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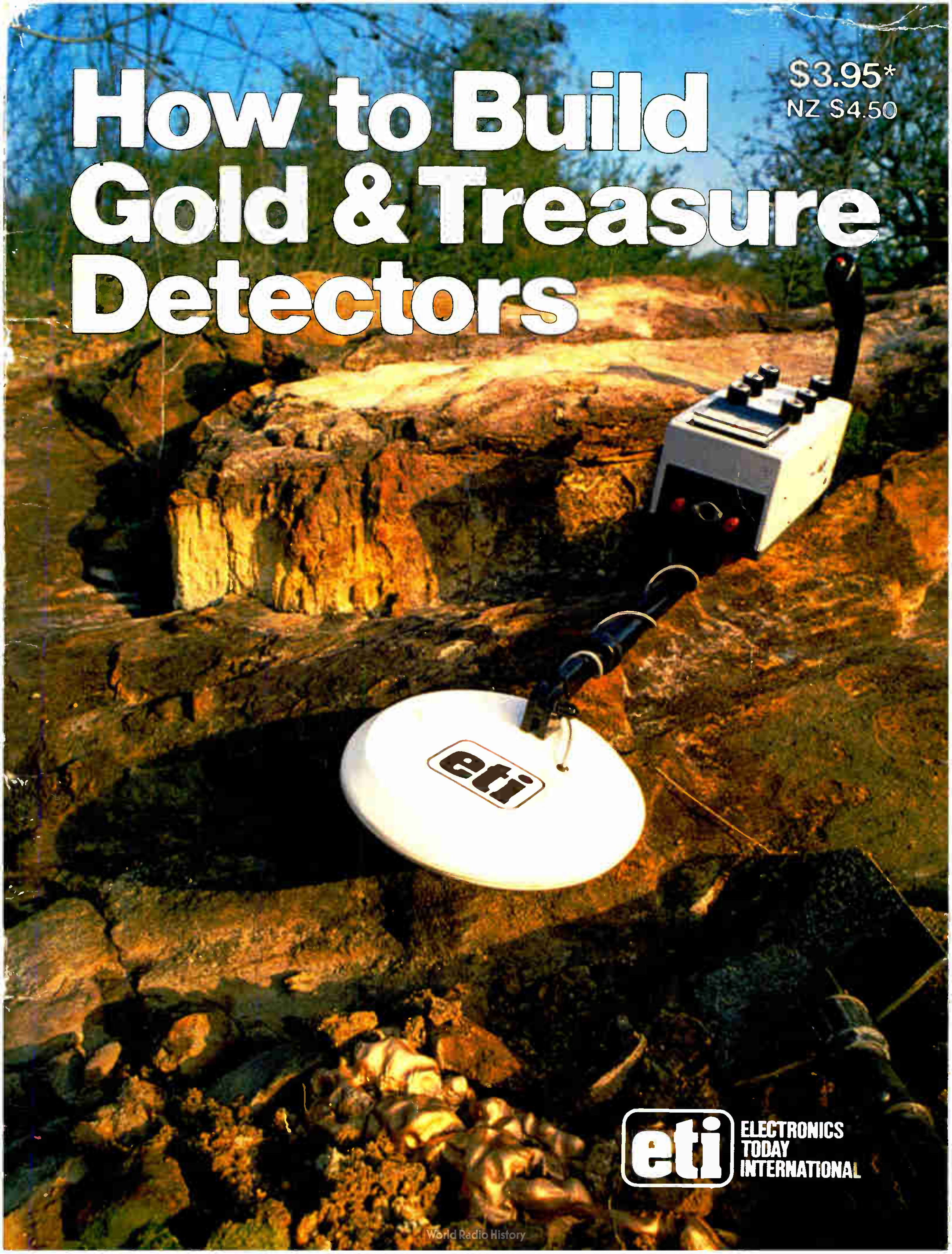

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How to Build Gold & Treasure Detectors

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Metal detectors — how they work and how to choose

Jennifer Whyte

Gold has long since fascinated man by its beauty and rarity. With a unique colour and consistency it quickly became the world's most sought after metal. No wonder that many spend their lives seeking this elusive treasure.

The recent invention of the metal detector has made searching much easier for the prospector. Treasure hunters too use them to locate old and valuable pieces. However the designs for detectors genuinely able to discriminate between 'trash' and 'treasure' have been well-kept trade secrets.

But there's really no reason for builders and users to be kept in the dark. In this introductory article Jennifer Whyte B.App.Sc. (Physics) explains how the various detectors work, and how to decide which is the best for your purpose.

AUSTRALIA owes a great deal of its early development to the discovery of gold. This brought a frantic rush of eager prospectors from all parts of the world. Gold fever in the 1800s saw new towns springing up. Some continued to prosper but many returned to the dust again. Men fought and died for this noble metal. Now, in the 1980s, gold fever is recurring. Its victims are giving up their steady jobs to set off in search of that elusive nugget. The economic situation has caused man to, once again, seriously consider the value of gold. As this metal is reappraised, so are the other precious metals.

Finding a gold nugget is everyone's dream and some lucky prospectors using metal detectors have found gold nuggets beneath the surface. The 27 kg Hand of Faith nugget found at Wedderburn in Victoria was unearthed by a couple of amateur fossickers using a metal detector. The majority of people, however, are disappointed when they find only ring-pull tabs from cans. These people find that the actual performance of their metal detector falls far short of their expectations. Expert handling and a lot of experience are needed before its potential is fully exploited. Even then, nothing exciting will be found unless careful research is conducted to determine suitable gold-bearing areas.

To make matters worse the novice treasure hunter is faced with a bewildering array of expensive detectors and needs some understanding of what is being dealt with in order to make a suitable purchase. The more experienced user should make sure that the equipment is being used properly so that optimum performance is being obtained.

How metal detectors work

Any coil of wire carrying an alternating current will be surrounded by a magnetic field. Metal detectors depend on detecting one of several effects that can be observed when a metal object influences the magnetic field surrounding the detector's search coil. The principal effects are that the pattern of the magnetic field surrounding the coil will be altered and the inductance of the coil will change.

The coil is placed in the search head and the alternating current is generated by a very accurate device (an oscillator) within the detector's electronic circuit. The changes that occur when a metallic target interrupts the field are detected and processed electronically until they are powerful enough, and in a suitable form, to produce a sound through a loudspeaker, and to give a reading on a meter. Non-metallic objects or material can also affect the coil in similar ways.

Penetration

One of the first things a newcomer to electronic gold seeking realises is that a metal detector will really only scratch the surface. At depths much greater than 200 mm only big targets will be located. Small gold nuggest are not likely to be detected at depths exceeding 100 mm.

The depths at which a detector will locate a target depend on so many variables that it is difficult to make any general rules. The size and composition of the target are important. So is the type of soil, the size of the search coils and the type of detector being used.

Large search coils penetrate the deepest, but on the other hand are less sensitive to small targets. Small loops (about 75 mm diameter) are particularly sensitive to very small items buried close to the surface, but present obvious problems when searching a large area.

Standard head sizes are 75 mm, about 200 mm and 300 mm. Some do go to 400 mm. The major disadvantage of the bigger heads is their weight, which soon tires the strongest arm. When very large search heads are used it is common to carry the detector with the assistance of a shoulder or hip mount. Some models have interchangeable heads which can be very useful, although special tuning techniques and different discrimination levels may have to be used as different heads are fitted.

Discrimination

A metal detector detects metal, whether it's a gold nugget or a chewing gum wrapper. Consequently, many of the targets are worthless rubbish. The most common find these days is likely to be the ring-pull tab off a soft drink can. The addition of a discriminator will enable the detector to differentiate between wanted and junk targets. This is difficult as a lot of common rubbish falls into the non-ferrous (non-magnetic) category — which includes gold nuggets and coins.

It has already been said that a metallic target will be detected by observing the change that it produces in the pattern of the magnetic field around the coil. One effect of this alternating current magnetic field is that it induces "eddy currents" in the targets. This depends on the electrical and physical characteristics of the target. Metals which are good conductors will have greater induced eddy currents than metals which are poor conductors. It is a fortunate accident of nature that gold and silver are good conductors, while iron (especially if it's oxidised or rusty) is not such a good conductor. If the target is ring-shaped then the eddy current effect is enhanced. If it's a broken ring or just a peculiarly-shaped mass, the eddy current effect is less pronounced. The orientation of the target will also affect the eddy current effects.

The variations in the eddy current effects can be detected, and a discriminator will use these variations to differentiate between the targets. The amount of discrimination is controllable but as it increases so too does the likelihood of rejection of some good targets — rings, coins, small nuggets etc. Some sensitivity and penetration (up to 50%) are usually lost, although the latest and most sophisticated VLF detectors claim discrimination without losses.

Many detectors don't include discriminators. But if you buy or build a model with the facility, it's worth checking the control settings against known targets and depths in soil to find just how much penetration is lost. Don't carry out air tests as these are not meaningful indicators of field performance.

Celtic brooch found with Beachcomber 4

Users who have had considerable experience with a detector can often tell by its response what sort of target they have located. It takes a lot of practice, but is better than losing good targets simply by trying to get the machine to reject junk.

If you are in a remote area where there is not a great deal of rubbish, leave your discriminator off to give greatest sensitivity, even if you have to dig up some rubbish. Small nuggets or coins may otherwise be missed.

Even though discrimination is one of the most confusing aspects of a metal detector, it is important to understand it and to know how to use it before heading for the hills.

Ground exclusion

Ground exclusion circuitry is intended to allow normal operation over mineralised ground, but is only really a useful addition to the top detectors which operate at frequencies that can penetrate mineralised soil reasonably well. On others the exclusion is obtained by setting back the tuning — which loses sensitivity and depth.

Beat Frequency Oscillator detectors

Beat Frequency Oscillator (or BFO) detectors were the first metal detectors on the market. They are based on the simplest technique of detecting the change in inductance of a single search coil when it is near a target. If this coil is part of the tuned circuit of an oscillator, then comparing the frequency of the 'search' oscillator with a stable reference oscillator will indicate the presence of a metal object. The two oscillators are set such that there is a slight difference in their frequencies and their outputs are mixed. A 'beat' note is produced which is equal to the difference between the two oscillator frequencies. When the search coil is brought near metal or mineral objects, the inductance of the coil is changed slightly, altering the frequency and thus the tone of the note. A tone is produced continuously when the instrument is in use. Metal is identified by a frequency change in the audio tone.

The most important characteristic of the search coil is its size. Surprisingly enough the actual inductance doesn't seem to have much effect on sensitivity. The greater the coil diameter the greater the pentration depth, but then it will be less sensitive to small objects. As a general rule the penetration is about equal to the search coil diameter. Sensitivity depends on the diameter of the object and also the distance between the coil and the object. If the object size is halved, the sensitivity is reduced to one eighth. If the depth is doubled the sensitivity is reduced to one sixty-fourth. So it's easy to see why all metal detectors which are designed to pick up small objects use small coils (150 to 300 mm diameter) and really only skim the soil surface. If the search coil is doubled in diameter for greater penetration the sensitivity to small objects falls to one eighth. This is the law of diminishing returns or reduction in rewards.

BFO detectors suffer from a distinct lack of sensitivity. To improve the penetration, while retaining the sensitivity, the field pattern can be modified to some extent by making the coil on the detector oval in shape.

BFO detectors will be practically useless if they are not fitted with a Faraday Shield to reduce capacitive effects on the coil. If the search coil is moved around, the capacitance between it and the ground or other objects changes. This changing capacitance 'pulls' the oscillator frequency and can completely swamp out the small change in inductance we are looking for. The Faraday Shield around the coil will screen out this capacitive effect. It is simply a wrapping of aluminium foil around the coil, broken at one point so that it doesn't short.

This type of detector also has poor tuning stability but this can be overcome by incorporating additional features into the circuit as has been done with the design described in this book.

Gold washing in the Sierra Nevada. *Voyages and Travels*

The main advantages of this type are simple circuitry and setting up, along with good pinpointing ability. This type is probably the easiest to build and set up yourself as there are no critical adjustments.

To use the BFO detector turn up the volume control and rotate the coarse frequency knob. You will hear a number of beats. One beat will be very strong and this is the one to use, although some of the weaker signals are more sensitive to buried objects than the stronger one. Set the fine frequency control to mid-range and set the coarse frequency control to the strong beat with the search head held away from the ground. When the detector is lowered to the ground you will notice a frequency shift. This is the effect of the ground and will vary between different types of soil. Use the fine frequency control to set the beat to a low pitch and sweep across the surface, keeping the search head at a constant distance from the ground. A metal object will cause a change in pitch which is easily heard.

The frequency of the search oscillator should increase when a non-ferrous (non-magnetic) object comes within range of the search coil. It will decrease when a ferrous (magnetic) object is within range. In practice this effect is difficult to detect as eddy currents in ferrous materials swamp the effect and they react much the same as non-ferrous metals. With the search oscillator set on one side of zero beat, metal objects near the search coil will cause the pitch to decrease. With the search oscillator set to the other side of zero beat, the opposite will occur. Practice is necessary to make the most of your metal detector.

Transmit-Receive detectors

TR detectors (also known as IB from their technical name, induction-balance) use two or more coils. The coils are set close together in the search head, but only one of them (the transmit coil) carries an alternating current. It is driven by a modulated oscillator. The receive coil (or coils) is connected to a detector and amplifier. The coils are carefully positioned with respect to one another such that the receiver coil picks up very little of the energy radiated by the transmitter coil when no metal or mineral material is nearby. When a metal object lies within the transmit coil's magnetic influence, the field pattern is distorted, greatly increasing the amount of energy picked up by the receive coil. The increased energy is detected and amplified, increasing the loudspeaker's volume as well as indicating it on a meter. This type of metal detector is sometimes referred to as an IB/TR detector.

Before use TR detectors are tuned to be almost silent at the height above ground they will be worked. The circuits are designed so that small increases in the received signal are magnified to give very noticeable increases in volume.

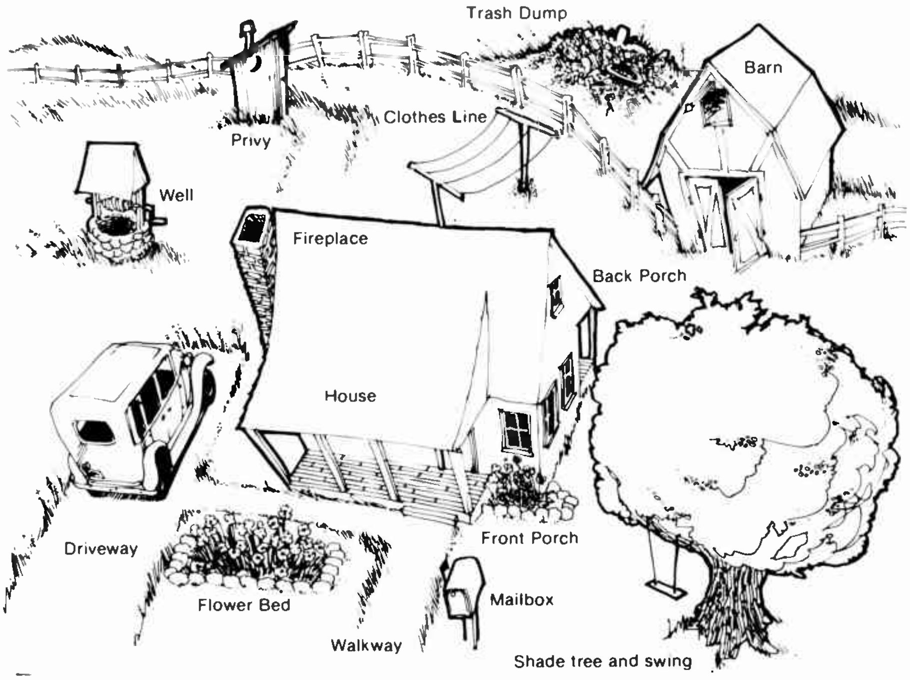
TR detectors are easy to tune, have good depth penetration, and are not sensitive to small ferrous objects, such as nails. The different TR ranges permit varying degrees of control with the discriminator potentiometer. Therefore it is possible to discriminate between wanted and junk targets of various types, although this is generally achieved by sacrificing sensitivity.

If the soil is highly mineralised the detector will react crazily. Such a soil is said to be conducting and contains an appreciable amount of iron minerals (magnetite, hematite, etc. — often referred to as "iron stone soils"). Under these conditions some detectors will become erratic perhaps completely unworkable, as the metallic salts in the soil shield the responses from targets. Even within a small area the soils can be quite different and the detector must be finely adjusted when the head is near the ground.

The degree of exclusion may be varied by selecting factory preset levels on a three or four position switch, or may be continuously varied by using a rotary switch. When the control is switched on, the detector will normally have to be retuned for optimum performance.

If prospecting in streams, where the search head is to be used under water, the ground cancellation circuit should be set with the search head submerged, and preferably after it has been switched on long enough to stabilise to an operating temperature.

When the TR control is set at mid-range, the meter should show "bad" for ferrous objects and "good" for non-ferrous objects, along with a tone from the speaker. It is unfortunate that ring-pull tabs from drink cans are aluminium and thus indicate along with other non-ferrous metals. But the discrimination ability of the instrument can be adjusted to exclude the small effect these targets generate — along with small trinkets, the smaller gold nuggets, etc. — but who wants the small ones anyway! As the discrimination controls are advanced, some non-ferrous objects such as brass will start to give a "bad" reading, while gold and silver will give a "good" reading. As the controls are advanced further aluminium will start to give a "bad" reading, and so on. As you use the detector you will become familiar with its operation.



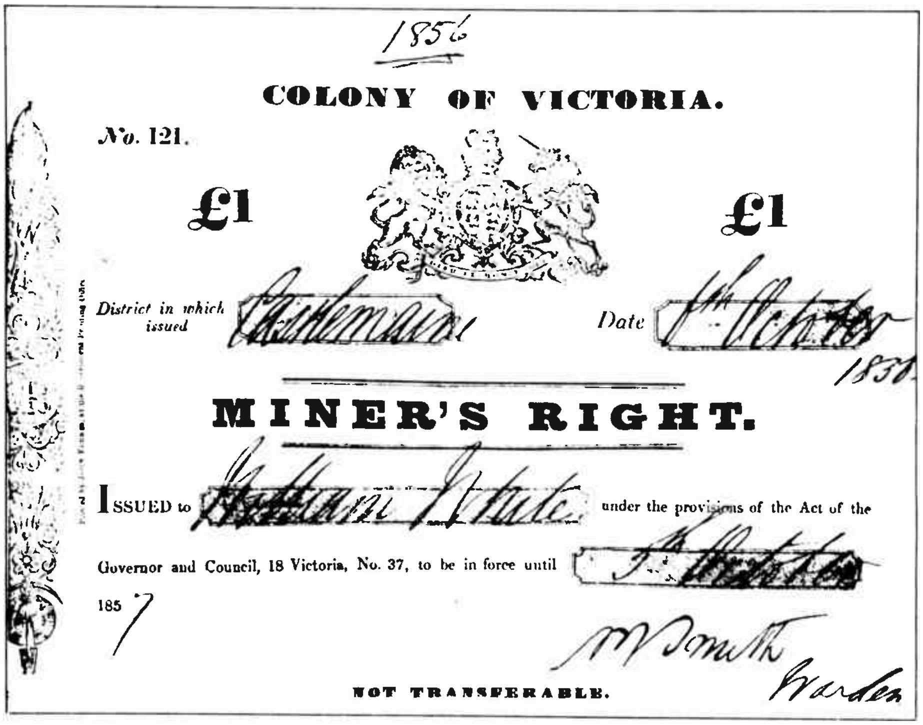
There's no end to the number of places where now-valuable objects may be found. Here are some of the more likely. (Drawing courtesy of Goldmountain Detectors).

The best way of setting the discrimination controls is to carry around a few sample objects of the type you want to discriminate against, just for this purpose. One thing to remember is that a corroded object will require a different setting of the controls from a non-corroded one, so carry samples typical of what you are likely to dig up.

By carefully setting the controls, unwanted objects can be tuned out, giving no meter movement at all. So the detector can be used to reject particular objects and at the same time discriminate between others.

TR detectors have good pinpoint capabilities, and battery drain is low. However, they also have some disadvantages. They are badly affected by mineralised ground, may be upset by wet grass or sand, and lose sensitivity when controls are included to negate the effects of mineralised ground. They are difficult to use over uneven ground, since they must be tuned for use at a constant height, and can give false readings when raised to pass over obstacles.

While TR detectors perform well, and in some cases are the most useful of all types, they are best suited for beachcombing or for use on reasonably level ground.



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Very Low Frequency detectors

VLF detectors were developed to overcome the failings of TR detectors on mineralised ground, and the two are similar in many respects. The main difference is that the alternating current passed through the transmit coil is at a lower frequency (about one-twentieth) and can penetrate most soils well.

The advantages of VLF detectors are good depth penetration and rejection of the effects of mineralised ground. Most have some form of auto-tuning which resets the sound to the original level if tuning has been affected by drift or ground conditions. This facility can be used to help in pin-pointing which is generally poor in VLF detectors.

The disadvantages of these detectors are high sensitivity to small ferrous objects and, because the detector must be run at high power to achieve good sensitivity on small targets, high battery drain. With their confusing array of switches and controls they are difficult to master and tend to be very expensive. They can only be recommended for experienced users.

As they have a high battery drain and poor pinpointing, VLF detectors are normally combined with TR circuits to give the best of both worlds. Searches are usually carried out with VLF sweeps, then the TR circuit is switched in for discrimination and pinpointing. A skilled user may be able to interpret VLF target responses to give some definition of target type, but normally TR discrimination is used.

Pulse Induction detectors

Pulse Induction detectors employ coils in the search head that are set up in much the same manner as the TR detector. However, the signal is transmitted in high energy bursts, or pulses, by the search coil. The receive coil (or coils) compares the phase (the relationship between time and magnitude) of the received signal with that of the transmitted pulse. When a ferrous or magnetic object is near the search coils the phase of the received signal is advanced with respect to the transmitted signal. The opposite occurs when a non-magnetic conductor is near the search coils. Thus, this type of detector can effectively discriminate between ferrous and non-ferrous metals as well as exclude ground effects — simply by setting the detection circuitry to exclude signals of the unwanted phase characteristics. Switching may be included for these modes. So a "Ground Exclusion" control is often featured with these detectors. As the strength of the received signal also varies, depending on the target characteristics, this effect may also be included in the detection process.

The advantages of PI detectors are good penetration and effectiveness on mineralised ground, and high sensitivity. Their disadvantages are high power drain, poor pinpointing, and, because of complex circuits, high cost. A PI detector presents many problems to the home constructor.

Buying a detector

There is no single detector that is good for all purposes, or can be used over all types of ground. The most commonly used are the TR and VLF/TR combinations, which should be satisfactory for most amateur fossickers. For beachcombers a simple TR model is an economic and effective tool, where a VLF device would be too sensitive and unnecessary.

Sometimes a detector can be *too* sensitive. On maximum sensitivity the detector will register small objects, such as nails, and give the same readings as for coins, making life difficult. So a high-low sensitivity switch can be important.

For the gold seeker or relic collector searching old mining areas, the TR detector's shortcomings on rough ground may give continual false readings. Then a VLF device, though more expensive and trickier to operate, is the experienced user's likely choice.

One problem often encountered is the lack of clear information on the operating principles of the detectors. Manufacturers often use confusing jargon in their catalogues. Although most detectors fall into one of the four categories described, many manufacturers introduce their own terms, like GEB (ground exclusion balance), GNC (ground neutralising circuitry), AGC (automatic ground cancelling), ADS (automatic detection system) and others. These all appear to be VLF detectors although sometimes it's difficult to be sure.

Using the detector

Finding buried metal is sometimes too easy. 95% will be junk, silver paper being a curse. The search head should be panned slowly over the surface taking care to overlap each sweep. The sensitive area of the search head is somewhat less than the diameter of the coil. The area you can cover thoroughly is very, very small, but this approach is far more successful than nipping all over the place. Try to keep the search head at a constant height — about 30 to 50 mm. If the height must be changed, check the ground cancel controls, if fitted, and if necessary retune the detector. When a target is detected by VLF sweeps, stop and try to pinpoint its location, using sweeps at right angles. Switch to TR mode with discrimination and recheck the location, trying to identify the target (trash or treasure).

Anybody can be successful with a metal detector, providing they have perseverance, a desire to learn and use commonsense to locate suitable areas.

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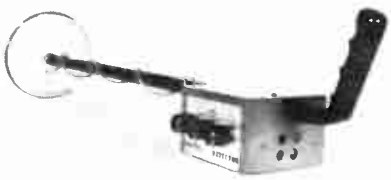

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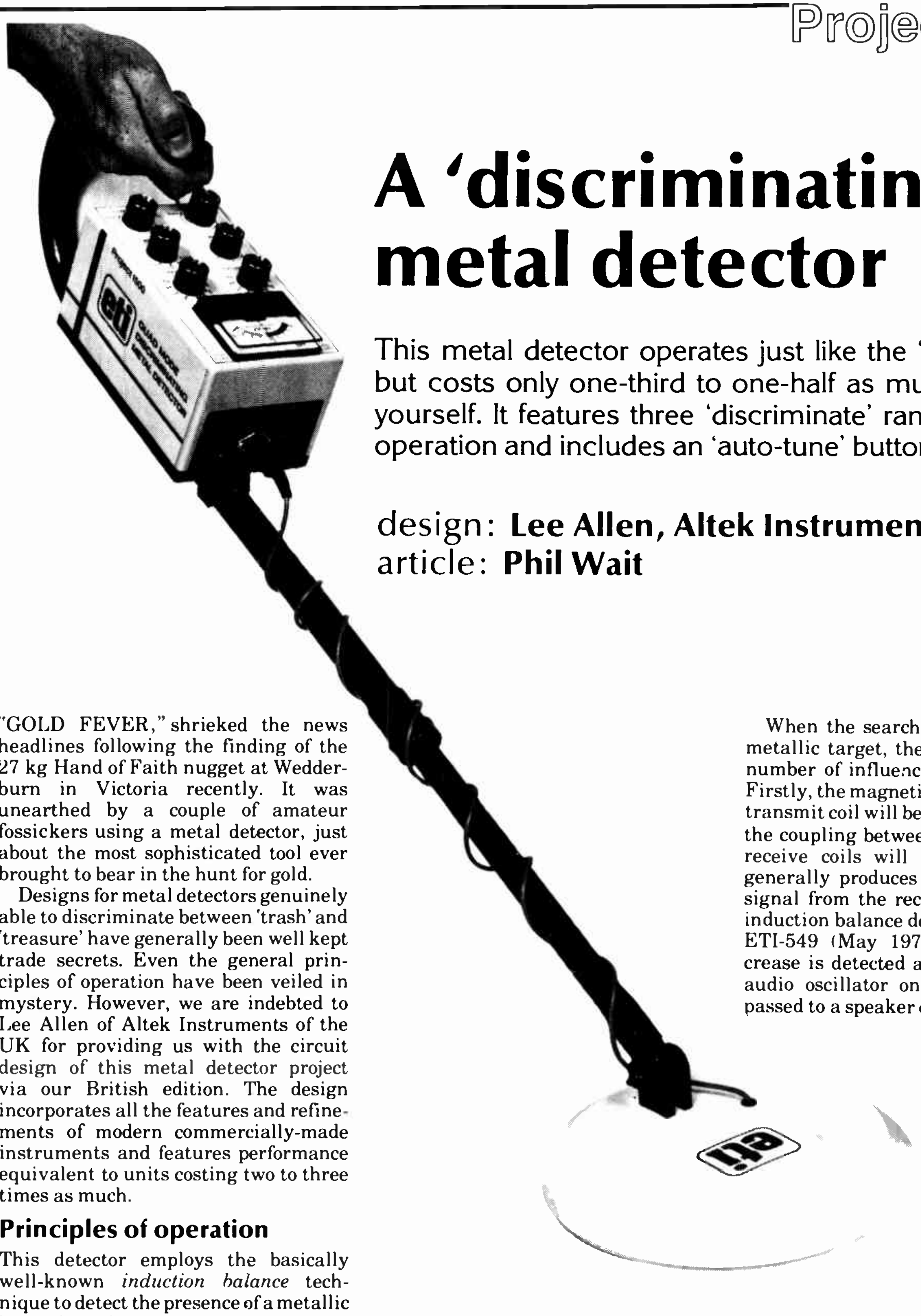
A 'discriminating' metal detector

This metal detector operates just like the 'bought ones' but costs only one-third to one-half as much to build it yourself. It features three 'discriminate' ranges plus VLF operation and includes an 'auto-tune' button.

design: **Lee Allen, Altek Instruments, UK**
article: **Phil Wait**



"GOLD FEVER," shrieked the news headlines following the finding of the 27 kg Hand of Faith nugget at Wedderburn in Victoria recently. It was unearthed by a couple of amateur fossickers using a metal detector, just about the most sophisticated tool ever brought to bear in the hunt for gold.

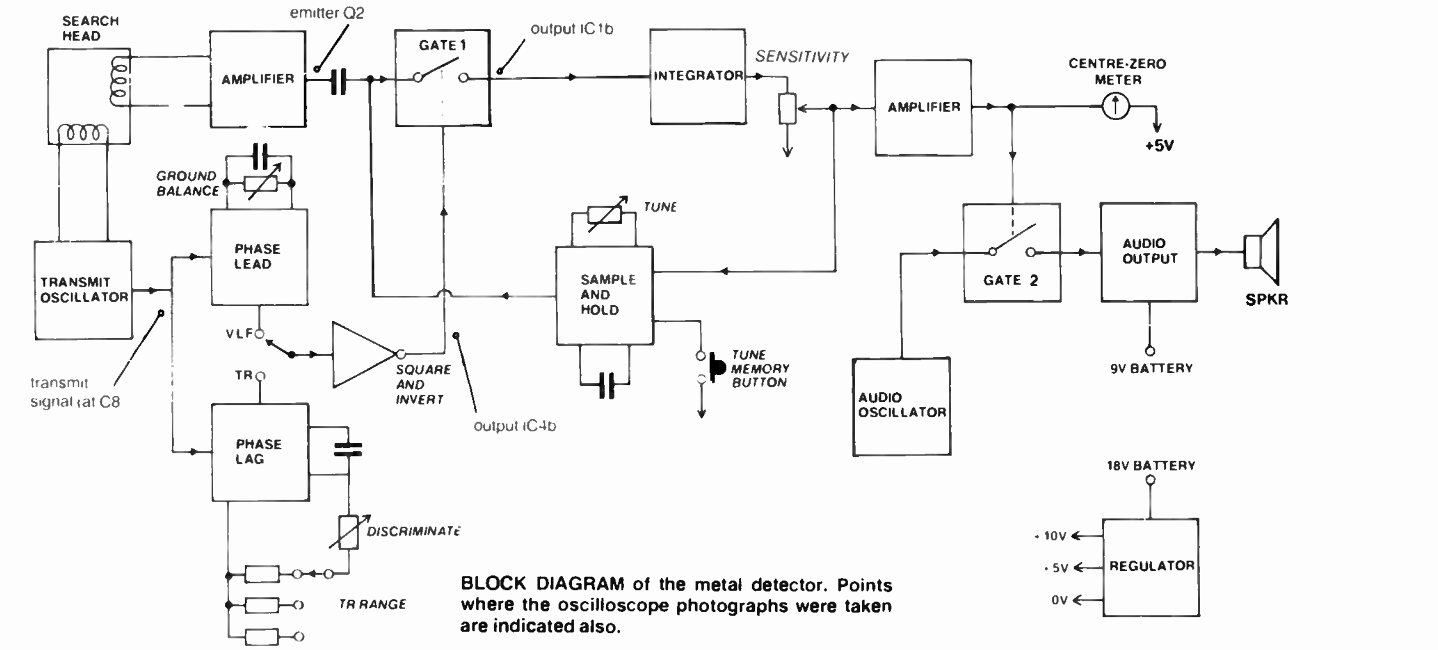
Designs for metal detectors genuinely able to discriminate between 'trash' and 'treasure' have generally been well kept trade secrets. Even the general principles of operation have been veiled in mystery. However, we are indebted to Lee Allen of Altek Instruments of the UK for providing us with the circuit design of this metal detector project via our British edition. The design incorporates all the features and refinements of modern commercially-made instruments and features performance equivalent to units costing two to three times as much.

Principles of operation

This detector employs the basically well-known *induction balance* technique to detect the presence of a metallic 'target' in the ground, but includes a number of refinements which respond to certain characteristics of the target. The 'search head' contains two coils: an outer coil which is connected to a low frequency oscillator operating somewhere in the range 15 - 20 kHz, and an inner coil which is placed so that it is only very loosely coupled to the outer coil. The latter is connected to the 'receiver' input of the instrument. Being only very loosely coupled, the signal induced in the receiver (inner) coil from the transmit (outer) coil is very small when a target is not in the vicinity of the search head.

When the search head approaches a metallic target, the target will have a number of influences on the two coils. Firstly, the magnetic field pattern of the transmit coil will be disturbed, and thus the coupling between the transmit and receive coils will be increased. This generally produces an increase in the signal from the receive coil. In simple induction balance detectors, such as the ETI-549 (May 1977), this signal increase is detected and used to gate an audio oscillator on so that a tone is passed to a speaker or headphones.

That's all quite straightforward, but there are other influences to be taken into account. The ground in which a target is buried can have quite a profound effect on the coils in the search head. Firstly, if the ground is basically non-conducting, then it will have a permeability considerably different to that ▶



BLOCK DIAGRAM of the metal detector. Points where the oscilloscope photographs were taken are indicated also.

of air. This will affect the coupling between the two coils in the search head, increasing the coupling if the transmit and receive coils are initially set up away from the influence of the ground. You can compensate for this effect by physically varying the position of one coil in relation to the other when the search head is near the ground. However, different soils will have different compositions and thus have different values of permeability — even within quite a small area. The best way to compensate is by electronic means and we'll go into that shortly.

If the soil contains an appreciable amount of iron minerals (maghemite, hematite etc . . . often referred to as "iron stone soils"), or mineral salts of one type or another, then it will be partly conducting.

Such soils will have a permeability often greater than basically non-conducting soils, affecting the coupling between the coils in the search head in a similar way to that just explained. Again, as the composition of the soils varies, so will the coupling. Another effect is that of 'eddy currents' induced in the conductive soil. The ac magnetic field of the transmit coil will induce a current in the ground beneath the search head and the eddy current has an effect opposing the permeability effect of the soil — and the whole effect varies in a complex and unpredictable way as you sweep the search head over the ground.

The only way to compensate for these varying, and generally unpredictable effects, is to devise circuitry that 'recognises' the effect.

Permeability effects will vary the phase as well as the amplitude of the signal coupled into the receive coil from the transmit coil while eddy current effects vary the amplitude. Knowing that, one can devise appropriate circuitry to take the effects into account.

However, we need to know how a metallic target affects the phase and amplitude of the receive signal. If the target is ferrous, it will have a much greater effect on the magnetic field of the transmit coil than will the surrounding soil as its permeability is greater and it will 'bend' or concentrate the field lines to a much greater degree. If the target is non-ferrous it will have a permeability effect opposite to that of ferrous targets, deflecting the field lines, but eddy currents also have some influence.

The eddy current effect in a target depends on the electrical and physical characteristics of the target. Metals which are good conductors will have greater induced eddy currents than metals which have a higher resistivity. It is a fortunate accident of nature that gold and silver are good conductors (low resistivity) while iron (especially if it's oxidised or rusty) is not so good a conductor.

If the target is ring-shaped then the eddy current effect is enhanced, whereas if it's a broken ring or just a peculiarly-shaped mass, the eddy current effect is less pronounced. The 'attitude' or orientation of the target will also affect the eddy current effects. If the main plane of the target object is aligned such that the field lines from the transmit coil cut it at right angles, then the eddy currents induced will be at a maximum. If the main plane of the target is aligned parallel to the transmit field then the eddy currents induced will be at a minimum. Obviously, the attitude of the target with respect to the transmit coil's field will vary as the head passes over it and the eddy current effect will vary accordingly — it may not be maximum beneath the centre of the search head.

The permeability and eddy current effects combine in the receive coil and the signal varies in phase and amplitude in characteristic ways.

The instrument

The best way to understand how this instrument operates is to look at it in block diagram form. The accompanying diagram shows the basic circuit blocks employed. The transmit oscillator drives the transmit coil in the search head and supplies a signal to two phase control circuit blocks. The signal from the receive head is first amplified and then ac-coupled to the input of a gate (gate 1). This gate is controlled by the output from one or other of the phase control circuits via a block which 'squares up' and inverts the signal. The output gate consists of an ac signal superimposed on a dc level. This passes to an integrator which obtains the *average* dc level of the composite signal. This is then passed to both a dc amplifier which drives a centre-zero meter, and to a 'sample and hold' circuit. The output of this block provides a dc level to the input of gate 1 which is a measure of the average dc level of the composite signal. The initial dc level applied to the input of gate 1 is actually established by the *tune* control. Thus, a dc negative feedback path is provided.

In addition to meter indication, an audio indication is provided. The output of the dc amplifier driving the meter controls a gate which switches on or off the output of an audio oscillator. This is applied to an audio amplifier and an on-board loudspeaker or headphones.

Power for the audio amplifier is provided by two 9 V batteries in parallel. The rest of the circuitry requires two supply rails at +10 V and +5 V with respect to the common rail (0 V). This is supplied by a regulator from an 18 V source consisting of two 9 V batteries connected in series.

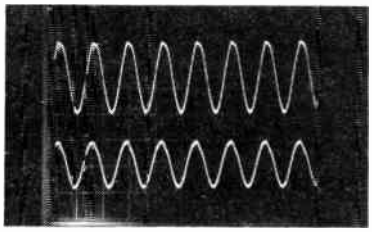
Initially, the instrument is set up in the 'VLF' mode. The search head is held in the air and the *tune* control adjusted to bring the meter to centre zero. This is done with the *tune memory* button depressed. This activates the sample and hold circuit, storing the dc level set by the feedback loop in the capacitor of the sample and hold block. Thus, a particular dc level at the output of the integrator corresponding to meter centre zero is set up.

The search head is then lowered to the ground. Naturally, this will upset the coupling between the transmit and receive coils and the output at gate 1 will change. This will change the dc level at the output of the integrator. The *ground balance* control is then adjusted to bring the meter back to centre zero. What the ground balance circuit does is to provide a signal which leads the phase of the transmit signal and thus leads the phase of the signal induced in the receive coil without the presence of ground. The ground balance control varies the phase of this signal over a range of about four to one. Thus, when you vary the ground balance control, this varies the phase of the signal controlling gate 1, thus varying the average level of the signal passed to the integrator.

The process is then repeated until no change occurs when the search head is lowered to the ground. This establishes a 'normal' condition for the output of the integrator and the sample and hold circuit maintains the appropriate dc level at the input to gate 1 such that the meter remains at centre zero.

If the search head then approaches a metallic object, the amplitude of the signal in the receive coil will vary as the coupling between the coils and the phase of the signal will be altered by the target. This will change the average level of the composite signal out of gate ▶

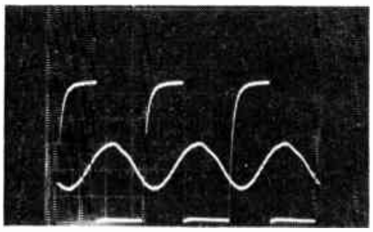
OSCILLOSCOPE PHOTOGRAPHS



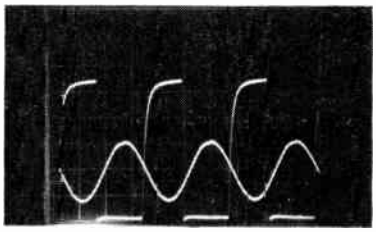
NOTE: As the effect induced by different targets is very, very small, we have had to use fairly large sample targets to show gross effects in order to demonstrate the operation of the instrument.

A) Top trace: transmit signal on C8 (Y-amp 5 V/div, ac-coupled)
Bottom trace: received signal on emitter of Q2 (Y-amp 5 V/div ac-coupled). Time base: 50 us/div.

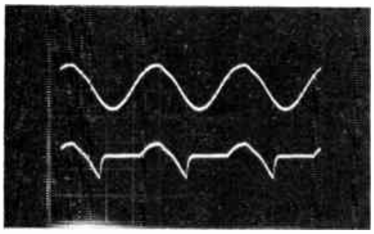
VLF MODE



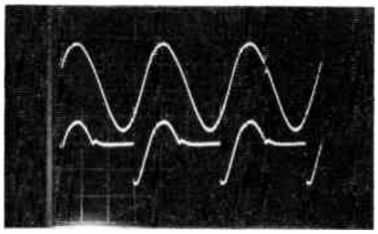
B) Received signal on emitter of Q2 (sine wave) superimposed on output of IC4b. (Both traces 2 V/div, ac-coupled: time base 20 us/div).



C) As per pic (B) but with aluminium target held near search head. Note the phase delay and change in amplitude of the received signal.

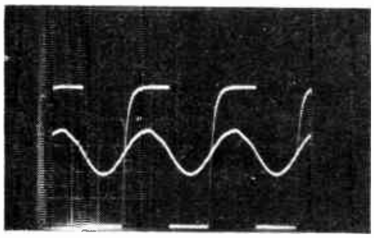


D) Top trace: received signal on emitter of Q2.
Bottom trace: output of IC1b showing composite waveform of received signal 'mixed' with a dc level. (Both traces 2 V/div, ac-coupled; time base 20 us/div).

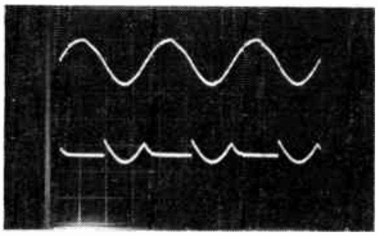


E) Same as pic (D) but with metal target near the search head. Note the increase in average dc level from the output of IC1b. The change in this signal is much larger for non-ferrous than for ferrous metals.

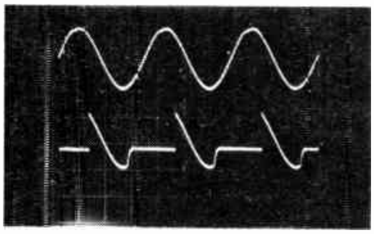
DISCRIMINATE MODE



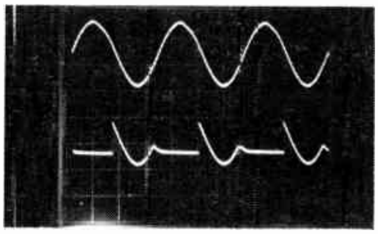
F) Received signal on emitter of Q2 (sine wave) superimposed on the output of IC4b. The phase difference between the two signals is adjustable through 180° by use of the course (TR1, TR2, TR3) and fine 'discriminate' controls. (Both traces 2 V/div, ac-coupled; time base 20 us/div).



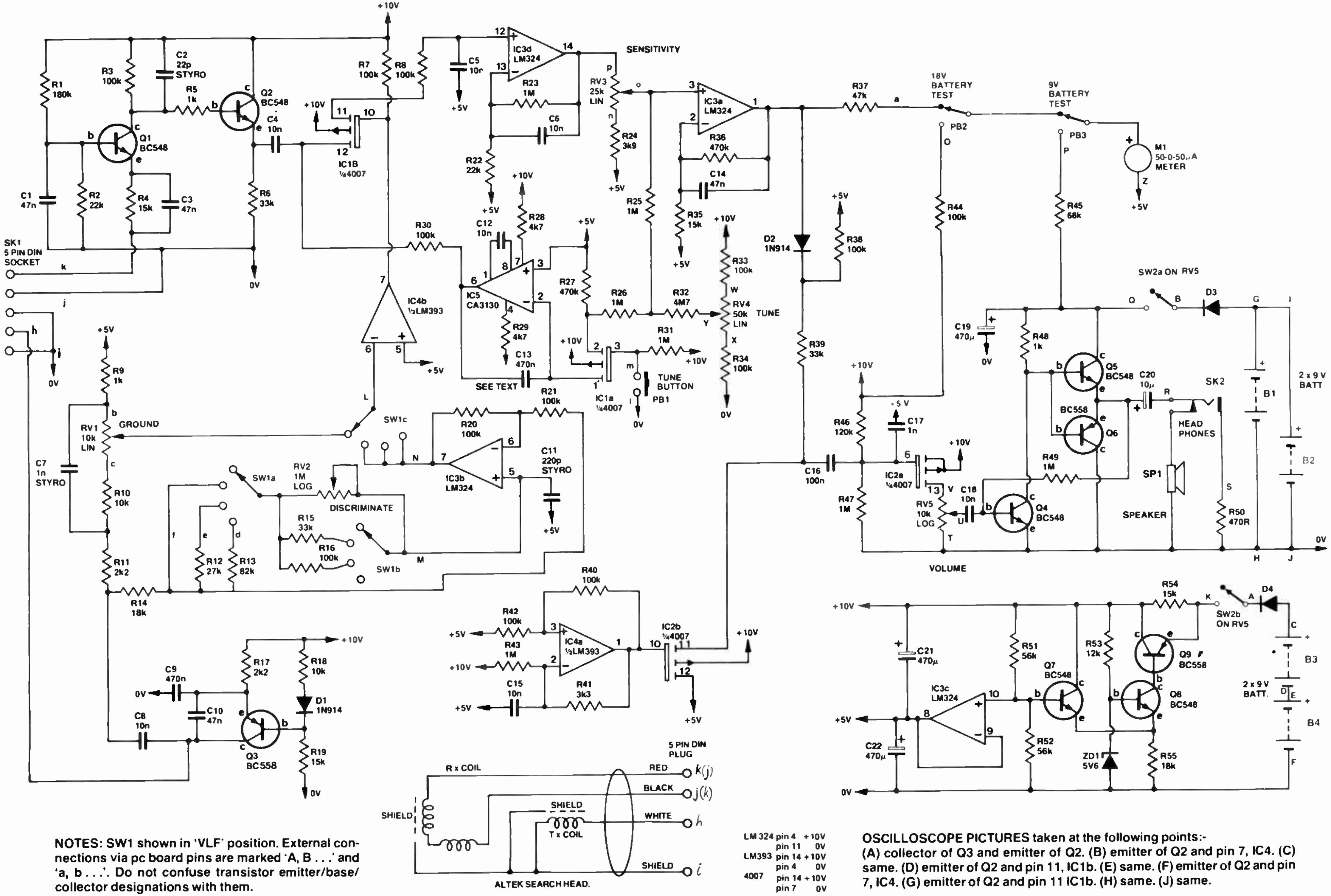
G) Top trace: received signal on emitter of Q2. Bottom trace: output of IC1b showing composite waveform of received signal 'mixed' with a dc level. Detector set to TR1 mode, discriminate control to 9. (Both traces 2 V/div, ac-coupled; time base 20 us/div).



(H As per pic (G) but brass target held near search head. Note the increase in the average dc level of the signal at the output of IC1b.



I) As per pic (G) but steel target held near search head. Note the decrease in average dc level of the signal at the output of IC1b, illustrating discrimination.



NOTES: SW1 shown in 'VLF' position. External connections via pc board pins are marked 'A, B . . .' and 'a, b . . .'. Do not confuse transistor emitter/base/collector designations with them.

LM324	pin 4	+10V
	pin 11	0V
LM393	pin 14	+10V
	pin 4	0V
4007	pin 14	+10V
	pin 7	0V

OSCILLOSCOPE PICTURES taken at the following points:- (A) collector of Q3 and emitter of Q2. (B) emitter of Q2 and pin 7, IC4. (C) same. (D) emitter of Q2 and pin 11, IC1b. (E) same. (F) emitter of Q2 and pin 7, IC4. (G) emitter of Q2 and pin 11 IC1b. (H) same. (J) same.

FEATURES

- VLF and T/R operation
- Three ranges of 'discriminate' (T/R) operation
- Can tune out aluminium ring-pull tabs
- Ground balance circuitry included
- Tune memory ('auto-tune') button
- High sensitivity (will detect 20¢ piece at depths over 250 mm)
- Pre-wound and aligned waterproof search head
- Straightforward construction, no alignment necessary
- Low battery drain
- Uses common No. 216 transistor radio batteries
- Costs around $200 in kit form

HOW IT WORKS — ETI 1500

As the general principles of operation have been discussed with regard to the block diagram in the text, this description is confined to the circuit alone.

Commencing with the transmitter, Q3 is configured as a Colpitts oscillator, the transmit coil in the search head forming the inductance which resonates with the combination C9 and C10. Bias is applied to Q3 via R18, D1 and R19. Emitter bias is provided by R17. The transmit signal to the phase-lead and phase-lag circuitry (ground and discriminate controls) is tapped off the collector of Q3 via C8 to the junction of R11 and R14. The ground control circuitry connects via R11 while the discriminate circuitry connects via R14.

The signal from the receive coil is amplified by Q1 and applied to gate 1 (see block diagram), one CMOS gate in IC1 (IC1b), via an emitter-following buffer stage, Q2. Note that Q1 is operated as a grounded-base amplifier. The phase of the received signal through Q1 and Q2 is not altered. Output from the emitter of Q2 is applied to the drain of IC1b.

The base of IC1b is driven by a square wave derived from the transmit signal, the phase of which can be varied by either the ground or discriminate controls.

In the VLF mode, the phase of the transmit signal tapped off from Q3 can be varied using RV1. This provides a phase-advanced signal that can be varied over the range from about +10° to +40°. A leading phase RC network is formed by R10 and RV1 in conjunction with C7. This signal is applied to the inverting input of an op-amp, IC4b. As this is operated at maximum gain with a high signal level at the input, it will 'square up' the signal at its output (pin 7), which drives the gate of IC1b.

In the discriminate mode, switch SW1 connects the transmit signal to circuitry which provides a lagging phase signal which can be varied over a range set by RV2 (the discriminate control) and a set of 'range' resistors: R12, R13, R15 and R16. These form a lagging phase RC network in conjunction with C11. The signal is then buffered by a non-inverting op-amp, IC3b, and applied to the inverting input of IC4b via SW1c.

The source of IC1b is connected to an integrator stage formed around IC3d. The output of this stage is connected directly to the sensitivity control, RV3. The wiper of this potentiometer goes directly to the input of a dc amplifier, IC3a, to which we shall return shortly. The wiper of RV3 is also connected to the sample and hold circuit, via R25, which involves IC5, IC1a, the tune control RV4 and the tune memory pushbutton, PB1.

The sample and hold circuit works in the following way. The junction of resistors R25, R26 and R32 will be at a dc level determined by the dc level at the wiper of RV3 and the dc level at the wiper of RV4, the tune control potentiometer. The dc level at the wiper of RV3 will depend on the signal level and phase switched through to the integrator by IC1b. When the tune memory pushbutton, PB1, is pressed, IC1a (also a CMOS switch) will apply a dc level to the input of the sample and hold circuit proportional to the dc level at the junctions of R25, R26 and R32. This will charge C13 and the output of IC5 will settle at this value. This dc level is then applied to the drain of IC1b, via R30.

Thus, the received signal and this dc level are 'mixed' at the input to gate 1 (i.e: IC1b), the composite signal being applied to the integrator.

The meter, M1, is driven by a dc amplifier, IC3a. The input to this op-amp comes from the sensitivity control and is applied to the non-inverting input (pin 3). This stage has a gain of about 30 and a little 'smoothing' (integration) of the signal is applied around the feedback by having a capacitor (C14) connected in parallel with the feedback resistor, R36.

Apart from driving the meter, the output of IC3a is fed to the source of IC2b which gates the audio oscillator through to the audio output stage (i.e: gate 2). The dc level from pin 1 of IC3a goes via D2 and R39 to pin 11 of IC2b. A positive bias is applied to the cathode of D2 from the +5 V rail via R38. Only when the dc level at the output of IV3a goes higher than 0.6 V above the bias applied to the cathode of D2, will IC2b be biased on.

The audio oscillator involves IC4a, configured as an astable multivibrator operating at a few hundred Hertz. The output, pin 1, is applied to the gate of IC2b. When IC2b turns on, the signal is applied to the input of the audio output stage.

One gate from IC2 is biased into its linear region and acts as a source-follower buffer at the input of the audio output stage. The volume control, RV5, is the source resistor for this stage and the output is taken from the wiper of RV5 to the base of Q4, capacitively coupled via C18.

The output stage is a simple complementary class-B stage employing a low power NPN/PNP transistor pair. The collector of Q4 drives the output stage, its collector load also providing bias to the output pair (R48). Both dc and ac feedback is applied to the base of Q4 by R49 from the output. Audio output can be from an 8 ohm speaker or headphones, via a dc isolating capacitor, C20. Headphone volume is reduced by a 470 ohm resistor, R50, in series with one lead to the headphone socket, SK2.

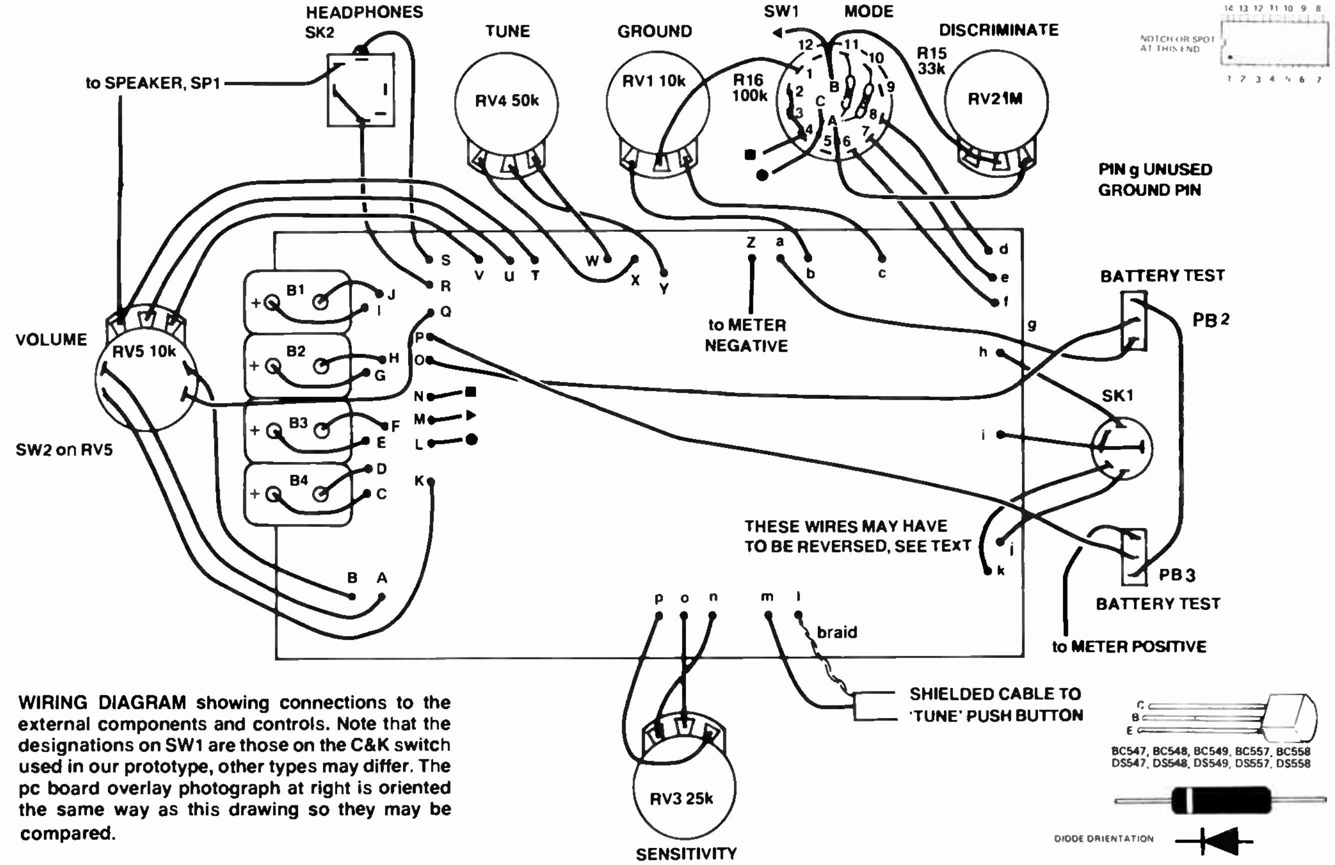
Power supply for the circuitry is split into two parts. The audio output stage is supplied by two 9 V batteries connected in parallel (B1 and B2). These are connected via a reverse-polarity protection diode, D3, and one pole of SW2 which is a switch on RV5.

The rest of the circuitry requires a +10 V and a +5 V rail, with respect to the common rail (0 V). This is derived from two 9 V batteries, B3 and B4, connected in series and applied to a regulator circuit via a reverse-polarity protection diode, D4, and the other pole of SW2. The regulator is basically a conventional series-pass circuit, Q9 being the regulator transistor.

The zener diode ZD1 provides a stable reference voltage for a differential pair, Q7 and Q8, the latter controlling the base current to Q9. Resistor R54 allows a small amount of current to pass to Q7/Q8 at switch-on to ensure the regulator 'starts' correctly. The base of Q7 is biased at half the upper supply rail voltage by R51 and R52. This voltage is buffered by an op-amp, IC3c, configured as a voltage follower, and used to drive the +5 V line. Decoupling is provided by C19, C21 and C22. Note that 'battery test' facilities are provided by R44/PB2 for the 18 V supply and by R45/PB3 for the 9 V supply.

TUNING

During the tuning operation, when the instrument is being initially set up, the circuit works in the following way: With the tune memory pushbutton operated, IC1a is gated on and a dc negative feedback loop is established from the output of the sensitivity control, back to the input of gate 1, the drain of IC1b, via the sample and hold circuitry. A portion of the voltage from the wiper of RV3 is added to the voltage determined by the voltage divider R33, RV4 and R34. This is applied to the source of IC1a. As the tune memory button is pressed, IC1a is conducting and capacitor C13 will charge to the value of the composite voltage applied to the source of IC1a. The op-amp IC5 is a low input current device and the output, pin 6, will settle at a value equal to the composite voltage applied to its non-inverting input (pin 2). This dc level is applied to the source of IC1b and the signal output from the receive coil amplifier is mixed with it. This will bring about a reduction in the dc level of the signal applied to the integrator input, and thus a reduction in the dc level at the input of IC1a and, within a second or two, a new dc condition is established. When the dc level around the loop settles, the meter will read zero (centre) and the tune memory switch is released. The dc level at the output of IC5 (and thus at the drain of IC1b) is maintained by the charge on capacitor C13. In practice, it will drift very slowly, as C13 will be gradually discharged by the input current of IC5 and the capacitor's own leakage. For this reason, the tune memory button is located on the crook of the handle where it can be operated by your thumb every now and then to re-centre the meter.



WIRING DIAGRAM showing connections to the external components and controls. Note that the designations on SW1 are those on the C&K switch used in our prototype, other types may differ. The pc board overlay photograph at right is oriented the same way as this drawing so they may be compared.

PARTS LIST — ETI 1500

Resistors all ½W, 5%.

R1	180k
R2, 22	22k
R3, 7, 8, 16, 20, 21, 30 33, 34, 38, 40, 42, 44	100k
R4, 19, 35, 54	15k
R5, 9, 48	1k
R6, 15, 39	33k
R10, 18	10k
R11, 17	2k2
R12	27k
R13	82k
R14, 55	18k
R23, 25, 26, 31, 43, 47, 49	1M
R24	3k9
R27, 36	470k
R28, 29	4k7
R32	4M7
R37	47k
R41	3k3
R45	68k
R46	120k
R50	470R
R51, 52	56k
R53	12k

Capacitors

C1, 3, 10, 14	47n greencap
C2	22p styroseal
C4, 5, 6, 8, 12, 15, 18	10n greencap
C7	1n styroseal
C9	470n greencap
C11	220p styroseal
C13	470n polycarbonate or styroseal
C16	100n greencap
C17	1n greencap
C19, 21, 22	470μ, 16V electrolytic
C20	10μ, 16V electrolytic

Potentiometers

RV1	10k linear
RV2	1M log.
RV3	25k linear
RV4	50k linear
RV5	10k log pot with DPST switch

Semiconductors

D1, 2, 3, 4	1N914, 1N4148
ZD1	5V6, 400mW zener diode
Q1, 2, 4, 5, 7, 8	BC548, BC108
Q3, 6, 9	BC558, BC178
IC1, 2	4007
IC3	LM324
IC4	LM393N
IC5	CA3130N

Miscellaneous

SW1	three-pole, four position wafer switch;C&K type RA
SW2	on RV5 (DPST switch)
PB1, 2, 3	SPST miniature momentary push buttons, push to make
M1	50-0-50 μA meter,see text
SK1	5-pin DIN socket
SK2	shorting type jack socket
SP1	small eight ohm speaker (75 mm dia.)
B1 - B4	nine volt transistor radio batteries (type 216)

Four battery clips for No. 216 batteries; ETI-1500 pc board; case (see text); handle (see text); search coil (see text); knobs; length of ribbon cable; two metre length of shielded cable; double-sided sticky tape to hold batteries in position, or a suitable clamp.

1 and thus the dc level at the output of the integrator will change. This will be amplified and the meter will show an indication. Also, gate 2 will be operated and a tone will be heard in the speaker.

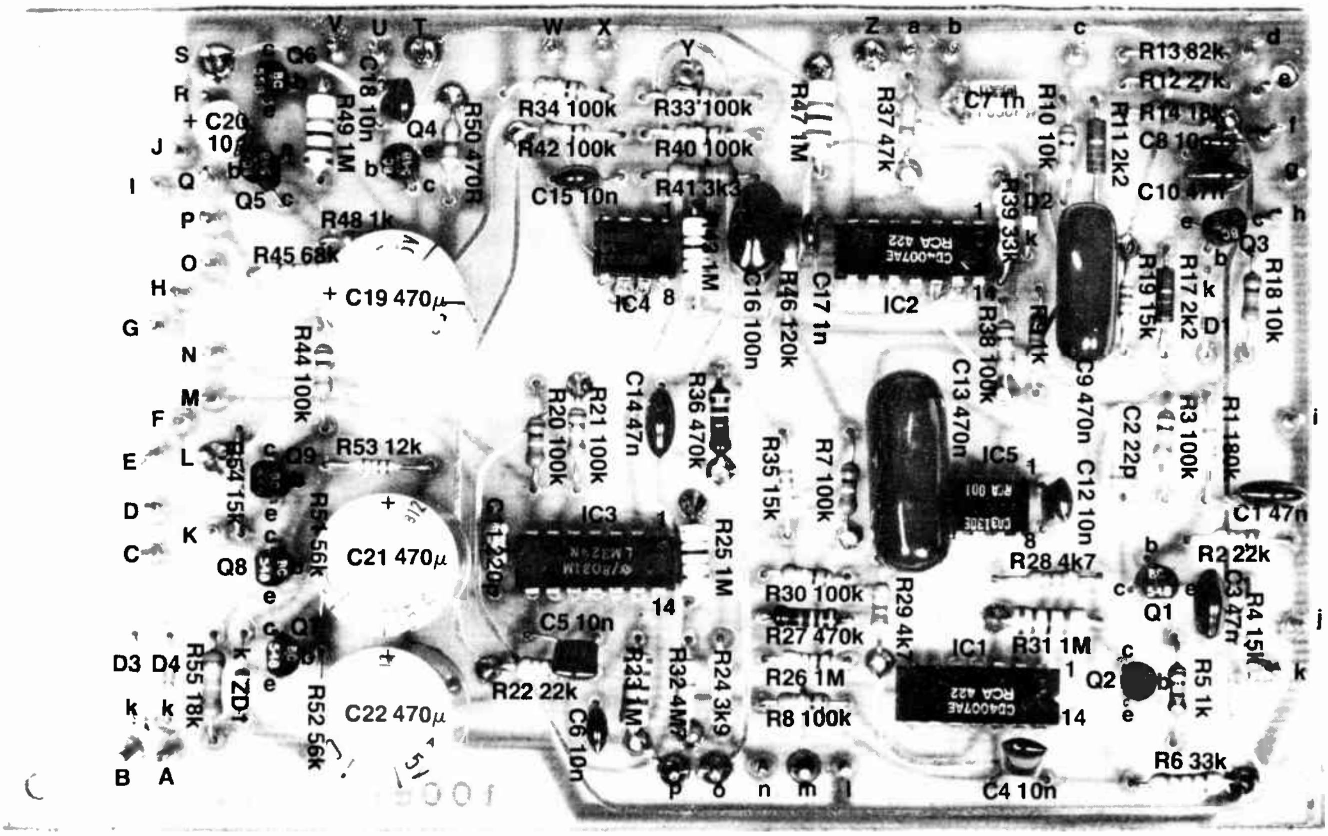
However, this method of operation will not indicate the difference between the characteristics of different targets.

In the discriminate or TR mode, the ground balance control is not used. The instrument is initially set up using the *tune* control to bring the meter to centre-zero. The different TR ranges permit varying degrees of control with the *discriminate* potentiometer. The phase-lag circuit block generates a signal which lags the phase of the transmit signal and the discriminate control provides a phase-variable signal to drive gate 1.

When a ferrous target is approached, the combined permeability and eddy current effects tend to reduce the amplitude of the signal picked up by the receive coil. This will cause a reduction in the dc level of the signal out of gate 1 and a reduction in the dc level out of the integrator. Thus, the meter will move to the negative (left hand) side of the scale. This side of the scale is marked "bad", obviously.

When a non-ferrous target is approached, the combined eddy current

NOTE: C20 +VE connects to emitters of Q5 and Q6.



and permeability effect tends to increase the amplitude of the signal picked up by the receive coil. This will cause an increase in the dc level of the signal out of gate 1 and an increase in the dc level out of the integrator. The meter will thus move toward the positive (right hand — "good") end of the scale.

The effects we are considering are actually quite small, hence the circuit has a considerable amount of dc gain.

Gate 2 only operates when the output from the dc amp increases (goes positive) and thus the audio output is only heard in the discriminate mode when the meter shows "good".

It is unfortunate that ring-pull tabs from drink cans are aluminium and thus indicate along with other non-ferrous metals. But, the discrimination ability of the instrument can be adjusted to exclude the small effect these targets generate — along with small trinkets, the smaller gold nuggets, etc — but who wants the tiddlers anyway!

If the dc level applied to the input of gate 1 drifts — and it may do for a wide variety of reasons, operating the *tune memory* button will restore the balance of the circuit and re-centre the meter. Quite a cunning arrangement.

Search head

The most important properties of the search head are its size, the relationship between the transmit and receive coils, and the shielding against capacitive effects between the coils and the ground. Surprisingly, the actual inductance of the coils is not of primary importance.

The greater the coil diameter the greater the penetration depth but the less sensitive the detector will be to small objects. Penetration using simple, circular coils is about equal to the search coil diameter for small objects such as coins, while sensitivity is roughly proportional to the cube of the object diameter (expressed as a function of the search coil diameter). Sensitivity is also inversly proportional to the sixth power of the distance between the coil and the object.

All this means that if the object size is halved the sensitivity is reduced to one-eighth. If the depth is doubled the sensitivity is reduced to one sixty-fourth. See why metal detectors designed to pick up small objects use small coils and really only skim the surface? If the search coil is doubled in diameter for greater penetration the sensitivity to small objects falls to one eighth, apart from the coil assembly becoming mechanically less rigid. The law of diminishing returns again or 'you don't get something for nothing'.

Our new detector improves penetration while retaining sensitivity by using a co-planar arrangement of coils in the search head which gives a slightly magnified field pattern downwards, into the ground.

We mentioned earlier that the two coils are only loosely coupled. The positioning of the receiver coil in relation to the transmitter coil is very critical and is the major factor affecting the performance of the instrument. In fact, misplacement by a millimetre or so will markedly affect the performance.

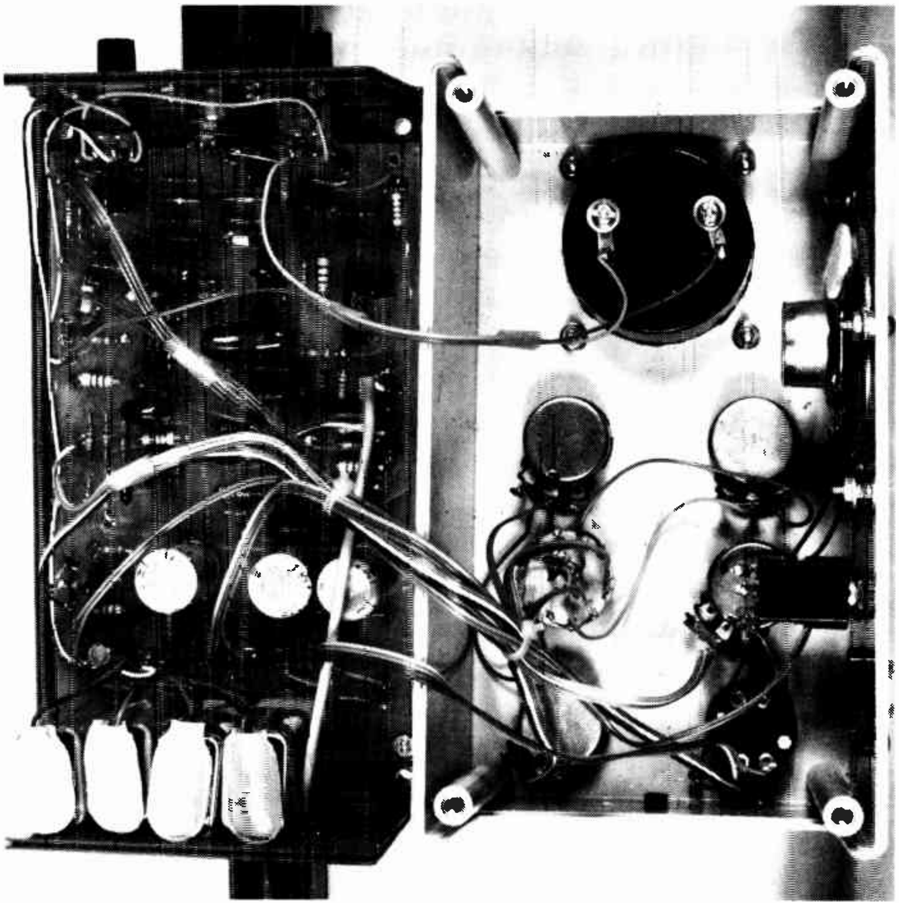
As the search head is moved around, the changing capacitance between the coils and the ground could completely mask the minute changes in the field we are looking for. To avoid this affect the coils are enclosed in a Faraday shield.

By now it should be obvious that construction of the search head is not a task to be tackled on the kitchen table on a rainy Sunday afternoon. In fact, construction and alignment of the search head would be beyond most readers' resources (anyone who has attempted our earlier induction balance metal detector knows what it's like). With this in mind we chose to use the commercially built, pre-aligned ▶

search head made by Altek Instruments. This will be available in Australia through All Electronic Components in Melbourne who have agreed to make the unit available wholesale to other suppliers, as well as retailing parts themselves, along with hardware — the plastic extendable handle and the case for housing the electronics.

Construction

The mechanical components for this project — the search head, handle and case, are available through Altek's Australian agent, All Electronic Components, as mentioned earlier. We recommend you obtain these as your finished instrument will then be a professional looking piece of equipment, with the features and operation of a 'bought one' two to three times the price. However, you can suit yourself and make your own handle if you so desire and we have designed the pc board such that it will also fit in a large jiffy box. You will have to use the search head recommended though, for the reasons we have explained previously.



Inside the completed unit. Most of the wiring to the controls and other components external to the pc board as done using ribbon cable. The colour coding of this cable assists greatly in avoiding confusion. We suggest you place the two units as shown in this photograph to accomplish the wiring. Note how the speaker is mounted. The batteries are held in place by a strip of double-sided sticky tape.

A view of the front panel of the project. The Scotchcal front panel and meter escutcheon will be available from the usual suppliers.

All the electronics mounts on a single, double-sided pc board. The Altek case has two clamps on the rear enabling it to be clipped on to the handle. The Altek handle has two sections, the lower section sliding inside the upper section enabling the operator to adjust the length of the handle to suit his height. Connection between the search head and the electronics is via a length of shielded cable (supplied with the head) and a five-pin DIN plug/socket arrangement. The *tune memory* pushbutton is mounted in the end of the 'crook' of the handle (see photographs) where it can be easily operated by the thumb. It connects to the electronics via a length of shielded cable passed through the handle.

Construction should commence with the pc board. As it is a double-sided board (i.e: copper tracks on each side), first identify the 'front' and 'rear' side. These are marked, respectively, ETI 1500f and ETI 1500r. The rear side has the more complicated pattern of tracks. The components are mounted on the *front* of the board, where there is the less complicated set of tracks. Note that some of the resistors, IC pins and pc board pins (used for connecting external wiring to the board) must be soldered to copper tracks on *each* side of the board.

Commence with the resistors. Take care with those that cross tracks that you don't create a short circuit where it's not wanted. Next mount the capacitors. Take care with the orientation of the electrolytics. Note that capacitors C2, C7 and C11 are styroseal types, used for their good temperature stability. Be careful when soldering them in place that you don't overheat the leads as this can cause melting of the capacitor's case, possibly damaging it. The sample and hold capacitor, C13, must be a low leakage type, preferably polycarbonate or mylar. We used a greencap successfully, but whatever you manage to obtain, make sure it's a good quality type from a well-known supplier.

Now mount the semiconductors. Take care with the orientation of these as you can destroy devices if they are incorrectly inserted when power is applied. Finally, solder the pc pins in place and the four battery clips. The latter all go along one edge of the board.

Overall assembly of the pc board is clear from the overlay picture on page 17.

Once you have everything in place on the pc board and you're satisfied that all is OK, you can turn your attention to the hardware. Start with the case that houses the electronics. If not pre-drilled, you'll need to mark out and drill all the holes in the case lid. The panel artwork can be used as a template. Note that we dressed up the case with a Scotchcal panel. These should be available through the usual suppliers. Centre punch holes before drilling. The cutout for the meter can be made with a hole saw or by drilling a series of 4 mm diameter holes just inside the marked edge of the hole. When you complete the circle, the centre piece can be snapped out and the edge of the hole cleaned up with a half-round file until the meter drops in neatly.

The speaker is mounted on the left hand side of the case lid (as you would normally view the unit in use). It is held in place by large washers placed under the nuts of three bolts spaced around the outer rim of the speaker. Alternatively, you can glue it in place. Be careful not to get any glue on the speaker cone or you might end up with a rather 'strangled' sound!

The pc board mounts in the bottom piece of the case, along with the DIN socket (for the search head connector) and two battery test push buttons. A small hole in the bottom passes the cable to the tune memory button. The case bottom has four integral moulded standoffs to provide support for the pc board which is held in place with screws.

Once all the mechanical work on the case is satisfactory, the Scotchcal panel may be stuck on. Take care when positioning it as it's almost impossible to move if you misalign it. Carefully smooth out all the bubbles toward the edge of the transfer.

The controls, meter etc. may be mounted next. Then you can wire all the external components to the pc board pins. We used lengths of ribbon cable where possible to simplify the wiring. The easiest way to accomplish this part of the assembly is to place the bottom of the box, with the pc board mounted in it, on your left and the lid, with the meter and controls etc. mounted, face down on your right. Follow the wiring diagram on page 16 and complete all the interconnections. You should now appreciate pc board pins!

The tune memory button mounts in a hole in the end of the 'crook' of the handle, as we explained earlier, and the shielded cable connecting to it passes through the handle, emerging through a small hole drilled in the handle near where the cable can enter the hole provided for it in the bottom of the box. This cable is best inserted before you mount the pushbutton. Remove the handgrip. Push the cable through the hole in the handle near the case, until it appears through the end of the handle. Solder the end of the lead to the pushbutton and mount the pushbutton in the hole in the end of the hand grip (easier said than done!). Put the handgrip back and you can pass the business end of the cable into the case and terminate it. If you're lucky, kit suppliers may sell the units with this part already assembled.

Holding the batteries in place is generally left to your ingenuity. We used double-sided sticky tape (ah, that's useful stuff . . .). The battery life is quite good as the circuit has been designed for low current drain. Reverse polarity protection is provided on the pc board to avoid problems should you inadvertently attempt to connect a battery back to front.

When all wiring is complete, push the case onto the handle and drill a small hole through one of the clamps and the stem of the handle. Insert a nail or a bolt and this will prevent the case from rotating on the handle. Mount the search head and adjust the length of the stem to suit yourself. Wrap the cable from the search head around the stem so that it is held quite rigidly and plug it into the DIN socket on the case.

You're ready to roll! . . . once you've tested it.

If you wish to make the search head completely waterproof, seal the hole through which the cable passes with Silastic rubber or some similar caulking compound.

Operation

When construction is complete and you're satisfied all is well, turn the detector on and advance the *volume* control. Set all other controls to mid-

A view of the forward end of the case showing the two battery test pushbuttons and the DIN plug and socket connection to the search head. The Altek cabinet is two-tone grey plastic. The upper section is a lighter hue. Note the "GT" stripes!

range and switch the *mode selector* to *VLF*. Hold the search head up in the air and well away from metal objects, press the *tune memory* button and rotate the *tune* control. The meter should swing either side of the centre position. Set the pointer to centre scale and release the tune button. The meter should remain at this position but may drift slightly, which it will tend to do immediately after switch on. Pressing the *tune memory* button at any time should return the meter to centre position, set by the *tune* control.

The next step is to determine that the polarity of the receive coil is correct. After tuning the detector as described, bring a piece of iron near the search head. If the meter swings to the right your circuit is correct, if it swings to the left you will have to reverse the two wires on the DIN socket that connect to the receiver section on the pc board. The meter should now swing to the right.

Ground balance

With the detector tuned, lower the search head to the ground. The meter may swing off scale. If it swings to the right turn the *ground* control to the left, if it swings to the left turn the *ground* control to the right. Raise the search head from the ground, press the tune button and the meter will return to centre scale. Lower the search head again and repeat the procedure until there is little difference in the meter reading when the search head is lowered. Setting the ground control is quite critical and may take some time to achieve the first time around. The detector can now be used in the VLF mode.

Sensitivity control

The *sensitivity* control sets the gain of the dc amplifiers in the detector and will generally give best results at mid-range. If the control is set fully clockwise the tuning will tend to drift, requiring more frequent operation of the *tune memory* button.

Discriminate controls

The mode switch selects one of three discriminate ranges: TR1, TR2 or TR3, while a vernier action is provided by the *discriminate* control. The discrimination ability of this circuit is extremely effective and it is possible to discriminate between an aluminium ring pull tab and a gold ring. Remember that discrimination depends on the resistivity of the target object.

When set to TR1, *discriminate* control at mid-range, the meter should show 'bad' for ferrous objects and 'good' for non-ferrous objects along with a tone from the speaker. As the discrimination controls are advanced, some non-ferrous objects such as brass will start to give a 'bad' reading, while gold and silver will give a 'good' reading. As the controls are advanced further aluminium will start to give a 'bad' reading, and so on. As you use the detector you will become familiar with its operation.

The best way of setting the discrimination controls is to carry around a few sample objects of the type you want to discriminate against just for this purpose. One thing to remember is that a corroded object will require a different setting of the controls to a non-corroded one so carry samples typical of what you are likely to dig up.

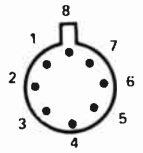
By careful setting of the controls, unwanted objects can be tuned out, giving no meter movement at all so the detector can be used to reject particular objects and at the same time discriminate between others.

Well, it's now up to you. Remember, the secret of success in metal detecting is more knowing where to look than the type of detector you have. There are many books available on the subject which could help put you on the right track.

Notes for constructors

(courtesy of G.N. Vayro, Broadmeadows, Victoria).

- Take special care with the orientation of IC5 (CA3130) if an 8-pin TO-5 (circular metal case) type is supplied. Refer to the pinout diagram below.



CA3130T TOP VIEW

- Take care with the wiring of the headphone socket as not all types have the same, or similar, connections. Check this by examination or with a multimeter before wiring.

- Take care when wiring the DIN socket that connects the search head. The search head wiring is colour-coded, as shown on the circuit diagram. The red and black wires come from the receive coil. This coil has a dc resistance of around 50 ohms. The transmit coil is connected via the cable shield and the white wire. It has a dc resistance of around 12 ohms. There may be a yellow wire in the cable. Ignore it as it is not connected. The Faraday coil shields are internally connected to the cable shield.

- The wiring to the two pushbuttons PB2 and PB3 should first be sorted out with an ohmmeter before soldering it in place.

- The pushbutton in the handle needs to have good 'feel' and positive contact. One of the small C & K or Swann types should fill the bill.

- If you have or are using a metal front panel, it should be earthed to reduce spurious capacitive effects. The body of the discriminate control should connect to 0 V (Pin 1) and a star washer should be inserted under its nut to provide a good contact to the panel. Otherwise, a plastic Scotchcal panel is recommended (one was used on the prototype).

- It is strongly recommended that a flux-removing solvent be used to clean the pc board following assembly. Whilst flux does not cause problems when 'new', many atmospherically bourne chemicals can and do react with the flux in time. This causes a leakage path to be established between the tracks and is especially troublesome in high impedance circuits, such as around IC5. A de-fluxed pc board will obviate later (or early) problems with the auto-tune circuit; it also looks more professional and aids identification of defective solder joints. The effort is worth it.

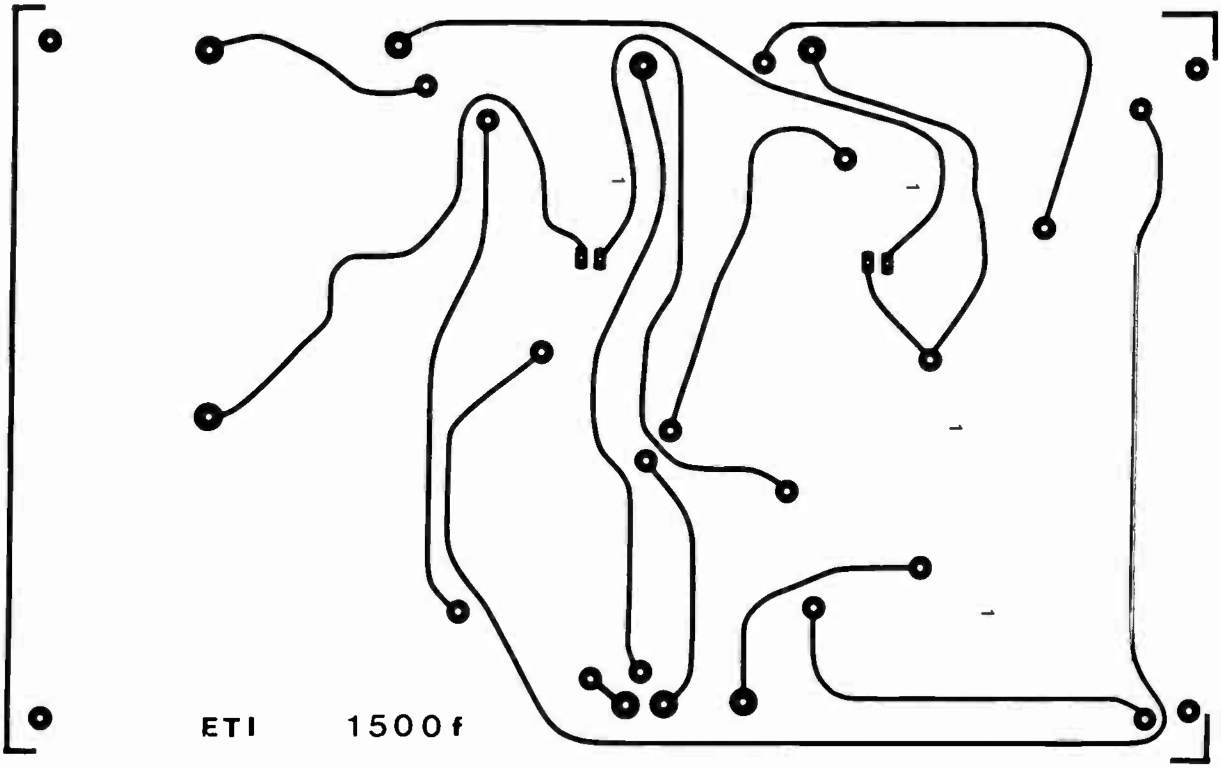
- If you have trouble with hand capacitance effects, plastic knobs or collet knobs may be used to advantage on the controls, particularly the variable discriminate control.

- The wiring to the pushbutton in the handle should be done with shielded cable, passed through a hole drilled in the rear of the case to avoid fouling the telescopic shaft in the retracted position.

- A battery clamp, fashioned from a small strip of aluminium, is recommended.

- The case should be mounted as close to the curve in the handle as possible for optimum weight distribution.

- A screw or bolt should be placed through the *rear* case mounting clip to stop the case rotating on the shaft. The rear clip is recommended to allow the shaft to be telescoped to minimum length. ●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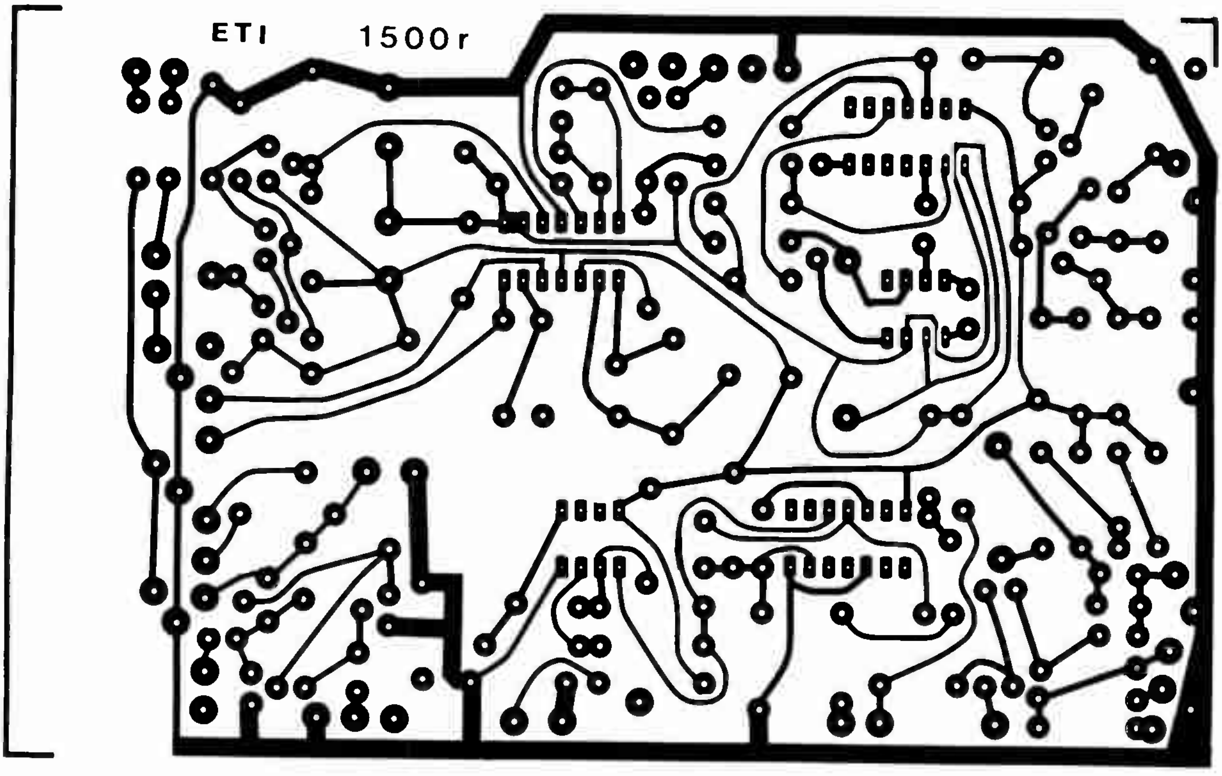
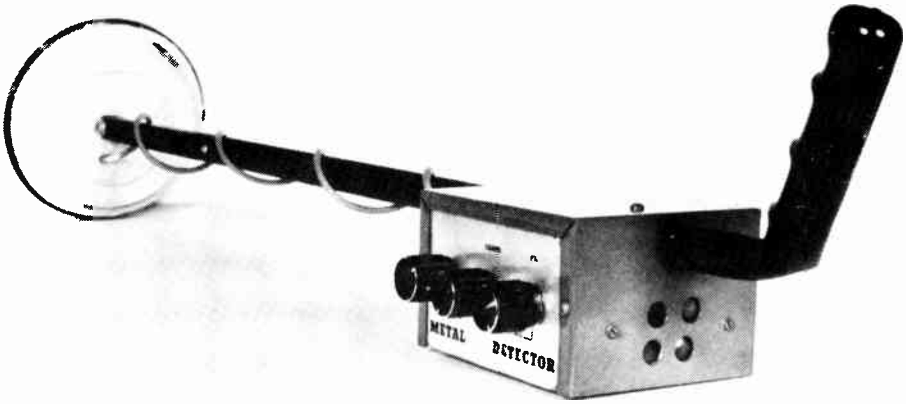

ETI 1500r

Project 561

Simple, sensitive metal detector

Phil Wait

The metal detecting hobby is enjoying quite a boom at the moment and treasure hunters are not just after gold. Though the price of the precious metal has fallen in recent months, at around $600 an ounce it's worth going after. Old coins and relics fetch high prices too, so there's lots to find out there . . .



METAL DETECTORS depend on detecting one of several effects that can be observed when a metal object influences the magnetic field surrounding a coil of wire carrying an alternating current. The principal effects are: the pattern of the magnetic field surrounding the coil will be altered and the inductance of the coil will change.

The various types of metal detector devised exploit these changes, electronically detecting the alteration induced in the coil by the metallic object. Non-metallic objects or material can also affect the coil in similar ways.

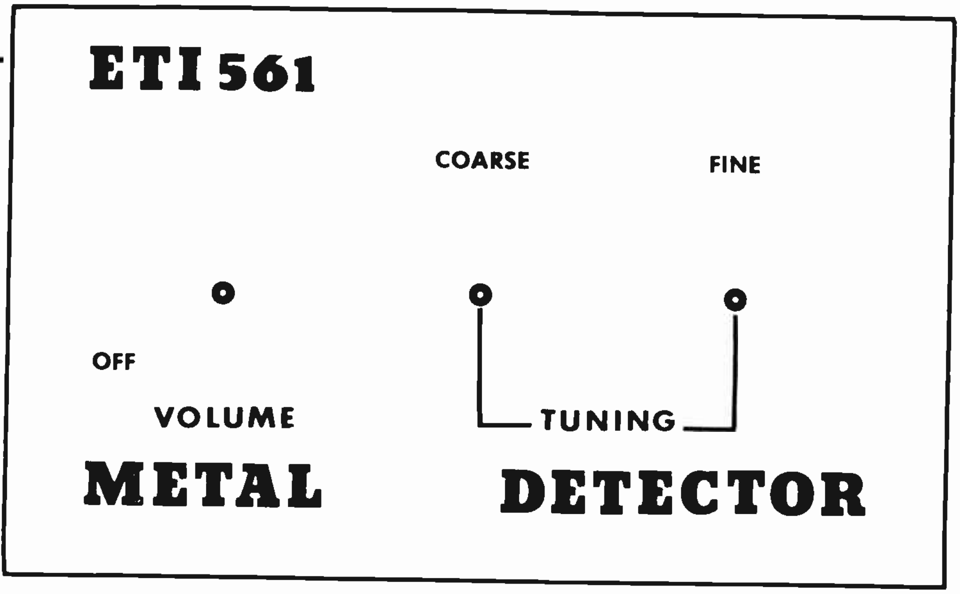
There are three basic methods employed to exploit the above effects. "Induction Balance" (IB) metal detectors employ two coils. One is driven by a modulated oscillator. The other is connected to a detector and amplifier. The two coils are carefully positioned with respect to one another such that the receiver coil picks up very little of the energy radiated by the transmitter coil when no metal or mineral material is nearby. When the coils are brought near a metal object, the field pattern is distorted, greatly increasing the transmitted energy picked up by the receiver coil. The modulated signal is detected and can be indicated by amplifying the recovered modulation to speaker level as well as indicating it on a meter. For obvious reasons, this type of metal detector is often referred to as a "transmit-receive" or TR detector, sometimes as an IB/TR detector. Chief advantages are good pinpointing ability and good depth penetration, and they are not sensitive to small ferrous objects. Sensitivity suffers badly in mineralised or ironstone ground. We described an IB/TR metal detector back in our May 1977 issue (Project 549) and it is still a popular project. The problem for the home constructor lies in correct construction and alignment of the coils.

Most IB detectors operate at a frequency between 85 kHz and 150 kHz. As they are badly affected by mineralised ground a technique was developed using very low frequency to energise the transmit coil. The 'VLF' types operate at frequencies around 4 – 6 kHz, a frequency range which penetrates all types of soil quite well. However, they need to run at a fairly high power to achieve sufficient sensitivity with small objects, hence battery drain is quite high, and pinpointing ability is poor.

"Pulse Induction" detectors employ coils in the search head that are set up in much the same manner as the IB detector. However, the transmitter is pulsed so that high energy bursts are transmitted by the search coil. The receiver then compares the phase of portion of the received pulse with the transmit signal. When a ferrous or magnetic object is brought near the search coils the phase of the received signal is *advanced* with respect to the transmit signal. The *opposite* occurs when a non-magnetic conductor is brought near the search coils. Thus, this type of detector can effectively 'discriminate' between ferrous and non-ferrous metals as well as exclude ground effects – simply by setting the detection circuitry to exclude signals of the unwanted phase characteristics. Thus, a "Ground Exclusion" control is often featured with these detectors. As the strength of the received signal also varies, depending on the 'target' object's characteristics, this effect may also be included in the detection process.

FEATURES

- Good sensitivity
- Excellent stability
- Good pinpointing ability
- Loudspeaker output
- Simple construction and set up
- Tuning allows for ground
- Low cost



Full size print of the front panel.

Clearly, an IP detector presents many problems to the home constructor.

The simplest technique detects the change in inductance of a single search coil. If this coil is part of the tuned circuit of an oscillator, then comparing the frequency of the 'search' oscillator with a stable reference oscillator will indicate the presence of a metal object. This detector is called the "Beat Frequency Oscillator" or BFO type. The two oscillators are set such that there is a slight difference in their frequencies and their outputs mixed. The resultant will be a 'beat' frequency which is equal to the difference between the two oscillator frequencies. The main advantages of this type are simple circuitry and setting up along with good pinpointing ability. In the past, most published designs have suffered from a distinct lack of sensitivity as well as poor tuning stability. A cunning mixing technique and a few other fillips can overcome these problems.

Hence, our new metal detector is a BFO type incorporating some modern refinements. It has proved to have similar sensitivity to our IB detector, the ETI-549, but is generally easier to build and set up, there being no critical adjustments.

Design features

Our new metal detector has three controls: COARSE frequency adjust, FINE frequency adjust and VOLUME on/off. The coarse frequency control is used to initially set the frequency of the search oscillator, compensating for the various factors affecting any drift in this oscillator (mainly temperature and battery voltage). The fine frequency control is then used to set the note to a low pitch when the detector is placed over the ground, permitting compensation for the effect of the ground on the frequency of the search oscillator. The volume control adjusts the loudness of the output from the speaker.

The two main design problems this type of detector presents are the frequency stability of the two oscillators and the minute frequency change which has to be detected.

The search oscillator we finally used was settled on after some experimentation. Our first try employed an LC oscillator built around a CMOS gate chip. This proved to be not as stable as we required and we found that trying to obtain dc control of the frequency by varying the supply rail voltage had drawbacks. After some experimentation with oscillator configurations we hit on a discrete component oscillator which we found behaved much as we were seeking.

The search coil in the circuit we used is the inductor in a Colpitts oscillator. However, this particular circuit may be a little unfamiliar to many readers. To increase the RF current in the coil, it is placed in the collector circuit of Q1. Feedback is between collector and emitter and the base is effectively at RF ground. The frequency determining capacitance of the tuned circuit is 'tapped' to provide feedback, C2 and C3 performing this function. Careful attention has been paid to the basic frequency stability of this oscillator. Good quality styroseal capacitors have been used for C2 and C3. These have a temperature coefficient roughly opposite to that of other temperature influences on the frequency of the oscillator. In general, the short-term stability of this oscillator is quite good.

The particular circuit configuration of the oscillator gave us a very useful bonus – dc control of the oscillator frequency over a small range. Varying the base bias on a transistor will vary the collector-base capacitance. In this circuit, the c-b capacitance is part of the overall 'stray' capacitance that determines the exact frequency of oscillation. As the base bias is increased the c-b capacitance decreases, increasing the oscillator frequency. In this way, the oscillator frequency can be varied over a range of about ten percent. We have provided two controls, the FINE control providing a variation of about one-tenth that of the COARSE control.

The search oscillator is loosely coupled via a 47p capacitor to a following CMOS Schmitt trigger and two inverters which square the output. The loose coupling isolates the oscillator from the subsequent circuitry, further enchancing the stability of the search oscillator.

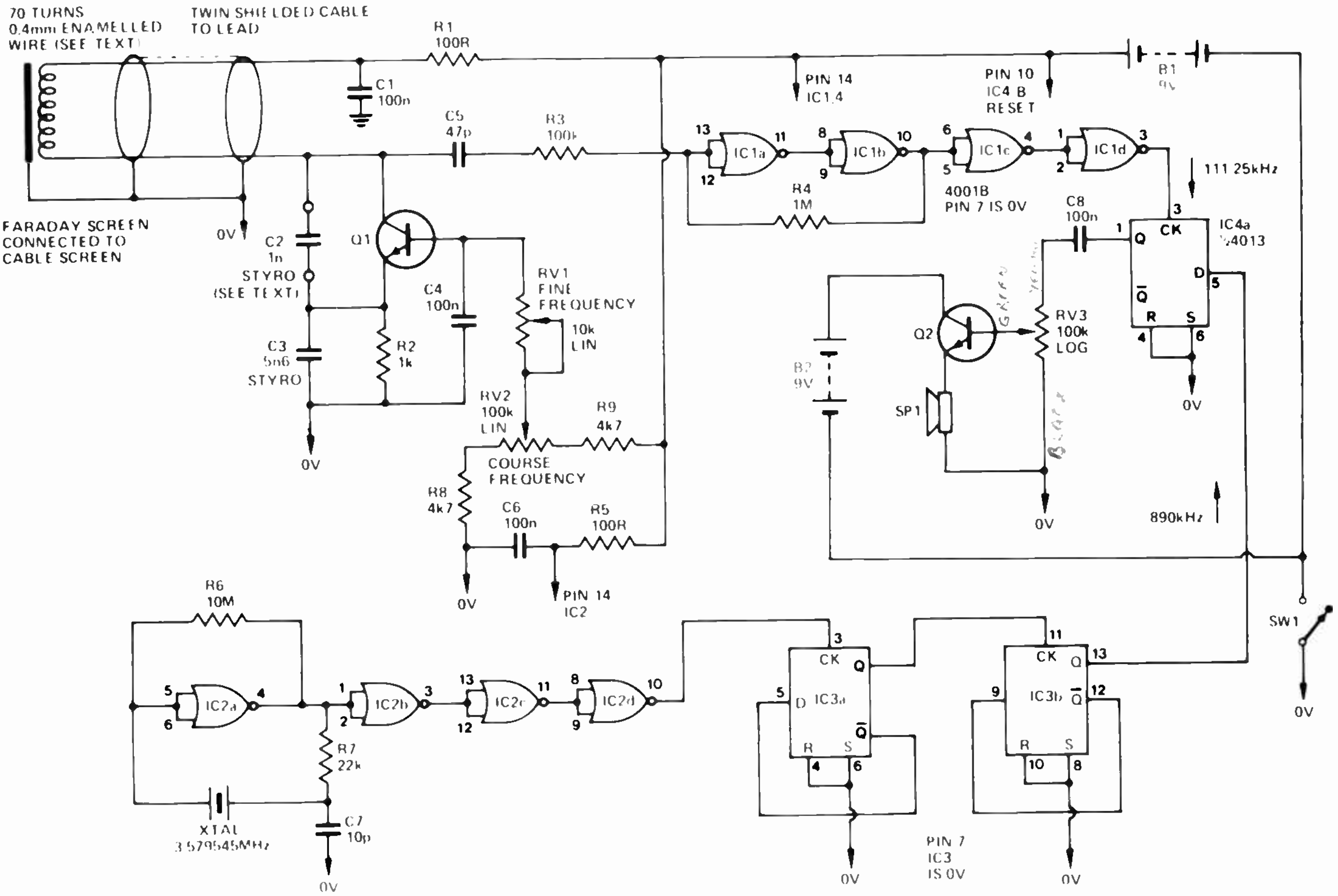
For the reference oscillator, we chose to use a crystal, because of its inherent stability. It has been argued that if an ordinary LC circuit is used for the reference oscillator it will have similar drift characteristics as the search oscillator and the overall drift will be reduced. In fact, the reference oscillator can be made using a standard 455 kHz IF transformer. In practice however, the two tend to drift at markedly different rates. We think the best approach is to make both oscillators as stable as possible. Hence the crystal – which is an easily available type and cheaper than an IF transformer!

The reference oscillator is a simple 'inverter' crystal oscillator built around one gate from a CMOS quad NAND gate, IC2. This has a square wave output and drives a divide-by-four circuit, IC3, via the other three gates in IC2, acting as buffers.

The crystal we used is a 3.579545 MHz type (NTSC chrominance subcarrier frequency) commonly available from a number of suppliers. We used one in our Electronic Tuning Fork (ETI-606) published November 1979. The output of IC3 is at a frequency of about 890 kHz. The *exact* frequency is unimportant, just so long as it's *stable*.

The search oscillator operates at a little above 100 kHz, about one-eighth of this frequency.

The secret of our metal detector's overall sensitivity lies in the mixer circuit. This employs one section of a 4013 flip-flop. The reference oscillator's divider output (at 890 kHz) is applied to the D input of IC4a and the squared-up search oscillator's output is applied to the clock input. If the clock frequency (i.e: the search oscillator frequency) changes by 1 Hz, the output beat (from the Q output of IC4a) will change by 8 Hz (see 'How it Works'), thus considerably *multiplying* the smallest changes in oscillator frequency. ▶



HOW IT WORKS · ETI 561 Metal Detector

The beat frequency metal detector employs two oscillators: a very stable reference oscillator and a search oscillator. The search oscillator uses a tuned circuit designed to be influenced by metal or mineral objects which are brought into its field. The two oscillators are adjusted so they are harmonically related and fed to a mixer. When the search frequency is adjusted so the reference frequency fed to the mixer is eight times the search frequency, the output of the mixer is zero. The search frequency is slightly adjusted so that an output appears from the mixer which is the difference between the two input frequencies. This can be adjusted to an audio tone.

When a piece of metal or mineral is brought near the search coil the frequency of the oscillator varies, which in turn varies the output frequency from the mixer. The change in pitch can easily be heard from the speaker.

The reference oscillator employs a crystal in a CMOS oscillator circuit using one gate from IC2a. The resistor R6 biases the gate into its linear region. IC2 b, c and d, are used as buffer stages to prevent oscillator "pulling" and to further square its output waveform. Two flip-flops, IC3a and b, divide the reference signal by four to 890 kHz.

The search oscillator uses a discrete transistor in grounded base configuration, with the search coil in the collector. Using the coil in the collector increases the strength of the field around the coil and hopefully overcomes some of the losses in the ground. Feedback is set by the ratio of C2 to C3 from collector to emitter and their value determines the frequency of the oscillator. The base is grounded at RF by C4.

By varying the bias on the transistor the inter-element capacitances can be varied. This varies the oscillator frequency as the transistor capacitances form part of the 'strays' in the LC circuit. RV1 and RV2 provide fine and coarse frequency control. The resistors R8 and R9 limit the maximum and minimum voltage on the base to prevent over-dissipation in the transistor or drop-out of the oscillator.

The output of the search oscillator is fed to a Schmitt trigger, consisting of ICla and b, where it is squared and further buffered by IClc and d. The search frequency is then fed to the mixer.

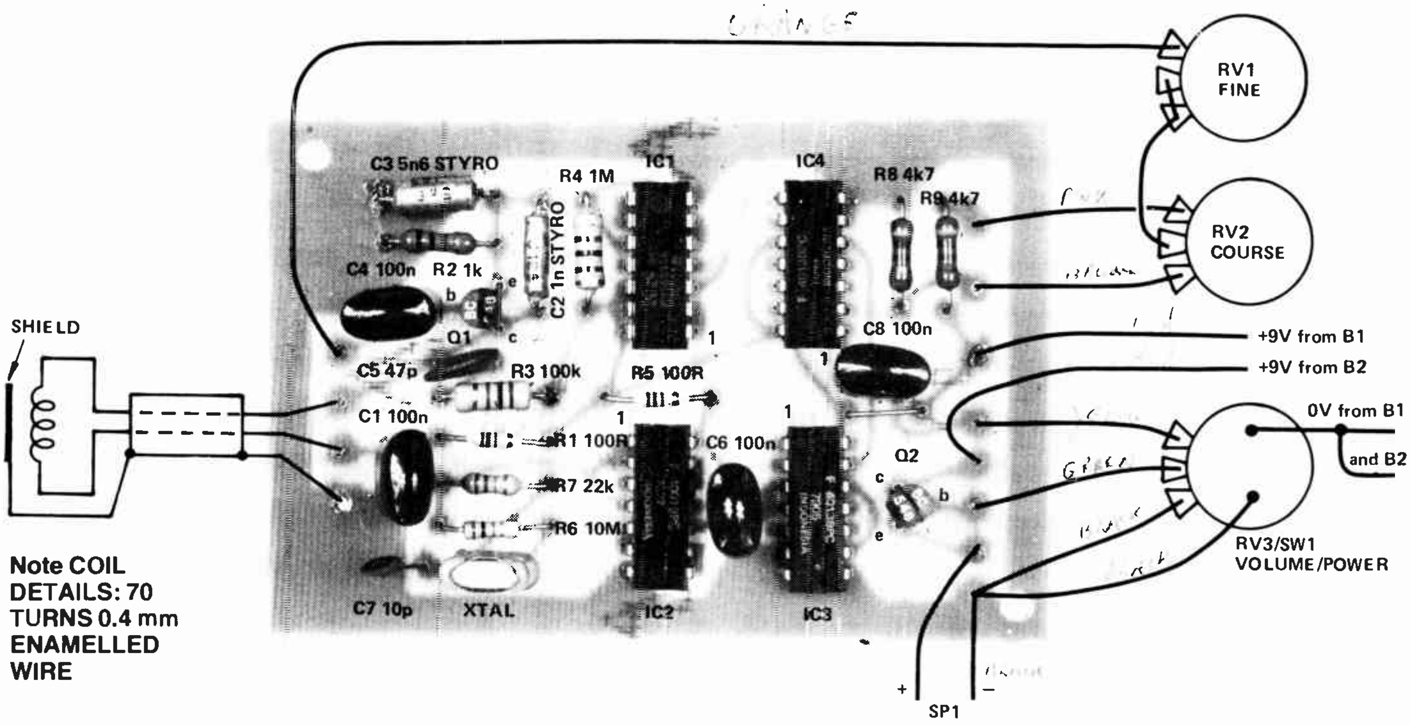
Both oscillators are decoupled from each other by supply line decoupling R1–C1 and R5–C6.

The mixer consists of half a dual-D flip-flop. The search and reference frequencies are fed to the clock and D inputs respectively. The flip-flop looks at the reference oscillator (D) on every positive transition of the search oscillator (clock), and transfers this level to the Q output until the next clock transition. If the two oscillators are exactly evenly harmonically related (i.e: 2nd, 4th, 6th, or in our case 8th, harmonic) the D input will always be the same level at each clock pulse. The output from the mixer at the Q pin will always be the same — no pulses.

However, if the search frequency is varied and the D and clock inputs are no longer harmonically related but are changing in phase with respect to each other, after a few clock pulses the D input will no longer be the same — the output will change state. The effect of all this is to produce a chain of square waves at the Q output, the frequency of which is eight times the change in frequency of the search oscillator.

Capacitors C8 and RV2 form a differentiating network which feeds a pulse to the audio amplifier, Q2, for each output transition from the mixer. Each cycle from the mixer produces two pulses in the speaker. If the frequency of the search oscillator is shifted one hertz the output of the mixer changes by eight hertz, producing an output of eight pulses per second in the speaker.

1N = 1000 PF or ·001 MFD | 5N6 = 5,600 PF or ·0056 MFD | 100 N = 100,000 PF or ·1 MFD



Note COIL DETAILS: 70 TURNS 0.4 mm ENAMELLED WIRE

The output of the mixer is fed to a simple audio amplifier driving a loudspeaker. The search and reference oscillators must be well decoupled from each other and buffered from the mixer stage to prevent 'pulling' of the oscillators, which would result in erratic operation, especially when set for a low frequency output. We have used supply line decoupling as well as buffer stages after each oscillator. We also found it necessary to use a separate battery for the audio stage to prevent the very short, but high current pulses to the audio stage affecting the oscillators.

The search coil

The most important characteristic of the search coil is its size. Surprisingly enough the actual inductance doesn't seem to have much effect on sensitivity. The greater the coil diameter the greater the penetration depth, but the less sensitive it is to small objects. As a general rule the penetration is about equal to the search coil diameter, while the sensitivity is roughly proportional to the cube of the object diameter (as expressed as a function of the search coil diameter). Sensitivity is also inversely proportional to the sixth power of the distance between the coil and the object.

All this means is that if the object size is halved the sensitivity is reduced to one-eighth. Also, if the depth is doubled the sensitivity is reduced to one sixty-fourth. It's easy to see why all metal detectors which are designed to pick up small objects use small coils, (150 to 300 mm diameter) and really only skim the soil surface. If the search coil is doubled in diameter for greater penetration the sensitivity to small objects falls to one-eighth. You rapidly encounter the law of diminishing returns.

Some of the more expensive metal detectors improve the penetration, while retaining sensitivity, by using a very complex arrangement of coils which modifies the field pattern. This can be done to some extent by making the coil on the BFO detector oval in shape.

We chose a round coil of 150 mm diameter to give good sensitivity to small objects giving about 100—150 mm penetration which is easy to build, but this is open to considerable experimentation. Remember though, that if the coil diameter is increased the number of turns will have to be reduced so that the search oscillator remains at the same frequency (about 110 kHz).

Faraday shield

If the search coil is moved around, the capacitance between it and the ground ▶

PARTS LIST - ETI 561

Resistors	all ½W 5%
R1	100R
R2	1k
R3	100k
R4	1M
R5	100R
R6	10M
R7	22k
R8, R9	4k7
Potentiometers	
RV1	10k lin
RV2	100k lin
RV3	100k log switch pot
Capacitors	
C1	100n greencap
C2	1n styroseal
C3	5n6 styroseal
C4	100n greencap
C5	47p ceramic
C6	100n greencap
C7	10p ceramic
C8	100n greencap

Semiconductors	
Q1, Q2	BC548, BC108, etc.
IC1, IC2	4001B
IC3, IC4	4013
Miscellaneous	
SP1	8 ohm speaker
B1, B2	9 Volt battery (type 216)
XTAL	3.579545 MHz NTSC colour xtal
ETI-561	pc board

Length of twin shielded cable, plastic pot stand (approx 150 mm dia), length of steel or aluminium tube (approx 600 mm long, 20 mm dia), length of plastic rod or wood dowel to fit inside pipe (approx 200 mm long), 0.4 mm enamelled wire, aluminium foil, Araldite, box to suit (approx 105 x 125 x 75 mm), three knobs, battery clips, insulation tape, two right angle brackets.

SEARCH HEAD CONSTRUCTION

1: Having wound the coil as described, wrap it with two layers of insulation tape.

3: Wind tinned copper wire over the shield, passing the end out where the coil leads pass out.

2: Next wind the Faraday shield using two strips of aluminium foil, leaving a break where the coil ends come out.

4: Cover the whole coil assembly with two more layers of insulation tape.

5: Press the assembled coil into the rim of the pot stand, terminate the wires as described and epoxy the coil to the pot stand.

or other objects changes. This changing capacitance 'pulls' the oscillator frequency and can completely swamp out the small change in inductance we are looking for. The coil can be screened from this capacitance effect by using a Faraday Shield around the coil. This consists of a ring of tubing, or in our case – a wrapping of aluminium foil, around the coil but broken at one point so it does not make a shorted turn. This shield is then connected to the common supply rail (OV) on the oscillator.

Construction

We have deliberately chosen commonly available mechanical and electronic components so that construction of this project is as easy as possible – especially for the newcomer. The search coil is mounted on a 165 mm diameter plastic pot stand which may be purchased at hardware stores and nurseries (if you must know, we used a Decor *497!). The electronics is mounted inside a simple aluminium box attached to a stem made from a length of tube which extends down to the search coil and serves as the handle. Connection to the search coil is via a length of shielded cable. The controls mount on one side of the box housing the electronics. Which side you mount them depends on whether you are right or left handed. The speaker mounts on the end of the box facing the operator. As can be seen from the picture, the handle was made with an upwards bend at the end which you grip. This balances the instrument reasonably well, avoiding arm strain.

Construction should commence with the electronics. Mount the components on the pc board, taking care with the orientation of the transistor (Q1) and the ICs. Do not substitute another type of capacitor for the styroseal types specified for C2 and C3 or performance may suffer. The crystal specified comes with flying leads and may be soldered in place. Don't use too much heat though, solder quickly and you will avoid possible damage to the crystal.

The next step is to make the stem. The easiest way is to take a length of 25 mm diameter electrical conduit about 850 mm long and make a bend about 100 mm from one end for the grip. To do this, heat the point of the bend over a flame (not *in* the flame) until it softens and then carefully bend it about 60° from straight.

A length of aluminium tube may also be used for the handle. The bend for the grip can be made by first flattening the point of the bend somewhat with a hammer then placing the short piece in a vice and carefully making the bend. A section of wood dowel or plastic tube should be placed between the search coil and the end of the metal tube to keep the mass of metal about 200 – 250 mm away from the search coil. A piece of wood dowel of the right size, jammed in the end of the aluminium tube, is generally the easiest way to go about it.

We used a small aluminium box which comes in two pieces. We drilled a hole in either end of the 'bottom' of this box so that it could be slipped over the stem (see accompanying photograph). A nut and bolt was used to secure it to the stem on the side 'below' the grip. The small speaker is mounted in this part of the box, before it is secured to the stem, on the end which faces upward toward the operator. A small hole is drilled in the opposite end and a grommet inserted. This permits entry of the cable to the search coil.

The pc board and controls are mounted to the 'lid' of the box. Position the controls on the side that suits your handedness. Our model was made for right handed operators.

Now for the search coil. This is wound so that it can be tucked inside the rim of the up-turned plastic pot stand. First make a cardboard former of the appropriate diameter. Roll a strip of heavy cardboard around the rim such that it fits loosely and tape or staple it securely (to avoid it popping open at an awkward moment).

Lift the former off the pot stand and

then wind the coil onto this former as per the details given in the parts list. Leave a short length of wire spare on each end to make the connection. Tie the coil up with a few lengths of string at various places and then slide it off the former. Now wind two layers of insulation tape around the coil, leading the two ends out at the same place.

Next, wind the Faraday screen. Cut some aluminium kitchen foil into strips about 15 mm wide and wind this around the coil to make two layers but leaving a small gap about 5 mm to 10 mm wide where the coil ends come out. It is very important that the two ends of the Faraday shield do not connect as this would make a 'shorted turn' and the coil would not work as intended.

To secure the foil tightly around the coil, and to make connection to the shield, wind a length of tinned copper wire around the shield with about a 10 mm pitch (i.e: about 10 mm between successive turns). The end of this wire is taken out at the same place as the coil connections.

Now wind another two layers of insulation tape around the whole assembly. Drill a 3 mm hole in the side of the pot stand and then press the coil down into the rim with the connecting wires adjacent to the hole. Pass the wires through the hole. Pour quick-setting epoxy over the coil to hold it in place.

The search head is mounted to the stem using two right-angle brackets and a bolt passed right through the end of the stem. Small pieces of metal here don't seem to adversely affect the operation of the detector.

Solder the coil connections to the twin shielded cable, the Faraday shield connecting to the cable's shield, and glue the cable and wires underneath the pot stand to hold them rigid. If you wish, the 'underside' of the pot stand may be completely filled with epoxy.

Wind the cable around the stem to keep it mechanically rigid and pass it through a grommeted hole in the box. Terminate the cable to the pc board.

Using it

When the construction is complete, turn on the detector, advance the volume control and rotate the coarse frequency knob. You will hear a number of 'heterodynes' or beats, one being very strong. This heterodyne is the one commonly used, the others being odd multiples of the reference signal beating with multiples of the search oscillator. You may find that some of these weaker signals are more sensitive to buried objects than the stronger one.

Set the fine frequency control to mid-range and set the course frequency control to near the strong heterodyne with the search head held away from the ground. Lower the detector to the ground and you will notice a frequency shift. This is the effect of the ground and will vary between different types of soil. Use the fine frequency control to set the beat to a low pitch and sweep across the surface. A metal object will cause a change in the pitch which is clearly audible.

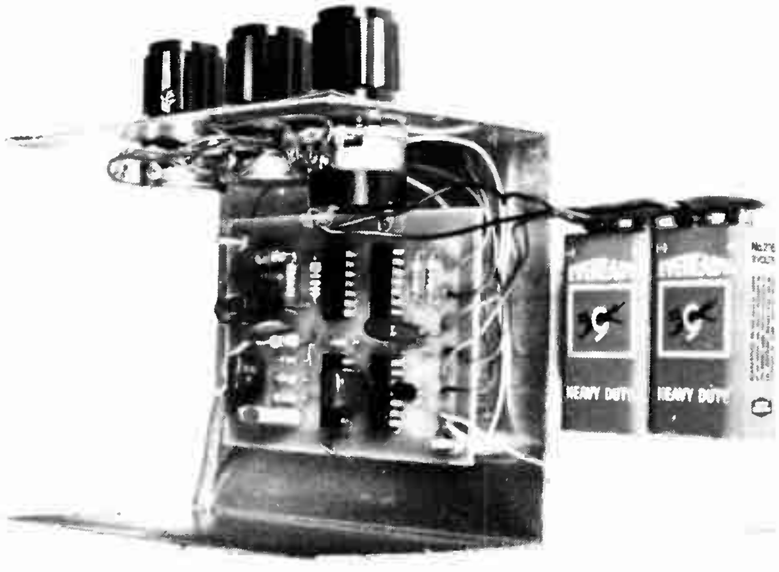
The ear is more sensitive to changes in pitch at low frequencies than at high frequencies and thus it is best to adjust the fine frequency control to a low pitch that can be heard at a comfortable volume from the loudspeaker.

Theoretically, the frequency of the search oscillator should *increase* when a non-ferrous object comes within range of the search coil and *decrease* when a ferrous (or diamagnetic) object is within range. This effect is difficult to detect in practice as eddy currents in ferrous materials swamp the effect and they react much the same as non-ferrous metals. However, minerals such as hematite may show the effect. With the search oscillator set on one side of zero beat, metal objects near the search coil will cause the pitch to *increase*, while magnetic minerals will cause the pitch to *decrease*. With the search oscillator set to the other side of zero beat, the opposite will occur.

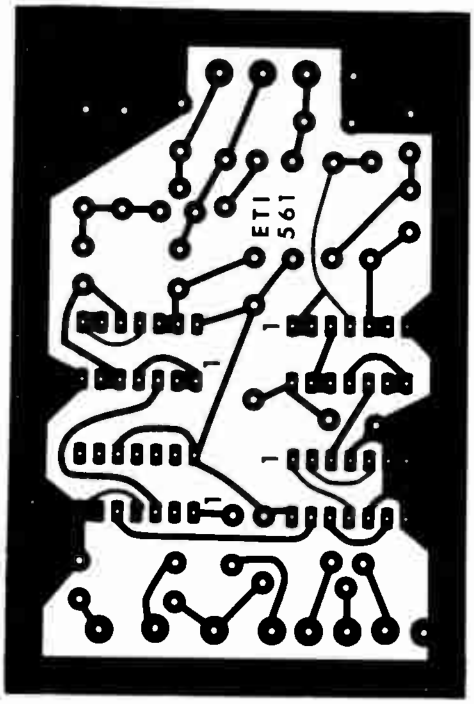
You could try a few experiments to show up this effect.

Enough theorising. In general operation, try to keep the search head a constant distance from the ground and sweep from side to side in a regular pattern. The right technique is easily developed with a little practice.

There are a number of books on metal detecting available and these show the sort of techniques the successful treasure hunter employs.



Internal view of the metal detector electronics showing general placement of the major components. We mounted the pc board using some 12 mm spacers, nuts and bolts. The speaker mounts on the box 'lid'.



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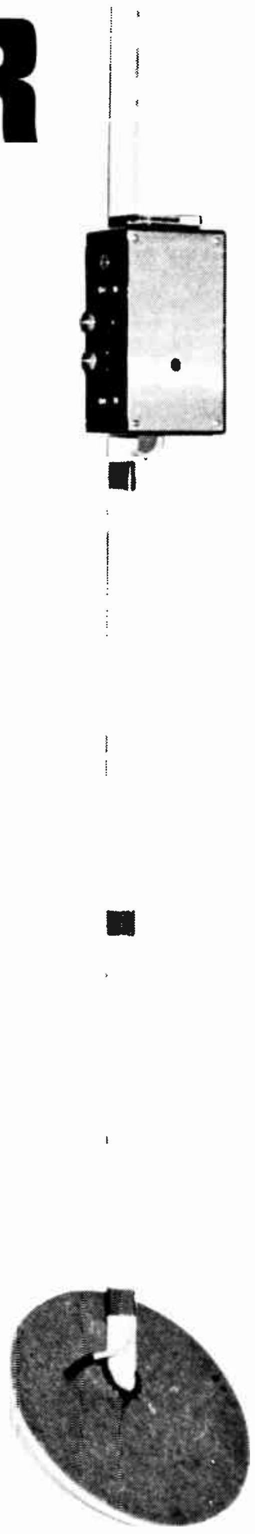
Project 549

INDUCTION BALANCE METAL DETECTOR

A really sensitive design operating on a different principle from that of other published circuits. This 'Induction Balance' metal locator will really sniff out those buried coins and other items of interest at great depths (depending on the size of the object).



"ANOTHER METAL LOCATOR," some of you will say. Yes and no. Several designs have been published in hobby electronics magazines around the world, some good, some downright lousy, but they have invariably been Beat Frequency Oscillator (BFO) types. There's nothing wrong with this principle – they are at least easy to build and simple to set up. The design described here works on a very different principle, that of induction balance (IB). This is also known as the TR principle (Transmit-Receive).

First a word of warning. The electronic circuitry of this project is straightforward and should present no difficulty even to the beginner. However, successful operation depends almost entirely upon the construction of the search head and its coils. This part should account for about three-quarters of the effort in construction. Great care, neatness and patience is necessary and a sensitive 'scope, though not absolutely essential, is very useful. It has to be stated categorically that sloppy construction of the coil will (not may) invalidate the entire operation.

IB Versus BFO

The usual circuit for a metal locator is shown in Fig. 2a. A search coil, usually 150 mm or so in diameter is connected in the circuit to oscillate at between 100 and 150 kHz. A second internal oscillator operating on the same frequency is included and a tiny part of each signal is taken to a mixer and a beat note is produced. When the search coil is brought near metal, the inductance of the coil is changed slightly, altering the frequency and thus the tone of the note. A tone is produced continually when the instrument is in use and metal is identified by a frequency change in the audio tone.

The IB principle, however, uses two coils arranged in such a way that there is virtually no inductive pick-up between them. A modulated signal is fed into one. When metal is brought near, the electromagnetic field is disturbed and the other coil picks up an appreciably higher signal.

Ideally the instrument is initially set up for no pick-up in the 'receiver' coil, but this is impossible in practice – the two coils are after all laid on top of each other. Another problem is that our ears are poor at identifying changes in audio level. The circuit is therefore arranged so that the signal is gated and is set up so that only the minutest part of the signal is heard when no metal is present. When the coils are near metal, a minute change in level becomes an enormous change in volume.

BFO detectors are not as sensitive as IB types and have to be fitted with a Faraday screen (beware of those which aren't – they're practically useless) to reduce capacitive effects on the coil. They are however, slightly better than IB types when it comes to pin-pointing exactly where the metal is buried.

Our detector is extremely sensitive – in fact a bit too sensitive for some applications! For this reason we've included a high-low sensitivity switch.

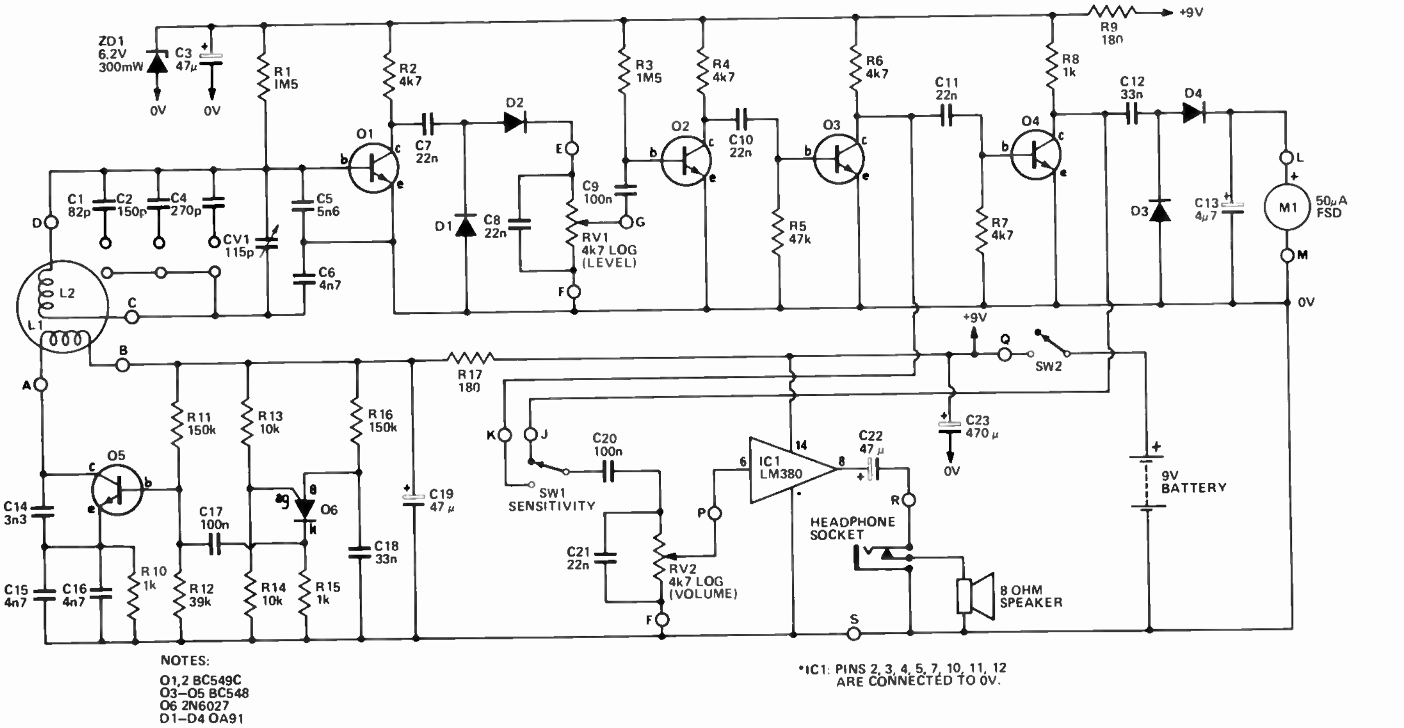


Fig. 1. Complete circuit of the metal locator. Note that though the electronics is simple using very common parts, the whole operation depends on the coil L1 and L2 which must be arranged so that there is minimal inductive coupling between the two. Note also that the leads from the circuit board to the search head must be individually screened and earthed at PCB.

You may ask why low sensitivity is useful. As a crude example, take a coin lying on a wooden floor: on maximum sensitivity the detector will pick up the nails, etc., and give the same readings as for the coin, making it difficult to find.

Treasure hunting is an art and the dual sensitivity may only be appreciated after trials.

Table 1 gives the distances at which various objects can be detected. These are static readings and only give an indication of range. If you are unimpressed with this performance you should bear two things in mind: first compare this with any other claims (ours are excellent and honest) and secondly bear in mind how difficult it is to dig a hole over 1ft of ground every time you get a reading. Try it — it's hard work!

Component Choice

We have specified Q1 and Q2 types as BC549C (highest gain group) for although lower gain transistors worked for us, they left little reserve of level on RV1 and really low gain types may not work at all.

RV1 is the critical control and should be a high quality type — it will be found that it has to be set very carefully for proper operation.

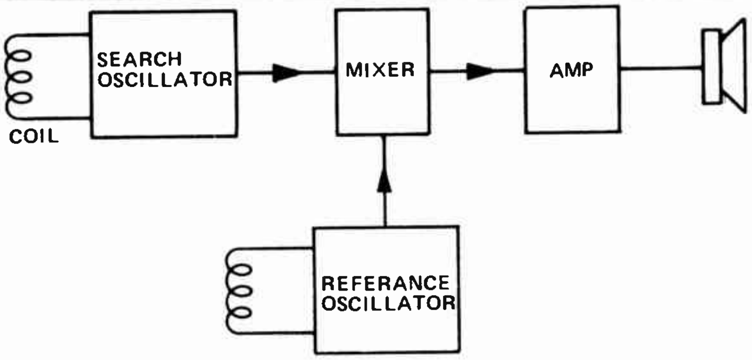


Fig. 2a. Block diagram of the common BFO type metal locator.

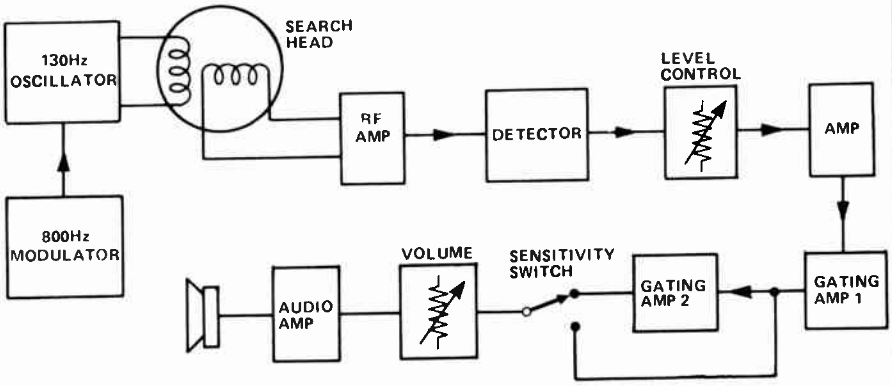


Fig. 2b. Block diagram of our IB design.

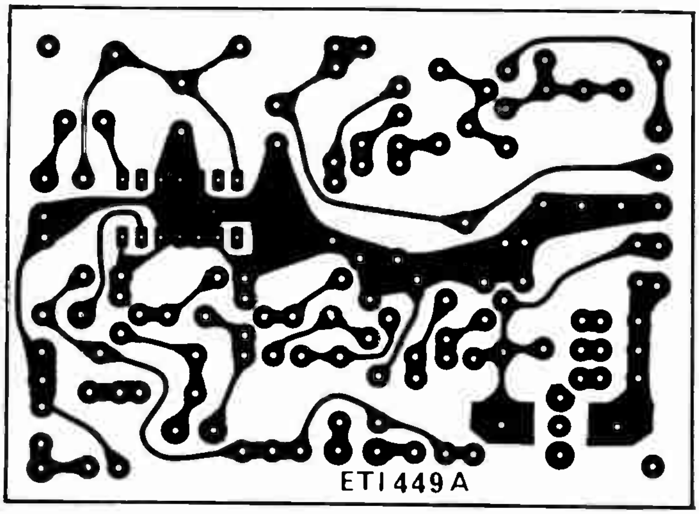


Fig. 3. Printed circuit layout. Full size 90 x 65 mm.

The choice of an LM380 may seem surprising as only a small part of its power can be utilised with battery operation. It is however inexpensive and widely available unlike the alternatives (note it does not require dc blocking at the input).

Output is connected for an 8 ohm speaker and to headphones. Stereo types are the most common and the wiring of the jack socket is such that the two sections are connected in series presenting a 16 ohm load (this reduces current consumption from the battery).

Construction: Control Box

The majority of the components are mounted on the PCB overlay and the additional wiring is shown in Fig. 4.

Exceptional care should be taken to mount all components firmly to the board. Poor connections or dubious solder joints may be acceptable in some circuits – not in this one. Take care to mount the transistors, diodes and electrolytic capacitors the right way around.

The PCB is fitted into the control box by means of 6 mm spacers. The control box has to be drilled to take the speaker, the pots, switches, headphone jack and the cable from the search head.

The Handle Assembly

The handle we used was simply a broom handle with the end cut off at about 45°. After assembling the head, the handle can be glued on with epoxy. A small woodscrew can be used to hold it in place until dry. This should be done before final setting up of the coils – in case the screw cannot be removed after the glue has set.

The Coil

Remember this is the key to the whole operation. The casing of the coil is not so critical but the layout is.

It is best first to make the 6 mm plywood circle to the dimensions shown in Fig.6. A circle of thinner plywood or hardboard is then firmly glued onto this – it's fairly easy to cut this after glueing. Use good quality ply and a modern wood glue to make this.

This now forms a dish into which the coils are fitted.

You'll now have to find something cylindrical with a diameter of near enough 140 mm (5½in). A coil will then have to be made of 40 turns of 32 swg enamelled copper wire. The wire should be wound close together and kept well bunched and taped to keep it together when removed from the

How It Works – ETI 549

Q5, Q6 and associated components form the transmitter section of the circuit. Q6 is a P.U.T. which operates as a relaxation oscillator, the audio note produced being determined by R16 and C18. The specified components give a tone of roughly 800 Hz.

Q5 is connected as Colpitt's oscillator working at a nominal 130 kHz; this signal is heavily modulated by C17 feeding to the base of Q5. In fact the oscillator produces bursts of r.f. at 800 Hz. L1 in the search head is the transmitter coil.

L2 is arranged in the search head in such a way that the minimum possible signal from L1 is induced into it (but see notes on setting up). On all the prototypes we made we reduced this to about 20 mV peak-to-peak in L2. L2 is tuned by C5 and C6 and peaked by CV1 and feeds to the base of Q1, a high gain amplifier. This signal (which is still modulated r.f.) is detected by D1, and D2. The r.f. is eliminated by C8 and connects to the level control RV1.

The signal is amplified by Q2 and then further amplified by Q3 which has no d.c. bias connected to the base. In no-signal conditions this will be turned off totally and will only conduct when the peaks of the 800 Hz exceed about 0.6V across R5. Only the signal above this level is amplified.

On low sensitivity these peaks are connected to the volume control RV2 (any stray r.f. or very sharp peaks being smoothed by C21) and fed to the IC amplifier and so to the speaker.

The high sensitivity stage Q4 is connected at all times and introduces another gating stage serving the same purpose as the earlier stage of Q3. This emphasises the change in level in L2 even more dramatically. Note that RV1 has to be set differently for high and low sensitivity settings of SW1.

Whichever setting is chosen for SW1. RV1 is set so that a signal can just be heard. In practice it will be found that between no-signal and moderate-signal there is a setting for RV1 where a 'crackle' can be heard. Odd peaks of the 800 Hz find their way through but they do not come through as a tone. This is the correct setting for RV1.

The stage Q4 also feeds the meter circuit. Due to the nature of the pulses this need only be very simple.

Since we are detecting really minute changes in level it is important that the supply voltage in the early stages of the receiver are stabilised, for this reason ZD1 is included to hold the supply steady independent of battery voltage (which will fall on high output due to the current drawn by IC1).

It is also important that the supply voltage to Q5 and Q6 does not feed any signal through to the receiver. If trouble is experienced (we didn't get any) a separate 9V battery could be used to supply this stage.

IC1 is being well underused so a heatsink is unnecessary.

Battery consumption is fairly high on signal conditions – between 60 mA and 80 mA on various prototypes but this will only be for very short periods and is thus acceptable. A more modest 20 mA or so is normal at the 'crackling' setting.

Stereo headphones are used and are connected in series to present 16 ohms to IC1 reducing current consumption.

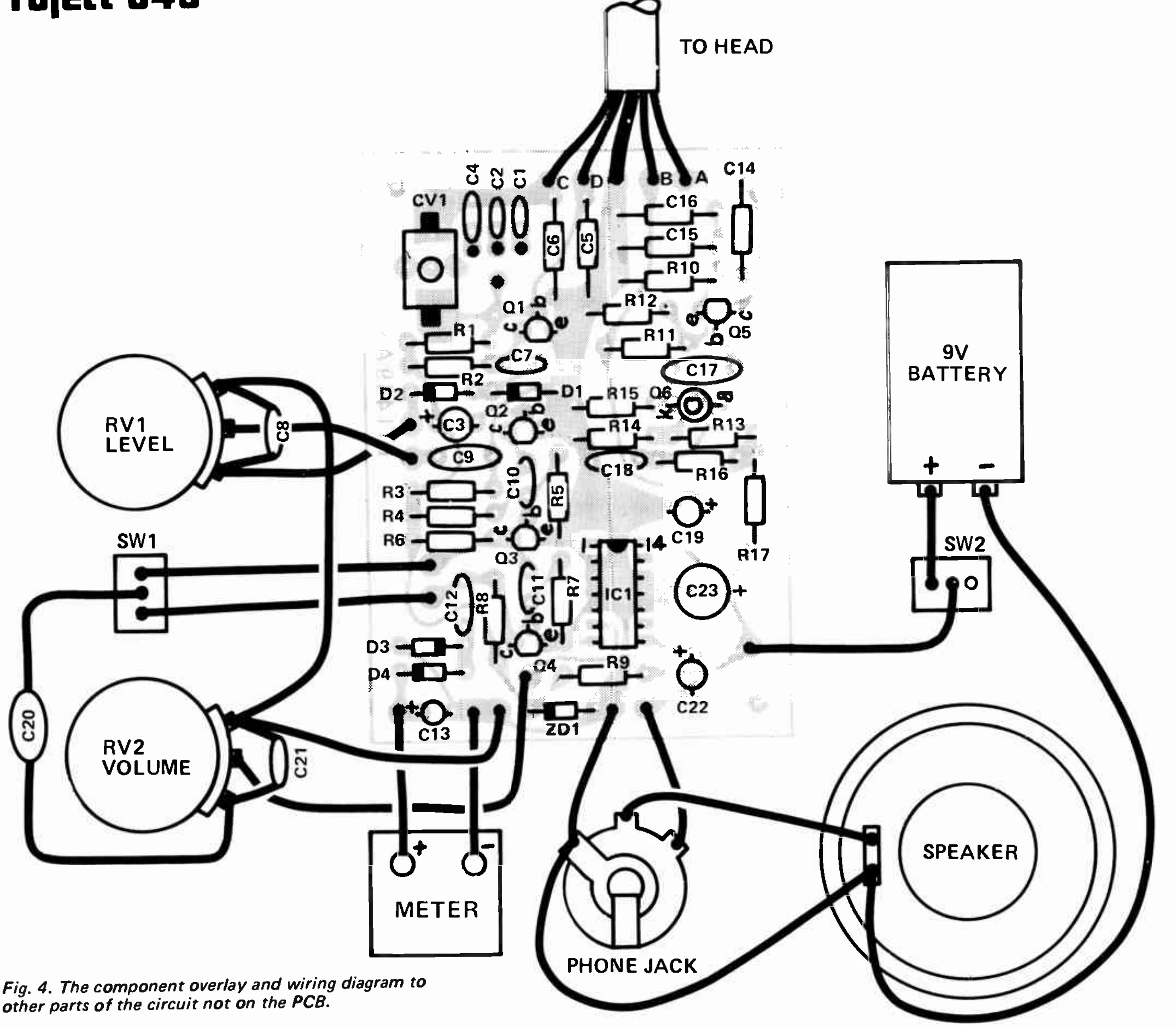


Fig. 4. The component overlay and wiring diagram to other parts of the circuit not on the PCB.

former. Two such coils are required. These are identical.

One of the coils is then fitted into the dish and spot glued in six or eight places using quick setting epoxy resin: see photograph.

L2 is then fitted into place, again spot glueing (*not* in the area that it overlaps L1). The cable connecting the coil to the circuit is then fed through a hole drilled in the dish and connected to the four ends. These should be directly wired and glued in place, obviously taking care that they don't short. The cable must be a four-wire type with individual screens — the screens are left unconnected at the search head.

You will now need the built up control box and preferably a 'scope. The transmit circuit is connected to L1. The signal induced into L2 is monitored; at first this may be very high but my manipulating L2 the level will be seen to fall to a very low level. When a very low level is reached, spot glue L2 until only a small part is left for bending.

Ensure that when you are doing this that you are as far away from any metal as possible but that any metal used to mount the handle to the head is in place. Small amounts of metal are acceptable as long as they are taken into account whilst setting up.

Now connect up the remainder of the circuit and set RV1 so that it is *just* passing through a signal to the speaker. Bring a piece of metal near the coil and the signal should rise. If it falls in level (i.e. the crackling disappears) the coil has to be adjusted until metal brings about a rise with no initial falling. CV1 should be adjusted for maximum signal, this has to be done in conjunction with RV1. The additional capacitors C1, C2 and C4 should be linked in, if the range is not available on CV1.

Monitoring this on a scope may mean that the induced signal is not at its absolute minimum: this doesn't matter too much. Now add more spot glueing points to L2.

You should now try the metal locator in operation. If RV1 is being operated entirely at the lower end of its track, making setting difficult, you can select a lower gain transistor such as a BC548 for Q2.

When you are quite certain that no more manipulation of the coils will improve the performance, mix up plenty of epoxy resin and smother both coils, making certain that you don't move

PARTS LIST – ETI 549

Resistors	all ½ W 5%
R1	1M5
R2	4k7
R3	1M5
R4	4k7
R5	47 k
R6,7	4k7
R8	1 k
R9	180 ohms
R10	1 k
R11	150 k
R12	39 k
R13,14	10 k
R15	1 k
R16	150 k
R17	180 ohms

Potentiometers	
RV1,2	rotary 4k7 log

Capacitors	
C1	82 p ceramic
C2	150 p ceramic
C3	47 µ 10 V electro
C4	270 p ceramic
C5	5n6 polystyrene*
C6	4n7 polystyrene*
C7,8	22 n polyester
C9	100 n polyester
C10,11	22 n polyester
C12	33 n polyester
C13	4µ7 25 V electro
C14	3n3 polystyrene *
C15,16	4n7 polystyrene *
C17	100 n polyester
C18	33 n polyester
C19	47 µ 10 V electro
C20	100 n polyester
C21	22 n polyester
C22	47 µ 10 V electro
C23	470 µ 16 V electro

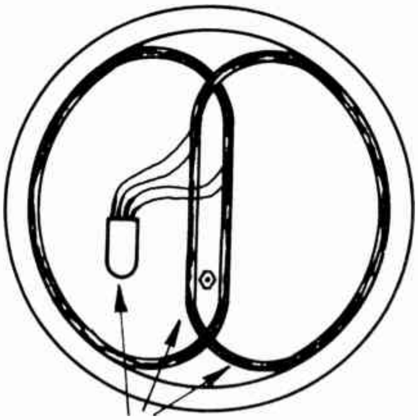
CV1	115pF trimmer (modify board if necessary to suit connections)

Semiconductors	
Q1,2	Transistors BC549C
Q3-Q5	Transistors BC548
Q6	PUT 2N6027
D1-D4	Diodes OA91, OA95
IC1	Amplifier LM 380
ZD1	Zener 6.2 V 300 mW

Miscellaneous

PC board	ETI 549 A
Meter	50 µA FSD

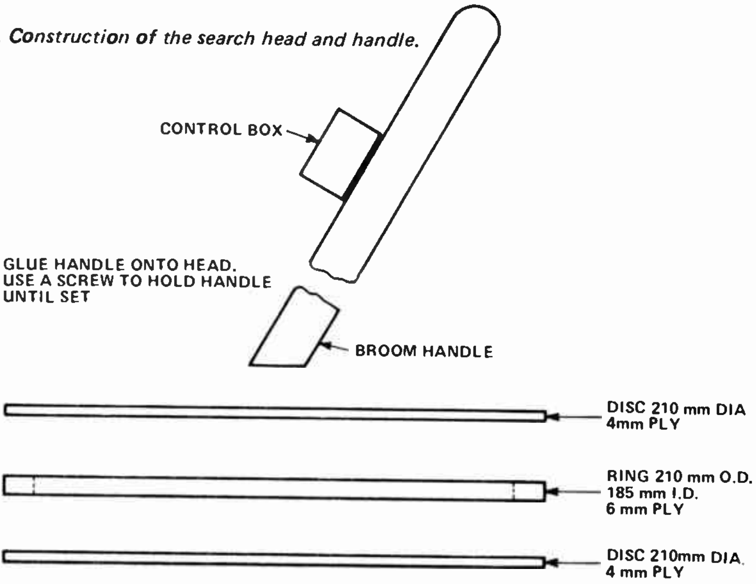
Search head as per Fig. 6.
Two changeover slide switches.
Two knobs
Suitable case (158 x 95 x 50 mm)
Phone socket
Small speaker
9 V battery clip
Six by AA battery holder
Six AA batteries.



COILS AND POWER CORD ARE GLUED INTO POSITION WITH FIVE MINUTE EPOXY.

Fig. 5. Diagram showing the position of the coils in the search head.

Fig. 6. Construction of the search head and handle.



them relative to each other.

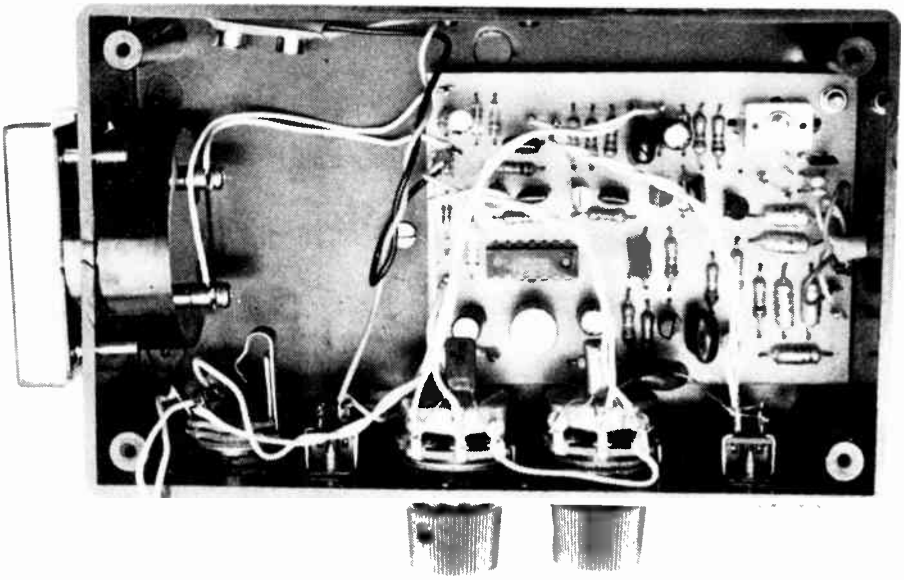
The base plate can then be fitted to enclose the coils, this should be glued in place.

If after glueing in place the balance between the coils is found to be not quite right it should be possible to glue a small piece of metal (such as a washer) somewhere on the head to cancel out the error.

Using The Metal Locator

You will find that finding buried metal is rather *too* easy. 95% will be junk – silver paper being a curse. The search head should be panned slowly over the surface taking care to overlap each sweep. The sensitive area is comewhat less than the diameter of the coil.

This type of locator will also pick up some materials which are not metal



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DS964AJ

– especially coke. And it is not at its best in wet grass.

Think very carefully about where you want to search: this is more important than actually looking. The area you can cover thoroughly is very, very small, but this approach is far more successful than nipping all over the place. As an example of how much better a thorough search is, we thoroughly tried on 25 square feet of common ground (5ft x 5ft); we found over 120 items but a quick search initially had revealed only two!

Treasure hunting is growing in popularity and those who do it seriously have adopted a code; essentially this asks you to respect other people's property, to fill in the holes you dig and to report any interesting finds to museums.

Meter Circuit

Since the circuit is basically sensing a change in audio level, a meter circuit can be incorporated. For the very first indication from the 'crackle' your ears are likely to be more sensitive than the meter but thereafter it will come into its own.

This part of the circuit is optional and the components are not included on the board.

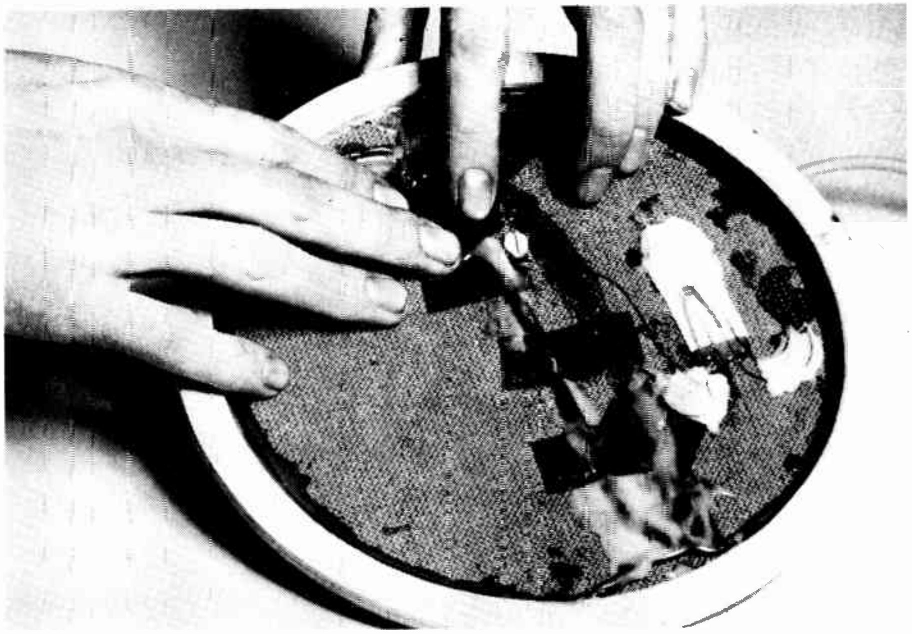
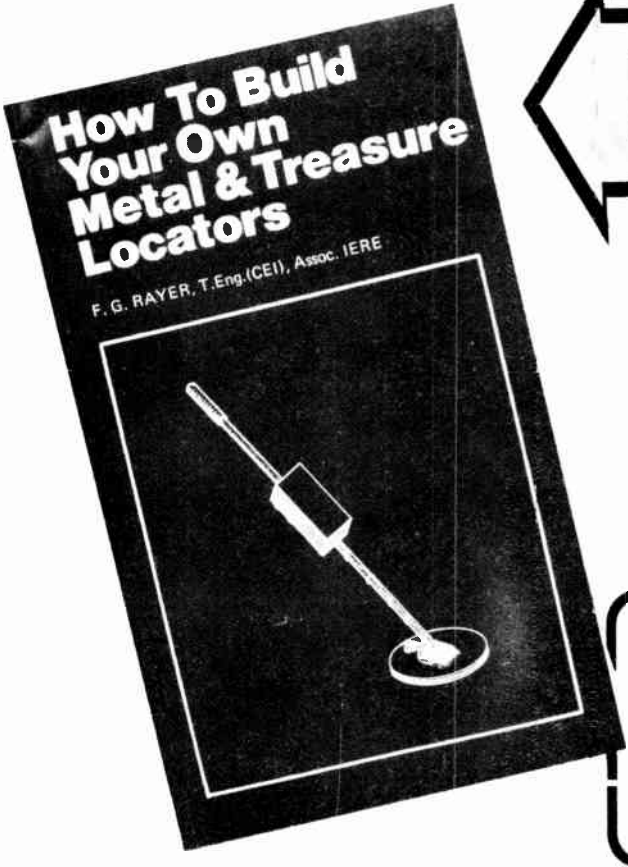


TABLE 1

OBJECT	20_c Coin	Beer Can	150 mm Square copper	150 mm steel rule	MANS Gold Ring
HIGH SENS	200 mm	450 mm	550 mm	300 mm	200 mm
LOW SENS	150 mm	350 mm	400 mm	220 mm	150 mm



Exploration archaeology —searching for our past

John M. Stanley

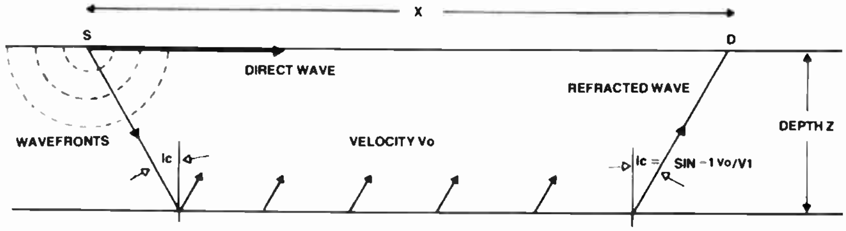


Figure 1. **Paths taken by the direct point S to detector D in two layered earth.**

TREASURES sought after by archaeologists differ between Europe and Australia due to the nature of the respective civilisations.

European communities produced lasting hardware of baked clay or metals. They built cities of permanent materials with considerable use of stone and bricks, and they often fortressed these with substantial walls. Although their civilisations have decayed, they left many remnants now submerged beneath windswept sands or buried by alluvial flood plains. Yet others have been built over by later communities. In common, these folk considerably altered the landscape where they built their cities. They left permanent relics of their handcraft and they frequently left written evidence of their existence.

The scene in Australia is very different from this. The aborigines rarely altered their habitat with permanent constructions, and rarely if ever, made use of bricks or metals. Consequently, the only lasting remains of their campsites are fireplaces, shell concentrations and humus-rich deposits where wandering tribes made seasonal camps when food was abundant. These "middens", as they are generally termed, do however contain small items, usually of chipped stone, which are of interest to our natural historians.

These differences require new exploration procedures. In the pursuit for remains of a highly developed community, it is logical firstly to search historic writings for clues as to where a township may have been situated. Aerial photography may then disclose surface formations not normally visible from the ground.

In the past it has been necessary to follow these activities with tedious drilling and trenching, but a great deal of this laborious work may now be replaced by the refined use of geophysical

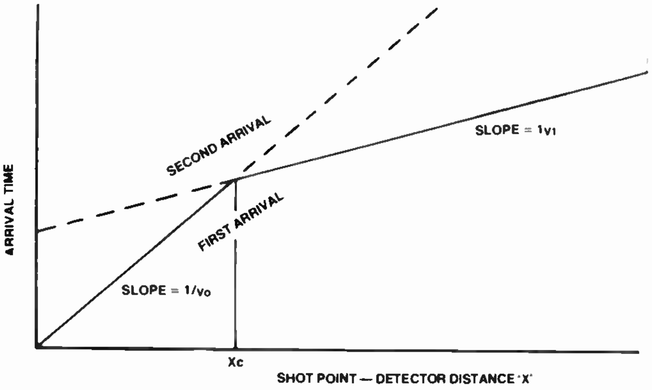


Figure 2. **Plot of first and second arrival times at a detector a distance X from the shot point. Xc corresponds to the point where the refracted wave overtakes the direct wave.**

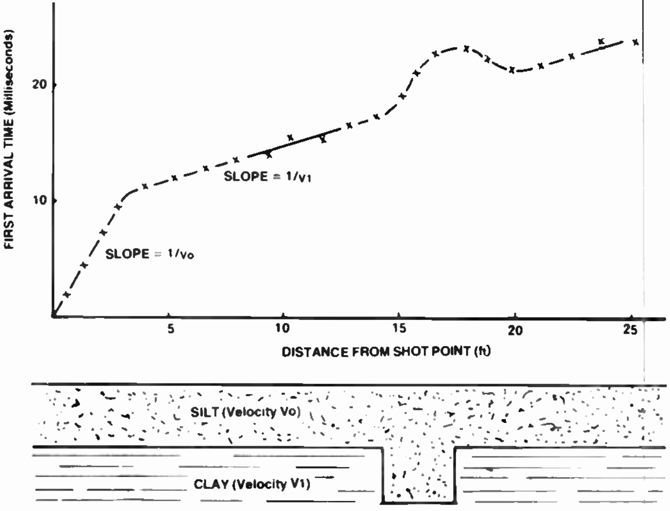


Figure 3. **Experimental refraction plot over a trench filled with silt.**

Earth Resistivity meter in use

methods, and the final excavations commenced with greater confidence of success.

Combining technology with the classical arts, today's archaeologist is a refined crossbreed of historian and geophysicist.

Our aborigines left no writings or photographable surface features indicating the whereabouts of their campsites. Fortunately for the archaeologist, much of the countryside in Australia has not changed very much since aboriginal occupation and it is logical that middens be associated with features providing a regular source of food. Lakes, river estuaries, rocky shorelines, natural springs and waterholes are our clues to past occupation. They are virtually the only means we have of confining the area of our search. In fact excavations have only been made in Australia in places where surface evidence of middens has been observed. But if geophysics can be employed successfully, then much older middens may be located buried at greater depths. The author is at present concerned with this possibility.

Geophysical methods in present use

There are three principal geophysical methods which have been applied to archaeological studies. They are: seismology, resistivity and magnetics. Their use depends upon the nature of the particular environment, the amount of finance available for equipment, and upon the experience of the operating crew.

Seismology

The principle of seismology is that shock waves travel at particular and well-defined velocities through material of different types. The denser the material, the faster the speed that shock waves will travel through it. The velocities vary from as low as 600 ft/sec in light and dry top soil, to 20 000 ft/sec in unseamed granite.

If the speed of the shock wave is measured, then the type, hardness and depth of the various strata can accurately be determined. This is relatively easy to do, for when a shock wave strikes an interface between two different types of material it will be refracted along that interface.

With the simplest types of seismographs the shock wave is initiated by striking the ground with a hammer. Figure 1 shows how the shock wave thus generated (at point 'S'), travels out in hemispherical wavefronts. If a detecting instrument is at point 'D' — a distance of 'X' feet from 'S' then the shock wave travelling horizontally through the top material (the 'direct wave') will reach the receiving instrument before any other wave — as long as 'X' is small. For longer distances, the wave travelling along the lower strata (which has a higher characteristic velocity) will arrive at the receiver before the direct wave.

Angle Ic is the 'critical angle' at which the shock wave is refracted along the interface. It is in fact the angle where Sine is V_0/V_1.

The most convenient way to represent this data is to measure and plot the arrival time of the first refracted wave vs the short distance 'X'. For example with two layered stratum (Figure 1) we would have the plot shown in Figure 2. From the gradient of the first arrival segments we can deduce the velocities V_0 and V_1 and hence calculate the depth to the interface. Figure 3 shows the experimental data plotted over a trench buried under a layer of silt.

In the far more complex situation of identifying echos from irregular archaeological objects, interpretation becomes a job for the expert. However, there are many cases when seismology is quite practical to use. These include buried tombs and building sites containing walls or similar large structures. Seismology has been successfully used to locate underground passages and tomb cavities within the Egyptian pyramids, and is ideal for sounding the depth of deposits in caves and rock shelters.

Portable instrumentation has recently become commercially available, but at a cost of about $3600! Quite prohibitive for the amateur treasure seeker! Such a "signal enhancement seismograph" is battery operated, weighs only 17 lbs and is exceeding accurate and easy to use. The seismic disturbance is made by simply hitting the ground with a 10 lb hammer.

Resistivity

Another characteristic of differing strata is electrical resistivity — in fact the range of electrical resistivities is enormous. It extends from 10^{-1} ohm/metre to 10^{19} ohms/metre. It follows that if we can measure vertical and horizontal resistivity profiles of the ground, we must be able to detect changes in composition, and hence deduce the existence of buried objects. There are many ways of doing this, some involving ac measurements and others using dc. Generally, the resistivity is far from uniform and so the measurement used is one of "apparent resistivity" — in effect it is a mean value depending on the distribution of rocks and their individual resistivities.

One of the most common electrode arrangements for measuring apparent resistivity is that known as the Wenner Array (illustrated in Figure 4). Using a Wenner Array (with electrode separation '*a*') on the surface of a semi-infinite solid with uniform resistivity p, then $p = 2\pi a\ V/I = 2\pi aR$ (where R is the resistance between the inner electrodes).

There are two applications of this formula. We may perform "electrical drilling" or "electrical trenching". In the former, a vertical profile of the resistivity may be measured by plotting p as the separation of electrodes '*a*' is varied. The depth at which p is measured is approximately 0.6 *a*. Apparent resistivity profile curves may be generated by a computer for different models of ground structure. Volumes of standard curves of this type have been published and these facilitate the interpretation of resistivity drilling.

TABLE 1

Material	Magnetic Susceptibility 10^{-6} emu	Resistivity Ohm. M.	Seismic Compressional Velocity M. Sec^{-1}
Air	0	Infinite	330
Water (fresh)	0	50	1450
Sand (dry)	-1.2	$>10^{10}$	300 - 800
Limestone	5	120 - 400	3,500 - 6,500
Granite	500	5,000 - 10^{6}	4,600 - 7,000
Clay	Variable	1 - 120	1,000 - 3,000
Sandstone	10	35 - 4,000	1,500 - 4,500
Marble	-0.75	$>10^{12}$	-
Basalt	2,000	-	5,000 - 6,500
Alluvium	2,000	Variable	500 - 600

Approximate values of magnetic susceptibility, electrical resistivity and seismic velocity for archaeologically relevant materials. All values tend to be highly variable depending on moisture content and mineral composition.

Electrical trenching is achieved by selecting an electrode separation corresponding approximately to the depth of interest, and moving the whole array along the traverse line. Figure 5 shows a typical set of results plotted over a buried wall.

Resistivity methods are applicable to similar situations as the seismic method. The field skills and interpretation complexity are comparable to those required for seismology but the cost of equipment is very much less. A quite effective ac resistivity meter may be purchased for less than $500) and a dc operated meter — such as that described immediately following this article — may be home assembled for very much less.

Magnetics

The Earth's natural magnetic field is perturbed by the magnetic properties of materials within its influence. If the Earth's field may be measured to an accuracy of the order of 1 part per 1000 this perturbation can be detected. Information concerning dimension, location and composition of the perturbing body may be extracted from carefully compiled maps of anomalies in the magnetic field.

During the mid 1950s, a team at Cambridge University developed a magnetometer, having a sensitivity of 1 part per 100 000, specifically for archaeological work. This instrument measured the frequency of protons in an organic fluid as they precessed about the Earth's field. The precession frequency was linearly related to the intensity of the magnetic field. The "proton precession" magnetometer is available now at a cost of about $500. More recently an instrument has been developed which measures the electron-nuclear spin of atoms in an alkali metal vapour. This spin frequency is also linearly related to the magnetic field, but yields an accuracy of 1 part in 1 million (ETI Jan, 1973). At present these instruments are expensive — in excess of $1000 — but as refining developments progress, this cost may be expected to decrease substantially.

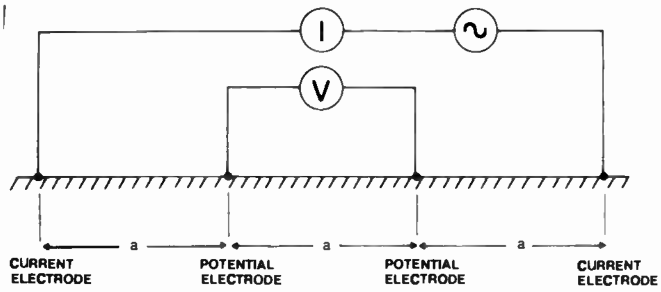


Figure 4. **The Wenner configuration of electrodes used in both "electrical drilling" and "electrical trenching". The electrode spacing used in resistivity calculations is the distance 'a'.**

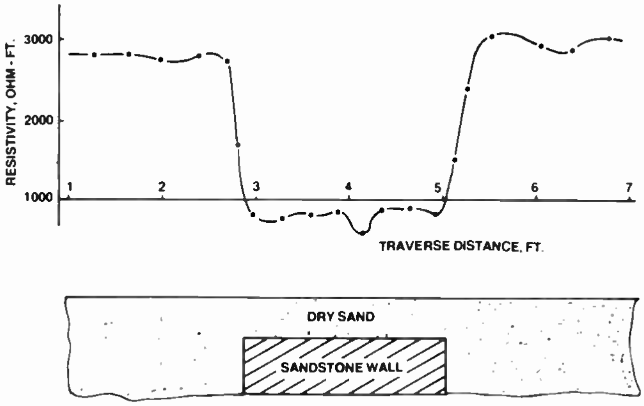


Figure 5. **A typical resistivity traverse over a sandstone wall buried under dry sand.**

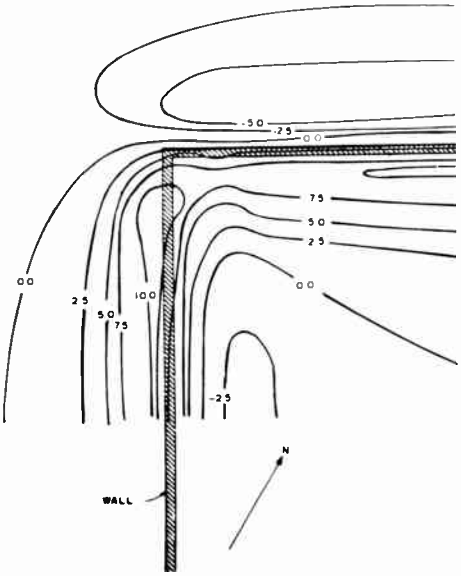


Figure 6. **This is a magnetic contour map over a corner of a stone wall buried at a depth of five metres. The plot was made using a differential magnetometer pair during the search for the lost city of Sybaris in southern Italy.**

The magnetic field on the Earth's surface is almost entirely (95%) due to stable sources within the core. The remaining 5% originates from variable causes, and may be divided into "temporal" (time) or "special" (position) variations. The temporal changes result principally from solar-induced currents in the Earth's crust, and magnetic pulsations in the magnetosphere. They range in frequency from a fraction of a second to diurnal. The amplitude of such variations is typically a few gammas but under severe conditions magnetic storms of several hundred gammas may be encountered.

Special variations arise principally from the degree of magnetism induced in materials of the Earth's crust. Different rocks and minerals exhibit a range of susceptibilities to magnetisation in the Earth's field and this magnetisation can readily be detected with modern instruments. A second very significant cause of special anomalies results from "remnant" magnetism exhibited by objects containing ferromagnetic minerals which have been heated strongly at some time. Within the crystals of the mineral are small, randomly orientated regions of uniform magnetisations, called domains, which become mobile above the Curie temperature of about 600°C. During cooling, many of the domains align themselves parallel to the Earth's magnetic field and are thus frozen in this alignment. Since they are parallel to the Earth's field they are also parallel to each other, thus creating a net magnetic effect. Pottery, kilns, hearths and baked rocks will frequently exhibit a measureable remnant magnetism.

If the archaeologist is to distinguish between temporal and special anomalies it is usual to use two magnetometers. Both will respond to temporal changes simultaneously so if the difference in field value between the two is measured while one instrument is kept stationary, then only the spacial changes will be recorded. Since the development of the extremely high resolution "alkalai vapour magnetometers" it has been possible to use such two instruments as a "gradiometer". Both field sensors are mounted with a fixed separation on a vertical staff. Again, both respond simultaneously to temporal changes and so the field value difference between the sensors yields the vertical spacial field gradient.

This data is of particular value to the archaeologist who is usually looking for objects buried under a quite shallow layer of sediments. This is because it effectively filters out background magnetic anomalies that originate in the deeper underlying geologic strata. It does this because the magnetic field of a dipole is inversely proportional to the cube of the distance from it. The significance of the inverse cube factor is apparent if we compare the anomalous intensities, at each of two sensors, from a buried wall overlying a geologic magnetic disturbance. Let us suppose that the two sensors are directly above the wall at distances of one and two metres, and that the wall overlies the geologic source at a distance of 10 metres. Then, if the geologic anomaly were even as large as the wall anomaly at the site of the lower sensor, the differential anomaly of the wall would be almost four times that of the geologic strata.

The interpretation of magnetic field and gradient data is certainly a task for the expert if full value is to be extracted from the data. The nature of the anomaly will depend upon a large number of factors such as size, shape, depth, magnetic susceptibility of the object, and its orientation relative to the Earth's field. Mineral and oil exploration research has developed computing prowess in this field and it is now possible to achieve exciting successful results if the right skills are applied to the data. Figure 6 shows an actual magnetic contour map over a corner of a stone wall buried at a depth of 5 m. This data was measured with a differential magnetometer pair during the search for the lost city of Sybaris in southern Italy.

Earth resistivity meter

John Stanley

From gold to archaeological remains — this simply constructed instrument will assist your prospecting.

AN EARTH RESISTIVITY meter can be used to identify the composition of various earth strata — and the depth at which each strata occurs — and by detecting changes in earth composition, to point to the existence of buried objects.

An earth resistivity meter may be used to locate archaeological objects — to assist in finding conditions favourable for alluvial gold or gemstones, or even for such prosaic duties as determining where to locate a septic tank!

These instruments are not expensive compared with most electronic instrumentation. Nevertheless at $1000 or so they are way above the budget of most amateur archaeologists or rock-hounds.

But for such people all is not lost — it is possible to construct a simple dc operated resistivity meter for a mere fraction of the price of commercial units.

For this to be possible we have to accept a few operating limitations — primarily of operating depth — for whereas a commercial unit may be used to depths of 100-200 metres, our unit is limited to 15 metres or so. But unless you are hoping to locate oil bearing deposits in your backyard the limitation on operating depth should not be a problem.

The basic instrument is extremely simple — four equally spaced electrodes are placed in line in the earth. An accurately known current is caused to flow from one outer electrode to the other — and a measurement is taken of the voltage between the two inner electrodes.

Having measured both voltage and current, a simple formula is used to establish depth and composition of the strata.

Professional earth resistivity meters use alternating current across the earth electrodes in order to eliminate the effects of the small galvanic voltages caused by the earth. This effect cannot be totally eliminated with dc instruments but it can be minimised by switching the battery across the electrodes in alternate polarities — a centre position of the switch (SW2) meanwhile short-circuits the two centre electrodes between readings to discharge the galvanic potential.

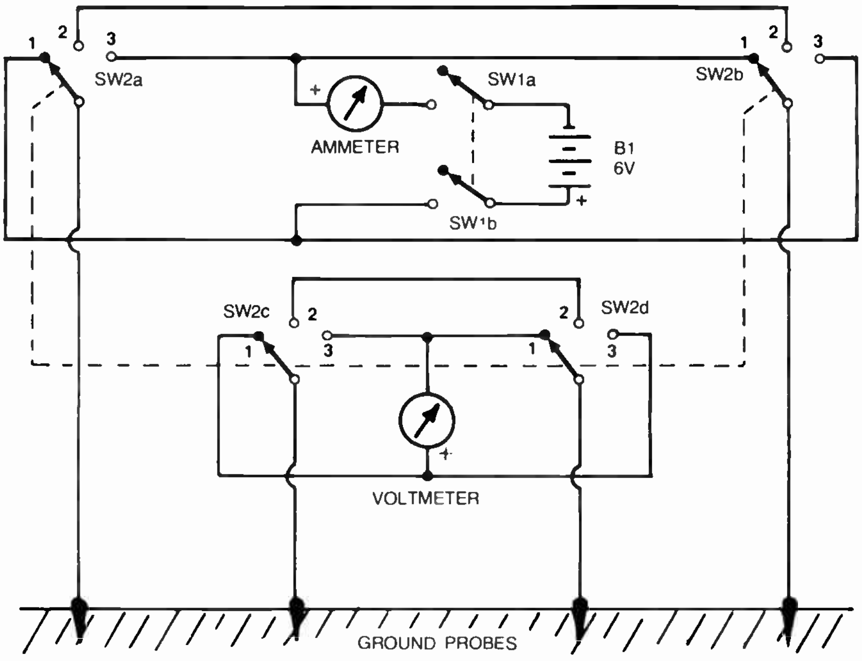


Figure 1. **Circuit diagram of resistivity meter.**

Figure 1 shows the circuit diagram of the instrument. A connection diagram is reproduced in Figure 2.

PARTS LIST

Double pole on/off switch
— MSP 625 or similar.

Four pole three way rotary switch
— OAK type AK 52259 or similar.

Six or twelve volt dry cell battery.

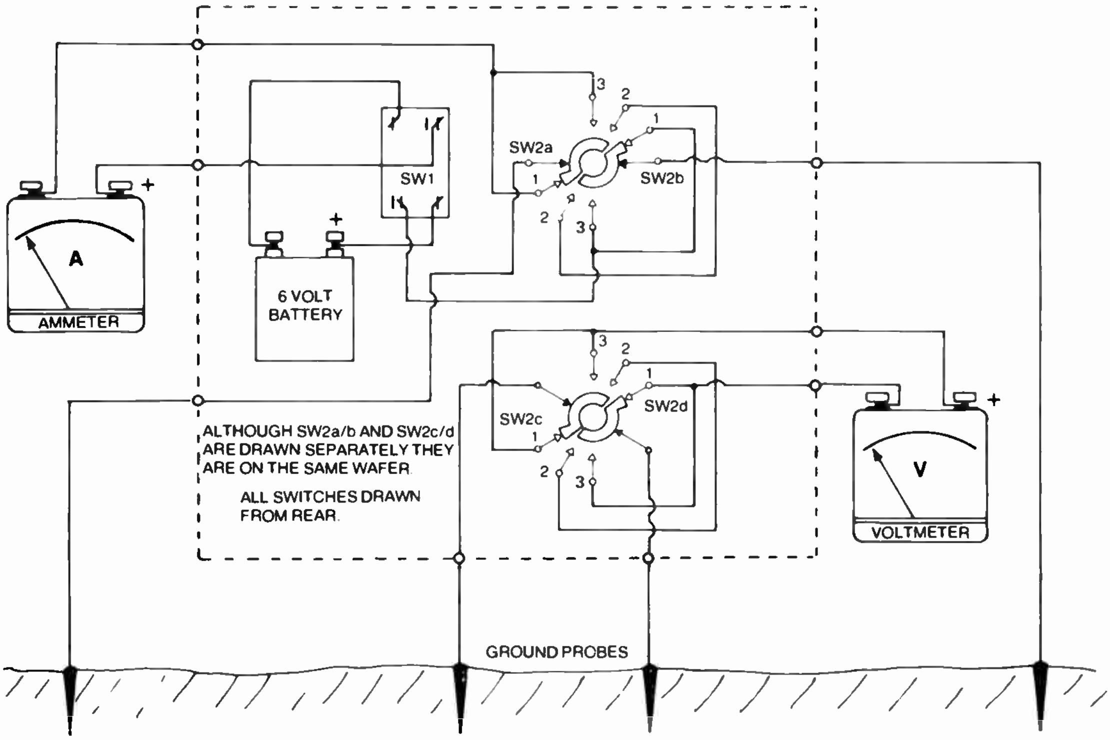
Knob for rotary switch.

Earth probes and cables.

Voltmeter — see text.
Ammeter — see text.

We have not provided any mechanical assembly drawings, for this will depend almost entirely upon the meters used. A pair of cheap multimeters are ideal — but if these are not available then a voltmeter and a milliameter with switchable ranges should be used. The milliameter should be capable of measuring from microamps to a maximum of 100 milliamps or so, the voltmeter should cover a range from approximately 100 microvolts to three volts or so and should have a sensitivity of about 20 000 ohms per volt.

Switch SW2 is a three-pole four-way wafer switch. All switching contacts are located on one wafer. Each of the four segments shown in the wiring diagram (i.e: SW1 SW2 etc) consists of a wiping contact and three fixed contacts — the



ALTHOUGH SW2a/b AND SW2c/d ARE DRAWN SEPARATELY THEY ARE ON THE SAME WAFER

ALL SWITCHES DRAWN FROM REAR

Figure 2. **How the components are interconnected.**

connections will be readily apparent when the wiring diagram is compared with the switch.

The ground probes should ideally be made of copper coated steel or brass — however electrodes made from 25 mm to 50 mm steel tubing or rod will work quite well as long as they are kept clean. It is of course essential that they make the best possible contact with the surrounding earth. Electrode cable connections must be securely made using proper terminals — remember that you are looking for fairly minor changes in earth resistance.

Operating voltage is not critical — a six or twelve volt dry cell is adequate for most applications.

Measuring earth resistivity

There are several methods of measuring soil resistivities, mostly variations of the original method devised by Wenner. This consists of driving four metal spikes (commonly called electrodes), into the ground, at equal intervals along a straight line as shown in Figure 3.

A current is passed through the outer electrodes C_1 and C_2 and the resulting voltage drop across the earth resistance is measured across the inner pair p_1 and p_2.

If the ground has a uniform resistivity p then

$$p = 2\pi a\ V/I = 2\pi a\ R$$

where 'R' is the apparent resistance measured between the inner potential electrodes.

Generally the current will flow in an arc between the electrodes and hence the depth penetrated will increase as the electrode separation is increased. The effective depth at which R is measured is usually taken as 0.6 times the separation 'a'.

For the greatest accuracy in determining the ration V/I it is desirable that the current flow I be maximised and hence in dry surface conditions it is common to moisten the soil about the electrodes to reduce the contact resistance. The depth to which the electrodes are inserted must not exceed one-twentieth of their separation. This is important if standard curves are to be used for the interpretation of the experimental data.

Having inserted the four electrodes an average value for both V and I must be determined for both polarities of the battery. Reversing the polarity removes the possibility that the earth may have its own potential due to galvanic reactions underground. From these measurements the resistivity p can be calculated.

Resistivity depth sounding

Consider for example the problem of measuring the depth beneath the ground of the water table or perhaps the thickness of soil overlying the bedrock. This type of situation is by far the most common — where a layer of resistivity $p1$ and thickness 'd' is overlying a layer of different resistivity $p2$.

We can determine the depth 'd' with the aid of 'standard curves'. The procedure is to measure the resistivity of the ground each time the electrode separation 'a' is increased about a central point. To use the standard curves provided it is necessary to plot the measured resistivity (p) on the vertical axis, against the electrode separation distance on log/log graph paper.

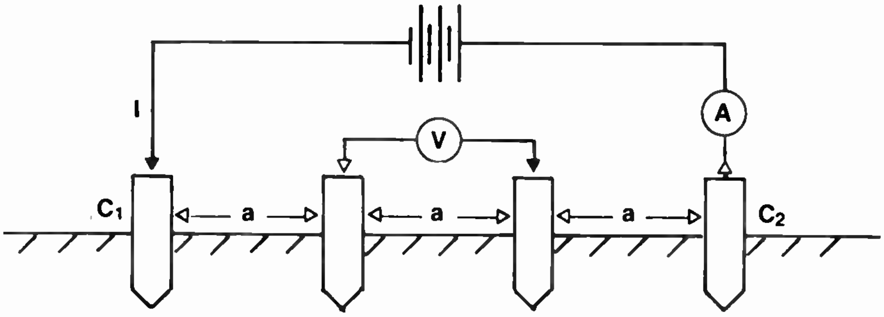


Figure 3. **The electrodes are driven into the ground at equal intervals and in a straight line.**

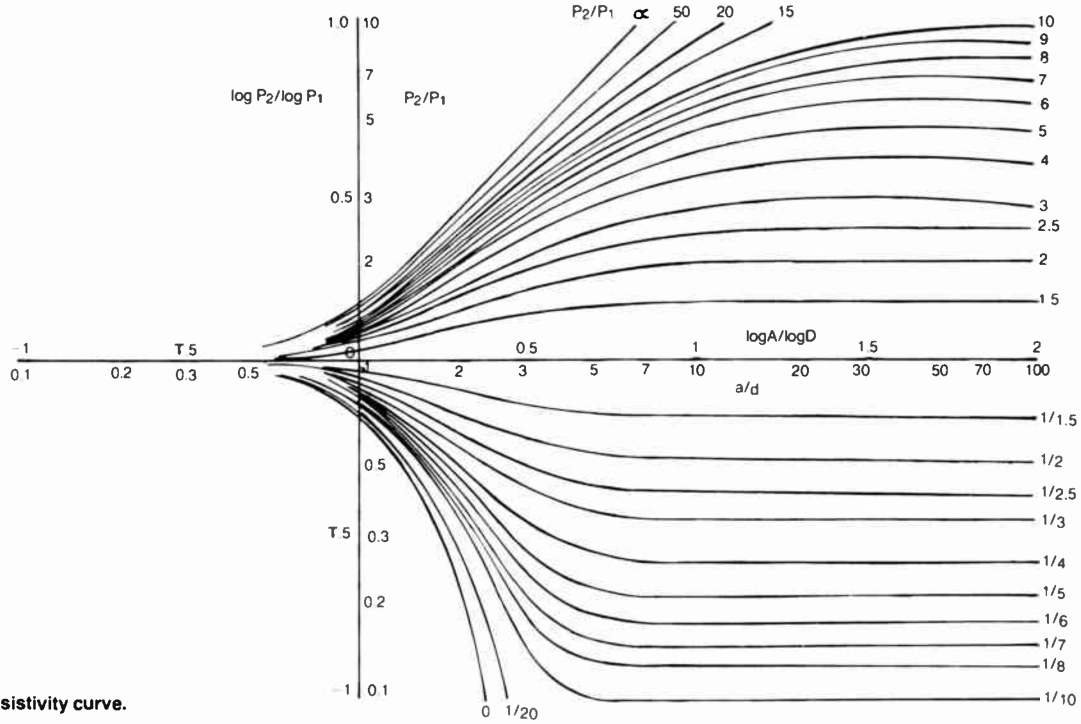


Figure 4. **Standard resistivity curve.**

The standard curves provided (Figure 4), are also constructed on log/log graph paper i.e: graph paper that is ruled in both directions at logarithmic intervals. Each major division on the paper corresponds to a power of 10 and is therefore called a decade. We suggest that for plotting your data you purchase semi-transparent paper that has three decades on either axis and a decade separation of 2½ inches. The 2½ inch decade separation is most important as paper having other decade separations will not allow your plotted results to be overlayed on the standard curves. This paper should be readily available from major stationary suppliers such as John Sands or Dymocks.

Figure 5 shows a typical plot of field data overlayed onto the standard curve.

To do this, place your plotted curve over the standard curve and slide it horizontally until you find the standard curve that best matches your plotted curve.

When the best matching curve has been found, note where the vertical axis of the standard curve intersects the 'ab' curve of your plotted data. This line extended vertically downwards to intersect the 'electrode separation' axis of your plotted data will show the depth of the first layer — in our example this is 4.25 metres.

We know from our plotted data that the resistivity *p*2 is about 1000 ohms/

Figure 5. **Typical field data plot superimposed over standard curve shown in Figure 4.**

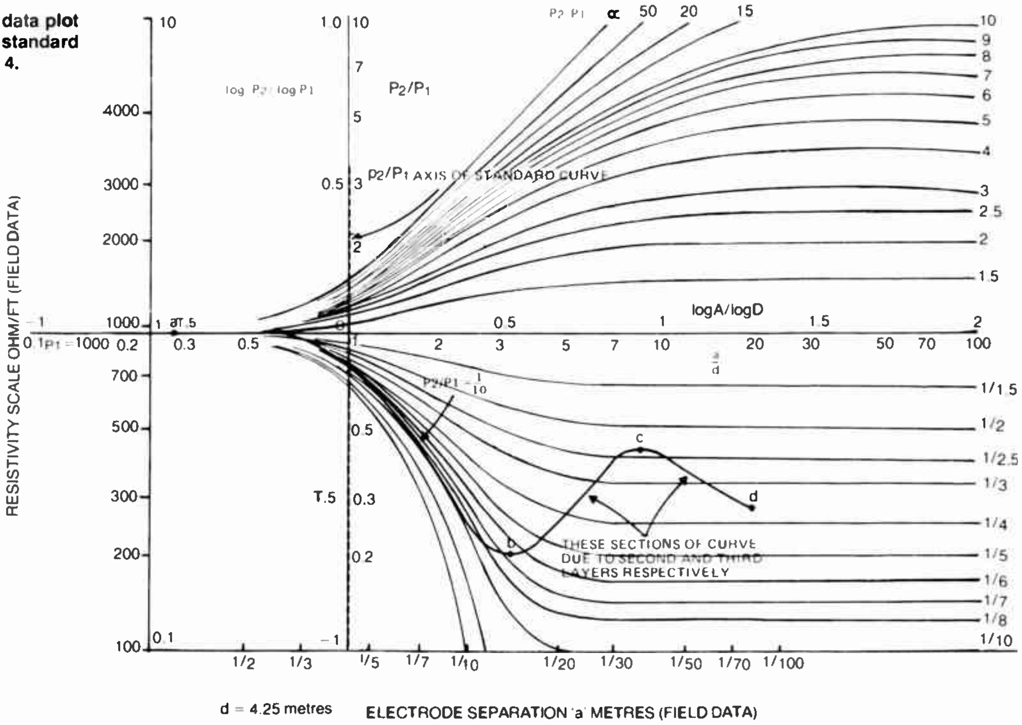


TABLE 1

Material	Resistivity (ohms/metre)
Clay	1-120
Water (fresh)	50
Sandstone	35-4000
Limestone	120-400
Granite	$5000-10^6$
Sand (dry)	$>10^6$
Marble	$>10^{12}$
Alluvium	Variable
Air	Infinite

metre and the standard curve that is a best match shows a $p2/p1$ ratio of one tenth, that is $p2$ equals 0.1 $p1$.

Thus $p2$ is approximately 100 ohms/metre. Relating these figures to Table 11 we see that the most likely strata formation is two layers of sandstone of different densities — or a top layer of sandstone and a lower layer of limestone.

From the section bc it is possible to calculate the resistivity and depth of the second layer but this requires the use of a second set of auxiliary standard curves. These are very complex and beyond the scope of this article. Similarly section cd provides data on the third layer and so on. There are a number of standard texts on such measurement and the interested experimenter should refer to these for further information.

Resistivity trenching

Another common application of the resistivity meter is in searching for buried objects such as large water mains, buried stream beds or underground sewerage tunnels. The method used is simply to decide approximately at what depth the object is likely to be found, and divide the distance by 0.6 to give a suitable electrode separation. Maintaining this same separation, the array of all four electrodes should be progressively moved in a line over the ground being explored. Readings of resistivity should be made at each point and the value plotted against distance moved. (See Figure 6 in our feature on Exploration Archaeology). The distance between each reading point should be no greater than half the dimension of the object to be located; in fact the closer the readings are taken, the greater will be the resolution.

If it is desired to follow the depth of bedrock beneath the surface, it is best to first carry out a vertical depth sounding to locate the bedrock. Then divide this depth by 0.6 to give the most suitable electrode separation. The depth sound will also tell you whether the bedrock has a higher or lower resistivity (from the ratio $p2/p1$). If $p2$ is greater than $p1$ then an increase in your measured resistivity will tell you that the basement is getting shallower and vice versa. Alternatively, if $p2$ is less than $p1$ an increase in resistivity will indicate that the basement is becoming deeper. This method is most suitable for looking for alluvial gold or heavy gemstones which tend to be concentrated in the hollows of the bedrock along alluvial creekbeds.

Earth electrodes should not be inserted into the ground to a depth greater than one-twentieth of the probe separation. Because of this, poor electrode/ground contact may result at close spacings. This problem can be reduced by using porous pots filled with copper sulphate solution. Electrodes specifically intended for such work are available from geophysical supply houses.

Figure 1. **The completed unit together with earpiece and search coil.**

The revealer

A.J. Lowe

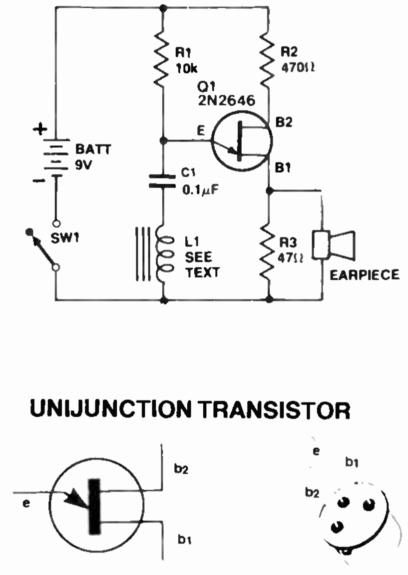


Figure 2. **Circuit diagram illustrates the simplicity of the unit.**

One of the simplest detector circuits of all times — its performance belies its simplicity.

HERE IS one of the simplest metal detectors of all time! It was originally designed to spot rust holes in cars which had been filled with epoxy, putty, etc, but has subsequently been used for a thousand and one other purposes where one needs to detect metal — or its absence — over short distances.

The detector consists of three elements — a search coil, the electronics (which are in a small tin) and the earpiece. The circuit generates a tone in the earpiece. When the search coil is placed over and close to steel, the tone changes significantly.

Thus by listening to the frequency of the oscillator one can readily tell whether there's steel — or something else — under the paint of a car. While moving the search coil over the suspect areas the note should remain steady. If it varies — take heed, all is not well.

The search coil

The search coil used in the prototype is a 1.5 henry choke of 85 ohms resistance and 10 mA rating, which happened to be on hand. The iron core is made of E and I laminations, with all the Es facing one way. After removing the choke from its mounting frame, the Is are discarded, thus leaving the choke with open-ended Es only.

The sensitivity of the search coil is increased by discarding about half of the E laminations, so that when the open ends of the remaining laminations are brought near any steel, then this steel makes a significant change in the inductance of the coil, and hence in the frequency of the oscillator.

On the prototype the remaining laminations were wedged securely with a wooden wedge, which also held a suitable small steel handle. See Figure 3.

Constructors who do not have a similar choke on hand should experiment with similar chokes, or small transformers. An old transformer with one winding open-circuited would do, as long as the coil in use is continuous. Practically any small transformer will work just try whatever is to hand. Naturally the smaller the search coil the better able it is to locate small flaws beneath paint.

Construction

Construction is not in any way critical. In the original model the components were mounted on a printed circuit board measuring 4.75 mm x 2.5 mm, and assembled with the battery in a small tin box which once held throat tablets.

The jack used for the earpieces was of the type used in some transistor radios,

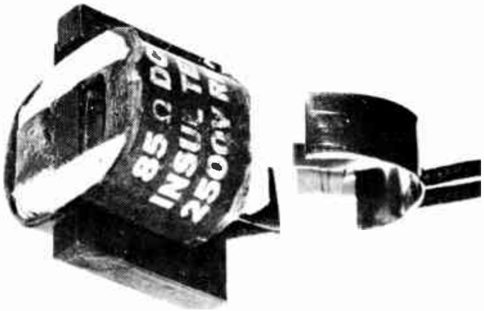


Figure 3. **The search coil may be constructed from an iron-cored coil having an inductance of 1.5 Henry and dc resistance of 85 ohms.**

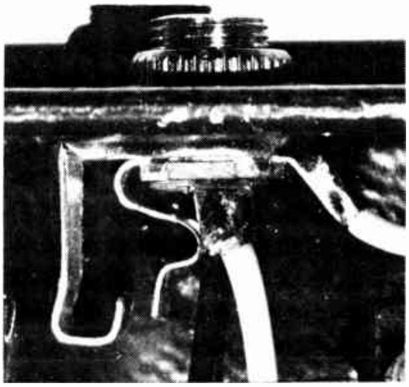


Figure 4. **The jack must be bent as shown so that the switch makes contact when the earpiece is inserted.**

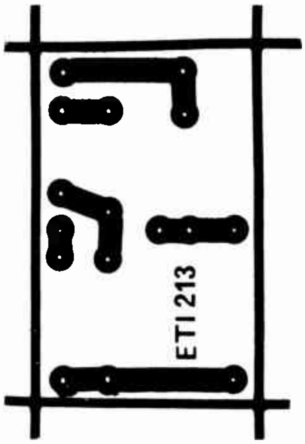


Figure 5. **A printed circuit board may be used (foil pattern shown here full size), or the unit may be assembled on tag strips or Veroboard.**

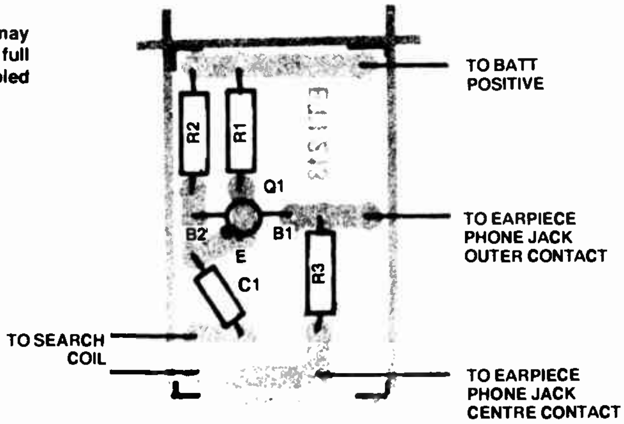


Figure 6. **Component overlay.**

with three terminals, and fitted with a normally-closed switch. Before use, this was adapted, by bending the fixed contact of the switch, so that the switch became normally-open, and was closed by the insertion of the earpiece plug. Figure 4 shows the jack after adaptation. The battery negative lead goes straight to one of the terminals of the jack.

This switch is used as the battery on-off switch, SW1 in Figure 2, so that the device is switched on simply by inserting the earpiece plug.

If constructors use a choke different from that in the original then they should experiment with the value of the capacitor C1 to adjust the frequency of the oscillator to a satisfactory value. The layout of the copper side of the printed circuit board is shown in Figure 5. Figure 6 shows the component positions on top of the pc board.

Constructors who are not equipped to make a little pc board could easily mount the components on a tag strip or on Veroboard.

Well there it is — a one evening low cost project, but it could save its maker hundreds of dollars on his next car deal.

HOW IT WORKS

The tone is generated by a unijunction transistor relaxation oscillator. This oscillator is quite conventional except — that, in addition to the usual capacitor between the emitter and negative rail, there is an inductor in series with the capacitor (Figure 2).

The value of this inductance determines the frequency and tone of the note generated.

The indicator is actually the search coil, and its inductance is varied by the proximity of steel to the open ends of its iron core.

When the inductor search coil is close to steel the frequency of the note decreases, when there's no steel there it remains high.

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.

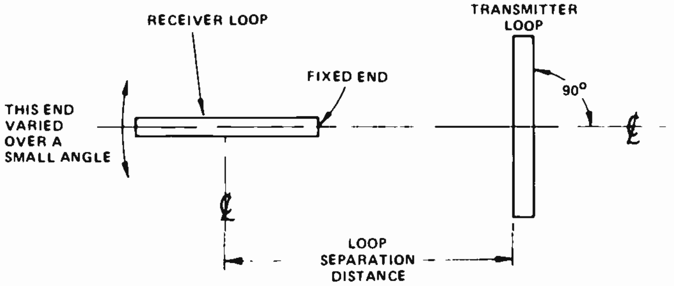


Figure 1. The 'Induction Balance' principle employed in the ETI-566.

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 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 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 frequency. 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

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.

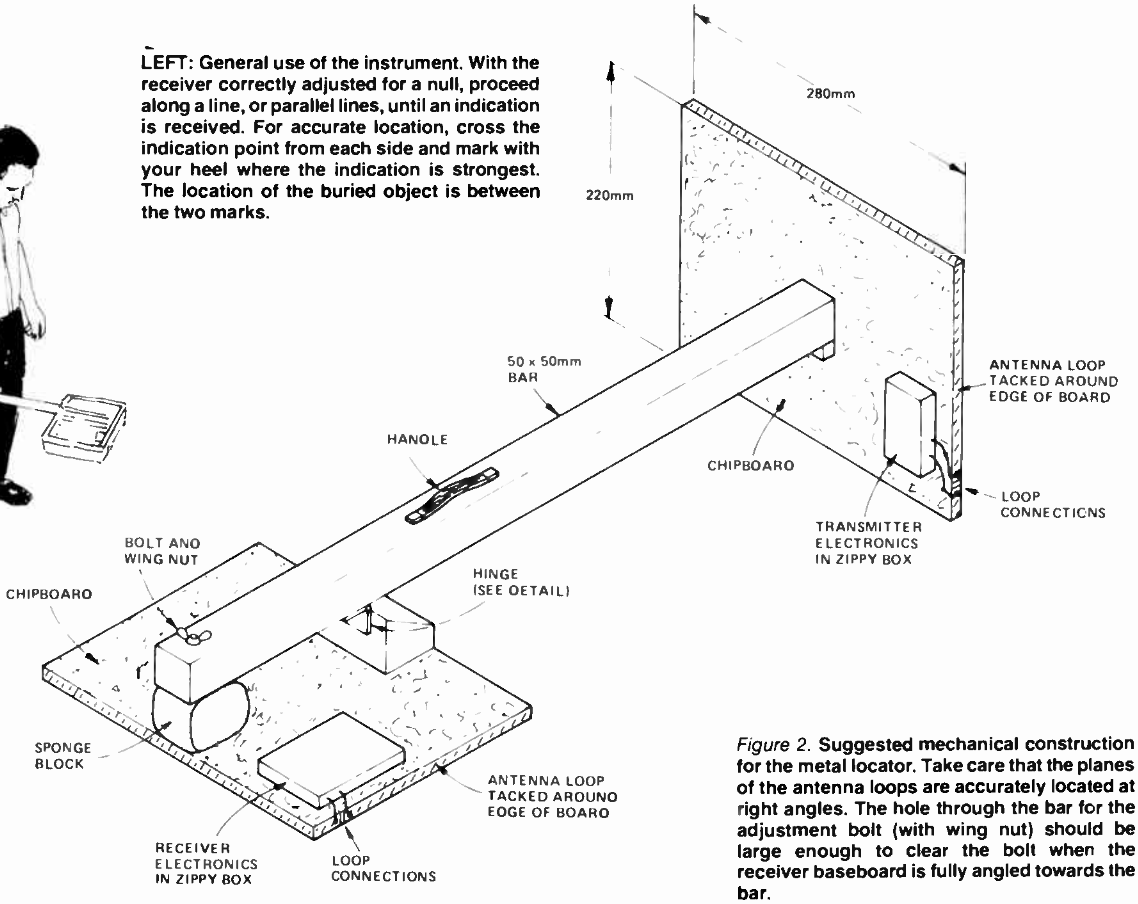


Figure 2. **Suggested mechanical construction for the metal locator. Take care that the planes of the antenna loops are accurately located at right angles. The hole through the bar for the adjustment bolt (with wing nut) should be large enough to clear the bolt when the receiver baseboard is fully angled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

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 unit's sensitivity to small objects, but at the expense of penetration.

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 it's practical! There are plenty of possibilities — which we'll 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 hingeing 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 ¼" Whitworth nut. The nut is forced into this hole. A corresponding hole is drilled in the bar. A ¼" Whitworth bolt, 6" (150 mm) long, with a wing nut screwed up to the head, 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 100 μA, 200 μA or 1 mA 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

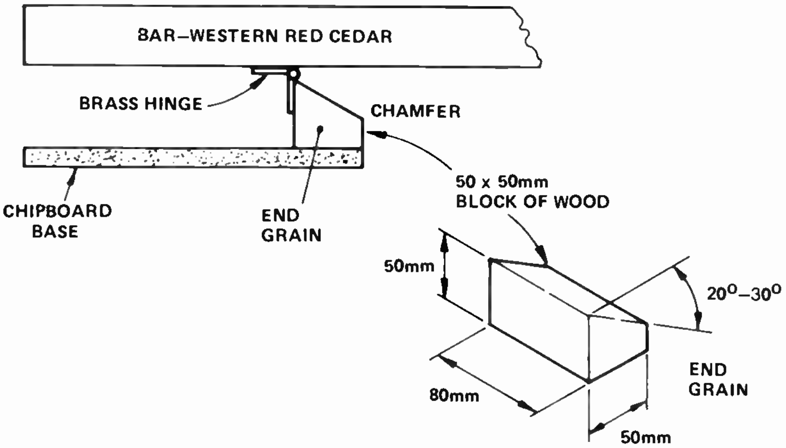


Figure 3. **Hingeing arrangement for the receiver antenna baseboard.**

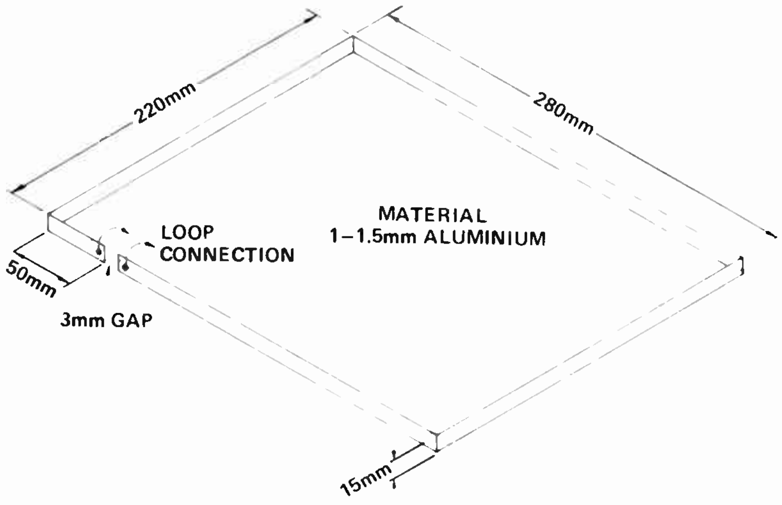
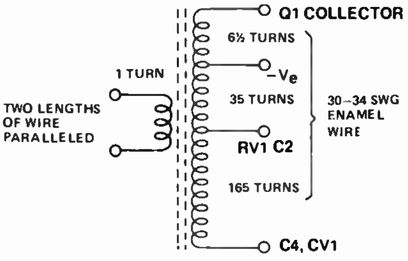


Figure 4. **Dimensions of the antenna loops. The 'break' for the loop connections need not necessarily be as indicated here, but could be located at a corner or midway along one side.**

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.



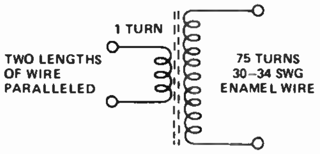
TRANSMITTER COIL (L1)

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

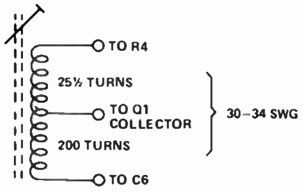


ETI-566B (Rx) — L1

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



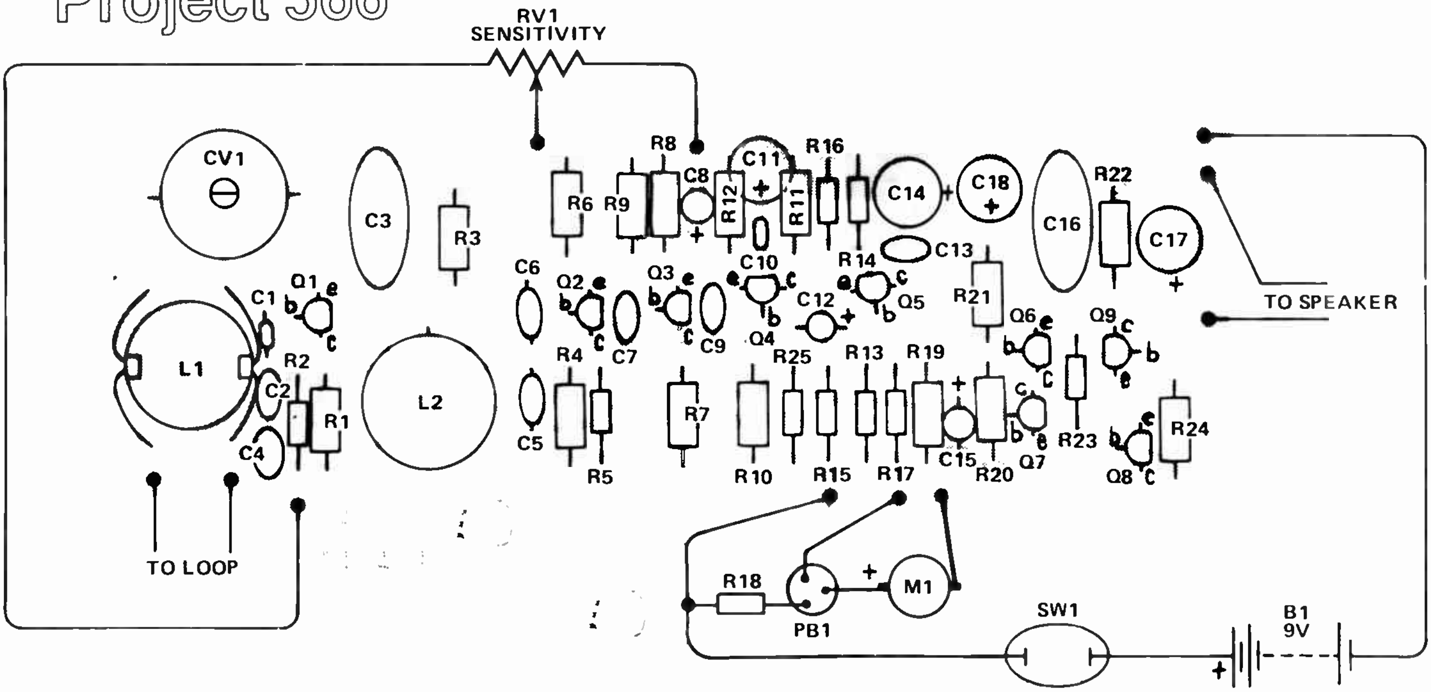
L = 16mH (ADJUSTABLE

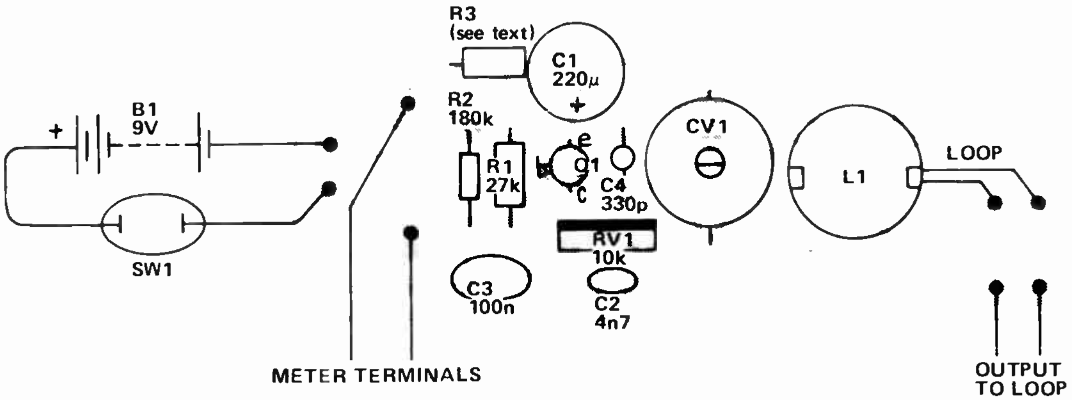
ETI-566B (Rx) — L2

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 ½W, 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 ½W, 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.

to accept a variety of trimmer capacitors.

The meter shown is a 200 μA type. However, if it is unavailable a 100 μA 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 9 V 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 9 V batteries may be used, but they won't last too long with prolonged use. (Alkaline types in this size might be OK, though).

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 adjustor 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 ¾ 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 arm's 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 ¾ 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 di-

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.

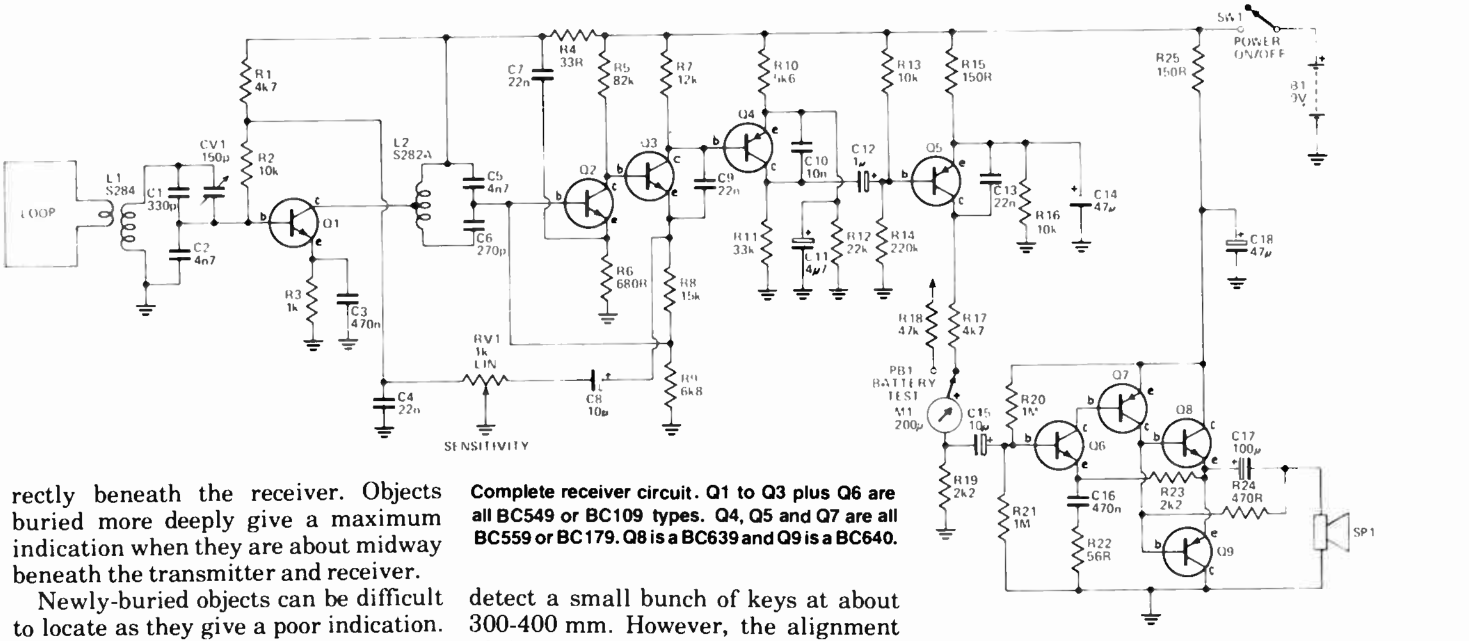
2) Turn on receiver and set the gain to about ¾ range.

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.

rectly 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.

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

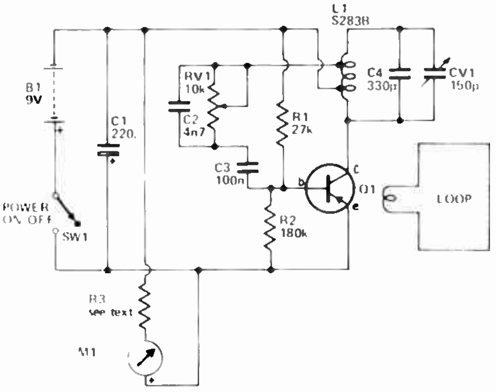
Experimentation

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



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 trimpot, 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.

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 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 arm's 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 it's 'fiddly' to adjust the receiver antenna alignment. An extra attachment could be fashioned to perform the same task. We'll 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, it's up to you. Good luck!

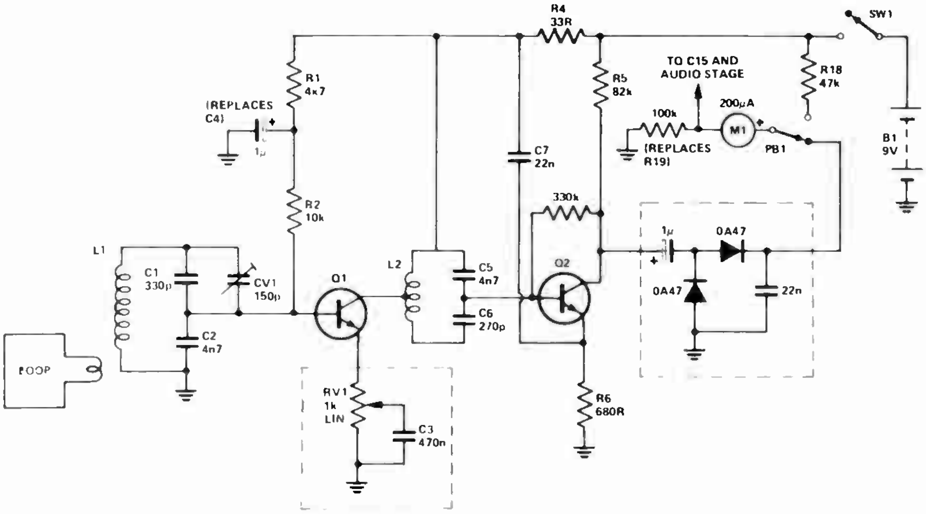
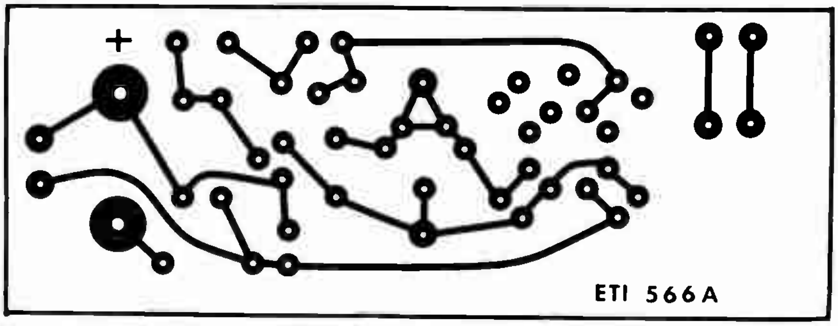
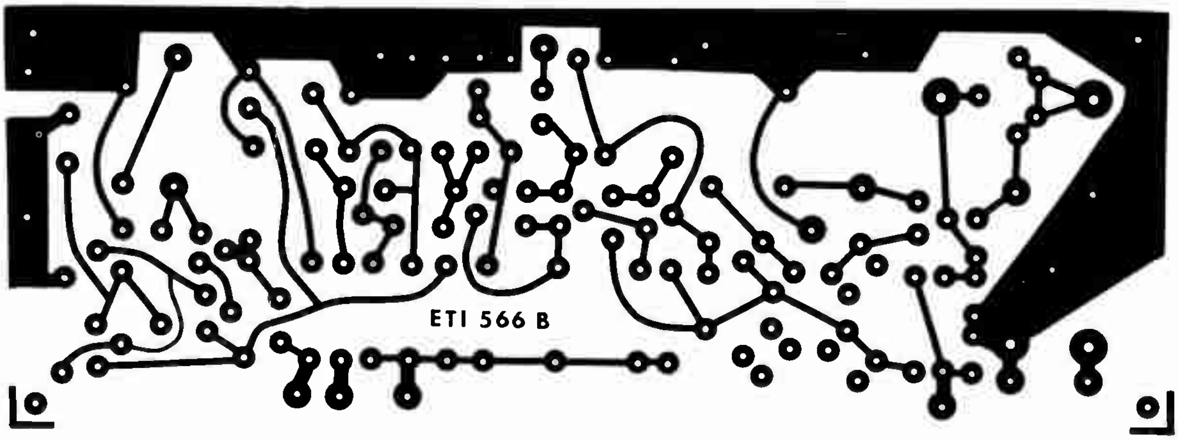
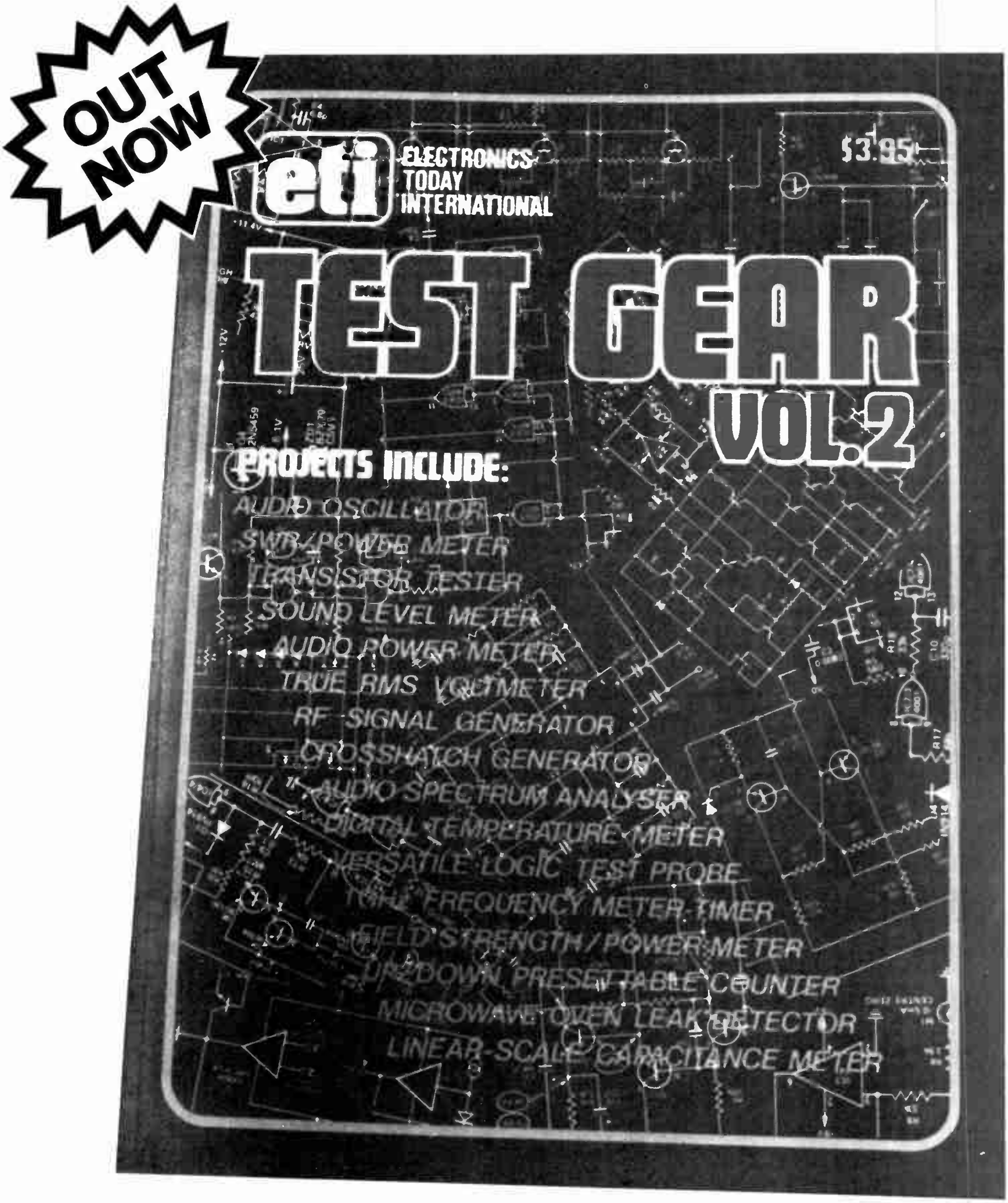


Figure 5. Suggested alternative for a simpler, lower gain receiver. This may prove a better proposition where small, close-spaced antenna loops are used. The original pc board may be used, the unnecessary components being removed. Major changes are shown inside the dashed squares. A voltage doubler diode 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.







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Simple, sensitive Geiger counter

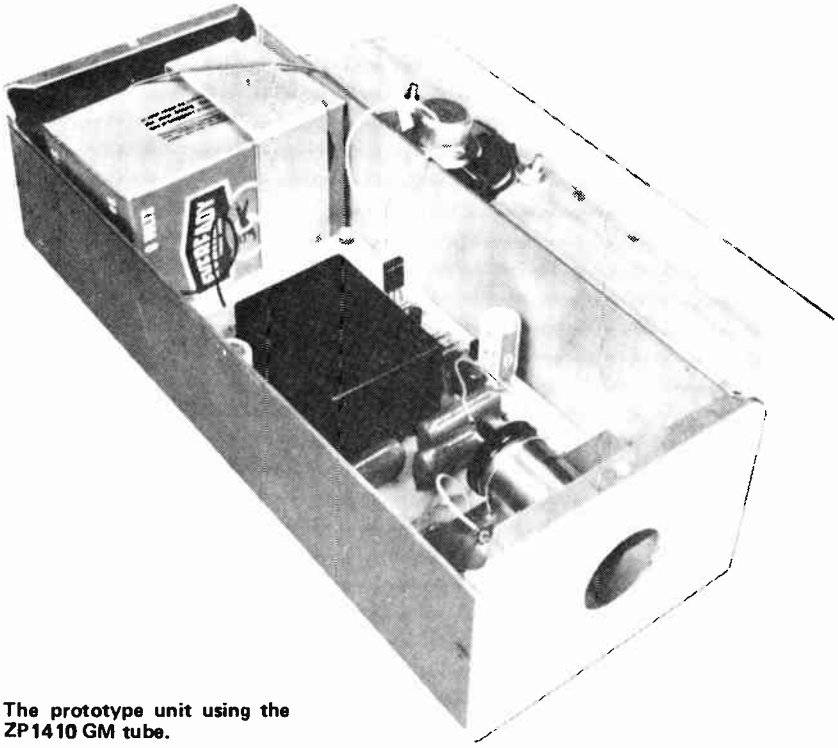
Radioactivity is a fascinating subject. The more you learn about it, the more questions there are to ask! This project is simple to construct and relatively inexpensive. It should prove of great interest to science teachers, students and anyone generally interested in radioactivity.

David Tilbrook

IN 1896, Henri Becquerel announced the discovery of radioactivity. He had been experimenting with the element uranium and found that it spontaneously emitted energy, without activation by another energy source. Immediately, researchers started the quest for other elements that might also exhibit this property of natural radioactivity. Pierre and Marie Curie isolated two new elements from a uranium ore called pitchblende. Naming these elements polonium and radium they discovered their new elements were enormously radioactive. Polonium for example, is approximately 10 billion times more active than an equivalent mass of uranium.

The radiation emitted by radioactive elements was at first likened to X-rays, discovered only four months earlier, but it was Ernest Rutherford who first found that there was more than one kind of radiation. The most obvious difference was the ability of the radiation to penetrate matter and he called the least penetrating radiation α (alpha) rays, and the other more penetrating radiation β (beta) rays. Magnetic field deflection of the rays showed that β rays were in fact free electrons. Further work carried out by Rutherford on the α ray showed that it consisted of particles also and had a positive charge equal to the charge of two protons. The particle of the α ray was later proved to be the nucleus of the element helium, consisting of two protons and two neutrons bonded together. The poor penetrating ability of the particle is thought to be due to its positive charge and the repulsive force it will experience if it approaches the nucleus of an atom.

In 1900 a third kind of radiation was discovered. Called 'gamma' (γ) radiation, it was found to have tremendous penetrating power because of its neutral charge. Gamma particles turned out to be electromagnetic radiation, the same as light, but with much higher energy.



The prototype unit using the ZP1410 GM tube.

Measuring radioactivity

With the development of the understanding of radioactivity it was necessary to invent detectors which would enable the radiations to be recognised and measured. The most sophisticated of these is the *bubble chamber*. A development of earlier cloud chambers, these devices enable the tracks of nuclear particles to be studied, the particles themselves being recognised by the characteristic 'tracks' they make in the chambers.

Just as important are the simpler radiation detectors, the *scintillation counter* and the *geiger counter*. These enable the presence of radiation to be recognised and measured quickly and conveniently.

Scintillation counters use a crystal that fluoresces when a particle travels through it. This crystal is mounted on top of a sensitive photomultiplier, which will detect any generation of a light pulse in the crystal. Scintillation tubes however are expensive and require a complicated power supply and amplifier, making them unsuitable for home construction. The geiger counter, on the other hand, is simple to construct and inexpensive.

Geiger counter

Since this project is designed as a general purpose geiger counter I have made it compatible with two GM tubes. These are manufactured by Philips and are designated ZP1310 and ZP1410. The ZP1410 is an end window α, β and γ sensitive tube and is therefore more expensive than the ZP1310. It is also more fragile and the end window should not be touched. The ZP1310 having no end window will only detect particles with sufficient energy to penetrate the tube, such as higher ▶

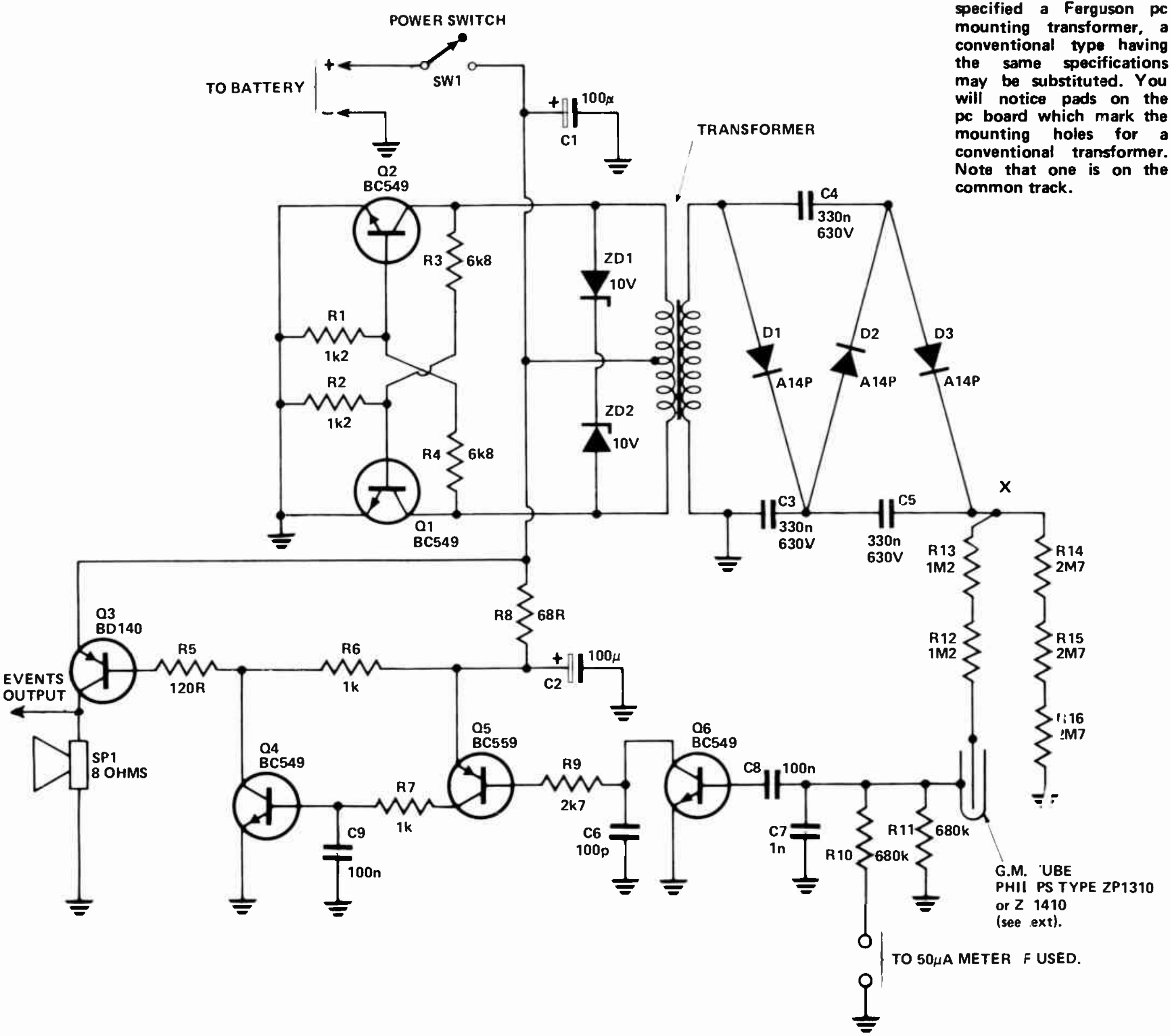
HOW IT WORKS – ETI 562

The geiger tubes specified for this project have plateau regions around 600 V. To obtain this voltage from a six or nine volt battery the circuit uses an astable multivibrator, formed by O1 and Q2, driving the 12 volt side of a Ferguson pc board mounting power transformer. This is normally the secondary side of the transformer but in this circuit it is used as the primary. Zener diodes ZD1 and ZD2 limit the voltage that can be applied to the primary of the transformer to around 10.5 volts, and this gives approximately 200 volts on the secondary. Diodes D1, D2 and D3, and capacitors C3, C4 and C5 form a voltage tripler that produces 600 V at the point marked X on the circuit diagram.

This voltage is applied to the anode of the GM tube via two 1M2 resistors R12 and R13. Most common ½W resistors have maximum voltage ratings around 270 volts, so it is necessary to use the series combination of R12 and R13 to provide the series anode resistance for the tube, rather than use a single 2M2 resistor. Resistors R14, R15 and R16 discharge the supply after turn-off and help to stabilise the anode voltage by providing a slight current drain on the tripler at all times.

When a particle enters the tube, ionisations take place and a current pulse flows through the tube via R11 to ground. This pulse causes a momentary voltage rise across R11. When this voltage gets to 0.6 volts the base emitter of Q6 is turned on, causing Q5 to conduct momentarily. This provides a pulse onto the base of Q4, driving Q3 to produce a pulse in the loudspeaker.

The capacitors C2, C6, C7 and C9 provide filtering, primarily to remove any injection from the multivibrator.



Note: although we have specified a Ferguson pc mounting transformer, a conventional type having the same specifications may be substituted. You will notice pads on the pc board which mark the mounting holes for a conventional transformer. Note that one is on the common track.

energy β particles and γ particles. Fortunately most radioactive elements emit all three radiations so the ZP1310 is entirely adequate for most purposes.

Construction

The construction is reasonably simple, since it is mostly confined to the printed circuit board. Start by mounting the resistors and capacitors on the pc board. Then mount the transistors, diodes and power transformer. Be sure the transistors, diodes and electrolytic capacitors are connected the correct way around. The pc board has provision to drive a 50 uA meter movement although I did not use this facility when building the prototype. The biggest problem is one of calibration. The meter is useless unless one has access to a calibrated reference instrument. For most purposes it is sufficient to use the click rate as an indication as to how radioactive a sample is.

If the ZP1310 tube is used it is mounted directly onto the pc board. Do not solder directly to the anode of the tube. The tube should be supplied with an anode connector. Solder this onto the pc board first and then plug the tube into it. If the tube is not supplied with an anode connector remove one of the socket pins from a 9-pin valve socket and use this instead. Once the anode is connected the cathode strap supplied with the tube can be soldered to the pc board. Do not solder directly to the GM tube to make the cathode connection. If you are using the ZP1410 tube, this must be mounted so that it is insulated from the case and connecting wires taken back to the pc board. I used a piece of pc board that is mounted on insulated 25 mm spacers. The tube is fixed to the board using two wire loops, around the tube and through holes drilled in the board. The cathode connection to the tube is made by soldering the cathode strap onto the small pc board. As with the ZP1310 do not solder directly to the anode of the tube. Use an anode connector if it is supplied or a socket pin from a 9-pin valve socket.

Once the board is completed it can be mounted in a suitable chassis. I used ▶

PARTS LIST - ETI 562

Resistors .... all ½W, 5%

R1	1k2
R2	1k2
R3	6k8
R4	6k8
R5	120R
R6	1k
R7	1k
R8	68R
R9	2k7
R10	680k
R11	680k
R12	1M2
R13	1M2
R14	2M7
R15	2M7
R16	2M7

Capacitors

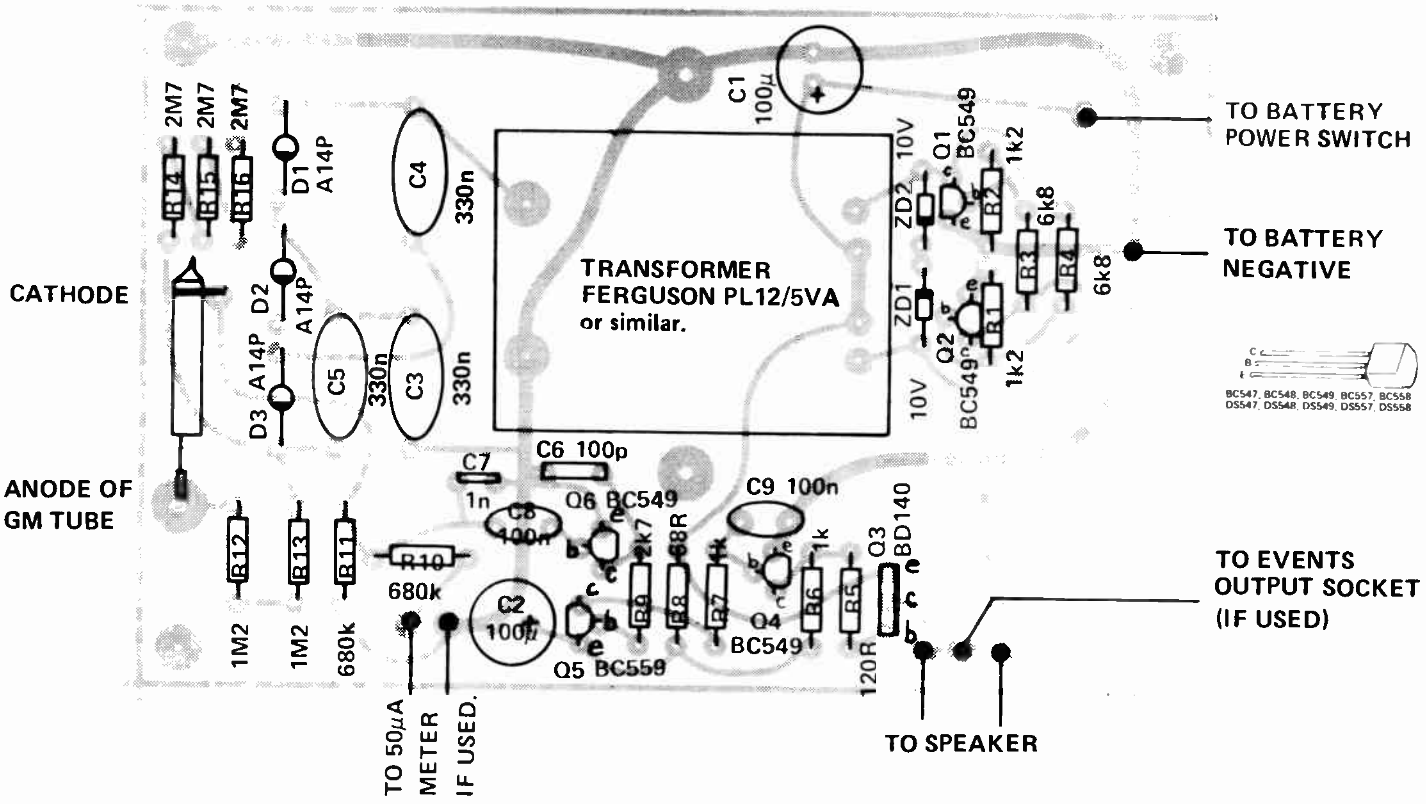
C1	100u 25V electrolytic
C2	100u 25V electrolytic
C3	330n 630V greencap
C4	330n 630V greencap
C5	330n 630V greencap
C6	100p disc ceramic
C7	1n greencap
C8	100n greencap
C9	100n greencap

Semiconductors

Q1	BC549
Q2	BC549
Q3	BD140
Q4	BC549
Q5	BC559
Q6	BC549
D1, D2, D3	A14P or similar 1000V piv diode
ZD1, ZD2	10V 400mW Zenner diode

Miscellaneous

1 x pc board ETI562; 1 x Ferguson pc mounting power transformer; 1 x ZP1310 or ZP1410 geiger tube (see text); 1 x Horwood aluminium chassis, type 34/10/DS; 1 x battery - Eveready 276-P or equiv.; 1 x on/off switch, spst; 1 x chassis mounting RCA socket; assorted nuts, bolts, washers etc.



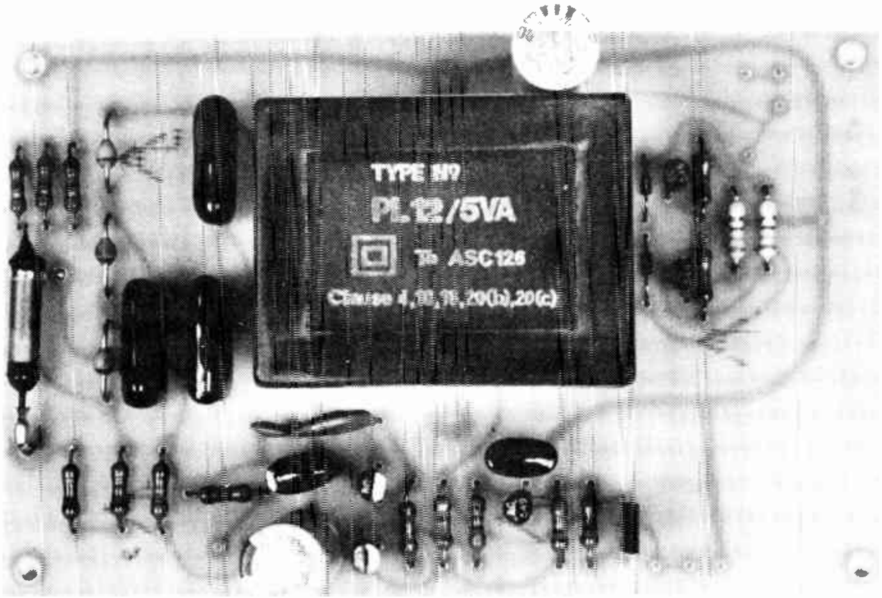
a Horwood type 34/10/DS, in which everything fits quite nicely. The circuit operates from six to nine volts and the battery used in the prototype was an Eveready type 276-P. This is a nine volt battery and is best mounted using a bracket of bent-up aluminium. The circuit pulls around 50 mA, so whatever battery you choose make sure it is capable of delivering this amount of current.

Powering up

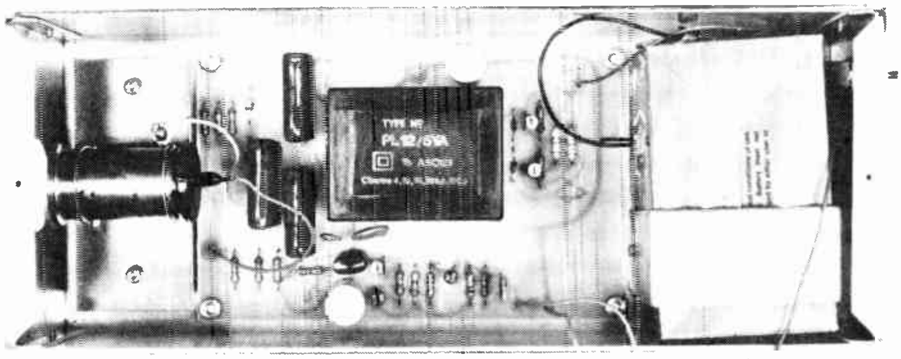
Before applying power to the circuit check the pc board layout. Make sure that all polarised components have been mounted on the pc board correctly. Make a special check of the two 10 V zener diodes. These regulate the voltage that is applied to the tube so it is important that they are inserted correctly. If all is well connect the battery and measure the voltage at point X on the pc board. This is the output of the voltage multiplier and the voltage at this point should be between 550 V and 650 V.

The moment the unit is turned on it will start to detect background radiation. The unit will 'click' once every couple of seconds. This background radiation is caused mainly by cosmic radiation.

Some older watches used small amounts of radioactive isotopes to activate the luminous dial. Even if the dial has long since lost its luminosity it will still be radioactive. If this watch dial is brought near the geiger counter the count rate will increase significantly. ●



Overall view of the pc board of one unit constructed using the lower cost beta/gamma GM tube, ZP1310. Be careful with the anode and cathode connections, as explained in the text.



The alpha/beta/gamma-sensitive GM tube is an end-window type and requires a different mounting method. I secured the ZP1410 to a small piece of pc board, as described in the text, mounted in the end of the case. The tube's window must be aligned with the hole in the case end.

THE GEIGER MULLER TUBE

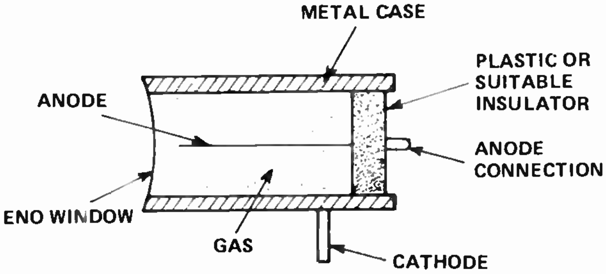
This consists of a metal tube or cylinder, hermetically sealed and filled with a gas at less than atmospheric pressure. If the tube is intended for the detection of alpha particles (as well as beta and gamma radiations), it will be constructed with an 'end window', as illustrated here. Since alpha particles have so little penetrating ability the window must be extremely thin. Thus, the windows are difficult to manufacture and are *fragile*.

Geiger tubes constructed to detect only beta and gamma radiations do not have an end window, otherwise construction is similar.

In the centre of the tube is a wire ANODE. The metal cylinder itself serves as a CATHODE. In operation, a high voltage is connected between the anode and the cathode, anode being positive with respect to the cathode.

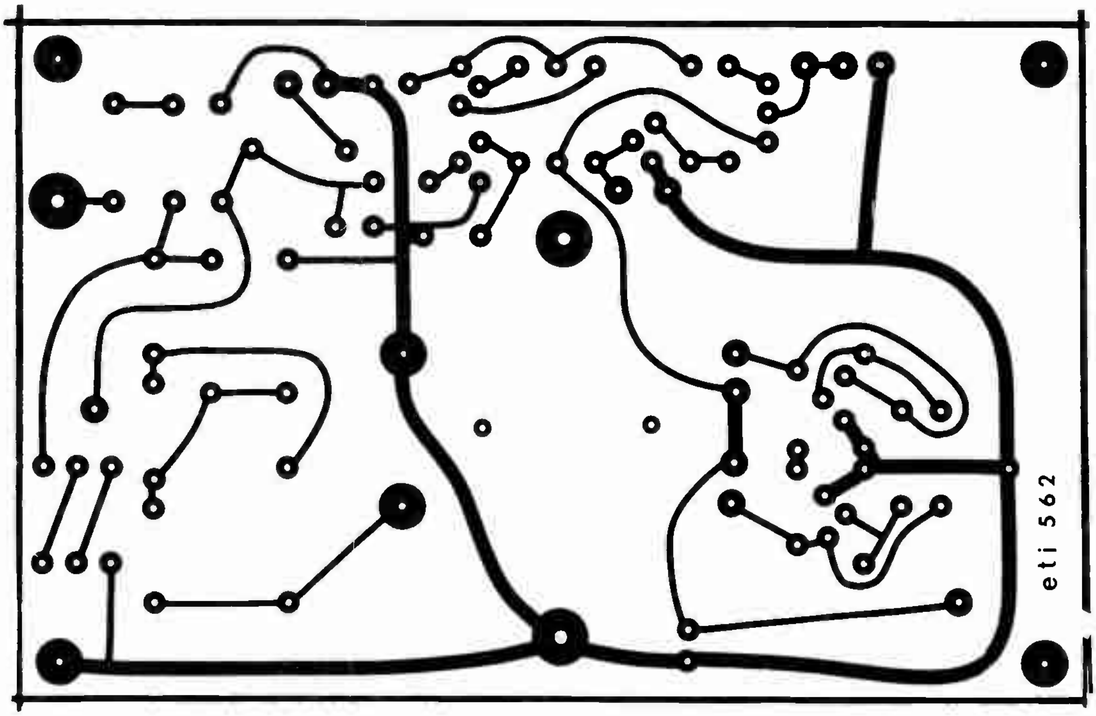
As the voltage between the electrodes is increased, the tube goes through three phases: if the voltage is lower than a particular value, the gas in the tube will not be ionised and no current will flow. Above this particular voltage (the 'striking' voltage), the gas ionises and a small current flows continuously through the tube. This is the phase in which the tube is operated — referred to as the "plateau region". If the voltage is increased even further still the tube will enter the third phase — that of arc discharge between the anode and cathode. If the tube is allowed to operate in these conditions it will almost certainly be damaged.

When a particle enters the tube operating in its plateau region, it ionises the gas further and the ions produced are accelerated towards the cathode, electrons towards the anode. These moving ions cause further ionisations and an avalanche of ions (and electrons) occurs.



A TYPICAL END WINDOW G.M. TUBE

When the tube is operated in its plateau region a single particle of radiation will cause an avalanche of millions of ions and electrons. Each avalanche is registered as a momentary increase in the current through the tube. This current pulse can be detected as a voltage pulse across a resistor connected in series with the tube. If the voltage pulse is coupled to a sensitive audio amplifier driving a loudspeaker, a sharp 'click' will be heard. Each 'click' from the geiger counter represents the incidence of a particle on the GM tube.


eti 562

ALL TOGETHER !

— the top projects from the past few years' issues of ETI !

Assembled in one great volume, here are more than 25 projects including: the Series 4000 stereo hi-fi amplifier system; the superb Series 4000 four-way speaker system; the monstrous 300 W amplifier module; Guitar Practice Amp; Fuzz/Sustain Unit; Electronic Tuning Fork; Aircraft Band Converter; Analogue Frequency Meter; Linear Scale Capacitance Meter; Electronic Ohmmeter; Ultrasonic Switch; Radio Remote Control Unit; Transistor Assisted Ignition; Theatrical Lighting Controller; Electromyogram; Disco Strobe . . . and many more.

On sale now at newsagents and selected specialist suppliers. If sold out (highly likely), you can obtain a copy from **Electronics Today International, Subscription Department, 3rd Floor, 15 Boundary St, Rushcutters Bay NSW 2011.** *Send $3.95 plus 65 cents post and handling.*

Tools and techniques in radiometric exploration

All areas of geophysical exploration are becoming increasingly dependent on electronic instruments in the search for minerals and energy sources. Radioactive minerals in particular are in great demand. Here's a rundown on the instruments used and how they are employed.

Malcolm J. Plunkett

URANIUM EXPLORATION started in earnest after the second world war when "every man and his dog" was selling up and heading for the bush with geiger counter in hand. At that time, the major deposits were discovered purely by surface indications of radioactivity. However, that era is virtually at an end, and future finds are more likely to be below the surface or in inaccessible areas. The Roxby Downs deposits in South Australia for example are over 300 metres below the surface.

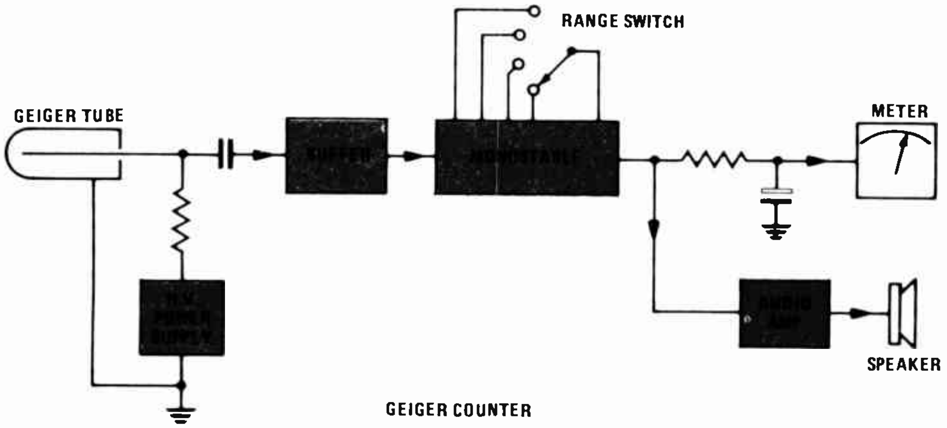
It has been necessary therefore to refine existing prospecting techniques, develop new ones, and improve the sensitivity and discrimination of all instruments in radiometric measurement techniques in common use, and to give some insight into the various methods of radiometric surveying.

As mentioned before, Geiger counters were the major instrument in use in early uranium exploration and while other detectors are now available, the Geiger counter still has a place in preliminary exploration and radiation monitoring. A Geiger tube consists of a hollow metallic cylinder with a centrally-located wire inside. The whole system is either sealed in a glass cylinder or the outer metal tube is used as the sealed chamber with appropriate end insulation. The cylinder is evacuated and filled with a gas such as helium, argon or neon, plus a small percentage of an organic or halogen gas as a 'quenching' agent.

A high voltage is applied between the central wire and the outer tube, so that when a gamma ray enters it, the gas filling ionises and causes a discharge. The discharge is quickly quenched or extinguished by the quenching agent, resulting in a relatively large current pulse through the tube that can be easily measured. The gamma rays must be stopped completely for a discharge to occur, which results in a very low conversion efficiency for Geiger tubes of only 1%, as only one in each hundred rays is completely stopped. This insensitivity can be useful however, as the Geiger counter can be used in areas of very high radioactivity without the count rate becoming excessive.

The Geiger counter circuitry shown in the accompanying block diagram is quite simple using a monostable to give a constant width to the pulses, which are averaged over several seconds so that the count rate is proportional to the average dc level. The range switch can change the monostable width, or the meter resistor, or both, to get the correct division ratios. To maintain accuracy with this system, it is important to keep a constant pulse height and stable pulse width. Although the high voltage supply can be very low powered, it is important to keep the output voltage stabilised and within the admissible operating voltage range (known as the counting plateau).

Block diagram of a typical commercial Geiger counter. The monostable has provision for selecting preset pulse widths ('RANGE') for differing count rates, depending on the level of radioactivity being measured. The monostable output is differentiated by a CR network and drives a meter calibrated in counts per second.



Scintillation counters

Scintillation detectors are the basis for almost all modern radiometric exploration instruments. As with the Geiger tube, the principal of operation is quite simple. However, the method by which the electrical pulses are produced is ▶

A typical scintillation counter manufactured and marketed in Australia. This model has selectable ranges and an audio output as well as a meter indicating counts per second.

completely different. The detector assembly consists of a scintillation crystal which is optically coupled to a photomultiplier tube. The crystal is usually made of thallium-activated sodium iodide which has the property of emitting a small flash of light (scintillation), when a gamma ray is stopped in it. The photomultiplier tube is a light amplifier which gives out an accurate, amplified reproduction of the light flash in the crystal, in the form of a short electrical pulse (approx. 2 us).

The great advantage of this rather indirect method of detection is in its efficiency, which approaches one hundred percent. Special protection is needed for scintillation crystals and photomultiplier tubes, which results in an instrument which is less rugged, more expensive, but far more sensitive than a Geiger counter. The circuitry of a simple scintillation counter is very similar to a Geiger counter, but usually with extra ranges for the higher count rates.

Radiometric ground surveying

In the search for unknown uranium deposits the ground is traversed on a regular grid, noting the readings at set intervals. The chance of finding an outcrop on the surface is very low, so it is important to note any change in the normal background radiation level, as even a metre or so of soil may have a considerable masking effect. If an area of high radioactivity is located, it would be very premature to stake a claim at this stage. Firstly, the material may be thorium, potassium, or uranium or a combination of them. These can be distinguished from each other because the radiation they produce has characteristic energy levels, resulting in different height pulses from the photomultiplier tube. By counting only three narrow ranges of pulse heights, the ratio of the three radioactive elements can be determined.

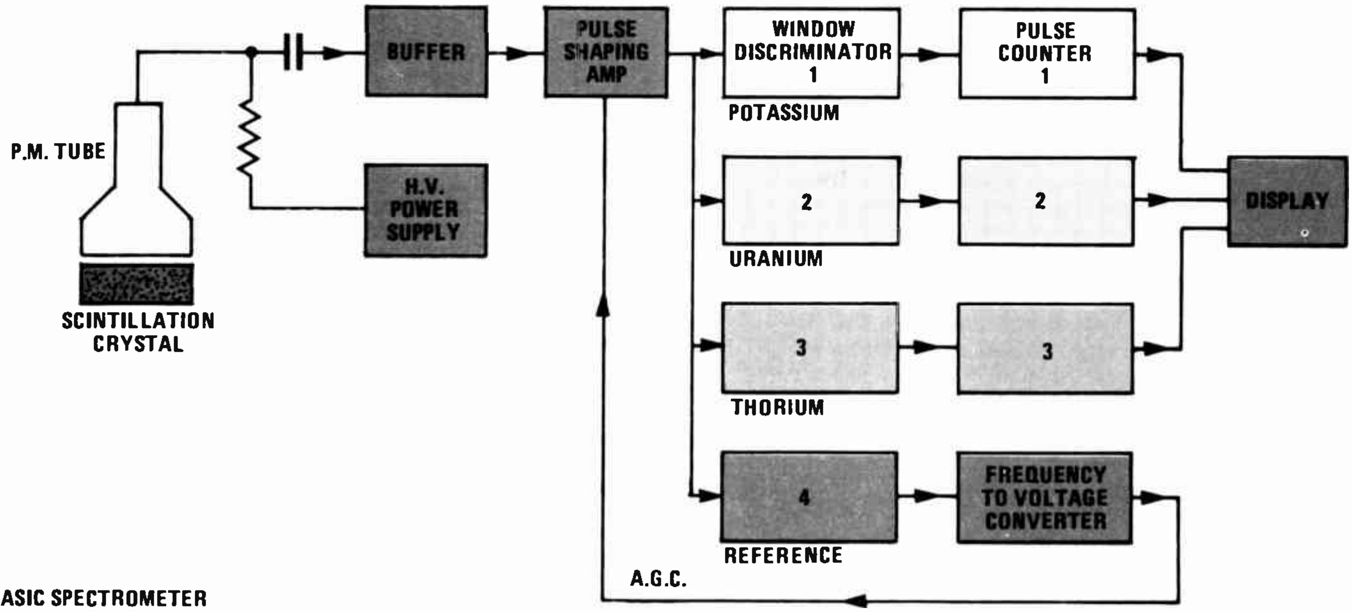
This is known as 'pulse height spectrometry' and is beyond the capabilities of a simple scintillation counter and impossible with a Geiger counter. The scintillation crystal used in spectrometers must be large to obtain good results, and the circuitry must be highly stable and temperature compensated. A fourth channel is sometimes used to monitor the pulses from a small quantity of radioactive material which is doped into the crystal, to allow automatic temperature compensation.

A problem encountered with all radiation measuring instruments is that the emissions are random, requiring the circuitry to be ready to accept pulses

THE BASICS

Uranium exploration is based on the measurement of naturally occurring radioactive elements. All igneous and sedimentary rocks contain variable amounts of the three main naturally occurring radioactive elements, uranium, thorium and potassium. The average concentration of these elements is only 0.1 — 10 parts per million, while uranium ore may have a concentration of several percent.

An element is considered to be radioactive when the atoms of which it is made disintegrate spontaneously, causing it to decay and form new elements known as daughter products. As it decays it may emit several types of radiation, however the one of interest to us is gamma radiation. Gamma rays have no mass, no charge, and can be regarded as highly penetrating electromagnetic radiation. The measuring device must therefore have a detector for converting these gamma rays into electrical pulses which can be counted for a fixed time period, or averaged as in a car tachometer.



BASIC SPECTROMETER

separated by only a few microseconds when the average time between pulses may be 100 milliseconds. It is clear then that a simple monostable system would not be suitable, and pulse height spectrometers must employ sophisticated pulse shaping and counting circuits to minimise these problems.

Even spectrometers cannot always determine the usefulness of a deposit, as leaching and weathering can remove the original uranium, leaving only the radioactive daughter products behind.

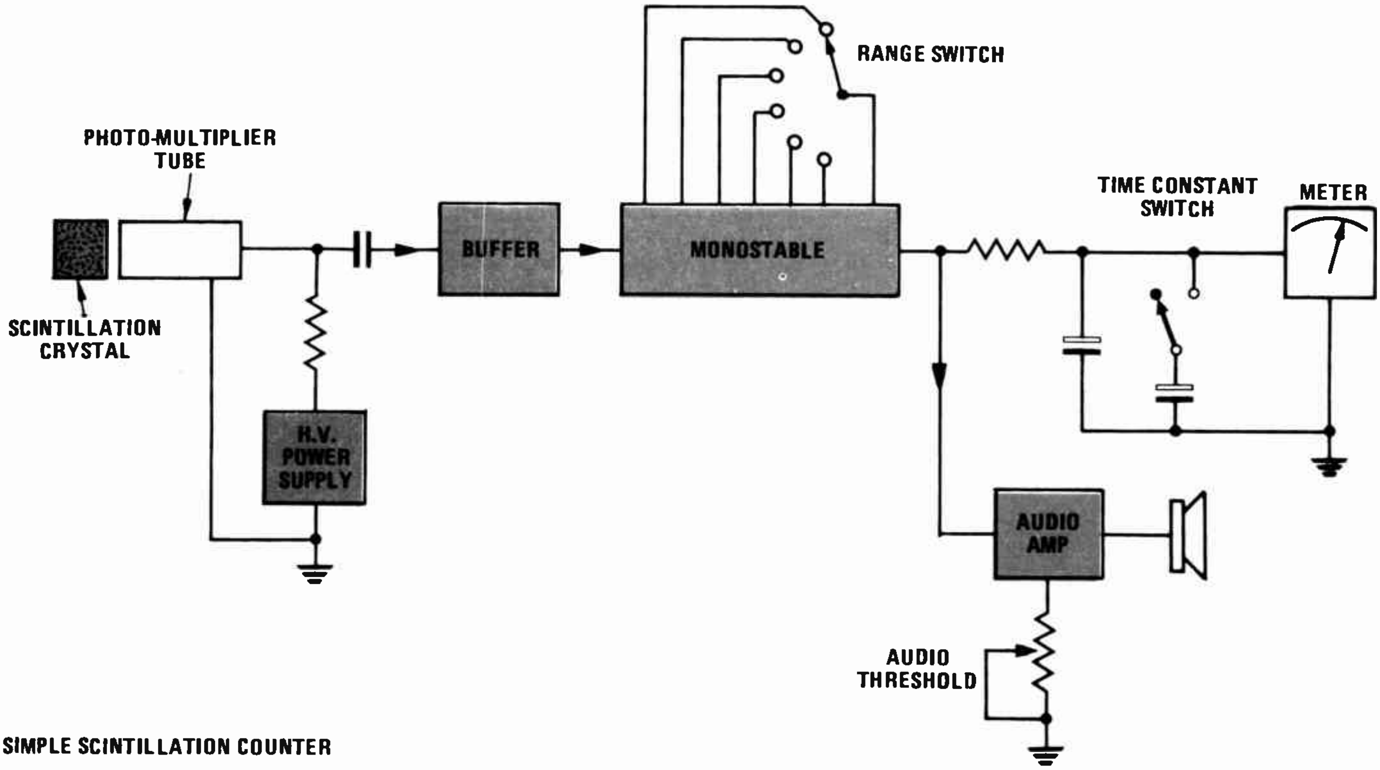
In conclusion, it can be seen that finding naturally occurring radioactive material is relatively simple, but finding out exactly what you have found is considerably more difficult!

Airborne radiometric surveying

Airborne radiometric surveys have been carried out for many years but even using the latest airborne spectrometers, the results can only be used as a guide. The plane must fly on regular grid lines recording the quantities of uranium, potassium and thorium, as well as the total radiation, on strip chart recorders or magnetic tape. The readings are used to produce radiometric contour maps on which the 'peaks' indicate areas of high radioactivity, known as anomalies. However the size and intensity of the anomaly cannot directly determine the actual extent of the deposit, due mainly to the masking effect of any overlying material. Problems also arise with pockets of airborne natural radon gas, uneven terrain, cosmic radiation and temperature changes.

The results then, are mainly used to eliminate areas which have very few anomalies, and to give a starting point for follow up ground surveys, or borehole drilling.

▶



SIMPLE SCINTILLATION COUNTER

A portable radiometric borehole logger. The logging cable, which conducts power to the head and signals back, is wound off the drum at the rear of the instrument.

Radiometric borehole logging

When boreholes are drilled to locate any type of deposit, it is a very costly procedure to recover core samples for laboratory analysis, particularly if the exact depth of the seam is not known. The usual procedure is to lower a probe into the hole and measure the natural radioactivity, which is recorded on a strip chart recorder, relative to the depth of the probe. The probe contains a Geiger tube or more commonly, a scintillation detector, together with its high voltage power supply and a signal buffer. As the cable usually has only one insulated inner conductor and a high tensile steel braid, the pulses must be coupled on to the dc supply to the probe and then picked off across an inductor at the surface. The surface electronics consists of an accurate ratemeter with several selectable averaging time constants, to allow low count rates to be resolved accurately.

These probes are extremely important in uranium exploration as they can give the exact depth and thickness of the deposit and also a reasonably accurate figure for the grade of ore. However, radiometric borehole logging is quite often not used to locate uranium.

Because the scintillation detector is so sensitive, it can measure the minute amount of radioactive material present in various rocks, and while the count rate cannot directly identify the rock type, the boundaries between different beds can be sharply defined. This is a very useful measurement because the hole can be air or water filled and steel cased or uncased, without greatly affecting the results.

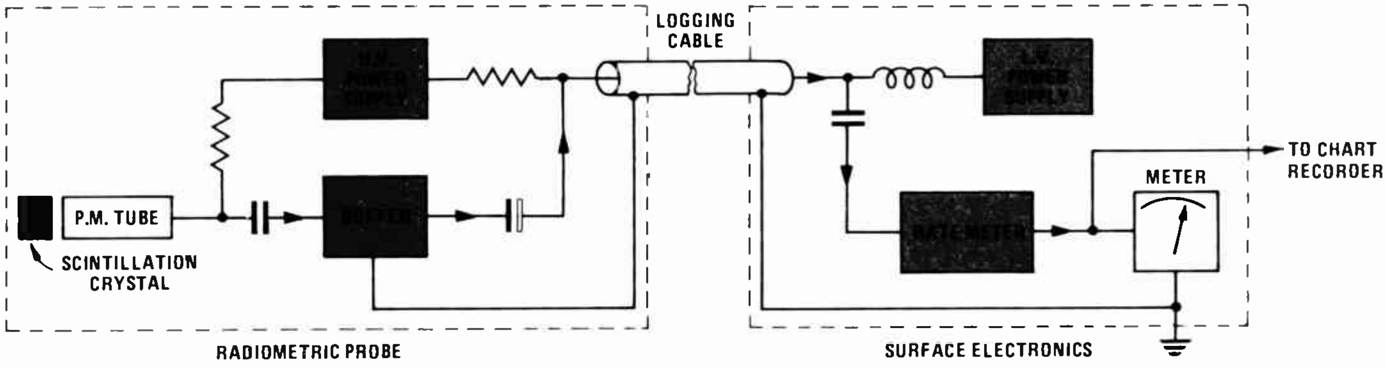
There are some problems however, as the probe must be watertight to depths of 1000 m or more and able to withstand the pressure at that depth. It must also be rugged and have a wide operating temperature range. This is an extremely harsh environment for sensitive electronic equipment, and careful design is essential.

Summary

Modern electronics and refined measurement techniques have greatly assisted uranium exploration and has led to radiometric borehole logging being accepted as a tool for exploration in general.

Spectrometer-type instruments have eliminated many errors in ground and airborne surveys and allow the field geologist using only a small portable instrument to gain enough information to decide if more detailed investigation is warranted.

In the future, microprocessor controlled spectrometers will undoubtedly become available, allowing automatic correction for the many variables involved in radiometric measurement. However, the measurement techniques will probably remain much the same. ●



RADIOMETRIC BOREHOLE LOGGER

Shoparound

IT'S DIFFICULT to provide a complete listing of products and 'who sells what' as new products come on the market all the time and distributors also change.

However, to help you with your search for various items in this field, we have assembled a list of companies we know of who sell metal detectors and related equipment.

Metal Detectors — distributors

All Electronic Components
118 Lonsdale St
Melbourne Vic 3000
(03) 622-3506

Arnold Muller
40 Albert St
Kilmore Vic 3601
(057) 82-1166

Australian Detector Company
369 Cressy St
Deniliquin NSW 2710
(058) 81-3173

Australian Goldfield Detectors P/L
P.O. Box 2126
Dangar NSW 2309
(049) 61-2652

Bounty Hunter Detectors
P.O. Box 11N
Avalon Beach NSW 2107
(02) 918-6667

C & G Detectors
58 Darwinia Terrace
Chapman ACT 2611
(062) 85-6630

Colmar Metal Detectors
450 Whitehorse Rd
Mitcham Vic 3132
(03) 874-3044

David Cooper
50 Henley St
Coopers Plains Qld 4108

Don Cooper
24 Gilles St
Adelaide SA 5000

Dick Smith Electronics
P.O. Box 321
North Ryde NSW 2113
(02) 888-3200

Electronic Agencies
115-117 Parramatta Rd
Concord NSW 2137
(02) 745-3077

Golden Nugget Prospecting Supplies
48A Unley Rd
Unley SA 5061
(05) 272-4296

▶

Gold Prospectors Supply
Shop 1, 332 Oxford St
Bondi Junction NSW 2022
(02) 387-5004

Gold Seeker Electronics
43 First St
Brompton SA 5007

Hendon Detector Company
P.O. Box 11N
Avalon Beach NSW 2107
(02) 918-6667

Hesperian Detectors
P.O. Box 317
Victoria Park WA 6100

Honor Bright P/L
7 Redfern Rd
East Hawthorn Vic 3123
(03) 813-1988

Interlap P/L
P.O. Box 6206
Hay St East
Perth WA 6007

John Stephens
126 Sandy Bay Rd
Sandy Bay Tas 7005

Jon Darcy Discounts
417 Nepean Highway
Frankston Vic 3199

Lordco (Aust) P/L
P.O. Box 50
Chatswood NSW 2067
(02) 406-4477

Lordco (Aust) P/L
P.O. Box 67
Abbotsford Vic 3067
(03) 41-5381

Melbourne Treasure Hunting Supplies
296 Doncaster Rd
Balwyn Nth Vic 3104
(03) 857-9767

Miner's Den
670-676 Canterbury Rd
Surrey Hills Vic 3127
(03) 88-8357

Old Gold Mines
325 Thomas St
Dandenong Vic 3175
(03) 793-3342

Prospectors Home
Shop 7, 71 George St
Parramatta NSW 2150
(02) 663-3969

Radio Despatch Services
869 George St
Sydney NSW 2000
(02) 211-0191

Tandy Corporation
280 Victoria Rd
Rydalmere NSW 2116
(02) 638-6633

Tasco Sales (Aust) P/L
12 Orchard Rd
Brookvale NSW 2100
(02) 93-5298

Toowoomba Stamps and Coins
33 Bell St
Toowoomba Qld 4350

Treasureland Australia
Unit 9, 66 Wellington St
East Perth WA 6000
(09) 325-8575

Warburton-Franki P/L
199 Parramatta Rd
Auburn NSW 2144
(02) 648-1711

Warburton-Franki P/L
220 Park St
South Melbourne Vic 3205
(03) 699-4999

Kits & Components

KITS FOR projects featured in this magazine may be obtained from the following suppliers (note that they may only stock some kits, not all).

All Electronic Components
118 Lonsdale St
Melbourne 3000

Electronic Agencies
115 Parramatta Rd
Concord 2137

Rod Irving Electronics
425 High St
Northcote 3070

Altronics
105 Stirling St
Perth 6000

Geiger tubes may be obtained from:

All Electronic Components
118 Lonsdale St
Melbourne 3000

Sycom
49-53 Tope St
South Melbourne 3205

301 Catherine St
Leichhardt 2040

Meters for these projects are made and distributed by:

University Graham Instruments
P.O. Box 204
Enfield 2136

Printed circuit board suppliers for the projects featured in this book:

All Electronic Components
118 Lonsdale St
Melbourne 3000

RCS Radio
651 Forest Rd
Bexley 2207

Radio Despatch Service
869 George St
Sydney 2000

Rod Irving Electronics
425 High St
Northcote 3070

Willis Electronics
993 Hay St
Perth 6000

Trilogy
40 Princes Hwy
Fairy Meadow 2519

Just starting out?