RADIANCE

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

Test Readiness Review

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Team Members: Brandon Antoniak, Lance Walton, David Varley, James Pavek, Alec Fiala

NCAR NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

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Aerospace Engineering Sciences
UNIVERSITY OF COLORADO BOULDER

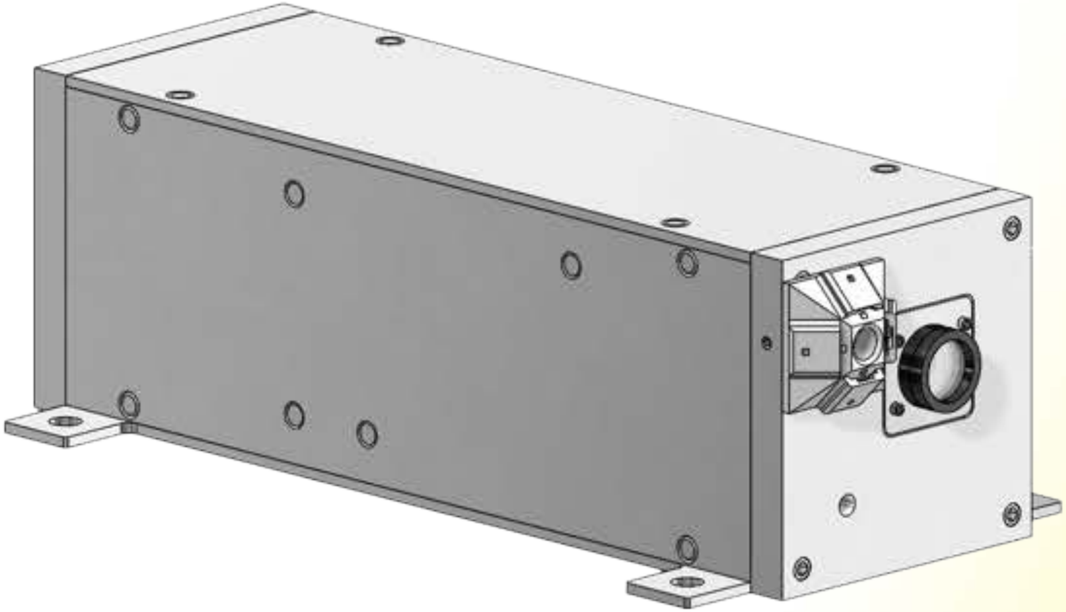
Project Statement

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



Baseline Design

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.

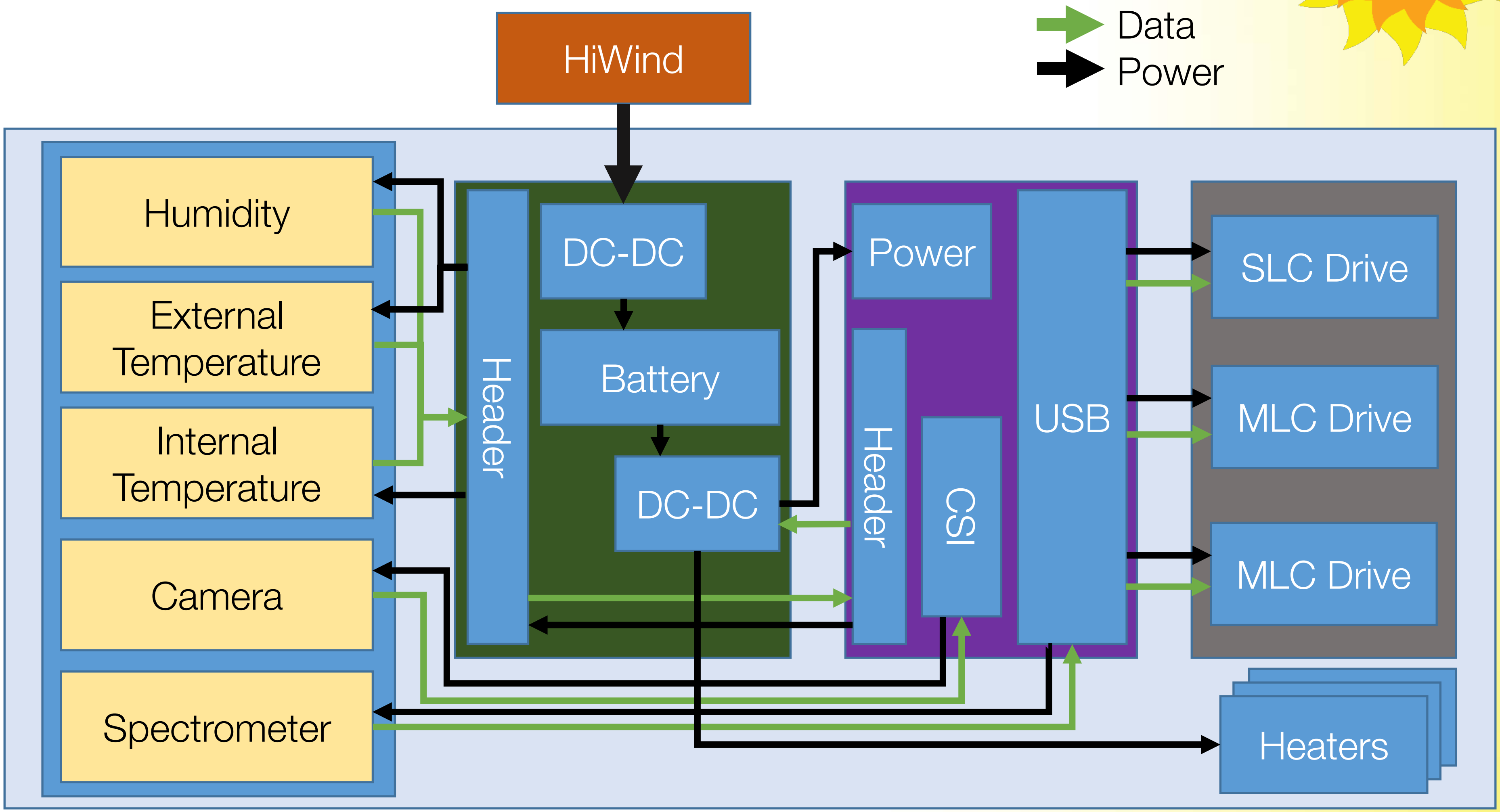
FR4: Determine its attitude.

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.

Functional Block Diagram



Levels of Success

System	Expected Level	Details	Date
Instr.	3	Take solar irradiance measurements at better than 1.5nm resolution covering 250-1000nm Capture 1 photo/min of the Sun for full flight Provide calibration of the instrument	**3/18**
C&DH	3	Record solar irradiance, attitude, environmental, and housekeeping data on a durable data storage device with sufficient capacity	**3/18**
Thermal	3	All systems survive and operate during the thermal conditions of the full flight	**3/31**

Levels of Success

System	Expected Level	Details	Date
ADS	2	Determine and record attitude to 1 arcminute of accuracy relative to the sun vector	**3/31**
	1	Determine and record attitude to 1° of accuracy relative to the sun vector	
EPDS	1	Package operates on HiWind power supply	**3/18**
Structure	1	Structure must be within 10cm x 10cm x 32cm Data is recoverable after up to 5 Gs on landing Structure can be affixed to HiWind	**Done**

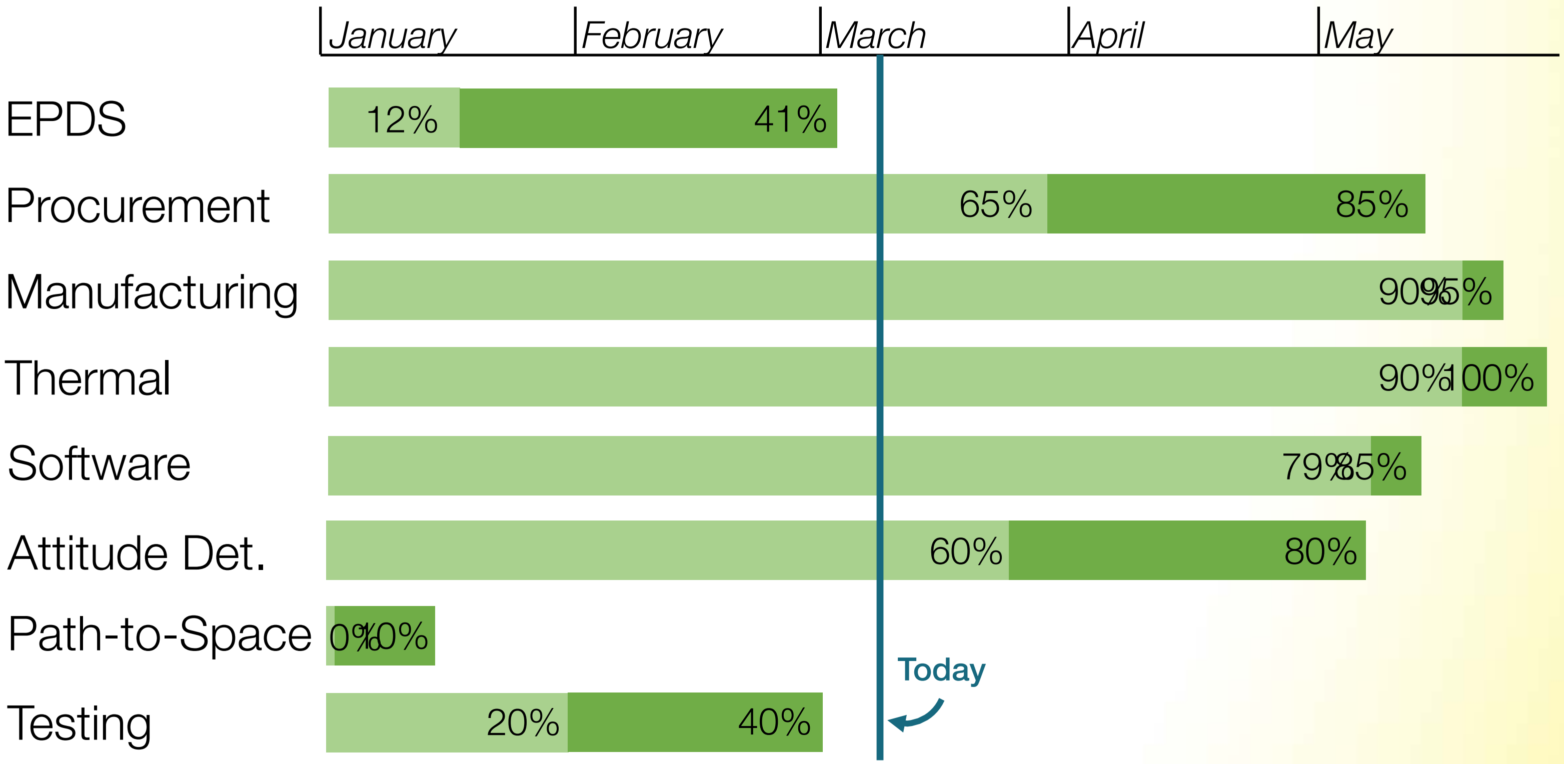
Critical Project Elements

CPE	Justification	FR
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
Camera, Lens	Challenging assembly to ensure in-focus images	6
Attitude Determination	Complex design, small parts, challenging hardware/software interface	4

No changes since MSR.

Schedule Status

Executive Summary



Testing Overview

Verification & Validation Plan

Component Testing	Subsystem Testing	Integration Testing
Verify that components operate as expected	Verify integrated operation of subsystems Model Validation	Verify integrated operation of full system Model Validation
Start Nov 21	Start Feb 22	Mar 10 — Apr 14

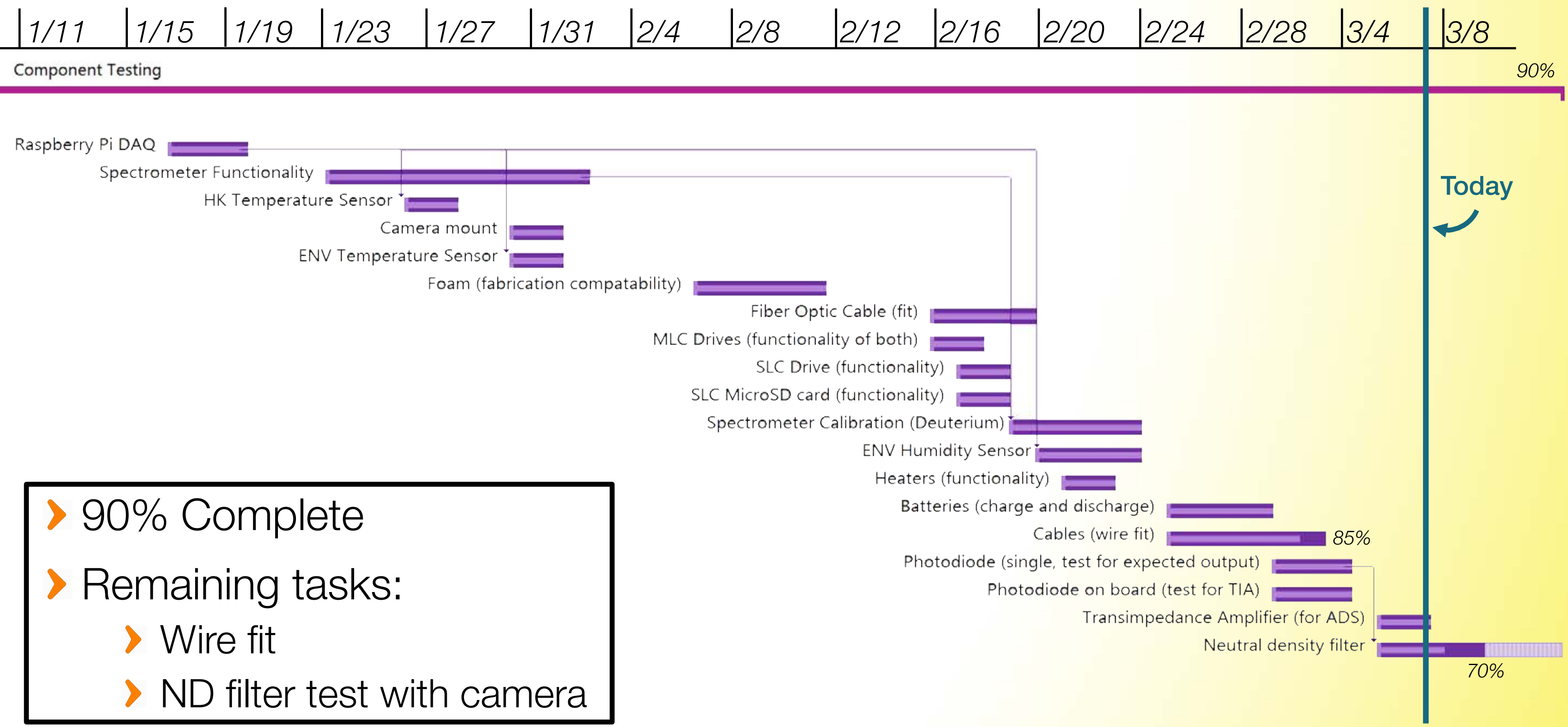
Component Testing

Purpose and Scope

Component Testing	Subsystem Testing	Integration Testing

- Purpose:
  - Verify components turn on, take measurements, and act according to data sheets
  - Investigate need for calibration & perform calibration
- Scope:
  - Sensors and science instruments
  - Microcontroller and storage devices
  - Power system and thermal control components
- Risks Reduced:
  - Camera lens modification

Component Testing Schedule



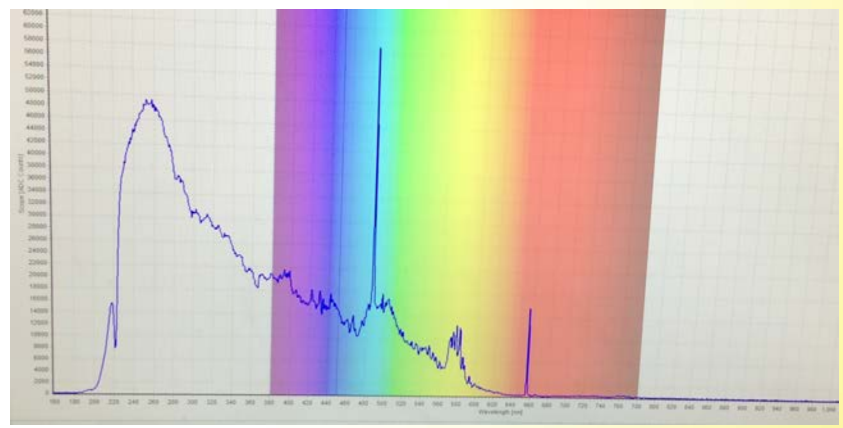
- 90% Complete
- Remaining tasks:
  - Wire fit
  - ND filter test with camera

Project Overview | Schedule | Component Testing | Subsystem Testing | Integration Testing | Budget

Spectrometer Calibration

- Avantes Deuterium light source
- AvaSoft calibration software
- Calibration stored on spectrometer

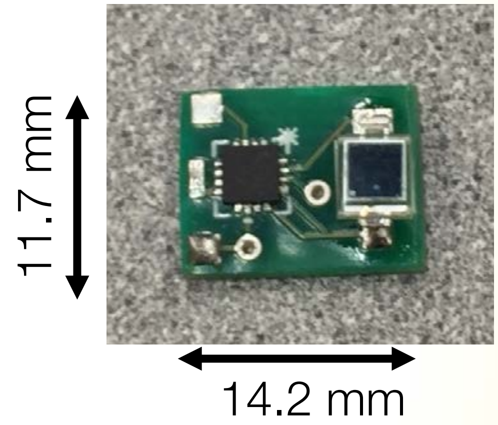
Scope [ADC Counts] (0-6000)

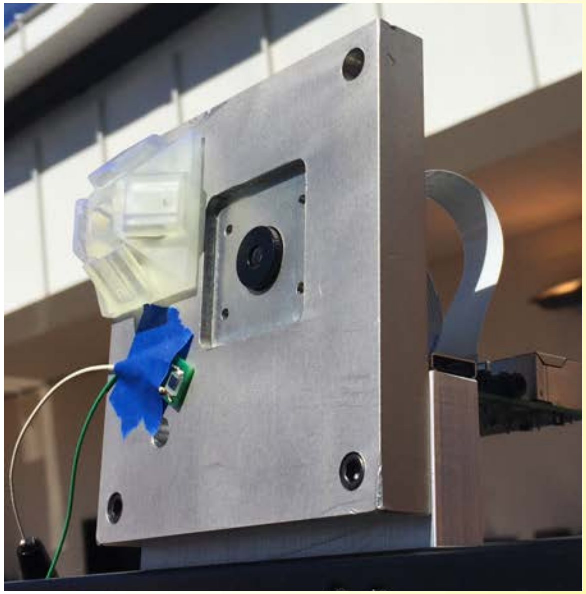


Wavelength (160-1000nm)

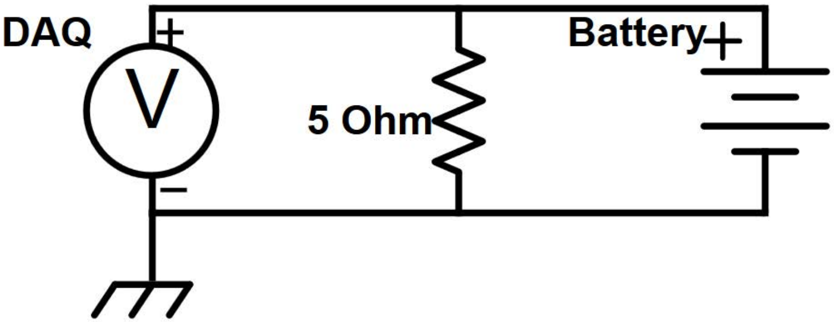
Photodiode Test

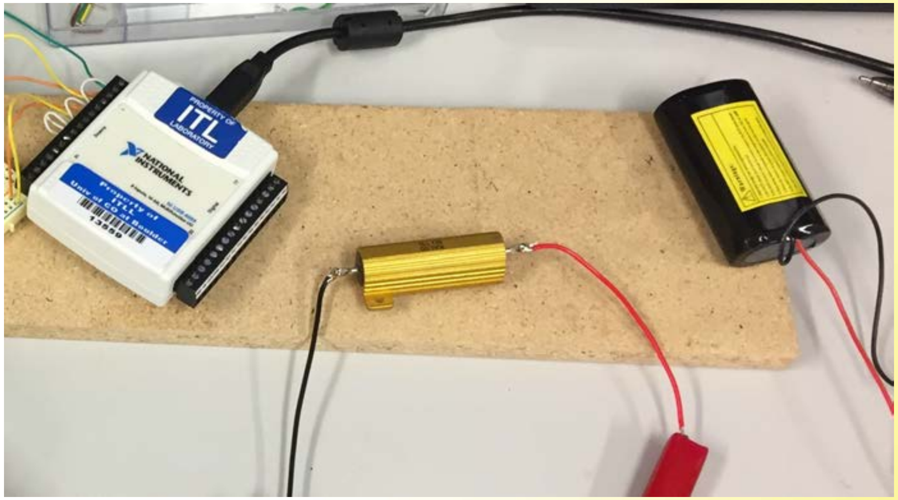
- Single photodiode
- Measure current with multimeter
- Verify response to small angular position changes
- Higher than expected current (2.51 mA)
  - Change feedback resistance from 5 kΩ to 1 kΩ





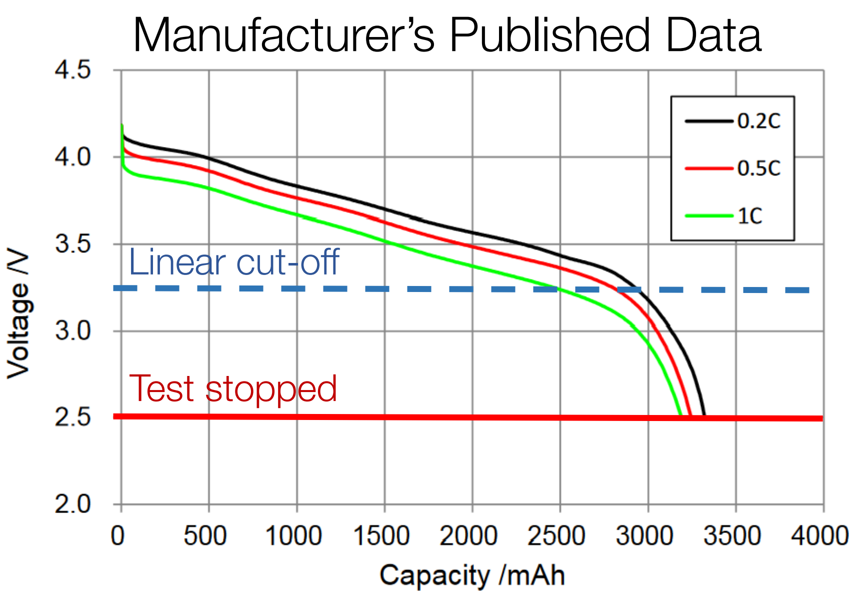
Battery Capacity Testing

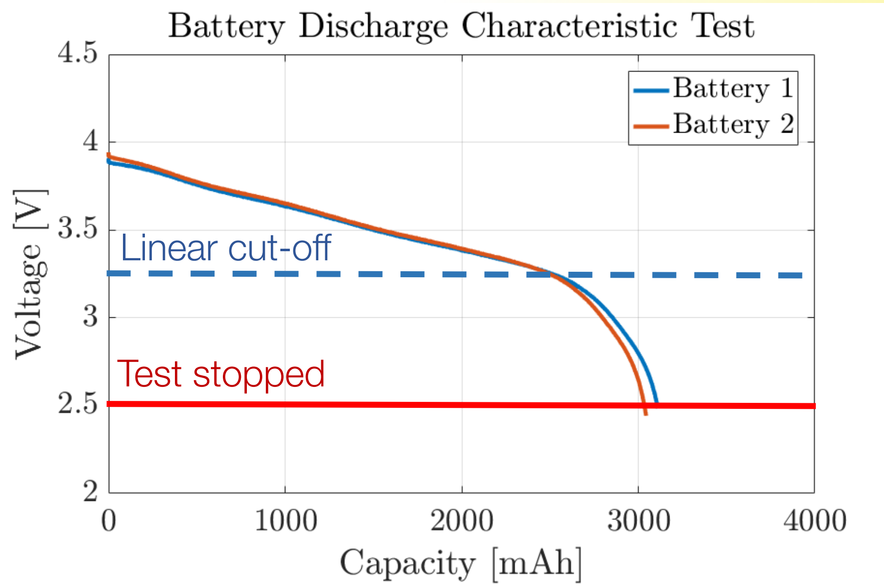




- Battery discharge across load resistor
- Voltage readings taken every 5 seconds
- 50W, 5Ω resistor used

Battery Discharge Testing

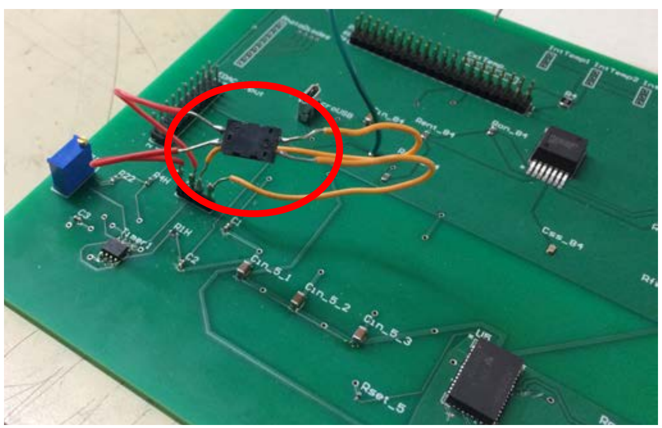


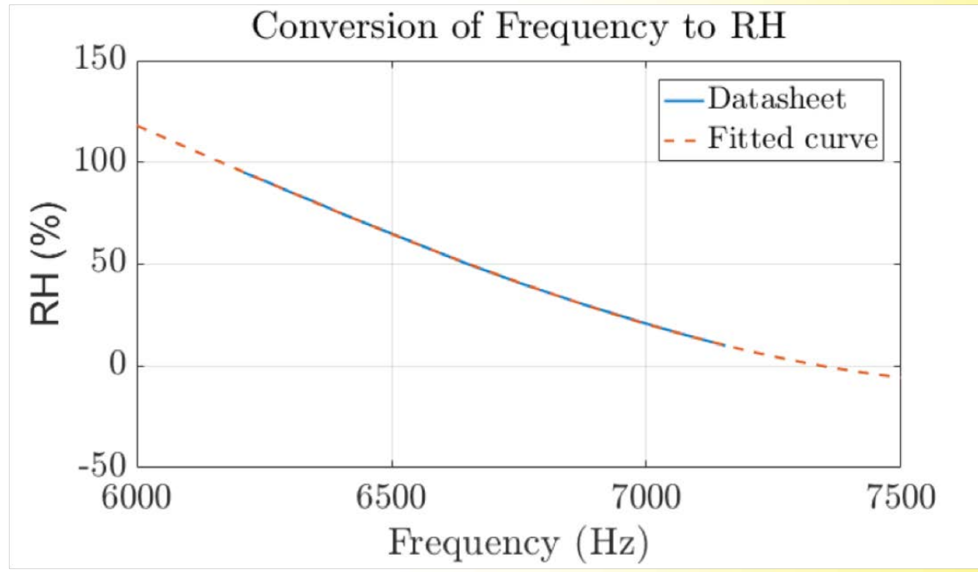


- Batteries charged to ~90%
- Tested at 0.5C discharge rate
- Linear voltage drop to ~3.25V
- Discharge test stopped at 2.5V

External Humidity Sensor

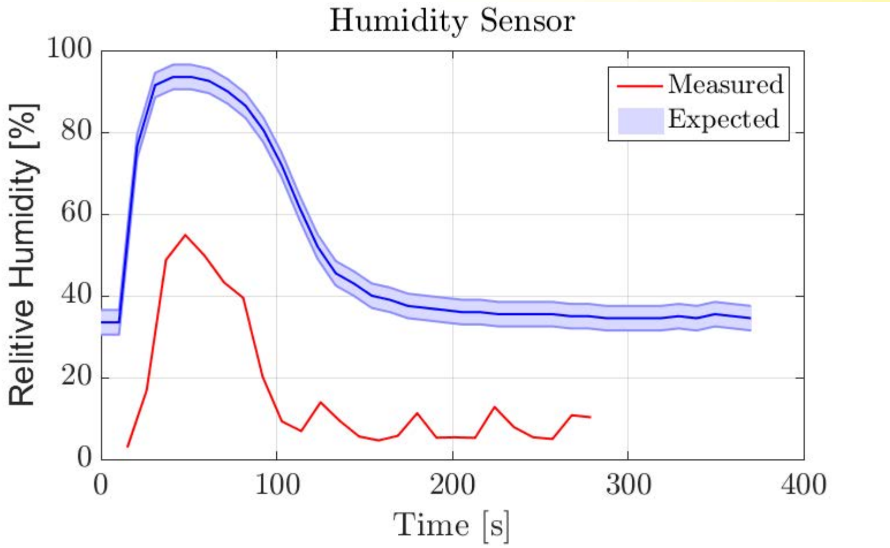
- Analog
- Measure frequency
- Placed on back of structure





Humidity Sensor Error

- Systematic error
  - ~36%
- Circuit produces up to 20% error
  - Propagated humidity error ~70%
- Requires calibration
  - EL-USB humidity sensor
  - Accurate to 3% RH



Status Summary

Completed & Passed	In Progress	Upcoming
• Batteries (2) • Camera • Env. Temperature Sensor • Env. Humidity Sensor • Housekeeping Temperature Sensors (3) • Raspberry Pi • SLC Flash Drive • MLC Flash Drive (2) • Heaters (2) • Photodiodes (4) • Spectrometer Calibration	• ND Filter • Wire fit • Humidity Sensor • SLC microSD card	• TVAC Temp Sensors (10)

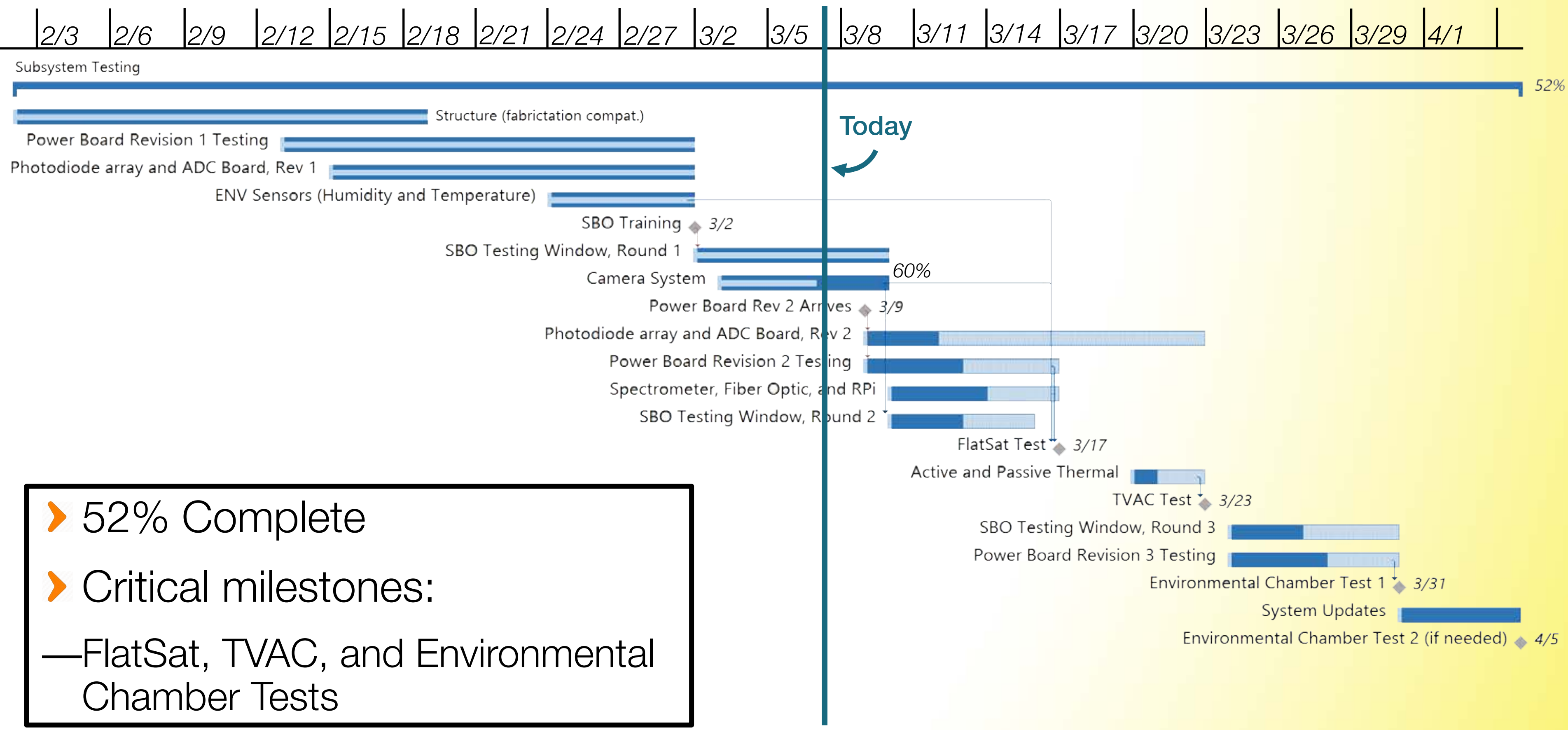
Subsystem Testing

Purpose and Scope

Component Testing	**Subsystem Testing**	Integration Testing

- Purpose:
  - Verify and integrate operation of subsystems, and interaction between software with hardware
  - Validate CAD model and ADS model
- Scope:
  - Power boards with batteries
  - Thermal, instrumentation, C&DH, and software
  - Structural integration
- Risks Reduced:
  - Fabrication incompatibility, improper data handling, and circuit issues

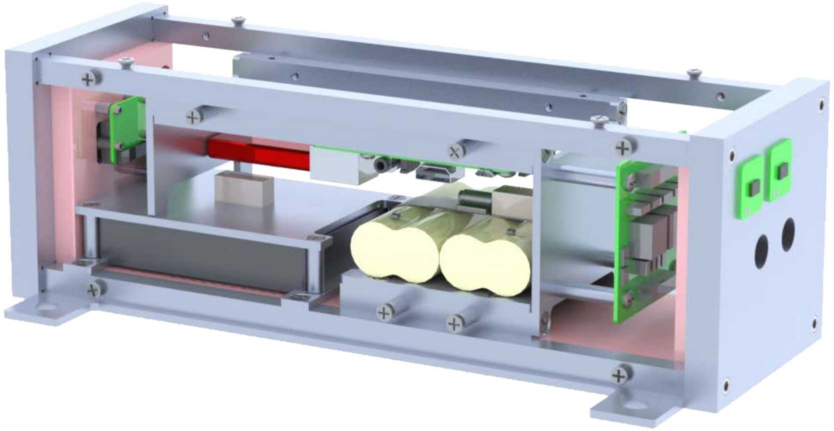
Subsystem Testing Schedule



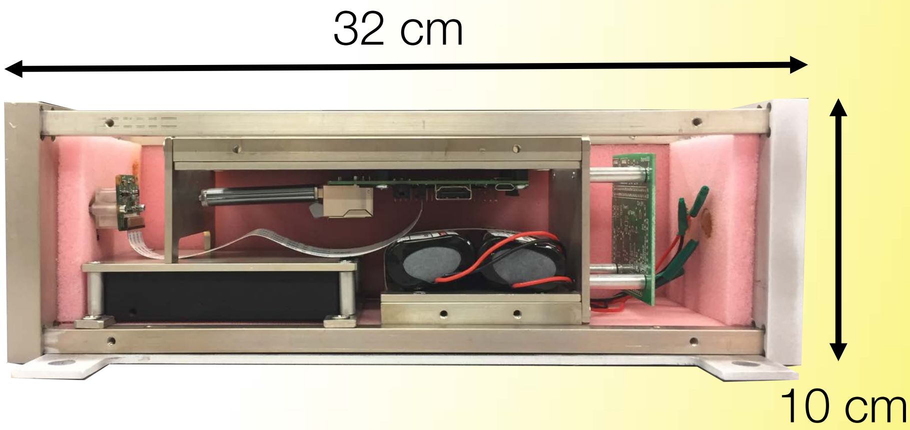
- 52% Complete
- Critical milestones:
  - —FlatSat, TVAC, and Environmental Chamber Tests

Structure Test Summary

Purpose	Test fabrication compatibility between purchased components and manufactured parts



Designed Assembly



Actual Assembly

Sommers-Bausch Observatory

- Used for testing ADS and camera
- Sun-tracking telescope with 2 arcsec/hour drift

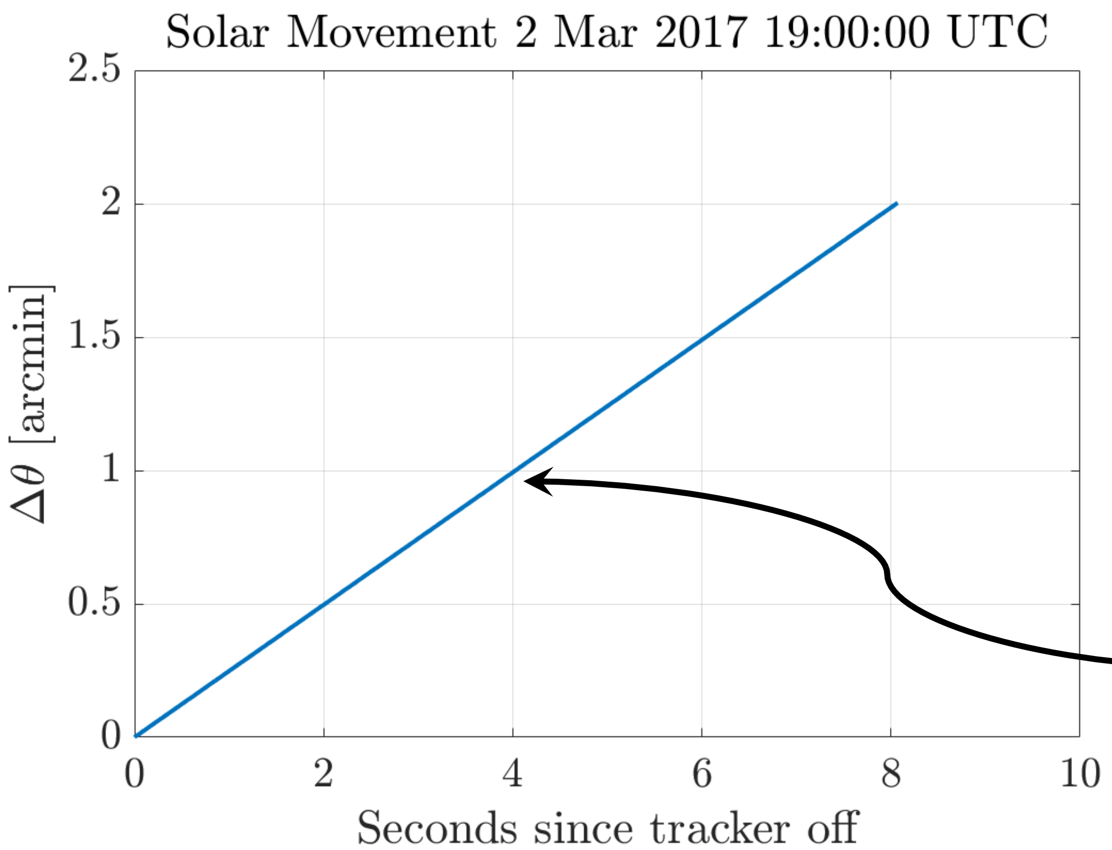
FR 4: RADIANCE shall determine its attitude.

FR 6: RADIANCE shall take images of the sun.

ADS Subsystem Test

- Photodiodes connected to ADC and Raspberry Pi
- Collect data with flight software, write to flash drive
- Compare computed angle with STK model

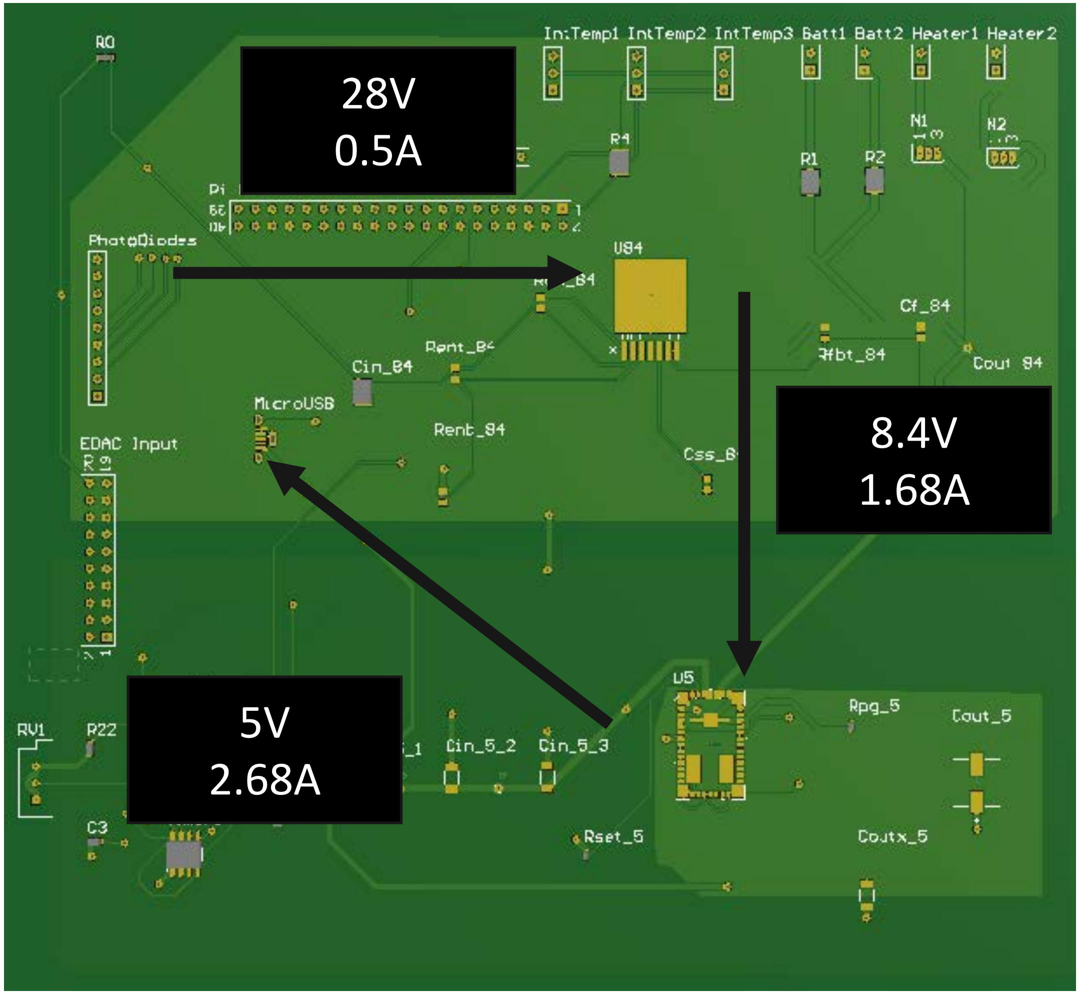
Ideal Results (STK)



Solar angle rate =
0.2482 ± 0.0003
arcmin/sec
(over 3 minute test)

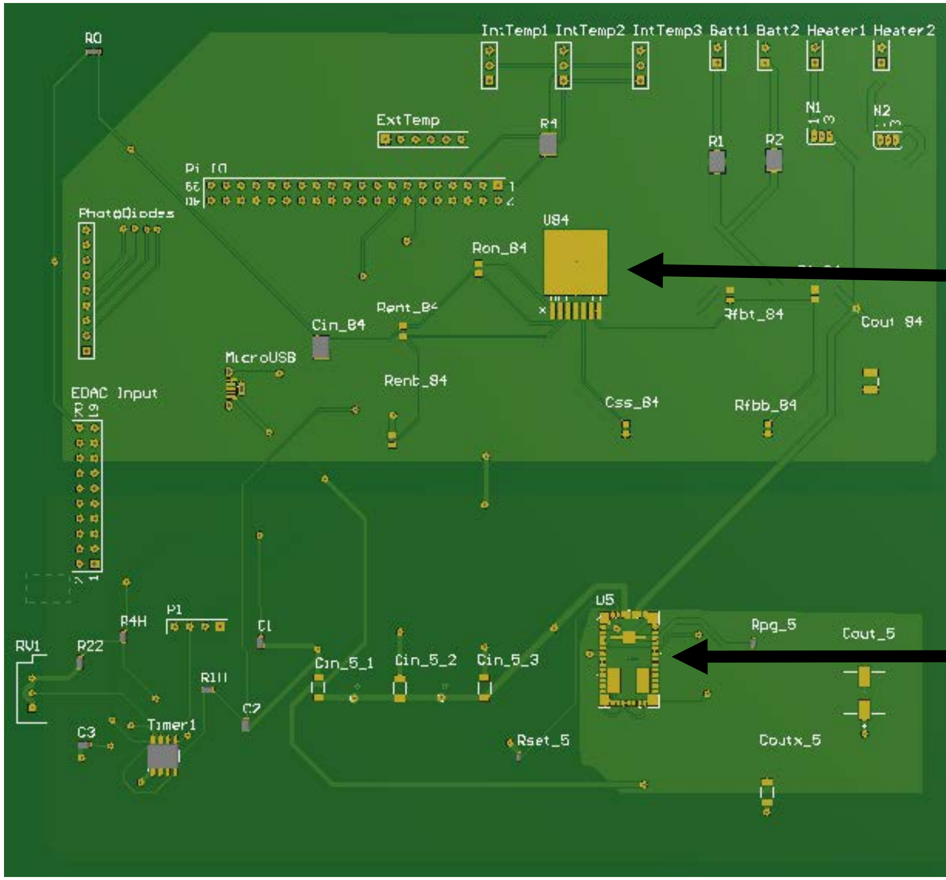
1 arcminute of movement occurs 4.03 seconds after turning off the sidereal tracker

Power Testing: Model



- Verify Voltage
  - 3 Modeled Points
  - Interfaces
    - Battery
    - Heater
    - USB

FlatSat Power Board Testing



Input of 28 V

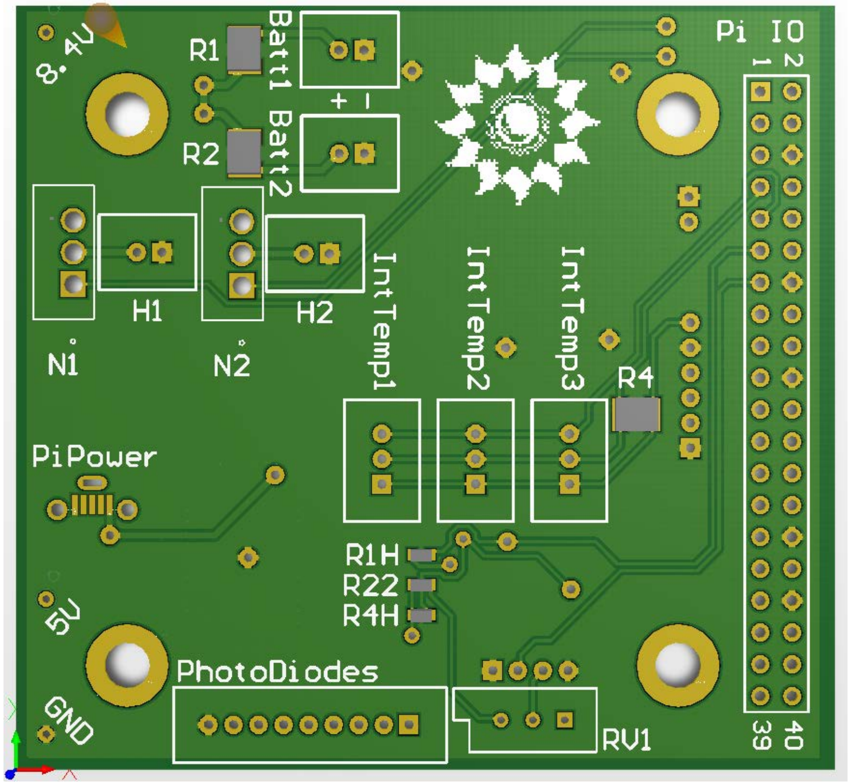
Expected: 8.4V
Measured: 8.6V

Update Voltage Divider

Expected: 4.95V
Measured: 4.3V

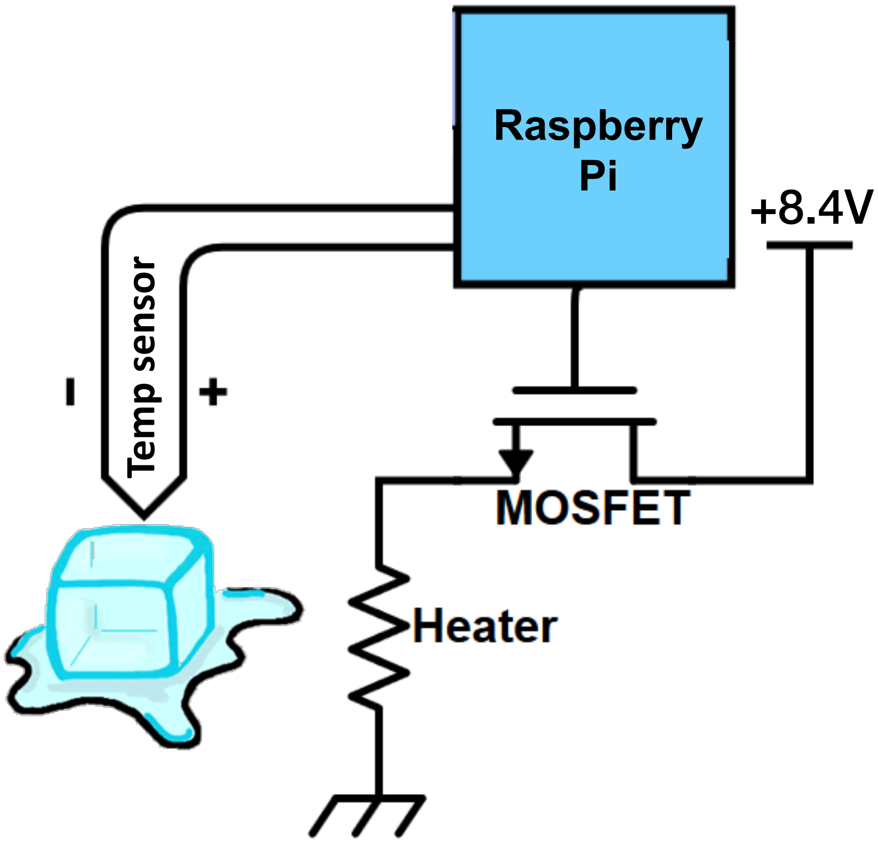
Solder Stencil Manufacturing

Revision 2 Power Testing



- Verify changes successful
- Verify power model
- Begin integration testing

Active Thermal System



- Verify Raspberry Pi turns heater on/off
- Verify software integration with hardware
- Confirm thermostat dead-zone

Status Summary

Completed & Passed	In Progress	Upcoming
• Structural Fit • Power Board Rev. 1	• Attitude Determination System • Camera System • Power Board Rev. 2 • Environmental Sensors with C&DH and Software	• Active Thermal Control System • Power Board Rev. 3

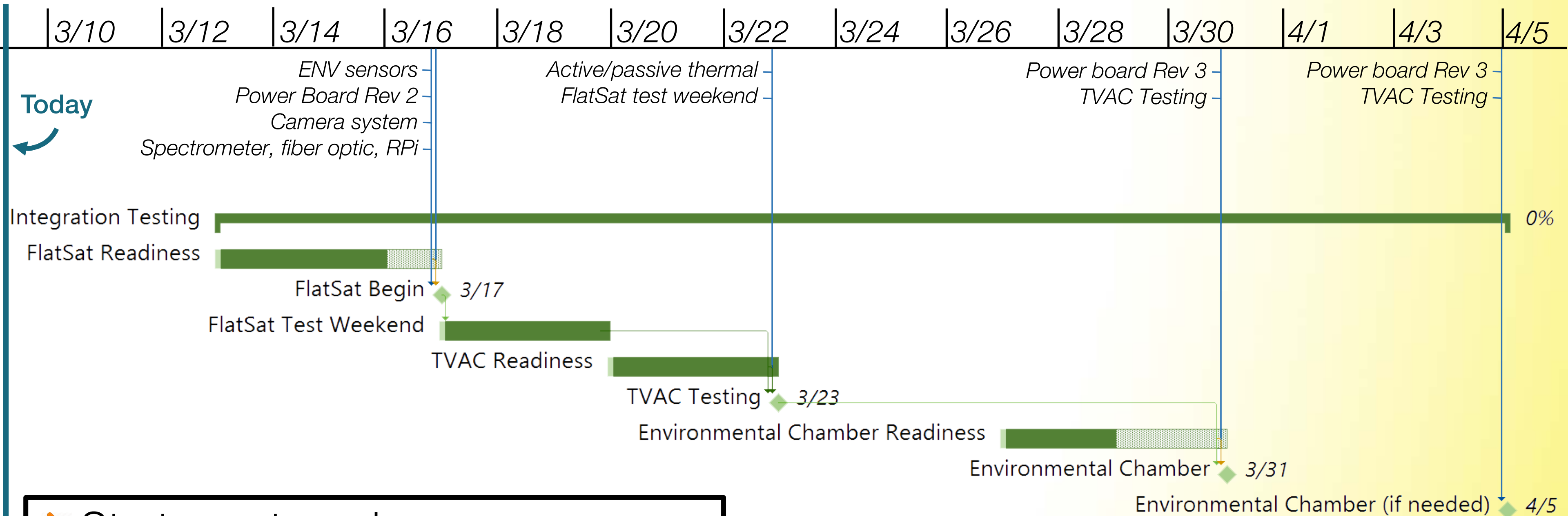
Integration Testing

Purpose and Scope

Component Testing | Subsystem Testing | **Integration Testing**

- Purpose:
  - Verify and demonstrate integrated operation of full system
  - Validate SolidWorks thermal, C&DH storage capacity, and timing models
- Scope:
  - Includes all hardware, electrical components, and software
  - FlatSat Tabletop Integration and Environmental Testing
- Risks Reduced:
  - Violating operational temperature bounds
  - Data overwrite error
  - Software lock-up

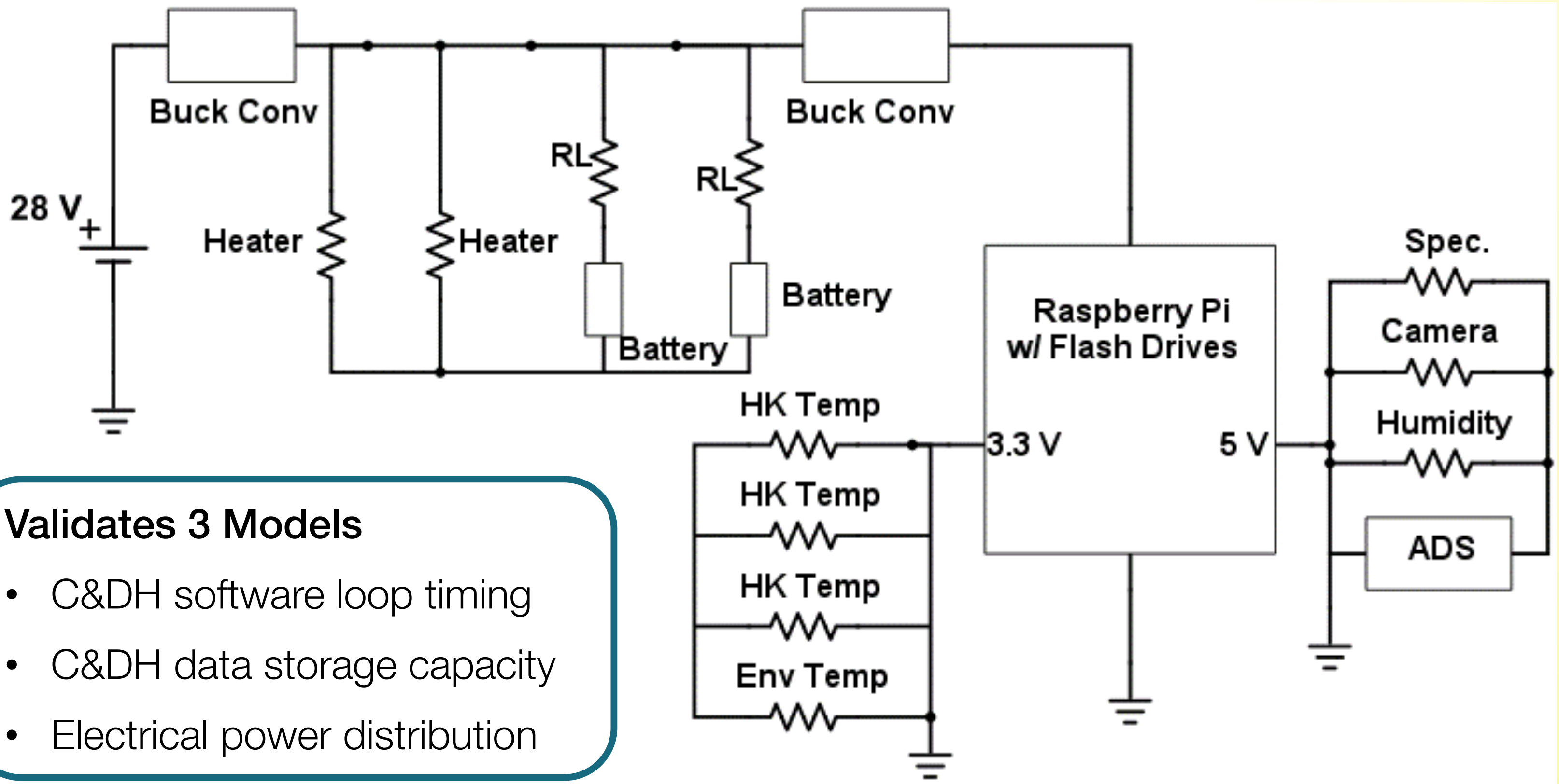
Integration Testing Schedule



- Starts next week
- Integration tests are the critical final steps to determine levels of success and requirements met

FlatSat Tabletop Integration

FR 2: The system shall return data.



Validates 3 Models

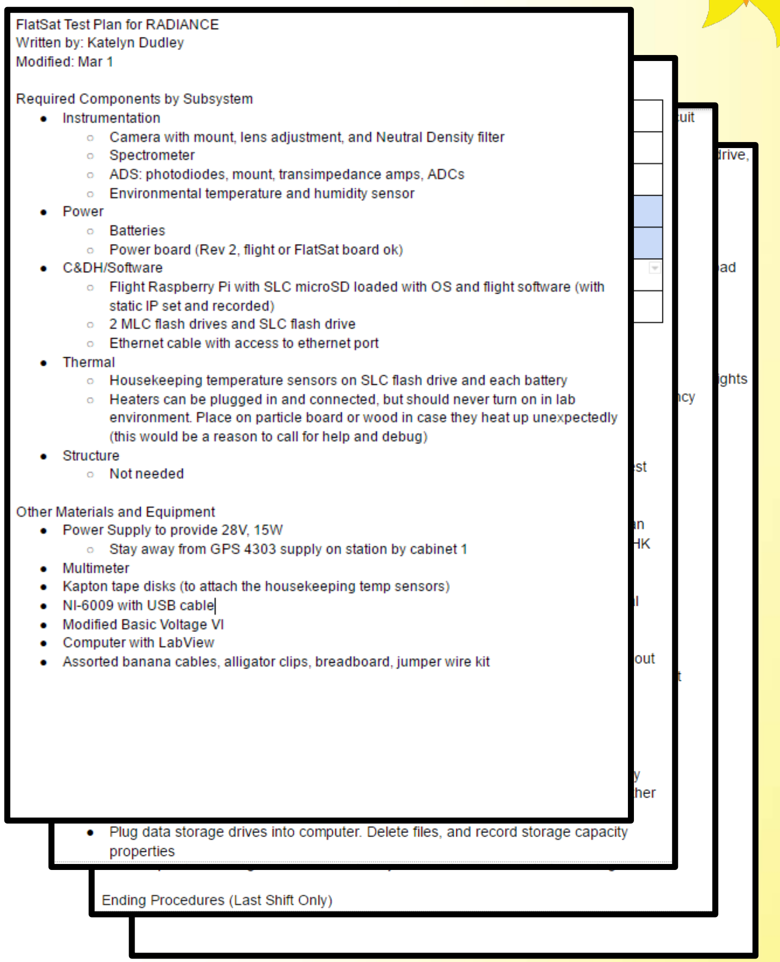
- C&DH software loop timing
- C&DH data storage capacity
- Electrical power distribution

FlatSat Tabletop Integration

48-hour continuously staffed test
March 17 to March 19

DAQ System:

- Flight system writes data from all sensors to onboard storage
- NI 6009 DAQ system to record voltages
- Manual backup of voltage measurements
- Heartbeat messages to terminal


FlatSat Test Plan for RADIANCE
Written by: Katelyn Dudley
Modified: Mar 1

Required Components by Subsystem

- Instrumentation
  - Camera with mount, lens adjustment, and Neutral Density filter
  - Spectrometer
  - ADS: photodiodes, mount, transimpedance amps, ADCs
  - Environmental temperature and humidity sensor
- Power
  - Batteries
  - Power board (Rev 2, flight or FlatSat board ok)
- C&DH/Software
  - Flight Raspberry Pi with SLC microSD loaded with OS and flight software (with static IP set and recorded)
  - 2 MLC flash drives and SLC flash drive
  - Ethernet cable with access to ethernet port
- Thermal
  - Housekeeping temperature sensors on SLC flash drive and each battery
  - Heaters can be plugged in and connected, but should never turn on in lab environment. Place on particle board or wood in case they heat up unexpectedly (this would be a reason to call for help and debug)
- Structure
  - Not needed

Other Materials and Equipment

- Power Supply to provide 28V, 15W
  - Stay away from GPS 4303 supply on station by cabinet 1
- Multimeter
- Kapton tape disks (to attach the housekeeping temp sensors)
- NI-6009 with USB cable
- Modified Basic Voltage VI
- Computer with LabView
- Assorted banana cables, alligator clips, breadboard, jumper wire kit

- Plug data storage drives into computer. Delete files, and record storage capacity properties

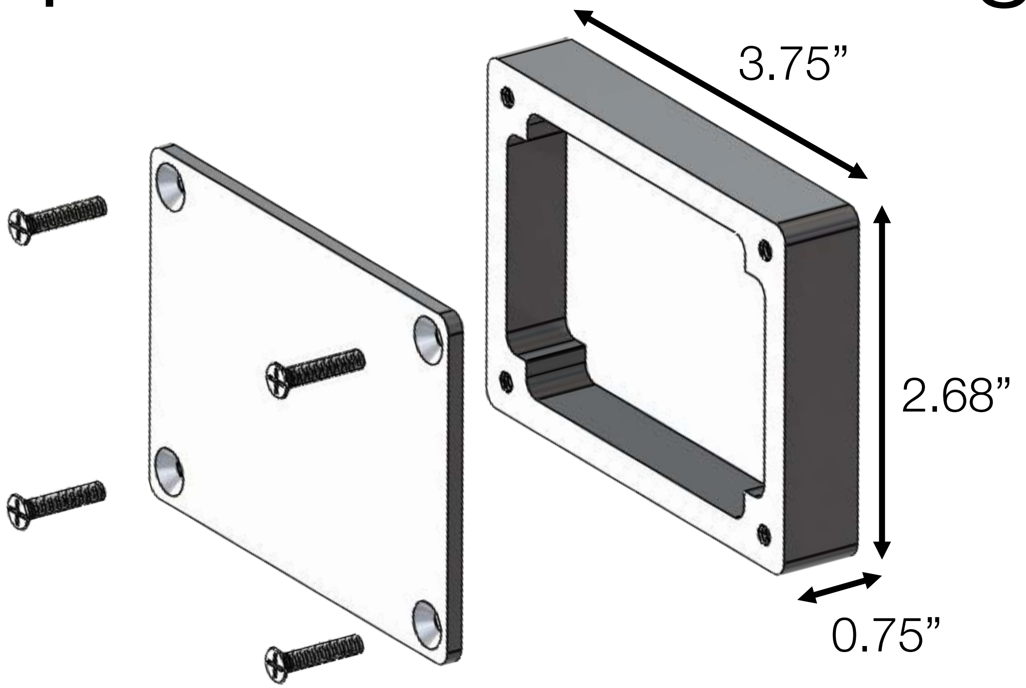
Ending Procedures (Last Shift Only)

Thermal Vacuum Chamber

FR 2: The system shall survive the environmental conditions of flight.

- TVAC at HAO NCAR
- Week of March 20
- Validate thermal models for cruise
- Chamber ratings:
  - 270 Pa, -20°C
- Our needs:
  - 200 Pa, 5°C

Spectrometer Analog



Circuit specifications:

$$P = 1.25\ \text{W}$$

$$R = 15.25\ \Omega$$

$$V = 4.37\ \text{V}$$

- Unacceptable risk to expose spectrometer to ENV tests
- Mimic mass (174 g), conductivity, and heat output
- 1D heater rated to 20W inside milled-out aluminum block

Environmental Chamber

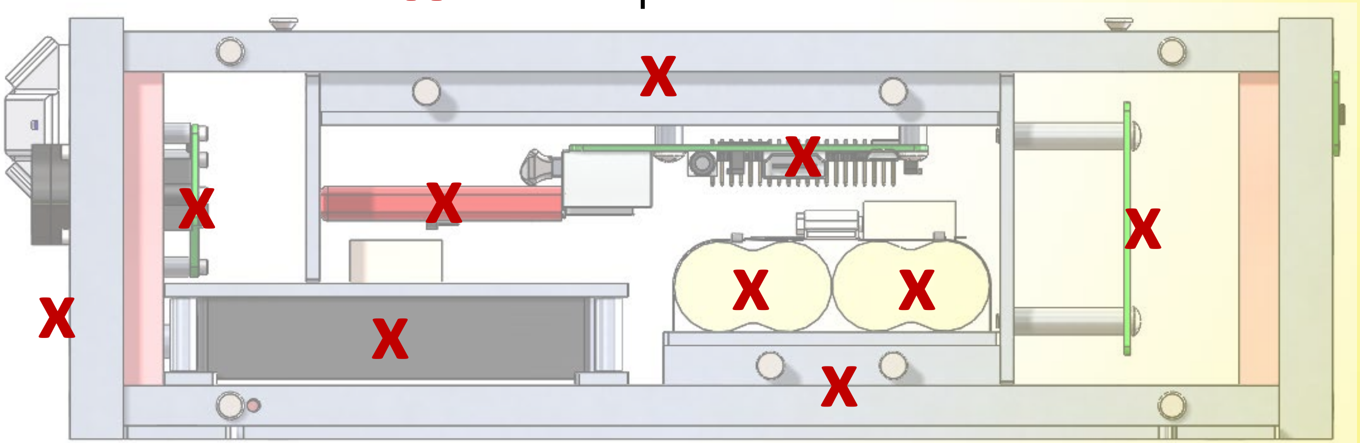
FR 2: The system shall survive the environmental conditions of flight.

- Payload will experience two full ascent profiles
- Narrow availability for chamber use
- Requires constant staffing
- Spectrometer analog will be used to avoid damaging expensive instrumentation

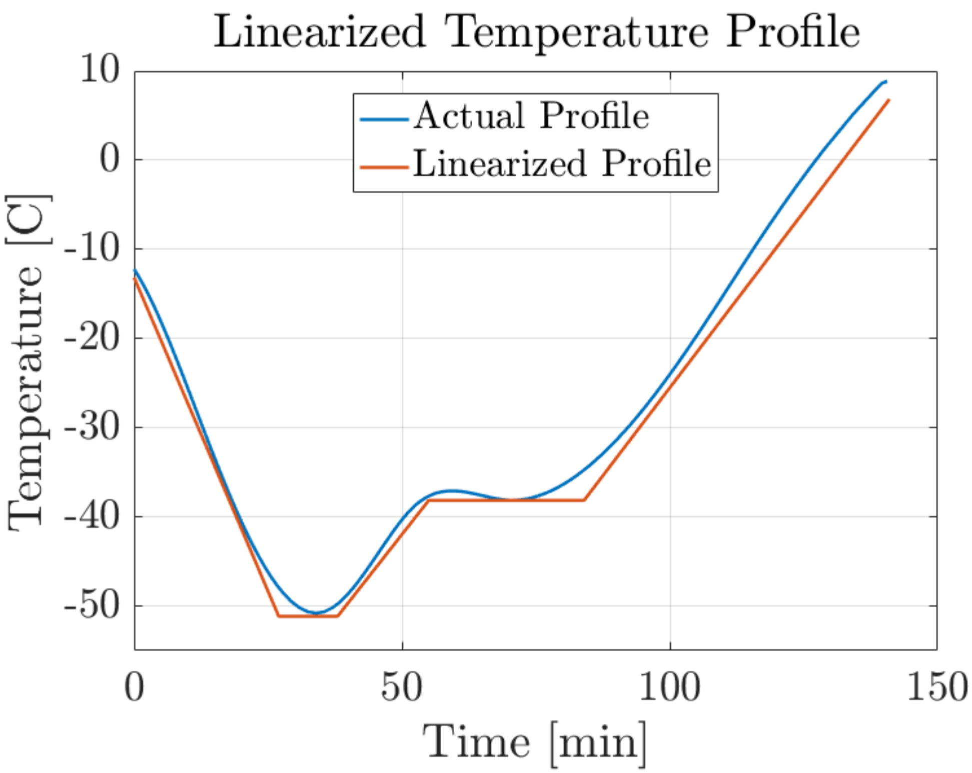
Environmental Chamber

- External DAQ and Power
- DAQ system: 10 temperature sensors in chamber sending data to DAQ-specific Raspberry Pi
- **System will function** as in flight (minus spectrometer)
- Wires feed through foam insulated port

X = Temperature Sensor



Environmental Chamber



- ENV chamber only takes linear inputs
- Temperature profile linearized to be harsher than reality
- Start test with 60 minutes at -10°C

Projects Risk Matrix – Post CDR

Likelihood	Consequences					
	Risks easily mitigated	1 FR Failed	2-3 FRs Failed	3-4 FRs Failed	5-6 FRs Failed	
Certain	1					5
Likely						4
Moderate	1					3
Unlikely		4				2
Rare	1	4	1		1	1
	1	2	3	4	5	

Testing and Risk Mitigation

Element	Value	Test
Overheating	5	TVAC
Frost on optics	5	Acceptable Risk
Heater failure	3	TVAC
Drive hardware failure	4	Acceptable Risk
Temporary power failure	3	FlatSat (Error Handling)
Software data write failure	2	FlatSat (Error handling)
Bit flip	2	Acceptable Risk
Drive connection failure	2	Acceptable Risk
Camera oversaturation	2	SBO
Pi software failure	1	FlatSat

Status Summary

Completed & Passed	In Progress	Upcoming
• None yet	• None yet	• FlatSat Tabletop Integration • Thermal Vacuum Chamber • Environmental Chamber

Budget Status

Procurement Status

Subsystem	Projected Cost	Procured	To be Procured	Margin (%)	Effect on Budget
C&DH	$ 167	$ 149	—	—	+$ 18
Sensors	$ 203	$ 127	—	—	+$ 76
Instrumentation	$2988	$3022	—	—	–$ 34
Power	$ 662	$ 374	$ 282	$ 56	–$ 50
PM	$ 84	—	$ 84	—	—
Structure	$ 418	$ 223	$ 4	$ 6	+$185
Testing	$ 250	—	$ 93	$ 157	—
Thermal	$ 66	$ 36	—	—	+$ 30
TOTAL	**$4613**	**$3931**	**$ 463**	**$ 219 (47%)**	**+$225**

Budget Status

Estimate	Cost
CDR Estimate	$4920
MSR Estimate	$4634
TRR Estimate	**$4613**

Item	Status	Notes
Avantes calibration hardware	Procured	Free
Professional board population	Planned	Included in budget
AIAA conference registration	Investigated	$270
Expedited Shipping	Optional	—

Thank you!

We welcome your feedback!

BACKUP

Requirements and Models

Requirement	Model	Test	Date
FR 1: Take solar irradiance measurements	---	Spectrometer Calibration	Feb 19
FR 2: Survive environmental conditions	SolidWorks Thermal	Thermal Vacuum Chamber Environmental Chamber	Wk of Mar 20 Mar 31, Apr 5
FR 3: Return data	C&DH, Storage	FlatSat Tabletop Integration	Mar 10-12
FR 4: Determine off-sun angle	Attitude	Photodiode Testing at SBO	Mar 2-8
FR 5: Interface with HiWind	---	Inspection	Continuous
FR 6: Capture images of the sun	---	Camera Testing at SBO	Mar 2-8

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Other Testing

Heaters

- Check resistance
- Check heat production
- Visually inspect for damage

Temperature Sensors

- Check 1Wire data operability
- Quantify Temperature sensor error with known sources (Boiling water/Ice)

Storage Devices

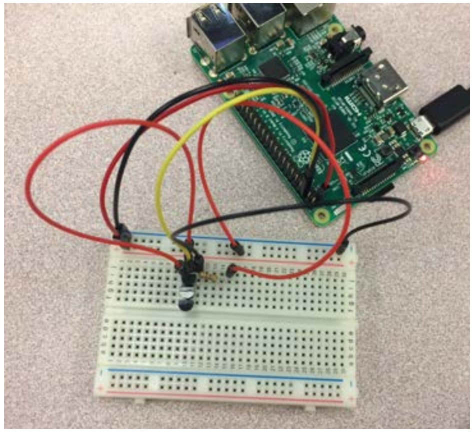
- Change formatting to EXT3 with Journaling
- Check data read/write
- Check unplugged data storage
- Check memory volume

Wire Fit

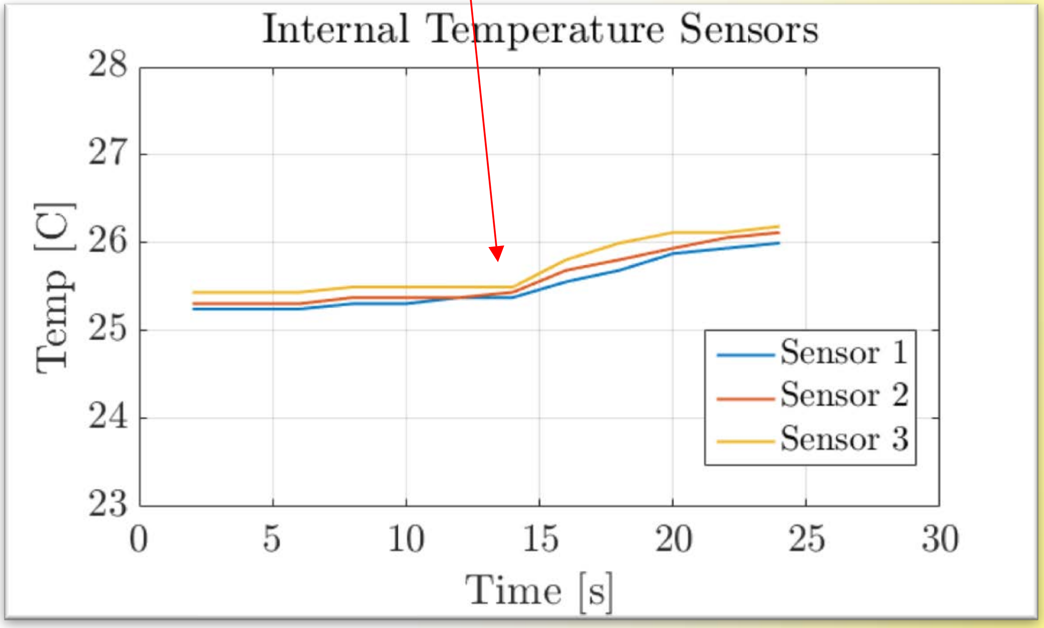
- Check wire turn needs
- Check slot clearance width and height
- Smooth possible abrasive corners

Internal Temp Sensors

- One-wire interface
- Placement
  - SLC drive
  - One per battery



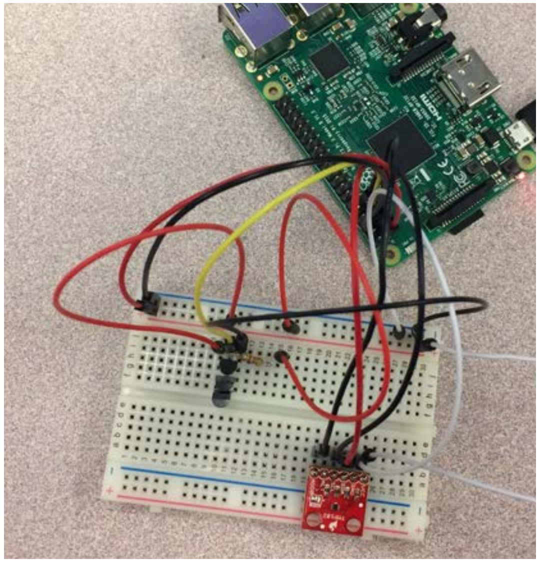
Placed hand on sensor

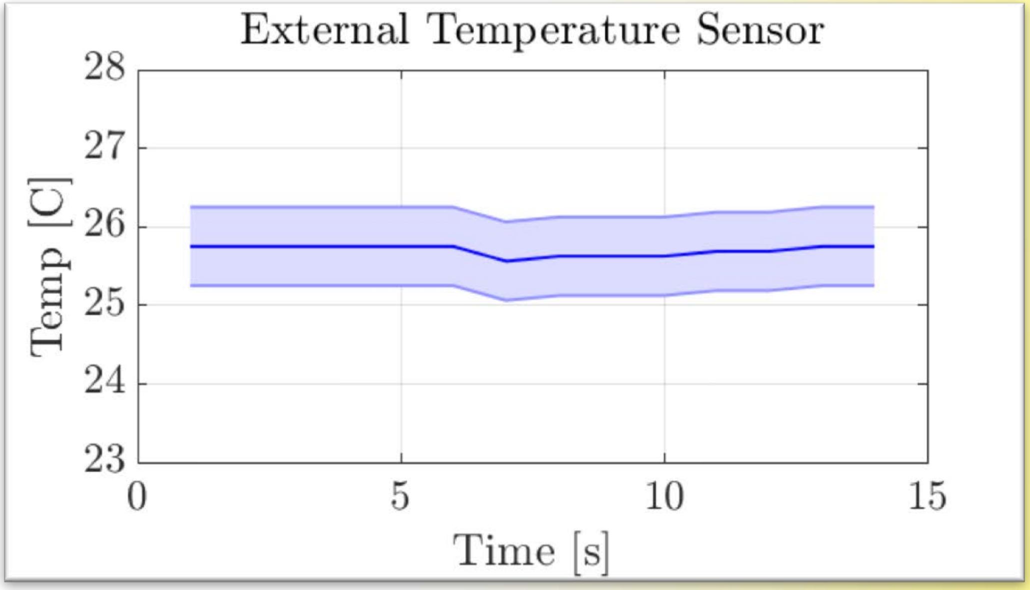


Note: Uncertainty is 0.5 °C on each measurement

External Temp Sensor

- I2C interface
- Placed on back of structure





Structure Test Results

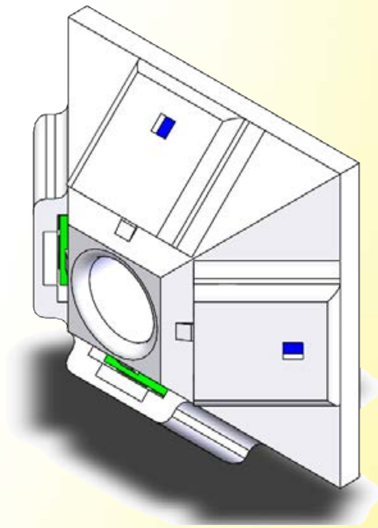
Test fit resulted in a few changes:

- Camera mount had to be 3D printed
- Longer screws needed in a couple places
- Using two screws for camera mounting
- Minor changes to photodiode array to fit boards
- New threads for neutral density filter

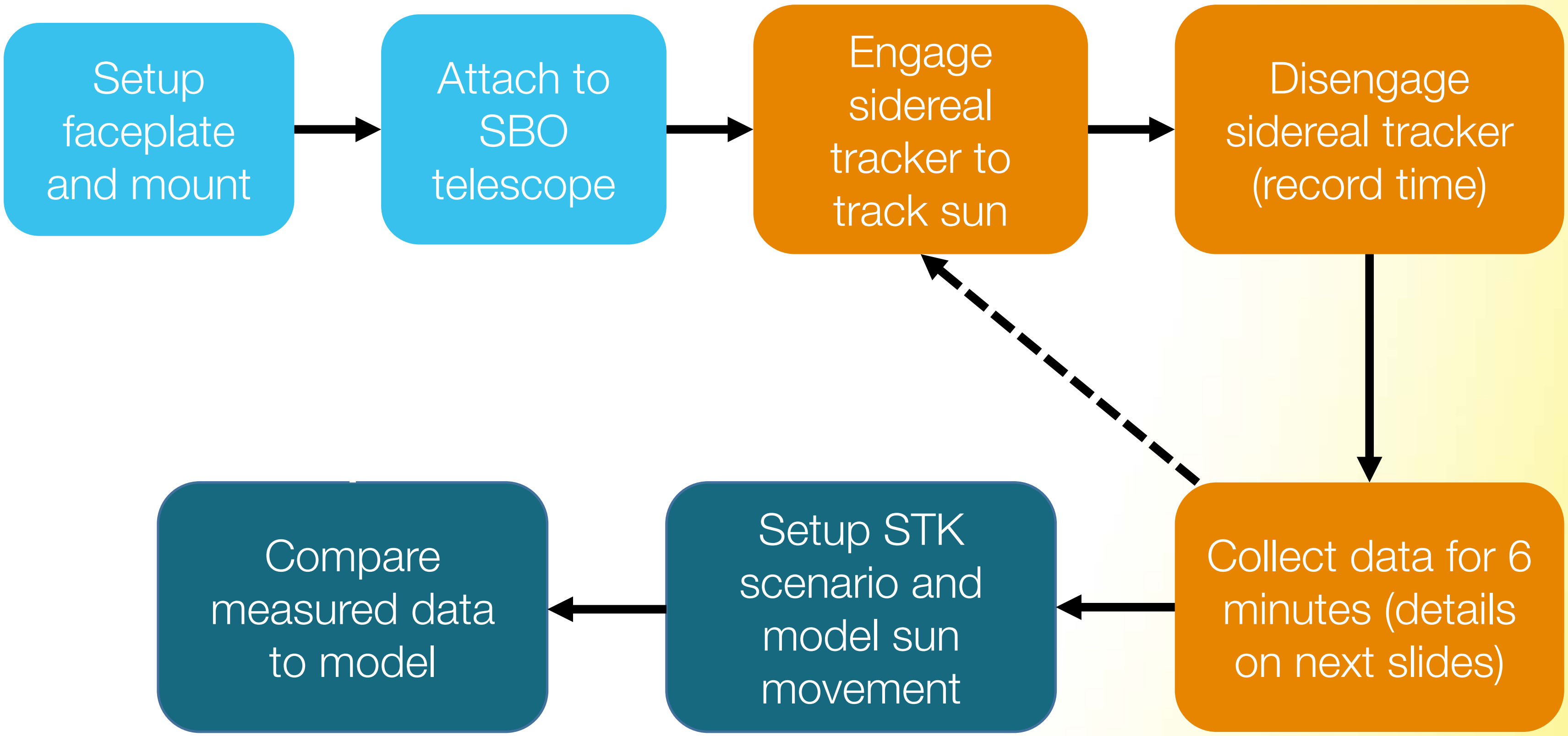
Attitude Determination System

- Photodiode array (heritage from MinXSS)
  - 4 photodiodes offset at 45 degrees from boresight determine relative position of sun
- Success Levels
  - Level 1: ± 1° accuracy
  - Level 2: ± 1 arcminute accuracy

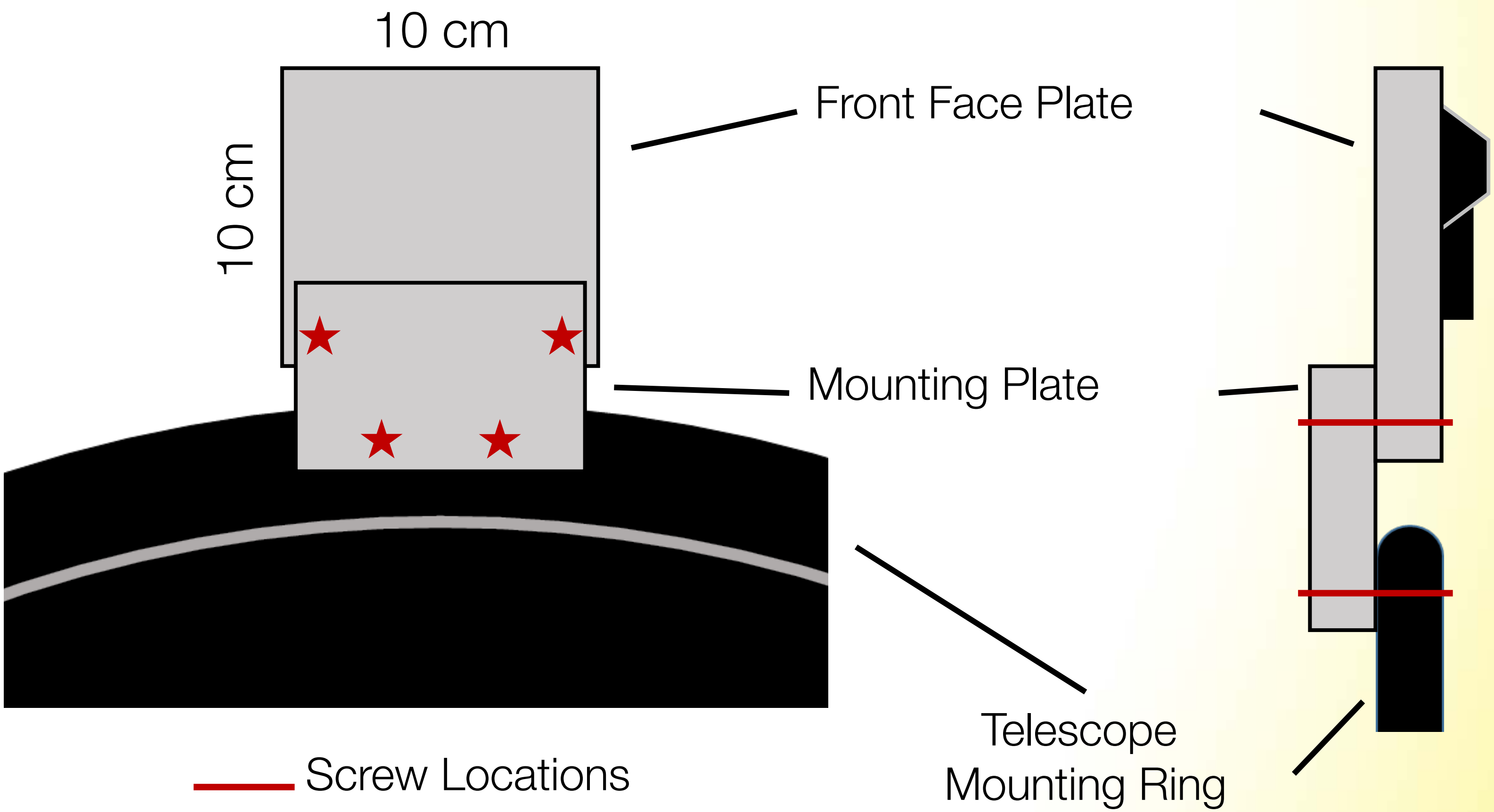
FR 4: RADIANCE shall determine its attitude.



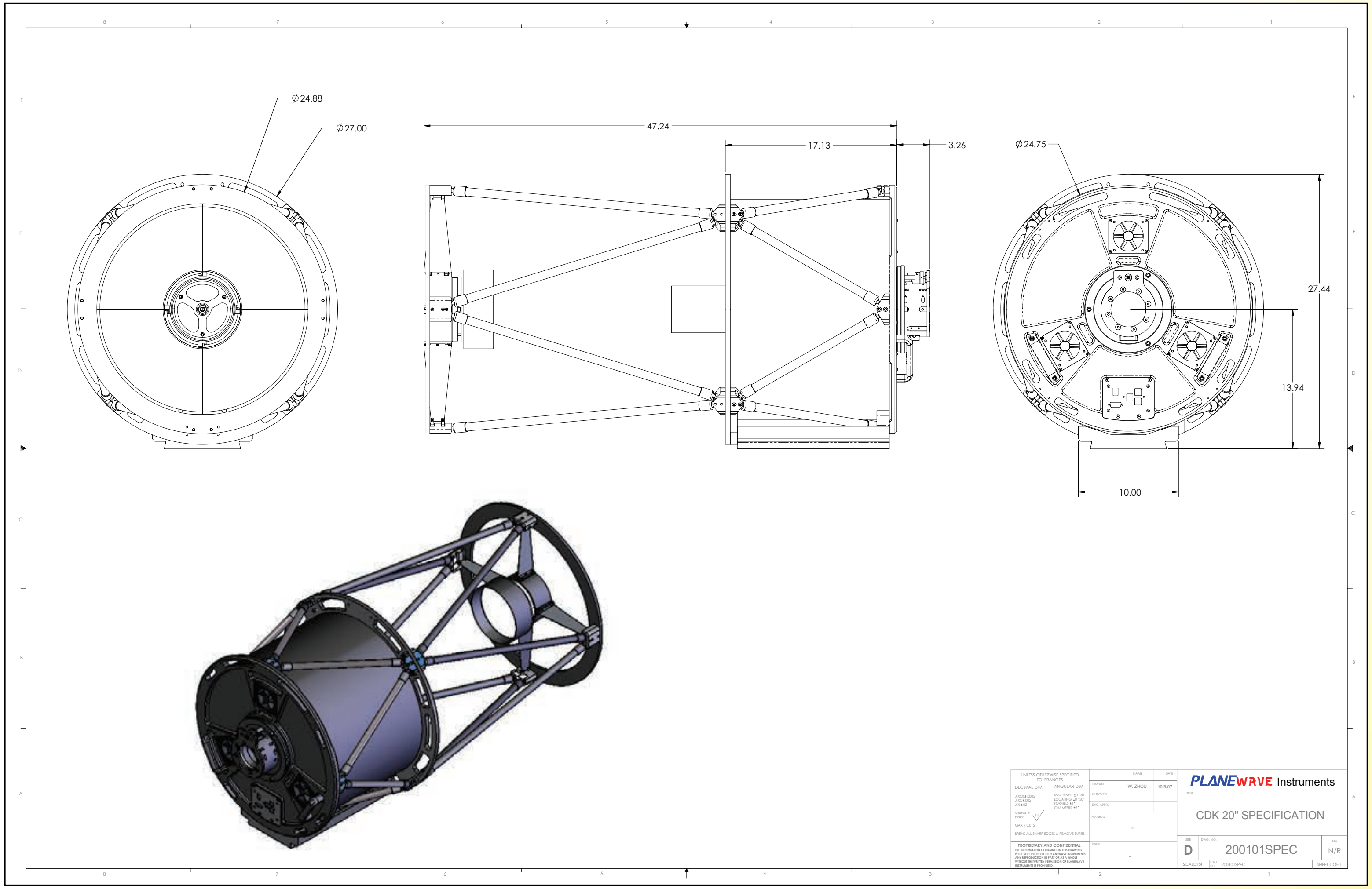
ADS Test Procedure



Telescope Mount for ADS Test



Telescope Mount for ADS Test



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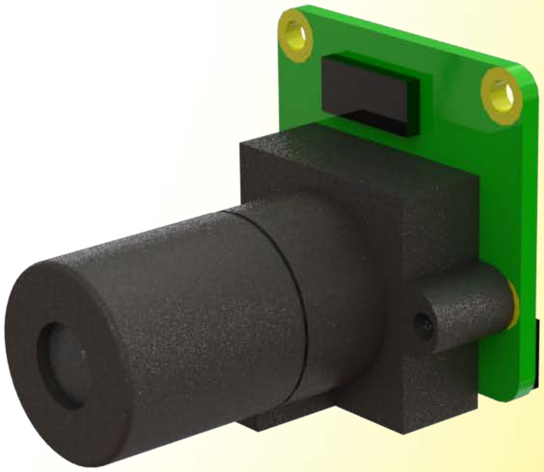
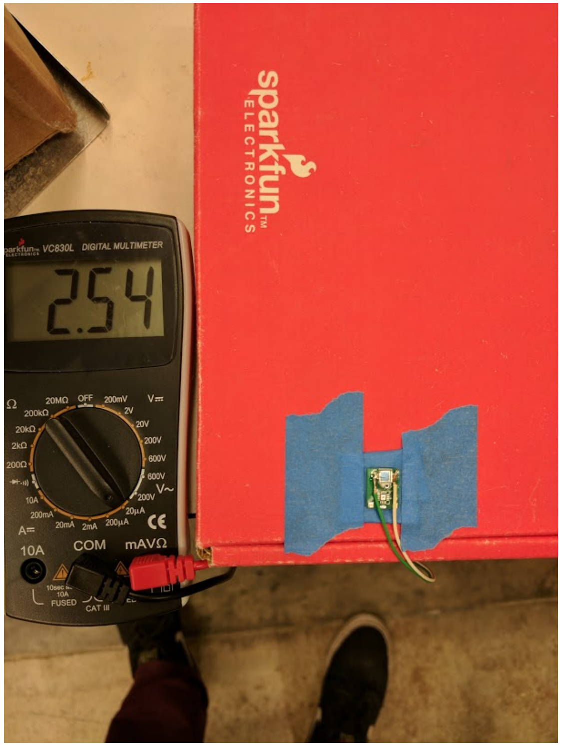
Camera/Lens System

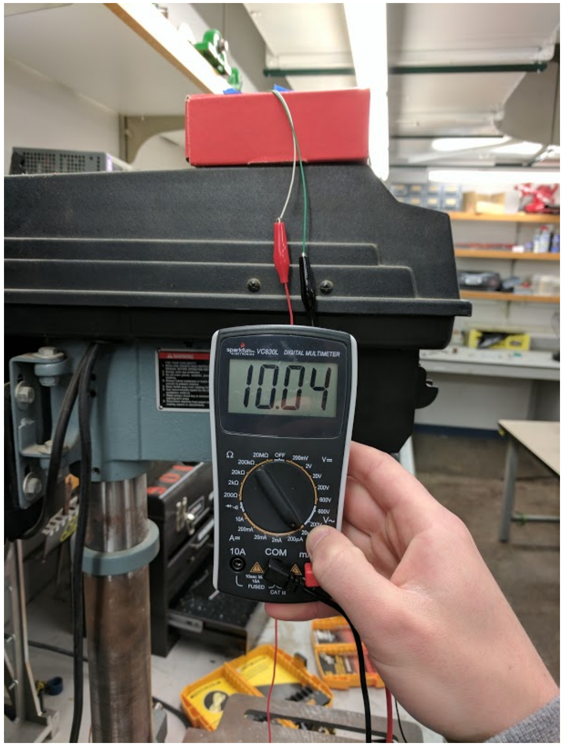
- Images provide context for spectrometer data
- Using neutral density filter
  - Optical density of 1.5
  - Protects camera electronics from saturation/damage
  - 6.3° field-of-view

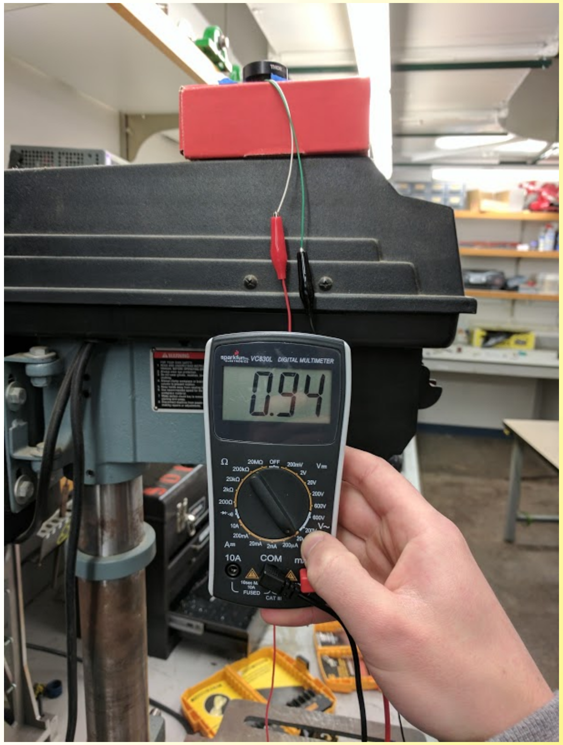
FR 6: RADIANCE shall take images of the sun.



Neutral Density Filter Test







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Power Testing

Purpose	Resources	Risks Reduced

Purpose

- Verify Voltage/Power draw
- Interfaces
  - Pi
  - Battery
  - Heater

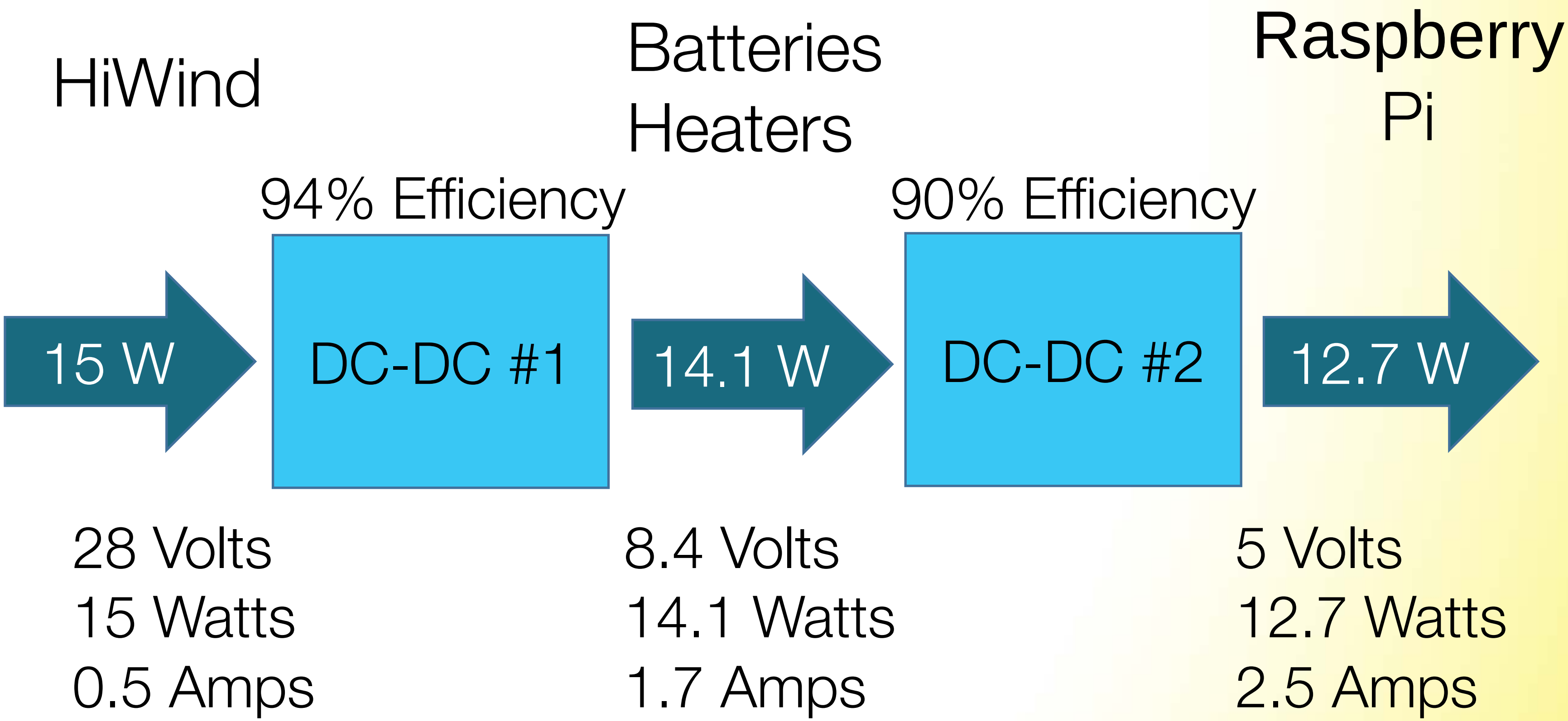
Resources

- Trudy's and Bobby's labs
  - Power Source
  - Multimeters

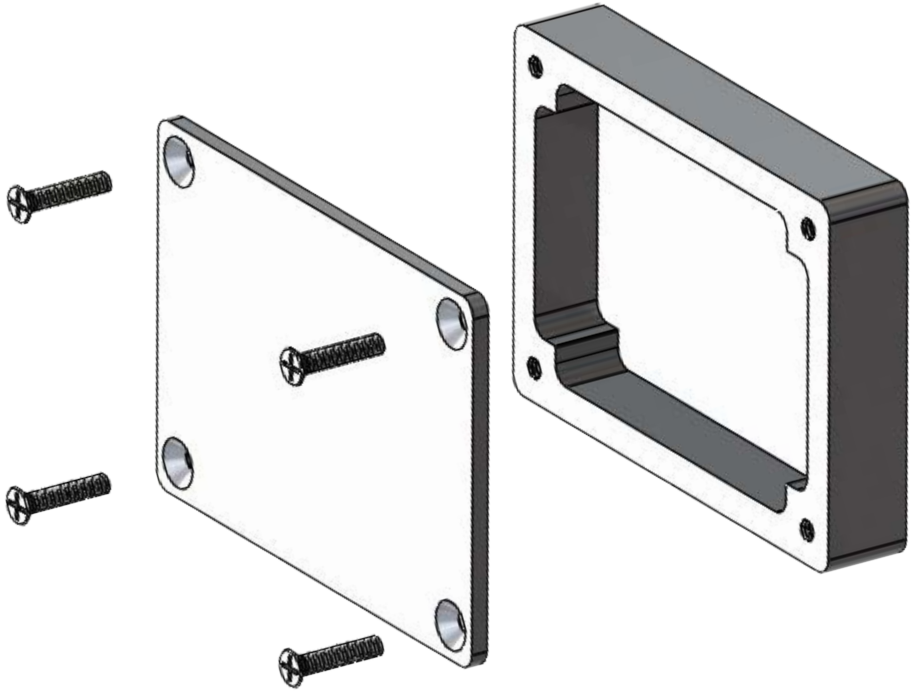
Risks Reduced

- Variable input voltage (28-33V)
- Voltage regulation

Power Distribution Model



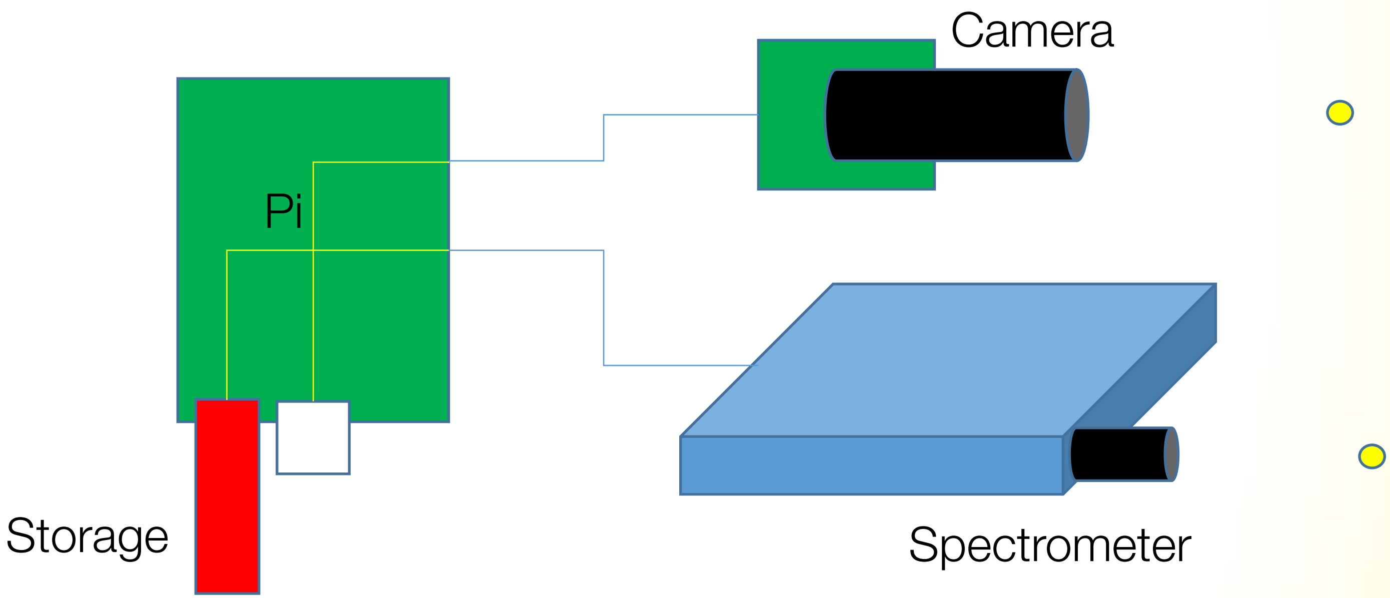
Spectrometer Analog

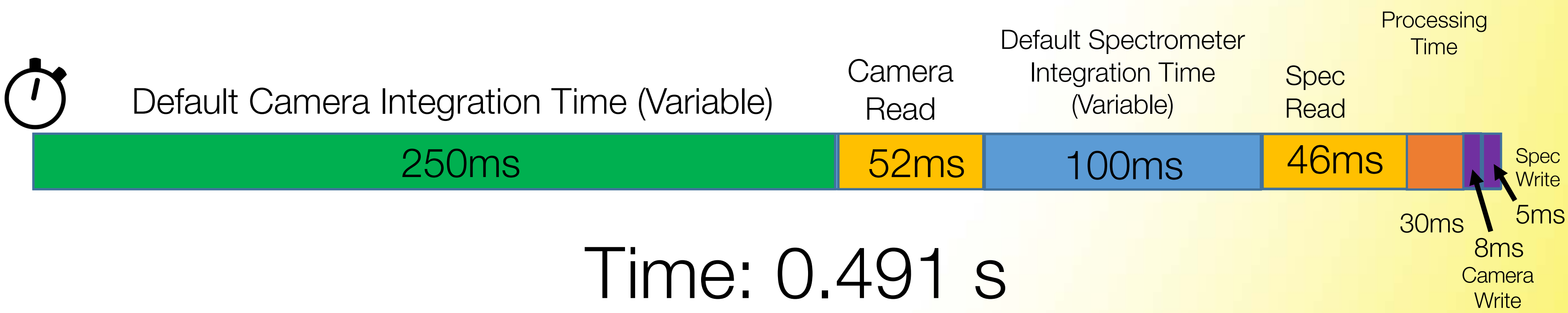


$$P = 1.25W$$
$$R = 15.25\ \Omega$$
$$P = I^2 R$$
$$I = \sqrt{P/R} = 0.29\ A$$
$$V = IR = 4.37\ V$$

- Unacceptable risk to expose spectrometer to environmental tests
- Mimic conductive properties, mass, and power output
  - Al 6061-T6, 174 g, 1.25 W
- 1D heater rated to 20W inside milled-out aluminum block

C&DH Timing Model





Time: 0.491 s

Data Storage Model – MLC

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

Data Storage Model – 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

Total: 10.64 GB

Software System Testing Status

- System testing not started
- Will start after unit testing is complete

Unit Testing Status

- Unit testing started
- 1/10 tests written

```
[==========] Running 1 test from 1 test case.
[----------] Global test environment set-up.
[----------] 1 test from DataHandlerTest
[ RUN      ] DataHandlerTest.CanInitialize
[       OK ] DataHandlerTest.CanInitialize (0 ms)
[----------] 1 test from DataHandlerTest (0 ms total)

[----------] Global test environment tear-down
[==========] 1 test from 1 test case ran. (0 ms total)
[  PASSED  ] 1 test.
```

Static Testing Status

- Static testing tests code without running
- Fixed 3/3 errors

```
10/12 files checked 73% done
Checking RADIANCE-main/src/sensors/spectrometer.cc...
Checking RADIANCE-main/src/sensors/spectrometer.cc: AS5216_EXPORTS...
Checking RADIANCE-main/src/sensors/spectrometer.cc: STATIC...
Checking RADIANCE-main/src/sensors/spectrometer.cc: USE_POSTMESSAGE...
Checking RADIANCE-main/src/sensors/spectrometer.cc: _M_X64...
11/12 files checked 97% done
Checking RADIANCE-main/src/systemhaltexception.cc...
12/12 files checked 100% done
```

Procured Budget Status

Subsystem	Projected Cost	Procured	To be Procured	Effect on Budget
C&DH, Inst.	$3424	$3304	------	+$ 120
Power	$ 662	$ 281	$ 382	------
PM	$ 84	------	$ 84	------
Structure	$ 418	$ 223	$ 10	+$ 185
Testing	$ 250	------	$ 250	------
TOTAL	**$4850**	**$3808**	**$ 726**	**+$ 205**

CDR Total (with margin and excess): $4,920

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