NanoSAM II

Nano-Stratospheric Aerosol Measurement

Spring Final Review

April 29, 2021

Ball Aerospace

University of Colorado Boulder
Department of Aerospace Engineering Sciences

Agenda

NanoSAM II
SFR

- Overview
- Design Description
- Test Overview
- Test Results
- Systems Engineering
- Project Management

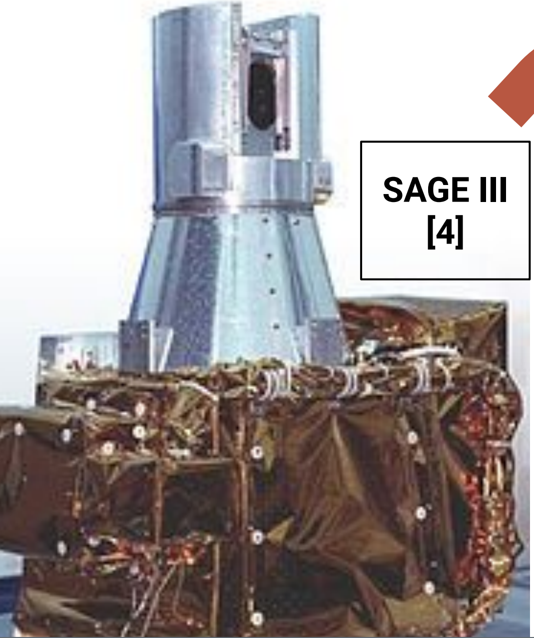
Project Overview

Jaret Anderson

Project Background & Purpose

SAM/SAGE Instruments
(1979-1984, 2001-2006, 2011-Current)

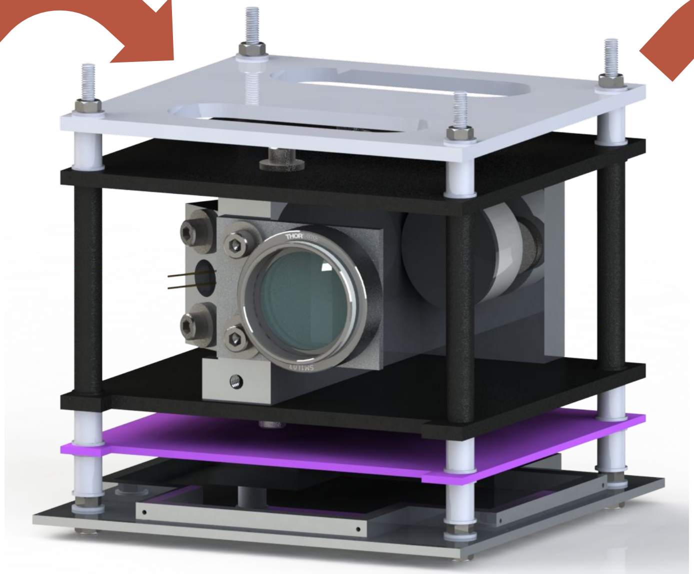
Bulky, High Cost, Low Data Volume



SAGE III
[4]

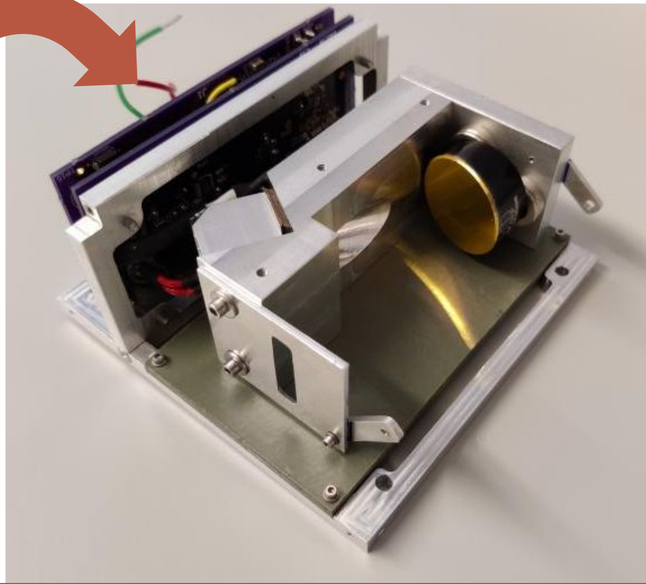
NanoSAM I
(2019-2020)

Optical Instrument for CubeSat Footprint

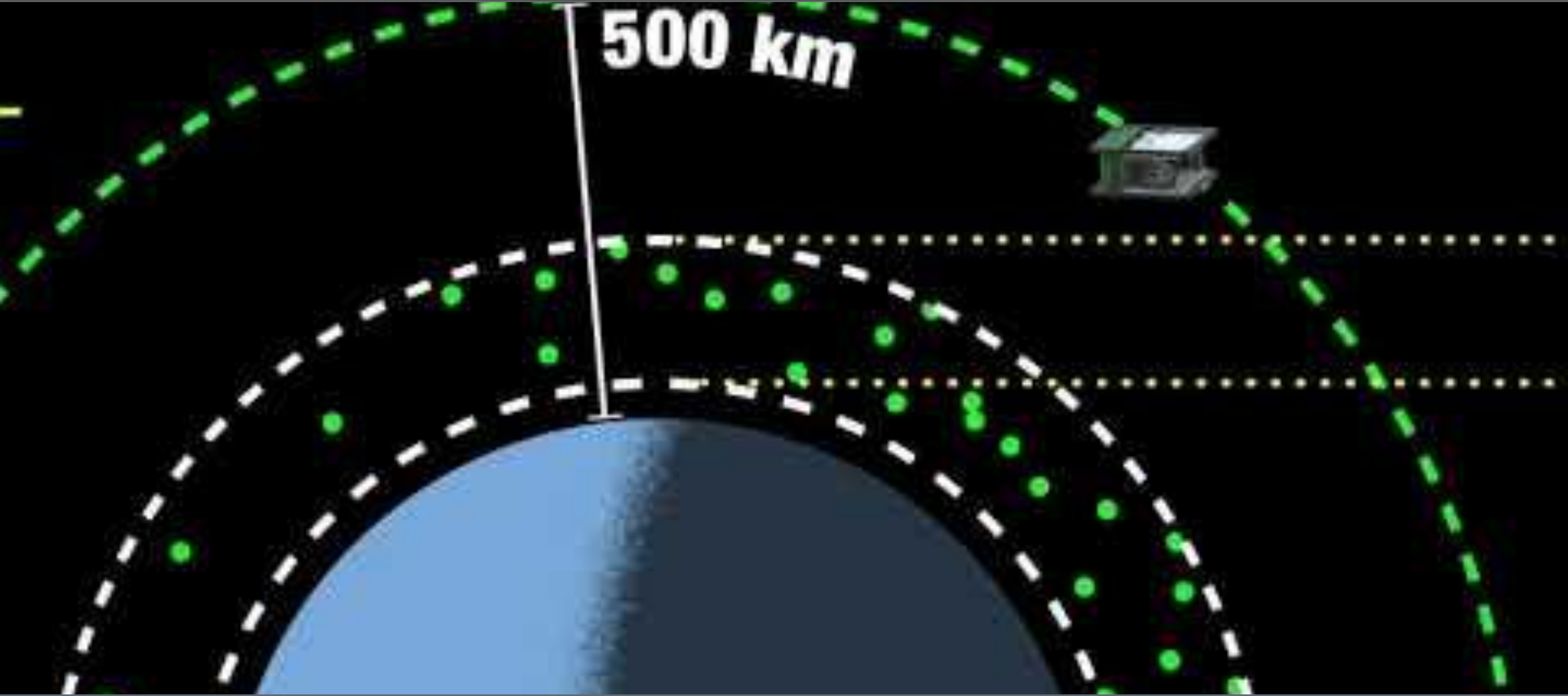


NanoSAM II
(2020-Current)

Integrated 0.5U CubeSat Payload



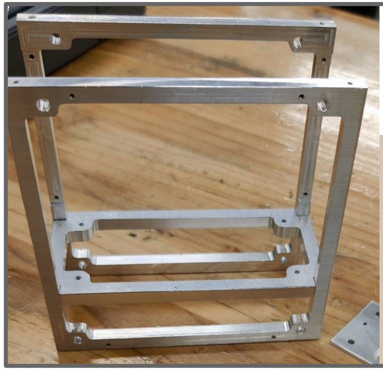
NanoSAM Mission CONOPS



Levels of Success

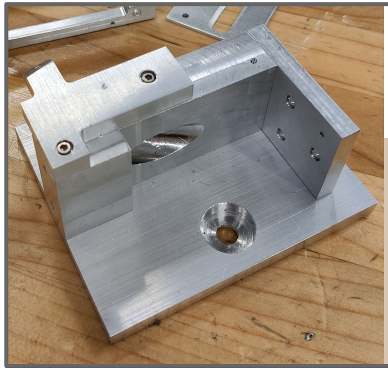
	Level 1 (solar tracking test)	Level 2 (Improved Ground Performance)	Level 3 (Flight Capability)
Payload Housing	The payload housing contains the integrated electronics board and optics bench inside a 0.5U enclosure.	The payload housing structural interface is compatible with an industry standard bus.	The payload housing functions within the operating temperature range of -20◦C to 50◦C and its lowest vibrational natural frequency is greater than 100Hz.
Data Capture	Software and electronics acquires, digitizes, packetizes, and downloads 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 a computer emulating an industry standard CubeSat bus communications system.
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 -20◦C to 50◦C and its lowest vibrational natural frequency is greater than 100Hz.

Critical Project Elements



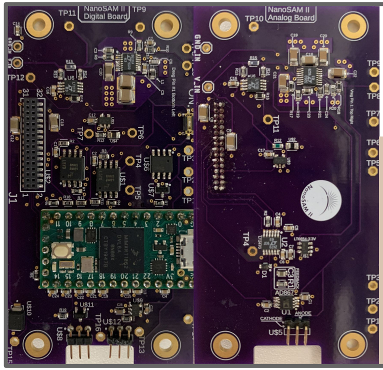
Structure

0.5U Payload Form Factor



Optics

Match SAM-II Instrument Legacy Performance



Electronics

Low-Noise Signal Processing

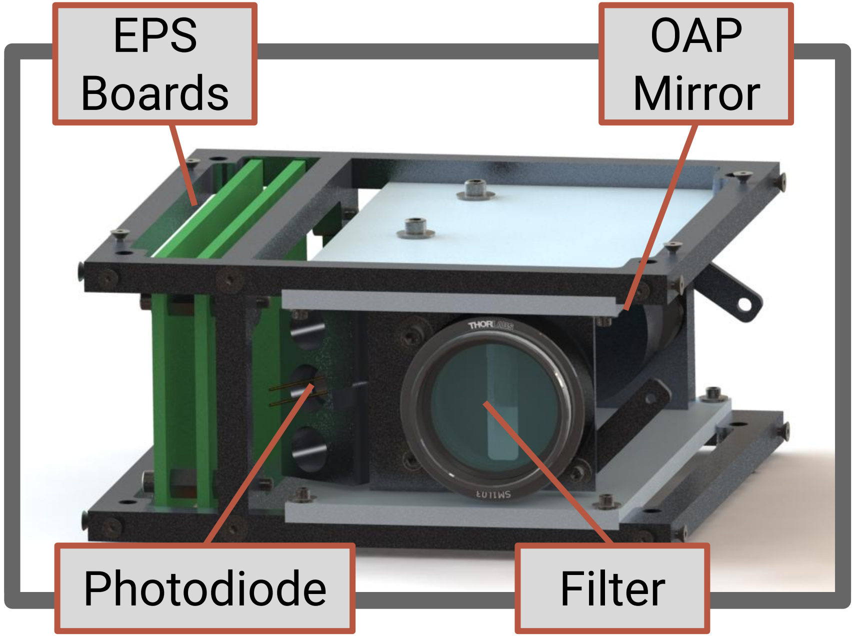
Software

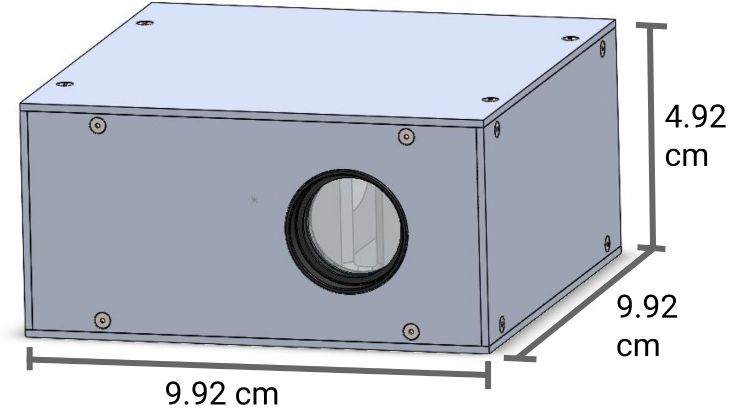
Timely and Reliable Data Collection

Design Description

Donavon Schroeder

NanoSAM II Payload



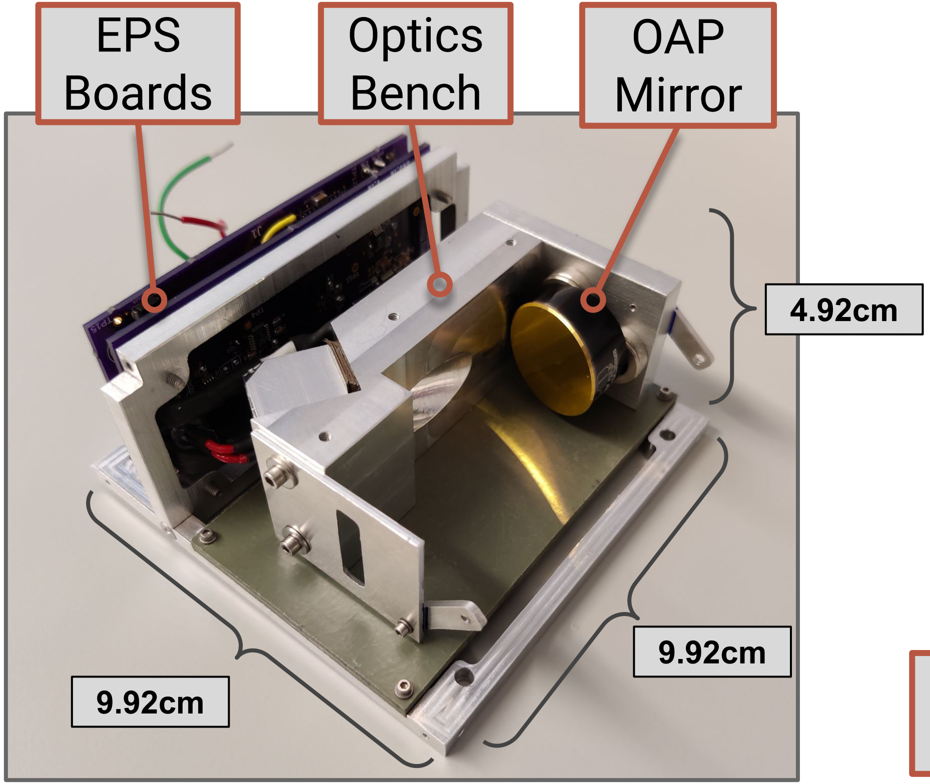


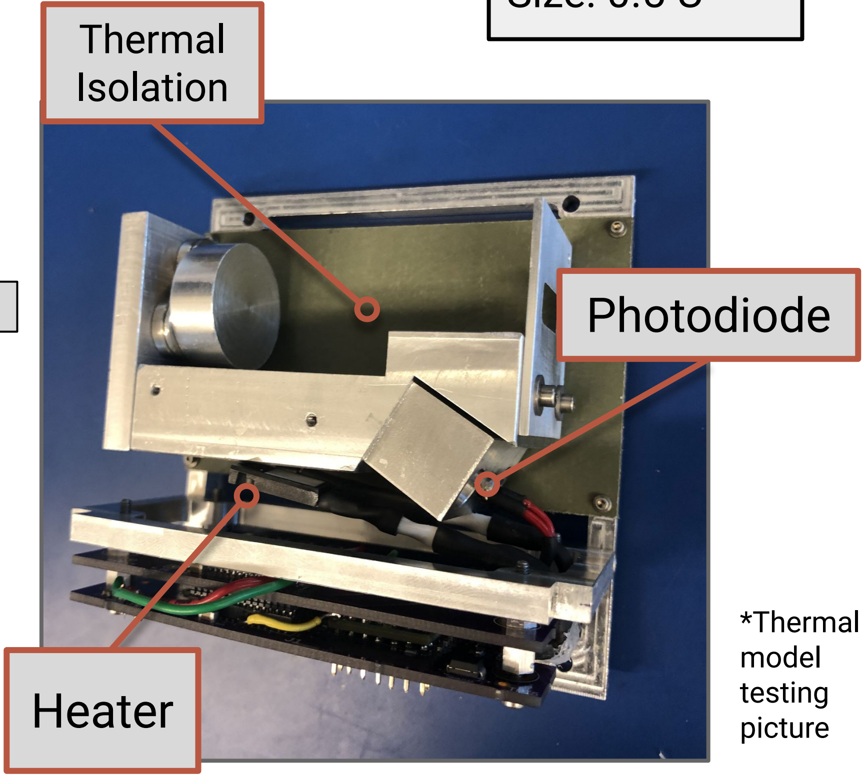
Mass: 0.48 kg
Size: 0.5 U

Gathers Irradiance Measurements at 50 Hz

Integrated Payload

Mass: 0.48 kg
Size: 0.5 U

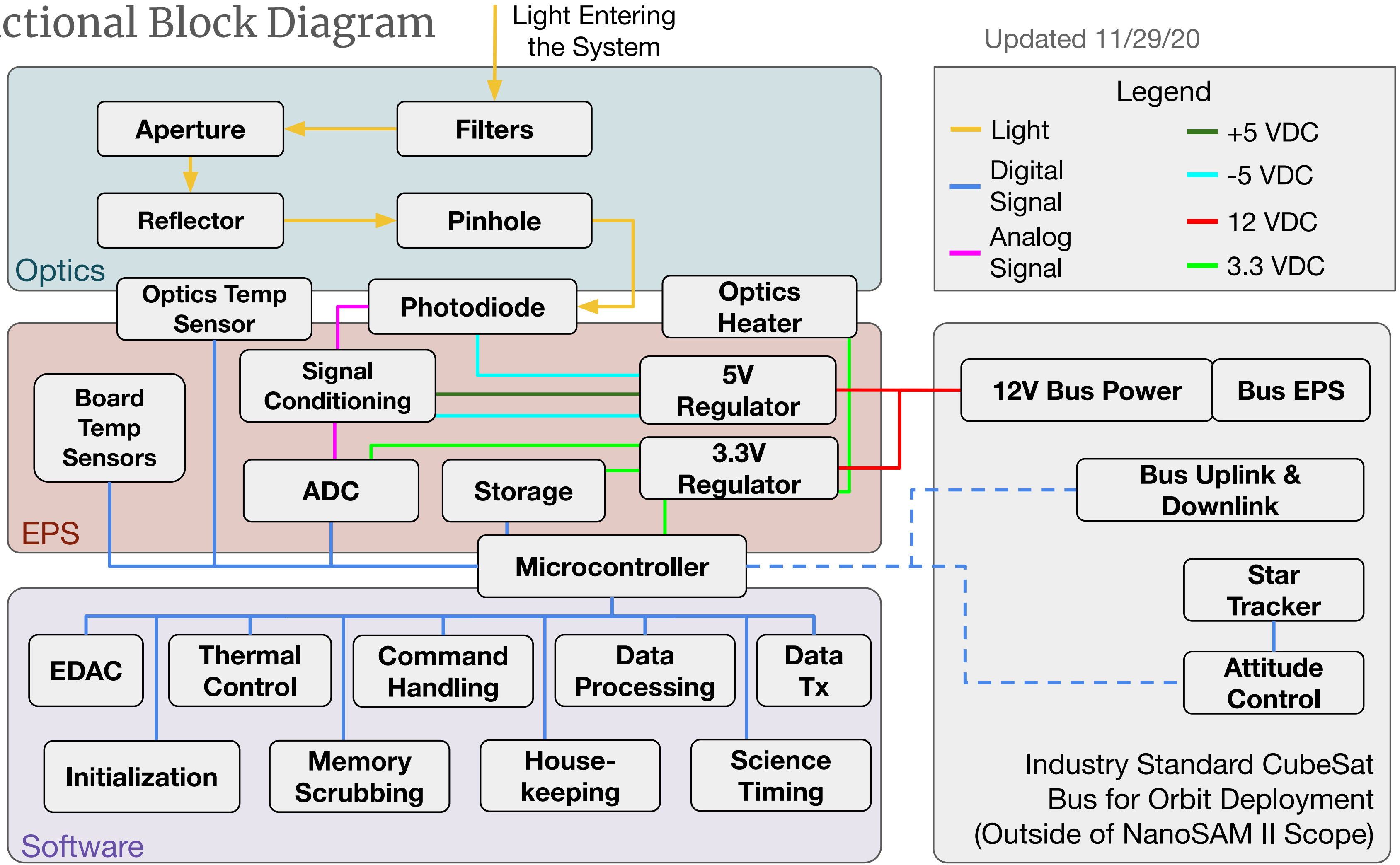


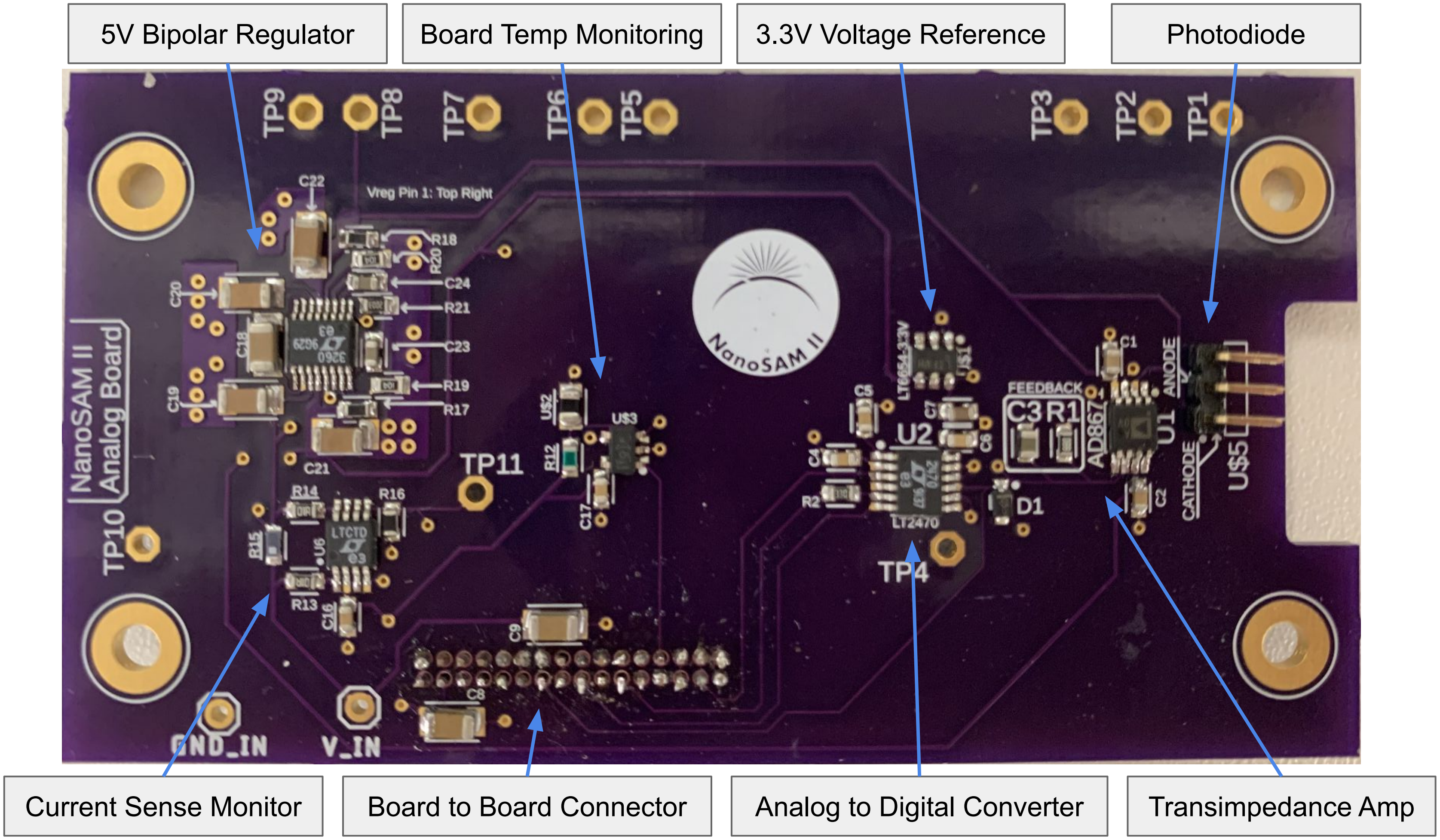


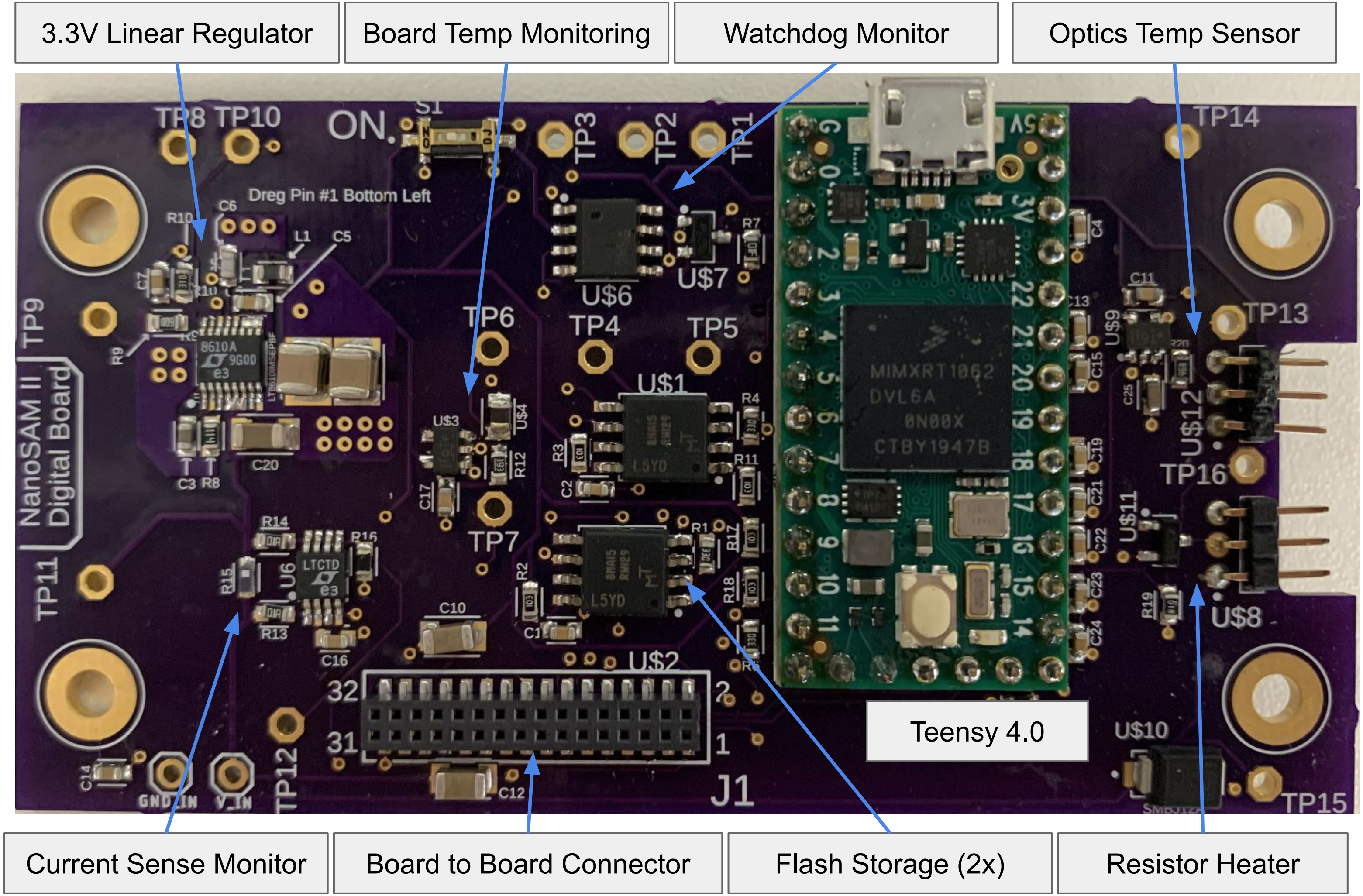
*Thermal model testing picture

Functional Block Diagram

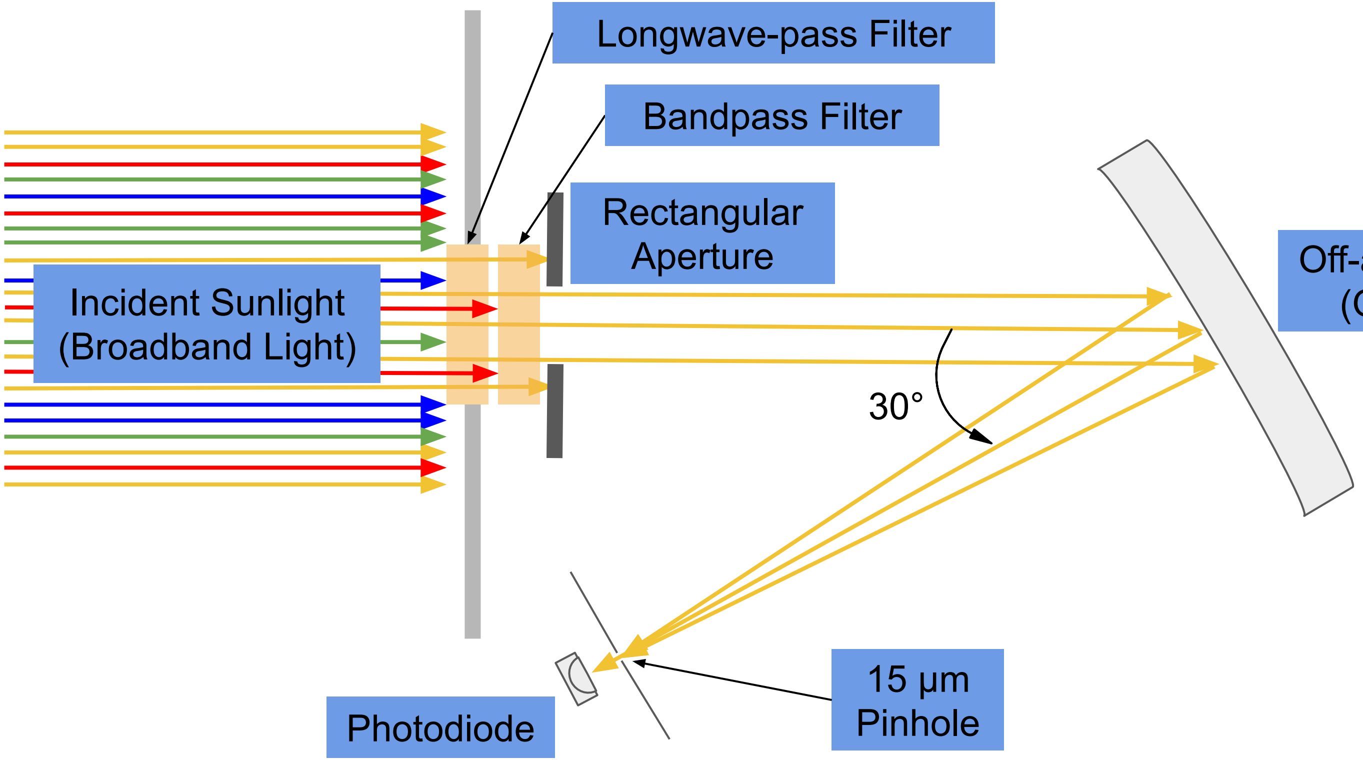
Updated 11/29/20

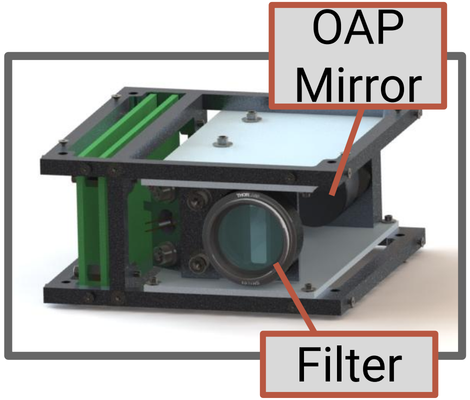


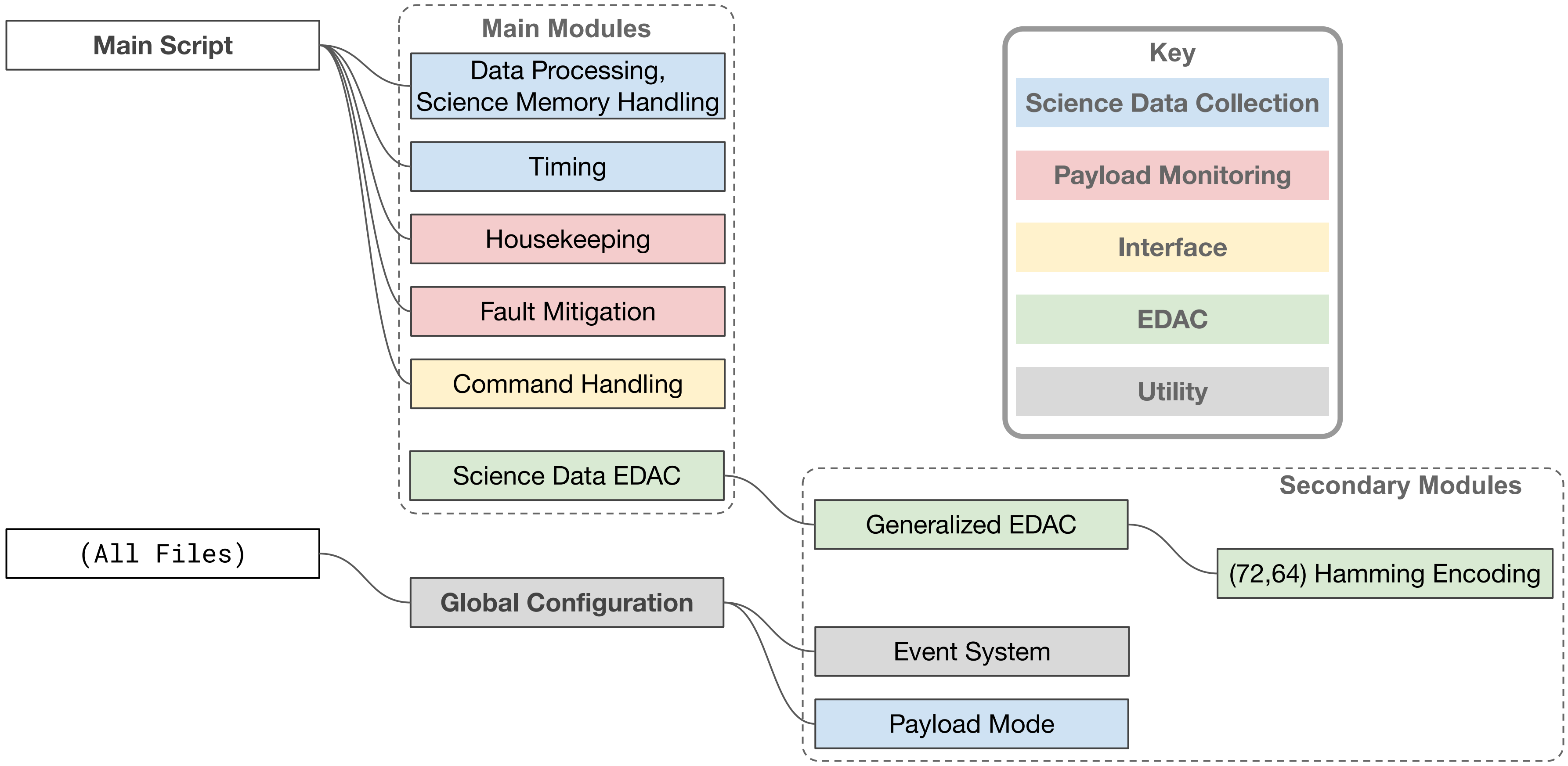

5V Bipolar Regulator
Board Temp Monitoring
3.3V Voltage Reference
Photodiode
Current Sense Monitor
Board to Board Connector
Analog to Digital Converter
Transimpedance Amp


3.3V Linear Regulator
Board Temp Monitoring
Watchdog Monitor
Optics Temp Sensor
Teensy 4.0
Current Sense Monitor
Board to Board Connector
Flash Storage (2x)
Resistor Heater
NanoSAM II Digital Board

Optics Final Design







Flight Software Header Tree

Software Data Parameters

Science Data

Photodiode sample rate:	**50 Hz**
Sample size (primary ADC):	**16 bits**
Sample size (backup ADC):	**12 bits**
Max window duration:	**240 sec**
Max data per window (encoded):	**27009 Bytes**
External flash capacity:	**2 x 128 Mb**
Minimum time to fill flash:	**38 days**

Persistent Payload Data

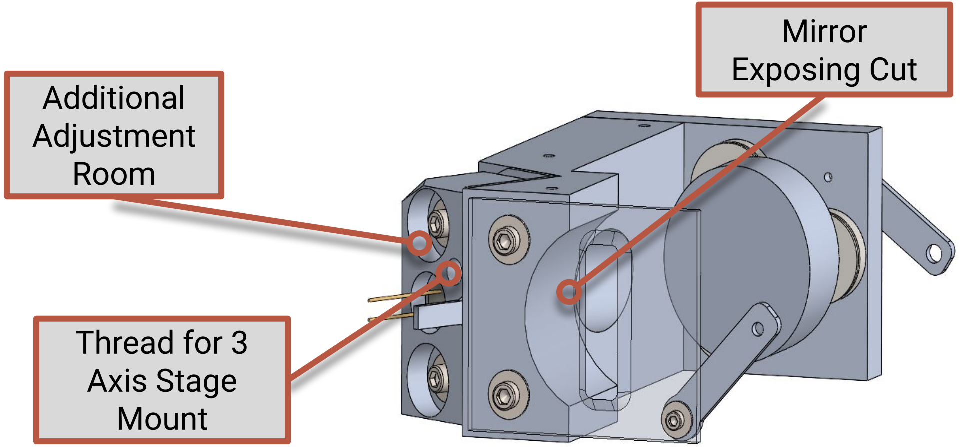
Persistent data size (encoded):	**90 Bytes**
EEPROM size:	**1080 Bytes**
Max EEPROM writes per address:	**100,000**
Max writes with address shifting:	**1,200,000**

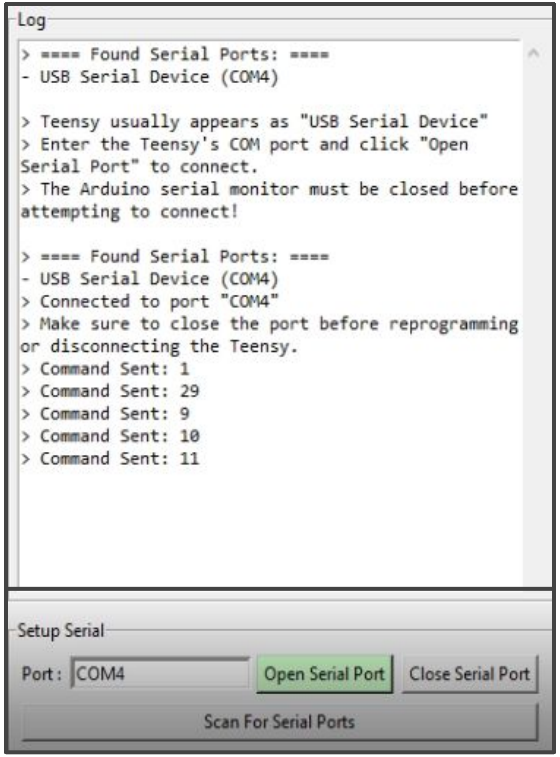
Housekeeping Data

Housekeeping sample rate:	**1 Hz**
Housekeeping sample size:	**32 Bytes**
Sample buffer size (5000 samples):	**156.25 kB**

Changes Since TRR

- Software GUI
- Electronics white wire
- Bench drawing modifications
  - Not able to implement in hardware this year, but will be useful for future teams





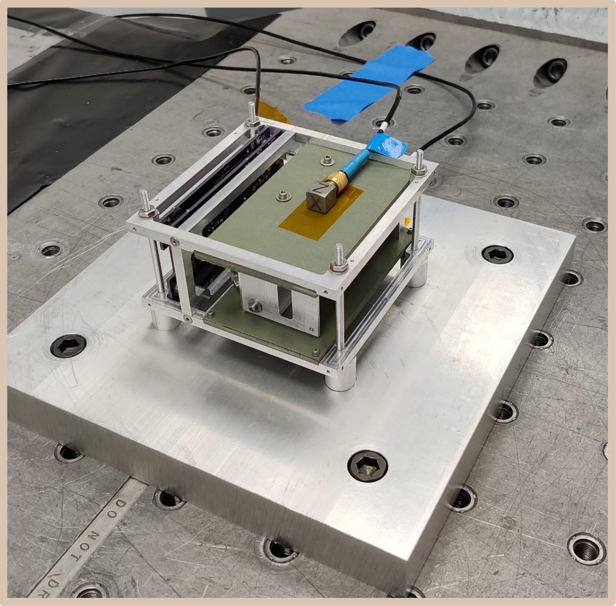
Test Overview

Ryan Smithers

Tests Conducted

Test	Requirements	Success Level
Electronics System	Electronics gather 12 bit photodiode samples at 50 Hz	Level 3 (Flight Capable)
Data Collection	Payload shall process and store ≥10 bit data at 50 Hz for the duration of a data window and communicate this data to a ground computer	Level 3 (Flight Capable)
Alignment	NanoSAM II shall have optical performance equivalent to or surpassing those of SAM-II	Level 1 (Solar Tracking Test)
Solar Tracking Test	The system shall demonstrate solar tracking accuracy of 1 mRad or finer during ground testing	Level 3 (Flight Capable)
Vibration Test	The system shall maintain optics performance following exposure to vibration, Lowest natural frequency shall be > 90 Hz	Level 2 (Improved Ground Performance)
Thermal Test	Payload contents shall operate across a temperature range of -20°C to 60°C	Level 1 (Photodiode data not collected as light source could not be used in chamber)

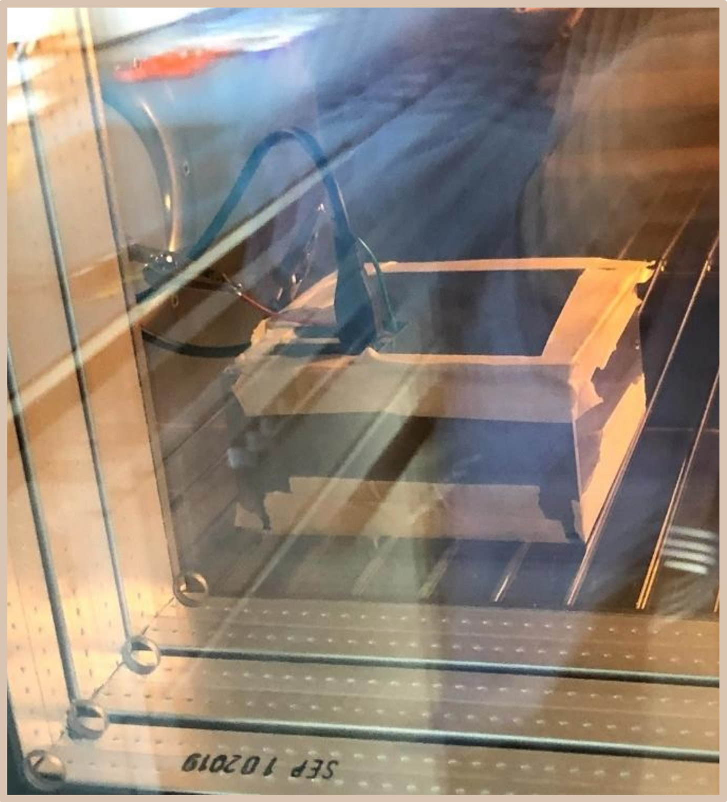
Vibration Test Objectives



- Determine the resonant frequencies along each payload axis
- Use experimental modes to validate our vibrational model
- Test hardware identical to final hardware, analogous versions of the optics and electronics were used
- Test carried out at Altius Space Machines (Broomfield, CO)

Related Requirements
The system shall maintain optics performance following exposure to vibration - not assessed since optic is not staked Lowest natural frequency shall be > 90 Hz

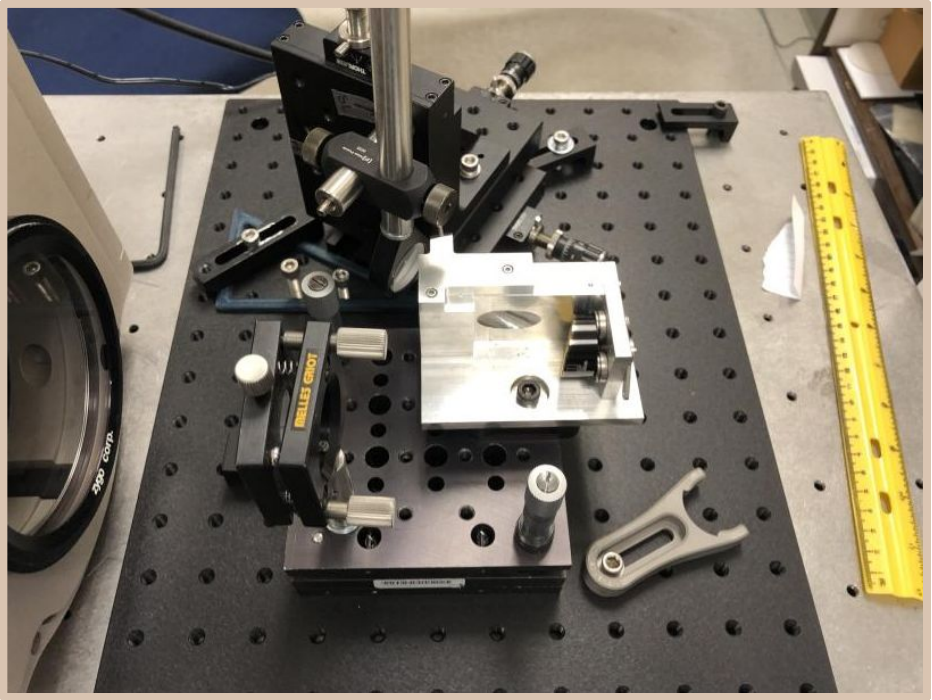
Thermal Test Objectives



- Gather data: temperature of the optics bench and electronics boards compared to ambient temperature
- Assess the effectiveness of the thermal isolation fiberglass boards used for isolating optics
- Ensure electronics continue to function as the payload reaches the extremes of the temperature requirements
- Test done in a CU thermal chamber

Related Requirements
Payload contents shall operate across a temperature range of -20°C to 60°C

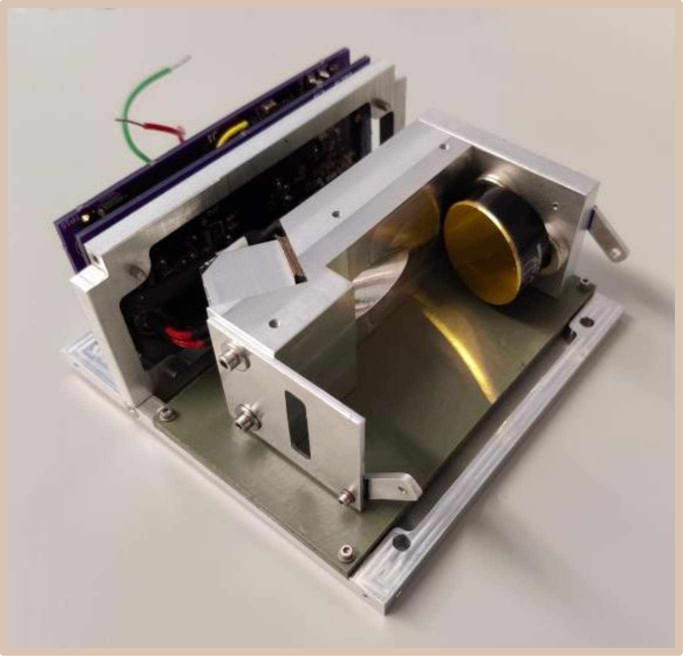
Optics Alignment Objectives



- Use an interferometer to align the optic as best as possible
- Limited timeframe as the interferometer usage has been donated to us by Meadowlark Optics
- Metrics to measure this are modulation transfer function (MTF), defocus, and radial displacement
- Target MTF (derived from SAM-II): 0.74

Related Requirements
NanoSAM II shall have optical performance equivalent to or surpassing those of SAM-II

Regulated Light Test Objectives



- Record photodiode output when receiving optical signal of known source
- Use results to characterize system accuracy by comparing to theoretical irradiance calculations
- Compare the 16-bit and 12-bit ADC results

Related Requirements
Payload shall process and store ≥10 bit data at 50 Hz for the duration of a data window and communicate this data to a ground computer

Solar Attenuation Test Objectives

- Full system test, requires all other subsystems to be functional before it can be conducted
- Track the sun as it passes across the horizon and continuously gather irradiance measurements
  - This is as close to our on-orbit operations as we can get with a ground test
- Result of this test is a Langley plot

Related Requirements
Payload shall process and store ≥10 bit data at 50 Hz for the duration of a data window and communicate this data to a ground computer

Test Results

Ryan Smithers & Dan Wagner

Validation Status

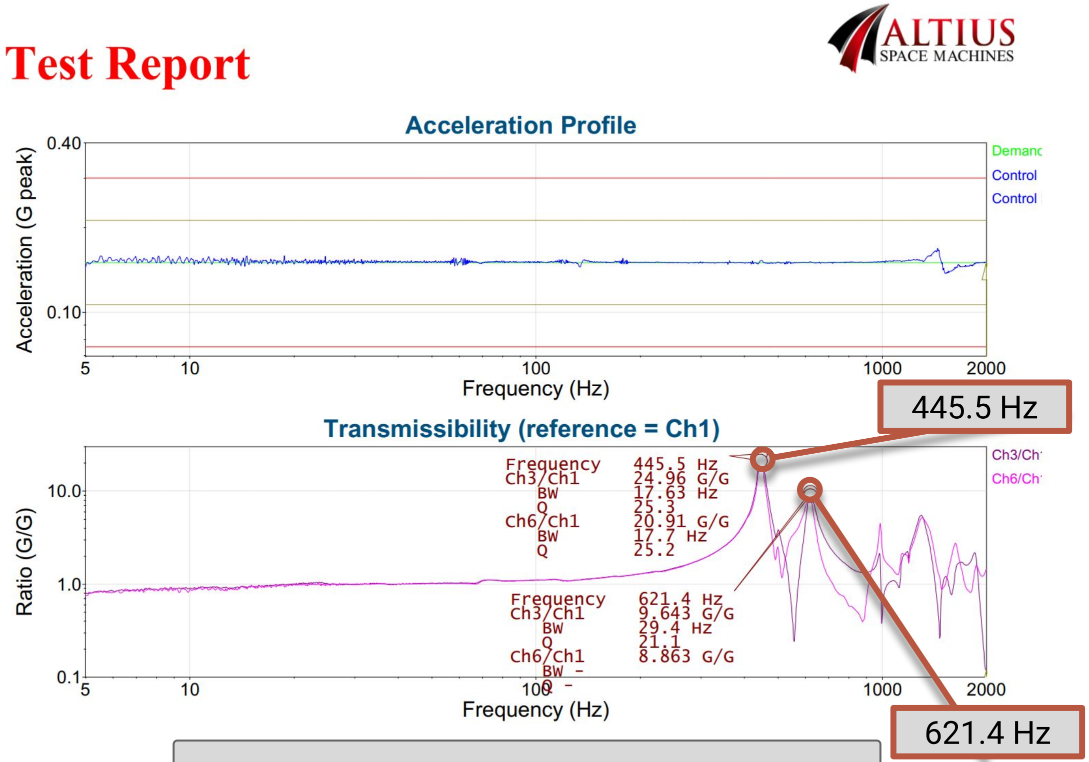
Functional Requirement	Tests	Success Level Explanation
0.1 Data Capture	**Thermal**, **Regulated Light, Solar Attenuation**	Pending Success, data captured and stored at the proper rate
0.2 Communications	**Thermal**, **Regulated Light, Solar Attenuation**	Pending Success, data properly formatted and communicated to ground computer
0.3 SAM II Equivalent Optics	**Optics Alignment**	MTF req. not met but light passing through system is adequate for testing
0.4 Payload Dimensions	**Measurement**	Dimensions are within 0.5U CubeSat volume/mass
0.5 Flight Testing	**Vibration**, **Thermal**	Vibrational Modes met requirement, Optic was not staked for testing, photodiode measurements were not taken during thermal test
0.6 Cost	**Analysis**	Project came in $1000 under budget

Success Level: Level 3, Level 2, Level 1, Failed, Pending

Vibration Test Results

Level 2 Success
Improved Ground Performance

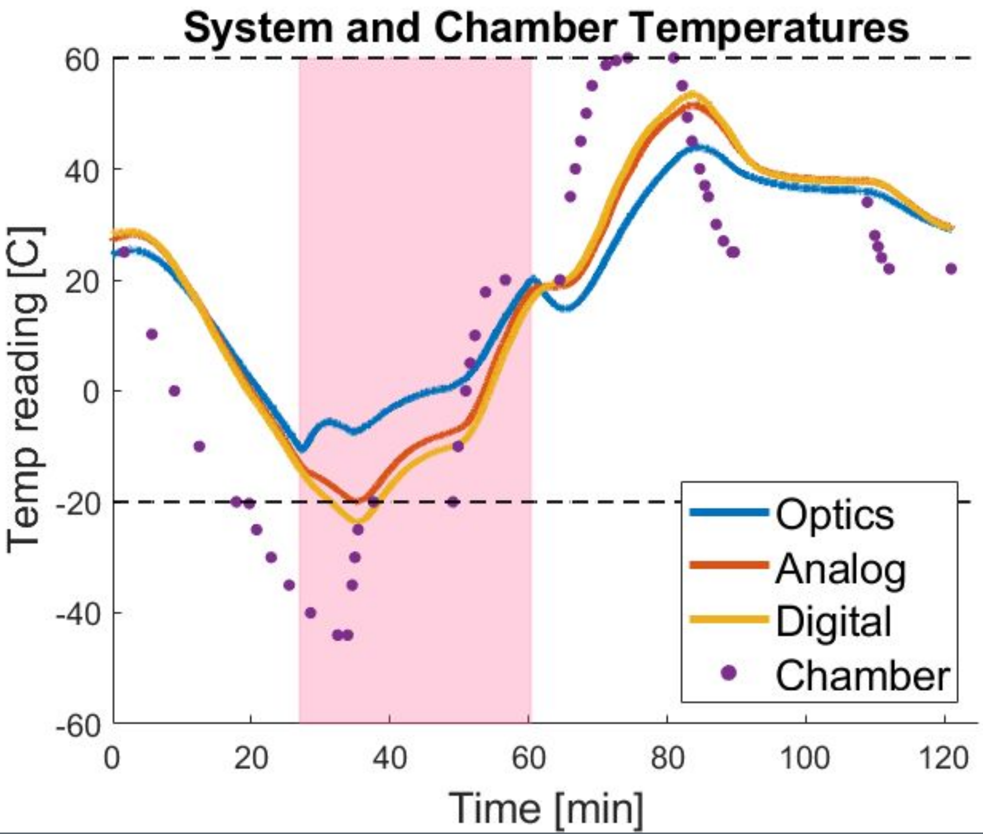
- 0-2000 Hz 3 Axis Resonance Survey Conducted at Altius Space Machines
- Meets requirement as there are no resonant frequencies below 90 Hz
- Lowest frequency from survey was 445 Hz compared to 962 Hz from Model
- Model extremely sensitive to boundary conditions



Test Results - Y Axis (Normal to Electronics Boards)

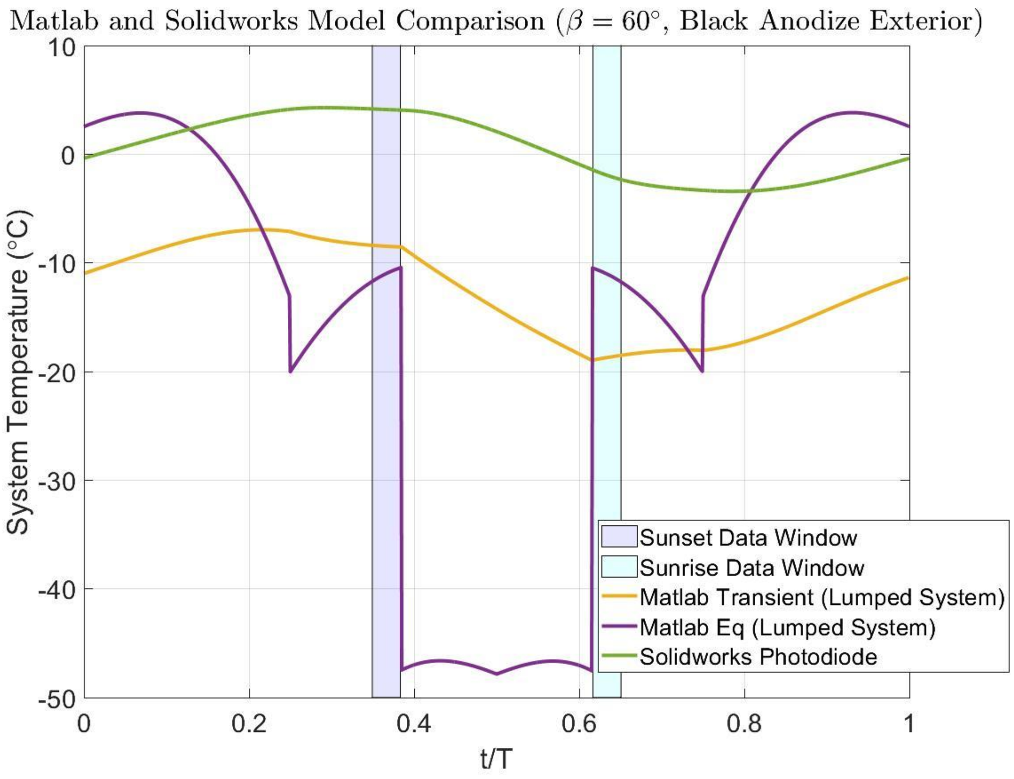
Thermal Test Results

Test results incomplete
No success level satisfied



- Photodiode data was not gathered so thermal requirements could not be fully verified by this test
- Shallower slopes in optics temperature curve compared to electronics temperature curves
  - Suggests thermal isolation efforts were effective
- No vacuum in this test, so it is not representative of spaceflight conditions
- We recommend adding a photodiode temp sensor to create a clearer profile of the entire bench

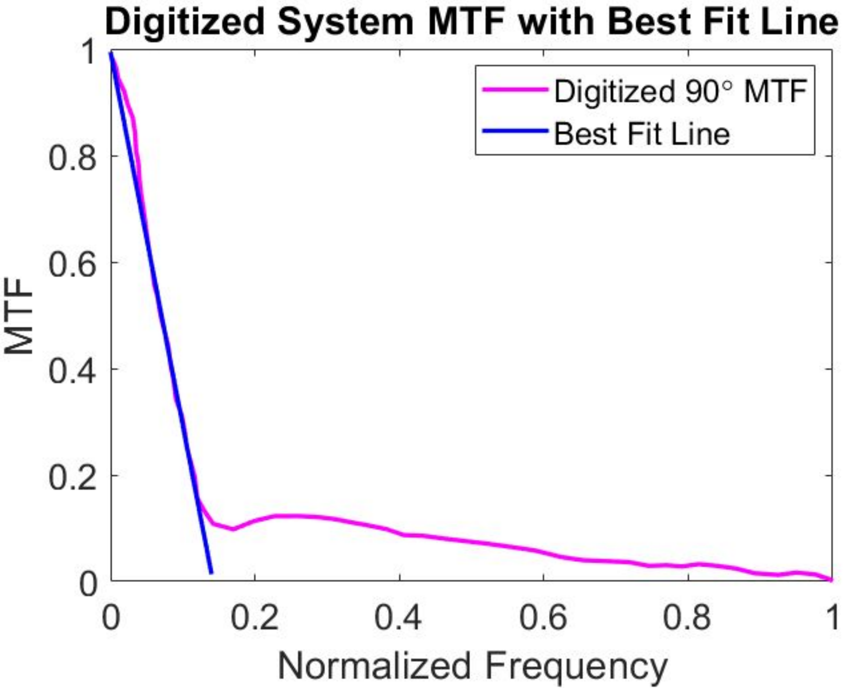
Thermal Model Validation



- Heater updated to dissipate 2.4 W (+/- 0.1 W), electronics boards produce negligible heat
- Temperature of the system still stays within the allowable range (-20 °C to 50 °C) with average conditions
- Further analysis needed
  - Equilibrium temperatures were extrapolated from data
  - Still large uncertainty in the power output of the heater and electronics boards due to nature of the test

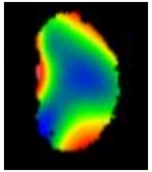
Optics Alignment Results

Level 1 Success
Solar Attenuation Test Capable

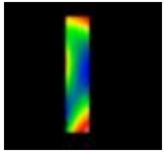


- Mirror MTF at 0.0815 (1 km): 0.4233
- System Target: 0.74
- NSI Mirror MTF: N/A

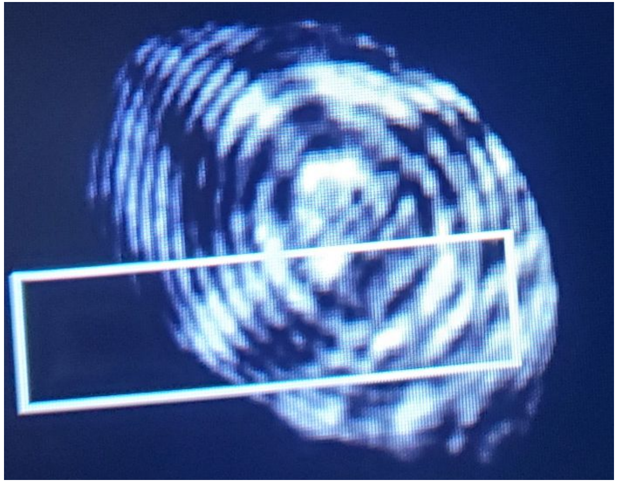
WFE Maps:
w/o aperture



With aperture



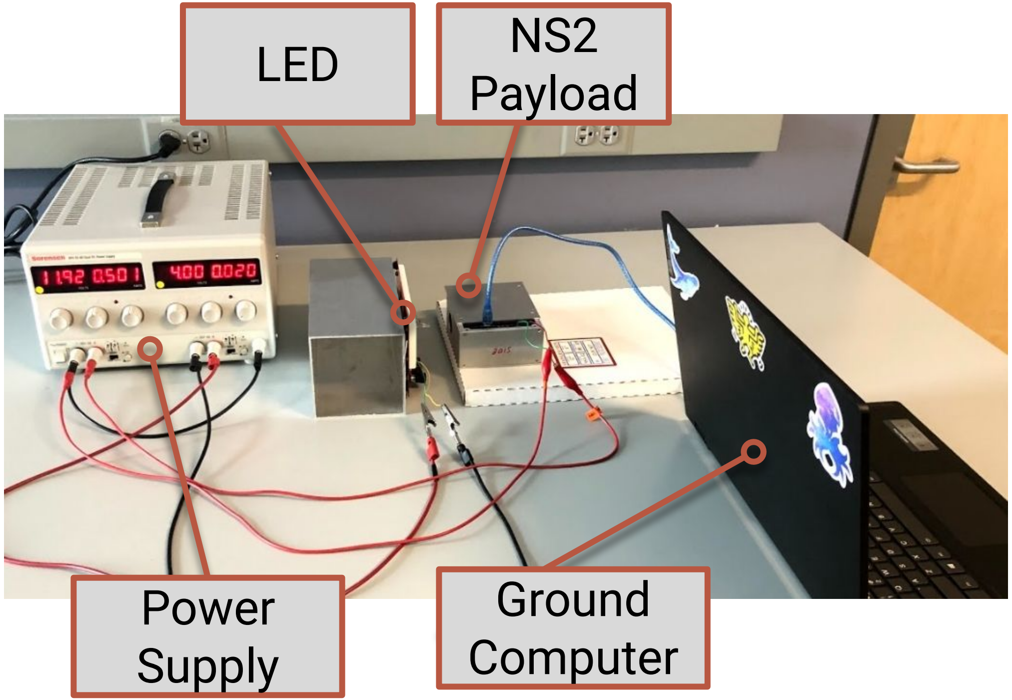
- System Defocus, ϵ_z: 0.2941 mm
  - Target: 0.045 mm
  - NSI Defocus: 0.735 mm
- Max Radial Displacement, ϵ_r: 0.0676 mm
  - Target: 0.030 mm
  - NSI Radial: 0.159 mm



Regulated Light Test

Failed
Due to test design

- Indoor test to quickly validate functionality before solar attenuation
- Test Failed
  - Incoming light rays were not parallel
- But there were positives...
  - Solar Attenuation Test covers remaining unknowns
    - SNR, Error, Measurement Stability
  - Pinhole and Photodiode work independently

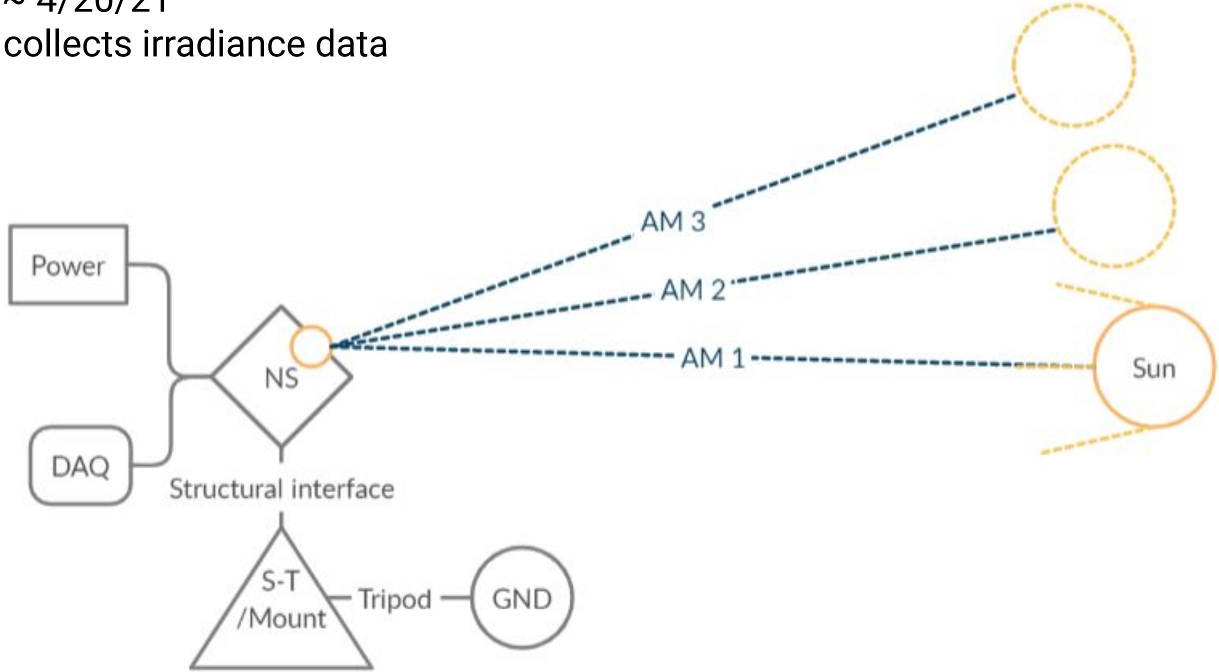


Solar Attenuation Test Status

Upcoming
Success level unknown

- Test with final assembly of NSII
  - Final assembly competed ~ 4/20/21
- Ground test, using solar tracker, collects irradiance data
- Dependent on weather
- Test data range: 4/(20-30)/21

Solar tracker



Reflection on PDD Requirements

PDD Functional Requirements
0.1 Data Capture
0.2 Communications
0.3 Monochromatic Imager
0.4 Vertical Resolution
0.5 Tracking Accuracy
0.6 Payload Size
0.7 Flight Testing

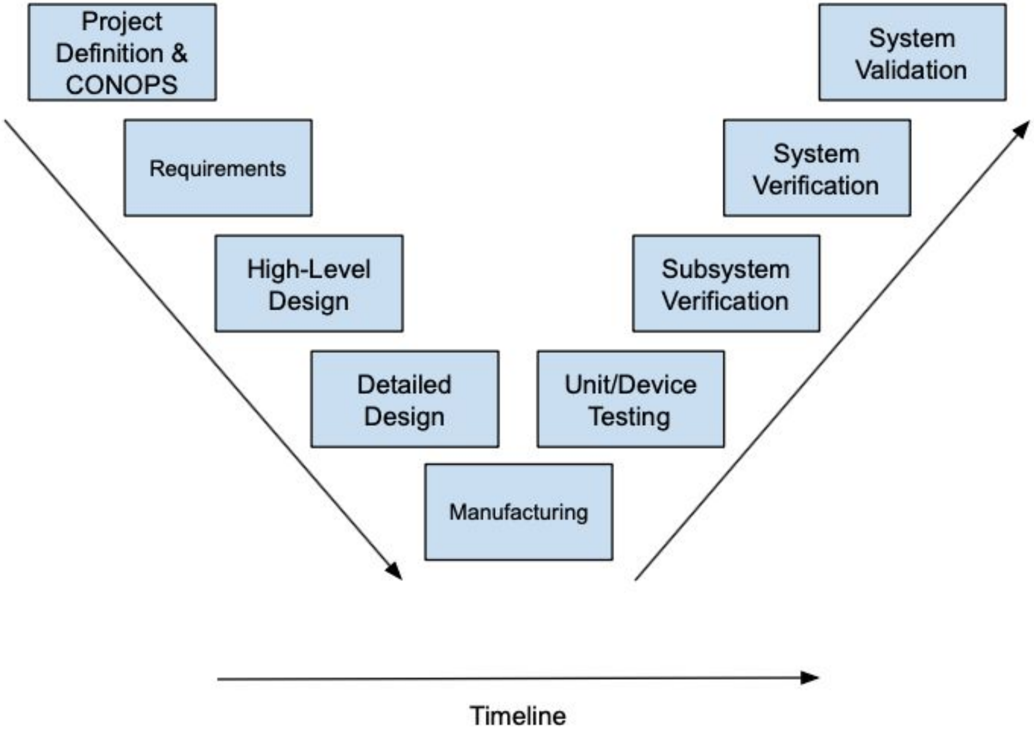
CDD Functional Requirements	Results Summary
0.1 Data Capture	Flight Capable & Pending
0.2 Communications	Flight Capable & Pending
0.3 SAM II Equivalent Optics	Solar Tracking Test Capable
0.4 Payload Dimensions	Flight Capable
0.5 Flight Testing	Solar Tracking Test Capable
0.6 Cost	Flight Capable

Success Level: Level 3, Level 2, Level 1, Failed, Pending

Systems Engineering

Donavon Schroeder

Systems Engineering Approach



Risks Predicted vs. Issues Encountered

	Negligible Impact	Low Impact	Moderate Impact	Extreme Impact	Catastrophic Impact
Almost Certain					
High Probability		Short inability to downlink			
Moderate Probability			Photodiode Temp Changes		
Low Probability	Single ADC Failure	Main loop below 50Hz		Structure fails vibration test	
Negligible Probability			Unable to get return sphere	Components not manufacturable	No alignment facility access

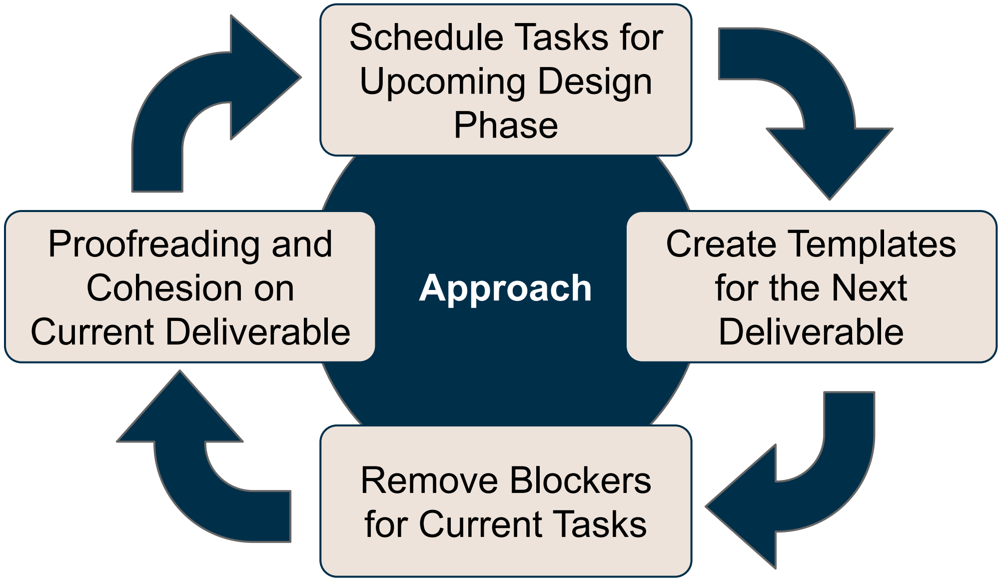
Lessons Learned

- Many of our official tests had overlap
  - Understanding of how the requirements are met
- Integration of subsystems was harder to anticipate than predicted
  - Individual assembly procedures were not continuous during full system integration
  - Heater adhesive
  - Photodiode connectors
- Even though everyone started with same documentation, gaps in knowledge developed
- Impact of subsystem changes to other subsystems
  - Status should include how changes may affect other subsystems

Project Management

Jaret Anderson

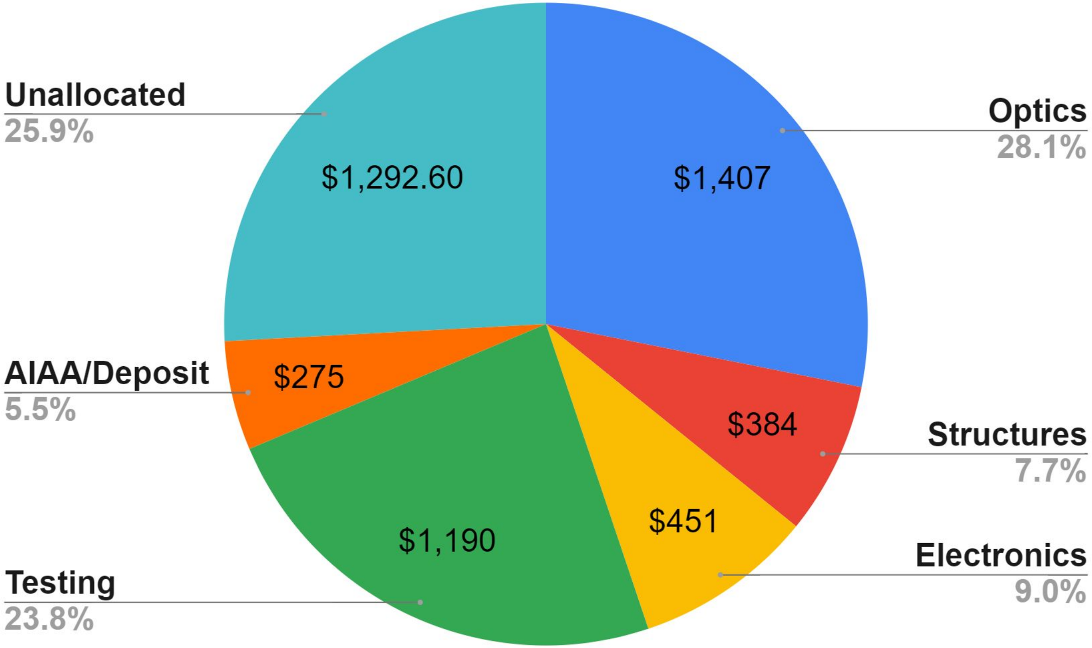
Approach & Lessons Learned



Lessons Learned

- Clear role expectations ensure that tasks are not forgotten, but can lead to uneven work distributions
- We used a peer-review system in software which worked really well
  - Three people all had to sign off on a commit before it was pushed to the main branch
  - Should have used this rigorous review system on our testing procedures as some of our tests ended up not being

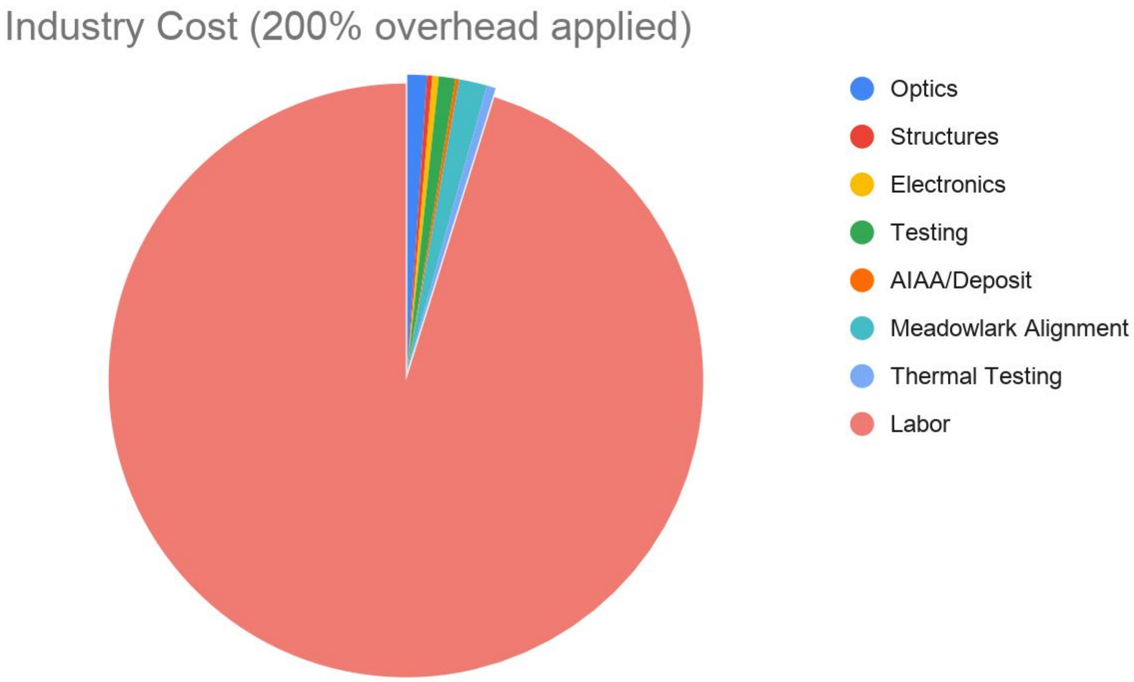
Final Budget Summary/Comparison



Reasons for changes

- Testing costs allocated
  - Uncertainty in facilities at CDR left margin for testing in the unallocated funds
- New OAP not ordered
- Minor electronics redesign required going over margin slightly

Total Industry Cost



Category	Cost
Optics	$2,814
Structures	$768
Electronics	$902
Testing	$2,380
AIAA/Deposit	$550
Meadowlark Alignment	$4,000
Thermal Testing	$1,300
Labor	$251,532
Total	$264,277

Acknowledgements

Our Customers:

Jim Baer & Jaykob Velasquez
Ball Aerospace

CU Aerospace Department:

Dr. Allison Anderson
The PAB

Our Peer Evaluators:

Lara Buri & Colin Claytor

… and all of our personal friends who should send us a bill for their time doing engineering review

Our Local Professionals:

Meadowlark Optics Inc
Blue Canyon Technologies
John Ferguson

Questions

References

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Backup Slides

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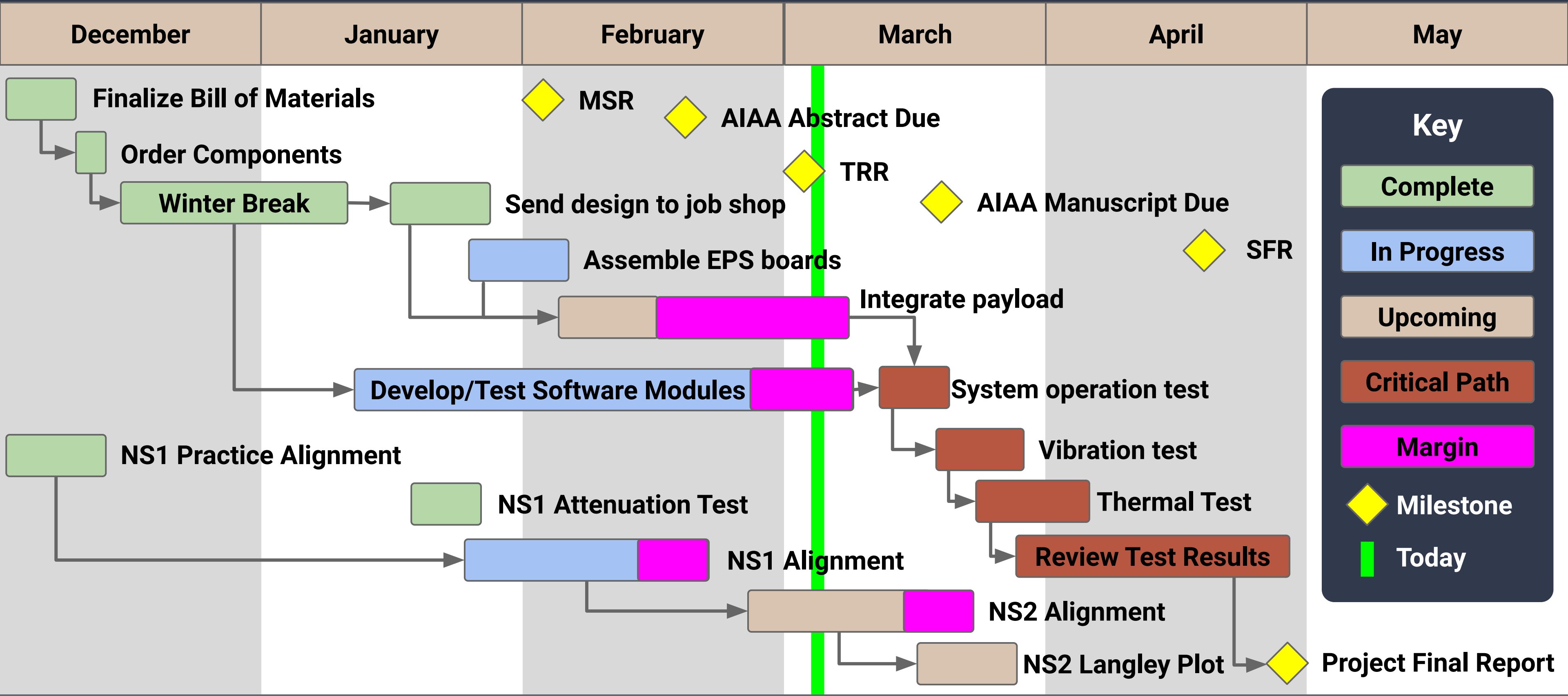
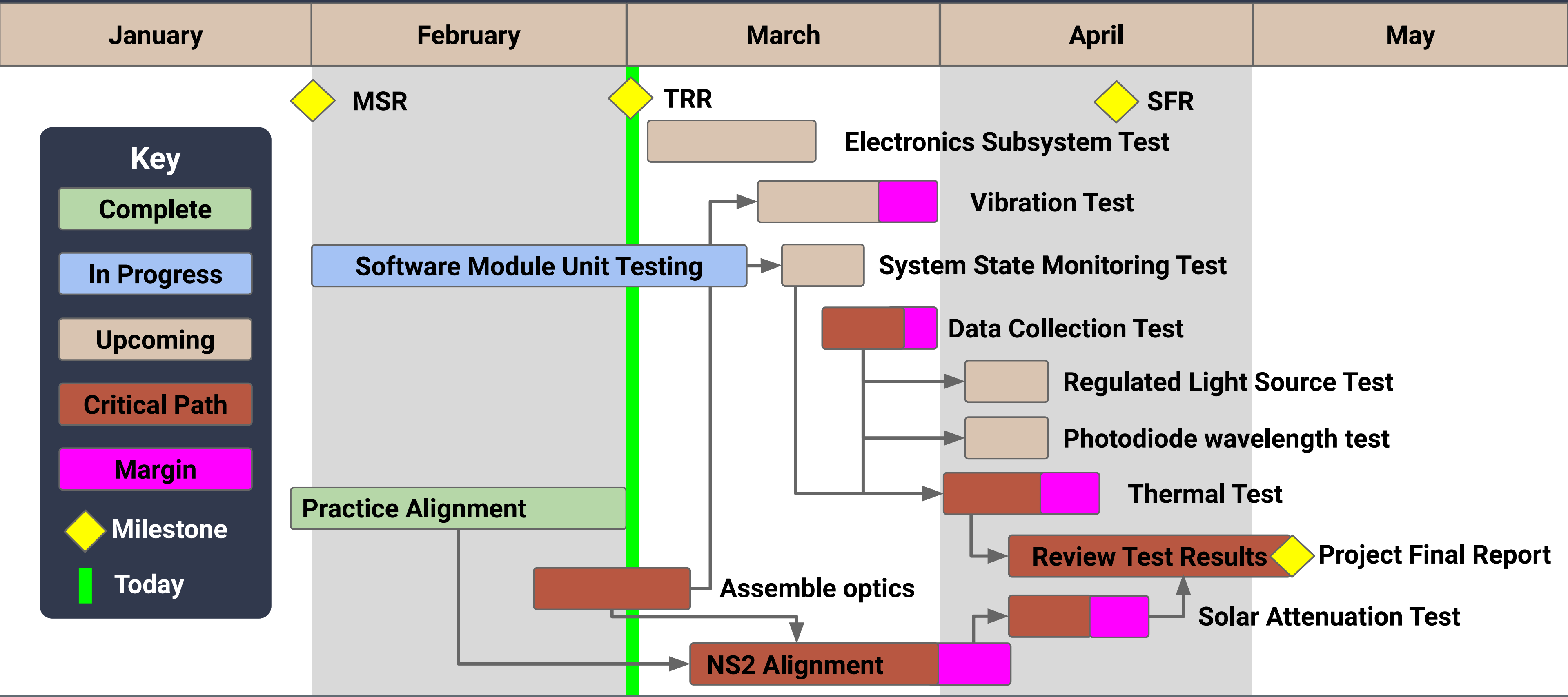
Backup Slides

Old Schedule



Schedule (Testing Focus)



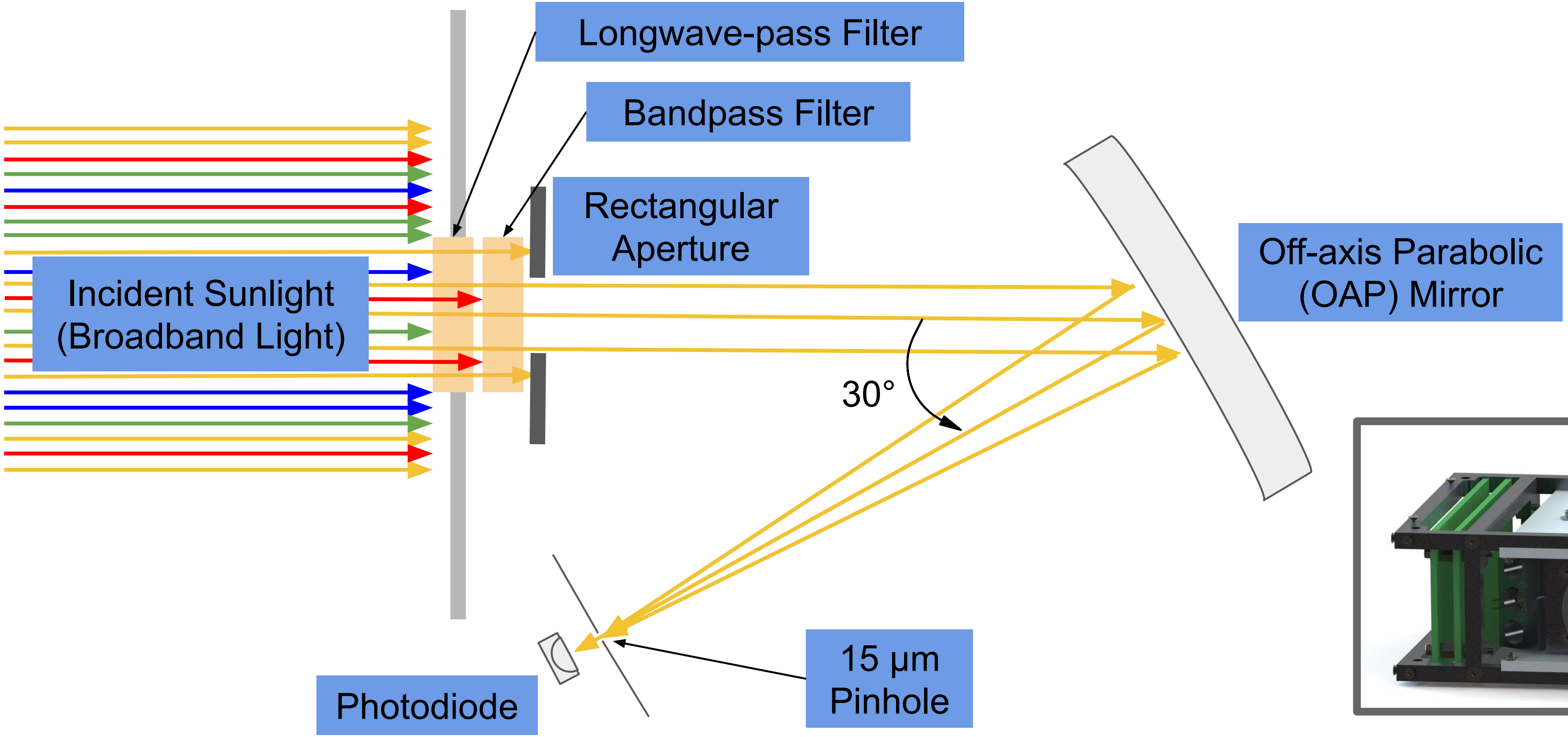
Work Breakdown Structure

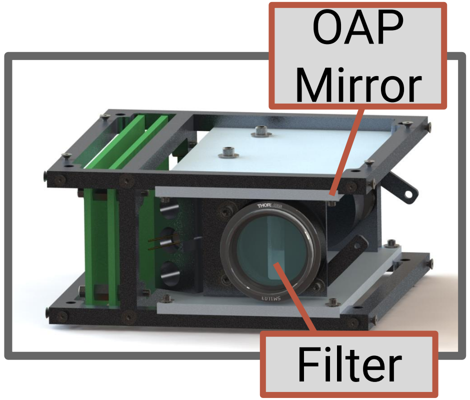
- Structures
  - Structure Design
  - Thermal Simulation
  - Vibrational Simulation
  - Order Parts
  - Manufacture Structure
  - Structure Integration
  - Vibration Testing
- Optics Design
  - Alignment Tooling Design
  - Machining Error Analysis
  - Order Parts
  - NS1 Hardware Alignment
  - MTF Determination
  - Optimize Aperture Size
  - NS2 Hardware Alignment
- Optics Testing
  - Solar Tracking Test (NS1)
  - Attenuation Test (NS1)
  - Langley Plot (NS1)
  - Above Tests w/ NS2 Hardware
- Software
  - Module Architecture
  - Module I/O
  - Dev Priority Selection
  - Module Pseudocode
  - Module Development
  - Unit Testing
  - Integration Testing
- Integrated Testing
  - System Operation
  - Attenuation Test (NS2)
  - Regulated Light Test
  - Thermal Test
  - Vibration Test

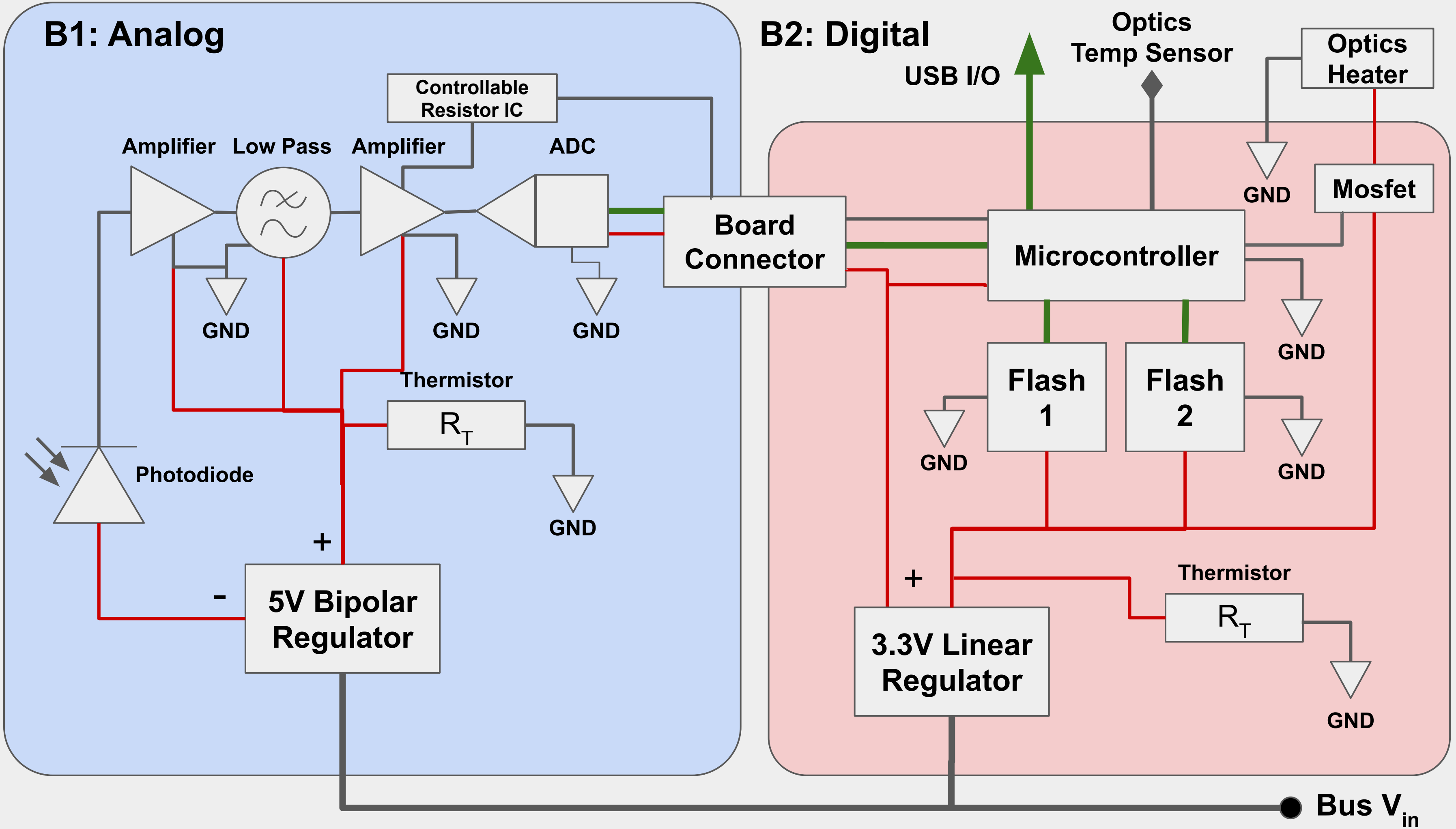
Key

- Complete
- In Progress
- Future Work

Optics Instrument Overview






B1: Analog
Controllable Resistor IC
Amplifier
Low Pass
Amplifier
ADC
GND
GND
GND
Thermistor
R_T
GND
Photodiode
+
-
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}

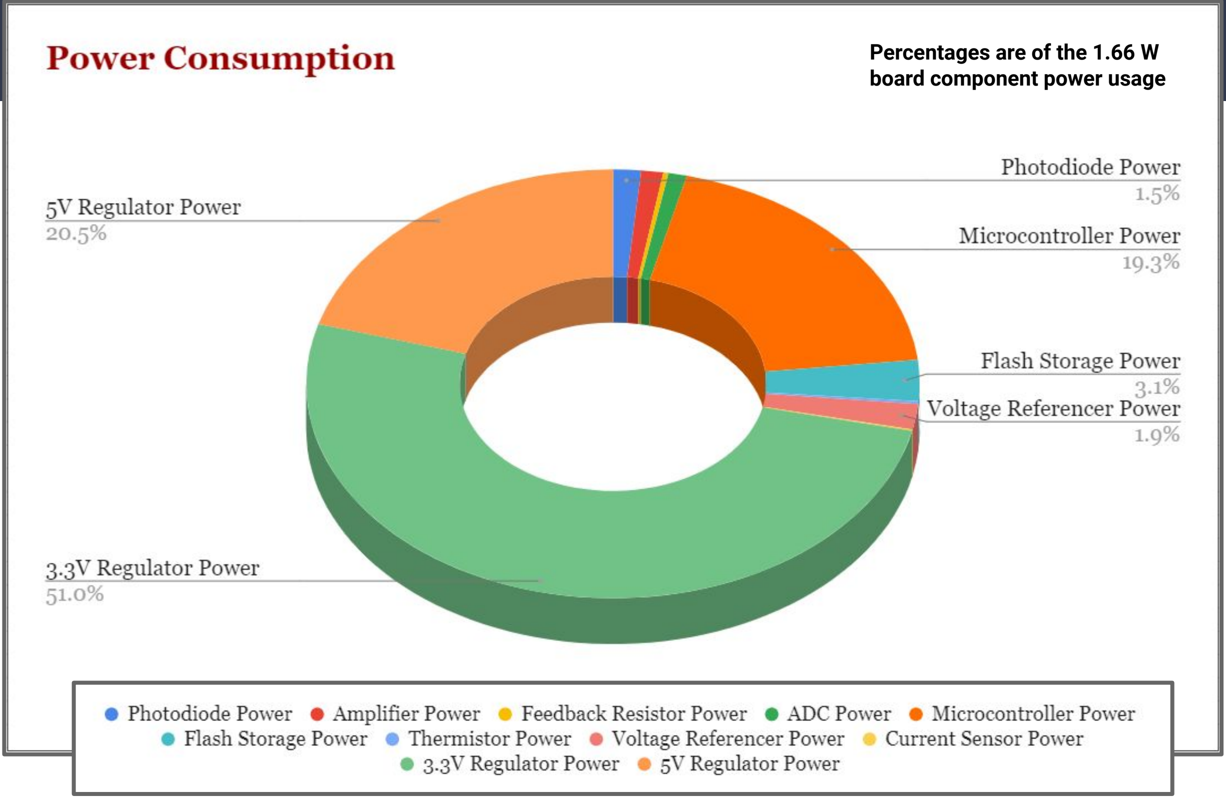
Power Budget

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)

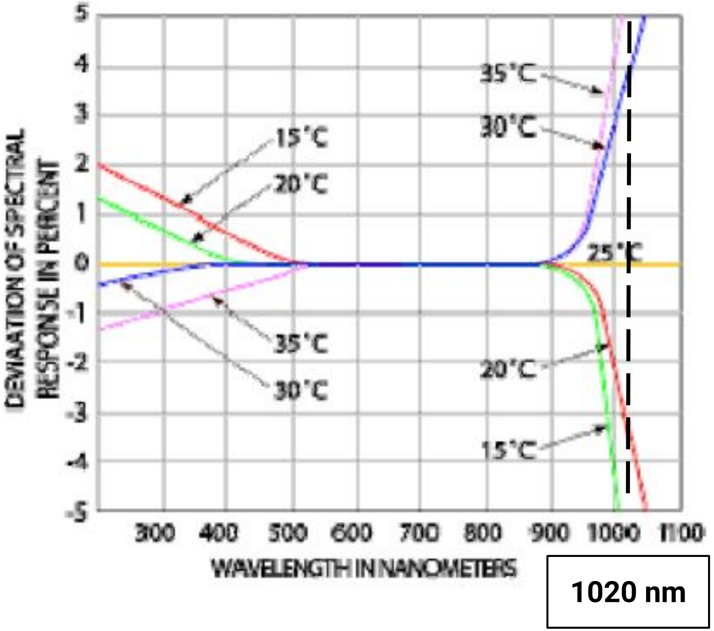
SNR Ratio
19% to 312%
(Estimate / Requirement)

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

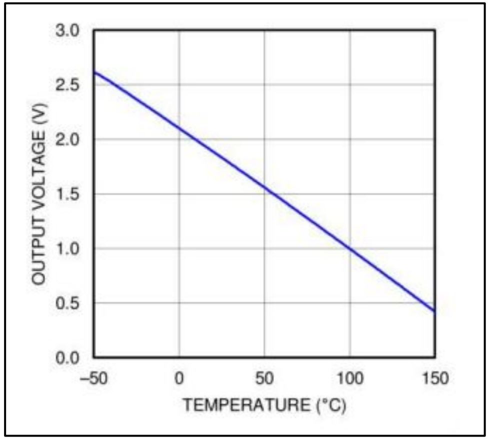
Temperature Monitoring Correction



Texas Instruments LMT86LP

-10.9 mV/°C slope

Sampled w/ 12 bit ADC:
= 0.8mV LSB
= 0.043°C resolution



High precision analog optics bench temperature sensor to track temperature-related errors, correct these errors in software - 0.0198 V/K

Electronics: Photodiode Saturation

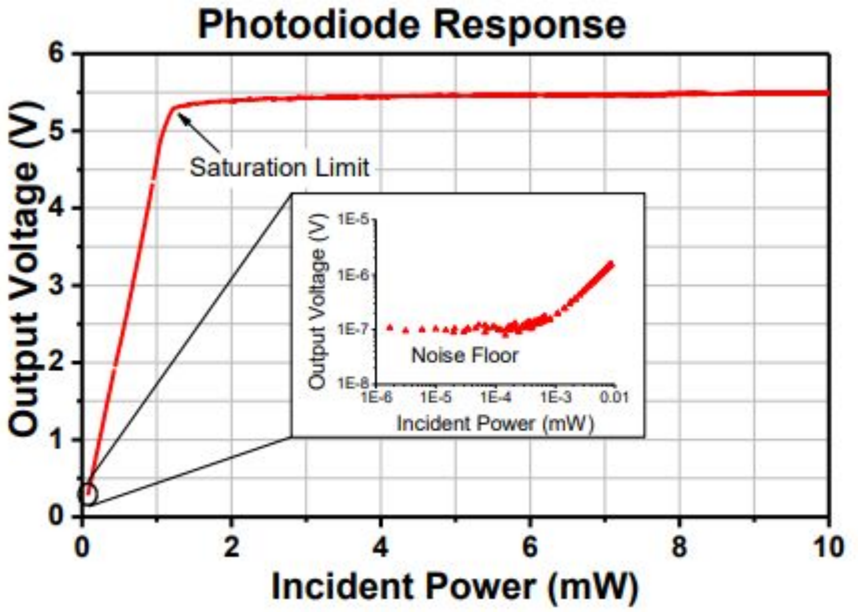
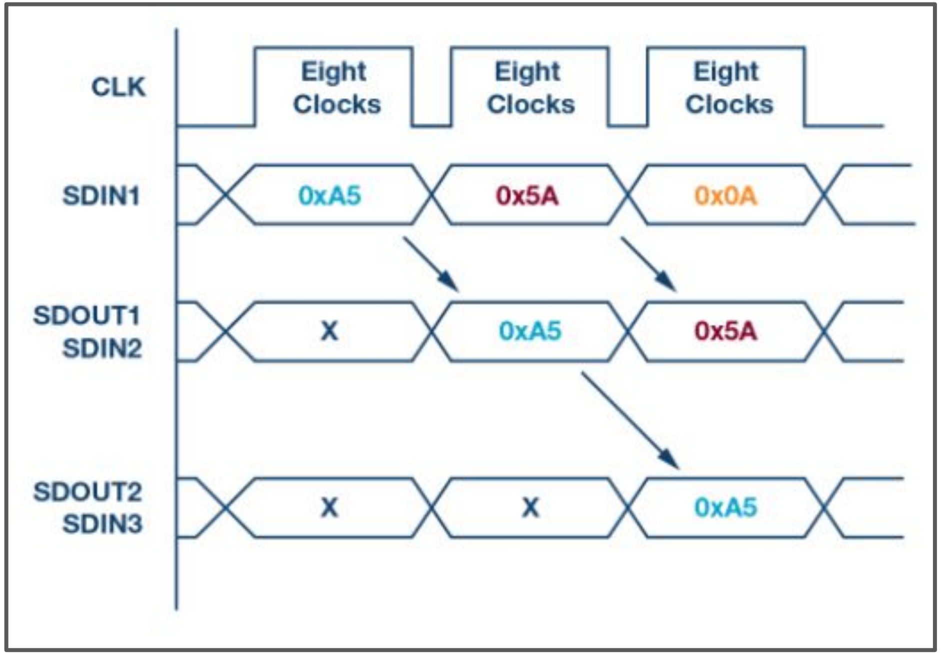


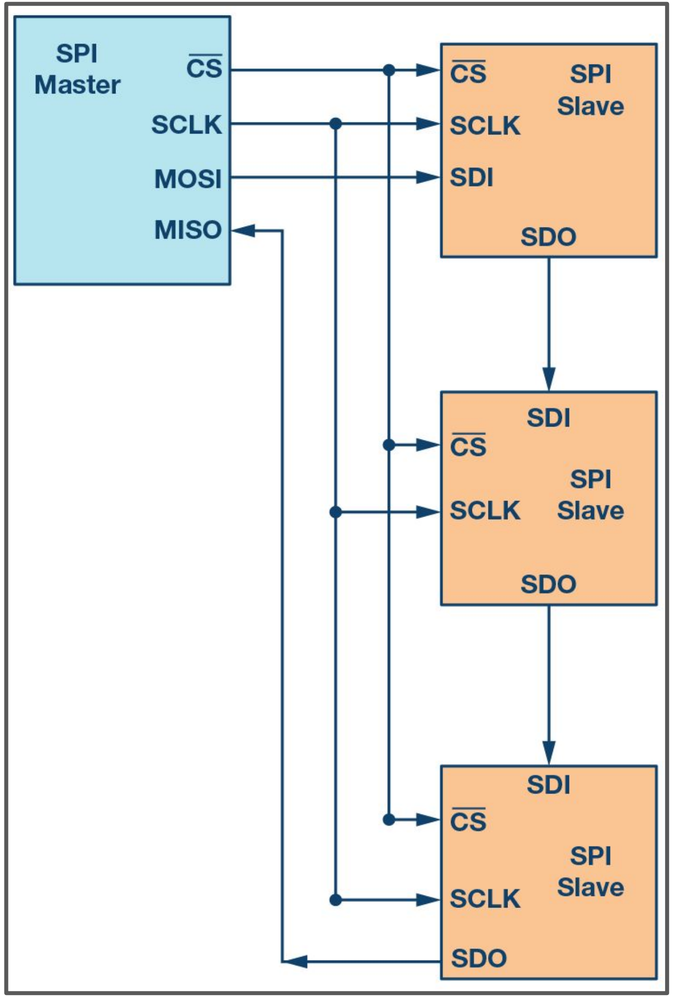
Figure 2: Measured response of a FDS100 silicon photodiode showing the noise floor and saturation limit for a 5 V bias from a DC power supply and 10 kΩ load resistor.

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: SPI Bus Connections





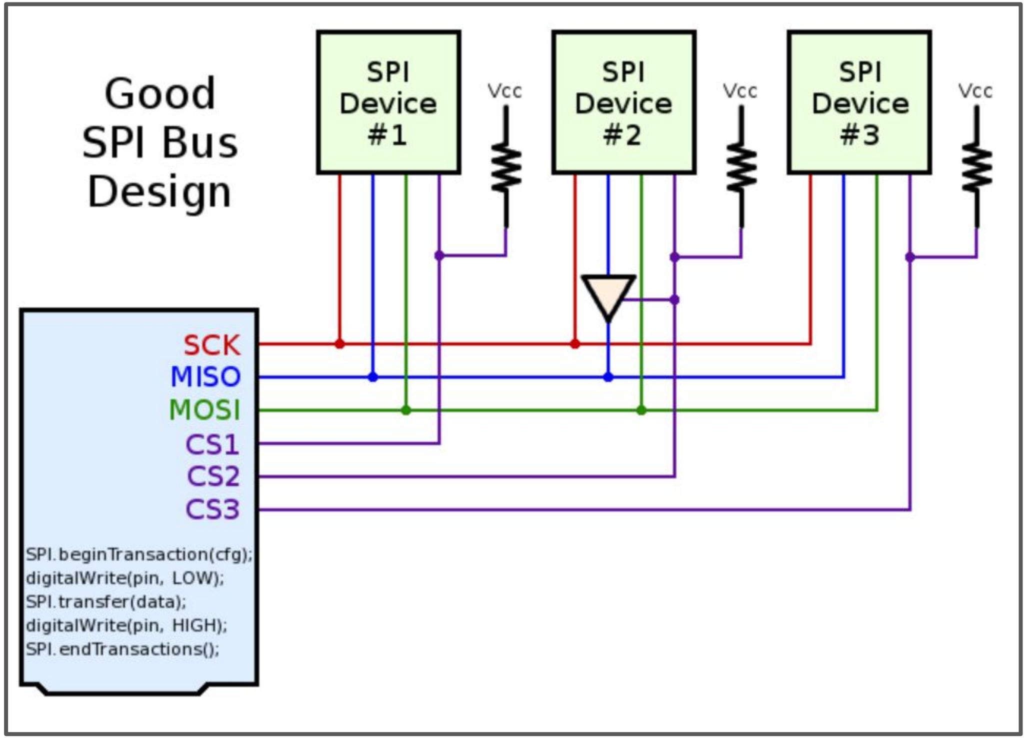
https://www.analog.com/en/analog-dialogue/articles/introduction-to-spi-interface.html

Electronics: SPI Bus Pull Up Resistors

Pull up resistors on the chip select pins ensure that the CS pin is high, thus the MISO/MOSI lines will disengage.

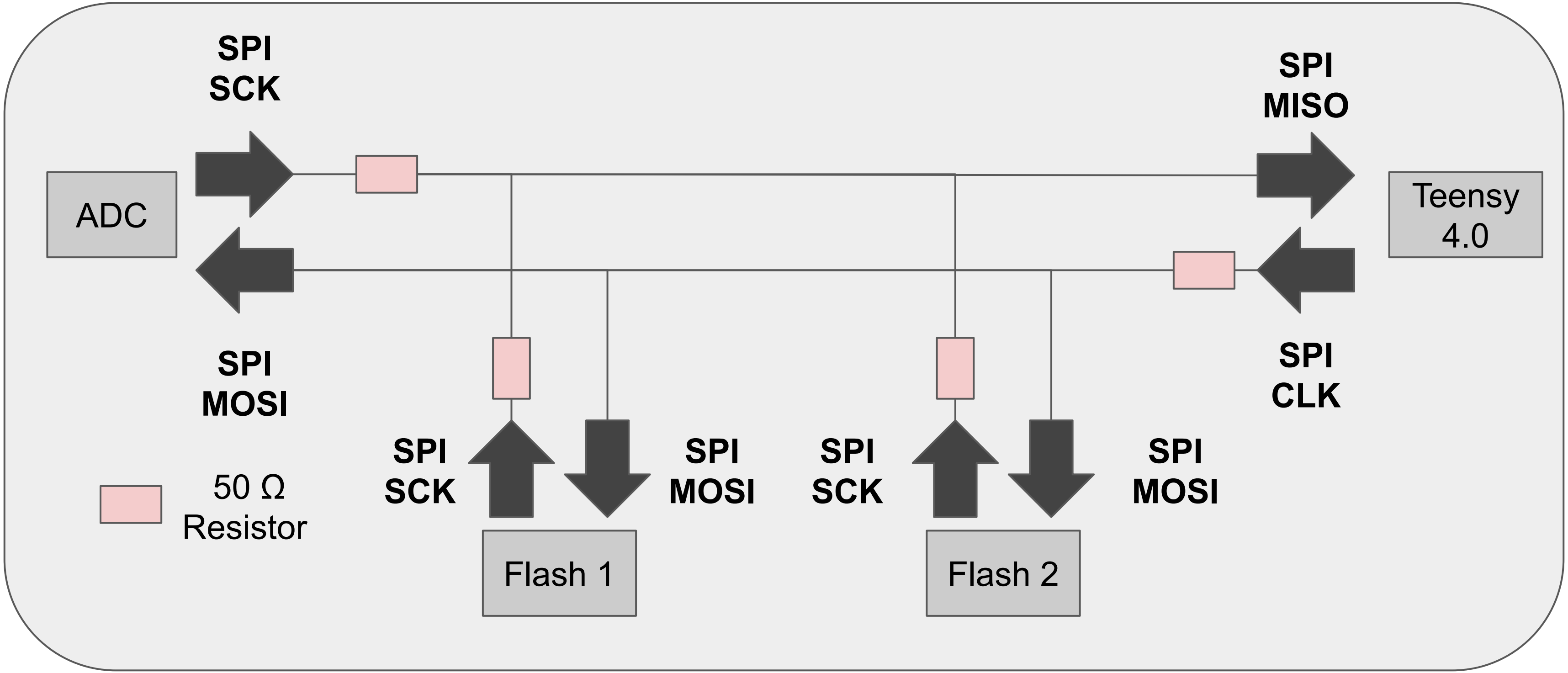
This makes sure a line is only transmitting when absolutely driven low by the microcontroller, reducing potential cross talk.

This can also be corrected in software, but it provides an extra layer of redundancy at little cost.



https://www.pjrc.com/better-spi-bus-design-in-3-steps/
https://hackaday.com/2016/07/01/what-could-go-wrong-spi/

Electronics SPI Bus Noise Considerations



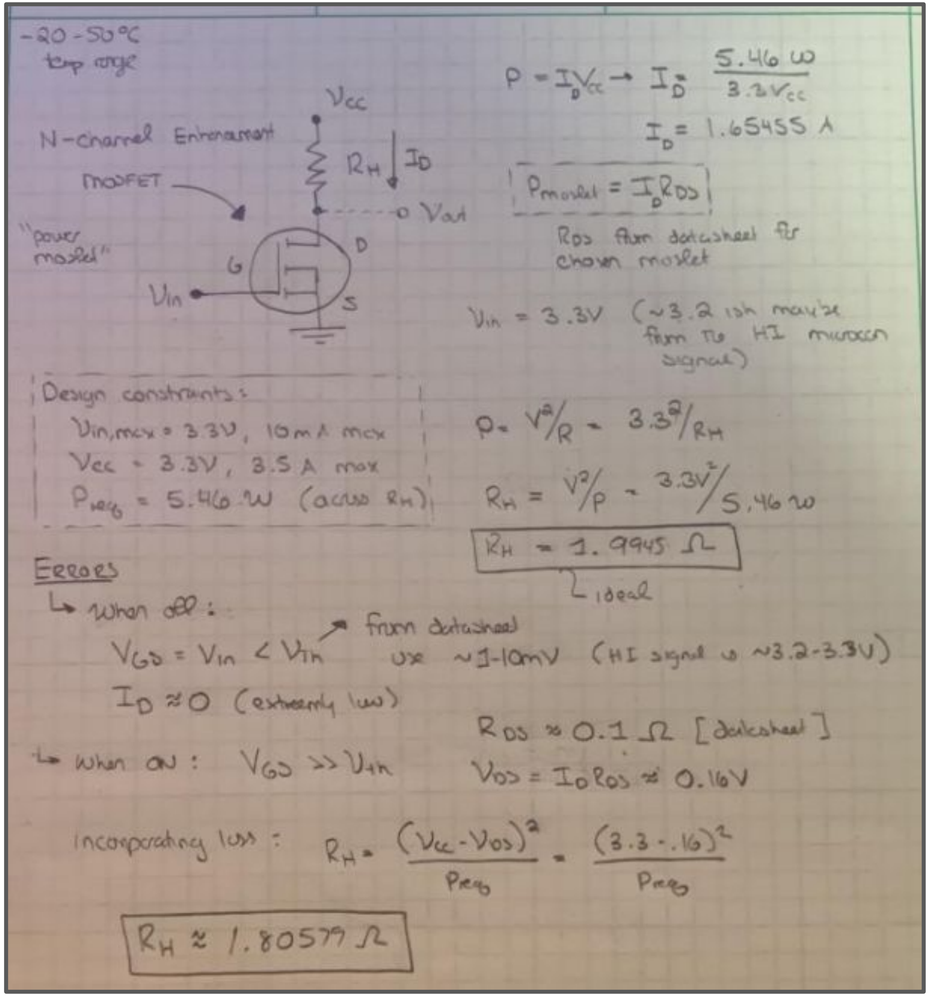
https://www.diodes.com/assets/App-Note-Files/AB023.pdf

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



Electronics: Extended Bill of Materials

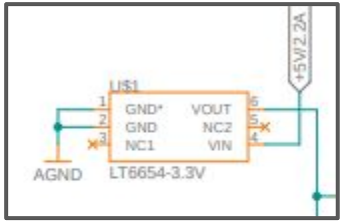
Part	Value	Device	Package	Size (mm^2)	DK Part #	Cost	Temperature Rating
U$2	TEENSY4.0	TEENSY4.0	TEENSY4.0	814.1	1568-DEV-16997-ND	24.38	-40°C ~ 85°C
U$3	AD8671	AD8671	SO8	31	AD8671ARMZ-ND	2.89	-40°C ~ 125°C
U$4	LT6105	LT6105	MSOP8	4.7925	LT6105HDCB#TRMPBFTR-ND	3.46	-40°C ~ 125°C
U$5	LTC2470	LTC2470	MSOP12	10.5	LTC2470IMS#TRPBFTR-ND	5.01	-40°C ~ 85°C
U$12	LT8610A	LT8610A	MSOP16	19.79	LT8610AEMSE#TRPBFTR-ND	9.5	-40°C ~ 125°C
U$16	MT25QL128ABA1ESE	MT25QL128ABA1ESE	SO-08M	48	557-1982-2-ND	2.29	-40°C ~ 85°C
U$17	MT25QL128ABA1ESE	MT25QL128ABA1ESE	SO-08M	48	557-1982-2-ND	2.29	-40°C ~ 85°C
U$19	THERMISTOR	THERMISTOR	M0805	2.58064	BC3395CT-ND	1.08	-40°C ~ 150°C
U$26	LTC2470	LTC2470	MSOP12	10.5	LTC2470IMS#TRPBFTR-ND	5.01	-40°C ~ 85°C
U$30	LT6105	LT6105	MSOP8	4.7925	LT6105HDCB#TRMPBFTR-ND	3.46	-40°C ~ 125°C
U$33	LT6654-3.3	LT6654-3.3	SOT23-6L	8.12	LT6654BMPS6-5#TRMPBFTR-ND	9.76	-55°C ~ 125°C
U1	LTC3260EMSEPBF	LTC3260EMSEPBF	MSOP-16_MSE	16	LTC3260EMSE#PBF	8.47	-40°C ~ 125°C
U2	LMV324	LMV324	SO14	9.15	LMV324QPW-ND	0.9	-40°C ~ 125°C

Total Size (mm^2)	Total Cost ($)	# Components	Clearence (mm^2)	Traces (mm^2)	Board Cost
5060.264744	517	129	14.5125	655.32	65

Temperature Effects on Components

Device	Temperature Effects (over -20C to 50C)
Transimpedance Amplifier	Output voltage high and low remain within our necessary bounds, supply current delta around 0.5mA, and slight increase in input offset voltage with temperature, overall negligible.
ADC	Gain error and offset error change by ~6-10 LSB, unavoidable but quite small. Calibrating for median temperature will help. Negligible change in conversion time.
Voltage Reference	~0.1mV change maximum, will not affect a significant amount of LSB.
5V Bipolar Regulator	~100mV change maximum, could introduce AD8671 op-amp noise, but we use decoupling capacitors. Does not veer outside of required operating range.
3.3V Linear Regulator	~5mV change in voltage output, not enough to affect digital component operation
Current Sense Monitors	0.01% gain error change, no concern

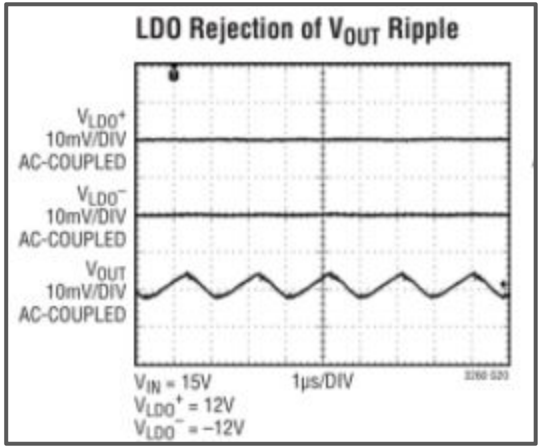
Reference voltage for ADC



Electronics: Voltage Regulator Output Noise

5V Bipolar Regulator		
Output Voltage Noise	100e-6 V	2 bins noise

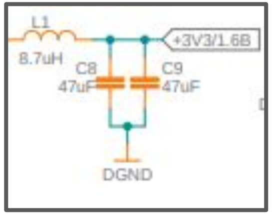
- + Decoupling capacitors on transimpedance amplifier Vcc



3.3V Linear Regulator

Table 1. Output Voltage Ripple vs Output Capacitance for LT8610AB when V_{IN} = 12V, V_{OUT} = 3.3V, and L = 4.7µH

OUTPUT CAPACITANCE	OUTPUT RIPPLE
47µF	40mV
47µF ×2	20mV
47µF ×4	10mV



Electronics: Recommended Voltage Regulator Routing

Analog Voltage Regulator

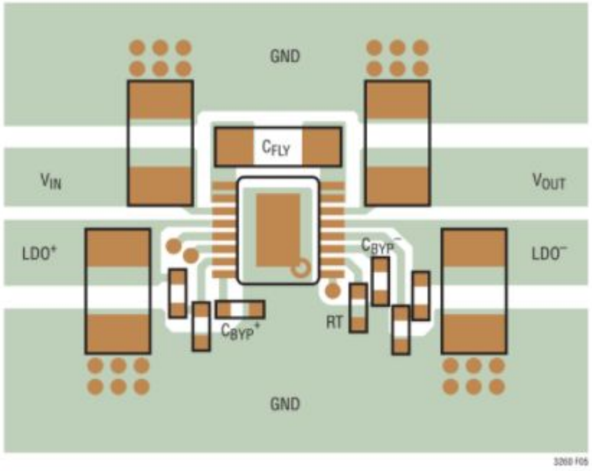


Figure 5. Recommended Layout

Digital Voltage Regulator

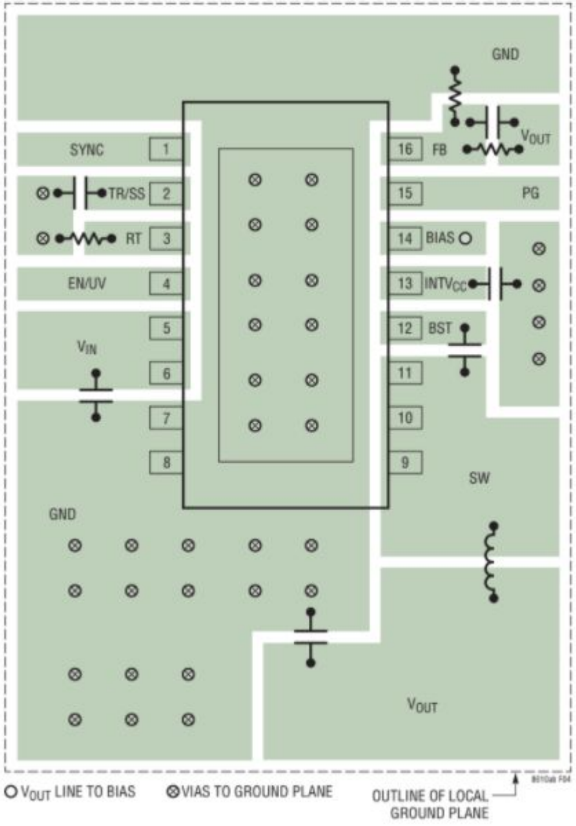
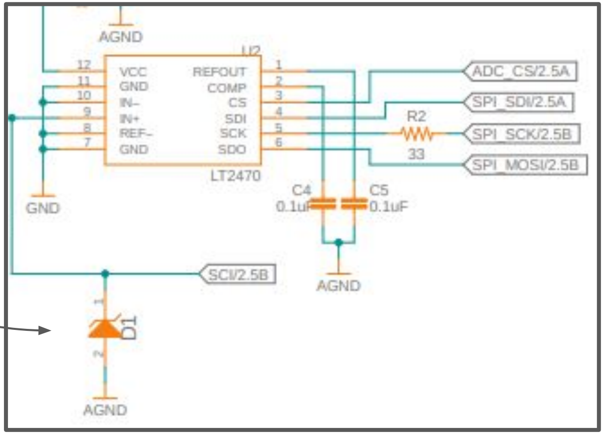


Figure 4. Recommended PCB Layout for the LT8610A/LT8610AB

Electronics: ADC Saturation

Maximum temperature (during data collection):	30 deg C
Responsivity at maximum temperature:	0.405 A/W
Maximum incident power:	0.006 W
Maximum output current:	0.00247 A
Feedback resistor for 3.3V	1268 Ohms

We also use a 3.3V zener diode on the ADC input to prevent overvoltage. The ADC COMP can only accept 3V to 3.6V (at 3.3V Vcc).



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.

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

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

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

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

$$V_{regulator} = 0.1mV$$

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

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

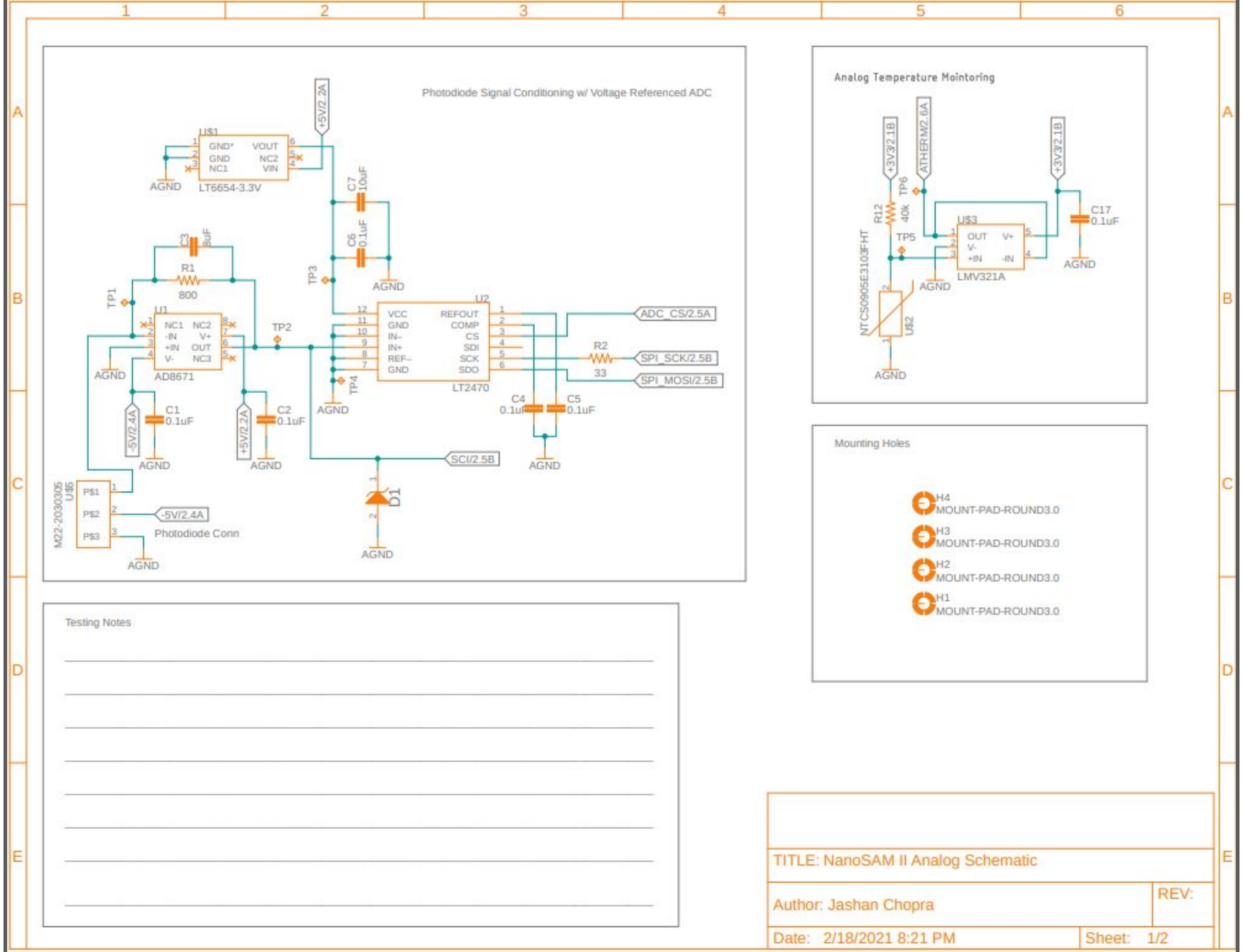
Electronics Risks

Risk	Mitigation
Voltage regulator noise	Low noise components, voltage reference for ADC, recommended routing patterns
Pin overvoltages	TVS diode on heating resistor, zener diode on ADC input, voltage regulators
ADC failure	Backup 12 bit ADC on Teensy meets SNR requirements
ESD component destruction	Test plan recommendations, ESD safety in test procedures
Signal integrity	Signal-ground connector layout, low frequency signals, off-board wire shielding, robust SPI communication design

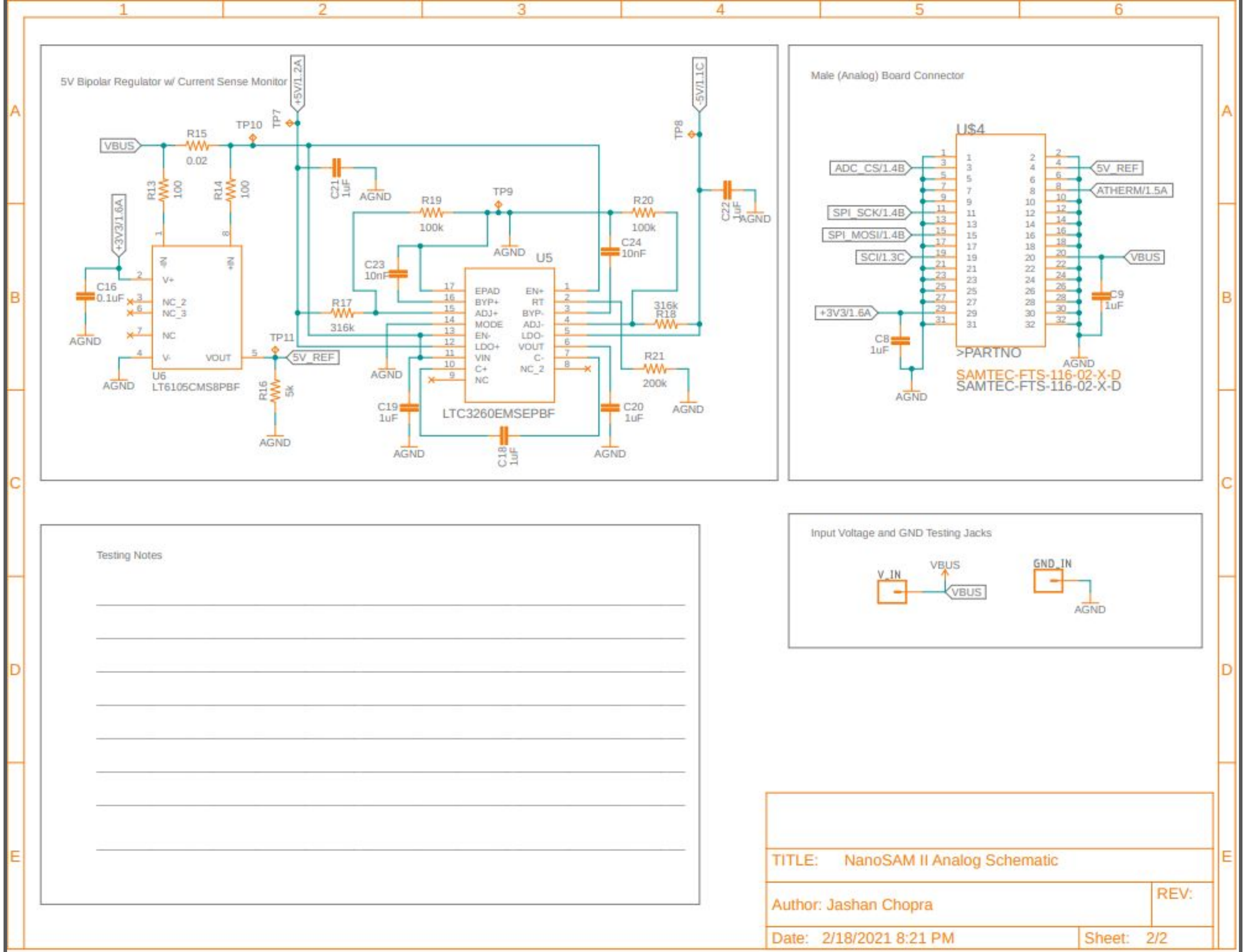
Electronics Risks

Risk	Mitigation
ESD damage or component issues go undetected	Abundant test points to check all input/outputs to each IC
Photodiode saturation	Reverse bias voltage applied on pin >3.3V
Photodiode responsivity changes	Software correction via high sensitivity optical temp sensor IC
ADC Dynamic Range	Feedback resistor sized for maximum expected output current with margin of error
Radiation triggers Teensy 4.0 latch up	External watchdog monitoring circuit and backup watchdog implementation in software (using microprocessor built in)

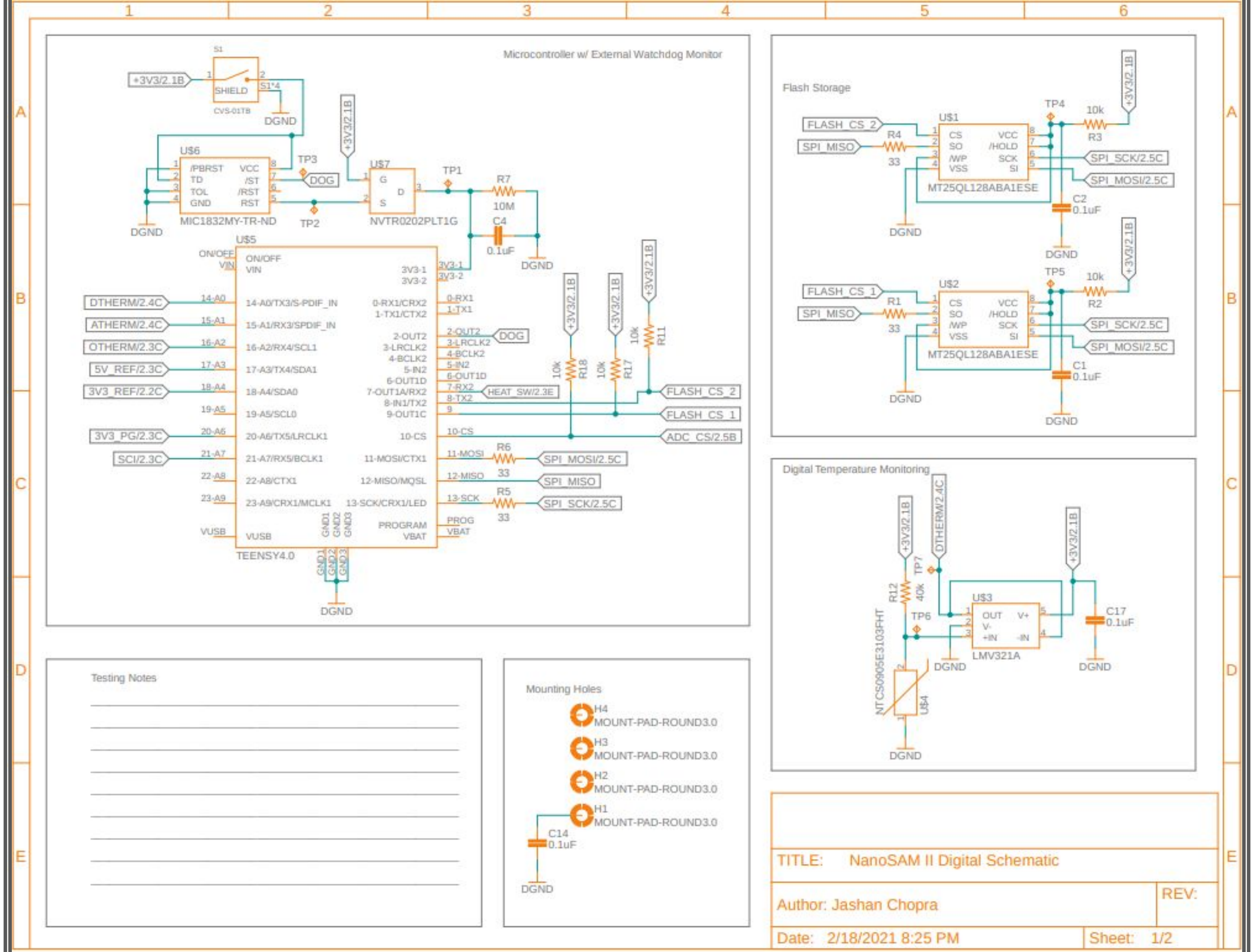
Analog Board (1/2)



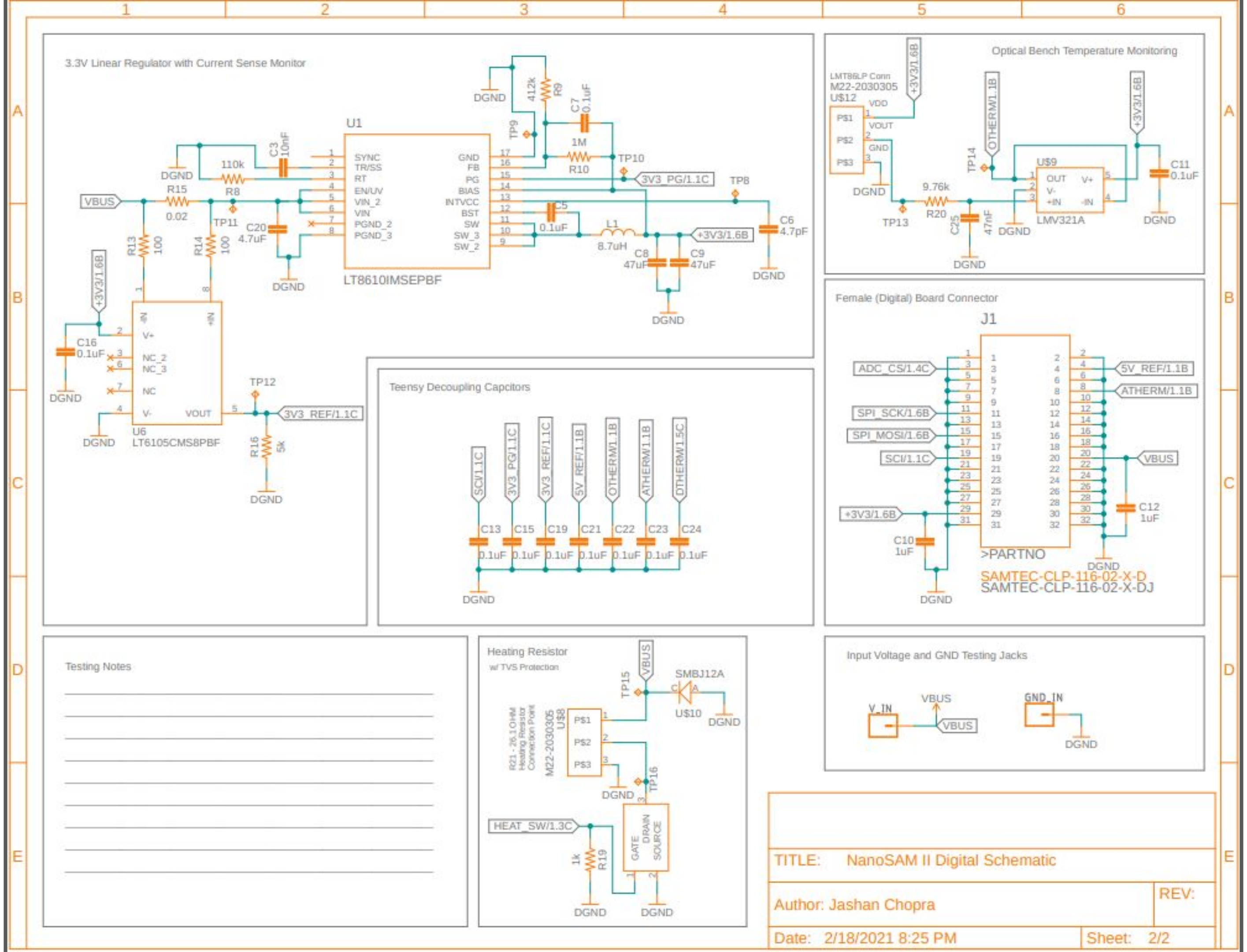
Analog Board (2/2)



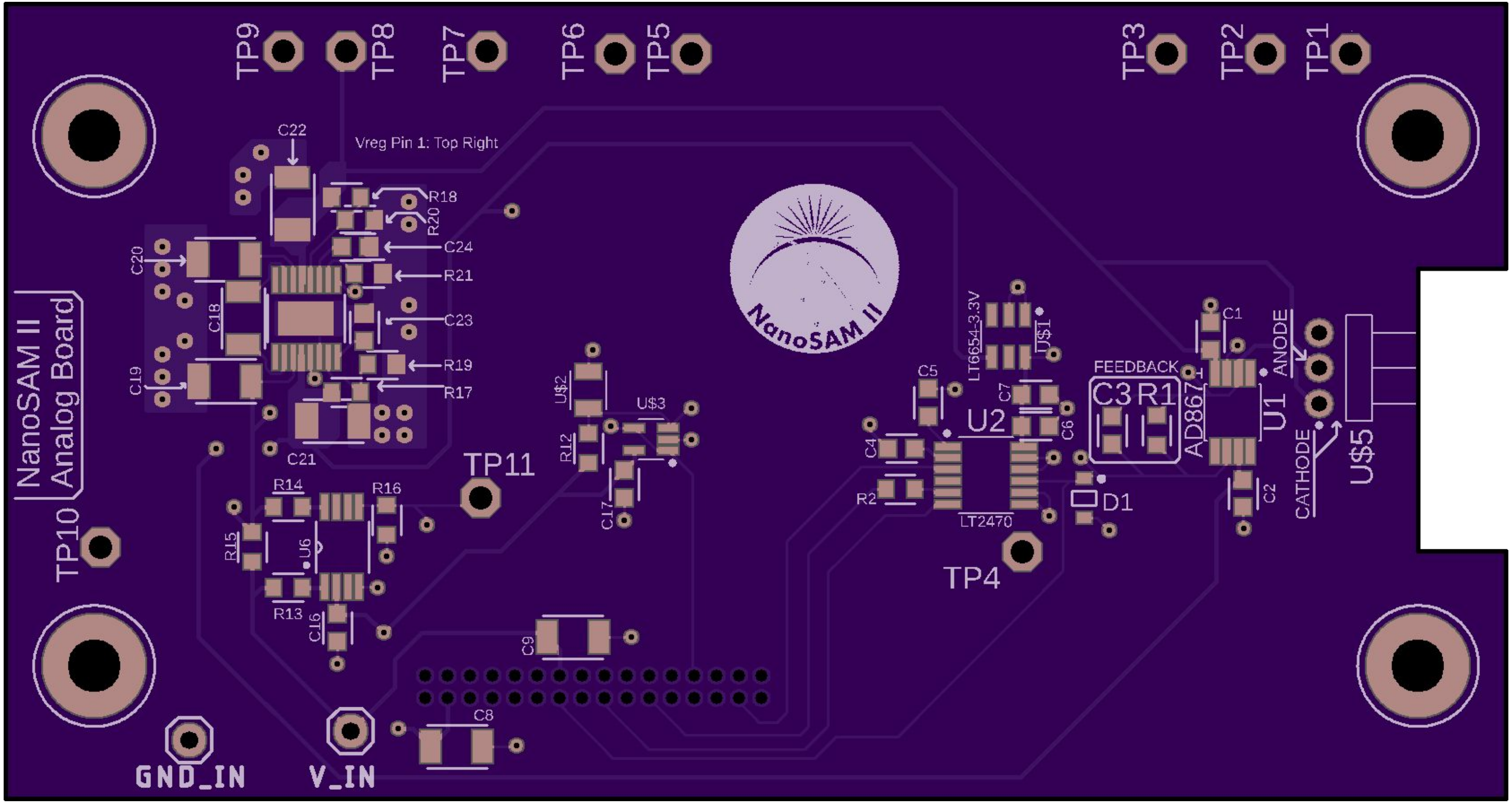
Digital Board (1/2)



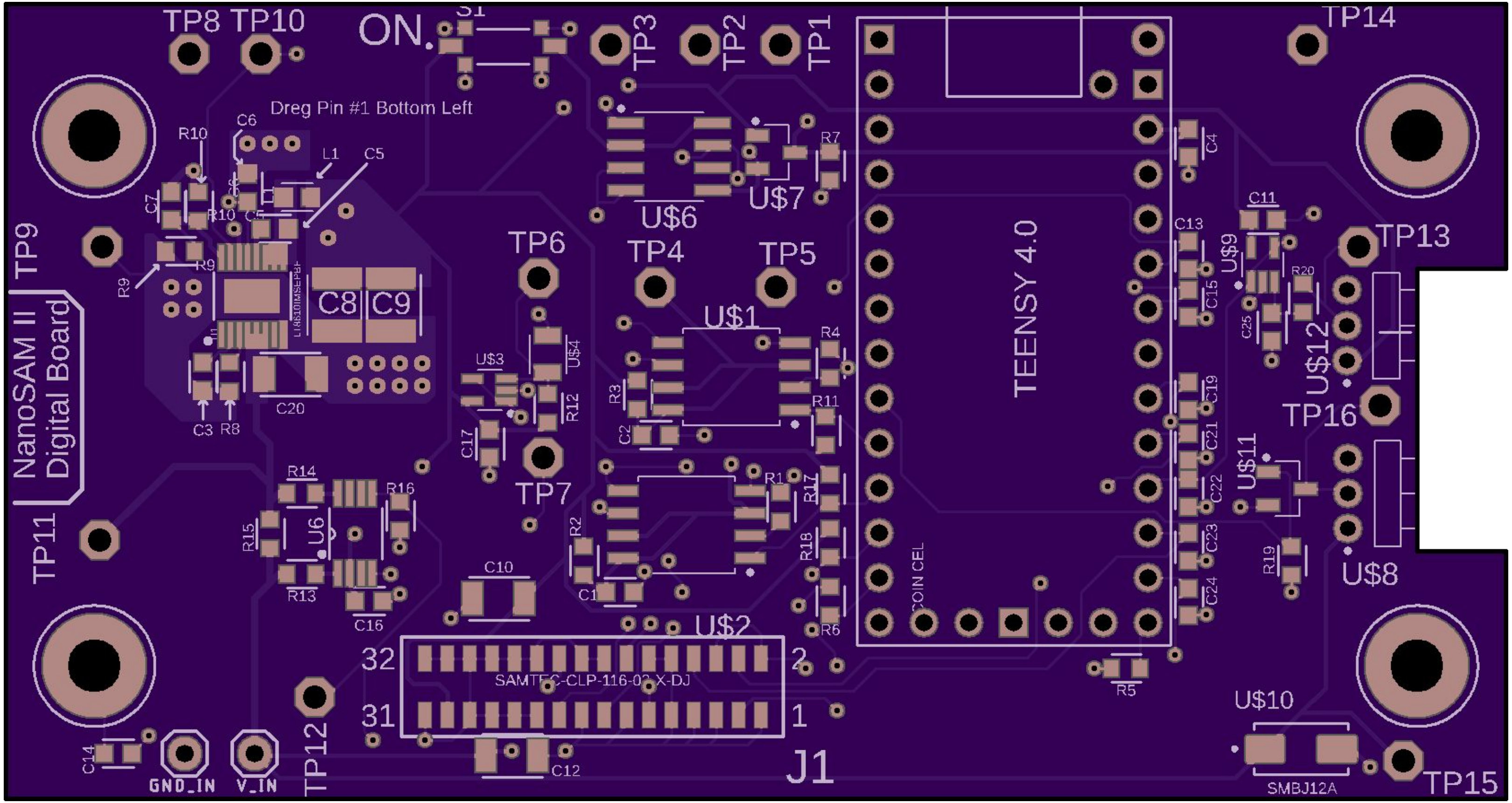
Digital Board (2/2)



OSHPark CAM Job Render [Analog]

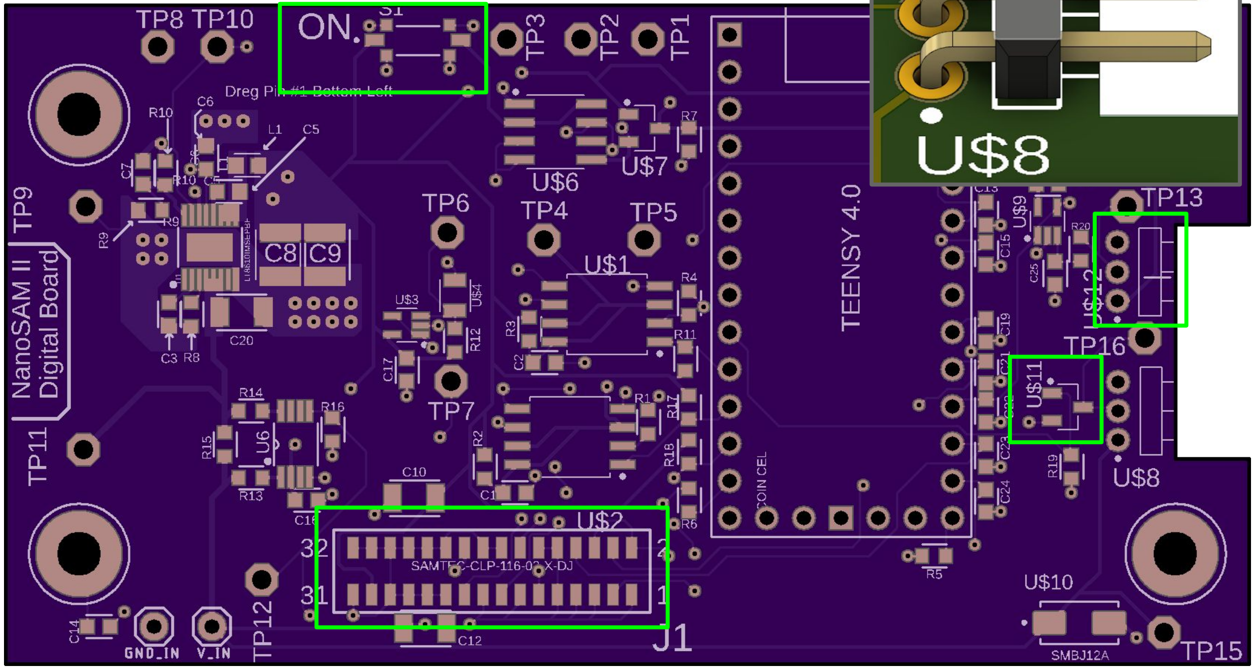


OSHPark CAM Job Render [Digital]



Electronics Design V2

- Manufacturing tolerance on B2B copper pads
- New digital B2B layout with surface mount
- Larger resistor heater MOSFET
- Watchdog hardware switch
- Clip Connectors for ease
- Increased isolation of the ground planes



Electronics System Tests

Requirements V&V

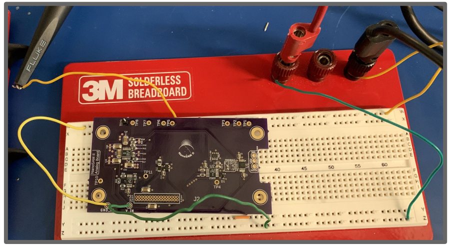
1.0: Data Capture
- The supporting electronics and software shall digitize, packetize, and store housekeeping data and information collected from the photodiode
- The system uses less than 7.3W with the heater running.

2.0: Communications
- Communicates with laptop for ground testing

3/4 - 3/9: Individual Analog Board Test → Individual Digital Board Test

3/11 - 3/16: Basic Integration and Teensy Test → Electronics External Devices Test

3/16 - 3/19: Create Test Setup for Software Integration Tests



Electronics System Tests Specifics

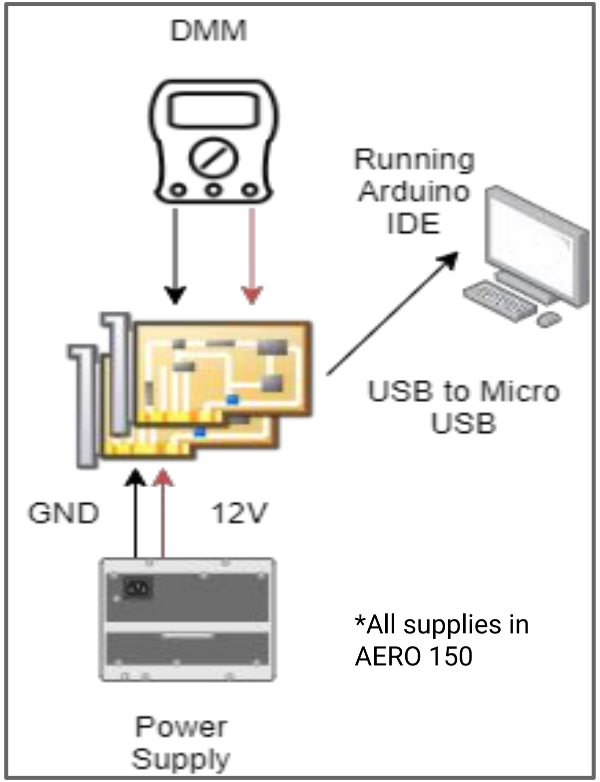
	Test operator must be grounded. Testing must be done on an ESD safe mat.	I.C
1	Set pow	
2	Orientat	
3	Connec corner c	
4	Connec board, r	
5	Connec Open Te	
6		

13	Measure the voltage of Teensy pin 15 Expected Value: Same as T5 Actual Value: _______________	
14	Measure volta Expected Valu	
15	Measure volta connector. Expected Valu	
16	Calculate the $R_T = [(T5/T3)$	
17	Calculate the equation. $T = [(ln(R_T /$	
18	Measure volta Expected Valu	

21	Shut off power supply, digital multimeter, and any additional used equipment.	
22	Disconnect GND_IN and V_IN banana plugs from the board.	
23	Place the disconnected board in an ESD safe storage location.	

Testing Notes:

Test Operator signature: _______________



Electronics Subsystem Test Results

Test Point	Actual Value	Expected Value
1	3-4mV floating	0V
2	2-3mV floating	0V
3	3.3V	3.3V
4	2-4mV floating	0V
5	2-4mV floating	0V
6	2-4mV floating	0V
7	4.99V	5V
8	-4.99V	-5V
9	2-4mV floating	0V
10	11.95V	12V
11	2-4mV floating	0V

Table 9 Analog Board Individual Test Results

Test Point	Actual Value	Expected Value
Analog 2	50-70mV [iPhone Flashlight]	[Depends on Light]
Board Connector Pin 19	2mV less than Analog 2	N/A
Digital 13	1.85V	1.77V at 30 deg C
Digital 14	1.85V	1.77V at 30 deg C
T14/T13 Low Pass Ratio	1	0.989775
Digital 15	12V	12V
Digital 16	6mV	0V

Table 12 External Connector Test Results

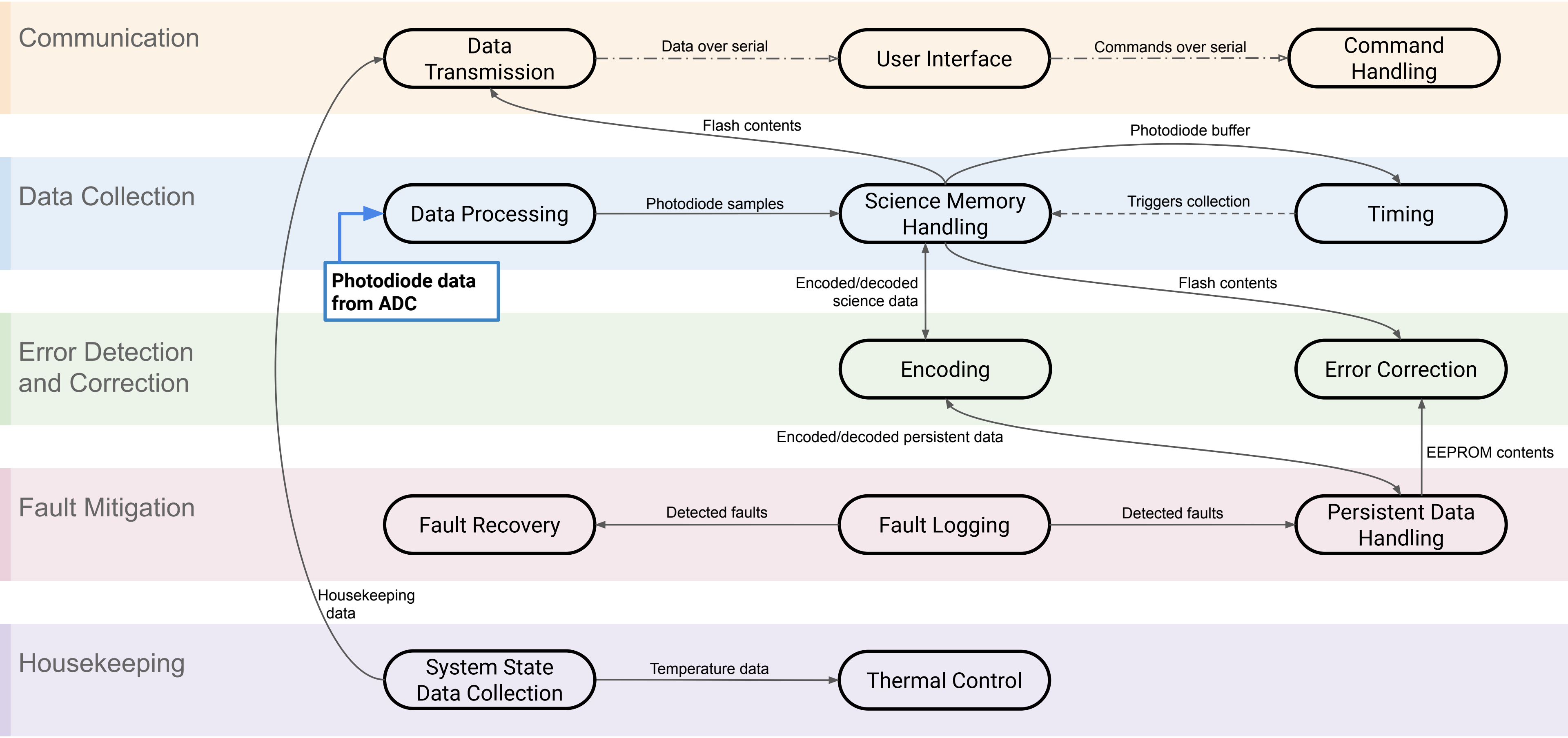
Test Point	Actual Value	Expected Value
1	Floating, 0.6V, 3.3V	0V [Teensy not on]
2	2-3mV floating	0V
3	2-3mV floating	0V
4	3.3V	3.3V
5	3.3V	3.3V
6	3.3V	0.6V
7	3.3V	0.6V
8	3.0V	3.3V
9	0.3mV floating	0V
10	0.35mV	3.3V
11	12V	12V
12	0.31V	Input Current, Variable
13	2-3mV floating	0V
14	47mV	0V
15	12V	12V
16	2-3mV floating	0V

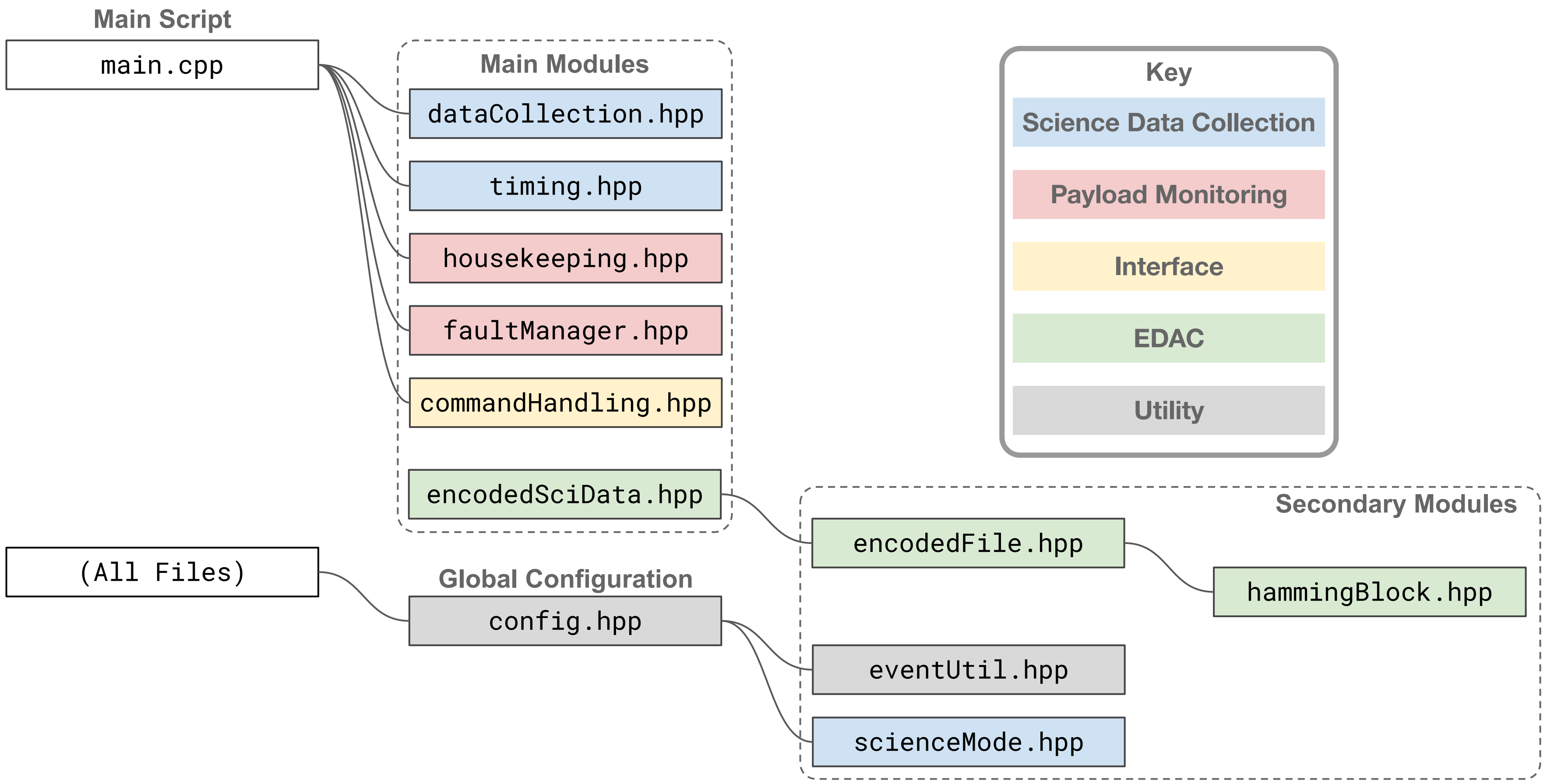
Table 10 Digital Board Individual Test Results

Test Point	Actual Value	Expected Value
Analog 1	3-4mV floating	0V
Analog 2	2-3mV floating	0V
Analog 3	3.3V	3.3V
Analog 4	3.7mV	0V
Analog 5	0.65V floating	0.6V [Room Temp]
Analog 6	0.61V floating	0.6V [Room Temp]
Analog 7	5.0V	5V
Analog 8	-4.97V	-5V
Analog 9	3.8mV	0V
Analog 10	12.01V	12V
Analog 11	3.8mV floating	0V
Digital 1	2.02V, 0.8V	3.3V [Teensy on]
Digital 2	N/A [Not Tested]	0V
Digital 3	N/A [Not Tested]	0V
Digital 4	3.3V	3.3V
Digital 5	3.3V	3.3V
Digital 6	0.367V	0.6V
Digital 7	0.367V	0.6V
Digital 8	3.3V	3.3V
Digital 9	4.6mV	0V
Digital 10	0.35mV floating	3.3V
Digital 11	12V	12V
Digital 12	5.6mV	Input Current, Variable
Digital 13	N/A [Not Tested]	0V
Digital 14	N/A [Not Tested]	0V
Digital 15	12V	12V
Digital 16	10mV	0V

Table 11 Board Integration Test Results

Software Conceptual FBD

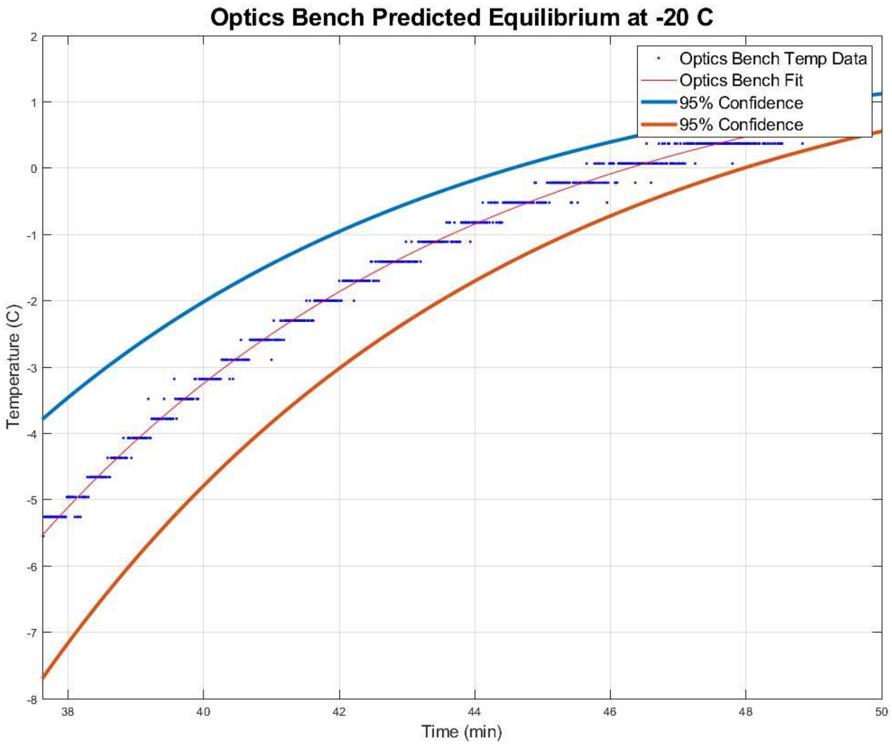




Flight Software Header Tree

Thermal Updates

Determining Heater Output Error Bounds



- Using MATLAB fit toolkit
  - Assuming high stability
  - Imperfect because of resolution inaccuracies that can be seen in the data
- Results from using Eq temperatures in Matlab model:
  - Heater output = 2.4 +/- 0.1 W
  - Electronics outputs below chamber equilibrium
    - Negligible output

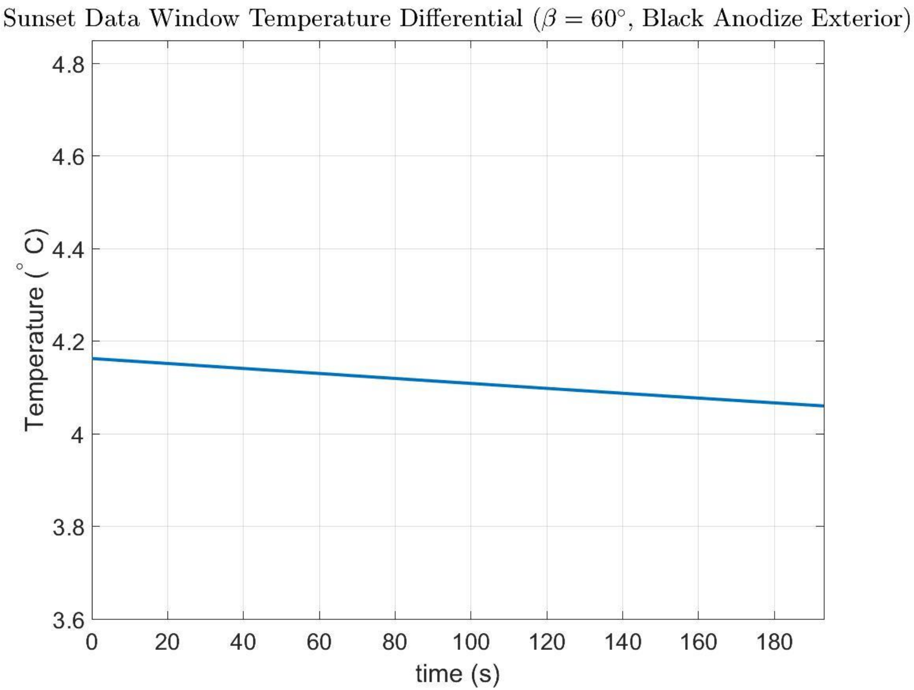
$$T(t) = T_{\text{env}} + (T(0) - T_{\text{env}})\, e^{-t/\tau}.$$

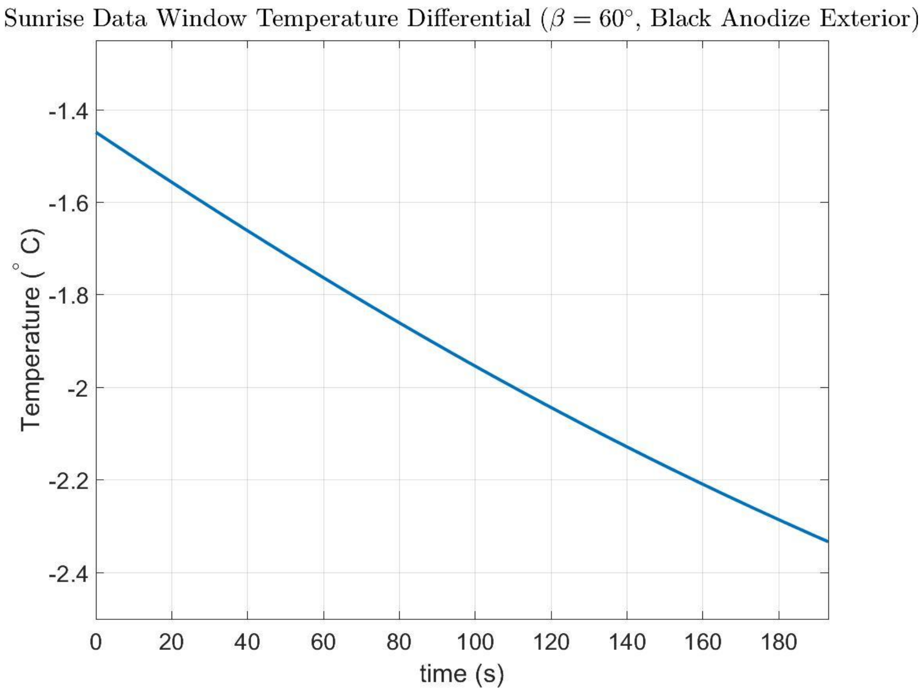
Temperature Change on the Photodiode Block

Data Window	Max ΔT (K)	Time (s)
Sunset	~0.1	192.6
Sunrise	~0.9	192.6

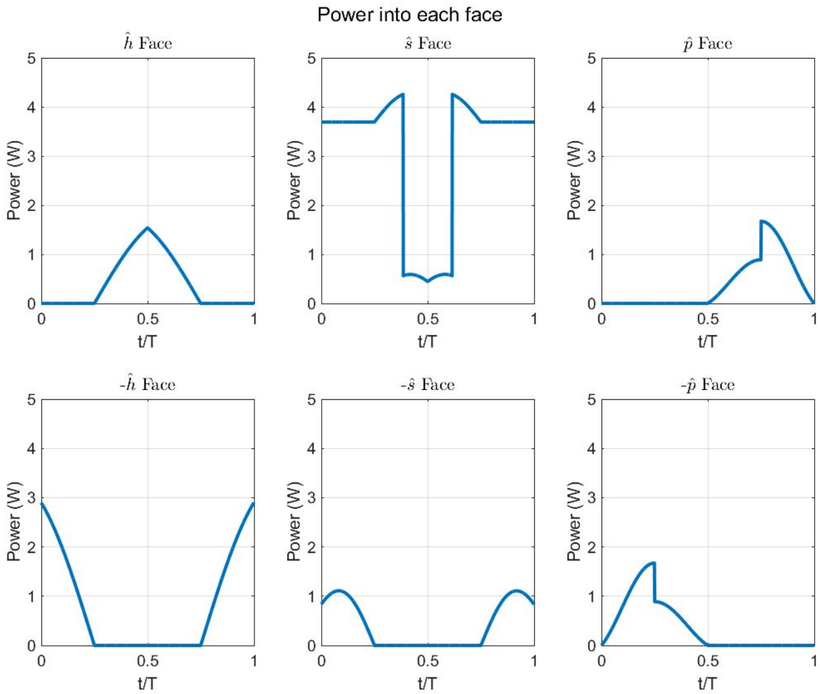
- Calculated for β = 60° (orbital parameters corresponding to maximum length data window)
- Average values used for albedo, IR, and solar radiation [2]
- Negligible electronics board power dissipation used in model alongside a 2.4 W heater
- Black anodize exterior coating [3]
- No longer lumped system analysis (done through Solidworks + MATLAB modeling)
    - Threads and screws removed along with small holes

Temperature Change on the Photodiode Block



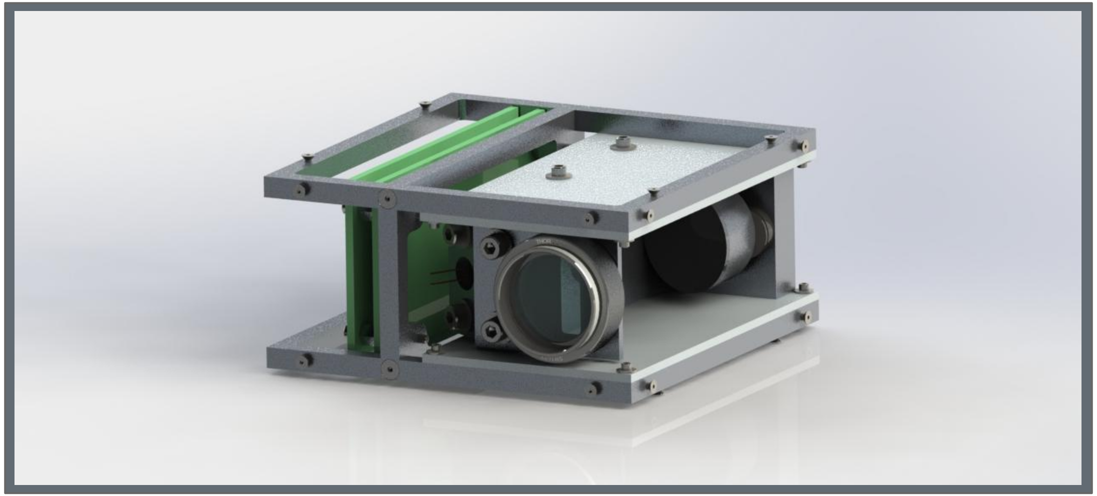


Temperature Change on the Photodiode Block



- Input into SolidWorks in order to account radiation from the Earth
  - Neither SolidWorks or ANSYS has this ability built in
- Still uses **area** factor analysis
- Modeled as surface sources alongside the heater and the EPS board power dissipation

Thermal Isolation of the Optics Bench



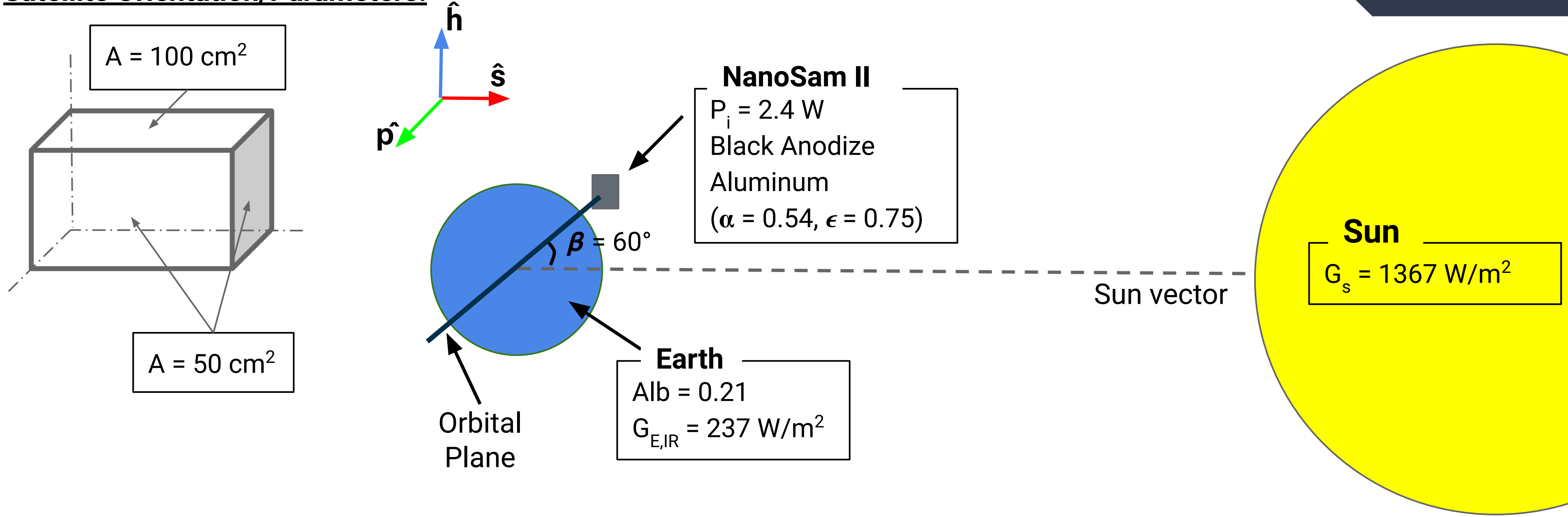
- Introduction of structural fiberglass on either side of the optics bench (S-Glass)

S-Glass Properties	
Density	2.49 g/cc
Thermal Conductivity	1.28 W/m-K
Specific Heat	738 J/kg-K

Thermal Model Diagram

Sources : [3] [4]

Satellite Orientation/Parameters:



Thermal Model Details

Key Assumptions:

- Bodies other than the Earth/Sun don't produce significant incident radiation
- Kirchoff's law ($\epsilon_\lambda(T) = \alpha_\lambda(T)$)
- Satellite surfaces are gray, diffuse, surfaces
- Radiation to deep space (0 K)

Key Equations:

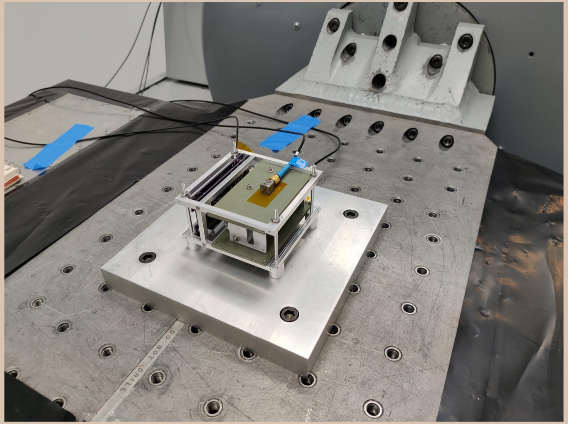
$$T_{sys,eq} = \left[\frac{\dot{Q}_{in,sun} + \dot{Q}_{in,A} + \dot{Q}_{in,IR} + P_i}{2\sigma\epsilon(2A_s + A_p)}\right]^{(1/4)}$$

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

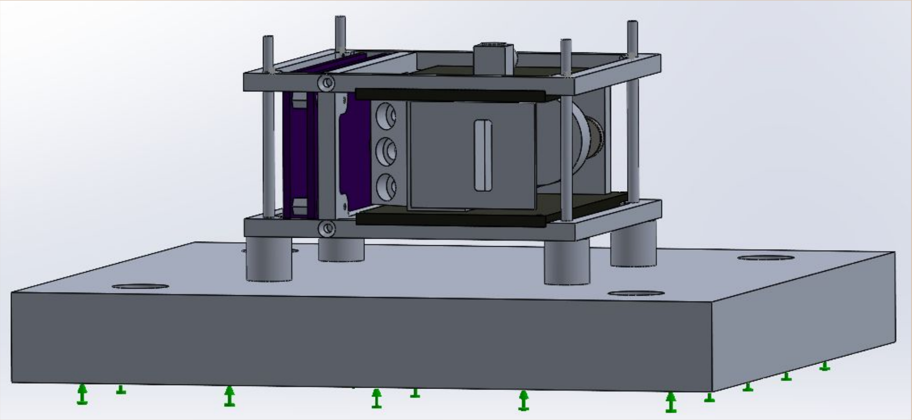
$$T_i = \frac{\dot{Q}_{tot}\Delta t}{mc_p} + T_{i-1}$$

Vibrational Updates

Vibration Test Results



Physical Setup



Model

Vibration Test Results

- 0-2000 Hz 3 Axis Resonance Survey Conducted at Altius Space Machines
- Requirement was no resonant frequencies below 90 Hz
- Lowest frequency from survey was 445 Hz
- **Model extremely sensitive to boundary conditions**

		Closest Solidworks Resonant Frequency (Hz)	
Axis	**Frequency (Hz)**	**Solidworks (Fixed Base)**	**Solidworks (Fixed Optics)**
x	493.3	982.6	416.8
x	901.1	982.6	873.9
y	445.5	982.6	416.8
y	621.4	982.6	636.5
z	619.5	982.6	636.5