

# Magnetometer

## Detects even the smallest changes

Rev. Thomas Scarborough

The circuit described in this article is incredibly sensitive to changes in the magnetic field. It can be used to detect earthquakes, but it can also function as a car alarm or for theft prevention. The construction is straightforward and only standard components have been used in the design.

The author, who lives in Cape Town, South Africa, originally designed this circuit to detect small earth tremors that could be possible precursors to more violent earthquakes. We know that earthquakes only occur very rarely in Western Europe, but this circuit also lends itself for use in several oth-

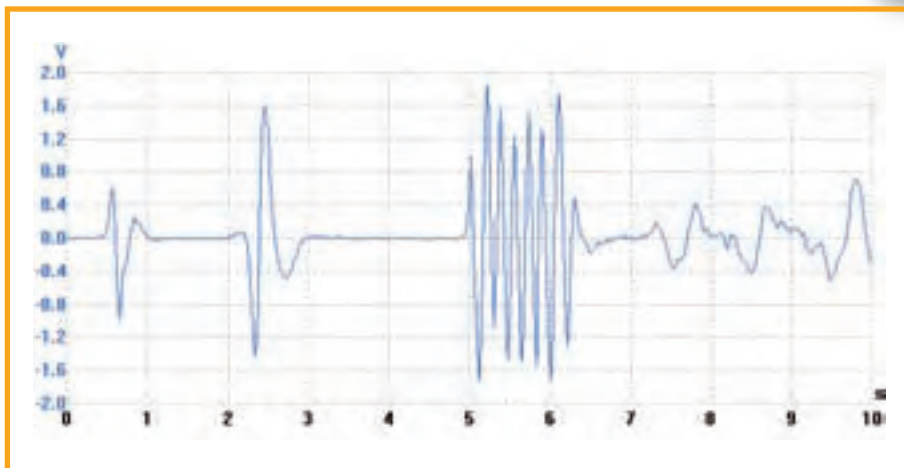


Figure 1. This oscilloscope trace shows the signals generated when a magnet is moved nearby (see text).

er applications. The circuit in question is fairly simple and it uses an ordinary mains transformer as a sensor coil. It is capable of picking up minute changes in the magnetic field strength. It is so sensitive that it can detect a passing train at a distance of two kilometres. Before we look at the principle of operation we'll take a look at several possible applications for the circuit:

- Theft prevention: fix a neodymium magnet to your laptop or briefcase and the magnetometer will immediately warn you when it's picked up.
- Car alarm: when the car is moved and changes its angle to the Earth's mag-

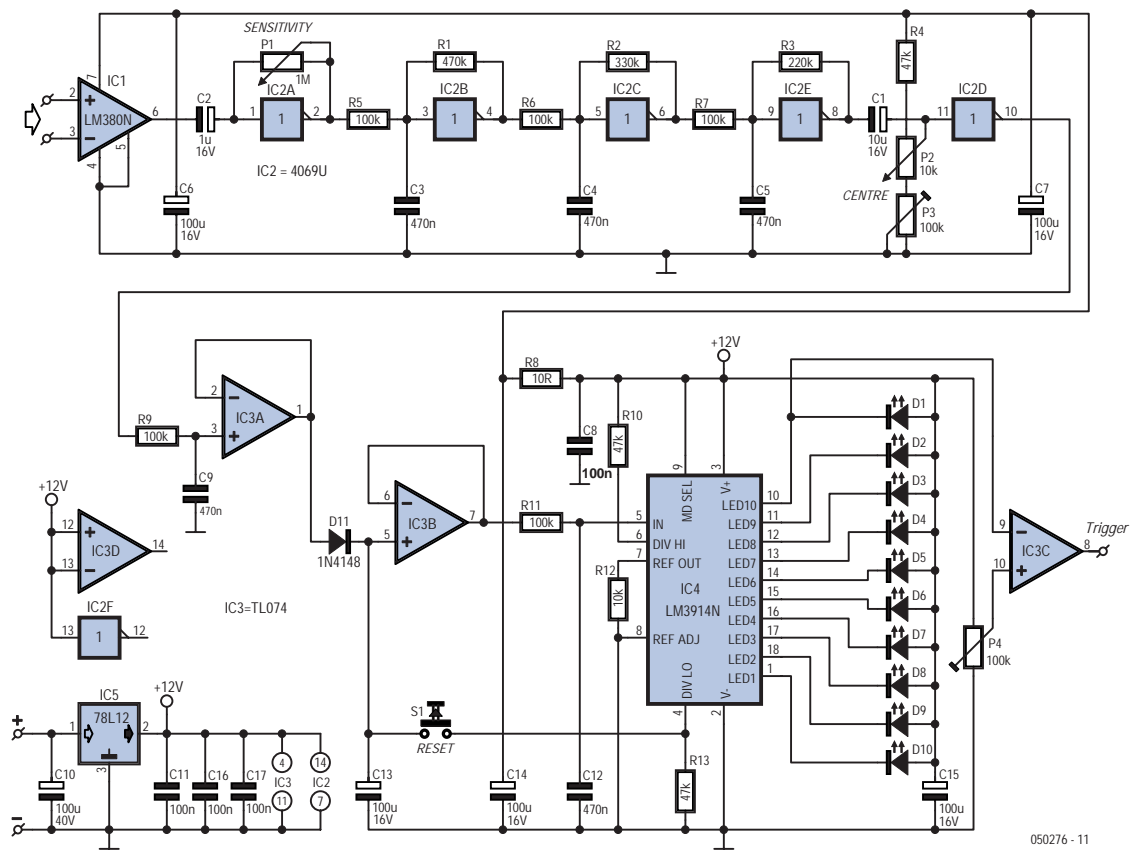


Figure 2. The circuit diagram shows the large number of amplification stages used. They ensure that even the smallest variations in the magnetic field can be detected.

magnetic field it will be detected by this circuit.

- Vehicle detector: approaching cars or trains can be detected over a large area around the magnetometer due to the vibrations they cause.
- Extremely sensitive vibration alarm: minute vibrations in the vicinity can be detected, such as a bouncing ball on a wooden floor tens of metres away.

- Magnet sensor: the circuit obviously reacts to nearby magnetised objects as well, such as a magnetised screwdriver half a meter away, or even an 'old-fashioned' 3.5-inch floppy disk.

- Cat flap opener: attach a magnet to the cat collar and when the cat comes close to the cat flap it will be opened automatically by the circuit.

### Concept

There are basically two types of magnetometer: ones that give an absolute value of the magnetic field strength and others that show the change in the field strength. This circuit detects the variations.

Figure 1 shows an oscilloscope trace of the output of the circuit, when a strong loudspeaker magnet was moved at a distance of about a metre away from the sensor (an old mains transformer). The magnet is first tilted one way (at 0.5 s), then the other way (at 2.5 s), then the magnet is shaken backwards and forwards (from 5 to 6.5 s) and finally the magnet is slowly rotated. It is interesting to see that you can tell from the shape of the waveform in which direction the field changed.

When this circuit was first designed the author wanted to create a seismometer that was inexpensive and could operate in a stand-alone fashion (i.e. without the use of a PC or data logger). This resulted in a fairly simple circuit that used standard components,

including a mains transformer as sensor and an LED bargraph as indicator. There is also a trigger (alarm) output that turns on when the full scale of the LED bargraph is reached.

### Practical circuit

The most important part of the magnetometer is the detection coil. In the prototype a mains transformer was used (230 V/12 V, 2 A), but in theory nearly any transformer or coil could be used. The author found that the above-mentioned model worked well and gave the circuit a very good sensitivity. The primary and secondary windings of the transformer were connected in series (and in phase) to increase the sensitivity.

The coil is connected to the inputs of a type LM380 opamp (see Figure 2). This is really a power-amp IC that can deliver 2.5 W, but it turns out to be just right for this circuit because it has a fixed gain (50 times) and the output automatically settles to half the supply

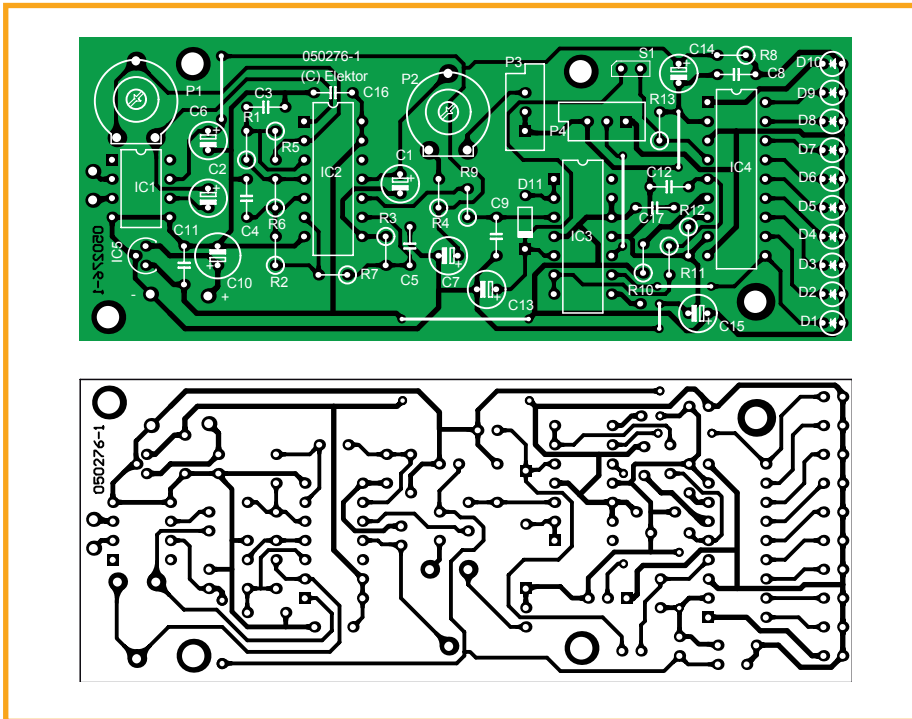


Figure 3. A PCB has been designed for the circuit to make the construction easier

voltage without the need for separate bias resistors at the inputs. The low-frequency signal is then amplified further using a number of gates from an unbuffered 4069UB CMOS IC. An unbuffered CMOS inverter can be made to function as an amplifier with the addition of a resistor between the input and output. In this case four inverters have been used as sequential amplifier stages (IC2A/B/C/E) with

passive RC low-pass filters in between (R5/C3, R6/C4, R7/C5). This provides an enormous gain to the output signal from the LM380. All the filter stages (another two follow later on) reduce frequencies above about 20 Hz, mainly to suppress interference from mains-borne signals. Next, IC2D adds another dose of gain to the signal, where the DC offset to the input of the gate is provided by po-

tential divider R4/P2/P3. After another RC filter (R9/C9) the signal is buffered by IC3A and fed to a half-wave peak rectifier (D11/C13), which supplies a DC voltage to the input of the LED bargraph circuit. In this way a peak-hold function is implemented, which shows and holds the largest measured value on the display. Pressing S1 resets the LED display. If you don't need this peak-hold function you can replace D11 with a wire link and leave out C13 and S1. All changes in the signal level will then be shown on the LED bargraph display.

The rectified signal is fed via a buffer (IC3B) and a final RC filter (R11/C12) to the input of the well-known LM3914 (IC4), a much used LED driver IC that contains all the electronics to drive a 10-segment LED bargraph display (D1 to D10).

The reference input of the LM3914 has been set such that the signal strength is indicated relative to LED D5. LED D10 is on continuously to indicate that the circuit is powered up; it may be left out of the circuit if not required.

Opamp IC3C provides a trigger output that generates a logic high when the LED for the strongest signal level lights up (D1). P4 is used to set the trigger level.

The supply to the circuit is provided by a 12 V regulator, since any mains ripple on the supply line would be disastrous for the small signals we're amplifying. The power supply can be any mains adapter that has an output voltage of about 15 to 20 V DC (50 mA is sufficient).

### Construction and setting up

With the help of the PCB artwork shown in **Figure 3** it shouldn't be too difficult to make a board or have one made for you. Make sure that you get the 8-pin package for the LM380 since the PCB has been designed for this. Keep in mind that you need the unbuffered version of IC2 (4069UB), otherwise the circuit will definitely fail to work! Use IC sockets for all ICs to make the construction easier and to help with any potential faultfinding. All resistors are mounted vertically. The reset switch is connected to the board via a pair of wires.

The circuit can be mounted in an enclosure that has suitable cutouts made for the LEDs, the reset switch and the power connector.

An old transformer works very well as a detector 'coil'. It should have all

## COMPONENTS LIST

### Resistors

- R1 = 470kΩ
- R2 = 330kΩ
- R3 = 220kΩ
- R4, R10, R13 = 47kΩ
- R5, R6, R7, R9, R11 = 100kΩ
- R8 = 10Ω
- R12 = 10kΩ
- P1 = 1MΩ preset
- P2 = 10kΩ preset
- P3, P4 = 100kΩ multiturn preset

### Capacitors

- C1 = 10μF 16V radial
- C2 = 1μF 16V radial
- C3, C4, C5, C9, C12 = 470nF
- C6, C7, C10, C13, C14, C15 = 100μF 16V radial
- C8, C11, C16, C17 = 100nF

### Semiconductors

- D1-D4, D6-D10 = LED, red, 3mm
- D5 = LED, green, 3mm
- D11 = 1N4148
- IC1 = LM380N-8
- IC2 = 4069UB (unbuffered version)
- IC3 = TL072CN
- IC4 = LM3914N
- IC5 = 78L12

### Miscellaneous

- S1 = pushbutton, 1 make contact
- L1 = coil, e.g. discarded mains transformer 230 V / 12 V @2A
- PCB, ref. 050276-1 from [www.thepcbshop.com](http://www.thepcbshop.com)

windings connected in series, and you should take care that they are all in phase, otherwise the sensitivity will be reduced. Two short pieces of wire should be used to connect the transformer to the board.

Once all components have been soldered onto the PCB we can connect the mains adapter and start with the adjustments. First set the sensitivity control (P1) midway, as well as P2. Now turn P3 until the centre green LED (D5) lights up on the LED bargraph. During normal use, P2 can be used to adjust the display (you could also use an ordinary potentiometer for this) as and when necessary. Especially when the sensitivity is set to a high value you'll find that the null-point can vary. When the sensitivity is lowered via P1 it should be possible to obtain a stable setting that shows very little drift.

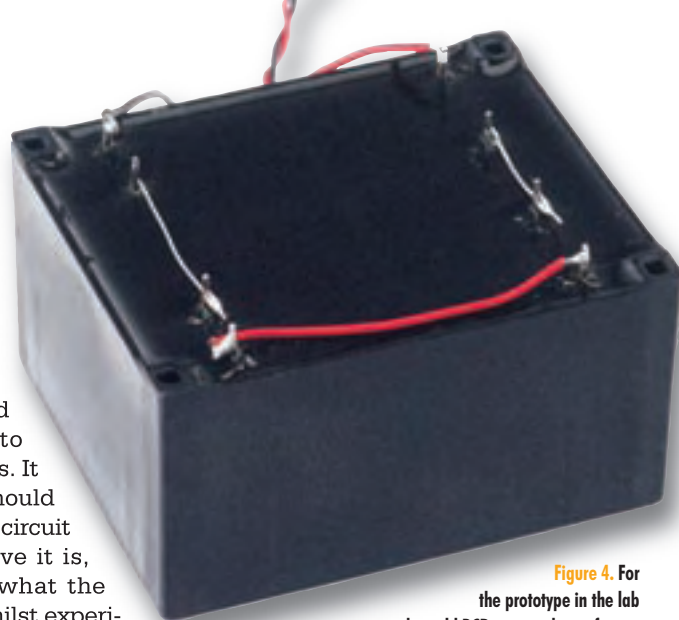
The final adjustment is the trigger level, set via P4. This isn't critical, and should be set such that IC3C switches reliably when LED D1 lights up and switches back again when D1 turns off.

### Application tips

At the start of the article we already showed a few possible applications for this magnetometer. Most of these are fairly straightforward and there is no need to give detailed instructions. It is important that you should first 'play' a bit with the circuit to find out how sensitive it is, what it reacts to and what the best setting is for P1. Whilst experimenting you should have as few metal or magnetic materials as possible near the circuit, since they interfere with its operation.

You can make a simple seismometer by hanging an old loudspeaker magnet from the ceiling using a long piece of string and placing it just above the transformer. P1 should then be adjusted such that the LED bargraph remains just unlit. To make a vibration alarm that can detect passing traffic you should attach a magnet to the end of a long ruler. The other end of the ruler

should be fixed to a large surface and the transformer should again be placed just below the magnet. You'll be amazed by the distance at which vibrations can be detected with this simple circuit!



**Figure 4.** For the prototype in the lab we used an old PCB-mounted transformer with all windings connected in series.