A Laser Transceiver for the ARRL 10-GHz-and-Up Contest

An optical transceiver you can build to get on the 6500-Å band.

By Lilburn R. Smith, W5KQJ

This paper describes the construction of a laser transceiver designed specifically for the ARRL 10-GHz-and-Up contest. Earlier versions of this transceiver were presented in *Microwave Update Proceedings* for 1998 through 2000. This version has been greatly simplified. The previous amplifier incorporated automatic gain control to prevent saturation, which was found unnecessary. Also, the detector-bias dc-dc converter has been eliminated; the detector is now biased from the negative battery supply. The result is a simplified transceiver with improved performance because of noise reduction from the above changes. The transceiver is becoming popular as an entry into laser experimentation. The beginner can build this transceiver and then use the electronics with a larger telescope for DX, perhaps graduating to a higher-power laser diode for even greater range. A PC board is now available from FAR Circuits that lets experimenters easily duplicate the transceiver.

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System Block Diagram

The system block diagram is shown in Fig 1. The receiver consists of an optical low-pass filter followed by a lens that focuses the laser energy on a silicon detector diode. The preamplifier and the audio amplifier (which drives the headphones) amplify the signal. The transmitter consists of a speech amplifier and modulator that amplitude modulates a laser diode. A single-lens telescope collimates the laser energy.

Receiver

A collecting lens is not required for direct-beam reception at one kilometer if the detector diameter is 1.5 mm or greater. However, the inclusion of a small focusing lens has a number of desirable features. The field of view and aperture become well defined, and the additional collecting area allows some gain margin to insure meeting the range requirement with a practical audio amplifier. A 25-mm (1-inch) lens with a focal length of 38 mm is available new from Edmund Scientific or Surplus Shed at low cost.[1, 2]

[1]Notes appear on page 19.

The laser detector is a large-area silicon detector from Edmund Scientific. The detector is available in several sizes. The price goes up as the size increases. The chosen detector has an area of 20.3 mm^2, a diameter of 5 mm (≈0.2 inches). The detector has a noise equivalent power of 8×10^{-13} $W\sqrt{H_z}$, which insures that the system will not be detector-noise limited.

The system will be dominated by sun noise in the daytime. Although a band-pass filter could be incorporated that would allow operation in daylight, the system would still be marginal for a one-kilometer range. In addition, a band-pass filter matched to the laser diode is not readily available at an affordable price. A deep red Wratten #29 filter is incorporated to remove the 60-Hz noise from incandescent or fluorescent lights. The optical-system parts chosen are shown in Table 1.

Audio Amplifier

The requirements placed on the audio amplifier in a laser receiver are severe because of the dynamic range required to accommodate the variations of the signal with range. The noise performance and gain required at minimum signal are set by the desire to have the receiver limited, in range, by the internal detector noise and the aperture, not by the shortcomings of the audio amplifier. The gain allowable at maximum signal is set by the requirement that the audio amplifier not saturate. Of course, saturation is allowable if the objective is to receive only CW, FM or PM signals. If AM voice is included in the requirements, the amplifier cannot saturate or compress excessively. The requirements for a low-noise amplifier and for high dynamic range conflict. If the receiver is to be capable of maximum DX, the audio amplifier should be designed for the least noise possible.

The amplifier presented here represents a compromise solution. The amplifier will saturate at close range. For test purposes, though, a neutral-density filter can be used to reduce the signal; the elimination of automatic gain control greatly simplifies the amplifier. The compromise audio amplifier has a gain of 96 dB and an input noise floor of about 10 μV. The dynamic-range requirements are met with a combination of switched gain and a manual audio-gain control. The transimpedance of the first amplifier is manually switched between values of 4.7 kΩ and 47 kΩ. The lower value is used for close-up tests and demonstrations, the higher value for DX. The audio-amplifier block diagram is shown in Fig 2.

The detector is operated in the photoconductive mode. A back bias is applied through a large-value load resistor so that the detector operates as a current source. The signal is capacitively coupled to a JFET op amp operated as a transimpedance amplifier followed by a fixed gain, 30-dB amplifier that has a low-pass filter incorporated. At maximum signal, the output of this stage is 10 V, which is applied to the audio-gain control. The remaining amplifiers have a gain of 66 dB.

Transmitter

The transmitter is constructed from a laser salvaged from one of the ubiquitous laser pointers available for a few dollars. The laser pointer consists of a battery power supply, a constant-current source, the laser diode and a laser detector used to control the constant current source. The laser diodes used in

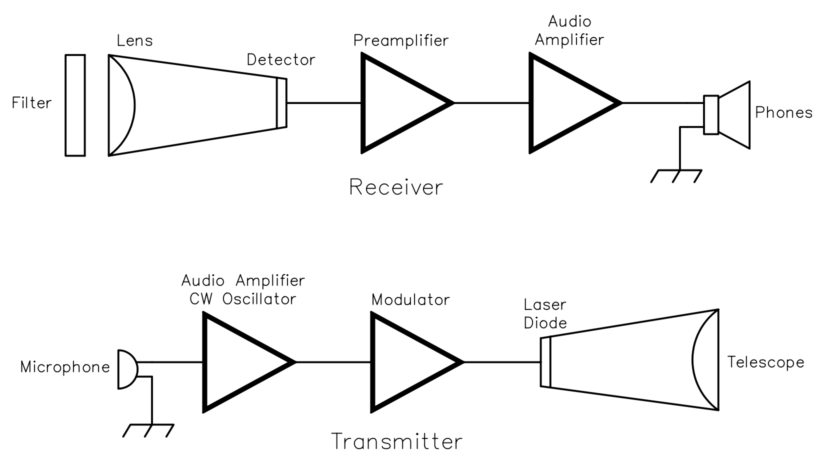

Fig 1—Transceiver block diagram.

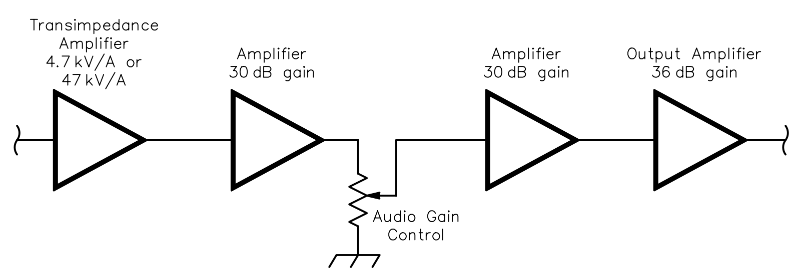

Fig 2—Audio amplifier block diagram.

Table 1—Optical Components

Lens: 25 mm diameter x 38mm focal length. F=1.5 Uncoated biconvex lens. Edmund Scientific Part Number H94822 at $10.10 each or Surplus Shed Part Number L1456 at $4.00 each.
Filter: Wratten No. 29, 620 nm low pass. Surplus Shed #L54-463, $21.20 each.
Detector: 5 mm diameter. Area = 20.3 mm^2, NEP = 8×10^{-13} $W\sqrt{H_z}$. Surplus Shed #L54-034, $33 each.

The chosen components yield an aperture of 25 mm and a field of view of 7.6°.

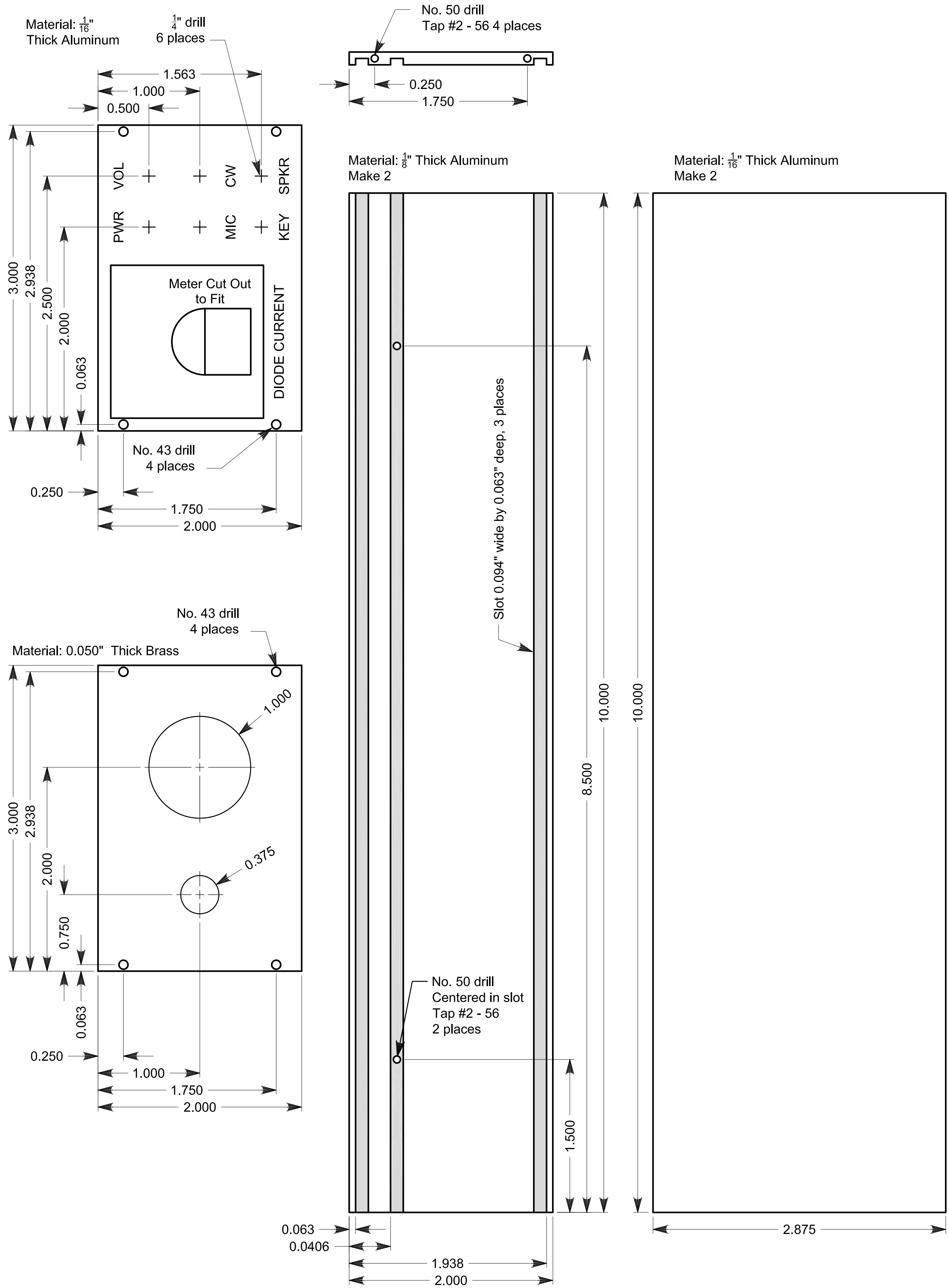

Fig 3—Details of sheet-metal parts.

the pointers are not high-quality parts. As current through a laser diode is increased, it emits light as a light-emitting diode until the lasing threshold is crossed. At that point, it emits laser light. If current is increased further, it goes into thermal runaway and destroys itself. In a good-quality diode, the threshold and thermal-runaway points are separated somewhat. In the cheap diodes, the two points are right on top of each other. A small silicon detector is added to the laser package to reduce the current and prevent thermal runaway. I have not been able to successfully drive the pointer diodes without the detector feedback. The diodes inevitably destroy themselves.

The pointer used for the prototypes was purchased from Harbor Freight Tools.[3] Their part number is 37431 and the item description is "Hi-Output Red Laser." Although any 3-V laser pointer will work, this particular one uses Sony diodes and the lens assembly is glass and brass instead of plastic. The price depends on the catalog from which you order. I have paid from $5.95 to $19.95 at various times. The latest catalog (551) lists the laser as part number 37431-6UEH and the price is $11.99. They go on sale often for half price.

Use the entire laser assembly, including the current-limiter PC board. Otherwise, you will surely experience laser-diode thermal runaway.

The transmitter electronics consist of an op amp that is used as an audio amplifier for voice operation and as an oscillator for CW operation. The output of the audio amplifier is centered on –3 V dc, which is the voltage the pointer uses. The modulation swings the voltage from ground to –6 V. The current supply in the original pen circuit limits the laser diode current. The limiter is such that it allows voice or CW modulation.

Transceiver Specifications

A brief summary of the transceiver specifications is given in Table 2. The transceiver circuit could be used with a better telescope to achieve DX operation. The 3-mW laser diode and low-noise detector will allow a maximum range of about 100 km with a large receiving lens. The transceiver is intended for contest operation at much shorter ranges. Long-range operation requires extremely good pointing accuracy and a line-of-sight path. The pointing requirements take up too much time for contest operation. The idea is to design a transceiver that can be easily duplicated in large numbers for contacts over the minimum path required by ARRL rules, which is 1 km for the 10-GHz-and-Up contest.

Construction

Construction of the transceiver should proceed in subassemblies followed by final assembly. The transceiver is built in a sturdy metal case. The sheet-metal parts are shown in Fig 3. Most of the pieces are aluminum; but the front panel and optical assembly are made of copper, since the optical housing is soldered to the front panel. Make two each of the sides and top pieces and one each of the front and rear panels. The top, bottom and printed circuit board are all mounted in slots in the side pieces, which are held captive by the front and back panels.

The optical assembly detail is shown in Fig 4. The lens holder is made of a 1-to-3/4-inch copper pipe-reducing coupling. The coupling is carefully soldered to the front panel, keeping the parts square with each other. The detector is mounted on a 3/4-inch pipe cap. The short section of pipe allows the image to be focused by sliding the cap back and forth. The filter is bonded to a ring made of 1-inch pipe. All solder work is done before mounting the optical parts,

Table 2—System Specifications

Receiver	
Lens Diameter	25 mm
Clear Aperture	22 mm
Field of View	7.6°
Noise Equivalent Power	10^{-8} W
Optical Passband	620-1200 nm
Optical Transmission	0.8
Detector Diameter	5 mm
Audio Gain	96 dB
Audio Passband	500-1500 Hz
Audio Output	5 V (RMS)
Headphones	32 Ω
Transmitter	
Wavelength	640 nm
Power	3 mW
Beam Divergence	0.5 × 1 milliradians
Modulation	AM, CW, data
Modulation %	100
Microphone	Electret
System	
Power Supply	12 AA cells
Size (including projections)	12×3×2.5 inches (LWH)

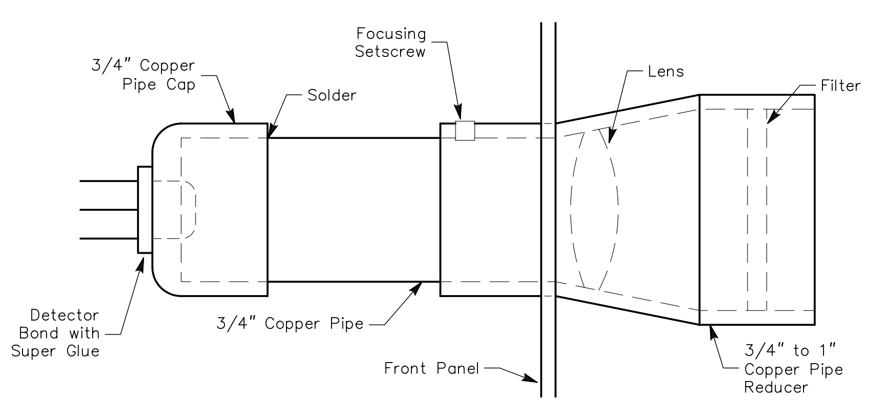

Fig 4—Details of the receiver optical assembly.

which would be destroyed by the heat.

The laser pointer is modified by carefully removing the plastic housing. Unsolder the battery clips. Remove the subminiature switch. Insert a jumper to replace the switch so that the laser is always on. Solder a wire to the "B–" pad and a wire to the ground pad. The laser is mounted to the front panel using a hardware-store bushing that is soldered to the brass or copper front panel before inserting the laser diode assembly. Shim the lens with metal tape for a tight fit.

The rear-panel assembly contains several controls (listed in Table 3), connectors and a meter. The rear panel layout is shown in Fig 5.

The transmitter and receiver are built on one PC board. The schematic is shown in Fig 6. The PC board is etched from G-10 1/16-inch-thick material and carefully trimmed to the exact dimensions shown, which fit in the slots in the sides. The component layout is shown in Fig 7.

The chassis wiring is shown in Fig 8. Use shielded wire for the **VOLUME** control and audio-output wiring. Dress all the short leads to the front panel so that the transceiver can be assembled without stressing the wires. The detector leads fit directly into pads on the PC board. Form the leads for minimum stress. The 3.3-Ω meter shunt is mounted on the meter terminals. The 0.22-µF capacitor is mounted between the switch and the jack terminals. The 47-kΩ resistor should be mounted directly on the switch with short leads. A 10-kΩ, RV6 variable resistor is used for the **VOLUME** control. The meter is a 250-µA movement bought surplus. Any suitable meter can be used, provided it can be shunted to provide an 80-mA full-scale deflection.

The recommended order of construction is as follows:

1. Make the side rails of aluminum. Mill or saw the slots. Tap the holes where required.
2. Make the front and back blank panels. The front panel is made from sheet copper and the rear panel is aluminum. Drill or punch all holes.
3. Make the top and bottom covers.
4. Do a trial assembly of the case. The front and rear panels should hold the rails squarely. The top and bottom covers should slide freely into their slots. If required, sand and file the case parts for proper fit.
5. Disassemble the case.
6. Paint the side rails on the outside surfaces only and lay aside to dry.
7. Make a temporary jig to hold the front panel, lens pipe reducer and laser bushing square. Solder carefully, using an absolute minimum of solder. Clean the solder flux and any excess from the assembly. Mask the inside surfaces of the reducer and bushing, and the back surface of the panel. Paint the remaining surfaces with good-quality gloss enamel and allow them to dry. Bake in a kitchen oven (not a gas oven!) at a low (warm) setting for two hours. Mask the painted surfaces and paint the inside of the reducer with flat-black enamel as sold for barbecue grills. Allow them to dry and then bake.
8. Mount the lens in the reducer, with the side that has the most curvature forward. Use "super glue" or model-airplane cement. Do not get cement on the lens surfaces. Model-airplane cement can be cleaned off with acetone but super glue is there for good.
9. Make a filter-mounting ring of 1-inch copper pipe. Paint only the inside surface with the black barbecue enamel. Cut the filter carefully to shape. Mount the filter on its mounting ring. Be careful to partially insert the filter ring into the lens holder before cementing to avoid wrinkling the filter. Use the absolute minimum cement and do not get it on the filter surfaces. Push the assembled filter into the lens reducer.
10. Make a detector holder from a 3/4-inch pipe cap and a short pipe. Drill or punch the hole for the detector. Cut the cap for a total length of 1/2 inch and solder it to the 3/4-inch pipe. Wait to bond the detector to the holder. Insert the detector holder onto the pipe. Take the entire optical assembly outside and hold a piece of thin paper to the back of the detector holder. Slide the cap back and forth while observing the sun image on the paper. *CAUTION*: *This step can be dangerous. Do not focus the sun's rays onto your eyes or any other part of your body.* Cut off the pipe if required to obtain focus. When the image is sharp, lock down the setscrew.
11. Bond the detector to the detector holder. Be careful to align the leads to fit properly in the circuit board.
12. Prepare the laser assembly as described above and mount it in the bushing using copper tape as a shim for a press fit. Be neat with the shim or the laser will not be aligned properly. Lay aside the optical assembly in a safe place.
13. Build and test the PC board. Notice that the holes are not plated through and solder the leads on both top and bottom. Some components must be mounted slightly raised to solder the leads. The board is tested with an audio signal generator and variable attenuator capable of 100-dB attenuation. Apply the audio signal to the detector input through a 4700-Ω resistor and check the board for gain.

Table 3—Rear Panel Controls and Connections

PWR	Controls power to receiver and transmitter
VOL	Controls receiver gain
MIC	Microphone input for transmitter
CW	Switch between voice and CW
KEY	Straight-key input to transmitter
SPKR	Receiver audio output
DIODE CURRENT	Laser-diode current meter

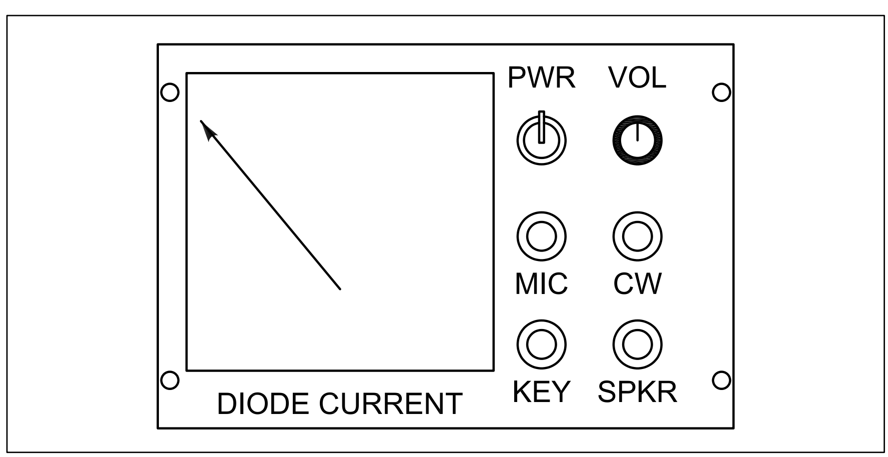

Fig 5—Rear-panel layout.

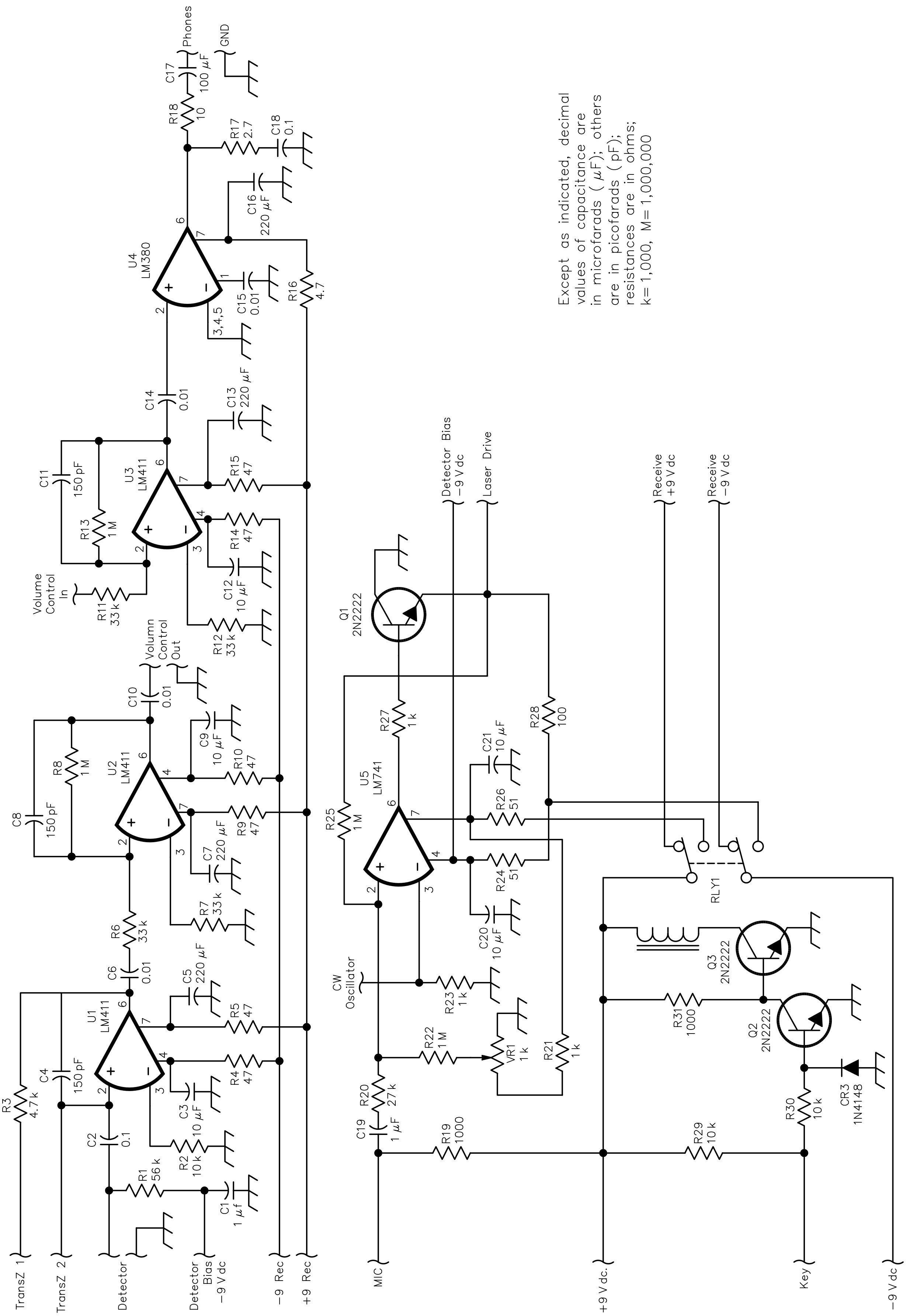

Fig 6—Schematic of PC-board circuit.

Troubleshoot as required. Temporarily connect the 10-kΩ **VOLUME** control to make the remainder of the tests. Reduce the signal level with the **VOLUME** control until the output stage is not distorted, then measure the gain. The gain from the **VOLUME** control wiper to the audio output is 66 dB. Check the noise floor of the amplifier. It should be better than –100 dBV. Without the laser connected, key the relay and set VR3 for exactly –3 V on the laser drive pad. Temporarily connect the microphone. The laser drive voltage should vary between 0 and –6 V when you key the mike and whistle. Check for the proper detector-bias voltage, which should be –9V dc. The testing of the PC assembly is complete.

14. Mount the parts and wire the front panel with sufficient lengths of wire to cut the wire to length in the next step.

15. Make a trial assembly with the side rails and the front and back panel assemblies, but without the top and bottom panels. Insert the PC board in its slots. Glue it in place with model-airplane cement. Cut the wires to length and wire the PC assembly. Do not cut the detector leads. They should be the proper lengths to reach the board with a gentle curve in the leads.

16. Mount the battery boxes on the top plate. The battery pack is made up of 12 AA batteries mounted in three holders of four cells each. The holders are screwed to the top plate. The batteries are arranged in +9-V and –9-V supplies. Wire all three in series, and make a tap at the center of the center box by inserting a #4-40, flat-head screw into the proper rivet. Attach the nut and ground lug. Cut the wires to length and wire the battery holders to the power switch. Ground the center tap to the PC board.

17. Assembly of the unit is somewhat tricky. Turn off the power switch. Insert the batteries. Check for ±9 V at the power switch with the switch off. Turn on the unit and make any checks you want. Turn power off. Remove the screws from the rear panel. Carefully slide the top and bottom covers into their slots. Be careful not to pinch any wires. Replace the screws.

The assembled transceiver is shown in Fig 9.

Results

Optical

Optical transmission through the lens and filter is 80%. The field of view is 7.6°. With the full-transmitted power illuminating the detector, the output of the transimpedance amplifier in the low-gain mode is 3 V. The beam divergence of the transmitter is 0.5×1 milliradians. The laser diode is modulated 100%.

Audio Amplifier

The completed audio amplifier displays a gain of 96 dB with the **VOLUME** control at maximum. The noise voltage at the input for minimum-detectable signal is 10 µV. The 6-dB frequency-response points are 500 and 1500 Hz.

Field Test

Two completed transceivers were set up 1096 meters apart. Reliable communication between W5KQJ and KD5FFW was demonstrated during the 1999 ARRL 10-GHz-and-Up Contest before members of the North Texas Microwave Society. The observed laser spot was an oval shape approximately one-half by one meter that was barely perceptible to the eye. As expected, the major problem in the test was positioning the laser spot. Two heavy-duty camera tripods with pan/tilt mechanisms

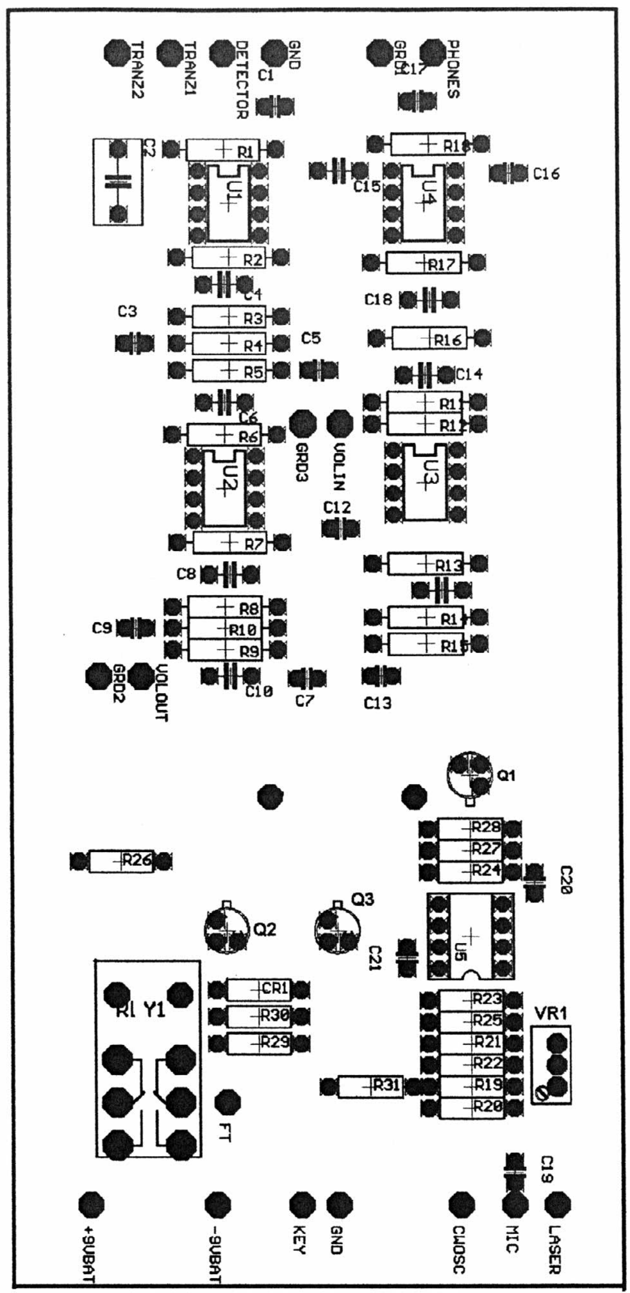

Fig 7—PC-board parts-placement diagram.

were used; but even so, positioning the spot was very difficult. The signal-to-noise ratio was excellent and appeared to bear out the mathematical model.

Other Applications

Uses of the laser transceiver are not limited to voice and CW or to contest use. By using *Hamcom* software and the usual simple interface, RTTY can be used. Slow-scan television can be transmitted using *JVFAX*. Packet is a natural. By removing the low-pass filter capacitors, video can be transmitted and received. The transceiver will work full duplex if the transmit-receive relay is replaced by appropriate jumpers. PSK-31 transmission and reception was demonstrated to the North Texas Microwave Society during the 2001 10-GHz-and-Up contest.

The PC Board

A PC board for the transceiver is available from FAR circuits. Send e-mail to **w5kqj@arrl.net** for information. Unfortunately, the tooling charges for a board with plated-through holes are too expensive, so the board must be soldered on both sides. Al-

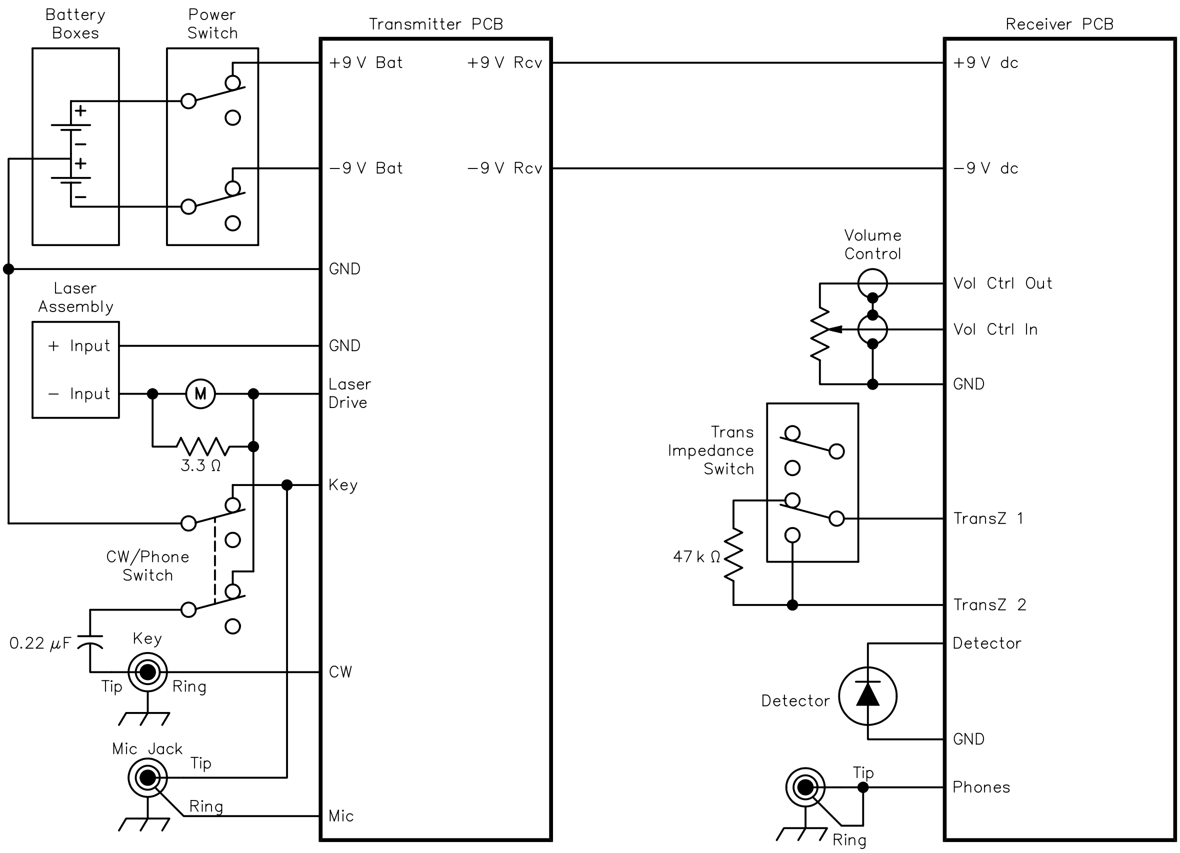

Fig 8—Chassis wiring.

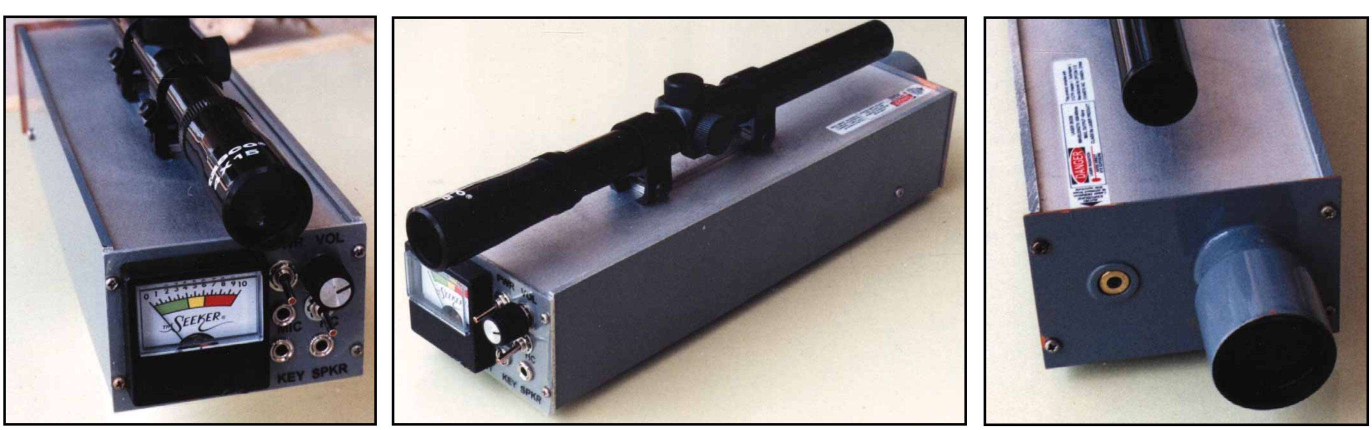

Fig 9—Several views of the completed transceiver.

Parts List

All resistors are 1/4-W carbon-film parts unless otherwise specified.

PC Board

C1, C19—1 µF tantalum (RadioShack 900-1662)
C2, C18—0.1 µF film (RadioShack 900-2265)
C3, C9, C12, C20, C21—10 µF tantalum (RadioShack 900-1605)
C4, C8, C11—150 pF ceramic (RadioShack 900-2203)
C5, C7, C13, C16—220 µF tantalum (RadioShack 900-1612)
C6, C10, C14, C15—0.01 µF film (RadioShack 900-2253)
C17—100 µF tantalum (RadioShack 900-1610)
Q1-Q3—2N2222 transistor (Digi-Key 2N2222AMS-ND)
R1—56 kΩ (Digi-Key 56KQBK-ND)
R2, R29, R30—10 kΩ (Digi-Key 10KQBK-ND)
R3—4.7 kΩ (Digi-Key 4.7KQBK-ND)
R4, R5 ,R9, R10, R14, 15—47 Ω (Digi-Key 47QBK-ND)
R6, R7, R11, R12—33 kΩ (Digi-Key 33KQBK-ND)
R8, R13, R22, R25—1 MΩ (Digi-Key 1.0MQBK-ND)
R16—4.7 Ω (Digi-Key 4.7QBK-ND)
R17—2.7 Ω (Digi-Key 2.7QBK-ND)
R18—10 Ω (Digi-Key 10QBK-ND)
R19, R21, R23, R27, R31—1 kΩ (Digi-Key 1.0KQBK-ND)
R20—27 kΩ (Digi-Key 27KQBK-ND)
R24, R26—51 Ω (Digi-Key 51QBK-ND)
R28—100 Ω (Digi-Key 100QBK-ND)
RLY1 —DPDT relay (preferred: Aromat DS2E-M-DC9V, Allied 788-1341; alternates: Aromat DS2E-M-DC12V, Digi-Key 255-1071-ND)
U1, U2, U3—LF411CN IC (Digi-Key LF411CN-ND)
U4—LM380N IC (Digi-Key LM380N-8-ND)
U5, U6—LM741N IC (Digi-Key LM741CN-ND)
VR1—1 kΩ variable resistor (Digi-Key 3299W-102-ND)

Chassis

Battery box, 4- AA
Transimpedance resistor—47 kΩ
Meter shunt—3.3 Ω
0.22 µF capacitor, film
Detector—See text
Wratten 29 optical filter
Key, mic, phones jack, two-circuit 3.5 mm
Laser assembly See text
Detector mount—3/4-inch pipe cap
Focus adjustmen/—3/4 inch pipe, 1 inch long
Filter Holder—1-inch pipe, 1/8 inch long
Lens holder—3/4-1 inch pipe reducer
Power, CW switches—toggle DPDT
Transimpedance switch—slide DPDT
Meter—250 µA from All Electronics, #MET-51
Volume—10 kΩ variable resistor #RV6
Note: All 900-series RadioShack part numbers are from their on-line catalog.
In-stores, the part numbers are different and much higher priced.

though the lack of plated-through holes is an annoyance in assembly, the board is of good quality and the result is good.

Conclusion

The laser transceiver described in this paper is capable of communication at a range of 1 km as required by ARRL rules. It is reproducible at a moderate cost without previous microwave or optical-communication experience.

Notes

[1]Edmund Scientific, 60 Pearce Ave, Tonawanda, NY 14150-6711; tel 800-728-6999, fax 800-828-3299; **scientifics@edsci.com**; **www.edmundscientific.com/**.
[2]Surplusshed.com, 407 US Rte 222, Blandon, PA 19510; tel 610-926-9226, fax toll-free in US and Canada 1 877-7SUPLUS (78-7758); **surplushed@aol.com**; **www.surplusshed.com**.
[3]Harbor Freight Tools, 3491 Mission Oaks Blvd, Camarillo, CA 93011-6010; tel 800-423-2567; **www.harborfreight.com**.

Lilburn R. Smith was first licensed in 1956 as WN5KQJ. He upgraded to W5KQJ in the same year. In 1977-1979, he lived in Orlando, Florida, where he was W4PMX. He holds an Extra license. He has a BSEE degree from Texas Tech University. He holds one patent for a Laser Guided Projectile and has one patent pending for an advanced display for IR images. Lilburn has been involved in microwave, VHF and laser design and development since 1959. He recently retired after a 41-year career in aerospace.