RADIANCE

Research at high **A**ltitude on **D**istributed **I**rradiance **A**board an i**N**expensive **C**ubesat **E**xperiment

Critical Design Review

Presenters: Russell Bjella, Katelyn Dudley, Jenny Kampmeier, David Varley, Lance Walton

Team Members: Brandon Antoniak, Alec Fiala, Jeremy Muesing, James Pavek

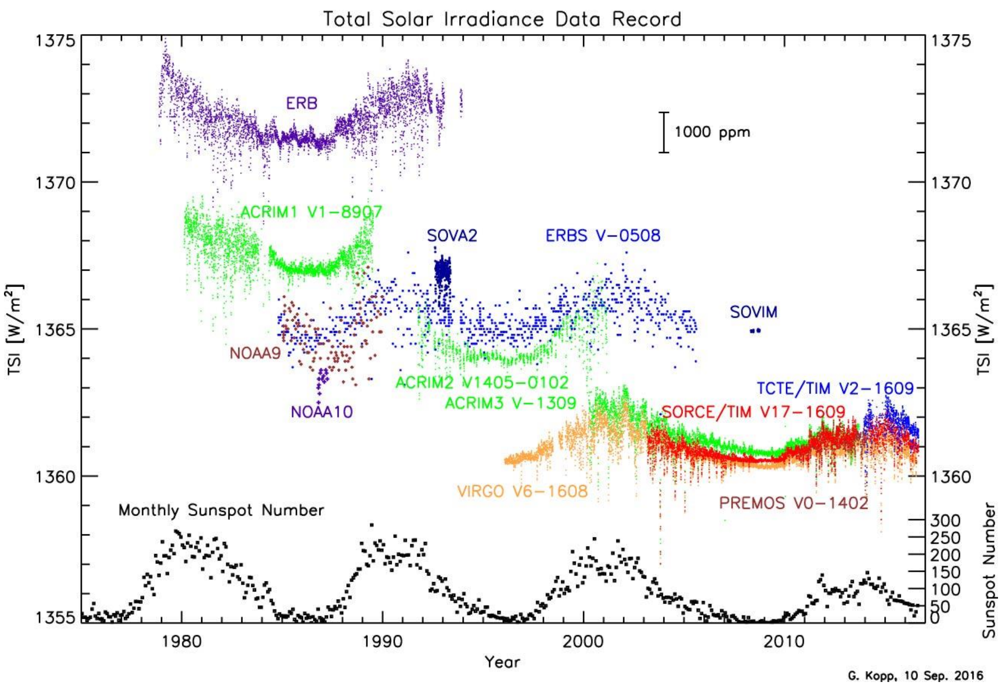
NCAR NATIONAL CENTER FOR ATMOSPHERIC RESEARCH HAO

Aerospace Engineering Sciences UNIVERSITY OF COLORADO BOULDER

Outline

Project Overview	Jenny, David	5%
Design Solution	Lance	10%
Critical Project Elements	Lance	5%
Detailed Analysis	Jenny, Katie, David, Russell	30%
Risks	David	10%
Verification and Validation	Katie, Russell	20%
Remaining Work	Jenny	20%

Project Motivation



Are these variations real? How does it inform climate science?

- Solar irradiance data is plentiful, but…
  - The record has gaps
  - Datasets vary between different instruments
  - Full-scale space missions are costly
  - Full-scale space missions are time-consuming

Project Description

- Mission Statement

  RADIANCE is a 3U CubeSat-style payload that will collect solar irradiance data, images, attitude information, and ambient atmospheric data during a 2-week circumpolar high-altitude balloon flight.

  The mission will launch from Antarctica between November 2017 and February 2018.

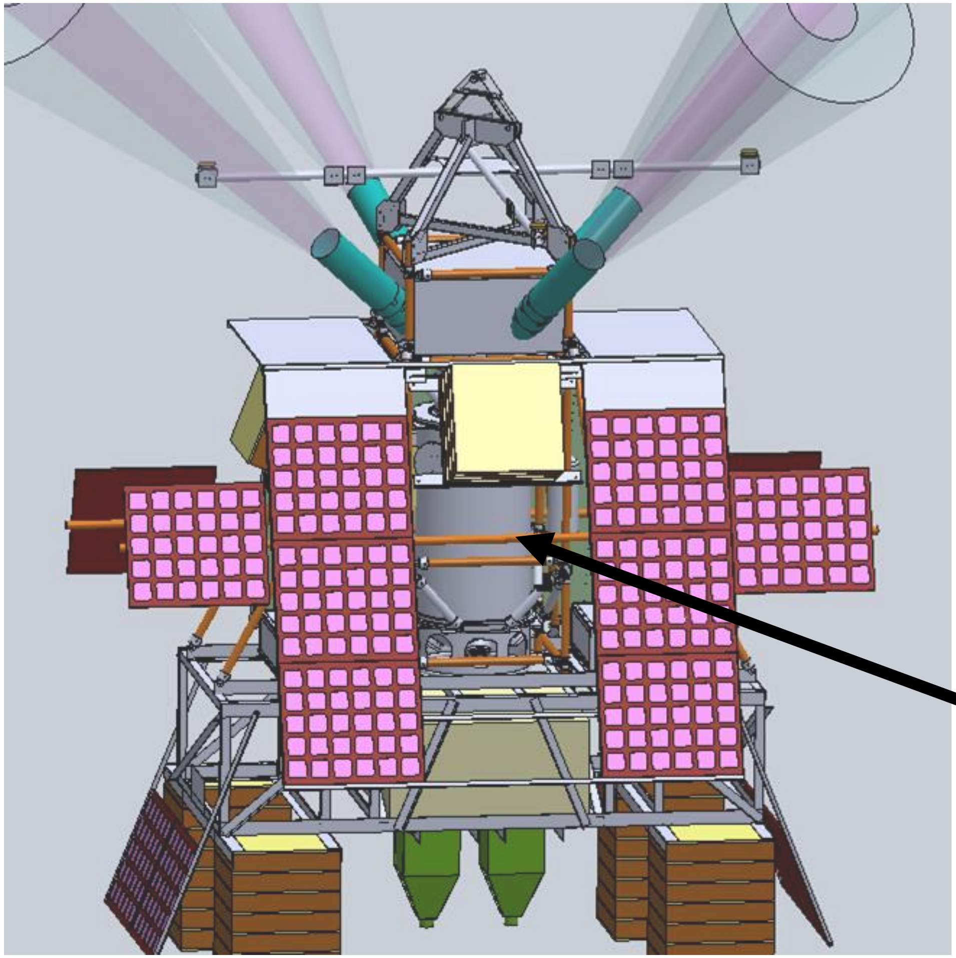
- Project Statement

  RADIANCE will design, build, test, and deliver a 3U CubeSat-style payload to collect solar irradiance data, images, attitude information, and ambient atmospheric data on a high-altitude balloon flight.

HiWind Gondola & Flight

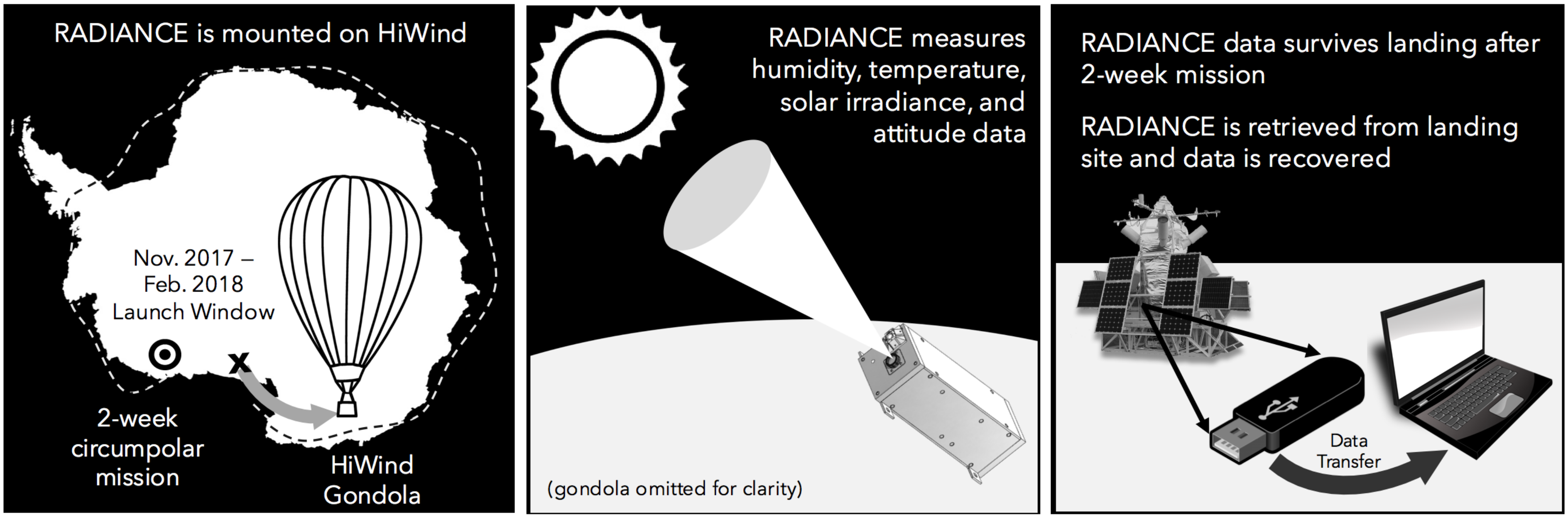
- Mission:
  - Ground: 8 hours
  - Ascent: 2 hours
  - Flight: 2 weeks
  - Descent: 1 hour

HiWind Gondola & Flight



RADIANCE mounting location

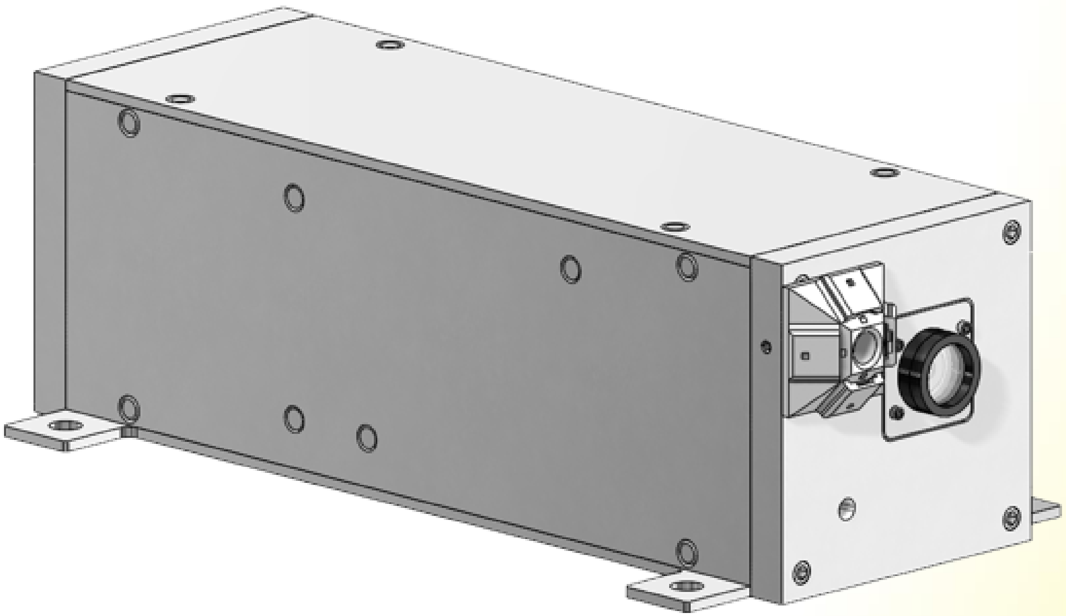
Mission-Level ConOps



Project-Level ConOps

Power Up

Using external power source equivalent to 15 W of expected HiWind power



Functional Requirements

RADIANCE shall…

FR1: Take solar irradiance measurements.

FR2: Survive the environmental conditions of a high-altitude balloon flight up to 40 km.

FR3: Return data.

FR4: Determine its attitude.

FR5: Interface with the HiWind Gondola.

FR6: Capture images of the Sun in the visible spectrum.

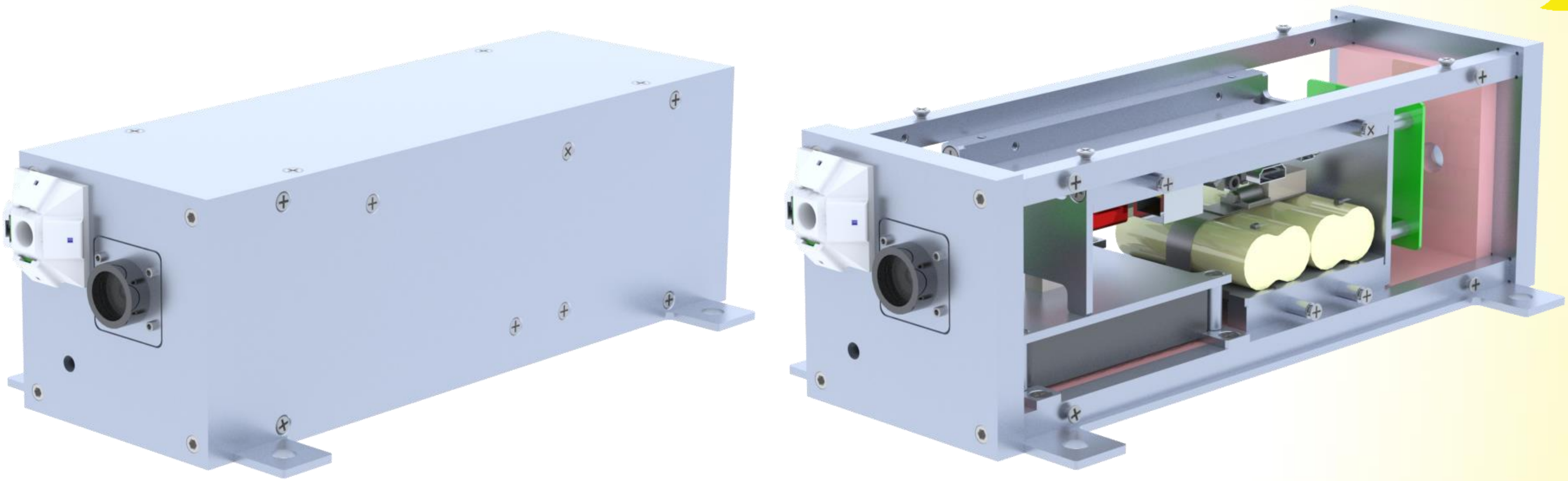
The project deliverables shall include a Path-to-Space report.

Changes Since PDR

Item	Level Achieved	Original Requirement	Design Solution	OK?
Spectrometer	2	Resolution= 1.0 nm Range = 250—1000 nm	Resolution = 1.4 nm Range = 200—1100 nm	✓
Camera	3	FOV = 5° ± 1°	FOV = 6.32°	✓
Sensors	3	Take environmental data	Descope pressure sensor	✓
Data	3	Data is recoverable	3 drives to protect against radiation	✓
EPDS	1	Independent power	Descope solar panels, use HiWind power	✓
ADS	1	Sub-arcminute accuracy	±1 arcminute accuracy	✓
Structures	2	Volume: $30x10x10 cm^3$	Volume: $31.81x10x10 cm^3$	✓

Design Solution

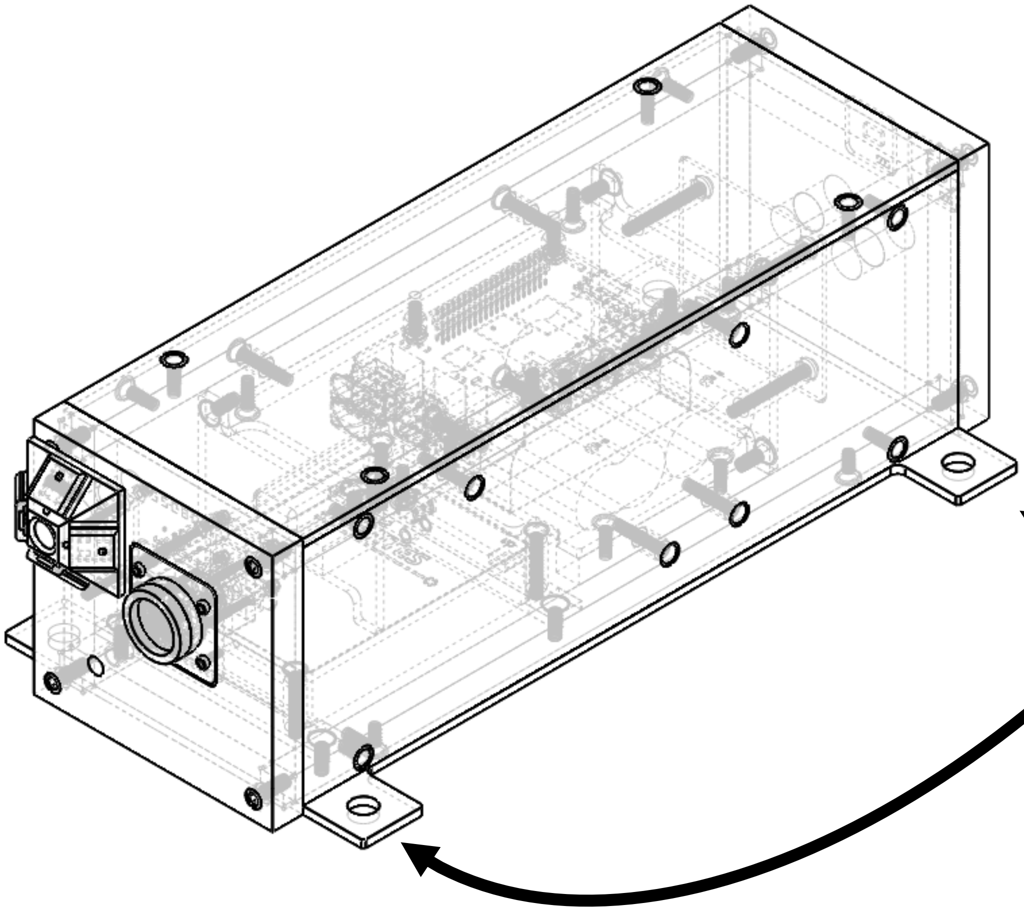
Overall System Description



Parameter	Overall Values	Req.	OK?
Dimensions	31.81 x 10 x 10 cm^3	DR5.1	✓
Mass	3.0 ± 0.2 kg	—	✓
Power	5.2 to 19.6 W usage, 7.7 W average at cruise	DR5.4	✓
Thermal	-3 to 30 °C internally, spot-heated in critical places	FR2	✓
Materials	Aluminum 6061, Photopolymer Resin, Polyurethane Foam	DR3.2	✓

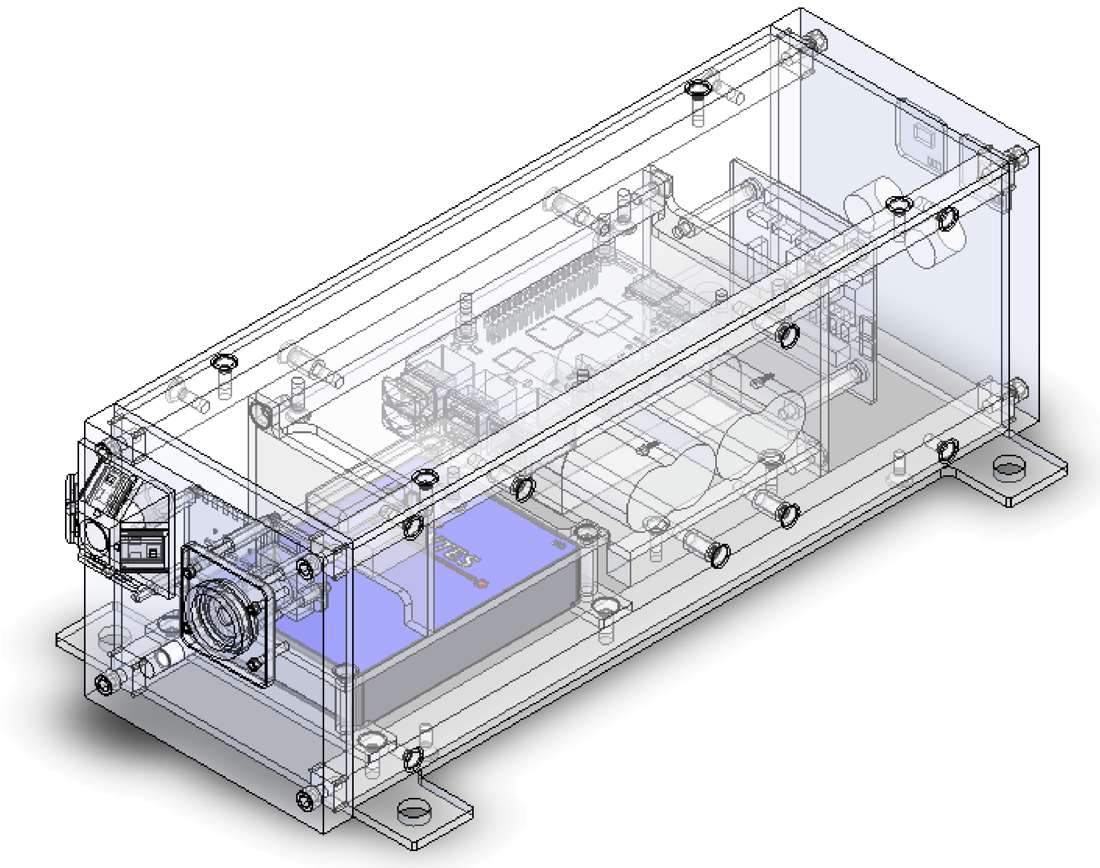
Complete Assembly

System Overview



- Exterior structure attached to internal struts with screws
- Attachment points to HiWind

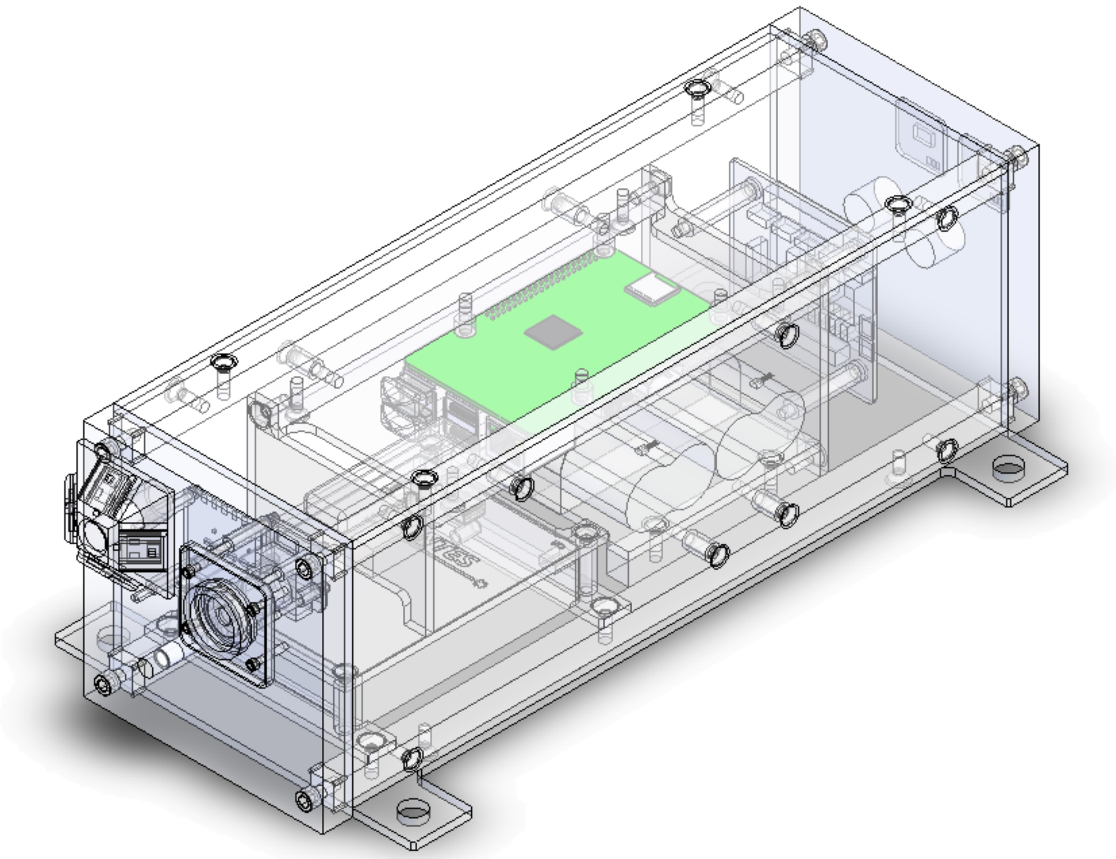
System Overview



- Avantes fiber optic cable and spectrometer

	Requirement	Solution
Resolution	1.4 nm	1.4 nm
Wavelength	250-1000 nm	200-1100 nm
Cost	~$3000	$2946
Size	Must fit	90x68x20 mm
Power	< 3W	1.25 W
Interface	RPi required	RPi capable

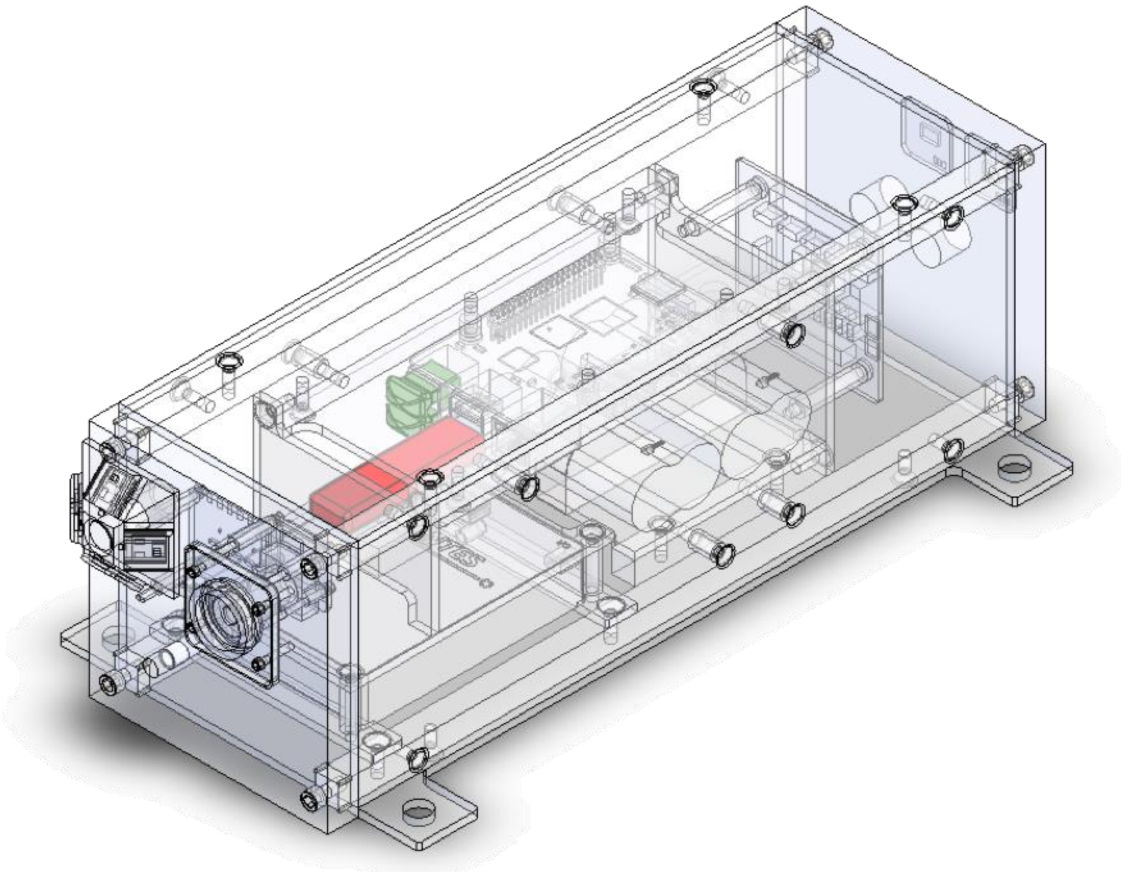
System Overview



- Raspberry Pi microcontroller

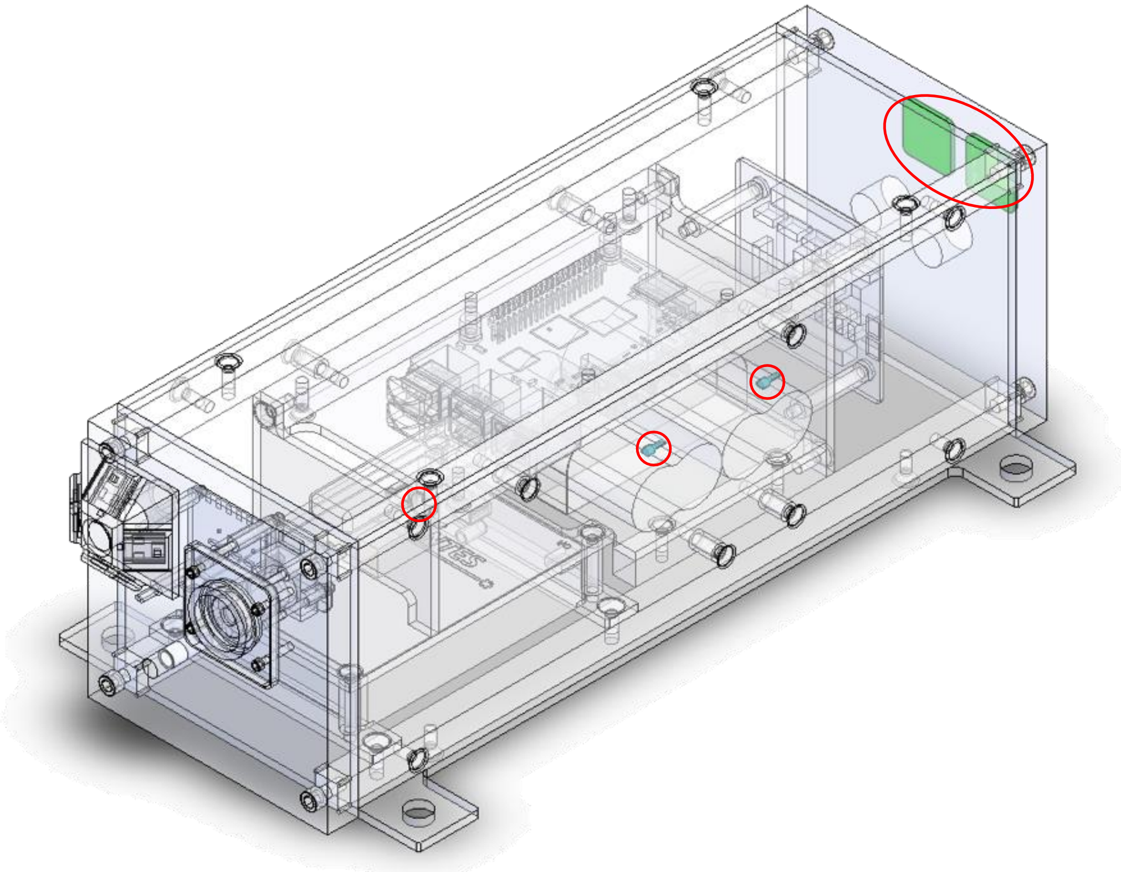
	Requirement	Solution
Size	Must fit	85x56x17 mm
Cost	<$100	$36
Versatility	High	COTS
Interface	RPi needed	RPi capable

System Overview



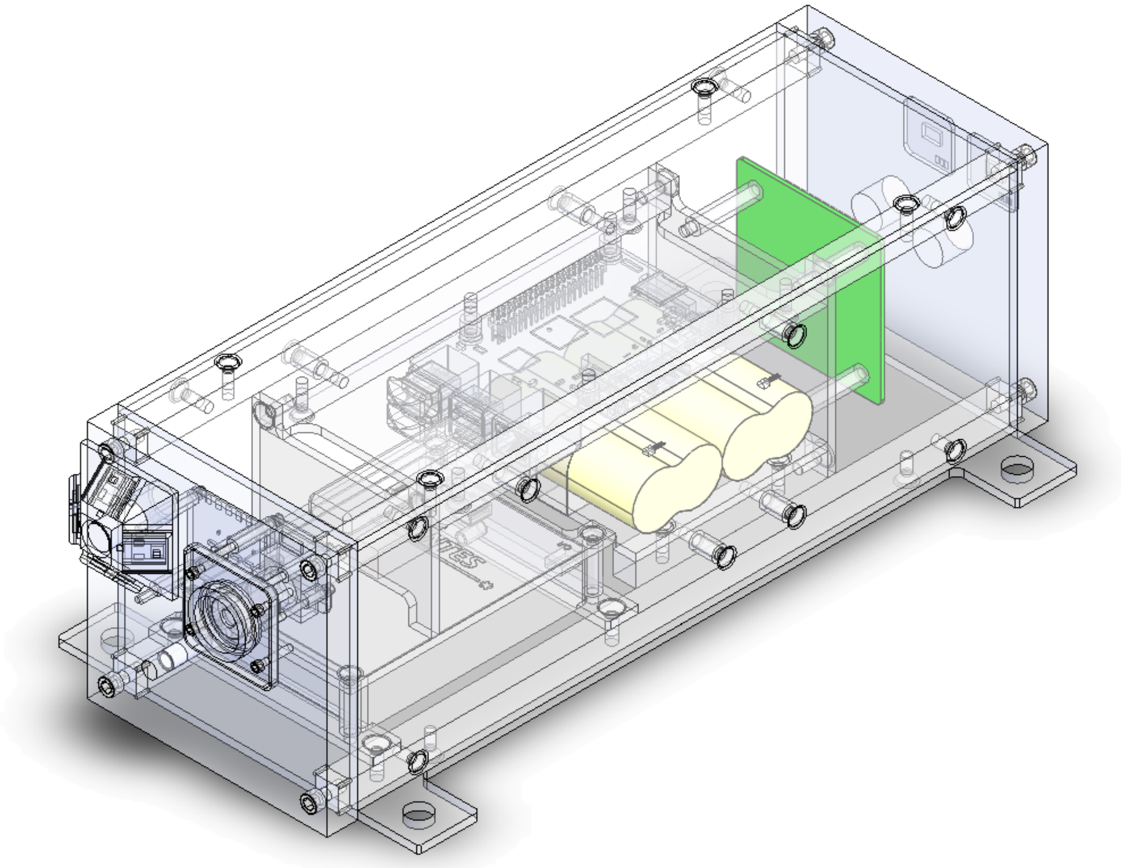
- Three USB storage devices:
  - 1 single-level cell (SLC) drive
  - 2 multi-level cell (MLC) drives

System Overview



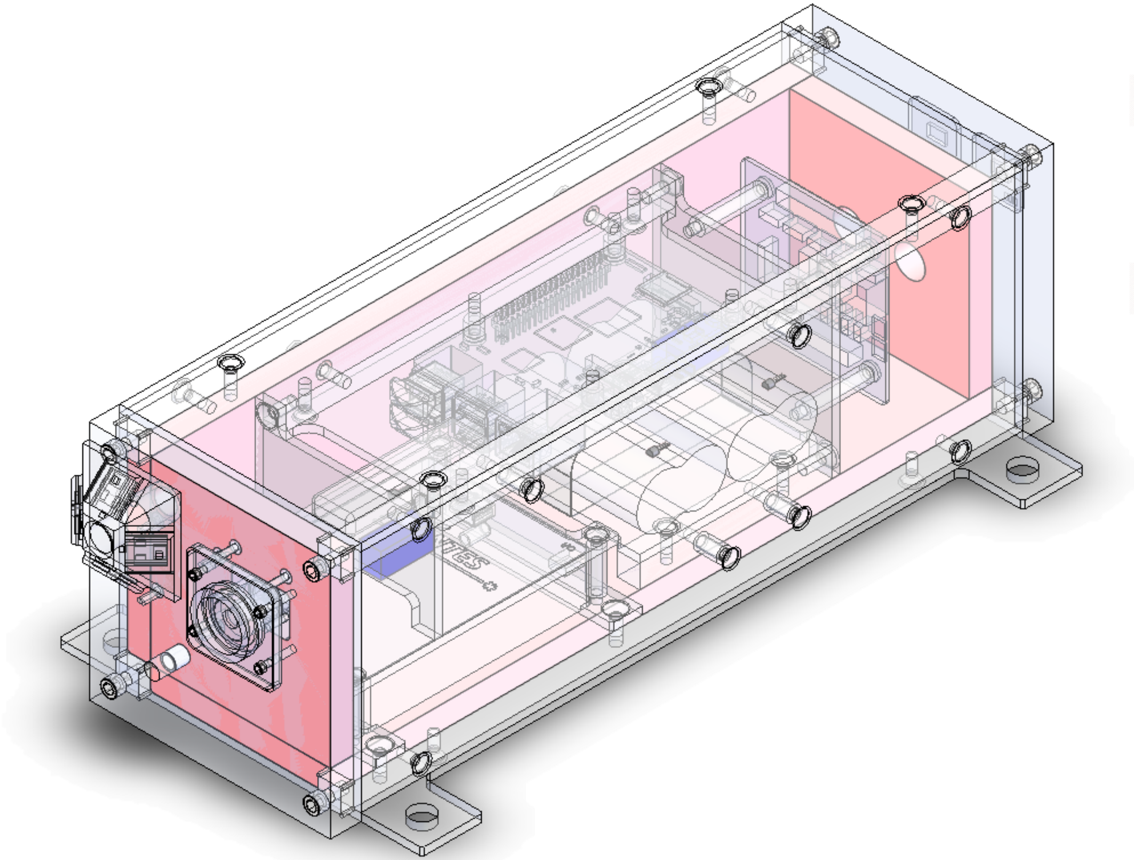
- External sensors (temperature, relative humidity) for atmospheric measurements
- Internal temperature sensors for active thermal monitoring

System Overview



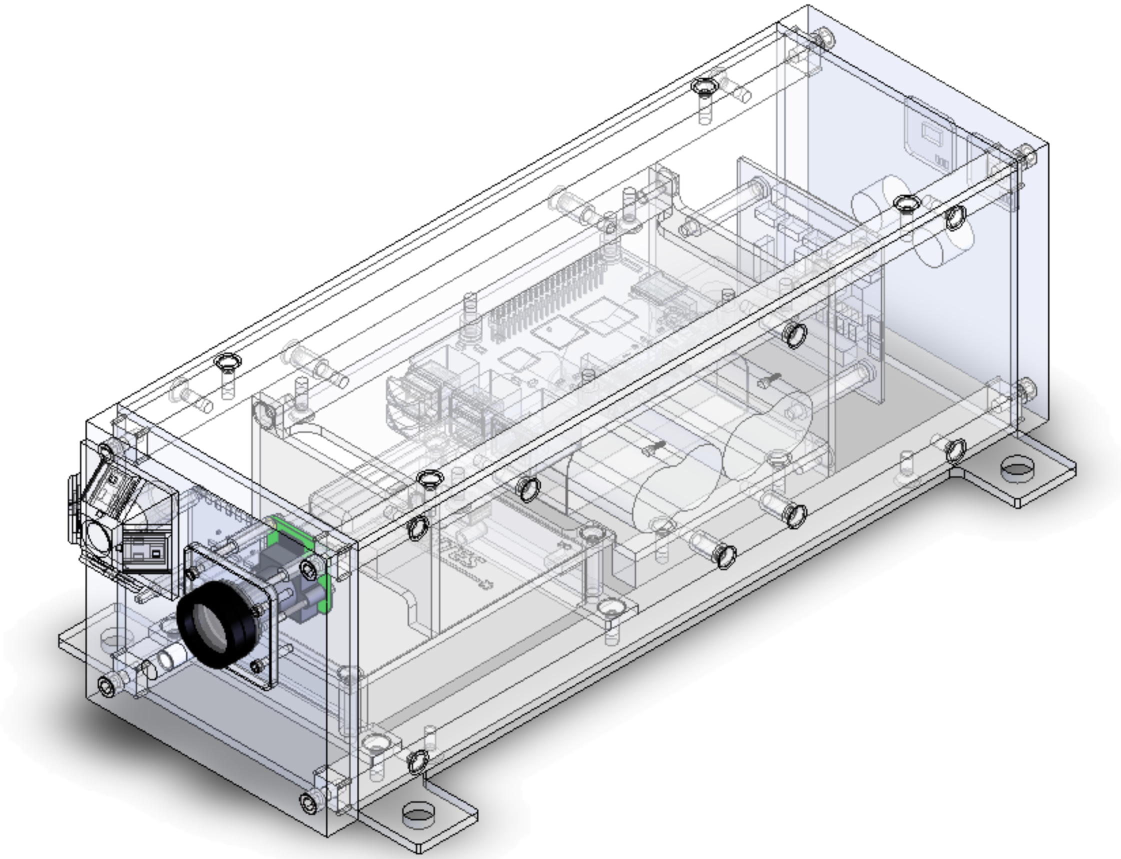
- Custom power board for control and distribution
- Two Lithium Ion (Li-ion) batteries

System Overview



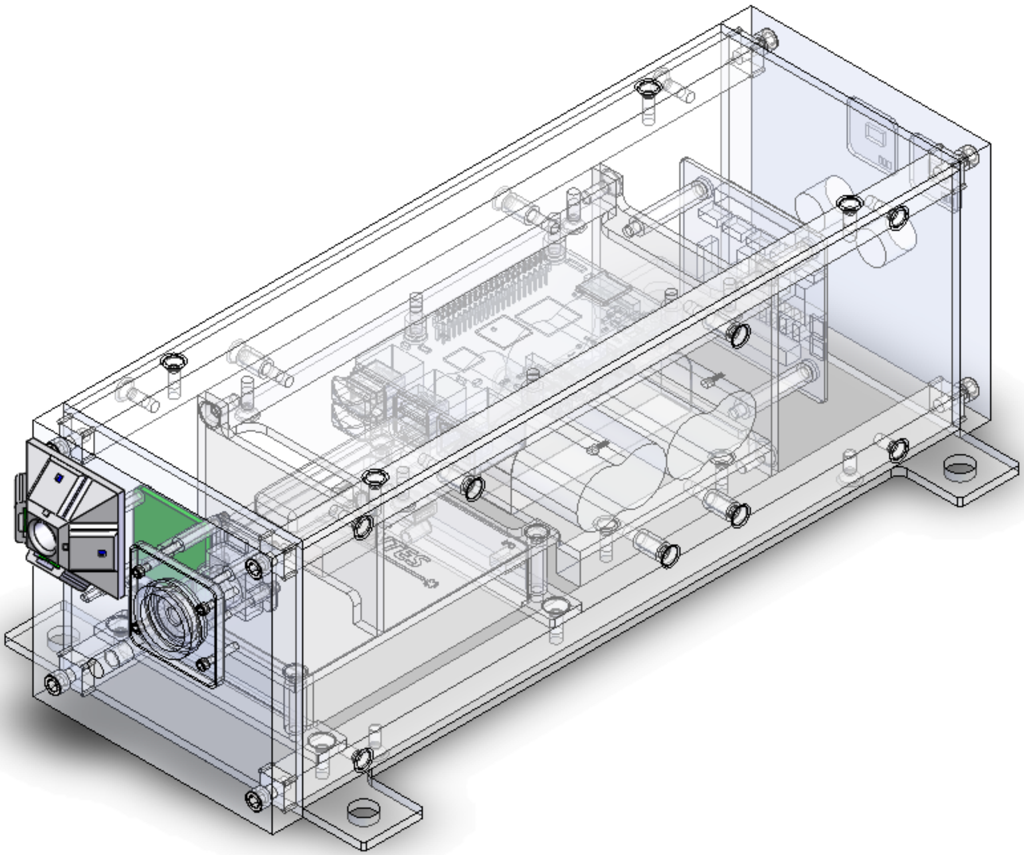
- Polyurethane foam insulation
- Thin film resistive heaters for active thermal control

System Overview



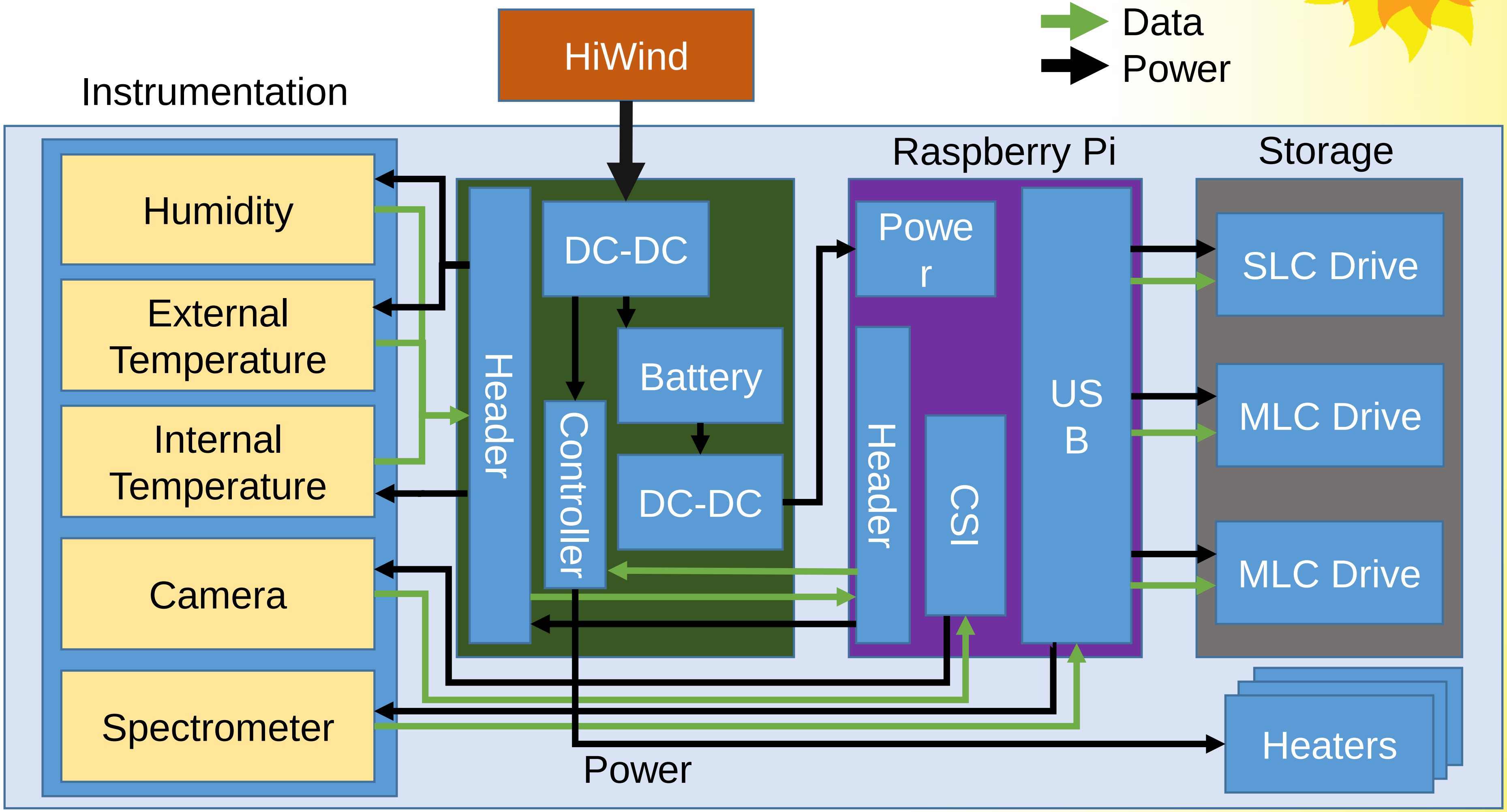
- Camera assembly, including:
  - Raspberry Pi Camera
  - Adjustable focus lens and mounting
  - Double-layer neutral density filter

System Overview



- Photodiode array and circuit board for attitude determination
- 4 photodiodes offset at 45° to determine off-sun angle

Functional Block Diagram



Critical Project Elements

Critical Project Elements

- **Structural**
  - Manufacturing
  - Integration with HiWind
  - Materials
  - Structure
- **Thermal**
  - Thermal Control
- **EPDS**
  - Power Distribution
  - Battery
- **C&DH**
  - Microcontroller
  - Software
  - Data Storage
- **Instrumentation**
  - Spectrometer
  - Camera and Lens
  - Environmental Sensors
  - Attitude Determination
  - Housekeeping Sensors

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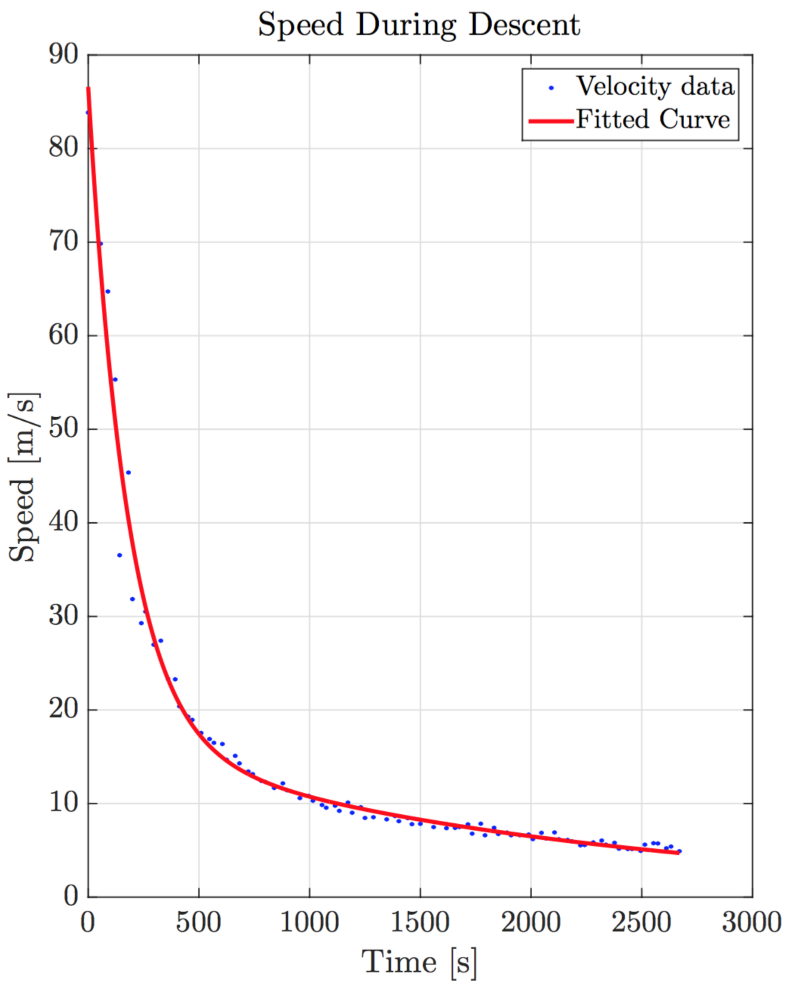
CPE Justification

CPE	Justification	FR
Manufacturing	Some small parts, many components to manufacture	5
Thermal Control	All components must meet thermal requirements	2
Power	Power board design is complex	5
Software	Efficient software design is critical to mission success	3
Data Storage	SEUs are possible, data must survive landing	3
Camera, Lens	Challenging assembly to ensure in-focus images	6
Attitude Determination	Complex design, small parts, challenging hardware/software interface	4

Design Requirements & Their Satisfaction

Structural Design Motivations



R3.2: Data storage shall survive landing

- Previous flight data: speed is 5.44 m/s at landing
- Equipped with parachute and crush pads
- Data only taken every ~30 seconds → must infer landing force using Δ in momentum

Structural Design

From previous data:	$\Delta v = 5.44\ \frac{\text{m}}{\text{s}}$ $m = 2092\ \text{kg}$
Estimated crash duration:	$t_{\text{impact}} = 0.17\ \text{s}$

Duration determined based on height of crush pads and speed

Fundamental equations: $$F = \frac{m\Delta v}{t} = \frac{(2092\ \text{kg})\left(5.44\ \frac{\text{m}}{\text{s}}\right)}{0.17\ \text{s}} = 67.75\ \text{kN}$$

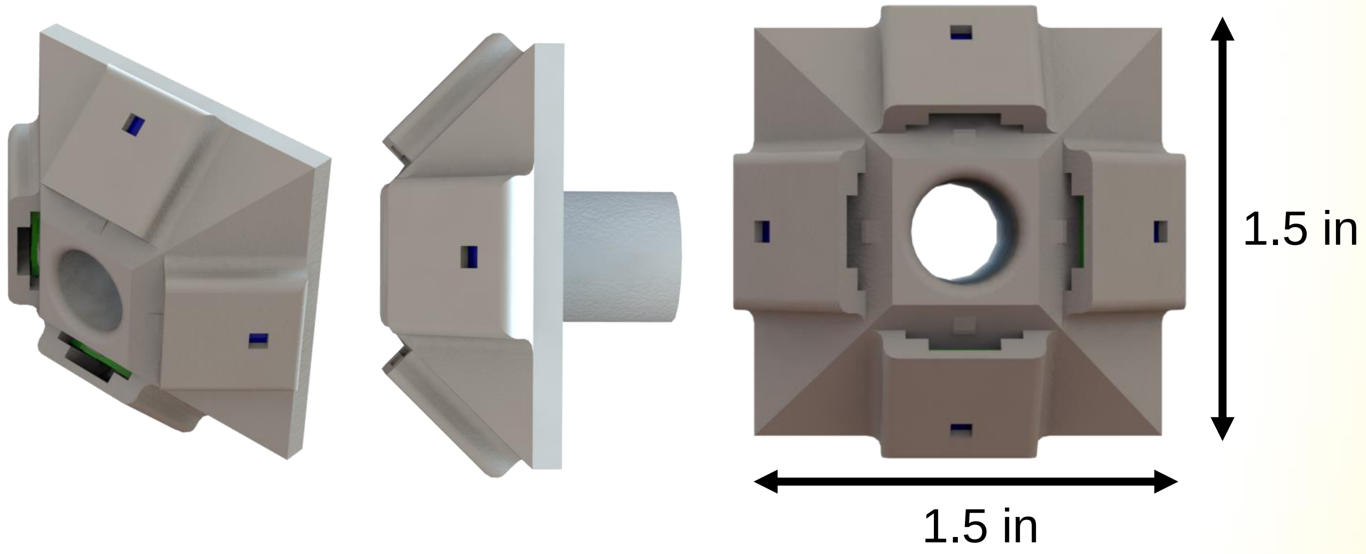
$$G = \frac{F}{mg} = \boxed{3.30\ \text{Gs}}$$

Landing Impact
3.30 Gs

$\ll$

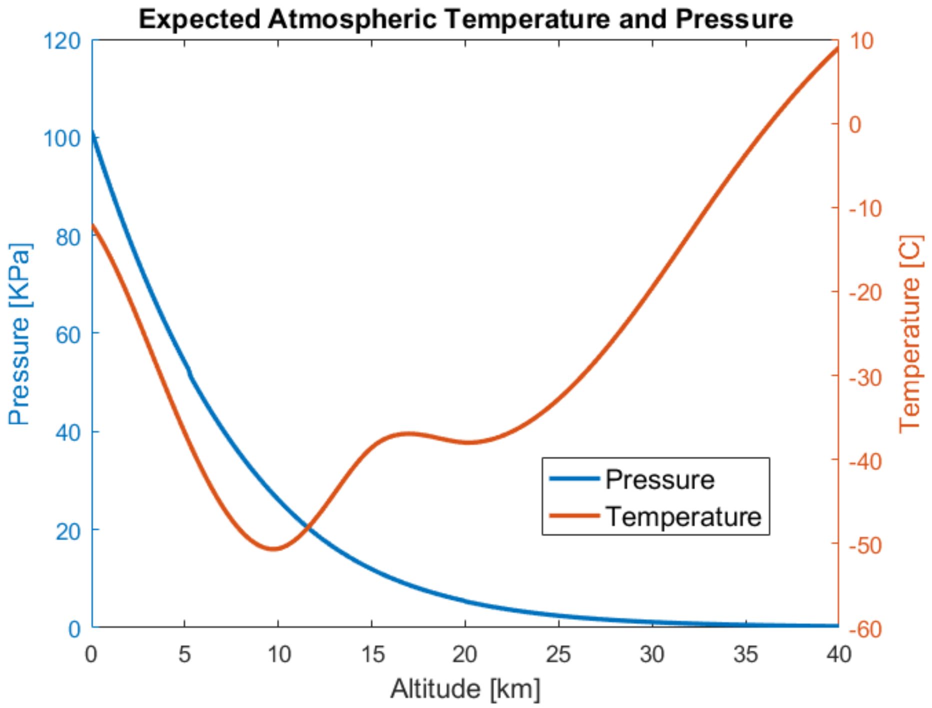
Flash Drive Rating
1500 Gs

Manufacturing Concerns



- Some small parts will be 3D printed, 140 μm precision
  - Photopolymer resin is a “low outgassing” material safe to use
- CNC manufacturing tolerance: ± 5 μm
- Foam insulation will be cut with hot wire to ~0.2 cm precision

Thermal Control Motivations



FR2: The system shall survive the environmental conditions of flight

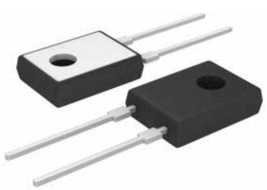
- Temperature ranges from -60° to 10° C
- Pressure Ranges from 100 kPa to 0.2 kPa

Key Temperatures

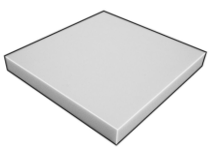
Critical components:

Component	Operational Range	Survival Range
Spectrometer	0 to 55 °C	-20 to 55 °C
SLC Flash Drive	0 to 70 °C	-45 to 85 °C
MLC Flash Drive	0 to 60 °C	-10 to 70 °C
Battery	Charge: 0 to 45 °C Discharge: -20 to 60 °C Storage: -20 to 50 °C	Charge: 0 to 45 °C Discharge: -20 to 60 °C Storage: -20 to 50 °C
Raspberry Pi	-40 to 85 °C	-40 to 85 °C

Thermal Control System



- Active Control
  - 5W 1D resistive heater on thermostat control
    - Temperature sensors on critical components input to RPi control



- Passive Control
  - Insulation —slow transient effects during ascent
    - 3/8" thick insulation
    - Not necessary for cruise (convection is negligible)
  - Radiative coating, ε = 0.85
    - Used to dissipate heat during cruise (negligible in tropopause)

Thermal Model — Assumptions

Radiation
- Bare aluminum is negligible
- HiWind has no radiative effect

Convection
- Negligible at cruise, exists otherwise

Conduction
- Perfect contact between components
- Components within 3mm are connected thermally
- Thermally isolated from HiWind

- Reaches steady state during cruise, on the ground, and in hangar
- Powered on the ground

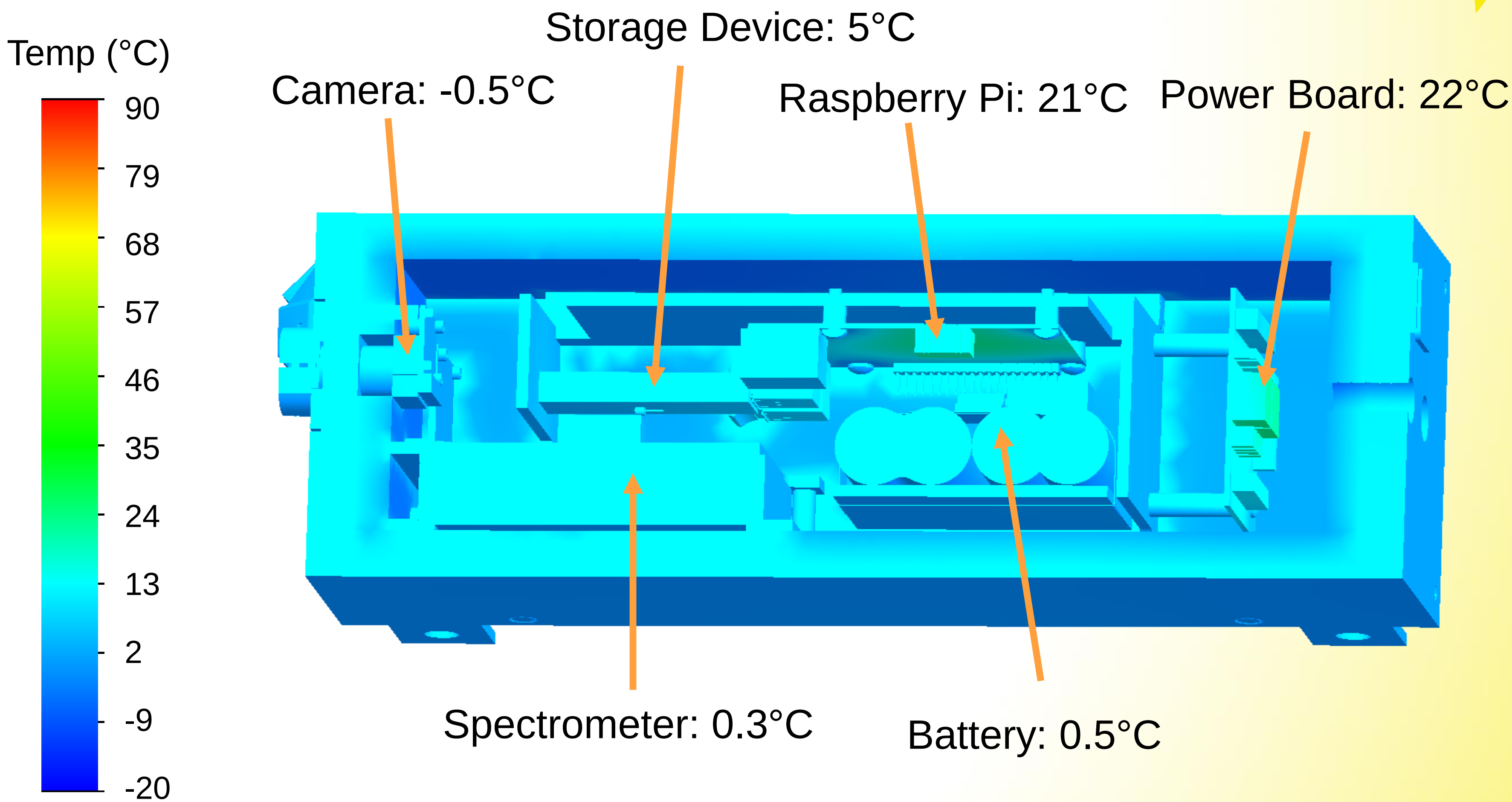
Boundary Conditions

Item	Value
Radiative coating emissivity	ε = 0.85
Electronics emissivity	ε = 0.70
Insulation emissivity	ε = 0.30
Air temperature, ground	260 K (-13.15 °C)
Air temperature, cruise	283 K (9.85 °C)
Air temperature, hangar	298 K (24.85 °C)
External convection, ground	H = 4.4 W/m^{2}K
External convection, cruise	H = 0.002 W/m^{2}K

- All heating done evenly throughout heating components

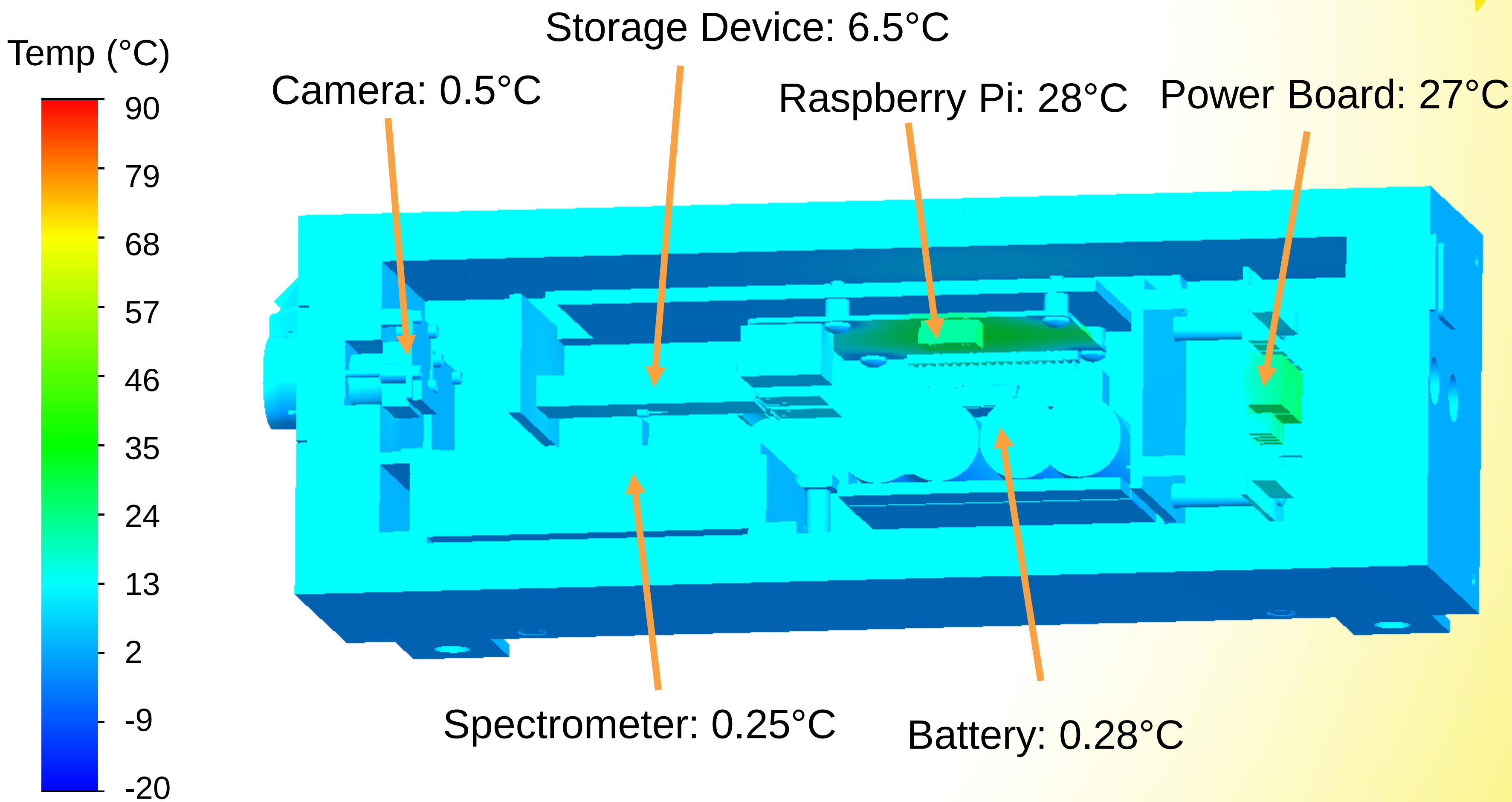
Thermal Analysis

Active control, on the ground, steady state model



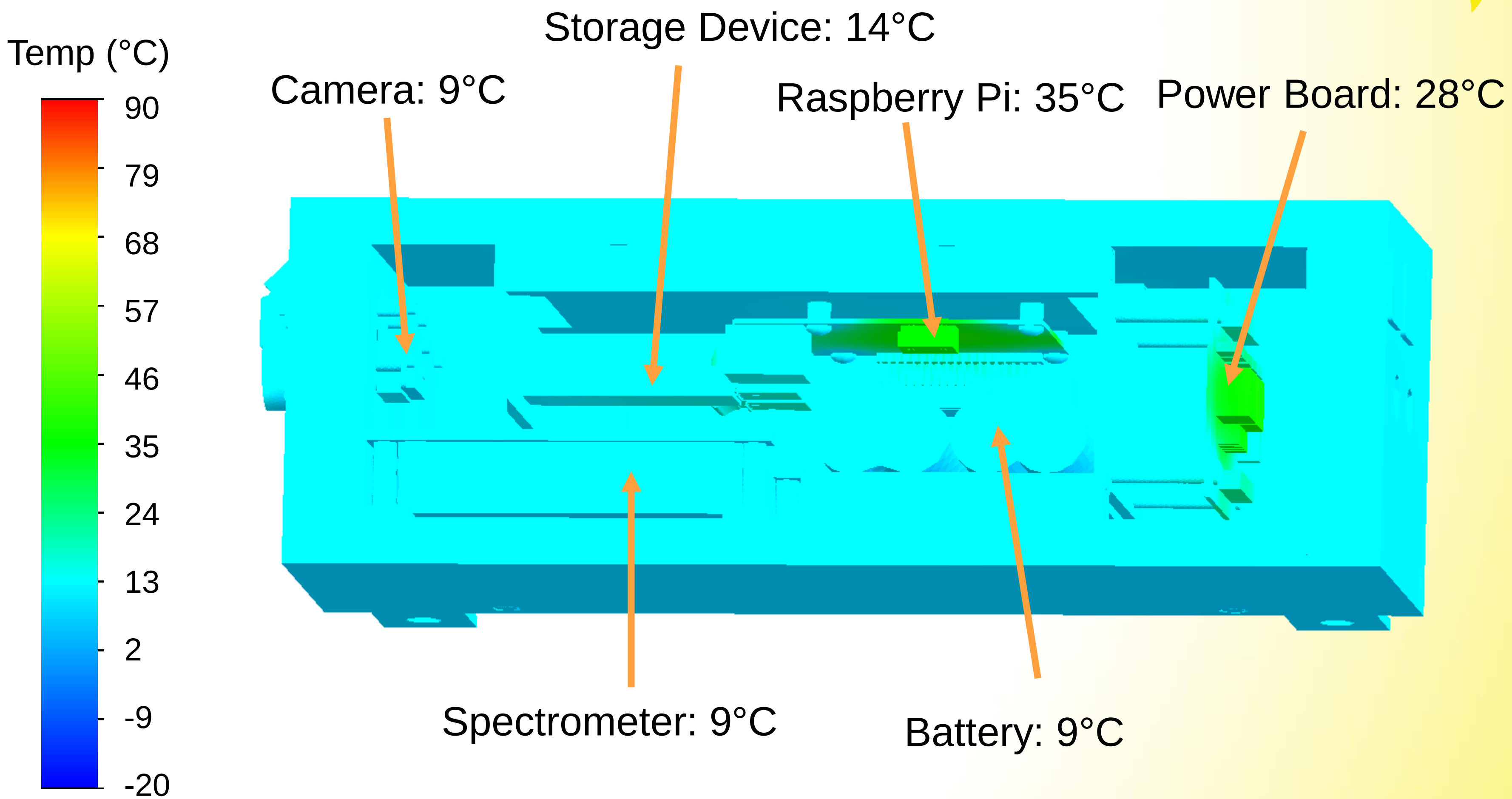
Thermal Analysis

Active control, during ascent, transient model



Thermal Analysis

Passive control, during cruise, steady state model



Power Motivation

FR5: The system shall interface with the HiWind gondola

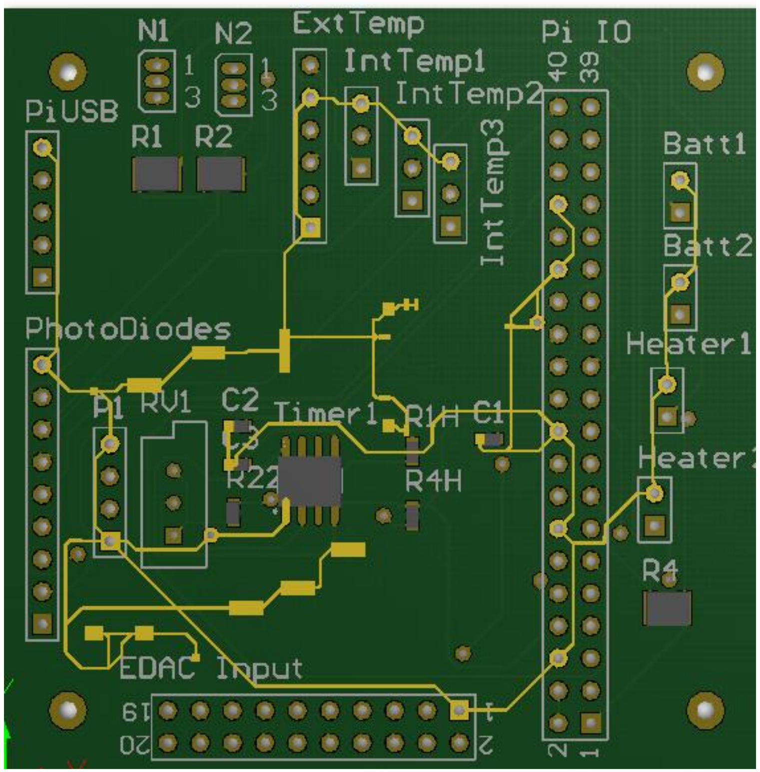
→

DR5.4: The system shall interface with the HiWind power line

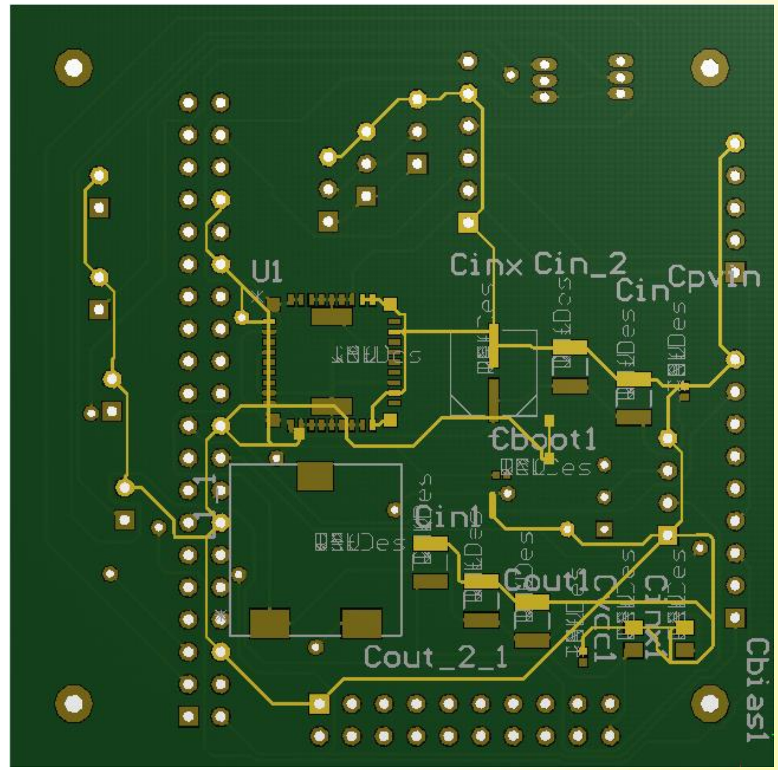
Requirement	Description
5.4.1	System shall not interfere with HiWind
5.4.2	System shall accommodate a 15W power supply
5.4.3	System shall accommodate a 26-28V supply
5.4.4	System shall accommodate an approximately 0.5A supply

- Must distribute power to subsystems

Power Board Design

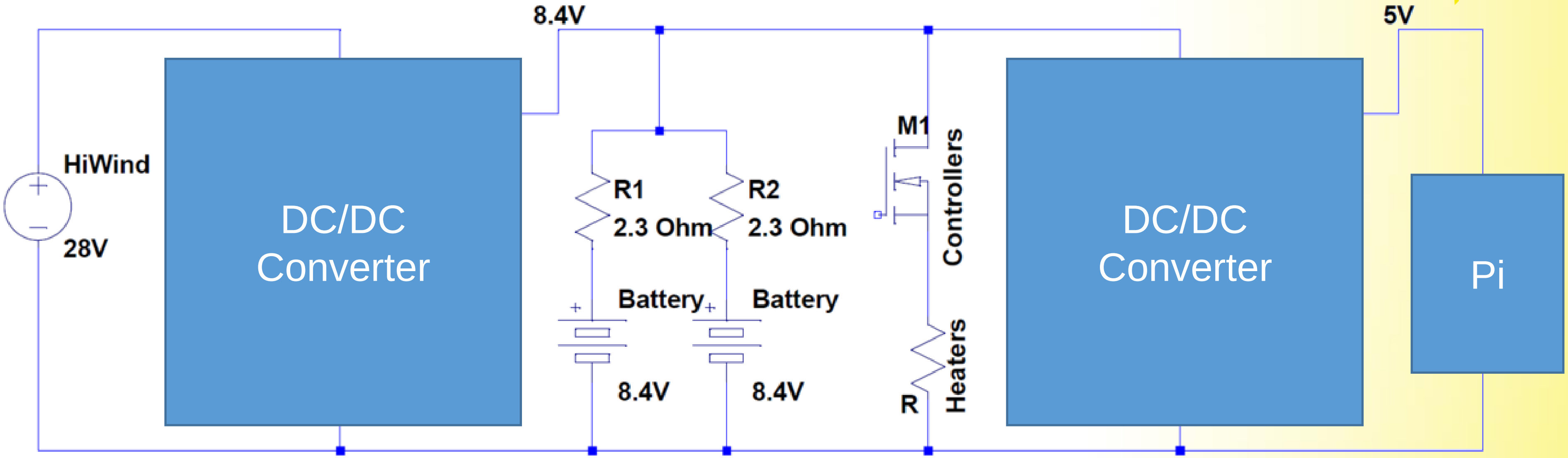


Front



Back

Power Board



- 8.4V line for batteries and heaters
  - Optimal charging and discharging
  - Minimize losses
- 5V line required for Raspberry Pi
- Heritage with QB50

Power Budget

Component	Nominal/Peak Power Draw	
Raspberry Pi	4.25 W	6.7 W
Spectrometer	1.25 W	1.3 W
Camera	0.7 W	0.7 W
Additional Sensors	0.1 W	0.1 W
Flash Drive (x3)	1.4 W	1.4 W
Heaters	4.7 W	9.4 W
Total	**12.4 W**	**19.6 W**
Limits	99.0 W	99.0 W
Margin	**87%**	**80%**

- **Nominal: Cruise Condition**
  - Sensors, spectrometer, flash drives, microcontroller, and **ONE** heater
- **Max Draw: Ascent**
  - Sensors, spectrometer, flash drives, microcontroller, and **TWO** heaters

Power Losses

HiWind

Batteries
Heaters

RPi

94% Efficiency

95% Efficiency

15 W → DC-DC #1 → 14.1 W → DC-DC #2 → 13.4 W

28 Volts
15 Watts
0.54 Amperes

8.4 Volts
14.1 Watts
1.68 Amperes

5 Volts
13.4 Watts
2.68 Amperes

C&DH Motivation

FR3: The system shall return data

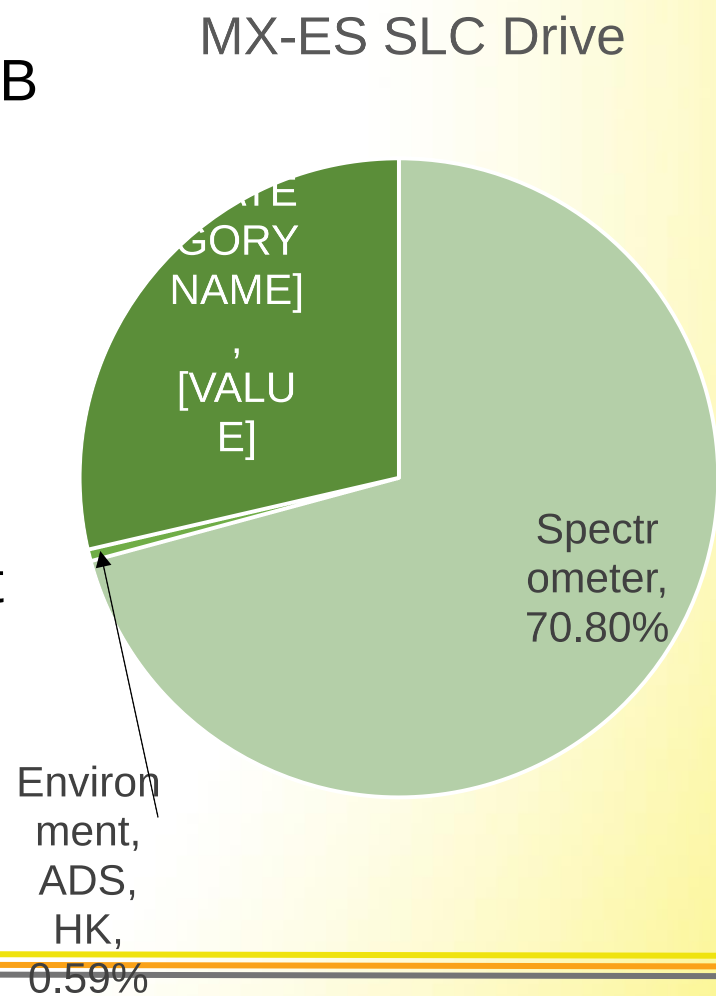
Requirement	Description
3.1.1	System shall record science data at least once per minute
3.1.2	Science measurements shall be recorded within 2 seconds of each other
3.1.3	Images shall be recorded once per minute

C&DH Overview

- Microcontroller: Raspberry Pi 3 Model B
  - High altitude ballooning and CubeSat heritage
  - Avantes library interfaces directly
  - Simple and robust camera interface
  - Safety features
    - Watchdog timer with autonomous reset
    - Current and voltage limitations

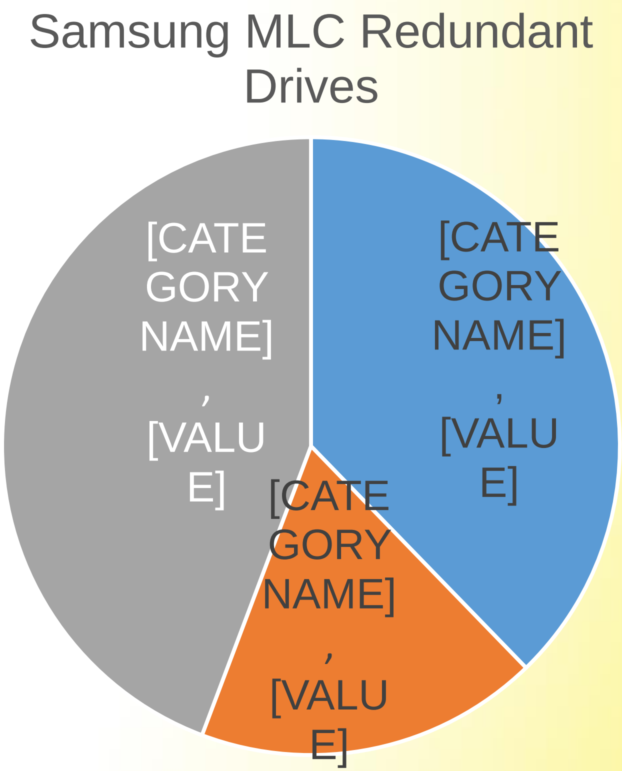
Data Storage — SLC Drive

- MX-ES 16 GB SLC Drive
  - 14.9 GB available, using 11 GB
  - Resistant to radiation/SEUs
- Spectrometer data
  - 10 kB per spectra @ 1 Hz
- Housekeeping, environmental, ADS
  - 4 byte or 8 byte measurement @ 1 Hz

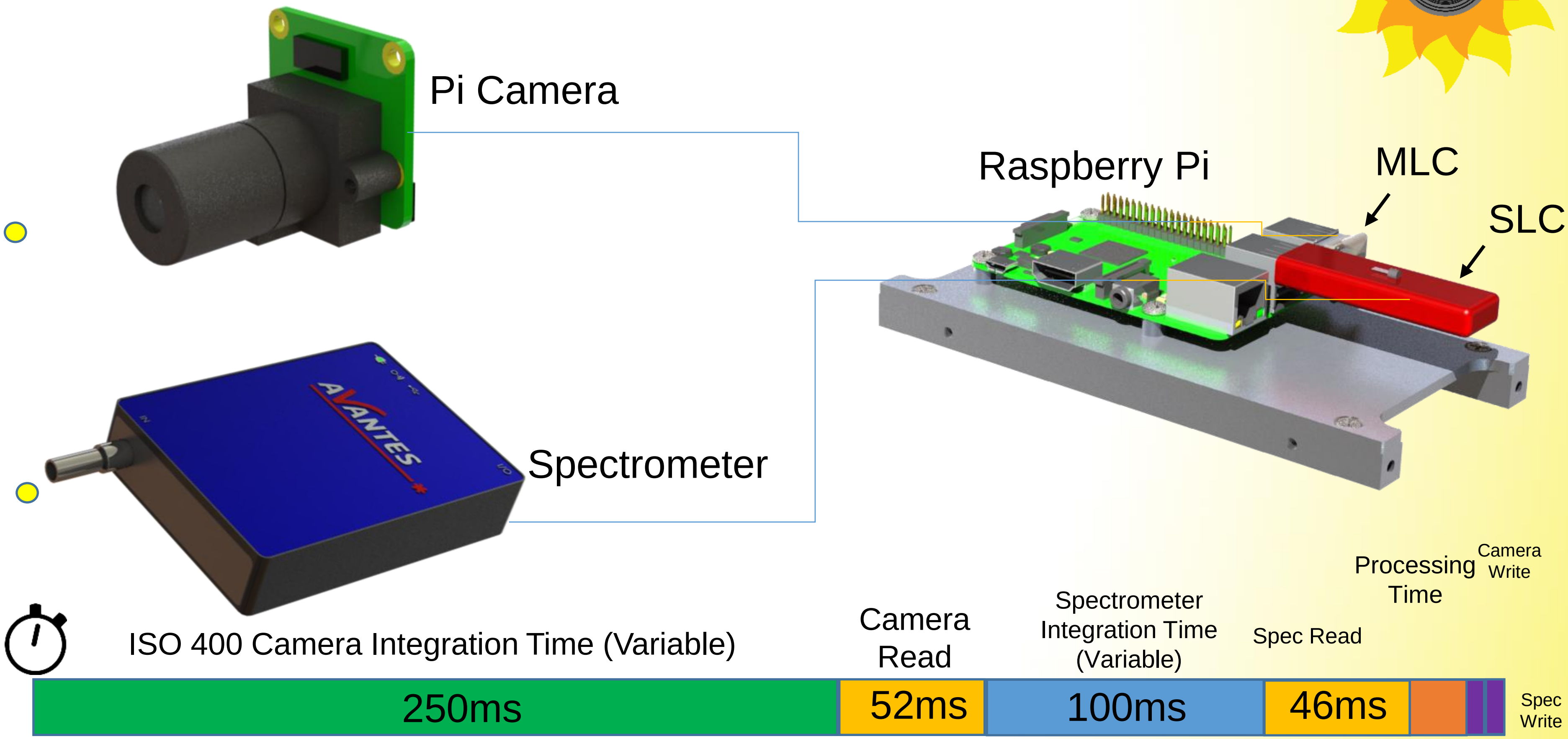


Data Storage — MLC Drives

- Samsung Fit MUF-64BB
  - 59.6 GB available
  - Redundant
- Camera images
  - 1.8 MB per image (with safety factor of 2)
  - One image every minute



Mock Data Test



Previous Estimate
Time: 0.613 s

Current Model
Time: 0.491 s

Mock Data Test

Assumptions

- No heating
- No housekeeping/environmental sensors
- Measurement times based on ground data

Test criteria: Inspection of spectrum and images

Previous Estimate
Time: 0.613 s

→

Current Model
Time: 0.491 s

Worst case margin is half a second!

ADS Motivation

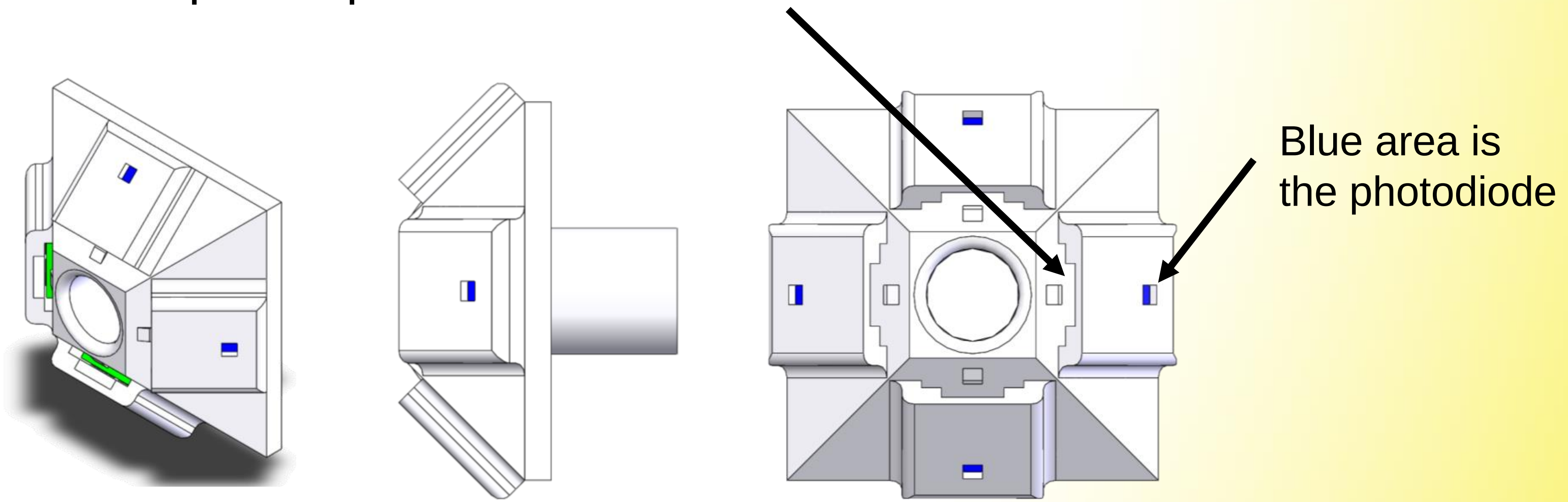
FR4: The system shall determine its attitude

Requirement	Description
4.1	Off-sun angle shall be determined within one arc-minute
4.2	Data shall be recorded synchronously with other data

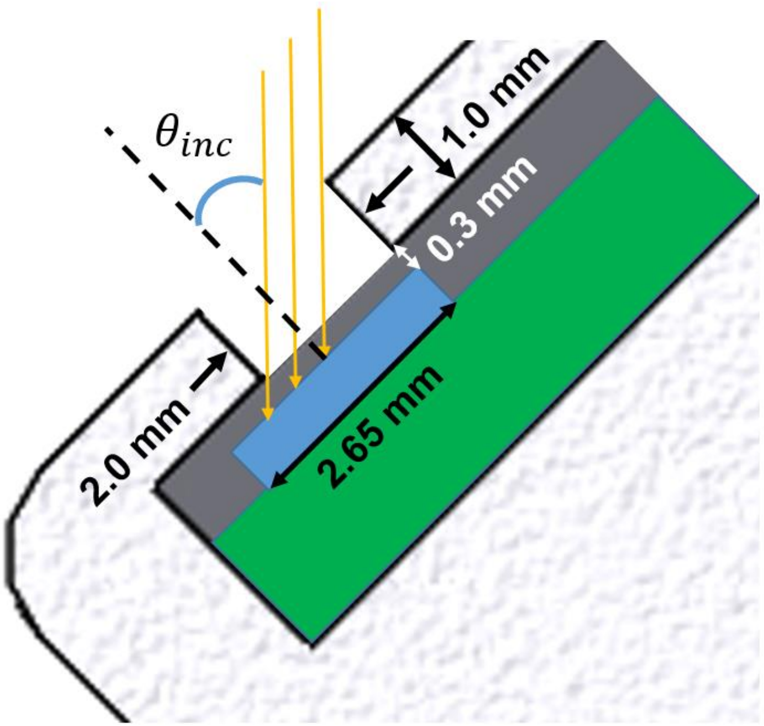
- Off sun angle needed to corroborate with spectrum data

Off-Sun Angle Determination

- MinXSS heritage
- Array of four photodiodes
  - Off-set at 45° from each other
  - Circuit board with photodiode slides into array mount
  - Square aperture



ADS Aperture Motivation



- Active area of PDB-C160SM photodiode proportional to incidence angle
- At ~59° incidence angle, light “misses” the photodiode → 14° FOV

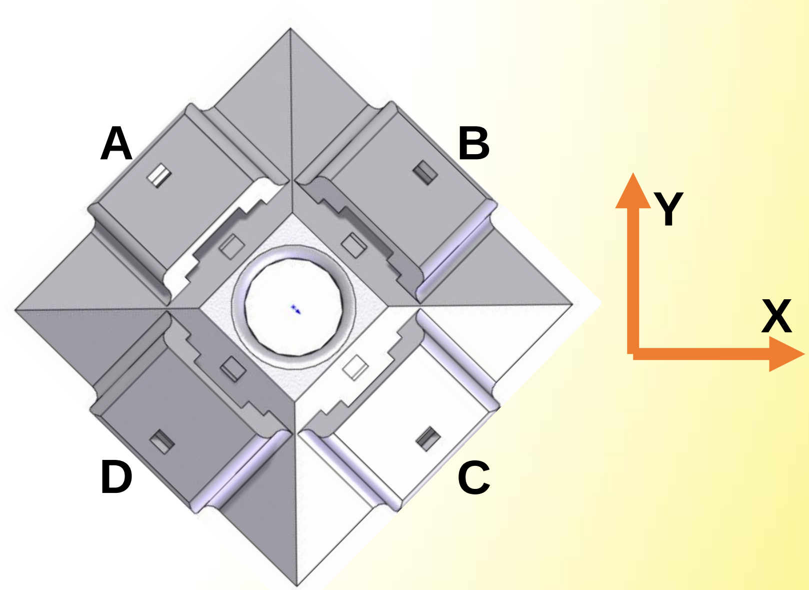
ADS Algorithm

- Utilizing algorithm used by MinXSS
  - Component of sun angle in +X and +Y directions computed by relative current in the photodiodes
  - Calibration factor *f* equal to conversion from DN to current divided by field of view (+/- 14°)

$$x = f\frac{(I_B + I_C) - (I_A + I_D)}{\Sigma I_i}$$

$$y = f\frac{(I_A + I_B) - (I_C + I_D)}{\Sigma I_i}$$

$$\theta_{sun} = \sqrt{x^2 + y^2}$$



Camera Motivation

FR6: The system shall take images of the sun in the visible spectrum

Requirement	Description
6.1	Images shall be stored
6.2	FOV should be 5° ± 3°
6.3	System shall take images once per minute

- Camera images provide context for spectrometer data

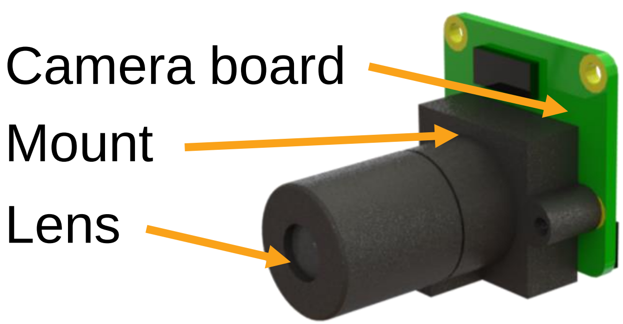
Camera

Field of View Calculation

Known parameters:

Default FOV $= 53.5°$ $\quad h = 2.76$ mm
Sun $= 0.5°$ $\quad f = 25$ mm

$$\text{FOV} = 2\tan^{-1}\left(\frac{h}{2f}\right) = \boxed{6.32°}$$



Neutral Density Filter Calculation

Flux on Ground $= 1050\ \frac{\text{W}}{\text{m}^2}$
Flux at 40 km $= 1200\ \frac{\text{W}}{\text{m}^2}$

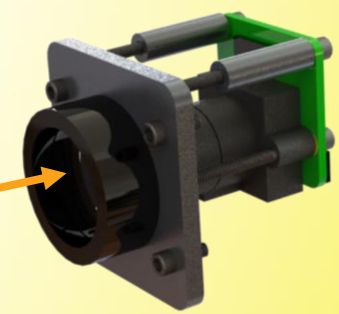
Using flux and size of the sun on the image sensor, find total power:

$$\begin{array}{ll} \text{Power on Ground:} & 6.986 \times 10^{-7}\ \text{W} \\ \text{Power at Cruise:} & 5.721 \times 10^{-5}\ \text{W} \end{array}$$

$$\frac{6.986 \times 10^{-7}\ \text{W}}{5.721 \times 10^{-5}\ \text{W}} = \boxed{1.22\%}$$

Result:

Choose filter with 96.875% attenuation (OD of 1.5)



Project Risks

Projects Risk Matrix

Likelihood	Consequences					
	Risks easily mitigated	1 FR Failed	2-3 FRs Failed	3-4 FRs Failed	5-6 FRs Failed	
Certain	H					5
Likely						4
Moderate		I, M				3
Unlikely		F, M		A, B, C, D		2
Rare		L	G	J	E, K	1
	1	2	3	4	5	

8 High Risk Elements

3 Moderate Risk Elements

Project Risks: High Risk

	Risk	Likelihood	Consequence	Total
A	Software Data Write Failure	1	2/4	2/8
B	Bit Flip	1	2/4	2/8
C	Drive Hardware Failure	2	2/4	4/8
D	Flash Drive Connection Failure	1	2/4	2/8
E	Overheating	1	5	5
H	Frost on Optics	5	1	5
K	Pi Software Failure	1	1/5	1/5

- A → Journaling
- B → SLC Drive
- C, D → Redundant Drives
- E → Thermal Model
- H → Clears in ~48 Hr
- K → Watchdog Timer

Project Risks: Moderate Risk

	Risk	Likelihood	Consequence	Total
G	Heater Failure	1	3	3
I	Temporary Power Failure	3	2/1	6/3
C	Camera Oversaturation	3/1	2	6/2

- Heater Failure → High Watt Heaters
- Temporary Power Failure → Automatic Pi Restart
- Camera Oversaturation → Neutral Density Filter

Verification & Validation

Verification Plan

Component Selection	Component Testing	Subsystem Testing	Integration Testing
Datasheets Operational, survival conditions Resolution	Component hardware DAQ Basic breadboard circuits Multimeter	Instruments: ENV/HK Sensors, Camera, Spectrometer C&DH: storage device, Raspberry Pi	All hardware and software integrated FlatSat TVAC Env. Chamber
Completed	Jan 30 - Feb 13	Feb 13 - Mar 6	Mar 9 - 20

TRR Due

Hard Testing End Date: Apr 7

Symposium: Apr 21

Functional Requirements

Take Solar Irradiance Measurements	Spectrometer Calibration
Survive Environmental Conditions	TVAC, Environmental Chamber
Return Data	FlatSat, Datasheet Inspection
Determine Off-Sun Angle	Photodiode Testing
Interface with HiWind	Inspection with ICD
Capture Images of the Sun	Camera Testing

Functional Requirements

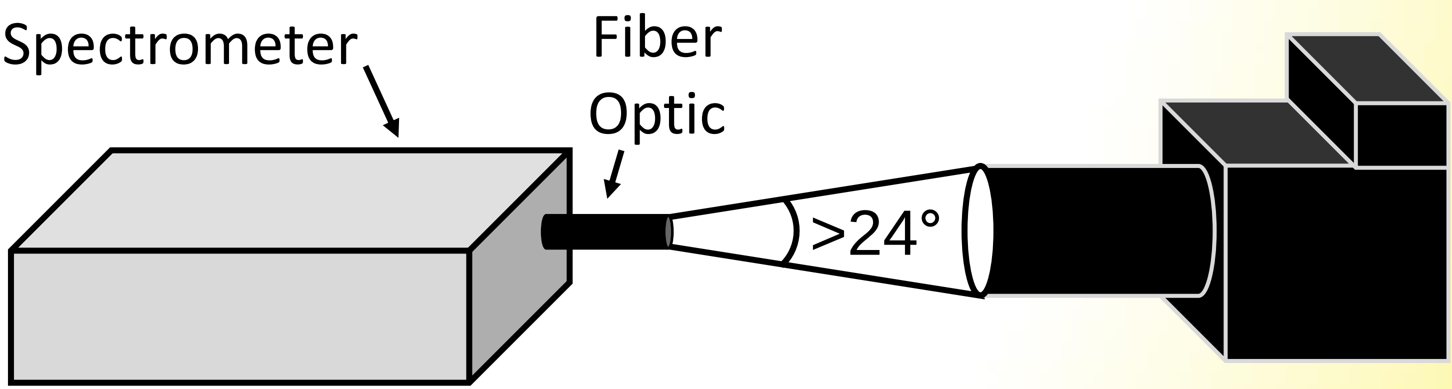
Take Solar Irradiance Measurements	Spectrometer Calibration
Survive Environmental Conditions	TVAC, Environmental Chamber
Return Data	FlatSat, Datasheet Inspection
Determine Off-Sun Angle	Photodiode Testing
Interface with HiWind	Inspection with ICD
Capture Images of the Sun	Camera Testing

Spectrometer Calibration

Verify spectrometer readings with known-output source

Verification Method: **TEST & ANALYSIS**

Keo *Alcor* Low-Brightness Source

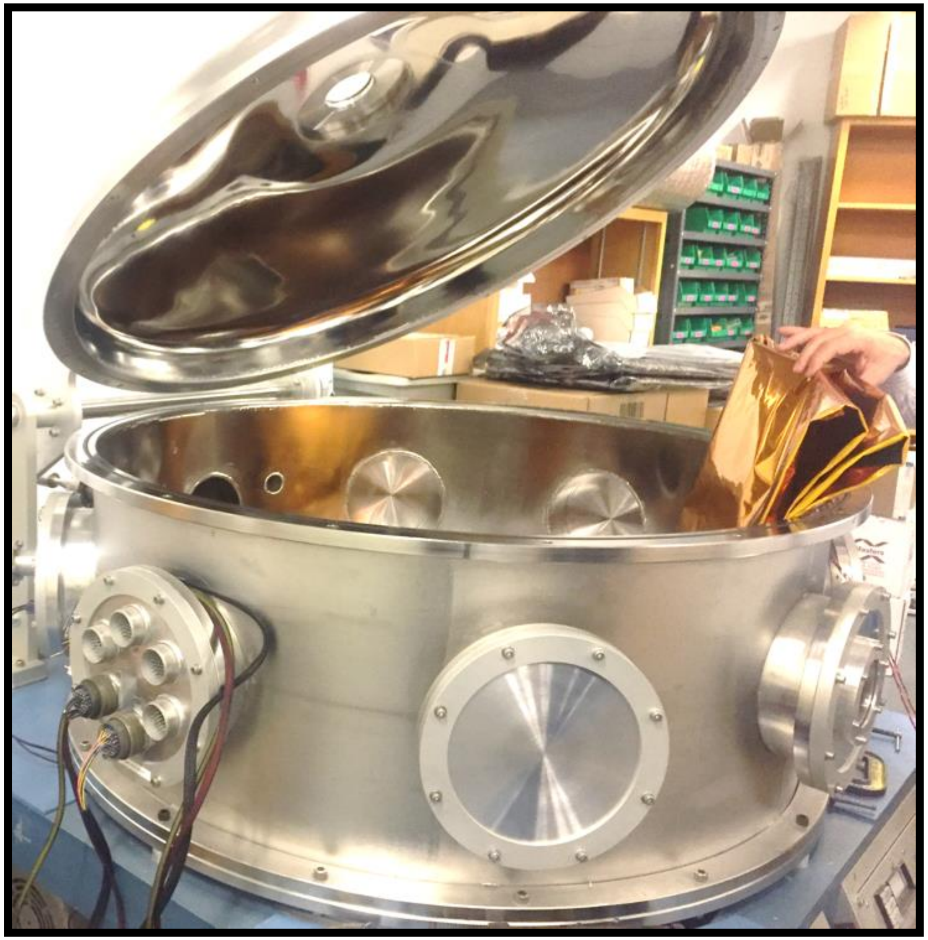


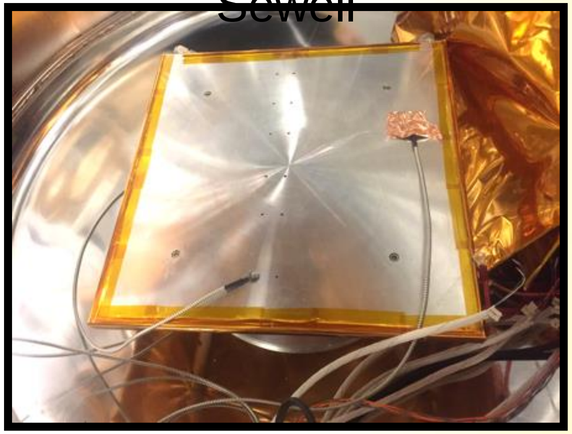
Calibration source provided by Dr. Bob Marshall

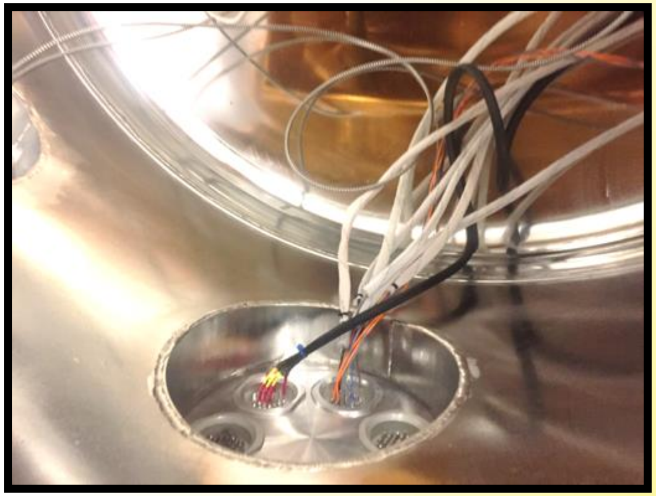
TVAC Testing

Validate thermal model at cruise conditions

TVAC facility provided by Dr. Scott Sewell







Environmental Chamber

Validate thermal model at most extreme ascent conditions

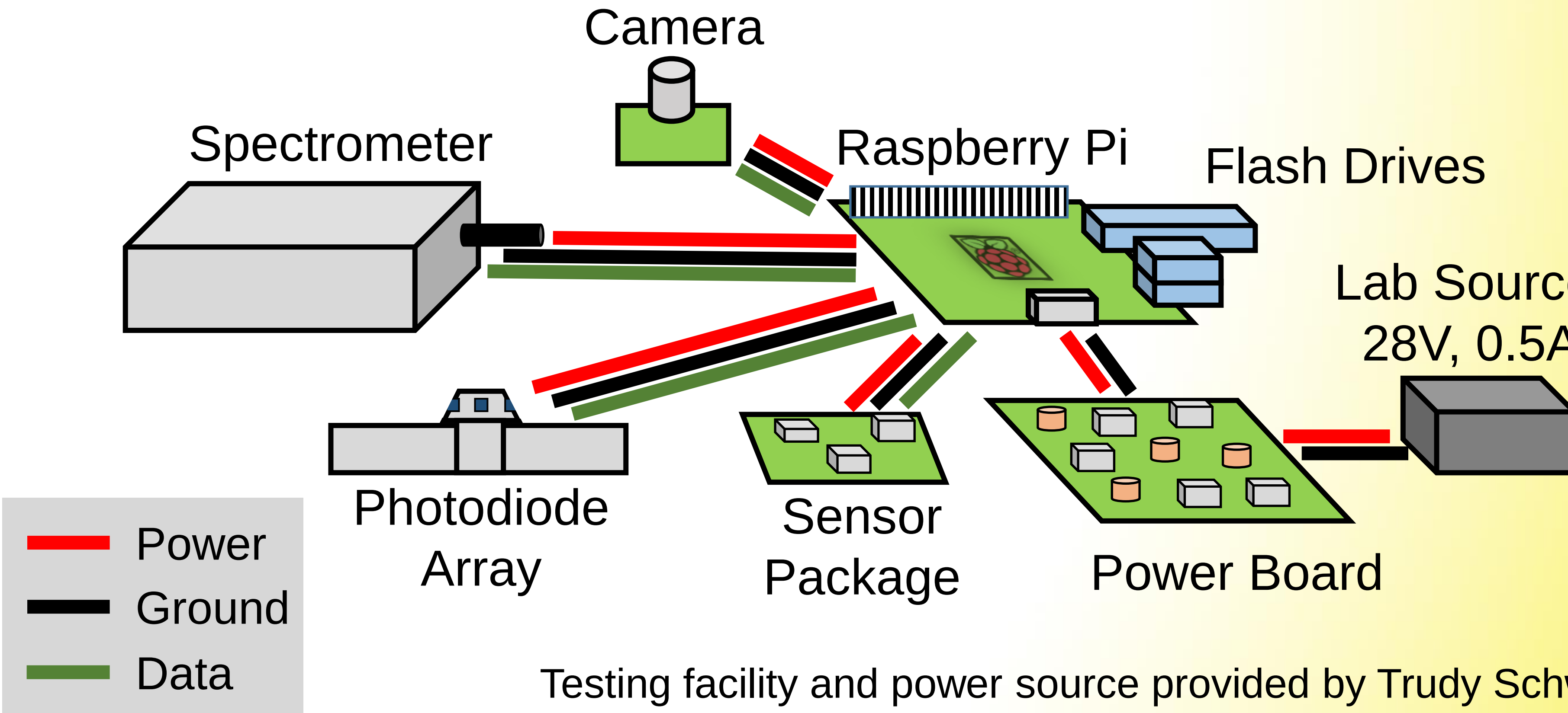
Russells Temperature Environmental Test Chamber

- Capable of temperatures down to -68°C
- Operates at ambient pressures
- Chamber size: 82 x 127 x 196 cm^3

Environmental chamber provided by Dr. James Nabity

FlatSat Integration Testing

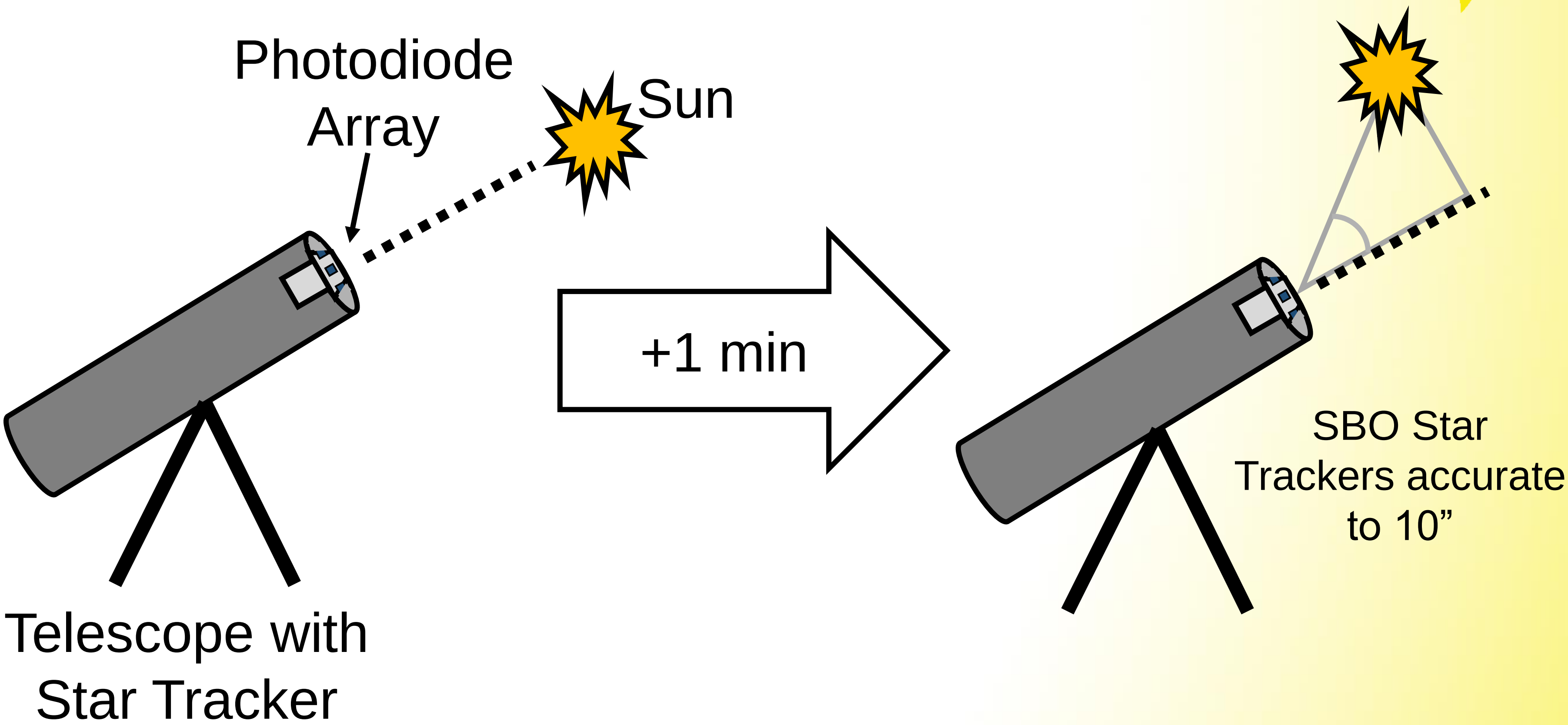
Validate data handling model
Verify interface and interoperation behavior
Verification Method: **TEST**



Testing facility and power source provided by Trudy Schwartz

Photodiode Testing

Validate photodiode angular determination model



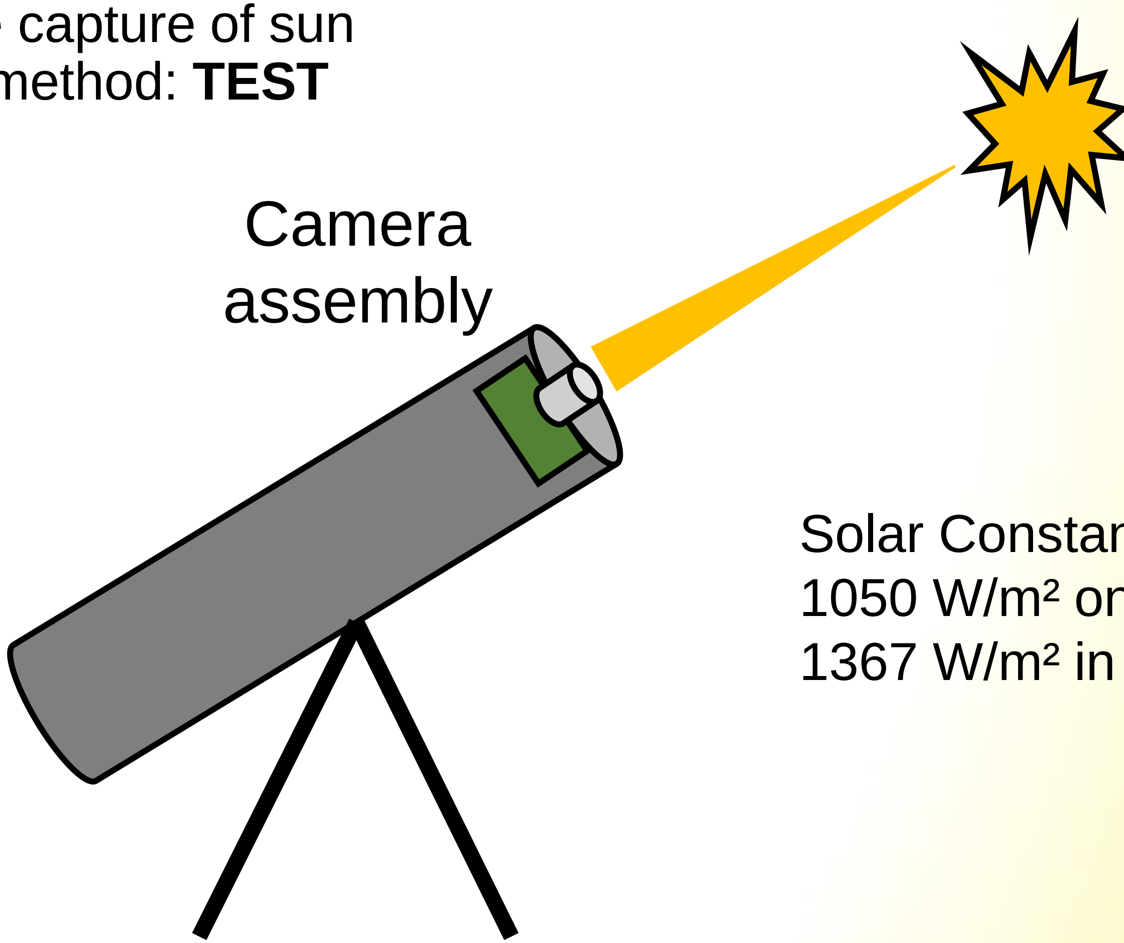
Telescope and star-tracking equipment provided by Fabio Mezzalira, SBO

Animation

- Angular rate of off-sun angle:
  - 0.232 arcmin/sec
  - 0.004 deg/sec
- STK simulation will be run for exact testing dates/times

Camera Testing

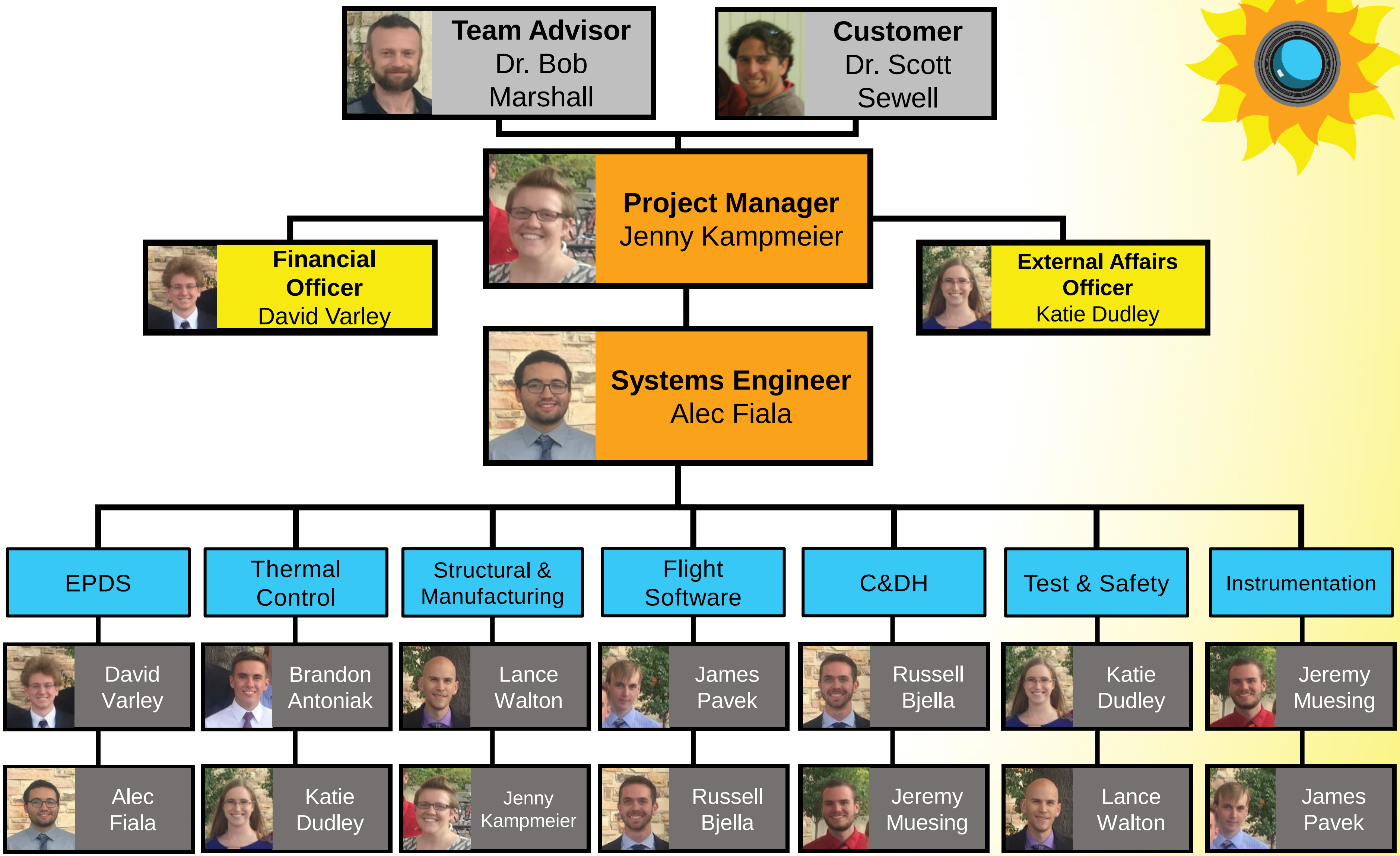
Verify image capture of sun
Verification method: **TEST**



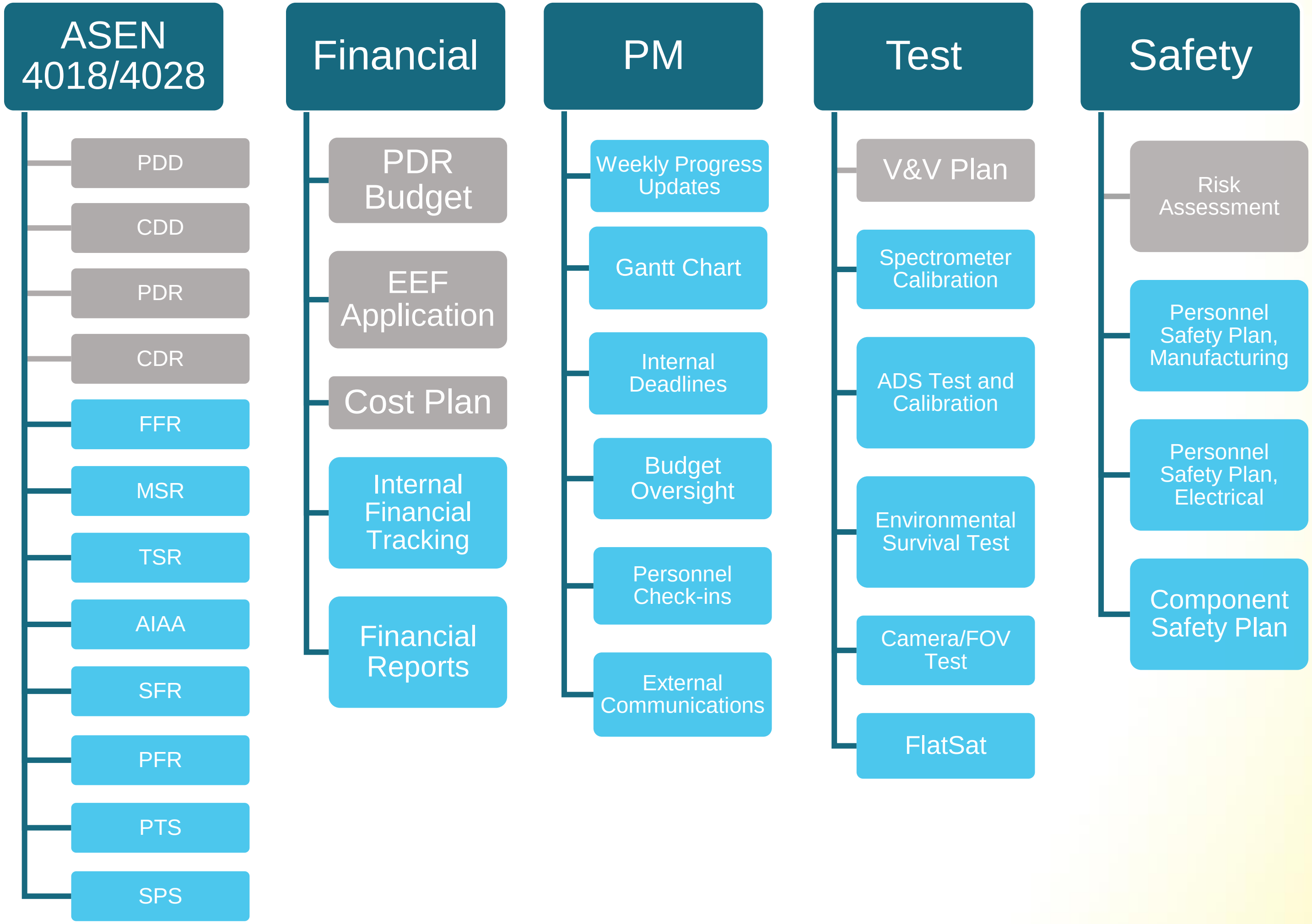
Solar Constant:
1050 W/m² on ground
1367 W/m² in space

Telescope and star-tracking equipment provided by Fabio Mezzalira, SBO

Project Planning & Remaining Work


Team Advisor
Dr. Bob Marshall
Customer
Dr. Scott Sewell
Project Manager
Jenny Kampmeier
Financial Officer
David Varley
External Affairs Officer
Katie Dudley
Systems Engineer
Alec Fiala
EPDS
David Varley
Alec Fiala
Thermal Control
Brandon Antoniak
Katie Dudley
Structural & Manufacturing
Lance Walton
Jenny Kampmeier
Flight Software
James Pavek
Russell Bjella
C&DH
Russell Bjella
Jeremy Muesing
Test & Safety
Katie Dudley
Lance Walton
Instrumentation
Jeremy Muesing
James Pavek

Work Breakdown Structure

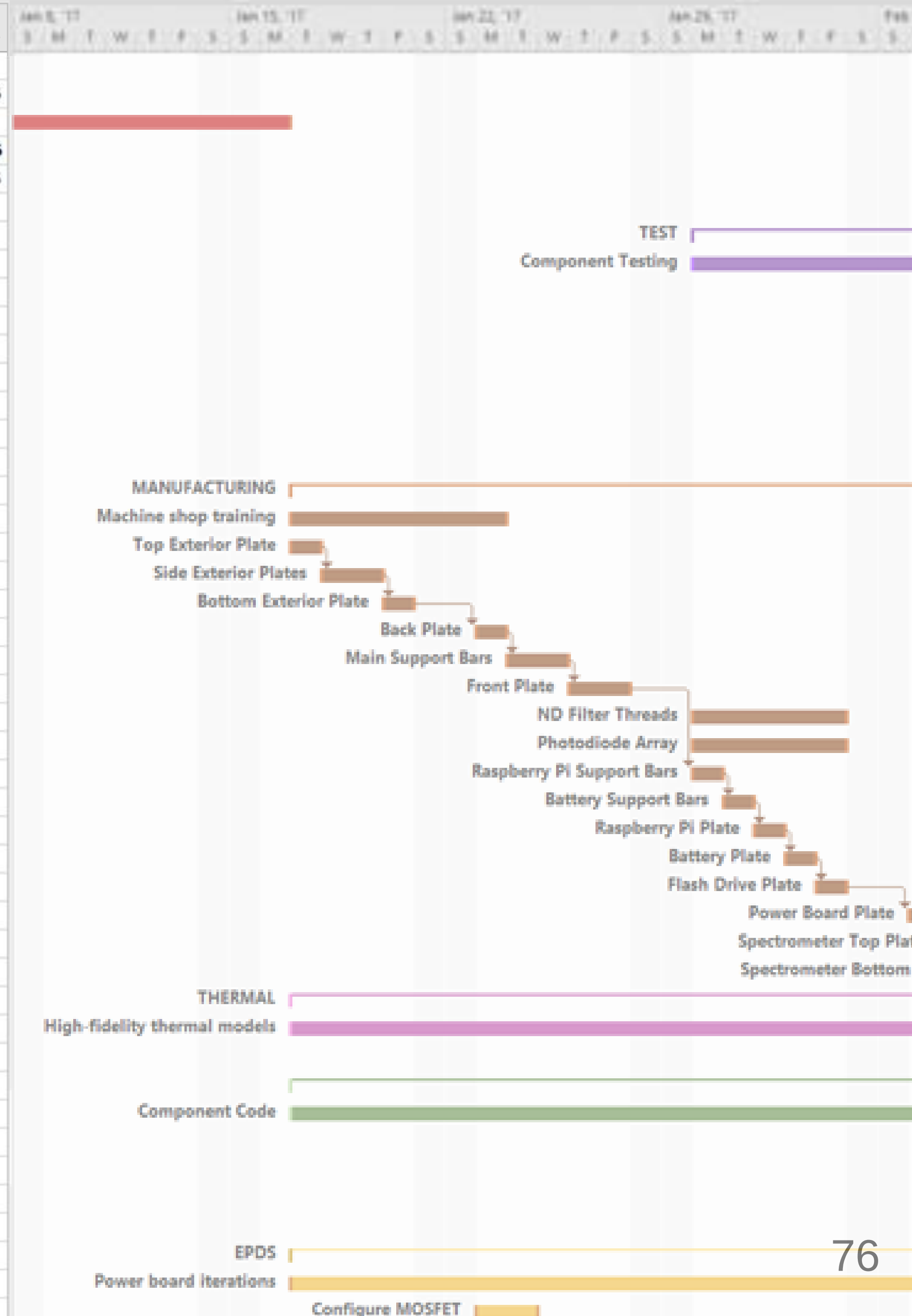


Work Breakdown Structure

- **EPDS**
  - Circuit Design
  - Circuit Models
  - PCB Design
  - PCB Iteration
  - Integration
- **C&DH**
  - RPi Interface Design
  - Data Volume Design
  - SEU Mitigation
  - Integration
- **Software**
  - Mock Data Flow System
  - Preliminary Flight Software
  - QA Testing
  - Final Flight Software
- **Instrumen-tation**
  - Sensor Package Design
  - Spectrometer interface
  - Camera FOV Design
  - Sensor Integration
  - Camera Integration
- **Structures Manufacturing**
  - Initial CAD Model
  - Final CAD Model
  - Manufacturing Schedule
  - Bill of Materials
  - Components constructed
  - Integration
- **Thermal**
  - 1D Thermal Model
  - CAD Model, Steady State, Passive
  - CAD Model, Steady State, Active
  - CAD Model, Transient, Passive
  - CAD Model, Transient, Active
  - High Fidelity Thermal Analysis

GANTT CHART

		Task Mode	Task Name	Duration	Start	Finish
1	✓		**EEF Proposal**	**13 days**	**Tue 10/11/16**	**Fri 10/28/16**
9	✓		**CDR**	**36 days**	**Mon 10/10/16**	**Mon 11/28/16**
36			Winter Break	22 days	Fri 12/16/16	Mon 1/16/17
37			**FFR**	**2 days**	**Tue 11/29/16**	**Wed 11/30/16**
38			Create outline	2 days	Tue 11/29/16	Wed 11/30/16
39			<New Task>			
40			**TEST**	**49 days**	**Mon 1/30/17**	**Fri 4/7/17**
41			Component Testing	11 days	Mon 1/30/17	Sun 2/12/17
42			Subsystem Testing	16 days	Mon 2/13/17	Sun 3/5/17
43			Test Status Review	0 days	Mon 3/6/17	Mon 3/6/17
44			Integration Testing	11 days	Mon 3/6/17	Sun 3/19/17
45			TVAC	2 days	Wed 3/8/17	Thu 3/9/17
46			Environmental Chamber	1 day	Tue 3/14/17	Tue 3/14/17
47			FlatSat	2 days	Sat 3/18/17	Sun 3/19/17
48			Internal Test Deadline	0 days	Fri 4/7/17	Fri 4/7/17
49			**MANUFACTURING**	**18 days**	**Tue 1/17/17**	**Thu 2/9/17**
50			Machine shop training	5 days	Tue 1/17/17	Mon 1/23/17
51			Top Exterior Plate	1 day	Tue 1/17/17	Tue 1/17/17
52			Side Exterior Plates	2 days	Wed 1/18/17	Thu 1/19/17
53			Bottom Exterior Plate	1 day	Fri 1/20/17	Fri 1/20/17
54			Back Plate	1 day	Mon 1/23/17	Mon 1/23/17
55			Main Support Bars	2 days	Tue 1/24/17	Wed 1/25/17
56			Front Plate	2 days	Thu 1/26/17	Fri 1/27/17
57			ND Filter Threads	5 days	Mon 1/30/17	Fri 2/3/17
58			Photodiode Array	5 days	Mon 1/30/17	Fri 2/3/17
59			Raspberry Pi Support Bars	1 day	Mon 1/30/17	Mon 1/30/17
60			Battery Support Bars	1 day	Tue 1/31/17	Tue 1/31/17
61			Raspberry Pi Plate	1 day	Wed 2/1/17	Wed 2/1/17
62			Battery Plate	1 day	Thu 2/2/17	Thu 2/2/17
63			Flash Drive Plate	1 day	Fri 2/3/17	Fri 2/3/17
64			Power Board Plate	1 day	Mon 2/6/17	Mon 2/6/17
65			Spectrometer Top Plate	1 day	Tue 2/7/17	Tue 2/7/17
66			Spectrometer Bottom Plate	2 days	Wed 2/8/17	Thu 2/9/17
67			**THERMAL**	**48 days**	**Tue 1/17/17**	**Thu 3/23/17**
68			High-fidelity thermal models	29 days	Tue 1/17/17	Fri 2/24/17
69			Thermal Report	5 days	Sun 3/19/17	Thu 3/23/17
70			**Software**	**62 days**	**Tue 1/17/17**	**Wed 4/12/17**
71			Component Code	20 days	Tue 1/17/17	Mon 2/13/17
72			Photodiode Algorithm	5 days	Tue 2/14/17	Mon 2/20/17
73			Data Handling Algorithm	10 days	Tue 2/21/17	Mon 3/6/17
74			Integrated Software	20 days	Tue 3/7/17	Mon 4/3/17
75			QA Testing	7 days	Tue 4/4/17	Wed 4/12/17
76			**EPDS**	**28 days**	**Tue 1/17/17**	**Thu 2/23/17**
77			Power board iterations	21 days	Tue 1/17/17	Tue 2/14/17
78			Configure MOSFET	2 days	Mon 1/23/17	Tue 1/24/17



Cost Plan

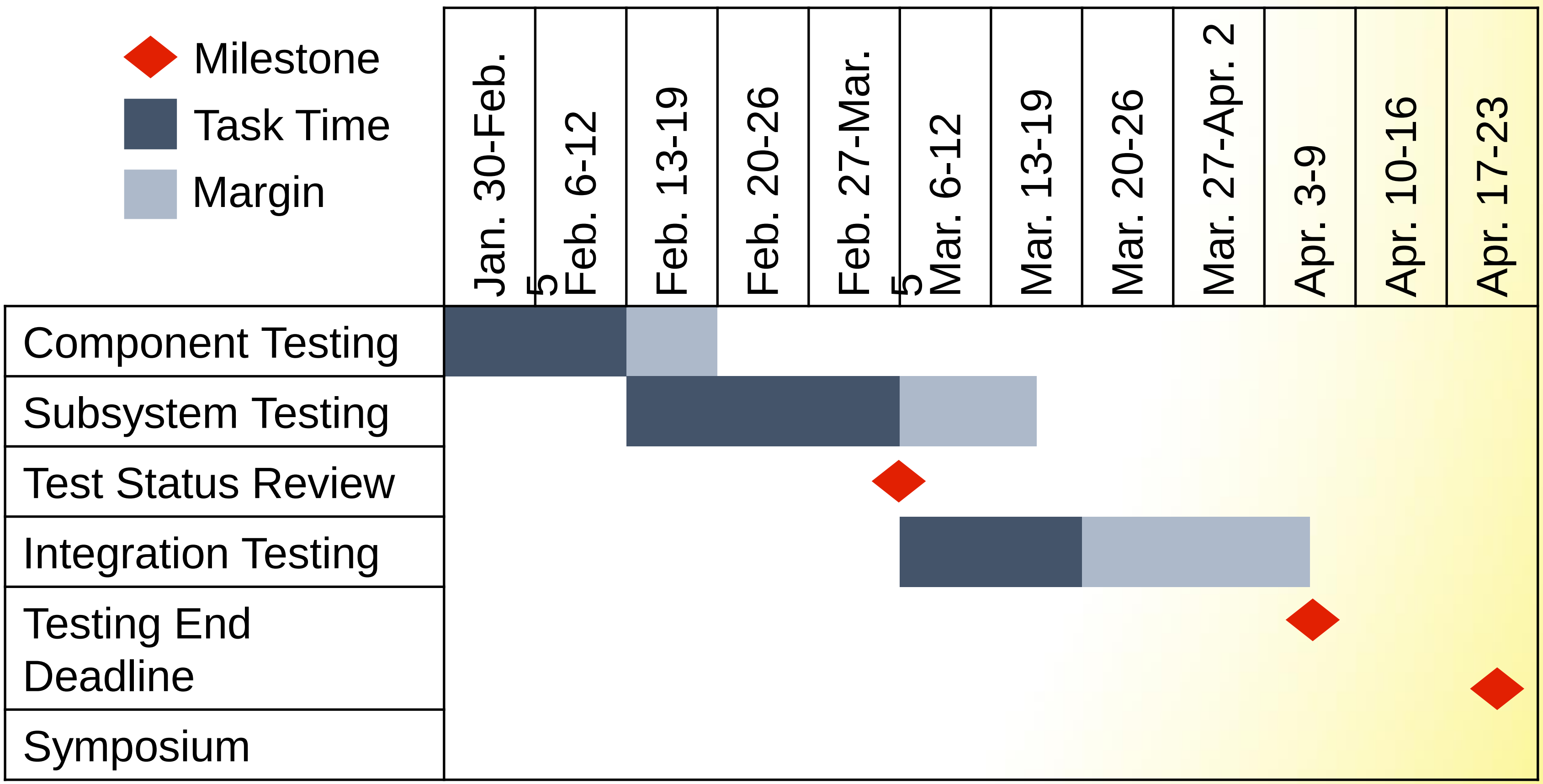
	Cost	Margin	%
Purchased	$55	$0	0%
Spectrometer	$2947	$0	0%
Components with no Margin	$119	$0	0%
Remaining Components	$1446	$362	25%
Total	$4567	$362	8%
Total w/ Margin	**$4929**		

No margin required

Component	Lead Time
Metal	1 Week
Spectrometer	3 Weeks

All other components are COTS

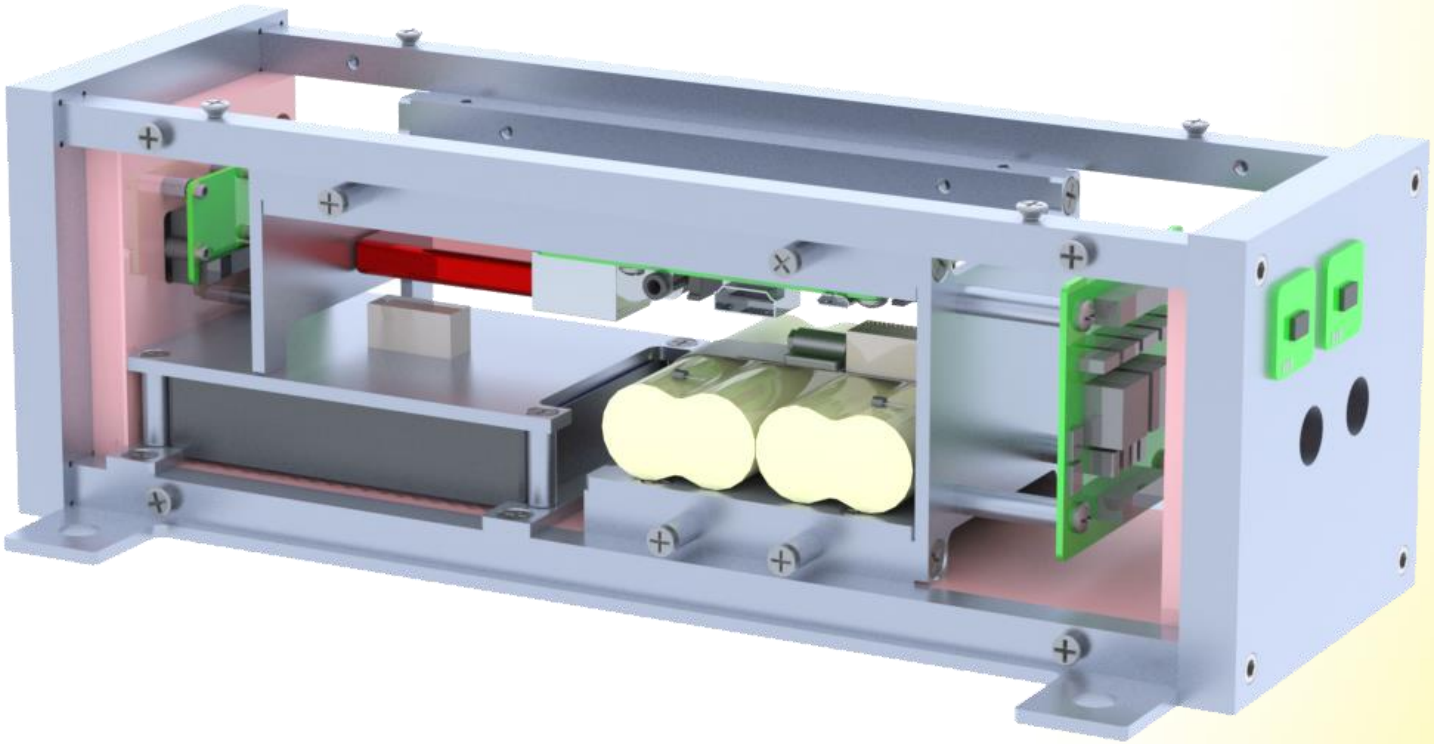
Test Plan



Milestone
Task Time
Margin
Jan. 30-Feb. 5
Feb. 6-12
Feb. 13-19
Feb. 20-26
Feb. 27-Mar. 5
Mar. 6-12
Mar. 13-19
Mar. 20-26
Mar. 27-Apr. 2
Apr. 3-9
Apr. 10-16
Apr. 17-23
Component Testing
Subsystem Testing
Test Status Review
Integration Testing
Testing End Deadline
Symposium

Thank you!

We welcome your feedback!



BACKUP

References

[1] Irom, Farokh, Duc N. Nguyen, and Gregory R. Allen. "Single Event Effect and Total Ionizing Dose Results of Highly Scaled Flash Memories." 2013 IEEE Radiation Effects Data Workshop (REDW) (2013): n. pag. Web.

[2] Powers, Charles E., and Stephen Waterbury. "Outgassing Data for Selecting Spacecraft Materials System." National Aeronautics and Space Administration. N.p., 13 Jan. 2016. Web. 15 Nov. 2016.

[3] Zwicker, Andrew P., Josh Bloom, Robert Albertson, and Sophia Gershman. "The Suitability of 3D Printed Plastic Parts for Laboratory Use." American Journal of Physics 83.3 (2015): 281-85. Web.

[4] Fluitt, Daniel. "Feasibility Study Into the Use of 3D Printed Materials in CubeSat Flight Missions." (2012): n. pag. Web. 14 Nov. 2016.

Image Credits

LASP Irradiance Data - http://spot.colorado.edu/~koppg/TSI/Publications/2007_Kopp_TRF_SPIE.pdf

HiWind Gondola Photos - http://stratocat.com.ar/globos/fotos/hiwind11b.jpg

HiWind CAD Models - Email from HAO-NCAR

Raspberry Pi - http://uk.rs-online.com/web/p/processor-microcontroller-development-kits/8968660/

SEU Chart – "Single Event Effect and Total Ionizing Dose Results of Highly Scaled Flash Memories."[1]

SLC – http://mx-technology.com/h5/en/flash2.php?sid=38

MLC - https://www.amazon.com/dp/B013CCTNKU/ref=twister_B0148N1COC?_encoding=UTF8&psc=1

Environmental Chamber – User's Manual G-Series Elite Family

EDAC - http://www.markertek.com/product/edac-106/edac-elco-516-020-000-402-20-pin-male-plug-with-fixed-nut

Battery - http://www.all-battery.com/li-ion1865072v3350mahbatterypcbmodulewith24awgbareleads-34042.aspx

Avantes Spectrometer - http://www.avantes.com/products/spectrometers/compactline/item/723-avaspec-mini

Calibration Equipment – Alcor User's Manual

Humidity Sensor – http://www.digikey.com/product-detail/en/te-connectivity-measurement-specialties/HPP804B130/HPP804B130-ND/697732

Temperature Sensor – https://www.sparkfun.com/products/11931

Pi Header - http://www.raspberrypi-spy.co.uk/2014/07/raspberry-pi-b-gpio-header-details-and-pinout/

Image Credits

Resistor - http://www.digikey.com/product-detail/en/riedon/PF1262-15RF1/696-1682-5-ND/2447965

Foam - https://www.grainger.com/product/GRAINGER-APPROVED-Foam-Sheet-5GCT5?functionCode=P2IDP2PCP

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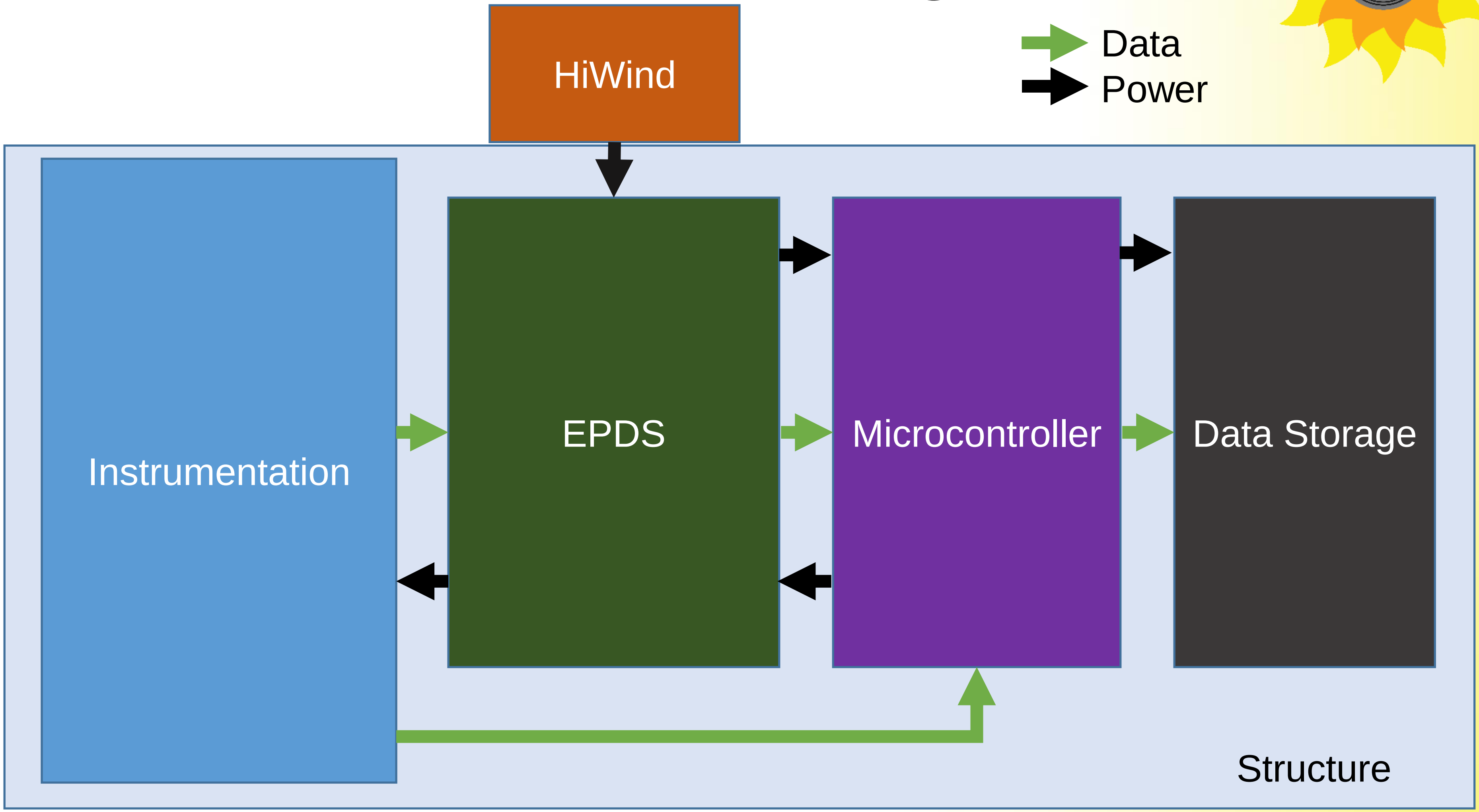
Table of Contents

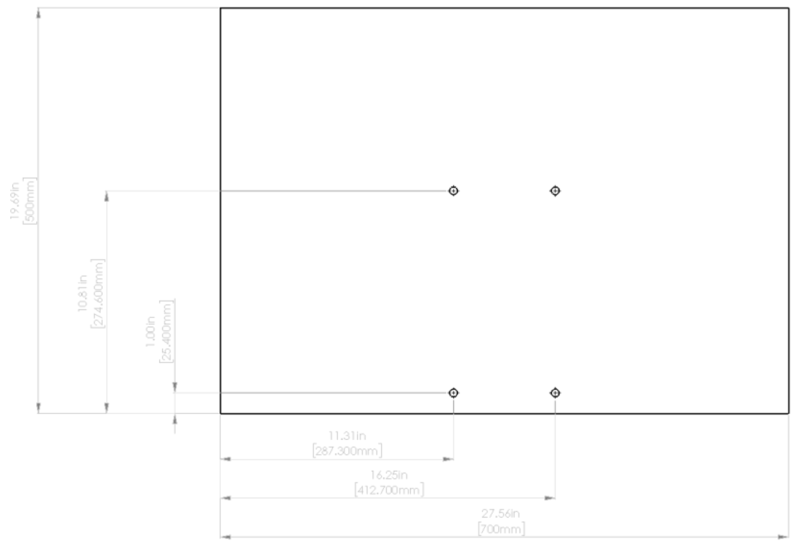
FlatSat Testing Plan

Shift	Person	Shift	Person
Fri 16:00-20:00	Katie	Sat 16:00-20:00	Jenny
Fri 20:00-00:00	Lance	Sat 20:00-00:00	Jeremy
Sat 00:00-04:00	Brandon	Sun 00:00-04:00	Katie
Sat 04:00-08:00	Alec	Sun 04:00-08:00	Russell
Sat 08:00-12:00	James	Sun 08:00-12:00	Jenny
Sat 12:00-16:00	Russell	Sun 12:00-16:00	Lance

Functional Block Diagram



Interface with HiWind



- Structure to be mounted with four 3/8 inch bolts
- Mounted normal to HiWind's solar panels

Risk	Cause	Mitigation
Critical Mechanical Interface Failure	Catastrophic failure of the mounting system	Use of locking bolts, and bolts rated at high loadings than expected.
Angle Error on Installation	RADIANCE installed at an off angle from HiWind's sun pointing face	Bolt pattern on RADIANCE and HiWind to minimize rotation and mounting errors.

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HiWind Integration: Elec.

- Power received from HiWind
  - 15W at 28V
- EDAC 20 pin connector
  - Subject to change
  - Final connector type has yet to be determined from HiWind

Risk	Cause	Mitigation
Supply power failure	Power supply to RADIANCE is ended prematurely	RADIANCE draws off of battery as long as possible
Supply power interruption	Power to the RADIANCE system is temporarily interrupted	RADIANCE automatic restart when power resumes
Any voltage received or produced by the RADIANCE system that is outside the expected voltage input range	Errors in circuit design or unintentional changes to circuit configuration in flight.	Design proper circuit interface protection that prevents back current and power surges
Reverse current through electrical interface	Lack of protection circuitry on RADIANCE	Design of reverse current protection circuit
Critical RADIANCE battery failure	RADIANCE's Lithium ion battery, which can fail from improper charging or puncture	Proper circuit protection and structural design that minimizes sharp points of contact with the battery

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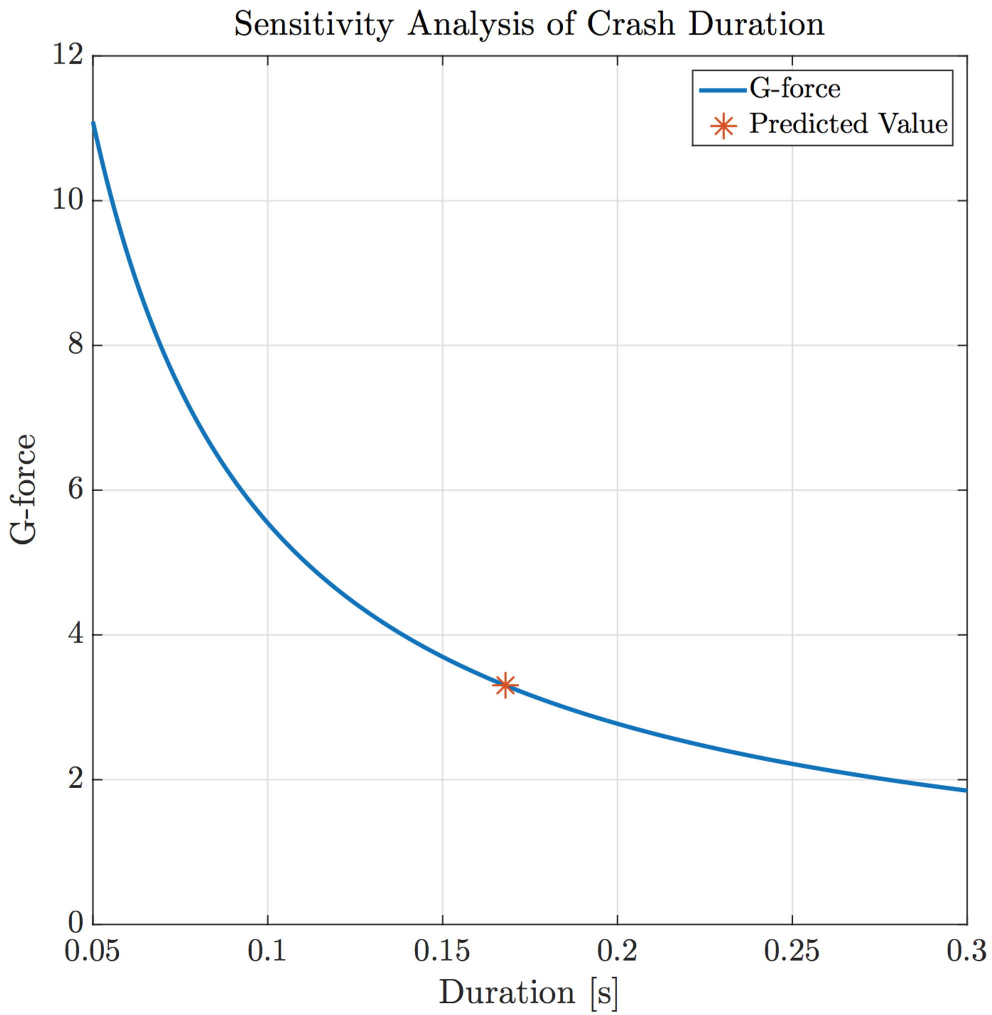
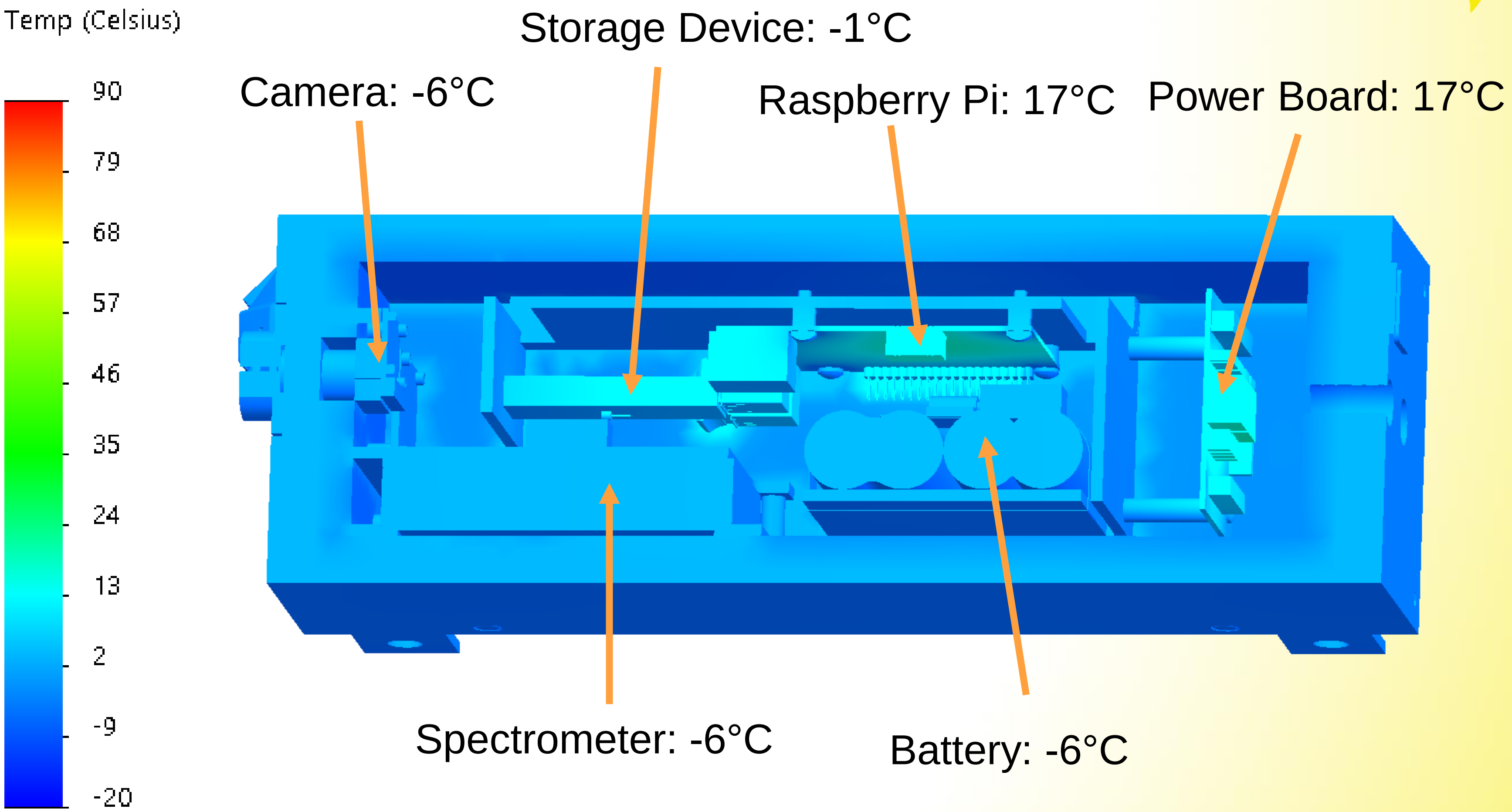
HiWind Landing Sensitivity



Thermal Analysis

Passive control, on the ground, steady state model



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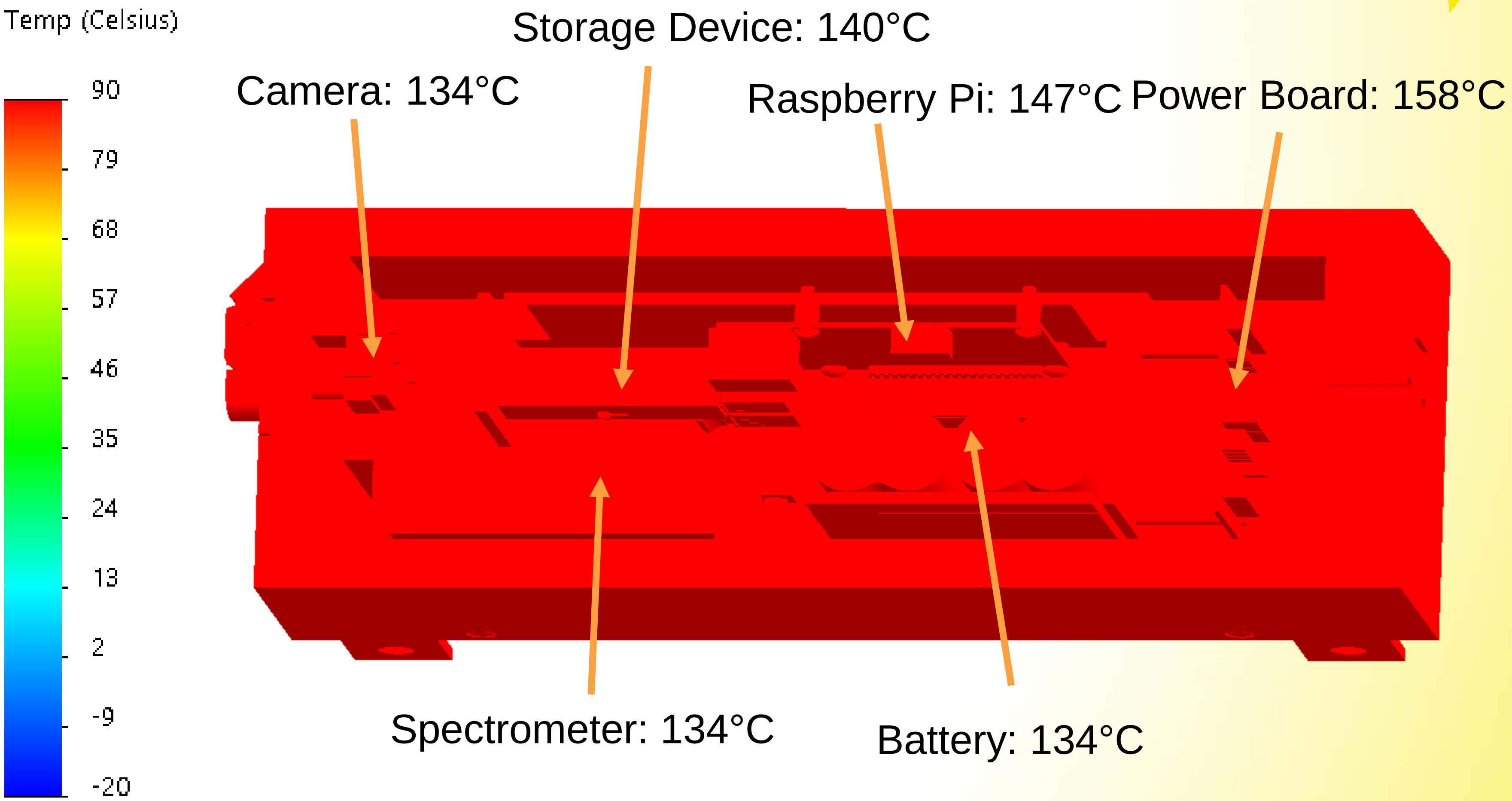
No Radiative Coating

Passive control, during cruise, steady state model



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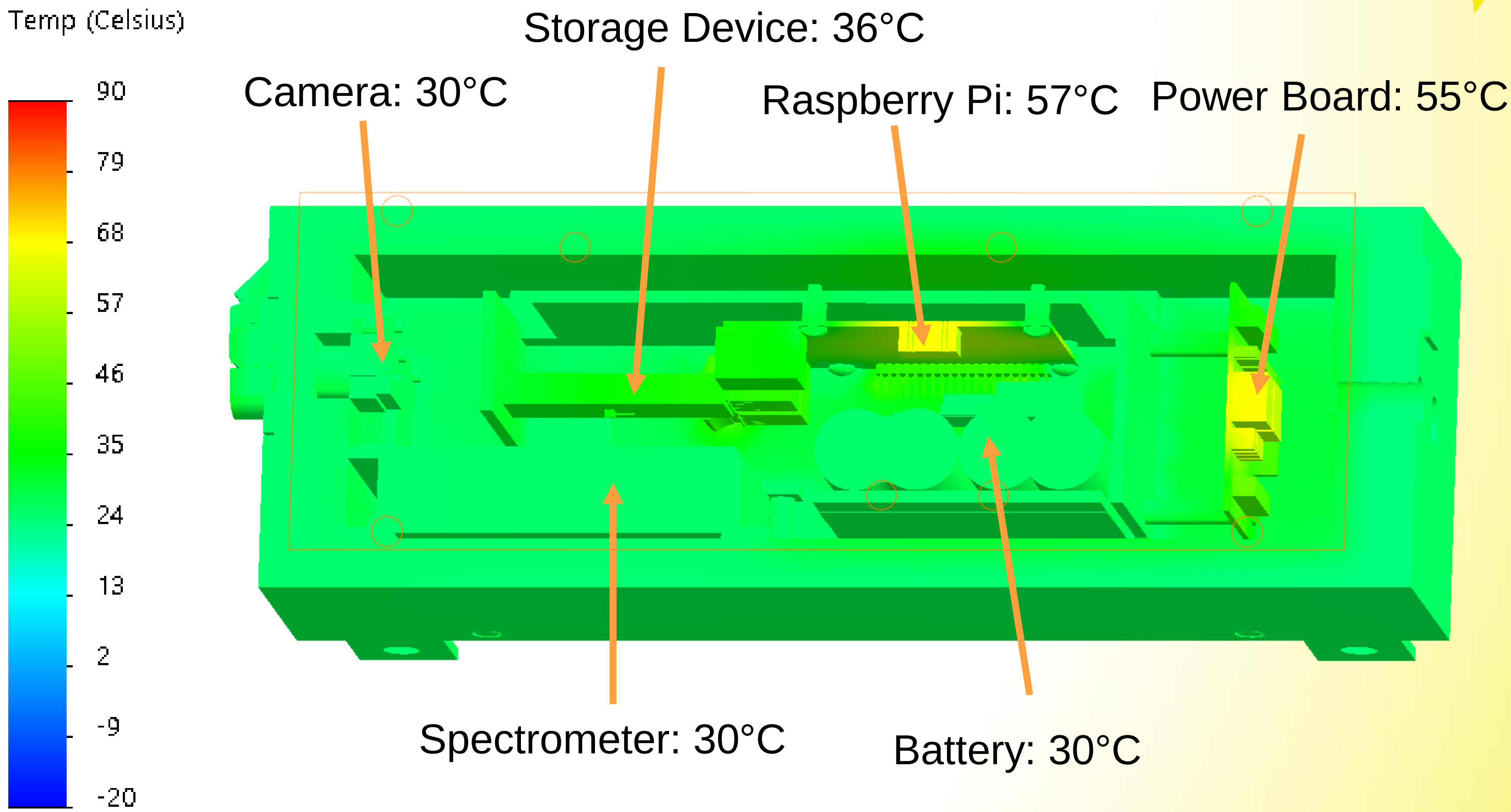
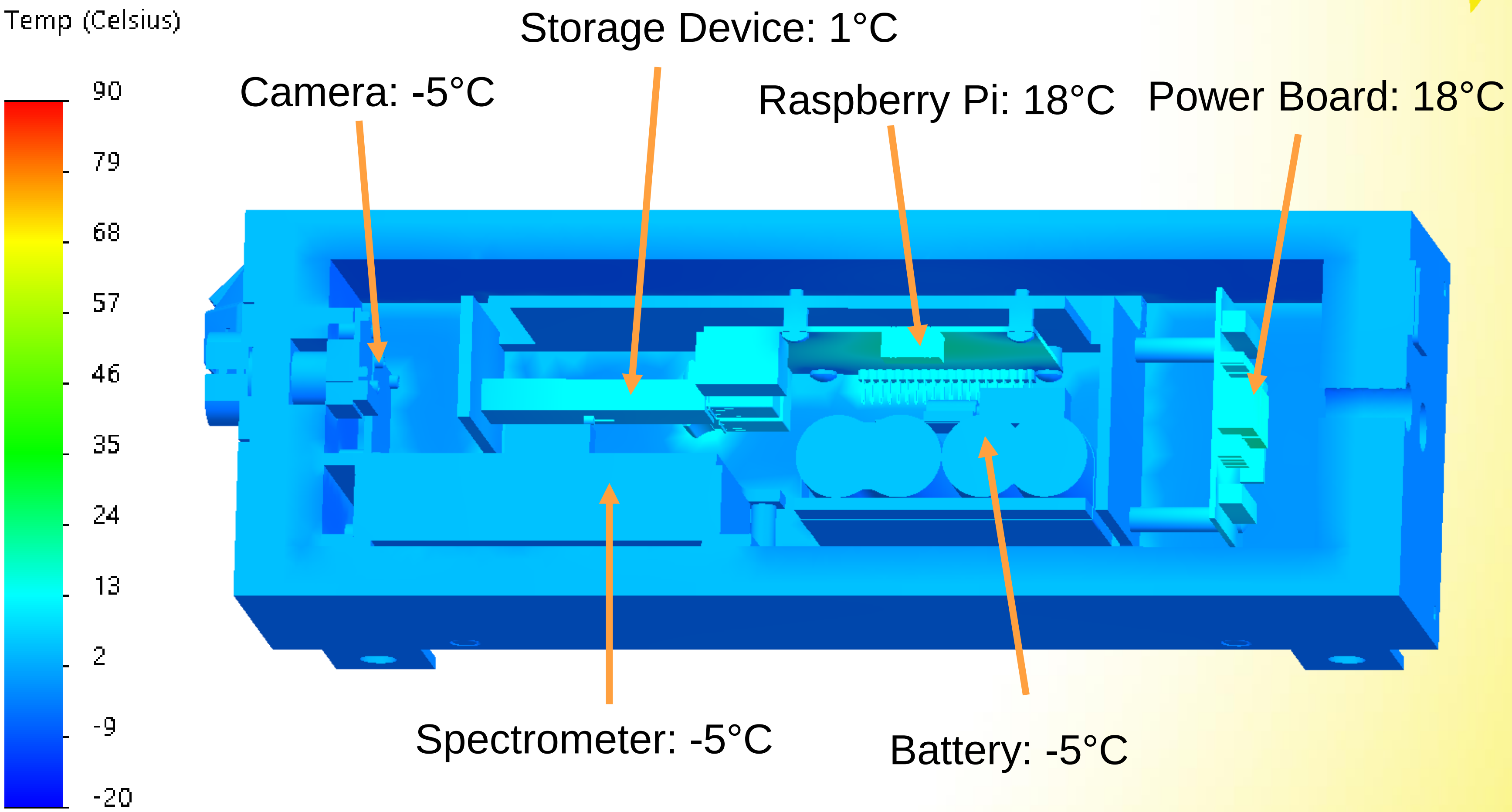
Emissivity = .5

Passive control, during cruise, steady state model



Emissivity = .5

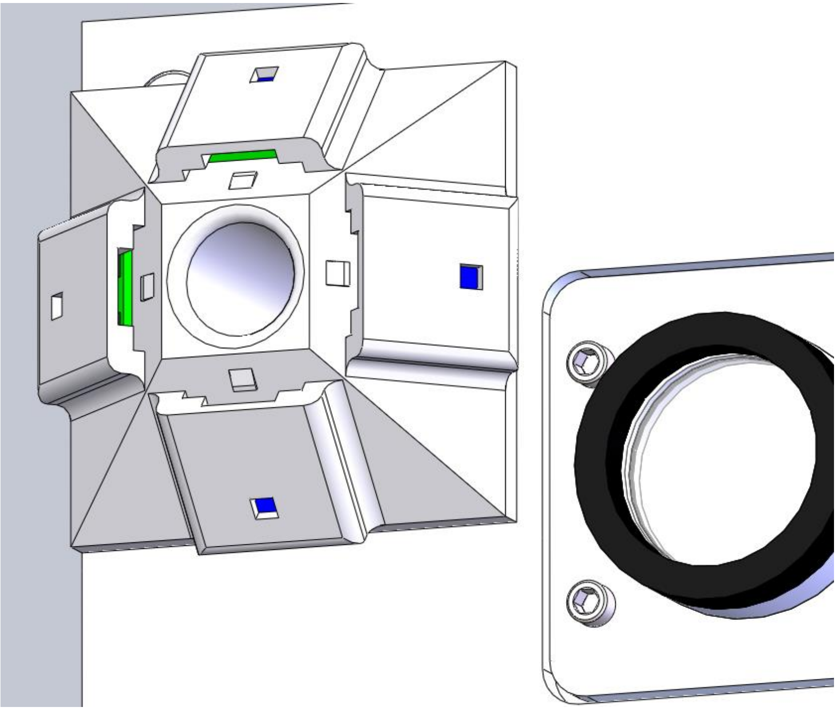
Passive control, on the ground, steady state model



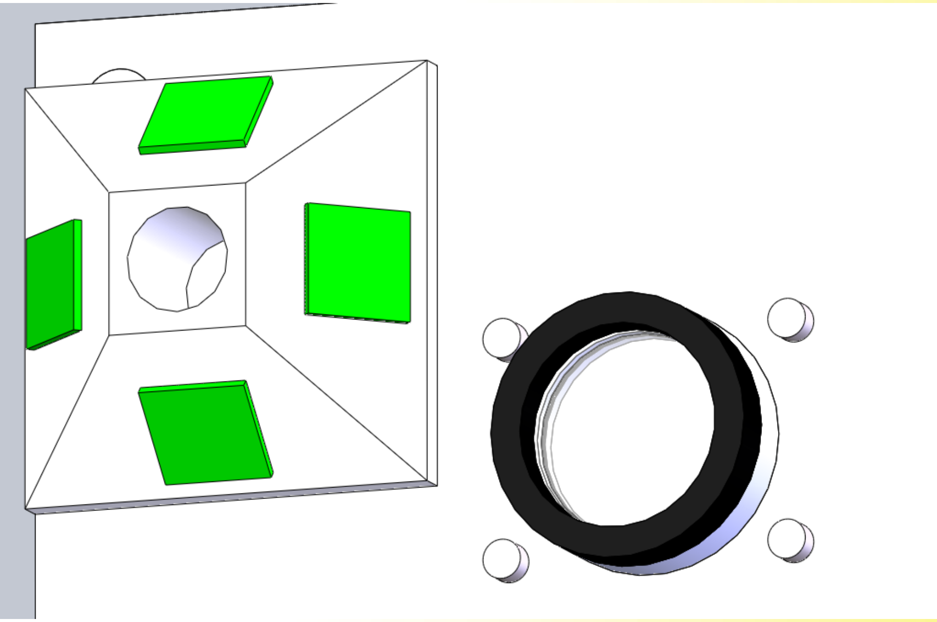
Thermal Simulations Setup

Step 1: Simplify Geometry

Before

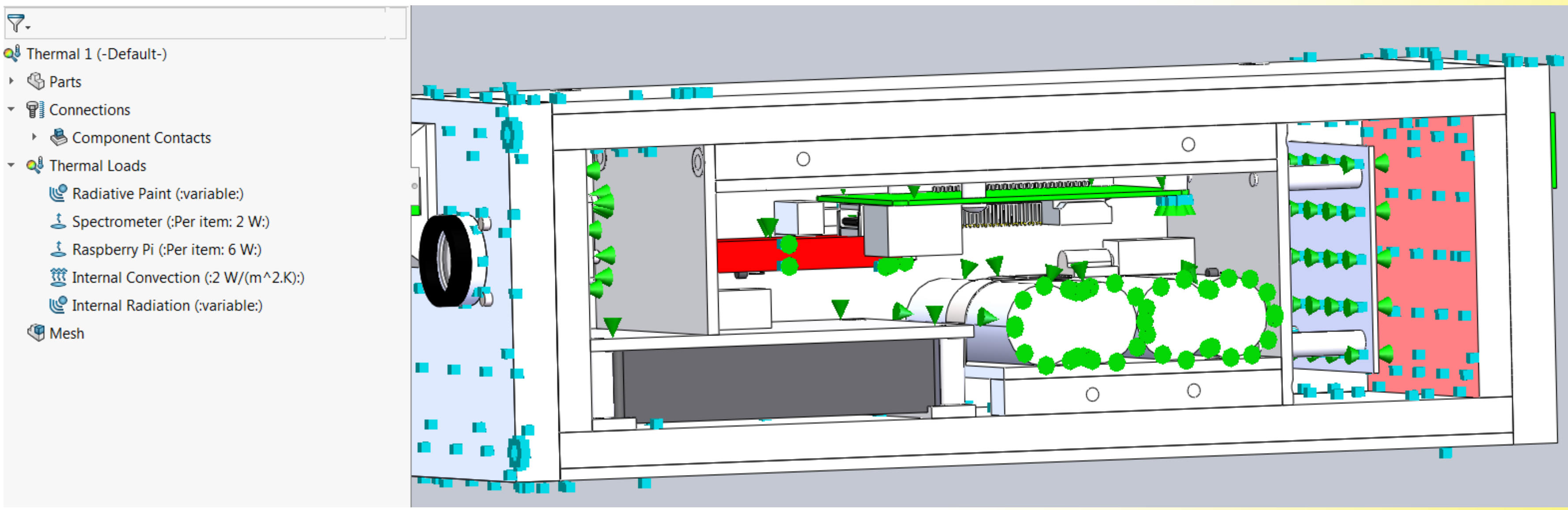


After



Step 2: Apply Boundary Conditions

- Temperatures
- Power Outputs
- Radiation
- Convection
- Heat Flux



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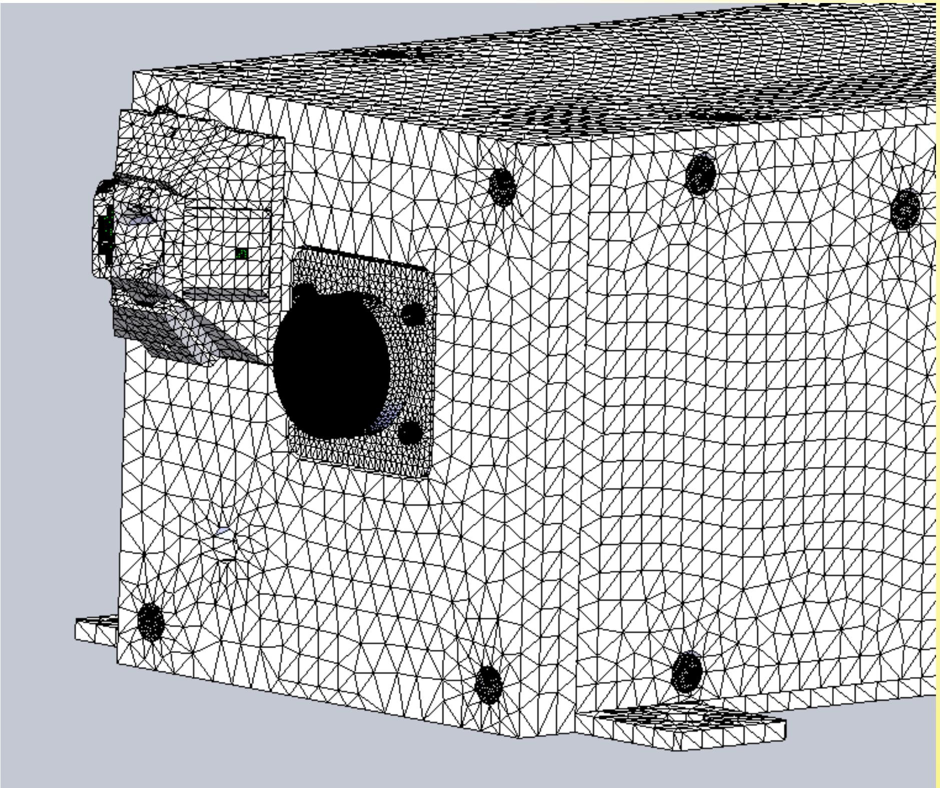
Step 3: Apply Contact Conditions

- Bonded Contacts:
  - Perfect Thermal Conduction
- Insulated Contacts:
  - Resistance between components
- Compatible Mesh
  - Nodes and members line up between elements
- Incompatible Mesh
  - Mesh optimized per component ignoring surroundings

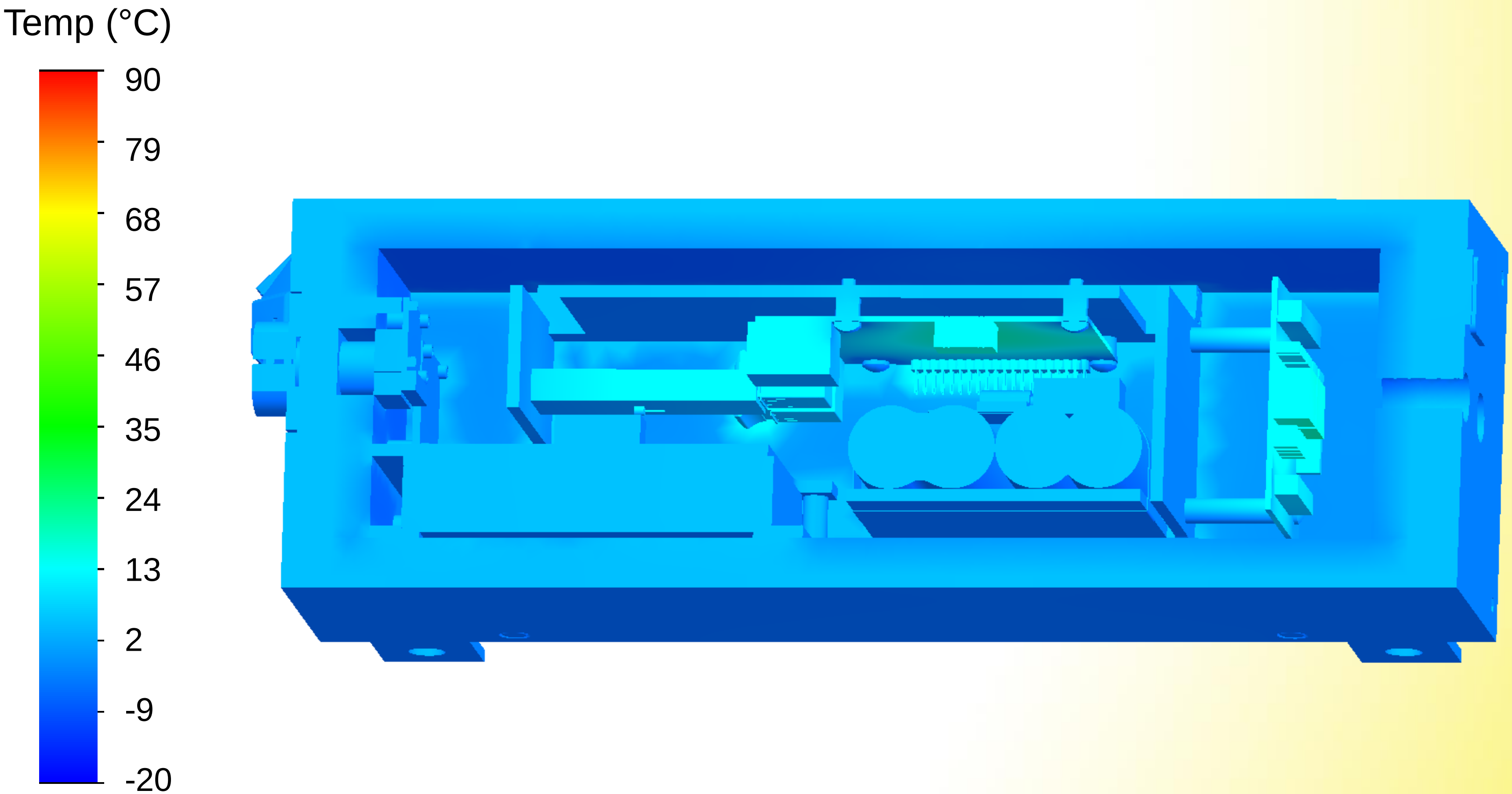
Step 4: Create Mesh

- Remesh until it works
- Jacobian equations derived from nodes
- Min element size: .06 mm
- Max element size: 17 mm



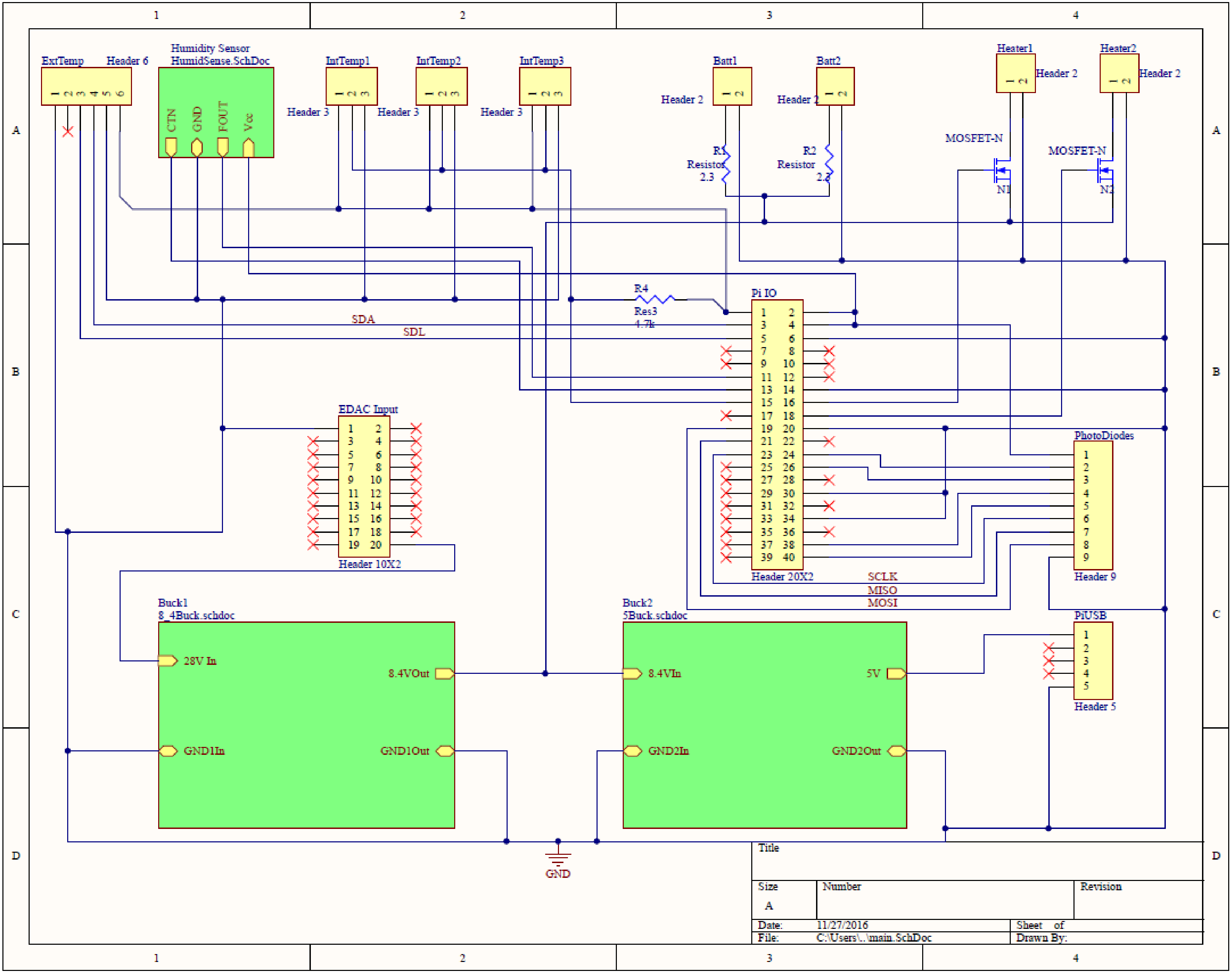
Step 5: Run Thermal Study

- Working results!



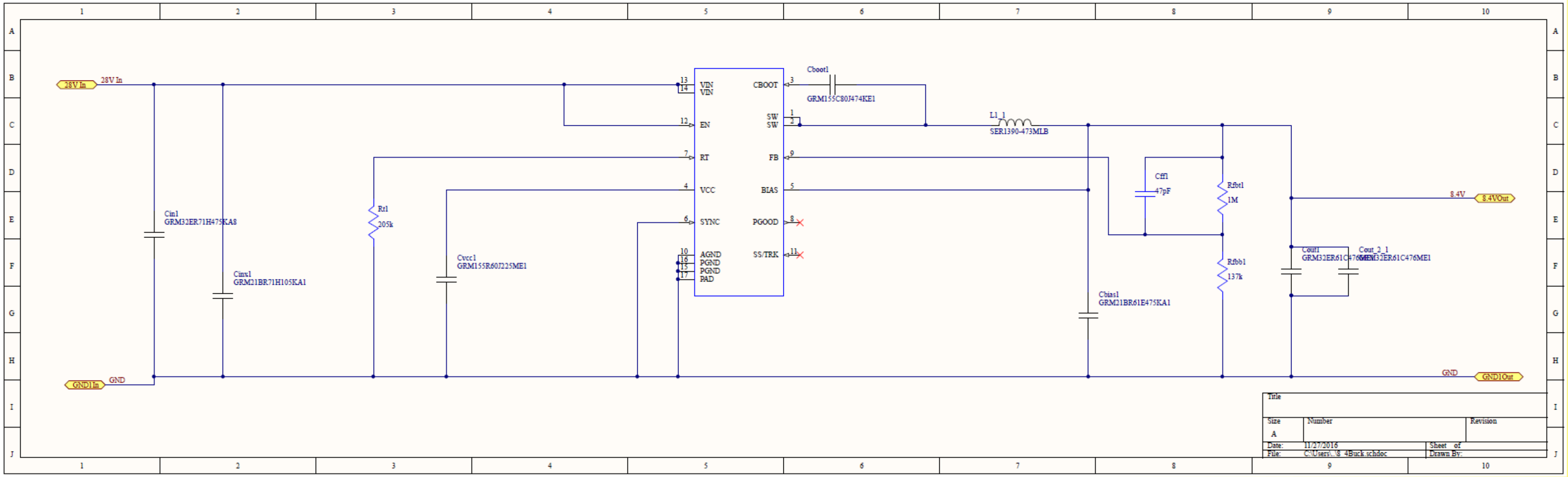
Future Thermal Plans

- Run full transient study of entire flight profile with maximum time step of 1 minute
- Run high fidelity modeling in Thermal Desktop
- Run individual components through transient to observe effects of convection and spot heating
- Provide sensitivity analysis for possible construction flaws

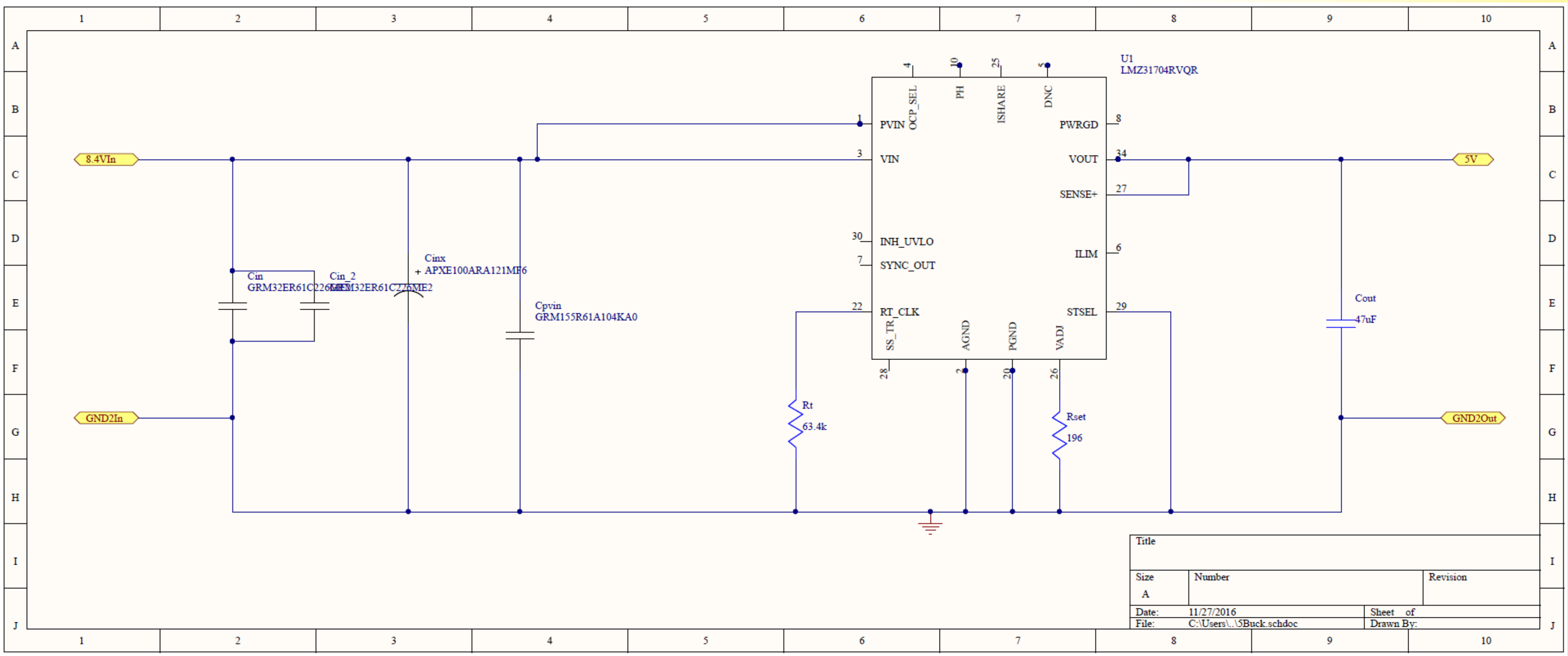


ExtTemp
Header 6
Humidity Sensor
HumidSense.SchDoc
CTN
GND
FOUT
Vcc
IntTemp1
IntTemp2
IntTemp3
Header 3
Batt1
Batt2
Header 2
Heater1
Heater2
MOSFET-N
N1
N2
R1
R2
Resistor
2.3
R4
Res3
4.7k
Pi IO
SDA
SDL
EDAC Input
Header 10X2
Header 20X2
SCLK
MISO
MOSI
PhotoDiodes
Header 9
PiUSB
Header 5
Buck1
8_4Buck.schdoc
28V In
8.4VOut
GND1In
GND1Out
Buck2
5Buck.schdoc
8.4VIn
5V
GND2In
GND2Out
GND
Title
Size
A
Number
Revision
Date:
11/27/2016
Sheet of
File:
C:\Users\..\main.SchDoc
Drawn By:

28 to 8.4V Buck Converter



8.4 to 5V Buck Converter



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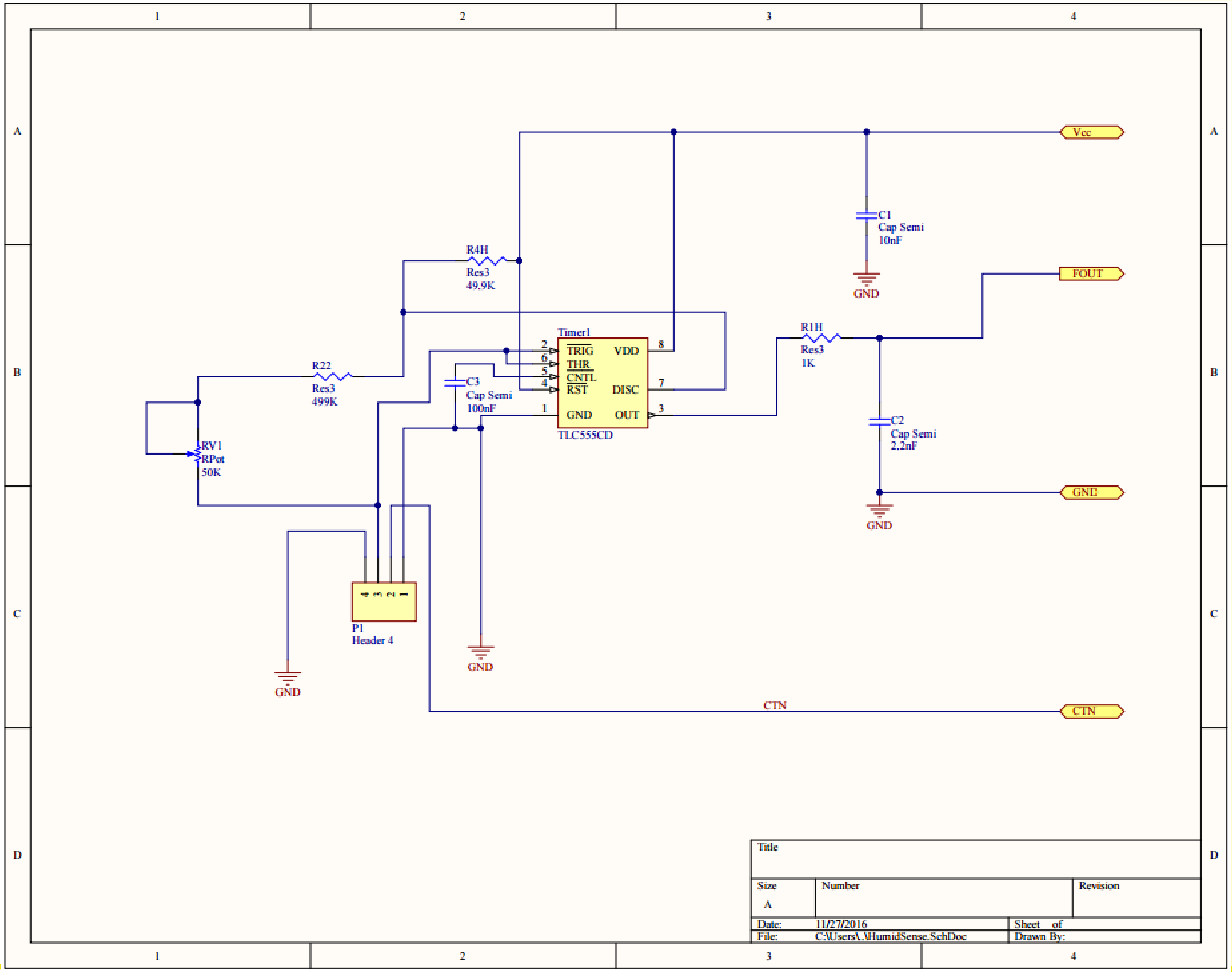
Humidity Sensor

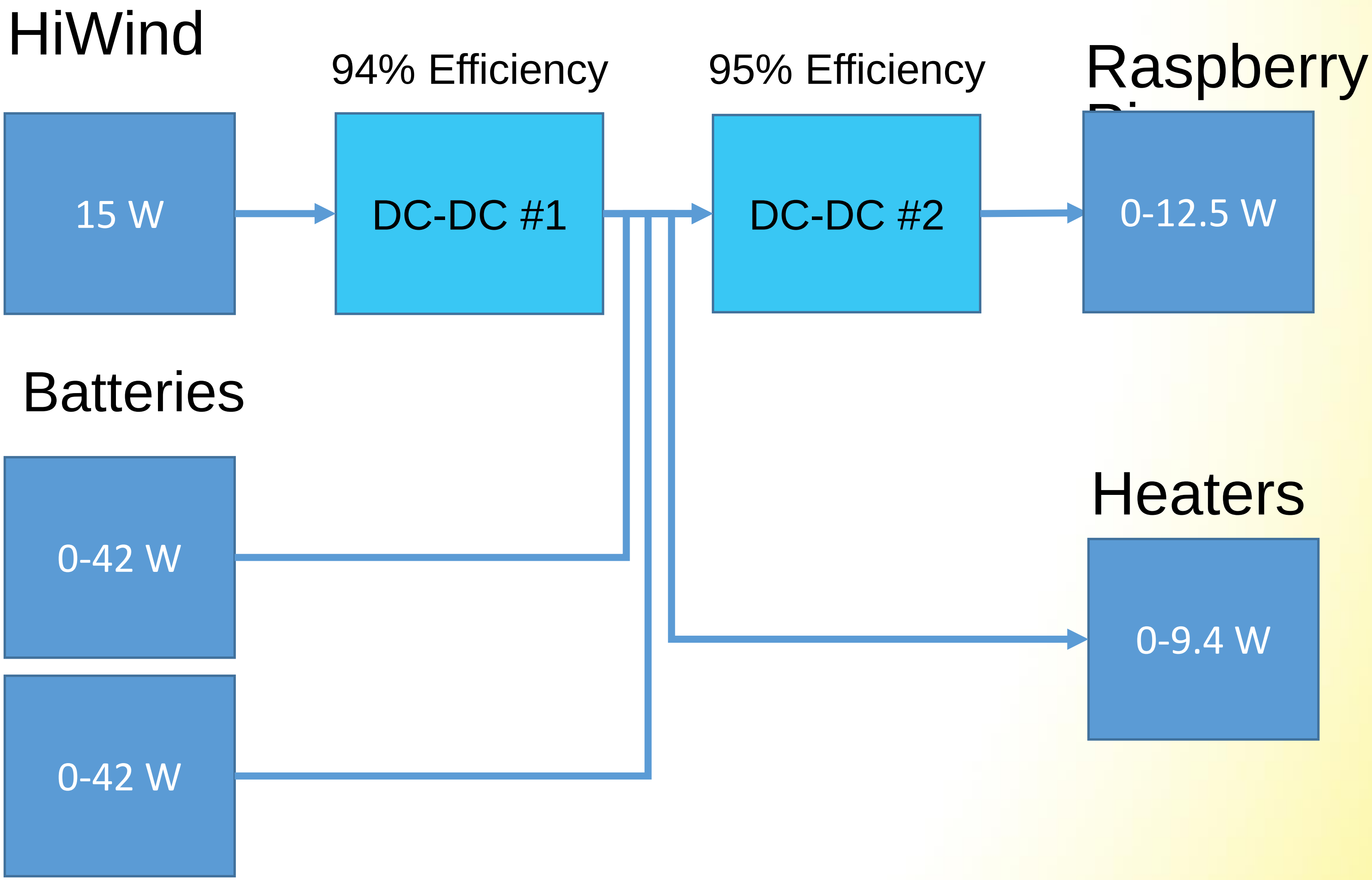


Raspberry Pi Power Draw

State	Average Power Draw	Max. Power Draw
Boot	1.75 W	3.75 W
Idle	1.5 W	N/A
Stress	4.25 W	6.7 W

- Only accounts for Pi, not power drawn from USB ports
- Assumed average stress power draw value for calculations needing Pi power draw

Power Sources

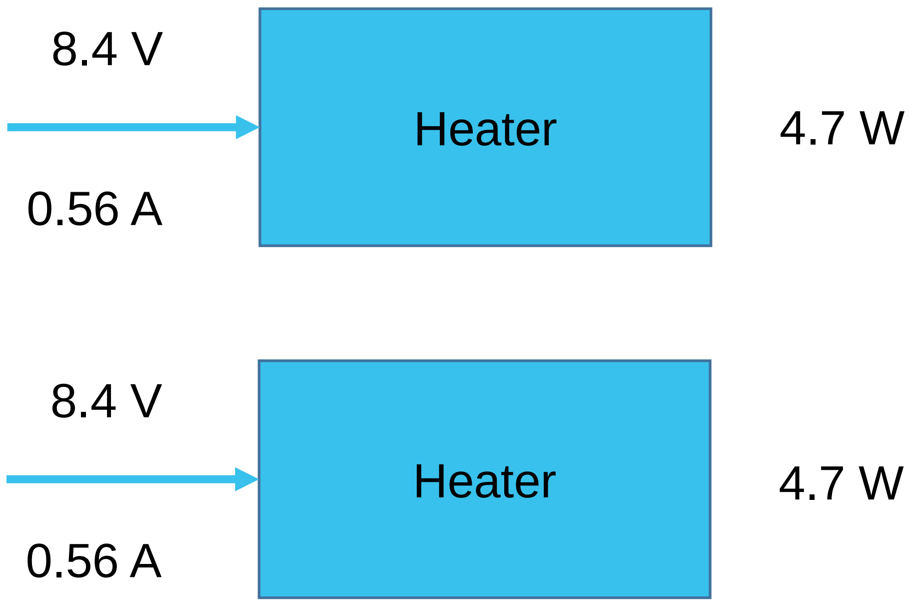


Case 1: One Heater On

- Allows for 8.8 W to the Pi

    Nominal Pi Power draw

Case 2: Two Heaters On



Heater Power Draw– 9.4 W
Pi Power Draw – 8.1 W
Total Overall Draw – 17.5 W = 14.1 From HiWind + 3.4W from Batteries

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Battery

- Li-Ion Battery
  - 3.35 A-hr capacity
  - Built in charge protection
  - 2 cell package
  - 7.2 V nominal
  - 5.0 A maximum draw
- Thermal Characteristics
  - Charging: 0° to 60° C
  - Discharging: -20° to 60° C

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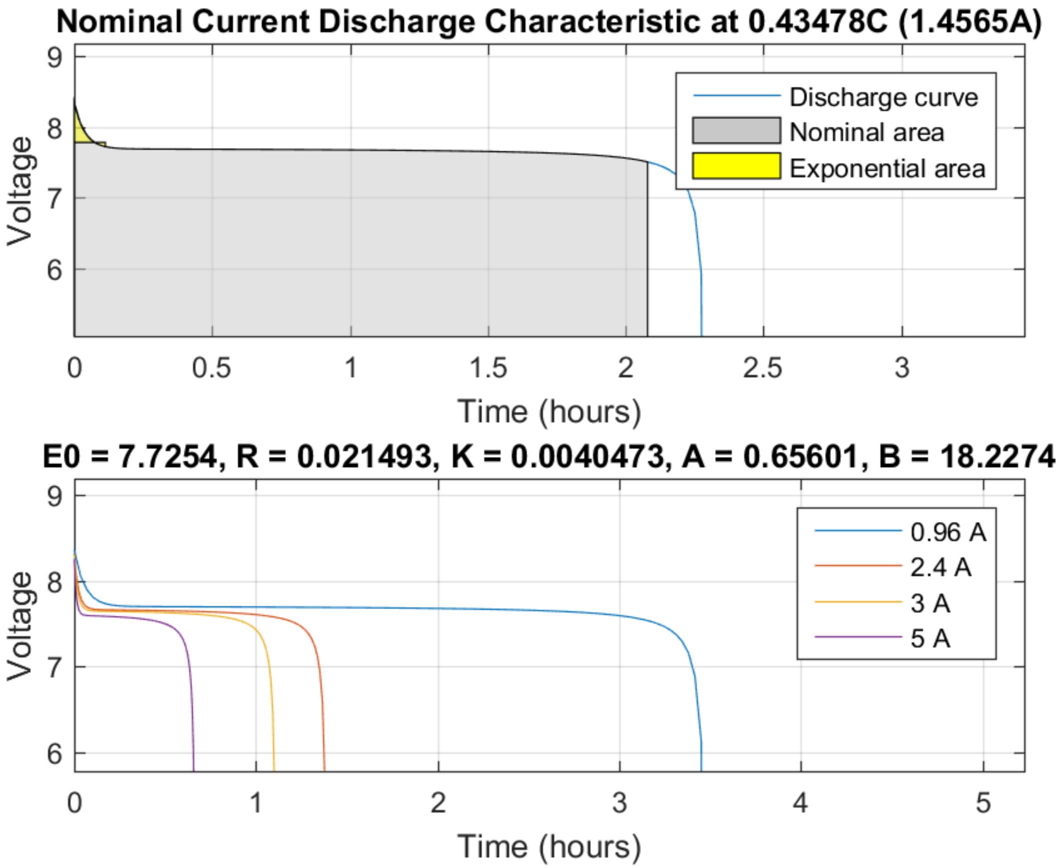
Battery Draw



- 0.96 A -> Nominal battery draw
- 2.4 A -> Cruise power draw
- 3 A -> Max system draw
- 5 A -> Max battery draw

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MOSFET Control

Use equation for average voltage:

$$\bar{y} = \frac{1}{T}\int_0^T f(t)dt = \frac{1}{T}\left(\int_0^{DT} y_{\max} - \int_{DT}^{T} y_{\min} dt\right)$$

Assume minimum voltage is zero:

$$y_{\min} = 0$$

Carry out integral for square wave:

$$\bar{y} = D y_{\max}$$

Heater voltage is linear function of duty cycle!

MOSFET Selection

Part Name	P-Channel MOSFET 20V 24A - low Vgs(th)
V_gs	0.7V
Max Power Dissipation	60W
I_DS @ 3.3V	30A
Typical Rise Time	On: 30 nS Off: 200 nS

Data Storage - SLC

Measurement	Size/data point	Frequency	Total
Spectrometer	16.384 kB	1 Hz	10.55 GB
External temperature	4 B	1 Hz	5.273 MB
Internal temps (x6)	24 B	1 Hz	31.638 MB
Humidity	4 B	1 Hz	5.273 MB
Photodiode (x4)	32 B	1 Hz	42.1875 MB
Sun angle	4 B	1 Hz	5.273 MB

C++ binary data files: floats are 4 bytes, doubles are 8 bytes

Data Storage - MLC

Measurement	Size/data point	Frequency	Total
Camera images	1.8 MB (max)	1/60 Hz	40.5 GB

All test images were within a few bytes of 0.9 MB. We doubled it to be sure.

SLC Micro SD Card

Panasonic Electronic Components RP-SMSC02DA1	
Storage	2GB
Price	$35.85 without margin
Temperature Range	-40 ºC to 85 ºC

- Reasons for selection:
  - Easy install of OS
  - Resistant to single event upsets

Component List

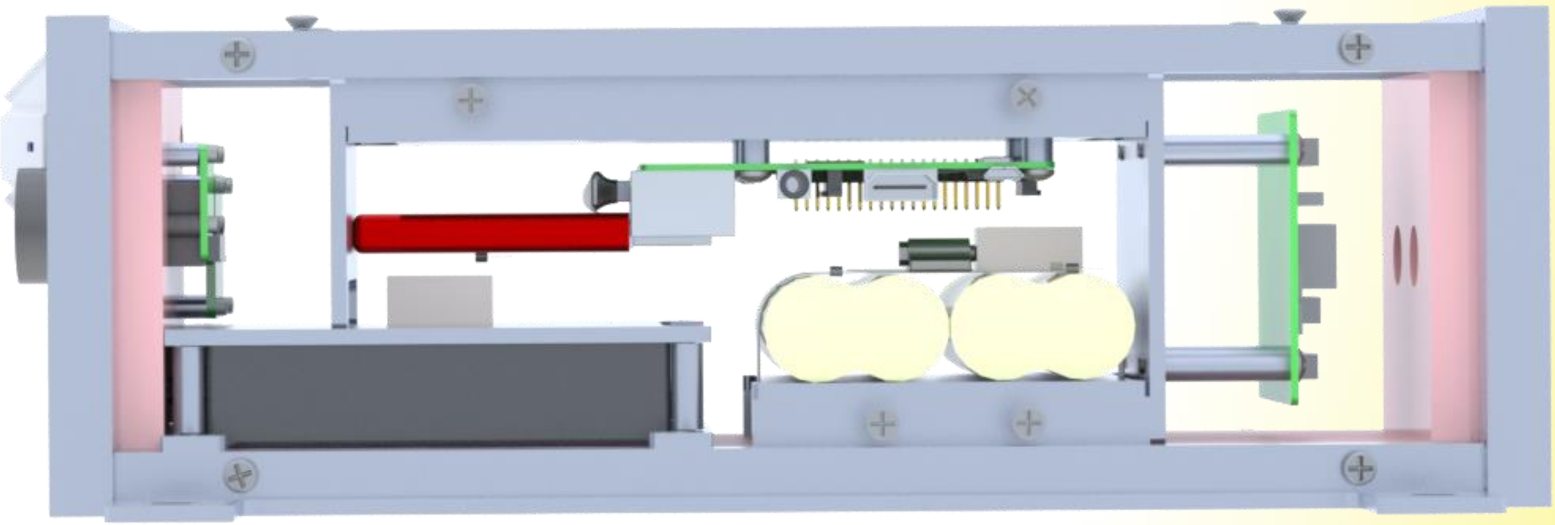
Components	Quantity
Manufactured Parts	26
3D Printed Parts	2
Electrical Boards	6
COTS	20
Screws	75
Spacers	26
TOTAL	**155**

- Does not include wires, cables, and other miscellaneous interfaces.

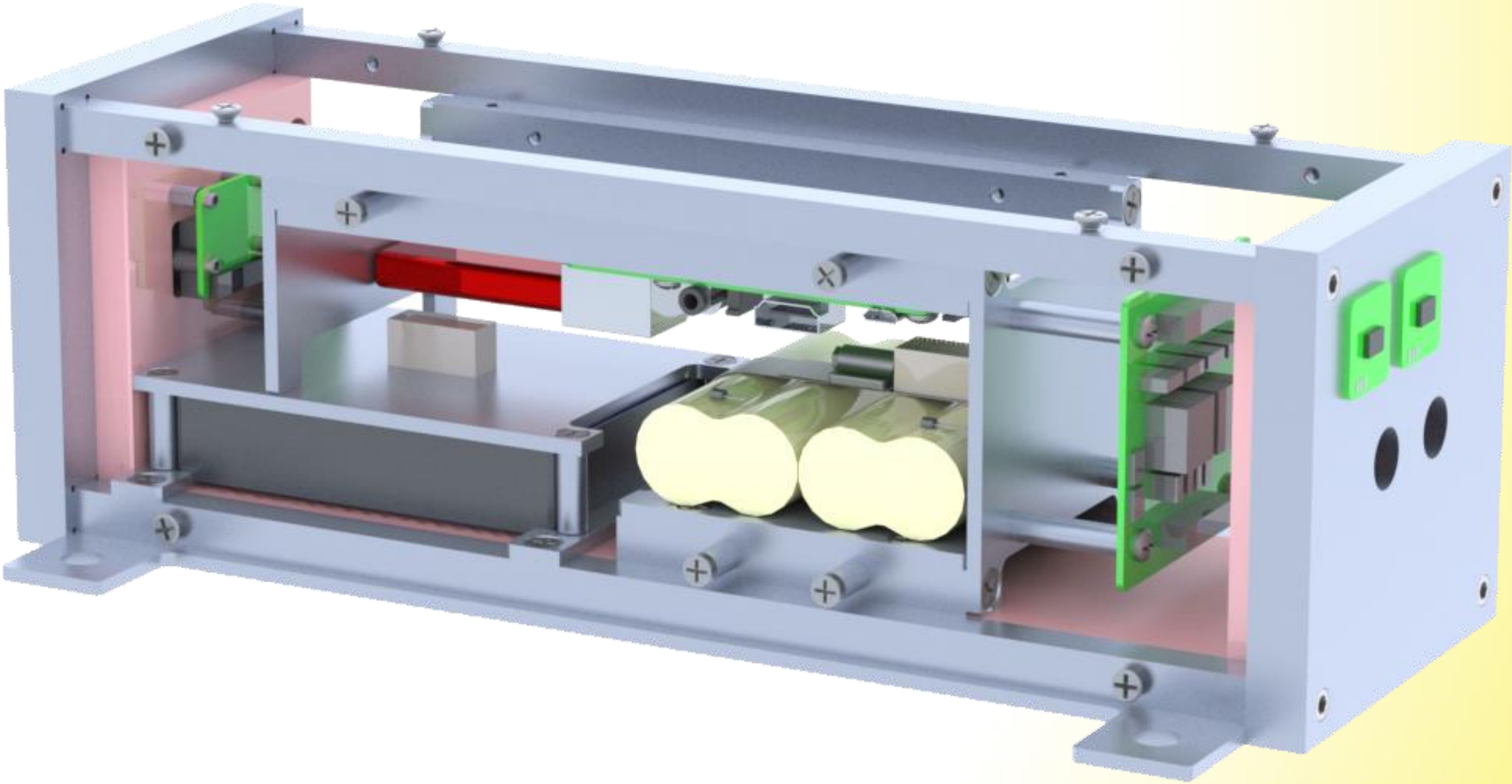
Manufacturing Tolerances

- Parts to be 3D printed:
  - Photodiode array
  - Neutral density filter threads
- 3D Printer: ±10 μm layer thickness ±140 μm in the x/y directions
- CNC Mill: ±0.002”

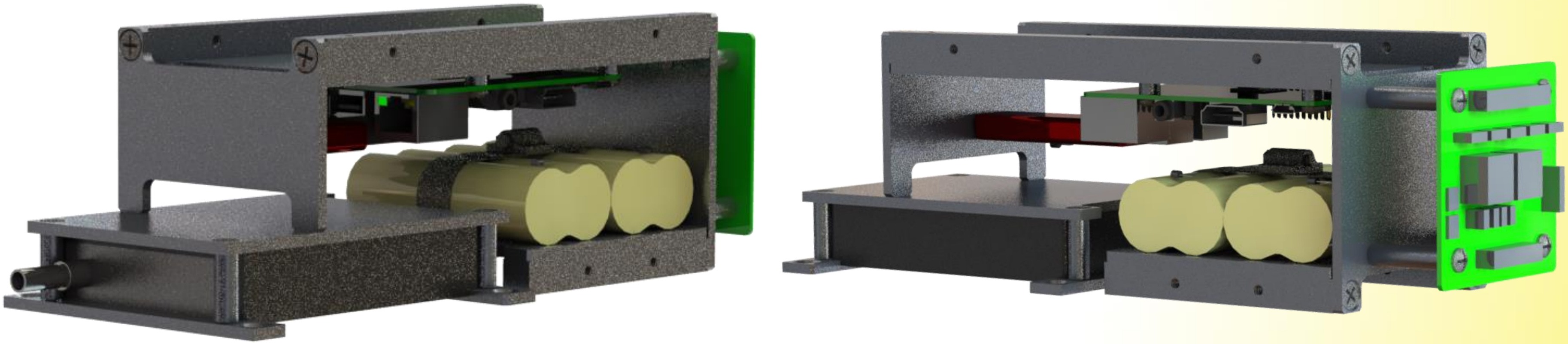
Renders



Renders



Renders



Outgassing of 3D Printed Materials

- "Low Outgassing" is defined by NASA using TML and CVSM
  - TML = Total Mass Lost
    - TML < 1.0%
  - CVCM = Collected Volatile Condensable Material
    - CVCM < 0.10%
- Bobby's Lab has a FormLabs Form 2 Printer
  - Uses methacrylate photopolymer resin, which is a proprietary material
  - Similar photopolymer resins have good outgassing profiles

Outgassing of 3D Printed Materials

Material	TML	CVCM	Reference
ABS Plastic, 3D Printed	0.94%	0.04%	NASA
PET Plastic (Makergeeks.com)	0.61%	0.05%	NASA
PLA Plastic (Makerbot)	0.56%	0.01%	NASA
P430 ABS Plus	0.37%	0.00%	NASA
ABS Plus	0.63%	0.08%	NASA
Acrylic Safety Glazing, Polymetholmethacrylate	0.68%	0.00%	NASA
PLA Plastic (Replicator 2 from Makerbot)	—	—	PPPL
Objet FullCure720 Photopolymer Resin	0.74%	—	CalPoly
DSM Somos Prototherm 12120 Photopolymer Resin	0.92%	0.10%	CalPoly
Windform XT Carbon Fiber Filled Nylon	0.14%	—	CalPoly

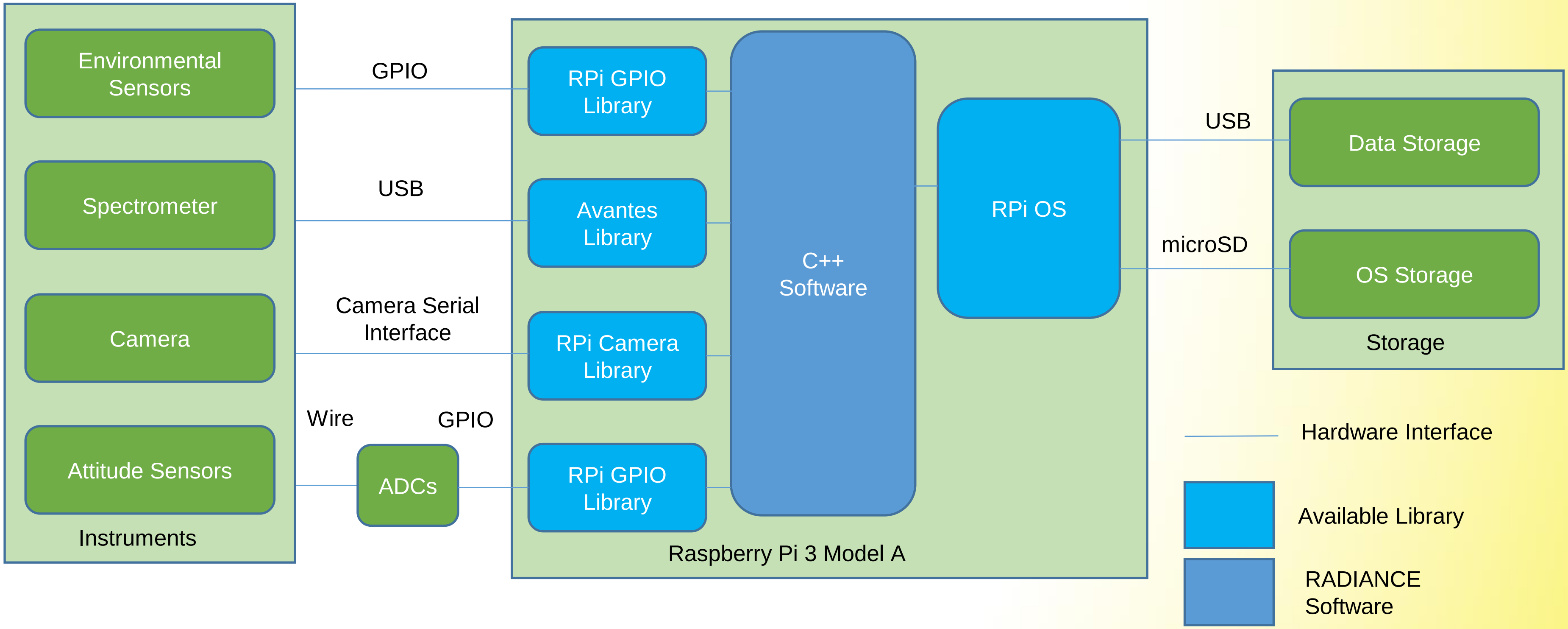
Outgassing Conclusions

- All 3D printable materials that NASA researched are considered "low outgassing"[1]

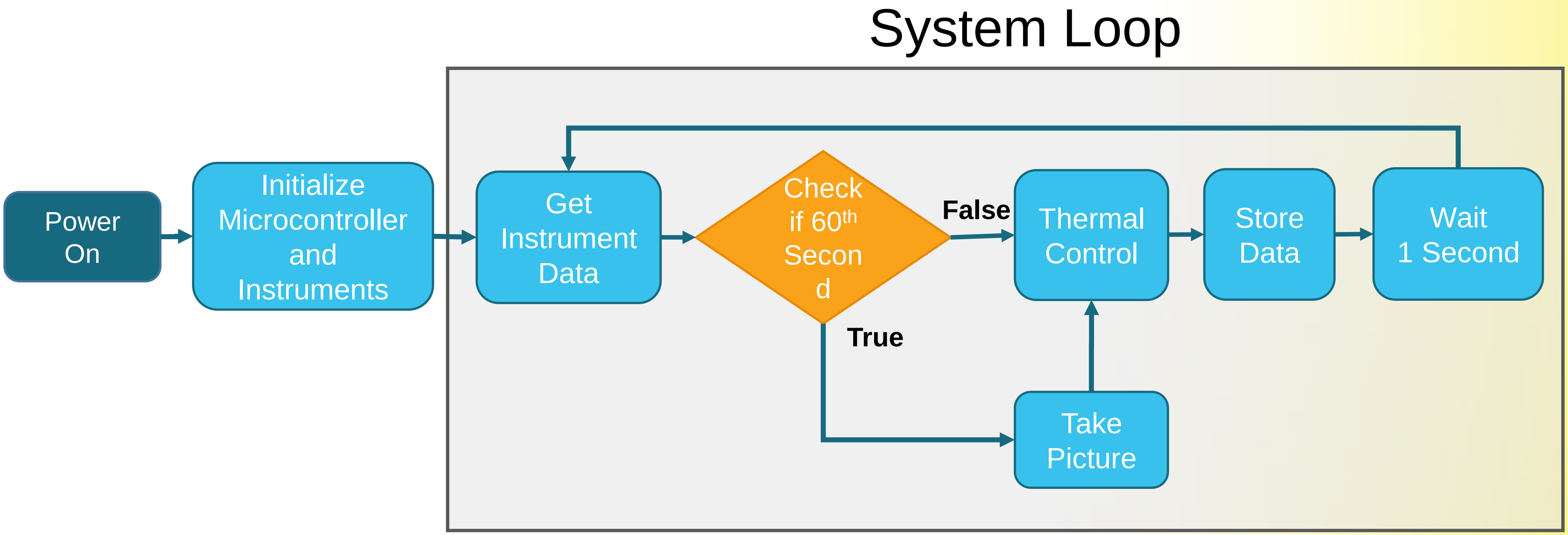
- Princeton Plasma Physics Laboratory (PPPL) found that PLA Plastic is suitable from 0.00013 Pa to 101325 Pa (not an ultra-high vacuum)[2]

- Cal Poly found three photopolymer resins that are suitable for low outgassing[3]

Software Interfaces



Software Flow

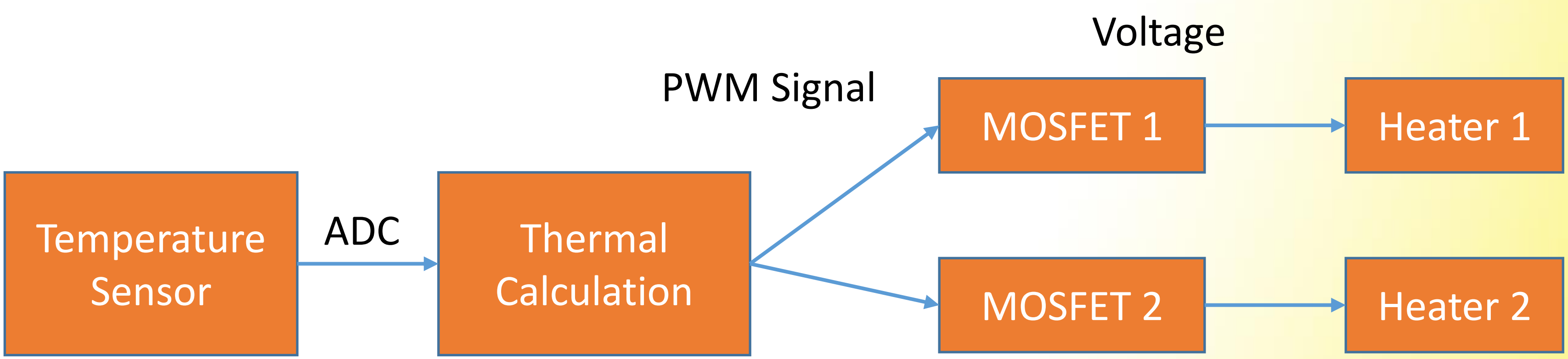


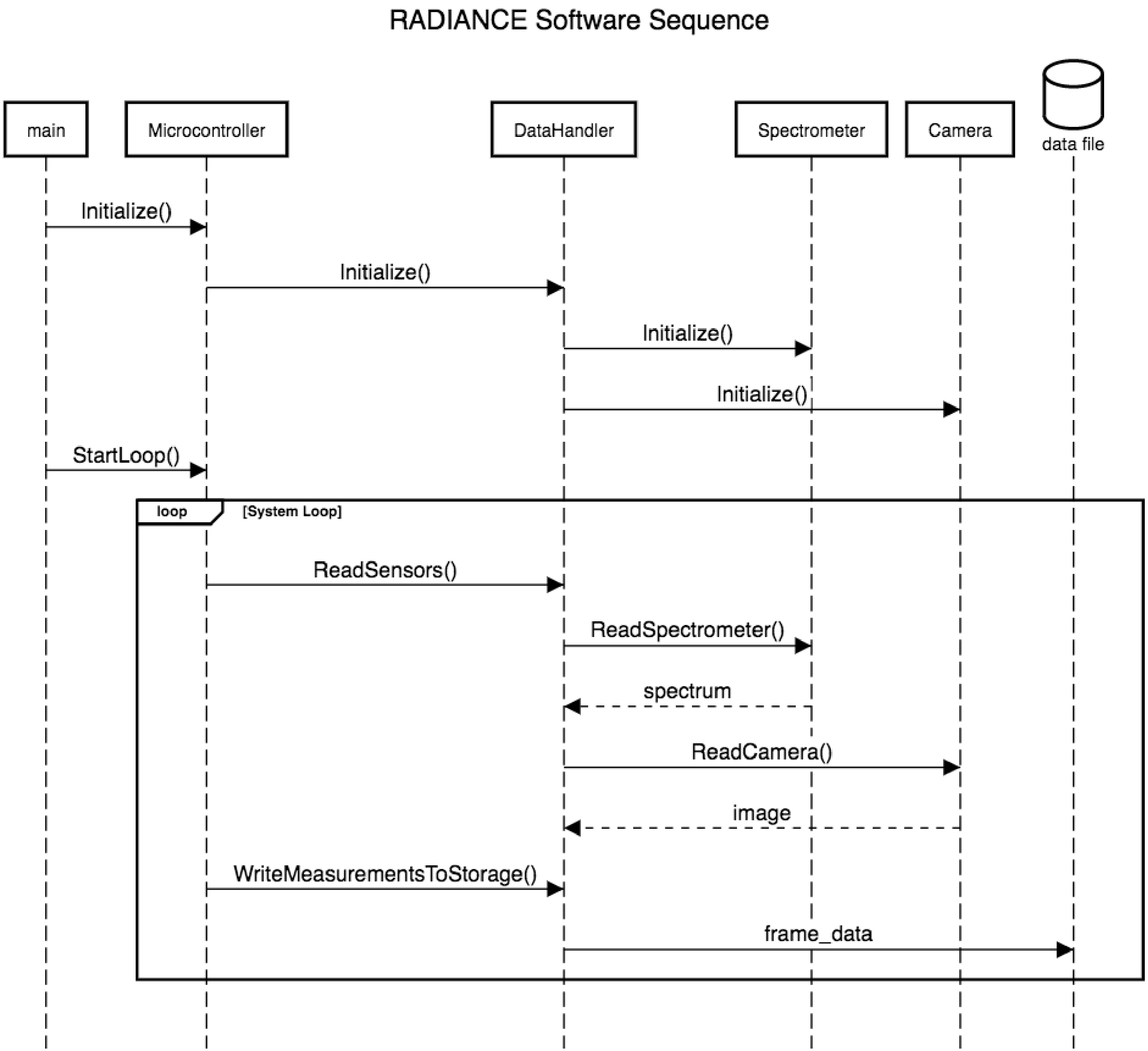
Heating Algorithm

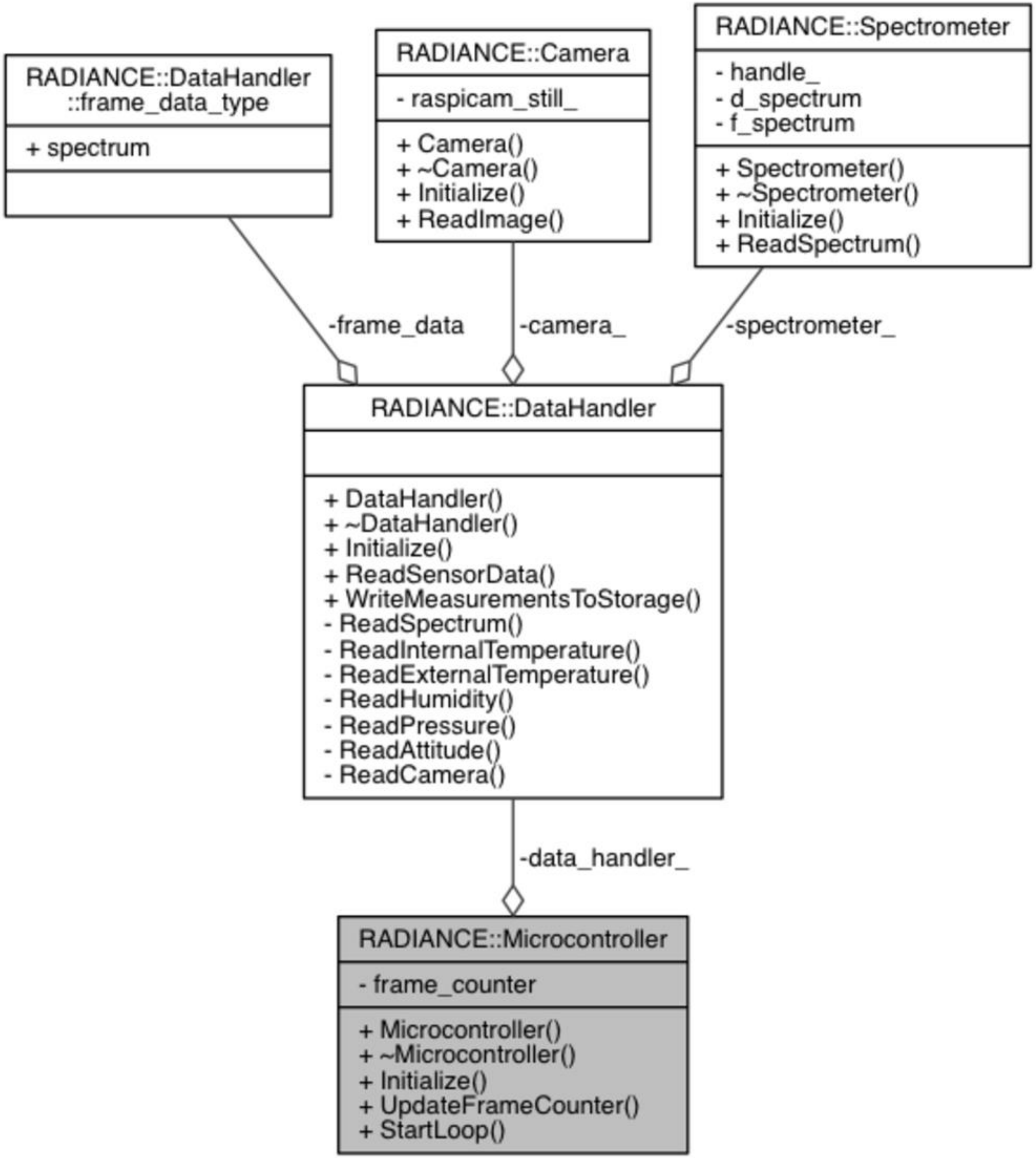
Pseudocode:

```
If(Temp < MinTemp)
  TurnHeatersOn = 1;
elseif(Temp > MaxTemp)
  TurnHeatersOn = 0;
end
```

- One calculation for each heater
- Approximate execution time: <1ms




RADIANCE Software Sequence
main
Microcontroller
DataHandler
Spectrometer
Camera
data file
Initialize()
Initialize()
Initialize()
Initialize()
StartLoop()
loop
[System Loop]
ReadSensors()
ReadSpectrometer()
spectrum
ReadCamera()
image
WriteMeasurementsToStorage()
frame_data


RADIANCE::DataHandler ::frame_data_type
+ spectrum
RADIANCE::Camera
- raspicam_still_
+ Camera()
+ ~Camera()
+ Initialize()
+ ReadImage()
RADIANCE::Spectrometer
- handle_
- d_spectrum
- f_spectrum
+ Spectrometer()
+ ~Spectrometer()
+ Initialize()
+ ReadSpectrum()
-frame_data
-camera_
-spectrometer_
RADIANCE::DataHandler
+ DataHandler()
+ ~DataHandler()
+ Initialize()
+ ReadSensorData()
+ WriteMeasurementsToStorage()
- ReadSpectrum()
- ReadInternalTemperature()
- ReadExternalTemperature()
- ReadHumidity()
- ReadPressure()
- ReadAttitude()
- ReadCamera()
-data_handler_
RADIANCE::Microcontroller
- frame_counter
+ Microcontroller()
+ ~Microcontroller()
+ Initialize()
+ UpdateFrameCounter()
+ StartLoop()

Spectrometer

Requirement	Implementation
Measure spectra from 250nm to 1000nm	Avantes Mini 2048L-UVI25 measures 200nm-1100nm
Measure with resolution of 1nm	Resolution of 1.4nm
Must be calibrated	Use provided Avantes software in conjunction with Dr. Marshall's light calibration source

Approved by customer

- Reasons for selection:
  - Fit spectra requirements
  - C++ Library for use on Rasbian
  - Cheapest one we could find

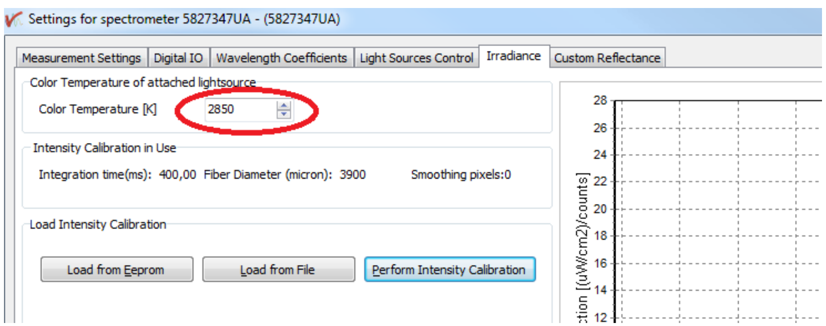
Spectrometer Calibration

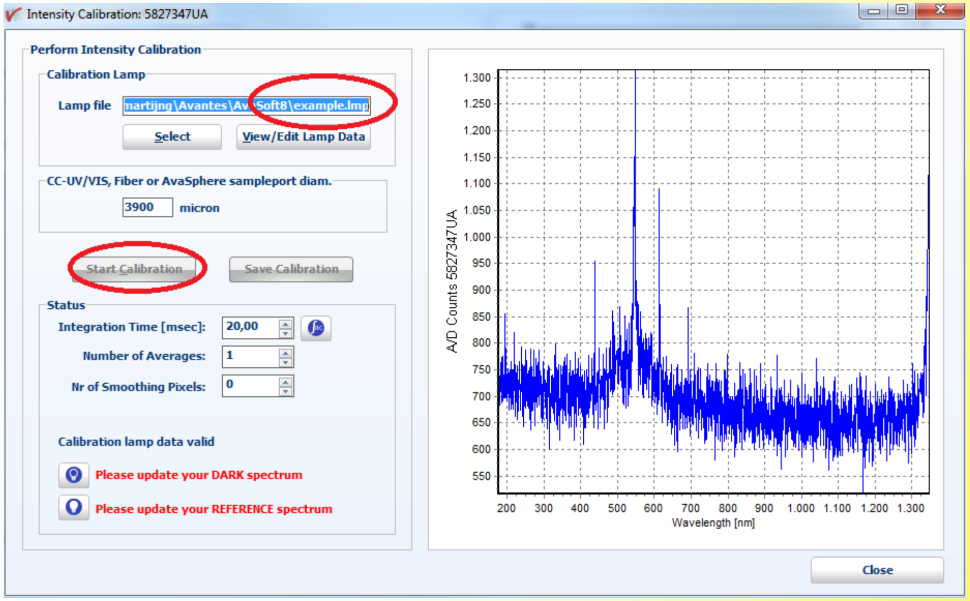
Specification	Approach	Resource	External Source
Calibrate spectrometer	Characterize spectrometer output against known light source	1. Light source with known output 2. Dark room 3. Optical cloth	Dr. Bob Marshall Dr. Scott Sewell, HAO
Measure from 250 to 1000 nm	380 nm to 1068 nm with errors below 3% from 460 nm 936 nm	Light source with known output	Dr. Bob Marshall
Measure from 250 to 1000 nm	Test full-range readings	Sunny day	N/A

Spectrometer: Calibration

- Use Avasoft calibration software

- Specify parameters of calibration equipment and size of sampleport (fiber cable)

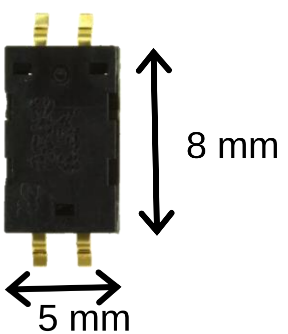


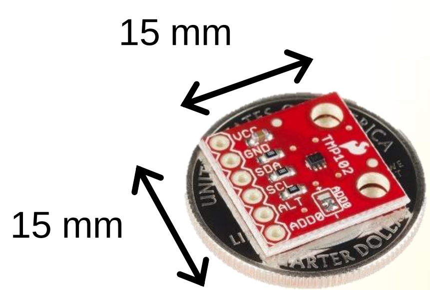


External Sensors

Requirement	Implementation
Take environmental measurements	TMP102 Temperature Sensor HPP04B130 Humidity Sensor

- Reasons for selection:
  - Humidity
    - Only one that can survive external environment
  - Temperature
    - Can survive environment
    - Provides accurate measurements at low temperatures (± .7C at -55C)





A Modest Proposal: Pressure

1. Temperature
Almost all manufacturers only test pressure sensors from -40C to 85C or 125C for industrial applications. While they can survive lower than that, the only way we can prove that to the PAB is to use a pressure sensor in excess of $2000. We can run a tube from the interior to the exterior but that would provide inaccurate measurements.

2. Pressure
We are in an extremely low pressure environment. Even pressure sensors rated to "ultra-low" pressure environments can only measure 10 in H20. 200Pa (our environment) is equivalent to 0.8 in H20. To measure at altitude, we would not be able to measure on accent without a second sensor (once again that cannot be guaranteed to the PAB to survive temperature and would not operate on coldest part of accent.)

3. Time
This is not a requirement and the environmental data we measure is completely our decision. The pressure at cruise will remain almost constant, meaning the entire effort would be placed into only a few hours of time on accent out of 2 weeks of total time. In order to get a pressure sensor that we can guarantee to survive the environment and we can afford, we would need to submit it to tests at temperatures at least as low as -55C taking even more time.

4. Money
In order to achieve this, we would need to spend 3-4 times the amount it costs to do all of our other sensors. Without EEF funding this is now out of budget.

Camera

Requirement	Implementation
Take images of visible spectrum	Raspberry Pi Camera Module v2.0
Field of View of 5° (±1°)	FOV 6.32°

Approved by customer

Example image at 18ft. Black circle is 2in in diameter. Approximately size of sun in the sky.

- Reasons for selection:
  - Made for easy interface with Pi
  - Small form factor
  - COTS lens
    - Adjustable

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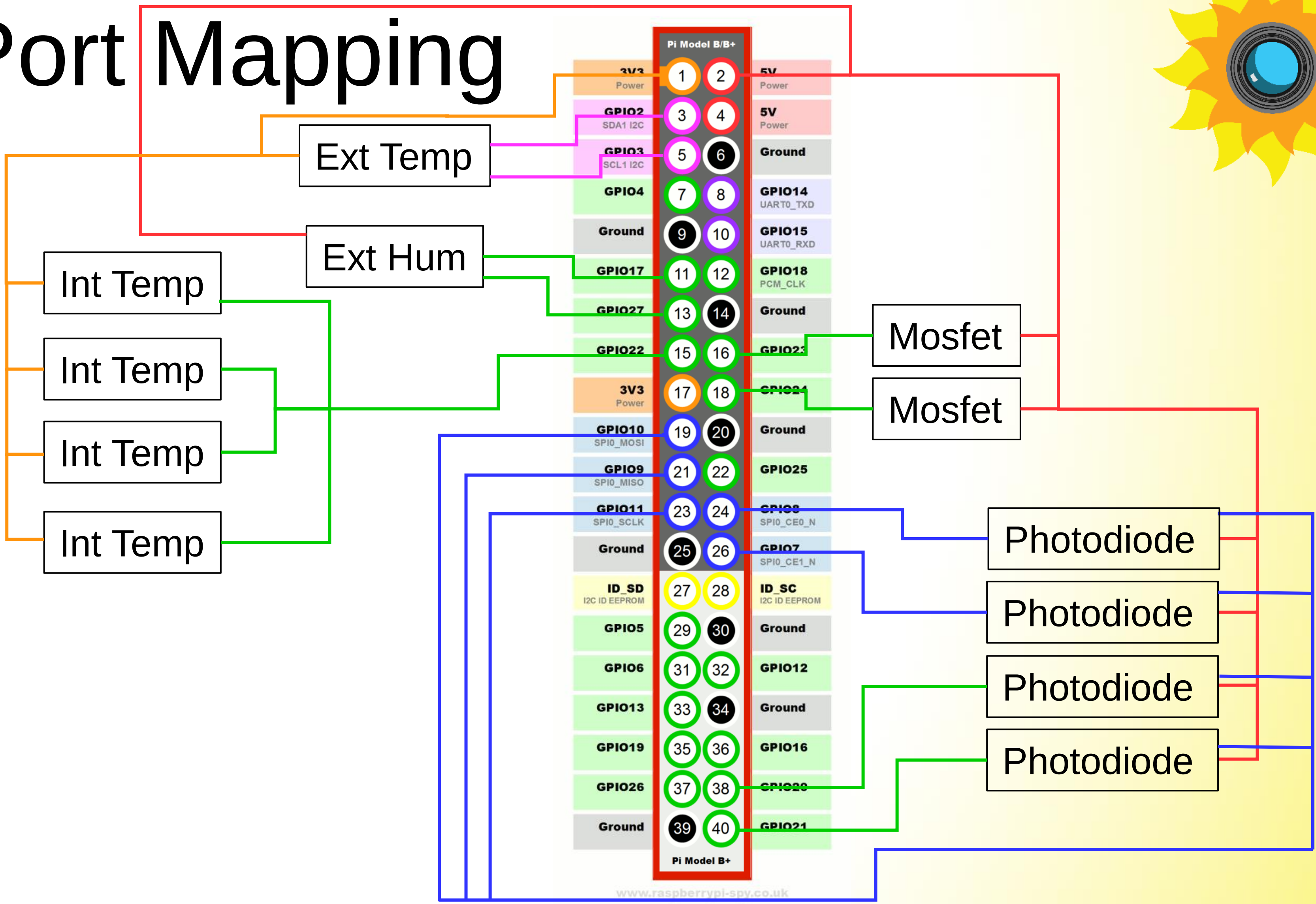
Port Mapping



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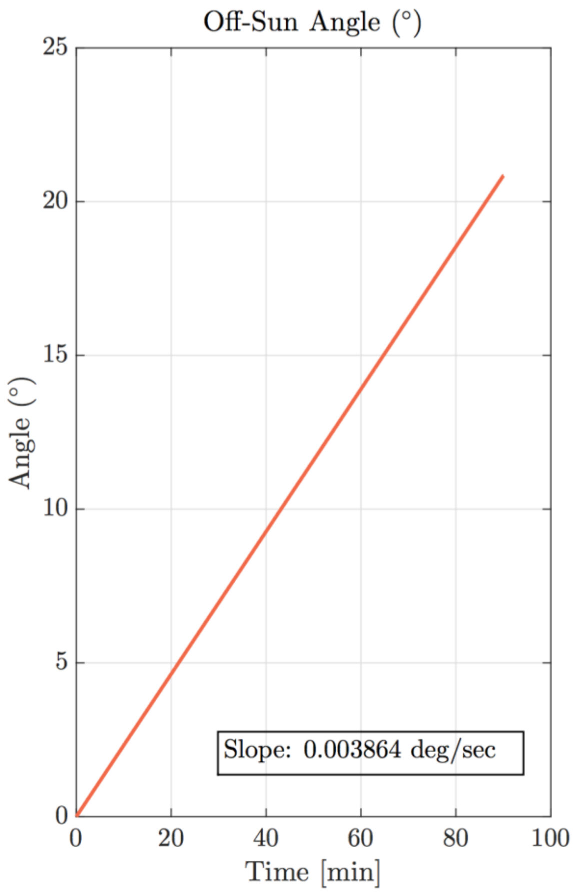
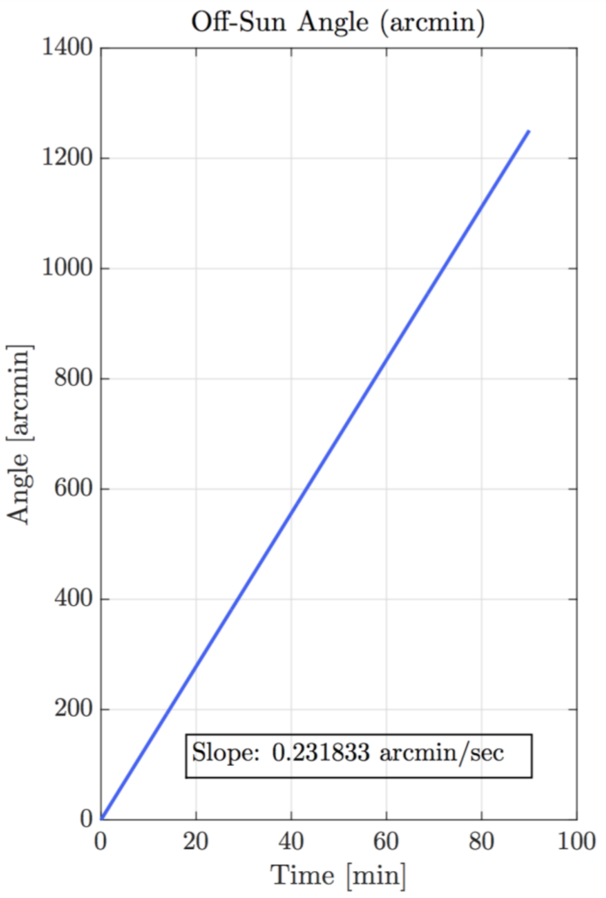
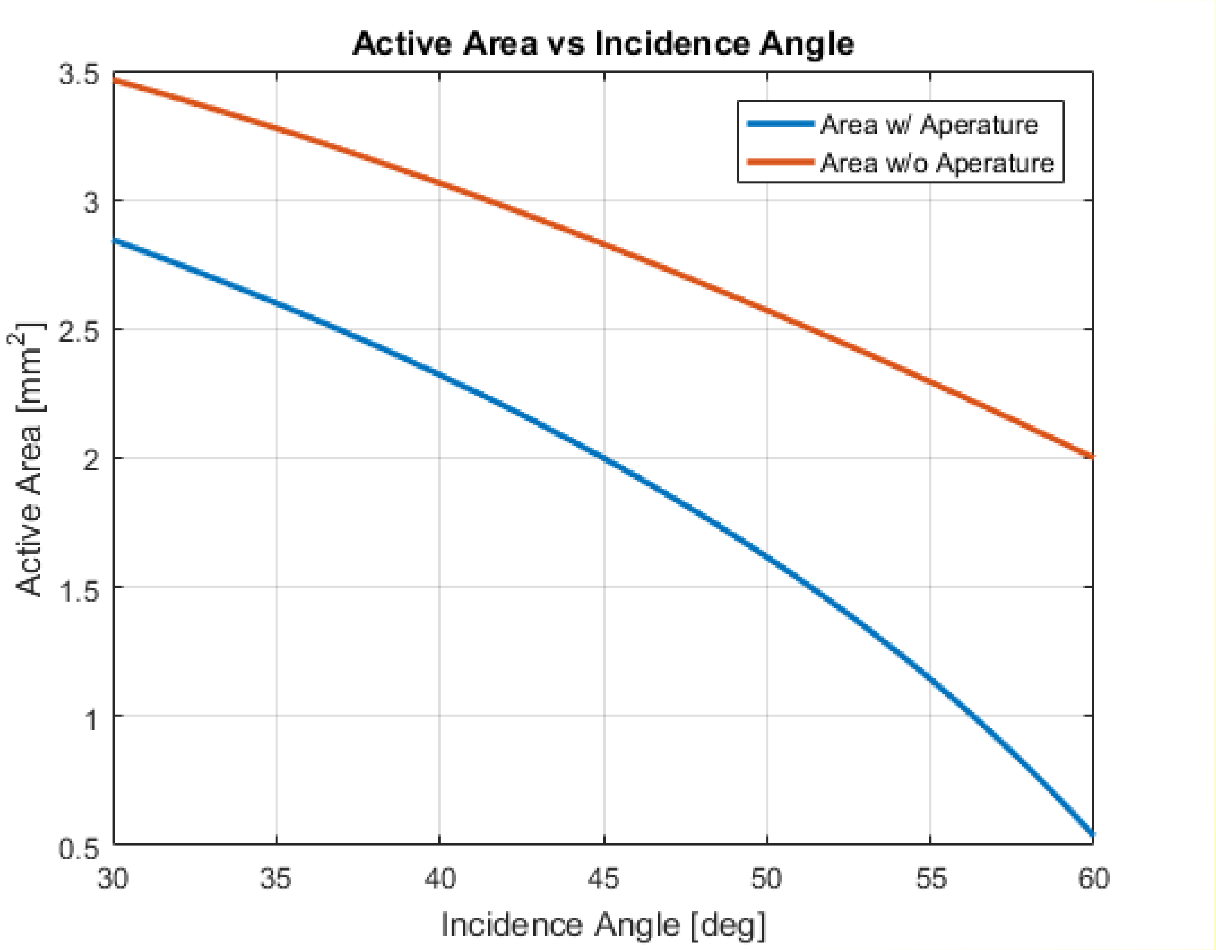
Off-Sun Angle Rates





ADS Aperture Sensitivity



ADS Noise Effects

$$I_{shot} = \sqrt{2qBI_{sig}} \qquad SNR = \frac{I_{sig}}{I_{shot}}$$

- System bandwidth *B* is 1 Hz
- *q* is the charge of an electron (C)
- Dark current (2 nA) SNR = 49 dB
- Short circuit current (90 µA) SNR = 72 dB

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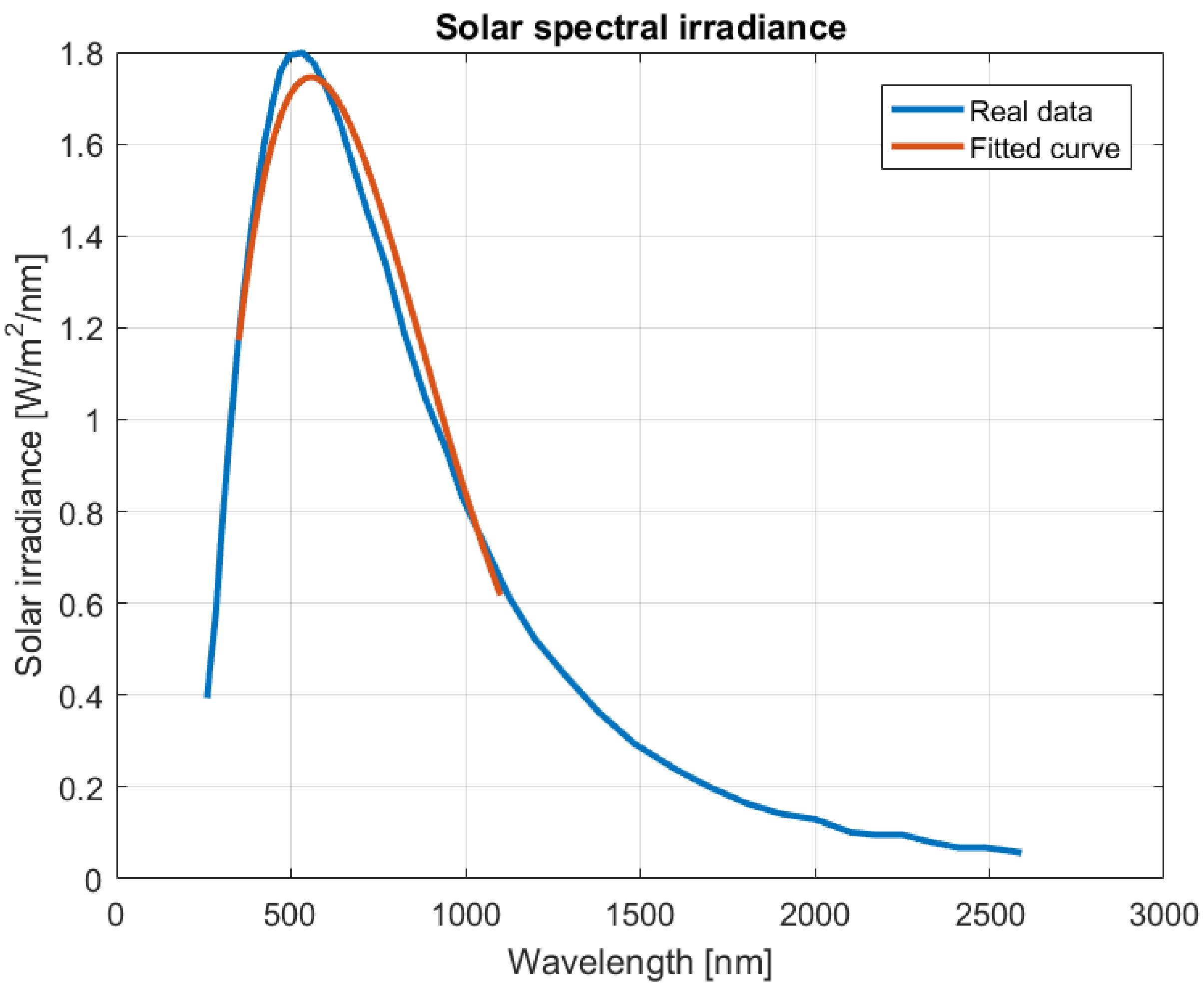
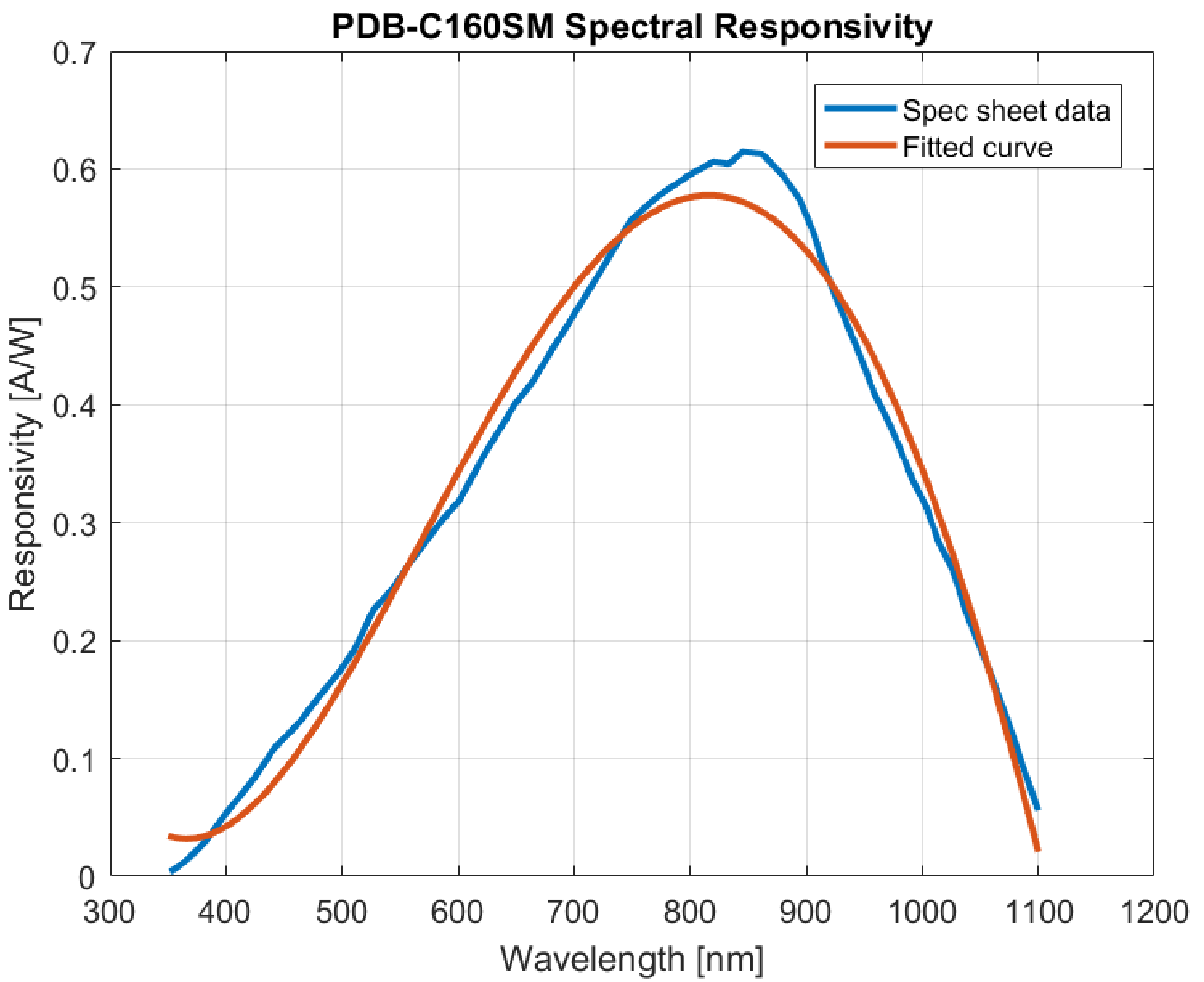
Aerospace Engineering Sciences UNIVERSITY OF COLORADO BOULDER

ADS Spectral Response



ADS Spectral Response



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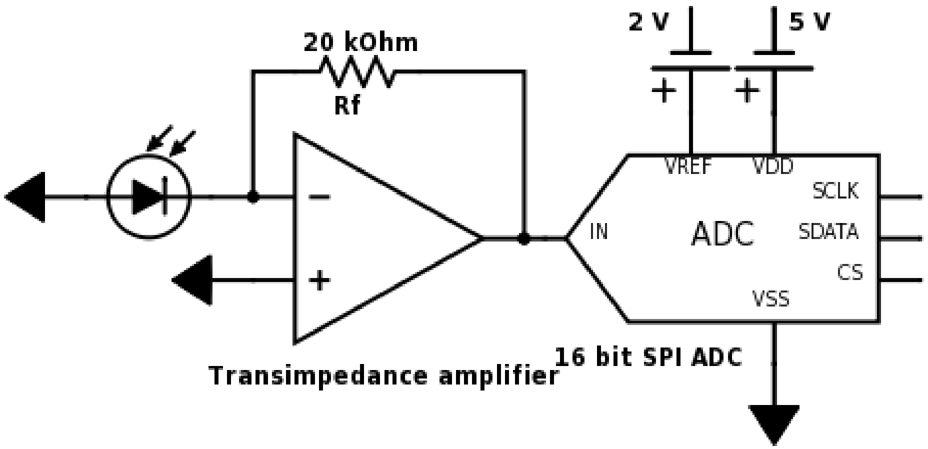
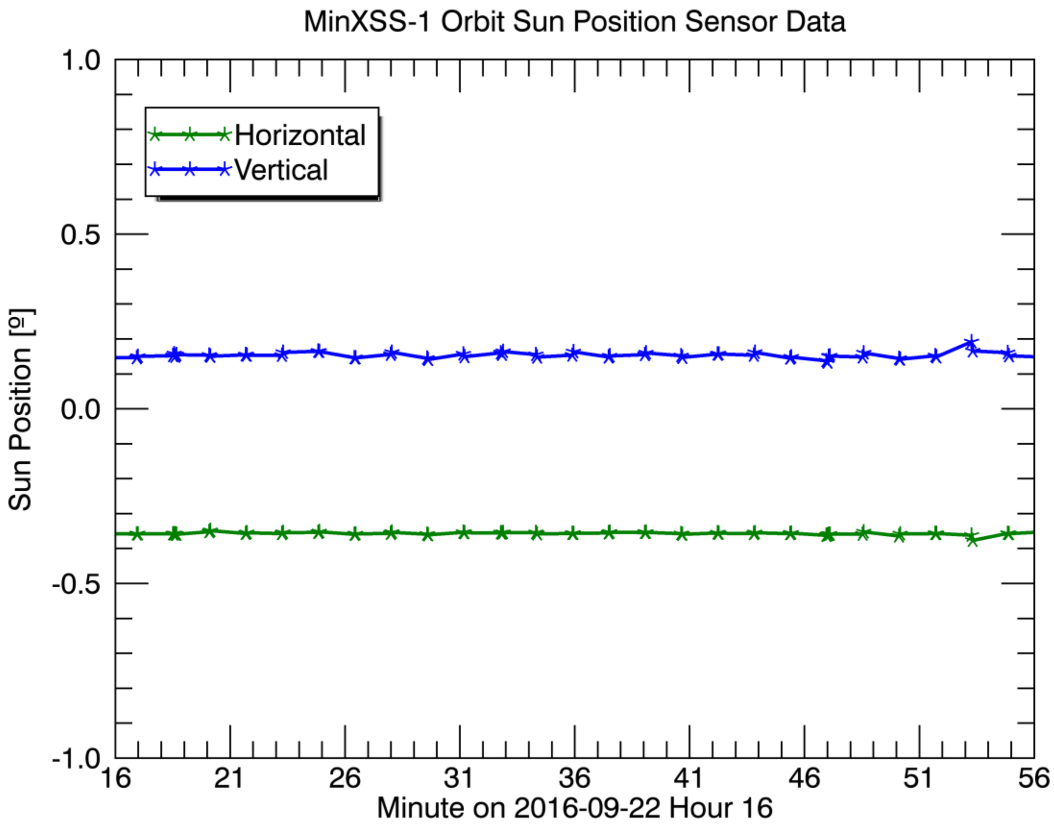
Aerospace Engineering Sciences
UNIVERSITY OF COLORADO BOULDER

ADS Circuit Design



- 16 bit SPI ADC (x4)
  - Require < 0.46 mV/DN
  - Achieves 0.03 mV/DN
  - Max accuracy: ± 0.07' (assuming no noise)
  - Actual (with shot noise): ± 0.1'
- Purchasing a transimpedance amplifier (x4)
  - Noise is specified by manufacturer
  - Sophisticated design for noise reduction
- Photodiode current between 30 μA and 340 μA

MinXSS Accuracy



- Standard deviation: 0.6 arcmin in either direction
  - 0.84 arcmin total error

Data Storage - SLC

Measurement	Size/data point	Frequency	Total
Spectrometer	16.384 kB	1 Hz	10.55 GB
External temperature	4 B	1 Hz	5.273 MB
Internal temps (x6)	24 B	1 Hz	31.638 MB
Humidity	4 B	1 Hz	5.273 MB
Photodiode (x4)	32 B	1 Hz	42.1875 MB
Sun angle	4 B	1 Hz	5.273 MB

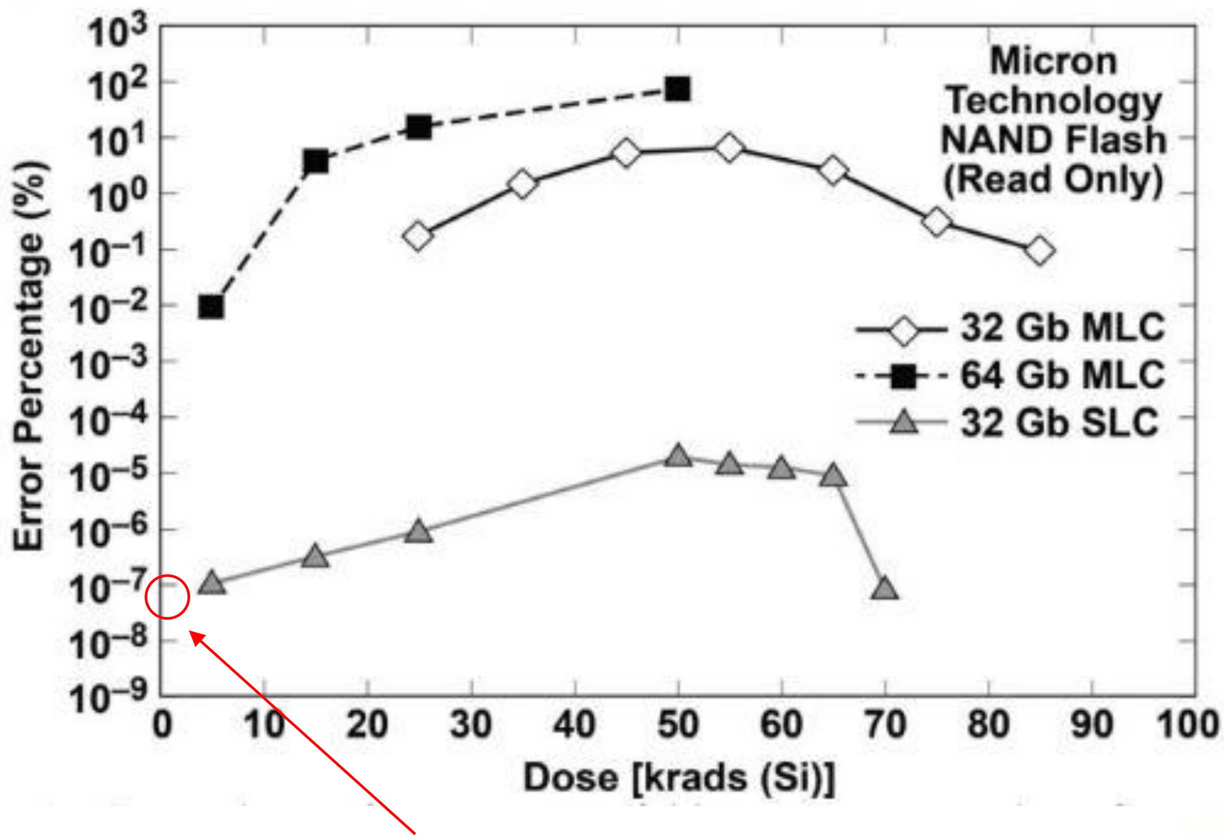
C++ binary data files: floats are 4 bytes, doubles are 8 bytes

Data Storage - MLC

Measurement	Size/data point	Frequency	Total
Camera images	1.8 MB (max)	1/60 Hz	40.5 GB

All test images were within a few bytes of 0.9 MB. We doubled it to be sure.

Data Storage — SEU Risk



- SEU = Single Event Upset
  - E.g. Bit flip
- Total Ionizing Dose Failure Experiment
  - Drives each exposed to radiation for total of 10 seconds
  - For reference: Satellites in LEO experience ~1 krad/year

- Expect ~ .0384 krad over flight

TVAC & Environmental Chamber

Specification	Approach	Resource	External Source
Survive exterior environment at -65°C	Environmental chamber testing	Environmental chamber	Dr. James Nabity
Operate at 5°C	Mimic cruise conditions	TVAC	Dr. Scott Sewell, HAO
Operate at 200 Pa	Mimic cruise conditions	TVAC	Dr. Scott Sewell, HAO
Verify thermal model	Additional temperature sensors on critical components and indicative points	N/A	N/A

FlatSat Integration Testing

Specification	Approach	Resource	External Source
Spectrum: 1/min	Software, data inspection	N/A	N/A
ENV data: 1/min	Software, data inspection	N/A	N/A
Camera images: 1/min	Software, data inspection	N/A	N/A
Spectrum and ENV data measurements recorded within 2 sec	Inspect data timestamps after test	N/A	N/A
All data stores in useable format	Insect data and run minimal plotting analysis after test to verify	N/A	N/A
System operates through 2 week cruise	Continuous test for 48 hours	24-hr Facility Power supply	Trudy Schwartz's Lab

Photodiode Testing

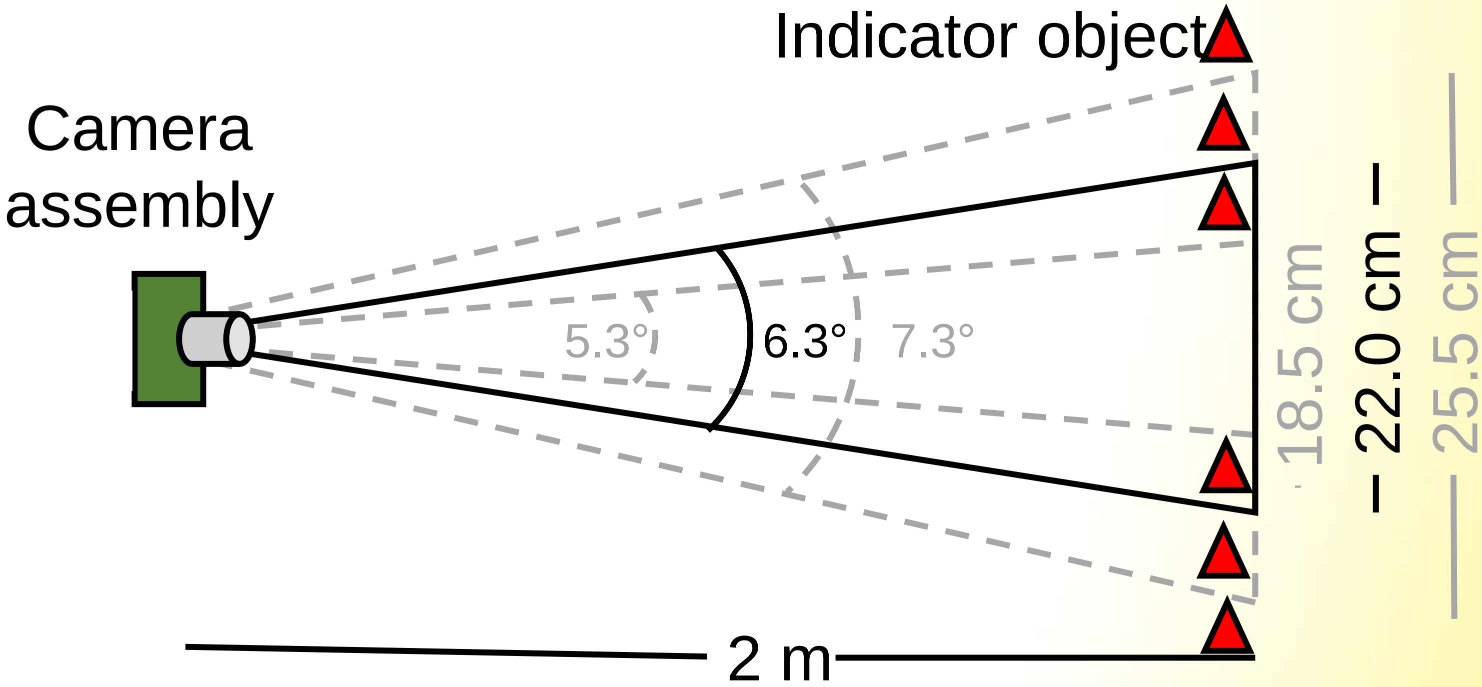
Specification	Approach	Resource	External Source
One arcminute precision	Mount to star tracker with better than arcminute precision	Star-tracking telescope from Sommers-Bausch Observatory (SBO)	Fabio Mezzalira, SBO
Analogous light source	Sun on a clear day	—	—
‘Zero’ condition	Star tracker pointing data Confirm by post-processing camera images	Star-tracking telescope from SBO Software, camera images	Fabio Mezzalira, SBO RADIANCE

Camera Testing

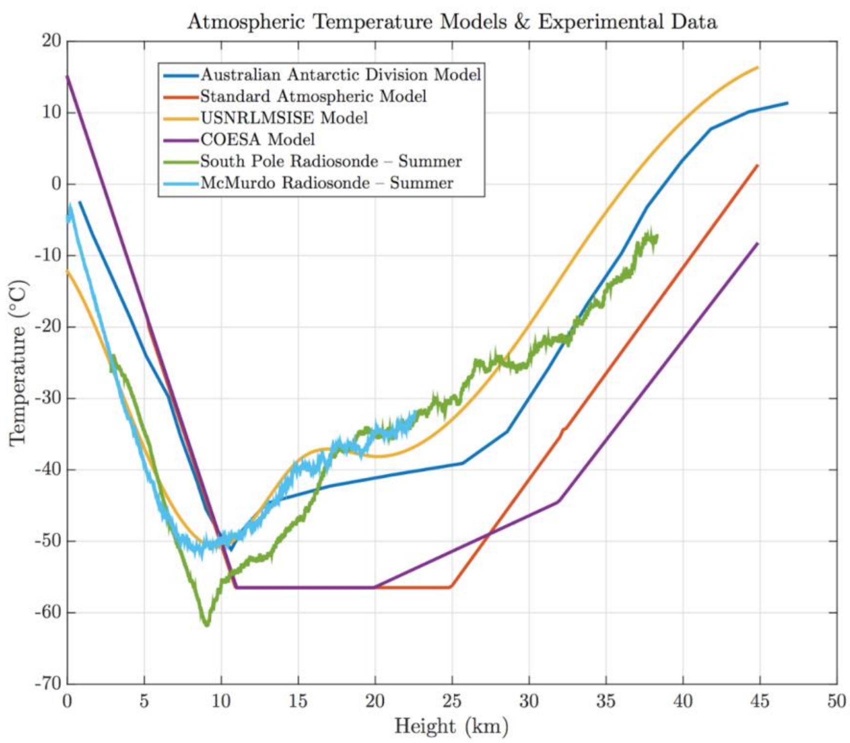
Specification	Approach	Resource	External Source
Images in focus	Visual inspection of test images	N/A	N/A
Analogous light source	Sun on clear day	Star Tracking Telescope	Fabio Mezzalira, SBO
4-6° FOV	Indicators at FOV boundaries	Non-specialized empty space, 2 m x 30 cm Non-specialized indicator objects—textbooks, water bottles, cans, etc.	ITLL N/A

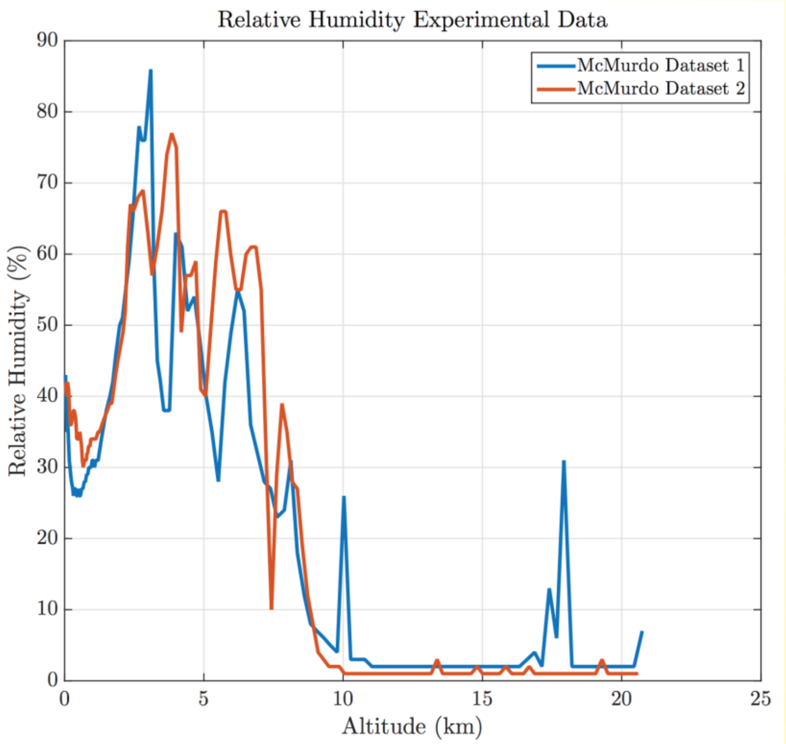
Camera Testing

Validate field of view model

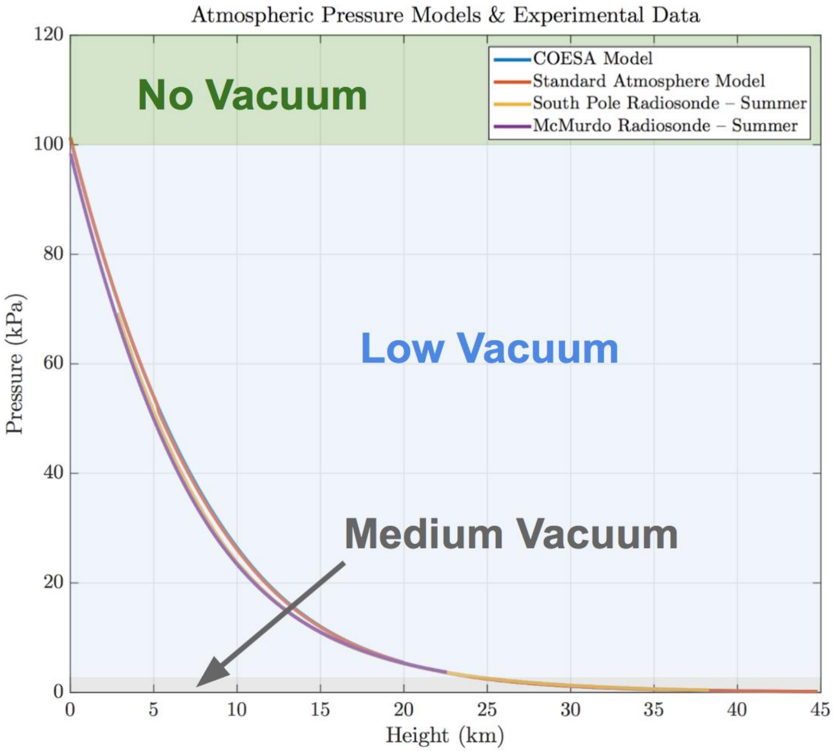


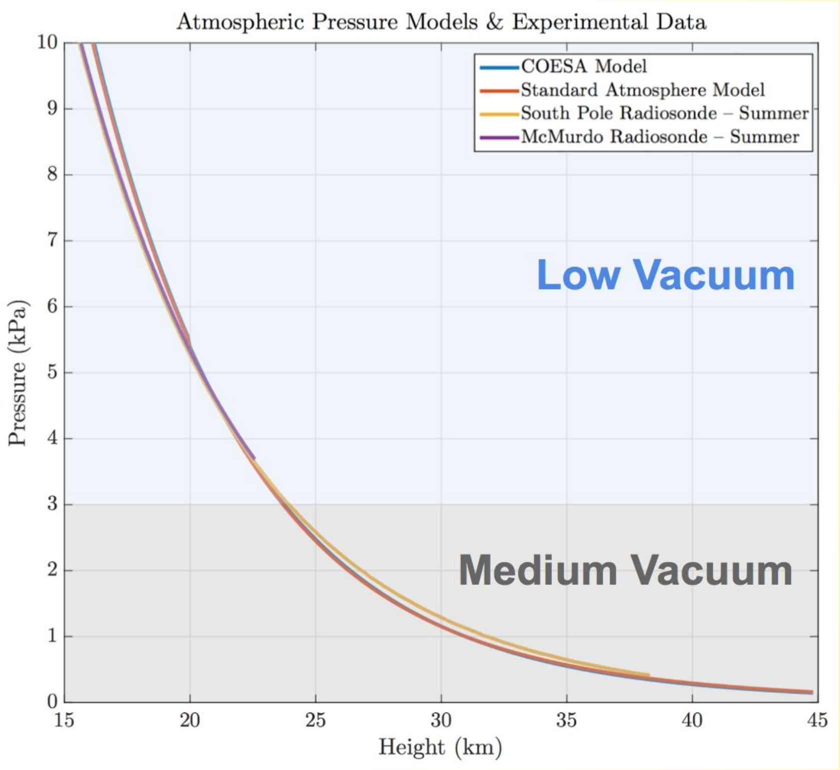
Atmospheric Models



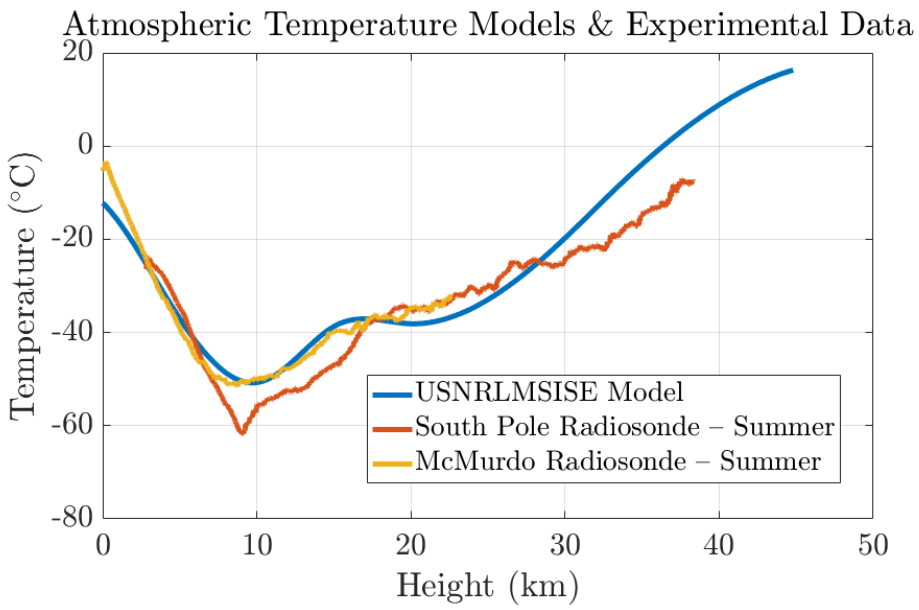


Atmospheric Models



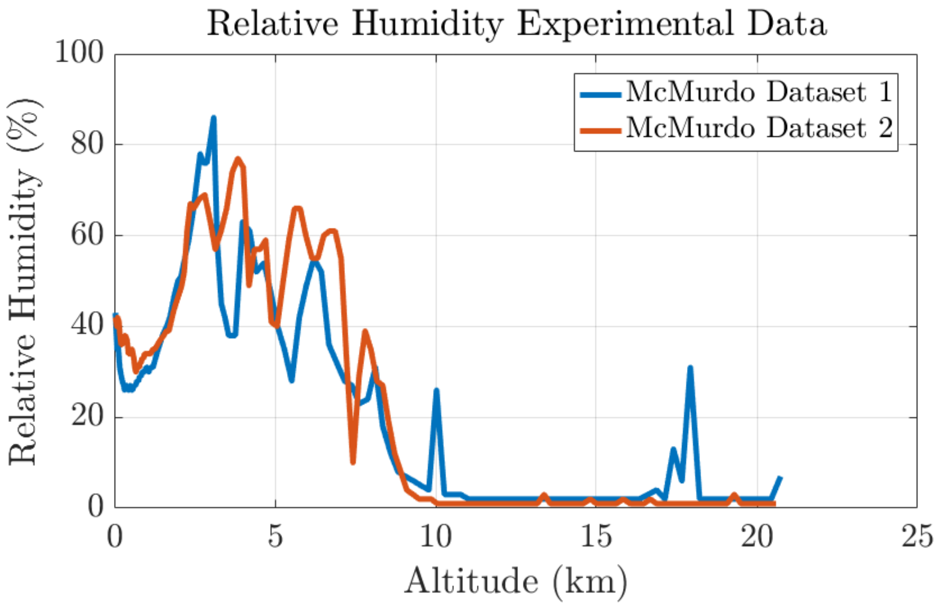


Atmosphere Justification



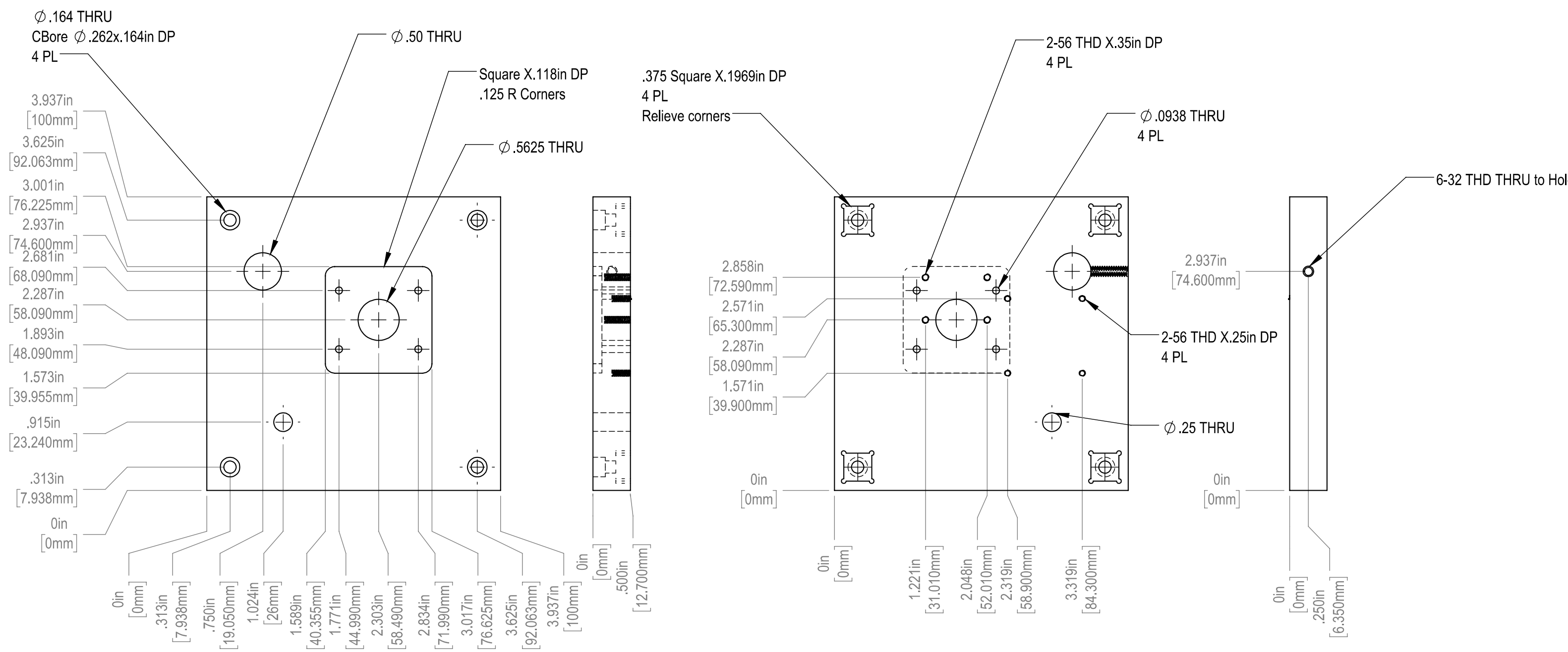
- Used USNRLMSISE model for continuity
- Both McMurdo datasets follow general trend of model

Atmospheric Humidity



- Humidity ranges between 0 and 90%
- Humidity decreases density which affects convection
- May result in condensation/icing on descent

VER.	DESCRIPTION	DATE	BY
1		1/5/2011	



NOTES:

1. The primary source for part dimensions is the solid model.
2. Material: Aluminum 6061-T6
3. Break edges
4. Remove burrs

ALL DIMENSIONS ARE SHOWN IN INCHES UNLESS OTHERWISE NOTED

RADIANCE

University of Colorado, Boulder
Department of Aerospace Engineering
ASEN-4018

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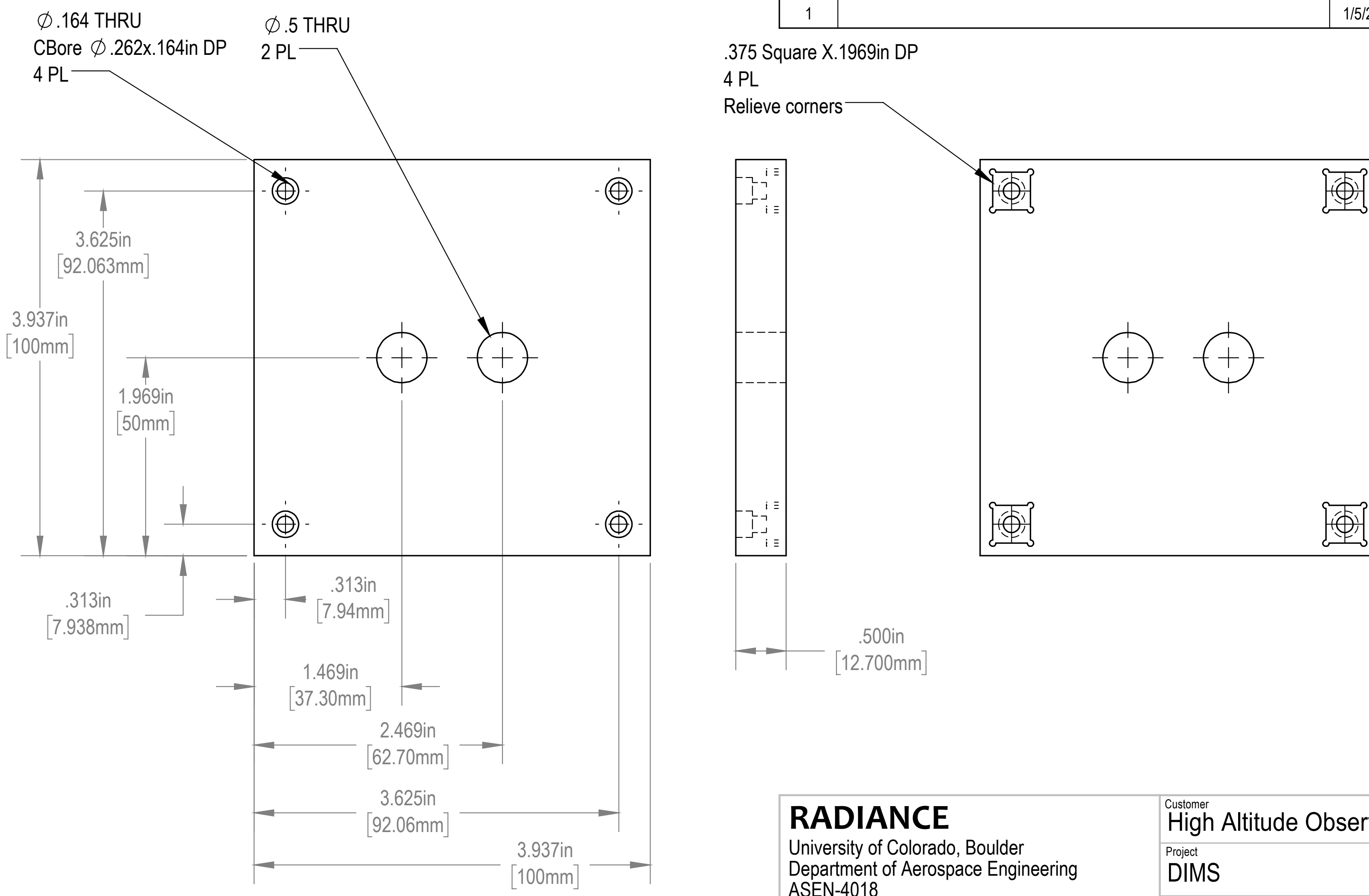
CAD Part Model: front end plate

Customer	High Altitude Observatory
Project	DIMS
Description	Front Interface and Exterior Plate
Part No	Front Face Plate
Drawn By	LGW
Sheet	SHEET 1 of 1
Scale	1:1.5
Dwg Size	B
Ver	1

VER.	DESCRIPTION	DATE	BY
1		1/5/2011	



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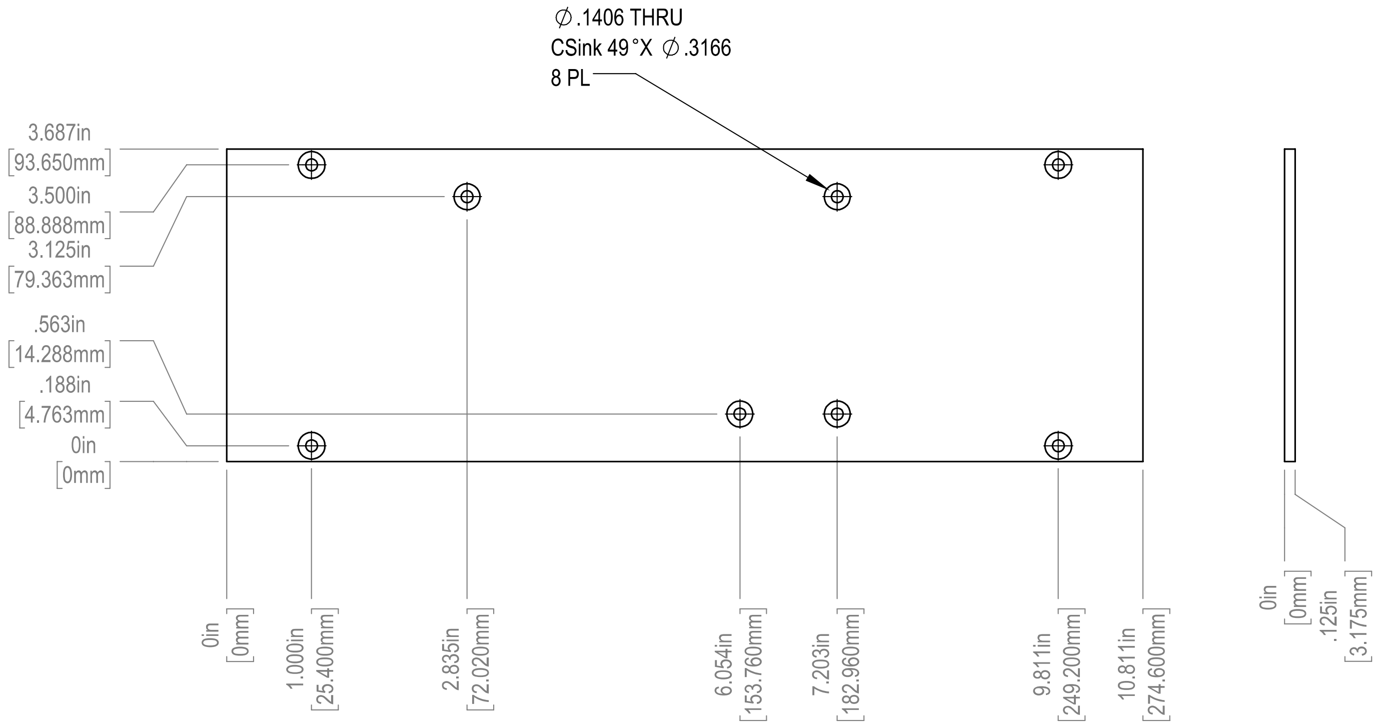
CAD Part Model: back end plate

Customer: High Altitude Observatory
Project: DIMS
Description: Aft exterior plate for RADIANCE system
Part No: Back End Plate
Drawn By: LGW
Sheet: SHEET 1 of 1
Scale: 1:1.5
Dwg Size: A
Ver: 1

VER.	DESCRIPTION	DATE	BY
1		1/5/2011	



NOTES:
1. The primary source for part dimensions is the solid model.
2. Material: Aluminum 6061-T6
3. Break edges.
4. Remove burrs.

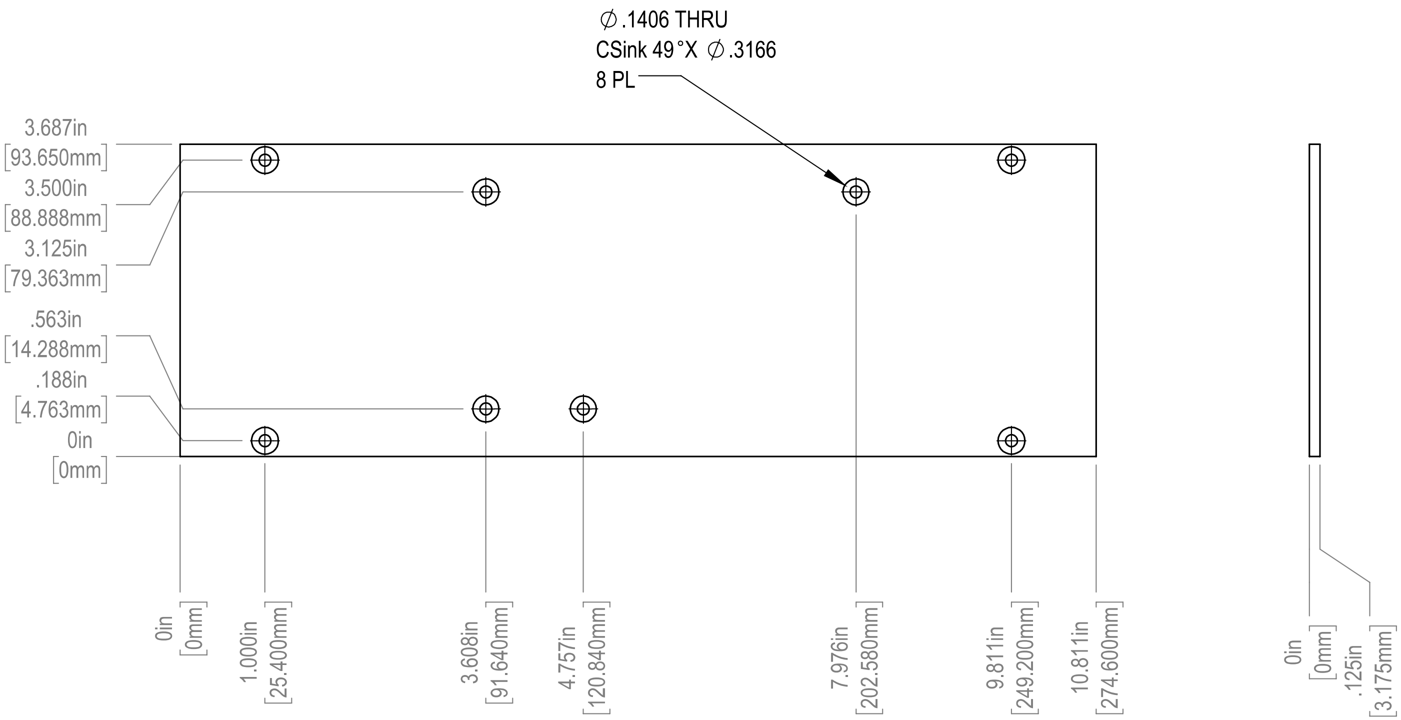
ALL DIMENSIONS ARE SHOWN IN INCHES UNLESS OTHERWISE NOTED

RADIANCE
University of Colorado, Boulder
Department of Aerospace Engineering
ASEN-4018

CAD Part Model: Port Plate

Customer: High Altitude Observatory
Project: DIMS
Description: Port exterior Plate
Part No: Port Plate
Drawn By: LGW
Sheet: SHEET 1 of 1
Scale: 1:2
Dwg Size: A
Ver: 1

VER.	DESCRIPTION	DATE	BY
1		1/5/2011	



NOTES:
1. The primary source for part dimensions is the solid model.
2. Material: Aluminum 6061-T6
3. Break edges.
4. Remove burrs.

ALL DIMENSIONS ARE SHOWN IN INCHES UNLESS OTHERWISE NOTED

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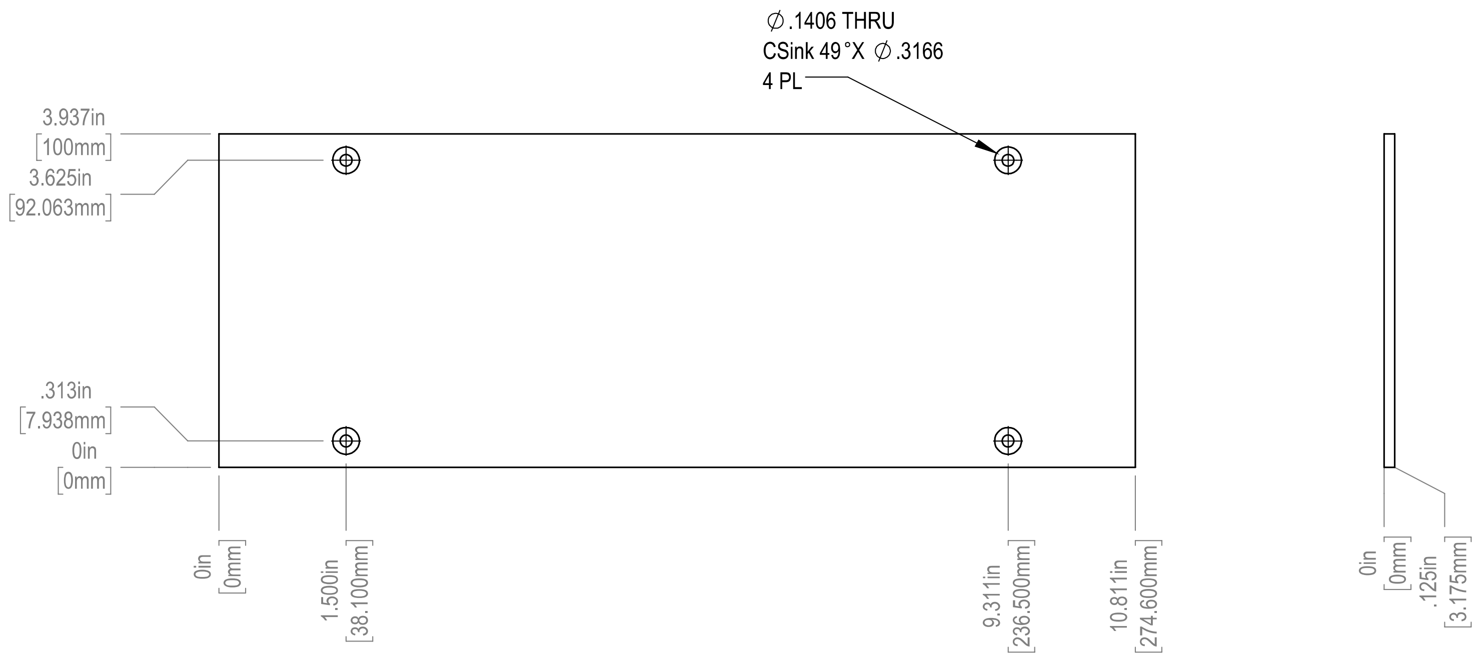
CAD Part Model: Starboard Plate

Customer: High Altitude Observatory
Project: DIMS
Description: Starboard exterior Plate
Part No: Starboard Plate
Drawn By: LGW
Sheet: SHEET 1 of 1
Scale: 1:2
Dwg Size: A
Ver: 1

VER.	DESCRIPTION	DATE	BY
1		1/5/2011	



NOTES:
1. The primary source for part dimensions is the solid model.
2. Material: Aluminum 6061-T6
3. Break edges.
4. Remove burrs.

ALL DIMENSIONS ARE SHOWN IN INCHES UNLESS OTHERWISE NOTED

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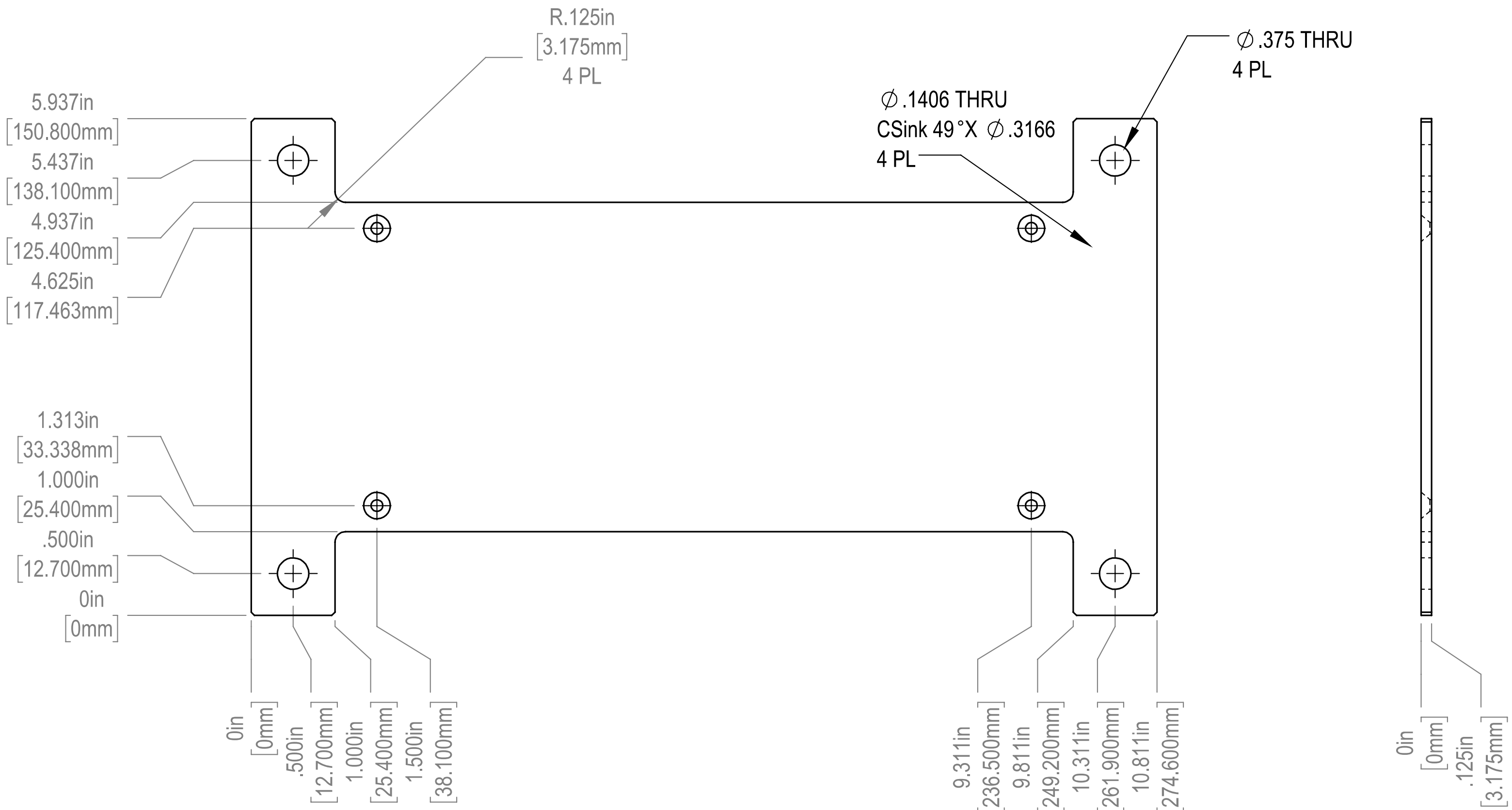
Field	Value
Customer	High Altitude Observatory
Project	DIMS
Description	Top Exterior plate
Part No	Top Plate
Drawn By	LGW
Sheet	SHEET 1 of 1
CAD Part Model	Top plate
Scale	1:2
Dwg Size	A
Ver	1

VER.	DESCRIPTION	DATE	BY
1		1/5/2011	



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Customer: High Altitude Observatory
Project: DIMS
Description: Exterior Bottom Plate with mounts for HiWind
Part No: Bottom Exterior Plate
Drawn By: LGW
Sheet: SHEET 1 of 1
CAD Part Model: Bottom Plate
Scale: 1:2
Dwg Size: A
Ver: 1

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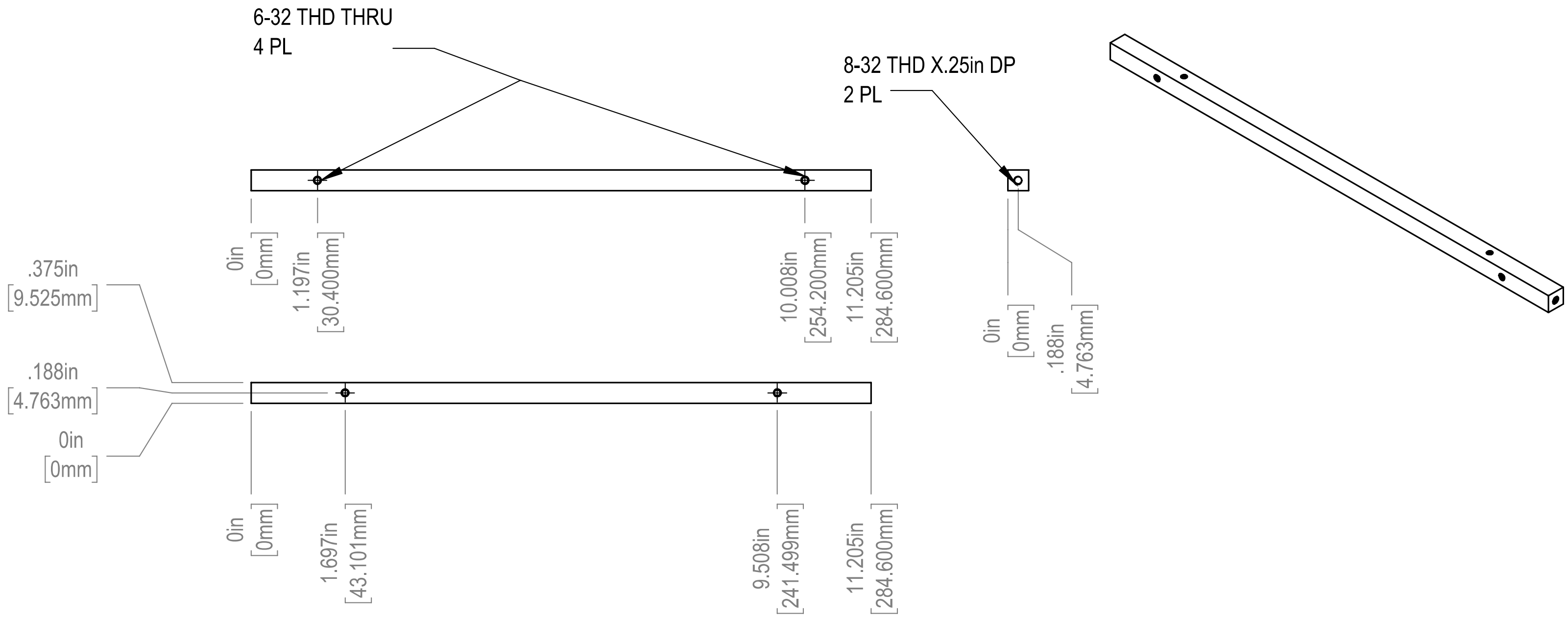
NOTES:
1. The primary source for part dimensions is the solid model.
2. Material: Aluminum 6061-T6
3. Break edges.
4. Remove burrs.

VER.	DESCRIPTION	DATE	BY
1		1/5/2011	



NOTES:
1. The primary source for part dimensions is the solid model.
2. Material: Aluminum 6061-T6
3. Break edges.
4. Remove burrs.

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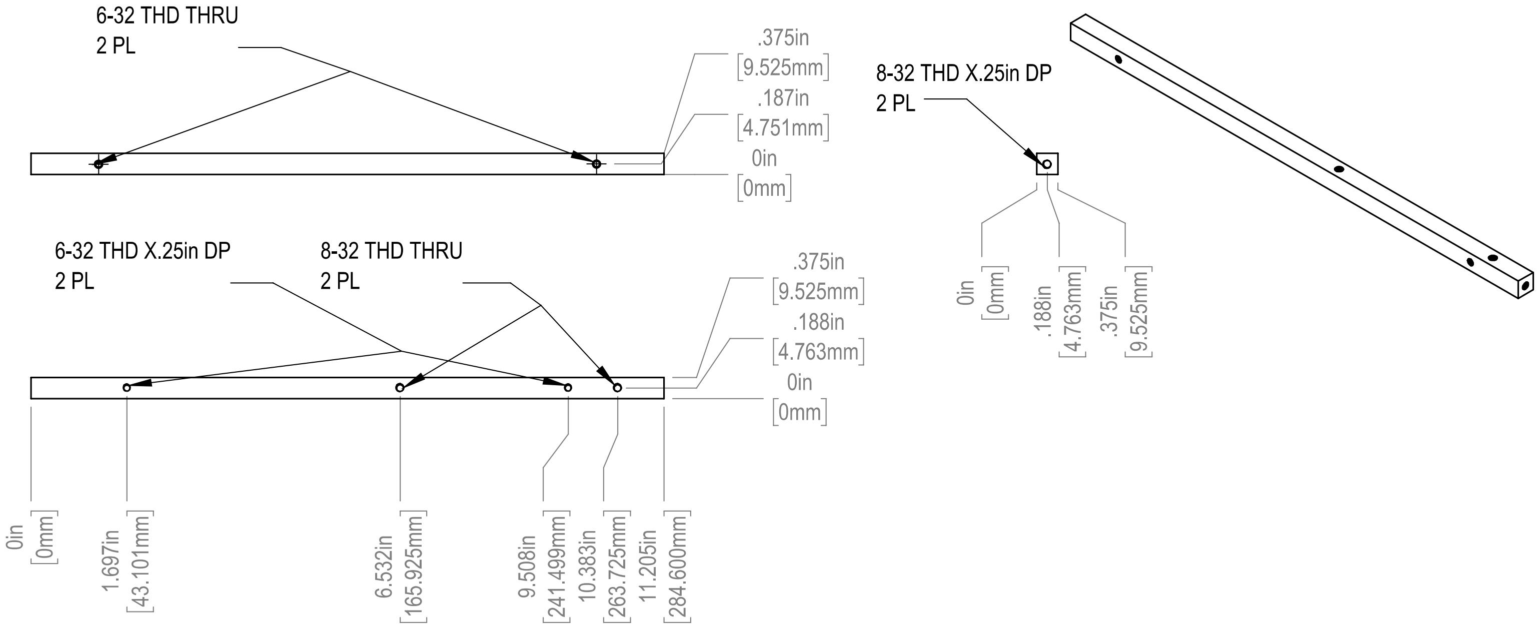
CAD Part Model: length spare 4

Customer: High Altitude Observatory
Project: DIMS
Description: Upper Main Support Bar
Part No: Upper Length Spar
Drawn By: LGW
Sheet: SHEET 1 of 1
Scale: 1:3
Dwg Size: A
Ver: 1

VER.	DESCRIPTION	DATE	BY
1		1/5/2011	



NOTES:
1. The primary source for part dimensions is the solid model.
2. Material: Aluminum 6061-T6
3. Break edges.
4. Remove burrs.

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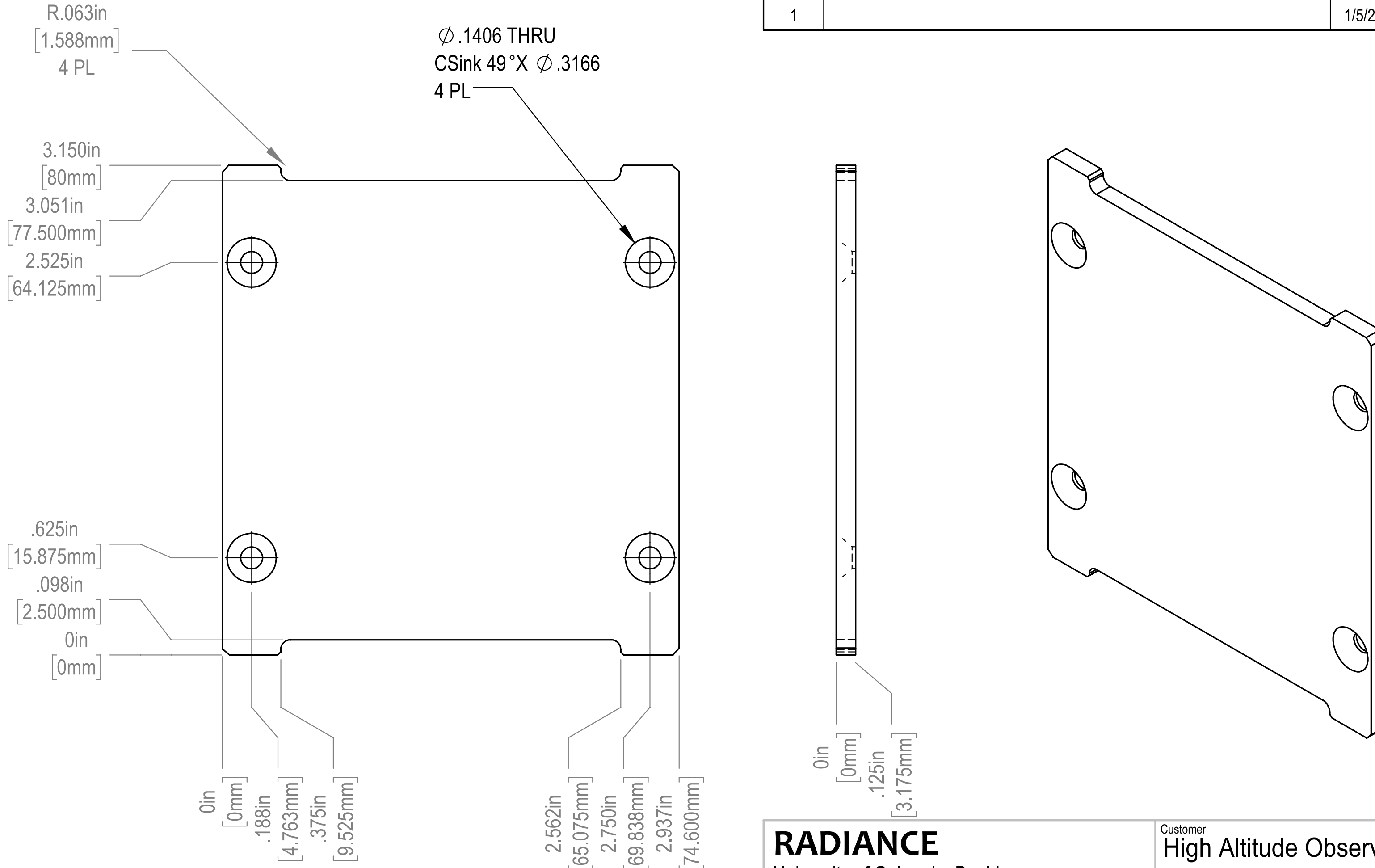
CAD Part Model: length spare 1

Customer: High Altitude Observatory
Project: DIMS
Description: Lower Main Support Bar
Part No: Lower Length Spar
Drawn By: LGW
Sheet: SHEET 1 of 1
Scale: 1:3
Dwg Size: A
Ver: 1

VER.	DESCRIPTION	DATE	BY
1		1/5/2011	



NOTES:
1. The primary source for part dimensions is the solid model.
2. Material: Aluminum 6061-T6
3. Break edges.
4. Remove burrs.

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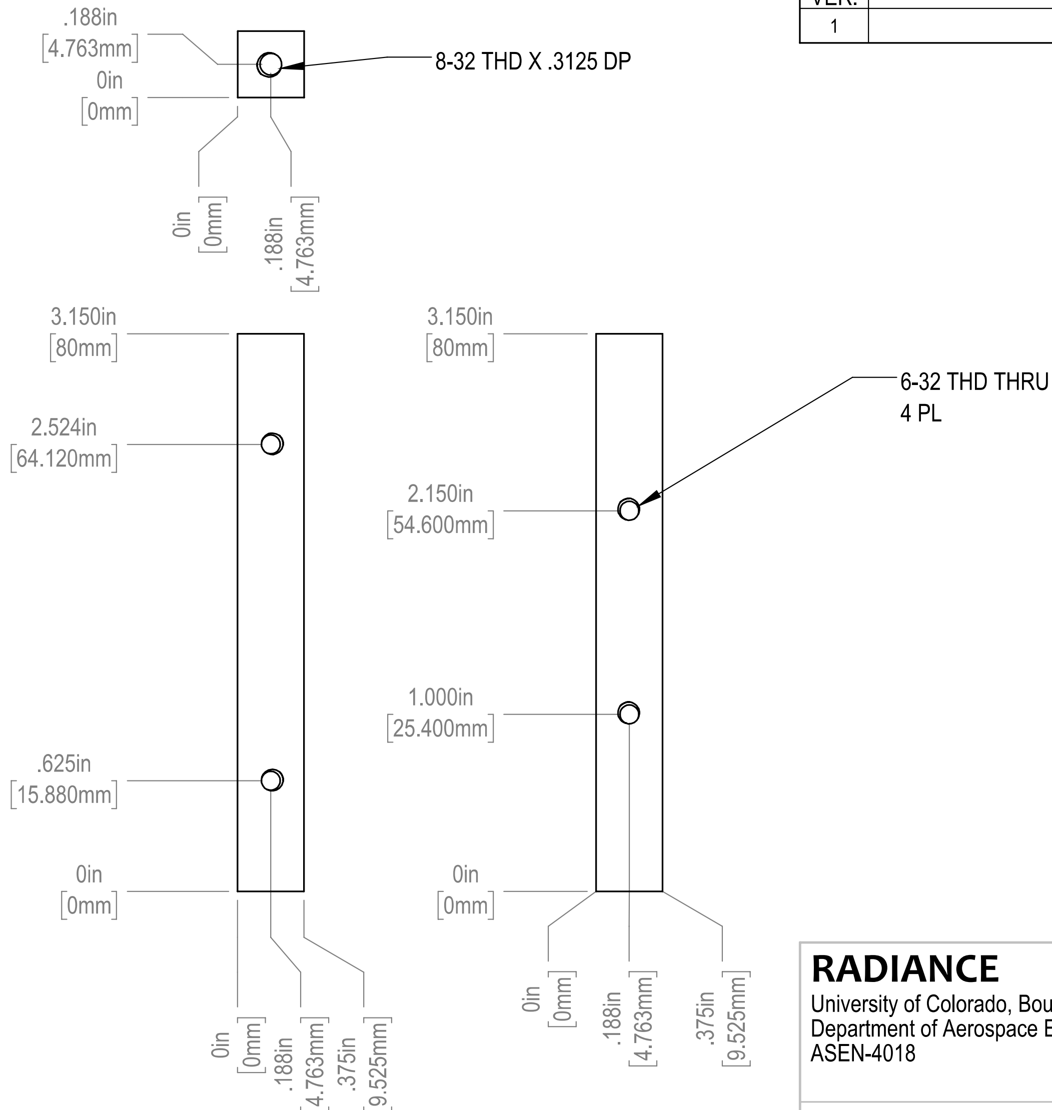
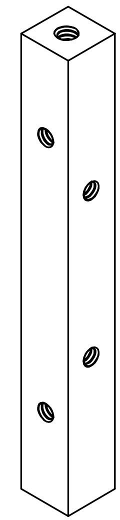
Field	Value
Customer	High Altitude Observatory
Project	DIMS
Description	Battery Mounting Plate
Part No	Battery Mounting Plate
Drawn By	LGW
Sheet	SHEET 1 of 1
CAD Part Model	Battery Mounting Plate
Scale	1:1
Dwg Size	A
Ver	1

VER.	DESCRIPTION	DATE	BY
1		1/5/2011	





NOTES:

1. The primary source for part dimensions is the solid model.
2. Material: Aluminum 6061-T6
3. Break edges.
4. Remove burrs.

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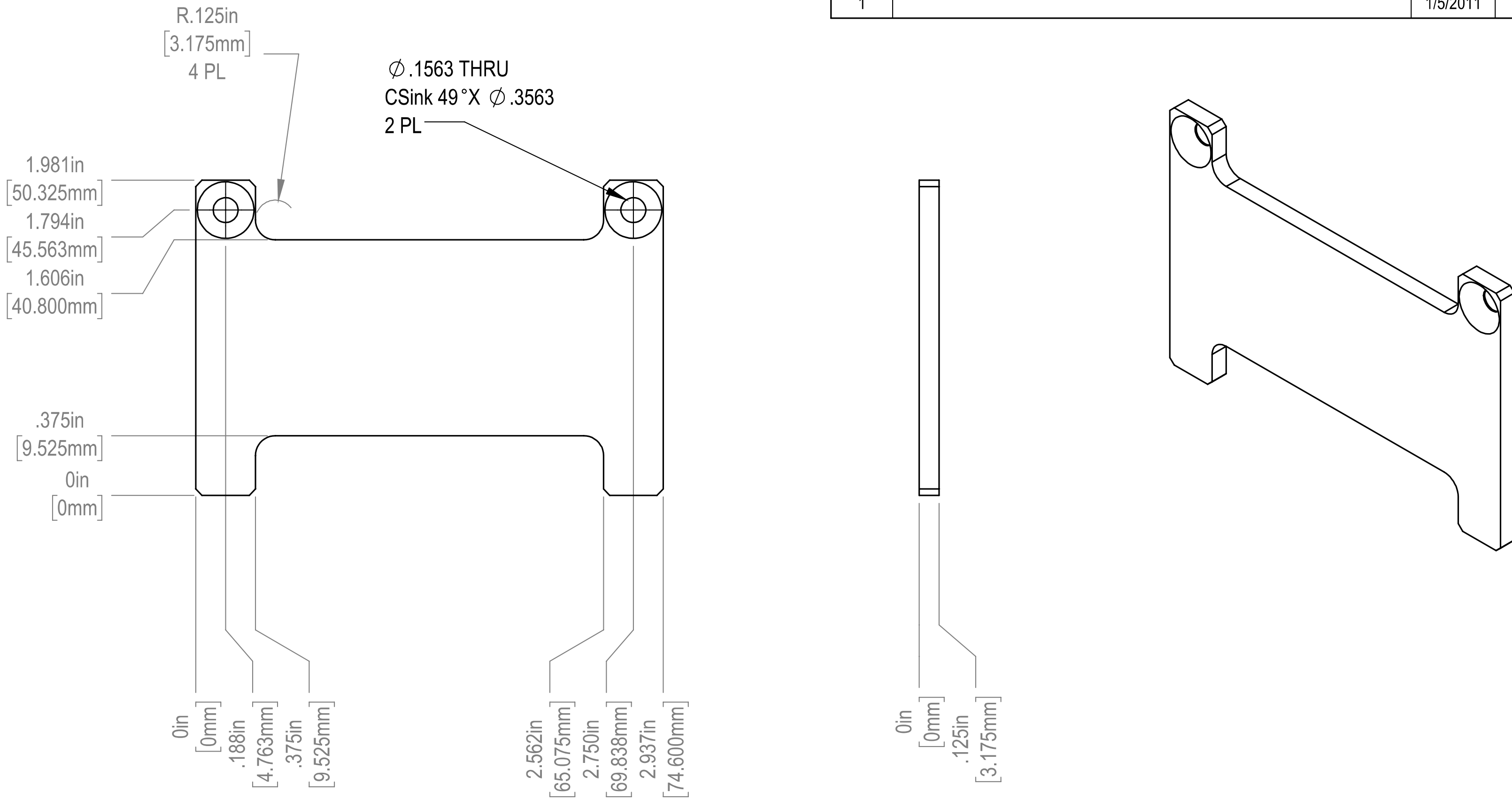
Customer: High Altitude Observatory		
Project: DIMS		
Description: Battery Mounting Bar for support plate		
Part No: Battery Mounting Bar		
Drawn By: LGW	Sheet: SHEET 1 of 1	
Scale: 1:1	Dwg Size: A	Ver: 1

CAD Part Model: Battery Support Bar Port

VER.	DESCRIPTION	DATE	BY
1		1/5/2011	



NOTES:
1. The primary source for part dimensions is the solid model.
2. Material: Aluminum 6061-T6
3. Break edges.
4. Remove burrs.

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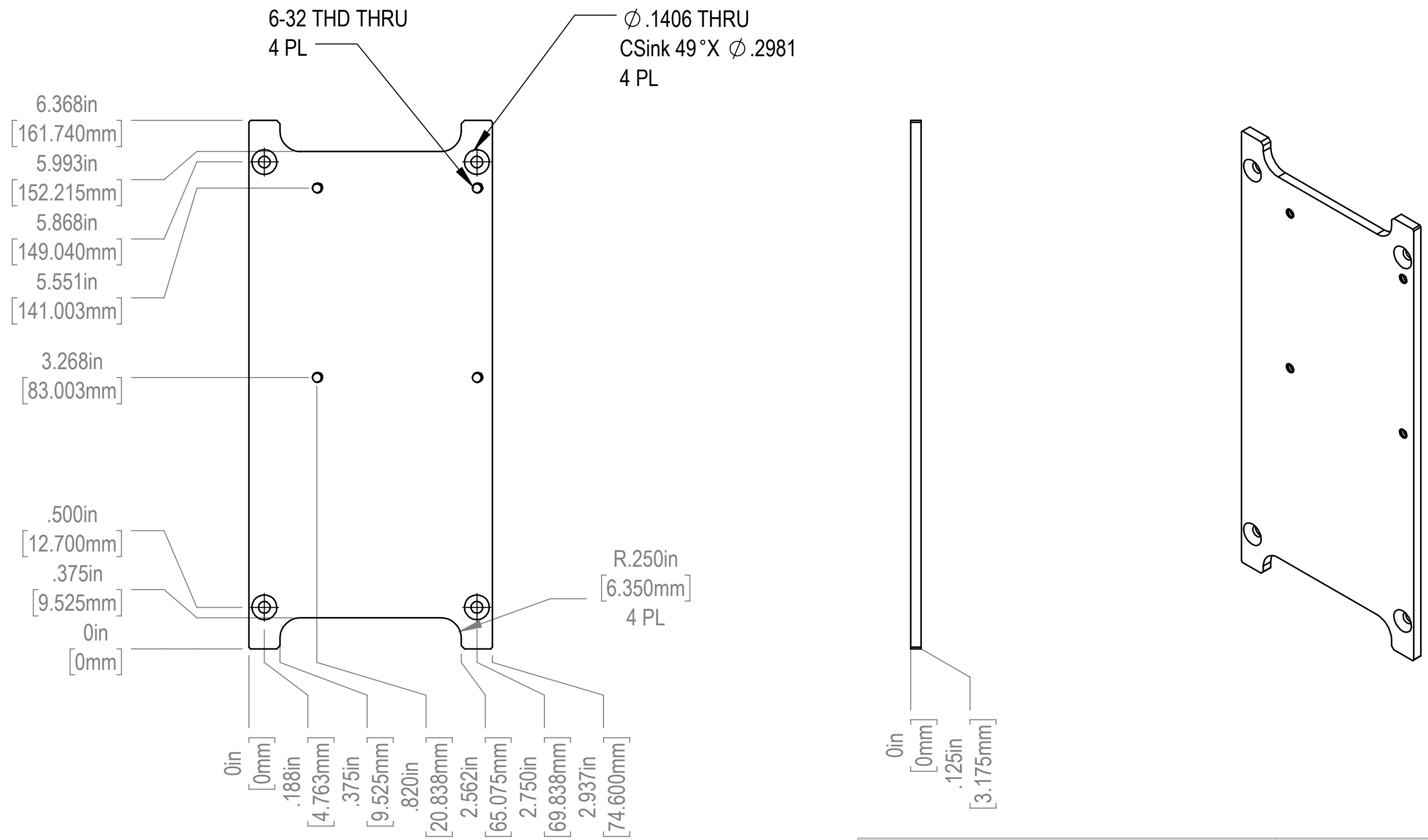
Customer	High Altitude Observatory
Project	DIMS
Description	Holds SLC Flash Storage device in place.
Part No	Flash Drive Securing Plate
Drawn By	LGW
Sheet	SHEET 1 of 1
CAD Part Model	Camera Mounting Plate
Scale	1:1
Dwg Size	A
Ver	1

VER.	DESCRIPTION	DATE	BY
1		1/5/2011	



NOTES:

1. The primary source for part dimensions is the solid model.
2. Material: Aluminum 6061-T6
3. Break edges.
4. Remove burrs.

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CAD Part Model: RaspberryPi Plate

Customer: High Altitude Observatory

Project: DIMS

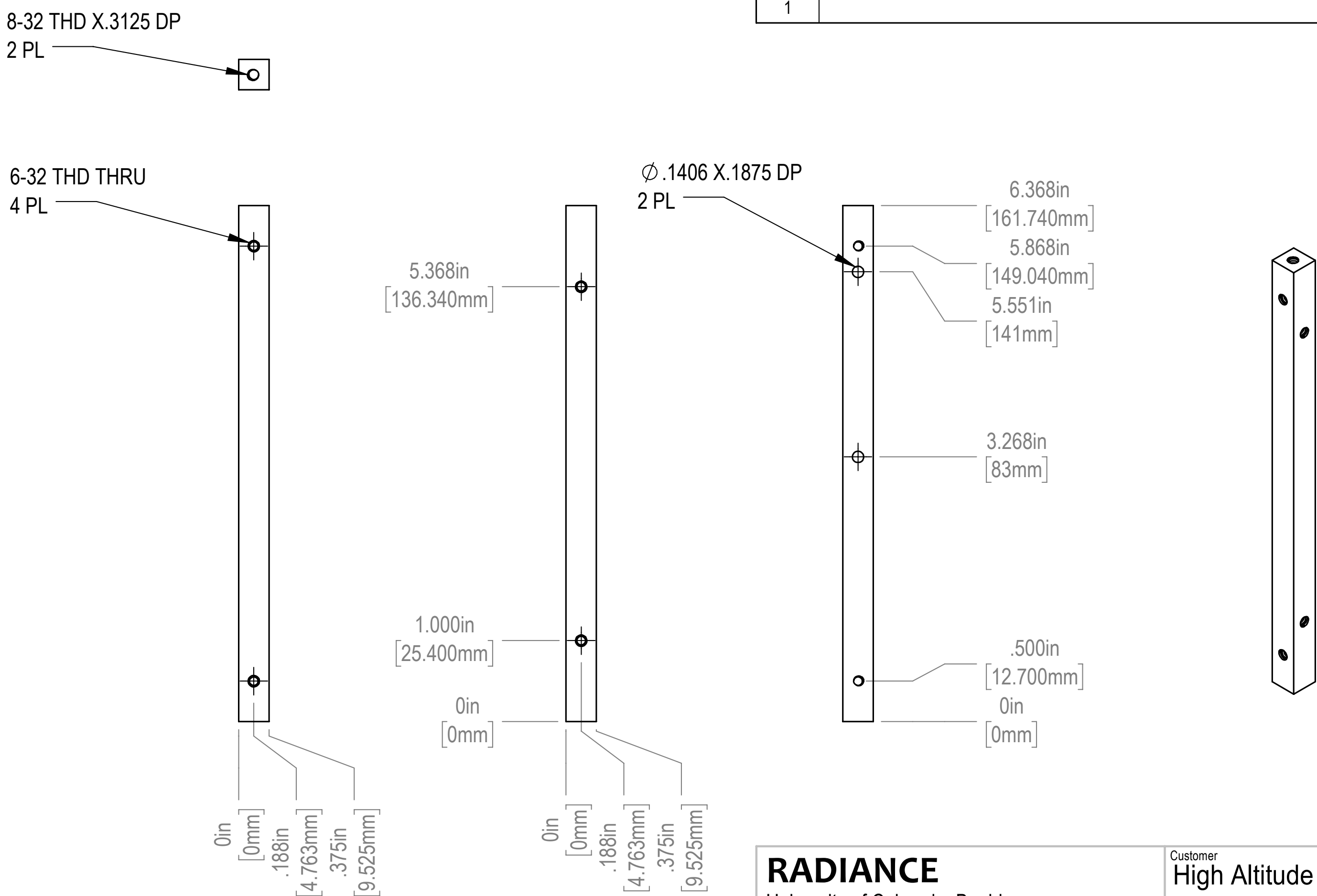
Description: Plate that the Raspberry Pi Mounts to

Part No: RaspberryPi Plate

Drawn By: LGW | Sheet: SHEET 1 of 1

Scale: 1:2 | Dwg Size: A | Ver: 1

VER.	DESCRIPTION	DATE	BY
1		1/5/2011	



NOTES:
1. The primary source for part dimensions is the solid model.
2. Material: Aluminum 6061-T6
3. Break edges.
4. Remove burrs.

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CAD Part Model: internal support bar 3

Customer: High Altitude Observatory
Project: DIMS
Description: Raspberry Pi Support bar with reliefs for screws
Part No: Internal Support Bar 3
Drawn By: LGW
Sheet: SHEET 1 of 1
Scale: 1:2
Dwg Size: A
Ver: 1

VER.	DESCRIPTION	DATE	BY
1		1/5/2011	

NOTES:

1. The primary source for part dimensions is the solid model.
2. Material: Aluminum 6061-T6
3. Break edges.
4. Remove burrs.

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CAD Part Model: INTERNAL SUPPORT BAR 4

Customer: High Altitude Observatory

Project: DIMS

Description: Raspberry Pi Support bar without reliefs for screws

Part No: Internal Support Bar 4

Drawn By: LGW

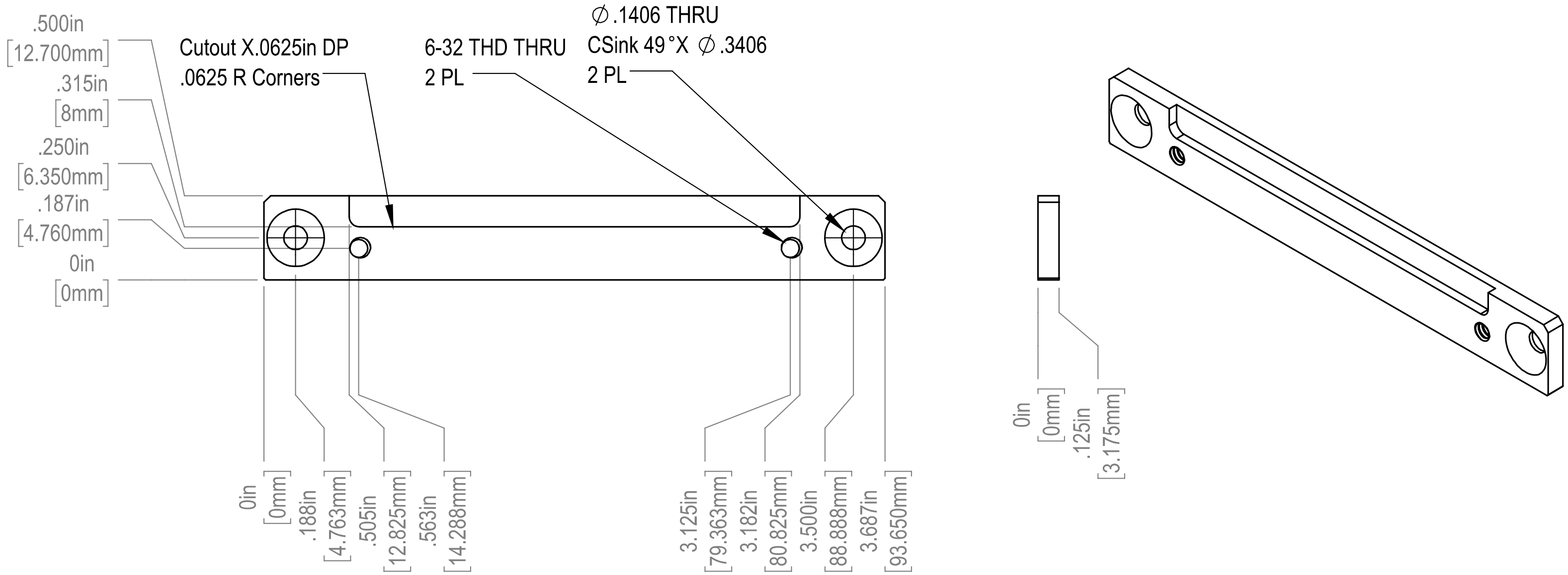
Sheet: SHEET 1 of 1

Scale: 1:2

Dwg Size: A

Ver: 1

VER.	DESCRIPTION	DATE	BY
1		1/5/2011	



NOTES:

1. The primary source for part dimensions is the solid model.
2. Material: Aluminum 6061-T6
3. Break edges.
4. Remove burrs.

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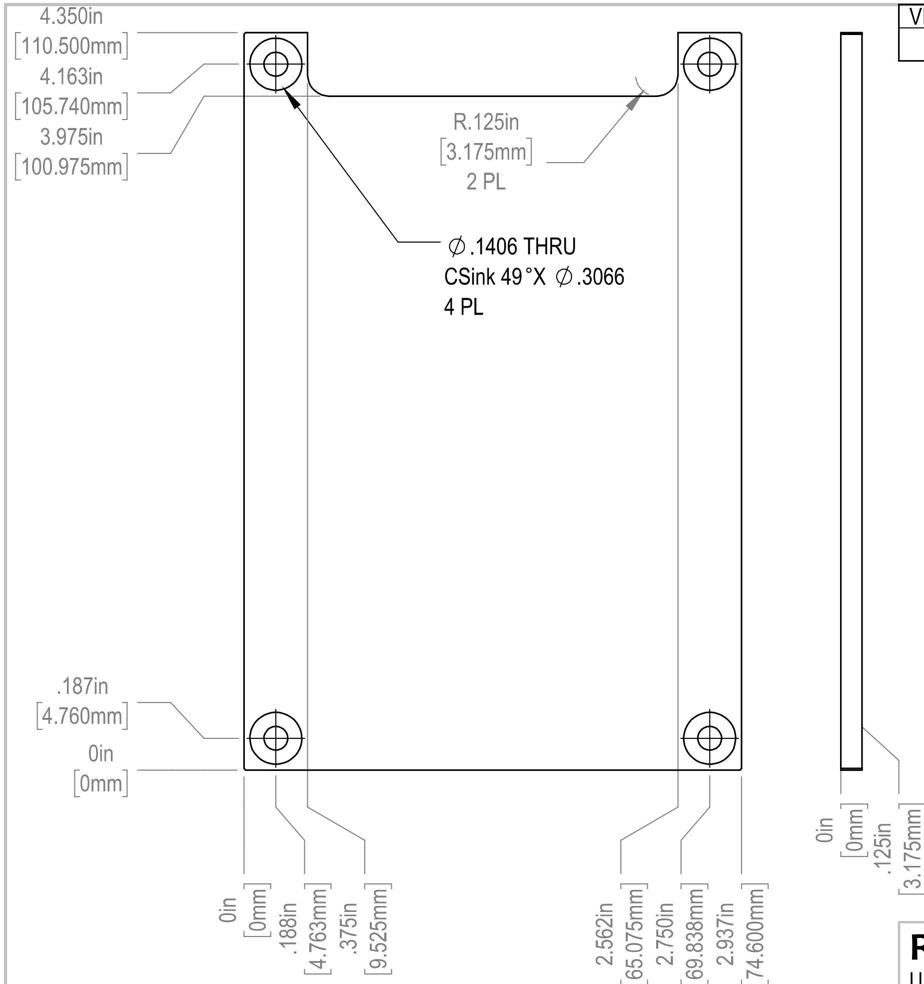
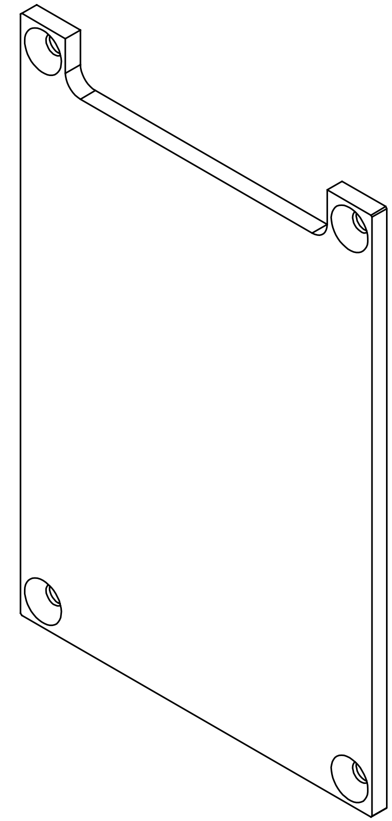
RADIANCE University of Colorado, Boulder Department of Aerospace Engineering ASEN-4018	Customer High Altitude Observatory	
	Project DIMS	
CONFIDENTIAL AND PROPRIETARY THIS DRAWING AND ANY ASSOCIATED MODEL(S) OR ASSEMBLIES ARE PROPERTY OF UNIVERSITY OF COLORADO AND CANNOT BE REPRODUCED WITHOUT PRIOR CONSENT	Description Lower plate that holds the spectrometer in place.	
	Part No Lower Spectrometer Plates	
	Drawn By LGW	Sheet SHEET 1 of 1
CAD Part Model Lower_spectrometer_plate	Scale 1:1	Dwg Size A — Ver 1

VER.	DESCRIPTION	DATE	BY
1		1/5/2011	





NOTES:

1. The primary source for part dimensions is the solid model.
2. Material: Aluminum 6061-T6
3. Break edges.
4. Remove burrs.

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CAD Part Model: Upper spectrometer plate

Customer: High Altitude Observatory

Project: DIMS

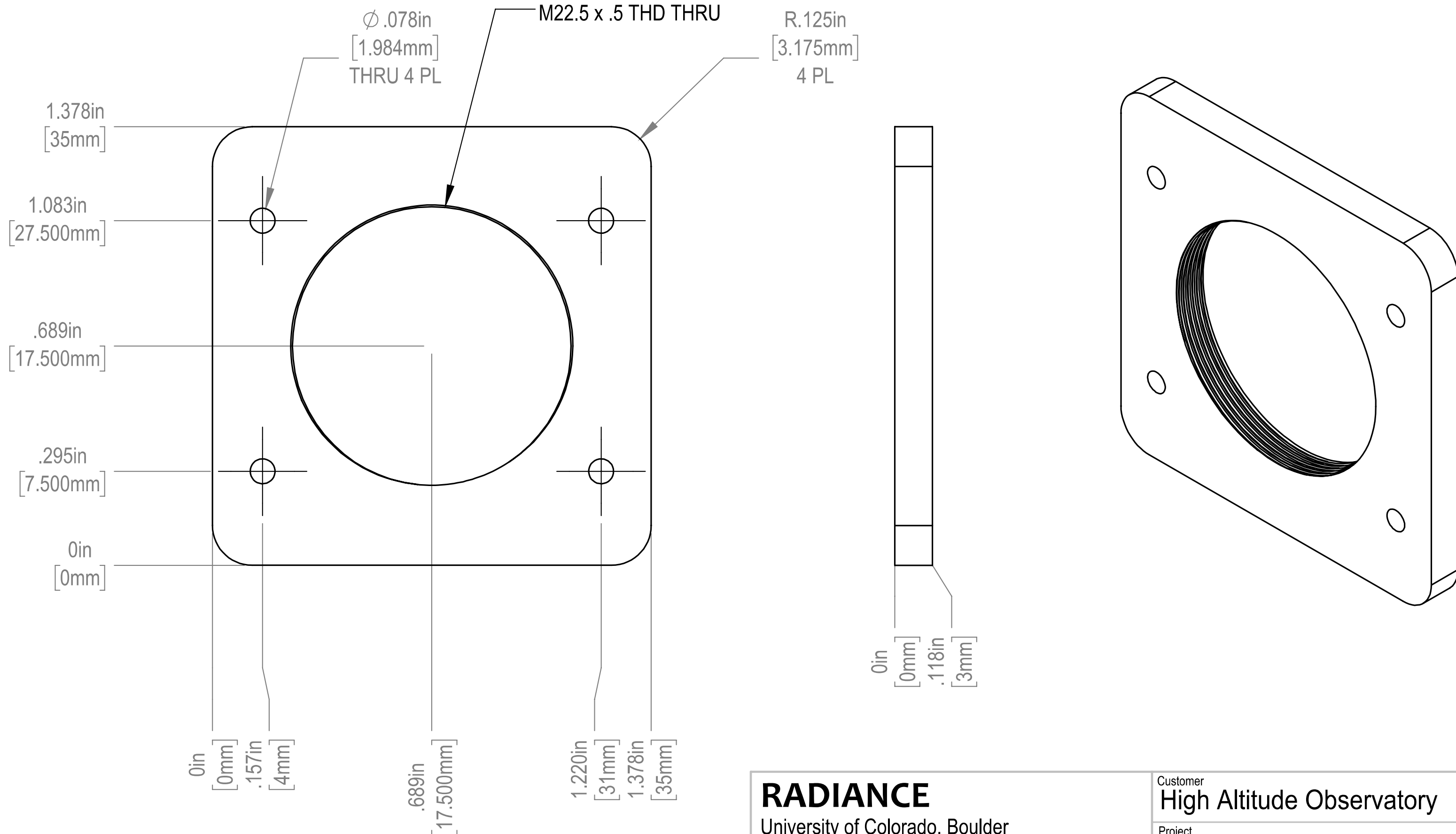
Description: Top Plate that holds the spectrometer down

Part No: Spectrometer Top Plate

Drawn By	Sheet	
LGW	SHEET 1 of 1	

Scale	Dwg Size	Ver
1:1	A	1

VER.	DESCRIPTION	DATE	BY
1		1/5/2011	



NOTES:
1. The primary source for part dimensions is the solid model.
2. Material: Plastic Resin TBD
3. Break edges.
4. Remove burrs.

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CAD Part Model: Neutral Density Filter Threads

Field	Value
Customer	High Altitude Observatory
Project	DIMS
Description	3D printed part for mounting the neutral density filter
Part No	Neutral Density Filter Threads
Drawn By	LGW
Sheet	SHEET 1 of 1
Scale	2:1
Dwg Size	A
Ver	1