

EE TREASURE HUNTER

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A highly developed pulse induction metal locator that has excellent performance for price and is easy to build and set up.

This metal detector project is the result of considerable thought and development. It is sensitive and easy to use and, most importantly, it can be assembled and tested without special tools and equipment.

The pulse induction principle is sensitive to both ferrous and non-ferrous metals and does not offer any discrimination between the two. It is relatively insensitive to foil and similar thin conductive items and very sensitive to coins, rings, and other small objects. Larger objects, of course, are easily detectable at considerable depth.

The best aspect of the pulse induction method is that it is virtually free of ground effect. So much so that it works perfectly well with the search-head under water (including sea water) provided the coil is adequately protected.

The sensitivity of this design is such that a 10p coin can be detected at up to 20cm from the centre of the coil.

DESIGN POINTS

The object of this design was simplicity, and the avoidance of special close tolerance components. This has been achieved by using a 40kHz quartz crystal to provide highly accurate timing for all of the necessary pulses in the system. This approach also removes many sources of jitter and background noise and so allows stable highly sensitive performance.

The use of a power MOSFET to drive the coil also helps to simplify the circuit. It can be driven directly from a standard CMOS gate and has a very low on resistance, a high voltage rating and also is able to switch rapidly between on and off.

Such devices are almost ideal to work with especially as they are very forgiving, easily withstanding short overloads.

The final aspect of the circuit design is the use of a simple voltage converter to provide a higher voltage than the battery (the boost supply). This allows the pulse amplifier i.c. to work with both of its inputs at the battery positive supply level, and also provides a higher drive voltage to the MOSFET.

HARDWARE

A full set of hardware is available for this detector, and provides a good looking, well balanced design at a reasonable price.

Other housings may be used and providing the coil is wound correctly the detector will work well. The search head must not have any metal parts within 60cm as this will be detected and reduce the sensitivity to wanted objects.

PULSE INDUCTION PRINCIPLE

The pulse induction or P.I. method of metal detection works by subjecting objects to a rapidly changing magnetic field. The field is first produced electromagnetically by switching on current to the search coil. The field is then forced to change very rapidly by switching off this current. As the field decays it induces a voltage back into the coil and also into objects near the coil.

Poor or non-conductive objects near the coil are unaffected. In conductive items however, a current flows producing a small magnetic field which opposes the decay of the original field. This opposing field means that when detecting metal objects the magnetic field around the search coil falls more slowly than it does without metal objects. The voltage in the search coil is produced by the falling magnetic field and so changes in the presence of metal.

An exaggerated view of the search coil voltage, measured at point B of the circuit diagram (Fig. 2) for one complete pulse is shown in Fig. 1. Initially TR1 is on and the coil current is building up from the battery. When TR1 turns off the voltage at point B flies to a very high voltage as the magnetic field around the coil falls rapidly. After a time the field has fallen almost to zero and the voltage across the coil also falls. Note that as point A of the coil is held at +9V, point B will also end up at +9V when the voltage across the coil is zero.

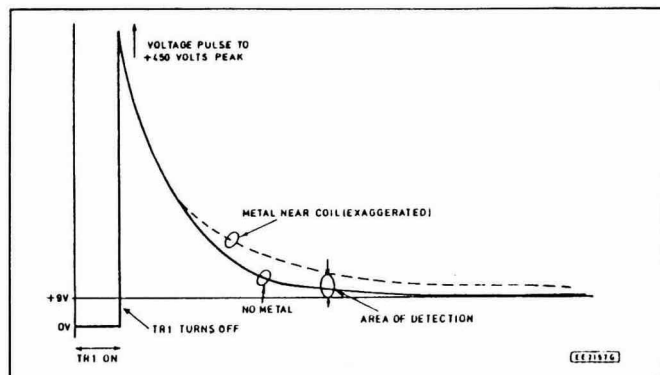


Fig. 1. Search coil voltage waveform, measured at point B on the circuit diagram.

The dotted section of the curve shows how metal near the coil reduces the rate of decay of the field so that the coil voltage is higher when metal is being detected. The scale of the voltage waveform has been stretched for clarity, and in fact the change detected is much less than one millivolt at the limit of detection. This must be detected following a pulse of over 400V!

CIRCUIT-OSCILLATOR

The full circuit diagram for the EE Treasure Hunter is shown in Fig. 2. Crystal oscillator IC1c provides an output of 40kHz which is the master clock. Resistor R6 provides d.c. bias for IC1c, and R5, C4, and C5 provide the correct feedback conditions for X1 to resonate correctly.

The output from the clock drives transistors TR2 and TR3 via resistor R4. These devices are connected as a complementary output stage and produce a 40kHz square wave that is coupled via capacitor C3 to rectifiers D3 and D4 to produce an additional seven volts which is added to the battery positive supply. This boosted supply voltage is smoothed by capacitor C2 and used to power TC1, IC2 and IC4 directly and IC3 via additional decoupling components R11 and C7.

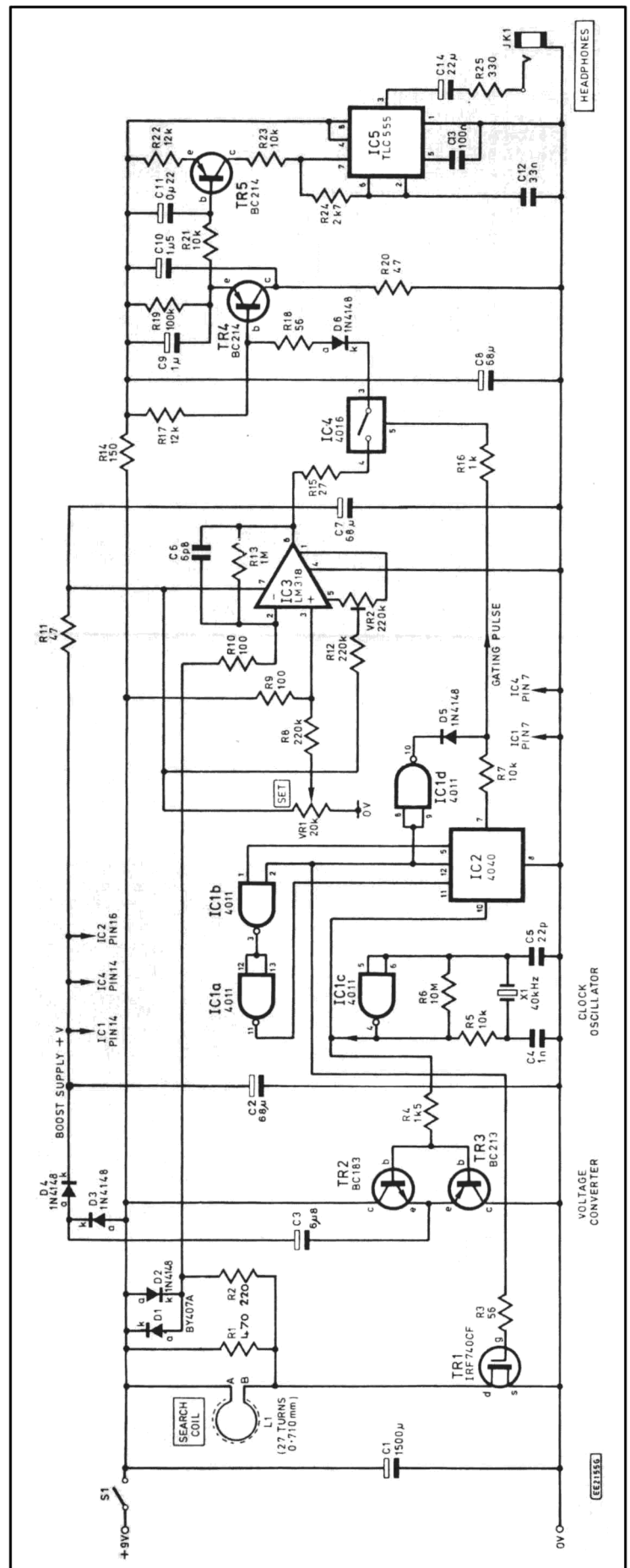
The 40kHz output from IC1 also drives the multi stage divider IC2. This i.c. consists of a series of divide-by-two stages the first of which is driven by an input to pin 10 and all of which can be reset simultaneously by a positive level on pin 11.

Two outputs from the chain of dividers are combined via IC1b and inverted by IC1a to produce a reset pulse. The two outputs are after 4 stages and 9 stages of division representing time intervals of 200 microseconds and 6.4 milliseconds. They are combined in such a way that a 200 microsecond pulse is produced after 6.4 milliseconds whereupon the dividers are reset and the cycle repeats. This pulse output appears at pin 12 of IC2 and is used to drive the MOSFET TR1 via R3 directly.

DETECTION

The pulses produced across the coil L1 have been discussed earlier. Resistors R1 and R2 provide loading for the coil so that the voltage pulse does not backfire into R1, and also that the coil does not act like a tuned circuit and ring with its own self capacitance producing an undesirable a.c. waveform. Diodes D1 and D2 clip part of the coil voltage passed via R2 and so limit the voltage swing which is passed to the amplifier IC3 to one volt.

Fig. 2. Complete circuit diagram for the EE Treasure Hunter. Note that the headphone socket (JK1) should be a stereo type.



The diodes are of different types because D2 has to handle only 50mA during the time that TR1 is turned on, whilst D1 must handle 3A peaks from the coil as TR1 is turned off. This clipping only affects voltages from the coil above one volt, it leaves the low level area of interest completely intact.

After clipping, the coil pulses are fed via R10 to IC3. This is an extremely fast op-amp i.e. which is particularly suited to the amplification of pulses. It has a very high slew rate which is a measure of the ability to change its output voltage at a fast rate and so reproduce pulses accurately. In this circuit it is connected as a standard inverting amplifier with feedback via R13 and C6. The non-inverting input is taken from the positive supply via R9 so that the output is biased correctly with its output at the battery positive supply.

Two controls around IC3 allow the output voltage to be adjusted. Preset VR2 is the standard offset null control and is used to set the output of the i.c. to zero when its inputs are connected to the same point; potentiometer VRI provides a means of unbalancing the circuit to allow the output to be set manually. This is used to set up the detector in operation to produce an audio signal to the preferred pitch.

ANALOGUE GATE

The output from IC3 is a clipped and inverted version of the coil voltage. The next step is to separate the part containing the low level wanted signal from the preceding relatively high pulse. This is achieved by means of the analogue gate IC4. This is a switch which can be opened by applying a voltage to its control pin. This control voltage is derived from IC2 via IC1d, D5, and R7 and consists of a pulse which is timed to open the switch just as the output from IC3 approaches zero (zero in this circuit is the positive battery supply).

The pulse is timed at exactly 50 microseconds after TR1 turns off. At this point the switch is opened and the output voltage from IC3 passes via R15, D6, and R18, and is rectified by the base-emitter junction of TR4 so that C9 is charged to the peak level. This is a negative peak of course because IC3 is an inverting amplifier.

The use of a transistor as a rectifier in this way is necessary because in order to reach the peak value, C9 must charge very quickly indeed. The current gain of TR4 adds to the base-emitter current so that most of the charge in C9 is provided via R20 so reducing the loading on the output of IC3.

The time constant of C9 and R19 is 100mS, this is long enough to change very little between pulses and short enough to respond rapidly as a piece of metal is swept into and out of range.

To reduce the number of components in the circuit, the gating pulse logic is simplified by allowing more pulses to follow the initial one. This is not a problem because the signal voltage decays after the first gating pulse and so subsequent gating pulses pass levels only below the peak already stored thus having no effect.

COMPONENTS

Resistors

R1	470	2W	carbon film 5%
R2	220	2W	carbon film 5%
R3, R18	56 (2 off)		
R4	1k5		
R5, R7, R21, R23	10k (4 off)		
R6	10M		
R8, R12	220k (2 off)		
R9, R10	100 (2 off)		
R11, R20	47 (2off)		
R13	1M		
R14	150		
R15	27		
R16	1k		
R17, R22	12k (2 off)		
R19	100k		
R24	2k7		
R25	330		

All 0.25W 5% carbon film except R1 and R2

Potentiometers

VR1	20k rotary, lin
VR2	220k skeleton preset, vertical

Capacitors

C1	1500µ radial elect 10V
C2, C7, C8	68µ radial elect 16V (3 off)
C3	6µ8 radial elect 16V
C4	1n ceramic plate 50V
C5	22p ceramic plate 50V
C6	6p8 ceramic plate 50V
C9	1µ radial elect by
C10	1µ5 radial elect 10V
C11	0µ22 radial elect 10V
C12	33n polyester 100V
C13	100n ceramic disc 50V
C14	22µ radial elect 10V

Semiconductors

D1	BY407A
D2-D6	1N4148 (5 off)
TR1	IRF740CF power MOSFET
TR2	BC183 npn general purpose
TR3	BC213 pnp general purpose
TR4, TR5	BC214 pnp highgain (2 off)
IC1	4011B CMOS quad NAND gate
IC2	40408 binary counter
IC3	LM318 high slew rate op-amp
IC4	4016B quad bilateral switch
IC5	TLC555 CMOS 555 timer

Miscellaneous

S1	s.p.s.t. mm toggle switch
JK1	panel mounting stereo 3.5mm jack socket
	6xAA battery holder and clip; 20m of 0.71mm enamelled wire; p.c.b. available from the <i>EE PCB Service</i> , order code EE652; Paxolin panel to form battery compartment; p.v.c. tape and sleeving; i.c. sockets - 2x8 pin, 2x14 pin, 1x16 pin; 7/0.2 connecting wire 0.5m; case 150x100x50mm; control knob; fixings and suitable headphones.

Special Hardware

Search head moulding; search head reinforcing plate 100x150mm; 1mx20mm dia. plastic shaft; right angle bend 20mm plastic; plastic angle 2x100mm 25/25mm; handgrip 20mm; 2x threaded end couplers 20mm; 2x saddle clips 20mm; 6xM4x10mm nylon screws and nuts; M5x50mm nylon screw and wing nut with captive washer.

AUDIO

The final part of the circuit is the audio oscillator section, this is a conventional 555 circuit except that the charge circuit for the capacitor C12 is not a resistor but a transistor TR5. TR5 is driven from the peak detector TR4 via a low pass filter consisting of R21 and C11.

Large pulses cause TR5 to turn on more and so C12 charges more quickly and the output pitch rises. This arrangement is at its most sensitive for the lowest pulse levels and so provides the ideal characteristic for sensitivity.

The output from IC5 is fed directly to a pair of personal stereo headphones via C14 and R25. The two earpieces can be connected in series by connecting to the tip and ring connections of the phones. This is more efficient than parallel connection and although the earpieces are then connected in antiphase this does not seem to matter in this type of application.

CONSTRUCTION

All components are mounted on a single printed circuit board (available from the EE PCB Service, code E6). Fig. 3 gives the component layout and the foil pattern, this is a compact board and so must be assembled with care. Before assembly it is wise to check that the board will fit into the guide slots of the case, and that all holes are clear.

Begin by fitting the resistors, diodes, and four wire links. Be careful to get all of the diodes the right way round with their cathode marking bands as shown.

Next fit sockets for the i.c.'s and the smaller capacitors. Note that all of the electrolytic capacitors must fit the right way round. They are usually marked with a string of signs down the side by the negative lead.

Depending on their size it may not be possible to get all of the capacitors flush to the board. This does not matter however, as the leads are generally thick and will support them well above the board.

Now fit the transistors, being careful to identify the different types and insert them the right way round; TR1 has a metal side which is shown as a thick line on Fig. 3. Take care with resistors R1 and R2 as these are large and must be mounted on end exactly as shown. A length of sleeving over the upper lead is advisable.

The crystal X1 should be fitted with care, its leads bent gently over, and its body glued to the board with Evo-Stick or similar. It can go either way round.

Larger components such as VR2 and C1 should be fitted last. Wires to the headphone jack, VR1, and the

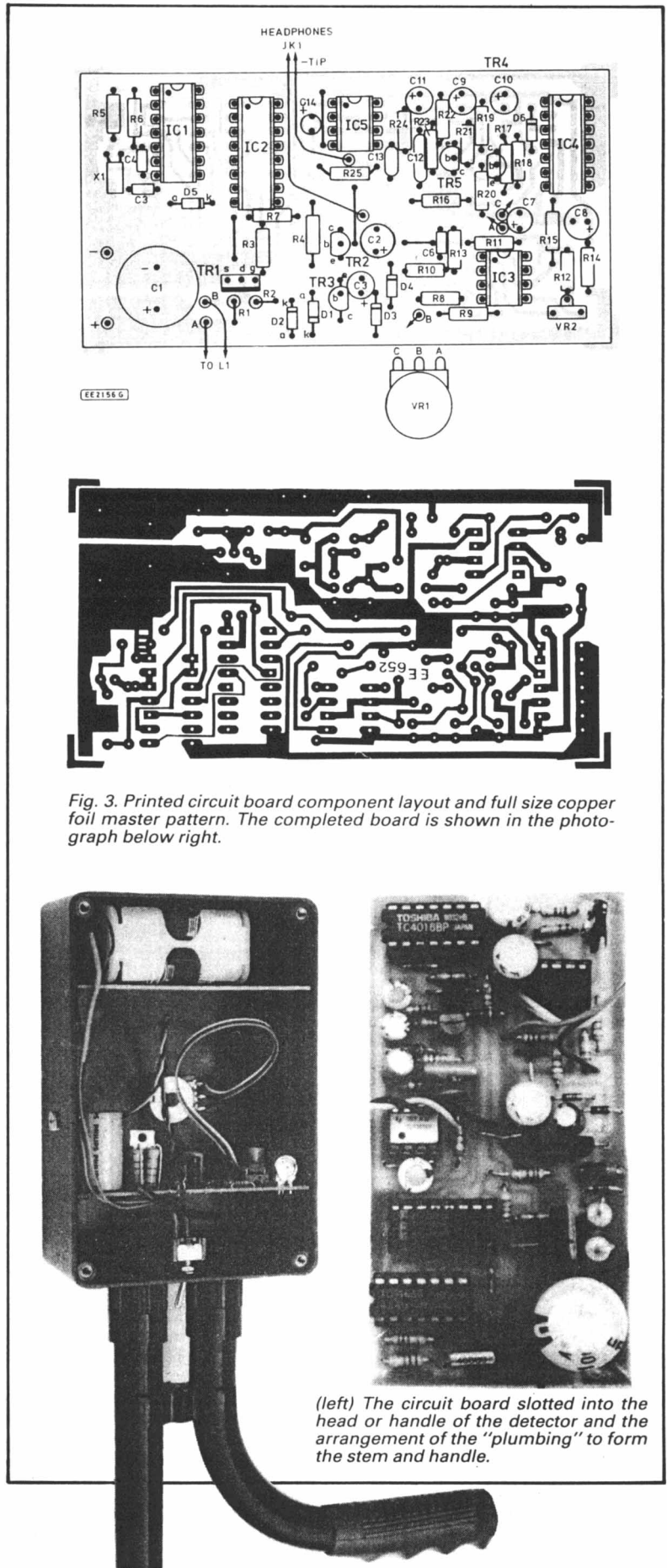


Fig. 3. Printed circuit board component layout and full size copper foil master pattern. The completed board is shown in the photograph below right.

(left) The circuit board slotted into the head or handle of the detector and the arrangement of the "plumbing" to form the stem and handle.

battery clip and switch should be connected directly to the board by stripping a short length of insulation from one end of the leads and passing the bared wire into the board from the component side and soldering it on the reverse.

SEARCH COIL

The winding of this coil is not difficult but the size and number of turns are critical. There must be 27 turns, each single turn being a loop from start to finish. This sounds obvious but it is surprisingly easy to misinterpret one turn especially the first and last ones.

To make a coil former all that is required is a piece of wood upon which a 190mm circle can be drawn. A veneered chipboard offcut is ideal. Use 16 panel pins or other small nails fitted with a 10mm length of sleeving and space them equally around the circle as shown in Fig. 4. The winding wire should be 0.71mm diameter enamelled copper and 20m long, leave a free length of 1.5m and carefully wind 27 turns around the pins.

It is not necessary to neatly layer the winding, as it will finally be hunched into a circular section. Secure the ends with P.V.C. insulating tape and then carefully slip short lengths of tape under the windings between the nails and fasten the ends together. Fit eight pieces of tape like this, then remove the winding from the board, either by bending or removing some of the pins. The result should be a neat coil that can now be bound with a spiral of tape to completely enclose it.

The start and finish of the winding must leave the binding at the same point and should be sleeved together with a 1m length

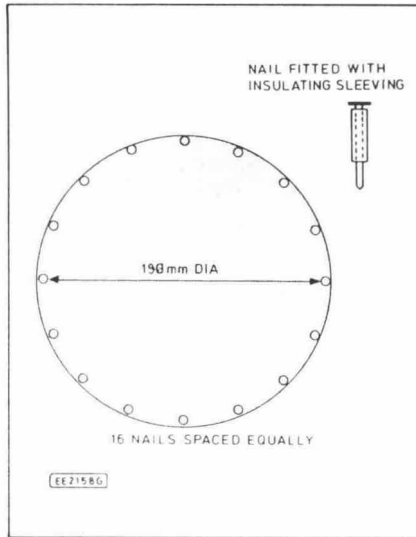


Fig. 4. Making up a search coil template from a piece of wood with insulated panel pins nailed around the circumference.

of p.v.c. sleeving. The end 30mm of the sleeving should be bound to the coil and the whole coil can then be given a further two layers of binding.

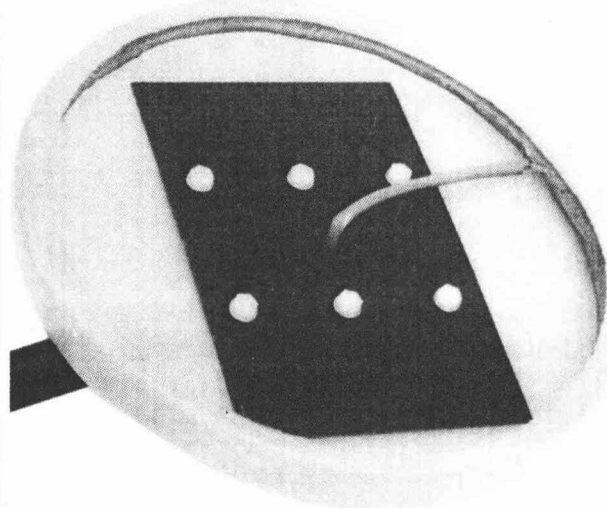
The coil is now suitable for most applications without further protection. There are numerous possibilities for complete waterproofing, but dipping the coil in varnish and allowing it to dry is probably the simplest way. Several coats can be applied and apart from the drying time the method is convenient and effective. The final appearance of the coil should be tidy if it has been carefully made, but this is not important as it will rarely be seen.

TESTING

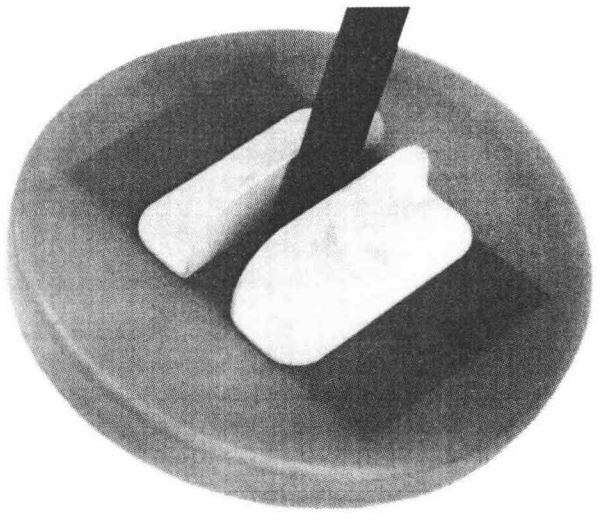
Before connecting the coil, it is possible to check some parts of the board for correct operation. Connect a set of headphones and a 9V supply preferably from six AA cells in a battery holder. Set both controls to mid position and switch on. A tone or clicking sound should be heard. Turn VR2 carefully until the tone becomes a steady clicking sound, and then check that VR1 has a similar but finer control over the pitch. Those with a multimeter can check that the voltage across C2 is approximately 16V and can set the output of IC3 to 9V (the battery supply voltage) using VR2, with VR1 set to mid position.

Connect the coil to the board (either way round) and position the coil on a cardboard box well away from any wiring and large metal objects. Note that as enamelled wire is used the thin coating must be scraped or melted from the wire ends before

The search coil is inserted in a small recess around the plastic search head. The cavity of the search plate can be filled with a resin so that it can be used when immersed in water.



Mounting the detector stem to the search coil is accomplished by using nylon brackets, nut, bolts and wing nut. Metal fixings MUST NOT BE USED.



soldering. If a solderable enamel is used the wire can be tinned directly by applying solder and heat from the iron.

Leave sufficient wire on the coil leads to allow the p.c.b. to be slid out of the box, and for the search head to be folded down. Once the coil is connected it should now be possible to set the circuit for a steady clicking noise which increases as metal is brought near. There may be a slight warble or rise and fall in pitch due to mains wiring in the area (not a problem when in use).

By setting the circuit for very slow clicks it is possible to get the maximum sensitivity. Move a 10p coin near and the clicking rate should rise at good distances. Note that metal rivets in the cardboard box and jewelry on the hands of the tester will be detected as well and metal chairs make themselves known from over a metre away.

A large object near the coil will produce a rather harsh sounding high pitched note. This is breakthrough of the very large pulse signal to the output. In normal situations this is unimportant as smaller signals are normally being sought.

The current consumption is around 80mA giving a good day's use from a fully charged set of AA NiCads and much longer from alkaline cells

HARDWARE CONSTRUCTION

As discussed before the hardware can take many forms. The printed circuit board has been made to fit the guide slots in the specified case, but other cases could be used. It is important to get the mechanical balance of the detector right and this is achieved by fitting the handle some way between the electronics box and the search head. The batteries are a particularly good counterbalance and are fitted as far back as possible in the prototype and held in place by a panel slotted into the housing.

The detector head can be made from any plastic material and fixed to the shaft using plastic angle and plastic nuts and screws. The prototype used a special moulding for the head and 20mm plastic tubing and fittings for the shaft and handle, plus a bicycle handgrip. A wing nut allows the head tube swivelled flat for easy transit. Wood could be used but the weight is rather a problem after an hour or two's use. School CDT departments will no doubt be able to go to town on this project and produce wonderful results.

For the kitchen table constructors a full set of hardware (undrilled) as used in the prototype and pictured here is available from Magenta.