Solar Wind Monitor
a school/home geophysics project

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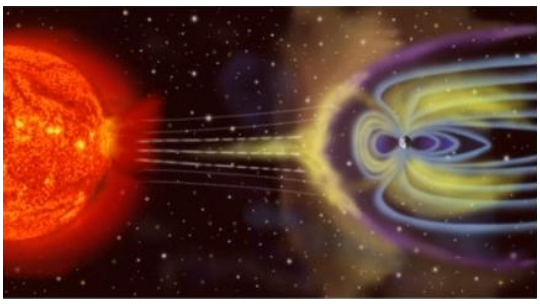
Abstract

Described is an established geophysics project to construct a solar wind monitor based on a nT resolution fluxgate magnetometer. Low-cost and appropriate from school to university level it incorporates elements of astrophysics, geophysics, electronics, programming, computer networking and signal processing. The system monitors the earth's field in real-time uploading data and graphs to a website every few minutes. Modular design encourages construction and testing by teams of students as well as expansion and refinement. The system has been tested running unattended for months at a time. Both the hardware design and software is published open-source - *see [1].*

1 Introduction

The sun emits about 10^9 kg of matter per second in the form of charged particles, mostly protons, electrons and alpha-particles. We are shielded from this radiation by the earth's magnetic field. The flux though is not constant and nor is the magnetic shielding. As this 'solar wind' varies the earth's field flexes. Rapid distortions of the field, on the scale of minutes to a few hours, observed at ground level indicate changes in the solar wind suggesting the likely appearance of aurora.



http://sec.gsfc.nasa.gov/popscise.jpg

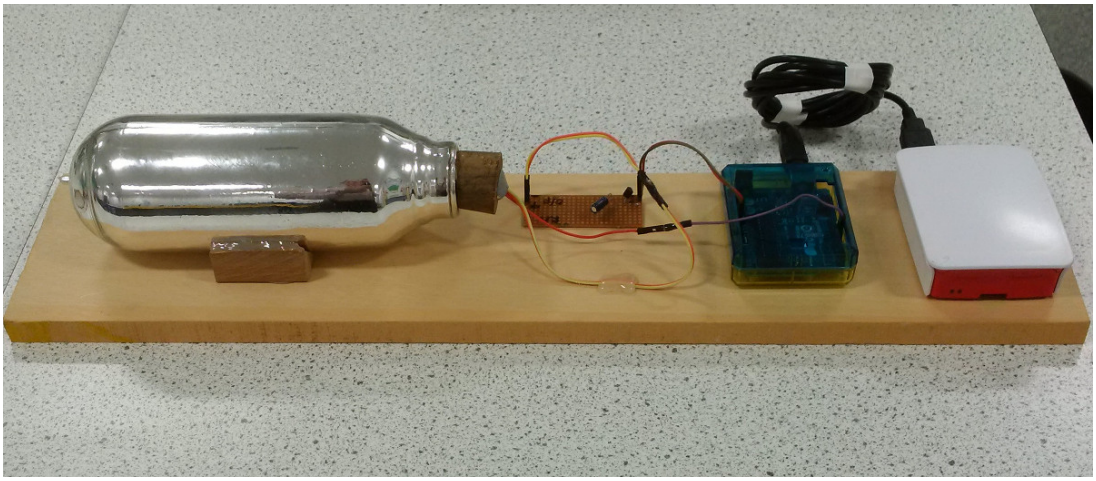
The magentic field at ground level depends upon position on the earth's surface [2]. To give some scale in North England the total field is approx 50,000 nT, the East-West component of which typically varies by about 100nT per day. This variation is partly diurnal with a fundamental period of 24 hours caused by ionisation of the upper atmosphere in sunlight [3, 4]. Overlaying this predictable diurnal cycle are irregular, sometimes dramatic disruptions caused by changes in the solar wind.

Thus counter-intuitively a ground based magnetometer of sufficient resolution indicates sunspots and solar storms.

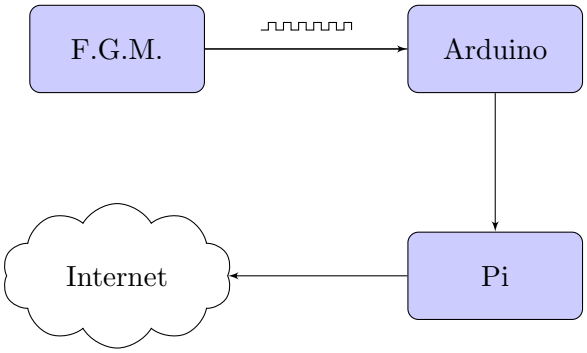
2 Why Geophysics?

In the U.K. few school students consider a career in geology or geophysics despite the excellent career prospects. Research quality projects in geophysics may be built using low-cost sensors and data-logging kit giving students access to real scientific data. Using existing opensource pre-coded analysis software introduces students to technical programming and signal analysis techniques.

3 System Overview



complete FGM rig with thermos housing



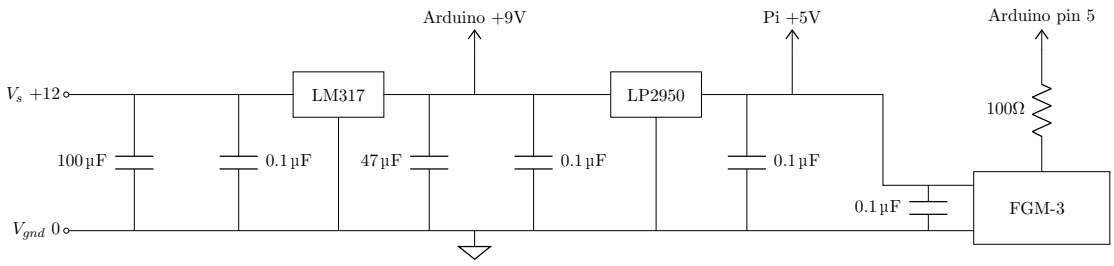
3.1 Fluxgate Magnetometer Sensor

Developed in the 1930s fluxgate magnetometers work by alternately magnetising and demagnetising a core of high magnetitic susceptibility [5]. The presence of an external field produces a phase shift between the magnetising current and that induced in a pick-up coil. The F.G.M. is a vector sensor, detecting the field along its axis rather than the total field. This is useful here as the East-West component of the earth's field is the preferred indicator of aurora. They are widely used on spacecraft and in the geophysics community - in part due to their electronic simplicity and stability.

There are several suppliers of reasonably priced FGMs. I have built a number of systems using those sold for many years by Speake Sensors. Their application in earth field geomagnetism is well documented [6] will the sensors noted for high sensitivity at a low cost of £30-£40. Following the death of Bill Speake production has been continued by FGsensors in Slovenia [7]. Unlike the more expensive Mayer [8] devices which give a voltage output Speake sensors output a TTL square wave pulse train the frequency of which is proportional to the external magnetic field with a resolution of the order of nano-tesla. Such resolution with the Mayer devices would require an additional 16 bit resolution A.D.C.

3.2 Stabilised Power Supply

A simple double-regulated power supply constructed on veroboard is used to provide a stable voltage to the sensor as well as powering the Arduino and Raspberry Pi thereby ensuring a common ground.

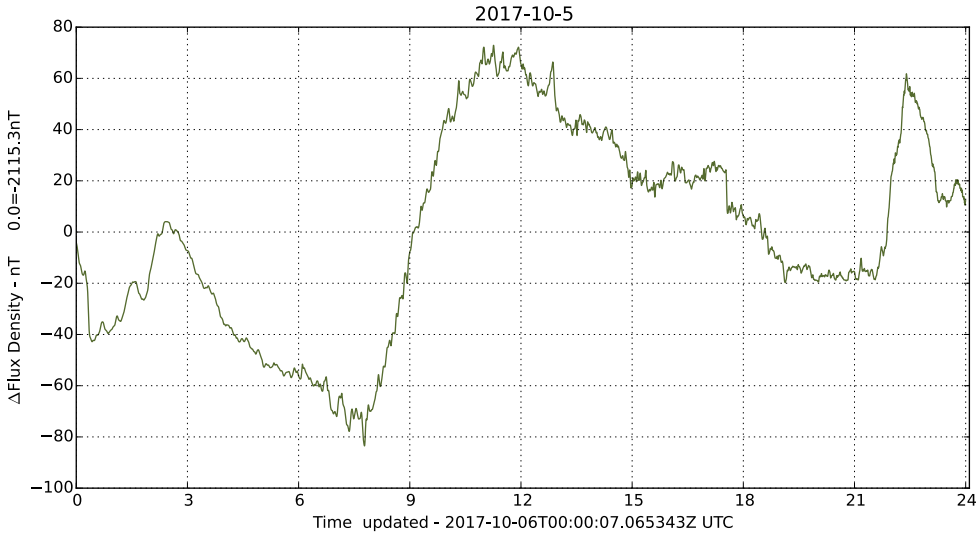


3.3 Frequency Counter

The Speake FGM pulses at approx 20-120 kHz, too high a frequency to be reliably counted by the Pi. Rather an Arduino Uno runs a simple program to count the pulses over an interval of a few seconds - converting this to a frequency presented to the Pi/PC via a USB line.

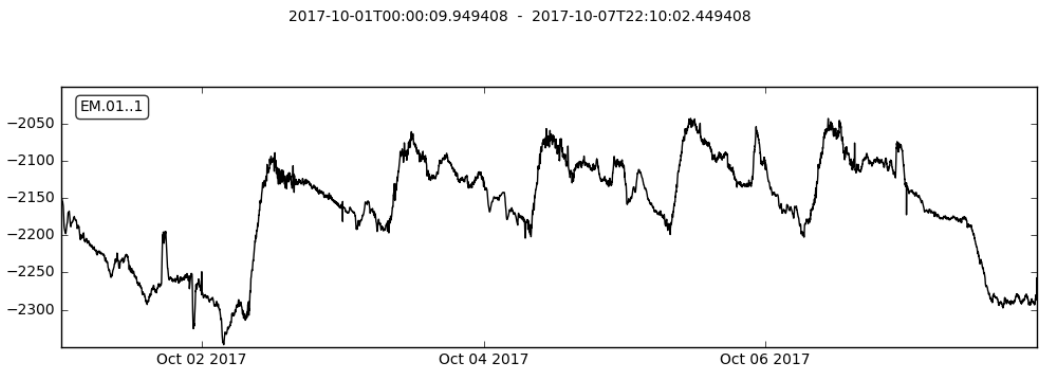
3.4 Logging Software

The python code has been kept simple to allow easy understanding and adaptation by students. It reads the frequency from the Arduino via a USB connection to a Pi, PC or other suitable device. Then converts this to a field in nT, performs simple signal



conditioning and saves the data. Every few minutes a graph of the day's data is produced using the excellent MatPlotLib routines. The PI is connected to a local network via Ethernet (wireless would also be possible though less reliable). Periodically a simple script uploads the data and graphs to a website for viewing and further analysis. The PI used here is cheap, rugged, lacks moving parts and consumes only about 10W.

Data is stored as *.mseed* files, a standard geophysics format. Files may be read using Obs-Py [9], an opensource suite of programs used to plot and analyse seismic data. Obs-py is an excellent introduction to python programming, producing publication quality plots and signal processing techniques such as F.F.T.



5 day plot using Obspy

4 Example - Minor Solar Storm

Part of the joy in building such sensors is the excitement on checking the daily plots. On 26/8/18 I noticed that the daily magnetometer plot looked atypical. During quiessence one expects a a diurnal cycle as shown in fig 4 - caused by ionisation of the upper atmosphere in sunlight. Fig 5 shows 26/8/18 a distinctly atypical plot indicating changes in the solar wind possibly heralding an aurora. For comparison fig 6 is the same day from the British Geological Survey instrument at Eskdalemuir, the yellow plot is for a magnetometer orientated East West as was this instrument. Note variations at 4-7, 16-17 and 21 hours.

This is the excitement that kids studying science need!

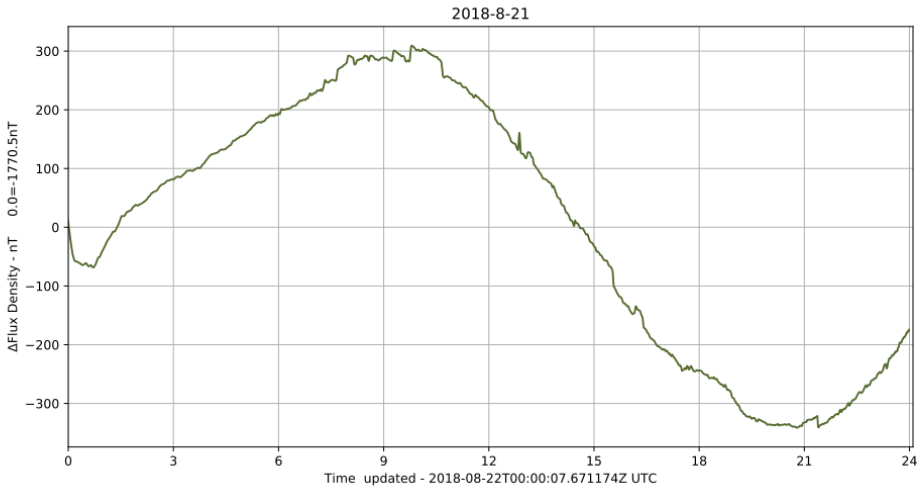


Figure 4: Typical plot during solar quiessence 21/8/18

5 Siting the System

FGM sensors require siting in a thermally stable environment, preferably at least 20m from traffic. Nearby static metal is not a problem though proximity to strong e/m sources such as power limes should be minimised. Schools have storage areas and loft space which may be suitable. Another option is to bury the sensor about 1m deep reducing temperature variation. The system has been successfully tested over 6 months in a buried location with 15m leads to the Arduino. The sensor needs to be orientated magnetic E-W. A waterproof housing may be made simply using glued 1" waste water pipe -fig 7.

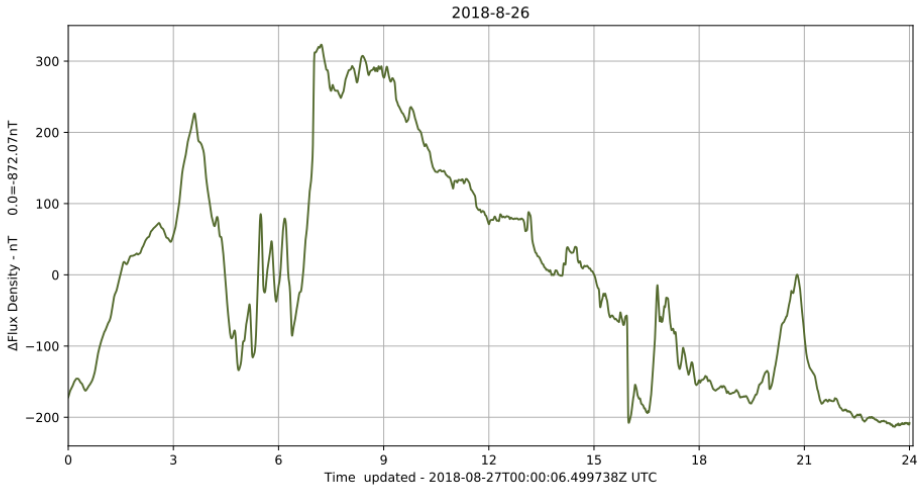


Figure 5: Local plot during minor solar storm 26/8/18

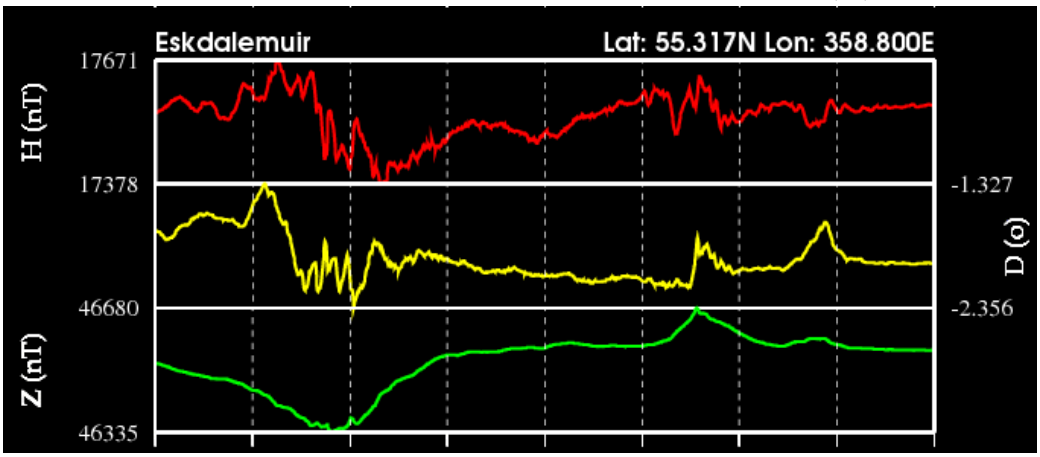


Figure 6: B.G.S. Magnetometer during minor solar storm 26/8/18 (yellow line)

6 Ideas for Student Projects

I suggest a team approach. One team building and testing the power supply, one testing the F.G.M, one configuring and testing the Arduino and another the Pi. Later students could look at building a suitable website and then conducting longer-term data analysis.

7 Further Development

- Replacing the Arduino with a Pi/Beagleboard fitted with a fast digital frequency sampler.

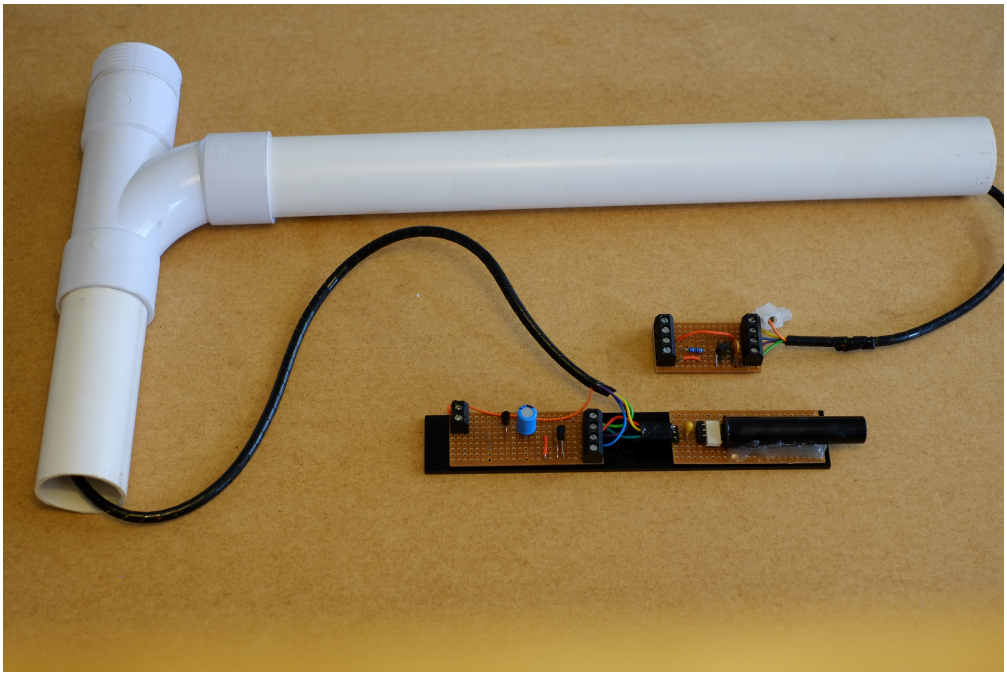


Figure 7: subsurface waterproof housing

- Adding a wireless interface.
- Calibrating the sensor using an external coil.
- Adding a thermistor temperature sensor.
- Adding one or two more sensors to monitor vertical and N-S components of the earths field
- Calculating the K.P. index.
- Having the code email/flag abrupt changes in K.P. index likely to indicate aurora.
- Replacing the Arduino with a PIC or similar.
- Observing trends over weeks or months.

8 In Summary

This project has provoked considerable interest in students with space science, programming and the possibility of spotting aurora. It has been developed over 2 years and works. It has been simplified to minimise cost and allow for easy upgrading and further development. Veroboard and through hole-components allow the hardware to be assembled by primary age students. Whilst aimed at younger students this could form

the basis of an undergraduate proect. It is a device of unusual sensitivity and capable of further refinement, particularly regarding analysis of the data. For less than £100 a school can have an ongoing 'real science' project delivering data 24/7 and displaying data on their website.

9 Author

Ian Robinson has taught physics and computing in Sixth Form Colleges for over 20 years whilst periodically running electronics/coding projects in primary & secondary schools. He recently completed a Ph.D in Computational Physics involving the Monte Carlo simulation of lattice gases. Outside of teaching he is developing a number of low-cost educational projects in geophysics sensing.

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