Understanding HamSCI Magnetometers Measurements and Observations: A Laboratory Experiment and Demonstration

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Abstract

Ground-based magnetometers are unique instruments that allow for remote sensing of the dynamics and structure of the geospace magnetospheric environment directly from the Earth's surface. Traditionally, science-grade magnetometers for this purpose have been prohibitively expensive for individuals to operate; therefore, geomagnetic observations are normally restricted to select sites operated by research institutions and government agencies. Recent technological developments by industry and citizen science organizations have brought down the cost of magnetometer ownership and operation to a level affordable by individuals. Such a magnetometer is part of the HamSCI Personal Space Weather Station (PSWS) suite, which includes not only a ground magnetometer for magnetospheric studies, but also radio receivers for ionospheric studies. While prior work at the University of Scranton has focused on supporting the radio instrumentation, the present study establishes a laboratory testbed for the HamSCI magnetometer system to develop expertise among faculty, staff, and students. This enables a deeper understanding of instrument operation, measurement capabilities, and limitations for the purpose of improved data analysis and support of the Citizen Science Community. In this presentation/demonstration, we will showcase how we are using it and our simulation of the Gannon Storm.

HamSCI Magnetometer Laboratory Testbed

We reproduce the Gannon Storm in a laboratory setting using W2NAF PSWS magnetometer data (41.34° N, -75.60° E, May 10, 2024) as the input signal for a computer-controlled arbitrary function generator. The generator produces a time-varying voltage waveform proportional to the recorded magnetic field variations (Fig. 1). The signal drives a pair of Helmholtz coils, generating a nearly uniform magnetic field at its center that is proportional to the applied current (Fig. 2). A HamSCI magnetometer, mounted horizontally at the coil midpoint, measures the resulting magnetic field. The HamSCI magnetometer system is unique as it employs a low-cost, commercial off-the-shelf, magneto-inductive sensor capable of measuring three-axis magnetic field variations with a resolution of less than 3 nT at 1 Hz (Fig 3). A Raspberry Pi-based system developed by HamSCI averages the sensor output and logs the magnetic field components in the unit of microtesla (μT) at one-second intervals.

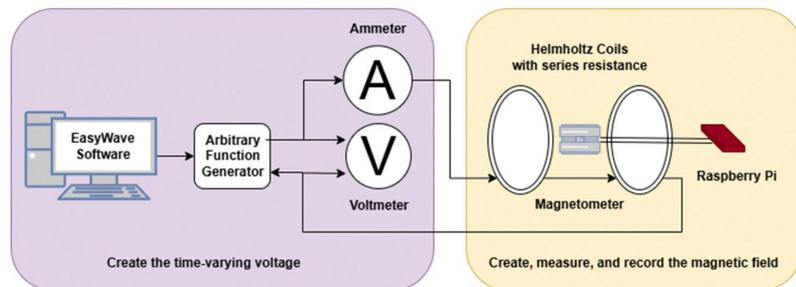Figure 1. Block diagram representatof laboratory testbed site showing computer-controlled arbitrary function generator, multimeters, and Helmholtz coils with magnetometer connected to Raspberry Pi microcontroller..

Figure 2. Gannon Storm data was used to generate a waveform that was applied to the Helmholtz coils to reproduce the event in laboratory conditions.

Methods

Prior to applying the simulated storm signal, a baseline magnetic field was established by averaging 600 s of magnetometer data collected with no current applied to the coils. This value represents the background x-component of the local magnetic field.

Magnetic field data from the W2NAF station recorded during the May 10, 2024 Gannon Storm were converted into a corresponding voltage waveform using a computer-controlled arbitrary function generator. The recorded magnetic field values were scaled that the peak disturbance corresponded to an output voltage of approximately − 5 V, producing a set of voltages proportional to the original magnetometer measurements.

The signal was applied to a pair of Helmholtz coils through a 2.4 kΩ series resistance, producing a current proportional to the applied voltage.

The coil current was monitored using a digital ammeter connected through a GPIB interface. A MATLAB script automatically recorded the measured current and corresponding UTC timestamp at one-second intervals, allowing the applied current waveform to be synchronized with the magnetometer measurements.

Two identical Helmholtz coils separated by a distance equal to their radius produce a nearly uniform magnetic field at the midpoint, proportional to the coil current. The magnetic field at the center is given by

$$\vec{B} = \left(\frac{4}{5}\right)^{3/2} \frac{\mu_0 N I}{R}$$

Where $N = 200$ is the number of turns per coil, I is the coil current, and $R = 10.5$ cm is the coil radius.

During the experiment, the HamSCI magnetometer positioned at the center of the coils continuously recorded the x-component of the magnetic field. The baseline value was subtracted from the measurements to isolate the magnetic perturbation produced by the simulated storm signal. The processed magnetic field variations are shown in Figure 4.

Results

Magnetometer data recorded at the W2NAF station during the Gannon Storm shows a clear magnetic disturbance with a peak deviation of approximately -1200 nT. The signal reflects the rapid development and recovery of the geomagnetic storm (Fig. 4).

Using these data as the input waveform, the Helmholtz coil system generated a corresponding time-varying magnetic field measured by the HamSCI magnetometer positioned at the center of the coils. The resulting laboratory measurements reproduce the overall temporal structure of the storm signal, including the rapid onset and gradual recovery of the magnetic perturbation (Fig 5).
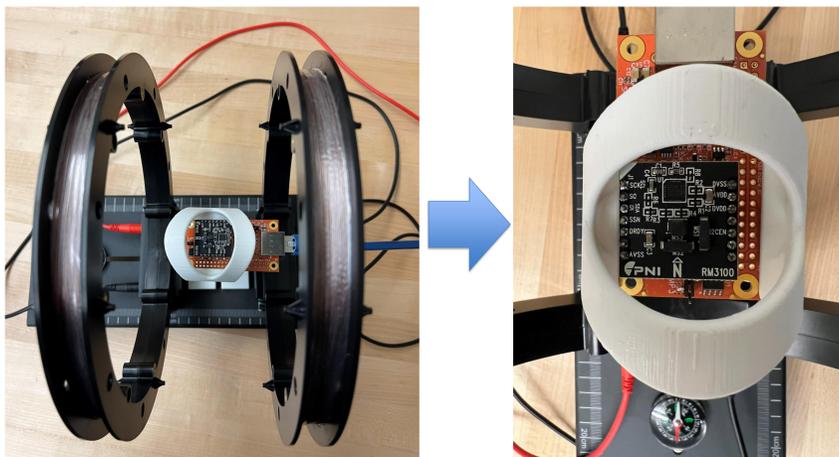

Figure 3. PASCO Helmholtz Coils with HamSCI magnetometer at the laboratory testbed site. The Helmholtz coils produce a magnetic field according to the current in the loop (left) Close-up view of the HamSCI magnetometer used in the Personal Space Weather Station (right).

Gannon Storm Data and Simulation Results

Figure 4. Gannon Storm data recorded on HamSCI magnetometer at W2NAF Personal Space Weather Station (41.34° N, -75.60° E) on May 11, 2024 showing a peak disturbance of approximately −1200 nT.
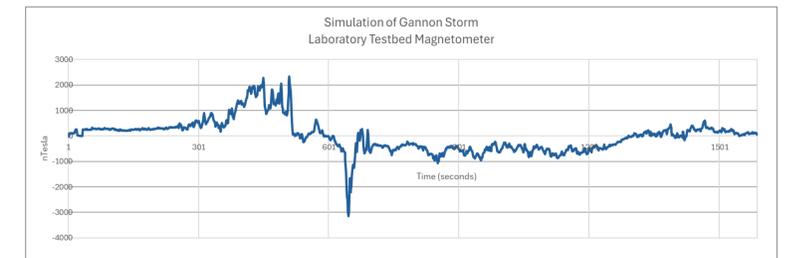

Figure 5. Simulated Gannon Storm magnetic field signal recorded by HamSCI magnetometer system within Helmholtz coils, reproducing the storm-like magnetic perturbation.

Discussion

The laboratory simulation successfully reproduces the time-dependent magnetic field variations characteristic of a geomagnetic storm. While differences exist in the absolute magnitude of the magnetic field, the overall temporal behavior of the signal is preserved.

Two factors account for the primary differences between the datasets. First, the original magnetometer data were recorded over a 24-hour period, while the laboratory simulation was performed over a 30-minute interval. Second, the field magnitudes differ due to scaling between the magnetometer measured values and the voltage applied to the Helmholtz coil system.

Despite these differences, the close agreement in signal structure demonstrates that geomagnetic storm magnetic field variations can be effectively reproduced in a controlled laboratory environment. This capability provides a valuable educational and experimental testbed for studying magnetometer response, validating instrumentation, and supporting the HamSCI citizen science network.

Future Research

- Develop educational modules allowing citizen scientists and students to replicate geomagnetic storm effects in small-scale, low-cost lab set-ups, reinforcing the connection between magnetospheric currents and ground magnetic field measurements
- Evaluate the response of different low-cost magnetometer designs under controlled lab environments to better understand sensor limitations and calibration needs.
- Conduct experiments in a magnetically shielded environment to reduce background noise, allowing more precise measurement of the simulated magnetic fields corresponding to events like the Gannon Storm.

References

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