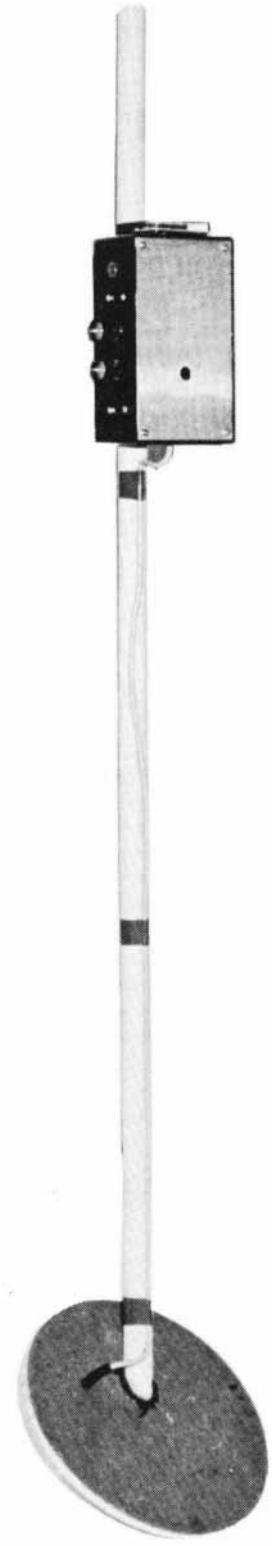
INDUCTION BALANCE METAL DETECTOR

A really sensitive design operating on a different principle from that of other published circuits. This 'Induction Balance' metal locator 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 hobby electronics magazines around the world, 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).

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 should account for about three-quarters of the effort in construction. 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 150 mm or so in diameter is connected in the circuit to oscillate at between 100 and 150 kHz. 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 tone is produced continually when the instrument is in use and metal is identified by a frequency change in the audio tone.

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

Ideally the instrument is initially set up for no pick-up in the 'receiver' coil, but this is impossible in practice — the two coils are after all laid on top of each other. Another problem is that 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 coils are near metal, a minute change in level becomes an enormous change in volume.

BFO detectors are not as sensitive as 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 pin-pointing exactly where the metal is buried.

Our detector is extremely sensitive — in fact a bit too sensitive for some applications! For this reason we've included

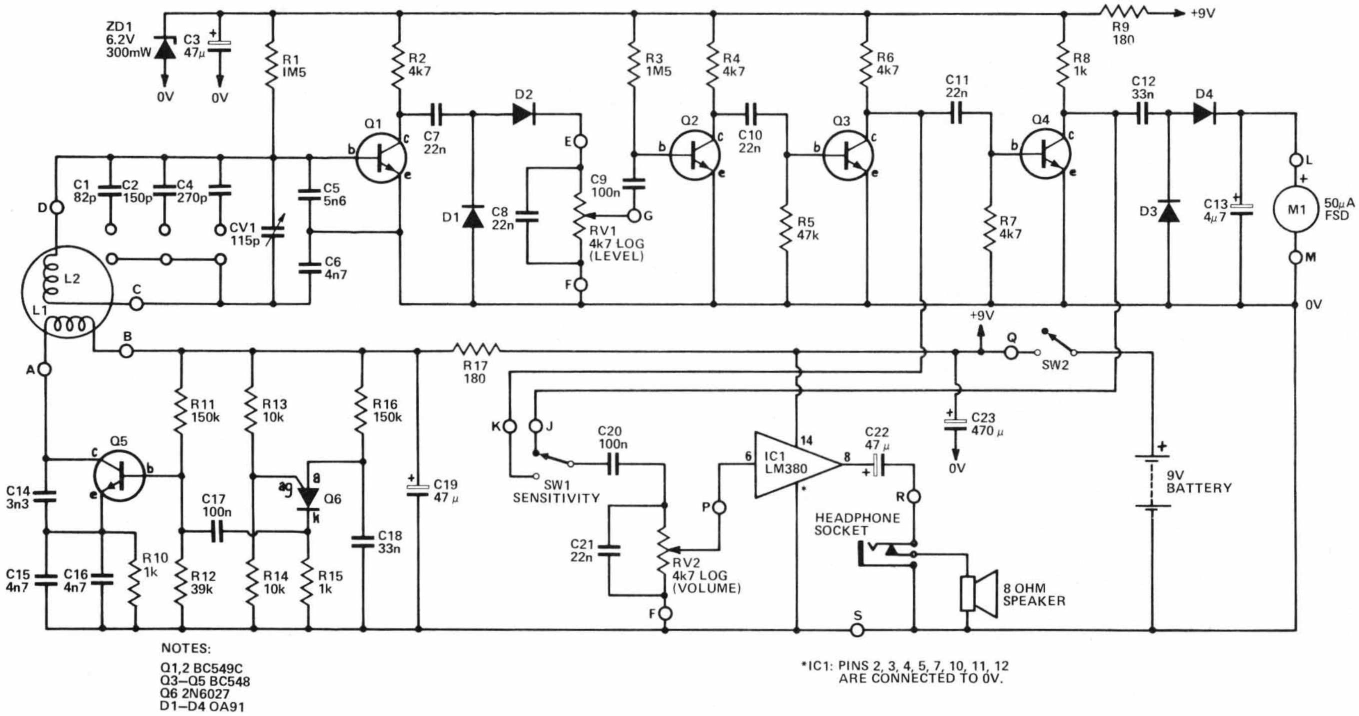


Fig. 1. Complete circuit of the metal locator. Note that though the electronics is simple using very common parts, the whole operation depends on the coil L1 and L2 which must be arranged so that there is minimal inductive coupling between the two. Note also that the leads from the circuit board to the search head must be individually screened and earthed at PCB.

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 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 1 ft of ground every time you get a reading. Try it — it's hard work!

Component Choice

We have specified Q1 and Q2 types as BC549C (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.

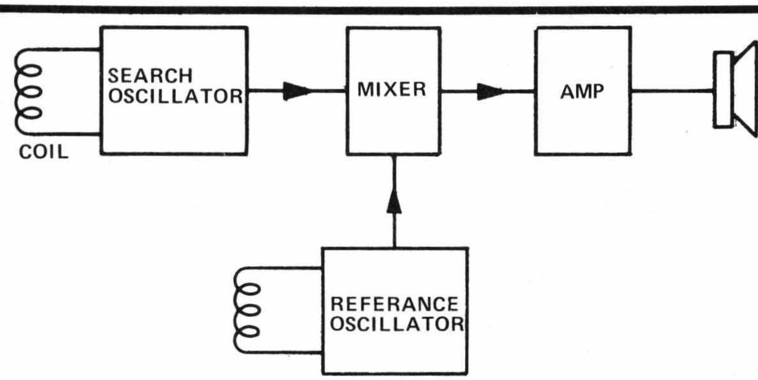


Fig. 2a. Block diagram of the common BFO type metal locator.

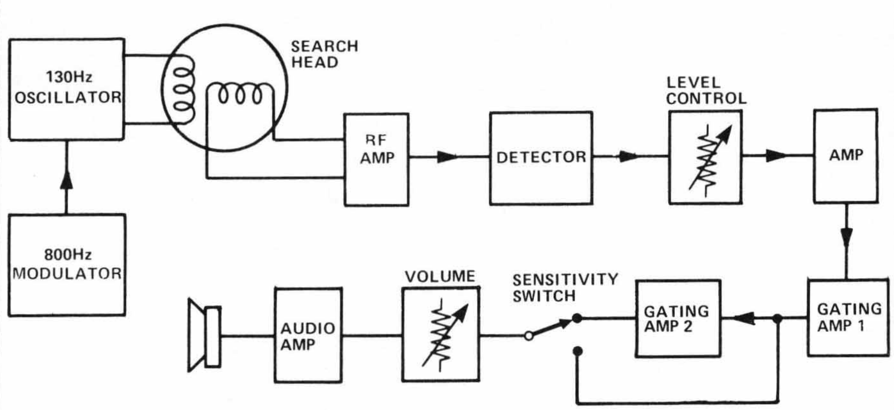


Fig. 2b. Block diagram of our IB design.

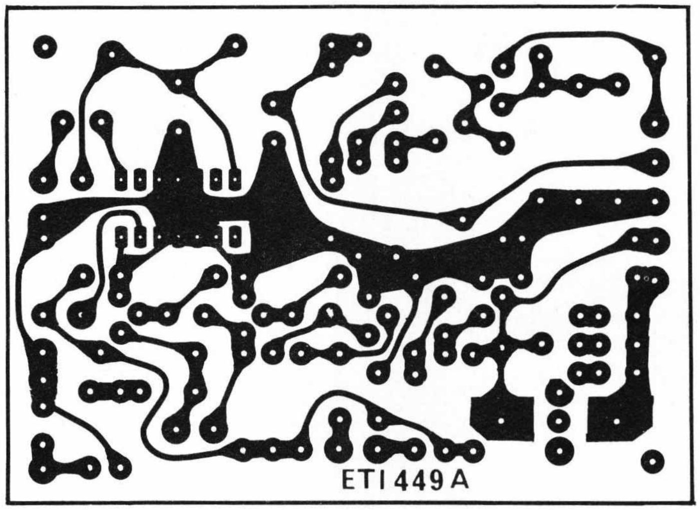


Fig. 3. Printed circuit layout. Full size 90 x 65 mm.

RV1 is the critical control and should be a high quality type — it will be found that it 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 dc blocking at the input).

Output is connected for an 8 ohm 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 16 ohm load (this reduces current consumption from the battery).

Construction:Control Box

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

Exceptional care should be taken to mount all components firmly to the board. 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 6 mm spacers. 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 we used was simply a broom handle with the end cut off at about 45°. After assembling the head, the handle can be glued on with epoxy. A small woodscrew can be used to hold it in place until dry. This should be done before final setting up of the coils — in case the screw cannot be removed after the glue has set.

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

How It Works — ETI 549

Q5, Q6 and associated components form the transmitter section of the circuit. Q6 is a P.U.T. which operates as a relaxation oscillator, the audio note produced being determined by R16 and C18. The specified components give a tone of toughly 800 Hz.

Q5 is connected as Colpitt's oscillator working at a nominal 130 kHz; this signal is heavily modulated by C17 feeding to the base of Q5. In fact the oscillator produces bursts of r.f. at 800 Hz. 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 20 mV peak-to-peak in L2. L2 is tuned by C5 and C6 and peaked by CV1 and feeds to the base of Q1, a high gain amplifier. This signal (which is still modulated r.f.) is detected by D1, and D2. The r.f. is eliminated by C8 and connects to the level control RV1.

The signal is amplified by Q2 and then further amplified by Q3 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 800 Hz exceed about 0.6V across R5. 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 C21) and fed to the IC amplifier and so to the speaker.

The high sensitivity stage Q4 is connected at all times and introduces another gating stage serving the same purpose as the earlier stage of Q3. 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 800 Hz find their way through but they do not come through as a tone. This is the correct setting for RV1.

The stage Q4 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 Q5 and Q6 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 60 mA and 80 mA on various prototypes but this will only be for very short periods and is thus acceptable. A more modest 20 mA 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.

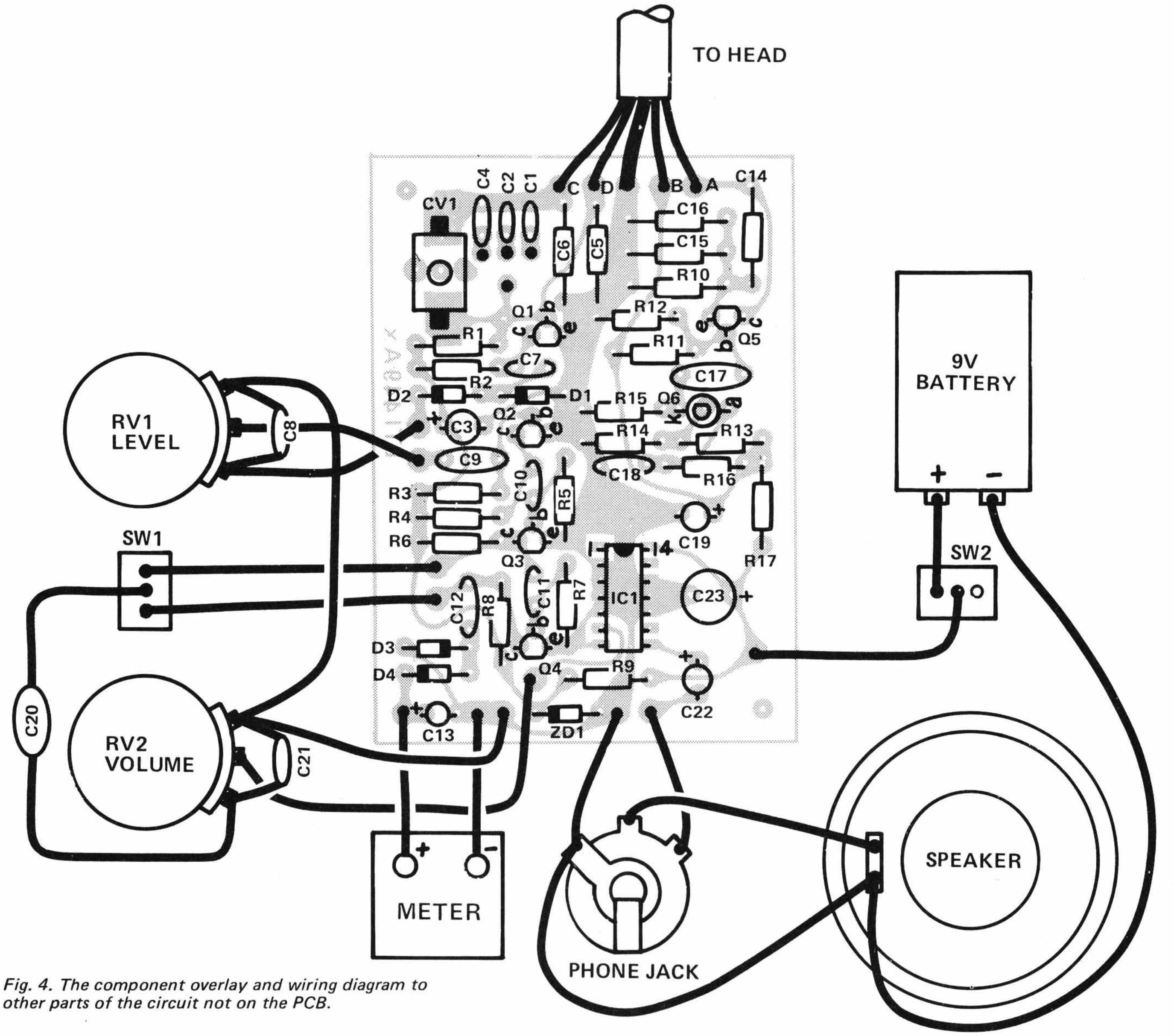


Fig. 4. The component overlay and wiring diagram to other parts of the circuit not on the PCB.

This now forms a dish into which the coils are fitted.

You'll now have to find something cylindrical with a diameter of near enough 140 mm (5½ in). A coil will then have to be made of 40 turns of 32 swg 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. These are identical.

One of the coils is then fitted into the dish and spot glued in six or eight places using quick setting epoxy resin: see photograph.

L2 is then fitted into place, again spot glueing (*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 preferably a 'scope. The transmit circuit is connected to L1. The signal induced into L2 is monitored; at first this may be very high but my manipulating L2 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. CV1 should be adjusted for maximum signal, this has to be done in conjunction with RV1. The additional capacitors C1, C2 and C4 should be linked in, if the range is not available on CV1.

Monitoring this on a scope may mean

PARTS LIST — ETI 549

Resistors	all ½ W 5%
R1	1M5
R2	4k7
R3	1M5
R4	4k7
R5	47 k
R6,7	4k7
R8	1 k
R9	180 ohms
R10	1 k
R11	150 k
R12	39 k
R13,14	10 k
R15	1 k
R16	150 k
R17	180 ohms
Potentiometers	
RV1,2	rotary 4k7 log

Capacitors	
C1	82 p ceramic
C2	150 p ceramic
C3	47 µ 10 V electro
C4	270 p ceramic
C5	5n6 polystyrene*
C6	4n7 polystyrene*
C7,8	22 n polyester
C9	100 n polyester
C10,11	22 n polyester
C12	33 n polyester
C13	4µ7 25 V electro
C14	3n3 polystyrene *
C15,16	4n7 polystyrene *
C17	100 n polyester
C18	33 n polyester
C19	47 µ 10 V electro
C20	100 n polyester
C21	22 n polyester
C22	47 µ 10 V electro
C23	470 µ 16 V electro
CV1	115pF trimmer (modify board if necessary to suit connections)

Semiconductors	
Q1,2	Transistors BC549C
Q3-Q5	Transistors BC548
Q6	PUT 2N6027
D1-D4	Diodes OA91, OA95
IC1	Amplifier LM 380
ZD1	Zener 6.2 V 300 mW

Miscellaneous

PC board ETI 549 A
Meter 50 µA FSD
Search head as per Fig. 6.
Two changeover slide switches.
Two knobs
Suitable case (158 x 95 x 50 mm)
Phone socket
Small speaker
9 V battery clip
Six by AA battery holder
Six AA batteries.

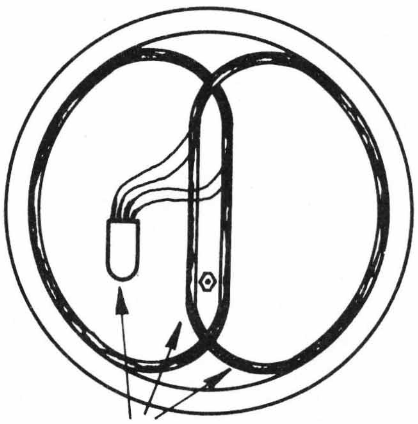
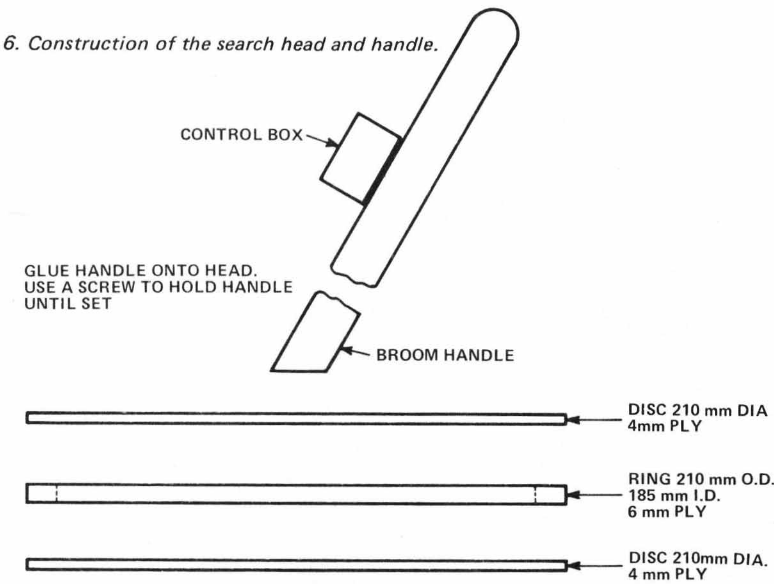


Fig. 5. Diagram showing the position of the coils in the search head.

Fig. 6. Construction of the search head and handle.



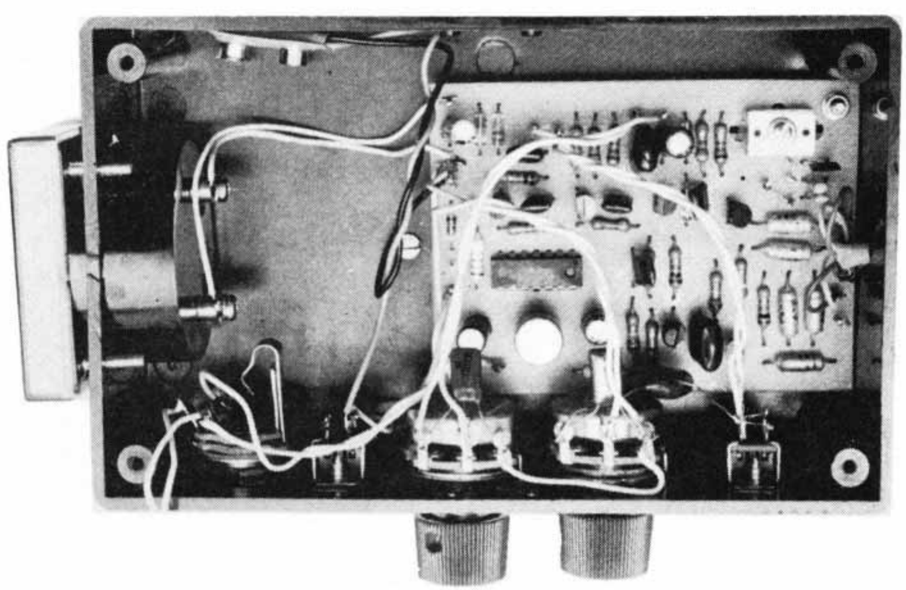
that the induced signal is not at its absolute minimum: this doesn't matter too much. Now add more spot glueing points to L2.

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 BC548 for Q2.

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 coils, this should be glued in place.

If after glueing in place the balance



between the coils is found to be not quite tight it should be possible to glue a small piece of metal (such as a washer) somewhere on the head to cancel out the error.

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 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 this approach 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.

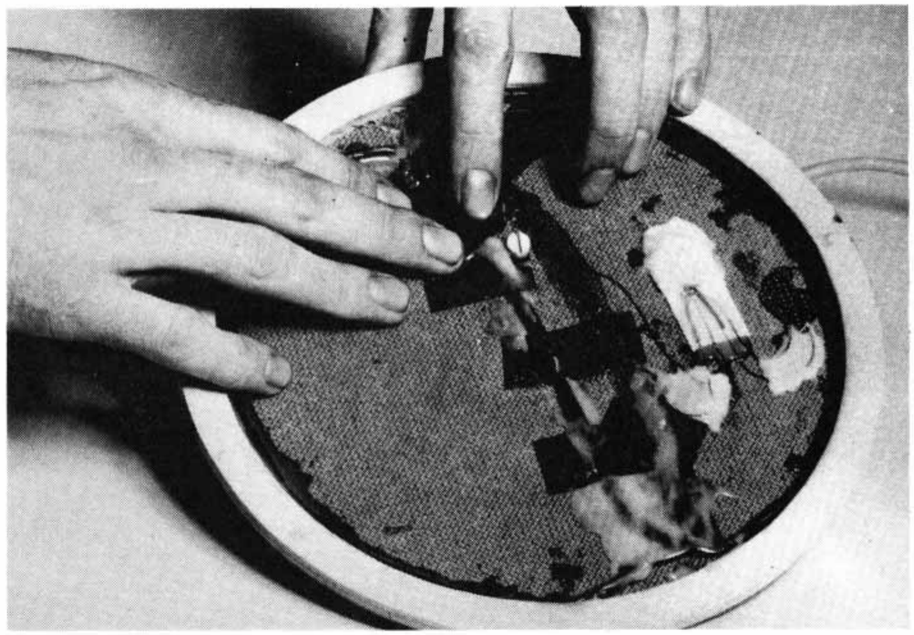


TABLE 1

OBJECT	20_c Coin	Beer Can	150 mm Square copper	150 mm steel rule	MANS Gold Ring
HIGH SENS	200 mm	450 mm	550 mm	300 mm	200 mm
LOW SENS	150 mm	350 mm	400 mm	220 mm	150 mm

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' 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.