“PHASER” METAL DETECTOR

BY THE PROF

THE SOUND OF XNORING

The Prof’s experimental design irons out the ground effect, but can’t quite grind out the iron effect! Using very low frequencies (for a metal detector) it uses small phase shifts in the search signal to trace useful objects.

Producing a new metal detector design for the home constructor is not an easy task these days. There have been a large number of metal detector projects published in the last fifteen to twenty years, making it much easier to come up with a revamped circuit than one of a totally new type. I will not claim that this detector relies on a totally new system as it works on a principle that has certainly been known for many years. On the other hand, I have not seen a previously published design of this type. The basic requirements for this project were as follows:

1. It should not be of a “standard” (BFO, IB, or PI) type.

2. It should be free from the “ground” effect without using any special shielding. The ground effect is one that results in an indication being produced by certain types of detector even when no metal is present in the ground.To combat this effect either the search coil must be suitably shielded, or the coil must be kept a fixed distance above the ground.

3. Construction of the search coil should be non-critical, and any electronic setting up should be simple and straightforward.

4. The unit should be easy to use, having a method of indication that is very obvious even for someone without a good sense of pitch (many designs indicate the presence of metal by giving a small change in the pitch of an audio tone).

5. It should have a level of performance at least as good as most simple BFO and IB designs.

PHASED OUT

When looking at the available options, the only kind of detector which seemed likely to fit these requirements was the very low frequency (VLF) phase detector type. This operates by detecting small phase changes in the signal in the search coil when metal is brought near to the coil. “Very low frequency” in metal detector terms generally means a frequency at the upper end of the audio spectrum, with something around 17KHz being quite typical. The point of using relatively low operating frequencies in metal detectors is that it avoids problems with the ground effect.

Practical experiments with VLF phase detector circuits proved quite encouraging. and the final design is quite simple but effective. In terms of performance it falls some way short of a kit-built IB unit that I have, but it can be built for what I would estimate at little more than a tenth of the price of this commercial unit. The higher sensitivity of ultra-sensitive detectors is often unusable anyway, due to problems with small amounts of iron or other metals in the soil giving a sort of pseudo-ground effect.

The performance of the unit is quite good for such a simple design. It will detect a 20p coin at a maximum range of about 60 to 80 millimetres. Larger pieces of metal can be detected at longer ranges, with a 50p coin being detectable at about 100 to 150 millimetres. Large chunks of metal can be detected at a maximum range of around 500 millimetres. This is better than most BFO designs, but is perhaps a little inferior to some simple IB circuits. This design is more simple than an IB design though, and in particular, the search coil does not need to be made very accurately. In this respect the unit is even less critical than a BFO design. Sensitivity is certainly high enough to provide good results. Note that the quoted sensitivities were obtained from “in-air” tests. Performance in practice depends on the characteristics of the soil, and the exact orientation of many objects seems to significantly affect how well (or otherwise) they are detected.

The block diagram of Fig. 1 shows the arrangement used in this detector. The search coil is actually a twin type, and is really a form of transformer. An audio oscillator drives the primary winding by way of a buffer amplifier. The purpose of the buffer is to ensure that metal close to the search coil does not “pull” the oscillator and affect the phasing of its output signal. It is not to produce a high drive current in the search coil, which only requires a very low drive level. A (more or less) squarewave signal is produced by the oscillator.

The output from the secondary winding is fed to a high gain amplifier and then to a trigger circuit. This gives a roughly squarewave signal at logic compatible signal levels. A form of mixer circuit processes the output of the audio oscillator and the output of the trigger circuit. This mixer is actually a 2 input xnor gate. XOR and xnor gates are probably the least used types, and some readers may not be familiar with their operation. An ordinary nor gate has an output which goes low if either input 1 OR input 2 is taken high. The output also goes low if both input 1 AND input 2 are taken high. An xnor gate differs from a nor type only in that taking both inputs high does not take the output low. An xnor gate therefore provides what could reasonably be regarded as the true nor action.

What we require in this application is a mixer circuit that converts phase lag into a proportional output voltage, because the output from the secondary winding slightly lags the input signal, but if metal is brought near the search coil the phase lag increases and decreases for ferrous and non-ferrous metals respectively. XOR and xnor gates may not seem to be of much use as phase detectors, but they can in fact operate very well in this mode. The waveforms in Fig. 2 help to explain the way in which this type of detector operates. Here we are assuming that an xor gate is used.

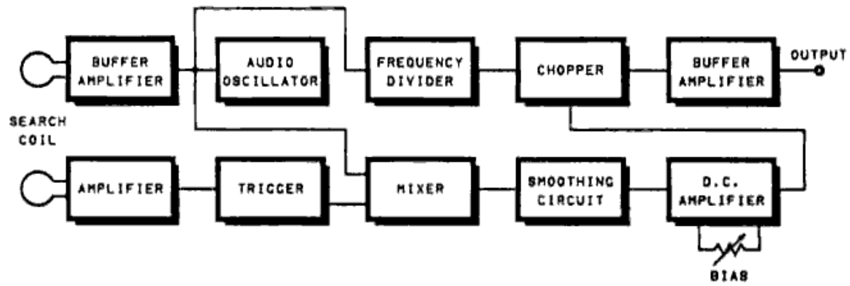


Fig 1. *Block diagram for the VLF phase detector.*

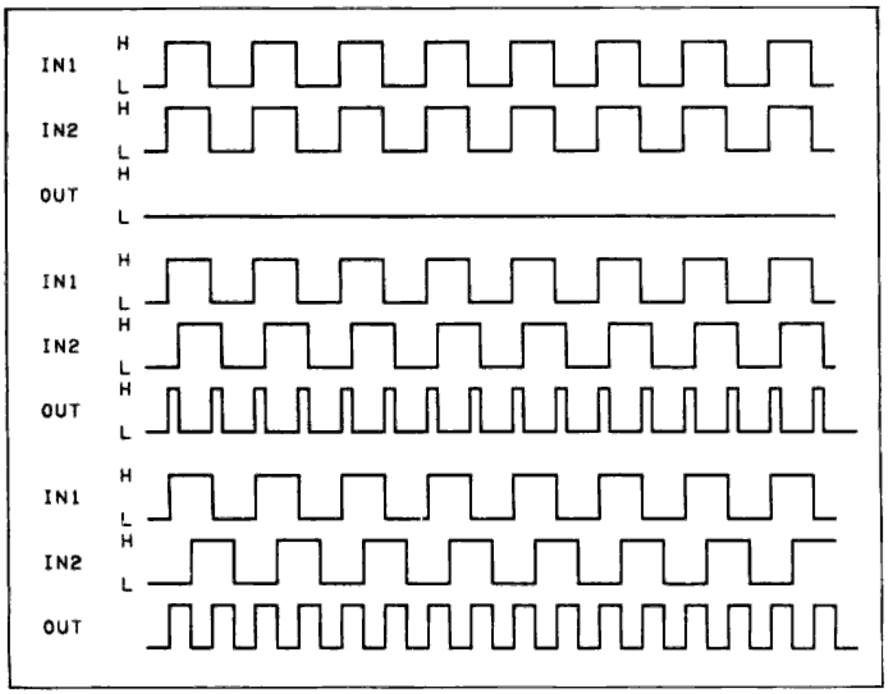


Fig 2. *XOR phase detector waveforms.*

The top set of three waveforms are those obtained with the two input signals perfectly in-phase. Both inputs of the gate are low, then they are both high, then low again, and so on. A state is never reached where the inputs are at opposite states, and so the output goes continuously low. In the middle set of waveforms the second input lags the first one by about 45 degrees. The two inputs are now at opposite states twice on each cycle, although only briefly. The output is high for about 25% of the time, giving an average output voltage of around one quarter of the supply voltage. In the bottom set of waveforms the phase lag has been increased to 90 degrees. This lengthens the periods during which the input signals are at opposite states, and gives longer output pulses, still with two per input cycle. The average output voltage is increased to about 50% of the supply voltage. By taking the two input signals 180 degrees out of phase the two signals would always be at opposite states, and the output would go permanently high. An xnor gate is effectively an xor type with its output inverted. Results using an xnor gate are therefore essentially the same, but the output is of the opposite logic state.

By smoothing the output pulses to obtain a reasonably ripple-free output equal to the average output potential, the required phase lag to voltage conversion is obtained. However, the phase changes produced by even quite large pieces of metal very close to the search coil are quite small. At most they seem to be just a few degrees, and small target objects more than a few millimetres from the search coil produce a phase shift of only a fraction of a degree. A high gain dc amplifier is therefore needed in order to produce a reasonably strong output signal to drive the subsequent stages. There is quite a large phase lag under stand-by conditions, giving a strong quiescent output voltage from the unit. A variable bias circuit in the dc amplifier enables this quiescent output voltage to be nulled.

The output stages of the unit are used to produce an audio tone that rises or falls in volume when metal is detected. Even people who have a good sense of pitch generally find a change in volume much more noticeable than a change in pitch. The output from the dc amplifier could be used to drive a panel meter if this method of indication is preferred. However, in my experience it is necessary to concentrate on control of the search head, making any form of visual indicator difficult to use properly.

A tone at a frequency of a few hundred Hertz is obtained by feeding the output of the audio oscillator stage through a frequency divider circuit. This drives a chopper circuit which produces an audio output signal having a peak to peak amplitude equal to the output voltage from the dc amplifier. This signal is fed to a buffer stage which drives the output socket. A crystal earphone and most types of headphone are suitable for use with this project.

CIRCUIT OPERATION

The full circuit diagram for the “Phaser” metal detector appears in Fig. 3. The audio oscillator is a humble 555 astable circuit. A low power version of the 555 (the TLC555CP) is used in the IC1 position in order to reduce the current consumption and extend the battery life. The operating frequency of the circuit is roughly 16KHz. The primary of the search coil (T1) is driven via an emitter follower buffer stage based on TR1. R3 limits the drive current to just a few milliamps. Both the primary and secondary windings of T1 are fitted with parallel “tuning” capacitors, and these seem to be essential if reasonable sensitivity is to be achieved. IC2 amplifies the output of the secondary winding, and the high gain of this amplifier gives a severely clipped output signal. VR1 is adjusted to give an output waveform having a suitable mark-space ratio.

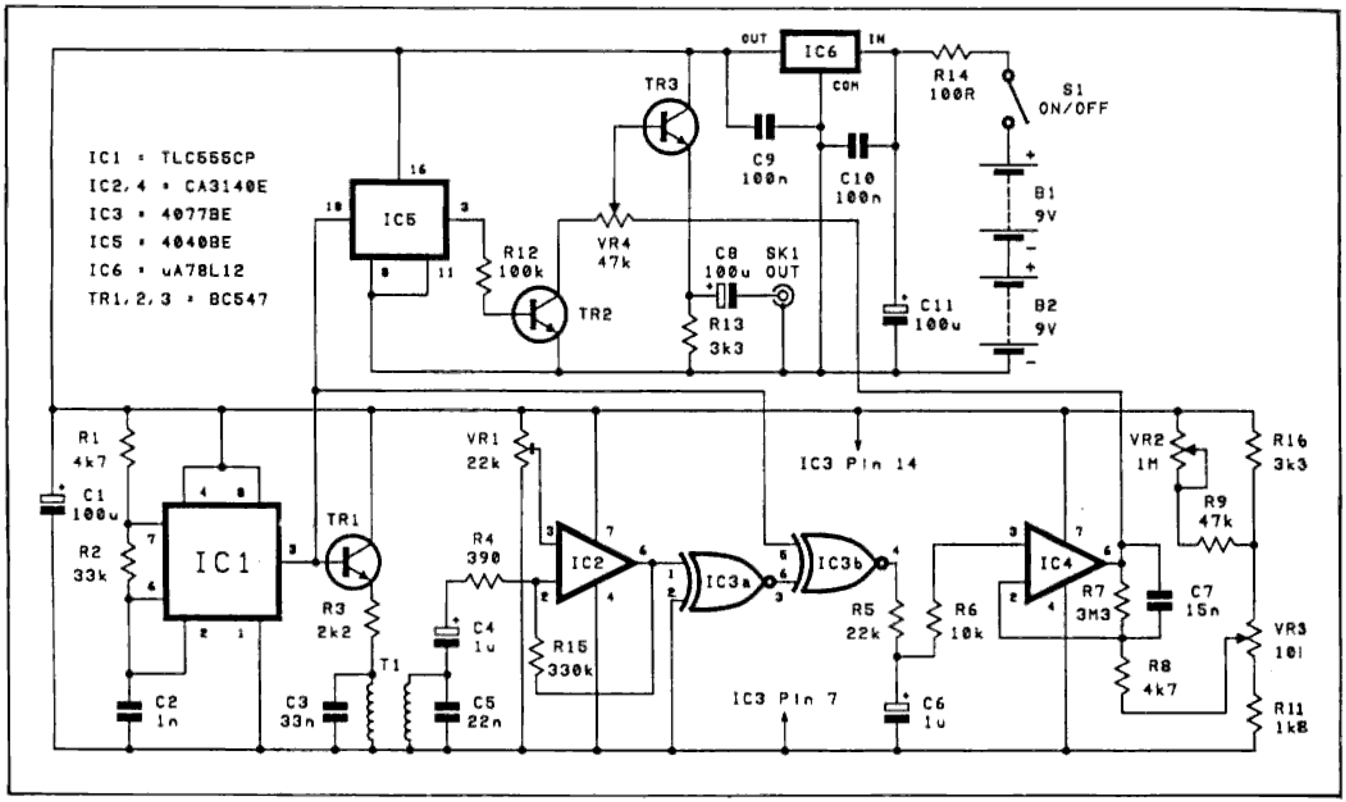


Fig 3. *The full circuit diagram for the “Phaser” metal detector.*

This signal is processed by IC3a which is a cmos xnor gate which functions here as a simple inverter stage. IC3b is the xnor gate which functions as the phase detector and it is fed from the outputs of IC1 and IC3a. Its output is smoothed to a reasonably low ripple dc signal by the single pole lowpass filter comprised of R6 and C6. IC4 acts as the basis of the dc amplifier, and this has a voltage gain of around 300 to 400 times. I cut down the voltage gain from its original level as I preferred lower drift to increased sensitivity. If you prefer higher sensitivity, then R7 can be made higher in value and (or) R8 can be replaced with a shorting link. Remember though, that the increased gain will result in any drift being amplified by a larger amount, and more frequent readjustment will be needed in order to keep the circuit adjusted for optimum sensitivity. Also, accurate adjustment of the bias controls becomes more difficult. These controls are VR2 (“fine”) and VR3 (“coarse”). C7 provides additional filtering which provides a very low ripple dc output signal.

The frequency divider is a cmos 4040BE 12-stage binary type (lC5). In this circuit only five stages are used. This gives a divide by 32 action, and an output frequency of about 500Hz. This signal is used to drive common emitter switching transistor TR2, which chops the output of IC4. VR4 is the collector load for TR2, and this acts as the volume control. TR3 is an emitter follower output stage.

A very stable supply in the range 9 to 15 volts is required. A single 9 volt battery is unsuitable as it would provide totally inadequate stability. Instead, two 9 volt batteries wired in series are used to provide a basic 18 volt supply, and monolithic voltage generator IC6 then provides a well stabilised 12 volt output from this. R14 reduces the dissipation in IC6 slightly, so that it operates slightly cooler and gives a more stable output The current consumption of the circuit is about 17 milliamps. This can be provided by two high power PP3 size batteries or rechargeable PP3 size nickel-cadmium batteries. If the unit is likely to receive a great deal of use it would probably be better to opt for higher capacity batteries, such as two sets of six HP7 size cells in plastic holders.

CIRCUIT BOARD

Fig. 4 shows the component layout for the printed circuit board. IC1 to IC5 are all mos types and consequently require the normal mos anti-static handling precaution to be observed. Note that IC1 has the opposite orientation to ICs 2, 3, and 4. Three link wires are required, and these can be made from 22 swg tinned copper wire (or trimmings from resistor leadout wires). The capacitors are all miniature printed circuit (vertical) mounting types. It could be difficult to use capacitors having the wron g physical characteristics, especially in the case of the polyester capacitors which should have 7.5 millimetre leadspacing. Be careful to fit the electrolytic capacitors with the correct polarity. At this stage of the proceedings only fit single-sided pins to the board at the points where connections to off-board components will eventually be made. Once fitted, generously tin the pins with solder.

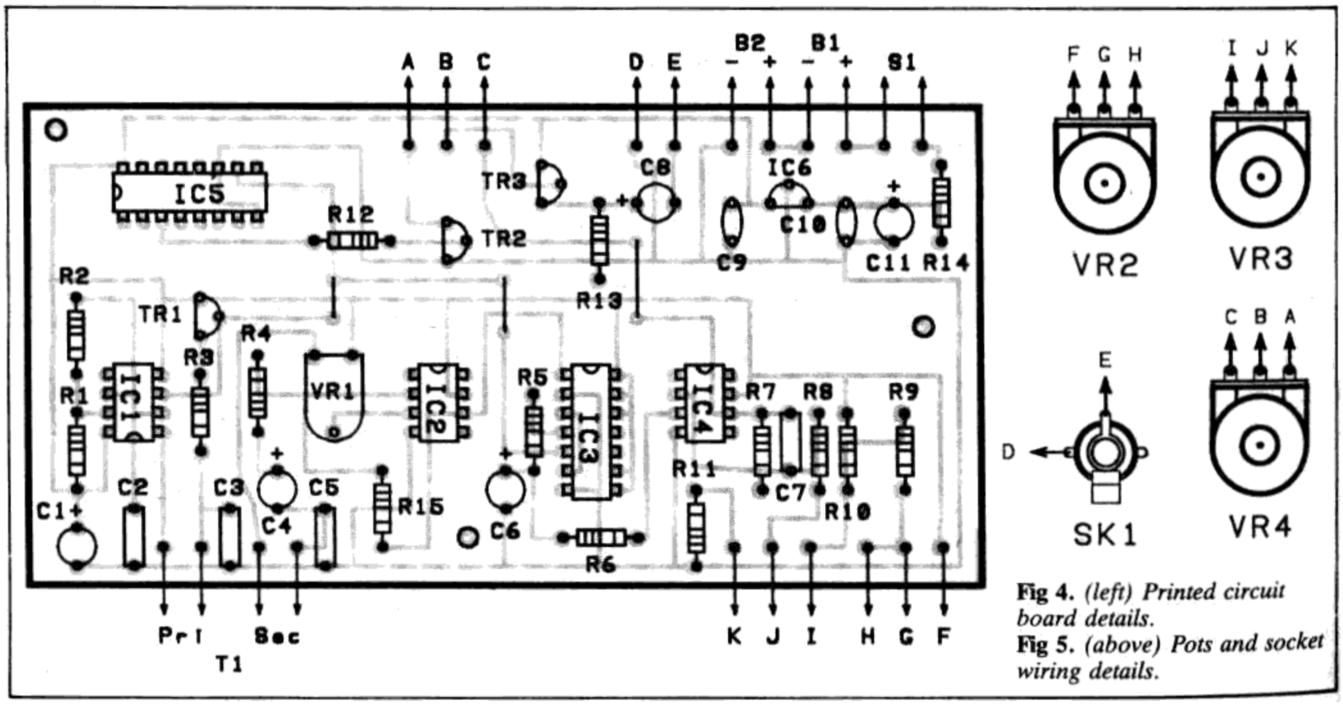


Fig 4. *(left) Printed circuit board details.*
Fig 5. *(above) Pots and socket wiring details.*

The unit will fit into a case having dimensions of about 150 by 80 by 50 millimetres, but this assumes that two PP3 size batteries will be used as the power source. If you opt for larger batteries such as a number of HP7 size cells a substantially larger case will be required. The case will eventually be fixed vertically on the stem of the unit. The controls and output socket are mounted on what becomes the lower section of the removable front panel. This leaves sufficient space for the batteries in the top section of the case. The component panel is mounted on the rear panel of the case using M3 or 6BA fixings, including some extra nuts or short spacers to hold it slightly clear of the rear panel. Note though, that printed circuit board can not be finally fitted in place until the case has been mounted on the stem of the unit.

All the point-to-point style wiring is quite straightforward and should not give any great difficulties. Fig. 5 in conjunction with Fig. 4 shows the interconnections between the three potentiometers, the output socket, and the circuit board. SK1 is a 3.5 millimetre jack socket on the prototype. I use the unit with a crystal earphone, or “Walkman” type headphones having their original (stereo) plug replaced with an ordinary mono type. The latter, with the two earphones wired in series, seem to give better volume and better results than a crystal earphone, and are probably worth the extra cost. Of course, rather than fit a different plug to the phones you might prefer to fit a stereo 3.5 millimetre jack in the SK1 position, but sockets of this type can be difficult to obtain. The unit seems to work with most types of headphone, incidentally. For low and medium impedance types it is best to use series connection, but for high impedance headphones parallel connection will probably be better. A low impedance magnetic earphone is unlikely to give satisfactory results.

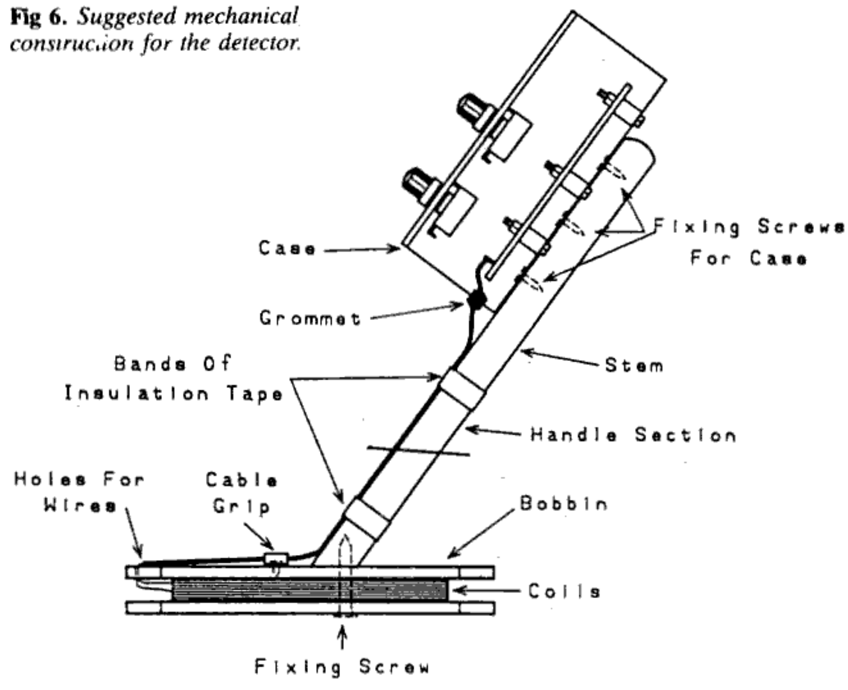
MECHANICAL CONSTRUCTION

Mechanically, construction of the detector is non-critical. You can opt for a fairly basic method of construction (as I did), or adopt more advanced techniques to give a more professional finish. Results using the unit will be exactly the same either way, and it is only the quality of finish that will be different. The method of construction suggested here is a basic one that anyone who is reasonably practical should be able to tackle without any real difficulty. It uses inexpensive and readily obtainable parts. It is up to you whether you follow this method of construction or try something a bit more difficult. If you do try out some ideas of your own there are a few points to bear in mind.

Unlike some types of metal locator, with a VLF phase detector a certain amount of metal within or near the search head is quite acceptable. The electronics can be adjusted to null this metal, and there is no obvious loss of sensitivity even with quite large amounts of metal close to the search coil. It is therefore quite in order to have a metal stem fixed to the search head by a metal bracket. It might even be acceptable to have the search head constructed from metal, but I have not tried this and cannot guarantee that it will provide satisfactory results. Physical balance is important as the unit will be difficult to use for long periods if it is top or bottom heavy. It is possible to produce a very neat search head using fibreglass, but as I know from previous experience, this can result in a very bottom heavy and unwieldly finished unit. If you use a heavy-weight material for the search head use as little of it as possible! The handle should be as close to the centre of balance as possible.

The method of construction I adopted is as outlined in Fig. 6. The stem is a piece of wooden dowel about 20 to 25 millimetres in diameter and around 1.2 to 1.3 metres long. Suitable dowels are readily available as replacement broom handles! The bottom end of the stem is angled at about 55 degrees to the search head, and it must be cut at the appropriate angle. The search head is made from thin hardboard or particle board. The material I used was thin particle board with a white plastic veneer on both surfaces. Apart from giving a neat finish the veneer also helps to make the unit weatherproof. The search head is really just an outside bobbin on which T1 is wound. Two pieces of the board about 200 by 150 millimetres form the top and bottom cheeks, while one or two pieces about 140 by 100 millimetres form the middle section of the bobbin. It is advisable to trim off the corners of the larger pieces and then round them off using a sander. This gives a neater appearance and avoids having sharp corners which can tend to get tangled in the undergrowth when searching overgrown ground. The three or four pieces of the bobbin are held together by a good quality adhesive such as an epoxy resin type. Drill three or four small holes (about 1.6 millimetres in diameter) well towards the front of the top panel. These are where the leads of the connecting cable will pass through the top panel. The search head is fastened to the stem using a woodscrew and some epoxy resin adhesive.

Fig 6. *Suggested mechanical construction for the detector.*



The case is fixed at the top end of the stem using three small woodscrews. The case must protrude slightly beyond the end of the stem, or the stem will get in the way and make it impossible to fit one of the circuit board's mounting screws in place. Having the case as high up on the stem as possible is a good idea anyway. It gives a better balance and keeps the case clear of the handle section of the stem (the section just beneath the case). An entrance hole for the cable which connects T1 to the circuit board is required in the bottom panel of the case, and a grommet should be fitted into this hole.

Twin individually screened cable is the obvious type to use for these interconnections. I found that twin overall screened cable was also perfectly suitable, with the outer braiding carrying the earth connections for both windings of T1. T1 consists of 100 turns of 36 swg enamelled copper wire for the primary winding, with 25 turns of the same wire laid on top of this to act as the secondary winding. The windings do not need to be particularly neat, but try to wind them quite tightly. Any turns left popping around could cause spurious indications from the unit. Prepare the ends of the screened cable's leads so that they can be passed through the holes in the top panel of the search head and connected to TI. At this stage it is probably best to leave these connections bare, but once the unit has been tested and is fully working it would be advisable to use some fibreglass filler paste or epoxy adhesive to cover them over and protect them. A cable grip secures the cable to the top of the search head, and some tape can be used to cover over the cable and produce a neat finish.

Some bands of insulation tape are used to fix the cable to the front edge of the stem. If you have a suitable tool for the purpose it would be a good idea to make a groove for the cable in the front edge of the stem. About half a dozen bands are sufficient to hold the cable in place. I used a couple of layers of tape over practically the entire stem in order to give a neat finish and a degree of weather-proofing. I used white tape for most of the stem, with black for the handle section. To finish off the unit, thread the twin screened cable through the hole in the case and connect it to the printed circuit board, and paint or varnish around the edges of the search head so that the hardboard or particle board is sealed against moisture absorption.

ADJUSTMENT AND USE

If you have access to an oscilloscope, VR1 can be adjusted so that the output from IC3b is reasonably symmetrical pairs of pulses. In the absence of suitable test equipment it is just a matter of trying VR1 at various settings in an attempt to find one that gives good results. Fortunately, adjustment of this preset seems to be far from critical, and any roughly central setting seems to give satisfactory results.

When using the unit, set VR2 at a roughly central setting, and turn the control knob of VR3 fully counter clockwise. With the volume control well advanced, adjust the control knob of VR3 slowly in a clockwise direction until a loud tone is heard from the headphones. Then adjust VR2 to reduce the volume of the tone so that it is quite quiet but still clearly audible. Placing the search coil close to a metal object should result in the tune increasing or decreasing in volume. Conventionally, the detector should be set up so that the tone increases in volume for non-ferrous metals, and decreases in volume for ferrous types. This is the action that will be obtained if you have the windings of T1 connected in-phase. I preferred to have items or interest (which mostly means non-ferrous metals) produce a drop in volume, as I found a small drop in volume to be much more apparent than a small increase. I therefore wired the windings of T1 out-of-phase (ie, one “start” lead earthed and one used as the non-earthy lead). You might like to try out the unit one way, and then reverse the connections to one winding of T1 so that you can try it out the other way, to see which system you find easiest to use.

As a point of interest, I found that ferrite rods and pieces of iron had the opposite effect to most other metals, but steel (which I would have thought counted as a ferrous metal) usually did not. Note that for optimum sensitivity you must keep VR2 adjusted so that the tone from the earphones is fairly quiet under stand-by conditions. The unit inevitably drifts slightly, and VR2 will accordingly need to be periodically trimmed in order to keep the unit at optimum sensitivity. Eventually you will find that very frequent adjustment of VR2 and VR3 is required, and this indicates that the batteries are nearing exhaustion. There seems to be no problem at all with the ground effect. If an area of ground always gives a small indication from the unit, this indicates that the soil has a significant metal content This phenomenon is not as rare as you might think, and can occasionally make an effective search very difficult.

FINALLY

There are a few final points that it is worth mentioning. I believe that licenses are no longer needed for metal detectors. To be legally usable in the UK they must fall within certain restrictions, but to the best of my knowledge this design falls comfortably within all these restrictions. Constructors outside the UK should ascertain that the unit can be used legally in their country, and should obtain any necessary permit prior to constructing and using the unit. You should obtain permission before searching any land that you do not own. Any sites of historic interest are out-of-bounds to treasure hunters. If you should find something that is likely to be of significant historic interest you should take it to your local museum and give them full details of where it was found. Try to leave places you search as unspoiled as possible. Fill in any holes you dig, and generally disturb the soil as little as possible.

COMPONENTS

RESISTORS

R1,R8	4k7 (2 off)
R2	33k
R3	2k2
R4	390
R5	22k
R6	10k
R7	3M3
R9	47k
R10,R13	3k3 (2 off)
R11	1k8
R12	100k
R14	100R
R15	330k

All resistors 1/4 watt 5% carbon film

POTENTIOMETERS

VR1	22k sub-min hor preset
VR2	1M lin carbon
VR3	10k lin carbon
VR4	47k log carbon

CAPACITORS

C1,C11	100µF 25v radial elect (2off)
C2	1n polyester (7.5mm pitch)
C3	33n polyester (7.5mm pitch)
C4,C6	1µF 63v radial elect (2 off)
C5	22n polyester (7.5mm pitch)
C7	15n polyester (7.5mm pitch)
C8	100µF 10v radial elect
C9,C10	100n ceramic (2 off)

SEMICONDUCTORS

IC1	TLC555CP
IC2,IC4	CA3140E (2 off)
IC3	4077BE
IC5	4040BE
IC6	µA78L12 (12v 100mA pos reg)
TR1,TR2,TR3	BC547 (3 off)

MISCELLANEOUS

B1,B2	9 volt (high power PP3 size, 2 off)
S1	spst sub-min toggle
SK1	3.5mm jack
T1	36 swg enamelled copper wire (see text)

Plastic case about 150 x 80 x 50mm, printed circuit board, control knob (3 off), 8-pin dil ic holder (3 off), 14-pin dil ic holder, 16 pin dil ic holder, battery connector (2 off), twin screened lead, insulation tape, wooden dowel, hardboard, cable grip, fixing screws, etc (see text).