Magnetometer Project

Stuart Green

July 2012

This note describes my home-made magnetometer which I use to measure deviations in Earth’s magnetic field caused mainly by the Sun during solar storms. During such events, charged particles are ejected from the Sun at high velocity which, when they arrive at our planet, buffet and distort our protective magnetic shield (the magnetosphere). We can detect this buffeting on the ground using sensitive instruments called magnetometers. Lucky observers in the far North and South may also be able to see the effects as glowing aurora.

My instrument is easy to assemble, very sensitive and apparently accurate in that it replicates even the small deviations displayed in published professional magnetometer reports such as those issued through SAMNET (later). The instrument comprises a FGM-3 flux-gate magnetic sensor from Speake and Co, Monmouthshire [http://www.speakesensors.com/PDF/detail.pdf](http://www.speakesensors.com/PDF/detail.pdf), a piezo-electric transducer (Maplin [http://www.maplin.co.uk/piezo-transducers-3202](http://www.maplin.co.uk/piezo-transducers-3202)) and ……wait for it….a ‘Bat detector’. Yep, but ignore the fact that it is a bat detector and think of it as an ultrasonic to audio frequency converter, which, of course is exactly what it is. In our case, however, instead of listening to bats, we’re using it to listen to the ultrasonic frequencies generated by the FGM-3 and projected by the attached piezo-electric transducer. I use a crystal controlled heterodyne detector from Magenta (Magenta bat-5) [http://www.nhbs.com/magenta_bat_5_tefno_156155.html](http://www.nhbs.com/magenta_bat_5_tefno_156155.html) as this gives precise frequency control and excellent stability which is what we need here. I’ve never seen or heard of anyone using an arrangement such as this, so I think it might be unique and it certainly works, although I’m sure that there are other, more elegant ways, of doing much the same thing. The reason I chose a bat detector was because I believe that it gives excellent audio resolution, which was a big issue with an earlier version that I tried building from scratch using a basic digital heterodyne made from a flip-flop chip. The scratch-built device had what I call ‘flat-spots’ in which the signal would hold steady for a period before jumping to a new state. This was most frustrating and not very satisfactory. The other advantage of using a bat detector is that someone else has done all the hard work designing and building the electronic circuitry, so final assembly is very straightforward. The results are excellent and considering that this costs significantly less than a commercial magnetometer of similar capability, I think it is a great way to utilise pre-existing materials/circuits in a unique format for a new purpose.

**Principles of operation**

Basically the FGM-3 generates a train of +5V pulses at frequencies well above the limits of human hearing, which is why we need an ultrasonic to audio converter. The specific frequency varies according to the strength and direction of the local magnetic field around the FGM-3. Speake and Co provide lots of good data on this, but basically, as the field increases, the frequency of the pulse train increases and so it is possible to ‘listen’ to the changing local magnetic field by listening to the output of the bat detector when tuned approximately to the frequency of the driven piezo-electric transducer connected to the output of the FGM-3. What you actually hear is the frequency
difference between the tuned frequency of the detector and the output of the FGM-3. The heterodyne circuit in the bat detector takes care of that.

**Configuration**

The FGM-3 requires a very steady +5V supply and it must be protected from temperature changes as both voltage and temperature influence the output frequency, which can lead to erroneous measurements of magnetic field. As prescribed by the supplier, I use a voltage regulator such as an L78S05 [http://docs-europe.electrocomponents.com/webdocs/0025/0900766b80025a7a.pdf](http://docs-europe.electrocomponents.com/webdocs/0025/0900766b80025a7a.pdf) which I feed with a DC 9V power supply. The +5V output is very steady and suitable for this application. A schematic of the arrangement that I use is shown below.

To protect the device from changes in temperature and to isolate it from extraneous local magnetic field variations, not related to what we are trying to record, I built a brick ‘box’ in my garden in which the sensor is housed. Ideally the sensor should be buried deep underground as there the temperature may be much more constant through the year, but in my case this was difficult, so the next best thing was to build a container using bricks and filled with foam (expanding type) to mitigate the changes in temperature on a daily basis. Additionally I’ve housed the FGM-3 in a vacuum flask, in foam, in the brick chamber, so I really think that daily temperature fluctuations can be largely ignored. I also house the bat detector and piezo-electric transducer within the brick-built chamber, keeping everything together in a plastic box inside. You can do the same, or have these items located somewhere else, as it is really only the FGM-3 that needs protection from temperature changes. The reason I do this is so that there is also some acoustic isolation and the detector only detects the output from the transducer. Actually, I have dismantled the bat detector and removed the guts of it so that I could re-house this in a small plastic container, re-wire the power feed from battery to +5V from the power feed and directly connect the output from the speaker (which I have removed) to circumvent the small jack socket output which I found to be unreliable and electrically noisy. It is IMPORTANT to orient the FGM-3 in an East-West direction and this should be true East, not magnetic East. The difference between the two can be significant depending upon your location. A handy tool for making corrections between true East and magnetic East can be found here [http://magnetic-declination.com/](http://magnetic-declination.com/)
From the brick housing in my garden I run a four-core shielded cable to my home and power supply, feeding the voltage regulator (L78S05) with +9V DC. The regulator is located close to the FGM-3 to keep this voltage as stable as possible. I also feed the bat detector using this same +5V DC voltage supply.

**Capturing the output**

It is interesting to listen by ear to the changes in the tones from the output of the detector produced by changing the magnetic field around the sensor (using ferrous objects or magnets), but our objective here is to monitor the changes in Earth’s magnetic field caused by natural phenomena, such as currents in the ionosphere, ion storms, solar wind, or as a result of the impact of a coronal mass ejection (CME). Such events are relatively slow and much more subtle than those effects caused by objects moving around the detector. To record these natural events requires a computer and some monitoring software which enables the output frequencies to be recorded and logged for later analysis.

I use Spectrum Lab for this purpose [http://www.qsl.net/dl4yhf/spectra1.html](http://www.qsl.net/dl4yhf/spectra1.html) by Wolfgang "Wolf" Buescher. This is superb software for the purpose, 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.

I use an Edirol UA-25 audio interface in my setup [http://www.roland.com/products/en/UA-25/](http://www.roland.com/products/en/UA-25/) and take a mono signal from the bat… ermm.. magnetic field detector and feed this into my computer via one of the two available channels. The software is configured to plot the audio frequency (which, remember, is now a ‘difference’ frequency courtesy of the heterodyne circuitry of the detector) as a function of time. The time period can be anything you choose, but I use 150 seconds (2.5 minutes) which gives sufficient resolution without generating too much data. However, it is possible to achieve sub-second resolution if required.

The output can be captured as a chart on the screen, which can be automatically stored as a JPEG file by the software at any period that you select. Personally, I have it store one image per day as at 2.5 minutes per cycle it means that I can store one complete day’s worth of data on one screen capture.

In addition, I also have the software 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 with suitable annotations and so on.

**Analysis**

Using Excel the lines of text are read as date, time and peak frequency. I use various mathematical functions to scale the data and present it in a form suitable for displaying as a chart, as shown below. Time is recorded as Universal time and the vertical scale is roughly nano-Tesla (nT) which I calculate using a scaling factor derived from the University of Lancaster’s magnetometer operated as part of the SAMNET network [http://spears.lancs.ac.uk/samnet/](http://spears.lancs.ac.uk/samnet/). Ideally I should use a solenoid type coil and known electric current to generate a known magnetic field to calibrate the FGM-3, but I’m
really more interested in looking at the fluctuations in local magnetic field rather than presenting a true measure of the field. I’ll leave it for the professionals to do that.

An example of a JPEG image captured on a daily basis is shown below. There is a diurnal rhythm to the magnetic field which is believed to be caused by currents in the ionosphere from external sources (solar radiation) which change from day to night as our Earth rotates on its axis. The sensor is clearly sensitive enough to detect these daily deviations. More information can be found here http://www.earthsci.unimelb.edu.au/ES304/MODULES/MAG/NOTES/diurnal.html.

As mentioned, each data point can be saved as a line of text in Notepad. An example of a few such data is shown below, where date, time and peak frequency are displayed.
This can then be copied and pasted into Excel to reproduce the chart which can now be scaled accordingly, as shown below.

This also allows other types of analyses to be performed, such as plotting the rate of change, subtracting background or anything else that may be required, such as plotting data over an extended period as I did recently for a CME impact event, shown below.
**Future developments**

As well as recording the East-West declination, it is also possible to record North-South variations, or even the vertical component (Z). I’m building a second magnetometer to measure N-S and then I can plot variations in E-W and N-S together. I’m also experimenting with ‘sonification’, turning the measured magnetic variations into more interesting sounds using MIDI files.....more to come on that.

I hope this has been of some interest.

Stu.