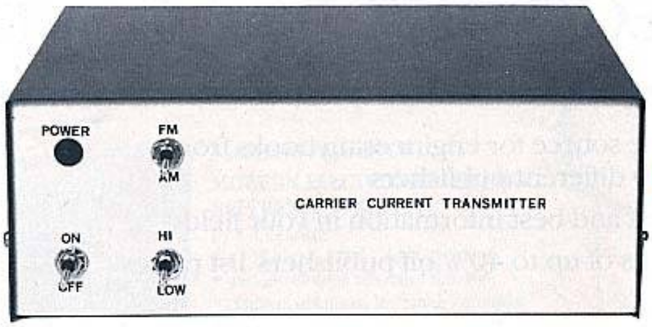

CARRIER CURRENT AUDIO TRANSMITTER

WILLIAM SHEETS and RUDOLF F. GRAF

Now you can set up your stereo speakers anywhere in your home, as long as there's an electrical outlet nearby!

THERE HAVE PROBABLY BEEN TIMES WHEN you wished you could send audio from one place to another without having to run any wires or cable. Well, now you can stop wishing, because such a method called *carrier current* does exist. It uses the existing AC lines in your home as the transmission medium, in which RF carriers in the range of 100–500 kHz are modulated with the information to be transmitted. (Simple AM, FM, or related modulation methods can be used to place the information on the carrier.)

Carrier-current techniques are also useful for coverage throughout a large building, or perhaps a complex of buildings. Some of the possible applications for carrier-current are wireless extension speakers, headphones, and wireless intercom and loudspeaker paging systems.

Obstacles

There are several problems that must first be taken into account before we can apply the carrier-current technique to practical use. The AC power system in the average home can often vary in its construction. But what is more important than that is that, because there can be any number of appliances operating at any given moment, the load on the power system is constantly varying.

Additionally, if the AC power lines are to be used as an RF transmission medium, the power line's indefinite impedance must be accounted for.

Complicating that fact is that certain loads may be a near short circuit to RF, especially if those loads have built-in RF bypassing.

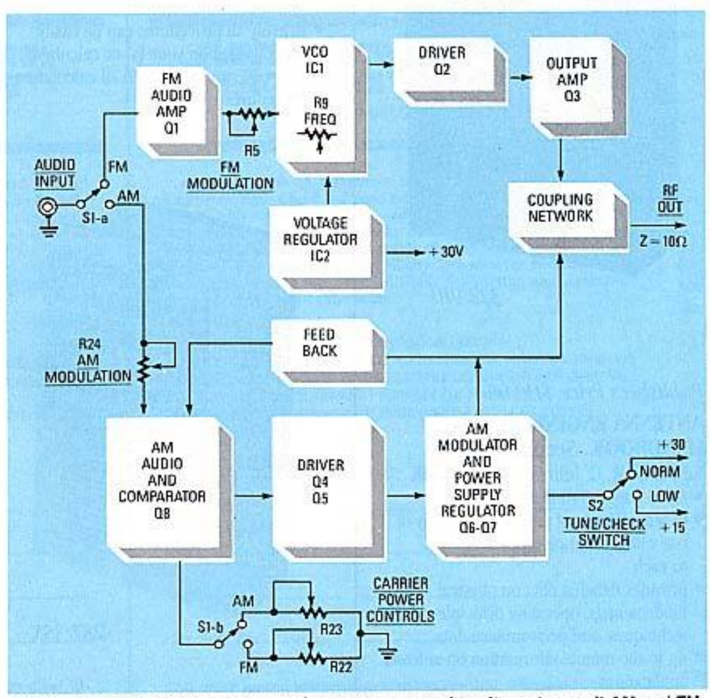

FIG. 1—BLOCK DIAGRAM of the carrier-current transmitter. It can transmit AM and FM.

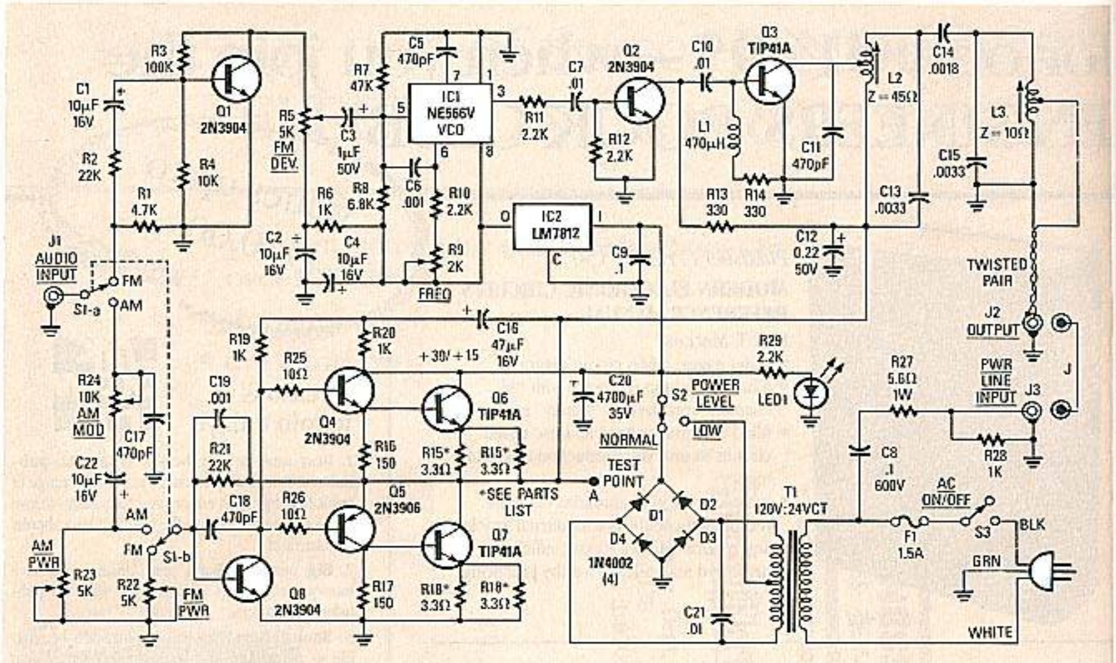

FIG. 2—THE COMPLETE SCHEMATIC of the carrier-current transmitter. Everything except the power-supply components, the switches, and the power-line coupling components are installed on the PC board.

Another problem is the presence of noise voltages generated by appliances that are connected to the power lines. Unfortunately, those noise voltages are within the frequency band of 100–500kHz, which can cause interference with carrier-current transmissions. Offenders are motors, fluorescent lamps, neon signs, relay contacts, triacs and SCR's, rectifier diodes, etc. In short, the AC powerline in the modern home is a hotbed of noise and interference.

However, the situation is not hopeless as it appears. The problems *can* be overcome, and this article will describe an effective carrier transmitter and receiver that can be used for many applications.

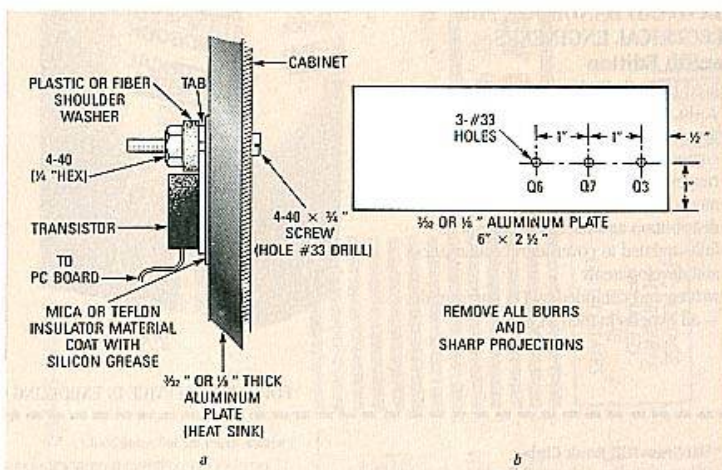

FIG. 3—THE TRANSISTORS SHOULD BE ATTACHED to the heat sink and cabinet as shown in *a*, and a drill guide for the heat sink is shown in *b*.

Carrier-current transmitter

The decision to use either AM, narrowband FM (less than 15 kHz), or wideband FM (greater than 30 kHz) depends on the application. For the transmission of music, FM is better because it has greater noise immunity. For speech or other noncritical applications, AM may be satisfactory. Our transmitter permits either mode by switch selection.

Looking at the block diagram in Fig. 1, audio is fed from switch S1-a to either the FM or AM circuitry. Starting with the FM section, amplifier Q1 accepts an audio signal in the 10-Hz to 20-kHz range of about 0.5 volts peak-to-peak. The audio gain is adjusted via R5 to provide up to 60-kHz deviation of the voltage-controlled oscillator, IC1, which is set to nominally 280 kHz. IC1 and Q1 are supplied with a regulated 12 volts from IC2. A square-wave signal from IC1 pin-3 drives Q2, and Q2 drives the output amplifier Q3. A coupling network is used to match the nominal 45-ohm

PARTS LIST

All resistors are ¼-watt, 5%, unless otherwise noted.
R1—4700 ohms
R2, R21—22,000 ohms
R3—100,000 ohms
R4—10,000 ohms
R5, R22, R23—5000 ohms, potentiometer
R6, R19, R20, R28—1000 ohms
R7—47,000 ohms
R8—6800 ohms
R9—2000 ohms, potentiometer
R10–R12, R29—2200 ohms
R13, R14—330 ohms
R15, R18—1.65 ohms (use two 3.3-ohm resistors in parallel for both)
R16, R17—150 ohms
R24—10,000 ohms, potentiometer
R25, R26—10 ohms
R27—5.6 ohms, 1 watt

Capacitors
C1, C2, C4, C22—10 µF, 16 volts, electrolytic
C3—1 µF, 50 volts, electrolytic
C5—470 pF, silver mica, 5%
C6, C19—0.001 µF, Mylar
C8—0.1 µF, 600 volts DC
C9—0.1 µF, 50 volts, Mylar
C7, C10, C21—0.01 µF, 50 volts, ceramic disc
C11, C17, C18—470 pF, ceramic disc
C12—0.22 µF, 50 volts, tantalum
C13, C15—0.0033 µF, 250 volts, 10% Mylar
C14—0.0018 µF, 250 volts, 10% Mylar
C16—47 µF, 16 volts, electrolytic
C20—4700 µF, 35 volts, electrolytic

Coils
L1—470 µH choke
L2—100–160 µH, 33% tap (see Fig. 4)
L3—100–160 µH, 14% tap (see Fig. 4)

Semiconductors
IC1—NE566, voltage-controlled oscillator
IC2—LM7812 or LM78L12, 12-volt regulator
Q1, Q2, Q4, Q8—2N3904, NPN transistor
Q3, Q6, Q7—TIP41A, NPN transistor
Q5—2N3906, PNP transistor
D1–D4—1N4002 rectifier diode
LED1—light-emitting diode, any color

Other components
J1–J3—RCA jack
F1—1.5- or 2-amp fast-blow fuse
S1—DPST switch
S2, S3—SPST switch
T1—117 VAC primary, 24-volt 1.5 amp secondary, center tapped

Miscellaneous: 3-wire line cord, PC board, cabinet, two RCA plugs, terminal strips, hardware, etc.

Note: The following items are available from North Country Radio, P.O. Box 53, Wykagyl Station, New Rochelle, NY 10804. A kit of parts containing a PC board and everything that is installed on it is available for $54.50, and a single PC board is available for $13.00. Add $2.50 to either order for postage and handling. NY residents must include sales tax.

output impedance of Q3 to the 10-ohm AC line impedance.

In the AM mode, audio is coupled to Q8 via R24 and then amplified again by transistors Q4 to Q7. The normally stable DC voltage at test point A is thereby varied at an audio rate. Because Q2 and Q3 obtain their DC V_{CC} from test point A, the VCO carrier input to Q2 is amplitude modulated by the varying V_{CC} amplitude. That produces an amplitude-modulated output from the transmitter. Careful setting of R23 (carrier level) and R24 (audio level) provides up to 100% modulation.

Circuitry

Referring to the schematic in Fig. 2, an audio input signal of nominally 0.5 volt peak-to-peak is fed into J1. Switch S1-a selects either FM or AM modulation. For FM modulation, audio appears across R1, which serves as a termination for a 5K audio source impedance. The input signal is applied to the base of Q1. The output of Q1, from the wiper of R5, is fed to IC1. An audio signal between 0.5 and 1.0 volt peak-to-peak appears at pin 5 of that VCO, as the modulation for a carrier of 200–350 kHz; the carrier frequency depends on the setting of R9. The AC component is coupled to the base of driver Q2 via R11 and C7.

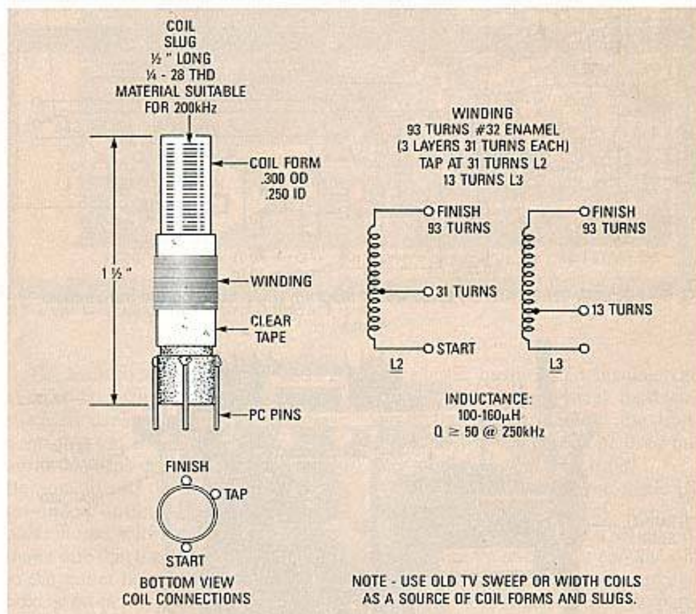

FIG. 4—YOU CAN MAKE COILS L1 AND L2 yourself. First you have to get some old coil forms and slugs with the specifications as shown. Then wind three layers of 31 turns each, wrapping a piece of clear tape around each layer. Remove the enamel coating from each end, as well as the tap point, and solder each point to the appropriate PC pin.

R12 provides a DC path to ground for the base of Q2 and allows Q2 to generate its own base bias. A square wave of about 8 volts peak-to-peak appears at the collector of Q2, and C10 couples that waveform to the base of Q3.

Transistor Q3 provides power amplification of the nominal 280-kHz signal from Q2. The collector of Q3 connects to a tap on L2 at about a 45-ohm impedance level. L2, C13, C14, C15 and L3 form a bandpass filter for the 200–350-kHz range, and also match the impedance of the collector circuit of Q3 to a nominal 10-ohm powerline load impedance. Q3 *must* be heat sinked, and the collector (which is also the tab) must be insulated from ground. A mica washer, with a light coating of silicone grease to aid in heat transfer is used for that purpose.

In the FM mode, Q6 and Q7 function as pass transistors, supplying V_{CC} for Q2 and Q3. A negative feedback circuit keeps the DC V_{CC} voltage at test point A stable during FM operation. Here's how it works. Transistor Q8 is connected as a common-emitter amplifier, receiving its bias from R21, which connects to the emitter of Q6 and collector of Q7, which is also the DC V_{CC} supply for Q2 and Q3. If the voltage at test point A rises, it will tend to turn on Q8 even more; Q8 will draw more current from R20 and R19, lessening the drive current to Q4 and increasing it to Q5. That makes Q6 conduct less and Q7 conduct more, lowering the voltage at point A. A similar but opposite effect occurs if the voltage at point A starts to fall. In that case Q8 tends to conduct less, Q4 and Q6 more, and Q5 and Q7 less, raising the voltage at point A. The exact voltage at point A depends on the ratio of R21 to either R23 for AM or R24 for FM, and the base-emitter turn-on voltage of Q8 (about 0.6 volt). Therefore, R23 and R24 can set the DC level at point A: 10–20 volts for FM and 12–14 volts for AM.

When AM modulation is used, audio is fed to R24 and C17, and coupled to the base of Q8 through C22 and S1-b. R23 determines the quiescent point of Q6 and Q7 and the no-signal resting (static) voltage to Q2 and Q3. Now, Q8, Q4, Q5, Q6, and Q7 function as an audio amplifier, producing a clamped DC voltage at test point A with a superimposed AC voltage that varies at an audio rate. The audio component can cause the voltage at test point A to vary from 0 volts to 27 volts. Remember, it's that voltage that amplitude modulates the VCO carrier at Q2 and Q3.

Components R29 and LED1 are used as a power indicator and may be omitted if desired. A small incandescent lamp rated for 30 or 36 volts can also be used.

To prevent excess radiation, the transmitter's output is connected to J2 via a twisted pair of insulated hookup wire about 6 inches long. RF from J2 is then fed into J3 via a short jumper wire (J) that has RCA plugs at both ends (the jumper uses only the center conductors of the plugs). RCA jack J3 is connected to the hot side of the AC power line via R27, R28, and C8, *after* the fuse, F1. Resistor R28 limits AC voltage on C8 to about five volts. Otherwise a mild but uncomfortable shock would be gotten from J3 if the center pin were touched. The 5.6-ohm 1-watt resistor, R27, provides a stabilizing effect on the impedance seen by the transmitter. It also limits AC line current in case C8 shorts; F1 will blow instantly in that case. C8 *must* be rated at least 600-volts DC or better.

Note: Never plug the unit into an ungrounded outlet (2-wire system), because the transmitter case must be grounded to either an earth ground, a cold-water pipe, or the electrical-system ground (conduit, metal boxes, etc.).

Switch S2 is used to select either the full transformer voltage or half of it. Normally, the full voltage is used. During testing, use the low position, because it reduces the chance of

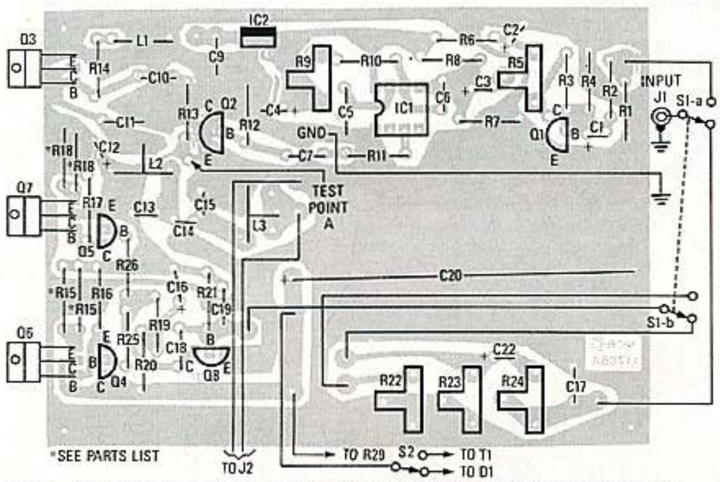

FIG. 5—FOLLOW THIS PARTS-PLACEMENT diagram when building the transmitter.

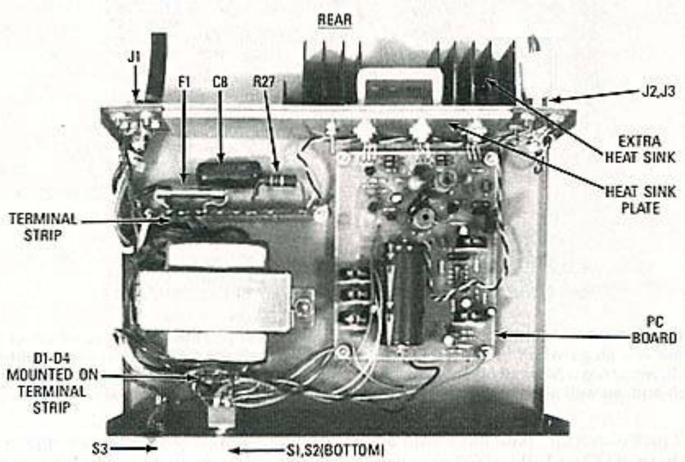

FIG. 6—THE INSIDE OF THE UNIT should be laid out as shown here. Just make sure that the transistors are insulated from the heat sink and cabinet.

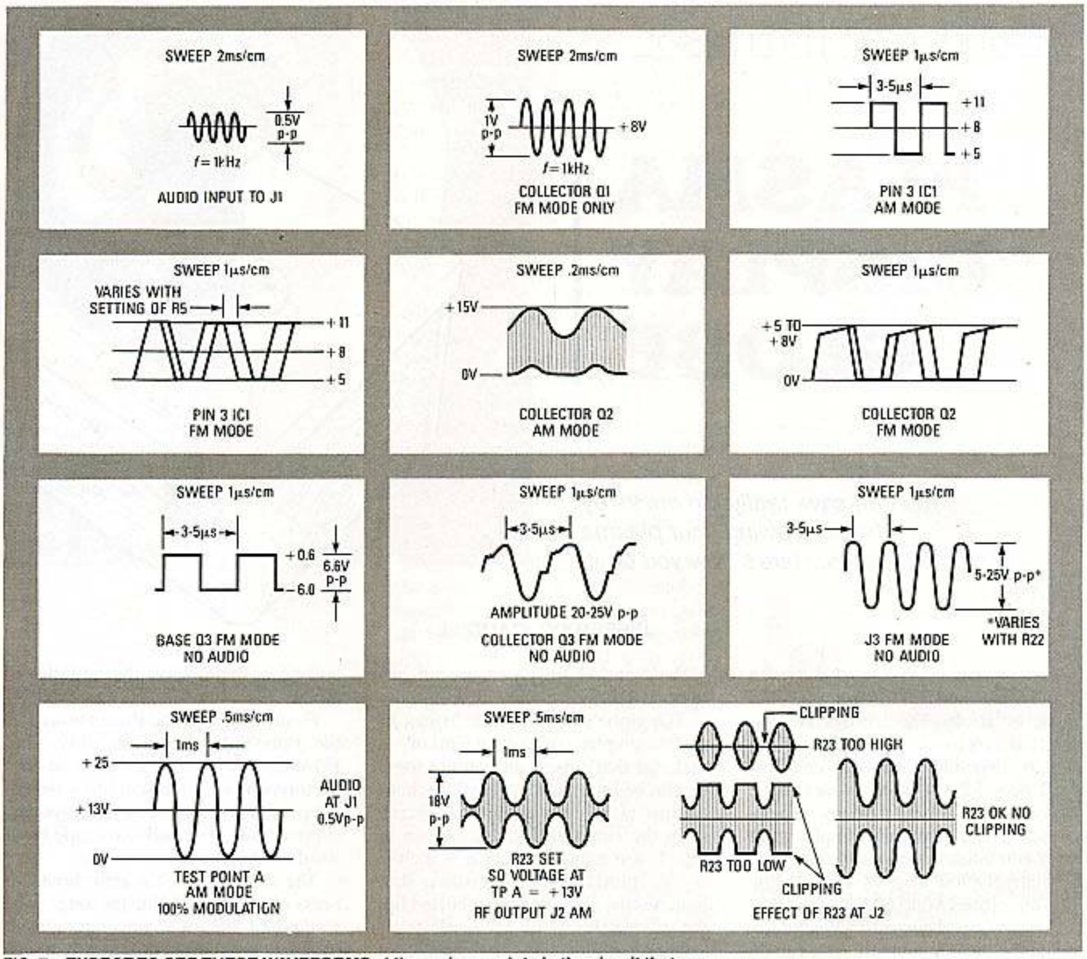

FIG. 7—EXPECT TO SEE THESE WAVEFORMS at the various points in the circuit that are mentioned below each diagram.

damaging something. Also, depending on R22's setting, the low position can be used (in the FM mode only) to reduce the transmitter's output.

Construction

The transmitter is built inside a metal case that is 8-¼ × 6-⅛ × 3 inches. Transistors Q3, Q6, and Q7 are heat-sinked to a piece of ⅛- or ³⁄₃₂-inch aluminum that is mounted flat against the rear of the case. Except for the power supply, the switches, and the AC line-coupling components, all of the transmitter circuitry is contained on the PC board. A foil pattern for the PC board is given in PC Service, and it is also available with or without a parts kit, from the source given in the Parts List.

The leads to and from J1, J2 and J3 should be either twisted pairs or shielded cables. Mount all components that are not on the PC board on terminal strips or standoff insulators. Be sure to use the unit only with a grounded outlet—if you live in an older home with two-prong outlets, make sure that the chassis is grounded to the outlet box (and that the outlet box is properly grounded), or run a ground wire to a cold-water pipe. Q3, Q6, and Q7 must be heat-sinked and electrically insulated from the metal chassis.

The mounting details for the transistors and a drill guide for the heat sink are shown in Figs. 3-*a* and 3-*b* respectively. Use sheet mica cut to fit (with a light coating of silicon grease) and plastic bushings to insulate the transistor tabs. 4-40 steel hardware should be used to mount the transistors; nylon screws can be used but they tend to loosen over time.

Coils L2 and L3 can be made by hand (see Fig. 4), but they, too, can also be purchased. If you decide to make them yourself, you can use old TV sweep or width coils as a source of coil forms and slugs. Follow the parts placement as shown in Fig. 5. The cabinet layout is shown in Fig. 6. As you can see from that photo, the prototype has an additional heat sink attached to the back of the cabinet. It may be required if the back of the cabinet seems to get excessively hot during operation.

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CARRIER CURRENT

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Alignment

After construction, make sure everything is properly positioned and assembled, and check for poor connections and solder bridges. Also, make sure that the tabs of Q3, Q6, and Q7 are not shorted to the case or to the heat sink. The V_{CC} line should read at least 200 ohms to ground.

Place S1 in the FM position, S2 in LOW, and S3 OFF. Plug in the unit, connect a DC voltmeter to the junction of D1 and D2, and turn on S3—you should read 25 volts DC. If you don't, quickly turn off S3 and correct the problem. If the voltage reading is okay, check for 15 volts across C20. Then turn off S3, connect the voltmeter to test point A, set R22, R23, and R24 to maximum resistance, and set R5 and R9 to their center positions. Connect a 6-volt flashlight bulb to J2, and set the slugs in L2 and L3 half-way into the windings (a plastic TV alignment tool will prevent damage to the slugs). Remove the jumper between J2 and J3 and short J3's center conductor to ground, and then apply power; the voltage at point A should be less than 5 volts. Then adjust R22 (S1 must be in the FM position) for about 8 volts at point A, and check for 12 volts at pin 8 of IC1.

Note: Do not operate this unit with J3 open. Always short J3 to ground when not used during testing, so that F1 will open in the event that C8 should short circuit.

Then make the following checks:

- Collector of Q1: about +8 volts.
- Collector of Q2: 4 to 10 volts.
- Collector of Q3: about 8 volts.
- Collector of Q5: between 0 and 0.5 volts
- Collector of Q4: between 1.0 and 1.5 volts higher than test point A.

If everything checks out, connect a frequency counter to the collector of Q2 and verify that R9 can adjust the frequency from approximately 200 to 350 kHz. Set R9 for 280 kHz—or a period of 3.57 μs on an oscilloscope. Figure 7 shows the various waveforms that are expected at different points in the circuit. Connect an oscilloscope to J2 (across a 10-ohm 2-watt resistor) and adjust L2 and L3 for a maximum output. Next, vary R9 to produce frequencies from 200 to 350 kHz; you should have a nearly constant output level from 220 to 340 kHz.

The 6-volt bulb connected to J2 should glow dimly; it can be used as an output indicator if an oscilloscope is not available. A 10-ohm 2-watt resistor can be used as a dummy load.

Next, place S2 in the NORMAL position and adjust R22 for 30 volts at point A; the lamp should glow brightly. Then set S1 to the AM position and adjust R23 for 14 volts at point A; the lamp should still glow brightly.

Apply a 0.5-volt pp 1-kHz sine wave to J1 and adjust R24 until 100% modulation is obtained (see Fig. 7). The bulb will brighten with modulation. Adjust R23 for the best possible modulation symmetry.

Switch S1 back to FM and re-check the waveforms shown in Fig. 7; adjust R5 if required. Finally, run the transmitter into either the light bulb or the 10-ohm, 2-watt resistor for an hour or so to check for overheating; Q3, Q6, and Q7 should not get too to touch them.

That completes the construction, alignment, and testing of the transmitter. In our next installment, we will show you how to build AM and FM line-carrier receivers. R-E