Magneto: Mapping the Earth's Magnetic Field at 300 km using COTS Sensors

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1. Mission

Magneto is a 1.5U CubeSat equipped with low-cost COTS sensors to measure Earth's Magnetic Field in Low Earth Orbit (LEO). Magneto's mission has the potential to illustrate the practicality of COTS sensors in space, which will in turn lower the cost of building future CubeSats.

2. System Overview

Magneto's bus system is comprised of a sun sensor, motherboard, a Pluggable Processor Modulator (PPM), an Electrical Power System (EPS), battery board, Bus In/Bus Out (BIBO) board, beacon board, and the quad antenna deployer. The EPS along with the battery board supply all system and payload components throughout mission life. The batteries provide a total of 20W-hrs and the EPS regulates their charging from the solar arrays while distributing power across three major lines. The Bus In/Bus Out (BIBO) board serves as a housing board for the beacon header, magnetometers, and the HamShield Mini as they cannot be directly connected to the motherboard.

3. Quad Aperture Antenna Design

A quad aperture is designed to house and facilitate the deployment of 2 magnetometers and 2 UHF whip monopole antennas. Carbon fiber was used to construct the magnetometer booms while the antenna housing was made from Vespel to ensure electrical isolation. To reduce costs, prototypes were tested with wax and 3D printed models. Prior to launch, the booms and antennas are in stowed with a nylon fishing line holding them in place. Once in orbit, two burn drivers are used to cut the fishing line to release the booms and antennas.

4. Single Sensor Attitude Determination

Attitude determination algorithms such as the triad method often require the use of a magnetic field model to transform magnetometer measurements to an inertial frame. Using spacecraft attitude combined with the COTS magnetometer measurements to map Earth's magnetic field is counter-intuitive if attitude is determined using a magnetic field model. The team thus proposed modifying the traditional triad method algorithm to accommodate the use of a single sun sensor by combining 2 measurements (taken at different times) with gyro measurements. The gyro measurements are used to transform a previous sun sensor measurement to the same reference frame of the current sun sensor measurement. Once the sun vector measurement from the previous sampling period is transformed to that of the most recent, using the spacecraft's known angular velocity at the time the earlier measurement was taken, the traditional triad algorithm is followed.

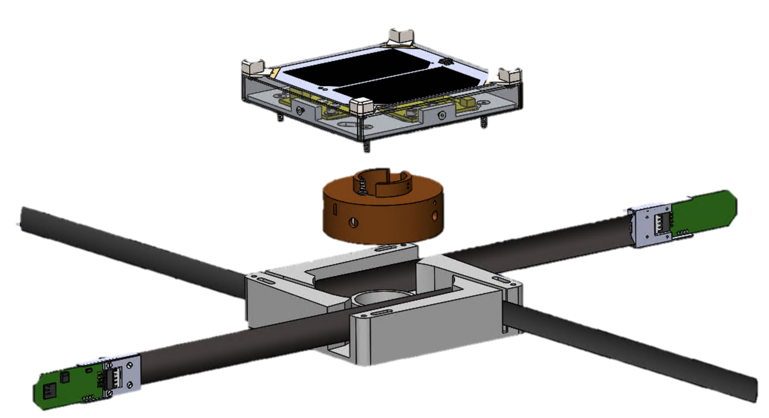


Figure 1: An exploded view of the Quad Aperture assembly

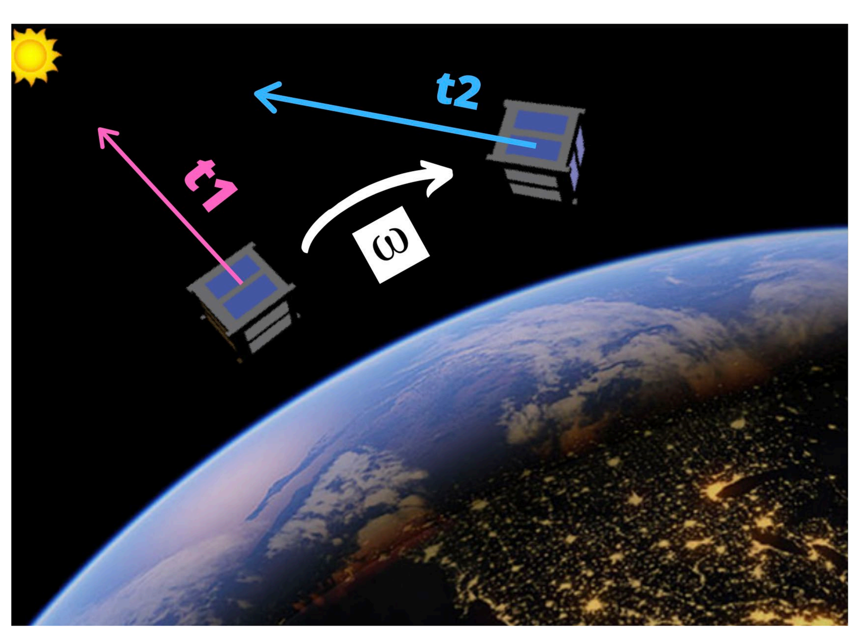


Figure 2: Diagram depicting CubeSat in orbit measuring the sun vector at two different instances, t1 and t2. Gyro readings, ω, are then used to transform the t1 measurement into the same frame as t2. Once this transformation is completed, the triad algorithm can be followed.

5. Orbital Position Updates Using Amateur Radio

Instead of relying of GPS, orbital position is determined by updating externally provided TLE data with the assistance of a global network of ground stations and the amateur radio community. Each ground site will be provided a decoder program to extract data from the hexadecimal encoded beacon signal. While decoding data, the ground stations will log the Time of Closest Approach (TCA) to correct the satellite's absolute frequency. As the TCA between Magneto's orbit and each ground station is determined, the SERC will be able to update the known ephemerides to greater accuracy. Additionally, the Magneto team can call on these amateur operators to record beacons from the CubeSat and relay magnetosphere measurements, along with attitude and position data, back to the team. Expected coverage from the proposed network of amateur stations was simulated using MATLAB and Systems Took Kit (STK).

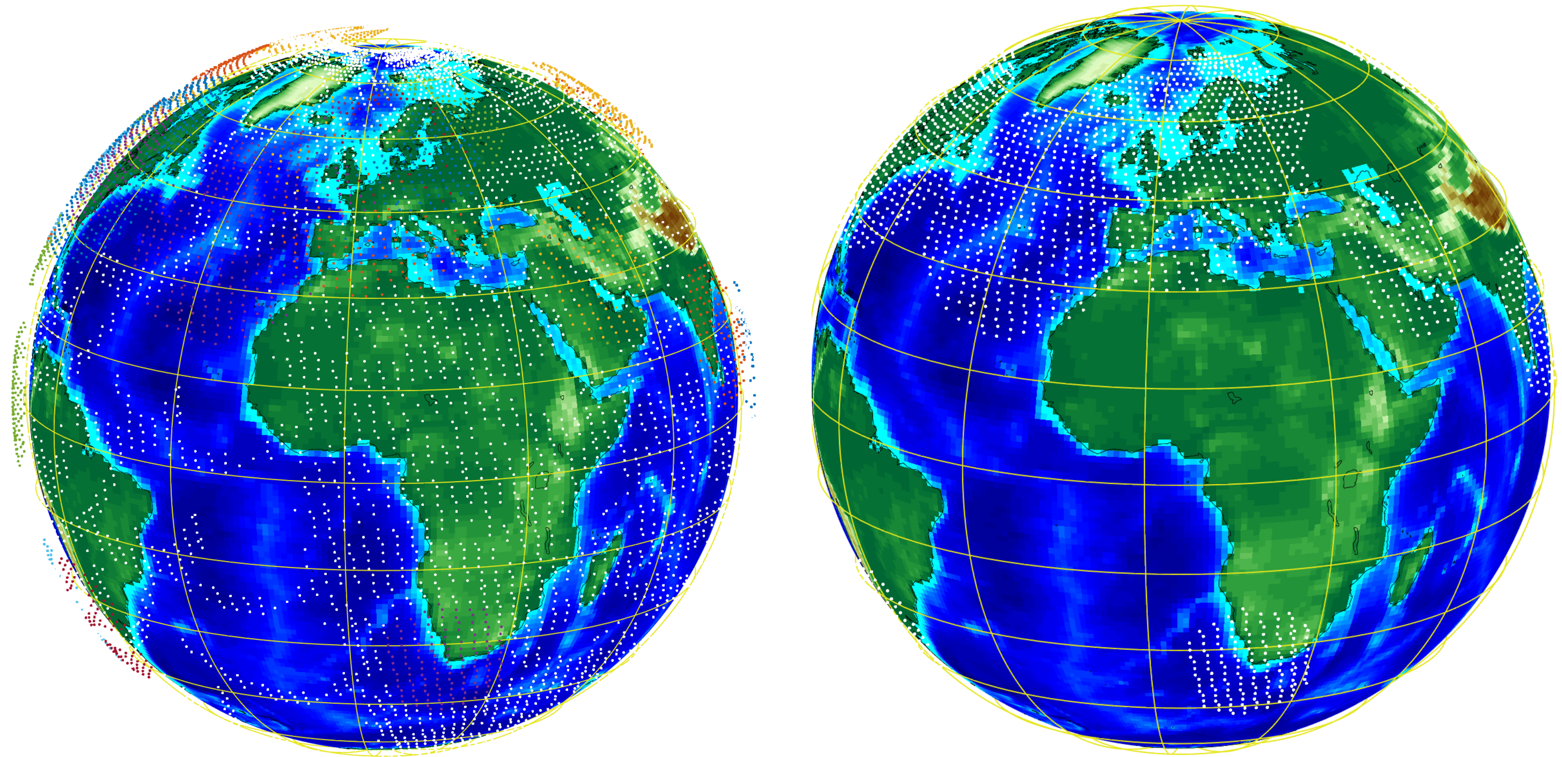
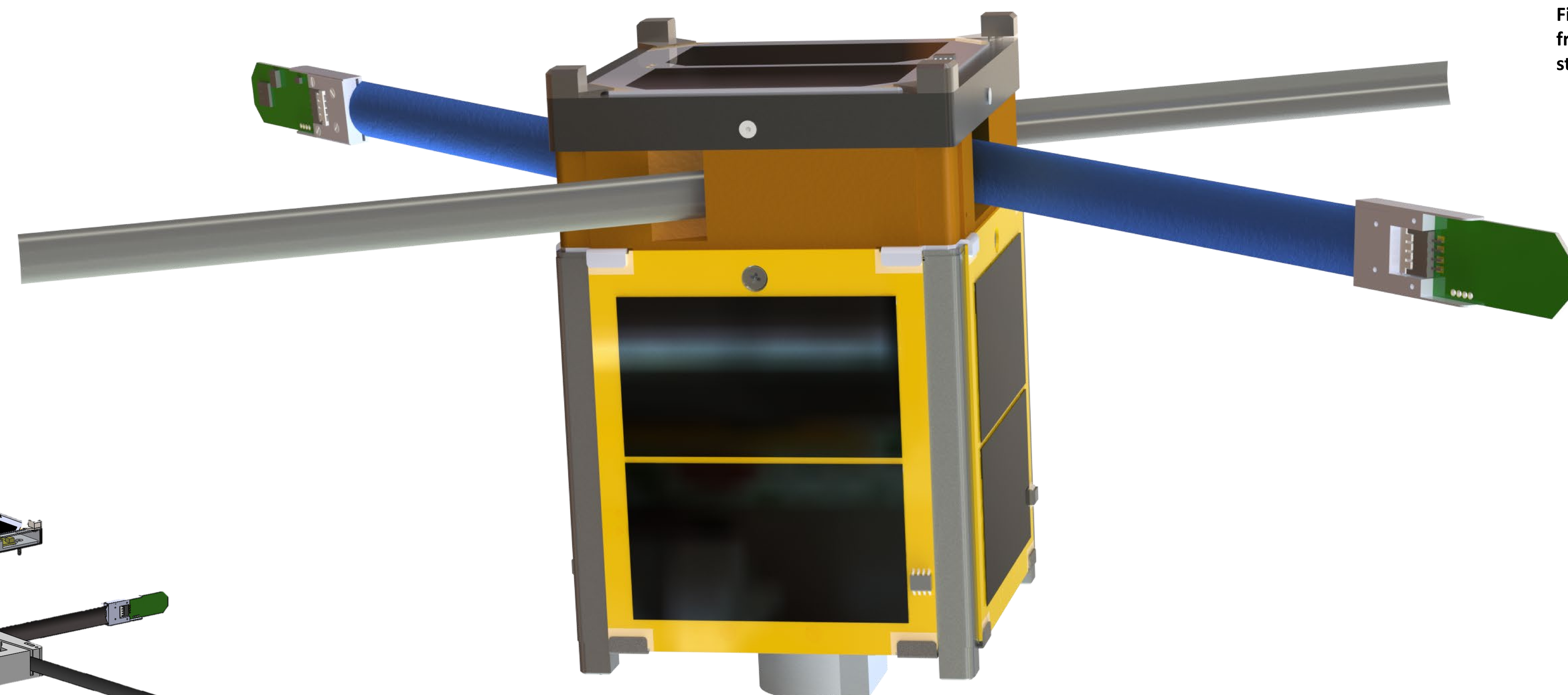


Figure 2: Left: Simulated global coverage of instantaneous magnetometer readings crowd-sourced from amateur ground stations. Right: Simulated global coverage with amateur ground stations and stored magnetometer data (both simulations over a period of 1 month)



Acknowledgments

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6. Modified Beacon Scheme

With limited flash storage and a low onboard power budget the downlink is divided into 3 independent beacons sent at 60 second intervals (2 for magnetometer data, 1 for spacecraft health and status), completing a full cycle every 3 minutes. The limited data length of the beacon (120 bytes) allows at most 7 historical magnetometer readings that are included in the 3-beacon system. Storing even just a small number of readings over each pass significantly increases global coverage.

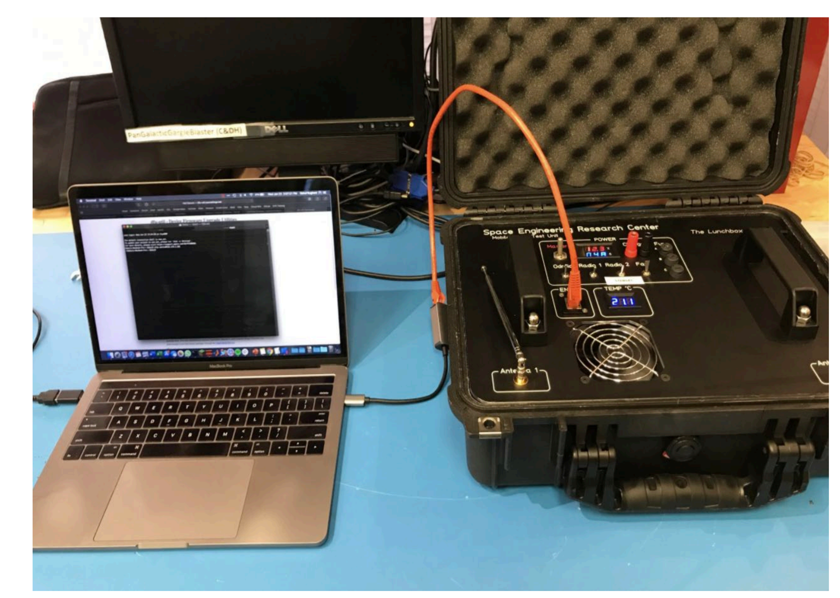

Figure 3: Mobile Radio Test Unit (MRTU) nicknamed "The Lunchbox", next to a laptop sending commands to the unit

7. Far-field Testing

A Mobile Radio Test Unit (MRTU) was developed to perform low budget far-field radio testing of flight components. It enabled full link testing of the entire CubeSat communications system without needing to purchase a second transceiver solely for testing. The MRTU consists of a rechargeable battery, a set of DC-DC power converters to provide multiple voltage rails for internal components, and an Odroid XU-4 microprocessor to control the radio transceiver.

8. Conclusion

The success of this mission would imply that low-cost COTS components would be viable options for higher fidelity science missions. The single sun sensor and gyros attitude determination algorithm may be helpful when a magnetometer or other Earth-based sensor is not affordable and spacecraft altitude it needed. Use of the amateur radio community provided the mission with greater data coverage. The team shares a few of these ideas in hopes of helping other teams in their development on low-cost CubeSat missions.