Build an induction balance metal locator

Main Features

- Easy to build & operate.
- Suitable for use over wet or dry ground including beach sand.
- Adjustment to exclude ground effects.
- Sensitivity control.
- Audible indication via head¦phone or loudspeaker output when metal detected.
- Sound increases in frequency as metal moves under search head.
- Counterbalanced handle for ease of use.

Most do-it-yourself metal locators are difficult to build & operate but not this one. This unit is a cinch to put together & is just the shot for finding coins, rings, watches & other valuable metallic items.

By JOHN CLARKE

Of course, as well as finding those more mundane items, a metal locator can also be used to locate the metal of our dreams — GOLD! But let's be realistic; not many of us are ever going to strike it rich on the goldfields, although metal locators have detected large nuggets for a few lucky prospectors.

No, a metal locator is more likely to be used for fun and any profits made from finding coins or jewellery are likely to be quite modest. Then again, you never know what might be hidden under the next few square metres of beach sand.

The big advantage of a metal locator is that it saves lots of digging. One only has to dig in locations where the metal locator indicates the presence of metal. Of course, not all finds will be of any value except maybe for the recyclers of cans and scrap aluminium.

To overcome this problem, some metal locators incorporate controls

which discriminate against various types of metals (eg, ferrous metals) which are likely to be of little value. Taken to the extreme, the ultimate metal locator would find only things of value. As expected, metal locators which can discriminate against unwanted metals are usually expensive and can be extremely complicated to use. They are best left for experienced prospectors.

The SILICON CHIP Induction Balance Metal Locator is not a discriminating type and is very easy to use. In fact, there are just three control knobs: Volume, Ground and Sensitivity.

The first control sets the volume of the output from the loudspeaker or headphones. The second control (Ground) is the most frequently used — it adjusts the sound from the loudspeaker so that it produces a low frequency growl when the search head is positioned over the ground. The frequency will then increase sharply when metal is detected.

The final control adjusts the sensitivity of the unit and sets the maximum depth at which an object will be detected.

Operating principle

Most simple metal locators operate on the principle of beat frequency oscillation (BFO). In this type of design, the search coil is used as the inductive component of an oscillator. When a metallic object is brought near the coil, the frequency of the oscillator changes slightly due to the resulting change in the coil's inductance. This frequency change is detected by mixing the oscillator frequency with a fixed frequency to produce an audible beat.

It is often claimed that BFO metal locators are able to detect the difference between ferrous and non-ferrous metals. This is because the inductance of the search coil increases with ferrous metals and decreases with nonferrous metals, corresponding to decreasing and increasing beat frequencies respectively.

In practice, however, the audible beat can also increase for ferrous metals since eddy current flow in the iron often masks out the effect of increasing inductance. It is therefore impossible to discriminate between the two different

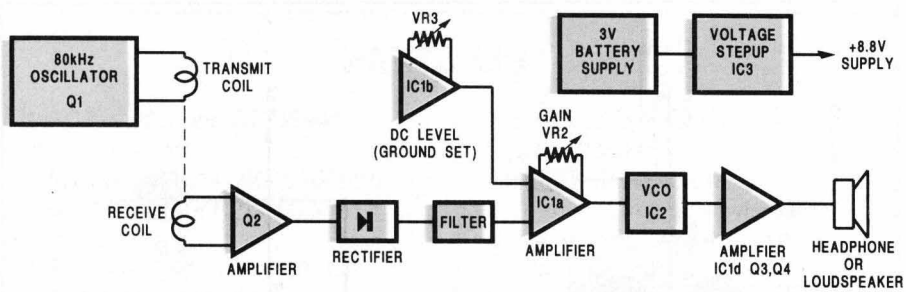
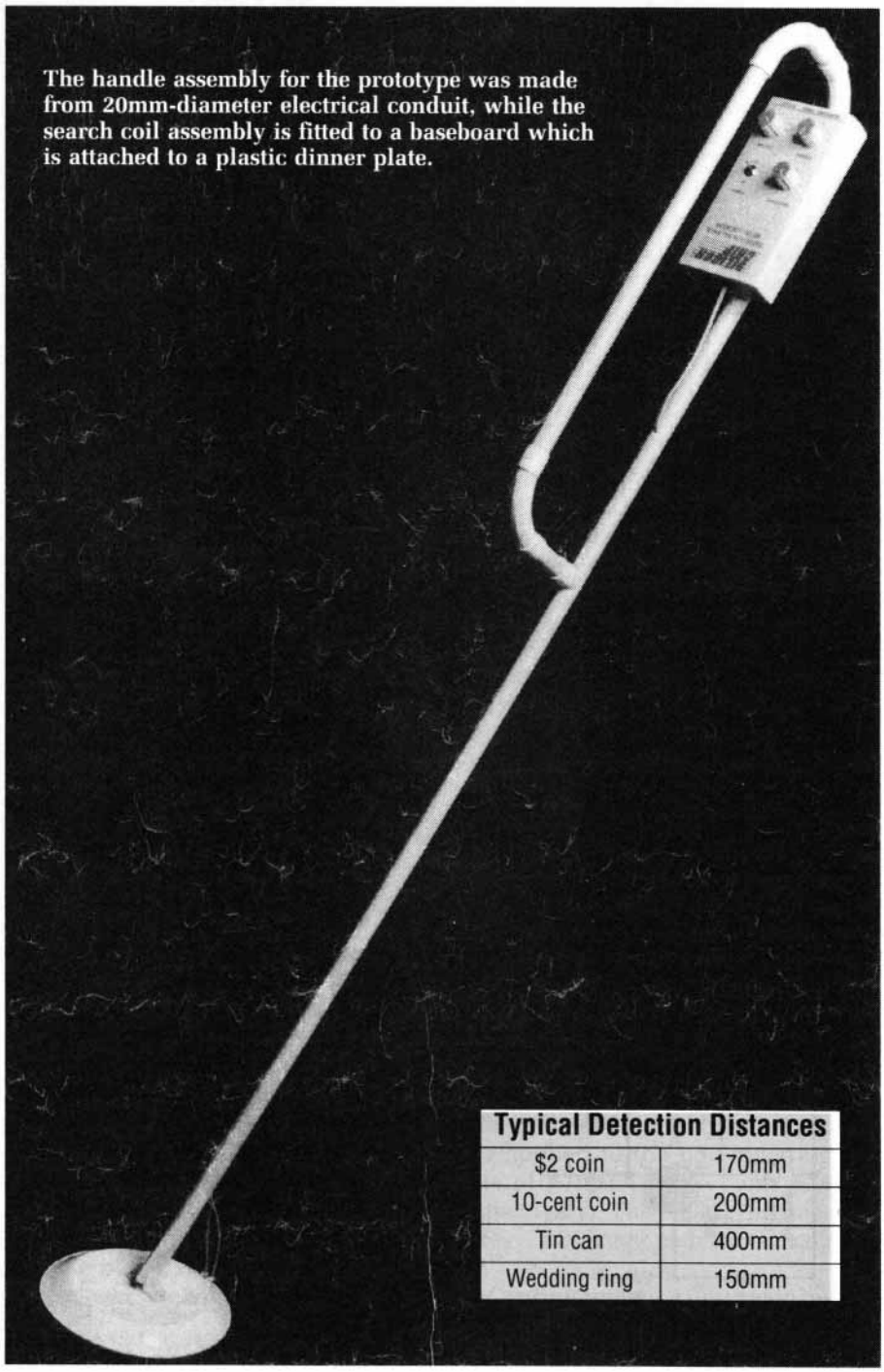


Fig.1: this block diagram shows the main circuit elements of the Induction Balance Metal Locator. The output from the receive coil assembly is rectified, filtered & amplified by IC1a. IC1a in turn controls the output frequency from voltage controlled oscillator (VCO) IC2. IC1b & VR3 set the DC bias on IC1a to null out ground effects.



The handle assembly for the prototype was made from 20mm-diameter electrical conduit, while the search coil assembly is fitted to a baseboard which is attached to a plastic dinner plate.

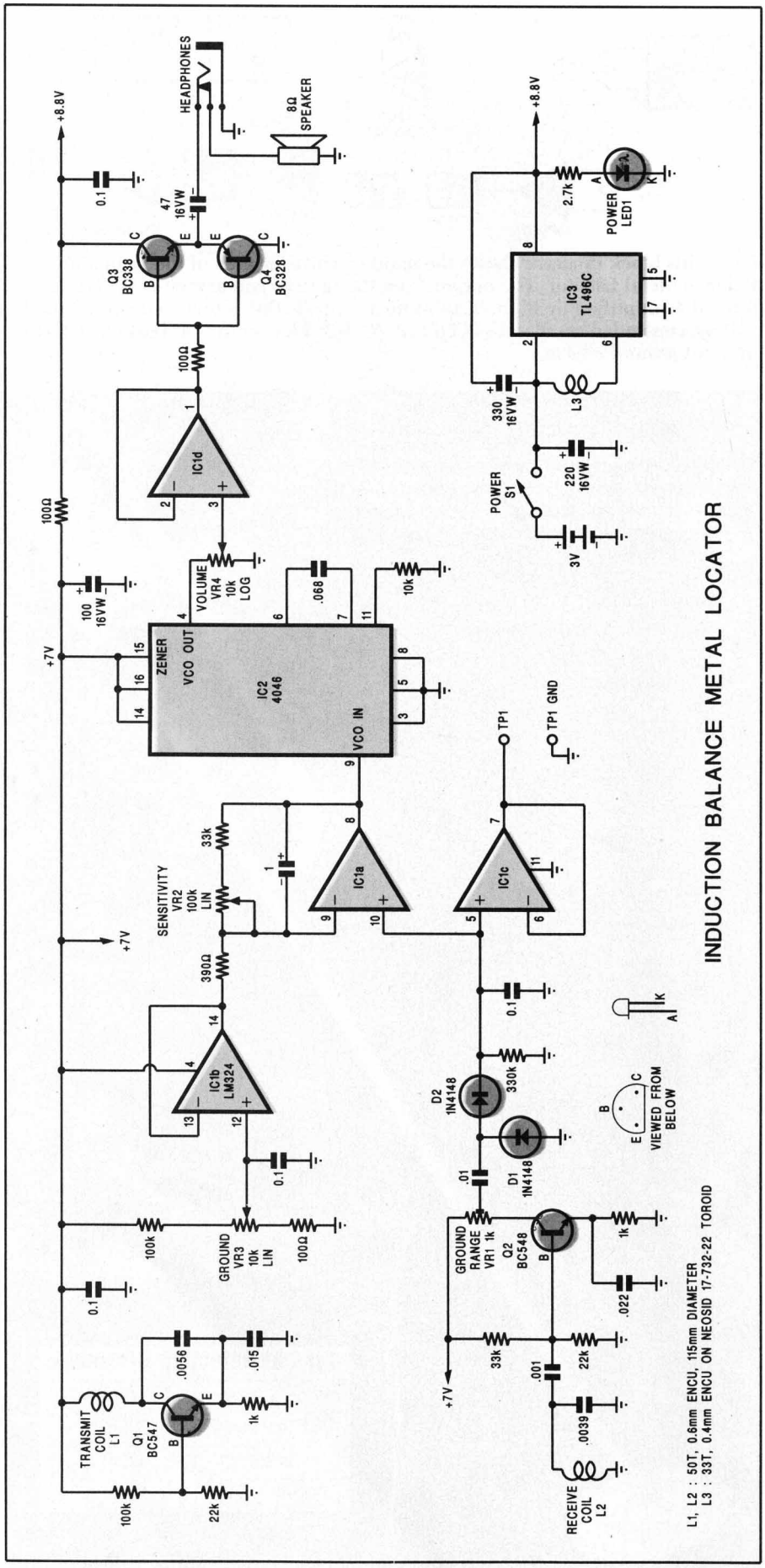


Fig.2: the final circuit is built around just three ICs. The transmit coil forms a tuned collector load for oscillator stage IC1a & its output is coupled into receive coil L2 which is positioned for minimum pickup in the absence of metal. L2's output is amplified by common emitter stage Q2 & rectified by D1 & D2 before being fed to amplifier stage IC1a which then drives the VCO. The output of the VCO appears at pin 4 & drives audio amplifier stage IC1d, Q3 & Q4.

types of metal.

By far the biggest disadvantage of the BFO technique is that the search coil must be shielded with a metal screen to prevent reaction with the ground. This significantly reduces the sensitivity of the BFO type metal locator, which means that small objects buried in a few centimetres of soil can easily be missed.

To eliminate this problem, the SILICON CHIP metal locator uses a completely different operating principle. Unlike the BFO type, it uses two coils in the search head, with one coil driven by an oscillator. The second coil is used to pick up signal from the first.

During construction, the two coils are positioned in an overlapping fashion so that the second coil has minimum pickup. When metal is introduced, however, the signal level in the second coil increases. This increased level is detected and the resulting signal used to drive circuitry to provide an audible indication that metal is present.

This principle of operation is called "Induction Balance" (also known as "Transmit Receive") and it provides a far more sensitive metal detector than the BFO type. Its only disadvantage is that the two coils must be carefully aligned during construction.

The depth to which the metal locator can detect metals under given conditions is set by the search head coil diameter. The larger the diameter, the deeper it will detect. However, large search coils suffer from lack of pinpoint accuracy in finding metals. We opted for a medium-sized search head which provides a good compromise between accuracy and depth.

Of course, there's nothing to stop you from experimenting with larger search heads if depth is important.

Block diagram

Fig.1 shows the block diagram of the Induction Balance Metal Locator. An oscillator operating at about 80kHz drives the transmit coil and signal from this is picked up by the receive coil. Amplifier stage Q2 boosts the signal output from the receive coil and the signal is then rectified and filtered to produce a smooth DC voltage.

IC1a amplifies the DC voltage from the filter. Its output is offset by a DC voltage provided by IC1b and this, in turn, is set by potentiometer VR3 (the Ground control). In operation, VR3 is set so that the DC output from IC1b is equal to the DC voltage from the filter, so that IC1a's output normally sits close to 0V (this is done to cancel out ground effects).

When the search coils are brought near metal, the signal level in the receive coil increases. This results in a higher DC voltage at the output of the filter and this is then amplified by IC1a to produce a control voltage for the following VCO (voltage controlled oscillator stage).

When IC1a is output is at 0V (ie, no metal is present), the VCO is off and no signal is produced. Conversely, as the search coils are moved closer to metal, IC1a's output rises and the VCO increases its output frequency from 0Hz to about 4kHz. This signal is fed to an amplifier stage (IC1d, Q3 & Q4) and the resulting output then fed to a loudspeaker or a pair of headphones.

Circuit details

Refer now to Fig.2 for the circuit details.

Q1 and its associated components form the transmit oscillator. This stage oscillates by virtue of the tuned collector load provided by coil L1 and the .0056µF positive feedback capacitor between collector and emitter. The 1kΩ emitter degeneration resistor provides a small amount of DC negative feedback to reduce sinewave distortion and provide a stable bias point.

The signal in L1 is coupled to receive coil L2. This latter coil is aligned with L1 so that the induced signal is normally at a minimum. The .0039µF capacitor across L2 forms a resonant circuit to ensure maximum pickup sensitivity.

The resulting signal from L2 is AC-coupled to the base of Q2 which is configured as a common emitter amplifier. Its DC bias is set by the 33kΩ and 22kΩ base resistors. The output from this stage is taken from the wiper of VR1 which allows the signal level to be adjusted from maximum (at the collector of Q2) down to full attenuation (ie, when the wiper is at the +7V rail).

Following VR1, the level-adjusted signal is AC-coupled to the rectifier stage (diodes D1 and D2). The resulting DC output voltage from this stage is then filtered by the 0.1µF capacitor and applied to the non-inverting inputs of IC1c and IC1a (pins 5 & 10 respectively). The 330kΩ resistor provides a discharge path for the capacitor.

IC1c functions as a unity gain buffer. Its output at pin 7 provides a convenient test point (TP1) for measuring the output of the rectifier during the setting-up procedure.

IC1a is wired as a non-inverting

PARTS LIST

1 PC board, code 04305941, 159 x 83mm
1 front panel label, 90 x 180mm
1 plastic case, 190 x 100 x 40mm
1 2-metre length of 20mm-dia. electrical conduit
3 90-degree 20mm conduit elbows
3 20mm conduit U-clamps
1 20mm conduit joiner
1 50mm-long spring toggle bolt
1 180mm diameter plastic dinner plate (eg, Decor #459)
1 180mm diameter x 3mm Masonite sheet (or equivalent material)
1 37-metre length of 0.6mm enamelled copper wire
1 660mm length of 0.4mm enamelled copper wire
1 100mm length of 0.8mm tinned copper wire
1 1.5-metre length of dual shielded cable
1 miniature SPDT toggle switch (S1)
1 1kΩ miniature horizontal trimpot (VR1)
1 100kΩ linear pot (VR2)
1 10kΩ linear pot (VR3)
1 10kΩ log pot (VR4)
1 Neosid iron powder toroidal core 17-732-22
2 C-cell holders
2 1.5V C cells
1 6.5mm mono headphone panel socket with switch
1 27mm mini 8Ω Mylar loudspeaker
1 3mm red LED (LED1)
16 PC stakes
4 4BA x 25mm Nylon screws, nuts & washers
5 6BA x 25mm Nylon screws, nuts & washers
4 3mm x 5mm screws
8 2mm x 10mm screws & nuts
2 self-tapping screws
1 12mm OD rubber grommet
3 20mm OD knobs
1 75-gram tube of neutral cure silicone sealant (eg. Selleys Roof and Gutter Sealant)
1 container of conduit glue

Semiconductors

1 LM324 quad op amp (IC1)
1 4046 phase lock loop (IC2)
1 TL496C 1.5V-9V converter (IC3)
2 BC548 NPN transistors (Q1,Q2)
1 BC338 NPN transistor (Q3)
1 BC328 PNP transistor (Q4)
2 1N4148, 1N914 diodes (D1,D2)

Capacitors

1 330µF 16VW PC electrolytic
1 220µF 16VW PC electrolytic
1 100µF 16VW PC electrolytic
1 47µF 16VW PC electrolytic
1 1µF 16VW PC electrolytic
4 0.1µF MKT polyester
1 .068µF MKT polyester
1 .022µF MKT polyester
1 .015µF MKT polyester
1 .01µF MKT polyester
1 .0056µF MKT polyester
1 .0039µF MKT polyester
1 .001µF MKT polyester

Resistors (0.25W, 1%)

1 330kΩ	1 2.7kΩ
2 100kΩ	2 1kΩ
2 33kΩ	1 390Ω
2 22kΩ	3 100Ω
1 10kΩ	

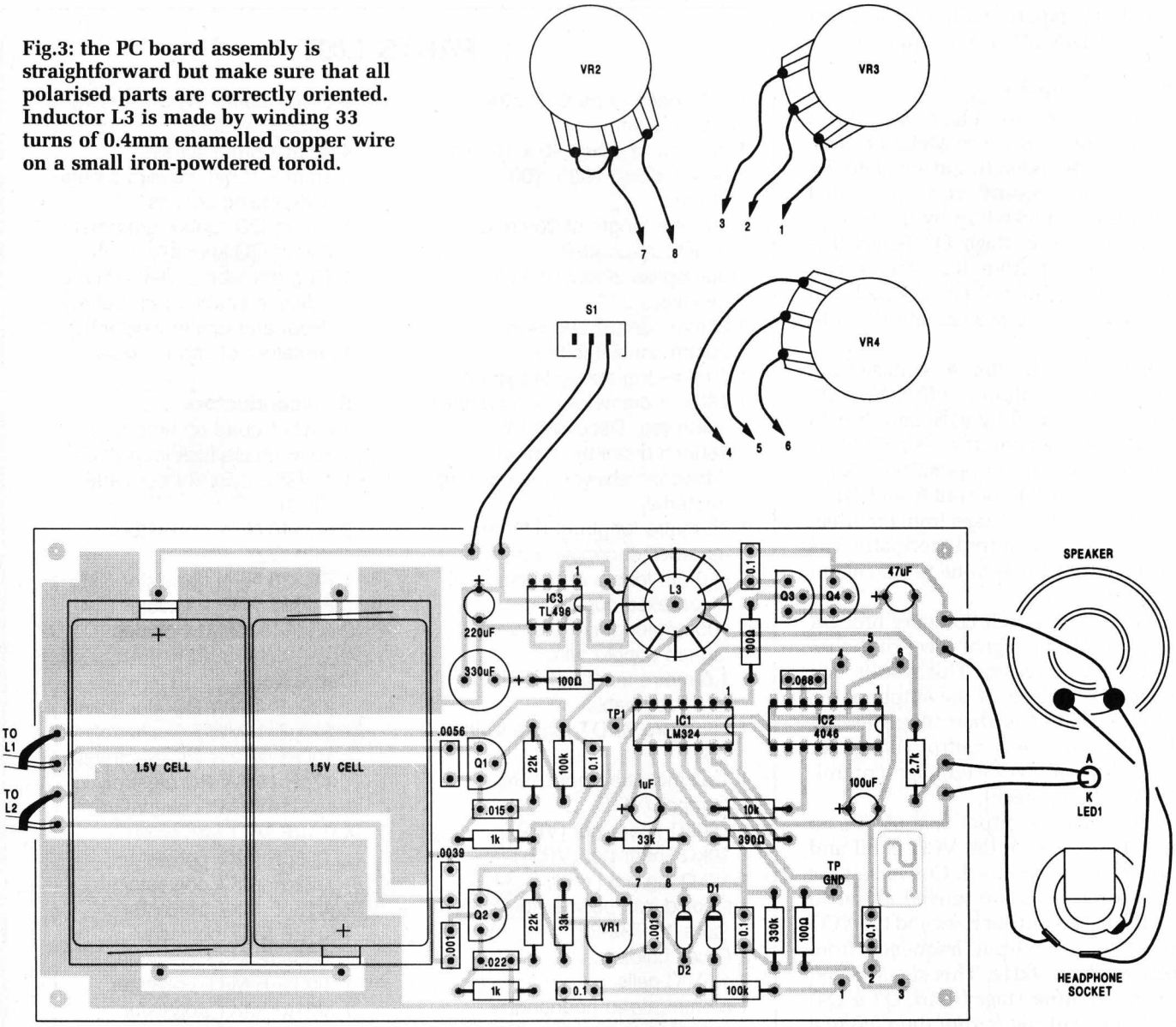


Fig.3: the PC board assembly is straightforward but make sure that all polarised parts are correctly oriented. Inductor L3 is made by winding 33 turns of 0.4mm enamelled copper wire on a small iron-powdered toroid.

amplifier with DC gain adjustable from 85 to about 340 using Sensitivity control VR2. The 1µF feedback capacitor between pins 8 & 9 rolls off the AC gain for frequencies above 5Hz at the low gain setting of VR2, and above 1Hz for the high gain setting. This roll-off reduces noise at the output of the amplifier.

IC1b functions as a buffer stage for the DC voltage set by VR3 at its wiper. This pot sets the DC voltage offset for IC1a and functions as the Ground control. Note that its voltage range has been restricted by connecting a 100kΩ resistor in series with it, to make the setting less critical.

The output from IC1a appears at pin 8 and drives the VCO input of IC2, a 4046 phase lock loop IC. In this circuit, we are only using the VCO section of the phase lock loop. The oscillator output appears at pin 4 and varies in frequency from 0Hz when pin 9 is at 0V to about 4kHz when pin 9 is at 7V. This upper frequency is set by the 10kΩ resistor at pin 11 and the 0.068µF capacitor between the pins 6 & 7.

The output signal from the VCO is fed to Volume control VR4 and thence to buffer stage IC1d. IC1d in turn drives complementary transistor pair Q3 and Q4, which act as high current drivers for the headphones or loudspeaker.

Power for the circuit is derived from two 1.5V "C" cells connected in series to provide a 3V rail. This 3V rail is boosted to 8.8V using IC3, a TL496 low-voltage switchmode IC. LED 1 provides power on/off indication.

IC2 has an internal 7V zener diode at pin 15 and this regulates the supply to 7V for the majority of the circuit. The audio amplifier output stage (Q1 & Q2) is powered directly from the 8.8V rail, however. Note that the 8.8V supply from IC3 is maintained until the battery output drops below 2V.

Construction

A PC board coded 04305941 is used to accommodate most of the parts, including holders for the two 1.5V "C" cells. This board fits neatly into a plastic instrument case measuring 190 x 100 x 40mm and this is attached to the top of a long carrying handle. The coil assembly mounts at the other end of the handle — see photos.

Fig.3 shows the board assembly

details. The order of assembly is not critical but make sure that all polarised parts are correctly oriented. These parts include the ICs, transistors, diodes, LED and electrolytic capacitors. Note particularly that three different transistor types are used on the board, so be careful not to get them mixed up. LED 1 is mounted with its leads left untrimmed so that it can later be pushed into its mounting hole in the top end panel.

Table 1 shows the resistor colour codes but it's also a good idea to measure the resistor values on your DMM since some colours can be difficult to decipher. Once these parts are in, fit PC stakes to all external wiring points on the board.

Coil L3 is made by winding 33 turns of 0.4mm enamelled copper wire onto a small iron-powdered toroid. Wind each turn adjacent to the previous turn and secure the completed toroid to the PC board using a Nylon screw, washer and nut through the centre hole. This done, trim the leads to length and tin them with solder before connecting them to the board.

Note: the wire is self-fluxing and requires heat from your soldering iron to melt back the enamel.

The two "C" cell holders are secured to the PC board using 2mm screws and nuts at each corner. Use the battery holders as templates to mark out the holes on the PC board, then drill the holes and mount the holders in position. Make sure that the holders are oriented with the correct polarity and note that they face in opposite directions to each other — see Fig.3.

The terminal ends of each holder are connected to the PC board using short lengths of 0.8mm tinned copper wire.

The PC board can now be installed in the base of the case and secured using 3mm screws which tap into the integral corner standoffs in the case. This done, attach the label to the lid of the case and drill out the holes for the control pots and power switch. These parts can now be mounted in position and firmly secured using their lock nuts.

The top end piece of the case must be drilled to accept the headphone socket and LED, and to make a speaker grill. This grill consists of a nine 3mm holes

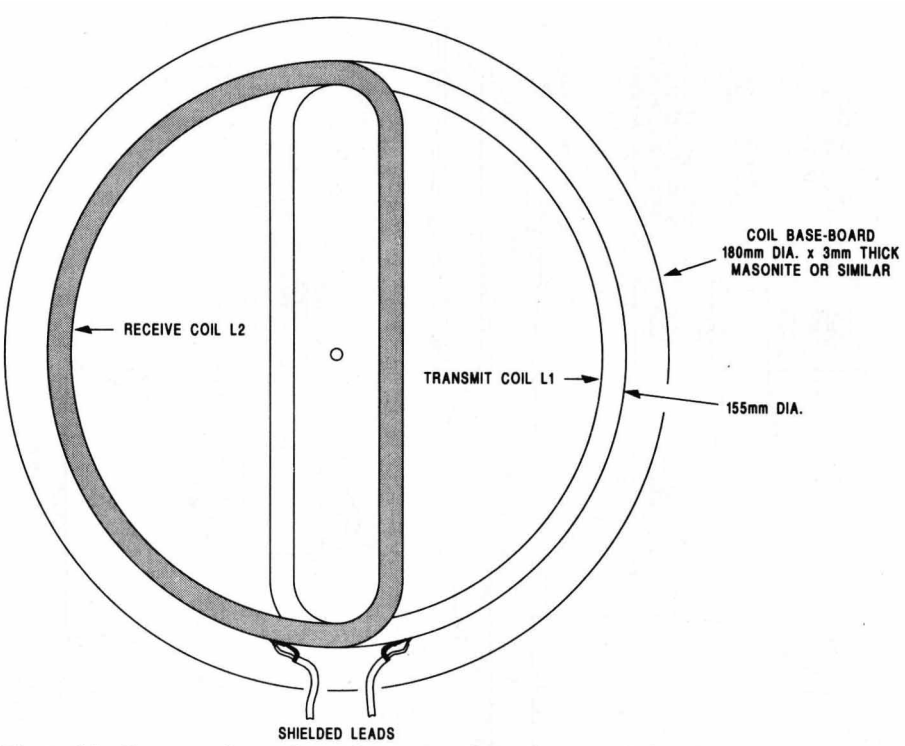
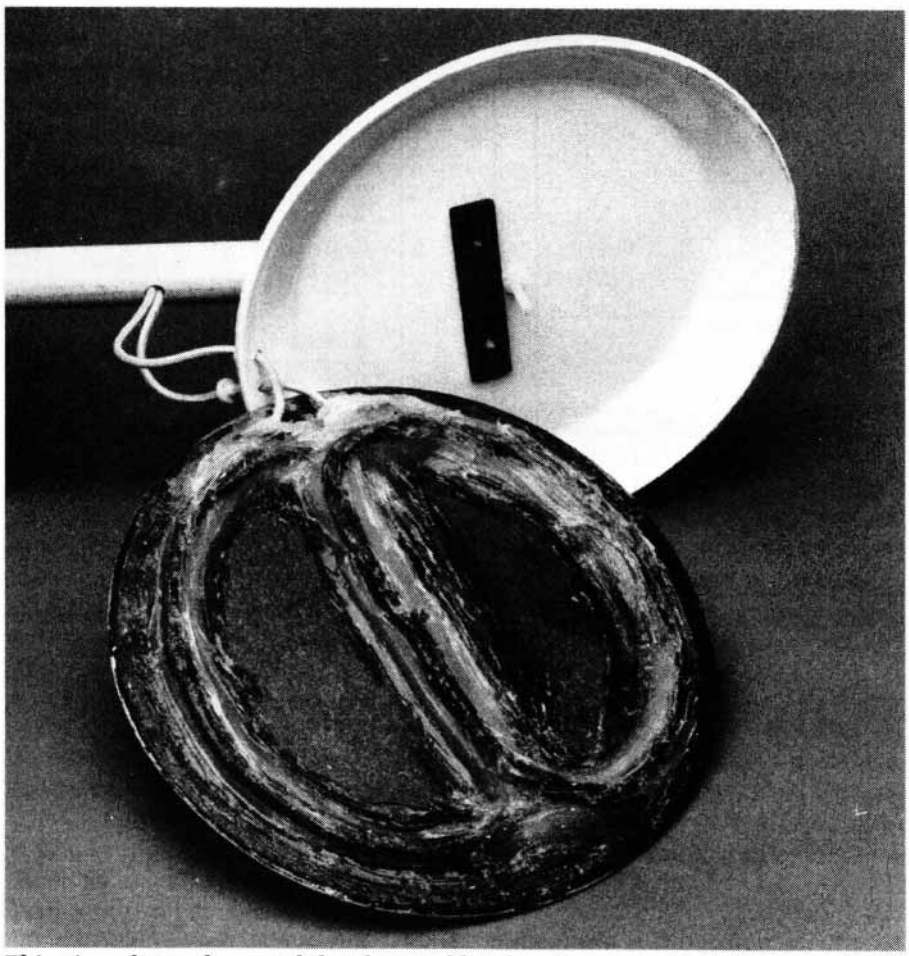


Fig.4: this diagram shows how the two coils in the search head are mounted on the baseboard. Adjust L2 for a signal null in the absence of metal by following the procedure described in the test.



This view shows the search head assembly after the two coils have been secured to the baseboard using neutral cure silicone sealant.

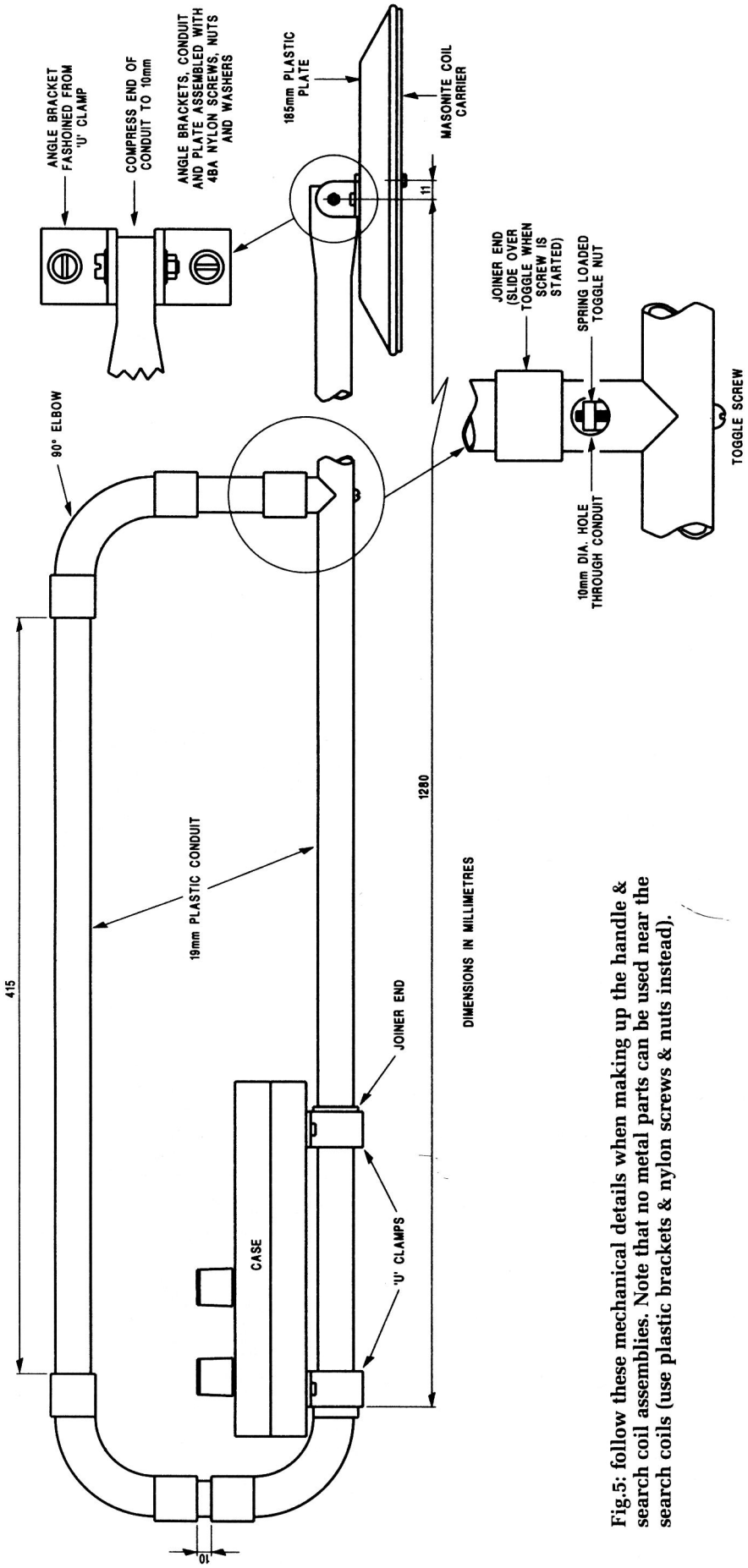


Fig.5: follow these mechanical details when making up the handle & search coil assemblies. Note that no metal parts can be used near the search coils (use plastic brackets & nylon screws & nuts instead).

directly in front of the speaker cone. Deburr the holes using an oversize drill, then smear silicone sealant around the edge of the speaker and attach it to the panel.

The hole for the LED should also be drilled to 3mm, so that the LED is a tight fit. The bottom end piece of the case is drilled with a single centre hole. This hole is fitted with a small rubber grommet and accepts the shielded cable that runs between the PC board and the two search coils.

Use light-duty hookup wire when wiring up the potentiometers, headphone socket, loudspeaker and on/off switch — see Fig.3. The figure-8 shielded cable that runs to L1 and L2 can also be connected to the PC board at this stage.

It's now time to do a couple of quick operational tests on the assembly so far. To do this, install the two "C" cells and switch on the power. Check that the LED lights (if it doesn't, it's probably wired incorrectly) and that pin 8 of IC3 measures 8.8V with respect to the TP GND pin. Check also that the voltage at pin 15 of IC2 measures about 7V.

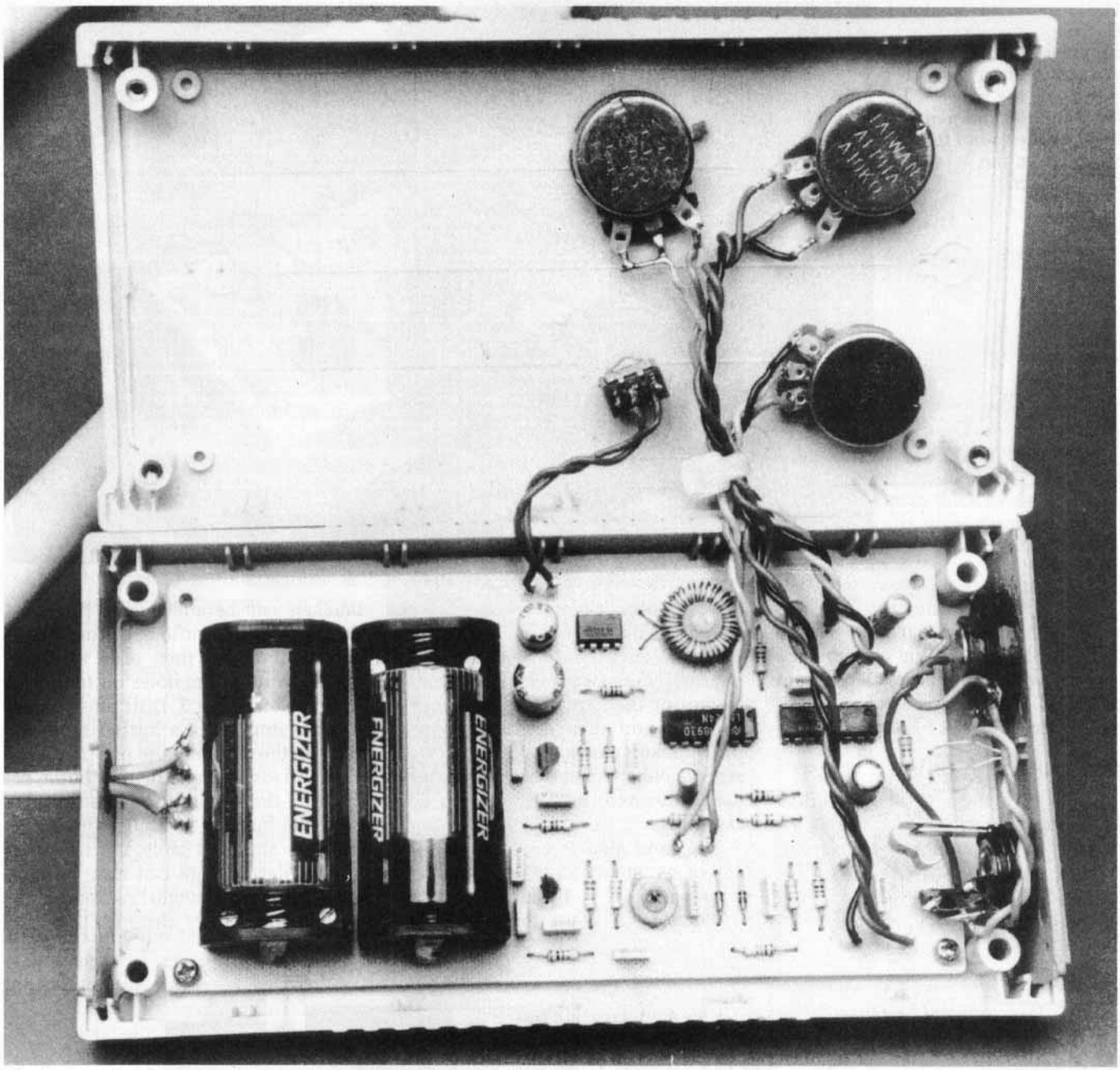
If these voltages are not within 10% of the nominated values, check the circuit for faults and clear the problem before proceeding further.

Search head

The search head, which consists of coils L1 and L2, is the critical part of the construction. As indicated previously, these two coils must be carefully aligned in order to ensure that the metal locator functions correctly.

Fig.4 shows the mounting details for L1 and L2. Each coil is wound using 50 turns of 0.6mm enamelled copper wire on a 115mm diameter former. After winding, wrap each coil tightly with two layers of insulation tape (note: the wire ends should exit from the same position).

The two coils are mounted on a sheet of Masonite which is cut to form a disc 180mm in diameter. Before mounting the coils, draw a 115mm- diameter circle on one side of the mounting sheet, then drill a hole in the centre to take a 4BA screw. The two coils can now be bent to shape and positioned as shown in Fig.4.



The battery holders are each secured to the PC board using four small machine screws & nuts. Twist the leads to the front panel controls as shown & bind them with a cable tie to minimise the chances of a lead coming adrift.

The two coils must now be carefully aligned to ensure minimum signal pickup in L2. This is done as follows:

(1). Temporarily connect the shielded cable to the coils and make sure that the assembly is well away from any metal items.

(2). Connect a voltmeter between TP1 and TP GND on the PC board and apply power. Rotate VR1 (Ground) fully clockwise and check for a high- frequency tone from the speaker if the volume control is wound up. If no tone is present, rotate the Ground and Sensitivity controls fully clockwise and adjust L1 and L2 until there is a tone. If no tone can be obtained, check the PC board for wiring faults.

(3). Turn down the volume and adjust L2 relative to L1 for a minimum reading on the voltmeter. This should be somewhere between 0.8V and 1.2V. You will need to bend the coils at the L1 and L2 intersection in order to obtain the lowest DC voltage at TP1. Note that the coils should not go outside the 155mm diameter limit.

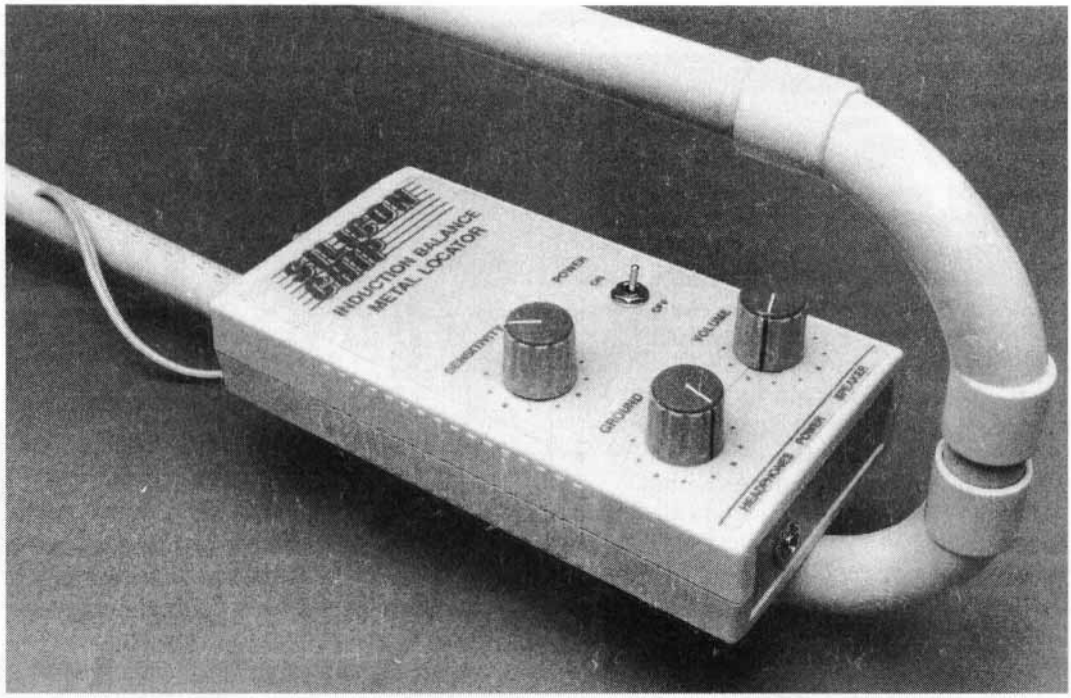
(4). Check that the voltage at TP1 increases if a piece of metal is now brought close to where the coils intersect. If the voltage falls, move the coils together until the voltage rises when the metal object is introduced.

(5). Turn up the Volume and adjust the Ground control for a low-frequency growl when no metal is near the coils. Now check that the tone frequency increases when metal is brought near the coils.

Once you are satisfied with the coil locations, they can be secured in position with silicone sealant. This process will take time, so do not rush the job.

First, unsolder the shielded cable and secure the transmit coil (L1) in position

The case containing the electronic circuitry is mounted near the top of the handle as shown here. Note the holes drilled in the end panel to allow the sound to escape from the loudspeaker.



flat on the mounting plate. The receive coil (L2) can then be secured as well, but only around the 115mm diameter perimeter section. Do not apply any sealant to the overlapping section of L2 at this stage so that you can make fine adjustments later on when the rest of the sealant has dried. This means leaving the assembly for at least 24 hours.

Mechanical details

Fig.5 shows the general mechanical details of the entire metal locator assembly. It uses 20mm-dia. electrical conduit and 90° elbow sections for the handle assembly, while the search coil assembly baseplate is attached to a plastic dinner plate.

Two plastic right-angle brackets are used to secure the plastic plate to the handle. These two brackets are made by cutting the curved section out of a U-clamp and then drilling holes in the brackets to accept 4BA Nylon screws. Note: metal parts must not be used anywhere near the search coil assembly.

The next step is to compress the end of a 1280mm length of conduit in a vyce until it is 10mm thick. Once this has been done, the right angle brackets can be attached to the conduit using a 25mm-long Nylon screw and the brackets then used to mark out their mounting holes on the plastic plate — see Fig.5. Drill these holes to size, along with a further hole exactly in the centre of the plastic plate. You will also have to drill a couple of holes in the side of the plate (in line with the handle) to accept the leads from the shielded cable.

The plastic plate can now be fastened to the right angle brackets using 4BA

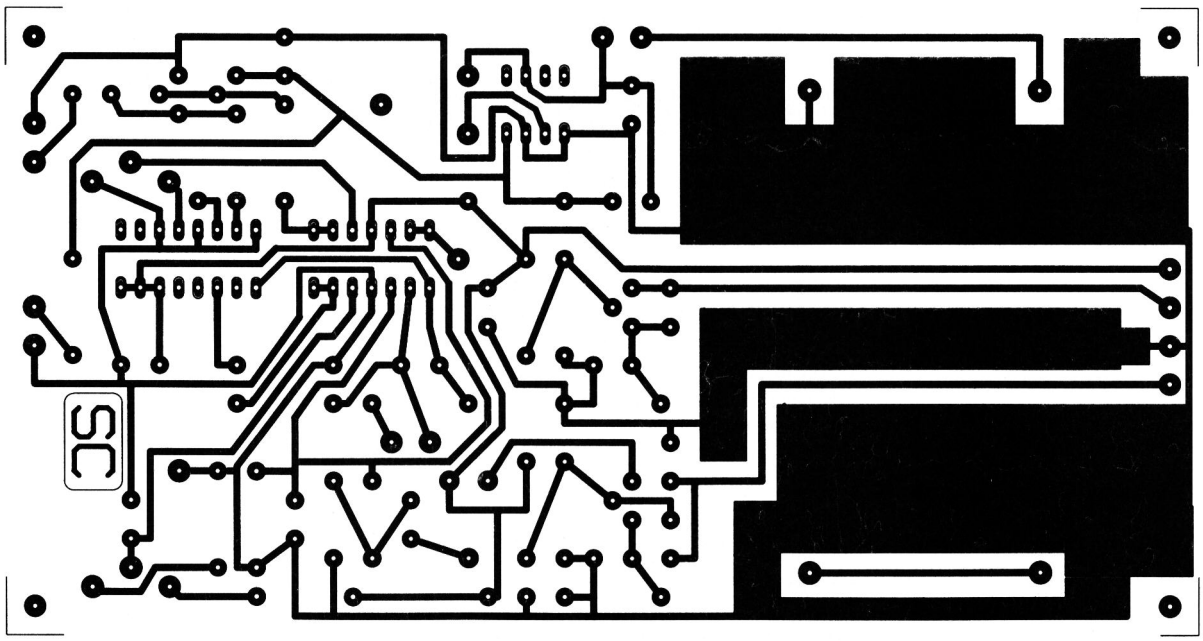


Fig.6: this is the full-size etching pattern for the PC board. Check the board for defects before installing any of the parts.

Nylon screws and nuts. Cut off any excess screw lengths using a sharp knife or sidecutters.

The other sections of conduit can now be cut to size and assembled as shown in Fig.5.

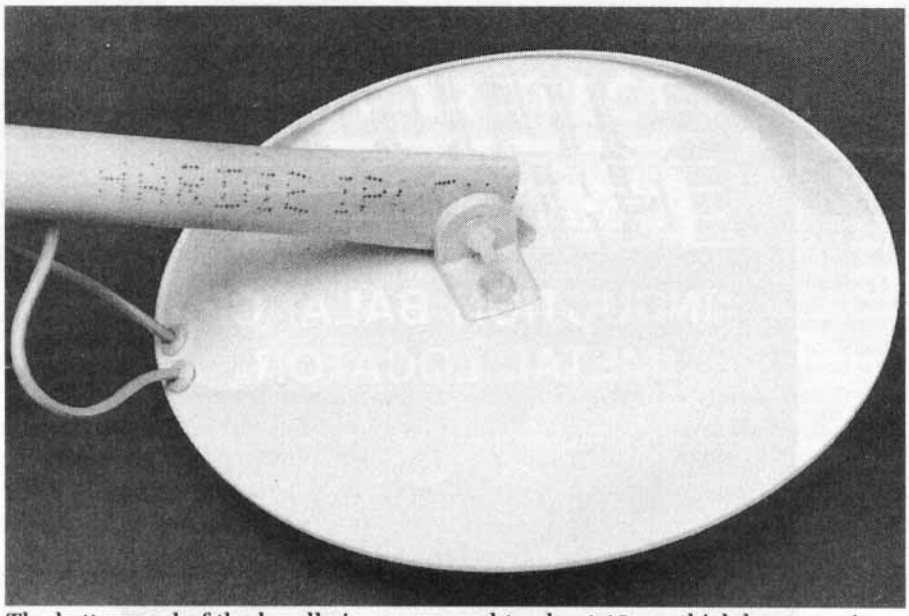
Note that the bottom end of the top handle section is secured to the main section using a toggle screw (see detail). Shape the end with a round file so that it mates neatly with the main section, then drill the holes to accept the toggle screw and its spring-loaded nut. This done, cut a sleeve from one end of an elbow piece and slide this over the shaped end of the top handle section so that it clears the 10mm holes.

The toggle screw can now be installed and the sleeve slid down over the 10mm holes after the nut is started. When the screw is tightened, the ends of the toggle should catch on the bottom edges of the 10mm holes to provide a secure assembly.

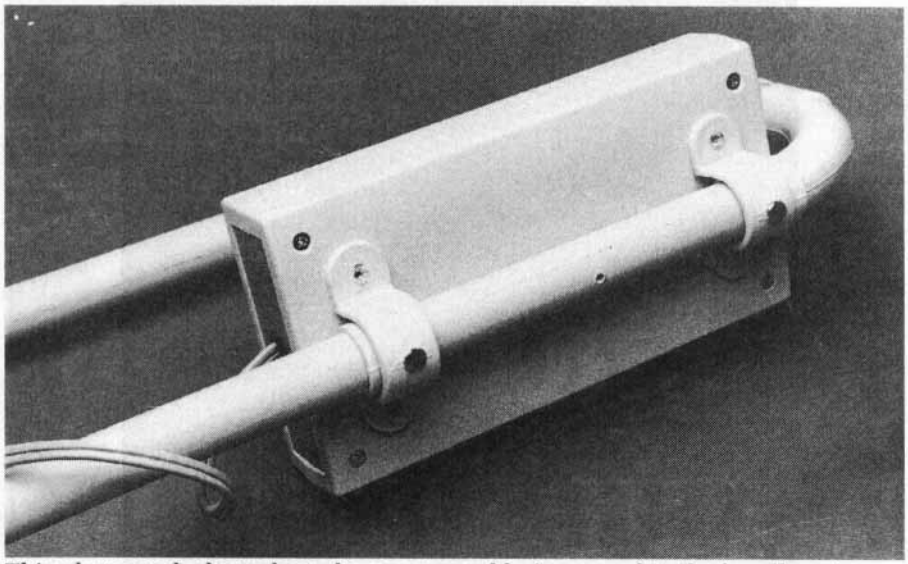
Once the basic handle assembly is completed, the instrument case can be attached to it using two plastic U-clamps. Note that the bottom clamp goes over a sleeve which is cut from the other end of the elbow piece mentioned above. The top clamp goes over the sleeve on the end of the adjacent 900 elbow piece.

Use the U-clamps to mark out the holes on the bottom of the case, then remove the PC board and drill the holes to accept 6BA Nylon screws. This done, mount the case in position, remove the excess screw lengths and remount the PC board. The U-clamps are secured to the handle using self-tapping screws.

The next step is to drill a hole in the handle just below the instrument case



The bottom end of the handle is compressed to about 10mm thick by squeezing it in a vyce. It is then attached to the cover plate using two plastic right-angle brackets & Nylon screws & nuts.



This photograph shows how the case assembly is secured to the handle using two U-clamps. The sleeve under the bottom U-clamp is obtained by cutting it from one end of a 90° elbow piece.

RESISTOR COLOUR CODES

❑	No.	Value	4-Band Code (1%)	5-Band Code (1%)
❑	1	330kΩ	orange orange yellow brown	orange orange black orange brown
❑	2	100kΩ	brown black yellow brown	brown black black orange brown
❑	2	33kΩ	orange orange orange brown	orange orange black red brown
❑	2	22kΩ	red red orange brown	red red black red brown
❑	1	10kΩ	brown black orange brown	brown black black red brown
❑	1	2.7kΩ	red violet red brown	red violet black brown brown
❑	2	1kΩ	brown black red brown	brown black black brown brown
❑	1	390Ω	orange white brown brown	orange white black black brown
❑	3	100Ω	brown black brown brown	brown black black black brown

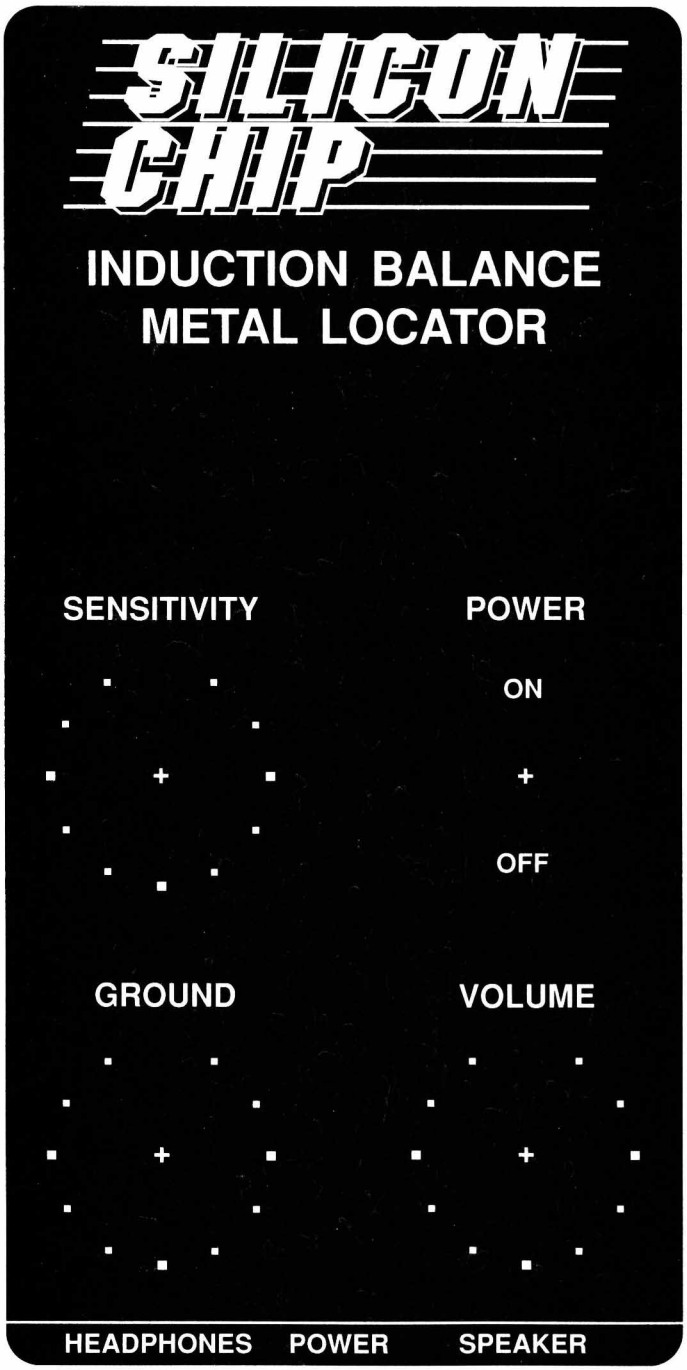


Fig.7: this full-size artwork can be used as a drilling template for the front panel or used to make your own label.

and another in the bottom of the handle adjacent to the search head. The shielded cable can now be fed down the inside of the conduit and out through the bottom hole, at which point it is separated and the leads connected to the coils.

Make sure that each lead goes to its designated coil. If you get the leads transposed, the performance will be compromised.

Finally, the conduit fittings can be glued with PVC adhesive and allowed to dry.

Assuming that the silicone sealant on the search coils is dry, you are now ready for the final alignment procedure. The step-by step procedure is as follows:

(1). Connect a voltmeter between TP1 and TPGND on the PC board and apply power. Turn up the Volume and adjust the Ground control for a low- frequency growl when no metal is near the coils.

(2). Adjust the receive coil (L2) by bending it over the transmit coil (L1) until the voltage at TP1 is at a minimum (this gives the correct null point).

(3). Disconnect the shielded cable again and fully secure L2 by applying additional silicone sealant. Wait until this sealant dries, then reconnect the shielded cable leads and cover the connections with insulation tape. Use a final coating of silicone sealant to secure the leads.

(4). When the sealant has fully dried, attach the search coil assembly to the plastic cover plate lid using a 4BA Nylon screw and nut. Finally, run some silicone sealant around the edge of the plate to produce a watertight assembly.

Using the metal locator

Once the sealant has fully cured, the metal locator is ready for use. You can hold the metal locator with one hand near the lower section of the handle, at the balanced position, and the other hand near the top end of the handle. The search head should be swivelled so that it is parallel to the ground.

Adjust the Ground control so that the sound is just a low frequency growl and sweep the search head across the ground. When metal is located, the frequency will increase.

Normally, the sensitivity control will be set at its maximum. However, in some cases, the sensitivity may need to be reduced if, for example, the ground is mineralised or if you only want to find larger objects.

VR1 is normally set to maximum (ie, fully clockwise). It should only be adjusted if the Ground control needs to be set almost fully anticlockwise to obtain a low-frequency tone (it's just a case of adjusting VR1 to provide a reasonable range for the Ground control).

Finally, note that the Ground control will have to be readjusted for changes in ground composition (eg, if you go from dry sand to wet sand), or if the distance between the search head and ground changes. For this reason, it's best to keep the search head at a consistent height. That said, the unit is extremely easy to use and you'll soon get the hang of it by practising on a few metal coins.