Experimenting With a Low-Cost Fiber-Optic Link

By Forrest M. Mims

UNTIL now high prices have prevented many hobbyists from experimenting with fiber-optic data links. General Electric has come to the rescue, however, with a fiber-optic designer's kit that sells for only $9.95. The kit includes a near-infrared emitter and a phototransistor detector, each of which is installed in a threaded plastic receptacle. Low-cost AMP Optimate™ fiber-optic connectors can be quickly mated to the receptacles.

The General Electric kit also includes a one-meter length of DuPont Crofon™ 1040 fiber-optic cable terminated with Optimate connectors at each end and a complete set of specification sheets and application notes. You can order the kit directly from General Electric (Semiconductor Products Dept., Optoelectronics, West Genesee St., Auburn, NY 13021).

The key feature of General Electric's designer's kit is the cleverly designed threaded plastic package into which the active emitting and detecting components are installed. Figure 1 shows the package and how it interfaces with a threaded Optimate plastic connector. Figure 2 is an internal view of a package that contains an infrared emitting diode. Note the use of a reflector and lens to collect radiation emitted by the diode and direct it toward the aperture in the package, where a terminated fiber will be connected.

The Emitter. The emitter furnished with the General Electric designer's kit is designated GFOE1A1. This device is a silicon-compensated, liquid-phase, epitaxial, gallium-arsenside diode that emits near-infrared radiation peaking at about 940 nanometers. At room temperature and 30 to 50 mA forward current, the diode has a power conversion efficiency of about 4%. The conversion efficiency increases to 5 to 6% at 200 mA (pulse drive).

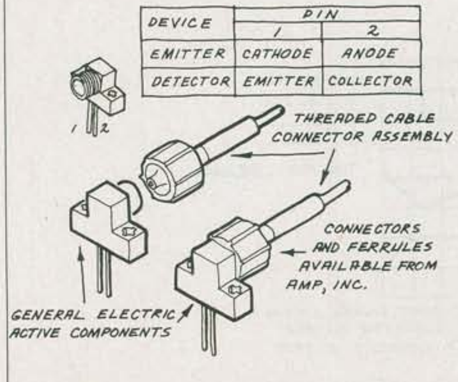
The diode is mounted behind a diffuse, molded-epoxy lens that provides a 1.2-mm diameter source having nearly uniform intensity across its surface. The large source size assures good optical coupling between the LED and the wide variety of different fibers to which Optimate connectors can be terminated.

At 50 mA forward current, a typical GFOE1A1 will couple more than 100 μW into a 1-mm diameter fiber. This is approximately 10% of the total power (i.e. a −20-dB loss) radiated by the chip and is comparable to the light injection efficiency of other low to moderately priced fiber-optic links.

The silicon dopant added to the GFOE1A1 increases both power conversion efficiency and wavelength at the expense of the diode's *response time* (the sum of delay and rise times or storage and fall times). Conventional GaAs emitters, for example, have response times measured in tens of nanoseconds or even less. A GaAs:Si emitter like the GFOE1A1, however, has a response time of nearly a microsecond. This places an upper limit of about 400 kHz on the modulation bandwidth of the GFOE1A1, which, of course, is more than adequate for many kinds of telecommunications and data-transmission applications.

The Detector. One of two different detectors can be provided with the General Electric designer's kit. One is an npn phototransistor (GFOD1A1), and the other is a photodarlington transistor (GFOD1B1). Both are installed in packages identical to those used for the GFOE1A1 emitter. Since the base of a phototransistor is not often used in optoelectronic circuits, neither device is provided with an external base lead.

The spectral response of both



DEVICE	PIN	
	1	2
EMITTER	CATHODE	ANODE
DETECTOR	EMITTER	COLLECTOR

Fig. 1. Construction of GE active fiber-optic components.

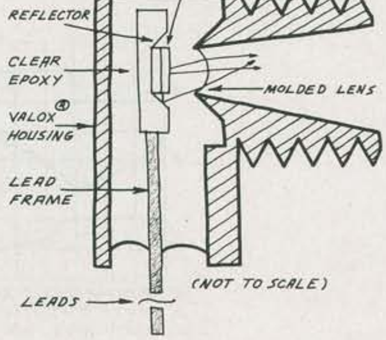
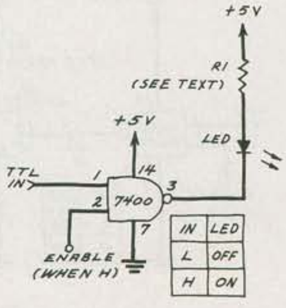


Fig. 2. Internal view of GE side-looking emitter.



IN	LED
L	OFF
H	ON

Fig. 3. Basic TTL compatible LED driver.

phototransistors peaks at about 850 nanometers. At the 940-nanometer wavelength emitted by the GFOE1A1 emitter, both phototransistors exhibit about 80% response efficiency.

When illuminated by radiation from a GFOE1A1 emitter transmitted to the phototransistor via a 1-m length of Crofon 1040 fiber, the GFOD1A1 exhibits a minimum responsivity of 70 μA per μW. The GFOD1B1 provides 1000 μA under the same conditions. The turn-on and turn-off times of the GFOD1A1 are each 3 μs when the load resistance is 0 ohm. The turn-on and turn-off times for the GFOD1B1 are, respectively, 10 and 25 μs when the load resistance is 0 ohms.

Digital Logic Application Circuits. Short fiber-optic links are ideally suited for transmitting digital data through noisy environments. The circuits that follow illustrate straightforward ways to send and receive signals through such a fiber-optic link.

TTL Emitter Driver Circuits. Figure 3 shows a basic TTL LED driver made from a single NAND gate. When the enable input is *low,* the LED is turned off irrespective of the logic level at the TTL input. When the enable input is *high,* the LED is forward-biased when the logic level input is high. When the input is low, the LED is turned off.

Series resistor *R1* limits current through the LED to a safe value. The output from a standard TTL 7400 gate can sink up to 16 mA. To drive the LED at this level means *R1* must be 312.5 ohms. (From Ohm's law, *R1* equals 5 volts divided by 16 mA.) The closest standard resistance value, 330 ohms, will provide a LED current of 15 mA.

Incidentally, the maximum current output from a LS TTL gate is only 5 mA. Therefore, you should use standard TTL in the circuit shown in Fig. 3.

In applications where higher infrared emission levels are required, more drive current can be provided by adding a transistor driver stage as shown in Fig. 4. Note that the transistor inverts the signal from the gate. Also note that since the transistor and not the gate drives the LED, a LS TTL gate can be used.

Resistor *R2* should be selected to limit the current (I) through the LED to the desired level. The combined voltage drop of *Q1* and the LED is about 2 V. Therefore, the series resistance is $(V_{cc2}-2)/I$. If V_{cc2} is 5 V and the desired current level is 50 mA, then *R2* should have a resistance of 60 ohms. Higher current levels can be achieved by increasing V_{cc2} or reducing *R2*'s resistance. It is essential, of course, that *Q1*, *R2*, and the LED emitter be rated for the selected current level.

Detector Circuits. Figure 5 shows two basic phototransistor detector circuits. In Fig. 5A, the phototransistor is normally off and the voltage across R_L is high. When the phototransistor is turned on by an incoming light pulse, the output is brought low.

While a basic phototransistor circuit is very sensitive, its response time is slowed by the RC time constant of the internal capacitance of the phototransistor and R_L. The delay induced by the load resistor is virtually eliminated by adding a common-base stage as shown in Fig. 5B. The low-resistance path provided by *Q2* greatly speeds up the charge-discharge time of *Q1*'s internal capacitance, thereby substantially improving its response time.

Figure 6 compares the response of the two basic phototransistor circuits in Fig. 5. Waveform A is the

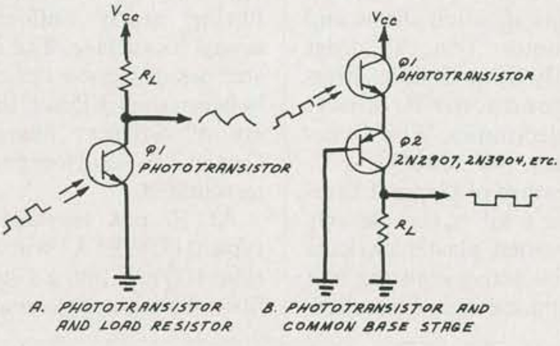


Fig. 5. Two phototransistor circuits.

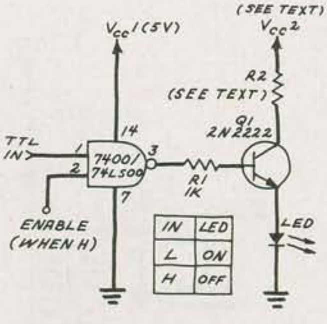


Fig. 4. TTL compatible fiber-optic LED driver with gain stage.

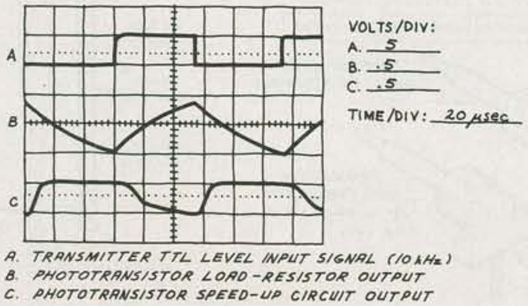


Fig. 6. Received signal waveforms for basic phototransistor detector circuits.

signal delivered to the TTL compatible LED driver shown in Fig. 4. The signal is inverted by the LED driver transistor. Waveform B is the output of a basic phototransistor load-resistor circuit (Fig. 5). Waveform C is the output of a phototransistor circuit to which a common base stage has been added.

Note the slow response of the phototransistor circuit in trace B. The rise time of the common base circuit in trace C is approximately ten times faster. Also note the phase reversal of the output from the two phototransistor circuits.

TTL Compatible Fiber-Optic Receiver. The outputs from the phototransistor circuits in Fig. 5 are not TTL compatible. To provide a fully transparent TTL fiber-optic link (one that accepts and outputs TTL level logic signals), amplification and pulse restoration is required.

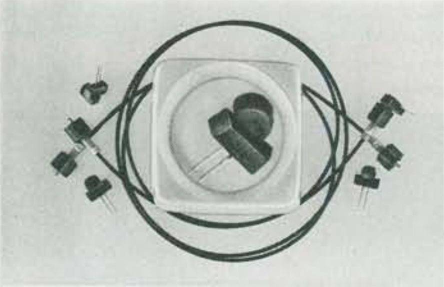
Figure 7 shows a fiber-optic receiver that provides a TTL compatible output signal. An optical signal received by *Q1* is delivered directly to the inverting input of a 741 operational amplifier. Potentiometer *R2* permits the gain of the 741 to be adjusted. The amplified signal from the 741 is coupled through *C1* into a Schmitt trigger formed by a 555 timer.

Figure 8 is a set of oscilloscope waveforms that confirms the transparent nature of this receiver. Waveform A is the TTL signal delivered to a TTL compatible LED transmitter (Fig. 4). Waveform B is the signal at the output of the 741. Waveform C is the TTL level signal at the output of the Schmitt trigger.

The 555 output is a phase-reversed image of the TTL input at the transmitter. The phase reversal can be eliminated simply by following the 555 with a TTL inverter.

The circuit in Fig. 7 requires an initial gain adjustment via *R2.* It may also be necessary to alter the transmitted signal level. Too much infrared at the phototransistor may result in failure of the phototransistor to follow the transmitted signal.

Though the phototransistor load resistor arrangement is very slow (trace B in Fig. 6), this circuit has a surprisingly fast response of about 60 kilobits per second. This performance is made possible by the Schmitt trigger stage. The oscilloscope traces in Fig. 8 were produced



GE components, Dupont cable, and AMP connectors.

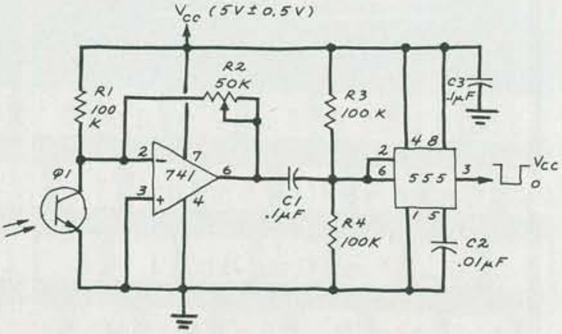


Fig. 7. Fiber-optic receiver with TTL output.

when the circuit was receiving a pulse train of 50 kilobits per second.

General-Purpose Fiber-Optic Receiver. The circuit in Fig.9 is a more versatile version of the preceding circuit. The Schmitt trigger stage has been replaced by a 555 connected as a monostable multivibrator. Optical pulses received by the phototransistor are amplified by the 741 and passed directly to the trigger input of the 555.

A negative-going pulse triggers the 555 into delivering a positive output pulse having a duration of 1.1*R3C2* seconds. With the values given in Fig. 9, the pulse duration is about 2.5 μs. This corresponds to an upper bandwidth of about 160 kHz. (Bandwidth is found by dividing 0.4 by the pulse duration.)

The circuit in Fig. 9 will provide a response greater than 100 kilobits per second. As with the circuit in Fig. 8, it is necessary to adjust the transmitted signal level and *R2* for optimum results.

Going Further. Though I used GFOE1A1 emitters and GFOD1A1 detectors in the test versions of the circuits described above, many other emitters and detectors can be used. Also, many kinds of fiber-optic cable can be used. In fact, over short distances, fiber is not required at all so long as infrared from the emitter can reach the detector.

The GFOE1A1 emitter and GFOD1A1 detector can also be used to transmit *analog* signals through a fiber-optic cable. Many suitable transmitter and receiver circuits have appeared in past installments of this column. Several of these circuits have recently been published in Chapter 2 of *The Forrest Mims Circuit Scrapbook* (McGraw-Hill, 1983). Additional circuits appear in *Engineer's Notebook II* (Radio Shack, 1982).

Finally, the GFOE1A1 emitter can also function as a detector. This means half-duplex, bidirectional transmission over a single fiber-optic cable can be achieved by placing a GFOE1A1 at each end of the link. ◇

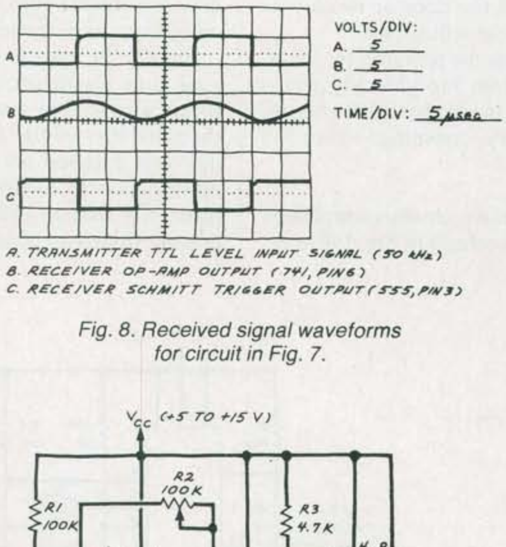


Fig. 8. Received signal waveforms for circuit in Fig. 7.

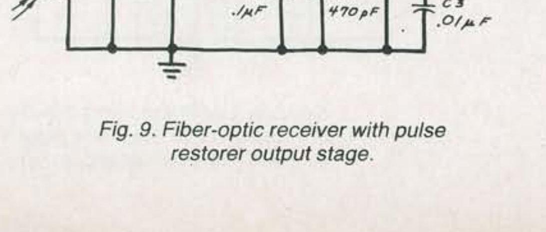


Fig. 9. Fiber-optic receiver with pulse restorer output stage.