Development of a Science-Grade Miniature Fluxgate Magnetometer for the SIGMA CubeSat Mission

Jung-Kyu Lee[1], Hyomin Kim[2], Ho Jin[1], Khan-Hyuk Kim[1], Jeongho Lee[1], Seongwhan Lee[1], Hyojeong Lee[1], Jehyuck Shin[1], Marc R. Lessard[3], Chrystal S. Moser[3], Mark Widholm[3]

[1]School of Space Research, Kyung Hee University, Korea
[2]Center for Space Science and Engineering Research, Virginia Tech, USA
[3]Space Science Center, University of New Hampshire, USA

Mission Overview

- A 3U CubeSat called SIGMA (Scientific cubesat with Instruments for Global Magnetic field and rAdiation) is being developed by School of Space Research at Kyung Hee University.
- A science-grade miniature fluxgate magnetometer is being developed for the SIGMA mission. If successful, it will be the first CubeSat-borne, ***miniaturized*** fluxgate magnetometer in space (led by Virginia Tech (PI: Hyomin Kim) and University of New Hampshire (PI: Marc Lessard).
- The technology obtained throughout this project will be the basis of a future deep space mission and lunar explorer [*Lee et al.*, 2014].
- ***The goal of this project is to develop a CubeSat-borne miniature fluxgate magnetometer whose performance is appropriate for observations of FACs and ULF waves in low earth orbit.***

List	Detail
Mission Orbit	Polar Orbit 450 km x 650 km (elliptical orbit)
Life Time	3 month
Launch	SpaceX Falcon9 3Q, 2015
Payloads	Primary: TEPC Secondary: MAG
TEPC Spec.	Range: 0.2 ~ 300 keV/um LET Resolution: 23.5% @5.4 MeV
MAG Spec.	Range: ±65536 nT Resolution: ~ 0.1 nT
Total Weight	3.5 kg (3-Unit)
Total Generation Power	4,059 mW

Science Motivation

- ***Field-aligned currents (FACs)*** and ***magnetic field waves*** are common phenomena observed by magnetometers and very important in understanding energy transport from the Sun to geospace.
- FACs span a wide range of scale sizes: large-scale (**Figure 1**) and small-scale (**Figure 2**, typically associated with auroral electron precipitation).
- Waves in the ultra low frequency (ULF) range are important events because of their close association with geomagnetic activities. In particular, ***electromagnetic ion cyclotron (EMIC) waves*** (f=0.1 to 5 Hz) are typically generated by the cyclotron instability of plasma sheet and ring current ions and play an important role in energy transfer through wave-particle interactions (**Figure 3**).
- FACs are seen as several tens (or hundreds) of nT perturbations whereas EMIC waves are detectable with a resolution of a fraction of 1 nT to several nT.

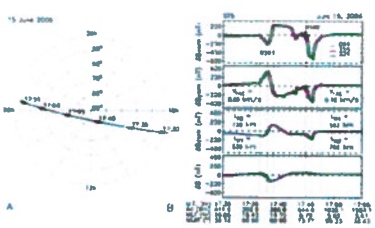

Figure 1. An example low altitude observation of FACs. (a) The ground track of the three ST-5 micro-satellites displayed in MLT and MLAT for a northern polar pass. The lead s/c is #155 (red), the middle s/c is #094 and the trailing s/c is #224 (blue). (b) The magnetic field measurements from ST-5 after subtraction of the background geomagnetic field. After Figure 2 from *Slavin et al.* [2008].

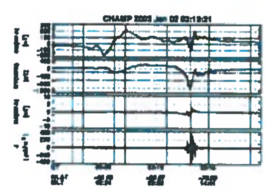

Figure 2. Magnetometer data from the CHAMP satellite, showing large-scale Region 1 and 2 currents (upper panels) and small-scale currents (bottom panel) embedded with these broader regions. After Figure 1 from *Rother et al.* [2007].

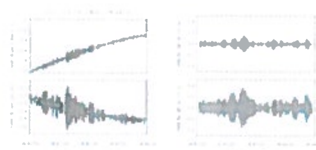

Figure 3. EMIC waves observed by the CHAMP satellite in the *F* region (left panel) and at Halley Station in Antarctica (right). Adapted from *Kim et al.* [2010]).

Engineering Motivation

- Miniaturization (for reduction in size and power consumption) of instruments is critical for small satellite missions such as CubeSats which is a new trend for space missions.
- Miniaturization of fluxgate sensors is challenging because their performance (e.g., sensitivity, noise, etc.) is often compromised while reducing the size of fluxgate sensors.
- Fluxgate type magnetometers still outperform other small-size sensors (e.g., magnetoresistive type) in terms of noise level, reliability and radiation tolerance. In addition, fluxgate magnetometers have proven space heritage for decades.
- Use of digital electronics which replaces analog electronics is advantageous for flexible, optimized design and low-power consumption.

References

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Miniature Fluxgate Sensor

- Remarkably miniaturized: size=22x22x22 mm^3, weight=15 g: reduction in mass and volume of a factor of ~20 over traditional fluxgate sensors; 3-axis in one package (**Figure 4 and 5**).
- Improved permalloy magnetic cores are used for a more pronounce performance in the smaller sensor (**Figure 4a**).
- Its compact design is appropriate for the SIGMA CubeSat boom (**Figure 6**).

Figure 4. (a) Ring core and (b) sense coils in a 3-axis configuration for the SIGMA fluxgate sensor [Moser and Lessard, 2014].

Figure 5. Sensor housing and connector assembly.

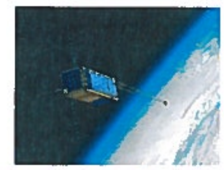

Figure 6. SIGMA CubeSat with the boom deployed.

Magnetometer Electronics

- Most of the signal processing is digital-based: drive and sense null signals are programmable (**Figure 7**).
- Sample rate: 8 samples/sec/axis (data 72 Mbits/day)
- Bandwidth selectable: 6.4 Hz, 3.2Hz, 1.6Hz , 0.8Hz

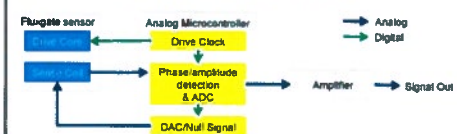

Figure 7. Diagram showing the operation of the digital magnetometer for SIGMA.

Figure 8. Electronics for the SIGMA fluxgate magnetometer.

Test Results

- Full scale range: ±52000nT.
- Resolution: 20-bit. 0.1035 nT/bit.
- Noise: 1nT/sqrt(Hz) rms (**Figure 8**): performed in a zero field environment using a high-permeability (μ) shielding case.
- Power: 360mW.

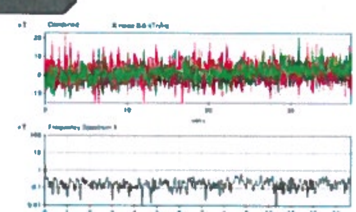

Figure 9. Noise level test results: time series (upper panel) and frequency spectrum (lower panel) in a zero field environment showing that the noise level is below 1 nT/sqrt(Hz) rms.

Future Mission: Lunar Magnetic Anomaly

- The technology obtained throughout this project will be the basis of a future deep space mission and lunar explorer.
- One of the science goals for the lunar mission is to measure magnetic anomalies on the moon using a CubeSat launched from a lunar orbiter.
- While descending along a linear trajectory to impact the lunar surface (**Figure 10**), the spacecraft will measure the fields at close ranges which have not been well explored before.

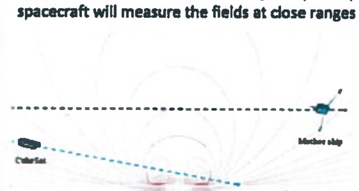

Figure 10. Trajectory of a CubeSat measuring magnetic anomalies on the lunar surface [*Lee et al.* 2014, *Garrick-Bethell et al.* 2013].

Acknowledgement

Support for the magnetometer research has been provided by NSF through grant AGS-1438419 to Virginia Tech and by NASA EPSCoR 143392 to University of New Hampshire. The CubeSat program is supported by the BK21 Plus program and NRF-2013M1A3A4A01075960 through the National Research Foundation (NRF) under the Ministry of Education of Korea.