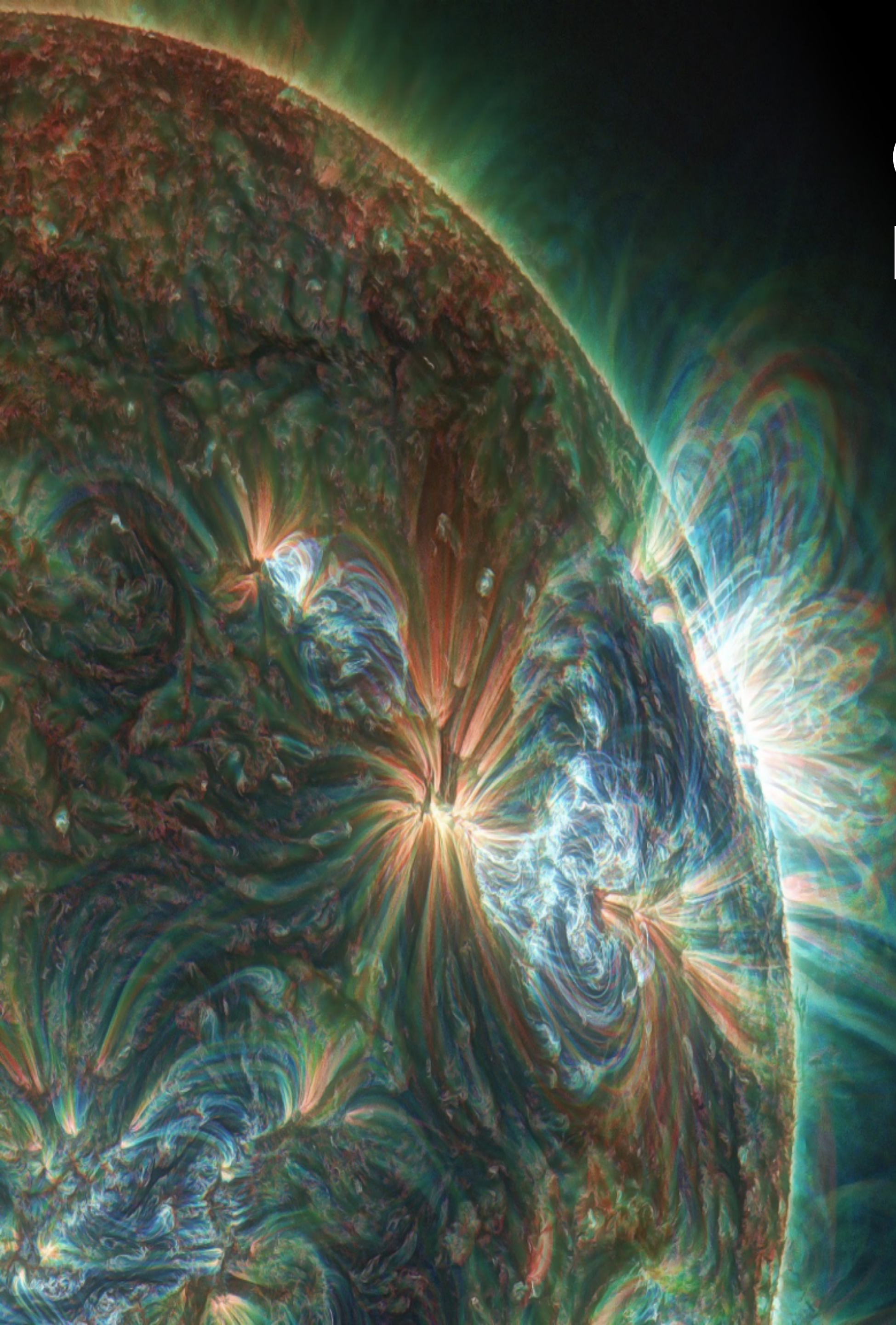


STOUT

Spectropolarimeter
Telescope
Observatory for
Ultraviolet
Transmissions

Presenters:

1. Andrew Arnold
2. Darin Brock
3. Matt Funk
4. Andrew Lux
5. Dawson Stokley

Advisor:
Francisco López Jimenez

Team Members:

1. Zach Allen
2. Caleb Beavers
3. Josh Bruski-Hyland
4. Ian Geraghty
5. Ryan Lynch
6. Matt Normile

Customer:
NCAR High Altitude Observatory

1. Phil Oakley
2. Scott Sewell

Project Overview

Motivation & Project Statement

Motivation:

- ➢ Solar phenomena present catastrophic risks to ground and space based systems
- ➢ 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 activity

Project Statement:

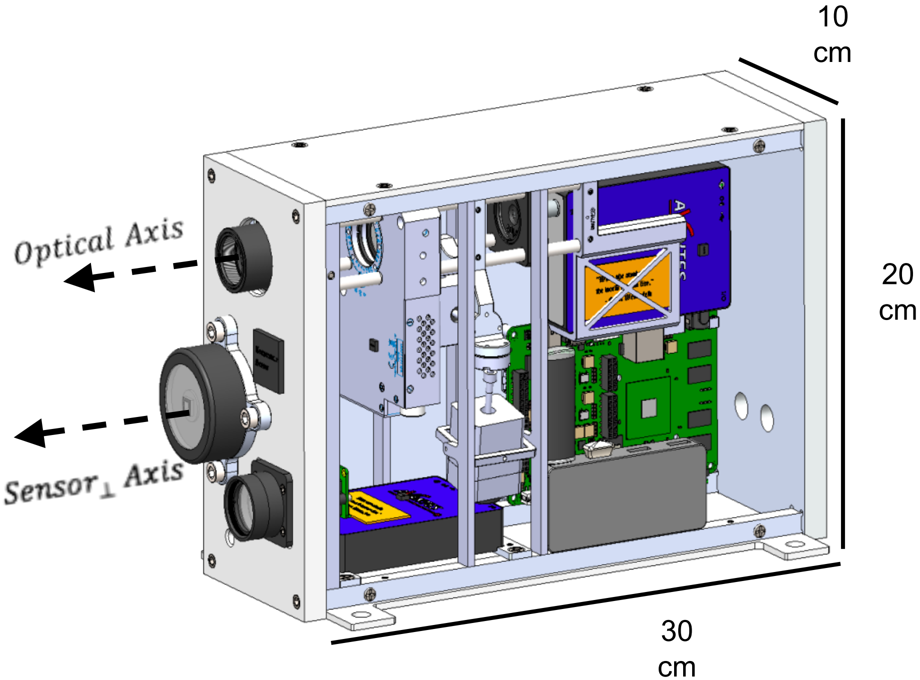
- ➢ STOUT will design and manufacture a 3U CubeSat payload capable of collecting UV spectra measurements and operating in high-altitude balloon flight.
- ➢ The team will utilize a variety of ground tests that simulate the expected high altitude environment in order to calibrate the module's data collection systems and verify the payload's flight readiness.

NASA Gondola

Mission

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

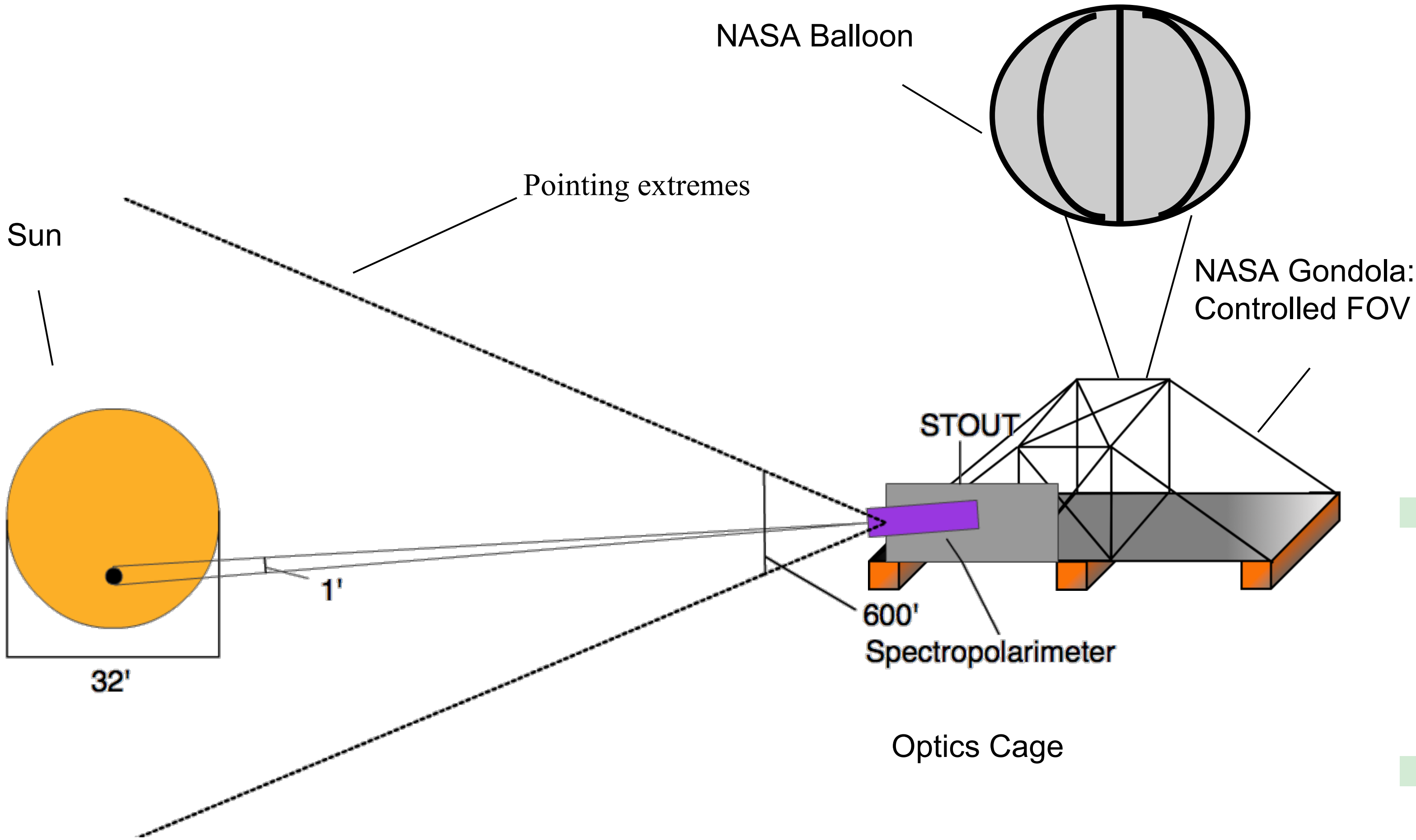
System Overview



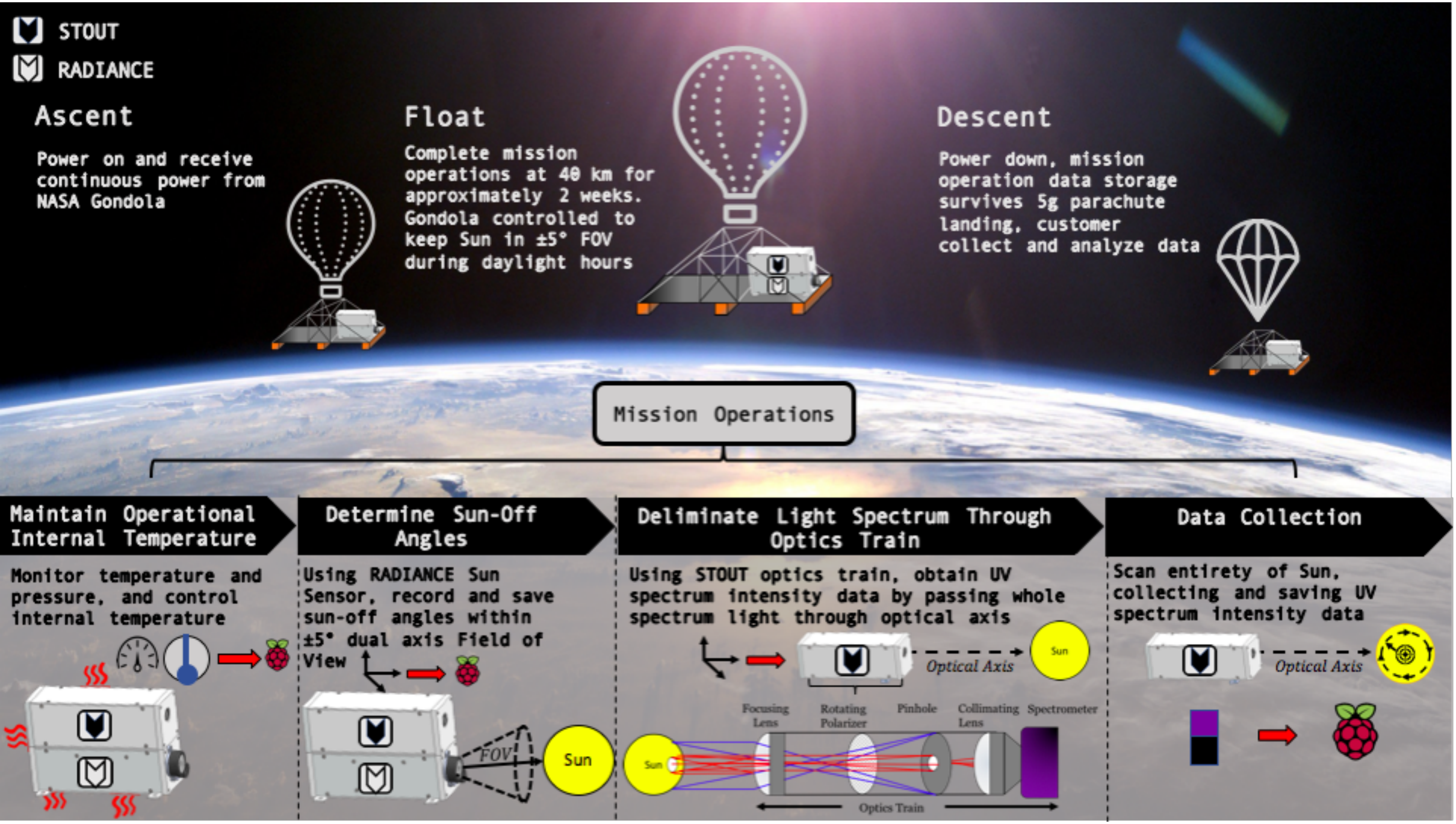
Summary

Parameter	Values
Dimensions	10x20x30 cm^3
Mass	4.4 kg
Power Consumption	74.5 W
Flight Environment	-70℃ - 20℃
Materials	Aluminum 6061 (Structure) Polyisocyanurate (Insulation)

Pointing Explanation

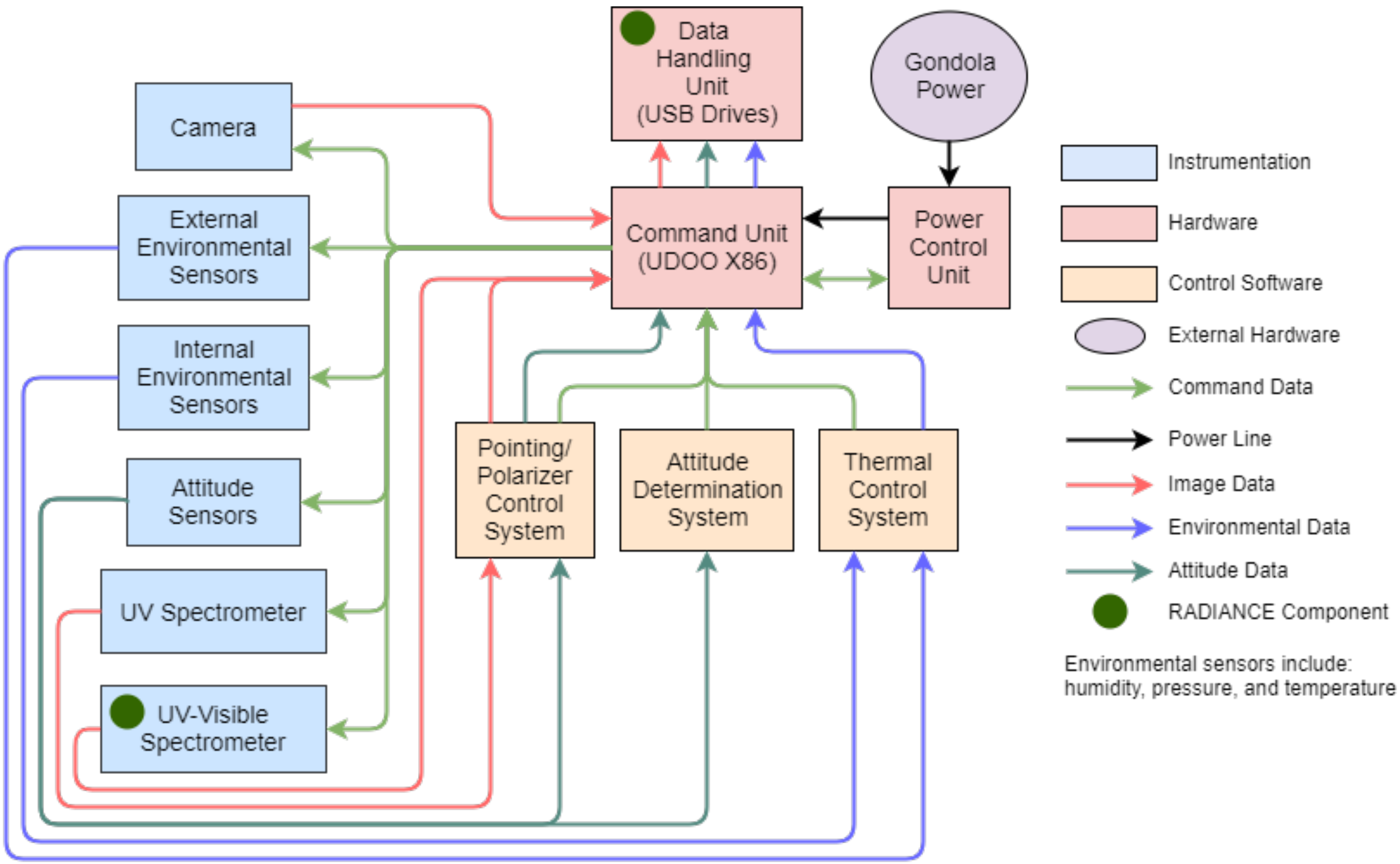


CONOPS

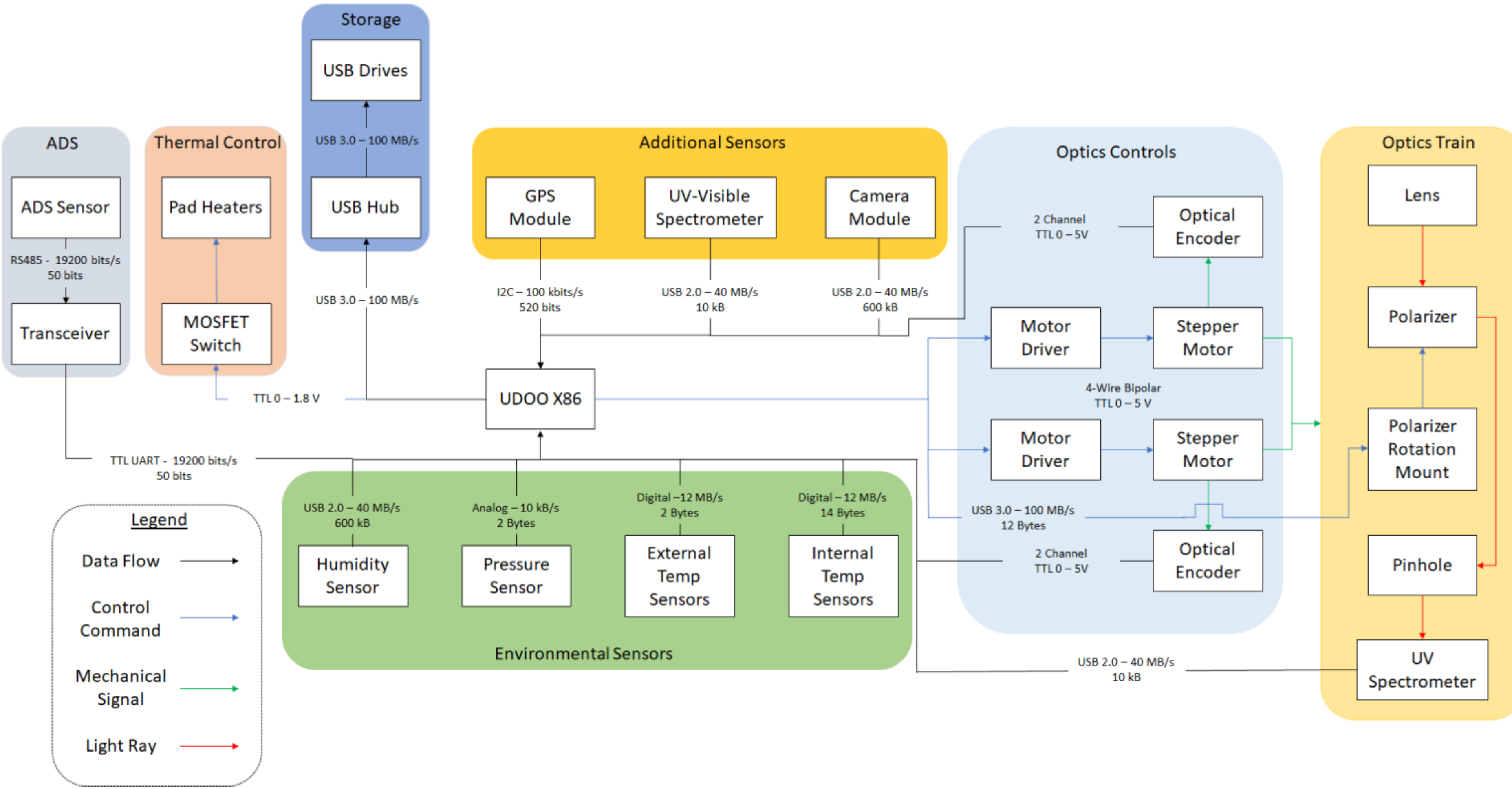


Overview

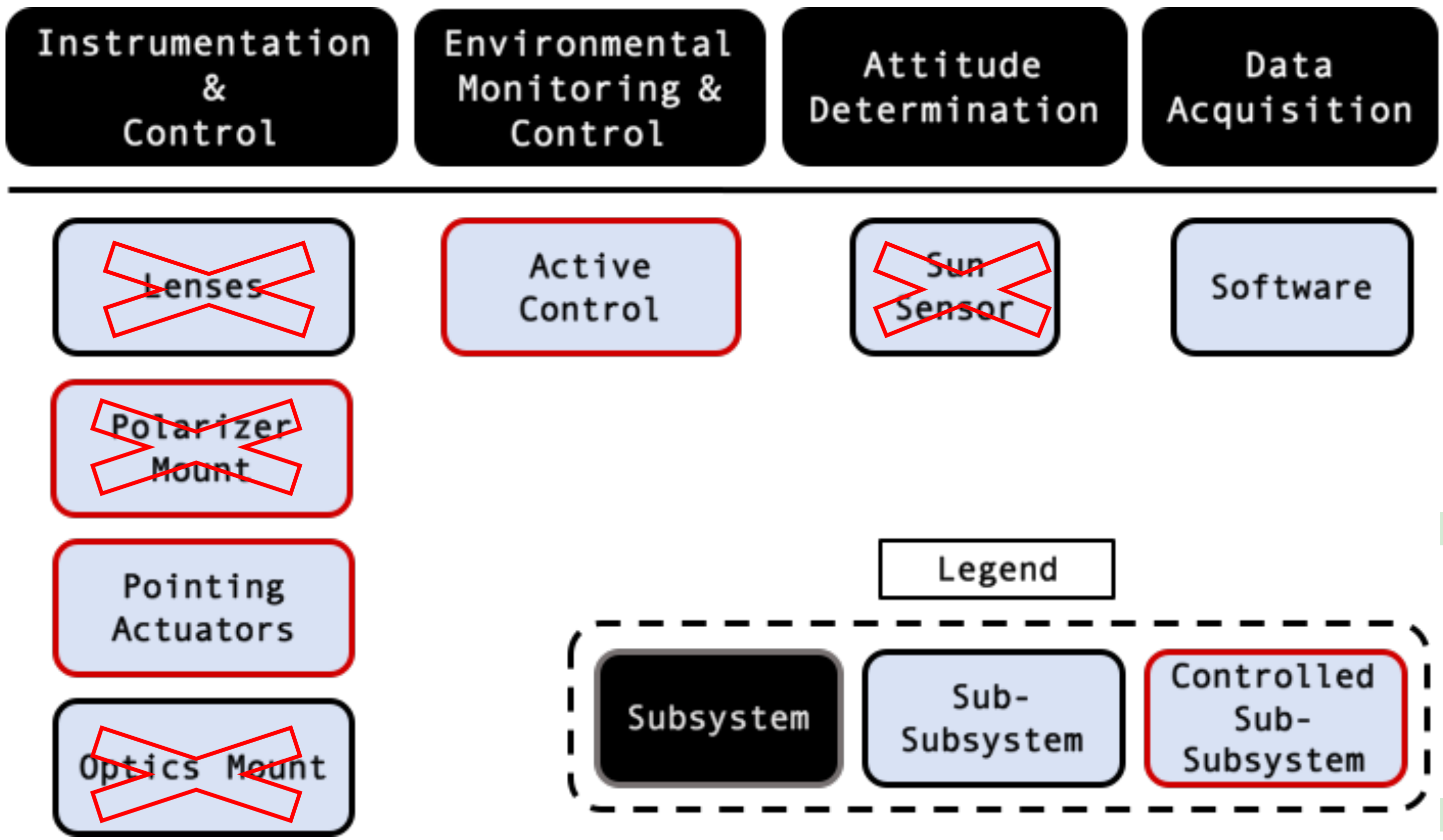
Functional Block Diagram



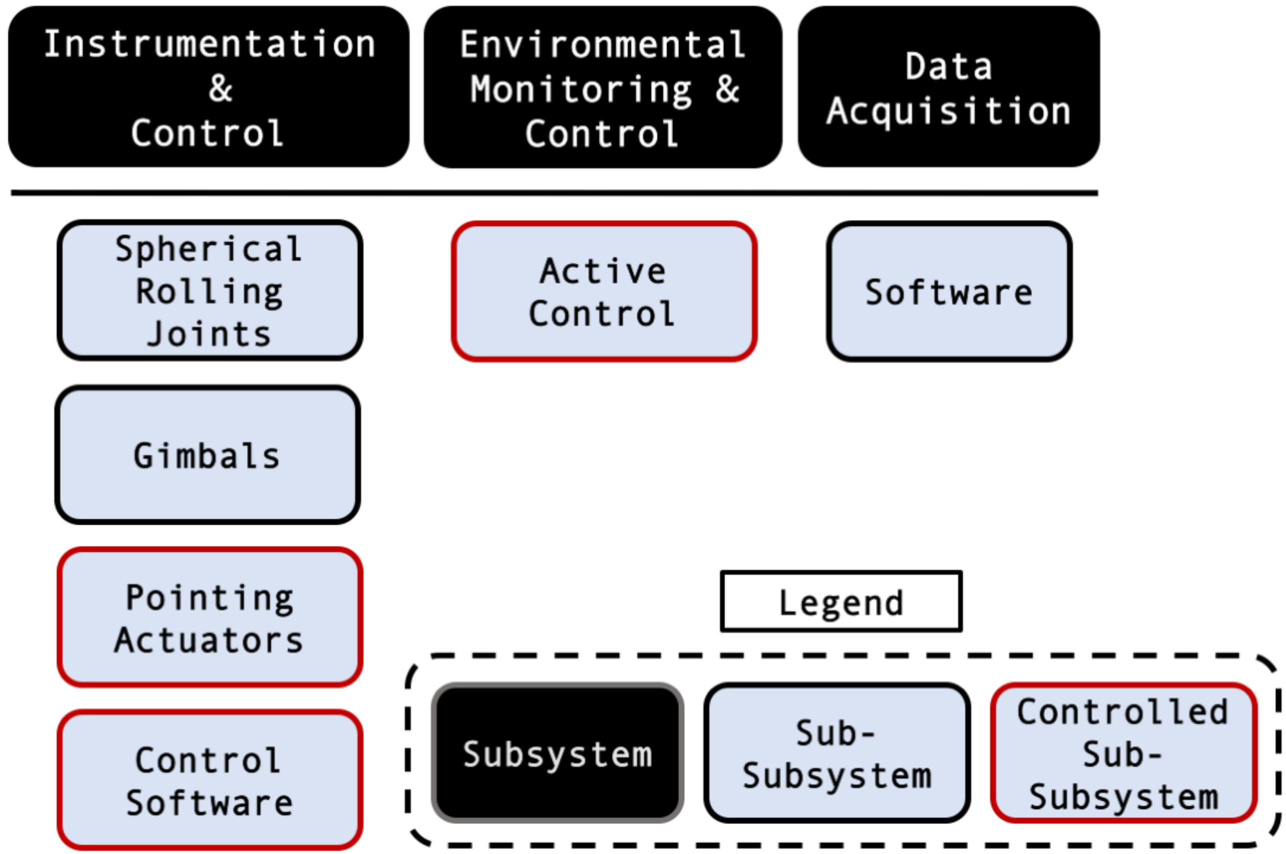
Hardware Architecture Diagram



CDR Critical Project Elements



MSR Critical Project Elements



Executive Summary

Changes from CDR

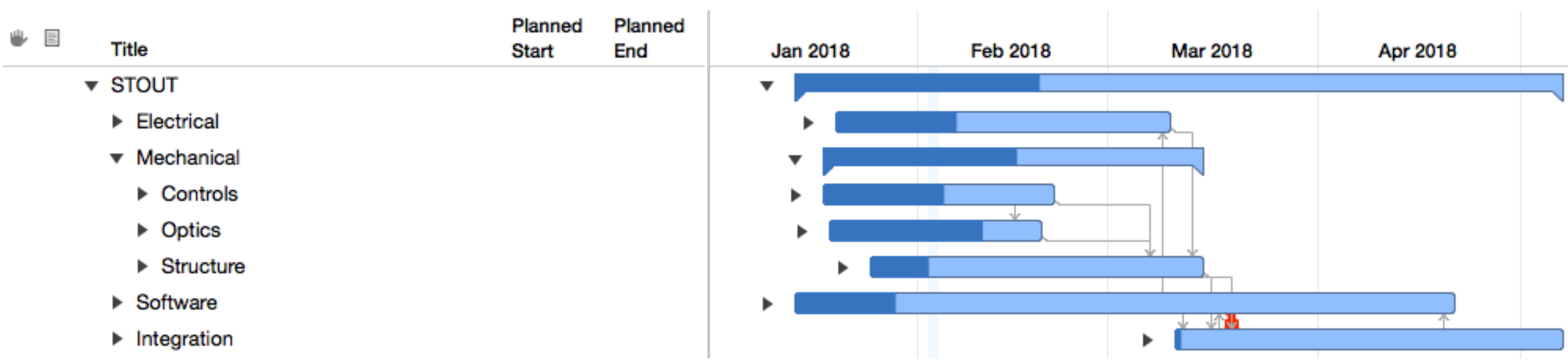
- Switched to 3D printing of several components
- Slight change in internal layout to bring horizontal motor lead screw within dimensional specifications of STOUT
- Redesign of optical pusher plate

Schedule

- On schedule, rearranged timing of several tasks to account for delays in part acquisition
  - Pushed back ADS and motor component testing
  - Moved up manufacturing and software dates

Budget

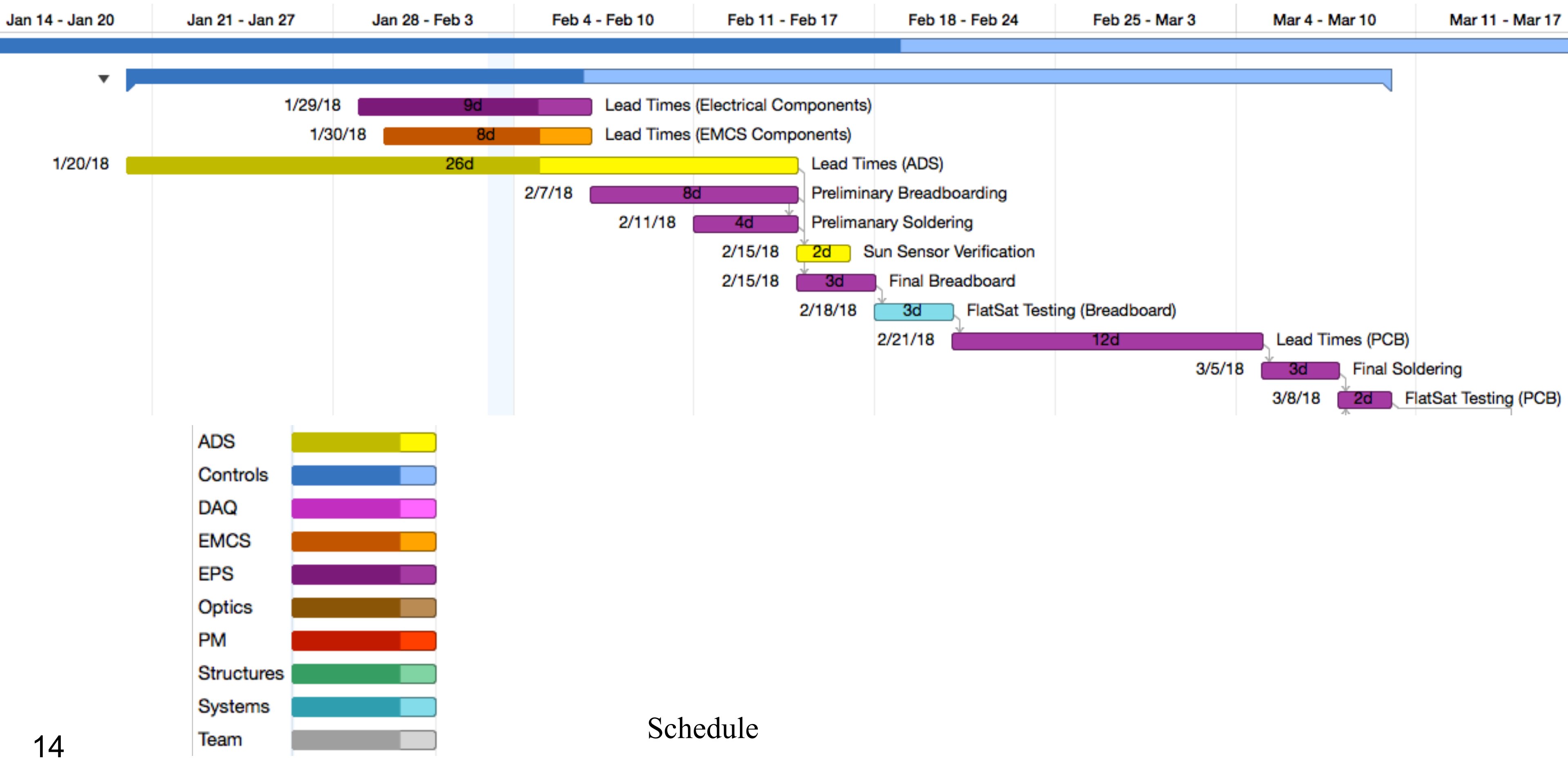
- No risk to budget, have spent $4055.29 expected expenses of $6181.39, out of $7377 budget (expanded by EEF)
- With 15% margin, expected expenses of $7108.59, down from $7364.47 at FFR



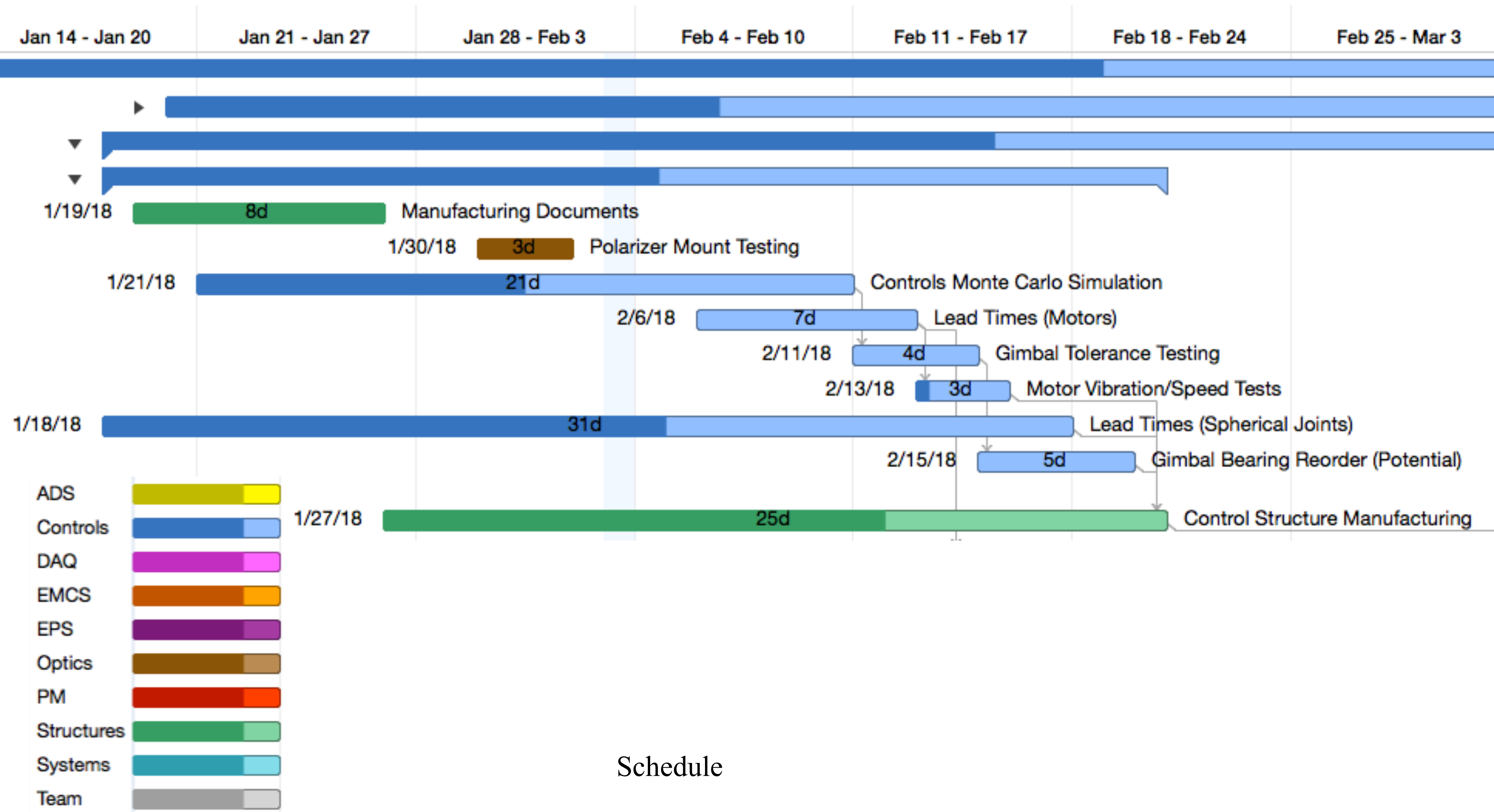
Overview

Schedule

Electrical Schedule

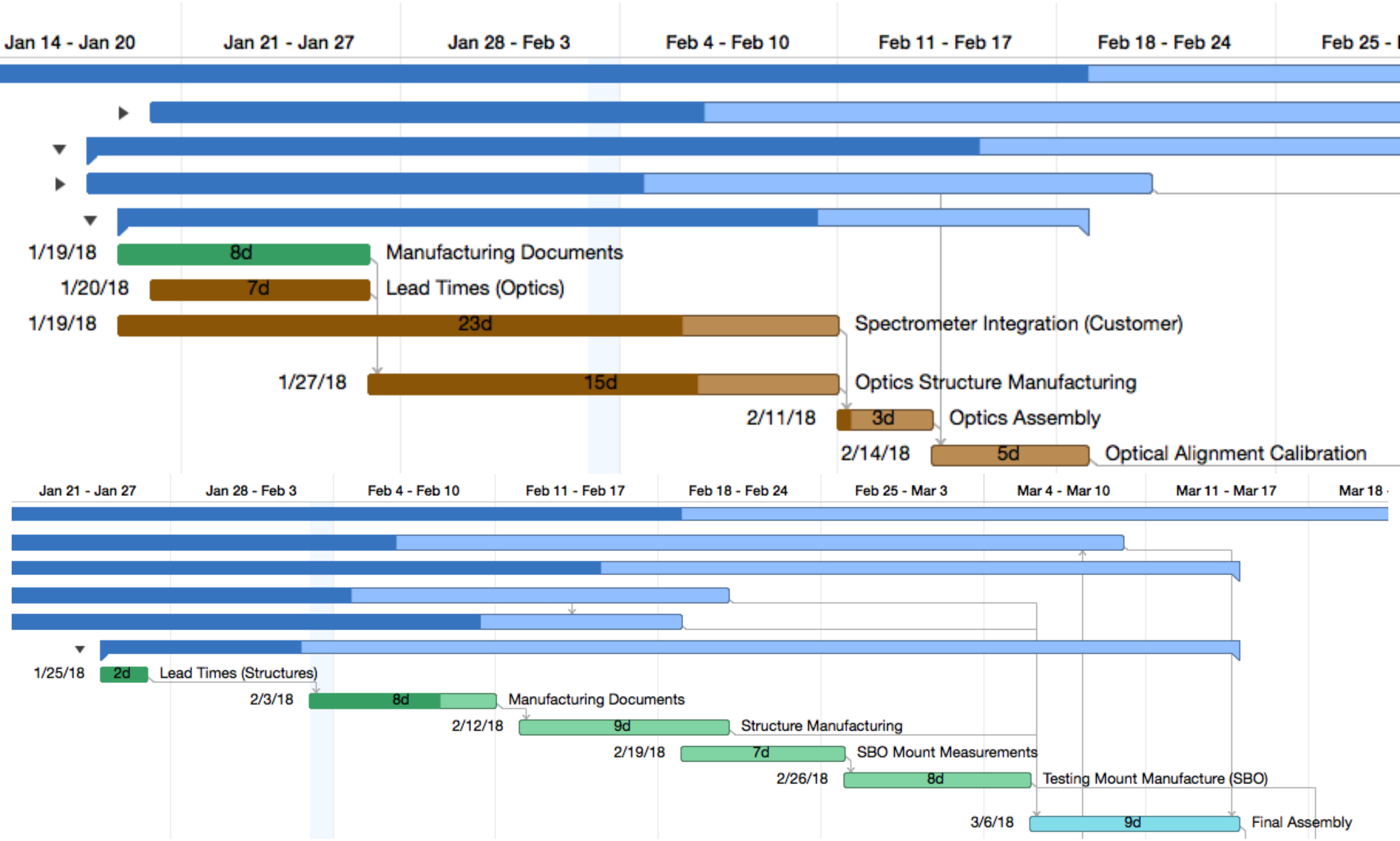


Manufacturing Schedule



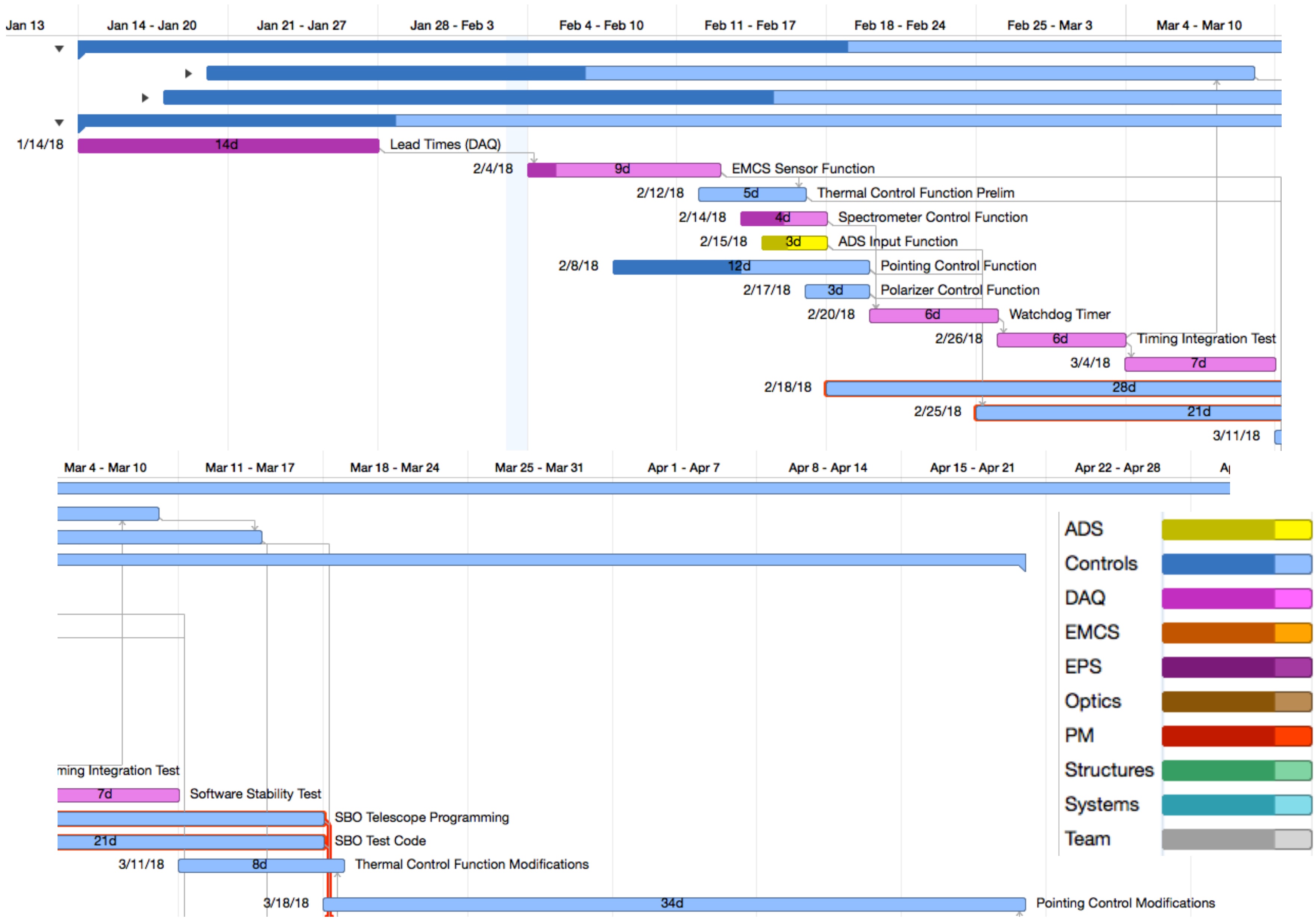
Schedule

Manufacturing Schedule

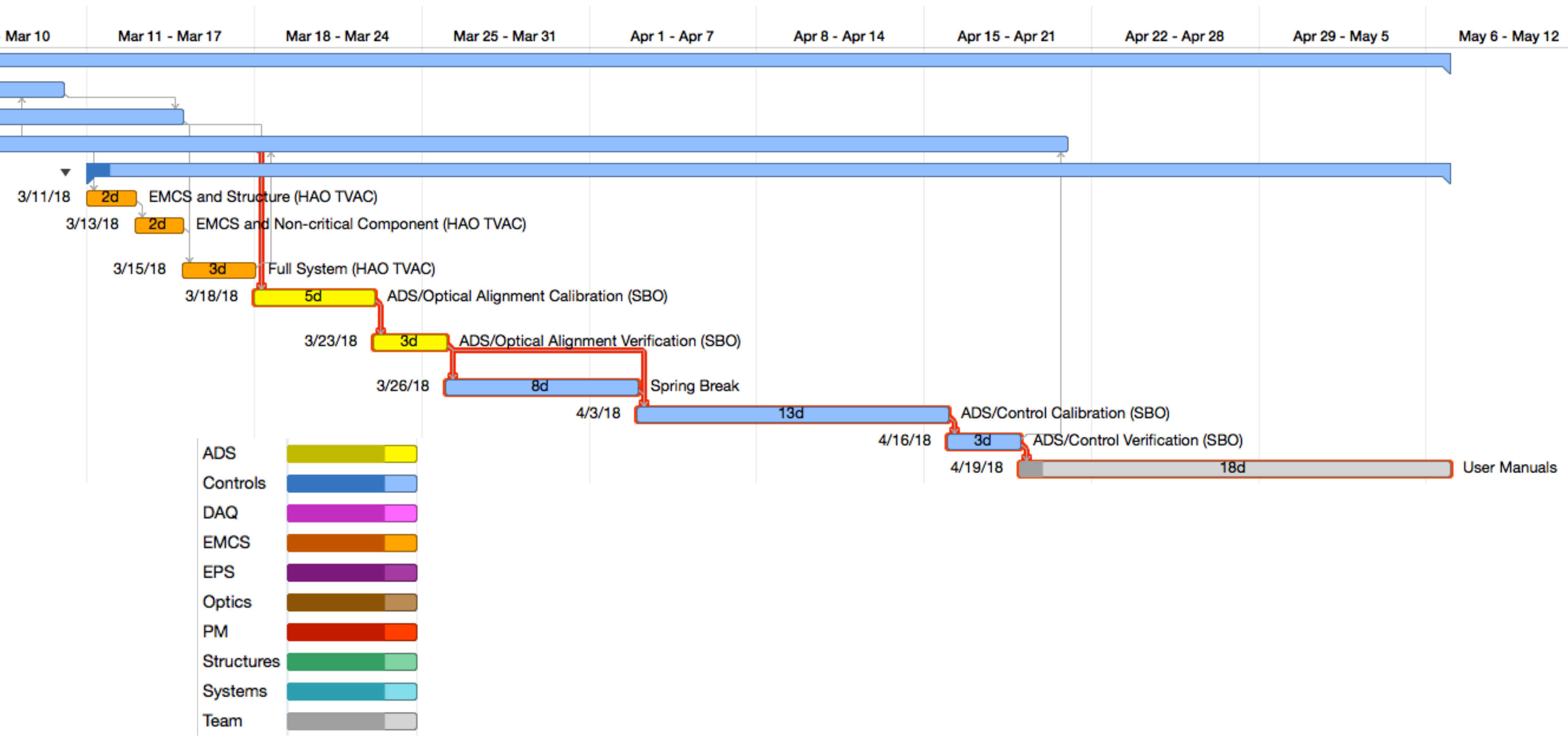


Schedule

Software Schedule

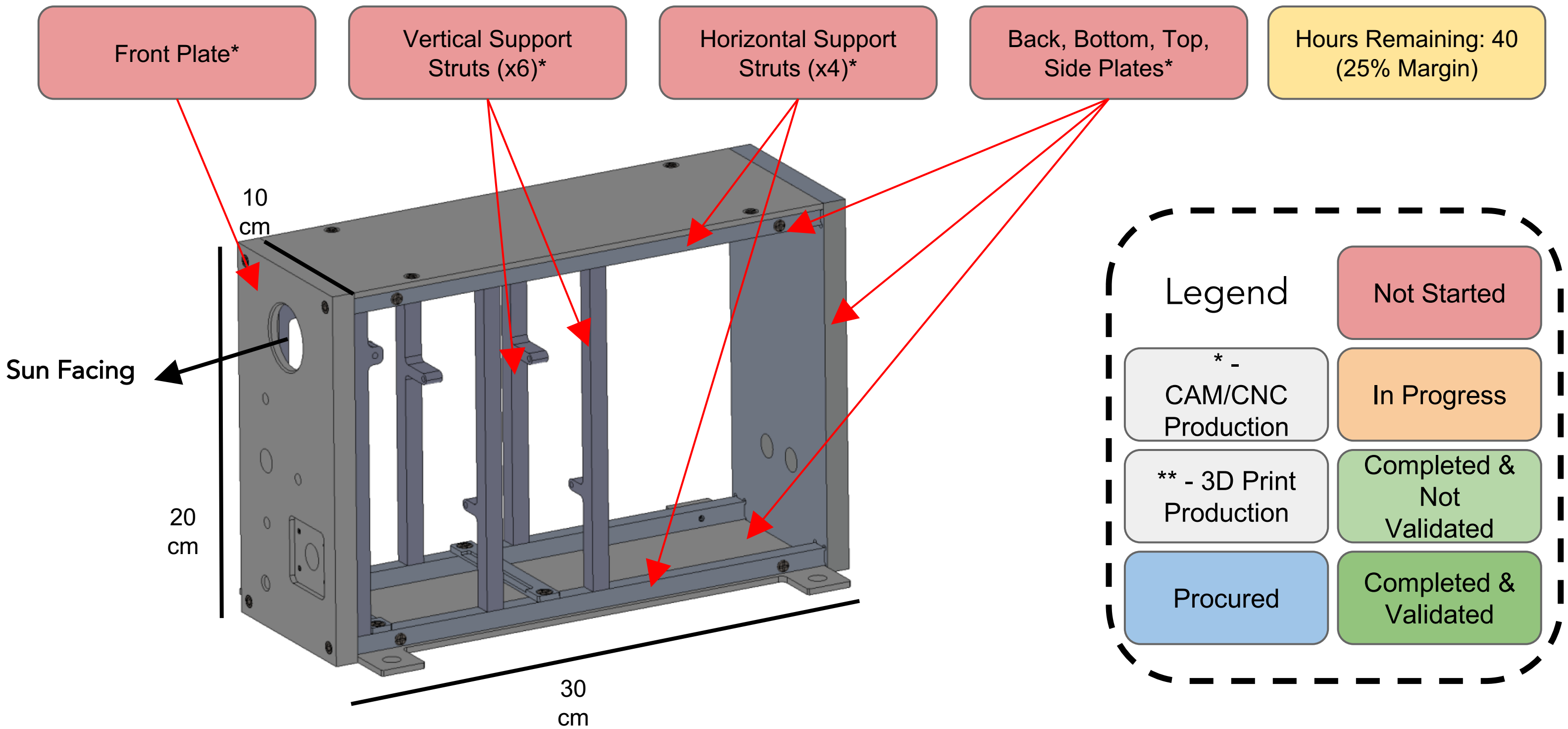


Integration Schedule



Manufacturing: Mechanical

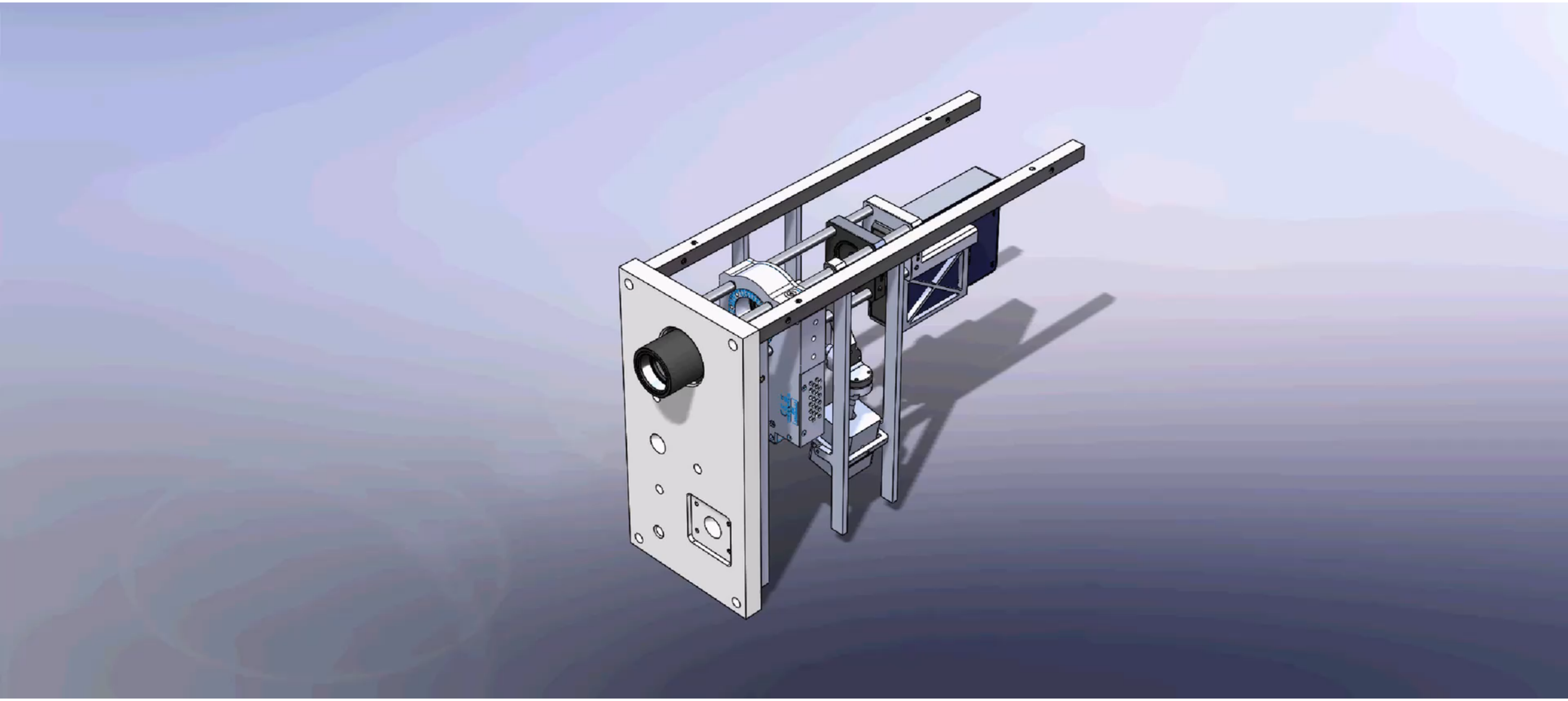
Structural Components



Summary

- ➢ Considerable time left but not a concern
- ➢ Simpler components for CAM/CNC manufacturing
- ➢ Approach of completing more complex components first

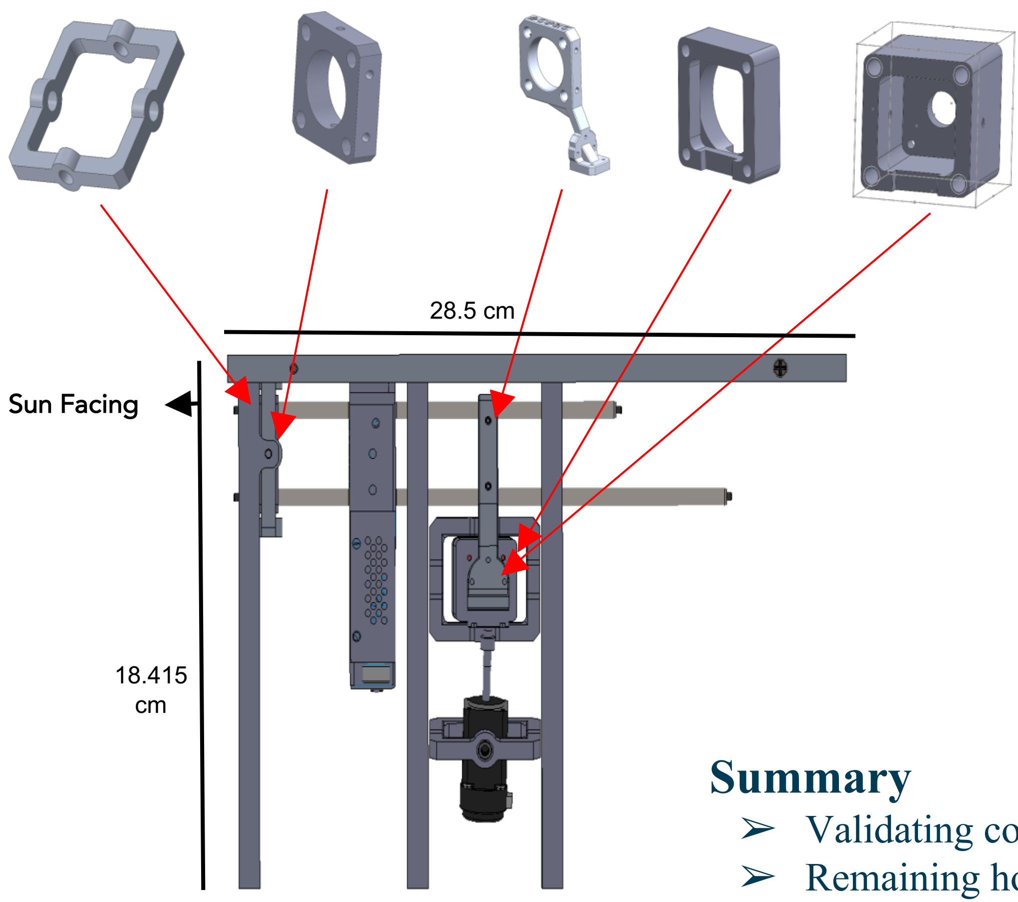
Pointing Control: Animation



Manufacturing: Mechanical

Controls Components

Box Gimbals (x3)**	Front Inner Gimbal**	Pusher Arm**	Front Motor Mounts (x2)*	Back Motor Mounts (x2)*	Spherical Rolling Joints (x2)	Gimbal Rolling Joints (x14)	Gimbal Axles (x12)	Hours Remaining: 30 (20% Margin)



Side View

Legend

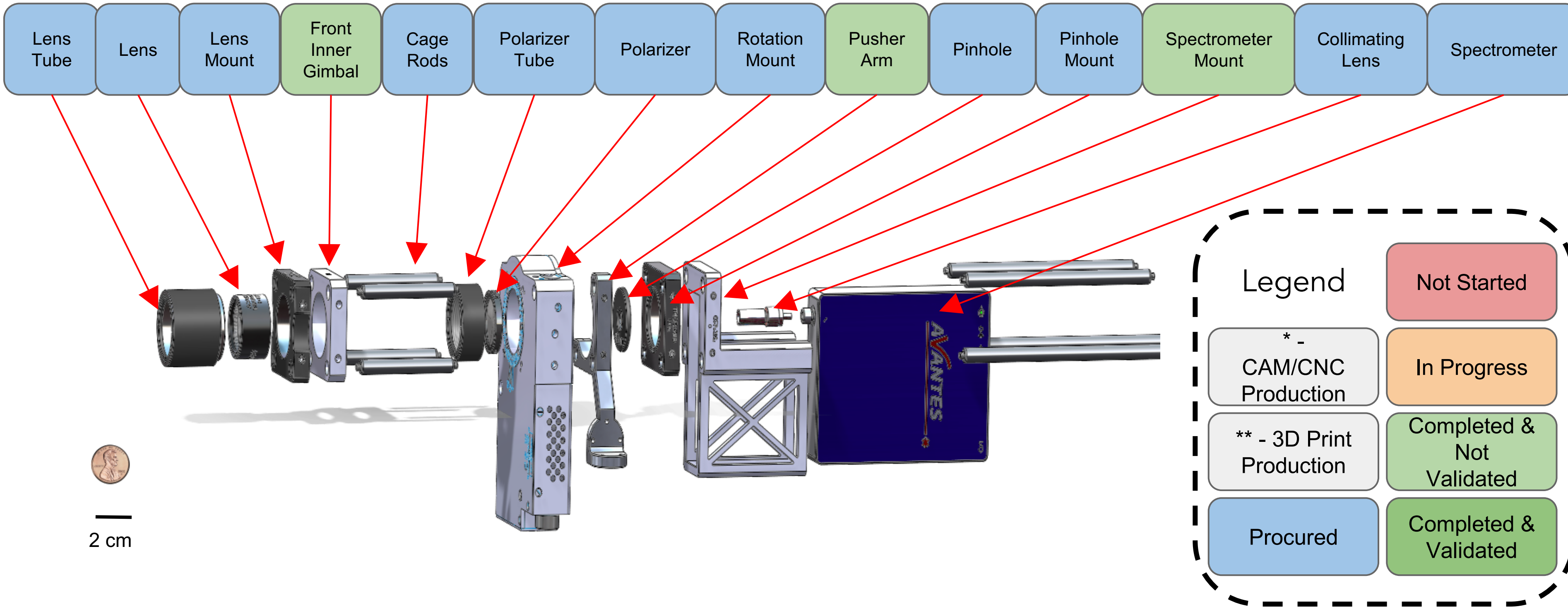
- Not Started
- * - CAM/CNC Production
- In Progress
- ** - 3D Print Production
- Completed & Not Validated
- Procured
- Completed & Validated

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)



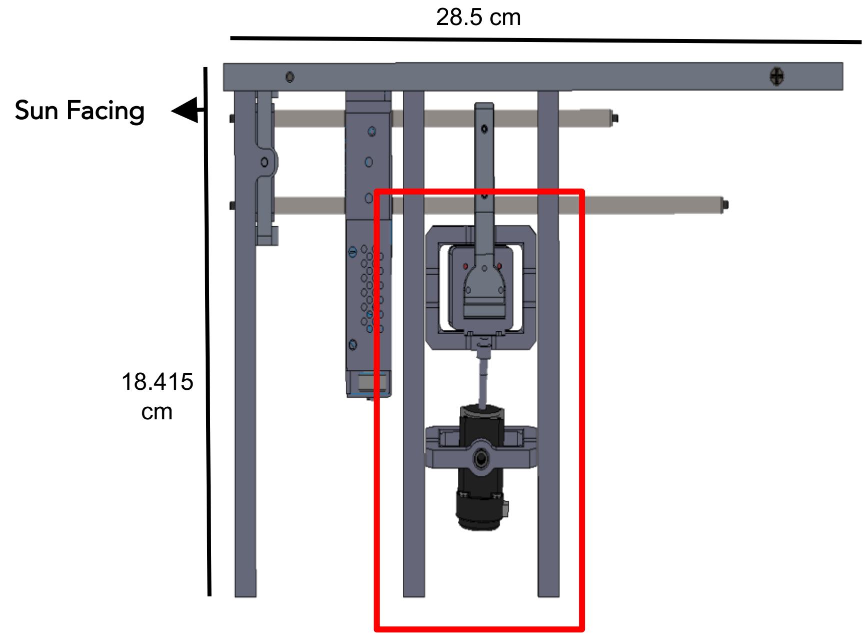
Summary

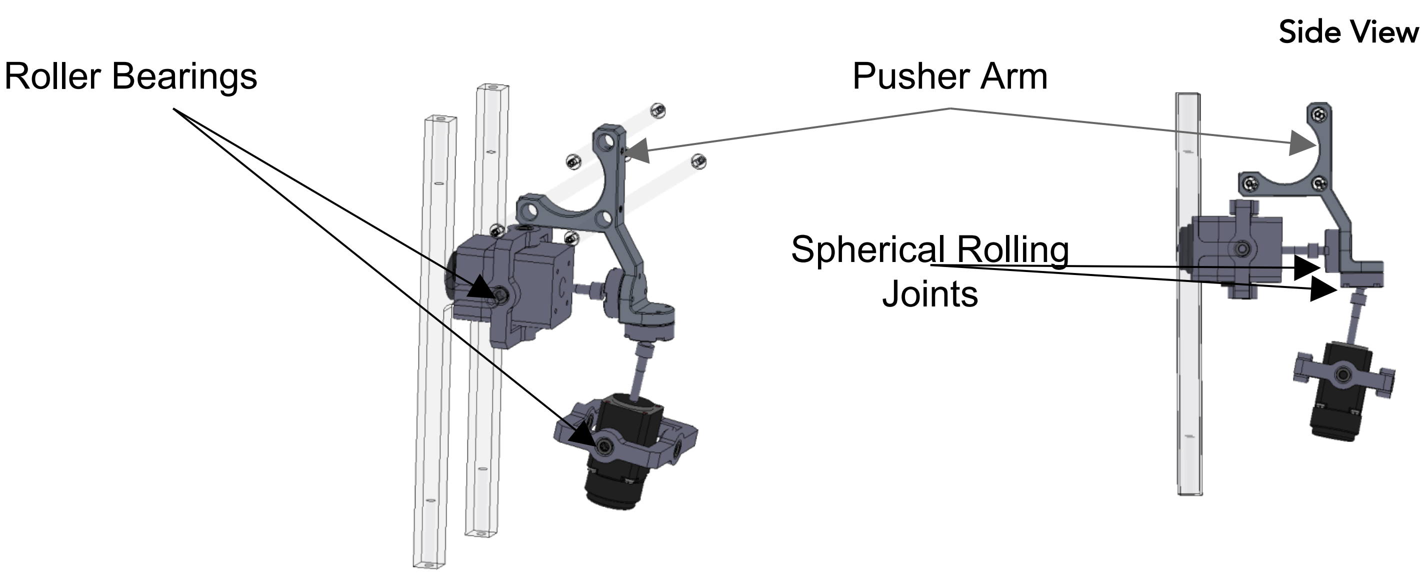
- ➢ Optics must still be assembled
- ➢ Need to validate 3D printed components to prevent breaking
- ➢ Remaining hours account for threading 3D printed parts and precise pinhole alignment, actual assembly will take ~3 hours

Critical Parts

Gimbal Assembly

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





Manufacturing: Mechanical

Critical Parts

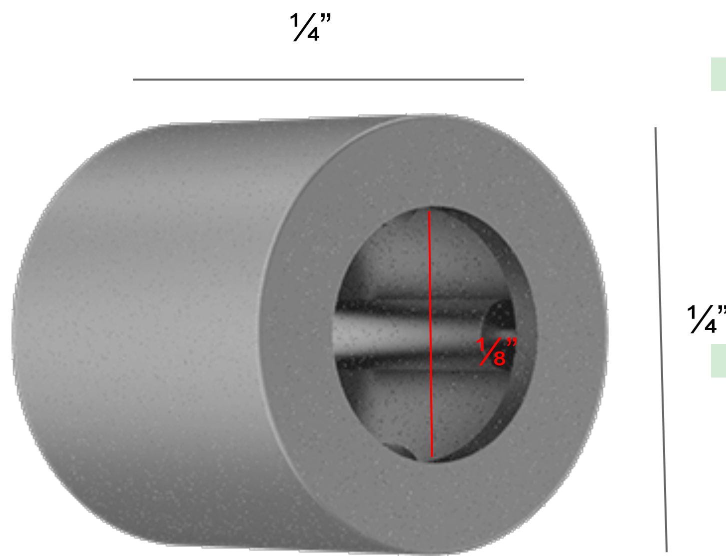
Needle Roller Bearing

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

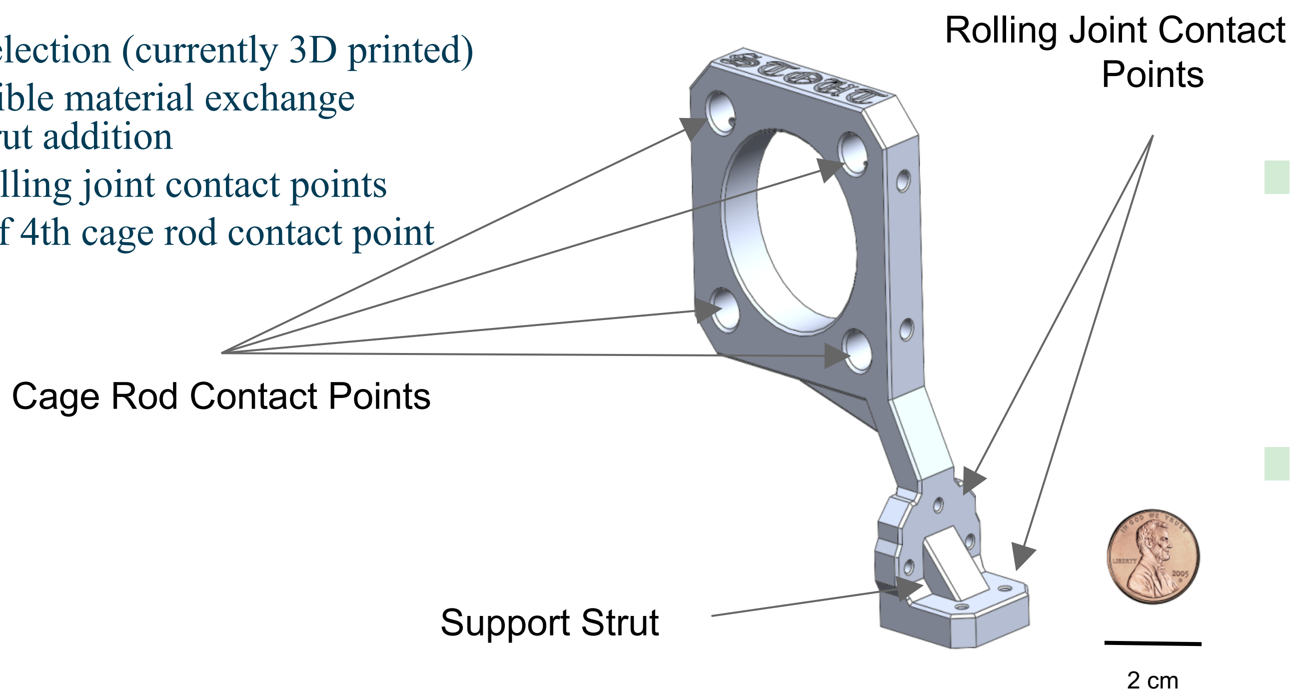
Pusher Arm

Possible Issue(s):

- "Give" in pusher arm could lead to pointing inaccuracies
- Possible cracking due to prolonged stress from pointing
- "Slipping" due to losended set screws

Solution(s):

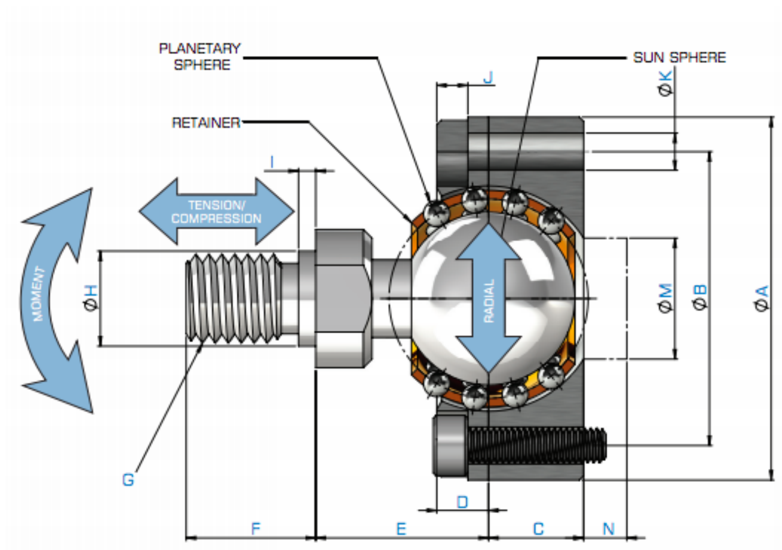
- Material selection (currently 3D printed)
    - Possible material exchange
- Support strut addition
- Squared rolling joint contact points
- Addition of 4th cage rod contact point



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
- ➢ Currently developing Monte Carlo Simulation (Ian), ran into problems with triangulating pointing angle after random displacements are added



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: Mechanical

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	Environmental Monitoring & Control	Instrumentation and Control	Data Acquisition	Electric Power System
Sun Sensor	Heating Pads (x2)	Spectrometer (x2)	UDOO	Converter Prototypes (x4)
	Thermal Couples (x7)	Stepper Motors	USB Sticks	Capacitors
	Pressure Sensor	Stepper Motor Encoders	USB Hub	Resistors
	Humidity Sensor	Stepper Motor Control Board		
	Camera	Rotating Mount		
		UV Photodiode		

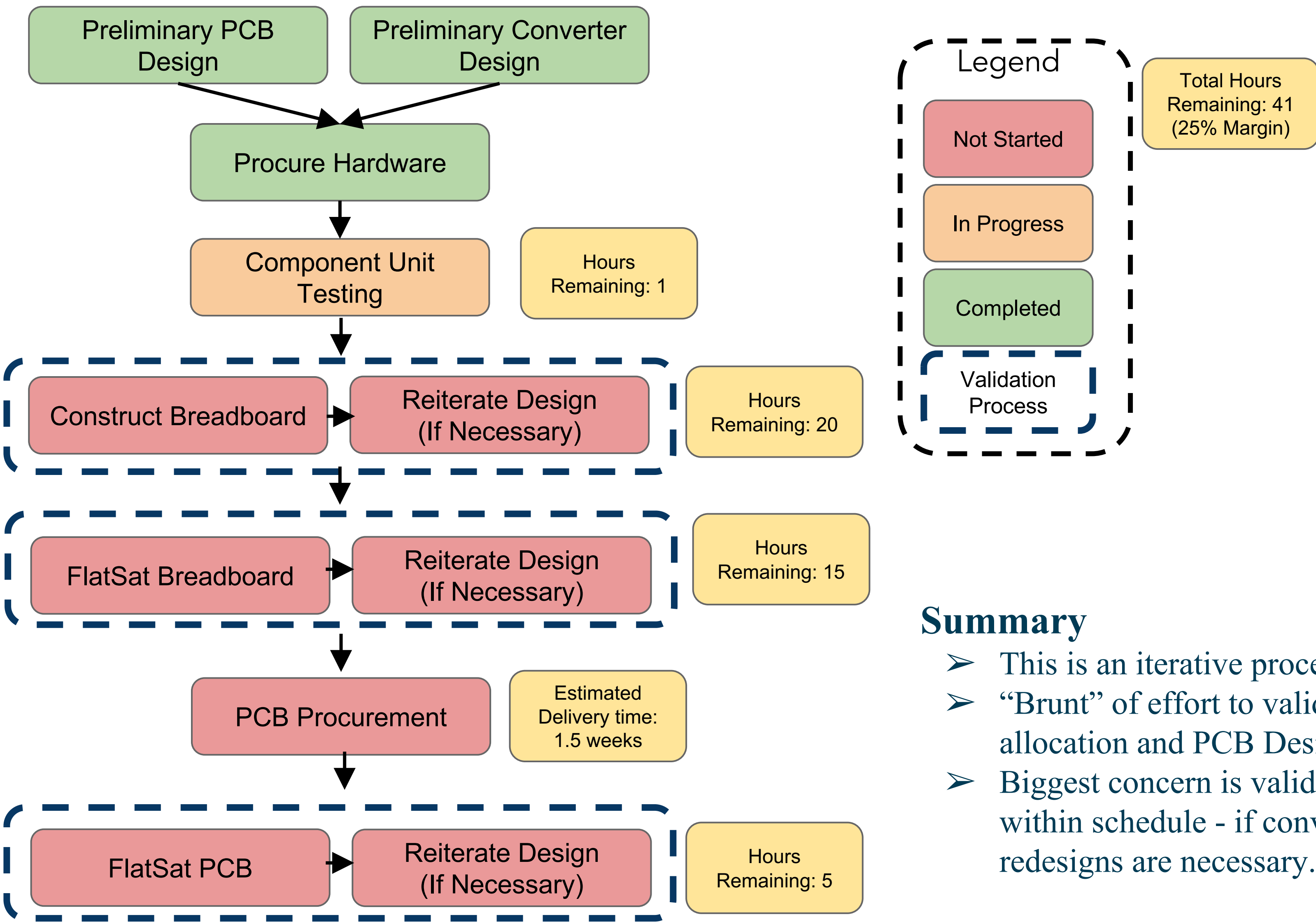
Legend
- Not Started
- In Progress
- Procured
- Sub-System

Summary

➢ Converters are the only component that will be manufactured

➢ Every other electrical component has been procured

Electrical Manufacturing Integration Plan



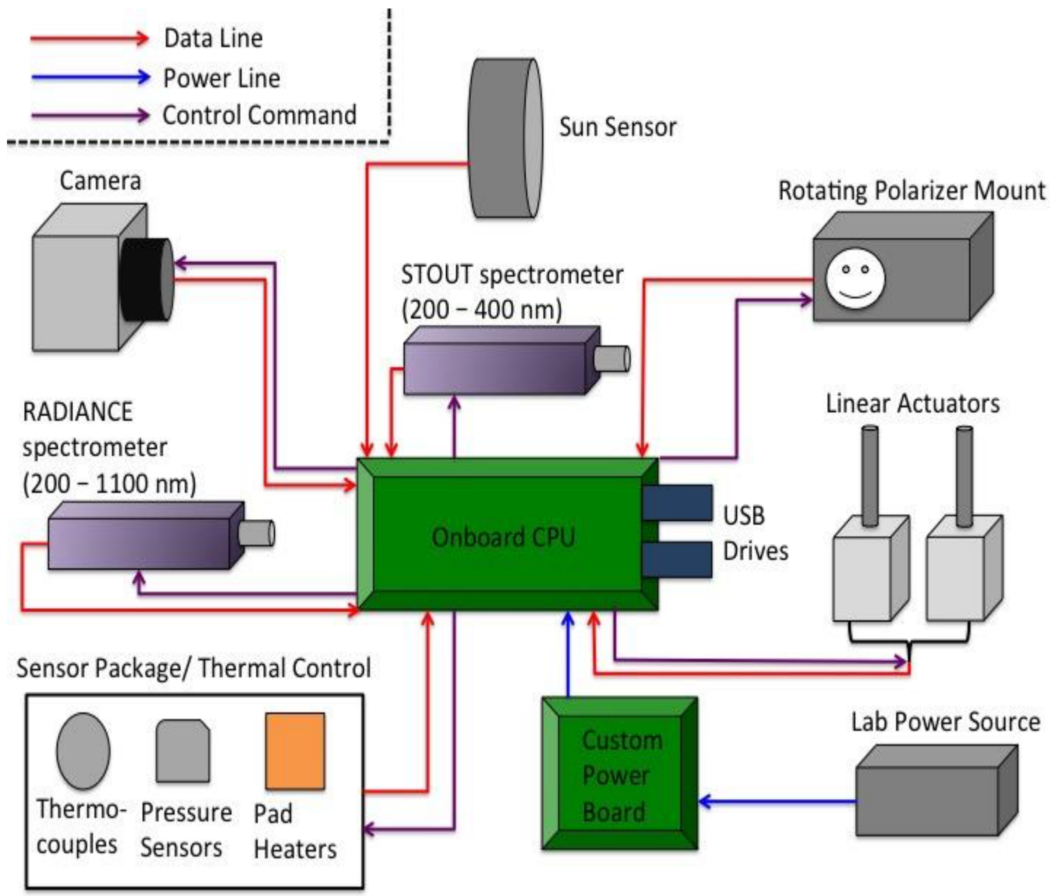
Summary

- 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.

FlatSat Test

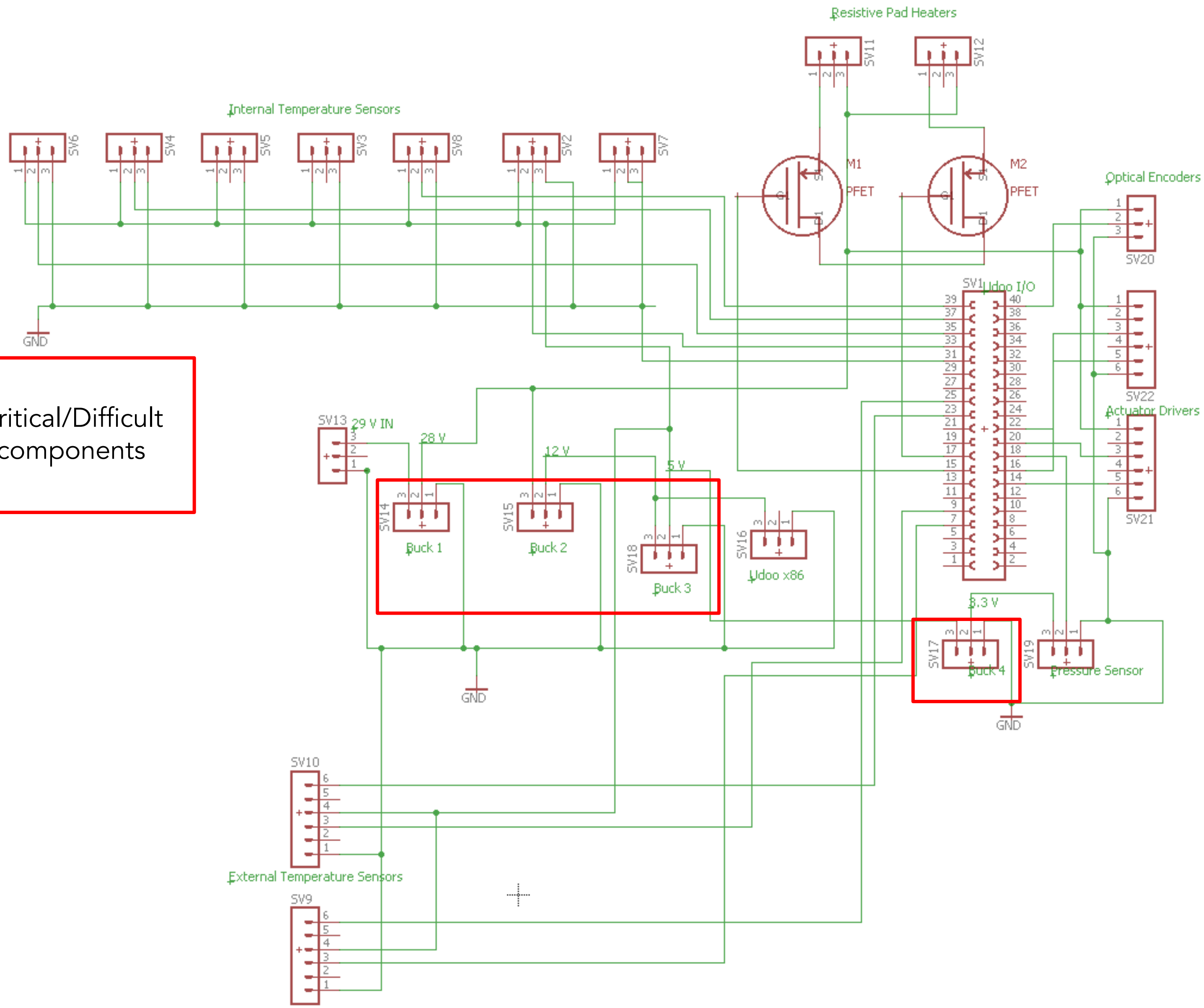
- **Purpose:** Determine that all of the components integrate and operate functionally
- **Procedure**
  - Integrate electronics outside of the CubeSat structure
  - Verify expected voltages and currents with a multimeter
  - Calculate and verify expected power draws

Simplified FlatSat Test Connections



Manufacturing: Electrical

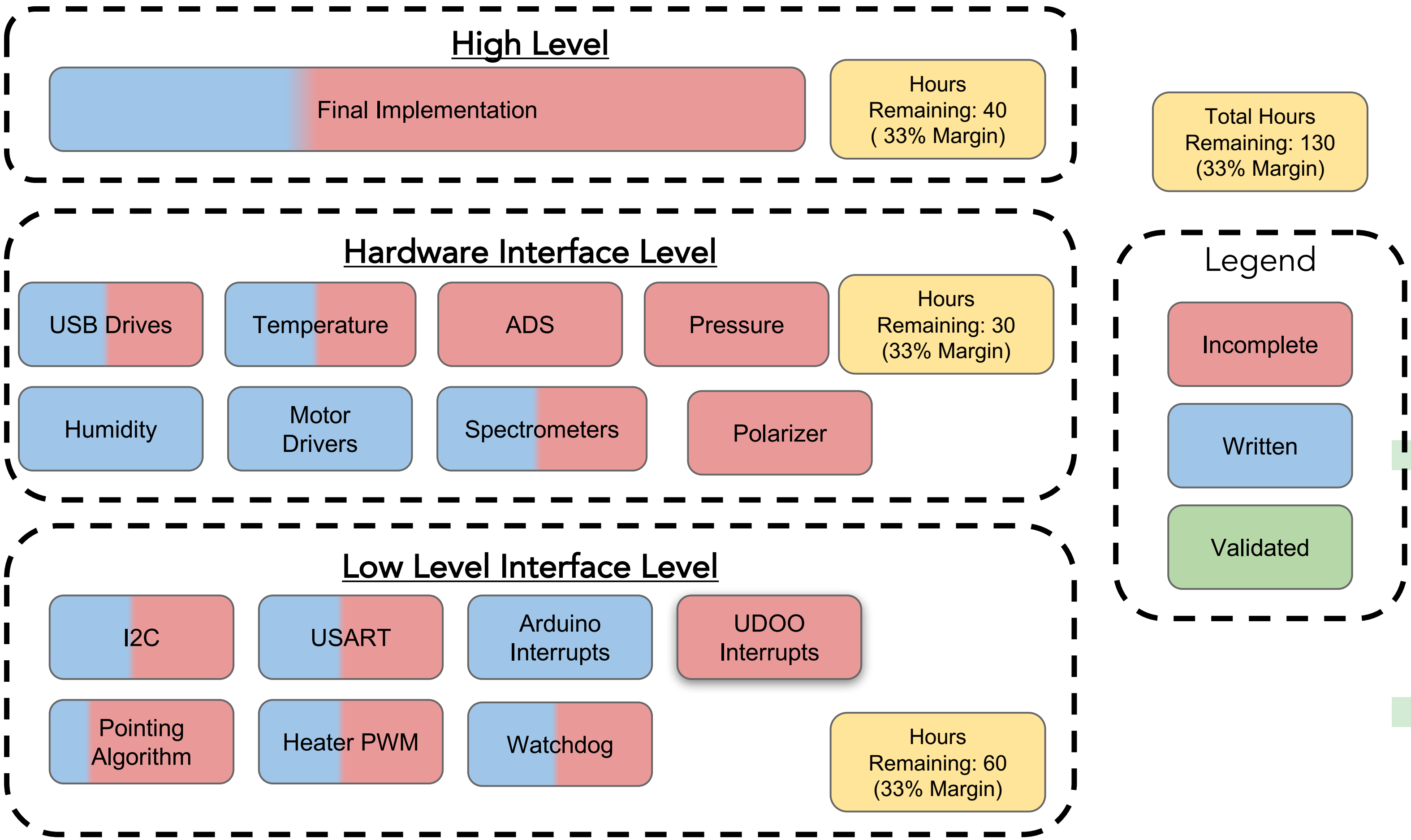
PCB Circuit Design



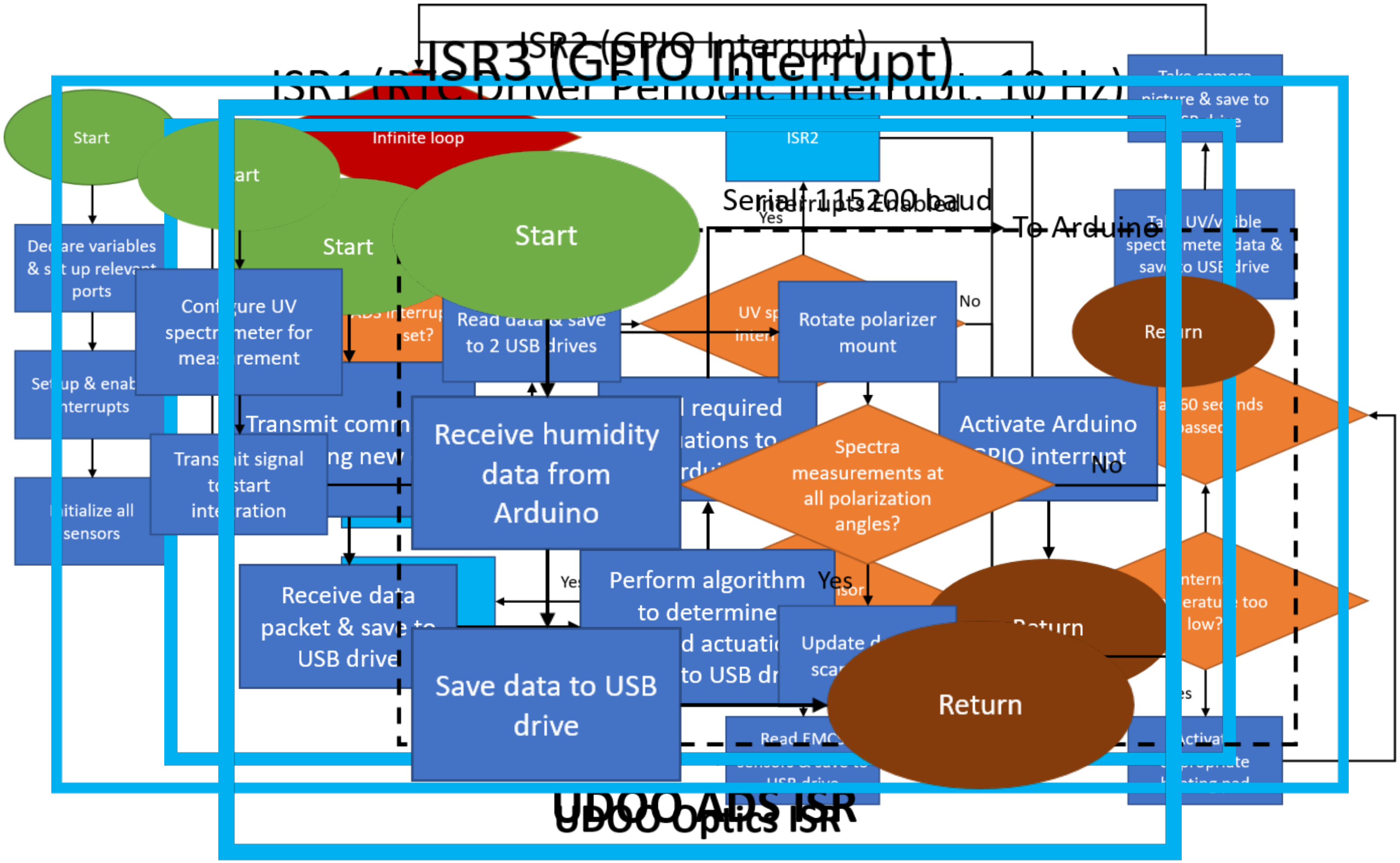
Critical/Difficult components

Manufacturing: Software

Software Status

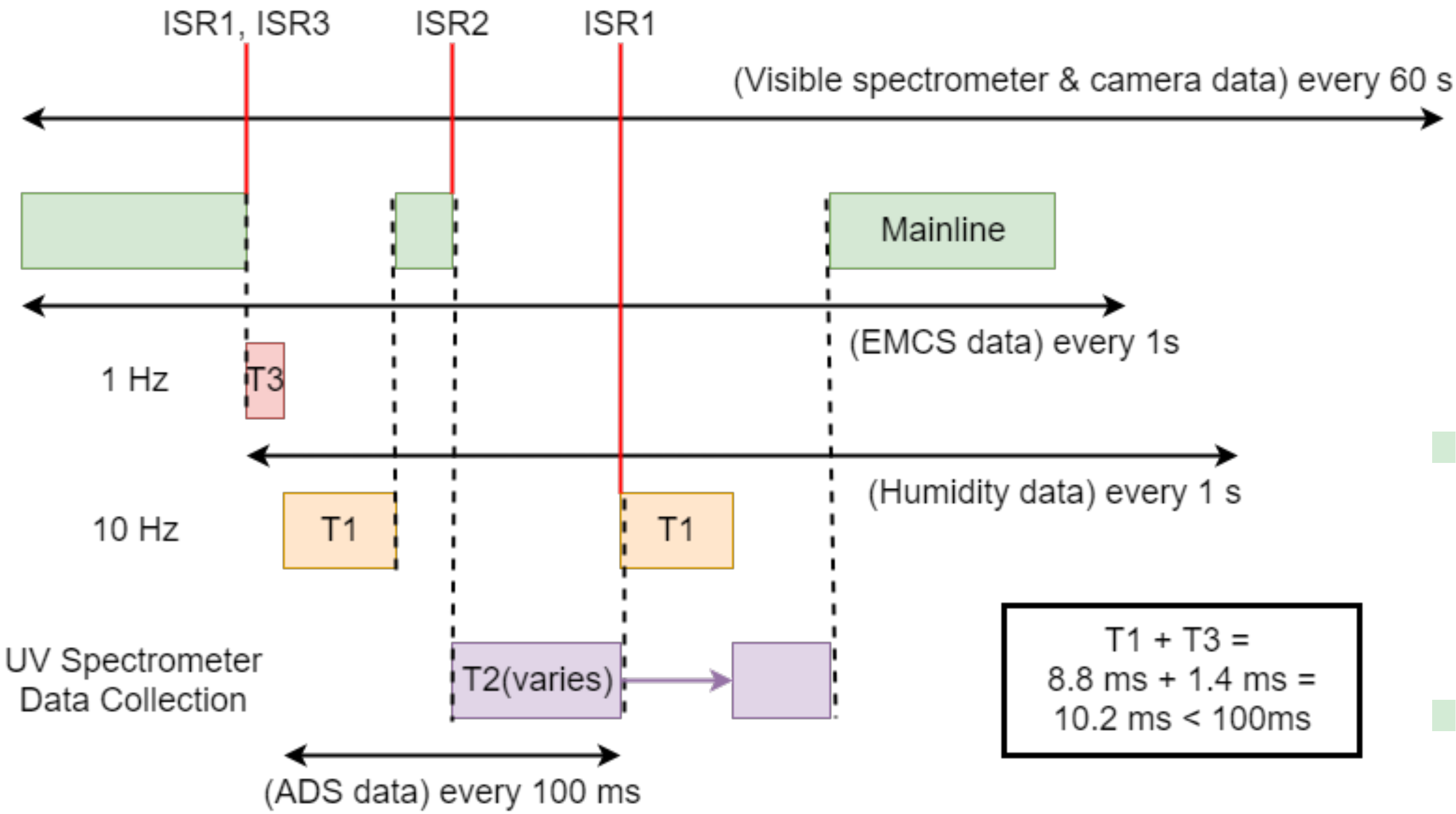


Software Flow: Single-Board Computer

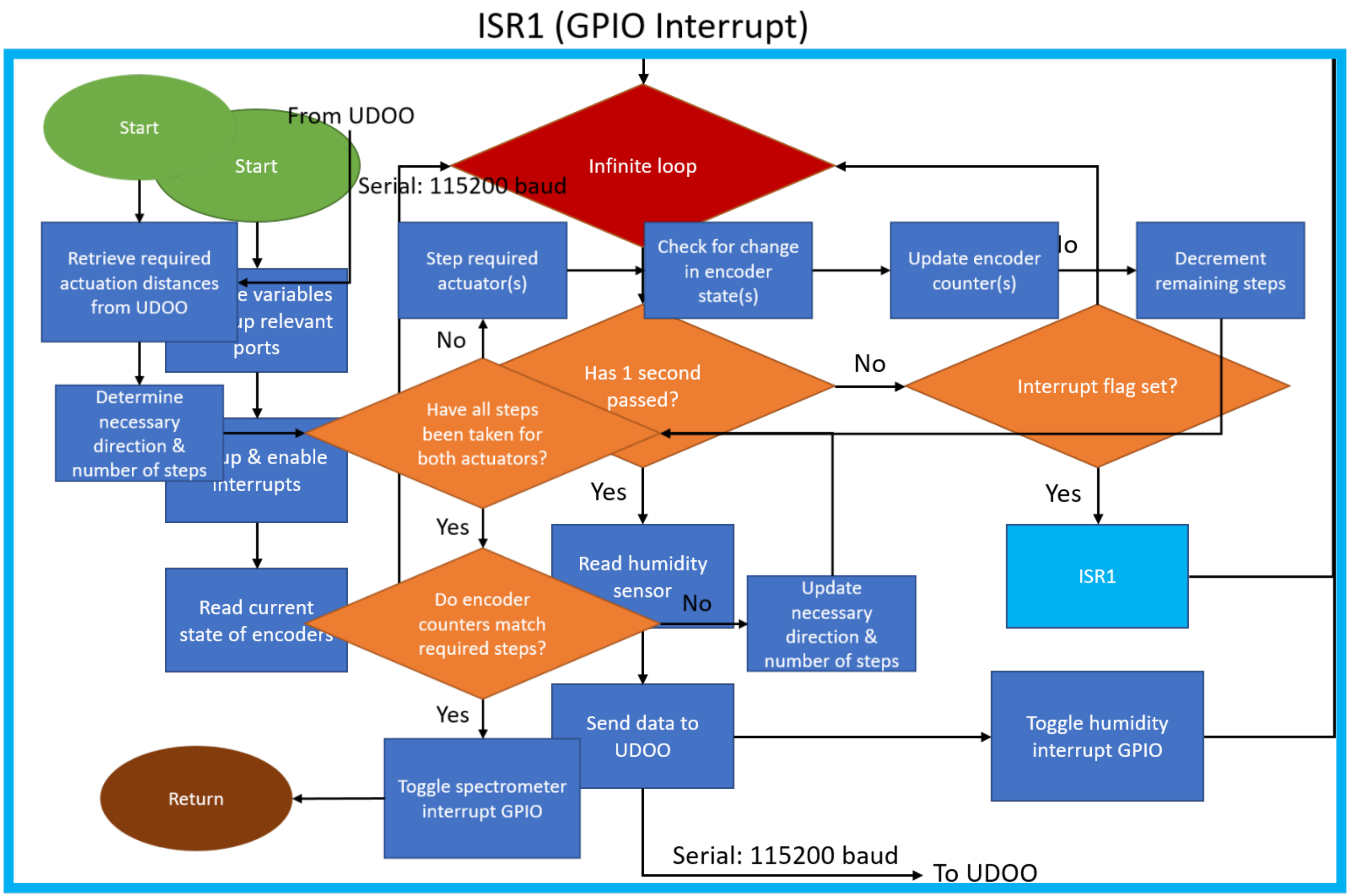


UDOO Humidity ISR

Software Timing: Single-Board Computer

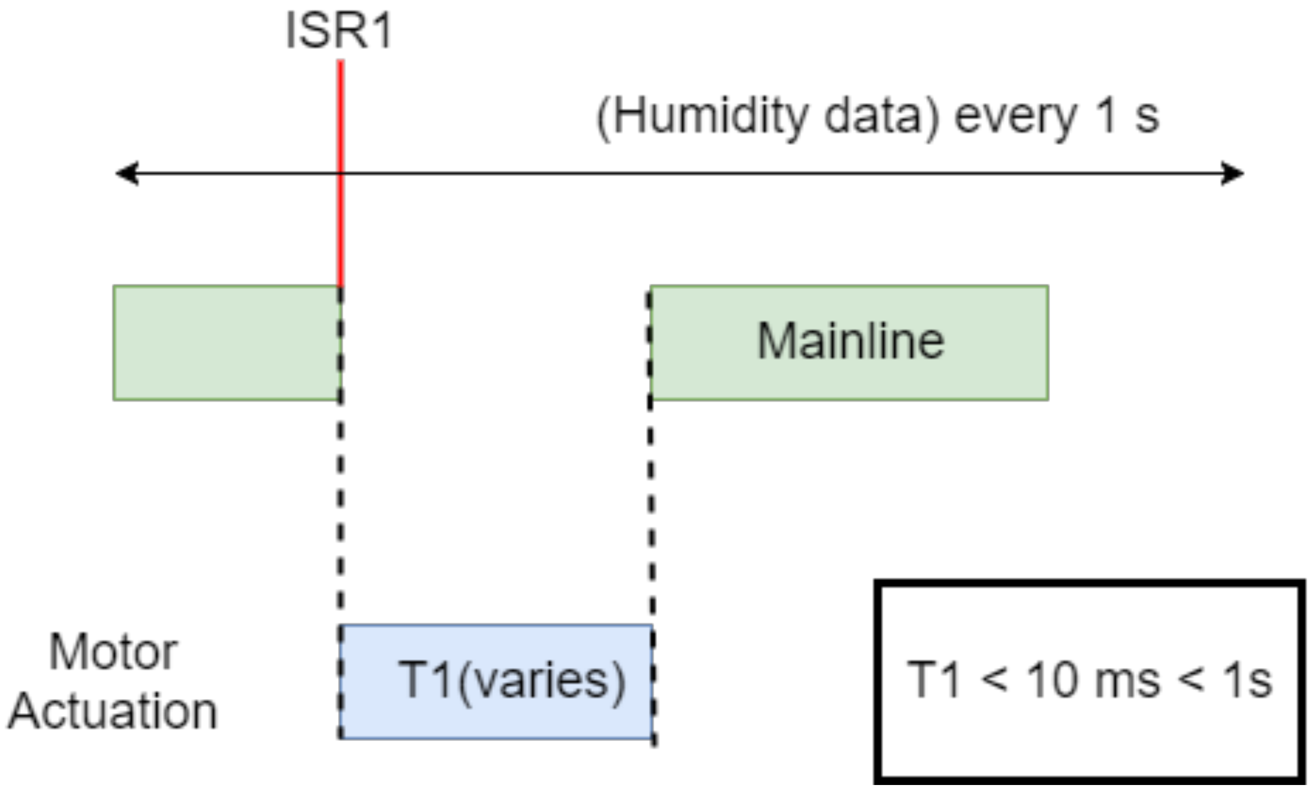


Software Flow: Microcontroller



Arduino Optics Controls ISR

Software Timing: Microcontroller



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

Budget

Budget

Total Expected Cost	With 15% Margin
$6181.39	7108.59

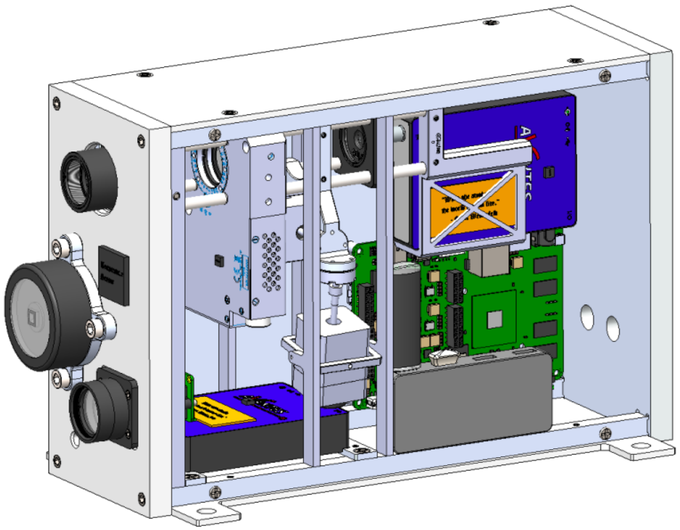
Total Budget with EEF Grant	Expected Remaining Funds (15% Margin)
$7377.00	$268.40

Subsystem	Part	Order Placed	Received	Cost($)	Expected Cost($)
ADS	Solar Mems Sun Sensor	Yes	No		900
	UDOO RS-485 Sheild	No	No		9.95
Optics	Main Lens	Yes	Yes	889.54	
	Polarizer Mount	Yes	Yes	1183.3	
	40um Pinhole	Yes	Yes	60.75	
	Lens/Pinhole Mounts	Yes	Yes	38.52	
	Cage Rods 2in	Yes	Yes	20.86	
	Cage Rods 6in	Yes	Yes	58.39	
	Lens Tubes	Yes	Yes	25.65	
	Thorlabs Shipping	NA	NA	9.02	
	Avantes COL-UV/VIS Collimating Lens	Yes	Yes	123.5	
	Lens Gloves/Cleaner	No	No		10
	UV Photodiode	Yes	Yes	70.39	
TCS	Temperature Sensors	Yes	Yes	15.8	
	Pressure Sensor	Yes	No		59.95
	Resistive Pad Heaters	Yes	No	72.6	
	Humidity Sensor	Yes	Yes	16.95	
	Transceiver Breakout	Yes	Yes	9.95	
	Thermocouples	Yes	Yes	59.36	
	Heatsinks	Yes	Yes	3.9	
	Insulation(to be returned/refunded)	Yes	Yes	50.55	
	Insulation	Yes	Yes	11.97	
	Lens Heater	No	No		50
	Thermal Tape	Yes	Yes	3.95	
Structure	Aluminum	Yes	Yes	300.43	
	Spherical Roller Bearing	Yes	No	391.5	
	Spherical Roller Bearing	No	No		391.5
EPS	Converters	Yes	Yes	36.81	
	Wires	Yes	Yes	16.95	
	PCB	No	No		160
Various	Gantt Chart Software	NA	NA	84.99	
	Printing	NA	NA	43.36	
Controls	Stepper Motor	Yes	No		494.7
	GPS	Yes	Yes	49.51	
	Motor Controller	Yes	Yes	29.9	
DAQ	Camera	Yes	Yes	45	
	USB Hub	Yes	Yes	16.99	
	USB Drives	No	No		50
	Logic Level Converters	Yes	Yes	28	
	UDOO x86 Ultra	Yes	Yes	286.9	
Totals				4055.29	2126.1

Table of Contents

Sections	Backups
Overview	EMCS
Schedule	ADS
Manufacturing: Mechanical	Optical Components
Manufacturing: Electrical	Instrument Control Components EPS
Manufacturing: Software	DAQ
Budget	Photodiode for Testing
	Pointing Angle Algorithm
	Parts to Manufacture

System Overview



Summary

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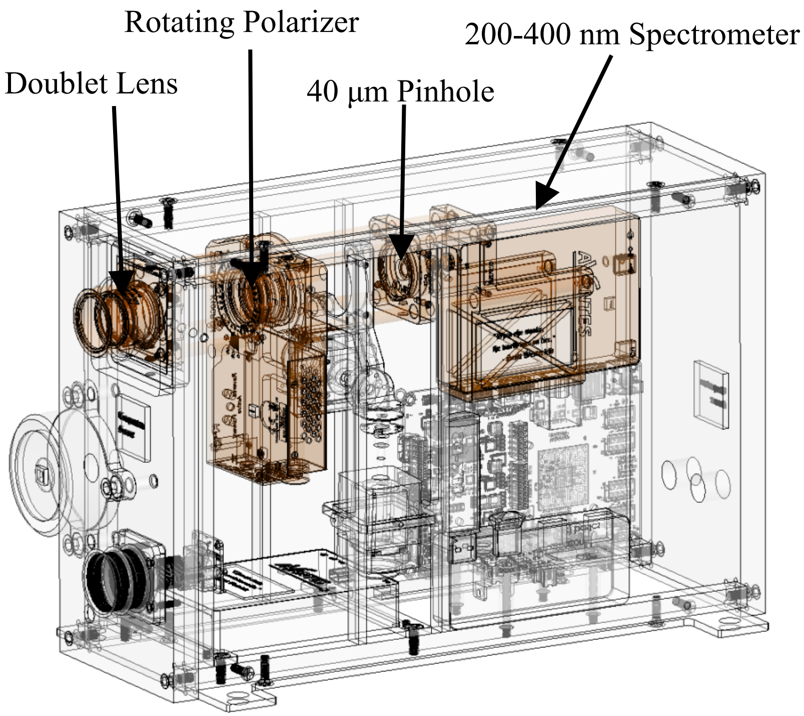
Power Consumption	74.5 W
Flight Environment	-70℃ - 20℃
Materials	Aluminum 6061 (Structure) Polyisocyanurate (Insulation)

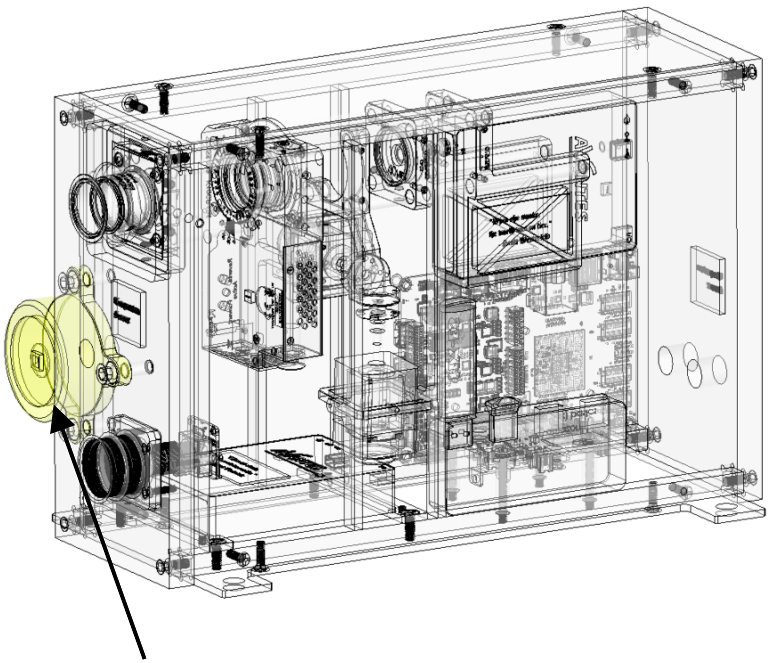
Optics



Components

- Thorlabs UV Doublet Lens: Focus light in UV spectrum
- Thorlabs Mounted Wire Grid Polarizer: Control input light polarization angle
- Thorlabs Precision Pinhole: Isolate spot on Sun
- Avantes Collimating Lens: Feed light into spectrometer
- Avantes Spectrometer: Measure light intensity as function of wavelength
- Thorlabs Optics Cage: Mount and align optical components

Attitude Determination System

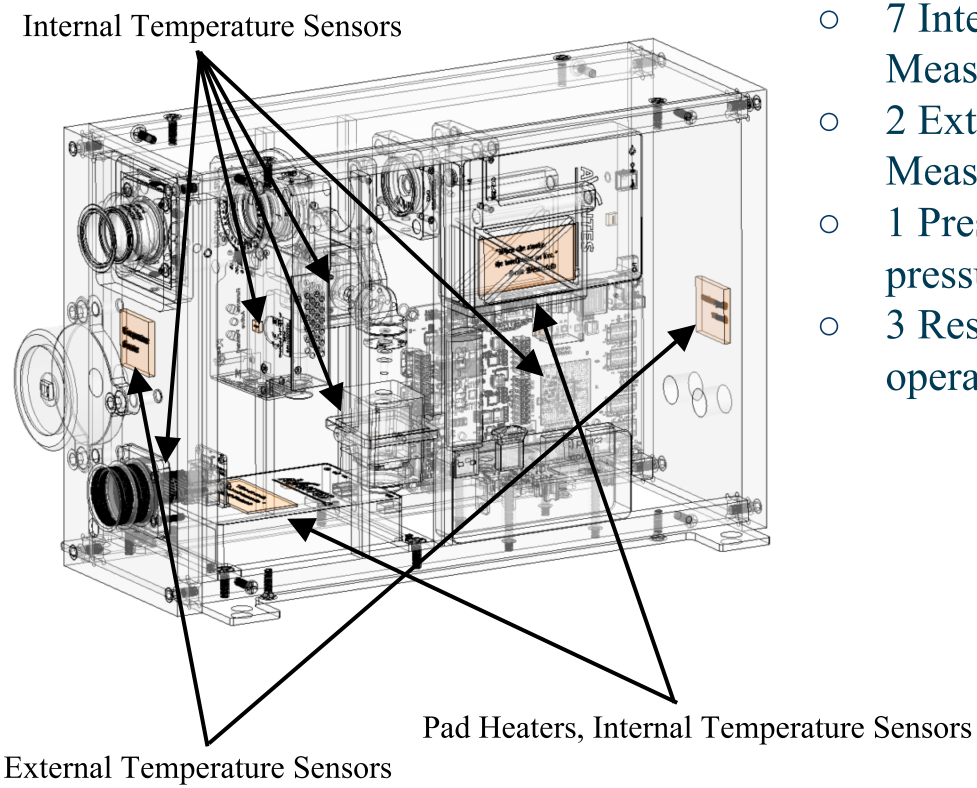


Sun Sensor

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

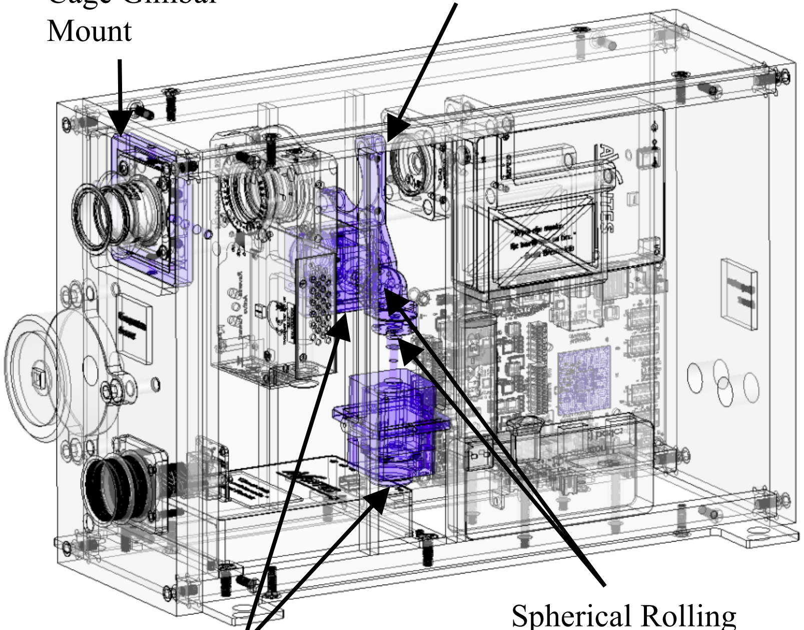
Environmental Monitoring & Control System



Components

- 7 Internal Temperature Sensors: Measure internal temperature
- 2 External Temperature Sensors: Measure External Temperature
- 1 Pressure Sensor: Measure external pressure
- 3 Resistive Pads: Keep module at an operable temperature

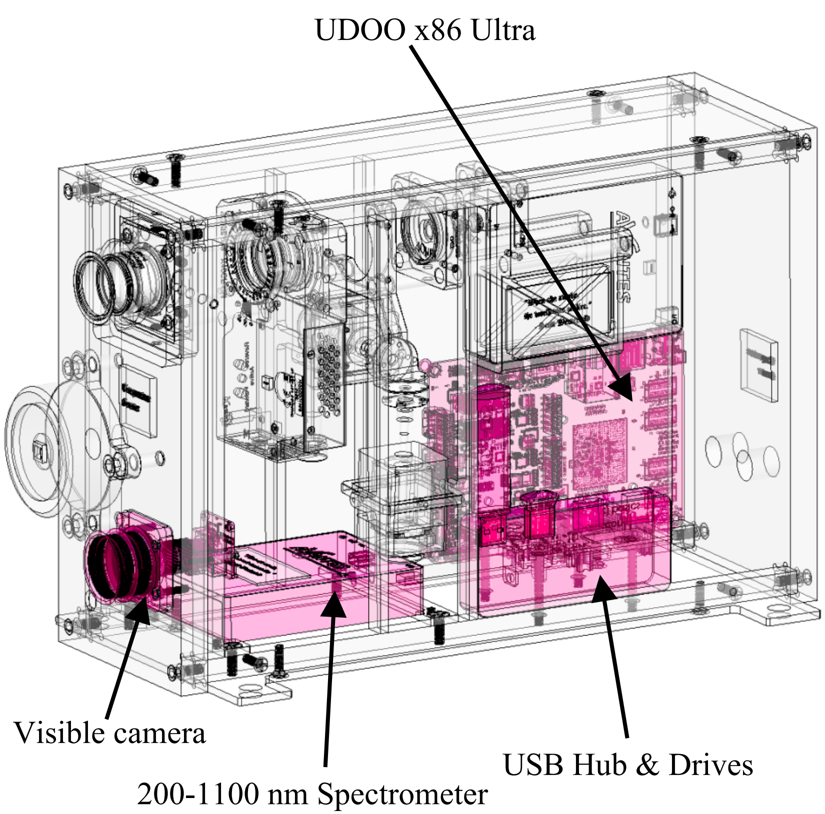
Pointing Controls



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

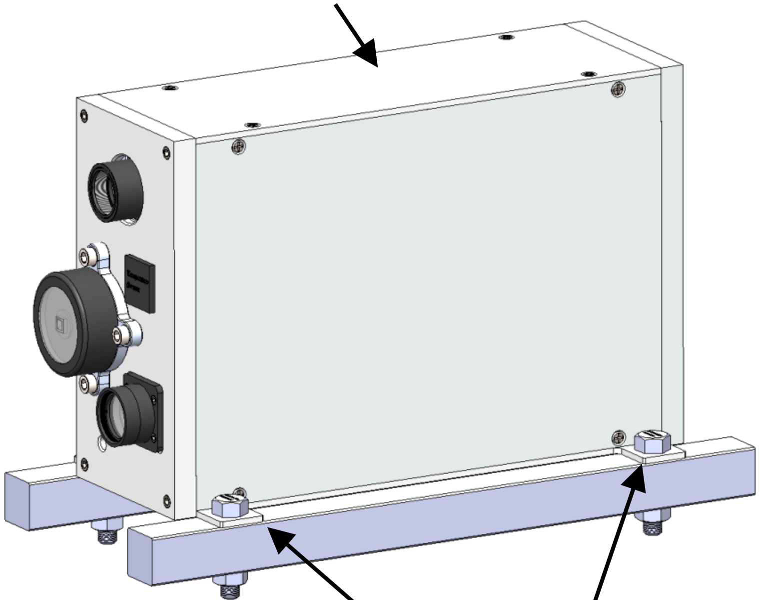
CPU and Data Acquisition



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

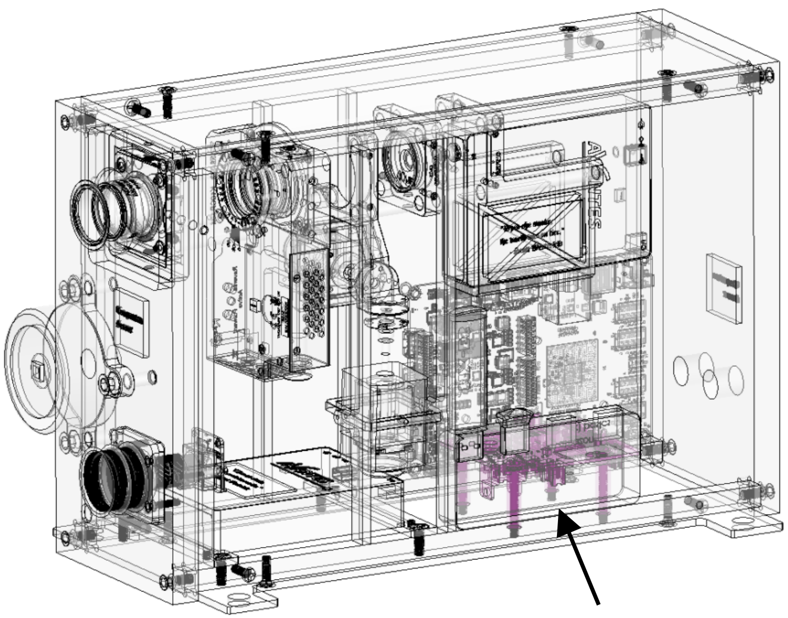
Structure



Components

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

Electrical Power System

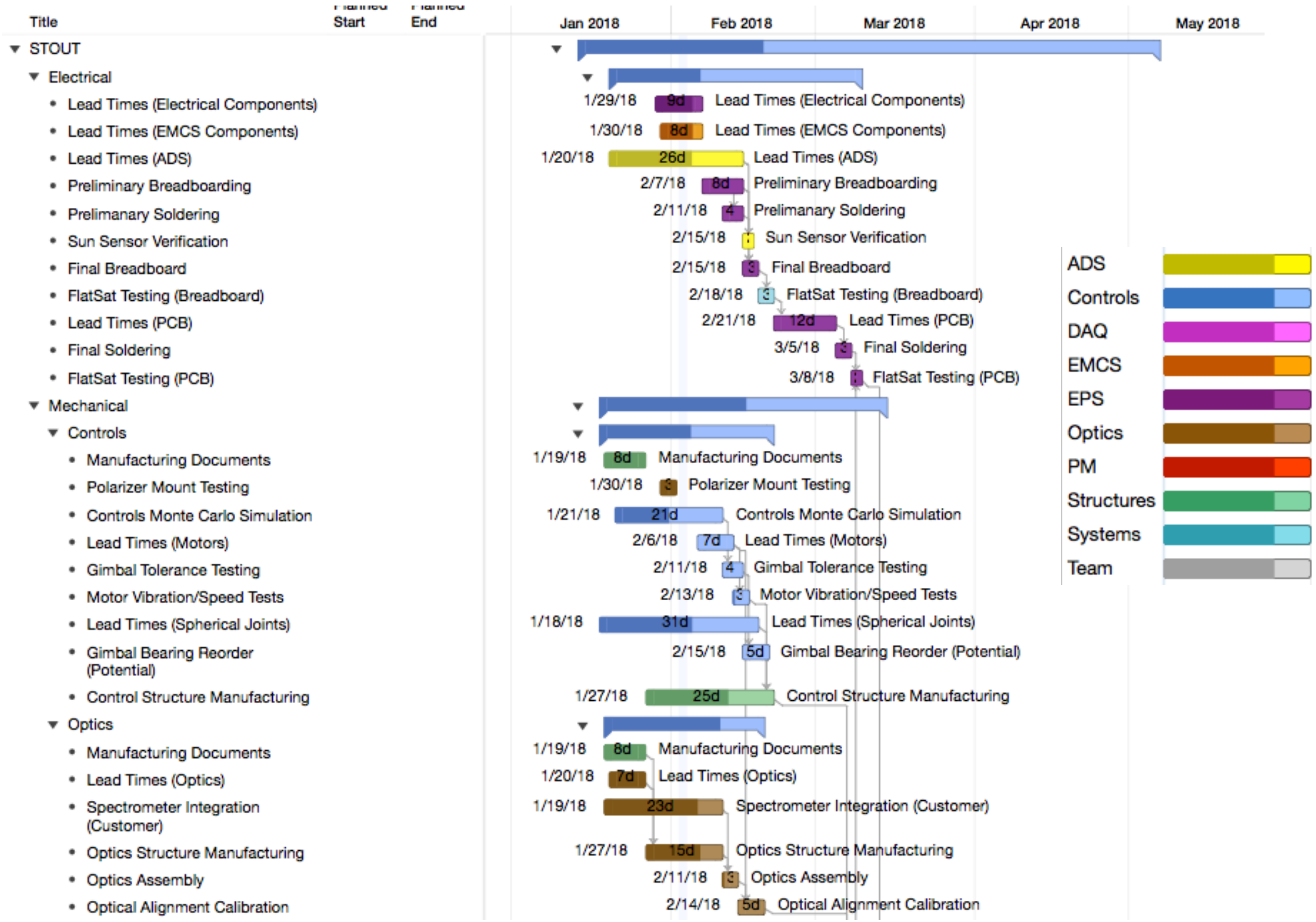


Printed Circuit Board

Components

- Custom PCB to distribute power to subsystems

GANTT Chart


Title
Planned Start
Planned End
Jan 2018
Feb 2018
Mar 2018
Apr 2018
May 2018
STOUT
Electrical
Lead Times (Electrical Components)
Lead Times (EMCS Components)
Lead Times (ADS)
Preliminary Breadboarding
Prelimanary Soldering
Sun Sensor Verification
Final Breadboard
FlatSat Testing (Breadboard)
Lead Times (PCB)
Final Soldering
FlatSat Testing (PCB)
Mechanical
Controls
Manufacturing Documents
Polarizer Mount Testing
Controls Monte Carlo Simulation
Lead Times (Motors)
Gimbal Tolerance Testing
Motor Vibration/Speed Tests
Lead Times (Spherical Joints)
Gimbal Bearing Reorder (Potential)
Control Structure Manufacturing
Optics
Manufacturing Documents
Lead Times (Optics)
Spectrometer Integration (Customer)
Optics Structure Manufacturing
Optics Assembly
Optical Alignment Calibration
1/29/18 9d Lead Times (Electrical Components)
1/30/18 8d Lead Times (EMCS Components)
1/20/18 26d Lead Times (ADS)
2/7/18 8d Preliminary Breadboarding
2/11/18 4 Prelimanary Soldering
2/15/18 Sun Sensor Verification
2/15/18 Final Breadboard
2/18/18 FlatSat Testing (Breadboard)
2/21/18 12d Lead Times (PCB)
3/5/18 Final Soldering
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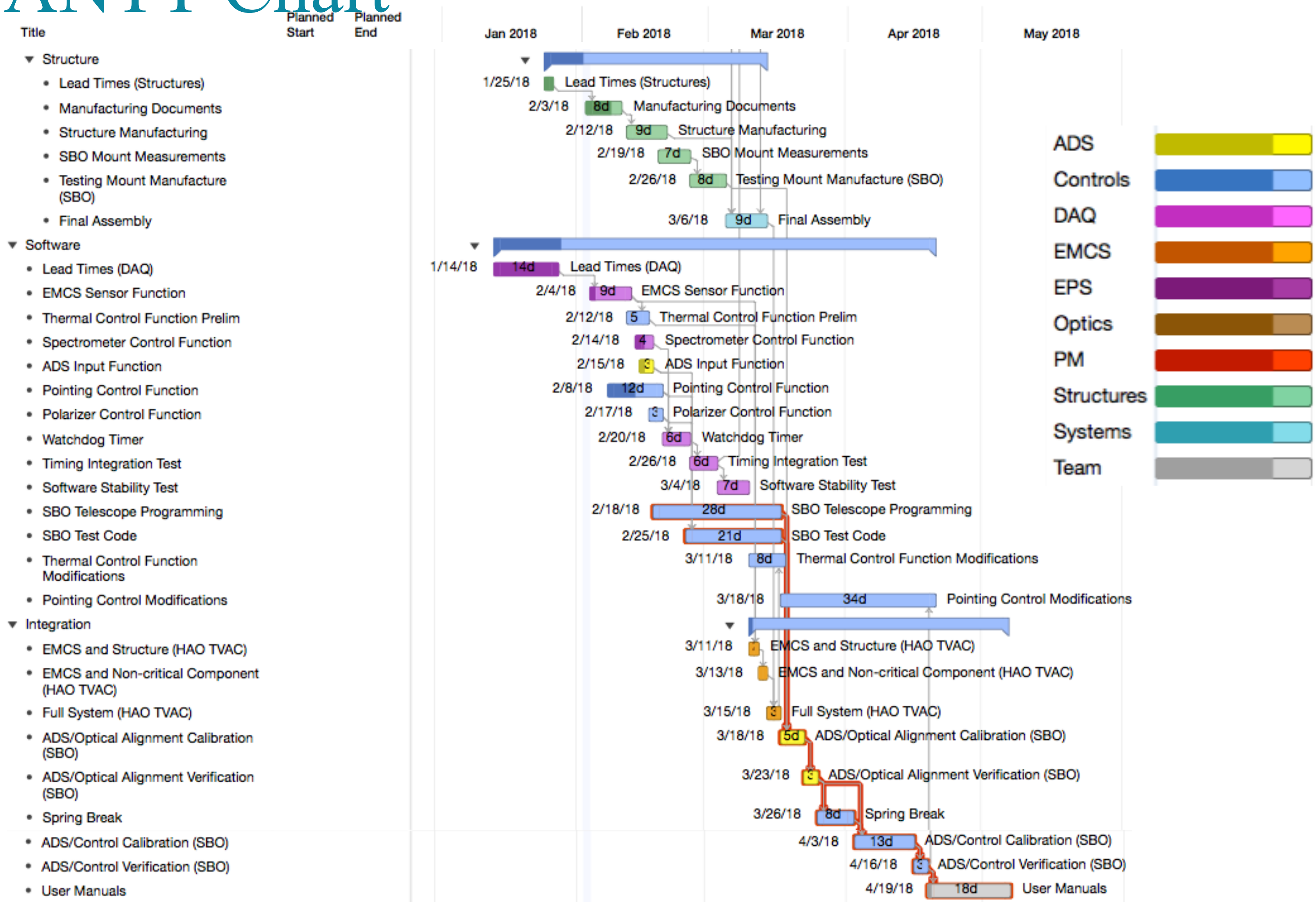
1/30/18 Polarizer Mount Testing
1/21/18 21d Controls Monte Carlo Simulation
2/6/18 7d Lead Times (Motors)
2/11/18 4 Gimbal Tolerance Testing
2/13/18 Motor Vibration/Speed Tests
1/18/18 31d Lead Times (Spherical Joints)
2/15/18 5d Gimbal Bearing Reorder (Potential)
1/27/18 25d Control Structure Manufacturing
1/19/18 8d Manufacturing Documents
1/20/18 7d Lead Times (Optics)
1/19/18 23d Spectrometer Integration (Customer)
1/27/18 15d Optics Structure Manufacturing
2/11/18 Optics Assembly
2/14/18 5d Optical Alignment Calibration
ADS
Controls
DAQ
EMCS
EPS
Optics
PM
Structures
Systems
Team

GANTT Chart



Title
Planned Start
Planned End
Jan 2018
Feb 2018
Mar 2018
Apr 2018
May 2018
Structure
Lead Times (Structures)
Manufacturing Documents
Structure Manufacturing
SBO Mount Measurements
Testing Mount Manufacture (SBO)
Final Assembly
Software
Lead Times (DAQ)
EMCS Sensor Function
Thermal Control Function Prelim
Spectrometer Control Function
ADS Input Function
Pointing Control Function
Polarizer Control Function
Watchdog Timer
Timing Integration Test
Software Stability Test
SBO Telescope Programming
SBO Test Code
Thermal Control Function Modifications
Pointing Control Modifications
Integration
EMCS and Structure (HAO TVAC)
EMCS and Non-critical Component (HAO TVAC)
Full System (HAO TVAC)
ADS/Optical Alignment Calibration (SBO)
ADS/Optical Alignment Verification (SBO)
Spring Break
ADS/Control Calibration (SBO)
ADS/Control Verification (SBO)
User Manuals
1/25/18
2/3/18 8d
2/12/18 9d
2/19/18 7d
2/26/18 8d
3/6/18 9d
1/14/18 14d
2/4/18 9d
2/12/18 5
2/14/18 4
2/15/18 3
2/8/18 12d
2/17/18 3
2/20/18 6d
2/26/18 6d
3/4/18 7d
2/18/18 28d
2/25/18 21d
3/11/18 8d
3/18/18 34d
3/11/18
3/13/18
3/15/18 3
3/18/18 5d
3/23/18 3
3/26/18 8d
4/3/18 13d
4/16/18 3
4/19/18 18d
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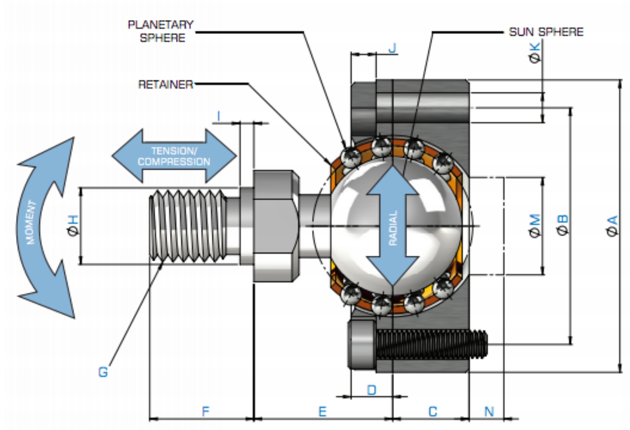
Critical Parts

Spherical Rolling Joint

- ➢ Component Conformance: “Each joint comes with a certificate of conformance indicating the actual tested accuracy” - Myostat Motion Control
  - ○ 2.5 um backlash
  - ○ 15 deg max swing angle
  - ○ 128 N Max Dynamic Load
  - ○ 100 N Max Static Load
- ➢ Relating error propagation in Rolling Joints, Pusher Arm, and Roller Bearings to optical pointing errors
- ➢ Currently developing Monte Carlo Simulation (Ian)



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

Electrical Schedule

- Tue 2/6 - converter components arrive
- 2/6 - 2/8 component unit testing
- 2/8 - 2/15 converter breadboarding and testing
- 2/6 - 2/15 PCB evaluation with Dr. Erickson (EE)
- 2/15 - 2/22 Flatsat testing on breadboard (adjust if this is supposed to happen later - can stretch the 2 above items)
- 2/22 PCB board ordered from Advanced Circuits (1 - 1.5 week delivery)
- Flatsat test with PCB after.

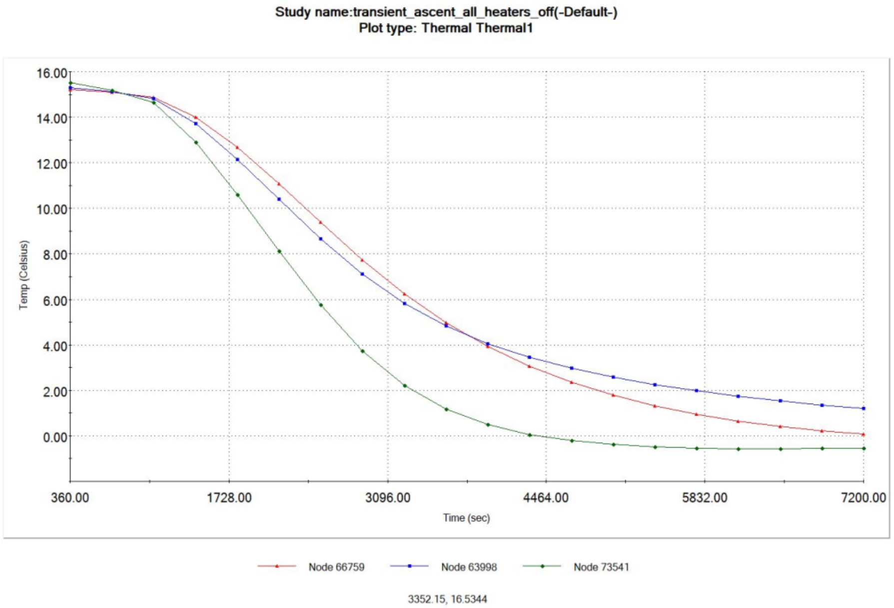
Mechanical Processes

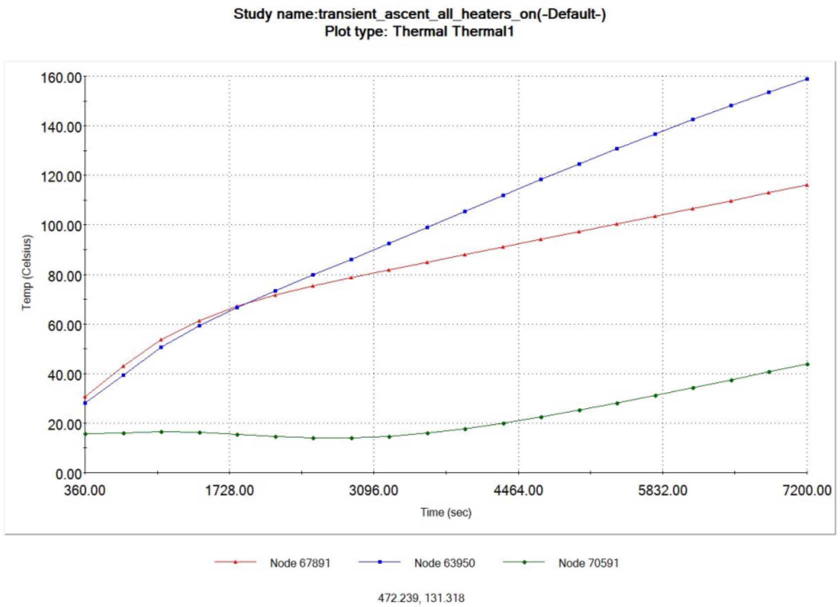
Computer numerical control (CNC) is the automation of machine tools by means of computers executing pre-programmed sequences of machine control commands

Computer-aided manufacturing (CAM) is the use of software to control machine tools and related ones in the manufacturing of workpieces

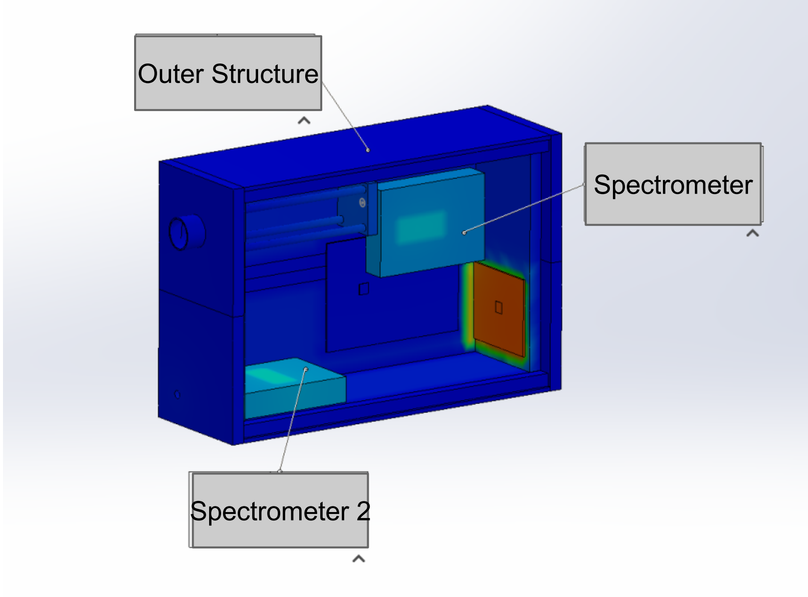
Stereolithography is a form of 3-D printing technology used for creating models, prototypes, patterns, and production parts in a layer by layer fashion using photopolymerization, a process by which light causes chains of molecules to link, forming polymers

Thermal Simulations



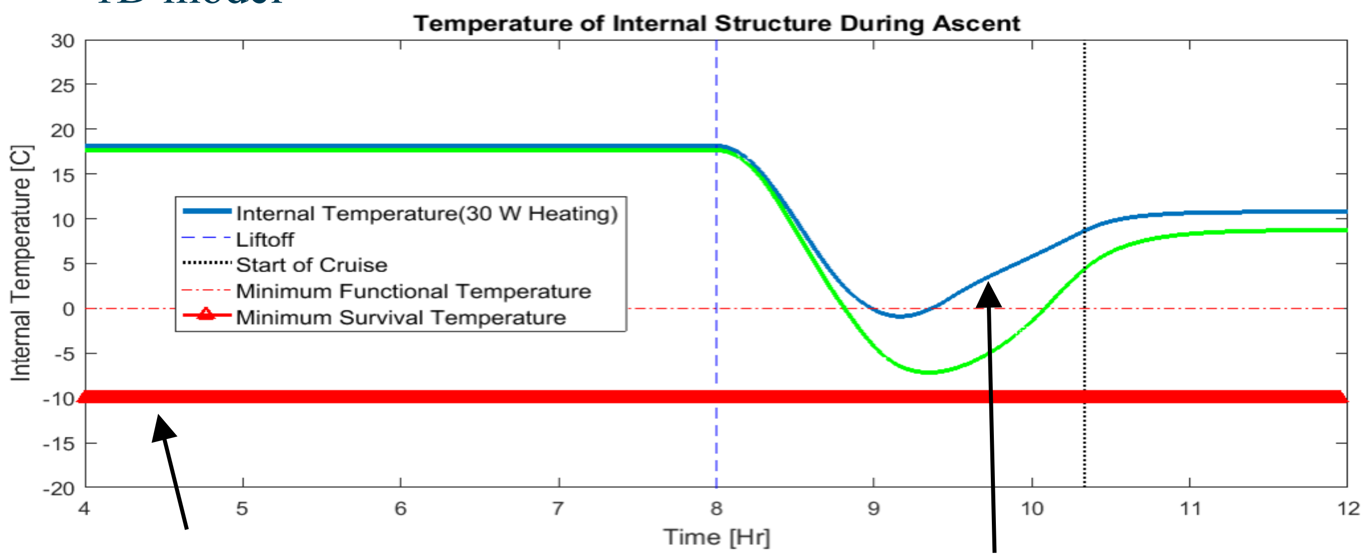


- Concerned about spectrometer survival during ascent
- Two simulations were ran simulating the environmental conditions of ascent; one with heaters on and one with heaters off
- With active heater control, we will be able to keep spectrometers at survivable temperature



EMCS Requirements

- EMCS proven valid during cruise and descent, however ascent operational temperature margins were too close to validate through 1D model



Survival temperature determined by spectrometer survivability temperature

Internal Temperature (20 W Heating)

Design Requirements: EMCS

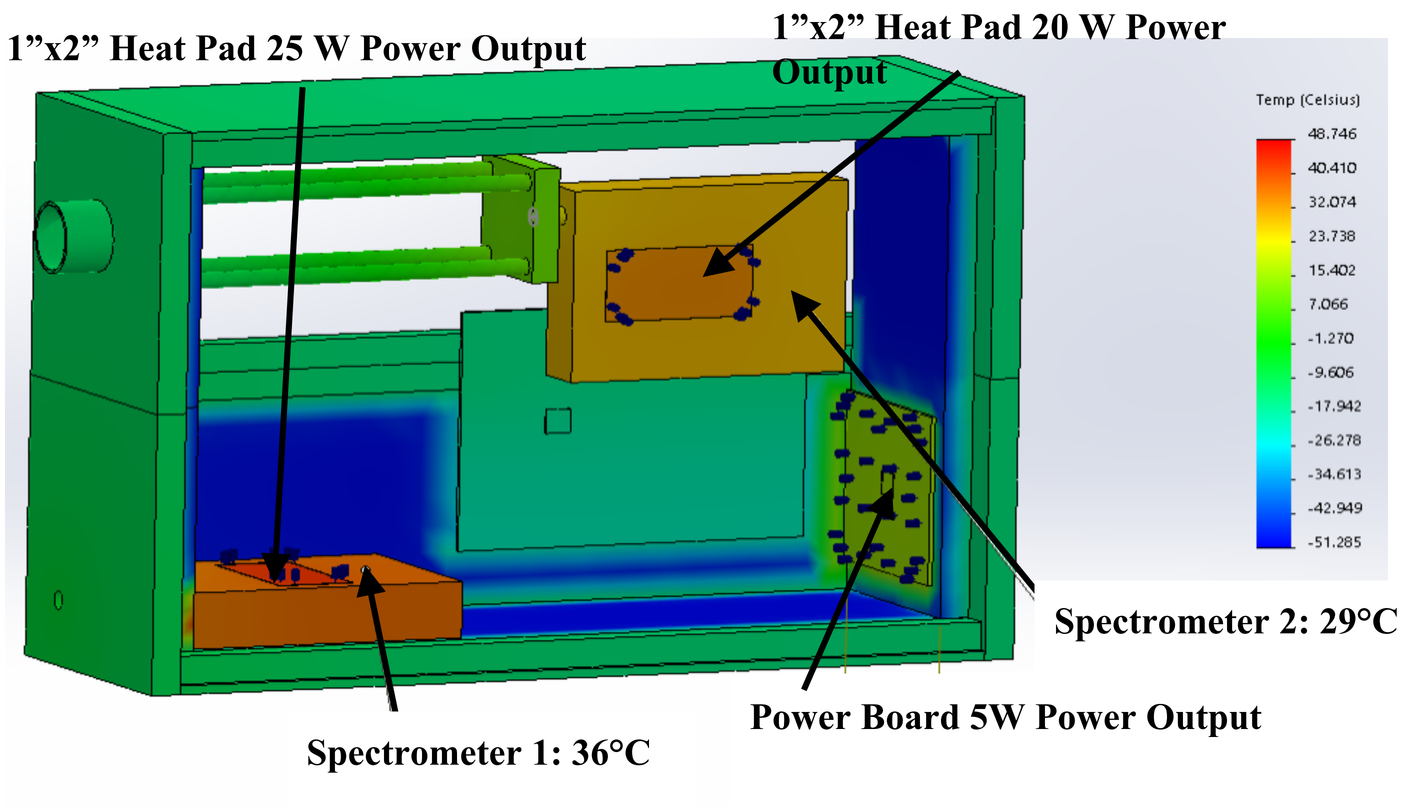
Solidworks 3D Thermal Modeling

- Partial transient model simulated at harshest ascent condition of approximately -65°C at 16 km altitude
- Assumptions
  - Perfect thermal conduction through bonded contacts
  - Convection, conduction and radiation accounted for
  - Power board, and heat pads are only notable heat sources (all other systems not operating during ascent)

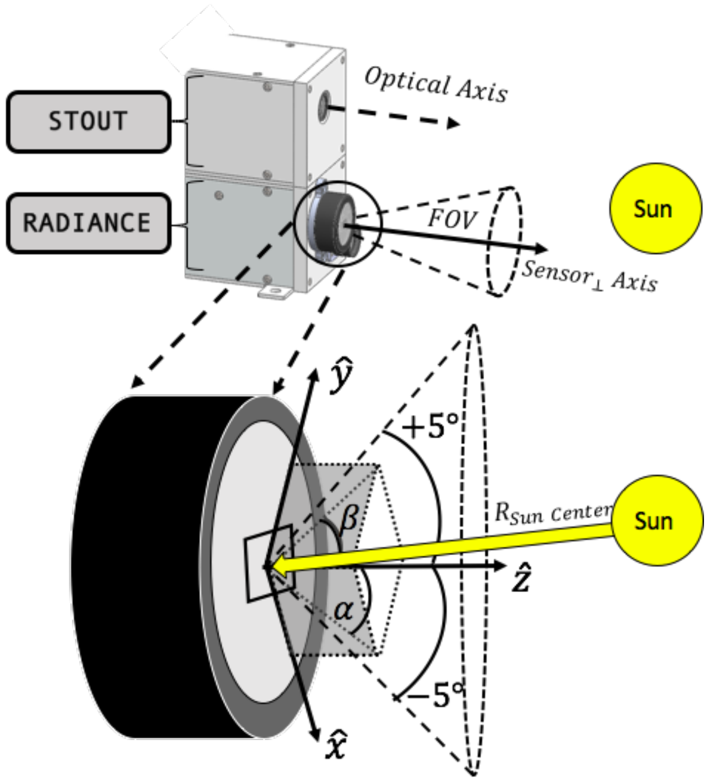
Initial Conditions

Item	Value
STOUT Internal Temp.	15°C (STD sea level)
Ambient Temperature	-65°C (Lower temperature limit of ascent)
Air Convective Heat Transfer Coefficient (External and Internal)	~5 W/m^2K

Expected Spectrometer Temperatures at -65°C Environment



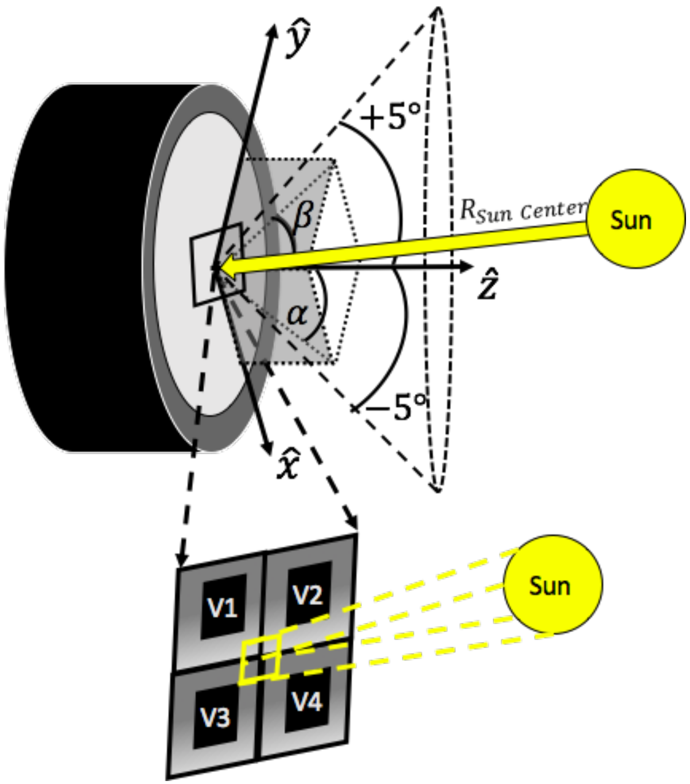
Attitude Determination System



Solar Mems Sun Sensor

- Quadrant photodetector used to measure off-sun angles from generated photocurrents for optics pointing control
- Field of View: dual axes ± 15°
- Accuracy: ± 0.02°
- Serial RS 485 Communication
- Output in Hex
- Requires calibration in conjunction with optical axis

Attitude Determination System



$$x_1 = V_3 + V_4 \qquad y_1 = V_1 + V_4$$

$$x_2 = V_1 + V_2 \qquad y_2 = V_2 + V_3$$

$$F_x = \frac{x_2 - x_1}{x_2 + x_1} \qquad F_y = \frac{y_2 - y_1}{y_2 + y_1}$$

$$\alpha = arctan(C * F_x) \quad \beta = arctan(C * F_y)$$

Parametric Value (C)

** Dependent on Sensor **

Sun Off-Angles (α & β)

- Communicates the sun's position relative to field of view to the system
- Data saved and used in optics controls

Optical System Requirements

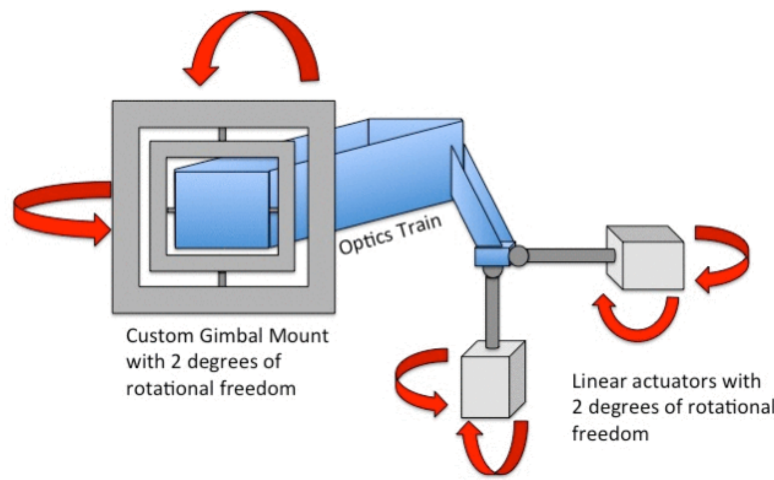
FR2: Take variable polarization angle UV spectrum of multiple points on the Sun

Requirement	Description	Level Met
2.1	Isolation of <= 1’ (0.0167°) spot in the FOV	1
2.2	Take spectrum measurements over the 270 - 400 nm range	3
2.3	Rotate polarizer with <= 0.5° accuracy	2
2.4	Pointing capabilities of +/- 1° in azimuth and +/- 5° in elevation	1

Optical System/Pointing Control

FR 2.4: Pointing capabilities of +/- 5º in azimuth and +/- 1º in elevation

- **Relevant Components**
  - Thorlabs 30mm Cage System
  - Custom Cage System Gimbal Mount
  - Haydon Kerk Pittman Hybrid Stepper Linear Actuator with encoder
  - Hephaist Spherical Ball Joints
  - Custom Gimbal Motor Mounts
- **Sources of Error**
  - Manufacturing error of the alignment of Thorlabs Cage System (+/- 180 μm)
  - Slack in ball joints (+/- 2 μm)
  - Slack in gimbal mounts



Risk Summary

Risk	Risk Description	Pertaining Functional Requirement
R1	Software Data Write Failure	FR 2, FR 3, FR 4, FR5
R2	Software Bit Flip	FR 2, FR 3, FR 4, FR5
R3	Under-heating of CubeSat Internal Components	FR 1, FR 2, FR 4, FR5
R4	Over-heating of CubeSat Internal Components	FR 1, FR 2, FR 4, FR5

		Severity				
		1	2	3	4	5
Likelihood	5				R8	
	4				R7	
	3			R3	R4	
	2			R2	R1/R6	
	1				R5	

Risk Summary

Risk	Risk Description	Pertaining Functional Requirement
R5	Operation Failure "Freeze" of UDOO X86	FR 1, FR 2, FR 4, FR5
R6	Loss of Attitude Determination Calibration	FR 3, FR 4
R7	Manufacturing/Calibration/Test Delays	FR 1-5
R8	Manufacturing creates optical precision errors	FR2, FR4

		Severity				
		1	2	3	4	5
Likelihood	5				R8	
	4				R7	
	3			R3	R4	
	2			R2	R1/R6	
	1				R5	

High Risk Mitigation

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

- [X] Budget
- [X] Technical
- [ ] Safety
- [X] Schedule

		Severity				
		1	2	3	4	5
Likelihood	5				R8	
	4				R7	
	3				R4	
	2					
	1					

Medium Risk Mitigation

Risk	Risk Description	Risk Mitigation
R1	Software Data Write Failure	• Watch Dog methodology
R3	Under-heating of CubeSat Internal Components	• Conduct thorough thermodynamic analysis
R6	Loss of Attitude Determination Calibration	• Allow larger calibration time in schedule • Transport safety plan

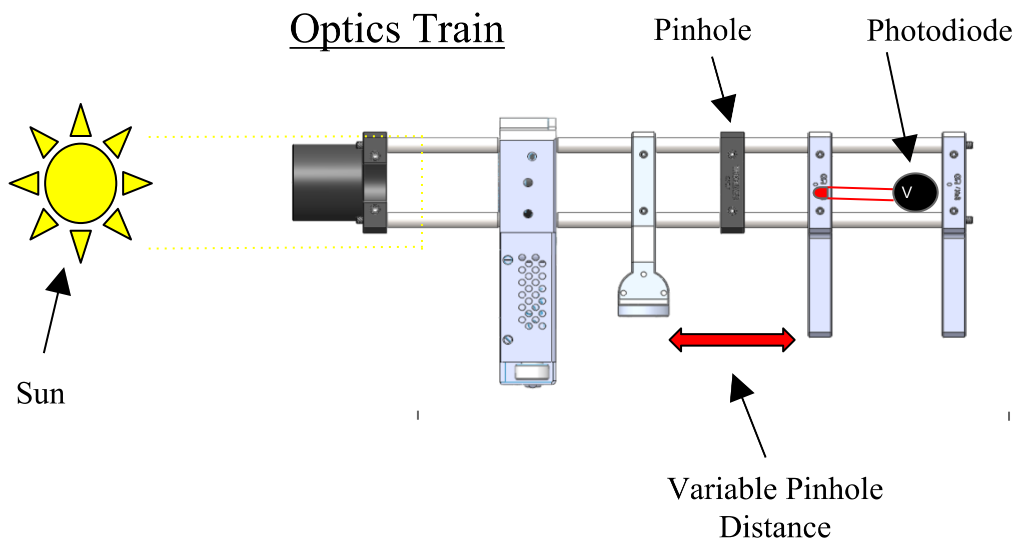
Types of Risks

- [x] Budget
- [x] Technical
- [ ] Safety
- [ ] Schedule

		Severity				
		1	2	3	4	5
Likelihood	5					
	4					
	3			R3		
	2				R1/R6	
	1					

Focal Length Determination Test

- **Purpose:** Experimentally determine the focal point of the main lens
- **Procedure:** Point optics train at Sun and use photodiode to verify pinhole placement within the optics train
  - Maximum voltage potential occurs across the photodiode when pinhole is located in the focal plane and Sun image is focused
  - Move pinhole incrementally until max photodiode voltage occurs

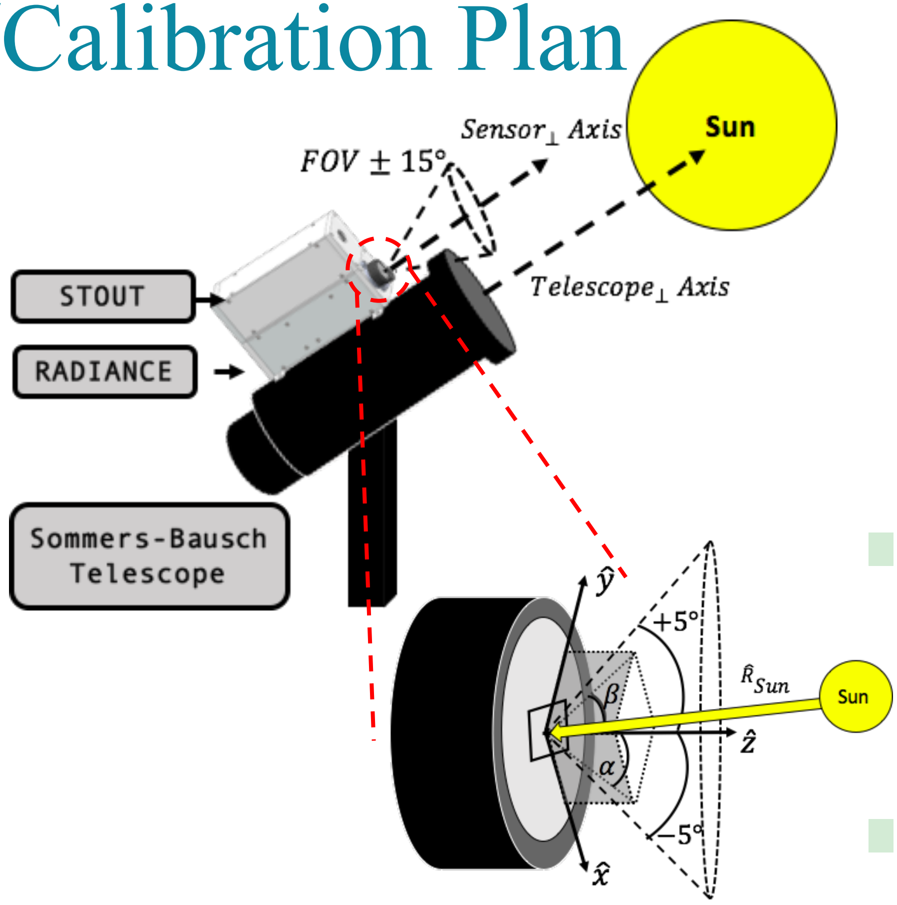


ADS Verification/Calibration Plan

Specifications

- Sommers-Bausch telescope has accuracy > 20 " ~ 0.0055º
- Accuracy of Sun sensor:
- 18" ~ 0.02º
- Total accuracy: 75.6" ~ 0.021º

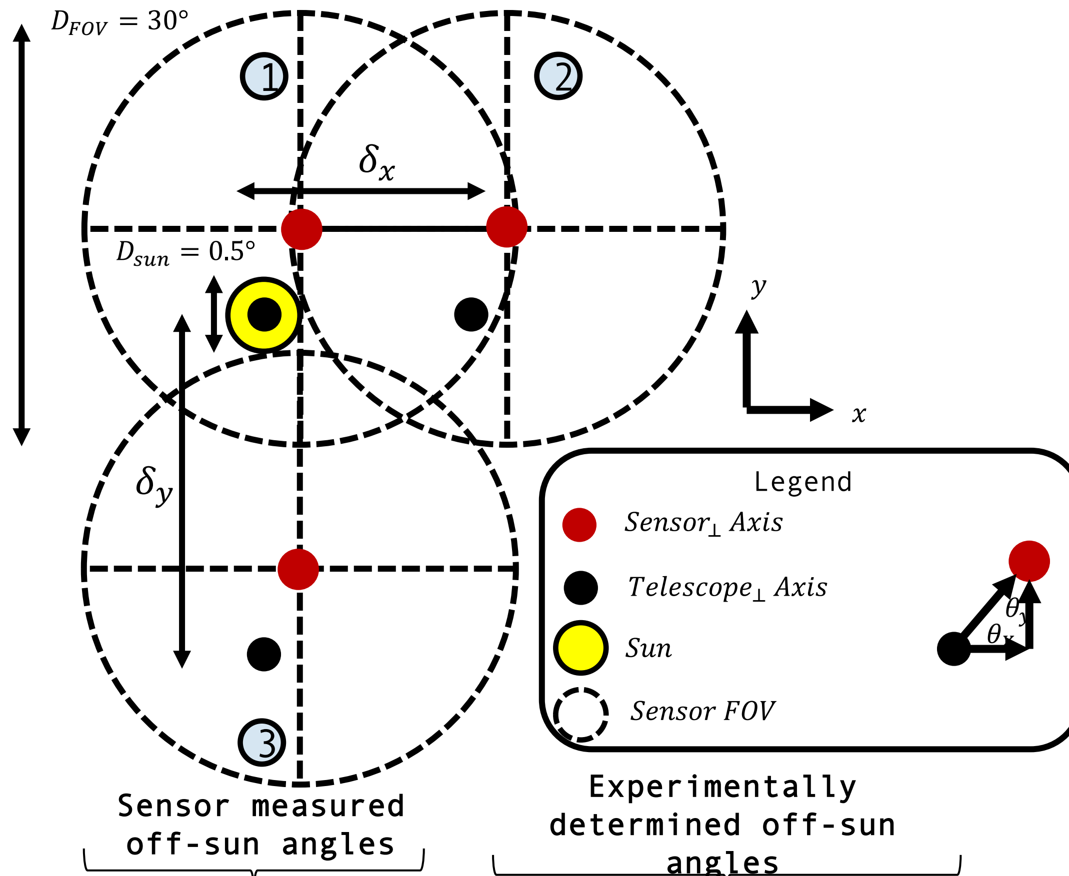
RADIANCE/ Telescope Mount



ADS Verification Plan

Verification Procedure

- Point telescope at Sun center
    - Save sensor off-sun angles
- Deviate telescope normal axis and measure deviations between sensor normal axis and sun center using sensor FOV
- Repeat process for multiple nodes to ensure accuracy
- Compare sensor off-sun angles to experimentally determined off-sun angles



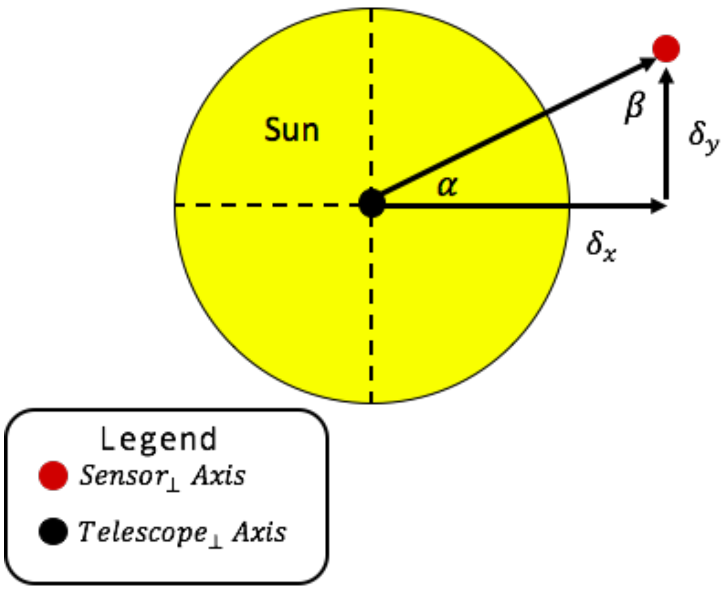
$$\alpha \approx \theta_{X-Offset} = \tan^{-1}\frac{\delta_y - 5°}{\delta_x - 5°}$$

$$\beta \approx \theta_{y-Offset} = \tan^{-1}\frac{\delta_x - 5°}{\delta_y - 5°}$$

ADS Calibration Plan

Calibration Procedure

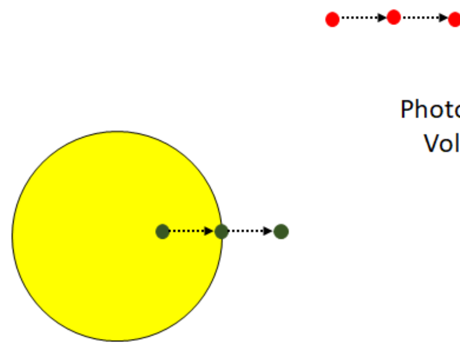
- Point Telescope at Sun center
- Record off sun angles
- Program deviation values in telescope software for optics calibration
- ADS now calibrated to Telescope mount
- Proceed with Optics Calibration

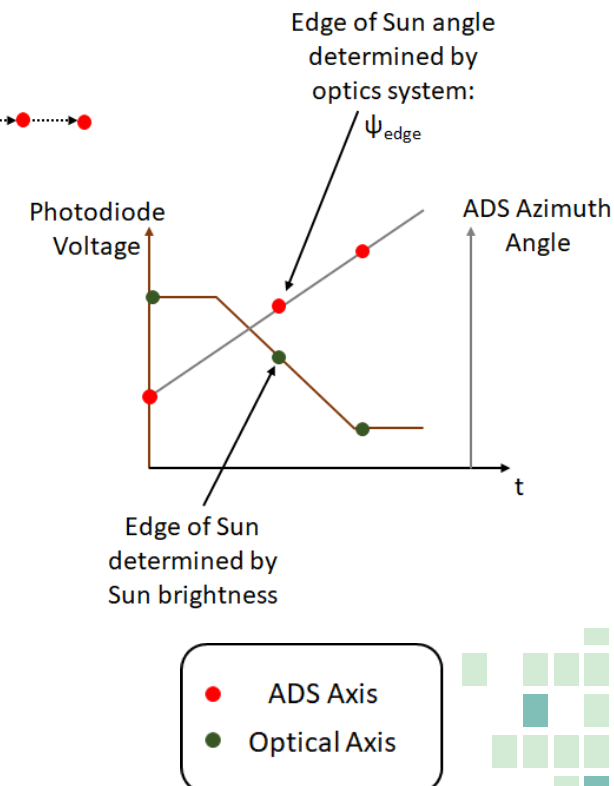


Optics Calibration Plan

Calibration Procedure

- Mount photodiode behind pinhole & verify optics train is pointed at the Sun
- Actuate telescope horizontally to move across edge of Sun
- Read photodiode voltage & ADS off-Sun angles as a function of time during movement
- Repeat for vertical actuation
- Post process data to determine offset between optics and ADS axes (dψ & dθ)



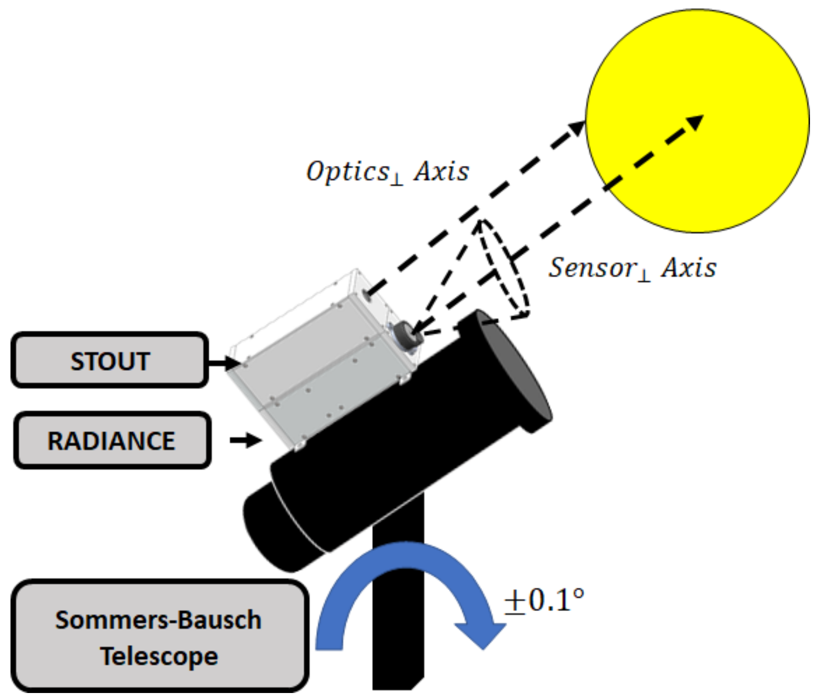


$$\delta\psi = \psi_{edge} - r_{Sun} = \psi_{edge} - 0.5333°$$

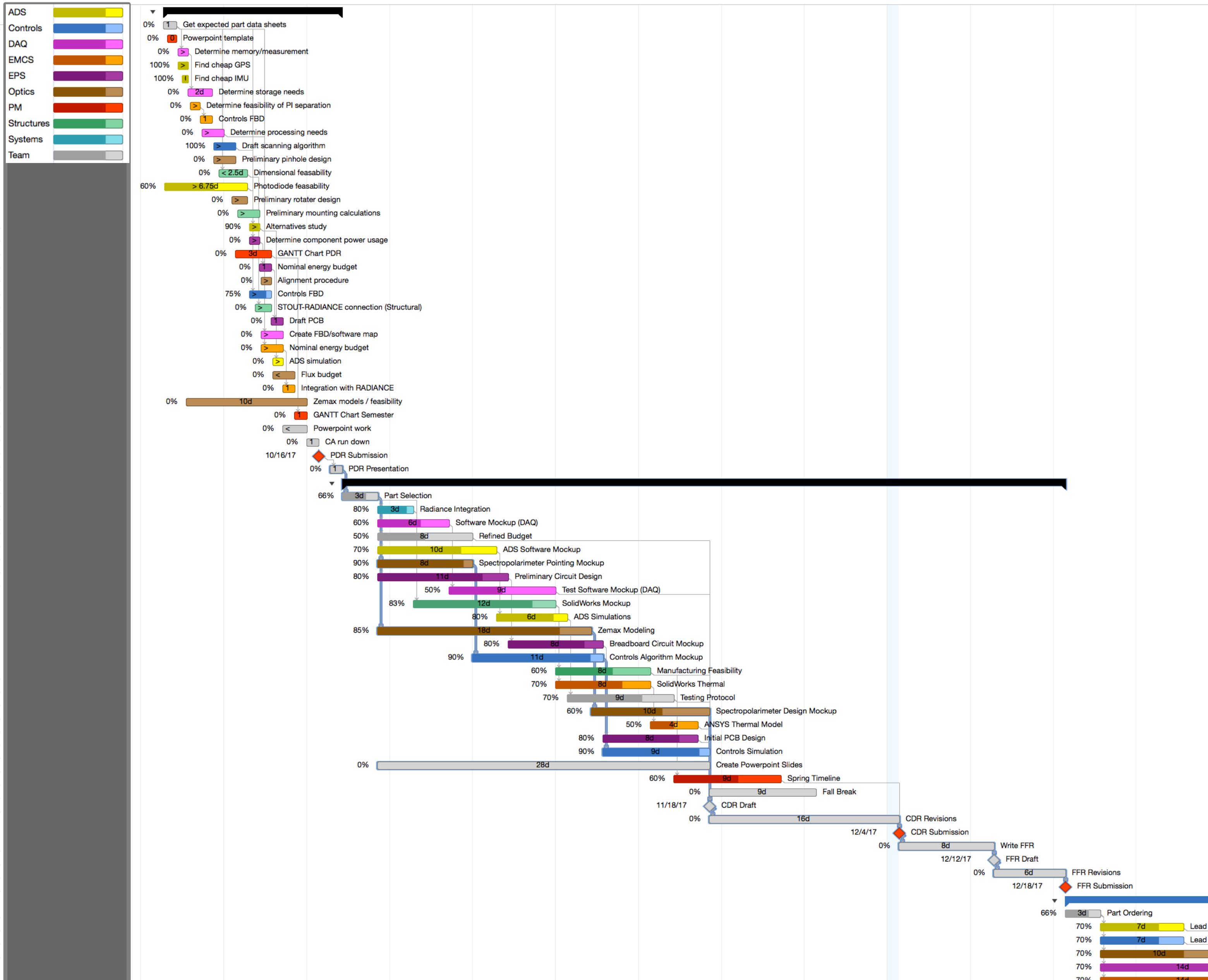
Pointing Control Verification Plan

Verification Procedure

- After ADS & Optics calibration are accounted for in software, functionality of pointing control can be verified
- Center Sun in ADS FOV using telescope
- Actuate optics system to the edge of the Sun
- Program telescope to move in pendulum motion to simulate gondola
- Control system will maintain constant photodiode voltage if the pointing system accurately accounts for movement



Title	Planned Start	Planned End
PDR	10/2/17	10/17/17
• Get expected part data sheets	10/2/17	10/3/17
• Powerpoint template	10/3/17	10/3/17
• Determine memory/measurement	10/4/17	10/4/17
• Find cheap GPS	10/4/17	10/4/17
• Find cheap IMU	10/4/17	10/4/17
• Determine storage needs	10/5/17	10/6/17
• Determine feasibility of PI separation	10/5/17	10/5/17
• Controls FBD	10/6/17	10/6/17
• Determine processing needs	10/6/17	10/7/17
• Draft scanning algorithm	10/7/17	10/8/17
• Preliminary pinhole design	10/7/17	10/8/17
• Dimensional feasability	10/7/17	10/9/17
• Photodiode feasability	10/3/17	10/9/17
• Preliminary rotater design	10/8/17	10/9/17
• Preliminary mounting calculations	10/9/17	10/10/17
• Alternatives study	10/10/17	10/10/17
• Determine component power usage	10/10/17	10/10/17
• GANTT Chart PDR	10/9/17	10/11/17
• Nominal energy budget	10/11/17	10/11/17
• Alignment procedure	10/11/17	10/11/17
• Controls FBD	10/10/17	10/11/17
• STOUT-RADIANCE connection (Structural)	10/10/17	10/11/17
• Draft PCB	10/12/17	10/12/17
• Create FBD/software map	10/11/17	10/12/17
• Nominal energy budget	10/11/17	10/12/17
• ADS simulation	10/12/17	10/12/17
• Flux budget	10/12/17	10/13/17
• Integration with RADIANCE	10/13/17	10/13/17
• Zemax models / feasibility	10/4/17	10/14/17
• GANTT Chart Semester	10/14/17	10/14/17
• Powerpoint work	10/13/17	10/14/17
• CA run down	10/15/17	10/15/17
• PDR Submission	10/16/17	10/16/17
• PDR Presentation	10/17/17	10/17/17
CDR/FFR	10/18/17	12/18/17
• Part Selection	10/18/17	10/20/17
• Radiance Integration	10/21/17	10/23/17
• Software Mockup (DAQ)	10/21/17	10/26/17
• Refined Budget	10/21/17	10/28/17
• ADS Software Mockup	10/21/17	10/30/17
• Spectropolarimeter Pointing Mockup	10/21/17	10/28/17
• Preliminary Circuit Design	10/21/17	10/31/17
• Test Software Mockup (DAQ)	10/27/17	11/4/17
• SolidWorks Mockup	10/24/17	11/4/17
• ADS Simulations	10/31/17	11/5/17
• Zemax Modeling	10/21/17	11/7/17
• Breadboard Circuit Mockup	11/1/17	11/8/17
• Controls Algorithm Mockup	10/29/17	11/8/17
• Manufacturing Feasibility	11/5/17	11/12/17
• SolidWorks Thermal	11/5/17	11/12/17
• Testing Protocol	11/6/17	11/14/17
• Spectropolarimeter Design Mockup	11/8/17	11/17/17
• ANSYS Thermal Model	11/13/17	11/16/17
• Initial PCB Design	11/9/17	11/16/17
• Controls Simulation	11/9/17	11/17/17
• Create Powerpoint Slides	10/21/17	11/17/17
• Spring Timeline	11/15/17	11/23/17
• Fall Break	11/18/17	11/26/17
• CDR Draft	11/18/17	11/18/17
• CDR Revisions	11/18/17	12/3/17
• CDR Submission	12/4/17	12/4/17
• Write FFR	12/4/17	12/11/17
• FFR Draft	12/12/17	12/12/17
• FFR Revisions	12/12/17	12/17/17
• FFR Submission	12/18/17	12/18/17
Spring	12/18/17	5/7/18
• Part Ordering	12/18/17	12/20/17
• Lead Times (ADS)	12/21/17	12/27/17
• Lead Times (Controls)	12/21/17	12/27/17
• Lead Times (Optics)	12/21/17	12/30/17
• Lead Times (DAQ)	12/21/17	1/3/18

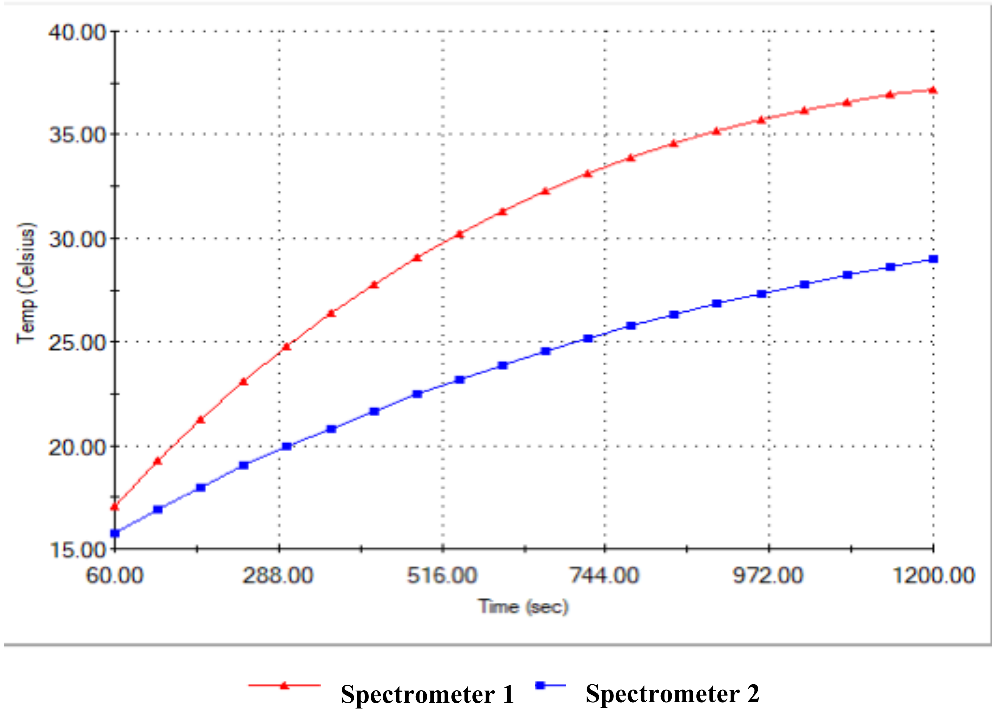


Solidworks Result

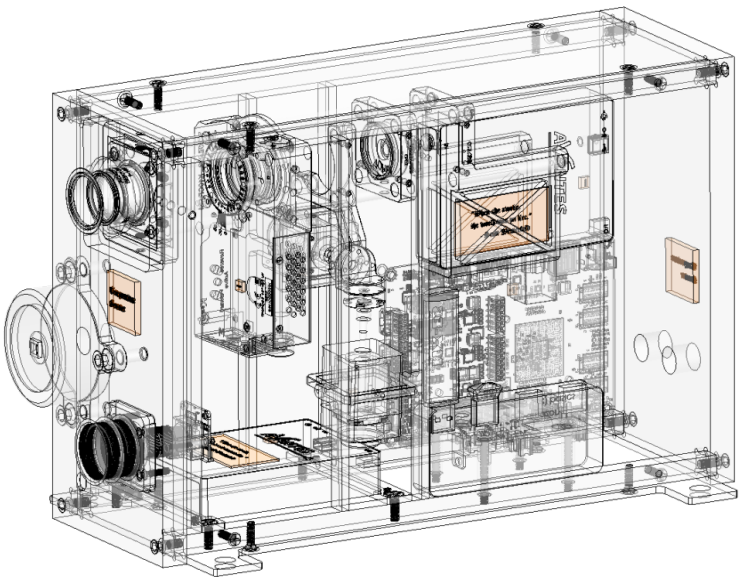
Partial Transient Time Profile

- 30 minute stimulation
- 60 second time interval

Spectrometer Temperature VS Time



Environmental Monitoring & Control System



Instrumentation

- 7 DS18B20 Temperature Sensors to measure the module’s internal temperature
- 2 K-Type Thermocouples w/ Amplifier Boards to measure external environmental temperature
- MS5803-14BA Pressure Sensor to measure external environmental pressure
- HIH-4030 Humidity Sensor to measure environmental humidity
- 2-3 Kapton Resistive Pad Heaters to keep the interior of the module at an operable temperature

Solidworks Result

Partial Transient Time Profile

- 30 minute stimulation
- 60 second time interval

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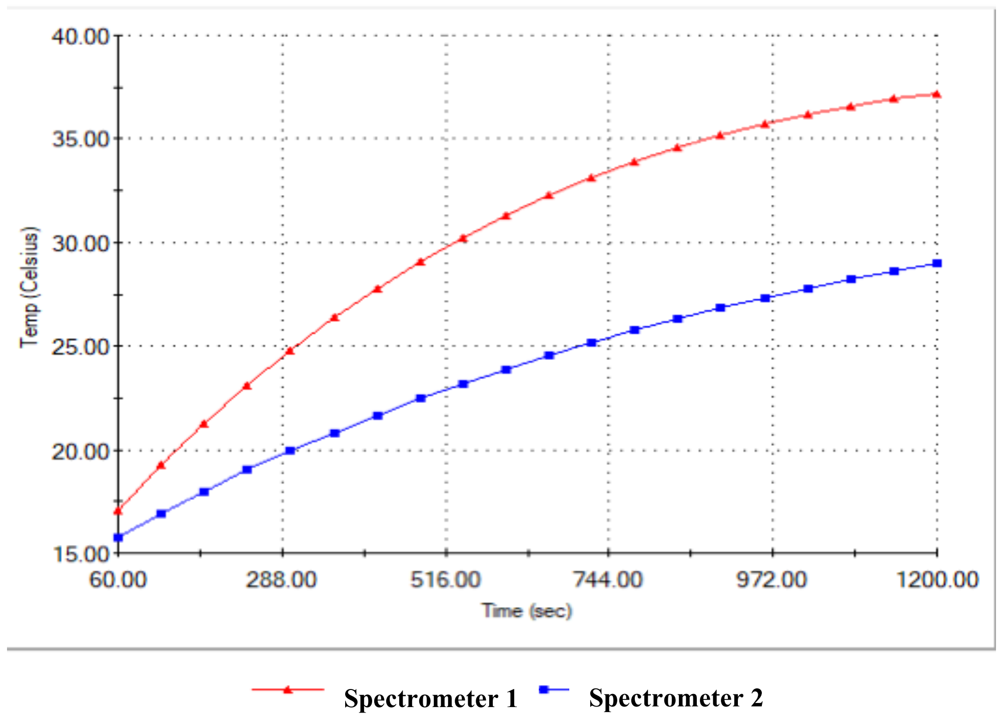
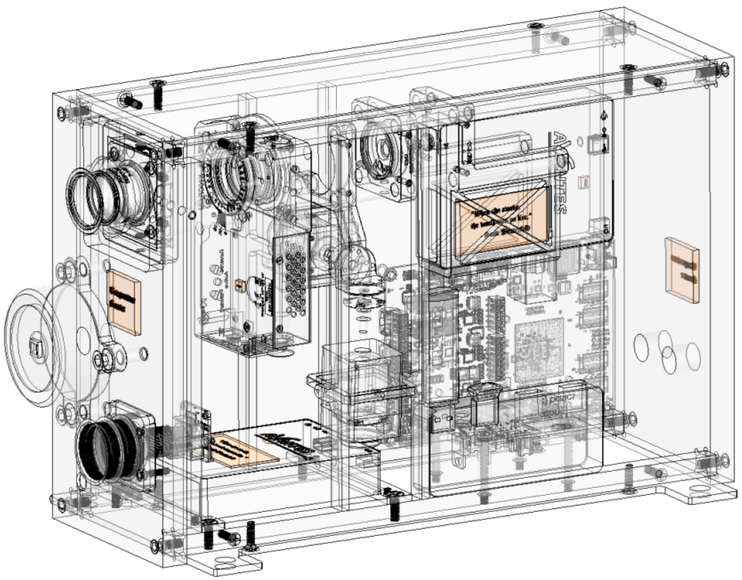


Environmental Monitoring & Control System



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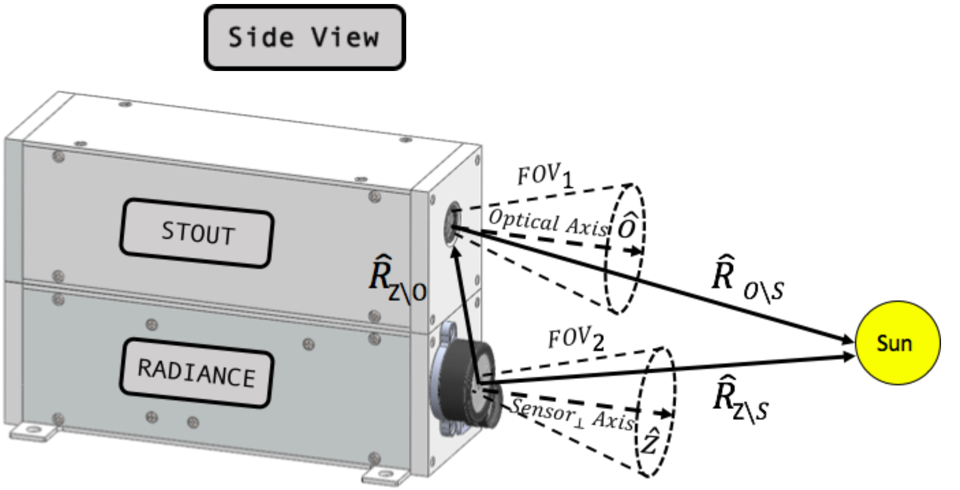
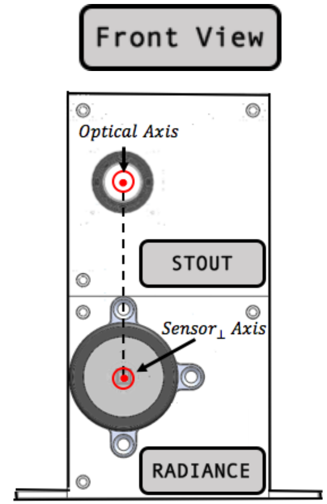
Attitude Determination Thermal Expansion

Purpose: Solve Off-Sun Angles





Assumptions

Sun within ± 15° of optical axis (given by customer)

Given

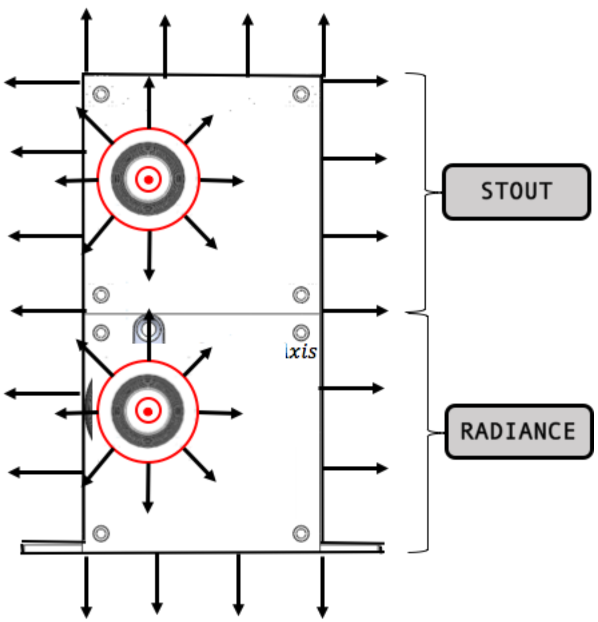
$\hat{o} = \hat{z}, \ \hat{R}_{O\backslash S}, \hat{R}_{Z\backslash S} >> \hat{R}_{S\backslash O}$

- $\hat{R}_{O\backslash S} = \hat{R}_{Z\backslash S}$

Conclusion

Sun off-angles relative to Sun Sensor axis is equal to that of the optical axis

Attitude Determination Thermal Expansion



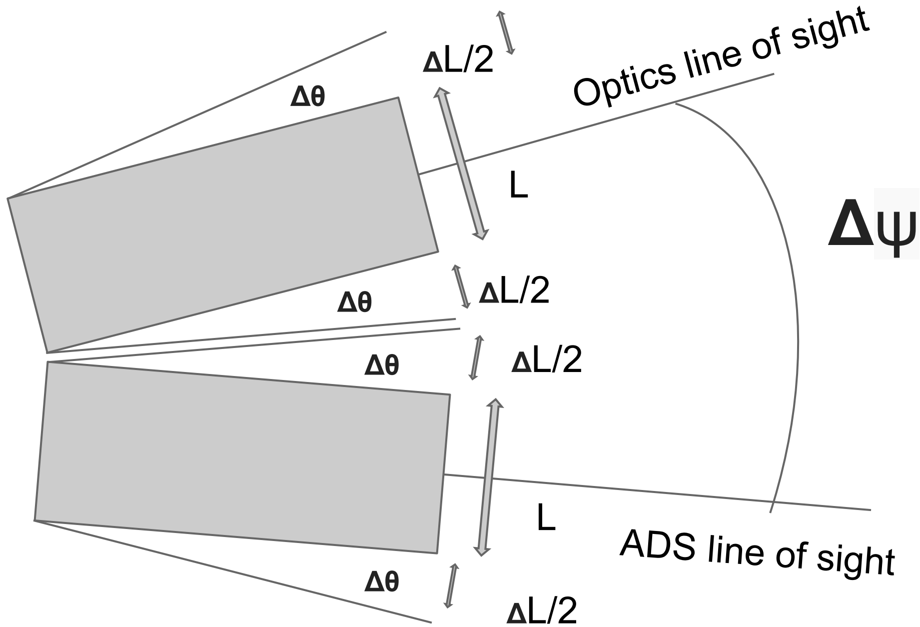
Thermal Expansion

- Expanding material assumed uniform
- Sun Face is assumed as flat plate
- Every linear dimension increases by the same percentage with a change in temperature, including holes.

Conclusion

- Expansions assumed negligible so long as linear expansion and no bending (Explained on next slide)

Attitude Determination Thermal Expansion

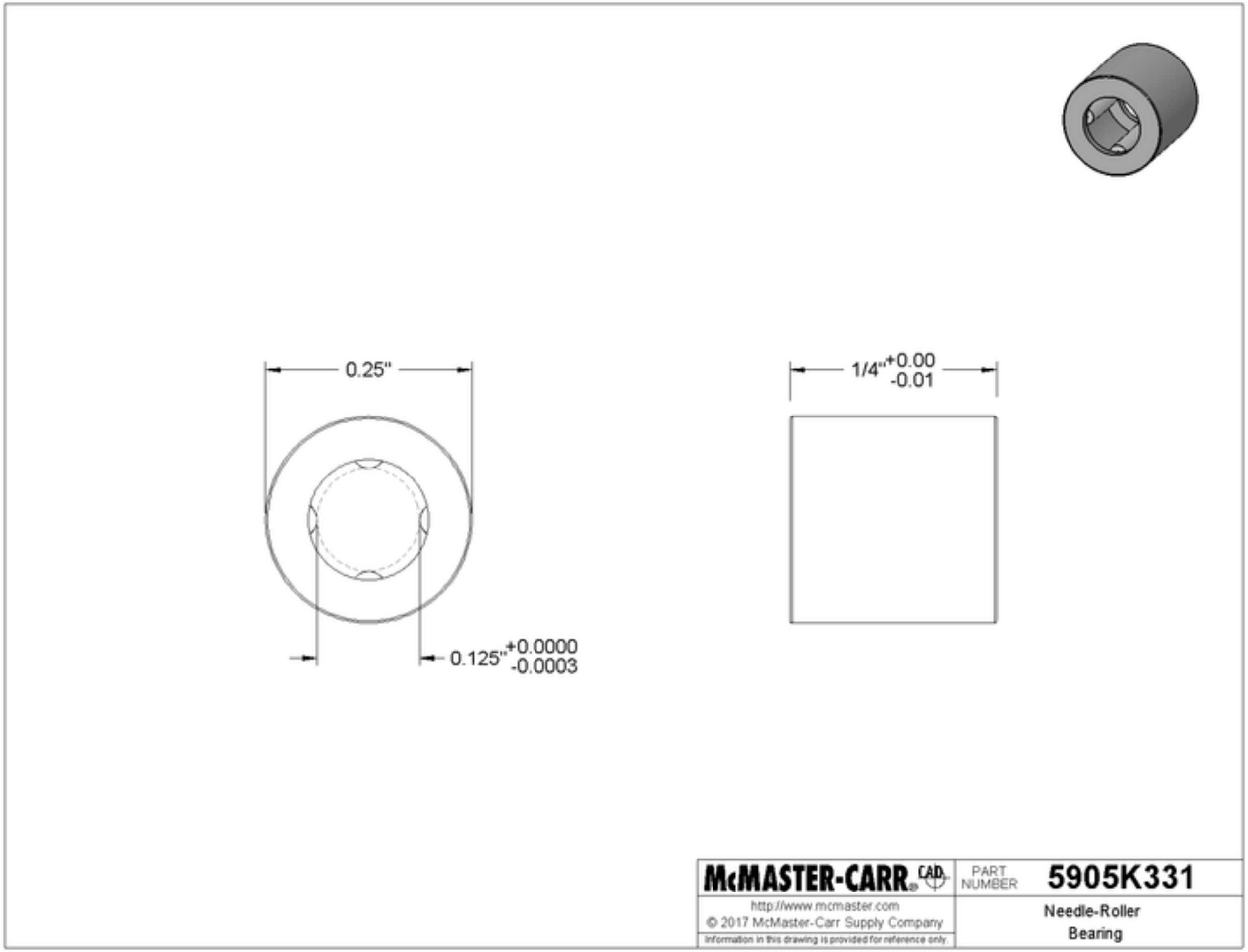


At an extreme variation in temperature where the front sun facing side is 20° K warmer than back side, the difference in optics and ADS line of sight will only be $\Delta\psi = 0.00886^{o}$

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



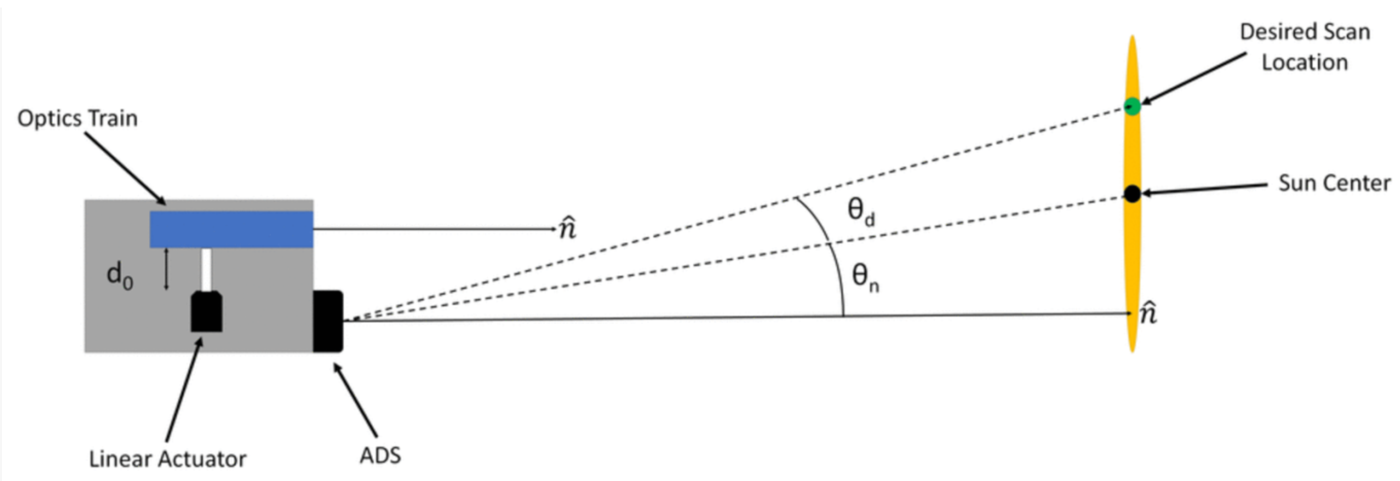
Software Run Time Calculations

Mainline Time Requirements							
Process	Data Size [B]	Quantity	Read Time [ms]	Write Rate [MB/s]	Interupt 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				

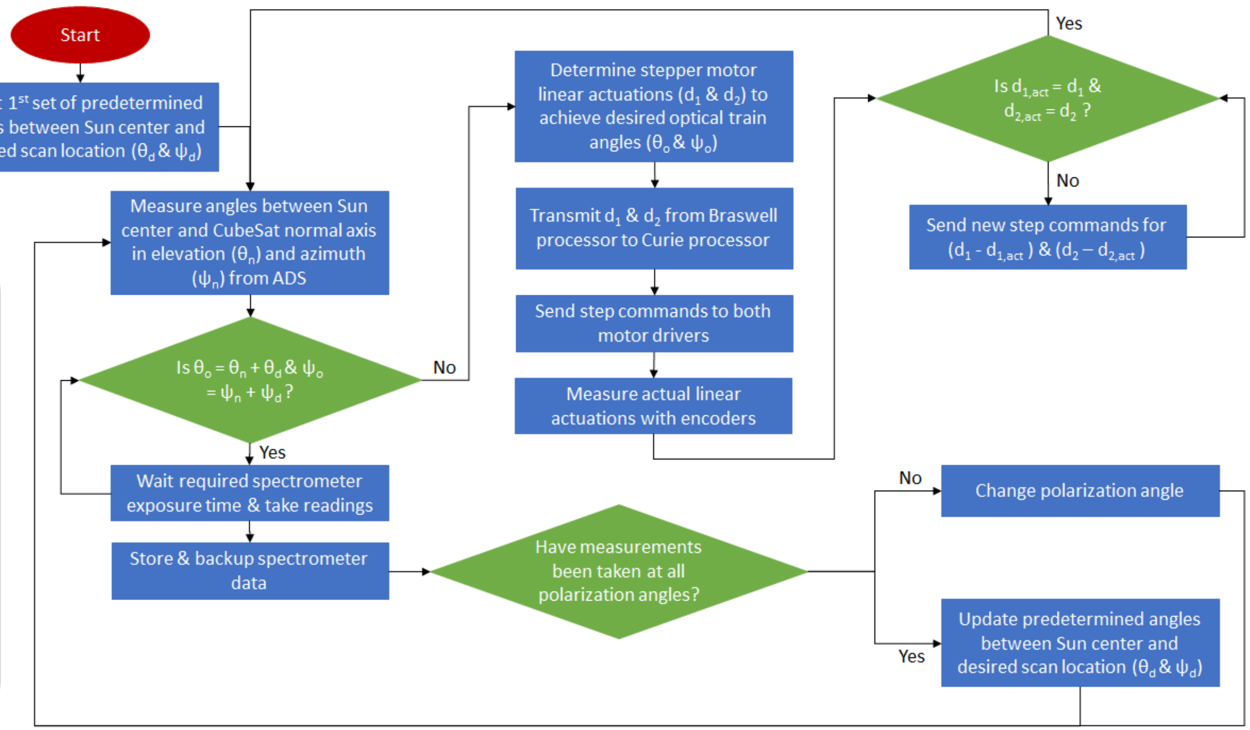
Software Run Time Calculations

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				

Pointing Control: Angle Explanation



Controls Software Flow



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

Pointing Algorithm

Pointing Equations

This document lays at the equations that are used for pointing the STOUT's optical instrument. Also attached in the document are images showing the vectors discussed overlaid on a diagram of the optics system. All units in the document are in mm and degrees.

Given: azimuth (θ) and elevation(ϕ) angle in [°]
Finds: horizontal and vertical actuation length [mm]
Date created: 12/04/17
Date modified: 12/12/17
Prepared by: Dawson Stokley - STOUT project manager

Housekeeping

This section allows the use of subscripts in variable names. Must be evaluated upon opening the document, before other cells are evaluated.

```
Symbolize[ r_ ]
Symbolize[ d_ ]
Symbolize[ L_ ]
```

Pointing Algorithm (Cont.)

Problem Setup

This section initializes the positions of the various components.

Position Declarations

This subsection initalizes the vector positions of the cage gimbal center ($\mathbf{r}_{cg}$), vertical motor gimbal center ($\mathbf{r}_{vg}$), horizontal motor gimbal center ($\mathbf{r}_{hg}$), vertical ball joint center ($\mathbf{r}_{vb}$), horizontal ball joint center ($\mathbf{r}_{hb}$), and the distance from $\mathbf{r}_{cg}$ to the apex ($\mathbf{d}_{ap}$). The apex is defined as a position on the optical axis, centered inside the actuation pushing plate. **O1offset** is used to translate the origin to $\mathbf{r}_{cg}$, as the SolidWorks origin is not alligned with this position. All values are taken from a SolidWorks assembly of STOUT.

```
O1offset={16.15,-9.28,45.78};
rcg={0,0,0};
rvg={41.45,-107.68,-45.09}-O1offset;
rhg={-2.14,-52.68,-46.16}-O1offset;
rvb={49.30,-65.72,-45.09}-O1offset;
rhb={36.79,-53.21,-45.09}-O1offset;
dap=90.865;
```

Pointing Algorithm (Cont.)

Apex Frame Position Vectors

This subsection calculates the vectors from the apex to the ball joint centers at a 0° pointing deflection. This is used later for finding the actuated ball joint centers. $\mathbf{r}_{apex,zero}$ is defined as the 0° apex position, $\mathbf{r}_{apex,vb,zero}$ is defined as the 0° vector from the apex to the vertical ball joint, and $\mathbf{r}_{apex,hb,zero}$ is defined as the 0° vector from the apex to the horizontal ball joint.

$$\mathbf{r}_{apex,zero}=\mathbf{r}_{cg}-\{0,0,\mathbf{d}_{ap}\};$$
$$\mathbf{r}_{apex,vb,zero}=\mathbf{r}_{vb}-\mathbf{r}_{apex,zero};$$
$$\mathbf{r}_{apex,hb,zero}=\mathbf{r}_{hb}-\mathbf{r}_{apex,zero};$$

Problem Solution

This section outlines the calculations used for pointing.

Azimuth/Elevation Input

This subsection allows the user to input desired azimuth ($\boldsymbol{\theta}$) and elevation ($\boldsymbol{\phi}$) pointing angles in degrees.

```
ϕ=0 Degree; (*Elevation*)
θ=0 Degree; (*Azimuth*)
```

Pointing Algorithm (Cont.)

Find Position of Actuated Apex

This subsection converts the inputted spherical coordinates $\boldsymbol{\theta}$ and $\boldsymbol{\phi}$ into a cartesian normal vector. This vector is multiplied by $\boldsymbol{d_{ap}}$ to find the location of the apex in its actuated position ($\boldsymbol{r_{apex}}$).

$$r_{apex}=\begin{pmatrix} -Sin[\theta]*Cos[\phi] \\ Sin[\phi] \\ -Cos[\theta]*Cos[\phi] \end{pmatrix}*d_{ap};$$

Convert $r_{apex,vb}$ and $r_{apex,hb}$ to Cage Gimbal Frame

This subsection sets up the rotation matrix (**RotMat**) used to convert $\mathbf{r_{apex,vb,zero}}$ and $\mathbf{r_{apex,hb,zero}}$ into the actuated apex frame. These new vectors are $\mathbf{r_{apex,vb}}$ and $\mathbf{r_{apex,hb}}$, respectively.

$$RotMat=\begin{pmatrix} Cos[\theta] & Sin[\theta]*Sin[\phi] & Sin[\theta]*Cos[\phi] \\ 0 & Cos[\phi] & -Sin[\phi] \\ -Sin[\theta] & Cos[\theta]*Sin[\phi] & Cos[\phi]*Cos[\theta] \end{pmatrix};$$

$$r_{apex,vb}=RotMat.r_{apex,vb,zero};$$

$$r_{apex,hb}=RotMat.r_{apex,hb,zero};$$

Find Ball Joint Locations

This subsection finds the actuated positions of the ball joints, $\mathbf{r_{cg,vb}}$ and $\mathbf{r_{cg,hb}}$ for vertical and horizon-

Pointing Algorithm (Cont.)

tal, respectively. This is done by adding $\mathbf{r}_{apex}$ to the respective apex frame position vectors of the ball joints. **O1offset** is added to the values so they can be verified with SolidWorks coordinates.

$$\mathbf{r}_{cg,vb} = \mathbf{r}_{apex,vb} + \mathbf{r}_{apex} + \mathbf{O1offset}$$
$$\mathbf{r}_{cg,hb} = \mathbf{r}_{apex,hb} + \mathbf{r}_{apex} + \mathbf{O1offset}$$

{{49.3}, {-65.72}, {-45.09}}

{{36.79}, {-53.21}, {-45.09}}

Calculate Actuation Length

This subsection finds the actuation lengths of the vertical and horizontal stepped motors, $\mathbf{L}_v$ and $\mathbf{L}_h$ respectively. These values are found by taking the normal between the gimbal and ball joint centers. **O1offset** is subtracted out to account for its addition above. These values are not the actual actuation lengths, but the distance from the motor gimbal centers to the ball joint centers. Upon recieving the stepped motors and ball joints from their respective manufacturers, precision measurements will be taken to determine the ball joint radius and position of the motor inside the gimbal. These values will be subtracted from the calculated values in order to find the actual actuation lengths.

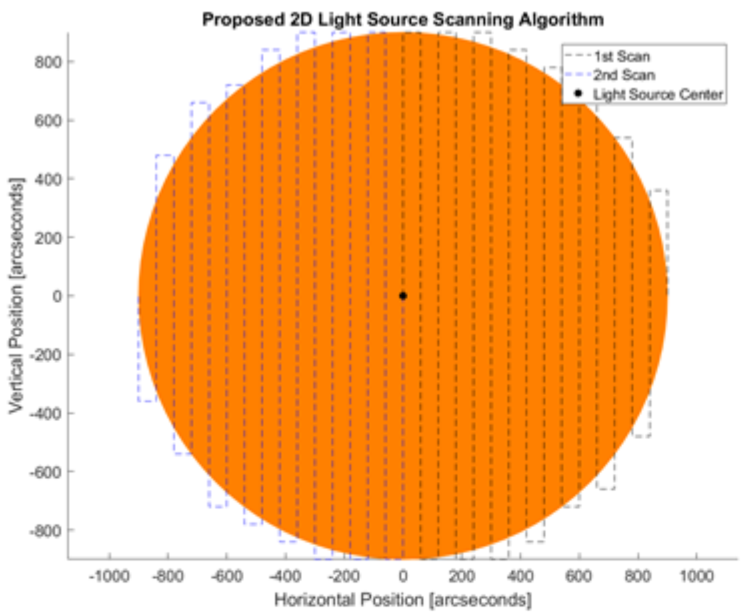
$$\mathbf{L}_v = \mathrm{Norm}\left[\mathbf{r}_{cg,vb} - \mathbf{r}_{vg} - \mathbf{O1offset}\right] \text{ "mm"}$$
$$\mathbf{L}_h = \mathrm{Norm}\left[\mathbf{r}_{cg,hb} - \mathbf{r}_{hg} - \mathbf{O1offset}\right] \text{ "mm"}$$

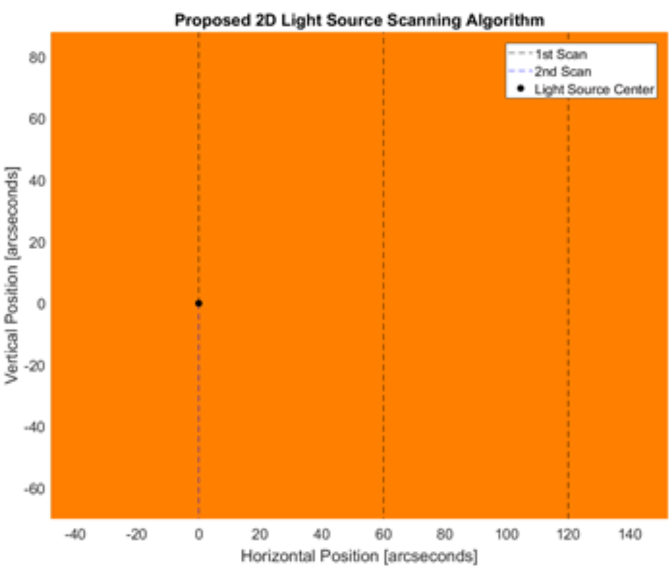
42.688 mm

38.9483 mm

Light Source Scanning Algorithm

- 1’ between scan points
- 788 scan points: 1.1 days to scan entire surface at every polarization angle



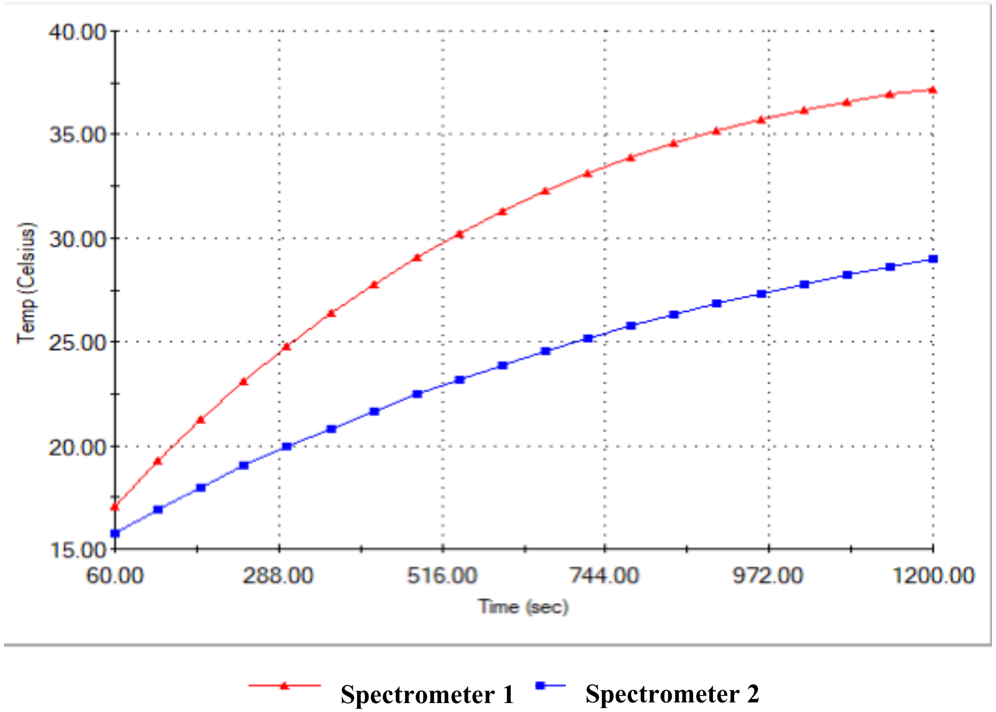


Solidworks Result

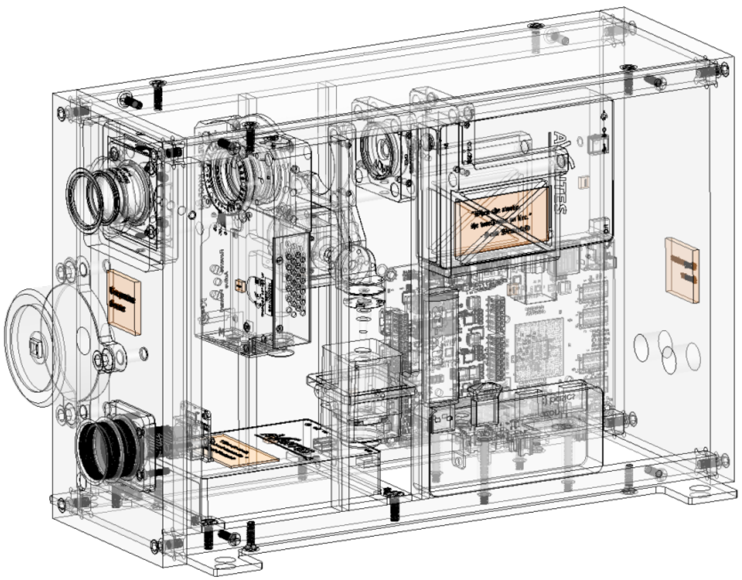
Partial Transient Time Profile

- 30 minute stimulation
- 60 second time interval

Spectrometer Temperature VS Time



Environmental Monitoring & Control System

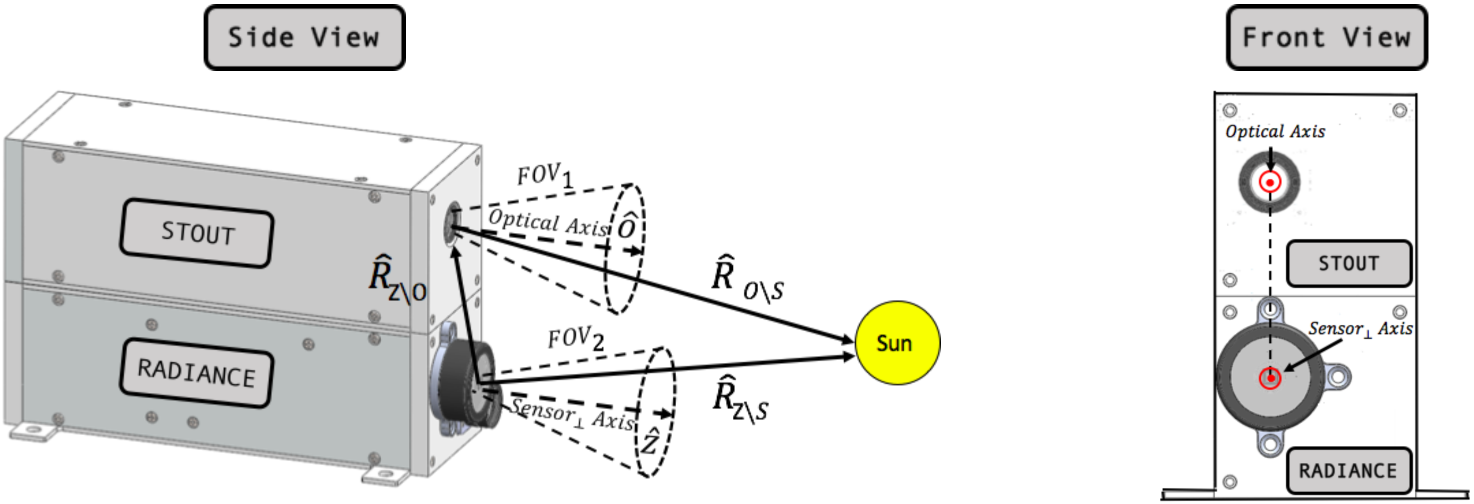


Instrumentation

- 7 DS18B20 Temperature Sensors to measure the module's internal temperature
- 2 K-Type Thermocouples w/ Amplifier Boards to measure external environmental temperature
- MS5803-14BA Pressure Sensor to measure external environmental pressure
- HIH-4030 Humidity Sensor to measure environmental humidity
- 2-3 Kapton Resistive Pad Heaters to keep the interior of the module at an operable temperature

Attitude Determination Thermal Expansion

Purpose: Solve Off-Sun Angles



Assumptions

Sun within ± 15° of optical axis (given by customer)

Given

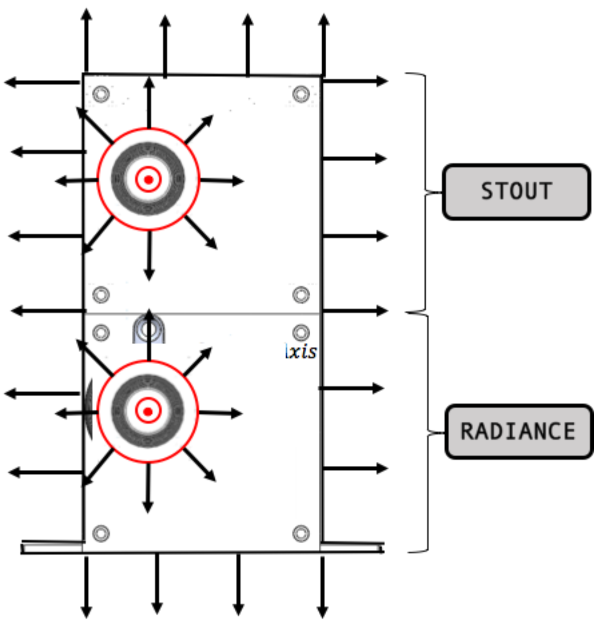
$\hat{o} = \hat{z}, \quad \hat{R}_{O\backslash S}, \hat{R}_{Z\backslash S} >> \hat{R}_{S\backslash O}$

- $\hat{R}_{O\backslash S} = \hat{R}_{Z\backslash S}$

Conclusion

Sun off-angles relative to Sun Sensor axis is equal to that of the optical axis

Attitude Determination Thermal Expansion



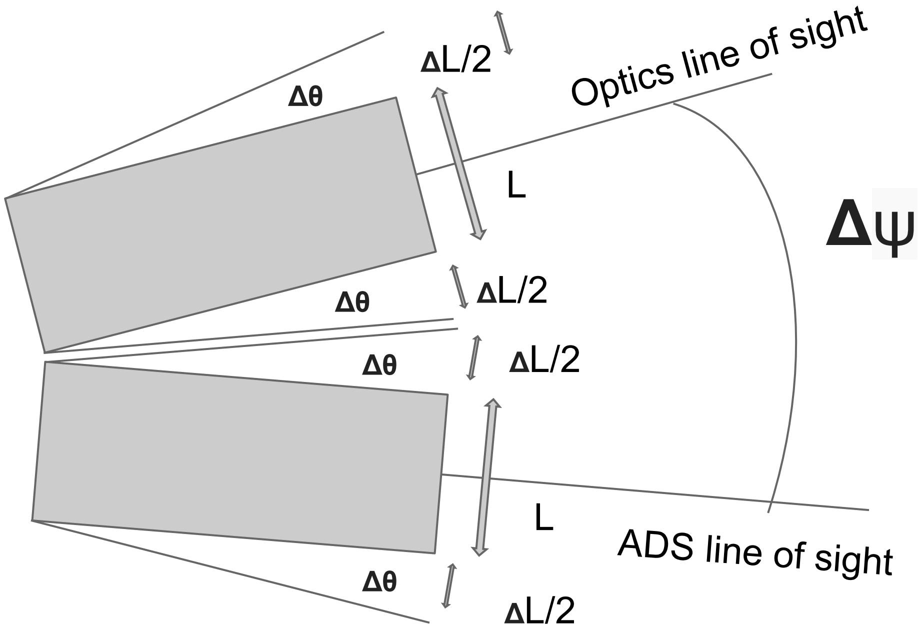
Thermal Expansion

- Expanding material assumed uniform
- Sun Face is assumed as flat plate
- Every linear dimension increases by the same percentage with a change in temperature, including holes.

Conclusion

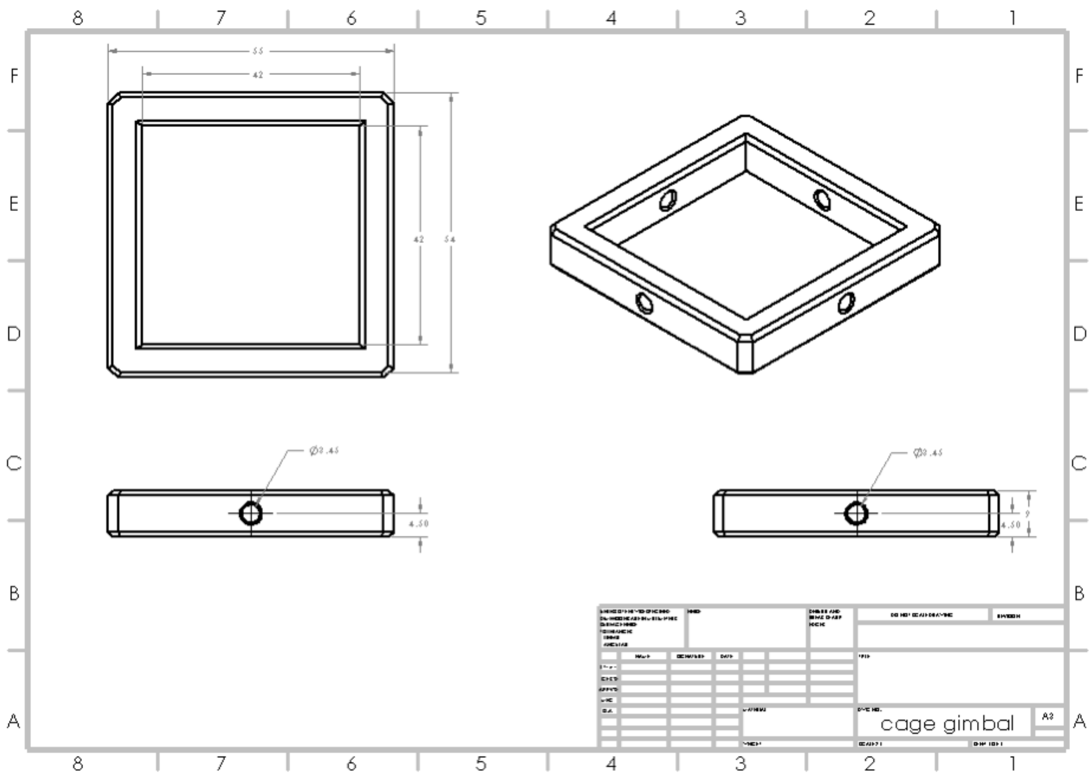
- Expansions assumed negligible so long as linear expansion and no bending (Explained on next slide)

Attitude Determination Thermal Expansion

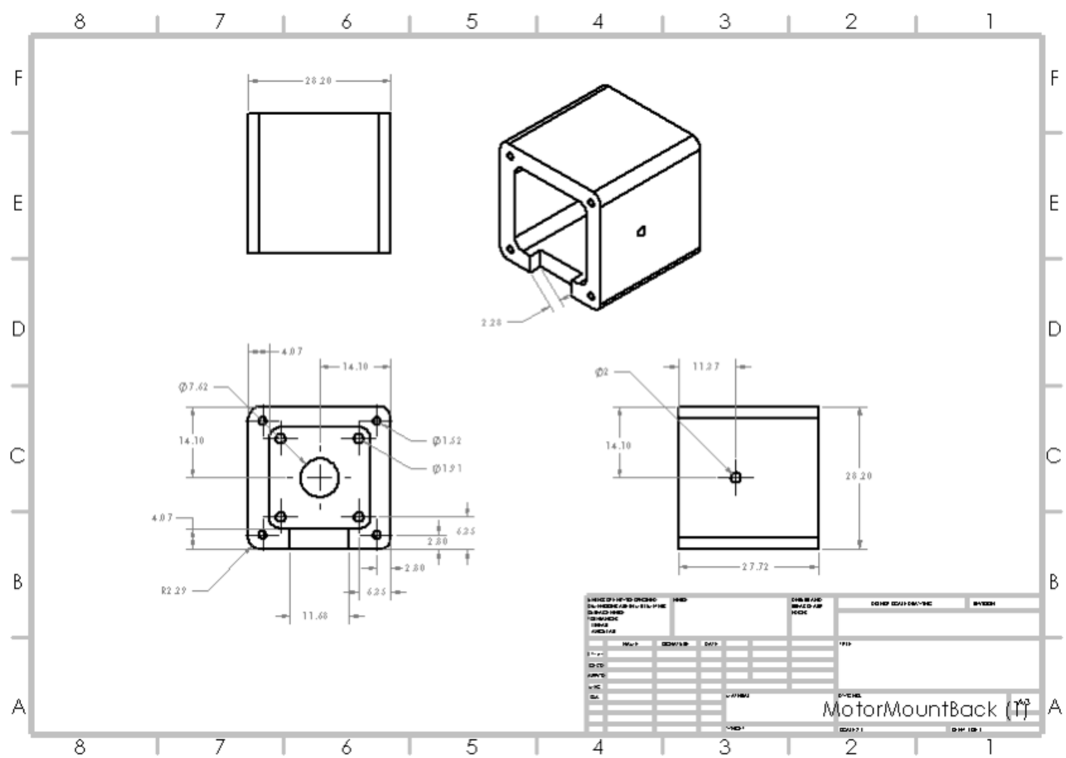


At an extreme variation in temperature where the front sun facing side is 20º K warmer than back side, the difference in optics and ADS line of sight will only be Δψ =0.00886º

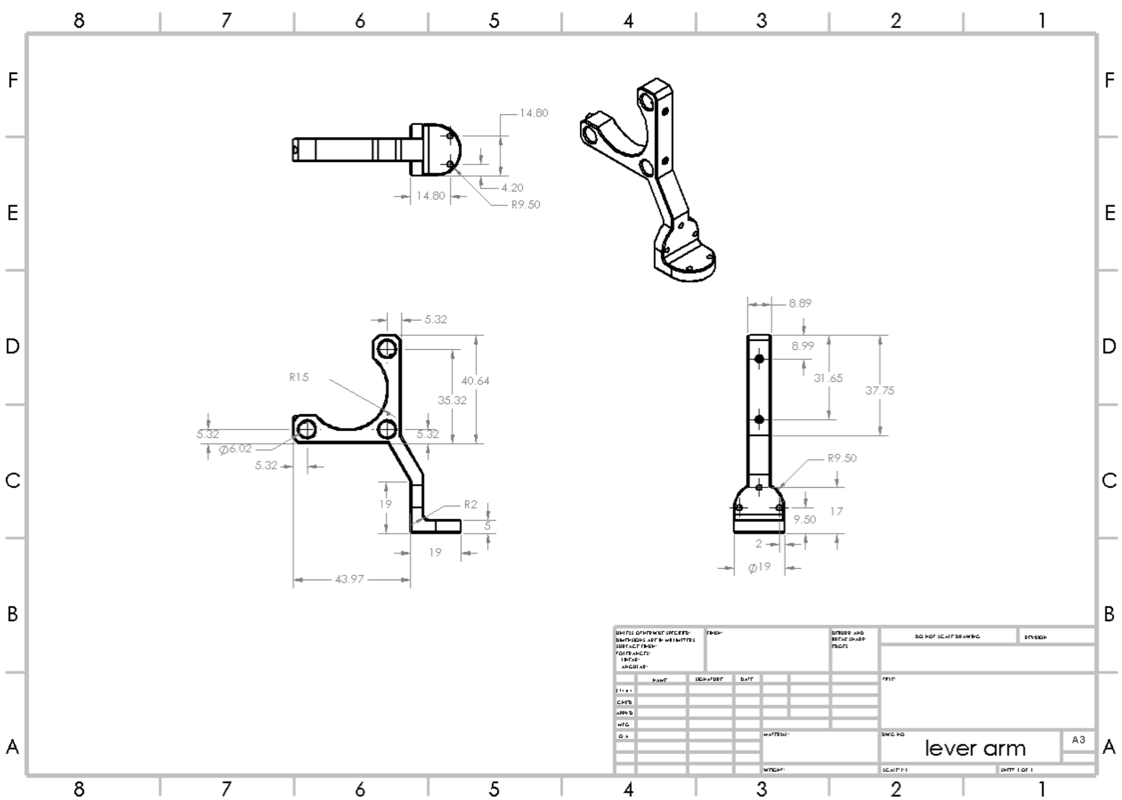
Cage Gimbal Drawing



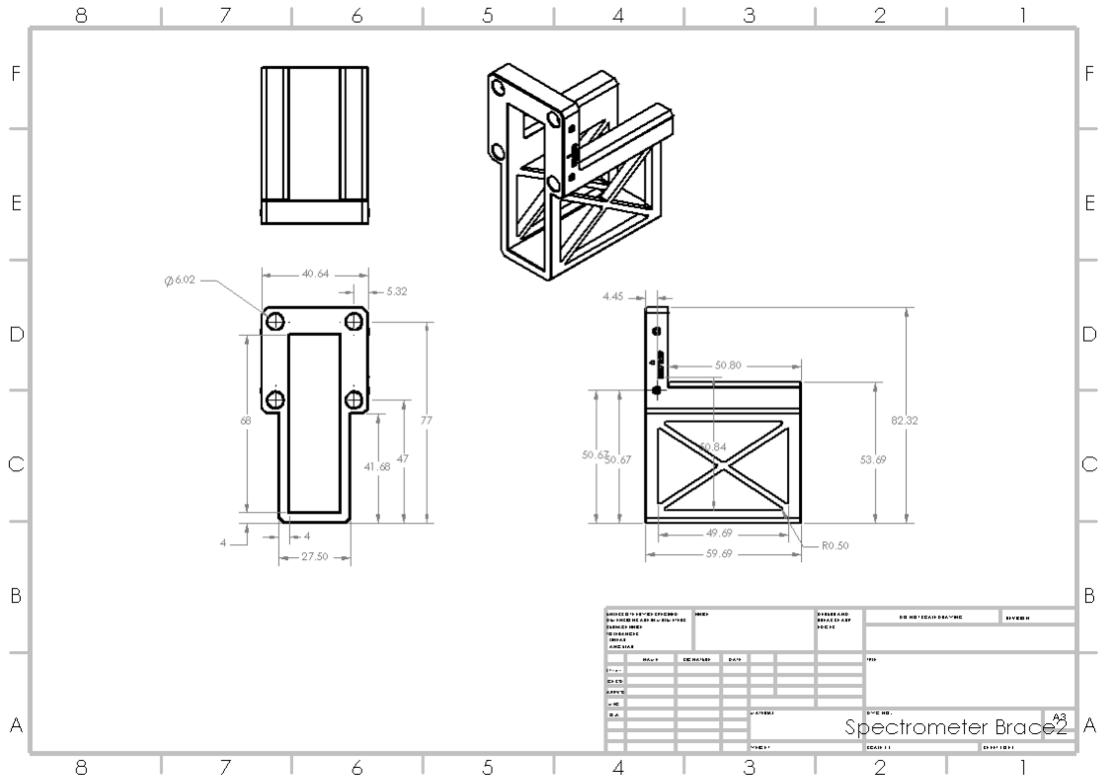
Motor Case Gimbal - Back Drawing



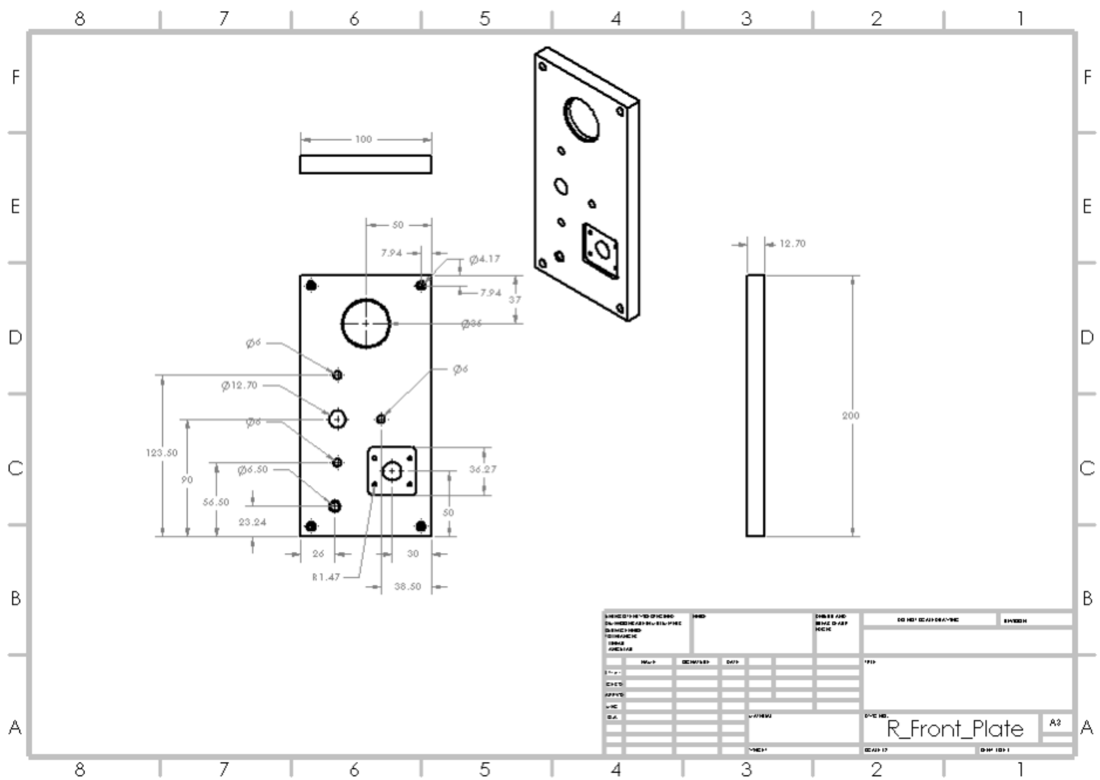
Actuation Arm Drawing



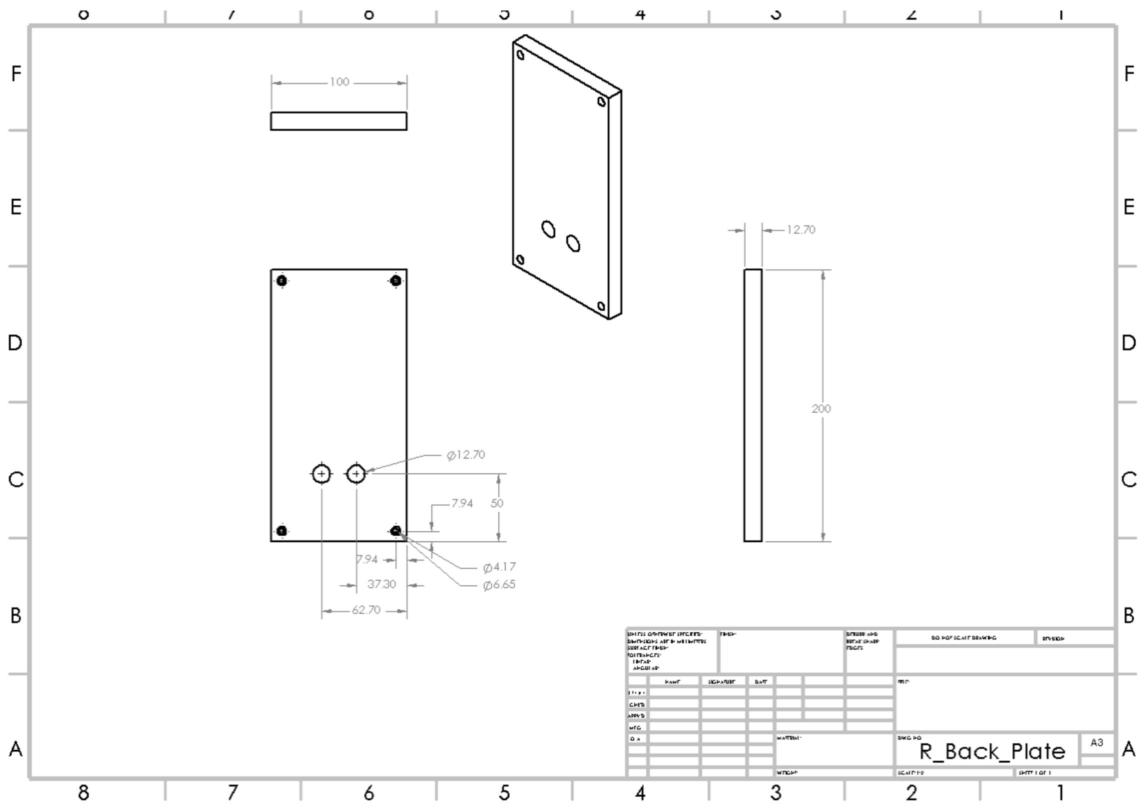
Spectrometer Brace Drawing



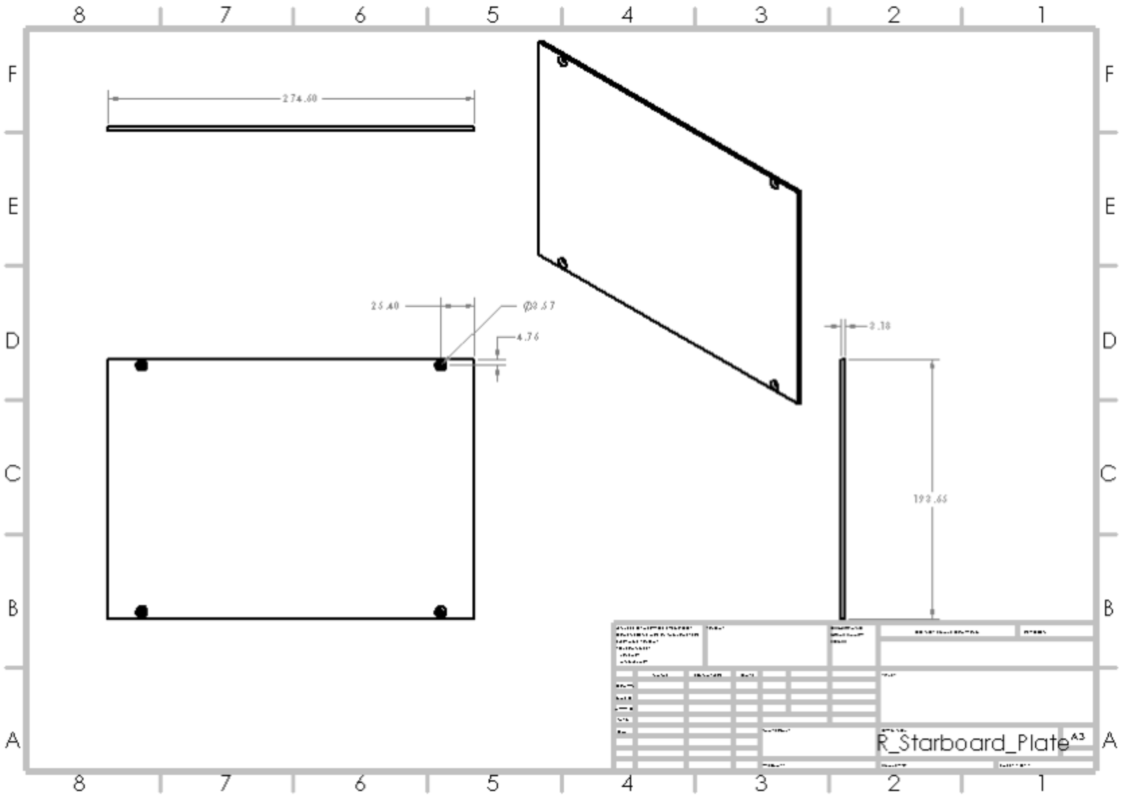
Front Plate Drawing



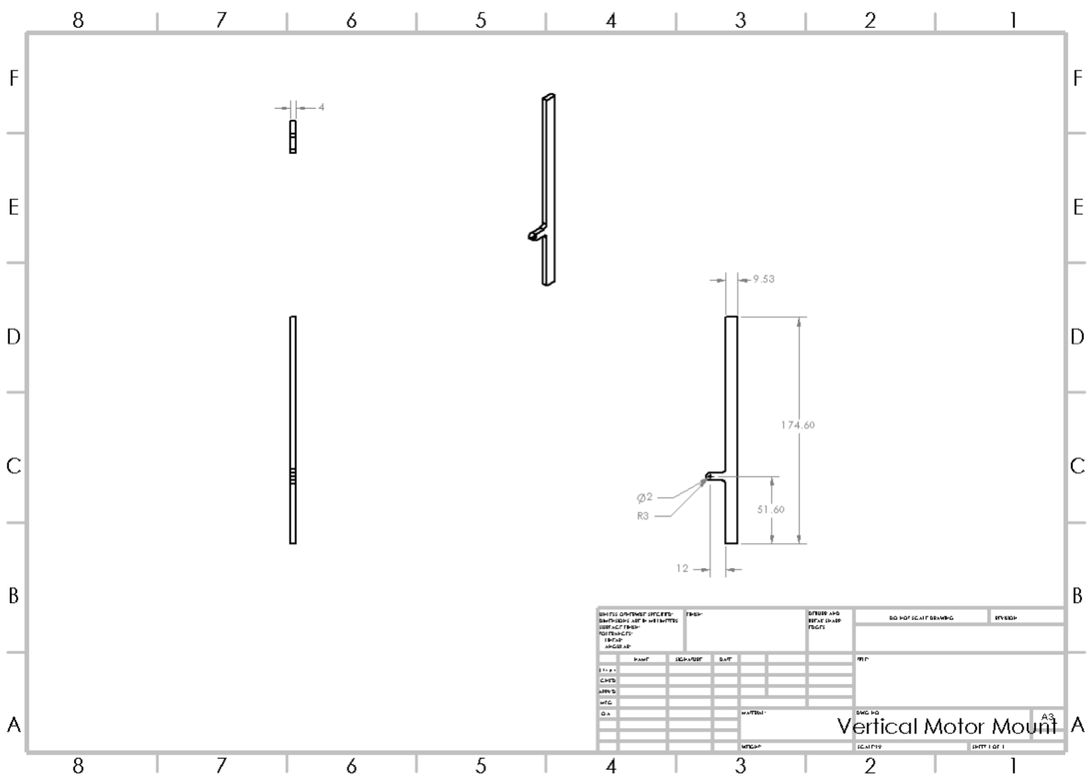
Back Plate Drawing



Side Panel Drawing



Vertical Motor Brace Drawing



Horizontal Motor Brace Drawing