TorqMag: Developing a Novel Integration of Magnetic Attitude Control and AC Magnetometry for Small Satellite Platforms

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Introduction

- Many CubeSats in Earth orbit utilize magnetorquers for attitude control. Simultaneously, AC magnetometry has gained prominence in advancing our understanding of Earth's magnetosphere, including fine-scales in field-aligned currents (FACs).
- We propose a novel dual-function subsystem, TorqMag (short for **Torquing Magnetometer**) integrating a magnetorquer and a search coil sensor to enable both attitude control and high-fidelity AC magnetometry in a single compact package of <1U.
- TorqMag offers significant mass, power, and volume savings for science missions and aims at high-sensitivity detection of magnetic waves (100 Hz–2 kHz) without the need for a deployable boom, while still maintaining sufficient torque authority.
- This poster presents the challenges in developing this instrument, as well as the strategies and successes in addressing them. This work is supported by NASA's H-TIDeS program as part of the HyMag-ADCS project at the University of Michigan.

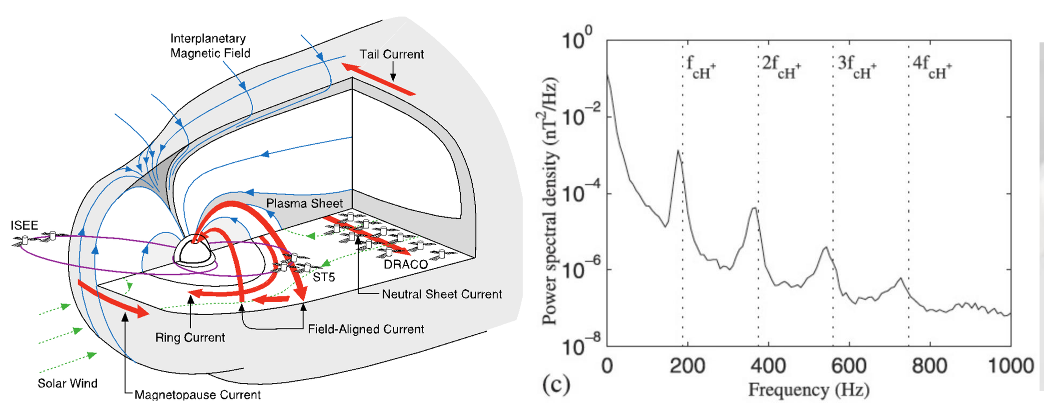


Figure Set 1: *Constellation missions for magnetospheric science (left) and data from search coil of NASA FAST mission (right)*

Figure Set 2: *Search Coil (left) and Torque rod (right) prototypes from Michigan Magnetics Lab and Michigan Exploration Lab respectively*

Functional Switching and In-space Degaussing

- A central challenge in combining torquing and AC magnetometry is **switching between the two modes**. Post high-current torquing, the magnetic core retains a **remanent field**, which degrades the coil's sensitivity to low-amplitude AC fields.
- **Proposed Solution**: *In-space degaussing*—injecting controlled AC signals into the coil to erase remnant magnetization after torque operations. This eliminates the need for external demagnetization, which is infeasible in orbit.
- We explored multiple **degaussing sequences** and found that:
  - ✓ **Exponentially modulated envelopes** reduce power consumption without degrading performance.
  - ✓ **Higher initial peak amplitudes** improve demagnetization but increase energy cost.
  - ✓ Tailored sequences achieved **1–2 orders of magnitude reduction** in residual field strength.
- These results validate in-space degaussing as a viable method for enabling high-fidelity AC magnetometry post-torque.
- Every attitude control command sequence will be followed by a degaussing routine. We propose using a CMOS SPDT analog switch IC to route signals between drive and sense modes, controlled by the onboard MCU.

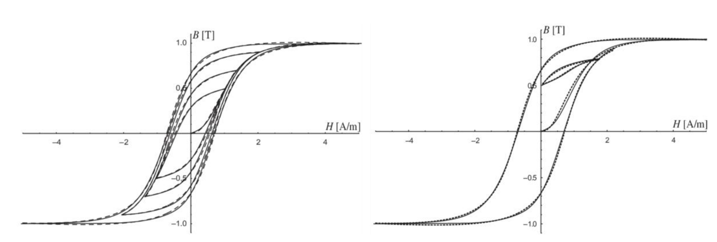


Figure Set 3: *Symmetric (left) and Asymmetric (right) minor hysteresis loops*

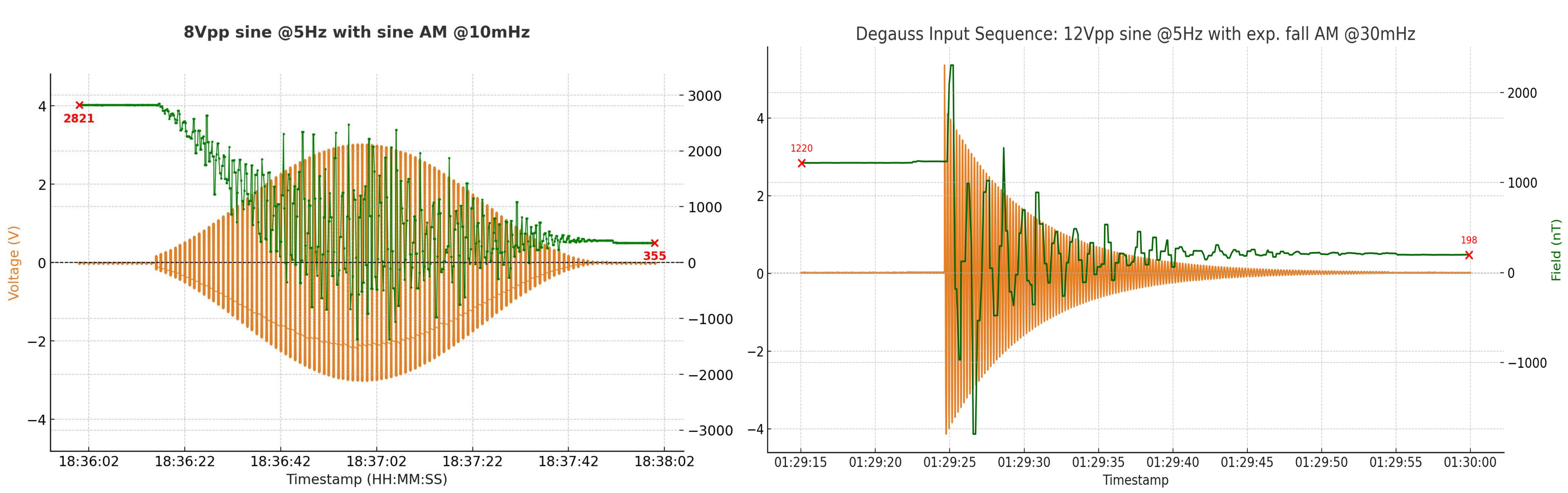


Figure Set 4: *Representative results of degaussing in two different scenarios with exponential (left) and sinusoidal (right) amplitude modulation*

Noise Cancellation and Boomless Magnetometry

- A key hurdle is reconciling the **internal placement** of torque rods (for effective attitude control) with the need for **magnetic isolation** in sensitive AC field measurements. Traditional boom-mounted magnetometers reduce spacecraft interference—but booms are impractical for torquing and in general, for CubeSats.
- **Proposed Solution**: *Algorithmic noise cancellation*—We implement **WAIC-UP** (Wavelet-Adaptive Interference Cancellation for Underdetermined Platforms)—a real-time, blind-source algorithm that removes magnetic interference using statistical correlation across multiple sensors in the wavelet domain. WAIC-UP requires no prior knowledge of interference signals and outperforms traditional PCA/ICA and compressive sensing in both speed and generality. Results show:
  - ✓ **RMSE reduction** from ~260 nT to **<10 nT** in controlled lab tests.
  - ✓ **>27 dB improvement** in signal-to-noise ratio (SNR) versus unfiltered sensor data.
  - ✓ **>0.99 Pearson correlation** with ground-truth ambient fields in high-interference simulations.
- These results demonstrate WAICUP-enables **boomless AC magnetometry** for CubeSats in noisy environments.

Scan for link to reference paper

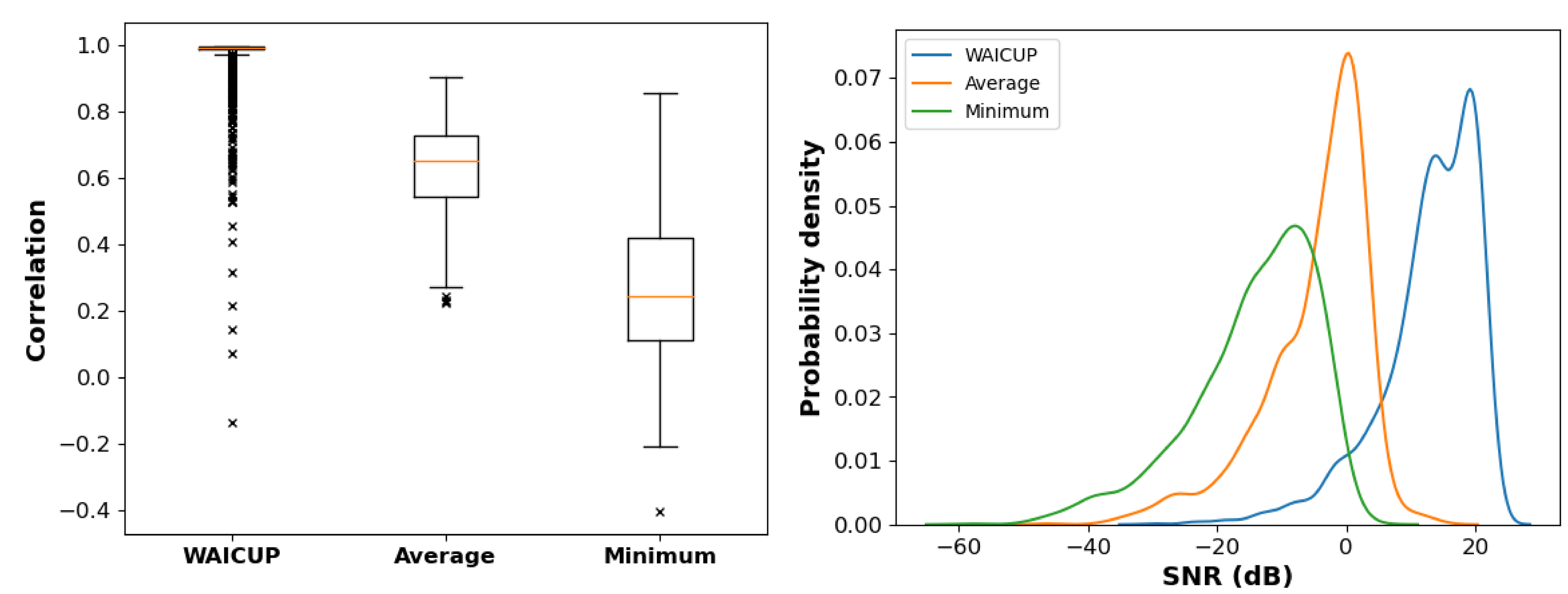
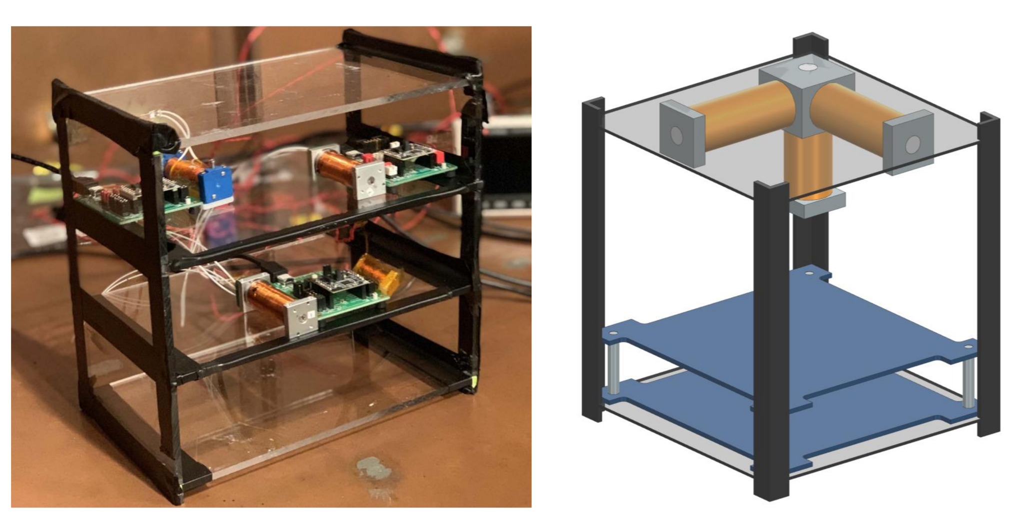


Figure Set 6: *(anti-clockwise from top right) Probability distribution function of the SNR (; and the boxplots of the correlation with the true ambient magnetic field signal) for the minimum, averaged, and WAIC-UP signals; Experimental setup with the mock CubeSat apparatus; Representative model of search coil in the HyMag 1U platform with the QuadMag DC magnetometer*



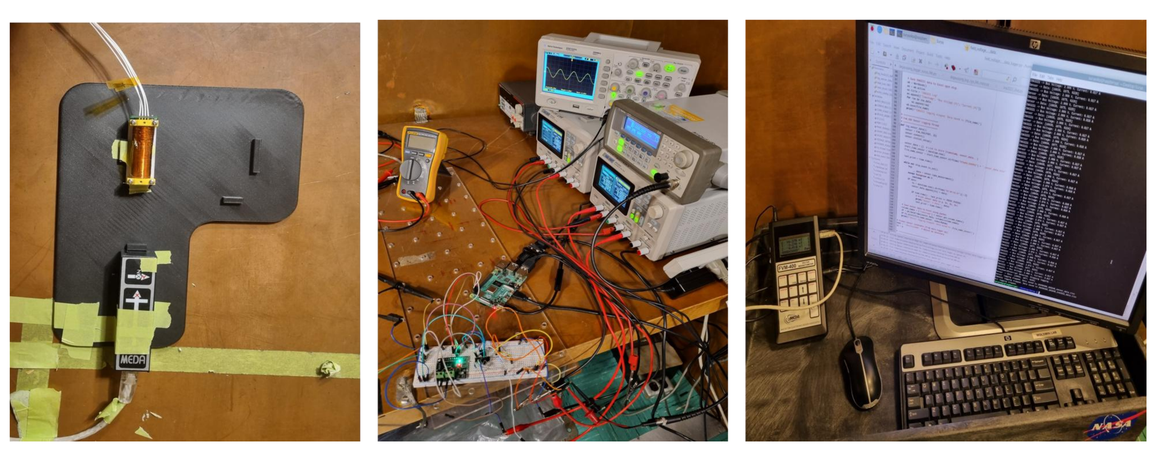


Figure Set 5: *(left to right) Jig with torque rod and fluxgate magnetometer; Drive (torque and degauss) and DAQ circuitry; DAQ Interface*

Conclusion

- TorqMag introduces a novel, dual-function magnetic subsystem that enables both attitude control and AC magnetometry in a compact form factor, eliminating the need for external booms.
- Our results demonstrate the feasibility of in-space degaussing and algorithmic interference cancellation, with significant advances in enabling high-fidelity magnetic science on CubeSats.
- Bringing this capability to CubeSat platforms further enables **cost-effective constellations to deepen our understanding of the magnetosphere and space weather**.

Future Work

- The optimized degaussing sequences must be coupled with the switch control circuitry and demonstrated using current prototype torque rods and sensing electronics.
- Simulate and demonstrate WAIC-UP performance in the **>100 Hz AC regime** using search coil prototypes and develop **CubeSat noise maps** and incorporate **ML-based filtering** for improved interference rejection.
- To optimize performance, **coil design trade-offs** must be addressed as **the 3rd challenge**: while **dimensions** and **core material** show similar trends for both functions, **turn count** and **frequency response** can conflict.