LOW FREQUENCY TRANSMITTER

Here's how to join the "lowfers" on the no-license-required 1750-meter band.

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RECENT DEVELOPMENTS IN SOLID-STATE TECHNOLOGY have pushed the high end of the usable RF spectrum well into the millimeter-wavelength region. Simply because there is so much emphasis on the very-short wavelengths, an electronics hobbyist might easily assume that there is little interest at the LF (*L*ow *F*requency) end of the RF spectrum. However, the truth of the matter is that the frequencies below the AM broadcast band—what is called "the basement of radio"—aren't deserted at all. In fact, the low frequencies are heavily populated, and they are wide open to hobbyist experimentation because the FCC has authorized unlicensed operation in the 160–190 kHz portion of the band. The only restrictions are that the antenna—including the feedline—must not exceed fifty feet, and that the power input to the transmitter's final amplifier must not exceed 1-watt.

Unlike the millimeter-wavelength bands where circuits take the form of critically-etched striplines on expensive substrates, often using high cost and hard-to-handle surface-mounted components, LF construction is simple even for a beginner. No delicate GaAsFET's are needed, audio transistors are adequate, and only normal audio-wiring techniques are required. If you can solder, you can build an LF Morse-code transmitter that will work right the first time!

How it works

Designing a 1-watt transmitter for 180 kHz is very straightforward. A few inexpensive FET's or transistors are all that are needed. Unfortunately, the price of the frequency-determining crystal is about $20, which is somewhat on the high side for experimentation.

But crystals for 1.8–1.9 MHz (the 160-meter band) can be found at hamfests and surplus dealers for almost pocket change, and almost as common as those surplus crystals are inexpensive 1.8432 MHz microprocessor-clock crystals. Even though those crystals will oscillate at ten times the desired 185 kHz transmit frequency, by dividing down with a simple CMOS divider, inexpensive 160-meter crystals can easily be used to generate a 1750-meter signal.

The complete transmitter circuit—including the antenna tuning network—is shown in Fig. 1. The crystal oscillator, which uses two sections of IC1, a 4001 quad 2-input NOR gate, is a standard and reliable design. The oscillator's 1.85-MHz squarewave output feeds IC2, a 4017 divide-by-10 counter. The count ENABLE and RESET terminals, pins 13 and 15, are normally held high by

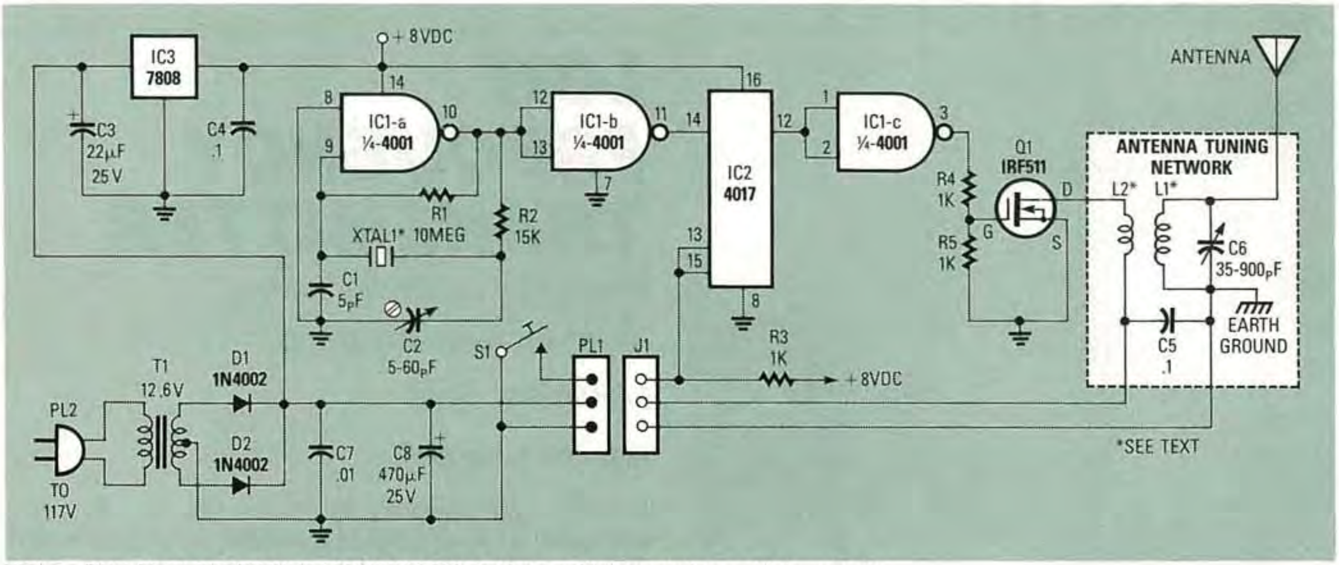

FIG. 1—THE HEART OF THE TRANSMITTER is the oscillator section, which actually divides the crystal frequency by a factor of 10.

resistor R3, and the counter is activated by bringing those pins low by closing telegraph key S1—an arrangement that guarantees that the final state of IC2 pin 12 is always high. The high on IC2 pin 12 is inverted by a third section of the 4001, IC1-c, to prevent DC current flow through power-amplifier Q1 during key-up periods.

Because it requires a low drive current, a VMOS transistor is used for the power amplifier. While the device is available from several manufacturers, note that the pinout isn't standardized, and devices having similar characteristics may not be directly interchangeable. The PC layout provided is for for an IRF511.

To ensure maximum stability and thereby prevent any trace of chirp caused by keying, the oscillator circuit is powered by a three-terminal voltage regulator (IC3). Power amplifier Q1 is powered by the same source that feeds the voltage regulator. The main power source, T1, D1, D2, etc., is external to the transmitter and can be assembled any way that you want. Although a transformer with a 12.6 volt secondary is specified in the Parts List, anything can be used that will result in 12–18-volts DC at 500 mA.

Building the oscillator

Wiring techniques aren't critical at 185 kHz and virtually any construction technique can be used; but to reduce the chance of wiring errors and assure repeatable results, a printed-circuit assembly is suggested, for which a foil pattern is provided in PC Service.

Parts placement and external connections to the PC board are shown in Fig. 2. Coils L1 and L2, and variable-capacitor C6 comprise an antenna-tuning network that is external to the oscillator circuit. Note, in particular, that an earth ground is shown for both the antenna-tuning network and the oscillator. While you can use a common ground for the circuit, that circuit must eventually connect to an earth ground because an earth connection is extremely important for propagation of the low frequencies.

Getting it all together

The prototype transmitter is shown in Fig. 3. It is actually assembled on a piece of 12 × 16-inch particle board. Since the transmitter will be mounted outdoors, several coats of paint are applied to the board to prevent decay, and a wood cover is installed over the board during severe weather. Coils L1 and L2, and capacitor C6, are mounted directly on the board. The remainder of the circuit—the oscillator—is mounted inside a 5¼ × 3 × 2⅛-inch aluminum cabinet. The power supply and key connections are brought in via the connector on the front of the aluminum cabinet.

Since any feedline is considered to be part of the antenna, it is convenient to install the transmitter at the base of the antenna, as shown in Fig. 4. The only maintenance it will require is to occasionally brush spider webs from the tuning capacitor.

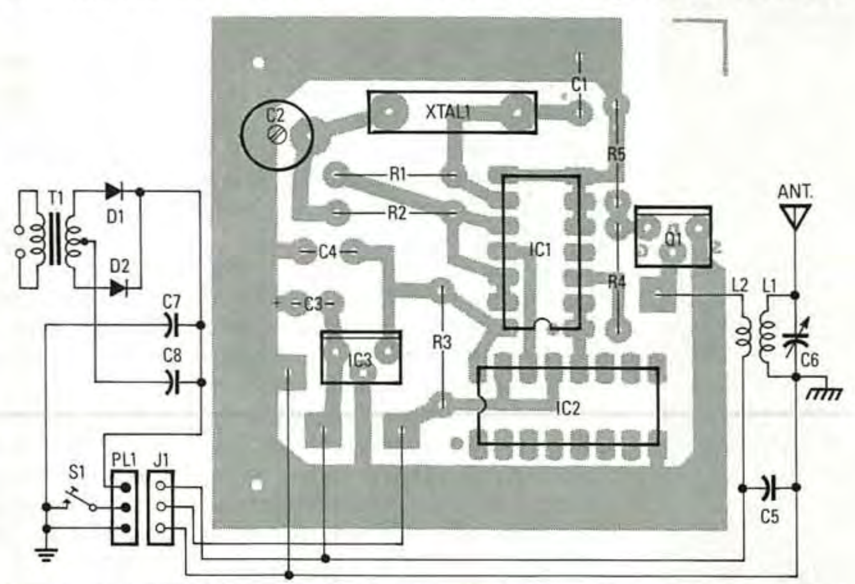

FIG. 2—The PC BOARD'S PARTS PLACEMENT. Coils L1 and L2, and C6 for an external antenna tuner.

Antenna and matching network

A resonant ¼-wavelength vertical antenna is approximately 1250-feet high at 185 kHz. Obviously, that's a shade too long for the average backyard so it must be shortened. But as an antenna is shortened its radiation resistance (R_{RAD}) decreases and the feedpoint becomes capacitively reactive. At a height of 50 feet, R_{RAD} has decreased to approximately .04 ohm, with about 7000 ohms of capacitive reactance (depending on the diameter of the radiating conductor). Looking at the formula for antenna efficiency:

$$\text{EFFICIENCY} = R_{RAD} / (R_{RAD} + R_{LOSS})$$

it is obvious that with a very short antenna (less than 1/10 wavelength) even a fraction of an ohm of loss resistance can tremendously reduce the radiated power.

Significant resistive losses will occur in two portions of the transmitter/antenna circuit: the ground system and the matching network's tank coil. The matching network is necessary to transform the high feedpoint impedance (consisting of a large capacitive-reactance component and a small resistive component) to the approximately 100-ohm output impedance of final-amplifier Q1. One might be tempted to eliminate tuning-network losses by eliminating the tuning network, but attempting to drive the antenna directly from power-amplifier Q1 will result in a tremendous mismatch, and essentially zero radiated power. The matching network also reduces harmonics from the transmitter; without it, the harmonic-rich square-wave signal could radiate overtones of the 185-kHz fundamental frequency.

The resistance of tank-coil L1 will be the primary source of matching-network loss. Losses are decreased by using larger-diameter wire for L1. Copper tubing would be ideal, but to obtain adequate reactance at 185 kHz, such a coil would be very large; the tank coil is therefore a compromise between efficiency and size. Because of the much higher circuit resistance, losses in coupling-link L2 are negligible and the size of the wire used for L2 isn't of great importance.

Coil L1 is close-wound from #16 enameled magnet wire on a 16-inch length of 3½" outside diameter PVC water pipe. A total of 200 turns are wound, covering slightly more than 10 inches of the form. The measured inductance of the tank coil is 0.86 mH, which gives an inductive reactance of about 1000 ohms. The coil form is attached to the chassis by a pair of 5" standoffs cut from a piece of broom handle. They help keep the magnetic field isolated from the lossy ground surface.

Tuning capacitor C6 is a dual-section broadcast-band variable unit having a measured range of 35–900 pF when both sections are connected in parallel. (The capacitor must be able to resonate with L1 at the transmit frequency—approximately 185 kHz). A smaller-value variable capacitor can easily be substituted by connecting one or more fixed-value capacitors in parallel to achieve the required range. In that instance, silver-mica capacitors rated for at least 600 volts are suggested.

Coupling link L2 is 30 turns of close-wound #20 stranded wire wound on a piece of tubing cut from a 3⅝" diameter polyethylene bottle. The required number of turns for L2 will vary depending on your antenna's impedance and the power-supply volt-

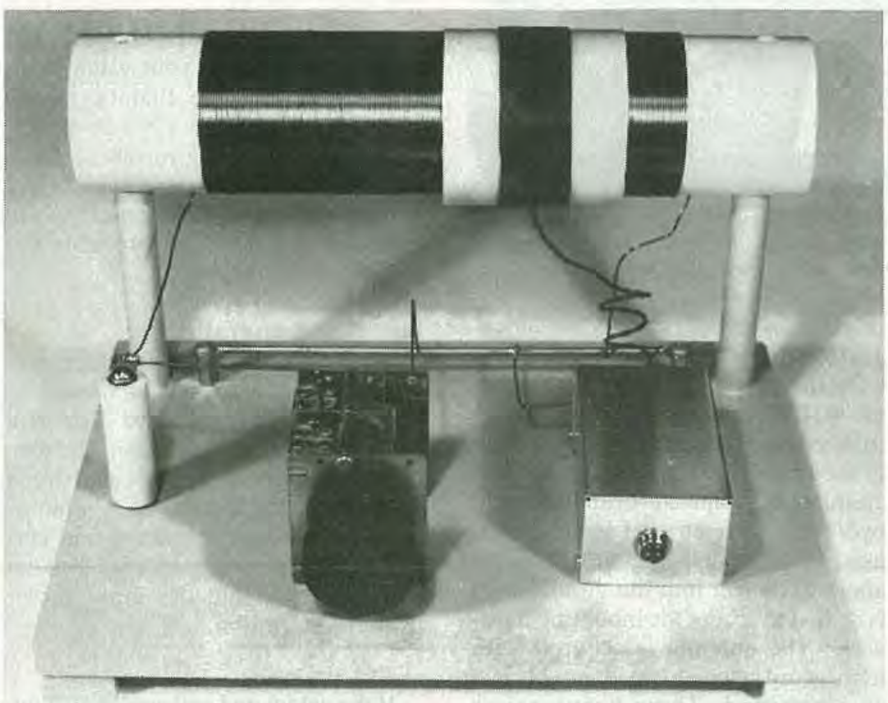

FIG. 3—THE TRANSMITTER IS ASSEMBLED on a breadboard. Note how the small link coil, L2, slides over the larger coil, L1.

PARTS LIST

All resistors ¼-watt, 5%.
R1—10 megohms
R2—15,000 ohms
R3, R4, R5—1000 ohms
Capacitors
C1—5-pF, ceramic disc
C2—6–50 pF, trimmer
C3—22 µF, 25 volts, electrolytic
C4, C5—0.1 µF, ceramic disc
C6—Dual-section air-variable capacitor, 18–450 pF per section, see text
C7—.01 µF, ceramic disc
C8—470 µF, 25 volts, electrolytic
Semiconductors
IC1—CD4001, quad 2-input NOR gate
IC2—CD4017, divided-by-10 counter
IC3—7808, 8-volt regulator
Q1—IRF511 or IRFZ10 power FET
D1, D2—1N4002, silicon rectifier
Other Components
PL1—Control cable connector, any type
PL2—AC powerline plug
S1—Telegraph key
T1--12.6 volts, 500 Ma, center-tapped
XTAL1—1.6 MHz to 1.9 MHz crystal
Miscellaneous: 5¼ x 3 x 2⅛ inch aluminum enclosure, 3" PVC pipe (16 inches required), #16 enameled magnet wire (approx. 180 feet)
NOTE: The following are available from Analog Technology, PO Box 8964, Fort Collins, CO 80525: Etched and drilled PC board, $3.75; PC Board kit (all parts required, including 184.320 kHz crystal, to build PC board assembly—does not include power supply, matching network, enclosure, etc.) $18.00. Antenna-matching network parts are also available (write for current prices). Add $1 postage and handling per order (Visa and MasterCard accepted).

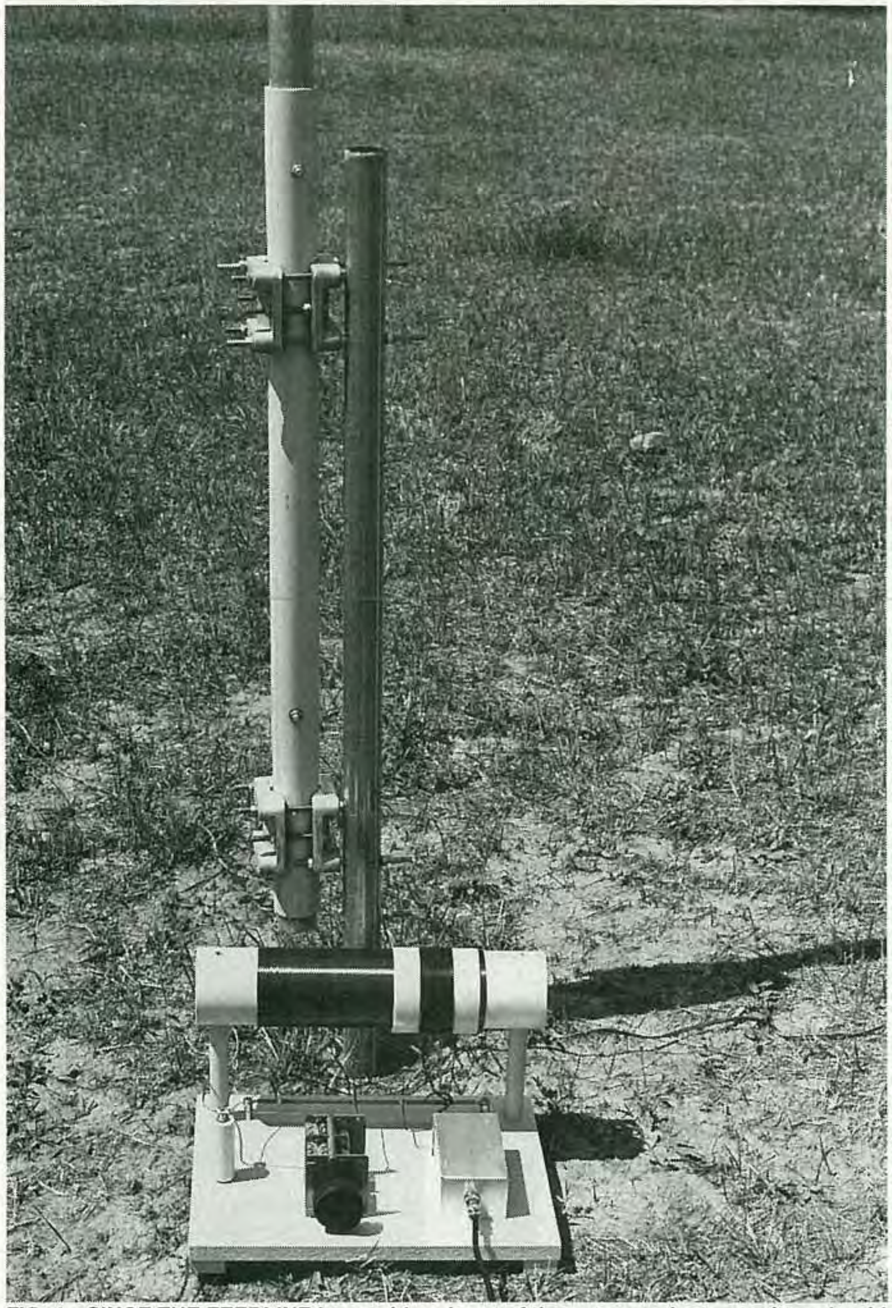

FIG. 4—SINCE THE FEEDLINE is considered part of the antenna, the transmitter should be installed directly at the base of the antenna. The antenna/ground post design allows the antenna to pivot on a single bolt, making installation a one-man job.

age to Q1; you can tweak L2's turns by measuring the RF radiated from the antenna. Coupling-link L2 slides over L1 to allow the coupling factor to be optimized in order to achieve the best match to the antenna.

For maximum efficiency, you should use a vertically-polarized antenna with a total height as close to 50 feet as possible. The antenna shown in the photograph at the top of the page is assembled from pieces of aluminum tubing salvaged from old ham-radio antennas. It tapers from a 2″ diameter at the base to ¼″ diameter at the tip. The tubing is all *6061-T6* (the preferred alloy and temper for antennas) with a .058 inch wall.

A four foot length of 2″ schedule-40 PVC pipe insulates the antenna from ground. It is attached to the base of the antenna with two bolts and two aluminum clamps. A seven foot long, two-inch diameter steel fence post is used as the ground anchor. It is driven about three feet into the ground, and is drilled to accept the mounting hardware. The antenna is secured with nylon-cord guys located at 24 feet above ground. Three heavy-gauge steel tent posts act as guy anchors.

Vertical antennas in that height range may also be constructed from sections of telescoping TV mast or similar thin-wall steel tubing. The key to building an efficient but inexpensive LF antenna is creativity; the antenna details are presented only as a guideline; your design will depend on the materials available. But whatever design you decide to use, ***be extremely careful of overhead power lines when erecting that or any other type of antenna!***

The ground system

Once you have built your antenna you must provide a ground system to carry the return current. Establishing a low-resistance ground for a vertical antenna can be a tedious job. An ideal ground system consists of 120 wires each about ½-wavelength long extending radially from the base of the antenna. Even if you have the acreage to lay 2500-foot radials, such a system would require almost 60 miles of wire. The design of your ground system will depend on existing grounds and local soil conditions. Highly resistive soils (granite, limestone, and sandstone) will require a more extensive ground system than conductive soils (clay, shale, loam). You should hammer several ground rods around the base of your antenna, connecting them with heavy-gauge wire or straps. The use of multiple rods significantly reduces ground losses through parallel connection of the individual ground-rod resistances. If possible, run a heavy wire to your water main (assuming, of course, that it is metallic). If you have access to a deep well with a metallic casing you are really in luck. Deep-buried grounds are a good choice for the experimenter, while limited radial fields are probably not worth the effort and wire.

Setup and operation

With the transmitter/matching network installed at the base of the antenna, apply voltage and key the oscillator. Quickly but carefully, turn C6 to resonance as indicated by a field-strength indicator or a monitor receiver, and check voltage and current to the power amplifier stage using a VOM. Compute the input power using the formula:

$$W = E \times I$$

If the calculated power is more than 1 watt, reduce the power amplifier's

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voltage or increase the number of turns on L2. Now you have to tune C6 again, and note the shape of the tuning curve. If you see only a single peak while tuning C6, try increasing the loading by moving L2 toward the "hot" end of L1. If you see a double-peaked tuning response, reduce the loading by moving L2 toward the ground end of L1. Repeat those steps as necessary in order to achieve the most efficient match at 1-watt input power.

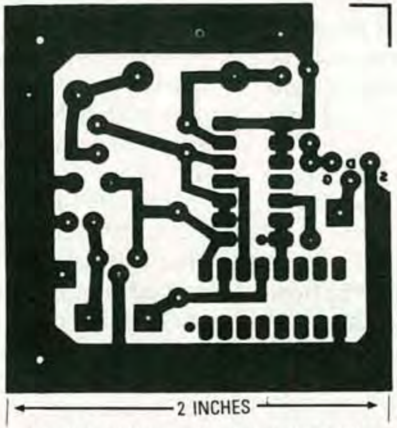
The exact transmit frequency can be trimmed by adjusting trimmer capacitor C2. The adjustment range will depend on the particular crystal used in your unit.

Fortunately for beginners and newcomers to "basement radio," slow-speed CW is the favored operating mode, so you won't have to do much brushing up on your dits and dahs. At 185 kHz the biggest enemy is noise—both atmospheric and man-made. It is for those and other reasons, that the best signal-to-noise ratio can be obtained by using a low data-rate mode (slow keying).

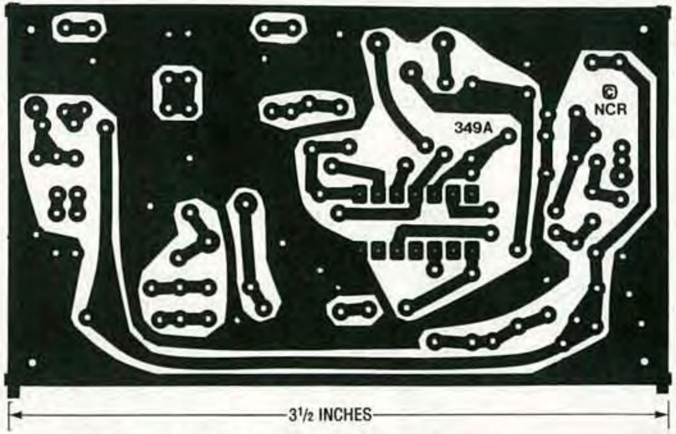
Most operators congregate toward the upper end of the band, centering around 185 kHz. Keep in mind that many stations use crystal control, so it is important that you tune your receiver as carefully as possible when calling CQ, and don't be surprised to hear a reply several kHz away from your calling frequency. The winter months are the most popular for experimental LF operation because northern latitudes suffer from extreme atmospheric noise from May through September. The best openings generally occur on cold winter nights when the band is stable and quiet. Under those conditions it is possible to establish regular contacts to 100 miles or so, with occasional DX of several hundred miles.

The trick to successful LF operation is experimentation, so don't hesitate to try different antenna and matching network designs. Even though you will find the transmitter useful, once you get hooked, you will find yourself constantly planning changes. You will always be on the lookout for a big spool of #6 magnet wire, and daydreaming about helium cooled, superconducting coils. **R-E**

PC SERVICE



LF TRANSMITTER FOIL PATTERN.



LF CONVERTER FOIL PATTERN.