Design and Fabrication of a Miniaturized Fluxgate Magnetometer for SIGMA and Other Cubesats

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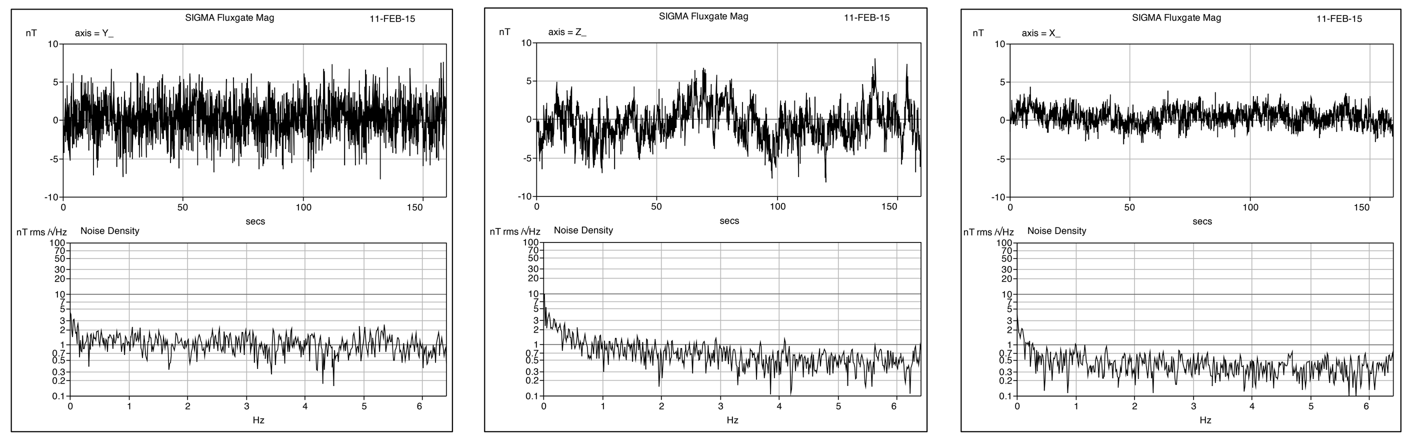
Challenges

- **Miniaturization**
  - Smaller components are fragile
  - Machine shops have limitations
  - Hybrid ring-racetrack core design reduces volume
- **Reducing the Noise Floor**
  - Small asymmetries are significant
  - Longer permalloy heat treatment creates larger magnetic domains
  - Low noise is essential for data collection



(a) (b) (c)

Figures 1a, b, and c above show the noise levels associated with the magnetometer readings. Figure 1a (far left) shows the greatest level of noise. Figure 1c (far right) shows reduced noise. The goal is to reduce noise as much as possible, in order to collect higher quality data.

Theory

- **Ambient field is perturbed with an induced B-field**
- **AC source drives cores to alternating saturations**
  - Follows a hysteresis loop
  - Saturation is a maximally induced B-field
- **The reaction in the sense coils is measured**
  - Voltage difference is proportional to change in B-field
  - This relation is used to determine properties of the ambient field

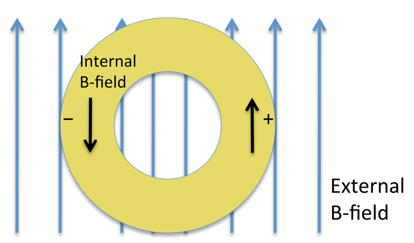


Figure 2: the ambient magnetic field shown against the drive core's induced magnetic field

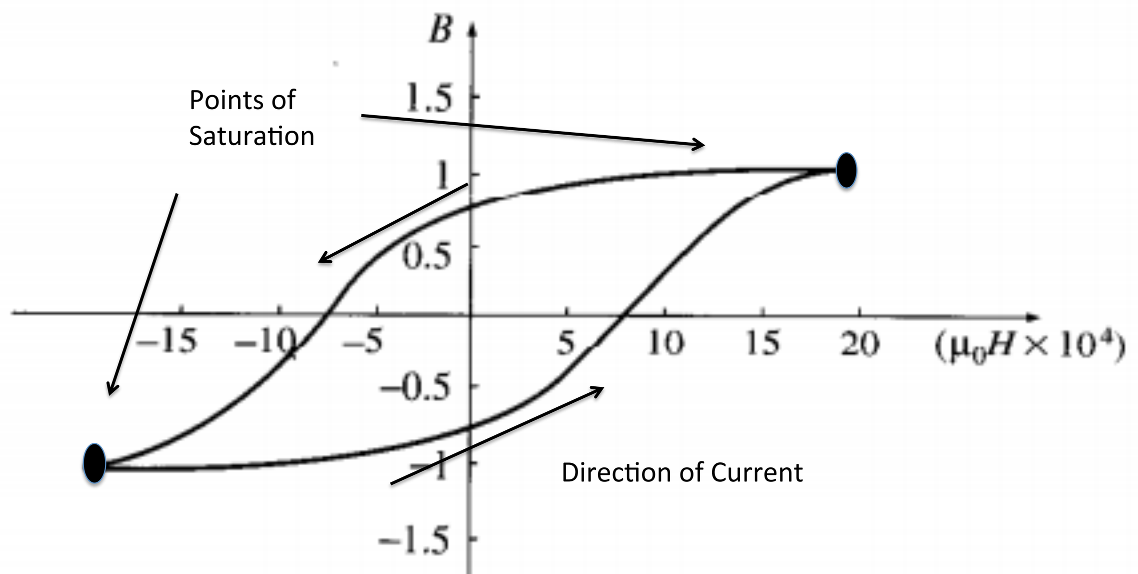
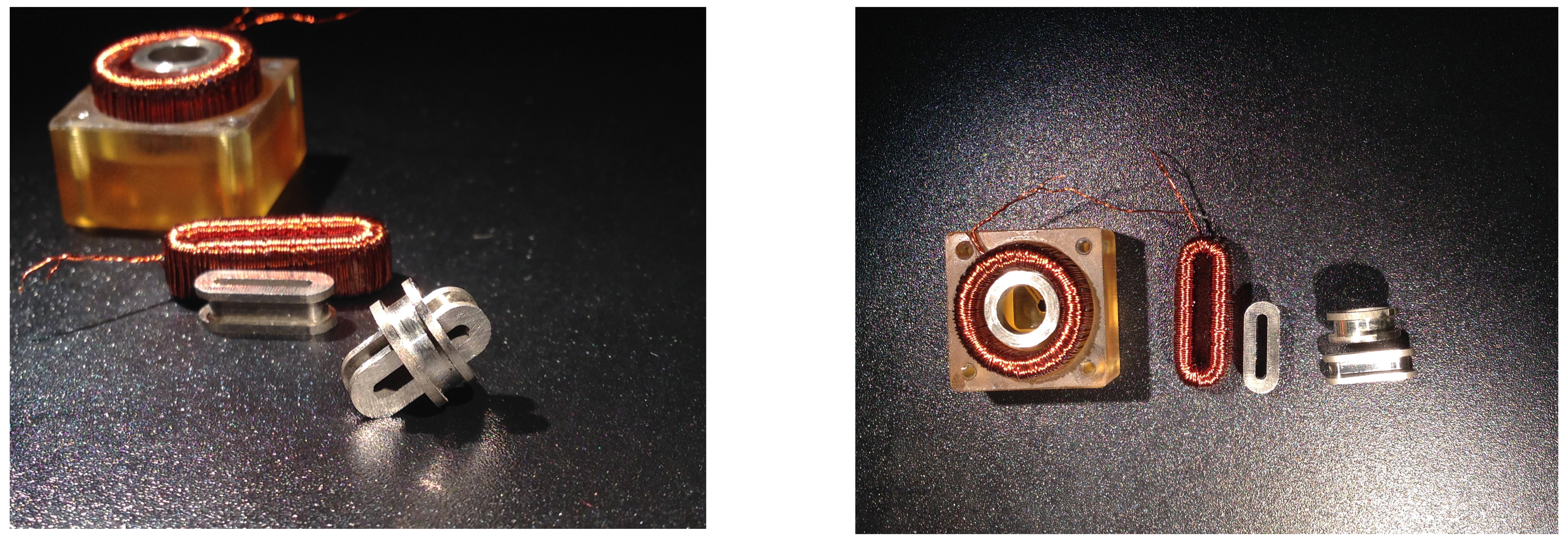


Figure 3: Hysteresis loop showing the paths to saturation (D. Griffiths, *Introduction to Electrodynamics,* 3rd ed. Chap.6 (New Jersey: Prentice Hall 1999))

Design

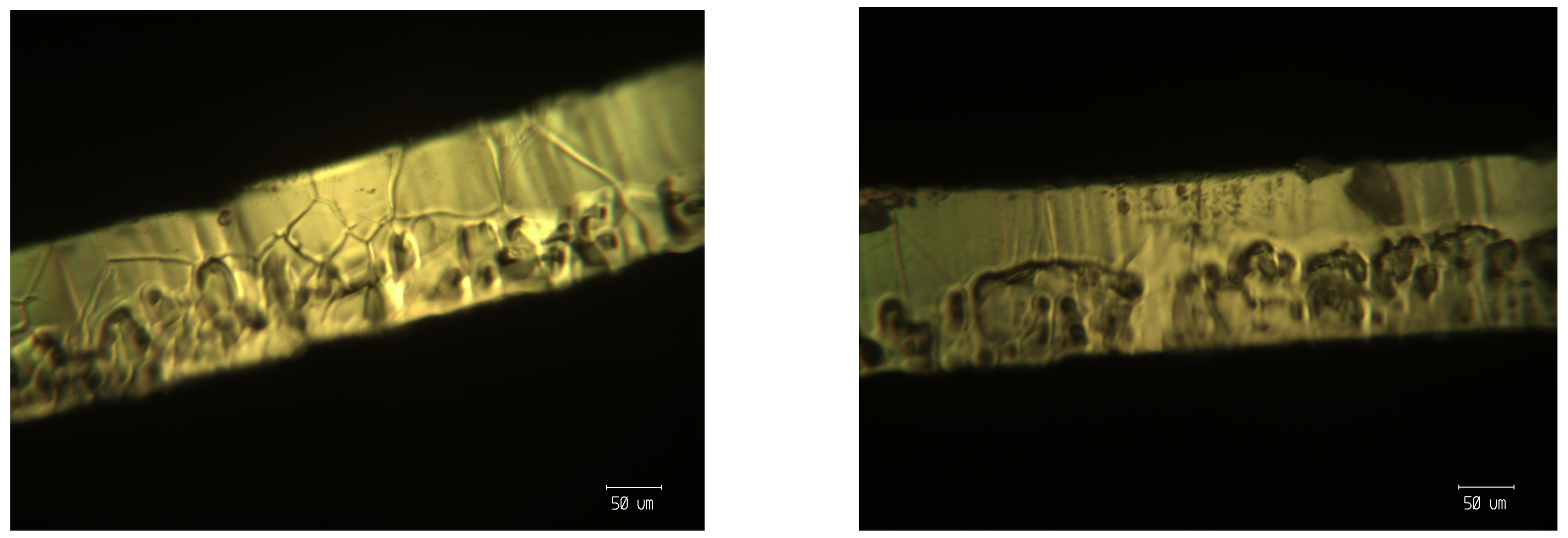
- **Drive Cores**
  - Ring or racetrack made of inconel (nickel-chromium based alloy)
  - Wrapped with heat-treated permalloy ribbon
  - Toroidal winding drives cores to alternating magnetic saturation
  - Hybrid ring-racetrack core design minimizes mass and volume
- **Sense Coils**
  - Two 40 gauge solenoid windings around each core
  - Voltage difference caused by magnetic flux of drive cores will shift in the presence of ambient B-fields
  - This shift is measureable and provides information about the surrounding magnetic field



(a) (b)

Figures 4a and b show the miniaturized ring and racetrack cores in comparison to their larger predecessors. Figure 4a (left) shows how the ring and racetrack cores sit together in the magnetometer. The larger ring cores are shown in half their housing unit; the adjoining piece connects with pegs to the four holes drilled in the housing piece shown.

- **Permalloy**
  - Helps to increase the induced B-field in drive cores
  - Heat treated to create larger magnetic domains
  - Larger domains reduce Barkhausen effect caused by rapid change in magnetization
  - Increases uniformity of saturation
  - Decreases the noise floor significantly
  - Nickel-iron alloy



(a) (b)

Figures 5a and b show permalloy after heat treatment. Figure 5a (left) shows permalloy after four hours of heat treatment. Figure 5b (right) shows permalloy after 24 hours of heat treatment. Heat treating the permalloy for longer periods of time at greater temperatures helps to create larger magnetic domains. This process significantly reduces the noise floor and increases the induced magnetic field in the drive cores.

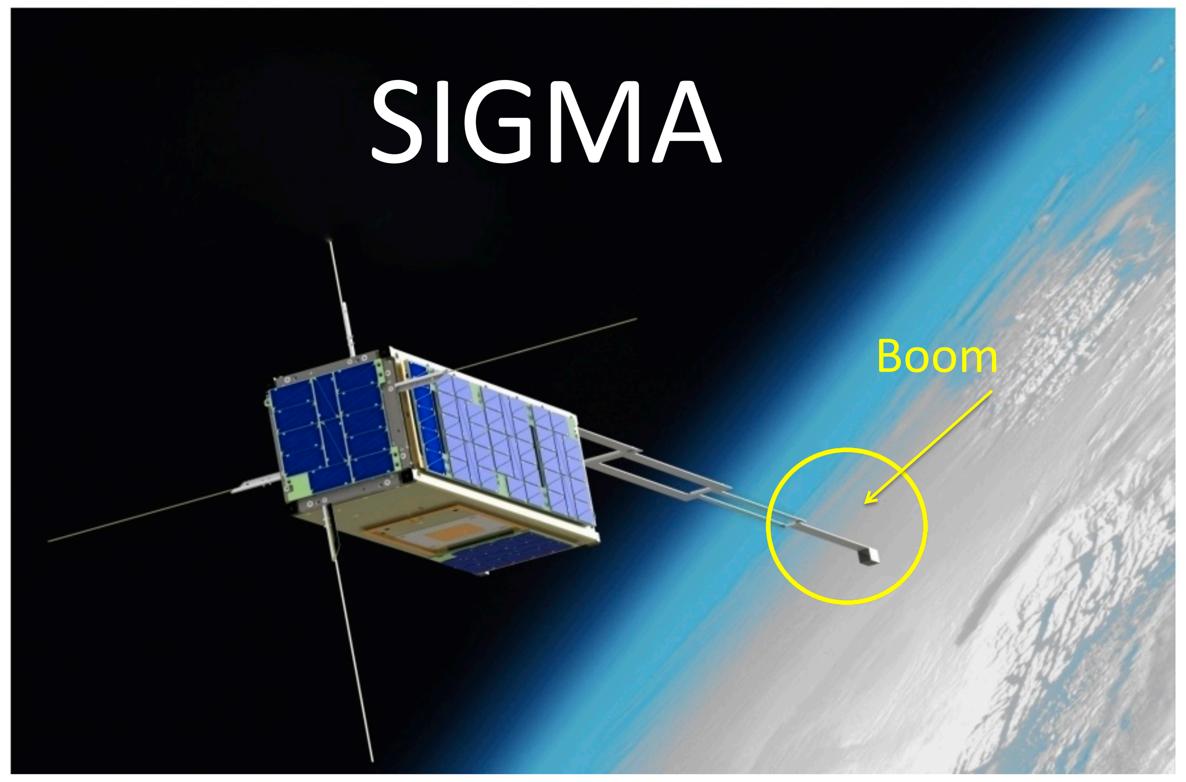


Figure 6: A visual model of the cubesat being developed by the Kyung Hee University in South Korea. The boom highlighted is where the magnetometer will be placed, away from the electronic noise of the satellite.

The Mission

- **Scientific Cubesat with Instruments for Global Magnetic Field and Radiation**
  - Developed by South Korea's Kyung Hee University
  - Magnetometer must be small enough to be mounted on SIGMA's lightweight boom
  - Part of a larger mission to investigate lunar magnetic anomalies
- **Goal**
  - Mother ship will orbit the moon
  - Cubesat will be launched to impact lunar surface
  - The lunar magnetic field will be measured at close proximity
  - To be launched by 2020

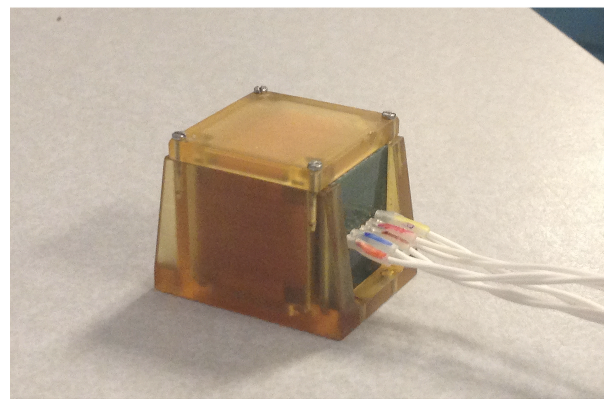


Figure 7: the complete sensor is shown wired into its housing unit. This is how the magnetometer will appear when installed in SIGMA.

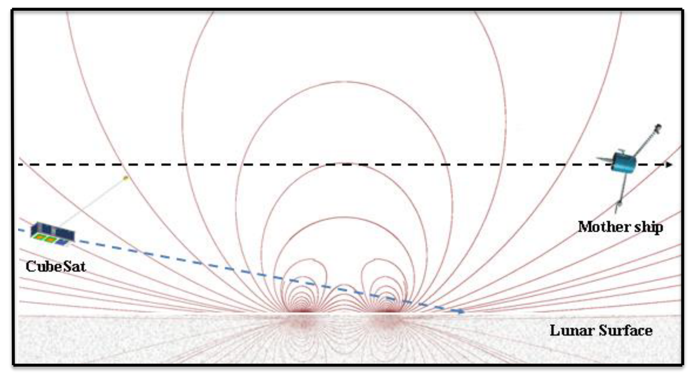


Figure 8: Visual representation of the path to be taken by the cubesat into the lunar surface.

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