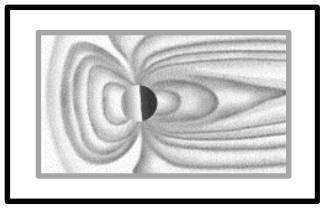
Earth Magnetometer Project **Updated July 2016**



Stuart Green

Figure 1below illustrates the effect on Earth's magnetic field of a passing coronal mass ejection (CME) as recorded on my magnetometer located in my garden at home in the UK. The recording shows significant structure and detail and is in very close agreement with records produced by professional magnetic observatories as can be found on the INTERMAGNET network, yet the equipment used to detect and record these data was obtained at a fraction of the cost of commercially available magnetometers and in its most basic form is very simple to set up and operate.

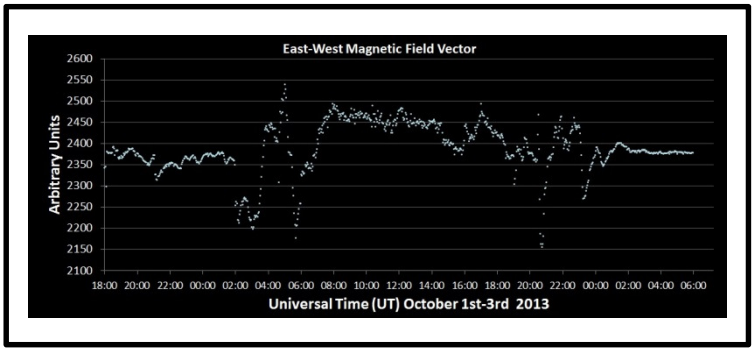


Figure 1

Magnetometer response to geomagnetic storm created by a passing CME

This note describes the design and construction of my magnetometer and how to set up, operate, log and present the results in graphical form. Construction is mostly about the power supply and waterproof housing for the sensor. I have kept the functioning magnetometer as simple as possible to avoid the need to build circuits beyond simple voltage regulation circuits.

The most basic form of the instrument comprises a magnetic sensor in a protective housing, an ultrasonic emitter, a detector in the form of an ultrasonic to audio frequency converter (Bat detector) and a computer to capture, record and display the data in graphical format, using free spectrum analysis software, as illustrated as a schematic in Figure 2.

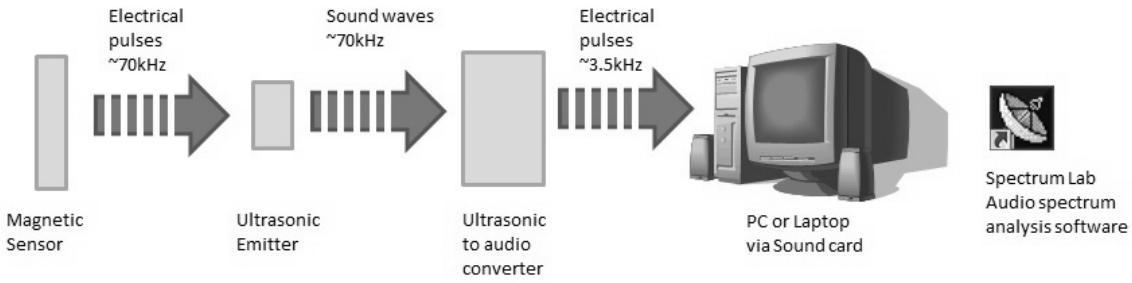


Figure 2

Schematic layout of magnetometer: Sensor to PC

The Magnetic Field Sensor

The magnetic field sensor used in this project is called a fluxgate magnetometer. The principles of this type of sensor can be found on the Web, for example, at http://www3.imperial.ac.uk/spat/research/areas/space_magnetometer_laboratory/spaceinstrumentationresearch/magnetometers/fluxgatemagnetometers/howafluxgateworks

The particular sensor used in this project is the FGM-3 flux-gate magnetic sensor (Figure 3) from Speake and Co, Monmouthshire http://www.speakesensors.com/PDF/detail.pdf



Figure 3

FGM-3 fluxgate sensor from Speake Sensors

In operation, the sensor is fed by a steady 5V supply (up to 7V max can be used) and it has built within it the necessary electronics to convert this into a pulse train of a frequency in the multi-kilohertz range. This is a wonderfully sensitive device that can detect minute changes in the magnetic environment. Increasing or decreasing the strength of the applied magnetic field changes the output frequency. Details can be found on the 'Speake Sensors' website, but the graph shown in Figure 4 illustrates the relationship. Earth's magnetic field is about 50uT (0.5 Oersted). Between ±0.5 Oersted the output period spans from about 20µs to 9µs, meaning that the FGM-3's output frequency changes from approximately 50 kHz to 110 kHz over this range. In practical terms, this means that if the FGM-3 is aligned towards Earth's North magnetic pole and then it is rotated by 180˚, pointing south, the output frequency will change over the indicated range. For our magnetometer, we are going to align the sensor in the East-West orientation in order to minimise the magnetic flux density running along its axis and allow us to measure tiny (sub nano-Tesla) variations in the E-W magnetic field vector.

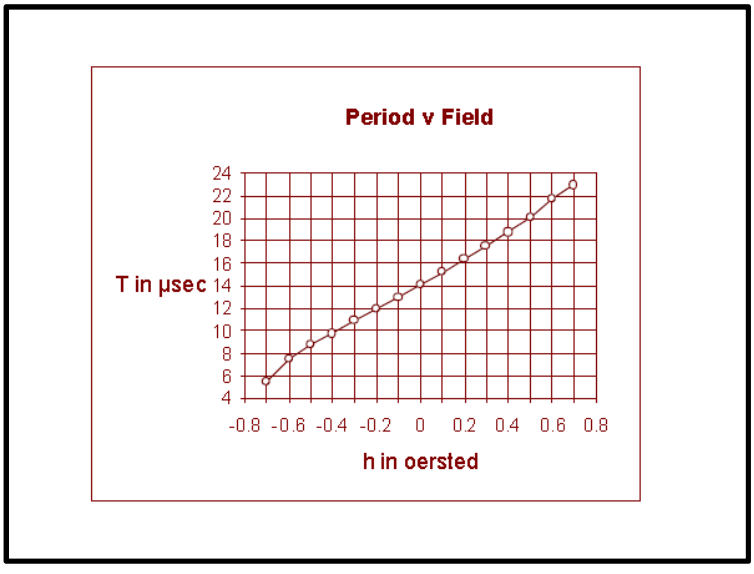


Figure 4

Time period as a function of field strength for the FGM-3 sensor

Ultrasonic (Emitter) transducer

The ultrasonic pulse train from the FGM-3 can be converted into ultrasonic sound using an ultrasonic transducer as illustrated in Figure 5. I used a general purpose transducer with a centre frequency of 40kHz, driven by a max. 10V signal voltage. This covers the range of frequencies produced by the FGM-3 very well and the drive voltage is within range of the output voltage from the sensor. These transducers are common and easily can be obtained from electrical component stores.

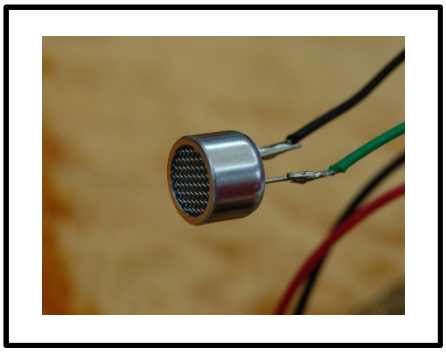


Figure 5

Ultrasonic transducer used to couple the output from the FGM-3 with the Magenta Bat 5

Ultrasonic to Audio Converter

There are various circuits described on the internet for converting ultrasonic frequencies (>20kHz) to audio frequencies (<20kHz) and these are of greater or lesser complexity depending on the conversion method and quality of reproduced sound. There are also pulse counting circuits that provide a direct conversion to frequency. The preferred method for this project is to use a heterodyne circuit in which the input signal is mixed with a reference signal of a close frequency to generate an audible output signal. The frequency of this audio signal will be equal to the frequency difference between input and reference frequencies. For example, if the input frequency is 100kHz and the reference frequency is 97kHz, then the difference between them (3kHz) is the output frequency. So by this process, the ultrasonic input frequency from the FGM-3 sensor is converted to an audio output frequency which can now be logged using a computer via the soundcard. Adjusting the reference frequency up or down the scale proportionally changes the output frequency. Conversely, if the input frequency varies (with a varying magnetic field as illustrated in Figure 1) then with a steady reference frequency, the output audio frequency will also vary substantially in proportion to the changing magnetic field.

For those so inclined and talented, such circuits off the web can certainly be built and deployed to measure Earth's magnetic field, but described here is an ultra-simple alternative for those who are not inclined to build a circuit from scratch. Commercially available magnetometers are expensive. However a digital heterodyne instrument can be relatively inexpensive and one suitable for this application can be purchased for about £90 in the form of a bat detector.

A bat detector is nothing more than a device that converts ultrasonic sound emitted from the bat into audio frequencies so that the operator can hear the calls from the animal. This is precisely what is required for this application, except that the obliging bat is replaced with the FGM-3 and ultrasonic transducer.

I use a crystal controlled heterodyne detector from Magenta (Magenta bat-5) http://www.nhbs.com/magenta_bat_5_tefno_156155.html as this gives sufficiently precise frequency control and excellent stability, which is what we need. The output is also of very high quality as an audio signal. Input is via an electret microphone located on the right hand side of the top edge of the instrument.

The Magenta bat-5 with ultrasonic transducer is illustrated in Figure 6.



Figure 6

Magenta Bat 5 ultrasonic to audio frequency converter

Conveniently, the Magenta Bat-5 also comes with a 3.5mm jack output socket intended for headphones, but which can also be used to pass the audio signal into the PC/laptop via the sound card. The device also comes with a tuneable oscillator conveniently operating over the frequency range of interest for this project and volume control.

Sensor Housing

The FGM-3 magnetometer is sensitive to changes in ambient temperature and its output frequency will increase and decrease appreciably between daytime and night time and summer and winter temperatures. This means that the sensor has to be located somewhere where the temperature fluctuations are minimised. Also, the sensor clearly has to be set away from local magnetic disturbances which will impact the instrument's ability to discern solar storms from general background clutter.

A good location for the sensor is underground and away from magnetic sources, as here the temperature can be relatively stable, with the surrounding soil providing sufficient thermal insulation to provide thermal 'inertia' against daily temperature swings. Being buried underground means that the sensor has to be housed in a waterproof container to prevent the contacts shorting out (all other components such as the bat detector and ultrasonic transducer remain above ground several metres away in a dry environment).

A suitable container can be made using plumbing hardware as illustrated in Figure 7. Here I've used 40&43mm ABS tubes and end-stops with screw-on end fittings and saddle clamp. The central tube was 2m long and had to be cut to length. The remaining hardware was purchased as shown. These are sold as pipe joining sleeves and blanking plates.

All of the pieces were assembled using suitable solvent from the supplier, which was used in accordance with the instructions provided, including health and safety for this volatile and flammable substance.

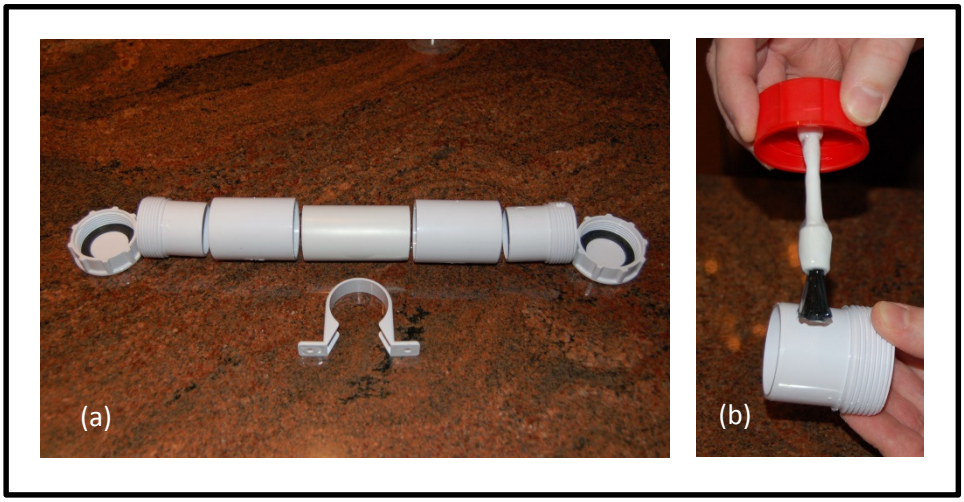


Figure 7

a) *Plumbing hardware layout ahead of assembly*
b) *Application of solvent to end fitting*

The assembled housing is shown in Figure 8. Also added is a cable gland to allow the cable to enter the housing via a watertight seal. This contains a rubber cuff that compresses onto the cable, forming a seal. The saddle clamp is added as a means of attaching the housing to a solid base prior to installing it underground. DO NOT apply solvent to the end cap fittings, as access to the tube will be required and these caps will need to be removed.

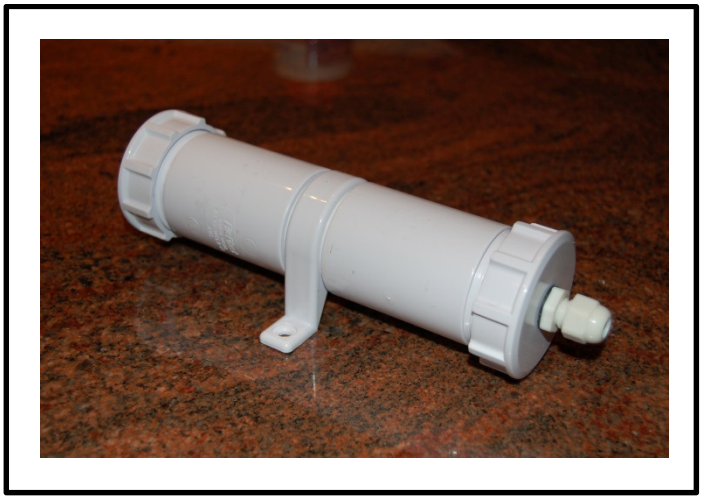


Figure 8

Assembled housing with saddle clamp for fixation to solid base

With the end caps removed install a length of copper pipe foam insulation sleeve. This again can be purchased from a hardware store and conveniently for this project it has an outside diameter slightly larger than the inside bore of the housing and a hollow core diameter slightly smaller than the diameter of the FGM-3 sensor. This is going to hold the sensor centrally within the bore of the housing which will be important during device set-up and operation. Cut the foam so that it extends about halfway down the length of the housing, as this will provide space in the housing for some basic voltage regulation electronics to be co-located with the sensor. Figures 9a and 9b show the housing with foam core viewed from each end.

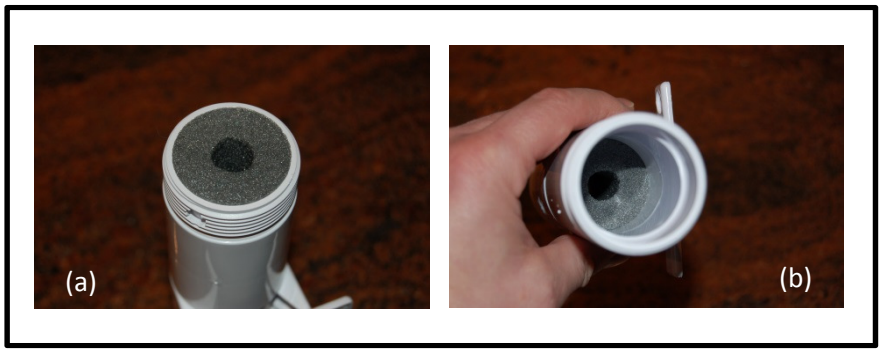


Figure 9

a) *Foam core with central open core to take the FGM-3*
b) *Opposite view with space in housing for voltage regulation electronics*

Wiring up the device

There are two schemes: the first (Type 1) is battery operated whilst the second (Type 2) is mains supplied and voltage regulated. The first is the easiest to set up, but like all battery operated devices it requires the batteries to be replaced periodically, whilst the second can be left to run permanently without further attention to the power source. However, the second does require some basic circuit board assembly skills, which the use of a bat detector was intended to avoid. Nevertheless, the circuit is very simple and it is worth the effort in order to have a permanently running system.

Type 1

The wiring arrangement for this set-up is shown in Figure 10. There are two sets of batteries required; one set (four AA batteries) runs the FGM-3 and the second set is located within the Magenta Bat-5 (four AAA batteries). A minimum 3-core cable is required for +ve, ground and signal. Depending on the degree of electrical noise in the local environment and the distance between the sensor and ultrasonic transducer/detector, it may be necessary to provide local decoupling to ground any unwanted noise on the supply line. This can be achieved using a 56nH induction coil and 33µF capacitor as shown. Leads can be soldered directly onto the pins of the FGM-3. It is advisable to use heat-shrink tubing on all soldered terminals to minimise the risk of shorting. The cable should preferably be one of the internally shielded types with wrapped foil, available from electrical stores.

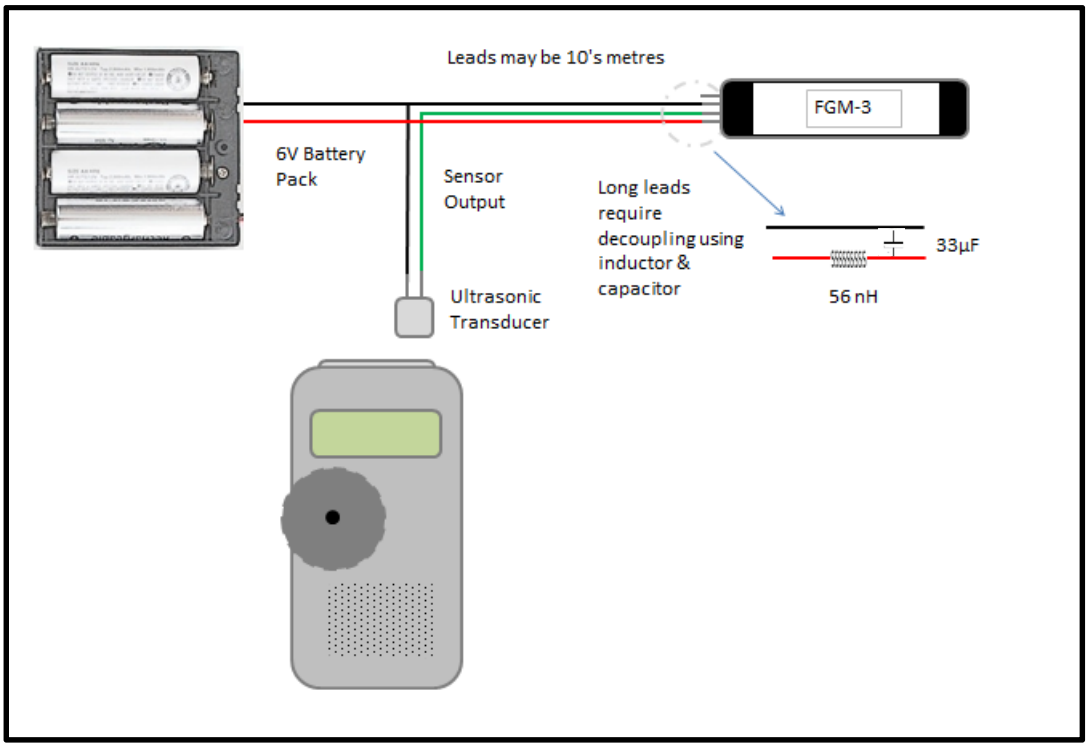


Figure 10

Type 1 version: battery operated sensor and detector

Type 2

The wiring arrangement and circuit for the type 2 set-up with mains supply is shown in Figure 11. A key factor in the successful operation of the FGM-3 sensor is a stable voltage supply, as without this the output signal will carry an imprint of any fluctuation in the supply voltage, thereby degrading the quality of the output from the device. Simple mains to +5V D.C. conversion using a standard power supply is not adequate for this purpose and instead it is necessary to introduce an electrical circuit in the feed. Details can be found on the 'Speake Sensors' web site and information will additionally be provided by Bill Speake with the sensor upon delivery. The components required are reproduced in Figure 11. Basically, the arrangement comprises two voltage regulators of the LM78xx series, available from any electronic components supplier, to step the applied voltage from +12V D.C. (provided by a low power mains transformer, such as might be used to power a laptop) to +9V D.C. and then to +5V D.C. with a high degree of stability. These components should be located close to the sensor. A 10µF capacitor may be added close to the sensor, as well, in order to provide further stability to the feed voltage. The Magenta Bat-5 can also be powered from the same12V D.C. power supply as for the sensor, using a single LM7805 (or equivalent) to provide a +5V supply and avoid using batteries. This is below the regular +6V provided by the four AAA batteries normally used, but is within the working voltage parameter for the device. Pin connections for LM78xx devices can be found on the manufacturer's web site. The feed from the LM7805 is simply soldered to the +ve and ground battery terminals within the battery compartment WITHOUT the batteries being in place. However, care must be taken not to overheat the connectors during soldering as the internal wiring can come unattached. If internal disconnection does occur, then simply open the detector using the

four screws, removing the tuning dial by loosening a small grub screw on the edge and then locate the red and black feed wires from the battery compartment and connect into these instead.

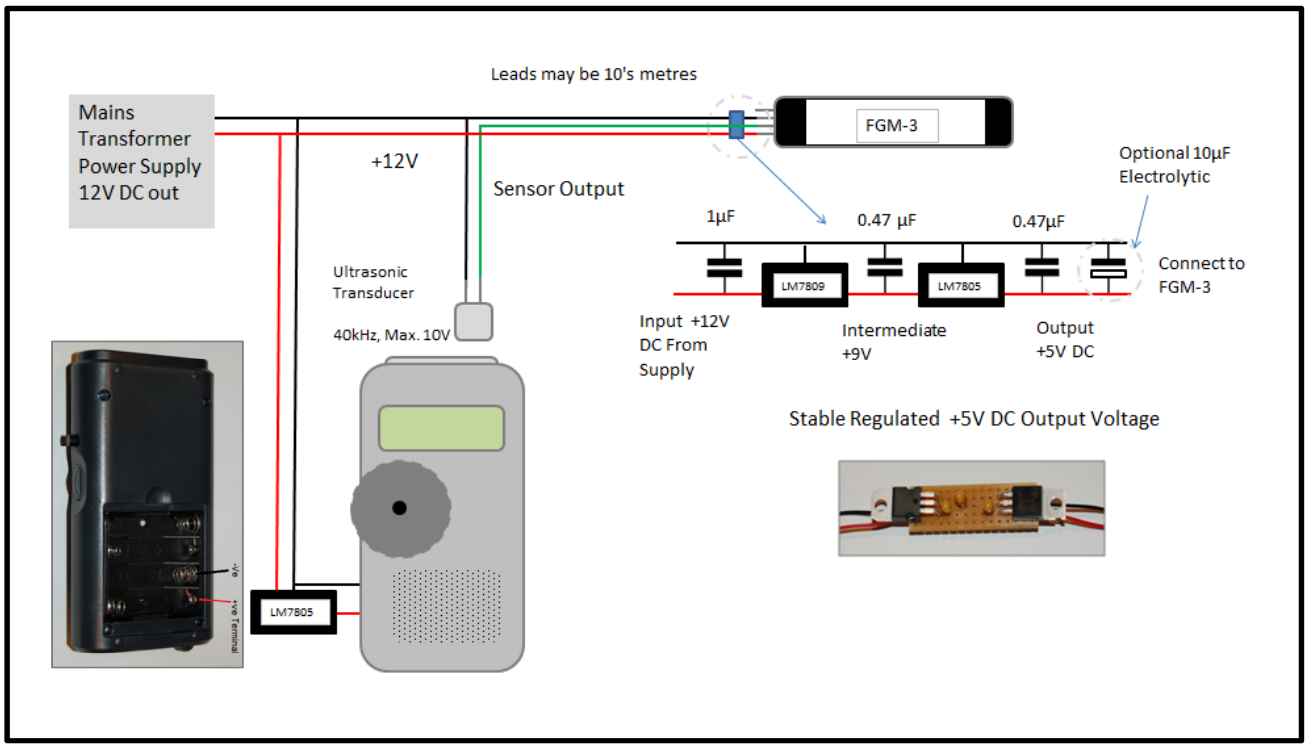
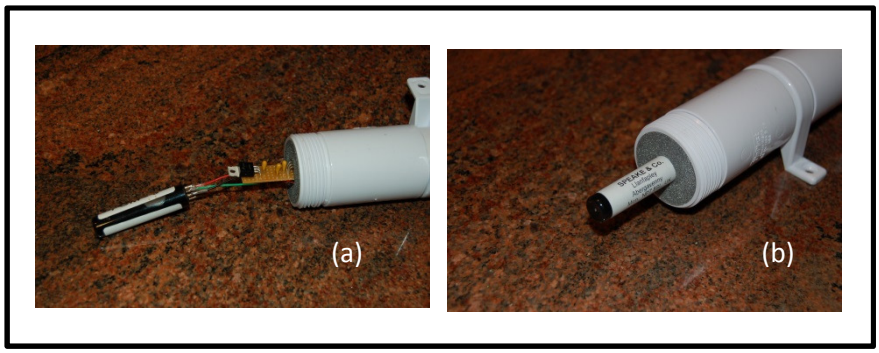


Figure 11

Type 2 version: mains supplied and voltage regulated sensor and detector

Loading the Sensor and Power Electronics in the Housing

With the cable pushed through the gland (loose), and through the housing, the voltage regulator circuit board can be soldered to the FGM-3 sensor and the cable can be soldered to the board. With the connections secured the board and FGM-3 can be pushed through the bore within the foam core as illustrated in Figures 12a and b. Continue to push the sensor back into the core so that it is flush with the end of the foam.



Figures 12 a & b

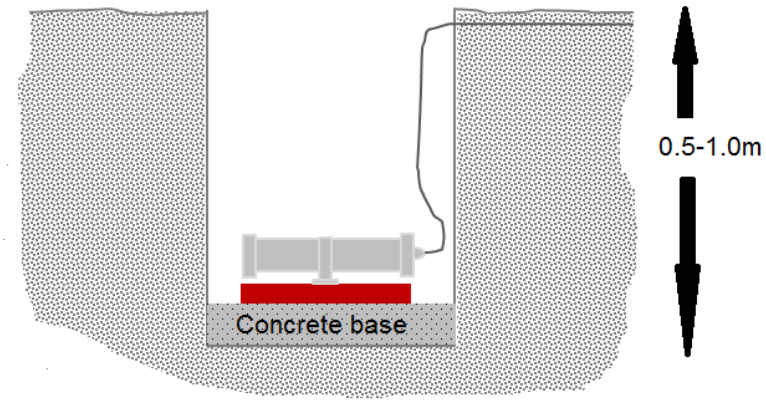
Introducing the voltage regulator and FGM-3 sensor into the housing using a foam core to locate the sensor centrally and hold it firm.

It is worth checking that the device works at this point. This can be done by powering up the sensor (either with batteries, or the 12V D.C. supply if voltage regulators are used) ensuring that the ultrasonic transducer is first connected between the output wire and ground. The Magenta Bat-5 should produce a steady tone when tuned close to the output frequency of the sensor and the audible frequency will decrease to zero and then increase as it is tuned 'through' the sensor's output frequency. The frequency will also change when the FGM-3 is moved around within Earth's magnetic field.

Preparing the ground

To minimise temperature fluctuations it is desirable that the sensor housing is buried as deep underground as practically possible. This will probably mean between 0.5-1.0m deep. Prepare the hole somewhat larger than the housing (about 350mm x 350mm) and add 75mm of concrete as a wet mix so that it self-levels in the bottom of the hole (Figure 13). This will ensure that the sensor will be level when installed. Using the saddle clamp, securely fasten the housing onto a 300mm x 300mm concrete paving slab using screws and plastic plugs. With all joints sealed with solvent, excluding the screwed end fittings, the housing should be watertight, but as a 'belt and braces' approach additional external sealant in the form of water resistant compound (such as gutter sealant) can be applied to each of the joints and around the gland.

Gently place the sensor housing on its paving slab base into the hole and onto the cured concrete at the bottom and orientate the housing in an East-West direction using a compass as a guide. True alignment can be achieved by rotating the housing 180˚ at which point the output frequency should be the same as it was in the previous orientation. If not, keep rotating back and forth with slight adjustments until both outputs match. This can be tricky to set up, but it is well worth the effort.



Figures 13

Housing connected to a paving slab seated on a flat bed of cured concrete to ensure that the housing is level. Correct East-West orientation is critical for effective operation of the device

Before refilling the hole it is prudent to check again that everything functions as required by connecting the power supply and monitoring the output using the Magenta Bat-5. It should be possible to tune the detector to produce a whistling tone. Once it has been established that the sensor is functioning correctly, the hole may be refilled, ensuring that the housing does not move during the refilling process.

Output Frequency

The frequency of the output will depend on the supply voltage, the temperature of the sensor, the tuned frequency of the Magenta Bat-5 and the orientation of the FGM-3 sensor. For a comprehensive summary of the performance of the FGM-3 sensor refer to https://www.cv.nrao.edu/~demerson/cs/magnet.htm and in relation to temperature https://www.cv.nrao.edu/~demerson/cs/magtherm.htm

Voltage

The frequency/voltage coefficient of the FGM-3 sensor is about 3.5% per volt at the nominal 5 volt supply level according to Speake Sensors. With the type 1 version, the output will drift, therefore, as the batteries run out of power and the voltage drops. However, useful results can still be obtained when recording over relatively short periods of time (couple of days) to capture specific events such as CMEs, the approach of which can be monitored by following space weather prediction websites such as Spaceweather.com to give the observer time to set up and monitor the magnetic interaction. For longer-term monitoring it is better to use the type 2 version with voltage regulation.

Temperature

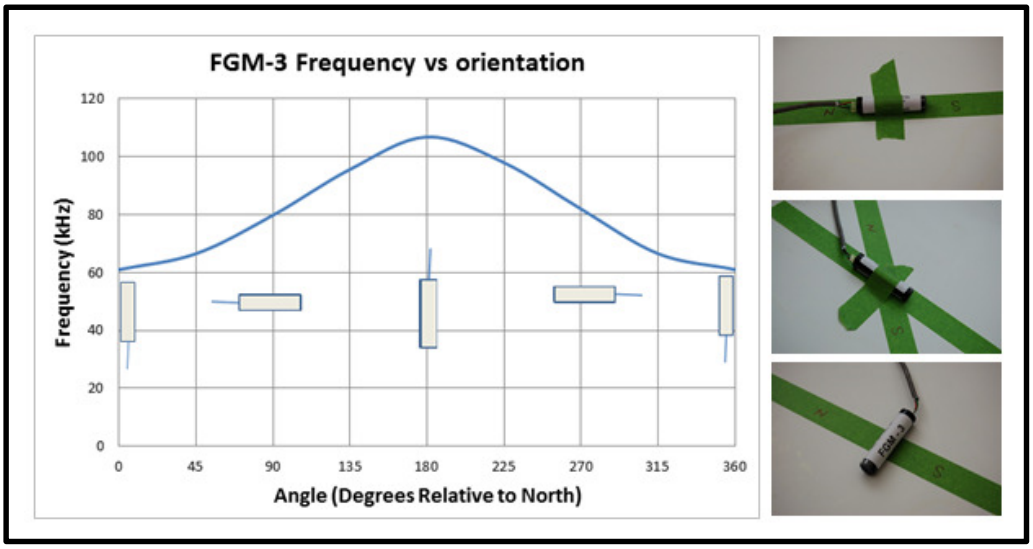
The output frequency will change depending on the temperature of the sensor. When the sensor is first installed it will not be at equilibrium temperature of its new surroundings, of course, so it will take a little time to equilibrate. Also, when the sensor is operating, the small amount of current running through the sensor (about 12mA) will produce a small amount of heat (about 60mW) which will also affect the output frequency. Again, it will be necessary to allow the sensor to equilibrate with its environment. The whole system may take a day or two to settle down. It should be noted that the Magenta Bat-5 detector also is temperature sensitive and the output frequency will change depending on the ambient conditions within which this is operating. This should also be housed somewhere where the temperature fluctuations are minimised. I house my Magenta Bat-5 in a box indoors and run the wire from it, to the buried sensor, through a hole in the wall.

Tuning the Magenta Bat-5 Detector

The detector can be tuned very easily using the dial. As the dial is rotated the audio output frequency will be heard to decrease, pass through a minimum and then increase again as it passes through the point at which it exactly matches the output frequency from the sensor. This is the 'null' frequency. This means that there are two possible positions on the dial at which the output audio frequency is within the desirable 3-4kHz range. The first being 3-4kHz above the null frequency and the second being 3-4kHz below the null frequency. The correct tuned frequency will depend on the orientation of the sensor in relation to the East-West direction.

Orientation

Figure 14 illustrates the output frequency from the FGM-3 in kHz as a function of orientation (the actual frequency will depend on the temperature and voltage as described above). This chart was obtained by experimentation using 6V batteries to drive the sensor, setting the sensor at different angles relative to north and tuning the detector to find the null point. As illustrated, the maximum frequency occurred with the sensor pointing south and minimum occurred with the sensor pointing north. Here the connection tabs to the sensor were selected to represent the 'tail' and the opposite end the 'head' of the sensor.



Figures 14

Sensor output frequency as a function of orientation relative to magnetic north

As can be seen, the output frequency in the East-West direction is the same (give or take with some experimental error) as the frequency in the West-East direction. However, the response to a fluctuating magnetic field will be different in these two cases and in practice one will be the mirror image of the other, rising in frequency whilst the other is falling under the same applied field. This means that the sensor in the ground will respond differently to the field fluctuations if oriented in one, or other direction. In other words, for a sensor that has its head pointing West, an increase in the strength of the magnetic field from the East (for example, as a result of a passing CME) may produce an increase in the detected output frequency, but for a sensor with its head pointing East, the same change in applied field may produce a decrease in the output frequency. Why is this important? It means that the output recorded on the data capture software (see later) could be the inverse of what is presented by professional networks, such as INTERMAGNET when the charts are compared, with upward trending data showing as downward trending data and vice versa. This problem easily can be overcome by using the null frequency and tuning 3-4kHz above this null, OR 3-4kHz below the null (depending on the orientation of the sensor East-West, or West-East), which will reverse the response of the sensor and bring it in line with published professional results. This means that the polarity of the buried sensor relative to east-west is not so important, as it can be corrected using this method.

Logging the output

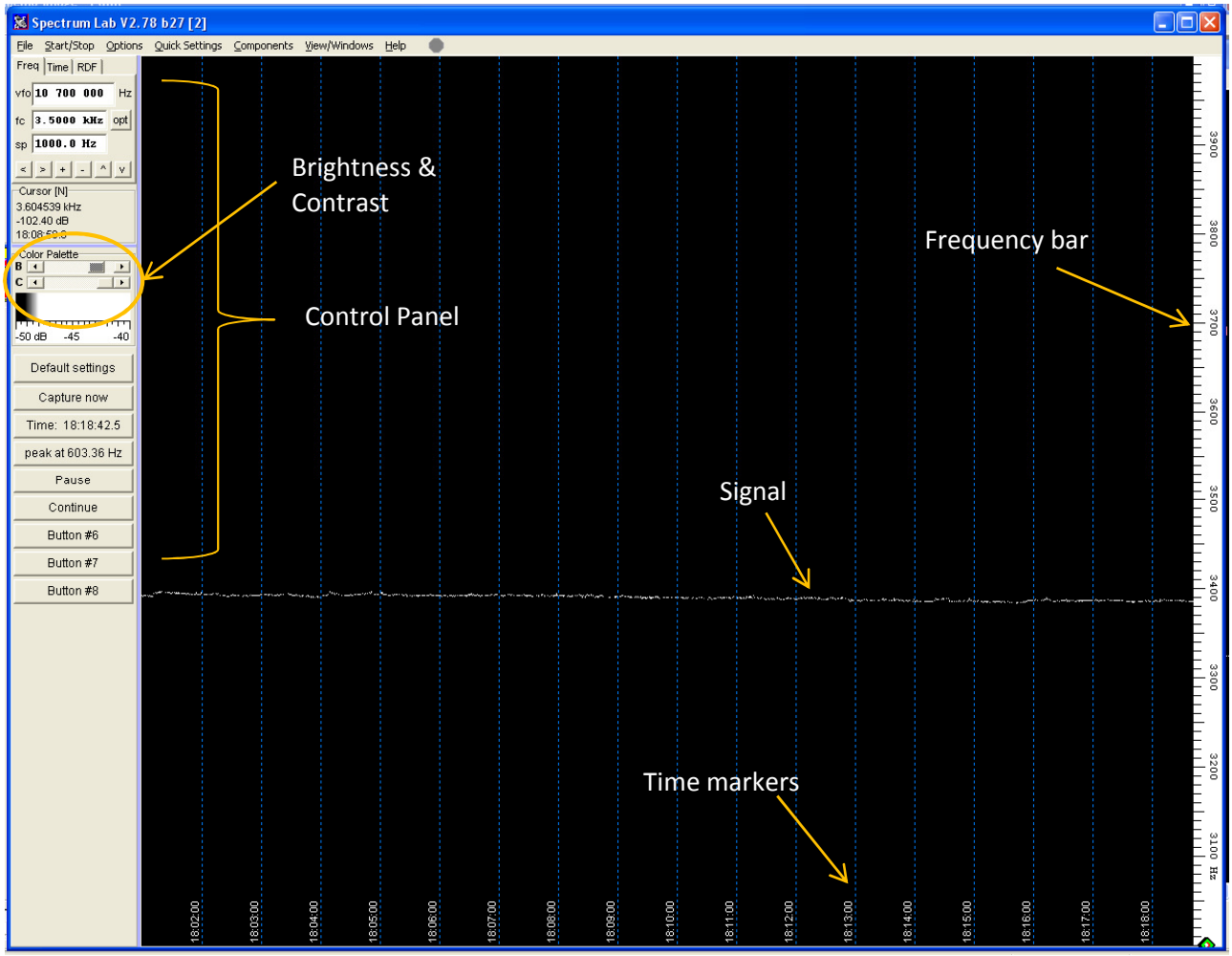
The Magenta Bat-5 detector can be connected to a computer's sound card via the line input socket using a 3.5mm jack to 3.5mm jack lead via the headphone output socket located on the base of the detector. When first connecting up, ensure that the detector volume is set to minimum and steadily increase until the signal registers on screen using the logging software.

A useful piece of software for the purpose is 'Spectrum Lab' http://www.qsl.net/dl4yhf/spectra1.html by Wolfgang "Wolf" Buescher. This is superb software not only because it is technically excellent, but also it is free. Like all unfamiliar software, it takes a little time to get used to the layout and features, but it is well worth the effort. The application can be configured to plot the audio frequency output from the detector as a function of time and sampling can be defined from fractions of a second to minutes or hours. A convenient period is 150 seconds (2.5 minutes) which gives sufficient resolution without generating too much data (576 data points over a 24hr period). However, data can also be captured very rapidly, if required, by selecting the appropriate sampling period in the configuration menu. The shortest period for practical purposes may be once per second to capture magnetic fluctuations in high resolution, providing 86400 data points over 24hrs.

The output from the detector can be captured as an image of the chart on the screen, which can be automatically stored as a JPEG file by the software at any period that you select (such as once per day). In addition, the software can be configured such that it stores every data point as a line of text in a memo-text file along with the date and time of capture. This is very convenient for later analysis, as the text can be copied and pasted into Excel, scaled and plotted as a chart.

Main screen

The main screen is shown in Figure 15. This has been configured to display frequency on the vertical axis and time along the horizontal axis, with new data joining the screen from the right (so the chart indexes left as each new data point is added). Initially, when first setting up the chart, it might show a whole series of lines, indicating that the frequency from the FGM-3 is not one single frequency, but may instead be composed of a mix of frequencies although there will be one dominant frequency, which is the one of interest. Fortunately, all unwanted clutter can be excluded from the display by adjusting the brightness and contrast bars highlighted on the display. Additionally, and conveniently, Spectrum Lab allows full configuration of background colour, pen colour, text colour, font, size, position and so on, so all of these parameters can be set according to taste to produce a clean image with a single line of data.



Figures 15

Configured Spectrum Lab main screen with frequency on the vertical axis

Logging data to file

In addition to enabling the screen image to be captured automatically, Spectrum Lab can also be configured to automatically log data to a predetermined file continuously at a chosen interval of time. This is achieved by selecting 'File' and the submenu 'Export calculated data (continuously)'. This will open a panel 'Spectrum Lab- File Export Format' as illustrated in Figure 16.

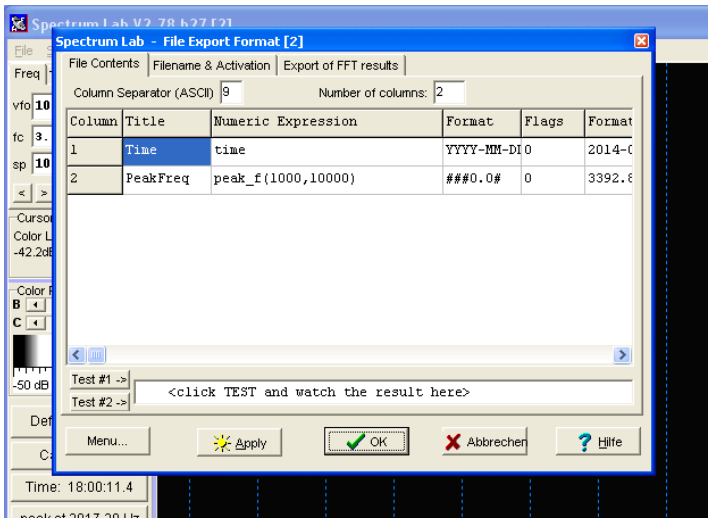


Figure 16

Spectrum Lab- File Export Format menu: File contents tab for defining date/time and peak frequency

Under ‘File Contents’ the information to be saved can be defined (date, time and frequency) and under the ‘Filename and Activation’ tab the file name, location of the file and write interval can be defined, as shown in Figure 17.

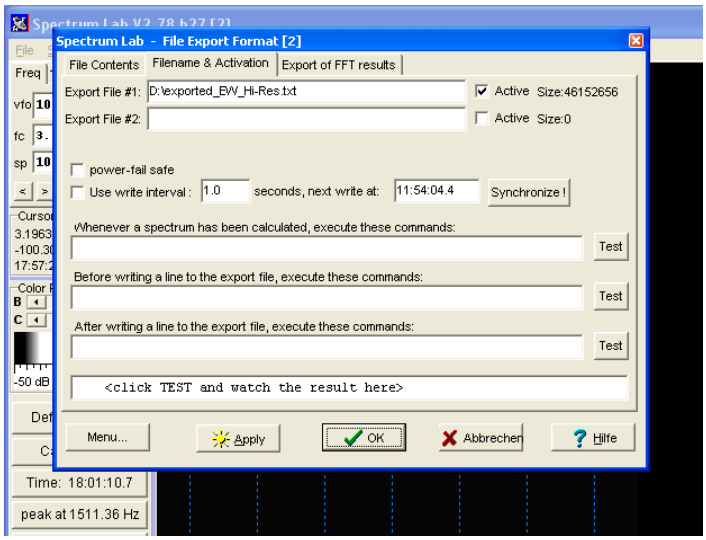


Figure 17

Spectrum Lab- File Export Format menu: Filename and activation to define filename, location and logging frequency

It is important to define the frequency band width in the file contents definition in order to ensure that only the frequency range of interest is logged. The defined contents are stored as a Comma Separated Values (CSV) notepad text file (Figure 18), which is added to with new data at the selected update period. Conveniently, the contents of this file (such as the data for a specific period in time) can be directly copied and pasted into an Excel spread sheet.

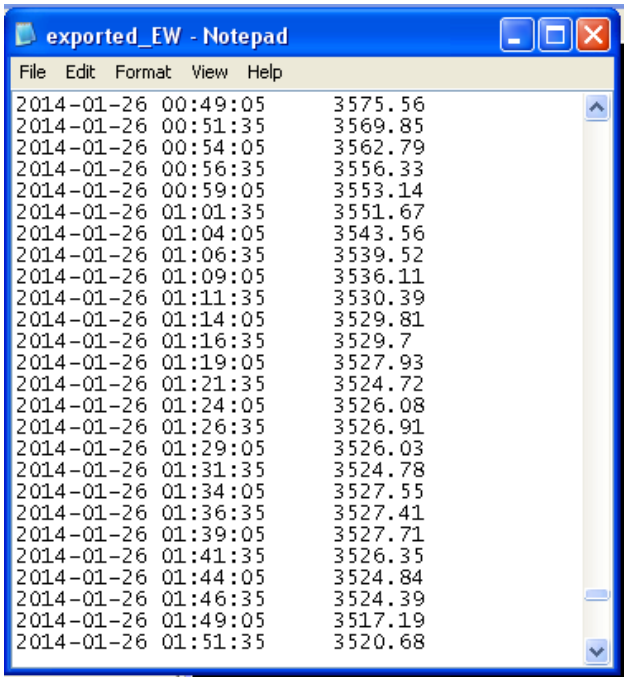


Figure 18

Partial dataset in CSV format saved as text file in Notepad

Analysis

It is convenient to transfer the data from Spectrum Lab to Excel. This is because of the flexibility in data presentation that Excel brings. It also means that data can be manipulated in multiple ways to zoom in on points of interest, run calculations, or compare data from different periods, add notes, or incorporate images as a means of illustration and so on. It is also a good way to convert the frequency output from the log to something close to nano-Tesla (nT). I say close to nT because at no point has the sensor been calibrated in this project, nor at this stage has there been any attempt to correct for temperature variation, or any frequency drift of the detector, or any other factors that might affect the accuracy of the output (such as passing traffic in the street, parked cars which come and go and so on). Remember, this is for the hobbyist and we are not intending to generate truly accurate scientific data.

Figure 19 shows a few lines of the worksheet that I use. The defined contents of the CSV file are copied from memo and pasted directly into the first column. Column B is the measured frequency value which is automatically extracted from this CSV file. Column C (frequency delta) is the difference between the measured frequency and the 'offset frequency' which itself is the difference between the null frequency (the frequency of the output signal from the sensor) and the frequency setting on the Magenta Bat-5 at the time the data are recorded. The 'total frequency' in column D is the null frequency less the frequency delta (column C). The time period (E) is simply the reciprocal of D with the necessary conversion factor to convert to µs. Finally, this allows the calculation of the strength of the magnetic field vector in nT using the relationship shown in Figure 4.

A	B	C	D	E	F	G	H
			East-West Data				
	Offset Frequency	**3.520** kHz		Null Frequency	69.970 kHz		
Start Date				Set Frequency	66.450 kHz		
				Null time period	14.292 µS		
Time							
	Measured Freq	Frequency Delta	Total Frequency	Time Period µS	µTeslar	Time (hhmmss)	(nT)
26/01/2014 00:01	3570.11	50.110	69919.890	14.3021	0.0854	00:01:35	18.97
26/01/2014 00:04	3570.11	50.110	69919.890	14.3021	0.0854	00:04:05	18.97
26/01/2014 00:06	3571.82	51.820	69918.180	14.3024	0.0883	00:06:35	19.62
26/01/2014 00:09	3575.78	55.780	69914.220	14.3032	0.0950	00:09:05	21.12
26/01/2014 00:11	3575.8	55.800	69914.200	14.3032	0.0951	00:11:35	21.12
26/01/2014 00:14	3581.95	61.950	69908.050	14.3045	0.1055	00:14:05	23.45
26/01/2014 00:16	3583.93	63.930	69906.070	14.3049	0.1089	00:16:35	24.20
26/01/2014 00:19	3586.42	66.420	69903.580	14.3054	0.1132	00:19:05	25.15
26/01/2014 00:21	3588.25	68.250	69901.750	14.3058	0.1163	00:21:35	25.84
26/01/2014 00:24	3587.41	67.410	69902.590	14.3056	0.1149	00:24:05	25.52
26/01/2014 00:26	3588.45	68.450	69901.550	14.3058	0.1166	00:26:35	25.92
26/01/2014 00:29	3585.05	65.050	69904.950	14.3051	0.1108	00:29:05	24.63
26/01/2014 00:31	3582.91	62.910	69907.090	14.3047	0.1072	00:31:35	23.82

Figures 19

Part of Excel spreadsheet used to convert measured output frequency to nT. There are 576 lines of data per 24hr period, captured at 2.5 minute intervals.

When correctly set up the instrument is more than capable of detecting changes in the magnetic environment as a result of geomagnetic storms and even in very quiet periods when geomagnetic activity is very low, the correlation between this instrument and professional instruments is, pleasingly, very good. An example of the degree of correlation is illustrated below in Figures 20a and

b using data collected on February 8th/9th 2014 during a weak CME impact event (comparative data taken from the INTERMAGNET website- Chambon La Foret data).

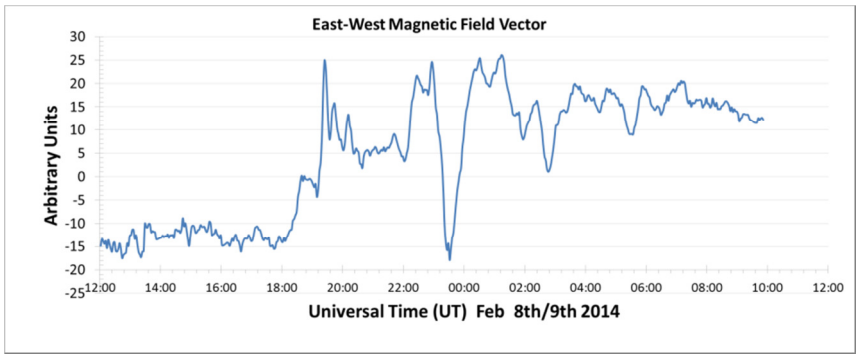


Figure 20a

Project magnetometer output

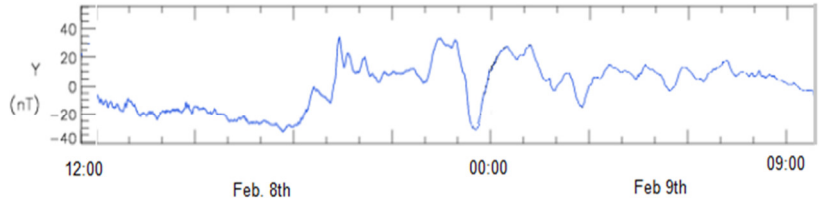


Figure 20b

INTERMAGNET data

The convention is that increasingly positive values equate to an increased deflection towards the east and negative values towards the west.

Helpful links:

http://www.geomag.bgs.ac.uk/education/earthmag.html

http://www.intermagnet.org/

http://en.wikipedia.org/wiki/Geomagnetic_storm

http://helios.gsfc.nasa.gov/magnet.html

Video:

http://www.youtube.com/watch?v=JNpPdOHfeLc

This is a video that I made with a friend in Tromsø using geomagnetic data recorded with a magnetometer such as this to create 'sounds of the solar wind' using music production software.

Appendix

Since my original tutorial on how to build a magnetometer, I've made some improvements, particularly in relation to the housing for the bat detector, which has shown undesirable temperature sensitivity leading to discrepancies between datasets. In order to stabilise the temperature environment, the detector now sits within a vacuum flask which has been fitted with sealable glands through which the various leads pass (digital thermometer (white lead), power supply, sensor lead and signal output lead) as illustrated in Figures 21&22. I've also directly bonded the ultrasonic emitter from the FGM-3 sensor to the input microphone of the bat detector as this gives more reliable coupling.

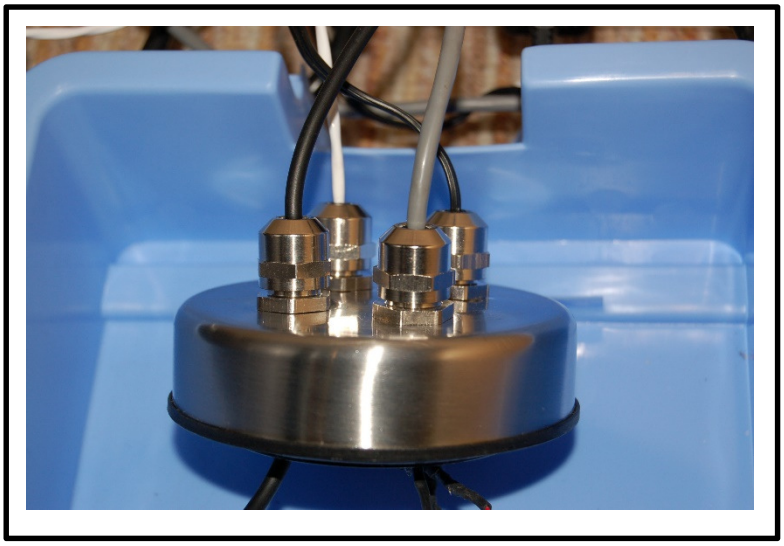


Figure 21

Cable glands fixed through the lid of a vacuum flask

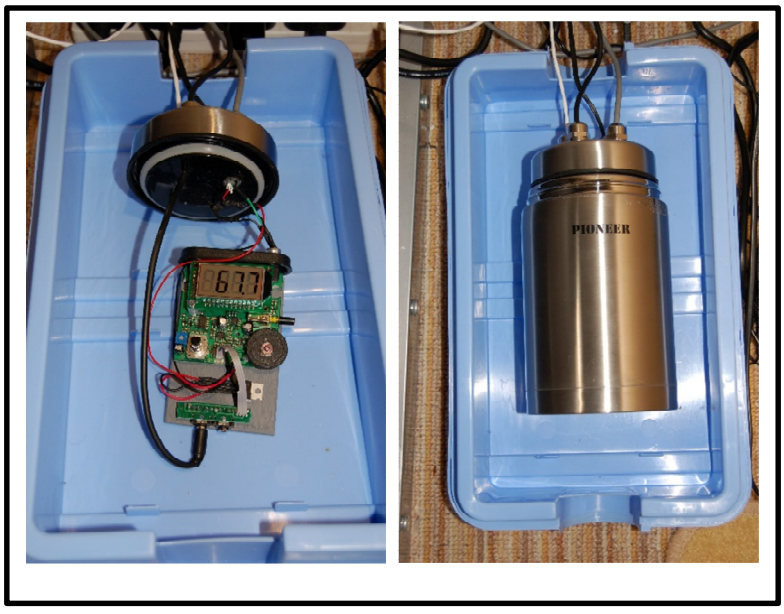


Figure 22

Internals of Magenta 5 bat detector mounted on wooden board along with voltage regulator and sealed within vacuum flask

The flask itself now sits within an inverted cool-box (inverted to allow easy access for the leads) and the cool-box is fitted with a digital thermostatically controlled internal heater. The heater I use is a Habistat 11"x 11" (12W) heater mat intended for use with a Vivarium. This is fastened to a sheet of

glass using tape to hold it flat and in position (Figure 23a). Finally, with the body of the cool box in position the internal environment is controlled using a Habistat dimming thermostat http://www.eurorep.co.uk/heating/digital-thermostats/habistat-digital-dimming-thermostat-dn-timer . Temperature variation within the vacuum flask can be remarkably good at +/- 0.2°C, although this will depend on the temperature of the environment around the outside of the cool box and the chosen temperature differential. Some experimentation will be required to achieve optimal settings for any particular arrangement.



Figure 23

a) 12W Habistat heater mat on glass.
b) Completed assembly- cool box with digital thermostat.

Disclaimer

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