Build an Earth's Field Magnetic Observatory!

PART I, Introduction

Introduction

In this series of articles, I will show you how to build a do it yourself backyard Earth's field geomagnetic observatory, a PC based, high resolution, high accuracy proton magnetometer. The backyard Earth's Field Magnetic Observatory project will let you see and detect tiny changes in the Earth's magnetic field in order to observe geomagnetic storms related to sunspots and solar flares. Since some of the indices that report geomagnetic activity are based on 3 hour readings, in some cases, you will be able to detect geomagnetic events before the official reports.[1] Also, unless you live very close to one of the few official geomagnetic observatories, your data will very likely be unique, and vary somewhat from your nearest station.

The proton magnetometer is rooted in the science of nuclear magnetic resonance (NMR). Working on first principles of physics, you can measure the magnitude of the Earth's magnetic field to very high accuracy and resolution. You can also measure some of the characteristics, such as the amplitude and time duration of the proton precession signal, for all kinds of common household fluids ranging from tap water to wine vinegar.

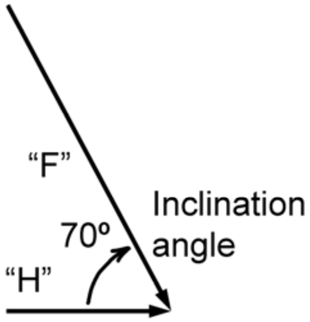
There are several parts to the backyard Earth's Field Magnetic Observatory project, the sensor coils and wood stand, the analog amplifier, the digital control board, and the PC software. We will build one section, or a part of a section, in each of our articles. The goal is for our backyard geomagnetic observatories to be up and running before the upcoming eleven year maximum in the sun spot cycle, expected around 2013[2]. Our company (www.gellerlabs.com) will offer printed circuit boards and electronic kits for the analog and digital control boards. We will also offer at no cost, software and software modules to operate the magnetometer. Our overall software has been tailored to the USB-6008 digitizer[3], available from National Instruments. Some experimenters may prefer to write some or all of their own software to support digitizers offered by other companies.

Let's begin the backyard Earth's Field Magnetic Observatory project discussion by discussing the magnetic field in my backyard. The magnetic field in my backyard, here in upstate, NY, is just over half a Gauss and the field points into the ground at a relatively steep angle. The local "inclination angle" or "dip angle", is about 70 degrees from the horizontal. A regular compass uses only the horizontal component of the Earth's magnetic field, here, on the order of 0.2

Gauss. A “dip needle” refers to a special type of compass which has a needle that can measure the inclination angle (in the vertical plane) in degrees. Notice that inclination is the vertical angle of the magnetic field into the Earth, while “declination”, is the difference between true north and magnetic north (in the horizontal plane).

To put geophysical magnetic units in perspective for our discussion which follows, the half Gauss (0.5 Gauss) in my backyard is equivalent to .05 milliTesla, 50 microTesla, or 50,000 nanoTesla.

While a compass or a dip needle indicates a direction, a magnetometer is an instrument that measures the value (strength or magnitude) of a magnetic field and in some cases, also the direction of the field. A sensitive, high resolution magnetometer is generally an electronic instrument.



Many amateur scientists and electronics hobbyists have built[4] or used a fluxgate magnetometer[5]. The fluxgate magnetometer is a relatively sensitive instrument and can be readily built or purchased by a hobbyist. One feature of a fluxgate magnetometer is that it is sensitive to the direction of the magnetic field, as well as the strength or magnitude of the field. For example, a fluxgate sensor sensitive along its length, when pointed at an angle of 70 degrees from the horizontal into my lawn, would read about 54 µT, the magnitude of the total “F” field. When held in a horizontal position and pointed to magnetic North, it would read about 18 µT, the magnitude of the horizontal “H” component of the total field. This feature of sensitivity to direction and magnitude is both a blessing (to understand the direction of a field) and a curse (since very tiny mechanical changes in the physical position of a fluxgate sensor can cause relatively large differences in the value of the measured field). Also, many low cost fluxgate sensors will have some sensitivity to temperature. Some standard geophysical measurements, such as the H, D, E, and Z values are routinely measured with fluxgate type instruments[6]. H is the horizontal vector component of the total magnetic field F vector. D is the magnetic field vector component in a direction of true North in the horizontal plane, E is the vector component in the East-West direction, also in the horizontal plane, and Z is the vertical vector component of the F magnetic field vector.

Bartington MAG-01 fluxgate magnetometer[7], sensor mounted on a plastic level

A proton precession magnetometer, on the other hand, measures only the total field strength (the magnitude of the field) and its accuracy is substantially insensitive to the sensor direction. Proton magnetometers are generally used to monitor the Earth’s total F field. In some applications, newer optical magnetometers are replacing proton magnetometers[8]. It turns out that a proton magnetometer works best when the sensor is perpendicular to the field, however moving the sensor position only changes the amplitude of signals used to measure the field and does not change the value of the measured magnetic field. Since a proton magnetometer operates on first principles of physics, once the frequency of a precession signal is accurately measured to some number of digits, the field is then known to that accuracy.

The only sense of calibration for a proton magnetometer is to correctly measure the frequency. Otherwise, once the frequency is known, the field is known. Given a measured frequency of the precession signal, the Larmor equation is used to calculate the magnetic field:

$$F = \frac{2\pi f}{\gamma_p}$$

where f is the precession frequency in Hz, γ_p is the gyromagnetic constant[9], and F is the magnetic field.

Since the measurement is based on a quantum phenomenon, a proton magnetometer is completely insensitive to temperature. It is only important that the working fluid not freeze to a solid. For example, with 125 mL (about 4 Oz) of Prestone® De-Icer windshield washer fluid as the sample fluid, our proton magnetometer works equally well from about -30 degrees F to over 100 degrees F, a wide enough temperature range for most backyard observatories.

To estimate the magnetic field in your backyard, go to the NOAA National Geophysical Data Center web resource http://www.ngdc.noaa.gov/geomagmodels/IGRFWMM.jsp . Enter your zip code, and click on the button compute magnetic field values. For now, we are mostly interested in the value of the "total field". Your field may differ slightly from the geomagnetic model data because of the presence of nearby ferrous (e.g. steel and iron) materials, cars, building materials, old iron furnaces, etc. or the magnetic properties of your local soil matrix down some feet below the surface, however your value should be relatively close to the calculated geomagnetic model value. My estimated value is 53,846 nanoTesla, however the actual measured value in my backyard is about 53,770 nT. That value varies around 20 nT with the daily (diurnal) variation on quiet magnetic days to well over that (>100 nT) at the onset of a geomagnetic storm. Our local field is also decreasing at a rate of about 114 nT / year.

Next, before we start building the project, let's discuss some helpful web resources. The NOAA / Space Weather Prediction Center, Space Weather Now page at http://www.swpc.noaa.gov/SWN gives a current view of the Sun and the current state of the Earth's magnetic field.

The USGS publishes its real-time plots at http://geomag.usgs.gov/realtime/ . For this project, we are most interested in the total "F" field plots. Similarly, Natural Resources of Canada web publishes total field "B_f" data from their observatories at http://geomag.nrcan.gc.ca/common_apps/mp-eng.php?ref=data&plot_type=b_plot . A guide to international geomagnetic observatories can be found at http://www.intermagnet.org/CtrylstInter_e.html .

The NOAA / Space Weather Prediction Center Space Weather Alerts page shows a bar chart of the geomagnetic "K" index over time as well as giving a link to the "Alerts" pages http://www.swpc.noaa.gov/alerts/k-index.html . Solarmonitor.org, shows various current views of the sun showing sunspots and solar activity http://www.solarmonitor.org/ . The NOAA / Space Weather Prediction Center Costello Geomagnetic Activity Index presents an interesting real-time prediction system for geomagnetic activity http://www.swpc.noaa.gov/rpc/costello/pkp_15m_24h.html . We will also post these links at the project website http://www.gellerlabs.com/PMAGThoughts.htm .

In the next article, we will discuss some of the recent amateur proton magnetometer projects with references to each. Following the survey of amateur proton magnetometer building, we will introduce our new FDM Proton Magnetometer[10] project in more detail, and then start construction by building the sensor stand and winding some coils.

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[1] For earliest notice of alerts and warnings, you can sign up for NOAA space weather alerts at the NOAA SWPC Product Subscription Service, http://pss.swpc.noaa.gov/ . After you sign up for the email notifications (bottom of the SWN page) be sure to go to the "subscription" page to check off which categories of the many types of notifications that are available that you want to receive (or, you get nothing).

[2] Solar Cycle Progression, NOAA/Space Weather Prediction Center, http://www.swpc.noaa.gov/SolarCycle/

[3] http://sine.ni.com/nips/cds/view/p/lang/en/nid/201986

[4] The FGM-3 fluxgate sensor is a hobbyist classic for building both amateur magnetometers and gradiometers, http://www.speakesensors.com

[5] Meda fluxgate magnetometers, also marketed under the Walker Scientific name, are another good example of a commercial fluxgate magnetometer, http://meda.com/umag.htm

[6] USGS Magnetic Sensors and Infrastructure http://geomag.usgs.gov/operations.php#sensors

[7] Bartington Instruments Ltd., Witney, United Kingdom http://www.bartington.com

[8] GEM Systems, Ontario, Canada, makes just about every type of NMR based magnetometer, including all types of proton and optical magnetometers, http://www.gemsys.ca .

[9] In 2010, the International Council for Science, Committee on Data for Science and Technology adopted a new value for the gyromagnetic constant: $\gamma_p = 2.675\ 153\ 362 \cdot 10^8\ T^{-1}s^{-1}$ *See:* http://www.iugg.org/IAGA/iaga_pages/pubs_prods/value.htm . *Also, see* our Part IX article for more guidance on how to use the Larmor equation and the gyromagnetic constant.

[10] The FDM MAGNETOMETER is a low cost high performance proton magnetometer (a digital magnetometer). It is based on a powerful and efficient software approach developed by Professor Mandelshtam of U.C. Irvine which performs the Filter Diagonalization Method "FDM" (harmonic inversion). The professor's papers are generally too advanced for most experimenters, however for very advanced experimenters, see Vladimir A. Mandelshtam, Howard S. Taylor, Harmonic inversion of time signals and its applications, Journal of Chemical Physics (1997), Volume 107, Issue 17, 1997, Pages 6756-6769. The professor very kindly supplied the code which I have adapted for this project. For most experimenters, FDM can be viewed as a frequency estimator module which replaces conventional counting or Fourier (FFT) approaches.