Design and Fabrication of a Miniaturized Fluxgate Magnetometer for SIGMA and other CubeSats

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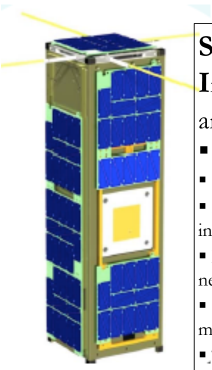


Figure 1: Drawing courtesy of the Kyung Hee University depicting the SIGMA 3U CubeSat

SIGMA: Scientific CubeSat with Instruments for Global Magnetic field and rAdiation (fig.1)

- Developed by Kyung Hee University
- 3U CubeSat with lightweight aluminum Boom
- Earth Mission: Sun synchronous, circular orbit, test instruments
- Lunar Mission: Lunar orbit, study magnetic anomalies near lunar surface
- Commissioned UNH to develop mini-fluxgate for both missions
- This sensor has already been integrated onto the SIGMA CubeSat and awaits launch (fig.10)

Drive Cores:

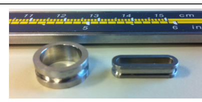


Figure 2: the two inconel cores used in the design of the sensor for the SIGMA mission

- Ring or Racetrack made of inconel (fig.2)
- Wrapped with heat treated Permalloy Ribbon
- Toroidal winding drives cores to alternating magnetic saturation
- Unique hybrid design (courtesy of H.Korth) of both a ring core (x-y axes) and a racetrack (z-axis) minimizes mass and volume (fig.3)

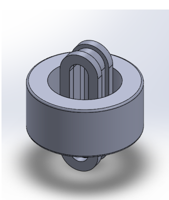


Figure 3: Solidworks assembly of the two drive cores nested to form the miniature hybrid design.

Permalloy:

- Helps to increase induce B-field in drive cores
- Heat treated to create larger magnetic domains (fig.4)
- Larger domains reduce Barkhausen effect caused by rapid change in magnetization
- Increase uniformity of saturation
- Decreases noise floor significantly

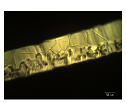
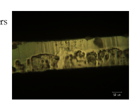


Figure 4: Permalloy after (left) 4 hours and (right) 24 hours of heat treatment. The photo on the top clearly has larger grain sizes than the photo on the left, corresponding to larger magnetic domains.



Sense Coil:

- 40 gauge Solenoid winding around each axis (up to 3 fig.5)
- Voltage difference caused by magnetic flux of drive cores will shift in the presence of an ambient B-field
- This shift is measurable and gives us information about the surround magnetic field.

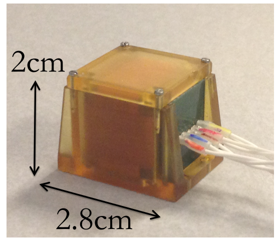


Figure 6: Photograph of the final sensor before being integrated onto the SIGMA CubeSat

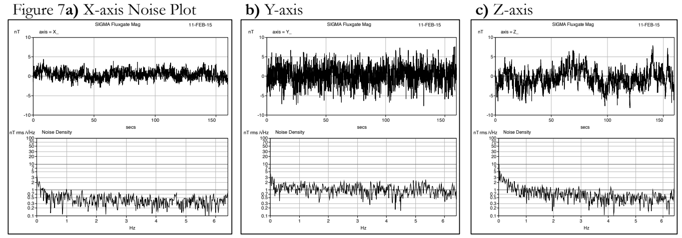
Mini-Fluxgate Results:

- Noise floor **500 pT/√Hz**
- Volume:**~2x2x2 cm³**
- Mass: **72g**
- Low Power Consumption: **< 350 mW**
- Technology Readiness Level **7**
- Relatively inexpensive to manufacture

Targeted Applications:

- Recent increase in number of smaller satellite missions
- Necessary to decrease size of instruments for smaller satellites (like SIGMA)
- Currently very few science grade fluxgate sensors that are small enoughLow Resource

Figure 7**a)** X-axis Noise Plot **b)** Y-axis **c)** Z-axis



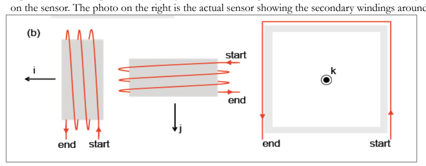
Noise:

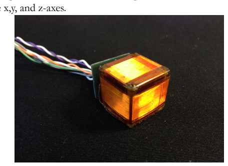
- Noise comes from the physical design of the sensor, relies on symmetry
- If sensor does not saturate in magnetization uniformly, the flux is different than expected, shifting the measured value from the true value of the B-field
- This non-uniformity can come from having many magnetic domains and asymmetry in the shape of the cores and permalloy
- Tiny asymmetries become more significant the smaller the drive cores become

Plots:

- The Cartesian axes were measured in a zeroed magnetic field to determine the noise produced by the instrument (fig7a-c)
- The top plots in each figure is the B-field [nT] vs. Time [sec]
- The bottom plots is the B-field [rms(nT)] vs Frequency [Hz]

Figure 5: The drawing on the left by Hyomin Kim showing the different direction the secondary winding must be wound in order to get the correct axes on the sensor. The photo on the right is the actual sensor showing the secondary windings around the x,y, and z-axes.





Future Work:

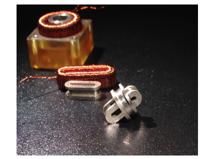


Figure 8: Photo of the new inconel cores compared to the drive cores used in the SIGMA mission.

- Acquire more permalloy to test to determine the best method to create the largest magnetic domains in order to decrease noise associated with saturation.
- Decrease the size of the drive cores (fig.8) to reduce overall volume and mass even further
- Increase the size of the dive cores in order to reduce noise associated with asymmetry

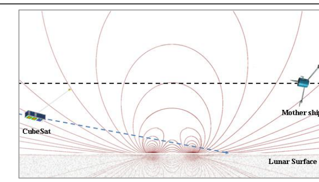
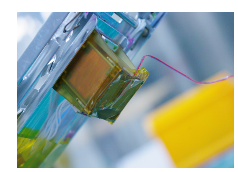


Figure 9: Depiction of the mother ship orbiting the moon and releasing the CubeSat to impact the lunar surface.

Future Missions:

- SIGMA will have a second mission to impact the moon and measure magnetic anomalies near the lunar surface (fig.9)
- Proposals in the process to include the mini-fluxgate on multiple future missions
- One mission will be to use multiple CubeSats study EMIC wave propagation near low earth orbit
- Another will be to study the magnetic anomalies associated with solar wind interaction with the magnetosphere at Mars using a CubeSat.

Figure 10: The Mini-fluxgate magnetometer being integrated onto the SIGMA CubeSat in South Korea for environmental testing



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