# ELECTRONICS NOTEBOOK

## A High-Sensitivity Lightwave Receiver

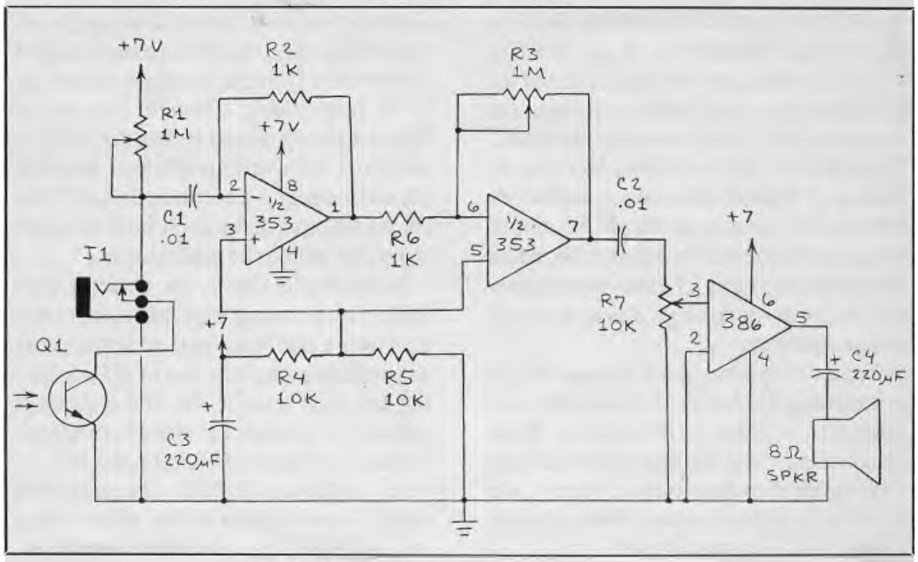

Fig. 1 High-sensitivity lightwave receiver

Near-infrared and visible lightwaves can be used to remotely control toys, garage doors, television sets, video recorders and audio equipment. They can also be used to transmit data between computers and audio signals from receivers to wireless speakers and headphones. The free-space operating range of most of these optical links usually doesn't exceed a few tens of meters. Injecting the radiation into an optical fiber can increase the range to a kilometer or more.

There are several ways to greatly increase the operating range of free-space lightwave links, several of which will be discussed here. Included will be a description of a miniature lightwave transmitter and a very sensitive lightwave receiver that you can assemble. These two units will allow you to conduct many interesting experiments in lightwave communications. In the process, you will learn much more about the practical aspects of this fascinating subject than any article or book can teach.

### *Visible Light vs. Near-IR*

The human eye can sense the optical wavelengths that range from around 380 nanometers to around 750 nm. I was careful to specify "around" because the human eye can actually see beyond these limits if the radiation is sufficiently intense. For example, the 780-nm radiation emitted by most of the laser diodes used in compact-disk players is clearly visible as a bright red light.

Near-infrared is the radiation that falls just beyond visible red light. In other words, near-infrared radiation is invisible to the human eye.

Light-emitting diodes emit either visible or near-infrared radiation. They are well suited for lightwave communications, since they are easily modulated and emit relatively monochromatic light. Until a few years ago, however, LEDs that emit visible wavelengths were not often used in free-space links, due to their very low output power. That all changed with the development of high-power aluminum-gallium-arsenide (AlGaAs) super-bright red LEDs. These new LEDs have an output power of several milliwatts or more, making them just as powerful as some near-infrared emitting diodes.

If you have built near-infrared lightwave communicators, you already know that trying to point an invisible beam at a distant receiver is very difficult unless you have an infrared image converter. The reverse procedure is just as difficult. Switching to 660 nm greatly simplifies alignment, since the bright red beam is visible over a considerable distance.

For obvious reasons, near-infrared emitting diodes have long been of high interest to the military. For example, one of the most common military applications for high-power near-infrared emitting diodes is in illuminators that emit narrow beams of intense but invisible near-infrared. These invisible beams supply the illumination for various kinds of viewing devices. They also function as designators for weapons that can home onto a target illuminated by an invisible beam.

Naturalists use near-infrared viewing devices and illuminators to observe nocturnal creatures without disturbing them. Forensic scientists use the same kind of equipment to inspect suspect documents. Various kinds of ink respond differently to near-infrared, some being almost transparent. Observing a document in the near-infrared can sometimes permit differences in ink to be detected. It can also make visible words, letters and numbers that have been covered by ink or other writing.

Some covert security systems use cameras that are sensitive to near-infrared. Near-infrared illuminators provide the illumination. Vidicons that have a light-sensitive surface with what is known as an extended red response can be used for this purpose. So can solid-state CCD-array cameras. CCD cameras are an ideal choice, since the silicon from which the sensor array is made has its peak optical sensitivity in the near-infrared around 850 to 900 nm.

Incidentally, monochrome CCD arrays are much better sensors of

the color filters applied to the CCD sensors block near-infrared. At least this is the case with the color CCD camcorder I have. If the CCD array retained its very high sensitivity to near-infrared, the resulting video image of the scene focused on it would not always be representative of its actual colors as perceived by the human eye.

Vegetation, for example, is a much better reflector of near-infrared wavelengths than green wavelengths. If the near-infrared wavelengths are not attenuated, the color balance of the resulting video image might be significantly distorted. Then there is the interesting fact that all shades of human skin have a similar reflectance in the near-infrared. No matter what your skin color happens to be, we all look various shades of green when someone looks at us through a near-infrared image converter.

A field of healthy grass appears bright green when displayed on a monitor connected to a color CCD camera. Since grass reflects slightly more than half the near-infrared radiation that strikes it, the same field appears white when a monochrome CCD camera is used.

## *Light-Emitting Diodes*

The most common near-infrared-emitting diodes are made from AlGaAs and silicon-compensated gallium arsenide (GaAs:Si). Most near-infrared AlGaAs diodes emit radiation with a wavelength ranging from 850 to 880 nm. AlGaAs diodes, however, can also be designed to efficiently emit radiation down to 660 nm, the wavelength of so-called super-bright red LEDs.

Near-infrared GaAs:Si diodes emit radiation with a wavelength ranging from 930 to 940 nm. While GaAs:Si emitters are several times as efficient as the GaAs diodes they have largely replaced, they are not as efficient as AlGaAs devices.

It is interesting to note that GaAs:Si diodes produce radiation that is more invisible than that emitted by AlGaAs diodes. This is because the radiation from LEDs is not perfectly monochromatic and the human eye can perceive as a red glow some of the low-wavelength edge of the radiation emitted by AlGaAs emitters. At least this is the case with some high-power AlGaAs I have observed.

## *A High-Sensitivity Near-IR Receiver*

Figure 1 is the schematic diagram for a straightforward but highly sensitive lightwave receiver circuit that can be assembled in a housing that measures only 5 centimeters (2 inches) square and 2 cm (0.75 inch) thick. Though this circuit shows a phototransistor detector *(QI),* it will work with various kinds of junction photodiodes and phototransistors. It includes features that permit both its sensitivity and gain to be easily adjusted.

Referring to Fig. 1, the detector converts the incoming near-infrared radiation into a photocurrent, which appears as a voltage at the junction of *QI's* collector and load resistor *R/.* If the signal is pulsed, *C/* transfers it directly to the inverting ( — ) input of one of the two op amps inside an LM353. The amplified signal is then passed to the second stage of the LM353 for additional amplification. The gain at this stage is controlled by the setting of *R3.* Finally, the signal is passed to the 386 audio amplifier chip that directly drives a small speaker. The signal level admitted to the 386, hence the volume from the speaker is controlled by voltage divider *R7.*

If you have previously built lightwave receivers, you might be wondering why a potentiometer is used for load resistor *RI.* The reason for this is to permit the receiver to work well with lightwave transmitters that emit pulses that have different durations. A high load resistance provides high sensitivity, but its response time is slower than a small load resistance. Since *RI* is a potentiometer, you can tune it for optimum results with the transmitter you are using. For example, I have found that a load resistance of around 180,000 to 210,000 ohms works best when the receiver detects pulses with a duration of around 17 microseconds.

Figure 2 shows the assembled receiver installed in a small plastic box with the dimensions given above. The pencil points to potentiometer *RI.* The two miniature potentiometers adjacent to *RI* along the side of the box are *R3* and *R7.* Access to their tiny screwdriver-adjustable rotors is provided by two small holes bored through the side of the enclosure.

The two ICs and the various other components are installed on a perforated board that measures 34 by 45 millimeters (1.3 by 1.75 inches). Located between *RI* and the jack labeled IN is *Q/.* The point-

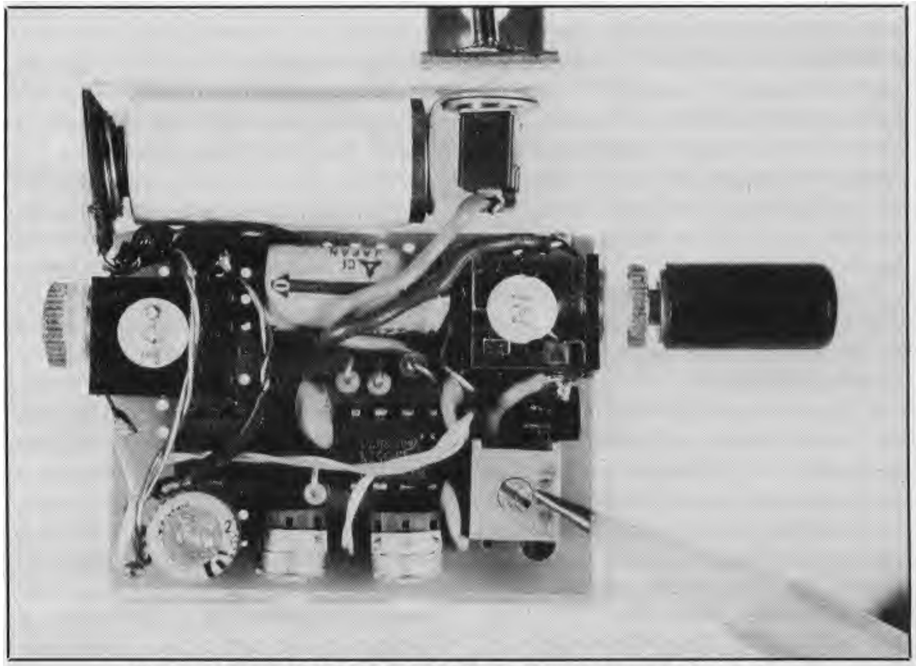

*Fig. 2. Assembled version of the lightwave receiver in Fig. 1.*

to-point wiring is not as neat as an etched circuit board, but it allowed me to build the receiver in one evening.

A single TR175 7-volt mercury battery powers the receiver. Though Fig. 1 does not show one, a miniature spst switch should be installed between the battery's positive ( + ) terminal and the circuit. The battery holder is made from a spring terminal salvaged from a plastic battery holder and a bent solder lug mounted on the switch. (Details for doing this are given later on.)

The jack labeled IN in Fig. 2 is *J1* in Fig. 1. This jack permits you to connect various detectors to the circuit. Connecting an external detector automatically disables internal detector *Q1*.

Note that the photo of the receiver in Fig. 2 shows a jack labeled OUT, which is not shown in Fig. 1 and is not absolutely necessary since a tiny, flat speaker only 30 millimeters (1.2 inches) square is mounted on the bottom of the box and is not visible in the photo. I installed the jack so the receiver could be used to drive an earphone, external audio amplifier or tape recorder. The jack is a three-terminal unit connected so that the speaker is disabled when a plug is inserted into it.

You do not have to install the receiver in a miniature housing, as I did. And if you don't, there is no need to use miniaturized components. For example, you can use larger potentiometers and a standard 9-volt transistor radio battery if you install the circuit in a larger housing. In any event, be sure to keep the leads between the battery and the circuit short. Keep the leads between *C1,* the photodetector and pin 2 of the LM353 as short as possible. And do not route the output leads anywhere near the circuit's input wiring. These steps will prevent the circuit from oscillating.

The easiest way to test the assembled receiver is to set the power switch to on when the unit is in the presence of a fluorescent lamp. First adjust *R1* and *R3* for a high resistance, and set *R7* to near its midpoint. The speaker should emit a fairly loud buzz when *Q1* detects pulsations from the lamp. Block *Q1* with a finger, and the buzz level should decrease.

If the receiver does not produce a buzzing sound, check to make sure the battery is fresh and installed in the correct direction. Then carefully check the circuit's wiring. It is possible the terminals on the input jack may have been connected incorrectly. Another possibility is a short-circuit between closely spaced terminals or leads on the circuit board.

Refer back to Fig. 2 for a moment and you will see a black plastic phone plug inserted in the jack labeled IN. This plug houses a photodetector. Figure 3 shows how you can make a miniature external photodetector like this by installing a photodiode or phototransistor inside a ⅛-inch phone plug housing. I have used this technique for many years, and it works well—if you make sure the detector lead soldered to the center terminal does not touch the plug's cap if it is the metal variety.

Note that Fig. 3 shows a small filter. If the receiver is intended to detect near-infrared signals, this is a small circle punched from a piece of unexposed, developed color film. If the receiver is intended to detect the red light (660 nm) from an A1GaAs emitter, you can use a circle punched from red acetate. You can also use other kinds of filters. Filters are so important that they warrant more discussion before moving on to describing a miniature lightwave tone transmitter.

## *Optical Filters*

Refer back to Fig. 1 for a moment and note that *C1* freely transmits fluctuating signals while blocking those that are continuous. For example, the signal from a modulated near-infrared source might be riding atop a steady level of sunlight. Capacitor *C1* passes the modulated light signal while blocking the sunlight signal.

If the steady signal from sunlight or an incandescent light source is sufficiently intense, it may saturate *Q1* and prevent detection of the intended, fluctuating signal. For this reason, the receiver works best when bright sources of near-infrared energy are not present.

One way to help the receiver to function in the presence of bright light is to place over the detector a filter that freely transmits the wavelengths of light emitted by the transmitter while blocking other wavelengths. For best results, a plastic or glass transmission filter designed specifically for this purpose should be used. Two principal types of filters are available.

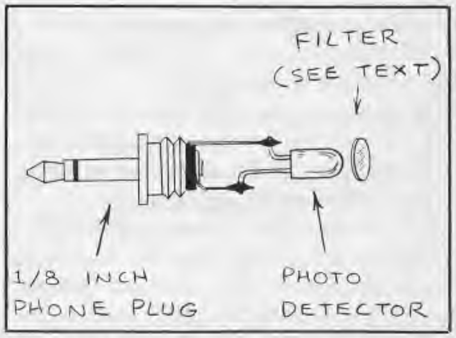

***Fig. 3. How to install a photodetector inside a phone plug.***

Long-pass color glass absorption filters block all the wavelengths below a certain point while transmitting those beyond that point. These filters designed for near-infrared applications appear black or deep red to the human eye.

Narrow-bandpass interference filters transmit only a narrow band of wavelengths. Typical interference filters have a bandpass of around 10 nanometers at the half transmission point. Interference filters have a mirror-like surface on both sides. Ordinarily, only one surface appears shiny since the other is usually covered by a glass or silica absorption filter that blocks harmonic wavelengths also transmitted by the interference filter.

Both glass absorption and interference filters are available from Edmund Scientific Co. (101 E. Gloucester Pike, Barrington, NJ 08007-1380). According to Edmund's 1990 catalog, the price for a 25.4-mm (1-inch) diameter absorption filter with a cutoff wavelength of 850 nm is $23. The price for a 25.4-mm diameter 880-nm interference filter with a bandpass of 10 nm is $78. Many kinds of visible-wavelength filters are also available from Edmund. Visible-wavelength interference filters cost $38, a significant savings over the near-infrared variety.

You can make a very inexpensive near-infrared absorption filter from a small piece of unexposed, developed color slide or negative film. This material exhibits practically no transmission below approximately 700 nm, and its transmission beyond 900 nm is excellent.

Some time ago, I tested a piece of developed Kodacolor negative film with various kinds of LEDs. If any of the light from green and yellow LEDs penetrated a single layer of this film, I could not see or measure it. The film transmitted only 0.2 percent of the radiation from a super-bright red LED that emitted at 660 nm (Stanley HK1).

The film became almost transparent when tested with near-infrared LEDs. It transmitted 79.3 percent of the 880-nm radiation emitted by an AIGaAs diode. And it transmitted 87.7 percent of the 940-nm energy from a GaAs:Si diode.

The filter shown in Fig. 3 was made by using a hole punch to cut a circle of film from a larger piece. For best results, use a sandwich of two or three layers of film. While this will block some of the near-infrared, the blocking effect on other wavelengths will be much greater.

Remember, of course, that the receiver needs a filter only when competing light sources are present. At night or inside darkened rooms, you can remove the filter and increase the receiver's range.

The best possible combination for an optical link is to combine a narrow-band source, such as a laser, with a receiver equipped with a narrow-bandpass filter. You can easily see the resulting improvement in signal-to-noise ratio with the help of an oscilloscope, and you can notice it during field tests.

A more dramatic proof is to observe a low-power laser outdoors on a sunny day with and without a narrow bandpass filter. I once did this with a GaAs laser diode that emits at 904 nm. The beam from the laser was collimated into a very tight beam by a small lens. The laser was mounted on a tripod around 300 meters (1,000 feet) away.

When the laser was viewed through a near-infrared image converter, it was barely visible against the sunlight-bathed landscape that dominated the view through the converter tube. This changed dramatically when I placed a 904-nm interference filter over the sensitive face of the image converter tube. The once-bright landscape became a dull grey and the laser became a brilliant point of light.

A note of caution is needed here. In spite of many safety warnings, I occasionally read of instances in which the eyes of professional laser workers are injured by lasers. You should never look directly into the beam from any laser unless the beam has spread out sufficiently so that its intensity is well below the level that might damage your eyes. This means you must be able to measure or calculate the level of radiation that might enter your eye. You must then be able to compare what you measure or calculate with the recommended safe viewing levels established by the Laser Safety Committee of the Laser Institute of America, the American National Standards Institute and other organizations. If you are unable to take these steps, play it safe and *never* look directly into the beam from any laser. For additional information, see "Laser Safety Guide," a publication of the Laser Institute of America. Call 1-800-34-LASER for information about ordering this booklet.

## A Lightwave Tone Transmitter

Shown in Fig. 4 is the schematic diagram for an ultra-simple two-transistor lightwave tone transmitter whose design will be familiar to long-time readers of this column. This circuit can be easily installed in a plastic case that measures only 5 x 2.5 x 1.8 cm (2 x 1 x 0.7 inches).

When the value of *C/* in Fig. 4 is 0.002 microfarad, the circuit drives the LED with pulses that have a duration of around 40 microseconds. The duration of the pulses is increased and the pulse rate reduced when C/'s value is increased. For example, when Cl is 0.03 micro farad (three 0.01-microfarad capacitors in parallel), the pulse rate is less than 100 Hz.

The LED should be an AIGaAs 660 red or 880 near-infrared emitter. Be sure to observe proper polarity when soldering the LED into the circuit. If you want the option of exchanging LEDs, solder a LED socket into the circuit. You can make a LED socket from two short lengths of thin brass tubing soldered to the circuit board. Brass tubing is available at most hobby shops. Take a LED along when you visit the hobby shop to ascertain that its leads will fit snugly inside the tubing.

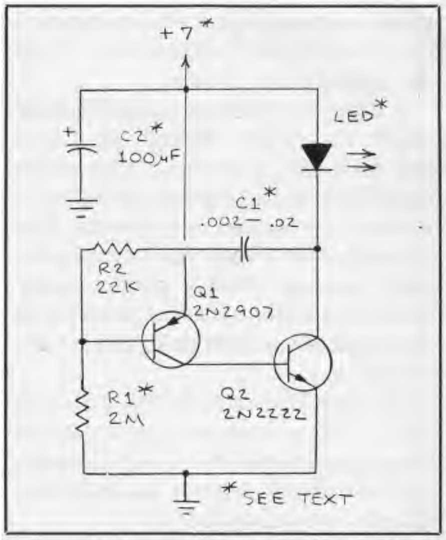

*Fig. 4. High-current LED tone transmitter.*

When the circuit is powered by a 9-volt battery, the peak current through the LED is around 650 milliamperes. This level is reduced somewhat when the circuit is powered by the TR175 7-volt battery you will need to use if you install the circuit in a miniature housing as I did.

Capacitor *C2,* which is connected across the battery, is not absolutely essential. When used, it provides a reservoir of charge that helps flatten out the top of the pulses through the LED.

A pictorial view of the Fig. 4 circuit is shown in Fig. 5. The components are in stalled on a perforated board that mea sures 2.7 x 1 cm (1 x 0.4 inches). Note it particular how the battery holder is mad from the spring end of a plastic AA o AAA battery holder and a bent soldc lug. The solder lug of the battery hold( for the receiver circuit shown in Fig. 2 attached to the switch. The solder li

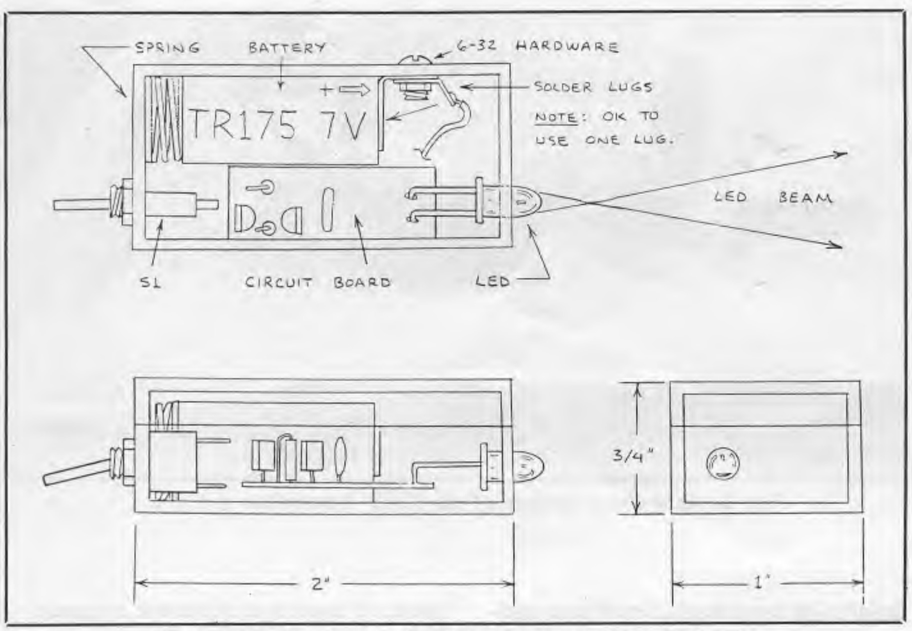

*Fig. 5. Pictorial view of the LED tone transmitter in Fig. 4.*

shown in Fig. 5 is attached to the side of the housing with a small screw and nut. Figure 6 is a photograph of an assembled version of the Fig. 4 circuit.

## *Testing the System*

When both the transmitter and receiver are switched on, the receiver should emit a buzz or tone if it is near the transmitter. Even if the two units are not pointed at one another, plenty of stray light from the transmitter should find its way to the receiver's detector.

If the transmitter does not appear to be working, switch the power off and check to make sure the battery is fresh and installed correctly. If you used a visible red LED that glows when the power is applied but does not elicit a tone from the receiver, it is possible the tone frequency is above the range of your hearing. Increase the value of Cl to around 0.03 microfarad to reduce the frequency.

If you have used a super-bright red LED in the transmitter, aligning the transmitter and receiver will be simple. One way I do this is to mount the transmitter on a camera tripod. Use tape if you are in a hurry. For better results, unscrew the nut on the on/off switch, place a small brass angle bracket over the threads and replace the nut. Then use a 10-20 wing nut to mount the angle bracket on the tripod. You can use this same method to mount the receiver.

After the transmitter is mounted on the tripod, you can easily aim it anywhere you choose. For initial tests, place a plastic bicycle reflector where you intend to receive the signal. Then adjust the transmitter until you see the reflection of its red beam from the reflector. Make sure the transmitter is firmly in place, walk to the reflector location and place the receiver in front of the reflector. You should hear the transmitter's tone from the receiver's speaker.

If you cannot receive the tone beyond a certain distance, you must add a lens to either the transmitter or the receiver. For very long ranges, you must add a lens to both the transmitter and receiver. A lens at the transmitter reduces the divergence of the LED's beam. A lens at the receiver collects more light from the LED. Either way, adding a lens makes pointing the two units at each other much more tricky.

You can use inexpensive lenses from department store magnifiers if your optical source is a LED. Glass lenses usually have better quality, but plastic lenses will also work. You can even use flat plastic Fresnel lenses. If you use a laser diode tone transmitter like the one I described in the December 1985 and January 1986 installments of this column, you will have much better results by using a better-quality glass lens, such as those available from Edmund Scientific and others.

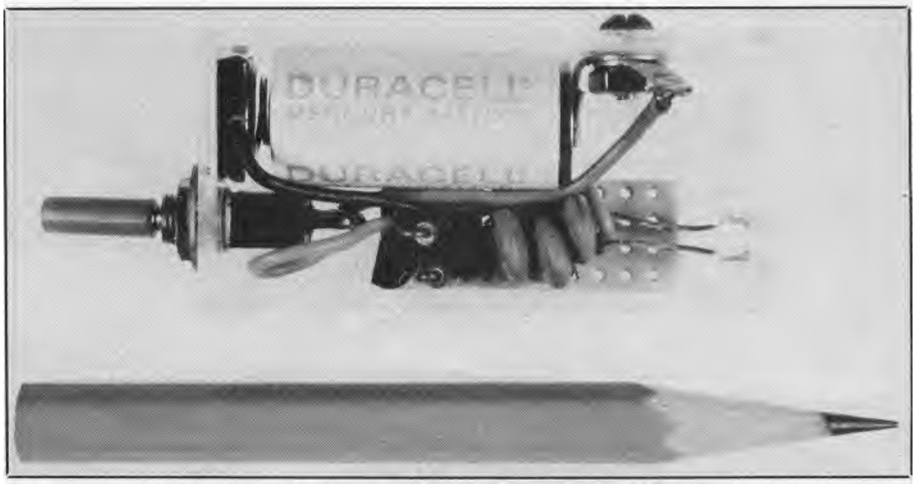

*Fig. 6. Assembled version of the LED transmitter in Fig. 4.*

## Going Further

The miniature lightwave transmitter and receiver described here provide an excellent means for learning much about the practical aspects of lightwave communication and control links. Besides adding lenses, you might want to try reflecting the transmitter beam from nearby objects and surfaces to see how far away the receiver can detect the reflected radiation.

You will soon find that shiny surfaces, such as waxed cars and windows, reflect the beam much like a mirror. This means you can detect the reflected beam over a considerable distance, but only if the transmitter and receiver are carefully aligned. Diffuse surfaces, such as fabric and wood, reflect the oncoming beam into a broad pattern that can be detected over a shorter distance but over a much wider angle.

Besides simple experiments like these, you may want to modify the receiver to include a threshold circuit that triggers an alarm when the beam is broken. A 555 timer connected as a missing-pulse detector works well in this application (see ***Mini-Engineer's Notebook: 555 Time, Circuits,*** Radio Shack). For amplitude. modulated voice communication, you can use the receiver without modifica tion. The transmitter can be any straight forward circuit that amplitude-moth lates a LED, laser or incandescent lamp (see ***Engineer's Mini-Notebook: Opt***
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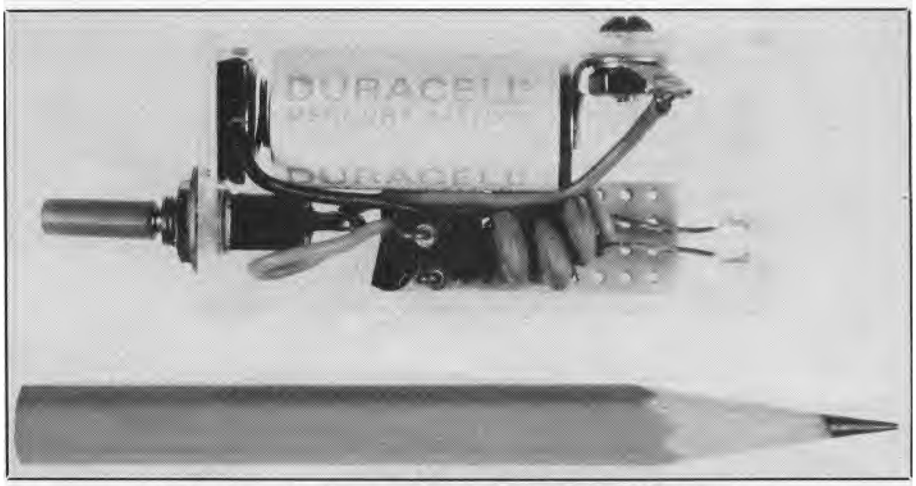

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