# Design and Performance of the AERO-VISTA Magnetometer

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*08-06-2022*

# Presentation Overview

1. Background and Design Constraints
   - Requirements
   - Magnetometer Device Selection
2. Design
   - Block Diagram
   - Component Selection
   - Expected Performance
3. Measured Performance
   - Across Operating Modes

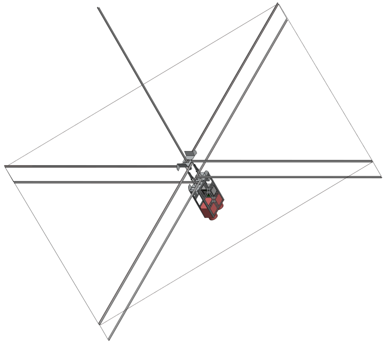
# 1. Background + Design Constraints

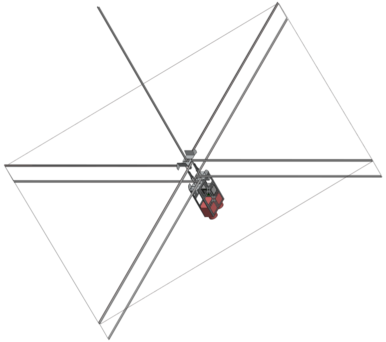
[1]

# Motivation

## Magnetic Sensing

- Attitude Determination
- Remote Sensing
    - Planetary Science
    - Space Weather





## AERO-VISTA

- Pair of 6U CubeSats
- Measure the Radio Aurora
    - 0.1 MHz – 15 MHz
- Determine RF propagation modes w.r.t. local magnetic field
- Compare measured B-field to magnetic maps to identify field aligned currents
    - Contextualizes RF science observations

# Design Goals

Need a steady-state magnetic sensing technology

## Requirements

System Precision: 100 nT

Angular Accuracy: 10°

Sample Rate: 10 Hz

## Design Targets

SWaP: Size, Power

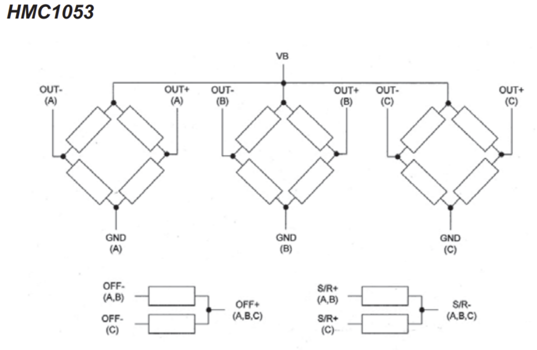
"Do no harm": EMI

Requirements → Repeatability + Noise Error (Precision)

| Parameter | Target |
|---|---|
| Size | <60 cm^3 or 20 cm^2 of PCB per 3-axis sensor |
| Power | <100 mW per 3-axis sensor |
| EMI | Electromagnetic interference (EMI) emissions below that already created by the spacecraft bus |
| Flight Heritage | Technology flown on previous small satellite mission (preferably CubeSat) |
| Repeatability + Noise Error (Precision) | 50 nT or better |

# HMC1053

- Honeywell HMC1053 Anisotropic Magneto-Resistive (AMR)
  - 3 orthogonal measurements
  - Analog small-signal differential output
    - Set/reset pulses swap polarity
  - Steady state operation -> low EMI
- Other programs (see ANDESITE or CINEMA) have used AMR for ~10 nT precision missions

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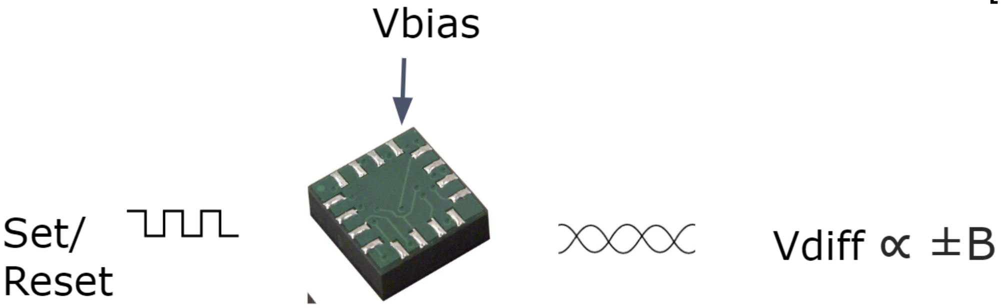
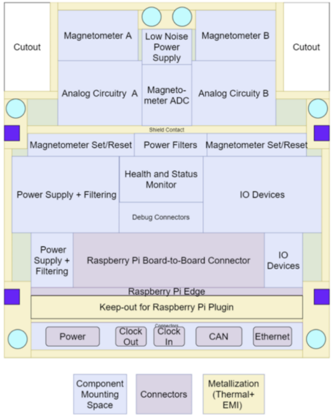
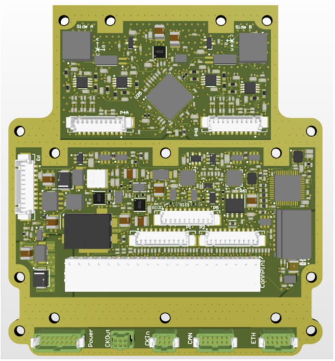
Implement circuitry around this component and preserve its performance.



AERO VISTA

# 2. Design



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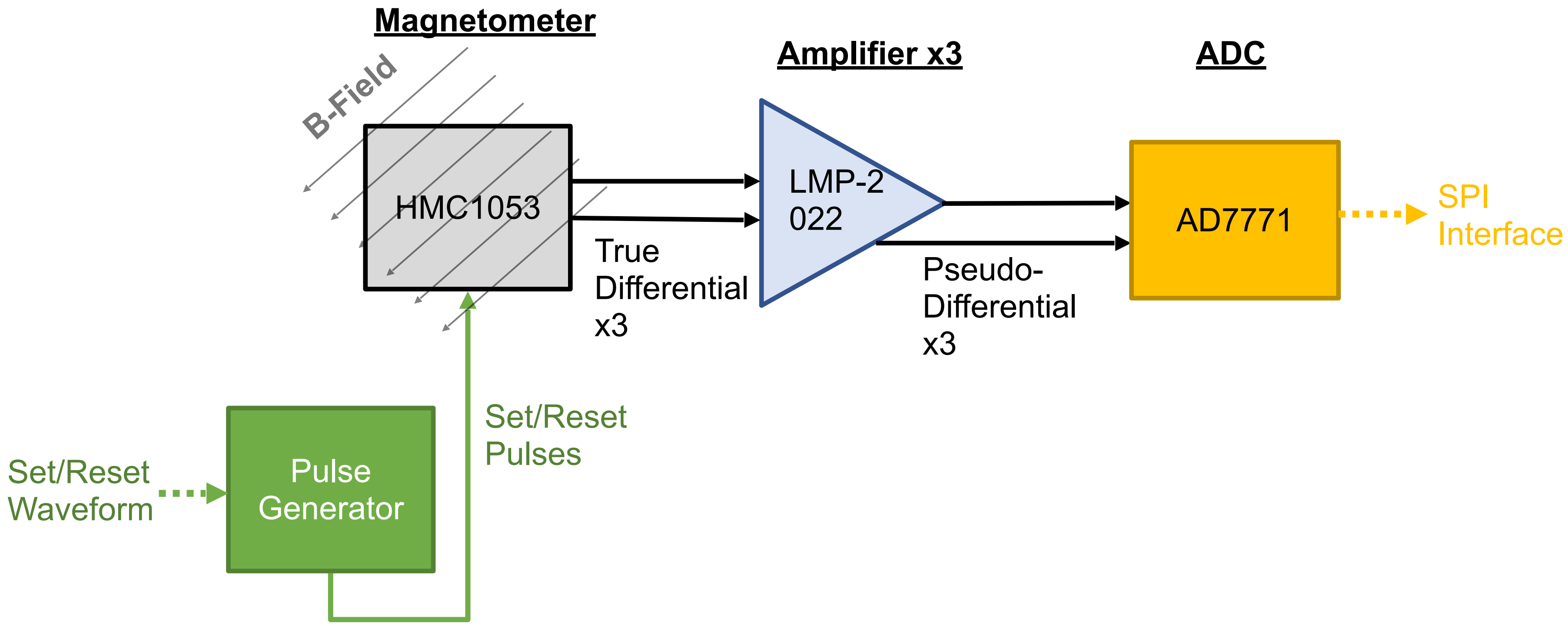
# Block Diagram



# Component Selection

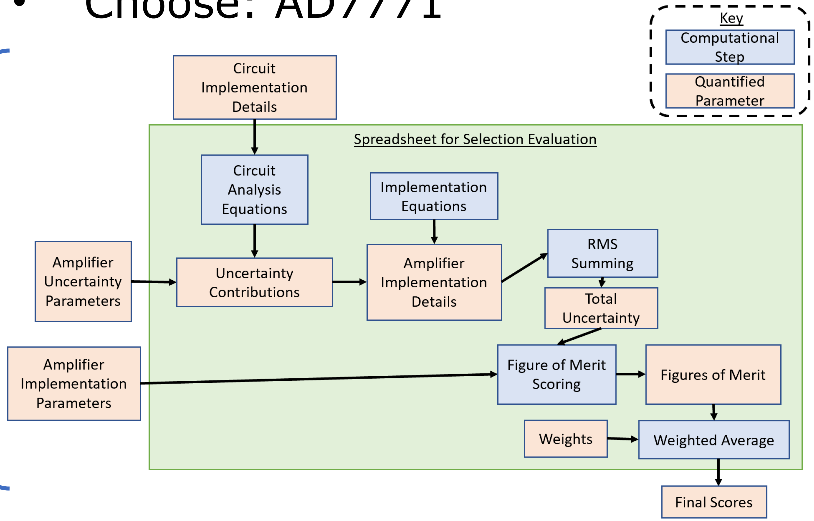
## Pre-Amplifier

- Parameterized fitness in four categories:
  1. Supply Voltage
  2. Power
  3. PCB Area
  4. Magnetic Uncertainty
- Choose LMP2022

Components convert small-signal analog output to digital interface

## ADC

- Simultaneous sampling
- >14 bit for dynamic range
- Low added uncertainty
- Choose: AD7771



# Implementation

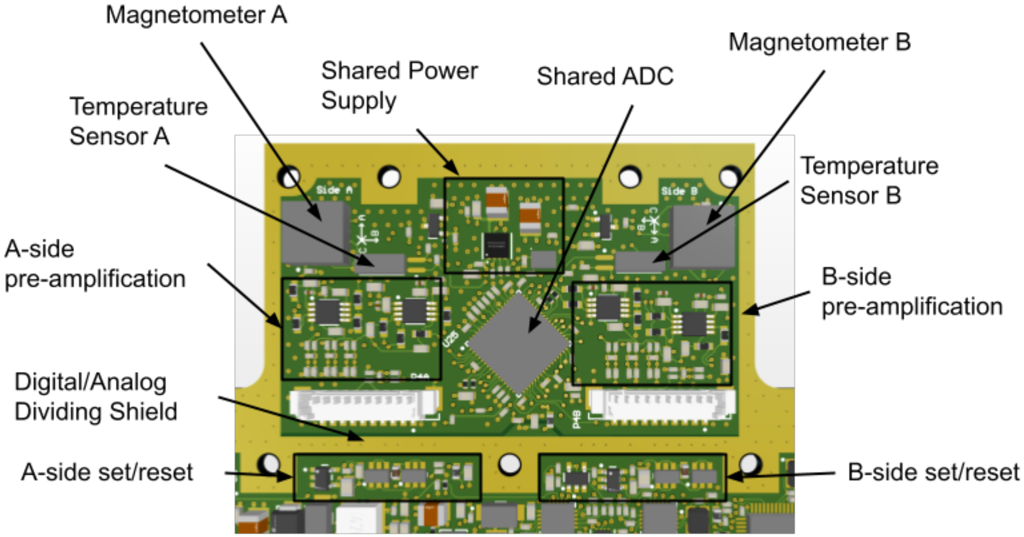
## Schematic Capture

**Magnetometers**
- ADC
- Bias Voltage

**Magnetometer Channel**
- Magnetometer
- Temp Sensor
- Pre-Amplifiers
- Set/Reset Switch

**Pre-ADC Filter**
- 50 Hz LPF

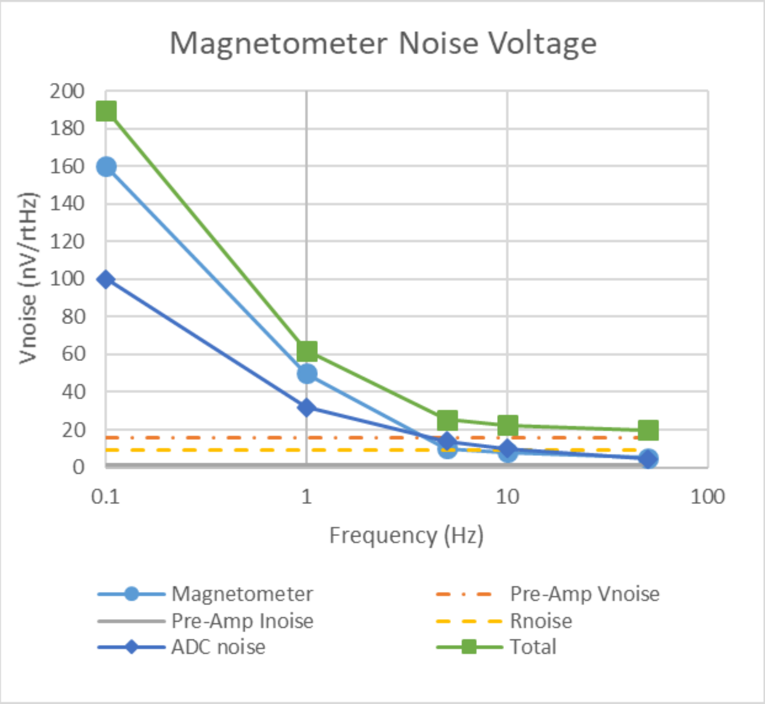
## Layout




[3]

# Expected Performance

- Analyze amplifier-input-referred noise contributions
- RMS summing / integration over frequency
  - 0.42 uVrms
  - 10. nTrms
- High frequency floor dominated by pre-amp
  - 0.4 $\mathrm{nT}/\sqrt{\mathrm{Hz}}$

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Expect to meet noise requirement by analysis

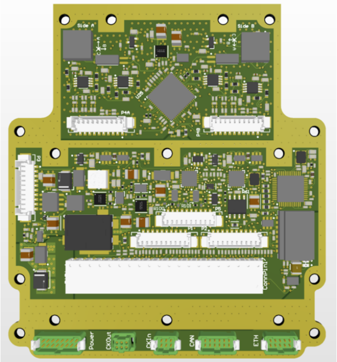
# Instrument Integration

AERO VISTA

## Auxiliary Sensor Package (ASP)

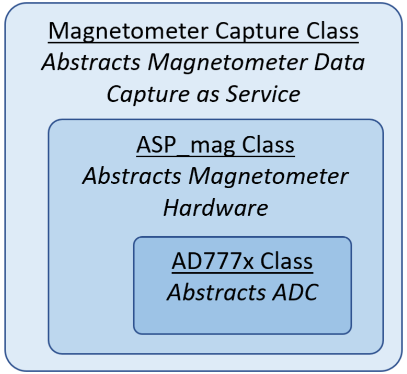
### Full PCB

- Raspberry Pi
- Power Supplies
- IO



### Software

- Python
- Layers of abstraction




### Enclosure

- Mechanical Support
- EMI Shields

Camera

[3]

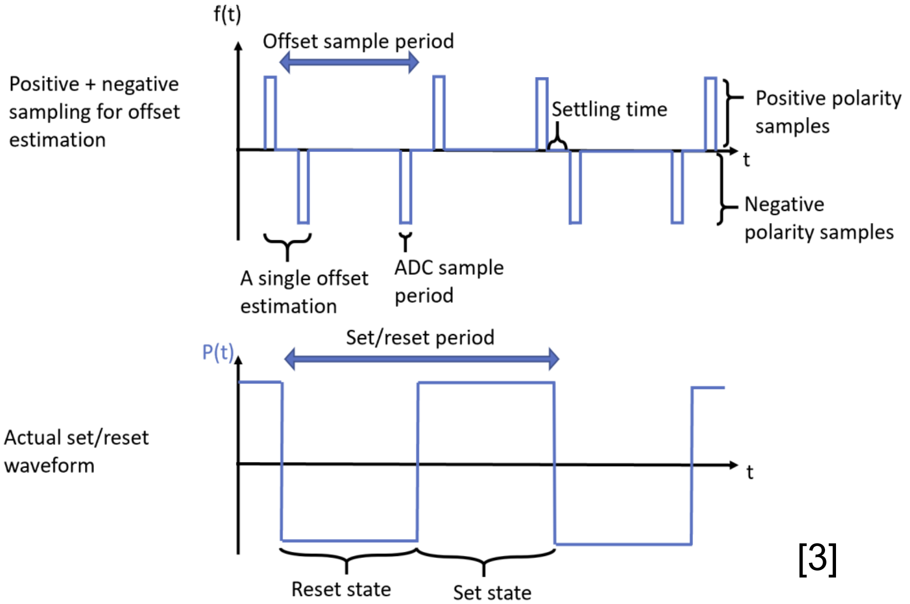
# Set/Reset Offset Calibration

$$M(t) = B(t) + O(t)$$

$$M(t) = P(t) * B(t) + O(t)$$

$$M(t) = P(t) * B'(t) + O'(t)$$

$$B(t) \approx B'(t) = \frac{M(t) - O'(t)}{P(t)}$$

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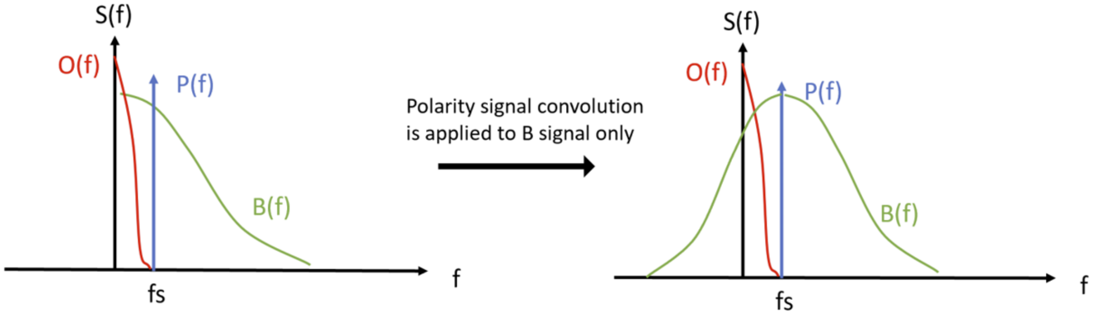
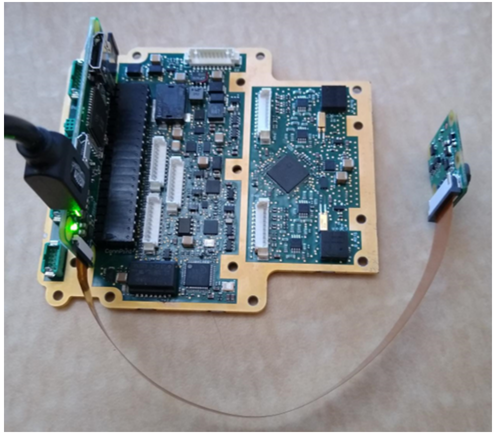


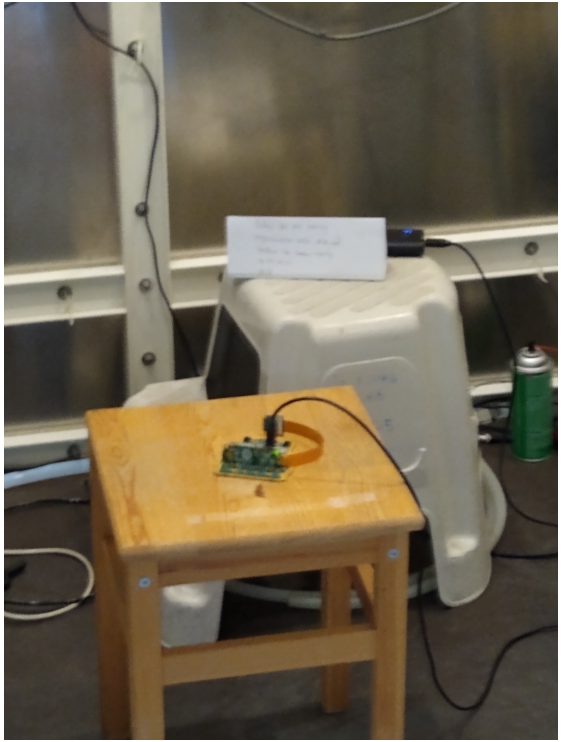

Switching polarity of B-field sensitivity can remove static instrument offset

# 3. Measured Performance



# Measurement Setup

- Engineering Model
- Mu Metal shielded room
  - 40 dB attenuation at 0.1 Hz
  - Expect noise below 10 nTpp



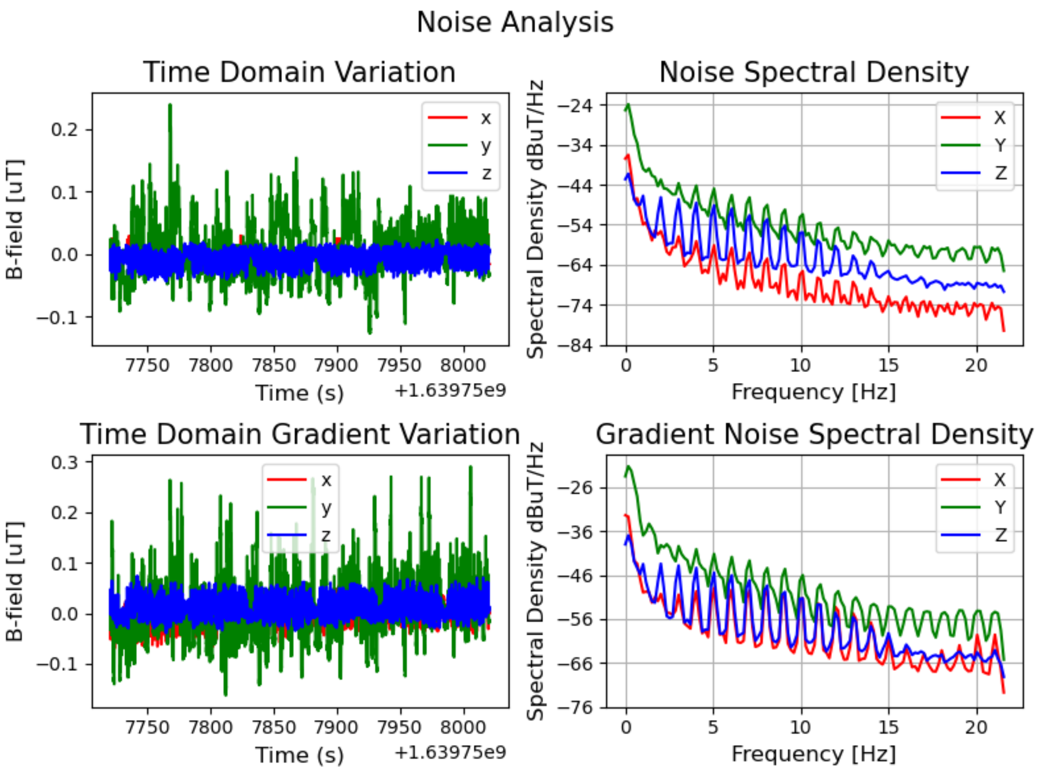
# Noise Performance

## Magnetometer Only

Channels

A

A-B

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# Noise Performance

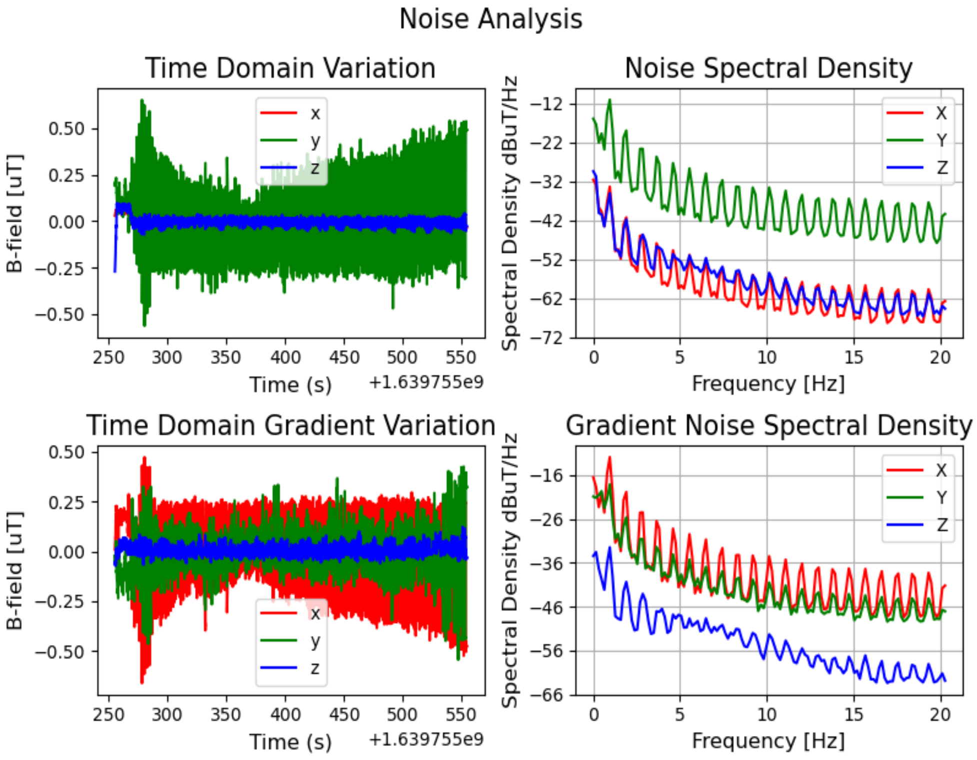
## Camera + Magnetometer

DC to 10 Hz Noise [nTrms]

| Operation | X | Y | Z |
|---|---|---|---|
| Magnetometer Only | 8.6 | 44 | 8.1 |
| Magnetometer + Camera | 20. | 196 | 25 |

A

A-B




Excess noise can be mitigated in operation

# Instrument Summary

| | |
|---|---|
| Configuration | 3-Axis |
| Independent Magnetometers per Instrument | 2 |
| Inter-Magnetometer Distance | 5 cm |
| Digital Interface | SPI + Set/Reset Input Signal |
| Supply Voltage | 5 V |
| Magnetometer Power | 160 mW total |
| Data Rate (nominal) | 50 SPS |
| Size | 20 cm^2 single-side placement PCB |
| Noise Floor | 10 to 200 nTrms depending on mode and axis |

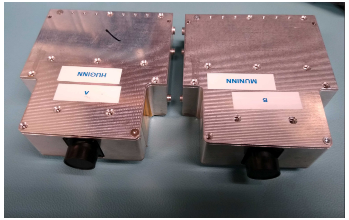
# Conclusion

## Summary

- Design with HMC1053
  - Wheatstone-bridge-like
- Choose Op-Amp and ADC for minimum noise
- Excess noise to be mitigated with conops
- All requirements met

## Next Steps

- FM instruments currently being assembled
- Expect integration with AERO + VISTA Q3 this year
- Launch of AERO-VISTA N.E.T end of 2023
- To be developed for other small sat applications?



# Image Sources


[1] NASA. 2020. *Stunning Aurora From Space*. [online] Available at: <https://www.nasa.gov/image-feature/goddard/2016/stunning-aurora-from-space>

[2] HMC1053 Datasheet. *Honeywell* Available at: https://media.digikey.com/pdf/Data%20Sheets/Honeywell%20PDFs/HMC1051,52,53.pdf

[3] N. Belsten, "Magnetic Cleanliness, Sensing, and Calibration for CubeSats," thesis, Massachusetts Institute of Technology, Cambridge, 2022.


Questions, comments?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