E.E. BUCCANEER INDUCTION BALANCE METAL DETECTOR

ANDY FLIND

An induction balance metal detector. Providing good sensitivity with ease of use and construction

Although the "boom" passed a few years ago, metal detecting remains a popular hobby, with some tens of thousands of enthusiasts in Britain alone. At least two magazines are devoted to the pastime, and many areas have clubs which organise outings and rallies. For most users the enjoyment lies in the interest of their finds, though the odd spectacular discovery still occasionally makes headlines.

Recently a hoard of ancient Church treasures valued at £5million was unearthed. Good metal detectors are expensive however, even a simple one is far from cheap and may not be very satisfactory to use. Luckily, it's not too difficult to build a detector effective enough for serious use; both the interest of construction and the saving in cost can be considerable.

TYPE

Of the many types of metal detector, the best known are Beat Frequency Operation, Pulse Induction, and Induction Balance. The first, though simple, is rather insensitive and now practically obsolete. The second can be extremely powerful and has the advantage (for amateur constructors) of simple coil construction. However, it is very sensitive to the minute scraps of iron found on many sites, making it tedious to use. The third, I.B. for short, has many different forms. Complicated (and expensive) models can reject iron, foil and false signals caused by the ground whilst some can almost distinguish what has been detected. Simpler versions cannot do all these things, but it is still possible to obtain good sensitivity whilst rejecting iron.

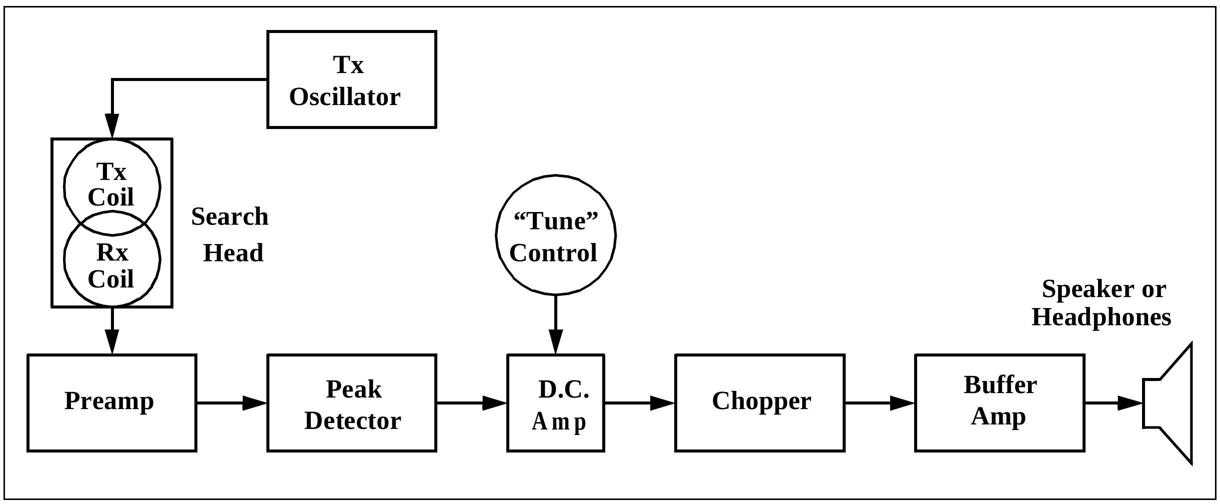

Fig. 1. Block diagram of the induction balance metal detector.

BLOCK DIAGRAM

The block diagram of such a detector is shown in Fig. 1. The "search head" contains two coils. One of these, the transmitter or "Tx" coil, is driven by an oscillator, setting up an alternating magnetic field. The receiving or "Rx" coil is positioned so that it partially overlaps the Tx. By adjusting the amount of overlap a point can be found where the voltages induced in the Rx coil "null", or cancel out so that little or no electrical output is produced. A metal object entering the field causes an imbalance, resulting in a signal.

In a simple I.B. circuit the rise in amplitude is used to signal the metal's presence, so the following stages consist of amplification, accurate conversion to "peak value" (a d.c. signal), further amplification, and a means of presenting the final output as an audible tone of increasing volume. An adjustable d.c. offset control is used to adjust the initial sound threshold, this being known as "tuning".

SENSITIVITY

In this type of circuit more sensitivity is obtained if the coils are, in fact, slightly offset from null. If this offset is in the direction of “too far apart”, iron and other permeable objects cause an initial reduction in amplitude, whilst conductive ones produce an immediate rise. In this way some iron rejection can be built in.

Simple detectors are notorious for great sensitivity to foil, or silver paper, because they often use fairly high search frequencies, where large “skin effect” currents are induced in the foil. The low search frequency used by the Buccaneer, around 20kHz, helps to reduce this problem to some extent.

CIRCUIT DESCRIPTION

The full circuit diagram of the EE Buccaneer appears in Fig. 2. The oscillator, based on IC1 and transistors TR1 and TR2, may appear a little strange. It is required to produce a reasonable amount of transmitted power with moderate battery consumption, whilst being very stable with varying temperature. The transistors supply the power, being driven into saturation they provide a squarewave drive of almost rail-to-rail amplitude. R6 controls the power sent to the coil.

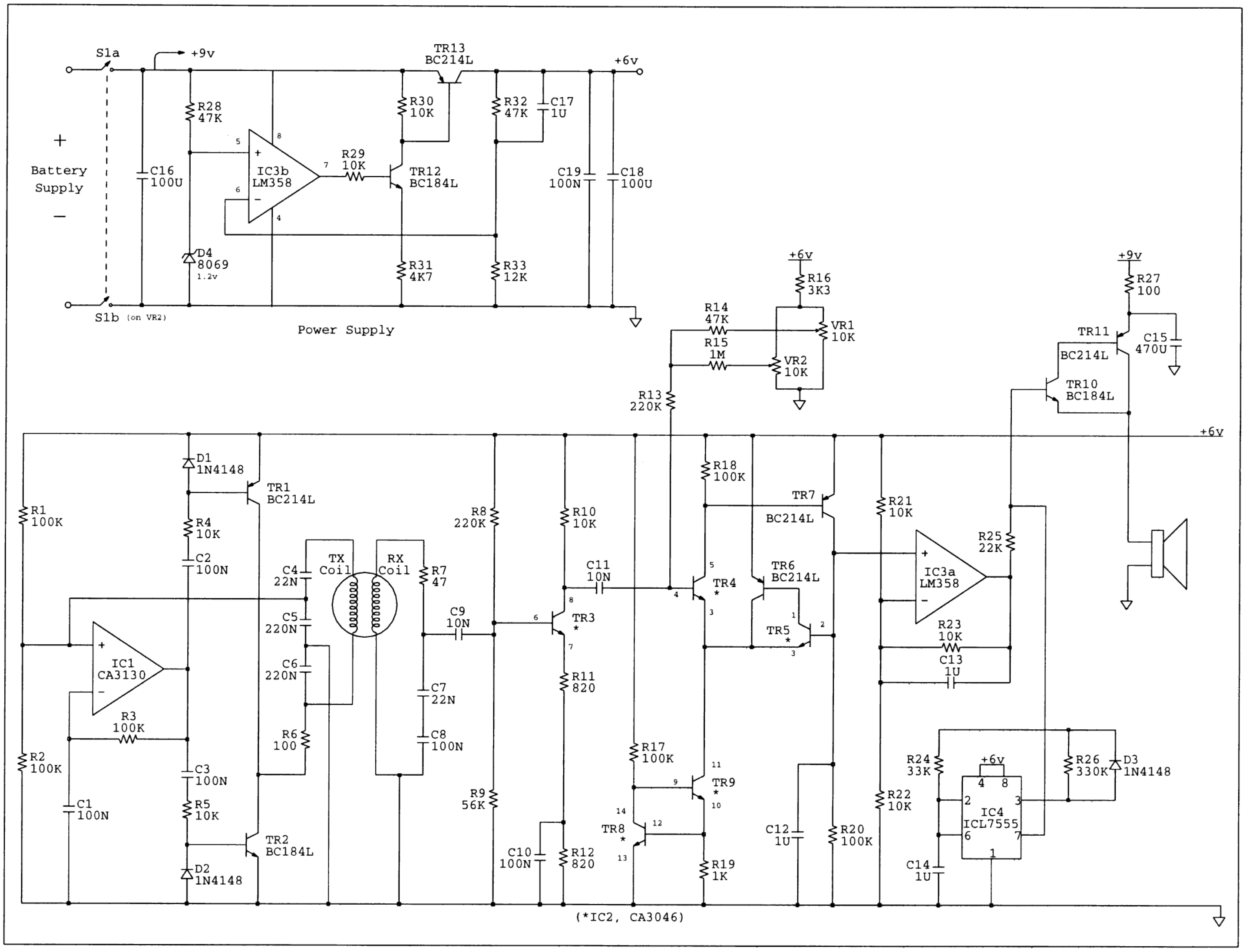

Fig. 2. Complete circuit diagram for the *EE* Buccaneer Metal Detector.

Impedance matching for the best possible efficiency from the resonant coil circuit is achieved by tapping the capacitance instead of the coil, as this simplifies coil construction. Feedback is sensed by IC1 which drives the transistors. Finally, again for efficiency, the coil is wound with thicker (28 s.w.g.) wire than usual to obtain a good “Q” factor.

Moving to the receiving section, this again begins with a tuned coil, set to the same frequency as the transmitter. At first-sight it would seem that a high “Q” factor here would also improve the sensitivity but in practice, it was found difficult to tune the two circuits accurately enough and the resulting detector was badly affected by signals from the ground (“ground effect”). The Rx coil is therefore damped a little by R7 to increase the bandwidth, and the drop in amplitude is made good by gain from TR3. The circuit must now detect the peak value of the amplified signal and convert this to a d.c. level. This cannot be done with a simple diode as changes in temperature would cause constant, annoying drift; overcoming this leads, as can be seen, to some complexity. The circuit is best explained with the help of the simplified drawing Fig. 3.

The maximum positive voltage reaching TR1 base consists of the reference voltage plus the peak positive value of the signal from C1. If this exceeds the voltage at TR2 base (from C2), TR1 will conduct, in doing so it will turn on TR3 which will raise C2's voltage until it matches the input. So long as transistors TR1 and TR2 are similar in type and closely coupled thermally, the effects of temperature on their base-emitter junctions will cancel having no effect on the output. Their emitters should be fed by a current source, shown here as a simple resistor.

TRANSISTOR ARRAY

In the complete circuit, all the npn transistors in this section are contained in a CA3046 integrated array. The numbers refer to the pins on the chip, which contains the emitter-coupled pair TR4 and TR5, ideal for this application, plus three extra transistors. Two, TR8 and TR9, are configured as a current source for the emitters, whilst the third is amplifier TR3. Because the operating conditions of TR4 and TR5 should be closely matched, and TR4 is "off" most of the time. TR6 has been added to take most of the current-carrying work away from TR5.

The input is applied through C11, the adjustable reference is supplied by VR1 and VR2, respectively "coarse" and "fine" tuning controls, and the output appears as a voltage on C12. The stability obtained with this admittedly rather complex arrangement has proved quite outstanding, enabling the detector to outperform almost any other design of its type.

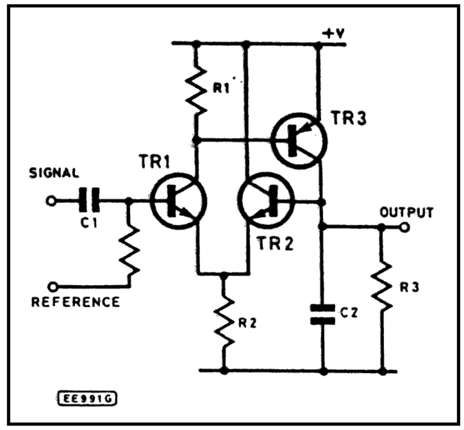

Fig. 3. The simplified peak detector circuit.

The remaining circuitry is quite straightforward. IC3a provides d.c. gain, the output being initially set (by VRI and VR2) just above zero, and rising to nearly six volts on a strong signal. It is necessary only to chop it up and buffer it to make it audible. Chopping is done by 1C4, a 7555 low-power timer connected as an oscillator. Pin 7 of this chip is the output of the transistor intended for discharging the timing capacitor, this being switched on when the "output" (pin three) is low. Here it is used to pull the voltage from R25 low.

Small speakers produce the most efficient loud noises when fed with short pulses, so the mark-space ratio of IC4 is arranged to convert the output into this form. Transistors TR10 and TR11 do the buffering, after which the output will drive speaker or headphones.

SUPPLY

For good stability a well regulated supply is essential. With only nine volts to start with, dropping below seven as the battery ages, the two volts differential required by most integrated regulators is unacceptable so the supply circuit shown was developed. This uses a 1.2v bandgap reference. IC3b compares this with a divided portion of the output from TR13, intended to be six volts, and drives the transistors as necessary. This circuit works with a differential, or "drop out" down to 0.1v.

CONSTRUCTION

Board construction for this project is straightforward providing some simple precautions are observed. Firstly, since the layout is fairly compact, a fine-tipped iron and reasonable soldering skill are required. The polycarbonate capacitors are the compact layer type supplied as "poly layer". C4 and C7 are both one percent tolerance, this being important for matching the tuned circuits. Transistors TR2 and TR6 emitter leads are bent to clear underlying tracks on the board, do this carefully before fitting them.

The bandgap device D4 may be supplied in a three-lead package identical to the transistors, or a slightly smaller two-lead version. The latter can be fitted using the lower two holes in the p.c.b., with the flat on the same side as before. Use sockets for all four integrated circuits as this simplifies testing and, where necessary, trouble shooting. It also provides protection for IC4, a rather static-sensitive device in the author's experience. The printed circuit board component layout is shown in Fig. 4 and the p.c.b. track pattern in Fig. 5. The board construction should be completed, but at this stage none of the i.c.'s should be plugged in as this will be done during testing.

CONTROL BOX

Before testing the board, the control box should be assembled as it will be found useful for much of the test procedure. As clearances in the box are small, precise drilling details are given in Fig. 6 to ensure it all fits. The speaker "grille" is a pattern of holes, there being scope for some personal artistry here! Assembly consists of fitting sockets, pots VR1 and VR2, and gluing the speaker into place. An impact adhesive such as "Evostick" is suitable for this purpose. Wiring is shown in Fig. 7.

COMPONENTS

Resistors

R1, R2, R3, R17, R18, R20	100k (6 off)	R15	1M
R4, R5, R10, R21, R22, R29, R30	10k (7off)	R16	3k3
R6, R27	100 (2 off)	R19	1k
R7	47	R23	470k
R8, R13	220k (2 off)	R24	33k
R9	56k	R25	22k
R11, R12	820 (2 off)	R26	330k
R14, R28, R32	47k (2 off)	R31	4k7
All 0.6 watt 1% type		R33	12k

Potentiometers

VR1	10k lin. carbon
VR2	10k lin. carbon with switch

Capacitors

C1, C2, C3, C8, C10, C17, C19	100n polyester layer (7 off)
C4, C7	22n 1% polystyrene (2 off)
C5, C6	220n polyester layer (2 off)
C9, C11, C13, C14	10n polyester layer (4 off)
C12	1µ polyester layer
C15	470µ axial elect. 10V
C16, C18	100µ axial elect. 10V (2 off)

Semiconductors

IC1	CA3130 C-MOS op-amp
IC2	CA3046 transistor array
IC3	LM358 dual op-amp
IC4	ICM7555 C-MOS 555 timer
TR1, TR6, TR7, TR11, TR13	BC214Lsiliconpnp(5 off)
TR2, TR10, TR12	BC184L silicon npn (3 off)
D1, D2, D3	1N4148 silicon diode (3 off)
D4	8069CCZR 1.2 volt Voltage Reference

Miscellaneous

Printed circuit board, available from EE PCB Service - Code EE570; d.i.l. sockets 8-pin (3 off): d.i.l. socket 14 pin; case, ABS box 150 x 80 x 50mm; control knobs (2 off); PP3 battery container with clip; DIN plug and chassis socket, 5-pin 240 degree; switched stereo jack socket; 8 ohm loudspeaker, 50mm diameter; 28 s.w.g. (0.375mm) enamelled copper wire; 2 metres twin individually screened cable; hardware; plastic plate, plastic bracket, PTFE tape, cooking foil, fibreglass repair kit, tubing for handle etc., see text.

The headphone socket connections face outwards, with the volume reducing resistor soldered to them so that it can be easily selected to suit the ’phones to be used. Its value will have to be found by experiment, a suggested starting point is around 200 to 300 ohms. A switched socket is required to turn off the speaker when ’phones are in use. It doesn’t matter if they’re connected in series or parallel, but there should be no possibility of short-circuiting the output as the plug is inserted and removed, as this can cause output transistor destruction. Socket wiring details shown in Fig. 8 are for the most common types. Connect the controls and the switch to the board, but leave the other connections for the time being.

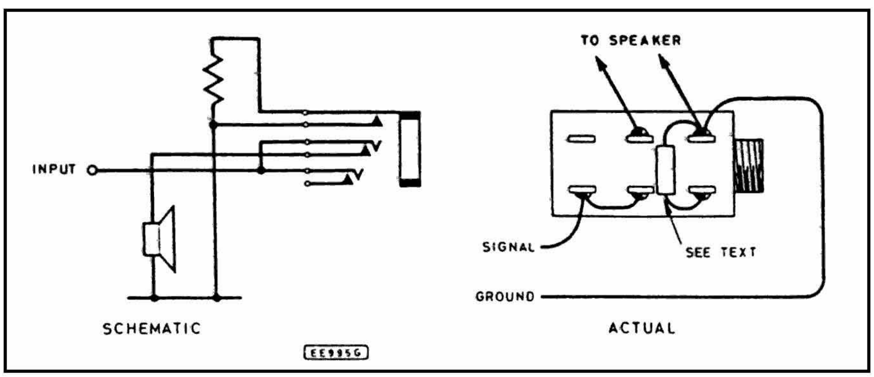

Fig. 8. Headphone socket circuit and wiring arrangement.

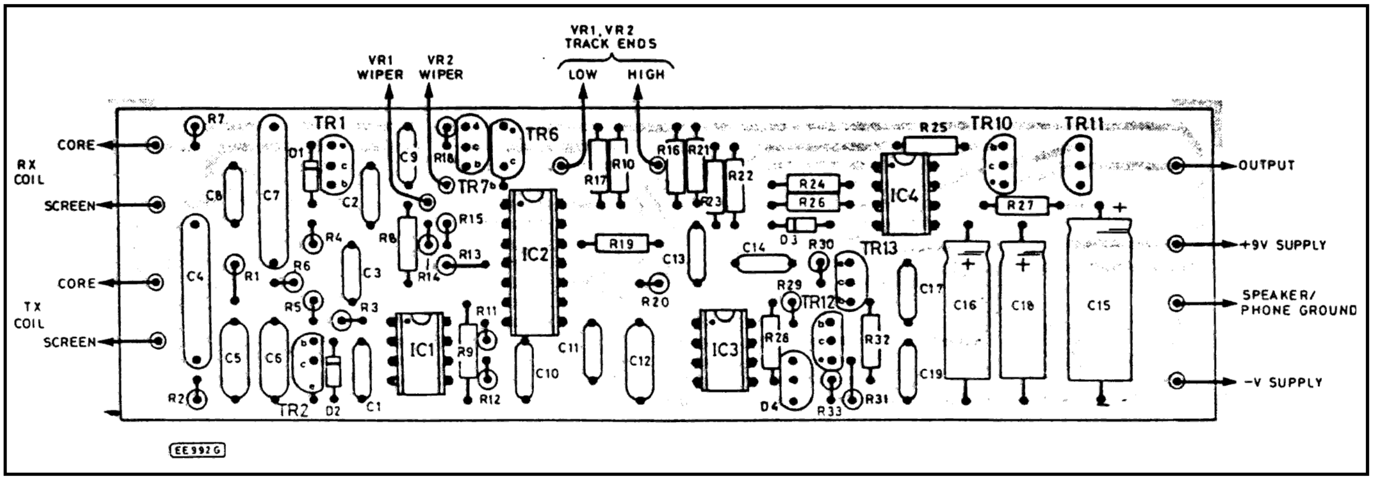

Fig. 4. Component layout on the printed circuit board.

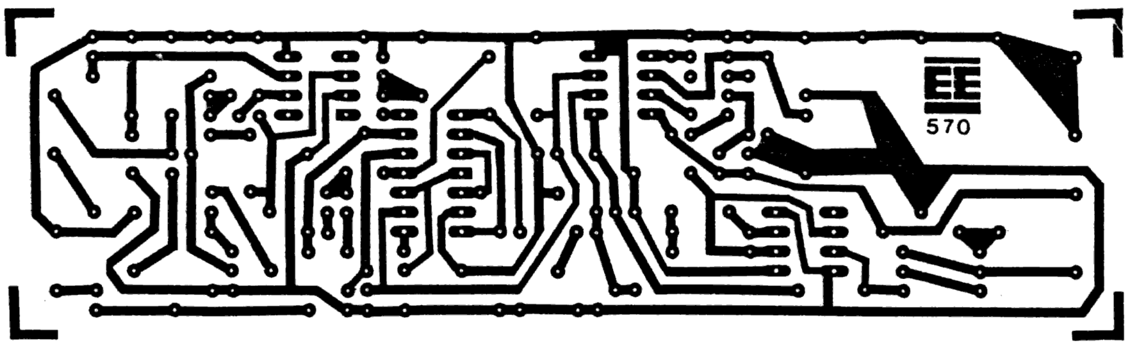

Fig. 5. Full size printed circuit board foil master pattern.

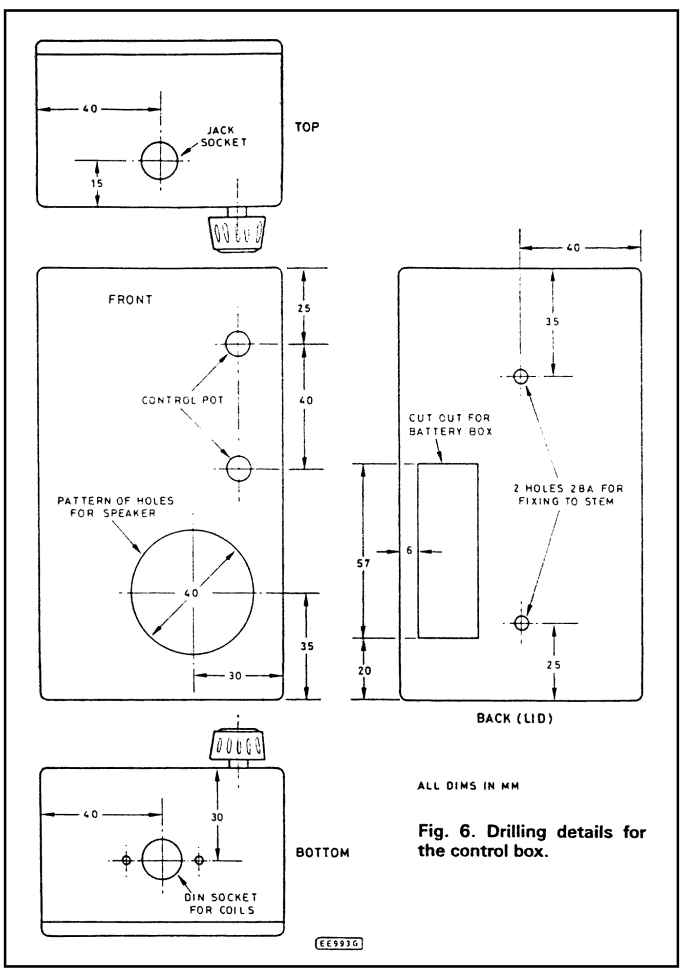

Fig. 6. Drilling details for the control box.

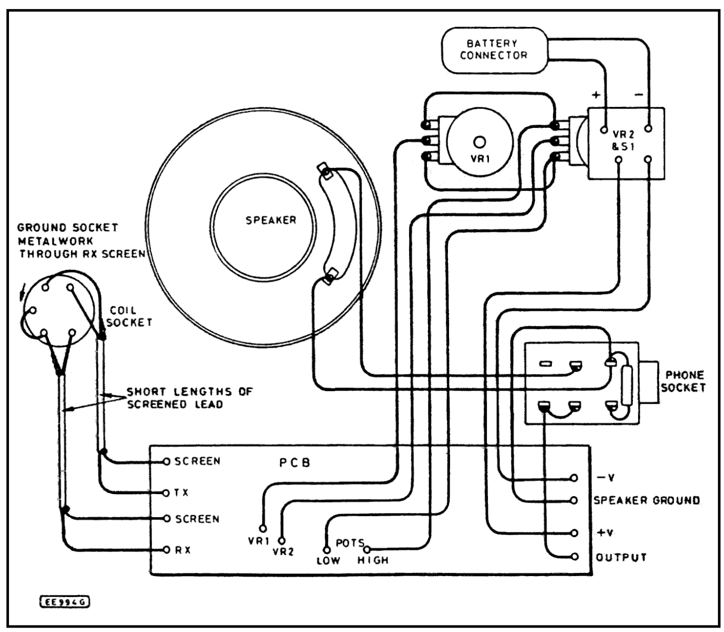

Fig. 7. Interwiring details for the off-board components mounted inside the control box.

TESTING

About the worst misfortune that can befall a constructor testing a new project is that some drastic fault causes heavy current drain and damages expensive components. A current limiter of some kind can prevent this. It may be that a limited bench supply is available but, if not, a few pence invested in the simple device shown in Fig. 9 is well worth while. This is placed in series with the positive supply and will normally have very little effect, but if a fault is present, it will limit the current to about 25 milliamps.

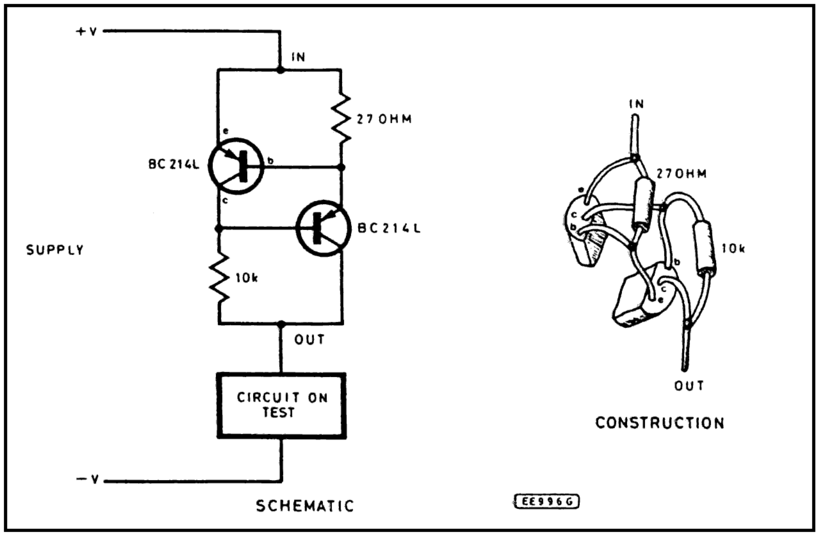

Fig. 9. Test circuit for current limiter.

Most of the circuit can be checked out as follows. With just controls and switch wired to the board, apply power through the limiter. Monitor the current taken with a meter. After an initial surge as electrolytics charge, the drain should drop to a very low value, about 0.2mA. Switch off, plug in IC3, and try again. This time the current should settle to about 1.8mA. Check the voltage across C18, which should be close to six volts as the regulator is now working.

Plug in IC2 (with power off; always switch off when working on the board) and check that drain rises to two or three milliamps. Check the voltage across C12 the 1µ polyester. This should be variable from zero to about four volts with the setting of coarse control VR1. If so, check the voltage on pin seven of IC4’s socket which should rise sharply from zero to within a volt or so of main supply at some point on VR1’s range. If all seems well connect the speaker, fit IC4 and switch on again, this time without the current limiter.

Adjustment of VR1 should turn a loud tone on and off. Try making it just audible using both controls. At this point, place a finger on the Rx coil input connection; this should increase the volume, due to injection of stray a.c. pickup from mains wiring, etc. Everything bar the oscillator, which needs the Tx coil, has now been tested so fit IC1 and complete connections to the box. When the coils are connected the complete circuit will draw around 12 to 14 milliamps, plus whatever is required to generate the sound when an object is detected.

SEARCH HEAD

Search head construction is next. Although this can be built in many ways, the method to be described has served well for several designs, producing a neat, pivoting waterproof head. The one slight disadvantage is weight, due to the resin used. The hardware consists of a rigid melamine plastic plate (flexible types are not suitable) 190mm in diameter. The prototype used a brand called “Style”, the best place to find these plates being caravan equipment stockists.

The inside of the plate should be roughened with emery paper so that resin will stick firmly to it. To the plate is screwed a pair of L-shaped plastic brackets, cut from a fixing intended for square section rainwater “downspouting”. This can be obtained from builders’ merchants; whilst there buy a reel of PTFE plumbers’ jointing tape. The stem fits between the brackets and is held by a threaded rod with a wingnut at each end, allowing the head to be tilted to the required angle and tightened by the user. A hole is drilled to allow entry of the “figure of eight” screened twin cable to the coils.

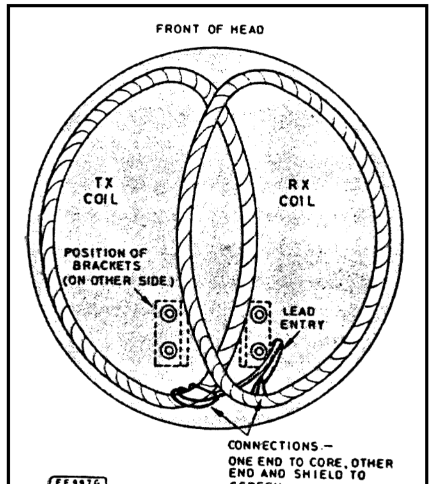

Fig. 10. Positioning and wiring of coils in the search head.

Coil warning starts with a sheer of paper taped to a soft board. A 110mm diameter circle is marked out and pins stuck around it at five to ten millimetre intervals, sloping outwards slightly. 100 turns of 28s.w.g. enamelled copper wire are wound around the circle (don’t use a different gauge as performance may be affected) Winding is easier if the wire is first passed through the tube from a ballpoint pen, it can then be “written” into place. The w ound coil is secured with temporary twists of wire and removed from the board. A binding of PTFE tape is applied, the wire ties bein g removed in the process. Bunching of the wire may prove a slight problem as “full circle” is approached, an initial looser binding of PTFE will help here. PTFE is used as it’s impervious to the resin used later for potting. The coil can now be bent into something approaching its final shape, a sort of lopsided oval as shown in Fig. 10.

With the coil tightly bound and insulated, a “Faraday” electrostatic shield is added. Thin, stranded hookup wire is stripped to a length of about three inches, the strands are then divided into two and wound around the coil in each direction starting near the connections. This provides a sound connection to the cooking Foil which is now cut into 10mm wide strips and wrapped around the coil. A gap of about 10mm is left at some point to prevent the shield forming a closed turn around the circumference of the coil. Finally, the coil is again bound and insulated with more PTFE. The two coils are identical, the second being made in exactly the same way.

SETTING UP THE HEAD

"Fastglas" resin is used to pot the coils into the head. Motoring accessory shops can supply a small kit containing resin, hardener, a measuring beaker and glass matting. A brush and cellulose thinners to clean it with are also needed. The approximate coil positions can be seen from Fig. 10. They should be connected by their lead to the circuit, with a meter arranged to read the voltage across C12. The sound can be silenced either by disconnecting the speaker or by inserting a spare plug into the headphone socket. VR1 should be turned right down. If the overlap of the coils is adjusted very carefully, a point will be found where the meter dips very sharply. This is the "null", or balance point, close to the final coil position. The coils should be clamped here, clothes pegs are useful for this, whilst their outer edges are fixed in place with some resin.

When the resin has set the pegs can be removed, and the central parts of the coils carefully adjusted to find the position giving lowest output. If the meter falls to zero, an adjustment of VR1 will cause it to read again. This should all be done well away from any metal of course, save for the screws in the assembly itself. When the lowest output has been found, move the coils in the direction of "too far apart" until the voltage on C12 has risen by about half a volt; this will give the detector greater sensitivity and enable it to reject most iron. Having set the coils to the correct point they can be fixed with more resin. In practice the process should proceed in several stages, fixing a little more of the coils at each step, mixing about 30cc of resin at a time.

If the coil is potted in solid resin it will be very heavy, so the larger gaps should be filled with something light and bulky. Expanded polystyrene cannot be used as alas, resin attacks it. In the past the author has used soft Balsa wood. but corrugated cardboard was tried for this design and appears just as effective. A covering of the glass matting is applied with the final coat of resin for a neat, tough finish.

The stem may be wood, plastic pipe, or metal. Aluminium tubing is best, and can be bent to shape with a pipe-bending tool or possibly a bending spring. Copper tubing would probably be as good, though heavier. If a metal stem is used, the last 150mm or so should be made from wood dowel glued to the tubing with Araldite to prevent the metal being placed hard against the most sensitive area of the head. As a finishing touch, a bicycle handlebar grip makes a neat handle.

IN USE

Detectors of this type are capable of surprising results. Simple, rapid operation means that on many sites users may find as much as those with powerful discriminators, since most buried objects are not. in fact at very great depths. As a guide to sensitivity, "in air" the prototype will just detect a 2p coin at about 200mm, by 150mm the signal is clear, and at 100mm it's really singing out. These figures will not apply "in the ground", where depth will depend largely upon the mineralisation present. On many sites false signals will be caused by "ground effect".

Most inland areas, especially those where man's presence has been concentrated, contain ferrous particles which cause a negative response with this detector. Salt-wet beaches are conductive and will usually produce a positive output. Good detecting consists of keeping the tuning adjusted as near the threshold as possible, holding the head at a constant height close to the ground, and searching slowly and methodically. Finally, most really successful treasure hunters engage in a lot of research before they venture out, studying old newspaper reports, ancient tithe maps and the like at their local libraries.