Design, Test, Calibration, and Data Processing of the Vectorized Scalar Magnetometer Onboard COSMO

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DATA-20

Abstract

The Compact Spaceborne Magnetic Observatory (COSMO) CubeSat mission is a 6U CubeSat, orbiting in low-Earth orbit, which aims to provide measurements of the Earth's magnetic field for the next-generation World Magnetic Model (WMM). COSMO is equipped with two optical rubidium scalar magnetometers within a triaxial coil system. Currents of a few mA are applied to the triaxial coil system on the cube to create modulation fields at designated frequencies. Modulation fields enable extractions of the vector components of the Earth's magnetic field. This vectorization approach is based on the triaxial modulation system developed for SWARM's absolute scalar magnetometer as a technology demonstration. A series of tests were conducted on our vectorized magnetometer at the NASA Goddard Space Flight Center Magnetic Testing Facility, which includes a three-axis 42 ft Braunbek coil system that can zero out the Earth's magnetic field and generate a designated magnetic field with high accuracy and precision in both magnitude and direction. Tests conducted in this facility were to assess and characterize the heading error, vector accuracy, linearity, and spacecraft biases, which enable the calibration of the in-flight COSMO data. Furthermore, two star trackers are included in the payload system, which provides attitude to transfer from the instrument coordinate system to an Earth-centered coordinate system. The accuracy and precision of the star trackers play a role in the quality of the magnetic field direction. Therefore, tests have been conducted under the planetarium and night sky to assess the star tracker's performance and to measure the absolute alignment of the star tracker relative to the magnetometer.

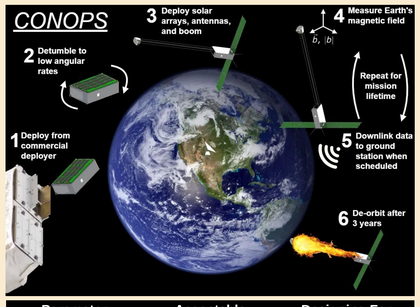
Introduction & Motivations

Introduction

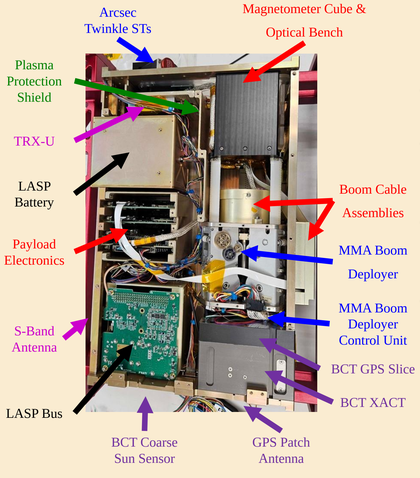
- A 6U CubeSat aims to provide scalar and vector magnetic field data.
- Payload includes two rubidium scalars and a triaxial coil system that ensures we can measure both scalar and vector data at 5 nT precision with lower cost.

Motivations

- Goal: provide scalar and vector magnetic field data for the World Magnetic Model (WMM) under the NGA MagQuest competition.
- The WMM needs both ground- and space-based measurements to update the model every 5 years.

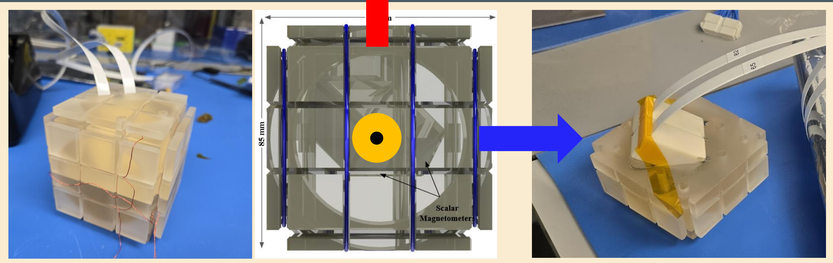


Parameter	Acceptable	Designing For
Altitude	531 - 556 km	550 km
Duration	3 - 8 years	6 years
Inclination	81° - 99°	97.675°
Spacecraft	6U XL	6U XL
COMMs	UHF/S-Band	UHF/S-Band
Ground Station	LASP + Commercial	LASP + Commercial

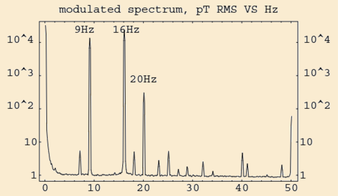


- Subsystems: payload, boom, C&DH, EPS, ADCS, communication, structure/thermal.
- LASP built the satellite bus, and LAIR built the payload, payload electronics, and structure.
- The payload will be deployed through the MMA boom to decrease the magnetic noises from the spacecraft.
- The magnetometer cube and two star trackers will be extended to obtain the most accurate attitude information.

Design



- The cube is made of the Zerodur low thermal expansion glass-ceramic.
- The triaxial coil system is designed to be orthogonal to each other.
- The two scalars are placed at the center of the cube, but do not align with any coils to avoid the dead zone of the scalars.



Measured magnetic field — Modulation frequency

$$|\vec{B}_{tot}| = \left|\vec{B} + \sum_{j=1}^{3} \beta_j \cos(\omega_j t)\, \vec{e}_j\right|$$

Unit vector of the j-th axis

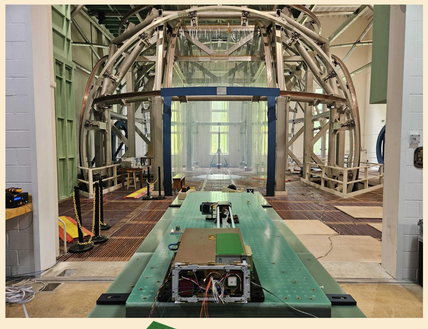
Modulation amplitude — Modulation amplitude

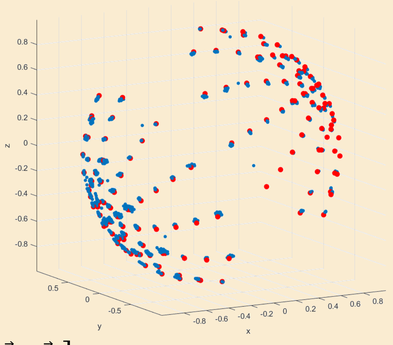
Principal harmonics (FFT amplitude)

$$(\vec{B} \cdot \vec{e}_j) = \frac{h_j |\vec{B}|}{\beta_j}$$

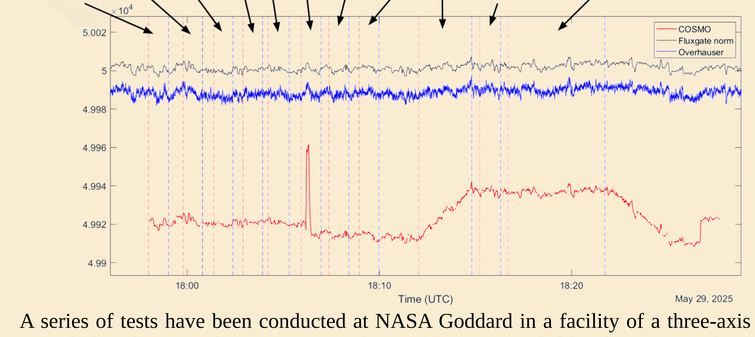
(Gravrand et al., 2001)

Testing & Calibration



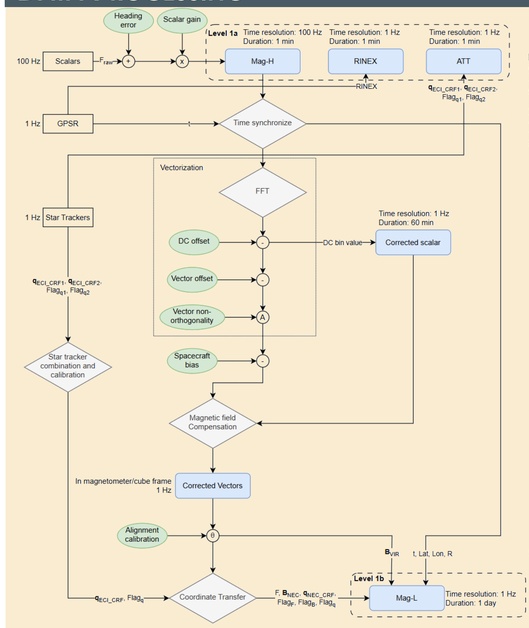


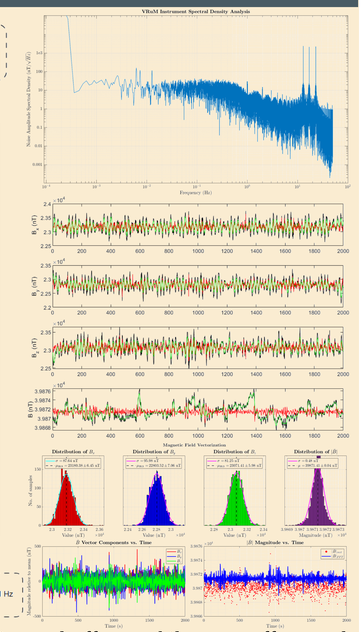
$$A = \begin{bmatrix} \vec{e}_1 \cdot \vec{e}_1 & \vec{e}_1 \cdot \vec{e}_2 & \vec{e}_1 \cdot \vec{e}_3 \\ \vec{e}_2 \cdot \vec{e}_1 & \vec{e}_2 \cdot \vec{e}_2 & \vec{e}_2 \cdot \vec{e}_3 \\ \vec{e}_3 \cdot \vec{e}_1 & \vec{e}_3 \cdot \vec{e}_2 & \vec{e}_3 \cdot \vec{e}_3 \end{bmatrix} = \begin{bmatrix} 1 & 0.0062 & 0.0025 \\ 0.0062 & 1 & 0.0206 \\ 0.0025 & 0.0206 & 1 \end{bmatrix}$$



- A series of tests have been conducted at NASA Goddard in a facility of a three-axis 42 ft Braunbek coil system that can zero out the Earth's magnetic field and generate a designated magnetic field.
- Tests are to assess and characterize the heading error, vector accuracy, linearity, and spacecraft biases, which will be applied to calibrate the in-flight data.

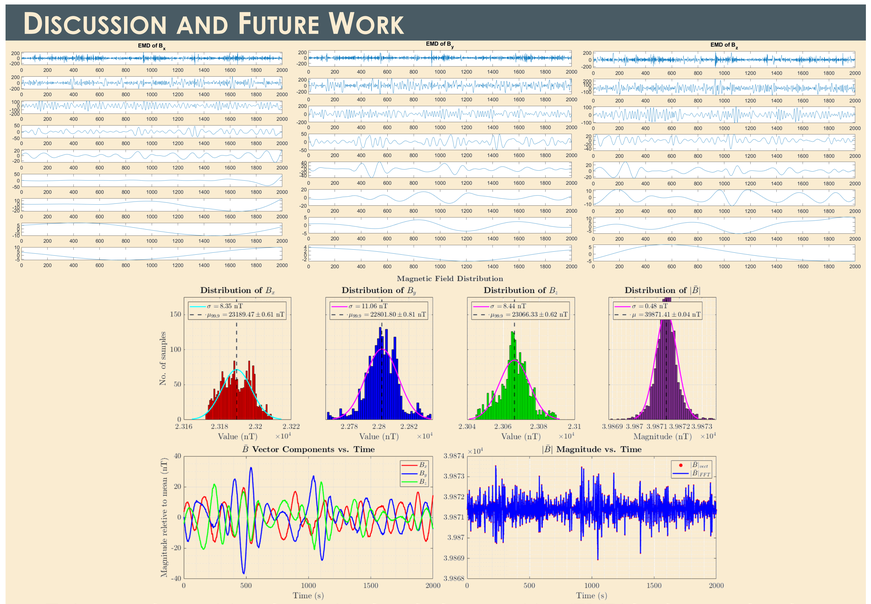
Data Processing





- The data processing procedure includes the calibration and offsets, while some offsets and biases are in a vector form and some are in scalar form.
- The Butterworth filter serves as a detrending method to reduce the noise of the data.
- The standard deviations of each component are 87.64, 95.98, and 81.25 nT, which are higher than expected. The possible cause is that the modulation current monitoring is not accurate enough, resulting in fluctuating magnetic field data and a higher precision value.

Discussion and Future Work



- To increase the precision, the empirical mode decomposition (EMD) has been employed.
- By using the suitable intrinsic mode functions (IMFs), the standard deviations of each component go to 8.35, 11.06, and 8.44 nT, which are about 10 times better!
- The standard deviations are limited by the noise floor of the facility.
- The internal modulation current monitor needs to be improved to get higher precision data.

The environmental tests will be conducted in the following months, and delivered to the launch service provider at the end of this year. COSMO plans to be launched in Q1 2026.

Acknowledgment: NGA and NASA