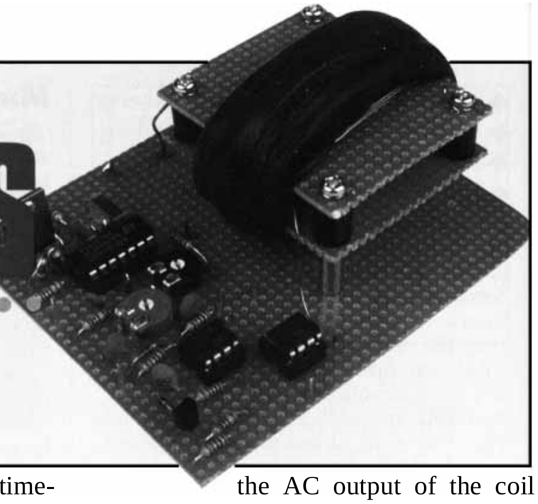
PROJECT
MAGNETUMETERS
PART 2

In part 2, Gavin Cheeseman gets down to some construction.



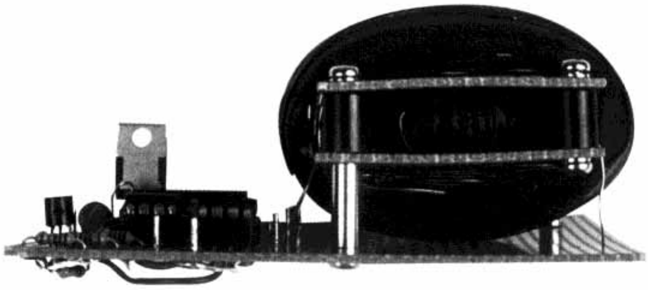
In part 1 we looked at some of the principles involved with measuring magnetic fields. This time, we take a more practical approach and look at some experimental circuits. The circuits illustrated are intended to provide a starting point and are therefore not fully optimised. They may, however, form the basis of a number of different control and measurement circuits.

Detector for Alternating Magnetic Fields

As discussed in last months article, probably one of the most effective detectors for alternating or transient magnetic fields is a coil of wire. When properly constructed this type of arrangement works very well, but to measure alternating fields the coil must be connected to an oscilloscope, multimeter or other device allowing the direct measurement of AC voltage. For many applications a DC voltage output would be much more useful.

Probably the easiest way to convert the AC output of the coil into a DC level is to use simple diode rectifier as shown in Figure 1. However, this method has the disadvantage that the output level from the coil must be enough to forward bias the diode on peaks. As a result, a simple rectifier is of very little use at small signal levels. In order to circumvent this problem an operational amplifier can be used to create a simple peak detector that will easily respond to very small signal levels. Figure 2 shows a typical example of a detector circuit using this principle. The output of the detector coil is fed to the input of operational amplifier IC1. Diodes Dl and D2 help to prevent overload, while rectifier diode D3 effectively forms part of the feedback loop of the opamp circuit. As a result, the opamp compensates for the voltage drop across the diode when it is forward biased. The output from the diode charges C3 as with a standard rectifier, and R1 provides a discharge path for the capacitor to prevent it from remaining charged for long periods. The DC voltage present at the cathode of D3 approximately corresponds to the peak voltage of the AC waveform produced by L1. Although this voltage can be used to drive a high impedance circuit directly, it is generally preferable to use a buffer and operational amplifier IC2 is used for this purpose.

It should be pointed our that



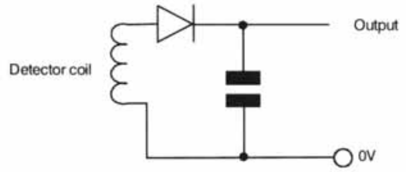


Figure 1. Simple diode rectifier to convert an AC signal into a DC level.

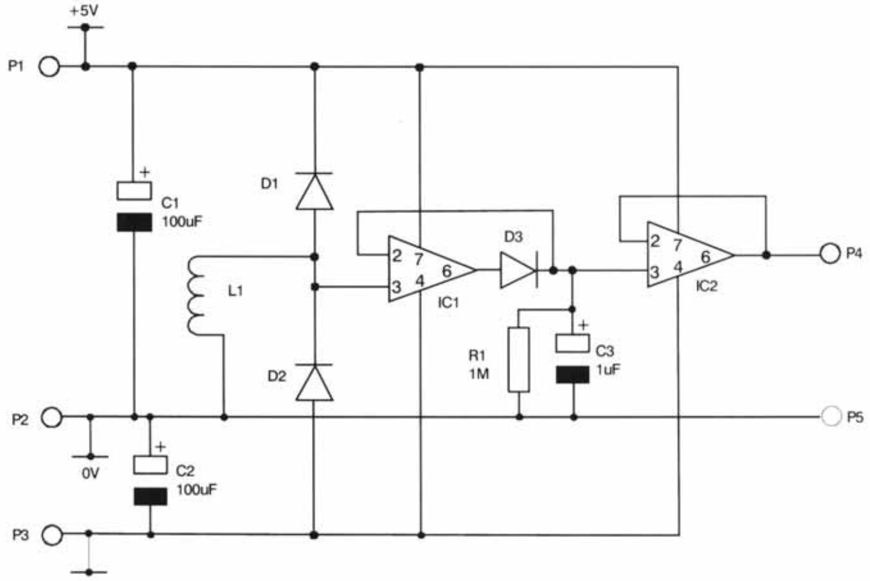


Figure 2. Alternating field detector using operational amplifiers.

the output voltage produced by this type of coil based detector is heavily dependant on the coil dimensions and the frequency of the field being measured. The coil may be air spaced or wound onto a suitable core.

Construction

The circuit can be built on matrix board, or even on bread-board if for purely experimental purposes, and is relatively straightforward to construct. The layout of the circuit is not particularly critical. As with most analogue circuits it is best to keep wiring runs as short as possible.

The coil dimensions depend on the application. For general relative measurement of low frequency alternating magnetic fields such as those related to AC power lines up to audio frequencies a few hundred turns of wire on a small ferrite rod are quite effective. Depending on the application it may be necessary to provide some screening around the coil to prevent the circuit from responding to ambient radio frequency signals which may affect the output voltage. Where this is the case a screening material that has minimal affect on the magnetic flux density must be used. It goes without saying that metals containing iron and other ferromagnetic materials are unsuitable for this purpose.

The speed at which the circuit will respond to changes in input level is, for the larger part, determined by the values of R1 and C3. Lower values provide a faster response but with the trade-off that at low frequencies a considerable amount of ripple may be present at the output.

Measuring a Static Magnetic Field

Hall effect devices provide a simple method of measuring the magnetic flux density of a static magnetic field such as that produced by a bar magnet where the magnetic flux density is relatively high. Devices such as the UGN3503U are simple to use and are completely self contained requiring little or no additional circuitry to function. Figure 3 illustrates just how simple it is to connect and use these devices. The output is in the form of a DC voltage proportional to the magnetic flux density. Readers wishing to experiment with these devices are recommended to refer to the manufacturers data sheets before commencing construction.

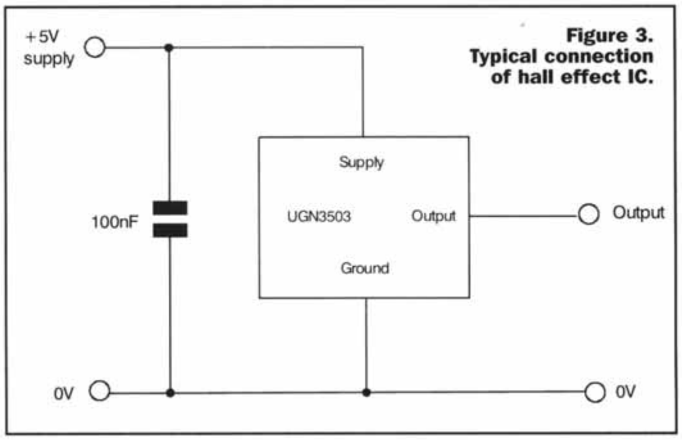


Figure 3. Typical connection of hall effect IC.

One use for this type of device is in a volume pedal for use with electric guitars and other electronic musical instruments. In this application the output of the Hall effect IC is used to control a voltage controlled amplifier. Another application is positional sensing.

A Sensitive Magnetometer

For some applications, for example when measuring the earth’s magnetic field, a more sensitive detector is required. A large coil of wire can be used to detect extremely small variations in magnetic flux density; however, to obtain good sensitivity it is necessary to use a coil of relatively large dimensions. This arrangement also has the disadvantage that it will only respond to changes in flux density. To make measurements of static magnetic fields using such a system, it is necessary to rotate the coil in the field. This provides very good results but often requires complicated mechanical arrangements especially since it is important to regulate the speed of rotation for accurate measurements.

As we discussed last month, there are various other methods of measuring static low level magnetic fields. The circuit described here makes use of a specific type of coil arrangement wound onto a Ferrite ring core and is capable of providing relative measurements of magnetic flux density. A coil wound toroidally onto the core is driven with low frequency pulses such that the core is in the region of saturation. A second (detector) coil is wound around the outside of the core. Under normal conditions when no external field is present, the magnetic field around opposite halves of the coil tend to cancel, and as a result, the net field produced around the outside of the core is negligible. However, when an external field is present, this creates an imbalance, resulting in an increase in the net field around tile outside of the core which is detectable as an induced current in the detector coil.

Circuit Description

Figure 4 shows the circuit diagram of the detector. Integrated circuit, IC1 (a CMOS hex Schmitt inverter) performs several functions within the circuit. ICla-IClc produce a low frequency short duration pulse for drive coil L1a. ICla forms a simple square wave oscillator. The output of the oscillator is fed via diode D2 to the input of IClb which, together with IClc, forms a retriggerable monostable. The output is of the same frequency as the output of ICla but with a much shorter duty cycle. IClc switches on Field Effect Transistor TR1 during the period that the output is in a logic high state driving L1a with current pulses. D5 helps to limit the switching transients produced by Lla. Llb is the detector coil. The height of the pulse produced by Llb is partially determined by any external magnetic field present. The output from Llb is fed to operational amplifier IC2 via coupling capacitor C10. Resistors R13 and R14 provide a half supply reference at the input of the opamp. Diodes D7 and D8 limit the amplitude of the input signal if it swings significantly above or below the supply rails. The pulse waveform produced by the detector is buffered by 1C2 and appears on pin 6 of the device. In addition to the required pulse there are also other unwanted transients. These are gated out by TR2 which switches the signal to ground except during the period that the required pulse is present. The drive signal for TR2 is produced by ICld - ICle

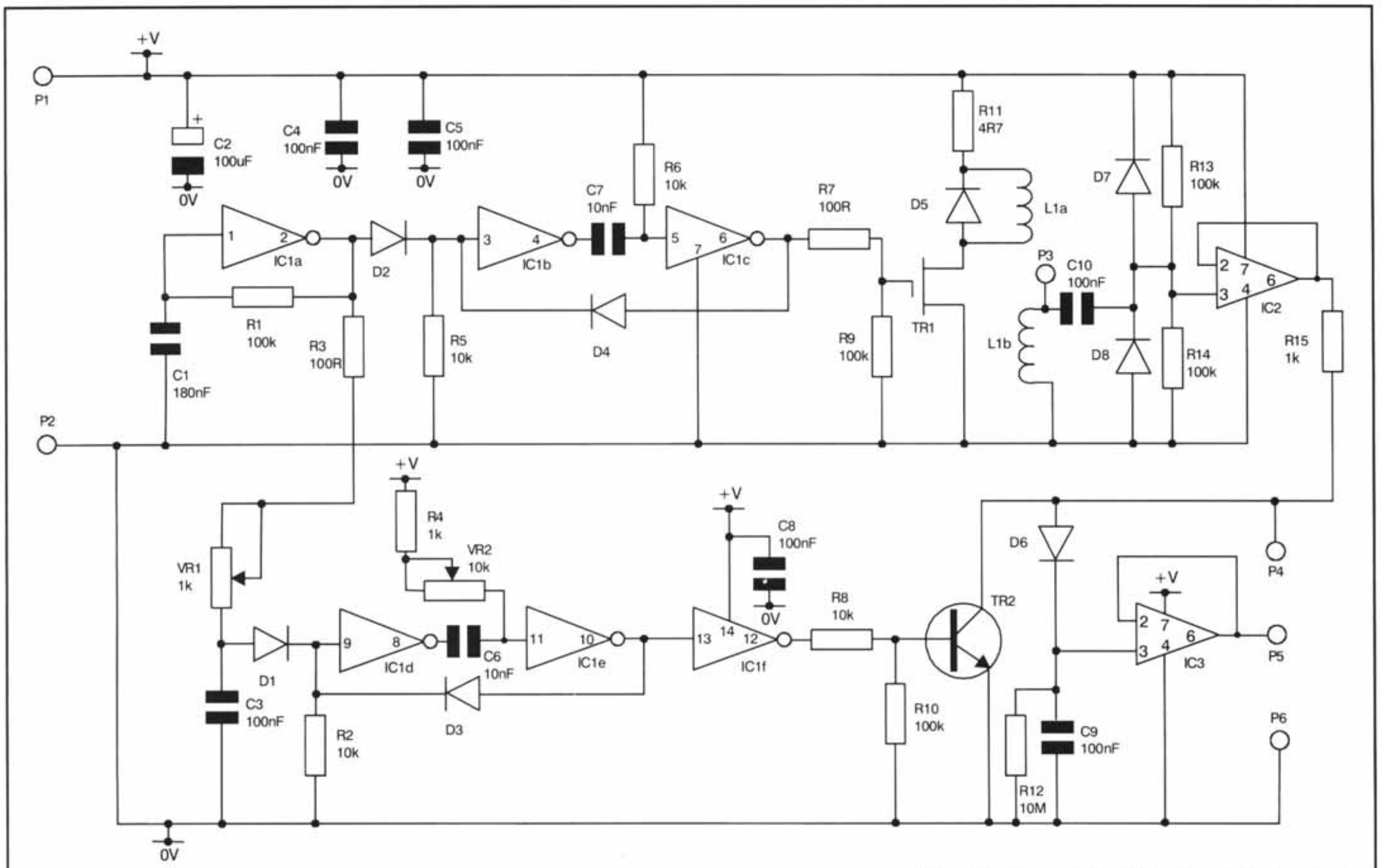


Figure 4. Sensitive Detector circuit diagram.

and associated components and is derived from the oscillator at ICla. There are two preset variable resistors. VRI together with C3 determines the point at which the monostable formed by ICld and ICle triggers. VR2 determines the length of the pulse produced by the monostable. IClf inverts the pulse output from ICle so that it is of the correct sense to drive TR2. The waveform produced at terminal P4 consists of the buffered output from the detector coil together with the pulse produced by TR2 switching. This signal charges capacitor C9 via diode D6 with R12 providing a discharge path. The resulting DC voltage is buffered by operational amplifier IC3 and is made available on terminal P5. The output voltage at P5 is proportional to the magnetic flux density of any external magnetic field to which the detector coil is exposed. The voltage is of course offset due to the half supply reference voltage for IC2 but for relative readings this generally does not present a problem.

Constructing the Detector

The circuit may be constructed using matrix board. The circuit layout is not particularly critical, but it is best to run separate supply rails to high current parts of the circuit, for example the coil drive section. It is probably best to arrange the orientation of the coil such that the plane of the detector coil is edge-on to the rest of the circuit as shown in Figure 5. Also try to avoid running any high current power supply wiring close to the detector coil. As the coil arrangement is quite bulky it is probably easiest not to fix the coil into position until all other components are fitted.

As usual, it is recommended that DIL sockets are used for the ICs to minimise the possibility of damage during installation. Make sure that all polarised components are fitted observing the correct polarity as incorrect connection may result in failure of the circuit to operate and may also be dangerous due to the possibility of explosion. The IC pinouts are shown in Figure 6 and the transistor and diode leadouts are shown

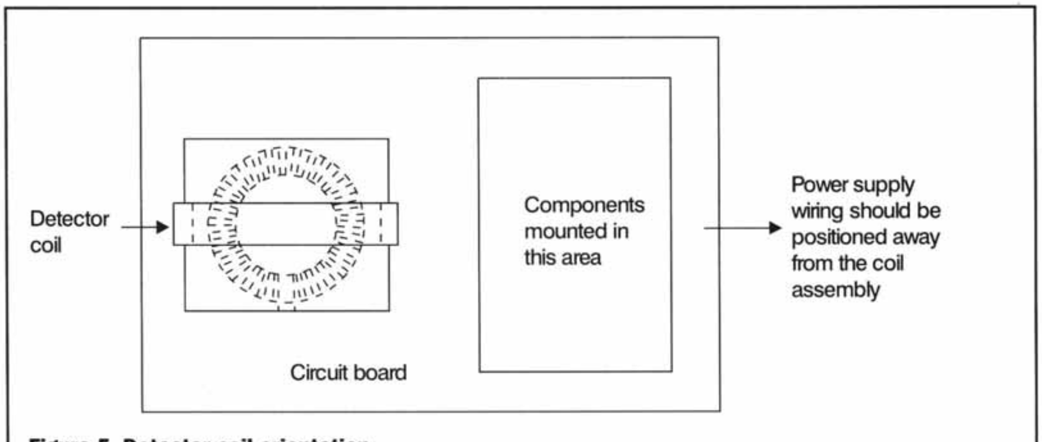


Figure 5. Detector coil orientation.

in Figure 7. Pay particular attention to polarity when connecting the electrolytic capacitors. The negative lead of the capacitor is usually indicated with a negative (-) symbol on the body of the component and is usually the shortest of the two leads.

The coil is wound around a standard ferrite ring core of the type used for RF interference suppression. Figure 8 shows the winding details. The drive coil is 60 turns of 22 SWG enamelled copper wire. Allow for about 2 metres of wire when winding the coil, and try to space the windings as evenly as possible. The windings can be held in place using electrical insulating tape if necessary. It is necessary to wind the detector coil around the outside of the core and this is easiest with the help of a former. A simple former can be created using two pieces of matrix board spaced apart using threaded spacers positioned at each of the four corners. The core is sandwiched between the two pieces of board and may be fixed in position using a suitable adhesive. The detector winding consists of 300 turns of 26SWG enamelled copper wire loose wound around the former. This winding may also be held in position with electrical insulating tape where necessary. The leadouts from the windings may be looped though the holes in the matrix board to provide additional anchorage. The whole coil assembly can be mounted onto the main circuit board using nuts bolts and washers positioned at each corner.

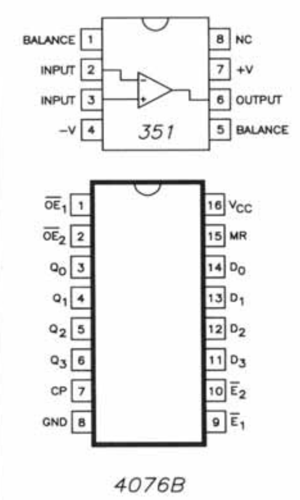
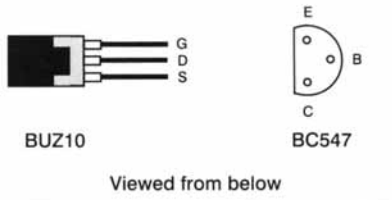


Figure 6. IC pinouts.

Figure 7. Transistor outlines.



Testing and Alignment

It is probably easiest to test and align the unit using an oscilloscope but this is not essential. Before applying power to the circuit double check the construction to ensure that there are no connection errors or poorly soldered joints. It is useful to connect a multimeter set to the current range in series with the circuit when first applying power so as to check that the current drain is not excessive.

The circuit requires a 9V DC regulated power supply. The wiring diagram for the unit is shown in Figure 9. It is important that the supply voltage is stable as the final output voltage is partially derived from this. If required, a suitable regulator may be used as shown in Figure 10. Variations in supply volt-

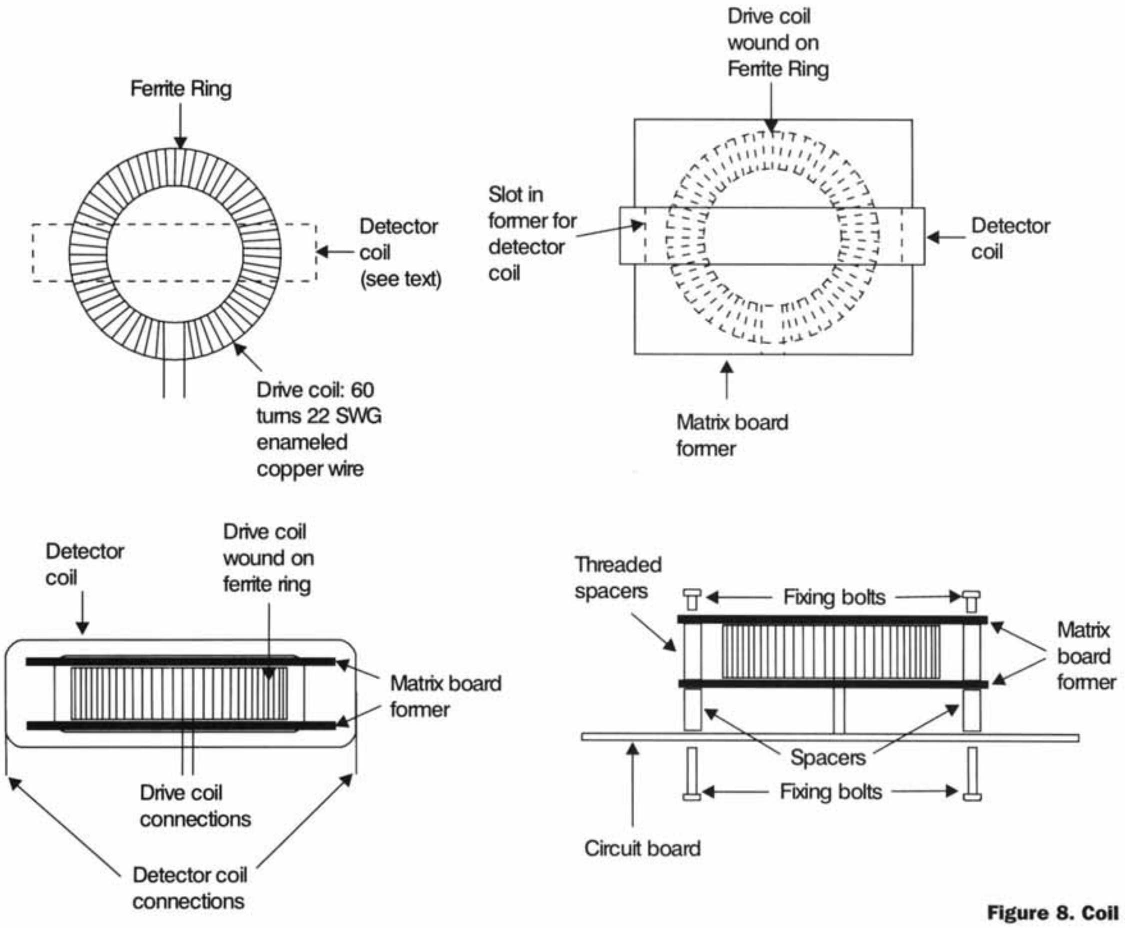


Figure 8. Coil Assembly.

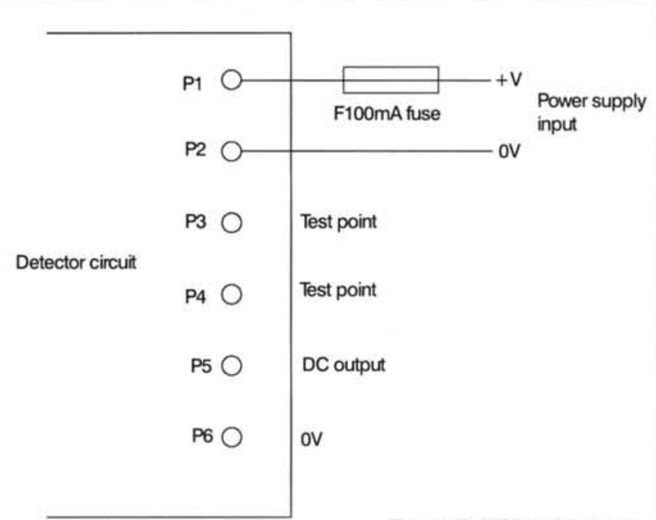


Figure 9. Wiring Diagram.

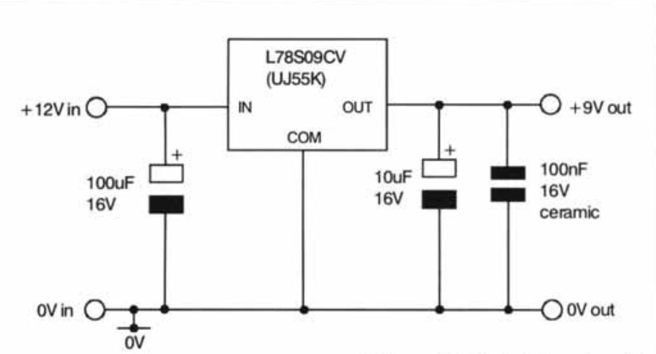


Figure 10. Regulator circuit.

age will affect the output voltage and hence the accuracy of the circuit. It may also be necessary to add additional supply filtering in some cases to prevent unwanted pulses being imposed on the power rails.

Important Note

Fusing of the power supply is required to reduce the risk of overheating in the event of a fault condition. It is recommended that an F100mA fuse is fitted in series with the positive (+V) supply rail to provide protection in the event of circuit failure. It is particularly important to provide protection, since if the oscillator stops this may result in a considerable increase in current consumption which may result in excessive heat being developed. In normal operation, the average current consumption is considerably less than 100mA due to the short pulse width used.

Some form of DC voltage indication is required to test the output of the circuit. An oscilloscope or multimeter are ideal. An alternative is to use a moving coil meter with a series resistor as shown in Figure 11. The preset resistor should be adjusted for a zero reading on the meter. The maximum output voltage from the circuit does not exceed the supply voltage when operating correctly. It is also useful to have a small magnet available - the magnet of a small unshielded loudspeaker is ideal.

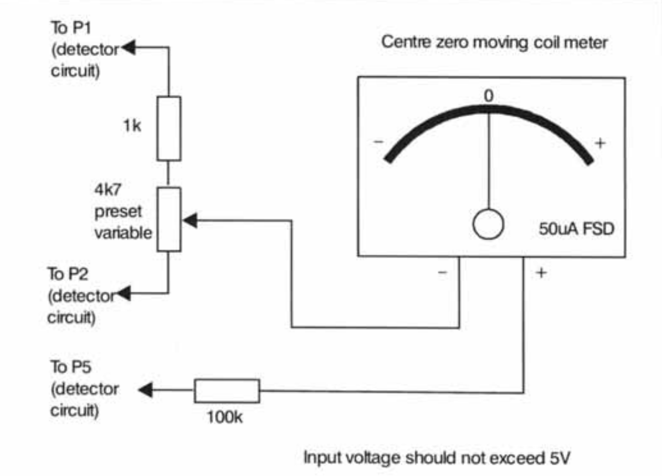
Apply power to the circuit and check that the current consumption is less than 100mA. Adjust variable resistor VR2 to maximum resistance. If an oscilloscope is available check the output waveform at terminal P4. This should be similar to that shown in Figure 12. Slowly move a magnet close to the coil as shown in Figure 13. This should result in a variation in the height of the pulse. Pointing the same pole of the magnet towards the opposite side of the detector coil should result in change of pulse height in the opposite direction. Try to avoid moving the magnet very close to the detector coil as this will tend to overload the input circuit resulting in erroneous readings. In addition to the required pulse it will be seen that other (unwanted) signal variations are present. In order to prevent the unwanted components of the signal from affecting the final output level from the circuit, it is necessary to adjust VR1 and VR2 such that only the required pulses are present. Figure 14 illustrates the type of waveform that can be expected at P4.

The DC output from the circuit is available at P5. This output can be checked using a multimeter set to the voltage range or a moving coil meter with the appropriate value of series resistor. If a strong external magnetic field is not present the output voltage should sit at approximately half the power supply voltage. Check that the output voltage changes when a magnet is moved towards the detector coil. A voltage change in the opposite direction occurs if the same pole of the magnet is positioned close to the opposite side of the detector coil. Once again, if the magnet is positioned in very close proximity to the coil this will tend to overload the circuit.

If an oscilloscope is not available alignment of the circuit is more of a trial and error process. Check the output voltage at P5 and adjust preset variable resistors VRI and VR2 to obtain the best sensitivity. This can be checked by slowly moving a magnet close to the detector coil. Set the presets such that the movement of the magnet is detected when it is as far away from the coil as possible. Once the unit is set up, try detecting the earth's magnetic field noting the change in output voltage as the detector is rotated through 360°.

Applications and Circuit Development

Applications of magnetometers were discussed in last months article. The detector is a general purpose experi-



Input voltage should not exceed 5V

Figure 11. Using a moving coil meter as a level indicator.

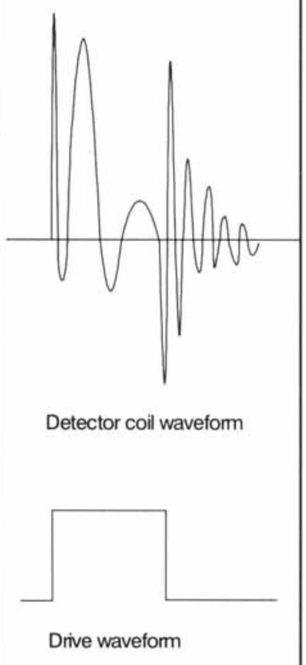


Figure 12. Typical detector coil output waveform.

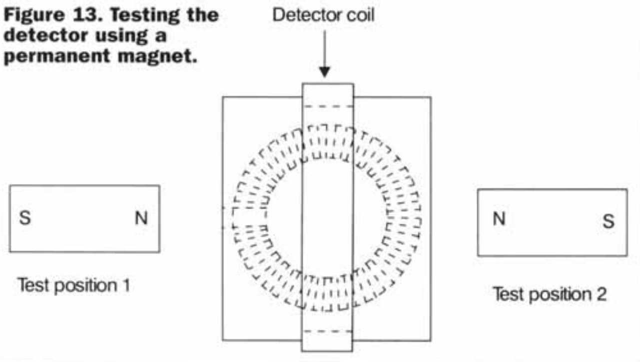


Figure 13. Testing the detector using a permanent magnet.

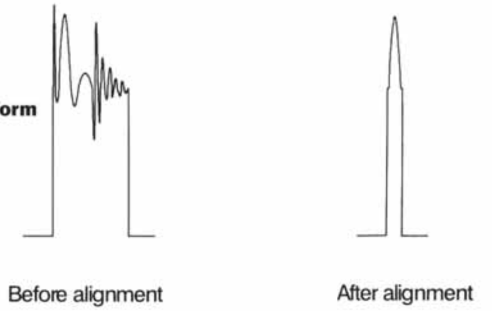


Figure 14. Typical waveform at P4.

mental circuit and serves to illustrate how a sensitive magnetometer can be constructed form standard parts without the need for specialised components such as hall effect devices or magnetoresistors. In this respect it has not been designed for a specific use but can be used in many applications requiring a moderately sensitive magnetic detector. As it stands, the circuit is not calibrated but in many applications where relative readings are required, this does not present a problem.

Where improved performance is required the unit may be modified in a variety of ways; for example, to improve sensitivity linearity and stability. If a smoother DC level is required at the output of the circuit this can be achieved using an active peak detector to detect the height of the pulses produced at P4.

It is possible to use alternative drive methods for the coil and different drive waveforms to improve the accuracy of this type of detector and more experienced constructors may wish to experiment along these lines. It is impractical to discuss the various configurations and design criteria in an article as short as this and readers are referred to relevant text books on the subject. It should be pointed our that when changing the duty cycle of the pulse driving the coil, attention should be paid to current consumption and the power dissipation in the output stage of the circuit. It may be necessary to increase the power rating of R11 and fit a heatsink to TR1.

It is also possible to wind further detector coils onto the same core (for example at right angles to the existing coil) enabling directional changes in the magnetic field to be monitored without the need to change the orientation of the coil. A magnetometer using this type of arrangement can be useful when making long term measurements of the earth's magnetic field for research purposes and in naviga-tional applications.

For monitoring applications over long periods the output voltage from the magnetometer may be used to drive a chart recorder or data logger via the appropriate interface circuitry. It may be useful to convert the output voltage into a frequency or to serial or parallel data. This is relatively simple to arrange using off the shelf voltage to frequency or analogue to digital converter ICs. As can be seen from a look through the semiconductor section of the Maplin catalogue, there are many different types available.

Finally

We have looked at a range of simple circuits that can be used to measure magnetic fields in a variety of situations. Although the circuits described are basic, they are surprisingly effective when correctly set up and it is hoped that those interested will be encouraged to look further at this fascinating area of electronics.

ALTERNATING FIELD DETECTOR PARTS LIST

RESISTORS			
R1	1M Min Res	1	M1M
CAPACITORS			
C1-3	GenElect 100μF 16V	3	AT40T
SEMICONDUCTORS			
D1-3	1N4148	3	QL80B
IC1,2	LF351N	2	WQ30H
MISCELLANEOUS			
P1-5	Pin 2145	5 pins	FL24B
	DIL Socket 8-Pin	2	BL17T

SENSITIVE DETECTOR PARTS LIST

RESISTORS			
R1,9,10,13,14	100k Min Res	5	M100K
R2,5,6,8	10k Min Res	4	M10k
R3,7	100R Min Res	2	M100R
R4,15	1k Min Res	2	M1K
R11	4R7 10W W/W	1	H4R7
R12	10M Min Res	1	M10M
VR1	Hor Encl Preset 1k	1	UH00A
VR2	Hor Encl Preset 10k	1	UH03D
CAPACITORS			
C1	Poly Layer 0.18μF	1	WW44X
C2	GenElect 100μF 16V	1	AT40T
C3,9	Poly Layer 0.1μF	2	WW41U
C4,5,8,10	Minidisc 0.1μF 16V	4	YR75S
C6,7	Poly Layer 0.01μF	2	WW29G
SEMICONDUCTORS			
IC1	HCF40106BEY	1	QW64U
IC2,3	LF351N	2	WQ30H
D1-4,6-8	1N4148	7	QL80B
D5	1N4007	1	QL79L
TR1	BUZ10	1	UJ32K
TR2	BC547	1	QQ14Q
MISCELLANEOUS			
P1-6	Pin 2145	6 pins	FL24B
	DIL Socket 8-Pin	2	BL17T
	DIL Socket 14-Pin	1	BL18U
	20mm QB 100mA 10 Pk	1 Fuse	GJ72P
	Ferrite Filter	1	AM35Q