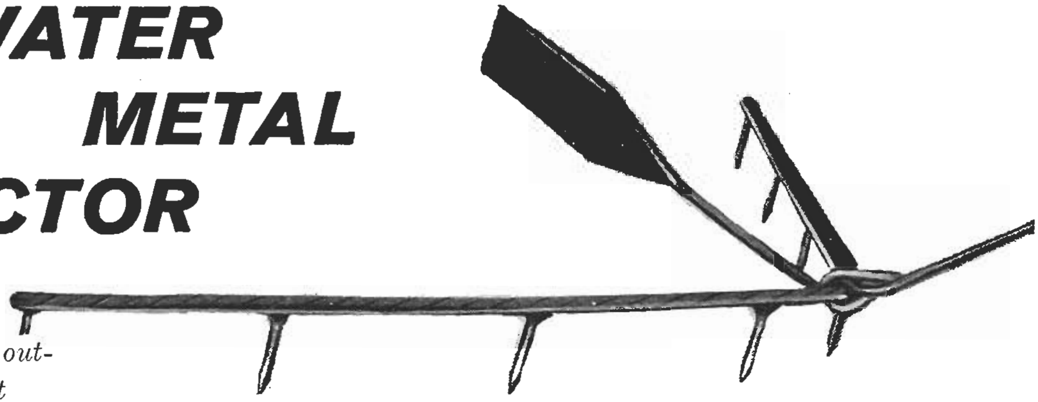
UNDERWATER METAL DETECTOR



Now you can locate that outboard or anchor you lost

By KENNETH RICHARDSON

FOR centuries man's imagination has been stimulated—and his urge for sudden wealth aroused, by tales of buried and hidden treasure and its discovery. From sunken Spanish or English treasure fleets of the 16th and 17th centuries to gold-carrying ships sunk in World War II, there are hundreds of authentic or semi-authentic treasure troves, not counting the pirate hoards and other land-buried or hidden wealth.

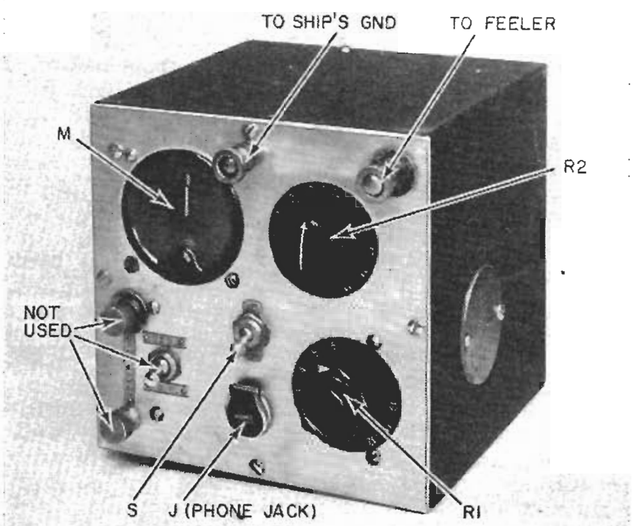
With the invention of the Hughes induction balance in 1879, a practical means of searching for such buried treasure was introduced for the first time and Hughes balance devices are still in use. Since 1929, improved methods for locating buried treasure have been available. None of these is as well suited for locating metal under water as the comparatively inexpensive electric-bridge instrument shown in the photo. It contains a battery, transformer, a sensitive meter and headphones. (The vibrator and associated parts were used in unsuccessful alternating-current experiments, and are not used in the instrument.)

Another photo shows the feeler, made of stainless steel, monel metal or copper, connected to the end of the insulated trailing cable.

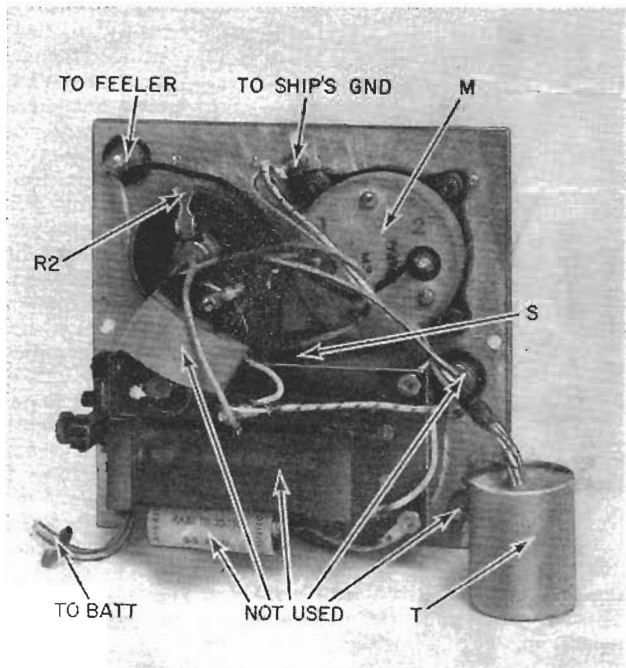
The feeler may consist of either single or multiple elements, whichever the operator prefers, in the form of pointed spikes made of the selected metal. Each type of feeler has both advantages and disadvantages. The single-element feeler composed of merely a single spike will register the greatest percentage change of current flow on the meter upon contact with a metallic object. The multiple-element feeler with the spikes (arranged in the form of a comb or rake, for example) will register proportionately less. The obvious advantage of the multiple feeler is that it covers a greater area. Personal experiment with feelers will assist the operator in determining the best type for his needs.

In the photo of the multiple-element feeler, note that the two legs of the "rake" are angled to minimize snagging underwater. Also note the small vane, which acts as a rudder to assure that the feeler scours the bottom with its spikes downward. A nylon rope is used to drag the feeler to relieve strain on the electric cable. As much of the feeler-frame surface as possible is insulated from contact with the water by tough plastic tubing and Vinylite tape. This will prevent loss of response due to leakage. Overall size may be anything from 2 feet to 6 or more, with the spikes spaced 6 to 12 inches apart.

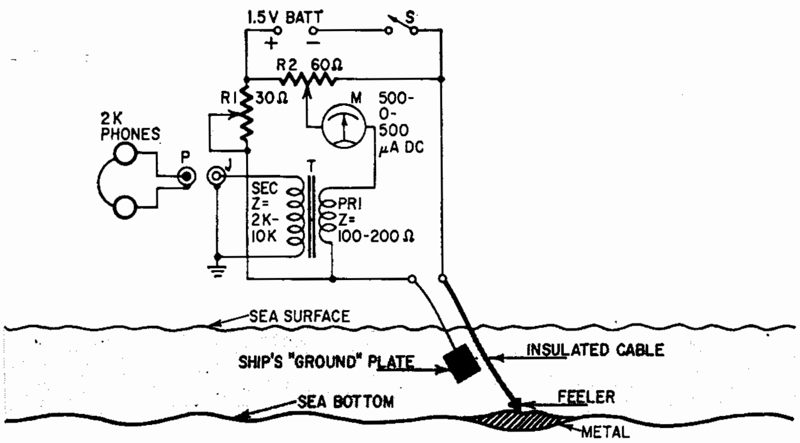
To adjust the instrument, first drop the cable to the bottom while the boat is under way, to assure that the multiple feeler, if used, scours the bottom with its spikes downward. Next, ground the instrument to the ship's engines or to an overside seaplate. Turn on the switch and set R2 to its approximate center position. Then adjust R1 until the meter centers, readjusting R2 slightly if necessary to secure perfect centering.



View of metal-detector control box.



Interior view of metal detector.



R1—pot, 30 ohms
R2—pot, 60 ohms
M—zero-center meter, 500-0-500 μa
J—phone jack
P—phone plug
T—carbon mike to grid transformer, 100 or 200 to 2,000–10,000 ohms (Triad A-1X or equivalent)
S—spst toggle
Battery—1.5-volt cell (the larger the cell, the longer the battery life)
Headphones, 2,000 ohms
Battery holder
Terminals for feeler and ground connections
Case
Feeler (see text)

Schematic of metal detector. If desired, an external shunt resistor may be used (15 to 30 ohms across R1) for salt-water use (since salt water has a lower resistance than fresh water, R1 should have a lower resistance).

In exploring any area, the operator maneuvers his boat back and forth, and the feeler sounds for metal along the sea bottom. As the feeler touches the surface of any metallic object, the meter reading will change, and a scraping sound will be heard in the headphones.

In areas of rocky bottom where the trailing method is more difficult, a weighted single spike is effective when repeatedly dropped vertically at short intervals as the boat maneuvers very slowly. These methods are suitable for locating sunken outboard motors and anchors, hundreds of which are lost annually, and also other metallic objects of value. Hulks of old wrecks containing valuable items repose in many of our bays, lakes and coastal areas. During his searching, the operator should be prepared to drop an anchored buoy immediately on the site of any strike, because of the ever changing currents and winds. We will not go into a discussion of actual salvaging operations, which may range all the way from simple skin diving in clear water to the elaborate expeditions required in turbulent and muddy areas.

The approximate locations of a vast number of wrecks are actually known, and information can be obtained by writing to the United States Coast and Geodetic Survey, Washington 25, D. C. Numerous books on the subject are also available.

An active summer is assured the seeker of hidden underwater treasure, and the United States Government will permit him to retain all finds, after taxes. END

ROUNDWORD PUZZLE

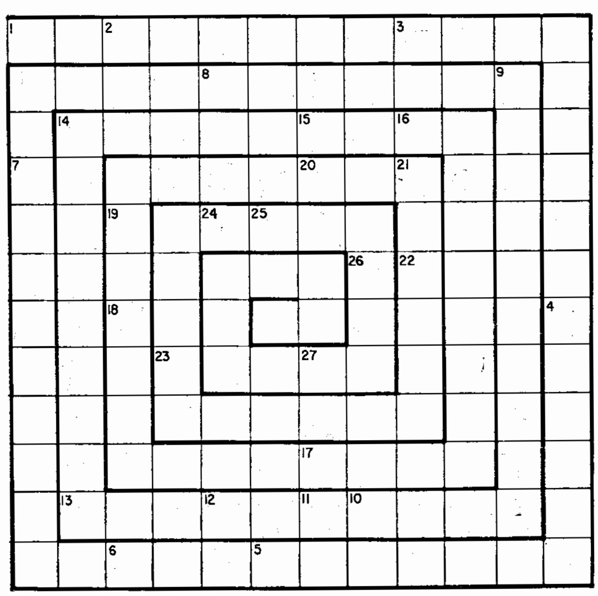
By MICHAEL L. NAHRWOLD

ARE you tired of the old across-and-down type crossword puzzle? Well, then, here is the thing for you—a *round-word* puzzle. Simply start at No. 1 and print the words on the outside squares of the puzzle, always going in a clockwise direction. The first letter of each word is always the last letter of the word preceding it. The words on the lower half of the puzzle will read backward and the words on the left half will read from bottom to top.

For example, the answer to the first definition must be a 3-letter word that represents ×1,000,000. Obviously, the correct answer is MEG and is placed in the first three boxes across the top of the puzzle—the M in the box numbered 1 and the G ending up in the box numbered 2. For our second answer we need a 7-letter word that starts with G and is a unit of magnetomotive force. GILBERT is such a word, but is it correct? As a check, is its last letter (T), which appears in the box numbered 3, the first letter of a 10-letter word that is the definition of a semiconductor? Try your luck and knowledge.

Answers on page 115.

1. ×1,000,000 (prefix)
2. Unit of magnetomotive force
3. A semiconductor
4. Feedback
5. Narrow-band frequency modulation (abbreviation)
6. .000,001 ampere
7. Section of a beam antenna
8. 4 element tube
9. Type of tweeter
10. Code (abbreviation)
11. Radio station run by the National Bureau of Standards
12. Unit of electromotive force or potential difference
13. Grid-controlled rectifier
14. Lowest class ham ticket
15. Electron coupled oscillator (abbreviation)
16. Test instrument incorporating CRT
17. Flow of electrons from tube filament or cathode
18. Net control station (abbreviation)
19. Hi-fi using 2 channels
20. Unit of resistance
21. Unit of conductance
22. First stage of a CW transmitter
23. Electromagnetic switch
24. Unmarried lady amateur (slang abbreviation)
25. Antenna used in radio direction finders
26. Male connector
27 Type of diode



COVER STORY

BUILD A Treasure Finder

Unique, inexpensive metal locator "picks up" all metals

By CHARLES D. RAKES

FINDING BURIED TREASURE can be fun. This construction project can lead you to lost coins on the beach, keys dropped in a snowdrift, water pipes, electrical wiring and just about any type of metal object. It will detect the presence of coins and other small objects 4 to 8 inches from the search loop, and larger objects at a range of several feet.

Two popular types of metal locators are the beat-frequency and transmitter–receiver models. This one is different. It is a tuned-loop oscillator and a crystal filter acting in combination to provide sensing and indicating signals. It is simple, stable and sensitive and is easy to build and operate.

Theory of operation

As shown in Fig. 1, transistor Q1, search loop L1 and associated components form a Colpitts oscillator circuit. The frequency of operation is determined by C1, C2, C3, C4 and the inductance of the loop. Oscillator output is loose-coupled from the collector of Q1 to the base of Q2, through C5 and R4. Operating as an emitter follower amplifier, Q2 has a voltage gain of less than one. From the emitter of Q2, the signal is fed through potentiometer R8 to Q3 through the 1-MHz crystal, XTAL 1.

If the oscillator is operating within the narrow passband of XTAL 1, the rf signal will pass through the crystal (in the series-resonant mode of operation). The rf is then rectified by D2 and the base–emitter junction of Q3. The resulting dc is amplified by Q3 and indicated on milliammeter M1.

Now let's see how the circuit operates as a sensitive metal locator. Assume that no metal is near the search loop and the power is on. Adjust the oscillator to the low-frequency end of the crystal bandpass and set R8 for a meter reading of about 0.2 mA.

If you bring the search loop close to a metal object, eddy currents will be induced. These currents decrease the loop inductance, changing the oscillator frequency. The crystal filter "looks" at this slightly higher frequency with a lower impedance; passes a greater amount of rf energy to the base of Q3. The result is an increase in the meter reading.

If the oscillator had been adjusted to the high-frequency end of the crystal bandpass curve, the meter reading will drop when the loop nears metal. More about this later.

Construction

I built the crystal-filter metal locator in a deep drawn aluminum box measuring 5″ x 3″ x 2″. All parts are mounted on the cover (Fig. 2). An aluminum utility box could be used but the mechanical stability of the deep-drawn box is preferable. Most components are mounted and wired on a section of perforated board 2⅝″ x 3⅜″ with push-in terminals. For best results your parts layout should follow Fig. 3 as closely as possible. Trimmer capacitor C4 is mounted facing one end of the case, as you can see in Fig. 2.

I used a removable hole plug to allow fine adjustment after the device was assembled.

Since the metal locator will be carried around, the wiring should be well fixed in place. The mechanical assembly must be rigid and free of mechanical vibrations. If not, you will be inviting instability and random operation.

Mount the perforated board on the front panel with two metal spacers 1¼″ long (Fig. 2). The front panel is held in position by a 10-32 x 2¼″ machine screw. For a handle, you can use a 3-foot piece of ⅞″ aluminum electrical conduit. The box is attached to the handle with a bracket made from ⅛″ x ⅜″ aluminum stock.

Search loop

Form the ⅜″ copper tubing into a 10½″-diameter circle with a gap of about 1 inch between ends. Push approximately 36″ of 6-wire cable through the circle of tubing. Let the cable extend out each end about 1 inch, and cut off the remaining wire. Then strip the plastic cover from the ends of the cable, exposing the 6 wires at each end of the tubing, then connect, solder and tape the connections to form a single 6-turn coil, as shown in Fig. 4. Ground only one end of the copper shield to the ground end of the loop—that is, the end of the loop connected to the shield of the coaxial cable.

The search loop is sandwiched between two 11½″ discs of ¼″ plywood (or similar nonmetallic material—see Fig. 6). I used a wing nut to mount the sandwich on the handle, so the loop angle is adjustable. A length of coaxial cable runs through the handle, from the control box to the search loop. The cable connects to the loop through J1 and P1.

Calibration

With the wiring completed, the loop connected and the battery in place, you can tune up the circuit. Position the search loop so that it isn't located near any metal objects, turn the power on and set potentiometer R8 about ⅛th turn clockwise from the end. Adjust the TUNE capacitor C1 so the plates are approximately half-meshed; then remove the hole plug and slowly adjust trimmer capacitor C4 until the meter swings up scale and pegs itself. Try to leave the trimmer set so there is a meter indication of greater than half scale. Replace the hole plug and adjust the TUNE capacitor for a meter reading of about 0.2 mA.

With the meter still indicating 0.2 mA, slowly bring the loop near a metal object. If the meter reading increases

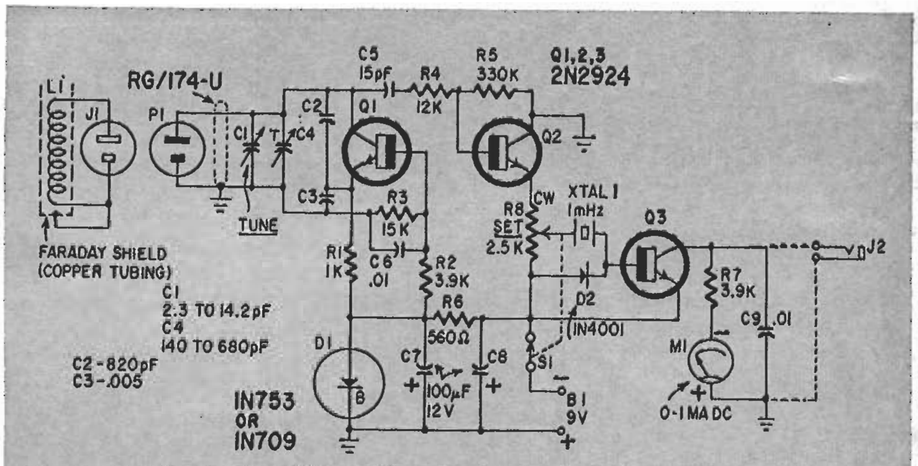


Fig. 1—Frequency of oscillator Q1 varies as search coil nears buried metal. The resulting variation in the rectified output of crystal filter shows on the meter.

Parts List for Metal Locator

B1—9-volt transistor battery, (NEDA 1604)
C1—2.3-pF to 14.2-pF miniature variable capacitor, (E. F. Johnson 160-107, or equivalent)
C2—820-pF silver mica capacitor (or better grade of disc ceramic)
C3—0.005-µF disc ceramic capacitor
C4—140-pF to 680-pF trimmer capacitor, (Elmenco 468 or similar)
C5—15-pF silver mica capacitor
C6, C9—0.01-µF disc ceramic capacitor, (Elmenco 468 or similar)
C7, C8—100-µF, 12-volt electrolytic capacitor
D1—6-volt Zener diode, (1N753, 1N709, or equivalent)
D2—Silicon diode (1N4001, 1N4002, 1N4003, etc.)
J1, P1—Two-conductor polarized connectors, one male and matching female, (Cinch-Jones or equivalent)
L1—Search loop, (see text)
M1—0-1 mA dc milliammeter, (Micronta miniature panel meter or equivalent)
Q1, Q2, Q3—Silicon transistors, (2N2924 or equivalent)
R1—1000-ohm resistor
R2, R7—3900-ohm resistor
R3—15,000-ohm resistor
R4—12,000-ohm resistor
R5—330,000-ohm resistor
R6—560-ohm resistor
R8—2500-ohm potentiometer with switch S1
All resistors ½-watt unless otherwise noted
S1—S.p.s.t. switch (part of R8)
xtal 1—1000 kHz crystal
1—34″ length of ⅜″-diameter copper tubing
1—36″ length of 6-conductor cable
1—41″ length of ⅞″ aluminum conduit or material
2—11¼″ diameter loop covers made out of plywood, Masonite or similar material
1—Unit mounting bracket (see text)
2—Aluminum "L" brackets for loop and handle assembly
2—1¼″ metal spacer, circuit board support
1—2⅝″ x 3⅜″ section of perforated phenolic board
25—Push-in terminals
1—6 foot section of RG-174/U (Belden 8216 coaxial cable or similar)
1—3″ x 5″ x 2″ Deep-drawn aluminum box, with a matching tight-fitting outside cover.
Misc. Knobs, screws, hookup wire, solder, plastic bicycle handle grip, battery holder and snap-on terminals, etc.

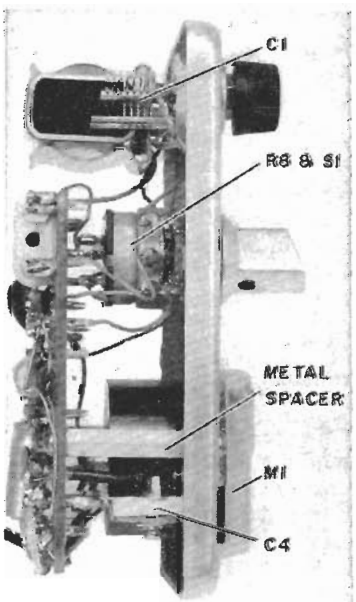


Fig. 2—Use spacers to hold perforated board on to panel.

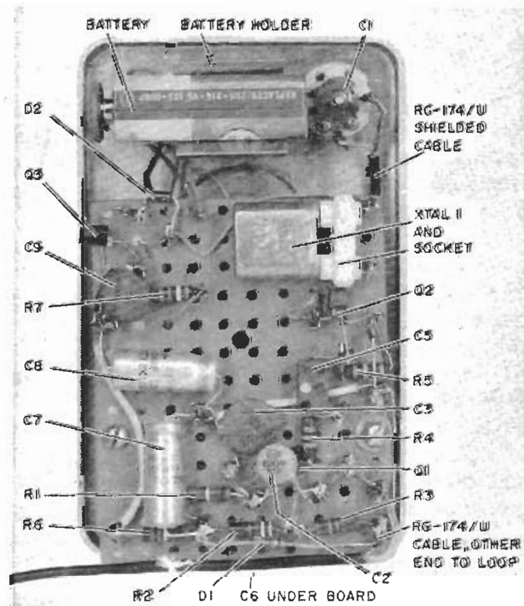


Fig. 3—Secure all components in place and follow this layout for reliable operation and stability.

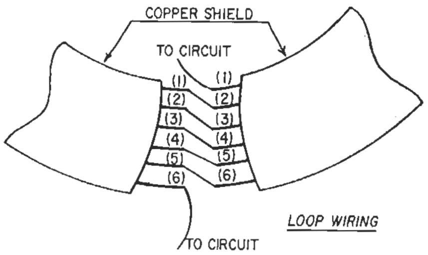


Fig. 4—Construction of the search loop is simplified by using 6-conductor intercom cable. Push it through the copper shield and connect the ends as shown.

Fig. 5—A meter and only two controls is an indication of the locator's simplicity and ease of operation. The jack at lower left is for the audible monitor.

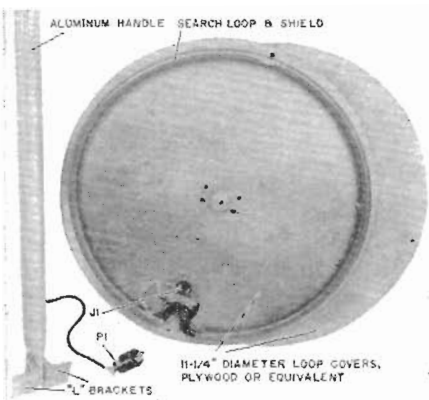


Fig. 6—Search loop is protected by plywood discs. P1 on end of coax cable connects loop (through J1) to oscillator in box on other end of handle.

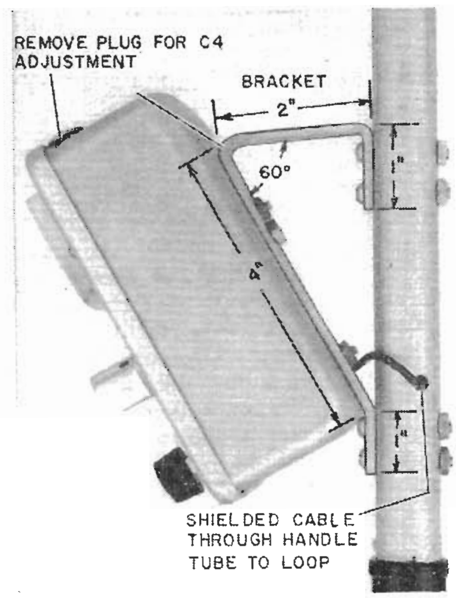


Fig. 7—Mount the oscillator box on the handle with a bracket constructed as shown from 1/8" x 3/8" aluminum stock. The angle is necessary so the meter can be easily read when operating the metal locator. Coax is threaded through handle.

sharply, the locator is adjusted to its most sensitive mode of operation. The oscillator is then working at the low-frequency end of the sharp crystal-filter curve. If the meter indication drops when the loop approaches a metal object, the oscillator is operating on the high-frequency end of the filter curve; it won't be quite as sensitive in this mode of operation.

Operation

Take the metal locator outdoors and set it up for the most sensitive mode of operation. Make these adjustments with the loop pointed away from the ground and any metal object. As the loop is lowered toward the ground the meter reading will drop slightly. This is caused by ground effect—the loop is coupling to the earth. To reduce this effect, operate the search loop approximately 4 to 6 inches above the ground.

After a bit of practice, you'll find the most sensitive operation occurs when SET potentiometer R8 is turned almost completely counterclockwise, and the TUNE capacitor C1 is set for a low scale indication.

For locating large objects near the surface of the ground, you may want to adjust the circuit for less sensitive operation. Turn SET control R8 completely clockwise and adjust TUNE capacitor C1 for a full-scale reading. Bring the loop close to a metal object—the meter reading should drop. If it does, the device is ready for large-object searching.

Sound monitor

While the basic circuit shown in Fig. 1 permits the most sensitivity, an audible indicator is sometimes useful. If you want to add what I call a Piggy-Back Squealer, build the circuit of Fig. 8. I used a 2¾ x 2" x 1⅝" metal box, and mounted it with a battery clip on the handle, below the meter box. You'll have to add jack J2 to the original circuit, connecting it in parallel with C9, as shown in Fig. 1. Any small speaker will do, if it has an 8- or 4-ohm voice coil.

The squealer loads the meter circuit slightly and reduces sensitivity somewhat. While this is no disadvantage for many jobs, you may want to unplug the squealer and go by the meter reading alone when you need all the sensitivity you can get. **R-E**

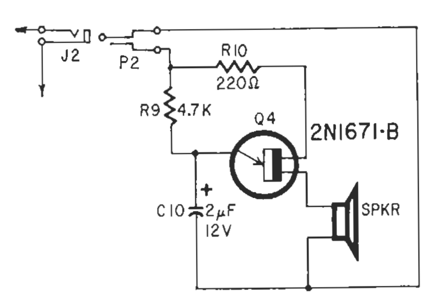
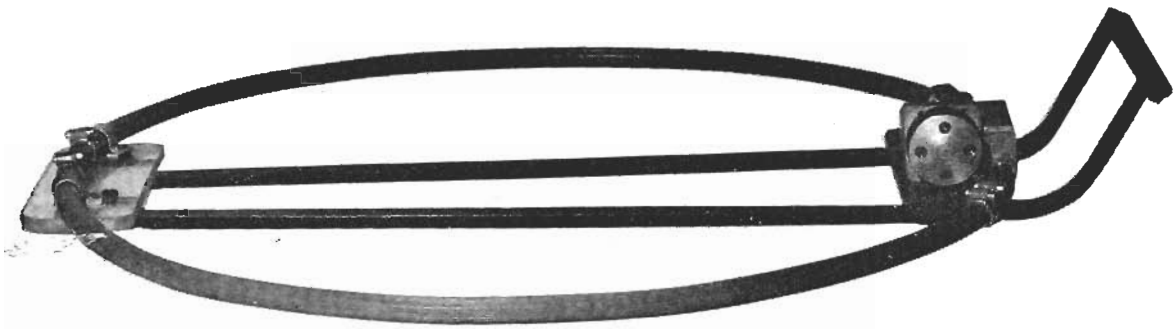


Fig. 8—A unijunction audio oscillator is the heart of the audible indicator.

Parts List for Optional Piggy-Back Squealer

C10—2-μF, 12-volt electrolytic capacitor
J2, P2—Miniature two-conductor phone jack and mating plug
Q4—2N1671B or almost any audio unijunction transistor
R9—4700-ohm, ½-watt resistor
R10—220-ohm, ½-watt resistor
SPKR—miniature speaker with 8-ohm voice coil
Misc.
Case, wire, hardware, etc.



Locator drags easily from line attached to boat. Note round magnet on oscillator box, used to turn unit on and off.

Underwater Metal Hunting for Fun or Profit

By OLLE KLIPPBERG

This low-cost detector finds lost motors, anchors—or treasure! It doesn't mind getting wet!

NOTHING STIRS THE IMAGINATION MORE than reading of ancient galleys that sank with great treasures aboard. I got the idea for this underwater locator from a friend of mine, a scuba diver, who asked me if I could construct an electronic device for a much less glamorous job: he wanted to hunt for a lost outboard motor. I tried a number of methods, and finally built a locator that really works well. You can build one that will do equally as well for you.

The treasure locator consists of a little transistor transmitter (Fig. 1) that is sunk into the water, with a tether to the boat. An ordinary transistor radio, outfitted with a beat-frequency oscillator (bfo), is used as a receiver. As a substi-

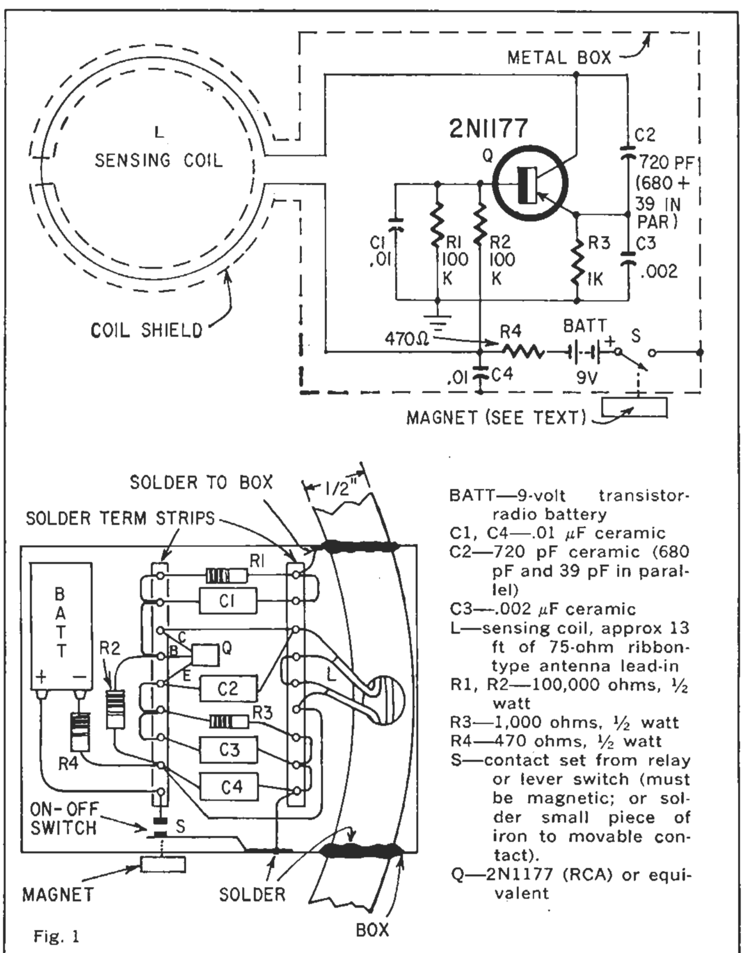


Fig. 1

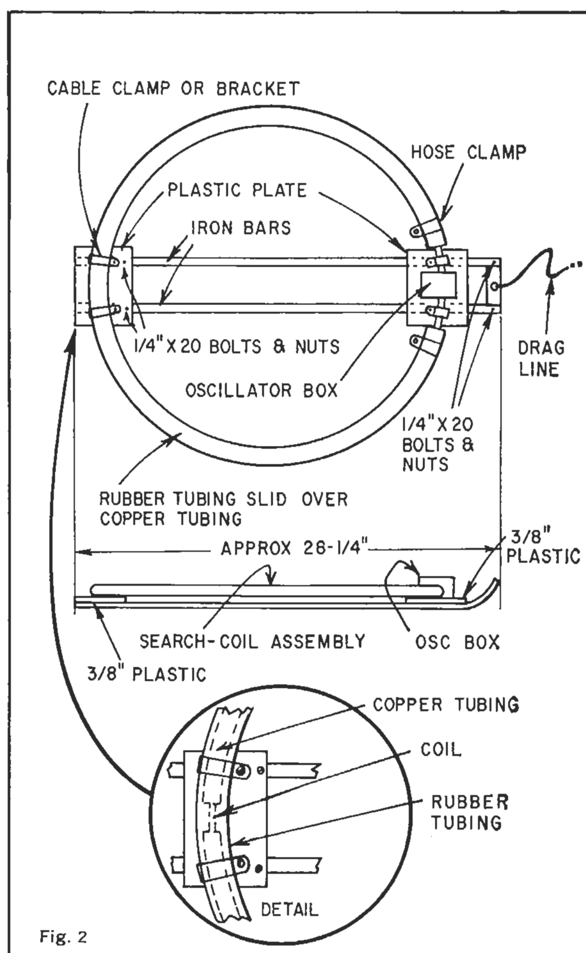


Fig. 2

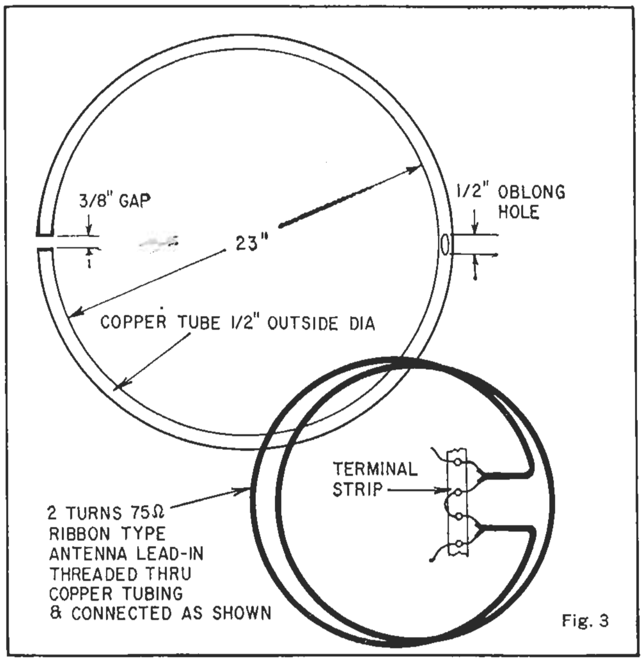


Fig. 3

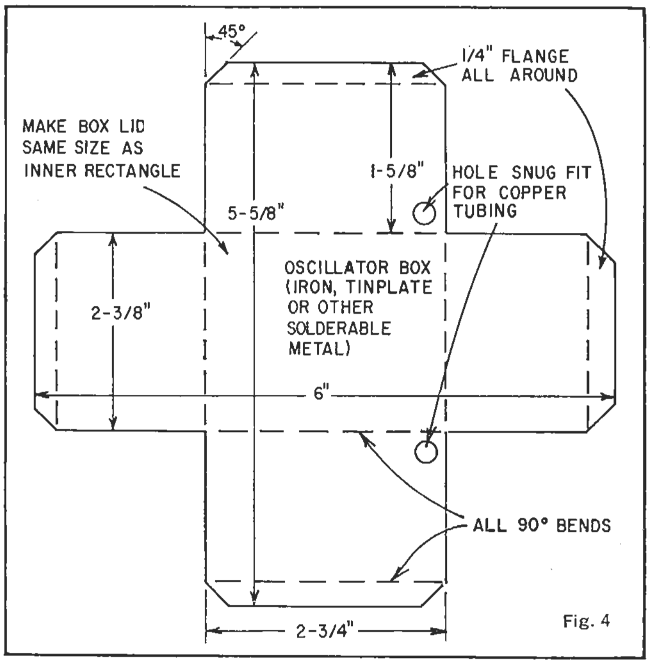


Fig. 4

tute for the bfo, you can couple back between two i.f. stages to make an oscillating i.f.

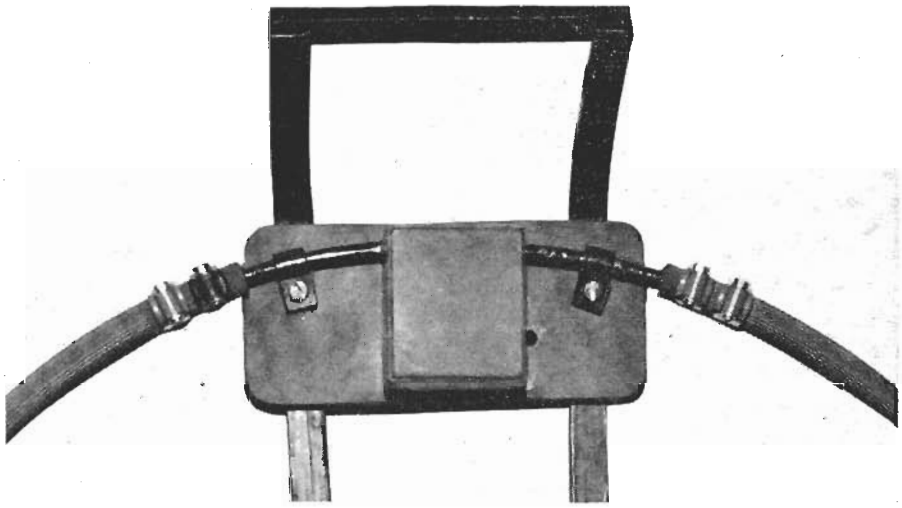
The transmitter operates at approximately 600 kHz. The signal is sent from the transmitter output coil to the receiver through the water, if the depth is not greater than about 30 feet. If you have to work deeper, connect an insulated antenna wire to the receiver and run it parallel with the tether down to the transmitter. There it can be connected to the same point as the drag line.

Any metal object near the transmitter coil will alter the coil's inductance, causing a shift in frequency. This frequency shift is registered in the receiver as a beat whistle in the speaker. To get the best results with the locator, the receiver should be tuned a little to one side of the null tone (zero beat). The field extends about 2 feet from the transmitter coil, which makes it possible to find objects covered with mud or slime.

The frame of the locator, which must be dense enough not to be buoyant, is made of strap iron 29 x 9/16 x 3/8 inches (Fig. 2). [These dimensions seem odd because they were converted from nice, round metric-system numbers. You can round off the figures in inches, but think carefully before you do anything permanent with your hacksaw!—*Editor*] Drill holes for fastening the transmitter coil and for the cross bars where the drag line will be attached. Two acrylic or polystyrene plates are then mounted on the strap iron. The transmitter coil's shield is made of ½-inch copper tubing (Fig. 3). A hole approximately ½ inch in diameter is made in the tube and the coil threaded through it.

The coil is made of two turns of 75Ω cable, threaded through the copper tube (Figs. 1 and 3). They are connected so that all four turns are in series. A rubber hose is threaded over the copper tube (Fig. 2). Its inner diameter is a snug fit over the tube; its outer diameter is about ¾ inch. To make the coil assembly watertight, fasten hose clamps at the ends, as shown in the photo. Fasten the coil and box to the frame with cable clamps and screws with lockwashers.

The oscillator case was made of tinplated steel, 1-mm tinplate (approximately 3/64 in.), formed as shown in Fig. 4. After the box is bent into shape, solder it on all edges and solder the copper tube to it carefully so that everything will be absolutely watertight when the top is soldered on.



Detail of junction between oscillator box and search-coil tube. Completed assembly must be watertight, and should get two coats of good glossy enamel to prevent corrosion and make it easy to clean. The oscillator box is then mounted on a plastic support plate.

The wiring of the transmitter itself is supported on two 9-terminal solder-lug strips, as shown in Fig. 1. They should also be soldered to the metal of the box, to prevent leaks.

A relay contact leaf is used as a switch. A small flat piece of soft iron is glued to it. Normally, a magnet is kept on the outside of the box to keep the transmitter turned off. When you want to use the locator, remove the magnet. (It can be a magnet from an old loudspeaker.) The battery is an ordinary transistor radio battery. It should last several months. [An 8.4-volt mercury cell is better.—*Ed.*] When all is adjusted and tested, solder the cover on. Be sure everything is watertight. END

SHORT CIRCUITS

This new series will describe straightforward projects but they are not necessarily simple in their operation or aimed at the beginner. We plan to carry between two and four such projects each month.

NEW SERIES

PATCH DETECTOR

THERE IT STANDS: gleaming. On the surface, a secondhand car in really good nick but think! Modern materials, especially resin body filler and a quick blow-over with the spray gun can make a rusty heap look like a new car.

Our Patch Detector will quickly find areas of the body-work which have been filled — or even patched with aluminium.

Only a handful of components are used. The key to the operation is the transistor output transformer; we used the best known, the LT700 in our prototype but we tried other types and all worked.

It is necessary to modify the transformer. First remove the shroud over the laminations. Then, using a pair of fine-nosed pliers carefully remove the laminations. These are held together by wax: the first lamination may be

Parts List

Q1	Transistor BC108 etc
R1	Resistor 47k ¼W
C1	Capacitor 0.1μF disc ceramic etc
C2	" 0.018μF "
C3	" 100μF 12V electrolytic
T1	Transformer LT700

Earphone: 8Ω type, 3.5mm jack plug
Earphone socket, 3.5mm
PCB to design shown
Vero box type "HAND HELD BOX"
Battery: PP3 and Battery clip

Total cost, inclusive of Box and VAT about £2.00

How it works

The circuit is a Hartley oscillator using an LT700 as the inductor. The primary of T1 is tuned by C2 and feedback is avoided by C1. The secondary of T1 connects via the socket/switch to the earphone.

Due to the modification of the transformer, when metal is brought near to the open end of the E laminations this alters the inductance of the primary and consequently the frequency of the note produced.

C1, C2 and R1 all affect the note produced and as long as R1 is not reduced below 33k, these may be modified to give the desired frequency. Current drain from the battery will be between 5 and 10mA.

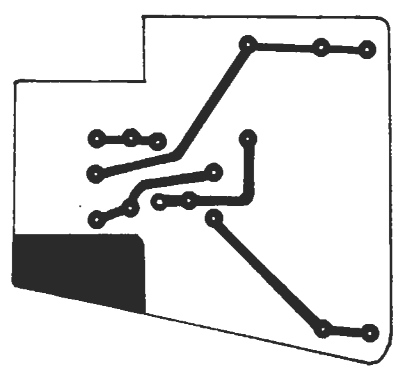


Fig. 3. PCB foil pattern — full size.

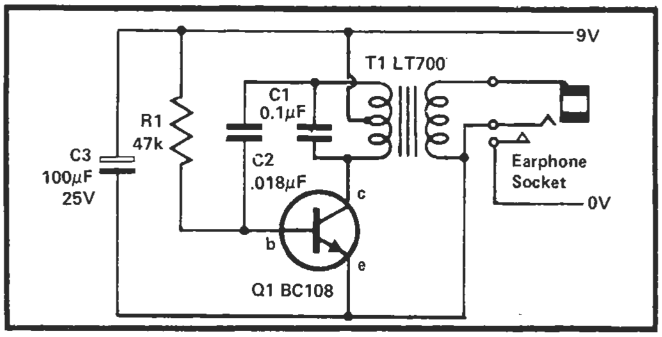


Fig. 1. Circuit diagram of the detector.

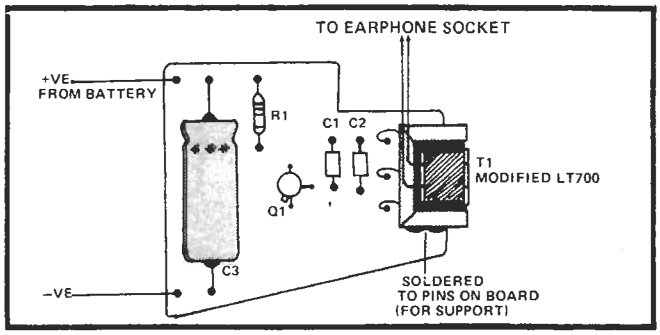


Fig. 2. Component overlay.

Short Circuits

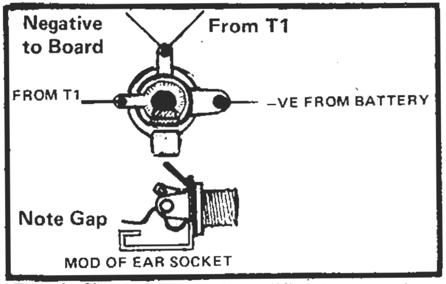


Fig. 4: The wiring and modifications to the earphone socket

tricky to remove but thereafter you won't have any difficulty. The laminations in the LT700 (and the others we tried) are E shaped with a bar enclosing the exposed end, they are layed alternately.

When all the laminations have been removed reassemble them all the same way round to form an E. Fit this back into the transformer and replace the shroud.

We used one of the new "HAND-HELD" Vero boxes and built a small PCB to hold the components. The transformer can't fit directly onto the PCB so two thick wires are soldered to the shroud, these in turn are soldered to the PCB, this effectively stands the transformer away from the board.

A hole is necessary on the short end of the plastic box to take the transformer's face; the open ends of the E should face out.

Internal view of our Patch Detector. Note how the transformer fits through a hole cut in the short end of the case.

The circuit is simple and will only be used with an earphone so an on-off switch will only complicate matters. Instead the switch section of the earphone socket is bent so that it switches on when the earphone is inserted.

A PP3/VT3 battery will fit nicely across the long end of the box if one of the plastic buttresses on the pillar and two pips inside the same area are cut away.

The circuit is really a simple metal locator. In free air an audio tone is heard but when run along the body of a car the note is lower. When filler is encountered the note rises: even aluminium causes note change. There is no danger of the unit scratching the paintwork as the only thing to touch the bodywork is the soft plastic of the transformer's former.

A change in note can be detected when sheet steel is about 10mm (3/8in) from the laminations. Greater sensitivity is not an advantage incidentally.

BUILD THE "BEACHCOMBER"

COVER STORY

By DANIEL MEYER

THE ALTER EGO OF OUR DEEP SEARCH "IC-67" LOCATOR WILL FIND THOSE SMALL METALLIC OBJECTS AND COINS

PROBABLY EVERY one of us has at one time or another had the urge to go searching for buried treasure. The "treasure" could be really valuable—a pot of gold coins buried during the Civil War, or a platinum locket lost on the beach—or it could be just a few cents dropped in some weeds or an old coffee can lid. A "treasure finder" or metal locator tells you where to dig.

Metal detectors come in two basic types. The one best suited to your needs will depend on just what you are searching for. The bulkier and more expensive transmit-receive detectors can find large objects at greater depths, but do not detect small objects easily. A simple single-loop beat-frequency locator, like the "Beachcomber," will detect objects at a depth of only about 2 feet maximum (depending on size) but can readily find small objects only 1 or 2 inches in diameter.

The Beachcomber can be a lot of fun to have along on a trip to the coast, or to an old battlefield to search for relics. It is lightweight, and operates 6 to 8 hours on an ordinary transistor radio battery. Its speaker is built in, so there are no headsets or wires to get in the way or get lost. And it only costs about $15 to build.

How It Works. The simple circuit (Fig. 1) consists of two r.f. oscillators—operating around 400 to 500 kHz, a detector, and an audio amplifier. The oscillators are identical, except for the coils used to tune them. One coil, *L1*, is tuned to make this oscillator's frequency slightly

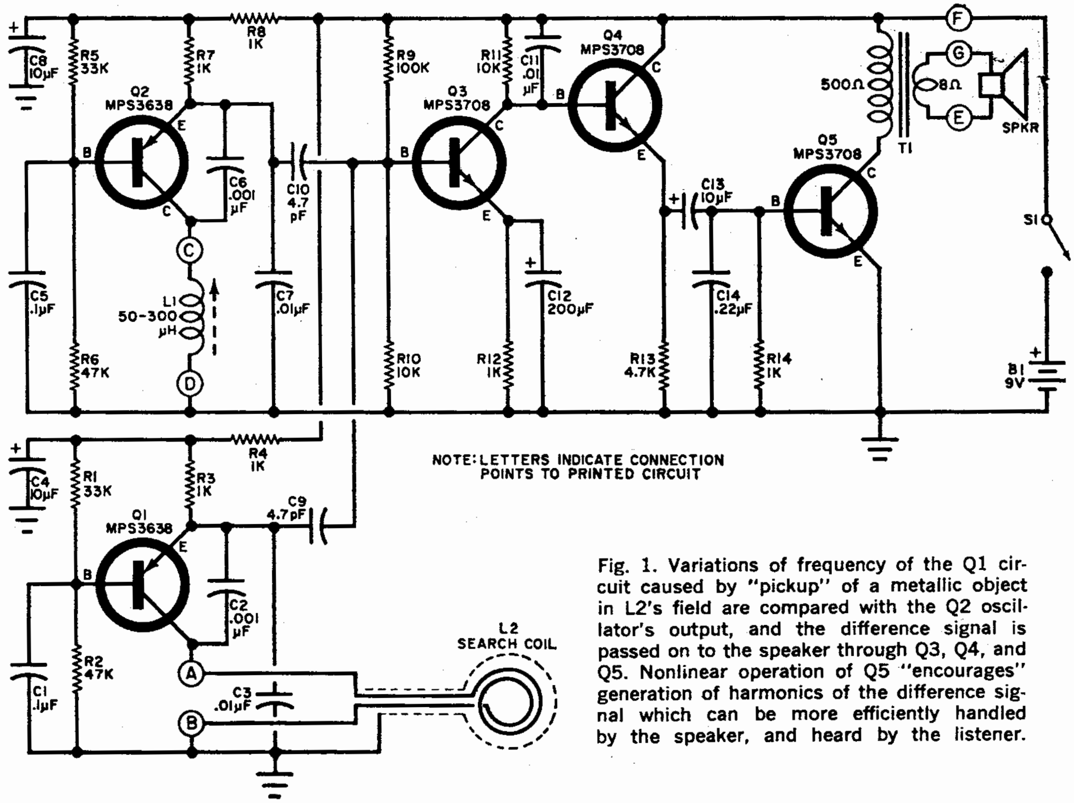


Fig. 1. Variations of frequency of the Q1 circuit caused by "pickup" of a metallic object in L2's field are compared with the Q2 oscillator's output, and the difference signal is passed on to the speaker through Q3, Q4, and Q5. Nonlinear operation of Q5 "encourages" generation of harmonics of the difference signal which can be more efficiently handled by the speaker, and heard by the listener.

higher or lower than that of the search coil oscillator. The two signals are combined in detector stage *Q3*, whose output is the audible difference between the two frequencies. This signal is fed to emitter follower *Q4* and output stage *Q5*, and finally to the speaker.

The search coil oscillator frequency changes slightly whenever the conductance of the material in the field of the loop changes. This means that if the coil passes over a metal object, the oscillator frequency will change slightly, and the pitch of the audio beat note you hear from your speaker will also change. It is easier to hear a small frequency change in a low-pitched sound than an equal change in a higher frequency tone.

To get the best results from the Beachcomber, set the oscillators as near the same frequency as possible. *Both oscillators must be very stable.* Good sturdy construction with no loose parts is a must. The circuit must also be so laid out as to reduce coupling between the two oscillators to the minimum. Other-

PARTS LIST

B1—9-volt battery
C1, C5—0.1-μF, low-voltage disc ceramic capacitor
C2, C6—0.001-μF polystyrene capacitor
C3, C7—0.01-μF polystyrene capacitor
C4, C8, C13—10-μF, 15-volt electrolytic capacitor
C9, C10—4.7-pF ceramic disc capacitor
C11—0.01-μF, low-voltage disc ceramic capacitor
C12—200-μF, 6-volt electrolytic capacitor
C14—0.22-μF low-voltage disc ceramic capacitor
L1—50-300-μH variable inductor (Thordarson WC-11, J. W. Miller #6196, or similar)
L2—Search coil—see text
Q1, Q2—MPS3638 transistor (Motorola)
Q3, Q4, Q5—MPS3708 transistor (Motorola)
R1, R5—33,000 ohms
R2, R6—47,000 ohms
R3, R4, R7, R8, R12, R14—1000 ohms
R9—100,000 ohms
R10, R11—10,000 ohms
R13—4700 ohms
(All resistors ½ watt)
S1—S.p.s.t. slide switch
T1—Transistor output transformer: primary, 500 ohms CT (do not use CT); secondary; 8 ohms, 150 mW.
Misc.—Miniature speaker, chassis box, battery clip, enameled wire, spacers, solder, etc.

NOTE: Printed circuit board for this project is available for $2.50 from DEMCO, 219 West Rhapsody, San Antonio, Texas 78216. A complete kit (excluding the coil form, chassis and rod) is also available for $15 postpaid.

wise, the oscillators will "pull"—suddenly lock together every time the beat frequency is brought down to a low pitch. That is why both oscillators are decoupled from the battery supply and from each other (through *R4-C4* and *R8-C8*) and why such small value capacitors are used for *C9* and *C10*.

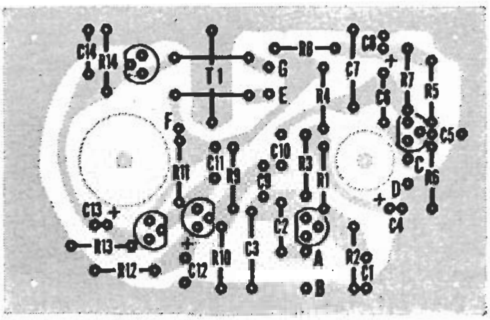
The output stage is purposely designed to produce "distortion," so that the low-frequency beat notes can be heard from the small speaker. If the audio circuit were designed for linear operation and little distortion, the speaker would produce little or no output below 150 to 200 hertz. In this circuit the audio output stage is not biased "on" at all. When it is driven with an audio signal from emitter follower *Q4*, transistor *Q5* conducts and produces an output on each positive half cycle. The signal to the speaker is therefore a series of pulses at the frequency of the beat signal. Since the pulses contain many harmonics, they can be heard down to a few hertz.

Construction. The electronic portion of the metal detector is easy to assemble, and there is no chance of coupling problems or shifting parts if the printed circuit board construction shown is used. The board (Fig. 2) serves as a template to locate the holes for *L1*, the mounting spacers, and the speaker.

Cut a $\frac{7}{16}$″-diameter hole for *L1* and another of the correct diameter for your speaker. Then mount the small parts by simply inserting them in the positions indicated by the parts numbers on the top side of the board, turning the board over, and soldering them in place.

File the switch hole in the cabinet to fit the type of switch used. Mount the switch, speaker, battery clip, and *L1* as shown in the photograph (Fig. 3). Wire the switch and battery clip as shown. The lead from the positive terminal of the battery goes to one switch contact, and a short lead should be soldered to the other contact—to go to point *F* on the board. A doughnut cut from plastic foam is placed around the rear of the speaker; the board compresses the foam when it is mounted, and thus holds the speaker snugly.

Now connect the battery and speaker wires to the underside of the board at the points indicated on the schematic diagram. Mount the completed circuit



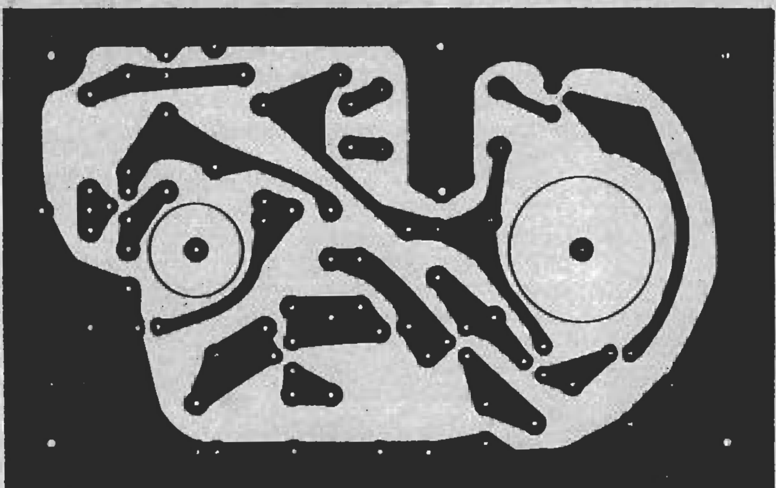


Fig. 2. Actual size drawing of foil side of printed circuit (left) will help you make your own board. Parts are installed on the plain side of the board as shown above. Figure 4 shows parts assembled on board.

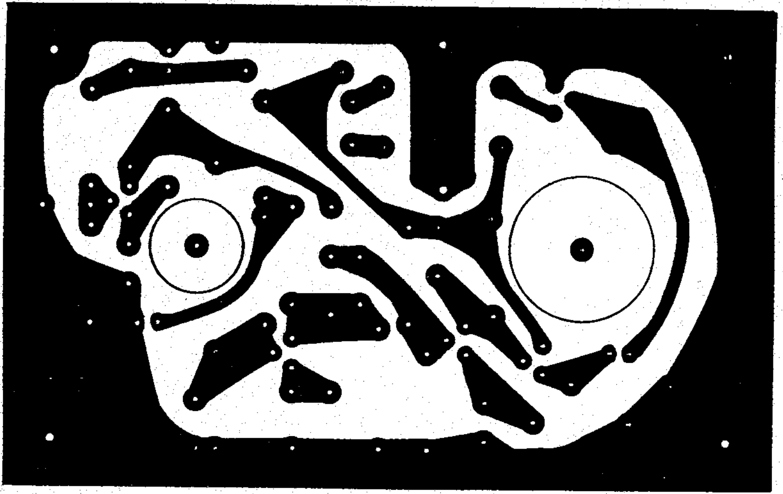


Fig. 2. A
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Fig. 3. Part of the speaker and coil L1 pass through the circuit board and must be carefully positioned to fit properly. The speaker is not bolted and can be shifted.

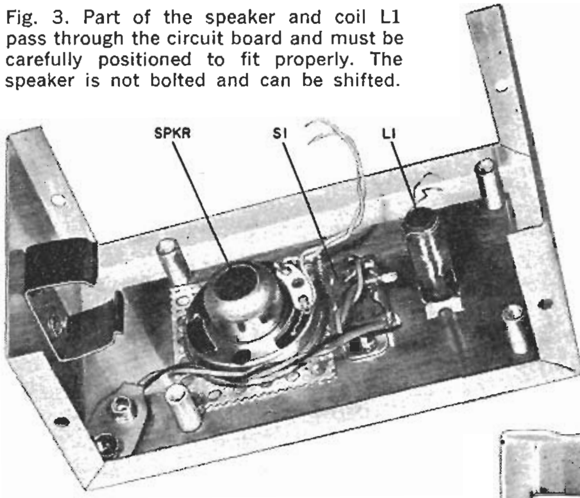
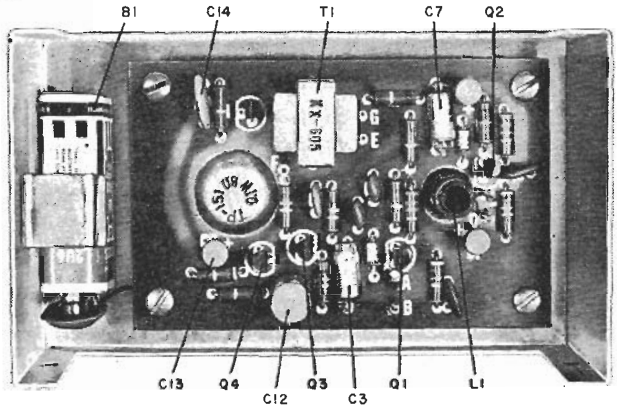


Fig. 5. Clean, firm assembly of internal as well as external components and other hardware means clean operation. Any variations due to movement of parts can cause false readings.



board (Fig. 5) and connect *L1* to the eyelets at points *C* and *D* on top of the board.

The Search Loop. This important part of the locator can be made in several ways. Of the two presented here, the copper tubing search coil shown in Fig. 6 is more rugged, but the plastic tubing loop will work well and is much easier to build.

To make the copper coil, obtain a piece of 1/4″ *soft* copper tubing 42 inches long and bend it into as smooth a circle as possible. (Be sure it is straight when you buy it—and bend it around a cylindrical object a little less than a foot in diameter.) Leave a quarter-inch gap between the ends. Drill a 1/8″-hole on the inside of the circle opposite the gap.

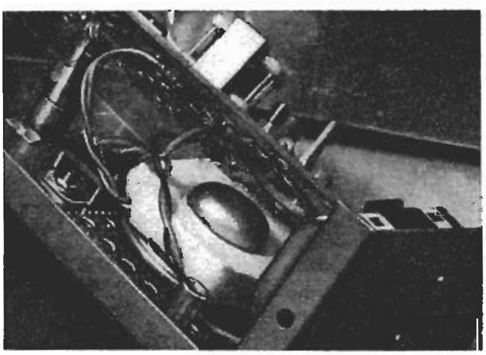


Fig. 4. A "doughnut" of foam rubber or plastic placed around the speaker holds it securely in its correct position when circuit board is installed.

Then take a hacksaw and split the tubing around its outside wall. (Cut through the outside wall only, not completely through the tube.) The edges of the cut can be smoothed with a small file. Solder about 6 inches of insulated hookup wire to one end of a 50′ length of No. 24 enameled magnet wire, and slip a piece of insulating tubing over the connection. Thread the insulated wire through the 1/8″-hole in the tubing from the outside (through the slot) and leave about an inch or two of insulated wire inside the split loop.

Now wind 14 turns of wire inside the copper tube through the saw slot, being careful not to pull the 1/4″ end gap together. Cut the magnet wire and solder another piece of hookup wire to that end. Insulate the connection and thread the hookup wire through the hole in the tubing. Finally, paint the coil of wire inside the copper shield with coil dope or white glue.

You can make the plastic loop (Fig. 6) in much the same way. Slip a 2″ length of 3/8″ plastic tubing over the ends of the

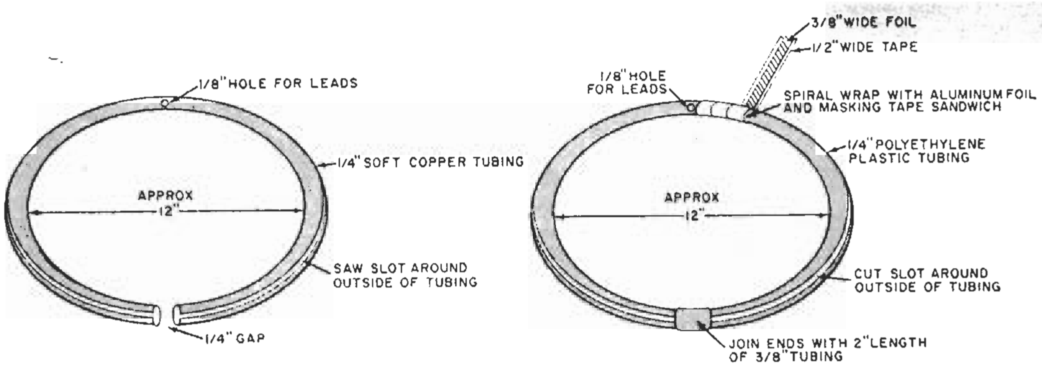


Fig. 6. Loop housing made of copper is shown above, and plastic tubing at right, above. If plastic is used, a metal outer covering can be made from aluminum foil. In either case, there must be a gap.

$\frac{1}{4}''$ plastic tubing to hold the ends in place. Then cut or drill a hole on the inside of the loop opposite the gap, and split the outside of the loop with a knife. Cut out a $\frac{1}{16}''$ strip all the way around the outside.

Make up the magnet wire as described for the copper loop and wind the search loop with 14 turns. Cement the turns together. Since the plastic loop does not shield the coil—as does the copper loop—it must be shielded before mounting.

You shield the plastic loop by cutting a piece about $\frac{3}{8}''$ wide from the end of a roll of aluminum foil. Stick the foil to a piece of $\frac{1}{2}''$ plastic masking tape, leaving a border on each side. Then strip the insulation off of about half of a 6″ piece of *stranded* hookup wire, and place the bare portion between the foil and tape at the beginning of the spiral roll.

Now, starting at the point where the connections come out of the loop, spiral-wrap the tape-foil sandwich around the coil form. When you have gone all the way round, tear the foil off and go round

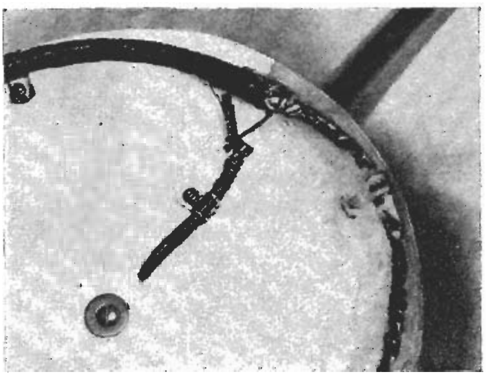
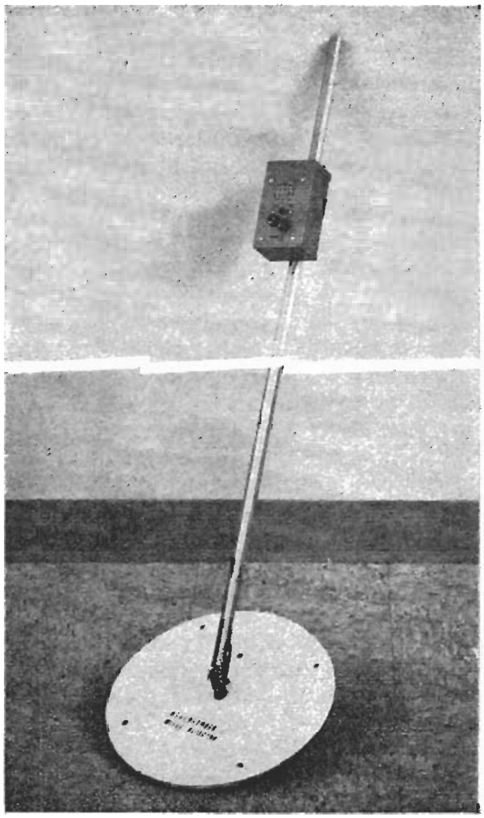
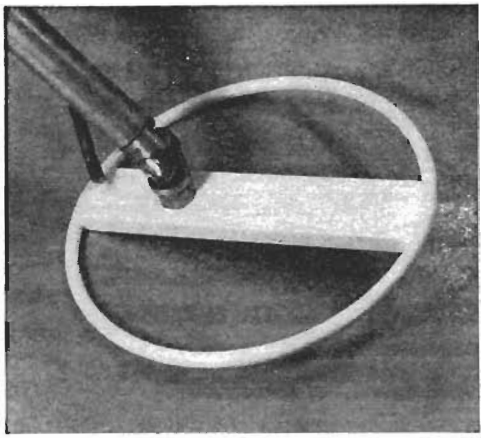


Fig. 7. Plastic-covered loop must be securely positioned. Use plastic cable clamps and putty or cement to hold the entire loop on the plywood board.



Completed "Beachcomber" is ready to "look for" buried treasure. Adjust loop so it is parallel to the ground while you hold unit at comfortable angle.



The copper tubing loop assembly is rigid enough to permit the use of a small wood brace for assembly. Some weight reduction can be gained in this manner.

again with the masking tape only, to hold everything firmly in place. *Note that the foil must not form a continuous loop.* Do not let the end of the foil—where you stop—touch the beginning of the winding.

The finished loop is mounted with plastic cable clamps to a 1/4" plywood base (see Fig. 7). Use at least four clamps. The plastic loop must be potted in place on the plywood base with water putty to make sure it won't move or bend.

Finishing Touches. The handle on the Beachcomber can be any convenient length of 3/4" aluminum tubing, and it can be fastened to the plywood base with a universal elbow made for 3/4" tubing. (These items were obtained by the author off a "do-it-yourself" rack in a local hardware store. If you have trouble finding them, the handle can be made of wood. Even an old hoe handle will do.)

Connect the two ends of the loop to the two wires and the shield to the shield braid of a two-conductor shielded cable long enough to run up the handle to the control box. Screw the bottom of the box to the handle and bring the cable through a hole in the bottom of the box to a three-lug terminal strip, which can be mounted with one of the screws that hold the box to the handle.

Connect circuit board points *A* and *B* to the loop wires at the terminal strip with about 3 to 4 inches of hookup wire twisted together. Clip in the battery, put the box together, and you're ready to go.

Using the Detector. The Beachcomber is simple to use and—with a little practice—you should be able to find buried metal easily. The first thing to do is to set the tuning control to produce a beat note. Since the adjustment range of the coil is very wide, you should be able to get a beat note even if your search coil is not identical to the one shown.

If you are not sure whether the circuit is operating, hold a transistor radio near the detector while you turn the tuning control. You should be able to get a strong signal near the low end of the broadcast band somewhere in the tuning control's range.

Place the search loop flat on the ground and adjust the tuning to give a low beat note. Raising the loop 4 to 6 inches above ground should not change the beat note very much. To search, you simply hold the coil near the ground and swing it from side to side, parallel to the ground. If you hear a change in the pitch of the beat note, move the coil slowly around the area to get an idea of the exact location and size of your find.

The change in beat note will depend on the size of the buried object and its area as seen from straight above. Thus, while you can easily find a coffee can lid buried flat, you might miss it if it were buried on edge. Figure 8 should give you a good idea of the results you can expect with the detector.

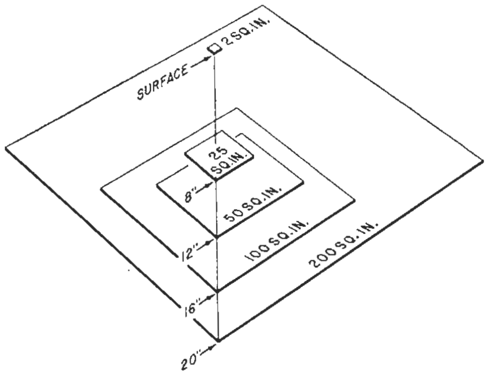


Fig. 8. When loop is on ground surface, you can pinpoint an object within 2 square inches. As loop is raised above ground, it will cover a wider area: about 50 square inches at a height of 12 inches, 100 square inches at a height of 16 inches, etc.

(*Continued on page* 84)

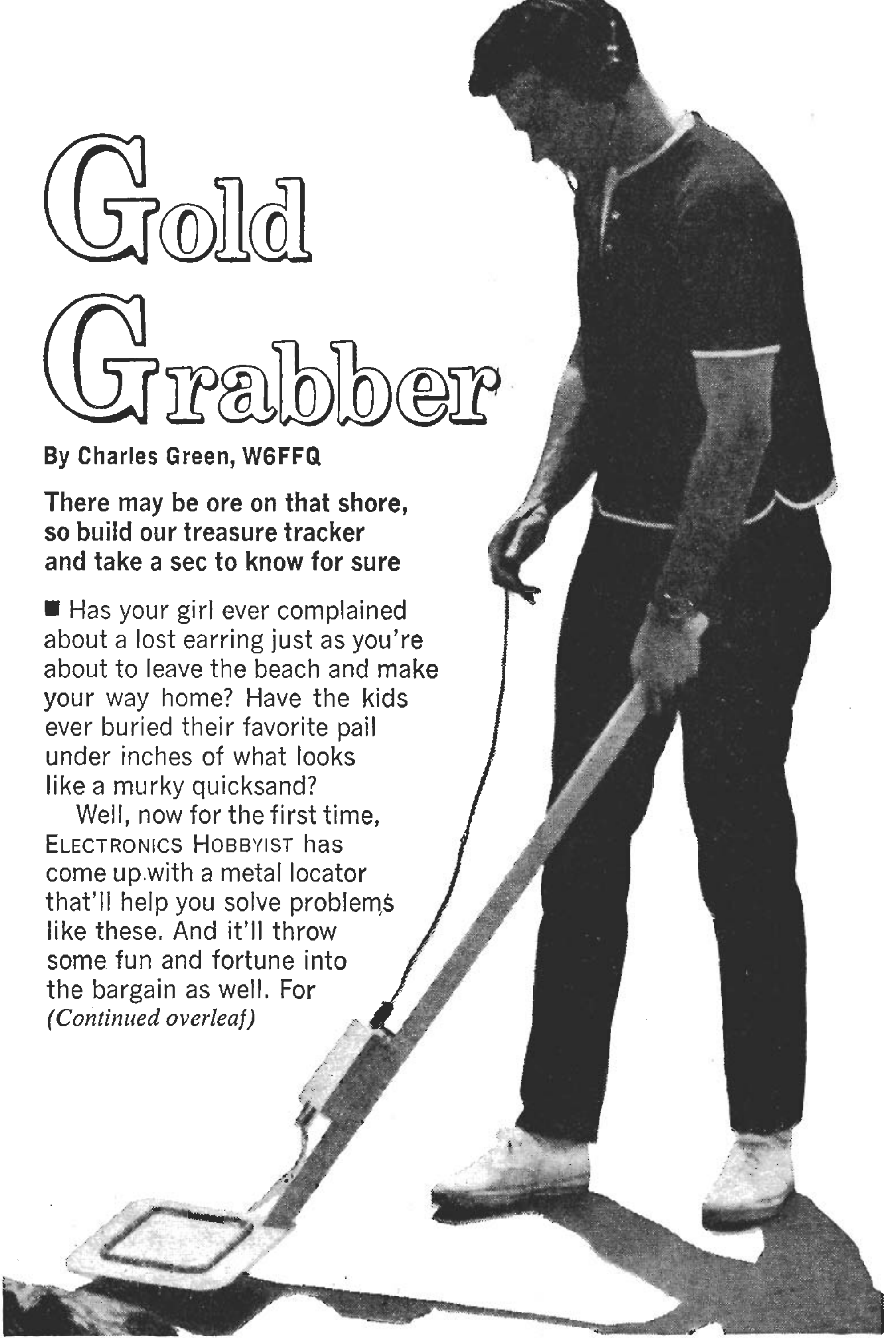
THE "BEACHCOMBER"

(*Continued from page* 32)

Operating Notes. Do not attempt to use the Beachcomber with the two oscillators operating at zero beat (the same frequency). This will reduce sensitivity by about half, due to the slight locking action caused by stray coupling. If you note any sudden changes in pitch when the search coil bumps the ground or vegetation, check the wiring and loop mounting for loose parts. Any movement of parts or wire, inside or outside, on or near the search coil can cause changes in pitch. The better the construction, the more reliable the indications.

If you are primarily interested in smaller objects, coins—for instance, you can make the detector more sensitive by using a smaller-diameter search coil. A 4" loop will work nicely. The only change necessary is to add two turns to the search loop coil. Keep in mind that the smaller loop will not penetrate as deeply as a larger one.

If you are interested in finding larger objects at a greater depth than the Beachcomber's maximum range, you might look into the deep-searching metal locator described in the January 1967 issue of POPULAR ELECTRONICS. -30-



Gold Grabber

By Charles Green, W6FFQ

There may be ore on that shore, so build our treasure tracker and take a sec to know for sure

■ Has your girl ever complained about a lost earring just as you're about to leave the beach and make your way home? Have the kids ever buried their favorite pail under inches of what looks like a murky quicksand?

Well, now for the first time, ELECTRONICS HOBBYIST has come up with a metal locator that'll help you solve problems like these. And it'll throw some fun and fortune into the bargain as well. For

(Continued overleaf)

Gold Grabber

whether it's minor disasters like the ones mentioned, or just a natural lust to go out adventuring. Gold Grabber will keep you busy like nothing you've ever seen.

Pieces of Eight. Lucky folks down in the Caribbean or in the California and Central America areas can go looking for the gold coins and relics which abound on some of the exotic beaches and landscapes. And the battlefields of Civil War fame are hunting grounds that should keep any buff busy for days on end.

You can also use Gold Grabber to find buried cables and conduits; to make up games for the youngsters so they can have fun looking for hidden objects; or just to help out a friend in need of a metal locator. In fact, every reader will be able to come up with countless ideas that'll increase the value of his instrument a thousandfold.

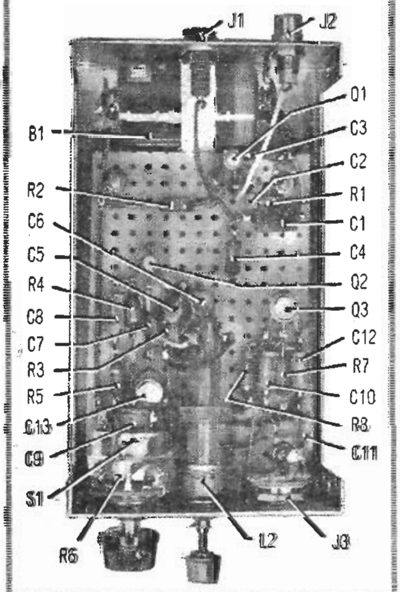
Easy Operation. Gold Grabber consists of a search loop and locator unit mounted on a wooden handle. Since the locator unit is all-solid-state and powered by a mercury battery, it is light enough to permit easy operation as a search tool. (As you can see from the photos, there are two versions of Gold Grabber—one jazzed up by the editors, and one constructed by the author. You choose the one best for you. But stay away from ferrous material! Brass screws will do, but epoxy glue would be best.)

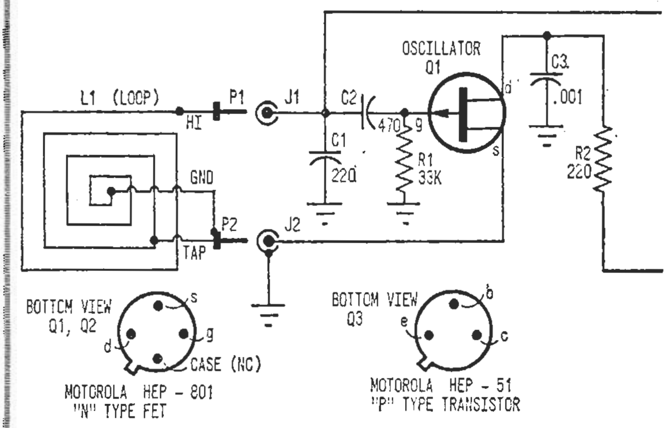
Most metal locators are complex to build, but Gold Grabber has a simplified design that makes for easy construction. The simplified circuit, of course, is not designed for great depth penetration in the earth. But metallic objects lying close to the surface should be no problem.

Two FETs (field-effect transistors) and a conventional transistor are used in an RF beat-frequency, metal-detector circuit which does not require any complex test equipment for initial adjustment.

The Circuit. Q1 (an n-type FET) is connected to L1 and C1 in a Hartley oscillator circuit operating at a frequency of approximately 500 kHz. The source electrode of Q1 is connected to a tap on L1 to obtain the RF feedback needed in this circuit. The C2/R1 combo form the gate-leak self-bias for Q1.

Layout shown below allows plenty of space for components. Check clearance of pot R6, and make sure that green index dot of L2 shows on top of coil. Parts must be anchored securely.





B1—8.4-V mercury battery (Mallory TR-286 or equiv.)
C1—220-pF mica capacitor
C2, C5, C7—470-pF, 50-V disc ceramic capacitor
C3—.001 uF, 50-V disc ceramic capacitor
C4—10-pF, 50-V tubular ceramic capacitor
C6—470-pF mica capacitor
C8, C10, C12—5-uF, 15-V electrolytic capacitor
C9, C11—.005-uF, 50-V disc ceramic capacitor
C13—10-uF, 15-V electrolytic capacitor
J1—phone pin jack

L1 is an external loop which radiates the oscillator RF energy. A small portion of this RF is coupled via C4 to the oscillating detector circuit of Q2. Note that Q2 is connected in a Hartley circuit similar to Q1, except that the gate leak is much larger, and the detected output is taken from the drain electrode.

Resonant circuit L2/C6 is tuned to a frequency very close to the operating frequency of the Q1 oscillator, thereby producing an audio beat-note signal from detector Q1. This audio signal is coupled through C8 and low-pass filter R5/C9 to volume control R6. The audio signal from R6 is amplified by the circuit of Q3 and direct-coupled to J3 and a pair of external 2000-ohm earphones.

When RF energy radiated from external loop L1 is absorbed by a nearby metallic conducting surface, the Q1 oscillator circuit changes its frequency. This change in frequency also changes the beat-note frequency of the Q2 detector circuit, thereby changing the frequency of the audio signal heard in the earphones.

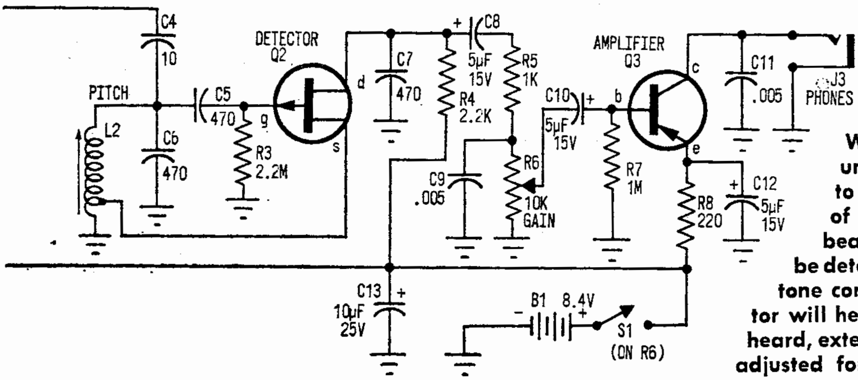
On Your Way. The Gold Grabber has two major assemblies: the external loop, and the oscillator/amplifier mounted in a 5¼x 3x2⅛-in. aluminum box. We'll start with the locator unit in the box.

Best way to begin construction is to install two 1¼-in. machine screws spaced two inches apart and centered on the long side of the box. The screws extend out from the bottom of the box and are used to mount the box to the loop assembly. Use serrated washers with the nuts to prevent any movement.

Cut a section of perforated wiring board to approximately 2⅝x4 in. and mount it as shown in the photo with machine screws and nuts. Position it ⅜ in. above the box bottom. Install two ground lugs as shown in the photo, and use serrated washers as required.

Mount the components on the sides of the box as shown, using washers to prevent movement. Position R6 to stay clear of the top cover and mounting screws. Battery B1 is fastened to the side of the box with a tape-covered aluminum strap. Position L2 so that its green index dot is on top of the coil.

Insert the push-in terminals, and mount the parts on the wiring board as shown in the photo. Make your connections with short, stiff leads to prevent movement. There



When working with units, it's important to adjust tuning slug of L2 so that change in beat-note frequency can be detected quickly. Audio tone comfortable for operator will help. If beat note isn't heard, external loop L1 must be adjusted for correct frequency.

PARTS LIST FOR GOLD GRABBER

J2—Phono jack
J3—phone jack
L1—Loop (see text)
L2—Tapped oscillator coil (Miller X-5496-C or equiv.)
P1—Phone tip plug
P2—Phono plug
Q1, Q2—HEP-801 FET (Motorola)
Q3—Pnp-HEP-51 pnp transistor (Motorola)
R1—33,000-ohm, ½-watt resistor
R2, R8—220-ohm, ½-watt resistor
R3—2,200,000-ohm, ½-watt resistor
R4—2200-ohm, ½-watt resistor
R5—1000-ohm, ½-watt resistor
R6—10,000-ohm, audio taper potentiometer (with S1)
R7—1,000,000-ohm, ½-watt resistor
S1—Spst switch (part of R6)
1—5¼x3x2⅛-in. aluminum box (LMB-780 or equiv.)
Misc.—⅛-in. masonite, ⅞-in. OD aluminum tubing, ¾-in. wooden dowel, #22 plastic-insulated hook-up wire, hardware, perf board and push-in terminals, knob to fit L2 tuning screw (optional) and knob for R6, 2000-ohm earphones, wire, solder, etc.

Gold Grabber

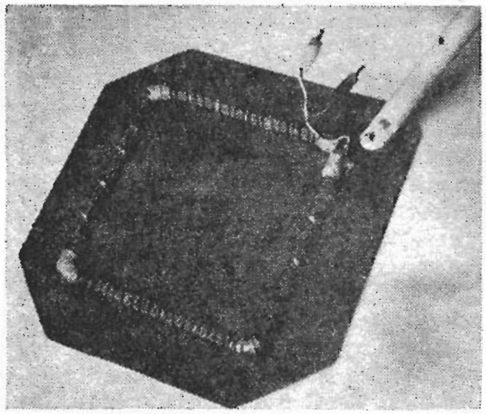
is no electrical connection to the case leads of Q1 or Q2, but the leads should be connected to push-in terminals to help support the FETs. Make sure that all parts and wiring are anchored down, or performance of the Gold Grabber will be affected. Use spaghetti over the leads of Q1, Q2, and Q3 to prevent shorts.

Looping The Loop. Fasten four nails in a 6-in. square of a piece of scrap wood. The nails should protrude approximately 1 in. Wind 10 turns of #22 plastic-covered wire (Belden 8530 or equiv.) around the square, and connect a length of wire at this point for the tap. Continue winding until there are 25 turns forming the square loop.

Carefully remove the nails and wire loop from the scrap, tape the corners of the loop with plastic tape, and connect a length of wire to the start of the loop (ground end). This done, wrap it tightly around one-half of the loop spaced approximately in ¼-in. turns. Tape the end to the loop. Then connect another length of wire to the ground end of the loop and wind it around the *remaining* side of the loop in the same way. Tape the end to the loop, making sure it does not short to the other length of wire.

Cut the three-loop leads to approximately 5 in. and connect them to P1 and P2 as shown in the schematic. Twist the leads of P2 together. Make sure the loop is firm, but use tape sparingly to hold it together.

Now cut a 10-in. square of tempered ⅛-in. hardboard and round the corners as shown in the photo. Center the loop on the board, and mark hole locations about an inch apart on both sides of the loop. Drill the holes and lace the loop onto the board with insulated tubing or fish line. Make sure the loop is tightly secured.



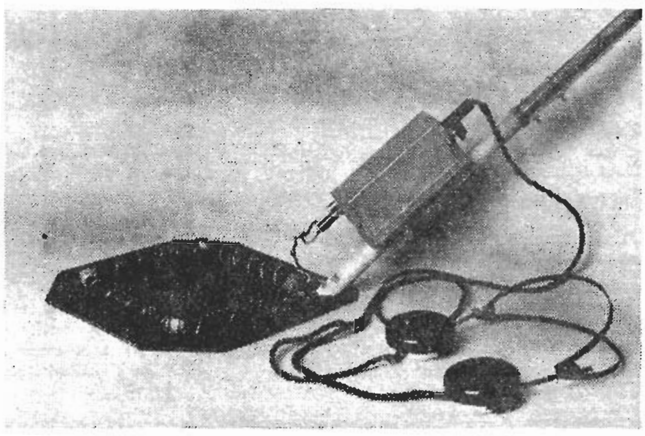
Loop should first be constructed on a piece of scrap wood, with three connections for Hi, Tap, and Gnd. Two wires from ground lead are wrapped around opposite sides of loop.

Hold On Tight. Cut one end of a 15-in. length of ¾-in. wood dowel at a 45-deg angle and fasten it to the end of the loop board with two machine screws and nuts (brass screws are a must).

Mount the aluminum box on the wood dowel approximately 3 in. up from the loop board. You can use a 44-in. length of ⅞-in. OD aluminum tubing for a handle, and fasten it to the dowel approximately 3 in. behind the box with two machine screws. (Since the tubing can be of any convenient length, you can make it as long as desired.)

Plug It In. To test the Gold Grabber, connect the loop to J1 and J2, plug a pair of 2000-ohm earphones into J3, and turn R6 full clockwise for maximum volume. Adjust

(Continued on page 109)



Photos of author's unit show slight variations from model on cover. Brass screws are a must, as use of any ferrous materials will affect metal locator's performance greatly.

Gold Grabber

Continued from page 36

the tuning screw of L2 until you hear a loud beat note. Further adjustment of L2 should cause the beat note to pass through the zero-beat point and back to an audio note again.

If a beat note cannot be heard with adjustment of L2, check the voltage on the gate leads of Q1 and Q2. The voltage should be measured with a VTVM. Our unit measured −3.5 V at the gate of Q1 (across R1) and −10 V at the gate of Q2 (across R3). The exact voltages are not critical, since they will vary with a particular FET.

If there's a negative voltage on the gates of Q1 and Q2, indicating that the circuits are oscillating, but a beat note is not heard, change the number of turns of L1 until the frequency of the Q1 oscillator circuit is close enough to the detector circuit of Q2 to zero beat.

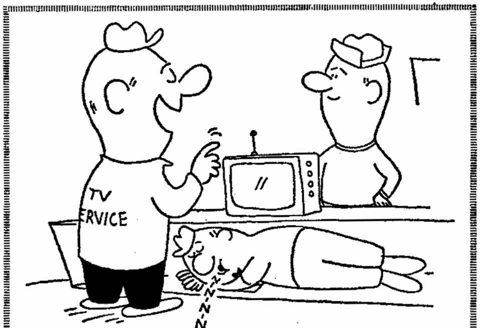
Finally, move a section of aluminum foil towards the loop. The beat note should change frequency and indicate the presence of metal.

Using It. Practice operating Gold Grabber by burying several sections of aluminum foil a few inches under the ground in locations with differing types of soil and gravel. Hold the metal locator close to the surface of the earth and adjust the tuning slug of L2 to a convenient audio pitch.

Pass the loop over the area until you hear a sudden change in the audio tone, then dig for the aluminum foil targets. Practice with different audio tones until your ear is accustomed to the change in audio pitch that denotes a metal object.

The sensitivity of Gold Grabber is dependent on the surface area of the metal, its depth below the surface, and the composition and moisture content of the earth.

The energy radiated by the loop will be absorbed by the earth in various degrees, depending on the mineral content, etc. The larger the surface of the metal and the closer it is to the surface of the earth, the easier it is to locate. Gold Grabber was able to find a 3x3-in. square of aluminum foil under several inches of gravel and earth. You can do better! Get out there and start grabbing. ■



"We'll go to work on it immediately. My 'ace' technician is within reach."

LOW-COST METAL LOCATOR

An easy-to-build locator that detects buried metal objects at depths of 6 inches

BY JOE A. ROLF

MOST inexpensive metal locators are "heterodyne" types where the output frequencies of a fixed and variable oscillator "beat." The fixed-frequency oscillator serves as a reference, while the other oscillator has a sensing loop that changes its frequency when brought near metal. The resulting heterodyne (difference frequency between the two oscillator signals) is amplified and fed to a speaker or meter.

The low-cost metal locator described here is a heterodyne unit. But it is less expensive and easier to build than most because it can be used with an ordinary portable AM broadcast-band receiver. The radio already contains everything but the sensing-oscillator circuit. The necessary oscillator and sensing loop are easily added.

How It Works. The schematic diagram for the sensing oscillator is shown in Fig. 1. Essentially, it is a tuned-gate, field-effect transistor (*Q1*) oscillator. Variable capacitor *C2* permits the circuit to be tuned across the middle frequencies of the AM band.

The sensing oscillator is first tuned exactly to a broadcast station (which must be done far away from any metal objects). Subsequently, any metal in the vicinity of the sensing loop (*L1*) will change the oscillator's frequency to produce a beat note at the receiver's speaker. Moving the loop away from the metal will cause the beat note to cease.

Construction. The oscillator circuit can be built into any 3¼-in. by 2⅛-in. by 1⅝-in. metal utility box. To simplify assembly, use a piece of perforated phenolic board and solder clips to mount the oscillator components as shown in Fig. 2. Referring to Fig. 3, machine the top half of the utility box and mount on it *B1* (in a battery holder), *C2*, *J1*, and *S1*. Then mount the board assembly with #6 machine hardware and ⅜-in. metal spacers. Refer back to Fig. 2 and interconnect the chassis-mounted and on-the-board components.

Drill two ⅛-in.-diameter holes and mount the bottom half of the utility box to the handle you plan to use for your metal locator. For the handle, you can use either ¾-in.-outer-diameter aluminum tubing or an old broom handle. Whichever you choose, cut it to a length of 36 in. and wrap the top with several layers of electrical tape

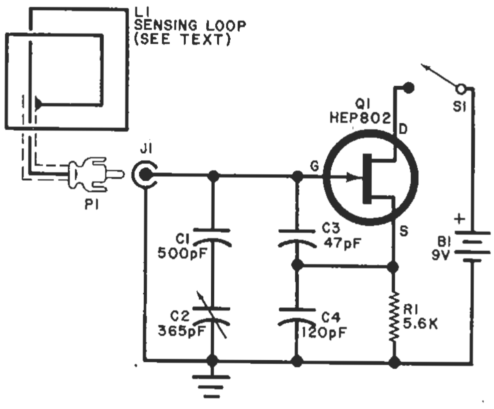


Fig. 1. Schematic of sensing oscillator that beats against any BCB receiver.

PARTS LIST

B1—9-volt transistor battery
C1—500-pF ceramic capacitor
C2—365-pF miniature variable capacitor
C3—47-pF ceramic capacitor
C4—120-pF ceramic capacitor
J1—Phono jack
L1—See text
P1—Phono plug
Q1—2N3819 or HEP-802 (Motorola) field-effect transistor
S1—Spst slide or toggle switch
Misc.—3¼" x 2⅛" x 1⅝" utility box; perforated phenolic board and solder clips; No. 32 enameled wire for L1; ¾" outer-diameter aluminum tubing or broom handle, cut to 36" length; coil form for L1 (see text); 36" Belden No. 8411 microphone cable; control knob; #6 machine hardware; spacers; battery holder; phono jack and plug for sensing coil cable (optional); solder; solder lug; etc.

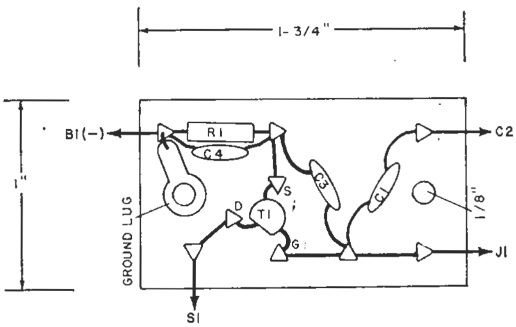


Fig. 2. Diagram shows how components are laid out on a perforated phenolic board.

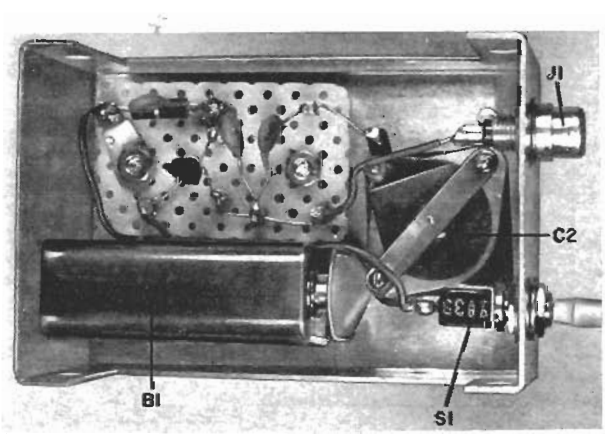


Fig. 3. Photo of prototype showing how the board and components go into chassis.

to provide a comfortable grip. Then mount the bottom half of the utility box to the aluminum tubing with sheet metal screws (wood screws if you are using a broom handle) as shown in Fig. 4.

An 8-in. by 6-in. lid for a plastic freezer container makes an ideal form for winding sensing coil *L1*. For durability, however, it should be made rigid by adding a 6-in. by 3-in. piece of ⅛-in. Bakelite or phenolic board as shown in Fig. 5. The board that adds rigidity can be fastened with three sets of #6 machine hardware, one set of which also anchors into place the U bracket required for fastening the sensing loop assembly to the handle of the metal locator.

Sensing loop *L1* consists of 20 tightly wrapped turns of No. 32 enameled wire around the rim of the freezer container lid. Secure the turns with coil dope and a turn or two of electrical tape. You can either bring the ends of *L1* out to a phono jack mounted on the freezer container lid, or solder the cable that interconnects loop and oscillator directly to the loop's leads. The connecting cable itself should not exceed 36 in. in length and should be a low-capacitance variety like the Belden No. 8411 used for lapel microphone cables.

In Use. To operate the metal locator, tune your transistor receiver to a strong station in the middle of the AM band and slowly tune *C2* back and forth. A beat note will be heard when you cross the station tuned on the receiver. Carefully adjust *C2*

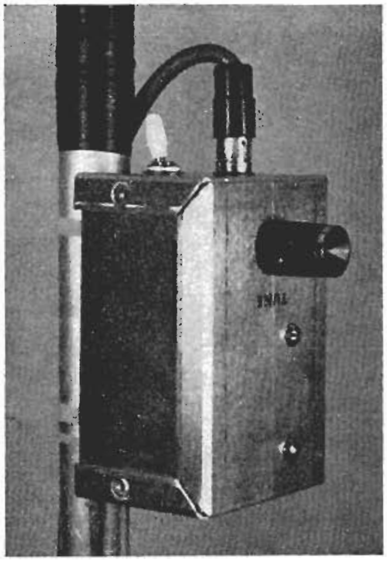


Fig. 4. Attach bottom half of box to handle and mount top half as shown.

until the beat note disappears, or is as low as possible. (Do not forget to do this with the sensing loop far away from any metal objects.) Now, sweep the sensing loop near to a metal object; the tone should re-occur.

The sensing loop described above is most useful for general-purpose work, but other sensing-coil configurations can be built for specific applications. A round (6-in.-diameter) plastic container lid with 25 turns of enameled wire can be used for exploring smaller areas, while a ferrite antenna coil (designed for use in transistor radios) inside a length of plastic tubing will provide a wand-type sensor that is useful for locating ducts, studs, and pipes in walls. Whichever sensor you plan to use, it is important that the cable between loop and utility box be less than 36 in. long.

While using the metal locator, you will discover that the audible indication you get is proportional to the size of the object being sensed, its depth below the surface of the soil, and soil condition. An object the size of a soup can at a depth of 6 in. is easily detected in dry soil, but at a lesser depth in wet soil. With practice, it is possible to determine the size and depth of an object—a good thing to know before you begin digging. ◈

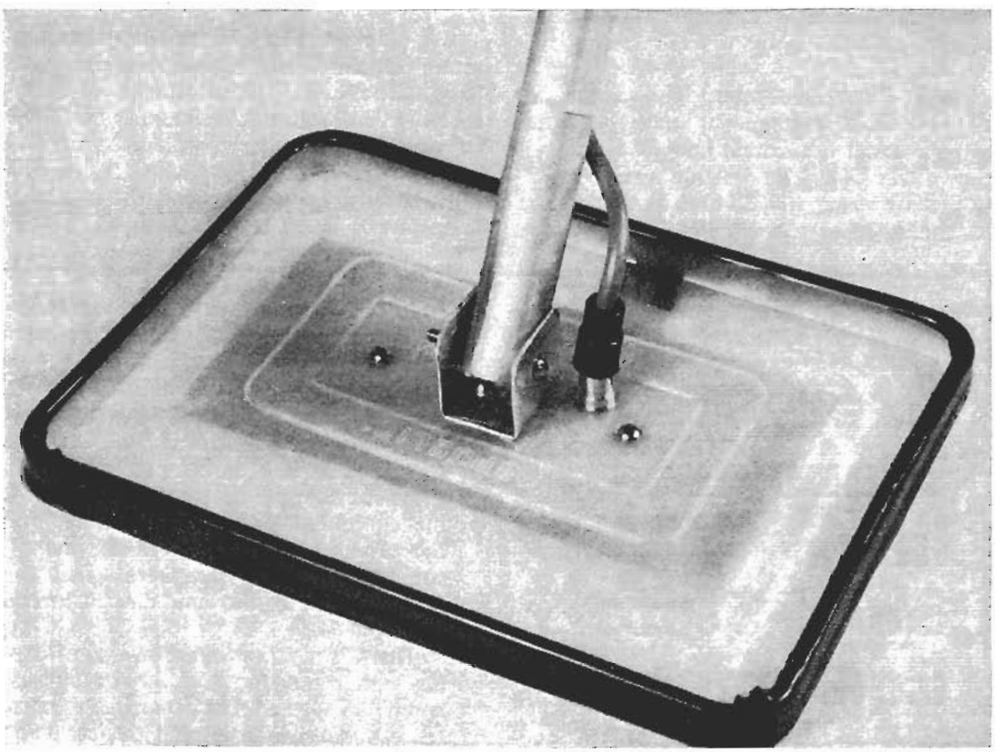


Fig. 5. The sensing coil is wound on a plastic freezer container lid that is stiffened with Bakelite or phenolic. A phono jack is used to connect loop to oscillator cable.

BUILD A "DIFFERENT" METAL LOCATOR

Use audio-frequency coupling for increased stability

BY LESLIE HUGGARD

TREASURE HUNTERS use all kinds of schemes and gimmicks in trying to find their fortune—divining rods, extra-sensory perception, ancient pirate maps, and so on. Experience has shown, however, that the most successful treasure hunters use some form of electronic metal finder.

The operation of most buried-metal locators is based on a type of heterodyning principle with the frequency of one of a pair of interacting oscillators being changed when foreign metal is near. One of the oscillators operates at a fixed frequency and the tuning coil of the other is usually a loop of wire at the end of a non-metallic carrying handle. When the loop is brought near metal, the oscillator frequency changes and an audio beat note is created between the two oscillators. This audio signal can be picked up on a speaker or headset. Metal detectors operating on this principle require semi-critical tuning of one of the oscillators for best results. Their operation can often be disturbed by nearby electrical noise sources or powerful radio stations in the vicinity.

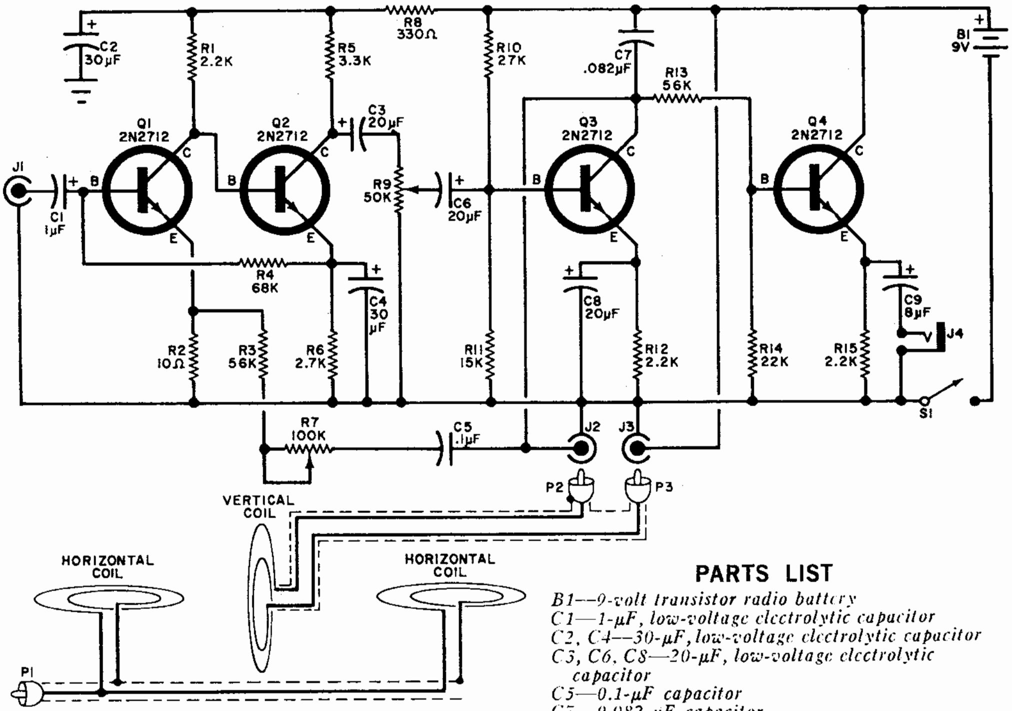


Fig. 1. Basically an unstable high-gain audio amplifier, the circuit breaks into oscillation when metal is detected between horizontal and vertical coils.

PARTS LIST

B1—9-volt transistor radio battery
C1—1-µF, low-voltage electrolytic capacitor
C2, C4—30-µF, low-voltage electrolytic capacitor
C3, C6, C8—20-µF, low-voltage electrolytic capacitor
C5—0.1-µF capacitor
C7—0.082-µF capacitor
C9—8-µF, low-voltage electrolytic capacitor
J1-J3—RCA phono jack
J4—Headphone jack
P1-P3—Phono plug
Q1-Q4—2N2712 or similar
R1, R12, R15—2200-ohm
R2—10-ohm
R3, R13—56,000-ohm
R4—68,000-ohm
R5—3300-ohm
R6—2700-ohm
R8—330-ohm
R10—27,000-ohm
R11—15,000-ohm
R14—22,000-ohm
(All resistors ½-watt)
R7—100,000-ohm potentiometer
R9—50,000-ohm potentiometer
S1—S.p.s.t. switch
Misc.—Headphones greater than 2000 ohms impedance, metal enclosure, perf board, spacers, battery connector, ½ lb #32 wire, wood for coil assembly and handle, six nylon screws, knobs, paint or varnish, plastic electrical tape, etc.

In spite of the considerable publicity that metal locators have received in the past few years, one type of locator has received very little attention because it has been used only in high-priced commercial equipment. The locator described here is of this type; it uses an "inductance bridge" method of detection. Audio-frequency coupling is used rather than r.f. The inductance bridge consists of two sets of coils, at right angles to each other, forming the input and output circuits for a high-gain audio amplifier. If the coils are constructed so that they are very close to being at right angles to each other, there is not enough inductive coupling between them to produce the feedback required to make the amplifier oscillate. However, if the coil set is brought near any metal, the metal forms a coupling between them, the amplifier oscillates, and an audio signal is produced.

Because the intensity of a magnetic field falls rapidly with distance and the influence on the magnetic field produced by a metallic conductor within it decreases rapidly as the conductor gets smaller, it is very difficult to make a device that will detect small objects at a distance. In the detector which uses a loop to locate the metal, varying the size of the loop can produce problems. For a given number of turns and a given amount of current in the loop, the field at a distance along the axis of the loop depends on the diameter of the loop. The greater the diameter, the farther the field extends. However, the greater the

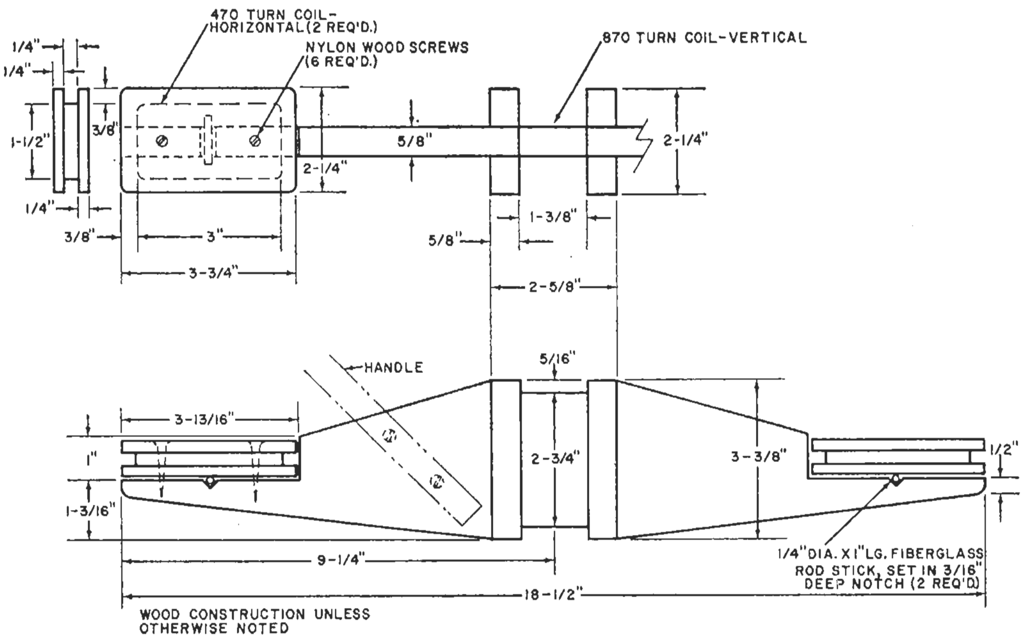
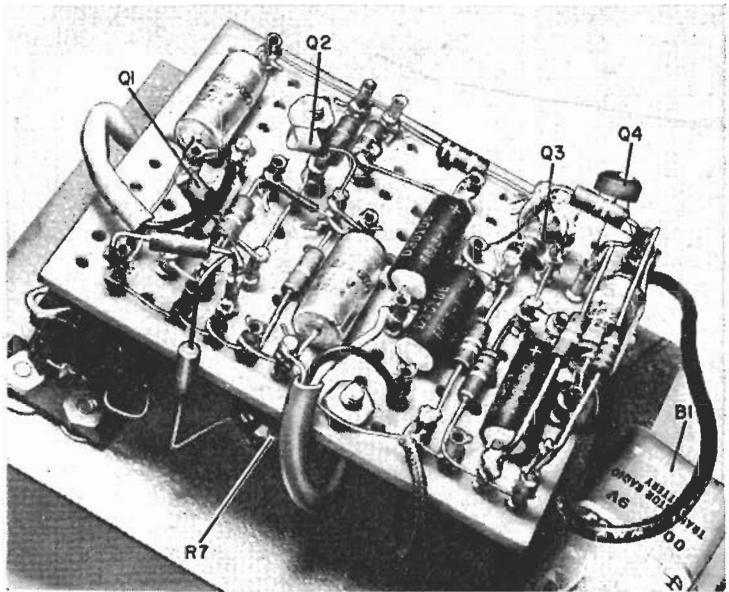


Fig. 2. Except for copper wire in the three coils, no metal is used in the search head construction. Nylon screws secure the two horizontal coils. Use a strong glue or cement for overall assembly.

loop diameter, the larger the metal object must be to have any effect on the field. Thus, in this type of locator, it is necessary to compromise between the size of the object to be located and the distance at which it can be located.

The locator described here will detect an aluminum bottle cap or a three-inch nail at a depth of 2 inches. Larger objects (such as a garbage-can lid) can be detected at a depth of 2½ feet. The locator is more sensitive to ferrous materials than others since iron-based metal has a greater effect on the magnetic field.



The electronics may be assembled on perf board. Any arrangement can be used as long as the input and output circuits are as far apart as possible to prevent unwanted coupling.

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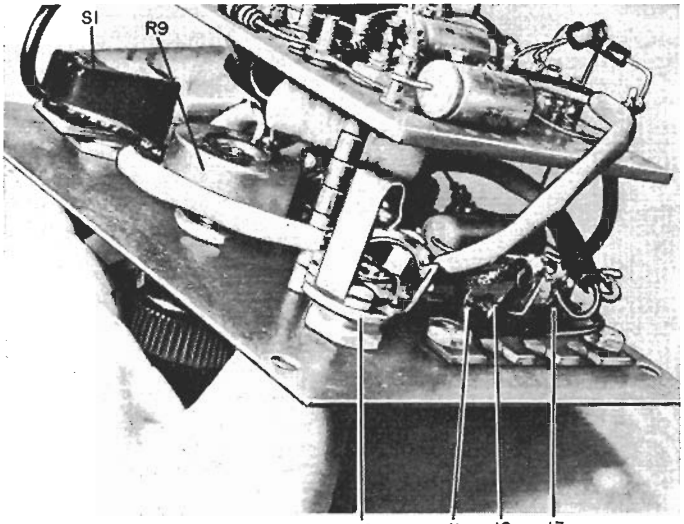
OUT OF TUNE

"Build a Different Metal Locator" (February 1969). The form for the vertical coil (as shown in Fig. 2, page 55) should be built up so that it is $1\frac{1}{2}'' \times 2\frac{3}{4}''$ instead of $\frac{5}{8}'' \times 2\frac{3}{4}''$.



The perf board is mounted on four long spacers to provide room for the front-panel components. The battery is secured in a clip affixed to the panel.

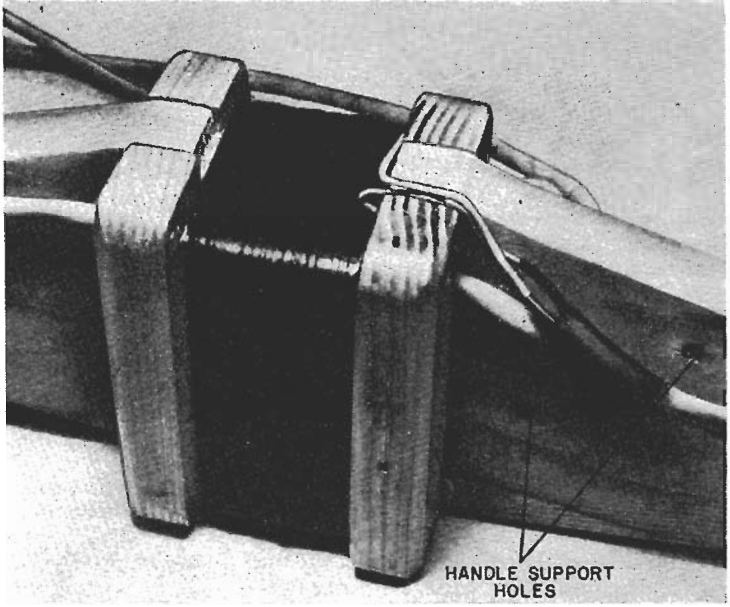
Construction. The locator consists of two principal parts: a search head which is a rigid assembly of three coils and a control box containing the electronic circuits which energize the coils and produce the audible output signal.

The electronic circuit, shown in Fig. 1, can be constructed on perf board. In laying out the components, be sure to keep the input components as far as possible from the output components to avoid unwanted feedback. The two potentiometers, *R7* and *R9*, switch *S1*, search-head jacks *J1*, *J2*, and *J3*, along with the headphone jack, *J4*, can be mounted on the front panel of a small metal box. The author used a 5″ × 4″ × 3″ aluminum enclosure. Once the front-panel controls are mounted, connect them to the perf board and mount the perf board on the front panel using insulating spacers. Use shielded leads between the three jacks and the two potentiometers. Ground the shields to the perf board common and make sure that the board common is well grounded to the metal enclosure. When wiring is complete, recheck the circuit for possible polarity errors in electrolytic capacitors and transistors and be sure that all resistor values are correct. Also check the solder connections for cold solder joints or accidental shorts.

In constructing the search head, there are three important points to remember: the assembly should be as rigid as possible, the two horizontal coils should be identical, and no metal other than the coil wire and leads should be used. This means *no* metal screws. All the parts making up the assembly are wood, and strong glue or wood cement should be used in fabrication.

Construct the wood head assembly as shown in Fig. 2. Note that nylon adjusting screws are used to tilt the horizontal coils slightly. This permits the setting of both horizontal coils exactly at right angles to the vertical coil. If you use care during the construction and make sure that the vertical and horizontal coils are as close to perpendicular as possible, the nylon screws will not have to be used. The horizontal coils should be made separately from the rest of the frame and not mounted until wound. All the wood parts should be given two coats of paint or varnish before winding the coils.

When starting to wind a coil, put a layer of plastic electrical tape around the core. Solder a length of fine multistrand plastic-covered wire to the end of the coil wire and insulate the joint carefully with plastic electrical tape. The piece of fine wire should be long enough to make one complete turn with enough left over to make a connection outside of the coil (two or three inches). Leaving this length of the fine wire hanging free (or anchored temporarily to some other object to keep it out of the way), wind the coil with the proper number of turns. Each horizontal coil requires 470 turns of #32 wire, while the single vertical coil takes 870 turns. Wind the coil wire as



Details of the vertical coil. After winding, wrap plastic electrical tape around the coil to prevent accidental damage and keep out any moisture.

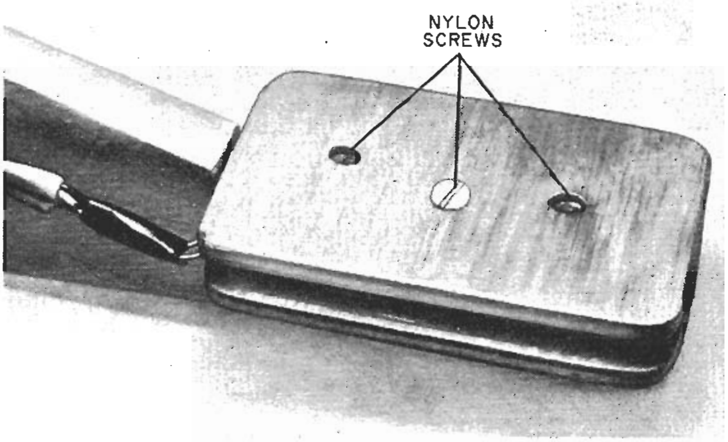
evenly and firmly as possible and avoid kinking the wire. When the winding is finished, protect it with a couple of layers of plastic electrical tape. Be sure that you can identify each end of the coil.

Winding the horizontal coil will be easier if you drill a hole in the center of the coil form and push a long machine screw through it. Anchor the screw at one end with a nut and clamp the screw in the chuck of a hand drill. Let an assistant operate the drill while you hold the wire and count the number of turns. In winding the vertical coil, drill a small hole at each end of the form and push a round nail (with the head removed) in each hole. Use one nail as a pivot and put the other in the hand drill. Be sure to remove the nails and bolts after winding the coils.

Once all three coils are wound, assemble them as shown in Fig. 2. The handle, fastened to the frame with nylon screws, can be any shape or length.

Use shielded twin-conductor cable about 6′ long to connect the coils to the appropriate jacks on the electronic package. Connect the vertical coil as shown in Fig. 1. For the horizontal coils, the two wires in the cable are connected together to form one lead with the shield used as the other lead. At this time, connect only one horizontal coil to the cable.

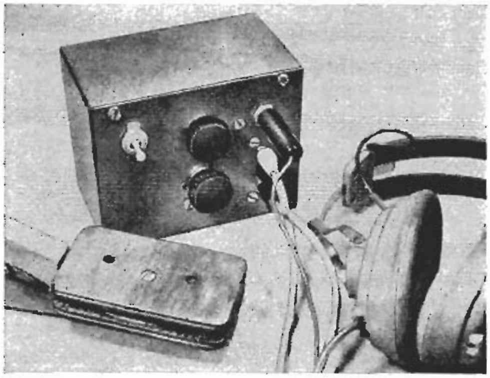
Testing. After the complete detector has been assembled, hang the search coil assembly so that it is well clear of any metal objects (about six feet). With the headphones plugged in and the power turned on (*S1*), turn up gain control *R9*.



Three nylon screws are shown here because the author trimmed the mounting for a true 90-degree fit. Normally, only the two outer screws are used and the coil form rotates about a thin plastic rod.

At some point, the circuit will oscillate and a tone of about 2000 Hz will be heard. Turn the gain down until the circuit just stops oscillating. At this point, turn up the feedback control (*R7*) until the oscillation is just audible. Bring a ferrous metal object (pliers, large screwdriver, etc.) near the coil assembly about midway between the vertical coil and the horizontal coil that is hooked up. At some short distance from the coil assembly, the circuit oscillation will increase rapidly, creating a loud tone in the phones. If it does not and the faint oscillation tone disappears instead, exchange the connections to the horizontal coil and repeat the test. Identify both leads of the horizontal coil, disconnect it, and repeat the procedure with the other horizontal coil connected. Identify these leads also and then connect both coils to the cable. After soldering the coil leads to the cable, insulate the connections with plastic tape. Then retest the entire locator head by bringing a metal object midway between the vertical coil and either of the horizontal coils. You can now experiment with various metal objects of various sizes to get the "feel" of the detector's operation.

To test for a true right angle between the vertical and horizontal coils, an external audio generator capable of delivering 2 kHz is required. Unplug both vertical coil connectors and insert a 2200-ohm, ½-watt resistor between *J2* and *J3*.



The complete assembly consists of the search coil, a pair of headphones and the electronics package.

Connect the audio oscillator, set at 2 kHz, to the vertical coil connectors, *P2* and *P3*. Rotate the feedback control, *R7*, fully counterclockwise (maximum resistance) and set the gain control, *R9*, at about its midpoint. Adjust the output of the audio generator until a tone is heard in the headphones. Very carefully tip one horizontal coil about the horizontal until the tone is minimized. Fix the coil in this position using the nylon screws. Repeat the procedure with the other horizontal coil. When the tone is at a minimum, the coils are at right angles and should be fixed that way. When this test is complete, attach the wooden handle with the two remaining nylon screws.

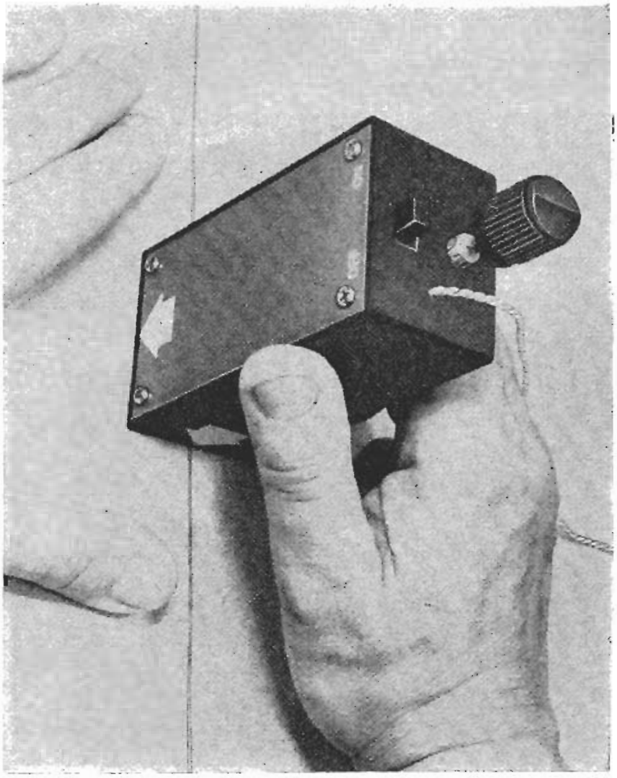
Operation. With the detector assembled, earphones plugged in and on the head, turn on the power. Hold the coil assembly up in the air so that it is well clear of the ground and any metal. Rotate the feedback control to full counterclockwise and turn up the gain control until oscillation is just heard. Then back it off slightly until the oscillation just stops. Adjust the feedback control until the circuit just trembles on the edge of oscillation. Now proceed with a search pattern, bringing the coil assembly down to ground level and making wide sweeping motions in arcs over the top of the ground. When a metal object is detected, the barely audible tone will suddenly increase in volume as the hidden metal reaches an area just midway between either horizontal coil and the vertical coil. —30—

HOW IT WORKS

The electronic circuit is basically a high-gain audio amplifier whose gain is controlled by *R9*. Positive feedback is provided through *R7* and *C5*. A tuned circuit consisting of the vertical coil and *C7* is connected to the collector of *Q3*.

The two horizontal coils are connected to the amplifier input. Because the coil sets are at right angles to each other, coupling and feedback are at a minimum. However, there is always some slight electrical noise in an amplifier, and this is sufficient to set up a weak magnetic field around the vertical coil.

The lines of flux along the axis of the vertical coil are parallel with the planes of the horizontal coil. If a metal object comes within this field, the lines of flux are distorted so that some of them link with a horizontal coil. The coils are connected so that the signal input to the amplifier is in phase with the output of the amplifier when there is a disturbance in the magnetic flux. When this happens, the circuit breaks down with positive feedback and the output is similar to the feedback obtained between an audio amplifier speaker and a microphone. The oscillation has a frequency of about 2 kHz. Unlike most r.f. beating systems used in metal locators, this circuit requires no tuning.



Carpenter's Mate

TINY METAL LOCATOR FOR TINY METAL

BY JOHN S. SIMONTON, JR.

THOSE LITTLE magnetic gadgets that carpenters use to locate studs work fine if you're looking for ferrous nails. They won't do the job, though, for a boat owner trying to avoid sanding and sawing the brass hardware used on his craft.

If you have this problem, you can save some of the time you're spending developing a sailor's vocabulary and some of the money you use replacing chewed up saw blades by building the "Carpenter's Mate." It locates ferrous or non-ferrous metals quickly and easily.

The Carpenter's Mate, not much bigger than a pack of cigarettes, works just the same as larger types of metal locators except that it has a very restricted range and better resolution (pin-point accuracy). By using a small search coil (mounted inside the plastic case) maximum range has been reduced to about 2 inches while resolution is increased so that even a small wire brad—detected head on—can be spotted. The Carpenter's Mate slips easily into your shirt pocket and can be put into operation as fast as you can turn it on.

Construction. The circuit of the Carpenter's Mate is shown in Fig. 1. Layout is critical and since radio frequencies are involved, good wiring practice should be followed and all leads should be as short as possible. A circuit board simplifies the construction. You can make your own using Fig. 2 as a guide or you can buy one.

Parts placement on the board is shown in Fig. 3. The leads of *Q1* and *Q2* are bent so that the flat sides of their bodies can be placed adjacent to one another and glued together. This helps to maintain the two transistors at the same temperature to stabilize the relative frequencies of the two oscillators.

The sensing coil, *L1*, is made by modifying a standard J.W. Miller #6300 or equivalent High-Q variable inductor. Make the modification by removing the tuning slug and carefully cutting the threaded brass tuning screw off flush with the ferrite core material. Then carefully unsolder the lead wires from the terminals on the side of the coil and use a sharp knife to cut the form so that the coil winding is centered between the ends

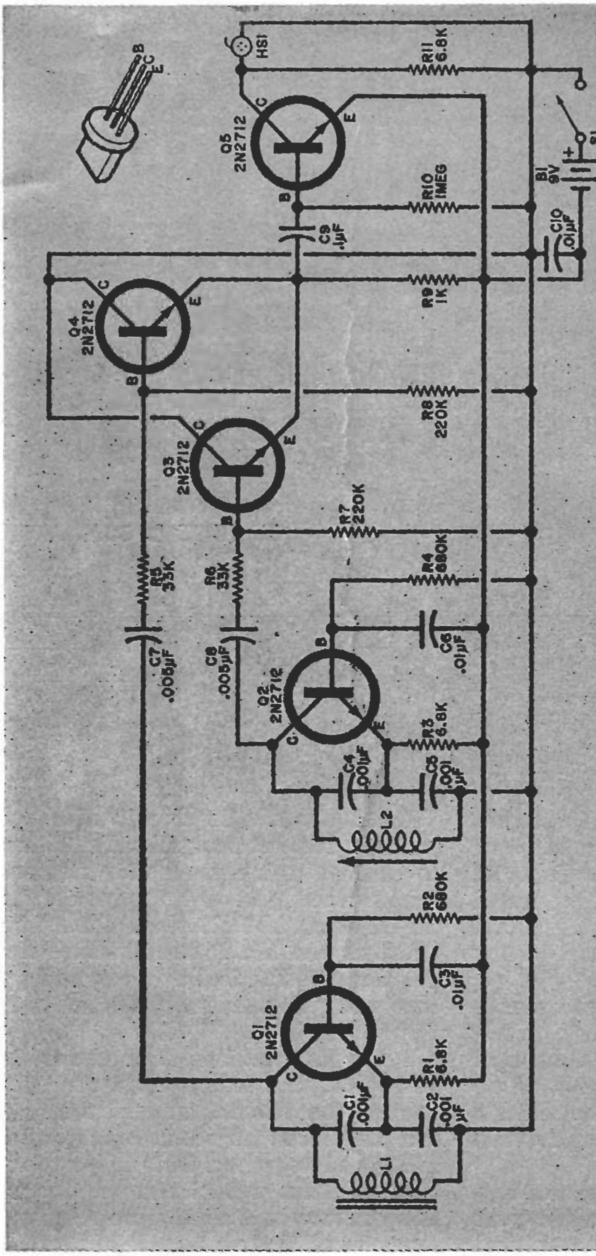


Fig. 1. The two r.f. oscillators (Q1 and Q2) mix in the two emitter followers (Q3 and Q4) and produce an audible sound that is a function of their frequency difference. This difference occurs when L1 is brought close to a piece of metal.

PARTS LIST

B1—9-volt transistor battery
C1,C2,C4,C5—0.001-µF ceramic disc capacitor
C3,C6,C10—0.01-µF capacitor
C7,C8—0.005-µF capacitor
C9—0.1-µF capacitor
HS1—High-impedance earphone
L1, L2—High-Q Ferrite Antenna Coil (J.W. Miller #6300 or similar)
Q1-Q5—2N2712 transistor
R1,R3,R11—6800-ohm
R2,R4—680,000-ohm
R5,R6—33,000-ohm
R7,R8—220,000-ohm
R9—1000-ohm
R10—1-megohm
(All resistors ½-watt)
Misc.—Plastic case 1⅝" x 4" x 2⅛" with metal cover, battery connector, battery clip, wire, solder, epoxy cement.
Note—The following are available from PAIA Electronics, P.O. Box 14359, Oklahoma City, Okla. 73114: etched and drilled PC board, $2.00; complete kit of parts including cement, $9.95; postpaid in continental U.S.A. Okla. residents, add 3% sales tax.

of the form. Slide the ferrite slug back into the coil and center it before securing it in place with a dab of cement.

The completed unit is housed in a 1⅝" × 4" × 2⅛" plastic utility box (see Fig. 4). To prevent tone changes associated with touching exposed metal hardware, all internal components, including *L1, S1,* and the PC board are glued in place with epoxy cement. Clean all mating surfaces thoroughly with steel wool before gluing. Blow away all steel-wool debris to avoid shorts. Drill a hole for *S1* at one end of the box and glue it in place. Then drill a hole on the same end for the mounting clip of *L2* and snap it into place. Drill a small hole near these two to pass the earphone cord. Make a knot at the inside end of the cord to prevent it from being pulled through.

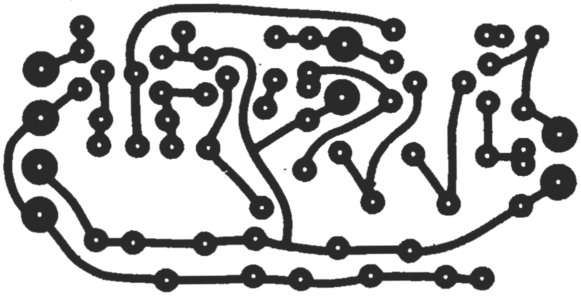


Fig. 2. Actual-size foil pattern to be used in making the PC board.

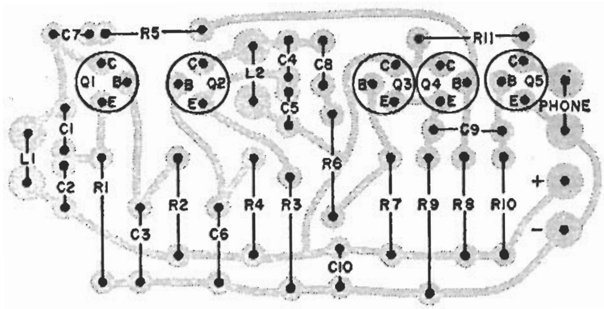
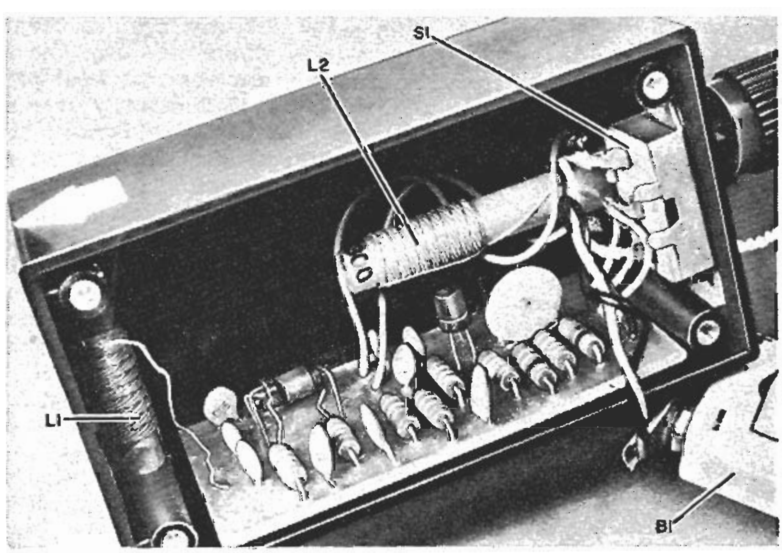


Fig. 3. Other than transistors, component polarities are not critical.

Mount *L1* at the center of the undrilled end of the box, using epoxy cement. Before mounting, make sure that the leads are long enough to reach the terminals on the PC board. If they are not, either unwind a little wire from the coil or solder on short extensions. Before mounting the PC board, connect up the circuit and put a small knob on the protruding shaft of *L2*. Turn on the power and adjust *L2* until a whistle is heard in the earphone. Once you hear this whistle,

Fig. 4. The entire instrument is easily mounted in a small plastic box. Place arrowheads to indicate the center of the search coil. All parts mount with epoxy.



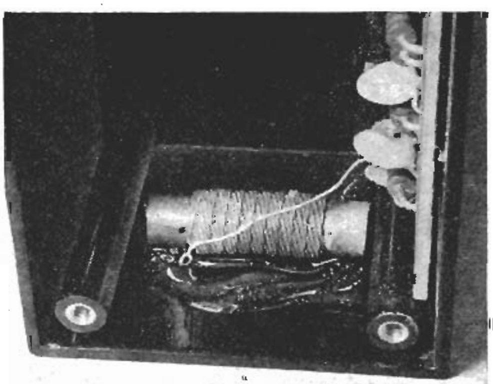
you know that the circuit is operating. Turn off the power and cement the board in place using a drop of cement at each corner.

When attaching the battery clip to the cover, place it slightly off center to keep it from interfering with the circuit board components when the cover is in place.

Operation. Hold the unit clear of any metal, turn it on, and insert the earphone in your ear. Withdraw the core from *L2* by turning its adjusting screw knob counterclockwise. As the slug passes through the coil, you will hear a rising and falling tone. While any position of the slug which produces a tone may be used as an operating point, the most desirable setting can be found in the following manner. Start with the slug screwed out about an inch. At approximately this point, a tone considerably louder than the others will be heard. Continue to withdraw the core until a null is reached. Slightly before this null point is the best position for locating non-ferrous metals. In this case, the presence of a non-ferrous metal causes a slight increase in the oscillator frequency, causing the signal to go toward the null point. For detection of ferrous materials, withdraw the slug so that the tone is slightly beyond the null point. The presence of a ferrous object then decreases the oscillator frequency, again bringing the tone down to the null. By positioning the slug on either side of the null, it is possible to identify either ferrous or non-ferrous materials. If you leave the slug so that a relatively low audio frequency is head, the frequency will go up or down depending on the metal detected.

To get some practice using the Carpenter's Mate, use a test surface which you know contains a piece of brass hardware. With the case held so that the side adjacent to the sensing coil is pressed lightly against the test surface, move the device over the area. The tone will decrease noticeably when the sensing coil is directly over the brass. With the proper adjustment of *L2*, the null point will be reached when the metal is detected.

Four clearly visible arrows can be drawn or pasted on the sides of the box at the *L1* end so that scribe marks can be made on the test surface to locate the detected metal under the center of the coil. If the coil is exactly centered in the end of the box, the arrows should be centered on the sides. It is possible to orient *L1* so that it butts against the end of the box. In this case, the sensitive area is greatly reduced permitting more accuracy in location. However, with this arrangement there is always the chance that the coil will be dislodged when the instrument is moved about. -30-



Coil L1 should be mounted with epoxy cement on the blank end of the box in exact orientation shown.

HOW IT WORKS

Transistors *Q1* and *Q2* and their associated components form two independent Colpitts oscillators. The outputs of these oscillators are combined in the mixer composed of *Q3* and *Q4* and the resulting signal appears across the common load resistor *R9*. Since the mixer is nonlinear, the output signal contains the two original frequencies and also the sum and difference of the two. However, only the difference signal is within the range of human hearing. This signal is amplified by *Q5* and used to drive the high-impedance crystal earphone.

When a metallic object (either ferrous or non-ferrous) comes close enough to *L1* to intercept and distort the magnetic field surrounding the coil, there is a change in the effective inductance of the coil. This causes a change in the frequency of the "sense" oscillator *(Q1)*. This relatively small change in the frequency of the oscillator can be heard as a significant change in the tone in the earphone.

To minimize "pulling" of the oscillators and the tendency of the two to lock on to the same frequency, the "local" oscillator *(Q2)* is adjusted to run at about twice the frequency of the "sense" oscillator.

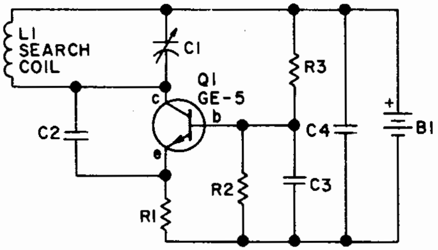
82 Lo-Parts Treasure Locator

UPDATED

☐ You won't find Long John Silver's buried treasure but you will have lots of fun finding bottle caps and uneaten sandwiches at the beach; maybe even some quarters and dimes.

This treasure locator keeps costs down by using a transistor radio as the detector. The unit is assembled on a perf-board, with rigid component mounting a must. It is strapped to a broom handle close to the bottom where the search head is mounted. A transistor radio is mounted near the top of the handle.

With the radio tuned to a "weak station," Capacitor C1 is adjusted so the locator oscillator "beats" against



PARTS LIST FOR
LO-PARTS TREASURE LOCATOR

B1—9-VDC transistor battery
C1—365-pF trimmer or variable capacitor
C2—100-pF, 100-V silver mica capacitor (Allied Electronics 782R0818)
C3—0.05-uF, disc capacitor
C4—4.7- or 5-uF, 12-V electrolytic capacitor
L1—Search coil consisting of 18 turns of #22 enamel wire scramble wound on 4-in. diameter form
Q1—RCA SK3011 npn transistor or equiv.
R1—680-ohm, ½-watt resistor
R2—10,000-ohm, ½-watt resistor
R3—47,000-ohm, ½-watt resistor

the received signal, producing a whistle in the receiver. When the search head passes over buried metal, the metal changes the inductance of L1, thereby changing the locator oscillator's frequency and changing the "beat tone" in the radio.

The search coil consists of 18 turns of #22 enameled wire *scramble wound* (which means don't be neat) on a 4-in. diameter form, which can be a cardboard tube or a wood puck or even plastic—anything but metal. After the coil is wound and checked for proper operation, saturate the coil with *coil dope* or G.E.'s *RTV* adhesive. If a single loop of the coil is not firmly cemented the unit will be unstable.

BY CARL KOHLER

LIVE WIRE WITH A LOOT LOCATOR

Return of the Irrepressible Experimenter

BEYOND an open window of the new workshack, the Gulf of Mexico murmured frothily upon a promising beach. Intently completing the electronic project at hand, I didn't hear Friend Wife approaching until she was already past the door I had unwittingly left unlocked and ajar.

Normally I might've fended her off with evasive tact or sickening diplomacy. Failing that, I have a grouch act calculated to strike terror in the heart of man or beast, child or distant relative. It works keen on the lady, too.

But she was shrewd enough to have brought with her the price of admission to my intellectual's sanctuary: the steaming pot of fresh coffee smelled wonderful and my defenses suddenly suffered undeniable voltage droop. Here, then, was my lovely, illogical bride—the lady who only last year saw fit to have my 3-element beam strung with Christmas lights, and then had the gall to feign hurt dismay at my resultant rage. Oh, I've been

". . . the lady of the house is a militant homemaker whose dwelling sparkles . . ."

on to her for years. It's staying ahead of her that keeps me sleepless and tossing fretfully some nights. The communications gap in the same generation is called Marriage.

"What'cha building *this* time that ain't gonna work?" she demanded, her eyes boldly narrowing at the sight of the excitingly designed, home-crafted instrument before me. "Hey, that gismo looks awful *familiar*, Buster!"

Smoothly sipping the delicious brew, I shifted position casually in a sly effort to block her view of the nearly finished electronic metal detector. "Don't let me keep you," I hinted delicately. "I know you must have many little tasks awaiting your skill and diligence, dear."

"*What* tasks?"

"Surely you want the neighbors, here, to know that the lady of the house is a militant homemaker whose dwelling sparkles with——"

She stepped forward, peering harshly over me at the detector. "I *loathe* housework and I don't care who knows it! Hey, I remember that screwy thing! It was supposed to find gold or uranium—or something! And all it ever found was a buncha lousy bones!" She chuckled meanly, grinning down at me with the expression of a woman who has just found an open wound to salt. "Yeah, that was really the craziest flop you ever butchered the budget to put together! *Remember*?"

I stared into the distance with dignity. She had me. It was true. I *had* built a rare earth detector. The same one, in fact, that now lay—considerably modified and improved—before her jeering eyes. Due to a cruel quirk of a heartless fate, I'd made a small miscalculation—substituting animal horn for bakelite in the search coil—which had caused the detector to respond only to bone, improbable as it still seemed these many years later.

"You have a fantastic memory," I said coldly.

"Sure have!" She sounded proud.

"Then, surely you must recall that memorable day when you brightly informed me that it took *two* coats of paint to cover all my QSL Cards." I smiled thinly up at her. "If we're going to relive old errors, let's be *impartial*, eh?"

"You had to *mention* it, didn't you?"

I shrugged. "No, I didn't have to. I could just as easily have recalled the time I caught you using my stock of expensive tantalum capacitors for hair-rollers or that shattering instance when you——"

"Never mind all *that*," she chattered hastily, pointing to the instrument atop the workbench. "What I wanna hear is what *this* piece of fancy junk is supposed to *be*, anyway."

Standing tall, I drew myself to my full height, assuming the patient mien of a man—a superbly gifted, saintly modest, highly intelligent and utterly articulate man—who is about to attempt the heartbreaking chore of explaining quantum theory to an aborigine in small, easily understood words (if not a language so explicit that it teeters on the borderline of basic babytalk). She stiffened just as she always does when she senses I'm going to talk down to her.

"This ultra-sensitive and rather sophisticated instrument is the *Kohler Loot Locator*," I informed her with a kindly smile. "It's modified and brought sternly up-to-date. Comprised of all manner of truly efficient components, including silicon transistors, a 9-volt alkaline battery, a varactor tuning-control, a Faraday shielded search coil, a Sonalert and a——"

"What's it *do*?" she whined impatiently.

"—very stable circuit of original design that is charmingly representative of every advance made in the art and science of solid-state technology, this stunningly effective prototype will operate most beneficently in our behalf."

"Doing *what*?" The doll was maddeningly single-minded. "What's it gonna *accomplish,* big shot?"

"In two words: locate loot."

"Locate *whaat*?" She wore a bewildered expression.

"Loot . . . swag . . . booty . . . treasure," I chanted, knowing a dreamy film of greed was glazing my eyes. "That beach out there is jam-packed with ancient pirate treasure—and the *Kohler Loot Locator* is going to find it!"

She hooted raucously, like a banshee trying to win a hollering contest. I've heard that damning laughter many times before during the years of our relationship. It generally indicates that she is of the opinion that I've lost my mind. I suffered the derisive snorting with a face carved from the granite of total resistance to ridicule.

"*Pirate treasure*! Oh, *wow*!" She wiped tears of merriment from her eyes with the back of her hand. Very ladylike, very graceful. "Man, you're too much! *Swag*! *Beautiful*!" She dissolved into another spasm of mirth, shrilling hysterically.

Restraint cracked. I spat cold coffee back into the cup, gesturing abruptly toward the door. "All right, laughing-girl, now you know what I'm preparing to do. Your morbid, unsympathetic curiosity has been satisfied. Kindly trudge back to your house and break a few dishes or burn some food."

A hand gently touched my arm.

"Aw, I didn't mean to hurt your feelings! Honest. I just lost my head when you were putting me on about looking for *loot* with—her mouth quivered with more laughter but she fought it back—that thing!"

"So who's putting you on?" I arched an eyebrow at her, questioningly. "I'm perfectly serious."

"You're perfectly nuts," she declared, all sham humility vanishing, "if you actually think you're going to find any—any swag or treasure with that bone-picking thingamajig!"

"It's been modified. And I have complete assurance from the oldest, most trustworthy residents of this area that there is indeed bona fide pirate loot stashed in those bleached sands." I clutched the light, mobile Locator protectively to my chest. "You'll change your tune when I prove there *were* pirates here!"

"Oh, I know there were pirates here. In fact, there still are!"

"I beg your pardon?"

"One of them sold me some bait, yesterday, when I went fishing!"

I glared at her in silence.

"Tell me," she said, softening her expression and voice. "Why didn't you try to find pirate treasure with this whatchamacallit when we were living on the California coast?"

"Simple. There never *has* been any pirate loot buried out there, no matter *what* the Los Angeles Chamber of Commerce may insist to the contrary."

"How do you know?"

I bent a pitying smirk of undisguised superiority upon her. "Sheer logic and a rudimentary understanding of human psychology would help you to recognize instantly the validity of my theory. Too bad, being female, you're naturally exempt from these necessary mental qualities, sister!"

"So?"

"So what self-determined pirate was likely to step ashore—much less be there long enough to bury his treasure—with all those *missions* along the coast. Why, there were probably even *more* of them during the pirating days."

"What's *that* got to do with it?"

"Just the risk of being apprehended and sent to church against their will, that's all." I grinned triumphantly. "Elementary logic. I can well imagine how your alleged mind balks at it."

"It doesn't even figure."

"It doesn't, eh?"

"Heck, no!"

I handed her the cup of cold coffee. "When was the last time you ever heard of a bunch of bank bandits burying *their* loot in a churchyard?"

She marched off to the house without another word of comment or argument. I sighed, returning to my work on the Loot Locator. She always loses. What stings, is, she refuses to *realize* it.

A week later I stopped walking along the pale sand to rest, momentarily letting the Locator lay at my feet. Mopping my sweating brow, I gave some dismally realistic thought to what the Locator had located in the past two days. Exactly 176 soda pop cans, 816 beer cans, 11 car bodies, 26 stoves and a couple of refrigerators—all of them in advanced stages of rusty disintegration. Regarding the compact trench-spade with distaste, I glanced at the beachcombing couple nearby, diligently peering at the sand as they strolled along the water's edge.

The sound of a car behind me diverted my attention. It was Friend Wife. Bringing me coffee and cruel amusement as usual. Having trailed me into this folly, she wasn't about to keep her distance and allow me to fail graciously. No, she wanted to be there for the kill—that moment of truth when I admitted I was finding nothing resembling pirate loot, and possibly even confessing that my Locator was a proven flop. I suspected she would settle for nothing less than the joy of hearing me voice my laboriously developed suspicions that no freebooters had ever stepped ashore here, either.

"How's it going, treasure hunter?" she jeered, handing hot coffee to me. "Need any help getting the troves of swag back to the house?"

"Uh . . . well, I'm working my way through quite a bit of trash that must be gotten past in order to reach the lower levels of deposit where anciently placed items—such as doubloons, pieces of eight and chests brimming with loot—were originally buried," I stalled lamely, trying for a nicely detached expression. "I expect to stumble upon a treasure cache anytime now."

"*Hogwash!*"

"How can you say that?"

"It's easy. *Hogwash!*"

Suddenly, in staring mutely at my feet, my eyes swept past the Locator, tilted so the search plate was partially exposed —and I saw a large, gleaming ring clinging to the magnetic plate. Swiftly I bent and picked it up, holding it before her face.

"Wh-What's that?" she stammered.

"Just a little piece of *hogwash,* dear! Just a small sample of what the magnificent Kohler Loot Locator is *doing* while the world snickers and smirks." I polished the ring on my damp shirt. Made of thick gold, it was studded with diamonds glittering in the sunlight. Visions of wealth beyond mine or the IRS's wildest dreams romped briefly through my head. I trembled with excitement, spilling hot coffee all over myself. "*Now* are you convinced that—"

"Podden me, buddy," said a booming voice just behind my right shoulder, "but that's my wife's ring you got there?"

I turned. He was King Kong in bermuda shorts and a gaudy shirt splashed with tropical fish on a background of garish crimson. The same guy I'd seen studying the water's edge a few moments earlier. He also looked tough enough to chew nails without his store-teeth and spit out their heads without bruising his gums. I smiled *intensely* up at him.

"Y-Your *wife's* r-ring, sir?" I chirped.

"Yeah, dat's right! She losted it out here a coupla days ago. We been looking fer it ever since, see?" He plucked the gem-encrusted ring from my fingers just as deftly as I could have taken candy from a baby. Now I knew how babies feel when somebody puts the snatch on their goodies. "Sure was nice of you to find it for us!"

"M-My pleasure," I lied manfully.

"Don't suppose you'd take a modest reward for finding a ring that means quite a bunch to my little woman, would'ja, buddy?"

"*Of course not!*" Mouthy chimed nobly from the car. "My husband wouldn't *dream* of accepting money for having accidentally found your wife's lovely piece of jewelry!"

For a tenth of a second I think I understood why some husbands are entirely capable of sending their wives to a better world slightly ahead of divine schedule. I nodded, my face probably a mixture of emotions—greed—disappointment—false cheer—anguish. The works, simultaneously.

"N-No reward, th-thanks," I croaked.

"Hey, that's a purty tricky little chunka stuff you got there!" King Kong squatted, running a hairy hand admiringly over the Locator. "Does it *work?*"

"Does a chicken have lips?" I said bitterly.

"Huh?"

"It found your wife's ring, didn't it?"

"Hey, *yeah!* Dat's right, it *did!*" He pondered the truth of this fact for a few seconds. Then, rising to his full eight feet of towering flab once more, he jerked a beefy thumb at the Locator. "I wanny *buy* it, buddy. How much ya want fer it?"

I hesitated, waiting for Mouthy to assure this character that I was also morally above business transactions but she remained silent. He misinterpreted by pause.

"Bet ya made the thingie yourself, huh?"

"Right!" I bit the word out, holding my chin high.

He named a sum that would comfortably purchase a *Heathkit* Color TV, a middling heap of Hewlett-Packard test equipment and still leave enough to take a mouthy wife to dinner at the best restaurant. Furthermore, he reeled it over in cash and I took it like a man getting rich in a dream.

"You sure this thingie works good?" he asked, turning to leave."We lose a lotta stuff in the sand, going around the world and seeing all them beaches, ya know!"

My fist tightened about the sheaf of bills it held. There're only two things I love better than electronics. One of them was keeping her yap shut. I was holding the other.

"That precision handcrafted instru-you just bought, sir," I assured him in a confident tone common to solvent men, "is so sensitive that it'll detect a germ with iron-rich blood!"

He departed, happy.

I got into the car, counting the bills with a reverence bordering on an ill-concealed mania. "Did that little old Locator ever find the loot or did it ever find the loot?" I babbled. "I no longer hear you chuckling with glee, kid."

"Y-you *pirate*!" she accused.

"The gentleman set the price."

"Talk about *piracy*!"

"Listen, sister," I said tartly. "Have you ever heard of pioneering?"

"Sure I have. Why?"

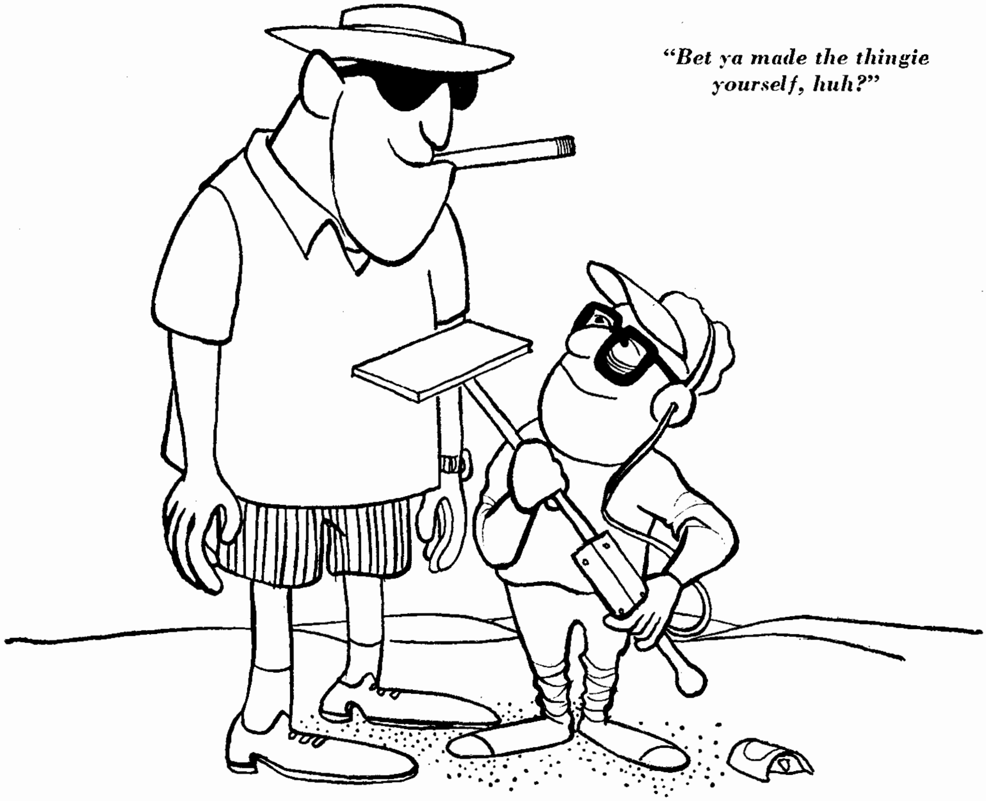
"Well, what you've just witnessed was a tidy example of another somewhat romantic endeavor along the same line as pioneering."

"What's that?"

"*Buck*-aneering, baby!"

And this time *I* dissolved into merry laughter. -30-

"Bet ya made the thingie yourself, huh?"



INDUCTION BALANCE METAL DETECTOR

A really sensistive design operating on a different principle from that of other published circuits. This Induction Balance circuit will really sniff out those buried coins and other items of interest at great depths depending on the size of the object.

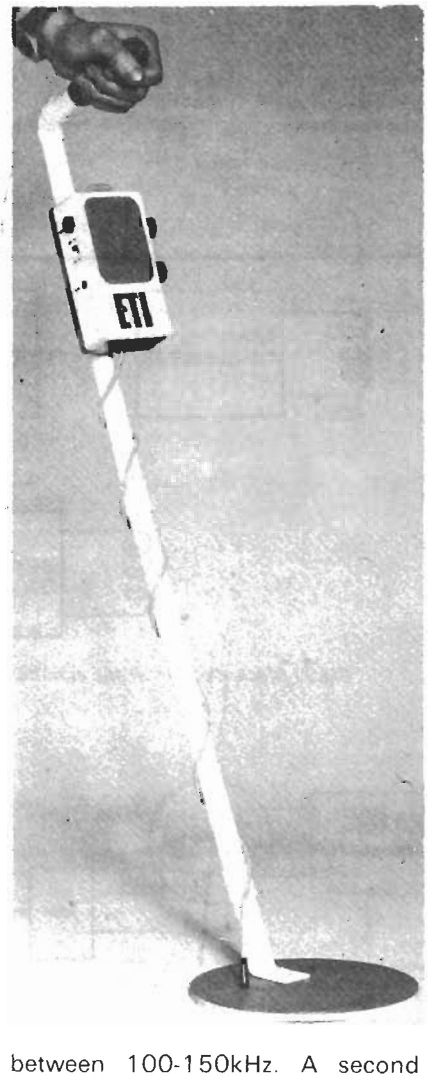
"*ANOTHER* METAL LOCATOR," some of you will say. Yes and no. Several designs have been published in the hobby electronics magazines; some good, some downright lousy but they have invariably been Beat Frequency Oscillator (BFO) types. There's nothing wrong with this principle — they are at least easy to build and simple to set up. The design described here works on a very different principle, that of induction balance (IB). This is also known as the TR principle (Transmit-Receive).

All metal locators have to work within a certain frequency band to comply with regulations and a licence is necessary to operate them. This costs £1.20 for five years and is available from the Ministry of Posts and Telecommunications, Waterloo Bridge House, Waterloo Road, London S.E.1.

First a word of warning. The electronic circuitry of this project is straightforward and should present no difficulty even to the beginner. However, successful operation depends almost entirely upon the construction of the search head and its coils. This part accounts for three-quarters of the effort. Great care, neatness and patience is necessary and a sensitive 'scope, though not absolutely essential, is very useful. It has to be stated categorically that sloppy construction of the coil will (not may) invalidate the entire operation.

IB VERSUS BFO

The usual circuit for a metal locator is shown in Fig. 2a. A search coil, usually 6in or so in diameter is connected in the circuit to oscillate at



between 100-150kHz. A second internal oscillator operating on the same frequency is included and a tiny part of each signal is taken to a mixer and a beat note is produced. When the search coil is brought near metal, the inductance of the coil is changed slightly, altering the frequency and thus the tone of the note. A note is produced continually and metal is identified by a frequency change in the audio note.

The IB principal uses two coils arranged in such a way that there is virtually no inductive pick-up between the two. A modulated signal is fed into one. When metal is brought near, the electromagnetic field is disturbed and the receiver coil picks up an appreciably higher signal.

However, it is impractical for there to be no pickup — the two coils are after all laid on top of each other. Also our ears are poor at identifying changes in audio level. The circuit is therefore arranged so that the signal is gated and is set up so that only the minutest part of the signal is heard when no metal is present. When the coil is near metal, only a minute change in level becomes an enormous change in volume.

BFO detectors are not as sensitive at IB types and have to be fitted with a Faraday screen (beware of those which aren't — they're practically useless) to reduce capacitive effects on the coil. They are however, slightly better than IB types when it comes to indentifying exactly where the metal is buried — they can pin-point more easily.

Our detector is extremely sensitive — in fact a bit too sensitive for some applications! For this reason we've included a high-low sensitivity switch. You may ask why low sensitivity is useful. As a crude example, take a coin lying on a wooden floor: on maximum sensitivity the detector will pick up the nails, etc., and give the same

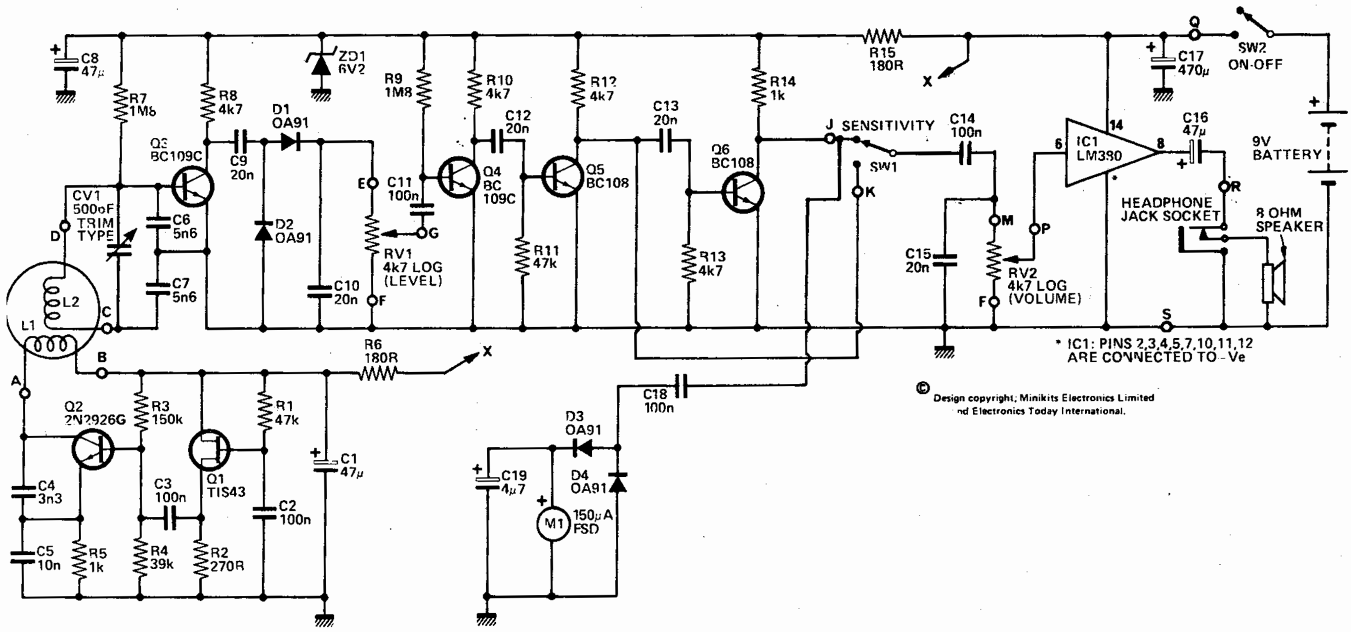


Fig.1 Complete circuit of the metal locator. Note that though the electronics is simple using very common parts, the whole operation depends on the coils Li and L2 which must be arranged so that there is minimal inductive coupling between the two. Note also that the leads from the circuit board to the search head must be individually screened and earthed at PCB.

readings as for the coin, making it difficult to find.

Treasure hunting is an art and the dual sensitivity may only be appreciated after trials.

Table 1 gives the distances at which various objects can be detected. These are static readings and only give an indication of range. If you are unimpressed with this performance you should bear two things in mind: first compare this with any other claims (ours are excellent and honest) and secondly bear in mind how difficult it is to dig a hole over 1ft of ground every time you get a reading. Try it — it's hard work!

COMPONENT CHOICE

The injunction Q1 is *not* the normal 2N2646; we found several examples of these erratic in their level — we are talking about tiniest fractions of one per cent which would normally not matter, but it *does* in this circuit. Even some examples of the TIS43 did not work well — see the note in How it Works. Secondly Q2 is deliberately a plastic type. Metal canned transistors usually have the collector connected to the case and due to the nature of the circuit we noted a very small change in signal level due to capacitive effects when metal can types were used.

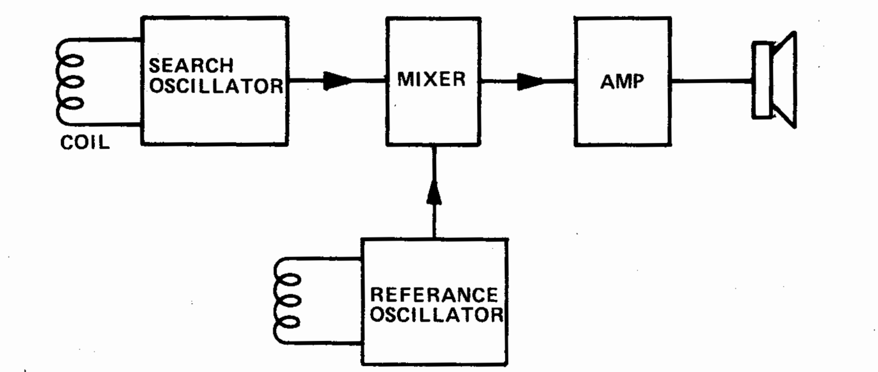


Fig.2a Block diagram of the common BFO type metal locator.

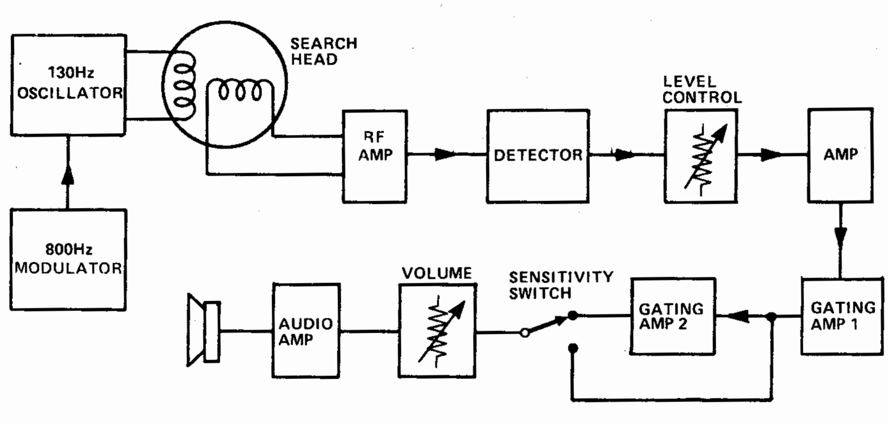


Fig2b Block diagram of our IB design.

Fig.3 The PCB pattern. Most components other than the meter circuitry is built on this.

HOW IT WORKS — ETI 549

Q1, Q2 and associated components form the transmitter section of the circuit. Q1 is a unijunction which operates as a relaxation oscillator, the audio note produced being determined by R1 and C1. The specified components give a tone of roughly 800Hz. R1 can lie in the range 33k to 100k if a different audio frequency is desired.

Q2 is connected as a Colpitt's oscillator working at a nominal 130kHz; this signal is heavily modulated by C3 feeding to the base of Q2. In fact the oscillator produces bursts of r.f. at 800Hz. L1 in the search head is the transmitter coil.

L2 is arranged in the search head in such a way that the minimum possible signal from L1 is induced into it (but see notes on setting up). On all the prototypes we made we reduced this to about 20mV peak-to-peak in L2. L2 is tuned by C6 and C7 and peaked by CV1 and feeds to the base of Q3, a high gain amplifier. This signal (which is still modulated r.f.) is detected by D1, D2 providing the bias for D1. The r.f. is eliminated by C10 and connects to the level control RV1.

The signal is further amplified by Q4 which has no d.c. bias connected to the base. In no-signal conditions this will be turned off totally and will only conduct when the peaks of the 800Hz exceed about 0.6V across R11. Only the signal above this level is amplified.

On low sensitivity these peaks are connected to the volume control RV2 (any stray r.f. or very sharp peaks being smoothed by C15) and fed to the IC amplifier and so to the speaker.

The high sensitivity stage Q6 is connected at all times and introduces another gating stage serving the same purpose as the earlier stage of Q5. This emphasises the change in level in L2 even more dramatically. Note that RV1 has to be set differently for high and low sensitivity settings of SW1.

Whichever setting is chosen for SW1, RV1 is set so that a signal can just be heard. In practice it will be found that between no-signal and moderate-signal there is a setting for RV1 where a 'crackle' can be heard. Odd peaks of the 800Hz find their way through but they do not come through as a tone. This is the correct setting for RV1.

The stage Q6 also feeds the meter circuit. Due to the nature of the pulses this need only be very simple.

Since we are detecting really minute changes in level it is important that the supply voltage in the early stages of the receiver are stabilised, for this reason ZD1 is included to hold the supply steady independent of battery voltage (which will fall on high output due to the current drawn by IC1).

It is also important that the supply voltage to Q1 and Q2 does not feed any signal through to the receiver. If trouble is experienced (we didn't get any) a separate 9V battery could be used to supply this stage.

IC1 is being well underused so a heatsink is unnecessary.

Battery consumption is fairly high on signal conditions — between 60mA and 80mA on various prototypes but this will only be for very short periods and is thus acceptable. A more modest 20mA or so is normal at the 'crackling' setting.

Stereo headphones are used and are connected in series to present 16 ohms to IC1 reducing current consumption.

Selection of Q1 and Q2

We found that Q1 and to a lesser extent Q2 required careful selection. Q1 should be chosen for the minimum possible 'crackle' — so that the transition from no-signal to hearing the 800Hz is as definite as possible. Some transistors for Q1 and Q2 can produce higher odds peaks than others.

We have specified Q3 and Q4 types as BC109C (highest gain group) for although lower gain transistors worked for us, they left little reserve of level on RV1 and really low gain types may not work at all.

RV1 is the critical control and should be a high quality type — it will be found that if has to be set very carefully for proper operation.

The choice of an LM380 may seem surprising as only a small part of its power can be utilised with battery operation. It is however inexpensive and widely available unlike the alternatives (note it does not require d.c. blocking at the input).

Output is connected for an 8ohm speaker and to headphones. Stereo types are the most common and the wiring of the jack socket is such that the two sections are connected in series presenting a 16ohm load (this reduces current consumption from the battery).

CONSTRUCTION: CONTROL BOX

The majority of the components are mounted on the PCB shown in Fig. 3. Component overlay and the additional wiring is shown in Fig. 4.

Exceptional care should be taken to mount all components firmly to the board. The trimmer capacitor CVI is mounted at right-angles to the board, its tags being bent over and soldered firmly to the copper pads. This enables it to be trimmed with the box closed. A plastic trimming tool should be used if possible. Poor connections or dubious solder joints may be acceptable in some circuits — not in this one. Take care to mount the transistors, diodes and electrolytic capacitors the right way around.

The PCB is fitted into the control box by means of long screws and pillars. The control box has to be drilled to take the speaker, the pots, switches, headphone jack and the cable from the search head.

THE HANDLE ASSEMBLY

The handle is made totally from standard parts. The general construction can be seen in Fig. 5. This is made from Marley 22mm cold water plumbing available from many plumbing shops. The hand grip is that for a bicycle — also easily available and a perfect fit onto the plastic pipe. A right-angled elbow and two sleeve connectors are specified. The elbow should be glued firmly and one end of each of the connectors should be glued also.

ETI Project 549

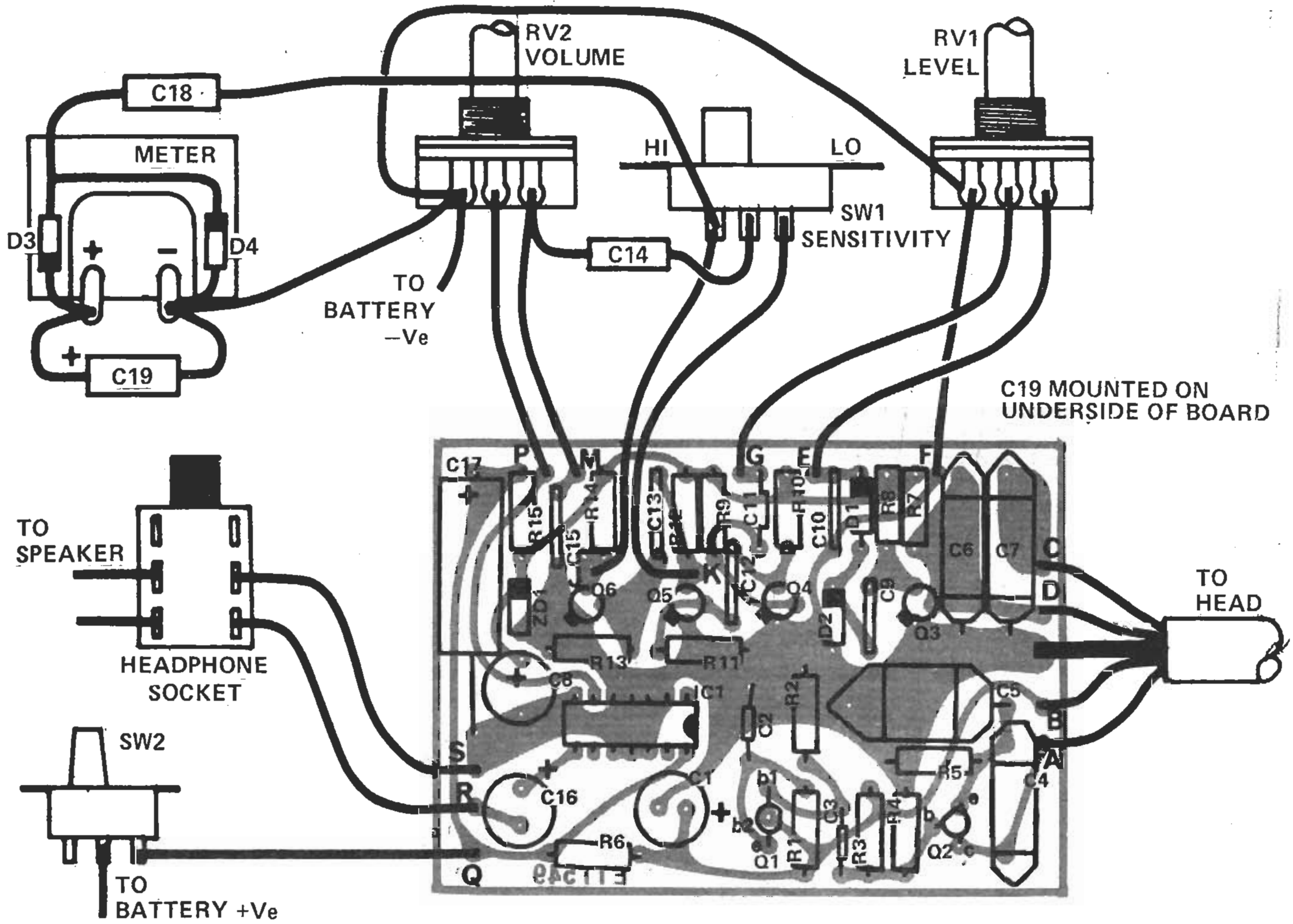


Fig. 4. The component overlay and wiring diagram to other parts of the circuit not on the PCB.

PARTS LIST — ETI 549

Resistors

R1	47k	¼W, 5%
R2	270R	¼W, 5%
R3	150k	¼W, 5%
R4	39k	¼W, 5%
R5, 14	1k	¼W, 5%
R6, 15	180R	¼W, 5%
R7, 9	1M8	¼W, 5%
R8, 10,11,12,13	4k7	¼W, 5%

Potentiometers

RV1	4k7	log rotary
RV2	4k7	log rotary

Capacitors

C1,8,16	47μF 16V electrolytic
C2,3,11,14,18	100nF ceramic etc.
C4	3n3 polystyrene 5%
C5	10n polystyrene 5%
C6,7	5n6 polystyrene 5%
C9,10,12,13,15	20n ceramic etc.
C17	470μF 16V electroytic
CV1	4μ7 16V electrolyric
C19	500p trimmer
	(Note 1n = 1000pF

Semiconductors

Q1	TIS43	Unijunction
Q2	2N2926	— see text
Q3, 4	BC109C	
Q5, Q6	BC108	
IC1	LM380	14 pin DIL
D1, 2, 3, 4	OA91	
ZD1	6.2 volt 400mW Zener diode	

MISCELLANEOUS

SW1 SW2, 2 pole, 2 way slide switches
Stereo jack socket
Miniature (2¼in etc) 8ohm loudspeaker
L1, L2 — See text and drawings
Vero box (65-2520J)
PCB Board, ETI 549
4 core, individually screened cable, 1.5 metres
Battery clip (PP6)
Battery, PP6
Wood and laminate for search head
2 Control knobs, 2BA Nylon Nut Bolt
M1 Signal level meter, 150μA movement
Marley 22mm Cold Water Plumbing (see text)
Bicycle Grip

The reason for the connector near the base is to facilitate easy removal of the head and the control box for testing and initial setting up.

The control box is held to the handle by means of two pipe clips — again available from plumber's merchants.

The connection to the search head is by means of a 4½in length of tubing which has to be modified. Put 1½in of this tube into boiling water for about half a minute to soften the plastic, take it out and quickly clamp it into a vice to flatten half the length,

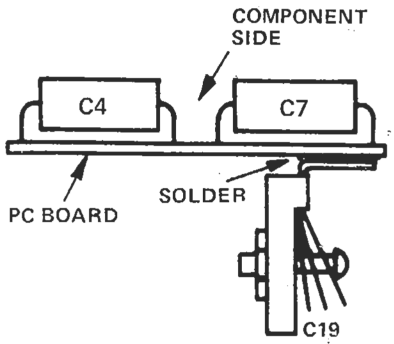
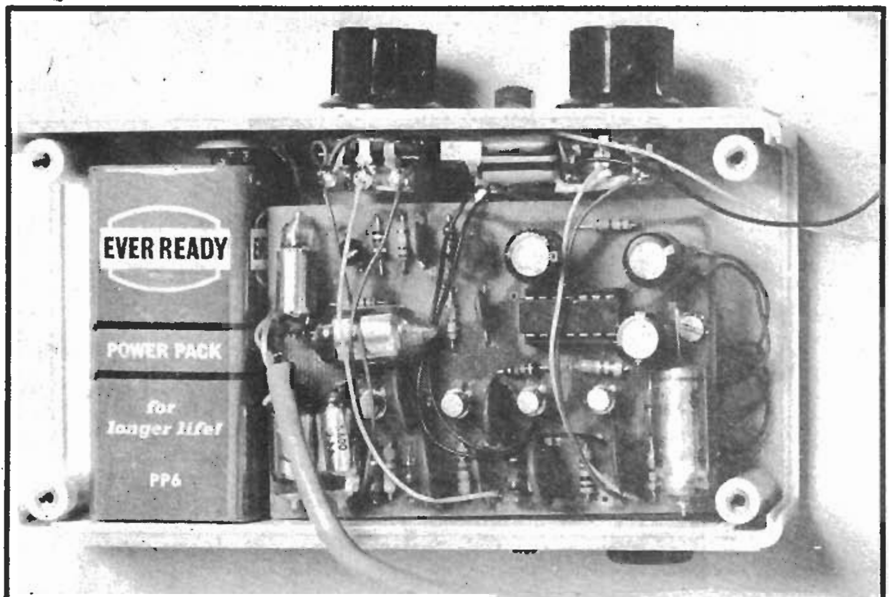


Diagram showing C19 mounted on copper side of P C Board



Internal photograph of metal locator control box.

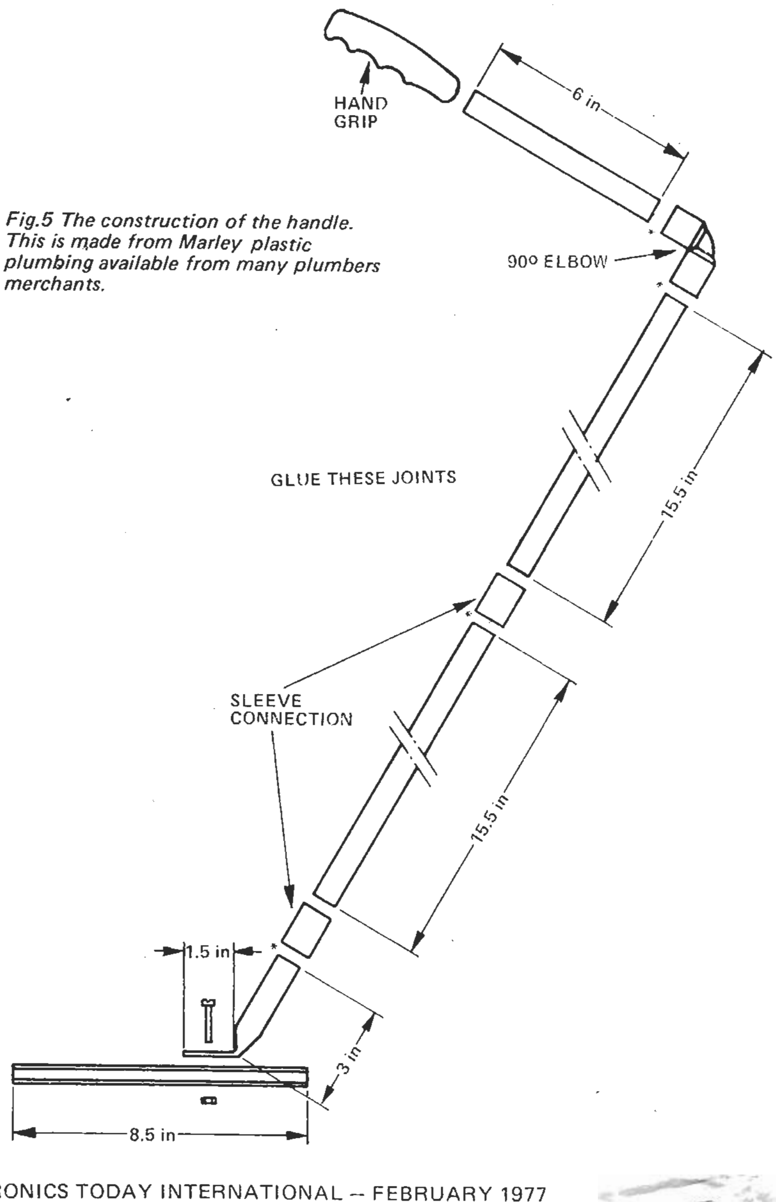


Fig.5 The construction of the handle. This is made from Marley plastic plumbing available from many plumbers merchants.

at the same time bending the flat to about 45° This will now lie across the top of the search head and is glued into position and held by a single 2BA nylon nut and bolt through the top of the search head.

THE COIL

Remember this is the key to the whole operation. The casing of the coil is not so critical but the layout is.

It is best first to make the 6mm plywood circle to the dimensions shown in Fig. 5. A circle of thinner plywood or hardboard is then firmly clued onto this — it's fairly easy to cut this after glueing. Use good quality ply and a modern wood glue to make this.

This now forms a dish into which the coils are fitted. The plastic connector to the handle should be fitted at this stage.

You'll now have to find something cylindrical with a diameter of near enough 140mm (5½in). A coil will then have to be made of 40 turns of 32 s.w.g. enamelled copper wire. The wire should be wound close together and kept well bunched and taped to keep it together when removed from the former. Two such coils are required: both are identical.

One of the coils is then fitted into the 'dish' and spot clued in six or eight places using quick setting epoxy resin: see photogaraph of the approximate shape.

L2 is then fitted into place, again spot gluing it *not* in the area that it overlaps L1. The cable connecting the coil to the circuit is then fed through a hole drilled in the dish and connected to the four ends. These should be directly wired and glued in place, obviously taking care that they don't short. The cable must be a four-wire type with individual screens — the screens are left unconnected at the search head.

You will now need the built up control box and preferrably a 'scope. The transmit circuit is connected to L1. The signal induced into L2 is monitored; at first this may be very high but by manipulating L2, bending it in shape, etc., the level will be seen to fall to a very low level. When a very low level is reached, spot glue L2 until only a small part is left for bending.

Ensure that when you are doing this that you are as far away from any metal as possible but that any metal used to mount the handle to the head is in place. Small amounts of metal are acceptable as long as they are taken into account whilst setting up.

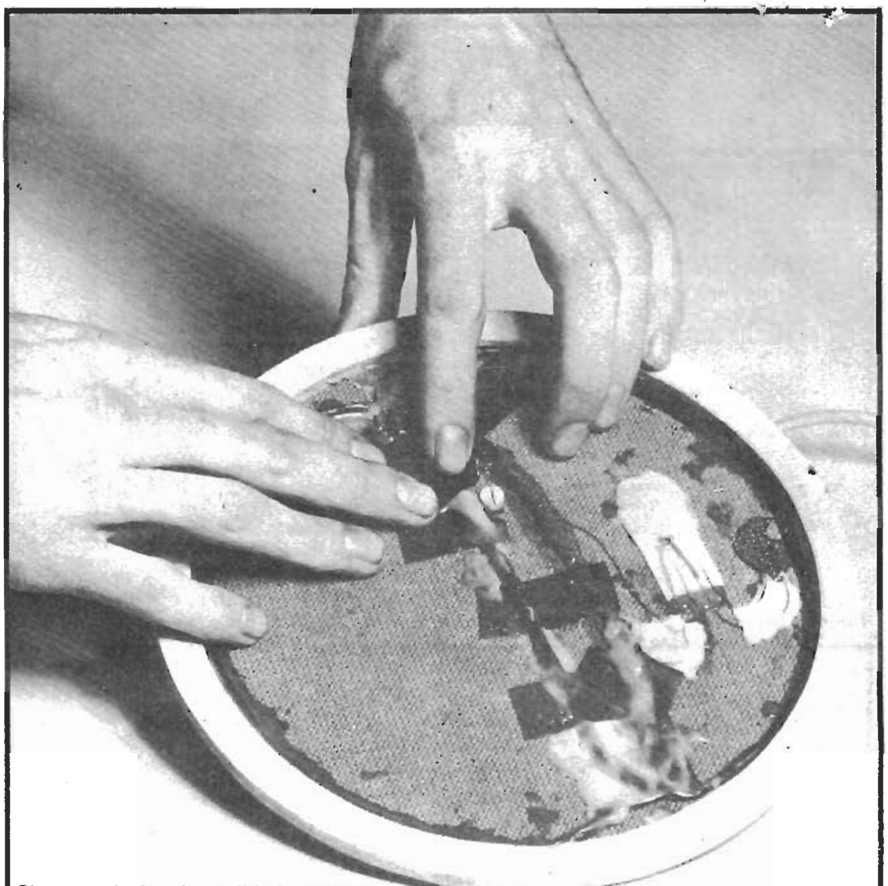
Now connect up the remainder of the circuit and set RV1 so that it is *just* passing through a signal to the speaker. Bring a piece of metal near the coil and the signal should rise. If it falls in level (i.e. the crackling disappears) the coil has to be adjusted until metal brings about a rise with no initial falling. CVI should be adjusted for maximum signal, this has to be done in conjunction with RV1.

Monitoring this on a scope may mean that the induced signal is not at its absolute minimum: this doesn't matter too much. Now add more spot gluing points to L2.

You should now try the metal locator in operation, If RV1 is being operated entirely at the lower end of its track, making setting difficult, you can select a lower gain transistor such as a BC108 for Q4.

When you are quite certain that no more manipulation of the coils will improve the performance, mix up plenty of epoxy resin and smother both coils, making certain that you don't move them relative to each other.

The base plate can then be fitted to enclose the coil, this should be glued in place.



Photograph showing coil being adjusted.

USING THE METAL LOCATOR

You will find that finding buried metal is rather *too* easy. 95% will be junk — silver paper being a curse. The search head should be panned slowly over the surface taking care to overlap each sweep: the sensitive area is somewhat less than the diameter of the coil.

This type of locator will also pick up some materials which are not metal — especially coke and it is also not at its best in wet grass.

Think very carefully about where you want to search: this is more important than actually looking. The area you can cover thoroughly is very, very small, but is far more successful than nipping all over the place. As an example of how much better a thorough search is, we thoroughly tried on 25 square feet of common ground (5ft x 5ft); we found over 120 items but a quick search initially had revealed only two!

Treasure hunting is growing in popularity and those who do it seriously have adopted a code; essentially this asks you to respect other people's property, to fill in the holes you dig and to report any interesting finds to museums. And do get a licence — it must be the best bargain available at 25p a year (rather £1.20 for five years).

TABLE 1

OBJECT	HIGH SENS	LOW SENS
2p COIN	8"	6"
BEER CAN	17"	14"
6" SQUARE COPPER	22"	16"
6" STEEL RULER	12"	9"
MANS GOLD RING	8"	6"

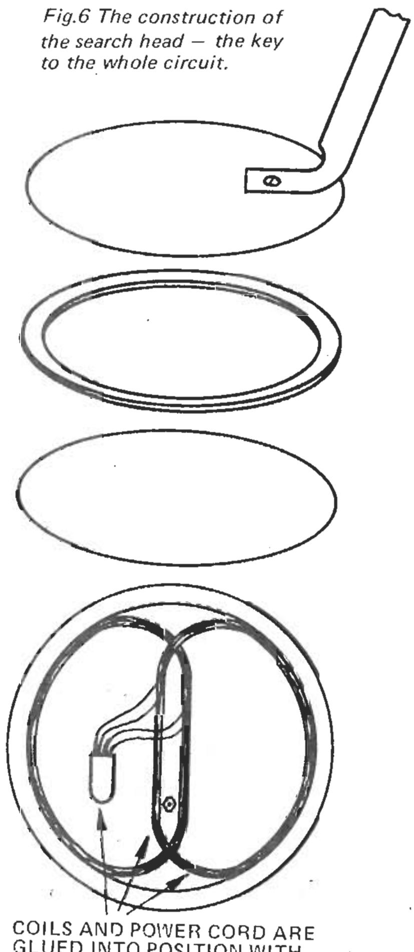
Table showing sensitivity of the metal locator in free air. (Buried objects can usually be detected at greater depths.)

METER CIRCUIT

Since the circuit is basically sensing a change in audio level, a meter circuit can be incorporated. For the very first indication from the 'crackle' (see later) to heavy crackle your ears are likely to be more sensitive than the meter but thereafter it will come into its own.

This part of the circuit is optional and the components are not included on the board. ●

Fig.6 The construction of the search head — the key to the whole circuit.



Metal detector

B.f.o. circuit using fifth search oscillator harmonic for enhanced sensitivity

by D. E. O'N. Waddington, M.I.E.R.E.

Metal detectors have fascinated people for a long time and a great many have been designed and built. Some work, but a high proportion have been abandoned as impractical by their disillusioned constructors. This article, in addition to giving the design for a practical metal detector, will explain some of the pitfalls and show how they may be circumvented.

All the metal detectors known to me use the modification of the magnetic field associated with one or more inductors to locate metal. Three main types are made commercially; b.f.o., induction balance and pulse induction. I will confine my description to the b.f.o., since this is the simplest to implement and, provided that due precautions are observed, it is adequate for most purposes.

Before proceeding any further, however, I think that it is as well to look at some of the legal aspects of metal detectors. Since, under the terms of the Wireless Telegraphy Act 1949 they have been deemed wireless telegraphy apparatus, they come under the jurisdiction of The Home Office who, at present, requires that a licence should be obtained for the use of the detector. Currently, this is £1.20 and permits the use of a "pipe finder" for a period of five years. In addition, the frequency of operation is limited to the range from 16 to 150kHz, with a forbidden band from 90 to 110kHz. In practice, the preferred bands are 85 to 90kHz and 110 to 144kHz. Before a detector may be used it must be "type approved" by the Home Office. Needless to say, the circuit to be described has approval.

With regard to the use of the detector for "treasure hunting" it is as well to observe a few rules:

- Never prospect a known archaeological site. If you do, you will incur the undying wrath of the archaeological fraternity in addition to possibly destroying historical information.
- Report unusual historical finds to your local museum.
- If you find any gold or silver, report the find immediately to the police, who will inform the local coroner. He will hold an inquest to decide to whom the find belongs. (A study of the laws relating to 'treasure trove' will help you to understand your rights.)
- If you find unexploded ammunition or a bomb, mark the place, leave well alone and inform the police.
- Do not leave a mess after excavating your finds.
- The issue of a licence does not absolve the licensee from obtaining any necessary consent before entering on any private property with any apparatus.

The principle of the b.f.o. detector is illustrated in Fig. 1. The outputs of two oscillators, tuned such that there is a small frequency difference between them, are mixed. The difference frequency is selected by a low-pass filter, amplified and fed to a loudspeaker or headphone. When a metallic object is brought near to the search coil, its inductance changes causing a change in the frequency of oscillator 1 and a corresponding change in the difference frequency. Non-ferrous metals will cause the frequency of the search oscillator to increase and ferrous metals should have the opposite effect. I use the word "should" since, in practice, both the shape of the object and its state of decomposition appear to affect the sense of the change. At first sight, it would appear a simple matter to apply this principle to a practical metal detector but there are a number of problems which need to be overcome before a satisfactory design can be achieved. The first of these concerns the search coil.

The frequency of oscillation will change if the reactance of the coil changes at all. Thus it is as susceptible to capacitance as to inductance changes. Indeed the change in coil capacitance caused by moving it relative to the ground may well exceed the inductance change caused by the object being sought. Fortunately, it is quite easy to minimize this effect by fitting a Faraday screen to the coil. This is done by wrapping the coil with a conductive foil, which is connected to the internal "earth" of the oscillator. There should be a break in the foil so that it does not constitute a short-circuited turn. When I first tried this out, I feared that it would reduce the sensitivity of the coil to metallic objects but measurements showed that the sensitivity was unchanged, while capacitive effects were reduced to negligible proportions. Another cause of spurious frequency change is heat: moving the coil from sunlight to shade can cause a large and fairly rapid frequency change. This effect can be reduced by suitable thermal insulation.

In order to select the best size of coil for the detector I made a series of tests plotting the frequency change caused

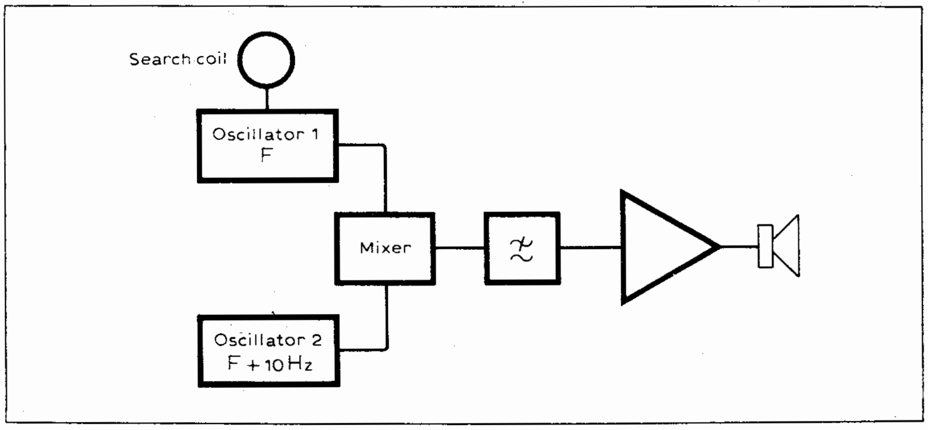


Fig. 1. Block diagram of a simple b.f.o. metal detector.

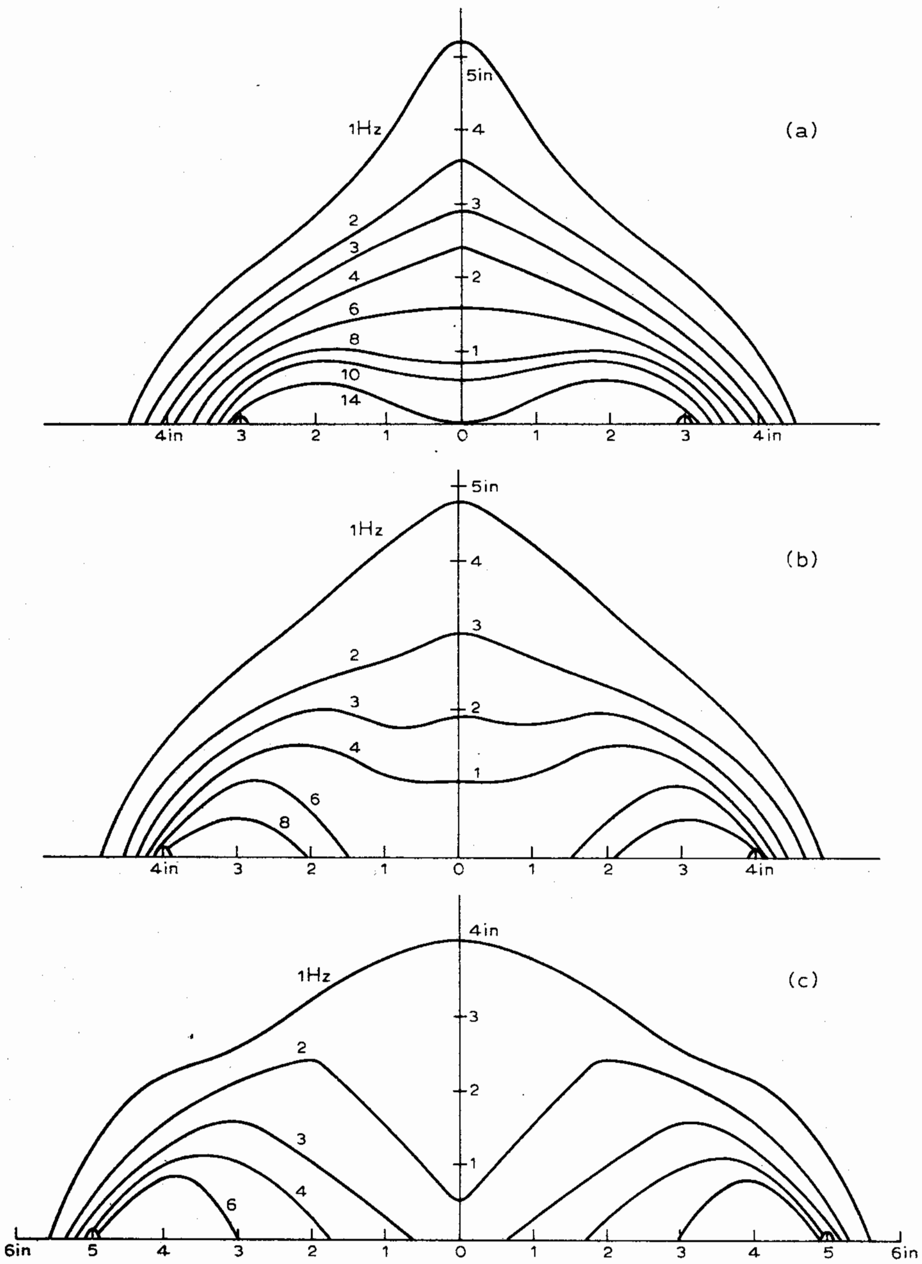


Fig. 2. The lines show the contours of equal frequency change for a ½p coin at a frequency of 100kHz with various coil sizes (a) 6″ (b) 8″ (c) 10″

by a ½p coin with various coils. The inductance of the coil does not appear to be an important factor, but the diameter is. The results for 6in, 8in and 10in coils are shown in Fig. 2. They may not be strictly accurate, since the measurement is a very tedious one, but they do show what is to be expected. The important points are:

- The frequency change is very small.
- The sensitivity at the centre of the smaller coils is much the same, while the 10in coil is less sensitive.
- The larger the coil, the larger the sensitive area. However, this is not always an advantage, since it is still necessary to pin point the article being sought and the smaller coil gives a much better "focus". For my own design I have chosen the 6in coil.

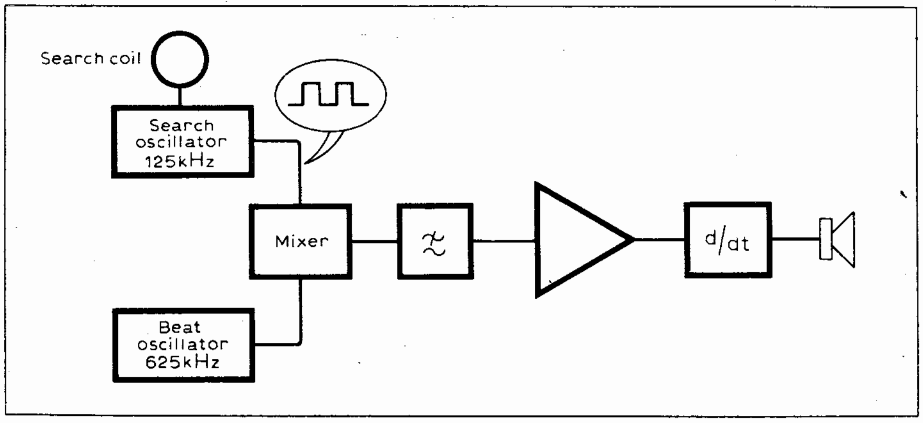
The magnitude (or should I say smallness), of the frequency change is one of the main problems in using a b.f.o. metal detector. One very practical solution is to set the oscillator frequencies such that the frequency difference is very small <10Hz. When this is done a change of one or two hertz is readily discernible. If the frequency difference were of the order of 250Hz this change could only be heard by a trained listener. Since a normal loudspeaker or headphone does not reproduce low-frequency tones, the low frequency waveform can be converted into a pulse train, which is then easily reproduced.

The sensitivity of the b.f.o. can be increased as shown in Fig. 3. Here the search coil oscillator is operated at a frequency of 125kHz and its output is converted to a square wave, which is rich in harmonics. The beat oscillator runs at a frequency of 625kHz, i.e. five times the search oscillator frequency. Thus, the beat oscillator is mixed with the 5th harmonic of the search oscillator so that any frequency change is multiplied by five. This makes it very much easier to hear a change in frequency, although the susceptibility to drift is much greater. A higher harmonic could be used but it should be remembered that, with a square wave, only odd harmonics are present and the amplitude of the harmonic will be equal to the amplitude of the fundamental divided by the harmonic number. The rather odd choice of frequencies has been dictated by the fact that most constructors will only have a medium-wave radio receiver for setting up purposes and will have no simple means of checking the frequencies. If the beat oscillator is set to 625kHz, the beat note will only be heard strongly if the search oscillator is tuned to an odd sub-harmonic (625/5 = 125 or 625/7 = 89.286) and the forbidden band from 90-110kHz will be avoided. This precaution is necessary as it is difficult to control all the stray capacities associated with the search coil.

Design

The circuit of a metal detector based on the above considerations is shown in Fig. 4. I chose the "long-tailed-pair" oscillator for this application because it is easy to design, the tuned circuit needs only two connexions and the output is isolated from the tuned circuit so that the frequency of oscillation is virtually unaffected by loading or signals fed to the output. This last is particularly important for this application, in which it is essential that the oscillators do not lock to each other when the frequency, or in this case, harmonic frequency

Fig. 3. Block diagram of an improved metal detector.



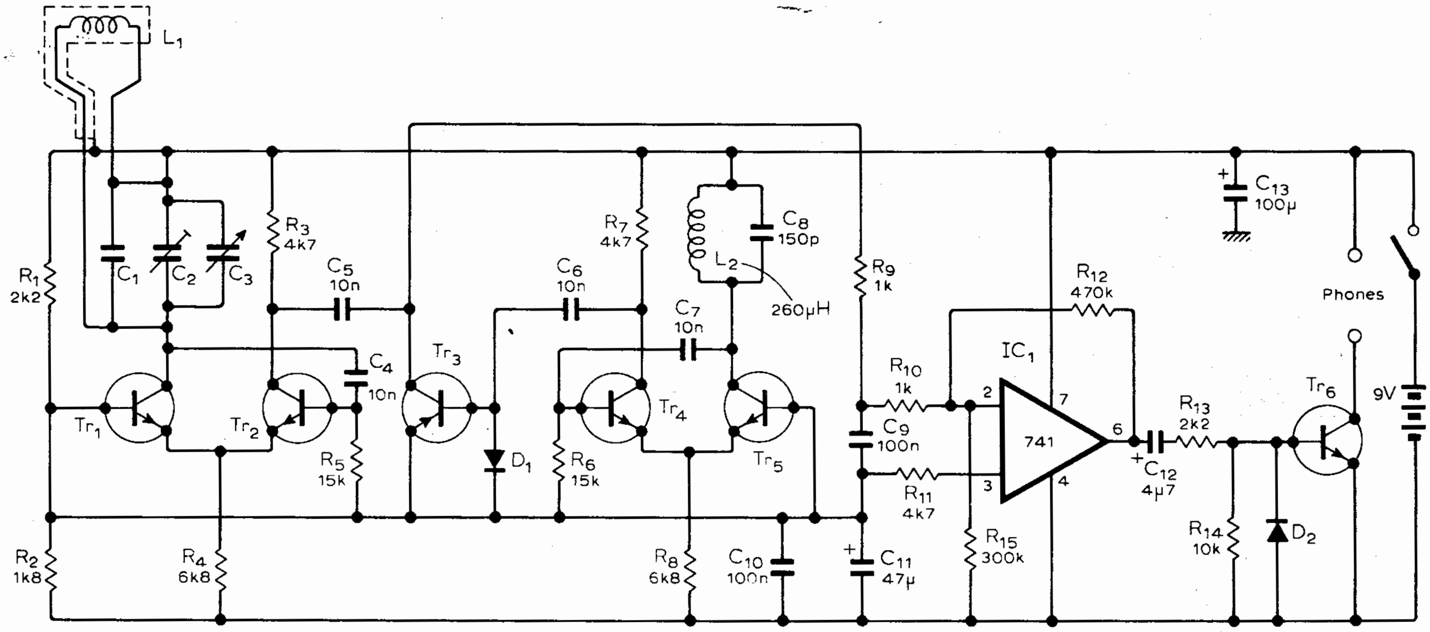


Fig. 4. Circuit diagram for metal detector.

difference is small. The search oscillator uses Tr_1 and Tr_2 with L_1, C_1, C_2 and C_3 forming the tuned circuit. It will probably be necessary to select C_1 to give the correct frequency, since the Faraday screen and the screened lead add an indeterminate amount of capacitance in parallel with the coil. This capacitance depends upon the physical construction of the coil and the materials used and is rather variable. Coarse tuning is carried out by C_2, while C_3 is used for fine adjustment. The search oscillator output is taken from the collector of Tr_2 to the mixer Tr_3. The beat oscillator uses Tr_4 and Tr_5; L_2 and C_8 form the tuned circuit, which resonates at 625kHz. The drive to the shunt gate mixer Tr_3 is taken from the collector of Tr_4. The difference frequency is selected by the low-pass filter, formed by R_9 and C_9 and is amplified by IC_1, differentiated and then fed to Tr_6, which drives the 'phones or loudspeaker. The volume can be controlled by connecting a variable resistor in series with the output.

Construction

The layout of the circuit does not appear to be critical – a practical version using matrix board is shown in Fig. 5. Mount the circuit inside a screened box so that hand capacitance does not affect the tuning.

The construction of the search coil is very important. It should be sufficiently robust to withstand rough handling, light, so as to be portable and adequately insulated against temperature change and moisture. I found that the construction shown in Fig. 6 works very well. First cut a ring of about ⅜in plywood as shown. To wind the coil, draw a 6¼in diameter circle on a piece of wood. Hammer ¾in panel pins at about 1in intervals around this circle and then wind 45 turns of 26 s.w.g. (0.46mm) wire around the pins. Tape the coil in four places to stop it springing undone. Remove the pins. Tape the coil tightly to the underside of the wooden ring, taking care that the ends of the winding come opposite to the tab for the handle. Cover the coil with a second layer of tape. Cut a strip of aluminium cooking foil about 1in wide and tape the coil with it, starting on one side of the tab and finishing at the other. It will probably be necessary to use more than one length of foil, in which case the ends should be overlapped. However take care that the start and finish of the coil do not short to each other. Bind the finish of the coil with 22 s.w.g. tinned copper wire and connect it to one end of the coil and to the screened lead. The other end of the coil is connected to the centre conductor of the screened lead. Cover the coil with a layer of tape. Cut a 1in wide strip of ⅛in thick expanded polystyrene sheet and wind this around the coil. Cover the whole with another layer of tape. Assemble the coil to the handle and paint it with white waterproof paint.

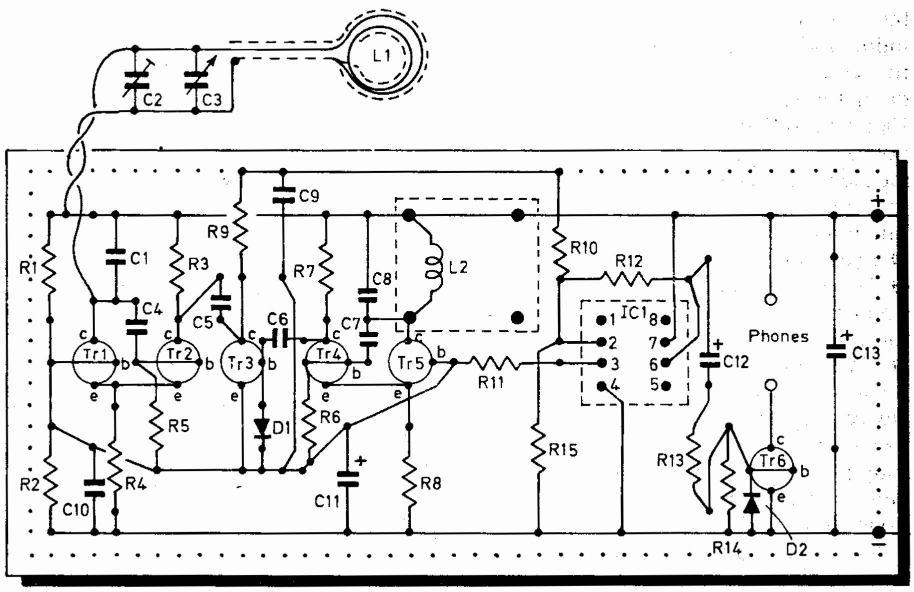


Fig. 5. Layout of circuit, using pin board (no copper tracks).

Setting up

The first step is to set the beat oscillator to the correct frequency.

- Short the search coil to disable the search oscillator.
- Switch on and adjust the core of L_2 so that the frequency of the beat oscillator is set to 625kHz. If you have no access to a frequency counter, a medium wave radio receiver may be used. Set the dial of the receiver to 625kHz (480m). If the receiver has an aerial connection, place the aerial lead close to the oscillator, but if it only has a ferrite rod aerial it will be necessary to place the receiver close to the oscillator. This setting up must be carried out with the detector circuit mounted in its screened box with the lid off. Tune for maximum signal. Remember that you will be looking for an

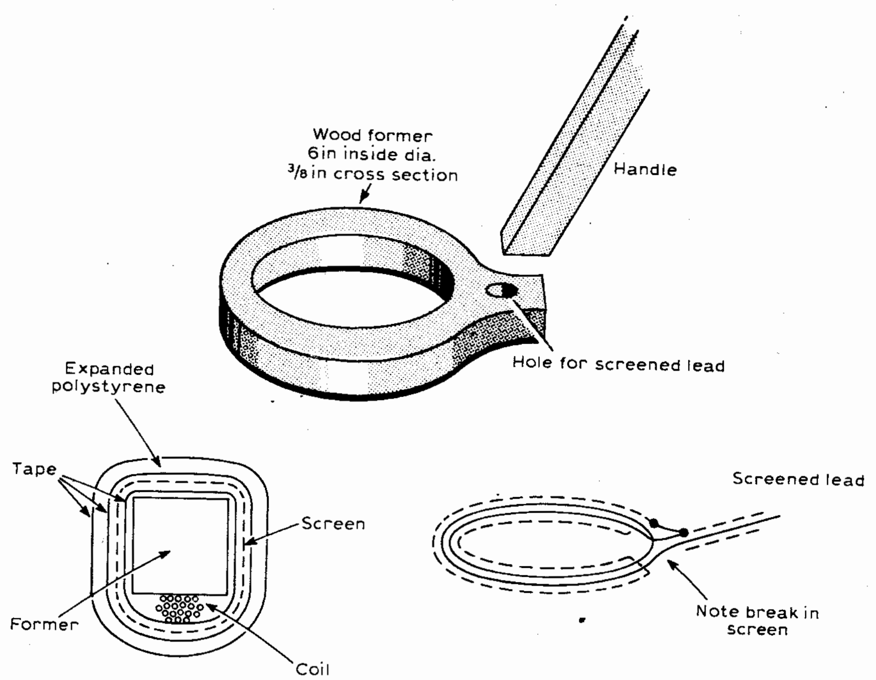


Fig. 6. Coil construction.

unmodulated carrier, so that only hiss will be heard. However, you can check whether you have the correct carrier by shorting the coil. The next step is to set the search oscillator to the correct frequency.

- Remove the short from the search coil.
- Set both the coarse and fine controls to mid-travel.
- Fit a 470pF capacitor for C_1.
- Adjust C_2 and check that a beat note can be obtained. If necessary increase the value of C_2 by 100pF.
- When a beat note is heard, check the frequency of the search oscillator as follows:

(*a*) Short the beat oscillator tuning coil.
(*b*) Using the receiver near the search coil, look for the harmonics of the search oscillator which should be as shown in Table 1. It is very probable that you will only be able to identify the odd harmonic frequencies.
(*c*) If the frequencies are too close together, the search oscillator will probably be running at 89.3kHz. Reduce the value of C_1 and repeat the procedure. If possible it is a good idea to select a value of C_1 which gives the correct frequency with C_2 set to mid travel. This will allow for any drift which may occur during the life of the detector.

Table 1

Harmonic Number	*Frequency*	*Wavelength*
5	625 kHz	480 m
6	750 kHz	400 m
7	875 kHz	342.85 m
8	1000 kHz	300 m
9	1125 kHz	266.67 m
10	1250 kHz	240 m
11	1375 kHz	218.18 m
12	1500 kHz	200 m
13	1625 kHz	184.615 m

PARTS LIST

Resistors

1	2k2	All resistors 1/4W ±5%
2	1k8	
3	1k	
4	6k8	
5	15k	
6	15k	
7	1k	
8	6k8	
9	1k	
10	1k	
11	4k7	
12	470k	
13	2k2	
14	10k	
15	300k	

Capacitors

1	560pF polystyrene (see text)
2	150pF variable
3	10pF variable
4	0.01µF disc ceramic
5	0.01µF disc ceramic
6	0.01µF disc ceramic
7	0.01µF disc ceramic
8	150pF polystyrene
9	0.1µF 100V P.E.T.
10	0.1µF 100V P.E.T.
11	47µF 10V electrolytic
12	4.7µF 10V electrolytic
13	100µF 10V electrolytic

$Tr_{1, 2, 4, 5, 6}$	BF238, BC108 or equivalent
Tr_3	BC308, BCY72 or equivalent
$D_{1, 2}$	1N4148
IC_1	µA741C
L_1	see text
L_2	49t 0.28mm wire or Mullard Vinkor LA1157 (260µH)

IB METAL LOCATOR MK2

A year ago we described a really excellent metal locator using the induction balance principle. The ETI Project Team have taken another look at the design and come up with an alternative way of using this principle.

EXACTLY A YEAR AGO, in the February 1977 issue of ETI we described the first (and to date only) DIY project yet published in Britain of an Inductance Balance metal locator. We know that literally thousands upon thousands of these were built and although a few readers did have problems, most of them were accounted for by poorly set up search coils.

Treasure Hunting

The hobby of treasure hunting using a metal locator started in America about ten years ago and has been growing in popularity ever since; in Britain the hobby has grown to enormous proportions. Commercial metal locators are not cheap — starting with kits at the £15 mark but with a big gap before most of the built models appear. The average price is in the £50 region (there are notable exceptions of course) yet the circuitry in these is by no means complex. The important part about an induction balance metal locator is the search head and no one should underestimate this — this accounts for a significant part of the total cost and, if you tackle this project, expect to devote a lot of time to lining up and experimenting with this.

The reason for the popularity of treasure hunting is that it works — using a reasonable metal locator you can hardly fail to find coins and other items lost or thrown away. Our fields and pathways are littered with metal which has been there for hundreds, even thousands of years. The art of knowing where to look is almost more important than the technical performance of the machine: a good detector helps of course but it's how it is used that's important.

Designing the Mark 2

Because of the enormous popularity of the Mark 1 we couldn't resist the temptation of having a good look at the circuit and design to see if it couldn't be improved upon. Readers who are interested in this field are strongly recommended to see the February 77 issue (not unfortunately available as a backnumber) or the reprint in Top Projects No. 5 (available).

Our first step was to look at the original design — in the light of experience could we improve it? We came up with a dozen variations to try but to our surprise we were unable to make any real improvement on the first circuit using the general principles. We could have reduced the package count by using an LM389 (which includes three independent transistors plus an audio

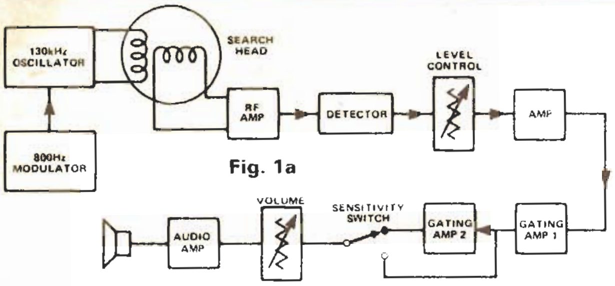


Fig. 1a

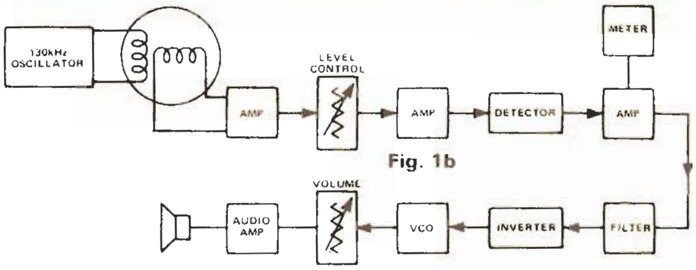


Fig. 1b

Fig 1. a) On the left shows the block diagram of the Mark 1. In this the peaks of the modulated signal were gated and enormously amplified. On the right is shown the new arrangement, the RF signal, which is unmodulated, is converted to a DC signal which drives a voltage controlled oscillator (VCO).

output amplifier) but that would have cost more with no real change.

In the original design the transmitter was modulated and the peaks of the detected signal were gated and enormously amplified (See How It Works and Fig 1a). Although we refer to the signal being modulated, it was actually switched on and off and this resulted in ringing in the tuned circuit.

After literally three weeks solid experimenting we decided to take another approach. We decided to dispense with a modulated transmitter and work with DC until the final stages. In the original design the audio frequency was fixed, being dependent upon the modulator and metal was sensed by an increase in audio level. However, our ears are highly insensitive to changes in level, they are, however, very sensitive to a change in audio frequency. Once we had decided to tackle it from this side everything fell into place. For a long while our voltage controlled oscillator was a unijunction transistor and although we achieved excellent results we were not satisfied with the unit in practice and eventually adopted the circuit shown in Fig. 3.

The Coil

We cannot emphasise enough that the search head is the key to the whole operation: be prepared to spend some time on this, our own workshop is full of discarded experiments.

The housing of the coils is not important. In the Mk 1 we adopted a circular head but this is difficult for the non-woodworkers to tackle so we went for a rectangular shape. The coils L1 and L2 should be sandwiched between two pieces of hardboard or plywood separated by thin battens — about 6mm thick. The top should be built first and the battens fitted — for a better appearance you can then file off the corners slightly.

To wind the coils you'll need to get hold of a cylinder about 140mm (5½in) in diameter. Using 32 swg enamelled copper wire, trap one end onto the former with a piece of tape and carefully wind 40 turns as close together as possible. Carefully remove the coil and then wrap tape around it at intervals to keep it from spreading.

Two identical coils are required.

Lay one of the coils into the dish formed from the top of search head and the battens as you see in the photograph and spot glue it into place except on the part near the middle. Lay the other coil next, again spot gluing it except near the middle. A hole should be made in this piece of wood to feed through the

Continued on page 36

Despite the extremely low emmission, all electronic metal locators used in the United Kingdom require a licence. This costs £1.20 for five years and application forms are available from:

**Ministry of Posts and Telecommunications,
Waterloo Bridge House,
Waterloo Road,
London SE1**

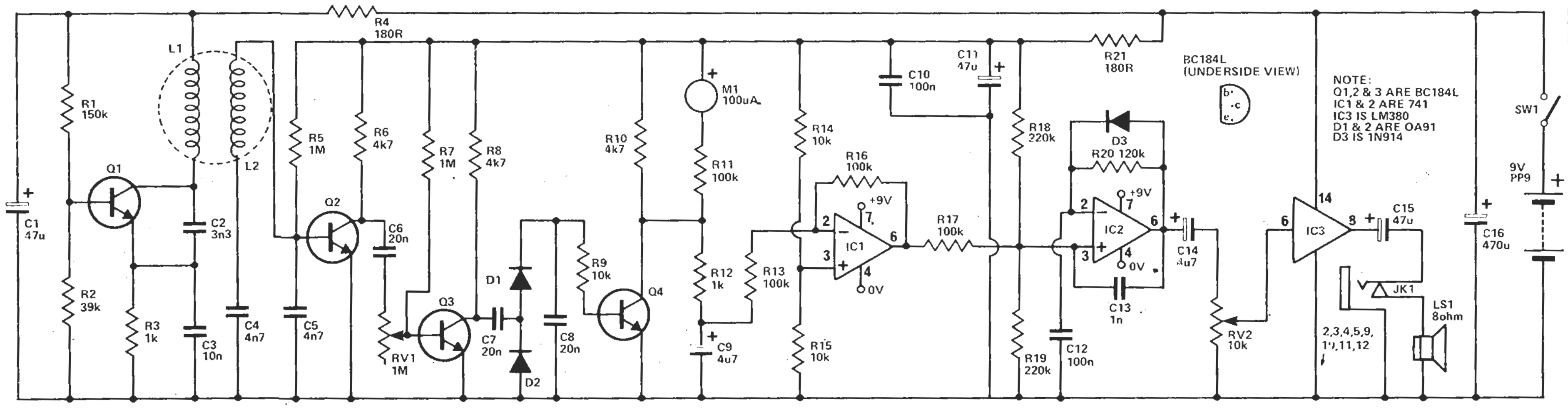


Fig 3. The complete circuit of the IB Metal Locator Mk 2.

HOW IT WORKS

The heart of the circuit is the search coil, L1 and L2. These two coils, which are essentially identical, are arranged in the same plane with a small overlap in such a way that there is practically no inductive coupling between the two. There is minimum pickup when the fields generated in L1 are cancelled in L2 when in free air. Any metal brought into the electro-magnetic field of L1 will distort the field, causing pickup in L2.

Q1 is a straightforward Colpitt's oscillator working at a nominal 130 kHz. This type of circuit is very stable and the use of polystyrene capacitors also help with stability. The supply to this stage is separately decoupled by R4 and C1.

The pickup coil L2 is tuned by means of C4 and C5 and amplified by Q2 which feeds to the level control RV1. This controls the "free air" state of the circuit and is set to the point where the later stages are just operating. The signal is further amplified by Q3 (here it is still an RF signal) and is detected by D1 and D2. When no metal is in the vicinity of the search coil and with RV1 correctly adjusted, a DC voltage of about 500 mV appears across C8. R9 increases the effective input impedance of Q4 as seen by the detector stage.

Q4 is just held off by the voltage available but as soon as any metal distorts the electromagnetic filed, L2 produces a larger RF signal, a higher voltage across C8 and a consequent fall (from 8 V) in the voltage at the collector of Q4. This voltage is also monitored by the meter in parallel with the load resistor of Q4. The fall in voltage is dependent upon the proximity and/or size of the metal near the search coil.

It is necessary to ensure that the DC voltage fed to the next stage is clean and R12 and C9 act as a filter to remove any residual AC even if this is at low frequencies.

IC2 (the next but one stage) is a voltage controlled oscillator — but to operate this so that metal is indicated by a rising note, rather than a falling one, the voltage at the junction of C9 and R12 has to be inverted and this is achieved by IC1: in "no-metal conditions there is about 2 V at the output of this op-amp which rises when metal is near. This stage quickly saturates to give about 7 V at pin 6. IC1 has unity gain.

IC2 is a voltage controlled oscillator. In "no-metal" conditions it gives about 70 Hz which rises to 500 Hz when metal is present, diode D3 gives a rapid recharge to C12 and affects the mark/space ratio of the output which results in lower battery consumption. R20 and C12 can be altered to give a different range of audio frequencies if desired.

The output is taken to a volume control and fed to the LM380 audio power amplifier which in turn feeds the speaker.

The levels of signal around Q2, 3, 4 are all dependent upon transistor gain, temperature and supply voltage but this doesn't matter because the level control RV1 is adjusted until Q4 just begins to conduct.

Current drain for the complete circuit is in the order of 50 mA.

PARTS LIST

Resistors. All ⅛W, 5%

R1	150k
R2	39k
R3, 12	1k
R4, 21	180R
R5, 7	1M
R6, 8, 10	4k7
R9, 14, 15	10k
R11, 13, 16, 17	100k
R18, 19	220k
R20	120k
RV1	1M linear (level)
RV2	10k log (volume)

CAPACITORS

C1, 11	47u 16V tantalum
C2	3n3 polystyrene, 5%
C3	10n polystyrene, 5%
C4, C5	4n7 polystyrene, 5%
C6, 7, 8	20n polystyrene
C9, 14	4u7 16V tantalum
C10, 12	100n polyester
C13	1n polyester
C15	47u 16V electrolytic
C16	470u 16V electrolytic

SEMICONDUCTORS

Q1, 2, 3, 4	BC184L or equivalent
IC1, 2	741 8-pin DIL
IC3	LM380
D1, D2	OA91
D3	1N914

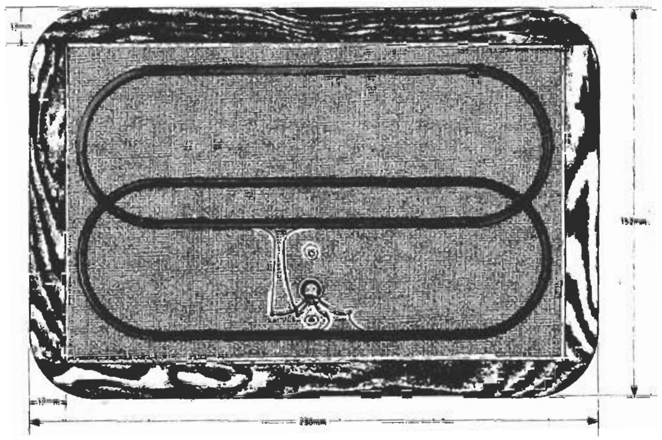


Fig 2. The search coil. This comprises L1 and L2 which are made from two coils originally wound on a 140 mm former and then squeezed into the shapes shown.

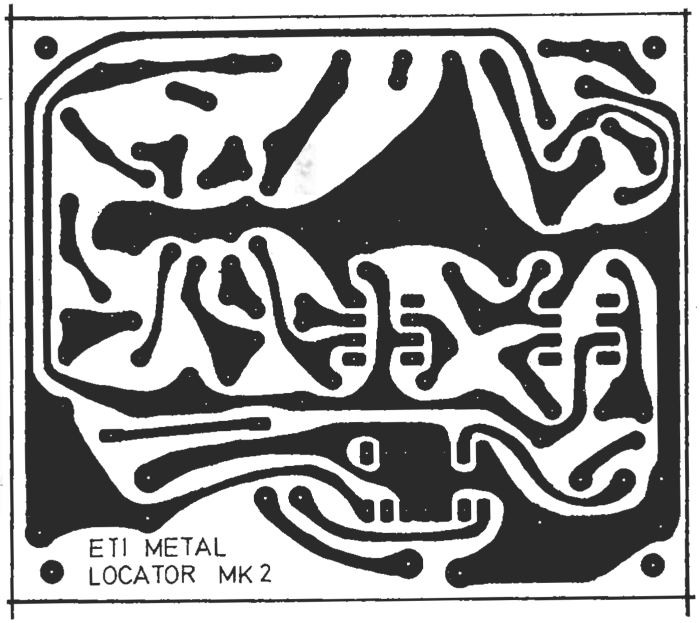


Fig 4. The PCB for the IB Mk 2. Full size is 89 x 77 mm.

MISCELLANEOUS
LS1 8 ohm miniature loudspeaker
JK1 stereo jack socket
M1 100uA level meter
L1, L2 — see text
PCB — see drawing
4-core, individually screened cable
Battery & clip (PP9)
Marley 22mm cold water plumbing
Bicycle hand grip
Verobox, 4¼" x 7½" x 2¼"

BUYLINES

No problems with the parts: your problems will only lie in setting up the coil. Enamelled copper wire is available on small reels from most retailers. Signal level meters are also widely sold though the actual appearance may vary from that in our photograph. The stem is made from Marley push-fit 22mm cold water fittings available from most plumbers.

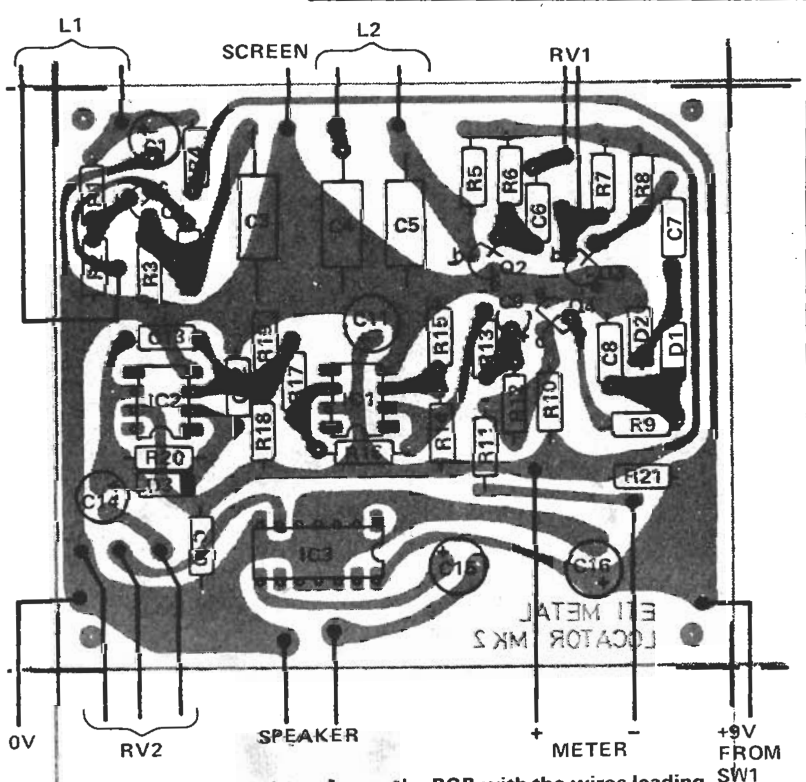
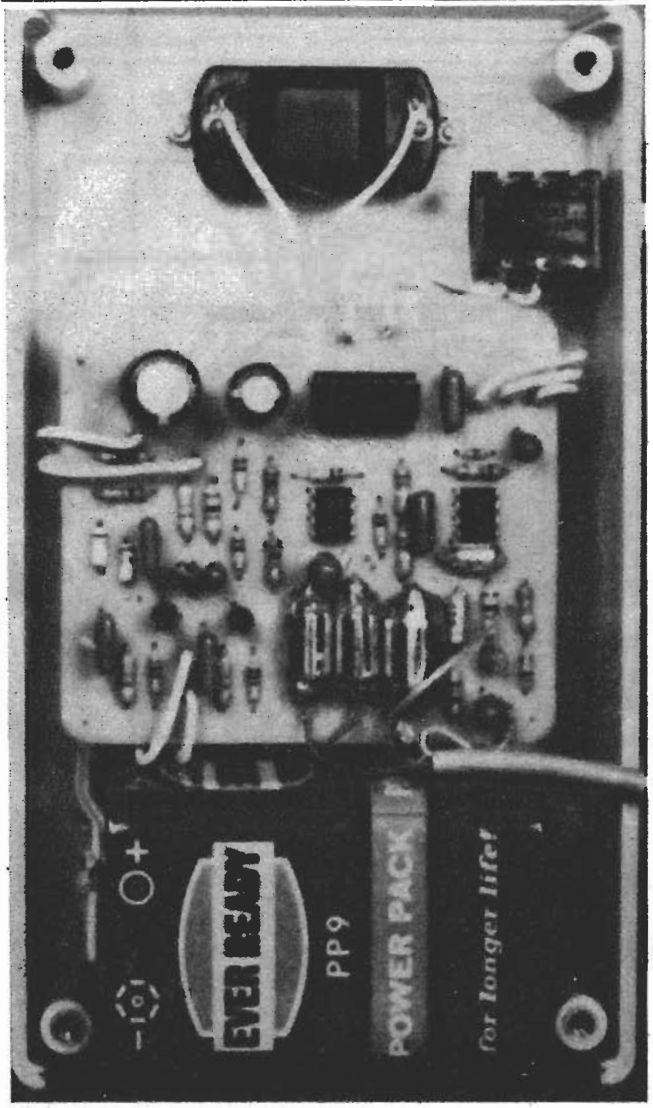
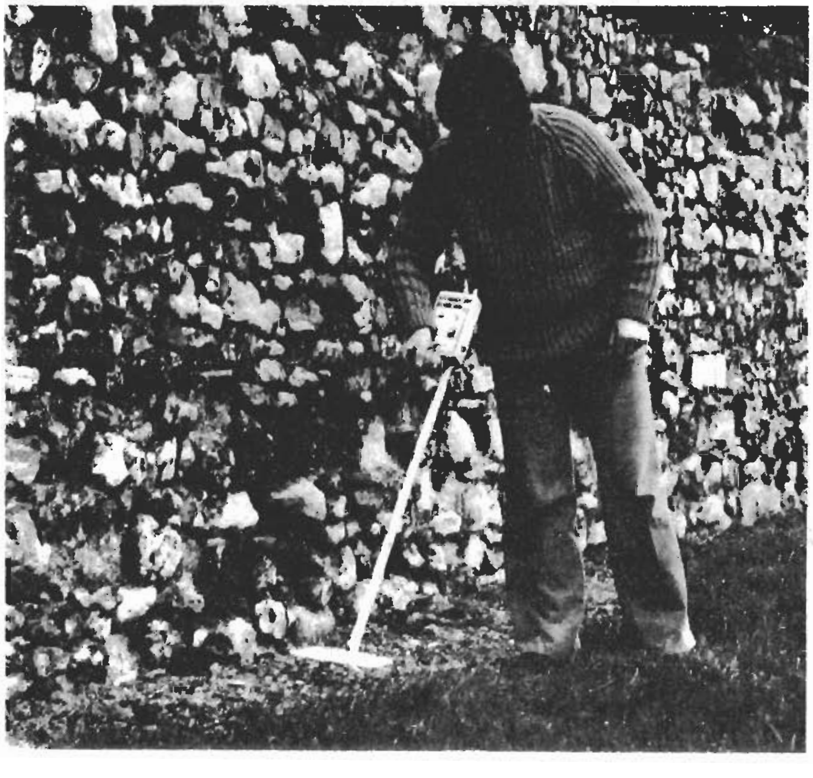


Fig 5. The component overlay on the PCB with the wires leading off to other parts of the circuit.



Internal view of the control box



Next time don't lose the map!

connecting cable to the main circuit. This cable must be a four-wire type with individual screening — the screens are not used at the search coil end but don't cut them too far back: we still have a few experiments to try out on our prototype and access to this screening may be used.

The Control Box

The circuit should be built up next. Everything except for the controls, the speaker and the meter are on a single PCB. Building this up should present few problems. Spacing is designed for eighth watt resistors and tantalums are used, again to save space though the control box has plenty of room in it.

Fit terminal pins to the points shown in the PCB overlay as this will make connections far easier to make later on.

Setting Up

We repeat — don't rush this part — it's what counts.

Assuming you haven't got the coil in exactly the right position by luck in the original setting, you should get an audio tone of about 700Hz from the speaker and the meter (if connected) will be hard over.

If you don't get this, adjust RV1 and it should appear. Back off RV1 until the frequency falls and then increase it a bit so that the tone is slightly higher than the minimum.

Now gently and slowly bend the coils and adjust the overlap till the tone falls. Add a few more blobs of glue but leave yourself with some adjustment. Readjust RV1 again and repeat. Continue to do this until you can no longer get any lower adjustment on RV1.

Now check that no metal is in the vicinity (don't forget cuff-links, watches and rings) and continue the manipulation.

If you use a scope, monitor the level of the signal of the collector of Q2: when you are near to a minimum the level should fall considerably.

If all works as described, bringing a piece of metal near the coil should result in the frequency rising. If the frequency falls instead of rising, continue adjusting. Near the minimum you can reach a point where the metal firstly adds to the cancellation.

Don't glue down the final tiny, tiny adjustments until you are quite certain that all is OK. The amount of final adjustment is extremely critical as you'll find out.

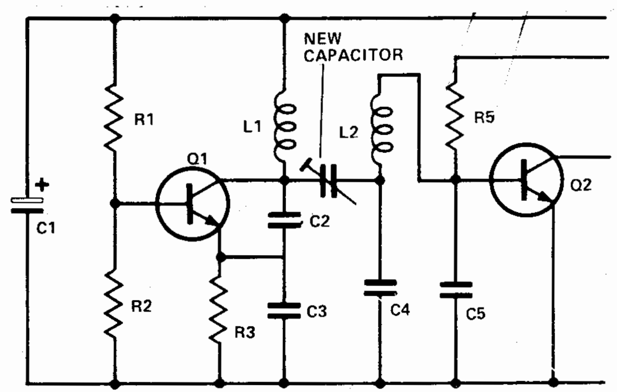
General Construction

The general design can be seen from the photographs. We used a Verobox to house the main circuit and cut a piece of broom-handle at an angle and fitted a bicycle hand-grip to this. The stem is made up from Marley 22 mm cold water plastic tubing, available from many plumbers. The connection to the search-head was accomplished by softening a short length of the stem plastic in hot water and quickly clamping this in a vice. The connectors on the stem are also Marley fittings. ETI

Balance Circuit For ETI Metal Locator

C. Bray

This modification is an improvement to the ETI IB metal locator Mark 2, as published in the February 1978 issue of ETI. The first two stages of the circuit showing have been redrawn showing the modifications, the additional trimmer capacitor is a Wingrove and Rogers type S60 multiturn tubular 2-25p, although any similar type giving smooth control between 1 and 8p will do. The function of the trimmer is to balance out coupling between the search head coils L1, L2.



In practice, the trimmer is set to approximately 3pf and the search head coils adjusted as in the original article.

Before a search is started, the trimmer should be adjusted for minimum meter reading, with gain control RV1 set as high as possible. This should be done in free air, but if it is found that lowering the head to the ground produces a slight change, this effect can also be trimmed out.

Even if the coils are mounted very substantially, and should not move, the degree of imbalance that occurs over quite short periods of time is surprisingly high and makes the fitting of this device well worthwhile.

C-MOS twin oscillator forms micropower metal detector

by Mark E. Anglin
Novar Electronics, Barberton, Ohio

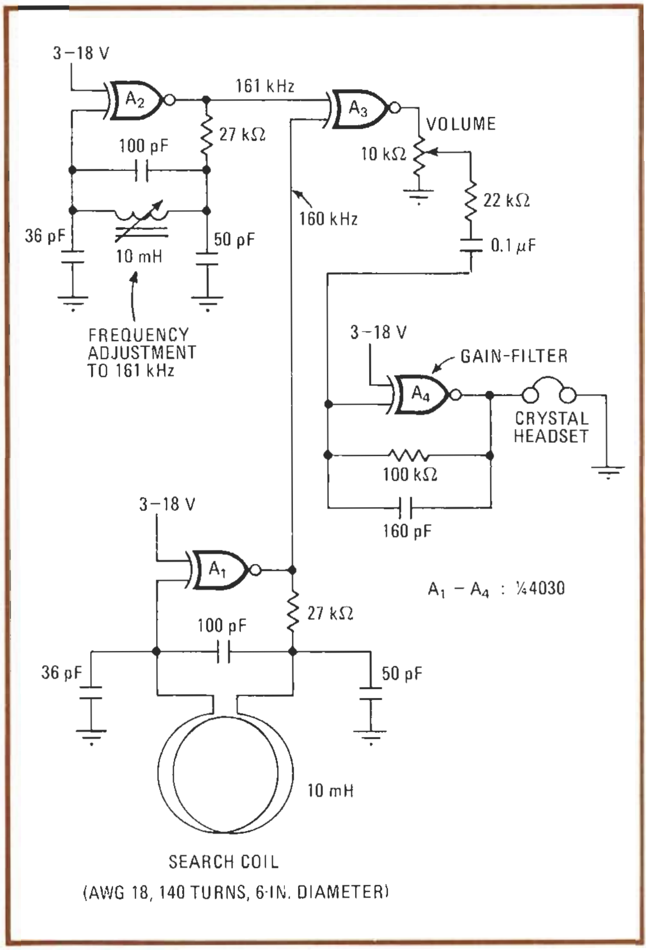
A battery-powered metal detector can be built with the four exclusive-OR gates contained in the 4030 complementary-metal-oxide-semiconductor integrated circuit. The gates are wired as a twin-oscillator circuit, and a search coil serves as the inductance element in one of the oscillators. When the coil is brought near metal, the resultant change in its effective inductance changes the oscillator's frequency.

Gates A_1 and A_2 in the figure are the active elements in the two simple oscillators, which are tuned to the fundamental frequencies of 160 and 161 kilohertz, respectively. A_1 serves as a variable oscillator containing the search coil, and A_2 oscillates at a constant frequency.

The pulses produced by each oscillator are mixed in A_3, and its output contains sum and difference frequencies at 1 and 321 kHz. The 321-kHz signal is filtered out easily by the 10-kHz low-pass filter at A_4, leaving the 1-kHz signal to be amplified for the crystal headset connected at the output. The headset has a high impedance (2,000 ohms) and therefore will not impose a big load on A_4.

A change in the output frequency indicates a frequency change in the variable oscillator due to the mutual-coupling effect between a metal and the search coil. The device's sensitivity, determined largely by the dimensions of the search coil, is sufficient to detect coin-sized objects a foot away.

This device's effectiveness derives from the twin-oscillator approach, because it is not feasible to directly vary a single oscillator operating at 1 kHz. An oscillator operating in this range requires high values of L and C, and these elements would load down the gate and consequently reduce circuit sensitivity. In addition, the cost of high-value inductors and capacitors is great. □



Metal detector. Two oscillators and a search coil form a simple metal detector. Objects near search coil change A_1's frequency of oscillation and the 1-kHz output note produced by the mixing of oscillators A_1 and A_2. A_4 amplifies and filters audio signal.

Discriminative metal detector

A sensitive instrument which can differentiate between ferrous and non-ferrous metals by measuring a phase change

by **R. C. V. Macario,** B.Sc., Ph.D., M.I.E.E., University College of Swansea

This metal detector combines high sensitivity with the ability to differentiate between ferrous and non-ferrous metals. Unlike conventional detectors, a visual display by l.e.ds is used for producing a sense of phase change. Headphones can also be used to give a Geiger counter type of audio indication. The complete unit will operate for over eight hours from a small battery.

THE ARTICLE by D.E.O'N. Waddington in *Wireless World* April 1977 was interesting because it outlined the rules by which metal detection may be legally carried out, and also showed how the sensitivity of a search coil alters with size. The sensitivity was discussed in terms of change in resonant frequency from a nominal value, which was shown to be a few hertz for a small object.

However, it is well-known that a change in frequency between one oscillator such as that connected to the search coil f_S, and another similar reference oscillator f_R, can be measured by observing the relative phase shift between the two oscillator signals[1]. For example, if the frequency difference between f_S and f_R is Δf, then the phase shift, which will be observed between the two oscillators after a time ΔT, is given by $\Delta\phi = 360.\Delta T.\Delta f$ ..... (1) Therefore if $\Delta f = f_S - f_R = 1$Hz, a phase shift of 360° will take one second. This effect is illustrated in Fig. 1 where f_S changes at time T_0 to a frequency slightly greater than f_R. After a time ΔT there is a considerable phase shift $\Delta\phi$ between the two signals. Clearly, if the phase differences can be observed, then very small differences of frequency can be detected and a very sensitive frequency difference detector can be built.

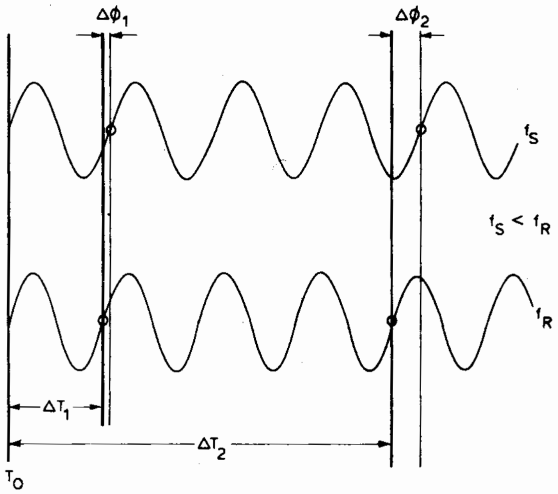


Fig. 1. *Oscillator waveforms showing phase difference changing with time.*

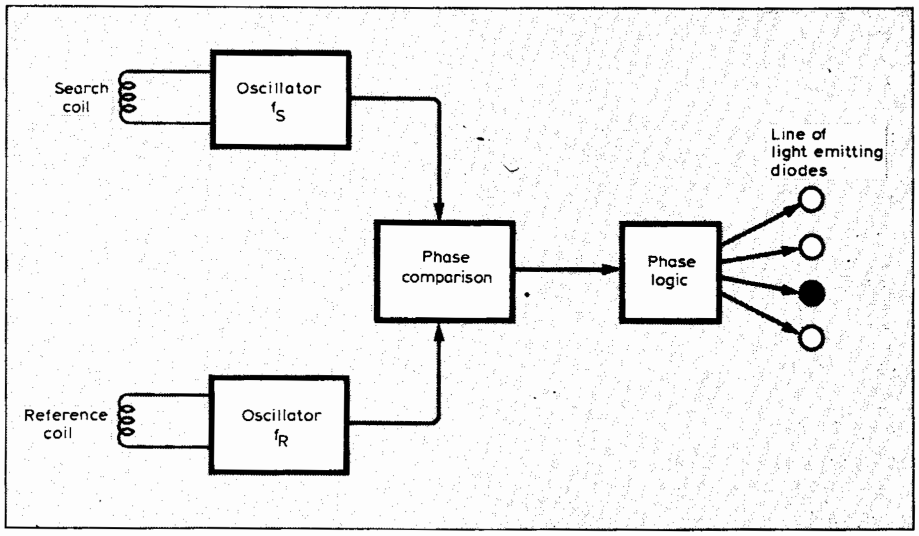


Fig. 2. *Basic detector arrangement.*

An interesting feature of this system is that the sign of $\Delta\phi$ is equal to the sign of the increasing or decreasing frequency. A metal detector based on the phase measuring principle will therefore have the ability to indicate whether a hidden object within the vicinity of the search coil is intensifying the magnetic field, ferro-magnetic, or diluting the magnetic field, dia-magnetic. In theory, differentiation between, for example, buried iron or brass objects can be indicated. Because the dia-magnetic effects are usually small, search coil self-capacitance and sample eddy-currents can mask the self-inductive effects. Nevertheless, the potential to differentiate exists and some investigators may find a study of alternative search coils worthwhile.

In the author's prototype system as shown in Fig. 2, the search coil oscillator phase is compared with a similar reference oscillator. The phase difference is displayed by a line of l.e.ds arranged to indicate in which quadrant the phase difference exists, see Fig. 3. As the phase changes a different l.e.d. is turned on. The rate of change is dictated by equation (1). For a frequency difference of 1Hz the illuminated l.e.d. will move along the row in one second, sweeping from left to right for a ferromagnetic object, and from right to left for a diamagnetic object. As the search coil moves closer to the object the speed of sweep increases until all of the l.e.ds appear to be on.

Circuit design

Because the circuit uses c.m.o.s. i.cs throughout, the current consumption of around 5mA is almost entirely used by the l.e.d. which is on. The oscillator design shown in Fig. 4 is very suitable for this application because it is clearly defined by a coil inductance and an associated tuning capacitor, therefore f_S, or $f_R = 1/2\pi\sqrt{LC}$. The output is also conveniently squared-up to the c.m.o.s. logic level.

The unit uses the search coil and frequency of 120kHz proposed by Waddington in *Wireless World* April 1977. The coil consists of 45 turns of 26 s.w.g. wire wound around a circle of 6½in diameter. A circular wooden former is used to support the coil and the complete assembly is covered with tape, aluminium foil, tape, expanded polystyrene and a final layer of tape. The foil is connected to the screen together with one end of the coil. Other coils and allowable frequencies, however, are just as suitable. The reference oscillator needs a frequency of four times f_S, i.e. 480kHz. This is also very convenient because a simple i.f. coil can be used.

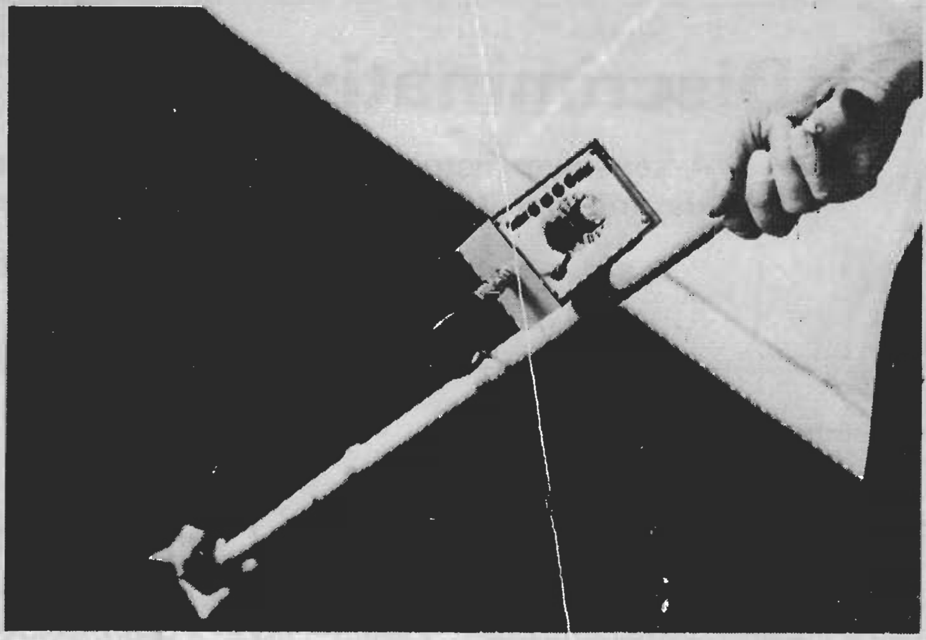
The circuitry for determining the phase difference between f_R and f_S uses two D type flip-flops as shown in Fig. 5. If f_S is applied to the two clock inputs, and the phase quadrant inputs of f_R are fed to the two D inputs, the input is only transferred to the output on a positive clock which produces the truth table below.

Phase quadrant f_R:f_S	0-90°	90°-180°	180°-270°	270°-0
Q_1	1	1	0	0
$\overline{Q_1}$	0	0	1	1
Q_2	1	0	0	1
$\overline{Q_2}$	0	1	1	0

The four outputs are then NANDed so that only one gate goes positive in each quadrant. The l.e.ds are arranged so that as the phase difference moves through the truth table, one device switches on after the other. To obtain the phase quadrature f_R signals, the well-known divide-by-four circuit shown in Fig. 6 is used. Another dual D-type flip-flop device is used to produce the outputs $f_R/4$ and $f_R/4 + 90°$ which is why f_R runs at $4f_S$.

The complete metal detector circuit is shown in Fig. 7. Five i.cs and four l.e.d. driver transistors perform all of the circuit operations. The signals are all square waves except at the oscillator coils where the frequencies f_S and $4f_R$ should be observed. The reference oscillator frequency can be tuned with a ferrite slug in the i.f. transformer coil L_2. The search coil is tuned by C_1 with the trimming capacitor in the mid position. When correctly tuned only one l.e.d. should be on which gives a stationary display except for the occasional hop. Adjusting C_{14}, or detecting an object, causes the light to run along the display in one direction or the other.

A suggested layout for the circuit is shown in Fig. 8. This printed circuit fits into an RS plastic box type 509-642 which measures 4½ × 2¾ × 2in together with all of the controls. The unit operates from a 9V PP3 battery which can be the rechargeable type. The



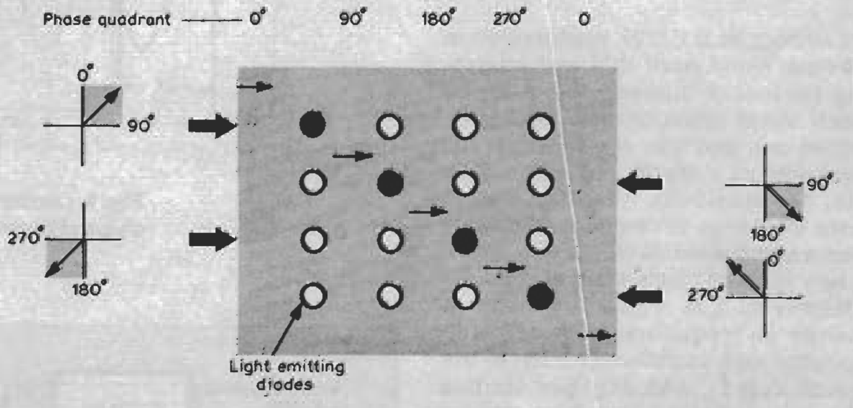


Fig. 3. *Line of l.e.ds indicating the four phase quadrants.*

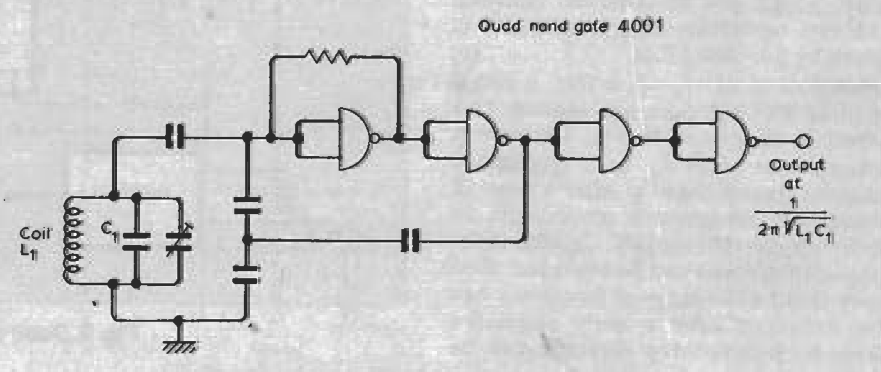


Fig. 4. *Basic l.c. oscillator using a quad NAND gate i.c.*

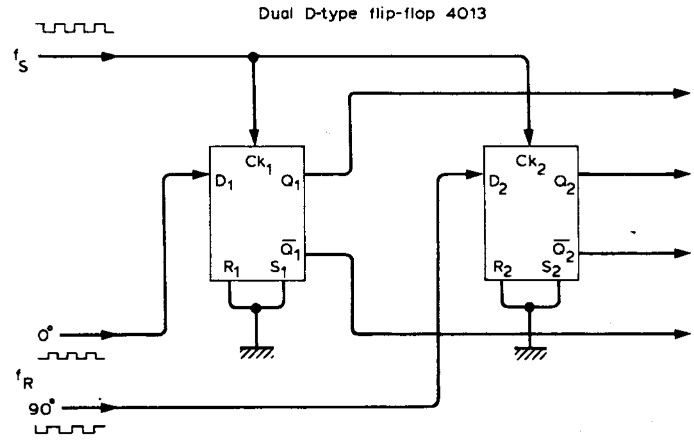


Fig. 5. *Phase quadrant comparison circuit*

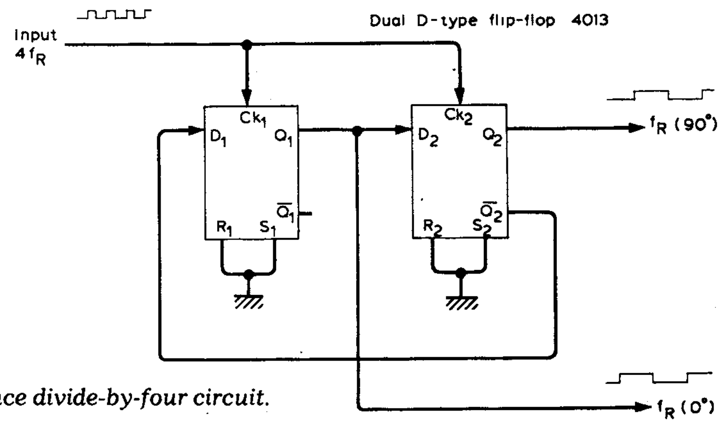


Fig. 6. *Reference divide-by-four circuit.*

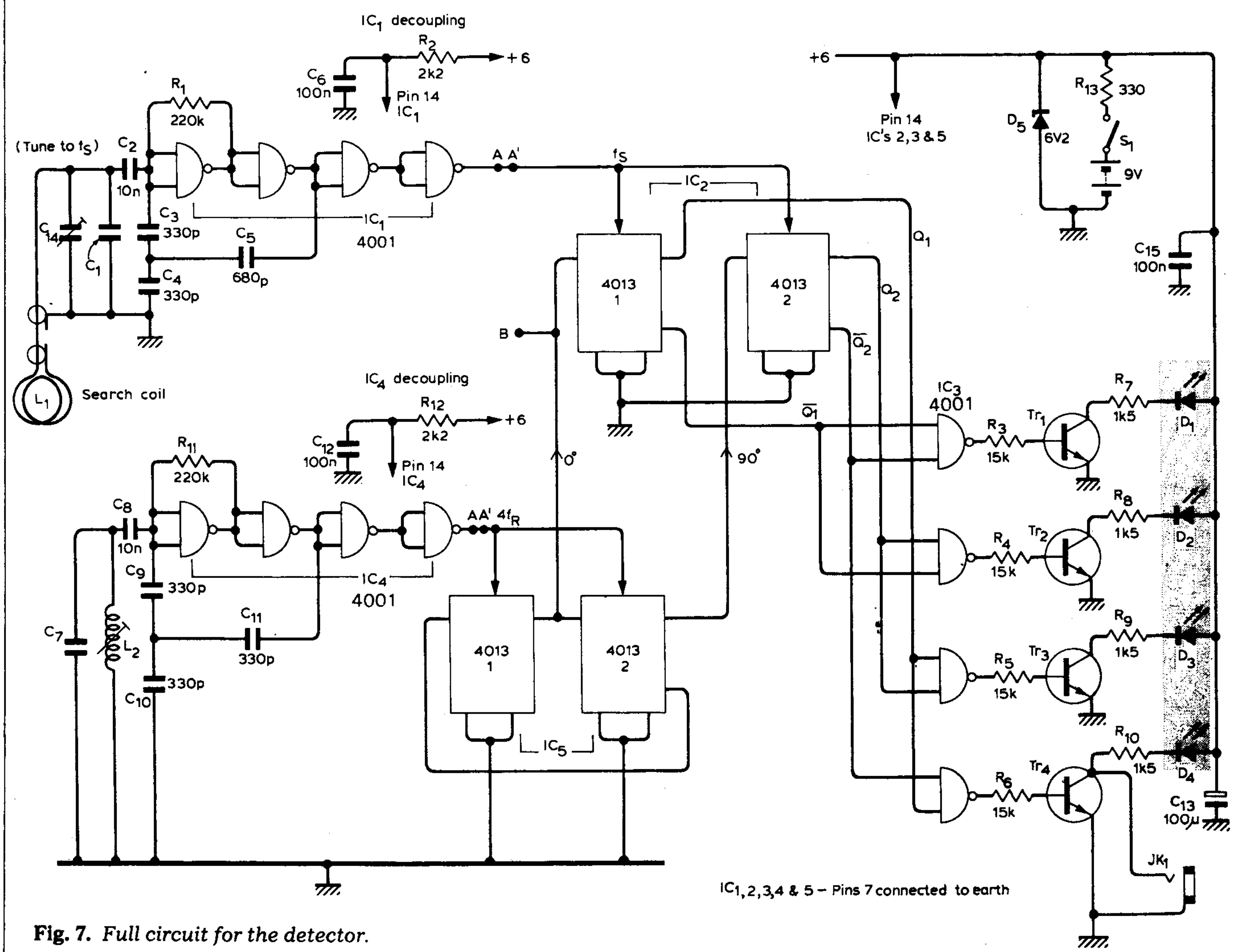


Fig. 7. *Full circuit for the detector.*

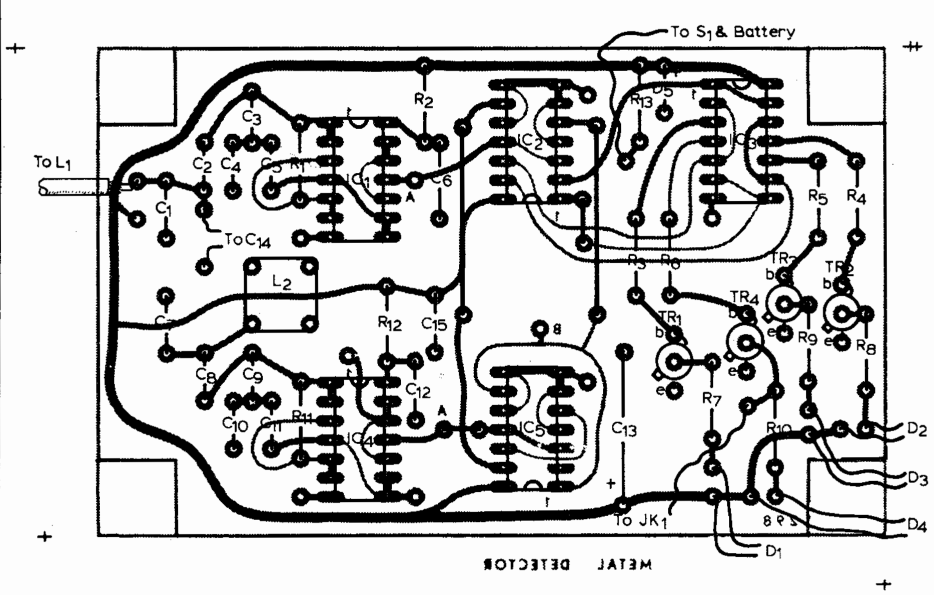


Fig. 8. *Printed circuit board layout and component overlay. A double sided board is used with the top copper layer forming a ground plane. All component leads connected to single pads are soldered to the top of the board. All other component connections are made on the underside of the board. The ground plane should be cleared with a small drill where necessary. Some additional pads have been provided on the layout to assist with the modification shown in Fig. 10.*

Printed circuit board

A double sided glass fibre p.c.b. for the metal detector will be available for £3.50 inclusive from M. R. Sagin at 23 Keyes Road, London, N.W.2.

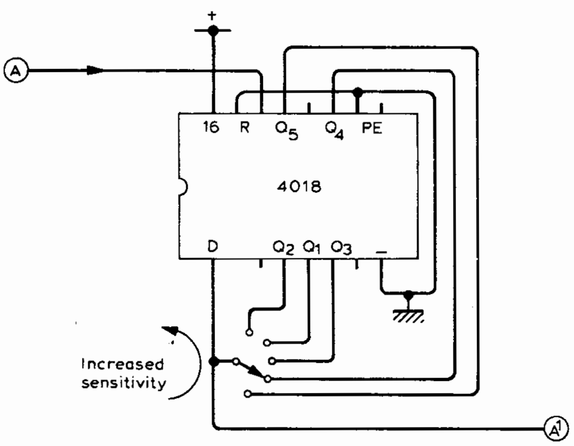


Fig. 9. *Divide-by-N circuit for variable sensitivity.*

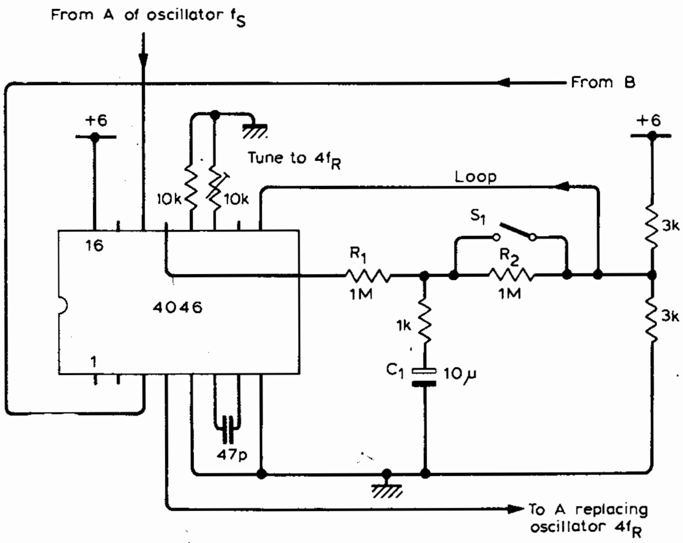


Fig. 10. *Voltage controlled oscillator This circuit replaces the f_R oscillator. The switch is a tune / operate control. When closed, C_{14} is adjusted for frequency balance, and when open the detector operates with a slow p.l.l. action. If the 4046 is mounted on the pcb in place of IC_4, the copper tracks should be cut where necessary.*

supply is regulated at 6V to reduce the tendency for f_R and f_S to lock.

Further considerations

The unit described is very sensitive to changing conditions around the search coil, and some form of sensitivity control is worth considering. The sensitivity is proportional to the frequency f_S, so a less sensitive version can be made by reducing the frequency of f_S and $4f_R$. One possibility is to reduce $4f_R$ to 120kHz and f_S to 30kHz, both of which are legal frequencies. A better method, however, is to divide f_S and f_R before comparison as shown in Fig. 9. Two identical divide-by-N circuits can be inserted between points A and A[1] of Fig. 7. With the switch connections shown, five sensitivity ranges can be selected from ½ to one-tenth of the full value.

Another characteristic which determines the sensitivity is temperature variation. Because the reference oscillator has to remain constant in frequency to within 1Hz, a frequency control is provided to compensate for small drifts. Although the problem is eased because both oscillators tend to drift in the same way, an interesting solution is to phase lock the two oscillators together. Fig. 10 shows a modification which can be made to the circuit shown in Fig. 7. A c.m.o.s. voltage controlled oscillator and phase detection device is used in place of the f_R oscillator. The v.c.o. section of the 4046 operates at $4f_R$, and the phase detection section compares f_S with the divide-by-four output of f_R to provide a control signal for the v.c.o. With this system the metal detector will always settle down and turn on the 0°-phase l.e.d. Moving the search coil past a buried metal object will cause the frequency f_S to change, but because f_R will then try and follow, a maximum indication may occur beyond the object. The choice of time constant can therefore depend on how fast the search coil is moved and is best determined by experimentation.

Because this metal detector has a visual display, headphones are not required. If the user prefers an audio indication and does not mind the loss of "directional" information for the type of magnetic material, a headphone can be connected across one of the l.e.ds which produces clicks rather like a Geiger counter.

Reference

1. Hewlett-Packard Application Note No. 52, 'Frequency and Time Standards,' 1962.

DISCRIMINATIVE METAL DETECTOR

I read the article "Discriminative metal detector" by R. C. V. Macario (July issue) with interest. Although the author states that eddy currents mask diamagnetic effects in non-ferromagnetic samples it is worth noting that these eddy currents do cause an increase in oscillator frequency. This is, of course, in the opposite direction to that caused by ferromagnetic samples, where the ferromagnetic effect usually masks the eddy currents.

The effect of eddy currents can easily be demonstrated by comparing the influence of a closed loop of thin wire with that of the same loop opened. [*Surely a coupled shorted-turn. – Ed.*]

The directional information could be restored with headphones by using the Q outputs of IC_2 to drive a simple resistor ladder and voltage controlled oscillator (eliminating IC_3, etc.).

M. Walne
Halifax

More letters on the metal detector will be published next month.–Ed.

LETTERS TO THE EDITOR

DISCRIMINATIVE METAL DETECTOR

The problem of distinguishing between ferrous and non-ferrous metal (July issue, p.43) is not quite as straightforward as it looks. To the search coil of a metal detector a piece of iron looks like a combination of two things: first, a loosely coupled 'short-circuited turn', since it conducts and loads the circuit, and secondly an iron core, since it has permeability which tends to increase the effective inductance of the coil. These effects oppose one another so the response of a detector to a piece of iron depends on their relative strengths. A detector operating at 100kHz or more is likely to 'see' iron more clearly by its conductance than its permeability, in which case it is not distinguishable from non-ferrous metal.

The present generation of metal detectors of the kind used by 'treasure hunters' attempts to solve this problem by means of a much lower operating frequency. Frequencies down to about 1kHz are in fact used. The permeability of a piece of iron is effectively greater and usually predominates over the conductance.

Working at audio frequency rather than a low radio frequency brings an additional bonus. At 100kHz, skin effect restricts current flow to the outside layer of metal, and all pieces of metal tend to look similar, if they are the same size and shape. At audio frequency current penetration is much greater; a piece of silver paper the size of a coin is 'seen' by the search coil as an object of lower Q. In the more sophisticated type of 'discriminator' detector this difference in Q is translated to a distinctive difference in the way the detector responds, and the 'treasure hunter' combing a holiday beach for coins can then avoid the time-wasting process of digging up endless ice cream wrappers etc.

There is, however, a continuing problem in the shape of the 'ring-pull' from a can of beer. This is aluminium and high-Q. A detector set to ignore it will also ignore valuable objects such as low-carat gold rings!

George Wareham
London WC2

Dr Macario's article on a metal detector (July issue) does not give the inductance of the search coil or the tuning capacitance but refers to Mr Waddington's, which I looked up. There the inductance is again not given so I assumed a diameter of 6 inches and a length of ½inch, and, using Nagaoka's constant, found an inductance of 680μH which with 500pF tunes to 250kHz, not 120kHz as stated by the author.

I wound the coil on a disc cut with a pocket knife from scrap polystyrene and the measured inductance agreed with the calculated. I then worked out the resonant frequency of the 625kHz oscillator and I found that it does not tune to 625kHz.

I have built several coils and cannot make the oscillator run anywhere near 125kHz except by adding about 2000pF.

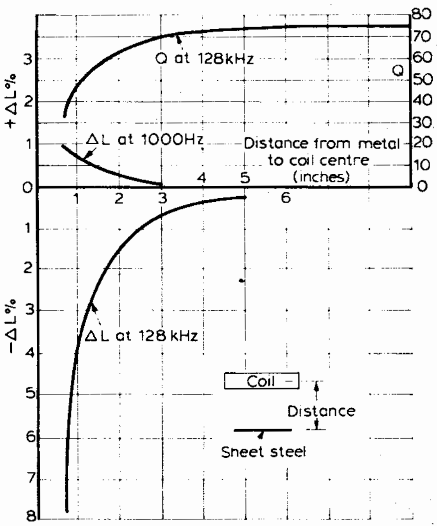
I used two different coils in the 625kHz oscillator. Mine runs at 750kHz.

The Waddington detector does have Home Office approval so it must work at the correct frequency.

The Macario oscillator has a lot of drive and a rough calculation indicates an r.f. voltage much larger than the supply voltage which is not possible with protective diodes on the c.m.o.s. input. The actual oscillator has a poor waveform because the tuned circuit is driven hard into the diodes. I could not deduce the actual oscillator frequency so I increased the capacitance to about 2400pF giving 130kHz.

All this has nothing to do with the point I originally intended to make, which is that I cannot see how the Macario detector can tell the difference between ferrous and non-ferrous metals. Over many years I have used a Q meter to measure r.f. coils mounted on a ferrous or non-ferrous chassis and I have always found the inductance is reduced by the proximity of any metal except, of course, dust iron or ferrite. The reason is that steel, which has magnetic properties increasing inductance at low audio frequencies, is a conductor and the eddy currents reduce the effective inductance. Which effect is more important depends on conductivity thickness and frequency.

The accompanying graph shows the change in inductance when a thin steel sheet (5½in x 3in, from a Polaroid film pack) is moved near the coil. Measurements of inductance were done both at 1000Hz and 128kHz. At 1000Hz the inductance increases slightly but at 128kHz there is a large change in the opposite direction. I have tried rusty steel. One piece increased the inductance, the rest decreased it.



My friends in the Chemistry Department cannot predict which oxide will be formed because it depends on the available water and oxygen. Most of the oxides will be non-magnetic but some magnetite might be formed and the remaining iron could be so divided that the eddy currents would be reduced. This would increase the inductance.

At 1000Hz it would be possible to make a detector to discriminate between ferrous and non-ferrous metals but not at r.f. using the beat frequency method of the Macario detector.

Another point concerns "pulling." When two oscillators work at nearly the same frequency one pulls the frequency of the other and they lock unless they are completely separate. In this case they are on the same circuit board and I am surprised to see that they can be adjusted to within a fraction of a Hz of one another. I built the Macario oscillator and set it up to give a Lissajous figure to check for locking. With 9 volts peak-to-peak from a signal generator (Marconi TF867) the exposed output lead (about 3 inches and a croc clip) was 4 inches at the nearest point from the oscillator. It locked over a range of about 12Hz.

Whether it locks on the complete detector will depend on the precise layout. If C_{14} and its wiring goes within a few inches of the 9-volt 120kHz reference from IC_7-point B, for example, it will lock.

There is other evidence for locking. When I removed the signal generator to avoid locking it was almost impossible to keep the Lissajous figure stationary because hand capacitance causes a shift of several hertz. After bringing the figure to rest, removal of the hand causes the figure to rotate. The oscillators should be in a screened box, not a plastic box.

If the two oscillators are free-running and the l.e.d. display is stationary this implies an oscillator stability and an accuracy of adjustment of a part in a million, which seems unlikely in a portable oscillator on the end of pole. Although I have not built the complete detector I am reasonably certain that the oscillators are not free-running but are in fact phase locked, not by design but by accident.

One last point, an l.e.d. display is almost invisible in sunlight.

M. D. Samain
Electrical Engineering Department
University of Salford

Dr Macario replies:
The letter by M. D. Samain is of importance as it outlines points which have been raised by a considerable number of other readers following my article in the July issue. Actually, the article was originally entitled "A different metal detector"; the word "discriminative" came in later, but as Mr Samain points out this is a much more complicated matter than just one word in a title allows. I did make it clear in the text that "the potential to differentiate exists . . .", and I would be interested to hear of any comprehensive reference on the effects of various small metal objects in the vicinity of a search coil. I did make a brief reference search at the time but without success.

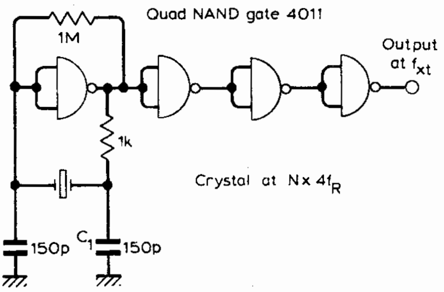
I had also made a few simple tests at 85kHz and noted the following:

1. Small solid brass/iron objects can be discriminated as theory suggests.
2. Large metal objects, such as Samain uses, cause a lowering of inductance due to eddy currents.
3. Small metal objects with holes such as washers act as a shorted turn and are not necessarily discriminated.
4. The orientation of a flat object with respect to the plane of the coil can alter the above findings.

I will return to the idea of using a lower frequency later.

The next point is that of not showing the coil inductance and tuning capacitance. The coil shown in the photograph in the article was a Waddington coil provided by a colleague and was simply tuned to 125kHz and/or 85kHz for test purposes. The capacitance C_1 used had to be much larger than that given by Waddington. The sensitivity of a metal detector may well depend on the number of the turns in the coil, rather than its inductance being matched to a particular tuning capacitor, and this is another area of useful investigation. The only data available to us at the present time is Waddington's.

The choice of inductance, tuning capacitance and frequency also affects the best ratio of feedback capacitors C_3:C_4:C_5. As the frequency is lowered they should all be made correspondingly larger. Then increase C_4 to obtain a good sinewave at the oscillator input. An excellent sinewave of about 2V peak-to-peak is available. A square wave



occurs at all other outputs except at the input of C_5.

Although the voltage swings of the two oscillators are large, in fact equal to the supply, the current is very small, and locking of the two oscillators is minimal. This is partly due to the use of a double sided p.c. board (which is always good practice when dealing with r.f. circuits) while all the components are inserted tight to the board. The board size shown in the article is, however, about the smallest one can use in practice. The circuit is also balanced and therefore the supply current remains constant for all phases. Actually, the circuit does just show a tendency to lock within the nearest Hz. This is useful in a way, because the display has a chance to settle down. Two improvements are: (1) put 10kΩ between points A and A^1, (2) place the earphone outlet between Q and $\bar{Q}$ of either 4013 output in series with 22kΩ.

This brings me to my main point which is that, like Mr Samain, I am extremely doubtful of the long term practicality of building an LC oscillator of very high stability with the inductor being waved around at the end of a pole. I did discuss this briefly in the article and put forward some ideas for experimentation. However, let us look at the question of going to a lower frequency again. If, for example, a detected object which caused a 10Hz change in frequency at 100kHz, only caused a 1Hz change at 10kHz, the sensitivity problem is not solved. However, if the change was 2Hz because there were more turns on the coil etc., then an improvement would result. As I said earlier, some information in this area is needed – at least by me.

Finally, the detector described is sensitive in theory to a change in frequency of ¼Hz in one second. This sensitivity can be increased by making the reference oscillator frequency $4f_R$ a multiple of this frequency, i.e. $N \times 4f_R$. For example, using a coil at 30kHz requires $4f_R$ = 120kHz. Making this a crystal oscillator running at 1.920MHz makes the detector eight times more sensitive (and also to variations of the search coil). A suitable crystal oscillator (stable to within 1Hz) is shown in Fig. 1. This uses a quad NAND (4011) or quad NOR (4001) device as already available in my detector, and replaces the reference oscillator. The frequency is set by adjusting capacitor C_1.

R. C. V. Macario
University College of Swansea

EARTH RESISTIVITY METER

eti project

From gold to archaeological remains — this simply constructed instrument will assist your prospecting.

AS the article on page 121 explains an earth resistivity meter can be used to identify the composition of various earth strata — and the depth at which each strata occurs — and by detecting changes in earth composition, to point to the existence of buried objects.

An earth resistivity meter may be used to locate archaeological objects — to assist in finding conditions favourable for alluvial gold or gestones, or even for such prosaic duties as determing where to locate a septic tank!

These instruments are not expensive compared with most electronic instrumentation. Nevertheless at £250 or so they are way above the budget of most amateur archaeologists or rock-hounds.

But for such people all is not lost — it is possible to construct a simple dc operated resistivity meter for a mere fraction of the price of commercial units.

For this to be possible we have to accept a few operating limitations — primarily of operating depth — for whereas a commercial unit may be used to depths of several hundred feet our unit is limited to fifty feet or so. But unless you are hoping to locate oil bearing deposits in your garden the limitation on operating depth should not be a problem.

The basic instrument is extremely simple — four equally spaced electrodes are placed in line in the earth. An accurately known current is caused to flow from one outer electrode to the other — and a measurement is taken of the voltage between the two inner electrodes.

Having measured both voltage and current, a simple formula (explained on page 121) is used to establish depth and composition of the strata.

Professional earth resistivity meters use alternating current across the earth electrodes in order to eliminate the effects of the small galvanic voltages caused by the earth.

This effect cannot be totally eliminated with dc instruments but it can be minimized by switching the battery across the electrodes in alternate polarities — a centre position of the switch (SW2) meanwhile short-circuits the two centre electrodes between readings to discharge the galvanic potential.

Figure 1 shows the circuit diagram of the instrument.

We have not provided any mechanical assembly drawings, for this will depend almost entirely upon the meters used. A pair of cheap multimeters are ideal — but if these are not available then a voltmeter and a milliameter with switchable ranges should be used. The milliameter should be capable of measuring from microamps to a maximum of 100 milliamps or so, the voltmeter should cover a range from approximately 100 microvolts to three volts or so and should have a sensitivity of about 20,000 ohms per volt.

Switch SW2 is a three-pole four-way wafer switch. All switching contacts are located on one wafer. Each of the four segments shown in the circuit diagram (ie. SW1 SW2 etc) consists of a wiping contact and three fixed contacts — the connections will be readily apparent when the circuit diagram is compared with the switch.

The ground probes should ideally be made of copper coated steel or brass — however electrodes made from ½" to 1" steel tubing or rod will work quite well as long as they are kept clean. It is of course essential that they make the best possible contact with the surrounding earth. Electrode cable connections must be securely made using proper terminals — remember that you are looking for fairly minor changes in earth resistance.

Operating voltage is not critical — a six or twelve volt dry cell is adequate for most applications. ●

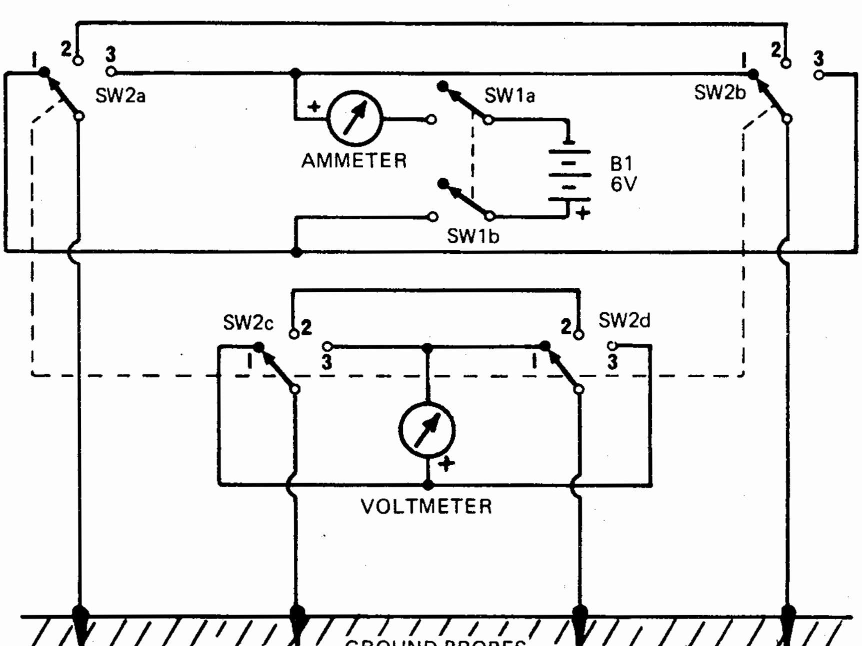


Fig. 1. Circuit diagram of resistivity meter.

Using a resistivity meter

MEASURING EARTH RESISTIVITY

THERE are several methods of measuring soil resistivities, mostly variations of the original method devised by Wenner. This consists of driving four metal spikes (commonly called electrodes), into the ground, at equal intervals along a straight line as shown in Fig. 1.

A current is passed through the outer electrodes C_1 and C_2 and the resulting voltage drop across the earth resistance is measured across the inner pair p_1 and p_2.

If the ground has a uniform resistivity p then

$$p = 2\pi a \, {}^{V}/_{I} = 2\pi a R$$

where 'R' is the apparent resistance measured between the inner potential electrodes.

Generally the current will flow in an arc between the electrodes and hence the depth penetrated will increase as the electrode separation is increased. The effective depth at which R is measured is usually taken as 0.6 times the separation 'a'.

For the greatest accuracy in determining the ratio V/I it is desirable that the current flow I be maximized and hence in dry surface conditions it is common to moisten the soil about the electrodes to reduce the contact resistance. The depth to which the electrodes are inserted must not exceed 1/20th of their separation. This is important if standard curves are to be used for the interpretation of the experimental data.

Having inserted the four electrodes an average value for both V and I must be determined for both polarities of the battery. Reversing the polarity removes the possibility that the earth may have its own potential due to galvanic reactions underground. From these measurements the resistivity p can be calculated.

RESISTIVITY DEPTH SOUNDING

Consider for example the problem of measuring the depth beneath the ground of the water table or perhaps the thickness of soil overlying the bedrock. This type of situation is by far the most common — where a layer of resistivity p_1 and thickness 'd' is overlying a layer of different resistivity p_2.

We can determine the depth 'd' with the aid of 'standard curves'. The procedure is to measure the resistivity of the ground each time the electrode separation 'a' is increased about a central point. To use the standard curves provided it is necessary to plot the measured resistivity (p) on the vertical axis, against the electrode separation distance on log/log graph paper.

The standard curves provided (Fig. 2), are also constructed on log/log graph paper i.e. graph paper that is ruled in both directions at logarithmic intervals. Each major division on the paper corresponds to a power of 10 and is therefore called a decade. We suggest that for plotting your data you purchase semi-transparent paper that has three decades on either axis and a decade separation of 2½ inches. The 2½ inch decade separation is most important as paper having other decade separations will not allow your plotted results to be overlayed on the standard curves. This paper should be readily available from major stationary suppliers.

Figure 3 shows a typical plot of field data overlayed onto the standard curve.

To do this, place your plotted curve over the standard curve and slide it horizontally until you find the standard curve that best matches your plotted curve.

When the best matching curve has been found, note where the vertical axis of the standard curve intersects the 'ab' curve of your plotted data. This line extended vertically downwards to intersect the 'electrode separation' axis of your plotted data will show the depth of the first layer — in our example this is 4.25 metres.

We know from our plotted data that the resistivity p_2 is about 1000 ohms/metre and the standard curve that is a best match shows a p_2/p_1 ratio of one tenth, that is p_2 equals 0.1 p_1.

Thus p_2 is approximately 100 ohms/metre. Relating these figures to Table II we see that the most likely strata formation is two layers of sandstone of different densities — or a top layer of sandstone and a lower layer of limestone.

From the section bc it is possible to calculate the resistivity and depth of the second layer but this requires the use of a second set of auxiliary standard curves. These are very complex and beyond the scope of this article. Similarly section cd provides data on the third layer and so on. There are a number of standard texts on such measurement and the interested experimenter should refer to these for further information.

RESISTIVITY TRENCHING

Another common application of the resistivity meter is in searching for buried objects such as large water mains, buried stream beds or underground sewerage tunnels. The method used is simply to decide approximately at what depth the object is likely to be found, and divide the distance by 0.6 to give a suitable electrode separation. Maintaining this same separation, the array of all 4 electrodes should be progressively moved in a line over the ground being explored. Readings of resistivity should be made at each point and the value plotted against distance moved. (See Fig. 6 page 29) The distance between each reading point should be no greater than half the dimension of

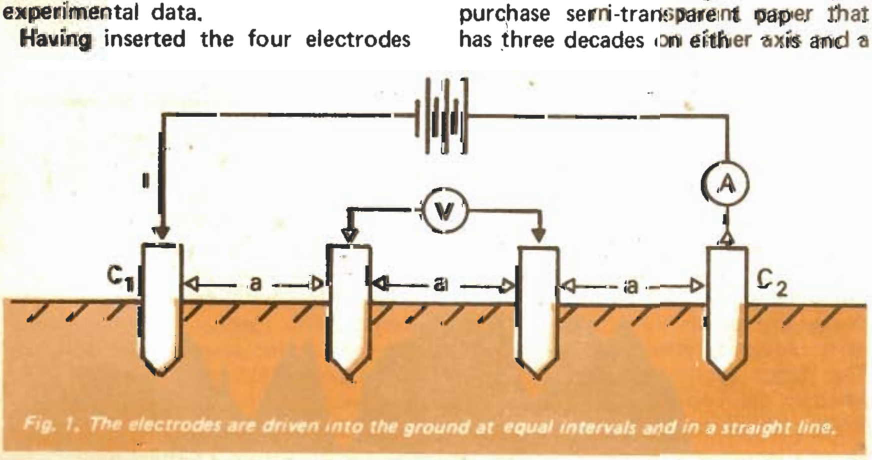


Fig. 1. The electrodes are driven into the ground at equal intervals and in a straight line.

TABLE I

Material	Resistivity (ohms/metre)
Clay	1-120
Water (fresh)	80
Sandstone	35-4000
Limestone	120-400
Granite	5000–10^6
Sand (dry)	$>10^6$
Marble	$>10^{12}$
Alluvium	Variable
Air	Infinite

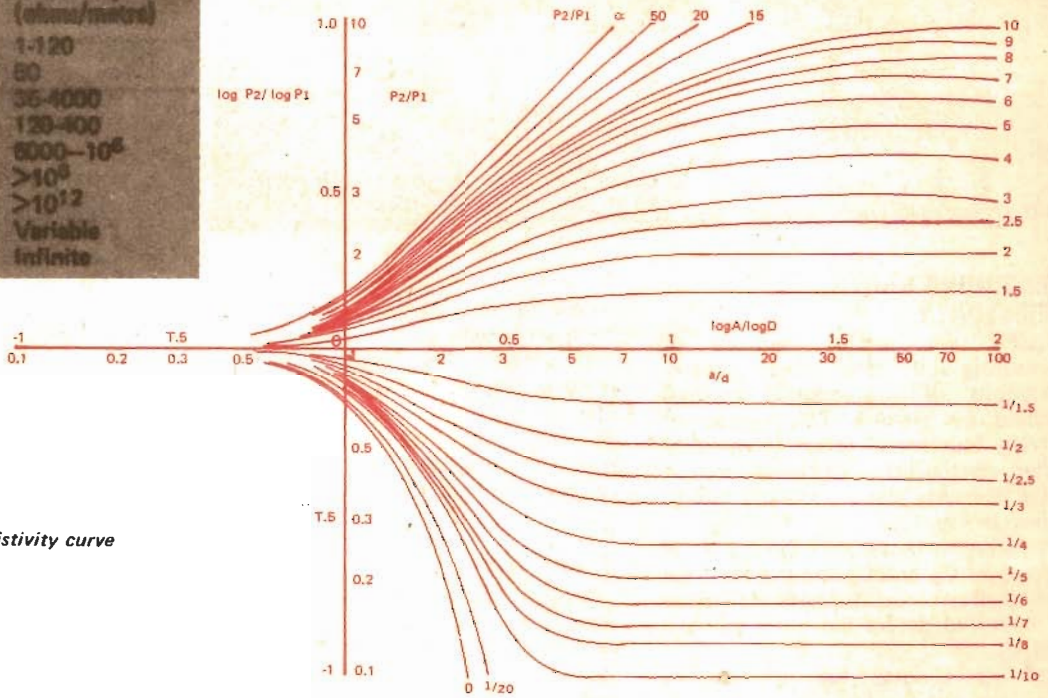


Fig. 2. Standard resistivity curve

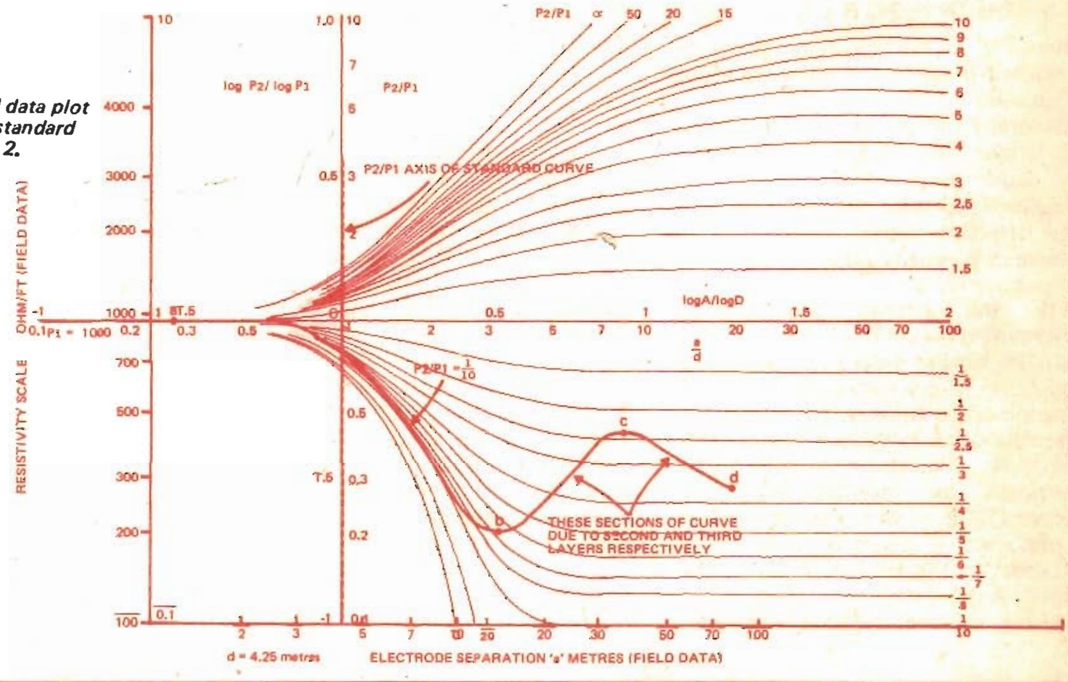


Fig. 3. Typical field data plot superimposed over standard curve shown in Fig. 2.

Earth electrodes should not be inserted into the ground to a depth greater than 1/20th of the probe separation. Because of this, poor electrode/ground contact may result at close spacings. This problem can be reduced by using porous pots filled with copper sulphate solution. Electrodes specifically intended for such work are available from geophysical supply houses.

the object to be located; in fact the closer the readings are taken, the greater will be the resolution.

If it is desired to follow the depth of bedrock beneath the surface, it is best to first carry out a vertical depth sounding to locate the bedrock. Then divide this depth by 0.6 to give the most suitable electrode separation. The depth sound will also tell you whether the bedrock has a higher or lower resistivity (from the ratio ρ_2/ρ_1). If ρ_2 is greater than ρ_1 then an increase in your measured resistivity will tell you that the basement is getting shallower and vice versa. Alternatively, if ρ_2 is less than ρ_1 an increase in resistivity will indicate that the basement is becoming deeper. This method is most suitable for looking for alluvial gold or heavy gemstones which tend to be concentrated in the hollows of the bedrock along alluvial creekbeds. ●

Metal Detector

J. P. Macaulay

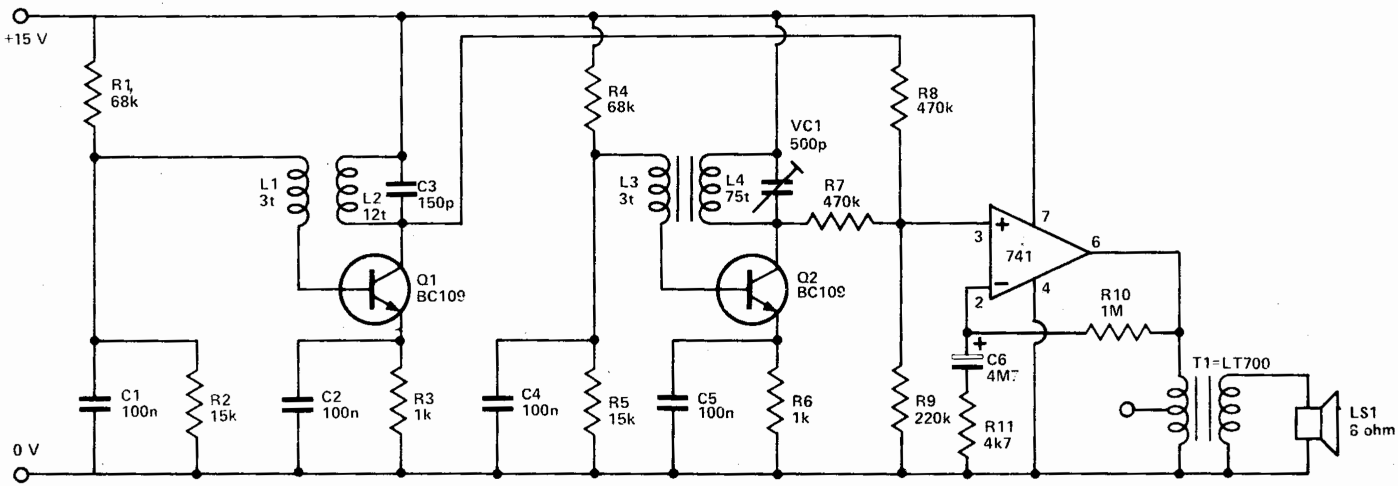
In common with most simple detectors, this circuit uses the fact that the inductance of the search coil changes when it nears a metallic object.

The search coil, L2, is 12 turns wound on a 6 inch diameter non magnetic former, using 26 SWG wire.

The pickup coil, L1, consists of 3 turns of similar wire wound next to L2 on the former. C3 tunes L2 to approximately 700 kHz and L2 and L1 are connected in the collector and base circuits of Q1 to form, with the associated components, a simple oscillator.

The local oscillator, built around Q2 is essentially the same as the search oscillator. L4 and L5 are however close wound on a .375 inch diameter ferrite rod, 3 inches long. Output from both oscillators is fed via a passive mixer, R7 and R8, to the non-inverting input of IC1. R9 in conjunction with R7 and R8 provide the IC with the required bias voltage.

Because of the IC's internal roll off it will not amplify the RF, but will pass the audio beat frequency. T1 interfaces the output of the IC to the speaker, LS1.



SENSITIVE METAL DETECTOR

Several readers have asked us to design a good metal detector. When our 'research and development' group took a closer look at the problem, they soon discovered why: most conventional designs are not really suitable for the home constructor!
In most designs, extreme care must be taken to screen the various sections of the circuit from one another and the power supply must be carefully filtered.
A different design approach was chosen for the circuit described here. With a little care, the average home constructor should be able to build a highly sensitive metal detector, which will be suitable for a wide variety of uses.

The normal way to construct a metal detector is to have two oscillators working on the same frequency. One of these is crystal controlled, and the other is connected to the pick-up coil (figure 1). The output of the two oscillators is fed to a mixer stage. When both oscillators are working at exactly the same frequency, the difference frequency is zero. However, when a metal object is brought into the vicinity of the pick-up coil the frequency of the VFO will change. This causes a 'beat' frequency to appear at the output of the mixer. This is filtered and amplified, and fed to a headphone. So far so good, or so one would think. The difficulty with this system is that the slightest amount of coupling between the two oscillators will 'pull' the VFO into lock with the crystal oscillator. When this is the case, quite a hefty lump of metal is required to get an audible indication.
A further problem is that the coil determines the frequency of the VFO. It has to be wound exactly according to specification, or else the tuning range of the VFO will not include the frequency of the crystal oscillator. Changing coils can be a major problem.
Both of these problems can be resolved to a very large extent by resorting to a different design approach. This is shown in the block diagram (figure 2) and the practical circuit (figure 3).
In the Elektor design the crystal oscillator has been replaced by a less expensive ceramic filter oscillator. The oscillation frequency is determined by a 455 kHz filter in the feedback path of T1. Granted, this oscillator will not be as stable as a crystal controlled unit but it is sufficiently stable for the purpose. The output from this oscillator is passed to a divide-by-10 stage (IC1), which will now deliver a 45.5 kHz square wave.

This output is passed through two pulse shapers in cascade (C4, R6, N1 and C5, R7, N2). This produces very short pulses with a repetition frequency of 45.5 kHz. This signal has a spectrum which extends well into the megahertz range, with 'spikes' every 45.5 kHz. Each spike can be used to produce a beat frequency with the VFO. This signal is passed to the mixer stage (T2).
The main components of the VFO are T4, C17, C18 and the frequency determining components C_T and L_S, the search coil. It oscillates at a very high frequency. As an example, if the search coil is made of three turns on a 3 inches diameter form, the frequency can be adjusted to approximately 3.5 MHz. This signal is fed to the mixer, through a buffer stage (T3).
The output from the mixer stage is passed through a low-pass filter and an amplifier to the headphones. The active devices used in these stages are gates N3 and N4, biassed to work as 'linear' amplifiers.
Since the 'fixed frequency reference' produces a broad spectrum, it is not difficult to find a 'zero beat' setting of the VFO. This has the added advantage that changing coils becomes a simple matter: there are so many spikes in the reference spectrum that almost any coil will produce a beat frequency somewhere within the tuning range. In practice, there will be 'loud' and 'soft' zero beats; obviously, it is advisable to select a loud and obvious one.
The coil diameter will depend on the

1

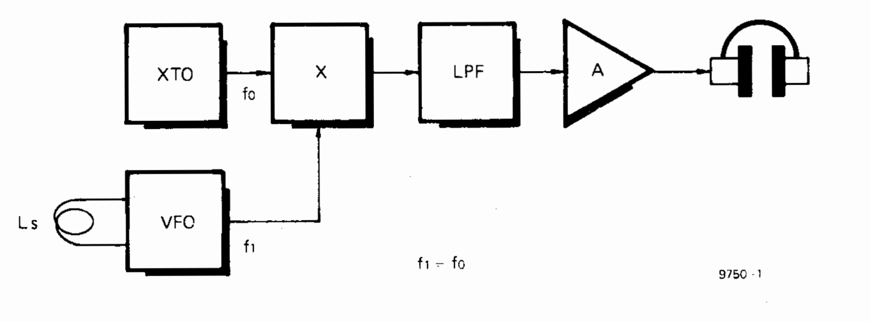


Figure 1. Block diagram of a conventional metal detector. The VFO is set at the same frequency as the crystal oscillator.

Figure 2. Block diagram of the metal detector described here. The output from the crystal oscillator is divided down to a lower frequency and then fed to a pulse shaper, producing a very broad spectrum of reference frequencies.

For the calculation of the value R_X, the following formula therefore applies:

$$R_X \approx \frac{1.5 \times V_{Tr} - V_{NiCad}}{0.01 \times I_{Ah}}$$

where

V_{Tr} = secondary voltage of the mains transformer;

V_{NiCad} = nominal voltage of the accumulator;

I_{Ah} = accumulator capacity in amp-hours.

In the event of a mains failure, the circuit receives it supply voltage via D2. Under these conditions, the noise output of the signal horn is perceptibly, but not drastically, reduced. If the Signal Horn is not switched on, then the current consumption is less than 15 mA. A small accumulator with a capacity of 100 mAh should be sufficient for most applications.

Note that it is highly recommended to inform the local police how to put the alarm out of action.

Use of the circuit as a game of skill

The circuit detects movements. It can therefore be used as a game of skill by attempting to 'beat' the detector by moving very slowly. The winner must exercise good muscle control in order to move sufficiently slowly. An element of luck is involved, however, since involuntary movements and reflexes will activate the alarm if the sensitivity is high enough.

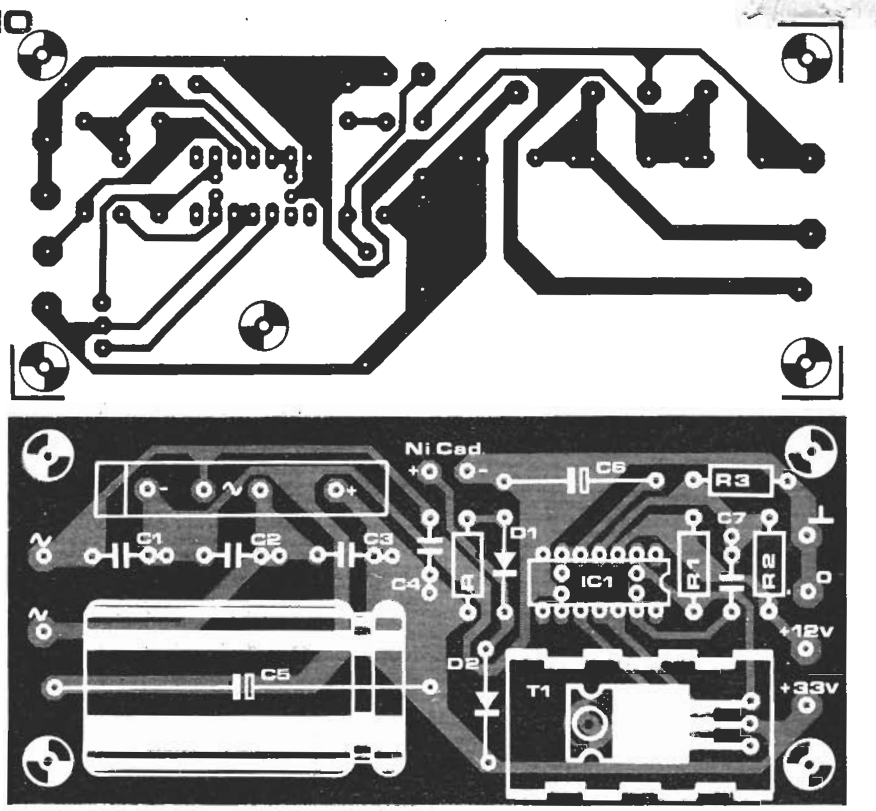
Figure 9. Printed circuit board for Albar (EPS 9428).

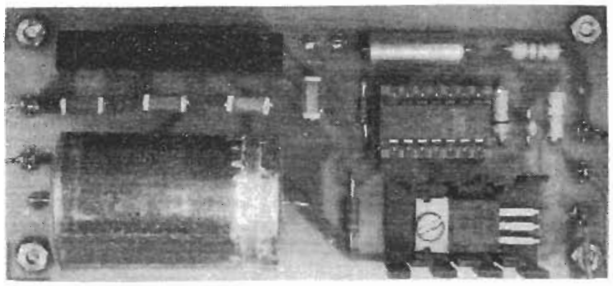
Figure 10. Printed circuit board for the mains unit of figure 11. It is capable of supplying the Signal Horn in addition to the detector circuits (EPS 9437).

Figure 11. Mains unit for the Albar(s) and the Signal Horn (which requires the 33 V supply).

Photo A. Some ultrasonic transducers. The Murata types (group 2 on the photo) are highly recommended. Other types (like the first one on the photo) may not be suitable in this circuit.

10





Parts list for figure 11.

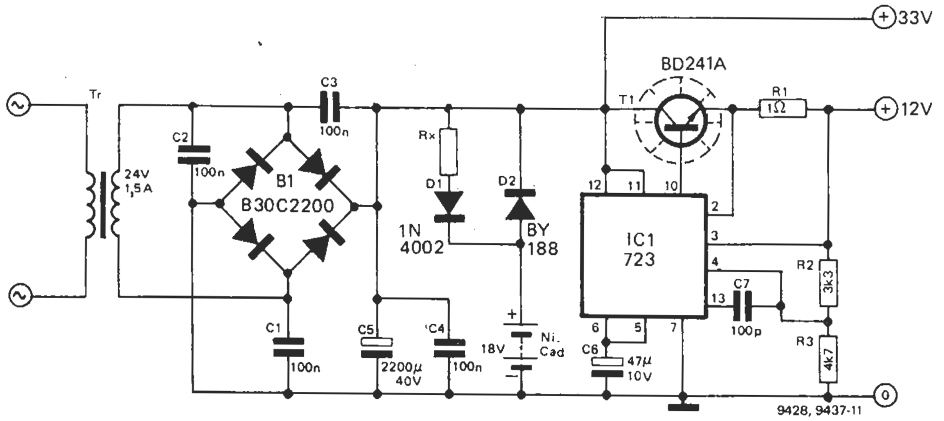
Resistors:
R1 = 1 Ω
R2 = 3k3
R3 = 4k7
R_X = see text

Capacitors:
C1 . . . C4 = 100 n
C5 = 2200 μ/40 V
C6 = 47 μ/10 V
C7 = 100 p

Semiconductors:
T1 = BD241A, MJE3055
D1,D2 = 1N4002, BY188
IC1 = 723

Miscellaneous:
Tr = Transformer, 24 V/1.5 A
NiCad Accumulator, 18 V (see text)

11



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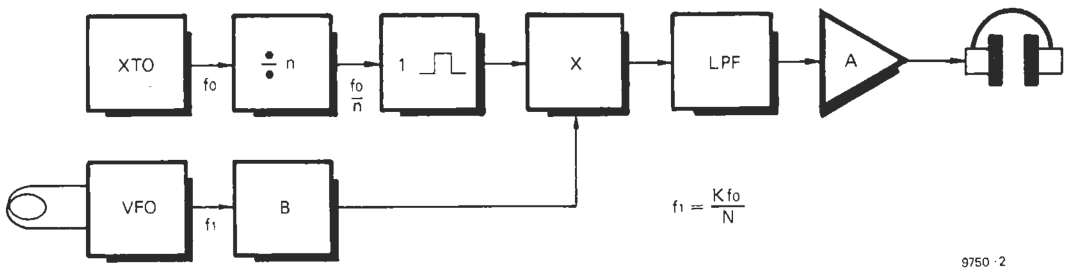
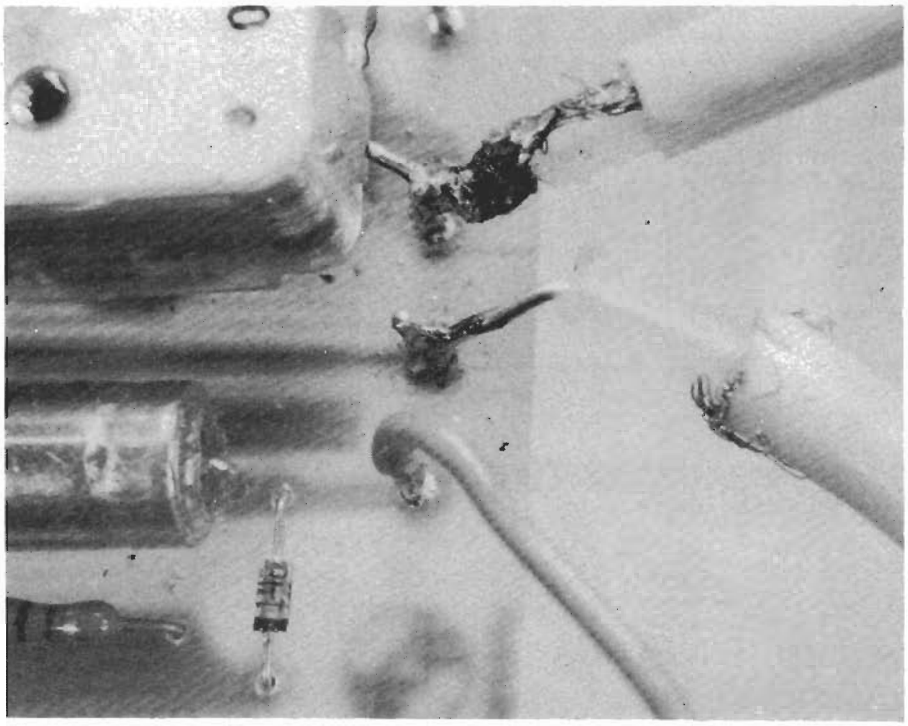
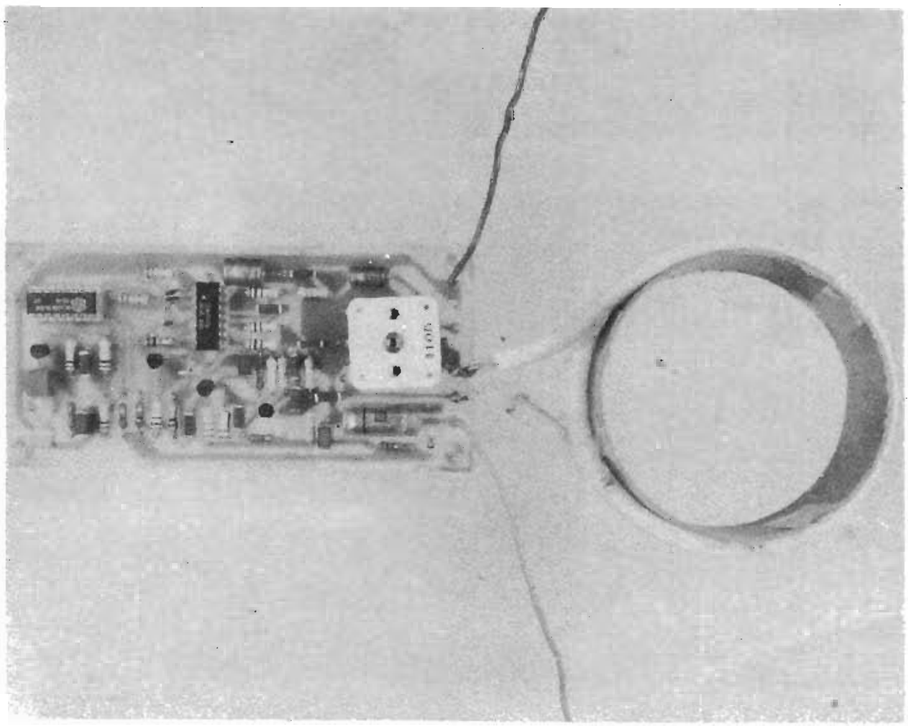






purpose for which the detector is to be used: a large coil is useful for approximate location of relatively large objects, whereas a small coil can be used to pin-point the exact position of even a small object. The coil former can be plastic tube, up to the maximum tube diameter available (8 to 10 inches). For larger coils it becomes more difficult — but who says a coil must be round? A square section is also quite permissible. The best material to use for the coil is screened cable or coax, with a closely-wound screening braid. The core is used for the coil, and the screen is connected at one end to supply common. Remember, the coil is supposed to respond to a *magnetic* field change — it is not supposed to pick up short-wave transmissions!

The value of the tuning capacitor (C_T) is not critical. Any trimmer that will fit on the board and has a value between 100 p and 350 p should be suitable.

The construction of the whole circuit, including the coil, must be mechanically rugged. This is one of the reasons for using a p.c. board.

Using the detector

Several 'field tests' have shown that this metal detector is quite sensitive. For instance, a very small piece of metal was buried at a depth of over 6 inches. When the metal detector was used to search in the general area indicated, a large number of objects were located — including several orange-coloured (ferrous?) stones . . . In another test, the position of an old brass farthing was accurately pin-pointed under a two-inch thick pile of papers.

The metal detector has also proved useful for locating electrical wiring conduits and the like in the walls of a house.

Results will depend, of course, on the skill of the operator. In general, the following rules should be observed:

1. Start with a relatively large search coil. Hold it close to the ground (or wall) and tune in to a loud and obvious zero-beat.
2. Search the area in slow parallel sweeps (like mowing the lawn on a small scale). If you have ever seen it done on TV you will know exactly

Figure 3. Circuit diagram of the metal detector.

Figure 4. Printed circuit board and component layout for the circuit shown in figure 3.

what is meant.

3. A change in tone indicates 'something'. This 'something' can be an object, but it can also be that the distance between the metal detector and the ground is not held constant. If several sweeps in the same area give the same indication, there is probably something there. A relatively sudden change in tone means that the object is close to the surface, whereas a gradual change in tone indicates an object at greater depth.
4. In the general area indicated by the last sweep, try a further search pattern at right-angles to the previous one. This will narrow the possible position down even further.
5. In some cases (specifically, if the object is small) it is advisable to switch to a smaller coil at this point. Repeat the search procedure described above within the general area already found. It should be possible to get a quite accurate indication of the position of the object.

Parts list.

Resistors:
R1,R3,R4 = 100 k
R2 = 3k3
R5,R14,R24 = 100 Ω
R6,R7 = 18 k
R8 = 1 k
R9,R11 = 10 M
R10,R13 = 1 M
R12,R20 = 4k7
R15 = 2k2
R16 = 10 k
R17 = 680 Ω
R18 = 68 k
R19,R22,R23 = 33 k
R21 = 220 Ω

Capacitors:
C1 = 330 p
C2,C15 = 100 n
C3,C8,C10,C14,
C16,C19 = 1 n
C4,C5,C20 = 33 p
C6 = 15 p
C7 = 470 p
C9,C18 = 4n7
C11 = 10 n
C12 = 10 μ/16 V
C13,C21 = 100 μ/16 V
C17 = 1n5
C_T = 300 p trimmer (see text)

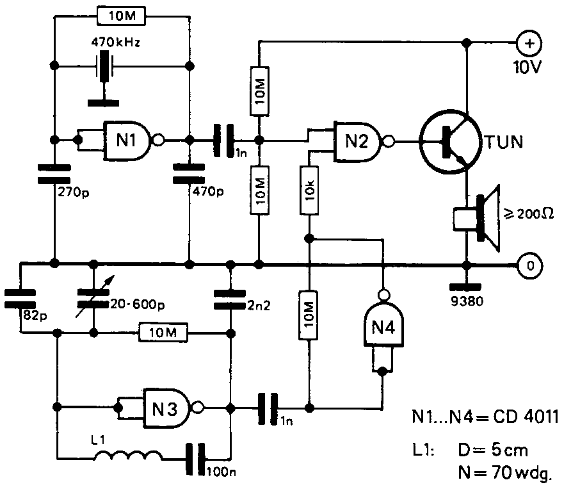
Semiconductors:
T1,T2,T3,T4 = BF 494
IC1 = 4017
IC2 = 4011
D1 = 1N4148

Sundries:
Fl 1 = SFD455
L_S = search coil, see text.

sixpence detector for christmas pudding

This handy metal detector will greatly increase one's chances of obtaining a piece of Christmas pudding with a sixpence in it, or if one is really lucky, a silver threepenny bit (Daddy, daddy, what's a threepenny bit?).

The principle of operation is simple and well-known. It consists basically of two oscillators, one of which is a fixed frequency reference oscillator, and the other an oscillator whose frequency-determining inductance is a search coil. Initially the two oscillators are adjusted so that their frequencies are nearly the same. The two outputs are fed into a mixer which will produce the sum and difference frequencies and the oscillators are adjusted so that the difference frequency (beat note) is in the audio band. If a metallic object is now brought near the search coil its inductance will vary, altering the oscillator frequency and hence the beat note.



The circuit is very simple and is designed around a CD4011 quad 2-input NAND gate. The reference oscillator uses an inverter (N1) as the maintaining amplifier and a 470 kHz ceramic filter as the frequency determining element for stability.

The variable frequency oscillator (N3) uses an LC resonant circuit with the search coil (L1) as the inductor. This can be a coil of about 70 turns of insulated wire and a diameter of approximately 50 mm (2"). The mixer is simply a NAND gate (N2), and the 4th NAND gate in the package (N4) is used as a buffer amplifier behind the variable frequency oscillator.

If a crystal earpiece is used, the transistor can be omitted – the output of N2 can drive the earpiece.

santatronics

"COINSHOOTER" METAL DETECTOR

Advanced circuit reacts to coins and other precious metal objects while ignoring chunks of iron and steel

BY WILLIAM LAHR

SEARCHING FOR coins and other lost articles along beaches and in parks can be both profitable and fun. The Coinshooter, a novel and inexpensive electronic metal detector, can make such outings more productive. Employing a sophisticated, vlf induction-balance detection system that responds only to the proximity of nonferrous metallic objects, it ignores items containing iron. Moreover, the project can be adjusted to compensate for the soil's mineral content, thus minimizing false indications.

The Coinshooter can detect a dime at an air gap of four inches or a half-dollar at nine inches. It cannot detect coins buried deep in the ground, but will yield excellent results if the coins are at depths of from 1 to 3 inches. Unlike detectors that employ conventional beat-frequency oscillator circuits, the Coinshooter does not require the user to monitor the pitch of a continuous tone. Rather, it alerts the user to the proximity of nonferrous metal by generating one or more beeps. Also, it is lightweight (about 2 lb) and well balanced. Total construction cost is approximately $35, and less if salvaged parts are used.

About the Circuit. The Coinshooter appears schematically in Figure 1. Coplanar search coils are formed by placing a receiving coil (*L3*) over a folded-loop transmitting coil (*L1* and *L2*) so that there is little if any coupling between them unless there is metal present in the search field. A Colpitts oscillator comprising *Q1* and its associated passive components generates a 6.2-kHz signal that drives the transmitting coil. Transistors *Q2* and *Q3* amplify the low-level signal induced across receiving coil *L3* when no metal objects are present in the search field so that a 1-volt p-p signal appears at the collector of *Q3*.

Capacitor *C7* couples this signal to the noninverting input of voltage comparator *IC1A*. The input circuit of the comparator rectifies the ac signal, resulting in the generation of a slightly

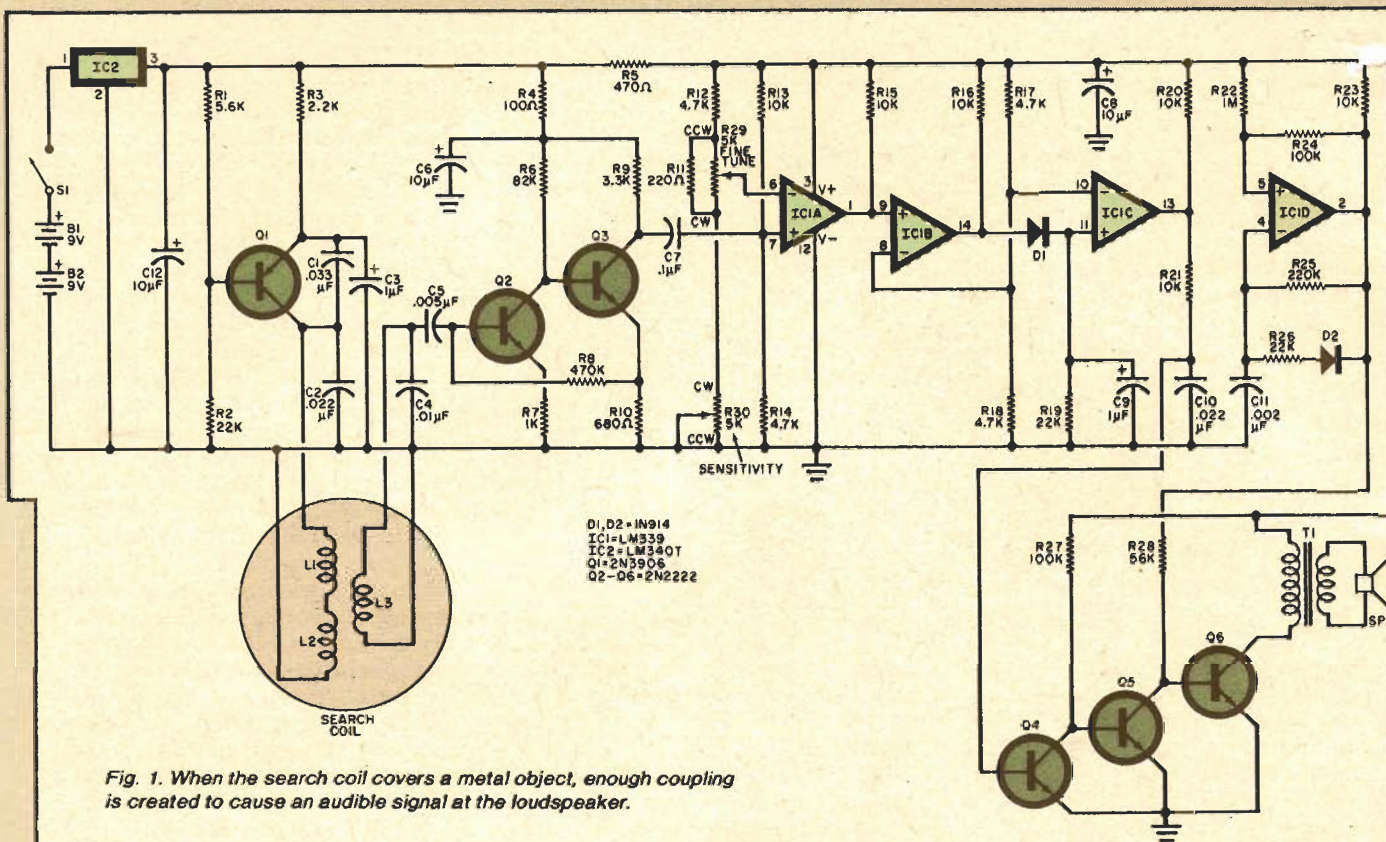


Fig. 1. When the search coil covers a metal object, enough coupling is created to cause an audible signal at the loudspeaker.

PARTS LIST

B1,B2—9-V alkaline battery
C1—0.033-µF, 50-V Mylar capacitor
C2, C10—0.022-µF, 50-V Mylar capacitor
C3, C9—1-µF, 16-V tantalum capacitor
C4—0.01-µF, 50-V disc ceramic capacitor
C5—0.005-µF, 50-V disc ceramic capacitor
C6, C8, C12—10-µF, 16-V aluminum electrolytic capacitor
C7—0.1-µF, 50-V Mylar capacitor
C11—0.002-µF, 50-V disc ceramic capacitor
D1, D2—1N914 silicon switching diode
IC1—LM339 quad voltage comparator
IC2—LM340T-8 +8-V regulator
L1, L2—Air-core inductor: 175 turns of No. 30 wire wound 9½ inches in diameter (see text)
L3—Air-core inductor: 550 turns of No. 38 enamelled wire on 3½" diam.
Q1—2N3906 or similar pnp silicon switching transistor
Q2 through Q6—2N2222 or similar npn silicon switching transistor

The following, unless otherwise specified, are ¼-watt, 5%-tolerance, carbon-composition fixed resistors.
R1—5.6 kΩ
R2, R19, R26—22 kΩ
R3—2.2 kΩ
R4—100 Ω
R5—470 Ω
R6—82 kΩ
R7—1 kΩ
R8—470 kΩ
R9—3.3 kΩ
R10—680 Ω
R11—220 Ω
R12, R14, R17, R18—4.7 kΩ
R13, R15, R16, R20, R21, R23—10 kΩ
R22—1 MΩ
R24, R27—100 kΩ
R25—220 kΩ
R28—56 kΩ
R29—5-kΩ, linear-taper potentiometer
R30—5-kΩ, linear-taper potentiometer with shaft-actuated spst switch

S1—Spst switch (part of R30)
SPKR—2¼-inch, 8-Ω dynamic speaker
T1—1kΩ:8Ω miniature audio output transformer
Misc.—Suitable enclosure, perforated or printed-circuit board, single-conductor shielded cable, hookup wire, No. 30 and No. 38 enamelled copper (magnet) wire, battery clips, battery holders, circuit-board standoffs, grommets or other suitable strain reliefs for shielded cable, PVC electrical tape or silicone cement or other suitable insulating material, 12-inch-by-12-inch sheet of ¼-inch plywood, monofilament fishing line, ¾-inch masking tape, epoxy, hot-melt, and PVC glues, 4 feet of ½-inch O.D., schedule 125 PVC pipe, 2 feet of ½-inch, schedule 40 PVC pipe, 90° elbow PVC pipe joint, 135° elbow PVC pipe joint, tee PVC pipe joint, PVC pipe cap, bicycle steering-bar handgrip, lead buckshot, resin sealant, white paint, solder, hardware, aluminum foil etc.

negative voltage that subtracts from the positive bias voltage supplied by divider *R13R14*. Potentiometers *R29* and *R30* determine the magnitude of the reference voltage applied to the inverting input of *IC1A* and hence the detector circuit's sensitivity. They are adjusted so that the voltages at the two inputs are practically equal.

When the voltage at the noninverting input of the comparator becomes more positive than that at the inverting input, the output terminal (pin 1) switches to the positive supply voltage. This positive pulse toggles comparators *IC1B* and *IC1C*, which are connected in cascade and whose inverting inputs are biased to one-half the positive supply voltage. The charging of *C9* via *D1* and the discharging of *C9* through *R19* stretches the pulse. Transistor *Q4* is triggered into conduction by the elongated pulse that appears at the output of *IC1C*, cutting off *Q5*.

When *Q5* is cut off, *Q6* amplifies the tone produced by the audio oscillator comprising *IC1D* and its associated passive components. The current flowing through the primary of audio-output transformer *T1* and transistor *Q6* increases the voltage drop across *R5*, and this upsets the bias applied to the inverting input of *IC1A*. As a result, the outputs of *IC1A, IC1B*, and *IC1C* go low, transistor *Q4* cuts off, and transistor *Q5* saturates, shunting the base drive of *Q6* to ground and cutting that transistor off. This silences the loudspeaker and allows *C8* to charge again to the full positive supply voltage. The higher voltage across the capacitor allows *IC1A* to change state again if the nonferrous metal object is still within the search field.

Iron objects or mineralized ground within the search field will produce an increase in the amplitude of the signal at the collector of *Q3* and thus a less positive bias at the noninverting input of *IC1A*. In contrast, the presence of coins or other nonferrous metal objects within the search field will cause a smaller signal to appear at the collector of *Q3* and a more positive bias at the noninverting input of the first voltage comparator. This allows the Coinshooter to locate coins and other items of interest while ignoring nails, bottle caps, and other junk pieces of iron and steel.

When a small nonferrous item quickly enters and exits the search field, the loudspeaker will generate a single beep. If the object enters and remains in the search field, a series of beeps will be produced. Its rate of repetition will vary with the settings of potentiometers *R29* and *R30*, the size of the object, and the distance between the object and the search coil. The pitch of the beep is determined by the values of *C11* and the resistances in the feedback loop, as well as by the supply voltage. Its frequency is nominally 1.3 kHz.

Power for the Coinshooter circuit is supplied by two series-connected nine-volt batteries. An IC voltage regulator provides a constant supply potential to the rest of the circuit until the batteries are nearly exhausted. Quiescent current demand is approximately 10 mA, so battery replacement should be infrequent if alkaline cells are used. If desired, the Coinshooter can be powered by a single nine-volt battery and the regulator IC omitted. However, the circuit is sensitive to changes in supply voltage, and this alternative is not recommended. But, if this approach is taken, an alkaline battery must be used.

Construction. Procure a circular form 9½" in diameter on which you can wind the transmitting coil. In assembling the prototype, a hamper lid was used, but a mixing bowl or cardboard cylinder would be suitable.

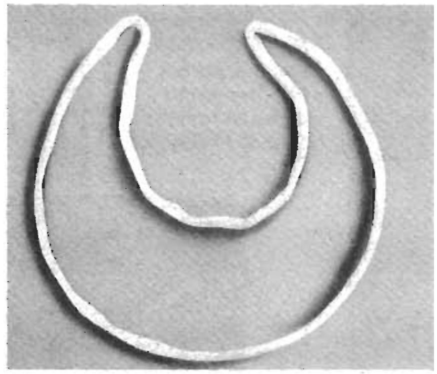


Fig. 2. Transmitting coil has been shaped to form L1 and L2.

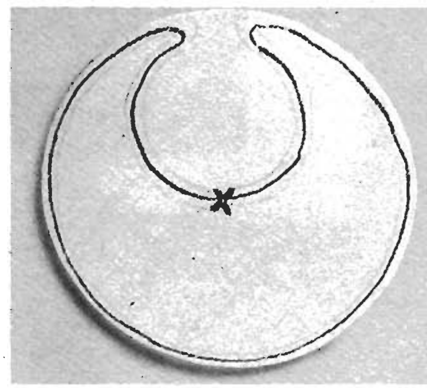


Fig. 3. Positions of L1 and L2 are marked on a plywood disc.

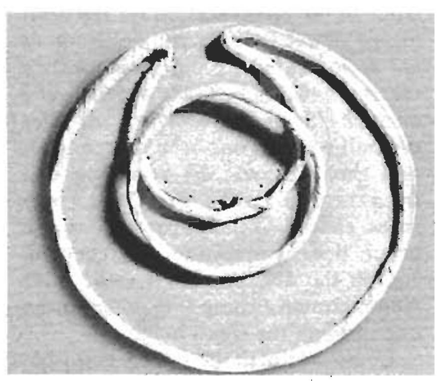


Fig. 4. The disc is shown with L1 and L2 tied in place and L3 on top.

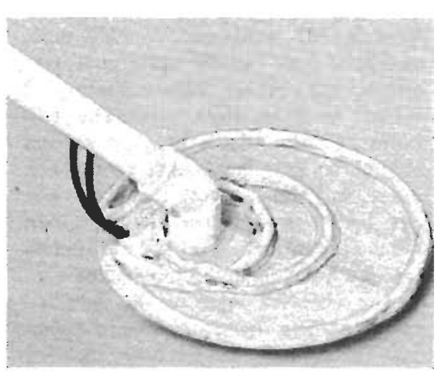


Fig. 5. The search-coil assembly with handle in place.

Wind a layer of masking tape ¾-inch wide around the form so that the adhesive side is exposed. The tape will hold the wire and make winding the coil much easier. Wind a total of 175 turns of No. 30 enamelled copper wire around the form, keeping the wire as close to the center of the tape as possible. The last turn should exit the coil at a point on the circumference 10 inches before the starting point is reached. Fold the tape around the coil and remove it from the form. Spiral-wrap the coil tightly with masking tape. Then shape the coil assembly as shown in Fig. 2 to form the transmitting coil. (*L1* is the large-diameter portion and *L2* is the small-diameter section.) The coils must be shielded so spiral wrap them (starting with *L1* opposite the lead wires) with 1" wide strips of aluminum foil. Cover the coils completely except for a ¼" gap between start and finish of the foil layer. Strip a 6" piece of hookup wire and lay it on the foil so that 2" exits next to one of the lead wires. Then spiral wrap the coils tightly with masking tape, covering the foil completely.

Next, cut a disc seven inches in diameter from a sheet of ¼-inch plywood. Lay the shaped coil assembly on the disc and trace pencil lines around the inside of *L1* and both sides of *L2* (see Fig. 3). Remove the coil assembly and drill a series of 1/16-inch holes spaced ½ inch apart along the pencil lines. Then place the shaped coil assembly back on the disc and tie it down with monofilament fishing line, looping the line through the series of holes.

Obtain a circular form 3½ inches in diameter on which you can wind the receiving coil. In assembling the prototype, a glass ashtray was used, but a cardboard cylinder would also be acceptable. The form should have a slight taper to facilitate removal of the coil after it has been wound. Apply masking tape to the form as was done in winding the transmitting coil, and wind 550 turns of No. 38 enamelled copper wire, keeping the windings as close to the center of the tape as possible. When the coil has been wound, fold the tape around the windings and remove the coil from the form. Spiral-wrap the coil tightly with masking tape. Wrap the coil with foil and another layer of tape as on *L1* and *L2* being sure to cover the foil completely. If the two foil shields are allowed to touch when the coils are positioned, the detector will not function.

Now assemble the circuit of the Coinshooter. In the construction of the prototype, a small (5 inches by 1-

3/4 inches) perforated board and point-to-point wiring were used. Printed-circuit assembly techniques are also acceptable. Because the circuit operates at very low frequencies, parts layout is not especially critical. Use an IC socket or Molex Soldercons for *IC1* rather than soldering the chip's pins directly to the circuit board.

Potentiometers *R29* and *R30* and the loudspeaker are not mounted on the board. Rather, they should be affixed to the enclosure housing the circuit board. Resistor *R11* can be soldered directly across the outer lugs of potentiometer *R29*. A total of four holes (two 3/8 inch in diameter spaced 2 inches apart, and two 1/8 inch in diameter spaced 1/2 inch above and below the larger holes) should be drilled in the bottom of the project enclosure so that two shielded cables can exit the enclosure and self-tapping screws can provide mechanical support. Additional holes might have to be drilled for circuit-board standoffs.

Prepare the inner conductor and shield at one end of each of two 48-inch lengths of single-conductor shielded cable. Color-code both ends of one of the cables with a dab of enamel paint or nail polish. Connect the shields of the prepared ends of both cables to circuit ground. The inner conductor of the color-coded cable should be connected to the node *C1, C2*, and collector of *Q1;* the inner conductor of the other cable should be connected to the node *C4, C5*. These cables should exit the enclosure housing the circuit board through the two 3/8-inch holes previously drilled through its bottom. Be sure to outfit these holes with grommets or similar bushings that prevent chafing of their outer plastic jackets and that provide strain relief.

When the circuit board has been assembled and mounted in the enclosure along with the other components, place the transmitting-coil assembly and the receiving coil on a desk or on the floor away from any metal. Prepare the free ends of the two shielded cables and tin their inner conductors and shields. Using clip leads, connect the color-coded cable's conductors to the transmitting coil, and the other cable's conductors to the receiving coil. Connect the coil shields to the outer cable conductors. Apply power to the circuit and connect an oscilloscope probe between *Q3*'s collector and circuit ground.

Referring to Fig. 4, position the receiving coil near the center of the plywood disc on which the transmitting coil has been mounted. Adjust the position of the receiving coil for the minimum signal level at the collector of *Q3* as indicated by the scope beam's vertical deflection. Trace a pencil line on each side of the receiving coil after the null position has been determined, and then remove the receiving coil from the disc. Drill a series of 1/16-inch holes, spaced 1/2 inch apart, along the pencil lines. Reposition the receiving coil on the disc and tie it down with monofilament fishing line, looping the line through the small holes.

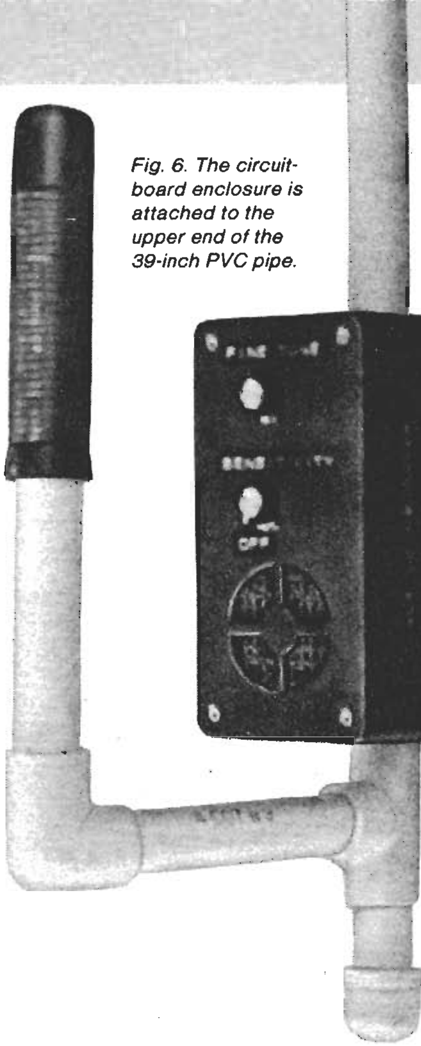


Fig. 6. The circuit-board enclosure is attached to the upper end of the 39-inch PVC pipe.

Using hot-melt or epoxy glue, cement a 135° elbow PVC pipe joint in the area between *L2* and *L3* so that its open end points toward the gap in *L1*. (See Fig. 5.) Cut a 39-inch length of 1/2-inch O.D., schedule 125 PVC pipe, and drill four 1/4-inch holes in it, one above the other, approximately 2 inches in from each end. The two holes at one end of the pipe section should be 2 inches apart from each other, but the holes at the other end can be closer. Also drill two 1/8-inch holes spaced 1/2 inch above and below the two holes spaced 2 inches apart.

Slip the free ends of the shielded cables exiting the circuit-board enclosure through the 1/4-inch holes that are bracketed by the smaller holes and pass the cables through the pipe until they protrude from the far end. Run bead of hot-melt or epoxy glue on the pipe and attach the bottom of the project enclosure to the pipe. Added mechanical support can be introduced by driving self-tapping screws through the two small holes in the bottom of the enclosure and into the matching holes that were drilled into the pipe section.

Feed the free ends of the shielded cables through the two holes at the other end of the pipe. Insert that end of the pipe into the elbow joint attached to the plywood disc so that the circuit enclosure faces away from the coil assembly. Then glue the pipe to the elbow joint using PVC cement, maintaining the orientation of the enclosure with respect to the coil assembly. (Note that PVC cement sets quickly.) Solder the conductors of the color-coded cable to the transmitting coil and the conductors of the other cable to the receiving coil. The polarities of these connections are unimportant. Connect the coil shield leads to the outer cable conductors. Insulate the solder joints using PVC electrical tape, silicone cement, or some other suitable material. Then cement the cables to the plywood disc in the area between *L3* and the gap in *L1* using hot-melt or epoxy glue.

Cut 6- and 9-inch lengths of 1/2-inch O.D., schedule 40 PVC pipe. Referring to Fig. 6, assemble a handle using the lengths of pipe, a 90° elbow PVC pipe joint, a tee PVC pipe joint, a bicycle steering-bar handgrip and PVC cement. The handgrip is glued to the 9-inch section of pipe, and one of the two collinear openings of the tee should be glued to the 39-inch pipe section to which the circuit-board enclosure and the search coil assembly are attached. PVC cement is fast-setting, so work quickly and orient the handle with respect to the circuit-board enclosure as it is in Fig. 6. The remaining end of the tee will be left open until the detector is balanced.

Apply power to the circuit and reconnect the oscilloscope probe between the collector of *Q3* and circuit ground. Suspend the search coil in the air away from any metal and rotate the shaft of *R29* to its minimum-sensitivity setting. Monitor the scope trace and, if necessary, slightly adjust the position of *L3* so that a 1-volt p-p signal appears at the collector of *Q3*. Pass a pair of pliers approximately three inches under the search-coil assembly while monitoring the scope trace. If the signal level decreases, shift *L3* through the null point and repeat the test. The signal must increase in amplitude when the pliers are brought near the search-coil assembly, or the detector will ignore coins and respond to the proximity of ferrous objects. Receiving coil *L3* should be positioned as close to the null point as possible yet still provide an increase in signal amplitude when iron or steel is brought near the search-coil assembly.

Next, pass a dime about three inches under the search coil and note the slight increase in signal level as displayed on the oscilloscope. Carefully fix the positions of the coils by bonding them to the plywood disc with quick-setting epoxy cement. When the epoxy has cured, remove the scope probe and button up the circuit-board enclosure. Advance the setting of the SENSITIVITY control until the speaker begins to beep. Then adjust the FINE TUNE control to silence the speaker. Pass a pair of pliers three inches below the search coil and note that the speaker remains silent. Then pass a dime three inches under the coil and note that the speaker starts to beep. The most sensitive area of the search coil is near its center.

The search-coil assembly can be coated with two thin applications of resin to seal it, and then it can be painted white so that it matches the PVC pipe. The coils must be bonded securely to the disc before the application of sealant and paint. To minimize the possibility of displacing the coils, use spray-on resin and paint.

If the coils have shifted position before the resin has cured, a compensating piece of iron or steel can be added to the search-coil assembly. Determine whether this has in fact happened by removing the top of the circuit-board enclosure and reconnecting the oscilloscope probe between the collector of *Q3* and circuit ground. Pass a ferrous object three inches below the search coil and monitor the scope trace. If the proximity of iron or steel causes a decrease in signal level, position a small steel washer on or near receiving coil *L3* to correct for the misalignment. Locate the required position by repeating the test for iron sensitivity and shifting the location of the washer until the correct response is obtained. Then fix the washer in place with epoxy cement.

Final Assembly and Use. Grasp the Coinshooter by its handgrip and check it for proper balance. The search-coil assembly should be parallel with and approximately 2 inches above the floor. Cut a 3-inch piece of ½-inch O.D., schedule 125 PVC pipe, and glue one end of it to a PVC pipe cap. Fill the pipe section with lead buckshot and tape its open end closed with PVC electrical tape. Then tape the shot-laden pipe section to the open end of the tee PVC pipe joint and recheck the balance of the project.

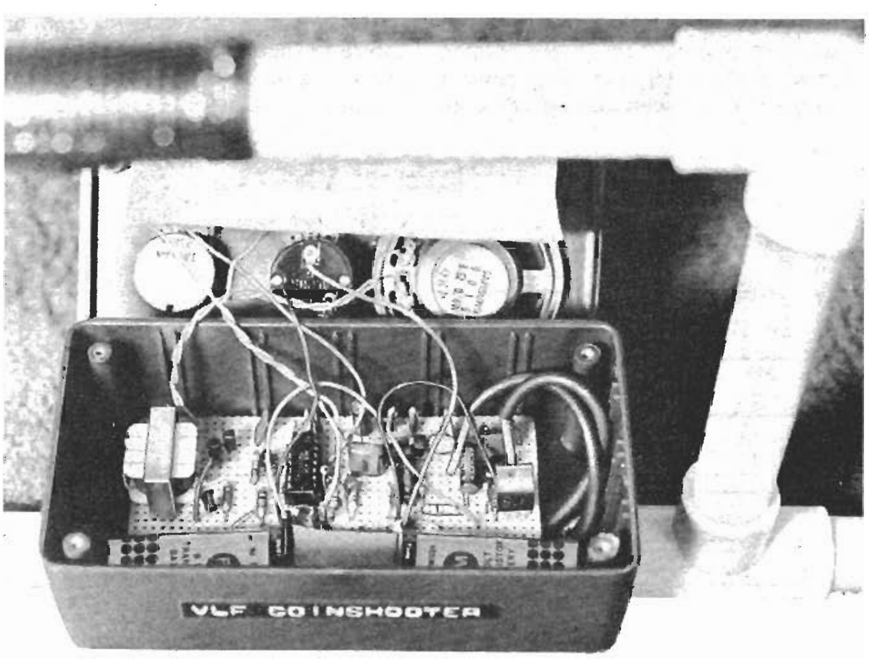
If it is unbalanced, untape the shot-laden pipe section, remove a little shot, tape the section closed again and reattach it to the tee PVC pipe joint. Recheck the balance of the Coinshooter. If necessary, repeat this procedure until the Coinshooter is properly balanced and feels comfortable to the hand. When the correct amount of shot has been determined, remove the pipe section from the tee PVC pipe joint, seal the shot in the pipe section with epoxy, and cement the section to the tee after the epoxy has cured. This completes assembly.

Take the finished project outdoors and hold the search coil 4 to 6 inches above the ground. Apply power to the project and adjust its controls so that the speaker emits a slow series of beeps. Lower the search coil until it is approximately 2 inches above the ground. The beeping should stop. This occurs because most soil is mineralized and affects the Coinshooter much like ferrous objects do.

The detector is now at maximum sensitivity and will detect coins at depths of from 1 to 3 inches, depending on their sizes and positions. Ferrous objects will not trigger the circuit unless they are very large or very close to the search coil or both. The Coinshooter will detect aluminum cans, caps and pull tabs, but it responds best to coins. Raise the search coil from time to time to check for the slow beeps that indicate maximum detector sensitivity. Although the circuit is very stable, the FINE TUNE control might have to be adjusted occasionally to compensate for changes in ground mineralization, temperature, and, if an unregulated power supply is used, battery voltage.

Always hold the Coinshooter so that the search-coil assembly is 1 to 2 inches above and parallel to the ground. Try to keep the search coil at a constant height above the ground. Swing the loop back and forth in front of you, making overlapping arcs. It is best to search slowly, but a coin will usually be detected even if the search coil passes over it quickly. For best results, operate the circuit as close to its switching threshold as possible.

When an object has been detected, move the search-coil assembly over it from front to back and from side to side to pinpoint its location. Keep in mind that the center of the search-coil assembly is its most sensitive point. Probe for the object with a small screwdriver or similar digging tool. If you search for coins in parks and woodlands, do so without disturbing the landscape. Always fill any holes that you make with your digging tool and place any turf that has been disturbed back in its original position. ◇



Photograph shows the circuit-board enclosure mounted on the PVC pipe. The top has been unfastened and laid aside.

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-

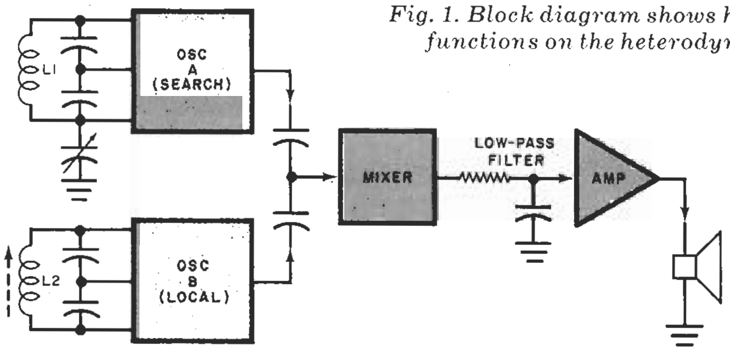


Fig. 1. Block diagram shows how the locator functions on the heterodyning principle.

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

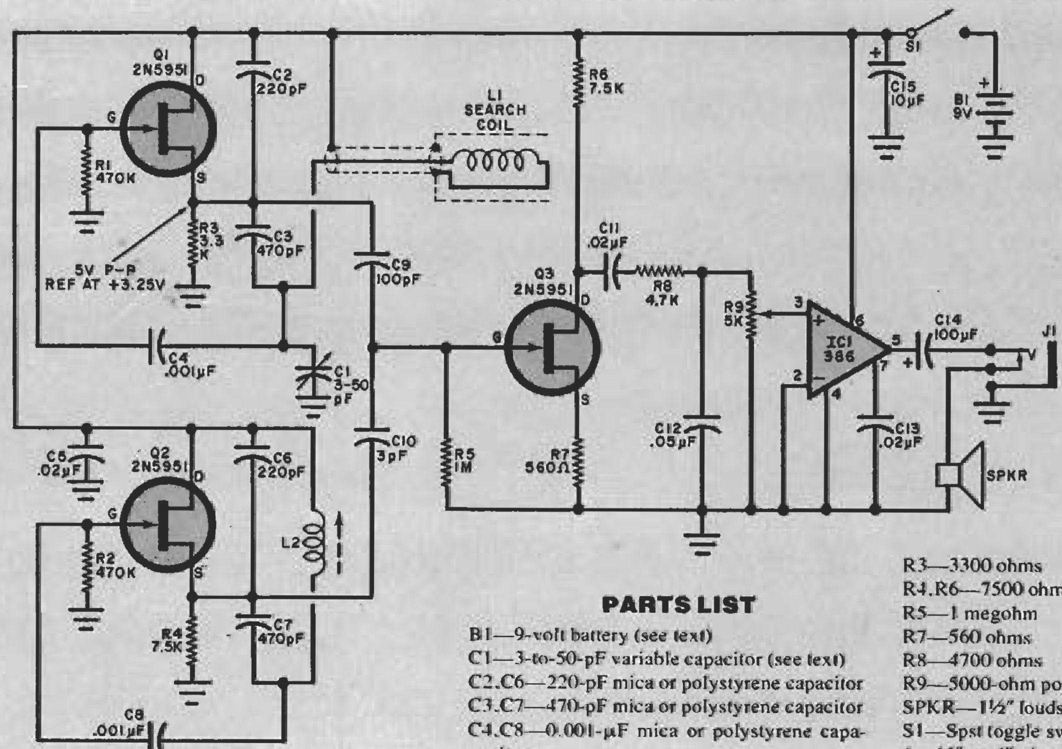


Fig. 2. Two stable Colpitts oscillators (Q1 and Q2) are tuned to operate in the 650-kHz range. They are essentially identical except for the two inductors.

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-

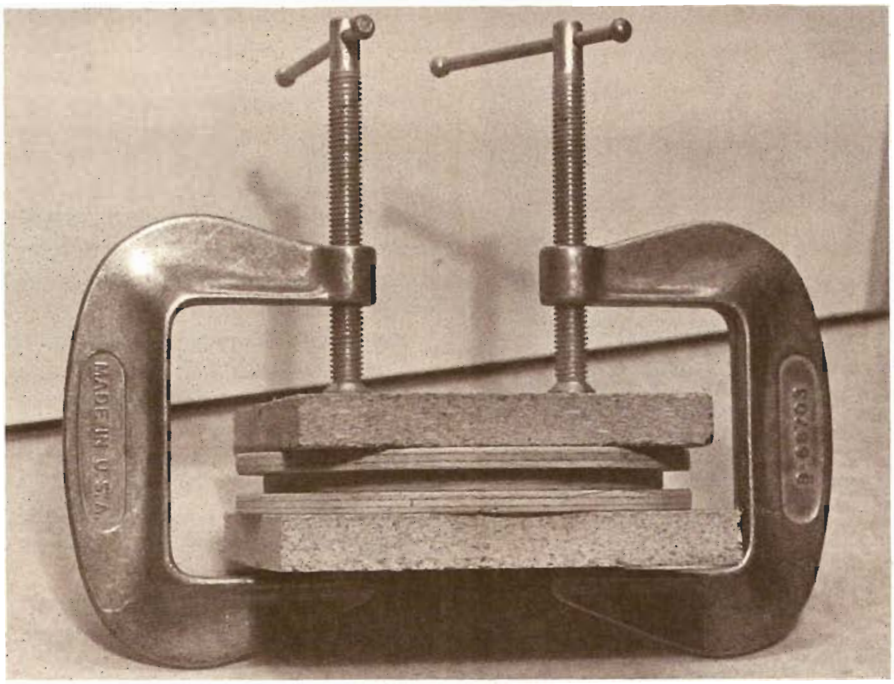


Fig. 3. Glue three plywood discs together with the smaller one in the middle. Use clamps or weights to ensure proper bonding.

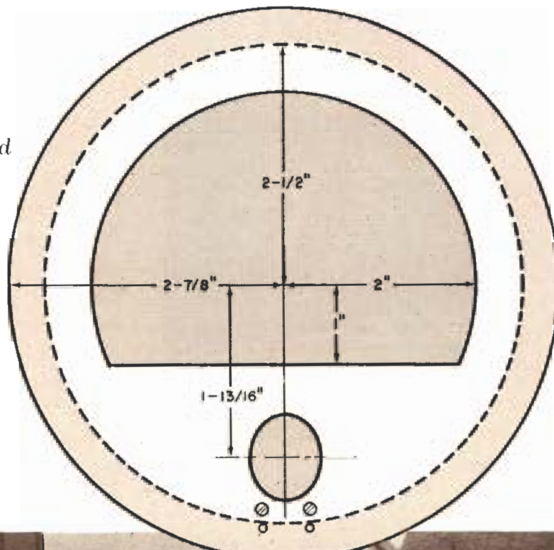


Fig. 4. When glue has had time to set thoroughly, draw a D-shaped form on the assembly as shown.

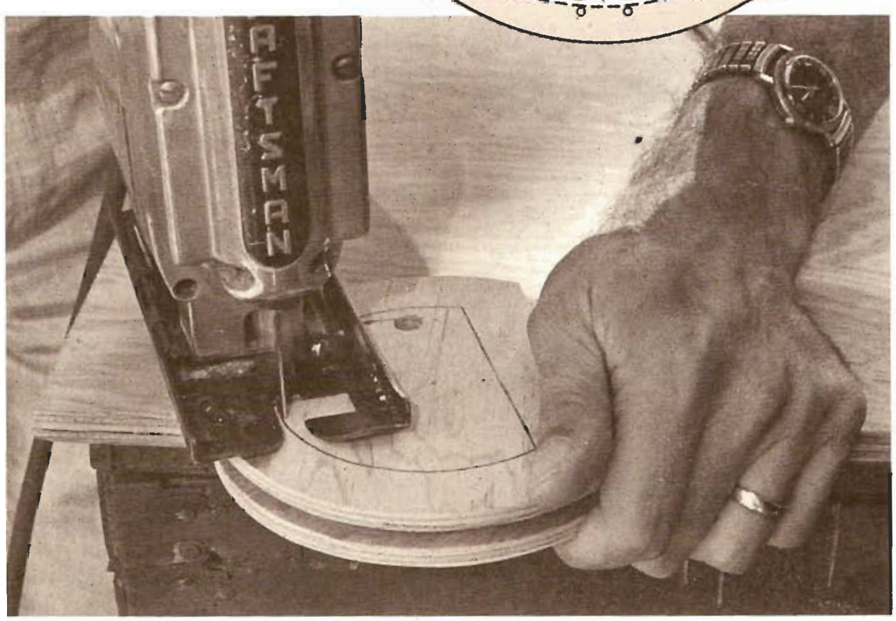


Fig. 5. Use a coping or sabre saw to cut out the form drawn on disc in Fig. 4.

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.

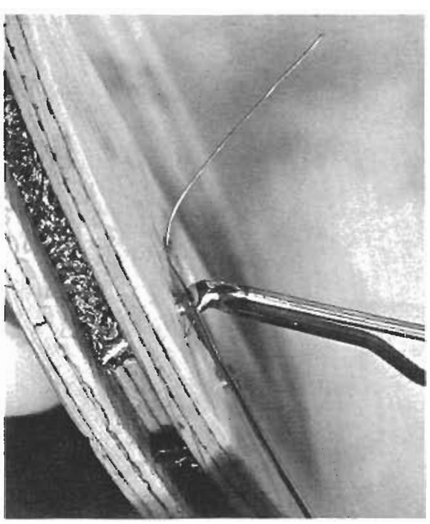


Fig. 8. Bring free end of braid up through plywood sandwich and solder to an adjacent screw.

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.)

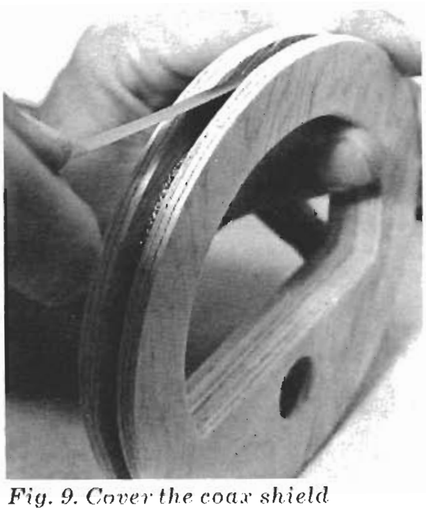


Fig. 9. Cover the coax shield braid with a single layer of plastic electrical tape.

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

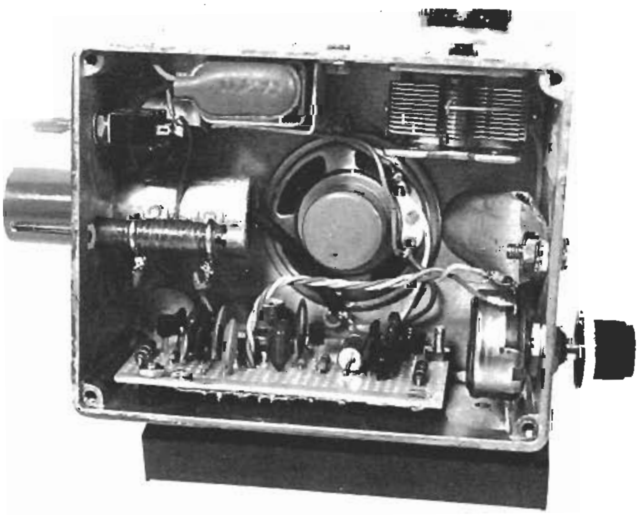


Fig. 11. Photo showing inside of author's prototype. The shaft fits through hole at left. Handle and speaker are shown on the back of enclosure here.

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. ◇