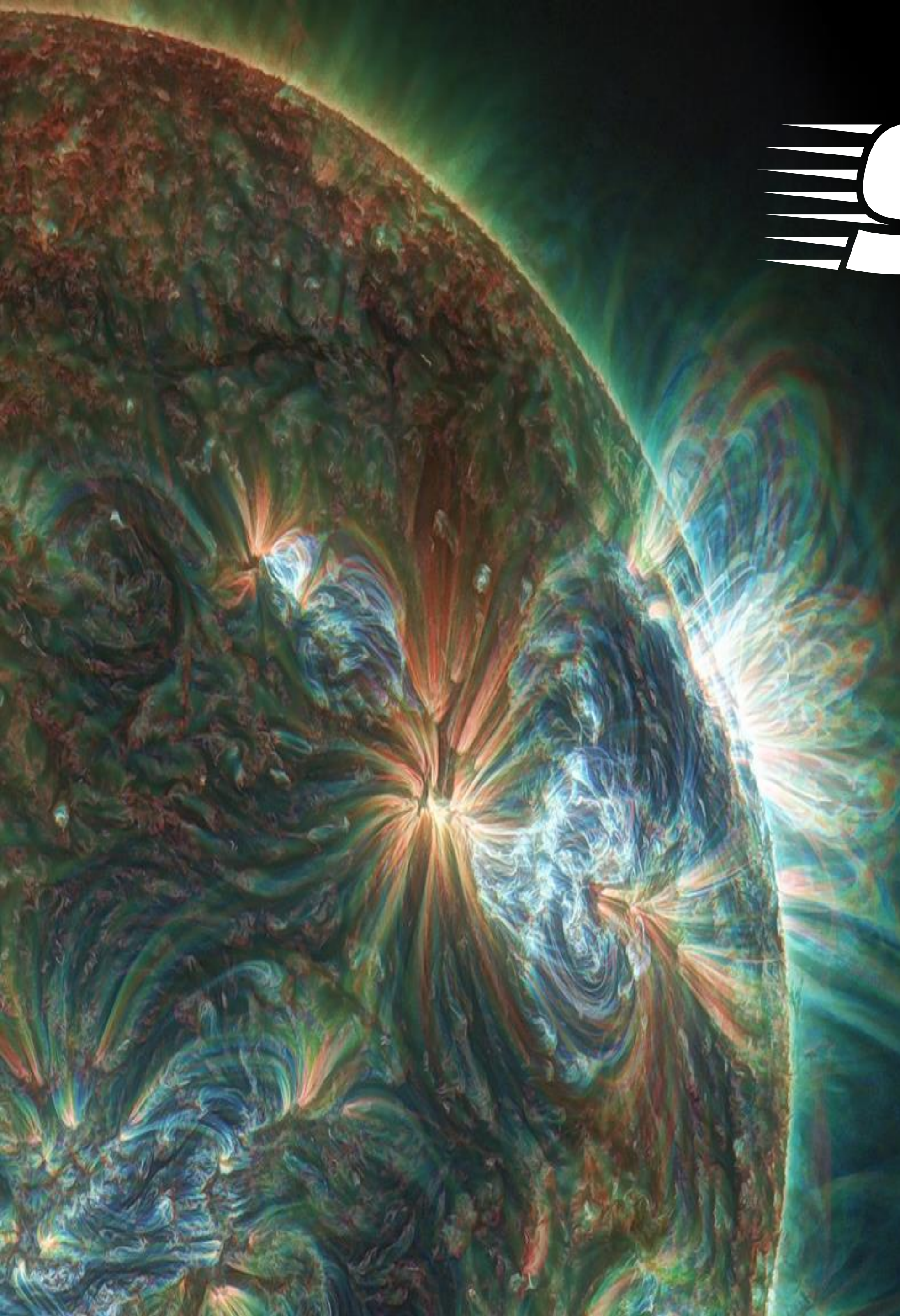


STOUT

Spectropolarimeter
Telescope
Observatory for
Ultraviolet
Transmissions

Presenters:

1. Andrew Arnold
2. Matt Funk
3. Ian Geraghty
4. Andrew Lux
5. Ryan Lynch
6. Dawson Stokley

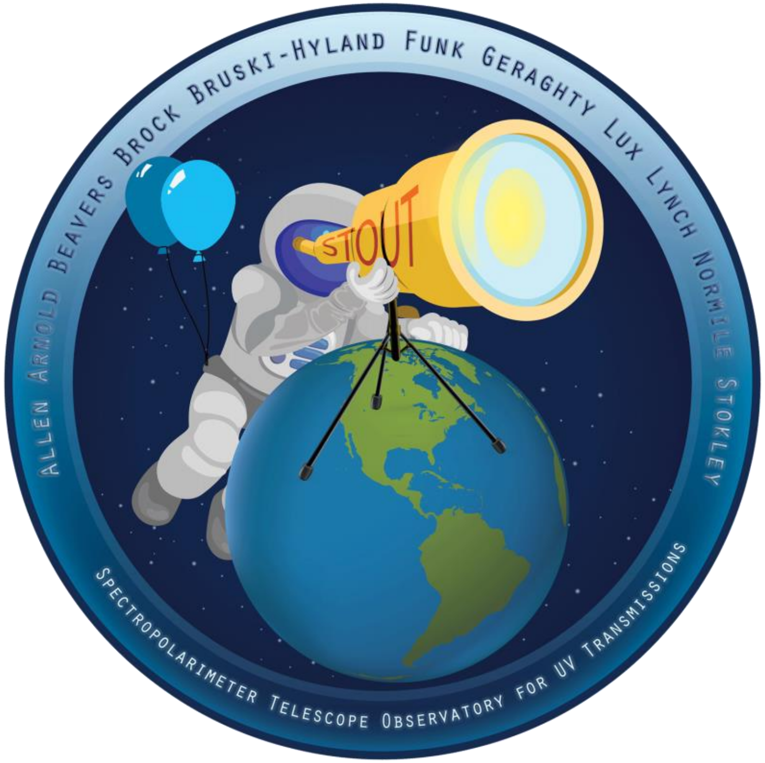
Advisor:
Francisco López Jiménez

Team Members:

1. Zach Allen
2. Caleb Beavers
3. Darin Brock
4. Josh Bruski-Hyland
5. Matt Normile

Customer:
UCAR High Altitude Observatory

1. Phil Oakley
2. Scott Sewell



Project Overview

Motivation & Project Statement

Motivation:

- ➢ Unpredictable solar weather presents a large risk to ground and space based assets present in modern society
- ➢ Measurements of UV spectra at varying polarization angles can be used to model solar magnetic field structure
- ➢ These models can be used to determine the preconditions to solar weather activity

Project Statement:

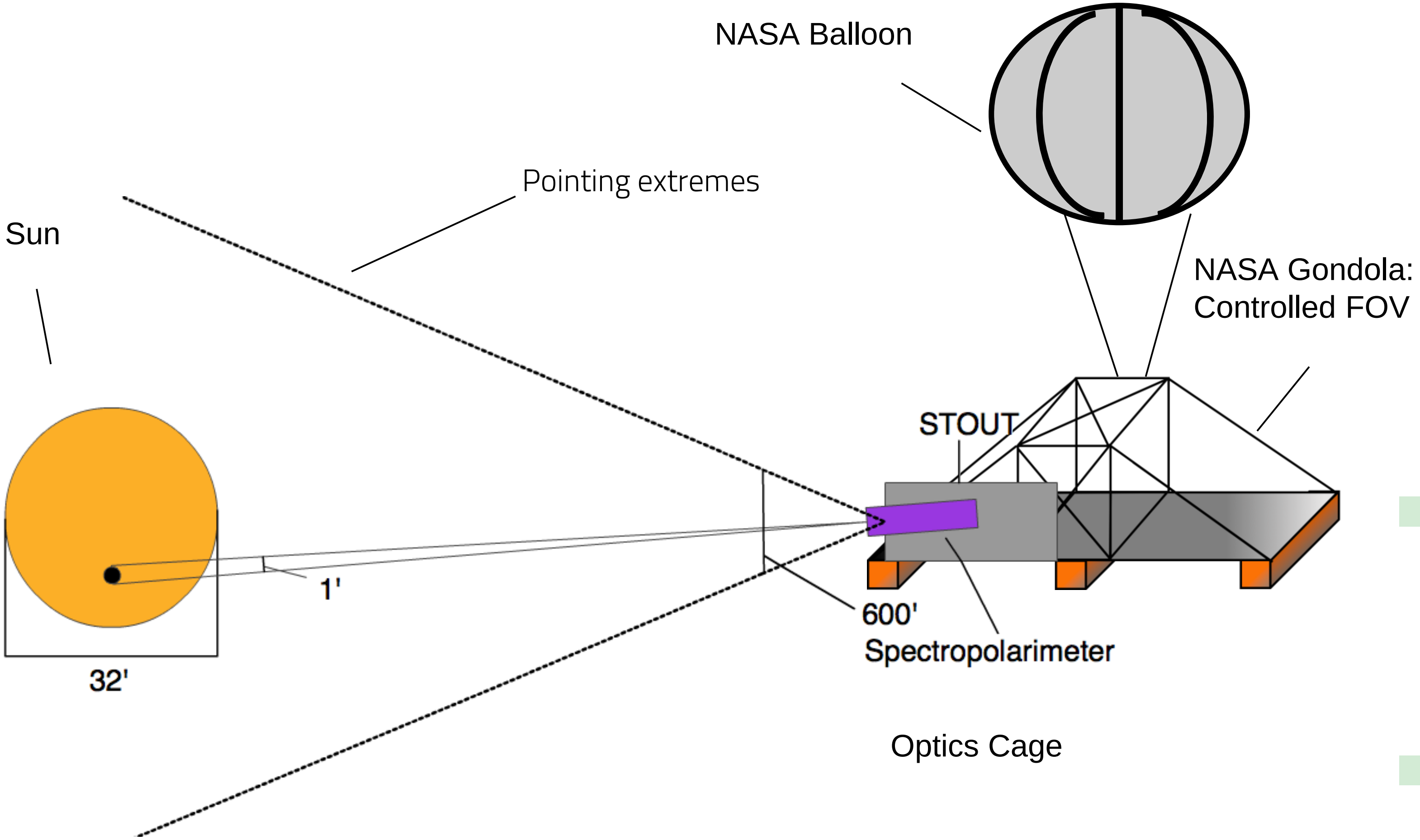
- ➢ To design and manufacture a 6U CubeSat style payload capable of collecting variable polarization UV spectra measurements at various points across the solar surface and operating in high-altitude balloon flight conditions
- ➢ The team will utilize a variety of ground tests that simulate the expected high altitude environment in order to calibrate the module's data collection systems and verify the its flight readiness.

NASA Gondola

Mission

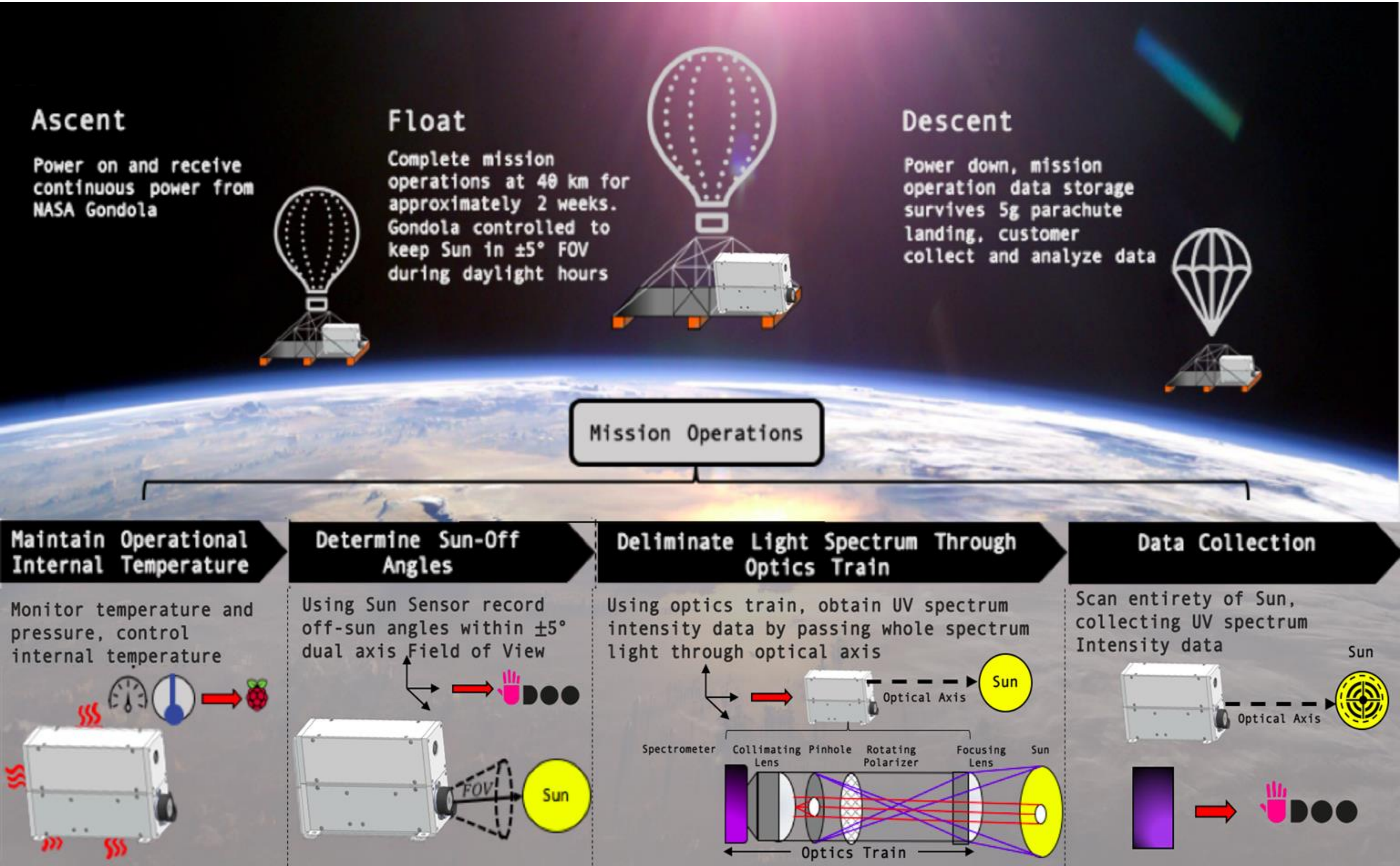
- ➢ Ground: 8 Hours
  - ○ Powered on and systems check
- ➢ Ascent: 2 hours
  - ○ Launched from Fort Sumner, NM
- ➢ Flight: 2 weeks at ~40 km
  - ○ Gondola platform puts the system FOV within +/- 5° of the Sun
  - ○ Solar irradiance data collected
  - ○ Polarized UV spectra collected
- ➢ Descent: 1 hr
  - ○ Customer retrieves data

Pointing Explanation



Project Purpose & Objectives

CONOPS



Ascent

Power on and receive continuous power from NASA Gondola

Float

Complete mission operations at 40 km for approximately 2 weeks. Gondola controlled to keep Sun in ±5° FOV during daylight hours

Descent

Power down, mission operation data storage survives 5g parachute landing, customer collect and analyze data

Mission Operations

Maintain Operational Internal Temperature

Monitor temperature and pressure, control internal temperature

Determine Sun-Off Angles

Using Sun Sensor record off-sun angles within ±5° dual axis Field of View

Deliminate Light Spectrum Through Optics Train

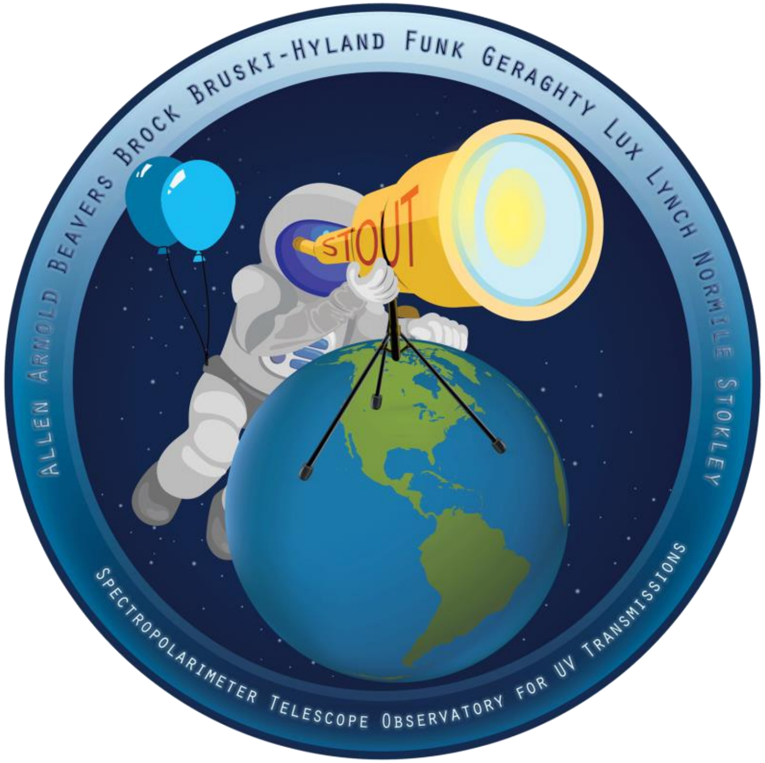
Using optics train, obtain UV spectrum intensity data by passing whole spectrum light through optical axis

Data Collection

Scan entirety of Sun, collecting UV spectrum Intensity data

Levels of Success

Subsystem	Functional Requirement	Level Met
Structure	Dimensions of the instrument are 10 x 20 x 30 cm	3
Environmental Control	Module survives temperatures of -70ºC and pressures of 10Pa	3
Attitude Determination	Measure attitude relative to Sun with accuracy of <= 0.05º	3
Optics	Take spectral measurements over the 270 - 400 nm range	3
	Rotate polarizer with accuracy of <= 0.5º	2
	Isolate a <= 1’ spot in the FOV	1
Pointing	Pointing capabilities of +/- 1º in azimuth and +/- 5º in elevation	1

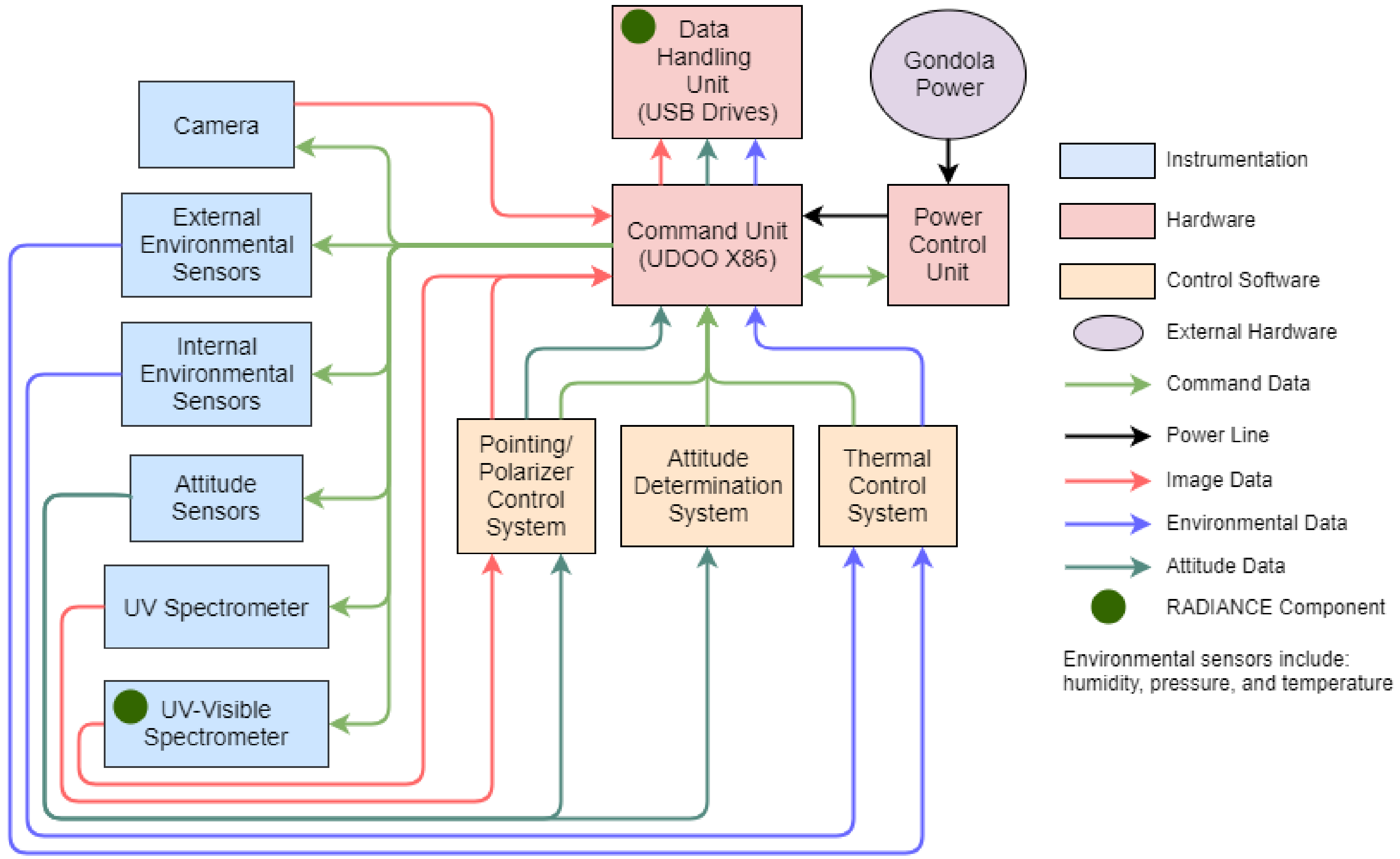


Design Solutions

Functional Requirements

- **FR 1:** The system shall integrate with RADIANCE module
- **FR 2:** The system shall take spectral UV measurements at varying polarization angles and at various points on the Sun
- **FR 3:** The system shall determine its attitude
- **FR 4:** The system shall take environmental measurements
- **FR 5:** The system shall survive the environmental conditions of a high altitude balloon flight to 40 km
- **FR 6:** The system shall record data
- **FR 7:** The system shall interface with the NASA balloon gondola

Functional Block Diagram

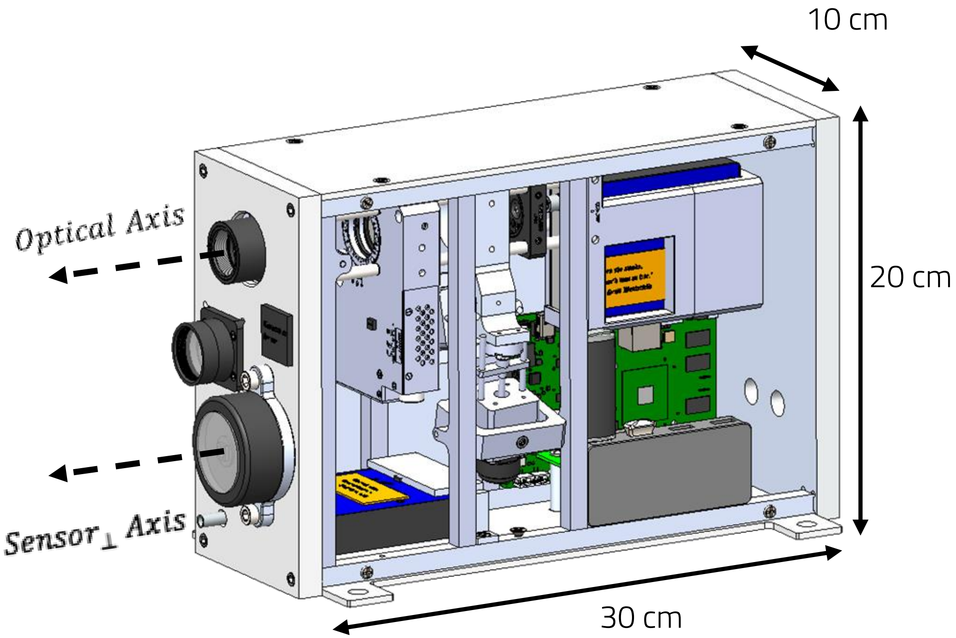


Environmental sensors include: humidity, pressure, and temperature

Design Description

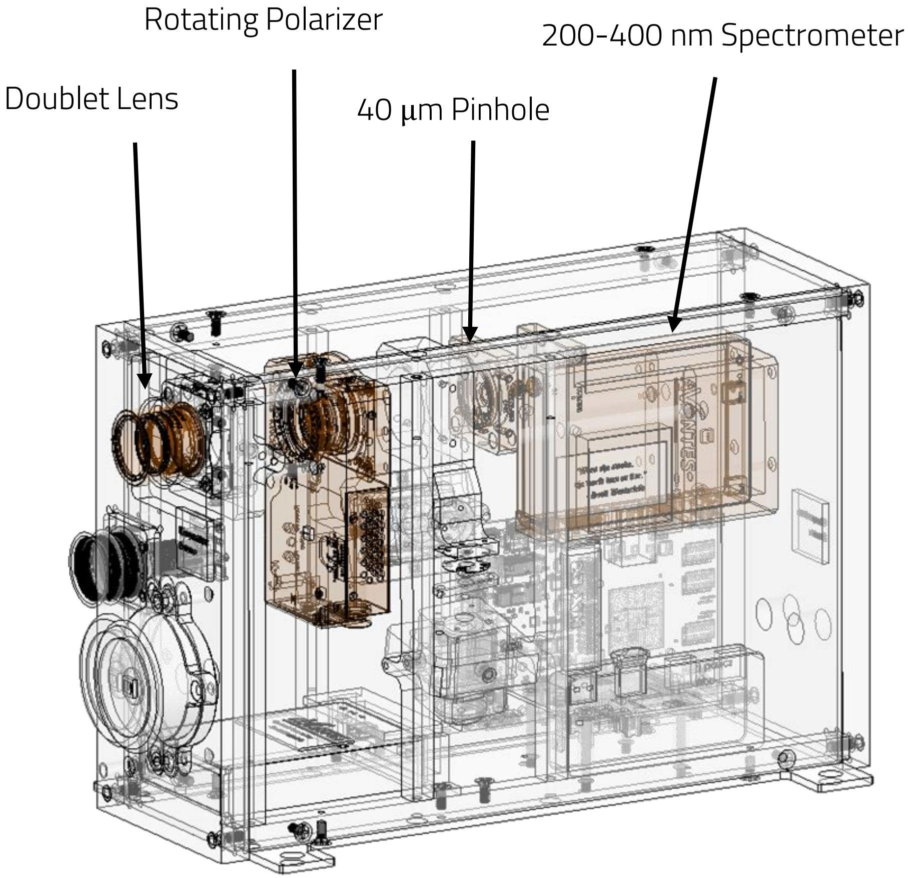
System Overview

Summary



Parameter	Values
Dimensions	10x20x30 cm
Mass	5.6 kg
Power Consumption	74.5 W
Flight Environment	-70 °C - 20 °C
Materials	Aluminum 6061 (Structure) Polyisocyanurate (Insulation)

Optics



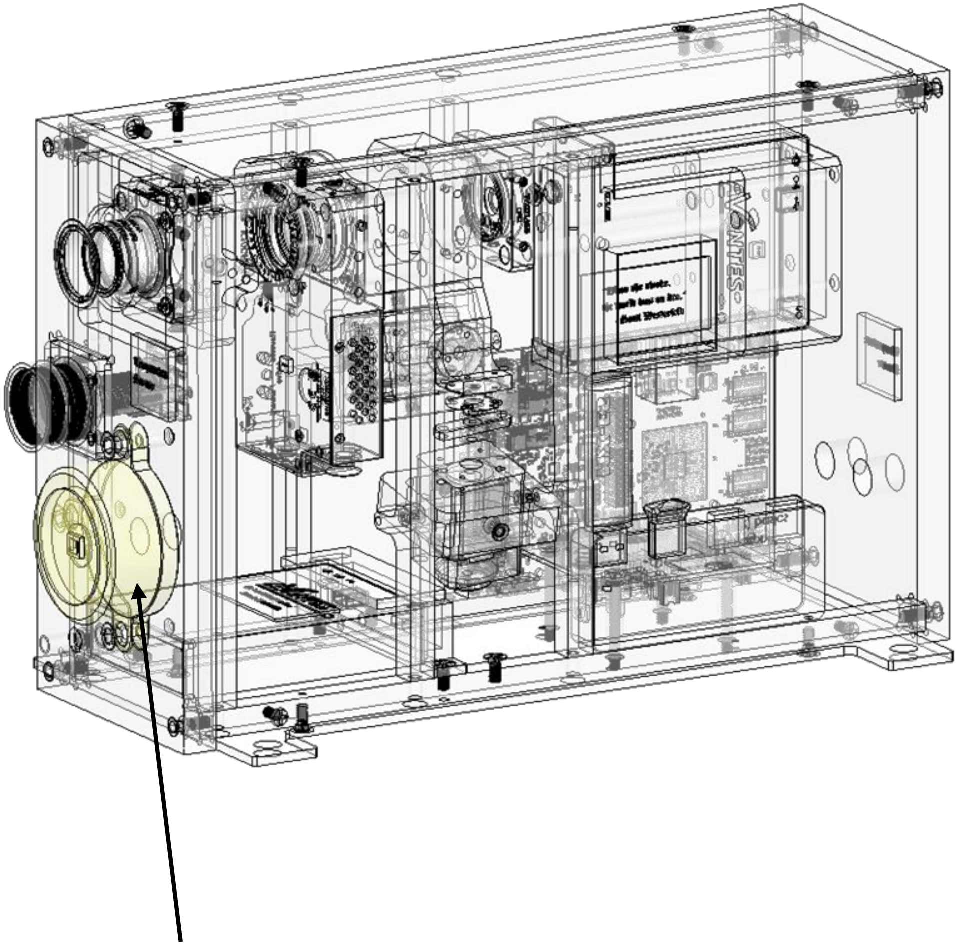
Components

- Thorlabs UV Doublet Lens: Focuses UV light
- Ultra Broadband Wire Grid Polarizer: Linearly polarizes UV light
- Thorlabs Stepper Motor Rotation Mount: Rotates polarizer with an accuracy of 0.14°
- Thorlabs Precision Pinhole: Reduces FOV to 55 +/- 0.1"
- Avantes Collimating Lens: Focuses light into the spectrometer
- Avantes Avaspec-Mini Spectrometer: Measures light intensity as function of wavelength over 200 - 400 nm
- Thorlabs Optics Cage: Mounts and aligns optical components

Changes

- A lens tube spanning the length of the optical train has been added to minimize stray light

Attitude Determination System



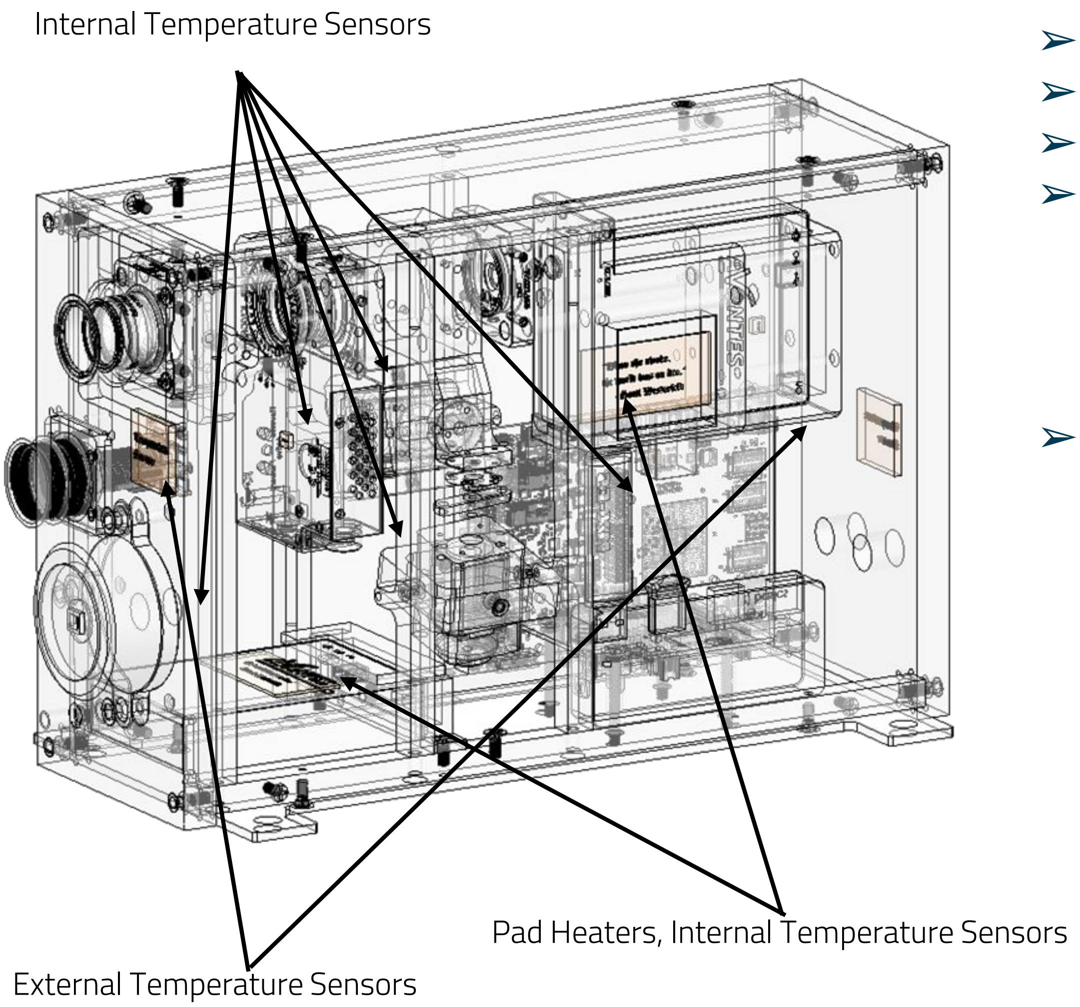
Components

- Solar Mems Sun Sensor: Determines Sun’s position in the system’s FOV
- Quadrant photodetector used to measure off-sun angles from generated photocurrents

Changes

- Sun sensor moved down to allow mounting of the camera

Environmental Monitoring & Control System



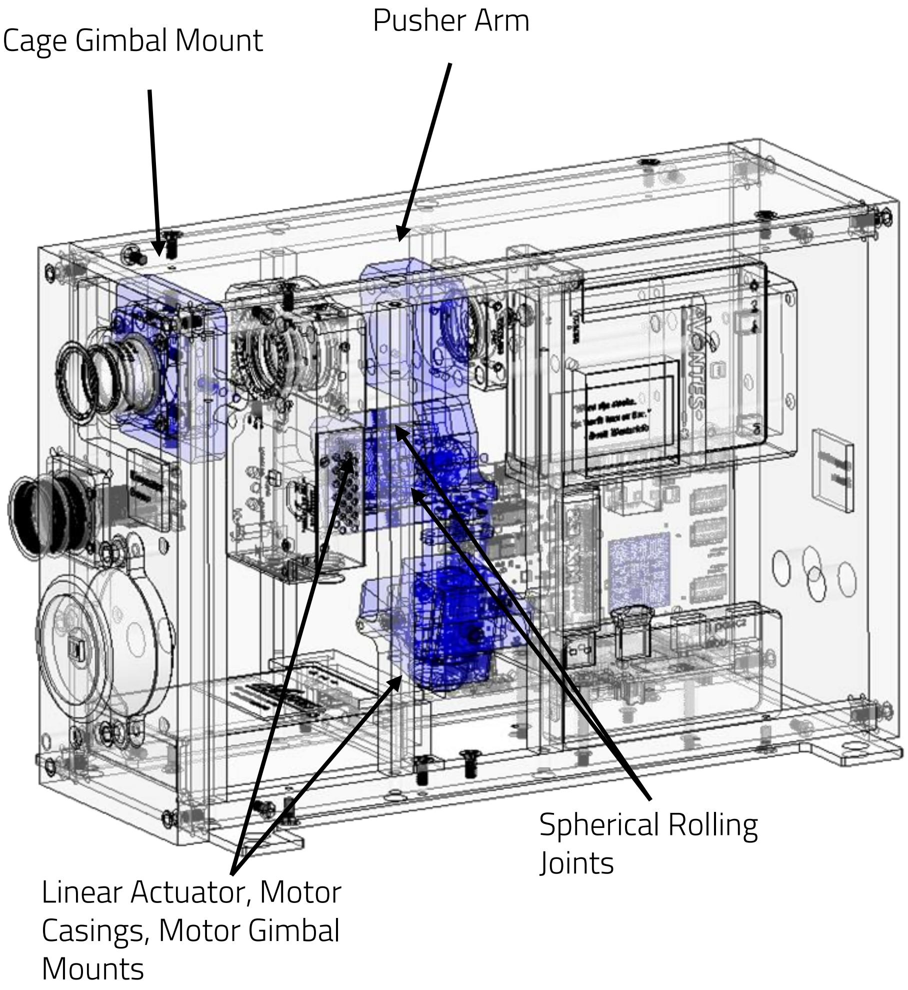
Components

- 8 Internal Temperature Sensors
- 2 External Temperature Sensors
- 1 Pressure Sensor
- 1 Humidity Sensor
- 2 Resistive Heat Pads: Keep module at an operable temperature

Changes

- Removed logic level shifters and replaced with MOSFET capable of lower trigger voltage (heat pad circuits)

Pointing Controls



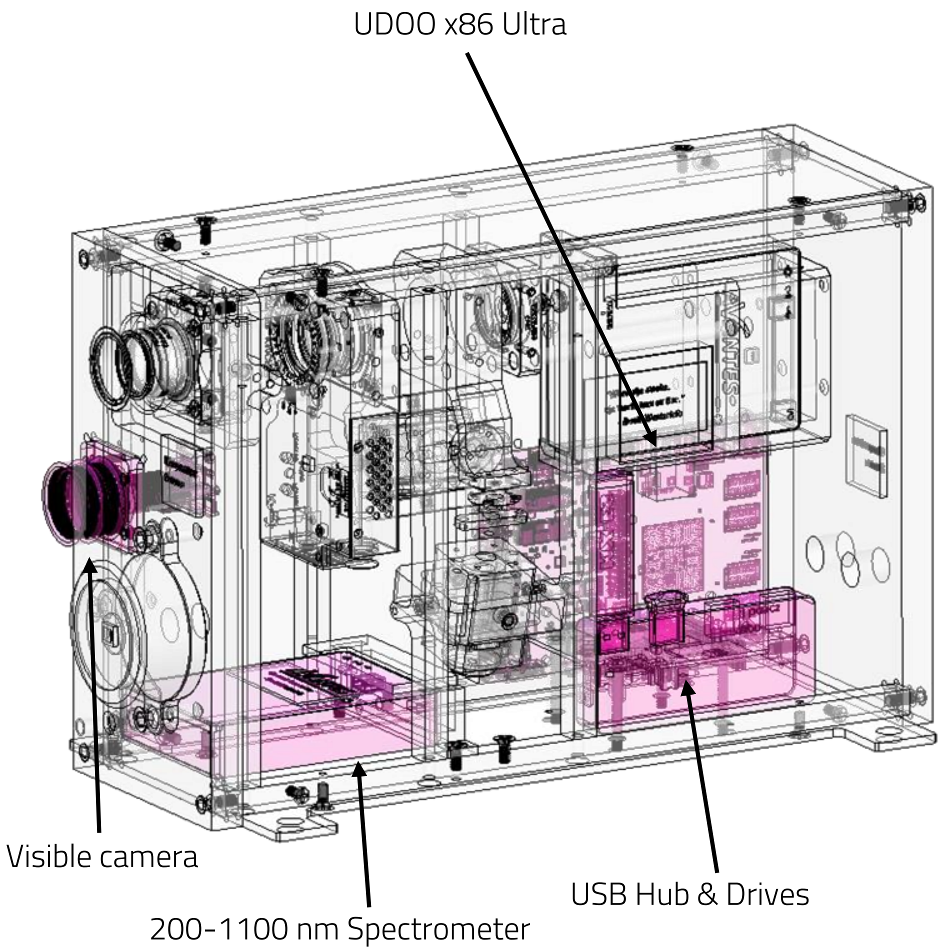
Components

- ➢ Custom Cage System Gimbal Mount
- ➢ 2 Haydon Kerk Pittman Hybrid Stepper Motor Non-Captive Linear Actuator
- ➢ Custom Motor Casings
- ➢ Custom Motor Gimbal Mounts
- ➢ Custom Cage System Pusher Arm
- ➢ Hephaist Spherical Rolling Joints

Changes

- ➢ Removed the rear motor casing mount due to encoder fit
- ➢ Added a collar and guide rods to the motor mounts to constrain motor lead rotation

CPU and Data Acquisition



Components

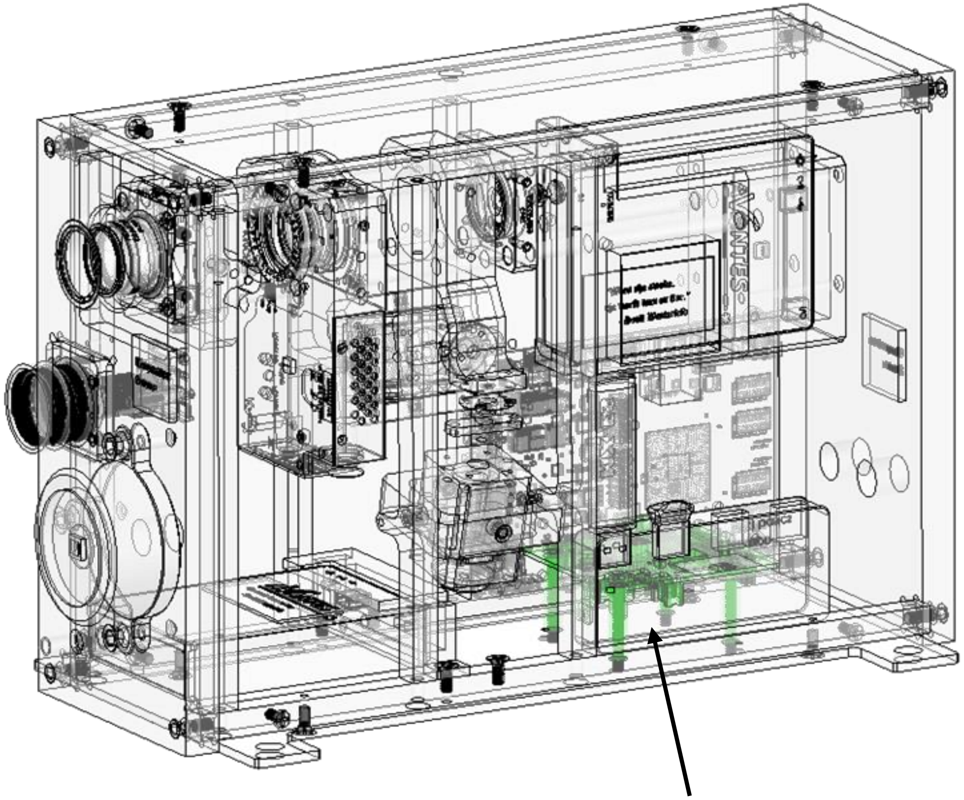
- UDOO x86 Ultra
  - 2.56 GHz Quad Core processor for control computation
  - Intel Curie Microcontroller for motor control
  - USB 3.0 for fast write rates
- USB Thumbdrives for data storage
  - One MX-ES Ultra 64 GB
  - One Samsung Fit 64 GB

- Sabrent 4 Port USB 3.0 Externally Powered Hub
- RADIANCE Spectrometer
- 2 MP Visible Camera

Changes

- Added a second USB Hub
- Temperature data recording moved to the embedded Arduino
- ADS sensor moved from UART to USB

Electrical Power System



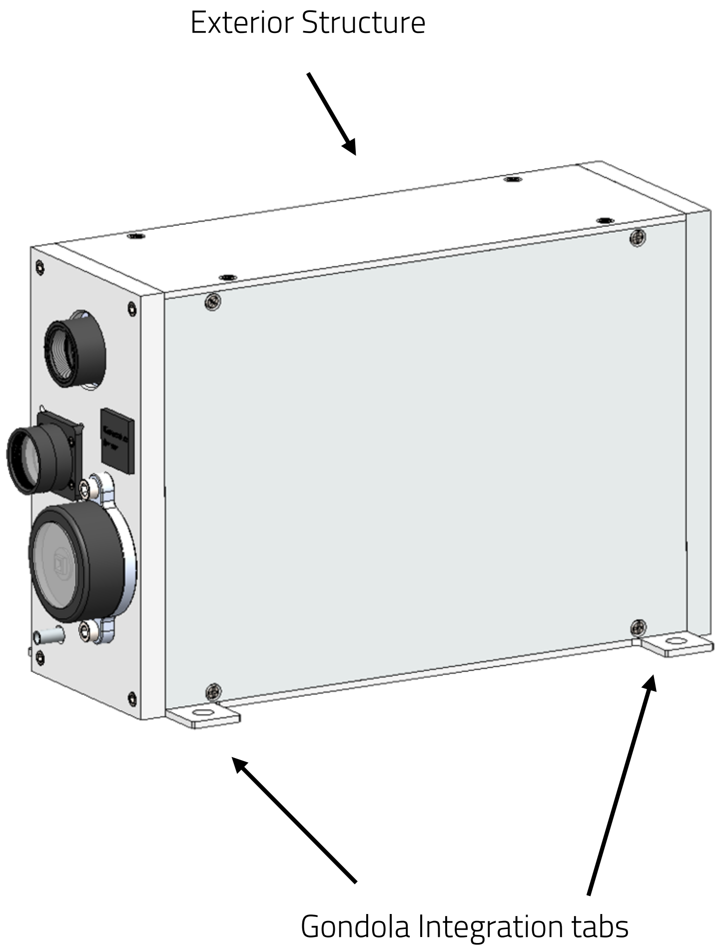
Components

- Custom PCB to distribute power to subsystems
    - 3.3V for environmental sensors
    - 12V for motor controllers and UDOO
    - 5V for USB hub and motor encoders
    - 28V for resistive pad heaters

Changes

- Mounting points to bottom plate

Structure



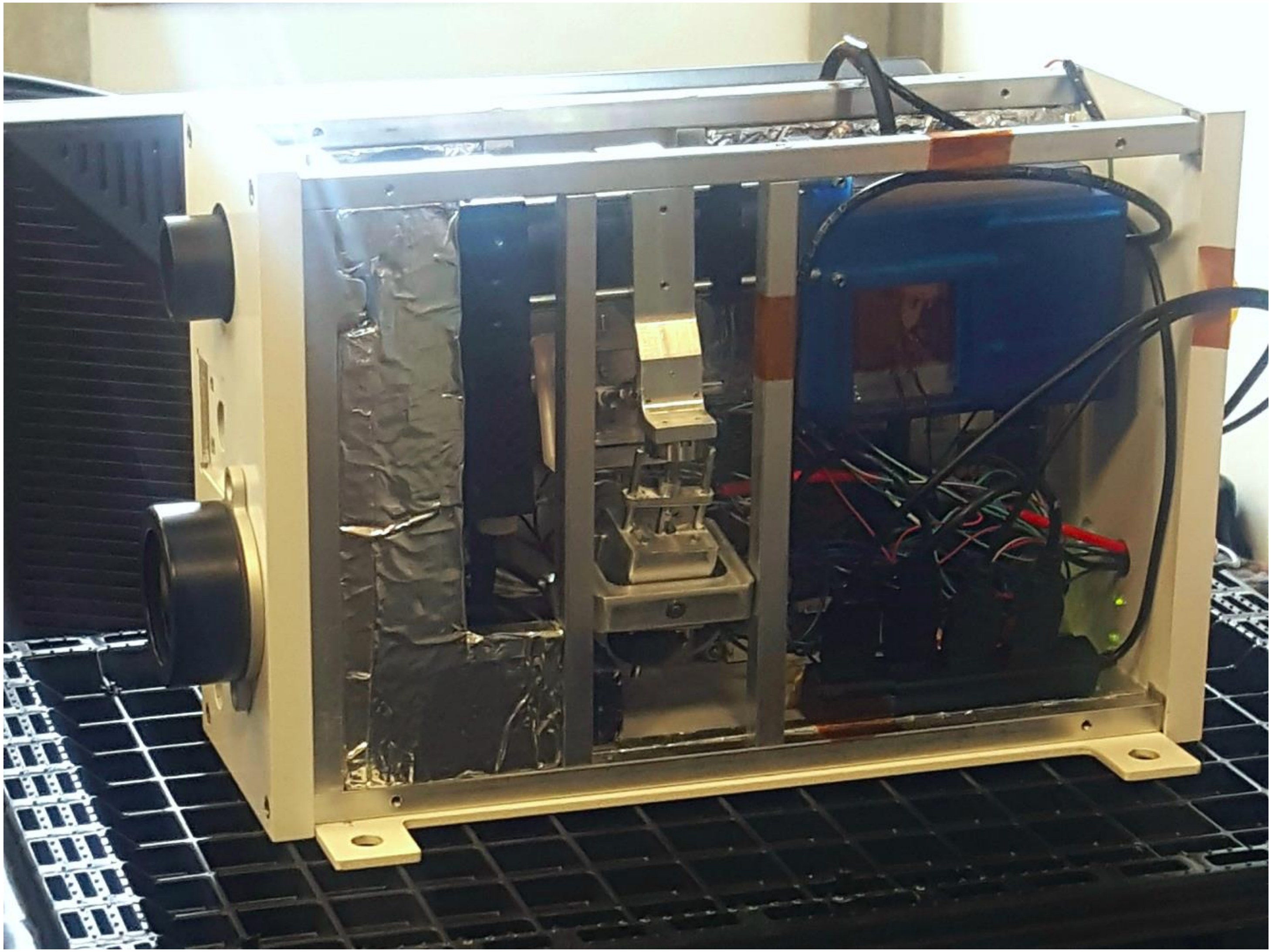
Components

- Aluminum 6061: Exterior plates and interior struts
- Tabs attach to balloon gondola

Changes

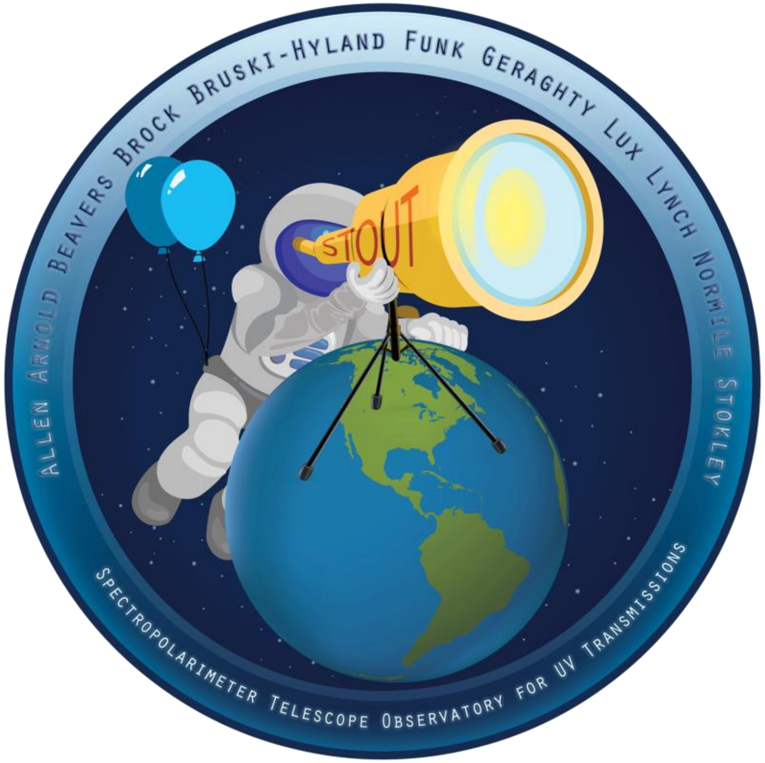
- None

STOUT



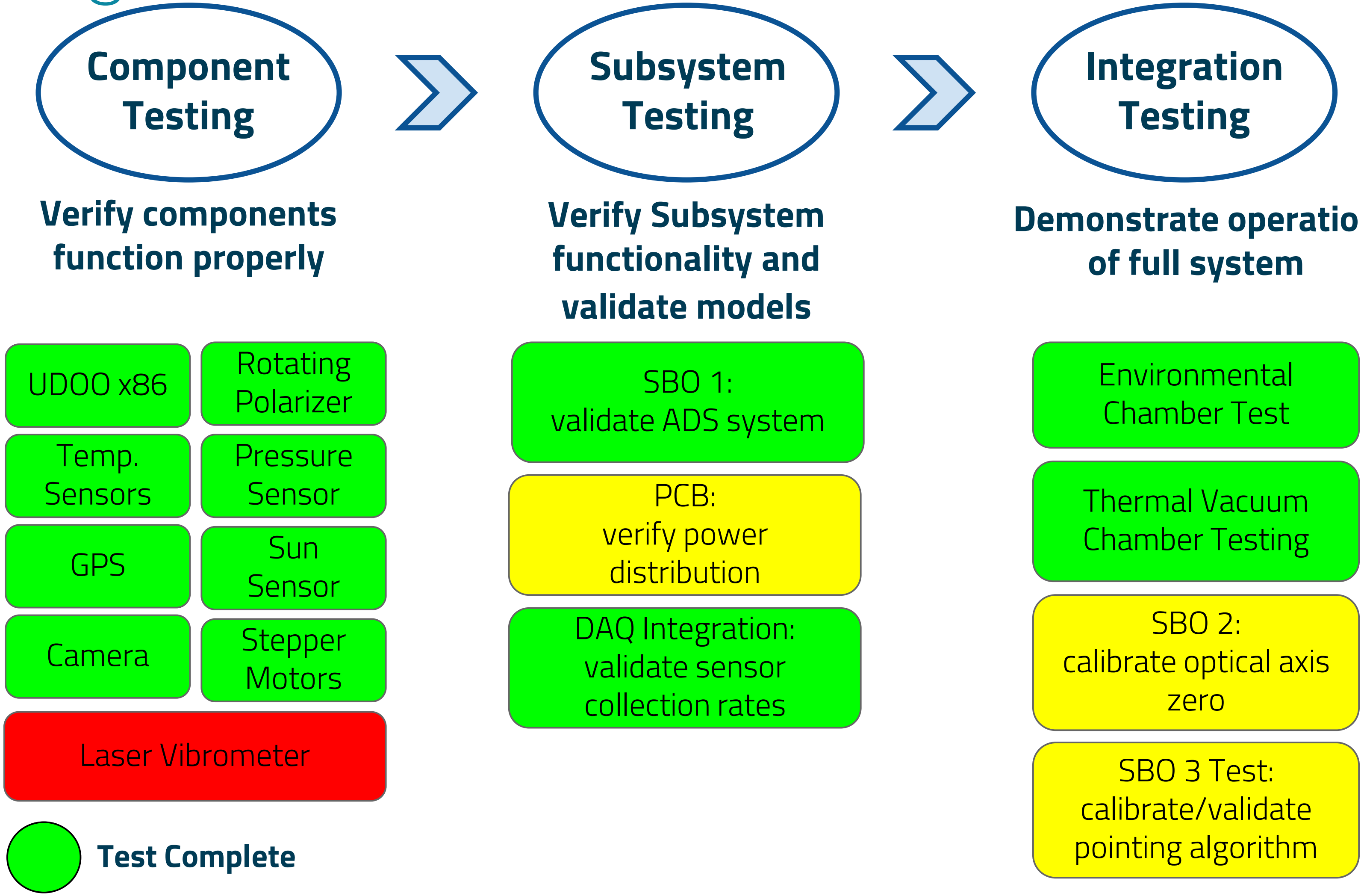
Critical Project Elements

Critical Project Element	Concern	Mitigation
ADS/Optics Calibration	Allocated time for calibration, complexity of calibration techniques	Sommers-Bausch testing week of 4/23
Software	Final Integration, Verifying Pointing algorithm	SBO Testing and Full TVAC
Electrical	Completing PCB before SBO testing, wire shorts, disconnections, static discharge	Completing PCB by 4/23, validating wire connections, using electrical tape on electrostatic sensitive components



Test Overview & Results

Testing Overview



Component Testing

Verify components function properly

- 🟢 UDOO x86
- 🟢 Rotating Polarizer
- 🟢 Temp. Sensors
- 🟢 Pressure Sensor
- 🟢 GPS
- 🟢 Sun Sensor
- 🟢 Camera
- 🟢 Stepper Motors
- 🔴 Laser Vibrometer

Subsystem Testing

Verify Subsystem functionality and validate models

- 🟢 SBO 1: validate ADS system
- 🟡 PCB: verify power distribution
- 🟢 DAQ Integration: validate sensor collection rates

Integration Testing

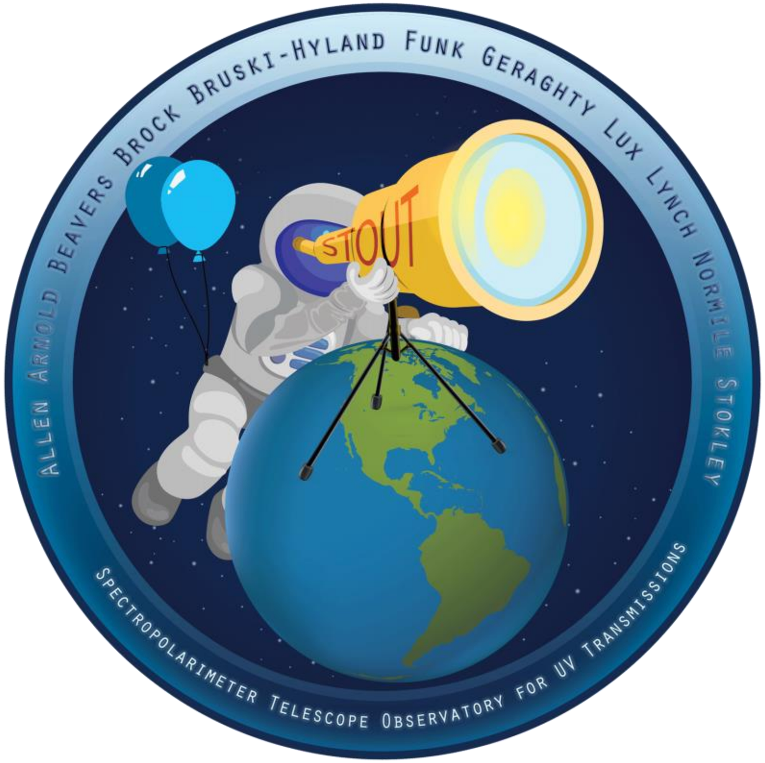
Demonstrate operation of full system

- 🟢 Environmental Chamber Test
- 🟢 Thermal Vacuum Chamber Testing
- 🟡 SBO 2: calibrate optical axis zero
- 🟡 SBO 3 Test: calibrate/validate pointing algorithm

🟢 **Test Complete**

🟡 **Test In Progress**

🔴 **Test Scrapped**



Test Overview & Results:

Subsystem Tests

DAQ Integration Overview

FR6: The system shall record data

Purpose

- Verify UDOO x86 functionality for taking and storing relevant data

Equipment and Facilities

- UDOO x86 and STOUT electronics package

Process

- Run all sensors simultaneously and record read and write times
- Read and write times include EMCS sensors, ADS, 2 spectrometers, and camera (31 kB data size)

Risks Reduced

- Shows the STOUT module data collection subsystems operate simultaneously

DAQ Integration Test Results: Timing

Operation	Predicted Time (ms)	Measured Time (ms)	Required Time (ms)
Read	207	98	N/A
Write	230	665	N/A
Total	437	763	1000

Test Implication

Completion of DAQ Integration demonstrates system ability to operate sensor package
USB 3.0 drive actual write speed less than benchmarked speed

Requirement Verified

FR2 The system shall take polarized UV spectrum measurements
6.1 The system shall record temperature data
6.2 The system shall record pressure data
6.3 The system shall record attitude data
6.4 The system shall record visible images
6.5 The system shall timestamp all data

EPS Test Plan

FR7: The system shall interface with the NASA balloon gondola

Purpose

- ➢ Verify power board provides the correct voltage to each component

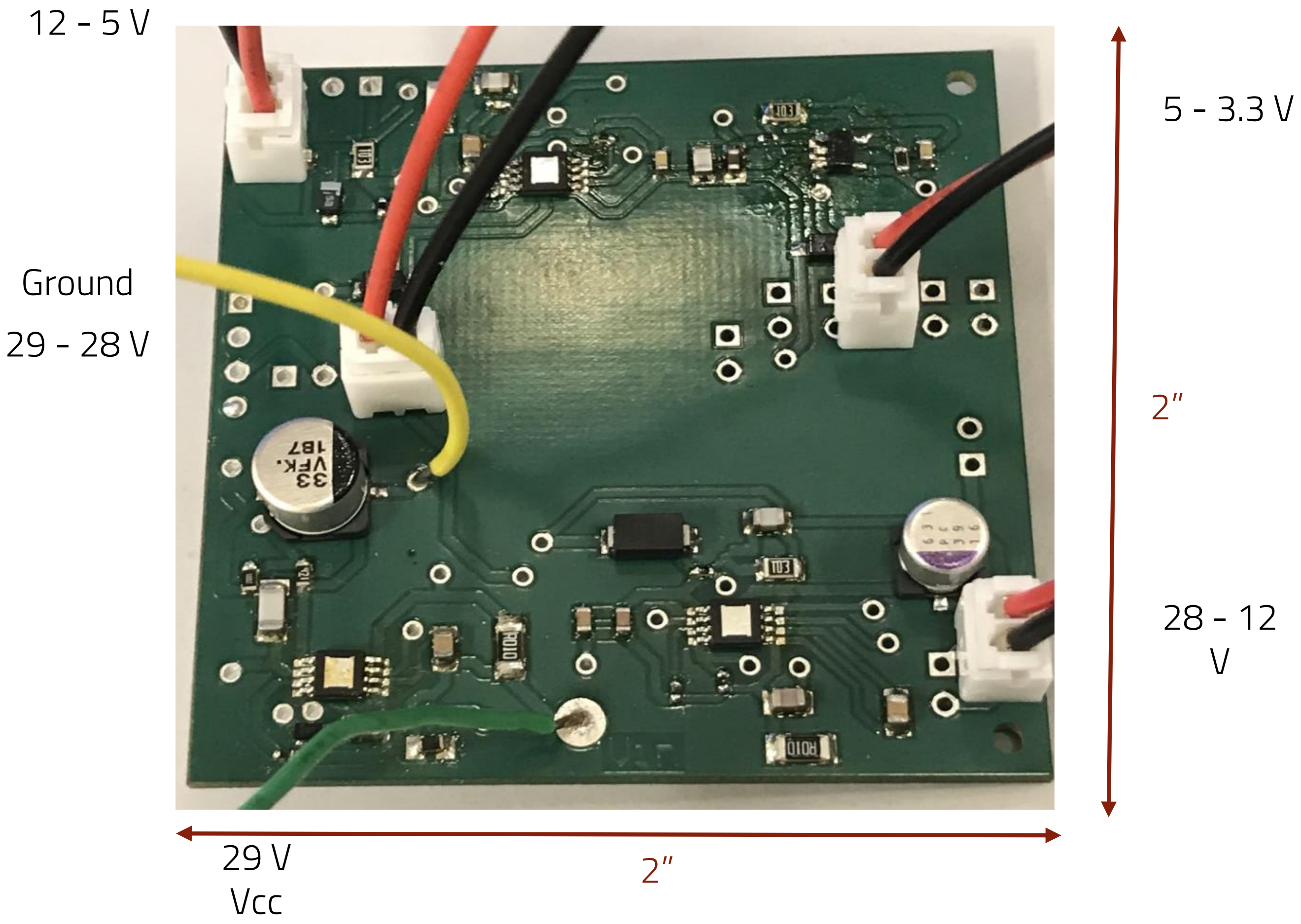
Equipment and Facilities

- ➢ Assembled power board, DC power supply (35V, 5A), multimeter, and oscilloscope

Process

- ➢ Plug in power supply to Vcc and ground wires with a current limit of 3.5 A
- ➢ Measure output of each individual converter pin using a multimeter and compare to manufacturer's datasheet to determine if the integrated circuit is properly configured and functioning
- ➢ Connect individual components to their corresponding converter tests
  - ○ 29-28 V: Pad heaters
  - ○ 28-12 V: UDOO & motor drivers
  - ○ 12-5 V: USB hub
  - ○ 5-3.3 V: Environmental sensors
- ➢ Take multimeter measurements and oscilloscope waveforms of voltage and current of through each component

EPS Test Plan



Test Implication

Completion of PCB verifies power distribution to subsystems

Requirement Verified

7.4 The system shall be able to interface with NASA Gondola Power Source

SBO 1: Validate ADS System

FR3: The system shall record its attitude relative to the center of the Sun

Purpose

- ➢ Verify ADS sensor accuracy
- ➢ Calibrate out misalignments between SBO and ADS due to mounting errors

Equipment and Facilities

- ➢ Sommers-Bausch Telescope with SkyX Pro control software
- ➢ SBO Mount
- ➢ Fully assembled STOUT module

Risks Reduced

- ➢ Shows the STOUT module can accurately locate the position of the center of the Sun with an accuracy of 0.05°

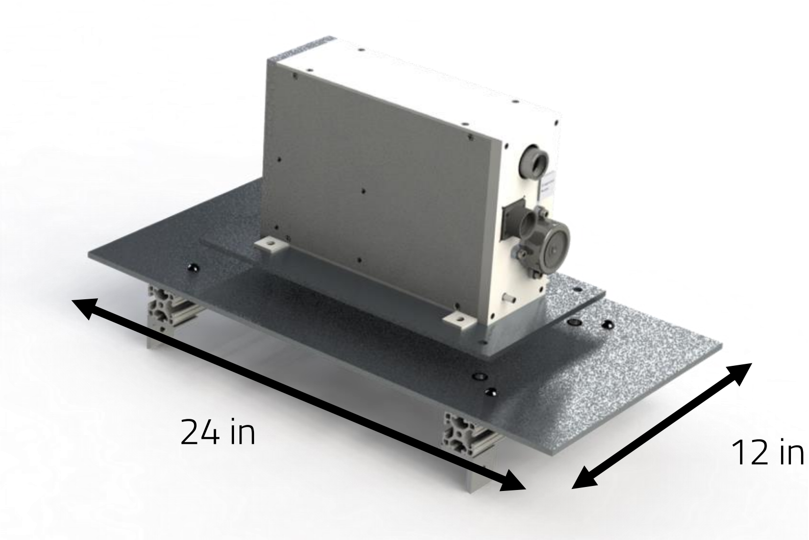
External Factors

- ➢ Need a cloudless sky for ADS sensor to take accurate measurements

SBO 1: Test Setup

Sommers-Bausch Telescope with STOUT

STOUT Telescope Mount

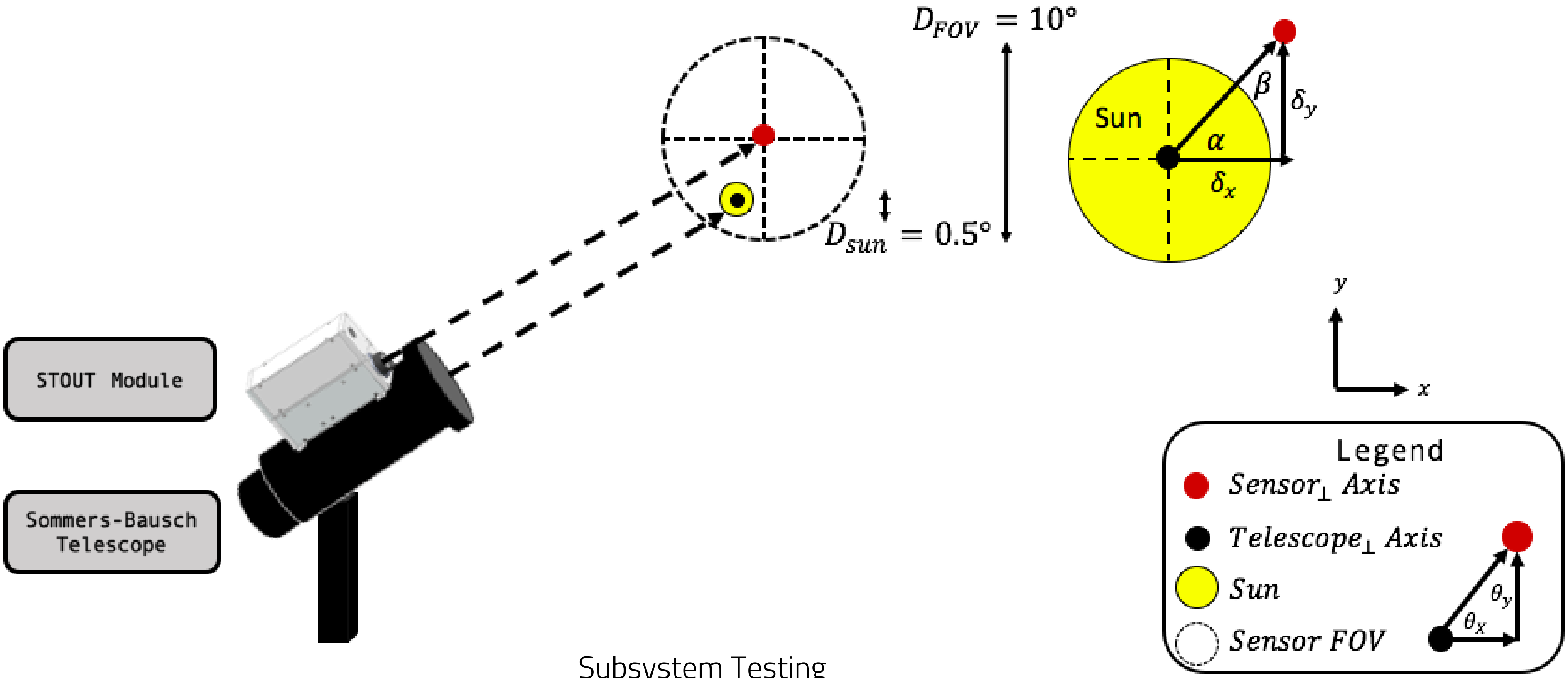


SBO 1: Test Setup

Specifications

- Sommers-Bausch telescope has accuracy > 20 " ~ 0.0055°
- Accuracy of Sun sensor:
- 18" ~ 0.005°
- Total accuracy: 38" ~ 0.0105°

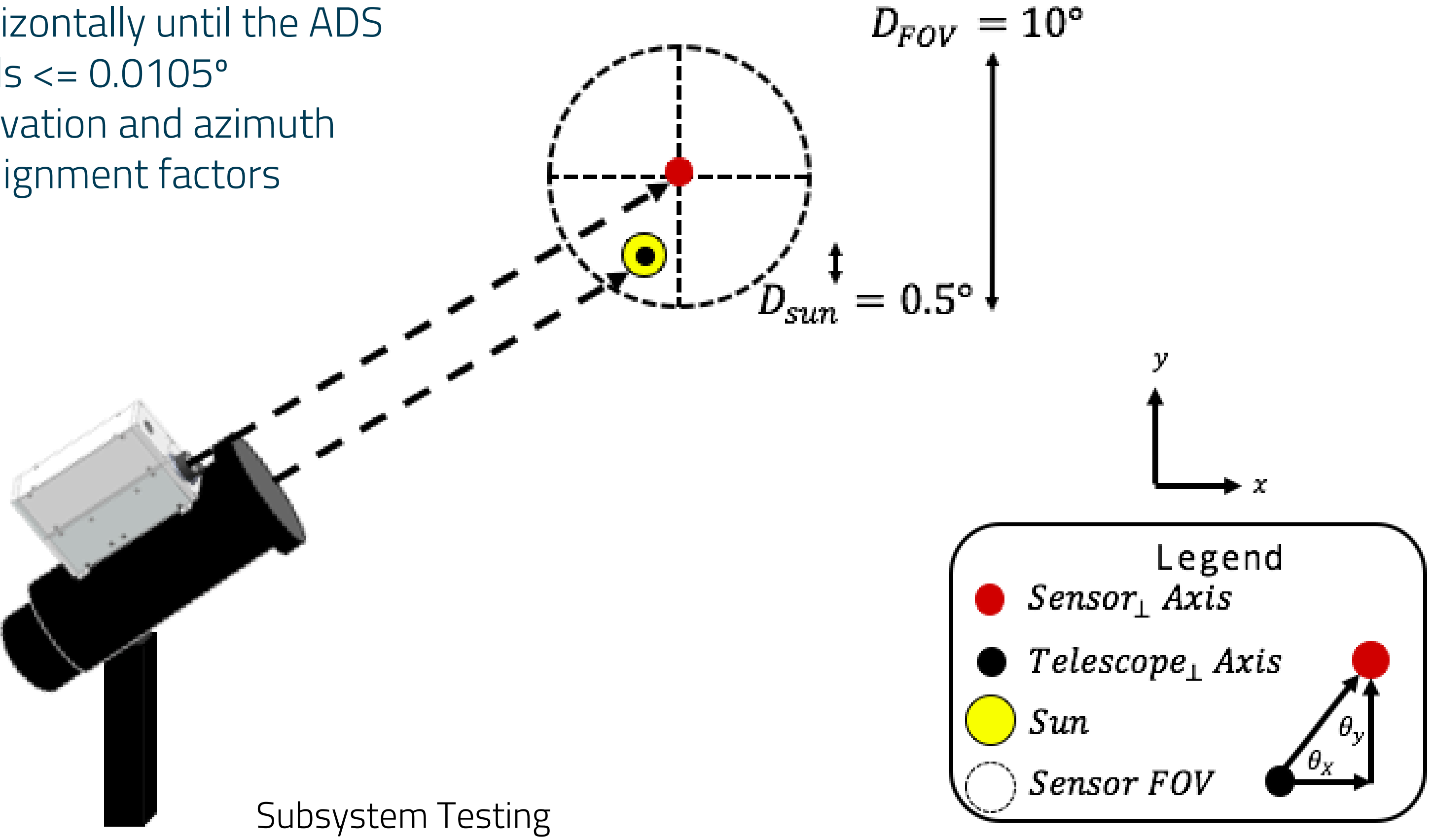
Data Source	Sampling Rate	Data Collected
Sun Sensor	10 Hz	Off Sun Angles α & β (deg)
Telescope Control Software	Hand-written for each actuation	Angular deviation from Sun center



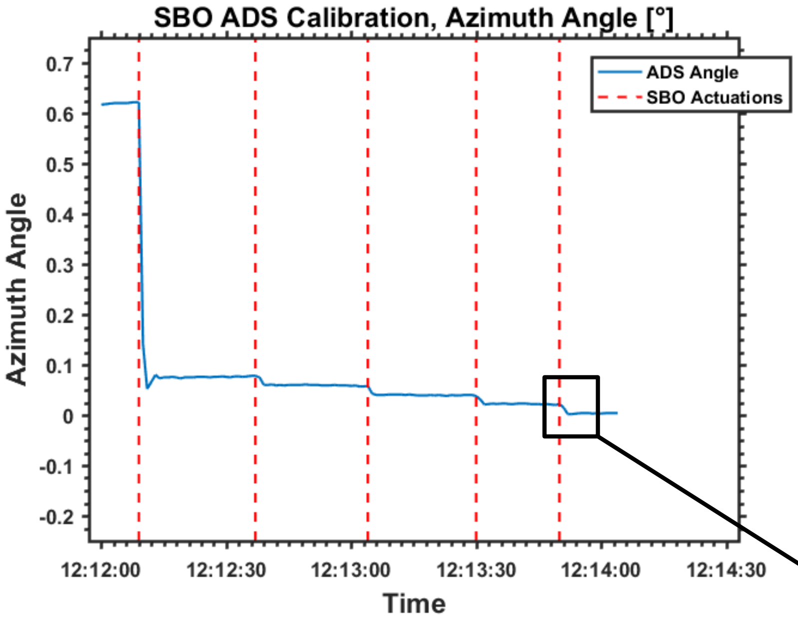
SBO 1: Test Procedure

Procedure

1. Point telescope at Sun center
2. Slew telescope vertically until the ADS elevation angle reads <= 0.0105°
   - ○ Save ADS elevation angle
3. Point telescope at Sun center
4. Slew telescope horizontally until the ADS azimuth angle reads <= 0.0105°
5. Save measured elevation and azimuth angles as the misalignment factors

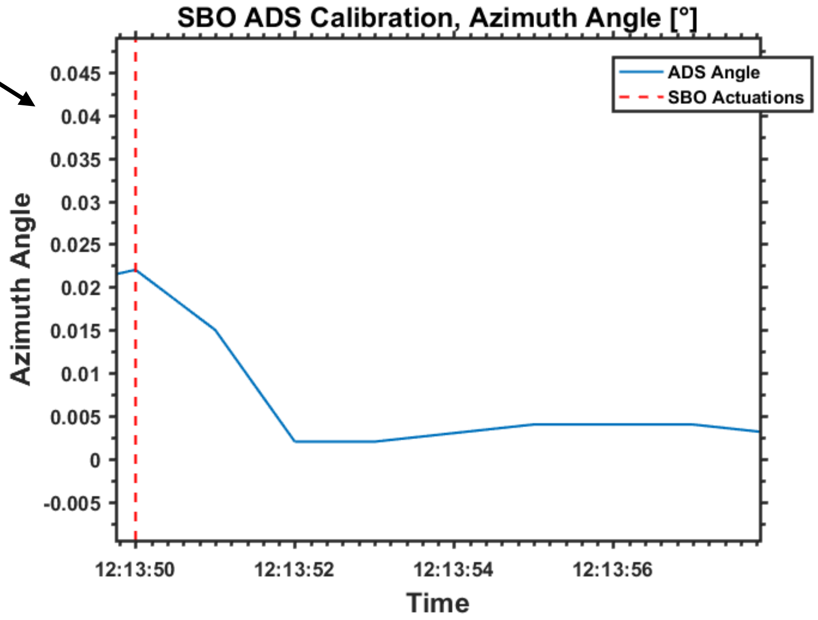


SBO 1 Test Results: Azimuth Angle

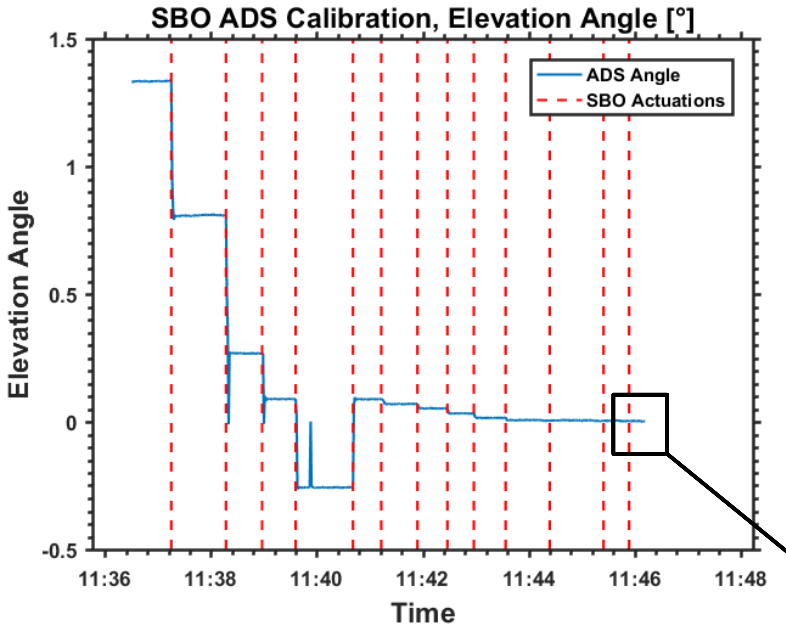


- ➢ Determined azimuth mounting error of 33 ′

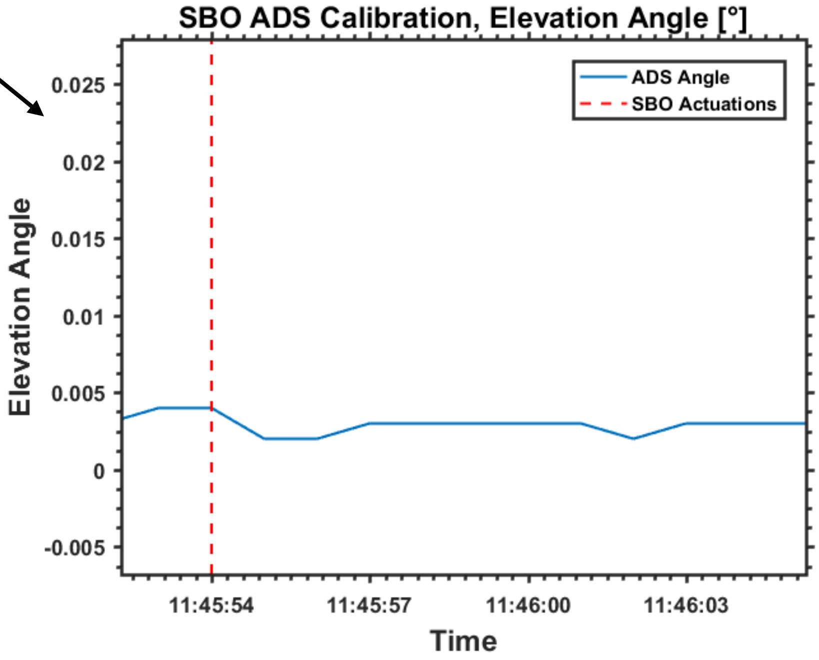
- ➢ Confirmed ADS azimuth accuracy ≤ 0.005 °



SBO 1 Test Results: Elevation Angle



- ➢ Determined elevation mounting error of -73 ′



- ➢ Confirmed ADS elevation accuracy ≤ 0.005°

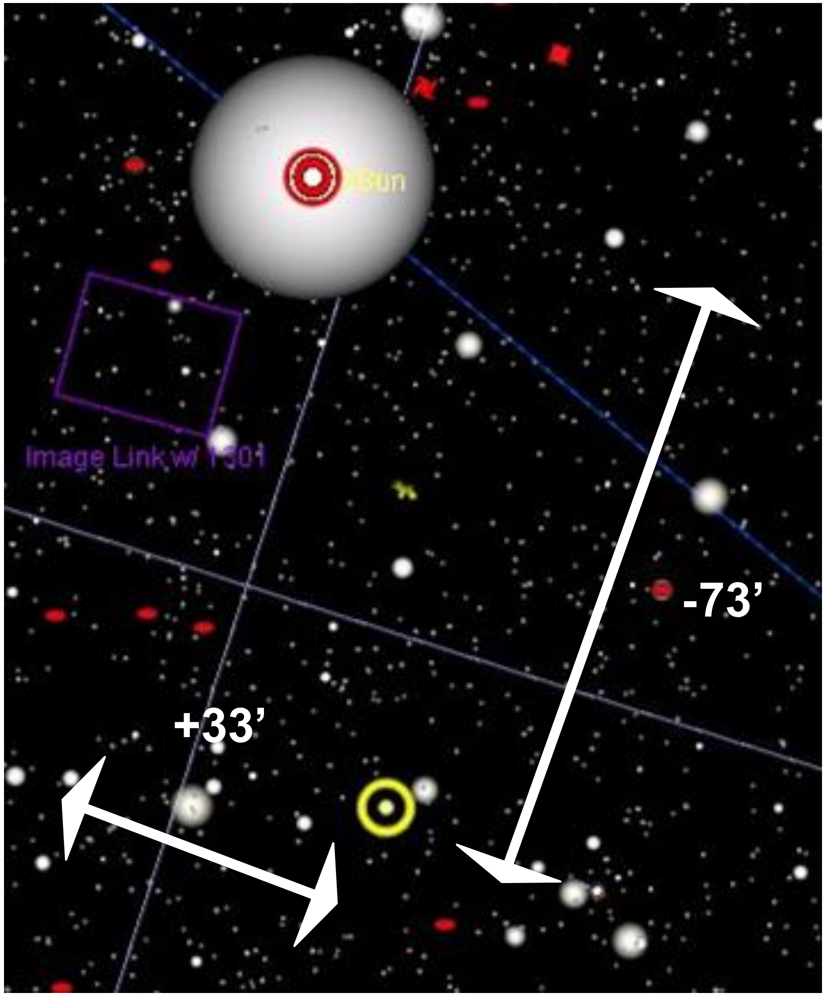
SBO 1: Test Results

Test Implication

- Validated ADS operation and sensor linearity
- Alignment must be repeated at the beginning of each SBO test

Requirement Verified

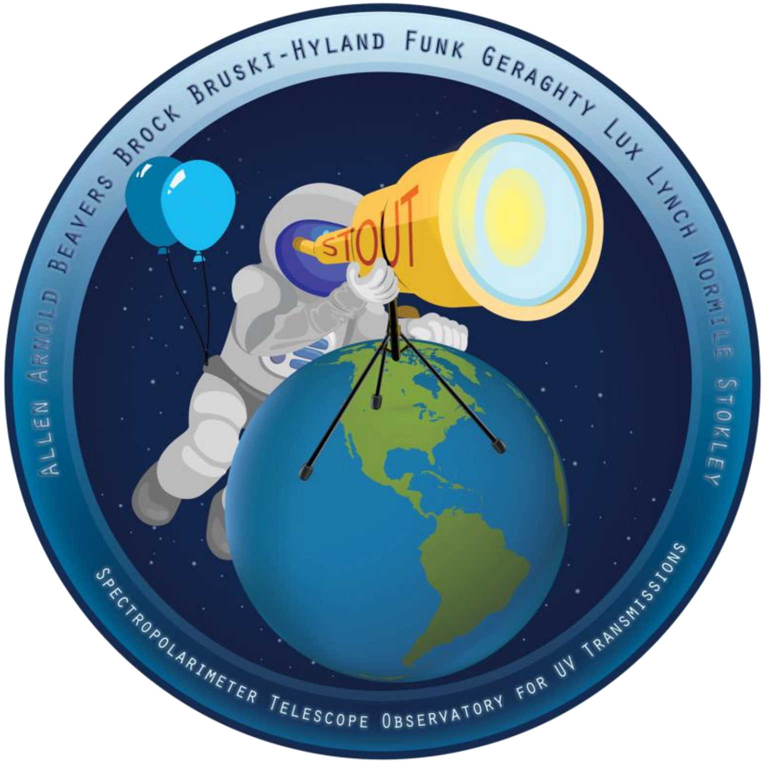
- 7.4 The off-sun angle shall be determined to within 0.05 degrees of Sun center



Offset as seen in Software Bisque - TheSkyX Observatory Control Software

◎ SBO pointing location

◎ Sun center



Test Overview & Results:

Integration Tests

Environmental Testing Overview

FR5: The system shall survive the environmental conditions of a high altitude balloon flight to 40 km

Purpose

- Model the flight conditions of the ascent, cruise, and descent phases
- Validate that the thermal control system keeps the module at survivable temperatures during ascent and descent
- Validate that the thermal control system keeps the module at operable temperatures during cruise
  - Spectrometer: 0 °C Polarizer Mount: 5 °C Motors: -10 °C Motor Encoders: -20 °C
- Verify previous thermal modeling by comparing them to resultant test chamber data

Key Requirements

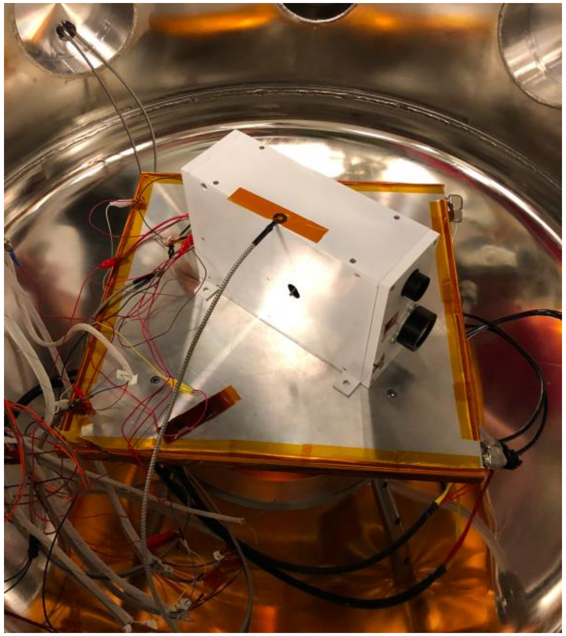
- 5.1 During ascent and descent the system shall survive temperatures ranging from -65°C to 20°C
- 5.2 During cruise the system shall operate at temperatures ranging from -25°C to -15°C
- 5.3 The system shall operate at pressures ranging from 100 kPa to 100 Pa

How it Reduces Risk

- Shows the system can survive the simulated flight profile of 40 km flight, enabling the fulfillment of mission requirements

Associated Model: SolidWorks Thermal Model

Environmental Testing: TVAC



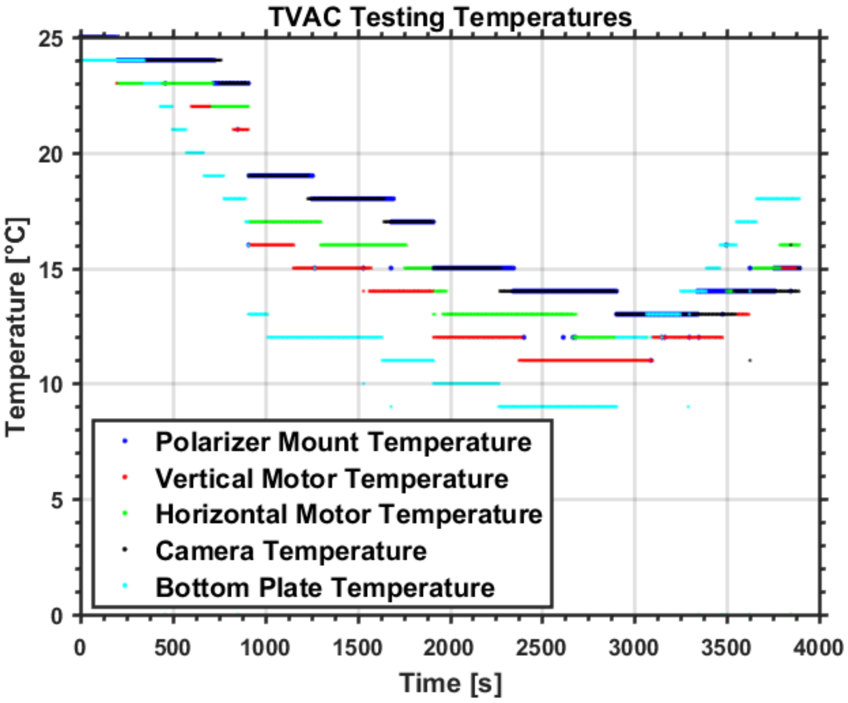
Thermal Vacuum Chamber Specifications

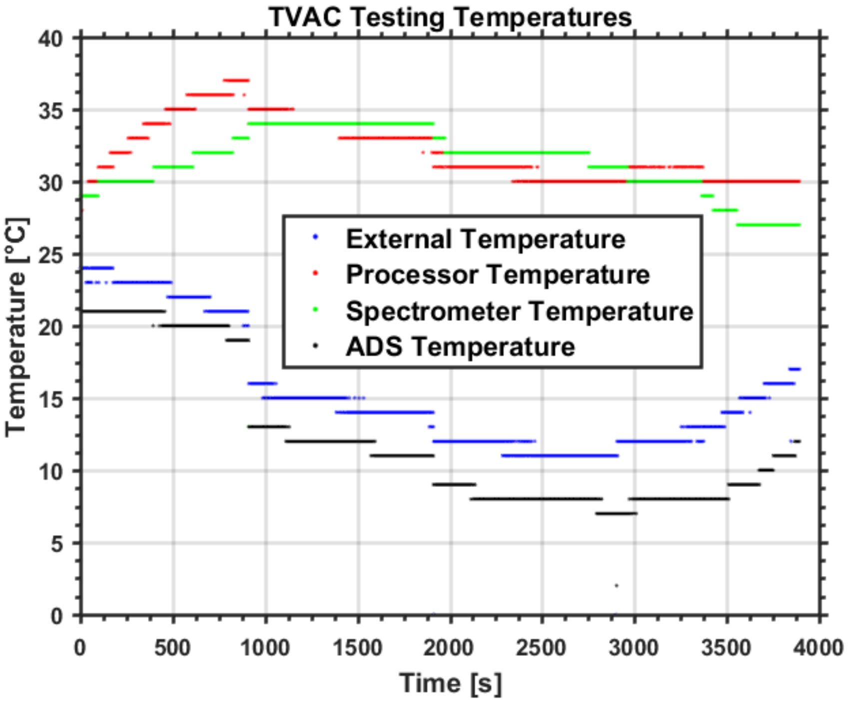
- UCAR HAO Facility
- Models temperature down to -20 C, and pressure as low as 130 Pa
  - Used to model cruise phase of flight

Data Source	Sampling Rate	Data Collected
Internal Component Temperature Sensors (2)	Every 1 second (1 Hz)	Temperature of UDOO and Sun Sensor
Internal Environment Temperature Sensors (4)	Every 1 second (1 Hz)	Temperatures at polarizer mount, motors, spectrometer
External Temperature Sensors (2)	Every 1 seconds (1 Hz)	Chamber temperature
Pressure and humidity sensor	Every 1 second (1 Hz)	Pressure and humidity (functionality checks)

Environmental Testing: TVAC Data

- ➢ Lowest chamber temperature: ~ 9 °C
- ➢ Lowest chamber pressure: ~ 130 Pa





Test Implication

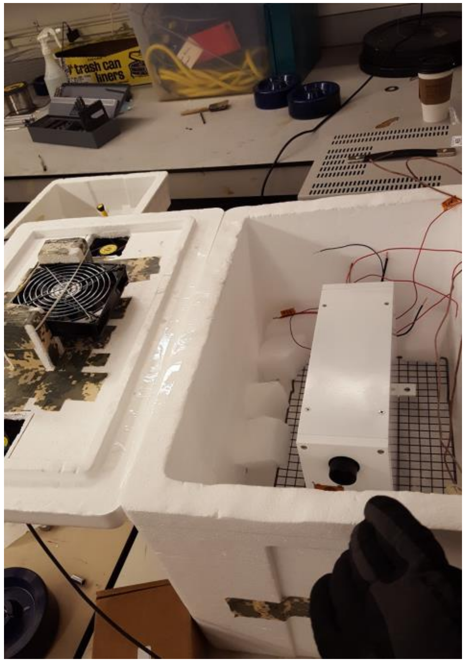
System can survive near vacuum conditions

Requirement Verified

5.3 The system shall survive pressure values ranging from 100 kPa to 10 Pa

- Equipment limitation did not allow testing to 10 Pa but results are sufficient

Environmental Testing: ETC



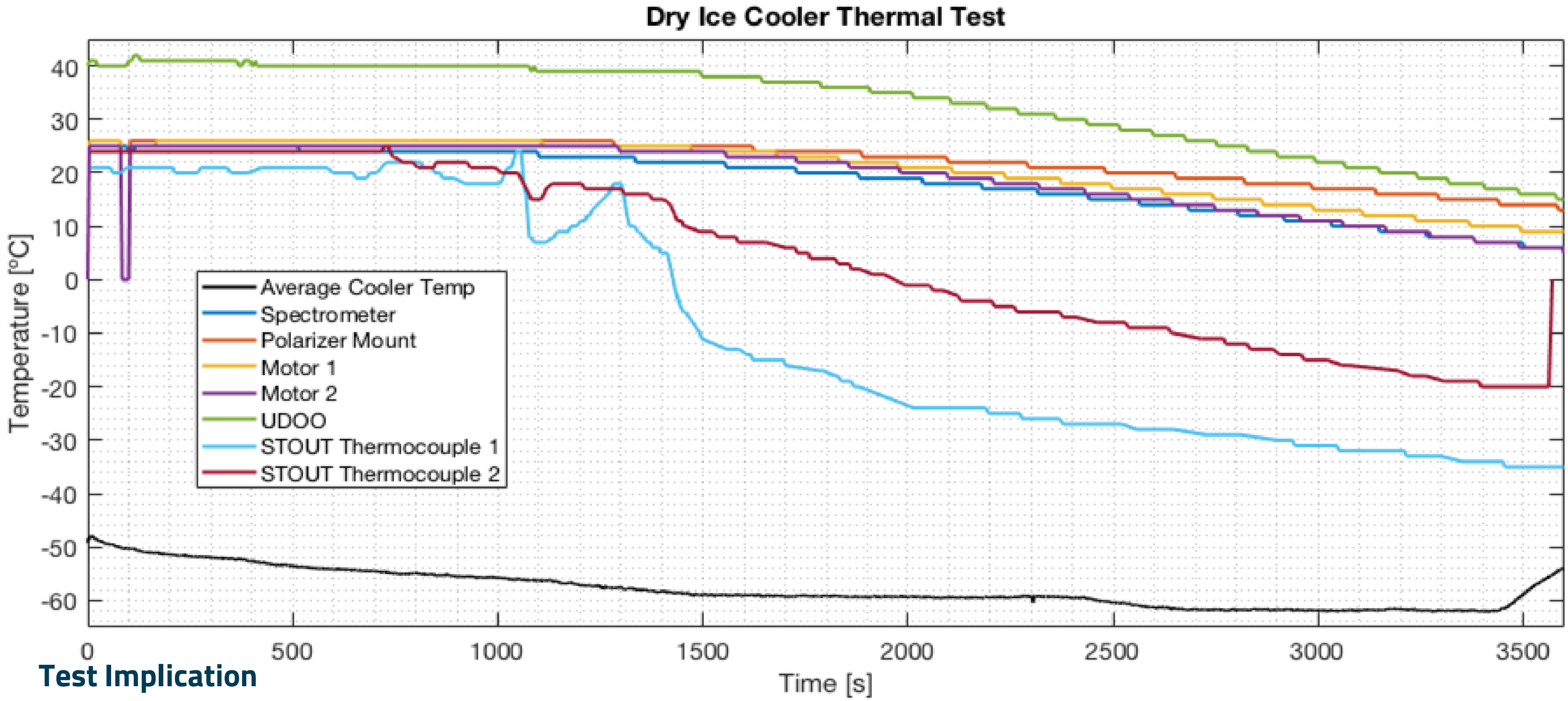
ETC Specifications

- Team ACES test chamber
- Styrofoam cooler with dry ice
- Decreases temperature to -78.5 °C and outputs temperature every 0.75 seconds
- Used to validate EMCS through temperature conditions of ascent flight phase

Data Source	Sampling Rate	Data Collected
Internal Component Temperature Sensors (4)	Every 2 seconds (0.5 Hz)	Internal temperature of Spectrometers, UDOO, Polarizer Mount, Motors
External Module Temperature Sensors (2)	Every 2 seconds (0.5 Hz)	Module temperature during ascent
External Cooler Temperature Sensors (4)	Every 0.75 seconds (1.33 Hz)	Atmospheric temperature during ascent

Environmental Testing: ETC Data

- Testing occurred at atmospheric pressure
- Lowest chamber temperature: ~ -63 degrees C



Test Implication

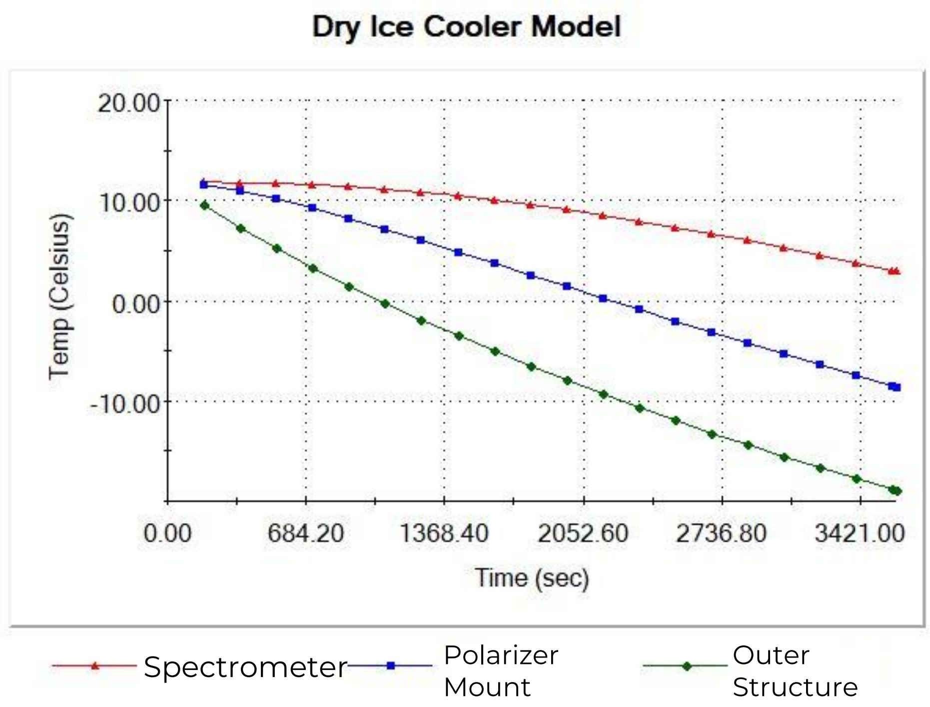
Thermal control maintains operable internal temperatures

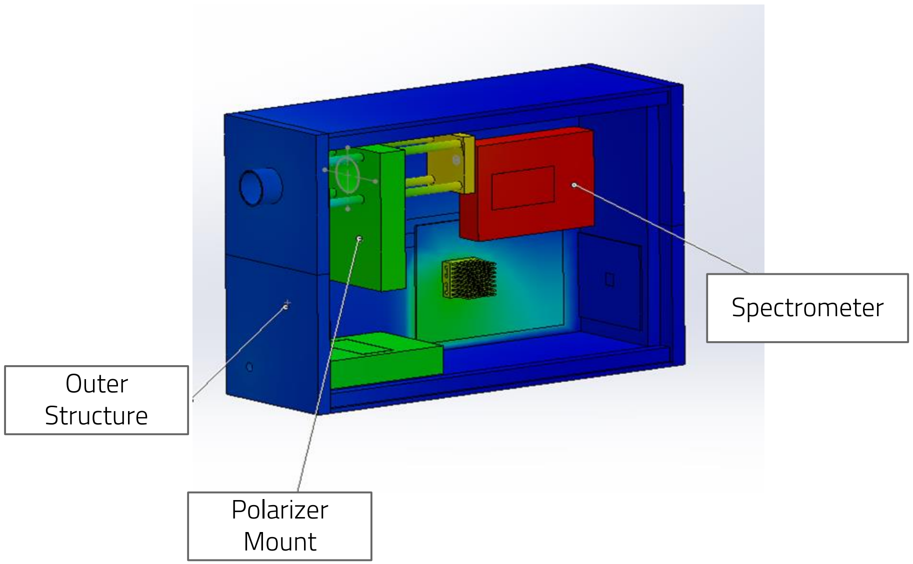
Requirement Verified

4.1 The system shall measure internal pressure and temperature

5.1 The system shall survive temperatures ranging from -65C to -15C

Environmental Testing: ETC Model Analysis





Model Comparison ~ 1 hr

Component	Predicted Temperature (C)	Measured Temperature (C)
Outer Structure	-20	-20
Polarizer Mount	-9	13
Spectrometer	4	8

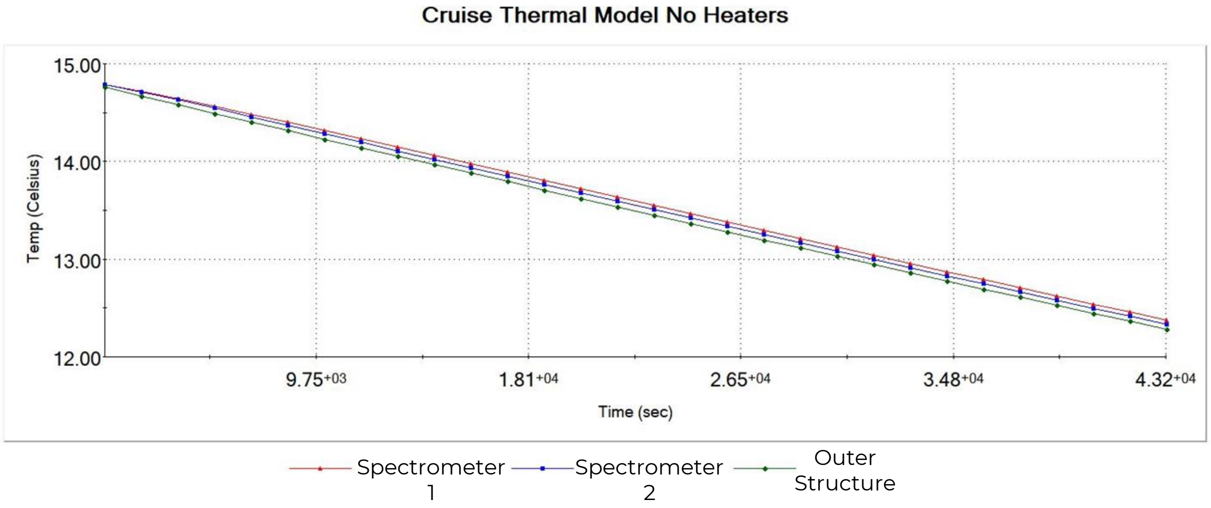
Model Implication

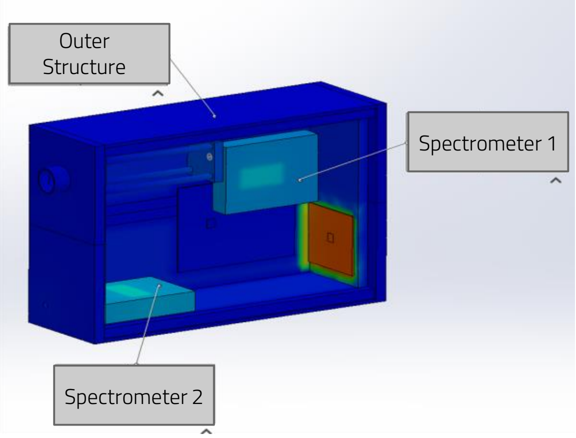
- Tested at desired temperature, longer duration, and higher pressure
- Thermal model validated
- Testing showed operable interior temperatures
    - Higher than model predicted

Model Discrepancies

- Low familiarity with software
- Oversimplification of components
- Electronics heat dissipation unaccounted for
- Lower thermal model mass, wiring unaccounted for

Environmental Testing: TVAC Model Analysis





Model Implication

- Transient thermal simulation to model cruise environment at 40 km altitude
- Demonstrates heaters not needed at cruise altitude
- TVAC Thermal model not validated
  - Longer test duration required for steady state
- Testing showed operable interior temperatures
  - Higher than model predicted

Model Discrepancies

- Low familiarity with software
- Oversimplification of components
- Electronics heat dissipation unaccounted
- Lower thermal model mass, wiring unaccounted for

SBO Testing: Overview

FR2: The system shall take polarized UV spectrum measurements at multiple points on the Sun

Note that the ADS sensor is assumed to be calibrated relative to SBO Telescope at this point in the testing procedure

Objectives

- ➢ Calibrate optical system pointing relative to ADS Sun Sensor
- ➢ Validate pointing control response to an external pointing deviation

Key Requirements

- ➢ 2.4 Pointing capabilities of +/- 1° in azimuth and +/- 5° in elevation

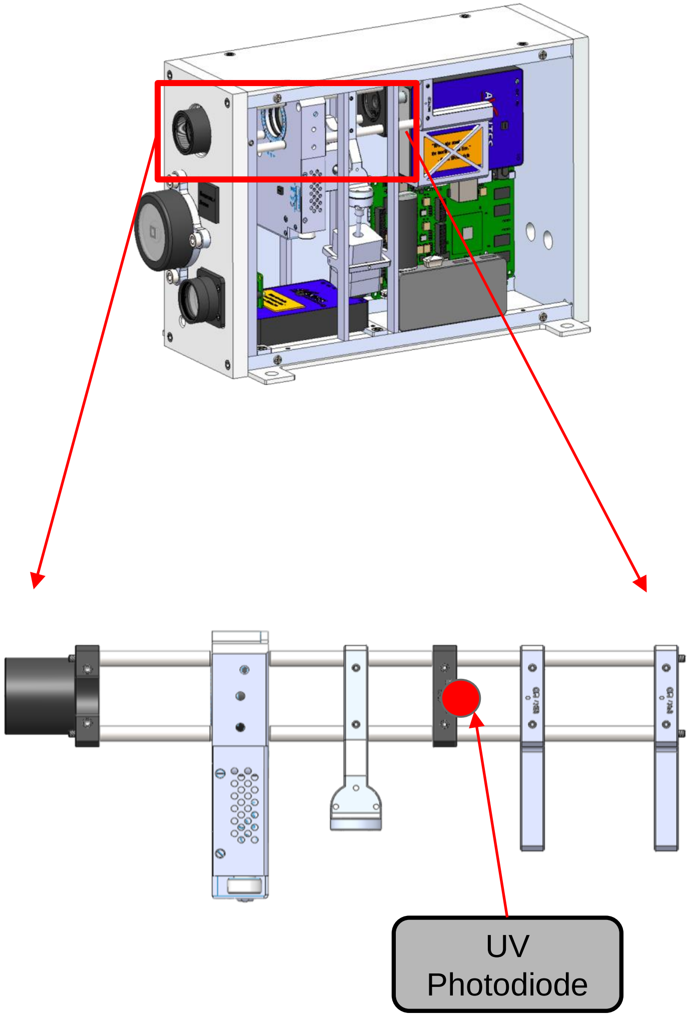
How it Reduces Risk

- ➢ Ensures that the optical system will point at the desired locations relative to ADS measurements

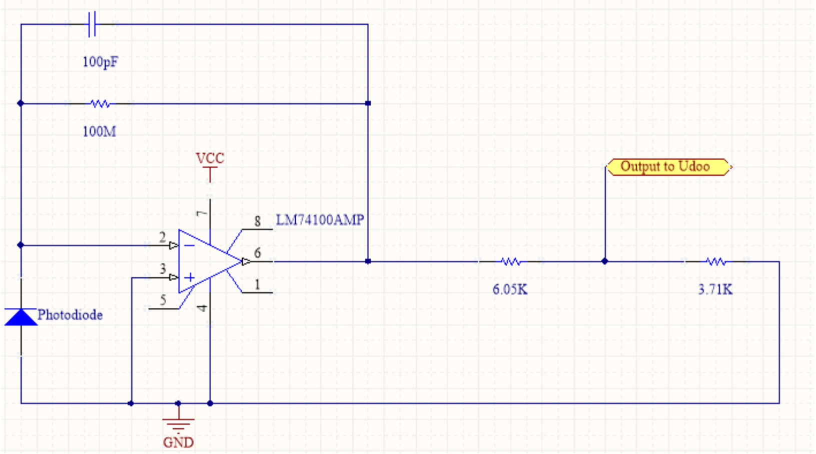
SBO 2: Calibrate Optical Axis Zero - Test Setup

Background

- Cannot use spectrometer for optics system calibration
- Replace spectrometer with UV photodiode in optics train
- Sensor outputs voltage with corresponding photocurrent generation
- Will indicate when optical axis is pointing at a location on the Sun



Linearizing Photodiode Circuit



SBO 2: Calibrate Optical Axis Zero - Test Setup

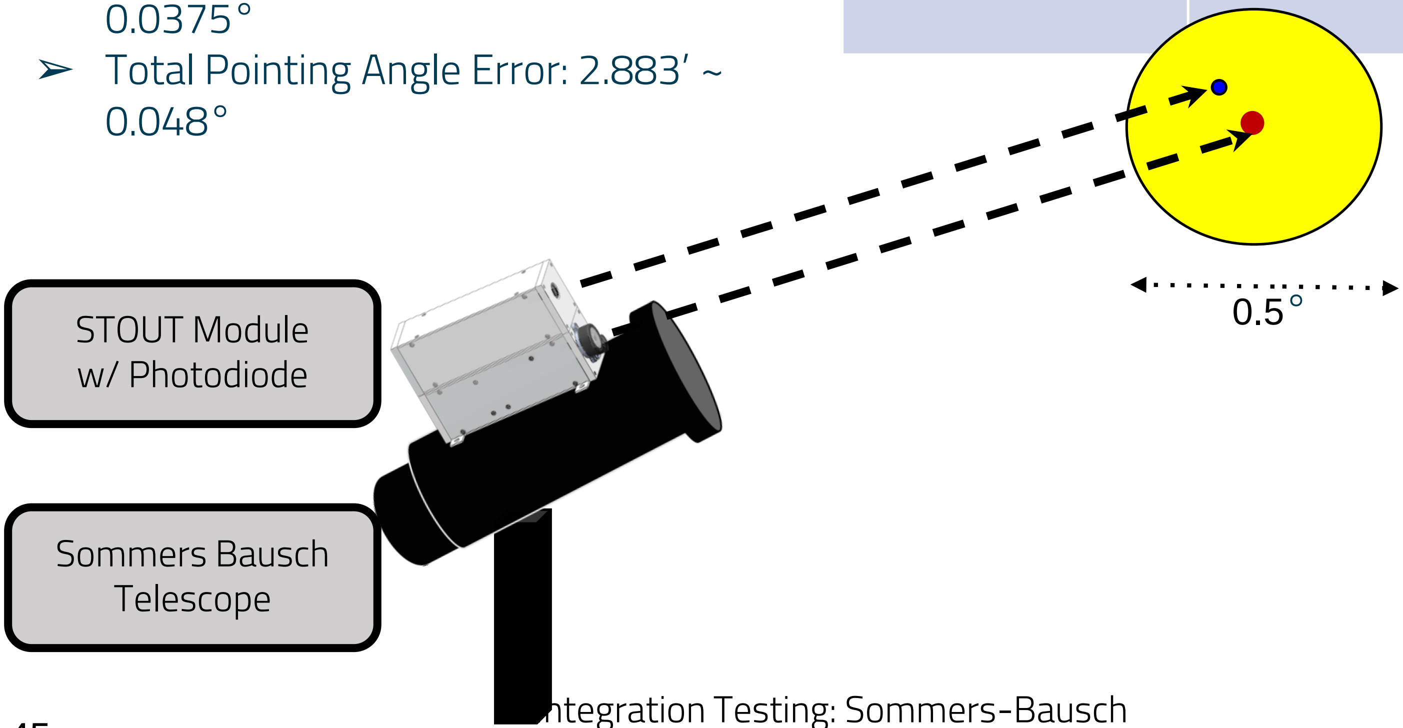
Assumptions

- ➢ Sun Sensor and Optical axis can be level mounted to ±0.25° so that optical axis will be on the Sun when ADS axis at the Sun center

Specifications

- ➢ Total ADS accuracy: 38″ ~ 0.0105°
- ➢ Optics Pointing Accuracy: 2.25′ ~ 0.0375°
- ➢ Total Pointing Angle Error: 2.883′ ~ 0.048°

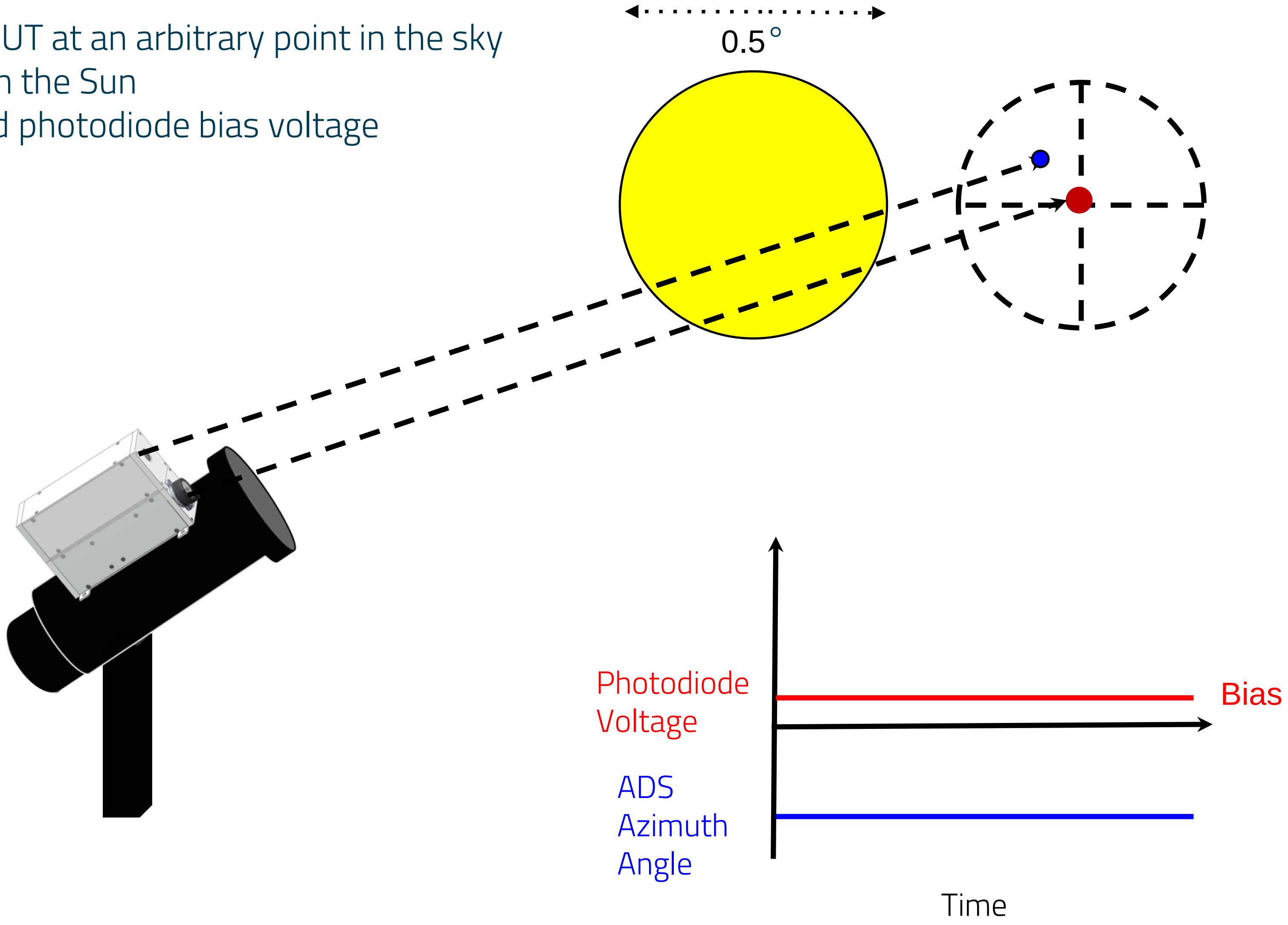
Data Source	Sampling Rate	Data Collected
Sun Sensor	10 Hz	Off Sun Angles α & β (deg)
Telescope Control Software	Unknown	Pointing position relative to Sun center
UV Photodiode	10 Hz	Light intensity dependent voltage



SBO 2: Calibrate Optical Axis Zero - Procedure

Procedure

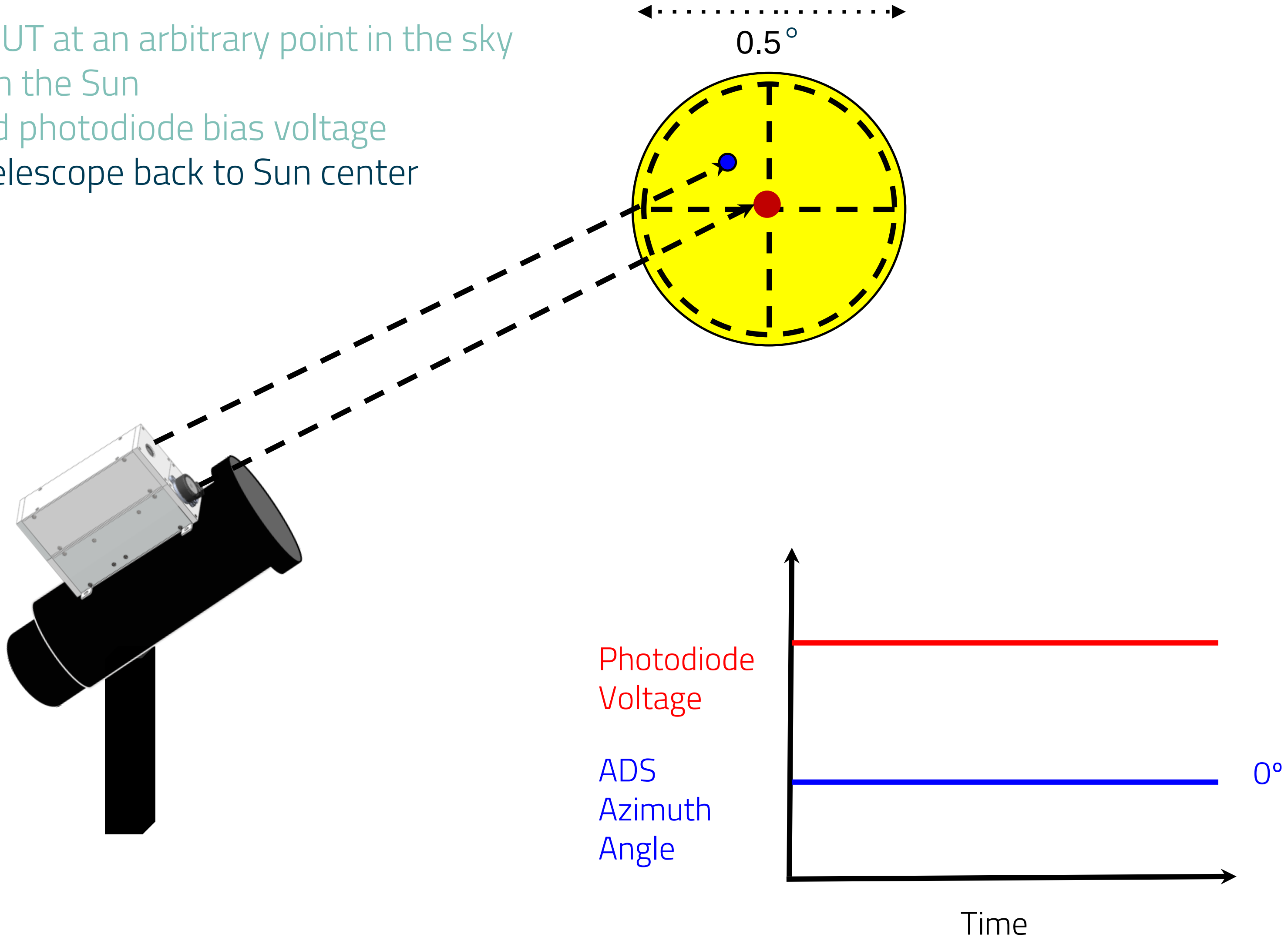
1. Point STOUT at an arbitrary point in the sky away from the Sun
   - ○ Read photodiode bias voltage



SBO 2: Calibrate Optical Axis Zero - Procedure

Procedure

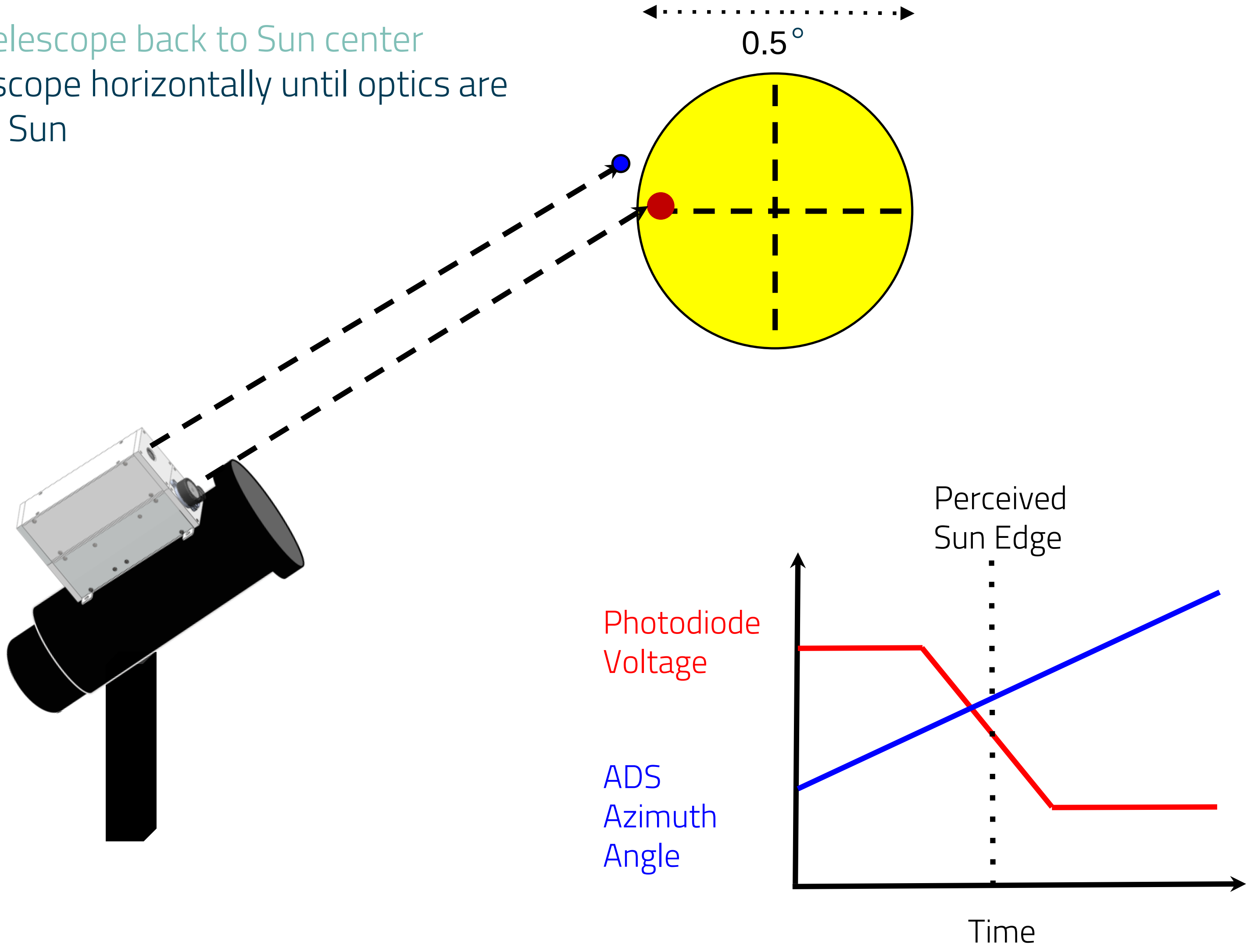
1. Point STOUT at an arbitrary point in the sky away from the Sun
    - Read photodiode bias voltage
2. Actuate telescope back to Sun center



SBO 2: Calibrate Optical Axis Zero - Procedure

Procedure

2. Actuate telescope back to Sun center
3. Slew telescope horizontally until optics are pointing off the Sun

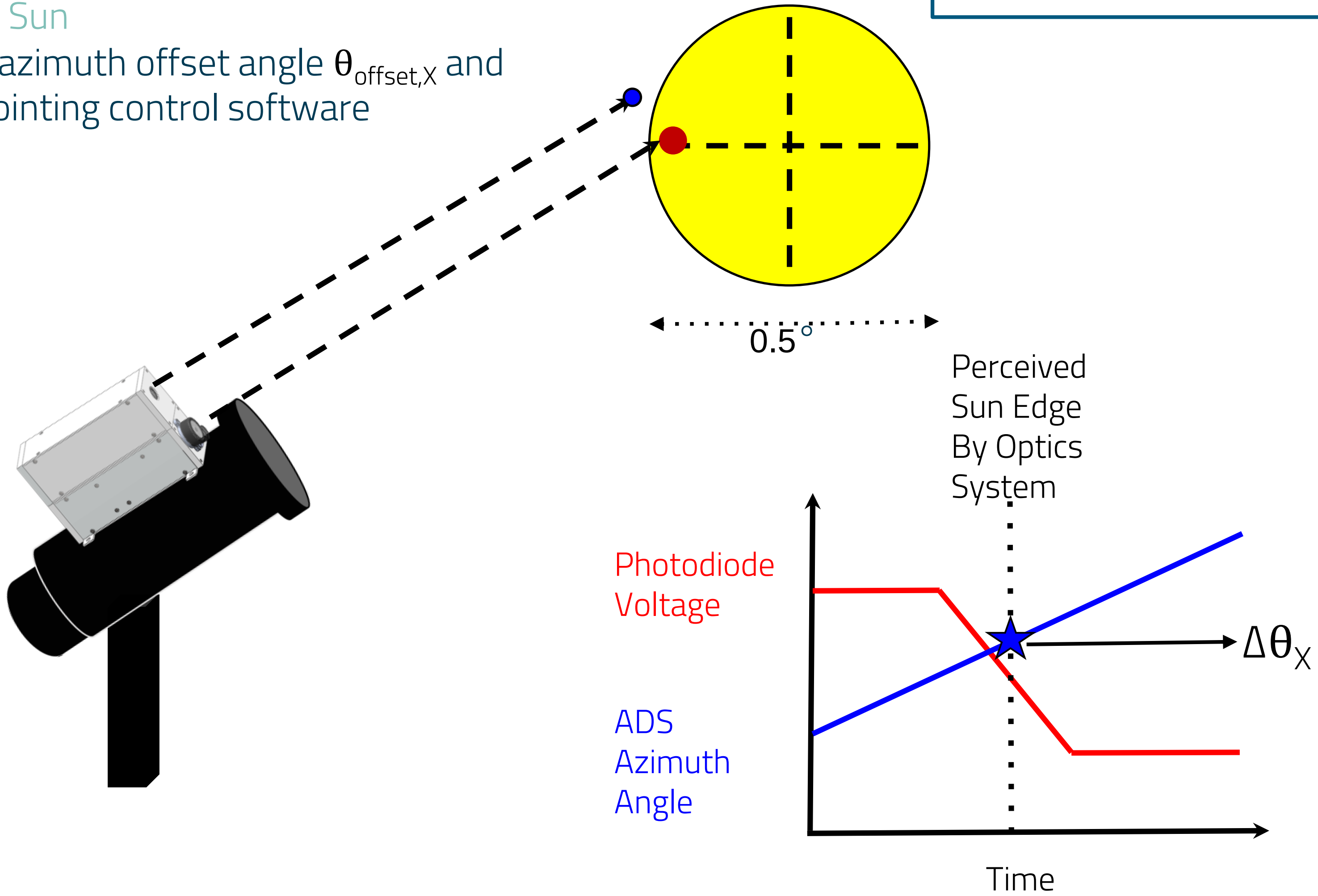


SBO 2: Calibrate Optical Axis Zero - Procedure

Procedure

3. Slew telescope horizontally until optics are pointing off the Sun
4. Calculate azimuth offset angle $\theta_{offset,X}$ and program into pointing control software

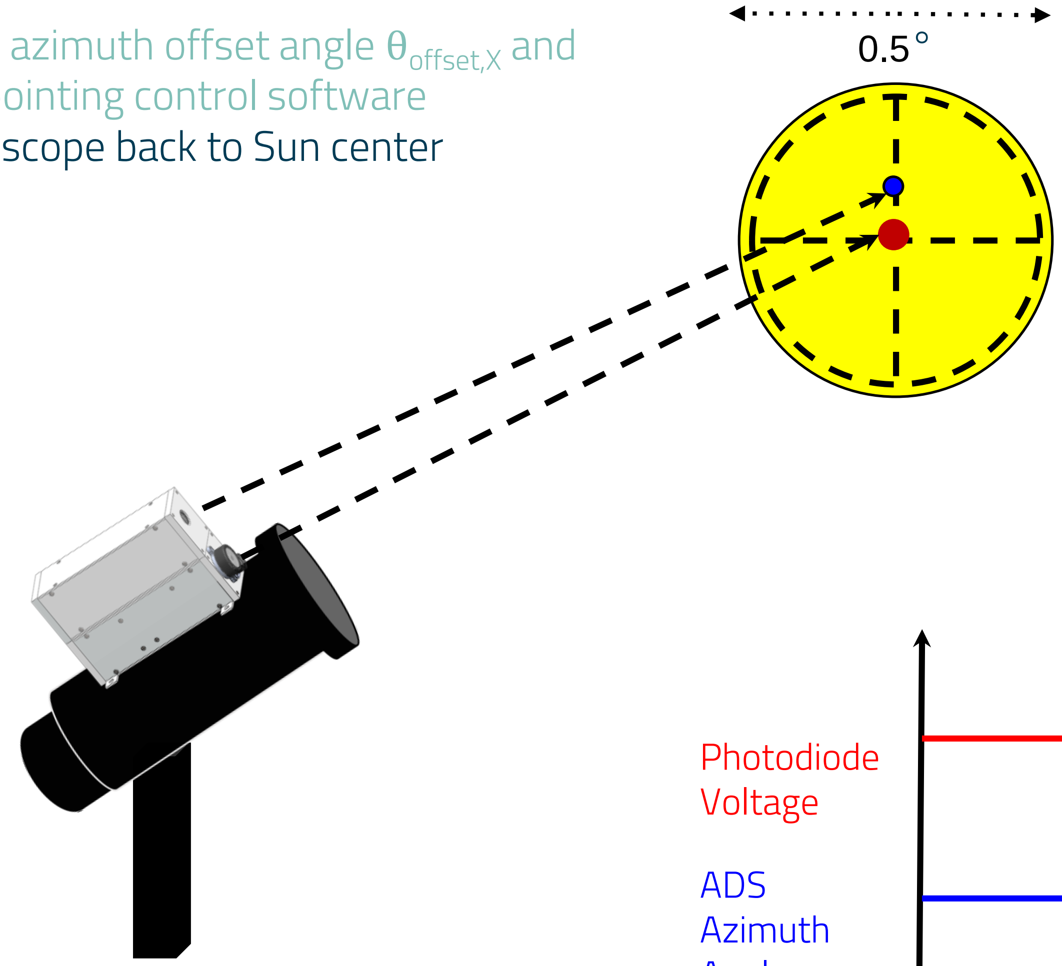
$$\theta_{offset,X} = (\theta_{Sun}/2) - \Delta\theta_X$$

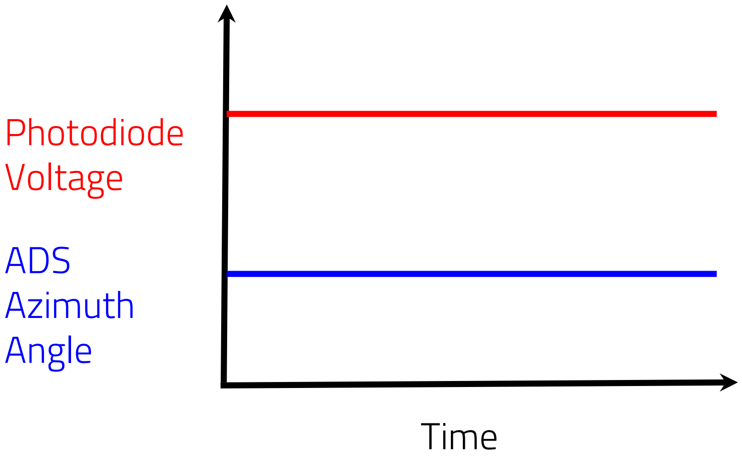


SBO 2: Calibrate Optical Axis Zero - Procedure

Procedure

4. Calculate azimuth offset angle $\theta_{offset,X}$ and program into pointing control software
5. Slew telescope back to Sun center

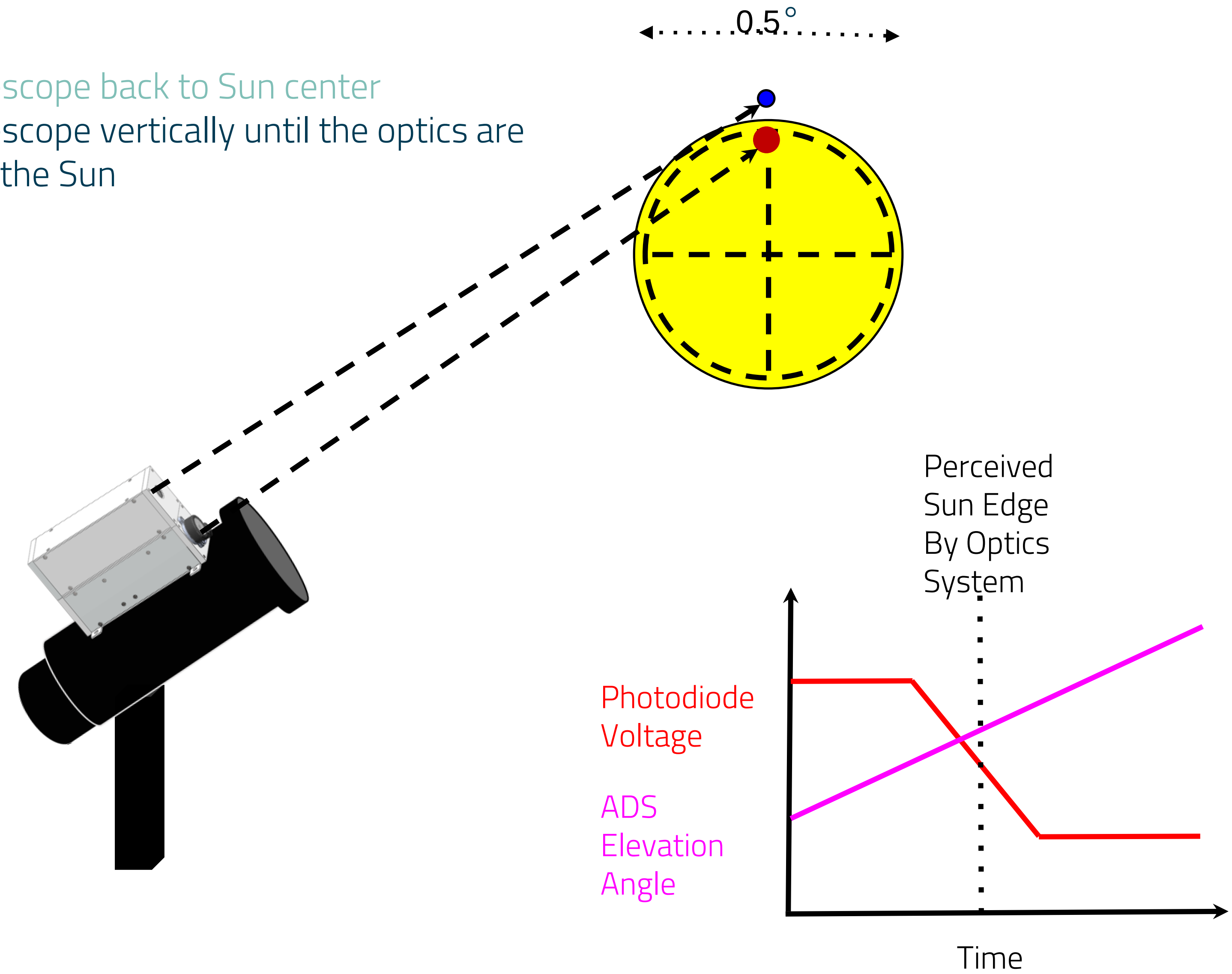




SBO 2: Calibrate Optical Axis Zero - Procedure

Procedure

5. Slew telescope back to Sun center
6. Slew telescope vertically until the optics are pointing off of the Sun

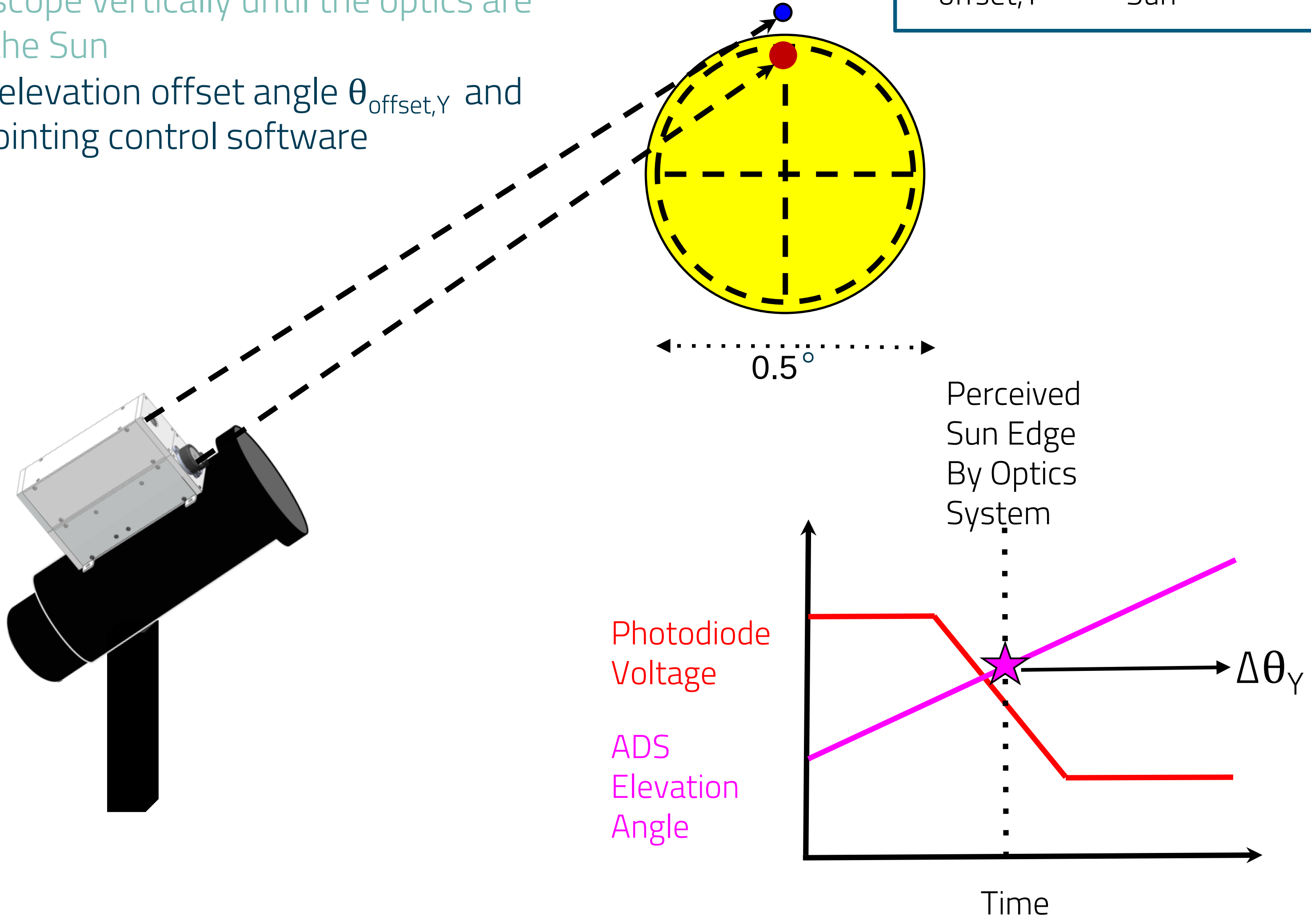


SBO 2: Calibrate Optical Axis Zero - Procedure

Procedure

6. Slew telescope vertically until the optics are pointing off of the Sun
7. Calculate elevation offset angle $\theta_{offset,Y}$ and program into pointing control software

$$\boxed{\theta_{offset,Y} = (\theta_{Sun}/2) - \Delta\theta_Y}$$

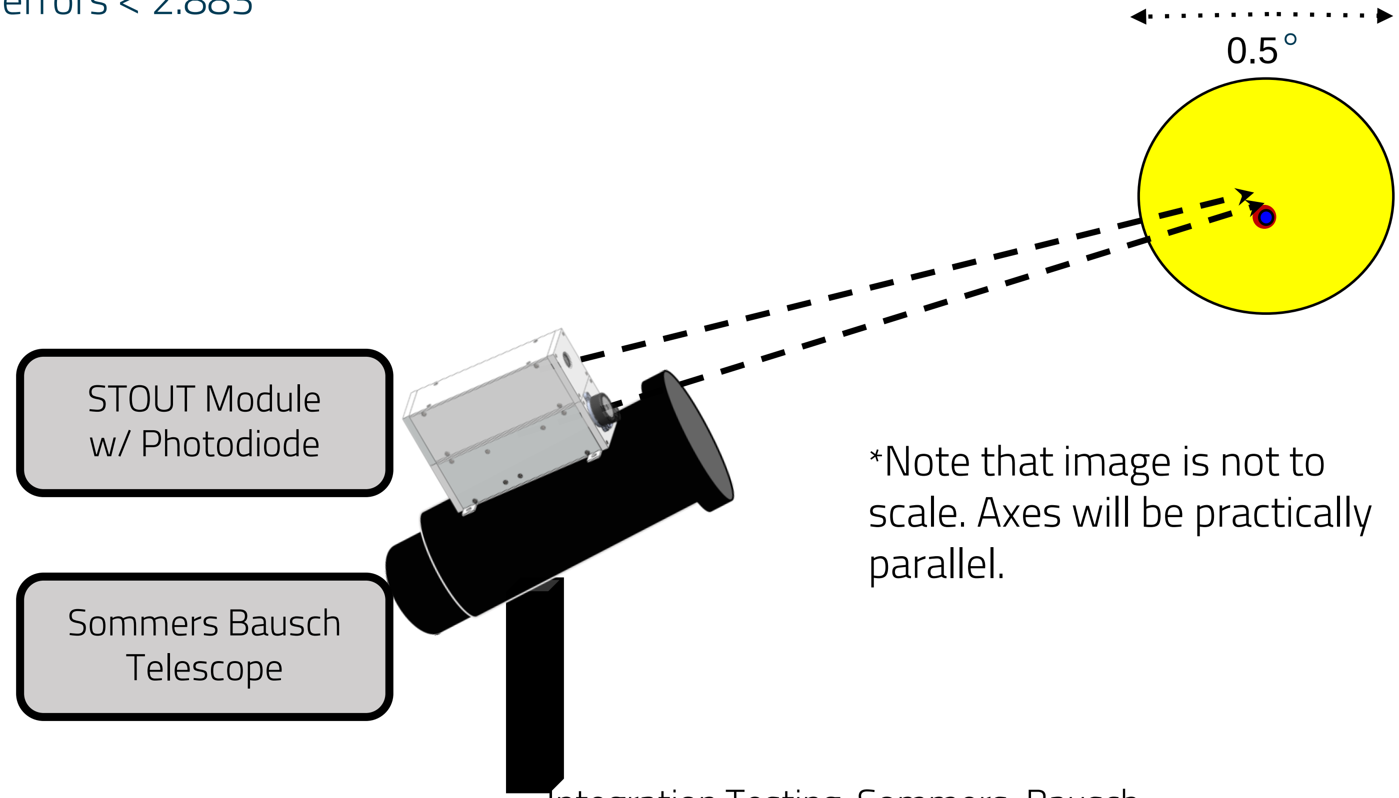


Integration Testing: Sommers-Bausch

SBO 2: Calibrate Optical Axis Zero - Procedure

Procedure

7. Calculate elevation offset angle $\theta_{offset,Y}$ and program into pointing control software
8. Repeat steps 1- 8 until offset angles $\theta_{offset,X}$ and $\theta_{offset,Y}$ converge to where any additional changes will be smaller than total pointing angle errors < 2.883'

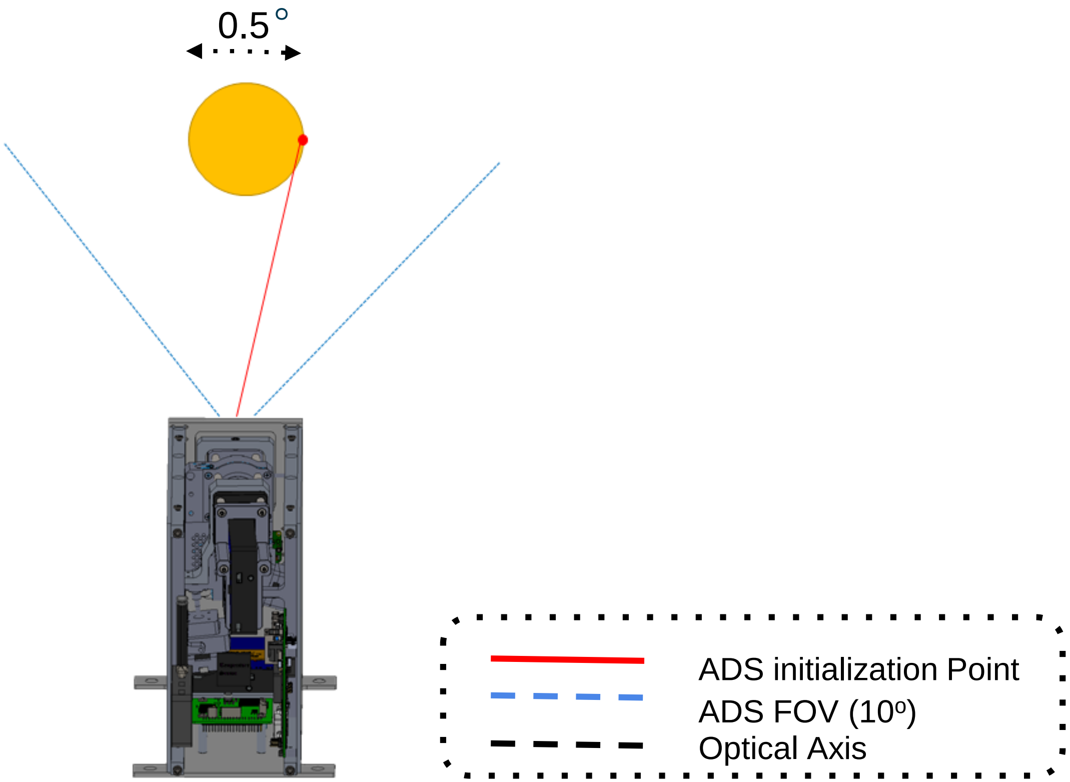


*Note that image is not to scale. Axes will be practically parallel.

SBO 3: Validate Pointing Algorithm

Procedure

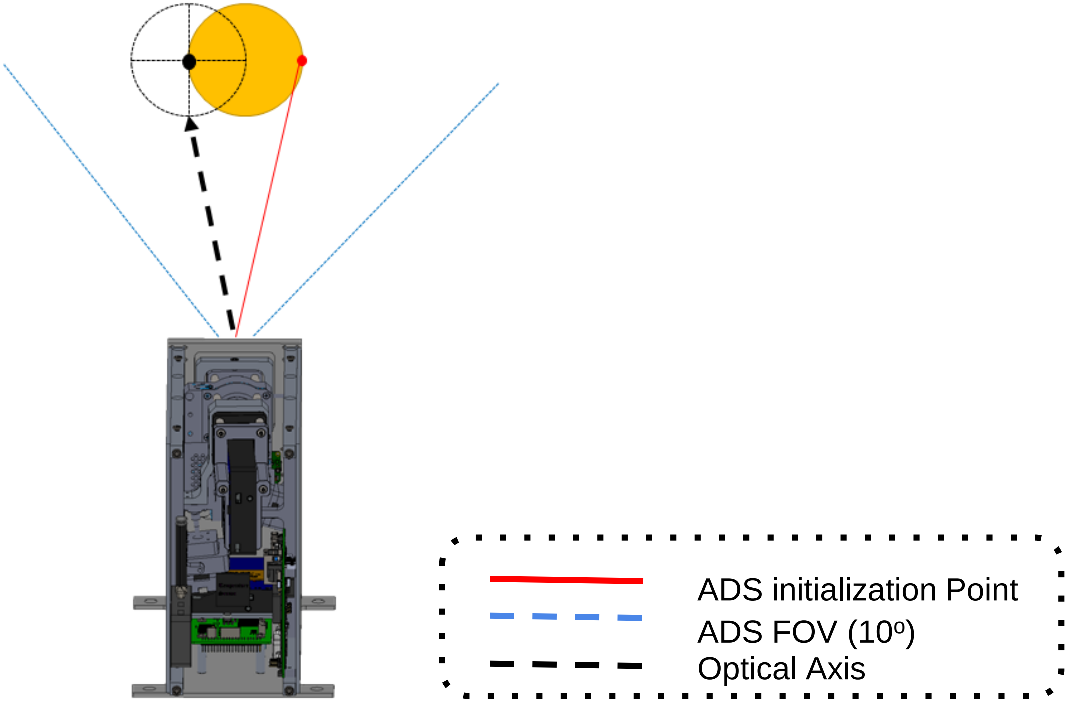
1. Initialized ADS on Sun’s right edge
   - ○ SBO telescope position will be locked



SBO 3: Validate Pointing Algorithm

Procedure

1. Initialized ADS on sun’s right edge
   - SBO telescope position will be locked
2. Lock optical axis on left edge of Sun
   - Validated by constant photodiode voltage

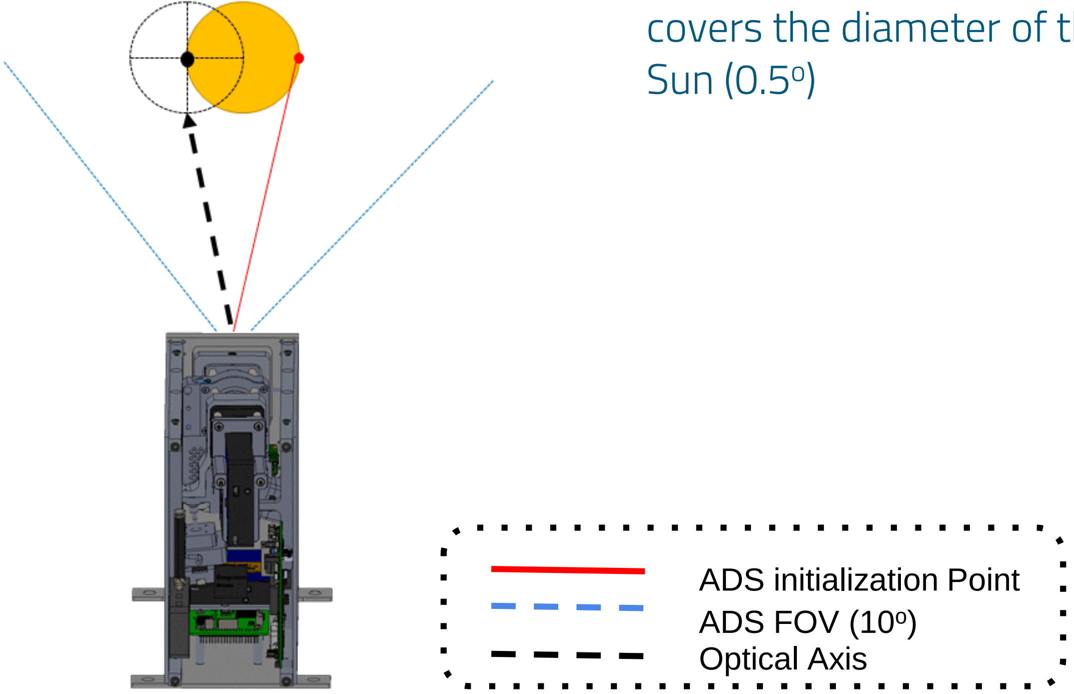


SBO 3: Validate Pointing Algorithm

Procedure

2. Lock optical axis on left edge of Sun
   - Accomplished through photodiode voltage
3. Initiate optics cage sweep
   - Validates internal solar angle sweep
   - Sweep concludes on left ADS exit

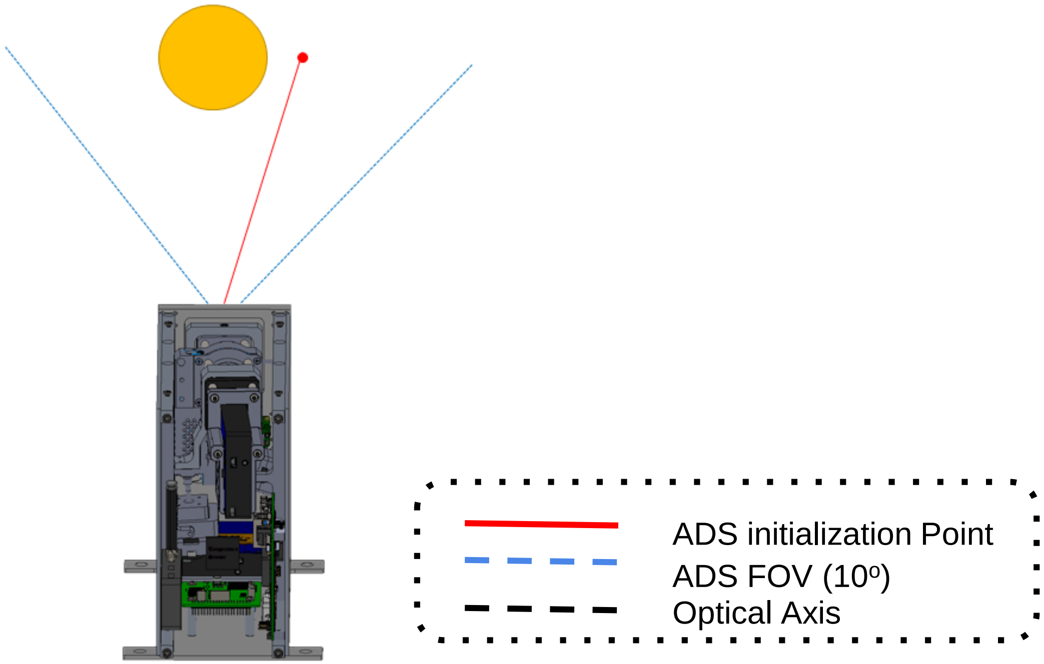
- **Note:** The sweep only covers the diameter of the Sun (0.5º)



SBO 3: Validate Pointing Algorithm

Procedure

3. Initiate optics cage sweep
    - Validates internal solar angle sweep
    - **Note:** The sweep only covers the diameter of the sun (0.5º)
4. Initiate ADS 3.5º from Sun's right edge
    - SBO Telescope position will be locked

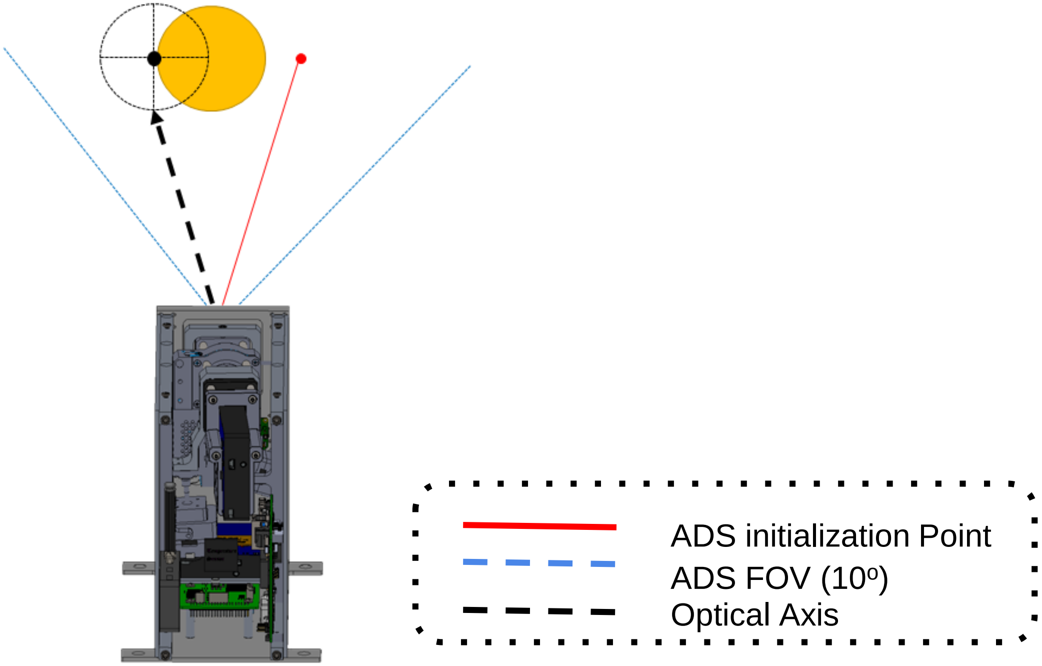


Integration Testing: Sommers-Bausch

SBO 3: Validate Pointing Algorithm

Procedure

4. Initiate ADS 3.5º from Sun's right edge
    - SBO Telescope position will be locked
5. Lock optical axis on left edge of Sun
    - Validated by constant photodiode voltage

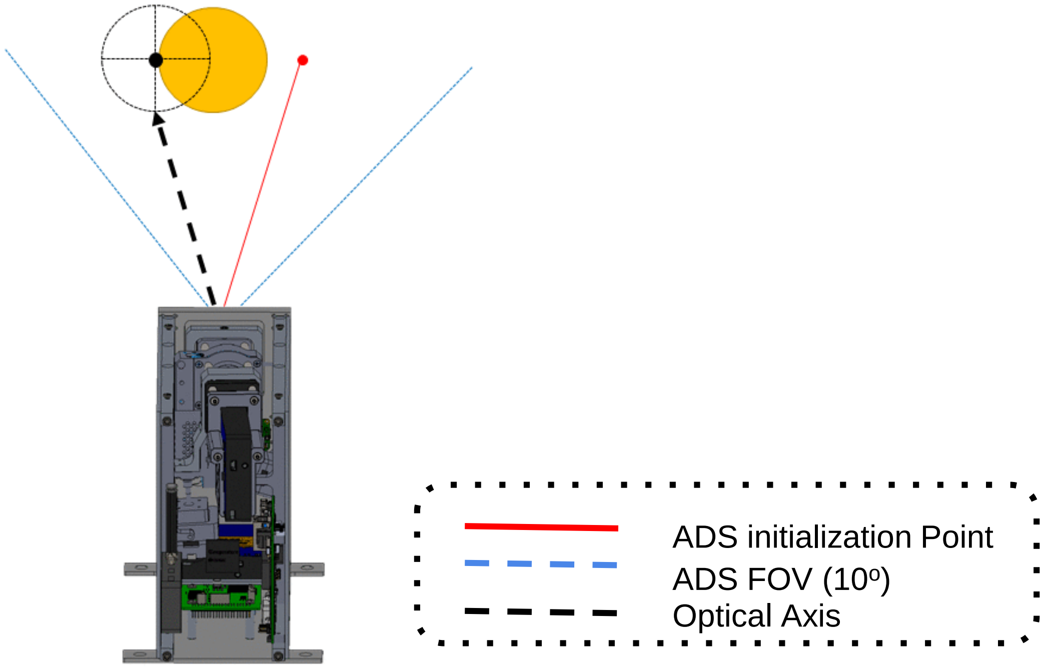


Integration Testing: Sommers-Bausch

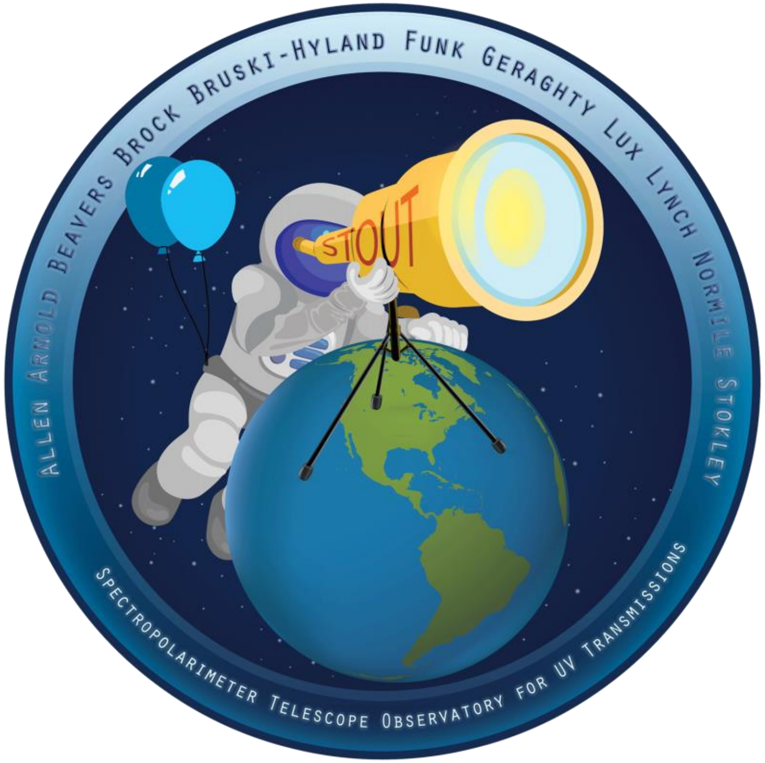
SBO 3: Validate Pointing Algorithm

Procedure

5. Lock optical axis on left edge of Sun
    - Accomplished through photodiode voltage
6. Initiate optics cage sweep
    - Validates full angle sweep
    - Sweep concludes on left ADS exit

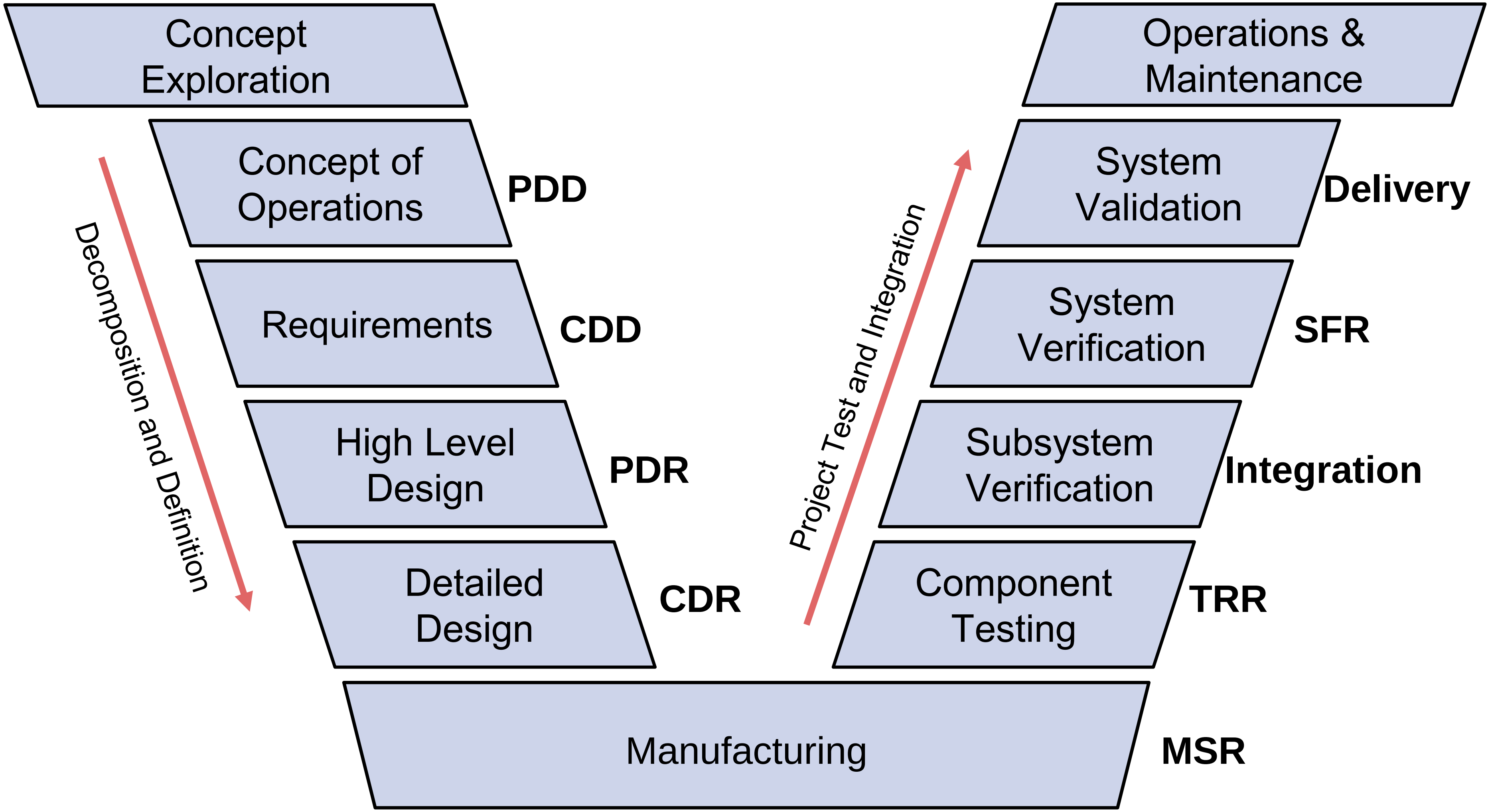


Integration Testing: Sommers-Bausch



Systems Engineering

Systems Engineering



Concept Exploration

Concept of Operations **PDD**

Requirements **CDD**

High Level Design **PDR**

Detailed Design **CDR**

Decomposition and Definition

Manufacturing **MSR**

Project Test and Integration

Component Testing **TRR**

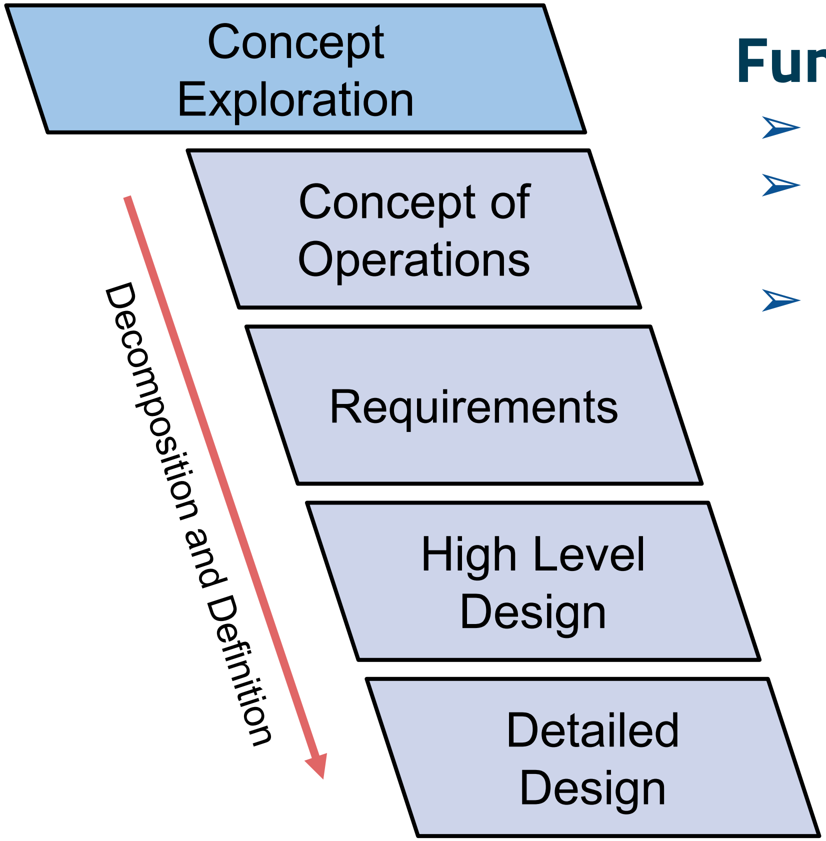
Subsystem Verification **Integration**

System Verification **SFR**

System Validation **Delivery**

Operations & Maintenance

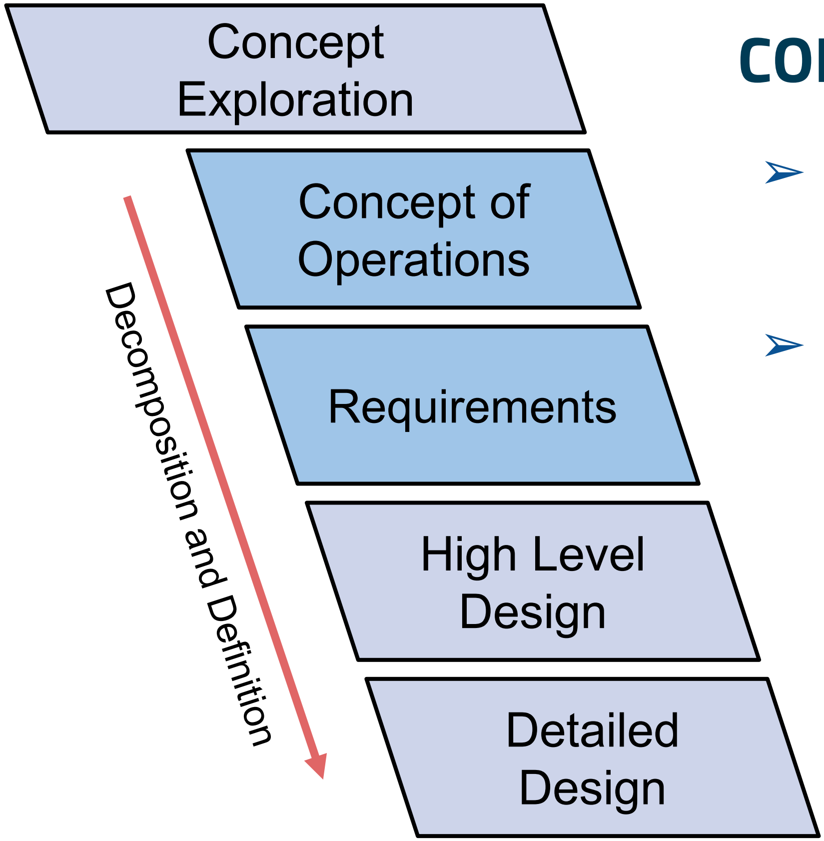
Concept Exploration



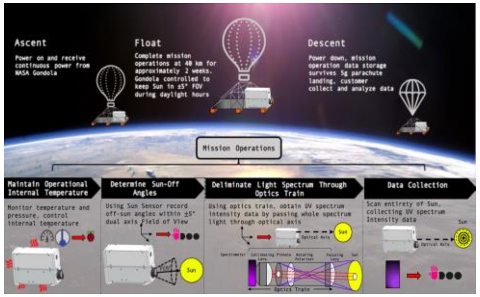
Functional Objectives:

- ➢ Locate Sun center
- ➢ Collect variable polarization UV spectrum measurements
- ➢ Operate in the flight environment of a high altitude balloon

Concept of Operations & Requirements



CONOPS:



Ascent

Power on and receive continuous power from NASA Gondola

Float

Complete mission operations at 40 km for approximately 2 weeks. Gondola controlled to keep Sun in ±5° FOV during daylight hours

Descent

Power down, mission operation data storage survives 5g parachute landing, customer collect and analyze data

Mission Operations

Maintain Operational Internal Temperature

Monitor temperature and pressure, control internal temperature

Determine Sun-Off Angles

Using Sun Sensor record off-sun angles within ±5° dual axis Field of View

Deliminate Light Spectrum Through Optics Train

Using optics train, obtain UV spectrum intensity data by passing whole spectrum light through optical axis

Data Collection

Scan entirety of Sun, collecting UV spectrum Intensity data

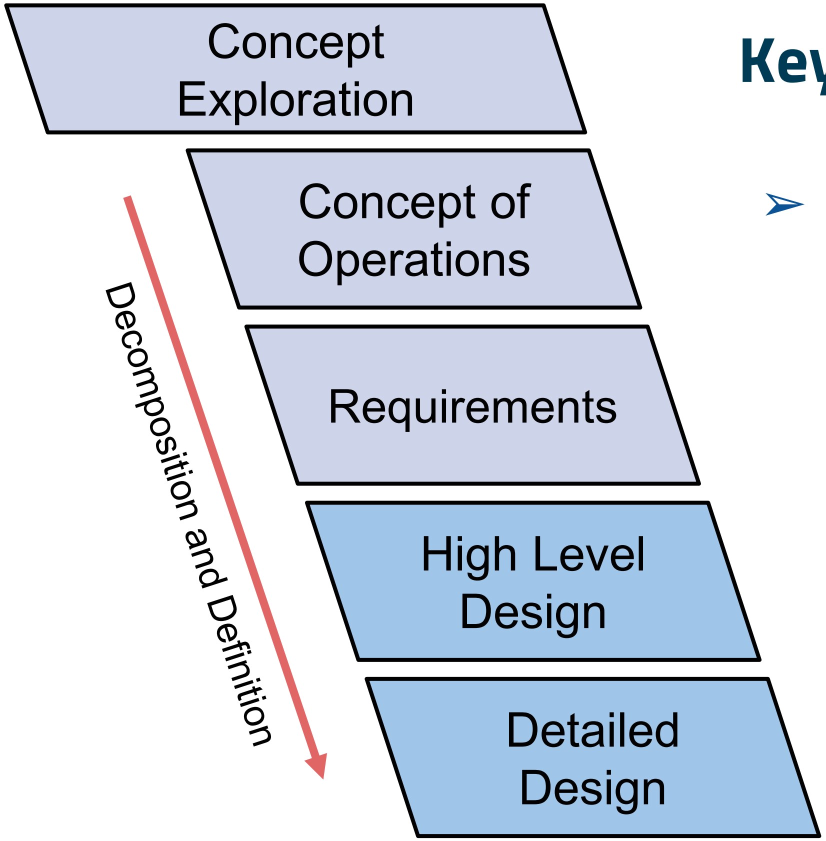
- ➢ Describes the characteristics of the STOUT system at a high level from stakeholder perspective
- ➢ Kept team aligned with project goals and customer requirements

Requirements

- ➢ Stemmed form CONOPS
- ➢ “Shall” statements
- ➢ Describe what system shall do, not how it will be done

Systems Engineering

High Level/Detailed Design



Concept Exploration

Concept of Operations

Requirements

High Level Design

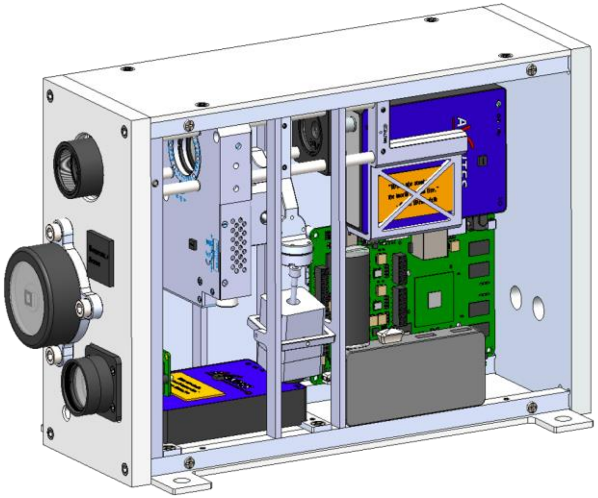
Detailed Design

Decomposition and Definition

Key Trade Study

- ➢ COTS Sun Sensor vs RADIANCE ADS

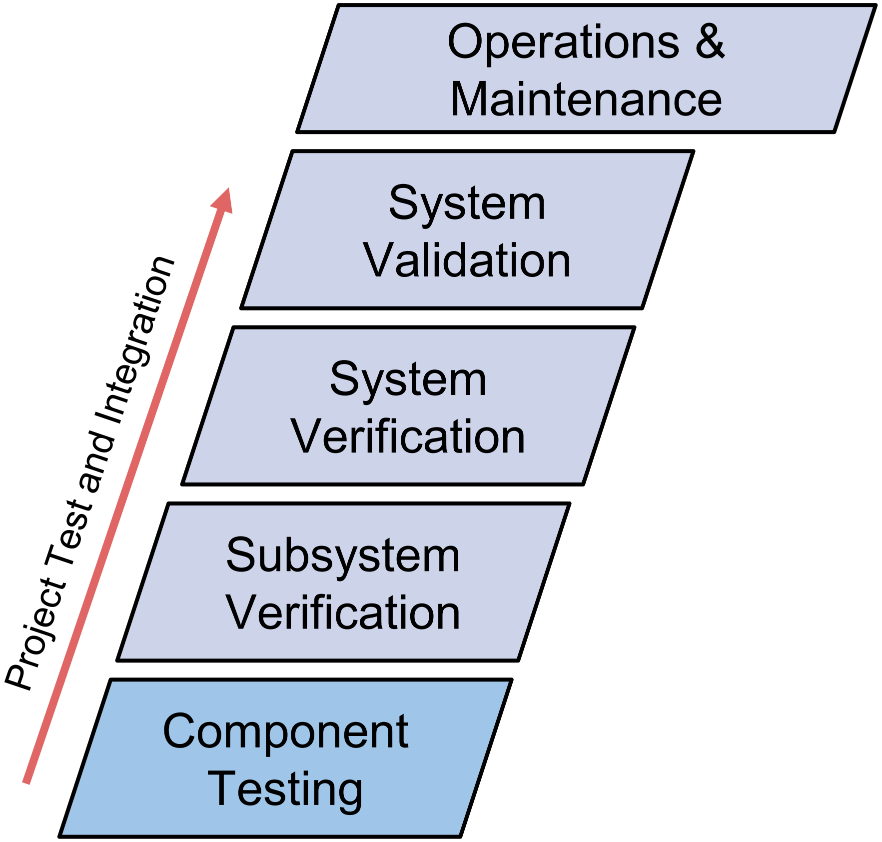
Detailed Design



Component Testing

Key Tests

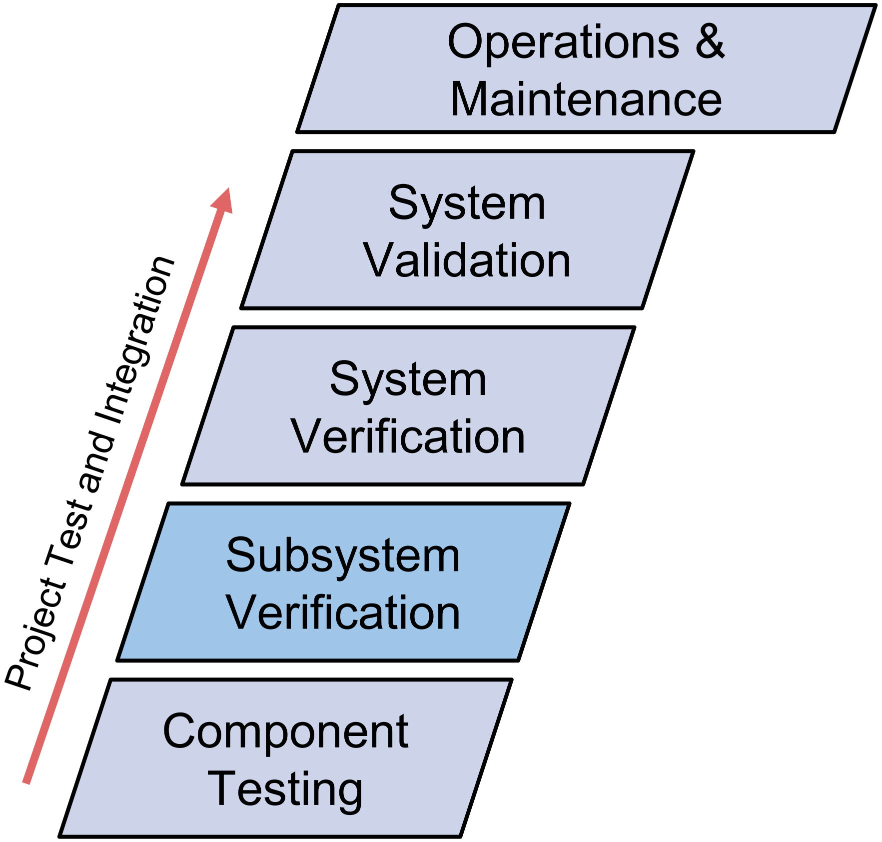
- Sun Sensor
- Thermal Pad Heaters
- Rotating Polarizer Mount



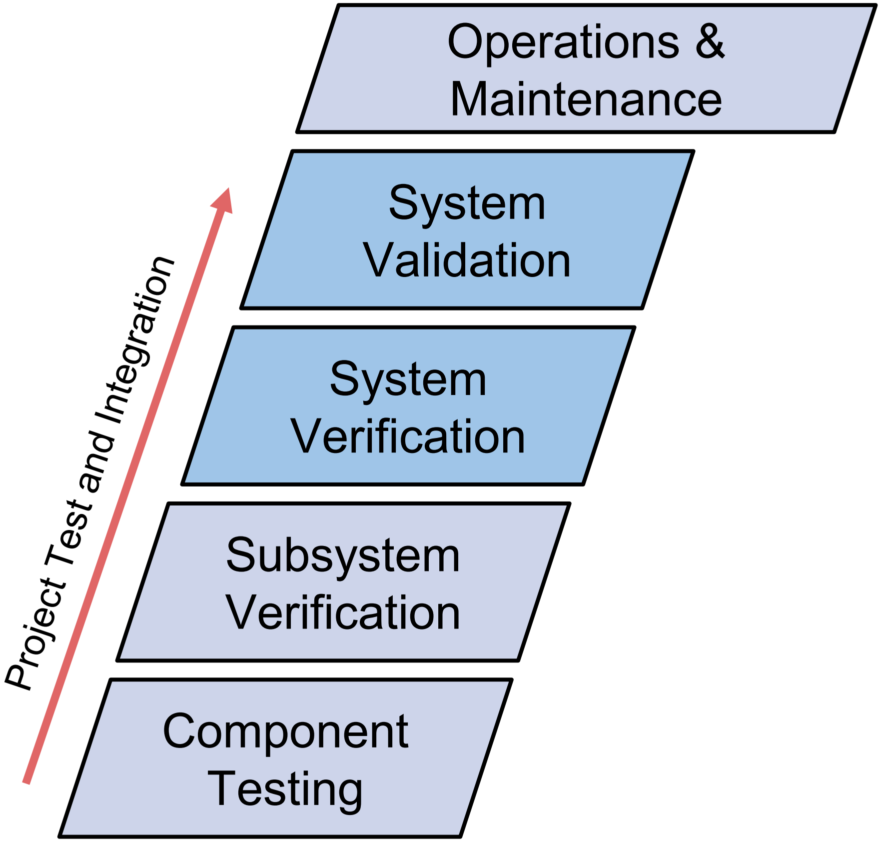
Subsystem Verification

Key Tests

- ADS
  - Sun locating functionality validation and calibration
- EMCS
  - Partial verification
  - Survive -60 °C and 130 Pa environment
- DAQ
  - Data collection and storage



System Verification & Validation



Pointing Control Validation Test

Goals:

- Alignment of optical axis and Sun sensor axis
- Validation of pointing algorithm
- Validation of pointing accuracy
- Characterization of pointing response time

Results:

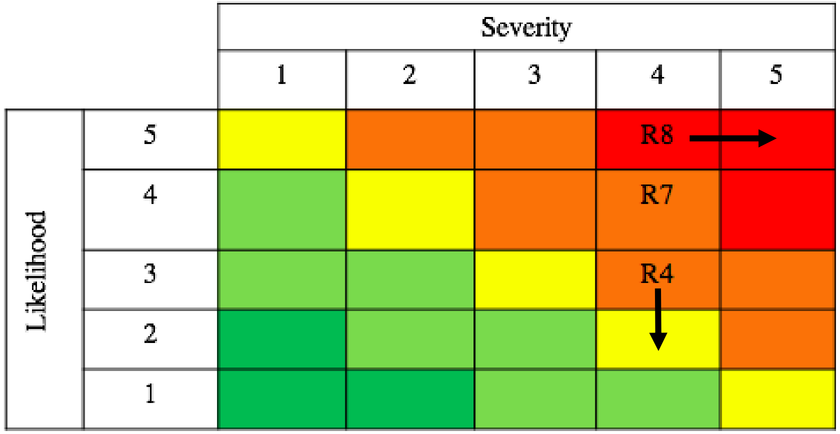
- Incomplete

CDR High Level Risks

Risk	Risk Description	Risk Mitigation
R8	Manufacturing creates pointing precision errors	• High precision machined gimbal mounts • Calibrate errors out in software & machine shop • Contact with AES machining faculty
R7	Manufacturing/Calibration/Test Delays	• Utilize machining, testing and staff resources • Finalize test plans early in Spring Semester • Follow hard timeline
R4	Over-heating of CubeSat Internal Components	• Conduct thorough thermodynamic analysis • Explore use of peltier devices

Types of Risks

☒ Budget
☒ Technical
☐ Safety
☒ Schedule



		Severity				
		1	2	3	4	5
Likelihood	5	🟨	🟧	🟧	🟥 R8 →	🟥
	4	🟩	🟨	🟧	🟧 R7	🟥
	3	🟩	🟩	🟨	🟧 R4 ↓	🟧
	2	🟩	🟩	🟩	🟨	🟧
	1	🟩	🟩	🟩	🟩	🟨

Issues and Challenges

Weather

- Required clear skies for Sommers-Bausch Observatory

Faulty Components

- UDOO x86 became inoperable due to faulty power cable providing incorrect voltage/current
- Motors did not come with specified dimensions
- Motor company applications engineer advertised the units as performing without need for rotational constraint of the lead

Delays

- Environmental chamber access lost due to Graduate projects
- SBO access lost due to Astronomy day
- PCB Manufacturing
  - Lack of funds for fully manufactured PCB
  - Backordered parts
- Changes from UDOO - Raspberry Pi - UDOO

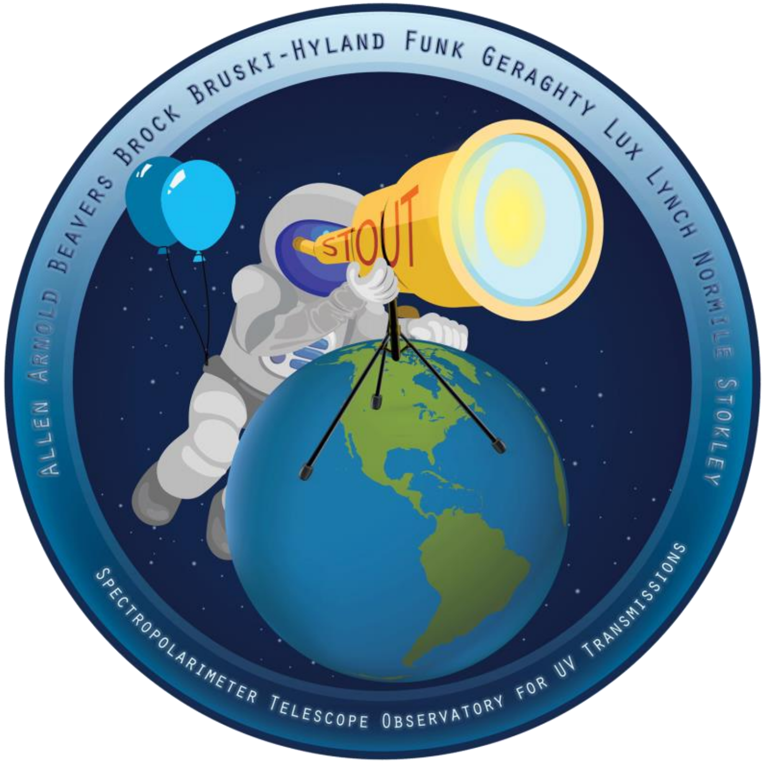
Lessons Learned

Systems Engineering Lessons

- A thorough trade study assists in initial design
- Really assess the feasibility of requirements
- Define more thorough requirements
  - Pointing accuracy requirement was ambiguous
- Scope the project appropriately
- Problems compound quickly
- Keep strong communication with customer

Improvement Strategies

- Monitor/tackle problems with an “Issues” Log
- Include a larger time and budget margin
- Finalize design more during the fall semester



Project Management

Management Process

Approach

- Was hands off, avoided excessive micromanaging
  - Let members determine own work tasks, stepped in to redirect when heading in wrong direction
- Extensive work with most subsystems allowed an understanding of challenges and time requirements

Communication

- 1-2 official full team meetings per week
  - Frequently had more with smaller portions of team
- Primarily used Slack for communication
- Frequent email communications with the customer
- Delivered status updates to customer in the form of a quad chart every 1-2 months

Subsystem Structure

- Every team member was a subsystem lead
- Team members worked across various subsystems when needed
- Leadership roles changes significantly as the year progressed

Management Successes/Difficulties

Successes

- Completed a highly complex project with many moving parts
- Kept team morale high
- Found roles to suite each team member's talents

Difficulties

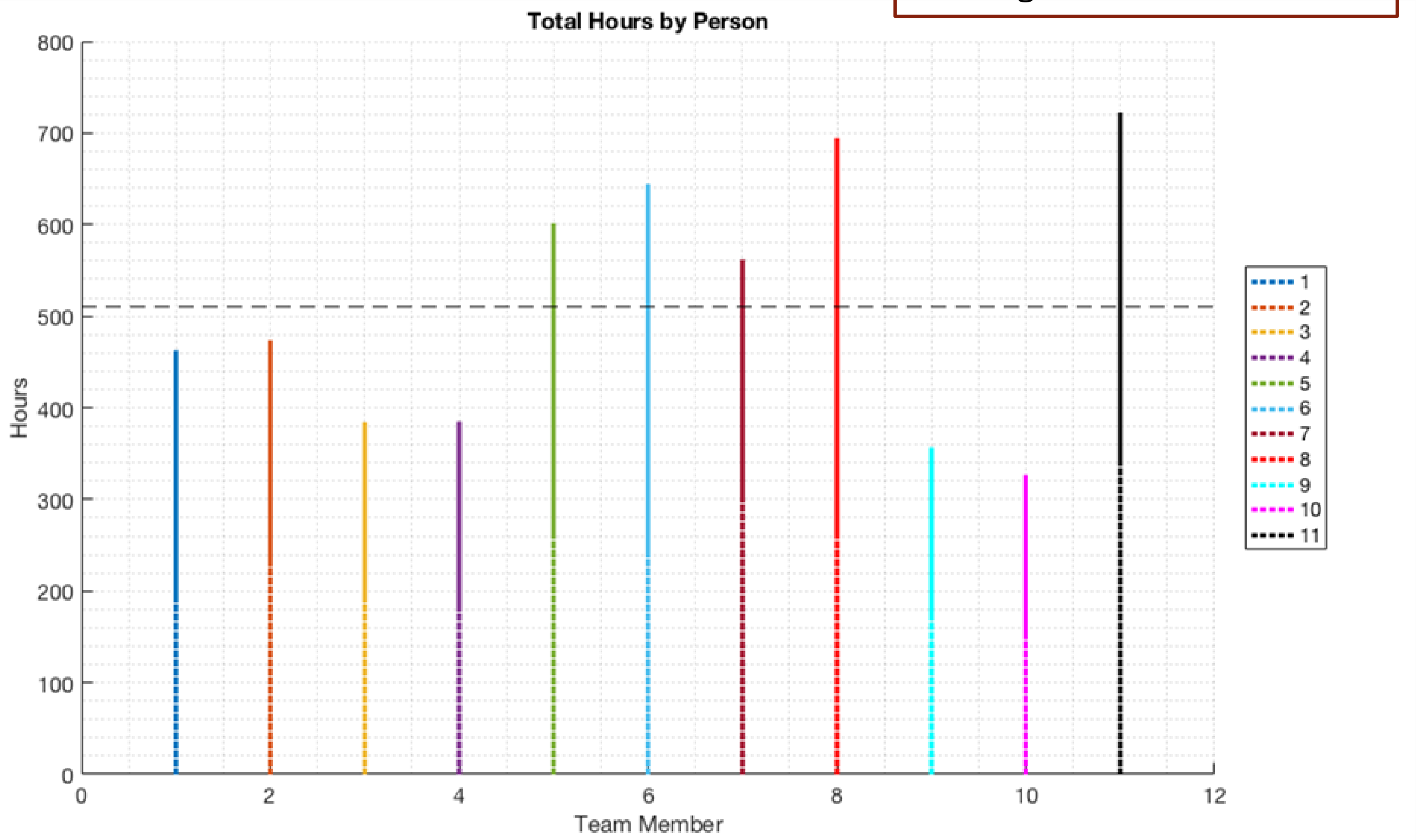
- Maintaining schedules
- Deliverables were completed last minute, need to plan ahead
- Knowing the status of each team member's current work
- Communication across subsystems

Lessons Learned

- Add more margin to timelines, estimates for nearly every task were lowballed, even when they already included substantial margins
- Keep a closer eye on team spending
- Spend less time on technical work and more time managing
  - Man hours lost from team members working on unnecessary tasks without an indication that a new focus was needed
  - Some important tasks needed a better distribution of team member time and expertise

Team Hours

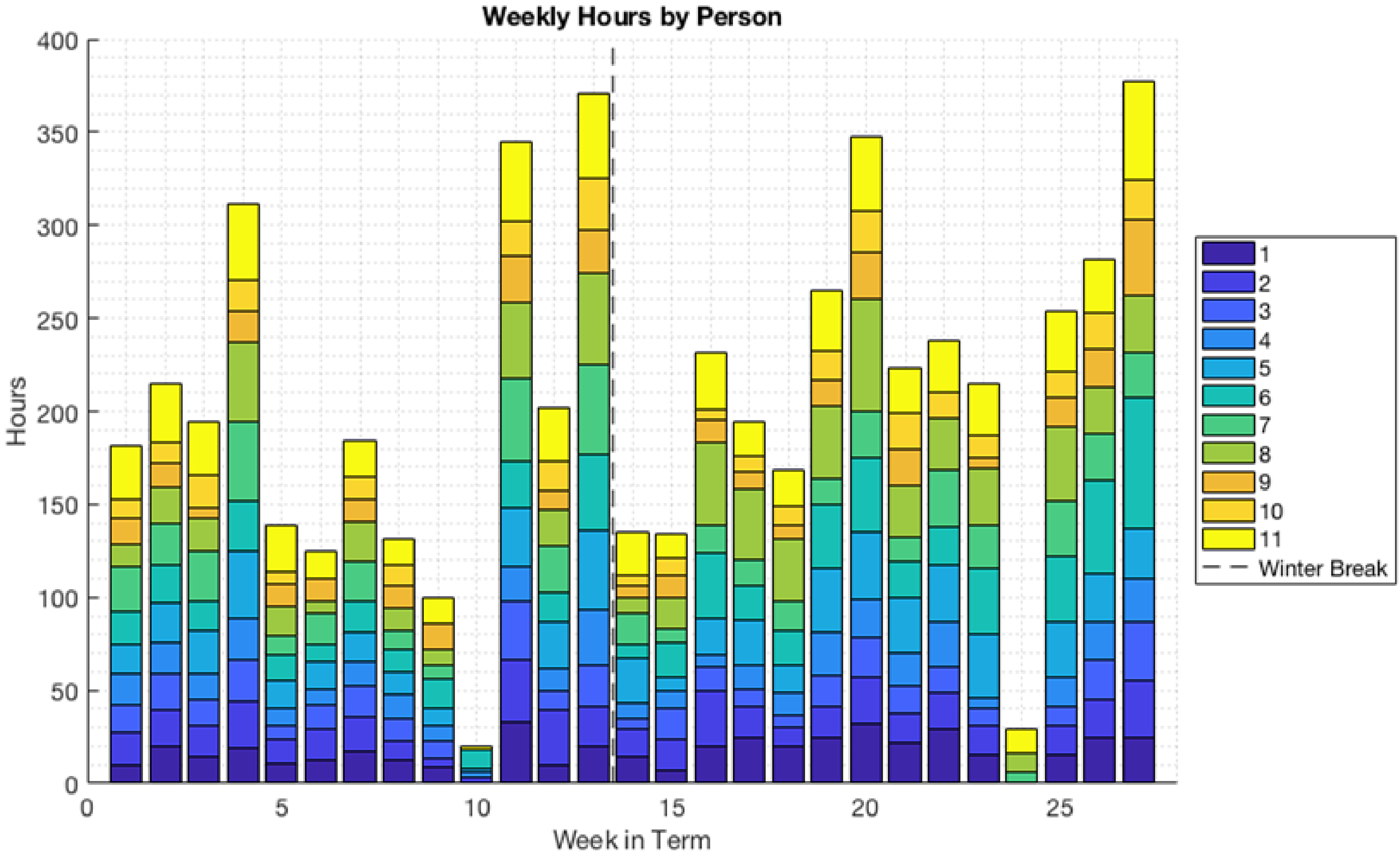
Total hours: 5613.75
Average total hours: 510.34



*Dashed line represents the fall semester, solid line represents the spring semester

Team Hours

Total hours: 5613.75
Average weekly hours: 18.90



CDR Budget vs Current Budget

Subsystem	Projected Cost ($)	Procured ($)	To be Procured ($)	Effect (%)	Effect on Budget ($)
ADS	909.95	909.95	-	0	0
Optics	2,715.49	2,690.87	-	- 0.91 %	- 24.62
Thermal	272.60	378.24	-	+ 38.8 %	+ 105.64
Structure	1,033.27	1,927.14	-	+ 86.5 %	+ 893.87
EPS	162.50	150.92	-	- 7.67 %	- 11.58
System	56.00	94.01	-	+ 67.9 %	+ 38.01
Various	100.00	128.35	50	+ 78.4 %	+ 78.35
Controls	524.60	507.51	-	- 3.37 %	- 17.09
DAQ	429.48	528.35	-	+ 23.0 %	+ 98.97
Totals	**6,203.89**	**7,315.34**	**50**	**+ 18.7 %**	**+1,161.45**

Final Expenditure:	**$7,365.34**
Original Budget:	**$7,377**
Remaining Margin	**$11.66 (0.158 %)**

External Costs: (Customer)	**~$7,000**
Project Cost:	**~$14,365.34**

Equivalent Industrial Cost

Estimate	Cost
CDR	$6,203.89
MSR	$6,181.39
TRR	$6,680.94
SFR	**$7,365.34**

Estimate	Cost
Hours	$5,613.75
Materials	$14,365.34
Overhead	200%
“Industry Cost”	**$569,385.08**

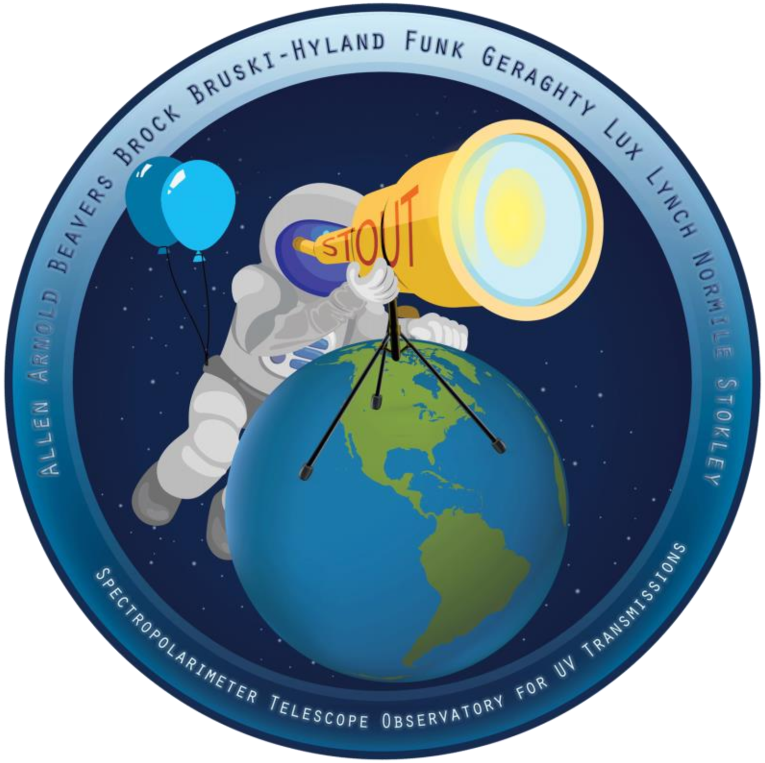
Cost Per Work Hour: $31.25
Determined using yearly wage of $65,000 and average of 2080 hours/year

STOUT

Thank you for listening! We appreciate your feedback.

Are there any questions?

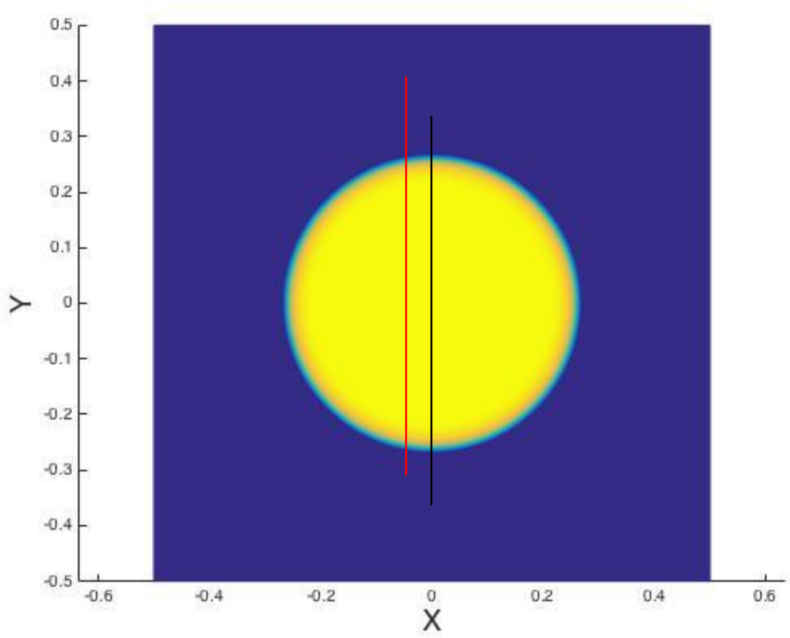
Table of Contents

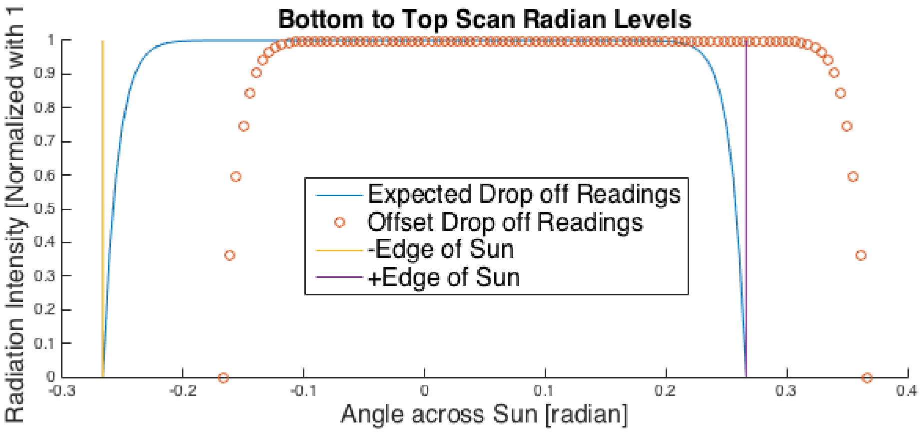


Backup Slides

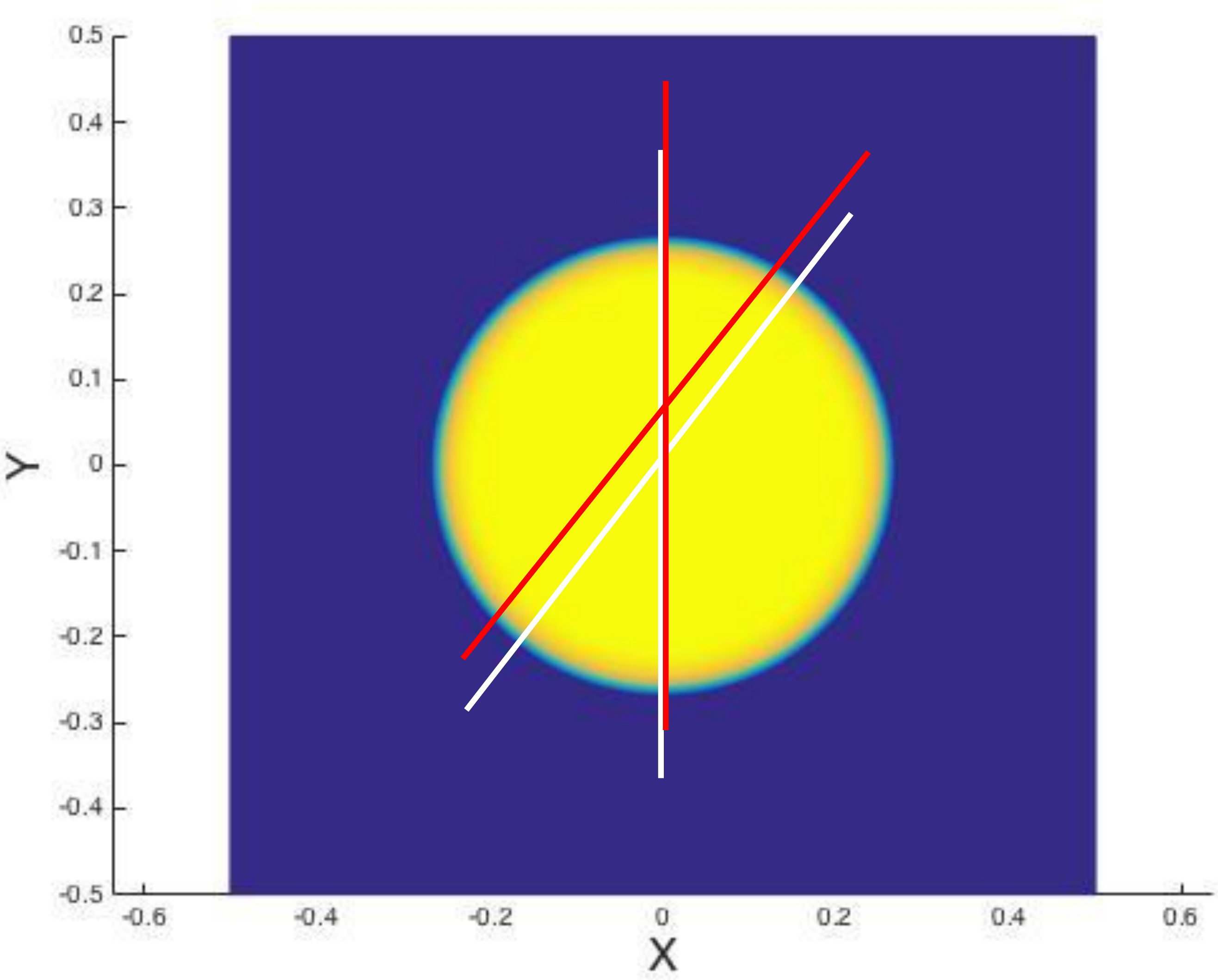
ADS Calibration Model Full Scan Check

- Move ADS FOV center on center of Sun and scan along the black doing full scan
- Verify incoming and outgoing photodiode reading slopes are the same





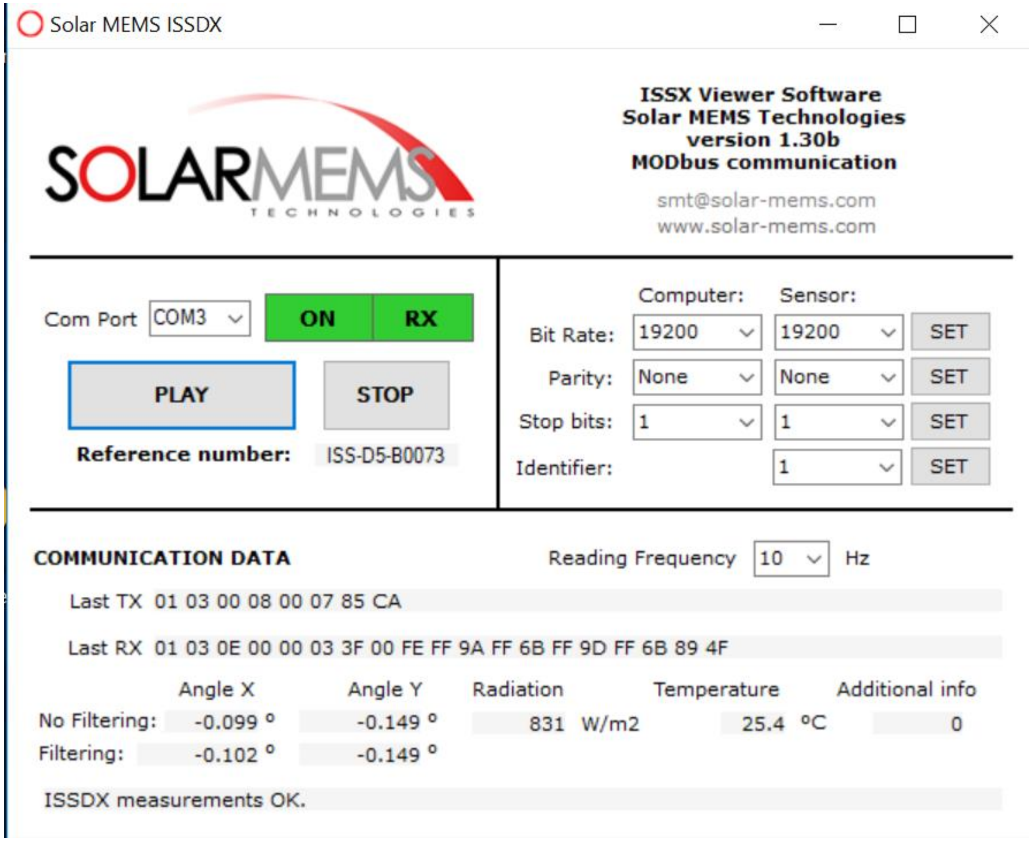
ADS Calibration Model Redundant Pattern



Integration Testing: Sommers-Bausch

ADS Component Verification

- Verify that code converts hexadecimal values from last RX into the angle measurements below



ISSX Viewer Software
Solar MEMS Technologies
version 1.30b
MODbus communication
smt@solar-mems.com
www.solar-mems.com

Com Port: COM3

Reference number: ISS-D5-B0073

	Computer:	Sensor:
Bit Rate:	19200	19200
Parity:	None	None
Stop bits:	1	1
Identifier:		1

COMMUNICATION DATA Reading Frequency 10 Hz

```
Last TX  01 03 00 08 00 07 85 CA
Last RX  01 03 0E 00 00 03 3F 00 FE FF 9A FF 6B FF 9D FF 6B 89 4F
```

	Angle X	Angle Y	Radiation	Temperature	Additional info
No Filtering:	-0.099 º	-0.149 º	831 W/m2	25.4 ºC	0
Filtering:	-0.102 º	-0.149 º			

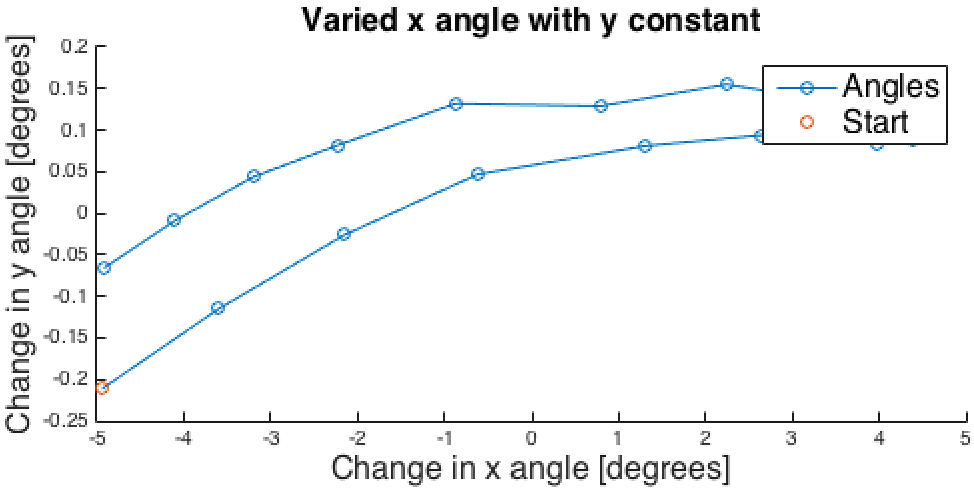
ISSDX measurements OK.

ADS Component Verification

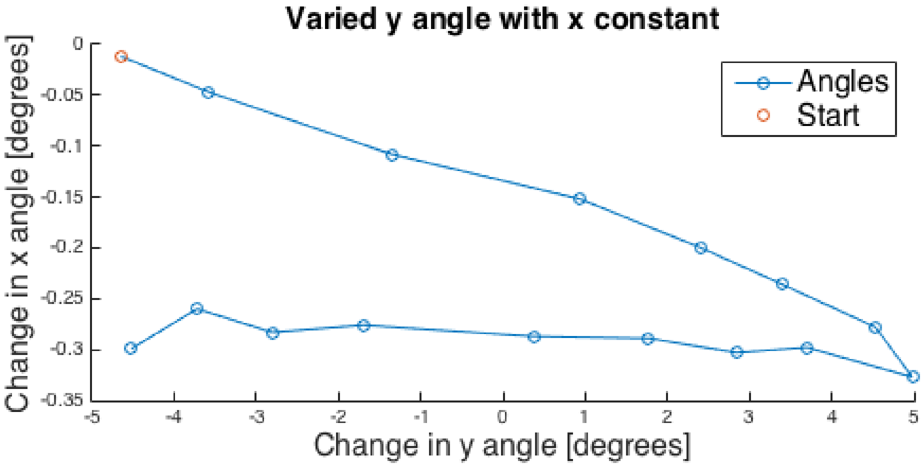
- Check for non-linearities by moving test mount in one dimension from ADS FOV end to end and recording opposite dimension
- Mounting ADS on stable tripod resulted in correction in ADS angle outputting code

ADS Component Verification

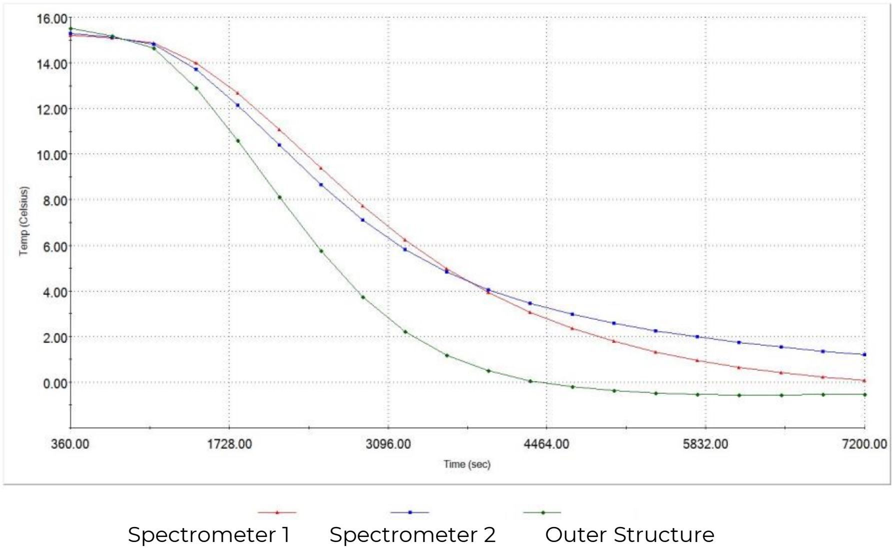
- Move test frame from right to left then back

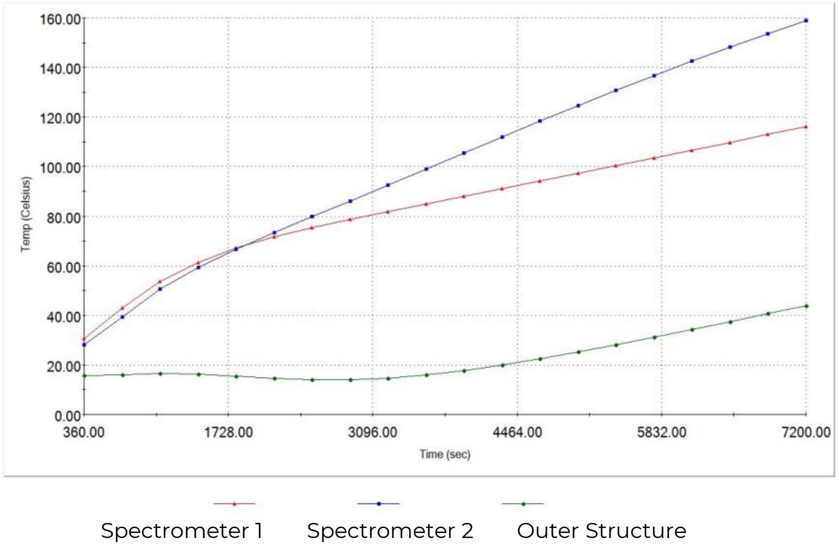


- Move test frame from bottom to top then back

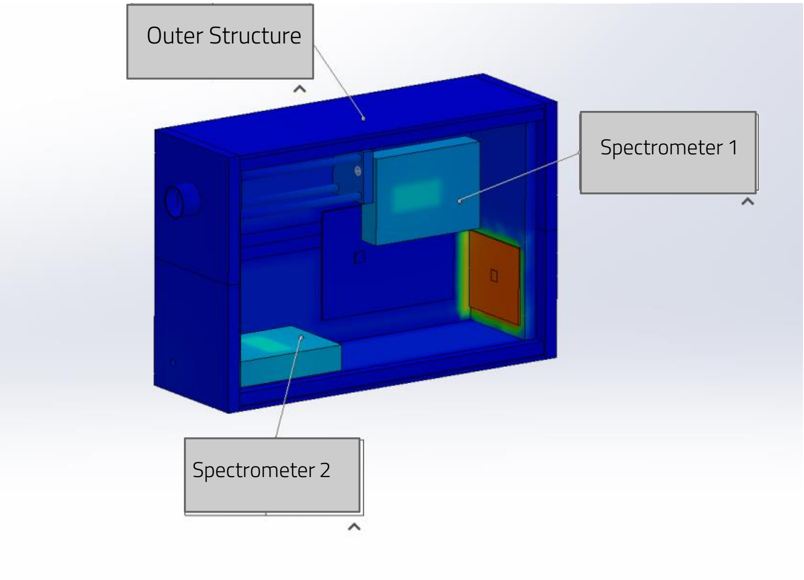


Thermal Simulations: Ascent


Ascent Heaters Off

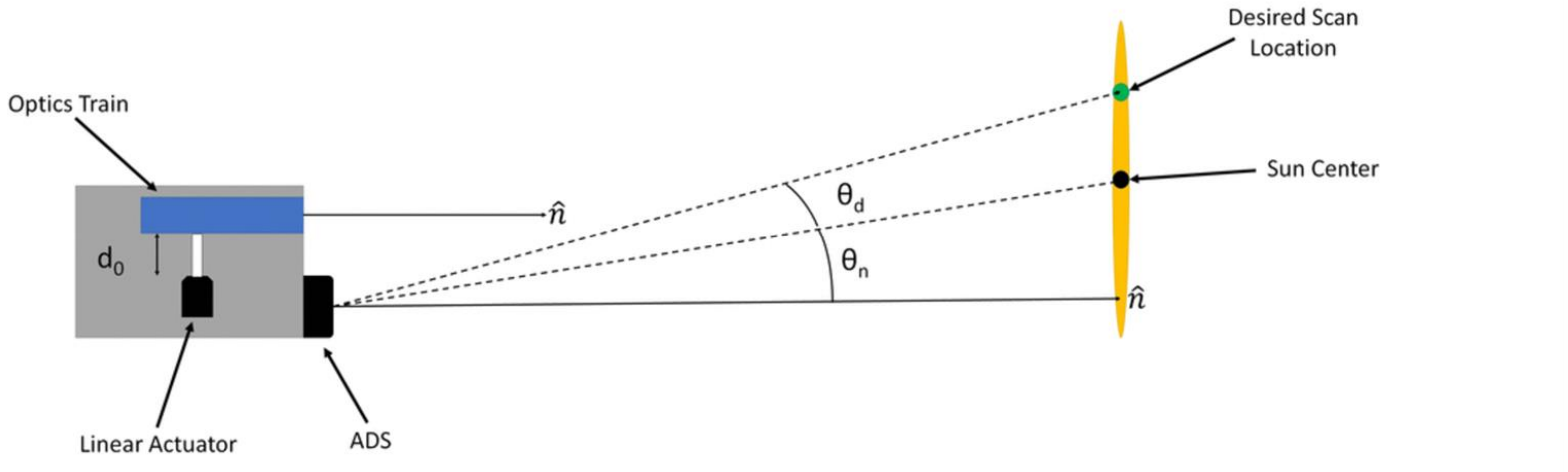

Ascent Heaters On

- ➢ Concerned about spectrometer survival during ascent
- ➢ Two simulations were ran simulating the environmental conditions of ascent; one with heaters on and one with heaters off
- ➢ With active heater control, we will be able to keep spectrometers at survivable temperature

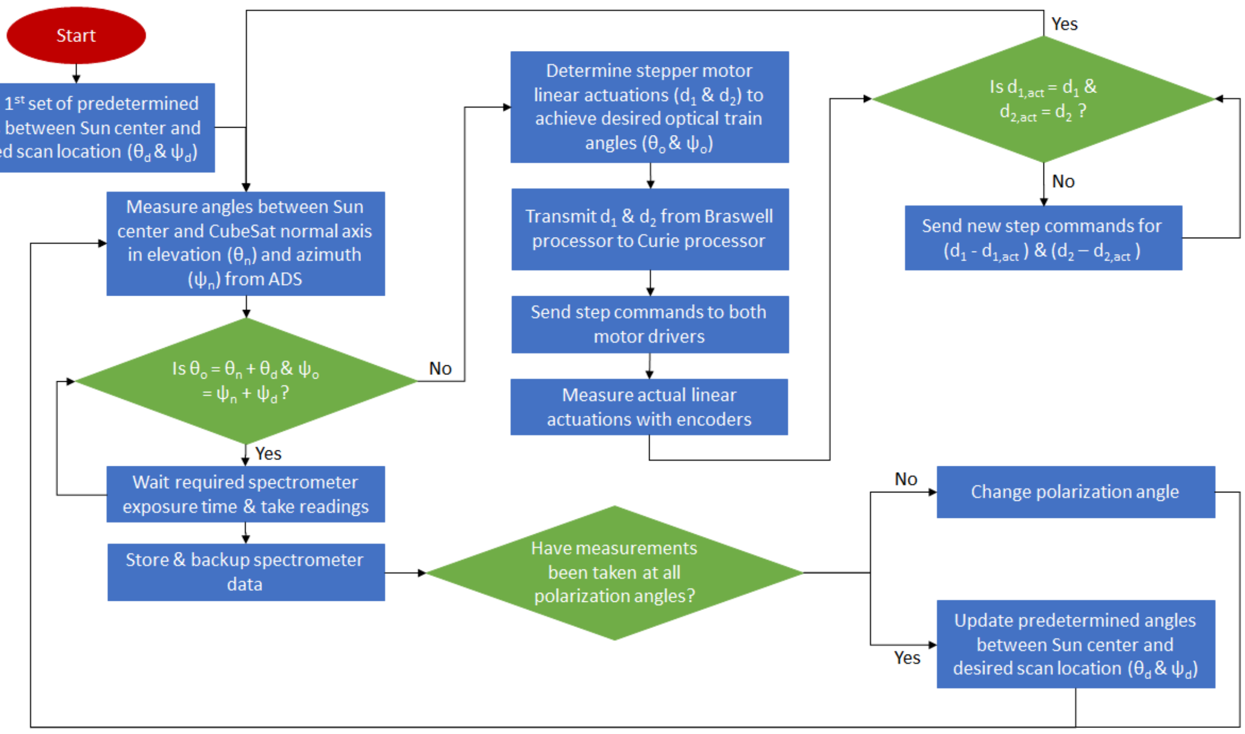


In

Pointing Control: Angle Explanation



Controls Software Flow



Start

Select 1st set of predetermined angles between Sun center and desired scan location (θ_d & ψ_d)

Measure angles between Sun center and CubeSat normal axis in elevation (θ_n) and azimuth (ψ_n) from ADS

Is $\theta_o = \theta_n + \theta_d$ & $\psi_o = \psi_n + \psi_d$?

No

Yes

Determine stepper motor linear actuations (d_1 & d_2) to achieve desired optical train angles (θ_o & ψ_o)

Transmit d_1 & d_2 from Braswell processor to Curie processor

Send step commands to both motor drivers

Measure actual linear actuations with encoders

Is $d_{1,act} = d_1$ & $d_{2,act} = d_2$?

Yes

No

Send new step commands for (d_1 - $d_{1,act}$) & ($d_2 - d_{2,act}$)

Wait required spectrometer exposure time & take readings

Store & backup spectrometer data

Have measurements been taken at all polarization angles?

No

Change polarization angle

Yes

Update predetermined angles between Sun center and desired scan location (θ_d & ψ_d)

Legend

θ: Elevation angles

ψ: Azimuth angles

d: Actuator displacements

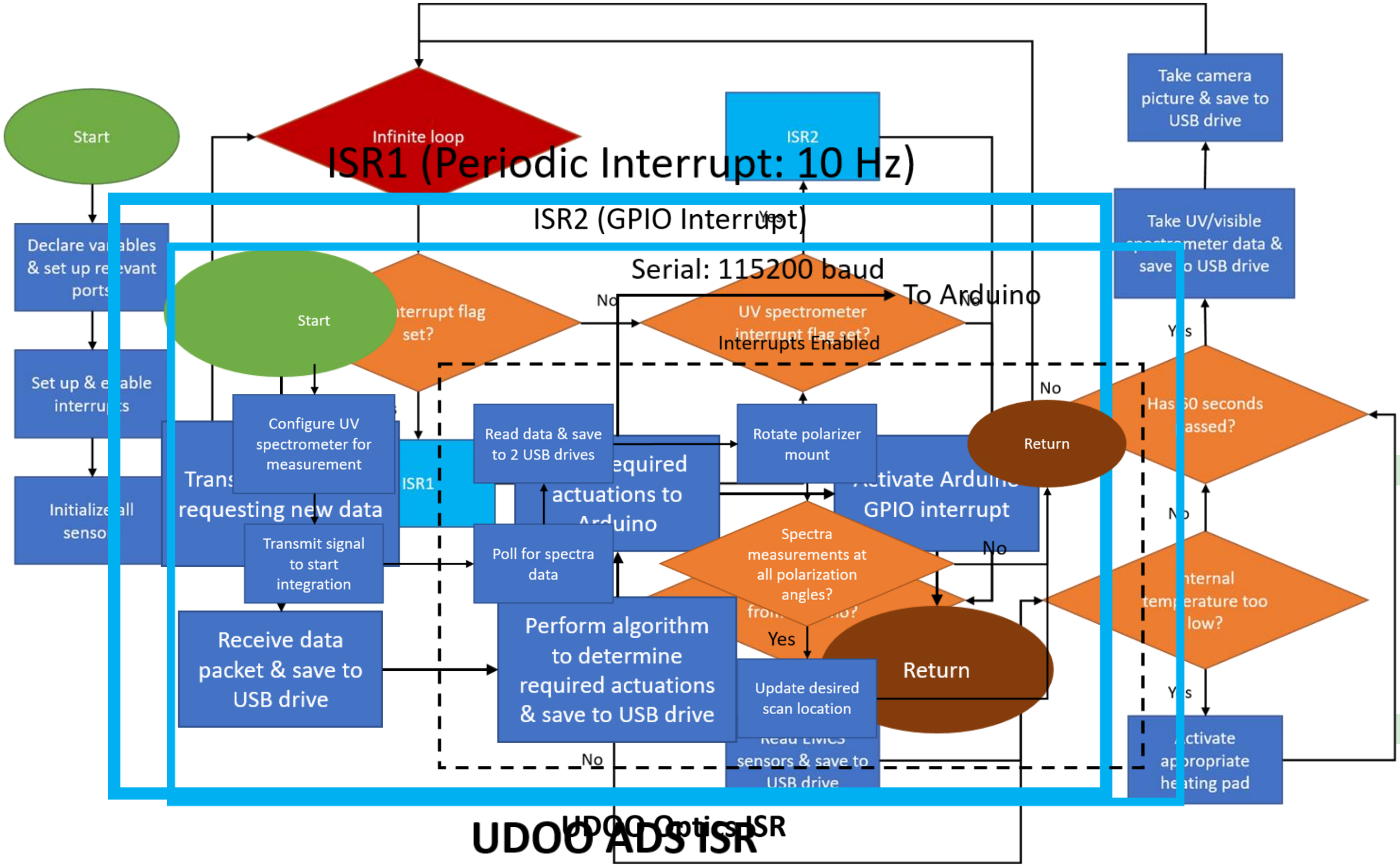
x_d: Angles b/t Sun center & desired scan location

x_n: Angles b/t Sun center & CubeSat normal axis

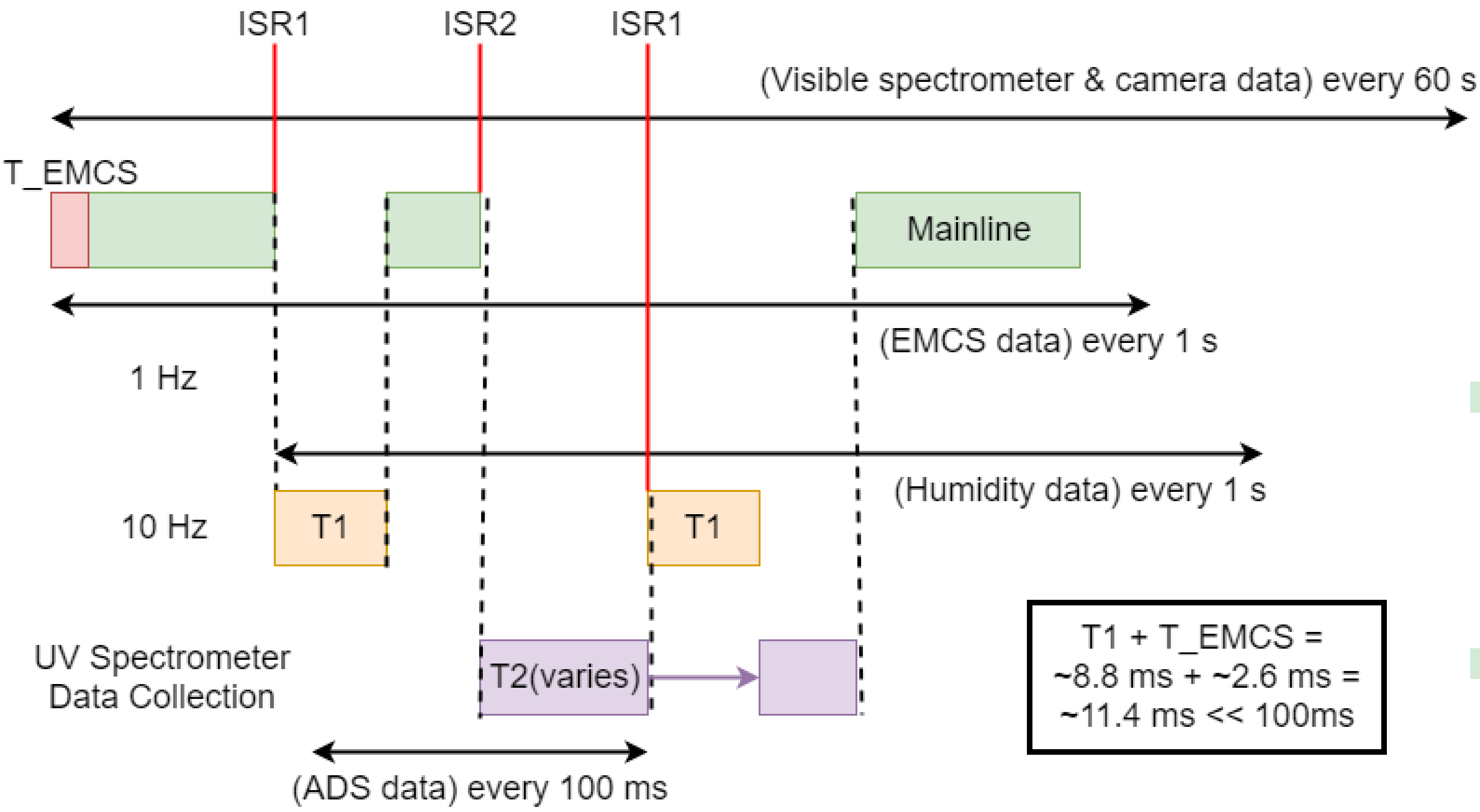
x_o: Angles b/t optical axis & CubeSat normal axis

x_{act}: Actual, measured value

Software Flow: Single-Board Computer

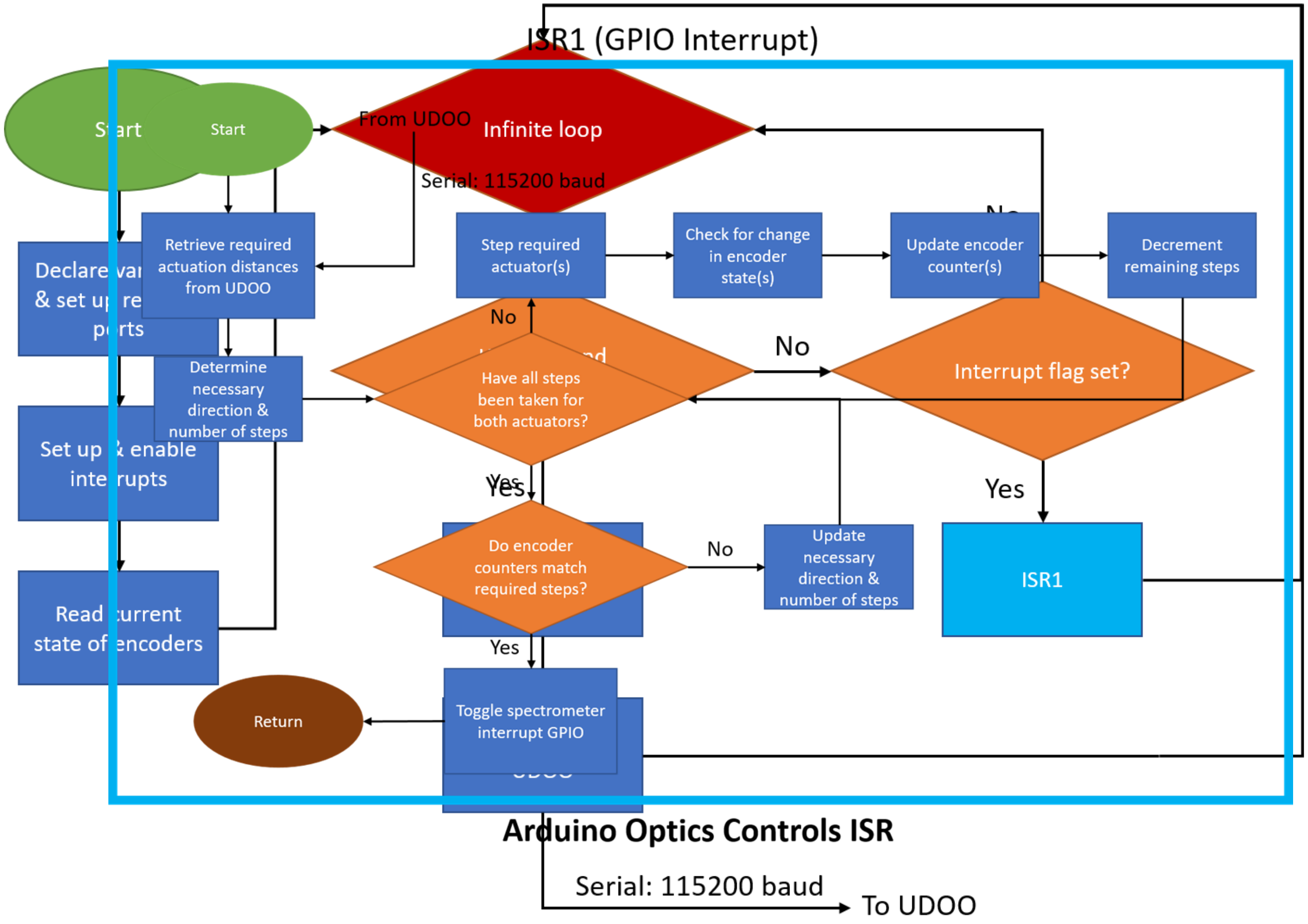


Software Timing: Single-Board Computer

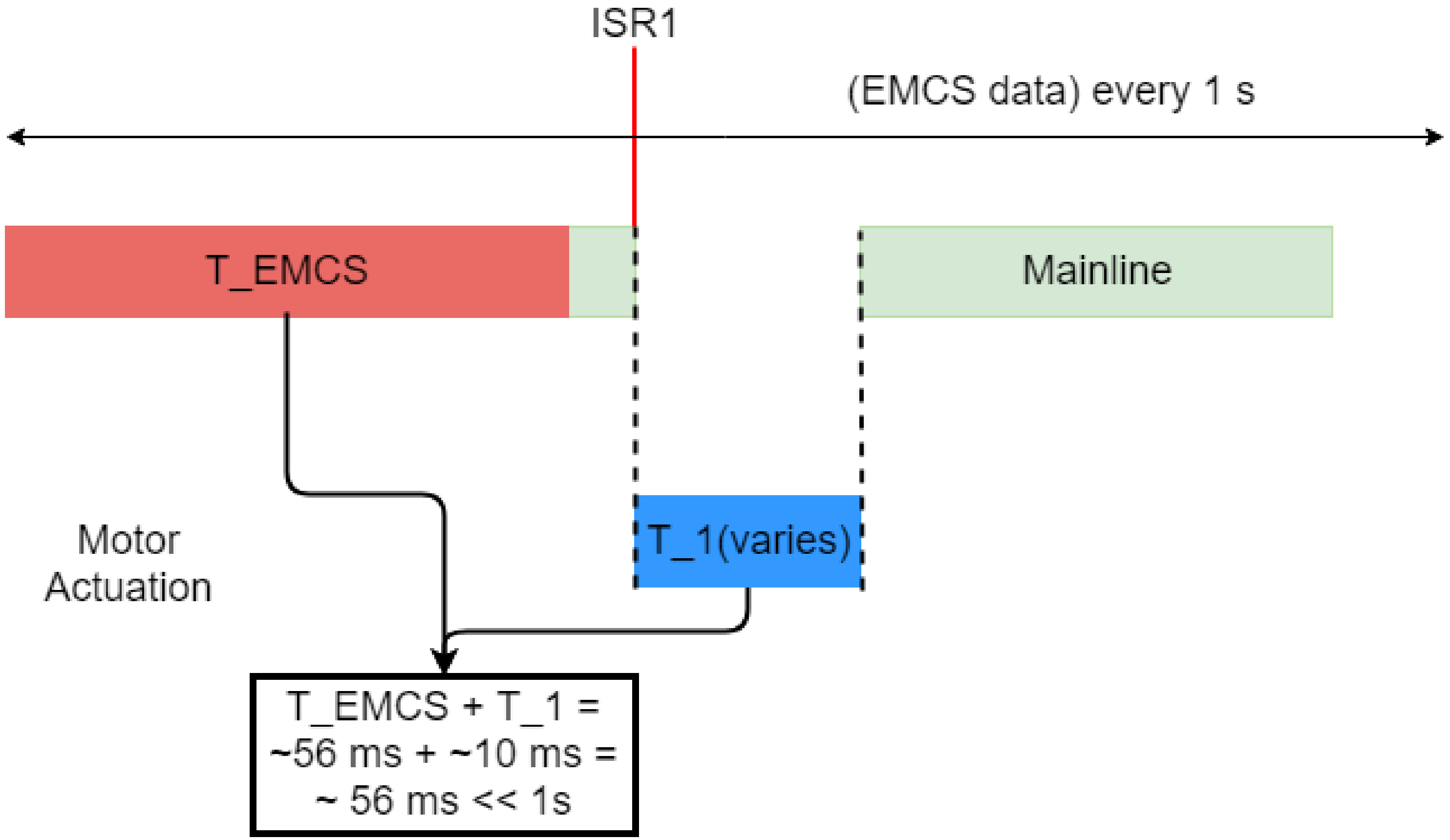


T1 + T_EMCS =
~8.8 ms + ~2.6 ms =
~11.4 ms << 100ms

Software Flow: Microcontroller



Software Timing: Microcontroller



ISR1

(EMCS data) every 1 s

T_EMCS

Mainline

T_1(varies)

Motor Actuation

T_EMCS + T_1 =
~56 ms + ~10 ms =
~ 56 ms << 1s

Software Path Forward

- Continue code development
  - UDOO (Linux) interrupts
  - Sensor interfaces
  - Watchdog timer
- Begin testing
  - Sensor unit tests
  - Controls tests
  - Timing evaluation
  - System tests

Most challenging to complete

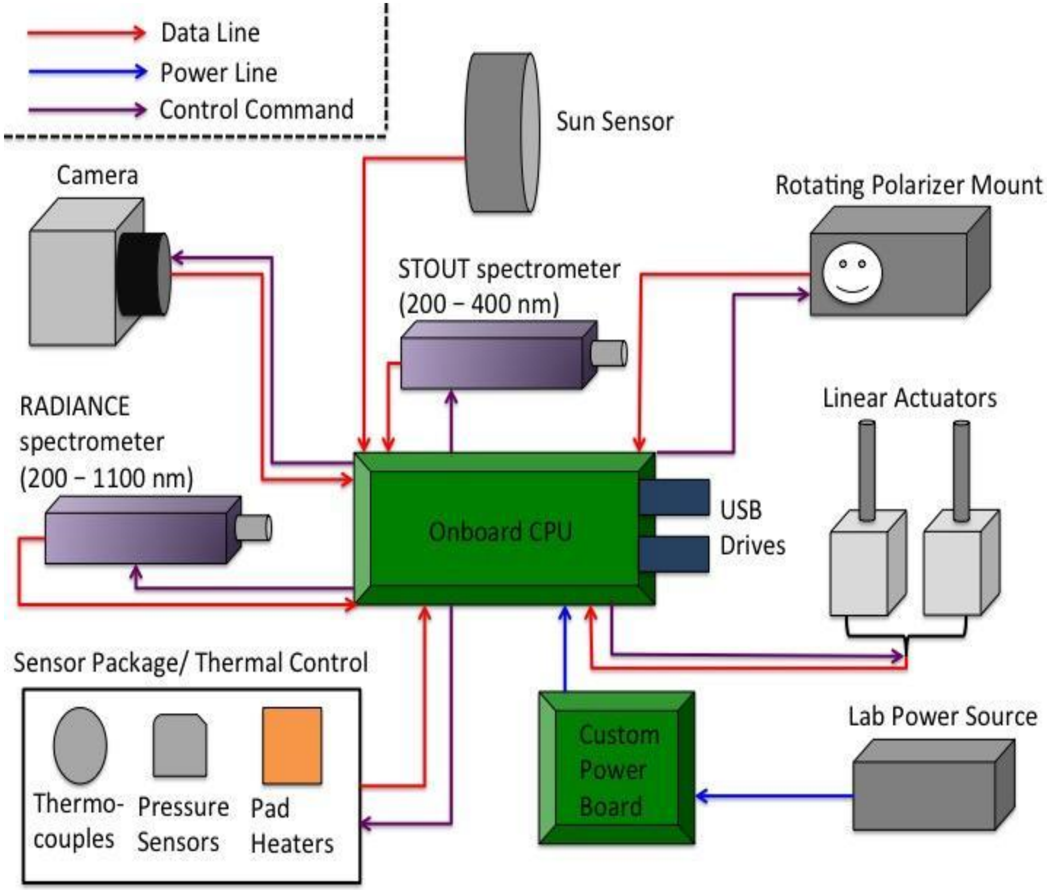
PCB Test Results

Test	Input (V)	Expected (V)	Measured (V)
29 - 28 V	29.0	28.0	28.06
28 - 12 V	28.04	12.0	In Progress
12 - 5 V	12.0	5.0	In Progress
5 - 3.3 V	5.0	3.3	In Progress

FlatSat Test

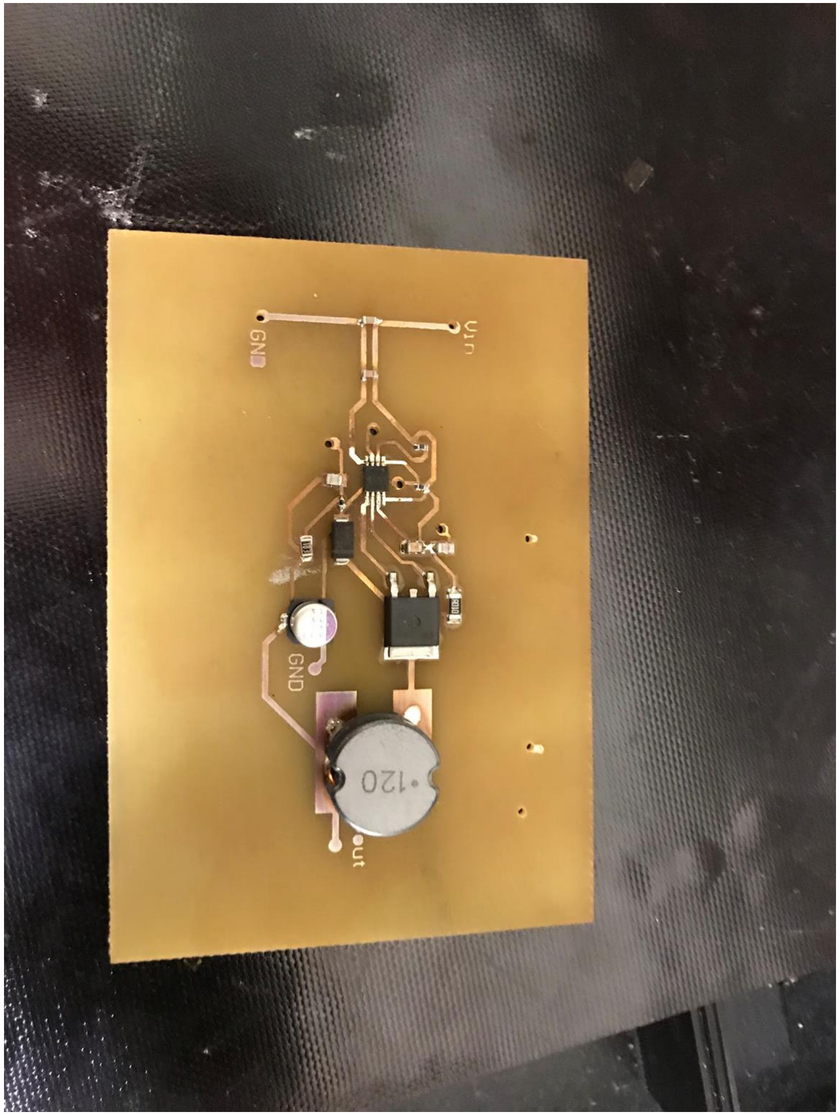
- **Purpose:** Determine that all of the components integrate and operate functionally
- **Procedure**
  - Integrate electronics outside of the CubeSat structure
  - Verify expected voltages and currents with a multimeter
  - Calculate and verify expected power draws

Simplified FlatSat Test Connections



Integration Testing: Environmental

PCB: Lessons Learned



- Surface-mount parts rather than through-hole
- Separate PCB for prototypes needed rather than simply breadboarding
- Hard to troubleshoot
- PCB size reconfiguration

EPS Path Forward

- Converter prototype troubleshooting and testing
- PCB redesign for size (concurrent)
- Flatsat testing
- Order PCB
- PCB unit testing and troubleshooting
- Flatsat PCB

PCB Converter Pin Voltages

Converter	Pin	Expected Voltage	Actual Voltage
29-28	1	29.0	29.07
	2	1.75	1.724
	3	1.25	0.00
	4	0.00	0.00
	5	29.0	29.11
	6	21.3	21.19
	7	21.3	21.19
	8	29.0	29.11

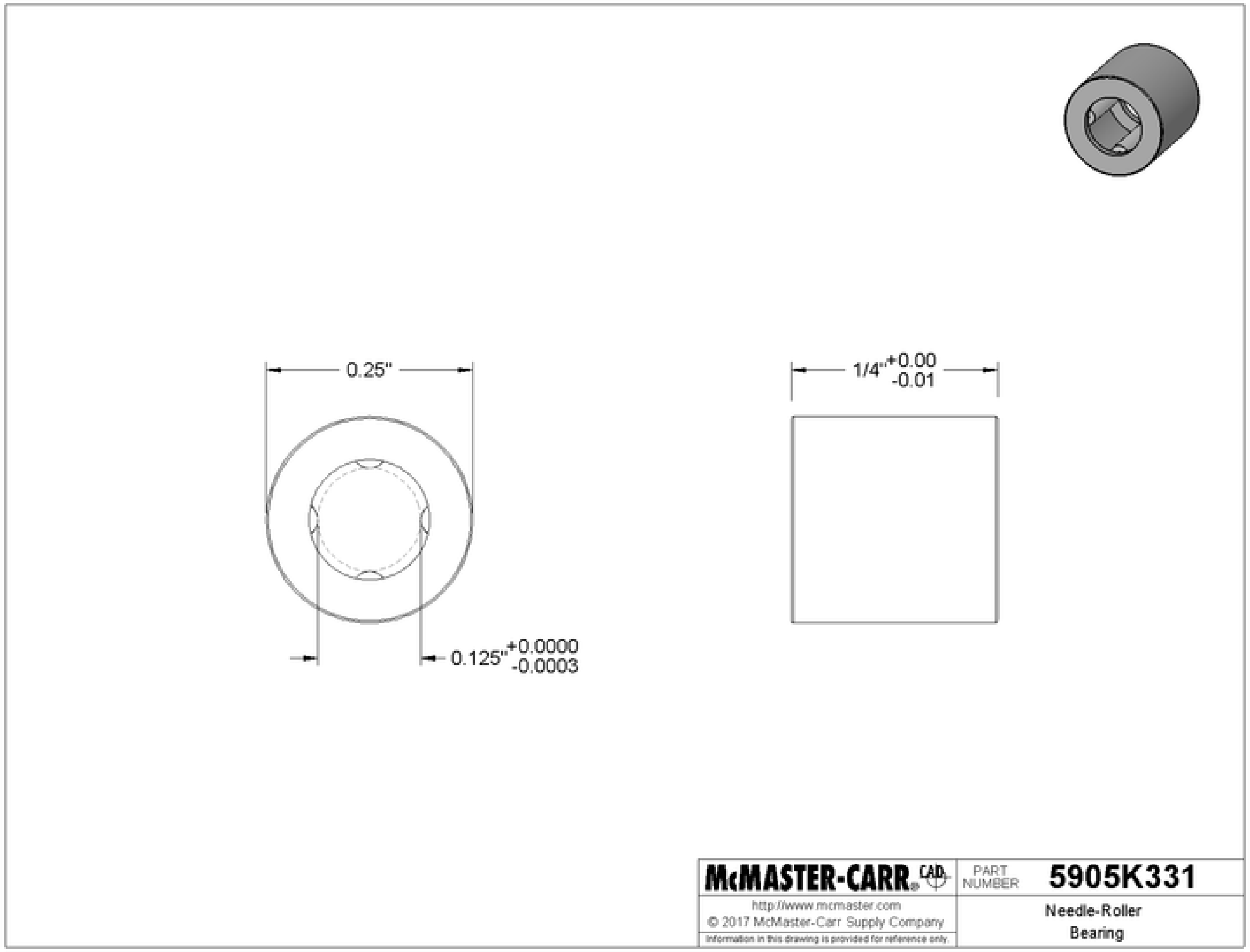
PCB Converter Pin Voltages

Converter	Pin	Expected Voltage	Actual Voltage
28-12	1	28.0	28.00
	2	1.75	1.986
	3	1.25	0.006
	4	0.00	0.00
	5	28.0	28.06
	6	20.3	20.18
	7	20.3	20.18
	8	28.0	28.06

Needle Roller Bearing Specs

Parameter	Values
Shaft Diameter	⅛”
Width	¼”
Width Tolerance	-0.01-0”
Shaft Tolerance	-0.0003-0”

Needle Roller Bearing CAD



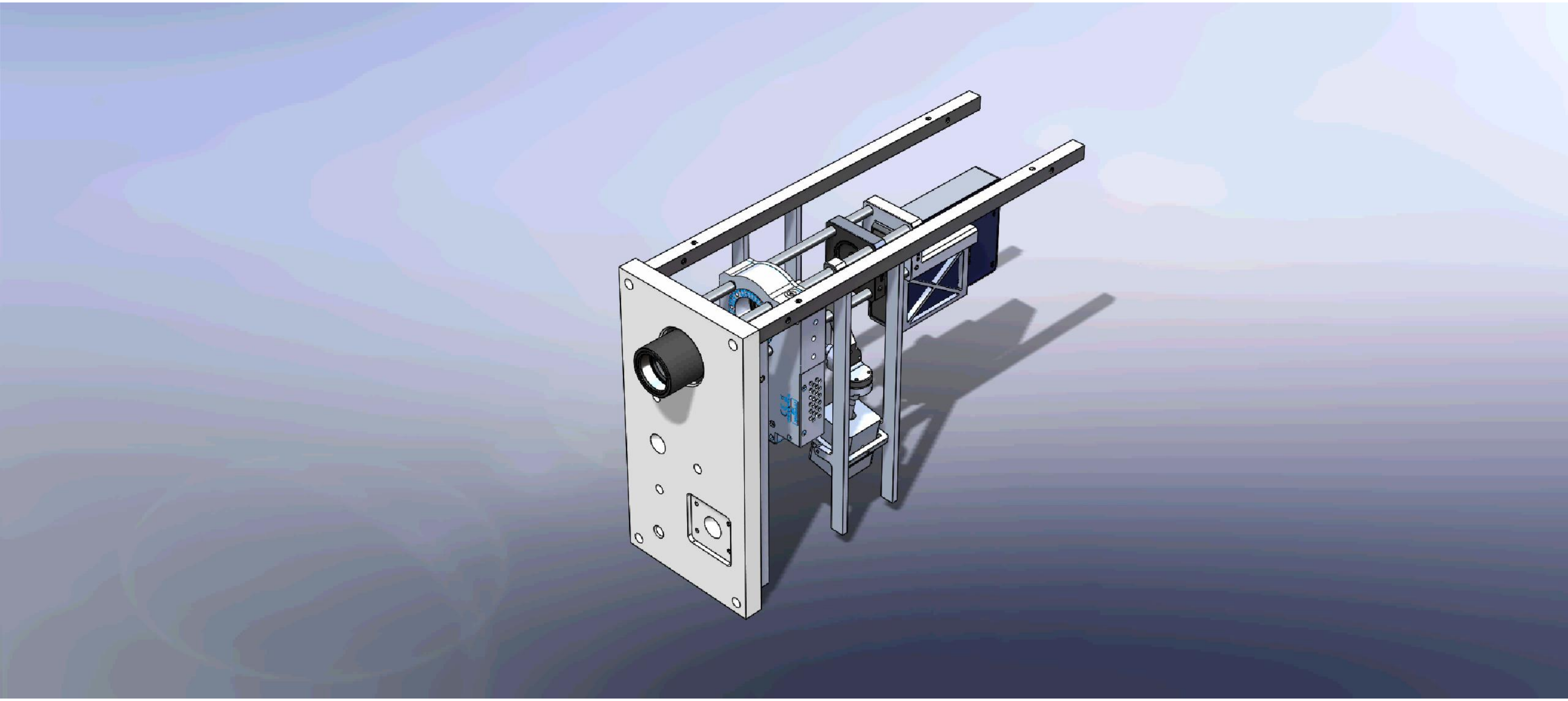
Mainline Time Requirements							
Process	Data Size [B]	Quantity	Read Time [ms]	Write Rate [MB/s]	Interrupt Time [ms]	Subtotal [ms]	
Internal Temp.	2	7	2.5	120	0	17.50011667	
External Temp.	4	2	2.5	120	0	5.000066667	
Pressure	3	1	8.22	120	0.5	8.720025	
Camera	600000	1	15	120	0	20	
Polarizer	0	1	1	120	0	1	
Spectrometer - Visible	10000	1	0.17	120	0	0.2533333333	
					Total:	52.47354167	
ISR1 (ADS)							
Operation	Data Size [B]	Comm. Rate [B/s]	Subtotal [ms]				
Request ADS Data	16	14400	1.111111111				
Wait for Data	0	0	5				
Write ADS Data to USB	16	14400	1.111111111				
Calc. Required Actuation			1				
Send Actuation (Serial)	8	14400	0.5555555556				
Arduino Interrupt			0				
		Total:	8.777777778				

Integration Testing: Sommers-Bausch

ISR2 (Spectrometer)							
Operation	Data Size [B]	Comm. Rate [B/s]	Subtotal [ms]				
Config. Spectrometer			0				
Signal Measurement			0				
Spectrometer Exposure			300		Not included in total		
Spectrometer Sampling			3				
Data Transmission			4.6				
Save Data (2x)	20000	120000000	0.1666666667				
		Total:	0.1666666667				
ISR3 (Humidity)							
Operation	Data Size [B]	Comm. Rate [B/s]	Subtotal [ms]		**Main Total:**	**61.69579722**	**ms**
Grab Humidity Data	4	14400	0.2777777778		**Max Allowable Total:**	**100**	**ms**
Save Data	4	120000000	0.00003333333333				
		Total:	0.2778111111				

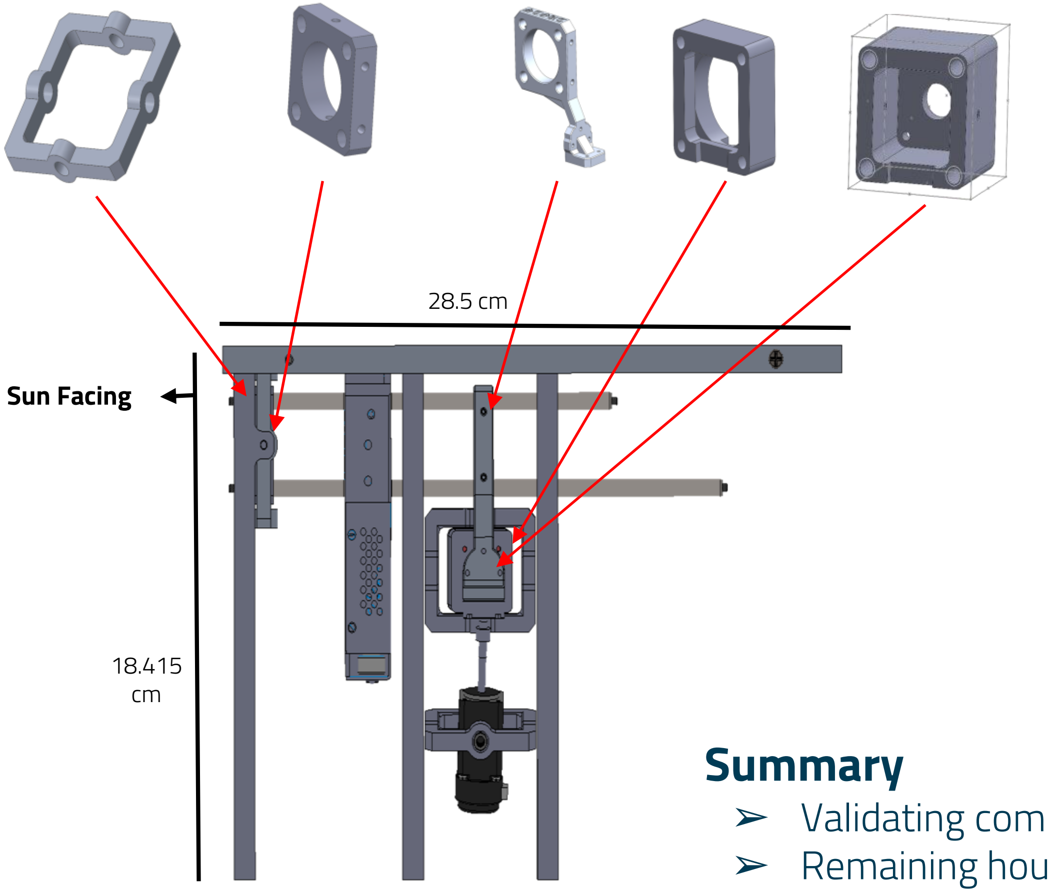
Integration Testing: Sommers-Bausch

Pointing Control: Animation



Controls Components

Box Gimbals (x3)**	Front Inner Gimbal**	Pusher Arm**	Back Motor Mounts (x2)*	Front Motor Mounts (x2)*	Spherical Rolling Joints (x2)	Gimbal Rolling Joints (x14)	Gimbal Axles (x12)	Hours Remaining: 0 (20% Margin)



Side View

Legend

Not Started

* - CAM/CNC Production

In Progress

** - 3D Print Production

Completed & Not Validated

Procured

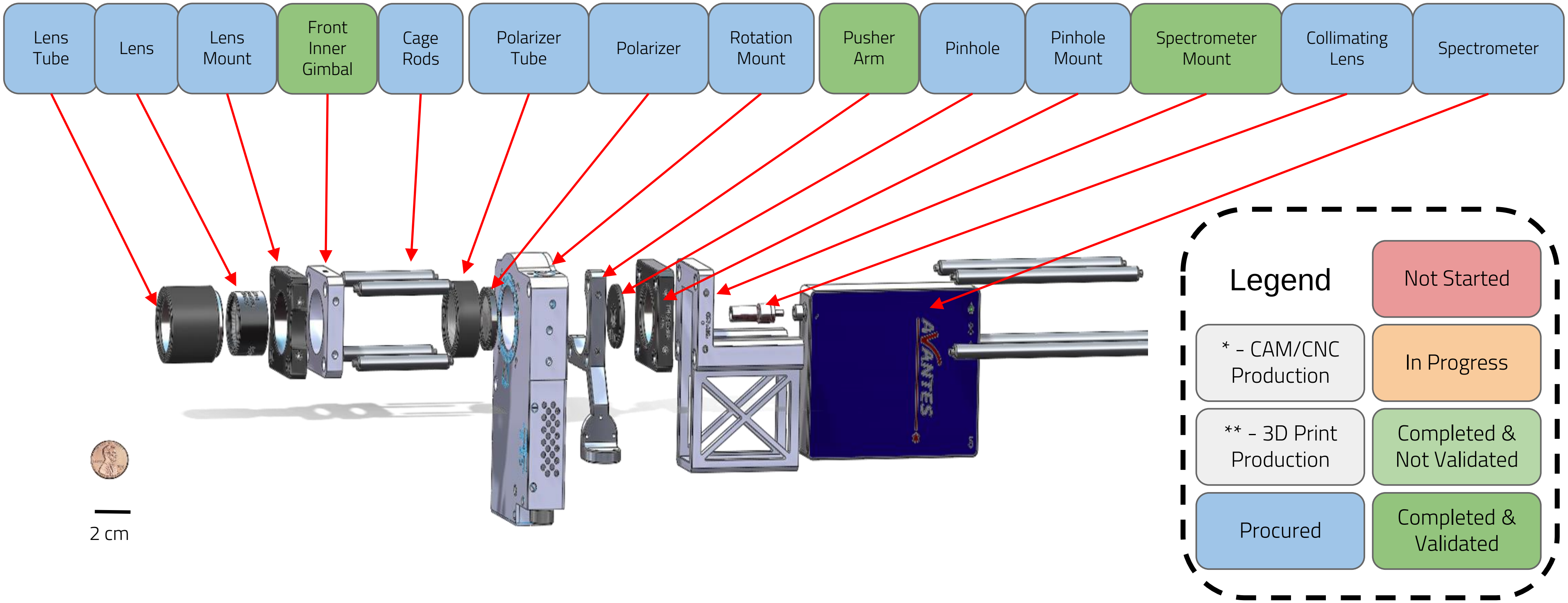
Completed & Validated

Summary

- ➢ Validating completed parts is a priority
- ➢ Remaining hours allocated to validating manufactured parts and finishing front motor mounts

Optics Components

Hours Remaining: 12 (20% Margin)



Legend

- 🟥 Not Started
- * - CAM/CNC Production
- 🟧 In Progress
- ** - 3D Print Production
- 🟩 Completed & Not Validated
- 🟦 Procured
- 🟩 Completed & Validated

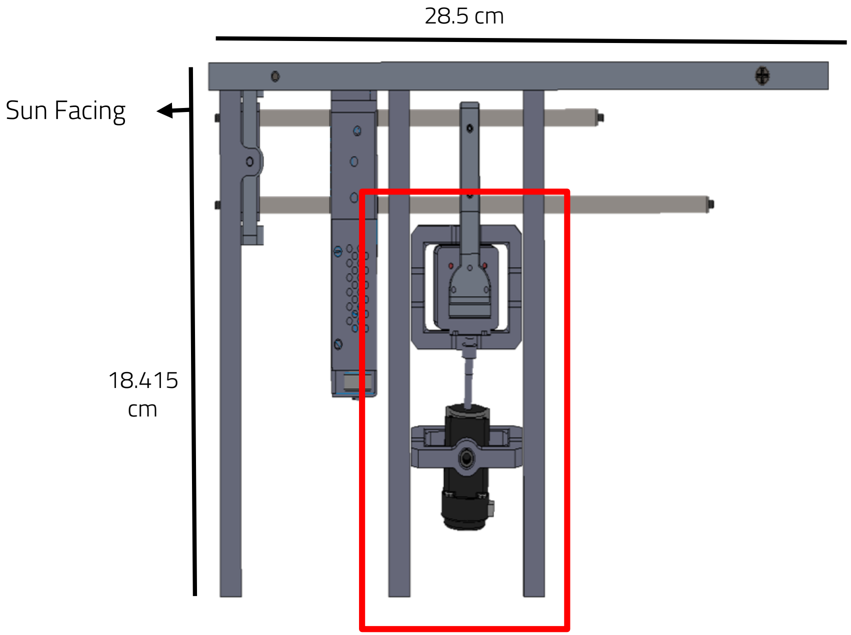
Summary

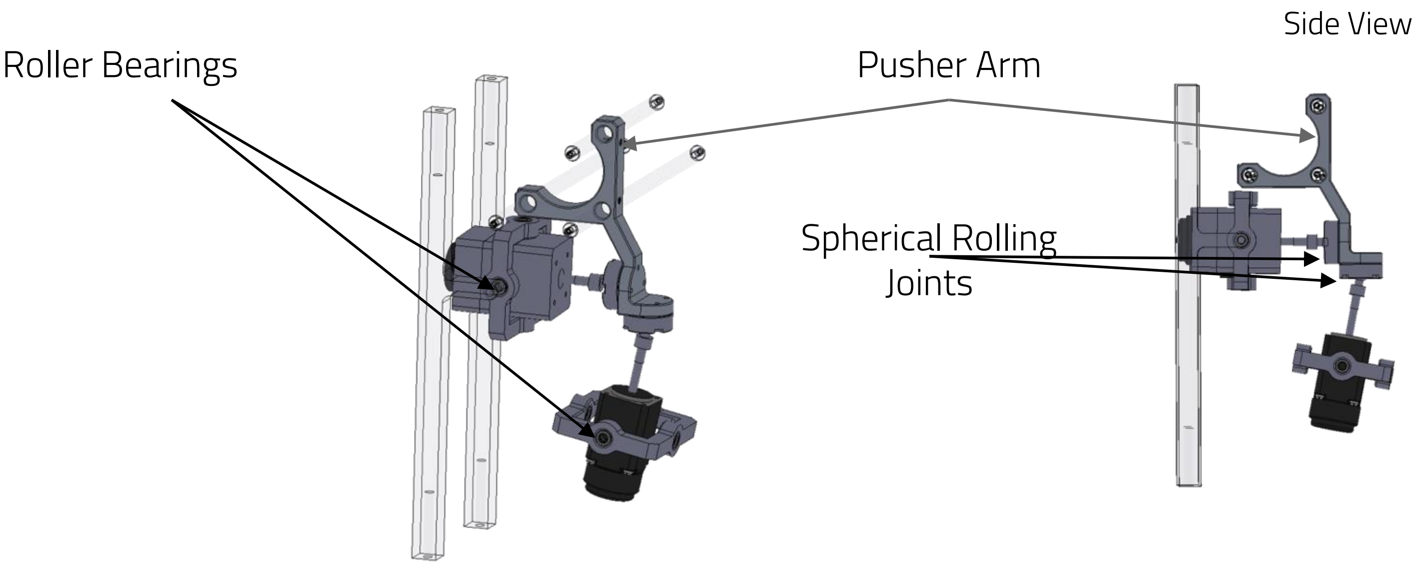
- ➢ Optics must still be assembled
- ➢ Need to validate 3D printed components to prevent breaking
- ➢ Remaining hours account for threading 3D printed parts and precise pinhole alignment, actual assembly will take ~3 hours

Critical Parts

Gimbal Assembly

- McMaster-Carr Needle Roller Bearings
- Pusher Arm
- Spherical rolling joints





Integration Testing: Sommers-Bausch

Critical Parts

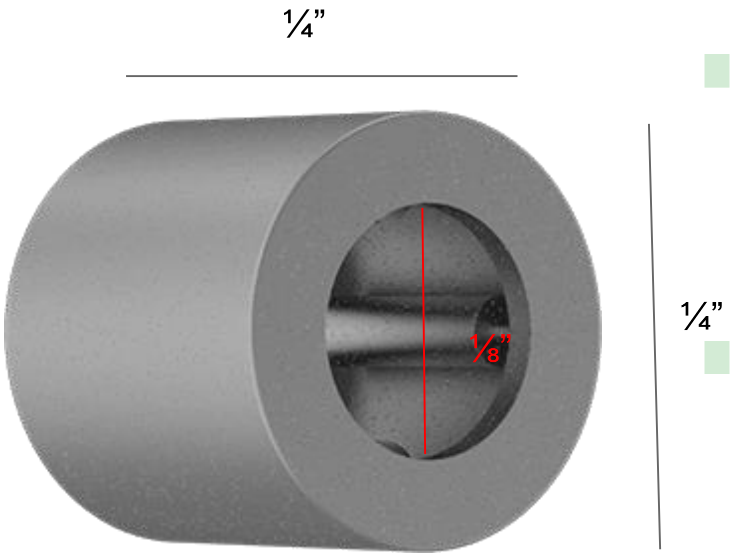
Needle Roller Bearing

Possible Issue(s):

- ➢ Bearing slack leads to inaccuracies in pointing angle

Solution(s):

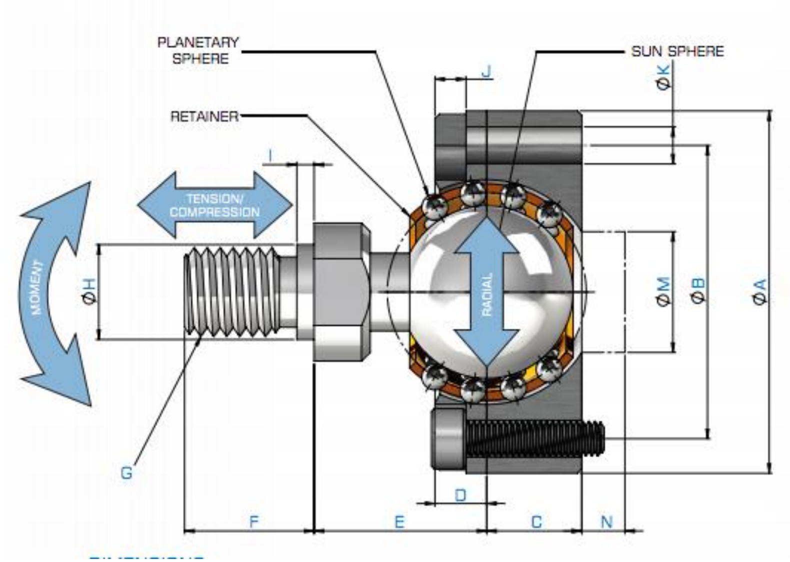
- ➢ Undersized gimbal holes
- ➢ Press fit into each gimbal
- ➢ Oversized pin press fit into bearing
- ➢ Minimizes bearing slack
- ➢ Manufacturing inaccuracies calibrated out

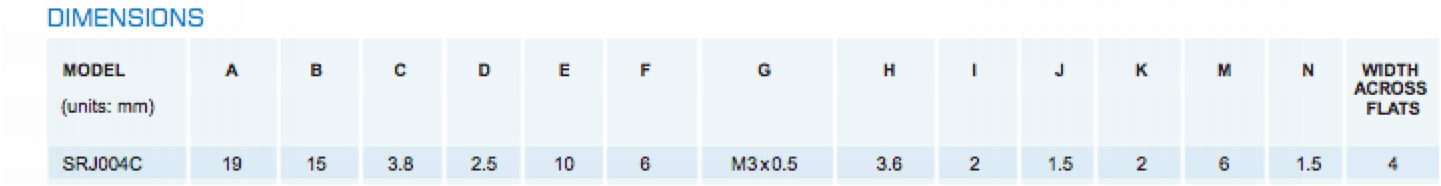


Critical Parts

Spherical Rolling Joint

- Skeptical to Component Conformance: “Each joint comes with a certificate of conformance indicating the actual tested accuracy” - Myostat Motion Control
- Concern: Relating error propagation in Rolling Joints, Pusher Arm, and Roller Bearings to optical pointing errors
- Monte Carlo simulation has been developed





DIMENSIONS

MODEL (units: mm)	A	B	C	D	E	F	G	H	I	J	K	M	N	WIDTH ACROSS FLATS
SRJ004C	19	15	3.8	2.5	10	6	M3x0.5	3.6	2	1.5	2	6	1.5	4

Manufacturing: Electrical

Electrical Overview

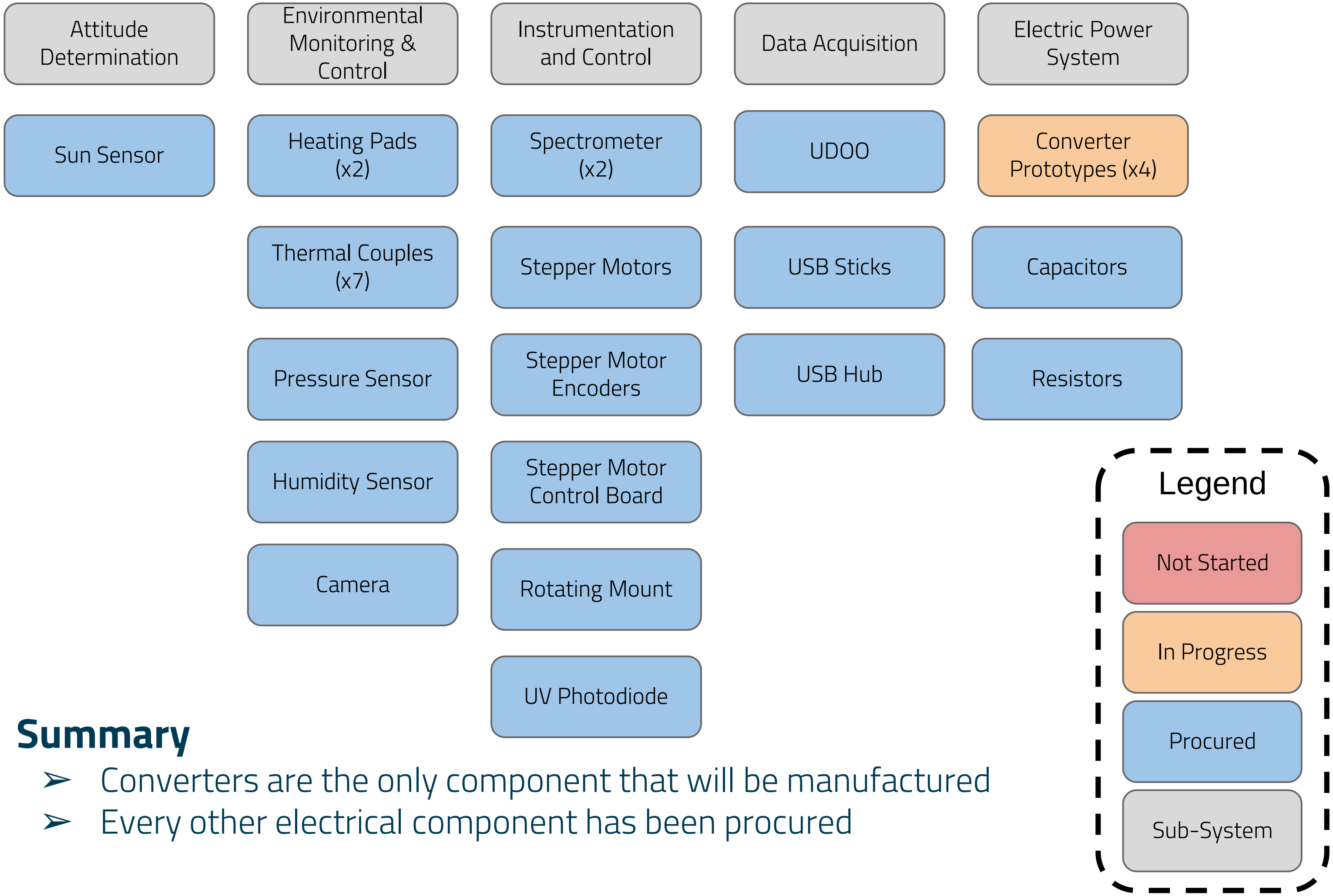
Component Overview:

- PCB designed using Altium
- Manufactured components: converter prototypes
- Procured components: Sub-system sensors and equipment, power PCB, and circuit prototype components.
- Design and validation assistance from Dr. Erickson (EE)

Integration Plan

- Iterative process of breadboarding and FlatSat testing,
- Once PCB design is validated it will be procured from Advanced Circuits to include designed converters

Electrical Hardware Manufacturing Overview



Attitude Determination
- Sun Sensor

Environmental Monitoring & Control
- Heating Pads (x2)
- Thermal Couples (x7)
- Pressure Sensor
- Humidity Sensor
- Camera

Instrumentation and Control
- Spectrometer (x2)
- Stepper Motors
- Stepper Motor Encoders
- Stepper Motor Control Board
- Rotating Mount
- UV Photodiode

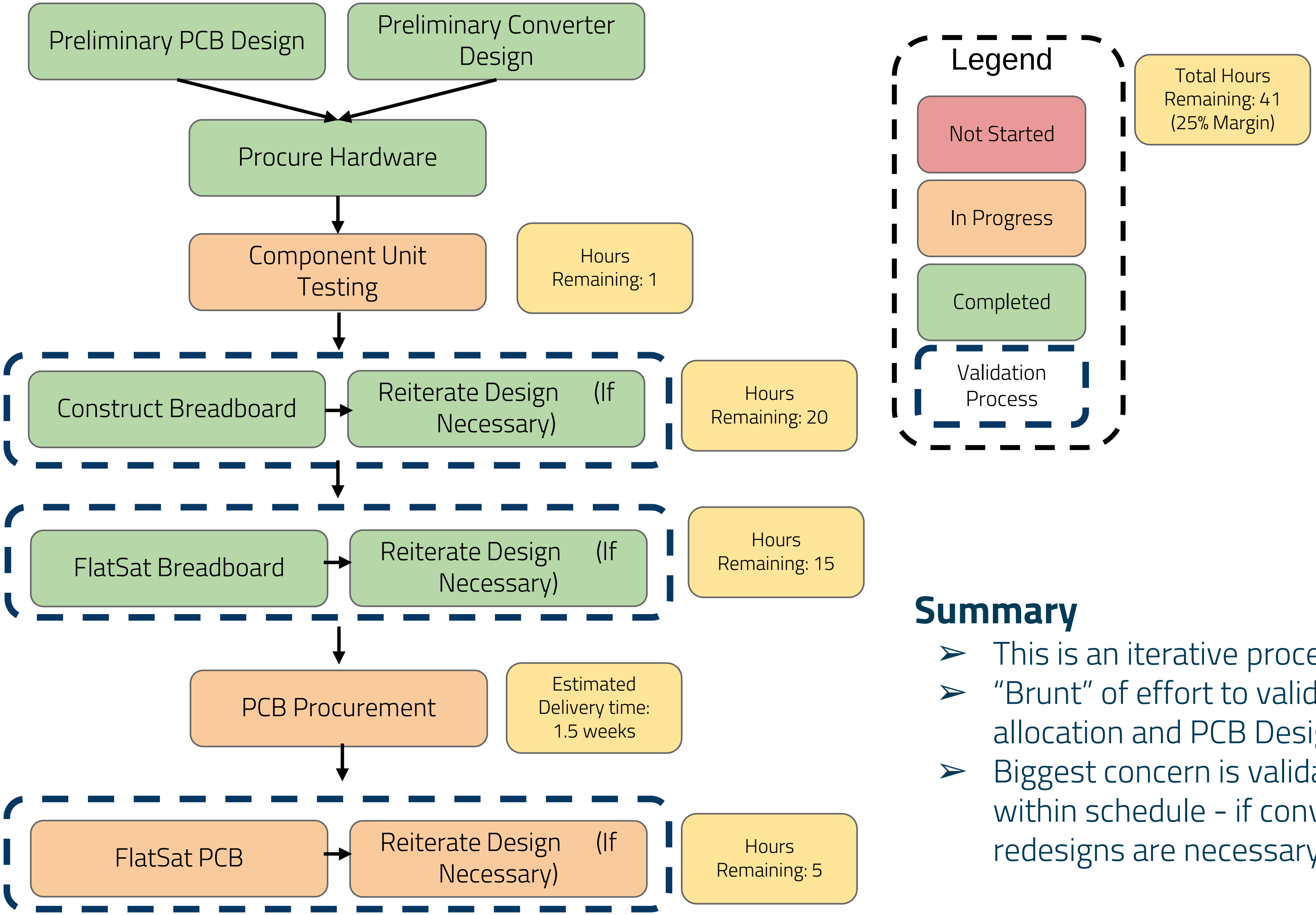
Data Acquisition
- UDOO
- USB Sticks
- USB Hub

Electric Power System
- Converter Prototypes (x4)
- Capacitors
- Resistors

Legend
- Not Started
- In Progress
- Procured
- Sub-System

Summary
- ➢ Converters are the only component that will be manufactured
- ➢ Every other electrical component has been procured

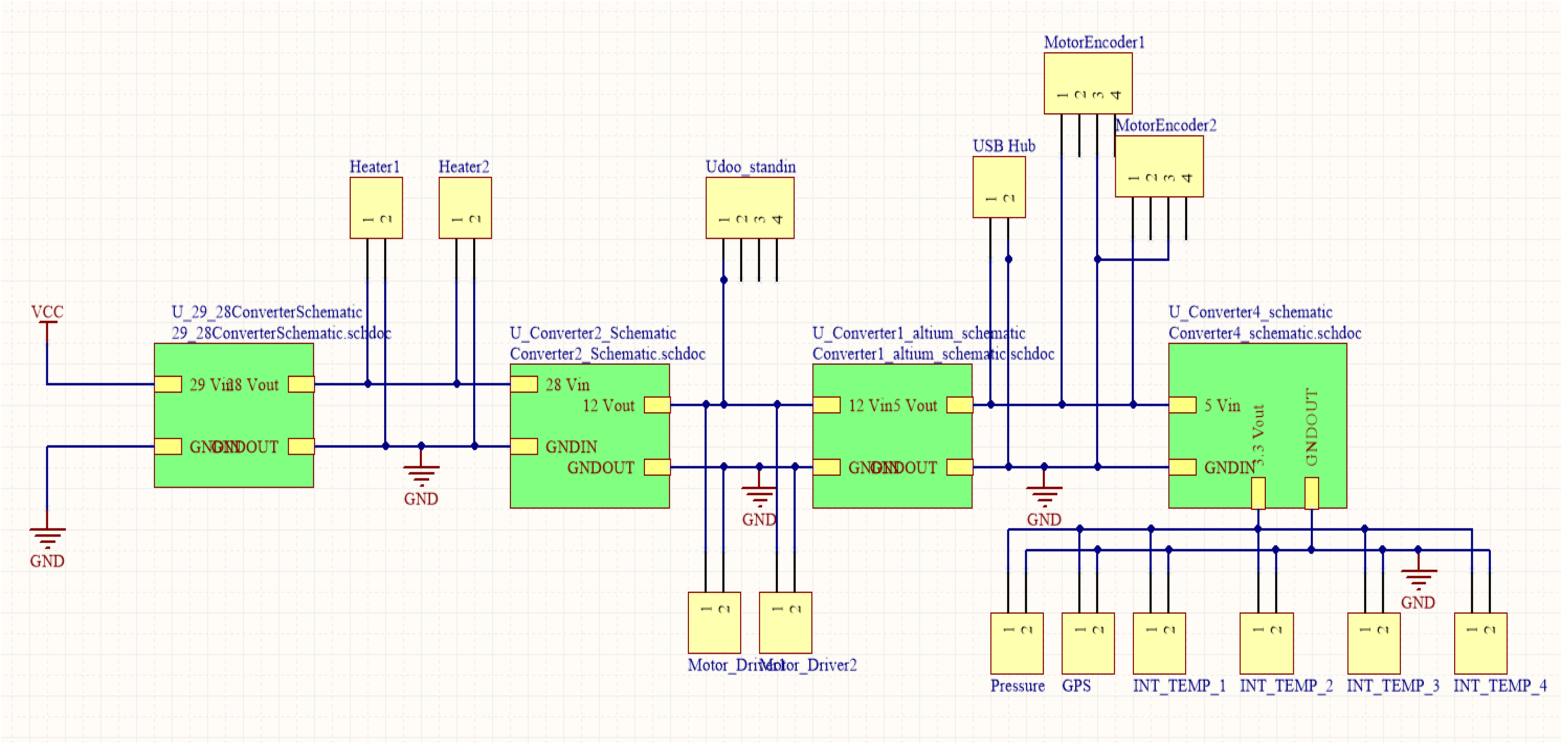
Electrical Manufacturing Integration Plan



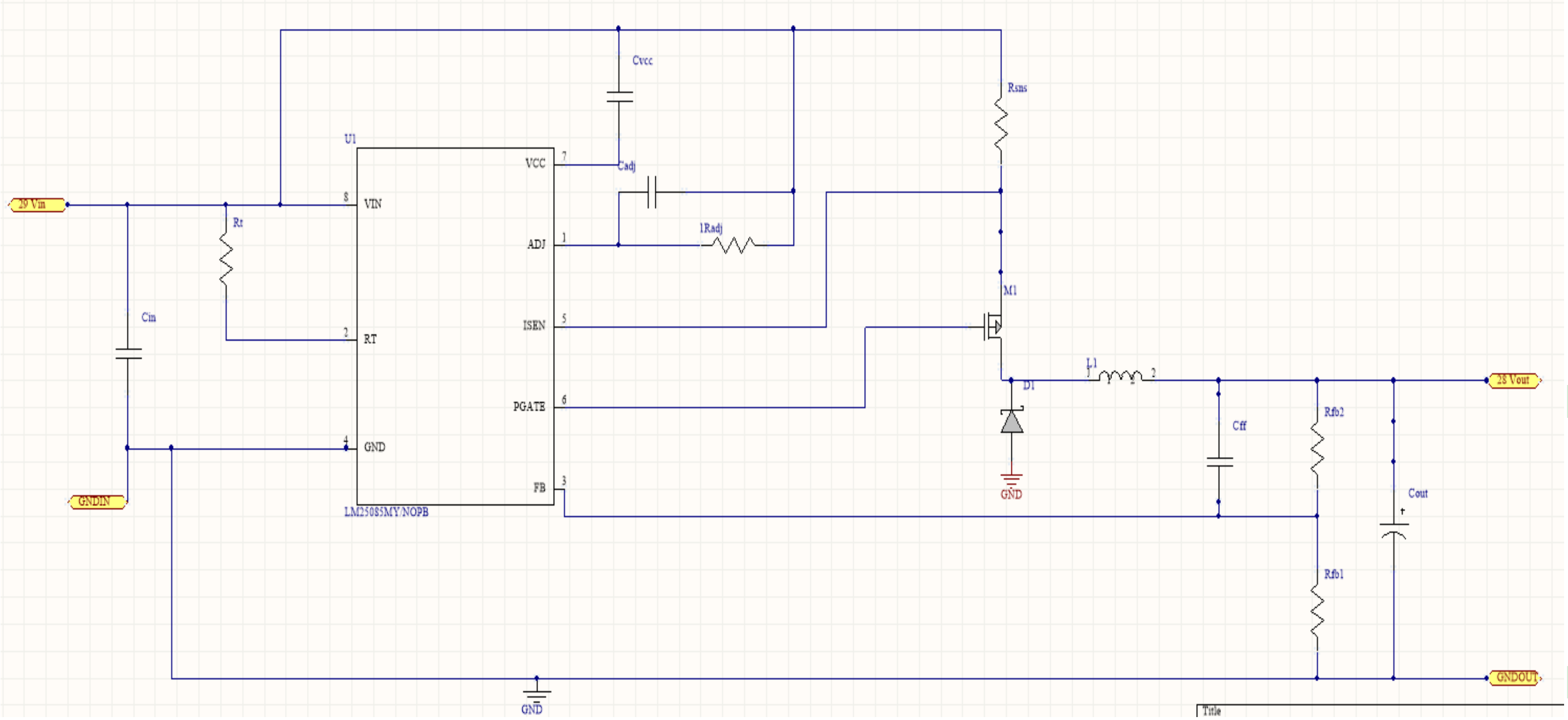
Summary

- ➢ This is an iterative process
- ➢ “Brunt” of effort to validating power allocation and PCB Design
- ➢ Biggest concern is validating PCB within schedule - if converter redesigns are necessary.

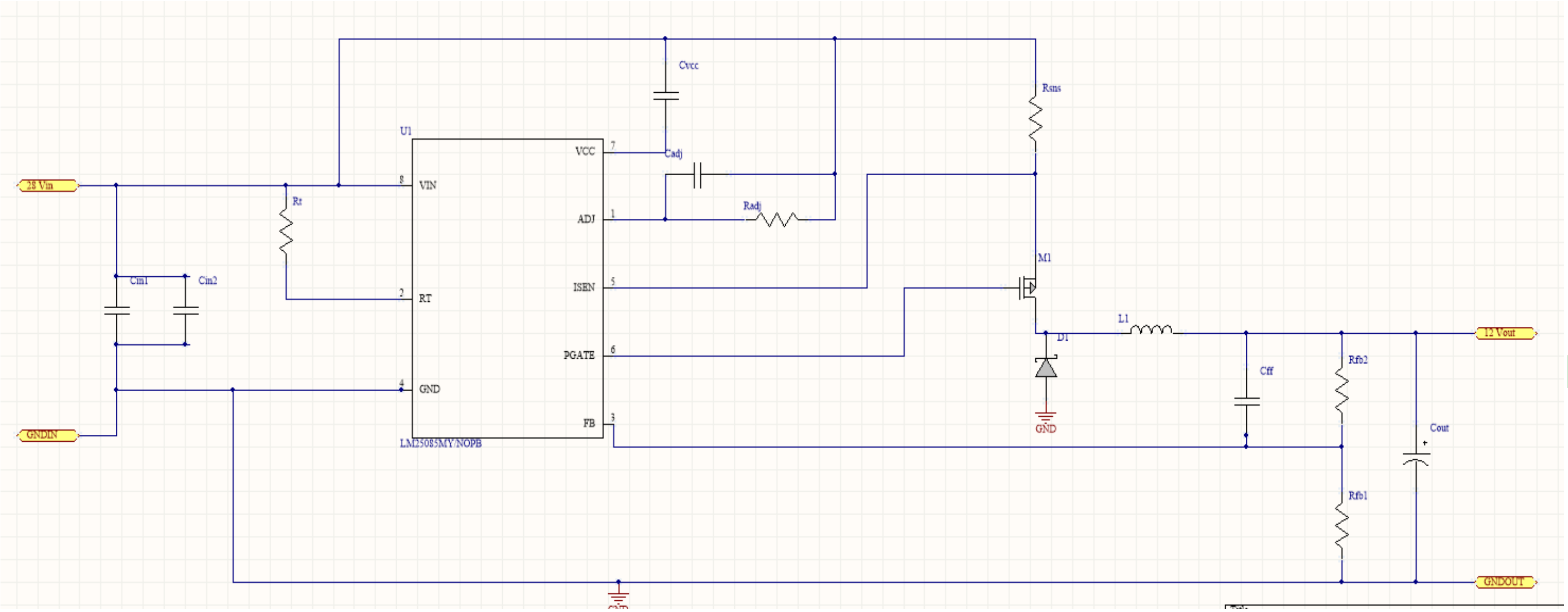
PCB Design


VCC
GND
U_29_28ConverterSchematic
29_28ConverterSchematic.schdoc
29 Vin
28 Vout
GNDIN
GNDOUT
Heater1
Heater2
Udoo_standin
U_Converter2_Schematic
Converter2_Schematic.schdoc
28 Vin
12 Vout
GNDIN
GNDOUT
Motor_Driver1
Motor_Driver2
U_Converter1_altium_schematic
Converter1_altium_schematic.schdoc
12 Vin
5 Vout
GNDIN
GNDOUT
USB Hub
MotorEncoder1
MotorEncoder2
U_Converter4_schematic
Converter4_schematic.schdoc
5 Vin
GNDIN
3.3 Vout
GNDOUT
Pressure
GPS
INT_TEMP_1
INT_TEMP_2
INT_TEMP_3
INT_TEMP_4

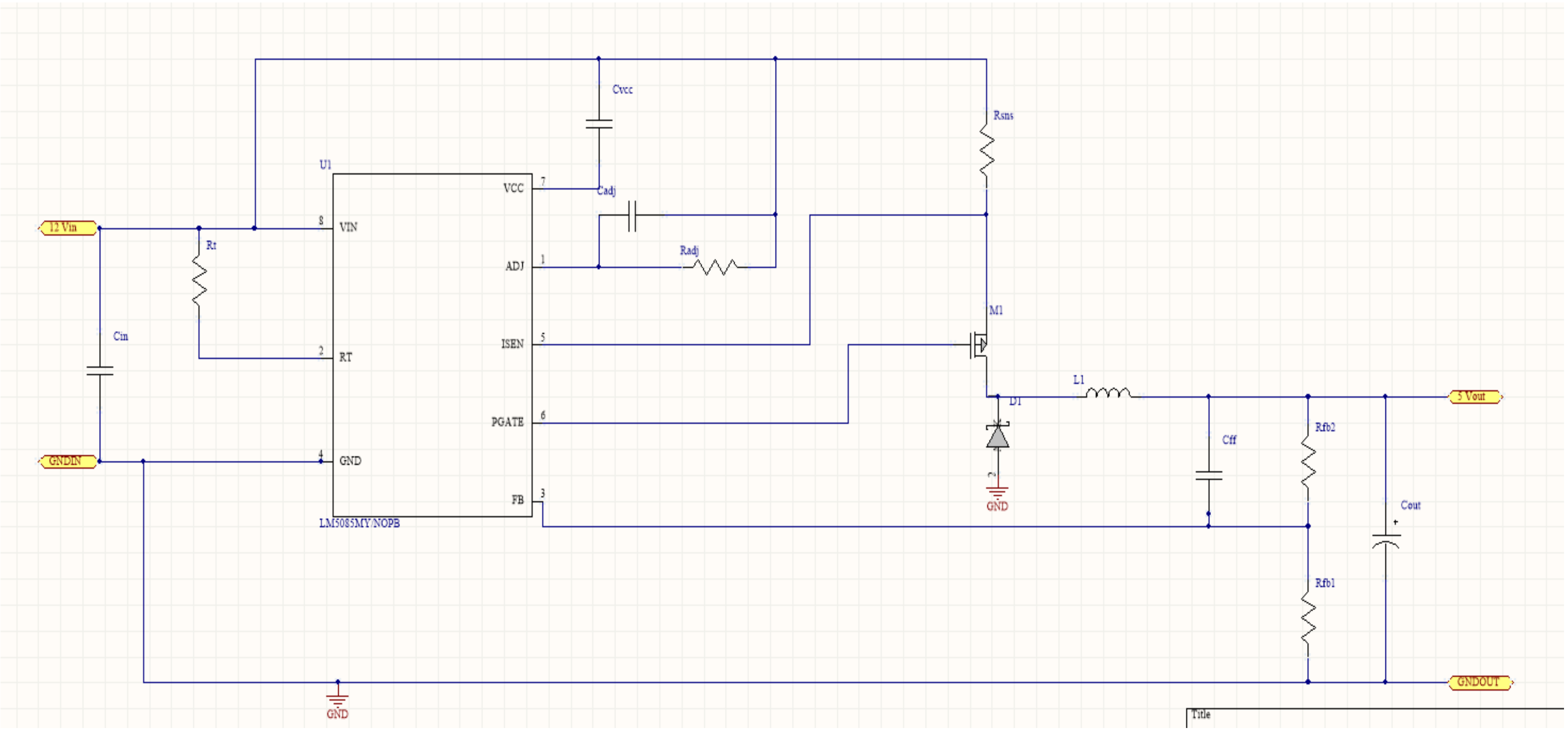
29 - 28 V Converter



28 - 12 V Converter

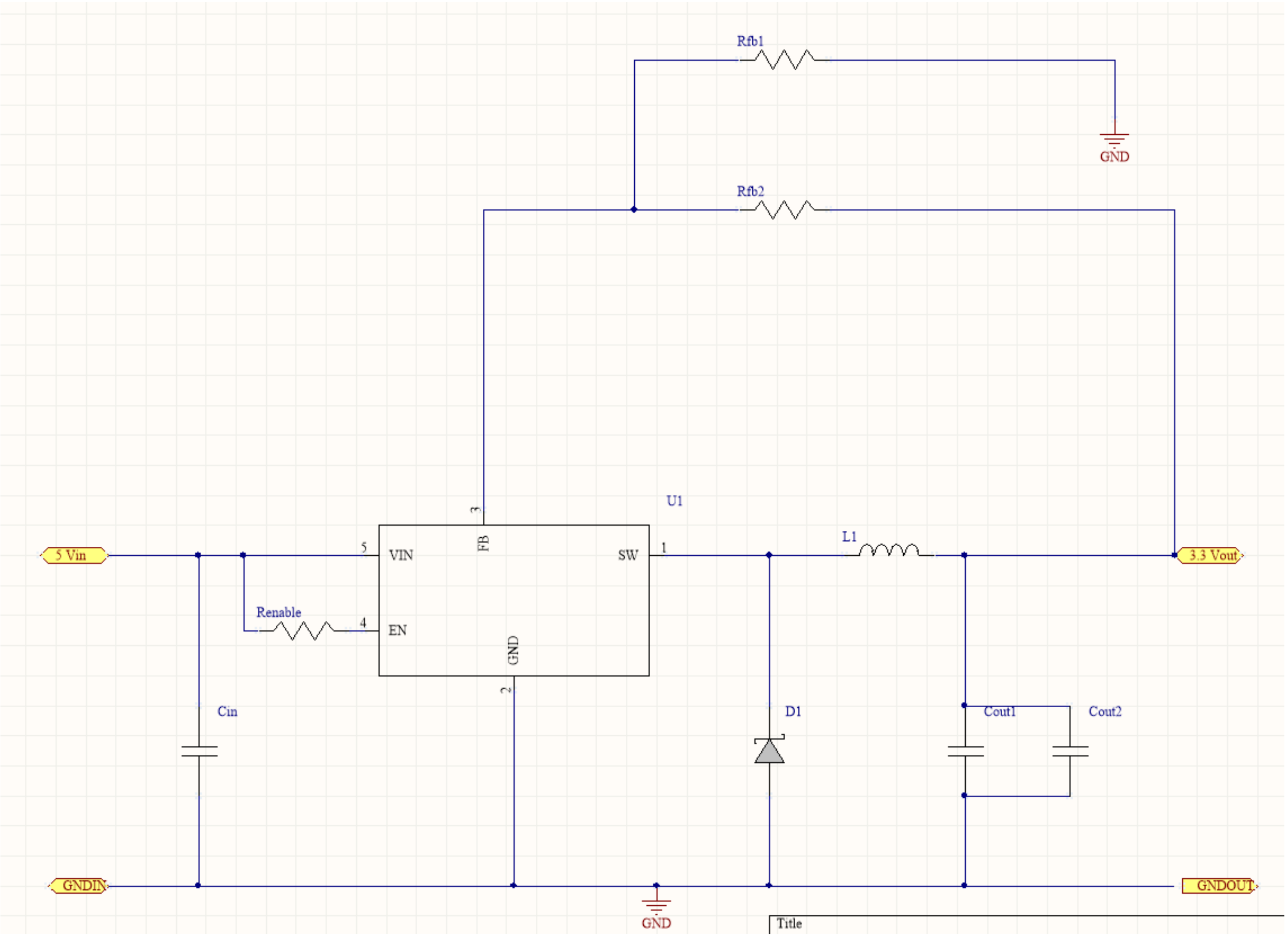


12 - 5 V Converter



Integration Testing: Environmental

5 - 3.3 V Converter



Integration Testing: Environmental

Sommers-Bausch Campaign Data

Accuracy of ADS during calibration maneuvers

Actuate telescope by known angle, compare to angle swept by Sun Sensor

Y Axis

Telescope Actuation Angle	Sun Sensor Data	Error [%]
30 arcminutes	31.56 and 32.28 arcminutes	6.4
10 arcminutes	10.8 arcminutes	8
1 arcminute	1.14, 0.98, 1.2, and 1.08 arcminutes	11.5
30 arcseconds	32.4 arcseconds	8
5 arcseconds	3.6, 3.6, and 3.6 arcseconds	28

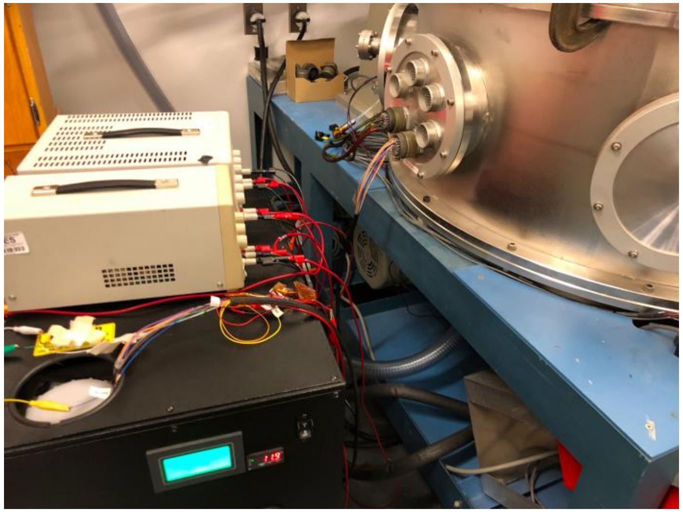
X Axis

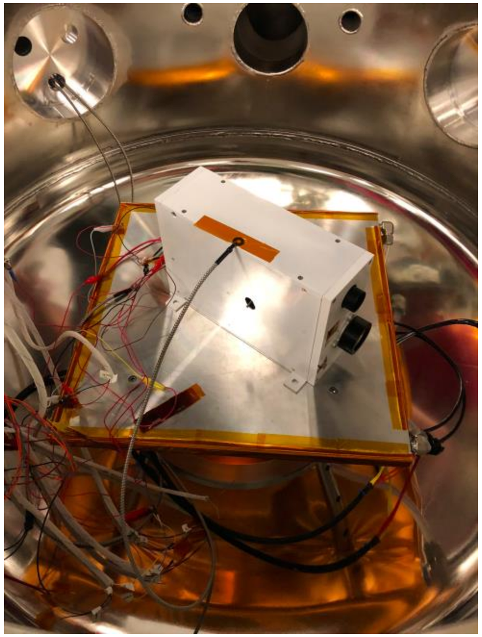
Telescope Actuation Angle	Sun Sensor Data	Error [%]
30 arcminutes	30.6 and 32.34 arcminutes	4.9
1 arcminute	1.02, 1.14, 1.08, and 1.08 arcminutes	8

Pictures

Test Results:

Pictures





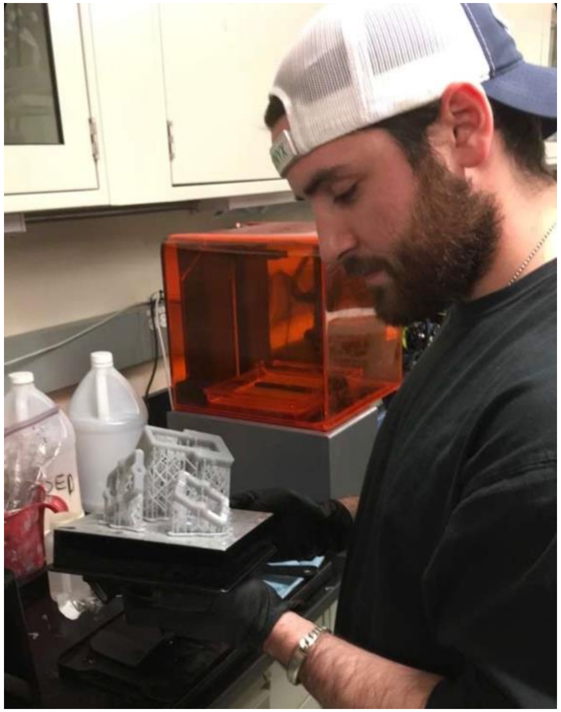
Pictures

Test Results:

Pictures

Test Results:

Pictures



Test Results: