INDUCTION BALANCE METAL DETECTOR

A really sensitive 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,

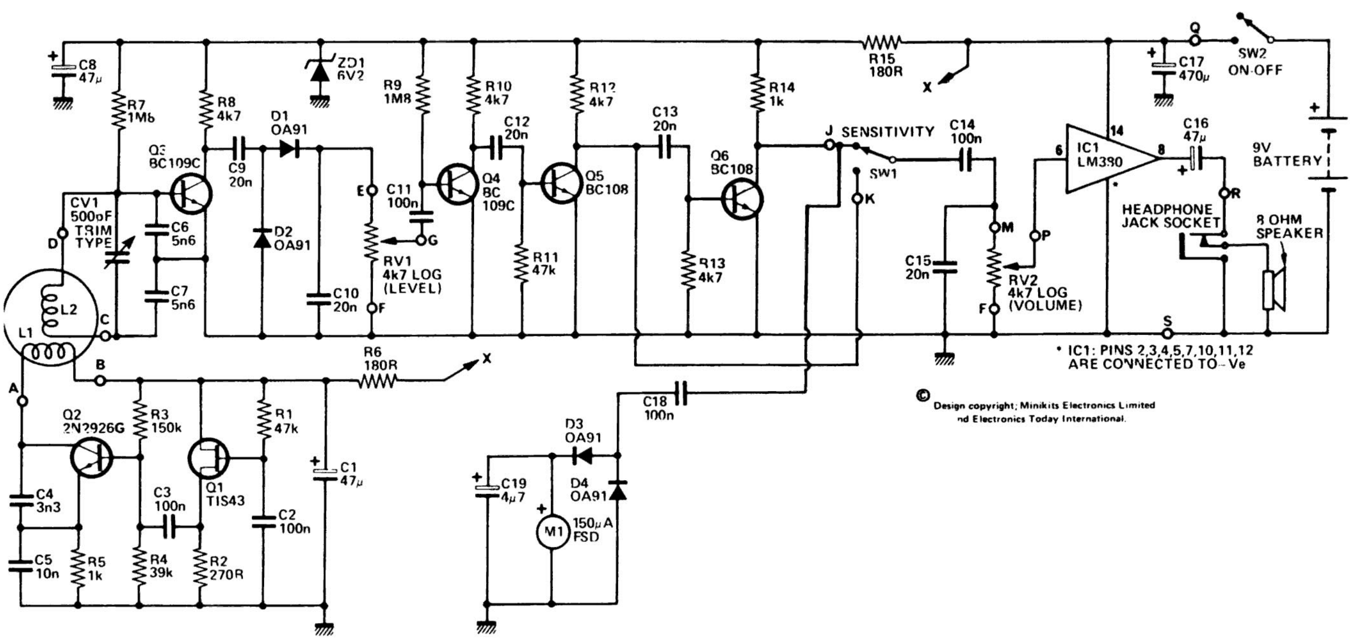


Fig. 1 Complete circuit of the metal locator. Note that though the electronics is simple using very common parts, the whole operation depends on the coils Li and L2 which must be arranged so that there is minimal inductive coupling between the two. Note also that the leads from the circuit board to the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

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.

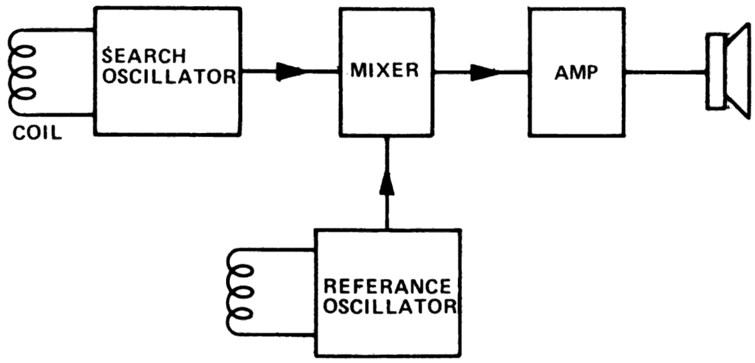


Fig.2a Block diagram of the common BFO type metal locator.

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 indentifying exactly where the metal is buried - they can pin-point more easily.

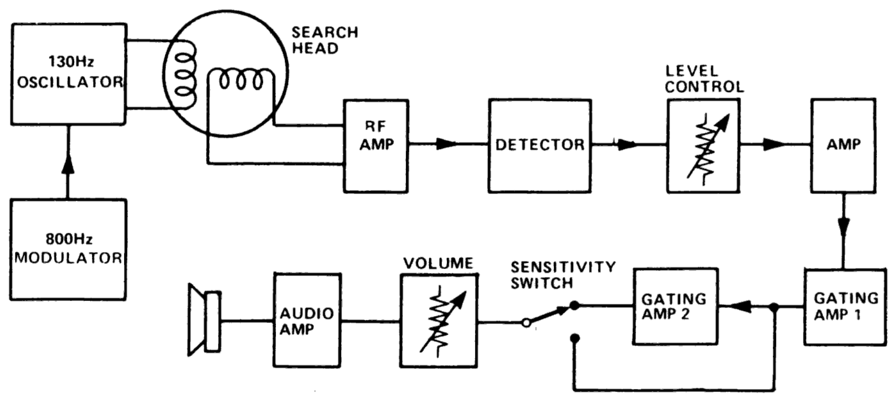


Fig2b Block diagram of our IB design.

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 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

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.

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 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 d.c. 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 l6 ohm 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 CV1 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.

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 4-1/2in length of tubing which has to be modified. Put 1-1/2in 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, at the same time bending the flat to about 45 degrees. 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 8mm 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.

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 1OOk 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 O.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.

lC1 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.

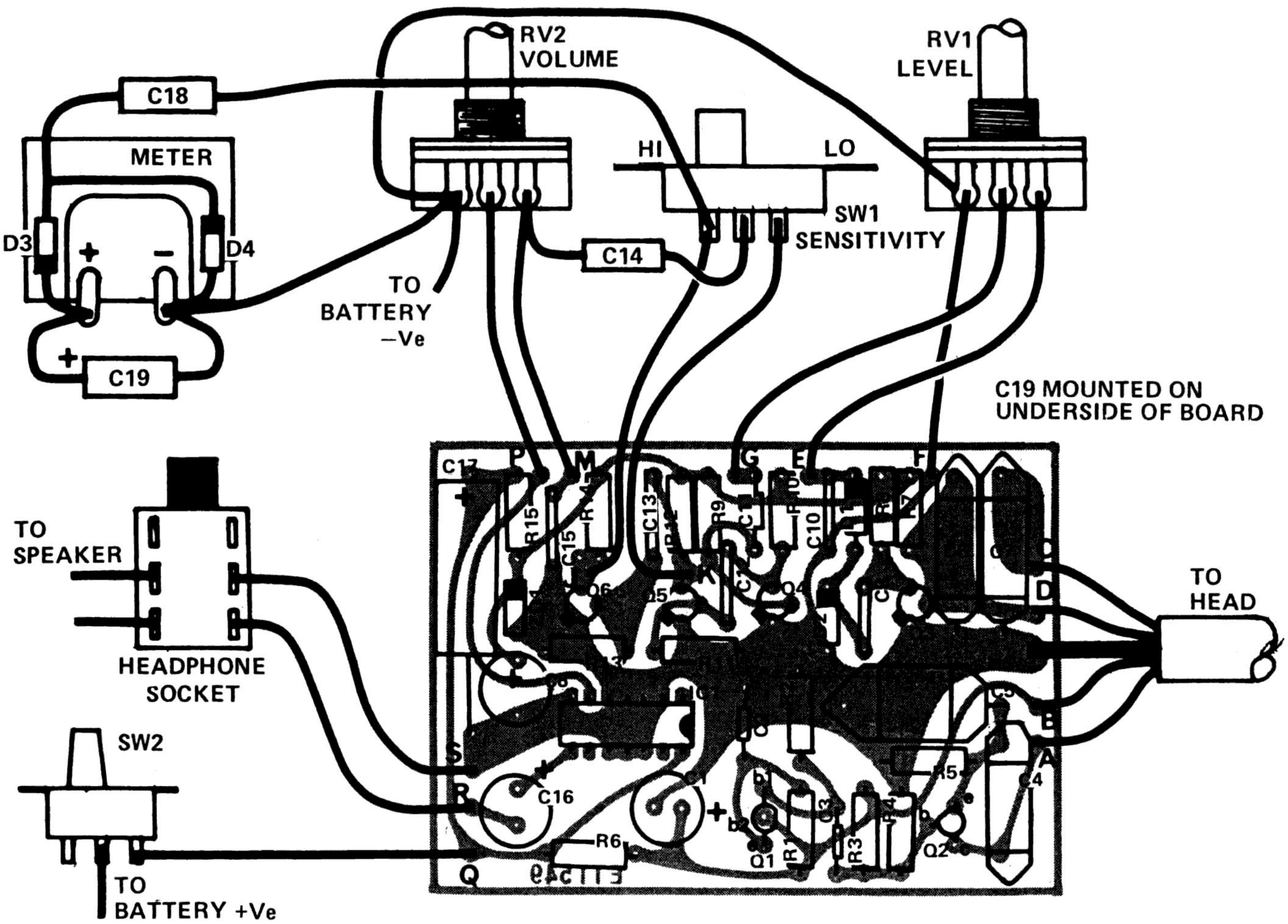


Fig. 4. The component overlay and wiring diagram to other parts of the circuit not on the PCB.

PARTS LIST - ETI 549

Resistors

R1	47k	1/4W, 5%
R2	270R	1/4W, 5%
R3	150k	1/4W, 5%
R4	39k	1/4W, 5%
R5, 14	1k	1/4W, 5%
R6, 15	180R	1/4W, 5%
R7, 9	1M8	1/4W, 5%
R8, 10, 11, 12 ,13	4k7	1/4W, 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 electrolytic
C19	4µ7 16v electrolytic
CV1	500p trimmer

Semiconductors

Q1	TIS43 Unijunction
Q2	2N2926 - see text
Q3, 4	BC109C
Q5, 6	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 (2-1/4 in etc) 8 ohm 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

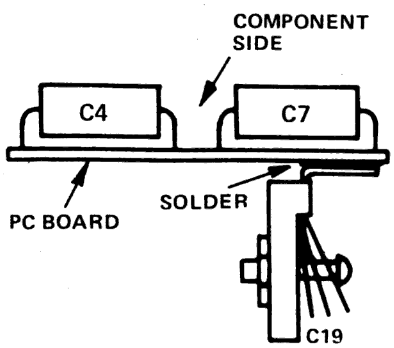


Diagram showing C19 mounted on copper side of P C Board

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 (5-1/2in). 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 photograph 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 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 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

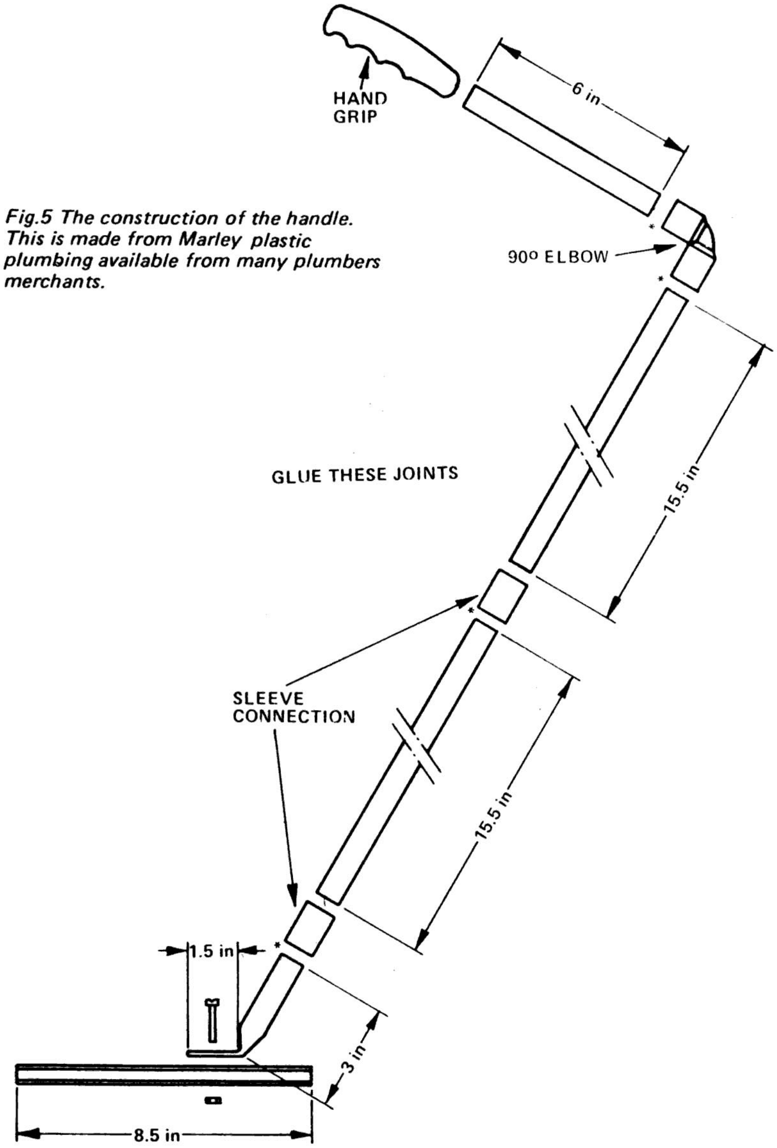
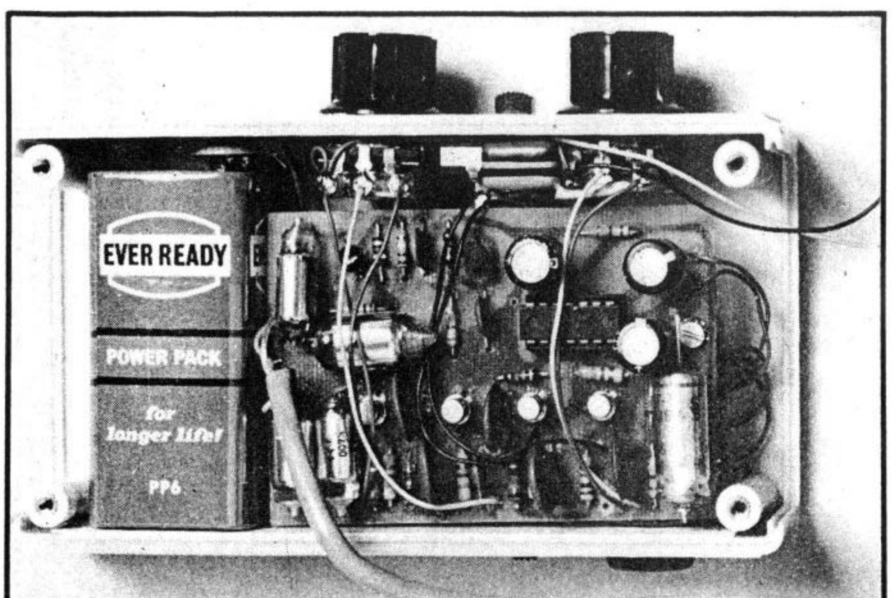


Fig.5 The construction of the handle. This is made from Marley plastic plumbing available from many plumbers merchants.



Internal photograph of metal locator control box.

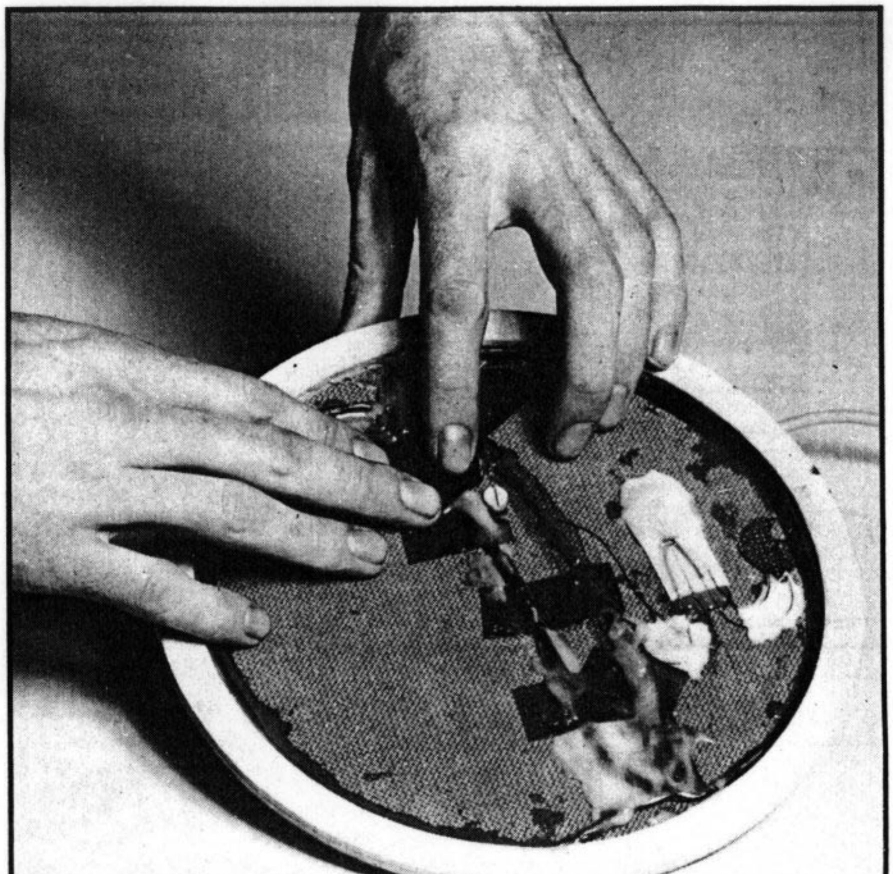
through a signal to the speaker. Bring a piece of metal near the coil and the signal should rise. If it falls in level (i.e. the crackling disappears) the coil has to be adjusted until metal brings about a rise with no initial falling. CV1 should be adjusted for maximum signal, this has to be done in conjunction with RV1.

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.)

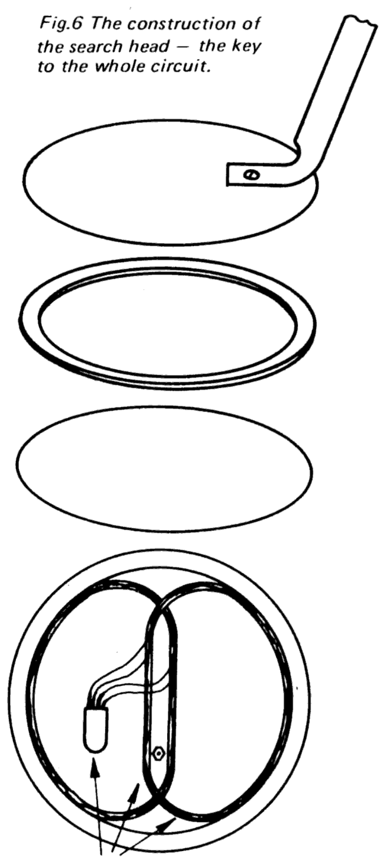


Fig.6 The construction of the search head — the key to the whole circuit.

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.