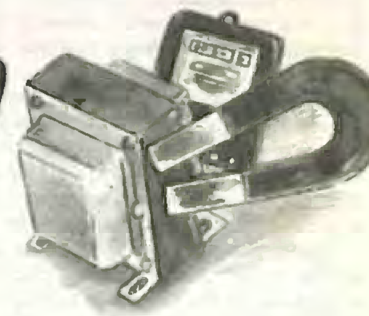
Starter Project

MAGNETIC FIELD DETECTOR



ROBERT PENFOLD

You will find the attraction with this novel, low cost, starter project.

THIS very simple project can detect fixed magnetic fields or fields that are varying at an audio frequency. Fixed or slowly changing field strengths are registered on a centre-zero meter, which indicates the polarity in addition to the relative field strength. Audio frequency fields, such as those produced around mains and audio transformers, are detected via a crystal earphone that can be used to monitor the output signal.

The unit is not intended to provide accurate measurement of magnetic field strength, and is aimed at those who like to experiment with something a bit different. Although quite simple the unit is reasonably sensitive. A small and not very powerful bar magnet can be detected by the prototype at about 100mm from the sensor, and drives the reading to full scale at a range of about 30mm.

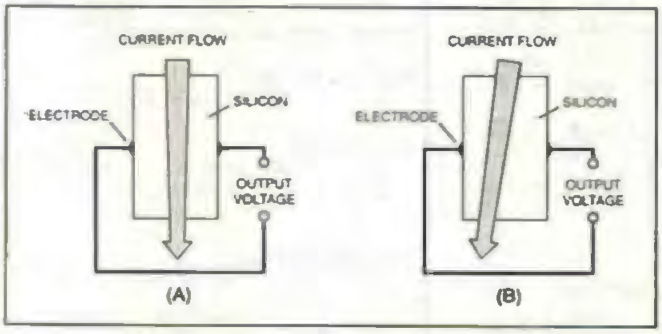


Fig.1. A Hall effect sensor is little more than a slice of silicon. (a) normal and (b) with magnetic field influence.

HALL EFFECT

Detecting varying magnetic fields is quite easy, and requires nothing more than an inductor to act as the sensor. Unfortunately, static fields do not produce any output from an inductor and require a totally different approach.

The only common form of magnetic sensor that "fits the bill" is a linear Hall effect device. A Hall effect sensor is a form of semiconductor, and is actually a very simple type of component. Fig.1 helps to explain the way in which a Hall effect device works.

The sensor is just a slice of silicon having electrodes on opposite surfaces. A current is passed through the silicon, and this produces a potential gradient in the silicon. There is zero volts at the bottom of the slice, the full supply potential at the top, and a certain portion of the supply voltage at intermediate points. The two electrodes are half way up the slice, and consequently there is half the supply voltage at each one. This gives zero output voltage across the two electrodes.

Applying a suitable magnetic field to the device "skews" the current flow and the potential gradient, producing an imbalance in the output potentials. The stronger the magnetic field, the greater the difference in the output voltages.

Applying a magnetic field of the opposite polarity skews the current flow in the opposite direction, giving an output signal of the opposite polarity. The output signal therefore indicates the strength of the magnetic field and its polarity.

It is important to realise that a Hall effect sensor only works if the magnetic field is applied to one side or the other of the silicon slice. Applying the field to the front, back, top, or bottom of the sensor does not affect the current flow in a manner that will produce any imbalance at the electrodes. Consequently it will not produce any output voltage.

SENSOR

Practical Hall effect sensors are more than just the sensing element itself, and they are invariably in the form of and integrated circuit containing the sensor plus some additional circuitry. Some sensors provide a switching action, and others provide an output voltage that is proportional to the applied field strength.

In this application it is only devices in the second category that are of any use, and the device chosen for this design is the UGM3503U. This is an inexpensive device but it has a very useful level of performance and is very easy to use.

It has just three terminals, which are the supply and output terminals. An internal differential amplifier boosts the output signal from the sensing element and produces a single output that is at about half the supply potential under standby conditions.

Placing a *north* pole of a magnet close to the surface of the sensor that carries the type number produces a reduction in the output voltage, and placing a *south* pole close to this surface gives an increase in the output potential (Fig.2). The frequency response of the device is flat from d.c. to 23kHz, which means that it encompasses the full audio range.

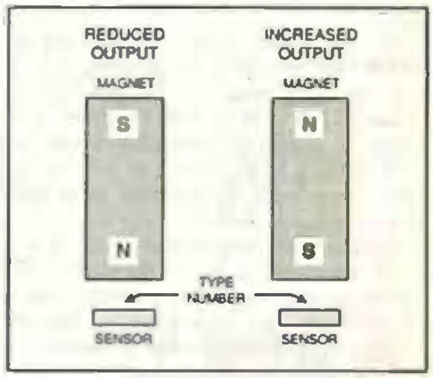


Fig.2. A Hall sensor indicates the polarity of the field as well as its strength.

CIRCUIT OPERATION

The full circuit diagram for the Magnetic Field Detector appears in Fig.3. IC1 is the Hall effect sensor and IC2, a precision op.amp, is used to provide some additional amplification. The amplifier is an operational amplifier inverting mode circuit, which has resistors R1 and R4 as the negative feedback network.

The innate voltage gain of IC2, or the "open loop" gain as it is termed, is extremely high at d.c. and low frequencies. In fact, it is over 100,000 times for a typical operational amplifier.

Using negative feedback reduces the voltage gain of the circuit as a whole to a more usable figure, and this "closed loop" gain is equal to resistor R4 divided by R1. This works out at a little over 300 in this case. Higher voltage gain would obviously give better sensitivity, but it would also give problems with noise and drift.

Op.amp IC2 amplifies the voltage difference between the input voltage to resistor R1 and the voltage at its non-inverting input (pin 3). This second voltage can be adjusted via potentiometer VR1, and in practice it is adjusted to produce a voltage that matches the normal output potential from IC1. This produces half the supply potential at the output of IC2.

The potential divider formed by resistors R5 and R6 also produces an output of half the supply potential. Meter ME1 is connected between the output of IC2 and this potential divider, and it therefore responds to the voltage *difference* between the two.

Under standby conditions both points will be at the same potential, giving zero voltage across the meter. An increase in the output voltage from IC1 produces a decrease in the output from IC2, and a negative deflection on the meter. A decrease in the output potential from IC1 has the opposite effect, producing a positive indication from the meter.

STRENGTH OF CHANGE

In both cases the greater the change in the output voltage from IC1, the higher the reading from the meter. The meter therefore indicates the relative field strength and the polarity of the magnetic field.

Applying a north pole close to the surface of the sensor that carries the type number produces a positive reading, and applying a south pole to it generates a negative reading. This may seem to be at odds with Fig.2, but bear in mind that IC2 inverts the signal.

The value used for resistors R5 and R6 controls the sensitivity of the meter circuit. The specified values permit ME1 to be driven to full scale in both directions provided the battery is reasonably fresh, but their value is high enough to prevent the meter from suffering anything more than very minor overloads.

Capacitor C2 couples the output of IC2 to earphone socket SK1. This enables the output signal to be monitored using a crystal earphone, but satisfactory results are unlikely to be obtained using any other type of earphone or with headphones.

A 6V battery supplies power to the circuit, and the current consumption is only about 9mA. **Do not use a 9V battery as this would result in the maximum supply voltage rating of IC1 being exceeded.**

GOOD PERFORMANCE

In order to produce good results in this circuit it is necessary for the operational amplifier to have good d.c. performance. Otherwise there could be major problems with drift, and d.c. offsets could make it impossible to zero the meter under standby conditions.

The op.amp also needs to be able to work properly with a supply potential of just 6V. The OP077GP is reasonably priced and gives good d.c. performance in this circuit. On the other hand, its open loop bandwidth of 600kHz equates to a closed loop bandwidth of only about 2kHz in this design.

If audio rather than d.c. performance is of most importance it would be advisable to use a TL071CP for IC2. This will give quite good d.c. performance plus a more respectable audio bandwidth of around 10kHz. To compensate for a lack of symmetry in the TL071CP's output stage resisstor R6 should be reduced from 33kilohm to 27 kilohm.

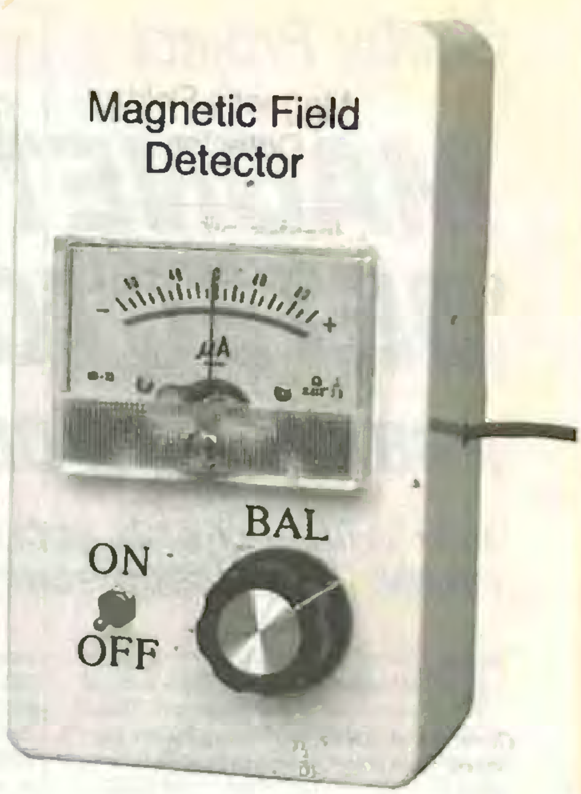
CONSTRUCTION

The stripboard layout for the Magnetic Field Detector is based on a piece that measures 19 holes by 20 copper strips. The component layout and interwiring, together with the positions of the breaks in the copper strips, are shown in Fig.4.

A board of the required size must be cut down from one of the standard sizes in which it is sold. The holes are very close together so use a hacksaw to cut along rows of holes rather than trying to cut between them. This inevitably produces quite rough edges but they are easily filed to a neat finish.

Next, drill the two 3mm diameter mounting holes and make the four breaks in the copper strips. A special tool for cutting the strips is available, but a handheld twist drill bit of about 5mm in dia. does the job just as well. Make sure that the strips are cut across their *full* width.

The circuit board is now ready for the components and link-wires to be added. With a small board such as this the order in which the components are fitted is not



Magnetic Field Detector front panel layout. The Hall effect sensor is mounted externally in a probe arrangement, such as an old pen case, and connected to the circuit board via the screened cable.

COMPONENTS

Resistors

R1	1k5
R2,R3	10k (2 off)
R4	470k
R5, R6	33k (2 off)

All 0·25W 5% carbon film

See SHOP TALK page

Potentiometer

VR1	1k rotary carbon, lin

Capacitors

C1	100μ radial elect. 10V
C2	100n polyester, 5mm lead spacing

Semiconductors

IC1	UGN3503U Hall effect sensor
IC2	OP77GP precision op.amp (see text)

Miscellaneous

S1	s.p.s.t. min toggle
B1	6V battery pack (4 x AA size cells in holder)
SK1	3·5mm jack socket
ME1	100μA - 0 - 100μA moving coil panel meter

Medium size plastic or metal box; 0·1 inch matrix stripboard, size 19 holes by 20 copper strips; 8-pin d.i.l. holder; battery connector (PP3 type); control knob; crystal earphone, with lead and plug; twin-screened cable, about 0·5 metres; multistrand wire; solder pins; solder etc.

Approx. Cost Guidance Only £16
excl. earphone, case & batts.

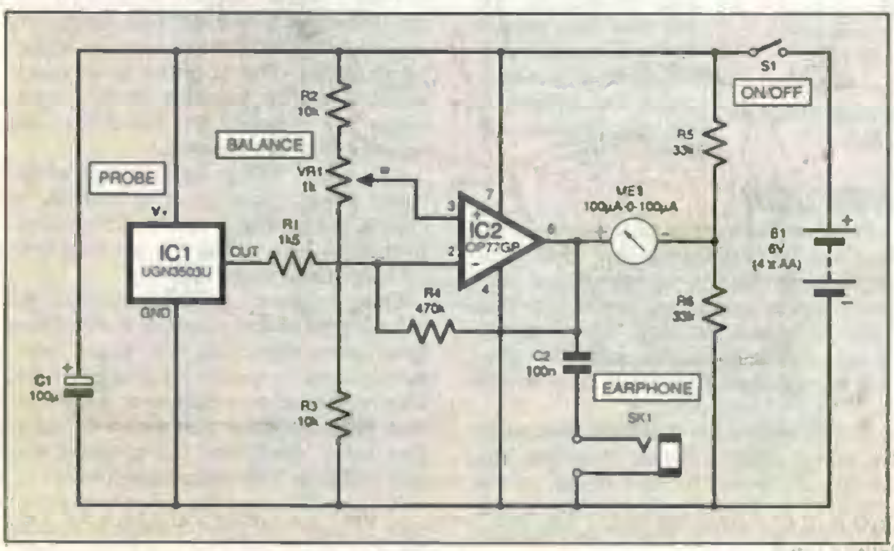


Fig.3. Complete circuit diagram for the Magnetic Field Detector.

Completed Detector showing earphone socket on one side panel.

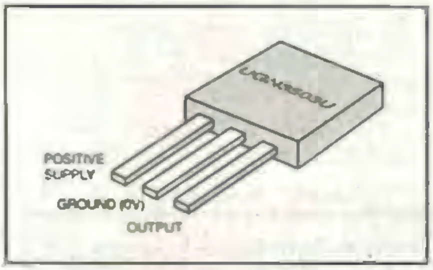


Fig.5. Connection details for the UGN3503U Hall effect sensor.

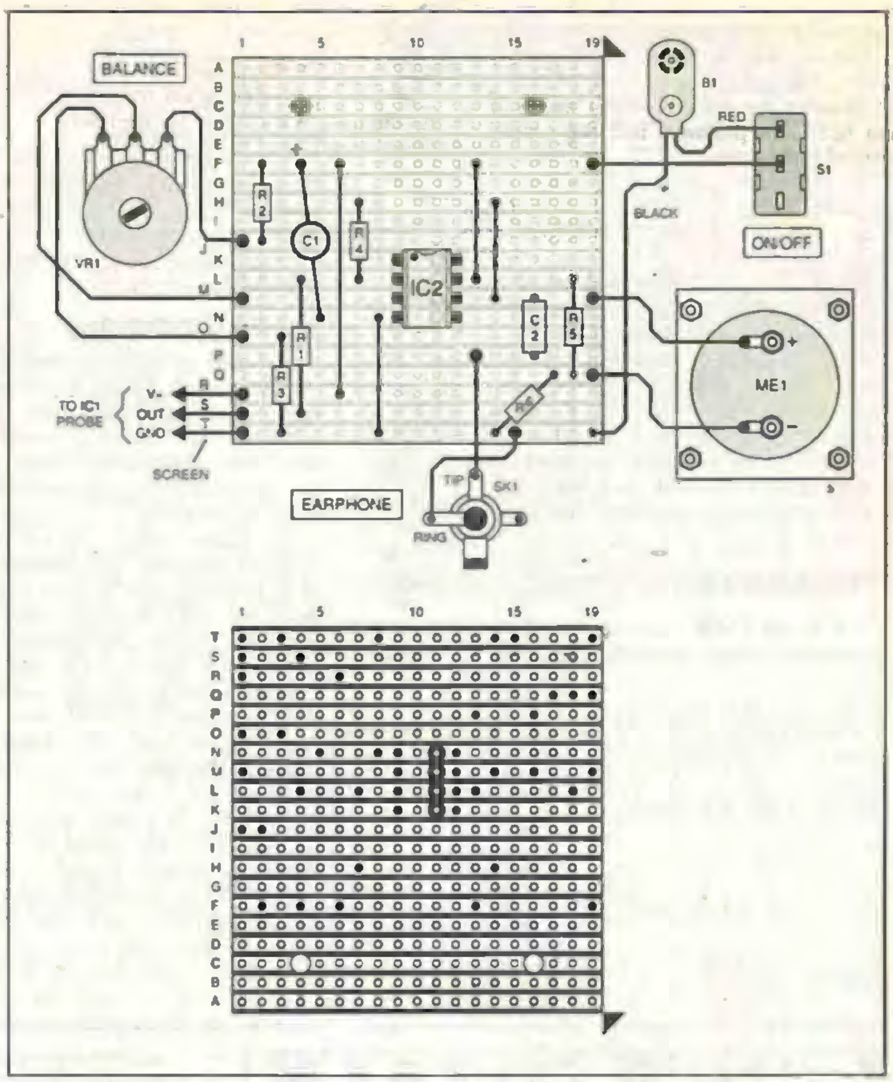


Fig.4. Stripboard component layout interwiring and details for breaks required in the underside copper tracks.

really important, but it is best to work methodically across the board so that nothing is overlooked.

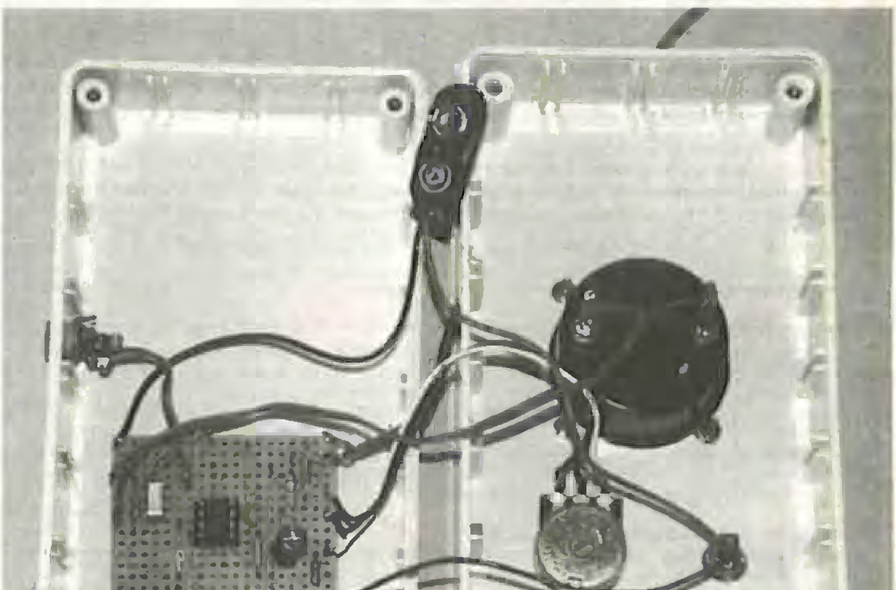
Neither the OP077GP or TL071CP is static-sensitive, but it is a good idea to use a holder for any d.i.l. integrated circuit. Be careful to fit IC2 and electrolytic capacitor C1 the right way round.

Fit single-sided solder pins at the points where connections will be made to potentiometer VR1, meter ME1, etc. It is one-millimetre diameter pins that are required for stripboard. "Tin" the pins with plenty of solder so that it is easy to make reliable connections to them.

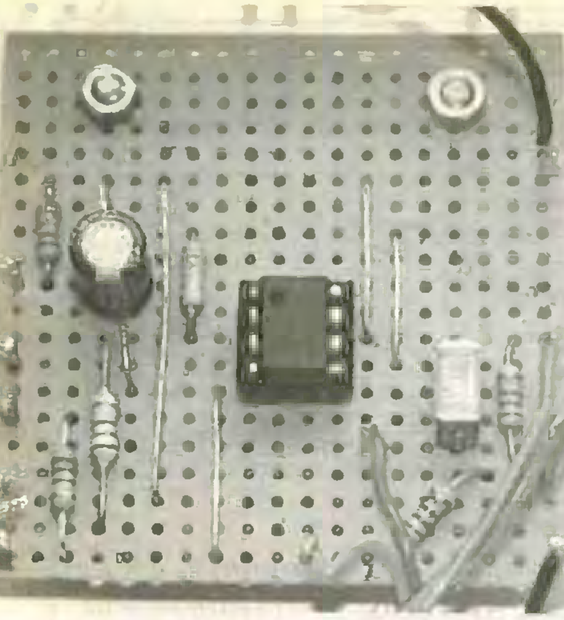
CASING-UP

Virtually any medium size plastic or metal case should be able to accommodate this project. However, be careful to choose one that has sufficient depth to take the meter and the battery pack. The latter consists of four AA size cells in a plastic holder. Connections to the holder are made using an ordinary PP3 style battery clip. Although the circuit has a fairly high voltage gain the layout is not critical, and it is just a matter of designing a layout that is easy to use.

One slightly awkward aspect of construction is fitting the meter onto the case, because this requires a large cutout to be



Layout of components inside the two halves of the case. Note the space for the battery pack.



Completed circuit board showing the four link wires and the op.amp C2 mounted in its holder.

made in the case. Most moving coil meters require a 38mm round mounting hole and the easiest way of making this is to use an adjustable hole cutter (also known as a "tank" cutter), and these are available from many DIY superstores.

Alternatively, it can be cut using a fretsaw, coping saw, or miniature round file such as an "Abrafile". Another method would be to mark out the cutout, drill a series of small holes just inside this mark and then "join-up" the holes to form the required cutout. With any of these methods it is advisable to cut just inside the perimeter of the required cutout, and then enlarge it to precisely the required size using a large round file.

Four smaller (3mm dia.) mounting holes are also required. The positions of these are easily located as they are at the corners of a 32 millimetre square having the same centre as the main cutout.

INTERWIRING

The hard wiring is reasonably straightforward. SK1 is a 3·5mm jack socket, and most sockets of this type have a built-in switch that is not required in this application. Accordingly, one tag of SK1 is left unconnected.

The Hall sensor (IC1) is mounted externally and connected to the main unit by way of a piece of twin-screened cable about 0·5 metres or so in length. An entrance hole for the cable must be drilled at a strategic point in the case, and if a metal case is used the hole should be fitted with a grommet to protect the cable. The screen is used to carry the ground (0V) connection.

Rather confusingly, the plastic encapsulation of the UGN3503U Hall effect sensor chip seems to be completely symmetrical. The only way of identifying the three leads is to use the type number on the body of the device as a reference point, see Fig.5.

Connect the sensor to the screened lead and use insulation tape or sleeving to ensure that the soldered joints cannot short-circuit together. The sensor will be neater if it is built into a probe, based on an old pen for example, but this is not essential.

TESTING

When the unit is first switched on it is likely that the meter will be driven fully positive or negative. With careful adjustment of Balance control VR1 it should be possible to zero the meter, and placing the probe near any magnetised object should then produce a suitable response from the meter.

The meter movement itself contains a permanent magnet, and placing the probe near this should produce full-scale deflection of the meter. Placing the opposite face of the probe near the meter should then produce full-scale deflection in the opposite direction.

As explained previously, applying the pole of a magnet to one of the four smaller surfaces of the sensor will not produce a significant output signal. In use the orientation of the sensor should therefore be adjusted to maximise the meter reading.

Placing the probe against the power cable of virtually any mains powered device that is switched on should produce a 50Hz "hum" from the earphone. Alternating fields will not produce an indication from the meter because the meter will register the average field strength. This will normally be zero due to the opposite poles in the signal cancelling out one another.

The circuit is reasonably stable, but occasional readjustment of VR1 will be required. □

SHOP TALK
with David Barrington

PIC Micro-Probe

The component listing for the *PIC Micro-Probe* calls for a piece of "i.c. holder" type stripboard, with a central channel, devoid of copper, running across the copper tracks. This will cost you around £5, but for just under £2 you can use a piece of standard stripboard and cut away the copper tracks as necessary. The rest of the components should be readily available.

The PIC used in this project should be the 10MHz version. For those who want a "plug-in and go" preprogrammed PIC16F84, one is available from **Magenta Electronics** (☎ *01283 565435* or *http://magenta2000.co.uk*) for the inclusive price of £5.90 (overseas readers add £1 for postage). For those who wish to program their own PICs, the software is available from the Editorial Offices on a 3·5in. PC-compatible disk, see *EPE PCB Service* page 937. If you are an Internet user, it can be downloaded *Free* from our FTP site: **ftp://ftp.epemag.wimborne.co.uk/pubs/PICS/microprobe**.

Magnetic Field Detector – Starter Project

Just a couple of pointers regarding purchasing of components for the *Magnetic Field Detector*, this month's starter project. The first concerns the 100μA "centre zero" meter, some readers may have difficulty in locating one. The meter used in the prototype came from **Maplin** (☎ *01702 554000*), code RW98G.

If you have trouble tracking down the UGN3503U Hall effect sensor, the above company list one as order code GX09K. They also supplied the OP77G precision op.amp, code UL05F. The alternative TL071CP low-noise op.amp should be stocked by most of our component advertisers.

Ginormous Stopwatch – Giant Display

This month we complete the *Stopwatch* project with the construction of a *Giant Digital Display* module. Most of the component supply "bugs" were ironed out last month.

The high voltage 4N25 opto-coupler, code AY44, and the ULN2003 Darlington array, code AD93B, are listed by **Maplin**. The BD681 Darlington transistor may be hard to find, but the suggested alternative TIP141 and TIP142 should be readily available. Note the differing pinouts for the TIP devices (Fig.2 last month).

Ready programmed PICs are available from the author for the sum of £10 each (for either the Display module or Stopwatch) or £50 for six in any combination, with free postage to anywhere in the world. *Payments should be made out to Mr. N. Stojadinovic.* His E-mail address is: **vladimir@u030.aone.net.au** or write to: **Mr. N. Stojadinovic, PO Box 320, Woden ACT, 2606, Australia**.

A programmed PIC16C54 is also available from **Magenta Electronics** (☎ *01283 565435* or *http://magenta2000.co.uk*) for the inclusive price of £5.90 (overseas readers add £1 for postage). For those who wish to program their own PICs, the software is available from the Editorial Offices on a 3·5in., PC-compatible disk, see *EPE PCB Service* page. If you are an Internet user, it can be downloaded *Free* from our FTP site:
ftp://ftp.epemag.wimborne.co.uk/pubs/PICS/stopwatch.

The two printed circuit boards are available from the *EPE PCB Service*, code 247 (Digit) and 248 (Port Conv.).

Loft Guard

Most of the components called-up for the *Loft Guard* project should be readily available from your usual supplier. The only problems that are likely to crop up may be finding the high value resistors.

The *single* 100 megohm resistor (R7) was only found listed under the "cermet film" range stocked by ***Electromail*** (☎ *01536 204555* or RS ***http://rswww.com***), quote code 158-222. As the article points out, you could use three 33 megohm resistors (in series); the p.c.b. is also designed to accept these. This resistor (33M) came from the **Maplin** "high voltage" metal film range, order code V33M.

Note that to make up the 20 megohm resistor (R10) you will need two 10 meg types. Once again, the "series" pads have been included on the p.c.b.

The last mentioned company also supplied the miniature light-dependent resistor (l.d.r.), code AZ83E, and the high power warning buzzer, code FK84F. Although most of our components advertisers should be able to offer something similar. You could, of course, use the good old standard ORP12 l.d.r. if you wish.

Even though the semiconductors are specific versions, they should be in plentiful supply. The p.c.b. is available from the *EPE PCB Service*, code 249.

Teach-In 2000

If you have only just picked up on our new *Teach-In 2000* series with this issue, and being a newcomer to electronics, you may feel a bit apprehensive about ordering the various parts for the demonstration "exercises". Fear not, some of advertisers have put together component and hardware packs specially for the new series. A few more will be added as the series progresses, but we do not expect that to be until at least part seven.

To date, participating advertisers are as follows and readers are advised to contact them for more details.

ESR Electronic Components (☎ *0191 251 4363* or web *http://www.esr.co.uk*) Hardware/Tools and Components Pack.

Magenta Electronics (☎ *01283 565435* or *http://www.magenta2000.co.uk*) – Multimeter and Components Kit 879.

FML Electronics (☎ *01677 425840*) – Basic Components Sets.

N. R. Bardwell (☎ *0114 2552886*) – Digital Multimeter special offer.

PLEASE TAKE NOTE

Demister One-Shot **Nov '99**

Page 844 Fig.4. On the p.c.b. component layout diagram, the "body" outlines of capacitors C1 and C2 should be transposed – see photograph at top of page 845. The electrolytic, shown as a circle, should connect to the IC1 pin 8 copper track (+) and the common GND track (–). The actual annotations are correct.