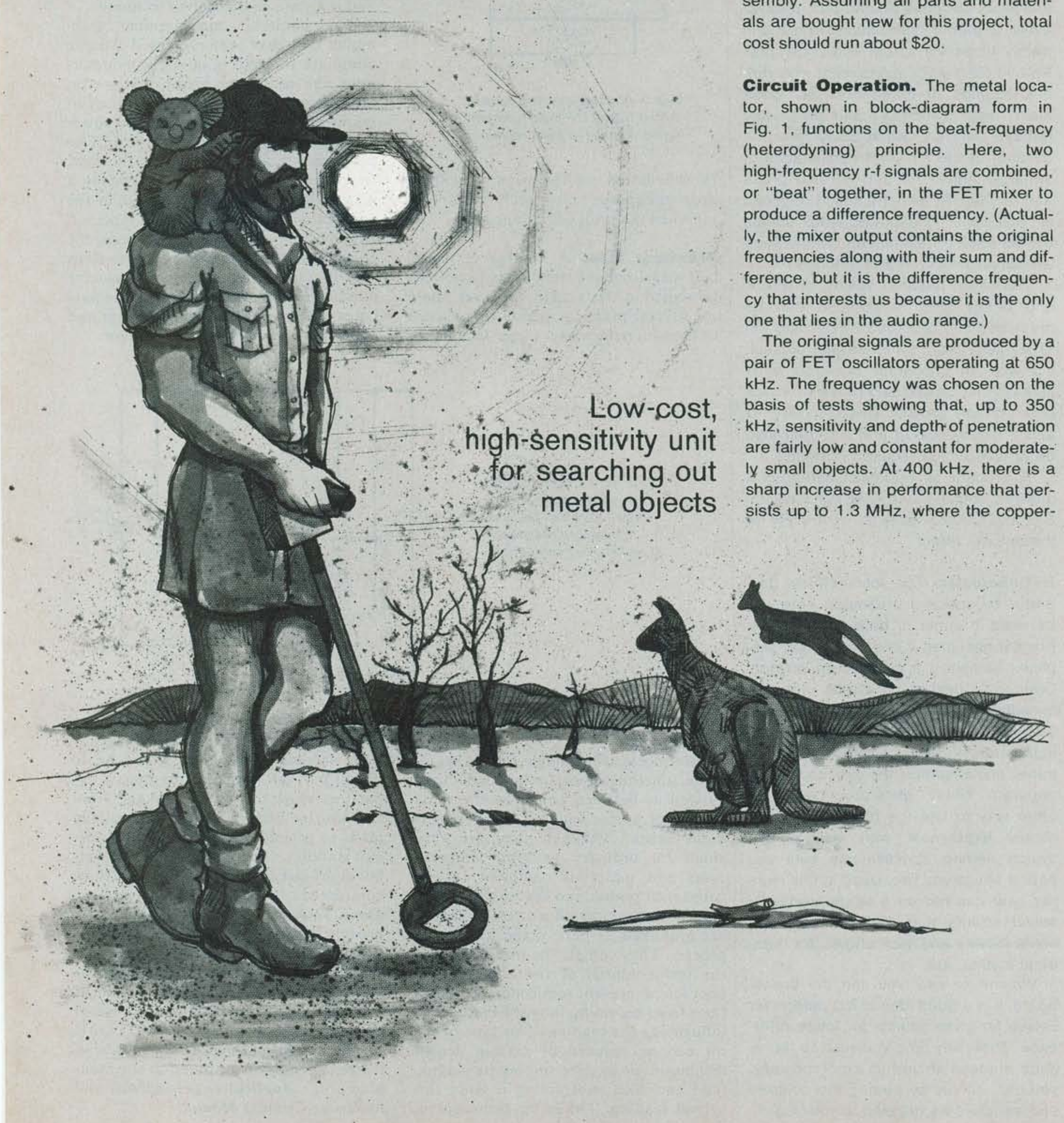
BUILD A

Metal Locator

BY ROBERT KRIEGER

Low-cost, high-sensitivity unit for searching out metal objects



WHETHER it is put to work in searching for buried treasure, locating sunken pipes, or combing the Australian outback for fragments of a fallen space station, a metal locator can be a useful instrument. The locator described here uses a highly sensitive superheterodyne circuit. It is a true "from-scratch" project in which you even fabricate the search-head pickup-coil assembly. Assuming all parts and materials are bought new for this project, total cost should run about $20.

Circuit Operation. The metal locator, shown in block-diagram form in Fig. 1, functions on the beat-frequency (heterodyning) principle. Here, two high-frequency r-f signals are combined, or "beat" together, in the FET mixer to produce a difference frequency. (Actually, the mixer output contains the original frequencies along with their sum and difference, but it is the difference frequency that interests us because it is the only one that lies in the audio range.)

The original signals are produced by a pair of FET oscillators operating at 650 kHz. The frequency was chosen on the basis of tests showing that, up to 350 kHz, sensitivity and depth of penetration are fairly low and constant for moderately small objects. At 400 kHz, there is a sharp increase in performance that persists up to 1.3 MHz, where the copper-

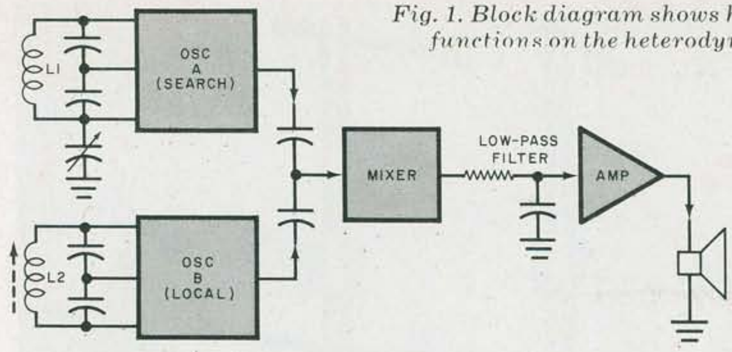


Fig. 1. Block diagram shows how the locator functions on the heterodyning principle.

braid Faraday shield (more about the shield later) loses its effectiveness. A frequency of 650 kHz gives excellent sensitivity and offers convenience in final adjustment. As designed, the metal locator can detect a nickel in free air at a distance of 6" (152 mm) or buried at a depth of 3" (76 mm) or more.

Assume that oscillators A and B in Fig. 1 are set to 650.454 and 650.400 kHz, respectively. Combining these in the FET mixer, we obtain signals at 650.454 kHz, 650.400 kHz, 1300.854 kHz and 54 Hz in the output. Since all we wish to pass on to the amplifier is the audible 54-Hz signal, the low-pass filter removes all higher frequencies. After amplification, the 54-Hz signal is heard from the loudspeaker.

When *L1*, the inductor that forms the search head, is brought near a metallic object (on the surface or buried), its inductance changes slightly. The deeper the object is buried, the less the change. With *L1* acting as one of the frequency-determining components of oscillator A, the variation in *L1* causes a frequency shift, say, to 650.440 kHz. Now, the difference between 650.440 kHz and the 650.400-kHz frequency of fixed oscillator B is 40 Hz. This means that the audible tone has shifted from 54 to 40 Hz to indicate the proximity to *L1* of a metallic object.

The metal locator contains two stable Colpitts oscillators (*Q1* and *Q2* circuits in Fig. 2) that are both tuned to operate in the 650-kHz range. The oscillators are essentially identical, except that one employs search-head coil *L1* as the inductive element and the other has small tunable inductor *L2*.

For operation, *C1* is set at its midpoint and then *L2* is adjusted so that both oscillators are at zerobeat (same frequency). Varying *C1* will then tune oscillator *Q1* out of zerobeat and cause an audio tone to be heard. Note that source resistor *R4* in the *Q2* circuit is greater in value than *R3* in the *Q1* circuit. Since the *Q1* circuit produces a low level of oscillation, it is necessary to damp the *Q2* oscillator

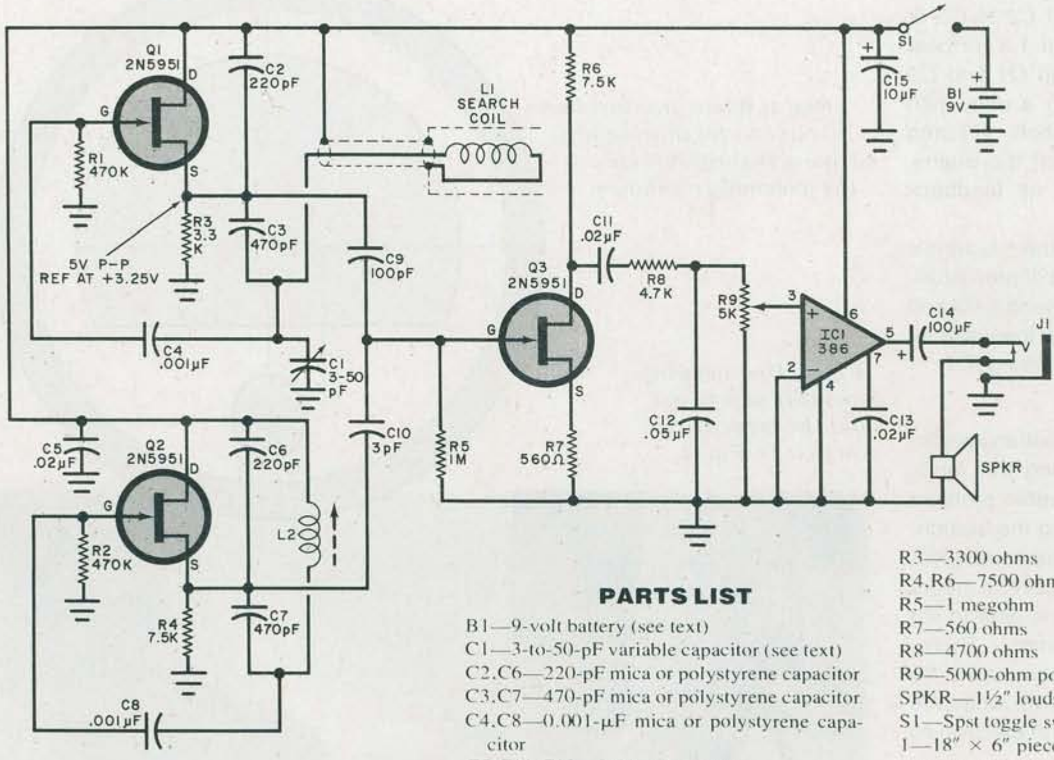


Fig. 2. Two stable Colpitts oscillators (Q1 and Q2) are tuned to operate in the 650-kHz range. They are essentially identical except for the two inductors.

PARTS LIST

B1—9-volt battery (see text)
C1—3-to-50-pF variable capacitor (see text)
C2,C6—220-pF mica or polystyrene capacitor
C3,C7—470-pF mica or polystyrene capacitor
C4,C8—0.001-µF mica or polystyrene capacitor
C5,C11,C13—0.02-µF capacitor
C9—100-pF mica or polystyrene capacitor
C10—3-pF capacitor
C12—0.05-µF capacitor
C14—100-µF, 16-volt electrolytic
C15—10-µF, 16-volt electrolytic
IC1—LM386 ½-watt audio amplifier IC
J1—Miniature transfer-type phone jack
L1—Search coil (see text)
L2—AM loopstick antenna with tunable slug
Q1,Q2,Q3—2N5951 n-channel FET
The following are ¼-watt, 10% tolerance resistors unless otherwise noted:
R1,R2—470,000 ohms
R3—3300 ohms
R4,R6—7500 ohms
R5—1 megohm
R7—560 ohms
R8—4700 ohms
R9—5000-ohm potentiometer
SPKR—1½" loudspeaker
S1—Spst toggle switch
1—18" × 6" piece of ¼" plywood for search-head coil form
1—36" length of ¾" diameter aluminum tubing
1—5' length of RG-58U coaxial cable
1—2' length of RG-8U coaxial cable
Misc.—Perforated board (or printed-circuit board—see text); socket for IC1; 9-volt battery clip; Bud No. CU234 or similar aluminum case; 40' No. 28 enamel- or Mylar-coated magnet wire; control knobs (2); white glue; epoxy cement; plastic tape; ½" foam insulation tape; plastic cement; two small brass screws; machine hardware; spacers; hookup wire; solder; etc.

to match the *Q1* oscillator. This is the reason for the greater value for *R4*.

The key to operation of a Colpitts oscillator is the pair of capacitors that form a voltage divider across the inductor (*C2* and *C3* for *Q1* and *C6* and *C7* for *Q2*). The capacitors and inductor in each circuit determine the frequency of operation for that circuit. In the *Q1* and *Q2* circuits, the FET's source is at signal ground. Therefore, because of the split capacitor action, the signal at the bottom of the inductor is 180° out-of-phase with that at the drain. Since the transistor inverts the signal by 180° and the split tank circuit inverts another 180°, an in-phase signal is fed back to the gate and sustains oscillations.

Increasing the value of *C3* or *C7* decreases the amount of feedback to the gate. If the value of this capacitor is made too large, there will not be enough feedback to sustain oscillation. Lowering its value to, say, 300 pF increases feedback and virtually guarantees oscillation, but the sine wave will not be as "clean" as it would be with a 560-pF capacitor value. The ratio of *C2* to *C3* or *C6* to *C7* should be about 1:3 for best overall operation. Although *Q1* and *Q2* appear to be arranged in a unity-gain source-follower configuration, *R3* and *R4* are actually working off the drains, since the sources are at feedback ground.

Mixer *Q3* heterodynes the r-f signals and provides some degree of preamplification for amplifier *IC1*. Resistor *R8* and capacitor *C12* make up the low-pass filter that prevents r-f from entering *IC1*.

Construction. There is nothing particularly difficult in assembling the metal detector. The only conceivable problem area might be in fabricating the search-head assembly, which requires relatively simple woodworking. Several hours are required for allowing the glue to set in the search-head assembly. Therefore, it is best to start construction by fabricating this assembly and, while the glue is setting, assemble the electronics package.

Cut two 5¾" (146-mm) and one 5" (127-mm) disks from a sheet of ¼" (6.4-mm) thick plywood. Lightly sand the cut edges to remove all splinters. Locate and mark the center of each disk and drill a 1/16" (1.6-mm) hole through each. Liberally coat both sides of the smaller disk with white glue and temporarily assemble the three disks with the smaller in the middle, using a nail to align the holes. Press lightly and then disassem-

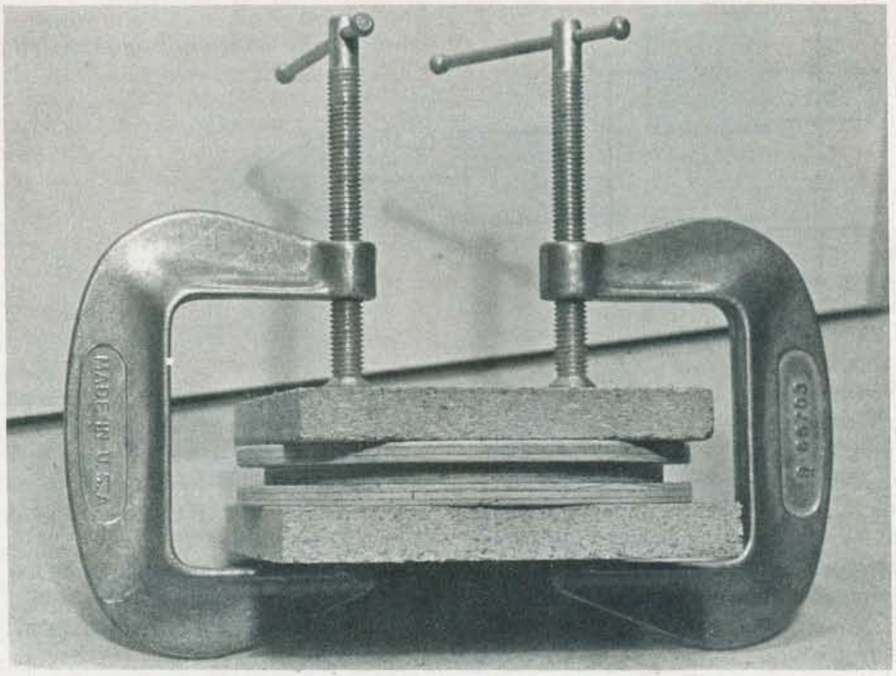


Fig. 3. Glue three plywood discs together with the smaller one in the middle. Use clamps or weights to ensure proper bonding.

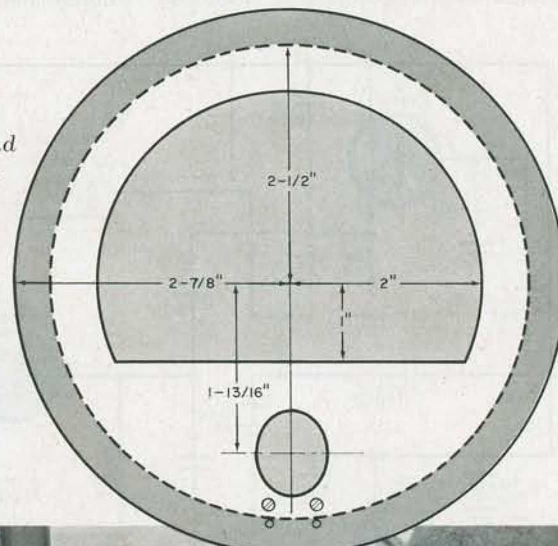


Fig. 4. When glue has had time to set thoroughly, draw a D-shaped form on the assembly as shown.

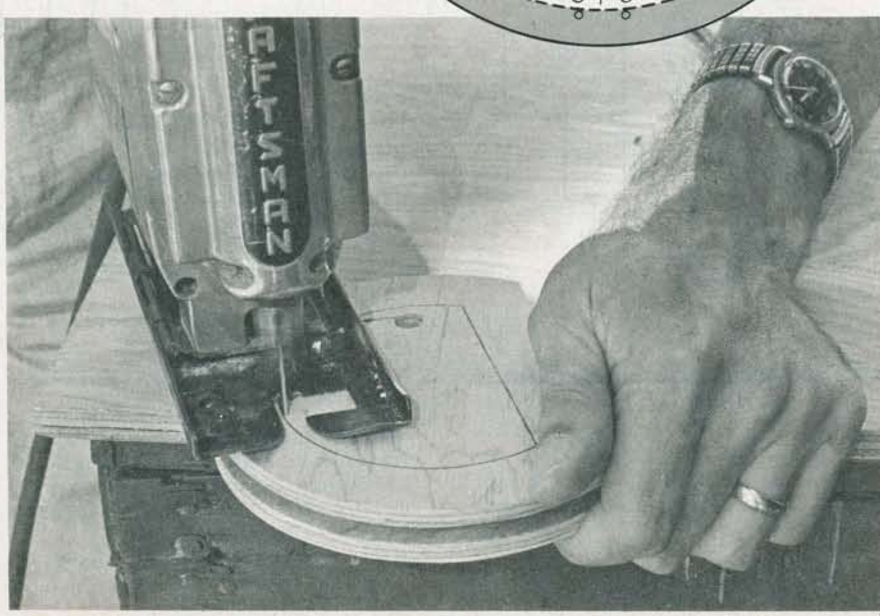


Fig. 5. Use a coping or sabre saw to cut out the form drawn on disc in Fig. 4.

Fig. 6. Drill shaft hole with wood bit, tilting it away from D cutout by about 18 degrees.

Fig. 7. The 20-turn coil is shielded with the braid from RG-8U coaxial cable.

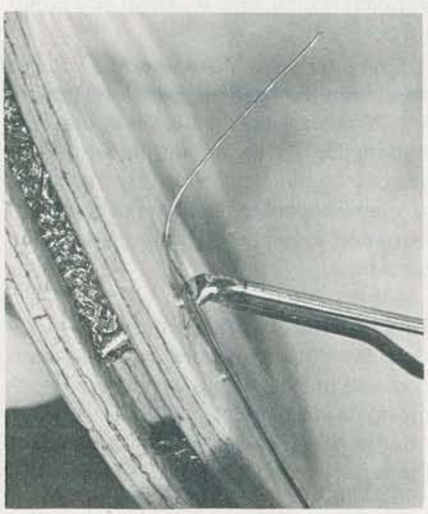


Fig. 8. Bring free end of braid up through plywood sandwich and solder to an adjacent screw.

ble. Allow the glue to air dry until the surfaces are just tacky. Then reassemble with the nail to assure proper alignment and clamp or weight the "sandwich" until the glue sets (Fig.3). Alternatively, you can use epoxy cement as the binder, aligning the disks with the nail and clamping or weighting immediately upon application. Set the assembly aside for at least 6 hours to allow the glue or cement to set solidly.

Meanwhile, referring back to Fig. 2, assemble the electronics package on a piece of perforated board, using either point-to-point or Wire Wrap techniques. If you are particularly ambitious, you can design and fabricate your own printed circuit board for the project. In any event, use a socket for *IC1* and, if possible, sockets for *Q1* and *Q2*.

Do not wire *L1* or *C2* into the circuit just yet or mount the circuit board assembly into the case until directed to do so. Note that *C1* specified in the Parts List is a standard 365-pF capacitor. To reduce it to 50 pF, carefully remove all but one of its rotor plates, taking care to avoid bending the remaining plate.

Once the glue or cement has thoroughly set in the search-head assembly, remove the clamps or weights. Pry out and discard the nail. Then, referring to Fig. 4, draw a D-shaped form on the assembly as shown. Use a sabre or coping saw to cut out this form (Fig. 5). Lightly sand the cut edges to remove all splinters and rough spots. Referring back to Fig. 4, locate the centers of the shaft and wire-exit holes. Drill the latter with a 1/16″ bit. Use a ¾″ (19.1-mm) wood bit to drill the shaft hole, tilting it away from the D cutout by about 18° (Fig. 6). The angle is not critical, but it should be between 15° and 20° from perpendicular to permit convenient handling of the metal detector.

The 20-turn coil to be wound in the groove formed in the search-head sandwich must be shielded to reduce ground capacitance effects. The shield is a length of copper braid removed from RG-8U coaxial cable. Carefully slit the outer plastic jacket from about a 24″ (61-cm) length of coax. Then slide the inner conductor out of the braid. With your fingers, flatten the braid and press one turn into the groove. Use a Phillips screwdriver to force the braid in place as shown in Fig. 7. Be sure to leave a gap of ⅜″ (9.5 mm) between the braid ends.

Drive two small brass screws into the top of the plywood sandwich near the shaft hole. Solder a length of hook-up wire to one end of the braid. Pass the free end up through one of the 1/16″ holes, and solder to the head of the adjacent screw. (Fig. 8). Cover the braid with a single layer of plastic tape, as shown in Fig. 9.

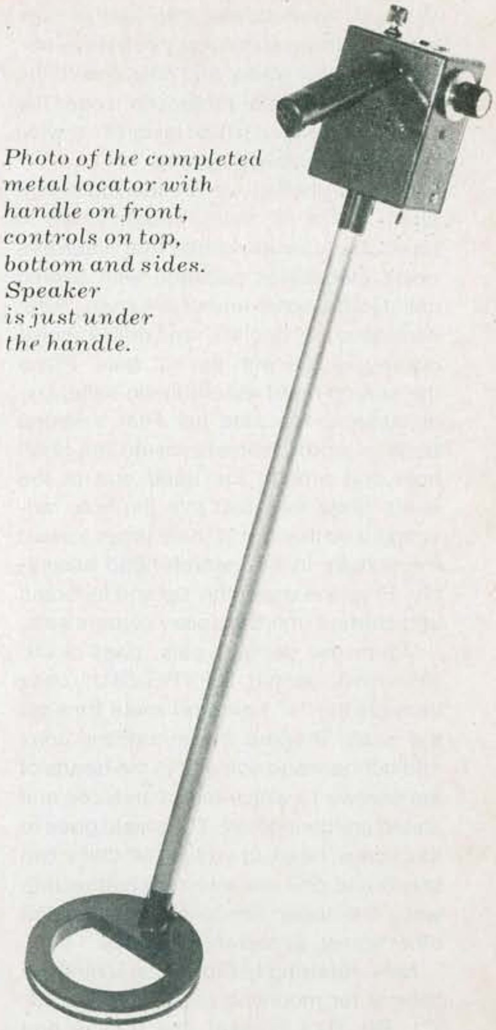


Photo of the completed metal locator with handle on front, controls on top, bottom and sides. Speaker is just under the handle.

Use No. 28 enamel- or Mylar-coated magnet wire to wind the search coil. Scrape away about ½″ (12.7 mm) of the insulation and pass the wire up through the same hole as the wire to the shield is routed to the brass screw. Solder to the same screw. Then wind 20 turns of the magnet wire into the groove. Pass the free end up through the other 1/16″ hole and solder to the screw adjacent to the hole. Coat the windings completely with plastic cement to prevent them from shifting and affecting frequency stability.

When the cement sets, cover the winding with a single layer of plastic tape. Lay in another turn of the wire braid, again leaving a ⅜″ gap between the ends and connecting one end, via a length of hookup wire, to the screw to which the inner braid and one end of the search coil is connected. Note, when you are finished with this part of construction there should be three wires soldered to one screw and only one to the other. For thermal protection, cover the outer braid with a single layer of ¼" wide polyfoam weather stripping.

Several inches up on the aluminum shaft, drill a ¼" hole through which to pass the coaxial cable that interconnects electronics package with search coil. On the other end of the shaft, measure down ½" and 1½" and drill ⅛" holes directly in line with the ¼" hole. Place the search-head assembly on a flat, level surface, top side up. Run a liberal bead of epoxy cement inside the shaft hole and around the head end of the shaft. Slide the shaft into the hole, orienting it so that the ¼" hole faces toward the screws in the search-head assembly. Prop the assembly up and let stand undisturbed until the epoxy cement sets.

When the cement sets, pass a 36" (914-mm) length of RG-58U coax through the ¼" hole and route through the shaft. Prepare the end of the coax and connect and solder it to the heads of the screws to which the search coil and shield are connected. The shield goes to the screw head to which the coil's two shield and one coil wires are connected, while the inner conductor goes to the other screw, as shown in Fig. 10.

Now, referring to Fig. 11, machine the cabinet for mounting *L2, SPKR, S1, J1, C1, R9, B1*'s bracket, the handle and shaft, and the circuit-board assembly. Carefully deburr all holes. Then mount the handle, shaft, and battery bracket, in that order, with appropriate machine hardware. (Note that the shaft fits through a ¾" hole at one end of the box and is held in place with two sets of 6-32 × 1¼" machine screws, nuts, and lockwashers through one wall of the box.)

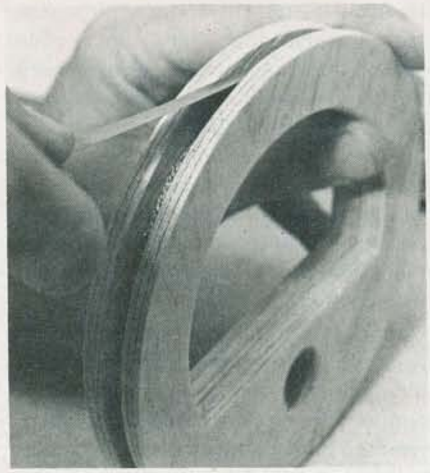


Fig. 9. Cover the coax shield braid with a single layer of plastic electrical tape.

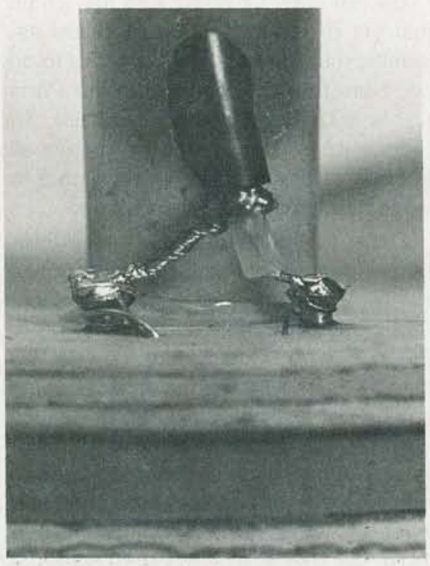


Fig. 10. Coax is routed to search coil through the shaft with ends soldered to the proper screws.

Next, mount the speaker, *C1, J1, S1, R9*, and *L1* in their respective locations. Mount these components in the order given and connect and solder lengths of hookup wires to their lugs. Referring back to Fig. 2, connect and solder the free ends of the wires to the appropriate points in the circuit. Then mount the circuit board assembly inside the box, using spacers and 6-32 hardware. Snap the connector onto the battery terminals and slip the battery into its bracket.

Operation and Use. The critical factor in a metal detector is in the adjustment of both its oscillators to function on the same frequency. If possible, each oscillator should be tested separately with a frequency counter. If a counter is not available, use a standard AM broadcast-band radio tuned near the low end of the band (about 650 on the dial) and defeat first one and then the other oscillator by temporarily opening the source circuit while tuning. Tune the search (*Q1*) oscillator first and then the local (*Q2*) oscillator to the same frequency, adjusting *L2* to bring the latter to the same frequency. When the oscillator and the radio are tuned to the same frequency, you will hear a "dead-air space," a band of silence resulting from the presence of an unmodulated carrier.

To use the metal detector, give it a couple of minutes to stabilize after first applying power. Adjust *C1* for zerobeat and then back off so that you hear a low-frequency tone from the speaker or earphone. Pass the search head over a metal object, and the tone should shift upward or downward in frequency, depending on the side to which you tuned off zerobeat.

One final note: Maintain a low volume level from the speaker to prolong battery life. You can use an 8.4-volt mercury battery for *B1* to provide superior service, since this type of battery maintains a relatively constant voltage over a longer period than can ordinary carbon-zinc batteries.

In Conclusion. As you use the metal detector described here, you will soon come to realize how well it works for locating buried metallic objects. Always bear in mind, however, that the smaller the object or the deeper it is buried, the more difficult it will be to locate. When working in noisy environments, such as at a beach with a pounding surf, use an earphone for best results. ◇

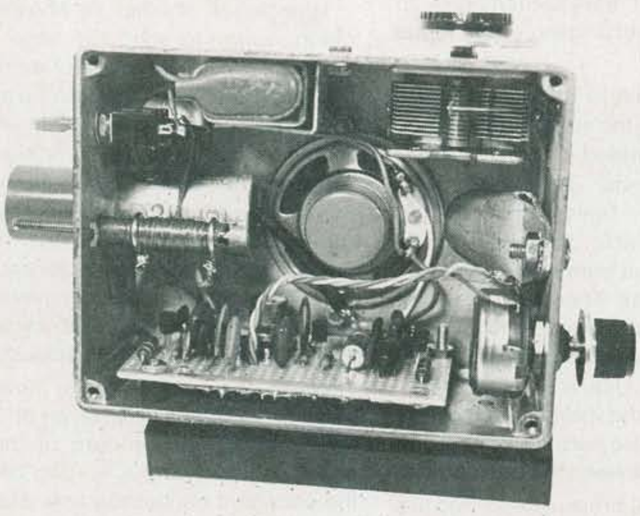


Fig. 11. Photo showing inside of author's prototype. The shaft fits through hole at left. Handle and speaker are shown on the back of enclosure here.