EXPERIMENT WITH A

For quite a few years laser technology has been cost and complexity of equipment. A new

PROBABLY THE MOST INTRIGUING electro-optical device around is the laser. And while many experimenters, engineers, and hobbyists would like to have one for their own use, costs thus far have been prohibitively high for most.

You need worry no more, since for a cash outlay of less than $20 any electronics experimenter can assemble his own full function laser pulse generator. Semiconductor diode laser prices (in addition to the price of the pulser) begin at less than $12 in single quantities, making this laser project one of the least expensive yet published.

How it works

For room-temperature operation, commercial semiconductor laser diodes require a very brief high-current pulse for proper operation. The current must be high to stimulate the atomic processes of laser action and the pulse must be brief to keep the tiny semiconductor chip that makes up the laser from burning up.

This pulser uses a common technique of generating a fast, high-current pulse—discharging a capacitor through an SCR. In the circuit diagram in Fig. 1, note that a unijunction oscillator supplies trigger pulses to the gate of a high-voltage SCR. The frequency of the pulses is adjusted with R2.

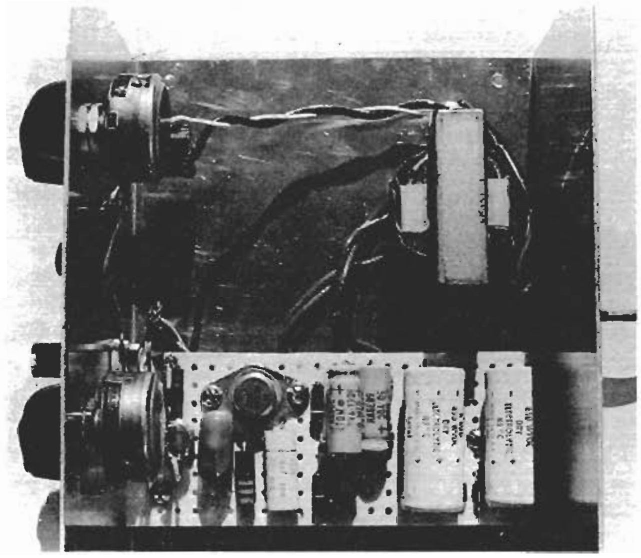
Between pulses of the unijunction circuit, capacitor C7 charges through R5 and R6. When the SCR gate is triggered ON, C7 discharges through the SCR, R7, and the laser diode. R7 is a one-ohm resistor that permits the peak current through the laser during a discharge pulse to be monitored accurately. Potentiometer R5 is used to adjust this current so the laser's peak current rating is not exceeded.

Summing up operation of the unit, the repetition rate can be increased to more than 500 Hz before peak current begins to fall (due to the charging time of C7) and peak current can be adjusted from zero to more than 40 amps. Pulse width is only 200 nanoseconds.

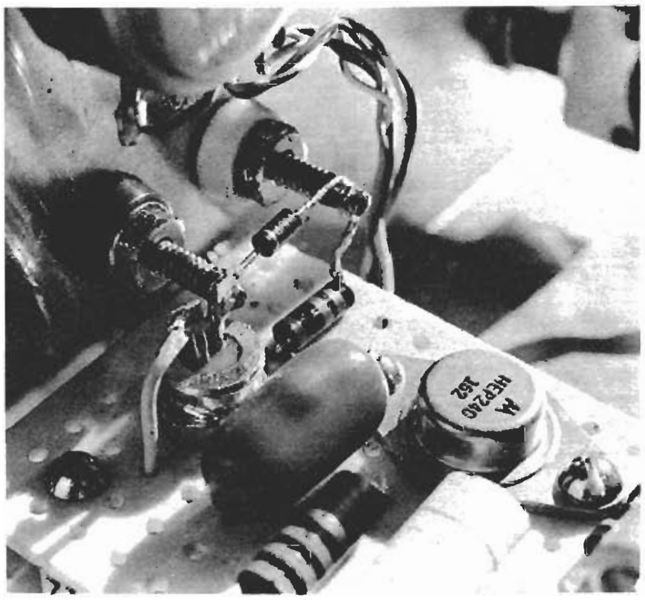
Put a laser together

Construction of the laser pulser is relatively straightforward, but several precautions must be followed for good results. We'll get to those later. First collect the necessary components and install them on a 2″ x 4¾″ perforated board as shown in the photo of the internal layout of the unit. Most of the parts values are not critical and substitutions, particularly in the power supply, are permissible so long as proper voltages are supplied to the circuitry. The high-voltage supply should deliver at least 300 volts dc and low-voltage supply 15 volts dc. With the parts values shown in the circuit diagram, the high and low-voltage supplies deliver 380 and 19 volts respectively.

Four components are critical and their values should not be changed They are the SCR (Q3), C7, R7, a D5. The SCR has been specially lected and only higher voltage types the same series may be substituted. is designed to permit maximum puls width permissible without damaging the laser. **Do not increase its value.** R7 is only one ohm, but **it must be included** in the circuit to calibrate the laser pulser. Removing R7 may cause the laser to receive far more current than it is rated for. And D5 is designed to reduce possible current undershoot.



INTERNAL VIEW OF THE LASER PULSER shows component layout. Power supply parts are on the right. Pulser parts are close together at left.

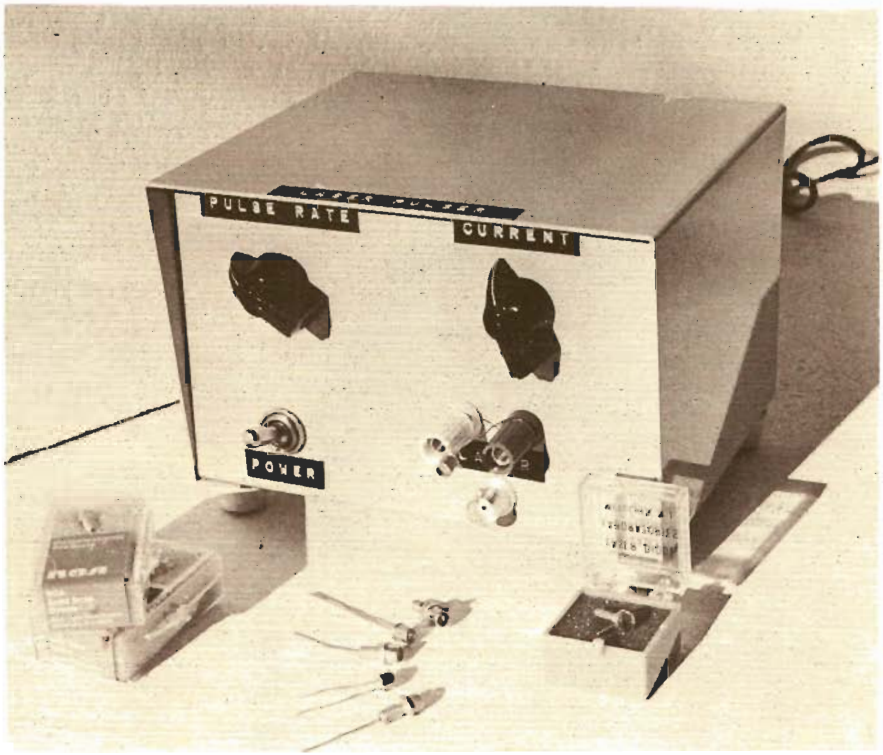


CLOSEUP OF PARTS in the laser discharge circuit. The SCR is soldered directly to one binding post to reduce lead length. C7 is the capacitor between the SCR and the HEP240 replacing the 2N3439 in this particular model.

$32 SOLID-STATE LASER

denied many experimenters because of the high low-cost laser opens experiments to all.

by FORREST MIMS

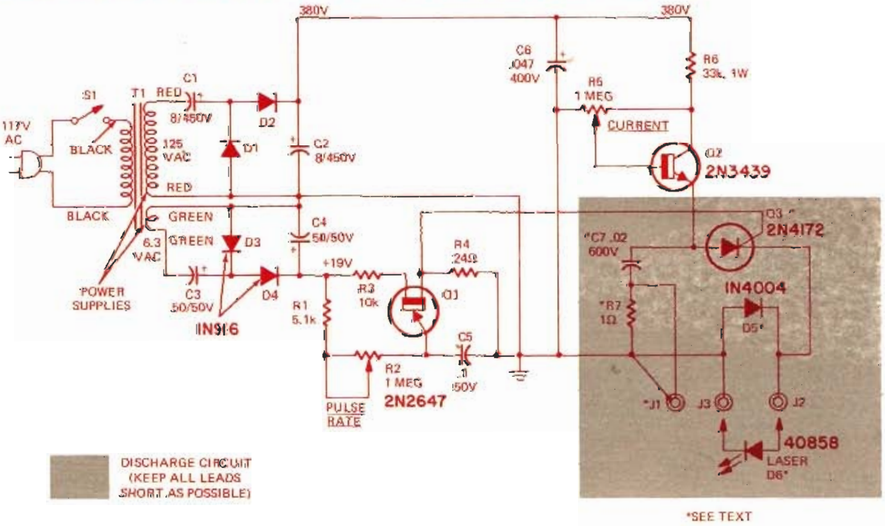


point-to-point wiring and spaghetti insulation where there is any chance of a short. Insulation is particularly important in the power supply circuitry.

When complete, trim all leads *except* those of R7. R7's leads are connected to a current monitoring terminal later. Also, note that D5 is not installed on the circuit board itself. D5's installation is described later.

The most important part of the circuit layout involves the four components described earlier. Since they form the pulse discharge circuit, the SCR, C7, R7, and D5, must be mounted as close as possible to one another. Excess lead lengths means increased inductance and the currents and pulse widths used here will result in ringing and undershoot with inductances measured in nanohenries. As mentioned earlier, this can be harmful to the laser diode.

FIG. 1—SCHEMATIC DIAGRAM OF THE LASER PULSE GENERATOR. The discharge circuit is in the shaded area. Keep all leads as short as possible here to insure proper operation.



PARTS LIST

R1—5100 ohms, ½ W
R2, R5—1 megohm pot
R3—10,000 ohms, ½ W
R4—24 ohms, ½ W
R6—33,000 ohms, 1 W
*R7—1 ohm, ½ W
C1, C2—8 μF, 450 V
C3, C4—50 μF, 50 V
C5—0.1 μF, 50 V
C6—0.047 μF, 400 V
*C7—0.02 μF, 600 V
D1, D2—HEP 58 or equal
D3, D4—1N916 or equal
*D5—1N4004 or 1N4007
D6—Laser diode (see text)
J1—BNC panel connector or equal
J2—Red insulated binding post (Cambion 3285-1-03 or equal)
J3—Black insulated binding post (Cambion 3285-1-03 or equal)
Q1—2N2647 unijunction
Q2—2N3439 (RCA) or HEP 240 (Motorola) 300-400 volt
*Q3—2N4172 SCR (Motorola)
S1—spdt toggle
T1—Power transformer: primary 117 Vac; secondary 125 V and 6.3 V (Calectro D1-760 or equivalent).
Misc.—Line cord, cabinet, hardware, stand-offs, perforated board, knobs (2), labels, marking pen, solder, hook-up wire, etc.

***Do not substitute (see text)**

Diodes other than the one specified may not perform this function properly and cause the laser to receive possibly damaging reverse current. Since semiconductor lasers don't like excess current, pulses wider than a few hundred nanoseconds, and reverse current, stick with the values specified for these four components for best results.

Install the components on the board, using a layout identical or similar to the one shown in the photo. Use point-to-point wiring and spaghetti insulation where there is any chance of a short.

When the circuit board is complete, compare it with the circuit diagram and photos to make sure there are no errors or shorts. Be sure that all diodes and capacitors are installed with proper polarity alignment. Then set the board aside

(continued on page 50)

and prepare the enclosure.

The prototype pulser shown in the photos is housed in an LMB No. 564 Glamor Cabinet (5" x 6" x 3"). The cabinet is ideal for the pulser since it's prepainted and supplied with rubber feet.

Actually, any enclosure can be used as long as it's functional. Prepare the housing by drilling appropriate holes for the transformer, controls, output terminals, and stand-offs. Drill a hole in the back of the cabinet for the line cord. Force a rubber grommet into the hole to prevent fraying and insert the exposed end of the cord. Tie a knot a few inches from the exposed end and solder one end of the cord to one of the black transformer leads. Carefully tape the connection with black electrical tape to prevent possible shorts and shock hazards. The remaining end of the cord is soldered to the power switch. Use an extension wire if necessary and be sure to tape the connection.

Next, mount the transformer with 4-40 hardware and install the controls and output terminals. The remaining wiring is straightforward. Connect the transformer leads to the circuit board, paying attention to the color code (high-voltage secondary is red and low-voltage secondary is green). Don't mix them up like I did the first time or you'll burn out some diodes!

It's a good idea to trim the leads to convenient lengths, but don't cut them too short. Next, wire the remaining switch terminal to the black transformer lead and hook up the two potentiometers.

If the laser terminal holes were drilled following the layout in Fig. 2, the cathode terminal of the SCR should be adjacent or very close to the solder portion of the right terminal when the circuit board is installed. If so, it may be possible to solder the cathode directly to the terminal. This is preferred since it results in the shortest lead length. The remaining terminal is connected to ground by a one-inch length of wire.

When the laser output terminals are connected, trim and bend the leads of D5, a 1N4004 diode, so that they fit between the two terminals. Solder the diode leads to each of the terminals so the diode's anode is connected to the ground terminal. The white band on one end of the diode will then be nearest the SCR terminal.

The only remaining wiring is hooking up the current monitoring terminal. If you have access to a fast (15 MHz) oscilloscope, go ahead and wire the terminal by connecting the grounded lead of R7 to the terminal ground and the remaining lead of R7 to the other terminal connection. For convenience, the prototype pulser used a BNC connector which can be easily connected to a scope via a short cable. Use care when soldering the leads of R7 to the terminal since they are under the already installed circuit board.

If you do not have access to a 15 MHz (or better) scope, read the calibration instructions before hooking up the monitor terminal. You may prefer to try one of the monitoring techniques which can be used with a slow scope or even a voltmeter.

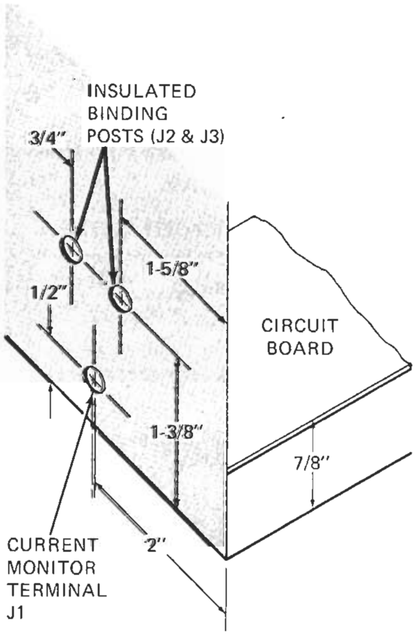


FIG. 2—LOCATION OF TERMINALS ON PANEL insures short leads to discharge-circuit parts.

Operating test

Before calibrating your laser pulser, test it to see if it's operating properly. Simply connect a length of hook-up wire between the laser output terminals (don't use a laser yet) and place a radio near the unit. When the power switch is turned on, you should hear a buzzing sound from the radio. If the sound is not present, try rotating the control pots until it is. The sound comes from the electromagnetic field radiated during the high-current discharge.

Another simple test is to carefully listen to the pulser itself. When operating, the discharge capacitor will emit a definite humming, with frequency dependent on repetition rate of the unit and amplitude dependent on the current setting. You may have to remove the top of the cabinet to hear the capacitor, but don't place your ear too close to the circuit board or you may receive a shock.

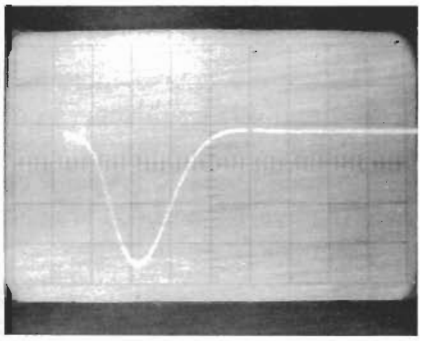
If these simple tests show that the pulser is not operating, recheck all wiring and components. Pay particular attention to the power supply circuits and look for possible shorts. Use a voltmeter to check the output of the power supply circuits. A scope can be used to check the unijunction pulser by looking across the gate of the SCR and ground (spikes) and the discharge capacitor C7 (high-voltage sawtooth waveform).

Calibration techniques

When the laser pulser is operating, it must be calibrated to prevent accidental application of excess current to a laser under test. First, make sure the current and repetition rate pots are connected properly so that rotation to the extreme left gives the least current and rep rate. It's easy to perform this procedure with the radio test. Repetition rate is easily heard as a buzz or tone and the higher the current the louder the tone. If necessary, reverse the outside (stator) contacts of either pot if it is connected backwards.

Three techniques can be used to calibrate the pulser and they are described in decreasing order of reliability. First and best is to use a 15 MHz or faster oscilloscope with triggered sweep (nearly all scopes rated at this frequency are triggered). The pulser can be quickly and accurately calibrated by making use of the one-ohm current monitoring resistor. Simply connect the scope to the monitor terminal (J1), insert a laser into the output terminals (using care to observe polarity; the SCR cathode terminal goes to the laser anode), and with both control pots turned to the far left activate the power switch.

Advance the REPETITION RATE control to a pulse rate of a few hundred Hertz (use the radio technique and estimate or connect the scope to the SCR gate to set the rep rate) and very slowly begin advancing the current control. With the scope set to a sweep speed of about 100 nanoseconds (0.1 microsecond) per division and a vertical amplitude of about 2 volts per division (compensate accordingly for a 10X probe if one is used), begin watching for



LASER OUTPUT PULSE looks like this on a fast scope. Sweep speed is 100 ns per division and amplitude is 5 volts or amps/div.

the current pulse. It may take a few minutes to find the pulse, but adjustments of the triggering (be sure it's set to negative) will soon show a very clean 200 nanosecond pulse.

CAUTION: Since an actual laser is being operated during calibration, be sure to avoid applying too much current. The inexpensive laser described in the Parts List, an RCA type 40858, can be operated at up to 25 amps but some lasers must be operated at much lower levels.

Do not advance the CURRENT control more than one third revolution when attempting to see the laser pulse for the first time with the 40858. If the pulse is not visible, the scope is not being operated correctly.

When the pulse is properly displayed on the scope, calibrate the current control by making a small mark at one-amp intervals. According to Ohm's Law, current is the quotient of voltage divided by resistance. Since resistance in this case is one ohm, the amplitude of the pulse displayed on the scope in volts equals the current amplitude. Knowing this, you can easily letter in current values every five amps.

If you don't have a fast oscilloscope, you can calibrate the pulser with practically any scope having a calibrated voltage setting for the vertical trace. Almost all but the most inexpensive scopes have a calibrated voltage setting. To perform the calibration, simply connect the scope across the positive side of C7 and ground and observe the capacitor's charging curve. It's amplitude will range up to 300 volts and more, depending on the current control setting (remember the cautionary information about the laser and start the calibration at zero current and *stop* at the laser's maximum rating).

Next, using the calibration graph shown in Fig. 3, mark the current output at one-amp intervals. It's important to note that this calibration graph applies only when the pulser is operated with a laser in the circuit (not a wire) and was made with the prototype pulser which used the discharge parts values specified

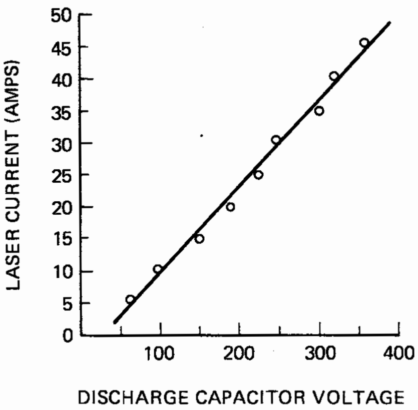


FIG. 3—CALIBRATION GRAPH for use with an ordinary "slow" scope to determine the panel markings for the current control potentiometer.

in the Parts List. While it is not as accurate as direct calibration with a fast scope, it is adequate for nearly all applications. In fact, if a fast scope will probably not ever be available, it's a good idea to hook up the monitor terminal to the capacitor and ground instead of the one-ohm resistor (be sure *not* to remove the resistor though). Also, the graph will always be handy if it is cut out and glued to the back of the case.

A third method of calibration can be used by the experimenter who doesn't have access to any kind of scope (though if at all possible a scope should be borrowed since calibration takes only a few minutes). This procedure requires a voltmeter and the calibration graph shown in Fig. 4. Simply connect the meter across the rotor of the CURRENT control pot and ground while monitoring the voltage as the control is slowly rotated. Use the graph to mark the current in amps. This method of calibration is not as accurate as either of the other two, but it will serve until a better method can be used.

Choosing a laser

A very economical laser which is ideal for this laser pulser is RCA's 40858. This laser emits a peak optical power of at least 3 watts at its maximum rated current of 25 amps. For more money, higher power lasers can be obtained. For example, the $23.20 40862 will emit at least 10 watts at 40 amps. For more information write the three main manufacturers of commercial semiconductor lasers:

Laser Diode Laboratories
205 Forrest Street
Metuchen, NJ 08841

RCA Semiconductor Lasers
New Holland Pike
Lancaster, Pa. 17604

Texas Instruments, Inc.
P.O. Box 5012
Dallas, Texas 75222

When writing, request data sheets and prices. Some lasers can be easily ordered through local electronics dealers (particularly RCA and TI types).

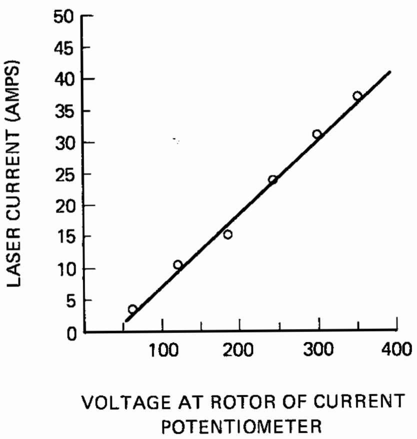


FIG. 4—IF YOU DON'T HAVE A SCOPE, use this graph and a vtvm for current calibration.

Applications

Since the beam emitted from nearly all commercial semiconductor lasers is invisible to the human eye, applications might seem tough. Not so. These little lasers are invaluable in detection-proof intrusion alarms, long range optical communications, short range IR (*I*nfra-*R*ed) photography, IR illumination, interferometry, and general experimentation. Optical radar is even a major application.

If there is enough reader interest, some of these applications can be described in detail in future articles. Meanwhile, the first general experimentation and fact book on semiconductor lasers has just been published by Howard W. Sams. Titled "Semiconductor Diode Lasers," the 192 page book is crammed with theory, applications, and dozens of circuits (all tested) for pulsers, receivers, and IR image converters. This book should keep anyone interested in semiconductor lasers busy for quite some time.

Laser safety

A final word about laser safety is in order. Though the semiconductor lasers used here are rated at average power outputs well below a desk lamp, the *peak* power output may be measured in watts. There are no known cases of eye injury resultant from observing a diode laser at close range, but play it safe and follow these simple precautions:

1. **Do not look directly into the laser at close ranges.** Since the beam spread is about 20°, increasing the distance from the laser greatly reduces the amount of light which can enter the eye.

2. **If a lens is used to collimate the laser beam, avoid looking into the lens itself.** A simple lens can easily be used to produce a 0.1° beam with the diode laser.

3. **Avoid aiming the laser at shiny surfaces.**

4. **Inform others in the area when the laser is being used** so that they will also follow the safety procedures. **R-E**

"It's only a bad tube, but by the time you get here we'll probably have to talk trade-in."

EXCLUSIVE DEVELOPMENTAL PROJECT

LASER BEAM COMMUNICATOR

AUDIO MODULATE OUR LOW-COST LASER

BY C. HARRY KNOWLES

COMMUNICATING by means of a laser beam is as fresh and new as the tomatoes picked from your garden tomorrow morning. The mere idea of being able to transmit information on a beam of coherent laser light suggests all sorts of possibilities for secret, non-jammable, interference-free communications. And it is possible today!

Communications by laser beam offers several advantages over conventional radio links. Neither atmospheric lightning nor airborne electrical noise affects laser communications though they can completely ruin radio communications. On the debit side, however, laser performance is degraded, over any reasonable distance, by heavy fog, rain, snow, or terrestrial heat.

Unlike radio, in which the signal is "sprayed" out over a wide area, a laser beam communications system operates on a line-of-sight basis and the beam is tight enough to provide excellent privacy. Of course, obstructions cannot be permitted to interrupt the beam but conventional optical mirrors can be used to bend the light beam around obstructions.

Two approaches to laser communications are described in this article. The

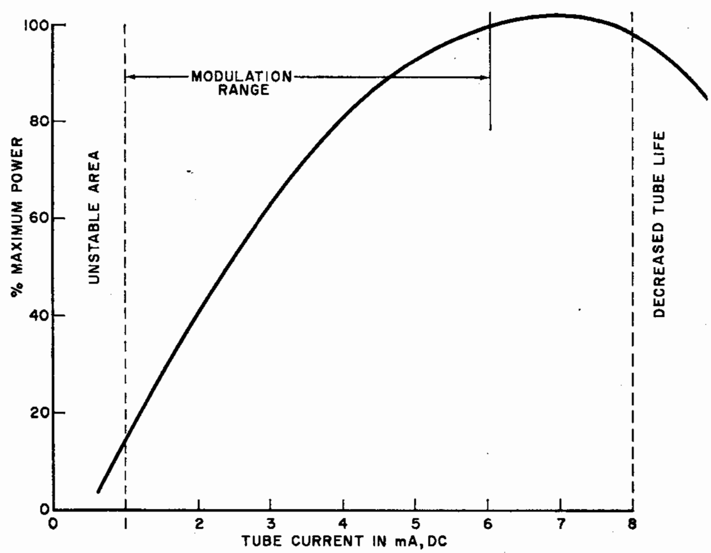


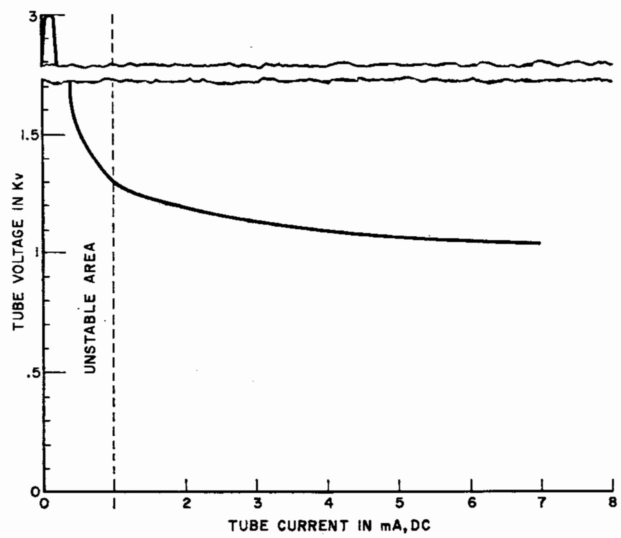
Fig. 1. Light output of the laser is a function of tube current. Modulation 90% or better can be obtained easily by this modulation method.

first involves only a simple addition to the basic laser described in the 1971 EXPERIMENTER'S HANDBOOK, Spring Edition. This system has a range of about 100 ft, and can be used for experimenting within a room and provides a "breadboard" for use in understanding modulated laser action. It also makes an excellent science fair project.

The second approach uses a modulation and receiving scheme similar to the first but it operates through conventional low-cost telescopes to achieve a range of several miles (depending on atmospheric conditions).

Laser Modulation. The light output of a gas laser such as the 0.5-mw helium-neon type described in our previous article is a function of the current flowing through the laser tube (see Fig. 1). At very low currents, the laser becomes unstable and

Fig. 2. Negative-resistance characteristic of the laser shows that a large-value variable resistance is required for stable operation over the entire operating range.



tends to turn itself off. The light output increases reasonably linear with tube current up to approximately 5 mA. Above that, the light output drops drastically and tube life is decreased. If the current is centered on the middle of the linear portion of the curve and varied about that point, the light output can be made to swing in a linear fashion and very high modulation levels can be obtained.

The voltage-current curve in Fig. 2 shows that the laser tube has a negative resistance characteristic (voltage decreases as current increases). Stable, linear operation thus depends on the use of a ballast resistor. When the tube is operating at 5 mA, approximately 1100 volts are required. At this point, the negative dynamic resistance is about 30,000 ohms. As the current is decreased the required voltage rises until, at about 1 mA, it is approximately 1300 volts. Here the negative resistance is 80,000 ohms. Therefore, the ballast resistor must have an effective value well above 80,000 ohms to keep the tube operating.

A basic modulator circuit, using a pentode with a large dynamic resistance, is shown in Fig. 3. The pentode is in series with the laser tube and forms a simple amplitude modulator. The dynamic resistance of the pentode is a function of the applied audio signal on its control grid. A potentiometer in the cathode circuit of the pentode determines the basic operating resistance of the tube and, hence, the operating point of the laser. Once the latter point (located on the curve in Fig. 1) has been set by the bias potentiometer, an audio input to the pentode causes the laser current to fluctuate about the operating point and the emitted light is amplitude modulated.

Almost any type of audio driver can be used to generate the input audio signal to the pentode.

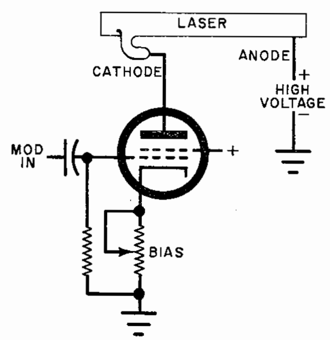


Fig. 3. The basic amplitude modulator uses a conventional pentode in series with the laser. The suppressor grid is electrically connected to the cathode.

Basic Modulator. The circuit for converting the original laser project into a light-beam transceiver is shown in Fig. 4. A photograph of the finished project is shown in Fig. 5. A complete vacuum-tube system is used simply because a high resistance device is required and the tube that will do the job is inexpensive and readily available. In addition, the +175 and 6.3-volt sources required by the pentode can be used elsewhere in the circuit.

The modulator circuit can be divided into two portions. The transmitter (*V1*) consists of the pentode modulator driven by the triode half of the tube acting as a microphone preamplifier. Potentiometer *R4* provides modulation level control. The three gas tubes in series (*I1-I3*) are 200-volt breakdown lamps which chop off the high-voltage spikes that trigger the laser. Although the operating plate voltage of the tube is below its maximum rating, a much higher voltage spike is used to trigger the laser. The three gas lamps limit this spike to 600 volts. Unlike semiconductors, a vacuum tube can withstand an overvoltage for a short time. The trigger spike here lasts only about one millisecond so no damage can be done to the tube. If you can't locate the gas tubes called for in the Parts List, use any combination of conventional neon lamps that add up to approximately 600 volts.

The receiving portion of the modulator consists of a three-stage conventional audio amplifier driven from the output of the solar cell. Unlike a conventional light-dependent resistor, a solar cell generates a voltage that is a function of the amount of light striking the photosensitive surface.

Construction. If you built the original laser project, the same metal chassis may be used. Drill or punch holes for two 9-pin and one 7-pin tube sockets. These may be located on the top of the chassis, next to the laser tube. (Be sure to remove the laser tube when doing mechanical work on the chassis.) On the wall opposite the high-voltage laser power supply, mount the three potentiometers (*R6,* bias; *R4,* modulation level; and *R12,* receiver volume), the microphone input jack (*J1*), and the photocell input jack (*J2*) (see Fig. 5). Mount power transformer *T2* on the outside of the chassis using the same mounting hardware as were used for the original 600-volt transformer. (It was *T1;* now it is *T3.*)

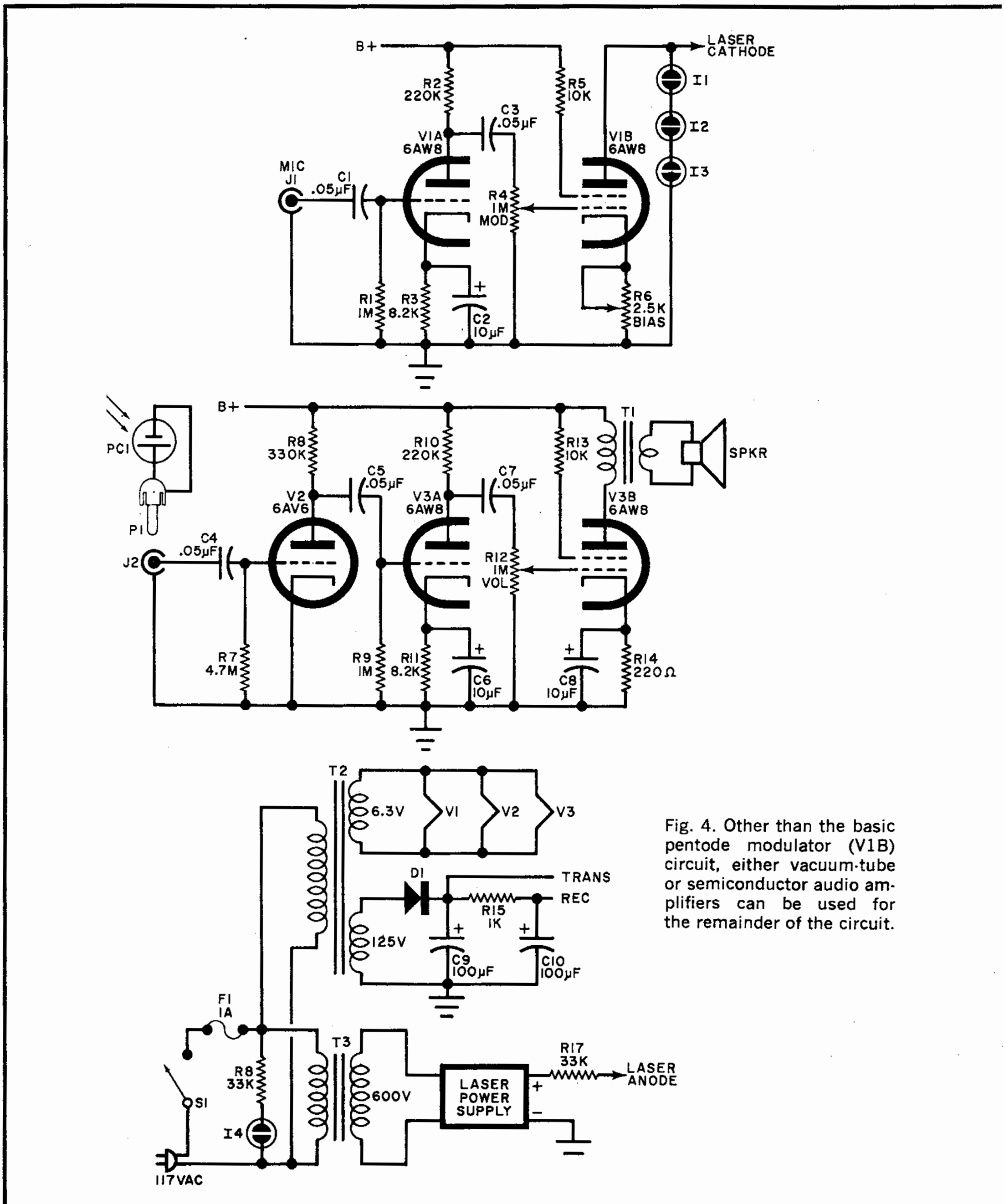


Fig. 4. Other than the basic pentode modulator (V1B) circuit, either vacuum-tube or semiconductor audio amplifiers can be used for the remainder of the circuit.

Once all the components are installed, wire up the circuit point-to-point (using terminal strips as required) following the circuit shown in Fig. 4. Of course, it is not necessary to use vacuum tubes for the microphone amplifier. You can use the 6AU6 pentode for the laser driver and, for the amplifier, any one of several commercially available transistor amplifiers. The author used one of the new RCA IC kits—the KC4000 microphone pre-amplifier—in one model and found that it worked fine. The solid-state receiver consisted of a KC4000 microphone preamplifier for the photocell preamplifier and a KC4003 ½-watt audio amplifier to drive the speaker.

The receiving photocell in this simple light communicator is mounted at one end of a dark plastic tube. (A cleaned out container of Polaroid print coater works very well.) If you use a cardboard tube, paint the interior a dull black before installing the cell. For testing and experimentation, make up a microphone cable with a phono connector at one end. Use a phone jack to make the connection to the earphone output of a conventional transistor radio. The radio is silent when the earphone jack is plugged in and produces a non-tiring audio signal for testing.

PARTS LIST
ONE-WAY COMMUNICATOR

C1,C3-C5,C7—0.05-μF capacitor
C2,C6,C8—10-μF, 15-volt electrolytic capacitor
C9,C10—100-μF, 250-volt electrolytic capacitor
D1—Silicon rectified diode (1N4001 or similar)
F1—1-ampere fuse and holder
IL—13—200-volt breakdown lamp (Signallite A-259 or similar)
I4—NE-2 neon lamp
J1,J2—Phono jack
P1—Phono plug
PC1—Solar cell (Solar Systems 11LC)
R1,R9—1-megohm
R2,R10—220,000-ohm
R3,R11—8200-ohm
R5,R13—10,000-ohm
R7—4.7-megohm
R8—330,000-ohm
R14—220-ohm
R15—1000-ohm
R16—33,000-ohm
(All resistors ½-watt)
R4,R12—1-megohm potentiometer
R6—2500-ohm potentiometer
S1—S.p.s.t. switch
Spkr—3.2-ohm speaker
T1—5000-to-3.2-ohm output transformer
T2—Power transformer; secondaries, 6.3 volts at 2 amperes and 125 volts at 50 mA (CTC PA8421 or similar)
T3—Power transformer; secondary 620-650 volts at 50 mA
V1,V3—6AW8A
V2—6AV6
Misc.—Laser power supply, laser, nine-pin socket (2), seven-pin socket, multi-lug terminal strip, mounting hardware, insulated wire, microphone, speaker, etc.
Note—The following are available from Metrologic Instruments Inc., 143 Harding Ave., Bellmawr, NJ 08030: laser model 205, 0.3 to 0.7 mW power output, 2.0 milliradians beam divergence, multimode, $50.50, postpaid; or laser model 215, 0.5 to 1.0 mW output, 0.8 milliradians divergence, single mode, $70.50, postpaid; model 60-141 power supply kit complete with PC board, all components and transformer, $18.50, postpaid; model 60-203 complete one-way communicator (except laser and its power supply) including chassis, PC boards, microphone, solid-state 1-kHz oscillator, amplifiers, speech compressor, power supply, solar cell, speaker, and instruction book, $74.25, postpaid (this kit is convertible for telescope transmission and reception).

Testing. Place the volume, modulation, and bias potentiometers in their minimum resistance positions. Connect up the speaker, photocell, and radio and turn on the power. The laser tube will start to blink at a low level until the modulation pentode warms up. Once the tube is hot, the laser will operate at its full brightness. A slight increase in the resistance of *R6* should cause the laser beam to dim slightly. This shows that the bias control is operating properly. Now set the control for full brightness. Increasing the volume control should produce some hum in the speaker. If conventional room light is allowed to fall on the sensitive face of the solar cell, it will produce a distinctive hum. This is the reason the solar cell should be mounted in a dark tube.

Separate the laser and the solar cell by a few feet and aim the beam at the receiver. Alternatively, aim the laser beam at a mirror so that it is reflected back to the cell. (The beam must be aimed straight down the cell tube and not at the interior wall.)

With the laser beam shining on the solar cell at full brightness, turn on the radio, tune to a station, and plug in the earphone jack. On the laser chassis, turn up the receiver volume control and note that, as the hand is passed through the laser beam, a thump is heard in the speaker.

Slightly reduce the bias control to dim the laser a little, and turn up the modulation control slightly. These two controls interact somewhat so you will have to "juggle" them for best modulation.

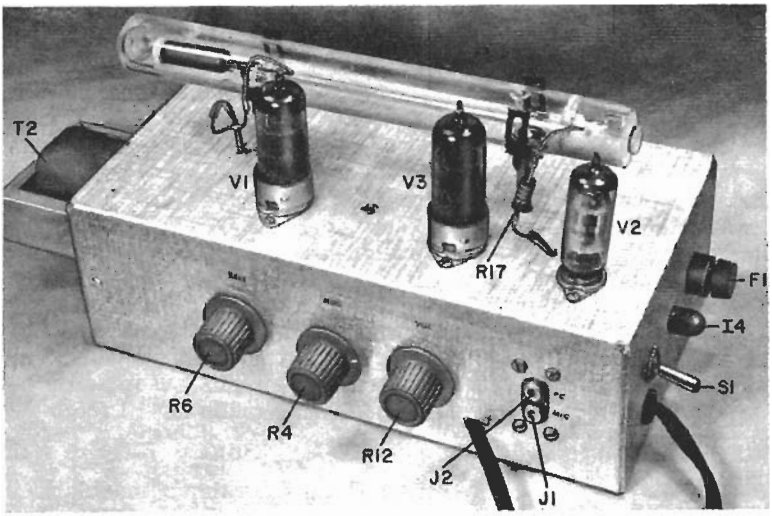


Fig. 5. The prototype was built on the original laser chassis (Spring '71 EEH). Any other layout will do as long as the pentode modulator is as close as possible to the laser.

Make sure that the radio volume is turned up sufficiently.

Once the communicator is working, you can experiment with the controls and the circuit (always retaining the pentode as the laser modulator) to increase your understanding of laser communications.

Optical Systems. Depending on how you want to use it, the laser communicator can be set up with any one of three optical systems. The simplest, which can be used for point-to-point communications around a room (to a total of 100 ft round trip), is as described above, without any lenses. To improve the reception somewhat, a simple lens can be placed in the beam path at the receiver end to reduce the size of the diverged beam.

The second type of optical system, requires the use of a set of binoculars, one eyepiece for the transmitter and the other for the receiver. Simple toy telescopes may also be used. The range for this type of system is a few hundred feet.

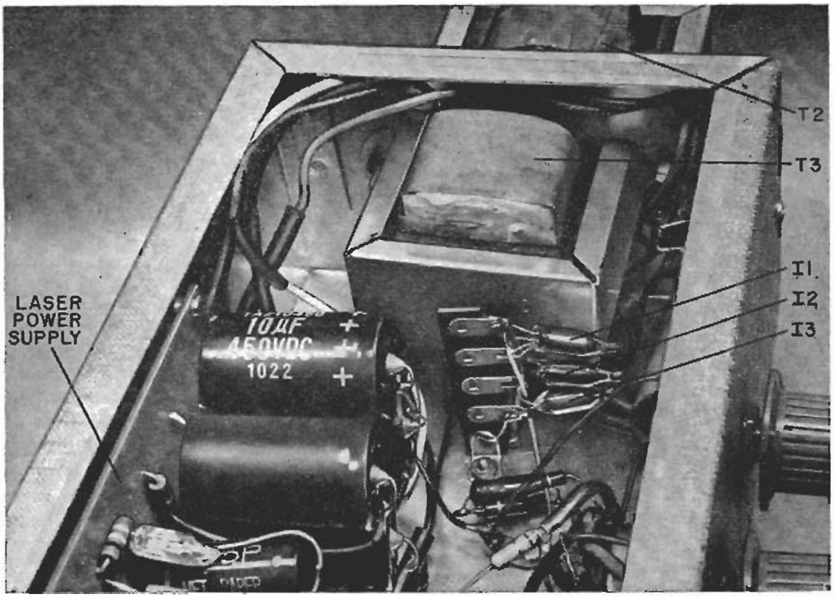
For communicating over greater distances, a reasonably high-power telescope is necessary. Such a telescope, attached to the laser communicator, acts like a high-gain antenna on a conventional radio system. In both cases the transmitted and received signals get a boost from the "antenna." And in both cases, the telescope or antenna is used for both transmitting and receiving through a simple mechanical switching process.

How far can you transmit using a telescope? It depends on a number of factors, the most important being beam divergence and atmospheric conditions. As the beam travels along its path, it tends to enlarge (diverge). This means that, although the beam leaving the laser is quite small (1 millimeter in the Spring 1971 EEH laser), it does enlarge considerably—though not as much as a comparable beam of conventional light. Using a telescope improves this condition considerably.

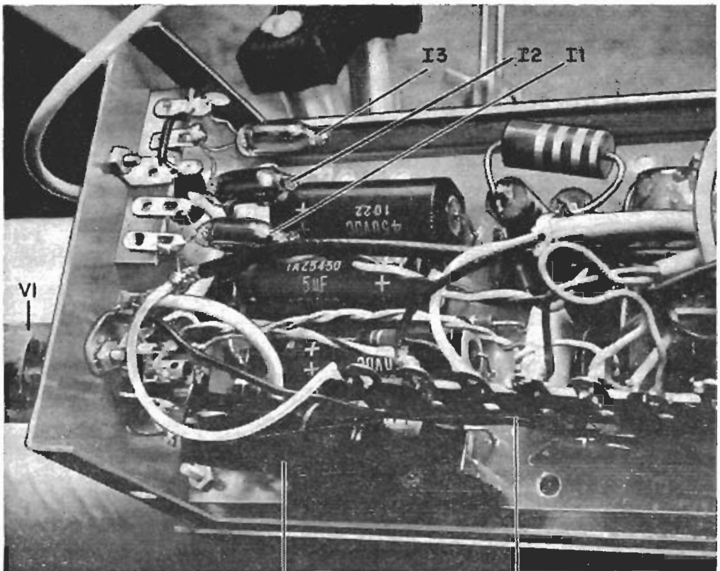
Atmospheric disturbances of the laser beam cause it to wander.

As the beam of light is projected over a long distance, it may encounter various forms of air turbulence, such as localized temperature changes. In each of these turbulences, the density of the air changes and each change in density acts as a prism as the beam passes through it, changing the beam's direction slightly. The amount of wander can be as much as several feet per mile. In the still, relatively even temperature of morning, before the sun has had a chance to warm up the air, beam wander may be as little as a few inches per mile.

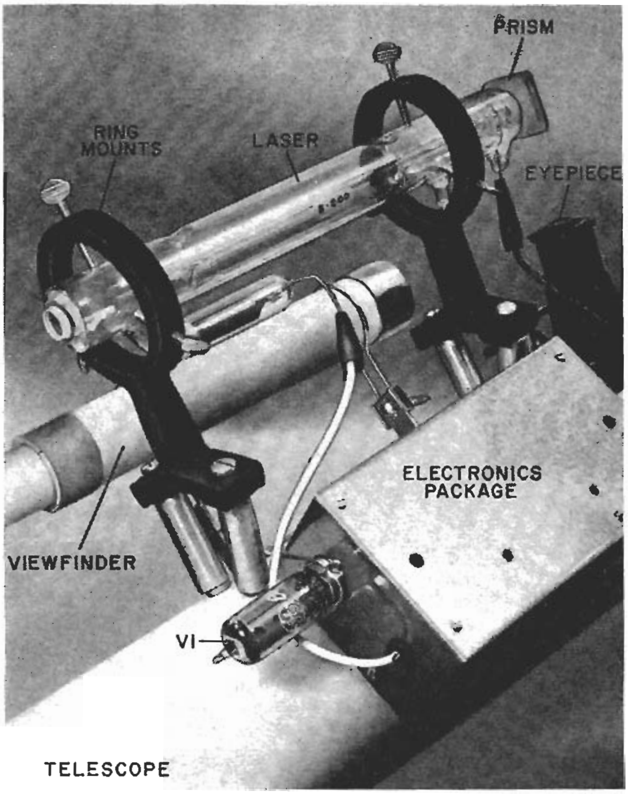
In using a reflector telescope such as that described later in this article, the beam should be collimated as closely as possible to the distant receiver, allowing for thermal refractive variations for the time of day and the atmospheric conditions. If the air is still and of an even temperature, the beam will wander only a few inches per mile. In this case, also,



Internal layout of the prototype transceiver (above) showing the laser power supply mounted on one wall with the rest of the components occupying the remaining space. The internal arrangement of the telescope electronics (shown below) shows the modulator tube and its associated components arranged within its smaller metal enclosure.



the beam may be focussed so that at the receiver, the beam diameter has diverged only about one foot per mile. If the atmosphere is clear, there is little absorption by airborne particulants (smoke, dust, etc.); and the overall result is that about 3 to 5% of the transmitted beam power is obtained at the receiver. This extremely high efficiency is one of the many attractive features of laser communications that will help make it the system of the future.



The complete telescope system can communicate as far as a 12-inch target can be clearly seen via the telescope. At night, this target will have to be illuminated. In good visibility, range can be very great but is dependent on certain conditions (see text). To assist distant communications, an optional 1-kHz audio oscillator is used to modulate the transmitter, and both ends must be "juggled" until the received audio tone is at a maximum. To get around opaque objects, a large-size front-surface mirror (not a ladies compact mirror) may be used to reflect the laser beam.

Note: Since this article was prepared, a solid-state modulator and receiver have been developed. For further details contact Metrologic Instruments Inc., 143 Harding Avenue, Bellmawr, New Jersey 08030.

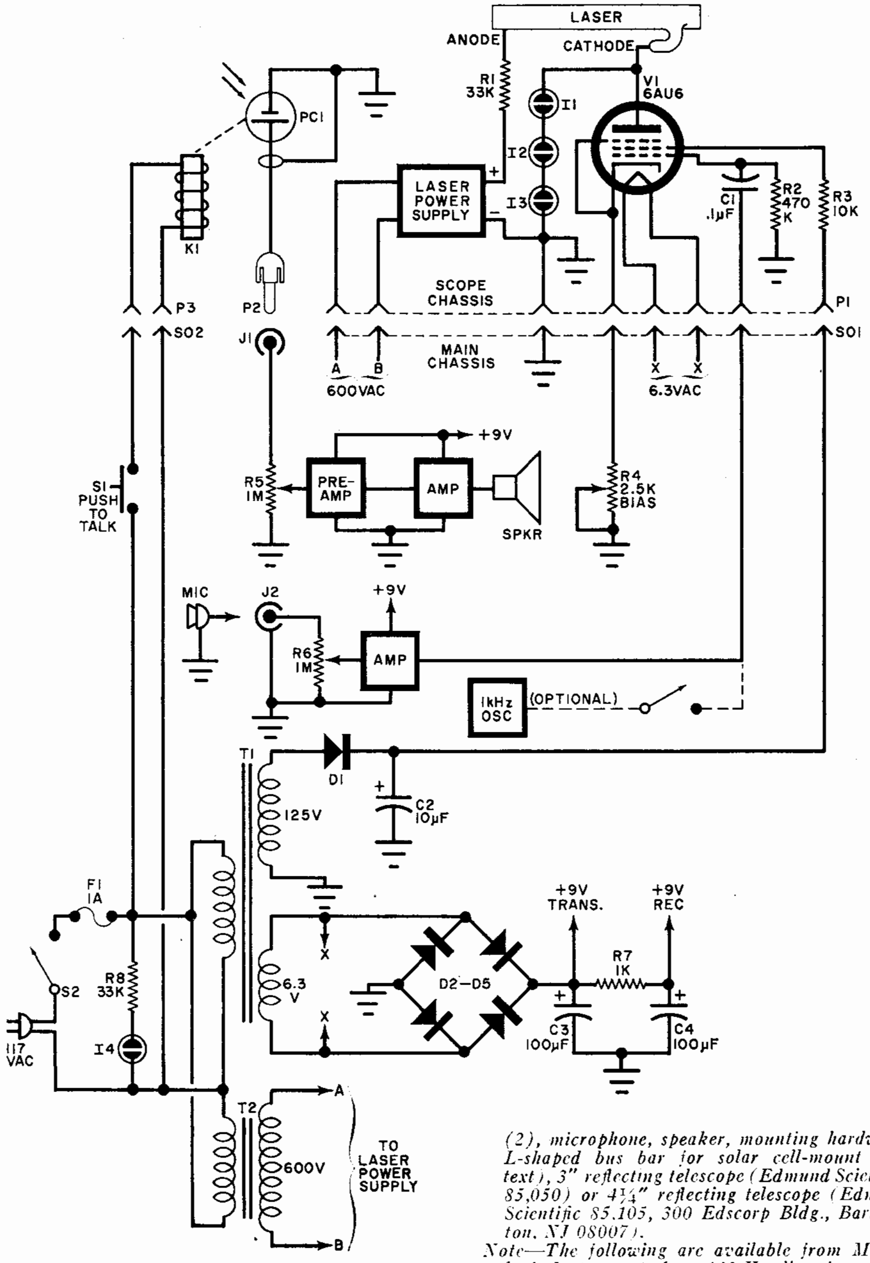
Reflector Telescope Construction. A telescopic system is shown in Fig. 6. The laser tube is supported by a pair of viewfinder ring mounts attached to the telescope tube. The laser is positioned within the mounts so that the light-emitting end is almost directly over the telescope eyepiece. (Check your laser tube to make sure whether the light beam comes out of the anode or the cathode. Some models are one way; some the other.)

Make up an L-shaped length of heavy bus bar with the long side about 2½"—the other about 1" long. Cement (with epoxy) the short end of the bus bar to the relay armature so that it swings back and forth as the relay is energized and de-energized. Position the relay about 90° from the telescope eyepiece so that when the long end of the bus bar is placed through a slot cut in the telescope tube and with the relay energized (talk position) the end of the bus bar is out of the beam path. With the relay de-energized (listen position) the wire should be in the beam path. Remove the telescope eyepiece to watch this.

Fig. 6. Complete telescope communicator showing the use of semiconductor audio amplifiers. Any neon lamps may be used for I1, I2, or I3 if their breakdown totals up to about 600 volts.

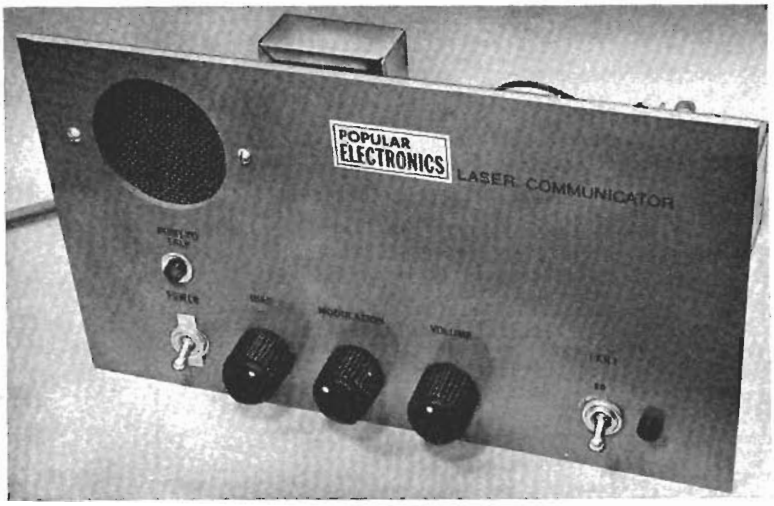
PARTS LIST
TELESCOPE COMMUNICATOR

C1—0.1-µF capacitor
C2—10-µF, 250-volt electrolytic capacitor
C3,C4—100-µF, 25-volt electrolytic capacitor
D1-D5—Silicon rectifier diode (1N4003 or similar)
F1—1-ampere fuse and holder
I1-I3—200-volt breakdown lamp (Signallite A259 or similar)
I4—NE-2 neon lamp
J1—Phono jack
K1—117-volt relay
P1—Octal plug
P2—Phono plug
P3—2-lead plug
R1—33,000-ohm, 2-watt resistor
R2—470,000-ohm, ½-watt resistor
R3—10,000-ohm, ½-watt resistor
R4—2500-ohm potentiometer
R5,R6—1-megohm potentiometer
R7—1000-ohm, ½-watt resistor
R8—33,000-ohm, ½-watt resistor
S1—Normally open s.p.s.t. pushbutton switch
SO1—Octal socket
SO2—2-lead socket
T1—Power transformer; secondaries, 6.3 volts at 2 amperes, 125 volts at 50 mA (CTC PA8421 or similar)



T2—Power transformer; secondary 620-650 volts at 50 mA
V1—6AU6 tube
Pre-Amp—Microphone preamplifier (RCA KC 4000 or similar)
Amp.—Half-watt amplifier (RCA KC4003 or similar)
Misc.—5¼" x 3" x 2" two-piece metal enclosure, main chassis, laser, laser power supply, 7-pin socket, multi-lug terminal strip, 90° plastic prism, lengths of multi-lead and coaxial cable, 2" ID telescope viewer mounting rings (2), microphone, speaker, mounting hardware, L-shaped bus bar for solar cell-mount (see text), 3" reflecting telescope (Edmund Scientific 85,050) or 4¼" reflecting telescope (Edmund Scientific 85,105, 300 Edscorp Bldg., Barrington, NJ 08007).

Note—The following are available from Metrologic Instruments Inc., 143 Harding Ave., Bellmawr, NJ 08030: a kit to convert from one-way to telescope reception and transmission, model 60-204, $24.50, postpaid, including deflection prism and tube mount, solar cell and solenoid, laser ring mounts, telescope mounting kit (for 3" to 6" tubes), and instruction book; 4¼" metal tube reflecting telescope with stand, model 60-205, $94.50 or 4¼" metal tube telescope without stand, model 60-206, $67.50 transportation charges collect. (These telescopes are complete with lenses and are suitable for astronomy).



The main chassis for the telescope communicator mounts the relatively heavy power supplies (except for the laser), all controls, and is connected to the telescope electronics via a multi-lead flexible cable. Microphone plugs into the rear.

On the solar cell called for in the Parts List of Fig. 4, the black side is the sensitive area. Cement the shiny side of the cell to the bus bar and then slide the cell and relay assembly into position. Make sure that the cell switches cleanly in and out of the beam path as the relay is operated. The two leads from the solar cell are taken out of the same slit and terminated on a two-lug terminal strip mounted near the relay.

Mount the empty half of the two-piece electronic chassis on the telescope tube, just below the two laser mounting rings, drilling mating holes in both chassis and telescope tube. Use short mounting hardware so as not to interfere with the beam path. Recheck all mechanical work and tighten the telescope tripod screws.

To keep weight to a minimum, only the modulator pentode and the laser power supply are mounted in the chassis on the telescope. This is necessary to reduce the possibility of oscillation in the circuits.

Mount the power supply on the inside of the chassis, using an insulated spacer (about 1/4″) at each corner. Be sure that the high-voltage end is far enough from the metal to avoid arcing. The seven-pin tube socket for the pentode is mounted at one end, while a multi-lug terminal strip supports the ends of the wiring. A 1/2″ grometted hole should be provided for the incoming cable.

The circuit for the scope-mounted electronics is shown in Fig. 7. Only the relay, solar cell, and laser are external to the chassis. The circuit above *SO1* is mounted at the scope. The lower portion is built in a larger conventional chassis.

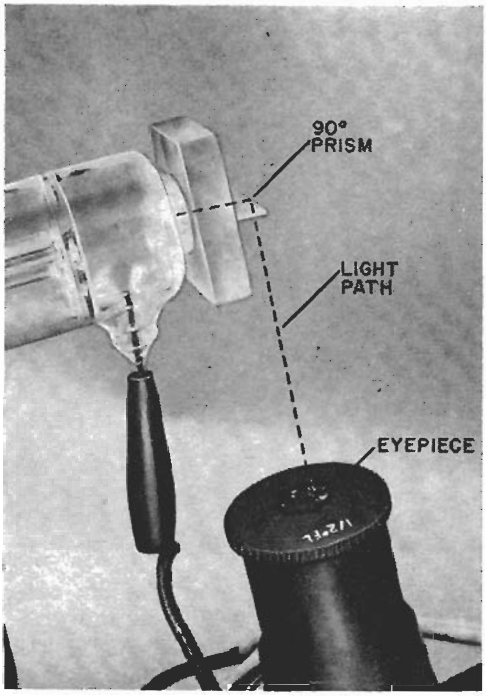
Once again, either vacuum-tube or semiconductor amplifiers may be used. The latter save quite a bit of work. Connections between the two chassis are made with multi-lead cable, with the exception of a small coaxial cable for the solar cell leads. Make the connections long enough to allow plenty of space between the telescope and the other chassis. The cables may be taped at intervals to keep them from separating.

When all electronic work is finished, attach the second half of the chassis to the one on the telescope. The cable should be placed where it will not interfere with scope operation.

Fully open the ring mount thumbscrews and slide the laser into position as described above. Tighten the thumbscrews gently to avoid damaging the tube. Attach the plus side of the high-voltage supply to the laser anode and the negative side to the cathode.

Make up a phono connector to connect the solar cell leads to *J1*. Connect the two leads to the relay.

Setup. Connect the far end of the multi-

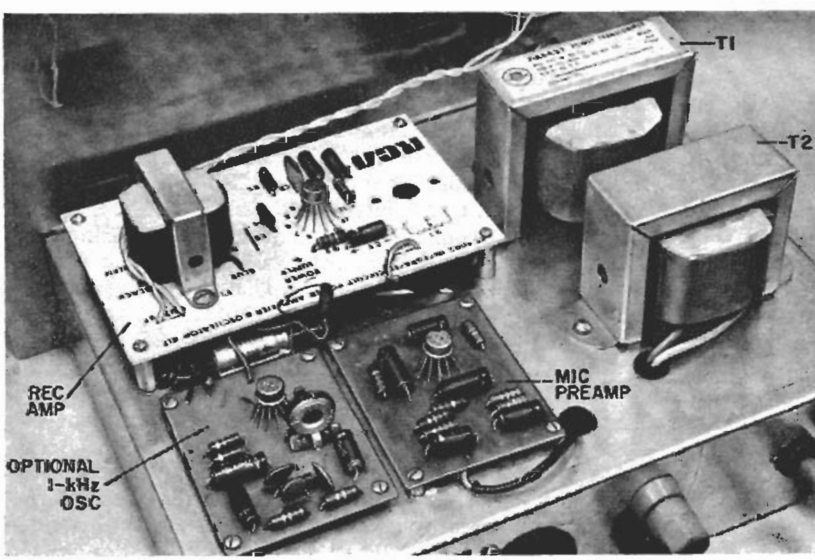


A small 90° prism is cemented to a plastic block to aim the laser light at the telescope eyepiece. The plastic block is press fit to the laser end.

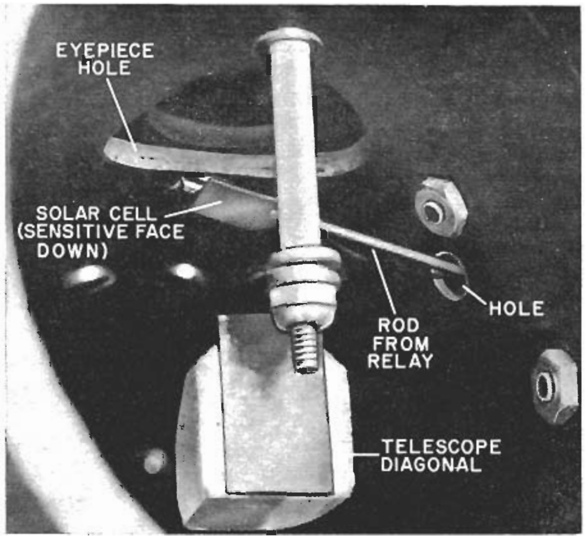
The transmit-receive relay is mounted to the telescope tube with the solar cell and rod passed inside through a hole cut in the telescope tube wall.

lead cable to the main chassis, along with the solar cell and microphone connectors. (You can substitute a radio for the microphone for testing.) The push-to-talk button may be temporarily shorted to keep the solar cell out of the beam path during the following optical alignment.

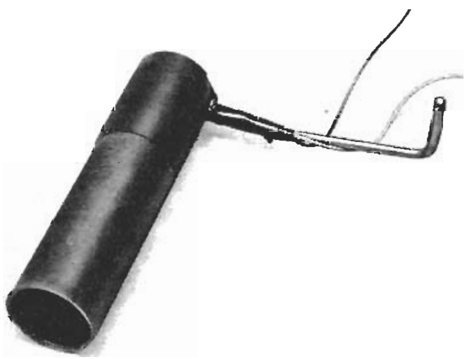
Three commercial IC audio kits were used for all stages except the pentode modulator. Power supplies are mounted under the chassis. Telescope cable termination is on rear apron.



View looking into end of telescope shows how the solar cell, in transmit condition, is out of beam path from laser to diagonal. In the receive mode, the cell enters the beam path between diagonal and eyepiece. Make sure that sensitive side of solar cell faces the diagonal.



In the simple transceiver, the solar cell is mounted within a tube having a dark interior—in this case, it's a clean Polaroid print coater. Cell is affected by ambient light so that it must be shielded during use. Any method of mechanical mounting may be used to position the cell correctly.



It is assumed that the telescope optics have been set up as described in the telescope operating manual.

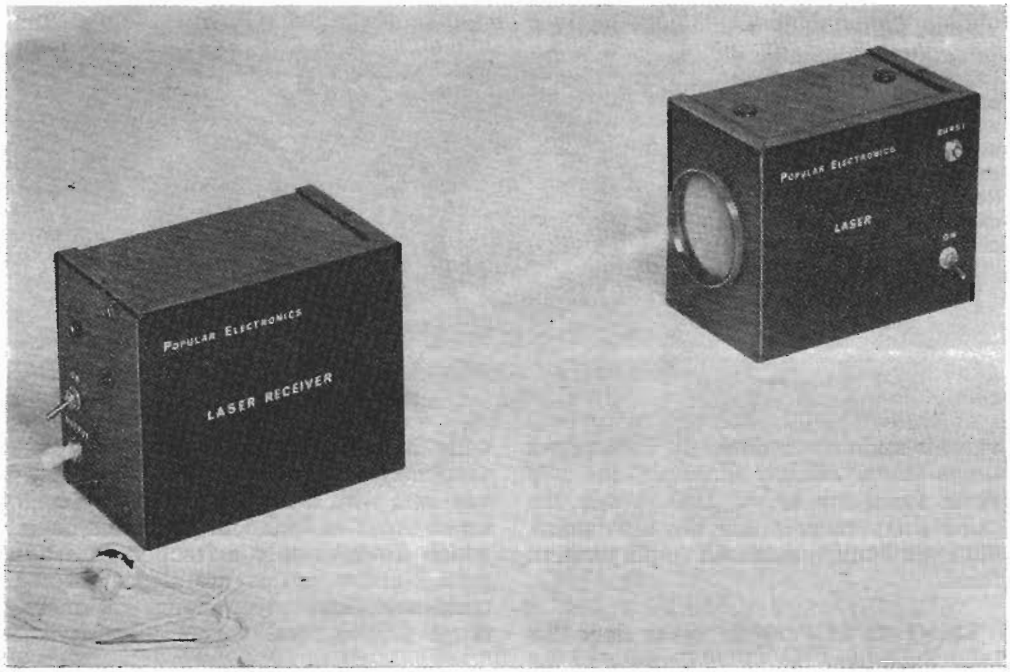
On the main chassis, set bias control *R4*, volume control *R5*, and modulation control *R6* to minimum resistance. Plug in the 117-volt line cord and turn on the power. The laser tube will blink a few times until *V1* warms up. After the laser starts to glow at full power, allow the entire system to stabilize for a few moments. Adjusting the bias control should cause the laser glow to diminish a little. Set this control for maximum laser brilliance.

Place the 90° plastic prism over the protuberance at the laser exit hole and adjust the prism so that the laser beam is reflected down the telescope eyepiece. Aim the telescope at a wall and keep adjusting the prism—and if necessary the position of the laser—until a red circle, with the diagonal mirror shadow centered in it, is clearly visible on the wall. At this point, the laser has been properly set up and should not be moved.

If you have to keep looking at the laser beam, a pair of blue sunglasses may be worn to reduce the red glare.

To test the system, aim the telescope at a distant mirror and reflect the beam back to a duplicate solar cell that has been connected to the main chassis. You can also use the second telescope of the communications system if you have built it at this time.

With the light beam shining on the solar cell, make sure that the radio is playing at a reasonable volume and turn up the laser volume control *R5*. If artificial light falls on the solar cell, a hum will be heard; so for best reception keep the ambient light dim. Slowly adjust the bias control (*R4*) until the laser dims a little. Then bring up slightly the modulation control (*R6*) until music is heard from the main chassis speaker. Since *R4* and *R6* are interlocking in their action, you will have to adjust them together to get the desired results. If *R4* is set for too low a beam level and *R6* is set too high, modulation peaks may extinguish the laser. The automatic power supply will retrigger the laser, but the controls should be adjusted to prevent the drop-out. Once clean modulation has been obtained, the radio can be replaced by the microphone and *R6* adjusted for this type of input. —30—



SOLID-STATE LASER FOR THE EXPERIMENTER

SAFE SEMICONDUCTOR DIODE MAKES AN IDEAL SECRET COMMUNICATOR

BY FORREST M. MIMS

THANKS to a recent breakthrough in semiconductor (laser) technology, the serious electronics experimenter can now work with a solid-state gallium arsenide (GaAs) laser costing less than $20. (One of the very first lasers suitable for experimentation was the HeNe device described in these pages in December 1969.)

Operating at 9050 Angstroms (see the article on page 35 for an explanation of how a solid-state laser works), the laser beam is totally invisible—even when shone onto a sheet of white paper. It is suitable for many applications, including secret communications and intrusion detectors. Because both the transmitter and the receiver operate from self-contained batteries, any system using the solid-state laser can be completely independent of the commercial power line.

Transmitter. The solid-state laser used here requires a current pulse of at least 5 but not more than 10 amperes to reach the lasing threshold. If the maximum current rating is exceeded, the laser will be destroyed. Since the laser chip is only 3 X 9 mils, the current pulse must be very short (about 200 nanoseconds) to prevent damaging buildup of heat.

The circuit of the transmitter is shown in Fig. 1. Transistor *Q1* can be any one of a number of switching transistors (such as HEP50) but it must be tested in

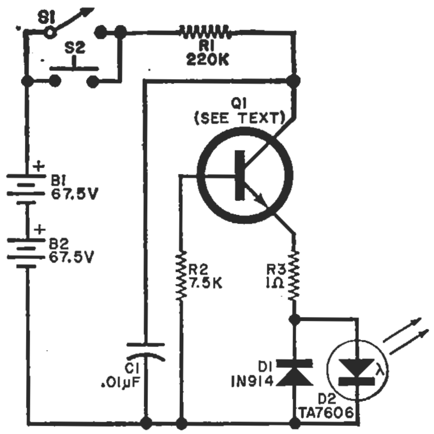


Fig. 1. The laser diode modulator is an npn switching transistor operating in the avalanche mode. One switch is for continuous operation, while the other is used for "burst" operation.

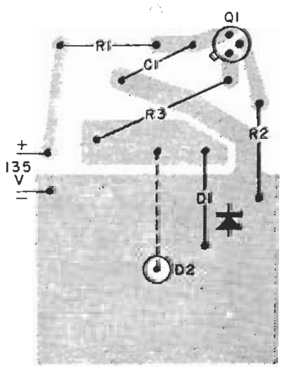
PARTS LIST
TRANSMITTER

B1,B2—67½V battery
C1—0.01-μF, 1kV capacitor
D1—1N914 fast recovery diode
*D2—Laser diode (RCA TA7606)**
Q1—Npn silicon switching transistor (see text)
R1—220,000-ohm, ¼-watt resistor
R2—7500-ohm, ¼-watt resistor
R3—1-ohm, ½-watt resistor
S1—Spst slide or toggle switch
S2—Normally open pushbutton switch
Misc.—3" x 4" x 5" aluminum untility box, battery clamps and clips, lens (see text), mounting hardware, wire, solder, etc.
**Available from RCA Electronic Components, Somerville, NJ 08876, for $18.85 plus postage*
Note—The following are available from MITS, 4809 Palo Duro NE, Albuquerque, NM 87110: etched and drilled PC board at $1.75; selected transistor for Q1 at $2.50; PC board and complete kit of all parts, including laser, lens, transistor, utility box, etc., but not batteries, at $26.00. When ordering complete kit, add $1.00 for postage and handling.

the circuit to make sure that it avalanches properly. Capacitor *C1* is charged up through *R1* until the collector-to-emitter breakdown voltage of *Q1* is reached. When *Q1* break down (avalanches), the energy in *C1* flows through *Q1, R3, D1,* and *D2*. To determine whether a transistor is avalanching, replace the laser diode (*D2*) with a conventional silicon rectifier. With a 135-volt source applied to the circuit, connect a scope across *C1*. When the circuit is oscillating (a small percentage of transistors may not), the amplitude of the displayed pulses is the breakdown voltage of the transistor. Do not use a transistor with a breakdown voltage greater than 45 volts since any higher voltage will provide more than 10 amperes to the laser.

A foil pattern and component layout for the transmitter are shown in Fig. 2. Mount *Q1, R1, R3,* and *C1* flush against

Fig. 2. Transmitter foil pattern and components. The cathode of the laser diode makes its connection via its mounting; the anode via a "flying" lead.



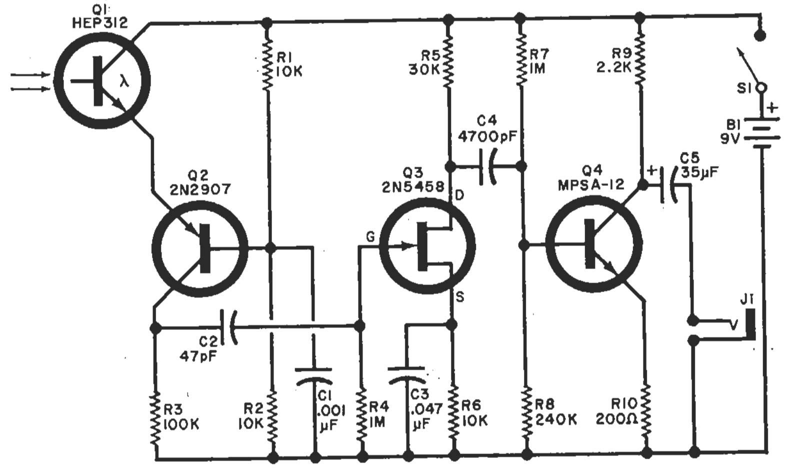


Fig. 3. The receiver is essentially a phototransistor driving a conventional audio system. Any phototransistor may be used as long as it will respond to the 9000-Angstrom laser output.

PARTS LIST RECEIVER

B1—9-volt battery
C1—0.001-μF, 10-volt capacitor
C2—47-pF, 10-volt capacitor
C3—0.047-μF, 10-volt capacitor
C4—4700-pF, 10-volt capacitor
C5—35-μF, 10-volt electrolytic capacitor
J1—Earphone jack and plug
Q1—HEP-312 phototransistor
Q2—2N2907 transistor
Q3—2N5458 or HEP801 FET
Q4—Darlington transistor (Motorola MPSA12)
R1, R2, R6—10,000-ohm, ¼-watt resistor
R3—100,000-ohm, ¼-watt resistor
R4, R7—1-megohm, ¼-watt resistor
R5—30,000-ohm, ¼-watt resistor
R8—240,000-ohm, ¼-watt resistor
R9—2200-ohm, ¼-watt resistor
R10—200-ohm, ¼-watt resistor
S1—Spst slide or toggle switch
Misc.—3" x 4" x 5" aluminum utility box, battery holder, lens (see text), mounting hardware, wire, solder, earphone, etc.
Note—The following are available from MITS, 4809 Palo Duro NE, Albuquerque, NM 87110: etched and drilled PC board at $1.95; PC board and complete kit of all parts, including, lens, utility box, etc., at $9.70. When ordering complete kit, add $1.00 for postage and handling.

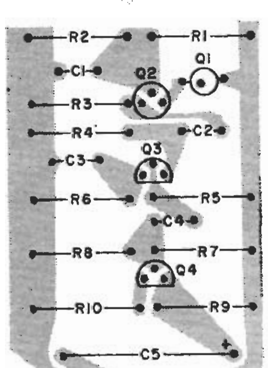
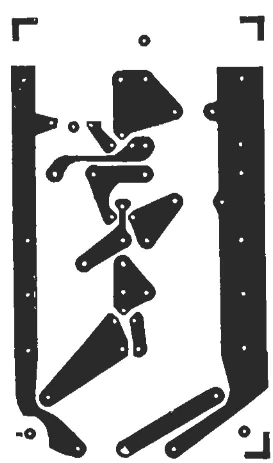
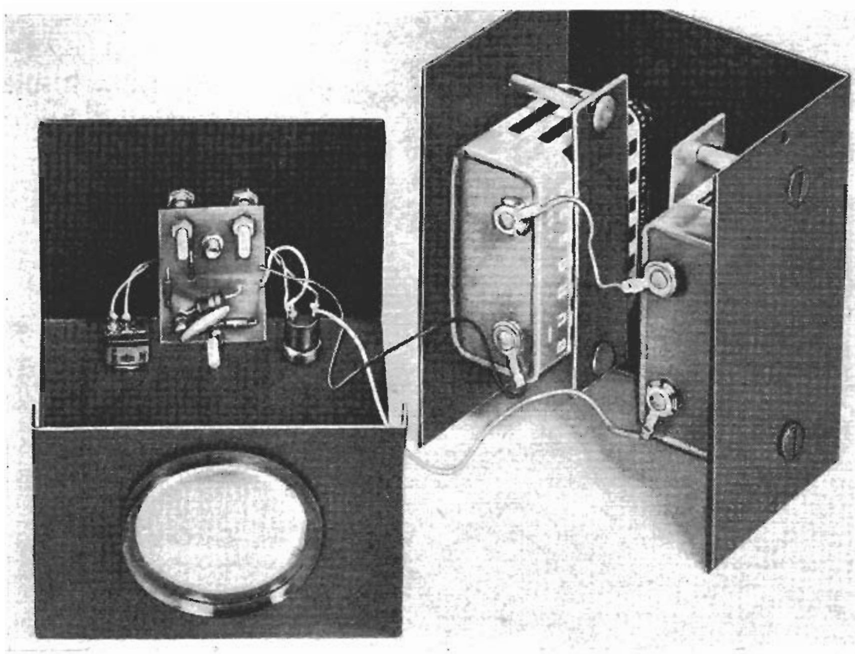


Fig. 4. The receiver foil pattern and component installation. Note that Q1 has only two leads, the light from the laser acts as the base input signal.





When mounting the transmitter, make sure the laser diode sits at the focal point of the lens. Three adjustable spacers are used to make this adjustment.

the board to reduce stray inductance. Despite its low value, do not omit *R3*. It

In the receiver, the phototransistor mounts at the focal point of the lens. In this case, the receiver, battery, switch and phone jack are mounted on one end of metal enclosure.

limits the laser current. Drill a 3/8″ hole at the spot where *D2* is to be mounted and use a hex nut to secure it in place. Its flat sides must be parallel to the narrow end of the board. Be careful when connecting the laser anode lead to its hole in the foil.

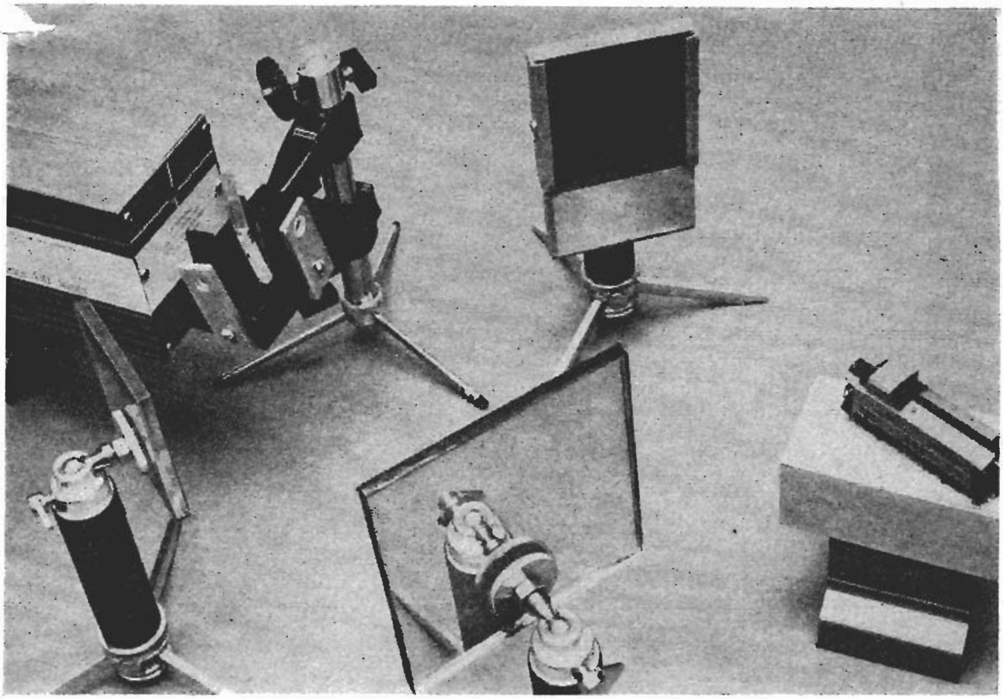
To test the transmitter, place it close to an operating AM radio and depress the burst switch, *S2*. A tone of approximately 1 kHz should be heard from the radio.

Receiver. The circuit of the receiver (Fig. 3) is essentially a phototransistor (*Q1*) driving a conventional audio system. A foil pattern and component layout are shown in Fig. 4. The phototransistor is mounted on the foil side of the board and protrudes through a hole in the board. Clip the excess lead length from it before soldering it in place and make sure that it is level.

To test the receiver, turn it on and aim the phototransistor at a fluorescent lamp. Various noises will be heard as the receiver is aimed at different areas along the lamp.

Mounting and Optics. Using a 3″ X 4″ X 5″ utility box, cut a 2″ diameter hole

(Continued on page 102)



DO IT YOURSELF LASER HOLOGRAPHY

TRUE THREE-DIMENSIONAL IMAGES ON FILM

BY C. HARRY KNOWLES

THE BASIC CONCEPT of the camera was first developed in the 10th century and ever since, man has attempted to make a photographic record of himself and the world around him. The camera and photographic techniques have improved continuously over the years and no one can say that the clarity and beauty of today's full-color photographs are not truly remarkable.

But there's something lacking! Using standard photographic techniques, it is still impossible to capture on film the three-dimensional quality that characterizes life itself. Many attempts have been made to create the three-dimensional illusion, including the use of multiple cameras and projectors, special glasses for the viewer, special filtering, and a large number of other, lesser-known methods. Most have eventually been discarded.

In the late 1940's, Dr. Dennis Gabor, working with an optical system, demonstrated that, by using coherent monochromatic light, it was possible to imprint a true three-dimensional image on photographic film emulsion. There was only one problem—a source of coherent light was hard to find. When the laser was discovered, a practical, dependable source of coherent light became available; and Dr. Gabor's brainchild, the hologram, was reborn.

Holography is based on the principle of recording interference patterns set up by a reference beam of laser light and the reflected light from a target. The result, a hologram (captured on film), is a true three-dimensional re-

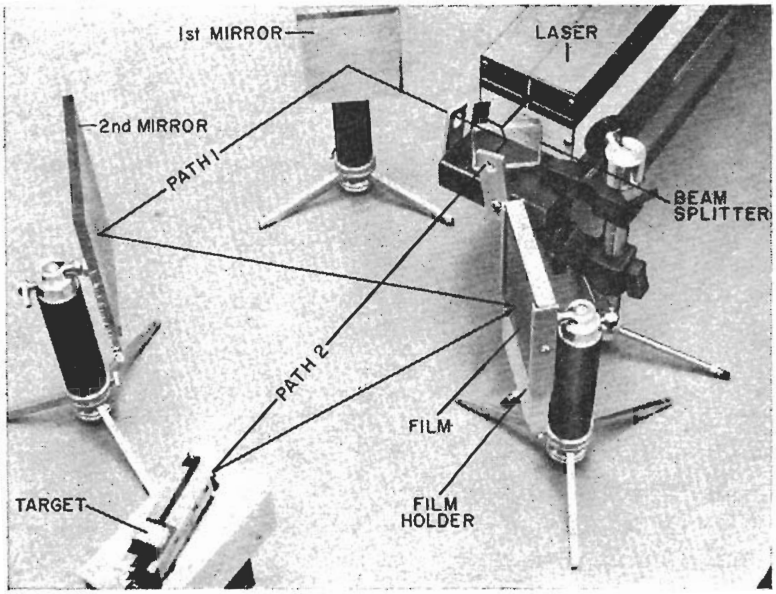


Fig. 1. The basic optical setup showing the two beam paths used to make a hologram. The mounting tripods are conventional camera tripods found in most camera shops. Remember that the most important item is stability—of both laser and optics.

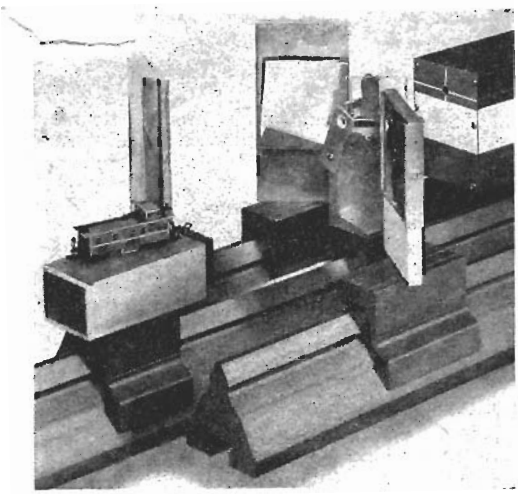
production of the target. The display technique requires no imaging lenses within the system, but does require a laser. (See "What Is a Hologram?" on page 30)

Although many uses have already been found for holograms, the technology is still essentially in its infancy and promises to play a very important role in our future as laser techniques continue to be developed. For instance, holographic road signs are being developed so that drivers in different traffic lanes will get directions applicable only to them. A system of credit card validation is being developed in which each card contains a very small hologram of its identifying number. The card is inserted in a holder containing a laser which projects the number onto a large-size master transparency. Within microseconds the number is compared with all delinquent account numbers stored on a master and, if a match occurs, an alarm is given.

One major tire manufacturer uses holographic interferometry in a routine inspection of its products. Holographic memories are being developed rapidly—your telephone number and all related information may soon be stored holographically. RCA recently announced a low-cost system of video recording using transparent tape containing holograms. When the tapes are passed between a laser (one quite similar to the one used here) and a TV camera, the images are converted to conventional video. In this low-cost system, the holograms are stored in cassette-type containers. Even color recording is practical.

Three recent developments now make holography a practical project for the electronic experimenter: the introduction of the safe, low-cost laser (POPULAR ELECTRONICS, December 1969); a new high-resolution, high-contrast, high-speed film (Agfa 10E75); and a low-cost high-quality optical kit complete with optics, film, and chemicals.

The experimenters' holographic system described here requires a working knowledge of electronics, basic optics, and photography. Assuming that the reader has the necessary background in electronics and optics, it is suggested that, before proceeding with construction and actual creation of holograms, he consult friends or some simple home photography manuals—particularly in the area of film development. A darkroom is required, both for setting up the holographic system and for developing the exposed film. It may also be used for proper viewing of a finished hologram.



This is a commercial holographic setup that uses heavy metal extrusions as stable base. The laser shown here, and in Fig. 1, is the low-cost laser mounted within a light-tight aluminum enclosure.

Making the Optics. There are six pieces of equipment required to make a hologram: a laser, a beam-splitter assembly, two reflecting mirrors, a film holder, and a platform for the target. A complete assembly is shown in Fig. 1.

The laser is the low-cost unit described in the December 1969 issue of POPULAR ELECTRONICS. It must be mounted in a light-tight enclosure made of wood or metal, painted flat black on the inside. Everything must be inside the enclosure with only a power cord coming out of it. Once the enclosure has been built, drill a small hole (about 1 mm) precisely in line with the exiting laser beam. Inside the enclosure, the laser should be placed so that its exit mirror is very close to the exit hole.

Mount the laser enclosure on a firm support. Stability is extremely important. Be sure that the enclosure does not rock or tilt in any direction. If necessary, place a weight on top of the enclosure to make sure that it sits firmly. Measure the distance from the supporting table or bench top to the laser exit hole. This distance above the table or bench establishes a horizontal plane which will be referred to frequently in the construction of the system.

The beam splitter assembly includes a glass beam splitter and a pair of diverging lenses. A piece of metal or a smooth block of wood about 2 inches square can be used for the beam splitter assembly mount. The height of the mount should be such that the laser beam will strike about the center of the beam splitter. The beam splitter is a small piece (about 1" square) of highly polished optical glass having exactly parallel surfaces. Using pitch, epoxy or other hard-drying cement, affix the glass beam splitter to the top of the wood block as shown in

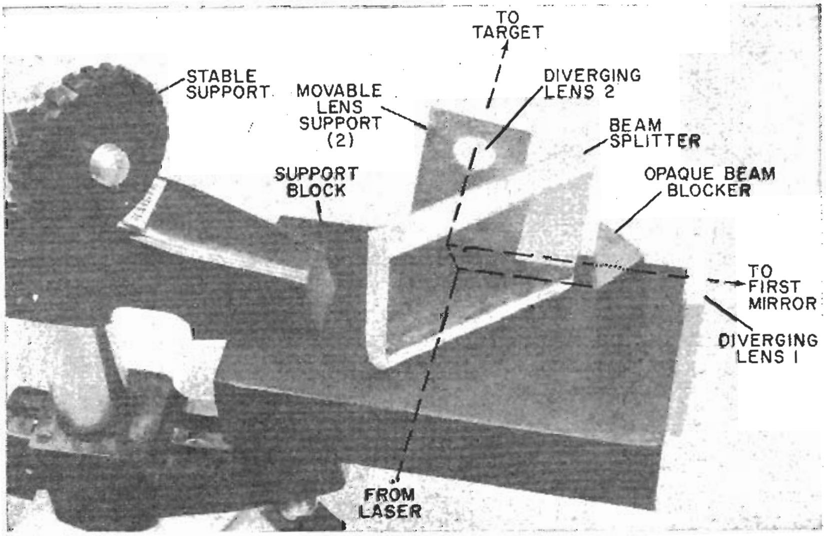


Fig. 2. Details of the beam splitter assembly. The opaque beam blocker is placed to cut out one beam from the glass splitter. The diverging lenses are oriented as required.

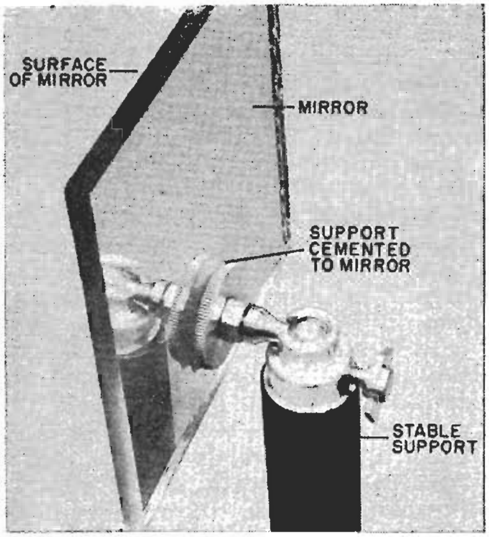


Fig. 3. Tripod support is removed and cemented to the rear surface of the front-surface mirror. Metal nut on tripod screw clamps the mirror tight.

Fig. 2. Mount the two diverging lenses in holes drilled in two pieces of aluminum ¾″ wide, 2″ long and ⅛″ thick. The lenses can be glued or friction fitted in place. Cut half-inch slots in the other ends of the strips to accommodate mounting screws. When mounted, the aluminum strips should be capable of being moved up or down and to left or right when the mounting screws are slightly loose. The centers of the lenses must be movable about the laser beam. The wooden vertical block on the beam splitter assembly should be ignored for the moment as it will be installed later.

The two reflecting mirrors are made from front-surface optical flat mirrors. The first mirror should be about 2 inches square. The second, larger mirror is about 3 inches square. Using firm, stable supports attach the mirrors with pitch or epoxy so that they are vertical and their centers are in the horizontal beam reference plane (see Fig. 3).

The film holder should be designed to support a piece of film 2¾″ square (70 mm) so that it fits flat against a back support. The easiest way to do this is to take a piece of solid aluminum stock ½″ or more thick and 2¾″ wide by 3″ high. Use this to fashion a holder. Secure this to a wood or metal block so that the 3″ length is vertical and the center of the piece of aluminum is on the horizontal

WHAT IS A HOLOGRAM?

A hologram of an object bears absolutely no similarity to a conventional photograph of the same object. It is not even visible unless observed under special conditions. A hologram viewed under normal incoherent light looks like a slightly dirty transparency with absolutely nothing to indicate that it is a three-dimensional view of an object. Despite the fact that the hologram looks so bleak, it contains far more actual information than can be placed on an ordinary photograph. All of this information can be seen when the hologram is viewed in the coherent light from a laser. Of course the most important information that the hologram contains is the third dimension of the object—color is not yet obtainable in a hologram but the possibility is being investigated.

Another remarkable fact about the hologram is that each part of it contains all of the target information. If the hologram is cut in half, each half contains the complete image, including the third-dimension information. In fact, each portion can be cut in two again and the information is still intact. As the hologram is subdivided, although each small piece still contains a complete image, resolution suffers and a point is eventually reached where the image is no longer clear and distinct. Scratches and smears do not affect holograms as much as they do conventional negatives since all parts of the hologram contain all of the image information.

In viewing a hologram, the eye (or camera) can be focussed on different parts of the three-dimensional image. As the hologram is moved farther from the diverging lens during viewing, automatic enlargement of the image occurs. If the hologram is turned over while viewing, a very peculiar "inside out" view is obtained.

In the system used here to make holograms, two sources of light reach the film emulsion. One comes from the reference-beam mirrors and the other is reflected from the infinite number of points that make up the target. The light striking the target is exactly in phase with the light in the reference beam.

The frequency of the light from the helium-neon laser is 4.7 x 10^8 MHz with a wavelength of 6328 A or 6238 x 10^{-10} meters. Thus one wavelength is very short so that the light reflected from different points on the three-dimensional target reaches the film at slightly different times, depending on the distance of each point from the emulsion. An interference pattern created by the phase relationships between the reference beam and the target reflections is created on the film. It is this interference pattern that is recorded.

Because the distances involved are so small, the film must be able to resolve interference lines spaced about a wavelength apart. This means that a film resolution of about 2000 lines/mm must be used to produce a useful image. (Conventional film can resolve only a few hundred lines per millimeter.)

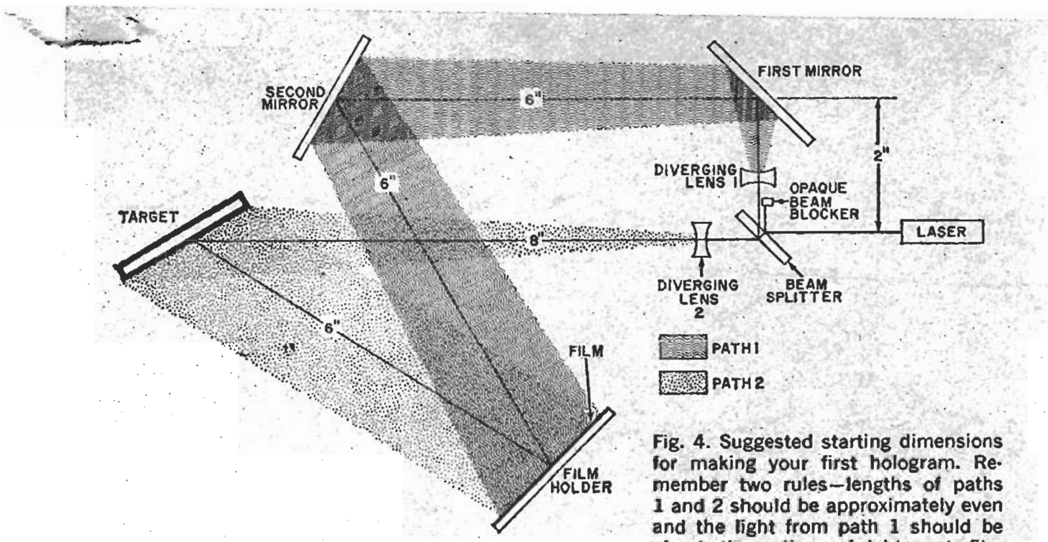


Fig. 4. Suggested starting dimensions for making your first hologram. Remember two rules—lengths of paths 1 and 2 should be approximately even and the light from path 1 should be about three times brighter at film holder than that from path 2 (target).

BILL OF MATERIALS

1—Beam splitter, plano-plano double-polished high-transmittance glass 1" x 2" x ¼" (Edmund Scientific 41,264, Edmund Scientific Co., 300 Edscorp Bldg., Barrington, N.J. 08007)
2—Diverging lenses, 10-mm diameter, 9-mm focal length, coated (Edmund Scientific 94,-726)
2—Front-surface mirror, high-reflectance coating on polished front surface, heavy glass, one 3" x 4", one 5" x 7" (Edmund Scientific 40,041 and 40,043, respectively)
Film (Agfa 10E75, Agfa-Gevaert Inc., Scientific Products Dept., 275 North St., Teterboro, NJ 07608)
Developer (Kodak D-19 or Metinol-U)
Hypo fixing bath
Developing trays (3)
Misc.—Mounting tripods for optics, adhesive, aluminum sheet ¼" x 2" x 3" and L brackets for film holder, metal strip for supporting lenses, alcohol and lint-free tissue for lens cleaning, stable, workbench, darkroom, acetic acid, etc.
Note—A complete kit of all items except those in Miscellaneous but including a test hologram and detailed instructions are available as Model 60-625 Holography Kit from Metrologic Instruments, Inc., 143 Harding Ave., Bellmawr, N.J. 08030, $34.75 postpaid. Mounting holders for optical components are also available for an additional $36. A complete holography kit plus a shock-mounted rigid base with three triangular tracks is available for $103 postpaid. For information on the laser and power supply, see the December 1969 POPULAR ELECTRONICS.

beam reference plane. Take two 3" lengths of L-shaped aluminum having one 3/16" lip and attach them to the 3" sides of the support so that the lips will hold both sides of the film (see Fig. 4). The target platform is a simple horizontal plate, made from metal or wood and mounted on a firm support so that the platform is about ½" below the horizontal beam reference plane.

Cleaning the Optics. All the optical surfaces must be cleaned very carefully. Any spots, smears, scratches or dust on any of the optical surfaces (including the transmission mirror of the laser) will show up as blotches or "noise" in a finished hologram.

An excellent way to clean the optics is with a fresh, untouched, lint-free facial tissue moistened slightly with pure alcohol. Take care not to let dust or fine grit that may be on a surface scratch the surface as you remove it. A soft cotton swab can be used to remove any residual particles that may be present before cleaning. After cleaning, make sure that no residue from the facial tissue is left on the optical surface.

Once cleaned, optical components should be protected with dust covers and should never be touched with the fingers.

Preparing the Developing Chemicals. Conventional darkroom techniques are

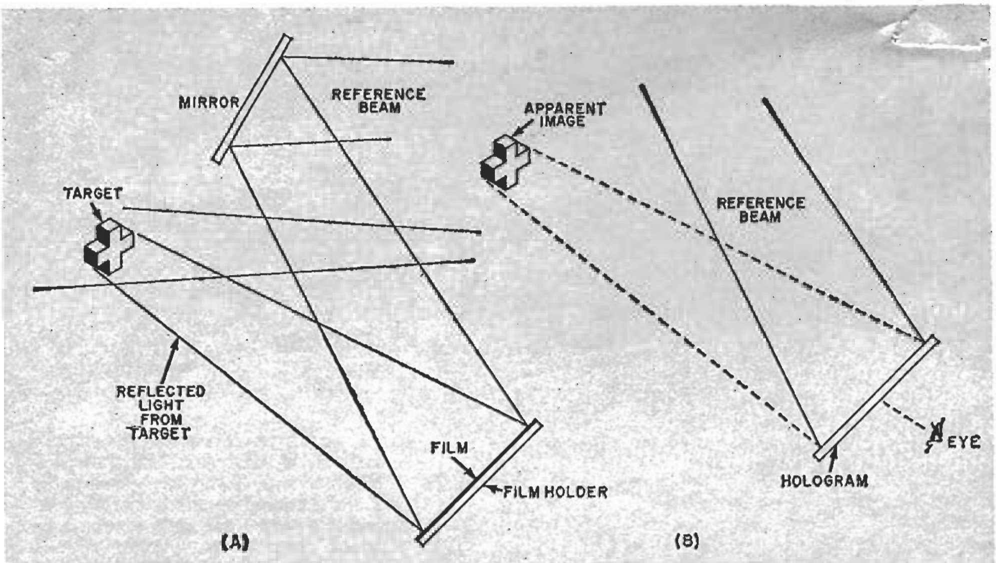


Fig. 5. To view the hologram, you must reproduce the optical arrangement used to make it, as shown in (A) and (B) above. The apparent image is difficult to see at first until you get used to it. Make sure the negative is positioned the same way it was taken and is straight. Viewing should be in a darkened room.

used in developing the hologram. Make up a solution of Kodak D-19 or Agfa Metinol-U developer in a tray. (Any other very fine-grain and high-contrast developer may be used.) Make up another tray of shortstop (dilute acetic acid) and one of fixer (ordinary hypo). Follow instructions provided with the chemicals.

A source of clean running water will be needed for washing finished negatives and you should have some type of darkroom timer to measure the seven or eight minutes required for developing. Allow all chemicals to stabilize to correct temperature. Now make sure that the darkroom can be made absolutely dark during hologram exposure and that all fans and air conditioners are shut off. Air in motion can ruin fine details on a hologram.

The film to be used is Agfa 10E75, which is very sensitive to red and blue light; therefore no safe light should be used while the film is being exposed and developed.

Setting Up and Making a Hologram. In making a hologram, you are dealing with distances as short as a wavelength of light—and shorter—so physical motion of the optical system and the air surrounding the experiment must be at a minimum. Select a very solid work surface that is not affected by building vibrations. The surface need be only a foot or two wide and about three feet long.

Position the laser at one end of the working surface so that the beam shines down the center of the area. Place the optical components as shown in Fig. 4. It is suggested that you use this layout to make your first holograms. Experiment later. Place the beam splitter about 2 inches from the laser beam exit hole, positioned so that it is at a 45-degree angle to the beam. With the laser operating, use a smoke cloud to show up the beam and note that there are three red lines. One passes directly through the beam splitter and shines on down the work table. Two others come off of the beam splitter at right angles. One of these two beams comes off the front surface of the splitter, while the other comes off the internal or rear surface. Position a wooden beam blocker so that it cuts off the beam coming from the surface closest to the laser. Now there should be only two beams—one shining straight down the work surface and one at right angles to it off of the splitter.

Position the first front-surface mirror (the smaller of the two) about 2 inches from the beam splitter and about parallel with the beam splitter surface. Orient this mirror carefully so that the beam from the splitter strikes close to the center of the mirror. Now there should be two separate parallel beams going down the table.

As can be seen from Figs. 1 and 4, two optical paths are required to make a hologram. One (path 1 called the reference beam) is from the beam splitter, through a diverging lens (to broaden the beam), through two front-surface mirrors, to the film holder. The other (path 2, called the target beam) comes from the beam splitter, through a diverging lens and shines on the target. The reflected light from the target shines on the film holder. The positioning of the target, the second reflecting mirror, and the film holder should follow two basic rules: (1) the lengths of paths 1 and 2 should be approximately the same; and (2) the light from path 1 should be about three times brighter at the film holder than the reflected light from the target.

For the target, it is best to use a bright, shiny white or red object less than two inches in any dimension. This type of target does not require long exposure times. A white or red chessman or an HO-gauge train car make good targets.

Once the optics are positioned as described, place a white card or piece of paper in the film holder. Adjust the mirrors in path 1 until the reference beam dot is centered on the film holder. Move the first diverging lens into position in the reference beam. The dot on the film holder should now be enlarged considerable. Do not use the exact center of the diverging lens to avoid unnecessary interference rings on the film plane. Adjust the reference beam mirrors so that the reference beam covers most of the white card in the film holder as uniformly as possible. The placement of the refference beam may also be adjusted by moving the first diverging lens.

Place the target in position and note that the path-2 beam strikes it. Position the second diverging lens for maximum coverage of the target by the beam. The reflected light from the target should cover the white card in the film holder. Block out the light from path 2 and note the level of light from path 1. Now block the light from path 1 and note that the path-1 illumination is about 3 times as strong as that reflected from the target.

Make sure that no stray light from the target illuminating beam strikes the second mirror. Also, check that extraneous light reflected from the optics or the target mounting does not fall on or near the film holder. To do this, remove the film holder and look into the reflected beams from the film holder position. (NOTE: It is quite safe to look into the *diverged* beam from a laser with power as low as this—less than 0.5 milliwatt. However, before looking into the beam or its reflection, *be sure* that the diverging lenses are in position.) Look at the target and the second reference-beam mirror—and other places—and make sure that only light from the reference beam and target strike the film plane. Use dull black paint to touch up any shiny spots and place dull-painted blocks to prevent any stray light.

Replace the film holder and recheck the beam illumination levels. The beam balance can be changed by moving the target one way or the other or by moving the reference beam mirrors. However, the length of the beam paths must remain equal within a couple of inches. You are now ready to expose the film—emulsion side toward the target and reference beams. But wait one more minute—observe these precautions! Since the film is extremely sensitive, the room must be absolutely dark. The laser must have been operating for at least a half an hour to allow it to stabilize. The movement of air in the room must be at an absolute minimum—no air conditioners or fans, no unnecessary body movement and no talking. Air turbulence destroys the fine fringes that make up the details of the picture.

Cut out a strip of black paper for use as a shutter to cut off the beam where it comes out of the laser. With this shutter in place and making sure that there are no other light leaks in the room, take a section of film, holding it by the edge, and place it, emulsion side out, in the film holder. Be sure not to buckle or touch the film emulsion. Allow a few moments for everything to stabilize—don't move or talk or allow air to move across

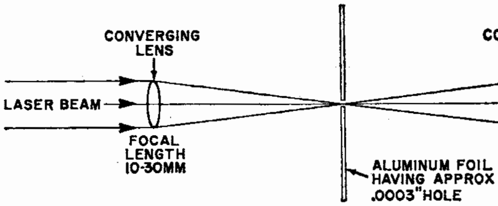


Fig. 6. A spatial filter cleans up laser beam to make better holograms. Sharp needle is used to make the fine hole required.

the beam paths. Now remove the shutter from the beam for 1½ seconds and then replace it. The hologram is now exposed and ready for development—but don't turn on the lights!

Film Development. Processing holographic film is not much different from normal photographic processing. The temperatures of the film storage area, the exposure area, and the chemical baths should be as nearly equal as possible. Handle the film as little as possible, taking care not to touch the emulsion. Place the exposed film in the developer for the recommended amount of time—about 7 or 8 minutes, usually. If anything, a little overdeveloping doesn't hurt. Then insert the film in the conventional stop bath and fixer. After fixing, the safe light can be turned on. Wash the film for about 10 minutes in running water.

Do not be surprised at what you see, or do not see, on a finished hologram. You are not recording a focussed picture

THE STABLE BASE

A stable base is required for the optical system if you are to make a good hologram. Ideally, you should use a heavy bench having a thick slate or metal top and sitting on a thick concrete or cement floor isolated from building vibrations. Such vibrations come from elevators, heavy machinery, passing vehicles, or a walkway used by a number of people.

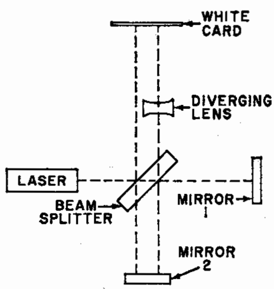
Unfortunately, such an ideal condition is difficult to find. As a substitute, find a location that is as close as possible to the ideal and then try either of the following vibration-reduction systems.

Partially inflate a truck or car inner tube and place it on top of your workbench. Obtain a piece of thick plywood—¾" or more—about four feet square and center it on the tube. Place heavy weights (stones or metal blocks) at each corner of the plywood and orient the weights so that the plywood is horizontal as indicated by a spirit level.

The second approach is the same as the first except that a thick layer of foam rubber—two inches or more—is used instead of the inner tube.

Once you have a stable platform, you can determine just how stable it is by using a simple interferometer setup as shown in the diagram. You can use the same equipment that is used to make a hologram.

Assemble the optical system, as shown, on the stable platform. The distances from the laser to the beam splitter and from the beam splitter to the white card are not important. However, try to make the distance from the center of the beam splitter to each mirror the same. Do not install the diverging lens at first. Turn on the laser. If things are properly positioned, two pairs of dots should be visible on



the white card. You can adjust the optics slightly to make both pairs visible. Further adjustment of the optics will cause one pair of dots to be superimposed on the other pair.

Now insert the diverging lens into one of the beam paths about three inches from the white card. One of the dots on the card will enlarge to a red area—actually, it is two areas superimposed on each other. If you examine the superimposed areas carefully, you will notice a number of black bars that may be stationary or slightly moving within the area. If you very gently touch one of the mirrors the black bars will move. These bars are the result of interference patterns and represent an optical "zero beat." Moving either mirror slightly changes the number of bars. Adjust one of the mirrors until a convenient and easily seen number of bars is visible. Leave the optical system alone and observe the bar pattern for a few minutes. The bars should not move more than about one quarter of the distance between bars over a few minutes' time. If you can obtain this type of vibration-free mounting, you can make good holograms.

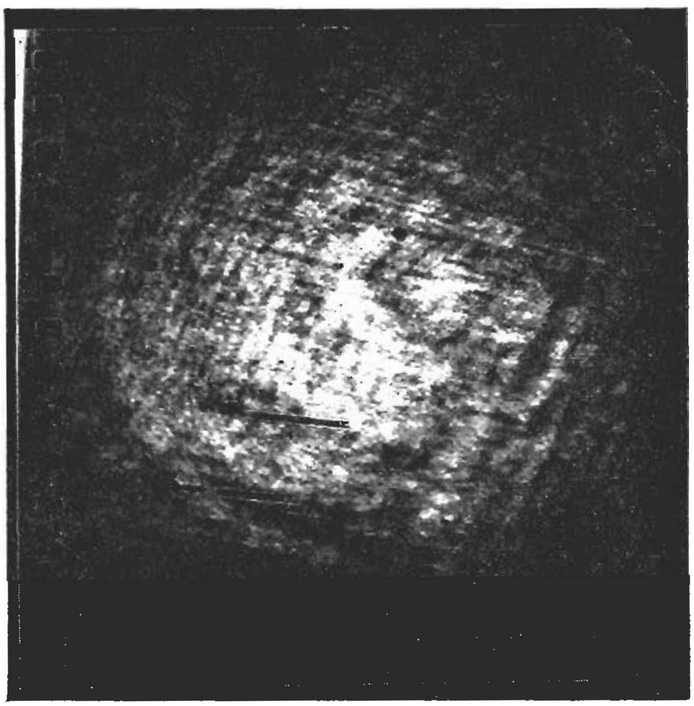
so there is no actual image on the film. The most that you will see is a somewhat smudgy negative full of whorls and lines. The dark areas are noise. The actual image is down at the molecular level and can be seen as interference fringes under a microscope.

Viewing the Hologram. This can be a little tricky until you get the hang of it. An important first step is to place the hologram (after it is air dried) in a metal frame so that it is flat. The frame should at least support the hologram by the two edges that have the most curl.

The hologram can be observed without disturbing the exposure setup. Looking at the exposure arrangement from the rear of the film holder, note the angles made to the film holder by the reference beam and the target reflection beam. Referring to Fig. 5, remove the film holder platform and place the hologram in the diverged reference beam at the point where the film was originally positioned. The image should appear where the original target was as you look through the back of the film. You may have to move the hologram around a little, and unless you remember the exact orientation of the film, you will have to turn it until you see the image. If the film is reversed, a weird, unrecognizable blown-up image will result. As previously mentioned, seeing the image is tricky until you are used to it. Have patience and try viewing a hologram that you know is good before giving up on the one you made. If you purchase the hologram optics kit mentioned in the Bill of Materials you will get a sample hologram to experiment with. Other holograms are available from Edmund Scientific Co., 300 Edscorp Building, Barrington, N.J. 08007.

Troubleshooting. If no picture can be found in the hologram, there are several possible reasons. The most probable is that something moved while you were making it. A relative motion of even a few millionths of an inch between target and other components can destroy the image. Also check the following: (1) Beam balance—ratio of approximately 3:1 must be maintained between reference and reflected beams. (2) Stray light from outside or from laser must be eliminated. (3) Exposure time may not be right. Keeping all conditions the same, vary the exposure time until you hit the

(*Continued on page* 90)



The finished hologram bears no resemblance to an actual picture. In fact, it may look like this. The hologram from this blotchy negative is quite an excellent three-dimensional image. The dark blotches, accentuated by the magazine printing process, are due to the random moding of the laser, and most can be cleaned up with a spatial filter. Small whorls and lines seen on the hologram are the result of small blemishes on the optics or dust motes on polished surfaces. They carry no picture information so they can be completely ignored. The actual hologram interference lines are so small they can be seen only with aid of a microscope.

HOLOGRAPHY

(*Continued from page* 35)

correct interval. (4) Film resolution may be lost due to poor developing techniques or uneven temperatures in the chemical developers.

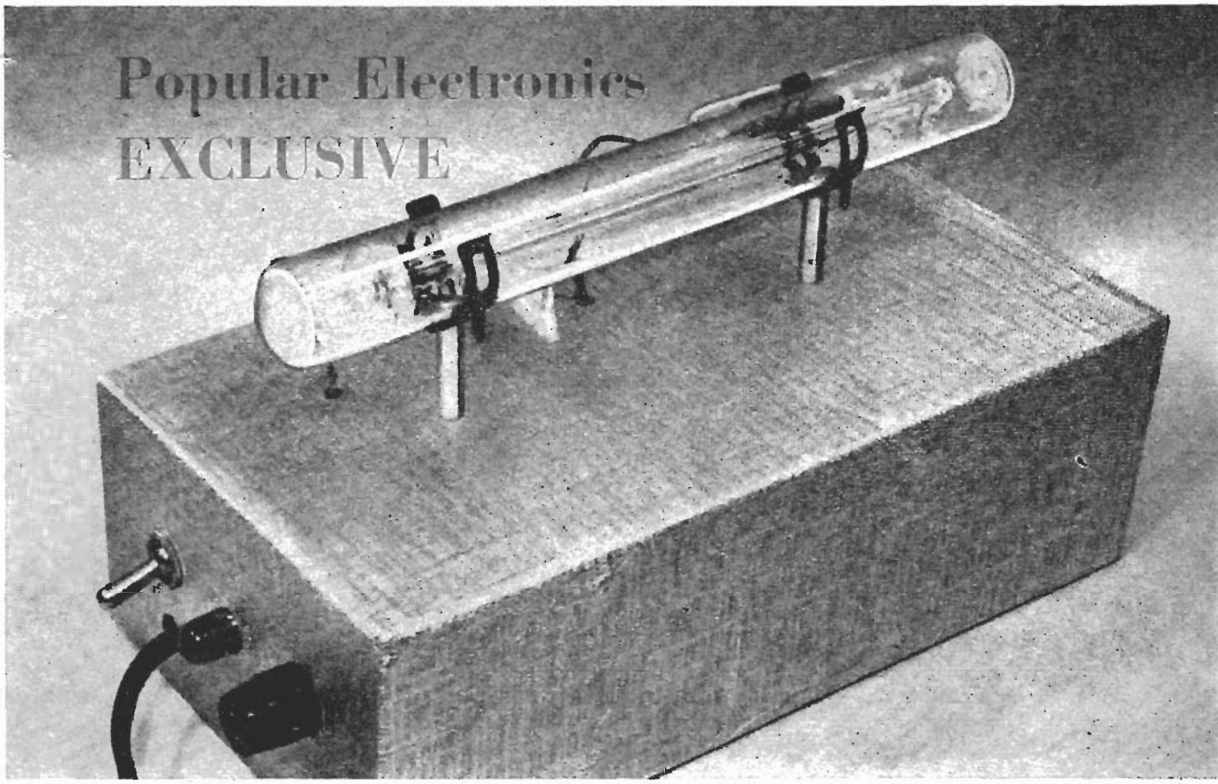
Refining the Hologram. Since holography is a new technology, perfection is not easy. However, there are a few things that can be done to improve the results a great deal and the serious experimenter will want to try them.

The first refinement is to "clean up" the laser beam where it leaves the housing. You will notice that no matter how you clean the optics, the laser beam is still inclined to be "blotchy." The blotches can be cleaned up by the use of a spatial filter. The latter is easy to make: two convex lenses of short focal length (10 to 30 mm) and a pinhole in a piece of aluminum foil are all you need. The arrangement is shown in Fig. 6. Place the assembly between the laser beam exit hole and the beam splitter.

Multi-mode lasers of the type used here cannot be completely "cleaned up" by this process. There may still be "holes" in the hologram—portions of the target that are not illuminated. To remedy this, you can try a single-mode laser ($69.95) in place of the multi-mode, low-cost laser.

Another refinement in holograms is to make them of larger objects. The optics described in this article are suitable for making larger holograms if you use a larger film holder and bigger film and lengthen the exposure time. However, if you lengthen the exposure time, the stability of the optical system becomes much more critical.

Finally, a really advanced refinement is to put two holograms of different targets on one piece of film. To do this, take one exposure (timed a little short), rotate the film 180 degrees, still with the emulsion side toward the target, change the target, and make another exposure (also timed short). When viewing a dual hologram, remember to rotate the film to see both images. -30-



Experimenters' Laser

SAFE, PRACTICAL LASER FOR HOME OR SCHOOL

BY C. HARRY KNOWLES

UNTIL NOW, the experimenter has found three things wrong with lasers: (1) they were expensive; (2) they were dangerous; (3) they were hard to get. That's why lasers have been used primarily by research laboratories and not by the ordinary electronics hobbyist.

In the last year or two, relatively low-cost laser assemblies have been available for use by schools, small research labs, and machinery manufacturers. However, many of these lasers bordered on the danger line with light outputs that could cause retinal damage to the eye if the laser were not handled properly.

With interest in lasers at an all-time high, it was inevitable that research would eventually produce a laser whose output was reduced to the point where the beam was no longer dangerous to the eye and whose price did not require a "government grant" to support experimentation. The result is the safe, low-cost laser described here. Priced at $49.50, this laser generates a modest 0.5 milliwatts at 6328 angstroms. The laser tube itself is available from a mail-order supplier (see Parts List) and the necessary high-voltage power supply may be assembled in a few hours.

Laser Basics. Without delving into the mathematics and quantum theory involved in the operation of a laser, the best way to describe the device is to

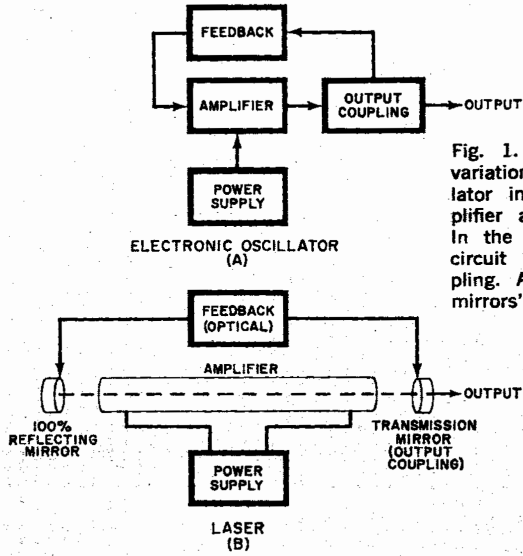


Fig. 1. The laser is essentially a variation of a conventional oscillator in that it has both an amplifier and a feedback mechanism. In the laser, part of the feedback circuit also forms the output coupling. Actually, "it's all done with mirrors"—made up in a special way.

compare it with a conventional electronic r.f. oscillator—the principles of operation of the two are quite similar.

As shown in Fig. 1A, an electronic oscillator has four main parts: an amplifier, a resonant feedback network, an output coupling port (including the antenna), and a power source. Figure 1B shows the corresponding parts of a laser. Here the amplifier can contain a mixture of gases or liquids, or it can be solid state. The laser described in this article contains a gaseous mixture of helium and neon.

When the laser's power supply delivers enough energy to cause a discharge in the gas tube, the neon atoms are elevated to a high energy state by colliding with the helium atoms. When the neon atoms drop back to their lower energy state, they give up energy at certain wavelengths. In this case the wavelength is 633 nanometers or 6328 angstrom units (in the deep red portion of the visible spectrum). As this light energy is propagated within the glass tube, it scatters helter-skelter in all directions. Some of the light is lost through the side walls of the glass tube, but the portion that travels down the center of the tube strikes other excited neon atoms within an internal glass capillary tube creating more light energy of the same wavelength.

Eventually the light strikes a mirror at one end of the laser and most is reflected back down the capillary tube. With a mirror at each end of the tube, the process continues—the beam bouncing back and forth until it builds up enough intensity to pass through one of the mirrors, which is only partially coated. The other mirror is 100% reflective and does not allow any part of the beam to escape in that direction. Thus we see how the laser gets its name —Light Amplification by Stimulated Emission of Radiation. It is important to note that this amplifier, and the critically spaced and designed optical feedback system, has a very narrow bandwidth around the 6328 A wavelength.

In the helium-neon laser, light amplification is only 1.02 on each pass of the beam from one mirror to the other. Thus all losses must be kept below 2%. Very special care is taken in fabricating the laser and in coating and aligning the two mirrors. The gas mixture is pure, containing no contaminants. The transmission mirror is coated to allow 0.8% of the generated light to escape. Thus, as intense as the beam emitted appears to be, it is less than 1/100 as intense as the beam between the mirrors. It will be noted that lasing occurs only in the precision capillary tube that delineates the exact path between the mirrors.

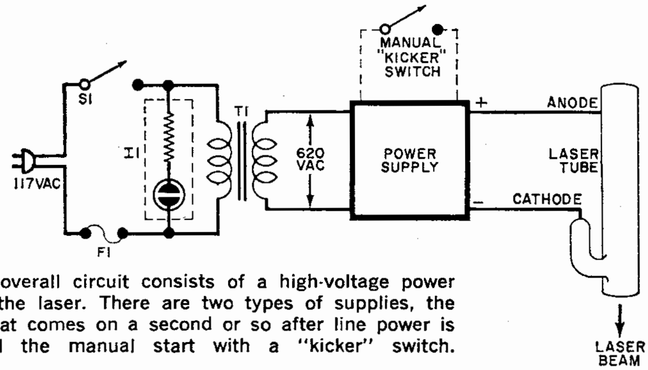


Fig. 2. The overall circuit consists of a high-voltage power supply and the laser. There are two types of supplies, the automatic that comes on a second or so after line power is applied, and the manual start with a "kicker" switch.

PARTS LIST
COMPLETE LASER

F1—1-ampere fuse with holder
I1—117-volt neon indicator and holder (can use NE-2 and 33,000-ohm resistor)
S1—S.p.s.t. switch
T1—Power transformer, 620-to-650-volt secondary

Note—The laser tube is available from Metrologic Instrument Inc., 143 Harding Ave., Bellmawr, N.J. 08030 for $49.50 plus $1.25 postage. A complete laser housing including an aluminum extruded case, steel base, power switch, pilot light, and all mounting hardware is also available from the same source for $15.

Properties of Laser Light. There are four unique characteristics of laser light that make the device itself such a useful tool. These are: directionality, coherence, intensity and monochromaticity.

The directionality of laser light is due to the fact that only the light that is on the axis between the mirrors can escape from the laser. The other light contributes nothing to the output beam. Thus, the laser light emerges inherently well collimated and highly directional, and thus useful for applications where an enormous concentration of light in a given direction is important.

The coherence (phase) of the light is due to the very high-Q resonant feedback network within the optical amplifier. Only light whose multiples of a half wavelength fits exactly between the mir-

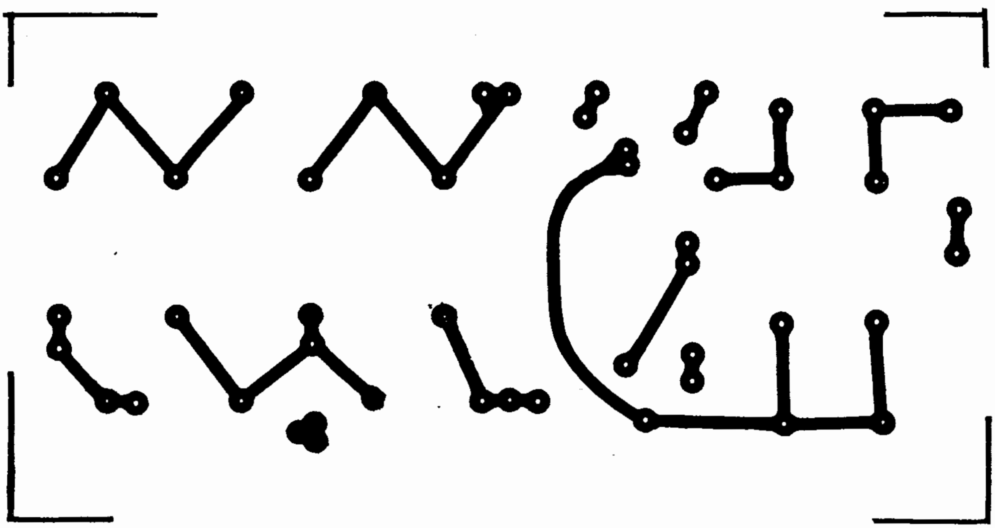
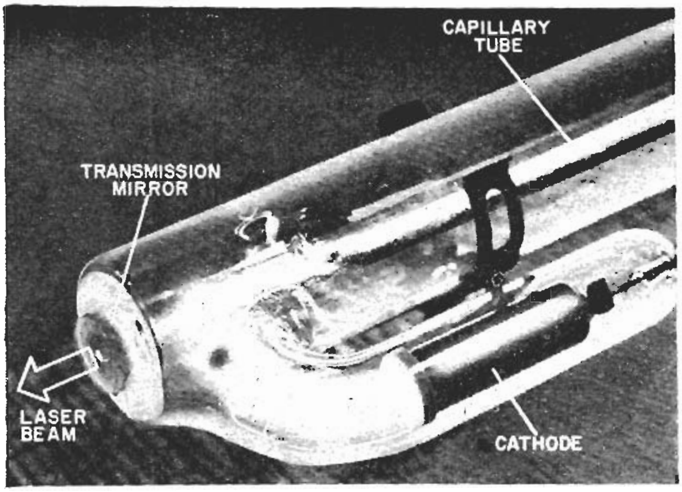


Fig. 3. Actual-size foil pattern for automatic start supply. Drill mounting holes at the four corners.



Close up of "business end" of the laser. Note use of capacitor clamps to secure laser in place. Make sure that exit optics are clean and laser is rigidly mounted on a chassis.

rors is allowed to propagate. Thus, standing waves are established between the mirrors and each light particle is in step with all the others—creating phase coherence.

Intensity and monochromaticity go hand in hand. Since the laser builds up energy of only one frequency, all the power in the laser beam is at that frequency. The spectral energy of the 6328 A light produced by the laser approaches the intensity of the similar frequency emitted by the sun.

Monochromaticity (one color) is a result of the narrow pass band of the amplifier, plus the selectivity of the resonant feedback mirrors. The pass band of the laser described here is about 1200 MHz at a frequency of 4.8×10^{14} Hz (a Q of 4×10^{5} in the amplifier section). In addition, the filtering of the resonant mirrors reduces the output to lines whose frequencies are separated by one half the speed of light divided by the distance between the mirrors. In our laser, this is about 620 MHz. These lines are extremely narrow—less than 1 Hz wide. Thus, the laser can have a monochromaticity purity of better than one part in 10^{15}. This permits very sharp filtering for laser communication to reduce background noise and provide an extremely high signal-to-noise ratio.

Construction. Before assembling the laser, a power supply must be built. You can use a supply that fires the laser automatically shortly after the line voltage is applied to the supply, or you can use a supply with a momentary contact switch to turn the laser on. In either case, once the laser fires, it remains on until the line power is removed.

The high-voltage source for both power supplies is a 620-volt transformer as shown in Fig. 2. The automatic supply can be assembled on a printed circuit board using foil pattern shown in Fig. 3 and the circuit in Fig. 4A. Assemble components as shown in Fig. 5. The switched power supply can be built on a perf board as shown in Fig. 6 using circuit in Fig. 4B.

Once a power supply has been built, mount it in the metal enclosure (using short spacers) along one of the long walls. Mount the associated power transformer on one of the shorter walls. Mount power switch *S1*, pilot light assembly *I1*, and fuse (in fuseholder) *F1* (see Fig. 2) on the short wall opposite the transformer. Make a small hole to accommodate the line cord, and put a rubber grommet in the hole to protect the cord. If the switched supply is used, mount the pushbutton switch in any convenient location.

The glass laser tube is supported by a pair of conventional electrolytic capacitor clamps, which are mounted on two spacers about an inch long. Mount the two spacers about 4½" apart on the long center line of the top of the metal enclosure and straddling the short center line. Mount a two-lug terminal strip (none grounded) inside the chassis

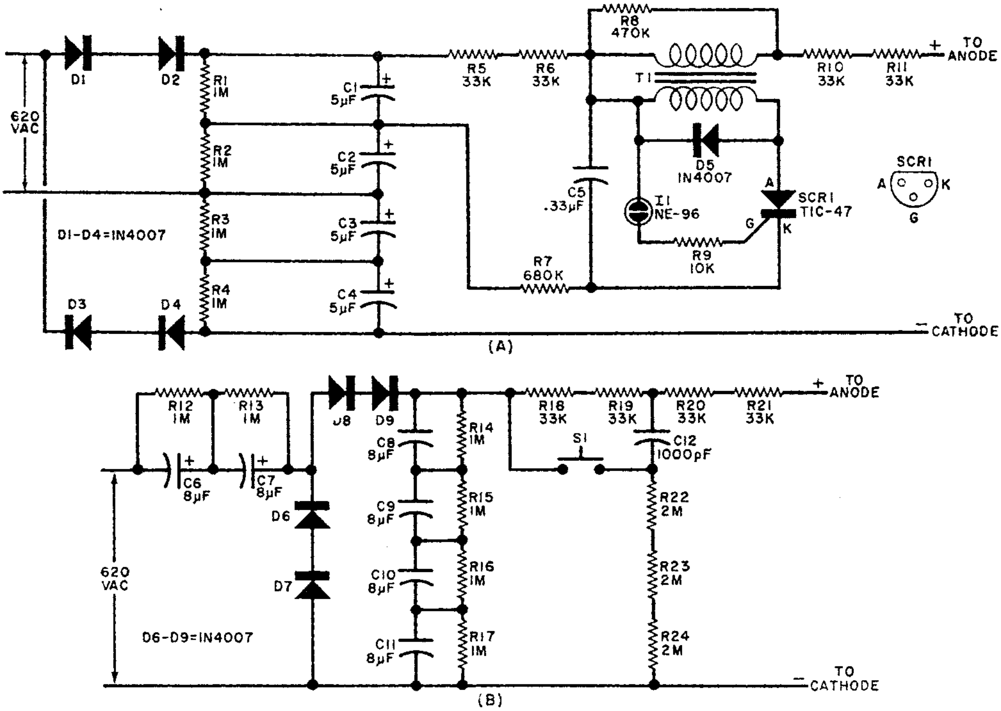


Fig. 4. You can use either of two power supplies—the automatic shown at (A) or the manual start shown at (B). As with all high-voltage power supplies, take great care once they have been turned on.

PARTS LIST (POWER SUPPLY)

C1-C4—5-µF, 450-volt electrolytic capacitor
C5—0.33-µF capacitor
C6-C11—8-µF, 450-volt electrolytic capacitor
C12—1000-pF, 1600-to-2000-volt capacitor
D1-D9—1N4007 diode
I1—NE-96 pilot light
R1-R4, R12-R17—1-megohm, ½-watt resistor
R5,R6,R10,R11,R18-R21—33,000-ohm, 2-watt resistor
R7—680,000-ohm, ½-watt resistor
R8—470,000-ohm, ½-watt resistor
R9—10,000-ohm, ½-watt resistor
R22-R24—2-megohm, ½-watt resistor
SCR1—C106B2 (GE) or TIC-47 (Texas Instruments) silicon controlled rectifier
S1—Normally open pushbutton switch, 2000-volt insulation (see photo page 32)
*T1—Ignition coil, 200:1 ratio**
Note—A complete power supply (automatic) including a PC board and all components is available from Metrologic Instrument Inc., 143 Harding Ave., Bellmawr, N.J. 08030, for $17.50 plus $1.00 postage.
**Conventional ignition coil, critically damped using a resistor across the secondary to produce a single spike. A flashtube trigger transformer (Amglo MT-55, Allied Cat. No. 60 F 0387) may be substituted.*

using the hardware for the laser mounting spacer that is closest to the controls.

Gently slide the laser tube into the clamps being careful to avoid the exhaust seal protruding from one side. Install the tube so that the cathode end (with the glass extension bulb) is toward the transformer end of the chassis.

Connections to the two leads on the laser must be made with clips, not solder. Bend the ends of both leads so that they point toward the top of the metal enclosure. Mark the enclosure at the two points where the leads are aiming. Remove the laser tube and drill holes at the two points. Make the holes large enough to accommodate an insulated power lead.

Once the equipment has been assembled, wire the circuit as shown in Fig. 2. Cover the negative high-voltage lead with insulation (plastic tubing will do) and feed it through the hole under the cathode of the laser tube (the end with the glass bulb extension). Allow this lead to protrude through the top of the metal chassis for about an inch. Make a

PARTS LIST (POWER SUPPLY)

C1-C4—5-μF, 450-volt electrolytic capacitor
C5—0.33-μF capacitor
C6-C11—8-μF, 450-volt electrolytic capacitor
C12—1000-pF, 1600-to-2000-volt capacitor
D1-D9—1N4007 diode
I1—NE-96 pilot light
R1-R4, R12-R17—1-megohm, ½-watt resistor
R5,R6,R10,R11,R18-R21—33,000-ohm, 2-watt resistor
R7—680,000-ohm, ½-watt resistor
R8—470,000-ohm, ½-watt resistor
R9—10,000-ohm, ½-watt resistor
R22-R24—2-megohm, ½-watt resistor
SCR1—C106B2 (GE) or TIC-47 (Texas Instruments) silicon controlled rectifier
S1—Normally open pushbutton switch, 2000-volt insulation (see photo page 32)
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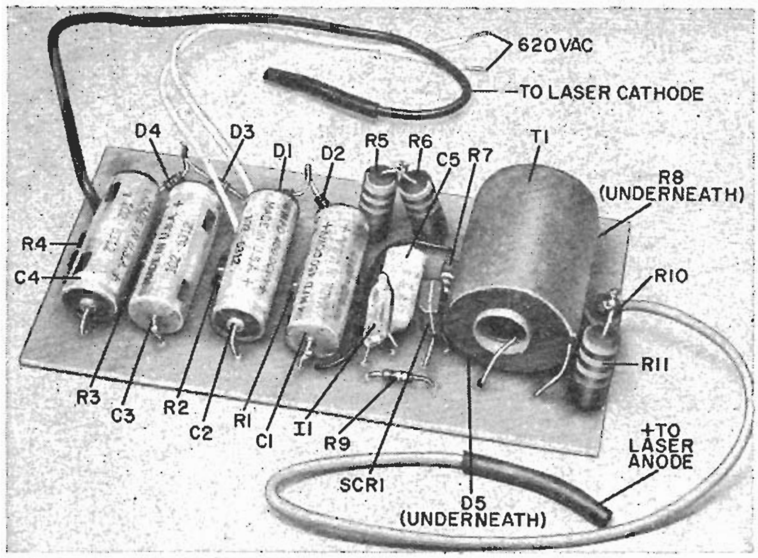


Fig. 5. Component installation on the automatic supply PC board. Transformer T1 is an ordinary ignition coil that has plastic case removed.

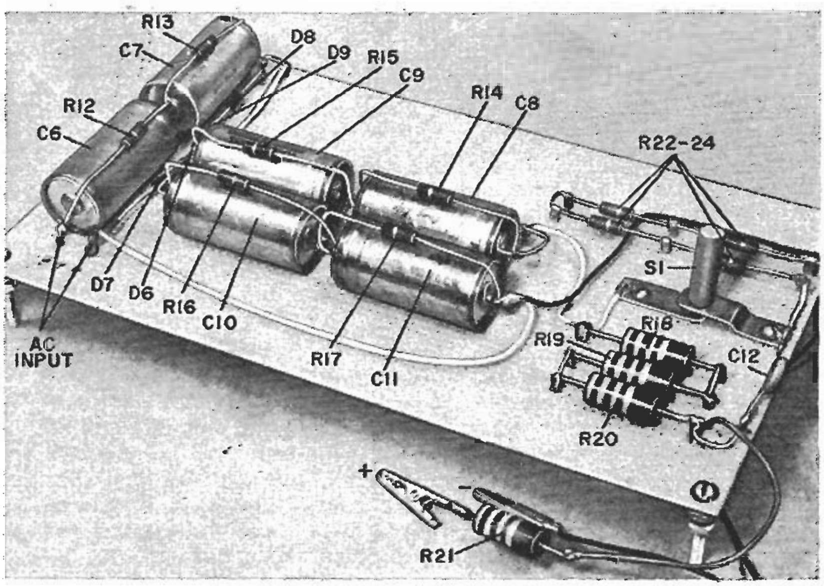
similar lead for the positive side of the supply and feed it through the hole to the laser anode.

Remove two pins from an old miniature tube socket and solder them to the leads from the power supply. Install the glass laser tube in the capacitor clamps making sure that the cathode end faces away from the controls. Orient the tube so that the cathode extension bulb is horizontal. Connect the power supply leads to the laser leads to make tight friction fits. Center the laser on the metal chassis.

Operation. Being careful not to aim the laser beam (coming out of the cathode end) at a shiny surface, turn on the line power. If you are using the automatic power supply, the laser will give a couple of short light bursts and then lase con-

(*Continued on page* 110)

Fig. 6. Switch S1 is made from two lengths of phosphor-bronze strip, one as fixed and the other as movable contact. Use a small piece of wood or plastic for pushbutton.



EXPERIMENTERS' LASER

(*Continued from page 32*)

tinuously. If you are using the switched power supply, depress the pushbutton and then release it to start the laser.

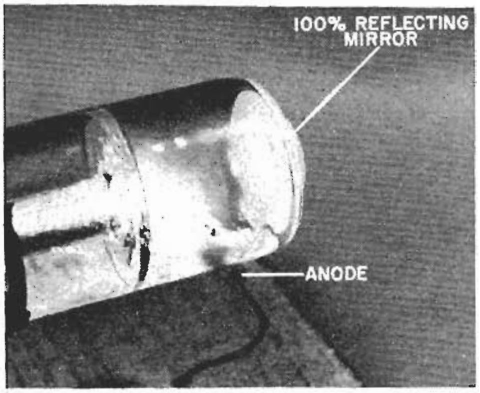
Troubleshooting. If all instructions have been followed carefully, the laser should start immediately. During operation, the glass tube will have the characteristic red glow of a neon lamp. If there is no glow, check the power supply operation by removing the laser tube and replacing it with a load made up of five 33,000-ohm, 2-watt resistors connected in series. Insert a 10-mA d.c. milliammeter in series with the substitute load. If the power supply is operating properly, there should be a load current of 5.5 mA. If not, check the power supply.

If the supply is OK, replace the laser tube, turn on the power, and turn the room lights out. See if there is a periodic red-orange glow discharge through the capillary tube. If the glow is there but the laser tube does not lase, short out either *R5* or *R18* in the supply. It is possible that the voltage is too low to operate the laser.

When the laser does light, it will not burn holes in anything; but remember, DO NOT shine it into anyone's eyes. Although this laser is well below the theoretical threshold of eye damage, the

LASER OPERATING PARAMETERS

Nominal power output: 0.5 milliwatts
Wavelength: 633 nanometers (6328 A)
Mode: random
Polarization: unpolarized
Beam divergence: 1.5 milliradians
Beam diameter: 1 nanometer
Operating current: 5.5 mA d.c.
Approximate operating voltage: 950 volts
Required trigger voltage: 2500 volts
Dimensions: 9.2" x 1" plus cathode bulb



At the anode end of the laser tube, the mirror is 100% reflective to keep light from escaping there.

HOW IT WORKS POWER SUPPLY

The 1600 volts required to drive the laser is developed in a conventional voltage doubling circuit. In the automatic firing circuit, as capacitor *C1* charges up, and before any current flows through *R5* and *R6* (the laser has not yet fired), capacitor *C5* begins to charge through *R7*. The voltage across neon lamp *I1* is the same as that across *C5*. When this voltage reaches the firing point of *I1* (approximately 130 volts), current flows through *R9* triggering *SCR1* on. Capacitor *C5 then* discharges through the primary of the 100:1 ignition transformer *T1*, generating a high voltage at the secondary. This fires the laser. Current flows through *R5*, *R6*, *R10*, and *R11* to keep the laser lit, simultaneously keeping the voltage across *C5* low enough so that *I1* does not fire. Therefore, as soon as the laser fires, the automatic circuit stops operating.

THE LOW-COST LASER TUBE

The outer glass tube (1" diam) contains a mixture of 85% helium and 15% neon. Although lasing takes place within a 2-millimeter precision-bore capillary tube inside the larger tube, the large tube provides a reservoir of gas to improve reliability. After several thousand hours of operation, some helium starts to diffuse through the tube walls and some neon is absorbed by cathode sputtering. Hence, the larger the volume of gas, the longer the tube life. Another function of the large tube is to provide rigid support for the carefully aligned and sealed mirrors.

There is an electrode at each end of the tube. The cathode, a cold cathode made from a nickel-plated iron shell, is coated on the inside with barium carbonate, a low-work-function electron emitter. With this type of cathode, the laser starts instantly. The anode is a simple stub of nickel wire.

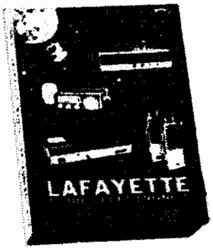
The two mirrors are not conventional. They are made from an uneven number of quarter-wavelength layers of dielectric. Alternate layers are made of a material having a high refractive index (zinc sulfide or titanium oxide); the other layers have a low refractive index (magnesium fluoride or sodium oxy-fluoride). The 100% reflecting mirror is 23 layers thick and the transmission mirror is 13 layers thick. Only in this way can reflectances of 99.9% be achieved for the one mirror. By contrast, the best aluminized mirrors have only about 90% reflectance.

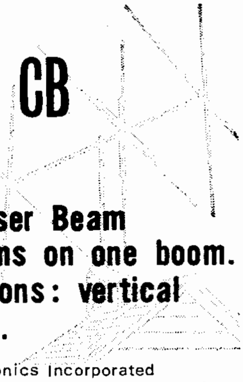
The voltage-current characteristic of the laser tube is not unlike that of a conventional neon voltage regulator tube. The capillary tube gives the laser a high voltage drop and a larger negative resistance. A trigger pulse, over 2500 volts, must be applied to fire the laser. The voltage across the tube then drops into the operating region. Because of the negative resistance in the operating range, a large-value ballast resistor must be used. In the equipment described here, this resistance is about 120,000 ohms. Thus, the power source must provide about 950 volts for the tube and 700 volts for the ballast resistance under operating conditions.

The glass tube itself is made of annealed, high-temperature borosilicate glass. Although it is rugged, it should be handled with care, especially around the metal-to-glass seals at the electrodes. The tube can be mounted in any position and even works underwater if the high-voltage leads are properly insulated.

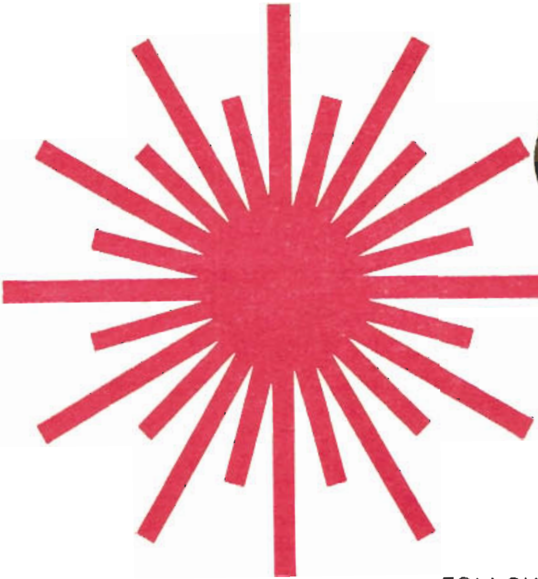
light is extremely bright and temporarily blinding.

When you look at the laser spot on a wall, note the specular quality (diffuseness) of the spot. This is a characteristic of coherent light. It is essential to the laser's use in holography, which will be described in an article in next month's POPULAR ELECTRONICS. Future issues will cover laser communications and unique instruments which use this low-cost laser. –30–





"Experimenters' Laser" (December 1969). Many readers see what appears to be a discrepancy between Figs. 1(B) and 6 where none actually exists. Four resistors are shown in Fig. 6 for *R22-R24*, while only three are shown in Fig. 1; and the location of the junction between resistors to which *C12* is to be connected is in question. The difference between the two figures is explained on page 110 under the heading "Troubleshooting." The figures are correct.



CAUTION LASER

FOLLOW THE RULES—
AND THERE'S NO PROBLEM

BY LEWIS B. LLOYD

PART OF ANY new scientific development (especially where electromagnetic radiation is involved—atomic, radio, or light) is the possibility that hazards to human safety may exist. The laser is no exception and, as the presence and use of lasers become more widespread, the importance of the possible hazards is receiving more and more attention.

The dangers involved with the laser are particularly important because they can be so easily overlooked. (Though to date there has been no major laser injury.) Many people fail to appreciate the fact that a simple beam of light can be dangerous. They seem to forget that the output of a weak laser directed at a small spot can be 100,000 times as intense as the same area on the surface of the sun.

Obviously, since the human skin and especially the eyes are very sensitive to light, the application of such an intense light to these photosensitive surfaces can cause permanent damage. Most important, where a laser is concerned, distance does not contribute to safety. At 10 miles, the beam from a 6-inch parabolic-reflector searchlight spreads out to approximately 1760 feet; however, at the same distance, an ordinary laser beam diverges less than four feet—and thus retains its extremely high intensity.

Another hazard connected with the laser is that specular reflections off a smooth surface can also be dangerous. Obviously, then, mirrors, bench tops, shiny tools, rings, wristwatches, etc. can be likened to "secondary lasers" and must be treated with the same caution as the actual laser.

Helium-Neon Laser. The helium-neon laser described in the article in this issue of POPULAR ELECTRONICS is widely used in alignment and fine measurements in a number of industrial and research activities. With a maximum light output of 0.5 milliwatts, it is considered to be little more dangerous than a white point-source light of comparable intensity. However, since laser effects have been virtually unexplored and because adequate data on chronic exposure do not exist, some general safety rules should be followed in working with this or any other laser. These rules should be followed even though the POPULAR ELECTRONICS laser output is considered to be far below the level of possible danger to the eyes.

Laser Safety Rules. Follow these rules at all times:

1. NEVER look directly into a laser

THE THIN RED LINE

The light output of a helium-neon laser is many thousands of times brighter than that of a high-pressure mercury arc lamp. That is why you should never stare directly into the beam.

A laser beam is visible for a considerable distance, even in daylight. At night, depending on the clarity of the atmosphere, the beam is visible (on axis) for many miles. The small laser described in this issue has been tested to slightly less than one mile.

In a typical gas laser, the beam is only a couple of millimeters in diameter when it leaves the laser and diverges (enlarges) at a rate of approximately one part in 2000. Typically, a laser beam would produce a circle about 1 foot in diameter at 2000 feet. Lenses can be used to reduce the circle size and to increase the range.

The laser beam can be reflected around corners using front-surface mirrors. It will also pass through fiber optics. In both of these applications, the laser beam retains its coherency.

beam (on axis) either with the naked eye or through binoculars or a telescope at a distance. Remember that a laser beam usually cannot be seen unless there are airborne particles (smoke, dust, etc.) to provide scattered reflecting surfaces. With some lasers, the beam cannot be seen even under these conditions.

2. DO NOT rely on tinted glass, sunglasses, or other eye-protective devices unless the filtering medium has been specifically designed to attenuate the wave-length of the laser in question. There is no one type of filter glass that protects at all laser frequencies.

3. NEVER leave an activated laser unattended. An unsuspecting person may accidentally look into the beam. A warning sign or audible signal should be used to indicate when a laser is operating.

4. For general experimenting, room lighting should be high (about 200 foot candles) to keep the eye pupil small and reduce the possibility of retinal damage due to inadvertent exposure.

5. Unless the experiment is fully protected, NEVER shine a laser beam on a specular surface since reflections may approach direct beam intensities. Such reflections are difficult to predict and can make off-axis viewing as potentially dangerous as direct on-axis viewing. Special care must be taken with watch crystals, metallic watch bands, rings, tools, glassware, door knobs, screw heads, etc. The floor, bench tops, cabinets, should be covered with a dark, light-diffusing material.

6. BEWARE of electrical hazards. All of the possible danger in a laser is not confined to the light beam. The laser power supply can also cause physical damage if high-voltage terminals are contacted. Remember that high-quality filter capacitors retain a charge after the system has been shut down. Capacitors should be discharged before attempting any adjustments to the laser tube or associated electronics. A protective cover should be placed over the laser tube (except for the end where the beam is emitted) to prevent accidental contact with the high-voltage leads. Adequate grounding should be provided for all metal chassis and other hardware.

7. DO NOT operate a laser in rain, snow, fog, or heavy dust. Here again, potentially dangerous secondary specular radiation can result.

8. DO NOT inadvertently or intentionally track vehicular or airborne traffic with a laser beam.

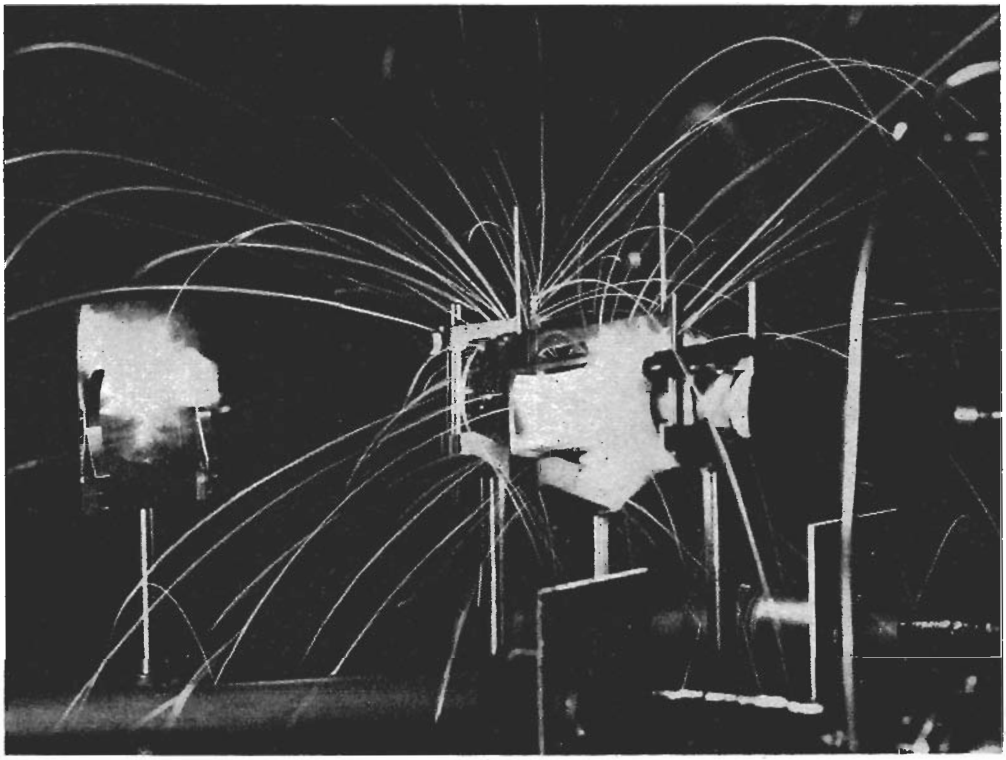
9. Set up a safe laser operating procedure. Make up a check list and follow it precisely each time the laser is used.

10. If a flash-tube pulsed laser is used, the flash tube should be shielded. If it isn't, avoid looking directly at the flash tube when it fires. Intense white light, ultraviolet, and infrared radiation occur at the instant of firing. Overexposure to ultraviolet can cause blindness.

Until a great deal more is known about the biological effects of a laser beam—even those of "safe" lasers—treat all laser beams with the greatest of respect. —30—

THE SMALL RED DOT

When a laser beam is aimed at a light-colored surface, there will not be a clearly defined spot. The spot seems to take on a "graininess" and to "dance" in place. This is caused by a complex afocal interference pattern that exists between the observer and the diffuse surface. The eye of the person looking at this spot tends to relax and he focuses behind the spot if he has normal eyesight (emmetropic) or is far-sighted (hyperopic). If he is near-sighted (myopic), the focus occurs in front of the surface. Because of parallax, if the observer moves his head from side to side, the granular pattern appears to move with him if he has normal eyesight or is far-sighted and opposite to the head motion if he is near-sighted. (All of this is obviously without the viewer's using corrective lenses.)



THE LIVELY LASER

IT KEEPS BUSY FINDING PROBLEMS TO SOLVE

BY JOHN P. ROBINSON, JR.

THE NUMBER of uses that can be found for a highly directional, extremely intense, coherent beam of light is staggering. The most recent—and most highly publicized—was in conjunction with the lunar landing of the Apollo 11 crew. Carefully placed on the lunar surface was a laser retro-reflector which will enable astonomers to determine not only how far the moon is from the earth, but to check the "wobble" of the lunar body in its orbit.

Only a laser with its enormous light concentration could have made this experiment possible. A beam of laser light can be focused to spread about one-third of an inch for each mile. The moon is about 238,350 miles away and the laser beam, on striking the surface of the moon, illuminates an area about one mile in diameter. By comparison, the beam from the best available radar transmitter would have enlarged to 200 miles in diameter and—if it could have been constructed—a beam from a powerful searchlight would have spread over 12,000 miles in diameter at that range.

Metalworking Tools. Possibly one of the greatest and most unique applications for laser beams will be in the cutting and welding of extraordinarily hard metals. Holes that are as small as 1/15,000 of an inch or as large as one-half inch can be drilled with ease. Holes can easily be drilled through diamonds, the hardest material known to man. In only a couple of minutes, minute holes can be drilled through diamonds so that the diamond itself may be used as a wire-drawing die to fashion extremely fine wire.

Another trick in the laser bag is in the

This detection system uses a gallium-arsenide pulsed laser and an image converter viewing tube to find targets up to 300 feet away in complete darkness. Developed by Laser Diode Laboratories.

balancing of a gyro motor while the rotor is spinning at speeds up to 30,000 r/min. The pre-1960 method involves stopping the rotor, drilling a small indentation to correct the balance and then firing up the rotor to full speed. Because this process might be repeated several times, it took literally hours to finally balance this delicate mechanism. With a laser beam, balancing can be accomplished in minutes. Auxiliary electronic equipment is used to locate the positions of the "unbalancing" metal while the gyro is spinning at top speed. Then a pulse laser is fired at the spot to vaporize some of the metal until a perfect rotor balance is achieved.

The construction industry is finding many uses for the narrow, directional beam of the laser. Bridges, tunnels, and any other construction project involving a long critically aligned surface (including the wings of large aircraft) may be unfailingly positioned with the aid of a laser. San Francisco engineers are using helium-neon lasers to ensure the alignment of the walls of a long aqueduct. At Stanford University, lasers were used to align the two-mile long linear accelerator tunnel which is used for 20-billion electron volt experiments.

Miracles in Medicine. One of the most publicized uses of lasers is in the medical field where they have been successfully employed in delicate eye surgery. Previously, a detached retina required complex surgery and a long recuperative period. Now one pulse from a laser and the retina is "spot welded" back in place. A few patients have even driven themselves home in their own cars immediately after the operation.

Melanomas, cancers of the skin, have been destroyed with the use of a pulse laser. The mechanism of how this is accomplished is not yet fully understood. A large number of competent medical workers are exploring this field with the latest laser equipment. Great emphasis is being placed on the non-thermal effects of laser beams while simultaneously attempting to develop a relationship to the post-radiation regression of tumors.

Even the dentist's drill may be replaced by a laser beam. One manufacturer doing research on the laser drilling

TYPES OF LASERS

Helium-Neon. Helium-neon lasers are typically of low power, but they are especially useful where stable single-frequency operation is important. Such systems usually operate at wavelengths of 6328 angstroms, 1.15 microns (11,500 A) or 3.39 microns (33,900 A) depending on resonator design.

A major application is in optical alignment tools. These types are being used increasingly in construction work—bridge building, etc. Most small He-Ne lasers have a beam diameter of 1 to 3 millimeters, which is expanded to about one inch. A fan-shaped beam has been designed so that a reference plane is produced rather than a line.

Carbon Dioxide. The limiting efficiency of approximately 25 per cent is the highest known for any gas laser system; also, the highest unclassified continuous-wave output power is in excess of 8 kW. The system operates at a wavelength of 10.6 microns in either the continuous-wave, pulsed, or Q-switched modes. With the introduction of O_2, He, H_2, argon, and H_2O to a high-power CO_2-N_2 system, the power is further increased by depopulating the lower laser level. The CO_2 laser is attractive for terrestrial and extraterrestrial communications because of the low absorption window in the atmosphere between 8 and 14 microns. This system can also be used for metal cutting and welding. The CO_2 is extremely versatile because one can easily produce a high degree of coherency, high continuous-wave power, or high peak powers through the use of Q-switching techniques. Of major significance from the hazard standpoint is the fact that CO_2 radiation at 10.6 microns can be present in enormous power, yet is invisible to the human eye.

Argon. This ionized gas laser system operates at wavelengths of 4880 A, 5145 A, or 4579 A in either continuous-wave or pulsed mode. Power generation is greatest when operating at 4880 A and 5145 A. Highest CW powers achieved have been on the order of 100 watts for one minute.

Solid-State Crystalline. The solid-state laser continues to find wide application. Of the ions with which laser action has been produced, perhaps Nd^{3+} in garnet or glass and Cr^{3+} in aluminum oxide have the greatest general interest. A most attractive host for the neodymium ion is garnet (yttrium aluminum garnet, YAG, or yttrium iron garnet, YIG) because the 1.06-micron laser transition line is sharper than in other known host crystals. Frequency doubling to 5300 A using lithium niobate crystals produces powers approaching the power available in the fundamental at 1.06 microns. In addition to frequency doubling, an interesting development which raises some questions about potential hazards is the production of picosecond (10^{-12} sec) pulses such as those obtained through modulation of the internal losses in the YAG-Nd system at the correct mode-locking frequency. Also, through the use of electro-optic materials such as KDP, barium strontium niobate or lithium tantalate, "tuning" or scanning for laser frequencies over wide ranges may be accomplished.

For example, a lithium niobate oscillator pumped at 5300 A by a Q-switched, frequency-doubled YAG-Nd laser, can operate over a range of 0.59 to 5.0 microns. These developments, particularly those involving the generation of multiple laser wavelengths or rapid scanning through wide ranges, require special consideration of the design of eye-protection devices. It should be noted that the Nd^{3+}-glass systems have produced the greatest laser powers known to date—well in excess of 100 joules per pulse or greater than 10^{10} Q switched. The ruby laser operating at a wavelength of 6943 A is especially well suited for high-power single-pulse operation where energies in excess of 10 joules per pulse may be realized.

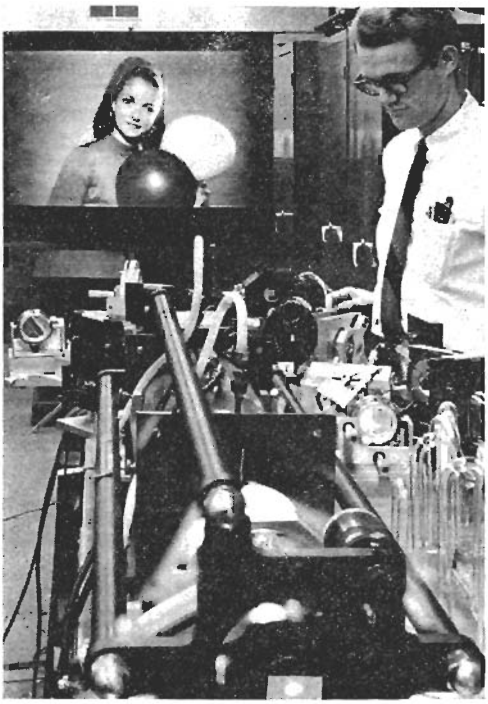
Semiconductors. The best-known example of an injection laser is the gallium-arsenide type whose operation depends on a *pn* junction. This device operates at a wavelength of 8400A but it should be noted that the wavelength range of all available types of semiconductor lasers is approximately 4560 A to 51,000 A. Generally speaking, the semiconductor is moderately low power in continuous-wave operation (milliwatts to several watts) and has a typically broad beam divergency (about 15 to 20°), unlike gas lasers which do not usually exceed a few milliradians. Certain semiconductor lasers are pumped by multi-kilovolt electron beams (for example, CdS at 4900 A) which may introduce the additional question of ionizing radiation hazard.

of teeth reports that the reflected laser light changes color as the decay is removed.

Similar to the dentist's laser drill is a micro-surgical knife which will not only cut delicate tissues with ultra precision, but also cauterize as it cuts. Micro-surgical treatment of glaucoma using a laser to remove a portion of the iris of the eye is showing great promise. In cosmetic medicine, doctors at a Cincinnati hospital have successfully removed a tattoo from a patient's arm. Because the laser beam penetrates translucent skin without harm, it can reach below the skin's surface where it will vaporize the darker pigment of the tattoo.

In one unusual application, an English tailoring firm has started to cut cloth with a carbon-dioxide laser. It is claimed that the use of the laser ensures a clean, heat-sealed cut with no fraying. A variation of this technique has also been used by electronic component manufacturers to "trim" the values of glass-encapsulated carbon-film resistors.

Fantastic Holography. An extremely interesting use of lasers is in the area of holography—which will be discussed on these pages in detail in the January 1970 issue. A hologram is an optical image resulting from the shining of a coherent light source (like a laser) through a special photographic negative. Unlike the flat, two-dimensional image one sees from a conventional piece of photographic film, the hologram is in true three dimensions. No special glasses or viewing screens are required. In fact, the viewed image seems to be suspended in air. What makes it so special is that you can look around the image and see its sides, just as you could if the original were actually suspended in front of the observer. It is undoubtedly possible that completely new filming techniques will result from holography.



Using three lasers (one for each basic color) and mechanical scanning methods, the projection system shown here provides a bright, 58" wide by 31" high TV display. Video comes from a conventional color TV receiver. The system is being developed by General Telephone and Electronics Laboratories.

Research is also taking place to use three different laser beams (one red, one blue and one green) to produce a very large, bright television viewing screen. Such screens would be useful for public TV viewing in theatres. A system of this type will be shown at the Osaka, Japan World's Fair.

Lasers will also revolutionize the entire communications industry. It is quite conceivable that, within the next decade, lasers will have supplemented or largely replaced many of the microwave communications links scattered throughout the world. The use of laser beams in such a fashion will enable each microwave link to carry literally thousands more signals. In fact, it is technically impossible, but theoretically predictable that a laser could be modulated with all of the radio frequency spectrum and still have plenty of room left over.

Laser beams will also be used for deep-space communications. Just like the enormous dishes used for radio frequency satellite communications, a laser beam can be directed so sharply that its ultimate accuracy is limited only by the optics and precision of the telescope used in aiming it. Thus, a laser used in conjunction with some of the larger astronomical telescopes would ensure—at least one way—communications to the edge of the solar system.

What Of The Immediate Future? Lasers are getting smaller and generating higher power. Sylvania Electronics recently demonstrated a very small laser with an internal heat exchanger to cool the gases in the lasing area. This cooling technique can help produce enough beam power to cut hard metals and refractory materials. This development may foreshadow the introduction of low-cost tools for the metalworking industry. It also indicates that we may soon see small but extremely powerful communication links between urban areas and greatly simplified intercontinental TV and telephone relay networks. —30—

BUILD A

SEMICONDUCTOR LASER COMMUNICATIONS SYSTEM

State-of-the art communicator uses pulse modulation to achieve a possible range greater than 3000 feet.

BY FORREST M. MIMS

COMMUNICATING on a light beam is fairly common with light-emitting diodes ("Experimenting With Light-Beam Communications," POPULAR ELECTRONICS, April 1975, p. 40), but for longer distances and greater efficiency, a laser light source is recommended. With the system described here, it is possible to get a range of more than one kilometer (3300 ft). Since it uses a PIN photodiode in the receiver, the system can be operated in daylight or darkness without an expensive infrared filter.

Though most light-beam communicators use amplitude or intensity modulation, this system employs pulse-frequency or pulse-rate modulation (PFM or PRM). This type of modulation is almost immune to transient atmospheric effects and noise from interfering light sources. Also, the output signal from the PFM receiver is constant in amplitude over the entire communicating range, while that from an AM system becomes progressively weaker as range is increased.

Transmitter. As shown in Fig. 1, a modular amplifier (*AMP1*) boosts the voice signals from a dynamic microphone. In a pulse-frequency modulator (*Q1* and *Q2*), *Q2* is a UJT connected in a relaxation-oscillator mode. With no input from *AMP1, Q1* is saturated (with very low emitter-to-collector resistance) and *Q2* oscillates at a frequency determined by the time constant of *C2* and *R6*. When an input is present on the base of *Q1*, the frequency of *Q2* is varied in direct proportion to the amplitude of the modula-

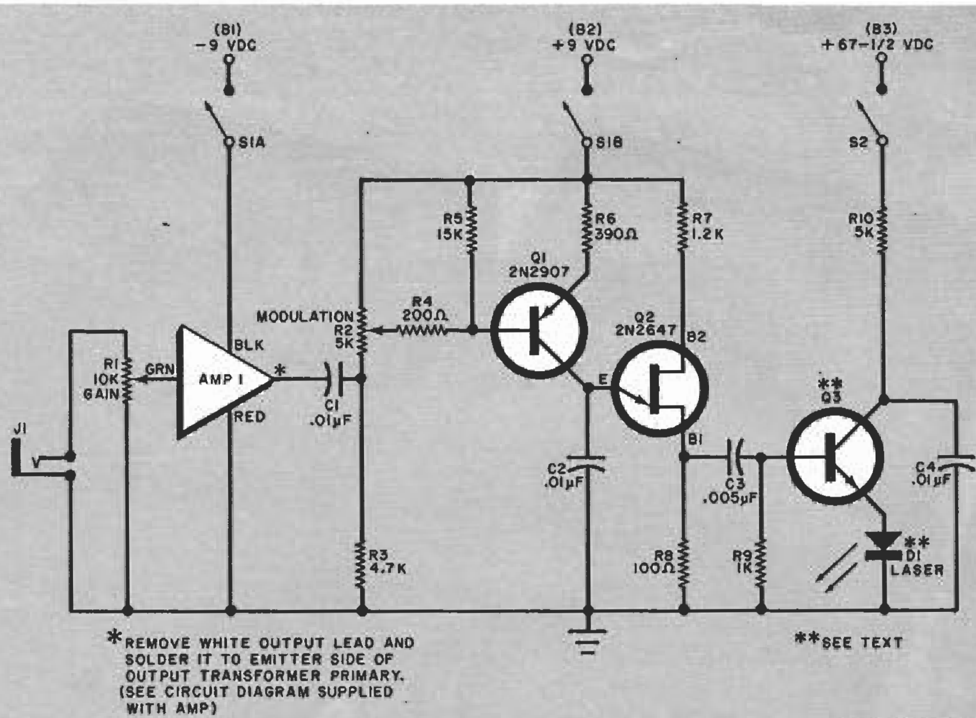


Fig. 1. A commercial modular audio amplifier modulates a UJT oscillator to drive the laser.

PARTS LIST (TRANSMITTER)

AMP1—Modular audio amplifier (Radio Shack 277-1240 or similar)
B1,B2—9-V transistor radio battery
B3—67½-V battery (Everready 457 or similar)
C1,C2—0.01-μF capacitor
C3—0.005-μF capacitor
C4—0.01-μF, 100-V capacitor (disc or paper only)
D1—Laser diode (see table at right)
J1—Microphone jack
Q1—2N2907 transistor
Q2—2N2647 UJT
Q3—Selected npn switching transistor (see text)
R1—10,000-ohm potentiometer
R2—5000-ohm potentiometer
R3—4700-ohm, ¼-W resistor
R4—200-ohm, ¼-W resistor
R5—15,000-ohm, ¼-W resistor
R6—390-ohm, ¼-W resistor
R7—1200-ohm, ¼-W resistor
R8—100-ohm, ¼-W resistor
R9—1000-ohm, ¼-W resistor
R10—5000-ohm, ½-W resistor
S1—Dpdt toggle switch
S2—Spdt toggle switch
Misc.—LMB B-H 643 enclosure, lens, battery retainers and clips, brass tubing, telescope, mounting hardware, 200-ohm dynamic microphone, epoxy, pc board, solder, etc.

SUITABLE LASERS

	RCA SG2001	RCA SG2002	RCA C30025	LDL LD22
Power output (W)*	1	2	0.5	6
Threshold current (A)	4	4	1.5	8
Peak current (A)	10	10	5	25

*Typical power output at peak forward current.
Note: The prototype laser has been successfully operated with all three of the RCA lasers listed above.

Addresses: The manufacturers will provide current prices and specifications upon request. Write to: RCA, Electronic Components, Box 1140, New Holland Pike, Lancaster, PA 17604; Laser Diode Laboratories (LDL), 205 Forrest St., Metuchen, NJ 08840.

tion frequency. The center frequency is determined by the setting of *R2*.

The resulting PFM signal across *R8* triggers a laser drive circuit comprised of relaxation oscillator *C4, Q3, R10,* and *D1*. Transistor *Q3* is an npn switching transistor operated in a nonconventional avalanche mode. A charge is placed on *C4* through *R10* until the breakdown voltage of *Q3* is reached. The capacitor then discharges through *Q3* and the laser. The pulse is very fast (50 ns) and high in current (5 to 10 A) to fire the laser. The cycle then repeats. The large current surge does not mean that the battery has to supply 5 or 10 amperes. The surge comes from the charge stored on the capacitor.

Transistor *Q3* oscillates independently of the modulator even when

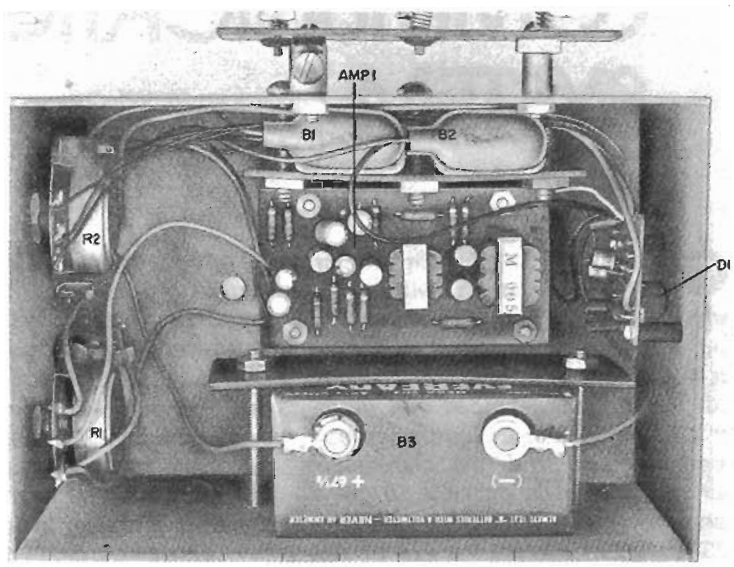
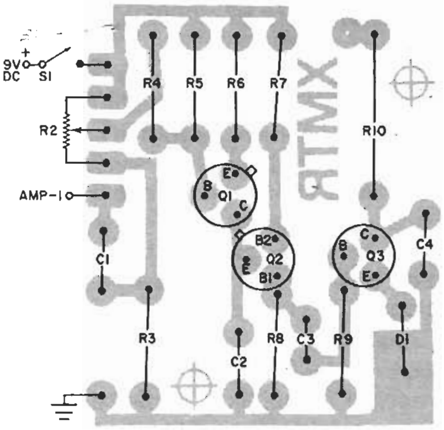


Photo shows layout of prototype transmitter. Mounting for boresighting telescope is at top.



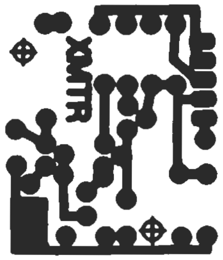


Fig. 2. Actual-size etching and drilling guide for transmitter is above, component layout at left.

the latter is in the relaxation mode. However, with an input, the oscillation varies with the signal. Potentiometer *R2* adjusts the carrier frequency to achieve the best modulation. A carrier of about 20 kHz gives the best results for the circuit used here. This is much higher than the 6 or 8 kHz required for acceptable voice transmission and insures good quality for both voice and music.

The transmitter is assembled on a printed circuit board as shown in Fig. 2. All components can be installed after the board is prepared, with the exception of *Q3* and the laser diode. Transistor *Q3* must be selected by using a test jig such as that shown in Fig. 3, which measures breakdown voltage. Ideally, a 15-MHz oscilloscope should be used to measure the current delivered by the transistor under test. This is done by measuring the pulse voltage across *R3* in the test circuit. Since this is a 1-ohm resistor, the voltage measured is equal to the current.

If a 15-MHz scope is not available, a lower-bandwidth scope, connected across *C1*, can be used to measure the transistor's breakdown voltage. The graph in Fig. 4 can be used to determine the peak current delivered by the transistor.

Not all transistors will oscillate in the test circuit. For best results, try common npn switching transistors such as 2N914, 2N2222, 2N3643, 2N4400, 2N5188, HEP50, etc. Select a transistor that gives a peak current between the laser's threshold and peak-allowable currents (as specified by the manufacturer). High currents give high output power. Install the transistor on the pc board and note its current for future reference.

Several lasers can be used, as listed in the table. Do not install the laser yet. Instead, connect an infrared LED (SSL-55C, TIL31, TIL27, etc.) in the circuit for preliminary testing. This permits you to get the circuit operating properly without the possibility of damaging the laser diode.

Receiver. In the receiver (Fig. 5), infrared radiation from the laser strikes PIN photodiode *D1* and generates a current which is amplified by *IC1*. Capacitive coupling between amplifier stages blocks dc signals from ambient sunlight and other light sources.

The output of *IC1* can be fed directly to an earphone for AM operation. For PFM, however, a threshold discriminator is necessary. The monostable multivibrator composed of *Q1* and *Q2* forms the threshold circuit. When an amplified pulse from *IC1* exceeds the trigger threshold of the multivibrator (a few tenths of a volt), *Q2* delivers a pulse of constant width and amplitude. This can be picked up at the collector of *Q2*, but best results are obtained by adding an amplifier (*AMP1*) for loudspeaker operation.

The pc board for the receiver is shown in Fig. 6. Use care when installing the IC to avoid bridging the copper portions.

Receiver sensitivity can be improved somewhat by the addition of potentiometer *R7*, which can be adjusted to reduce the threshold of the multivibrator and permit detection of weak signals. (There is no provision for *R7* on the pc board. It can be added by removing a short section of foil from the negative line to *Q1* and *Q2* and soldering the potentiometer's leads across the gap.)

The photodiode used in the prototype was a high-quality EG & G device costing about $15. This diode has a highly linear response and can be operated in broad daylight. Less expensive detectors (even ordinary silicon solar cells) can also be used; but light baffles, shields, or an infrared filter will be necessary for daylight operation.

Assembly. Check the pc boards for errors and then mount them in suitable enclosures. The enclosures noted in the parts lists were used in the prototype because the hinged lids permit rapid access to the batteries and pc boards.

Assemble the receiver first. Use a chassis punch or nibbling tool to cut a hole in one end of the cabinet for the lens. A 2" plastic lens was used in the prototype, but most any simple lens can be used as long as its focal length is 4¼" or less. The larger the lens, the better its light gathering power.

Use L brackets to mount the pc board in the enclosure with the photodiode at the exact center of the lens opening. For the lens given in the parts list, the diode should be exactly 4¼" from the inside cabinet wall in which the lens hole is cut.

Mount the threshold adjust pot (*R7*, if used), gain control (*R15*), and power switch (*S1*) on the end of the case opposite the lens opening. Use appropriate mounting hardware for the

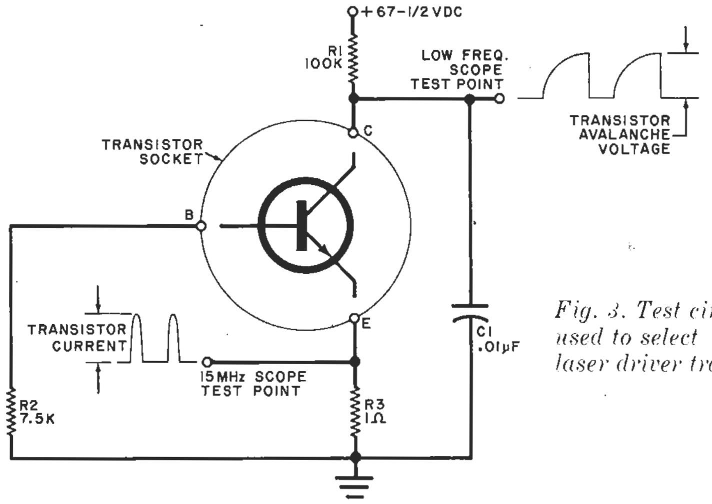


Fig. 3. Test circuit used to select laser driver transistor.

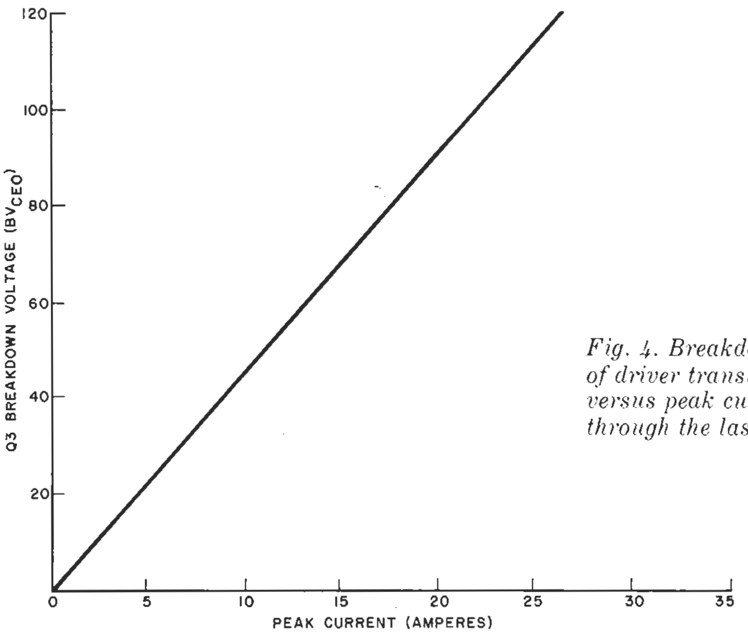


Fig. 4. Breakdown voltage of driver transistor versus peak current through the laser diode.

speaker, *AMP1*, and the two 9-volt batteries. Scraps of pc board 1" x 3" make good battery retainers. Use rubber grommets as standoffs for *AMP1*. Complete receiver assembly by wiring the various components to one another. Then mount the lens using a flexible adhesive such as Dow Corning Silastic®. The plastic lens mentioned in the parts list can be mounted by bending its shoulders with a hot soldering iron.

There are two steps to the transmitter assembly. First, prepare appropriate mounting holes for the controls, hardware, and lens tube assembly. A 9/16" hole should be adequate for the lens tube. Then install all components and batteries except the laser pc board. Make the necessary connections to the board but don't mount it.

Install an infrared LED (note proper polarity) instead of the laser. Test the receiver by pointing it toward a line-powered incandescent lamp. If the receiver is properly aligned with respect to the lamp, a 120-Hz buzz should be heard from the speaker.

Now point the transmitter LED toward the receiver lens and turn on the power. Talk into the microphone or place it near a radio while adjusting *R2*. It should be possible to get good-quality audio from the receiver. If not, make sure the transmitter LED is properly aligned with respect to the receiver. Then try adjusting *R7* in the

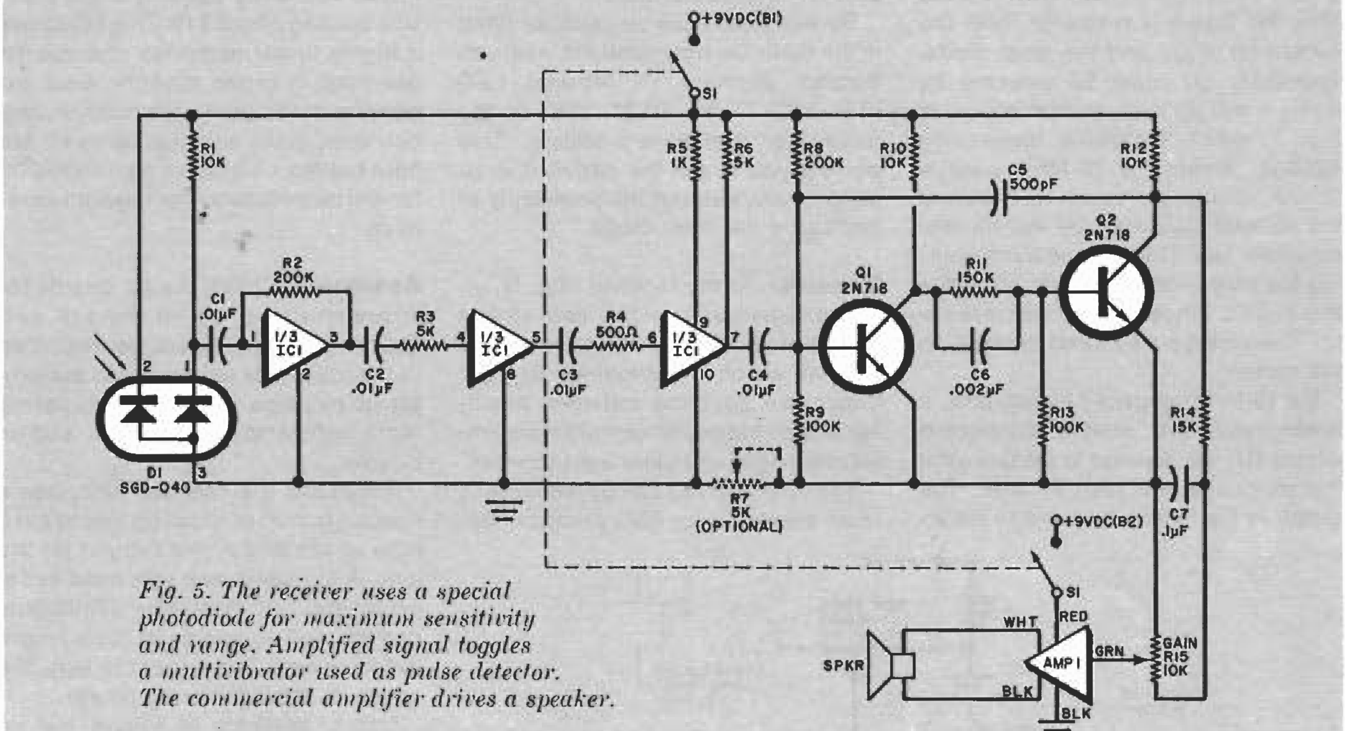


Fig. 5. The receiver uses a special photodiode for maximum sensitivity and range. Amplified signal toggles a multivibrator used as pulse detector. The commercial amplifier drives a speaker.

PARTS LIST (RECEIVER)

AMP1—Modular audio amplifier (Radio Shack 277-1240 or similar)
B1,B2—9-V transistor radio battery
C1 to C4—0.01-μF capacitor
C5—500-pF capacitor
C6—0.002-μF capacitor
C7—0.1-μF capacitor
D1—SGD-040B PIN photodiode (EG&G; available from Cramer Electronics, 85 Wells Ave., Newton, MA 02159, for $15 plus postage; see text)
IC1—CA3035 amplifier array (RCA)
Q1,Q2—2N718 npn switching transistor (or equivalent)
R1,R10,R12—10,000-ohm, ¼-W resistor
R2,R8—200,000-ohm, ¼-W resistor
R5—1000-ohm, ¼-W resistor
R3,R6—5000-ohm, ¼-W resistor
R4—500-ohm, ¼-W resistor
R7—5000-ohm potentiometer (optional, see text)
R9,R13—100,000-ohm, ¼-W resistor
R11-150,000-ohm, ¼-W resistor
R14—15,000-ohm, ¼-W resistor
R15—10,000-ohm potentiometer
S1—Dpst toggle switch
Spkr—8-ohm miniature speaker
Misc.—LMB B-H 643 enclosure, lens, battery retainers and clips, mounting hardware, cement, solder, pc board, etc.

receiver. If no signal is heard, check the transmitter wiring. Also, the LED may be bad, *Q3* may not be oscillating, or one or more of the batteries may be weak.

If the receiver oscillates, it may be necessary to reduce the gain of the amplifier by increasing R3 or R4 somewhat. Adding R7 may also help eliminate receiver oscillation.

Proper operation of the system is obvious since a slight misalignment of the transmitter with respect to the receiver will cause loud noise and oscillation from the receiver and then silence. This illustrates the PFM mode of operation. Unlike simple AM systems, a PFM light-beam communicator gives constant receiver amplitude at all ranges out to the threshold cut-off point.

Final Transmitter Assembly. When the system is operating properly, remove the LED from the transmitter and install the laser. Mount the laser with its glass window on the back side of the pc board and secure it in place with a #8-32 nut. The plane of the laser junction should be parallel with the narrow side of the pc board. (See Fig. 7.) Next, carefully bend the laser's flying lead so that it goes into its mounting hole. Make sure the lead doesn't short against the laser mounting stud.

CAUTION: Do not connect a VOM to the laser diode. The small amount of current delivered by the meter will destroy the laser chip.

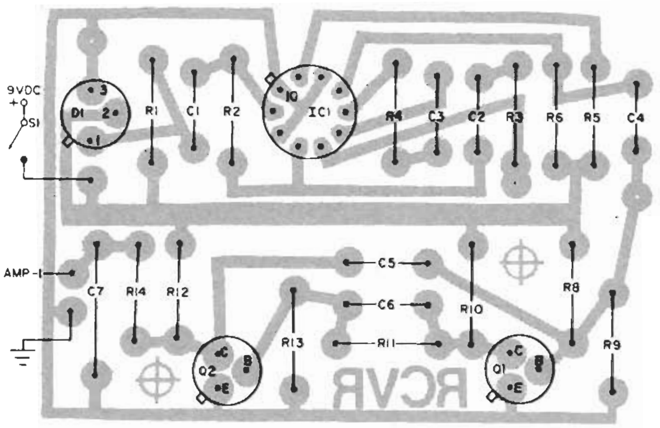
With the laser in place, test the system again. If it works properly, a ½" length of brass tubing (available from hobby shops) is carefully soldered to the back of the pc board with the laser chip at the exact center. Cut a slot from the tube as shown in Fig. 7 to prevent possible shorts. If the tube is not soldered properly the first time, try again until it is centered and level. This tube becomes the laser lens receptacle.

Next use two 7/16" standoffs to mount the laser pc board in the cabinet. A telescoping lens tube made as shown in Fig. 7 is inserted in the tube receptacle. Use a simple lens with a diameter of 12 to 15 mm and a similar focal length. Use epoxy to secure the lens in place.

Optical Alignment. Both transmitter and receiver must be aligned with infrared light for best results. This is no problem with the receiver if the lens called for in the parts list is used since its infrared focal length is 4¼". For other lenses, add perhaps a quarter of an inch to the visible focal length.

Alignment of the transmitter is more difficult due to the small size of the laser source. An approximate alignment can be made by placing the lens a millimeter or so farther from the laser chip than the visible focal length of the lens. An approximate alignment will give a broad beam suitable for communications up to about 1000 feet. For long ranges, the beam must be made nearly parallel by adjusting the lens for as small a beam spread as possible. This is easily done if an infrared image converter is available.

Surplus sniperscopes are ideal for



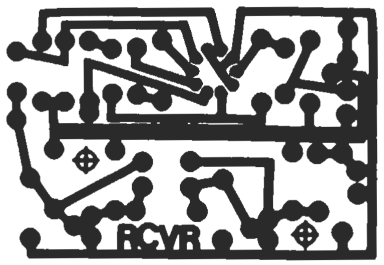


Fig. 6. Actual-size etching and drilling guide for receiver at right. Component layout is at left.

SAFETY CONSIDERATIONS

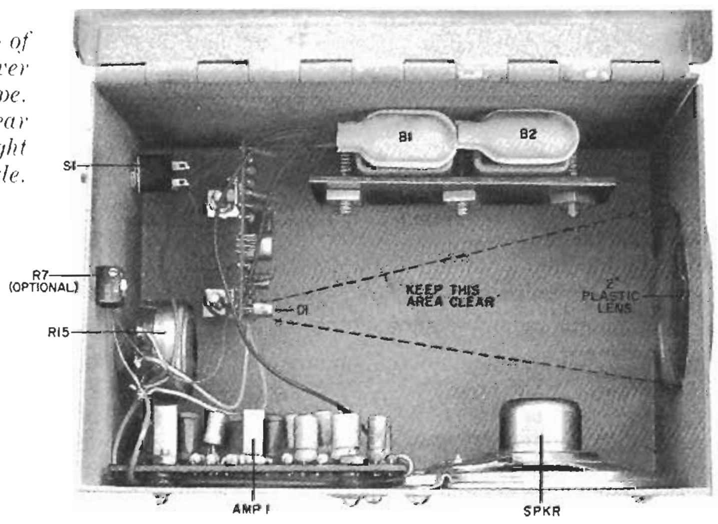
The GaAs laser used in this system has a peak optical power output of a few watts if operated at maximum current. That is a lot of light compared to the output of low-power helium-neon lasers; but the optical pulses are brief so that the average power is far less than that of most helium-neon devices.

According to the U.S. Air Force School of Aerospace Medicine, GaAs lasers emitting 10 watts per pulse are not capable of producing detectable eye damage. Three principal factors contribute to this safety margin: the absorption of the infrared in the eye's vitreous humor, imperfect focusing of the infrared, and the laser's low average power.

Nevertheless, a few basic precautions must be followed to insure utmost safety:

1. As with any source of bright light, do not look directly into the laser beam.
2. Avoid pointing the laser at shiny surfaces (mirrors, unpainted metal, etc.) because reflected light can be as potentially dangerous as direct light.
3. Do not point the laser in a direction in which bystanders might look into the beam.
4. Turn off the laser transmitter when it is not in use, to preserve its life and that of the battery.

Photo of receiver prototype. Leave a clear path for light to hit diode.



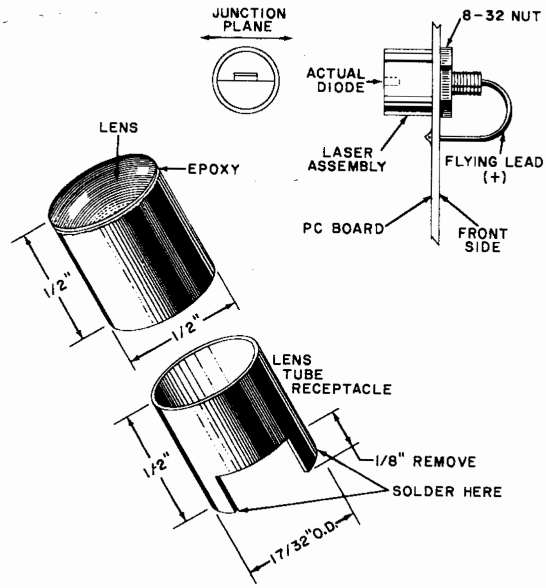


Fig. 7. Mounting details for laser and lens tube.

this purpose, but they are expensive. Kodak makes infrared-sensitive phosphor screens which glow orange when struck by a beam from an IR laser or LED. These screens cost about $25 (a lot less than electronic image systems). Write Special Product Sales, Kodak Apparatus Div., Eastman Kodak Co., Rochester, NY 14650 for details and prices.

Align the laser lens by pointing the beam at a white card (or the phosphor screen) at least 3 feet away and focus the lens for the smallest spot size. Use the infrared viewer to see the spot if the white card is used.

When the optimum focus point for the lens is found, use white glue to secure the lens in place and prevent need for realignment.

Telescope Alignment. Range tests of a few hundred feet are relatively straightforward, but long-range operation requires the addition of an alignment telescope for the transmitter. You can use any spotting or rifle telescope of 3X to 10X as long as it has a cross hair. For the sake of economy, in the prototype, an inexpensive 10X pocket telescope was obtained from Radio Shack for about $3 (Cat. No. 63-844). (Also available from other electronics outlets.) A cross hair was added by cementing two human hairs to a ⅜" washer which was then cemented to a shoulder inside the telescope eyepiece section.

The telescope must be boresighted with the laser. Make an adjustable mount similar to the one shown in Fig. 8. Use two sections of pc board for the mounting platform. Solder three nuts to the back of one board and use springs to permit adjustment.

Aligning the telescope is fairly easy if a phosphor screen or infrared viewer is available. The transmitter is mounted on a tripod with an appropriate nut and the laser is caused to illuminate a fixed spot at least 50 feet away. The telescope is then aligned until the crosshair falls on the target. Recheck the laser to make sure it still illuminates the target and alignment is complete. Perform the alignment at night for fast results and use a flashlight to illuminate the target when the telescope is being used.

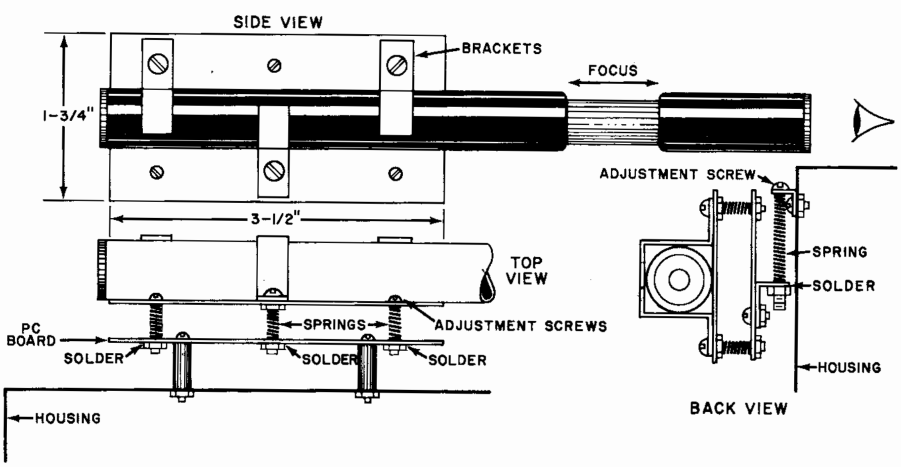


Fig. 8. Details for mounting the telescope which is used to boresight the transmitter.

Range Testing. When the telescope is boresighted with the laser, the system is ready for long-range testing. Begin by mounting the laser on a tripod and pointing the telescope at a fence post, car, or other object at least 1000 feet away. Place the microphone near a radio to get a continuous audio signal. Proceed to the target site, and point the receiver toward the transmitter. It will be necessary to move the receiver about until the optimum detection angle and point are found. If no signal is received, the laser beam has probably crossed the telescope field of view at a point beyond the range of the initial alignment target. Therefore, proceed a few feet toward the telescope side of the laser until the signal is received. An infrared viewer is helpful in finding the brightest spot in the projected beam (which is only a few feet across at ½ mile).

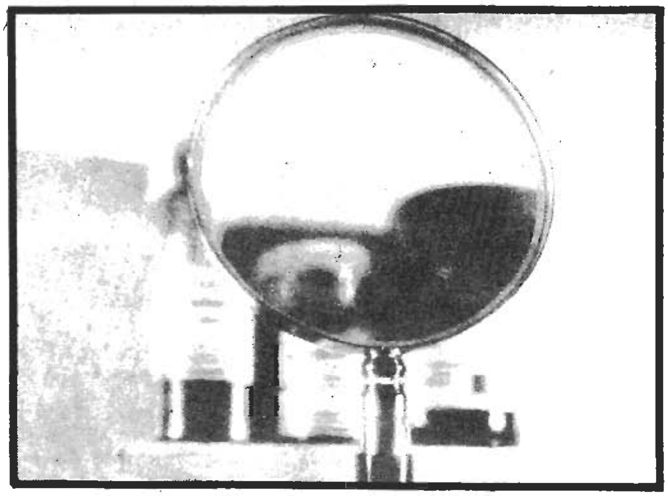
The prototype communicator has been used to achieve a range of 3380′ (1.03 km). This could be increased to well over a mile by increasing the laser current, reducing the transmitter beam width, or increasing the receiver lens size. For example, the prototype uses a laser with a threshold current of 4.1 amperes. While the laser can be operated at a top peak of 10 A, transistor *Q3* delivers only about 5 A. Therefore, the laser output is only a few hundred milliwatts, while more than a watt would be available at 10 A. With the full 10-A current, the optical-communication range equation shows that range would be slightly more than doubled.

Similarly, a diverging beam of light follows the inverse square law, so doubling the diameter of the receiver lens from 2 to 4 inches will double the range.

More Information. For further reading on laser communications, see: *Semiconductor Diode Lasers,* R.W. Campbell and F.M. Mims, Howard W. Sams & Co., 1972; and *Light Beam Communications,* F.M. Mims, Howard W. Sams & Co., 1975. ◈

HOLOGRAMS

Holography is the art of making three dimensional photographs, as Anne Sullivan explains. If you think your collection of slides takes up a lot of space now. . .



At first not a very impressive shot (above); a magnifying glass (in focus) with out -of-focus bottles in the background but these two photographs together demonstrate well the wonder of holograms for if we refocus the bottles appear sharp. We can also move to the left which would bring the bottles on the right into view — and still in focus.

Holography records light waves reflected from an object and reconstructs them to produce a three-dimensional image. Holograms can only be recorded using a strong coherent light, so, to explain holography it is important to understand the nature of light itself. All light travels in waves. White light is composed of all the colours of the spectrum, each colour having its own wavelength. Because white light is composed of many different wavelengths and phase orientations travelling together, it is known as incoherent light. Coherent light is composed of waves of identical length and frequency travelling in phase, such as that produced by a laser.

Mirror, Mirror. . . .

All objects reflect light, the amount varying in intensity according to the shape and nature of the object. A hologram is recorded when wavelengths of coherent light that are in phase overlap to produce a wavefront known as an interference pattern. The interference pattern, which records the dimensions and depth of the object, is recorded on a photographic plate and when the interference pattern is reconstructed, we see what appears to be a three-dimensional image of the original object — a hologram.

Holography was discovered by Dennis Gabor in 1948 at the British Laboratories in Rugby. His early holograms confirmed this theory, but the images were dim and blurred. Development was hindered by a lack of a sufficiently strong source of coherent light and photographic emulsions of a high enough quality. In 1960 with the invention of the laser, a strong source of coherent light became available and in 1964 two American scientists, Emmett Leith and Juris Upatnicks were able to further the pioneering work done by Gabor. Leith and Upatnicks produced the first bright holograms and the system they developed is known as 'off axis transmission holography'.

Object Lesson

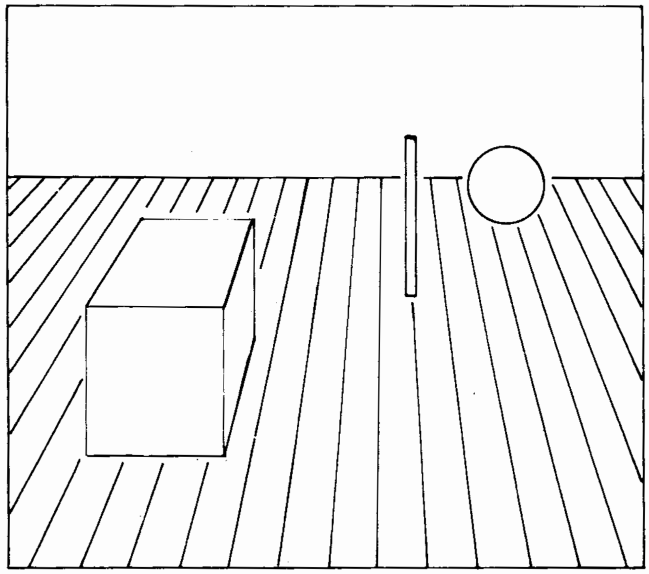
To make a hologram the light from a laser is split into two beams using a beam splitter. One beam is directed onto the object to be recorded (the reference beam). The intensity of the lightwaves reflecting from all the points of the object combine with waves of the reference beam to produce an interference wavefront in the emulsion. The photographic plate (which is an extremely fine grain silver halide emulsion) is then developed and fixed in a similiar way to conventional photographic film. The developed plate which contains the interference pattern is a hologram.

Image Making

To reconstruct or view the hologram, the reference beam from the laser is directed at the holographic plate at the same angle as in the recording stage. When it emerges it recreates the light waves from the original object and reconstructs a three-dimensional object behind the holographic plate. this type of hologram where the image is reconstructed behind the plate is known as a '*virtual image hologram*'.

Reconstruction of a hologram where the image appears in front of the plate (a '*real image hologram*') is more complicated. If the procedure is reversed and the holographic plate is lit from behind, the image that is reconstructed in front of the plate will be back to front and with reverse perspective; that is, the objects in the background will appear larger than those in the foreground. This inside-out image is known as pseudoscopic.

In order to create a real image hologram a second hologram is made of the pseudoscopic image. When the second generation hologram is reconstructed, the image appears in front of the plate the correct way round ie orthoscopic, the image having been reversed twice.



Two dimensional picturas such as this do not charge with different viewing angles. With a hologram the sphere would move behind the pole, and the cube could obscure the pole if viewing angle was changed, by moving your head.

Another type of hologram was developed in the Soviet Union in the early sixties by Y.N. Denisyuk which eliminated the need for a laser to reconstruct the image and so helped to bring holography out of the laboratory and make it more accessible to the public. This type of hologram is known as *'white light reflection hologram'* and, although a laser is required to make the hologram, the image can be reconstructed using a white light source.

Daylight 3-D

In white light reflection holography, Denisyuk also eliminated the need for a beam splitter. A beam of coherent light is passed through the holographic plate and acts as both the object and reference beam. It illuminates the object to be recorded and is then reflected back through the holographic plate. The emulsion records the interference between the beam and the reflection from the object. The hologram is viewed by directing white light onto the holographic plate. The plate acts as a filter and selects only the coherent light to reconstruct the hologram.

Another method of making white light reflection holograms uses the pseudoscopic image of a laser transmission hologram (in a similar way to making a real image transmission) but with the reference beam of the second hologram coming from the opposite side of the plate.

In 1969 Dr. Stephen Benton, working for the Polaroid Corporation developed a system that enabled a *'real image hologram'* to be viewed in white light. Making a so-called 'white light 'rainbow' transmission hologram' is a more complicated process, but it basically involves two stages. Initially, a transmission hologram is made. Then a second hologram is made in the same way that a *'real image hologram'* would be recorded except that just a horizontal slit (3-5mm) of the master is illuminated. The slit is projected in-front of the hologram and the white light passing through it acts as a filter. The white light passing through the slit is diffracted and produces a rainbow effect, so, depending on the viewing angle the holographic image appears in all colours of the spectrum. Dr. Benton has since modified his process and is now able to produce achromatic (black & white) images. Another type of reflection hologram known as a *'dichromate gelatin hologram'* was developed in the USA in the sixties. These holograms are made using ammonium dichromate instead of a silver halide plate. This method produces holograms with a very bright image, but limited depth. Its major application so far has been in the production of holograms in the forms of pendants.

Life Class

In all the methods of holography previously described the subject matter has to be an inanimate object, as any movement, even breathing, would disturb the interference pattern of the wavelengths and no image would result. However, animate objects can be recorded holographically using a pulsed laser. A pulsed laser emits intense flashes of coherent light, rather like a flashgun, which freeze the movement of the subject long enough to record the image. Using a pulsed laser it has even been possible to make a hologram of a bullet in flight. Pulsed lasers can also be used to make holographic portraits of people, but when making a hologram of a person a large sheet of frosted glass has to be used to diffuse the light from the laser for safety.

Another type of hologram, an *'integral hologram'* incorporates movement. Integral holograms are not

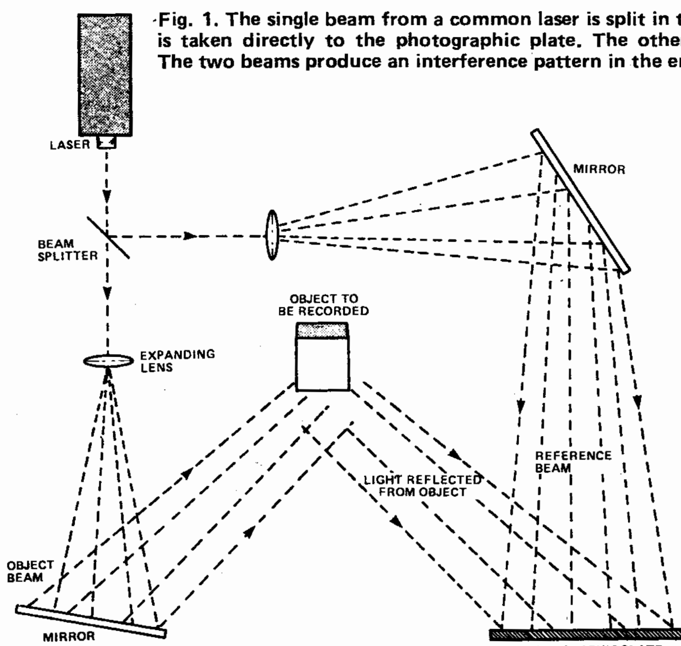


Fig. 1. The single beam from a common laser is split in two. One beam (reference) is taken directly to the photographic plate. The other gets there via the object The two beams produce an interference pattern in the emulsion.

strictly holograms, but a marriage of cinematography and holography as the subject matter is not recorded with a laser, but with ordinary 16 or 35mm black and white film. An integral hologram is basically a series of holograms joined together to create movement. The process was developed by Lloyd Cross of the Multiplex Co. in 1974. An integral (or multiplex) hologram is also made in two stages. First the subjects is filmed on a turntable which moves at a fixed speed. Any movement to be recorded has to be slow and smooth or the resulting hologram will have blurred or jerky movement. The black and white film is then scanned by a laser and each frame is made into a vertical strip hologram using a technique similar to the 'Rainbow' method. The resulting series of vertical strip holograms are contained on a flexible photographic sheet. To reconstruct the holograms the film is usually placed in a 120° cylindrical container (360° holograms can also be made). The container is illuminated from below by an ordinary incandescent light source. Integral holograms are popular as they eliminate some of the problem of the other types of holography, in that they are not confined to same size reproduction, allow a certain degree of movement, can be copied relatively cheaply and they can be reconstructed easily using an ordinary light source.

Applications

The applications of holography are numerous — among them, storing digital information, recording works of art and preserving them for posterity, as point of sale displays for advertising, in education to demonstrate complex forms such as molecular structures, as a completely new medium for artists to work in and as an art form in the home. ●

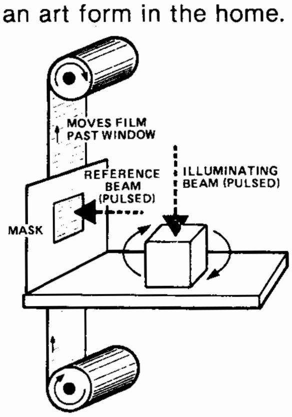


Fig. 6 One method of producing a holographic film of a moving object. A pulsed beam illuminates the spinning cube.

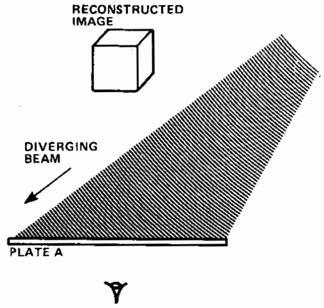


Fig. 2 Recovering a holographic image. A beam of light (white or laser, depending on the method of recording used) is directed at the photographic plate at the same angle as that of the reference beam during recording.

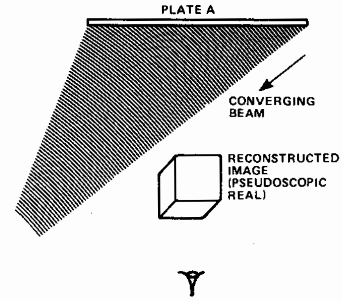


Fig. 3 The image can be made to appear in front of the plate by illuminating it from the front. However, the image is reversed in all respects. Objects in the background appear to be larger than those in the foreground.

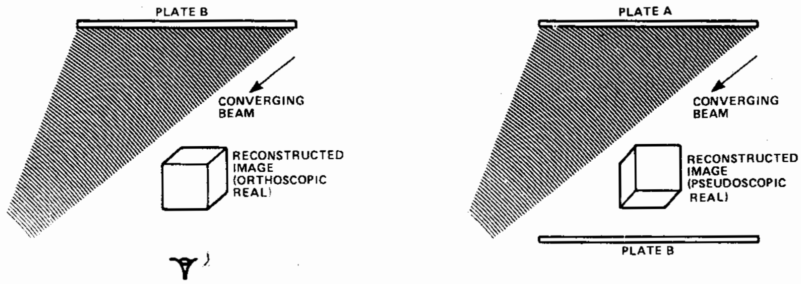


Fig. 4 To return the perspective to normal, a second hologram must be made from the first.

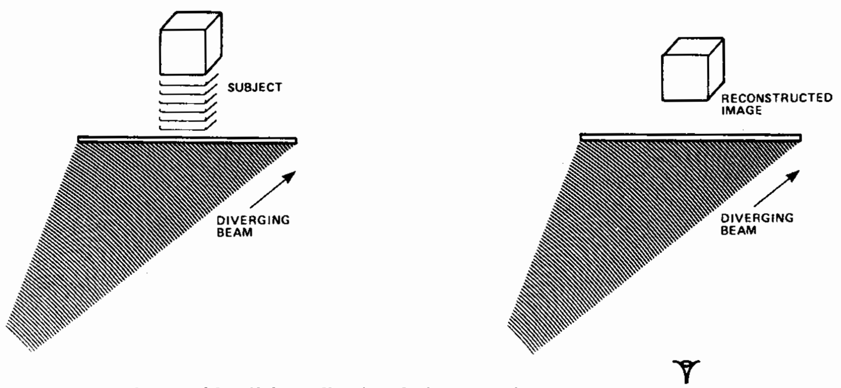


Fig. 5. To make a white light reflection hologram, the recording reference beam and object to be recorded are on opposite sides of the plate. The back of the plate is often coated with black to give a dark viewing background during reconstruction.

AN OPEN LETTER

Editors Note: The following letter comes to us from Dr. Iacobucci and we are printing it as an open letter to our readers who may be concerned about the proliferation of unnecessary regulations concerning lasers in entertainment use. We sent a request for a response to the addressee at the BRH and as of press time, had not received a reply.

Mr. Walter E. Gundaker
Acting Director
Division of Compliance
Bureau of Radiological Health
5600 Fisher's Lane
Rockville, MD 20857

Dear Mr. Gundaker,

This letter is in response to your recent mailing with proposed amendments to the Federal Performance Standard for Laser Products; in particular, as they relate to entertainment applications.

Roctronics is the manufacturer and seller of a laser scanning device, used to create entertaining images by scanning a laser beam. We do not manufacture lasers, but only the optical head which scans an existing beam of light. You asked for our comments, here they are:

1. The most meaningful comment I could make as a taxpayer would be to suggest that you abolish your department entirely, thereby saving the American taxpayer a lot of money, and the laser industry a lot of costly paperwork. There is certainly ample common law precedent and liability legislation to make any person who causes injury to another fully liable for his negligent actions. It is no more necessary for you to have a complex expensive federal bureaucracy to warn people about the hazard of bright laser light than it is to warn them about not sticking their hands into the fire of a stove, not standing in front of a moving train, keeping out of the path of speeding bullets, etc. However, since this radical suggestion would not only save the taxpayers money, but put you out of a job, it is unlikely it will receive a hardy welcome from you. Hence, I will continue with less radical proposals.

2. The only requirement that the federal government need promulgate for the protection of the public from abuses in the entertainment area is as follows:

"No person operating a laser device, no facility manager utilizing a laser device, no performer utilizing a laser device, shall allow any visible laser light in excess of (some energy density for some period of time determined scientifically to be dangerous to the eye or skin) to fall upon any person . . . (audience, performer, worker, artisan, etc.). The penalty for allowing this to occur shall be $ (as appropriate)."

All of your other detailed, wordy, legalistic, cumbersome, unintelligible, pedantic, bureaucratic requirements are totally unnecessary.

3. More specifically, as to 21 CFR 1041.11, we comment:

a. Class I radiation is too feeble to be useful in entertainment.

b. Your paragraph VI suggesting three meters vertical and 2.5 meters horizontal separation is helpful but not necessary in view of our above statement. Your paragraph VII is also useful but unnecessary. Your paragraph VIII is useless verbage.

4. Your paragraph 2:

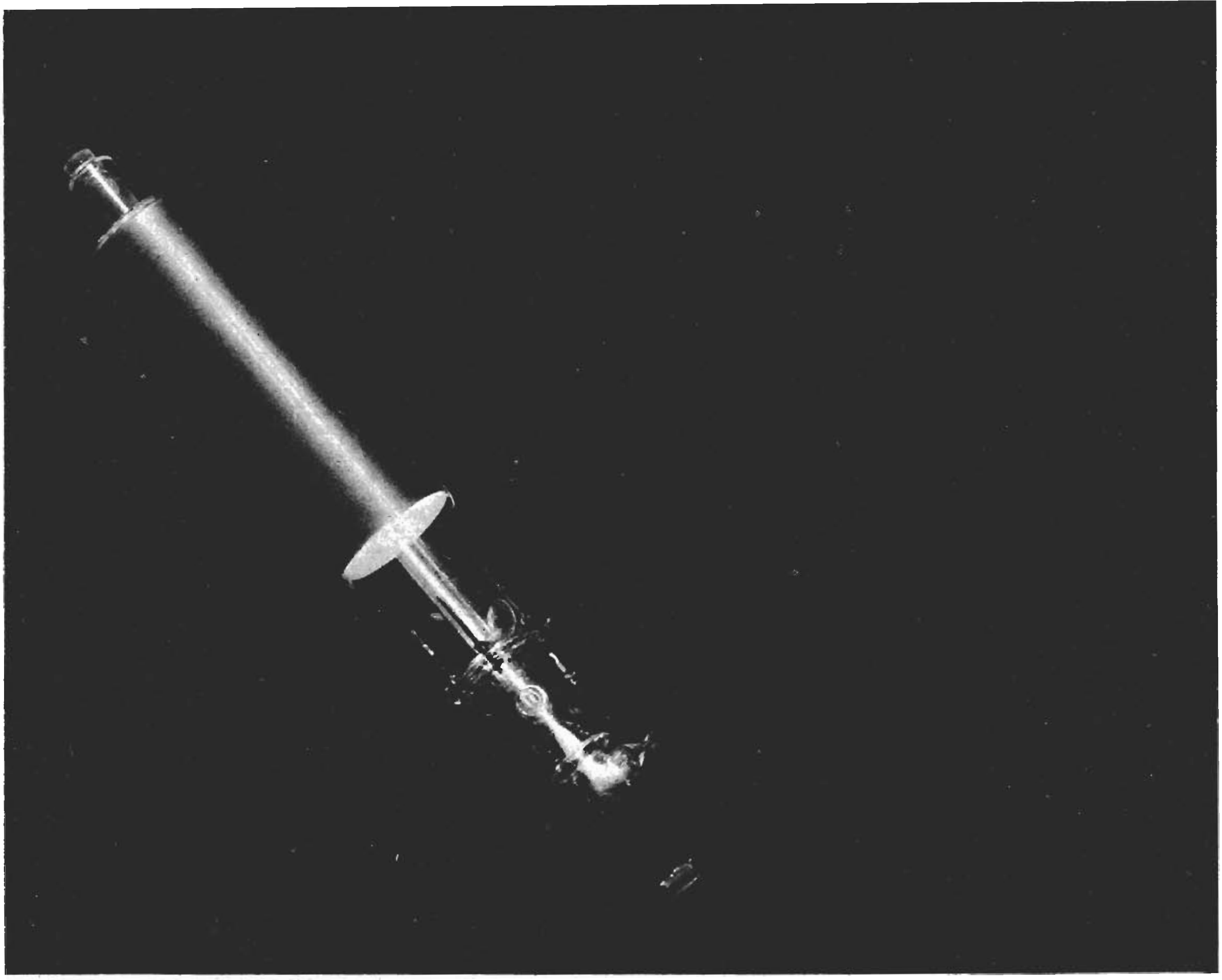
Labeling requirements are great if every user is a lawyer, otherwise absurd. Do you honestly think anybody would stop to read such a long and complex bunch of jargon with strange sounding code letters?

5. Your paragraph 3 informational requirements are outrageously restrictive and totally unnecessary. To require extensive advance notice of a light show is impossible under the notice conditions typical to the industry. It is not necessary for the show producer to show you the operational configuration because it makes no difference as long as the beam is kept away from the audience as provided in your previous regulations.

6. To list the special effects utilized in the show is unrealistic because these are often created spontaneously during the show, and in any event, how do you list an artistic composition: "Special Effect KX3"? The place and date of the show again is unnecessary since there is ample legislation and legal precedent to protect people from injury without the government having to send an inspector around to view every show.

In summary: considering that the number of people in this country who are killed or maimed by automobiles, firearms, even smoking cigarettes and drinking alcohol is thousands of times greater than the number of people, if any, that have been injured by a laser light show. There is no justification for your elaborate expensive bureaucracy to concentrate on laser light shows while neglecting other far more harmful life experiences.

Sincerely,
Dr. Richard Iacobucci, President
Roctronics
Pembroke, Massachusetts



AN INTRODUCTION TO LASERS

A fascinating rundown on these devices, the physics of their operation and the various types by David Tilbrook.

THE FIRST LASER was built in 1960 by Theodore Maiman, a research scientist working for the Hughes Aircraft Corporation. His research paved the way for the development of a fantastic array of fascinating devices and very useful tools. Today, lasers are used in surveying, geophysical measurements, medical applications, electronic component manufacture, atomic fusion research, precise distance measurement and a host of other applications.

The word laser stands for *light amplification through stimulated emission of radiation.* Whilst this implies that lasers are amplifiers, they are generally configured as oscillators. The light radiation they produce is very 'pure' — occuring at a specific frequency (or frequencies) — and the beam is well collimated, that is, it diverges only a tiny amount rather than spreading as does the beam from a flashlight.

The unique properties of laser light make the laser a prime candidate for wide application in technology and physical measurement. Many different types of laser have been developed but all employ the same basic principle of operation. All lasers have two fundamental components — a 'laser medium' and an energy source. The latter is used to excite the laser medium by a process called *pumping* — but I'll explain that further when I get into the physics behind the laser. First, let's look at the various 'breeds'.

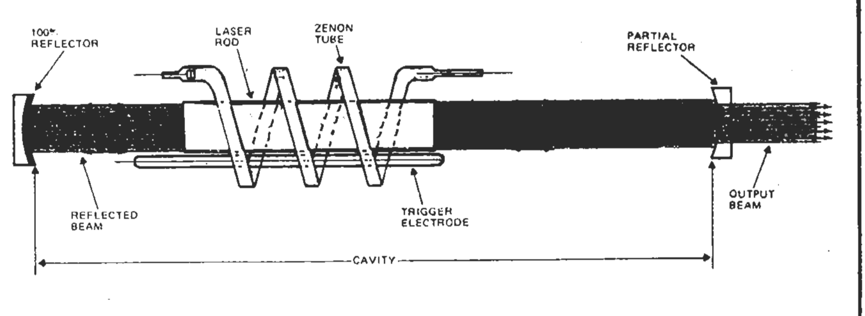
Solid-State Lasers
In laser physics, solid-state does not refer to semiconductor lasers but to a breed having a laser medium that is formed by doping a crystalline or glass material with an impurity material which produces the laser action when pumped. The most common of these is the ruby laser.

This type of laser consists of a central, cylindrical synthetic ruby crystal made from aluminium oxide as a base material and doped with chromium as the impurity. The crystal is mounted with mirrors at each end and is surrounded by a zenon-filled flash tube (or tubes). These xenon tubes provide optical pumping—a requirement of all solid-state lasers. One of the mirrors is 100% reflective while the other is very slightly transmissive so that a small portion of the laser light produced within the crystal is tapped off.

When the xenon flash tube is fired, laser action occurs within the ruby and laser light travels back and forth down the crystal, exciting further laser action and generating an intense pulse of light that passes through the slightly transmissive mirror.

One of the early problems with solid-state lasers was to achieve a continuous output. In 1962 a solid-state laser was built at Bell Telephone Laboratories. It consisted of the base material calcium tungstate, impregnated with neodymium. More recently, solid-state lasers have been built with continuous outputs of over 1000 watts.

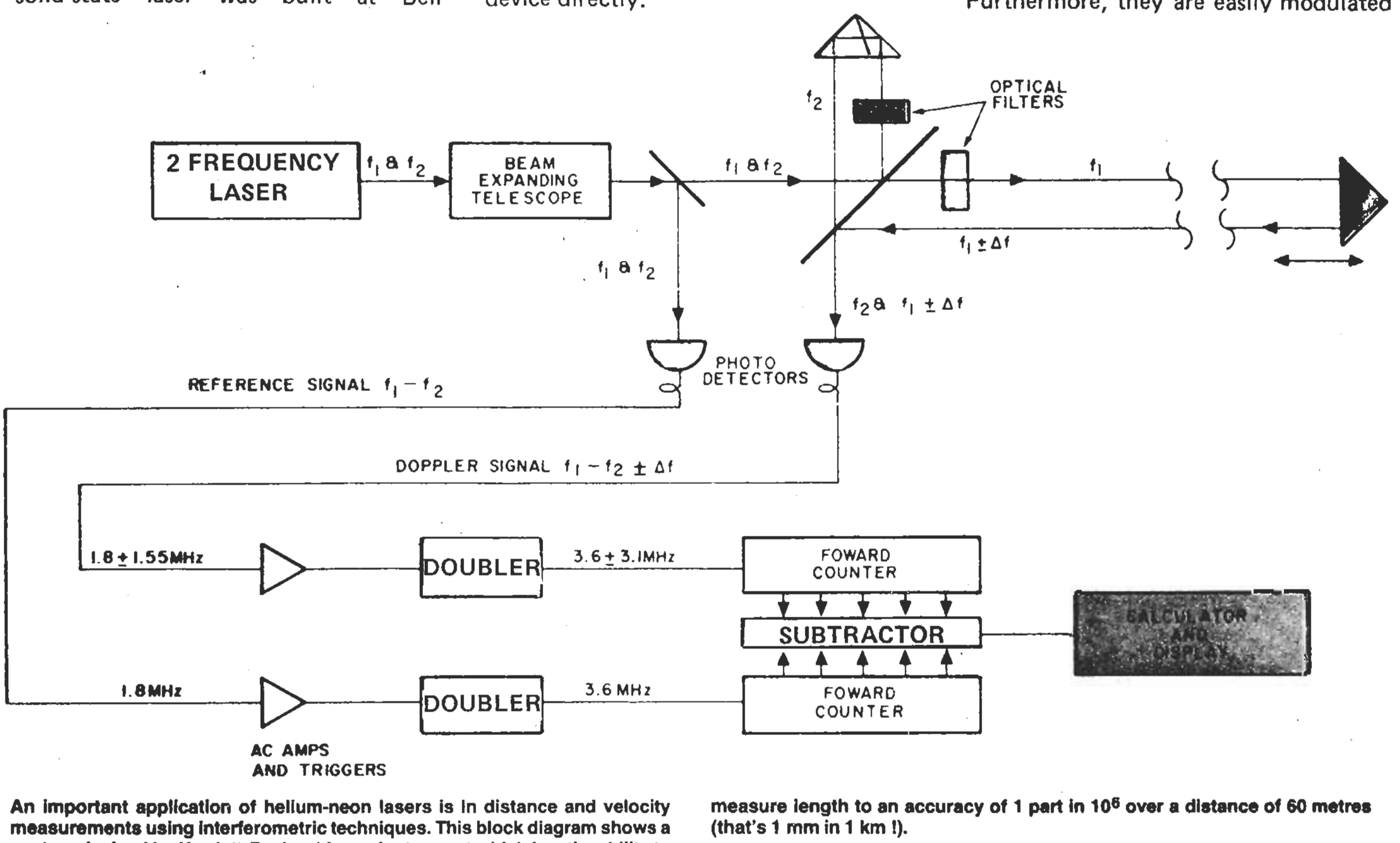
Much experimenting has been done to optimise the method of pumping solid-state lasers. One means developed by RCA in 1962 used a 300 mm hemispherical mirror to focus sunlight onto a laser crystal of calcium fluride immersed in liquid helium. This laser produced a continuous output of 50 W, and was the first laser to use sunlight to power the device directly.



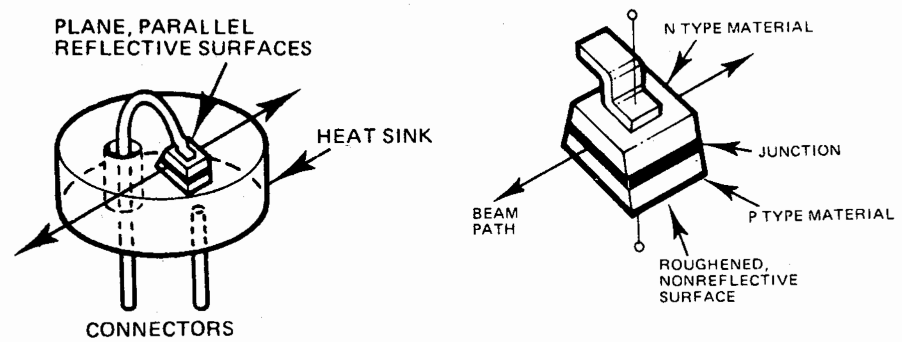
In the ruby laser, as first developed by Theodore Maiman, "pump" light from a xenon flash tube raises the energy level of chromium atoms in a ruby rod until a pulse of coherent red light emerges from the partial reflector (at right).

Semiconductor Lasers
Semiconductor lasers are relatives of the common light emitting diode, or LED. The most common of these is the **gallium arsenide laser,** and consists of a semiconductor diode junction formed by gallium arsenide doped with two different impurities to form the p and n materials. When forward bias is applied, a large number of electrons and holes move towards the junction where they recombine and generate laser light.

Typical power outputs of gallium arsenide lasers are low, around one watt maximum, but efficiency is very high. Furthermore, they are easily modulated



An important application of helium-neon lasers is in distance and velocity measurements using interferometric techniques. This block diagram shows a system devised by Hewlett-Packard for an instrument which has the ability to measure length to an accuracy of 1 part in 10^6 over a distance of 60 metres (that's 1 mm in 1 km !).



The semiconductor laser comprises a gallium arsenide junction doped with two different impurities. Construction of the junction is illustrated on the right, this is mounted on a heatsink header in the practical device, as shown at left.

and for this reason should be of great importance in optical communications in the future.

Liquid Lasers

Most liquid lasers use an organic dye as the laser medium and are optically pumped. Their big advantage over other types lies in the fact that the frequency of light generated can be varied. For this reason they are called **tunable lasers** and are being used experimentally to 'steer' chemical reactions.

Often the optical pumping of liquid dye lasers is done by other lasers, such as the nitrogen gas laser which has an output in the ultraviolet spectrum.

Gas Lasers

Gas lasers are probably the most important single category. The **carbon dioxide** laser for example provides the highest continuous power outputs of any breed. Furthermore, its output is in the infra-red spectrum which makes it useful commercially for cutting applications.

The most common gas laser is the **helium-neon** type. It provides a continuous output of red laser light that has been used commercially in distance measuring equipment as well as a general purpose "straight line". It is also used extensively in laboratories for diffraction, for general optical experiments and in interferometers. It has evolved into an inexpensive and reliable device.

The HeNe laser consists of a mixture of the gases helium and neon, placed in a sealed tube at low pressure. Originally, HeNe lasers were excited by high frequency ac current (around 28 MHz) but these days high voltage dc is used. As in most other lasers, mirrors are used at each end of the tube, so that most of the light produced is trapped within the laser itself, maintaining a special condition needed for laser action called *population inversion.*

In order to understand the laser phenomenon in any greater depth it is necessary to look at some of the physics of atomic structure.

Quantum physics

When studying the universe we apparently find two fundamentally different types of quantities, those quantities with a continuum of values and those with only a discrete or 'quantised' number of values. For instance, the speed of an object can range from zero up to the speed of light and seems to consist of an infinite number of possibilities. Similarly, the set of all numbers in infinite. These are examples of continuous quantities, but not all quantities are continuous. A dice can only show 1, 2, 3, 4, 5 or 6 on its upper face and this is a quantised quantity.

Similarly, standing waves on a violin string, resonances of a quartz crystal, or harmonics of a square wave are all quantised - they occur only at fixed frequencies.

Quantum physics is based on the discovery that a large number of quantities involved with molecular, atomic and sub-atomic physics are quantised. Many of these quantities were assumed to be continuous in "classical physics" and it has only been through the recognition of their quantised nature that modern physics has been able to achieve a reasonably workable model of atomic structure.

Most light sources today consist of either a solid (like a tungsten filament) or a gas (as in the fluorescent tube) through which an electric current is

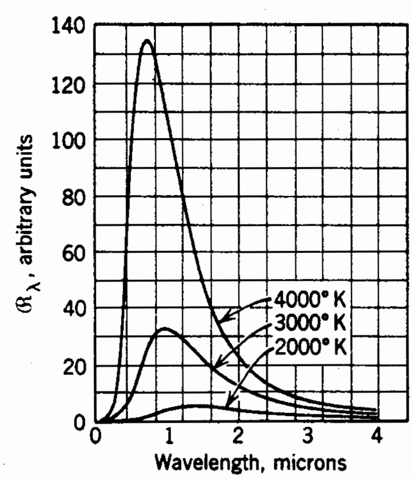
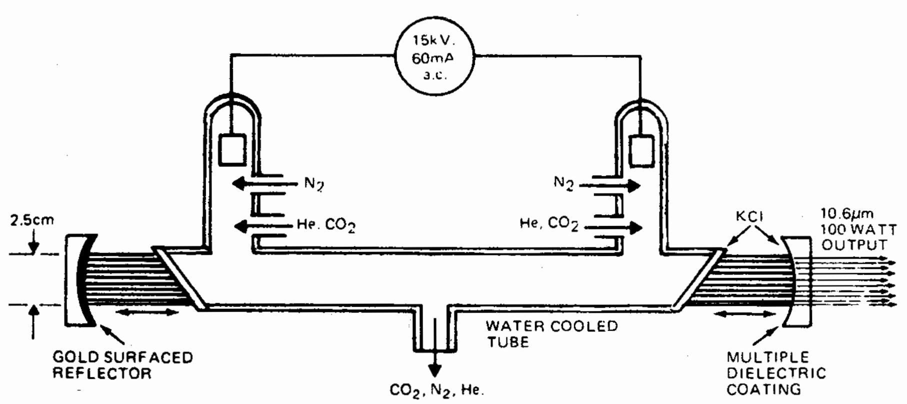


Figure 1. The spectral radiancy for cavity radiation at three different temperatures. (After Halliday and Resnick, "Physics for Students of Science and Engineering".)

passed. This current heats the filament or gas to incandescence and light is emitted. Using a spectrometer, it is possible to measure the relative intensities of the different light wavelengths emitted. If the temperature of the heated objects is varied the relative intensities change. All of these results can be plotted to make a family of curves on a graph like Figure 1. Each curve represents a different temperature and the shape of these curves is related to the particular material that is being heated.

The number of variables in the case of a heated solid makes any mathematical analysis unnecessarily complicated so scientists sought an idealised



Some gas lasers can generate enormous output powers. This diagram illustrates the general construction of a carbon dioxide laser.

heated solid. They called this a *cavity radiator,* and the light emitted proved to be largely independent of the material used to make the cavity radiator. Furthermore, the light emitted was found to vary in a fairly simple way as the temperature was varied.

Practical cavity radiators simply consist of a hollow container with a small hole drilled in one side (see Figure 2). If the cavity radiator is heated,

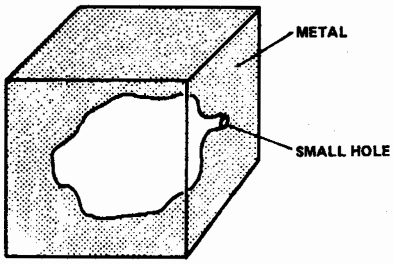


Figure 2. Representation of a cavity radiator. At a particular temperature, light emitted from the hole is brighter than that radiated by the body of the material.

more light is emitted from the hole than from the outside walls. The light emitted from the hole is called *cavity radiation* (sometimes called *black body radiation*) and was of intense interest in the later part of the nineteenth century.

The explanation of the related intensities of the various wavelengths emitted in cavity radiation was one of the outstanding problems for classical physics. Several attempts had been made but all of these had only fitted the experimental data partially.

In 1900, a German physicist, Max Planck, derived a formula that fitted cavity radiation perfectly. He was forced to the conclusion that the atoms inside the cavity radiator were acting like tiny electro-magnetic oscillators. They could emit light into the cavity and absorb light energy from it, but only at certain characteristic frequencies.

Planck was forced to make the radical assumption that an oscillator cannot have a continuum of different energies. These energies were quantised so that the only possible values were given by the equation.

$$E=nh\nu$$

where 'E' is the energy
'n' is an integral number, i.e: 1, 2, 3, 4, 5, etc.
'h' is a constant (now called Planck's constant)
and 'ν' is the frequency of the oscillator

The oscillators could not radiate light continuously but only in jumps, or 'quanta', and only when the atom jumped from a high energy state to a lower one. If the atom jumped just one energy state then 'n' in the above equation becomes equal to one, and the equation becomes:

$$E=h\nu$$

This is known as *Planck's equation* and is one of the more important equations in modern physics.

This was the start of quantum physics. A physical event could only be explained by assuming that atoms radiate integral amounts of energy.

Planck's ideas were reinforced several years later by Albert Einstein who applied the concepts of quantisation to another area of physics that was to revolutionise our understanding of the nature of light. Up to this time, light was thought of as an electromagnetic wave. Even though Planck had quantised the energies of atomic oscillators in the cavity walls, he still regarded the radiation within the cavity as a wave. This wave picture of light had been enormously successful in explaining light phenomena up to that time, but Einstein was to point out its inadequacy in some circumstances.

The Photo-electric Effect

This effect was another experiment which had not been satisfactorily explained in terms of classical physics. Figure 3 shows a circuit diagram for the apparatus used in the photo-electric experiment. If light is shone onto a clean metal surface some electrons are liberated from the metal. If the metal is placed in an evacuated glass cylinder, the liberated electrons (called *phote-electrons*) can be made to constitute a current flow, which will register on the

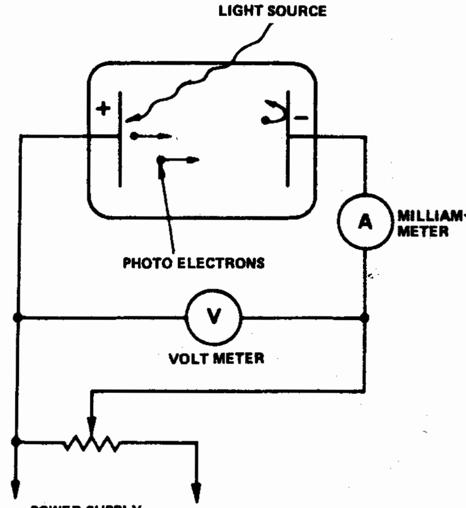


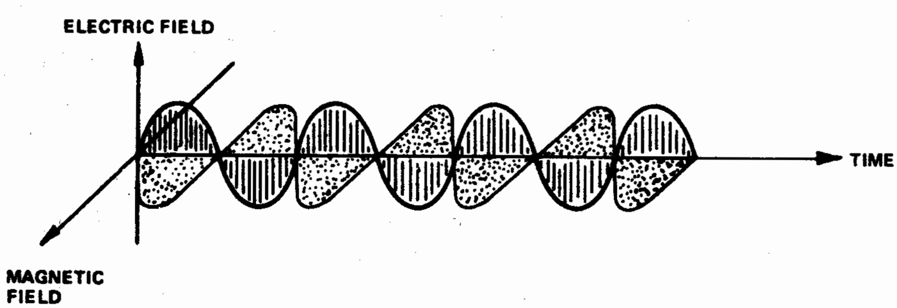
Figure 3. Circuit diagram of the apparatus used in the photo-electric experiment.

meter. If the other electrode is now made negative with respect to the first, by connecting the two to a power supply, the negative electrode will tend to repel the photo-electrons and decrease current flow. When the voltage is great enough, the photo-electrons can be brought to a stop. If the voltage is increased even further the photo-electrons are turned back toward the anode. The voltage applied to the plates is called the retarding potential and can be used to measure the energy of the photo-electrons.

When the experiment is carried out it is found that photo-electrons are emitted almost instantaneously when the light is turned on. If the wavelength of the incident light and the retarding potential are kept constant, then the current flowing is found to be proportional to the intensity of the light beam. Furthermore, for any particular metal the energy of the photo-electrons is found to be independent of light intensity, but varies with frequency of the light.

These results were difficult, if not impossible, to explain on the basis of the wave theory of light. Since light was thought of as a continuous wave, the energy absorbed on the photo-electric surface should have been proportional to the light intensity. If the intensity was decreased enough it should have taken a certain amount of time for sufficient energy to be absorbed by the electrons before any emission could start. So the wave theory of light could not explain why photo-electric emission starts instantaneously, even if the intensity of light is decreased.

Similarly, the fact that the energy of the photo-electrons varies with the frequency of the light and is in no way affected by the intensity of the light,



According to the electromagnetic wave theory, light is seen as a continuous wave of oscillating electric and magnetic fields.

cannot be explained by the classical theory.

A quantum approach

In 1905, Albert Einstein applied quantum theory to the problem of photo-electric emission and obtained a theory that explained all the observed characteristics. He postulated that light was not a continuous wave but consisted of small quanta of light called *photons.* Each photon has an energy, 'E', that is related to the wavelength of the light by Planck's equation.

Any single photon can interact with a single electron so the energy imparted to this electron will depend only on the energy of the photon. i.e: its frequency. Increasing the intensity of the light beam increases the number of photons and will only increase the number of photo-electrons emitted. Emission will start instantaneously, as all the energy needed for a photo-electron to escape the surface of the metal is contained in any single photon.

The photo-electric effect occurs because the energy imparted to the photo-electron by the photon has exceeded that needed by the electron to break bonds that normally bind it to the metal surface; but it is not the only example of electron-photon interactions. In the photo-electronic effect the electron struck is a bound electron, inside an atom. The photon disappears and the electron is dislodged. However if the electron is a free electron it will recoil and cause the generation of a second photon of lower energy. This is called *the Compton effect.*

Another set of electron-photon interactions are called *pair production* and pair *annihilation*. If a photon is given enough energy it can convert into an electron and a *positron* when passing another heavy particle. A positron is an antimatter electron. It has all the properties of a normal electron except that it has a positive instead of a negative charge. This process is called pair production. Pair annihilation occurs when a positron and an electorn interact. Both are annihilated and two photons are generated.

All these electron-photon interactions are manifestations of a single process, the exchange of photons, called *virtual photons,* between charged particles. Indeed, it is this effect that gives rise to the attractive and repulsive forces between charged objects. The study of photo-electron interactions is called quantum electrodynamics and is one of the major fields of research in modern physics.

Spontaneous and stimulated emission

When a photon interacts with a bound electron it may not have sufficient energy to overcome the binding forces. In this case the photon is absorbed by the electron, as would happen in the photo-electric effect, but the electron is not liberated from the atom. Instead, it jumps up to a higher energy level or orbit. Quantum physics has determined that electorns cannot have a continuum of different energy levels, only energy levels that are integral multiples of a fixed amount. When the electrons of an atom are in their minimum energy states the atom is said to be in its ground state. If an atom is in its ground state, say with energy E_1, it can be forced to a higher energy level, say E_2, by absorption of a photon. If the photons absorbed have energy $E = h\nu$ then the increase in electron energy will be exactly $h\nu$, i.e: E2
be exactly $h\nu$, i.e: $E_2 - E_1 = h\nu$.

After a certain amount of time, approximately 10^{-8} seconds, the electron will drop back down to its lower energy level, automatically emitting a photon, again with energy $h\nu$.

The excited atom was initially at rest and has no preferred direction in space. As a result the photon can be radiated in any direction while the atom recoils in the opposite direction. This process is called *spontaneous emission.* If a group of atoms are excited in this way they will generate photons in all directions randomly, as excited atoms return to their ground states; see Figure 4.

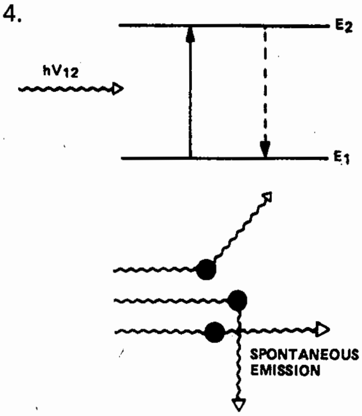


Figure 4. Energy level diagram for the process of spontaneous emission.

If an electron at energy level E_2 interacts with another photon of energy $h\nu$, the electron is forced to return to its ground state with the emission of a second photon. This process is called *stimulated emission* and is the basis of laser action.

The most important point about stimulated emission is that both photons leave the atom with the same phase and direction as the incoming photon, see Figure 5. The two photons are said to be cohernet. It is essential that the two photons be coherent. If they were even slightly out of phase cancellation would occure between them, violating the law of conservation of energy. If a group of atoms is

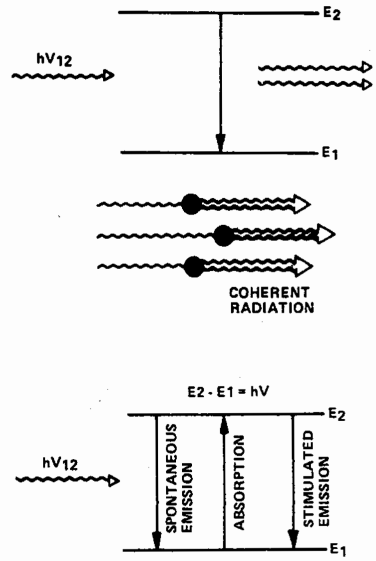


Figure 5. Energy level diagram for the process of stimulated emission.

excited in this way the initial beam of photons will be augmented by additional photons, so the beam is amplified.

Population inversion

If a material is in thermal equilibrium at a temperature T, the distribution of atoms in a lower energy state to those in a higher energy state is normally accented heavily toward the lower energy state. If N_1 is the density of atoms in the lower state and N_2 the density of atoms in the more excited state, then the ratio of N_2 to N_1 is given by the equation

$$\frac{N_2}{N_1} = \exp(-h\nu/kT)$$

where 'T' is the temperature of the material in Kelvin
and 'k' is Boltzmann's constant.

If the material is at 10^3K, then:

$$\frac{N_2}{N_1} = 10^{-5} \quad !$$

So, only one atom is 10^5 is in the excited state.

The condition in which the number of excited atoms exceeds the number of atoms at the ground state is a non-equilibrium condition called *population inversion,* but it is precisely this con-

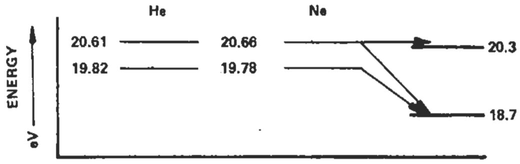


Figure 6. Energy level diagram for the helium-neon laser.

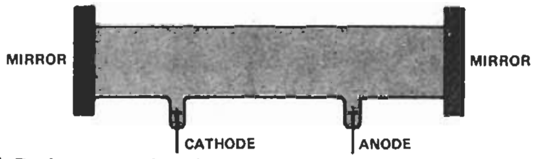


Fig. 7. Basic construction of a gas laser. A glass cylinder, containing a gas at a low pressure, has two mirrors placed at either end — one is totally reflective, the other slightly transmissive. When current is passed through the gas, population inversions of the atoms occur and laser action results.

dition that is needed to maintain laser action. If the vast majority of atoms are in the non-excited state, only spontaneous absorption followed by spontaneous emission, can occur. If, on the other hand, a population inversion can be maintained then stimulated emission will occur leading to photon multiplication. *Pumping* is simply the process used to maintain the population inversion.

A closer look at the HeNe laser

In the helium-neon laser, population inversion is maintained by generating a glow discharge in a low pressure mixture of helium and neon gases. Figure 6 is a simplified energy diagram for a HeNe laser.

The helium energy levels at 20.61 and 19.82 electron volts (eV) are called *metastable levels*. Once at a metastable energy level an atom cannot move to a lower state by the emission of a photon. It can only be de-excited by some other process. A transition from a metastable level to a lower level is called a *forbidden transition* and the fact that these transitions are not permitted is predicted by quantum theory. So, once an atom has been excited to one of these energy levels it will stay at that energy level for a relatively long period of time, approximately 10^{-3} seconds, hence large metastable populations can exist.

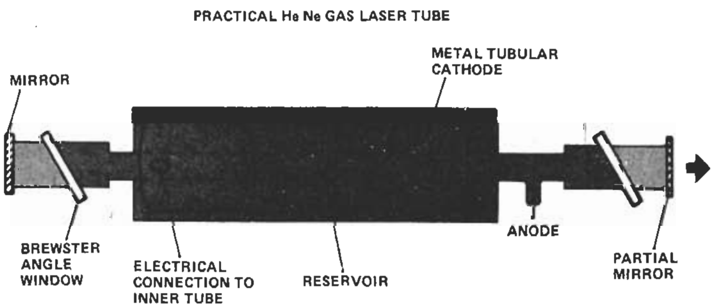
Two of the energy levels of neon closely coincide with those of the metastable levels of helium, these are at 20.66 and 19.78 eV. An energy transfer will occur between helium metastable atoms and neon ground state atoms, exciting neon atoms to the 20.66 and 19.78 eV energy levels. As a result, very large populations of excited neon atoms are produced. The population of neon atoms in these energy levels vastly exceeds that achievable from direct excitation by the electric discharge. Below these two highly populated energy levels there are two lower neon levels that are only populated by direct excitation and consequently have much smaller populations, and this is a population inversion.

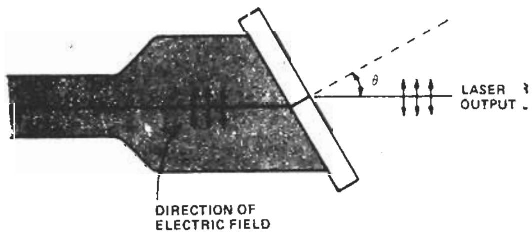
Whenever an excited neon atom jumps to one of these lower energy levels a photon is emitted, and the frequency of the photon will depend on the difference in energy between the two levels. The three possible transitions are shown in Figure 6 and are: 20.66 eV to 20.3 eV (3391 nm in the far infrared), 19.78 eV to 18.7 eV (1152 nm in the infrared), 20.66 eV to 18.7 eV (633 nm in the visible spectrum). Figure 7 shows the basic elements of a helium neon laser. The tube contains roughly 90% helium and 10% neon gas at a pressure of one to three Torr.

When a current is passed through the tube a variety of collision processes take place. Among these are the collisions that lead to population inversion. As neon and helium atoms jump between higher and lower energy levels, photons are emitted randomly in all directions. However, since there are large populations of neon atoms at the 20.66 and 19.78 eV energy levels, any photon with one of the above three wavelengths has a high probability of causing stimulated emission of a second, identical, photon. Those photons travelling parallel to the axis of tube are reflected back and forth between the two end mirrors, and each pass through the tube gives rise to further identical photons by the process of stimulated emission. A limit is finally reached when the rate of production of neon atoms at the higher energy levels equals the rate of stimulated emission.

If one of the mirrors is made a few percent transparent, (i.e: slightly transmissive) a portion of the coherent radiation can escape from the tube and this is the laser output. The word laser stands for *light amplification through stimulated emission of radiation,* but the helium neon laser is not really an amplifier, it's more of an oscillator generating coherent electromagnetic radiation at three distinct frequencies.●

A practical HeNe laser tube





TRANSMISSION OF LIGHT THROUGH A BREWSTER ANGLE WINDOW.

A practical HeNe laser tube is shown in the diagram. It features a number of improvements over the basic system. The cathode consists of a large metal cylinder instead of a single wire electrode. This decreases the current density around the cathode and increases the rate of excitation of helium atoms to metastable states. Plane mirrors are very difficult to align accurately and a common system used to overcome this difficulty is the use of slightly concave mirrors, separated by their radius of curvature.

Another configuration employed, and the one used in the tube for the project, is referred to as a "hemispherical" configuration. This uses a totally reflective, flat-backed mirror and a concave front mirror with a radius of curvature of around 1.4 times the tube length. The mirrors used are designed specifically for laser use and constitute a significant portion of the cost of the device. The mirrors are used as bandpass filters to optimise the particular output required. The tube specified for the project uses a system like this to enhance tube operation at the 633 nm emission wavelength and to suppress operation at the other two dominant wavelengths. The front mirror is approximately 0.9% transmissive at 633 nm but considerably less transmissive at the two longer wavelengths. The rear mirror is almost totally reflective at 633 nm, but more transmissive at longer wavelengths. HeNe tubes often employ a "Brewster angle polarizing filter". This is a glass disc placed in the light beam at an angle determined by its refractive index. Light of the correct polarization is transmitted through the filter. All other polarizations suffer high reflections and are attenuated. This does not cause any loss in the light output of the laser since any one polarization will be amplified by stimulated emission to produce a full output intensity coherent laser beam with a single polarization.

Military Lasers

Will the real Buck Rogers please sit down? Plans are afoot to build weapons normally associated with Hollywood sci-fi. Roger Allan separates the reality from the wishful thinking.

WITH THE Reagan Administration announcement some months ago that the United States was to embark on a massive military upgrading program, an embarkation which is to include development of particle beam and laser weapons systems, a veritable panoply of articles and commentary has descended on the unsuspecting public. The possibility of Buck Rogers type warfare is dealt with, on a scale previously unimagined. As with most such **Star Wars** articles, a great deal has been written which is essentially nonsense, better confined to the pages of second-rate science fantasy articles than to the quality publications in which such material so frequently appears. The separation of the fantasy from the fact, in the public's mind, has become increasingly difficult as more and more supposed experts vent their opinions on subjects without really explaining what they mean, how much is reality, how much is potentially possible and how much is just wishful thinking. When one digs into the primary data on this subject, however, one finds that it is quite easy to separate the wheat from the chaff, as it were, and it mostly turns out to be chaff.

To begin at the beginning. The development of a laser-damage weapon system was felt by the military to have some particularly attractive features. For example, since light travels at a speed of 186,000 miles per second, the lethal flux would arrive at the target almost instantaneously, and there would be no requirement to lead the target, except at very long ranges. It takes six millionths of a second for laser light to travel one mile, and in that time, a supersonic airplane travelling at twice the speed of sound will travel only a little more than one-eighth of an inch. Also, a laser weapon could be used to selectively attack and destroy single enemy targets in the midst of a host of friendly vehicles or equipment.

Laser Basics

But first a laser of sufficient power had to be developed, one which could produce power in the range of megawatts. Although many different lasers were discovered in the 1960s, none was suitable for high energy applications. In the mid-60s, a discovery led to efficient lasers which generated their energy in the infrared portion of the spectrum. A concomitant discovery was that flowing the laser gas through the optical cavity at high speed could solve the waste heat problem and greatly increase the power output of the laser. The next step was to invent a way to generate the energy required to operate the laser in an efficient and upwardly scalable manner. The required invention was made in 1967, and consisted of the carbon dioxide gas dynamic laser, or CO_2GDL.

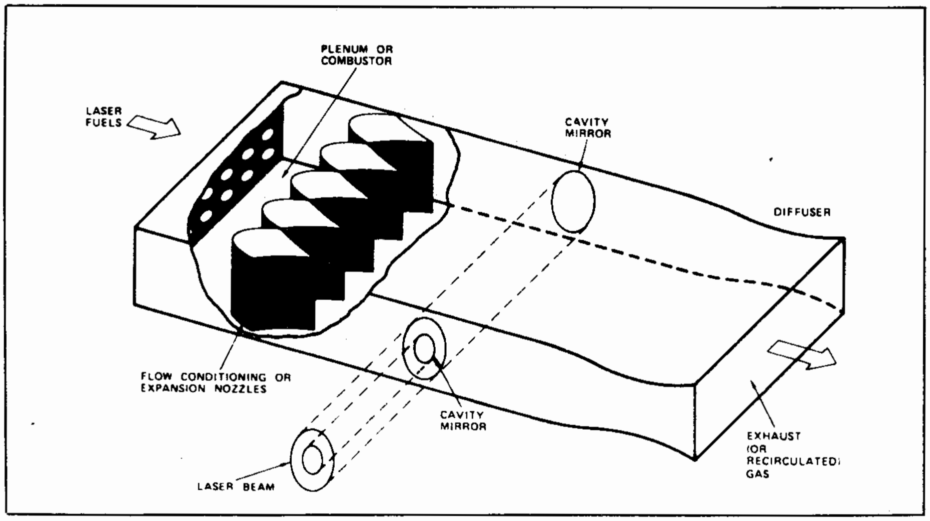
The energy required for operation of the CO_2GDL is generated by combustion of carbon monoxide with an oxidizing agent such as nitrous oxide. This combustion produces energetic molecules of CO_2 capable of releasing photons. This energetic state is maintained by dynamic expansion of the hot gases through a bank of supersonic nozzles; this also provides the conditions of flow necessary for extraction of the photons with good beam quality. The optical energy is extracted from the energetic CO_2 molecules with mirrors looking across the flow field just after the flow leaves the nozzles. The photons extracted move across the flow field, picking up other photons as they go. The photons leave the laser cavity as an intense beam of energy at a wavelength dictated by the type of molecule giving up the energy; 10.6 micrometers since the molecule is CO_2. Subsequently, upwardly scalable lasers include the electric discharge laser, the chemical laser, the excimer laser and the free electron laser.

A laser system is expected to handle a large number of targets even if the targets are coming from all directions. For each "shot" the laser takes, relatively small amounts of fuels are used to generate the beam. Thus, there is the potential for storing a large number of shots per installation (or a large magazine per weapon). Finally, since the beam is steerable by moving mirrors, the laser weapon has the potential to move rapidly from target to target over a wide field of view.

Disadvantages

But simply spitting a laser ray in the direction of a target is not enough. A successful laser engagement occurs when the beam burns through the target surface and destroys a vital component such as its guidance system, or ignites a fuel or warhead. Thus, since the energy is delivered instantaneously, the laser must dwell on the target to destroy the target. Furthermore, jitter of the focussed spot over the target smears the energy in the beam over a larger effective spot size, increasing the time required to damage the target. Thus the beam's control subsystem must hold the beam steady on the target aimpoint. To do this, the target tracking and beam point functions must be especially accurate.

A second difficulty with such a weapons system is the effect the atmosphere has on the laser beam. As a function of the wavelength of the laser energy, the atmosphere absorbs some of the energy being propagated, causing the beam to "bloom" or defocus, and adds the above-mentioned jitter to the beam. Interactions between the high power beam and the atmosphere effectively increase the spot size on target, lowering the peak intensity and thereby increasing the dwell time. The next effect is that for a given range there is a critical power level beyond which intensity on target decreases as the power radiated by the weapon increases. This effect is most pronounced when the line of sight to the target is fixed (as is the case where the attacker is headed directly at the laser and the wind velocity is low). In bad weather or in the presence of clouds or aerosols such as smoke, more of the energy in the laser beam is absorbed, effectively limiting the rage of the laser weapons.



Basic diagram of a high-powered laser

"The separation of fantasy from fact has become increasingly difficult as experts vent opinions without explaining how much is reality."

In the vacuum of space, the laser beam does not have to contend with the degradations caused by the atmosphere, and space has often been referred to as the "natural" environment for laser weapons. In this vacuum, potential applications include anti-satellite, counter-air, and ballistic missile defense. Some have argued that the potential exists to create a damage limiting ballistic missile defense system with space-based laser weapons; in the vacuum of space, one could achieve the very long weapon ranges of operation needed to contend with the vast volume of near earth space. At long ranges, the stressing requirement to point accurately is ameliorated somewhat by the low angular tracking rates required. However, at ranges typical of space engagements, it is necessary to lead the target.

In response to Congressional requests, a report on the subject of space laser weapons was made in May of 1981, and a space laser program approved by the Secreatry of Defense was forwarded to Congress in June of 1982. This plan provides for continuing development of necessary technology and concomitant system effectiveness and mission utility analysis over the next few years, leading to a decision in the later 1980s whether to proceed with an in-orbit demonstration of an integrated battle station for some mission application. Such technology development for the next few years is necessary because of significant uncertainties, not only in the technology for the proposed space battle station itself but also in target damage and vulnerability, potential target hardening, command and control, surveillance and warning, and launch and support.

Development of laser weapon systems had previously hissed and sputtered through the 1960s, dying out in 1971. In 1973, it was determined that the Soviet Union was devoting significant resources to the development of laser beam weapons. Their high energy program, even today, is three to five times the US effort. It began in the mid-1960s, when they commenced pursuing chemical laser development, and later, work on the gas dynamic laser and the electric discharge laser. The Soviets also pursued related technologies such as the development of efficient electrical power sources and the capability to produce high quality

Continued on page 72

optical components in quantity. They have developed a rocket driven magneto-hydrodynamic (MHD) generator which produces 15 megawatts of short term electric power, a device which has no counterpart in the West. The Soviets have committed to development moderate-power systems capable of short range ground-based applications such as tactical air defense and antipersonnel weapons. It is believed that by the latter half of this decade, it is possible that the Soviets could produce laser weapons for several other ground, ship and aerospace applications.

In response to the perceived threat, the US re-introduced studies in high energy weapons systems (including particle-beam weapons) under the aegis of the Defense Advanced Research Projects Agency (DARPA). Simultaneously, the three forces commenced studies of their own. While complementary in some respects, these were being designed for different end-user functions.

Army-Navy Game

The Army, for instance, has two weapon systems under research and development: one, a lower power system, is designed to "craze" the optical and infrared sensors of missiles and divert them from their targets. The other, a higher-powered system, would destroy helicopters on the NATO front. The Army's success to date, at least publicly, was the destruction of winged and helicopter drones at the Redstone Arsenal, Alabama, in 1976.

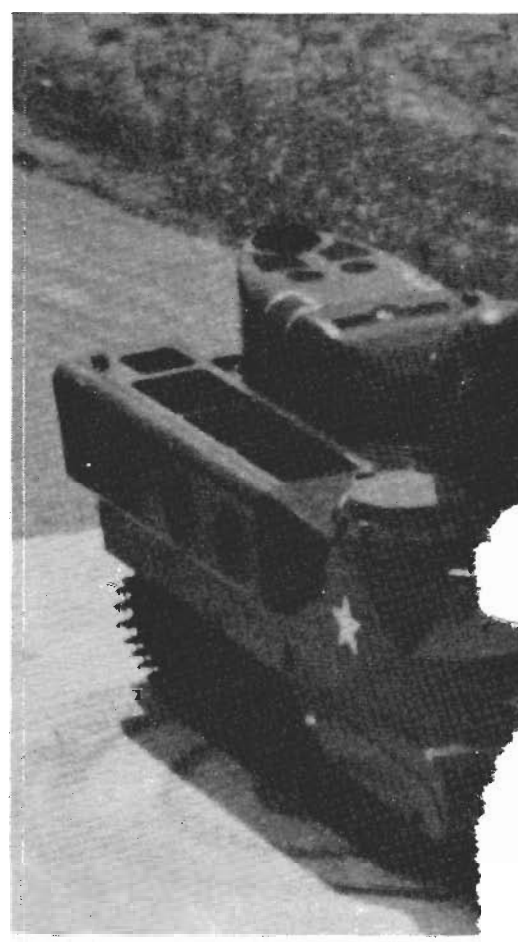
The Navy's perception of the utility of such weapons is primarily point defense of ships, whereby a single laser (code names **Sea Lite**) would be computer controlled to focus and aim a beam and keep it steady until a series of targets had been destoryed. As such, the primary thrust of their research has been in perfecting the computer controlled sub-systems. DARPA, in general, needs a similar capability for the space-based laser fire-control and tracking system in order to knock out batches of oncoming intercontinental ballistic missiles long before they have reached earth orbit and are able to release their weapons. Their major public success to date was when a chemical laser of moderate power developed by DARPA, combined with a Navy developed pointer/tracker, successfully engaged and destroyed in flight a TOW antitank missile launched by a crew of Army technicians. This test was part of the Unified Navy Field Test Program conducted at San Juan Capistrano, California, at a site near Camp Pendleton in 1978.

It is the Air Force, however, under their newly created Space Command, which has done most of the non-DARPA work. Their efforts have been to develop a way to prevent vibration aboard an aircraft when a laser is shooting photons at a power level of more than 1 million watts. Vibration upsets the alignment of the mirrors that focus and reflect the laser's beam and keep it steady until a series of targets had been destroyed. As such, the primary thrust of their research has been in perfecting the compuer controlled sub-systems. They have two published successes. The first was in 1973, when they used a high energy gas-dynamic laser of moderate power and an on-gimbal telescope to shoot down a winged drone at the Sandia Optical Range at Kirtland AFB, New Mexico. Most recently, in July of this year, the Air Force used an airborne laboratory aboard a converted NKC-135 plane to successfully destroy five **Sidewinder** missiles travelling at 3,000 km/hour fired at it by an A-7 fighter-bomber.

Space Lasers

Next to Air Force expenditures, the largest proportion of the almost half billion dollars being spent in 1984 on High Energy Laser (HEL) research is being spent by DARPA for its space battle station. Their main interest is in the development of a space battle station for strategic purposes. One of the main problems they face is the optical tracking and locking-in process, code named Project Alpha in general, with the tracking unit known as Talon Gold. Talon Gold has shown enough promise that it is expected to be tried aboard the space shuttle some time in 1986 or 1987.

DARPA officials are optimistic that the laser battle station they are planning will be able to shoot down enemy satellites, submarine launched missiles or flights of bombers. But such objects will be sitting ducks compared to countering land-based intercontinental missiles which could be launched by the hundreds or thousands at the US and must be destroyed in the early moments of flight. The cost of such a shield would be enormous, involving at least several tens of such battle stations and "at least 200 billion dollars", according to Pentagon sources. To reduce the cost, there is some thought that DARPA should abandon its chemical laser work and concentrate on developing X-ray or free-electron lasers, work that is currrently being pursued at Avco Corp and at the Defense Department's Lawrence Livermore and Los Alamos Laboratories. Because free-electron lasers are able to transmit power at shorter wavelengths than gas dynamic or chemical lasers, they should permit the design of smaller weapons, but to generate power, they need vast amounts of either electrical or nuclear energy. Moreover, short wave-



length lasers also need very precise optical subsystems that are not now available.

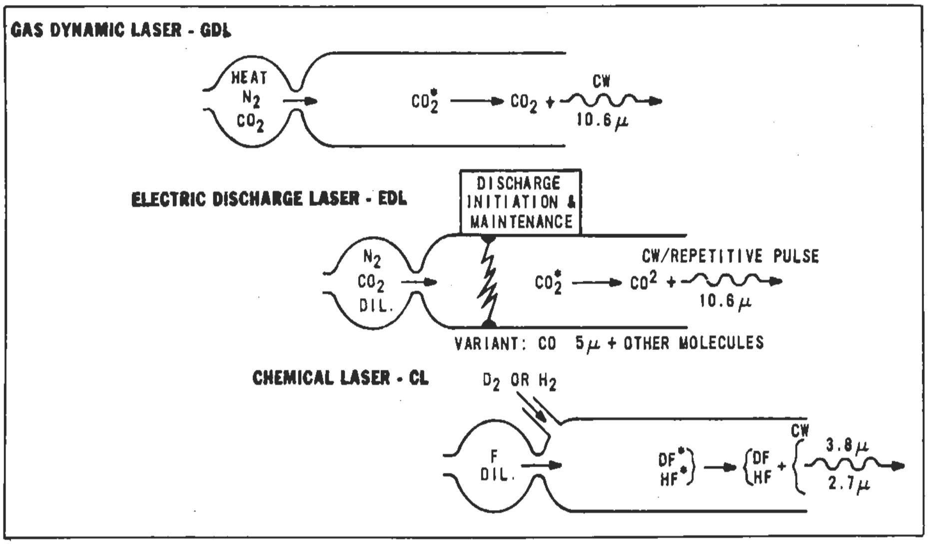
Reality Steps In

Yet when all is said and done, it appears that while the Army can knock down helicopters and the Air Force **Sidewinder** missiles, the potential for a space battle station to actually work is almost negligible. There are two main reasons. The first is atmospheric interference, even allowing for the considerable problems of storing and generating enormous bursts of energy, aiming the weapons and verifying that the target has been hit. Moreover, effective countermeasures against lasers are known, and it is likely that they could be devised for future weapons of this genre.

However, the most effective countermeasure against satellites, whether battle stations or communications satellites, is also the most chilling form of space warfare, namely the detonation of a nuclear weapon in space. Such explosions are expressly prohibited by the 1963 Partial Test Ban Treaty, but military analysts have nonetheless become anxious about the effect of nuclear explosions on satellite weapons systems.

Gamma rays and other forms of high energy radiation from a nuclear explosion would expel electrons from the metal skin of a satellite and thereby generate an electric field inside the satellite, the potential of which could reach a million volts per metre. The electric field would disrupt or destroy the electronic circuitry of the satellite. The effects of a one-megaton explosion would extend through a spherical volume of space 50,000 kilometres in diameter. Any unprotected satellite in this range, but not in the radiation shadow of the earth, would be made useless by the explosion (see **Military Communication: The Chaos Factor,** ETI, Aug. 1983).

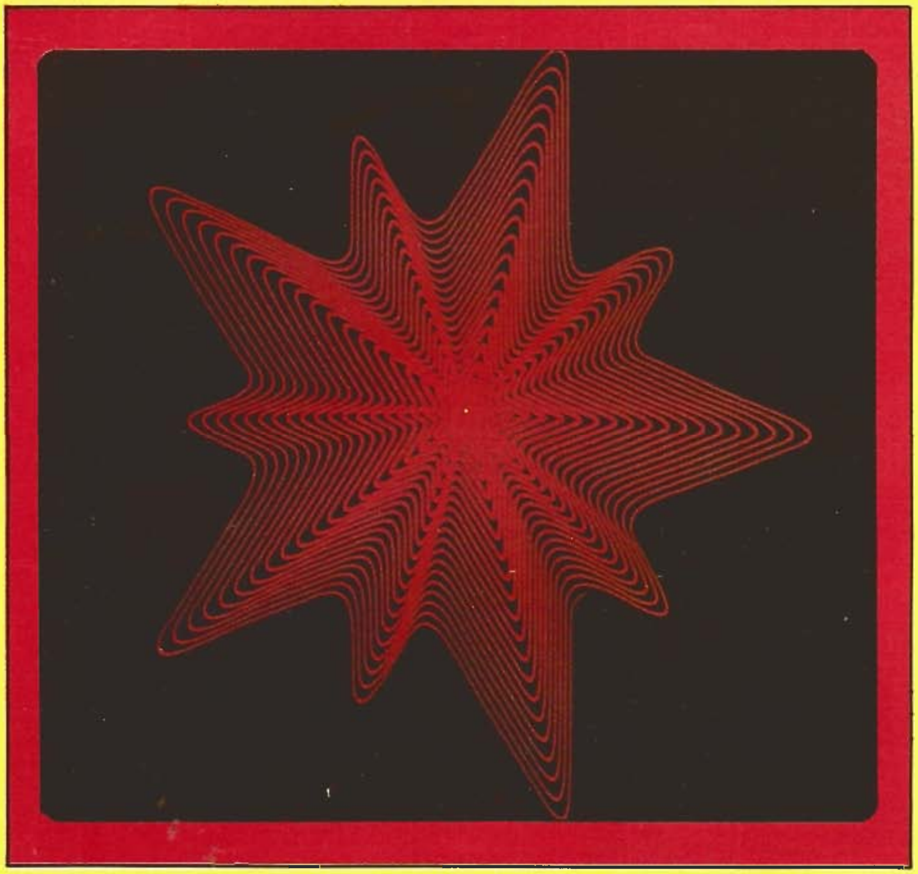
Unless these two problems can be overcome, which is highly unlikely, President Reagan's hope that lasers and other particle-beam technology can be employed by the end of the century to render strategic nuclear weapons obsolete seems just so much chaff. ETI



Three types of lasers used in weaponry.

LASER GRAPHICS

By Jennifer Morris
Image Engineering Corporation



Graphic Basics

Image Engineering deals principally with applications of laser-scanned graphics, a particular technique whereby animated line drawings are projected in laser light. The laser beam is deflected by mirrors mounted on closed-loop X-Y 'scanners' controlled by electronic signals. These scanners direct the laser beam to repeatedly trace out the desired image on a projection surface. If this 'refreshing', as it is called, takes place at a sufficiently high rate, the perceived image is a continuous line of light, resembling neon, but of a different texture.

Initial work in scanned laser graphics concentrated on the use of electronic oscillators which drove the scanners with various waveforms, producing lissajous figures, that is, spirographic geometric patterns. Many current entertainment applications of lasers still rely heavily on this approach. More recent work introduced the use of digital signal generators and computer-based systems to allow controlled image generation — illustrations, logos, text messages and the like — all of which may be electronically animated.

The quality of any laser-scanned graphic is governed by the motion of the scanners, which has certain limitations. Tradeoffs must be made between accurate representation of complex images, and 'flicker,' the effect that occurs when refresh rates are very low. Artists in the medium soon learn to adjust their designs accordingly. However, the limitations of laser graphics are, in a great many applications, more than outweighed by advantages unobtainable in any other medium:

- the contrast ratio is effectively infinite: unlike film or video, the laser projector sends no light to any part of the screen except where it is drawing. Consequently, no 'frame' is apparent around the image.
- the brilliant range of colors can match, and often exceed that of other media when the laser primaries are carefully mixed.
- because laser light is so concentrated, very large images may be readily created without losing image intensity.
- the laser beam is in focus at any distance, so image abberations ('keystoning') introduced by off-center projection angles may be readily compensated for by electronic means.

Lovelight: A Pioneer Planetarium Show

Among the earliest practical realizations of image programming was one executed at General Scanning Inc., under the direction of President Jean (Coco) Montagu. A device known as the Path Controller was developed at GSI by Engineer Peter Selverston. It utilized a touch-tone type keyboard system in which each key corresponded to a compass point (N-NE-S-SW, etc.) The laser projection could be viewed as the user constructed a drawing point-by-point. Information from the keyboard was accumulated in digital memory, and fed through digital-to-analog converters to be output to the scanners. The effect was similar to using an Etch-A-Sketch, but with considerably more refinement. Completed images could be stored and fetched from a cassette, and manipulated with waveforms such as those generated by a music synthesizer.

GSI also considered ways of storing moving sequences for automatic playback. Before undertaking further systems development, however, they set about researching applications and located a company with audio-visual production experience that complemented their engineering talent. That company was Intermedia Systems Corporation, and the two firms launched a joint venture that introduced a new level of accomplishment in laser entertainment.

Production Begins

Intermedia Systems asked me because of my experience with electronic synthesis, to become the laser artist of this joint venture. The Charles Hayden Planetarium of Boston's Museum of Science had been considering laser entertainment for some time. They sponsored an event known as "Laser Day" in May of 1976 to promote exchange between planetarium personnel and laser producers. On the strength

of a ten-minute laser presentation (of which the Path Controller was a vital element) they offered Interscan, the association of GSI and ISC, a contract to produce a full-length show for evening presentations in their dome.

The hardware developed for this production included an electronic graphics studio, a four-color laser projector using a krypton laser, and a unique multichannel recording system. Each laser color had its own scanning system which required three information channels: X (horizontal) axis, Y (vertical) axis, and blanking, or intensity, control. A Hewlett-Packard instrumentation recorder was chosen to allow multiplexing of FM-encoded information; in the end, 14 channels were packed onto a 7-inch reel of quarter-inch recording tape. Included were "event markers" — signals that triggered the special optical effects incorporated in the projector.

Some of these optical effects, designed by GSI's Dean Paulsen, were quite unique: along with the usual stippled plastic and diffraction gratings, Lovelight's projector also held high-speed 'resonant' scanners which created broad, soft spirals of light, and a vibrating mercury pool that provided an effective underwater texture.

Graphics for Lovelight were generated on a data-tablet drawing system designed by Dr. Brian O'Brien. Drawings were traced with an electronic pen, and the coordinates of the line traced were stored and displayed after the tracing was completed. A number of other devices — rotators, multipliers, etc. — were used to animate the drawings and to generate geometric patterns. Manually operated sequences were laid down on the instrumentation recorder and edited to match the soundtrack. The result was a show that started with the touch of a button and ran for forty minutes.

Lovelight Opens

Lovelight's original script concept, supplied by Gerd Stern of ISC, was ambitious in scope, calling for more elaborate animation than could be practically rendered by this system. A modified treatment, executed by Director Walter Gundy and the author, relied on shorter animated sequences, and attempted to exploit the inherent graphic qualities of laser projection. Complex images were achieved by registering the discrete laser colors — red, blue, green and yellow — to create a composite, multi-color drawing. We received invaluable assistance and ingenious ideas from the numerous artists and engineers involved in the production. Lovelight had a gala opening in February 1977, and ran five nights a week for six months to enthusiastic audiences.

Unfortunately, the pressures of mounting such a monumental effort created conflicts; and shortly after the opening, GSI and ISC decided to dissolve Interscan and plan no further joint ventures. However, the attention this show received was beginning to generate more opportunities in laser production. In that year, we undertook work for IBM and WBZ-TV in Boston. Looking for new sources of programming equipment brought us into contact with Laser Displays Inc., whose fledgling organization has already produced some unusual and highly user-oriented hardware. We immediately put this to use in making animated logos for laser projections that were coordinated with slide and film projections in promotional events. Fred Fenning, LDI's electronics designer, seemed to have anticipated many of the needs of artists working in this medium and had provided a system that integrated and expanded the capabilities we'd become accustomed to.

Wendy's: A Convention Extravaganza

Val Habjan, a California A/V producer, called me regarding a three-day convention for Wendy's International, the hamburger chain, which would include a programmed multi-media production, fog machines and chaser lights, a high-school chorus, and even (last minute) Bob Hope. Laser projection was an integral part of his design, and Val had an excellent grasp of what was appropriate to this medium. There were four basic motifs for the laser graphics: signatures, which were drawn on the screen for every speaker's introduction; the corporate logos and slogans, which were coordinated with slide projection; a cartoon character, who was animated and given live voice to interact with a marketing v.p.'s speech; and graphic devices to enhance the convention's awards presentation — the "Golden Spatula Awards" — with appropriate Hollywood-style razzle-dazzle.

Engineers Fred Fenning and Erick Eisack, who had just resigned from LDI, chose nonetheless to meet a personal commitment to Val and Wendy's, and contributed their technical presence. Their particular expertise was essential, in my mind, to this project, as several non-standard systems were involved. Val left for the convention site in Los Angeles, and we three stayed in Boston to complete the system and prepare the show for delivery.

With only two weeks to the convention's opening day, we began work. The system involved a dual projection head, so that identical images could be aimed at screens flanking a center stage. Images were transferred from the computer to memory chips which were installed in a playback machine which also incorporated zoom, rotation, positioning and other manually controlled animation effects. A remarkable feature of the system was the rainbow color control, with which a single image could be made to cycle through bands of color produced with combinations of the laser primaries. Two playback units were set up with a switching system and CRT, so that we had the ability to preview images on the tube before projecting them with the laser.

All this equipment had to be carefully broken down and packed for shipment to L.A.'s Bonaventure Hotel. The sight of two $15,000 lasers on a fork lift made me more nervous than any audience ever did! All arrived intact, however, and the next few days were spent in set-up: scaffolding, power and water feeds to the lasers, checking baffling and BRH safety systems, and, of course, rehearsals. Several changes were made to the program in the process, requiring image memories to be shipped back and forth across the country, and a detailed cue sheet developed. All cues were manually commanded, and as operator, I had to be as alert and responsive as possible. Fred provided quick solutions to the unanticipated requests of the producer, and Eric worked through till morning coaxing the maximum performance from a recalcitrant laser.

Teaming Up For The Future

The success of our efforts on the Wendy's show encouraged us to make our association a permanent one. With computer expert Peter Wolfe joining us, we had an inter-disciplinary team with the skills and experience required to produce high-level laser graphics to professional production standards. Peter, whose twelve years of programming experience at MIT's Draper Laboratory included work with advanced computer graphic simulation and editing software, had formulated a design for a computer-based animation system that could be applied to laser projection. Such a system would expand the potential applications of laser graphics to include advertising displays. Eager to see our concepts in action, Fred, Eric, Peter and I incorporated as Image Engineering in May of this year.

We have addressed our efforts towards solving some of the problems associated with image quality and flexibility of systems operation. The technical refinement we've aimed for is perhaps more important in industrial shows than in amusement parks, but producers of all kinds have expectations, and may underestimate the level of expertise necessary to meet them. Small, but crucial elements, such as bandwidth of a scanner amplifier, or delays between blanking and X-Y signals, can make the difference between a barely acceptable graphic and an elegant one. Therefore, our computer-based drawing system will permit image data stored for laser playback to be otpimized for the particular response of the scanners, eliminating many distortion problems. To assist the artist, this system also incorporates many of the graphical editing features that are elements of the on-going development of our animation system.

A playback unit housing this data provides push-button selection of images, which reside on plug-in cards that may be readily swapped by the operator. Manually programmable functions, including interpolation from one image to the next, rotations, pans and zooms, can be performed live or be stored on magnetic tape. Animated sequences may thus be repeated reliably and accurately. Our projector, designed to be compact and road-able, maintains control over color hue and intensity while maximizing light output. Computer interface to the projector allows multi-color image programming.

These systems, and the services provided with them, make it possible to integrate and coordinate laser effects with a total show concept. Interfaces to audio and lighting systems are provided, and we can include our Memory Multichaser™ programmable lighting controller in a package that will handle a complete lighting environment.

In future perspective, the laser activities of the past few years may look much like the old nickelodeon days of film, when many thought it was just a novelty that would fade with time. In fact, laser technology advances almost daily: new methods in laser manufacture, in scanner control and computer systems, improved recording techniques and better human engineering of systems are all factors contributing to the growth of this new medium. □

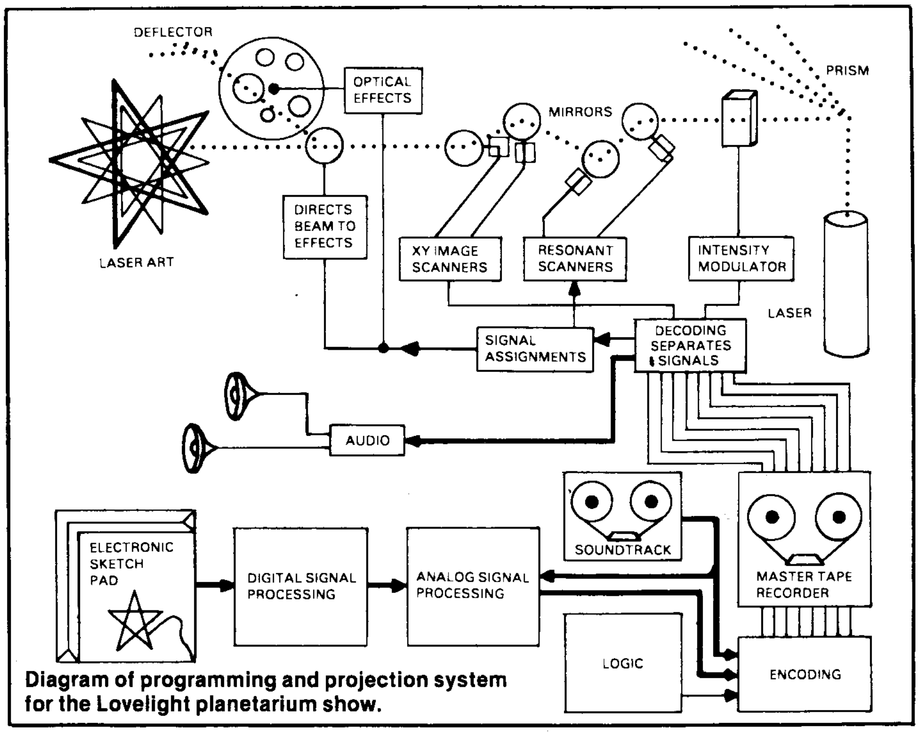


Diagram of programming and projection system for the Lovelight planetarium show.

Cashing in on Coherent Light

The Investment

Laser light is to lighting designers what a Maserati is to high-minded drivers: beautiful, dangerous and expensive. Beautiful? Designers will agree that the keen, clear light generated by oscillating radiation in those slender plasma tubes is something incoherent light just can't match for brillance and flexibility.

Dangerous? We all know that a Class III laser (from 1 mW to .5 W) can damage the eye of an unwitting viewer in less than a second of direct exposure. And monitor though it may, the BRH still hears mysterious tales every month of eye-zapping and high-powered beams in low-ceilinged rooms.

Expensive? A planetarium-housed show such as "Laserock" involves initial investment in equipment and its preparation; programming ("choreography"); advertising; installation; musicians' royalties; salaries for designers, installers, performers, planetarium staff and security — while operating costs include program development, maintenance, labor, and replacement of aging or faulty components. A full-capability, completely installed disco system similar to Xenon's in New York can cost up to $30-$40,000, depending on optional features and laser power requirements. Tunable argon-krypton lasers run from $7,000-$8,000; modulators, drive equipment, mirrors, screens, etc. bring the cost of an average system to the $10-12,000 range. Most schools and small theatres would have to sink two to three years' special projects budget into such a design tool. Naturally these figures lead to the belt-tightening question, "are laser systems worth the cost?"

The Returns

Even with laser show tickets in the $3.50-5.00 range, weekend and some midweek shows are still sellouts nationwide. I asked waiting audience members at Denver's Gates Planetarium what they expected of "Laserock," an elaborately choreographed show created by Laser Images of Van Nuys, Calif. "Excitement. I hear it's pretty intense," said one first-time viewer. Laserist Steve Lavinsky provided precisely that: 55 minutes of oohs and aahs gave rather vocal testimony to his skill.

"Since Ivan Dryer created the first 'Laserium'," says Lynn Condon of Laser Images, "over seven million people have seen our shows." Lynn declined to comment on total gate receipts, but a glance at one's ticket stub and a turn at the abacus suggest that Laser Images — and host planetariums — are doing a healthy business. Theatrical productions employing laser light effects have discovered, (like the Lunt-Fontanne's *Peter Pan;* Tom Skelton, LD) there is high public interest in laser effects. Journalists are drawn to lasers' sensational properties, and getting reviews is facilitated.

Major corporations are also pleased with laser graphics supplied for trade shows and display use. Last fall Laser Displays of Boston with Imero Fiorentino Associates created effects to introduce 1979 models for Chrysler and Cadillac. Laser Displays' graphics also were used this month in celebrating Libya's tenth year of independence, according to Bart Johnson, president. Lasers mounted on a hotel and power plant projected Arabic political slogans on artificial clouds over Bengasi, the nation's capital. Johnson says prayer-prompting in mosques with portable laser projectors may be next.

Despite their cost, for lighting design flexibility, popular appeal, and mind-bending applications, laser special effects are indeed worthy of designers' consideration for contemporary performance situations.

. . . Jill Marks

THE XENON FILE

By Dick Sandhaus
Photos by Tetsu Okuhara.

The Design Challenge

We were recently called upon to provide a state-of-the-art laser system for the Xenon discotheque in New York. The design challenge was to safely and legally provide a broad range of effects that would directly involve all of a large audience in a large space. The goal was to produce a large, bright and kinetic energy field that Xenon's patrons could, from time to time, touch and be touched by.

Xenon wanted a single special effects system that would fill the entire space with tremendous motion and energy. Xenon's owners, Howard Stein and Pepo Vanini, had these requirements:

1) Cover 40 x 25 drop with multi-colored laser patterns synchronized to music.

2) Fill the theatre's principal space with moving light sculptures.

3) Scan laser patterns on the floor and, most importantly, on the dancers.

The first design problem was finding the best location for the laser system. Xenon is a renovated Broadway theatre. What was the stage and forward portion of the orchestra is now the dance floor. Banquette seating and a bar occupy what was the rear half of the orchestra. The first balcony is used for seating and a wide variety of activities; the second balcony is not used. The "mothership," a 30-foot diameter circular lighting truss, hangs high over half the dance floor and descends briefly each night to the height of the first balcony rail. The theatre's original fly system is intact, and is used to lower large lighting and scenic elements over and onto the other half of the dance floor.

Scanning laser beam sends whirling tracers off mirror ball at Xenon.

Placement of the laser system was limited not only by Xenon's physical design, but also by federal regulations regarding the physical distance between the audience and the laser system's output aperture. The Bureau of Radiological Health (BRH) requires a three-meter vertical separation between the laser and the highest (floor) surface patrons can stand on, and a 2.5-meter lateral separation. Given the areas we had to fill with laser scans, this left only two possible mounting positions: high on the back (upstage) wall or suspended out from the first balcony rail. High positions in the second balcony were ruled out because the "mothership" truss would have interrupted the path of the scanning laser beams.

We eventually chose the center of the balcony rail because it allowed a long throw distance for symmetrical front projection onto the 40 x 25 drop screen. Short-throw rear projection onto a suitable rear projection surface was possible, but this would have added the costs of scan expanding optics and a special screen, Rear projection would also have blocked the operator's view of the laser projection system when the screen was in place.

Isolating the laser from excessive vibration was another consideration. Xenon's back wall is its sound system, a massive complex of loudspeakers including enormous low range speakers that literally shake the floor. Because any laser and scanner system incorporates critically

Cone of laser light over Xenon's floor.

aligned optics, it is desirable to isolate laser systems from vibration that might cause misalignment. When this is impossible, a suitable shock-mounting system must be used. Suspended from the balcony rail, however, the Xenon system requires no special mounting and only a minor fine-tuning alignment once every few weeks. This procedure takes about five minutes. The system's remote control panel was placed in Xenon's lighting booth, a glass-walled enclosure at a front corner of the balcony. This gives the lighting operator unobstructed views of the laser projection system and every area reached by laser scans.

The Laser System

Xenon wanted a "full-color" system, so they bought one of our three-channel systems with independent programming control over each of the three primary color lines. We used a mixed-gas argon-krypton laser manufactured to our specifications by Control Laser Corporation. This mixed-gas laser produces an almost white beam with red, green and blue lines that are roughly equal in luminous power.

The laser we chose for the Xenon installation has a total output power of 1.5 watts. Because our scanning systems have an optical throughput efficiency of seventy to eighty percent, the actual all-lines output of the Xenon system is about 1.2 watts or slightly less than half a watt per channel. This is in accordance with the BRH guideline that limits a system's output power to what is absolutely necessary to perform its function.

As the accompanying photos illustrate, the less than half-watt output per color is quite adequate to produce very large and bright images. The brilliance of the patterns projected across the forty-foot scrim compete successfully with all of Xenon's traditional lighting effects, including strobes and neons. When the laser is used with little or no competing light, the whirling images appear to jump off the screen into three-dimensional space. The laser beam's coherence allows the projection of images against a true black. Given no other light sources, the contrast ratio of image to background is on the order of 300:1. This compares very favorably with still or motion film projected images where the film's best "black" allows transmission of a significant amount of light and results in a contrast ratio of less than 70:1. The greatly enhanced contrast between the bright laser image and the truer "black" background produces the effect of "no background". Hence the appearance of the huge, bright images floating and spinning through space.

This apparently three-dimensional effect is used dynamically in Xenon to set up the audience for truly three-dimensional uses of the laser. Two mineral oil-based fog machines put enough scattering medium in the air to make the scanning laser beams visible throughout the theatre. Kinetic planes and tunnels of light appear overhead, and scans broken and reflected by mirror balls send thousands of moving beams through the air.

Finally, the tunnels of light lower and converge on the floor, using the dancers as screens, as live elements of the light performance. These scanning laser light sculptures surround people like animated neon and never fail to produce cheers and applause. This effect has great impact, the Xenon is careful not to overuse it. The audience is teased with this "touchable" light only for a few minutes at a time, two or three times each night.

Safety Factors

Within safety and legal parameters, Xenon is able to directly expose its customers to laser light. This is possible because our scanning systems incorporate a number of design features which prevent exposure to excessive laser light radiation. The basic safety feature is a scan-loss shutdown, whereby a shutter is activated to prevent laser emission in the event of scanner malfunction.

This feature is of primary importance because an unscanned — or improperly scanned — laser beam is potentially dangerous. An *un*scanned beam of nearly a half-watt would almost certainly cause significant, permanent eye damage if viewed directly. This is because the entire output is concentrated into a spot only a few millimeters in diameter. When this focused light energy intersects the retina, much of it is absorbed as heat energy. This can destroy cells if the eye is directly exposed for too long a duration to a sufficiently strong beam.

By scanning the beam (i.e., tracing a pattern many times per second to create the appearance of a continuous line image), we insure that there can be only momentary exposure to it. The rate, or frequency, of scanning is therefore very important. If the scan rate is too slow, the beam passes across the retina too slowly and may constitute excêssive exposure. If the scan rate it too fast, the retina may be exposed to too many brief passes per second, the cumulative effect of which may be excessive. This is because the eye doesn't have sufficient time between repeated momentary exposures to dissipate the heat energy it has absorbed from immeditely previous exposures. So it's really the velocity of the scanning beam that is of key importance here. Because the velocity is determined by the scan frequency and the size of the scanned image, we also place a lower limit on scan size and an upper limit on cumulative exposure time.

These time and size parameters will vary according to the size and layout of individual spaces. In Xenon, most of what is done with the laser does not directly expose people to laser radiation. Projection of images on the scrim and light sculptures overhead are confined to inaccessible areas. The Xenon control panel has a small, locked panel containing presets which define boundaries beyond which the laser cannot scan. In the event of scanner malfunction, the shutter closes.

This locked panel also contains the preset adjustment for minimum scan size. When the operator calls up an image size that is too small, the shutter is activated. In Xenon, this limit is particulary important when the scan is reflected by the mirror ball toward people. To prevent the scanning beam from passing across any mirrored facet at too low or high a velocity, the minimum preset scan size is greater than eighty percent of the diameter of the mirror ball. Additionally, the total distance (about sixty feet) a beam travels from aperture to mirror ball to nearest person is long enough for the beam diameter to expand to considerably more than seven millimeters. That's the maximum pupil diameter of the dark-adjusted eye, so exposure to a "fatter" beam means that only a portion of the beam's light energy actually enters the eye.

The position of any image is controlled by a joystick. When specific image patterns are aimed down to the floor, thereby exposing dancers to direct laser radiation, an internal timing circuit is automatically activated. This circuit registers the elapsed running time of cumulative exposure to raditation. In the case of Xenon, a person standing absolutely stationary and staring into the laser aperture would be exposed to accumulated radiation in excess of BRH's Class I limit after nineteen minutes and forty seconds. So the Xenon system is preset to shutdown after eighteen minutes of running time with the joystick positioned below the appropriate lower limit.

Because Xenon uses this direct exposure effect to a very limited extent, the timing circuit has never run out to its full limit. If it ever does, this time limit can be reset by the system operator every 10^4 seconds, or two hours and forty-six minutes. This is the time duration that the BRH standard specifies in its measurement parameters for exposure to the kind of radiation we're dealing with at Xenon. It's based on experimental biological effects data which demonstrate the eye's ability to absorb and dissipate up to a certain level of cumulative laser radiation within a period of 10,000 seconds. Despite the fact that the laser scans are continually changing and that it's quite unrealistic to expect a dancer at Xenon to stand still and stare into a laser aperture for nineteen minutes, much less two and three-quarters hours, the BRH guidelines are based on theoretical worst cases. So in the case of Xenon, this is something we had to be con-concerned with and comply with. The BRH sends representatives to examine all laser systems as part of their routine measurement program. They visited Xenon one evening to see how the laser was actually used, and then spent all of the next day measuring laser emissions in various parts of the theatre to be sure there was no failure to comply.

Operation

When you're just trying to produce a blockbuster lighting effect, this may seem like an awful lot to contend with. That's why we designed and built the Xenon system, and all our systems, to contend with this automatically. Although we install all of our systems and administer a complete training program to operators, we designed the Xenon system so it could be operated by the person who controls the entire lighting system.

Because Xenon's LD also runs the laser, he uses a variety of audio-interfaced presets to provide continuous variation in a sort of "automatic pilot" mode. Each control channel has separate control pots for each of the eight visual elements that define the shape of a pattern (its size, complexity, speed of rotation in various planes, etc.). Although these elements can be controlled individually by hand, one or more of them can be assigned to respond to an audio signal. So Xenon's laser patterns and sculptures change size and reconfigure themselves in sync with the music.

For easy manual operation, several or all of these control elements can be reassigned from their individual rotary pots to a single slide pot. This allows the operator to create radical changes and motions with one finger. This is particularly important in a three-channel system like Xenon's, where one hand can control three independent images placed in very different parts of the theatre. On occasion, Xenon's LD will create three identical images (in different colors) by assigning one control channel to a "master" function and the other two to "slave" functions. Working the three joysticks, he then has the ability to converge the patterns and steer them around the space.

Cost

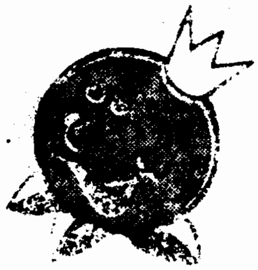
A system like the Xenon unit will cost between $30-40,000, varying according to certain optional features and the laser power requirements. The cost of a full-capability single-channel system with a quarter-watt output is under $10,000. If that sounds like a lot for one special effects system, its cost effectiveness is summed up by Xenon's Howard Stein: "The laser is our strongest effect because it's constantly changing the energy of the entire space. All our other lights, props and drops decorate the space, and eventually people get used to them and expect them. But the laser is completely unpredictable — it does something new to the whole environment every minute, every night."

Like any other lighting element, the laser must be properly designed into its overall setting. Unlike other lighting elements, a well designed and well used laser system can continually energize and define an entire space in an infinite variety of new ways.

Dick Sandhaus is the president of The Science Faction Corporation, 445 Park Avenue, New York, New York, (212) 688-7786. His company designed and manufactured the SFC-2000 Series Laser System that is featured in Xenon. LD

HALFTIME SHOW

THE MIAMI HERALD JANUARY 2, 1980 SPECIAL SOUVENIR ISSUE



Lasers Beam Out Halftime Sparkle

By STEPHEN DOIG
Herald Staff Writer

Laser rays and disco daze. Banjo strains and railroad trains. Marching bands and clapping hands. Paddlewheel steam and beauty queens.

All that and just about everything else from dancing golf carts to more than 50,000 balloons boogied and bounced across the Orange Bowl on New Year's Night.

It was the 1980 half-time spectacle, a $75,000, 12-minute extravaganza meticulously planned to convince the sell-out crowd at the stadium and millions of television viewers that there's no such word as "excess."

The gala started in the skies a mile northwest of the stadium with streams of white smoke released by a cropduster. The hazy clouds were formed to make the laser beams sparkle, but the chilly wind promptly blew most of them away.

But it didn't matter at all. The lasers were the twinkling stars of the show anyway.

"I THOUGHT they could only do stuff like that on TV," marveled camerman Todd Klein. "I haven't seen anything like that since Battlestar Gallactica was cancelled."

While the twin lasers hummed an eerie tune high atop the stands, the blue-green beams laced the playing field with dervish images of dueling banjos and bolts of lightning.

More than 500 bandsmen and dancers

Turn to Page 4D Col. 1

PLEASE SEE REVERSE SIDE...

FROM PAGE 1D

from Coral Gables, Miami Southridge and Miami Central high schools performed melodies from the days of the riverboat to the electronic disco of tomorrow.

But each time the lasers came on in the darkened stadium, all eyes followed the entrancing beams as they danced and swirled on the field and into the sky. The beams twinkled off mirror balls, fanned across the stadium like scimitars and rotated into coiled springs.

THROUGH it all the spectators shrieked and cheered. When 10 stands of skyrockets and sparklers climaxed the show, the fans roared and shook yellow balloons given them as they entered the stadium, making the Orange Bowl resemble a field of daisies under alien attack.

"It was fantastic," said Red Taylor of Miami. "It was the most beautiful show I've ever seen in my life. And I've been coming to the Orange Bowl for 20 years . . .

"They'd have to be geniuses to have put this on."

The lights were rated "very, very effective" by Ruth Massingill of Miami, but she found the balloons "the messy part."

Orange Bowl Princess Kathy Hall rode the disco train and wondered who from her home state of California might be watching.

"The show took a lot of preparation," said the 20-year-old Miami-Dade Community College South student.

THE CONCEPTION and preparation for this frenetic blend of high-energy plasma physics and high-camp showbiz took most of a year.

It began shortly after Orange Bowl 1979 when Don McNamara, executive director of the Orange Bowl Committee, by chance stopped in Las Vegas to watch singer Ann-Margaret perform.

McNamara wanted a unique ingredient for his next half-time recipe. Then he saw flashing blue and green laser beams, produced by a California company called Laser Images, supply the spark for Ann-Margaret's sparkle.

"It was the most mind-boggling thing I ever saw," McNamara recalls. Zap! Lasers would be this year's Orange Bowl centerpiece.

Next, McNamara wanted a musical ingredient different from the usual brassy 76-trombones sound. He picked the banjo, what he calls "that uniquely American instrument."

Because the banjo and the laser are an Atomic Age apart, McNamara wanted a third ingredient to bridge the gulf between vibrating steel strings and vibrating krypton ions.

He found it in the North Miami sound studio of John St. John, specialist in the Moog electronic synthesizer, the Cuisanart of music.

THE MOOG looks like the illegitimate off-spring of a pipe organ and a telephone switchboard. It can conjure up sounds ranging from the croon of a clarinet to the snap, crackle and pop of a toaster oven with a bad case of the shorts.

St. John had written a Moog ditty called "Disco Express" that McNamara decided would be perfect counterpoint to a laser bombardment.

The marching bands and mobile displays presented only the usual logistics problems. But the lasers were something else again.

"We've done planetarium shows and things like the Ann-Margaret act all over the U.S.," Jim Hannigan, the young special effects technician for Laser Images, said last Friday as he tinkered with his gear. "But I don't know of anyone who has done this in a half-time show."

Hannigan had to take unusual care in installing his two $33,000 lasers on the sides of the Orange Bowl.

EACH LASER, about the size of a 6-foot loaf of French bread, needs 30 kilowatts of power to operate. That's enough to run the color televisions in about 300 homes.

To handle the load, city electricians wired special 480-volt lines to the stadium roof, but all that power created a different problem.

A laser beam at its source produces just 20 watts of light output. Most of the other 29,980 watts of input power, said Hannigan, turns into surplus heat. So hoses gushing 5 gallons of cooling water per minute were installed to keep the lasers from melting into slag in milliseconds.

"Think of them as very expensive water heaters," Hannigan said.

But the trickiest set-up problems of all were posed by the seemingly-scant 20 watts of output power.

The reason is the special nature of laser light: while a 20-watt light bulb is too dim to read by, a 20-watt laser produces a pencil-thin beam that can burn and blind if used improperly.

A LASER works somewhat like a fluorescent light bulb. An electric current is sent through a gas-filled glass tube; when enough power is applied, the gas begins to glow.

But in a laser, partially silvered mirrors at each end bounce the increasingly energetic light particles (called "photons") back and forth until they pack enough power to shine through the mirrors. The result is a thin beam of high-energy photons blasting tightly in the same direction.

Thus, the federal Bureau of Radiation Hazards (lasers radiate light, but aren't radioactive) had to approve the show.

A specialist from the bureau flew into Miami Friday to test the beams. He ensured that when they reached the nearest spectators, their distance-reduced power would be at the safe microwatt level that couldn't burn an unshielded retina.

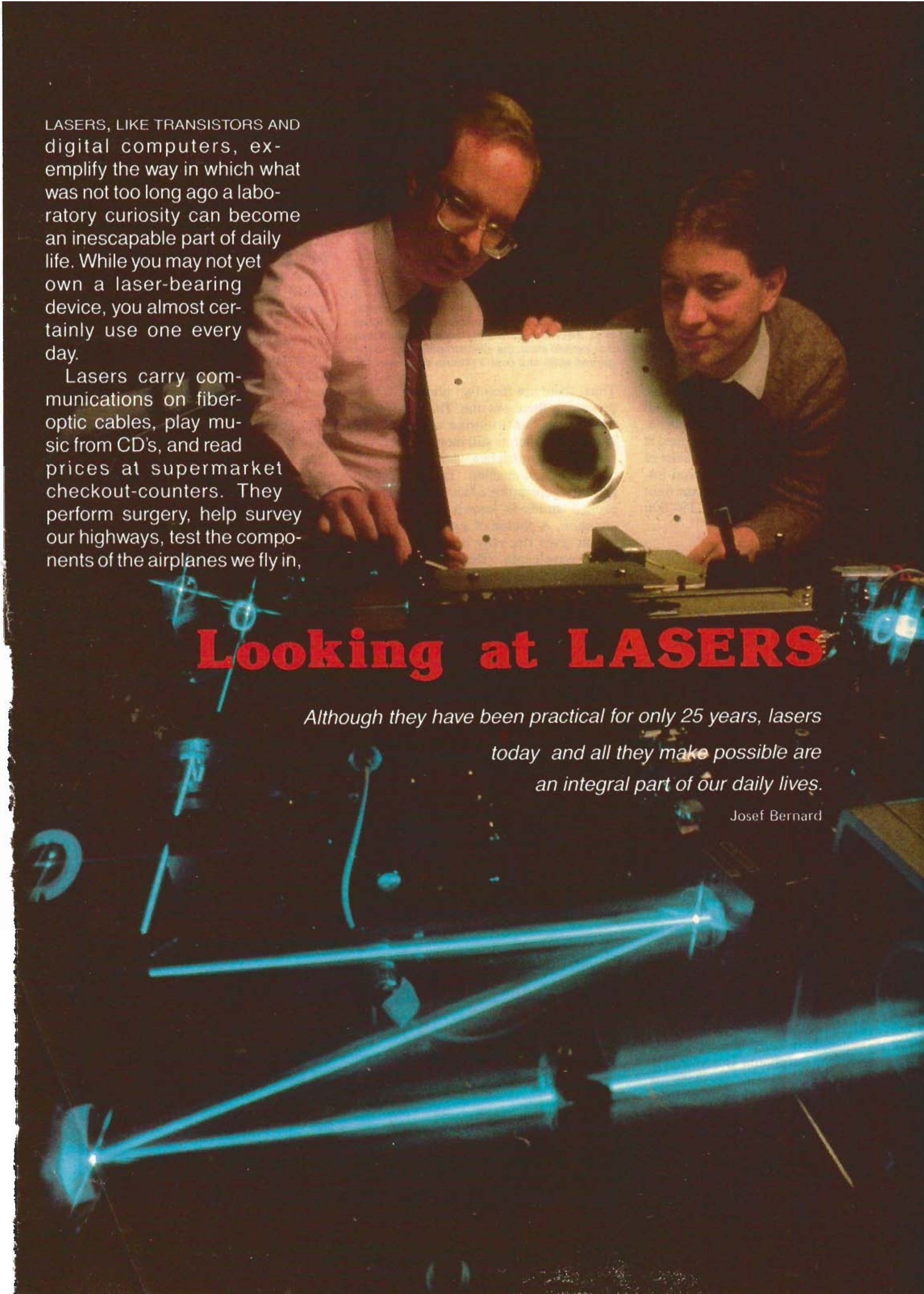
AS FOR the magical visual effects, they're all done with mirrors, Hannigan explained.

The laser beam is aimed into a complex of adjustable mirrors. The precisely movable reflectors trace the beams into shapes and words so rapidly that the human eye sees the moving dot of light as a whole pattern.

Laser entertainment someday may have more dazzling effects to offer, Hannigan predicts. Scientists are working on ways to use laser light to produce three-dimensional "holograms" of objects that seemingly appear in midair.

If so, picture this for the 1990 Orange Bowl: a holographic orange tree towering over the field, while from its branches hang 200 singers dressed as cans of frozen juice concentrate singing "Disco Citrus."

Best yet, McNamara could clean up the whole mess in time for the second half just by throwing a switch.



Looking at LASERS

Although they have been practical for only 25 years, lasers today and all they make possible are an integral part of our daily lives.

Josef Bernard

LASERS, LIKE TRANSISTORS AND digital computers, exemplify the way in which what was not too long ago a laboratory curiosity can become an inescapable part of daily life. While you may not yet own a laser-bearing device, you almost certainly use one every day.

Lasers carry communications on fiber-optic cables, play music from CD's, and read prices at supermarket checkout-counters. They perform surgery, help survey our highways, test the components of the airplanes we fly in, and entertain us at rock concerts. They also make formidable weapons.

What is a laser?

A laser (which stands for *L*ight *A*mplification by *S*imulated *E*mission of *R*adiation) is a source of intense light that has several unusual and useful properties. The light is monochromatic, which means that it is a single, very pure, color whose frequency can be measured and used as a precision standard in and out of the laboratory. Laser light is coherent—all the waves of a beam are in phase. Unlike natural and most artificial light sources, whose emissions are incoherent, or phased randomly, a laser produces packets of photons all "marching in step", and possessing a great deal of energy. Finally, because of the way they are generated the rays of light produced by a laser are all parallel to one another, or very nearly so. A pencil-thin beam of laser light aimed at the moon will spread out to a diameter of only 1½ miles. That may not sound impressive—until you consider that the light would travel a distance of about 250,000 miles before diverging that far.

How lasers work

The principle behind the laser is called stimulated emission. That term refers to the fact that an atom, when in an excited state, can be made to emit a photon when bombarded by other photons or by another high-energy source such as a source of electrons.

That needs a little explaining. Figure 1-*a* shows a simple hydrogen atom—just a proton and an electron. The "height" of the orbit of the electron depends on the amount of energy that the electron is carrying and is very strictly defined by nature. Further, for an electron to be forced to jump from one orbit to another requires a precise amount of energy, or quantum, to be added to it.

In its lowest orbit, no energy has been added and the electron is in its normal, or ground, state. When just the right amount of energy is applied, the electron will jump to a higher orbit, and it is said to be excited (Fig. 1-*b*). That excited state, though, is unstable, so the electron quickly returns to its ground state. When it does that it gives up the energy that was applied to it, in the form of a photon, or particle of light. (Light is electromagnetic radiation but it frequently behaves like a particle. For that reason, a photon is sometimes called a "waveicle.") That spontaneous emission of photons is where laser light begins.

If you get enough excited atoms together, spontaneously emitting photons as they undergo the transition from the excited to the ground state, an interesting thing happens. When one of those photons strikes an already excited atom, it changes state and emits its own photon (Fig. 1-*c*).

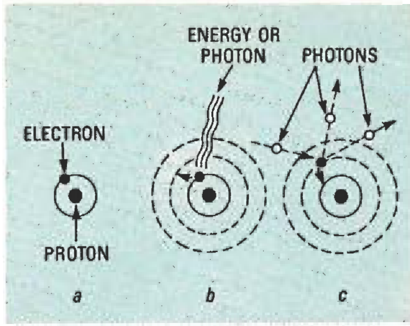


FIG. 1—A SIMPLE HYDROGEN ATOM is shown in *a*. If a precise amount of energy, or quantum, is added to the atom (*b*), the electron makes a transition from its normal ground state to a less-stable excited state and jumps to the next higher orbit. If a photon strikes the electron while it is in that excited state, the electron will return to the ground state and emit a photon of its own (*c*).

Thus, there are then two photons where previously there was one. Those two photons can go on to strike other excited atoms and generate still more photons—a process very much like what happens in a nuclear-fission reaction. That process of photons generating other photons from excited atoms is known as stimulated emission. A photon of a particular wavelength gives rise only to photons of the same wavelength. Thus, laser light is monochromatic; it contains only a single color.

The trick, of course, is to get together in one place a large number of excited atoms of the same kind, so the that stimulated emission of photons can take place. That is done by pumping the atoms in a material up to an excited state by bombarding them with intense light or with some other source of energy such as a beam of electrons. With a ruby laser—the type used by Theodore Maiman on July 7, 1960 when he demonstrated the first laser—as an example, let's examine the lasing process.

A simple diagram of a ruby laser appears in Fig. 2. The heart of that device is a rod of synthetic ruby whose ends are finely ground and polished so they are optically flat and are exactly parallel to one another. Both ends of the rod are silvered to reflect light back into it, but the reflecting surface at one end is not a perfect reflector—it allows perhaps ten percent of the light generated within the rod to escape. That light is the laser beam.

The rod is surrounded by a spirally-wrapped xenon flash tube similar to those used in electronic flash-units. The light produced by that tube will excite the atoms in the ruby rod. Because of that, that type of laser is known as an optically pumped laser. (As we shall see, there are other types of excitation commonly used.) The cooling equipment is present to remove the heat generated by the lasing device. Lasers are extremely inefficient—only one or two percent of the power they consume is transformed into usable laser light; the rest is given off as ordinary light and lots of heat. That isn't really too bad though—an ordinary incandescent bulb is only about two percent efficient, and the light it produces can't begin to compare with that from a laser.

When the flash tube discharges, the photons it emits enter the ruby rod through its sides and excite the material's chromium atoms, which absorb green and blue light. (Those atoms are what give the ruby its reddish color; you may remember from physics that whatever light a material doesn't reflect or transmit, it absorbs.) When those excited atoms decay from their excited state they give off photons, which trigger other excited atoms to release photons, and so on. The whole process in a ruby laser takes place in about 300 microseconds, and an intense burst of ruby-red light is produced.

We now have lots of light, but we still don't have a laser. That's where the reflective end surfaces of the rod come in. Most of the red light generated within the rod escapes through the sides, but some of it is reflected back into the rod, and that gives rise to the stimulated emission of more red light (hence the "amplification" in the word "laser").

A portion of the light is not reflected, however, but escapes from the rod through the end that is only partially silvered. That

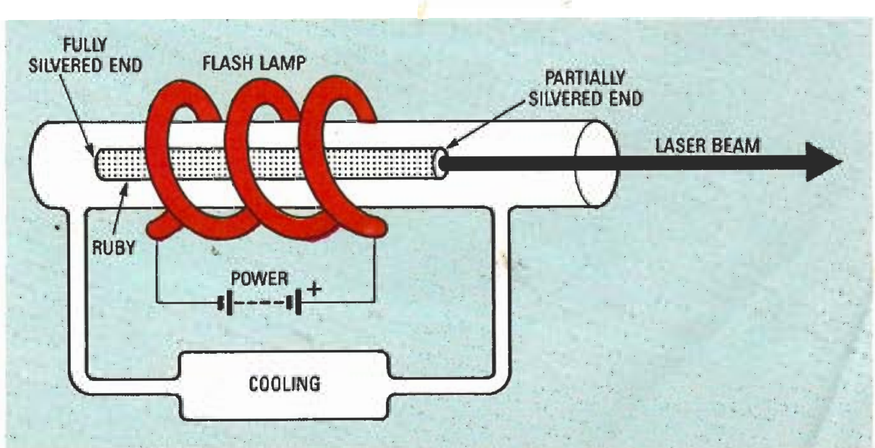


FIG. 2—IN THIS OPTICALLY-PUMPED LASER the light produced by a xenon flash lamp is used to excite the atoms in a ruby rod.

is the laser beam. It is monochromatic because the photons that trigger stimulated emission give rise only to photons like themselves. It is also coherent—all the light waves are in phase. That, too, is a result of the process of stimulated emission; the phase of the photons generated is identical to that of the stimulating photon. The rest of the light reflected by the rod's mirrored ends bounces back to interact with more chromium atoms and produce more photons.

Figures 3-*a* and 3-*b*, respectively, represent coherent and incoherent (random phase) light. As is the case with any wave phenomenon—we're now considering photons as waves rather than as particles—out-of-phase waves tend to cancel each other. Because all the waves of a laser beam are in phase, it is much more intense and powerful than a beam of ordinary incoherent light.

Finally, all of the photons in a laser beam travel parallel to one another. That is the result of the orientation of the reflecting surfaces at the ends of the lasing element. The beam of even an inexpensive laser has a divergence of only about one-twentieth of a degree, which means that the energy it carries is not diffused appreciably over distance.

There are many, many types of lasers, and their characteristics and modes of operation tend to overlap. The following examples are just a small cross section of what has been developed in the past 25 years.

Crystal lasers

This is the category to which the original ruby laser belongs. Those lasers are optically pumped and have a relatively low-power output, in the milliwatt range. The most common type is the neodymium-YAG (for *Y*trium-*A*luminum-*G*arnet) laser, which emits light in the near-infrared. YAG lasers can be operated continuously because the material from which they're made conducts heat, which would otherwise destroy the laser rod, relatively well.

Another member of the crystal-laser family is the neodymium-glass laser. It is less expensive to produce than the YAG type (glass is cheaper than garnet, even the synthetic kind), but it must be pulsed, or operated on a one-shot basis. It cannot sustain continuous operation because of glass's poor heat conductivity.

Gas lasers

There are more gas lasers than there are any other type. Over 5000 types of laser activity in gases are known. Gas lasers are not usually optically pumped, but are energized by passing an electric current at a potential of several thousand volts through the gas, which is contained in a tube with polished and silvered faces similar to the ends of the ruby rod described earlier. As

FIG. 3—IN LASER LIGHT, all of the waves are in phase; thus they are said to be coherent (*a*). In normal light, the waves have no phase relationship (*b*).

the current flows through the gas, the electrons transfer some of their energy to it, bringing it to a state where the stimulated emission of photons can occur. Because of the way they're constructed, gas lasers can be cooled more efficiently than crystal types, and lend themselves better to continuous operation.

The most widely used gas laser is the helium-argon laser, which can be built for a modest sum by almost any experimenter. It is able to produce no more than 50 milliwatts, but its tight beam of red light, about a millimeter across, makes it ideal for laboratory and experimental use.

Argon and krypton lasers can produce a wide range of colors, but are still relatively low in power. It is not feasible, for example, to construct an argon laser more powerful than 100 watts. Argon lasers with their green light are frequently used in medical applications.

The infrared carbon-dioxide laser is more of a heavyweight. It can have an output as high as several hundred kilowatts. Moderate-sized lasers of that sort are widely used in industry.

Liquid lasers

Organic dyes dissolved in organic compounds such as alcohol can be made to lase, too. Organic lasers are unusual in that one laser can produce a wide range of colors. That spectrum can be optically tuned, and a very precise selection of light of a single color can be made. That capability makes the dye laser a very valuable laboratory tool.

Semiconductor lasers

Semiconductor lasers (Fig. 4) are members of the LED family. They differ from ordinary LED's in that they consume considerably more current and the edges of the semiconductor die are polished to form interior reflecting surfaces. Because of their extremely small size—about as big as a grain of salt—and the difficulty of removing the heat they generate, those lasers do not have a very high output. Still, there are many applications to which they are well suited, among them fiber-optic communications and compact-disc players.

Laser applications

In the 25 years since they came into existence, lasers have proven themselves invaluable in a diverse range of fields. Here are a few of them:

Industry: The high temperatures produced by focused laser beams make them excellent tools for welding, cutting, and drilling. A pinpoint of coherent light can cut or bore much more cleanly than its mechanical equivalent, with much less waste. (An informal, and entirely unofficial, system for rating the strength of lasers measures their power in terms of "Gillettes"—the number of razor blades that a beam of laser light can successfully punch through.)

Photographs taken by laser light can be used to determine stress regions and faults

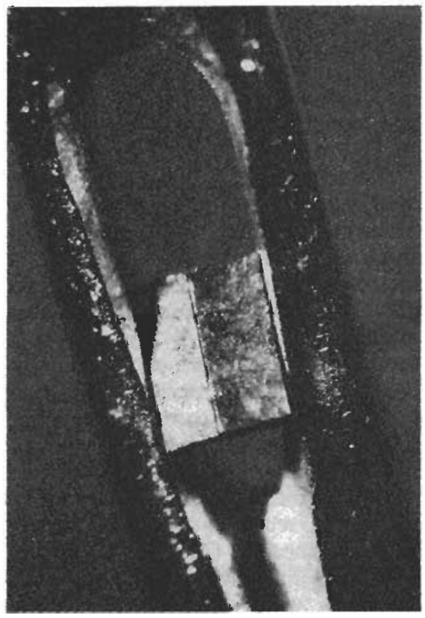


FIG. 4—THIS SEMICONDUCTOR LASER is so tiny that it can fit in the eye of an ordinary sewing needle. Photo courtesy of ATT Bell Laboratories.

in materials, simplifying and improving quality control procedures in critical applications. Lasers are also used in industry for non-contact monitoring of a wide variety of systems. See Fig. 5.

Medicine: Lasers find applications in numerous areas of medicine, among them dermatology, gynecology, and many areas of surgery. The finely focused beam of a laser can operate in areas (such as the inside of the eye) inaccessible to the traditional scalpel.

Science: Lasers have helped scientists both to refine existing knowledge and to learn more about our universe. Using lasers, it has been possible to determine

FIG. 5—LASERS HAVE many applications in industry. Here's a device that uses a laser to monitor the performance of an ultrasonic wire bonder, which is used in electronics production.

the speed of light (186,282.398 miles/second; 299,792.458 kilometers/second) with an accuracy hitherto unknown, and other units of measures have also benefited. A laser beam follows what must be the world's straightest line, a boon for surveyors and the like. Lasers in the laboratory have also allowed the development of new techniques to perform tasks that were previously impossible. Nuclear fusion reactions making possible the generation of enormous quantities of inexpensive electricity from plain seawater will probably be initiated and sustained by lasers.

Communications: Right now fiber-optic communications links using semiconductor lasers are in limited use, but their potential for carrying vast quantities of information makes it certain that as new installations are made, they will become much more common. In space, where laser light cannot be attenuated by air, it may carry communications and data from satellite to satellite, or even to earth. Lasers also are the heart, of course, of the laser printers; those devices, with their high-quality outputs, are now becoming popular in computer circles.

Entertainment: Laser-light shows are popular at rock concerts, and lasers are also used to record and read the information contained on CD's and most videodiscs. Holography, practical only with laser light, makes possible 3-D photography without a camera or special viewing device, and has given birth to a new art form. One day we may enjoy holographic movies, although holographic television at this point seems rather farfetched because of the limited resolution of even the most sophisticated video systems. The applications of holography, of course, are not limited to the world of entertainment. Holographic techniques are also used in devices like scanners for UPC (*U*niversal *P*roduct *C*ode) readers in stores, and in the restoration of artwork.

War: Like dynamite, lasers can be put to both peaceful and destructive uses. Currently in the headlines is the "Star-Wars" technology that will take the science of war into the peace of space. Lasers are also used in the navigation systems of missiles and in targeting devices.

New uses for the unique qualities of laser light are constantly being conceived. Among some of the more unusual and esoteric areas being explored are dental holography, gene manipulation, acupuncture, laser-based optical computers, and the use of lasers to transmit power from solar-energy-gathering satellites. Future applications of the laser may only be limited by the scope of human imagination.

It doesn't take much to see that the invention of the laser is one of the most significant things to come out of the laboratory in this century. **R-E**

BUILD THIS

HELIUM—NEON LASER

Build this simple helium-neon laser and start having fun with photons!

ROBERT GROSSBLATT and ROBERT IANNINI

BACK IN THE HEYDAY OF SCIENCE FICTION'S era of purple prose, tales of bug-eyed monsters, death rays, and the like filled many a pulp magazine. Of course, we knew then that it was all just fantasy; you could no more have a "death ray" than you could travel faster than sound or put a man on the moon.

While those bug-eyed monsters (or BEM's, for short) have yet to pay us a visit (to the best of our knowledge), much of yesterday's science fiction is today's science fact. We even have a death ray, of sorts. Of course, we are referring to the laser, which can be a powerful weapon in the hands of those who wish to use it as such.

But the laser is also a great tool for science and industry. In just 25 years the laser has gone from far-fetched notion, to scientific reality, to common noun. Hardly a day goes by where some part of our lives is not affected by lasers. Today, the laser has joined the transistor as a hallmark of modern electronics.

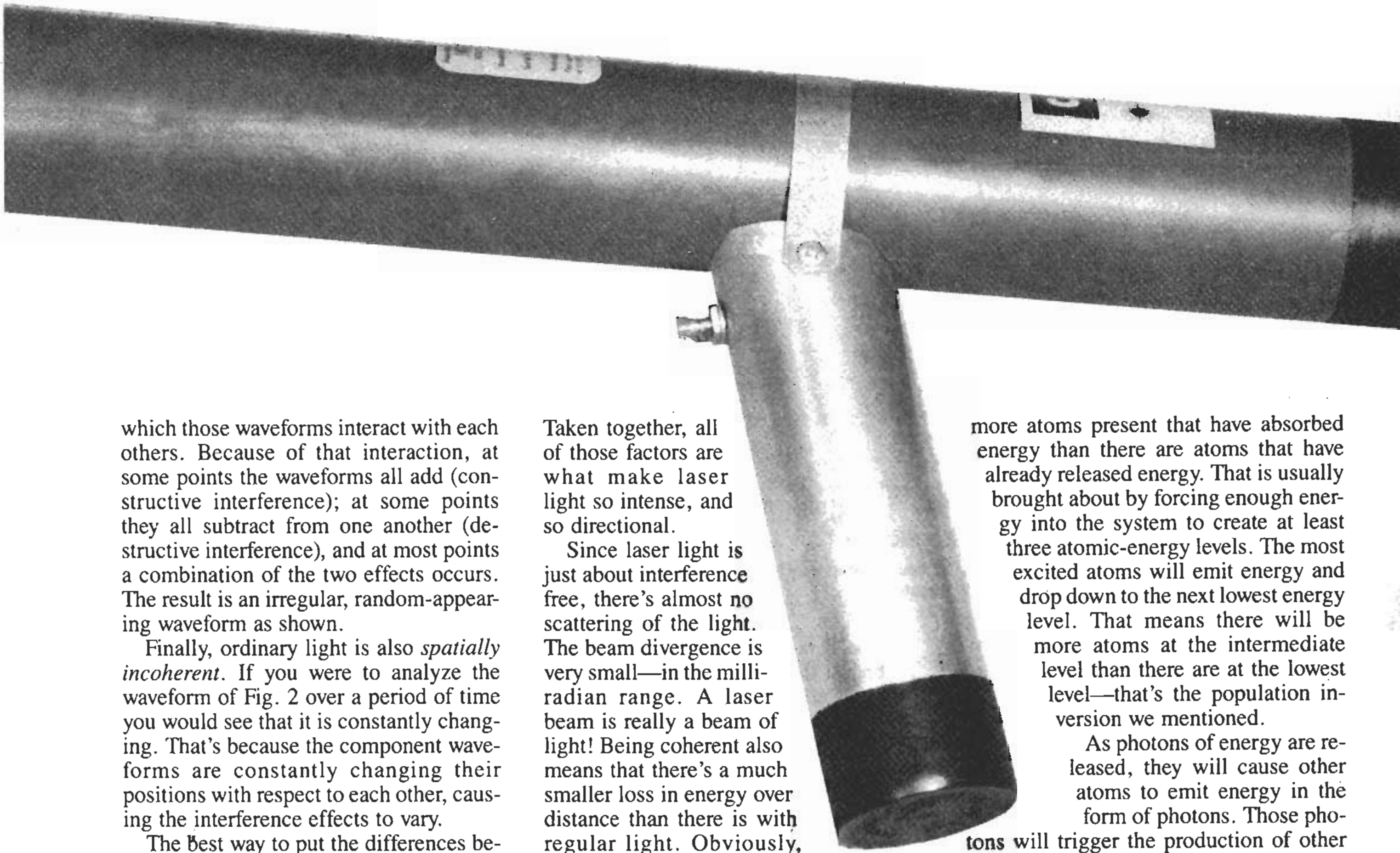
What's a laser?

The word *laser* is an acronym for *L*ight *A*mplification by *S*imulated *E*mission of *R*adiation. But for most of us, that provides a poor explanation of what a laser is and how it works. To find a better explanation, we have to leave electronics for a while, drop into the world of physics, and talk a little bit about the nature of light. You can't understand laser light until you have some familiarity with the properties of light in general.

There are three ways in which laser light differs from ordinary light, and each of those differences contributes to the special characteristics of a laser. Let's begin by looking at some of the characteristics of ordinary light.

Ordinary light has a relatively wide bandwidth. That means that a spectrographic analysis would reveal that regular light is made up of many different wavelengths. Just about everybody has seen, or done, the experiment in which a beam of white light is directed through a prism and split into different colors. The ordinary light we see as white, therefore, is actually made up of different color elements—it's *polychromatic*. Figure 1 shows the composition of visible light, and the relative sensitivity of the human eye to various wavelengths.

Ordinary light is also *temporally incoherent*. By that we mean that the various components of the light do not share any time relationship; they are all randomly out-of-phase with respect to each other. Thus, if you were able to look at the waveform of a beam of ordinary light, you would see something that looks like Fig. 2. The irregularity and random appearance of that waveform is caused by the presence of waveforms of differing frequencies in the light, and the ways in



which those waveforms interact with each others. Because of that interaction, at some points the waveforms all add (constructive interference); at some points they all subtract from one another (destructive interference), and at most points a combination of the two effects occurs. The result is an irregular, random-appearing waveform as shown.

Finally, ordinary light is also *spatially incoherent*. If you were to analyze the waveform of Fig. 2 over a period of time you would see that it is constantly changing. That's because the component waveforms are constantly changing their positions with respect to each other, causing the interference effects to vary.

The best way to put the differences between ordinary and laser light in perspective is to compare light to sound. Ordinary light, because of all the things we just talked about, can best be compared to noise. The waveforms at any moment in time are not only randomly spaced, but there's an unpredictable mix of frequencies as well.

Now, if regular light is like noise, then laser light can only be thought of as the purest sound imaginable. For openers, laser light is highly monochromatic—a spectrographic analysis would show that it is composed of light of only one wavelength. And where regular light is temporally incoherent, a laser is temporally coherent—all of the light waveforms are in phase with each other. That is one of the reasons why a laser puts ut light of such pure color. Being monochromatic helps, of course, but being temporally coherent as well means that there's almost a complete absence of what would be called distortion in a sound wave.

As you might have already guessed, laser light is also spatially coherent. If you looked at the waveforms over a period of time, there would be absolutely no shifting or movement. Considering the absence of interference effects, that is exactly what you would expect to happen. Taken together, all of those factors are what make laser light so intense, and so directional.

Since laser light is just about interference free, there's almost no scattering of the light. The beam divergence is very small—in the milliradian range. A laser beam is really a beam of light! Being coherent also means that there's a much smaller loss in energy over distance than there is with regular light. Obviously, since laser light is so different from regular light, it can't be produced the same way. And in order for us to understand how it's produced, let's see how regular light is produced.

Electromagnetic waves in general, and light in particular, is produced when an atom gives off energy. Now, an atom either takes on energy (absorption), or gives off energy (emission), by having its electrons move from one energy level to another. Once energy has been supplied to the system, and absorbed by the atom, emission can occur in one of two ways—it can happen spontaneously, or it can be stimulated.

Spontaneous emission is the result of natural atomic decay. The electrons randomly drop in energy level and produce the kind of waveforms shown in Fig. 2. When you power up a light bulb, for example, the atoms in the filament absorb energy and release it as a combination of heat and ordinary, incoherent light.

Stimulated emission is a completely different process. The idea is to keep the atoms from releasing their absorbed energy in a random manner. In order to do that, you have to create a state of affairs called a "population inversion." In simple terms, that means that there have to be more atoms present that have absorbed energy than there are atoms that have already released energy. That is usually brought about by forcing enough energy into the system to create at least three atomic-energy levels. The most excited atoms will emit energy and drop down to the next lowest energy level. That means there will be more atoms at the intermediate level than there are at the lowest level—that's the population inversion we mentioned.

As photons of energy are released, they will cause other atoms to emit energy in the form of photons. Those photons will trigger the production of other photons. And if the emission is bounced back and forth between two mirrors the production of photons will continue to build in phase and the result will be, you guessed it, a beam of laser light with a waveform that looks like that shown in Fig. 3.

Making a laser

Now, understanding the basic theory and putting it into practice are, as we all know, two completely different things. Creating the population inversion you need to produce a laser beam is really an iffy, ticklish business. Everything has to be just so or nothing will happen. The mirrors have to be of a certain type to produce the in-phase coherent energy needed for a laser. And enough energy of the right type has to be forced into the system to make the whole thing work.

The kind of energy you have to pump into the system depends on the type of material you're trying to make lase. Semiconductor and gas lasers are pumped up with electrical energy while crystalline lasers, such as those made from ruby rods or YAG (*Y*trium-*A*luminum-*G*arnet) are usually pumped up optically with xenon flash tubes or arc lamps.

The laser we're building here is a gas

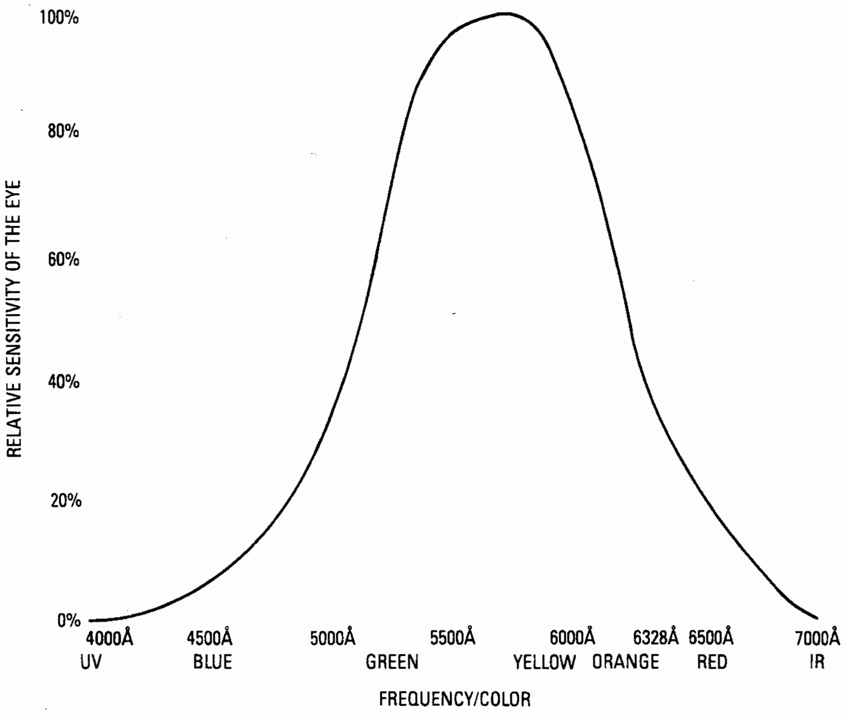


FIG. 1—THE VISIBLE SPECTRUM, and how the human eye responds to it. The wavelength of the light emitted by our helium-neon laser is 6328 Angstroms.

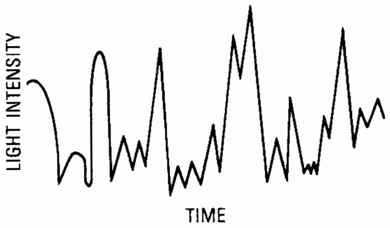


FIG. 2—THIS RANDOM-APPEARING waveform is that of ordinary light. The waveform is made up of all of the various frequencies that make up such light.

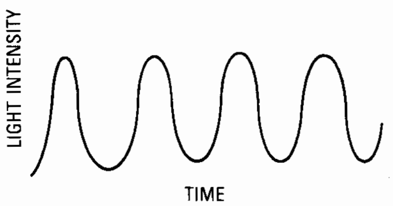


FIG. 3—LASER LIGHT is made up of light of just one frequency. It is the purest type of light possible.

laser—more specifically a helium-neon laser. The frequency of the light is 6328 Angstroms and the laser puts out about 1 milliwatt with a beam divergence of 1.3 milliradians. Now, 1 milliwatt may not sound like a lot of to you, but that's because you're still thinking in terms of regular light. Remember that the laser produces a highly directional beam of coherent, monochromatic light. The laser we're talking about here generates a beam that can be spotted on a wall more than two miles away!

Helium-neon lasers are extremely inefficient and, in order to make them work, the mechanical setup of the laser tube has to be just about perfect. It has to be properly sealed and contain the correct gas mixture. Also, the mirrors have to be perfectly aligned dielectric ones so enough reflection takes place at the proper frequency to cause the device to lase. Those mirrors must be highly reflective, within a couple of decimal places of 100%; by contrast, the silver mirrors we use every day have a reflectance factor of only 95%.

Making a helium-neon laser tube is a project that is beyond the means of most of us as it requires a fair amount of skill and equipment. Among other things, you need to have the skills and equipment required to create a precise mixture of gasses, and you need to be adept at glass blowing. All of that is not impossible, of course, but in most cases its a task that is best left to someone else; we recommend that you purchase rather than build a tube. (One source for laser tubes is mentioned in the Parts List.)

Once you have a working laser tube, actually making it produce a beam is surprisingly simple. The only electronic assembly needed is a power supply that will deliver the right voltage to make the tube fire. Figure 4 is the schematic of a power supply that can be used to trigger the laser. If it looks familiar, that's because its front end is essentially the same one used in the construction of the infrared viewer that appeared in the August 1985 issue of **Radio-Electronics**.

The power supply is a switcher with Q1, Q2, and their related components forming an oscillator that switches a squarewave through the primary windings of T1, a high voltage step-up transformer. That part of the circuit takes the battery voltage and produces about 400 volts AC at the secondary of T1. Diodes D3–D6 and capacitors C2–C5 form a voltage multiplier that takes the 400 volts from T1 and boosts it to the 1600-volts DC needed to ignite the laser tube.

The high-voltage pulse needed to ignite the tube comes from an 800-volt tap on the voltage multiplier. Resistors R3 and R4 divide that voltage to provide the 400 volts needed to charge up C9, the dump capacitor. When the SCR fires, the charge on C9 is dumped into the primary of the trigger coil, T2. Capacitor C11 charges up and, since it's in parallel with the laser tube, when the voltage builds enough to excite the gas, ignition takes place and current flows through the tube. That causes a voltage drop across R10, which turns on Q4 and turns off Q3.

As soon as the laser tube ignites, therefore, the ignition circuitry is turned off. That saves battery power because the laser tube can sustain firing at a lower voltage. The relaxation oscillator made up of Q3 and Q4, and their related components is only needed to control the firing of the SCR. Once the tube starts to lase, the voltage drop across R10 keeps the ignition circuitry turned off. If the tube stops lasing, the R9–R10 junction will drop to ground again and Q4 will turn off and unclamp Q3. The SCR will start firing again and, we hope, re-ignite the tube.

Construction

Before we actually start building the circuit, there's one very important thing you *must* keep in mind:

CAUTION! The power supply can produce as much as 10,000 volts at about 5 milliamps. That is enough juice to do a lot of damage. If you're not careful you can give yourself a severe shock. Remember that the capacitors take a while to discharge completely. You can get a real jolt even if the circuit has been turned off for five or ten minutes. Treat the circuit with respect and make sure to discharge the capacitors if you want to do some work on the circuit.

Now that that's out of the way, you can build the power supply on perfboard or use the PC board that's provided in our PC Service section, elsewhere in this magazine. If you use perfboard, remember to keep the leads as short as possible because there's a lot of high-frequency AC running around part of the circuit. Whichever method you use, make sure to keep any metal objects and your fingers away from the output section located around T2 and R11. Those are the points of the circuit where the highest voltages can be found. One short second of carelessness on your part and you're going to get zapped. If you're lucky, all it will do is hurt a lot.

The only other components in the cir-

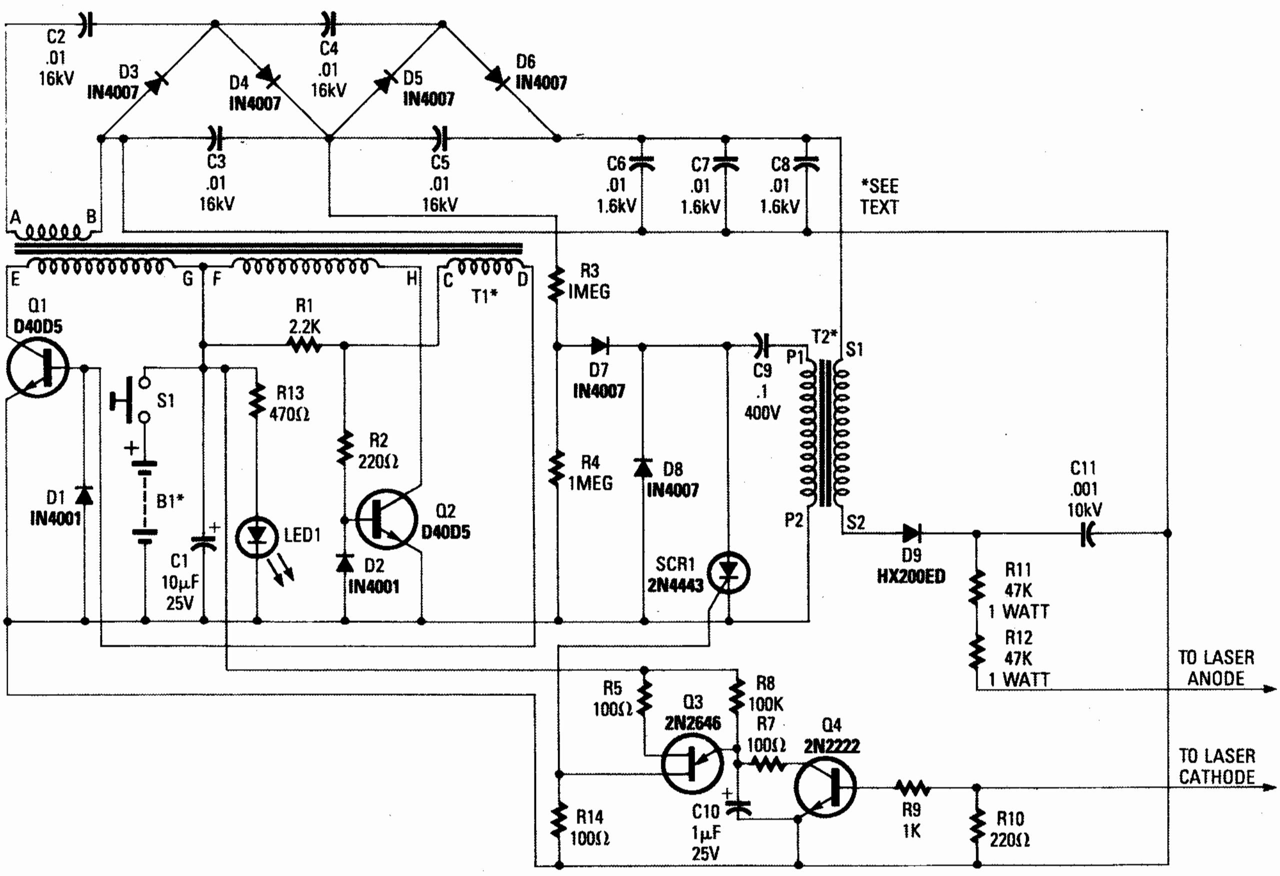


FIG. 4—THIS POWER SUPPLY is all you need to drive a laser tube like the one available from the supplier mentioned in the Parts List.

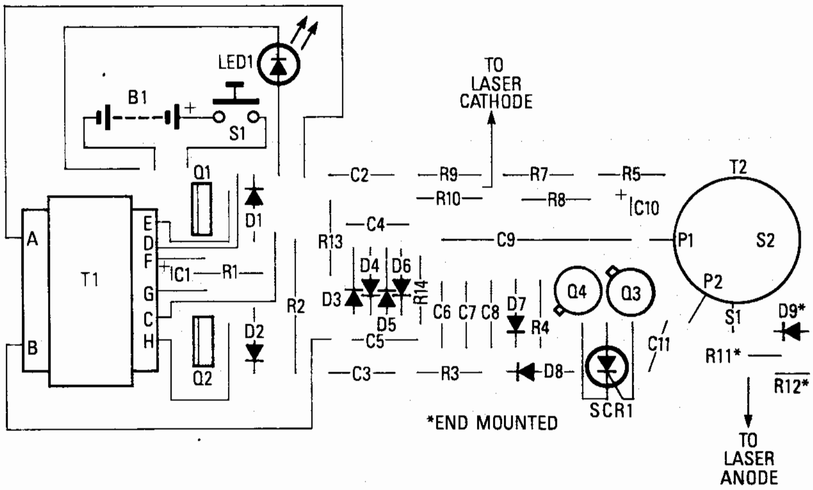


FIG. 5—IF YOU CHOOSE to use the PC board provided in our PC Service section, use this parts-placement diagram.

cuit that require special attention are the switching transistors, Q1 and Q2. The maximum current draw from the batteries is about 750 mA, so those transistors will be handling a lot of juice and getting hot. The PC-board layout shown in Fig. 5 is designed so that the transistors can be placed in such a way that their tabs can be stuck against the laminations of T1. If you are using perforated construction board, be sure that your layout allows for that, too. Use some heat-sink compound to get good thermal contact, and using small heat sinks wouldn't be a bad idea.

After you've identified the components and found their position on the board, solder them in using a minimum of solder. Once you've done that, use some high-voltage putty, paraffin, or varnish to cover the traces (or wires if you're using perf-board) that connect to all the components on the secondary side of T2 and the laser tube. That part of the circuit has the highest voltages and it's likely that arcing will take place if all the bare metal isn't covered. You may find it necessary to use the same material on the component side of the board as well.

When you finish the board, check for bridges, opens, bad solder joints, and so on. If everything seems OK, you're ready to test the power supply. Take the two leads that normally would go to the laser tube and tape them down so that they're ⅛-inch apart. Connect 10 volts to the power supply. You should see arcing across the laser-tube leads at a rate of about once a second or so; the circuit should be drawing approximately 250 mA. If the spark becomes continuous, the current draw should jump to about 750 mA—the full operating current of the laser tube. If you measure the voltage across the output of the supply, you should see an open circuit voltage of about 2500. Once the laser tube is connected, the voltage will be in the neighborhood of 1500.

If you've gotten this far without any brain damage, you're ready to connect the tube to the supply.

CAUTION! The laser tube is an expensive, delicate piece of equipment. In order to connect it to the circuit you'll be soldering leads to the metal collars at either end of the tube. Use a minimum of solder and apply heat for a minimum amount of time. Don't ever forget that the tube has a high vacuum inside and you can damage more than the tube if you destroy the integrity of

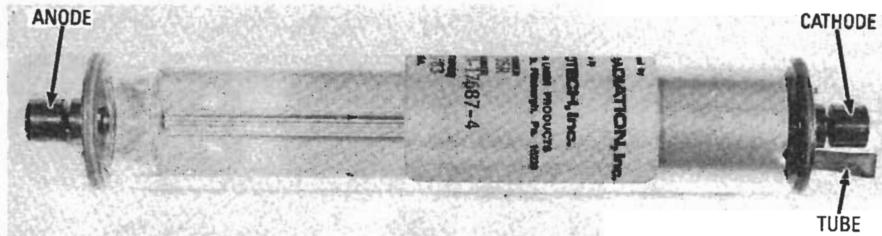


FIG. 6—A HELIUM-NEON laser tube. The cathode end can be identified by the small tube used to fill the laser tube with gas.

the seal. Use a low-power iron and a lot of common sense when you solder to the tube. Tin the wires ahead of time to keep the soldering time to a minimum.

The laser tube has an anode and a cathode end. The anode is the clear glass end of the tube and the cathode can be identified by finding the small metal tube used

PARTS LIST

All resistors ¼ watt, 10% unless noted
R1—2200 ohms
R2—220 ohms, 1 watt
R3, R4—1 megohm
R5,R7—100 ohms
R6—not used
R8—100,000 ohms
R9—1000 ohms
R10—220 ohms
R11, R12—47,000 ohms, 1 watt
R13—470 ohms

Capacitors
C1—10 µF, 25 volts, electrolytic
C2–C8—0.01 µF, 1.6 kV, ceramic disc
C9—0.1 µF, 400 volts, paper dielectric
C10—1 µF, 50 volts, electrolytic
C1—0.001 µF, 10 kV, ceramic

Semiconductors
D1, D2—1N4001
D3–D8—1N4007
D9—HX200ED, 20 kV diode
LED1—Red LED
Q1, Q2—D40D5, NPN power transistor
Q3—2N2646—UJT transistor
Q4—PN2222 NPN transistor
SCR1—2N4443 SCR

Other components
T1—12 to 400 volts, 10 kHz switching transformer
T2—10-kV trigger transformer, 400-volt primary
B1—14.4 volts, 12 nickel-cadmium cells, or equivalent
S1—SPST switch, momentary pushbutton, normally open

Miscellaneous: PC board, helium-neon laser tube, PVC tubing for case, battery holders, wire, solder, etc.

Note: The following are available from Information Unlimited, PO Box 716, Amherst, NH 03031: PC board, $4.50; switching transformer (T1), $14.50; trigger transformer (T2), $11.50; 1-milliwatt laser tube, $149.50; 0.4-milliwatt laser tube, $99.50; high-voltage diode (D9), $3.50; high-voltage capacitor (C11), $3.00.

to fill the laser tube with gas. See Fig. 6. Once you have the ends of the laser tube identified, solder the lead from R12 to the anode, keeping that lead as short as you can. The voltage at R12 is about 1100 volts when the tube fires, so that is the point where arcing or some other type of parasitic power loss is most likely to occur. Keeping the lead as short as possible will go a long way toward eliminating any potential problems.

Connect the cathode of the tube through an ammeter to R10 and apply 10 volts to the supply. The tube should start sputtering as it tries to ignite. As you raise the voltage *slowly*, ignition will take place and the tube will fire. If you raise the supply voltage to 12 volts, you should find the tube drawing about 5 mA and the supply will be putting out about 750 mA. The operating current of the laser tube should be kept in the range of 4.5 to 5.5 mA. Less than that and the tube won't operate reliably; more than that and you'll cut down its operating lifetime. You can trim the values of R11 and R12 to get the operating current into the safe range. Just make sure you keep the total resistance of R11 and R12 at about 100,000 ohms.

The current through the tube is going to vary a lot as the battery voltage changes. If you use nickel-cadmium cells, remember that the operating voltage is going to be 1.2 in each cell for most of the lifetime of each charge. Freshly charged nickel-cadmium cells, however, can have a voltage as high as 1.5. Admittedly that doesn't last very long, but we'll mention it because adjusting the laser tube's operating current with freshly charged batteries could cause you to choose artificially high values for R11 and R12. So before you start trimming the resistors, make sure the batteries are at 1.2 volts per cell

Since the operating current is tied to the supply voltage, it's natural to think about voltage regulation. Well, there is nothing wrong with regulating the input voltage, but there are a few things to keep in mind. If you use 12 nickel-cadmium cells, you'll have a supply voltage of 14.4 and you'll be drawing as much as 750 mA from that supply. A three-terminal regulator like the 7812 would seem to be an ideal choice, but asking it to supply 750 mA is really asking a lot unless you use a 7812C, which can handle 1 amp with a good heat sink. An LM317 can be set up to put out 12 volts and it can supply 750 mA.

The biggest problem with using an IC voltage-regulator is the voltage loss that's inherent in those devices. In order to supply 12 volts, a regulator needs an input voltage of about 14.5 volts. Now that's just about the maximum you can get from the batteries. And if your particular tube wants a little bit more than 12 volts, or some of the power-supply components are a little bit lossy, you're in a lot of trouble.

So, you ask, what's the bottom line. Well, after all's said and done, unless you want to do an awful lot of circuit design, the best thing to do is let the power supply look directly at the batteries. It's not the best solution in the world, but it's probably the best thing in this situation.

The case for the laser can be as simple or as fancy as you like. Perhaps the simplest and most functional approach would be to use some lengths of standard PVC tubing. But if you do that, or completely enclose the circuit in any way, you could run into an overheating problem because of the amount of heat produced by the power supply. Because of that, it's a good idea to limit the on-time to less than a minute; keeping it under 30 seconds is even better. Further, giving the supply a 5-second or so rest between uses will increase its lifetime tremendously. Also, the better you heatsink Q1 and Q2, the better off you'll be.

Having fun

The output of the laser tube is about 1 milliwatt (or 0.4 milliwatt if the lower-powered tube offered by the supplier mentioned in the Parts List is used) and, at that power, it can't do any damage. If you had thoughts of burning your way through steel, forget it. Lasers that can do that are worlds away from the one we're building. However, that doesn't mean you can treat the light from this laser with no respect whatsoever.

CAUTION! Even a 1-milliwatt laser can be hazardous if you look directly at the beam. While we assume that anyone considering building a laser would know enough about those devices to never, never even consider doing something so foolhardy, the very nature of laser might make it very easy for accidents to happen. The beam is highly directional and very intense; to compound matters, the reflected beam is just as dangerous as the emitted beam. It's a simple matter to have the beam bounce off some shiny object and reflect back to you. You can wear safety glasses, but even if you do, be careful where and how you use the laser.

While you can use this laser, which throws an intense red beam, for such things as target spotting, perhaps its greatest use is as an introduction to the world of lasers in general. Watching the tube fire is truly fascinating and the more you experiment with it, the more you'll learn. R-E

BUILD THIS

UNIVERSAL LASER POWER SUPPLY

Here's a power supply that can easily be adapted for use with various kinds of hobbyist and experimenter laser tubes.

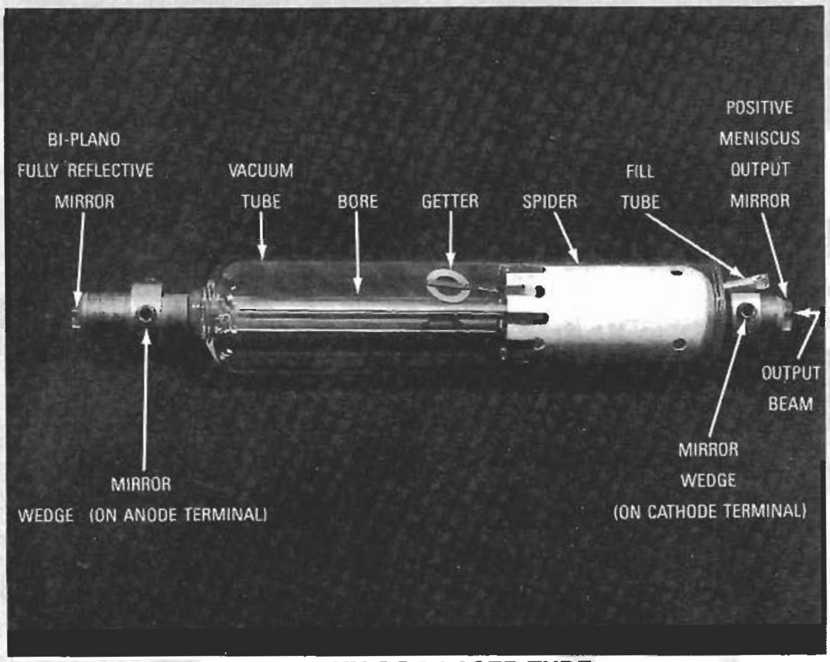
GORDON McCOMB

IT'S EASY TO GET STARTED EXPERIMENTING WITH LASERS. ALL YOU NEED IS A LASER TUBE, A power supply, and a protective enclosure of some kind. Getting a tube is usually no problem, because "surplus" and even used helium-neon (He-Ne) tubes are commonly available. But since the characteristics of He-Ne lasers vary considerably from model to model, a hobbyist's laser power supply should be able to work with all of them, which is exactly the case with our pulse-modulated He-Ne power supply.

Caution!

Before building the power supply, let's take time out for a few words of caution. All gas lasers—including the popular helium-neon variety—require a high-voltage power supply that boosts the main voltage, from 12-volts DC or 117-volts AC, up to 1200–3000 volts. Although the supply's output voltage is relatively high, the circuit-current, or the *laser current* is low.

Because of the low laser current, some laser experimenters tend to disregard the high voltage, possibly because they believe that as long as the current is low, a high voltage can't do more than give a nasty shock. Not so! The byproduct of a nasty shock can result in severe injury, so take extra care to prevent your coming in contact with any "live" power-supply circuits or connections. To that end, all components and wires of a laser



ANATOMY OF A LASER TUBE

The helium-neon tube is the staple of the laser experimenter. He-Ne tubes are in plentiful supply, especially in the surplus market. They emit a bright, deep-red glow that can be seen for miles around. Although the power output of He-Ne tubes is relatively small compared to other laser systems, it is perfectly suited for many homebrew and school experiments in diffraction, reflection, etc.

The helium-neon laser is a glass vessel filled with 10 parts helium and one part neon, pressurized to about 1 mm Hg. (The exact gas pressure and ratios vary between laser manufacturers.) Electrodes placed at the ends of the tube provide a means to ionize the gas, thereby exciting the helium and neon atoms. Mirrors mounted at either end form an optical resonator, or *Fabry-Perot* resonator. In most He-Ne tubes, one mirror is totally reflective and the other is partially reflective. The partially reflective mirror is the output of the tube.

Modern He-Ne lasers are composed of few parts, all fused together during manufacturing. Only the very old He-Ne tubes, or those used for special laboratory experiments, use external mirrors. The all-in-one design costs less and the mirrors are not as prone to mis-alignment.

Helium-neon lasers are actually composed of two tubes: an outer plasma tube that contains the gas and a shorter and smaller inner bore or capillary, where the lasing action takes place. The bore is attached to only one end of the tube. The loose end is the output and faces the partially reflective output mirror. The bore is held concentric by a metal element called the spider. The inner diameter of the bore largely determines the diameter of the laser beam.

The ends, where the mirrors are mounted, typically serve as the anode (positive) and cathode (negative) terminals. On some lasers, the terminals are mounted on the same end. A strip of metal or wire extends to the cathode on the other end. The output mirror can be on either the anode or cathode end, but on most tubes, it is the cathode. Many manufacturers prefer that arrangement, claiming it is safer and more flexible.

Metal rings with hex screws are often placed on the mirror mounts as a means to tweak the alignment of the mirrors. Unless you suspect that the mirrors are out of alignment, you should NOT attempt to adjust the rings. They have been adjusted at the factory for maximum beam output. Tweaking them may degrade the performance of the laser.

He-Ne lasers are available in two general forms: bare and cylindrical head. Bare tubes are just that—the tube is not shielded by any type of housing and should be placed inside a tube or box during operation for protection. Cylindrical-head lasers (or just "laser heads") are housed inside an aluminum sheath. Leads for power come out of the back end of the laser. The opposite end may have a hole for the output beam, or may be equipped with a safety shutter. The shutter prevents accidental exposure to the beam.

power supply must be properly insulated and covered. In particular, you must avoid operating a laser's power supply in the open. Play it safe, and you won't be sorry.

Most laser power supplies use high-voltage capacitors at the output stage. Like all capacitors, they can retain a charge even after the power supply has been turned off. So when working with a laser, make sure the power supply is off and disconnected from its power source, then temporarily short the output leads of the power supply together, or simply touch the supply's positive output connection to ground. Like the capacitors, the laser tube itself can retain an electric charge after power has been removed. That current should be drained by shorting the tube's terminals or leads together, or to ground.

How it works

Regardless of their size or output power, the operating conditions of helium-neon laser tubes vary widely. A new tube starts easily and runs very efficiently; an older or used tube is harder to start and needs more current to lase continuously.

The pulse-modulated laser power supply shown in Fig. 1 was designed to accommodate a wide variety of helium neon tubes—both old and new—up to a maximum laser power output of about five milliwatts. Using pulse-width modulation (that is, varying the duty cycle of the square wave), the power supply individually controls the laser's start and run currents.

Potentiometers R12 and R13 determine the pulse width of the square wave applied to the inverting transformer, T1. In the start mode, R12 varies the pulse width until there is sufficient voltage to start the laser tube—typically 3–4 kV. Potentiometer R13 is switched into the circuit by relay RY1's contacts as current starts to flow through the laser. R13 is adjusted for the minimum current possible while still allowing the tube to lase.

The power supply operates from a 12-volt, 750-mA source; either a battery or an AC-to-DC converter. Timer IC1 operates as a 16- kHz astable multivibrator. Relay RY1 is initially not energized, so R13 and R8 are disconnected from the circuit. The setting of R12 determines the duty cycle, and thus the pulse width of the square wave at pin 3 of IC1. That signal driv-

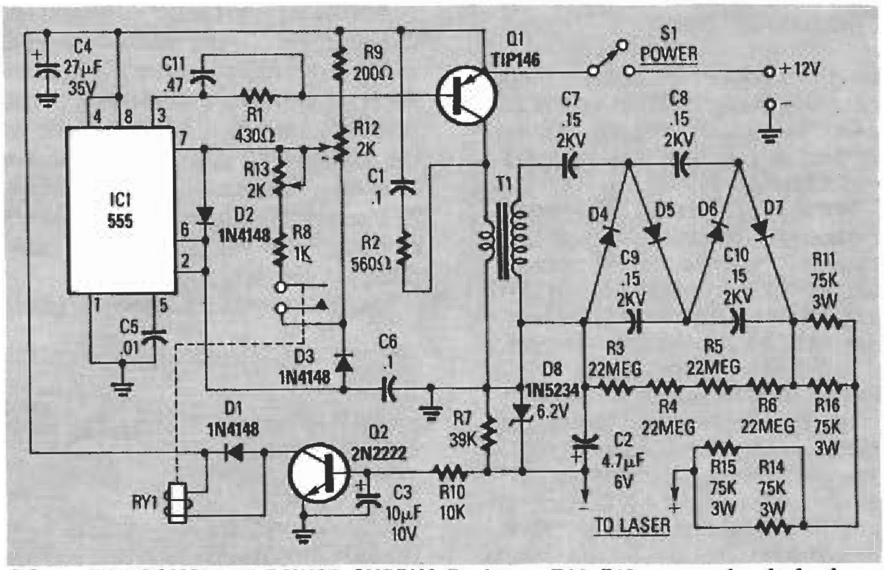


FIG. 1—THE COMPLETE POWER SUPPLY. Resistors R14–R16 are used only for laser tubes rated more than 1 mW.

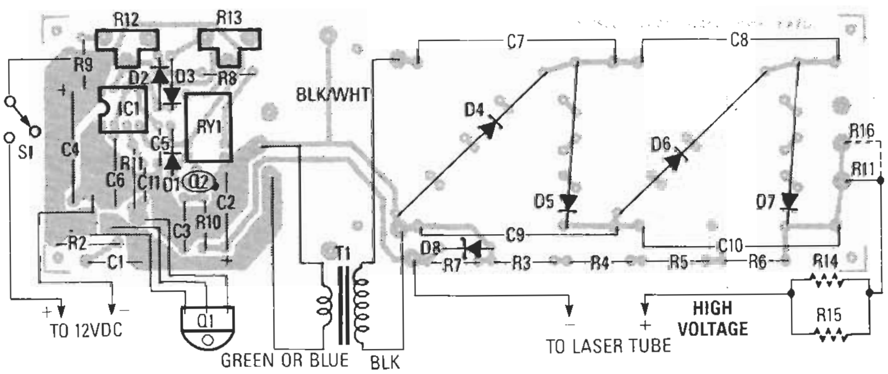


FIG. 2—THE PARTS LAYOUT. Although R16 mounts on the PC board, R15 and R16 are spliced into the laser tube's anode wire.

es the base of power transistor Q1 through current-limiting resistor R1.

Transistor Q1, which operates as a high-current/low-voltage chopper, delivers a series of square waves to the primary winding of step-up transformer T1.

With a 12-volt square wave at T1's primary, the output voltage at the secondary is between 800 and 2000 volts AC, the precise value depending on the setting of R12. Capacitors C7–C10, along with diodes D4–D7, form a standard voltage doubler ladder. The unloaded DC output of the voltage doubler is about 3–5 kV.

As the laser tube begins to conduct, current flows through R7, which causes a voltage to appear at the junction of R7 and R10. That voltage turns on Q2, which activates relay RY1, thereby switching resistors R8 and R13 into IC1's timing circuit, changing the square wave's duty cycle.

Potentiometer R13 must be readjusted to control the laser tube's current. The best position is determined by adjusting R13 clockwise until the relay chatters, then turning it counter clockwise until the relay remains latched in the energized position.

Resistors R3–R6 provide safety when handling the supply (with the power source disconnected) by draining the charge from the voltage doubler's capacitors, as well as the electrostatic charge from the laser tube. Note that the very high resistance of R3 through R6 prohibit them from quickly draining the excess charge, so you should still manually short the power supply's output terminals together before handling the laser or its power supply.

Resistors R11 and R14–R16 depend on the laser tube. For 1-mW tubes, only R11 is used. R16 is eliminated, while R15 and R15 are replaced by a wire.

Construction

The laser power supply is assembled on a printed-circuit board for which a template is provided in PC Service. Alternatively, an etched and drilled PC-board can be ordered from the source given in the Parts List.

Install the parts on the PC board as shown in Fig. 2. First mount R1 through R11. If you intend to use a laser tube rated for more than 1 mW, install R16 in the extra hole that is adjacent to R11. All resistors are installed flush on the board except for R11 and R16, which are mounted on end—and only one lead of each re-

LASERS AND SAFETY

Lasers emit electromagnetic radiation, usually either visible light or infrared. The level of "radiation" is generally quite small in hobby lasers, having about the same effect on external body tissues as sunning yourself with the livingroom lamp.

Skin is fairly resilient, even to exposure up to several tens or hundreds of watts of laser energy. But the eye is much more susceptible to damage, and it is the effects of laser light on the retina that is of the greatest concern. Even as little as 20–50 milliwatts of focused visible or infrared radiation can cause immediate eye damage.

The longer the eye is exposed to radiation, and the more focused the beam, the greater the chance that the laser will cause a lesion on the surface of the retina. Retinal lesions can heal, but many leave blind spots. Retinal damage when using hobby lasers—those having outputs of less than five or ten milliwatts—is rare, but can occur if you stare directly at the beam for extended periods of time. Therefore, NEVER look directly at the beam, or its reflection from a mirror or a metallic surface.

Keep these points in mind when working with laser:

- Any laser power supply delivers high voltages that, under certain circumstances, can injure or kill you. Use extreme caution when building, testing, and using lasers and high-voltage power supplies.
- Do not attempt to build your own power supply unless you have at least some knowledge of electronics and electronics construction.
- Although the power-supply project is not difficult, it should be considered suitable only for intermediate to advanced hobbyists.
- Power supplies and laser tubes retain a charge even after electricity has been removed. Be sure to short out the output of the power supply as well as the terminals of the laser tube before touching the laser or high-voltage leads.

BUYING AND TESTING HE-NE TUBES

Apart from size and output power, tubes vary by their construction, reliability, and beam quality. After buying a He-Ne tube, you should always test it; return the tube if it doesn't work or if its quality is inferior.

Should you need a laser for a specific application that requires precision or a great deal or reliability, you may be better off buying a new and certified tube rather than one from surplus; it will come with a warranty and certification of power output.

He-Ne's emit a deep red beam at 632.8 nanometers because it is the strongest wavelength produced within the tube. Although other colors are produced, they are weak or may not be sufficiently coherent or monochromatic. Yet there are some special helium-neon lasers that are made to operate at different wavelengths, namely 1.523 micrometers (infrared) and 543.5 nanometers (green). Green and infrared He-Ne lasers are exceptionally expensive and rare in the surplus market.

The first step in establishing the quality of the tube is to inspect it visually. If the tube is used, be on the lookout for scratched, broken, or marred mirrors. After inspection, connect the tube to a suitable power supply, point the laser toward a wall, and apply power. If the laser is working properly, the beam will come out of one end only and the beam spot will be solid and well-defined.

Occasionally, the totally reflective mirror allows a small amount of light to pass through and you see a weak beam coming out the back end (that is especially true if the mirror is not precisely aligned). Usually, that poses no serious problem unless the coating on the mirror is excessively weak or damaged, or if the mirrors are seriously out of alignment.

All lasers exhibit satellite beams—small, low-powered spots caused by internal reflections that appear off to the side of the main spot. In most cases, the main beam and satellites are centered within one another, so you see just one spot. But slight variations and adjustment of the mirrors can cause the satellites to wander off axis. That can be unsightly and if it matters to you, choose a tube that has a solid beam.

Should the tube start but no beam comes out, check to be sure that nothing is blocking the exit mirror. If the beam still isn't visible, the mirrors may be out of alignment and the laser should be returned for a replacement.

If the tube doesn't ignite at all, check the power supply and connections. Try a known good tube if you have one. The tube still doesn't light? The problem may be caused by:

- Bad tube. The tube is "gassed out," has a hairline crack, or is just plain busted.
- Power supply too weak. The tube may require more current or voltage than the levels produced by the power supply.
- Insulating coating or broken connection. New and stored tubes may have an insulating coating on the terminals. Be sure to clean the terminals thoroughly. A broken lead can be mended by soldering on a new wire.

Some "problems" with laser tubes are really caused by the power supply. In fact, if your laser doesn't work, expect the power supply first. One common problem is that the tube sputters when you turn it on. That fault is most often caused by a tube that isn't receiving enough current, either because the connections from the power supply are loose or broken, the power supply is not producing enough current for the tube, or the ballast resistor is too high or too low.

Hard-to-start tubes flick on but quickly go out. If the power supply incorporates a trigger transformer, the tube may "click" on and off once every 2–3 seconds (correlating to the time delay between each high-voltage trigger pulse). Tubes that haven't been used in a while can be hard to start, so once you get it going, keep it on for a day or two. In most cases, the tube will start normally. Hard starting may also be caused by age and degassing, two factors you can't fix.

sistor is connected; the other leads remain free for now. Then mount D1 through D8; C1 through C11; finally, IC1 and Q2. Q1 will be mounted on a heat sink, but its connections to the PC board should be made now. Simply solder insulated wires about 2½-inches long to Q1's terminals, and connect the free ends to the printed-circuit board.

One support

As shown in Fig. 3, the PC board is mounted on a metal plate—along with Q1, S1, and T1. The plate is 2⅜-inches wide × 5⅝-inches long. S1 and Q1 are mounted at one end on a ⅞-inch fold. You can't see it in Fig. 3, but there is a ¼-inch fold along the entire length of the bracket that provides overall rigidity. If you decide to attach the laser to the power supply as shown in Fig. 3, use the ¼-inch fold as the support, and secure the laser to the bracket with plastic tie-wraps that pass through two holes drilled along the long folded edge. Note that the laser tube shown in Fig. 3 is enclosed in a metal tube. It was manufactured that way, but it works the same as any other He-Ne laser tube.

Using a suitable insulating washer,

PARTS LIST

All resistors are ¼-watt, 5%, unless noted otherwise.
R1—430 ohms
R2—560 ohms
R3–R6—22 megohms
R7—39,000 ohms
R8—1000 ohms
R9—200 ohms
R10—10,000 ohms
R11, R14–R16—75,000 ohms, 3 watts
R12, R13—2000 ohms, miniature potentiometer

All capacitors rated at least 12-volts DC unless noted otherwise
C1—0.1 µF
C2—4.7 µF
C3—10 µF, 10 volts, radial tantalum
C4—27 µF, 35 volts, axial electrolytic
C5—0.01 µF, ceramic disc
C6—0.1 µF, polystyrene
C7–C10—0.15 µF, 2–3 kV, ceramic or Mylar
C11—0.47 µF, polystyrene

Semiconductors
IC1—555 timer
Q1—TIP146 NPN power transistor
Q2—2N2222 NPN transistor
D1–D3—1N4148 diode
D4–D7—High voltage (8–10 kV, 20-mA) diode
D8—1N5234, 6.2-volt Zener diode

Other Components
RY1—6-volt SPST printed-circuit relay
T1—High-voltage step-up/step-down transformer, 12 to approximately 280 volts.

Miscellaneous: wire, tubing, metal bracket, insulator, spacers, cabinet, etc.

Note: The following items are available from General Science and Engineering, PO Box 447, Rochester, NY 14603 (716) 338-7001: Etched and drilled PC board, $9; transformer T1, $15; complete kit of parts, including PCB and T1 (excluding project box), $39. For each order add $3 for shipping and handling. COD's accepted. New York residents must include applicable sales tax.

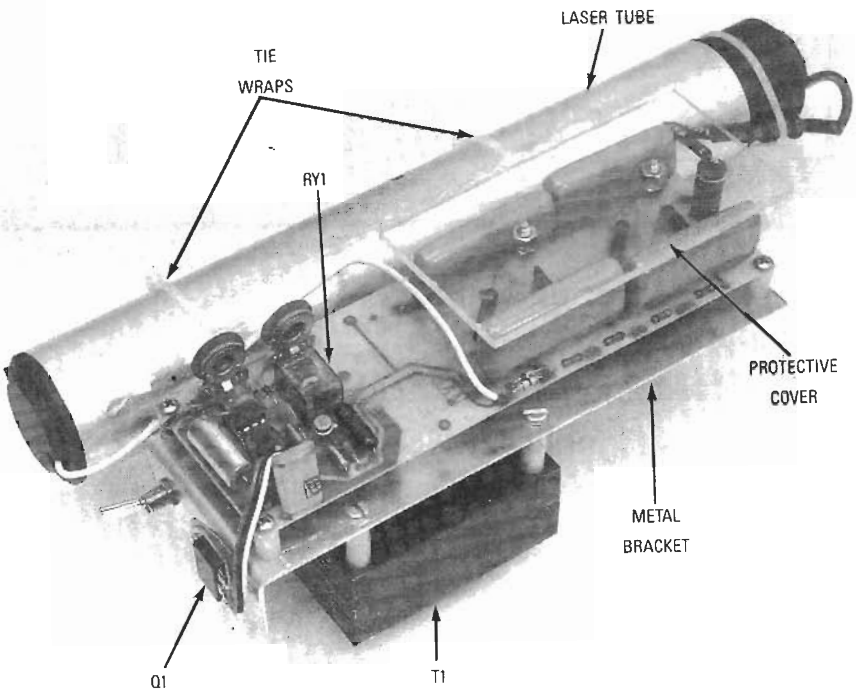


FIG. 3—FULLY ASSEMBLED, the tube is held to the bracket with plastic straps.

an insulator, and heat-transfer paste, mount Q1 on the folded end of the metal bracket. Use an ohmmeter to check for a short between the metal tab of Q1 (which serves as an alternate connection to Q1's collector) and the metal bracket. Remount Q1 if your meter indicates a short.

Transformer T1 is mounted on the bottom of the metal bracket. A ⅜-inch hole drilled in the bracket opposite T1 is used to pass the wires through to the underside of the PC board. The wires from T1's secondary are soldered to the pads labeled A and B on the foil side of the PC board. (The leads will protrude through the board to the component side.) In a similar way, the wires from T1's primary are soldered to the pads labeled C and D.

Connections

Make two 8-inch high-voltage leads from high-dielectric wire. Strip and tin ½-inch of each end and slip a 6-inch length of clear neoprene (aquarium) tubing over both wires. Solder one wire into the NEGATIVE OUTPUT hole near R7. Solder the remaining wire to the top of R11. If you use R14 and R15, cut the wire connected to R11/R16—and its tubing—in half and splice in R14 and R15; then cover the resistors with plastic or heat-shrinkable tubing.

If your laser tube has flying leads (wire leads already installed), then just connect them to the power-supply output leads later on. If your tube has its power terminals on its ends, then an electrical contact can be made by wrapping a length of wire around them.

Before using the power supply, inspect it carefully for solder bridges, loose connections, and improperly installed components.

Using the supply

Operating the power supply is straightforward. Secure the power leads to the tube and, if necessary, wrap high-voltage putty or electrical tape around the leads to hold them in place, but be sure that you don't block the laser's output mirror. Position the power supply so that you are facing R12's and R13's adjustment "dial" and set each potentiometer to its center position.

Apply power and observe the laser tube. Slowly adjust R12 clockwise until the tube triggers: You will hear the relay click in, and possibly a high-pitched whine. Both effects are normal. If the relay chatters and the tube sputters, keep turning R12 until the relay locks in and the tube stays on. If even a full clockwise adjustment fails to get the tube to ignite, adjust R13 slightly counter-clockwise.

THE PROPERTIES OF LASER LIGHT

- Laser light is monochromatic. Laser light coming from the output mirror consists of one wavelength or, in some instances, two or more specific wavelengths. The individual wavelengths can be separated.
- Laser light is spatially coherent. The term spatial coherence means that all the waves are in tandem. That is, the crests and the troughs of the waves that make up the beam are in lock-step.
- Laser light is temporally coherent. Temporal coherency is when the waves from the laser (which can be considered as one large wave, thanks to spatial coherency) are emitted in even, accurately-spaced intervals. Temporal coherence is similar to the precise clicks of the metronome, timing the beat of music.
- Laser light is collimated. Because of monochromaticity and coherence, laser light does not spread (diverge) as much as ordinary light. The design of the laser itself, or simple optics, can collimate the laser light into a parallel beam.

The four main properties of laser light combine to produce a shaft of illumination that is many times more brilliant than the light of equal area from the sun. Because of their coherency, monochromaticity, and low beam divergence, lasers are ideally suited for a number of important applications. For example, the monochromatic and coherent light from a laser is necessary to form the intricate swirling patterns of a hologram. Without the laser, optical holograms would be more difficult to produce.

Coherence plays a leading role in the minimum size of a focused spot. With the right optics, it's possible to focus a laser beam to an area equal to the wavelength of the light. With the typical infrared-emitting laser diode, for instance, the beam can be focused to a tiny spot measuring just 0.8 micrometers wide. Such intricate focusing is the backbone of compact audio discs and laser discs.

Minimum divergence (owing to the coherent nature of laser light) means that the beam can travel a longer distance before spreading out. The average helium-neon laser, without optics, can form a beam spot measuring only a few inches in diameter from a distance several hundred feet away. With additional optics, beam divergence can be reduced, making it possible to transmit sound, pictures, and computer code many miles on a shaft of light. The signal is intercepted by a receiving station in the light path.

LASER OPERATION

Some basics first. Albert Einstein was responsible for first proposing the idea of the laser in about 1916. Einstein knew that light was a series of particles, called photons, traveling in a continuous wave. These photons could be collected, using an apparatus not yet developed, and focused into a narrow beam. To be useful, all the photons would be emitted from the apparatus at specific intervals. Much of the light energy would be concentrated in a specific wavelength, or color, making the light even more intense and powerful.

Photons can be created by a variety of means, including the ionization of gas within a sealed tube, the burning of some organic material, or the heating of a filament in a light bulb. In all cases, the atoms that make up the light source change from their usual stable or ground state to a higher excited state by the introduction of some form of energy, typically electricity. The atom can't stay at the excited state for long, and when it drops back to the ground state, it gives off a photon of light.

The release of photons by natural methods results in spontaneous emission. The photons leave the source in a random and unpredictable manner, and once a photon is emitted, it marks the end of the energy-transfer cycle. The number of excited atoms is low, so the majority of photons leave the source without meeting another excited atom.

Einstein was most interested in what would happen if a photon hit an atom that happened to be at the excited, high-energy state. He reasoned that the atom would release a photon of light that would be an identical twin to the first. If enough atoms could be excited, the chance of photons hitting them would be increased. That would lead to a chain reaction where photons would hit excited atoms and make new photons—the process continuing until the energy source was removed. Einstein had a name for that phenomenon and called it the stimulated emission of radiation.

Raising atoms to a high-energy state is referred to as pumping. In common neon light, for example, the neon atoms are pumped to their high-energy state by means of a high-voltage charge applied to a pair of electrodes. The gas within the tube ionizes, emitting photons. If the electrical charge is high enough, a majority of the neon atoms will be pumped to the high-energy state. A so-called population inversion occurs when there are more high-energy atoms than low-energy ones. A laser cannot work unless that population inversion is present.

Protons scatter all over the place and, on their own, they simply escape the tube and don't strike many excited atoms. But assume that a pair of mirrors are mounted on either end of the tube, and that some photons may bounce back and forth between the two mirrors.

At each bounce, the photons collide with more atoms. If many of those atoms are in their excited state, they too release photons. Remember: The new photons are twins of the original, and share many of their characteristics, including wavelength, frequency, polarity, and phase. The process of photons bouncing from one mirror to the next, each time striking atoms in the path, constitutes light amplification.

In theory, if both mirrors are completely reflective, the photons would bounce back and forth indefinitely. Rub a little of the reflective coating off one mirror, however, and it passes some light. Now, a beam of photons passes through the partially reflective mirror after the light has been sufficiently amplified. In addition, because the mirror is partially reflective, it holds back some of the light energy. That reserve continues the chain reaction inside the tube.

The combination of light amplification and stimulated emission of radiation makes the laser operate. As you probably already know, the the word "LASER" is an acronym for its theory of operation—*L*ight *A*mplification by *S*timulated *E*mission of *R*adiation.

current variations. If the laser doesn't trigger or run after adjusting R12 and R13, try reducing the value of the ballast resistance, but avoid going below 60K. If the tube begins to flicker after warming up, readjust R13.

Most 1-mW tubes draw between 750-mA to 1-amp from the 12-volt DC source. You will find that you need higher current when operating a laser with greater power output. For example, a typical 5-mW laser draws 2.5–3 amperes from the 12-volt DC power source. However, take note that the power source *must* be able to deliver an initial surge of 3–5 amps. If your 12-volt power supply cannot handle that requirement, try powering the laser supply with a 12-volt alkaline lantern battery. Also, two 6-volt lead-acid, or gel-cell batteries in series make a good 12-volt source.

Once the tube lights, adjust R13 clockwise until the tube begins to stutter and the relay chatters. That marks the tube's *threshold*. Turn R13 just a *smidgen* counter-clockwise until the tube turns back on and remains steady. Every tube, even those of the same size and having the same output, has slightly different current requirements. You might have to readjust R12 and R13 for every tube you own.

Resistors R11 and R14–R16 form the ballast for the laser tube. With the components shown in Fig. 1, the total resistance is about 75,000 ohms. You can safely use ballast values from 60K to 120K; use R13 to adjust for tube-

The enclosure

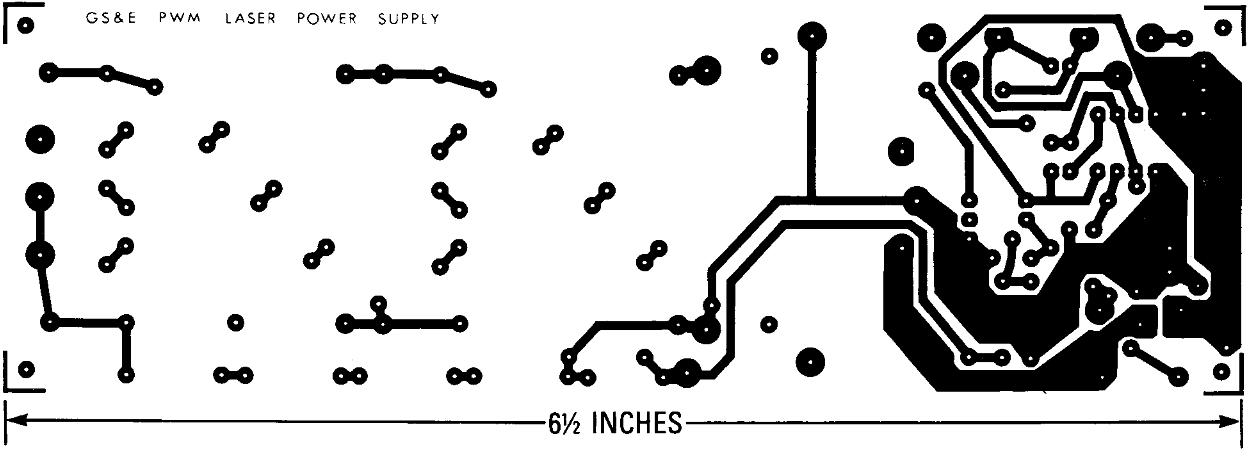
Your laser power supply should never be used without placing it in a protective, insulated enclosure. Electronics stores sell project boxes of all sizes. If you plan on using the supply to power a number of tubes, use heavy-duty (25-amp) banana jacks to provide easy access to the anode and cathode leads. Keep the jacks separated by at least one inch and apply high voltage putty around all of the terminals to prevent arcing. Avoid using power leads longer than 6–9 inches especially for the anode connection. If, for some reason, you intend to test the supply outside of its cover, we suggest you cover the high-voltage section with a piece of plastic, as shown in Fig. 3.

Experiments

With your power supply working, it's time to experiment with laser light. Try doing some simple experiments with optics, mirrors, and lenses. At night, aim the laser at the wall of a distant building to see how far the beam travels before spreading out. Try to measure the width of the beam and calculate its divergence. Then, insert a small telescope or rifle scope backward in the path of the beam (the beam goes in the objective and exits the eyepiece). With some adjustment the beam's divergence should be drastically reduced.

There are many other projects you can try, including holography, metrology (the study of measurement), or a light show. **R-E**

PC SERVICE



USE THIS FOIL PATTERN for the laser power supply.

LETTERS

LASER PROJECTS

Readers who enjoyed my article entitled "Universal Laser Power Supply" (**Radio-Electronics**, March 1989) might find my new book, *The Laser Cookbook: 88 Practical Projects*, to be helpful in applying lasers in real-world uses. The book presents numerous hands-on projects in helium-neon and semiconductor laser technology, including holography, light shows, seismology, and optics. It also provides additional information on helium-neon laser testing, operation, and use. The book is published by TAB Books (catalog No. 3090).

GORDON McCOMB
Canoga Park, CA

Laser resources

Until recently, I guess I was pretty much down on the laser people. After all, those turkeys have had over 25 years to get their act together, and the best they have offered us hackers are some overgrown neon lamps that are fragile, insanely overpriced, grossly inefficient, short-lived, color-limited, hard to power, and harder yet to modulate, linearly.

Worse yet, our $49.95 homeshop radial-arm laser is nowhere in sight and, worst of all, that ongoing SDI starwars atrocity is giving the entire laser industry a bad name.

But things just might be changing. There are a few new developments, especially several new high-volume solid-state *visible* laser diodes that should drop down into the $5 range in a year or two. So today just might be a good time to review some laser resources that are suitable for hardware hacking. Several of them appear over in the *Laser Resources* sidebar.

So what's the big deal about lasers and lasing? A laser is nothing but a special kind of light bulb. Apply power and it puts out light. The light gets created by exciting electrons to a higher energy level through a *pumping* process. As the electrons drop back down to their normal energy levels, they output a precise packet of energy, usually in the infrared, visible, or ultra-violet portions of the spectrum.

There are several very interesting properties of laser light that let lasers solve problems that can be difficult or impossible to do otherwise. Let us look at some quickly.

Laser light often turns out to be *monochromatic,* meaning that it is all one color, just like a single pure audio tone or radio carrier. That

NAMES AND NUMBERS

Coilcraft
1102 Silver Lake Road
Cary, IL 60013
(800) 322-COIL
Hewlett-Packard
PO Box 10161
Palo Alto, CA 94303
(415) 857-1501
Hygenic Corporation
1245 Home Avenue
Akron, OH 44310
(216) 633-8460
Lambda Semiconductors
121 International Blvd.
Corpus Christi, TX 78406
(512) 289-0403
Maxim
120 San Gabriel Drive
Sunnyvale, CA 94086
(408) 737-7600
Miller-Stephenson
George Washington Hwy
Danbury, CT 06810
(203) 743-4447
Murata-Erie
2200 Lake Park Drive
Smyrna, GA 30080
(404) 436-1300
National Semiconductor
2900 Semiconductor Drive
Santa Clara, CA 95051
(408) 721-5000
OKI Semiconductor
785 North Mary Avenue
Sunnyvale, CA 94086
(408) 720-1900
Panel Components
PO Box 6626
Santa Rosa, CA 95406
(800) 662-2290
Rohm Corporation
Box 19515
Irvine, CA 92713
(714) 855-0819
SGS-Thompson
1000 East Bell Road
Phoenix, AZ 85022
(602) 867-6100
Synergetics
Box 809
Thatcher, AZ 85552
(602) 428-4073
Xicor
851 Buckeye Court
Milpitas, CA 95035
(408) 432-8888

quickly leads to such things as red, blue, and green projection television or for computer displays; or for color laser printing; or for laser light shows at laseriums or rock concerts.

Monochromaticity is also useful for chemistry and pollution control, where some reactions take place best at very specific light wavelengths. Monochromatic light is very easy to focus into a continuous and non-divergent beam. Such a beam of light is called a *collimated* beam. Think of it as a non-sagging red string that you can point anywhere you like.

Now, ordinary light bulbs obey an *inverse square law,* which means that if you double the distance, you get only one quarter the intensity, and so on. But with a collimated beam, you can sometimes gather in your *entire* beam at the receiving site.

In theory, inverse square-law loses can be entirely eliminated. In practice, they can be dramatically reduced. Thus, a laser gives us *unattenuated action at a distance,* which leads us to blackboard and lecture pointers; or survey gear; or construction levels. Out here in Arizona, cotton farmers use laser beams to level all of their irrigation fields precisely to one inch per acre or less, very much reducing their need for irrigation water while producing a more uniform crop. Collimated laser beams can also be used as *aiming devices,* both for use on weapons or for supermarket bar-code readers.

Some laser beams are not only monochromatic but also will maintain a very precisely controlled phasing over their entire beam. That leads to *coherent* light. Important uses of coherent light are for creating and viewing a three-dimensional *holographic* image, or sometimes for the super-precise measurements of extremely small distances.

As an example, one of *Hewlett Packard's* favorite photos is an end-supported six-inch thick "I" beam. Their laser *inferometer* will easily measure the deflection sagging of the beam as the weight of a single dime is added or removed. Other uses of laser inferometry include earthquake detection, solid-state gyroscopes, and for the generation of extremely short power pulses.

Most laser beams are not all that powerful. But that power can now be concentrated over a very small area, leading to a very high beam *power density.* For instance, a 5-milliwatt laser imaged on a 1 mil spot has an energy density of 8 kilowatts or so per square inch, or over *one megawatt per square foot!*

That in turn, can lead us to laser welding and cutting. Medical uses include blasting out clogged arteries or optically welding detached retinas in place. Industrial uses include both welding the unweldable and precision cutting to extreme accuracy. Artistic uses include laser carving of wood or plastics, and upgrading the quality of diamonds by zapping any included impurities.

A rather interesting new use for high energy density ultraviolet laser beams involves *stereo lithography,* where three-dimensional objects are selectively hardened out of a liquid photo polymer resin. That can be the ultimate *Santa Claus* machine where a plastic copy of anything can be replicated any place and any time. Detroit model-making time can drop from months to minutes with stereo lithography. *3-D Systems* is a major supplier of that sort of thing.

Some laser beams can be rapidly turned off and on at high frequencies. We say that the beam is *modulatable.* By turning the beam off and on, we can place information onto that beam. Three of the highest-volume uses of lasers are for CD players, desktop-publishing printers, and fiber-optic communication. All of those crucially depend on laser-beam modulation to operate.

So where can you start? Far and away the best source of hacker laser parts in the country is *Meredith Instruments,* who also have a new light-show BBS up and on line at (602) 867-7258. Their competitors include *Herback and Rademan* and *Jerryco,* along with a number of other sources that advertise in *Nuts and Volts* and right here in **Radio-Electronics**.

The really big news is the new TOLD-9200 visible-red solid-state laser by *Toshiba.* Those dudes are now in volume production, are easy to modulate, rugged, foreverlasting, and simple to battery-power. And costs should drop ridiculously in the future. Among its numerous other features, that new product can single-handedly quadruple the storage on a CD disk or double the resolution of a desktop-publishing laser printer. Not to mention the fact that you can actually see where the beam is pointing.

Sharp has a very interesting *Laser Diode User's Manual* out. This one is both free and an essential resource. Many infrared laser diodes now have built-in photodetectors, such that a feedback loop can be used for constant optical power.

Two obvious sources of educational laser stuff include both *Heathkit* and *Edmund Scientific.* Picking a few names at random, *LaserCraft* does beautiful wood carvings for yuppie desk accessories, while the *Applied Laser Tech* folks have some interesting laser engraving machines with features that you might want to check into. And, as we have seen, *3-D Systems* is now in the center of laser stereolithography.

There are a number of free laser trade journals. As always, you can subscribe to them by getting a qualification card using your business letterhead. Four of the more useful laser trade journals include *Laser Focus World, Lasers and Optonics, Fiber Optic System News,* and that *Photonic Spectra.* Those bar-code trade journals that we've looked at in a previous issue also have lots of laser stuff in them.

Those new solid-state red laser diodes should open up all sorts of new hacker opportunities. For our contest this month, just tell me what you would do with some of them, especially if they cost only $5. There will be all of the usual *Incredible Secret Money Machine* book prizes, along with an all-expense-paid (FOB Thatcher, AZ) *tinaja quest* for two going to the very best of all. As usual, send your entries directly to me at *Synergetics,* and *not* to **Radio-Electronics** editorial department.

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BUILD A SEMICONDUCTOR LASER SYSTEM

Visible-light laser diodes are here! In the first article of its kind, we'll show you how to build a handheld, rechargeable, semiconductor laser system.

ROBERT IANNINI

THE INTRODUCTION OF LASERS IN 1963 has brought about many changes in our lives, from the supermarket check-out counter to "Star Wars" weapon technology. Very few scientific developments have had as much of an impact on both the technological and everyday world.

"Laser" is an acronym for "light amplification by stimulated emission of radiation." Lasers are used in many applications, including gun sites, pointers, printers, construction and surveying aids, compact-disc players, bar-code readers, light shows, and several others. The helium-neon gas laser is one of the most familiar types, with its bright red directional beam. It's been a workhorse for years, despite its fragile glass laser tube and its requirements for costly high-voltage power supplies. But laser diodes promise to open a whole new world of applications. To demonstrate how they can be used, we've developed a hand-held battery-powered laser that runs on four rechargeable batteries. The batteries are inductively charged using a special charger. The unit is shown in Fig. 1. How is that possible?

The recently developed TOLD-9200-series of laser diodes from Toshiba emit coherent laser light in the visible spectrum, and don't require a high-voltage power supply. Because they're small, low-cost, and fairly rugged, laser diodes are well-suited for many applications.

Before proceeding further, lets review some basic laser theory, but first we must talk about regular light for a minute. When you turn on a light bulb, light energy is emitted in what is referred to as "spontaneous" form. It is an integration of many individual atomic energy level changes, each producing its own little "packet" or photon of light energy, with each photon having a particular phase.

In the case of a light bulb, electrical energy "pumps" the filament electrons to higher-than-normal atomic energy levels (see Fig. 2). Photons are emitted when the electrons return to their initial states and give up that energy in the form of light. The frequency of the light is dependent on the difference between the previously excited and normal energy level states; the larger the difference in energy levels, the lower the wavelength of light. The light produced by the process of spontaneous emission is incoherent or random (see Fig. 3).

Unlike spontaneous emission, laser light is highly directional. The radiant energy is released in-step, or in synchronism, resulting in coherent reinforced light where all of the waves are in phase. In other words, all of the rays are parallel and at the same wavelength. To achieve that requires that the number of excited atoms in the higher energy state exceeds that of the initial or rest state. That condition, referred to as "population inversion," normally doesn't occur in nature and must be "forced" or pumped.

Given a population inversion, each energized atom is then "stimulated" to return to its lower energy state by the emission energy, or incident light of an adjacent atom (see Fig. 4). The result is coherent light waves as shown in Fig. 5. An optical cavity with mirrored ends is usually necessary to provide the right amount of stimulated energy for laser light. As shown in Fig. 6, the light is reflected back and forth within its confines until it is a powerful beam that is allowed to exit the cavity as useful laser light energy.

A laser diode is similar to an ordinary light-emitting diode (LED) in that both are composed of a semiconductor PN junction (see Fig. 7). An electrical potential causes a flow of holes and electrons that, upon recombination, emit light. The LED produces spontaneous light, while the laser emits light by stimulated emission. The laser diode also contains two reflecting mirrors that form what's called a Fabry-Perot cavity, and permit the emitted light to be highly directional, an important laser property.

In spite of a laser diode's apparent physical ruggedness, it is very sensitive to temperature changes, electrical transients, and operating-current parameters. It is totally unforgiving of errors, so our circuitry and construction techniques must take that into consideration.

Safety first

Before proceeding, you should be aware of the potential hazards associated with lasers. Laser diodes can produce a continuous power in excess of 3 milliwatts. **That energy, when collimated, or viewed near-field, can cause retinal damage, so never look directly into the laser beam or through any lenses when the system is activated.** The laser that we are building is a Class IIIa device, and must be in compliance with U.S. safety standards for laser products (21 CFR 1040.10 and 1040.11).

Our device must bear a label like the one shown in Fig. 8. It must also have a label certifying that it conforms to classification specifications. At the output it must have the following label: **"Avoid Exposure, Visible Laser Radiation is Emitted From This Aperture."** Safety glasses should be worn when working with lasing devices of this power. Laser Peripherals, Hingham, MA is a good source; their model #DO-40 is suggested.

To prevent damage to the laser diodes, be sure not to exceed maximum ratings, even momentarily; or you could destroy the diode or cause it to require more current to produce its rated output (which will quickly lead to failure). Transients or spikes from switching both on and off can also destroy the device. Heat-sinking is required; the amount depends on whether the device will be used intermittently or continuously. Keep in mind that a temperature rise reduces the output for a given current, and merely supplying more current will lead to a thermal problem.

Be aware of electrostatic discharge when handling laser diodes. Normally, assembly requires grounded mats, wrist straps, floor mats, etc. However, the hobbyist can either work on a hot humid day or use a vaporizer or humidifier to maintain a degree of moisture in the air—that will reduce the static charge.

Do not operate the unit near high-frequency or high-power pulse circuitry, an RF field, a Tesla coil, plasma, magnetic discharge, etc. Never stress the diode leads or distort the hermetically sealed case. The device

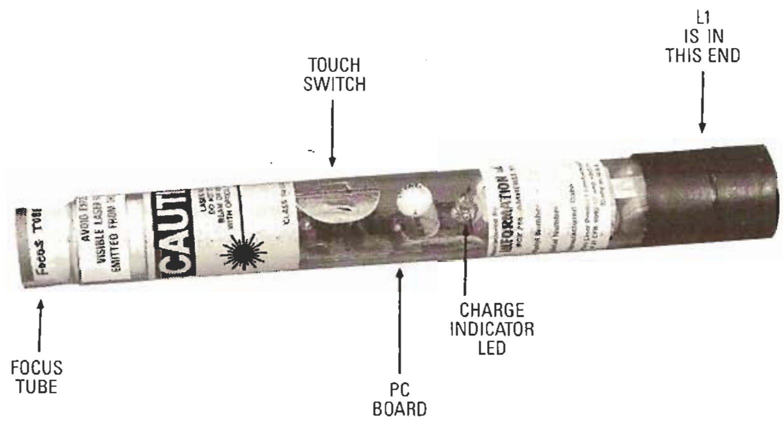


FIG. 1—OUR HAND-HELD LASER is powered from four rechargeable Ni-Cd batteries, which are inductively charged.

should fit snugly into the heat sink cavity with minimal force. Never touch the window because scratches and contaminants will distort and decrease the optical output. Use a cotton swab and ethyl alcohol to clean the window.

Circuitry

A laser diode operates like an ordinary forward-biased diode and shows the operating curve in Fig. 9. The vertical axis corresponds to optical output while the horizontal axis is the forward diode current. I_{OP} is the operating current, which determines the optical output. Lasing starts at the threshold value (I_{TH}). The maximum rated input current must never be exceeded. However, anything below I_{TH} will produce the effects of a regular LED. The curve shows a very steep slope where laser operation takes place, and the input-current "window" on the horizontal axis is very narrow; consequently the driver circuit must operate within those limits or you'll end up with one of the worlds most expensive medium-powered LED's.

The schematic of the hand-held laser is shown in Fig. 10. The Toshiba 9200 laser diode (D3) is actually an assembly that contains a laser-emitting section (LD) and a photodiode section (PD). The photodiode allows the circuit to monitor the laser diode's output and to produce the feedback necessary to control the circuit and protect the diode from voltage transients.

The laser diode is connected in series with current-limiting resistor R4 and the collector of Q4. The current through Q4 is controlled by Q3. Zener diode D2 maintains the voltage across Q3, and R3 limits the Zener current. The collector current of Q3, which is also the base current of Q4, is controlled by its base which is connected across R5 and R6. Current from the photodiode develops a voltage across those resistors that is proportional to the optical output energy. That constitutes the feedback required for output stabilization. Increased output causes Q3 to conduct less base current to Q4, resulting in less laser diode current. Potentiometer R6 presets the value of quiescent current. Capacitor C5 limits transients at the base of Q4 while C4 limits them from the V_{CC} line.

The system turns on when Q2 is conducting and close to saturation. Touch-switch S1's electrodes consist of small pieces of metallic tape that, when bridged by finger contact, cause a small amount of base current to flow into Q1. The collector current of Q1 flows into the base of Q2, causing it to saturate and supply current to the laser diode. Base current to Q1 is limited by R2, while R1 and C2 reduce the circuit's sensitivity to stray AC or static fields that could cause premature turn-on.

The laser is powered by four rechargeable Ni-Cd batteries. They are charged by induction coupling to the charging module. The batteries are connected in series with rectifier diode D1, LED1, and the pickup coil, L1. High-frequency energy from the charger is coupled into the coil, and is rectified and filtered by C1. When the batteries are being charged LED1 turns on.

The charger schematic is shown Fig. 11, and a photograph of a prototype unit is shown in Fig. 12. It uses a 120-to-12 volt AC step-down transformer, T1, whose output is rectified by diodes D4–D7; capacitor C6 removes any ripples. Switch S2

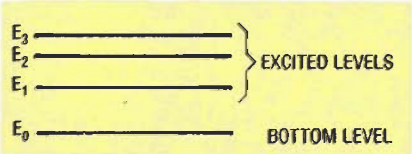


FIG. 2—LIGHT IS THE RESULT of radiation produced within an individual atom by an electron being "pumped" to a higher than normal energy level by an external energy source.

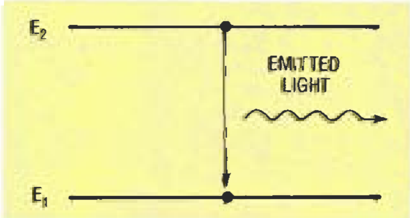


FIG. 3—A LIGHT BULB EMITS "spontaneous" light, which does not allow the energy packets to reinforce one another in phase or position.

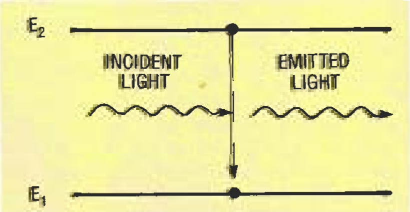


FIG. 4—WHEN MORE EXCITED ATOMS exist in the higher energy state than in the initial or rest state, each energized atom is "stimulated" to return to its lower energy state by the emission energy, or incident light of an adjacent atom.

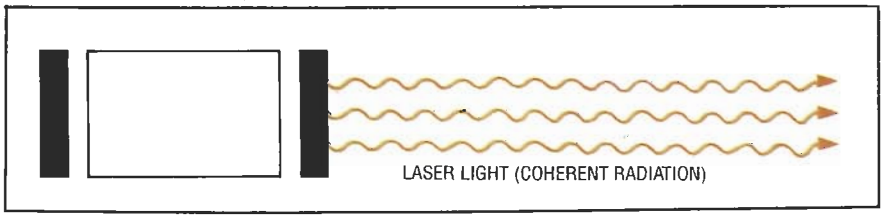


FIG. 5—A LASER BEAM IS THE RESULT of an "in lock step" train of coherent light waves.

supplies power to the circuit, and LED2 indicates when the power is on. The ground lead of PL1 is connected directly to the metal chassis of the charger.

The rectified 12–14 volts DC energizes a simple oscillator circuit consisting of Q5 in series with L2. That winding couples energy into the pick-up coil (L1) of the laser section for battery charging. To charge the batteries, the pickup coil physically slides over the coil assembly of the charger module. No electrical connections are necessary to provide the charging current.

Coil L3 (which is wound on the same ferrite core as is L2), and resistor R9 provide the necessary

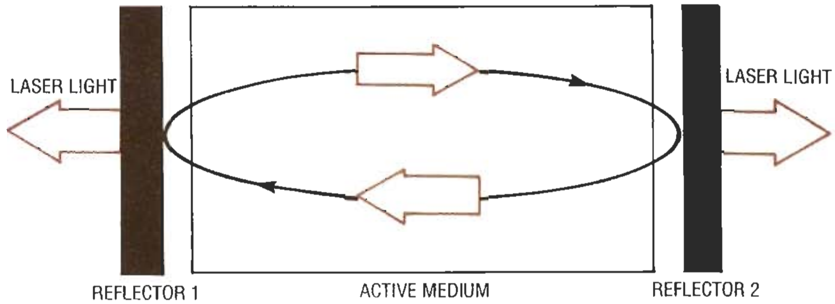


FIG. 6—AN OPTICAL CAVITY having mirrored ends provides the right amount of stimulated energy for laser light. Light is reflected back and forth within its confines until it is a powerful beam that is allowed to exit the cavity as useful laser radiation.

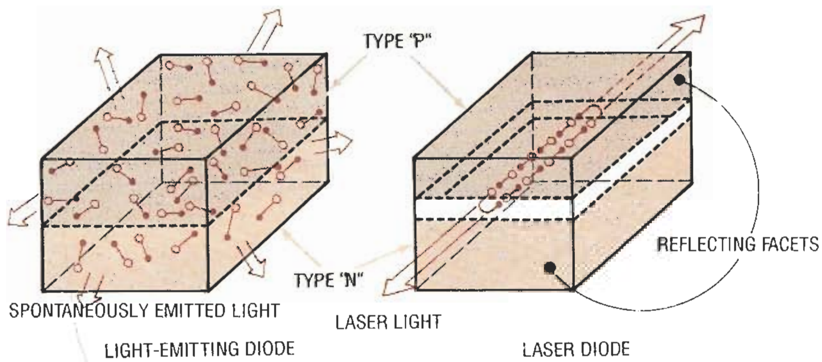


FIG. 7—A LASER DIODE IS SIMILAR to an ordinary LED, except that the LED produces spontaneous light, while the laser emits light by stimulated emission where the wavelengths and temporal relation are coherent. A laser diode also contains two reflecting mirrors that form a cavity and permit the emitted light to be highly directional.

PARTS LIST FOR THE LASER

All resistors are ¼-watt, 5%, unless otherwise noted.
R1—5.6 megohms
R2, R5—1000 ohms
R3—470 ohms
R4—15 ohms, ½-watt
R4-a—100 ohms (optional, see text)
R6—5000 ohms, trimmer potentiometer
Capacitors
C1—100 µF, 16 volts, electrolytic
C2—0.1 µF, 16 volts, ceramic disc
C3—0.01 µF, 16 volts, ceramic disc
C4—1 µF, 16 volts, electrolytic
C5—10 µF, 16 volts, electrolytic
Semiconductors
D1—1N4001 diode
D2—1N5221 Zener diode (2.4 volts)
D3—TOLD 9200 laser diode (Toshiba)
LED1—yellow light-emitting diode
LED3—red light-emitting diode (for the simulated laser diode)
Q1, Q3—PN2907 NPN transistor
Q2, Q4—PN2222 NPN transistor
Q5—L14G3 or ECG3036 phototransistor (for the simulated laser diode)
Other components
B1–B4—1.25-volt Ni-Cd cell, VARTA 100 R.S.
L1—pickup coil, 10 turns #18 wire, ½-inch diameter
S1—2 pieces of adhesive-backed metal tape (see text)
Miscellaneous: PC board or perforated construction board, small transistor socket (for laser diode), special aluminum heatsink and diode retainer with hardware, #24 vinyl wire, #20 vinyl wire, 7¾-inch long by 1-inch diameter by 1⁄16-inch wall thickness (transparent or colored), 13⁄16 plastic rear cap, 1⅝-inch by ⅞-inch focus tube, 1 × 6 mm short focal length lens, 1-inch plastic caps, ⅞-inch diameter shoulder washer (to mount lens on), warning labels, etc.

FIG. 8—ANY LASER DEVICE must contain warning labels according to the specific type of device. Our hand-held laser must display this warning, in addition to a label stating that it conforms to specifications and a warning at the laser aperture.

feedback to sustain oscillation. Resistor R8 initiates the action by turning Q5 on. A resonating capacitor (C7) is connected across L2 to adjust the frequency to approximately 250 kHz.

Construction

All of the parts are available from the source mentioned in the parts list. A foil pattern has been provided if you wish to etch your own board for the laser unit, and a parts-placement diagram is shown in Fig. 13.

If you wish, you can certainly install the circuit in any kind of housing that you like—you don't have to follow our unit exactly. Just make sure you follow the circuitry and the precautions concerning the laser diode.

The specifications for L1 are described in the parts list. Position it as shown in the handle of the laser so that it can slide over the charging coil (L2). DO NOT install the laser diode in the circuit at this time; install only its socket. The circuit must be checked and calibrated beforehand. Don't forget to build the "simulated laser diode" shown in Fig. 10. It is used later on for testing and calibrating the laser system, without the fear of damaging the actual laser diode.

A cylindrical plastic enclosure houses the board, the batteries, and the optics. After the board is finished and checked out, it slides inside the plastic tube and the leads for S1 (the touch switch) are brought outside through two small holes. (Wait until we check out the board before installing it in the tube.) Two pieces of metal tape are used for the contacts. The lens is secured at the end of another tube using an appropriately sized washer. The lens assembly then slides in and out of the main tube, allowing you to focus the beam.

The charger circuit can be built on a small piece of perforated construction board and wired according to the schematic in Fig. 11. In the prototype, Q6 is heatsinked by attaching it to the surface of the metal cabinet. It must be insulated, so use a nylon screw and a mica washer to mount it (or use a separate heatsink). Coils L2 and L3 are wound on a ferrite core (see parts list), then wrapped with tape. The assembly is then centered in the charger tube and secured with epoxy filler (see Fig. 12).

Figure 14 shows how the laser section and the charger go together. If you don't follow the prototype exactly, simply follow Fig. 14 as a rough layout.

PARTS LIST FOR THE CHARGER

All resistors are ¼-watt, 5%, unless otherwise noted.
- R7—470 ohms
- R8—22,000 ohms
- R9—10,000 ohms

Capacitors
- C6—1000 µF, 16 volts, electrolytic
- C7—0.047 µF, 50 volts, Mylar

Semiconductors
- D4–D7—1N4001 diode
- LED2—green light-emitting diode
- Q6—D40D5 or NTE210 NPN power transistor

Other components
- L2, L3—coils wound on ferrite core (core is 1-inch in length, ¼-inch diameter) L2 is 10 turns #24 wire, L3 is 10 turns #30 wire.
- T1—120/12-volt AC step-down transformer, 100 mA
- S2—SPST switch
- PL1—3-wire line cord

Miscellaneous: perforated construction board, 6-32 × ½-inch nylon screw and nut with mica washer (to mount Q6 to case), 2½-inch plastic tube to fit over laser tube, metal cabinet (or use separate heatsink for Q6), line cord bushing, LED mounting bushing, double-sided tape, hardware, wire nuts, #24 vinyl wire, epoxy, etc.

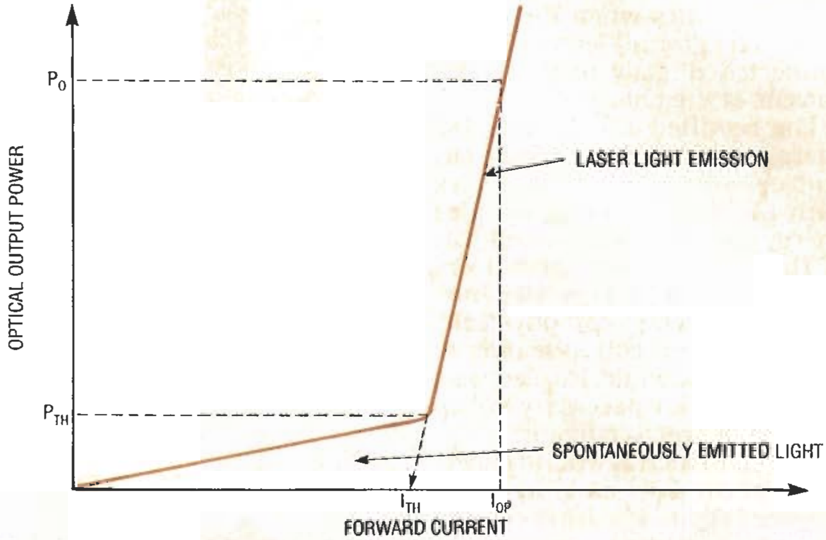


FIG. 9—A LASER DIODE OPERATES similarly to a forward-biased diode. The vertical axis corresponds to optical output while the horizontal axis is the forward diode current. I_{OP} is the operating current, and anything below I_{TH} will produce the effects of an LED.

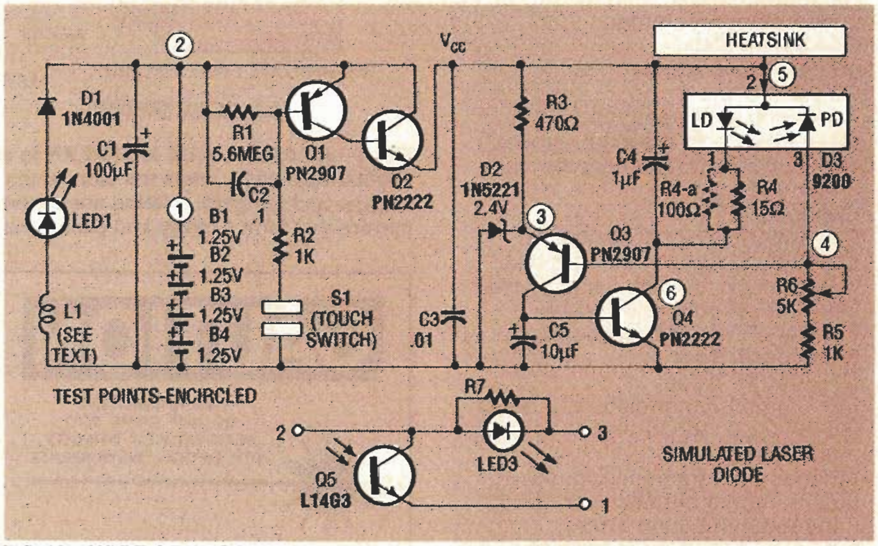


FIG. 10—HERE'S THE SCHEMATIC of the hand-held laser. The laser diode (D3) consists of the laser-diode (LD) and photodiode (PD) sections. That allows monitoring of the output energy and produces the feedback necessary to control the circuit.

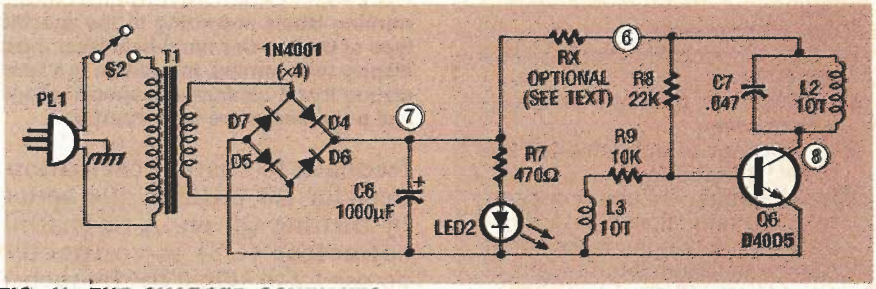


FIG. 11—THE CHARGER SCHEMATIC, charging current is inductively coupled to the hand-held laser.

Checkout

First make sure you do not have the laser diode in the circuit at this time. Plug the charger into a grounded AC outlet and check for 12–14 volts DC at test point 7 on the charger schematic. Check to see that LED2 turns on when you close S2.

Open up the lead at test point TP6 on the charger and check for a reading of 100–125 milliamps (assuming the batteries aren't already charged). In rare cases, if the current is excessively high, a resistor (RX) may be required as shown in the schematic to limit it. If a scope is available you may

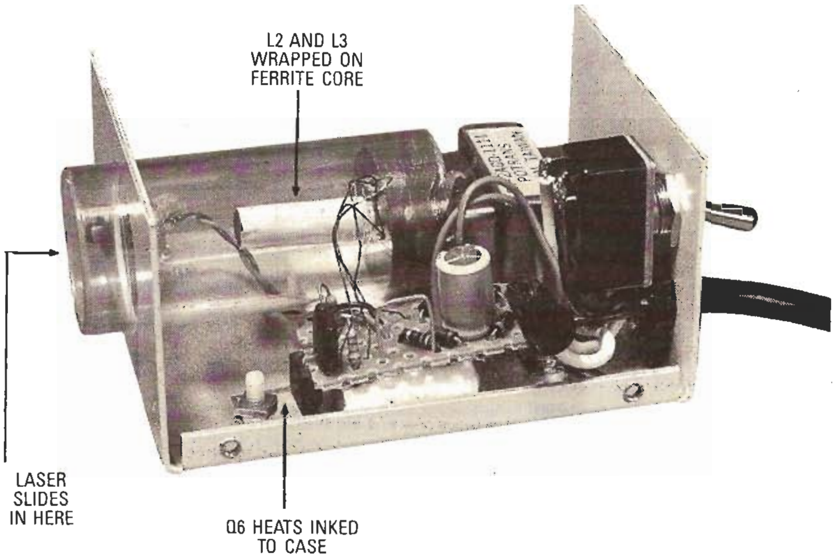


FIG. 12—THIS IS THE CHARGING UNIT; the amount of current coupled to it depends on how far the laser is inserted into the charger.
in the charger, more or less current is coupled to it.

ORDERING INFORMATION

A kit of all parts for the hand-held laser except the laser diode, heatsink, and retaining hardware (#VRL2-LHK), is available for $39.50. The special aluminum heatsink and diode retainer with hardware (#HS3) is $9.50. The price for the Toshiba laser diode (TOLD 9200) is continually dropping, although it is currently $74.50. A kit of all parts for the charger (#VRL2-CMK) is $34.50. A kit of parts for the entire system, including batteries and charger is $158.50. Contact Information Unlimited, P.O. Box 716, Amherst, NH 03031. FAX: 603-672-5406. Toll-free order line: 800-221-1705.

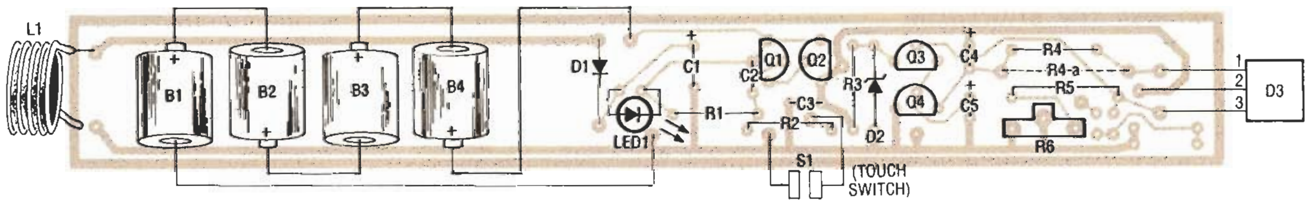


FIG. 13—PARTS-PLACEMENT DIAGRAM for the laser. Do not install the laser diode until everything has been thoroughly tested.

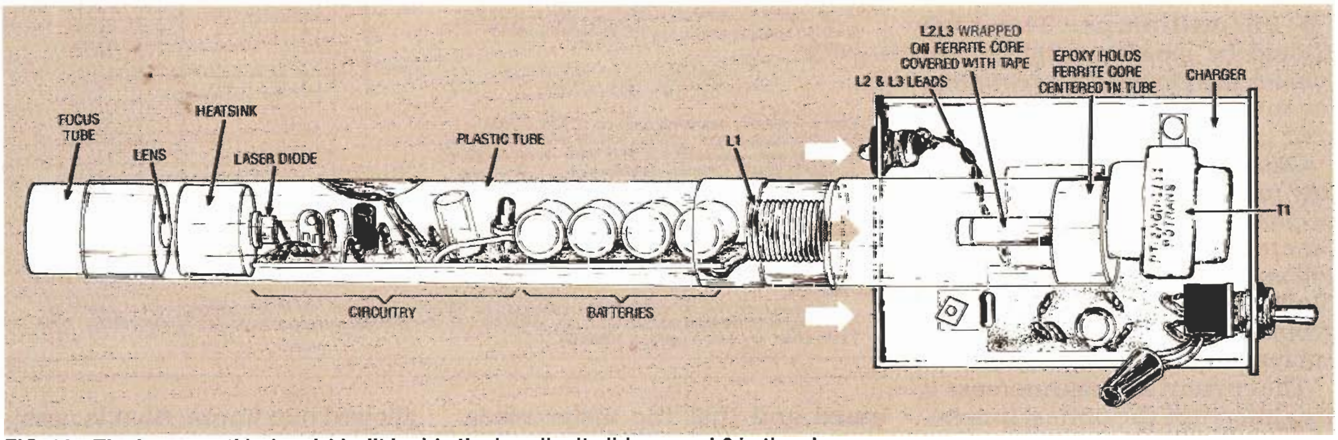
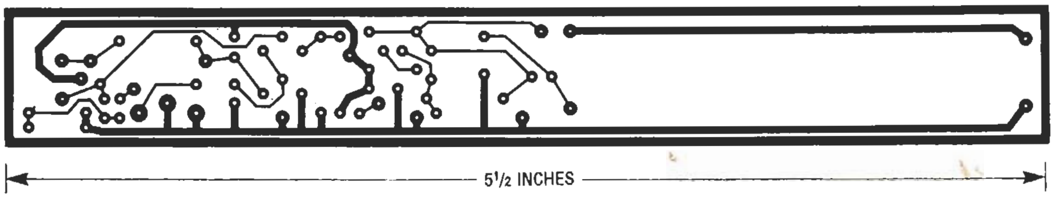


FIG. 14—The laser section has L1 built inside the handle; it slides over L2 in the charger.



THIS FOIL PATTERN for the hand-held laser can be used if you wish to etch your own board.

want to verify an approximate sine-wave shape of 25–30 volts peak to peak at a frequency of 250–300 kHz at test point TP8. This verifies proper operation of the charger.

Connect an ammeter in series with test point 1 on the laser. Slide coil L1 of the laser over the ferrite core of L2 on the charger. Check for a current reading of 10–25 milliamps and that the charge indicator (LED1) is lit.

The laser may be positioned in the charger socket for either a fast charge of 20 milliamps at a 6–8 hour rate, or the recommended 10 milliamps at a

14 hour rate. Monitor the charging current as you slide the laser in and out of the charger.

Make sure that the batteries are fully charged before you proceed with the following. Remove the laser from the charger. Note that the current goes to zero and LED1 goes out. Check on the lowest meter range; any current flowing into the circuit above a fraction of a microamp will cause premature discharging of the batteries. Check for defective components, flux paths, excessive moisture, etc., if any current is detected in this step.

Using the negative lead of B4 as a ground point, check for 5.6 volts at test point TP2. Adjust R6 to a maximum value (fully counter-clockwise in our layout). Short out the touch-switch leads and note a current of 10–15 milliamps. Remove the short and bridge the leads with dampened fingers; the current flow should be slightly less than the previous reading. This verifies the control circuit.

If you haven't yet built the simulated laser diode (shown in Fig. 10), do so now, and insert it into the circuit. Short out the touch switch and note a current of 75–85 milliamps. The LED should be glowing brightly. Adjust R6 in a clockwise direction to its midpoint and note the current increasing to over 100 mA.

Check for a smooth control, as any jumps can spell disaster, especially at the end of the potentiometer travel. Short the phototransistor section of test laser diode with a 470-ohm resistor to ground. You should note that the current increases further.

The current will also increase if you interrupt the optical link between the phototransistor and the LED. That verifies that the feedback circuit is operating properly. CAUTION: Re-adjust R6 back to maximum resistance (fully CCW). As a reminder, adjustment of R6 must be done with the batteries fully charged.

Remove the touch-switch short. With a metal screwdriver, short out all pins of the laser-diode socket. Do not go any further if you suspect a high-static electrical condition. Wait for a damp day or use a humidifier or vaporizer in your work area. Make sure the touch-switch leads are separated and that the meter reads zero current. Carefully insert the diode into the socket.

Bridge the switch with your finger and note the laser diode lighting and a meter current of 70–80 milliamps. The laser diode should be lasing at this level. Short out the touch switch and note slightly higher current.

At this point your laser is producing about 0.5 to 0.7 milliwatts—so you might want to stop here. However, the actual laser-diode current is the meter reading (70–80 mA) minus the 10–20 milliamps at the touch-switch leads, which is still well below the allowed maximum. So it is possible to get more power out of the laser diode. However, if you do decide to challenge Murphy's laws, the next step should be done with a laser power meter. That's because the output level is critical when adjusting for maximum. We used a *Metrologic* model number 45-540 laser power meter.

Couple the head of the power meter to the laser diode and set it for the 20-milliwatts range. Use a piece of clay for temporarily securing them together. Short out the touch switch and note a

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Applications and Notes

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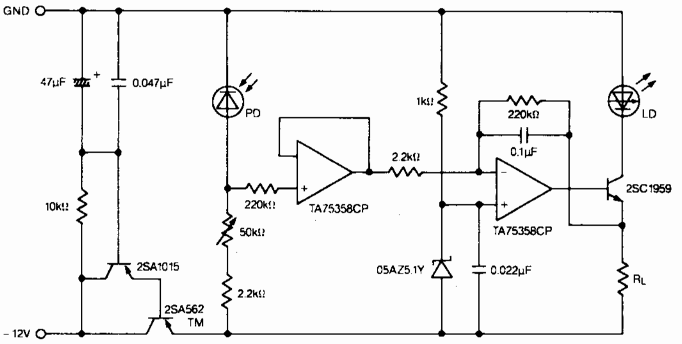
An Example of Driving Circuit for TOLD9200



Note:

- Use the laser diode after attaching it to a heat sink. Use a larger heat sink during the evaluation stage of deciding the operating condition. A copper or aluminum heat sink is recommended.
- Set the variable resistance VR (50kΩ) for its maximum value, then turn a power supply on. And regulate VR to adjust optical output power.
- When adjusting the optical output power, monitor both the drive current and the optical output power, never exceed the maximum optical output power rating. To monitor the optical output power, use an optical power meter or a calibrated photodiode that has a large active area. In case of using the above driving circuit, the heat sink will have positive potential.
- An Example of the Design of a Heat Sink
  The relationship among the case temperature T_c, ambient temperature T_a, and the thermal resistance of the heat sink θ_f is shown in the following simplified equation:

$$\theta_f \doteqdot \frac{T_c - T_a}{I_{op} \times V_{op}} - (\theta_s + \theta_c)$$

θ_s: Thermal resistance of insulator sheet
θ_c: Contact thermal resistance

Example:

In the case of $T_c = 50°C$, $T_a = 45°C$, $I_{op} = 100mA$, $V_{op} = 2.5V$, $\theta_s = 0$ (no insulator sheet), $\theta_c = 8°C/W$, from the above equation:

$$\theta_f \doteqdot \frac{50 - 45}{0.1 \times 2.5} - 8 = 12°C/W$$

Heat sink thermal resistance must be 12°C/W or less. From the figure on the right, the surface area of the aluminum heat sink—assuming it is 2mm thick—must be 25cm² in order to obtain a thermal resistance of 12°C/W or less.

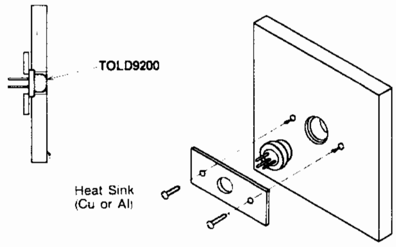
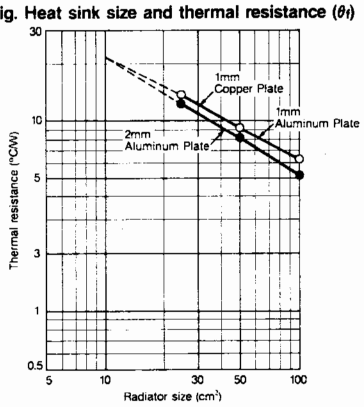


Fig. Heat sink size and thermal resistance (θ_f)



IMPORTANT NOTICES

The circuit examples illustrated herein are presented only as a guide for the performances of the applications of our products.

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SEMICONDUCTOR LASER

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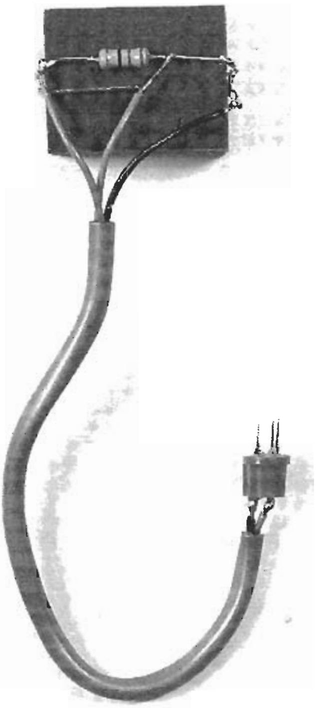
power output of 0.5 milliwatts or so. *Slowly* rotate R6 noting the "indicated output" on the power meter increasing. Note how "slope" sensitive it is when comparing it to the change on the current meter. That is a direct indication of the slope efficiency of the device as shown in Fig. 9.

Adjust to an output of 2.4 milliwatts—any more would constitute a more severe optical hazard, and would require a "DANGER" label. An output below 2.4 milliwatts requires only a "CAUTION" class IIIa label. **Safety glasses should be worn at this point.**



PROTOTYPE VERSION of the simulated laser diode. A hole drilled in the block provides a light path.

Remove the touch-switch short and bridge it with damp fingers; Note the power still going to 2.4 milliwatts, but the current reading on the meter is lower. This verifies the power-control circuitry is functioning properly.

This completes the electronic testing. It is suggested that you return R6 to its lower output adjustment before proceeding. And, again, always make sure that the batteries are fully charged before re-adjusting R6. R-E