

# Metal Detectors - Part 1

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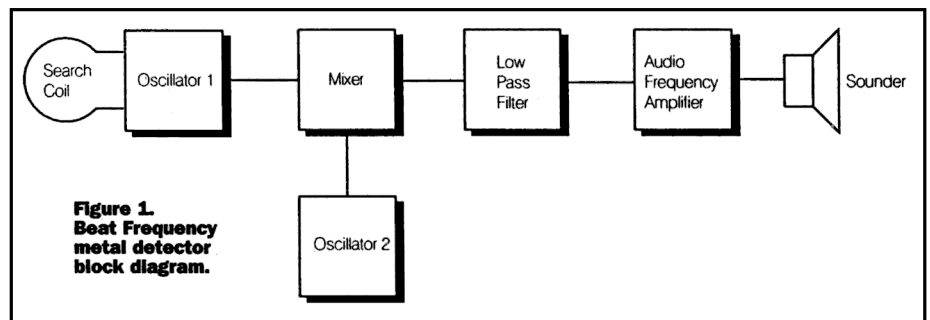
## Introduction

Metal detectors have many different uses ranging from detecting studs in walls to searching for archaeological artifacts or treasure buried in the ground. There are also many applications in industry. Over the years, a variety of different methods have been devised for remotely detecting and locating metal objects. The technologies used vary considerably depending on application. In this article we look at a selection of different types of metal detector and investigate the general theory behind the devices. Some practical considerations are also covered.

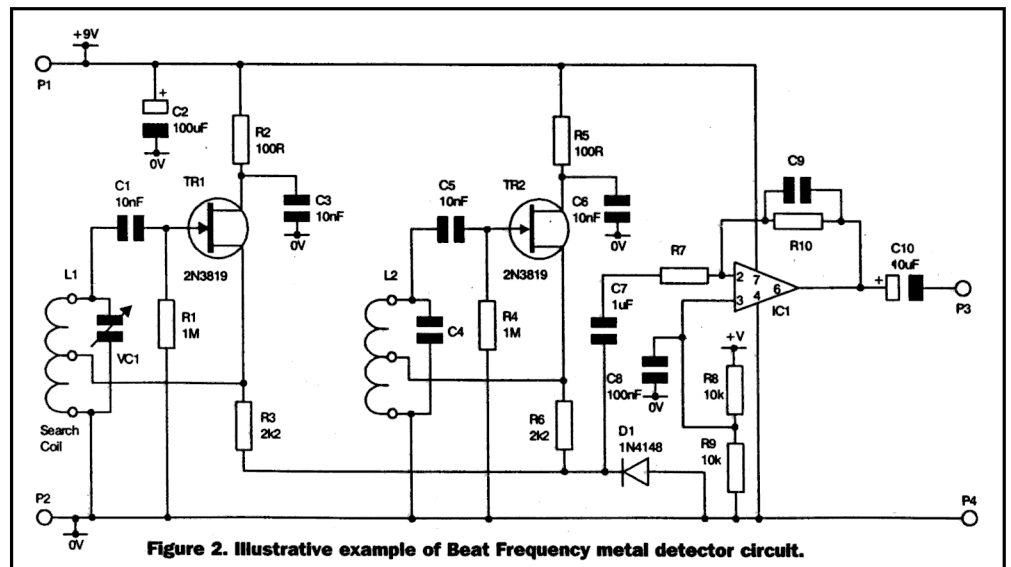
The simplest circuits are designed to detect the presence of metal objects independent of composition and do not provide any further information about the properties of the material detected. More specialised detectors allow discrimination between metals of different types or respond only to ferrous metals. The circuits and ideas discussed are intended as examples and may require considerable development and modification in order to produce a working unit.

## Some Examples

Most simple metal detectors and some more specialised types make use of proximity effects whereby the presence of metal close to a search coil modifies the characteristics of the circuit. Metal detectors of the Beat Frequency Oscillator or BFO type operate using this principle. Figure 1 shows the block diagram of a simple metal detector using the BFO principle. The detector is based on the principle that the resonant frequency of a tuned circuit varies if a metal object is placed in close proximity. If the tuned circuit forms part of an oscillator then the output frequency will be modified by the presence of a metal object. The variation in output frequency depends on the oscillator frequency chosen. In general, the higher the frequency the greater the change and the more sensitive the circuit. However, if the frequency is too high, the practical range may be reduced by the absorption effects of soil, building materials etc. In a practical circuit, the oscillator often operates at a frequency well outside the range of human hearing and therefore it is necessary to provide some indication that the resonant frequency is changed. BFO metal detectors do this by mixing or 'beating' the output of the oscillator with that of a second (fixed frequency) oscillator to produce a mixing product or 'beat note' within the audible range. In simplified designs the functions of more than one of the stages shown may often be performed by one active component and the low pass filter may be as simple as a capacitor and a resistor.



The frequency of one of the two oscillators is normally adjustable to allow the most appropriate audio frequency to be selected. This is not simply for the comfort of the listener. Variations in pitch are more obvious at some frequencies than others. It is also possible to 'zero beat' the two oscillators so that the output is silent under normal conditions. When a metal object is detected, the frequency of the search coil oscillator changes producing an audible output corresponding to the difference in frequency between the two oscillators. When used in this way the detector will effectively



be less sensitive as slight changes tend to result in only small changes in frequency. Therefore the audio note produced may be below audible frequency range. Also, depending on the design and coupling arrangements, there is sometimes a tendency for the two oscillators to automatically lock to the same frequency. If this occurs, a considerable change in the resonance of the search coil tuned circuit is required to pull the oscillators out of lock and onto different frequencies. Once again, this effect results in reduced sensitivity but can be useful in some applications.

Figure 2 shows a circuit example of a detector based on the beat frequency principle. The circuit shown is intended to illustrate how simple design techniques may be used to produce this type of detector. Component values shown are approximate. Because some parameters will vary depending on the chosen operating frequency, some values are omitted.

Inductor L1 forms the search coil and is resonated by variable capacitor VC1 to form a high Q tuned circuit. The tuned circuit forms part of an oscillator stage based around field effect transistor TR1 and associated components. VC1 allows the operating frequency of the oscillator to be varied. A second oscillator stage is formed by L2, C4, C5, R4 and TR2, this time operating at a fixed frequency. The output of the two oscillator stages is fed to D1 via limiting resistors. D1 introduces a nonlinear element into the signal path that effectively mixes the two oscillator frequencies. The result is an output rich in frequencies corresponding to the sum and difference of the two oscillator frequencies and associated harmonics. The oscillators are tuned to operate on closely adjacent frequencies such that the difference frequency falls within the audible region. For example if one oscillator is tuned to 100kHz and the second oscillator is tuned to 10kHz this will result in a difference frequency of 1kHz. The output of the diode mixer is fed to an audio amplifier comprising IC1 and associated components. This stage is based around a standard operational amplifier and would normally be capable of driving a high impedance earpiece or headphones. The value of capacitor C9 is chosen to limit the response of the amplifier at high frequencies which could otherwise result in undesirable effects. The gain required from the audio amplifier will depend on the amplitude of the signal at D1. This in turn depends on the oscillator frequency and the Q of the tuned circuits amongst other factors. The gain of the audio amplifier is determined by the value of resistors R7 and R10. In some applications it may be desirable to drive a small loudspeaker. Where this is the case the output at P3 could be connected to a small power amplifier.

Because the design of the circuit is very simple it will tend to suffer from problems such as frequency drift. This is not always a serious problem. However, where necessary unwanted drift can be reduced considerably by regulating the supply voltage and using high tolerance capacitors with the appropriate temperature coefficient. Component layout also plays an important part.

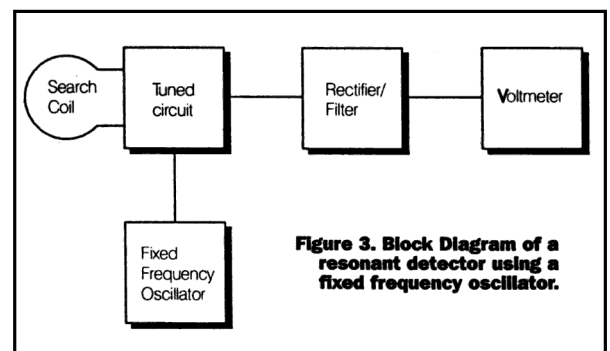
## Search Coil Design

The size and form of the search coil depends on the required sensitivity of the detector and on dimensional restrictions determined by the application. Also, different types of search coil provide varying degrees of accuracy. For example, the coil used in a simple handheld detector of the type often used in the building industry is normally relatively small so as to allow for compact construction and accuracy when determining the position of metal objects in walls etc. Conversely detectors used for locating objects buried in the ground normally have much larger search coils to provide high sensitivity and are not usually required to be particularly compact. However, a larger diameter coil may mean a reduction in accuracy. The shape of the coil can also have considerable influence on the overall response of the detector. A simple linear coil wound on an open former may be used for a hand held unit where it is intended for use at close range. In more specialised metal detectors, circular or square search coils are common.

A further consideration in relation to search coils forming part of a resonant circuit is the affect of non metallic objects on the Q and resonance of the tuned circuit. These effects are often related to capacitive loading of the circuit by nearby objects and can result in spurious operation whereby the circuit acts as if it is detecting metal when there is in fact no metal present. Capacitive effects can be reduced by the use of an earthed non-ferrous shield placed around the search coil. This shields the coil from electrostatic influences but has negligible effect on the magnetic characteristics of the circuit.

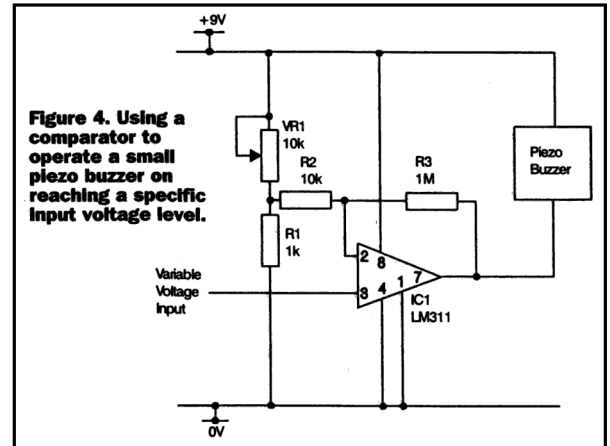
## Other Resonant Detectors

There is another form of detector that also makes use of the detuning effects of metal on a resonant tuned circuit. Figure 3 provides a conceptual illustration. A fixed frequency oscillator is used to drive a tuned circuit comprising the search coil and a variable capacitance. The inductance of the search coil and the associated capacitor are chosen so that the tuning range of the tuned circuit covers the oscillator frequency. In use the detector is placed in a position away from metallic objects and the tuned circuit is adjusted to resonate at the oscillator frequency using the variable capacitor. When correctly adjusted, this results in a peak in output signal level. Moving the search coil close to a metal



object results in a shift in the resonant frequency of the tuned circuit; however, this time the oscillator frequency is fixed and as a result the signal level developed across the tuned circuit drops. For the circuit to work effectively, the oscillator must exhibit good frequency stability. A simple method to ensure that the frequency remains stable is to use an oscillator circuit based on a quartz crystal. Relatively simple but effective detectors providing a reasonable level of sensitivity can be produced using this principle. As with most simple metal detectors, the sensitivity is determined by the size and shape of the search coil. The practical sensitivity of the circuit is also determined by the method of indication. For example, the voltage developed across the tuned circuit could be buffered, rectified and used to drive a moving coil meter. With careful circuit design making use of stable, high tolerance components it is possible to achieve good sensitivity. The voltage produced could also be used to drive a voltage controlled audio frequency oscillator to give an audible indication.

It is also simple to set a 'detect' threshold by connecting a comparator to the DC output of the circuit. An example of how this may be achieved is shown in Figure 4. By setting a specific switching threshold for the comparator, the circuit can be arranged to produce a switched output when metal is detected. In the example this is used to drive a small piezo buzzer. R1 and VR1 determine the switching threshold. R3 provides hysteresis to prevent the comparator oscillating around the trigger point. Using this principle, the sounder remains inoperative until a metal object is detected that is large enough to drive the comparator input over a predetermined switching threshold. By making the switching threshold adjustable, different levels of sensitivity may be set.

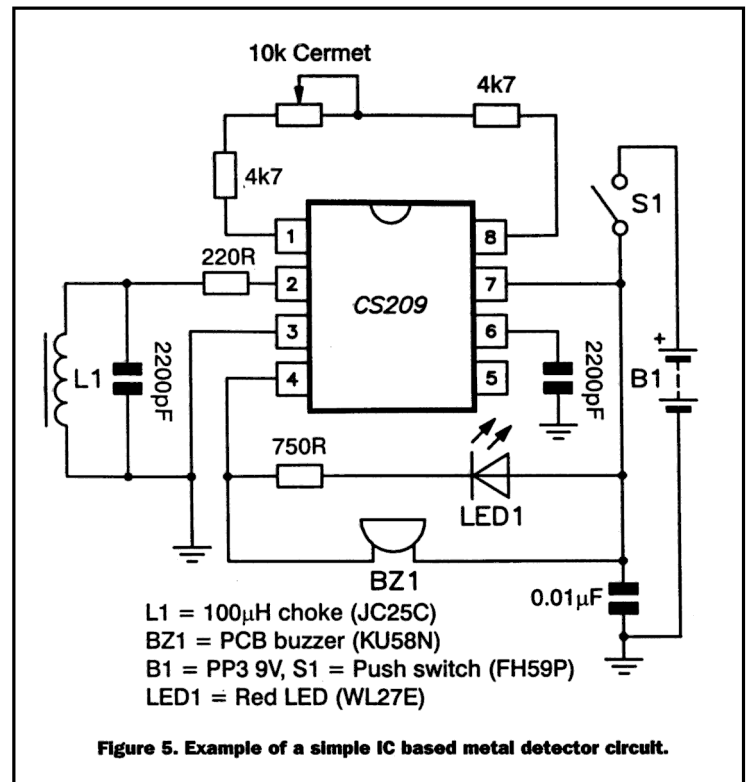


## IC Based Metal Detectors

Off the shelf IC's are available that are designed specifically for use in metal detector circuits. An example is the CS-209A IC (Maplin stock code UH59P). The device makes use of the fact that metal in close proximity to an oscillator tuned circuit affects the Q of the circuit and hence the signal amplitude. A level detector monitors the oscillator output and switches when a preset threshold is reached. An example of a simple circuit using the IC is shown in Figure 5 for reference. The device is ideal for use in applications such as hand held detectors for searching out wires and studs in walls.

## Detectors making use of variable coupling

A slightly different design makes use of variations in the degree of coupling between two coils when metal is placed in close proximity. There are various arrangements for this type of circuit which is sensitive to ferrous metals. The block diagram of a detector using this principle is shown in Figure 6. The output level from coil 2 is monitored. When a ferrous metal object is placed close to the coils the output level from coil 2 increases with the coupling. The unit may be set to trigger an audible or visible indication when the output level from the coil reaches a preset threshold. A moving coil meter or bargraph display may also be used to provide a level indication. This type of detector is generally not suited to applications requiring high sensitivity and has few practical advantages over other detector types.



## Magnetometer Based Detectors

All of the detectors mentioned so far work by directly affecting the characteristics of components in the metal detector circuit. These provide good general purpose performance in a wide range of applications. However, they are only really suitable for use over a short range where the metal object is relatively close to the detector. Therefore, if you are trying to detect metal buried deep in the ground (metres as opposed to centimetres) different techniques are required.

One method of detecting large ferrous objects buried deep in the ground is to look for localised variation in the earth's magnetic field. Sensitive magnetometers may be used to measure variations of this type. Because field variations may be very small, detectors of this type can be somewhat complex to construct. Also, the detectors can often be influenced in an unwanted way by ambient magnetic fields from power lines, geological features etc. Nevertheless, if you are looking for something large and iron buried deep in a remote location, a magnetometer based metal detector may provide the best chance of finding it.

Techniques used to produce magnetometers are varied. Linear hall effect devices that produce an output voltage proportional to magnetic flux are readily available in IC form. These are convenient but produce a relatively small output voltage. Therefore, to provide reasonable performance, when the changes in the magnetic field are small it is often necessary to follow the hall effect device with a low noise, low offset DC amplifier. Other devices for the measurement of magnetic fields include Flux Gate and Proton magnetometers. These can provide good sensitivity when properly aligned.

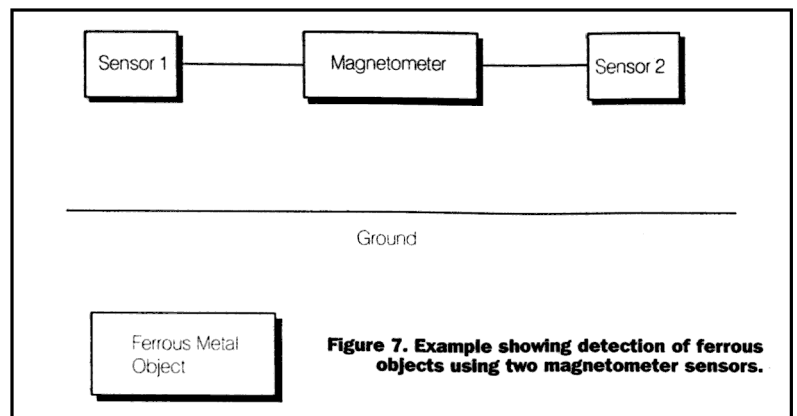
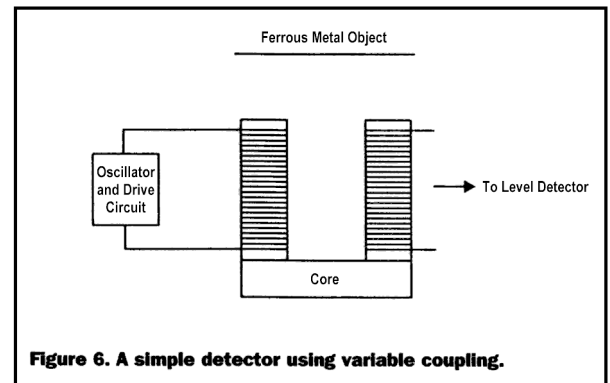
One of the easiest ways to detect localised variations in the earth's magnetic field is to compare the output from two magnetometer sensors spaced some distance horizontally apart, as illustrated in Figure 7. When the magnetic field is undistorted, the output from both sensors is similar (once any differences due to tolerance are ironed out). However a metallic object positioned immediately below one of the sensors results in distortion of the field and a variation in magnetic flux. Because the distortion is localised and one of the sensors is closer to the metal object than the other, a difference in the output of the two sensors results. This difference can be amplified to provide an audible or visible reading.

In addition to the presence of ferrous metal objects, there are also other possible reasons for localised variation of the earth's magnetic field. Therefore magnetometers of the type discussed can only be used to indicate where objects may possibly be buried and do not give 100% certainty. Also, as with most metal detectors, it is sometimes difficult to distinguish between a small object buried near to the surface and something larger buried several metres deep.

## Indicators and Interpreting Results

How a metal detector indicates that it has detected a relevant object can be quite important. In most cases the output from the detector circuit may be used to drive an appropriate meter. This could be a simple analogue meter, a bargraph or a digital display. In most applications, however, it is not practical to watch a meter reading all the time. If the circuit provides a switched output that becomes active when a metal object is detected, this may be used to switch on a lamp or buzzer. An audible indication is often much more appropriate, especially if you are walking around a field looking for buried coins. In this situation, probably the last thing you need is to continuously watch a meter. As we have seen, some types of metal detector, such as the beat frequency type, automatically produce an audible output and for these units this is the normal mode of operation. It can still be useful to have a meter reading in addition to help the user determine the degree of response when an object is detected. For metal detectors that produce an output in the form of a variable voltage, this can easily be converted to an audible output using a voltage controlled audio frequency oscillator. This will produce a note that varies in pitch similar to the BFO unit when an object is detected.

Using peak hold techniques it is possible to make the response of a metal detector dynamic to aid pinpointing of a find once it has been detected. Multiple search coils can also be used. These may be switchable so that, for example, a large coil is used to initially detect the presence of metal whilst a smaller coil provides more accurate pinpointing of the find.



Magnetometers are sometimes used to detect very large ferrous objects or mineral deposits. Interpreting and making sense of the data produced in such circumstances can be very complex. In this type of specialised application, it is useful to provide a digital interface so that the reading and precise location can be stored in memory and loaded onto a personal computer for processing.

## Discriminating between different materials

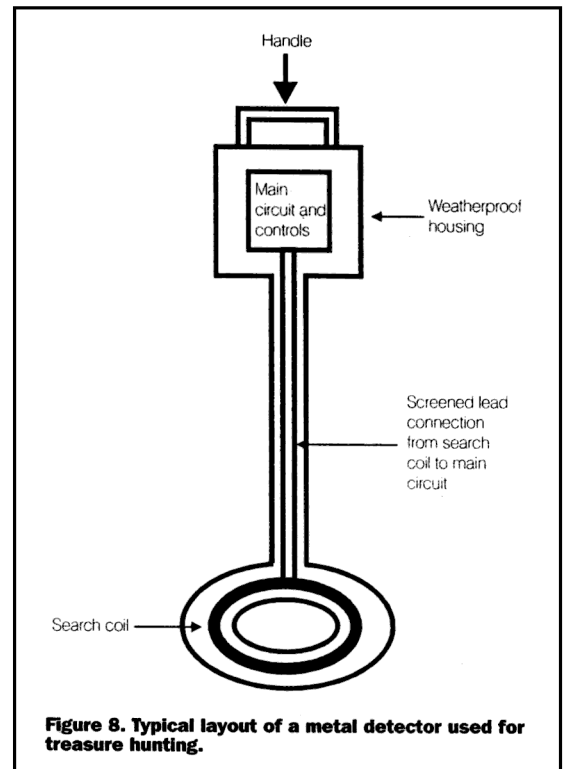
For some applications it can be useful to discriminate between different types of metal. As mentioned, some types of detector will only respond to ferrous metals. Also metals of different types result in different proximity effects. For example, the variation in frequency produced when a metal object is close to the search coil of a BFO based detector will not only depend on the size and position of the object but also on its composition. Ferrous metals (containing iron) produce a totally different response to non-ferrous metals such as copper, gold and silver. This effect can be used to great advantage when searching for precious metals (coins etc.) buried in the soil.

## Housing Considerations

So far we have covered some electrical design criteria and fundamental theory relating to metal detectors. Of course, when producing a practical unit, the physical aspects of construction are almost as important. A metal detector should be constructed and housed so as to be as simple to use as possible. For example, a detector designed for DIY use in the home should preferably be compact enough to fit in your tool box. Conversely, if the unit is designed for outdoor use, it is important to consider such aspects as weatherproofing. Some applications may require the search coil to be submerged in water requiring complete waterproofing. If your hobby is searching for buried treasure you will want the detector to be as light weight as possible and so on. An example of a typical layout is shown in Figure 8. The shape and dimensions of some metal detectors are heavily influenced by the design of the circuit itself. This is particularly the case with some magnetometer based units and detectors requiring large search coils. Although these considerations may be fairly obvious, they are an important factor and can affect the circuit layout considerably.

## Next Month

This month we have looked at the basics of metal detector design so as to form an overview of the type of techniques commonly used. Next month we will look at the construction of a metal detector and consider specific requirements at a practical level.



**Figure 8. Typical layout of a metal detector used for treasure hunting.**