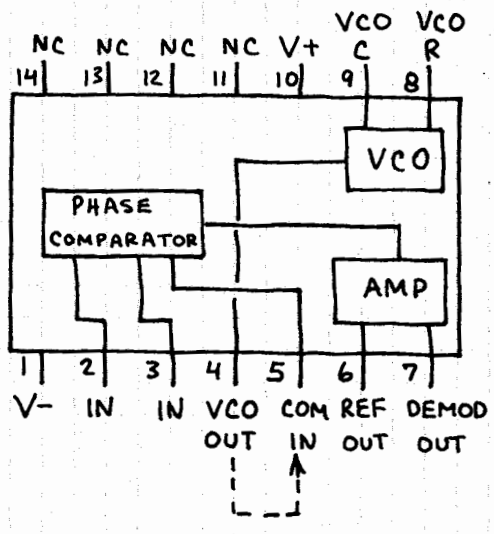
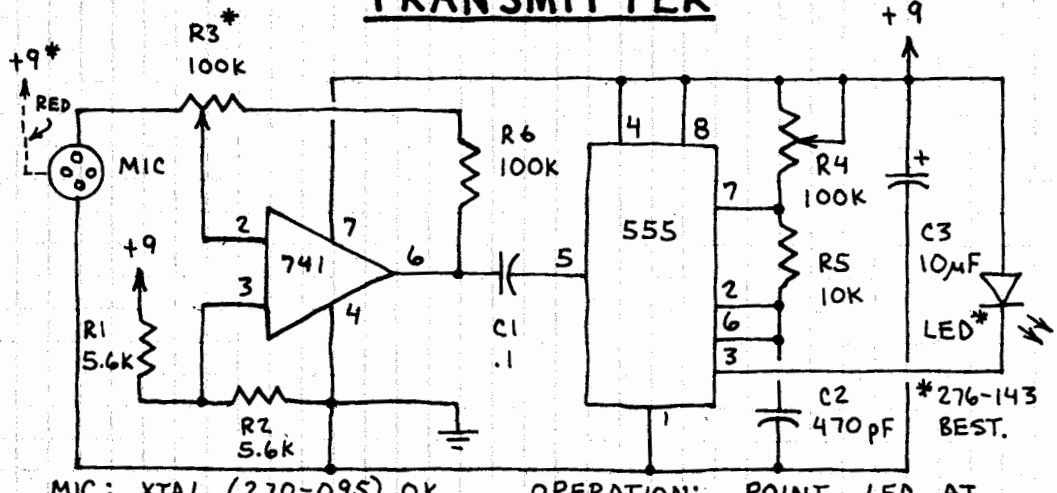
PHASE-LOCKED LOOP
565

SOPHISTICATED ANALOG SYSTEM THAT AUTOMATICALLY TRACKS A FLUCTUATING INPUT SIGNAL. VOLTAGE CONTROLLED OSCILLATOR (VCO) FREQUENCY IS CONTROLLED BY OUTPUT VOLTAGE FROM PHASE COMPARATOR. THIS CAUSES VCO FREQUENCY TO MOVE TOWARD INPUT SIGNAL. THE COMPARATOR VOLTAGE OUTPUT IS AMPLIFIED AND AVAILABLE FOR COMMUNICATIONS APPLICATIONS ... AS SHOWN BELOW. SEE RADIO SHACK DATA BOOK FOR MORE INFORMATION.



PULSE-FREQUENCY-MODULATED INFRARED COMMUNICATOR

TRANSMITTER



MIC: XTAL (270-095) OK.
* ELECTRET (270-092) BEST.
R3: TRY 1M FOR MORE GAIN.

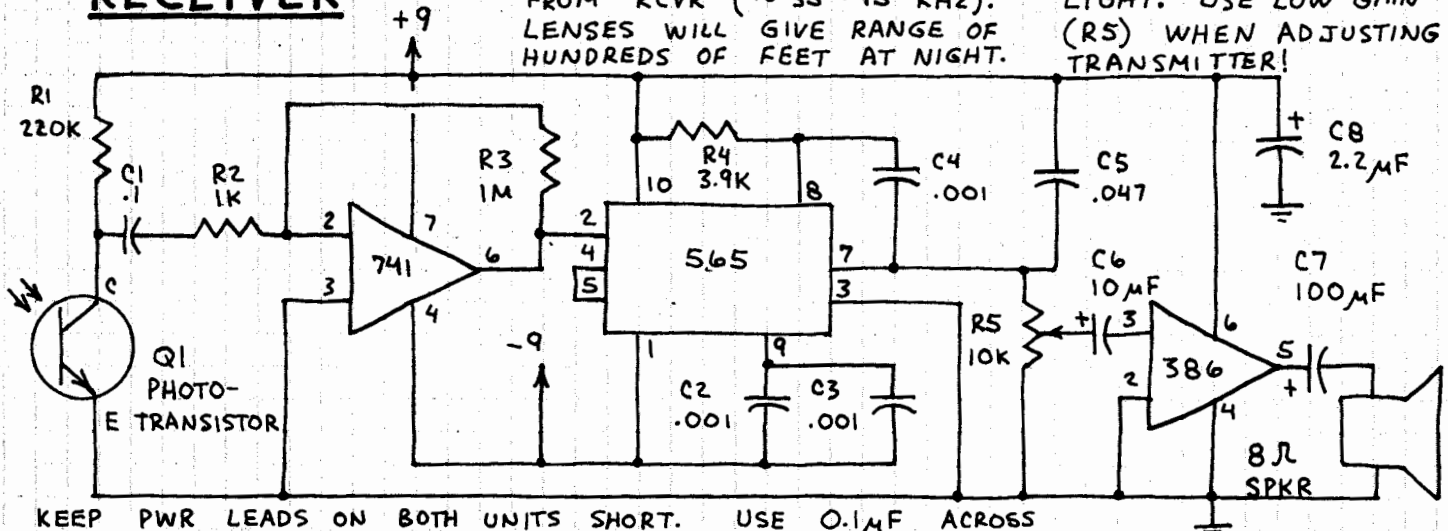
*276-143 BEST.

OPERATION: POINT LED AT Q1. APPLY POWER AND ADJUST R4 IN XMTR UNTIL GOOD QUALITY SOUND HEARD FROM RCVR (~35-45 KHz). LENSES WILL GIVE RANGE OF HUNDREDS OF FEET AT NIGHT.

TRANSMITTER: R3 CONTROLS GAIN. R4 CONTROLS CARRIER FREQUENCY. FOR INITIAL TESTS, REMOVE MIC AND CONNECT TRANSISTOR RADIO PHONE OUTPUT TO R3 VIA 4.7 μF AND GND. USE LOW VOLUME SETTING. R3 MUST BE 100K.

RECEIVER: RS CONTROLS GAIN. C2 AND C3 GIVE VCO CENTER FREQUENCY OF ~40.6 kHz. SHIELD Q1 WITH TUBE TO BLOCK EXTERNAL LIGHT. USE LOW GAIN (RS) WHEN ADJUSTING TRANSMITTER!

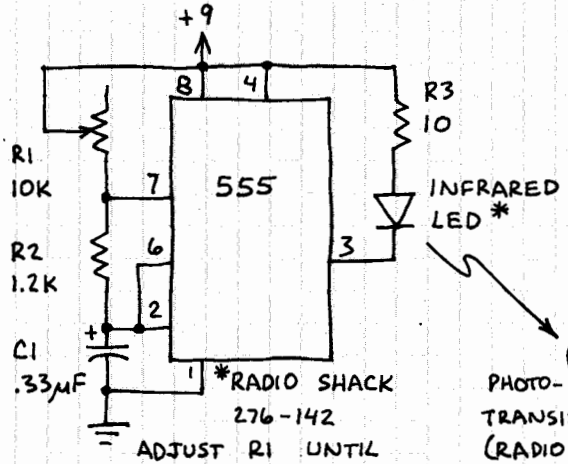
RECEIVER



KEEP PWR LEADS ON BOTH UNITS SHORT. USE 0.1μF ACROSS PWR CONNECTIONS (AT CHIPS) IF OSCILLATION OCCURS. HAVE FUN.

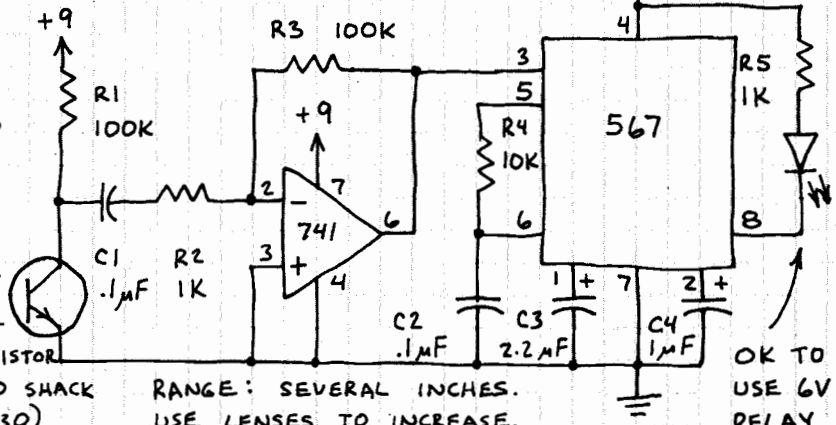
INFRARED REMOTE CONTROL SYSTEM

TRANSMITTER



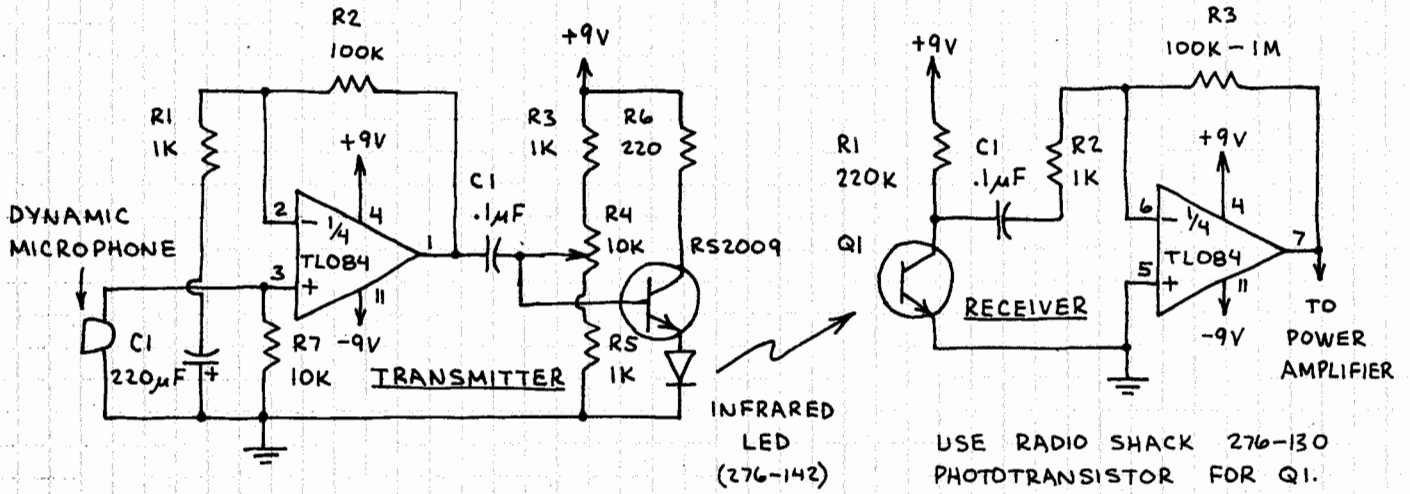
ADJUST R1 UNTIL RECEIVER LED GLOWS.

RECEIVER



RANGE: SEVERAL INCHES. USE LENSES TO INCREASE.

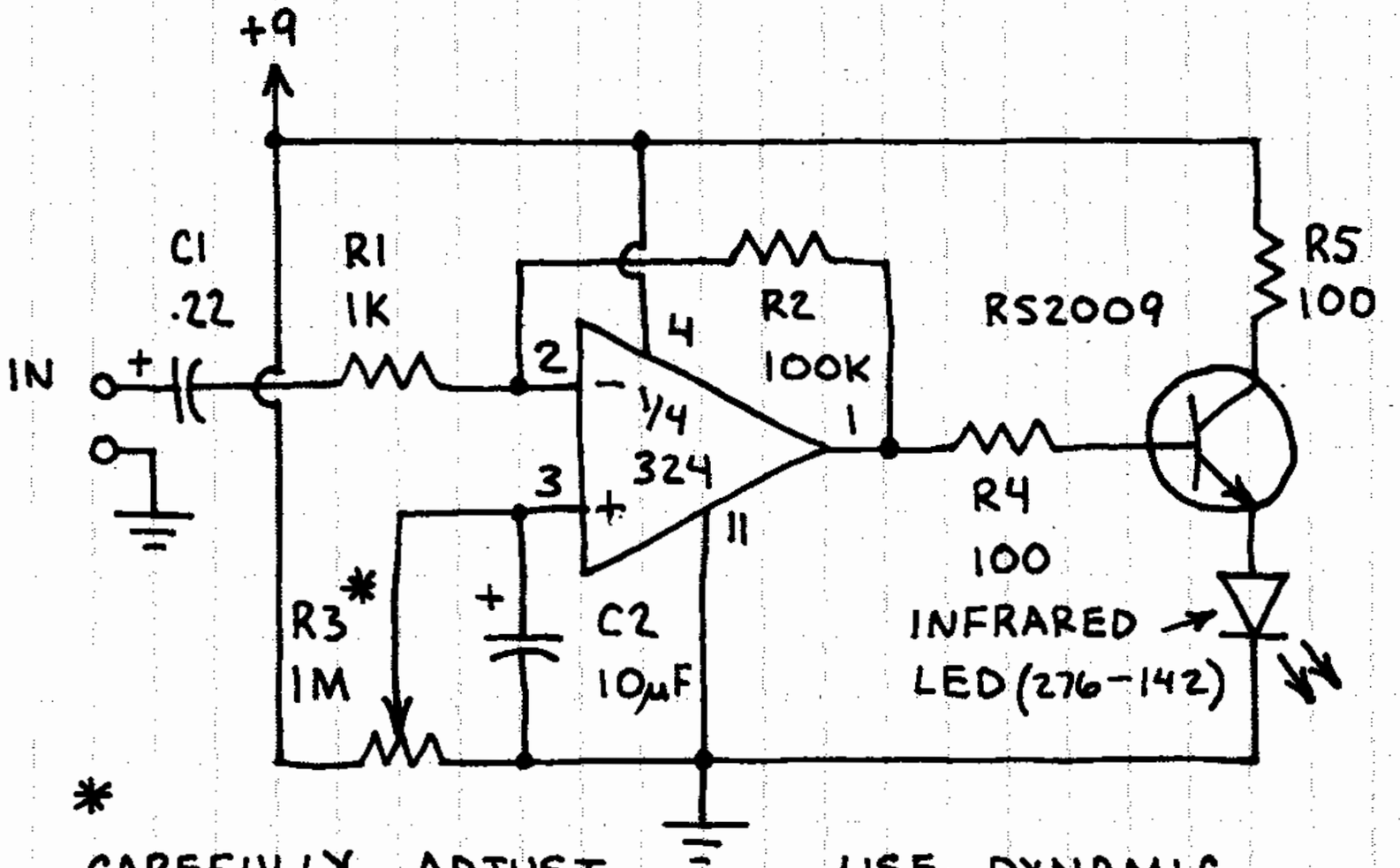
INFRARED VOICE COMMUNICATOR



POINT THE LED AT Q1 AND ADJUST R4 UNTIL BEST VOICE QUALITY IS OBTAINED. (R4 APPLIES PREBIAS TO LED.) R6 LIMITS MAXIMUM LED CURRENT TO A SAFE 40 mA.

USE RADIO SHACK 276-130 PHOTOTRANSISTOR FOR Q1. MAXIMUM RANGE: HUNDREDS OF FEET AT NIGHT WITH LENSES AT Q1 AND LED. POWER AMP: SEE LM386.

INFRARED TRANSMITTER



*

CAREFULLY ADJUST R3 FOR BEST VOICE QUALITY. FOR MORE POWER REDUCE R5 TO 50Ω... BUT DO NOT ALLOW MORE THAN 30 mA THROUGH LED!

USE DYNAMIC MICROPHONE AT INPUT. RECEIVE SIGNAL WITH PHOTOTRANSISTOR PLUS OP-AMP.

LIGHT BEAM COMMUNICATOR

Now, using our top-secret device, you and a partner can communicate across a void at the speed of light—on a beam of light!

ROGER SONNTAG

IF YOU'RE LOOKING FOR A purely *fun* project, then this light beam communciator is for you. It not only contains the usual electronics, it also has an ingenious mechanical assembly whose operation is interesting in its own right. You're sure to find it a refreshing change from the usual board-in-a-box project. But don't think that this light-beam communictor is just for fun. The powerful transmitter and extremely sensitive receiver take this project out of the realm of toys—you can do some pretty serious work with our device!

A complete *L*ight-*B*eam *C*ommunicator (LBC) consists of a transmitter and a receiver, installed inside 2 tube-like assemblies, along with various optical components. Two complete LBC's are required for two-way communication, but you will need only one transmitter and one receiver for one-way communication. Full-duplex operation is provided, meaning that you can talk and listen at the same time—there is no transmit/receive switch.

Figure 1 shows the block diagram of the transmitter. The transmitter houses a high-intensity LED, powered from a constant-current source, as well as the circuitry necessary to modulate an audio signal from a microphone onto the LED's light output. Using the optics, the modulated light from the LED is focused into an intense, narrow beam.

That narrow light beam travels a surprisingly long distance. The standard unit has about a ¼-mile range. The high-power unit has an amazing range of better than ½-mile! (When testing the range of the units, we used small "toy" 100-mW walkie talkies to assist with setup and aiming—the walkie talkies "ran out of gas" long before the LBC did!) At the end of its travel, the beam is received by another identical LBC that turns the modulated light beam back into the original audio signal. The receiver's block diagram is shown in Fig. 2. Let's examine the individual sections more closely.

The difference between the standard LBC and the high-power LBC is the LED that is used. The standard unit has a high-intensity 3-candela-power (3,000 milli-candela or mcd) LED manufactured by Hewlett Packard (a *candela*, formerly candle, is a measure of luminous intensity). The high-power unit has a very-high-intensity 12-candela (12,000 mcd) LED, also manufactured by Hewlett Packard. Both of those LED's are much brighter than a normal LED, and they have a focusing rather than a diffusing lens. However, *any* LED will work but the useful range of the LBC will be greatly reduced if a high intensity LED is not used.

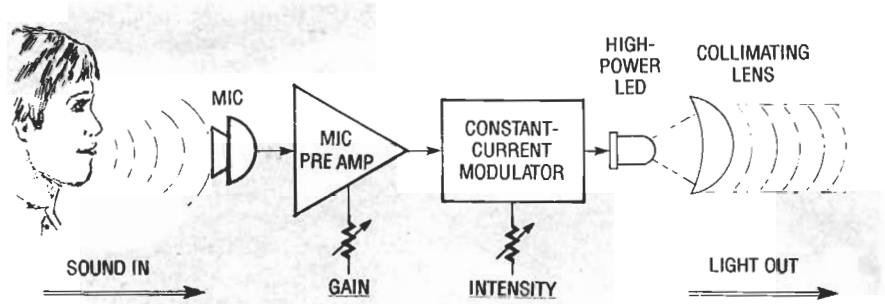


FIG. 1—BLOCK DIAGRAM OF THE TRANSMITTER. This circuit contains a high-intensity LED, powered from a constant-current source, and the circuitry necessary to modulate an audio signal onto the LED's light output.

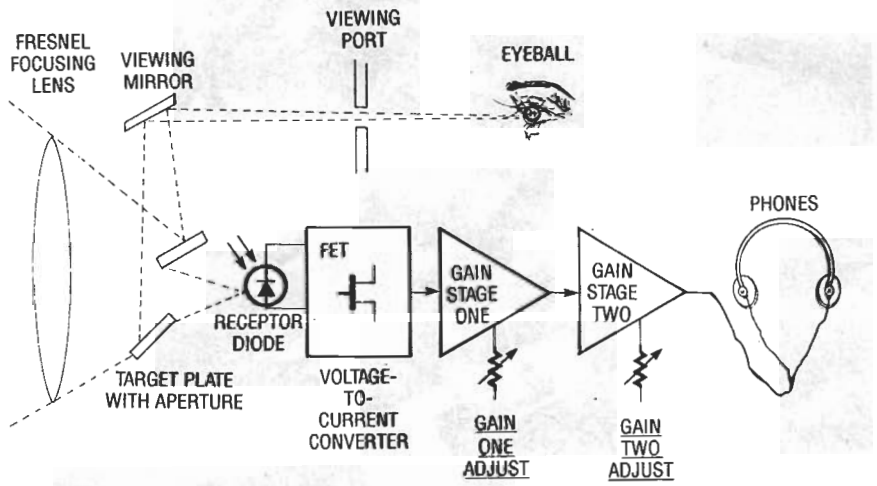


FIG. 2—RECEIVER BLOCK DIAGRAM. This circuit turns the modulated light beam back into the original audio signal.

The transmitter

There are two stages in the transmitter: a microphone preamplifier and a constant-current modulator (see Fig. 3). Each stage uses half of a 5532, which is an internally compensated, dual low-noise op-amp. After the microphone output is preamplified by IC1-a, the output signal from pin 1 is fed through C6 to pin 5 of IC1 where it is further amplified.

An adjustable constant-current source is fed to Q1, an NPN transistor capable of handling at least 3 amps. The audio signal at pin 7 of IC1 drives the base of Q1, modulating the signal onto the LED's light output. (An infrared LED can be used for this project, and will, in fact, increase the range. Unfortunately IR light is invisible, so it is not easy to work with. However, among the interesting things you can "hear" with the LBC are IR remote controls and IR burglar-alarm sensors.) Basically, the AC signal either adds or subtracts from the average DC level. Transistor Q1 and LED1 are in the feedback loop of the op-amp, and the DC current flowing through the LED remains constant due to the setting of R9. The DC current can be adjusted via R9 through a range from 1 to 50 mA.

The transmitter assembly, shown in Fig. 4, is fitted inside one end of a rugged cardboard tube that has a collimating lens at the other end. That lens focuses the light beam into a very narrow, intense beam, giving the light from an LED such an unusually long range.

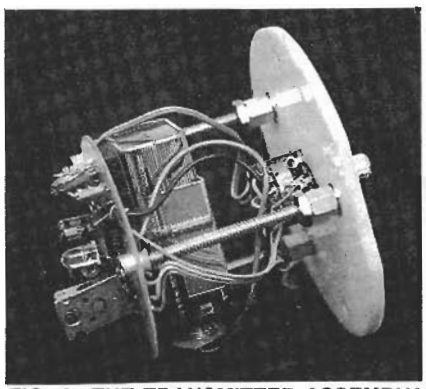


FIG. 4—THE TRANSMITTER ASSEMBLY. It is fitted inside one end of a rugged cardboard tube that has a collimating lens at the other end.

The receiver

The schematic for the receiver section of the LBC is shown in Fig. 5, and the receiver assembly is shown in Fig. 6. The receiver assembly is mounted inside one end of a large tube, which has a fresnel lens at the other end. The fresnel lens concentrates the light beam, and directs it to the photodiode, D1. The photodiode provided in the kit is actually a Kodak part, and not available to the general public. That part is well suited for this application, and it is more sensitive to infrared light than most photodiodes; but if you don't buy the kit, any silicon photodiode or phototransistor

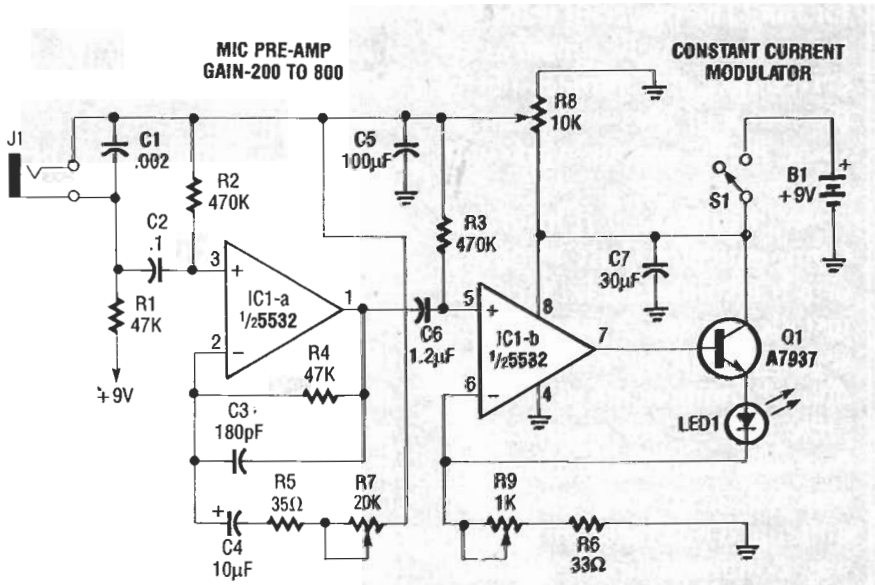


FIG. 3—THE TRANSMITTER CONTAINS TWO STAGES: a microphone preamplifier and a constant-current modulator. Each stage uses half of a 5532 op-amp.

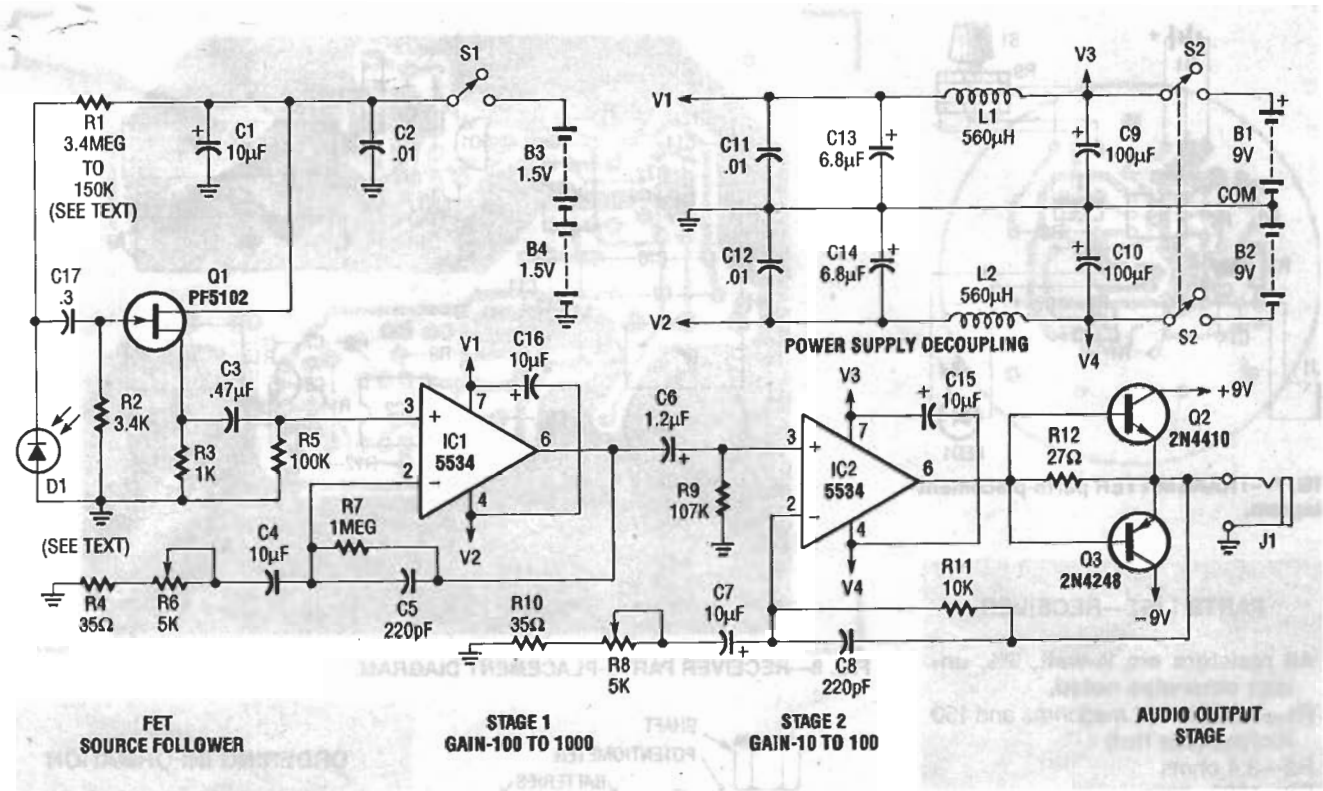


FIG. 5—THE RECEIVER SCHEMATIC.

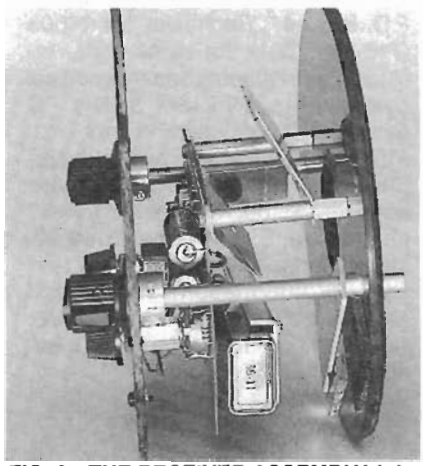


FIG. 6—THE RECEIVER ASSEMBLY. It is mounted inside one end of a large tube, which has a fresnel lens at the other end.

should do. The small signal that is generated by D1 is fed to pin 3 of IC1 via FET Q1.

Op-amp IC1 is the first gain stage in the receiver, and it amplifies the signal from Q1 100 to 1000 times, depending on the setting of gain-control potentiometer R6. The signal from pin 6 of IC1 is then fed through C6 to pin 3 of IC2, which is the second gain stage; the gain of the second stage is variable from approximately 10 to 100 via gain-control potentiometer R8. Two gain-control potentiometers are used to help improve stability, because stray oscillation is hard to avoid in a circuit with so much gain.

The signal at pin 6 of IC2 is then fed to R12, which is connected across the base-emitter junction of both Q2 and Q3. The voltage across R12 turns Q2 and Q3 on and off; those transistors are capable of driving a pair of low-impedance headphones.

Note that R1 is listed as being 3.4 megohms or 150 kilohms. That's because, if you use a value near 3.4 megohms, the receiver will be extremely sensitive, resulting in the greatest possible range. On the other hand, a value near 150K will decrease the sensitivity while providing a wide bandwidth, giving the unit higher fidelity. You can use any value between 3.4 megohms and 150 kilohms, but do not use a potentiometer, as it will be a source of noise in the circuit.

Construction

Let's start by building the transmitter board. Foil patterns for both boards are provided in PC Service. Figure 7 is the Parts-Placement diagram for the transmitter. First install the resistors, then the capacitors (bend the leads, solder, and then trim), and then the potentiometers. Cut some ribbon cable into 6 2-conductor pieces (3 for now and 3 for later), 1½-inches long, and then separate and strip the ends. (Any thin,

PARTS LIST—TRANSMITTER

All resistors are ¼-watt, 5%, unless otherwise noted.
R1, R4—47,000 ohms
R2, R3—470,000 ohms
R5—35 ohms
R6—33 ohms
R7—20,000 ohms, PC-mount potentiometer
R8—10,000 ohms, PC-mount potentiometer
R9—1000 ohms, combination potentiometer/switch (incorporates S1)

Capacitors
C1—0.002 µF, 50 volts, ceramic
C2—0.1 µF, 50 volts, ceramic
C3—180 pF, 100 volts, ceramic
C4—10 µF, 10 volts, electrolytic
C5—100 µF, 10–25 volts, electrolytic
C6—1.2 µF, 20 volts, electrolytic
C7—30 µF, 20 volts, electrolytic

Semiconductors
IC1—NE5532 dual low-noise op-amp
Q1—7937 3-amp NPN transistor
LED1—high-intensity light-emitting diode, can be Hewlett Packard HLMP-8103 (3000 mcd) or HLMP-8150 (12,000 mcd), or any other high-intensity LED.

Other components
B1—9-volt battery
S1—SPST switch (part of R9)
J1—mono phone jack
Miscellaneous: 9-volt-battery clip, 8-pin DIP socket, wire, solder, etc.

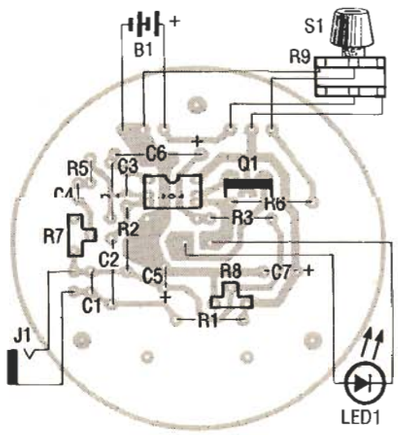


FIG. 7—TRANSMITTER parts-placement diagram.

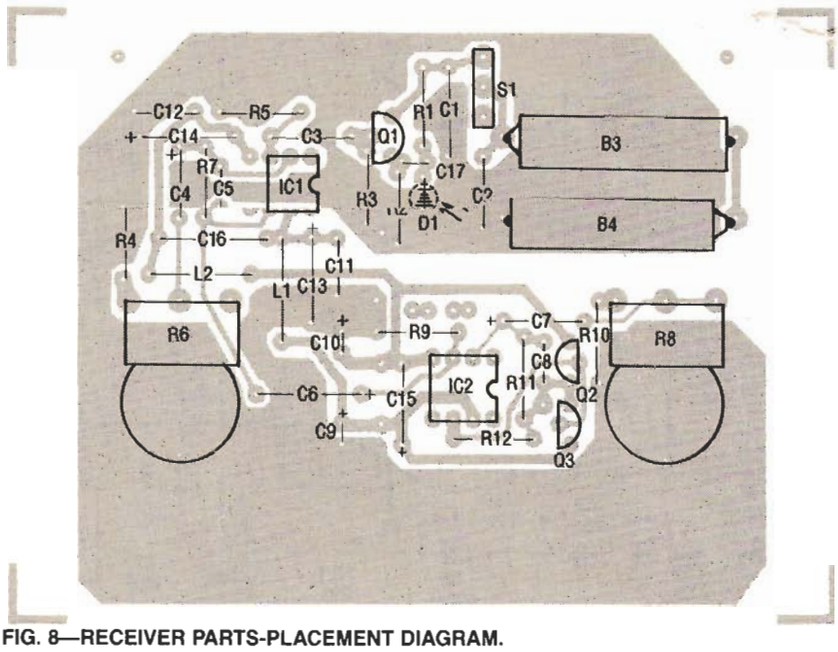


FIG. 8—RECEIVER PARTS-PLACEMENT DIAGRAM.

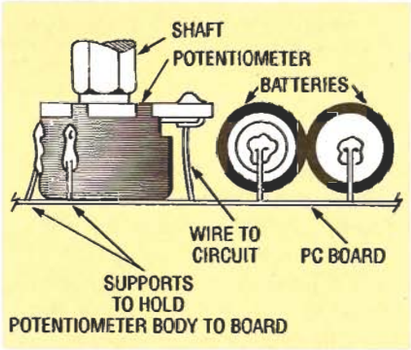


FIG. 9—YOU MUST USE PIECES of bus wire to attach potentiometers R4 and R6 securely to the PC board.

PARTS LIST—RECEIVER

All resistors are ¼-watt, 5%, unless otherwise noted.

R1—between 3.4 megohms and 150 kilohms (see text)
R2—3.4 ohms
R3—1000 ohms
R4—35 ohms
R5—100,000 ohms
R6, R8—5000 ohms, potentiometer
R7—1 megohm
R9—107,000 ohms
R10—35 ohms
R11—10,000 ohms
R12—27 ohms

Capacitors

C1—10 µF, 50 volts electrolytic
C2, C11, C12—0.01 µF, 10 volts, ceramic
C3—0.47 µF, 20 volts, ceramic
C4, C7—10 µF, 10 volts, electrolytic
C5, C8—220 pF, 100 volts, ceramic
C6—1.2 µF, 20 volts, electrolytic
C9, C10—100 µF, 15 volts, electrolytic
C13, C14—6.8 µF, 20 volts, electrolytic
C15, C16—10 µF, 25 volts, electrolytic
C17—0.3 µF, 50 volts, ceramic

Semiconductors

IC1, IC2—NE5534 single low-noise op-amp
D1—Siemans BPW-33 silicon photodiode (see text)
Q1—PF5102 field-effect transistor
Q2—2N4410 NPN transistor
Q3—2N4248 PNP transistor

Other components

L1, L2—560 µH
S1—SPST switch
S2—DPDT switch
B1, B2—9-volt battery
B3, B4—1.5-volt N-size battery
Miscellaneous: 2 9-volt-battery clips, DIP sockets, wire, solder, etc.

stranded wire will do if you don't have ribbon cable.) Then use one piece to connect the microphone jack, J1, to the pads indicated in Fig. 7, and two more to connect R8/S1.

Connect a 9-volt battery clip to the appropriate pads on the board, and then install IC1. (It's a good idea to use a socket for IC1.) Last, position LED1 (observe its polarity) so that it is standing perfectly straight off the PC board, then solder it in place.

For the assembly of the receiver board, see Fig. 8. First install resistors R1–R12, and then install the capacitors observing polarity where indicated. Then install L1 and L2, and sockets for IC1 and IC2. Using pieces of bus wire, attach potentiometers R4 and R6 securely to the PC board as shown in Fig. 9. Prepare B3 and B4 by soldering a short length of bus wire to each terminal (see Fig. 9) so that each battery can be PC mounted. PC-mount S2 and solder it in place. Now turn the board over, and solder D1 (the photodiode) in place observing its polarity indicated by a painted dot on its anode.

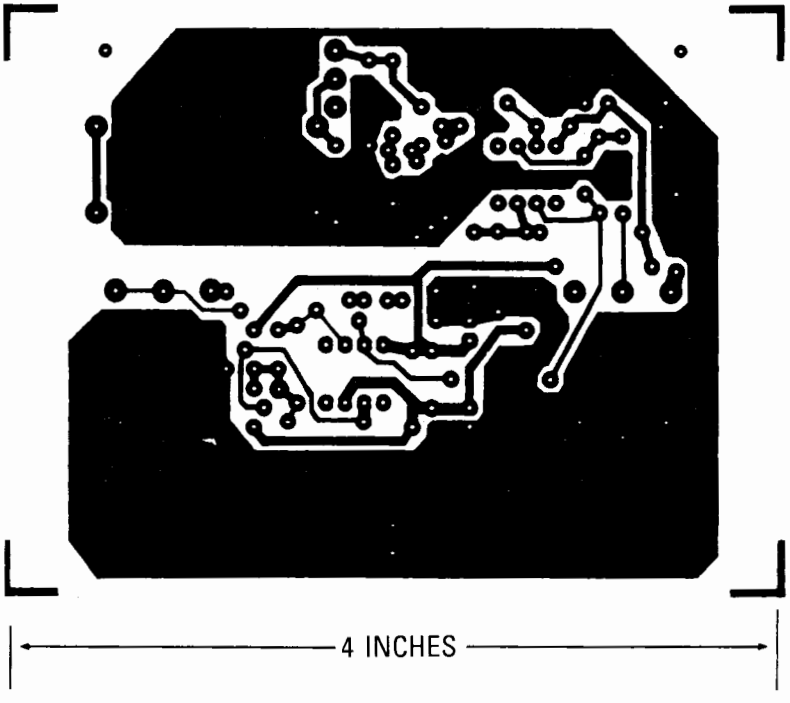
Take two 9-volt-battery clips and, on one of them, clip the red lead down to 1 inch and the black one to 2½-inches; on the other battery clip, cut the black lead down to 1 inch and the red to 2½ inches. Solder the leads to the PC board as shown. Using three more pairs of leads (as was shown in Fig. 8), connect J1, the headphone jack, and S2.

Well, the boards are finished, but that's all we have room for this month. Next month we'll finish the project by detailing the mechanical assemblies. We'll also present a list of the necessaray mechanical components. **R-E**

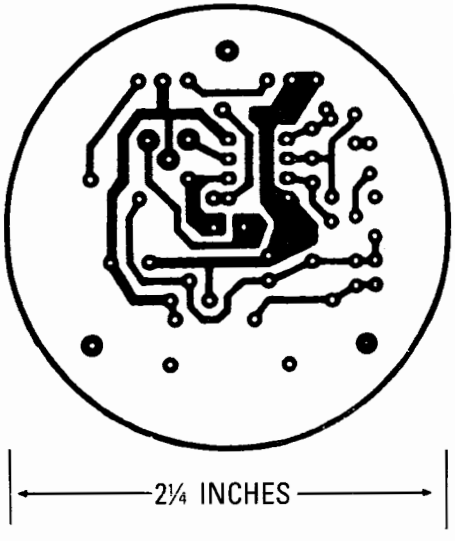
ORDERING INFORMATION

The following are available from General Science and Engineering, P.O. Box 447, Rochester, NY 14603 (716-338-7001): Kit of all parts, including all electronic and mechanical components, $98; Set of two PC boards, $12.00; 6-inch Fresnel lens, $15.00; A headset with built-in microphone, $12.00; Telephone-type handset, $5.00; Siemans BPW-33 photodiode, $3.50; HLMP-8150 12-cd LED price to be determined (call GSE for information); Assembled and tested communicator, $198. Note: the spotting scope is not available from GSE.

PC SERVICE



THE LBC'S RECEIVER BOARD.

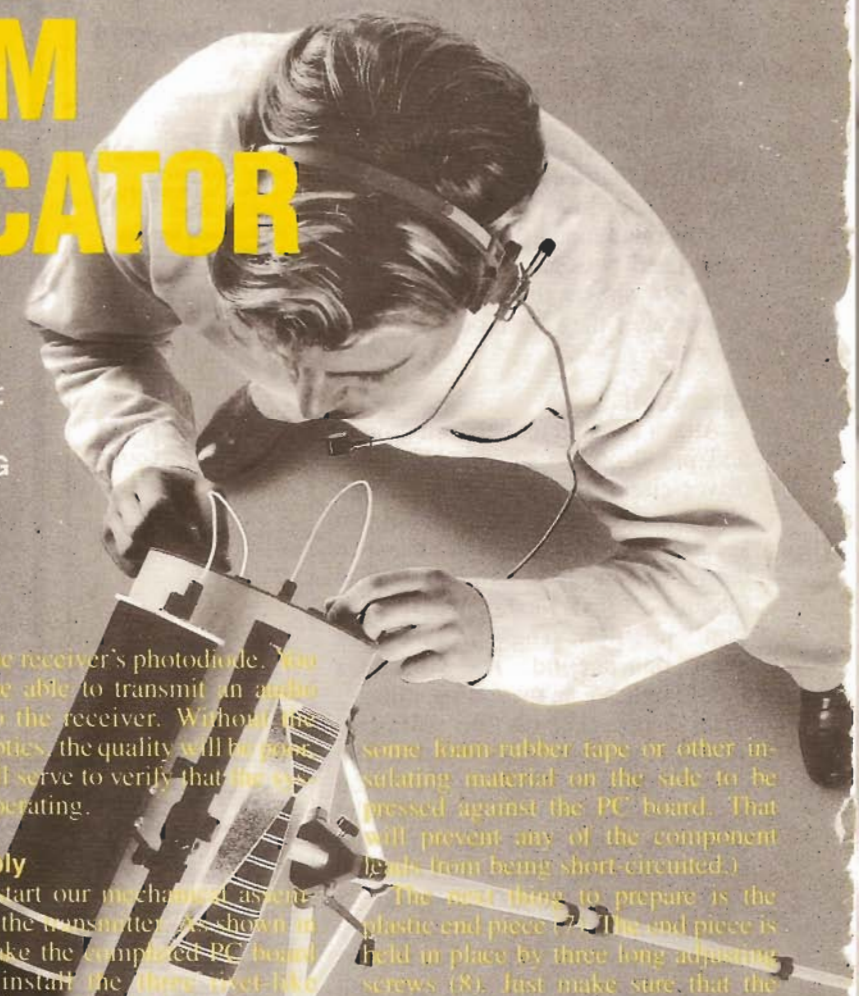


THE LBC'S TRANSMITTER BOARD.

LIGHT BEAM COMMUNICATOR

It's time to get out your tools and assemble our light-beam communicator.

ROGER SONNTAG



LAST MONTH WE DISCUSSED HOW TO build the transmitter and receiver PC boards for the *L*ight *B*eam *C*ommunicator (LBC), and gave you the necessary list of parts. We assume that, by now, you have completed assembling the two boards, and that you have checked and double checked your work. Before we get into the mechanical construction details, there are a couple of quick tests to verify that the boards operate.

The transmitter, as you may recall, consists of a high-intensity LED whose light output is modulated by an audio signal. Connect a microphone to the jack on the transmitter, and turn the transmitter on. Turn up the gain control, and speak into or tap the microphone. You should be able to see the light flicker somewhat. An even *better test is to connect an* oscilloscope across the LED, and observe the signal there. It should "follow" your voice as you speak into the microphone. If you're not getting a signal at the LED, start at the input to the first op-amp (IC1-a from Fig. 3 in the July issue), and trace until you can find where you lose the signal.

The receiver can be quickly tested by connecting a pair of headphones to the output jack, and powering up the circuit. If you hear some hissing, the circuit is probably functioning correctly. Reduce the receiver gain and position the two completed boards about a foot or so apart, so that the light from the transmitter's LED strikes the receiver's photodiode. You should be able to transmit an audio signal to the receiver. Without the proper optics, the quality will be poor, but it will serve to verify that the system is operating.

Assembly

Let's start our mechanical assembly with the transmitter. As shown in Fig. 1, take the completed PC board (1) and install the three rivet-like threaded inserts (2). That is normally done by first inserting the narrow end of an insert through each of the three holes on the edge of the PC board. (The narrow end should now be *protruding on the solder side* of the board.) By resting the wide end of the insert on a *solid* surface, the narrow end is spread apart, by giving it a whack with a tapered punch. Otherwise, you can use some *Krazy Glue* or RTV silicone to secure them to the board.

Next, take two ⅝-inch-long screws (3), insert them in the proper holes, and secure them with a nut (4). Then place the battery holder (5) over the ends of those screws as shown in Fig. 1, and secure the battery holder with two ⅜-inch long threaded spacers (6). (The battery is held down by tightening those spacers with the battery in place. Just be sure that the battery has some foam rubber tape or other insulating material on the side to be pressed against the PC board. That will prevent any of the component leads from being short-circuited.)

The next thing to prepare is the plastic end piece (7). The end piece is held in place by three long adjusting screws (8). Just make sure that the heads of the adjusting screws are on the side of the end piece that has two countersunk holes, and be sure to use the washers (9) where needed. (The countersunk holes are for the two screws that *hold the entire assembly* to the cardboard tube, but we'll worry about that later.) Place another washer (10) over each screw so that the end piece has a washer on both sides of each adjusting screw. Now screw a ¾-inch long threaded spacer (11) onto each adjusting screw and tighten to the point of snugness—the screws should be able to rotate without wobbling. Put a nut (12) over each screw and tighten each one against the threaded spacers to permanently set the screw's tightness.

The potentiometer (13—the one that should be wired to the PC board) has a shaft with a nut (14) on it. First, remove the nut; then you must break

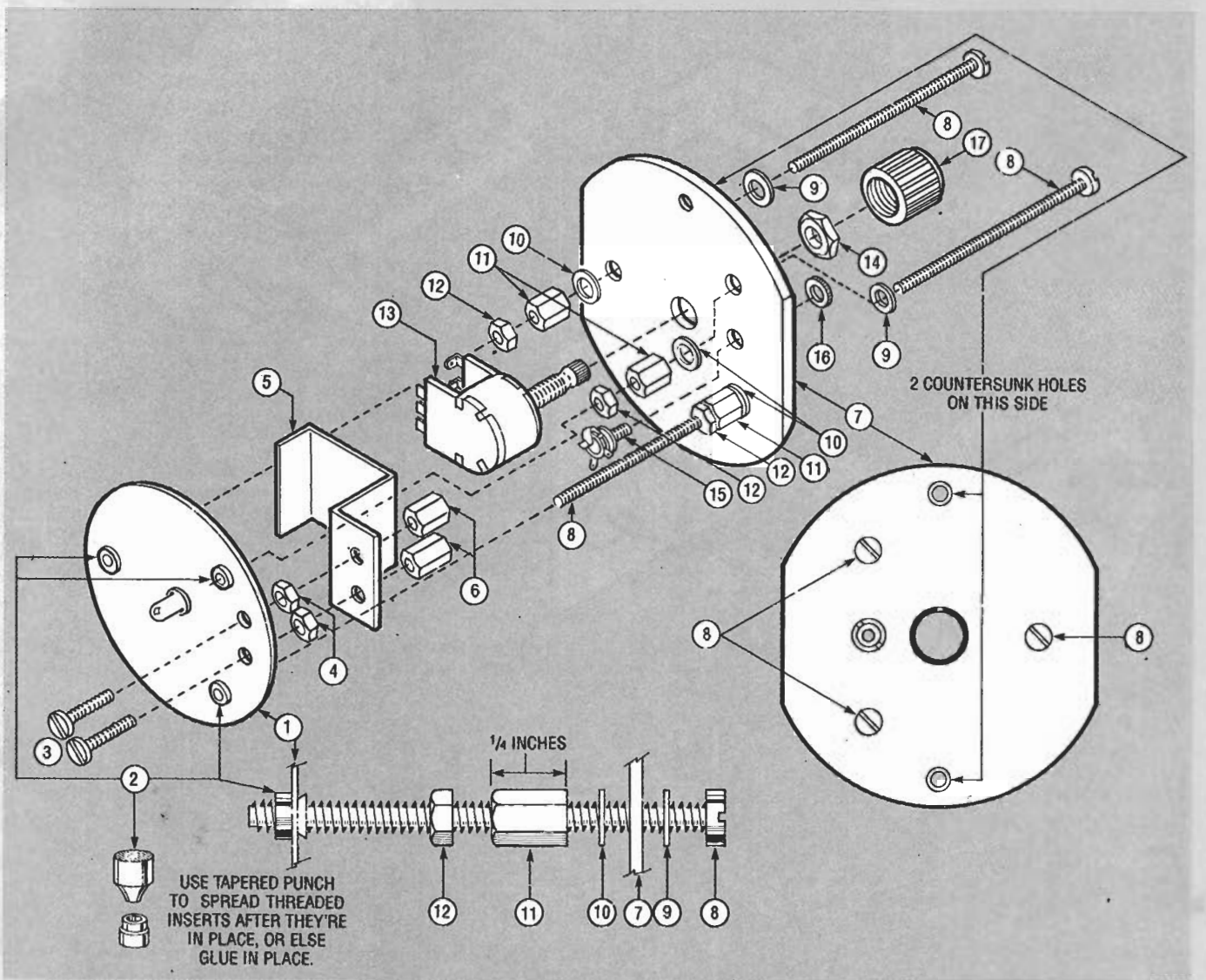


FIG. 1—THE TRANSMITTER is assembled as shown. Look over the assembly instructions carefully before starting the project.

PARTS LIST FOR THE TRANSMITTER (FIG. 1)		
Part #	**Quantity**	**Description**
1	1	PC BOARD
2	3	THREADED INSERTS
3	2	SCREWS, 4/40 × 3/8"
4	2	NUTS, 4/40
5	1	BATTERY HOLDER
6	2	THREADED SPACER, 4/40 × 1/4"
7	1	PLASTIC END PIECE
8	3	SCREWS, 6/32 × 2 1/8"
9, .10	6	WASHERS, 6/32
11	3	THREADED SPACER, 6/32 × 1/4"
12	3	NUT, 6/32
13, 14	1, 1	POTENTIOMETER & MOUNTING NUT
15, 16	1, 1	MICROPHONE JACK & MOUNTING NUT
17	1	POTENTIOMETER KNOB

off the potentiometer's anti-rotation tab, or else it won't properly connect to the plastic end piece. Put the shaft through the center hole in the end piece, and then replace the nut. Install the microphone jack (15—it, too, should be wired to the PC board) in the proper hole in the end piece (7), and secure it with its screw-on collar (16) in the same manner as you secured the potentiometer shaft. For now, line up the three adjusting screws with the three PC-board inserts (2), and screw each one in a few turns, just to hold the assembly together. Also push on the potentiometer knob (17). Place the transmitter assembly aside for now, as we get started on the receiver.

The receiver

For the receiver assembly, use Fig. 2 as a guide. The PC board (1) should already have the headphone jack, the on/off switch, and the potentiometers attached. Put a ½-inch long Phillips-head screw (2) in both of the PC-board's holes. Put a ¼-inch spacer (3)

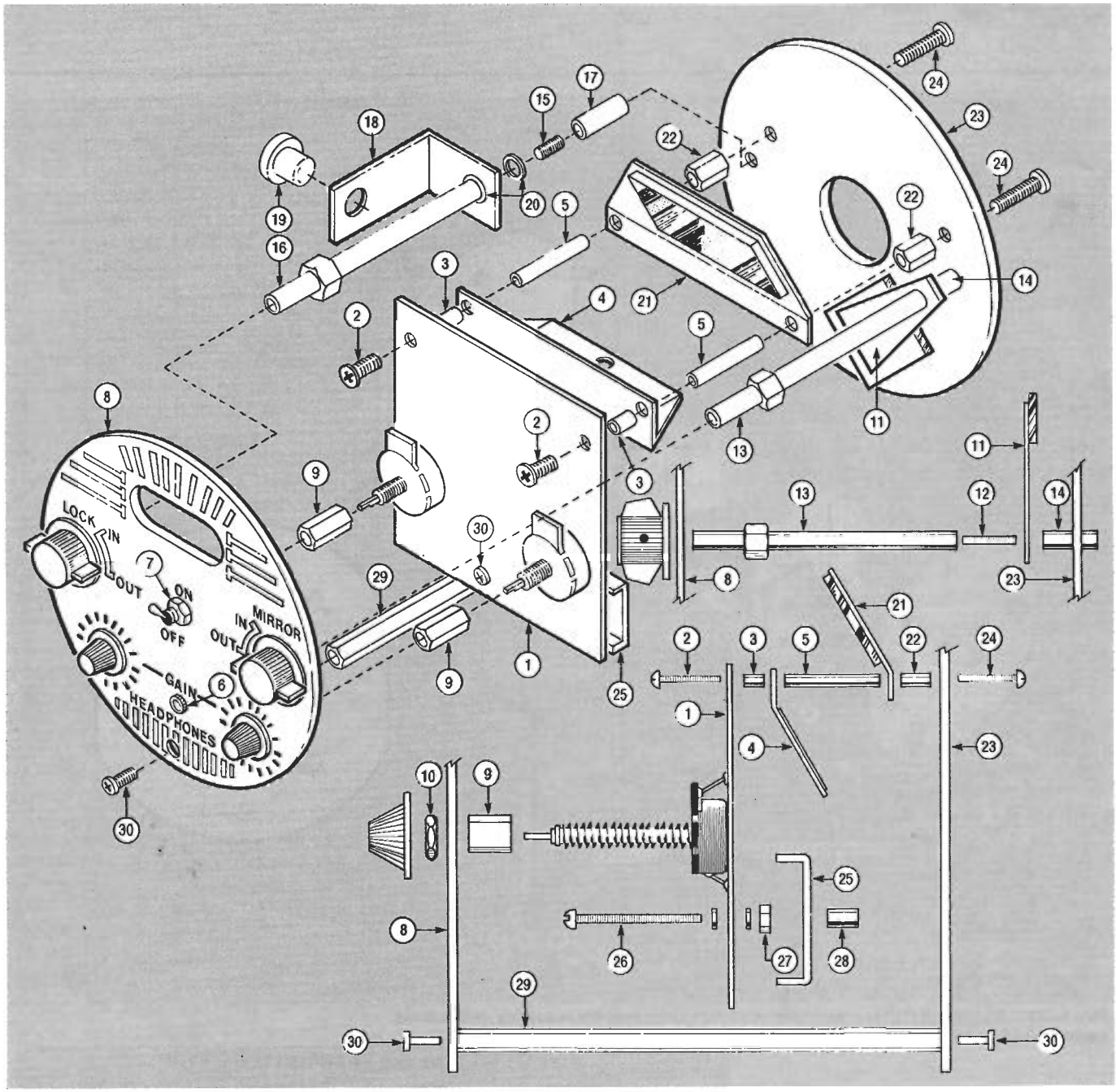


FIG. 2—THE RECEIVER is a little more complicated than the transmitter. Identify all parts before assembling them.

over each screw, put the viewing bracket (4) in place, and a 1¼-inch long threaded spacer (5) onto the end of each screw.

The headphone jack and the on/off switch (parts (6) and (7) respectively) have threaded collars. Remove their collar nuts and push the jack and the switch through their appropriate mounting holes in the plastic end panel (8). Replace the collar nuts. Now take the two ½-inch long spacers (9) with the large holes in them, and fit them over the threaded shafts of the two potentiometers. Fit the threaded ends of those shafts through the holes in the plastic end panel (8), and tighten a nut (10) on each one.

If you purchase the kit, you'll find that the pivoting-mirror bracket (11) comes with the mirror glued to the bracket. You will, however, have to attach it to the two-piece shaft as follows: Screw the threaded stud (12) into the long end of the 3-inch shaft (13), put the mirror bracket over it with the mirror facing as shown, and tighten a ¾-inch threaded spacer (14) onto the end of the stud.

In a manner similar to the mirror bracket, you can assemble the bracket that locks the receiver assembly in

ORDERING INFORMATION

The following are available from General Science and Engineering, P.O. Box 447, Rochester, NY 14603 (716-338-7001): Kit of all parts, including all electronic and mechanical components, $98; Set of two PC boards, $12.00; 6-inch Fresnel lens, $15.00; A headset with built-in microphone, $12.00; Telephone-type handset, $5.00; Siemans BPW-33 photodiode, $3.50; HLMP-8150 12-cd LED price to be determined (call GSE for information); Assembled and tested communicator, $198. Note: the spotting scope is not available from GSE.

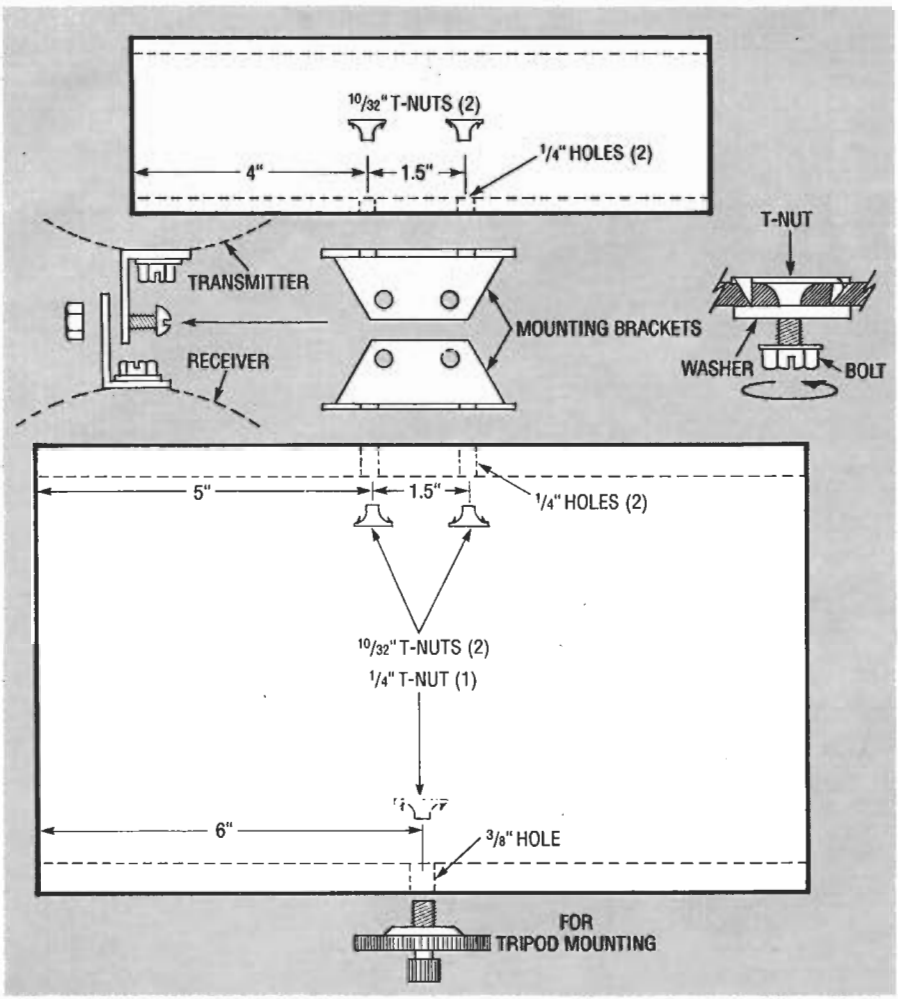


FIG. 3—THE CARDBOARD TUBES go together as shown. Spray paint the inside and both edges of both tubes flat black before assembling.

PARTS LIST FOR THE RECEIVER (FIG. 2)

Part #	Quantity	Description
1	1	PC BOARD
2, 24	4	SCREWS, 4/40 × 5/8"
3	2	SPACER, 1/4"
4	1	VIEWING PLATE
5	2	THREADED SPACER, 4/40 × 1 1/4"
6	1	HEADPHONE JACK MOUNTING RING
7	1	ON/OFF SWITCH MOUNTING NUT
8	1	PLASTIC END PANEL, FRONT
9	2	SPACER, 1/4" HOLE, 1/2" LONG
10	2	POTENTIOMETER MOUNTING NUT
11	1	PIVOTING MIRROR BRACKET
12,15	2	THREADED STUD, 6/32 × 7/8"
13, 16	2	THREADED SPACER, 6/32 × 3"
14, 17	2	THREADED SPACER, 6/32 × 3/4"
18	1	L-BRACKET
19	1	RUBBER GRIPPER
20	2	LOCK WASHERS, 6/32
21	1	MIRROR BRACKET
22	2	SPACER, 3/8"
23	1	PLASTIC END PANEL, REAR
25	1	BATTERY HOLDER
26	1	SCREW, 4/40 × 1"
27	1	NUT, 4/40
28	1	THREADED SPACER, 4/40 × 1/4"
29	1	THREADED SPACER, 6/32 × 2 7/8"
30	2	SCREWS, 6/32 × 1/2"

place inside the tube. The locking bracket is made up of the threaded stud (15), 3-inch shaft (16), 3/4-inch threaded spacer (17), the L-shaped bracket (18) with its rubber gripper (19), and the two locking washers (20). Those two assemblies now fit through the two appropriate holes in the plastic end panel (8), and a knob should be put on the end of each shaft, so that the two shafts can turn, but with some resistance.

Before continuing, the rear plastic end panel (23) requires a layer of black felt-like material glued onto the side that faces the lens side of the tube. That material cuts down on reflections inside the tube, and it is included in the kit. Use part number (23) as a template to cut the felt piece to the right shape, and to mark the holes for the metal shafts and screws to pass through. Then, using any kind of suitable glue, affix the felt.

With that out of the way, position the mirror bracket (21), the two 3/8-inch spacers (22), and the rear plastic end panel (23), and secure everything with the two 5/8-inch long Phillips-head screws (24). (Note that the ends of the two rotating shafts merely pass through the holes in rear panel (23), and are not held on in any way. The battery holder (25) is held in place by the screw (26) and nut (27) that are secured to the PC board as shown. The battery-holder bracket fits over the end of screw (26), and the 1/4-inch threaded spacer (28) is screwed on to hold it in place. The last part to install is the 2 7/8-inch long threaded spacer (29), and the two 1/2-inch long Phillips-head screws (30).

Tube assemblies

Before you prepare the tube assemblies, spray-paint the inside and both ends of both tubes flat black. Then, following Fig. 3 as a guide, mount the two brackets that hold the two tubes together. Basically they are L-brackets that are secured to the cardboard tubes using T-nuts. (See the detailed view in Fig. 3 on how to install T-nuts.) You also have to install a larger T-nut for tripod mounting.

The transmitter assembly is mounted on the end of the tube opposite the lens, and is held in with the two screws as shown. The receiver just sits in the tube and is locked in place with the locking bracket.

After all of the hardware is

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