.

Q3 is connected in a darlington configuration to **Q2** for maximum amplification of incoming optical power. Light striking **Q2** is converted to electric current and amplified. The resulting emitter current is applied into the base of **Q3**, further amplified and controls the voltage signal across **R7**. The pattern of the signal at the collector of **Q3** will be inverted in relation to that of the fiber optic transmitter. **R6** provides a DC path for the leakage current from **Q2**, and a discharge path for stored charges in the base-emitter junction of **Q3** when no optical power is incident upon the base of **Q2**.

Digitizer

Gate “**e**” converts the analog signal across the collector of **Q3** to a digital logic level. It performs this by switching its output whenever the voltage goes just above, or just below, a valid logic low or high at the input. Output of gate “**f**” provides an inverted version of the input data. The NAND gates are a SCHMITT type, with operational benefits previously discussed in the Transmitter section.

Summary

Typical flow of operation for the receiver is as follows: With no light striking **Q2** (equivalent to a logic low from the transmitter), only leakage current flows into **R6** and the base of **Q3**, leaving it essentially turned off. Since no current flows through **R7**, the collector of **Q3** is high, and the input to gate “**e**” is a logic high. As a result, the output from gate “**e**” is a logic low, and that from gate “**f**” a logic high. When the transmitter output is a logic high (digital “1”), the LED (D1) is turned on. Light from the LED travels the length of the fiber cable to the phototransistor **Q2**, where it is converted to electric current and fed into **Q3**’s base. **Q3** further amplifies its base current in the form of collector current, which flows through **R7**, which in turn causes a voltage drop across **R7**. As a result, **Q3**’s collector voltage drops. When the voltage to gate “e” drops below the threshold for logic low, it switches its output high, reconstructing the condition at the transmitter. Output of gate “**f**” provides an inverted version of the data.

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 center line of the core.

Analog. A type of information system in which the information is constantly varying. 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 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.

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 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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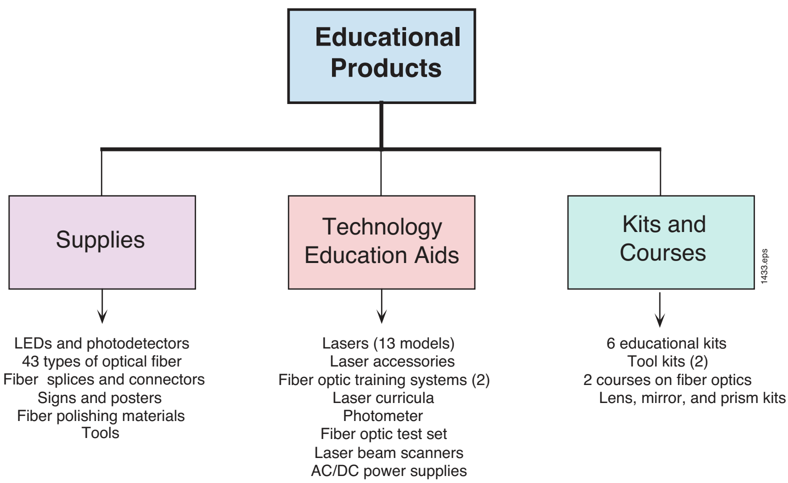

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