The UKRAA Magnetometer

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The UK Radio Astronomy Association is a not for profit entity established to encourage amateur interest and participation in radio astronomy. To support this UKRAA manufactures and sells a small range of instruments including a magnetometer.

Our aim in this article is to encourage more people to become involved in observing the Earth's magnetic field and join an established group of observers.

The Earth's Magnetic Field

Planet Earth generates a strong magnetic field in its iron core which surrounds the Earth and interacts with streams of charged particles emitted from the Sun known as the solar wind. The Aurora Borealis around the north polar region is the most visible and best known result of this interaction. The solar wind affects the Earth's magnetic field. These disturbances can be detected all over the Earth's surface and are well within the capabilities of amateur astronomers and scientists to monitor and study. Using a magnetometer the changes in the magnetic field can be recorded showing the magnetic storms which produce aurorae and the longer term variations through the year.

In this article John Cook and Andrew Thomas describe the design and use of the UKRAA Magnetometer.

In the following sections John Cook describes the design and theory of the UKRAA Magnetometer. John is the Director of the British Astronomical Association (BAA) Radio Astronomy Section and collates a monthly report of magnetic and ionospheric observations.

Magnetometer

In 2002, my employer handed me a data sheet for a magnetic sensor, knowing my interest in astronomy and radio astronomy. This was for the Honeywell HMC1022 series of anisotropic magneto-resistive (AMR) dual axis sensors, intended for medical devices, navigation, and oil drilling guidance systems. Reading through the specifications showed that it could make a very sensitive magnetometer for amateur use.

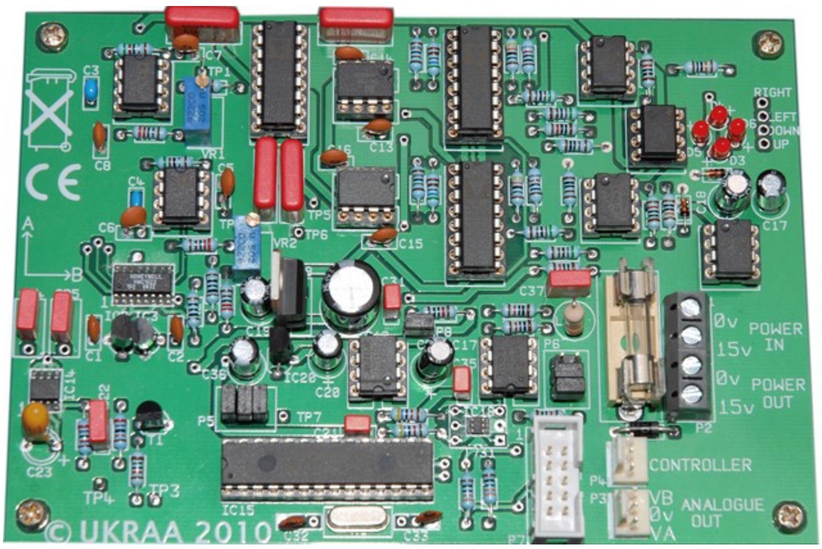

Figure 1 UKRAA Magnetometer

Theory of Operation

The sensing element is in the form of a four arm bridge of Permalloy (nickel-iron) resistors. A magnetic field applied across each element alters the resistance such that the output voltage from the complete bridge varies with that field. On the HMC1022, two such bridges are arranged at right angles so that a dual-axis sensor can be made. Modern integrated circuit technology allows the sensors to be included with the necessary electronic circuits required to make a sensitive and stable magnetometer sensor.

In its basic form, the Permalloy bridge would be very sensitive to temperature changes, and could also be disrupted by large magnetic fields. These effects are inherent in the physics behind the AMR process, and depending on the ultimate use of the device, various methods can be used to control them. This accounts for most of the extra circuitry on the magnetometer PCB.

The fact that large magnetic fields can disrupt the response can be utilised in the design to help overcome its temperature sensitivity. Very large fields will cause the polarity of the resistance change to 'flip' or invert. The HMC1022 includes low value resistive elements laid over the AMR bridge, such that a large current pulse (3 or 4 amps) will generate enough magnetic field to cause a polarity flip, inverting the voltage output measured across the bridge. A second current pulse will then flip it back to its original state. By subtracting the bridge output voltages measured in each phase, internal electronic offsets and temperature induced offsets are cancelled out, giving a much more sensitive and accurate reading of the magnetic field being measured. This process only requires about 1 µs per phase, and by applying a train of current pulses at about 2kHz a near-continuous output voltage can be produced.

Design

In the UKRAA design, a series of instrumentation amplifiers are used to buffer the bridge output voltage and then subtract the alternating voltage samples. The gain of this process can be selected so that the ultimate sensitivity of the magnetometer suits the environment in which it is to be used.

A microcontroller chip is used to create the correct sequence of pulses required for the bridge and subtraction circuits. The remainder of the circuitry stabilises the sensor bridge supply voltage, as well as driving a set of alignment LEDs that can be used to assist in physically orientating the magnetometer to the Earth's magnetic field. This will set the output voltage to a mid-value so that magnetic disturbances in either a positive or negative sense will produce a shift of the output voltage to match.

Initial tests demonstrated the device's sensitivity to be well suited to detecting the Earth's magnetic field. The magnetometer is best used to observe the relative changes over time in the Earth's magnetic field. It is not intended to give a calibrated absolute value of the field in nanotesla (nT).

In the following sections Andrew Thomas gives a first hand account of setting up and using the UKRAA Magnetometer and identifies some of the pitfalls for a novice to avoid. Andrew is a Trustee of UKRAA and newcomer to amateur radio astronomy and geophysics.

Setting the Magnetometer up for use

The magnetometer is a single PCB mounted in an enclosure on an adjustable tilt mechanism. There are two output channels, A for the 'east-west' component and B for the 'north-south' dip component.

Figure 2 UKRAA Magnetometer in custom enclosure

The magnetometer output voltage is 0-5 V with the centre point at 2.5 V. Change of the magnetic field in one direction causes the output to fall towards 0V and change in the other direction causes the output to increase towards 5 V. When the horizontal axis is pointing to magnetic north the output is 2.5 V this changes as the magnetometer is rotated towards the east or west. The vertical axis works in a similar way.

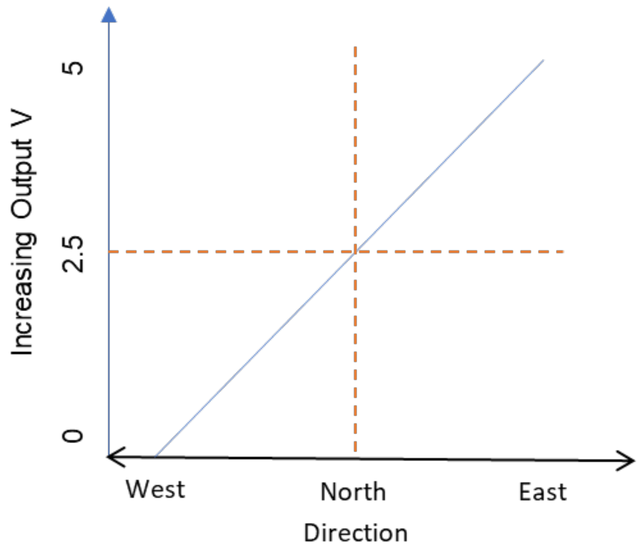

Figure 3 Illustrates the relationship between direction and output voltage for the horizontal axis.

Before any observations can be made the magnetometer needs to be aligned to the local magnetic field. The magnetometer has four LEDs that indicate which direction is mis-aligned. The brighter the LED the greater the misalignment. When correct the four LEDs are all off. Monitoring the output of the magnetometer with a voltmeter or recording device will allow fine tuning of the alignment.

Aligning the instrument was relatively straightforward. I found the instructions in the manual clear and easy to follow. Simply stated, the procedure is to point the enclosure towards north and rotate left and right to align the A axis, and then use the screw to change the tilt to align the B axis until the indicator LEDs are all out. This gives a rough alignment which needs fine tuning to get as close to 2.5 V from each output as possible.

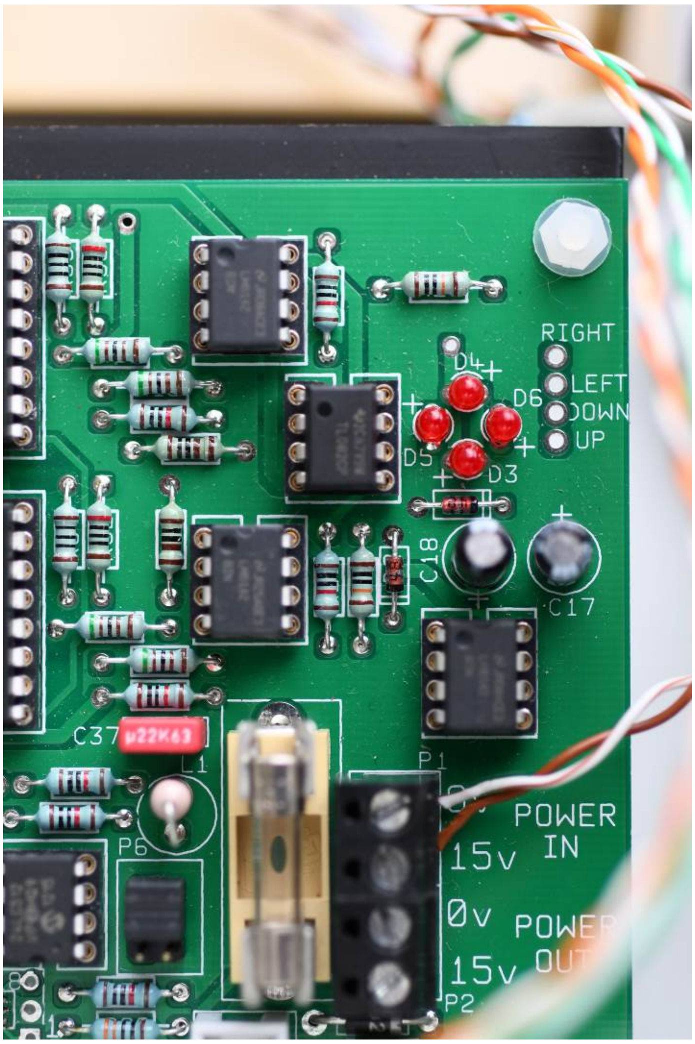

Figure 4 Detail of the board showing the four alignment LEDs

I noticed that movement on one axis would also change the output on the other. This was due to the bench not being level. Rotating the enclosure would slightly change the tilt of the PCB making the final alignment an iterative process. Patiently making adjustments to both axes achieved an output very close to the null point.

Recording the results

I have used two methods to capture the output from the magnetometer. My initial short trial used a LabJack U3-HV data acquisition device (DAQ) connected to a Windows laptop running Radio SkyPipe software (RSP). RSP is a datalogging and display program. It will read data from the LabJack, record it to a data file and display the data on a rolling display reminiscent of a paper chart recorder. RSP is available free for a single channel version and $49.95 for a non-commercial licence.

In the tests reported for this article I replaced the laptop with a RaspberryPi running a development version of a future UKRAA datalogger program. More about this later.

The LabJack, has four 10 V inputs and four 2.4 V inputs all of which can be read by RSP. The magnetometer was connected to 0-10 V inputs.

Practical Experience

As described previously the UKRAA Magnetometer is a sensitive instrument and to make useful measurements it is best used where the local magnetic field is not disturbed by artificial electromagnetic fields, moving ferrous metal objects or moving magnets. I decided to test the magnetometer in my garden cold frame. This has an aluminium frame and is on a wooden base. Mains power is available in the adjacent shed for the magnetometer and things only move or are powered up when I am present.

Figure 5 Magnetometer setup in Cold Frame under a plastic bag rain cover

My first attempt was with the magnetometer on the work bench in the larger shed. This did not work very well there are a lot of metal tools and shelving and any work in the shed disturbed the magnetic field. Using the cold frame was much more successful and made it much easier to align the magnetometer.

Pleased with the set up I left it for an extended run.

A bit of fine tuning was needed during the first couple of days. The magnetometer was moved slightly to provide a better cable entry and a plastic rain cover was added but after this it settled down to provide steady data. This can be seen in Figure 6, which shows a quiet day with a slowly varying magnetic field over a 24 hour period.

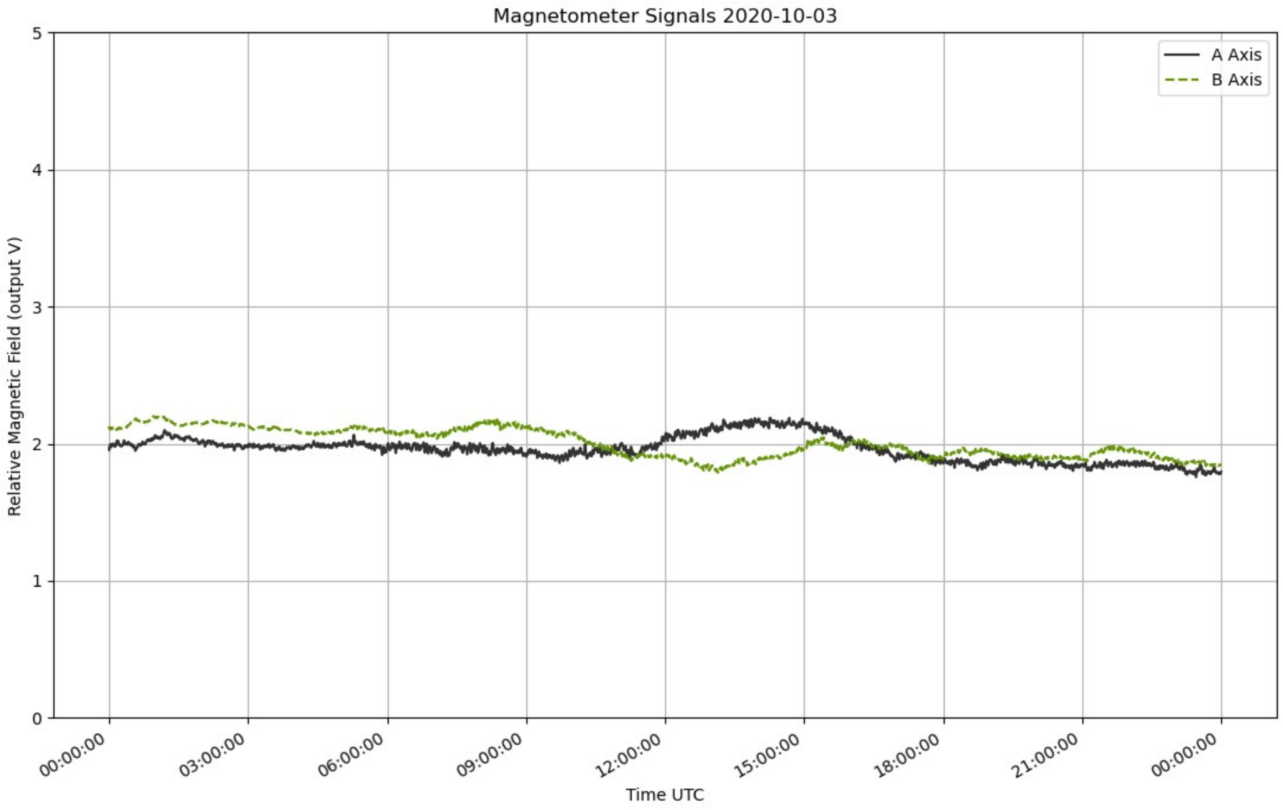

Figure 6 A Quiet Day, Slow variation of the Earth's magnetic field over 24 hours.

It is possible to identify human activity. Figure 7 shows a clear disturbance when I removed the wheelbarrow from the shed and later replaced it. Human disturbances tend to be sharp "instant" changes, often during the day, whilst natural changes occur over slower timescales.

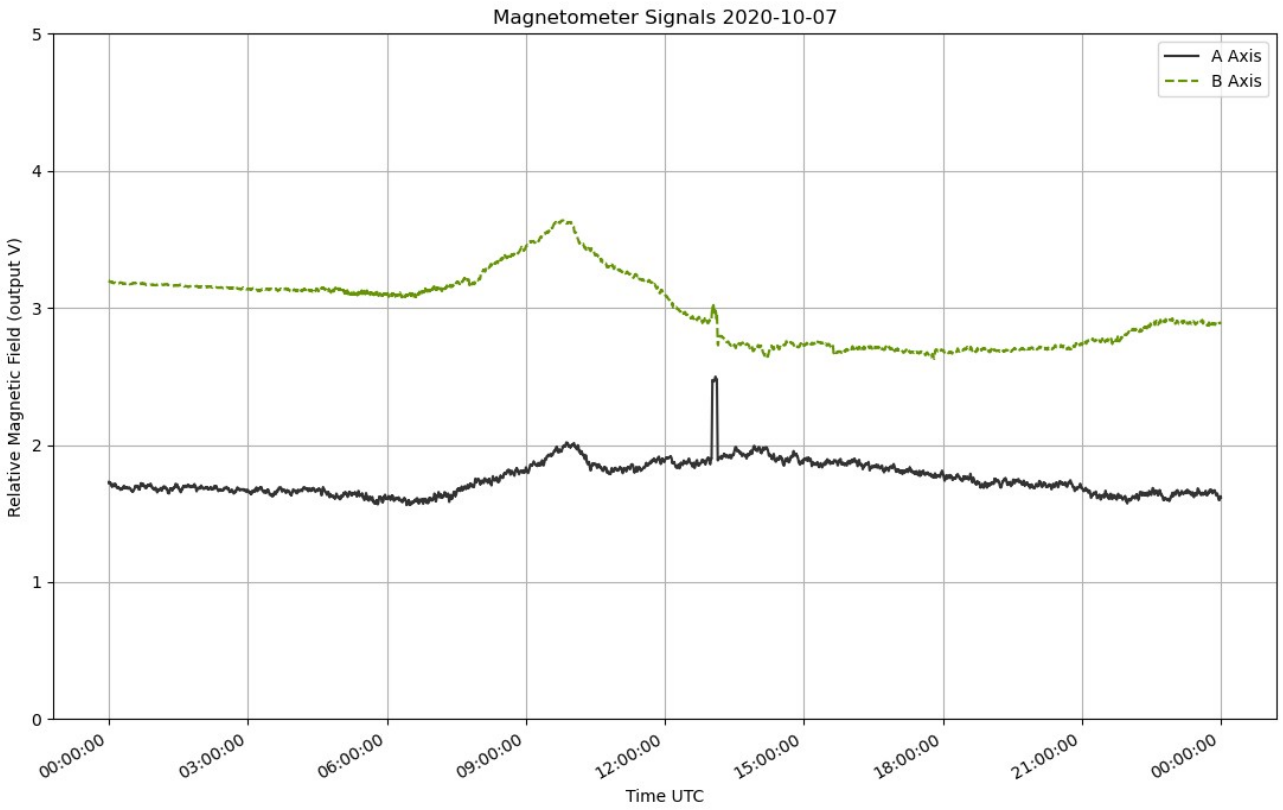

Figure 7 The effect of gardening activities. Note the sudden change in the field around 13:00 UTC.

My installation is far enough from the road not to be disturbed by passing cars. Other observers are not so lucky, Figure 8 shows a record of cars arriving and departing from the road outside their house. Other anecdotal sources of interference include cat collars with magnets to activate the cat flap.

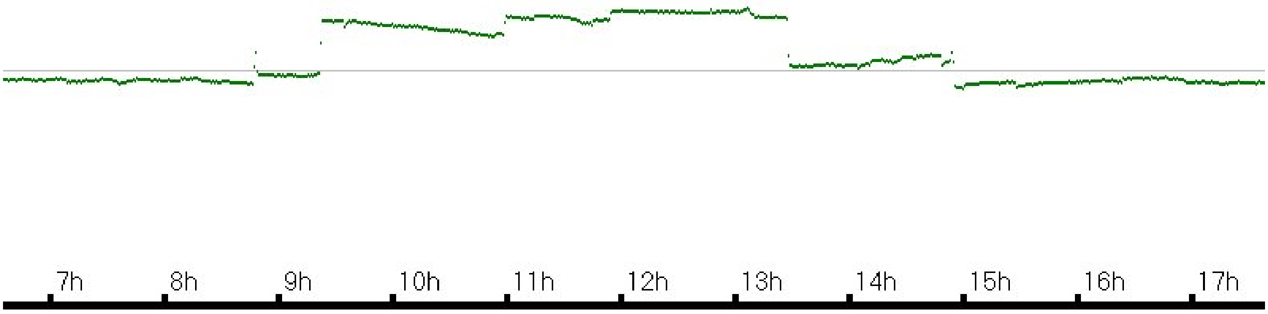

Figure 8 Cars arriving and departing from an adjacent road

Over the following days recordings were made of both quiet days and a minor geomagnetic storm.

It was lucky that this test run was able to detect real disturbance in the Earth's magnetic field. Solar activity is at a minimum in 2020 with only occasional small outbursts of activity. On the 27th and 28th September the solar wind from a coronal hole interacted with the Earth's magnetic field to create a minor geomagnetic disturbance. This was recorded as a G1-G2 (Minor to Moderate) geomagnetic storm by the US National Oceanic and Atmospheric Administration (NOAA) space weather centre (swpc.noaa.gov).

In Figures 9 and 10 the storm can be seen developing after 18:00 UTC and continuing into the following day. It disturbs the magnetic field in both axes of the magnetometer. The straight line between approximately 10:00 and 12:00 UTC is due to the system being turned off to allow me to work on the cable routing.

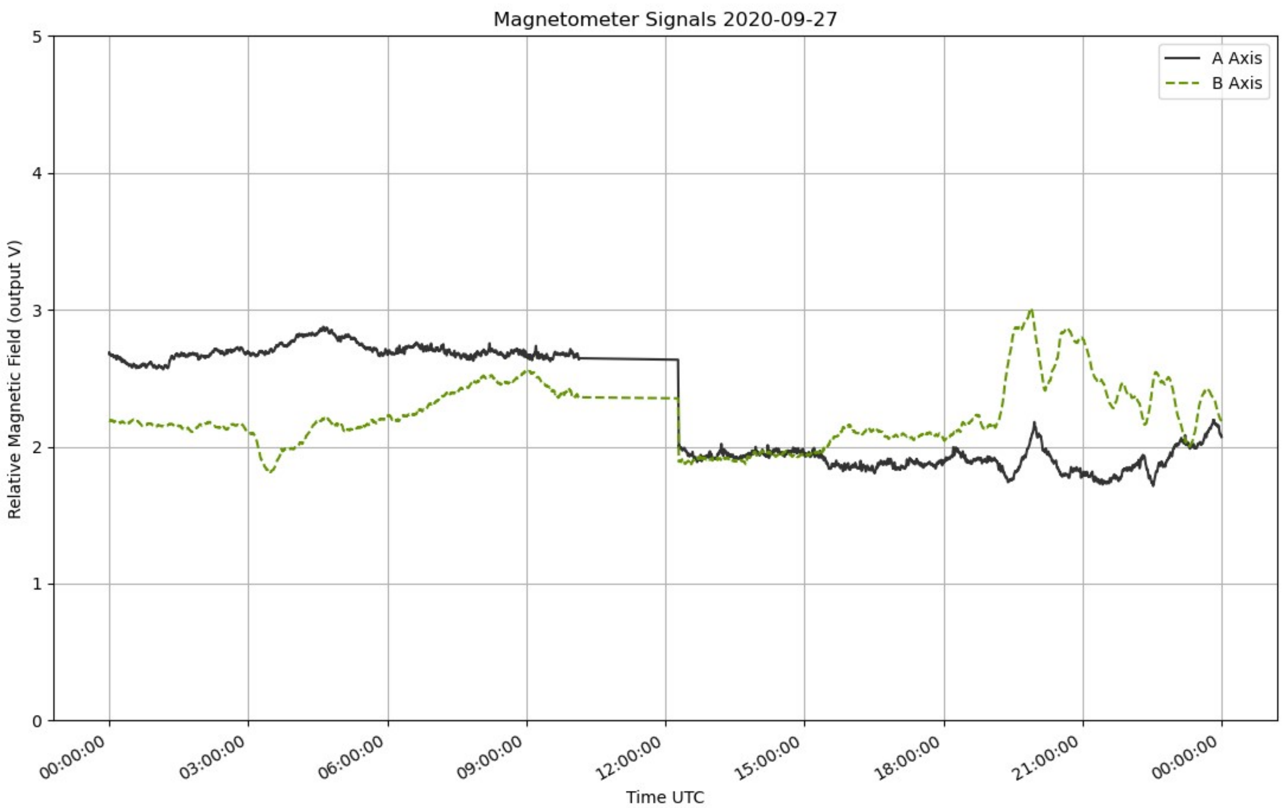

Figure 9 Shows the disturbance developing after 2020-09-27 18:00 UTC

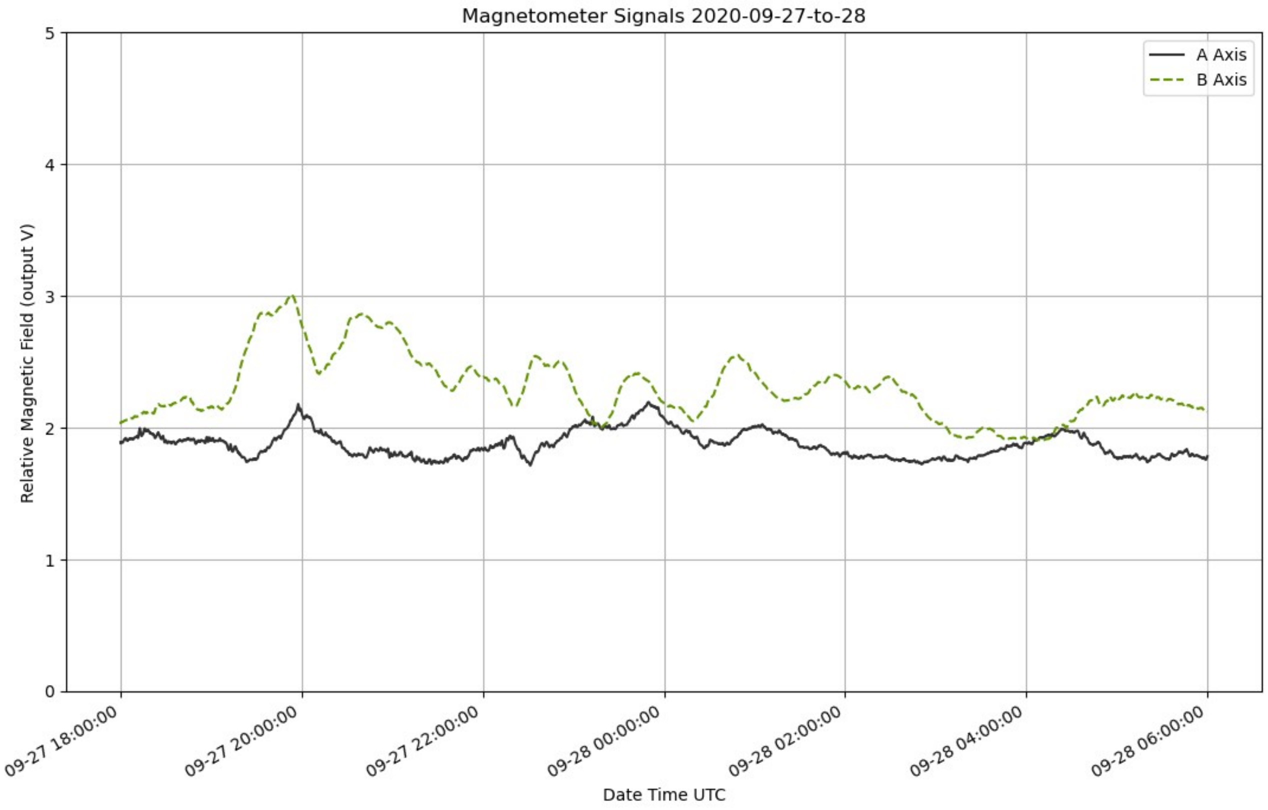

Figure 10 shows the magnetic disturbance continuing up to 06:00 UTC the following day.

Next Steps

I was not happy with my initial setup; leaving a laptop in the garden shed did not seem to be a good idea. The shed is insecure, spiders and laptops don't mix and it stopped the laptop being used for other activities. During the Covid-19 lockdown the laptop became indispensable for online meetings, classes and video calls.

Magnetometer LabJack U3HV RaspberryPi

Figure 11 Datalogging System

A RaspberryPi was an ideal solution. It is low cost, low power and a fellow UKRAA colleague has written code for a datalogger in Python. As soon as this was working satisfactorily I started to use it with my magnetometer. This has proved to be a reliable solution to data logging, eliminating the need to use a laptop. The RaspberryPi reads the digital data from the Labjack and records it in a CSV file for later processing. A new file is started at midnight every day and yesterday's file is copied to a USB memory stick. It is UKRAA's intention to develop the datalogger and make it available for sale in 2021.

This project encouraged me to learn more about the RaspberryPi and Python. I eventually learnt enough to be able to process the data to produce the graphs in this article and to display my data live online.

Next Steps

Overall I was pleased with the outcome of the trial and I am now confident that it is feasible to use the magnetometer in a suburban garden. There will be disturbances, but these can be allowed for when examining the results from the observations.

The next step is to find a permanent location for the magnetometer. This needs to be weatherproof, non-metallic and sturdy to limit accidental disturbances. Could another shed be needed?

Resources and further reading

If this article has tempted you to have a go there is a lot of information and advice available on line.

For further information on geomagnetism and magnetic storms the British Geological Survey publishes real time observations of the Earth's magnetic environment at http://www.geomag.bgs.ac.uk/data_service/space_weather/current_conditions.html

The US National Oceanographic and Atmospheric Administration Space Weather has a wealth of background information as well as the forecast for future magnetic storm events at https://www.swpc.noaa.gov/ .

The British Astronomical Association Radio Section also has background material at https://britastro.org/section_front/24 .

All the equipment described in this article and a selection of relevant books is available from UKRAA at https://www.ukraa.com/ .

Radio SkyPipe software is available from http://radiosky.com. It is free for a single channel version. An eight channel version for non-commercial use costs $49.95.

About the Authors

John Cook is the Director of the BAA Radio Astronomy Section, an honorary member of SARA and a UKRAA member. I have always been interested in both electronics and astronomy. Tuning around on an old 1155 ex-aircraft receiver in the 1960's sparked in interest in the link between radio signals and the Sun, but I took it no further until 1990 when I became a BAA member. The solar section taught me how to safely observe the Sun, and also provided links to the radio side of solar activity.

Working as an electronics design engineer I was soon able to get a VLF receiver working to detect solar flares, followed by a basic 'Jam-Jar' magnetometer. This had its problems as surrounding ferrous objects quickly became magnetised and spoiled its performance. With a magnet suspended on a length of cotton, it did however record the tremor from a minor earthquake in 2002. As mentioned in the introduction, the AMR design followed, and has proved to be very useful. As well as the radio work, I make solar drawings whenever the weather allows, and look after the activity charts for the BAA Solar Section.

Andrew Thomas is a Trustee of UKRAA and a member of the BAA. I found that my long standing interest in astronomy was re-energised when I discovered amateur radio astronomy. This was due to a chance encounter at a business conference with a self declared 'amateur radio astronomer'. Prior to that I had no idea that such things were possible. I enjoy building the instruments needed for making observations and encourage others to have a go. I currently observe Very Low Frequency (VLF) signals and ionospheric disturbances and occasionally meteors. My current project is to add a magnetometer to my observatory and observe the impact on the Earth's magnetic field of solar wind and coronal mass ejections.

UKRAA is the UK Radio Astronomy Association, a charitable body which historically developed from the British Astronomical Association Radio Astronomy Group. UKRAA promotes the science of radio astronomy and all branches of radio astronomical research by designing, manufacturing, and selling radio astronomy equipment for amateur astronomers.

UKRAA sells radio astronomy equipment through its online store at [www.ukraa.com.](http://www.ukraa.com)