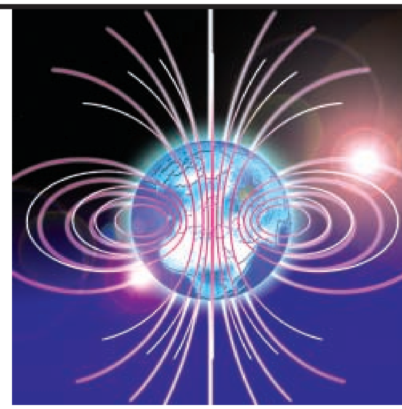
PIC Magnetometry Logger

Part One

John Becker



Logging your search for magnetic fields that might reveal hidden artifacts.

MAGNETOMETERS are instruments for measuring the direction and/or intensity of magnetic fields. Such fields are created by electrical current flow and also exist naturally in ferromagnetic substances, such as iron and nickel.

It is the latter fields that this magnetometer has been designed to detect, particularly those associated with man's activities, principally in relation to iron-based artifacts, although not solely so.

Anthony Clark in his book *Seeing Beneath the Soil* says that, "Iron constitutes about six per cent of the Earth's crust, but little of it is readily apparent. Most of it is dispersed through the soils, clays and rocks as chemical compounds which are very weakly magnetic.

"Man's activities in the past have redistributed some of these compounds and changed others into more magnetic forms, creating tell-tale patterns of anomalies in the Earth's field, invisible to a compass but detectable with sensitive magnetometers."

FGM Sensors

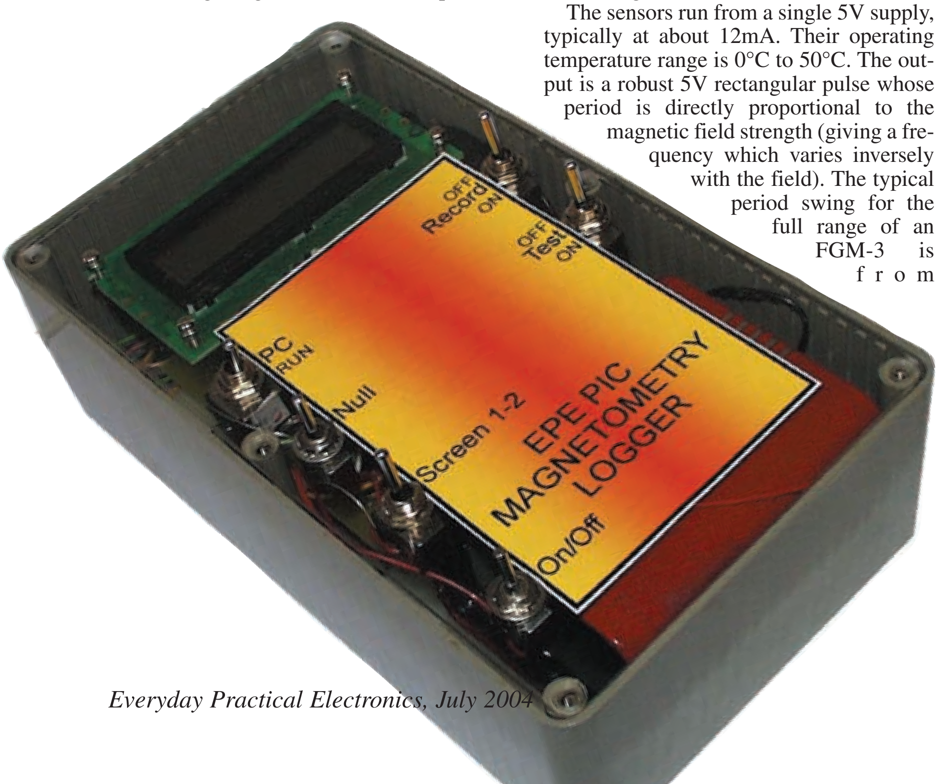
Several sophisticated techniques exist for sensing magnetic fields. Perhaps the most well-known implementation, and probably the most sensitive, is known as the proton magnetometer. Hall Field Effect devices can also be used, although they are less sensitive and are prone to temperature drift. Fluxgate sensors are in widespread use, too, but they are notoriously difficult for the hobbyist to construct from scratch.

However, Speake & Co manufacture a range of fluxgate devices, the FGM-X series. Speake describe them as "very high sensitivity magnetic field sensors operating in the ±50 microtesla range (±0·5 oersted)." This range covers the Earth's magnetic field (they can also be used in electronic compasses).

Browsing the web, it is apparent that one of the series, the FGM-3, is the device "of choice" in many magnetometer designs.

The data sheet states that applications include conventional magnetometry, ferrous metal detectors, internal vehicle re-orientation alarm sensors, external vehicle or ship passage sensors, wreck finders, non-contact current sensing or measurement, conveyor belt sensors or counters, magnetic material measurement and archaeological artifact assessment.

The sensors run from a single 5V supply, typically at about 12mA. Their operating temperature range is 0°C to 50°C. The output is a robust 5V rectangular pulse whose period is directly proportional to the magnetic field strength (giving a frequency which varies inversely with the field). The typical period swing for the full range of an FGM-3 is from 8·8μs to 25μs (approximately 120kHz to 50kHz).



A more sensitive sensor is also available from Speake, the FGM-3h. It produces a 1Hz change in frequency for a 1nT change in magnetic field. The author has not tried it, though.

Speake say that "unlike Hall Effect field sensors . . . the FGM series has a very low temperature coefficient". They do not quantify this statement, however.

Design Concept

Two FGM-3 sensors are used in this design, aligned in same direction at about 0·5 metres apart within a plastic tube (standard 18mm plumbing pipe). They both "see" the same absolute magnetic field, irrespective of orientation, as long as they remain aligned with each other. If there is a local magnetic source closer to one sensor than the other, the output frequencies from the sensors will vary accordingly.

This arrangement is widely known as a *gradiometer* because it detects *gradients* in magnetic fields. However, the general term of *magnetometer* will be used in this article. The sensor assembly can be used vertically or horizontally (discussed in Part 2).

Speake also make a device (SCL007) that can be used with two sensors in gradiometer mode, producing an 8-bit digital output relative to the difference between the frequencies of the sensors. It was decided, though, that the use of a PIC16F877-20 microcontroller would be preferable. This is used to monitor the sensor output frequencies separately and store the results to a non-volatile serial memory, from where they can subsequently be downloaded to a PC-compatible computer for detailed analysis and graphical display.

The design has also been provided with an alphanumeric liquid crystal display (l.c.d.). This is for basic monitoring use "in the field", but its associated switch controls do not affect the sensor values recorded to the serial memory.

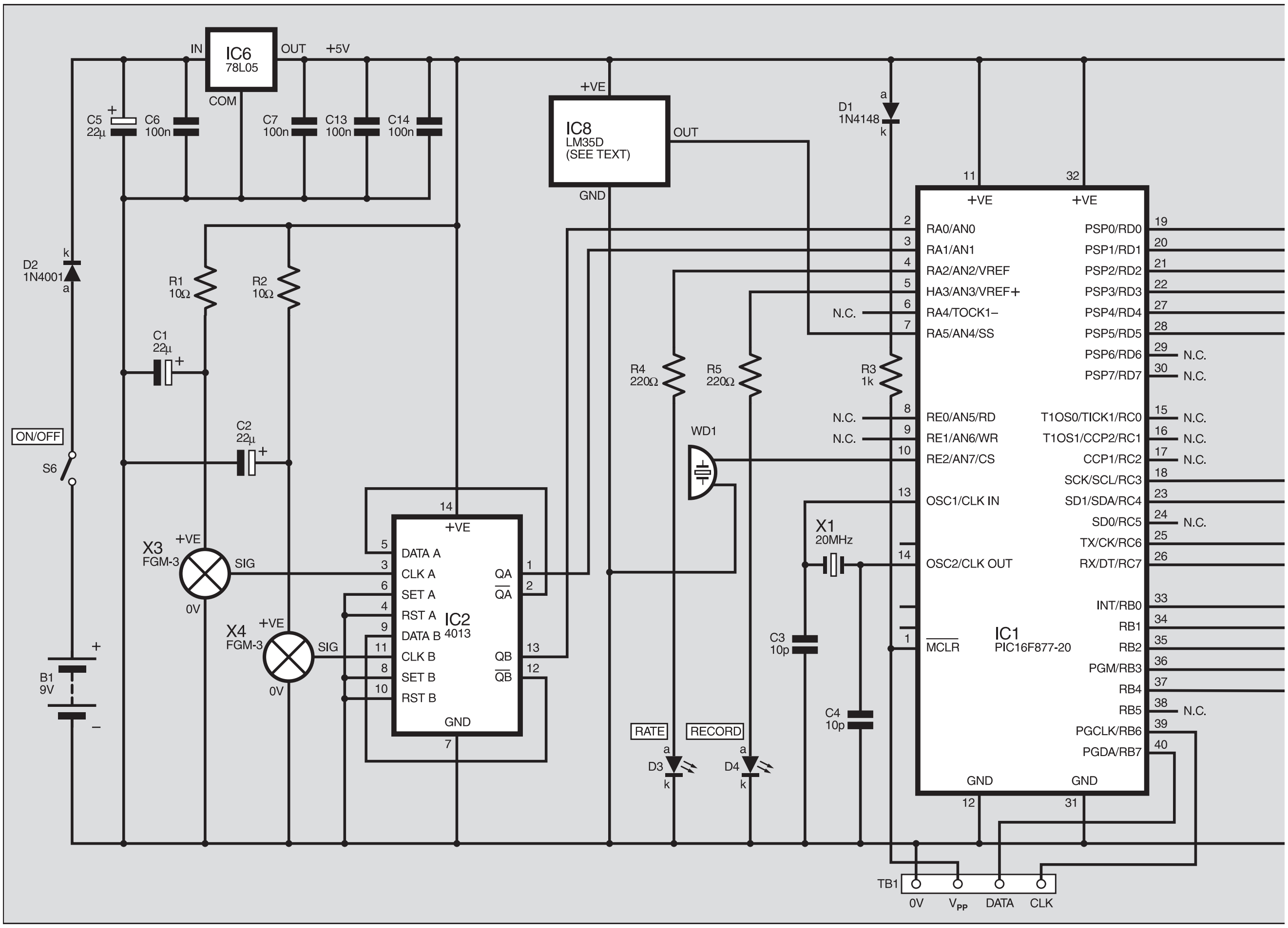


Fig.1. The complete circuit diagram for the Magnetometry Logger.

Facilities to connect a GPS (Global Positioning System) handset to the unit have also been provided. Its use is optional – see later.

Software

It is worth noting at this point that the PC software for this Magnetometry Logger can also be used with the author's *Earth Resistivity Logger* (*ER*) of April/May '03. More on this in Part 2.

Software, including source code files, for the PIC unit and PC interface is available on 3·5inch disk from the Editorial office (a small handling charge applies – see the *EPE PCB Service* page) or it can be downloaded *free* from the *EPE* Downloads site, accessible via the home page at **www.epemag.wimborne.co.uk**. It is held in the PICs folder, under Magnetometer. Download all the files within that folder.

This month's *Shoptalk* provides information about obtaining pre-programmed PICs.

The PIC program source code (ASM) was written using *EPE Toolkit TK3* software (also available via the Downloads site) and a variant of the TASM dialect. The run-time assembly is supplied as an MPASM HEX file, which has configurations embedded in it (crystal HS, WDT off, POR on, all other values off).

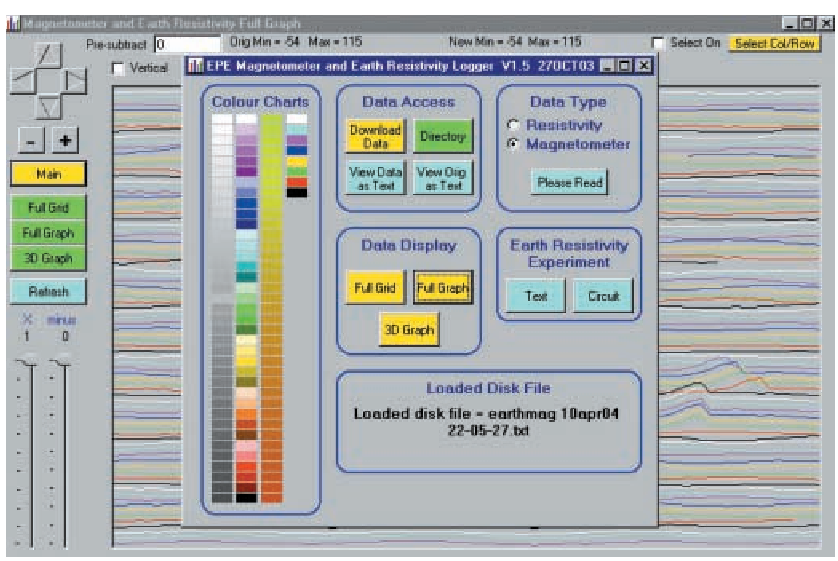
The PC interface software was written under Visual Basic 6 (VB6), but you do not need VB6 on your PC in order to run the software.

Whether or not VB6 is installed, copy *all* of the Magnetometer files (except the PIC files if you prefer) into a new folder called **C:\Magnetometer**, or any name of your choosing, on Drive C (the usual hard drive letter).

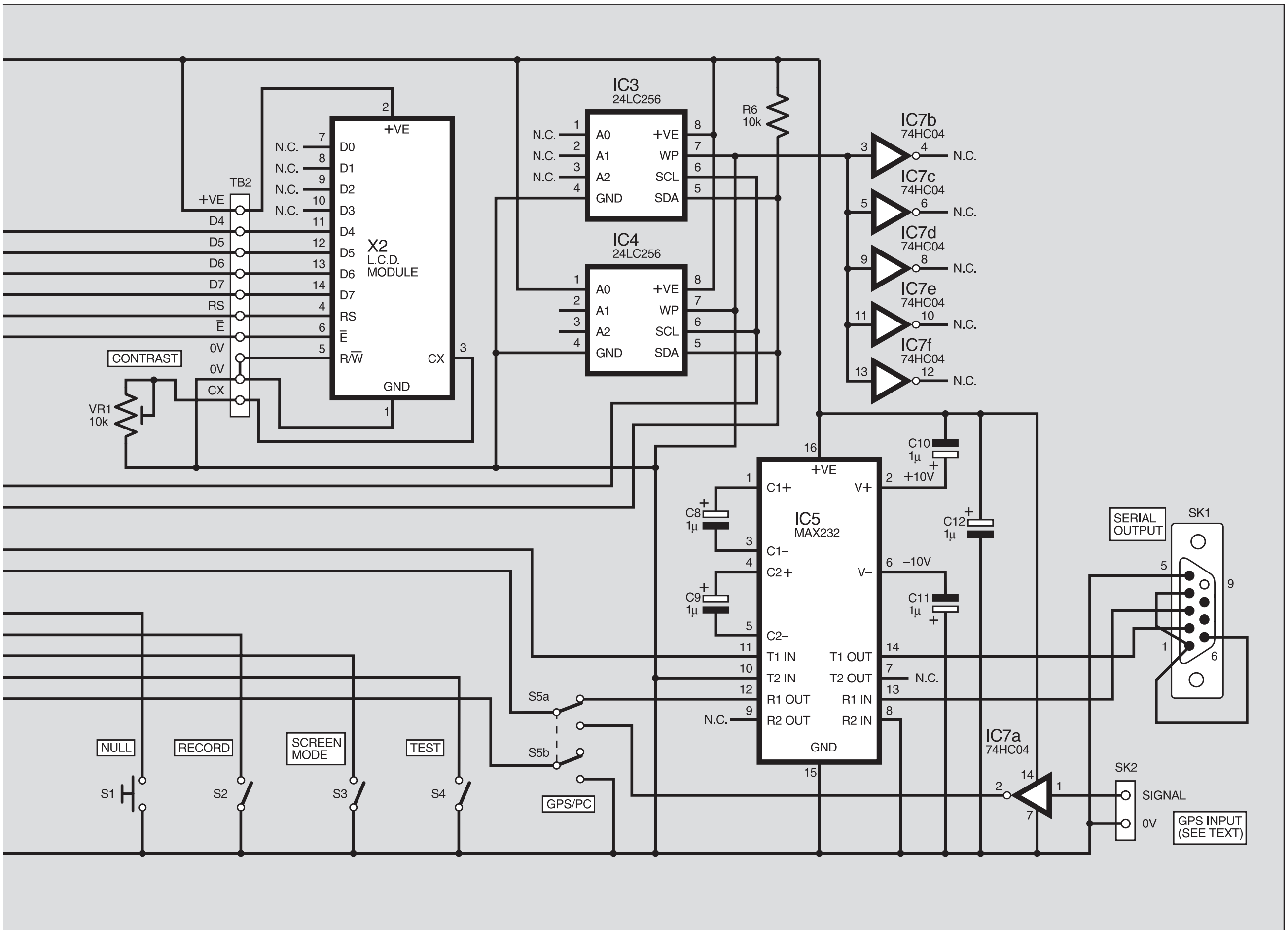
If you do not have VB6, you also need three other files, **comdlg32.ocx, Mscommctl.ocx** and **Msvbm60.dll**, held on our 3·5inch disk named Interface Disk 1, and in the Interface folder on our Downloads site (they are also included with the *TK3* software, in Disk 2). These files must be copied into the same folder as the other Magnetometer files.

These three files are not supplied with the Magnetometer software as they are common to several *EPE* VB6 projects and amount to about 1MB of data.

Additionally, the VB6 source code makes use of Joe Farr's excellent *Serial Interface for PICs and VB6* (Oct '03) software. In order to access (and perhaps modify for your own purposes) the Magnetometer VB6



Main control screen superimposed on the Full Graph screen in the background.



source code files, you need to have Joe's software installed on your PC as well (see his published text). This is also available via our Downloads site.

Without Joe's software installed, if you try to access the Magnetometer source code, it will crash.

Note that you should not attempt to "install" the Magnetometer VB6 files via Explorer or other similar PC facility. Use Windows' own normal Copy facility.

Circuit Description

The complete circuit diagram for the Magnetometry Logger is given in Fig.1.

The PIC16F877-20 microcontroller is shown as IC1. It is operated at 20MHz, as set by crystal X1 in association with capacitors C3 and C4.

At about one-second intervals the PIC behaves as a dual-frequency counter, counting the pulses derived from the two FGM-3 sensors, X3 and X4, via flip-flop IC2 and input pins RA0 and RA1. The use of IC2 was found to be necessary in order to "square" the non-uniform sensor output pulses prior to the PIC polling its RA0/RA1 inputs during the counting cycle.

As the sensors are mounted off-board via a cable that can be several metres long, the positive power lines feeding them are decoupled at the sensor end. This simply involves the inclusion of resistors R1 and R2, and capacitors C1 and C2. Without this decoupling, the sensors could react to each other's output frequency and "lock-on" to each other.

Each pair of frequency count values is stored to non-volatile memory *exactly as received*. It was decided to let the PC computer software perform the analysis of the values following their download, without any intervention from the PIC software.

There is, though, a certain amount of data processing performed by the PIC. This is purely for immediate monitoring purposes and does not affect the stored data. It will be described later, when the mode control switches S1 to S5 are discussed.

Two serial memory chips are provided, IC3 and IC4, although IC4 may be omitted if preferred (the PIC software recognises how many memory chips are used and behaves accordingly). The devices retain their data even after power has been switched off.

In common with the author's similar logging designs, the memory chips are Microchip type 24LC256, each having 256 kilobits (32K bytes) of data storage accessed in I^2C mode via the PIC's RC3 and RC4 pins. Pull-up resistor R6 is common to the outputs of both chips.

Selection of whether IC3 or IC4 is accessed is determined by the software and the binary address code set via the chips' A0 to A2 pins, which are internally biased low when unconnected.

The l.c.d., X2, is a standard 2-lines by 16 characters per line module, controlled in the author's usual 4-bit mode, via Port D on this occasion. Preset VR1 sets the l.c.d. screen contrast.

External Interfacing

Serial connection to the PC is via IC5, an RS232 interface device, Maxim type MAX232 (again as has become standard in many *EPE* designs). It is operated in both input and output modes at 9600 Baud with handshaking. Connection to the PC is via a 9-pin D-type female connector, SK1.

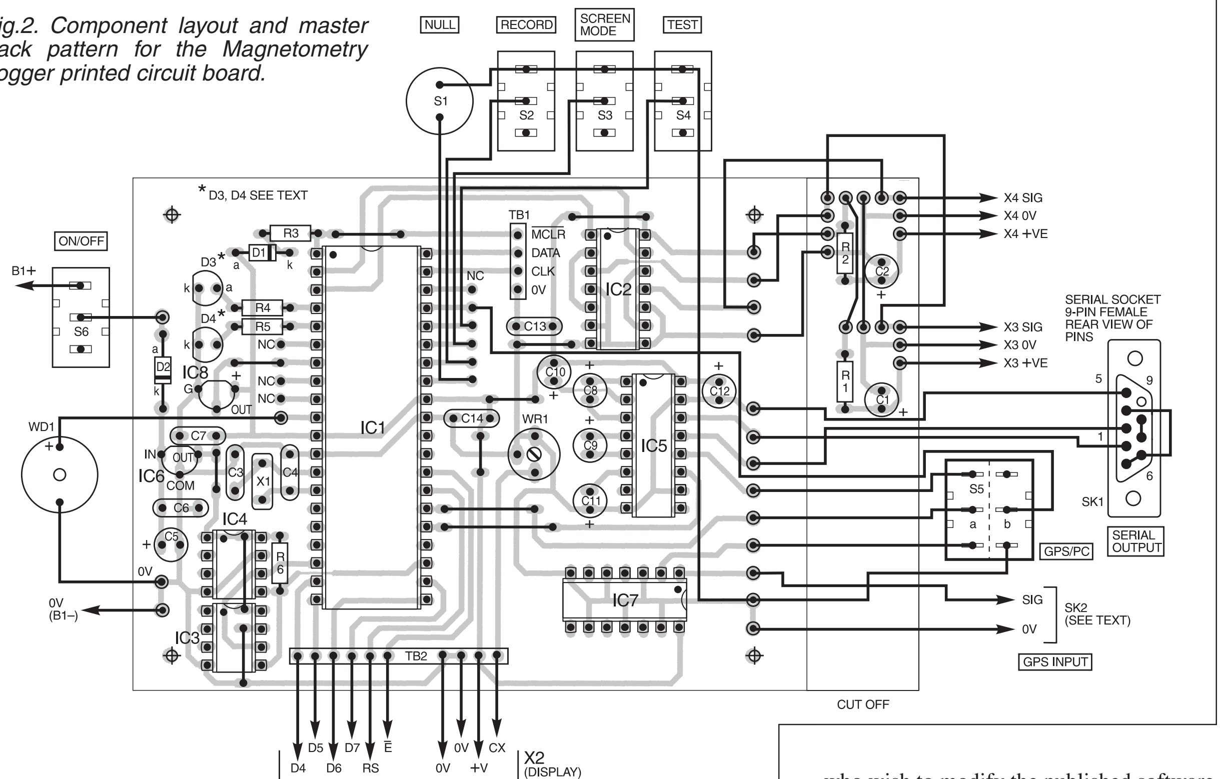
GPS handset interfacing was discussed in *EPE* Jan '04, in which the common NMEA 0183 protocol was described and example decoding software provided. The GPS handset is connected by two leads, signal and 0V input via socket SK2. A 3·5mm jack socket and plug were used in the prototype, but other connectors may be used. The signal is inverted by IC7a prior to connection to the PIC through switch S5. The GPS should be used at 4800 baud, the basic NMEA 0183 standard rate.

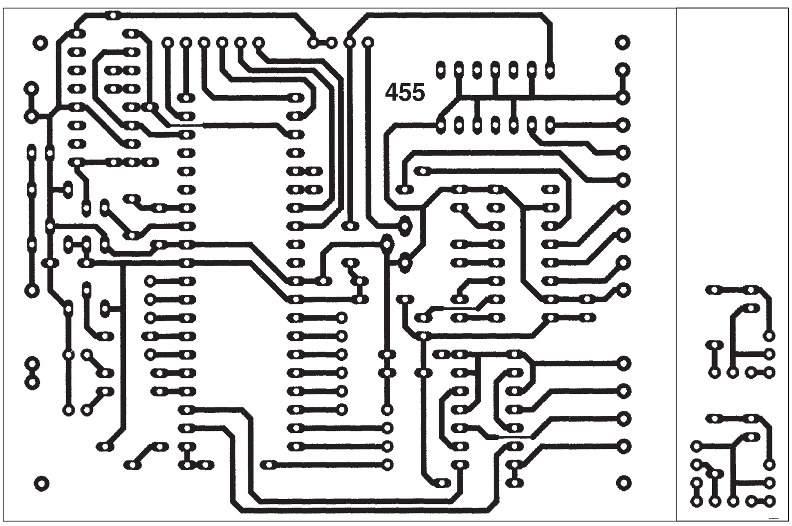
Switch S5a selects whether the signals from IC5 or IC7a are routed to the PIC's serial-receiving pin, RC7. Switch S5b informs the PIC about which data path has been selected. Note that the switches are monitored by Port B, used with its internal pull-ups held high.

Light emitting diodes D3 and D4 are buffered by resistors R4 and R5. D3 flashes at the sensor sampling rate (about 1Hz), and D4 is illuminated when the software is in Record mode. Buzzer WD1 "beeps" as each sample is taken.

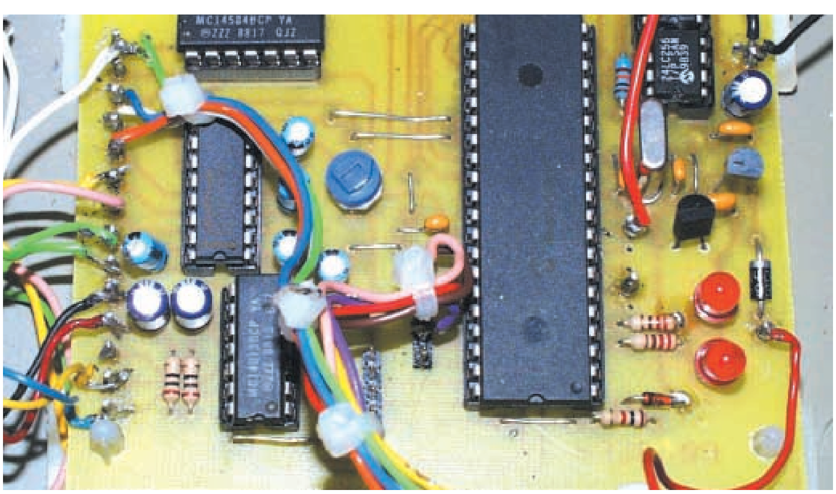
Connector TB1 is the author's standard PIC-programing access point for readers

Fig.2. Component layout and master track pattern for the Magnetometry Logger printed circuit board.





4·35in. (111mm) x 2·83in. (72mm)



who wish to modify the published software for their own needs and then send to the PIC *in situ*. Diode D1 and resistor R3 prevent programming voltages adversely affecting the unit's 5V supply line.

A temperature sensor, IC8, was included with the prototype. Its use is optional, as will be discussed further on.

The circuit is intended to be powered by a 9V PP9 battery. This is switched into circuit by S6, through polarity-protection diode D2, and to the voltage regulator IC6. This outputs a well-stabilised +5V, as required by the rest of the circuit. Current consumption is somewhat higher than had been expected, typically at about 45mA.

Construction

Details of the component and track layouts for the printed circuit board (p.c.b.) are shown in Fig.2. This board is available from the *EPE PCB Service*, code 455.

Before assembling the board, cut off the two sub-sections on which components R1, R2, C1 and C2 are to be mounted. These sub-assemblies are ultimately mounted close to the sensors within their housing.

Assemble the main and sub-section p.c.b.s in any preferred order, ensuring that all on-board link wires are included (noting that two are under i.c. socket positions), and that all polarity-sensitive components are the correct way round. The use of sockets for all dual-in-line (d.i.l.) i.c.s is recommended; it is *essential* to use one for the PIC, IC1.

Treat all i.c.s as static sensitive and discharge static electricity from yourself before handling them, by touching the bare grounded metal of an earthed item of equipment, for example.

Double-check the perfection of your soldering and component positioning before applying power. Do not insert any of the d.i.l. i.c.s, or the l.c.d., until the correctness

COMPONENTS

Approx. Cost Guidance Only **£75** *excl. batt*

See **SHOP TALK** page

Resistors

R1, R2	10Ω (2 off)
R3	1k
R4, R5	220Ω (2 off)
R6	10k

All 0·25W 5% or better

Potentiometer

VR1	10k min. round preset

Capacitors

C1, C2, C5	22µ radial elect. 16V (3 off)
C3, C4	10p ceramic disc, 5mm pitch (2 off)
C6, C7, C13, C14	100n ceramic disc, 5mm pitch (4 off)
C8 to C12	1µ radial elect. 16V (5 off)

Semiconductors

D1	1N4148 signal diode
D2	1N4001 rectifier diode
D3, D4	red l.e.d., high brightness (2 off)
IC1	PIC16F877-20 microcontroller, pre-programmed (see text)
IC2	4013 dual type-D flip-flop
IC3, IC4	24LC256 serial EEPROM (2 off) (see text)
IC5	MAX232 RS232 interface driver
IC6	78L05 +5V 100mA voltage regulator
IC7	74HC04 hex inverter
IC8	LM35DZ temperature sensor (see text)

Miscellaneous

S1	min. s.p. push-to-make switch
S2 to S4, S6	min. s.p.s.t. (or s.p.d.t.) toggle switch (4 off)
S5	min s.p.d.t. toggle switch
SK1	9-pin D-type female connector
SK2	see text
X1	20MHz crystal
X2	2-line 16-character (per line) alphanumeric l.c.d. module
X3, X4	FGM-3 magnetic flux sensor (2 off)
WD1	active buzzer (optional)

Printed circuit board, available from the *EPE PCB Service*, code 455; plastic case, 190mm x 110mm x 60mm (see text), grey body, clear lid; 40-pin d.i.l. socket; 16-pin d.i.l. socket; 14-pin d.i.l. socket; 8-pin d.i.l. socket (2 off); self adhesive p.c.b. supports (4 off); PP9 9V battery or equivalent, plus clip; 1mm terminal pins; mono screened lead (approx 0.7m); 4-way intruder alarm cable (length as needed, see text); connecting wire; solder, etc.

PROBE ASSEMBLY MATERIALS

For Fig.5 (see text).
Plastic plumbing tube, 22mm o.d., 17mm i.d., approx 0.7m; T-junction; in-line connectors (2 off); end-caps (3 off).

of the +5V output regulator IC6 has been proved.

The main electronics are enclosed in a plastic case whose base measures 190mm × 110mm × 60mm. In the prototype, this was one half of a case whose transparent lid had been used in another application. In this Logger it was replaced by a sheet of acrylic (Perspex) cut to the same rectangular size, suitably drilled for the switches and securing holes. The l.c.d. was bolted behind the acrylic.

It is best to mount the l.e.d.s in the lid as well rather than on the p.c.b. (as they were with the prototype). Holes for the serial connector, GPS socket and the sensors cable were drilled at the rear of the case.

Probe Assembly

Schematic details of the FGM-3 sensor are outlined in Fig.3. It will be seen that it has four pins, one of them marked F/B (feedback). This pin is not used in this design and should be left unconnected.

To achieve maximum benefit from the two sensors they must be aligned with each other as accurately as possible within their tube. The external construction is shown in the photograph. Anthony Clark says on this point:

"The practical effect of any misalignment of the detectors is to make the instrument direction sensitive . . . if it is rotated."

He also comments that, whereas a sensor separation of one metre used to be common, 0·5 metres (1·6 feet) is now in general use. This makes the necessary rigidity of the assembly easier to achieve.

It is stressed that the materials used in the sensor housing should be totally non-magnetic and incapable of disrupting the sensors' fluxgate response. Some commercial assemblies use square-section aluminium tube. Browsing the web, it was found that right-angled aluminium section can also be used, providing excellent rigidity.

Additionally, Carl Moreland (**www.tthn.com/geotech**) describes a fluxgate magnetometer based on the FGM-3 and SCL007 devices, followed by an audio output stage, with which he mounts the sensors in a 2-inch (50mm) diameter PVC tube. Carl illustrates two techniques for mounting the sensors in the tube, as shown in Fig.4.

The author, though, used a 0·5m long right-angled aluminium section, to which the sensors were initially secured using Blu-Tack. This was subsequently reinforced by hot melt glue once the alignment had been achieved. The assembly was then placed within a plastic plumbing pipe of the same length and having an internal diameter of 17mm (externally 22mm).

Whichever technique is used, and referring to Fig.5, first connect the sensors to their p.c.b. pins. As the sensors have rigid pins spaced at 0·1-inch pitch, a pin header (or cut-down i.c. socket) can be used as a connector. DO NOT solder leads directly to the sensor pins which might damage the assembly. Keep the distance between the p.c.b. sections and the sensors reasonably short (say 1cm to 2cm).

A schematic of the author's full "probe" assembly, including the other connection cables, is shown in Fig.6. The "handle" is also useful in showing the orientation of the assembly during a survey.

It may be necessary to file off the entire edge of the external "V" of the aluminium section so that it slides easily into the plastic tube.

Full alignment of the sensors can be a bit tricky, and can only be done once the electronics are fully functional. To a small extent, though, absolute alignment is probably not essential for many of the applications in

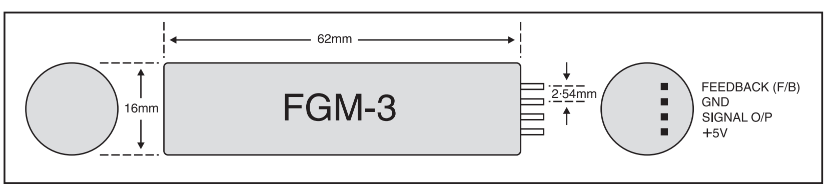


Fig.3. Details of the FGM-3 sensor module.

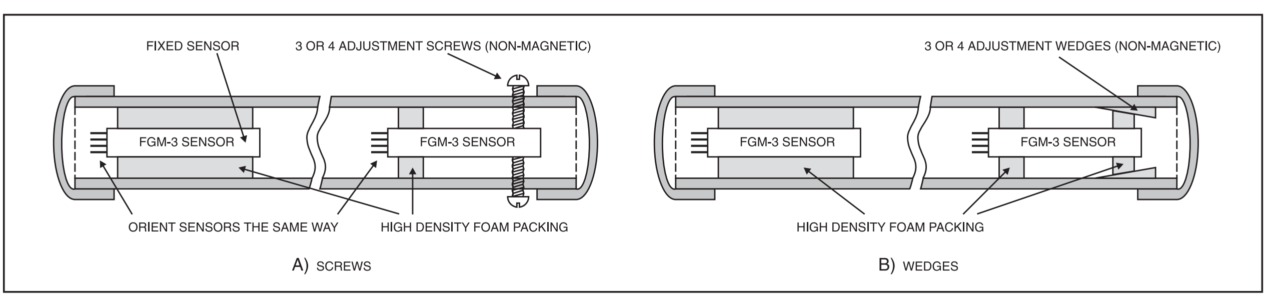


*Fig.4. Alternative techniques for mounting the FGM-3 sensors, as used by Carl Moreland (**www.tthn.com/geotech**).*

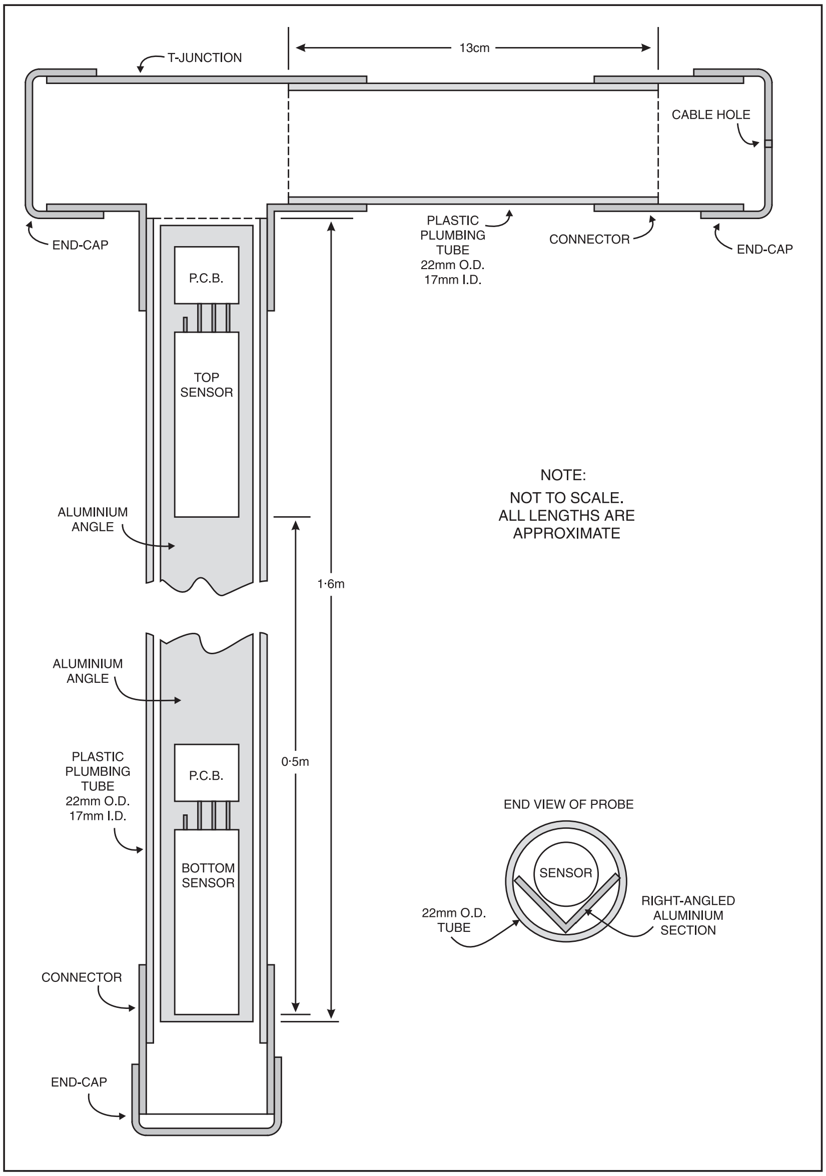


Fig.5. Probe assembly details.

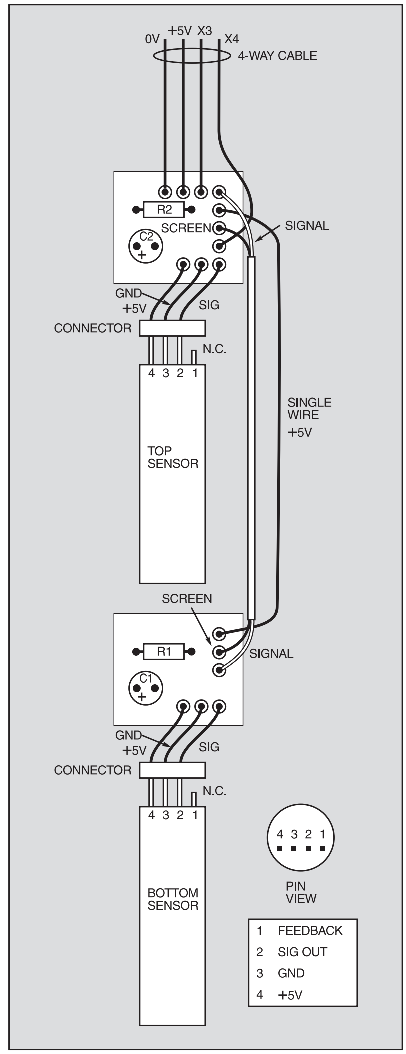


Fig.6. Sensor wiring details.

which the magnetometer is likely to be used.

Provided that the sensors are maintained at a constant angle with respect to the Earth's magnetic field, any local magnetic anomalies should become apparent when the recorded survey data is displayed via the PC screen. Sensor alignment is detailed in Part 2.

It is important that screened cable should be used as shown in Fig.6, to avoid the signal from the bottom sensor interfering with the response of the top sensor. It was found that 4-way intruder alarm cable was satisfactory for connection between the probe assembly and the unit.

The sensor cable was soldered to the main p.c.b. in order to avoid the danger of a plugged connection separating during a survey.

First Tests

For the first test of the Magnetometer, set preset VR1 midway and the switches as follows:

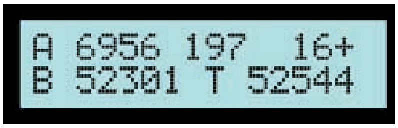
Record off (S2 up), Screen Mode 2 (S3 down), Run on (S5 down), Test on (S4 down), Power off (S6 up). Although Null switch S1 is seen as a toggle switch in the photograph, a push switch should be used here – ignore the switch for the moment.

With the sensors connected to the main p.c.b. (don't worry about their alignment at this stage) switch on the power (S6). A "title" message will appear briefly on the l.c.d. screen top line (adjust preset VR1 for the best screen contrast). Line 2 shows the number of serial memory chips that the software has detected, two if both are installed.

Also note that l.e.d. D3 now flashes at about once per second. This is the rate at which each pair of sensor samples is being taken. The other l.e.d., D4, should be off.

After a couple seconds or so, the screen will change to show Test Mode details.

On the top line, the value shown following letter *A* indicates the total number of



recordings made to the serial memory chip(s). This is followed by another value, showing the number of samples recorded when Record mode was last used. Both numbers could have any value at this stage until the serial memories have been reset (see later).

At the right of the top line you may see either a value or a series of asterisks, and which may be followed by a negative sign. This part of the line normally shows the difference in the values of the two sensors in relation to a "null" reference value (more later).

The asterisks are shown when the value is greater than 999.

On line 2 are two values preceded by the letters *B* and *T*. These values show the actual frequency count being detected from the sensors by the PIC. The value for the bottom sensor in the probe assembly is preceded by *B*, and the top sensor value by *T*. The actual values seen will depend on the magnetic field strengths present in the room where you are testing the unit. In the author's workshop they are typically in the region of about 60000.

Magnet Test

Bring something magnetic (something with iron or nickel in it – even a small magnet) into proximity with each of the sensors in turn and observe how the values change.

You will find that the closeness of the object and its angle in relation to the circumference of the sensor determines the count value, as will the orientation of the probe assembly in relation to the magnetic fields in your room. You will also observe when the probe is well away from household artifacts that the sensors are sensitive to the compass direction in which they face.

In the sensor alignment process, the sensors positions are adjusted while referring to these values in relation to the Earth's magnetic field.

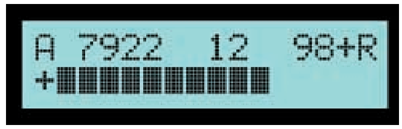
Now briefly press the Null switch, S1. This causes the software to store the current sensor values as references. The word NULLED appears at the top left of line 1 until the switch is released.

When the switch is released, the value at the right of line 1 should now show as 0 (although it may shift up or down due to the fluctuating magnetic fields in your room).

The software takes the two sensor readings, subtracts their above reference values, and calculates the difference between these two results. This value is displayed on the top line, followed by a plus or minus sign as appropriate. **This value is purely for "in the field" information and does not affect the sensor values actually recorded when in Recording mode.**

Switch off Test switch S4. The top screen line continues to show the same details, but the bottom line now displays a

bargraph representing the absolute (ignoring minus signs) difference value divided by four. Each value unit controls one vertical line of pixels across the display. There are five of these lines per character cell, so the display has a resolution of 80 values. Observe how the bargraph changes in relation to the magnetic fields detected by the sensors.



Switch on Record switch S2. The letter *R* will appear at the top right of line 1 and l.e.d. D4 will turn on, indicating that the unit is now in Record mode. The value at the centre of line 1 is simultaneously set to zero.

At each flash of l.e.d. D3, the sample values read from the two sensors are stored *without modification* to the serial memory. Data recording is done in strict ascending address order, following on from the address at which the previous recording session ended.

The current total recording count is shown to the left of line 1, incrementing by four for each sample. This represents the number of memory locations actually used. Each sample requires four locations, two for each of the sensor values, allowing for a maximum value of 65535 (two 8-bit bytes).

The number of samples taken during this Recording session is shown at the centre of line 1, incrementing by one for each complete sample recorded. **There is no limit to the number of samples recorded in any one session, other than that imposed by the memory capacity.**

To end the recording session, switch off S2, at which the message RECORDING ENDED will be displayed briefly.

At both switch-on and switch-off, additional data is also recorded to the serial memory: the geographical location if a GPS handset is connected, and the current value read from the temperature sensor.

If a GPS handset is not connected, the letter "a" is written to the same number of memory locations as would be the GPS data.

Discussion of downloading recorded data to a PC will be covered in Part 2. Switch S5 controls this mode, causing the l.c.d. screen to display the message WAITING PC TRIG when switched on. The mode is exited when S2 is switched back to Run. You may try this now without disrupting anything even though the PC is not presently connected.

GPS Interfacing

A GPS handset may be interfaced with the Logger to record the geographic location at the start and end of each recording session. This will be of particular benefit when doing a large-scale survey across a broad area. **GPS use is optional.**

As discussed in the article *GPS to PIC Interfacing* in the Jan '04 issue, GPS handsets can output their navigational data to a PC or other digital destination via a serial link, for which a connector is provided on the handset.

Data can usually be output under a variety of format protocols, depending on the type of handset. All handsets should offer the "standard" protocol that conforms to what is known as NMEA 0183. NMEA stands for National Marine Electronics Association. This standard specifies the serial Baud rate at which data is output, and in what format.

To set the handset to output under this protocol, refer to your handset's manual, which will also give the pinouts for the set's connector. Using a connector suited to the handset, make connections from the handset for the signal output and the 0V (ground) lines, using a screened lead of any length you prefer. Connect the leads to the Logger. Ignore any other pins that the handset connector may have.

With the GPS and the Logger switched on, switch on S3 to select Screen Mode 2. Once the GPS has acquired satellite data, that giving the handset's current latitude and longitude coordinates will be displayed, using both l.c.d. screen lines.

For as long as S3 is on, this data will continue to be updated. If data is not being adequately received, a screen message will tell you so.

Following S3 being switched off, the GPS data is only read immediately prior to and following the start and end of a recording session, at which point it is also stored to the serial memory, as said earlier.

It was decided not to record GPS data for each recorded sample for several reasons. First, it would consume a great deal of serial memory. Secondly, it takes about a second to select and decode the data coming in from the GPS (which outputs all sorts of navigational data in batches). This, coupled with the required one-second period for sampling the sensors, would have made sampling too slow to be convenient.

With the Logger only dependent on a one-second sensor sampling rate, it is easy to survey a site at a normal walking pace, in time with the flashing l.e.d. D3.

Thirdly, GPS handsets can be prone to "losing" the satellite signals. The author's Garmin GPS12 handset does not like trees or other cover above it, for example. If the handset lost the signal while recording a stream of samples, the sampling rate could become inconsistent.

By sampling the GPS only at the start and end of a recording session, there is the opportunity to read the l.c.d. screen to establish whether a valid GPS location is being received at that time.

The software has been written so that Recording mode can be entered while switch S5 is set to GPS reception and display. For the above reasons, the screen then reverts to show sensor data. At the end of recording, it changes back to GPS display.

Temperature Monitoring

In GPS mode, the l.c.d. screen also displays, at the bottom of line 2, the value read from the temperature sensor IC8.

This value is not quantified in relation to Celsius or Fahrenheit, it is just the analogue value from the sensor as assessed by the PIC's internal analogue-to-digital conversion (ADC) routine. This value is also recorded to the serial memory at the start and end of a recording session.

The facility was included by the author to see if any significant temperature drift occurred while recording any batch of sensor data. Drift was found to be insignificant and so the software has not been provided with any temperature correction routines.

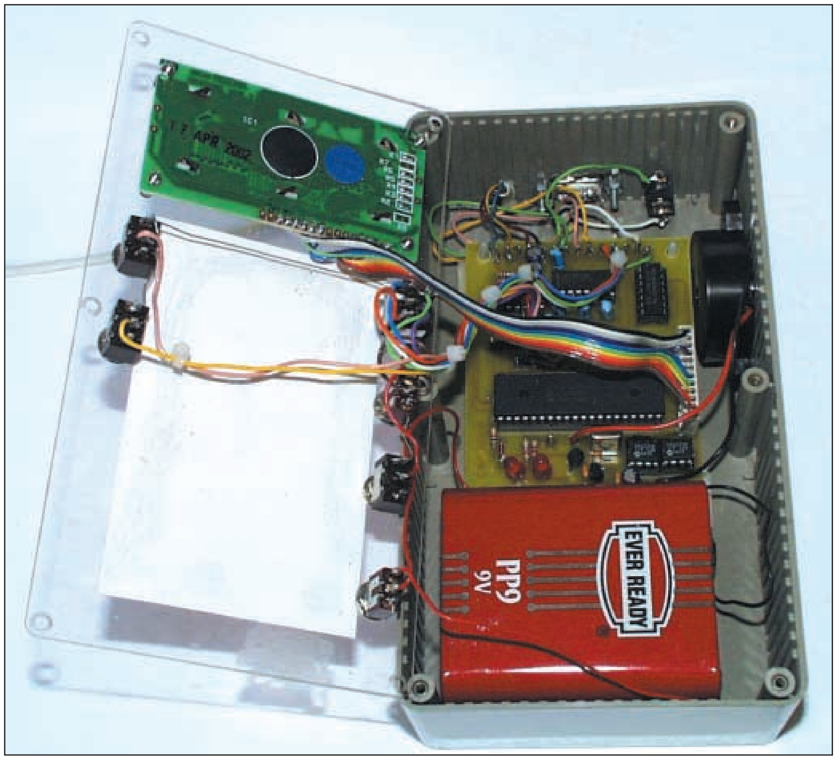
The sensor may be omitted if preferred, but if you do so, link IC1 pin 7 (RA5) to the 0V line to prevent it from "floating". Note that the PIC will continue to read this pin for an ADC value and record it to the serial memory even if the pin is grounded.

Memory Clearance

A "safety" feature prevents the serial memory data from being reset unwittingly. To reset the memories, first switch off the power and wait a few seconds to allow the power line capacitors to discharge.

Press down Null switch S2 and hold it pressed. Switch on the power and wait until you see the screen message stating CLEARING EEPROM, then release S2.

The resetting process is somewhat slow as the memories require minimum pause durations during the process. It takes about three and half minutes per memory chip. The l.c.d. shows the progress of the reset count.



Sensor Alignment

For optimal performance, the Logger's sensors need to be aligned. It is worth commenting though, that in the early stages of software development, a probe with unaligned sensors was used to gather data around the garden. Some very respectable results were achieved from small artifacts scattered around at random.

Precise alignment is best done outdoors, well away from the influence of domestic magnetic fields. The probe assembly should be positioned in an east-west orientation, held in such a way that it cannot shift from that position, but can be rotated about the main axis of the probes themselves. Two 22mm pipe clips could be used for this, bolted to a stable surface and the main probe tube clipped into them.

It is important that the probes *are* in a true east-west position since the alignment must be made with respect to the Earth's magnetic field. Use a compass to check this (but move the compass well out of sensor range before carrying out final alignment of the sensors).

To set the sensor alignment, you now need patience! If you are using Carl's assembly mentioned earlier, adjust the screws (which must be non-magnetic) or the wedges to change the orientation of the sensors. If using the author's probe assembly, take advantage of the flexibility of the Blu-Tack to move the sensors.

With the unit switched on and in Test mode, observe the count values displayed for the sensors. First adjust the sensors so that their connectors appear to be in the same relative positions horizontally. Look along the length of the assembly and check that the sensors are horizontally in line with each other along their axes.

Observe the l.c.d. values. Very carefully adjust the precise orientation of the sensors until the two readings are as close to each other as you can achieve. There is always likely to be a difference, however, due to the individual characteristics of each sensor.

Now rotate the entire tube assembly about its axis within the pipe clips, while still observing the l.c.d. values. If the values change disproportionately to each other as rotation continues, minutely adjust the sensor positions until this is minimised.

When you are satisfied with the alignment, the sensors can be secured in position with hot melt glue.

Wellyquipped!

It is important that you should not wear any potentially magnetic materials during alignment and general survey. In early static tests with the prototype (while looking for temperature drift) the author was puzzled by unexpected changes in the recorded results when viewed on the PC. Further investigation showed that he was partly responsible for them, moving to and from the stationary unit over the several hours during which the test was conducted.

The effects turned out to be due to: a metal buckle on his belt; a 90mm × 100m × 10mm tin in one pocket; many plastic cards with magnetic strips in his wallet in the other; the ancient wrist watch being worn; his glasses to a very small extent; a passing cat (twice) which had a magnet on its collar to allow controlled access to a cat-flap!

So be warned – when setting-up or using the magnetometer, be very wary of what you wear. Probably the only way to be sure is to employ survey apparel that only consists of green wellies! (and even they should be given the boot if they have buckles . . .)

Next Month

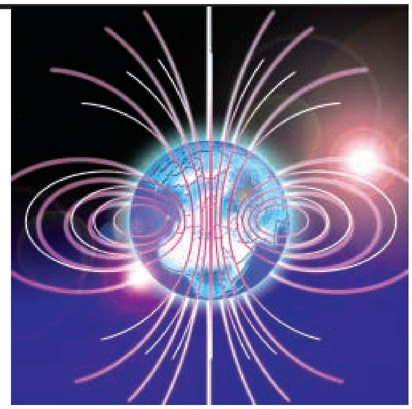
In the concluding part next month, the PC software will be described.

Constructional Project

Magnetometry Logger

Part Two

John Becker



Logging your search for magnetic fields that might reveal hidden artifacts.

HAVING described in Part One the concept of this Magnetometry Logger, its construction and initial testing, we now conclude by discussing its PC monitoring and display software.

PC Software

Recorded magnetometry data can only be viewed via a PC screen using the specially written software referred to in Part One.

To run the program, open the Magnetometer folder and double-click on **Maggy.exe**. The first time that the program is run it creates several additional files to which it refers each time the program is subsequently loaded. These include various settings which may be changed by the user from within the program, and details of file data paths accessed via the Directory function.

Following this brief procedure, a nearly full-screen display on which graph data will later be drawn is shown. Superimposed on it is a small sub-screen, known to the program as the Main screen.

To the left of the Main screen are four colour charts. These are used by another screen that can be called, the Grid screen, described presently. The various click-buttons will be described as we go along.

First, though, note the box at the top right. Two "radio" buttons are shown, with captions Resistivity and Magnetometer. As said in Part One, this program can be used with the *Earth Resistivity (ER)* project featured in the April/May '03 issues. More on this later.

The Magnetometer option will be seen to be highlighted at present (black dot at the button's centre).

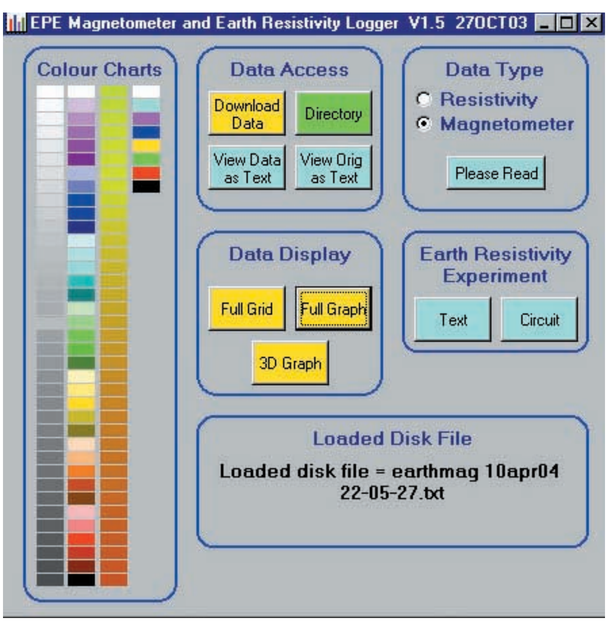
Download Data

The next button of immediate interest is the Download Data button. It is via this option that survey data recorded by the PIC is downloaded.

Note that the data in the PIC's serial memories is unaffected by the download and remains intact. Further recordings may even be made to the memories following a download, and the whole batch input as a block at a later time.

Assuming that you have first Reset the memories, and have already been recording data in several blocks of recording sessions, click on the Download button to reveal the Download screen. Two more radio buttons offer a choice of whether the PC's serial connector path is COM1 or COM2. Connect a standard serial port cable (the same type as you use with a modem) into the COM port socket that you wish to use, and into the Magnetometer connector at the other end. Set the screen COM port choice accordingly.

Follow the screen's instruction to press the PIC's download button (switching S5 to the PC setting – also set the other Mode switches upwards).



Main control screen of the Magnetometry Logger.

On the Magnetometer's screen the message WAITING PC TRIG l.c.d. will be seen. The PIC now waits for a handshake command from the PC.

Click the Start button on the PC's Download screen. It sends the handshake command (the letter "G", for Go), the PIC acknowledges by sending back the letter "R", for Received, and starts to output the stored serial memory data to the PC, in blocks of 1024 bytes.

On receipt of each data block the PC and PIC again exchange "G" and "R" and another block is sent. This continues until the PIC recognises two zeroes in the data being extracted from the memories, or until the data in all memory locations has been sent. The PIC "knows" how many memories are installed and behaves accordingly.

A bargraph shows the download progress. Data is transferred at 9600 Baud, 8 bits, no parity.

Once the PIC has sent all the required data, it displays the message SET BACK TO RUN, meaning that you should switch S5 back to the Run setting. Once the PC recognises that a time-out has passed during which it has received no data, it exits Receive mode and outputs the received data to two text (TXT) files in the same folder as the other Magnetometer files are held.

These are named with prefixes of "EarthMagOrigData" and "EarthMag", followed by a unique date and time identity, as applies at the time of the download.

The first file contains the original data as received from the PIC, but now in ASCII text format compiled from the binary format in which the PIC sends it.

The second file comprises "processed" data in which the values of the two sensors are subtracted from each other and output as the difference value. It is this file that the PC uses when it displays graphics generated from survey data.

With both files the values are output as separate "sentences" whose length depends on the number of values received for each recording session. Both files contain the GPS and temperature data recorded at the start and end of each recording session, placed at the end of each line.

Viewing Data

The files can be viewed as text data by clicking the Main screen's View Data as Text and View Orig as Text. The data is input to either Windows Notepad or Wordpad, depending on its length.

Note that it is possible to amend the "processed" data file and for the amended values to be input next time the file is loaded via the Directory option. Whilst the original data can also be changed via the text editor through which it is viewed, the file cannot be "recompiled" to a "processed" file, so changing it has no practical benefit.

Text file viewing is only available once the complete download cycle has been completed. Once the text files have been stored to disk, the program automatically hides the Download screen and reveals the Full Graph screen, plotting the processed data onto it as waveforms relating to the data values. The speed at which this happens depends on the amount of data being processed and the speed at which your PC operates.

Before plotting each waveform line, the software reads its first value and then subtracts this value from itself and all other values in the line. This is to standardise the relative starting position of the separate lines on the screen.

Before examining the options available via the Full Graph screen, click on the top-left button marked Main to return to the main screen via which you can examine the two text files just created. This action is purely for interest at this stage. To return to the graph screen click on the Main screen button named Full Graph.

Graph Display

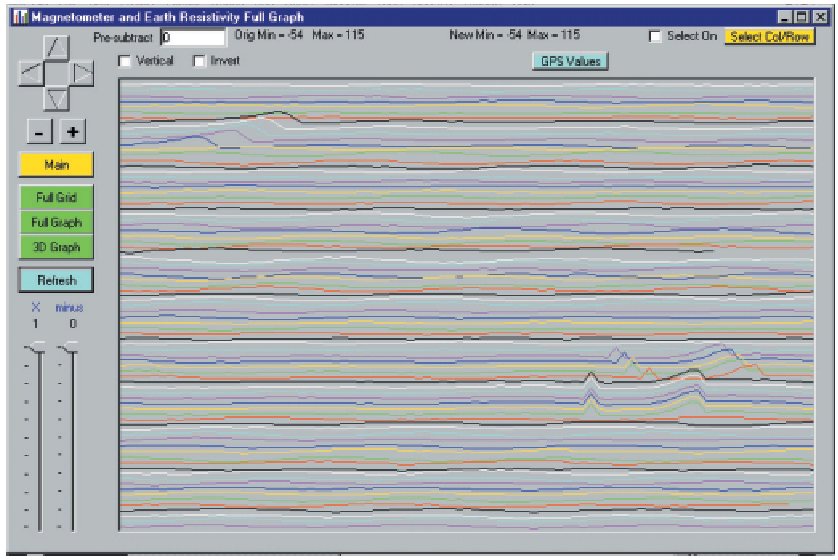
There are several click-options on the Full Graph screen which allow you to manipulate and examine the waveforms in greater detail. Their functions are briefly described by a "tooltip" text box if you hover the mouse cursor over them.

At the top left four "arrowed" buttons arranged in a cross allow the display to be scrolled and panned. Below them the buttons marked "–" and "+" are zoom controls.

The "pre-subtraction" text box at the top allows you to enter a value which is then subtracted from the survey values for each waveform line. Values may be positive or negative.

To the right of this box are stated the original minimum and maximum values found in the survey block being displayed. To their right are stated the minimum and maximum values after subtraction and correction according to the sliders at the bottom left.

Above the sliders will be seen a division ("/") symbol and the word "minus". The



Typical example of the Full Graph screen.

positional values of the sliders are respectively divided into and subtracted from the survey values. Respectively clicking on "/" and "minus" swaps the functions for multiply ("X") and "add". Again clicking them reverts back to the previous function, on an alternating cycle. The Refresh button must be clicked to implement any slider change. The slider ranges are 100 and 1000.

The Invert box allows the waveforms to be drawn "the other way up", peaks becoming troughs, and vice-versa. Click the box to change direction.

Clicking the Vertical box alternates between the waveforms being drawn horizontally and vertically. This will be explained more fully when survey plotting is discussed.

Selected Viewing

Two controls at the top right are used to select which survey columns and rows are displayed, allowing better examination of selected survey areas. Clicking on the Select Col/Row button displays a sub-screen in which the individual tick boxes allow the required rows or columns to be activated. Their selection is made by clicking their box. It is an alternating on/off cycle.

The Tick All and Untick All buttons affect all tick boxes equally within the row or column zones. The Active tick boxes affect only the blocks immediately below them.

The waveforms are redrawn when the Redraw button is clicked, which also closes the Selection screen. However, for the selection to be implemented, the Select On box on the full Graph screen must be ticked. This function when clicked alternates between on and off.

It is important to note that any new tick selection in the sub-screen is only valid if the screen's Redraw button is used. If you use the Windows X button at the top right to exit the screen, all the boxes will revert to their default of all unticked and the graph will not be redrawn when the screen closes.

GPS Values Button

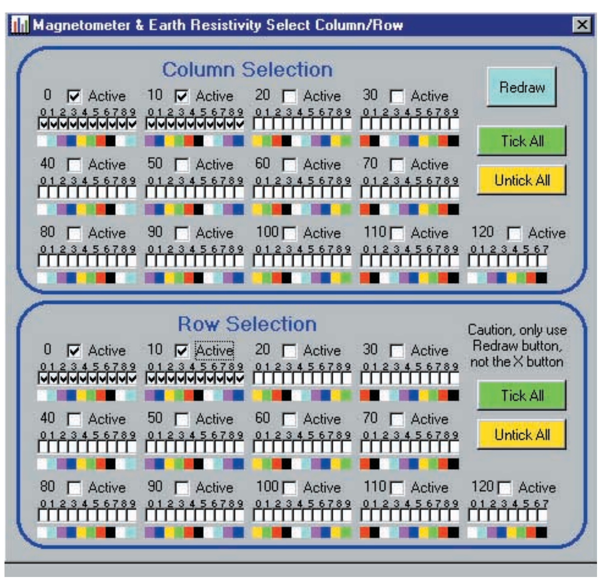
Clicking on the GPS Values button reveals a box in which the GPS start and end coordinates of the numbered survey grid lines are listed. If GPS has not been active during a survey line, the message "No GPS recorded" is shown.

To the right of each list line are shown the start and end values read from the temperature sensor. As said earlier, they are only for information and have no practical value.

Clicking the button again hides the list and redraws the graph.

3D Graph Display

Clicking on the 3D Graph button at the left of the Full Graph screen selects the display mode in which data is plotted



Screen through which data columns and rows can be selected or inhibited for viewing.

as vertical bargraphs which have been given a bit of a "3D" appearance.

It has to be said, though, that the 3D effect is not as good as Windows Excel can produce. The VB6 Learning Edition in which the Magnetometer software was written does not allow selective colour painting of bordered areas (unlike QBasic, which has a very useful Paint function for colour-flooding selected areas).

All the functions described for the Full Graph screen are available in this mode.

Full Grid Display

Clicking the Full Grid button calls up a screen in which the survey data is plotted as rectangles, tinted according to the value. This is a display that was written for *ER* but which is less useful for the Magnetometer data.

The reason is that the *ER* data values fall into a much narrower range than Magnetometer values. As a maximum of only 36 shades are available for the rectangles, it is far less easy for the Magnetometer data to be corrected to show meaningful shade differences.

The function has been retained, though, as this software can also be employed by *ER* users. Nonetheless, for the sake of good order, the screen is used as follows:

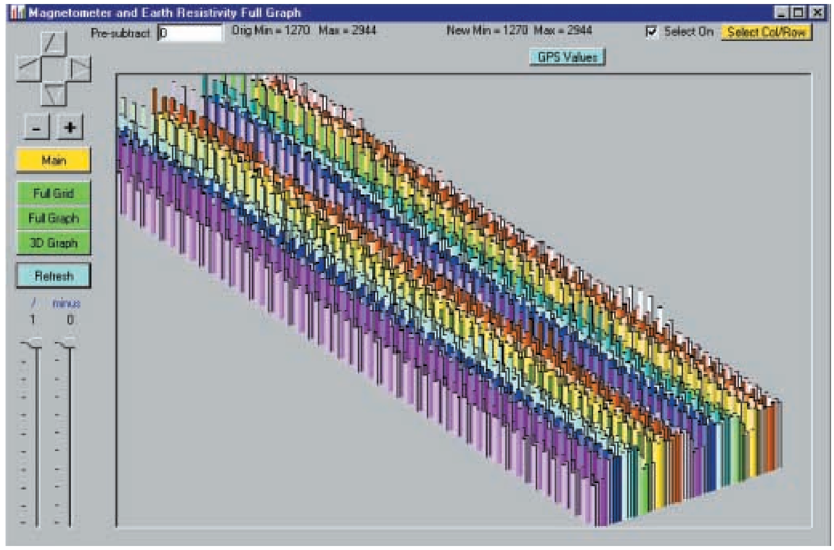
Panning and scrolling are performed by using the sliders immediately above and to the left of the display area. Zooming is performed by using the small slider at the top left of the screen.

Pre-subtraction values can be entered in the same way as with the Full Graph, with minimum and maximum values shown to the top right. The values can also be adjusted by the two sliders at the left.

To implement the slider changes, click on the Refresh button.

Above the sliders, the four radio buttons allow the colour scheme to be selected. The colour options are those shown at the left of the Main screen. Changing the colour option causes the display to automatically redraw in the new colours.

The Invert option behaves in the same way as with the Full Graph screen.



Example of the 3D Graph display.

The Matrix button when ticked causes the display boxes to be drawn to a size related to the survey value.

When in Matrix mode, the Show 0 button alternates between matrix dots being shown or not shown when survey plot values are less than one (which are always limited to a minimum of zero).

(When used with *ER* data, a Current click box is also shown, whose function is described in the published *ER* text.)

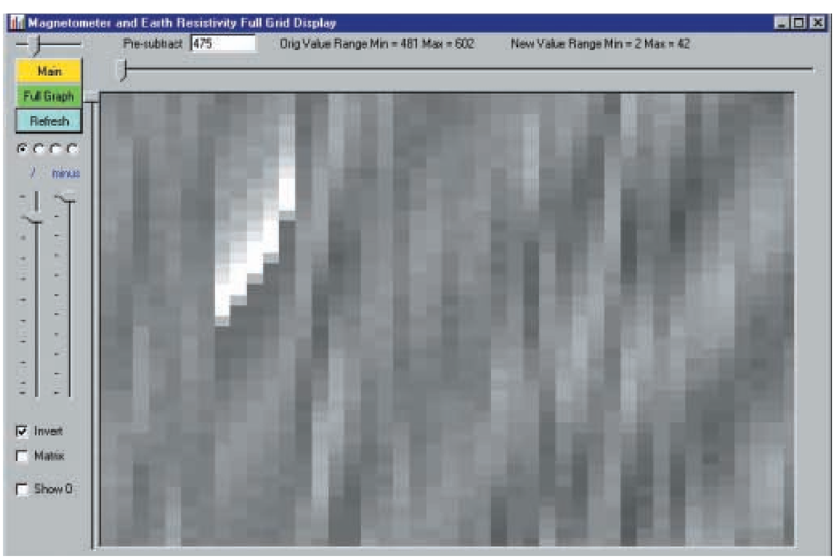
A "show coordinates" option is available with the Grid display. Click the mouse on any square and its column and row coordinates are shown at the bottom left. The mouse can be moved while its button is held down and the values change accordingly.

From the Grid screen an exit to the Full Graph or Main screens can be made via their allocated buttons.

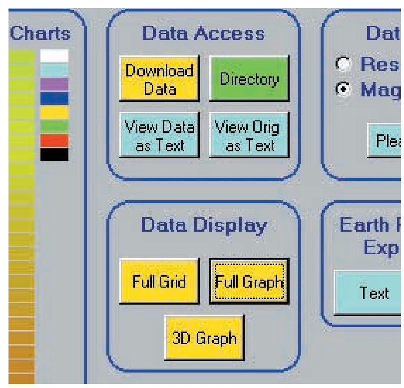
Main Screen Again

On the Main screen, it will be seen that the Full Grid, Full Graph and 3D Graph screen can be called via click-buttons.

The Directory button allows you to select previously recorded data files for display. The Directory screen is similar to those used with the author's other VB6 programs. Full details of its use can be read via the Notes button.



Example of the Full Grid screen, a facility better suited to Earth Resistivity monitoring rather than to magnetometry.



Commonly used control buttons on the Main screen.

In brief, folder paths are selected via the lefthand path menu, and files within a selected path selected by double-clicking on a named file in the righthand list. This causes the Directory sub-screen to close and the file data to be loaded. If a file name is only clicked once, it is not actually selected, but is just highlighted and a return to the Main screen can be made by using the Exit button.

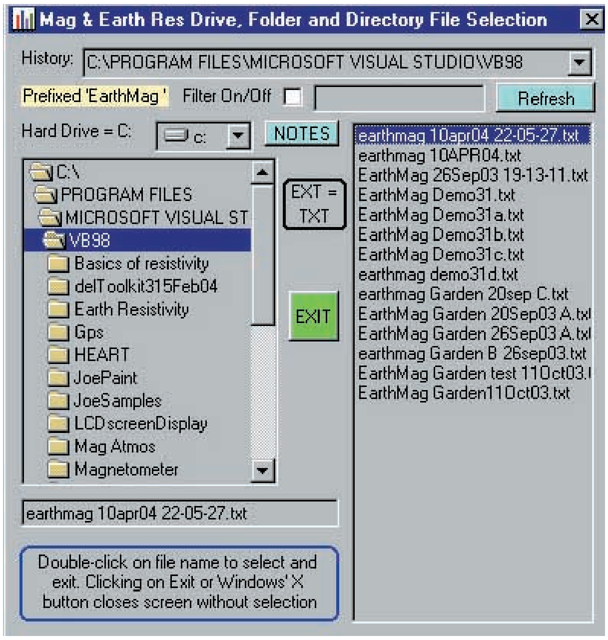
All path files are pre-selected for a prefix of either "EarthMag" or "Earth Res", depending on which Logger option has been selected on the Main screen.

You may also add your own filter to this prefix via the text box provided, allowing file names that only conform to the prefix and filter characters to be listed, so permitting selection by date, for example. The filter function can be turned on and off via its click box.

A history of the folder paths accessed is recorded to disk when new ones are selected. This is recalled each time the program is loaded and a particular path can be selected via the dropdown History option.

Experiment Buttons

The Earth Resistivity Experiment buttons at the right of the Main screen are



Example of the Directory screen through which files prefixed "EarthMag" can be selected for input.

for the interest of *ER* users. They respectively reveal a text file describing an experiment, and an illustration of a circuit for it.

Final Exit

The only way to totally exit from the Magnetometer program is to use the Windows X button at its top right. On other screens, the X button only causes a return to the previous screen.

Earth Resistivity

Several references to the *Earth Resistivity Logger* have made during this article. The Magnetometer program is an enhanced version of that written for *ER* and is compatible with the hardware of both designs.

Although the *ER* program itself can be used with the Magnetometer hardware, it is strongly recommended that the Magnetometer should ONLY be used with the software described here.

If you are an *ER* user you may use either *ER*'s own program as described in the published article, or the Magnetometer program, selecting the correct option via the main screen. However, there are a few matters that *ER* users should consider:

The *ER* software offers two options through which data could be downloaded from the hardware. One was based on a DLL function, the other via Joe Farr's OCX, as used in the Magnetometer.

The Magnetometer does not include the DLL download function and those who are currently using *ER* with the DLL need to make minor changes to its p.c.b. These changes are described both in *ER* itself and via the Please Read button on the Magnetometer's Main screen.

Secondly, it will be seen that this Main screen differs from the *ER* Main screen. That screen included small graph and grid display areas, limited to a 20 × 20 matrix. Magnetometer surveying can cover much vaster areas than required for an *ER* survey and so these sub-display options are irrelevant and have been dropped.

If you are an *ER* user and would like to use the Magnetometer software instead, DO NOT copy the Magnetometer files into the *ER* folder otherwise unpredictable conflicts might occur. You must only copy the Magnetometer into its own folder as described in Part 1.

The files from either Logger can be accessed from either program.

Magnetometry Surveying

The whole scope for surveying using a magnetometer is much greater than for *ER* logging. In the latter, more painstaking techniques are used within a small grid area. With the magnetometer you can stride great distances, recording data at whatever stride length and rate you prefer.

The program has been written so that a survey area is covered by walking in one direction to any point of your choosing, whether it is 10 paces or 1000 (or more). The recording is switched on at the start of the walk and switched off at the end of the chosen distance or number of paces. You then shift to the right of the first track by whatever amount you want, turn around, switch on recording and pace back to the original base line, in parallel with the first track, and switch off recording.

This process can be repeated for as many "columns" as you want so that the whole area required is covered. If aching feet cause you to break between columns, just resume when you are ready.

There is a protocol that should be observed, though, as illustrated in Fig.7. The software assumes that recording for the first column starts at the bottom left of the survey grid (C1/R1) and proceeds to the top left for a given number of paces (as can be viewed on the l.c.d.). You then turn right into column two and return for the same number of paces as for column 1. Then repeat along the other columns in numerical order.

It is important that the Record switch should be switched off at the end of a column and switched on again for the next column. Failure to do so will cause the software to regard two or more columns as a single one of much greater length.

When downloading the recorded data, it is retrieved in strict numerical order of memory locations. It is then split into separate columns whose length is the number of samples taken before recording is stopped. Odd-numbered columns (e.g. 1, 3, 5 etc.) keep the data in the original order. Evenly-numbered columns (e.g. 2, 4, 6 etc) have their data order reversed.

This alternating order makes it easier for the software to display the recorded values in a meaningful sequence.

On Full Graph screen, however, the columns are plotted *across* the screen from left to right, top to bottom. Column 1 thus starts at the top left of the screen and ends towards the right. Column 2 starts at the left of the next allocated position downwards, and so on (see Fig.8).

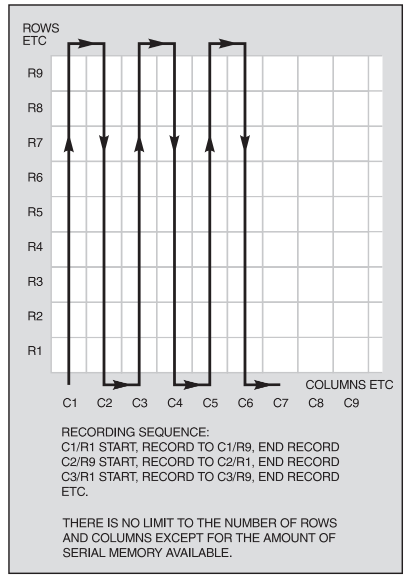


Fig.7. Order of surveying columns and rows of a survey area.

Experiment showed that the variations in waveform values were much more readily viewable when plotting in this fashion, with peaks pointing upwards, rather than plotting with waveforms peaking to the right.

Vertical plotting can be selected, as mentioned earlier. This, though, shows waveforms relative to the value differences between column coordinates in the same row. You will probably agree that it is less easy to interpret!

Full Grid displays are in the same direction as for Full Graph.

With 3D Graph displays, the data is plotted as shown in Fig.9. The start of column 1 is at front right, its end at front left. Column 2 is behind it, etc.

Note that it is moderately important that the pace count should be the same for each survey column. A few paces different between columns should not cause significant displacement of the results on screen. But don't have widely different column pace counts otherwise displacement will occur, since all columns are assumed to be positioned at the same upper and lower base lines.

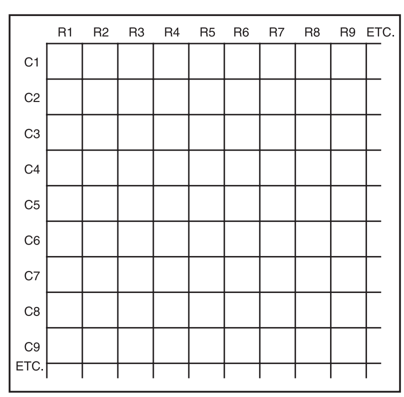


FIg.8. Orientation of columns and rows as displayed on PC screen when in Full Graph mode.

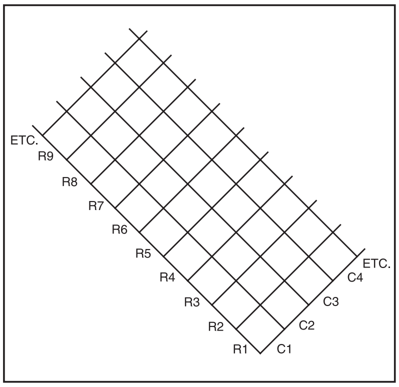


Fig.9. Orientation of columns and rows on PC screen when in 3D Graph mode.

Obviously, pace lengths as well as pace counts should be pretty consistent otherwise again displacement will occur. It is believed that the 1Hz sampling rate is easy to follow when pacing a column.

Probe Orientation

Three points to note about using the probe – in order to nullify as much as possible the influence of the Earth's magnetic field upon the probes, surveying should be carried out from east to west (or west to east). Furthermore, in case your sensors are not *absolutely* aligned, always keep the probe assembly facing in the same direction relative to north. (Remember this when turning from one column to another!) The "handle" on the author's probe assembly assists direction keeping.

Thirdly, the probe assembly may be used in a vertical or horizontal position. Horizontal positioning, with the probe bar held out in front of you across your body, provides the widest field of coverage, but with reduced sensitivity. Holding the probe vertically in front of you provides best sensitivity to small changes in magnetic field density, but has a narrower field of coverage.

Graphical Analysis

The downloaded survey data is formatted suitably for use with Windows Excel software. Excel, or variants of it, is available as standard on many PCs and is believed to be part of the Windows Office suite. As well as offering graphing facilities, Excel provides for mathematical expressions to be computed. These options allow the survey data to be examined in more substantial detail than the Magnetometer program can offer.

Brief information about using Excel was given in *ER* Part 2, page 363. Excel's own Help file, though, taught the author all he knows about it. Read it and experiment to find what Excel can do!

Survey Courtesy

Anyone may use the magnetometer to search for magnetic sources on their own property. You may also, of course, set up the unit on your own property and monitor the movement of magnetic fields beyond it, such as vehicles passing.

Remember, though, that all land in the British Isles belongs to someone and so any surveying on it requires the permission of its owners. However, the author feels that there should be no intrinsic problem about carrying an active magnetometer along public footpaths and across common land where the public are permitted free access.

What you MUST NOT do, is to dig on any of that land without permission. If you find a location that has magnetic anomalies that you wish to further investigate, permission must be obtained. Furthermore, if you suspect that the anomaly is due to something of archaeological interest, do not dig in that area without the involvement of someone with archaeological knowledge. You could otherwise destroy vital historical evidence.

To get archaeological help, contact a local archaeological society, whose details can be obtained through your library.

Having said that, there are many ways in which a magnetometer can be beneficially used to search for magnetic artifacts that are not of archaeological interest. A short list of possible uses was quoted in Part 1, in relation to what Speake & Co say about their FGM-3 sensors.

MAGNETIC VALUES

Magnetic Flux Density

	gauss	tesla	gamma
1 gauss	1	10^{-4}	10^{5}
1 tesla	10^{4}	1	10^{9}
1 gamma	10^{-5}	10^{-9}	1

Magnetic Field Strength

	amp/metre	oersted
1 amp/metre	1	0·01257
1 oersted	79·58	1

Speake & Co say that technically the FGM-3 sensor measures flux density, in gauss, but since in vacuum (and virtually in air) the units of flux density are the same magnitude as those of field strength, and since the sensor can only really be used in air, oersted can be regarded as equivalent to gauss.

In the past, the author has also been involved with magnetometers on scuba diving forays off the UK coast, searching for wrecks (and finding them!). If this is your intention, make sure that the entire electronics and probe assembly are fully protected from sea water damage. Note, too, that equipment on the boat will affect readings.

In answer to some questions that periodically appear on our *Chat Zone*, the design is not suited to locating precious metals or other non-ferrous materials.

Acknowledgements

The author gratefully offers his thanks to the following:

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Carl W. Moreland and his website at **www.tthn.com/geotech**, which gave the author further insights into magnetometry.

Speake & Co, and Bill Speake in particular, for providing the author with some FGM-3 sensors and informative application notes. Website **www.speaksensors.co.uk**.