RADIANCE

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

Manufacturing Status Review

Presenters: Lance Walton, Jenny Kampmeier, David Varley, James Pavek, Alec Fiala

Team Members: Brandon Antoniak, Jeremy Muesing, Katie Dudley, Russell Bjella

NCAR NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

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Aerospace Engineering Sciences
UNIVERSITY OF COLORADO **BOULDER**

Outline

Project Overview	Jenny	10%
Schedule	Jenny & Alec	20%
Mechanical	Lance	20%
Electrical	Alec & David	20%
Software	James	20%
Budget	David	10%

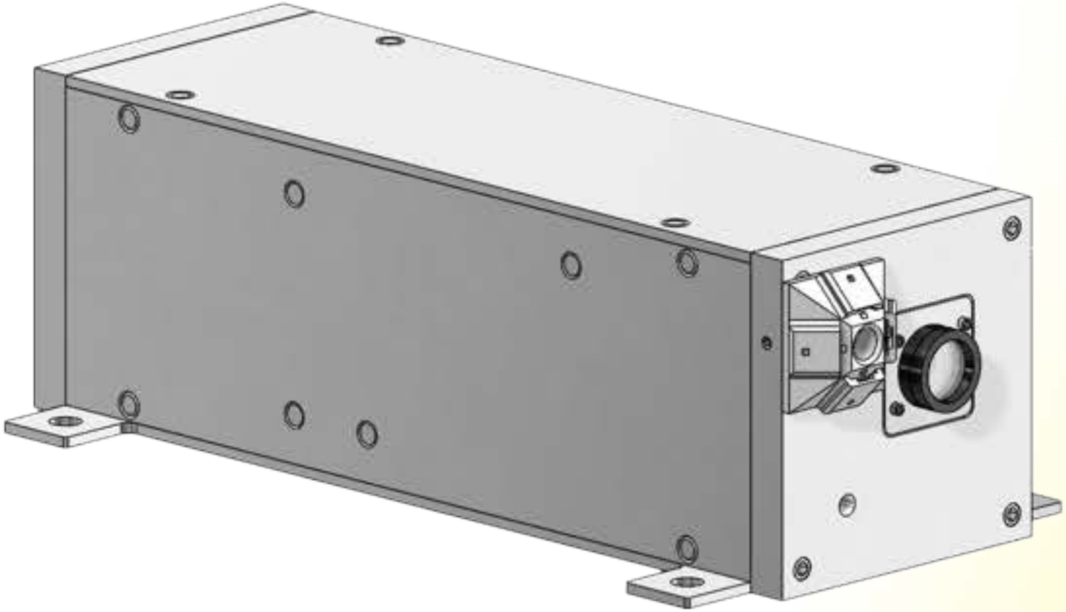
Project Statement

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.

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.

Levels of Success

System	Achieved
Instrumentation	3
Thermal	3
C&DH	3
EPDS	1
ADS	2
Structure	1

- Minimum or no risk of not meeting Level 1 for EPDS and Structure
    - Structure is completed and meets requirements
    - EPDS relies on HiWind for power

CDR 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

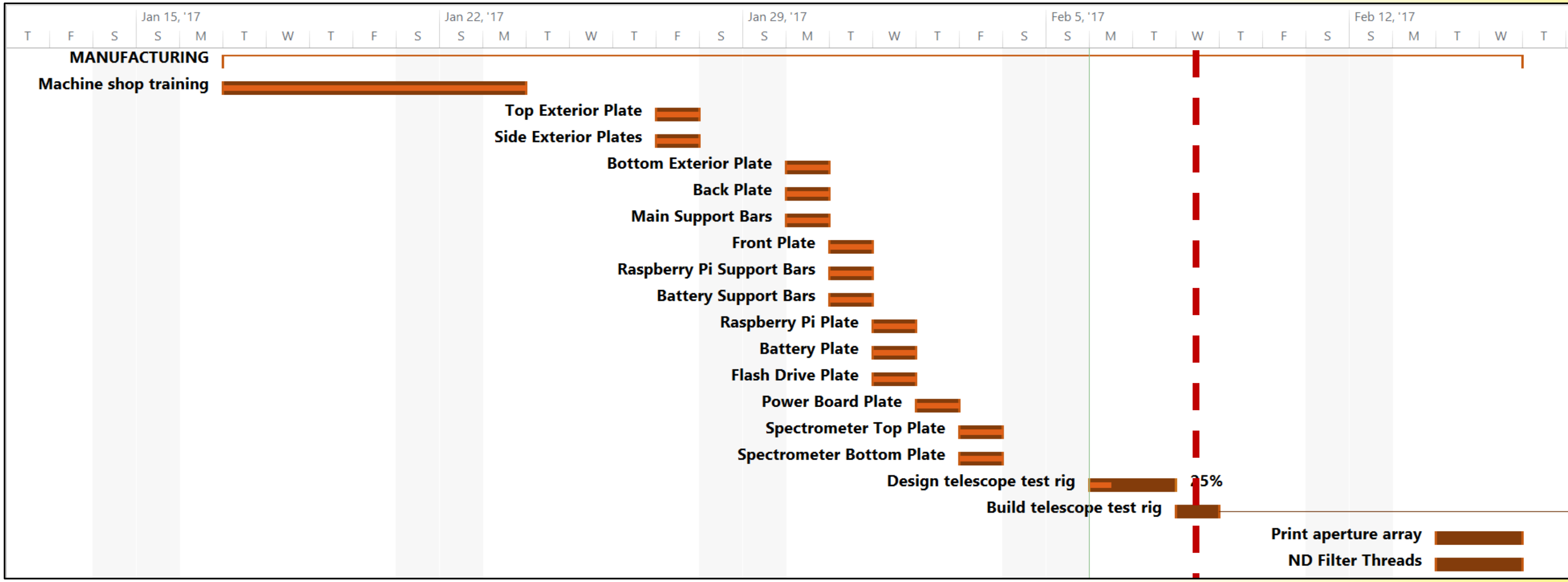
Remaining CPEs

- **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

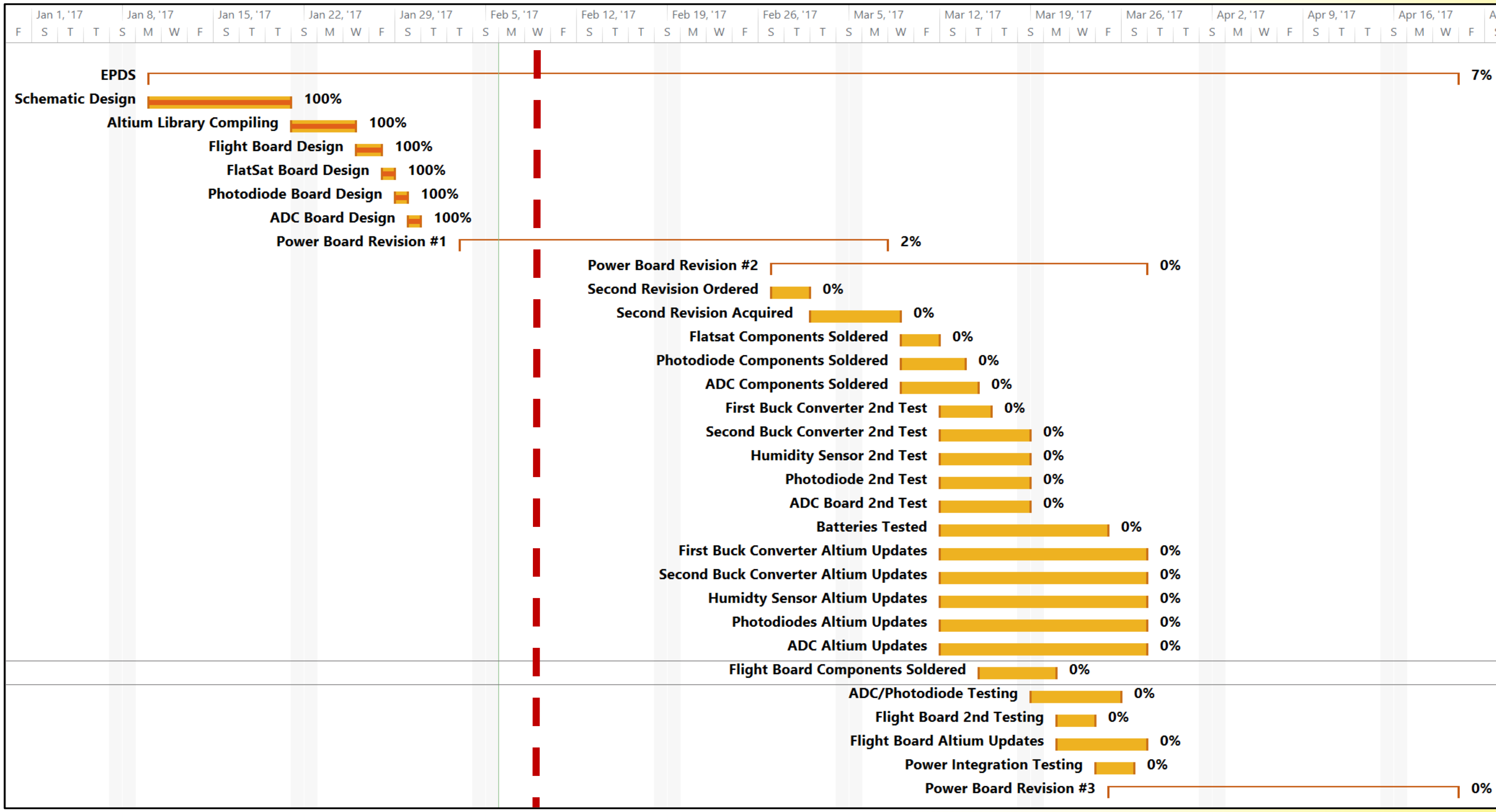
Executive Summary

System	Percent Completed
EPDS	12%
Procurement	65%
Manufacturing	90%
Thermal	90%
Software	79%
Attitude Determination	60%
Course Milestones	15%
Path-to-Space Report	0%

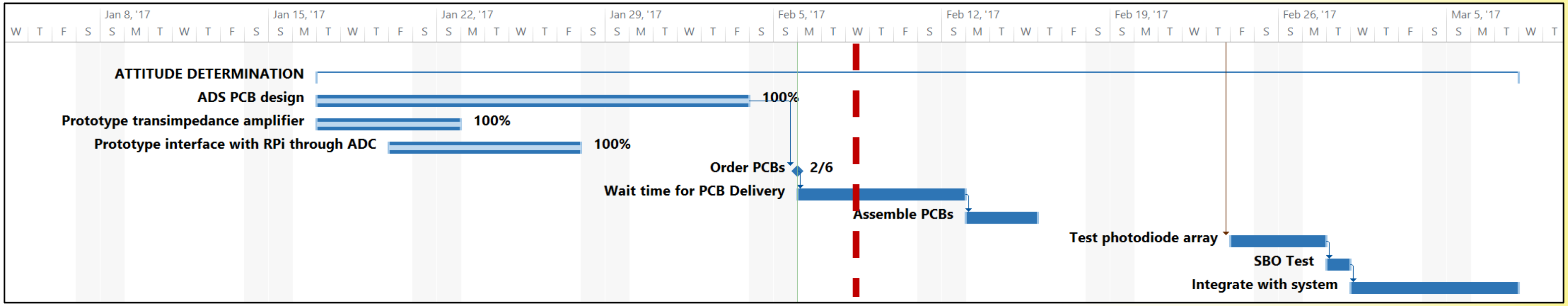
Mechanical Schedule



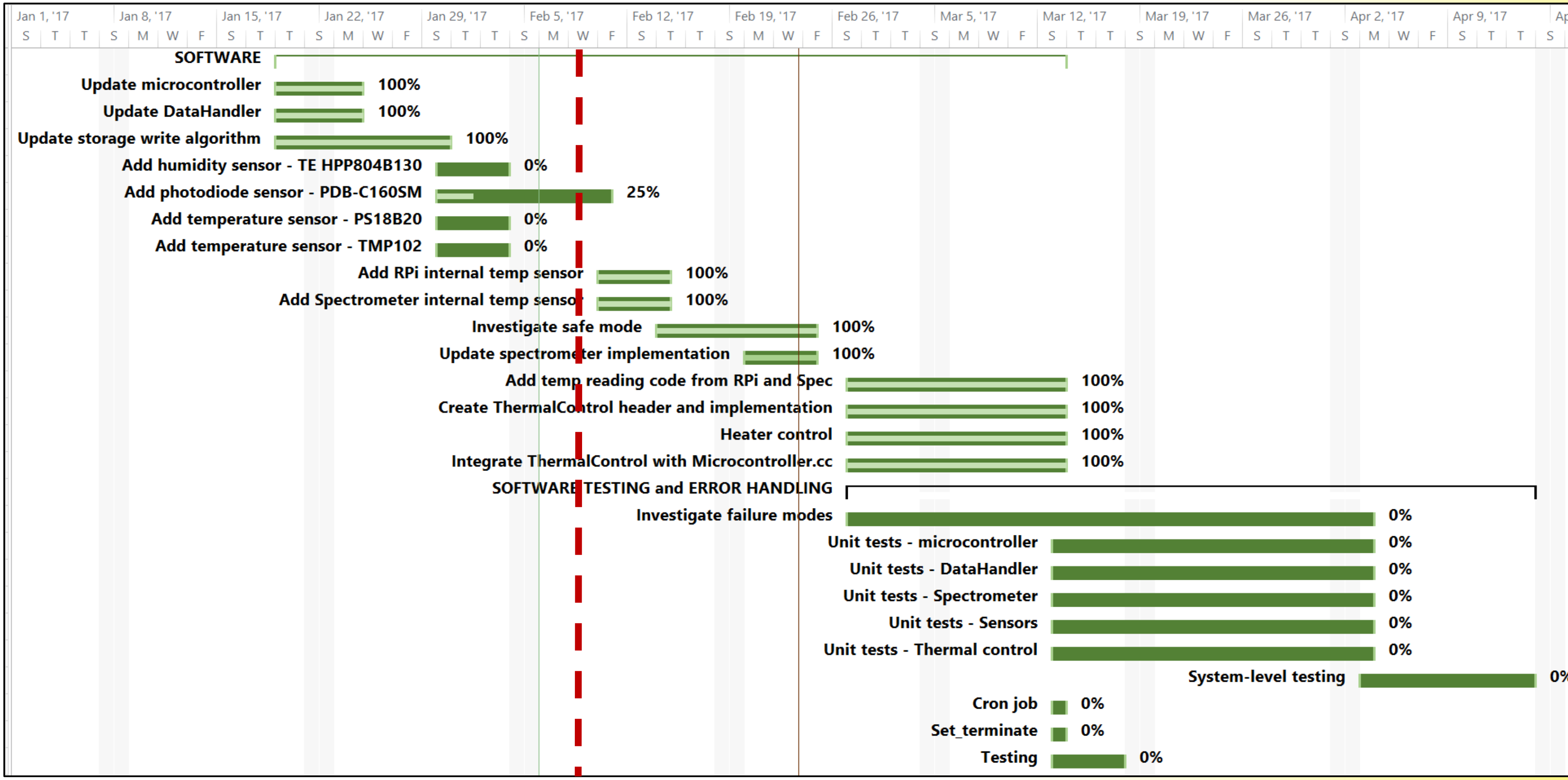
Electrical Schedule



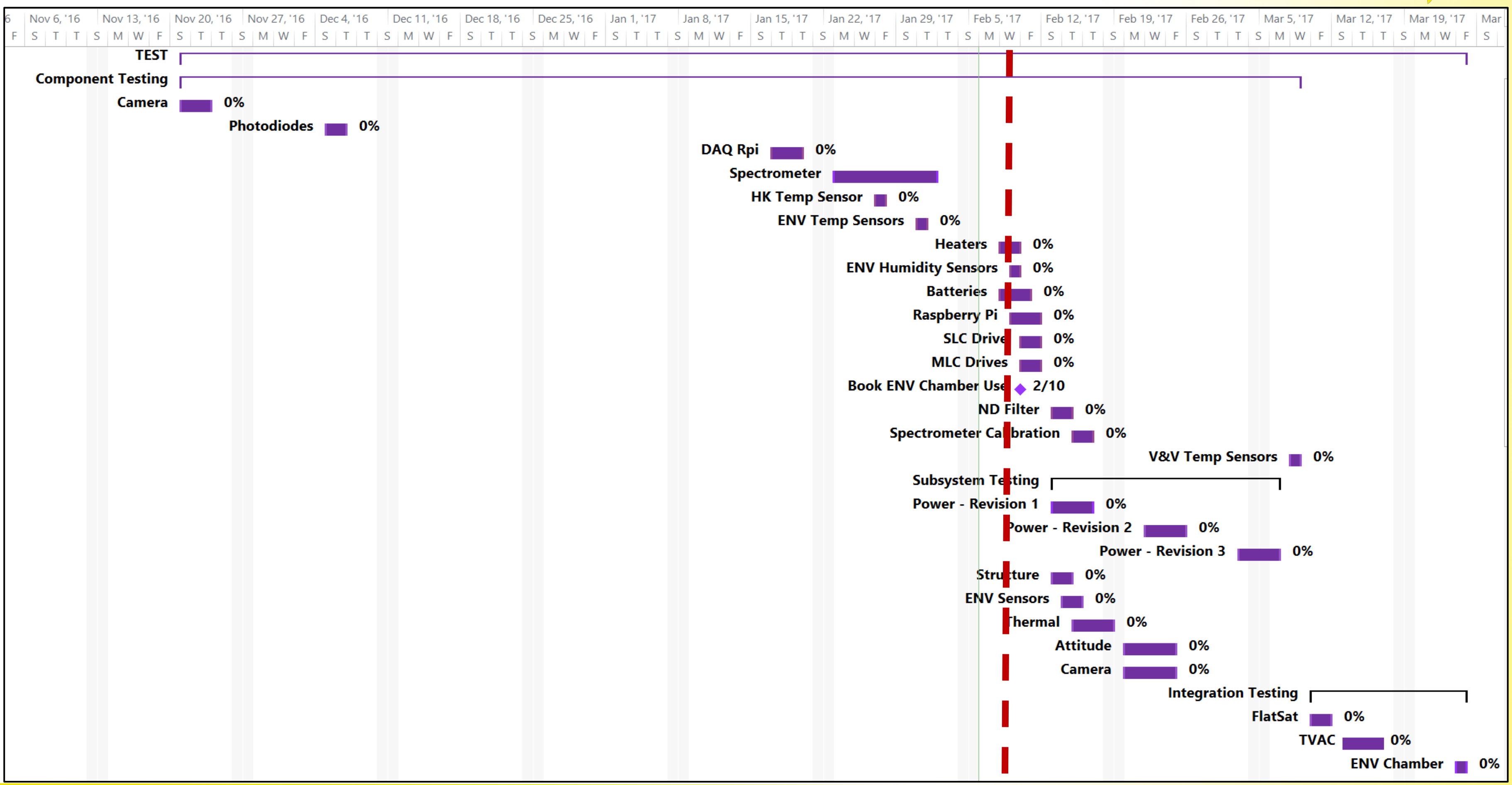
ADS Schedule



Software Schedule



Testing Schedule

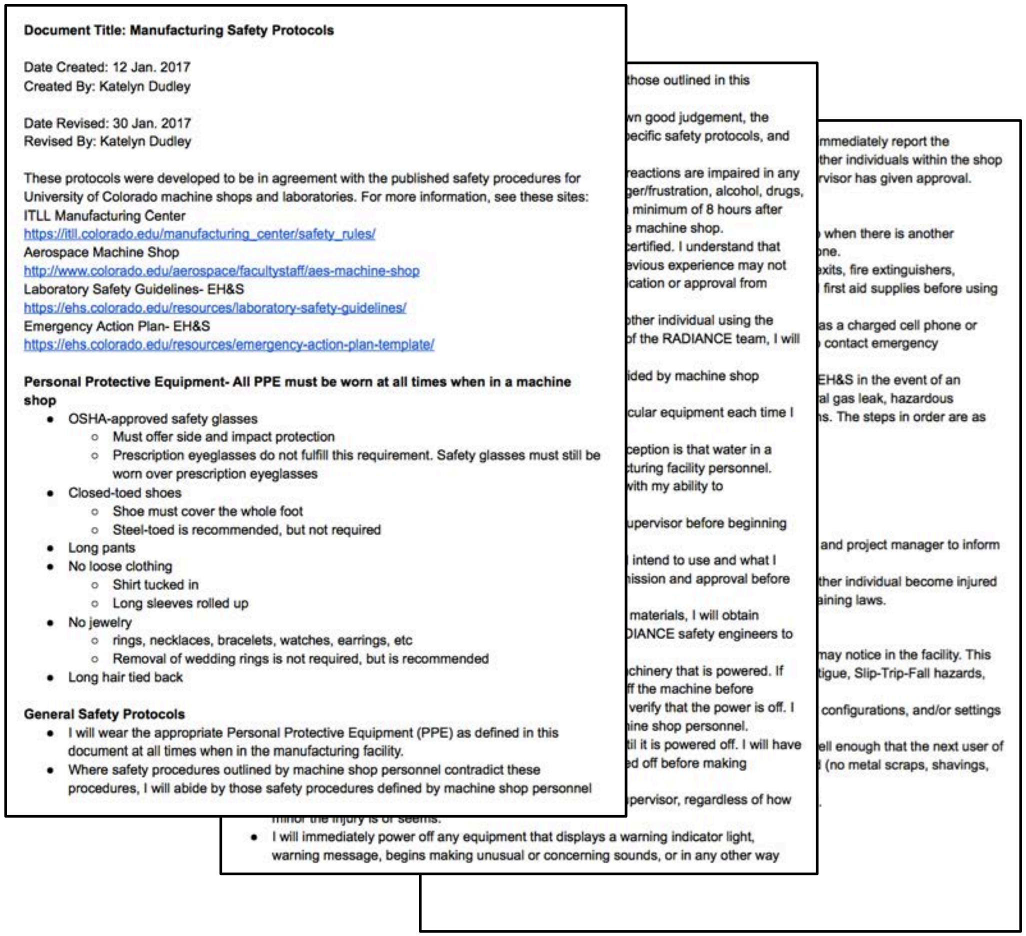


Mechanical Status

Mechanical Preparation

- SolidWorks drawings finished
- Ordered aluminum stock and other components
- Machine shop training
- Photodiode array prototype
- Manufacturing procedures (safety, handling, etc.)

Safety Procedures


Document Title: Manufacturing Safety Protocols

Date Created: 12 Jan. 2017
Created By: Katelyn Dudley

Date Revised: 30 Jan. 2017
Revised By: Katelyn Dudley

These protocols were developed to be in agreement with the published safety procedures for University of Colorado machine shops and laboratories. For more information, see these sites:
ITLL Manufacturing Center
https://itll.colorado.edu/manufacturing_center/safety_rules/
Aerospace Machine Shop
http://www.colorado.edu/aerospace/facultystaff/aes-machine-shop
Laboratory Safety Guidelines- EH&S
https://ehs.colorado.edu/resources/laboratory-safety-guidelines/
Emergency Action Plan- EH&S
https://ehs.colorado.edu/resources/emergency-action-plan-template/

Personal Protective Equipment- All PPE must be worn at all times when in a machine shop

- OSHA-approved safety glasses
  - Must offer side and impact protection
  - Prescription eyeglasses do not fulfill this requirement. Safety glasses must still be worn over prescription eyeglasses
- Closed-toed shoes
  - Shoe must cover the whole foot
  - Steel-toed is recommended, but not required
- Long pants
- No loose clothing
  - Shirt tucked in
  - Long sleeves rolled up
- No jewelry
  - rings, necklaces, bracelets, watches, earrings, etc
  - Removal of wedding rings is not required, but is recommended
- Long hair tied back

General Safety Protocols

- I will wear the appropriate Personal Protective Equipment (PPE) as defined in this document at all times when in the manufacturing facility.
- Where safety procedures outlined by machine shop personnel contradict these procedures, I will abide by those safety procedures defined by machine shop personnel

- I will immediately power off any equipment that displays a warning indicator light, warning message, begins making unusual or concerning sounds, or in any other way

- Manufacturing Safety Protocols document created with information from all shops
- Includes emergency procedures from EH&S
- Hardware Safety Protocols document to reduce wear and tear on parts

Mechanical Changes

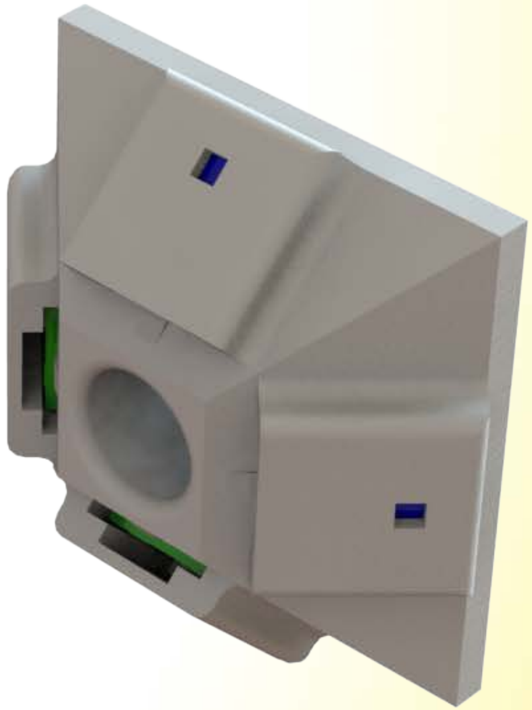
Item Changed	Justification
4-40 screws used on ND filter threads	Incorrect size hole was machined.
Longer screws for spectrometer mounting	Only a ¼ turn engagement with current screws. Purchased screws were shorter than expected.
Raspberry Pi holed slightly enlarged	The provided CAD drawing was different from the purchased product.
3D Print camera lens mount	Part holes do not line up with camera holes.

Mechanical Progress

Item	Status	Notes
Structure	Complete	—
Foam	Cut to size	Must be finished for integration, holes for components and spacers must be cut.
Testing Hardware	Roughly designed	Includes telescope mount and thermal spectrometer analog
3D Printed Parts	Designed	To be printed
Assembly	Incomplete	Fully integrate remaining hardware

3D Printing – Photodiode Array

- Waiting on PCB for photodiode test fit

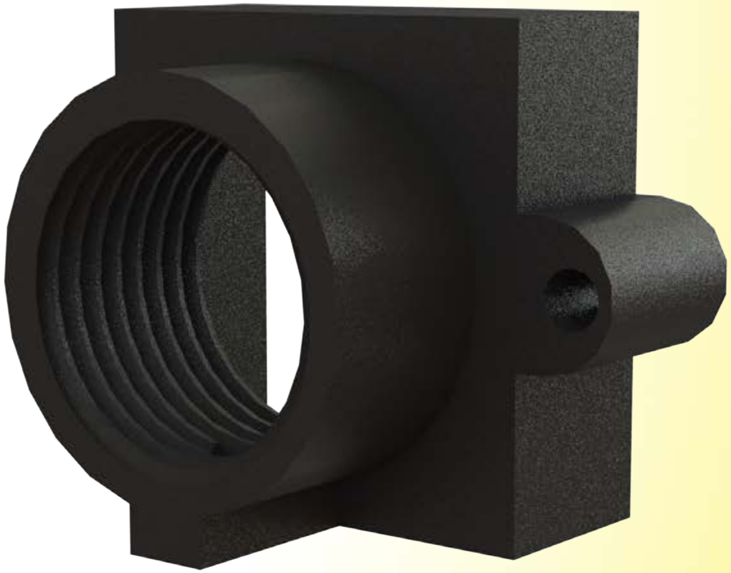


3D Printing - Neutral Density Filter Threads

- Waiting on neutral density filter to verify thread size

3D Printing - Camera Lens Mount

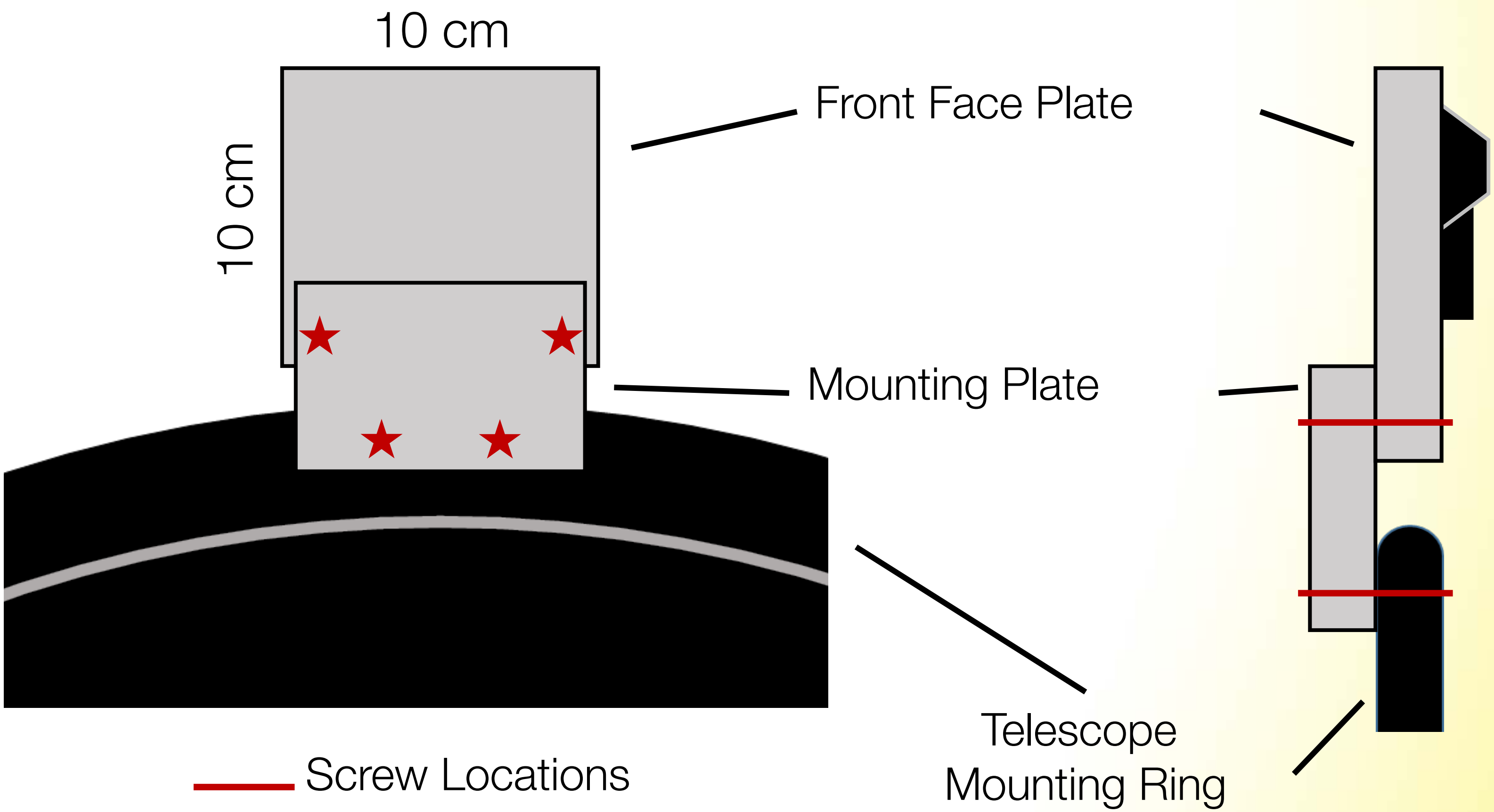
- 3D printing due to misaligned holes



Spectrometer Analog for TVAC

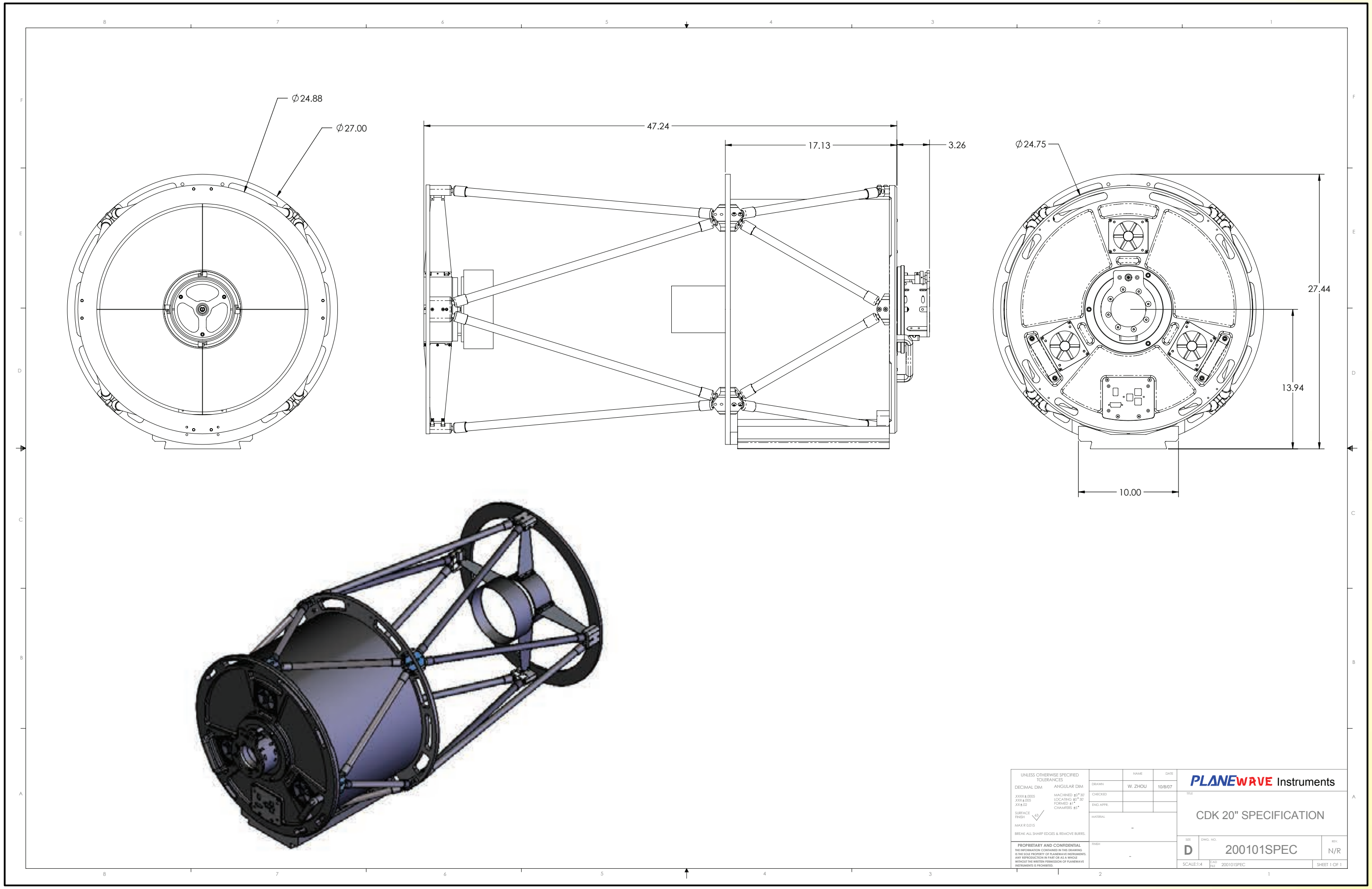
- Part machined from leftover aluminum to mimic spectrometer mass and size
- Resistive heater circuit to mimic heat output of operational spectrometer

Telescope Mount for ADS Test



Project Overview | Schedule | Mechanical | Electrical | Software | Budget

Telescope Mount for ADS Test



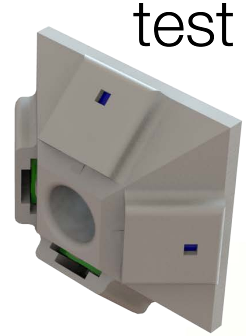
Mechanical Summary

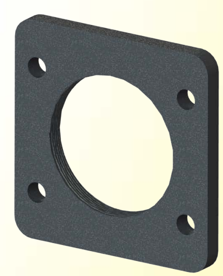
Completed Work

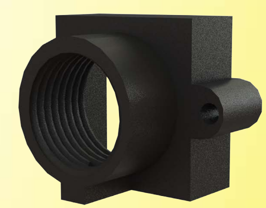
- All aluminum parts complete
- 3D printed parts designed
- Structure assembly complete

Future Work

- Print 3D printed parts
- Finish insulation holes
- Machine parts for testing
- Continue integrating components
- Design of parts needed for test





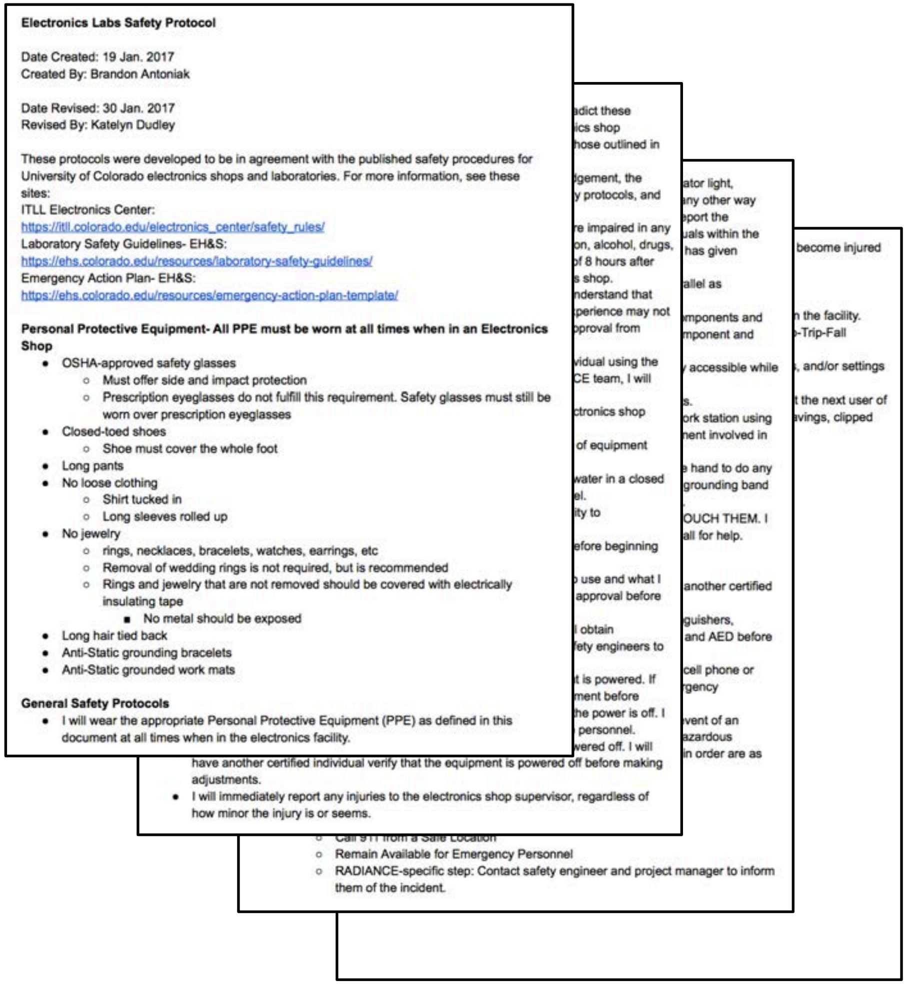


Power & Attitude Status

Electrical Preparation

- Designed power board in Altium
  - Selected appropriate footprints and libraries
  - Design board layout
  - Prepared board to Advanced Circuit's specifications
- Assembled lists of part numbers on DigiKey
- Ordered components

Electrical Safety Procedures



Electronics Labs Safety Protocol

Date Created: 19 Jan. 2017
Created By: Brandon Antoniak

Date Revised: 30 Jan. 2017
Revised By: Katelyn Dudley

These protocols were developed to be in agreement with the published safety procedures for University of Colorado electronics shops and laboratories. For more information, see these sites:
ITLL Electronics Center:
https://itll.colorado.edu/electronics_center/safety_rules/
Laboratory Safety Guidelines- EH&S:
https://ehs.colorado.edu/resources/laboratory-safety-guidelines/
Emergency Action Plan- EH&S:
https://ehs.colorado.edu/resources/emergency-action-plan-template/

Personal Protective Equipment- All PPE must be worn at all times when in an Electronics Shop

- OSHA-approved safety glasses
  - Must offer side and impact protection
  - Prescription eyeglasses do not fulfill this requirement. Safety glasses must still be worn over prescription eyeglasses
- Closed-toed shoes
  - Shoe must cover the whole foot
- Long pants
- No loose clothing
  - Shirt tucked in
  - Long sleeves rolled up
- No jewelry
  - rings, necklaces, bracelets, watches, earrings, etc
  - Removal of wedding rings is not required, but is recommended
  - Rings and jewelry that are not removed should be covered with electrically insulating tape
    - No metal should be exposed
- Long hair tied back
- Anti-Static grounding bracelets
- Anti-Static grounded work mats

General Safety Protocols

- I will wear the appropriate Personal Protective Equipment (PPE) as defined in this document at all times when in the electronics facility.

have another certified individual verify that the equipment is powered off before making adjustments.

- I will immediately report any injuries to the electronics shop supervisor, regardless of how minor the injury is or seems.

- Remain Available for Emergency Personnel
- RADIANCE-specific step: Contact safety engineer and project manager to inform them of the incident.

- Electrical safety procedures document created by Safety Lead
- Includes emergency procedures from EH&S

Project Overview | Schedule | Mechanical | Electrical | Software | Budget

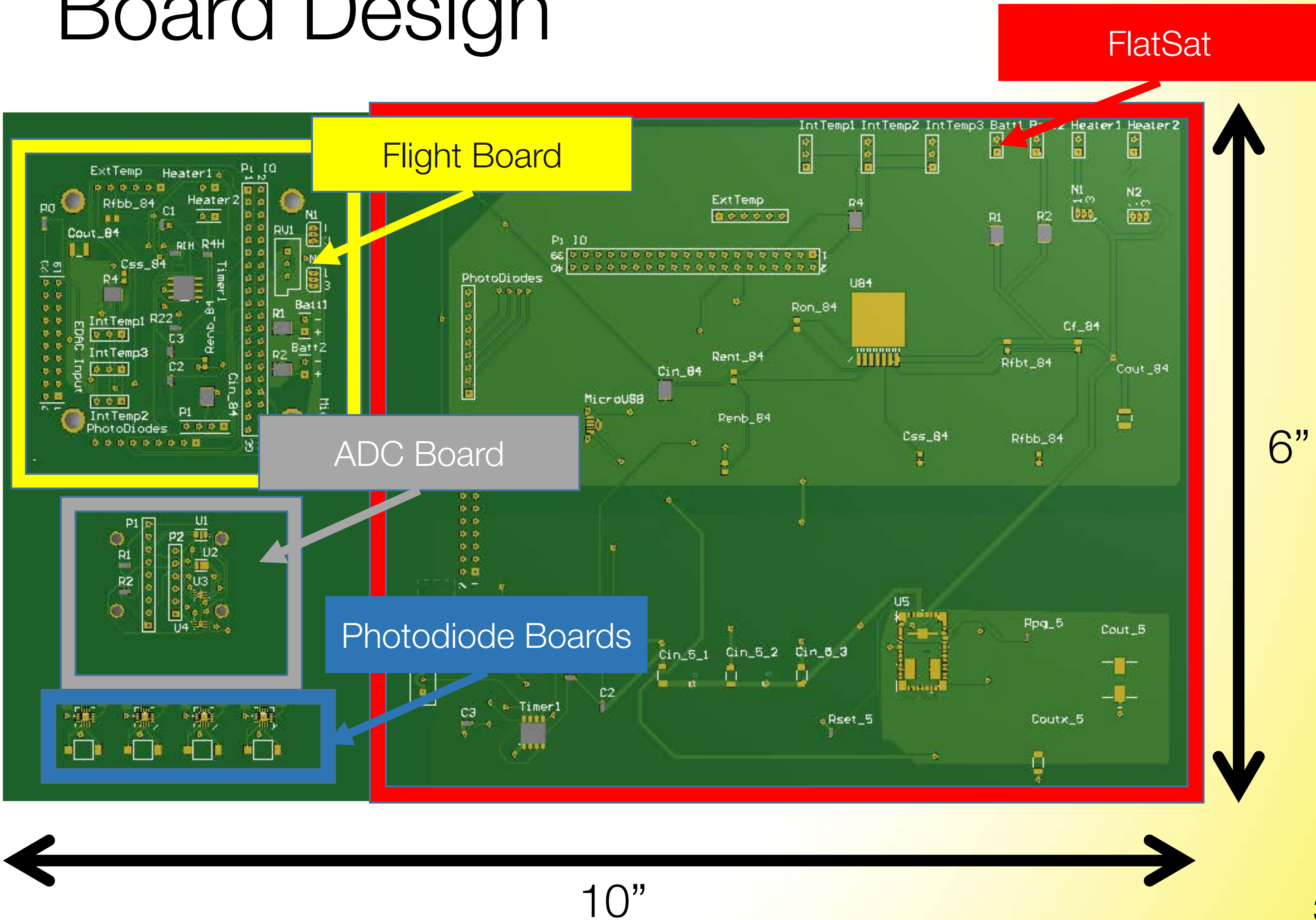
Electrical Changes

Item Changed	Justification
Longer mini USB cable	Does not reach the spectrometer as expected.
Buck converter design changed	Original components out of stock.
New ADCs	Lower cost and better resolution.
Added flatsat board	Easier board to test on.

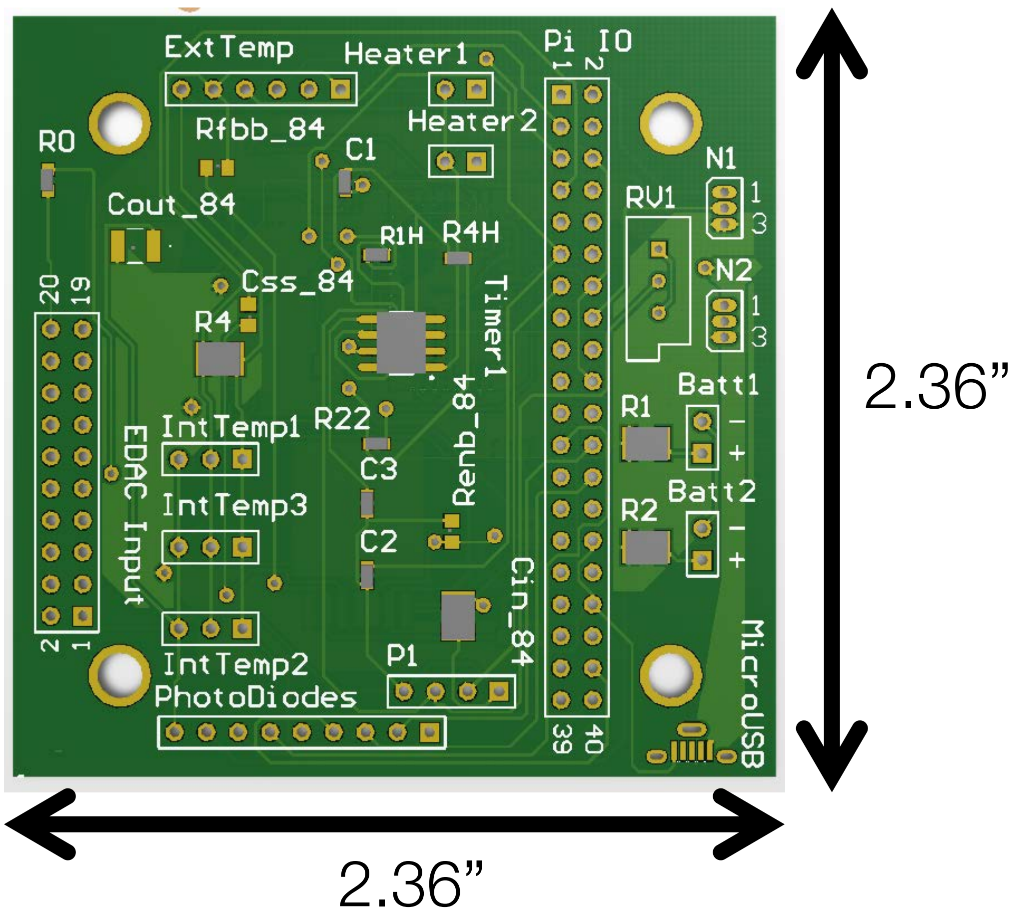
Electronics Status

Item	Status	Notes
Design	Complete	Some tweaks may be needed.
Revision 1	Ordered	To be picked up within a week
Revision 2	Testing Dependent	Time and money budgeted
Revision 3	Testing Dependent	Time and money budgeted
Integration	Phased Start	Must be fully tested and integrated with all subsystems. Completed in phases.

Board Design

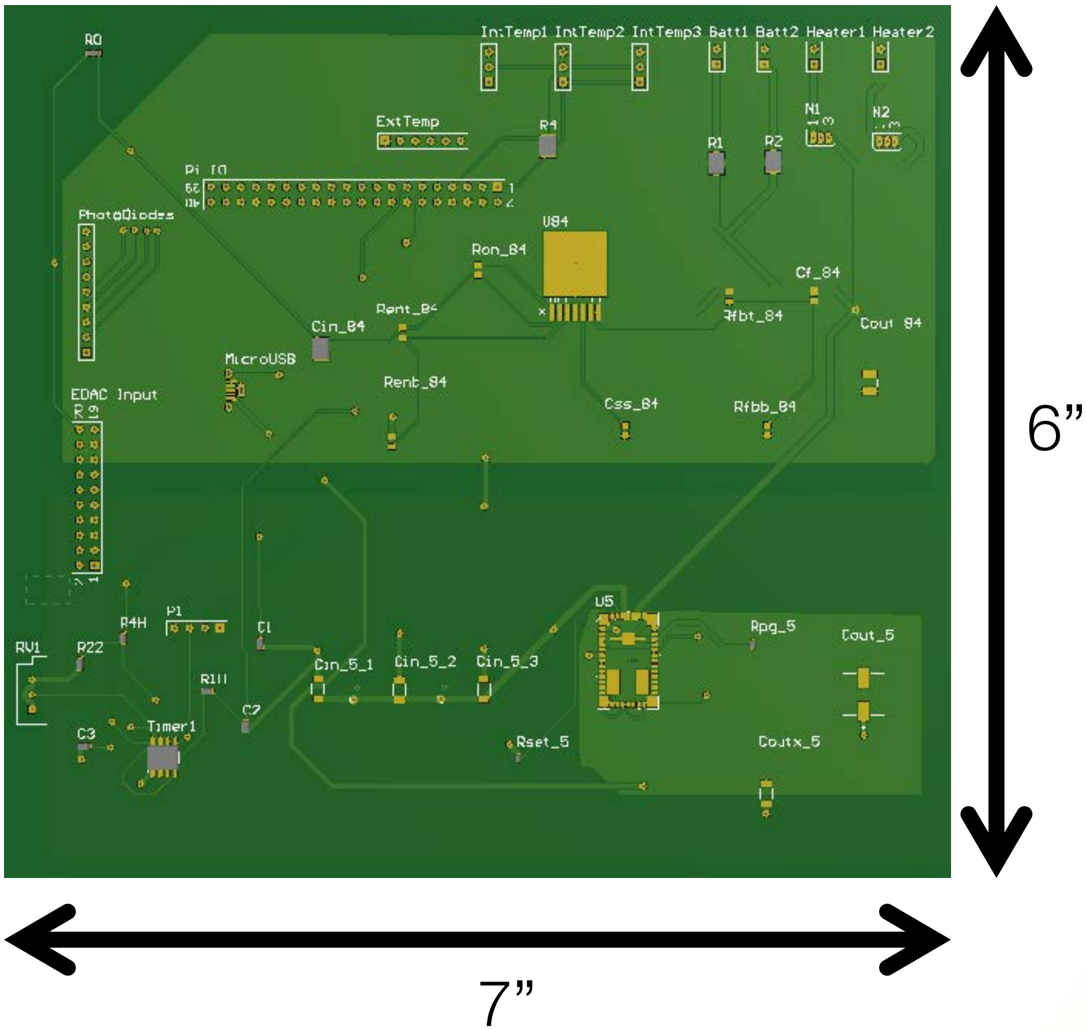


Flight Board



- Updated design and components since CDR
- 2 layer board with polygon pours for testing
- Possibility of 4 layer board with internal ground and power planes for flight

FlatSat

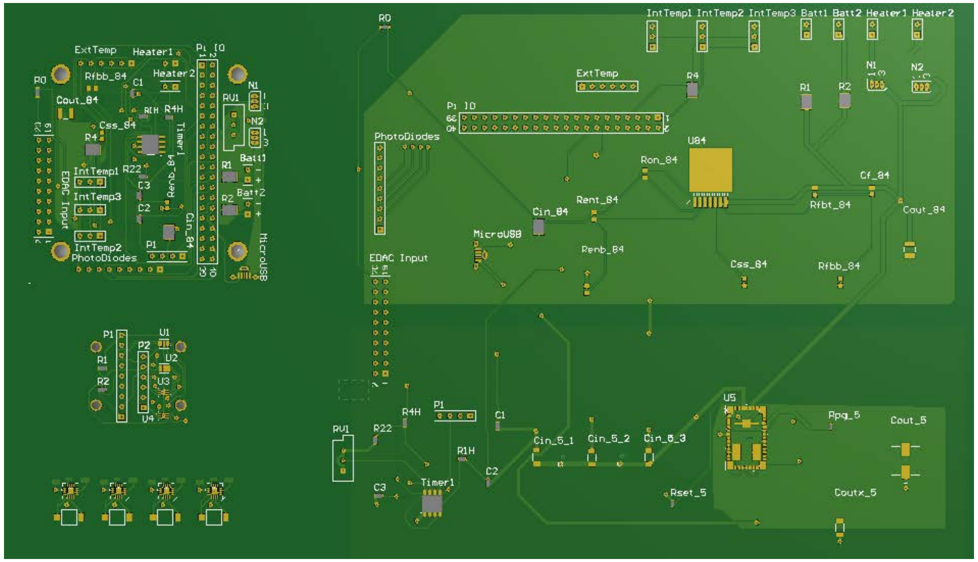


- Made for testing utilizing available space
- Additional vias added
- Space allows for easer assembly and testing

Electrical Summary

Completed Work

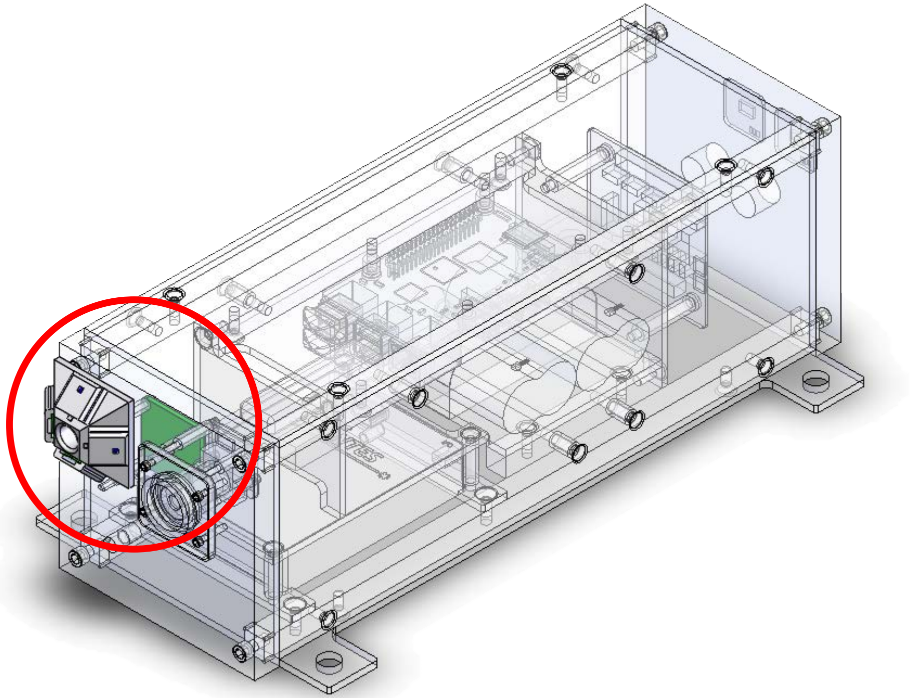
- Revision 1 board designs
- Altium files created
- Components ordered



Future Work

- Revision 1 soldering
  - Work with flatsat's larger space to become comfortable with in house surface mount soldering equipment
- Component testing
- Integration testing
- Make required changes, order next revision

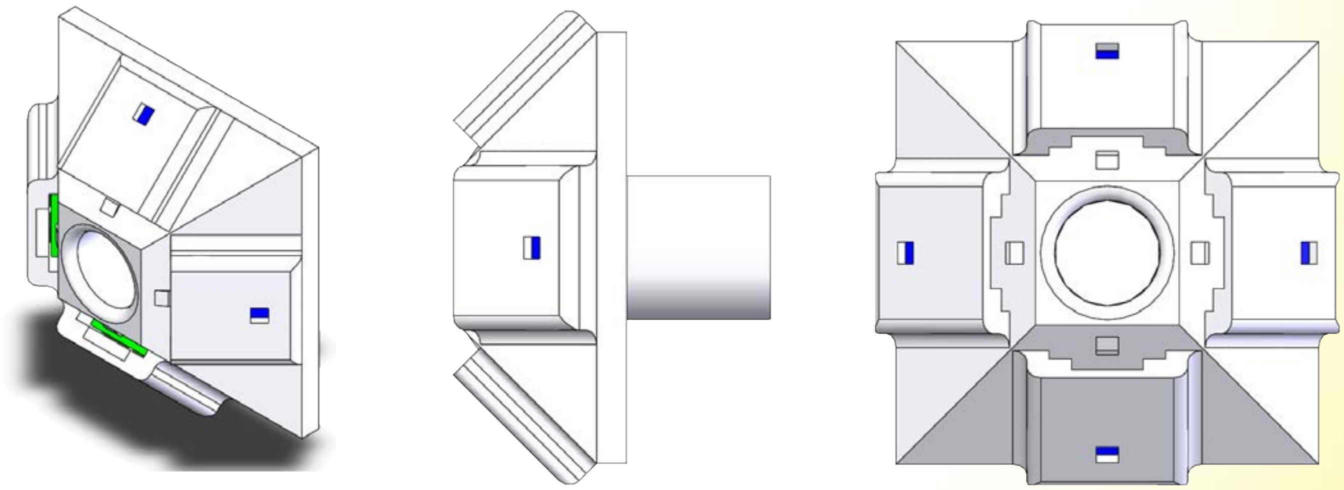
ADS Design Overview



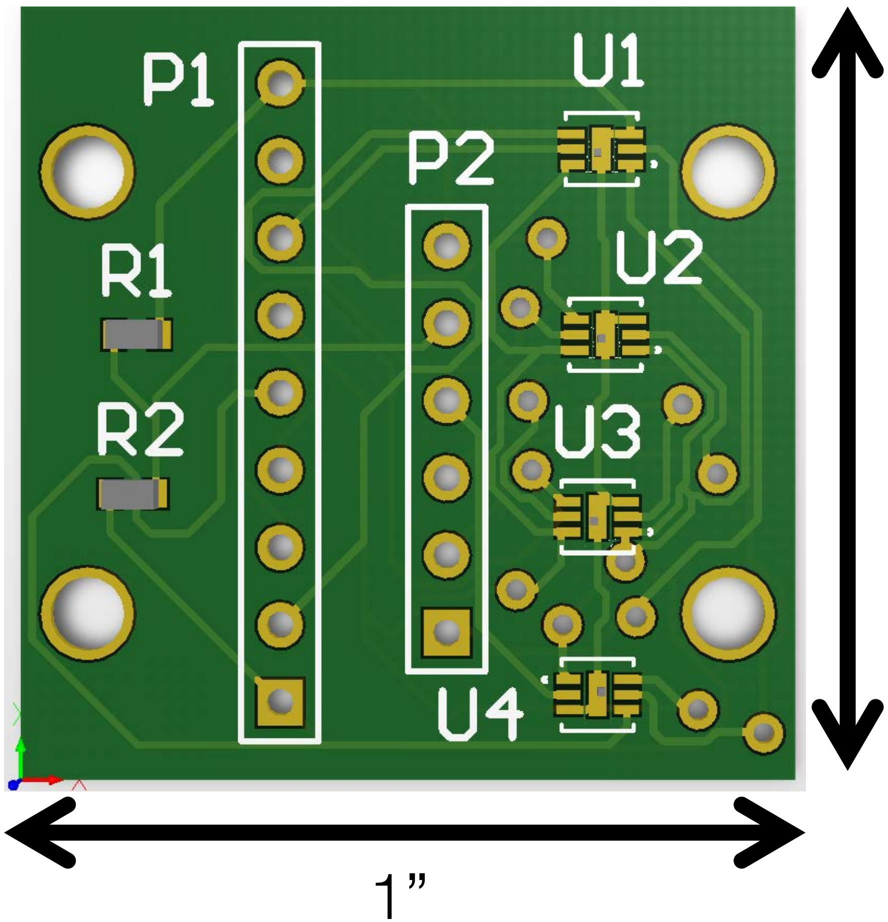
- 4 photodiodes offset at 45° from each other
- Relative currents define sun position
- Location of the sun provides context for spectrometer data

ADS Design Overview

- 3D printed aperture casts shadow on photodiodes based on incidence angle
- Increased response to changing sun angles vs bare photodiode

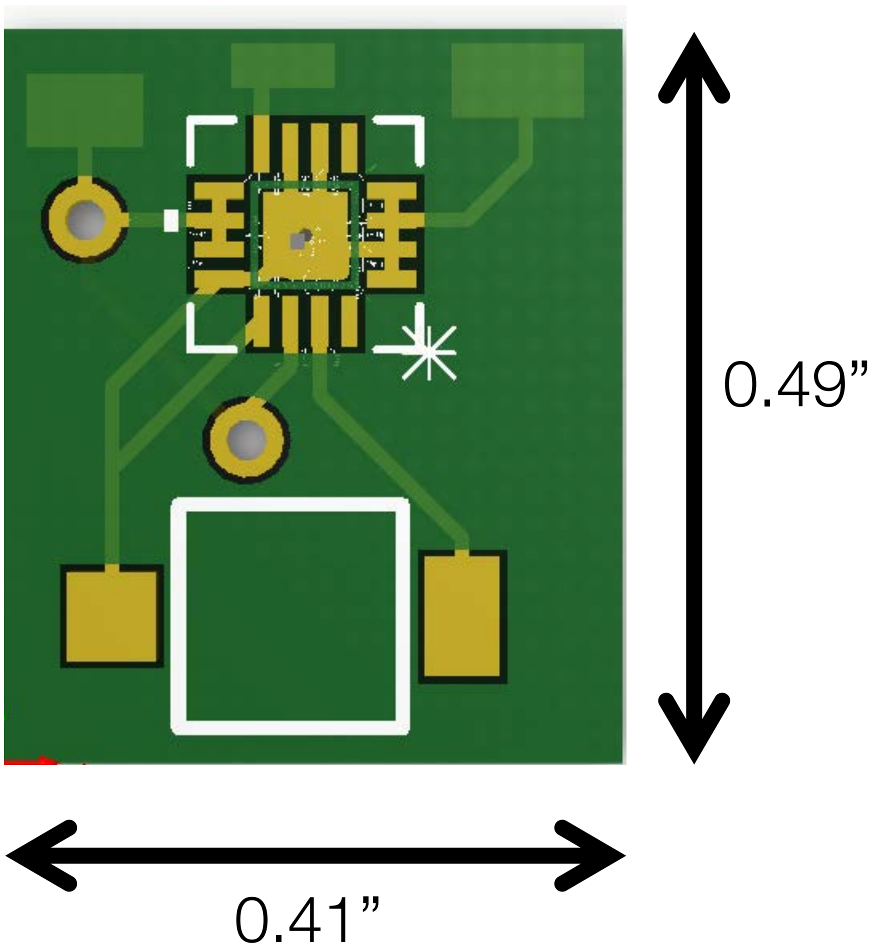


ADC Board



- Accommodates 4 ADCs
  - New ADCs since CDR
- Power input changed from 3.3V to 5V for greater resolution
  - Voltage divider used to get 3.3V to photodiodes

Photodiode Board

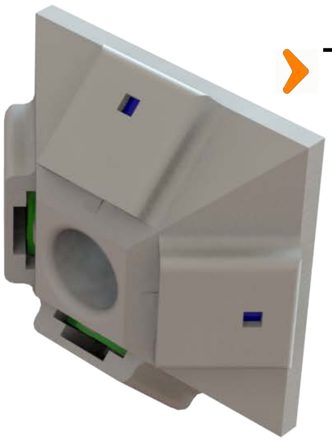


- Boards printed as part of first power board revision
- Will be cut and sanded to correct size

ADS Summary

Completed Work

- ADC board design
- Photodiode board design
- Altium files complete
- Photodiode array designed
- Components ordered



Future Work

- Assembling board
  - Measure precisely for aperture
  - Verify functionality
- Print Aperture
- Testing and Calibration
  - Sommer-Bausch Observatory

Software Status

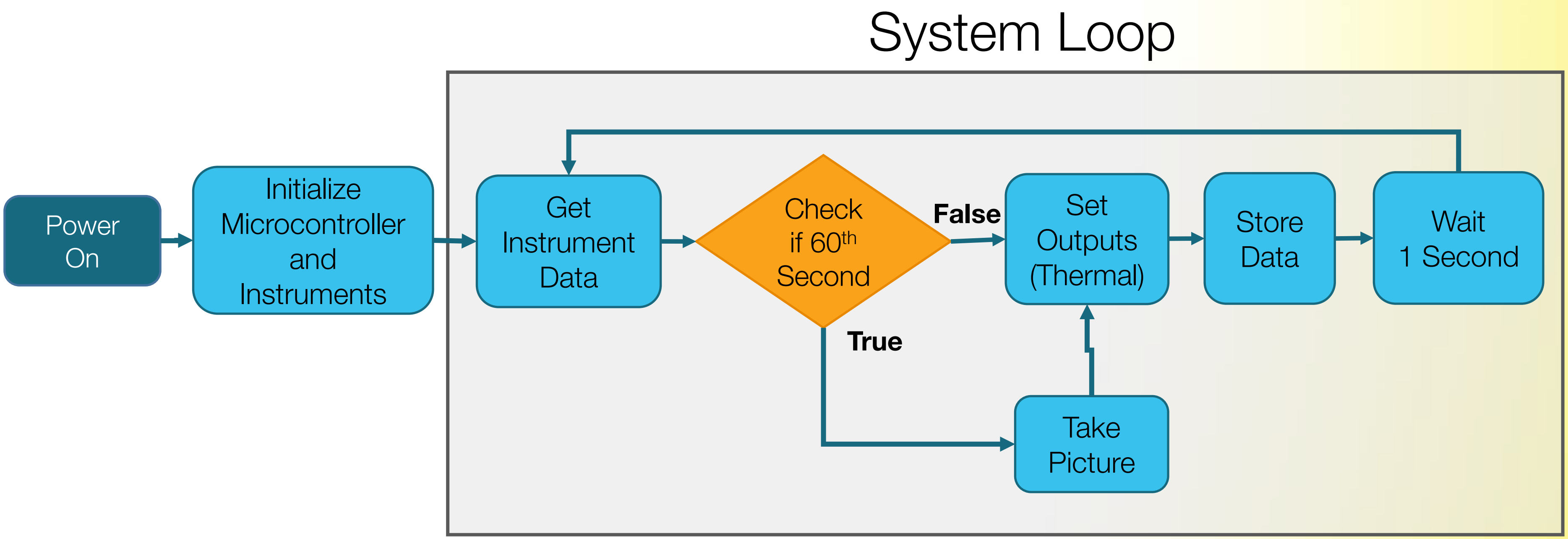
Remaining CPEs

- 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

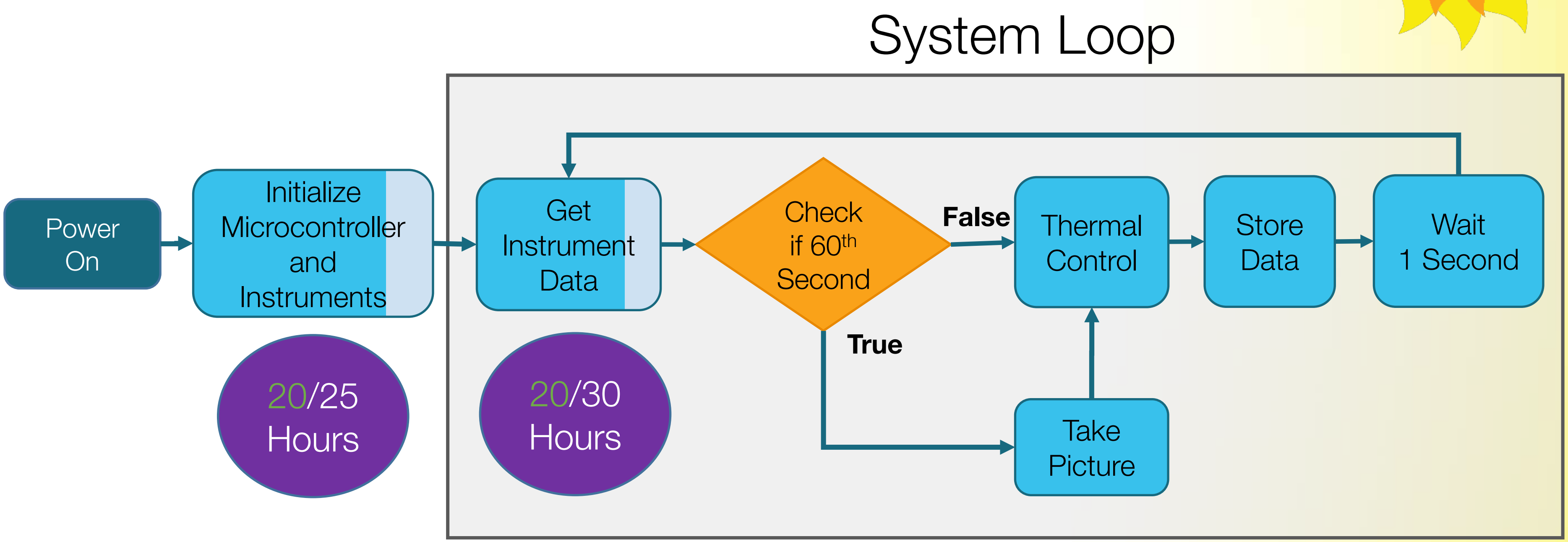
Software Executive Summary

Item	Status	Notes
Microcontroller integration	Complete	—
DataHandler	Complete	—
Thermal control algorithm	Complete	—
Spectrometer integration	Complete	—
Sensor integration	In Python	Needs to be converted to C++
Unit and System Testing	Not started	Will begin once development is finished
Error handling	Investigated	Will be added to the code

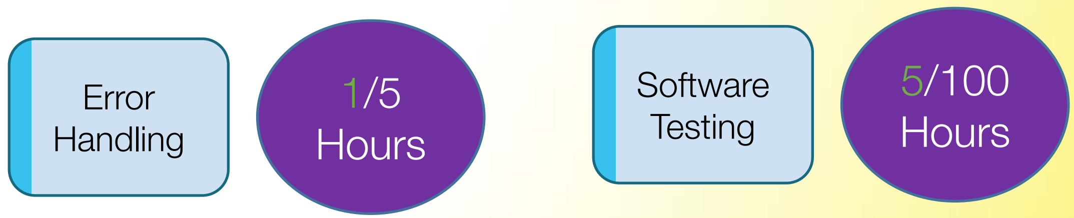
Software Flow

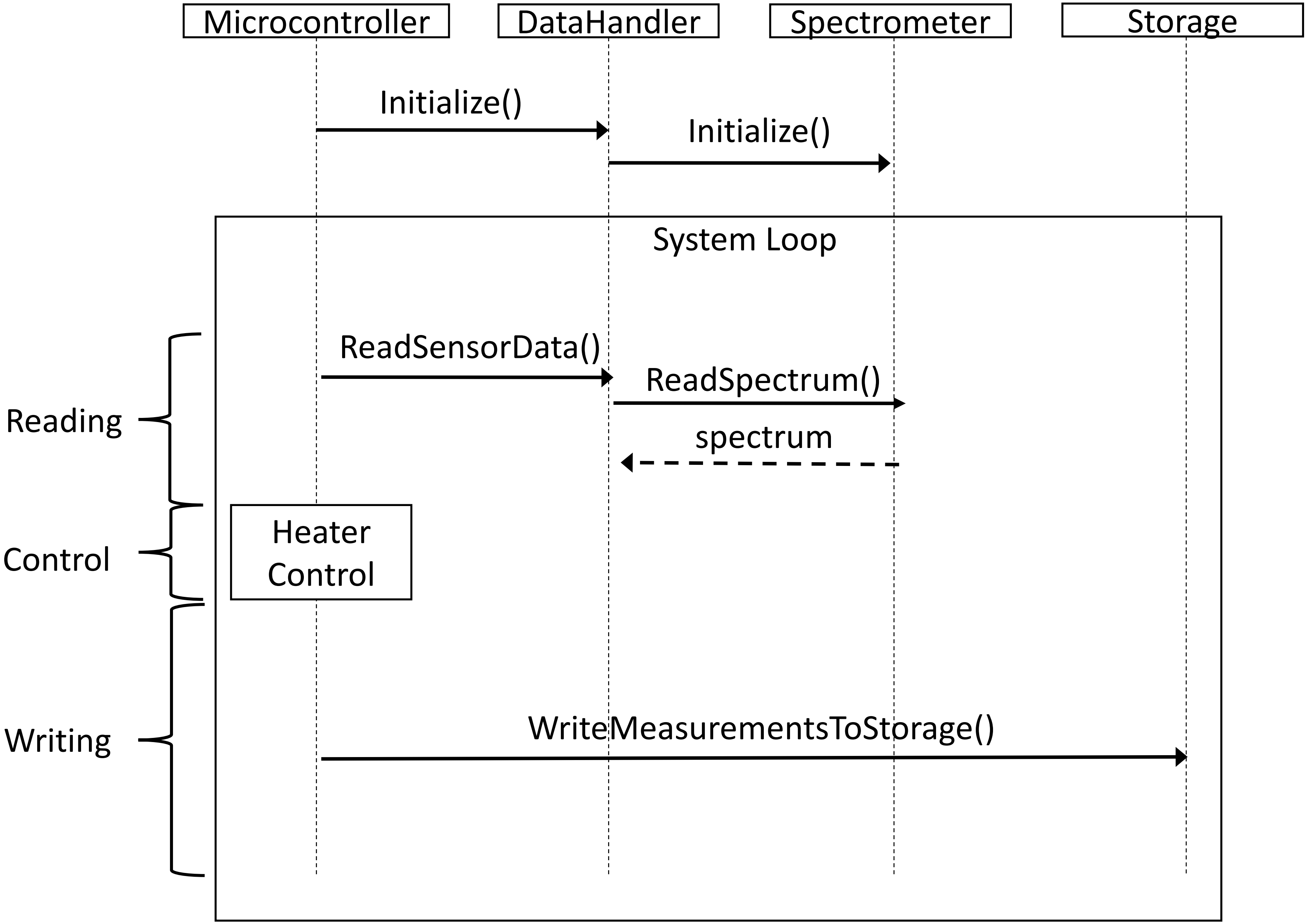


Software Flow



Miscellaneous



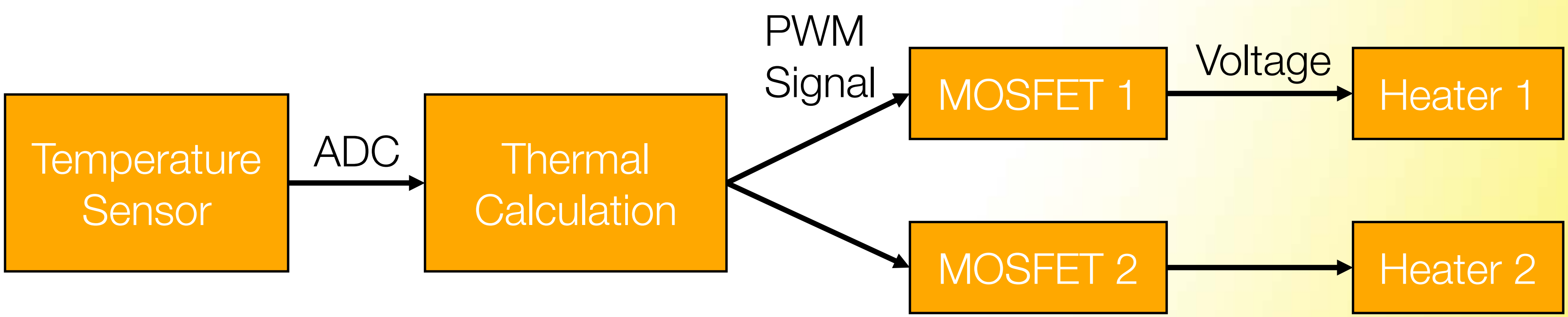

Microcontroller
DataHandler
Spectrometer
Storage
Initialize()
Initialize()
System Loop
ReadSensorData()
ReadSpectrum()
spectrum
Reading
Control
Heater
Control
Writing
WriteMeasurementsToStorage()

Heating Algorithm

Pseudocode:

```
if (temp < MinTemp)
    TurnHeatersOn = 1;
Elseif (temp > MaxTemp)
     TurnHeatersOn = 0;
end
```

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



Software Path Forward

- Finish code development
  - Continue documentation
  - Finish small sensor interfacing (15 hours)
  - Investigate failure modes and errors (5 hours)
- Start software testing (100 hours)
  - Static tests
  - Unit tests
  - System tests

Budget Status

Procured Budget Status

Subsystem	Projected Cost	Procured	To be Procured	Effect on Budget
C&DH	$166.73	$148.79	$0.00	+$17.94
Sensors	$203.15	$67.41	$91.00	+$44.74
Instrumentation	$2988.13	$2992.34	$0.00	–$4.21
Power	$662.45	$185.74	$476.71	$0.00
Structure	$418.40	$222.66	$0.00	+$195.74
Testing	$250.00	$0.00	$250	$0.00
Thermal	$66.31	$35.83	$0.00	+$30.48
TOTAL	**$4634.02**	**$3652.77**	**$981.25**	**+$284.69**

Total (with margin and excess): $4,918.71

Potential Purchases

- Hire Advanced Circuits to assemble power boards
- Purchase specific calibration equipment from Avantes
- AIAA Conference Registration
- Expedited shipping if necessary

Thank you!

We welcome your feedback!

BACKUP

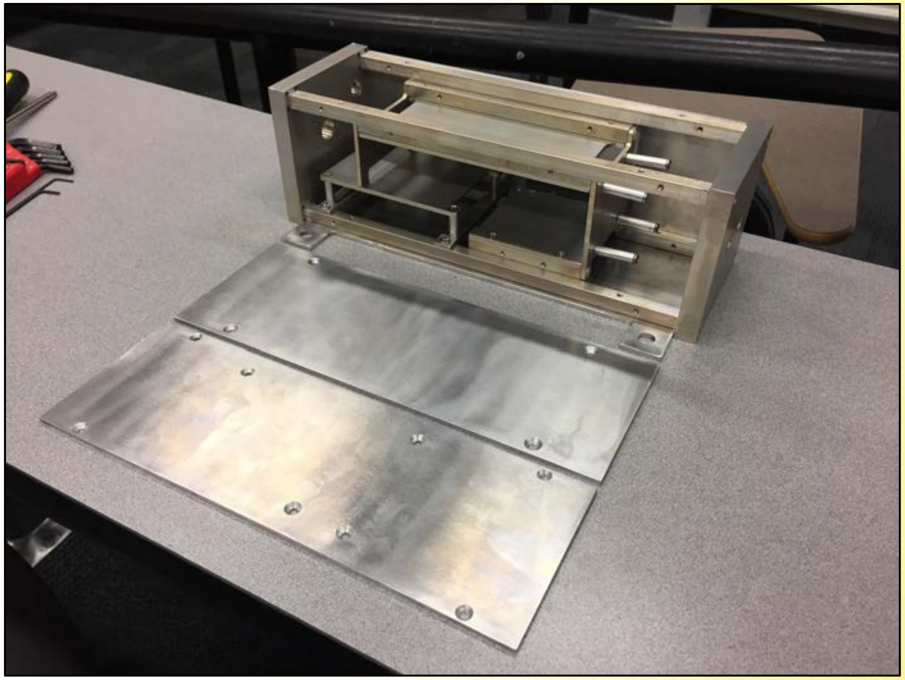
Hardware Safety

- Document created for team awareness of hardware safety → meant to reduce wear and tear

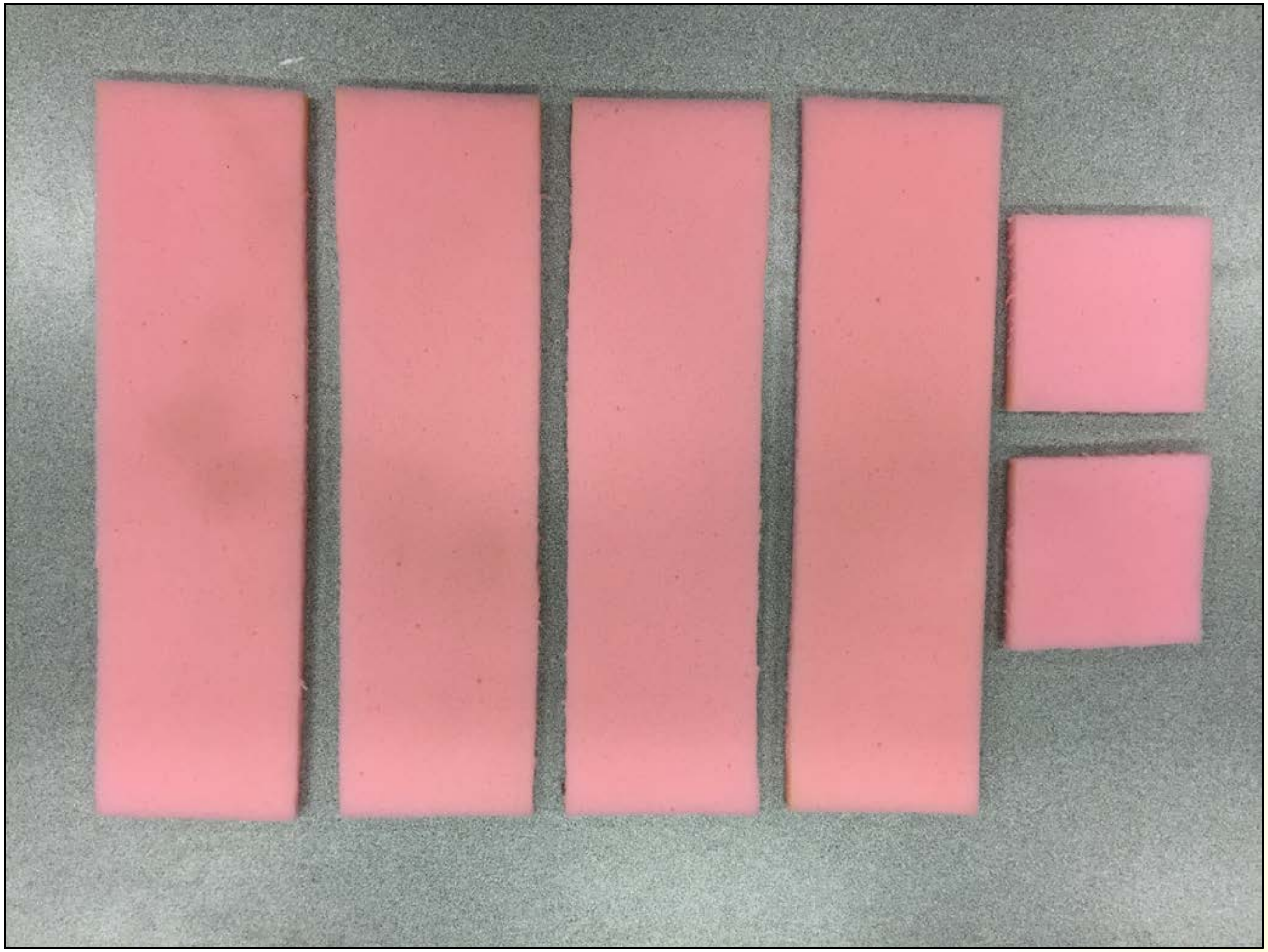
Rules for Handling Manufactured Hardware

1. Do **NOT** over torque screws or other hardware. Hand tighten when possible.
2. Do not drop parts.
3. Do not whack, rub, bang, or otherwise mishandle manufactured parts. Handle all parts with care.
4. Always make sure screws are new and undamaged. Do not use screws if dropped on the floor.
5. If you are unsure how to handle or use a part, ASK.
6. Get permission before integrating components to structure.
7. Make sure all components have been wiped clean with dry rag. No dust or small metal fragments on parts.
8. Put components back in their proper encased location.
9. Do not touch if you do not need to.
10. If electronic components are attached, make sure that you aware of static discharge.
11. Always lay components on a large, flat, level surface to prevent warping.
12. Get permission before accessing completed parts.

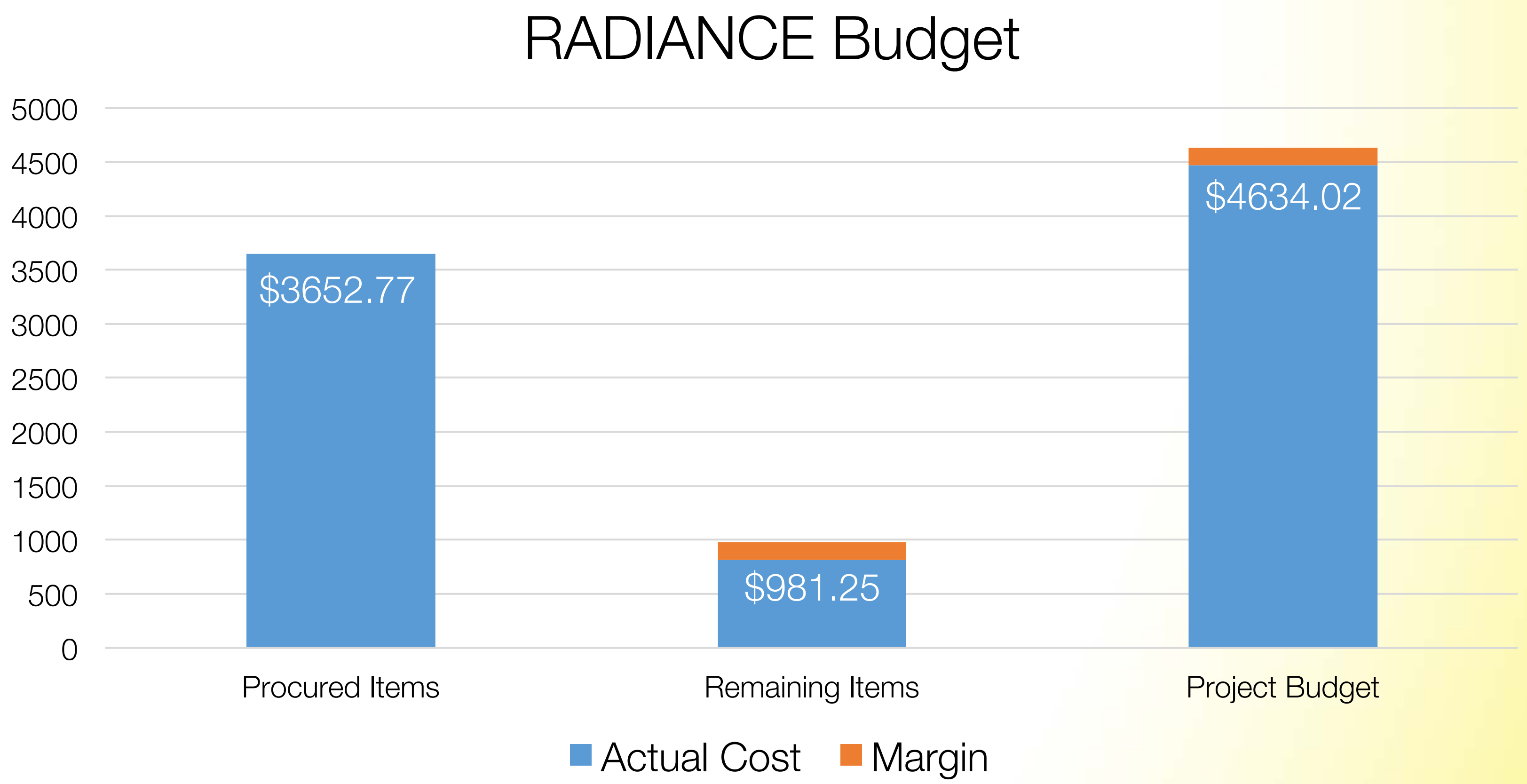
Aluminum Structure



Foam Insulation



Budget Status



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Levels of Success

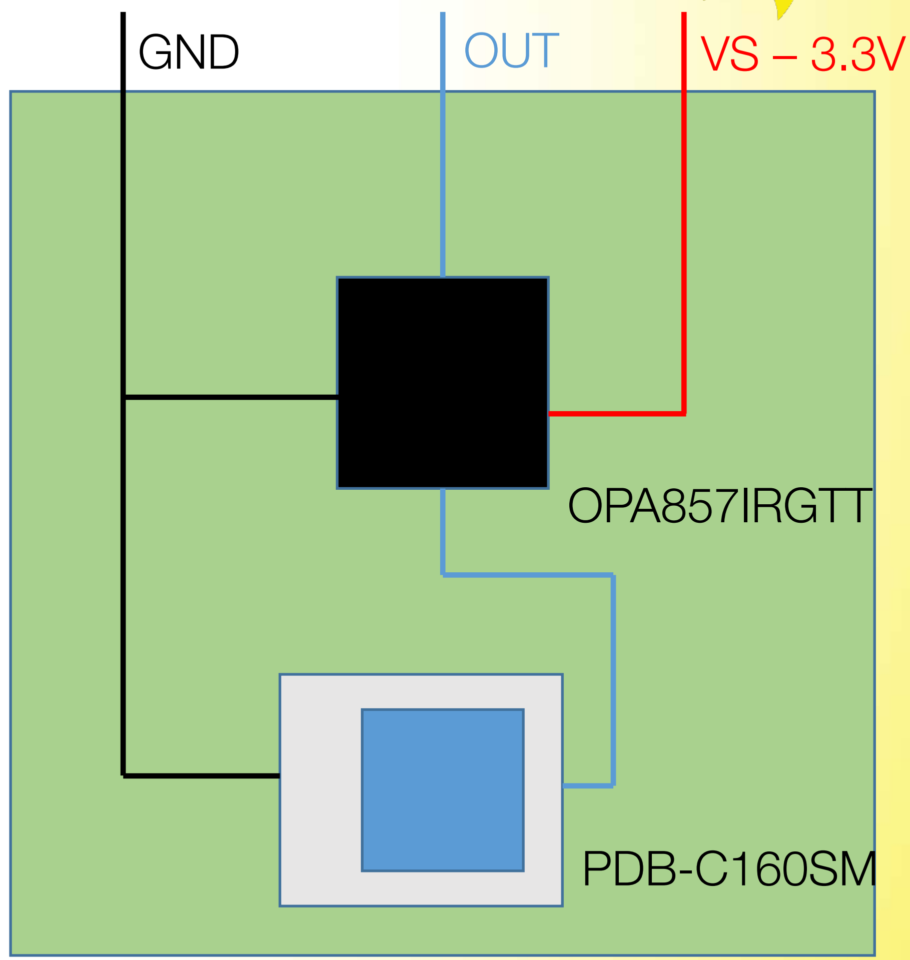
	Achieved	Description
Instr.	3	• Take solar spectra at better than 1.5nm resolution and 250-1000nm during the full flight • Capture 1 photo/min of the Sun for full flight • Provide absolute calibration data of the instrument
Thermal	3	• All systems survive and operate during the full flight
C&DH	3	• Record solar irradiance, attitude, environmental, and housekeeping data to meet relevant Level 3 requirements
EPDS	1	• Package operates on HiWind power supply
ADS	2	• Determine and record attitude to 1 arcminute of accuracy relative to the sun vector
Structure	1	• Structure must be 10cm x 10cm x 32cm • Data is recoverable after experiencing up to 5 Gs on landing • Structure can be affixed to HiWind

ADS Board from Altium

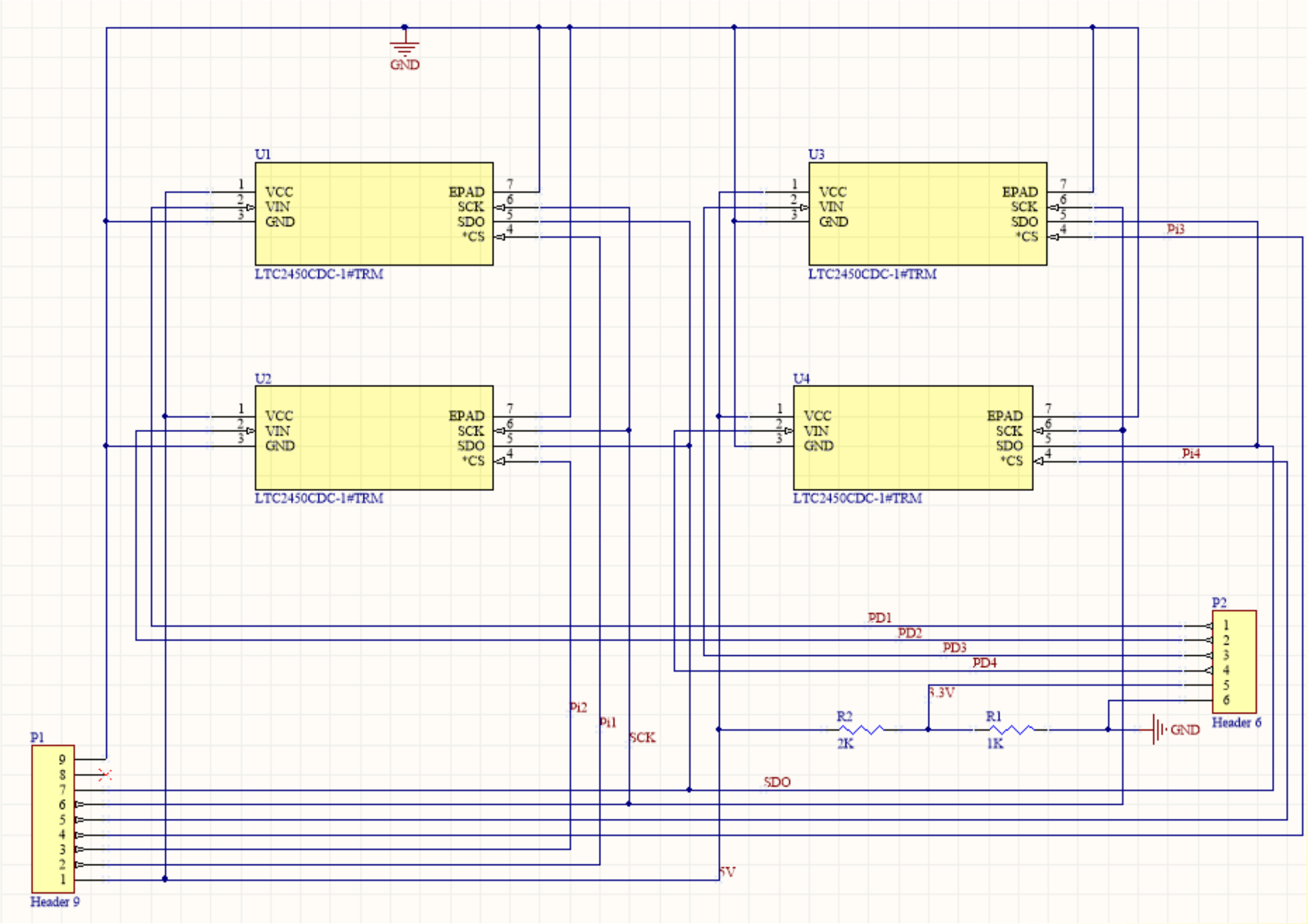
- Design has been done (details in backups)
- What has been purchased already (photodiodes)
- Board has been ordered

ADS Photodiode Board (x4)

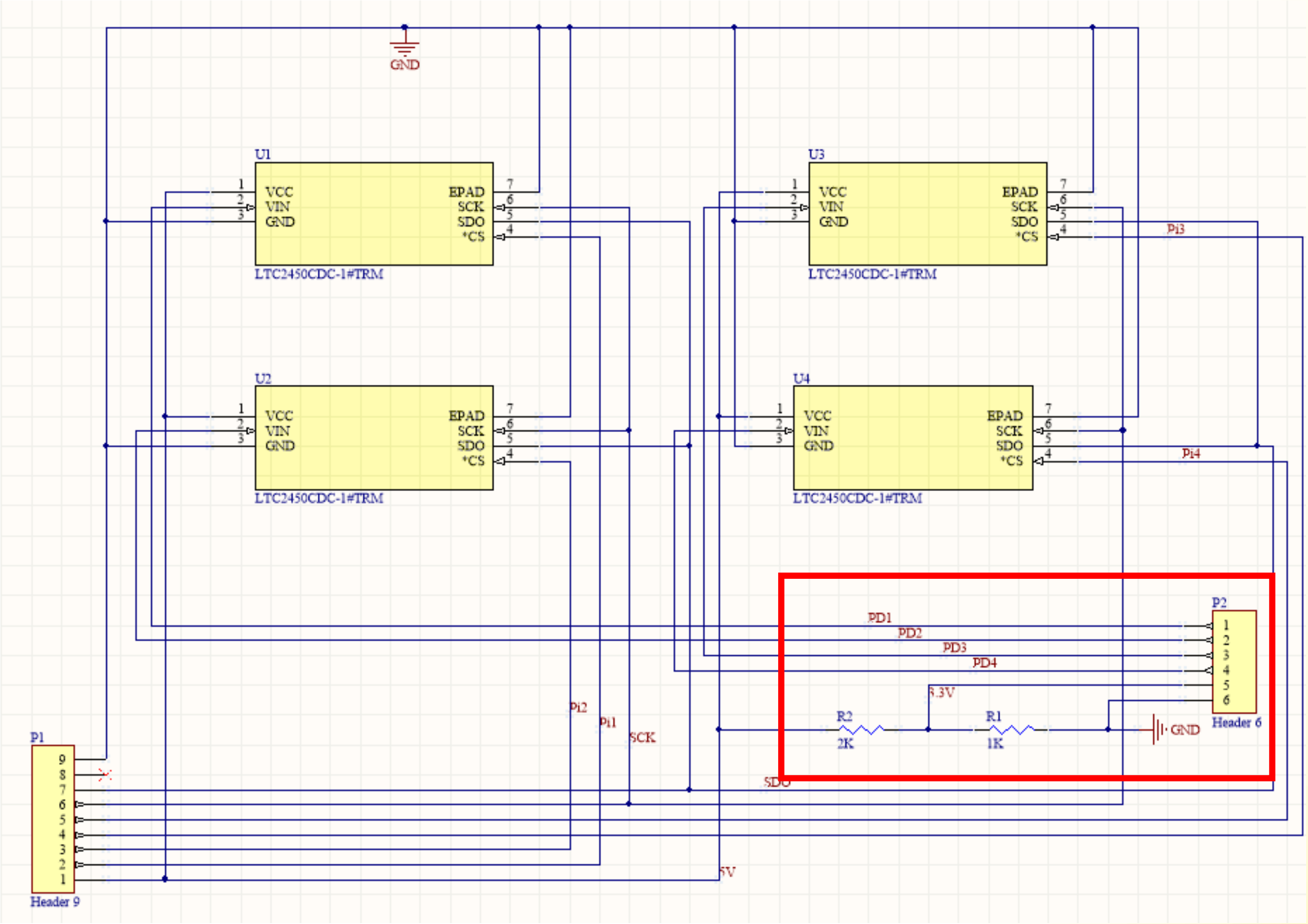
- PDB-C160SM photodiode
  - Purchased
  - Produces ~250 µA in full sunlight
- OPA857IRGTT transimpedance amplifier
  - 5K feedback resistance



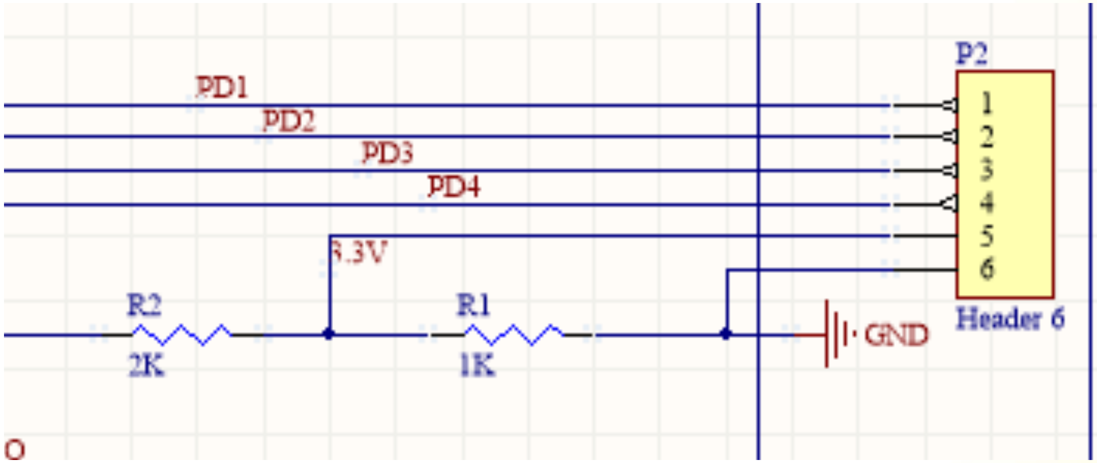
ADS ADC Board



ADS ADC Board

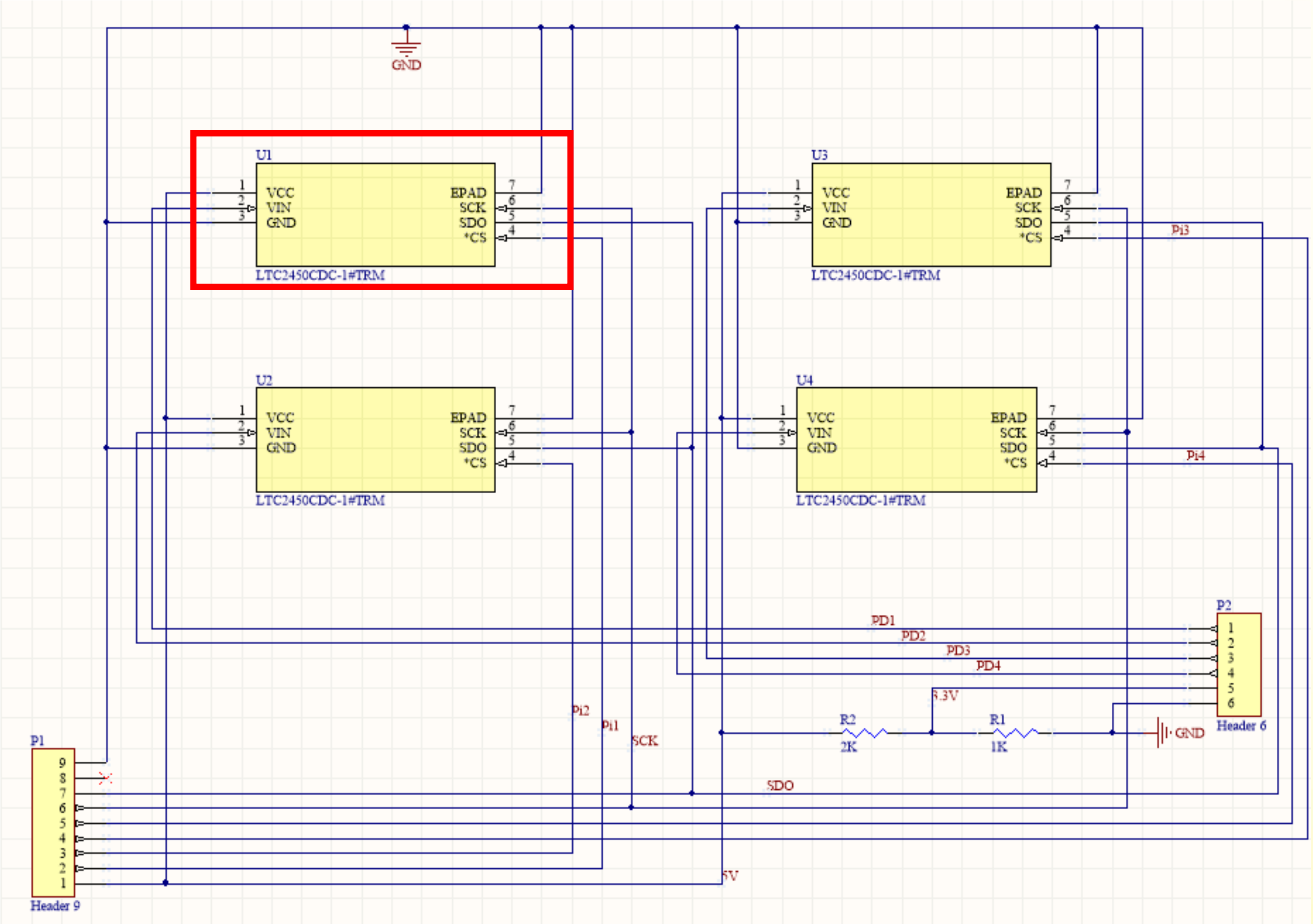


ADS ADC Board

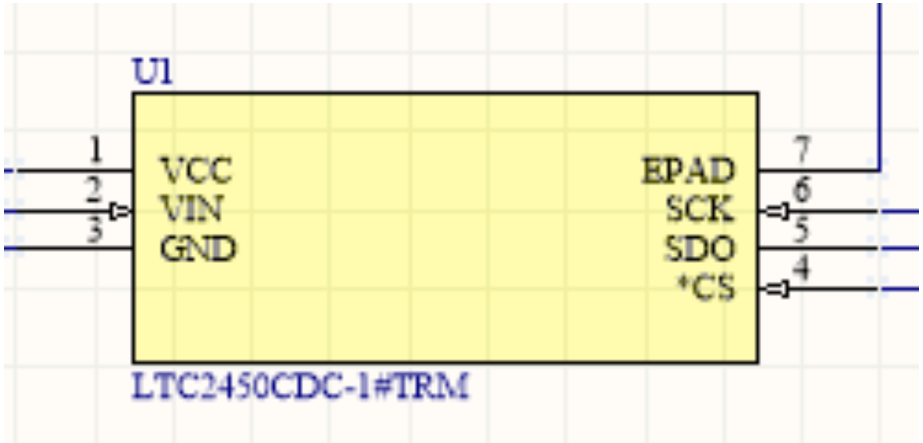


- Voltage divider to provide 3.3V and GND to all photodiode boards
- Transimpedance amplifiers on photodiode boards output to ADCs (PD1-4)

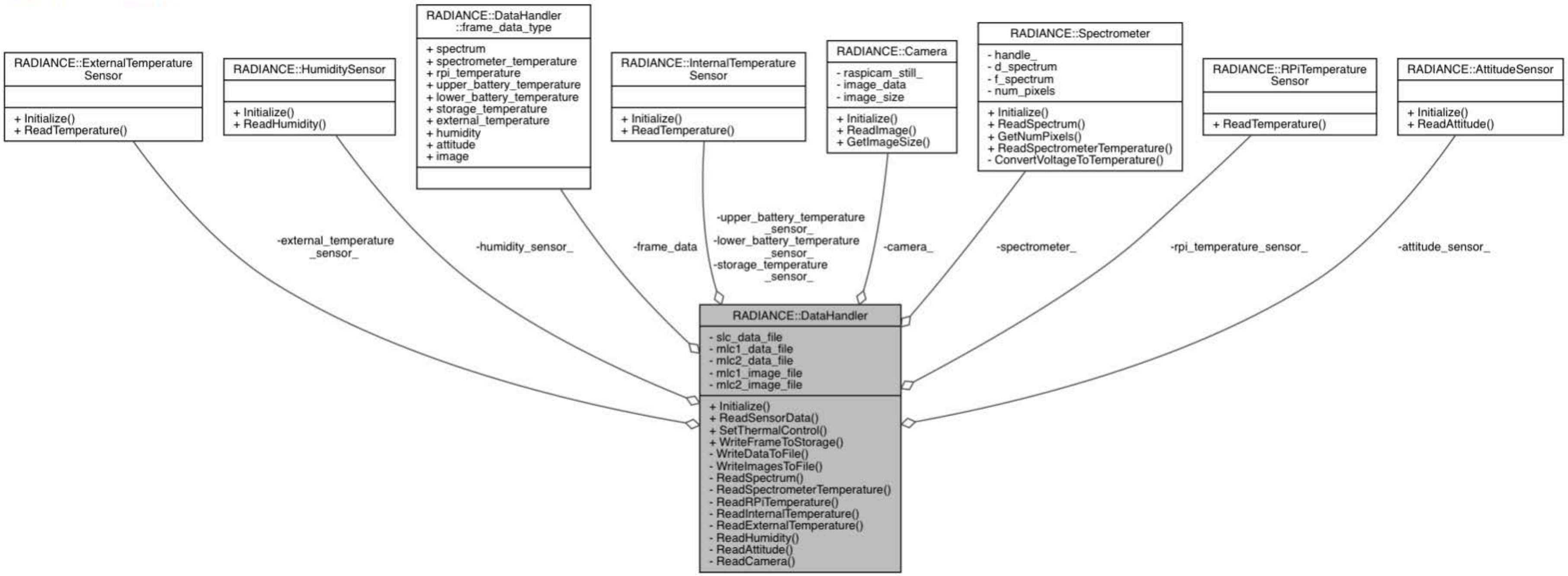
ADS ADC Board



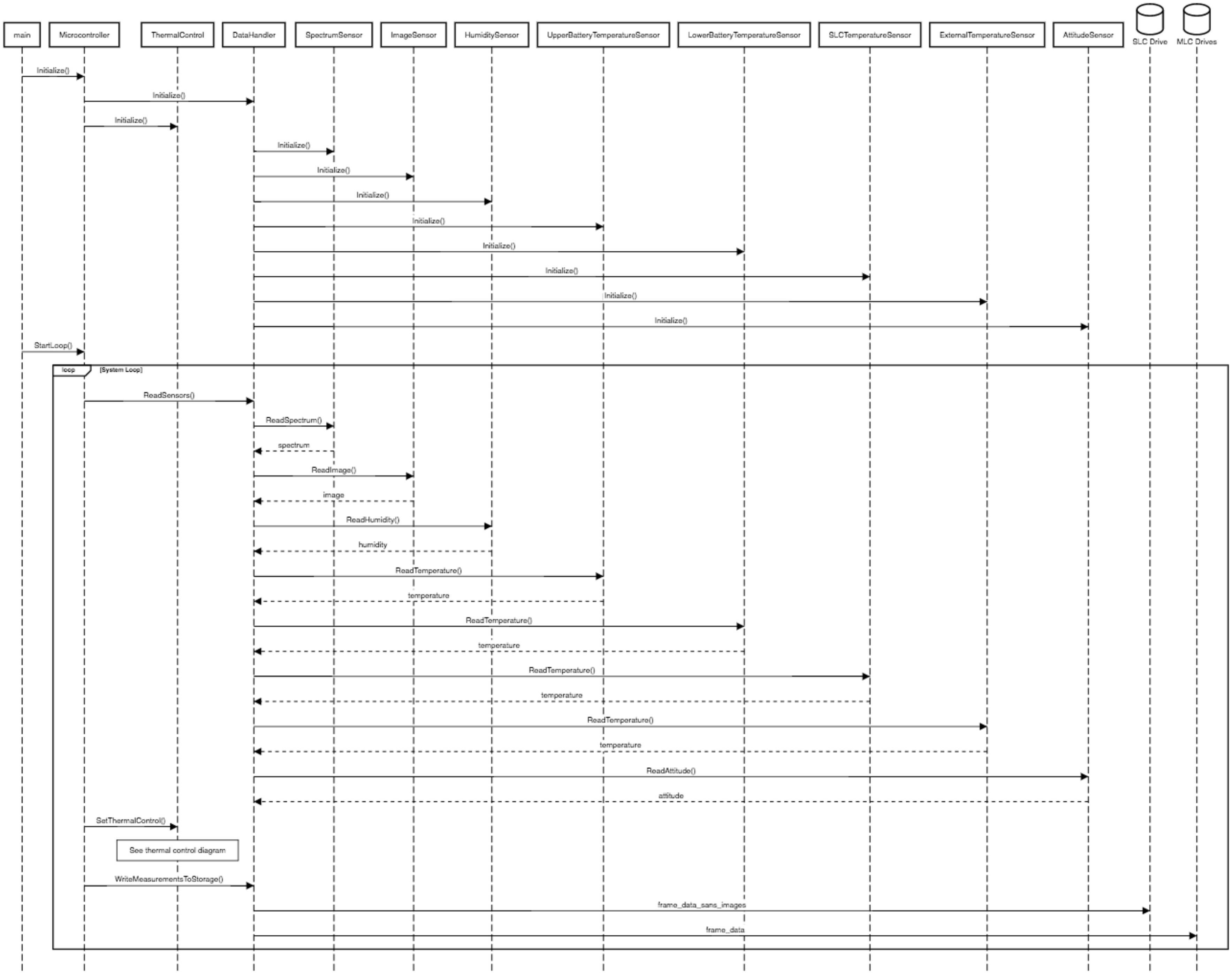
ADS ADC Board



- 16 bit SPI ADC (x4)
- Shared SCK, SDO
- CS selects photodiode being measured
- Supply voltage 5V, VIN from photodiodes


RADIANCE::ExternalTemperature Sensor
+ Initialize()
+ ReadTemperature()
RADIANCE::HumiditySensor
+ Initialize()
+ ReadHumidity()
RADIANCE::DataHandler ::frame_data_type
+ spectrum
+ spectrometer_temperature
+ rpi_temperature
+ upper_battery_temperature
+ lower_battery_temperature
+ storage_temperature
+ external_temperature
+ humidity
+ attitude
+ image
RADIANCE::InternalTemperature Sensor
+ Initialize()
+ ReadTemperature()
RADIANCE::Camera
- raspicam_still_
- image_data
- image_size
+ Initialize()
+ ReadImage()
+ GetImageSize()
RADIANCE::Spectrometer
- handle_
- d_spectrum
- f_spectrum
- num_pixels
+ Initialize()
+ ReadSpectrum()
+ GetNumPixels()
+ ReadSpectrometerTemperature()
- ConvertVoltageToTemperature()
RADIANCE::RPiTemperature Sensor
+ ReadTemperature()
RADIANCE::AttitudeSensor
+ Initialize()
+ ReadAttitude()
-external_temperature _sensor_
-humidity_sensor_
-frame_data
-upper_battery_temperature _sensor_
-lower_battery_temperature _sensor_
-storage_temperature _sensor_
-camera_
-spectrometer_
-rpi_temperature_sensor_
-attitude_sensor_
RADIANCE::DataHandler
- slc_data_file
- mlc1_data_file
- mlc2_data_file
- mlc1_image_file
- mlc2_image_file
+ Initialize()
+ ReadSensorData()
+ SetThermalControl()
+ WriteFrameToStorage()
- WriteDataToFile()
- WriteImagesToFile()
- ReadSpectrum()
- ReadSpectrometerTemperature()
- ReadRPiTemperature()
- ReadInternalTemperature()
- ReadExternalTemperature()
- ReadHumidity()
- ReadAttitude()
- ReadCamera()

RADIANCE Software Sequence



Data file example

Measurement file:

```
0008030: 74b0 a844 bfc1 a844 0cd3 a844 59e4 a844  t..D...D...DY..D
0008040: a4f5 a844 f006 a944 3b18 a944 8629 a944  ...D...D;..D.).D
0008050: d03a a944 1b4c a944 5335 0742 b81e 2342  .:.D.L.DS5.B..#B
0008060: cdcc cc3d cdcc cc3d cdcc cc3d cdcc cc3d  ...=...=...=...=
0008070: cdcc cc3d cdcc cc3d                      ...=...=
```

```
>>> import struct
>>> struct.unpack('f','\x53\x35\x07\x42')
(33.80207443237305,)
```

Error Handling

- Pi configuration safety checks:
  - Start the RADIANCE executable on every startup
  - Restart the Pi if the RADIANCE software is not running
  - Enable the internal (hardware) watchdog timer
- RADIANCE software safety checks:
  - On exception(null pointer) restart the Pi

Thermal Updates Since CDR

- Mesh independence study has been run
  - Study shows mesh is independent
  - Temperature spikes may exist
  - Average temperatures are accurate
- Videos of different ascent profiles are complete!
  - Heaters are important for operational temperatures
  - Not needed for survival temperatures
  - https://www.youtube.com/watch?v=dXv1SI_j354
  - https://www.youtube.com/watch?v=S_LX7o7dVY4

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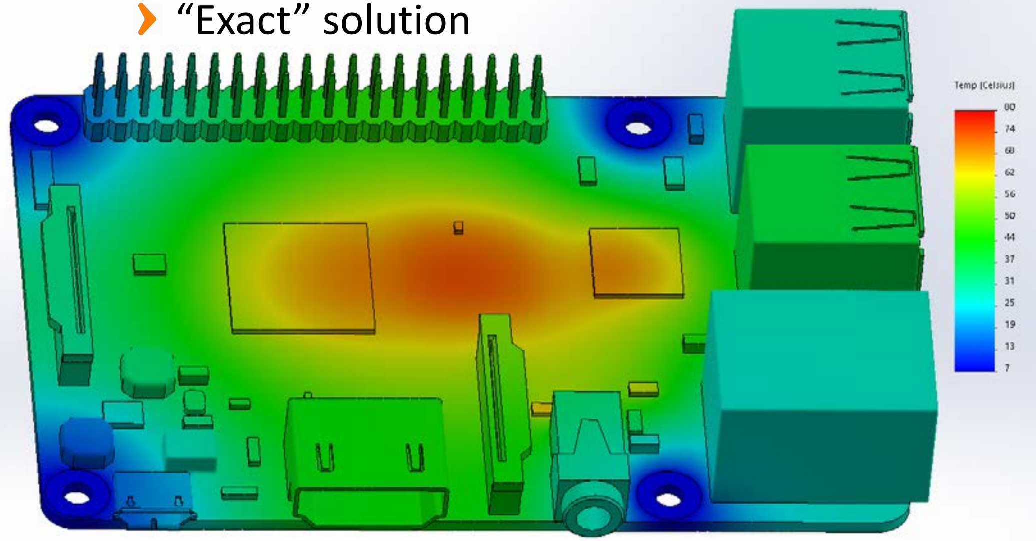
Thermal To Do

- Run full length simulations in Thermal Desktop
  - SolidWorks can't handle full length assembly simulations
  - Too many elements
  - Thermal Desktop uses finite difference rather than finite element
- Get access to Janus
  - May be able to run SolidWorks simulations on Janus

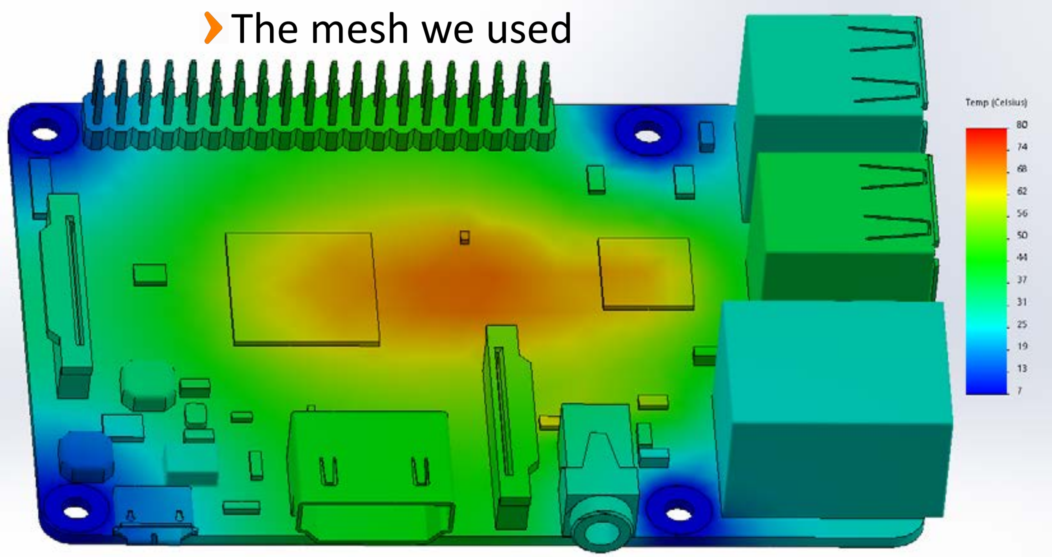
Mesh Independence Study

- Finer mesh shows higher temps
  - Average temperatures similar
  - Adds margin in our favor
- Larger study showed same results
  - Data lost due to unforeseen circumstances

- “Exact” solution

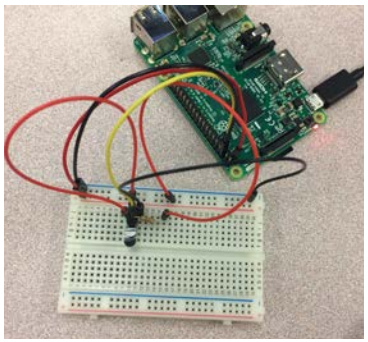


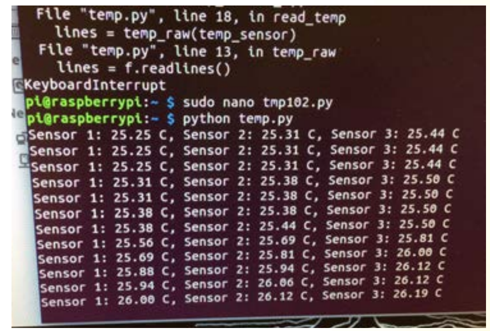
- The mesh we used



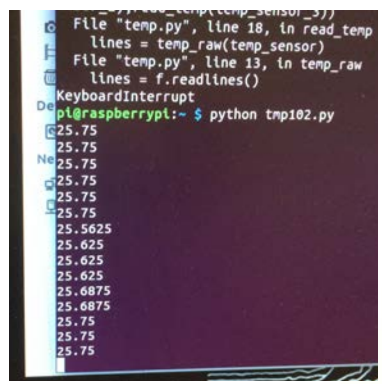
Temperature Sensor Status

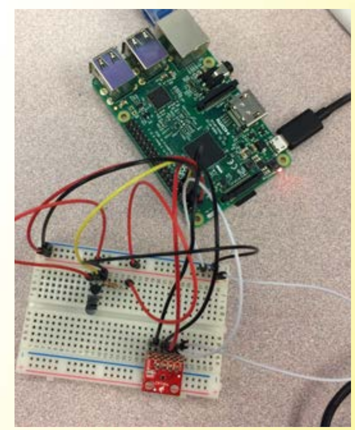
- DS18B20 One Wire Temperature Sensors
  - Receiving readings from all sensors on single pin





- TMP102 I2C Temperature Sensor
  - Receiving readings





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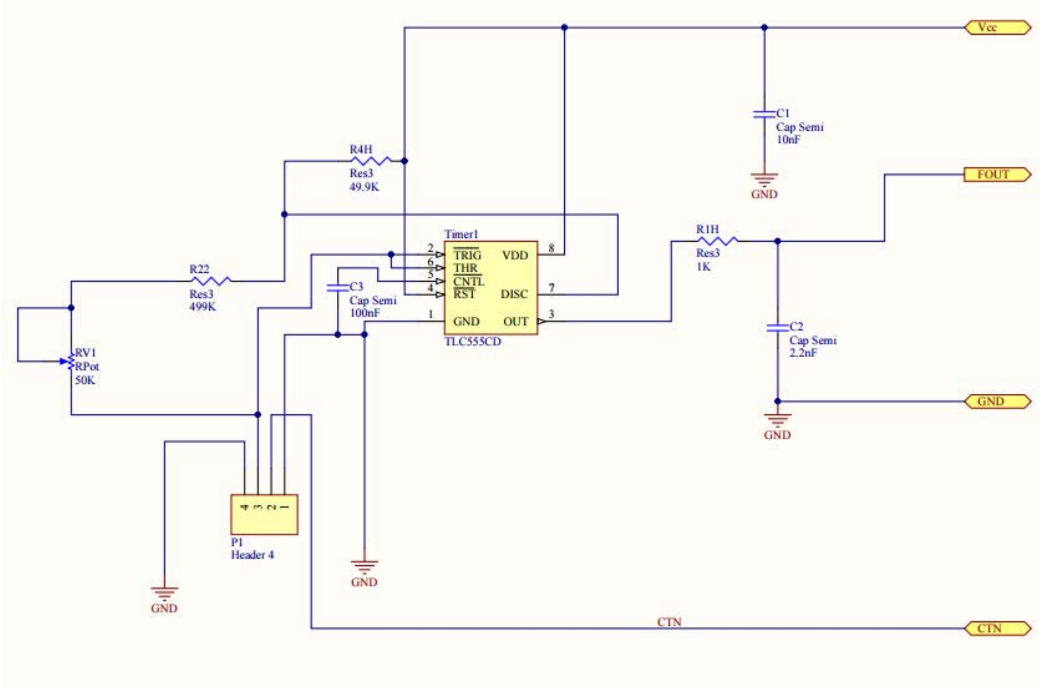
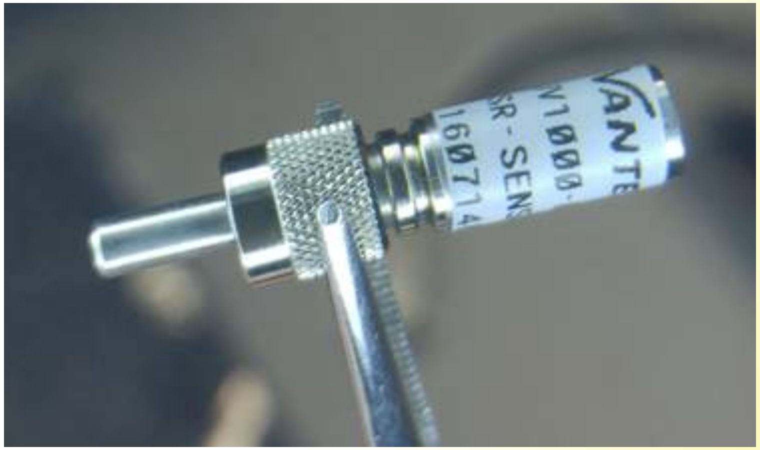
Humidity Sensor Status

- Circuit designed
- Part received
- Awaiting PCB to begin testing



Spectrometer Status

- Received from manufacturer
- Fits inside enclosure
- Fiber cable provided is different than test unit
  - Does not fit in current structural design
  - Getting replacement from manufacturer
- Not yet calibrated



Visible Range Camera Status

- All parts received
- Tests on
  - Ability to receive images from camera
  - Accuracy of new lens
  - Lens fits inside structure