ELECTRONICS NOTEBOOK

Experimenting with CW Laser Diodes

Part 1: How-To Basics and a Laser Pulse Transmitter

By Forrest M. Mims III

Thanks in large part to the success of compact disk audio technology, laser diodes capable of continuous wave (CW) operation at room temperature are now available at very reasonable prices. When I first built circuits incorporating such lasers in 1975, individuals lasers cost several hundred dollars or more. Now several different low-power CW laser diodes are available for as little as $26 each in single quantities from electronics distributors that represent Sharp Electronics (10 Sharp Plaza, Paramus, NJ 07652).

These new low-power laser diodes are designed to emit up to about 3 milliwatts at a wavelength of 780 nanometers near the extreme end of the visible spectrum. Newly developed, highly visible red "super" LEDs made from AlGaAs can emit twice this power level when driven at similar current levels (50 to 60 milliamperes). But the laser diode is the preferred choice when a very narrow optical beam is required for applications like free-space communications and intrusion alarms.

Emission from each end facet of a laser diode chip generally forms a fan-shaped beam having a divergence of about 15 × 30 degrees. Virtually all the radiation emitted from the front facet of a laser diode can be collected and collimated into a pencil-thin beam by means of a simple lens. Since LED chips are much larger than laser diode chips, it's not possible to focus their emission into as tight a beam. Moreover, because LEDs emit radiation in all directions, only a small fraction can be collected by a lens.

An important advantage of laser diodes over LEDs in some applications is the highly coherent nature of their emission. The new generation of CW laser diodes emit beams having a coherence that rivals or even exceeds that of the popular helium-neon laser.

Though CW laser diodes offer several important advantages over noncoherent LEDs, they are easily damaged if handled or operated improperly. For instance, most LEDs can withstand momentary surges of drive current. The drive current applied to a CW laser diode must never exceed the rated level or the device will be permanently damaged. Though the chip may continue to function as a low-power LED, the portions of the facets that provide the end mirrors for the laser will be destroyed by the high optical power (several hundred thousand watts per square centimeter) produced by a current surge.

Most CW laser diodes can be damaged or destroyed by electrostatic charges or

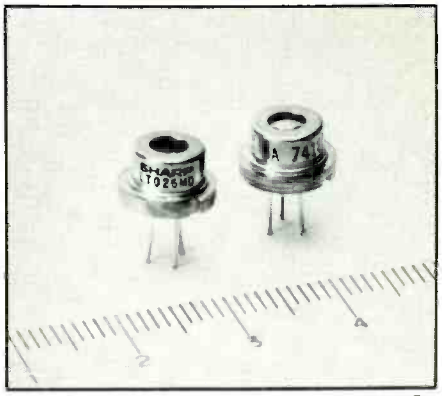
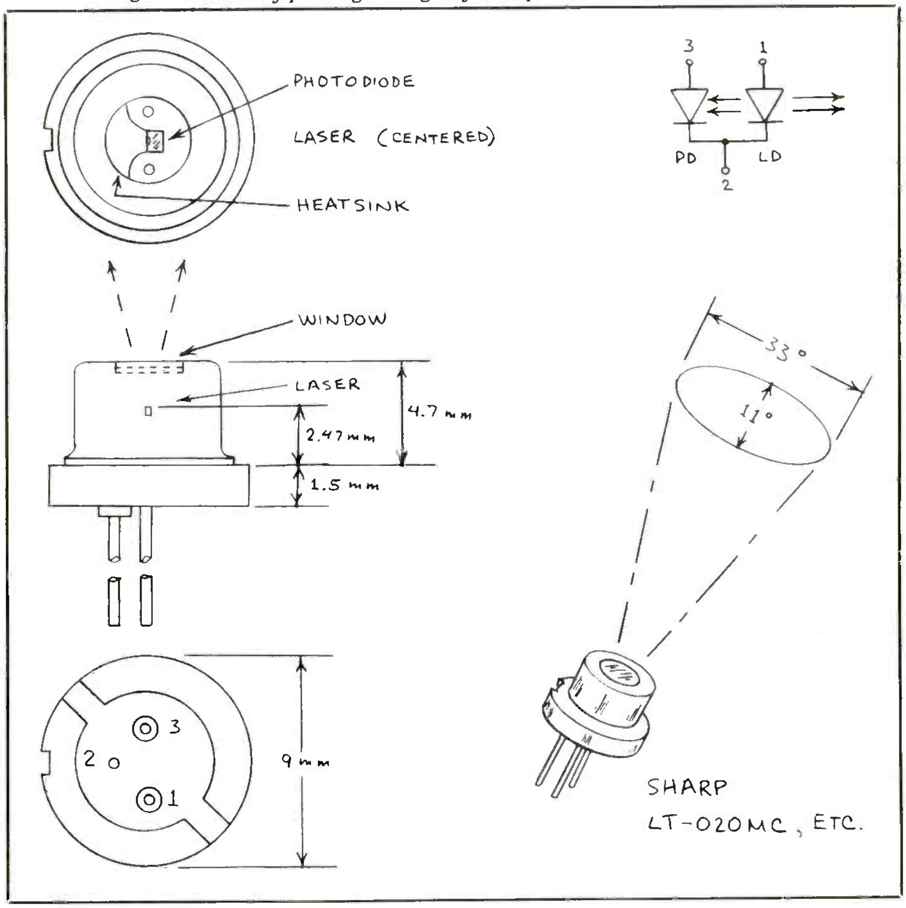


Fig. 1. Photo shows Sharp's LT026MD visible-spectrum (780-nanometer) CW laser diodes. Note windows at top.

Fig. 2. Details of package design of Sharp's LT-020MC laser diode.



even the voltage spike that often occurs when a switch is flipped on or off. For these reasons, I have devoted a substantial portion of what follows to safe operating procedures for CW laser diodes. For best results, it is essential that you read and heed these procedures. Having zapped my fair share of CW laser diodes over the years, I can assure you it pays to be very careful when installing and working with these devices.

Low-Cost Laser Diodes

While preparing this column, I contacted most manufacturers of laser diodes and managed to receive price information from several. Of these, the CW lasers made by Sharp Electronics Corp. are by far the least expensive and the easiest to buy. Single-mode CW laser diodes having lower thresholds and operating currents are available from Ortel, M/A-COM Laser Diode, Mitsubishi and others, but they cost four to fifty times more than the $26 Sharp lasers used in the circuits in this and a subsequent column.

Figure 1 shows a pair of Sharp LT026-MD CW laser diodes housed in packages similar to those used by other makers of CW laser diodes. The LT026MD and other members of the Sharp laser diode family include a photodiode to monitor the power emitted from the rear facet of the laser chip. The current from this photodiode is proportional to the light emitted from both facets of the laser. Therefore, the photodiode provides an effective sensor for a closed-loop regulator circuit designed to apply sufficient current to the laser so that its output remains stable as ambient temperature changes.

Figure 2 shows details of Sharp's LT020MC single-mode laser diode package, along with it's beam dimensions. (The package dimensions shown in the figure apply to many CW laser diodes.)

Note the internal connection of the laser diode and photodiode. This common-cathode configuration is by no means universal. In some Mitsubishi lasers, for example, the anode of the laser is internally connected to the cathode of the photodiode. In other devices the laser diode and photodiode are not internally connected, and all four points are available externally.

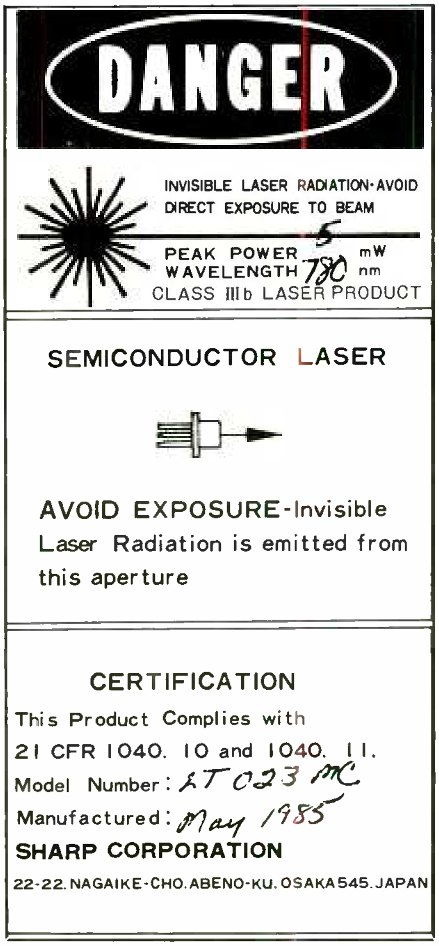


Fig. 3. An example of a Class IIIb laser safety warning label.

Handling Precautions

There are many different kinds of laser diodes, and most being among the most delicate of semiconductor devices. Because of the very narrow width of their stripe-geometry junction, CW laser diodes are as susceptible to damage from destructive electrostatic breakdown as MOS semiconductors and integrated circuits. For this reason, CW laser diodes must be shipped and stored in packaging materials that do not generate or store electrostatic charges. Similarly, you must remove any charge on your body before handling a CW laser diode. This can be done by touching a grounded object immediately before handling the laser. A ground strap affixed to a wrist is even better. When soldering, it is important to make sure the iron is either battery-powered or free of voltage leaks.

The laser diode's glass window should be considered a precision optical component. Dust and scratches on it will reduce the output power and disturb the beam pattern. Sharp recommends that the windows of its laser diodes be cleaned with cotton soaked in ethanol.

The design of the laser diode package plays a vital role in removing heat from the delicate laser chip. Therefore, never cut, drill or machine the package. Since the laser chip is affixed to its heatsink with a low-melting point solder, never attempt to solder a heatsink or wire to it.

Operating Precautions

Laser diodes can be instantaneously and irreversibly damaged or destroyed by current surges that exceed the maximum allowable. Consider a CW laser diode that emits 5 milliwatts. For a typical stripe-geometry device, the light is emitted from regions of the front and rear facets measuring about 0.6 × 3 micrometers each. This corresponds to a power density of about 280,000 watts per square centimeter! From studies conducted at RCA and elsewhere, the facets of CW laser diodes can be irrevrsibly damaged when power falls in the range of 200,000 to 400,000 watts per square centimeter. Therefore, a current only slightly greater than the rated maximum can cause a CW laser to emit enough power to damage its reflecting facets.

Because of their exceptional vulnerability to damage, it is essential that you exercise great care when using CW laser diodes in circuits. Here are some precautions which, if followed, can save your lasers from the unfortunate fate several of mine have met:

(1.) Never connect the probes of a multimeter across the leads of a laser diode.

(2.) Always make sure the leads of a laser diode are installed correctly.

(3.) Never connect a CW laser diode to a battery through a series resistor. For CW operation, always drive the laser with a closed-loop current regulator that derives its feedback signal from the photodiode inside the laser package.

(4.) Never connect a laser diode directly to a line-powered power supply. Voltage spikes generated when the supply is turned on can destroy the laser.

(5.) When testing or troubleshooting a drive circuit, use great care to avoid shorting the leads of the laser diode to other circuit leads.

(6.) If your workbench is metal, it should be at the same potential as the ground line of the laser's power supply.

(7.) Use care when operating laser diodes near equipment that generates high-frequency surges. The leads of the laser may couple such surges into the chip and destroy it.

(8.) The threshold current of a laser diode increases with temperature. For this reason alone, it is important to drive CW laser diodes with a photodiode-coupled current regulator (see 5 above).

(9.) Follow the manufacturer's recommendations about proper heat sinking. Sharp recommends a copper or aluminum heatsink measuring about 20 × 30 × 2 millimeters. Some lasers include heat sink attachment holes. Use a spring-loaded or push-on heat sink for those that do not. A solderless RG59/U cable connector (Radio Shack No. 278-215) snaps snugly over laser diodes made by Sharp.

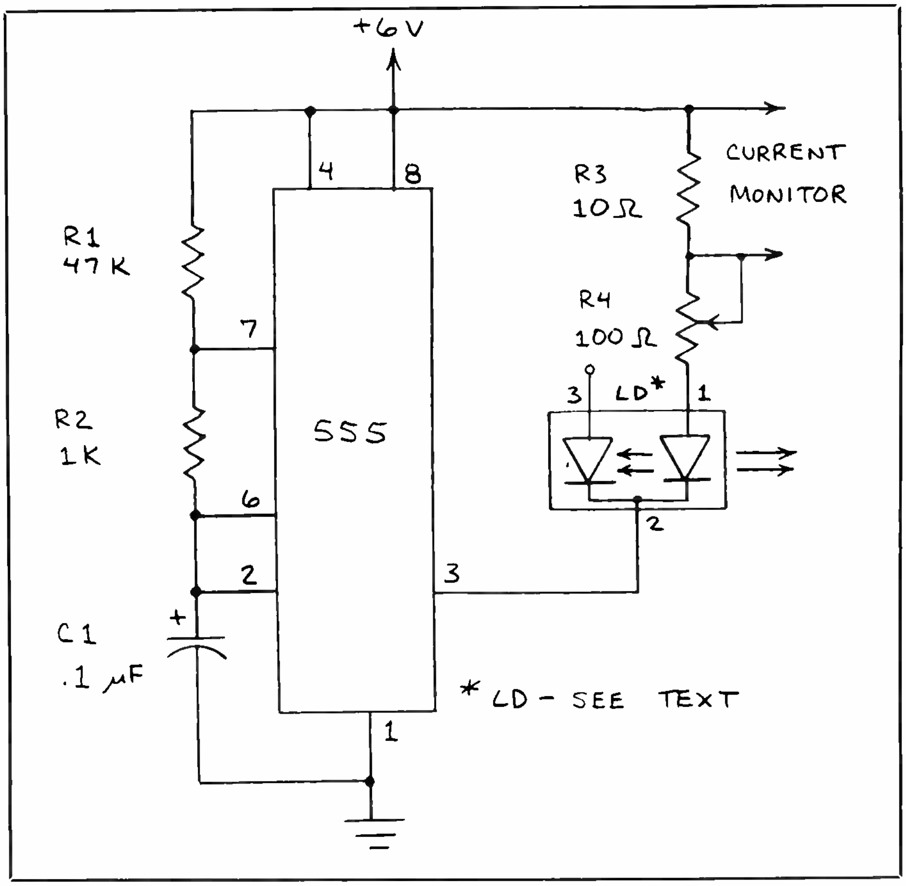


Fig. 4. Schematic diagram of a miniature laser diode pulse transmitter.

Laser Safety

It's important to be aware of safety precautions that apply to the use of laser diodes. The Bureau of Radiological Health, now the National Center for Devices and Radiological Health (NCDRH), has formulated extensive regulations governing the safe operation of all types of lasers. Under these regulations, Class 1 lasers are exempt from regulation. Most laser diodes are Class 3B devices and are required to bear a warning label that reads in part: "Danger—Invisible laser radiation. Avoid Direct exposure to beam." Since laser diodes are much too small for such a verbose warning label, manufacturers usually include a replica of the label in the laser's specification sheet or attach a label to the box in which the laser is shipped. Figure 3 shows the label supplied with Sharp laser diodes.

There is an ongoing controversy about the government's efforts to regulate laser diodes. Since the beam from such lasers is much more divergent than that from most other kinds of lasers, the safety hazard may be more imagined than real. Indeed, some light-emitting diodes can produce a greater power density at the eye than low-power (3-to-5-milliwatt) CW laser diodes when both devices are viewed at the same distance (but the laser radiation will be focused to a smaller spot on the retina).

A recent research project funded by Bell Labs and the U.S. Army explored the effect on the eyes of monkeys exposed to CW and pulsed beams from various kinds of laser diodes. One conclusion of this project is worth including here: "It required from 6 to 8.4 mW of GaAs radiation entering the eye for periods ranging from 400 to 3000 seconds to produce a detectable lesion [on the retina]. Since the spot size on the retina was >50 micrometers in diameter, it is difficult if not impossible to imagine how the human eye could remain focused on such a source for an appreciable time, even if 8 mW were entering the pupil." (William T. Ham, *et al, Applied Optics,* July 1, 1984, pp. 2181 through 2186.)

Though this study seems to indicate that low-power CW laser diodes are relatively safe, the authors recommend that government safety standards be followed until more data becomes available. Therefore, you should follow these safety precautions when working with CW laser diodes:

(1.) Avoid staring at the raw beam from a laser diode closer than arms length.

(2.) Never stare at the beam of a laser diode whose emission has been focused into a narrow beam by a lens.

(3.) Never point the beam from a collimated laser diode toward the eyes of onlookers or toward specular surfaces that might reflect the beam toward you or onlookers.

(4.) Observe the beam from laser diodes with an infrared image converter or infrared phosphor screen. If the wavelength of the beam falls in the visible spectrum, you can safely observe the beam by directing it toward a nearby white card (with matte, not glossy, surface) in a dark room.

Should you wish to use laser diodes in a product to be sold, you may be considered a "laser manufacturer" by the NCDRH and the governments of some 11 states. For additional information, obtain a copy of "Performance Standards for Laser Products" (21CFR 1040) from the NCDRH (8757 Georgia Avenue, Silver Spring, MD 20910) and "ANSI Standard for the Safe Use of Lasers" from the American National Standards Institute (1430 Broadway, New York, NY 10018).

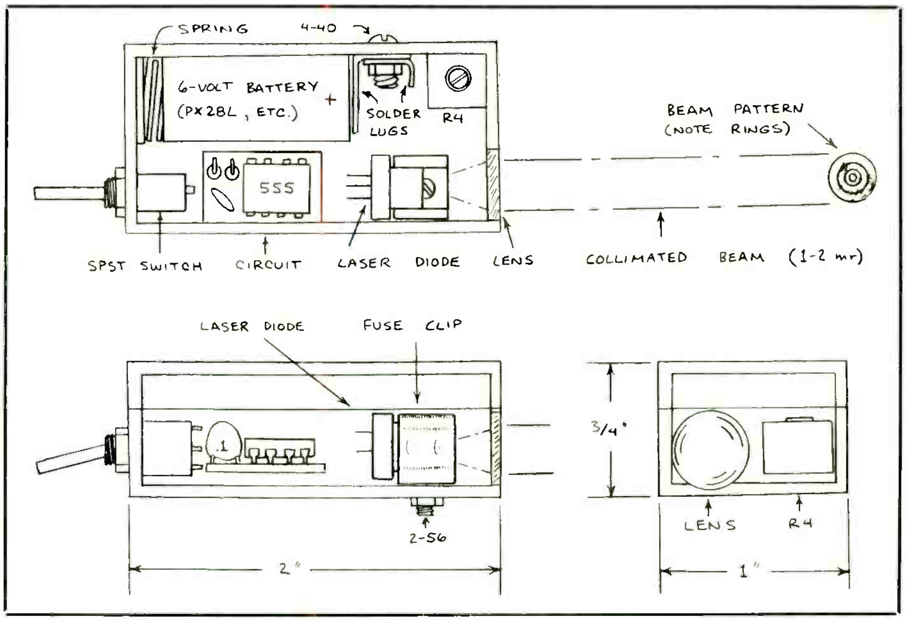


Fig. 5. Assembly details for the Fig. 4 laser-diode pulse transmitter.

Laser Diode Transmitter

Figure 4 shows a simple circuit designed to deliver curent pulses to low-power CW laser diodes such as Sharp's LT020MC or LT022MC. In operation, the 555 timer is connected as a pulse generator whose oscillation frequency is given by $1.44/[(R1 + 2R2) \times C1]$. With the values in Fig. 4, frequency is about 320 Hz and pulse duration is 60 microseconds.

Resistor *R4* permits current applied to the laser to be adjusted to a safe operating level, a procedure which requires an oscilloscope. The scope's probe is connected across *R3*, a 10-ohm resistor that serves as a current monitor. From Ohm's law, the current in amperes passing through *R3* is the voltage across *R3* divided by 10. Since *R3* is in series with the laser, the current flowing through *R3* also flows through the laser.

Incidentally, reducing *R1* will increase pulse repetition rate of the circuit. This may also affect the current delivered to the laser diode. Therefore, always monitor *R3* when the circuit's pulse repetition rate is altered.

Important: Before applying power to the circuit for the first time, it is absolutely essential that *R4* be set for maximum resistance. If you have any doubts, practice performing the adjustment that follows with a red LED installed in place of the laser diode. Before removing the LED, adjust *R4* for highest resistance and switch off power to the circuit.

Adjust *R4* to give a current midway between the laser diode's threshold (usually about 50 milliamperes) and the maximum allowable operating current (usually about 60 milliamperes). Though this means the laser will not emit the full 3 milliwatts of which it is capable, the likelihood of irreversible damage will be greatly lessened.

Important: If you did not receive a data sheet giving theshold and operating current levels for the laser(s) you purchased, check with your supplier. Each individual laser has unique operating specifications. Never attempt to guess the specifications of a laser or operate a laser without knowing its specifications! Some companies (Mitsubishi, M/A-COM Laser Diode Labs, etc.) provide threshold and operating current values on the packages or boxes in which lasers are shipped. In the case of Sharp laser diodes, these numbers are given on a batch printout that lists the specifications of 50 serially numbered lasers. The serial numbers are marked on small adhesive labels affixed to each laser.

The circuit in Fig. 4 does not take advantage of the laser's monitoring photodiode. Therefore, it is important to adjust *R4* when the transmitter is at the temperature at which you plan to operate it. Should the temperature later rise, the threshold of the laser will rise, and the laser's output power will then be reduced. Should the temperature later fall, the threshold of the laser will also fall. The output of the laser will then increase, perhaps to a point at which the laser may be irreversibly damaged.

Figure 5 shows how the laser transmitter, complete with battery and lens, can be installed in a small plastic box. I used a box measuring ¾ " × 1 " × 2 " which was purchased from an arts and crafts store. Note how the laser diode is installed in a fuse clip mounted inside the box. The clip secures the laser in place and doubles as a heat sink.

The collimating lens should be a convex lens with a small f/number. I used a 10-mm diameter lens having a focal length of 12 mm (f/1.2). The lens is installed in an aperture carefully reamed in-

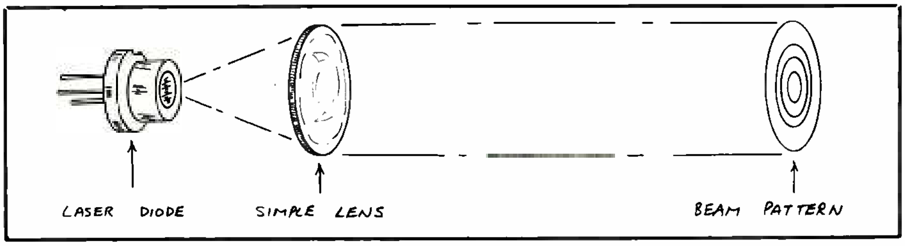


Fig. 6. Using a lens to collimate the beam emitted from a laser diode.

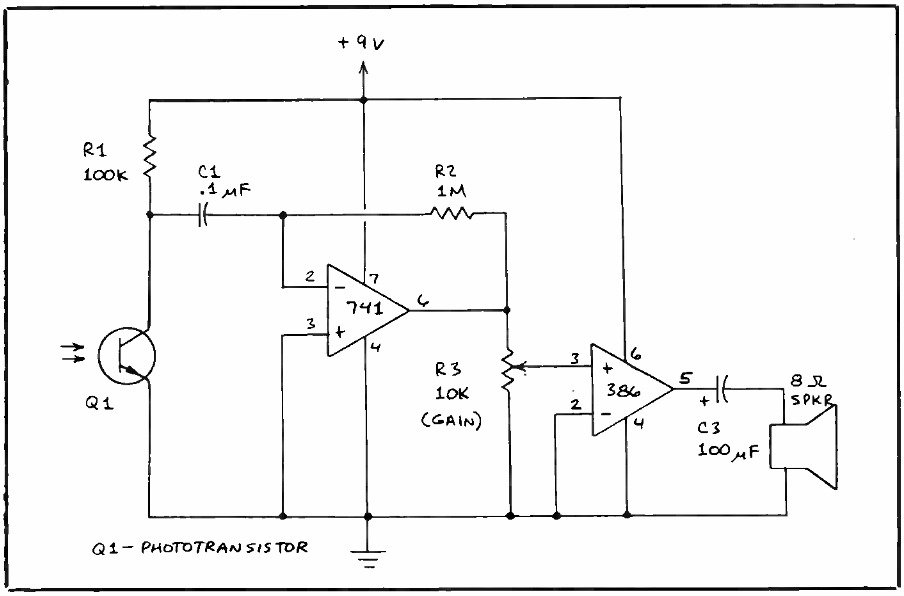


Fig. 7. Schematic diagram for a simple pulsed laser-diode receiver.

to the end of the box and secured in place with silicone cement. An excellent variety of lenses is available from Edmund Scientific (101 E. Gloucester Pike, Barrington, NJ 08007).

The mounting hole for the fuse clip should be made larger than necessary so the laser can be properly focused. Then the clip can be secured in place. Since the beam from the laser is just barely visible when focused onto a white card in a dark room, this difficult task will take time.

I have adjusted the laser in the prototype transmitter to give a perfectly circular pattern 6 inches in diameter at a distance of 285 feet. This corresponds to a divergence of 1.75 milliradians, about the same as that of many helium-neon gas lasers.

Figure 6 shows the beam pattern produced by the prototype transmitter. The concentric rings of light that form the beam are caused by spherical aberration of the lens. This effect can be eliminated and the beam made narrower by using a more expensive achromatic lens. A 35-mm camera lens can also be used with excellent results.

Laser Receiver

Figure 7 is the schematic diagram of a

simple lightwave receiver you can build to transform the pulsed emission from the laser transmitter into an audible tone. If the divergence of the laser beam is adjusted to be as narrow as possible, this receiver will detect the laser at ranges in excess of 1,000 feet. Detection range can be extended by placing a lens in front of the phototransistor.

The receiver allows the laser to be used as a remote signalling device or for demonstrations. If a missing pulse detector is added to the receiver, an excellent break-beam intrusion alarm can be built. A 567 tone decoder circuit can be added to the basic receiver to form a long-range remote-control system. Suitable circuits are given in *The Forrest Mims Circuit Scrapbook* (McGraw-Hill, 1983) and various other books I've written for Radio Shack.

It's important to realize that receiving the laser beam can be very difficult if you don't have an infrared image converter. One possibility is to place a large bicycle reflector at the receiver's location. Then place the transmitter on a camera tripod and, while looking along the top of the transmitter, carefully adjust the device until you observe a red reflection from the reflector. The laser beam will now be centered on the reflector, where it can be easily detected with the receiver.

This method works only when it is dark. Of course, this makes it difficult to know where to point the laser. In other words, be prepared to spend lots of time learning how to align the laser. I have problems pointing the laser in Fig. 4 across a room. At 20 feet the beam is not much larger than the end of a thumbtack.

Caution: Do not stare at a nearby reflector illuminated by the laser. The reflector should be placed far enough away so that the laser beam spreads to at least several inches in diameter where it strikes the reflector.

Going Further

This is the first of two columns about using CW laser diodes. In the next installment I'll discuss applications for the laser transmitter described here. And I'll describe in detail two miniature CW laser-diode illuminators that have several interesting applications that were once possible only with bulky helium-neon lasers costing several hundred dollars. Be sure to keep this column handy, since much of what has been covered here will be applicable in the next installment. ME