

# A 'deep seeking' metal locator

Phil Wait

Roger Harrison

The induction balance technique is employed in metal detectors in many different forms. The principle of operation is at least 50 years old. Those early machines were unwieldy, employed valves and heavy batteries (which didn't last long), but paved the way for the booming field we have today. Solid state electronics has revolutionised metal detectors, but the principles have altered little.

This instrument can be used to locate metal objects buried at considerable depths. The construction can be varied to suit the application and there is considerable scope for experiment. Using the dimensions and electronics described, the unit will detect objects the size of a one-litre paint can at depths up to several metres below the surface of the ground — depending on how long it has been buried and the type of soil, etc. Somewhat smaller objects can be discerned at shallower depths. It will not detect individual coins, rings, etc., unless modified. Suggestions are given at the end of the article for those wishing to experiment.

as there is minimum magnetic coupling between the two. To permit accurate alignment, the receiver antenna loop can be varied over a small angle.

The transmitter puts out a pulsed signal at 20 kHz. The pulsing is principally to provide a modulated signal for the receiver that may be demodulated and put through a speaker or headphones for the convenience of the operator. The pulse repetition frequency may be set to some convenient pitch in the audio range between about 200 Hz and 1.5 kHz.

The alignment of the antennas is adjusted such that, with no metal object within the field of the instrument, there

quency. The transmitter antenna loop is oriented vertically to give maximum ground penetration of the transmitted signal and maximum induction into buried metal objects.

With the instrument near the ground, the effect of the ground on the field patterns of the two antennas will result in some distortion of their fields but this can be compensated for by realigning the receiver antenna for a null (minimum signal).

When a buried metal object is encountered, eddy currents induced in the object will cause a distortion in the field pattern of the transmitter antenna. As the antenna is tightly coupled to the oscillator, this will also bring about a distortion in the field pattern of the antenna at the harmonic frequencies. This will increase the coupling between the transmitter and receiver antenna loops and a signal will be heard in the receiver.

Metal objects buried close to the surface will affect the field pattern of both antennas, but deeply buried objects will primarily influence the transmitter antenna field.

The 'depth sensitivity' of the instrument is dependent on a number of factors — primarily the 'loop separation distance' (see Figure 1), the size of the antenna loops, the power of the transmitter and the sensitivity of the receiver. Ground mineralisation also affects sensitivity and penetration.

The ability of the instrument to detect small objects depends largely on the loop separation distance and the size of the loops. Smaller loops and closer spacing improve the units sensitivity to small objects, but at the expense of penetration.

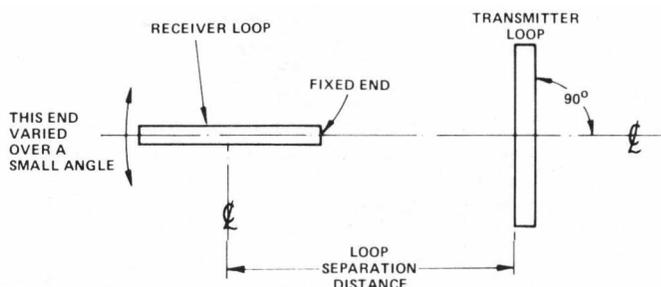


Figure 1. The 'Induction Balance' principle employed in the ETI-566.

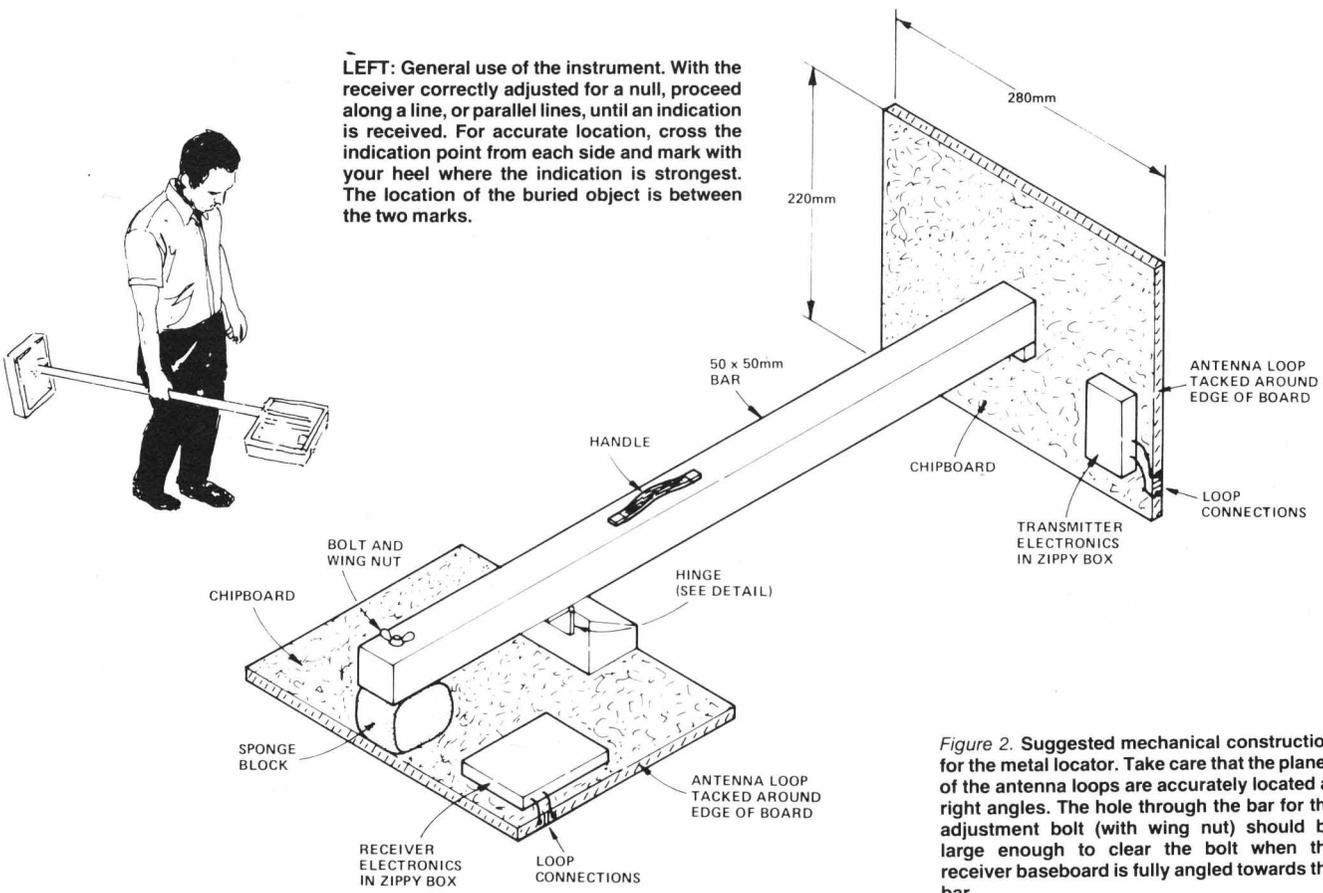
## Notes on the principle of operation

First of all, to be able to experiment with the construction of the instrument, it is useful to know something of the principle of operation.

The unit employs an *induction balance* technique. As illustrated in Figure 1, the transmitter antenna loop and the receiver antenna loop are located with their planes at right angles and a small distance apart. This provides the minimum induction of the signal from the transmitter loop into the receiver loop

is minimum (or no) received signal.

The receiver is tuned to the *third* harmonic of the transmitter, i.e: 60 kHz. This provides better sensitivity than if it were tuned to the transmitter at 20 kHz. It seems to work like this: the transmitter is deliberately designed to have a considerable harmonic content in its output. The inductive coupling between the antenna loops is greater at the third harmonic than it is at the fundamental frequency, but ground penetration is better at 20 kHz than 60 kHz as the ground resistivity increases with fre-



**LEFT:** General use of the instrument. With the receiver correctly adjusted for a null, proceed along a line, or parallel lines, until an indication is received. For accurate location, cross the indication point from each side and mark with your heel where the indication is strongest. The location of the buried object is between the two marks.

**Figure 2.** Suggested mechanical construction for the metal locator. Take care that the planes of the antenna loops are accurately located at right angles. The hole through the bar for the adjustment bolt (with wing nut) should be large enough to clear the bolt when the receiver baseboard is fully angled towards the bar.

Constructed to the dimensions illustrated, a football-sized object can be detected at depths as great as two to five metres, depending on ground mineralisation and how long it has been buried. Small diameter pipes can be readily detected at depths of one metre below ground level.

**Mechanical construction details**

Mechanical construction is shown in Figure 2. It ain't pretty — but its practical! There are plenty of possibilities — which well leave to your ingenuity — but keep the basic principles in mind.

Two pieces of chipboard, 15-19 mm thick, serve as bases to mount the antenna loops. The latter are made from aluminium (or copper — if you can afford it!), as shown in Figure 3, and tacked around the edge of each board. The connections to the loops should be as good as you can make them to ensure low resistance contact. Solder lugs pop-riveted to the edge of the loops at the break make good connection, or you could use pk screws and solder lugs — with shakeproof washers on both sides of the solder lugs to ensure a good bite into the metal and a secure connection.

The transmitter and receiver pc boards can be mounted in 'zippy' boxes

of convenient sizes — the receiver board is amply accommodated in one measuring 196 x 113 x 60 mm or thereabouts, the transmitter board in a box measuring 130 x 68 x 41 mm, or similar. They should be mounted near the breaks in the antenna loops to keep lead length to the loops as short as possible. Twist the leads.

The wooden bar which holds the two chipboard antenna bases could be a length of 50 x 50 mm dressed western red cedar (to minimise warping). Alternatively, you could use a length of square-section aluminium tubing. Overall length of the bar should be about one metre for best depth penetration with this arrangement. However, there is plenty of room to experiment. All wooden parts should be sealed and painted or given several coats of 'Estapol' or similar clear lacquer finish to preserve them from the effects of the weather. Do this prior to final assembly.

The hinging arrangements for the receiver antenna baseboard are shown in Figures 2 and 3. An 80 mm length of 50 x 50 mm dressed timber is chamfered as indicated and fixed to an edge of the receiver baseboard, in the centre. A hole is drilled in the middle of the opposite side, just smaller than the outside diameter of a 1/4" Whitworth nut.

The nut is forced into this hole. A corresponding hole is drilled in the bar. A 1/4" Whitworth bolt, 6" (150 mm) long, is passed through the bar and into the nut in the receiver baseboard. A block of sponge rubber serves as a 'spring'. The diagram in Figure 2 makes it all clear.

A brass hinge is fixed to the chamfered block and the underside of the bar, as illustrated in Figure 3.

The transmitter baseboard is mounted flush on the end of the bar. Note that this end must be cut as square as possible. The underside of the bar is 60 mm above the horizontal centre line of the baseboard. Fix the baseboard to the bar with a single long wood screw. This allows you to rotate the transmitter antenna to achieve correct alignment. The small block shown under the bar, against the transmitter baseboard, is glued in place after the antenna is aligned.

**The electronics**

The transmitter is quite simple, using only one active component. The pc board may be mounted on the back of the meter to simplify the mechanical construction. Start by assembling the pc board as shown, taking care with the

electrolytic capacitors and transistor. This unit has been specially designed around a germanium transistor and a silicon type *cannot* be substituted.

The pc board has been designed to accept a variety of trimmer capacitors. You will see two different circles of holes in the board. The innermost circle accepts the Philips potcore pins, the outermost are not used here.

Run the wires to the switch, battery and the loop antenna, keeping the wires to the loop as short as possible to avoid any stray radiation upsetting the field pattern. Twist them lightly.

The meter on the transmitter is only used as a battery indicator and may be more expensive than you wish. It can however be replaced by a LED if the value of R3 is reduced to about 270 or 330 ohms. This will increase the current drain from the battery but should not be a problem. If you stick with the meter, either a 100µA, 200µA or 1mA movement can be used by choosing the value of R3 to be 100k, 47k, or 10k, respectively.

The receiver is quite a bit more complex than the transmitter but as all the components are mounted on the pc board it shouldn't prove too difficult. Watch out for the orientation of the electrolytic and tantalum capacitors. Again, the pc board has been designed to accept a variety of trimmer capacitors.

The meter shown is a 200µA type. However, if it is unavailable a 100µA movement can be used. If you do this, increase the value of R17 to 10k and R18 to 100k. Note that R18 is mounted off the pc board between the meter test button (PB1) and the power switch (SW1). Keep the leads to the loop as short as possible and well away from the speaker leads.

As for batteries, a No. 2362 or 2364 9V battery may be used in the receiver with the size box suggested, while a No. 2362 battery will fit in the box suggested for the transmitter. Alternatively, No. 216 size 9V batteries maybe used, but they wont last too long with prolonged use. (Alkaline types in this size might be OK, though).

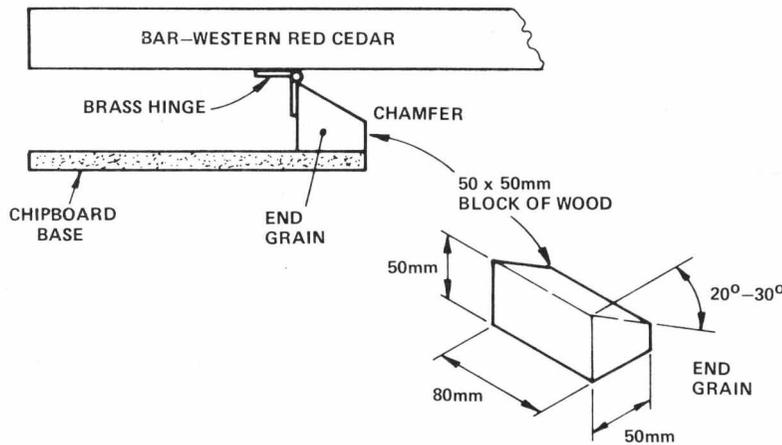


Figure 3. Hinging arrangement for the receiver antenna baseboard.

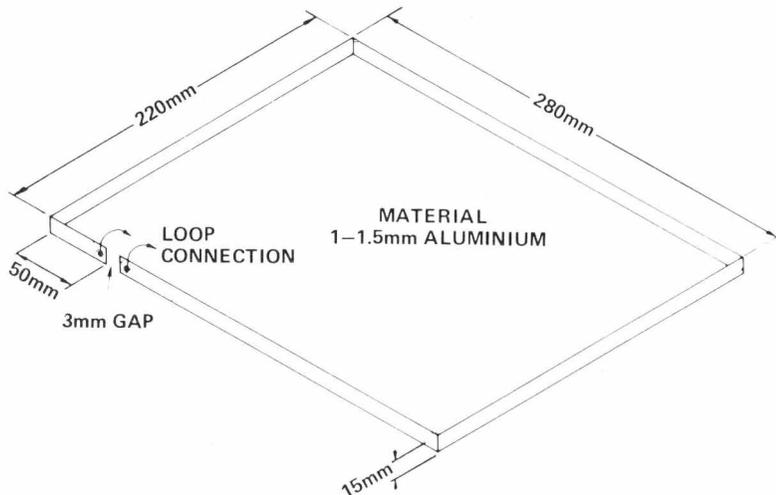
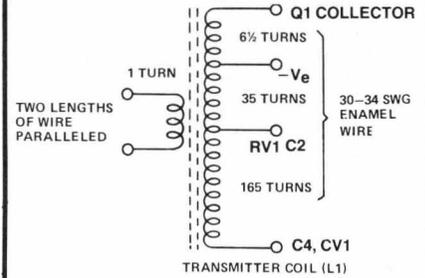


Figure 4. Dimensions of the antenna loops. The 'break' for the loop connections need not necessarily be as indicated here, but could be located at a corner or midway along one side.

### COIL DETAILS

Note that, as these coils are jumble wound on the formers they will have varying self-capacitance from unit to unit. This will result in some variation in the tuning but there should be sufficient adjustment in the trimmer capacitors in the transmitter and receiver and the core adjuster in L2 in the receiver. If any difficulty is experienced, C4 in the transmitter and C1 in the receiver could be reduced to 270 pF each. In addition, C6 in the receiver could be reduced to 220 pF.

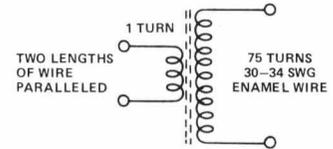


#### ETI-566A (Tx) — L1

Inductance — 160 mH. Wound on potcore assembly, primary and secondary turns and tappings as illustrated. Potcore is Philips type P18/11, 3H1 material, ungapped, with two-section bobbin, can and tag plate.

##### Part Numbers

Potcore —	4322 020 21510
Bobbin —	4322 021 30280
Can —	4322 021 30530
Tag plate —	4322 021 30450

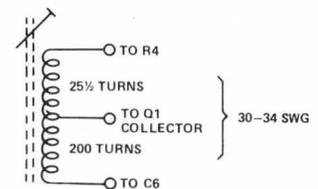


#### ETI-566B (Rx) — L1

Inductance — 20 mH. Wound on potcore assembly, turns of primary and secondary as illustrated. Potcore, Philips type P18/11, 3H1 material, ungapped with two-section bobbin. This assembly is bolted to the pc board through the central hole.

##### Part numbers

Potcore —	4322 020 21510
Bobbin —	4322 021 30280



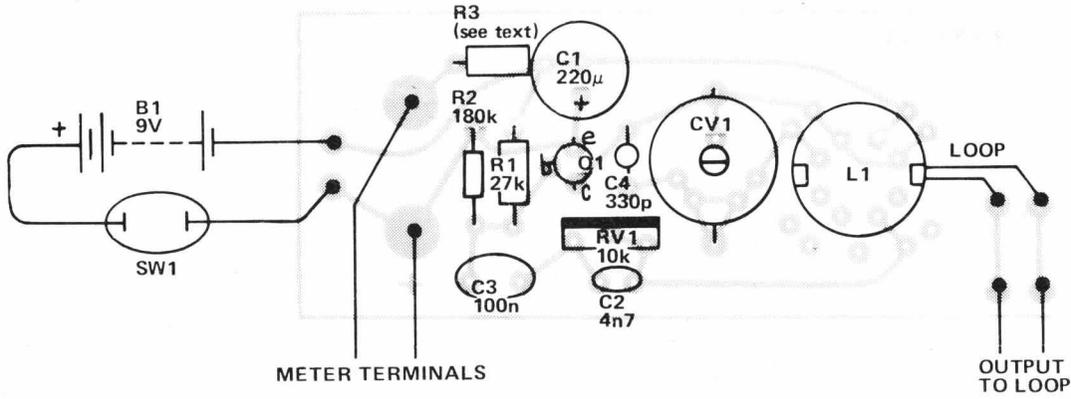
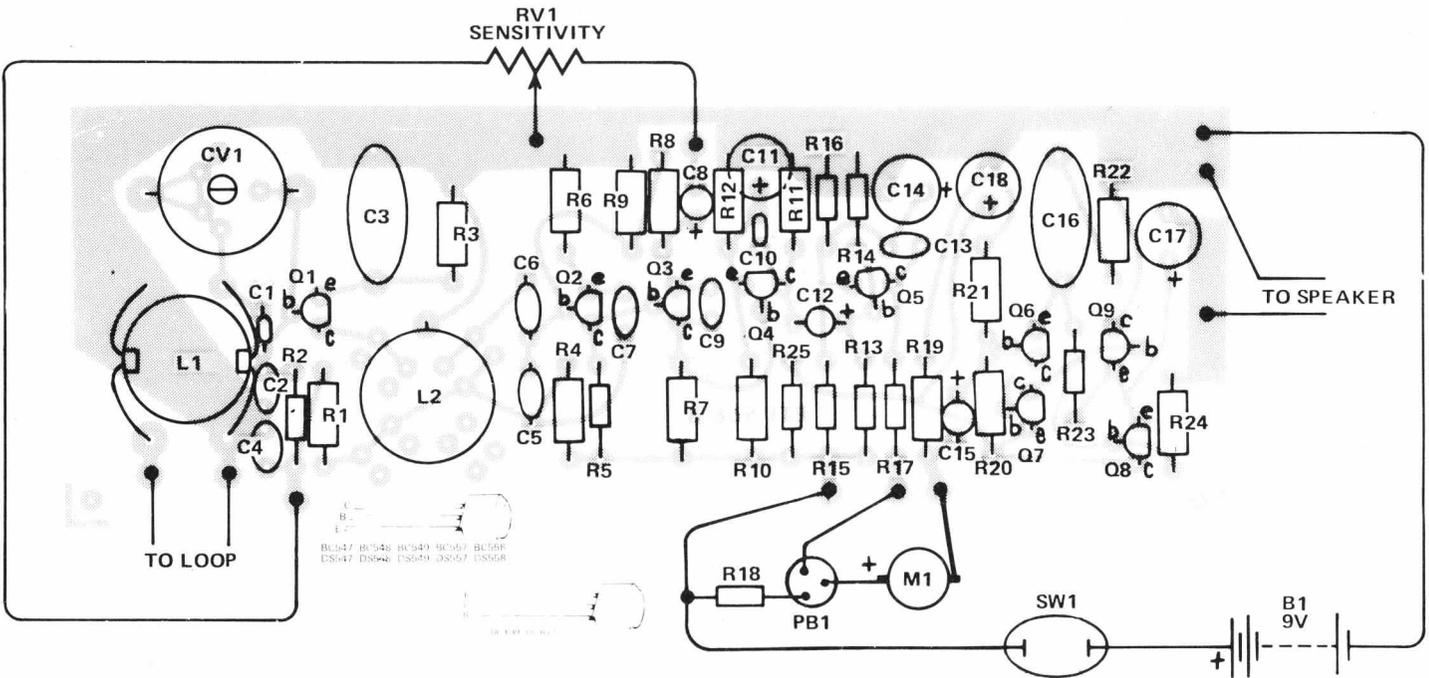
L ≈ 16mH (ADJUSTABLE)

#### ETI-566B (Rx) — L2

Inductance — approx. 16 mH, adjustable. Wound on potcore assembly, turns and tappings as illustrated. Potcore, Philips type, P18/11, 3H1 material (ue = 150), with single-section bobbin, adjuster (colour-coded white), can and tag plate.

##### Part numbers

Potcore —	4322 022 24275
Adjuster —	4322 021 32130
Bobbin —	4322 021 30270
Can —	4322 021 30530
Tag plate —	4322 021 30450



**PARTS LIST — ETI 566B**

- Resistors** ..... all 1/2W, 5%
- R1 ..... 4k7
  - R2 ..... 10k
  - R3 ..... 1k
  - R4 ..... 33R
  - R5 ..... 82k
  - R6 ..... 680R
  - R7 ..... 12k
  - R8 ..... 15k
  - R9 ..... 6k8
  - R10 ..... 5k6
  - R11 ..... 33k
  - R12 ..... 22k
  - R13 ..... 10k
  - R14 ..... 220k
  - R15 ..... 150R
  - R16 ..... 10k
  - R17 ..... 4k7
  - R18 ..... 47k (see text)
  - R19 ..... 2k2 (see text)
  - R20, R21 ..... 1M
  - R22 ..... 56R
  - R23 ..... 2k2
  - R24 ..... 470R
  - R25 ..... 150R

- Capacitors**
- C1 ..... 330p styroseal
  - C2 ..... 4n7 styroseal

- C3 ..... 470n greencap
- C4 ..... 22n greencap
- C5 ..... 4n7 styroseal
- C6 ..... 270p styroseal
- C7 ..... 22n greencap
- C8 ..... 10u 16V electro
- C9 ..... 22n greencap
- C10 ..... 10n greencap
- C11 ..... 4u7 16V electro
- C12 ..... 1u tantalum
- C13 ..... 22n greencap
- C14 ..... 47u 16V electro
- C15 ..... 10u 16V electro
- C16 ..... 470n greencap
- C17 ..... 100u 16V electro
- C18 ..... 47u 16V electro

- Variable**
- RV1 ..... 1k linear pot
  - CV1 ..... 150p or 100p variable capacitor

- Semiconductors**
- Q1-Q3, Q6 ..... BC549, BC109
  - Q4, Q5 ..... BC559, BC179
  - Q7 ..... BC559, BC179
  - Q8 ..... BC639
  - Q9 ..... BC640

**Miscellaneous**

M1 — Moving Coil Meter 40 mm x 48 mm, University TD-48 or similar (see text); SW1 — SPST toggle or pull switch; PB1 — SPST momentary push button; SP1 — Eight ohm speaker approx 55 mm dia.; ETI 566 pc board, knob, standoffs.

**PARTS LIST — ETI 566A**

- Resistors** ..... all 1/2W, 5%
- R1 ..... 27k
  - R2 ..... 180k
  - R3 ..... see text
  - RV1 ..... 10k trimpot

**Capacitors**

- C1 ..... 220u electrolytic
- C2 ..... 4n7 greencap
- C3 ..... 100n greencap
- C4 ..... 330p styroseal or silver mica
- CV1 ..... 150p compression trimmer

**Semiconductors**

- Q1 ..... AC128

**Miscellaneous**

ETI-566A pc board; M1 — see text.

## Tuning up

After the two units are assembled the oscillator must be adjusted for correct operation and the transmitter and receiver set to the same frequency. The trimpot (RV1) in the transmitter should be set at mid-point resistance prior to alignment and adjusted to produce a suitable pitch in the receiver after the initial alignment.

Lay the two units on a table about a metre apart and turn them on, By advancing the sensitivity control a tone may come from the speaker. If not, adjust the trimpot in the transmitter and the tone should appear. Set the trimpot for a maximum reading on the receiver meter. The oscillator is now working correctly.

The two units now have to be set to the same frequency. The exact frequency is unimportant so long as they're the same. Lay the two units about two metres apart and set the trimmer capacitor and potcore adjuster on L2 in the *receiver* to half adjustment. Adjust the trimmer in the *transmitter* for a peak in the receiver meter, and then go back to the *receiver* and adjust the trimmer and potcore for a peak in the reading. Be careful when adjusting the potcore not to strain the thread, as it is very fragile.

During the tuning procedure it will be necessary to adjust the sensitivity control for a convenient meter reading. Be careful not to move the units as this will change the coupling between them, giving a false variation in the meter readings.

## Antenna alignment

Following initial alignment of the electronics, the antenna baseboards can be attached to the bar and the transmitter antenna aligned. Standing well clear of metal objects (at least 5-6 metres) align the receiver baseboard such that it is parallel with the bar. Turn on both units and adjust the receiver sensitivity to obtain a convenient indication on the meter. Rotate the transmitter baseboard to get minimum received signal, adjusting the sensitivity if necessary. Tighten the screw securing the transmitter baseboard. Check that you can get a good null with the receiver baseboard adjusting screw; the receiver sensitivity should be advanced at least 3/4 at the point of minimum signal. If so, glue a small block of wood in place, as per Figure 2, on the underside of the bar where it meets the transmitter

baseboard.

That's it. Happy hunting!

## How to use it

Condensed instructions are included here and we suggest you cut them out and stick them to the receiver front panel as a handy reference. Protect it with perspex or clear Contac.

Hold the instrument by the centre of the bar with the receiver in front of you. The instrument should be held at arms length, parallel to the ground. Your body should be midway between the two units. Wind the adjusting screw fully in (clockwise), and turn the two units on. Advance the sensitivity control to about 3/4 range and a tone should appear. Wind the adjusting screw out (anti-clockwise) until the tone disappears and continue turning the adjuster in the same direction until a slight indication is shown on the meter. The instrument is now ready to operate.

Walking over a buried object will cause a meter deflection and a sound from the speaker. Make sure when you are adjusting the instrument that there are no buried objects, cars, fences or pipes nearby to upset the balance.

To accurately pin-point the location of an object, cross it from each side and with your heel, mark the position on the ground where the signal is strongest. The object will be located mid-way between the two heel marks.

Something can be learnt about the shape of an object by passing over it from different directions. Obviously a pipe will be easy to identify because it will run along the ground for a long way. Other objects will appear more

symmetrical.

Careful operation of the sensitivity control can help accurately locate an object. Having located something with the instrument set at the normal settings (as described above) reduce the sensitivity a small amount and repeat your crossing of the location. The signal will be heard over a much smaller distance. This method is useful for separately locating closely adjacent objects.

Greater depth penetration can be obtained by lowering the instrument to the ground by means of a strap attached to the handle. The instrument is first adjusted as per normal, then lowered to the ground as close as you can go without upsetting the receiver indication. The instrument should be held so that the receiver is angled a little downward. It may be necessary to reduce the sensitivity slightly.

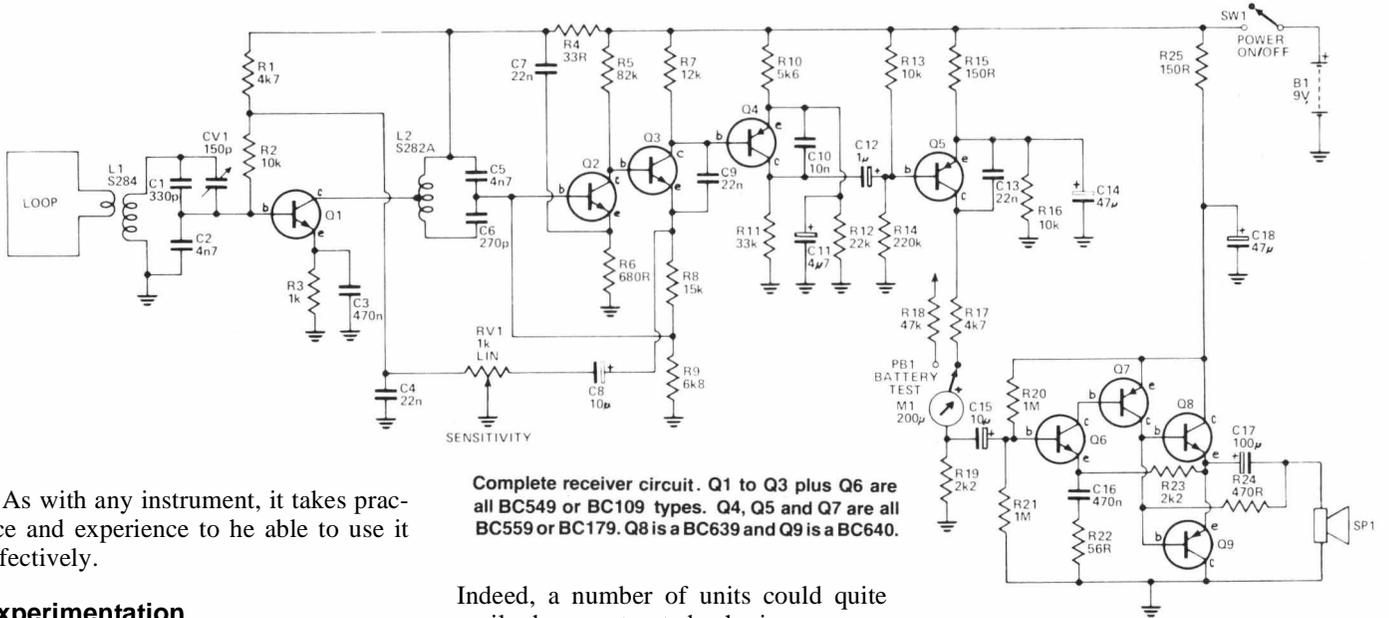
The best way to get used to the instrument is to experiment with known buried objects. You will note that objects which are only at a shallow depth give a maximum indication when they are directly beneath the receiver. Objects buried more deeply give a maximum indication when they are about midway beneath the transmitter and receiver.

Newly-buried objects can be difficult to locate as they give a poor indication. The detectability of an object improves with time as the soil surrounding the object compacts and corrosion improves the soil conductivity.

When operating in conductive soils (heavily mineralised), you will need to reduce the sensitivity and adjust the null as previously outlined.

### CONDENSED INSTRUCTIONS

- 1) Set receiver angle adjustment fully clockwise so that the front of the receiver is close to the bar. Keep away from cars, fences and metal objects when setting up the instrument.
- 2) Turn on receiver and set the gain to about 3/4 range.
- 3) Turn on transmitter. A loud tone should be heard in the receiver.
- 4) To adjust the instrument, hold it level at normal arm length beside your body. Adjust the receiver angle until no tone is heard and/or no meter reading is obtained. Continue adjusting the receiver angle in the right direction until a slight indication is obtained. The instrument is now ready for use.
- 5) If a correct 'null' cannot be obtained, check you aren't near a metal object and then reduce the sensitivity control.
- 6) To locate metal objects, proceed along a series of parallel lines until an indication is received. To accurately locate the object, cross this indication point from each direction along your line and mark, each time, with your heel where the indication is strongest. The object will be midway beneath the two marks.



**Complete receiver circuit. Q1 to Q3 plus Q6 are all BC549 or BC109 types. Q4, Q5 and Q7 are all BC559 or BC179. Q8 is a BC639 and Q9 is a BC640.**

As with any instrument, it takes practice and experience to be able to use it effectively.

### Experimentation

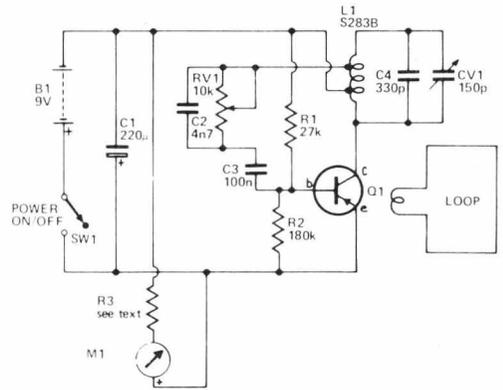
The following details are suggestions for the dyed-in-the-wool experimenter.

The instrument can be constructed to improve sensitivity to small objects by decreasing the 'loop separation distance' (see Figure 1). We tried a bar only 600 mm long and found the unit would detect a small bunch of keys at about 300-400 mm. However, the alignment of the receiver antenna is much more critical.

Smaller antenna loops will improve sensitivity to small objects, at the expense of penetration, as discussed earlier. This, combined with closer spacing, should provide a good starting point for further experimentation.

Indeed, a number of units could quite easily be constructed, sharing a common bar perhaps, with different antenna loop dimensions. Incidentally, the loops need not be square or rectangular, but could be circular.

With close-spaced loops, the receiver may be over-sensitive. A modified circuit is suggested in Figure 5. The original pc board may be used but only the first two stages involving Q1 and Q2 are necessary, along with some of the original components. Major changes are shown in the dotted lines. The gain control is shifted to the emitter of Q1 and provides various amounts of degeneration as the bypass capacitor, C3, is connected across a greater or lesser part of the emitter resistance of Q1, formed



**ABOVE: Transmitter circuit. The meter, M1, is optional and could be replaced with a LED, in which case R3 would need to be about 270 or 330 ohms.**

### HOW IT WORKS — ETI 566

The general principle of how the induction balance technique of metal location works is explained earlier in the text. This description will be confined to the electronics.

#### TRANSMITTER 566A

Transistor Q1 is operated as a self-modulating RF oscillator. To provide RF output, Q1 and the tuned circuit — L1, C4, CV1 — are connected as a modified Hartley oscillator operating at around 100 kHz. The feedback has been arranged so that the oscillator "squeggs" at a frequency around 800 Hz, modulating the transmitted signal.

After power is applied, the Circuit will oscillate at the frequency determined by the tuned Circuit and C2-C3 will charge up via the rectifying action of the base-emitter junction of Q1. When this is sufficient to reverse bias the b-e junction of Q1, the RF oscillation will cease and C2-C3 will commence to discharge (via the bias resistors and RV1). Eventually, Q1 will turn on again and RF oscillation will commence once again and the whole process will repeat.

The transmitter signal is coupled to the

loop antenna via a winding on L1. The trim-pot, RV1, provides control over the feedback. The meter is used both as an on/off indicator and a battery level indicator. A LED may be substituted as explained in the text.

#### RECEIVER 566B

This consists of a single tuned RF amplifier stage followed by a broadband, direct-coupled amplifier and a class-B detector. A simple audio amplifier provides output to a loudspeaker.

The receiver antenna loop is coupled to the first tuned circuit, L1, via a link winding. The base of Q1 is impedance-matched to the tuned circuit via a capacitive 'tap'. The collector of Q1 is matched to the second tuned circuit, L2, by tapping down the coil.

A three-stage broadband, direct-coupled amplifier follows L2. The base of Q2 is impedance-matched to the second tuned Circuit by a capacitive tap once again. Some negative feedback is provided by C7. Sensitivity is varied by simultaneously varying the base bias of Q1 and the emitter bypassing at Q3. Gain is maximum when the wiper of RV1

is at the end connected to C8.

Transistor Q5 is biased so that it is not quite turned on. When a signal appears at the end of the amplifier chain (collector of Q4), Q5 will turn on, the base-emitter junction rectifying the signal, the modulation then appearing at the collector. As the signal strength increases, Q5 will turn on harder, thus the collector current may be used as an indication of signal strength. Resistors R17 and R19 (plus the meter) form the collector load of Q5. Audio is tapped off via C15 and passed to the audio amplifier.

The audio amplifier employs a complementary-symmetry output stage (Q8, Q9), transistors Q6 and Q7 being configured as a modified Darlington driving stage. The frequency response is 'peaked' with the RC network of C16 and R22. Feedback from the output to the input is provided by R23 and feedback around the output stage is provided by R24. Any small speaker having an impedance between 8 ohms and 40 ohms may be used.

by RV1. Greatest gain is provided when C3 is connected across the whole of RV1.

A simple half-wave voltage doubler diode detector is coupled from the collector of Q2. A 330k bias resistor is connected between base and collector in this circuit as Q2 in the original circuit had the base bootstrapped to the emitter circuit of Q3 (now removed).

This circuit should provide a stable receiver of adequate sensitivity for close-spaced antenna loops.

As suggested, lowering the unit closer to the ground from the natural carrying position at arms length improves penetration. However, it upsets the alignment of the receiver antenna a little and you have to stoop down and re-adjust it. Carrying the instrument in this position is a pain in the... whatever... so if you can devise some method of carrying it such that the antennas are placed closer to the ground, results can be improved though its 'fiddly' to adjust the receiver antenna alignment. An extra attachment could be fashioned to perform the same task. Well leave that to your ingenuity, once again — *but it must not be metal.* When using the unit close to the ground, it is generally most effective if the bar is not horizontal, but tilted forward slightly so that the receiver antenna is angled towards the ground.

From here on in, its up to you. Good luck!

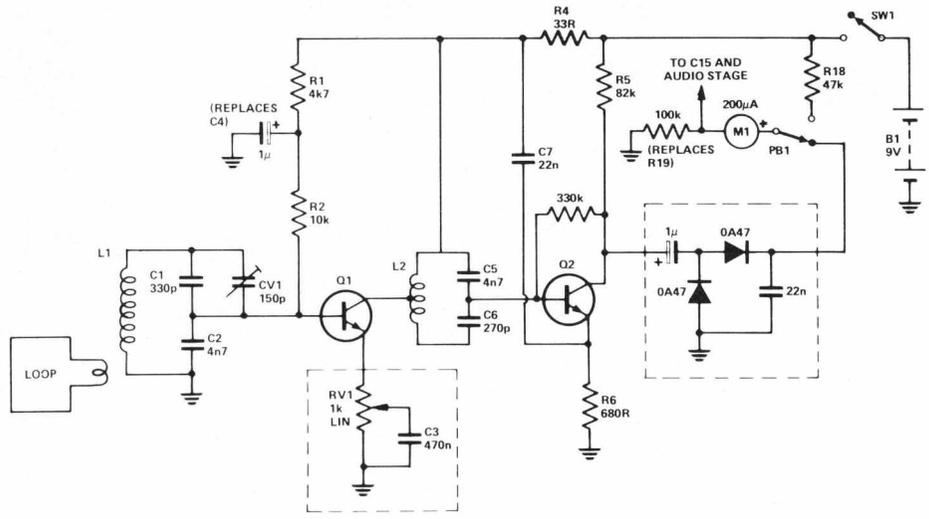


Figure 5. Suggested alternative for a simpler, lower gain receiver. This may prove a better proposition where small, close-spaced antenna loops are used. The original pc board may be used, the unnecessary components being removed. Major changes are shown inside the dashed squares. A voltage doubler diode detector is coupled directly from the collector of Q2, its output being taken to the pushbutton PB1. R19 is replaced with a 100k resistor; the original audio stage is retained. If you only want to use headphones, the audio stage could be removed also and the phones (Hi-Z) capacitively coupled to the 100k resistor. The construction should be arranged so that there is only a short lead between the gain pot (RV1) and the emitter of Q1. Mount C3 on the pot. Note that C4 is replaced with a 1uF tantalum capacitor.

