NanoSAM II

Nano-Stratospheric Aerosol Measurement

Preliminary Design Review

September 13, 2020

Ball Aerospace – & – University of Colorado Boulder Department of Aerospace Engineering Sciences

Agenda

- Project Description
- Evidence of Baseline Feasibility
    - Enclosure
    - Electronics
    - Software
- Status Summary & Remaining Studies

Project Description

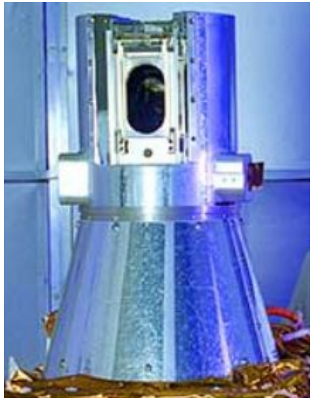
Abby Hause

Previous Work and Heritage

SAM II
(1975-1996)

First attempt at stratospheric aerosol measurement on orbit

SAGE I, II, III
(1979-2020)

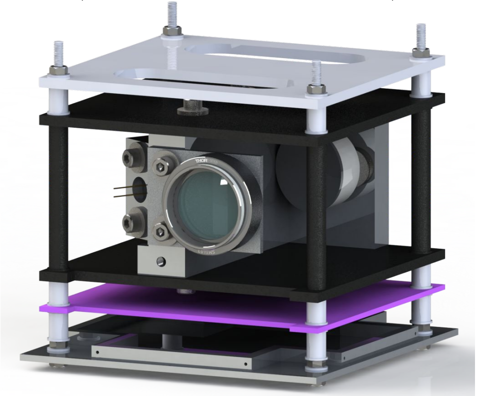


Measures multiple wavelengths

Large & expensive

Data quantity limited by orbital period

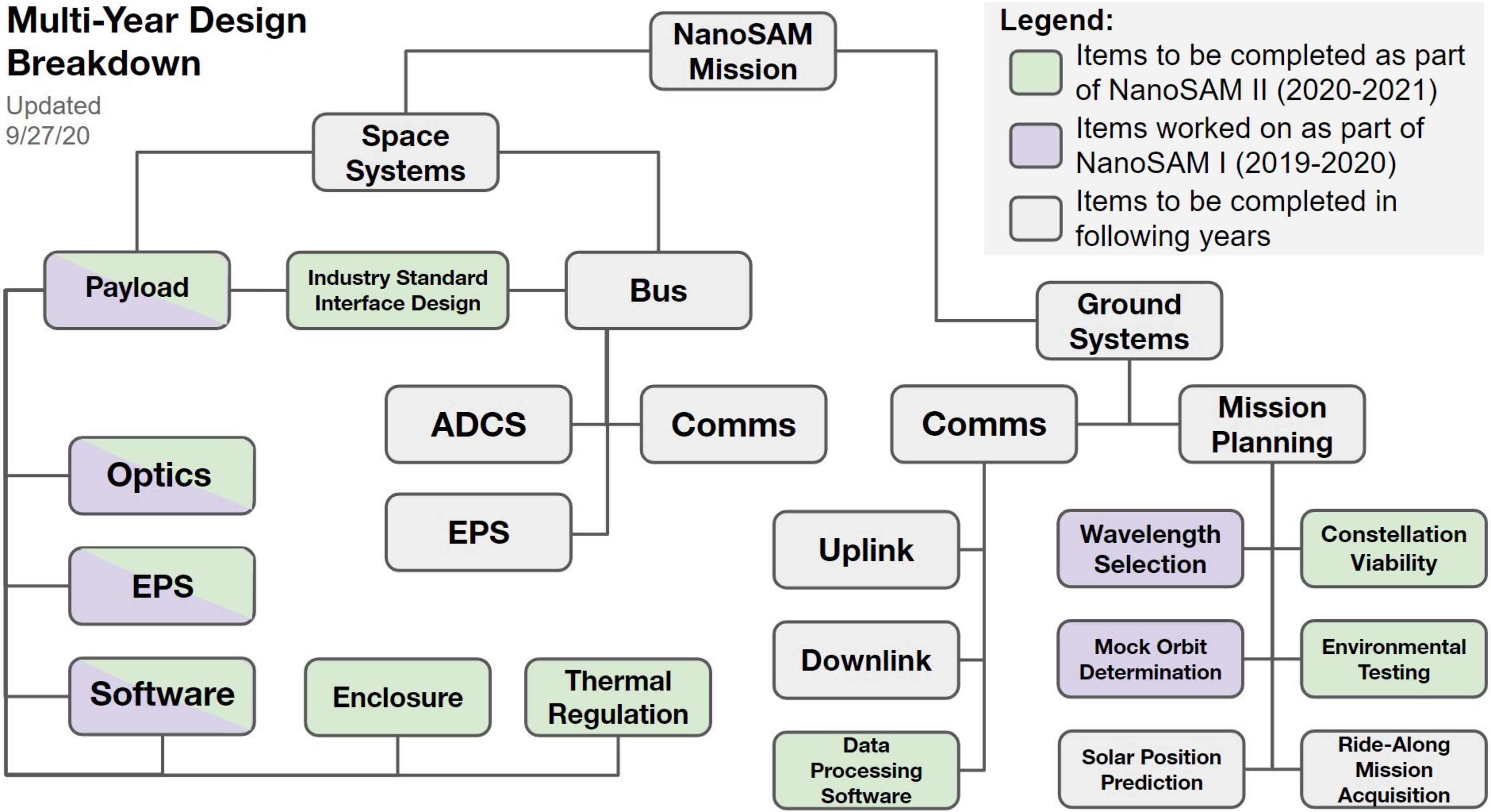
NanoSAM I
(2019-2020)



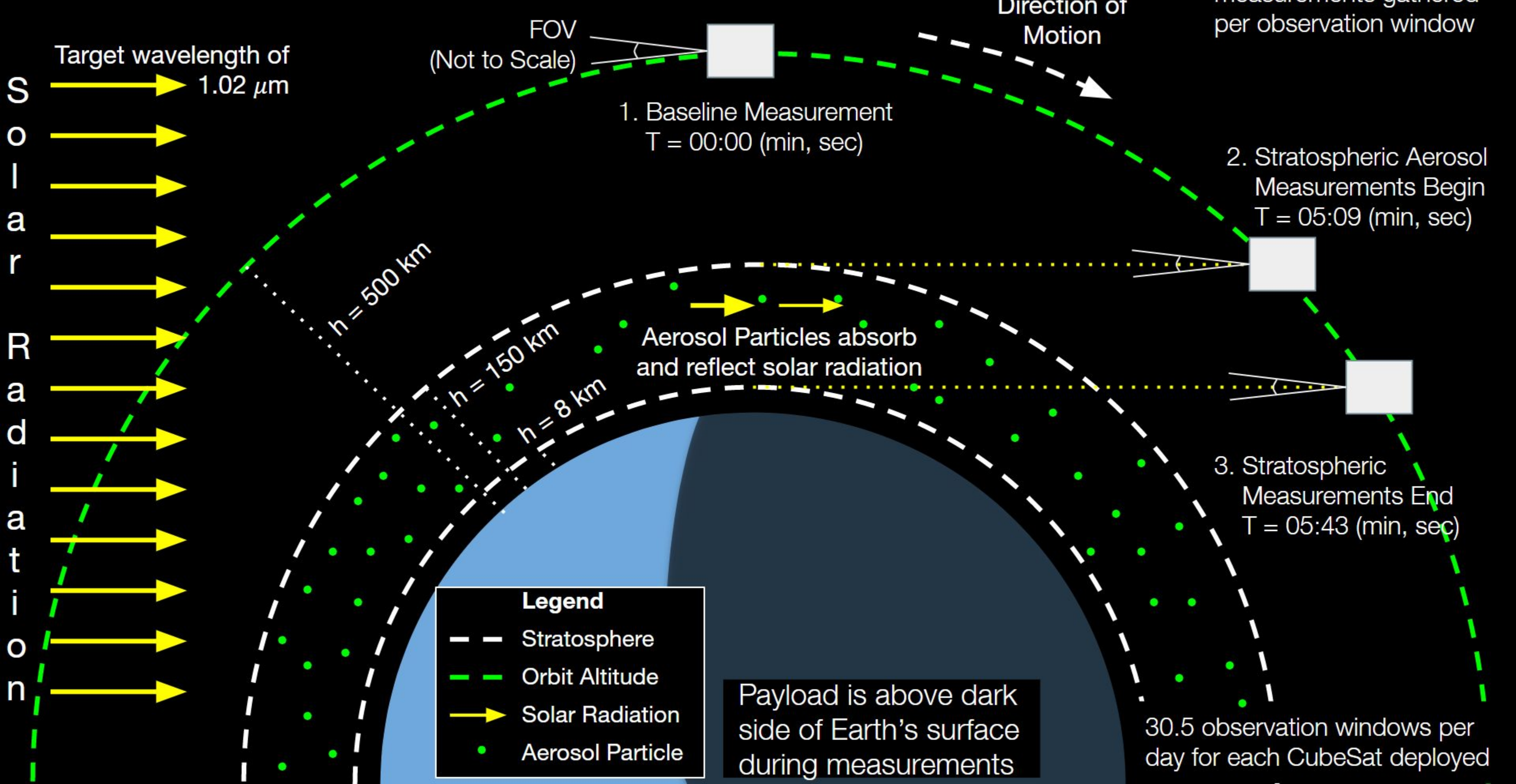
Developed an optical system to meet or exceed the capabilities of SAM II in a CubeSat footprint

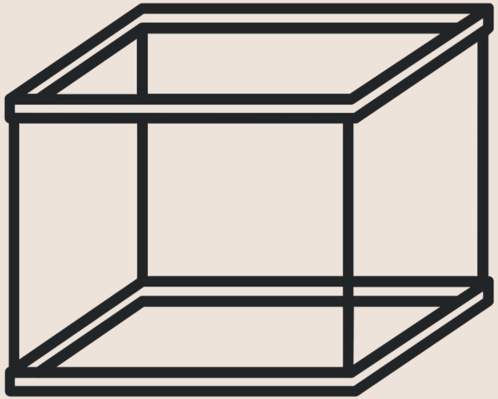
Multi-Year Design Breakdown

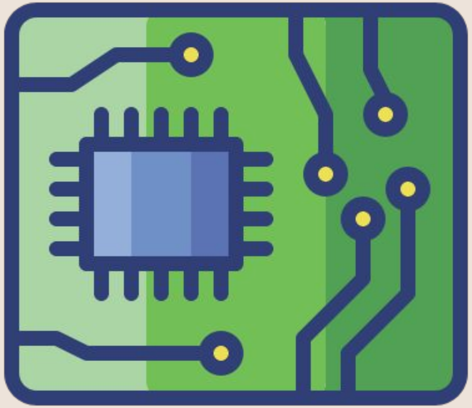
Updated 9/27/20

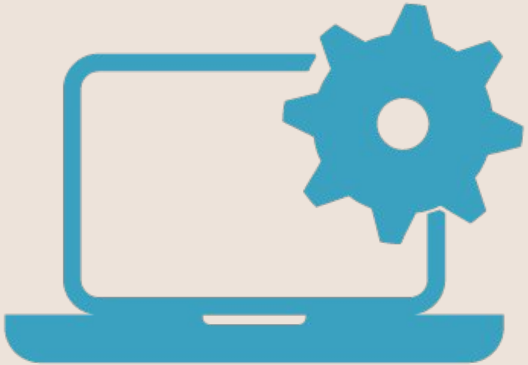


NanoSAM Mission CONOPS







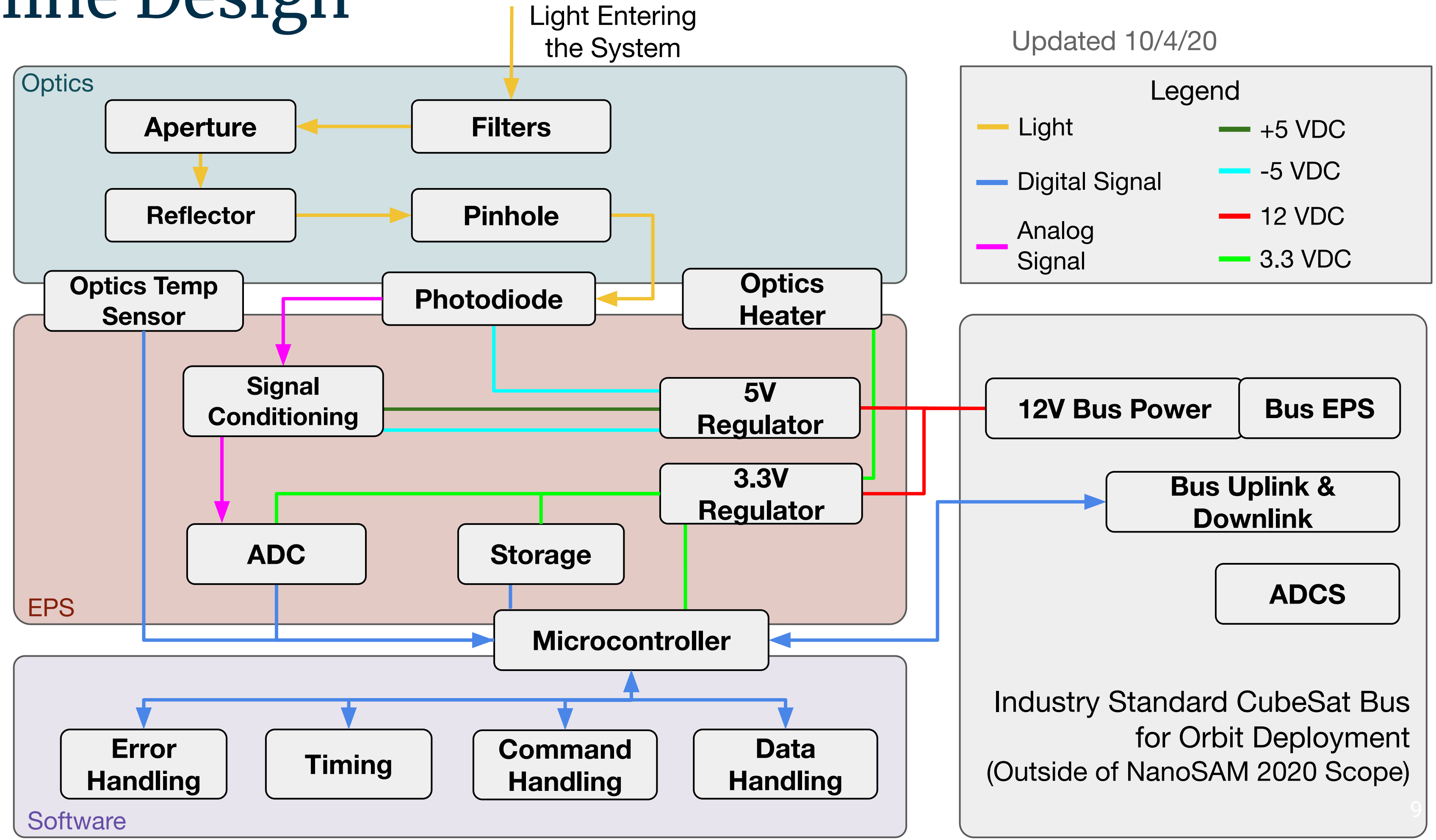


Objectives

Functional Requirements

1	**Data Capture**	The supporting electronics and software shall digitize, packetize, and store housekeeping data and information collected from the photodiode.
2	**Communications**	The supporting electronics and software shall communicate digitized data to aground computer during testing, and to a standard bus for downlink during on-orbit operations.
3	**SAM-II Equivalent Optics**	NanoSAM II shall have optical performance capabilities that are equivalent to or surpass that of SAM-II.
4	**Payload Dimensions**	The payload shall have dimensions to allow for integration with an industry standard CubeSat bus in future years
5	**Flight Testing**	All payload components shall maintain their design requirements through space environment testing
6	**Cost**	The project shall limit all spending to a budget of $5,000.

Baseline Design



Electronics

Jashan Chopra

Relevant Requirements

1.0: Data Capture

- Communicates via photodiode with optical bench
- Samples, processes, and stores data at a rate greater than 50 Hz
- Data is collected in a 10 bit resolution
- Enough storage space for downlink periods
- Housekeeping data is stored (temperature, power usage)
- The system uses less than 8W

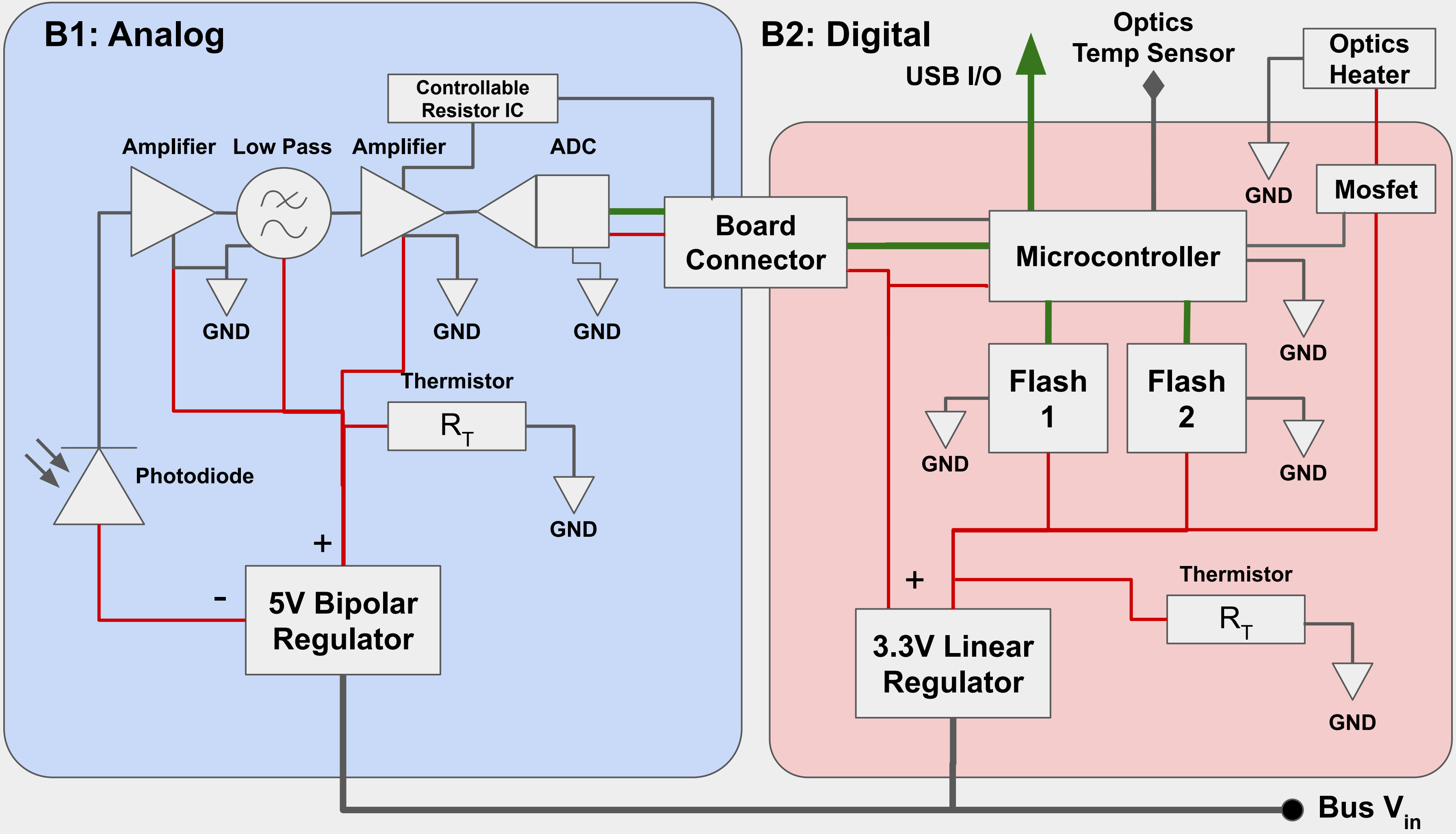
2.0: Communications

- Comms with laptop for ground testing, standard bus system for flight
- Signal to noise ratio greater than 3500

4.0: Payload Dimensions

- Payload size must be less than 0.5U
- Payload mass less than 0.615 kg

- Photodiode attached via twisted pair shielded wire
- 16 bit ADC, 833 Hz sampling
- External Flash provides 256 Mb of space
- Thermistor temperature monitoring
- Analog inputs on microcontroller for other housekeeping
- USB I/O for testing and bus communications



B1: Analog
Controllable Resistor IC
Amplifier
Low Pass
Amplifier
ADC
GND
GND
GND
Thermistor
R_T
Photodiode
GND
+
-
5V Bipolar Regulator
B2: Digital
USB I/O
Optics Temp Sensor
Optics Heater
GND
Mosfet
Board Connector
Microcontroller
GND
Flash 1
Flash 2
GND
GND
+
Thermistor
R_T
3.3V Linear Regulator
GND
Bus V_{in}

Key Characteristics

Used Surface Area
(worse case scenario)
~ 5044.43 mm^2

~ 56 % of
Total Space
(9000 mm^2)

2x (S.A of all parts +
5x minimum clearance +
2x trace estimate)

Estimated EPS Cost
(worse case scenario)
~ $581.86

11.6% of
Total Budget
($5,000)

2x individual parts +
estimated board cost + $50

Required Storage Space
(worse case scenario)
~ 6.36 Mb

2.2% of
Total Storage Space
(280 Mb)

Science Data: 0.916 Mb
Housekeeping: 5.44 Mb

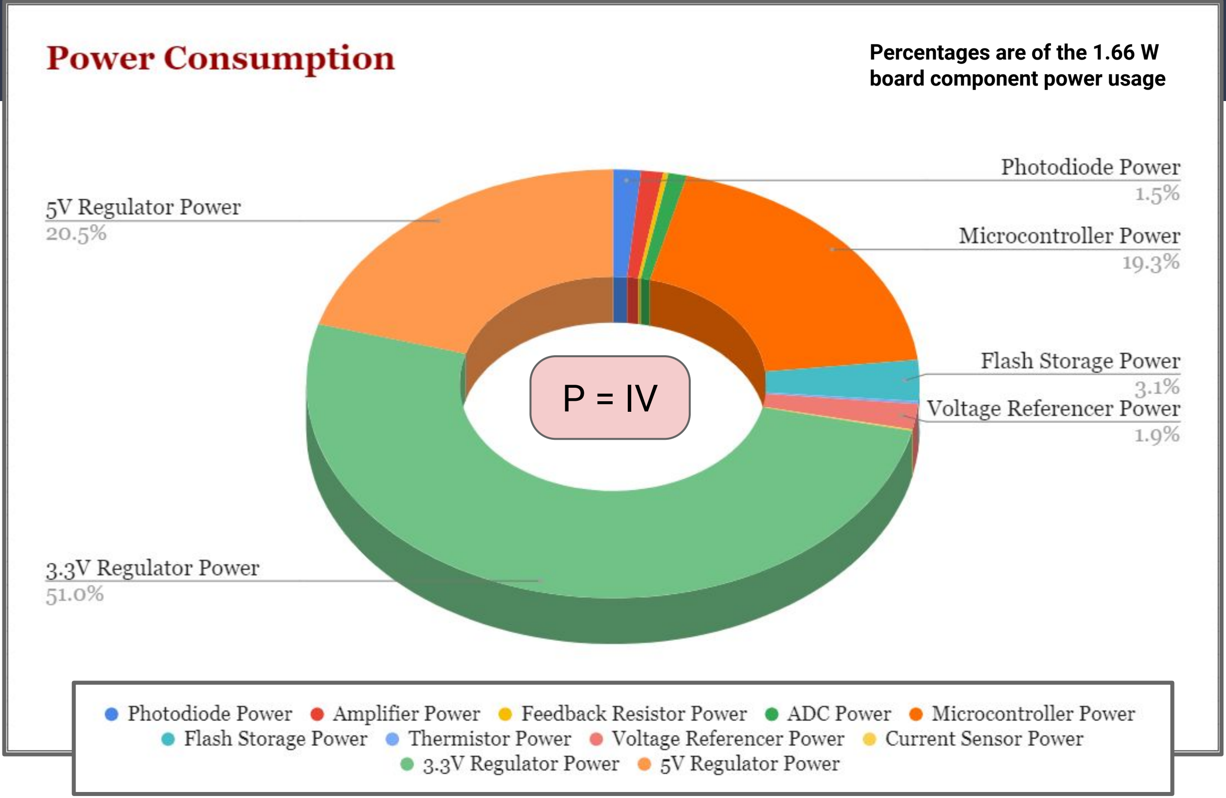
Power Budget

Power Requirement
8 W

Estimated Power Usage
(worst case scenario)
~7.17 W w/ heater
~1.66 W w/o heater

Power Usage Ratio
89.6%

Power estimates for digital I.C's are based off maximum DC characteristics, and are not representative of the typical power draw, merely the maximum possible at any given point



Signal to Noise Ratio (SNR)

Estimated Range

Required SNR
3500

Estimated SNR

10924	(ADC calibrated)
5531	(backup ADC)
1631	(no correction)
656	(worst-case)

SNR Ratio
19% to 312%
(Estimate / Requirement)

Noise Sources [ref. 5]

Photodiode
Dark Current
Johnson Noise
Shot Noise
1/f noise

Circuitry / Transmission
Loss in op-amp
5V Regulator Uncertainty
Quantization noise (ADC)
ADC Offset Noise

Enclosure

David Perkins & Danny Barth

Relevant Requirements

4.0: Payload Dimensions

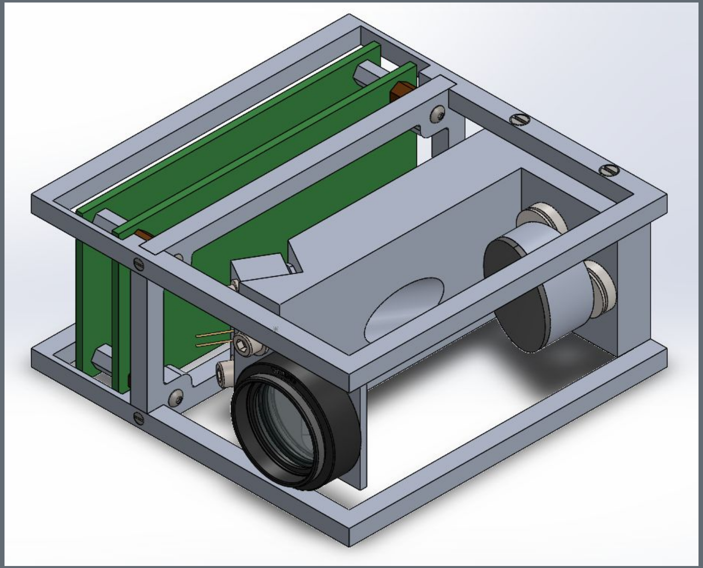
- Payload size must be less than 0.5U
- Payload mass less than 0.615 kg

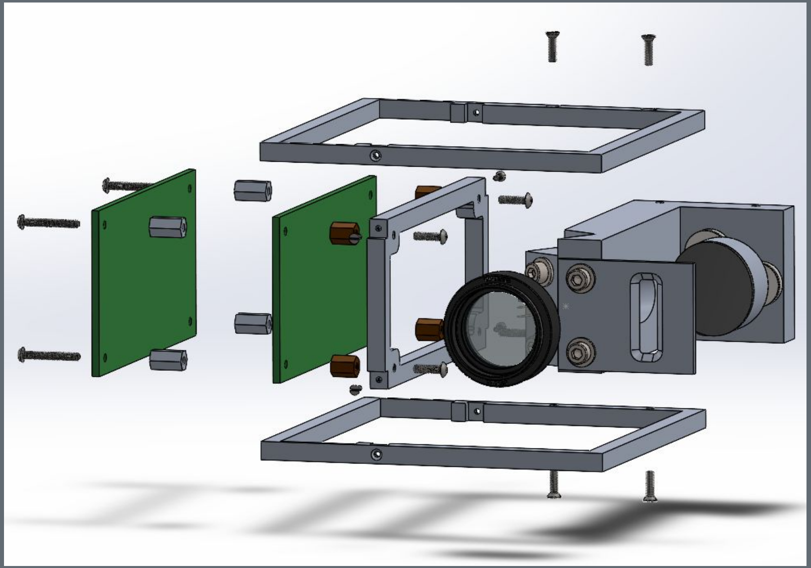
5.0: Flight Testing

- Payload maintains functionality in space
- Payload can survive vibrational, thermal, and vacuum testing
  - No resonant frequencies below 100Hz [1]
  - Survives a temperature range of -20°C to 50°C [1]

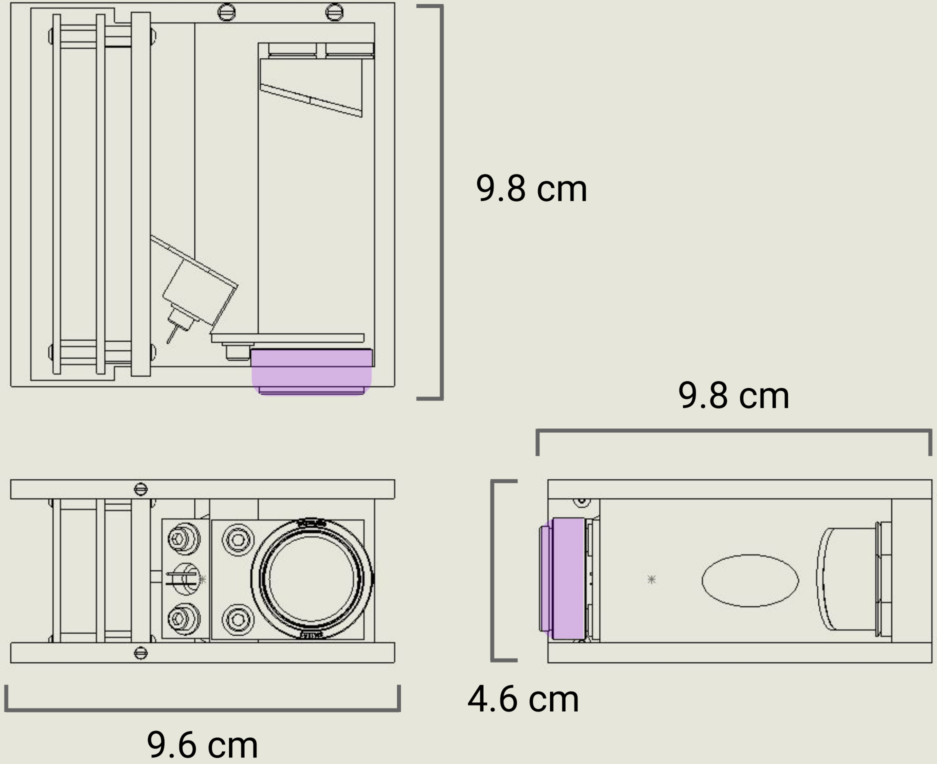
- Current dimensions: 9.6cm x 9.8cm x 4.6cm
- Current mass of .276kg w/o filter or light-blocking walls
- Estimated Maximum Total Mass: .450kg
- Lowest resonant frequency: ~385Hz
- $P_{heater,max}$ = 5.46W
- $425 (Projected, 2.5x FOS)

Enclosure – Structural Model Baseline





Enclosure - Structural Model Baseline



Proof Of Concept

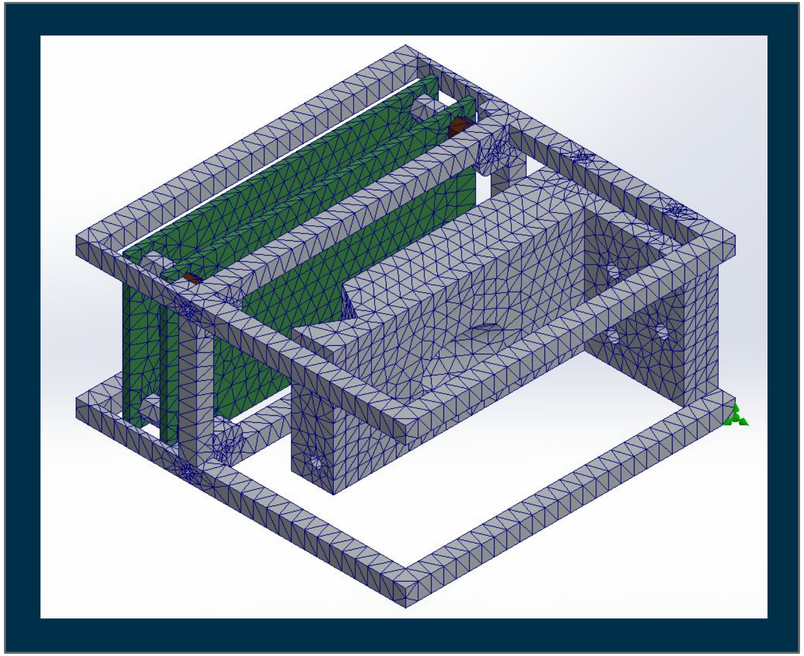
- Size without final structural walls fits within 0.5U
  - 0.5U = (10cm x 10cm x 5cm)
  - Size = (9.6cm x 9.8cm x 4.6cm)

- Filter mounts flush with a 2mm thick external wall

Enclosure – Structural Model

Resonant Frequency Preliminary Study

- Meshed in Solidworks
  - Removed any threads or interfacing screws
  - Two contact methods analyzed
    - Screws → Pin Joints
    - Autointerface
- Boundary Conditions
  - One fixed corner (green on right)
  - Expect these to evolve, but current results demonstrate feasibility



Simplified Finite Element Model

Structural Model – Vibrational Simulation

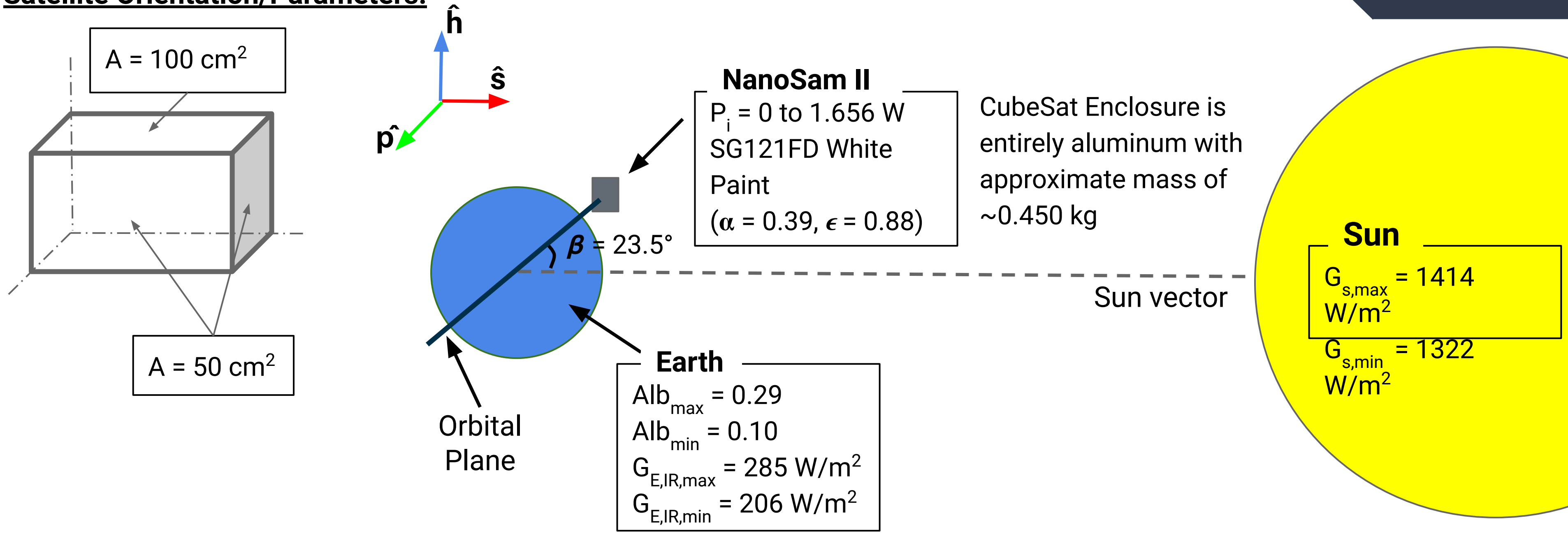
Due to whole-body rotation

	Model Type	
Mode Number	**Pins**	**Auto**
1	0.0298 Hz	0.000974 Hz
2	0.0304 Hz	0.00180 Hz
3	0.0759 Hz	0.00223 Hz
4	386.26 Hz	384.96 Hz
5	544.04 Hz	541.55 Hz
6	578.00 Hz	575.09 Hz
7	694.73 Hz	690.95 Hz

Thermal Model Diagram

Sources : [3] [4]

Satellite Orientation/Parameters:



Thermal Model Assumptions/Equations

Key Assumptions:

- Parallel rays from the sun
- Albedo/longwave radiation travels parallel along the radial line from the Earth to the satellite
- Bodies other than the Earth/Sun don't produce significant incident radiation
- Lumped system
- Kirchoff's law ($\epsilon_\lambda(T) = \alpha_\lambda(T)$)
- Satellite surfaces are gray, diffuse, surfaces
- $T_{surr} = 0$ K

Key Equations:

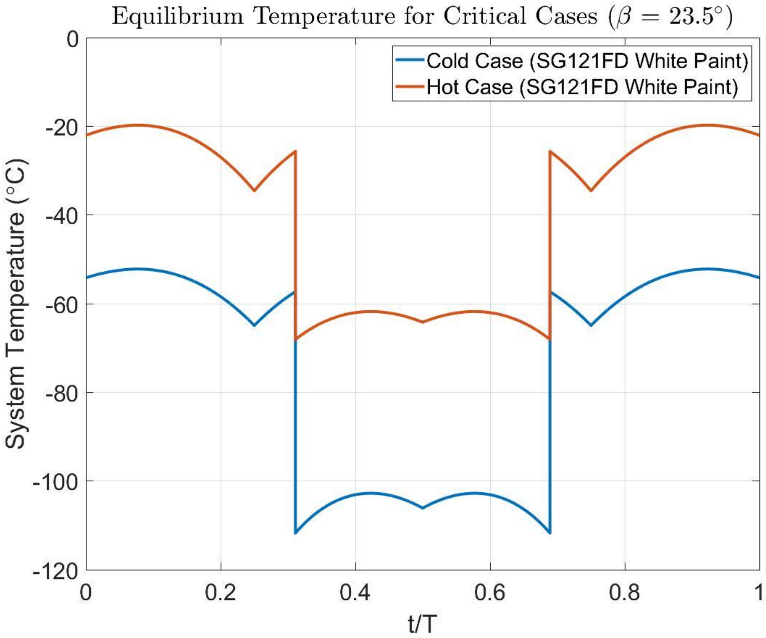
$$T_{sys,eq} = \left[\frac{\dot{Q}_{in,sun} + \dot{Q}_{in,A} + \dot{Q}_{in,IR} + P_i}{2\sigma\epsilon(2A_s + A_p)} \right]^{(1/4)}$$

$$\dot{Q}_{tot} = \dot{Q}_{in,A} + \dot{Q}_{in,IR} + \dot{Q}_{in,sun} + P_i - \dot{Q}_{out}$$

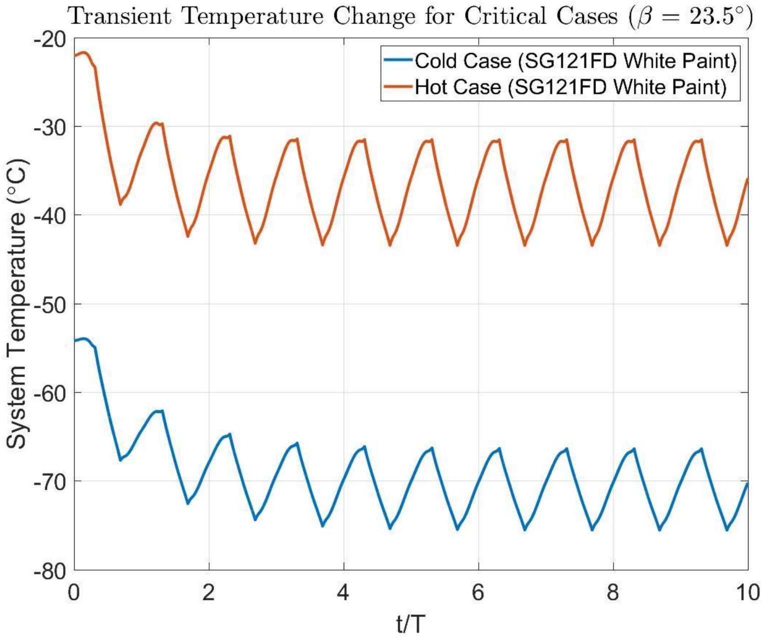
$$T_i = \frac{\dot{Q}_{tot}\Delta t}{mc_p} + T_{i-1}$$

Passive Thermal Control Results

Equilibrium Results:

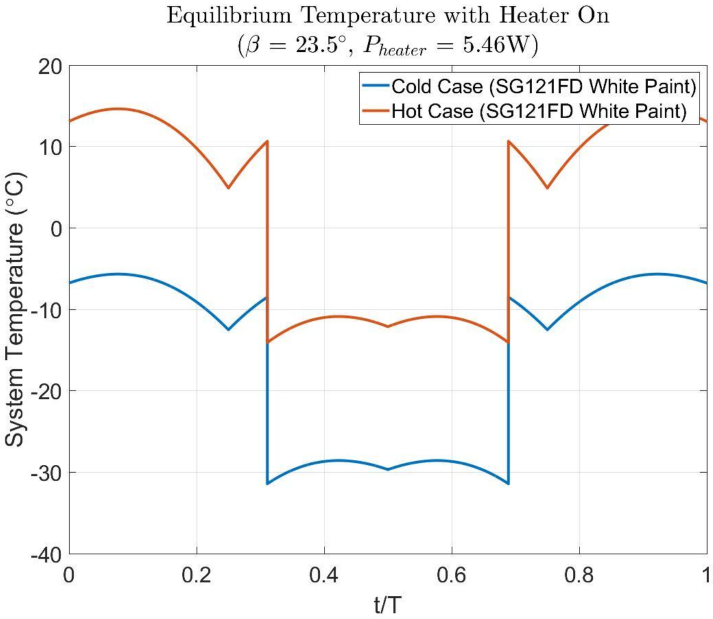


Transient Results:

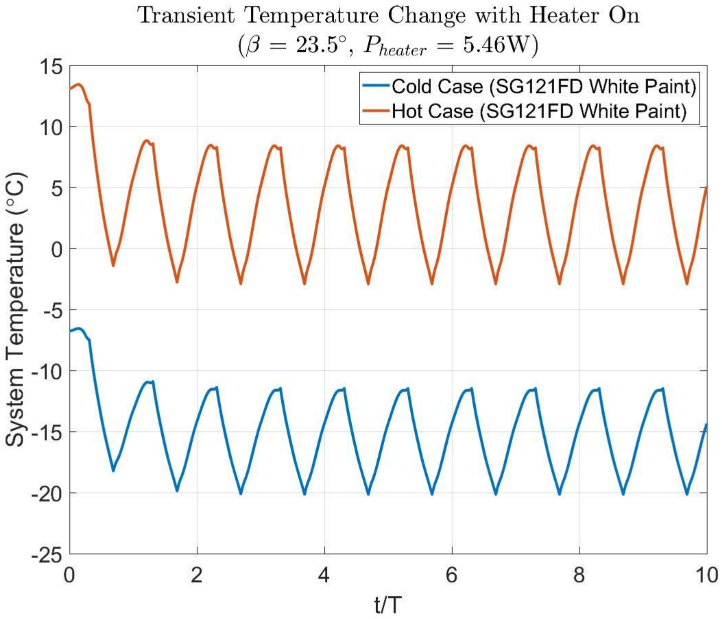


Active Thermal Control Results

Equilibrium Results:



Transient Results:



NOTE : P_{heater} does not include power dissipated by the electronics board passively

Software

Jackson Kistler

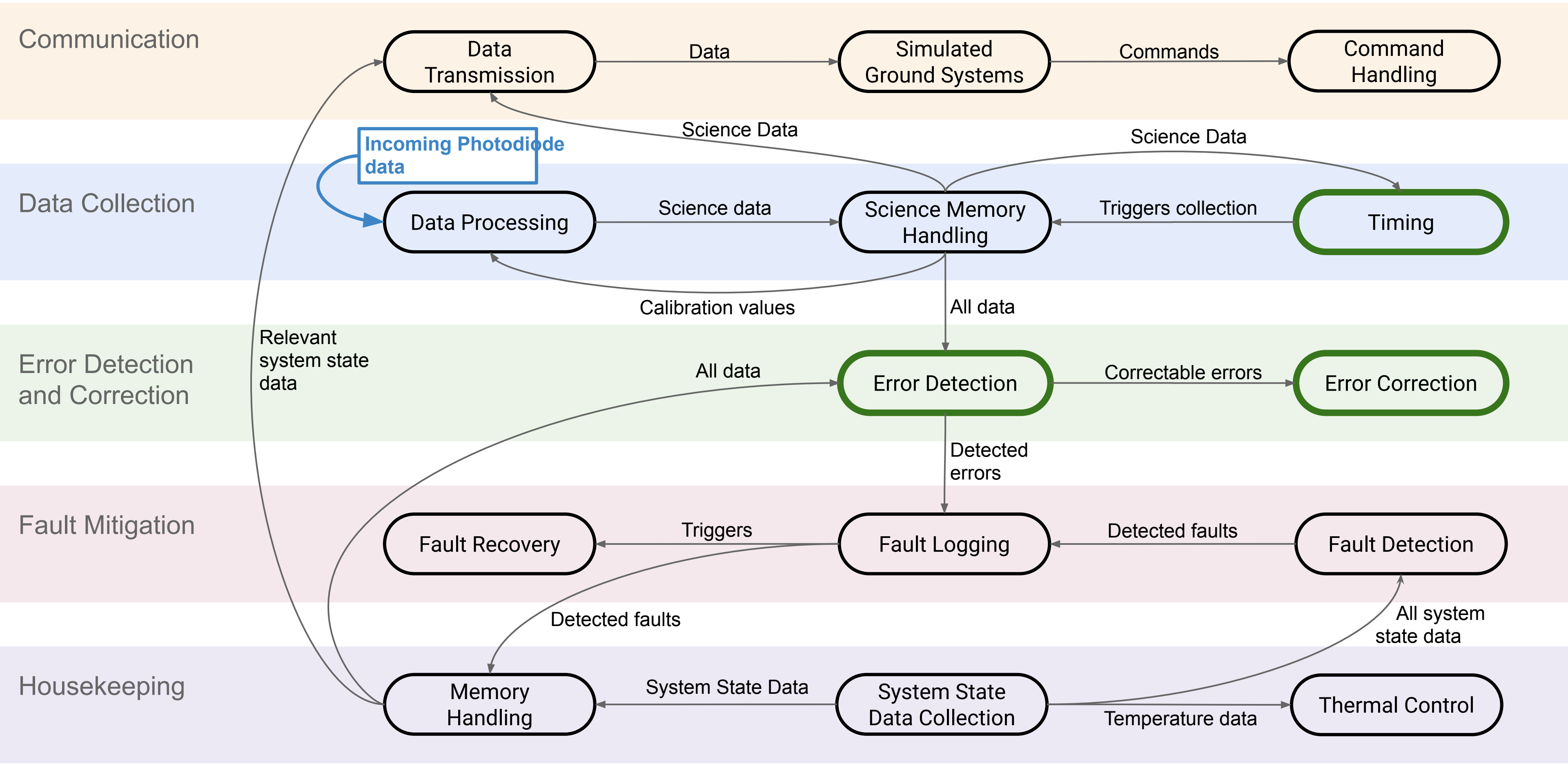
Relevant Requirements

1.0: Data Capture

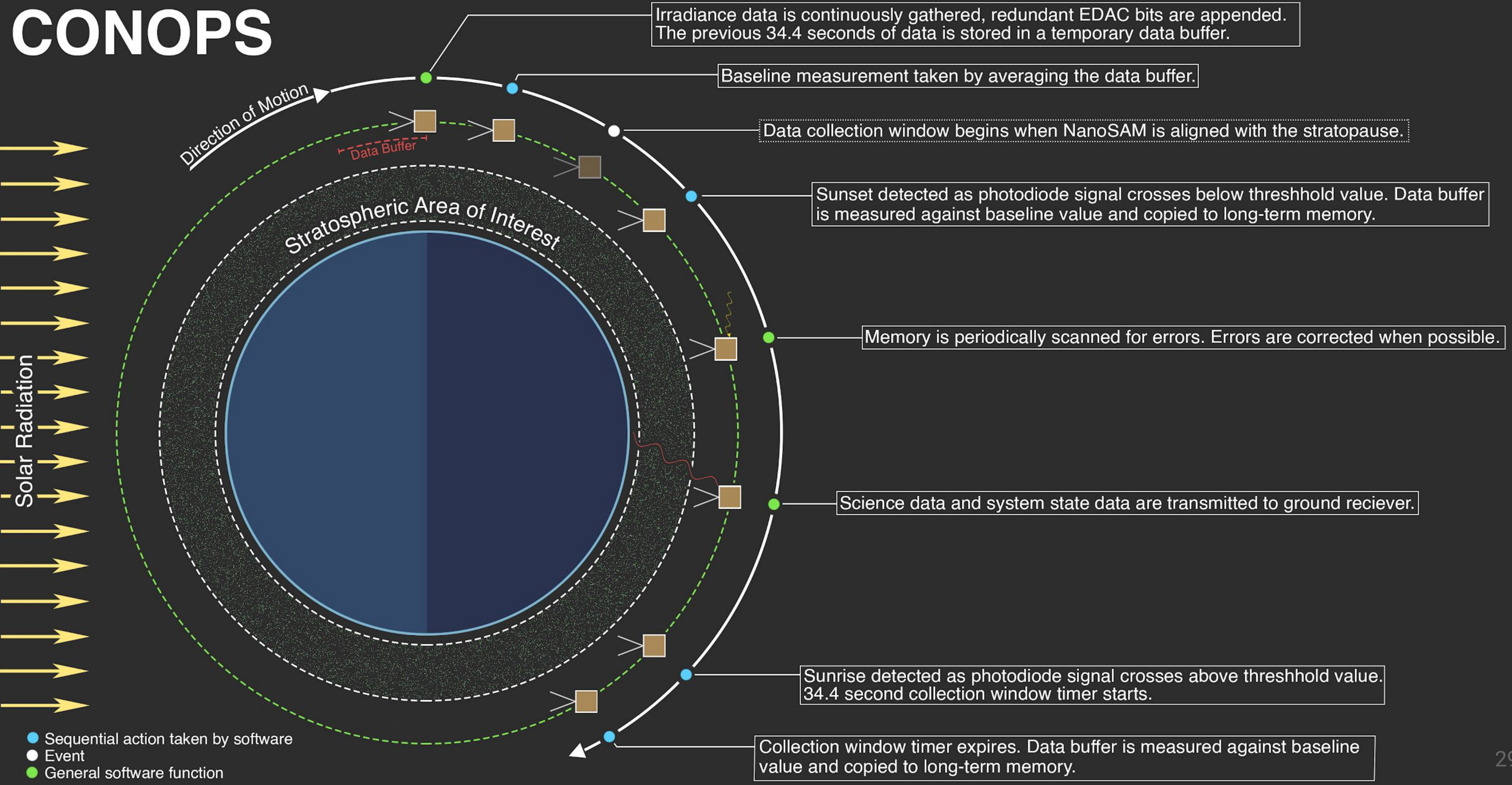
- Data collection is timed to capture both sunrise and sunset through the stratosphere
- Samples, processes, and stores data at a rate greater than 50 Hz
- Baseline irradiance data is measured prior to data collection
- Housekeeping data is stored and monitored for irregularities (temperature, power usage)
- Errors in data are detected and corrected

2.0: Communications

- A warning is downlinked when an anomaly in housekeeping data is detected
- Total data volume, including EDAC, does not exceed the data volume of a 9.6 kbps downlink over a 5 minute window.


Communication
Data Collection
Error Detection and Correction
Fault Mitigation
Housekeeping
Data Transmission
Data
Simulated Ground Systems
Commands
Command Handling
Science Data
Incoming Photodiode data
Science Data
Data Processing
Science data
Science Memory Handling
Triggers collection
Timing
Calibration values
All data
Relevant system state data
All data
Error Detection
Correctable errors
Error Correction
Detected errors
Fault Recovery
Triggers
Fault Logging
Detected faults
Fault Detection
Detected faults
All system state data
Memory Handling
System State Data
System State Data Collection
Temperature data
Thermal Control

SOFTWARE CONOPS



Error Detection and Correction

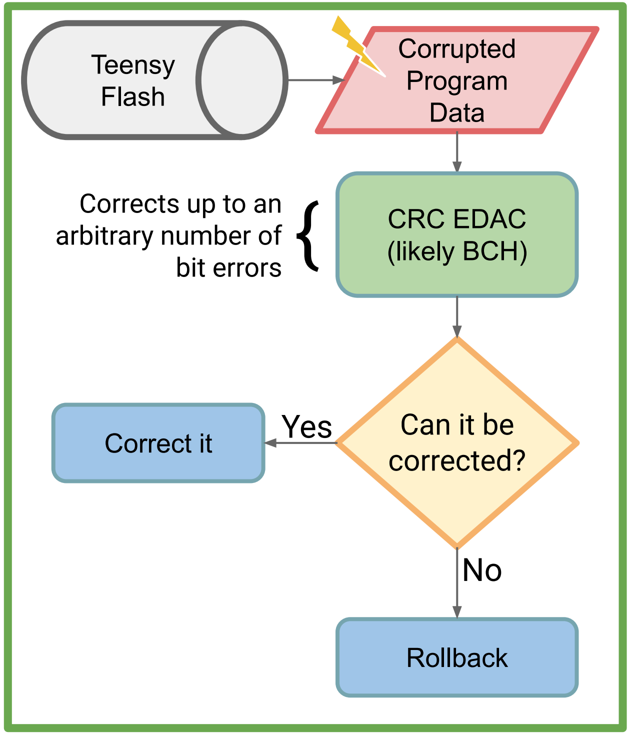
Single Event Errors

Single Event Upset Rate:
10^{-4} errors/bit-day [6]
(10^{-5} errors/bit-day typical)

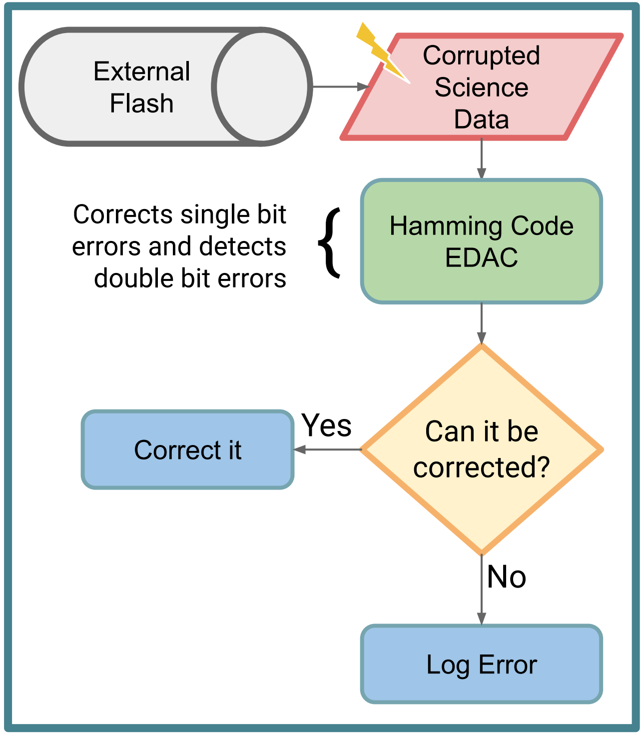
Teensy Flash:
1.6 errors/day
Each Data Window:
0.1 errors/day

Multiple Bit Errors in Teensy Flash:
0.05 errors/day (3%)
=
18 errors/year

Program Data



Science Data



Status Summary &
Strategy for Conducting Remaining Studies

Axel Haugland

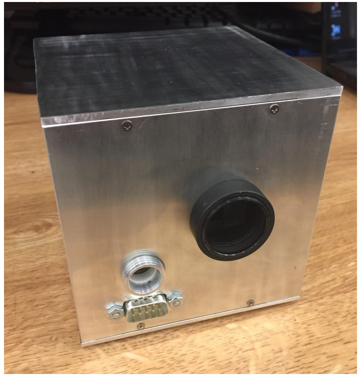
Status Summary

1	**Data Capture**	• Sufficient Storage • Sufficient ADC sampling frequency
2	**Communications**	• USB Communication for Ground Testing • Data size is small enough to fit in link budget for similar CubeSats
3	**SAM-II Equivalent Optics**	• Using proven optic from NanoSAM I • SNR can be maintained with this year’s electronics design
4	**Payload Dimensions**	• Critical Project Elements fit within 0.5U dimensions • Mass is less than the NASA recommendation for 0.5U
5	**Flight Testing**	• Thermal requirements are feasible with feedback heater • Vibrational requirements
6	**Cost**	• Current components use less than 20% of the budget • As component selections are finalized this will be reevaluated

Testing NanoSAM I

- Running a Solar Occultation test on the NanoSAM I provides a baseline for our optics design
  - Will use Orion star tracker mount (obtained by the NanoSam I team)
- Some chosen design aspects in the baseline design are the same
  - Verify these aspects are valid early on
- The Customer wants the performance of the previous system to be evaluated
- Receive reference values for our requirements
  - MTF, SNR, Power, etc.

NanoSam I Enclosure



Orion star tracker mount

Enclosure

Remaining Studies

- Pseudo-Random Vibration test based on QB50 random vibration requirements
- Improved Boundary Conditions
  - Multiple cases studied
  - Removal of millihertz modes
- Thermal Model within Solidworks
  - Higher confidence temperature change on optic

Future Work

- Explore thermal isolation options for the optics bench
- Finalized CAD based on orderable parts
  - Ensure Machinability
- Price quotes on materials/components picked for final design

Software

Remaining Studies

- Data collection window duration
  - Sensitivity to orbital parameters
  - Variation with time
- Estimate BCH code computational cost
  - Scales with maximum correctable error size
- Single Event Upset simulation method for testing

Future Work

- Refine system architecture
  - Finalize module responsibilities
- Hardware integration

Questions

References

[1] QB50:System Requirements and Recommendations. Issue 7, Section 1.6 "Thermal Control" and Section 2.2 "Resonance Survey." Published 13 Feb 2015. https://www.qb50.eu/index.php/tech-docs/category/QB50_Systems_Requirements_issue_76e8e.pdf?download=89:qb50-docs

[2] Stafford, George. "Blue Canyon Technologies XB1: Enabling a New Realm of CubeSat Science", slide 6. Accessed Sep 10, 2020. <http://mstl.atl.calpoly.edu/~workshop/archive/2012/Summer/Day%201/1200-Stafford-XB1.pdf>

[3] Anderson, B. & Justus, C. & Batts, G.. (2001). Guidelines for the Selection of Near-Earth Thermal Environment Parameters for Spacecraft Design.

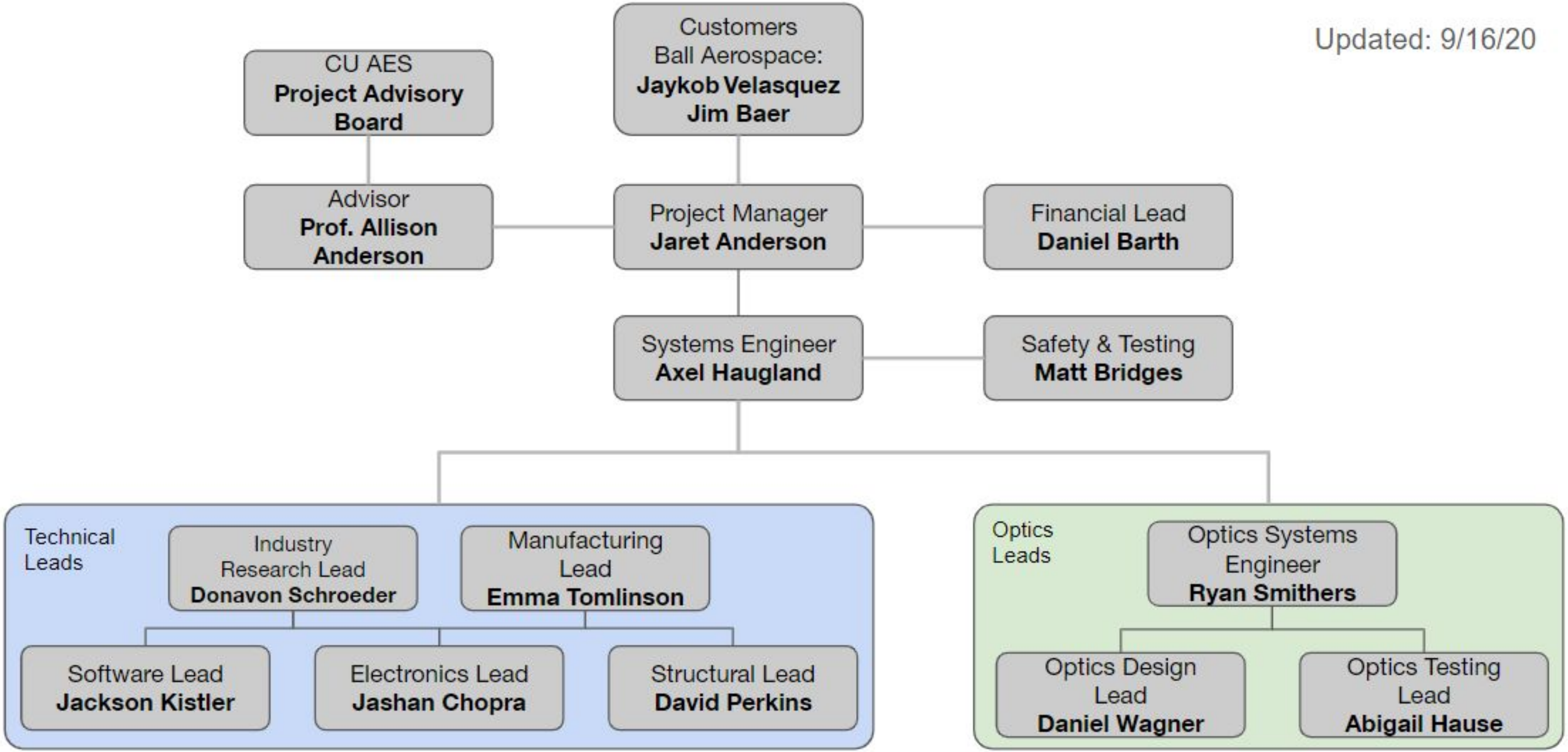
[4] Kovo, Y. (2020, March 12). Thermal Control. Retrieved October 06, 2020, from https://www.nasa.gov/smallsat-institute/sst-soa/thermal-control

[5] Llopis, O, et al. “Photodiode 1/f noise and other types of less known baseband noises in optical telecommunications devices”, University de Toulouse, ICNF 2013. Accessed 2 Oct 2020. https://hal.archives-ouvertes.fr/hal-00849396/document

[6] Bell, Michael. “Space Radiation Effects on Electronic Components in Low-Earth Orbit”, Published 01 Feb 1999. https://llis.nasa.gov/lesson/824

Backup Slides

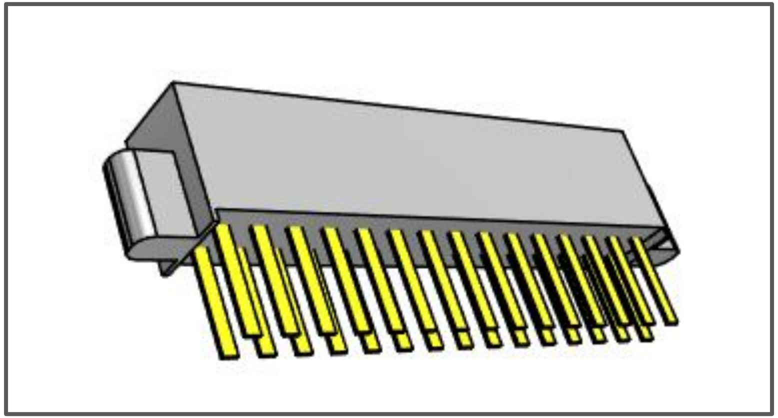
Organization Chart

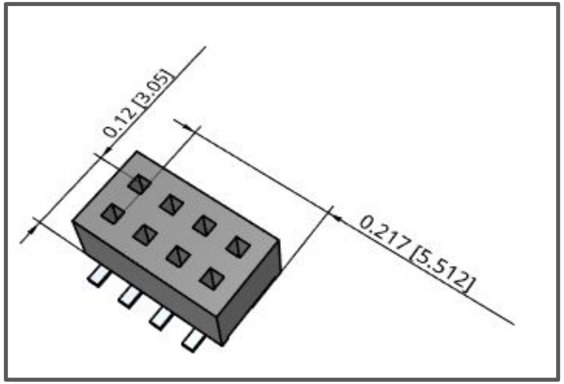


Tabulated Specific Objectives

	Level 1 (Solar Tracking Test)	Level 2 (Improved Ground Performance)	Level 3 (Flight Capability Testing)
Payload Housing	The payload housing contains the integrated electronics board and optics bench inside a 0.5U enclosure.	The payload housing structural interface is compatible with an industry standard bus	The payload housing functions within the operating temperature range of -20C to 60C and its lowest vibrational natural frequency is greater than 90Hz [1].
Data Capture	Software and electronics acquires,digitizes, packetizes, and down-loads raw data from a photodetector to a computer at a rate of at least 50Hz within the mission-specific measurement schedule detailed in the CONOPS	Error checking measures are implemented in the ground software to detect data corruption occurring during transmission	Data is transferred from the payload to an industry standard CubeSat bus communications system[2].
Electronics & Control	The redesigned electronics board successfully controls and powers all on-board operations and has a footprint compatible with the 0.5U payload enclosure	The redesigned electronics board supports all optical design improvements.	The redesigned electronics board remains within the operating temperature range of -20C to 60C and its lowest vibrational natural frequency is greater than 90Hz [1].

Electronics: Split Board Connection



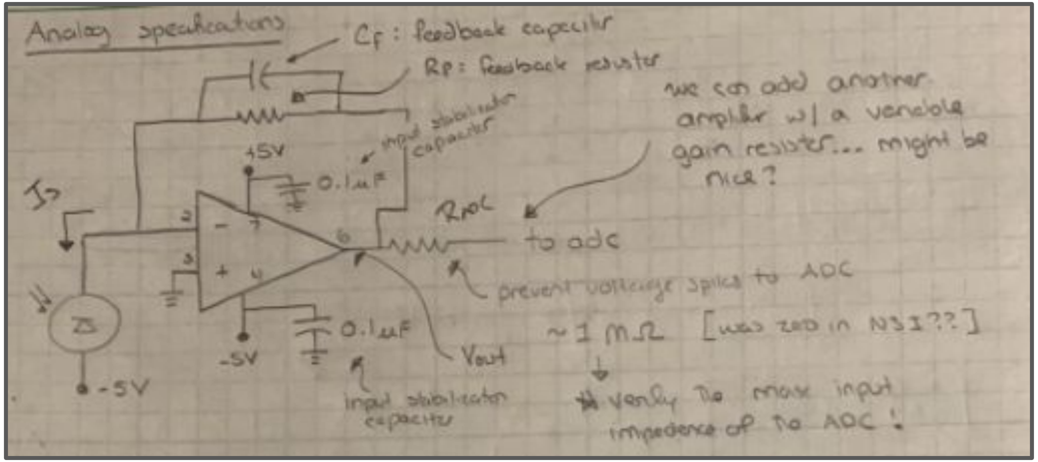


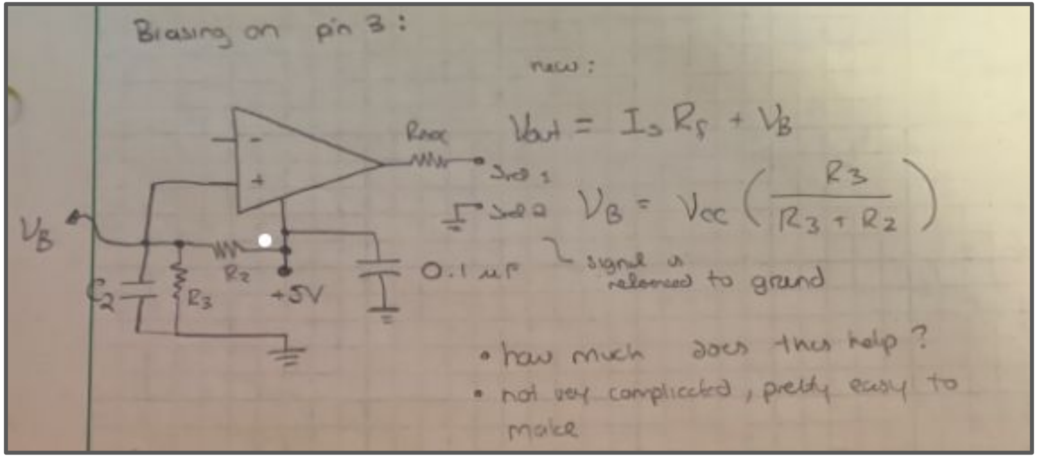
An inboard through hole connector will provide more space and reliability than a curved cord connector.

With 16 I/O pins as the regular, we will be able to route all signals required between boards.

Separation of data line and voltage line noise is possible due to the large length.

Electronics: Analog Signal Conditioning





$$f_{BW} = \frac{1}{(2\pi)R_L C_J},\ t_R = \frac{0.35}{f_{BW}}$$

$$V_{out} = I_s R_f + V_B$$

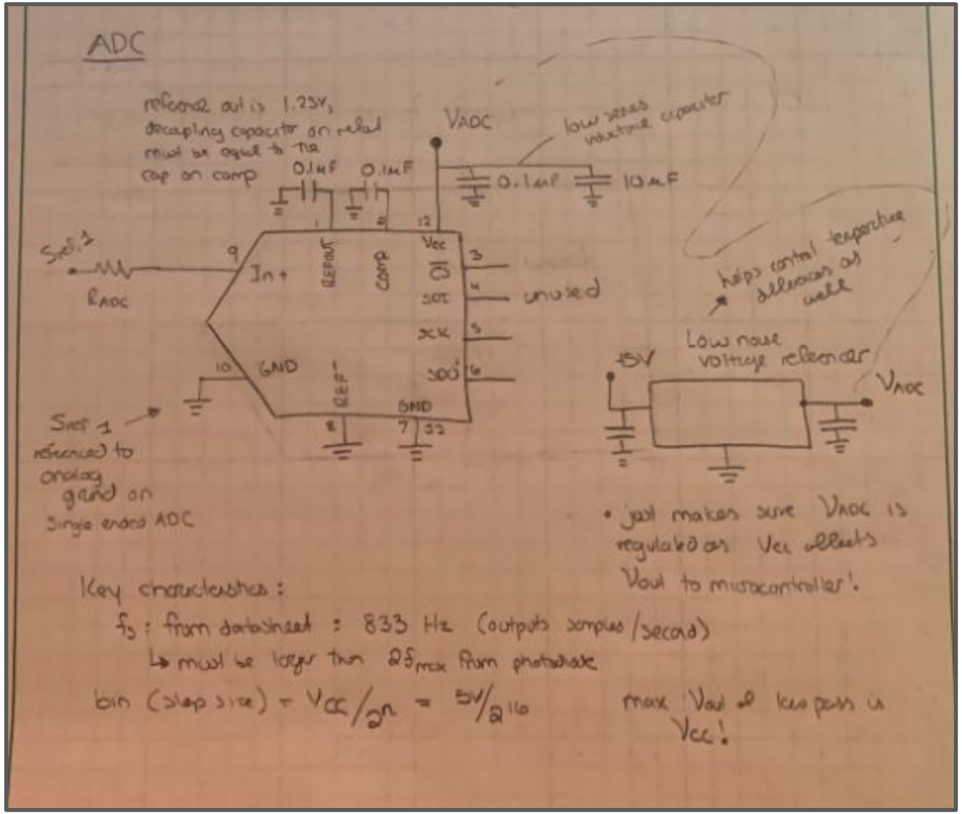
$$V_B = V_{cc}\left(\frac{R_3}{R_3 + R_2}\right)$$

$$I_s = R P_o$$

$$C_f = 0.5\pi f R_f$$

$$GBP = 2f^2\pi R_f(C_f + C_J)$$

Electronics: Analog To Digital Converter



$$LSB = \frac{V_{cc}}{2^n}$$

Other key characteristics:

- Sampling frequency (833 s/sec)
- Accuracy of reference with temperature (—10ppm/°C)
- Offset error (1mV)
- Gain Error (0.01%)
- Supply current (3.5mA)

Electronics: Photodiode Saturation

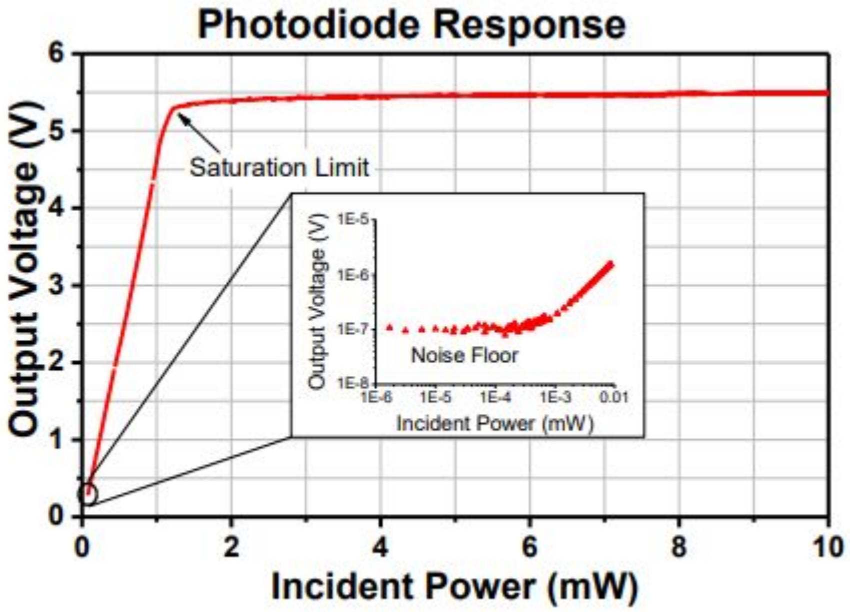
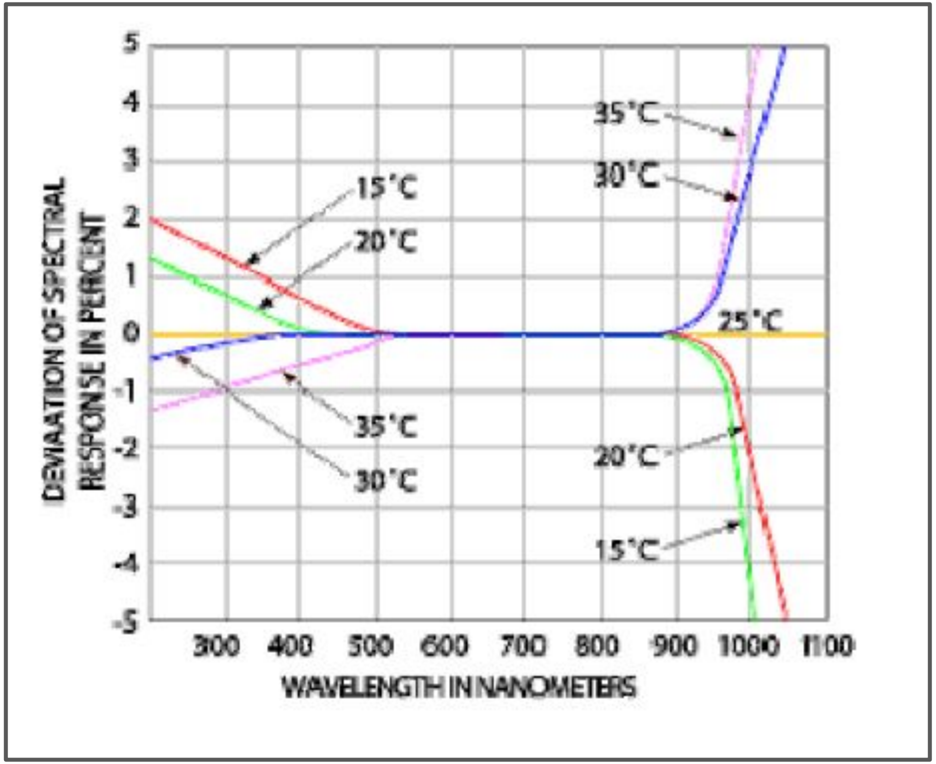


Figure 2: Measured response of a FDS100 silicon photodiode showing the noise floor and saturation limit for a 5 V bias from a DC power supply and 10 kΩ load resistor.

The photodiode output will saturate when the output voltage approaches the reverse bias voltage on the photodiode.

Our reverse bias voltage should be greater than the maximum output voltage, which is 3.3V.

Electronics: Photodiode Temperature Effects



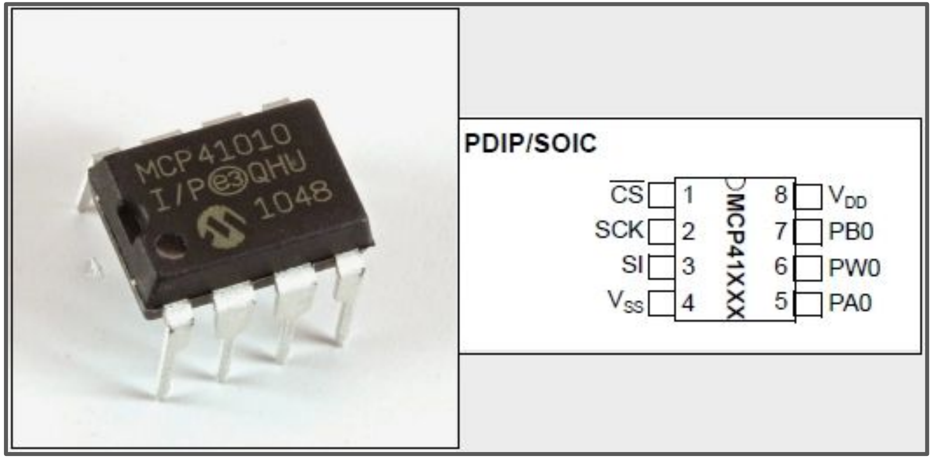
~3% deviation for 5K change, leads to 0.0027 A/W per K change in responsivity. This is equivalent to a 0.0198 V/K response in our output voltage (with 5121 ohm feedback resistor).

This is 393 bins / K (0.6% error in voltage read out per kelvin).

We must size the feedback resistor for the estimated responsivity at the expected temperature of the photodiode during the data collection window. From our thermal analysis, we must make sure temperature cannot fluctuate in the 34.4 second data capture window.

“Optical Detectors”, Wang, Wei-Chih, National Tsing Hua University.

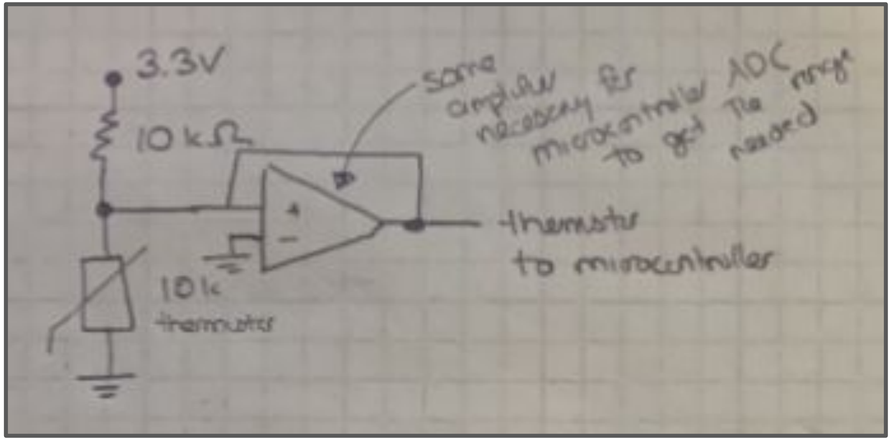
Electronics: Controllable Gain Resistor



Simple, cheap integrated circuits allow for a variable resistor controlled via SPI interface from our microcontroller

Using this as the feedback resistor in the second amplifier stage would allow for controllable gain, although this might not be necessary.

Electronics: Thermal Regulation & Measurement



Resistance of the thermistor changes depending on the temperature, and thus affects the voltage measurement in the typical voltage divider equation.

We amplify the output because the change in resistance is quite small.

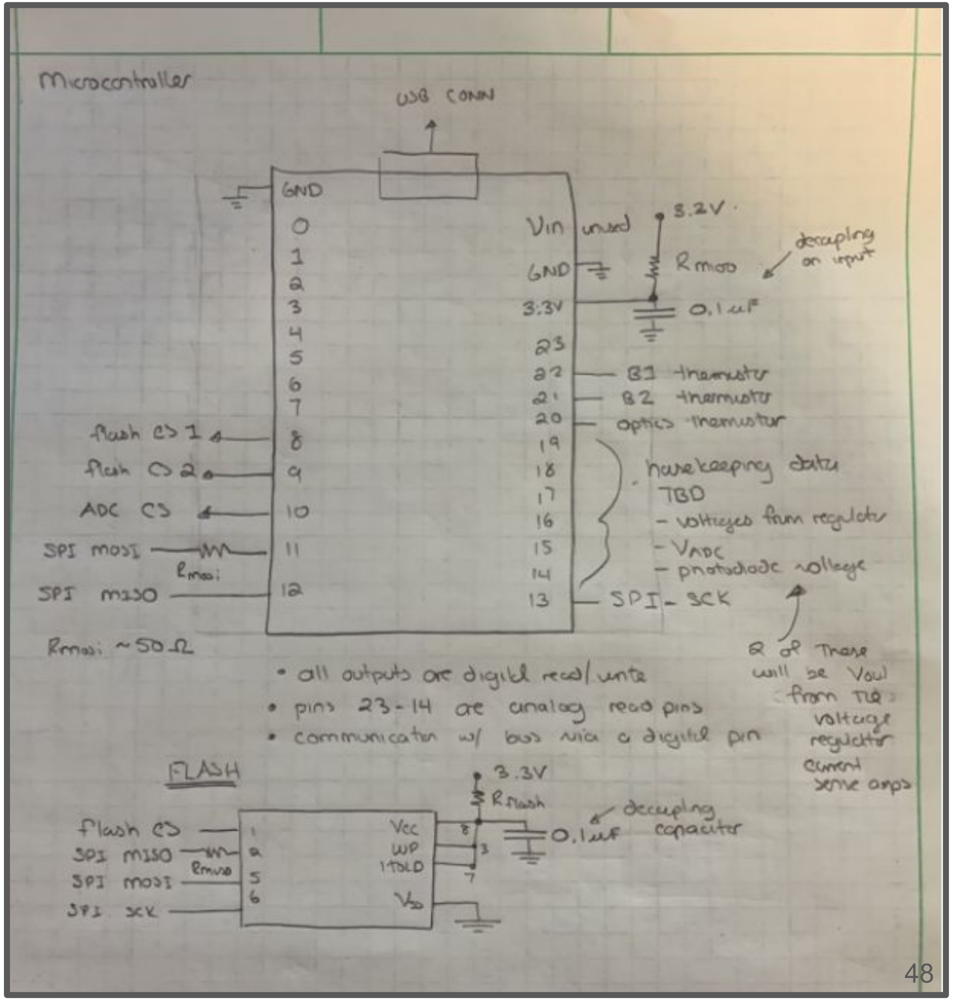
Electronics: Microcontroller & Flash

Serial Programmable Interface (SPI) for the ADC and Flash I/O.

Nine analog read pins:

- 1-3: Thermistor
- 4-5: Voltage regulator current monitors
- 6: Raw photodiode current
- 7: 3.3V Regulator output
- 8-9: Unused

Additional pins can all be used for digital I/O, and most digital pins can be used for analog write commands.



Electronics: Required Storage Space

Science Data: (833 s/sec)(34.4 sec)(16 bit)(2 periods) = 916966 bits

- ADC Range: 16 bits
- ADC Sampling Maximum: 833 s/sec
- Data collection window: 34.4 sec
- Number of data collection periods: 2

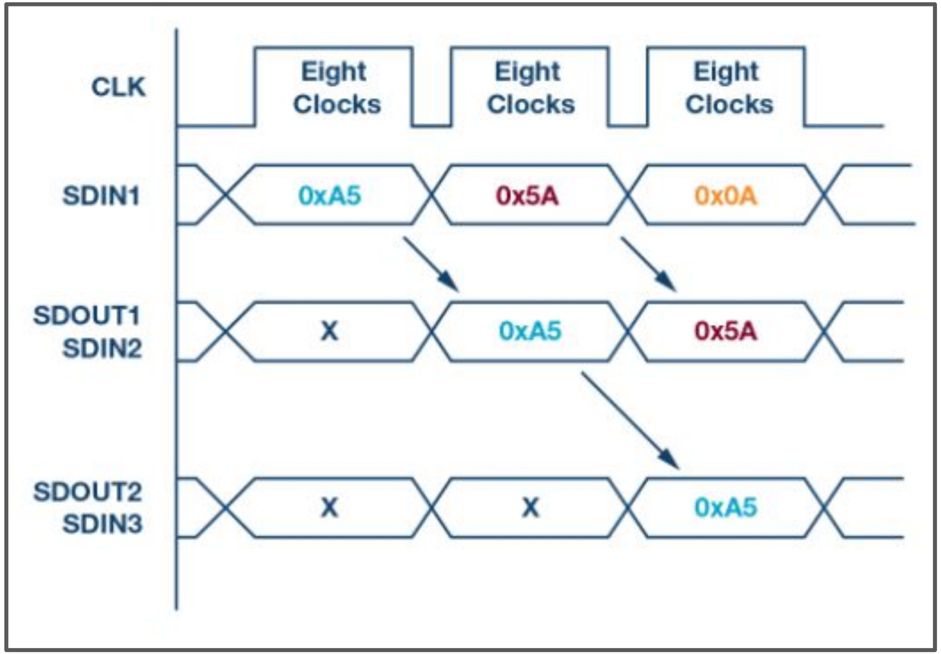
Housekeeping Data: (8 pins)(12 bit)(10 s/sec)(5670 sec) = 5.44e6 bits

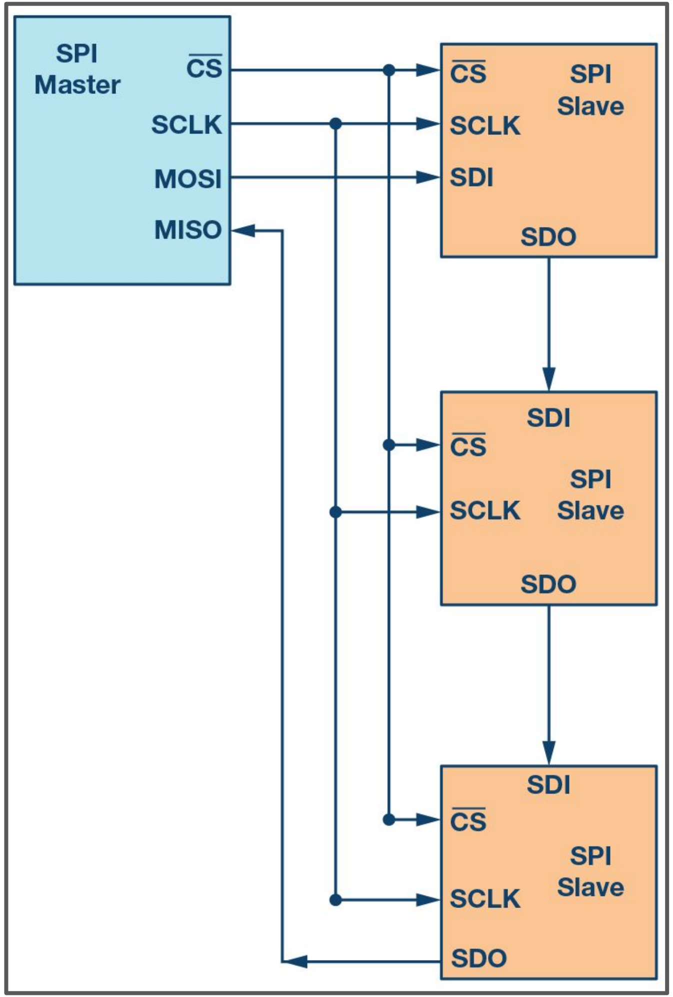
- Number of analog read pins: 8
- Microcontroller ADC Range: 12 bit (can be lowered)
- Microcontroller Sampling: 10 s/sec (can be lowered)
- Data collection window: 1 orbital period = 5670 seconds

Available: 280Mb

Flash 1: 128 Mb, Flash 2: 128 Mb, Teensy Flash: 15.872 Mb, Teensy RAM: 8.192 Mb

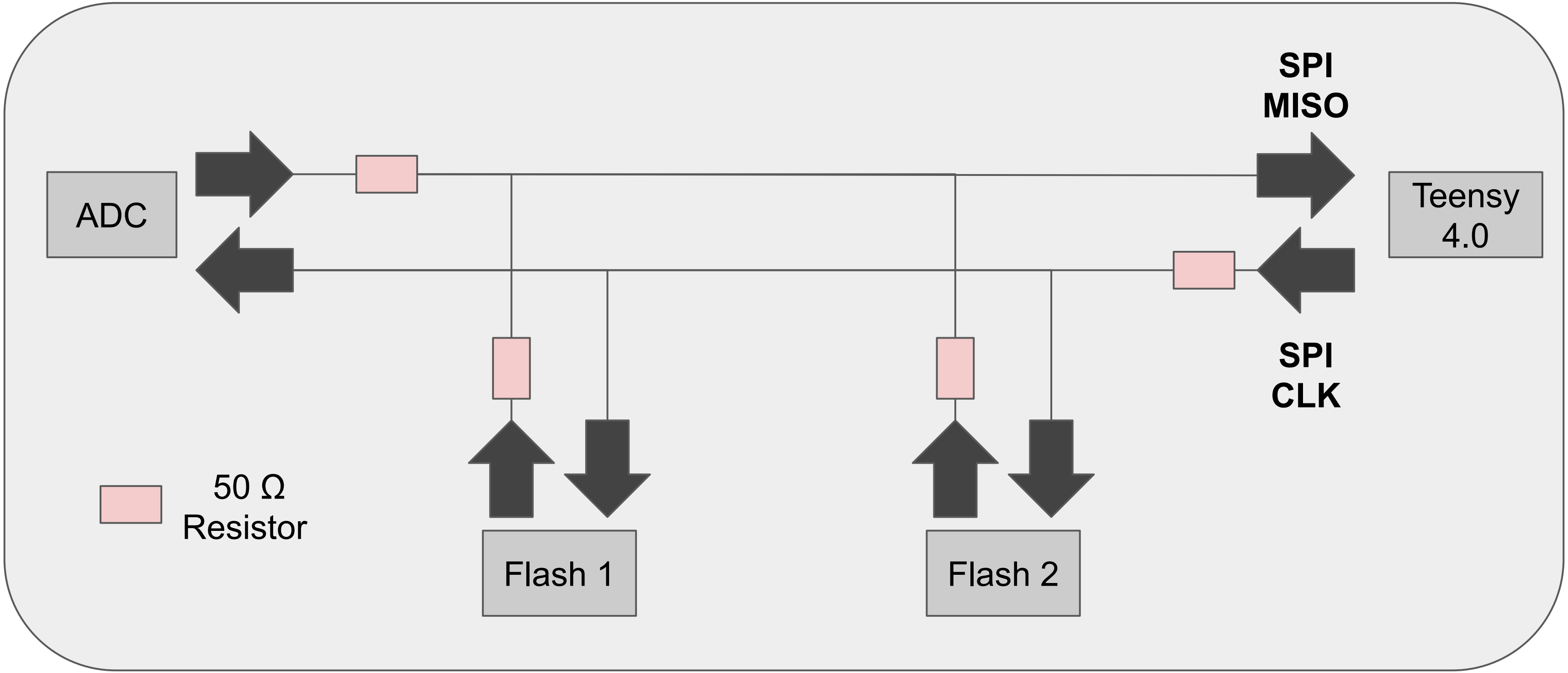
Electronics: SPI Bus Connections





https://www.analog.com/en/analog-dialogue/articles/introduction-to-spi-interface.html

Electronics SPI Bus Noise Considerations



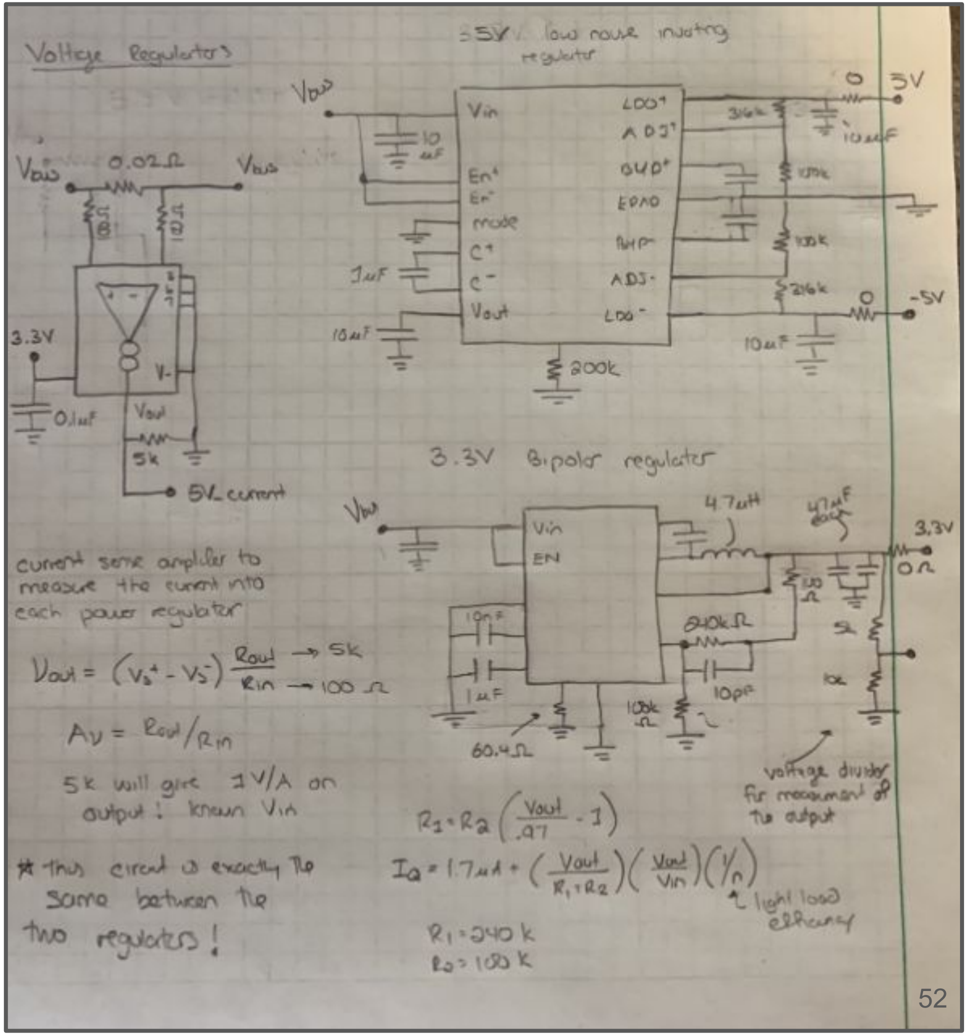
https://www.diodes.com/assets/App-Note-Files/AB023.pdf

Electronics: Voltage Regulation

A current sense amplifier is used for the load into each regulator.

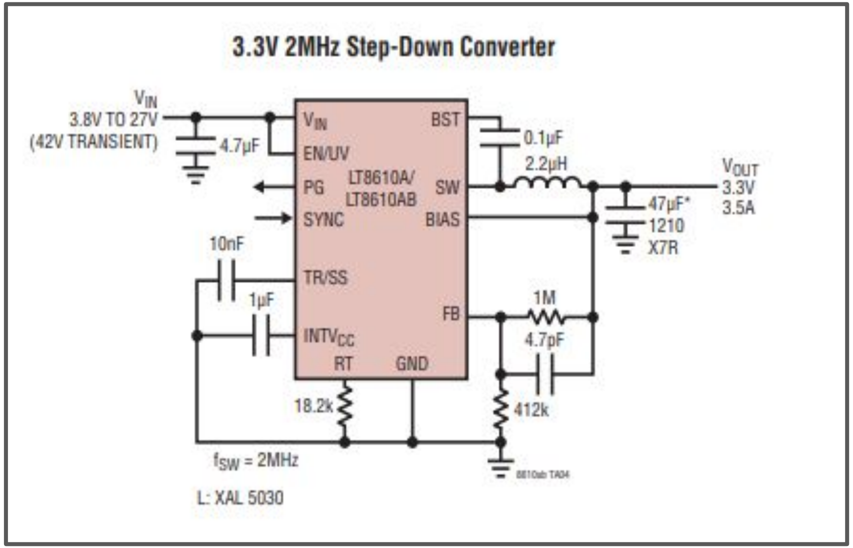
The 5V regulator is a low noise inverting dual supply regulator, turning the bus voltage into a positive and negative 5V for the analog supply.

The 3.3V regulator is a bipolar step down regulator, turning the bus voltage into a 3.3V signal for digital electronics.

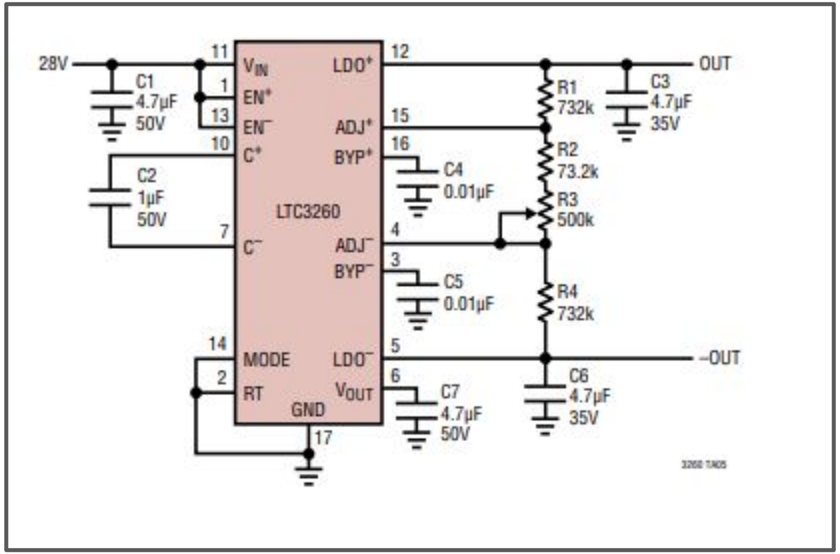


Electronics: Recommended Voltage Regulator Layouts

Digital Voltage Regulator



Analog Voltage Regulator



Electronics: Risk Management

Primary

1) Analog to Digital Converter
2) Flash Storage
3) 5V Voltage Regulator
4) 3.3V Voltage Regulator

Backup

1) Microcontroller 12 bit on board ADC
2) Secondary flash storage could hold all data required. Microcontroller flash storage could hold science data only.
3) No backup planned for voltage regulators. If 3.3V regulator fails, microcontroller will lose power. If 5V regulator fails, photodiode data will be unreadable.

Electronics: Extended Bill of Materials

Part	Value	Device	Package	Size (mm^2)	DK Part #	Cost	Total Size (mm^2)	Total Cost ($)	# Components
C1	100pF	0.1UF-0603-25V-5%	603	1.16	478-11510-2-ND	0.37	**3969.956744**	**453.24**	**131**
C2	0.1uF	0.1UF-0603-25V-5%	603	1.16	478-11510-2-ND	0.37			
C3	0.1uF	0.1UF-0603-25V-5%	603	1.16	478-11510-2-ND	0.37			
C4	4.7uF - 25V	4.7UF-1206-16V-(+80/-20%)	1206	4.645152	311-2011-2-ND	0.29			
C5	1uF	4.7UF-1206-16V-(+80/-20%)	1206	4.645152	311-2011-2-ND	0.29			
C6	4.7uF	4.7UF-1206-16V-(+80/-20%)	1206	4.645152	311-2011-2-ND	0.29			
C7	.01uF	4.7UF-1206-16V-(+80/-20%)	1206	4.645152	311-2011-2-ND	0.29			
C8	.01uF	4.7UF-1206-16V-(+80/-20%)	1206	4.645152	311-2011-2-ND	0.29			
C9	10uF	4.7UF-1206-16V-(+80/-20%)	1206	4.645152	311-2011-2-ND	0.29			
C10	10uF	4.7UF-1206-16V-(+80/-20%)	1206	4.645152	311-2011-2-ND	0.29			
C11	0.1uF	0.1UF-0603-25V-5%	603	1.16	478-11510-2-ND	0.37			
C12	0.1uF	0.1UF-0603-25V-5%	603	1.16	478-11510-2-ND	0.37			
C13	0.1uF	0.1UF-0603-25V-5%	603	1.16	478-11510-2-ND	0.37			
C14	0.1uF	0.1UF-0603-25V-5%	603	1.16	478-11510-2-ND	0.37			
C15	0.1uF	0.1UF-0603-25V-5%	603	1.16	478-11510-2-ND	0.37			
C16	1uF	4.7UF0603	603	1.16	478-11510-2-ND	0.37			
C17	0.1uF	0.1UF-0603-25V-5%	603	1.16	478-11510-2-ND	0.37			
C18	0.1uF	0.1UF-0603-25V-5%	603	1.16	478-11510-2-ND	0.37			
C19	.1uF	0.1UF-0603-25V-5%	603	1.16	478-11510-2-ND	0.37			
C20	.1uF	0.1UF-0603-25V-5%	603	1.16	478-11510-2-ND	0.37			
C21	0.1uF	0.1UF-0603-25V-5%	603	1.16	478-11510-2-ND	0.37			
C22	0.1uF	0.1UF-0603-25V-5%	603	1.16	478-11510-2-ND	0.37			

Electronics: Power Budget Calculations

P = IV

Photodiode: (5V)(5mA) = **0.025 W** [Maximum]
Amplifier: (3.3V + 3.3V)(12nA + 3mA) = **0.0198 W** [Maximum]
Feedback Resistor: (5V)^2 / (5121.04 ohms) = **0.004882 W** [Maximum]
ADC: (3.3V)(5 mA) = 0.0165 W [Maximum]
Microcontroller: (3.3V)(100 mA) = **0.33 W** [Expected]
Flash Storage: (3.3V)(8 mA)(2 modules) = **0.0528 W** [Expected]
Thermistors: (3.3V)(170 uA)(3) + (3)(3.3V)^2 / (20e3 ohms) = **0.003317 W** [Expected]
Current Sense Amps: (12V)(150 uA) = **0.0036 W** [Expected]
3.3V Regulator: (12-3.3V)(100 mA) = **0.87 W** [Maximum]
5V Regulator: (12-5V)(50mA) = **0.35 W** [Maximum]

Total: 1.656 W

Electronics: SNR Detailed Calculations

All noises are converted to an equivalent voltage, and compared to the expected voltage signal to the ADC. For a worst case scenario, we assuming the typical signal will be 50% of our dynamic range, or 1.65V.

$$V_{shot} = R_f * \sqrt{2q(I_s + I_d)f}$$

$$V_{johnson} = R_f * \sqrt{\frac{4k_B T f}{R_{shunt}}}$$

$$V_{dark} = R_f * Idark$$

$$V_{lowpass} = \frac{28nV}{\sqrt{f}}$$

$$V_{regulator} = 0.1mV$$

$$V_{quantization} = \frac{LSB}{\sqrt{12}}$$

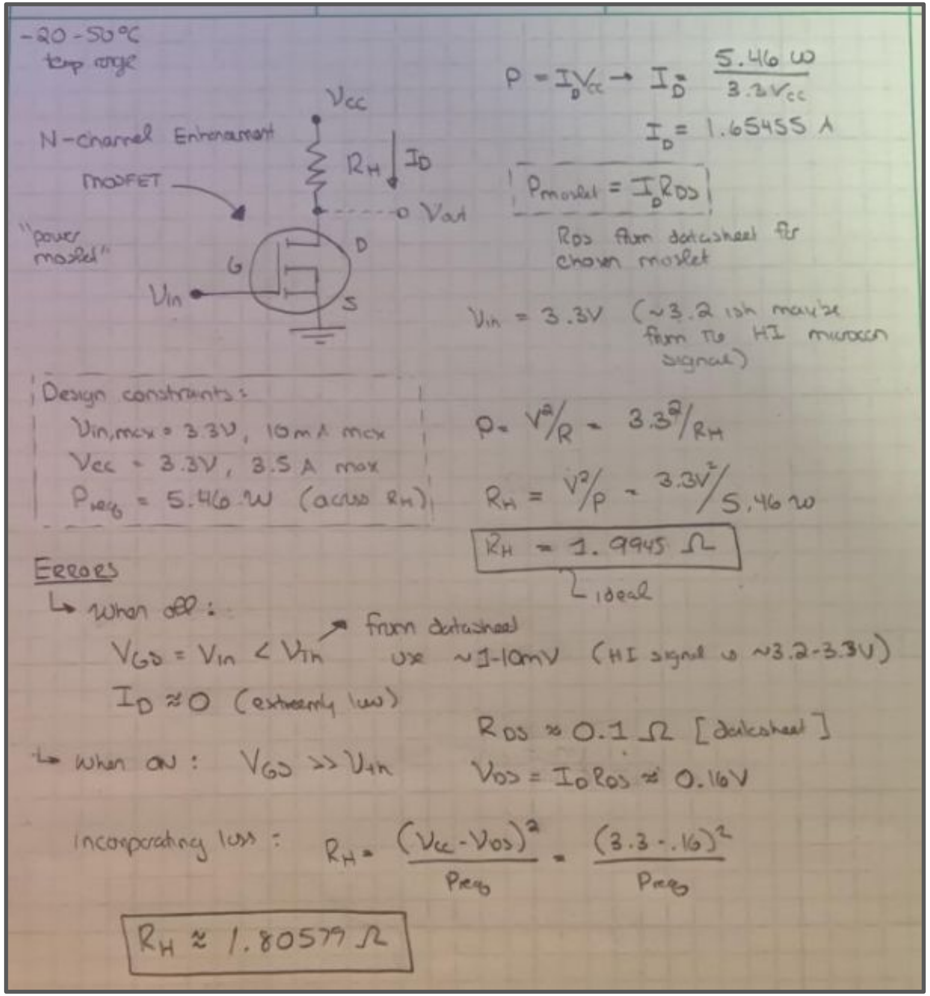
$$SNR = \frac{0.5 * I_s R_f}{\sqrt{V_{quantization}^2 + 2V_{regulator}^2 + V_{lowpass}^2 + V_{dark}^2 + V_{johnson}^2 + V_{shot}^2}}$$

Electronics: Resistor Heater

3.3V Linear Regulator can supply the needed 1.65 A. This increases the power requirement of the system a lot. We can directly use the 12V input to save power usage, controlling the input with a TVS diode.

MOSFET provides a very low voltage drop, but can be accounted for in resistor sizing.

Microcontroller can supply the activation signal with a PWM output



Optics

Relevant Requirements

1.0: SAM-II Equivalent Optics

- The optics system shall capture light at a center wavelength of 1.03 µm
- The optical design shall have a vertical resolution of 1 km
- The FOV shall be 1.3 arcminutes to achieve a vertical resolution of 1 km
- The imager shall have a MTF of 0.74 in order to meet the resolution and contrast of the SAM-II system
- The system shall demonstrate solar tracking accuracy of 1 arc-min/mRad or finer during ground testing

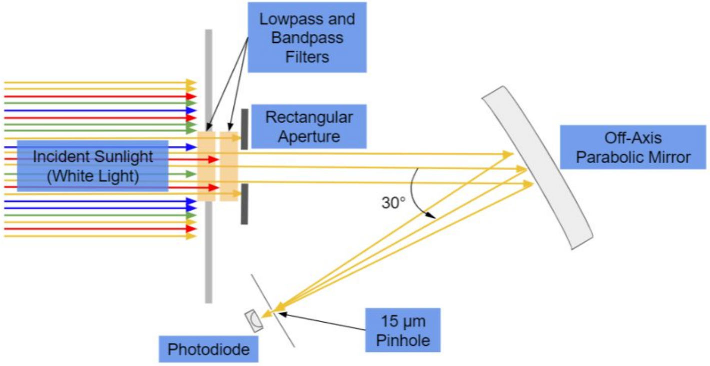
4.0: Payload Dimensions

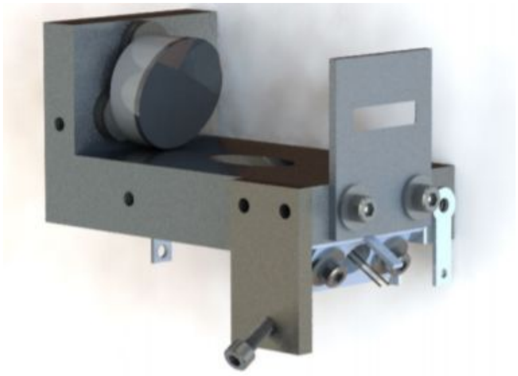
- Payload size must be less than 0.5U
- Payload mass less than 0.615 kg

- Herschelian Telescope with 25.4 mm diameter OAP mirror
- 20 x 5 mm aperture
- Pinhole of 15 µm diameter
- Focal length of 54.45 mm
- Bandpass and longpass filters
- Fits within the dimensions described in the enclosure section

Feasibility of NanoSAM I Design

The optical system designed by NanoSAM I is composed of a Herschelian telescope using an Off-Axis Parabolic (OAP) mirror. This system also had a rectangular aperture of dimensions 20 x 5 mm and a pinhole diameter of 15 μm. Filters used to isolate light with a CWL of 1.03 μm. Optical bench designed to hold optical system





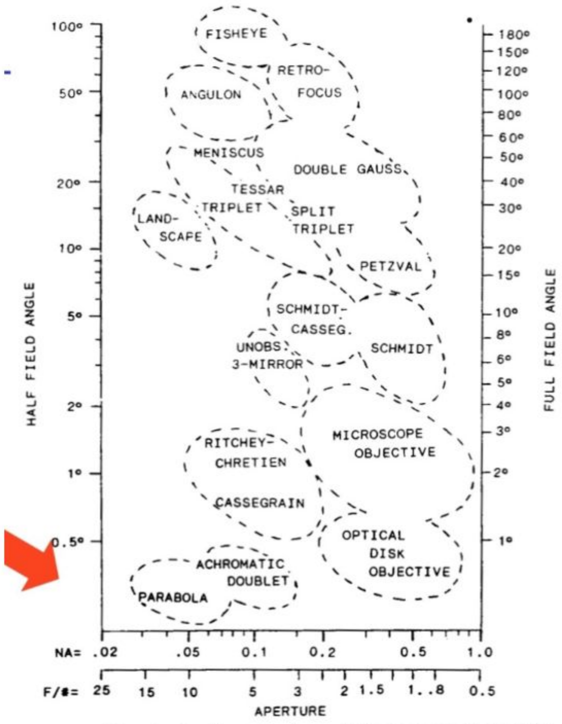
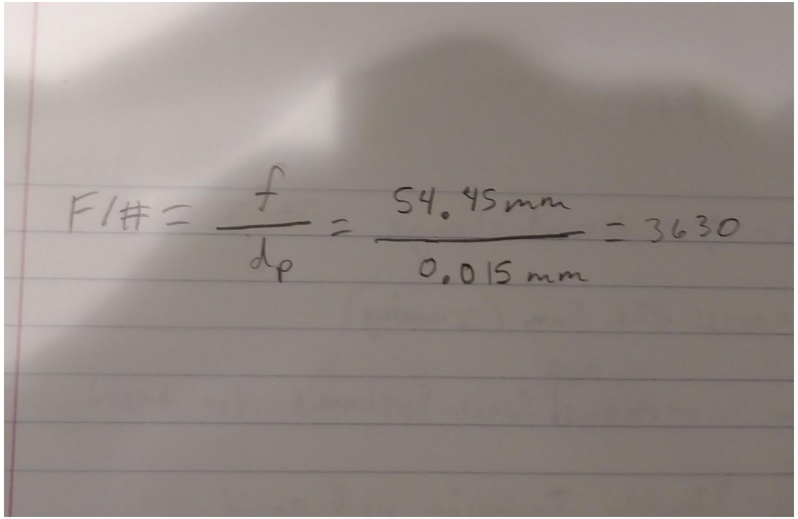


Figure 2.3 Map showing the design types which are commonly used for various combinations of aperture and field of view.

F-Number



The system has a pinhole diameter of 0.015 mm and a focal length of 54.45 mm, therefore it has a large F-number of 3630

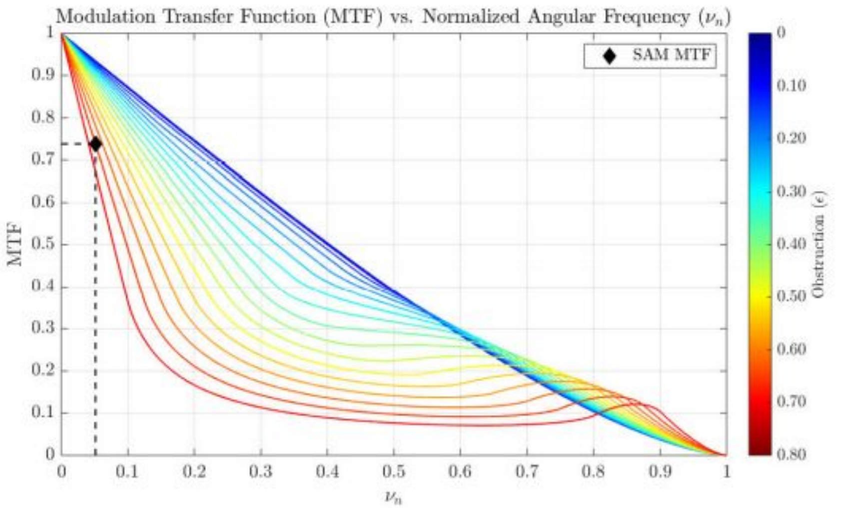
Field of View (FOV)

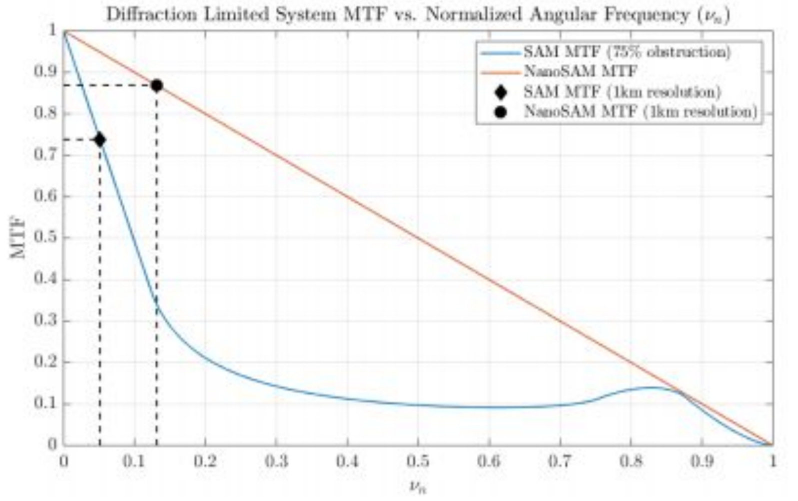
An estimate for the field of view can be found using the equation of 57.3 divided by the F-number which yields a value of .9471 arcminutes. This is good as the value of 1.3 arcminutes is the absolute maximum possible value for the vertical resolution requirement as any larger a FOV, will cause the resolution to be larger than 1 km. This value good to design for as it provides a margin for the system to actually achieve a value much closer to 1.3 arcminutes, as the true value can be calculated using convolutions.

$$FOV = 57.3 \frac{1}{F/\#} = .015785^{\circ} = .9471'$$

Modular Transfer Function (MTF)

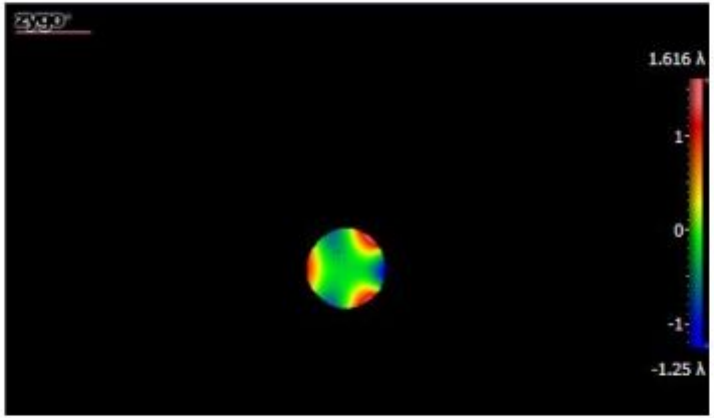
The graph on the right shows the NS1 calculated MTF vs. SAM-II MTF. It can be seen that the MTF of NS1 was found to be larger than the MTF of SAM-II

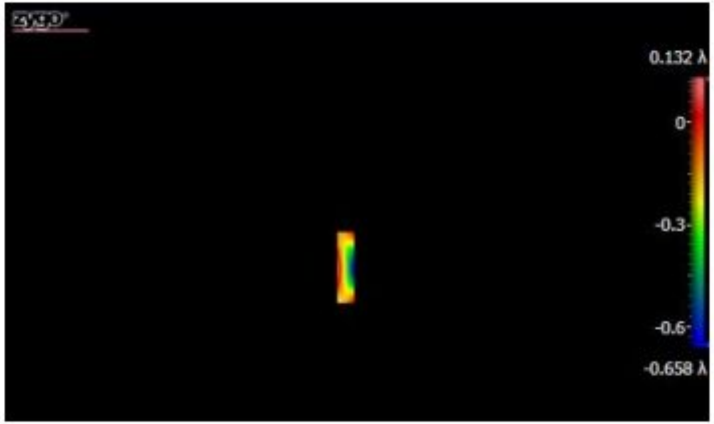




OAP Feasibility

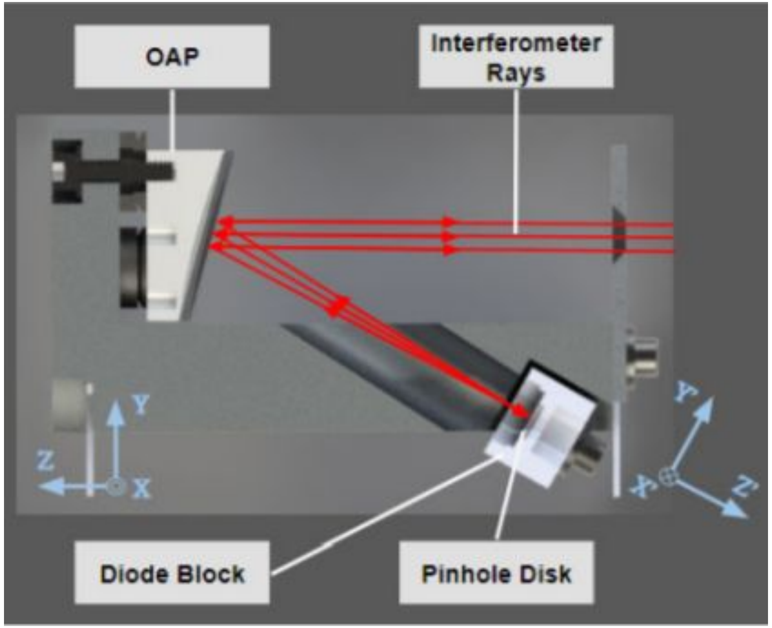
The study conducted by the NS1 team concluded that the WFE due to aberrations caused by deformations on the surface of the OAP was within acceptable levels due to a minimal decrease in MTF





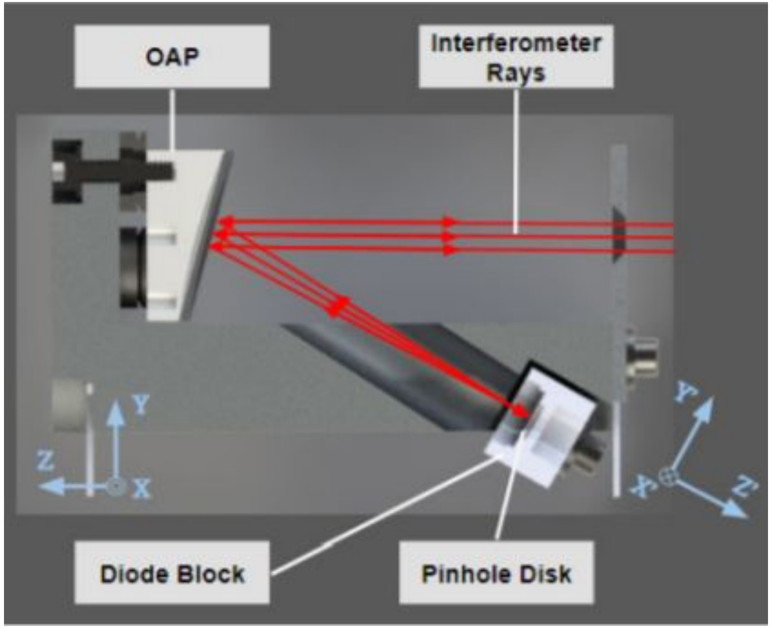
Alignment Procedure

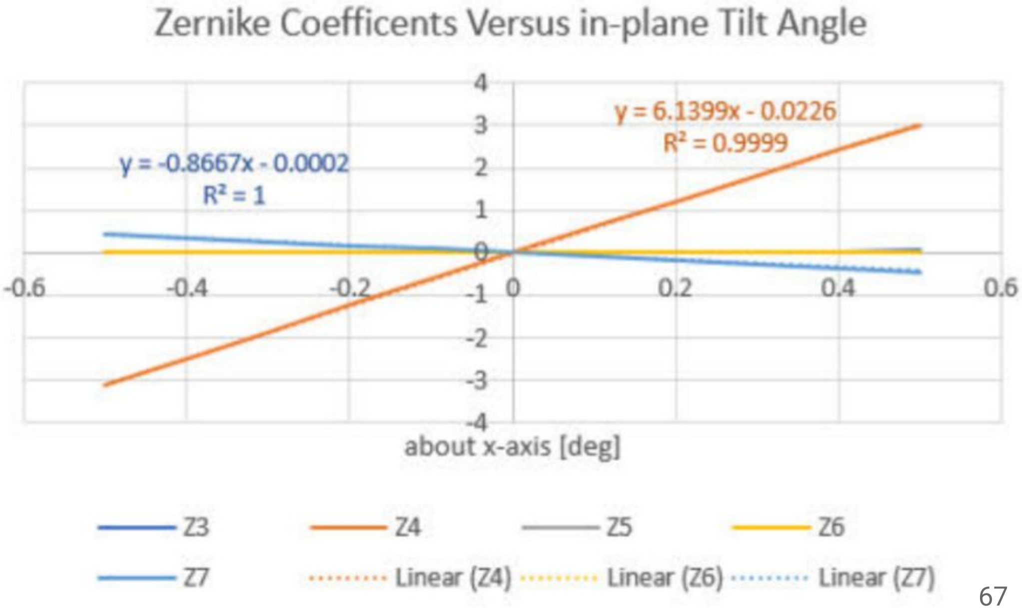
1. Align OAP Mirror optical axis parallel to Interferometer (INT) Beam axis using tilt micrometers
   a. Photodiode Block mounted to 3-axis stage
   b. Use INT Return Half Sphere to align OAP-INT Beam
2. Aligning Pinhole Disk on Focus Point
   a. Chrome Half Sphere (HS) centered over pinhole
   b. Interferometer measurements are taken to approximately locate the OAP’s focus point relative to HS
   c. Shims are inserted and the Photodiode block is firmly placed into the optical bench mounting point
   d. Interferometer measurements are taken to measure focus point offsets
   e. Steps (c) and (d) are repeated until the pinhole is centered on the focus point within required tolerances



Alignment (cont.)

The main testing to be done on the optical system is alignment testing, which is performed using an interferometer

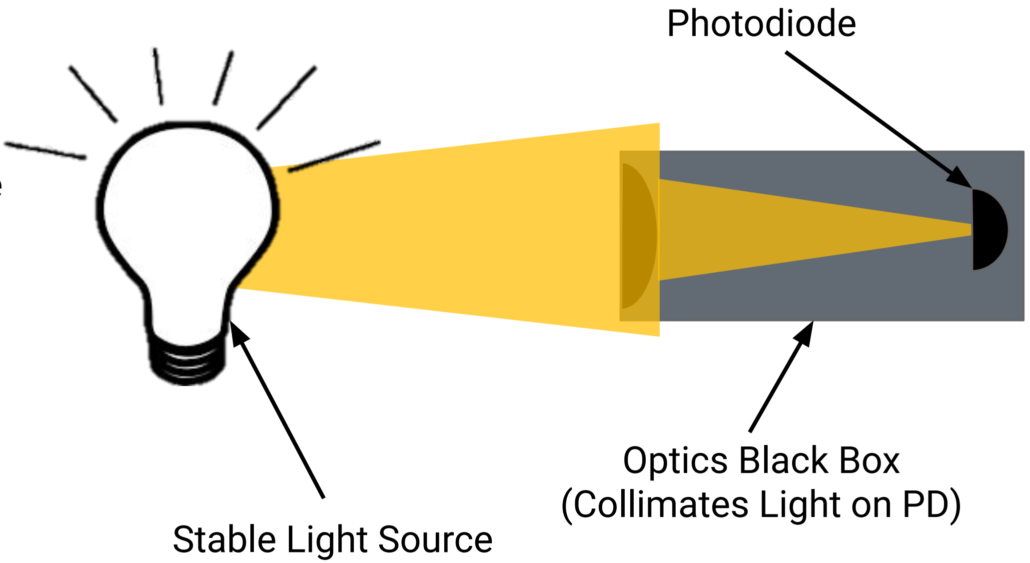




Indoor Testing - Irradiance Verification

Indoor Testing:

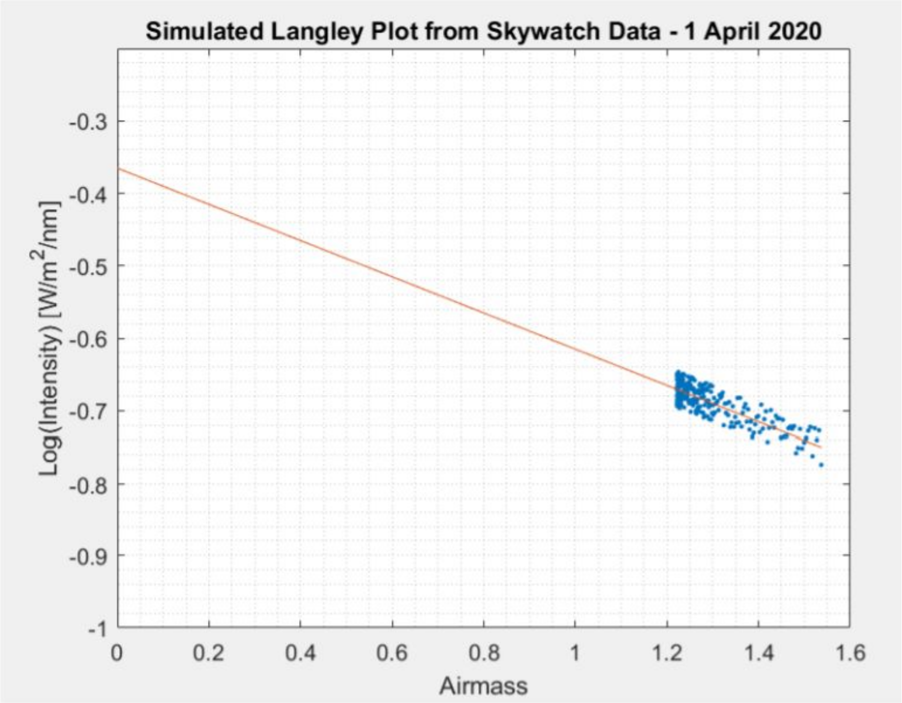
- Use optical system to measure irradiance in a dark room with no lights on
- Place lightbulb with known irradiance in front of optical system
- Measure irradiance using optical system - ensure that photodiode is both receiving and accurately measuring light



Outdoor Testing – Langley Plot

Outdoor Testing:

- Take solar irradiance measurements outdoor periodically over a set period of time (Ex: every minute from 10am to 3pm)
- Compare solar irradiance measured to that measured by the CU boulder skywatch observatory
- Create Langley plot based off of collected data, and extrapolate it to find the solar irradiance at zero airmass and compare to expected value
- Zero airmass solar irradiance extrapolated from Langley Plot is used to estimate photodiode saturation (target of ~80%)



Langley Plot Simulated by NanoSAM I

Optics Summary Slide

Overall, the optical system designed will meet or exceed SAM II performance

- Using the chosen filters, a center wavelength of 1.03 micrometers will be captured
- With a pinhole of 15 micrometers, the field of view of 1.3 arcminutes will be met, which will allow for a vertical resolution of 1 km.
- NanoSAM I was modeled to have an MTF of about .88 at the given frequency, exceeding the MTF requirement of .74
- The solar tracker purchased by NanoSAM I meets the 1 arc-min/mRad requirement tracking accuracy requirement

Enclosure – Thermal Model

Key Equations:

$$\dot{Q}_{out} = 2\sigma\epsilon T_{sys,eq}^4(2A_s + A_p)$$

$$\dot{Q}_{in,sun} = \alpha AF_{s,sun}A_sG_s$$

$$\dot{Q}_{in,A} = \alpha A_sG_{E,A}[A_s(AF_s+AF_{-s})+A_h(AF_h+AF_{-h})+A_p(AF_p+AF_{-p})]$$

$$\dot{Q}_{in,IR} = \epsilon A_sG_{E,IR}[A_s(AF_s+AF_{-s})+A_h(AF_h+AF_{-h})+A_p(AF_p+AF_{-p})]$$

$$T_{sys,eq} = \left[\frac{\dot{Q}_{in,sun}+\dot{Q}_{in,A}+\dot{Q}_{in,IR}+P_i}{2\sigma\epsilon(2A_s+A_p)}\right]^{(1/4)}$$

$$\dot{Q}_{tot} = \dot{Q}_{in,A}+\dot{Q}_{in,IR}+\dot{Q}_{in,sun}+P_i-\dot{Q}_{out}$$

$$T_i = \frac{\dot{Q}_{tot}\Delta t}{mc_p} + T_{i-1}$$

Symbol Definition

σ	- Boltzmann Constant [W/m^2K^4]
ϵ	- IR emissivity of the external surfaces of the CubeSat
G_S	- Heat flux from sun [W/m^2]
$T_{sys,eq}$	- System temperature equilibrium [K]
A_i	- Area associated with **ith** side sides [m^2]
α	- Solar absorptivity of the external surfaces of the CubeSat
$AF_{i,sun}$	- Sun area factor of **s** surface
$G_{E,A}$	- Albedo radiation flux density from Earth [W/m^2]
$G_{E,IR}$	- Longwave radiation flux density from Earth [W/m^2]
AF_i	- Albedo area factor of **i** surface
$\dot{Q}_{in,sun}$	- Power into the system from the Sun [W]
$\dot{Q}_{in,A}$	- Power into the system from albedo [W]
$\dot{Q}_{in,IR}$	- Power into the system from long-wave radiation [W]
P_i	- Internally dissipated power [W]
$\dot{Q}_{out}$	- Power out of the system [W]
$\dot{Q}_{tot}$	- Net power into/out of the system [W]
Δt	- Transient timestep [s]
m	- Mass of aluminum external structure [kg]
c_p	- Specific heat of the external structure [kJ/kg-K]
T_i	- Temperature at ith timestep [K]

Enclosure: Thermal Area Factor Analysis

Area factor determines the effective area exposed to radiation and results in the following equations for each side:

$$AF_h = -sin(\theta_h)$$

$$AF_s = -cos(\theta)cos(\theta_h)$$

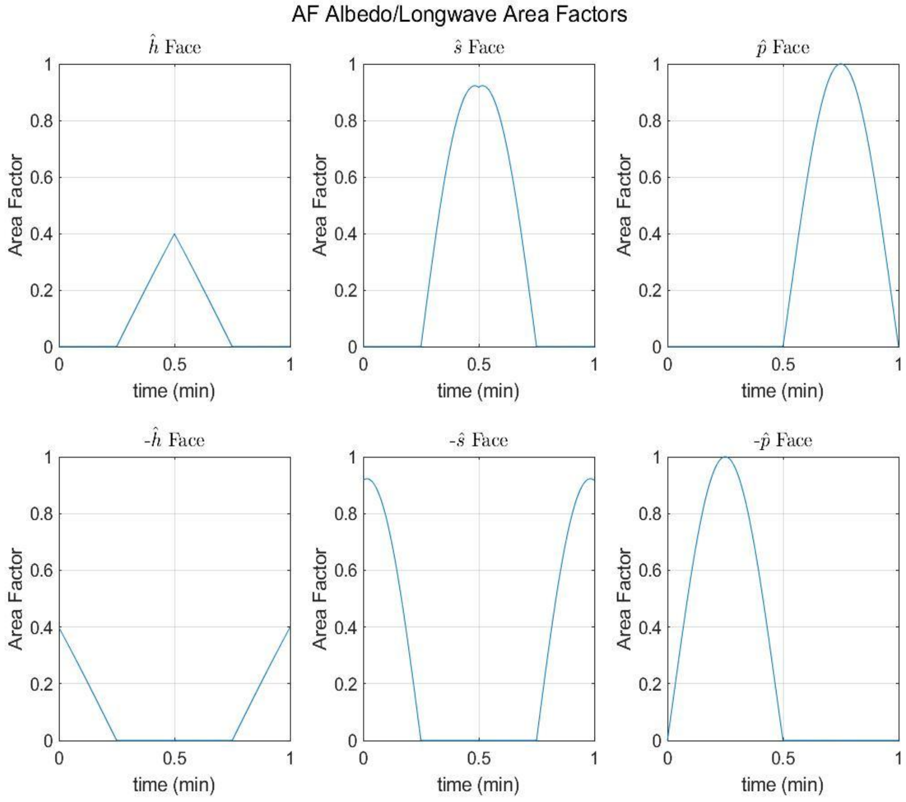
$$AF_p = -sin(\theta)cos(\theta_h)$$

$$AF_{-h} = sin(\theta_h)$$

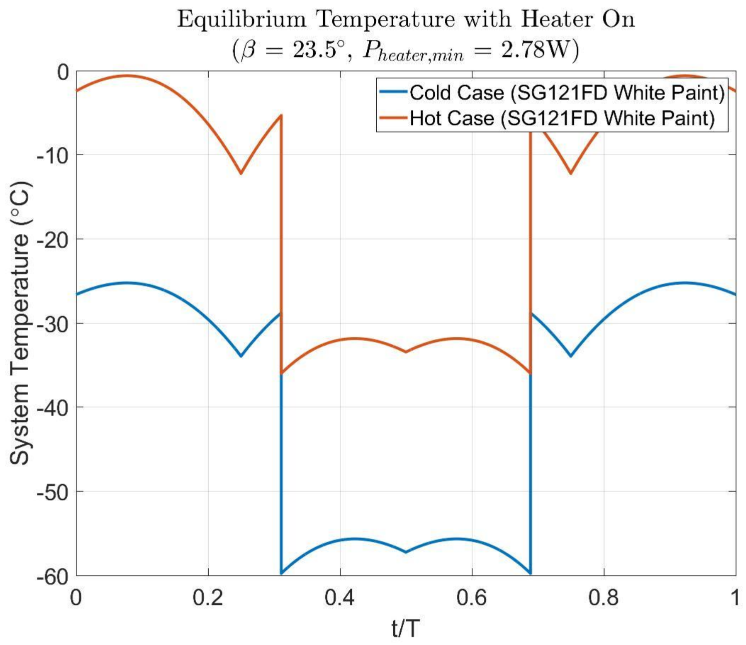
$$AF_{-s} = cos(\theta)cos(\theta_h)$$

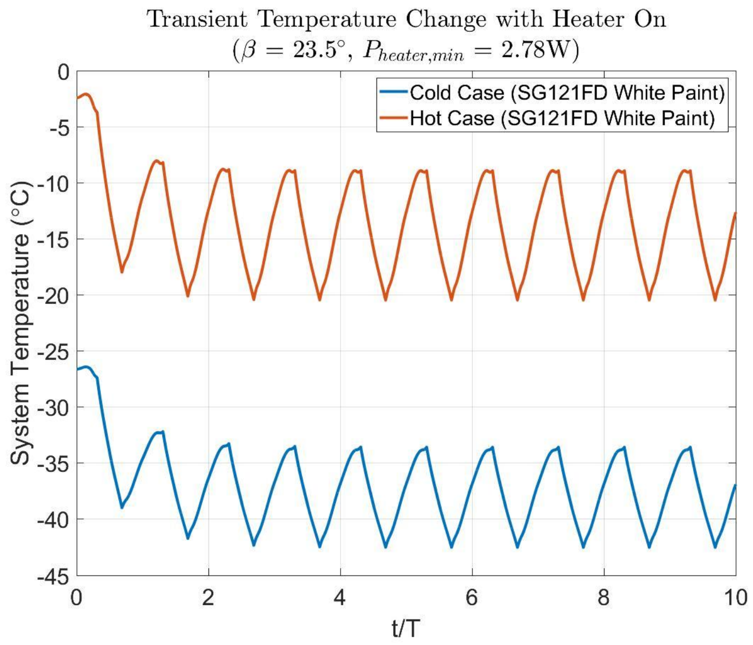
$$AF_{-p} = sin(\theta)cos(\theta_h)$$

θ_h - angle derived from the beta angle of the orbit (position above/below the solar plane)
θ - angle derived from satellite position in orbit (offset from argument of latitude)



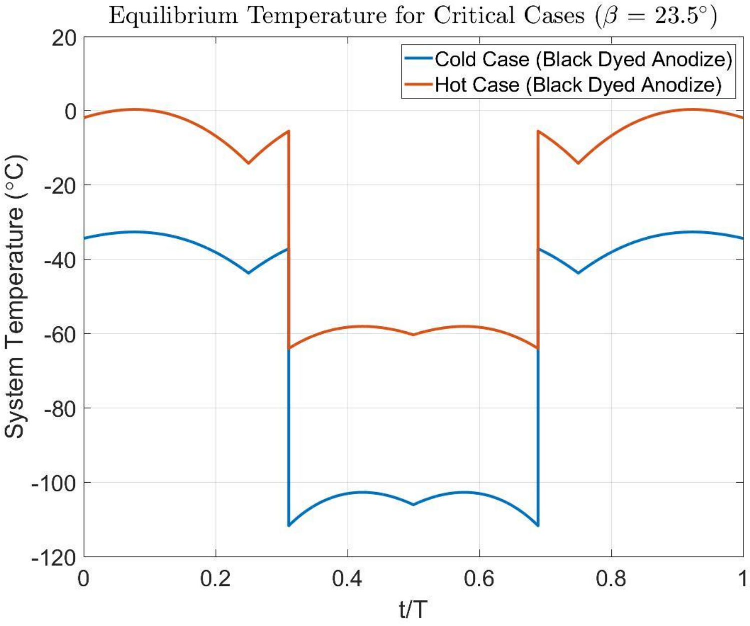
Minimum Power For Heater (SG121FD White Paint)

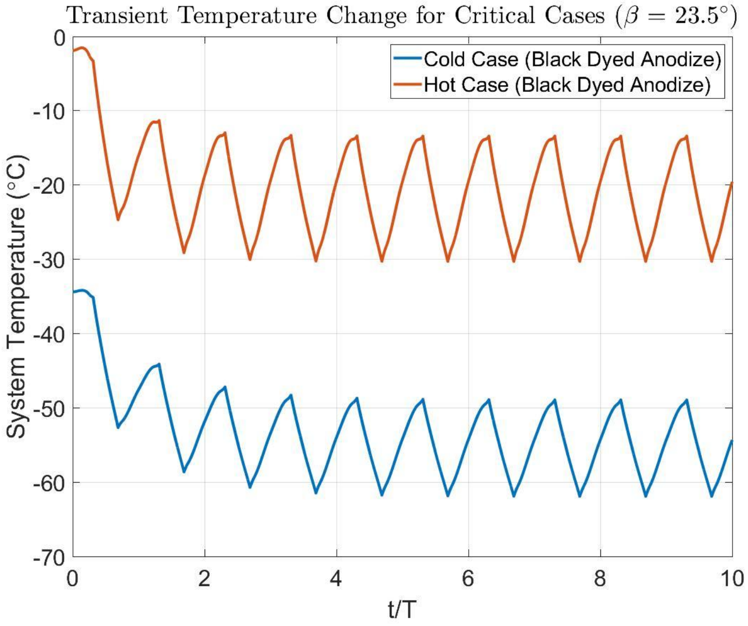




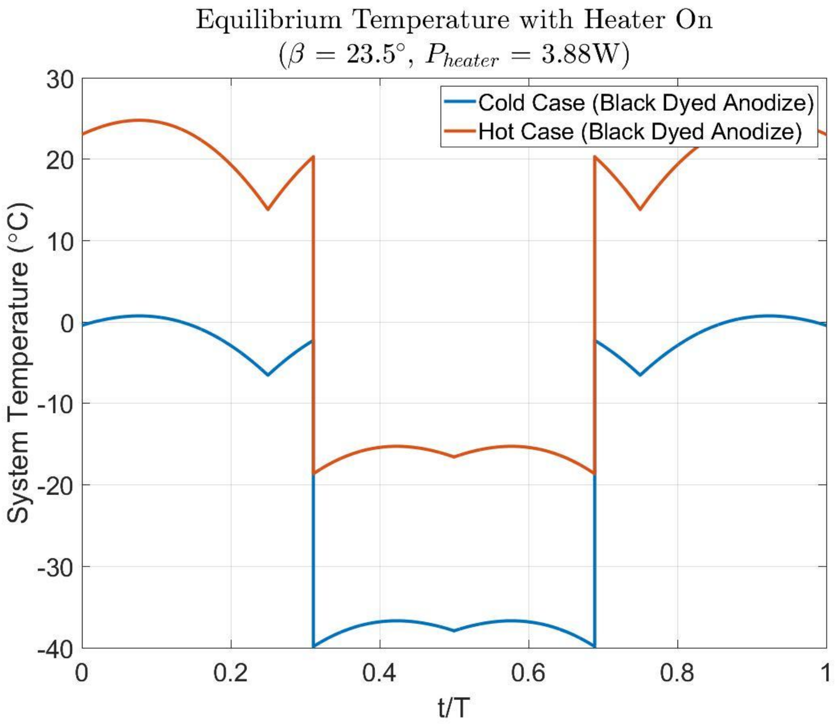
Thermal Coating Alternative: Black Dyed Anodize

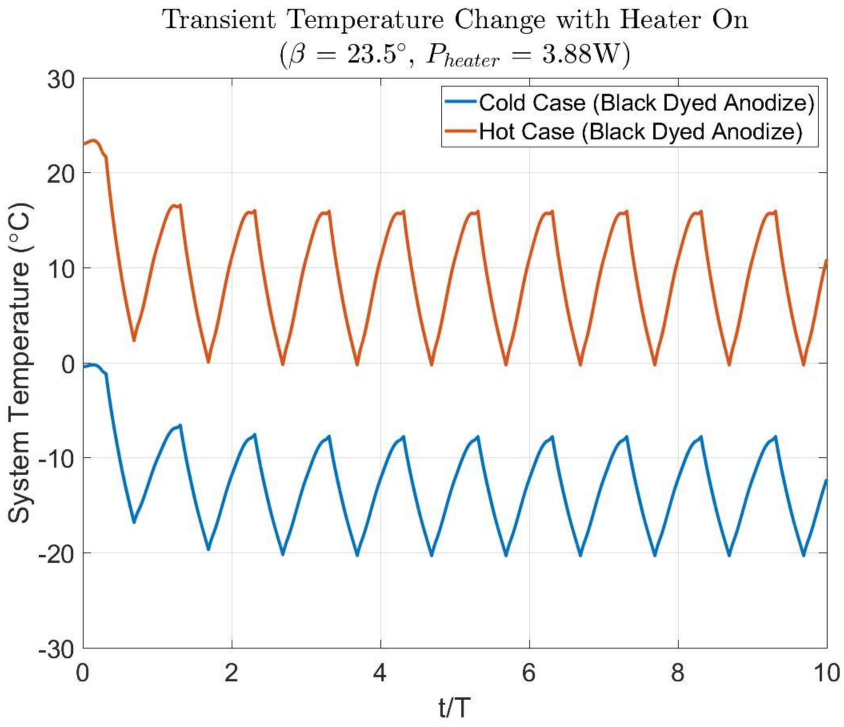
α = 0.54, ϵ = 0.75





Thermal Coating Alternative: Black Dyed Anodize (Cont.)



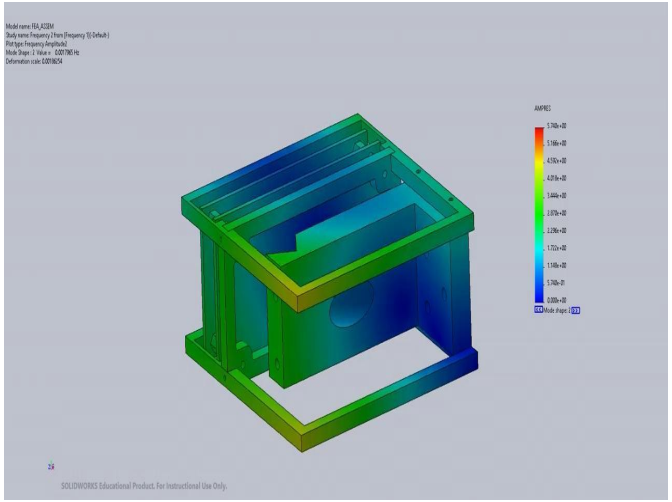


Temperature Differentials

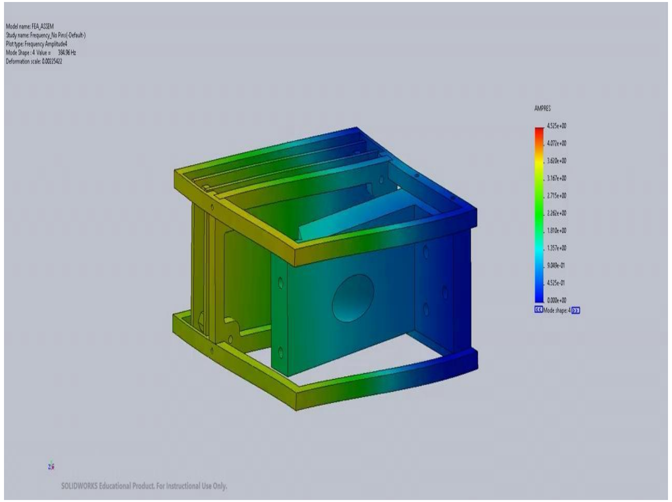
Largest Temperature Differentials During Data Collection (w/ Heater) :

CASE	ΔT (K)	Time (min)	ΔT/t (K/min)
Cold (sunrise)	1.076	5.730	0.188
Cold (sunset)	0.161	5.730	0.028
Hot (sunrise)	1.442	4.668	0.309
Hot (sunset)	0.124	2.943	0.042

Enclosure – Frequency Study



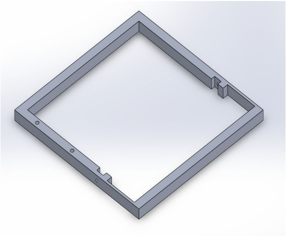
0.0017965Hz Mode (Auto Interface)



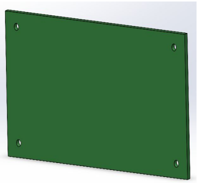
384.96Hz Mode (Auto Interface)

Enclosure – Frequency Analysis

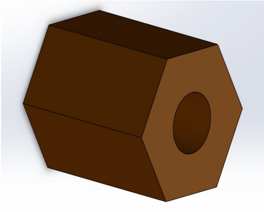
Any **metal parts (Structural Ribs, Optics Base) are Al-6061-T4 (SS)** within Solidworks. These are modeled with tetrahedral **linear elastic** elements.



The **PCBs are FR-4**, a common PCB material. These are modeled with tetrahedral **linear elastic** elements.



The **LORD Nut/Nut elastomers** (commercially available thermal/vibrational isolator) **are modeled as silicone rubber**. These are modeled with tetrahedral **hyperelastic** elements. This model was selected as silicone rubber is decidedly not linear elastic. The methodology for selecting the coefficients required is discussed in "A comparative study of several material models for prediction of hyperelastic properties: Application to Silicone-Rubber and Soft Tissues" by Pedro et al.



Enclosure – Cost Breakdown

New components to purchase:

Widely Available from McMaster Carr.

- Structural Aluminum
  - Al 6061-T6 (high tolerance): 4” x 12” x 6mm ($67.18)
- Connecting Screws
  - Screw type 2-56 5/16” - $6.50
  - Screw type 2-56 5/8"   - $4.38
  - Screw type 0-80 3/16” - $8.09
- Elastomers
  - Parker LORD Nut/Nut - (TBD)
- Housing Siding
  - Al 6061-T6 (high tolerance): 6” x 12” x ⅛” ($84.00)
  - Should consider other materials to reduce cost and mass

Components not included in cost:

- Optical Bench
- Filter Unit
- Electronics Boards

Total:

$67.18 + $6.50 + $4.38+ $8.09 + $84.00 =

$170.15 → x2.5 = $425

Software – previous system