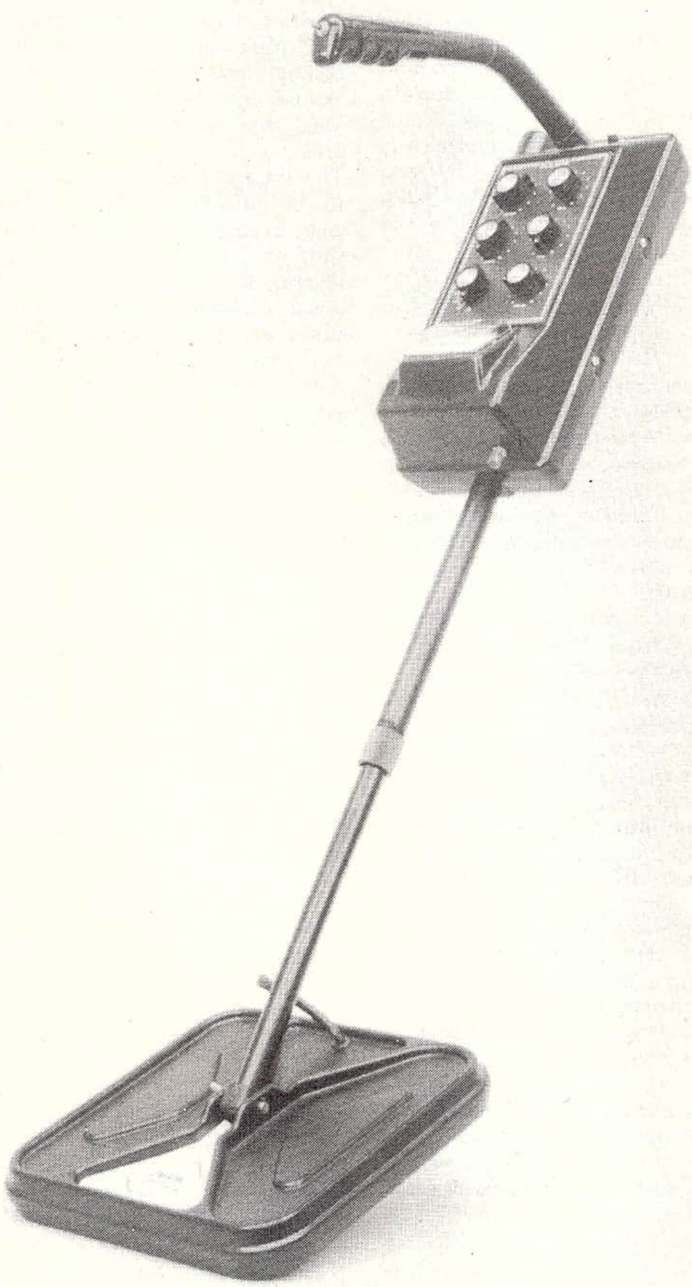
metal detector

high performance and simple construction

One of the problems that govern the fast growing hobby of treasure hunting is that economical metal detectors are notoriously unstable and suffer from a lack of sensitivity while the good ones are very expensive. The design featured in this article is both highly stable and sensitive and presents no problems in construction. It is professional in appearance and operation and performs better than many high-priced commercial detectors.



One of the projects near the top of ‹ 'most requested projects' list has, some time, been a metal detector. T reason for the delay in publishing article on the subject is due to the f that construction of a good detec (and not one that just detects sor thing) is a very difficult propositi The very first major problem that re its head is that of stability since thi dependent on a number of aspects. achieve a stable circuit design is not e when cost is taken into considerati The design and construction of search head is also a formidable obstr tion to obtaining a high performa while still remaining within the ca bilities of the average enthusiast.

Furthermore, the search head must robust and remain stable after the v critical setting-up procedure it requi In other words, it must not be prone 'headaches' when knocked. Even difficulties of waterproofing and res ance to temperature changes problems enough in themselves if others are not enough.

What of the circuit itself? There are course, a number of methods by wh metals can be detected with the use electronics but stability is the govern factor in performance. It is possible design a circuit using microprocess and the like that will work wonders t will require a find of gold sovereig every day for a week to cover its cost. Overall, the difficulties will appear now to be unsurmountable and y may well be asking how we managed do it at all. It took a little time but, r assured, it has been done and the resu have been well worth waiting for. T Elektor metal detector performs v well and is easy to construct due to t fact that the ultimate horror — search head — does not have to be c structed by the reader. A compl hardware assembly, including the he is available to readers, ready-made.

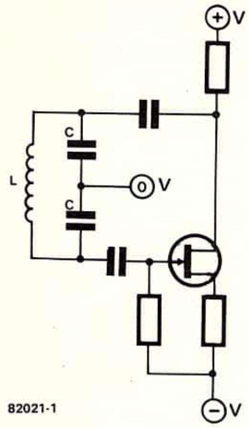
How has it all been done? Bef reading on to find out, a note warning. Firstly, reading the arti carefully and paying attention to de during construction are essential produce a high performance me detector. Secondly, and not quite obvious, treasure hunting with a metal detector is much like horse ridi it takes time and practice to beco proficient at it. Don't expect it happen in one day!

Surveying the field

Various methods are used in the des of metal detectors and they all h their various advantages and disadv tages.

BFO — beat frequency oscillator

These units are cheap, easy to build, t suffer due to the high frequencies u (for economic reasons). They are very sensitive to metals, suffering ba from instability and ground effect a they do not discriminate between diff



ɪre 1. A simplified diagram of a
ʲentional oscillator circuit. No form
ɔmpensation is included to allow
ːhanges in the value of capacitor C
to temperature variations.

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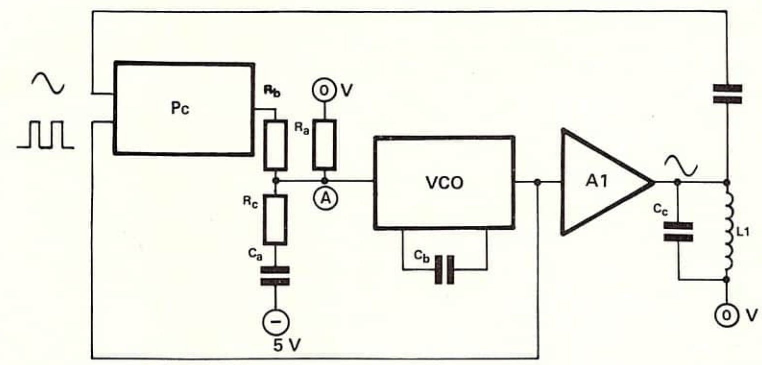

Figure 2. The Elektor metal detector employs a phase locked loop design to provide the basis of a highly stable oscillator with immunity to drift.

materials. They work on the hetero-
e principle of beating two fre-
ncies together and obtaining an
io tone relative to the difference
veen the two signals. The basic trick
ıat the oscillator has the search head
:s frequency determining component
inducing a metal object into its
ıity will increase or decrease the
ch frequency so producing a change
udio tone.

B — transmit-receive/induction-balance

se metal detectors are much better
BFO types as regards general
itivity but still suffer from stability
ɔlems and do not discriminate be-
ɛn metals. This type requires very
ırate relative positioning of the coils
can be extremely difficult to set up.
ther disadvantage is the fact that a
ıt knock 'on the head' can cause
signals.

— very low frequency

most expensive metal detectors are
ılly of this type. Various circuits
(a) make the unit sensitive to
als, (b) discriminate between metals
(c) provide ground effect control
overcoming a lot of shortcomings
rent in cheaper detectors. However,
to the low frequencies used, these
ːs still suffer from instability. The
dvantages are cost (which can be
) and difficulty in setting up the
l assembly.

pulse induction

e induction is used in professional
industrial metal detecting systems.
ɔod design can be extremely costly
construction and calibration is
ɔnd the realms of the average elec-
ics enthusiast.

Elektor metal detector to be de-
ɔed is a high performance VLF
lel utilising phase locked loop
ıniques for stability, good discrimi-
on between metals and elimination
ɡround effect. It features a better detection range than BFO and TR/IB types and does not suffer from instability problems. To achieve all this 'icing on the cake' it will be obvious that the circuit must therefore be more complex. However, a glance at the circuit diagram in figure 4 will show that it is not as complicated as some readers may have expected, and furthermore calibration is extremely simple.

Instability and PLL

As previously mentioned the major disadvantage of cheaper metal detectors is that of instability. In cases of severe instability, the process of detecting metal can be hampered to the degree that it becomes impossible to differentiate between the detector itself being 'off tune' and a 'find'.

Why is the Elektor VLF circuit more stable than others? The simplified circuit diagram in figure 1 is that of the more conventional VLF design. The problem is that the low frequencies used with a VLF design require a large number of turns in the search head coil. This also necessitates that the value of C in the circuit is relatively large. This is the point in the circuit where instability will occur since any capacitor will change value when exposed to heat. If it happens that the capacitor is included in the tuned circuit of an oscillator, it follows that the oscillator frequency will therefore be prone to drift.

In this type of oscillator the drift cannot be compensated for and the problem is further aggravated by the susceptibility of the circuit to voltage fluctuations in the power supply (creating more instability). As if this were not bad enough, the oscillator has a fairly high current-consumption and therefore batteries have a very short life.

To overcome these shortcomings the Elektor phase locked loop design was developed. This effectively compensates for any drift in the oscillator frequency due to changes in the value of the capacitor. This design is slightly more complex but with the help of figure 2 is fairly easily understood.

The centre frequency of the VCO (Voltage Controlled Oscillator) is initially set by Ra, Rb, Rc and Ca, Cb. This produces a square wave, which is converted into a sine wave by the amplifier A1 and is fed to the search head L1. A proportion of this signal is capacitively coupled back to the input of the phase comparator PC, the output of which is passed to the control input of the VCO via the low pass filter consisting of Rc and Ca. The output of the VCO is also fed back to the other input of the phase comparator. These two feedback loops provide an immunity to drift and form the basis of this highly stable oscillator.

The Elektor metal detector

It has already been stated that the circuit of the metal detector is fairly complex. However, the diagram in figure 3 shows the details of the circuit in block form and it will be understood more easily if each block is treated separately, bearing in mind that each one refers to a section of the main circuit in figure 4.

Since the first block of the diagram, the PLL oscillator, has already been described, we can move on to the phase locked loop discriminator. A discriminator enables the user to reject unwanted materials, for example metal paper foil. This part of the circuit has again been designed with high stability in mind and for this reason a second PLL is used. The adjustment of the phase relationship between the transmit oscillator and the received signal, provides a method of sampling a proportion of the received signal. This provides the phase sensitive detector with its gate input.

The phase sensitive detector 'chops up' the input signal from the receive head and, after filtering, the DC voltage output is used by the meter and audio

circuits.
The auto tune is another special feature of the Elektor metal detector. Briefly the principle is to achieve an offset voltage, by storing it in a capacitor across an FET opamp which is used as a slow/fast integrator. By feeding this voltage level back to the phase sensitive detector we can reset the output voltage of the PSD, in order to zero the meter at the flick of a switch. This means that manual retuning is not necessary when changing modes or altering the sensitivity of the detector.
The meter circuit is straightforward and incorporates a battery status check, as well as indicating the accepted and rejected finds.
The final section of the block diagram is the audio stage, but this does not consist solely of an ordinary amplifier. A gated chopper circuit is also included which takes the search oscillator frequency and divides it down to approximately 270 Hz. This is used to chop the DC voltage output of the PSD before feeding it to the audio output amplifier thus providing an audio tone when metal is received.
This covers the basic building blocks of the metal detector and we can now move on to discuss the finer points of the circuit in detail.

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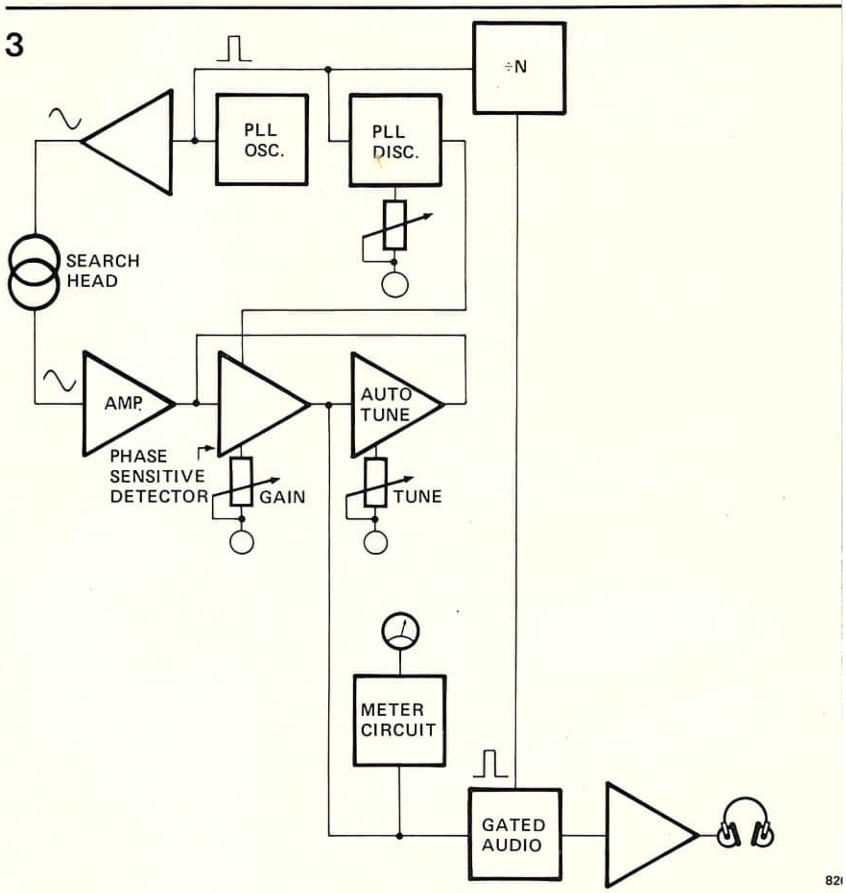

Figure 3. The block diagram of the Elektor metal detector. Each block corresponds to a part of the circuit diagram in figure 4.

The circuit diagram

The PLL oscillator is formed around IC1 in the circuit diagram shown in figure 4. The frequency is set by the components C3, R12, L1 (the search head), C2 and R10. The value of R10 is chosen to set the VCO initially at mid frequency. The square wave output of the VCO (pin 4) is coupled via R7 to the search amplifier which is formed by transistors T1 . . . T4. A portion of the sine wave is fed back via C1 and R11 to the signal input of the phase comparator (pin 14) where it is compared to the signal at pins 3 and 4. The resultant output at pin 2 is used to adjust the VCO to its resonant frequency thus forming a stable oscillator.
The VCO output at pin 4 of IC1 is also fed to the input of the phase locked loop discriminator IC2. The configuration of this IC provides a convenient method of adjusting the phase relationship by simply changing the value of a resistor at pin 11. The actual 'resistor' value is selected by S1, P4 and P5 and the resistor networks connected to pin 11 pf ES5 and pin 8 of ES6. The level at pin 11 of IC2 selects either ground effect or reject mode with the aid of the CMOS switches ES5 and ES6. The phase shifted square wave output of the discriminator IC2 is the gate signal for the phase sensitive detector formed by IC4 and A2. The receive signal from the search head is passed through an impedance converter T12 and then amplified (by a factor of 50) by the opamp A1 before being passed to the phase sensitive detector. It is this signal

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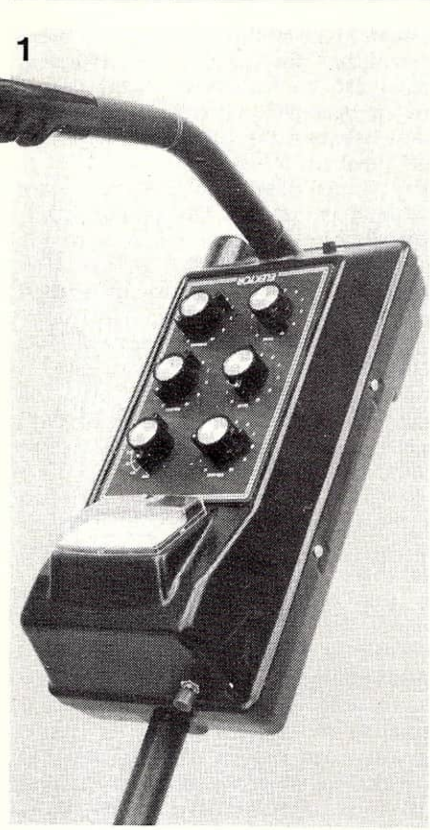
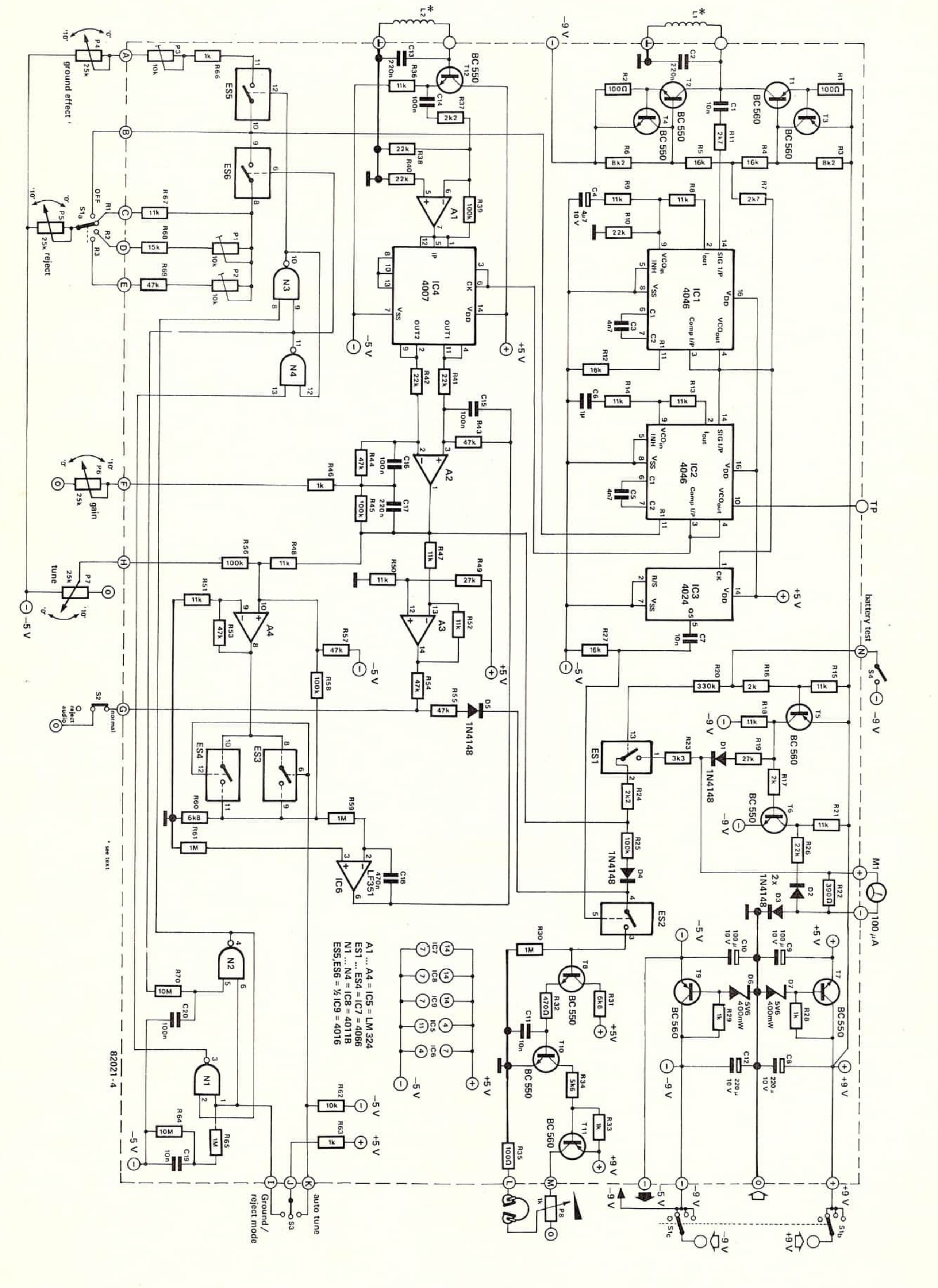


Photo 1. The handle and case assembly of the metal detector showing the high standard of the finished project.

that is then chopped and sampled IC4 and converted to a DC voltage l by opamp A2. The gain of this stag variable by means of potentiometer F The output of A2 is a voltage level t varies in relation to the size and cont of any metal object in the proximit the search head. This signal is r provided with a variable offset by tune control P7 in order to allow meter to be zeroed.
Manual tuning can become tedious i is required after every change of m and therefore an auto tune is a desira feature of the circuit. This is carried by storing a voltage level in C18. T voltage is the sum or difference of output of A2 and the position of tune control. A4 together with IC6 fo the basis of the auto tune circuit wh functions as follows. When the t CMOS switches S3 and S4 close, output of A4, an opamp with a g of 4, will be fed directly to the in of IC6 and cause this opamp to act fast integrator. Since its output is back to the non-inverting input of the original voltage level on the out of this opamp will be restored. A tune is brought into operation flicking the handle switch S3 mom tarily. This action will turn on CMOS switches ES3 and ES4 t increasing the voltage level on pin 2 IC6 by a factor of 4.
S3 also serves as the mode cha switch when operated in the ot



ure 4. The complete circuit diagram for the metal detector. This drawing can also be used for wiring information for the tches and potentiometers.

direction, changing from ground effect to reject mode or vice versa. It will be apparent then that S3 is effectively a three-way switch. Mode change is achieved by the gates N1 . . . N4 which are configured as a flipflop (although they may not appear to be so in the circuit diagram!). The complementary outputs of the flipflop control the two CMOS switches ES5 and ES6.
Many readers may find the going a little tedious by now, but take heart: we are almost at the end, in fact only the meter and audio sections of the circuit are left. The two functions of the meter are selected by the CMOS switch ES1. This is 'normally closed' and the meter will be connected to the detector circuit. Pressing the battery check switch S4 will open ES1 and at the same time, cause T5 and T6 to conduct. The meter will now be connected across the batteries via R19/D1 and R26/D2.
The remaining part of the circuit is the audio stage. It is slightly unusual but fairly straightforward. The output from the PLL oscillator (IC1) is fed to IC3 where it is divided by 32 to produce a 270 Hz square wave. This is then 'sharpened' by C7 and R27 to provide a control pulse for the CMOS switch ES2. In the normal modes an audio signal will only be heard when the meter moves to the right, indicating the presence of a wanted 'find'. This is when a rising positive voltage appears at the output of A2 and is fed via R25 and D4, through the CMOS switch to the output stage via T8.
It is also possible to use an audible signal for rejected finds. This may not be obvious at first but after some experience with the metal detector this feature will be found to be a useful extra. When S2 is switched off, the output of A3 is allowed to pass, via R55/D5 and again ES2, to the output stage. The audio amplifier consists of transistors T8, T10 and T11 with T10 acting as a level converter.

Construction

Readers will be in no doubt by now that the Elektor metal detector has a very professional appearance and in no way suffers from the usual nuts, volts and tobacco tin look that usually grace home construction projects of this type. The good news is that, yes, your metal detector can look exactly the same as that shown in the photograph here. Even more important, the major problem that prevents construction of a really good metal detector, that of winding and setting the coils in the search head, is completely taken care of. The entire case and hardware assembly, together with the potted, waterproofed and tested search head, has been made available to readers via Crestway Electronics Limited and it can be purchased with or without electronics. The overall design is to fully professional standards and the finished metal detector will outperform many high quality commercial units.

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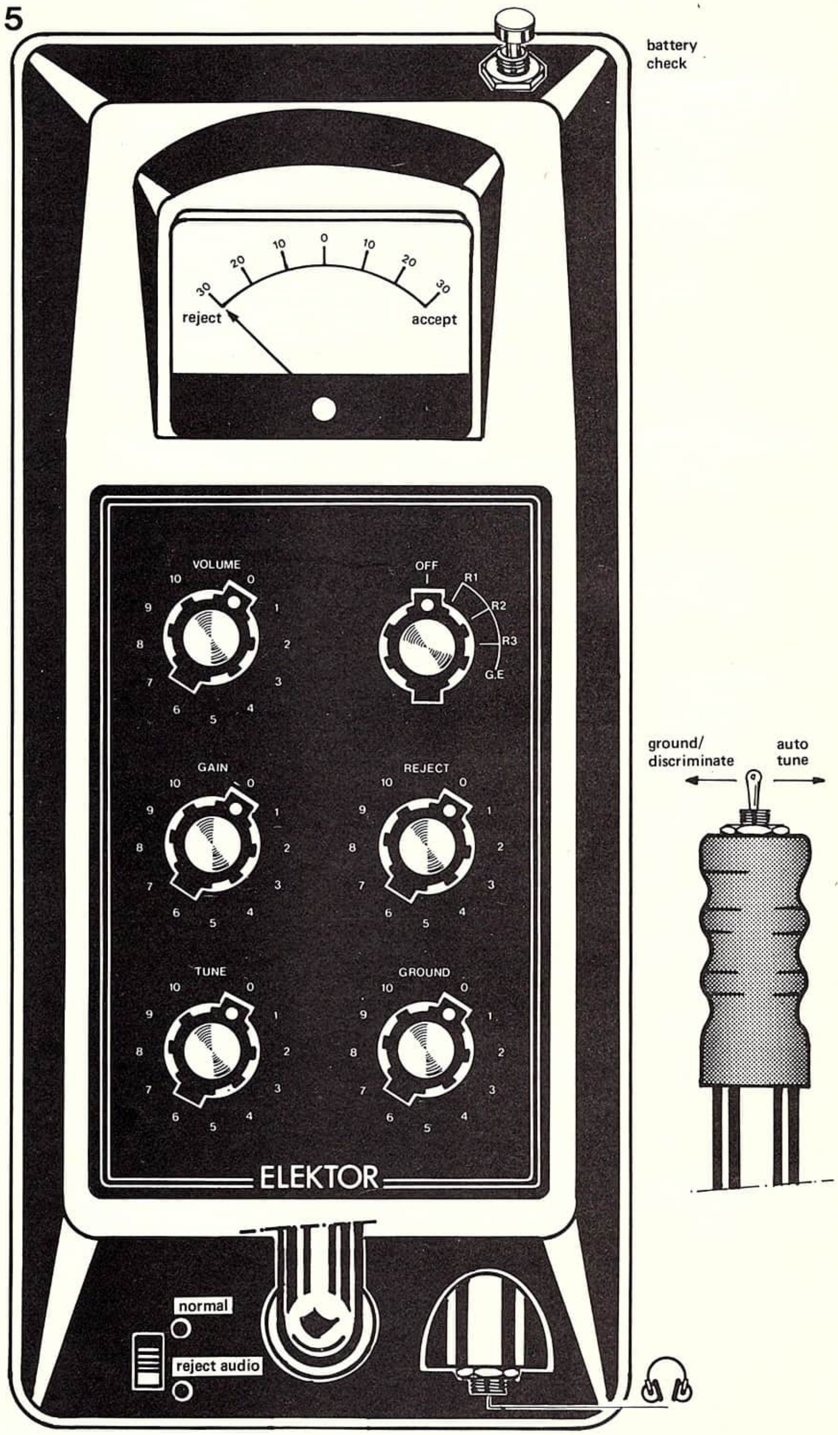

Figure 5. The front panel layout and controls for the metal detector. It is important that the switches and potentiometers are wired correctly. This diagram can be used with the operating instructions.

Should any reader wish to produce his own search head it is just possible although not very practical, since the setting of the coils is extremely critical and their position makes the difference between a very good detector and no detector. However, for those interested the head consists of two 10" coils with 80 turns each of 29 swg enamelled copper wire slightly flattened (to form a D) and overlapped by approximately 1". The critical setting is then found by trial and error.
The electronics of the metal detector surprisingly easy to construct. In fact, the printed circuit board is used, it w present no problems at all. Assembly the board is carried out in the usu manner after which the point to poi wiring is completed, using figure 4 as guide.
Particular attention should be paid the wiring of the potentiometers or t direction of the rotation may be inco rect. If one of them does appear to the wrong way round, exchanging t

ring at each end of the track (the out-le tags) will provide a solution.
ıe handle switch S3 (ground effect/ect mode and auto tune) is a momen-'y two-way switch with a biased ntre off position. This must be wired rrectly to avoid confusion in use. The itch should be fitted so that auto ne is operated when the switch is ked to the right. The contact that is ade' in this position (usually the left-nd one) should be the one connected K on the printed circuit board.
note on the printed circuit board, ere are two points marked −9, these ve to be wired together externally. If reo headphones are used they should converted to mono by shorting the t and right leads together (not the mmon lead).
will be wise to ensure that all connec-ns are correct before connecting the tteries.

libration

ny electronic device will only be as od as its calibration and for this ason the setting of the three preset tentiometers P1, P2 and P3 should be rried out with care. Some readers tend get a little alarmed at this point but can dispel any worries right away. e metal detector has been specifically signed to allow the calibration to be rried out — with nothing more sophis-ated than an ordinary multimeter th reasonably accurate 1 V and 10 V nges.
tially all controls must be turned ly clockwise. The unit can now be itched on by turning S1 to the R2 sition. The first check is the positive pply rail and this is carried out by nnecting the meter (switched to V DC) across C9 — taking note of the larity. The reading should be between V and 5.3 V. The negative supply n be checked across C10, again with ention to polarity, and in this case a ding between −4.7 V and −5.3 V ll be fine. If either reading is outside ese limits the components in the sup-regulators must be checked before ing on.
the supply voltages are correct the eter can now be connected between e test point (TP, pin 10 of IC2) and V (negative lead). With the meter itched to the 1 V range adjust P1 for reading of 0.55 V. Switch S1 to the 3 position and adjust P2 for a reading 0.15 V. After flicking the handle itch to select ground effect mode, P3 n be adjusted for a reading of 0.82 V. nd that is all — the calibration has en completed!

perating instructions

. Switch S1 to the R3 position.
. Press handle switch S3 to right and hold.
. Rotate tune control until meter reads zero.
. Rotate gain control to position 8.
. Release handle switch.

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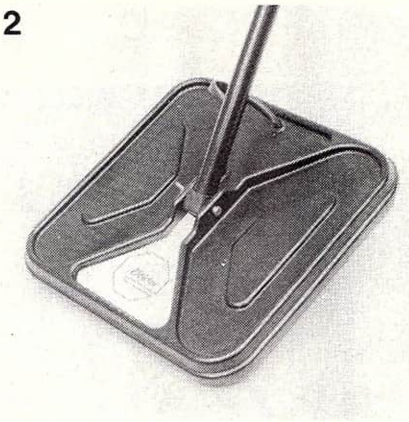

Photo 2. Possibly the most important part of the metal detector, the search head, is supplied as a complete and finished assembly.

6. Adjust volume control to 1/2 way position.
7. Using a gentle sweeping motion sweep the ground in front of you with a left-right-left movement while walking slowly forward. The maximum sweep should be about 18".
8. Practice for a while using this procedure and try to receive signals from all types of metal.

Once you are confident in the use of the basic procedures of the machine then move on to the following: using steps 1-6 set up the machine in basic operation mode and carry on with the following steps.

9. Flick handle switch to the left and release.
10. Rotate the reject mode control and check that the mode is correctly selected by a swing on the meter, if not return to step 9 and repeat.
11. Switch S1 to the R2 position and set the reject mode control to 1/2 way.
12. Flick the handle switch to the right (auto tune) momentarily and release.
13. At this point you should be rejecting tinfoil silver paper etc. but accepting coins (cupronickel) bronze, brass, silver and hopefully gold.
14. Rotation of the reject control towards zero will decrease the amount of rejection, and towards 10 will increase rejection.
15. Practice using the above until you are familiar with the machine, then try the following.
16. The coarse settings of positions R1, R2, R3 on S1 works as follows:

R1 will give the maximum rejection of metals.
R2 will give average rejection and is the most used position.
R3 will give a minimum metal rejection, in other words, receives most metals.

17. **Ground effect control**
On some soil the so-called ground effect may be experienced, due to mineralised soil. The same effect will appear when using the detector on beaches. This phenomenon produces the effect of an almost continual and apparently haphazard series of finds. The indication of ground effect can be verified by a drop in audio output when lifting the search head away from the ground. It must be noted that ground effect is a phenomenon that all metal detectors have to overcome. The Elektor metal detector is able to eliminate this problem when the procedure described here is followed:
18. Depress handle switch to the left momentarily and release.
19. Rotate the ground effect control whereupon the meter should move.
20. Adjusting this control from zero to 10 will increase or decrease the compensation for ground effect and the best setting is when you can lift the head away from the ground, with no change of signal.
21. **Gain control**, this control sets the sensitivity of the machine and is normally turned up towards position 10 for most of the time. However, if a beach is being searched for coins, which will usually be just on the surface, then turning the gain down will make the detector sensitive to coins on or just below the surface and anything buried deeper will be ignored.
22. **Auto tune switch**
At any time in use, if changing mode or resetting of the gain, reject and ground controls, then momentarily operation the handle switch to the right will reset the tune position back to zero

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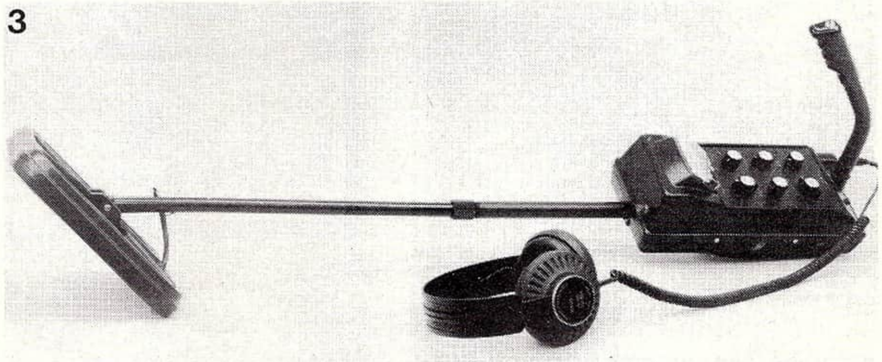

Photo 3. The distance between the head and the handle is fully adjustable.

Parts list

Resistors:
R1,R2,R35 = 100 Ω
R3,R6 = 8k2
R4,R5,R12,R27 = 16 k
R7,R11 = 2k7
R8,R9,R13 . . . R15,R18,R21,R36,R47,
R48,R50 . . . R52,R67 = 11 k
R10,R26,R38,R40 . . . R42 = 22 k
R16,R17 = 2 k
R19,R49 = 27 k
R20 = 330 k
R22 = 390 Ω
R23 = 3k3
R24,R37 = 2k2
R25,R39,R45,R56,R58 = 100 k
R28,R29,R33,R46,R63,R66 = 1 k
R30,R59,R61,R65 = 1 M
R31,R60 = 6k8
R32 = 470 Ω
R34 = 5k6
R43,R44,R53 . . . R55,R57,R69 = 47 k
R62 = 10 k
R64,R70 = 10 M
R68 = 15 k
P1 . . . P3 = 10 k preset potentiometer
P4 . . . P7 = 25 k lin. potentiometer
P8 = 1 k lin. potentiometer

Capacitors:
C1,C7,C11,C19 = 10 n MKM
C2,C13,C17 = 220 n MKM
C3,C5 = 4n7 ceramic
C4 = 4μ7/10 V
C6 = 1 μ MKM
C8,C12 = 220 μ/10 V
C9,C10 = 100 μ/10 V
C14 . . . C16,C20 = 100 n MKM
C18 = 470 n MKM

Semiconductors:
D1 . . . D5 = 1N4148, 1N914
D6,D7 = 5V6 400 mW zener diode
T1,T3,T5,T9,T11 = 2N4126, BC 560
T2,T4,T6,T7,T8,T10,T12 = 2N4124, BC 550
IC1,IC2 = 4046
IC3 = 4024
IC4 = 4007
IC5 = LM 324
IC6 = LF 351, 3140, or equ.
IC7 = 4066
IC8 = 4011 B
IC9 = 4016

Miscellaneous:
S1 = three-pole four-way switch
S3 = SPDT biased centre off switch
S4 = single pole push to make switch
S2 = SPST slide switch } included in complete
L1,L2 = search head } casework kit from
M1 = 100 μA meter } Crestway Electronics Ltd.
headphones = 8 Ω
batteries = 2 x PP6

A complete kit of parts including all metal work is available from Crestway Electronics Limited.

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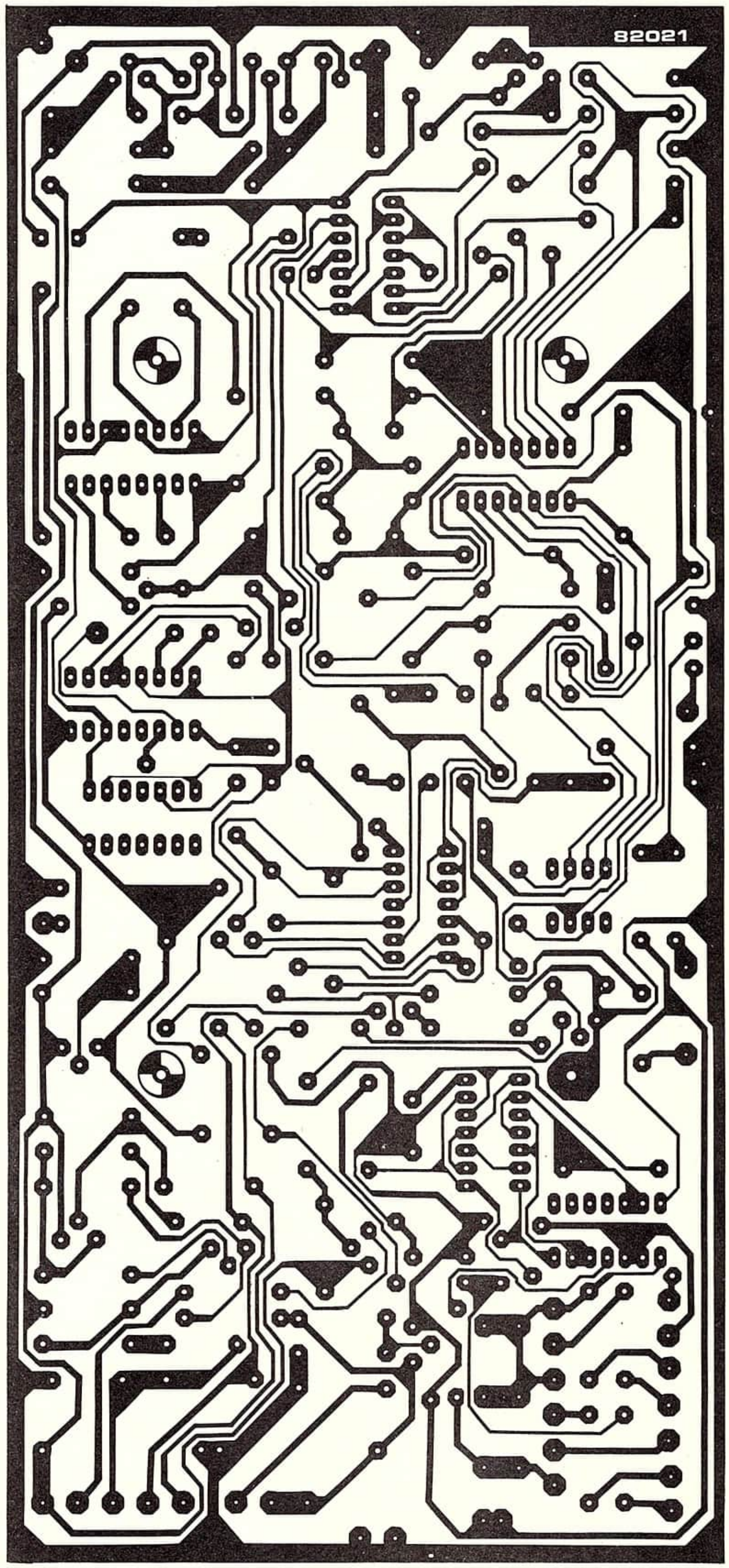
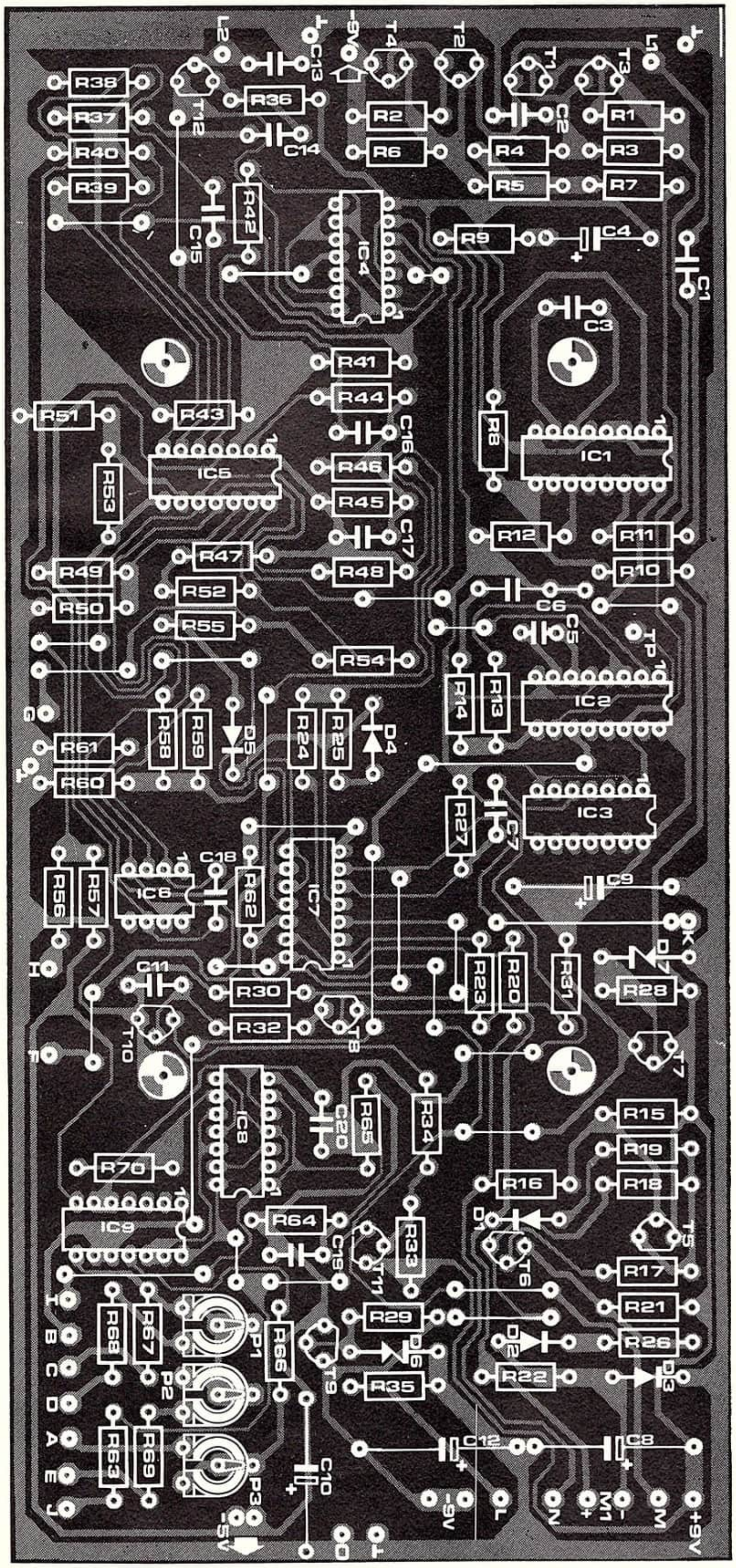


Figure 6. The printed circuit board and components layout for the metal detector. The two points marked −9 are wired together externally.



on the meter, but note: do not hold this switch over while actually searching for metal as the fast integrator circuit will be constantly in use.

23. The slide switch S2, at the left hand rear of the case, is normally in the nearest position to the front panel. This corresponds to an audible indication when the meter moves towards the right. If the switch is in the other position then an audio signal will be present at all times whether the meter is moving towards the right or the left, but a change in tone will be heard as metal is detected. This mode is useful for general searching, since you do not need to look at the meter all of the time.

24. **Battery test button**
Pushing this will give a meter reading indicating the state of the batteries. The batteries should be replaced when the meter reading falls below 10 on the right hand half of the scale.

Notes for treasure hunters

Successful treasure hunting with any metal detector requires plenty of luck and experience. We are of the opinion that the former is somewhat unreliable but the latter can be gained with practice. After a period of use and time in which to become familiar with the metal detector, you will get to know little tricks like telling the difference between ferrous and non-ferrous materials from indications given by the detector alone. Steel is indicated by a more rapid movement of the meter. It is not really understood why, but bronze tends to give a warbling note in the headphones. Small coins and rings lying on edge in the ground will produce a very sharp on/off signal. It is also useful to know that the larger the size of a buried object, the more area the signal will be on for. We are also reliably informed that gold actually gives a double pulse in the form of an echo.

For consistent results, do not move too fast (neither sweeping nor walking) and keep the head within 1/2 to 1 inch above the ground. This becomes a lot easier with practise. After use always clean the search head with a damp cloth.

Above all, respect other people's property, and request permission before searching an area of land, it is almost always granted. The Elektor metal detector head is perfectly water-proof and can therefore be used in rivers which can prove quite fruitful.

We are given to understand that growing a beard and rising at unheard of hours does bring a measure of success but we have no documentary evidence to prove this. The seasoned treasure hunter can be recognised by this downcast, glazed expression and constant mumbling. His hand never leaves the shovel that travels everywhere at his side and he wears headphones in bed!

Treasure hunting can be rewarding, frustrating and damaging to your social life but it will never be boring.