Metal Detectors - Part 2

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In last months article we looked at some of the fundamental principles behind metal detector design. This month we take a more practical approach and look at the construction of a simple but effective metal detector using some of the techniques discussed.

Many different types of detector are available ready built, some of which provide advanced functions and are microprocessor controlled. The intention is not to try to emulate the performance and features of these units as top of the range detectors are often complex and costly. The project is aimed at those who are new to metal detecting and are interested in experimenting with a basic detector that is relatively easy to build.

Overview

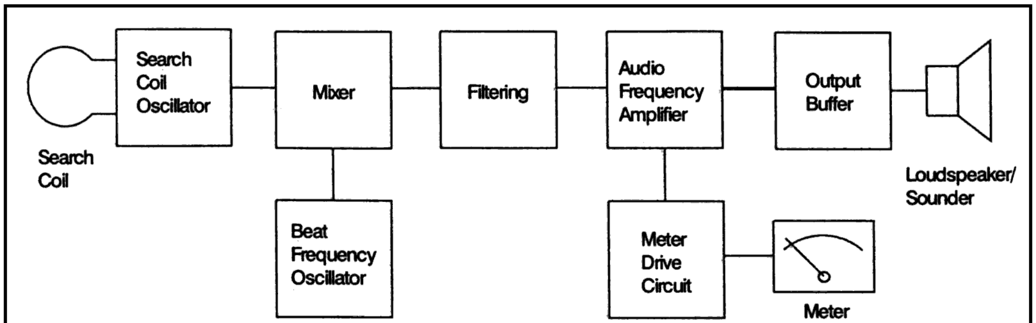

Figure 1. Simplified block diagram.

The design makes use of the beat frequency principle whereby a metal object in close proximity to a search coil modifies the frequency of an oscillator. When mixed with a second oscillator, a mixing product relating to the difference in frequency between the two oscillators is produced in the audible frequency range. This is known as a beat note, hence the term beat frequency oscillator. The change in frequency depends on the size of the metal object and distance from the search coil. When amplified the audio frequency output may be used to drive a small loudspeaker or headphones. Figure 1 shows a simplified block diagram for the circuit.

Circuit Description

Figure 2 shows the circuit diagram for the unit. Electrolytic capacitor C1 decouples the 9V power supply line. This helps to ensure that the power supply rails remain relatively free of noise. Regulator RG1 provides a stabilised 5V supply for the oscillator stages of the circuit. Decoupling of the 5V supply is provided by C2 and further high frequency filtering is accomplished by R1, C5, R4 and C8. Inductor L2 is the search coil, and together with capacitors VC1, C3 and C4 it forms a parallel resonant tuned circuit. The tuned circuit determines the operating frequency of the oscillator formed by field effect transistor TR1 and associated components. C3 and C4 effectively act as a capacitive tap and provide a suitable point to apply feedback to the tuned circuit without the need to tap the search coil directly. This simplifies the construction of the search coil. Resistor R2 ensures that there is a DC path for TR1 and sets the DC bias level.

TR2 and associated components form a second oscillator which is mixed with the search coil oscillator to produce a beat frequency. This time the operating frequency is determined by tuned circuit T1, a standard IF oscillator tuning can with an integral capacitor. The operation of this stage is slightly different to the search coil oscillator as the feedback is applied directly to a tap in the inductor as opposed to using a capacitive tap.

The outputs from the search coil oscillator (TR1) and the beat frequency oscillator (TR1) are fed to the next stage comprising TR3, R6 - 11, C9 - C13, and D1. This section acts to mix the signals from the two oscillators and provide a filtered audio frequency corresponding to the difference between the oscillator frequencies. The circuit is relatively simple but nevertheless generally provides an acceptable level of performance in this application. Preset variable resistor VR1 allows the level of the search coil oscillator to be adjusted as required.

The level of the audio frequency output produced at D1 is relatively small (in the region of a few mV) and is generally not enough to usefully drive a transducer. Operational amplifier ICla is used to amplify the signal up to a higher level. Resistors R12, R13 and C14 provide a reference level for the device whereas R14 and R15 set the amplifier gain. The output is fed to volume control VR2 via coupling capacitor C16 and then on to a buffer stage formed by ICld and associated components. C18 acts as a DC blocking capacitor at the output.

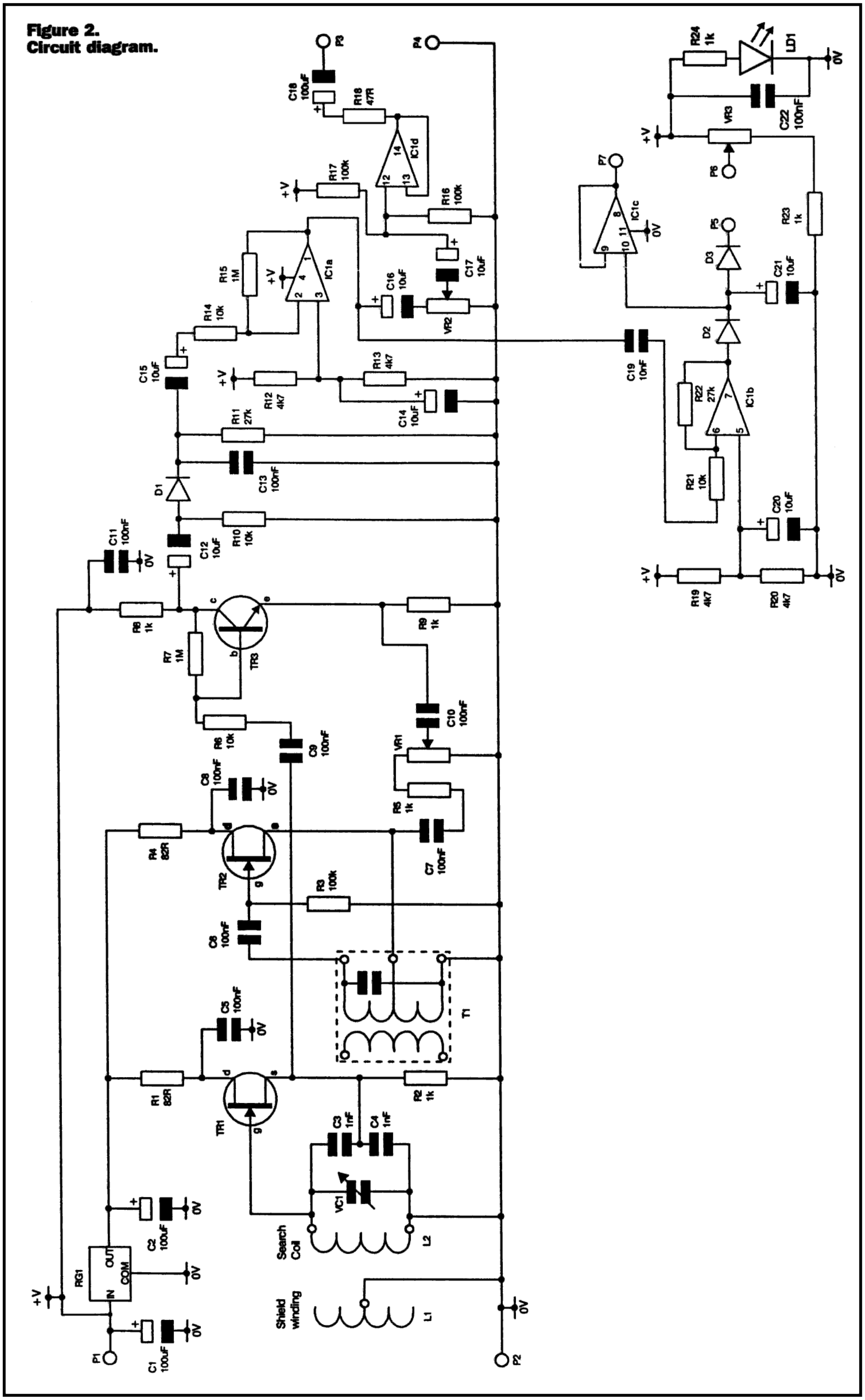

Figure 2.
Circuit diagram.

A further stage based around IClb produces a DC level derived from the A.F. signal at the output of ICla. This may be used to drive a moving coil meter (specifically LB80B). A second (auxiliary) DC output is provided at P7. The meter can be useful when tuning the oscillators to 'zero beat' and also provides some indication of battery condition when correctly set up. Variable resistor VR3 and resistor R23 set the maximum deflection of the meter. It should be noted that ICla - ICld all form part of the same quad op-amp package.

Construction

There are several aspects to consider with regard to construction. In addition to building and aligning the circuit it is also necessary to construct a suitable housing. It.is also possible to use different coil arrangements to modify the response of the detector. These points are dealt with separately.

Circuit Construction

The circuit may be built on matrix board or printed circuit board. It is necessary to provide a means of fixing the circuit board into the case. For the prototype unit, threaded spacers were used at each of the four corners of the board (Figure 3). Depending on the housing it may be necessary to replace the screws supplied with the spacers with longer types. It is advantageous to work out the required position for the circuit board in the case and drill any necessary fixing holes in the board before mounting any components. It is worth taking some time over this, as trying to drill holes at a late stage in a completed circuit board is awkward and it is easy to damage components if the drill slips. Similarly, it is sensible to double check the connections and layout of the completed board visually before it is installed into the case. There is nothing worse than completing the construction and installation only to realise that some critical component is missing or wrongly connected.

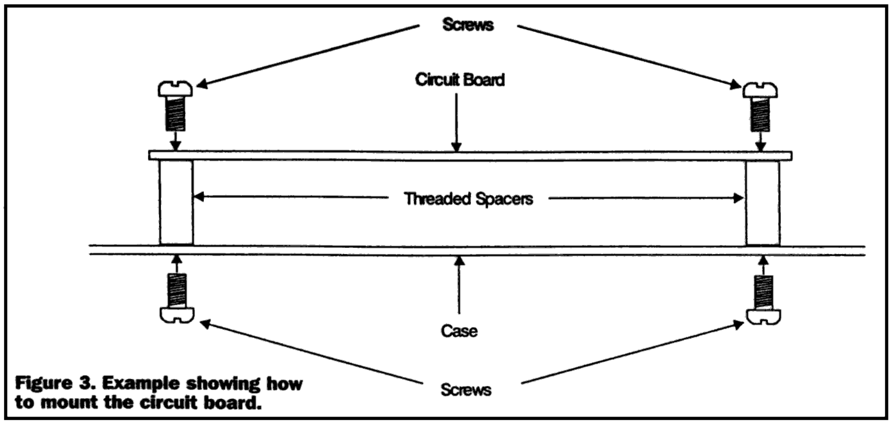

Figure 3. Example showing how to mount the circuit board.

Although the layout of the circuit is not over critical, there are relatively high frequencies involved so the usual common sense rules should be applied. In particular avoid long wiring runs between components on the circuit board as stray coupling may otherwise result. The components should be set out in a similar order to that of the circuit diagram. Try to keep high frequency decoupling capacitors as close as possible to associated components as this helps to reduce noise and instability on the supply rails.

When fitting polarised components such as semiconductors and electrolytic capacitors, please ensure that the devices are connected observing the correct polarity. Connecting components incorrectly may result in damage to the circuit and can also present a safety hazard. Figure 4 gives semiconductor pinout information. The polarity of diodes is indicated by a band on the body of the device adjacent to the cathode lead. The cathode lead of LED's is normally the shortest of the two and is often also indicated by a flat edge on the component body as shown in Figure 5. As regards electrolytic capacitors, the negative lead is normally indicated by a negative (-) symbol on the capacitor body adjacent to the relevant lead. The negative lead is also normally the shortest of the two. It is recommended that a DIL socket is used for IC1.

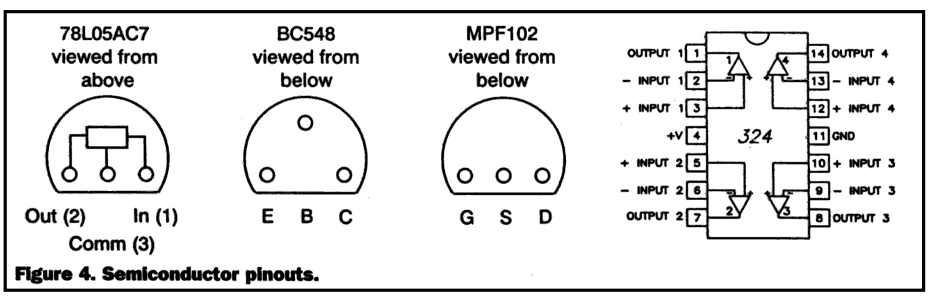

Figure 4. Semiconductor pinouts.

It is required to mount some of the components off board, the most obvious being the search coil. The volume and tuning controls may either be mounted directly onto the circuit board or wired off. The wiring to the tuning control is effectively part of the search coil tuned circuit and therefore should be kept as short as possible so as to avoid proximity effects and mechanical instability. Screened lead may be used to reduce these problems if necessary. Variable capacitor connections are shown in Figure 6 for guidance. It may be necessary to extend the capacitor spindle depending on the type of housing used. When mounting the VC1, take care not to insert the fixing screws too far into the capacitor case as this may damage the component. Figure 7 shows battery,

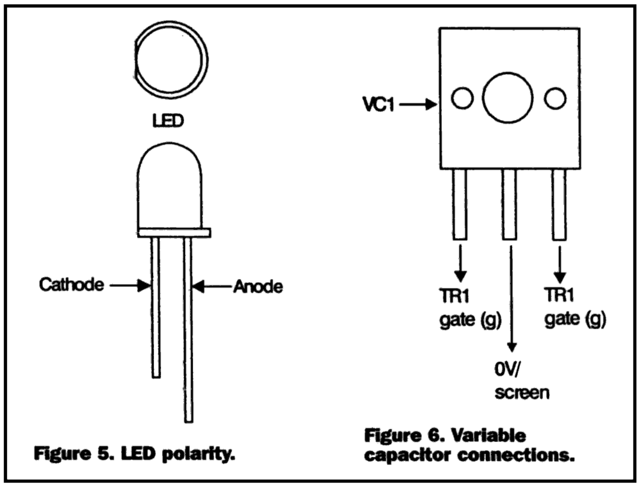

Figure 5. LED polarity.

Figure 6. Variable capacitor connections.

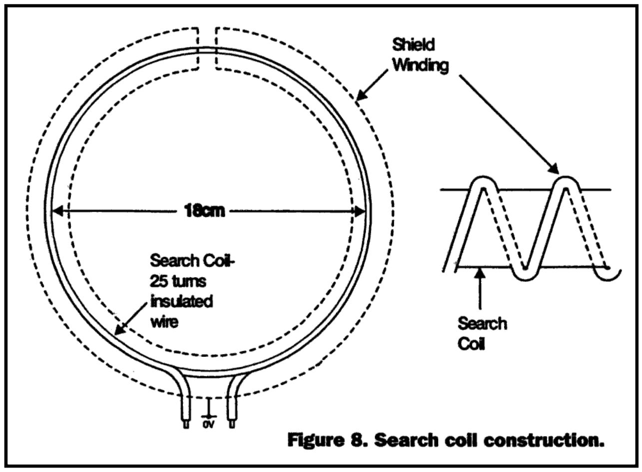

Figure 8. Search coil construction.

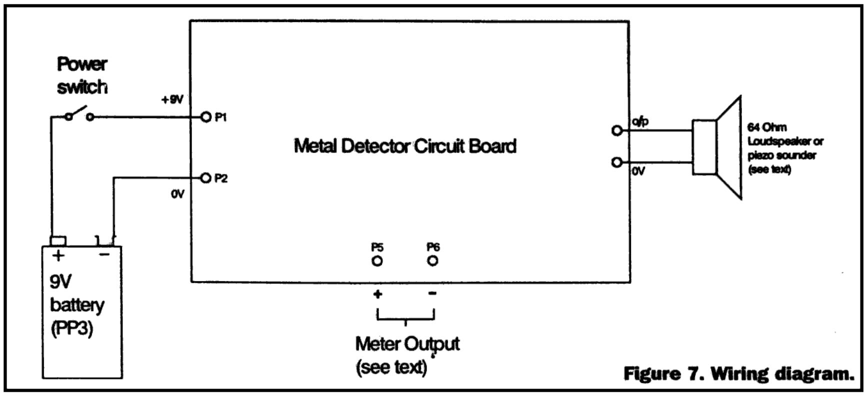

Figure 7. Wiring diagram.

meter and sounder wiring. The meter may be fixed into the case using a suitable adhesive. There are also optional items such as a headphone socket that may be considered.

As discussed earlier, the audio output of the circuit is derived from the output of an operational amplifier via a small limiting resistor. Therefore the output level is limited but should be loud enough in many circumstances. The circuit may be used to drive high impedance (64Ω) loudspeakers (e.g. YT27E) or piezo transducers (e.g. YU82D). In noisy environments it may be useful to use headphones. A switched headphone socket may be fitted so that the output normally connects to a loudspeaker but when the headphones are inserted the loudspeaker is disconnected.

Coil Construction

There are several different methods of constructing the search coil. The coil used for the prototype was constructed from insulated hook-up wire (BL00A) and consists of 25 turns of 18cm diameter. This is illustrated in Figure 8. It is important to use the correct dimensions and number of turns so that the resonant frequency falls within the correct range. If different parameters are used, it will be necessary to take steps to ensure that the circuit resonates at the correct frequency. An old paint can was used as a former when winding the coil. The turns may be secured using electrical insulating tape. The shape of the coil affects the response and sensitivity of the metal detector. In general a smaller coil will provide less sensitivity than a larger coil but will also provide better pinpointing accuracy. Therefore, there is always a compromise. It is also possible to modify the response by forming the coil into different shapes. For example by forming a large coil into a 'double D' or dumbbell configuration (Figure 9A) it is possible to obtain a null for pinpointing whilst still maintaining some of the sensitivity of a larger coil. The example shown in Figure 9B provides narrower coverage that can also be useful for pinpointing a find. Other than the requirement to resonate the circuit at the correct frequency, it is entirely up to the user to decide on the final size and configuration of the coil. The search coil should be connected to the circuit board using coaxial cable.

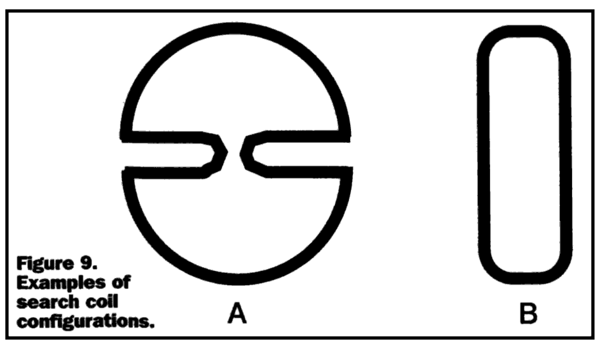

Figure 9. Examples of search coil configurations.

In addition to the main coil winding there is also a shield winding that helps to reduce electrostatic effects when the search coil is in close proximity to non metallic objects. The centre of the shield winding is connected to 0V. The shield winding must be broken half way along its length so that it does not act as a short circuit secondary winding to the search coil, as this would result in undesirable effects such as quenching the oscillator. Once again, although less than ideal, insulated hook-up wire has been found to be quite effective. The shield winding should be close spaced and cover the whole of the search coil as far as possible. The precise number of turns is not particularly critical. An alternative is to use metallic tape. There will inevitably be some detuning of the search coil circuit but this can be compensated for when aligning the circuit.

Choice of Housing

The choice of housing is up to the user. Figure 10 shows a typical example. It is not necessary to purchase specialised pans to produce an effective housing, readily available household materials may be used. The parts that are not stocked by Maplin are available from DIY stores etc. A length of standard plastic water pipe was used to create the boom section and a conveniently shaped utility hook forms the handle. The overall length of the boom may be adjusted by drilling a number of mounting holes along the length of the plastic pipe. An alternative is to slide a length of smaller diameter pipe into the main boom as illustrated in Figure 11.

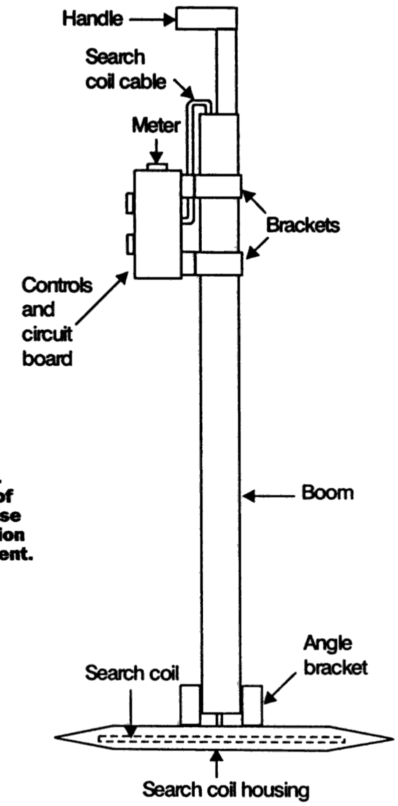

Figure 10. Example of typical case construction arrangement.

In keeping with the best traditions of children's television, the search coil housing is nothing more than a pair of plastic dinner plates bolted or glued together. The presence of metal objects in proximity to the search coil (such as fixing bolts) will obviously modify the frequency of the search coil oscillator but this is not generally a problem as long as the final circuit alignment is carried out after mechanical construction is complete. It is important that the search coil is held firmly in position inside the search head. Any variation in position relative to metal fixings will affect the oscillator frequency and can produce an annoying form of mechanical instability. The coil should be as close to the base of the search head as possible so as to provide the maximum effective detection range. If necessary the search head can be waterproofed using silicone rubber sealant. The search head is mounted to the boom using two angle brackets as shown in Figure 12.

Fixing hardware such as bolts, nuts and washers have not been specified as the requirements will vary with individual housings and fixing arrangements. Suitable fixings can be found in the Fixings and Hardware section of the current Maplin catalogue or in most good DIY stores.

As mentioned the search coil is connected to the circuit board using coaxial cable. This may be fed through the centre of the boom for convenience. The circuit board is housed in a plastic box stock code BZ74R. Make sure you leave enough space for the loudspeaker or transducer. The box is mounted onto the boom using suitable brackets. The final position should be chosen to allow a clear view of the meter and easy access to controls. It is useful to label the controls as illustrated in Figure 13.

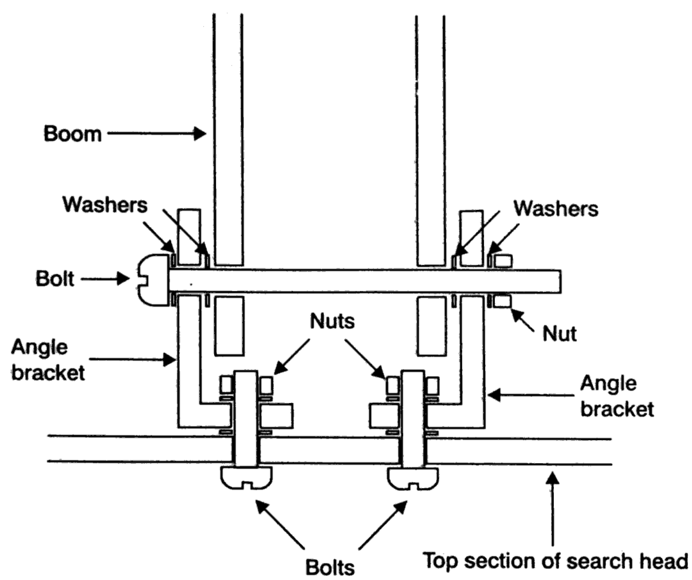

Figure 12. Attaching the search coil housing.

Depending on the intended application for the metal detector, it may be wise to waterproof at least the lower pan of the unit. Silicone rubber is often the best type of sealant for this application but, in any case, it is always wise to check that the sealant is suitable for the material it is being used on. It maybe possible to encapsulate the search coil in epoxy resin without significantly degrading the performance but remember that once this has been done it is not normally possible to make any further modification to the coil dimensions etc. It is therefore advisable to ensure that the detector is aligned and working correctly before carrying out any final waterproofing.

Testing and Alignment

Testing and alignment of the unit is possible without any specialised test equipment; however, an oscilloscope or frequency counter make the job considerably easier. It is also advisable to connect a multimeter set to measure current in series with the power supply to the metal detector in order to check the input current is not excessive at switch on. Before connecting the battery, please ensure that VR3 is set to the +V end of its travel; this helps to avoid the meter hitting the endstop which may result in possible damage.

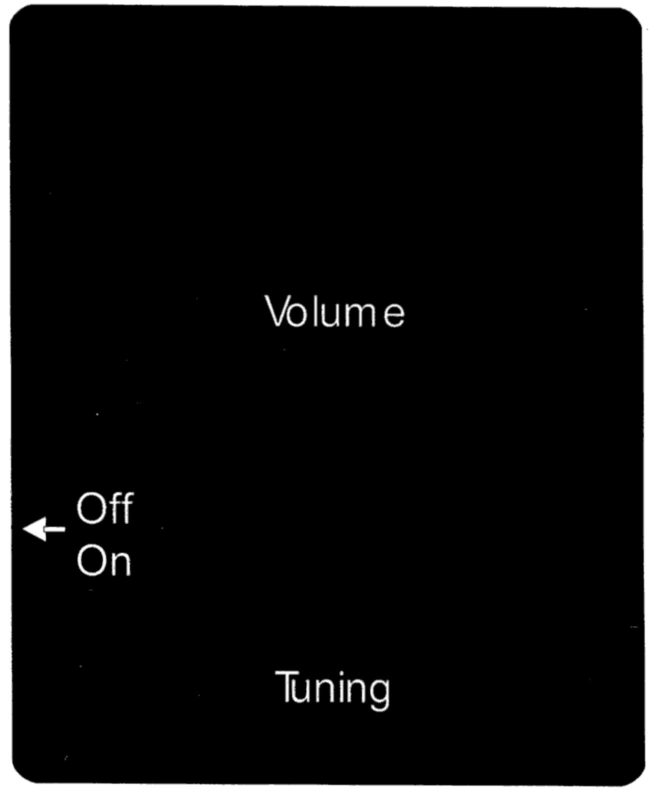

Figure 13. Front panel label template.

Apply power to the detector circuit. The power supply connects between P1 (+V) and P2 (0V). The circuit is designed to operate from a 9V PP3 battery. Please ensure that you connect the battery observing the correct polarity as the circuit may otherwise be damaged. Set the power switch to the 'ON' position. Set VC1 to the centre of its travel, VR1 to mid position and VR2 to maximum. At this point, it may be useful to check the voltage at the output of RG1 (5V).

For the circuit to operate correctly it is necessary to align T1 so that the beat frequency oscillator (TR2) operates at approximately the same frequency as the search coil oscillator (TR1). The exact operating frequency is not too critical from an operational point of view as long as the frequency of the two oscillators approximately coincide. The frequency is typically in the 400kHz - 500kHz range. If a frequency counter with a high impedance input is available, this can be used to check the oscillator frequencies making the whole process somewhat easier. If not, the simplest way is probably to slowly adjust the core of T1 until an audio frequency note is heard from the output transducer. Once you have an A.F. output, adjust VR1 for optimum performance. This adjustment is relatively important as if the oscillator level is too high, distortion will often result. Once optimised, carefully trim the setting of T1 to reduce the pitch of the A.F. output until a 'zero beat' is produced (oscillators at the same frequency). It should now be possible to change the pitch using tuning capacitor VC1. The zero beat should occur around mid position but this will tend to vary with external factors such as temperature.

As with most analogue circuits of this type where some parameters may vary considerably it may occasionally be necessary to make small changes to circuit values to allow correct alignment. In particular, depending on the search coil arrangement, it may be necessary to disconnect one gang of the tuning capacitor VC1 to allow the oscillators to be aligned to the same frequency (if the search coil oscillator frequency is too low). Conversely, if the frequency is too high connecting an additional small capacitance (a few pF) in parallel with VC1 will result in the oscillator running at a lower frequency.

If everything appears to working correctly the meter circuit may then be aligned. Set tuning control VC1 to provide an output frequency of around 1kHz and adjust VR3 until the meter reads full scale deflection. When the tuning control is returned to zero beat position, the meter should then read zero. Take care to avoid the meter indicator hitting the end stop. If the meter deflects in the wrong direction at any stage switch off and recheck the circuit connections.

Hold a metal object close to the search coil. The meter should deflect and the audio frequency should change. Try different settings of VC1 to obtain the most sensitive setting.

Using the detector

Once alignment is complete, the detector is ready for use. The unit should be capable of detecting metal objects up to a few cm away from the search coil (depending on size). The detector may either be set to zero beat such that it is silent until a metal object is detected or can be set so that it produces a continuous tone which varies if metal is present. The latter method is useful for detecting small objects which may only produce small changes in pitch. Non-metal objects may also produce a response under some circumstances but this should generally be less pronounced than when metal is detected.

Experimentation

The circuit shown is not fully optimised and more experienced readers may wish to experiment with different component values and configurations and with different search coils. As mentioned, it is relatively simple to change the operating frequency to suit individual requirements by changing the number of turns on the search coil and by connecting additional capacitance in parallel with T1. It may also be possible to improve stability by using higher tolerance components in the oscillator stages.

An audio power amplifier is not included as it was considered that the additional current consumption would reduce battery life. However, there is no reason why a small audio amplifier cannot be added if extra volume is required. A glance through the semiconductors section of the Maplin catalogue will show that there are a wide variety of off-the-shelf power amplifier ICs that are suitable for this purpose. Examples are the well tried and trusted TBA820M and the TDA7052.

Legal Requirements

There are various legislative requirements regarding metal detectors and ‘treasure hunting’ in general. It is outside the scope of this article to cover these issues and readers are advised to make themselves aware of any specific requirements before using the detector. In any case, uses should always seek the permission of the land owner before using a metal detector at any location.

Finally...

The metal detector described in this article is relatively simple but illustrates how a basic unit may be produced at relatively low cost. Even simple units of this type can provide surprisingly good results when carefully set up and used. Who knows what treasures you may find?

Project Parts List

RESISTORS			
R1, 4	82R	2	M82R
R2,5; 8, 9,23, 24	1k	6	M1K
R3, 16, 17	100k	3	M100K
R6, 10, 14, 21	10k	4	M10K
R7, 15	1M	2	M1M
R11, 22	27k	2	M27K
R12, 13, 19, 20	4k7	4	M4K7
R18	47R	1	M47R
VR1, 3	Hor Encl Preset 10k	2	UH03D
VR2	Pot Log 4k7	1	FW21X
CAPACITORS			
C1, 2, 18	GenElect 100µF 16V	3	AT40T
C3, 4	1% Polysty 1nF	2	BX56L
C5 - 11, 13, 22	MiniDisc 0.1µF 16V	9	YR75S
C12, 14-17,20,21	GenElect 10µF 63V	7	AT77J
C19	Ceramic 10nF	1	WX77J
VC1	Min AM Tuner Cap	1	FT78K
SEMICONDUCTORS			
TR1, 2	MPF102	2	QH59P
TR3	BC548	1	QB73Q
RG1	LM78L05ACZ	1	QL26D
D1-3	1N4148	1	QL80B
IC1	LM324N	1	UF26D
MISCELLANEOUS			
	DIL Socket 14-pin.	1	BU18U
T1	YMCS17104	1	YG32K
P1-6	Pin 2145	6 pins	FL24B
	SPST Ultra Min Tggle	1	FH97F
	Sig Strength Meter	1	LB80B
	Knob K7B	2	YX02C
	7/0.2 Wire 10M Blk	1	BL00A