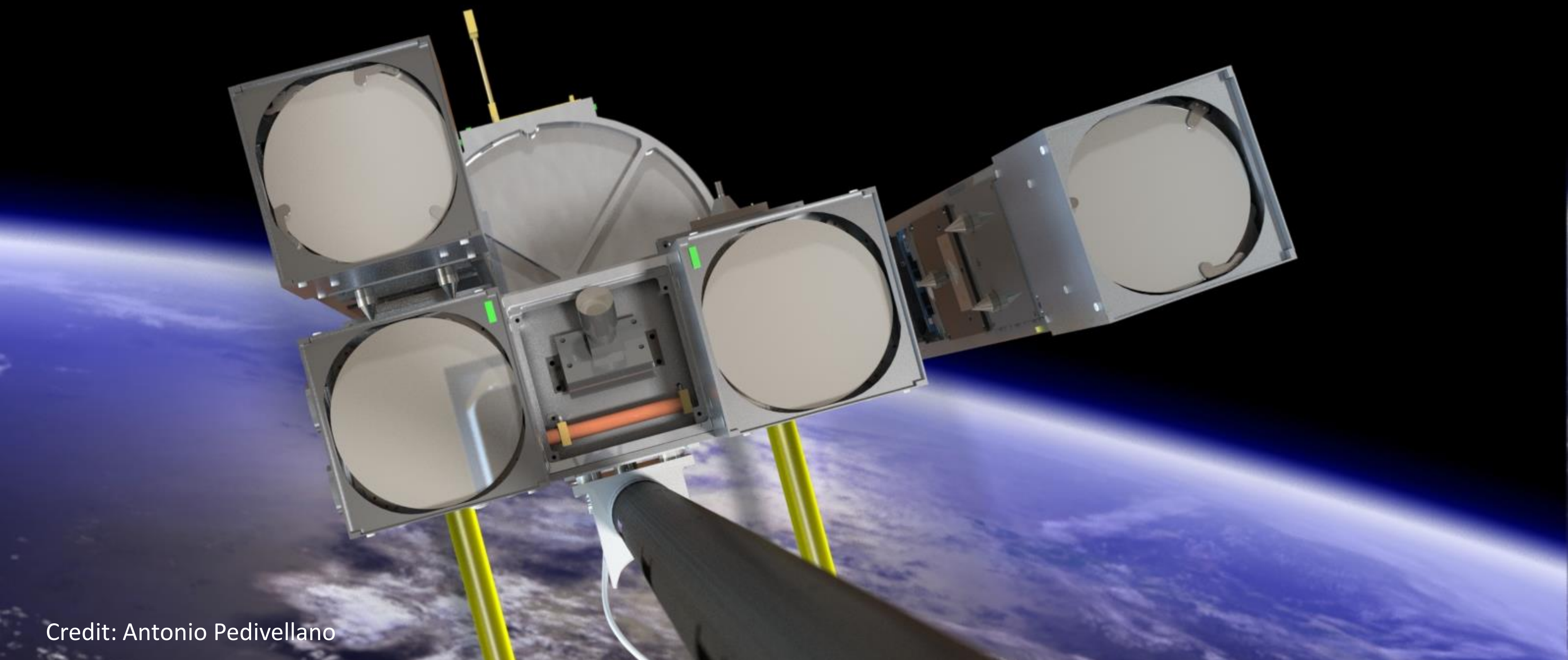
AAReST: Autonomous Assembly of a Reconfigurable Space Telescope

Ae 105 Final Presentations 2018



Credit: Antonio Pedivellano

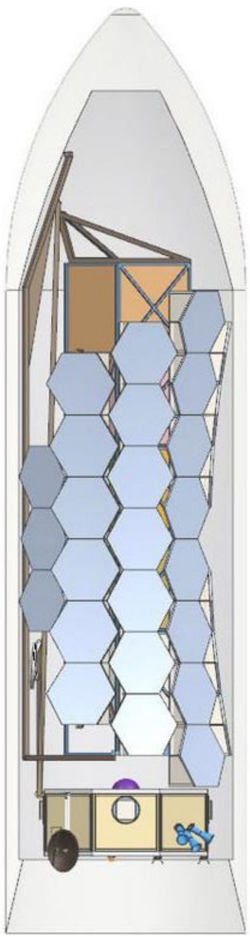
Mission Overview

Fabien Royer

Building Large Space Telescopes

- Mirror dia. of current and planned space telescopes limited by constraints of a single launch
  - Hubble (1990): Ø 2.4 m
  - JWST (2018): Ø 6.5 m
  - HDST (2030+): Ø 11.7 m
- New paradigms needed for Ø 30 m+ segmented primary:
  - Autonomous assembly in orbit
  - Active ultralight mirror segments
- Active mirrors relax tolerances for assembly and manufacturing, correct thermal distortions
- Modular, robust, low-cost architecture

JWST



HDST

Caltech

Building Large Space Telescopes

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  - Hubble (1990): Ø 2.4 m
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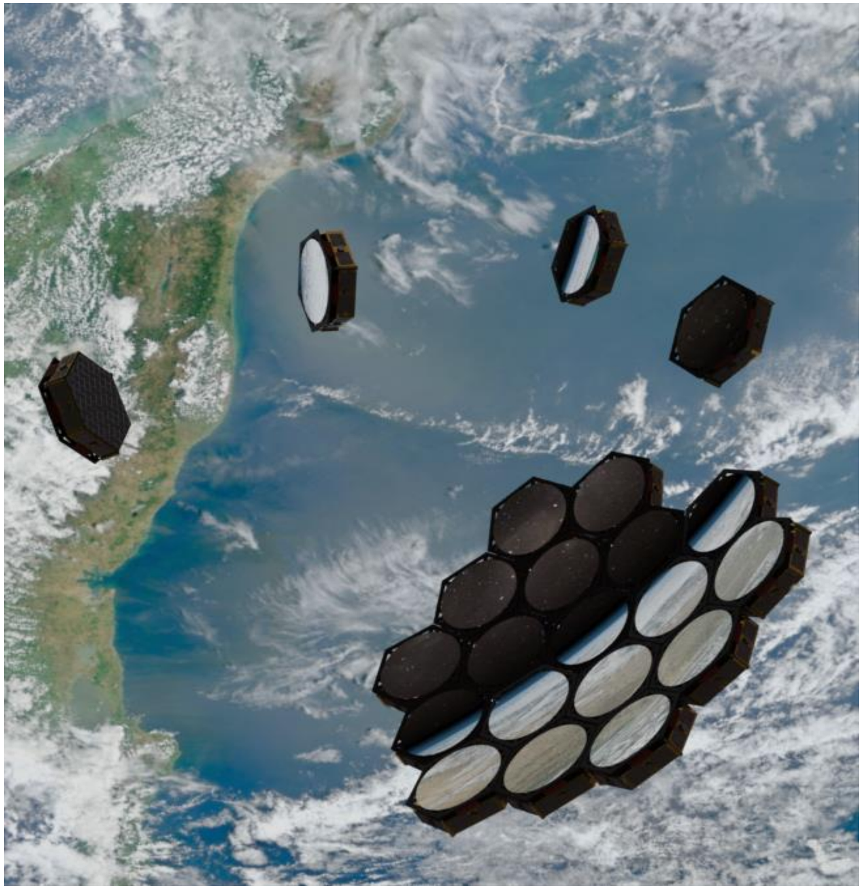

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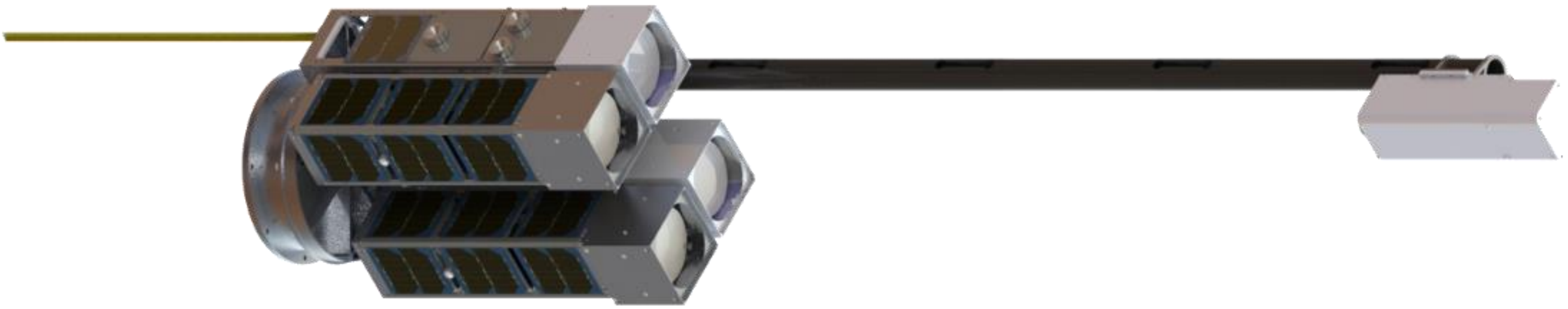
AAReST Mission Objectives

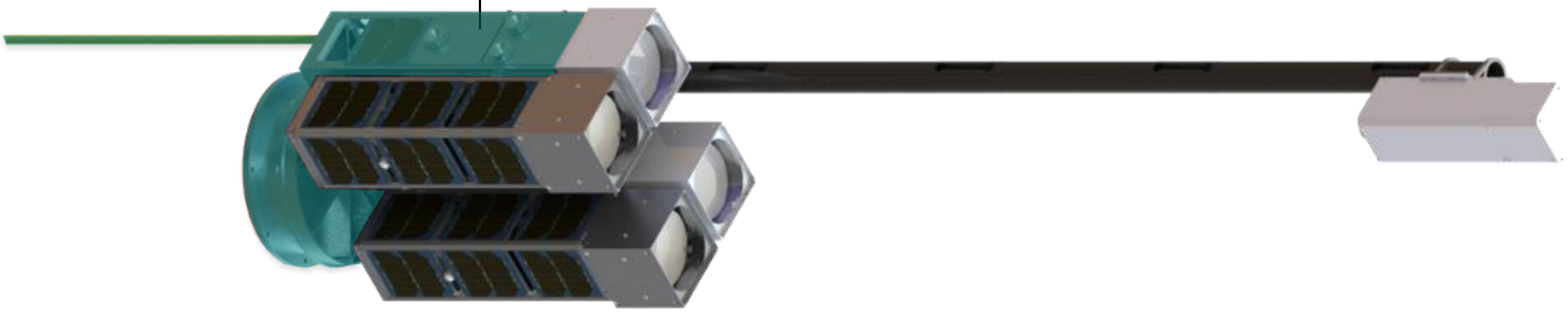
- Demonstrate key technologies:
  - Autonomous assembly and reconfiguration of modular spacecraft carrying mirror segments
  - Active, lightweight deformable mirrors operating as segments in a primary
- Operate for as long as necessary to accomplish the objectives (~90 days)
- Gather engineering data to enable development of the next system

AAReST Spacecraft

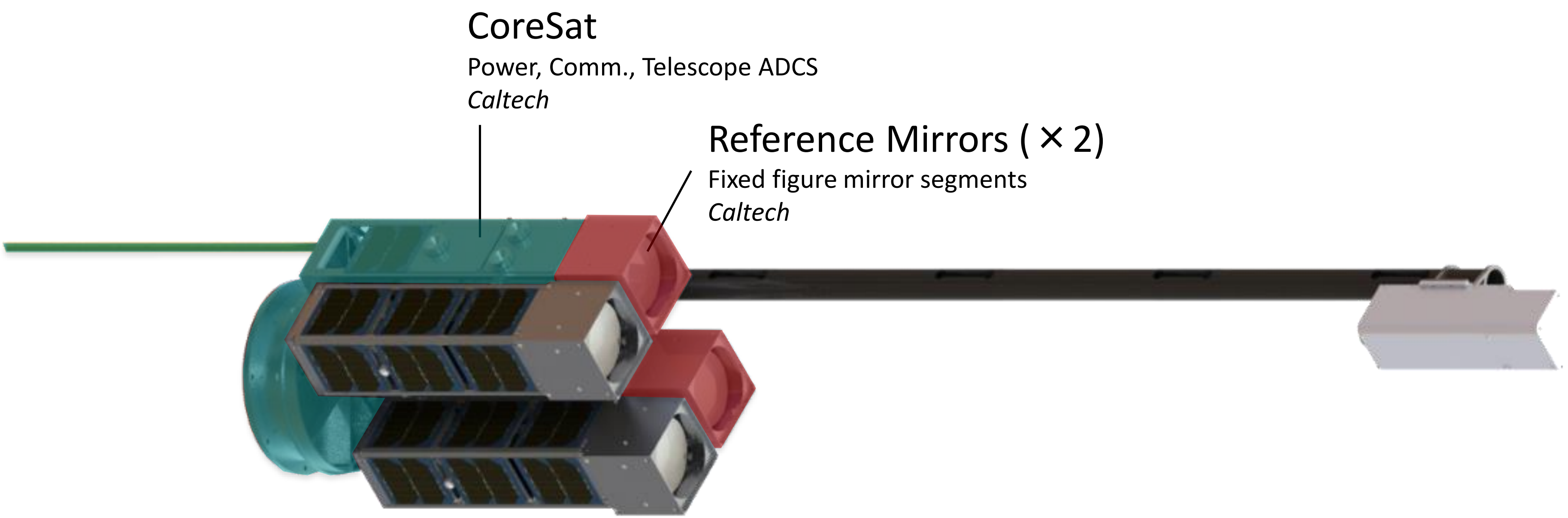


AAReST Spacecraft

CoreSat
Power, Comm., Telescope ADCS
Caltech



AAReST Spacecraft

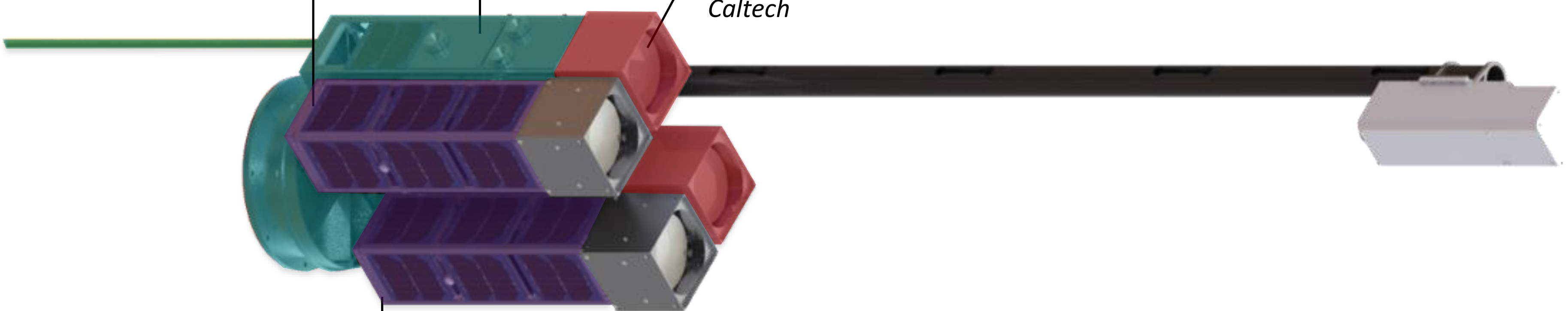


AAReST Spacecraft

MirrorSat (× 1)
Reconfigurable free-flyers
U. of Surrey

CoreSat
Power, Comm., Telescope ADCS
Caltech

Reference Mirrors (× 2)
Fixed figure mirror segments
Caltech



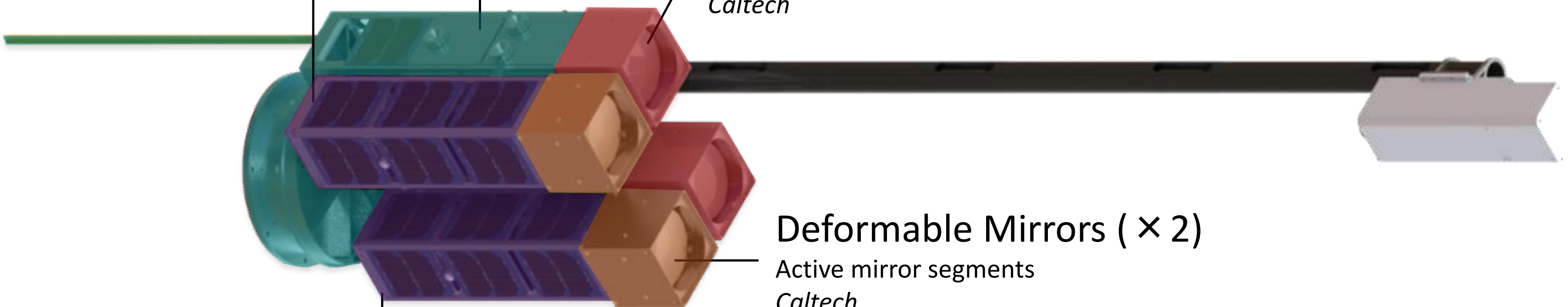
MirrorSat (× 1)
Reconfigurable free-flyers
IIST

AAReST Spacecraft

MirrorSat (× 1)
Reconfigurable free-flyers
U. of Surrey

CoreSat
Power, Comm., Telescope ADCS
Caltech

Reference Mirrors (× 2)
Fixed figure mirror segments
Caltech



Deformable Mirrors (× 2)
Active mirror segments
Caltech

MirrorSat (× 1)
Reconfigurable free-flyers
IIST

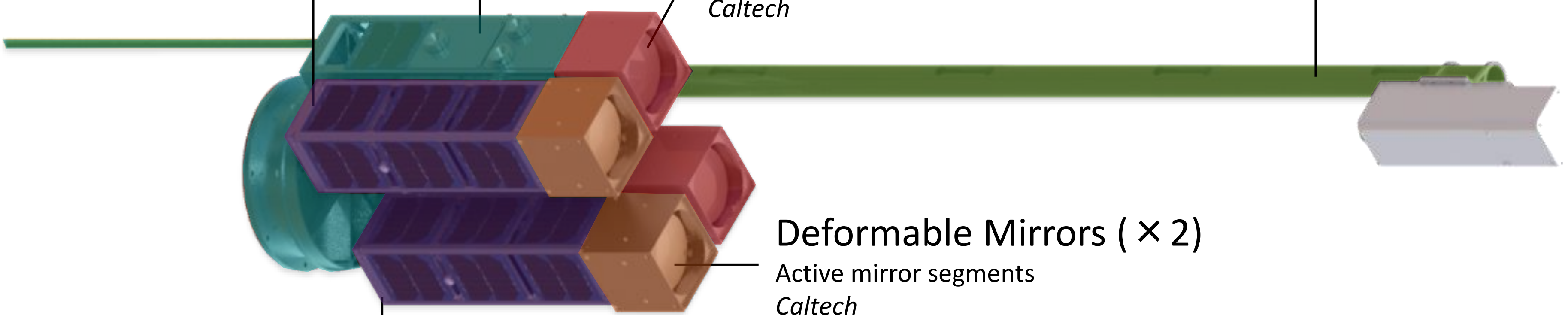
AAReST Spacecraft

MirrorSat (× 1)
Reconfigurable free-flyers
U. of Surrey

CoreSat
Power, Comm., Telescope ADCS
Caltech

Deployable Boom
Composite structure provides 1.2 m focal length
Caltech

Reference Mirrors (× 2)
Fixed figure mirror segments
Caltech



Deformable Mirrors (× 2)
Active mirror segments
Caltech

MirrorSat (× 1)
Reconfigurable free-flyers
IIST

AAReST Spacecraft

MirrorSat (× 1)
Reconfigurable free-flyers
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CoreSat
Power, Comm., Telescope ADCS
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Reference Mirrors (× 2)
Fixed figure mirror segments
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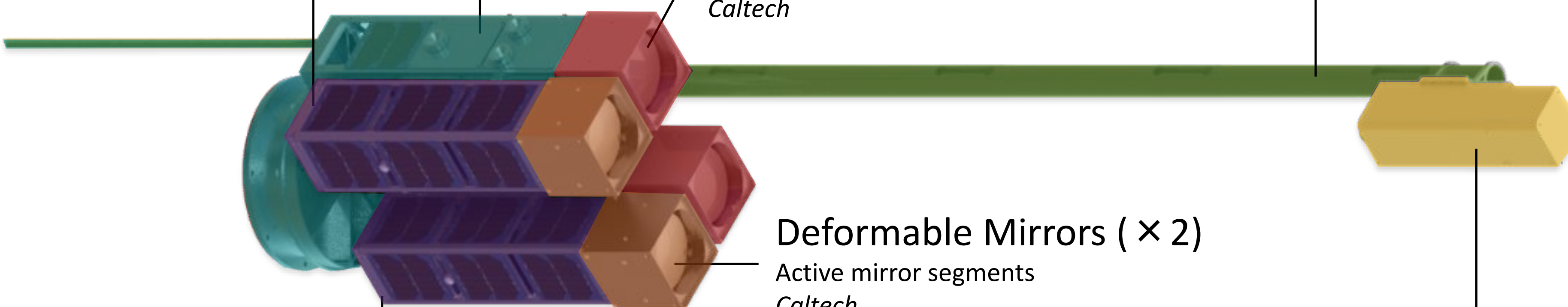


Deformable Mirrors (× 2)
Active mirror segments
Caltech

Camera
Imaging, Wavefront Sensing and Control
Caltech

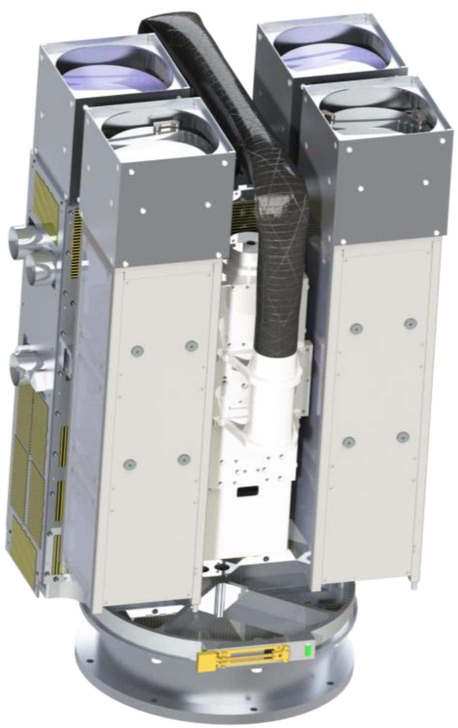
MirrorSat (× 1)
Reconfigurable free-flyers
IIST

Mission Requirements

- Minimum mission
  1. Produce one focused image from a deformable mirror
     - 80% encircled energy radius from point source < 25 μm
  2. Perform at least one in-flight autonomous spacecraft reconfiguration maneuver to demonstrate space assembly capability
- Extended mission
  1. Produce one focused image from a deformable mirror after reconfiguration
  2. Coalign images to improve SNR and demonstrate precursor to co-phasing
  3. Produce at least two images of other sources (e.g. Earth and Moon) for outreach purposes

Concept of Operations

1. Launch	2. Telescope Deployment	3. Telescope Calibration & Imaging	4. Reconfiguration	5. Telescope Recalibration & Imaging	6. Extended Mission



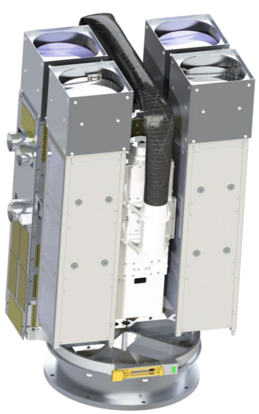
Launch in a compact, stowed volume

- 46 cm × 34 cm × 30 cm

Concept of Operations

1. Launch	2. Telescope Deployment	3. Telescope Calibration & Imaging	4. Reconfiguration	5. Telescope Recalibration & Imaging	6. Extended Mission

- Satellite health check, detumble, antenna deployment
- Deploy boom in two stages
- Uncage deformable mirrors



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Concept of Operations

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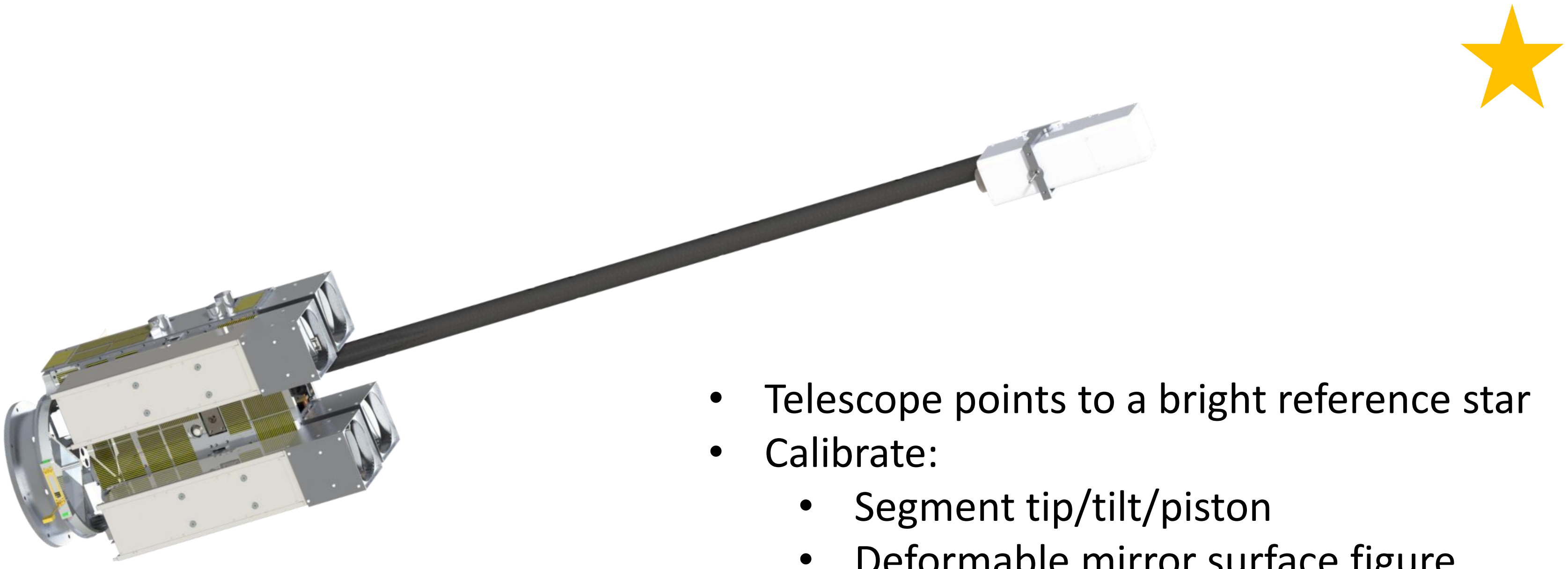
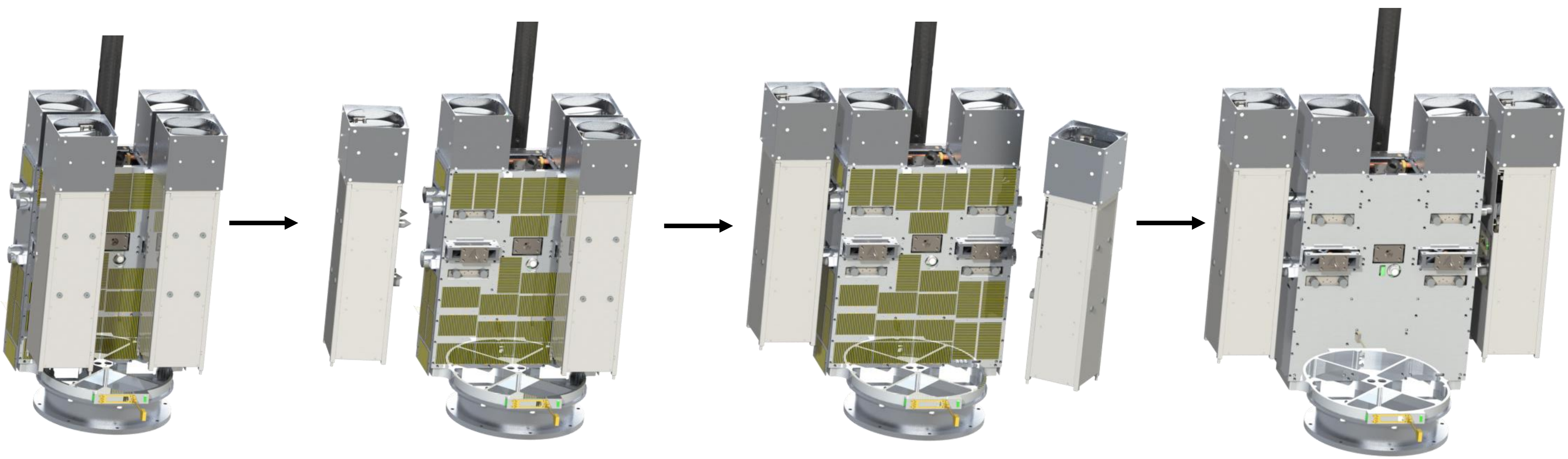


- Telescope points to a bright reference star
- Calibrate:
    - Segment tip/tilt/piston
    - Deformable mirror surface figure
- Camera provides feedback for segment calibration

Concept of Operations

1. Launch	2. Telescope Deployment	3. Telescope Calibration & Imaging	4. Reconfiguration	5. Telescope Recalibration & Imaging	6. Extended Mission

- MirrorSats release from CoreSat using electromagnets
- Fly out ~10 – 30 cm
- Re-dock into "wide" configuration



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Concept of Operations

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Concept of Operations

1. Launch	2. Telescope Deployment	3. Telescope Calibration & Imaging	4. Reconfiguration	5. Telescope Recalibration & Imaging	6. Extended Mission

- Co-align star images from different segments to improve SNR
  - Pre-cursor to co-phasing
- Produce images of extended sources (e.g. Moon, Earth) for outreach
- Perform orbital maneuvers using thrusters

AAReST History

2008 November: Large Space Apertures KISS workshop

2010 June: Ae105

- Initial mission design

2012 September: Mission Concept Review

2013 September: Preliminary Design Review

2014 September: Detailed Design Review

2015 September: Complete Design Review

2016 June: Ae105

- Telescope systems

2017 January: Telescope Complete Design Review

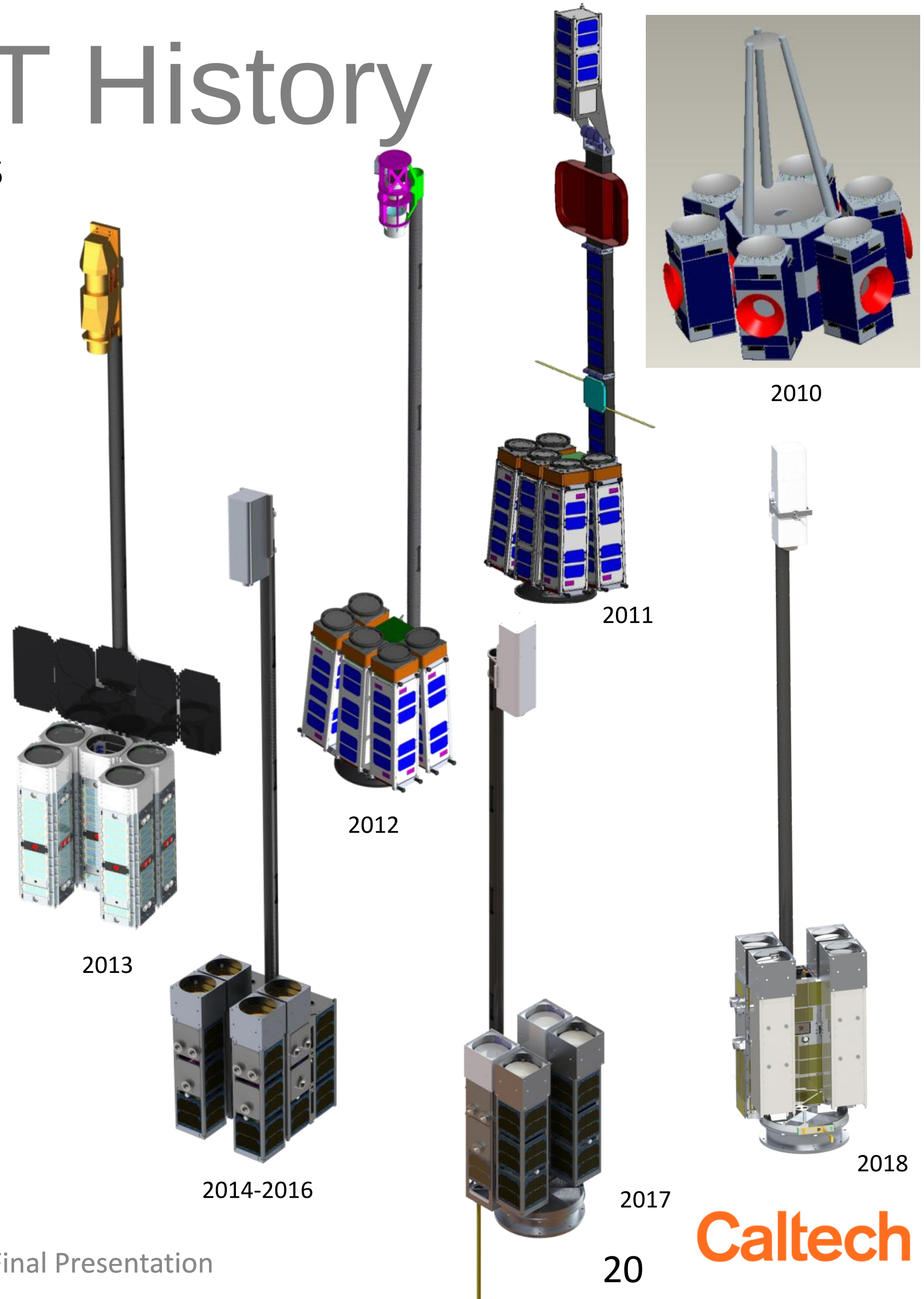
2017 June: Ae105

- Preliminary design of CoreSat

2017 September: Complete Design Review of three satellites

2018 June: Here we are!

- CoreSat hardware assembly and testing



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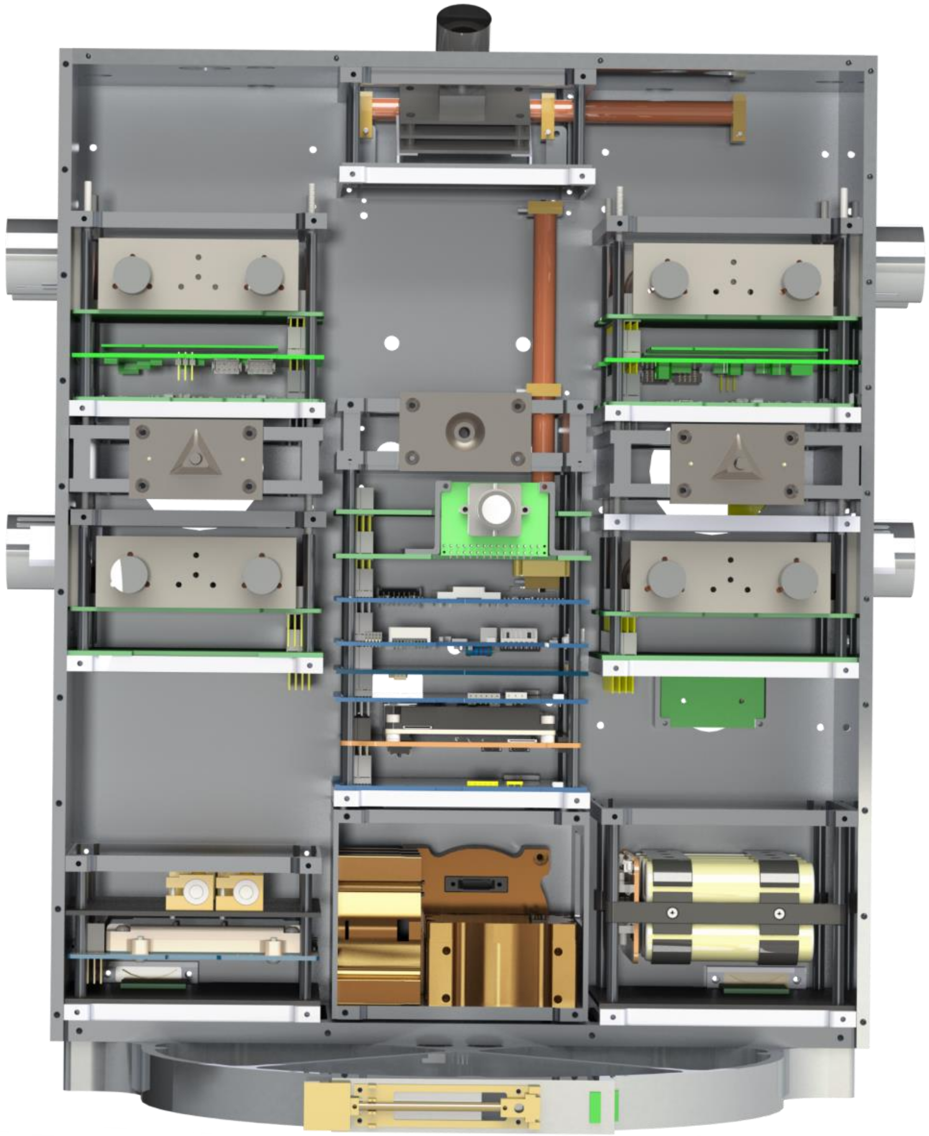
CoreSat Overview

LEFT STACK
- Electromagnet Board UL
- Payload Interface Computer
- Payload Switch Board
- MirrorSat Frangibolt
- Electromagnet Board LL
- Interface Board
- Z Torque Rods
- Radio
- Antenna Board

CENTRAL STACK
- Star Camera
- Camera Frangibolt
- Interface Boards
- ADCS
- EPS board
- OBC
- Reaction Wheels



RIGHT STACK
- Electromagnet Board UR
- Payload Interface Computer
- Payload Switch Board
- MirrorSat Frangibolt
- Electromagnet Board LR
- Interface Board
- Z Torque Rods
- Battery
- Antenna Board

Acknowledgement

The AAReST project is supported by:

- The Keck Institute for Space Studies
- Division of Engineering and Applied Science
- Provost's Innovation in Education Fund
- JPL (providing mentoring)

Outline

2:00 pm: Introduction & Mission Overview

2:15 pm: Structures

2:40 pm: Mechanisms

3:55 pm: ADCS

3:20 pm: Thermal

4:35 pm: Onboard Software

4:00 pm: Telecom

4:25 pm: Avionics

5:00 pm: Reception

Structures Team

Yunsang Choi
Kanthasamy Ubamanyu
Haojie Zhuang

Mentor: Antonio Pedivellano

Overview and Objectives

Goal: deliver a launch-qualified flight structure

- Vibration test to ensure the structural soundness of the CoreSat, MirrorSats
  - Design representative mass model
  - Manufacture and assemble mass model
- Study the structural dynamics of the spacecraft through FEM

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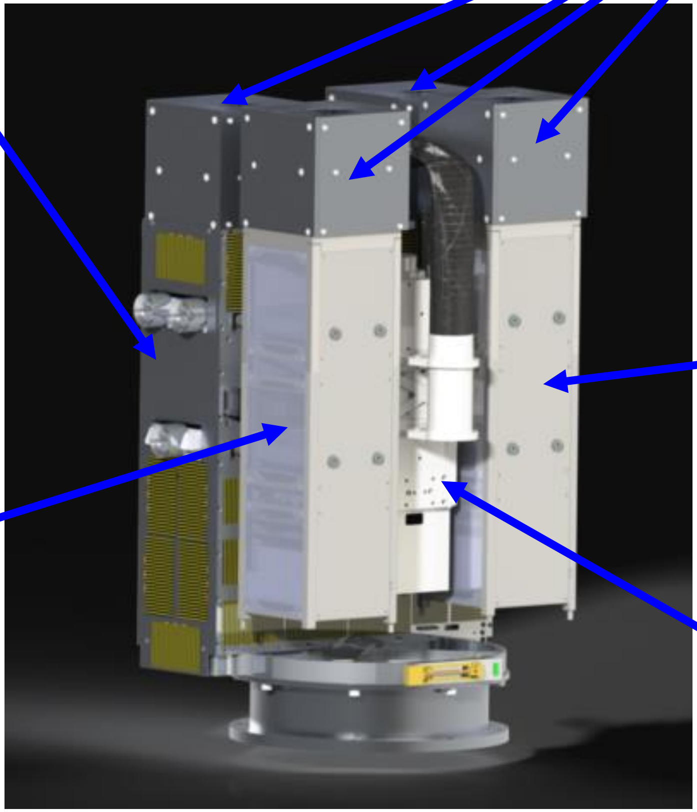
AAReST Mass Model

CoreSat
(Caltech)

MirrorBoxes
(Caltech)



MirrorSat
(Surrey)

MirrorSat
(IIST)

Camera
(Caltech)

Task breakdown

- Yunsang and Haojie
  - Manufacture AAReST Model for vibration testing
  - Integrate subsystems and perform fit checks
  - Document procedures and improvements
- Uba
  - Design of interface plate for vibration test
  - Finite element simulations

Task Changes

- Fit test and assembly time frame extended
  - Numerous errors in outsourced components
  - Components modified and fixed in house
- Vibration test postponed due to delay in arrival of Mirrorsats from IIST and Surrey

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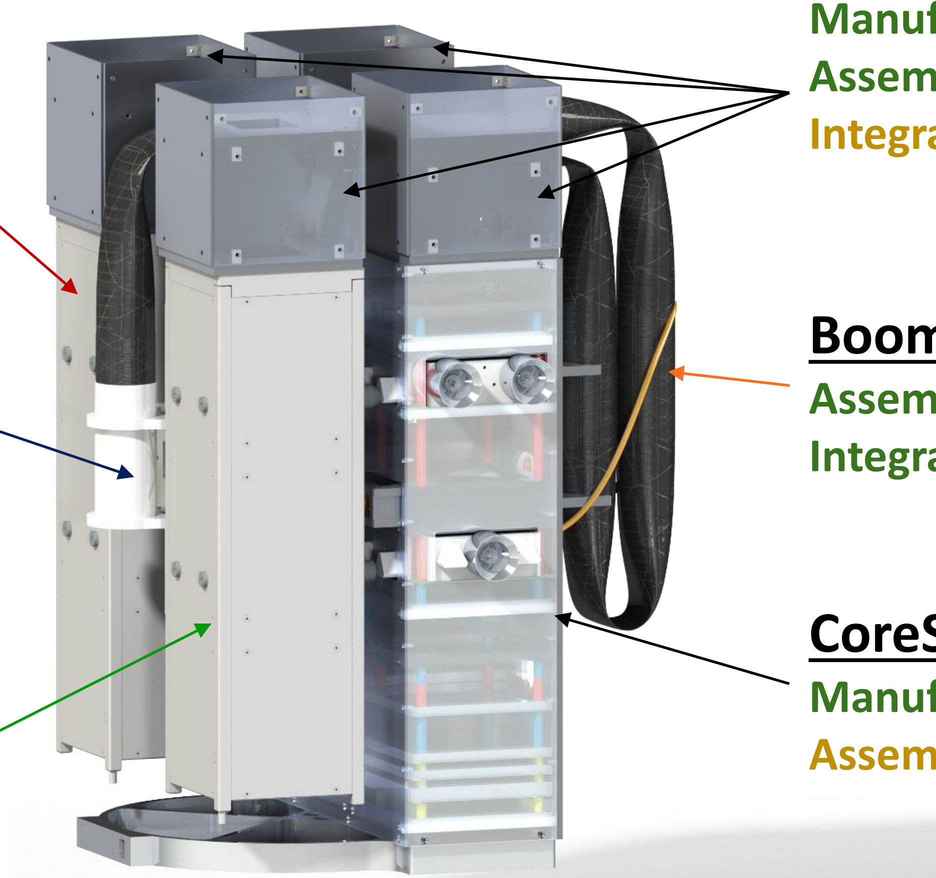
Current Status

IIST MirrorSat
Received

Camera
Manufacturing: 100 %
Assembly: 100 %
Integration: 100 %

Surrey MirrorSat
Not yet shipped

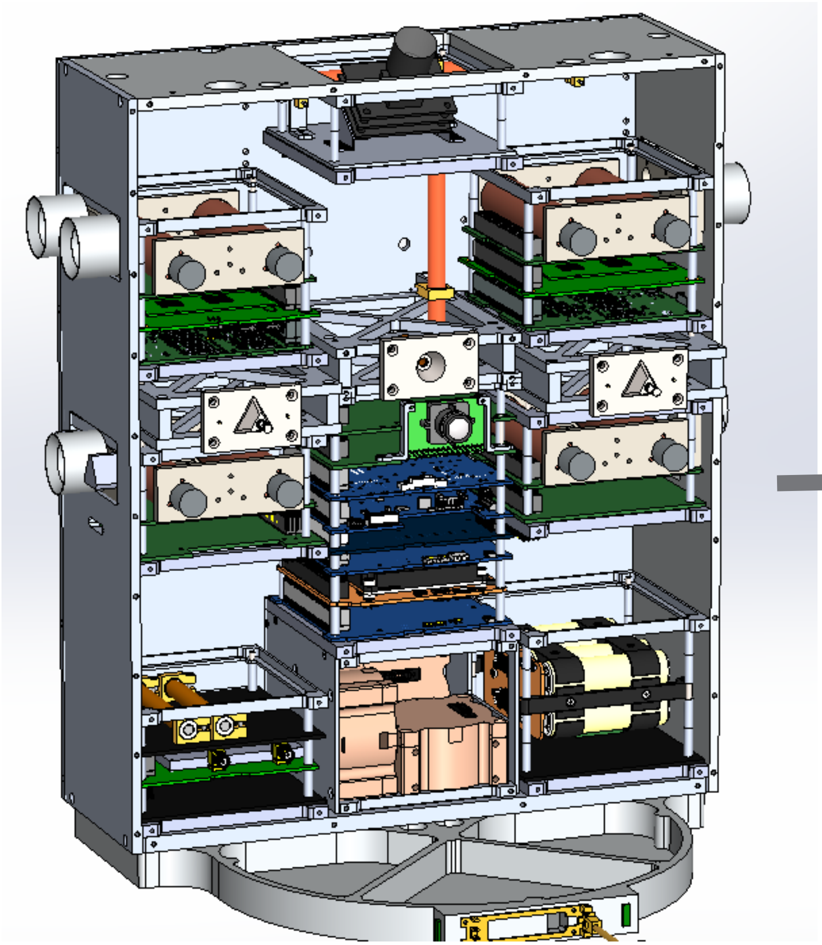


MirrorBoxes
Manufacturing: 100 %
Assembly: 100 %
Integration: 50 %

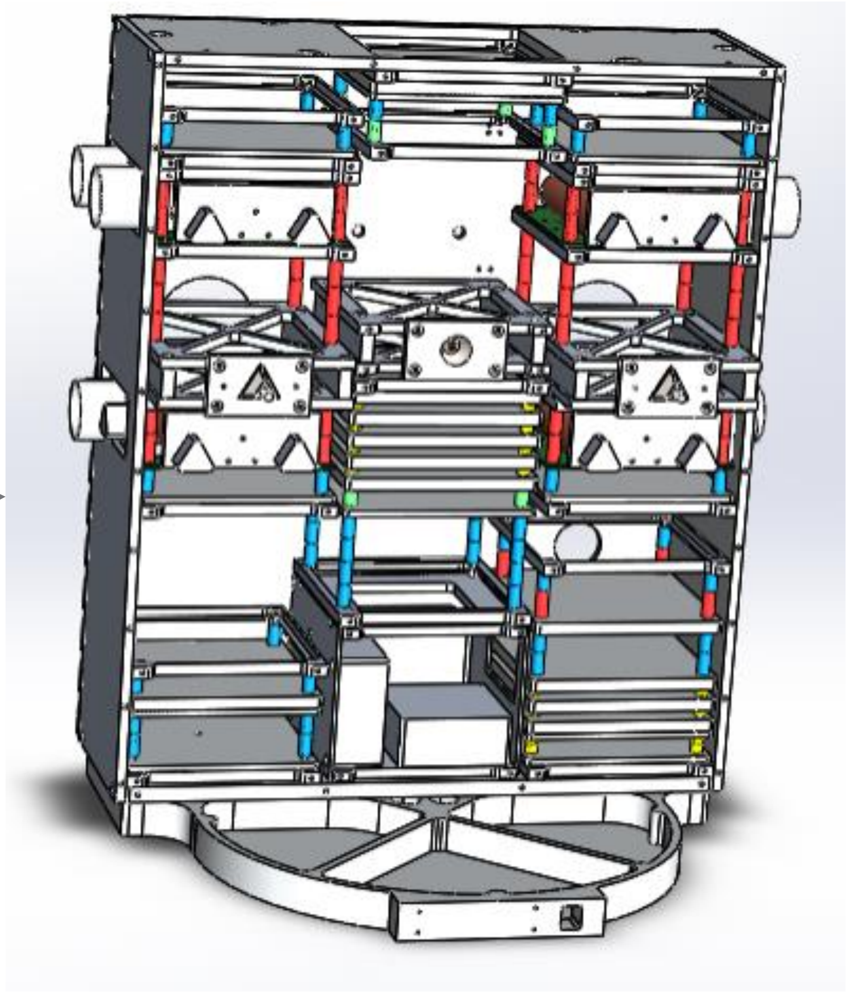
Boom
Assembly: 100 %
Integration: 100 %

CoreSat
Manufacturing: 100 %
Assembly: 85 %

CoreSat Mass Model Design



Flight CAD



Representative Mass Model

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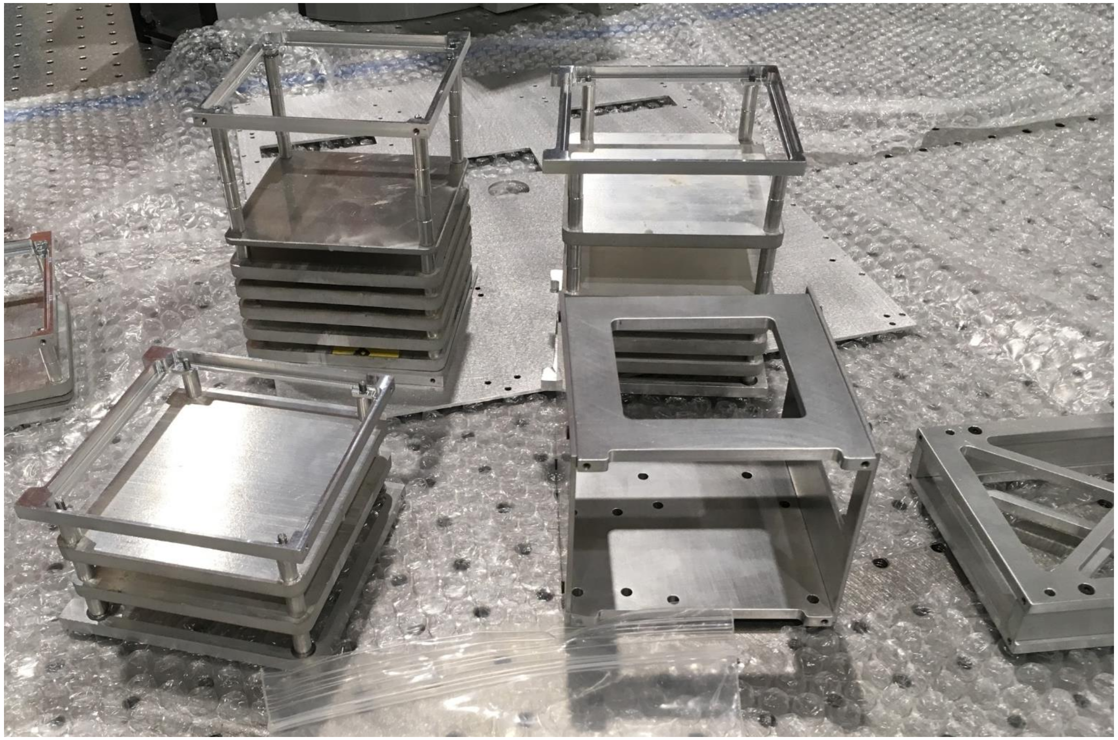
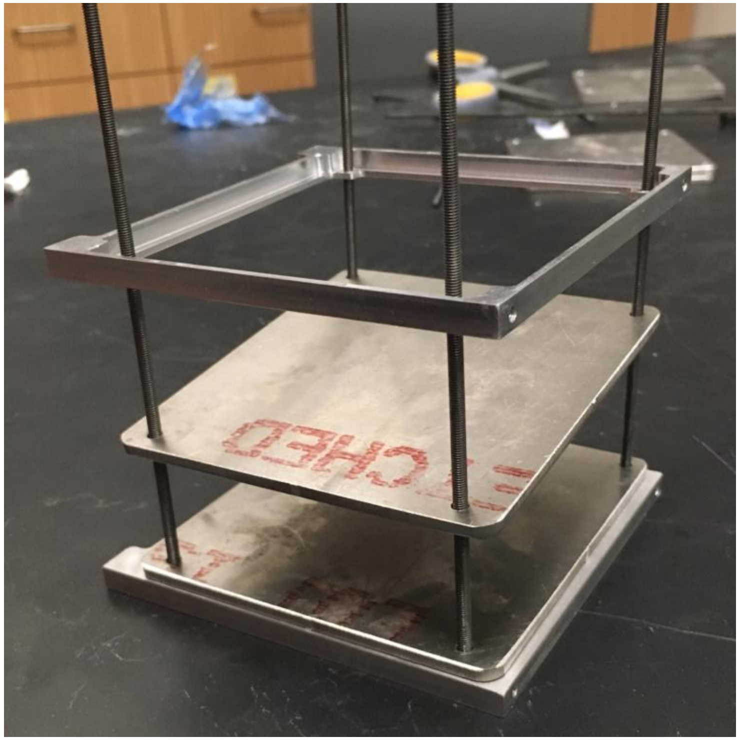
CoreSat Internal Stacks



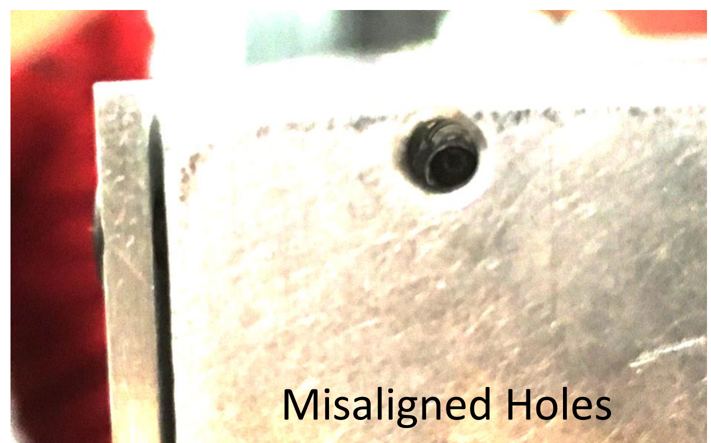
Example of internal representative mass stacks



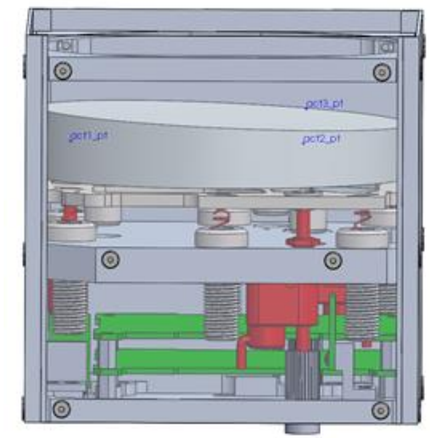
Threaded rods and frame

Manufacturing Errors


Remanufactured +X Face Plate

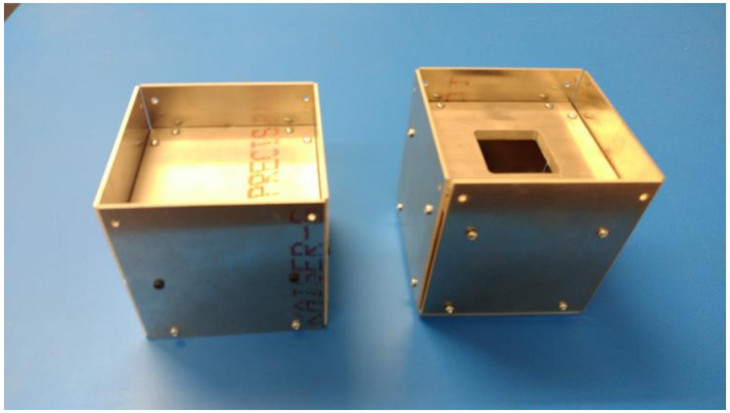

Misaligned Holes

MirrorBox Mass Model

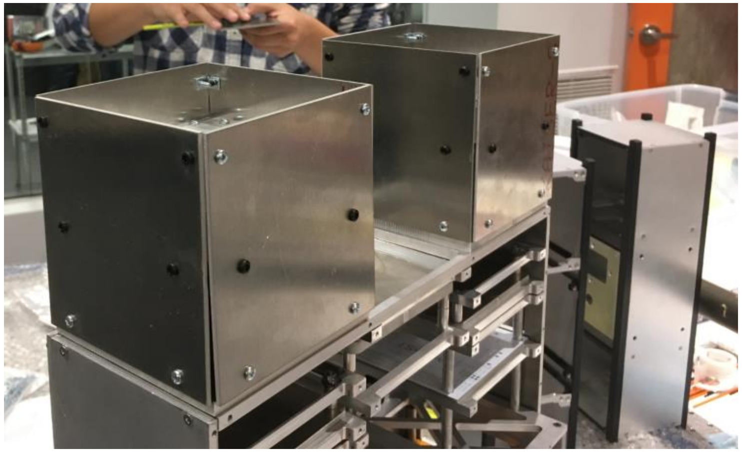


Flight CAD

Mass Model Design



Assembly



Integration

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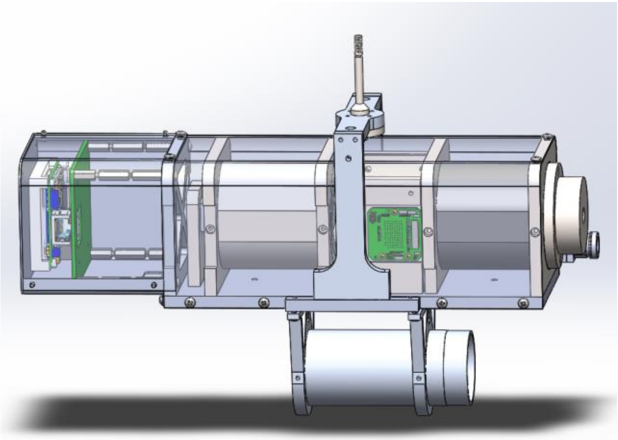
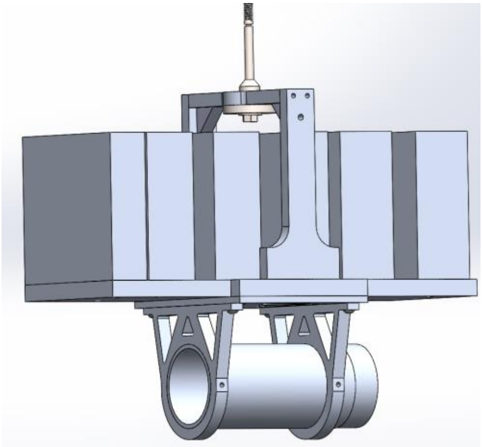
Camera Mass Model

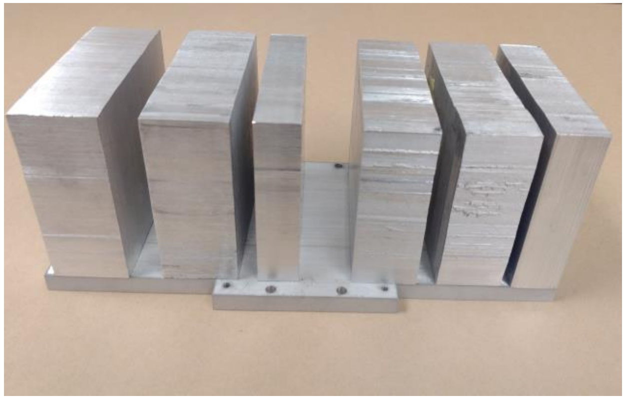
- Manufacturing delayed by waterjet breakdown
- Switched to bandsaw manufacturing
- Waiting on Frangibolt interface and mount



Flight CAD



Mass Model Design



Assembly

Mass Comparison

	CAD Mass (g)	Measured Mass (g)
Center Stack	1345	1520
Right Stack	1377	1401
Left Stack	866	932
Total	**3588**	**3853**

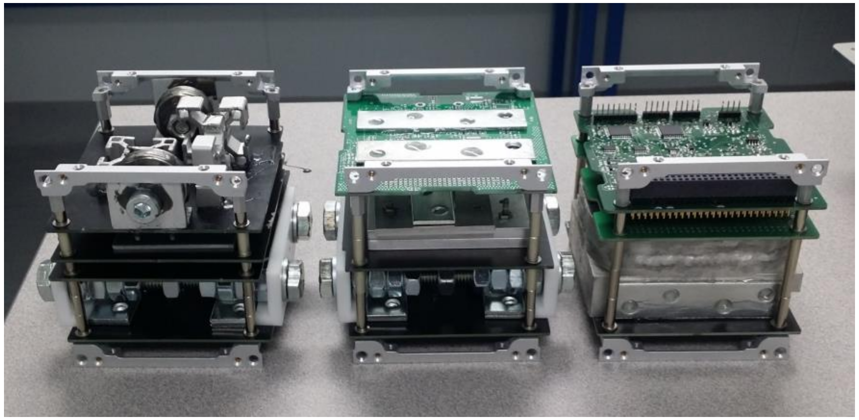
Mass difference: 265 g (6.7% deviation)

Deviations:

- 80 gram resolution for masses (up to 40 grams ~1% deviation)
- The CAD model lacks fasteners and cable harnessing

MirrorSats

- Representative model required for vibration testing
  - MirrorSats attached to CoreSat via Frangibolt (provided by Caltech)
  - Electromagnet provided by Surrey
- IIST MirrorSat received
- Surrey MirrorSat not yet shipped



Surrey MirrorSat masses

IIST MirrorSat

Integrated Mass Model

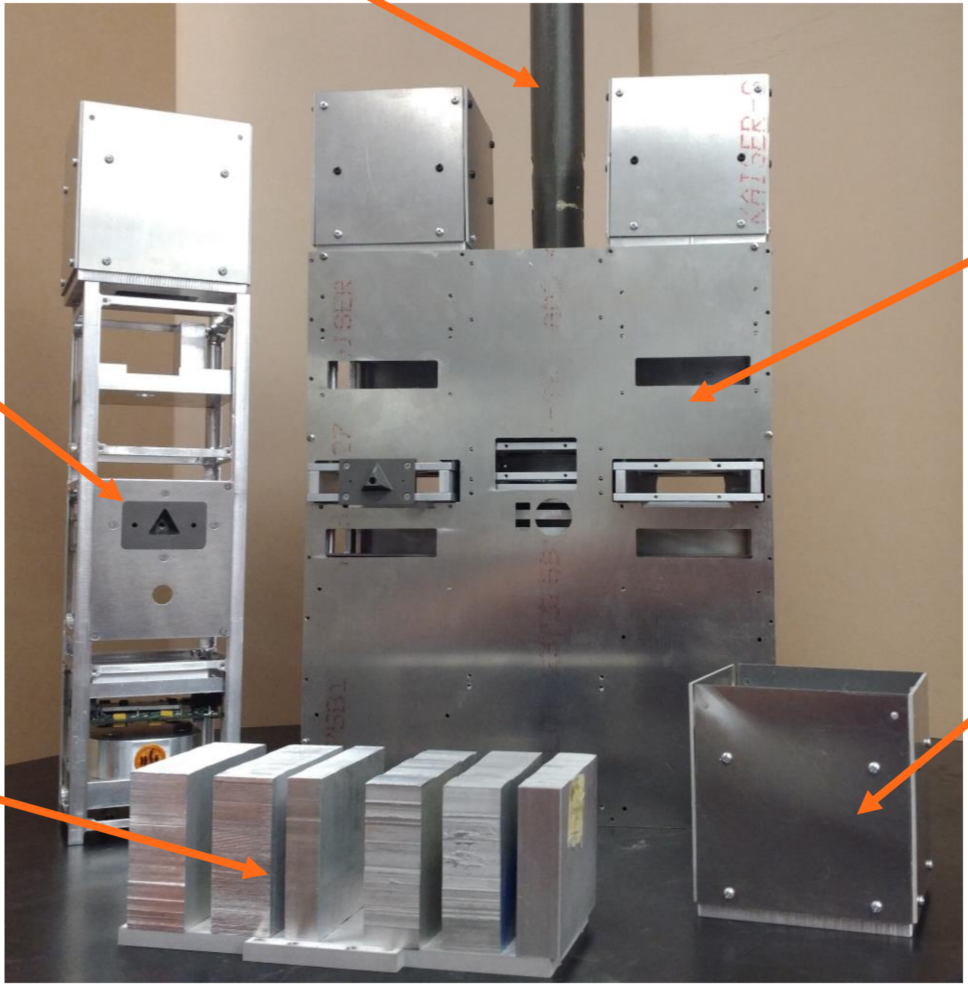
Deployable boom

CoreSat

IIST MirrorSat

Deformable MirrorBox

Camera



Vibration Table Interface

- Mount AAReST to the vibration table
- Requirements
  - Lowest natural frequency > 2000 Hz
  - Match actual boundary conditions
  - 3-axis vibration test

Figure 1: Example of Vibration table [1]

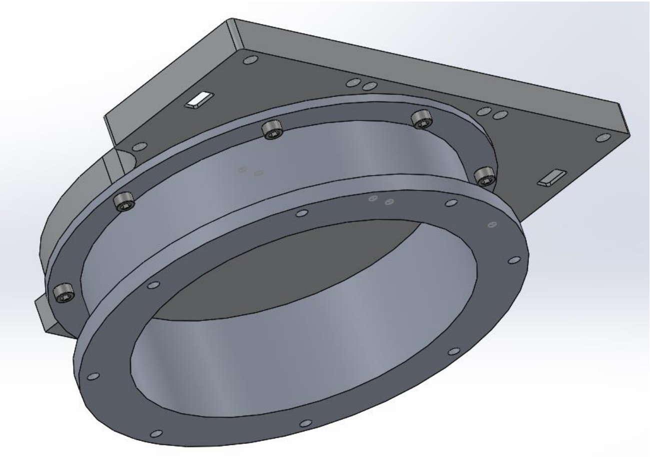


Figure 2: Flight LV interface

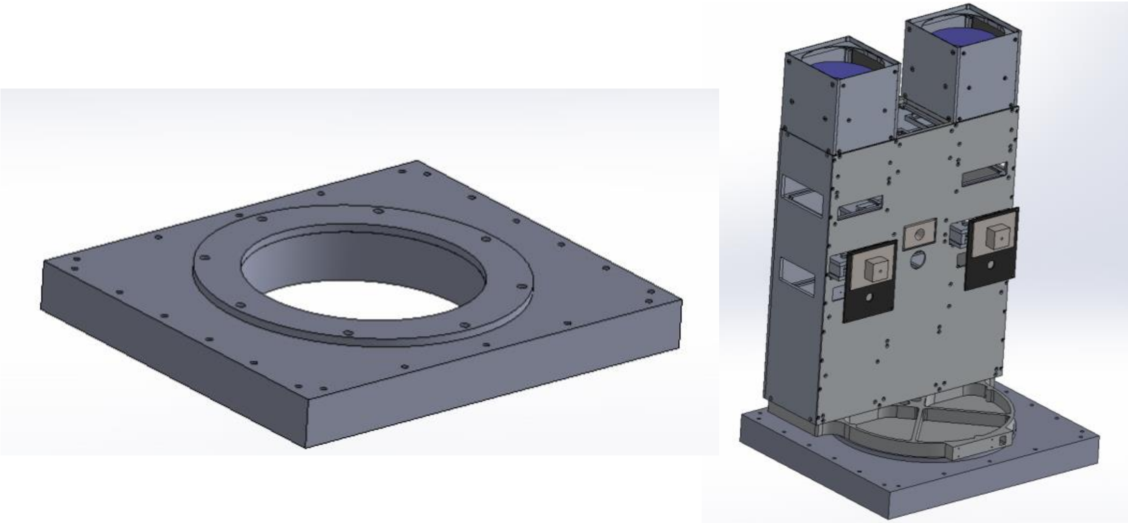


Figure 3:a) Proposed interface; b) Interface with AAReST

[1] http://www.sentekdynamics.com/vibration-testing-specifications-and-standards/

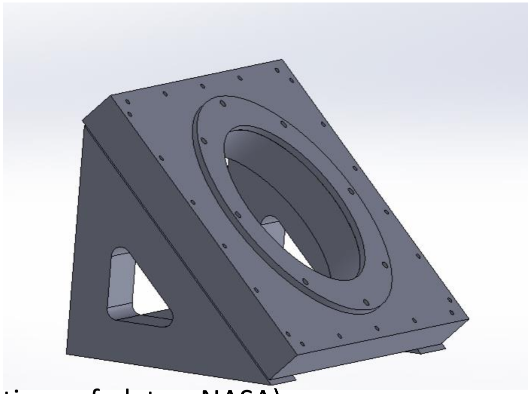
Design of Interface Plate

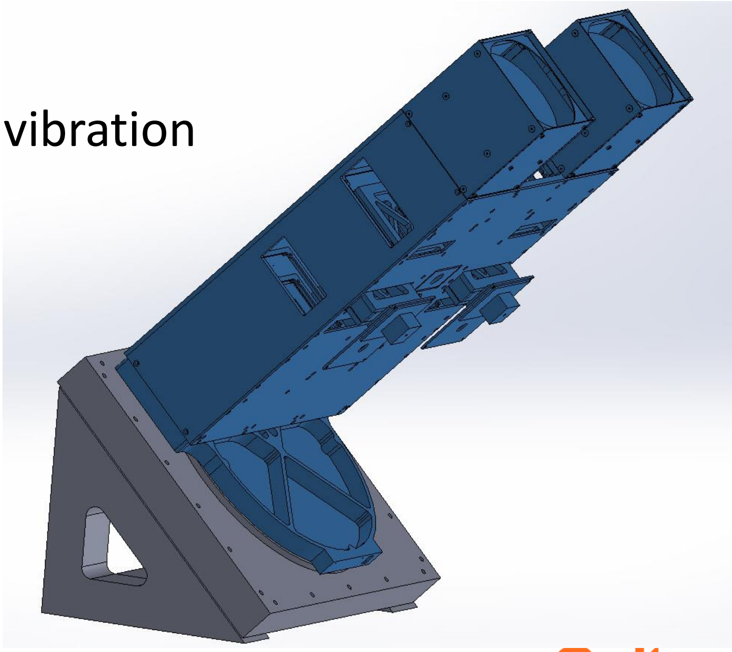
- Initial estimation for thickness [2]
  - Rectangular plate simply supported along all edges

$$\omega^2 = \frac{\pi^4 D}{a^4 \rho}\left\{\left(\frac{a}{b}\right)^4 + 2\left(\frac{a}{b}\right)^2\right\}; \quad where, D = \frac{Eh^3}{12(1-\nu^2)}$$

38.1mm (1 ½") thick rectangular plate of 350mm x 300mm

- 3-axis vibration test
  - vibration table often allows only lateral vibration
  - 45° angled mount





[2] W. Leissa,1969, Vibrations of plates, NASA)

Numerical Simulation

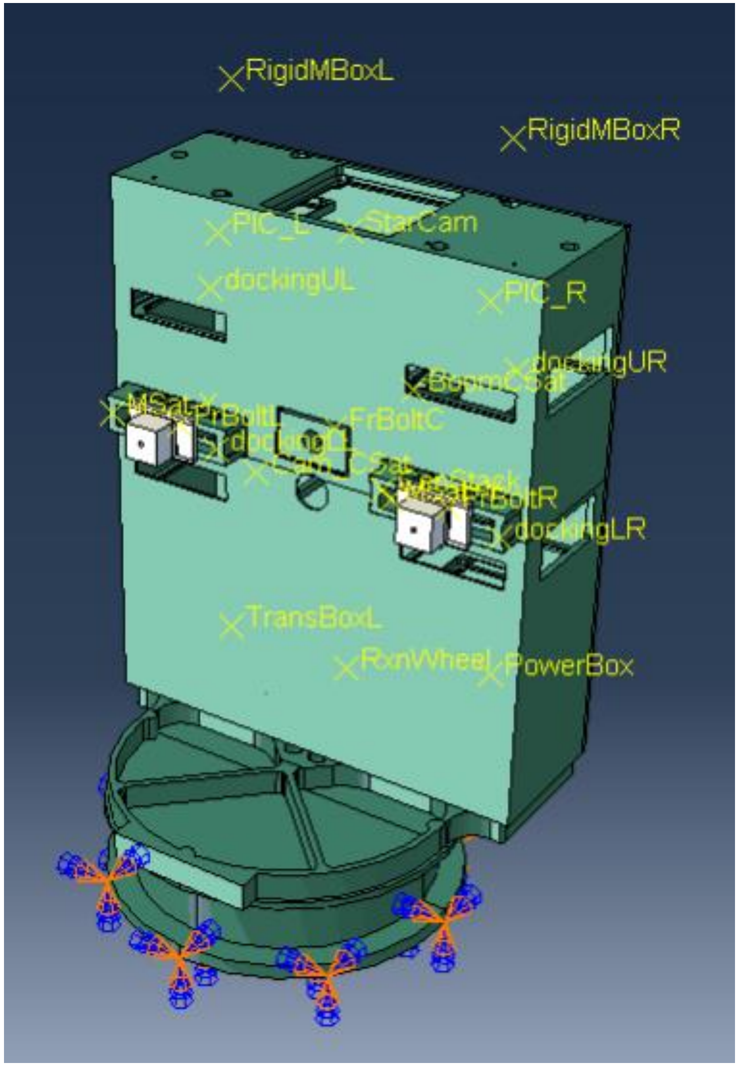
Motivation

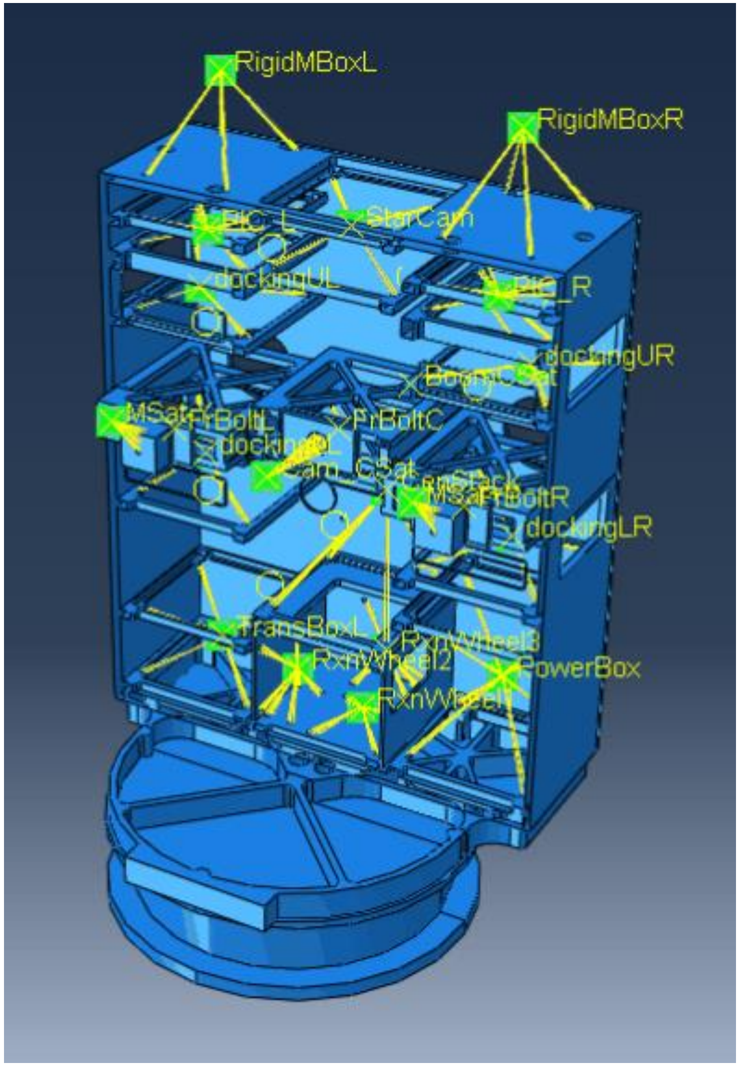
- Efficient tool for evaluating design changes and sensitivity studies
- Easy to obtain stress and strain distributions
- Required by launch provider
  - Modal frequency analysis
  - Random environment analysis
  - Shock analysis

Objective

- Study the structural response of the CoreSat
  - Develop a “representative” FE model
  - Fidelity of FE model correlated against vibration test results

Finite Element Model





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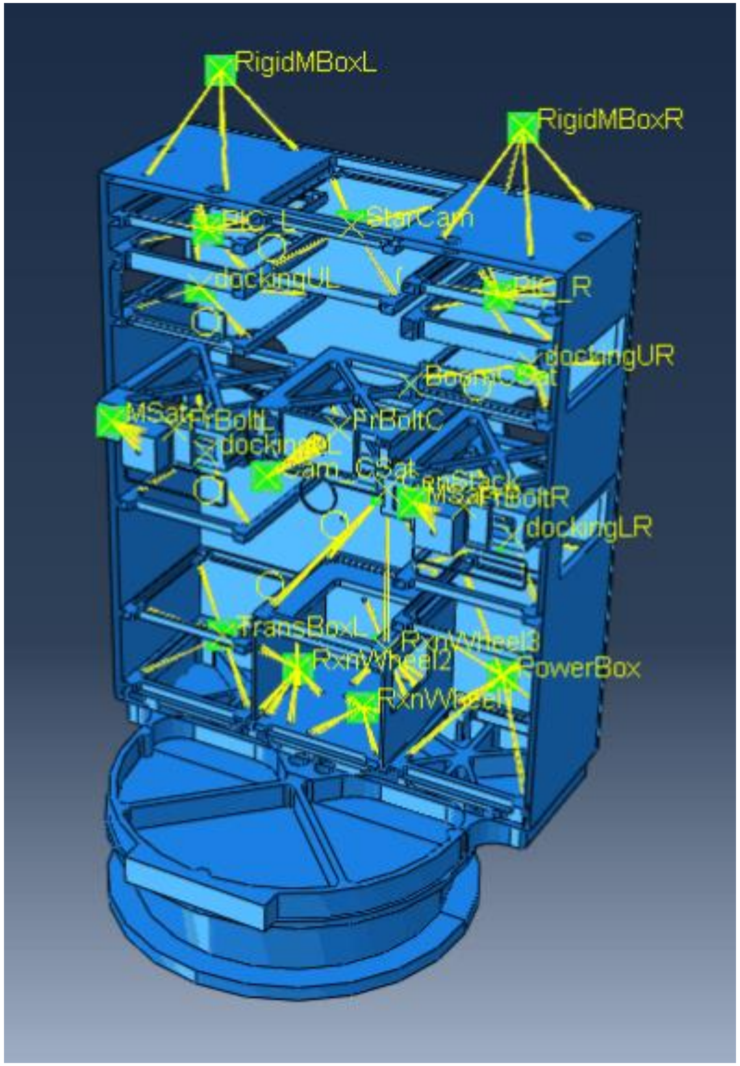
Finite Element Model

- Simplified geometry of the model
  - Single part for entire external structure
  - Sub systems included as point masses
- Connection type
  - Tie constraint - no relative motion between them
  - Coupling constraint - allowing control over the transmission of forces
- Element type
  - C3D10 - 10 node quadratic tetrahedron
- Boundary condition
  - Clamped at Launch vehicle interface



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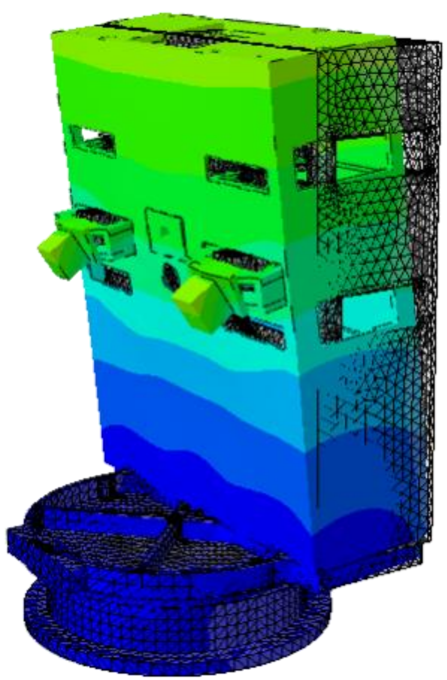
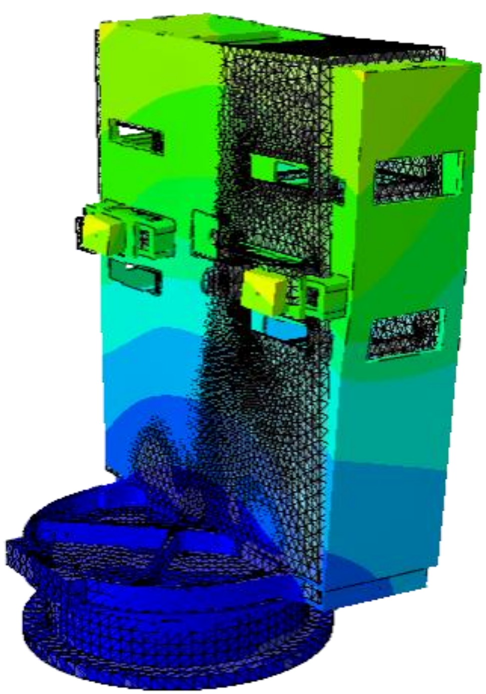
Modal Analysis

PSLV Stiffness requirements

- For base-fixed conditions
- Lateral > 45 Hz Longitudinal > 90 Hz



Mode 1
Lateral Mode (X)
65.1 Hz



Mode 4
Lateral Mode (Y)
109.4 Hz

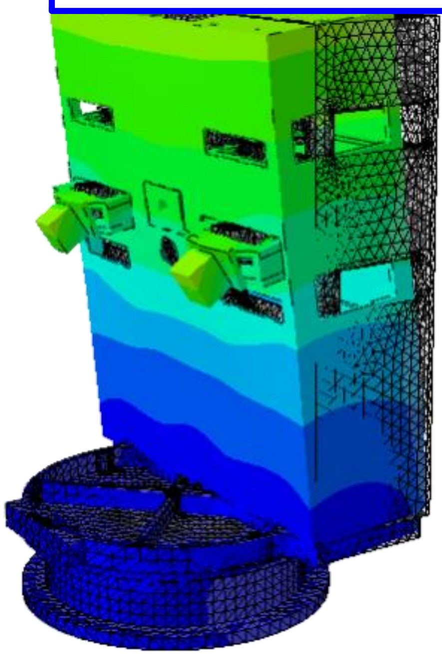
Mode 5
Longitudinal Mode (Z)
111.4 Hz

Modal Analysis

PSLV Stiffness requirements

- For base-fixed conditions
- Lateral > 45 Hz Longitudinal > 90 Hz

Requirements satisfied!
with a margin of 22% for longitudinal and 44% for lateral



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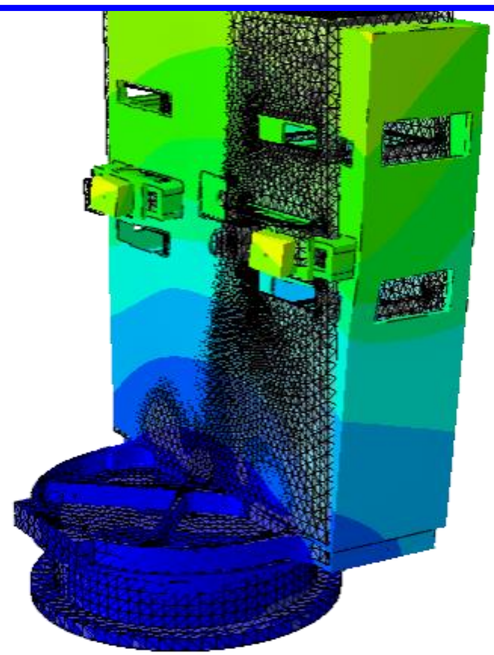


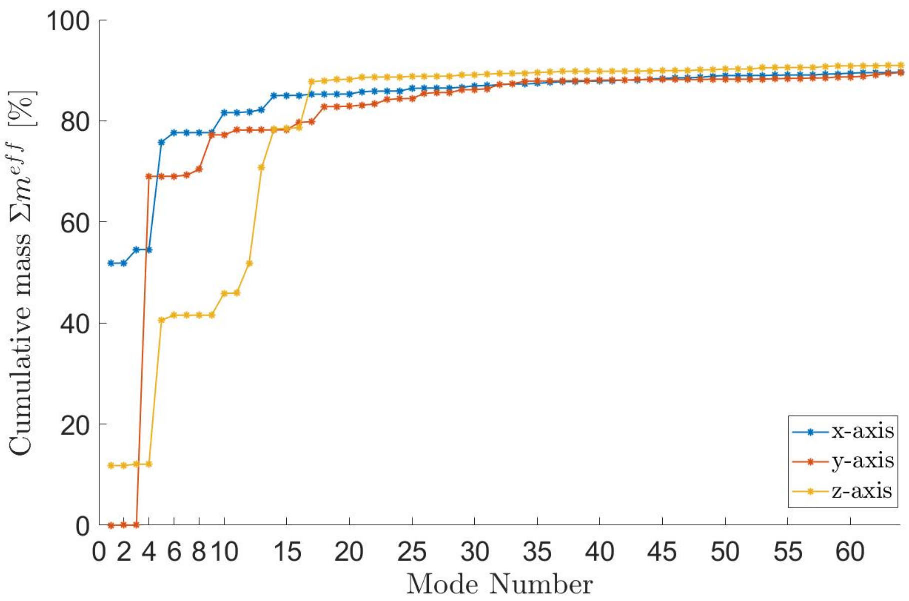
Mode 4
Lateral Mode (Y)
109.4 Hz

Mode 5
Longitudinal Mode (Z)
111.4 Hz

Random Response Analysis

- Random environment load analysis
  - Load analysis using extracted eigenmodes for base-driven random vibration

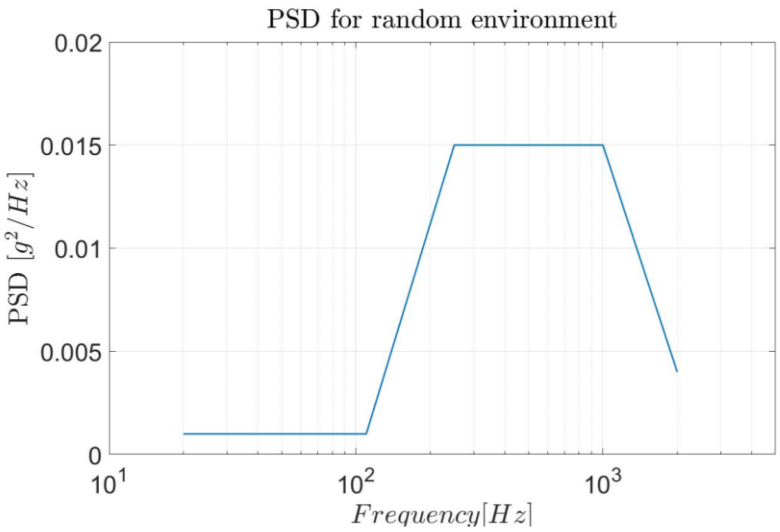
- Extracted range of modes sufficiently spans the mass of spacecraft
  - 90% of total mass captured along each axis



[2] V. Adams and A. Askenazi, 1999, Building Better Products with Finite Element Analysis, OnWord Press, Santa Fe, N.M.

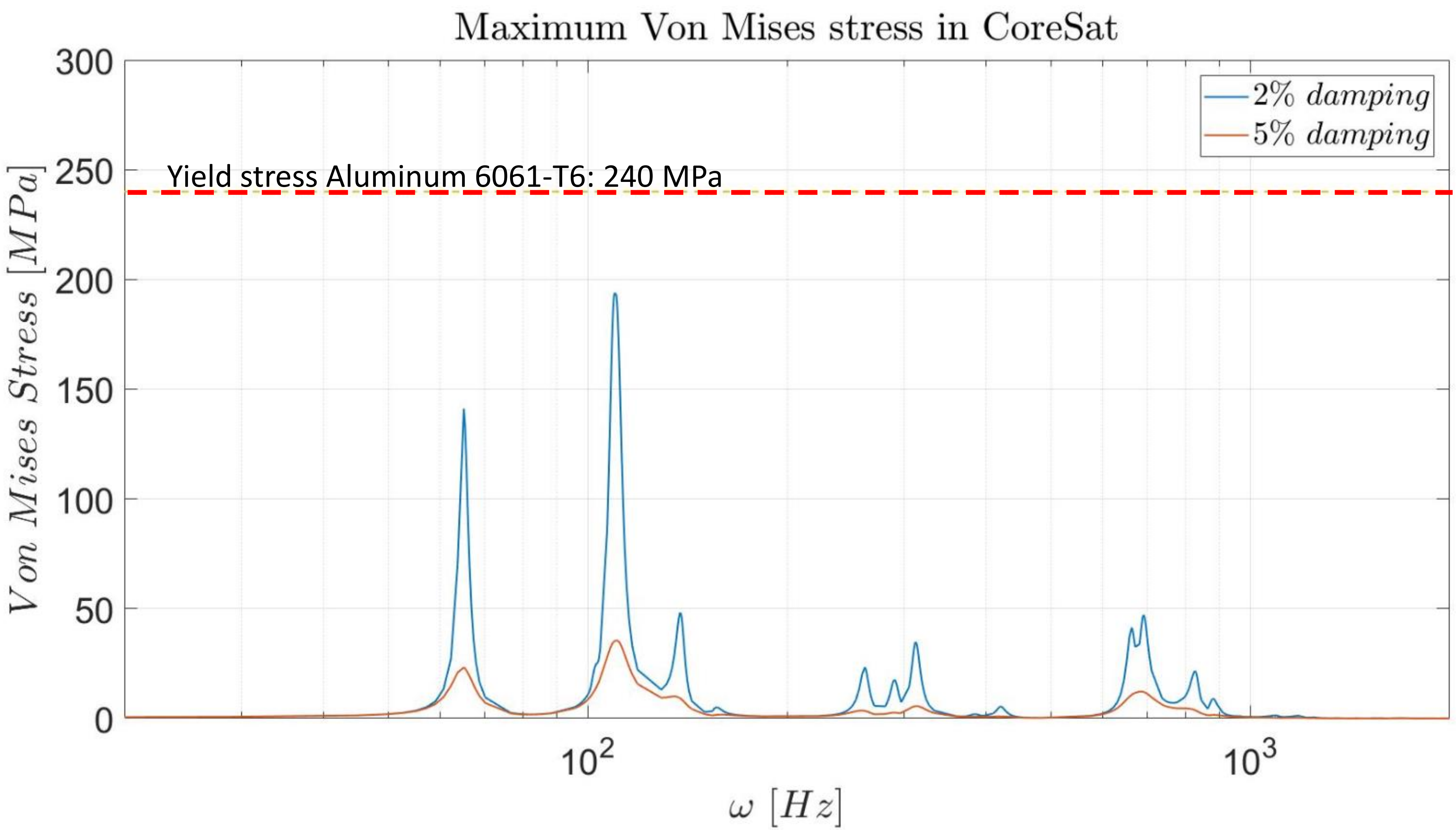
Random Response Analysis

- Random environment load analysis
  - Load analysis using extracted eigenmodes for base-driven random vibration
- Extracted range of modes sufficiently spans the mass of spacecraft
  - 90% of total mass captured along each axis
- Parameters used for analysis:
  - Damping 5% [2]
  - Apply base motion as PSD along all 3-axes



[2] V. Adams and A. Askenazi, 1999, Building Better Products with Finite Element Analysis, OnWord Press, Santa Fe, N.M.

Results



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Deliverables

- Assembly procedure
  - Include information regarding how to assemble and put together AAReST mass model
  - Facilitate future assembly work that would have to be performed
- List of recommendations
  - Suggest possible improvements for flight structure, from design perspectives to outsourcing tips
- Numerical simulations
  - Simplified, representative finite element model
  - Modal analysis results
  - Random environment analysis results

Conclusion

- Internal and external structures of AAReST are assembled
- Awaiting parts from IIST and Surrey
- Satisfied PSLV frequency requirements
- Nominal stress levels are below yield stress

Future work

- Optimize the design of interface for vibration table
- Perform vibration and shock test
- Refine and calibrate the model depending on the results
- Perform shock analysis via FEM

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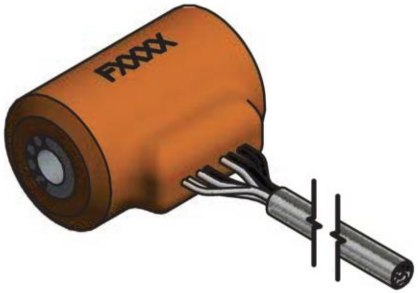

Mechanisms Team

Mouadh Bouayad David Watson

Mentor: Christophe Leclerc

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Validation and Characterization of Separation Interface

- Role of separation interface:
  - Holds MirrorSat and camera to CoreSat during launch
  - Release MirrorSat for reconfiguration, release camera for boom extension
  - Responsible for power transfer from CoreSat to MirrorSat

Frangibolt: Separating device

- Upon actuation of separating device (Frangibolt), energy is released into MirrorSat
  - Will Frangibolt actuation cause the ejection of a MirrorSat?
  - How can we determine when the Frangibolt has actuated?

Location on AAReST

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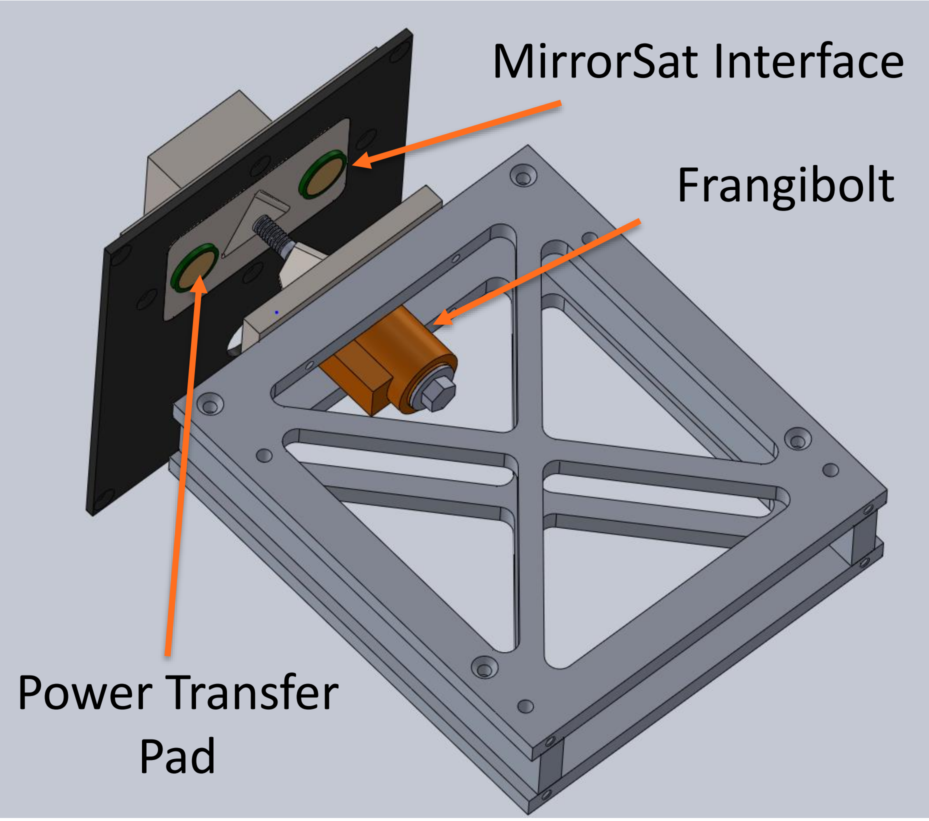
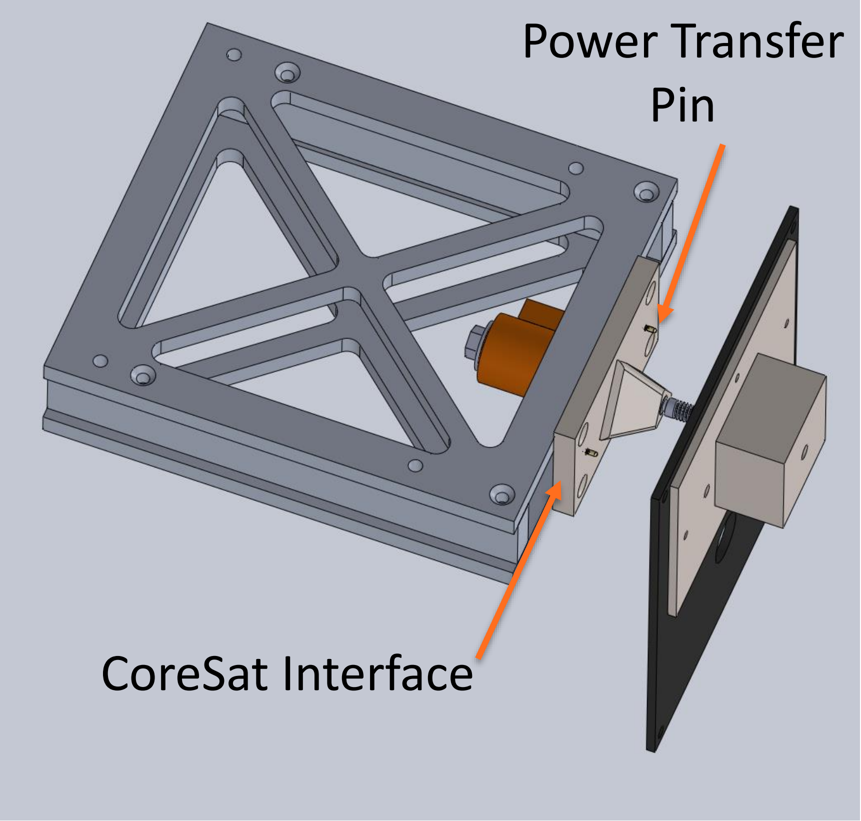
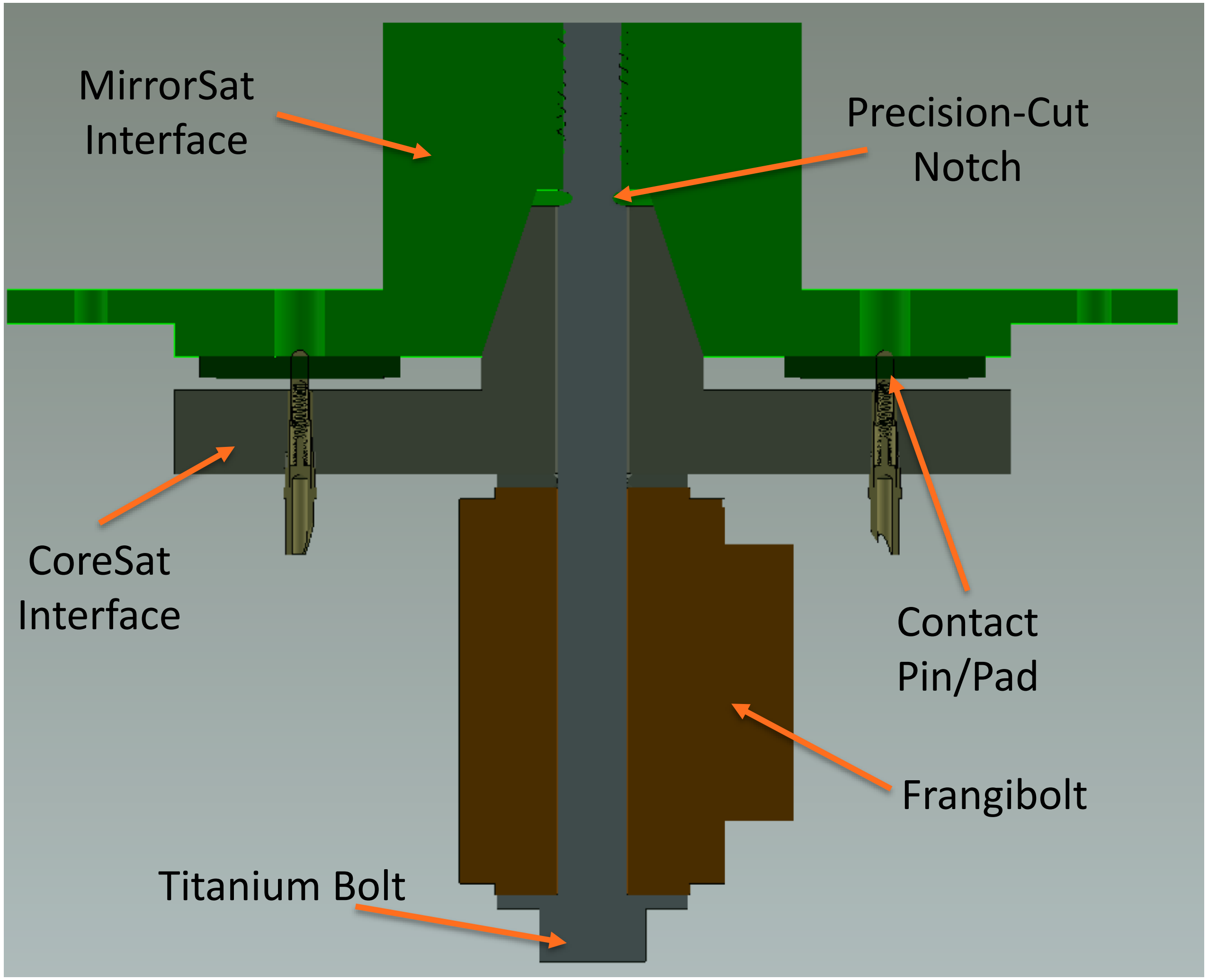
Interface System





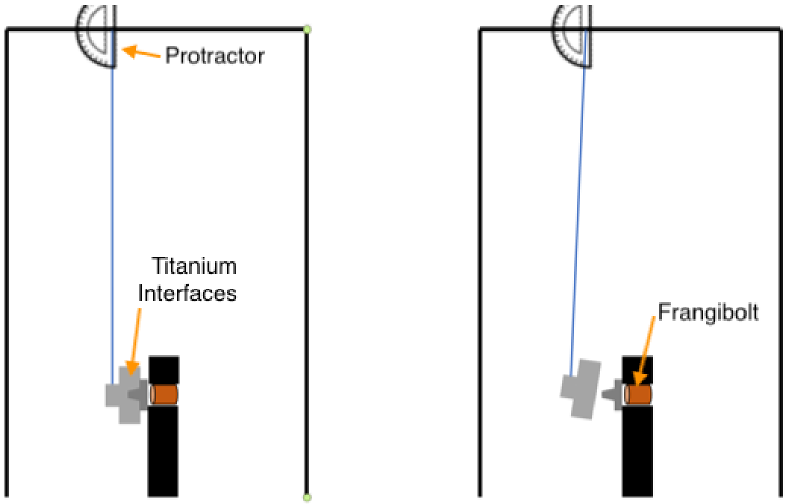
Frangibolt System



Deliverables

- Estimate recoil energy, velocity, impulse of separation
  - Derive MirrorSat motion upon Frangibolt actuation
- Record actuation time for Frangibolt
  - Compare at various input voltages
  - Determine power consumption of Frangibolt
- Measure temperature profile
  - Determine when to cut power to Frangibolt
- Determine the power transfer capability of interface
  - Transfer 4.5V @ 2A

Recoil Energy – Testing Design



- A pendulum was chosen to measure the energy released during Frangibolt actuation
  - Energy chosen for ease of direct measurement
  - Minimal friction during motion
  - Pendulum theory used to easily verify results
- Three tests using only the titanium interfaces, powering the Frangibolt with different input voltages:
  - Minimum voltage : 26.8 V
  - Nominal voltage: 29.6 V
  - Maximum voltage : 33.4 V
- Fourth test using a mass dummy to simulate motion of a full MirrorSat after actuation

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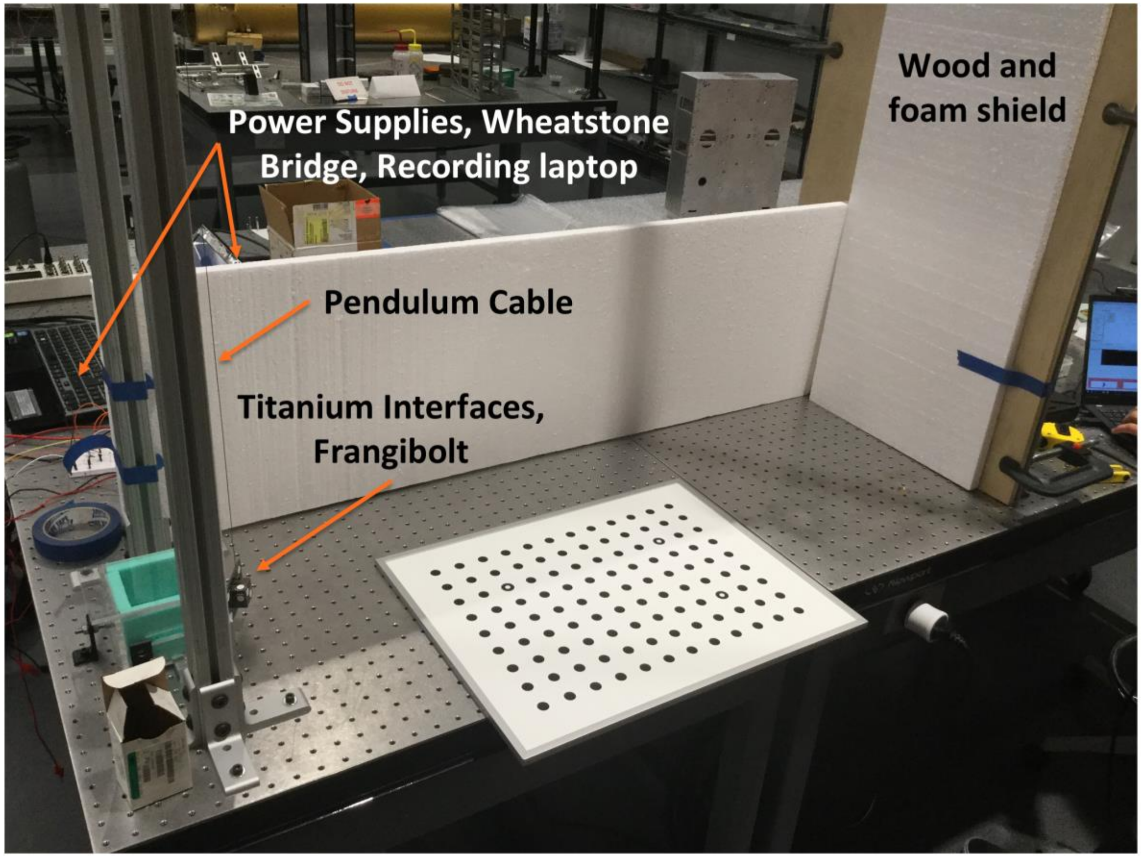
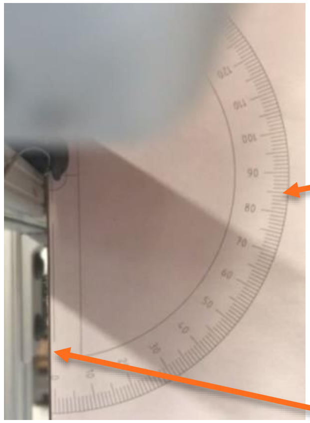
Recoil Energy – Constructed Test Setup

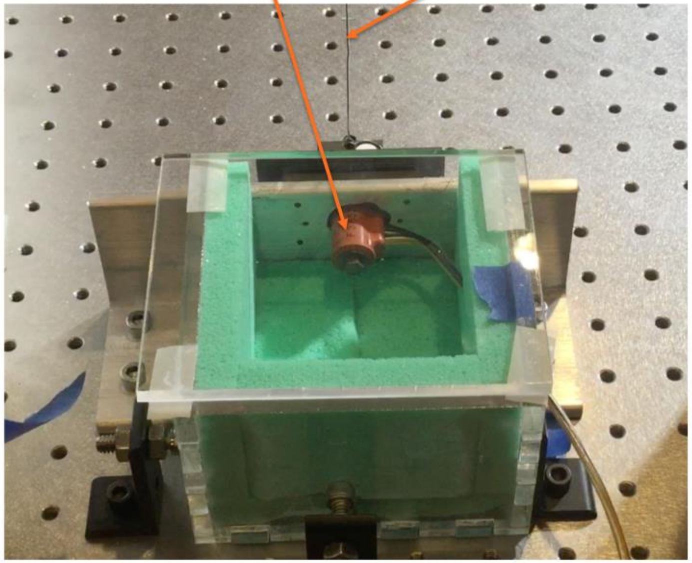




Protractor

Frangibolt

Pendulum cable



Acrylic and foam Frangibolt Containment box

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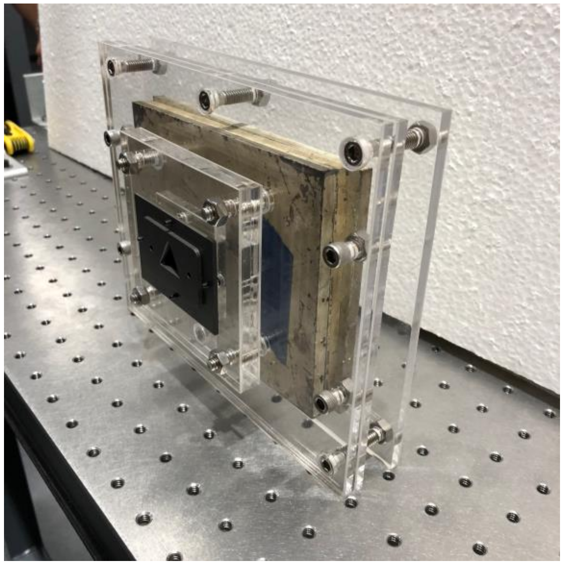
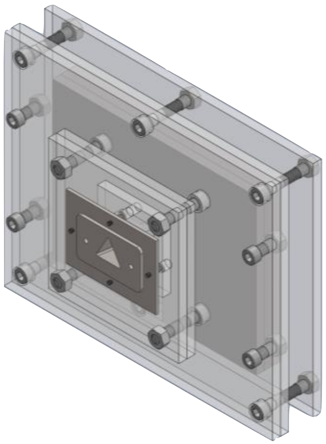
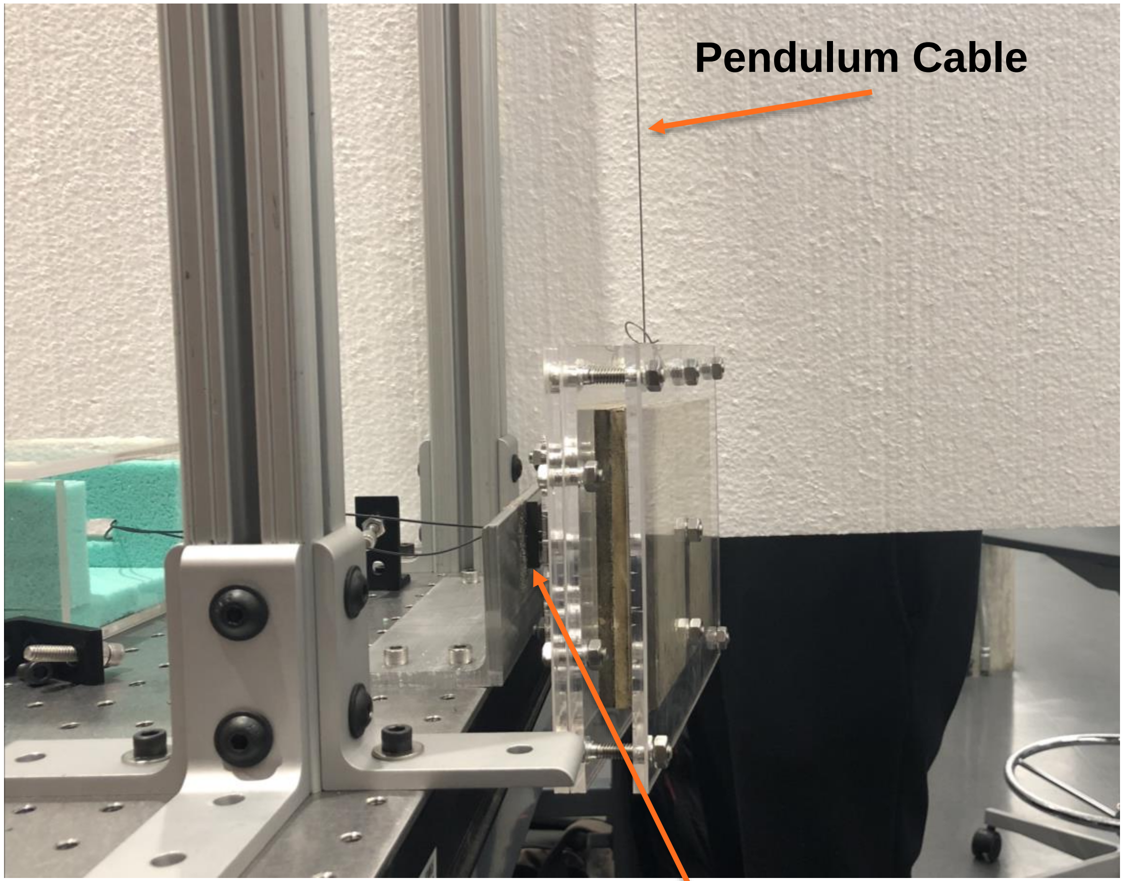
Recoil Energy – Dummy Mass Setup

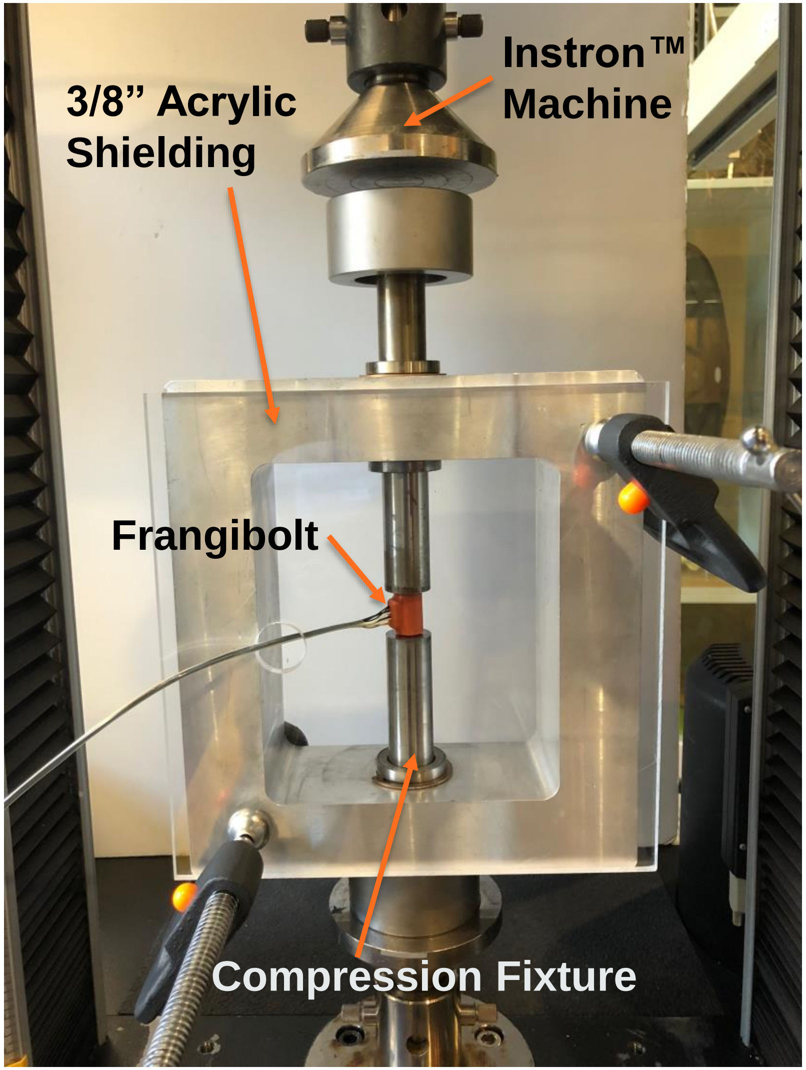






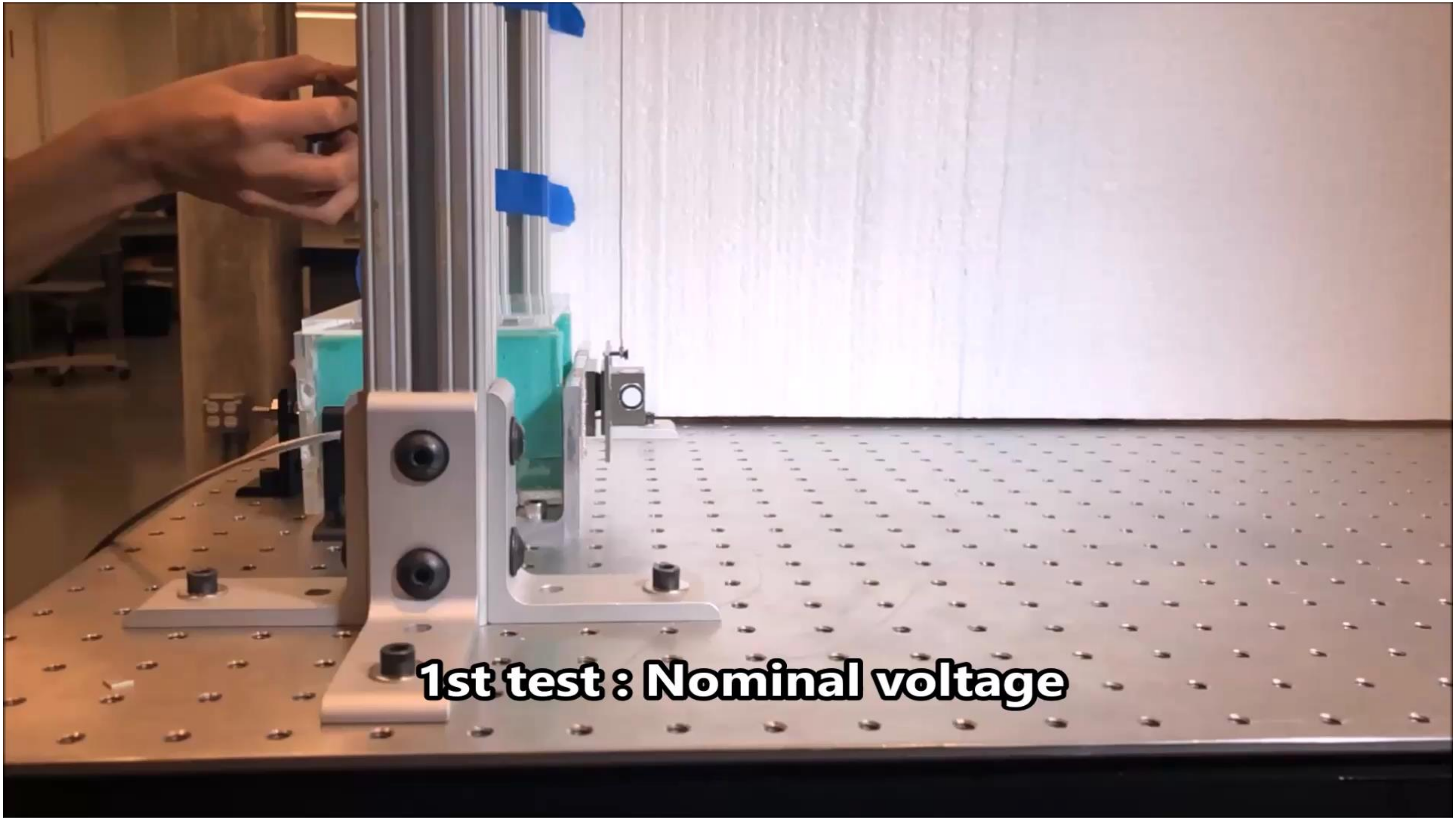
$$m = 3.8\ kg$$

Reloading Frangibolt for Actuation



- Prior to each use, Frangibolt required to be reset
- Requires $3{,}400\ lbf$ of compressive force
- Used compression fixture to apply parallel force
- Measured length after compression required within $\pm\, 0.005$” specified by Manufacturer

Video Results of All Tests



Recoil Energy –Test Results

- Interface tests:
  - Velocity measured thanks to both protractor and slow motion camera
  - For each test, both velocity measurements concur within 10%
  - Estimate recoil energy as $E_k \approx 0.08\ J$
  - Initial velocity estimated for full MirrorSat: $v_0^{exp} \approx 0.2\ m/s$

- Dummy mass test:
  - Only slow motion measurement (protractor not reliable)
  - Initial velocity measured lower than expected:

$$v_0^{mes} \approx 0.06\ m/s < 0.2\ m/s$$

Recoil Energy – Discrepancies

- Large discrepancy between the mass dummy test and the interface tests
  - Energy measured about 10 times lower than expected

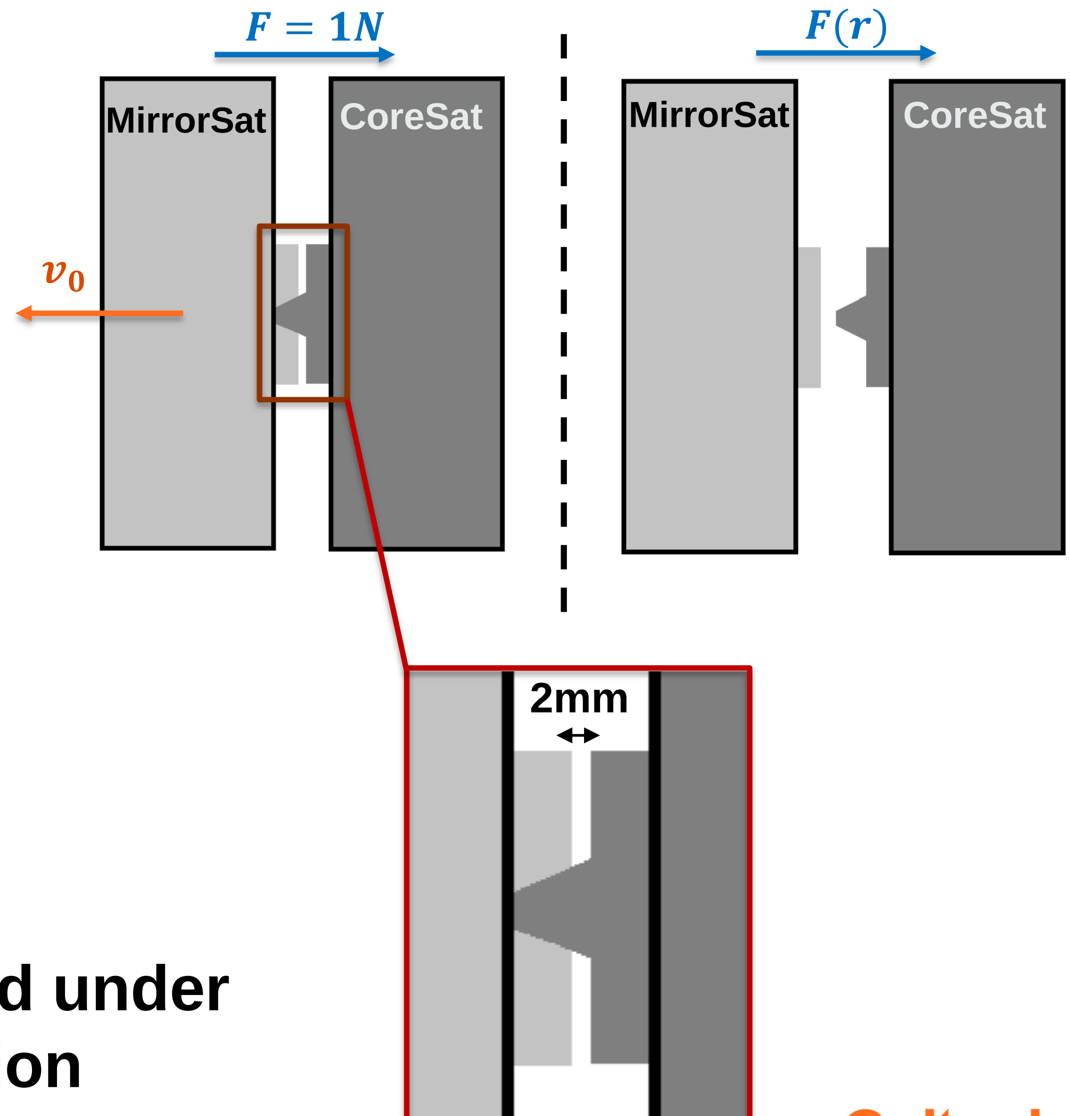
- Possible causes:
  - Rotation of the dummy mass
  - Solid friction between the interfaces
  - Testing setup wasn't perfectly rigid

- The testing setup can be improved:
  - Improve movement of pendulum
  - Frame can be stiffer

Recoil Energy – MirrorSat Simulations

- Simulation of MirrorSat's movement produced
- Assuming a magnetic force of 1N at 2mm
- If $v_0 > 0.03\ m/s$, the MirrorSat is ejected
- $v_0^{exp} \approx 0.2\ m/s$ expected from tests
- $v_0^{mes} \approx 0.06\ m/s$ was measured in tests

$\Rightarrow$ **MirrorSat is ejected under current configuration**



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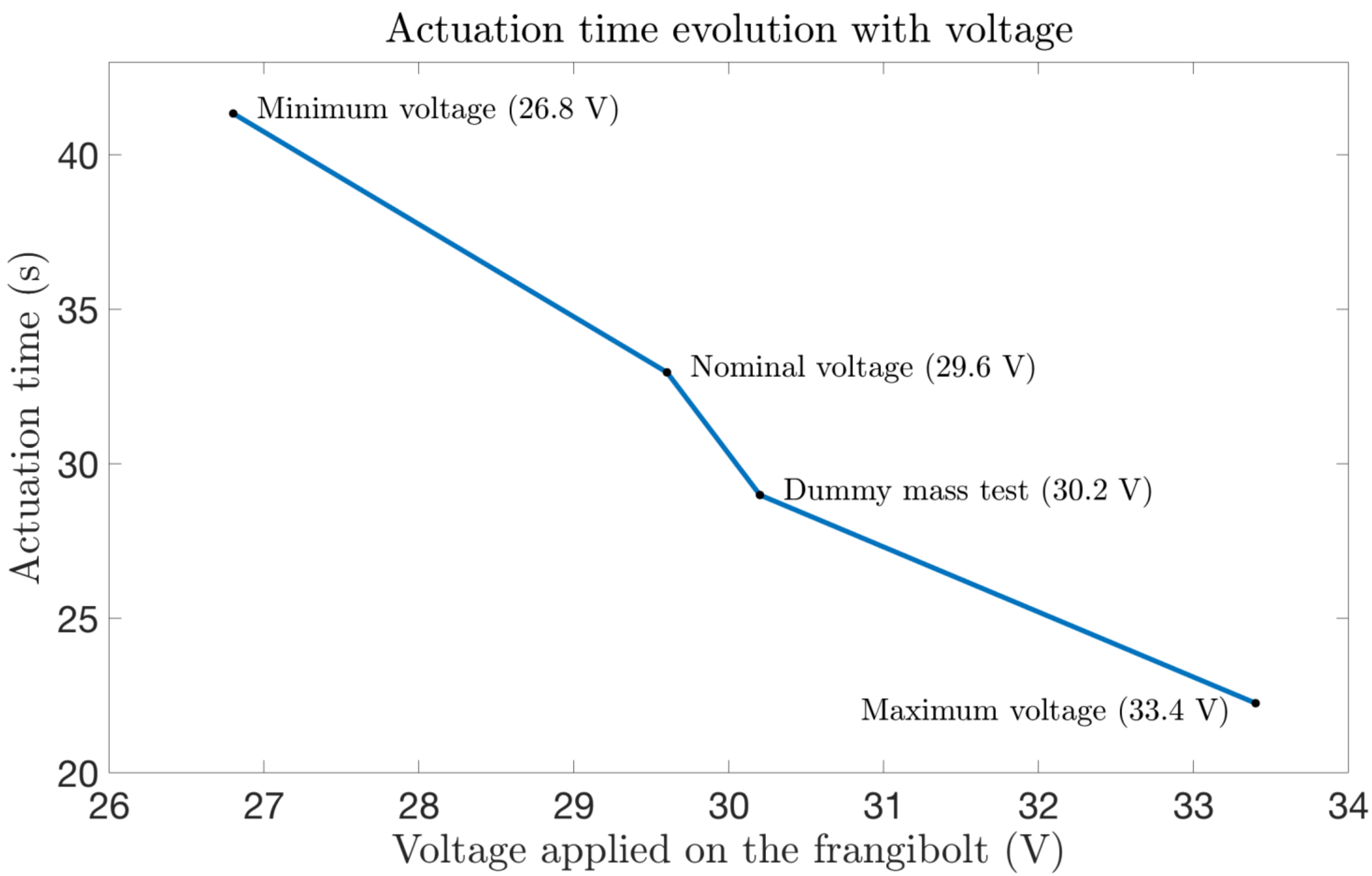
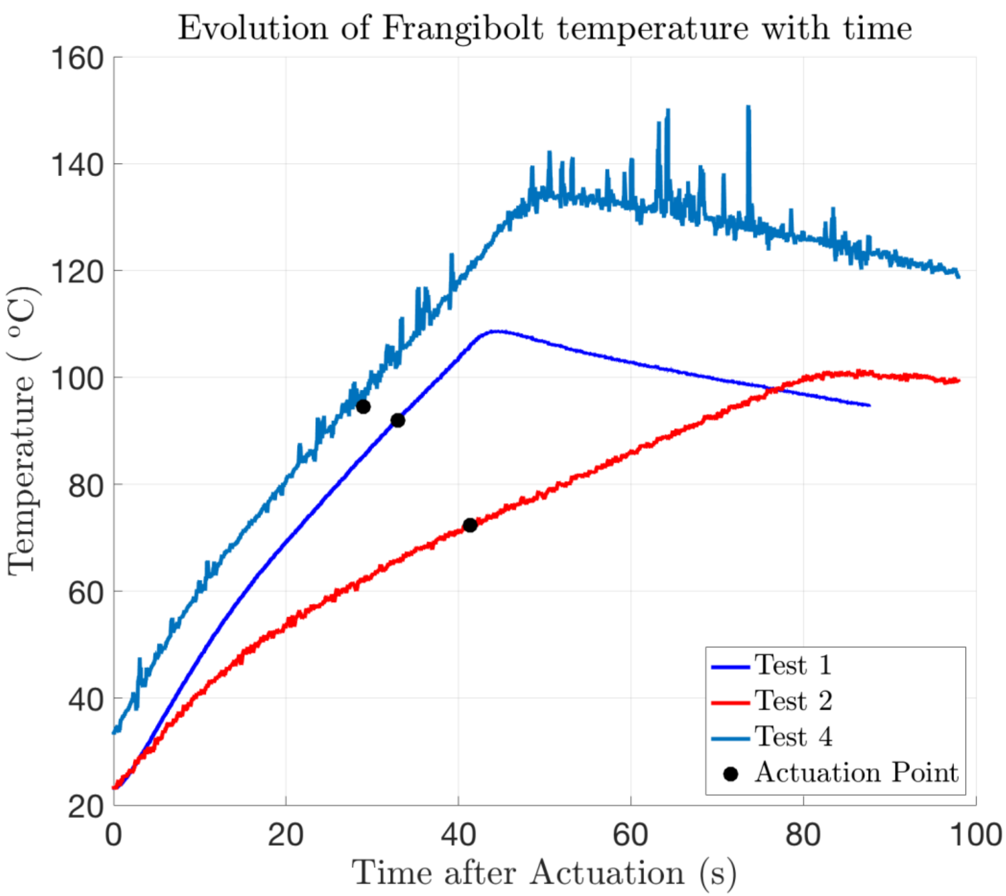
Actuation Times for All Tests



- Actuation time is within [20, 50] seconds
- Decreasing and proportional function of input voltage

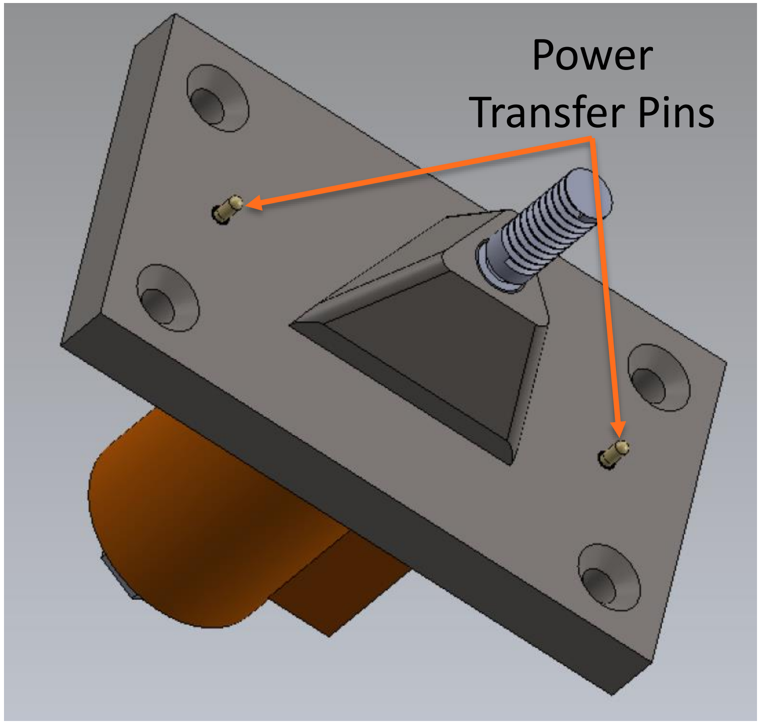
Temperature Profiles of All Tests



- Profile varies by input voltage
- Inconsistent temperature at actuation
- No change in profile after actuation

Power Transfer Capability

- MirrorSat interface will transfer power as designed
- CoreSat interface shorts over conduction pins
  - Pins are press-fit
  - Causes removal of anodization when inserted
  - Creates a short across the interface
  - Solution: increase hole size and isolate pins



Pin-Pad resistance: $\boldsymbol{R = (0.3 \pm 0.1)\Omega}$

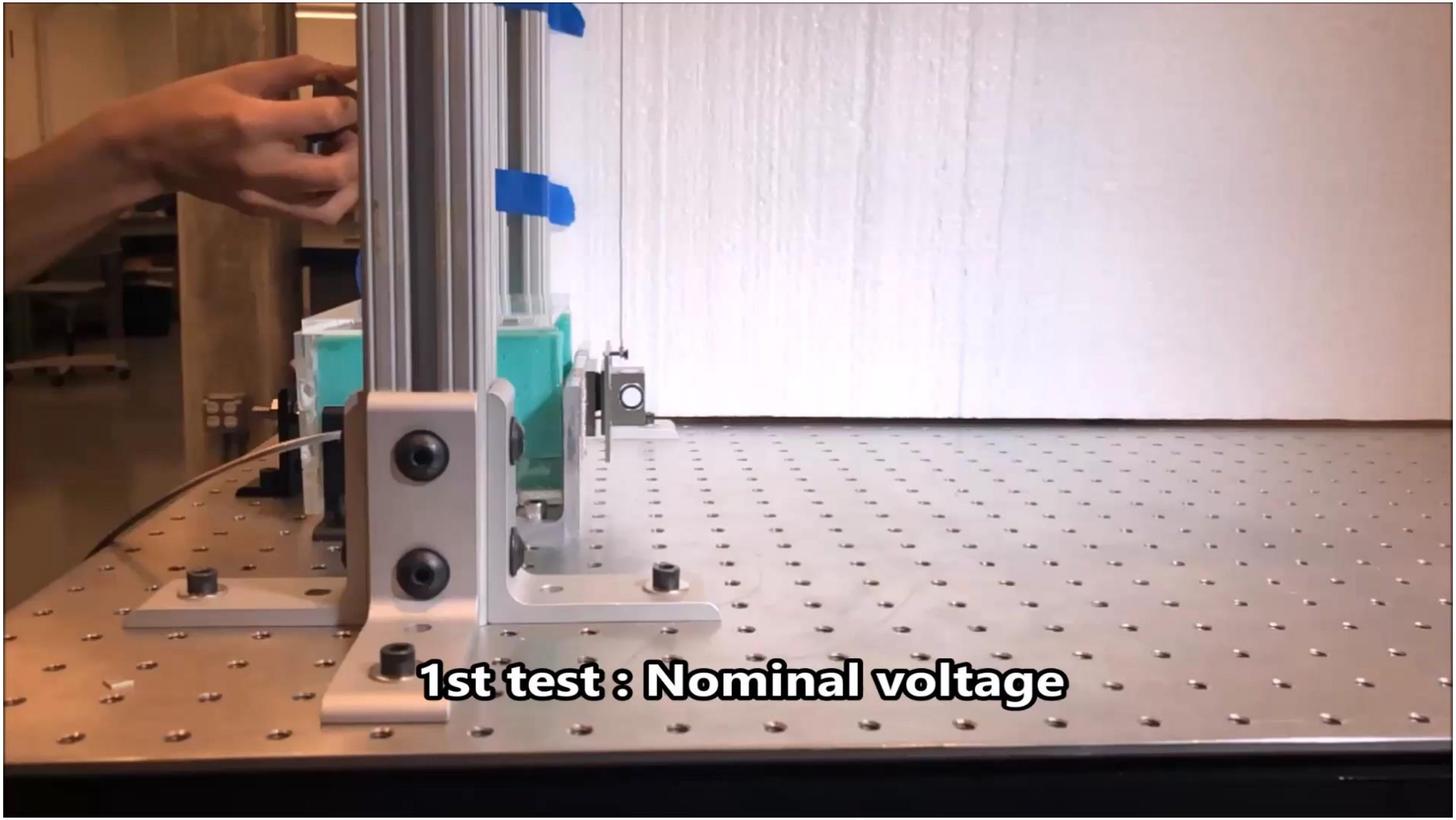
Conclusion

- Frangibolt releases $\approx 0.08\,J$ of energy upon actuation
  - This results in a MirrorSat exit velocity of $v_0 \approx 0.2\,m/s$
- As designed, the 1 N at 2 mm permanent magnetic force is not strong enough to hold the MirrorSat upon actuation
  - Electromagnets may be used instead (stronger)
- Power transfer is possible once pins are isolated from CoreSat interface
- Temperature profile data is inconclusive for actuation point

Future Work

- A test in a vacuum to measure the RTD data will provide an accurate temperature profile for actuation in space
- An improved testing setup for the Mass Dummy test will provide more accurate results
- A stronger electromagnet needs to be tested for holding MirrorSat in place
- A new method for determining when Frangibolt actuation has occurred is necessary, since RTD data is inconclusive

Questions?



AAReST Attitude Determination and Control System (ADCS)

Avinash Chandra
Mike O'Connell
Hiroyasu Tsukamoto

Mentor: Michael Marshall

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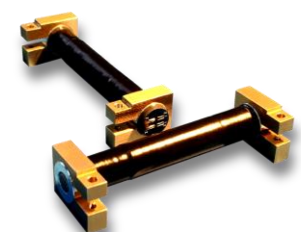
Overview

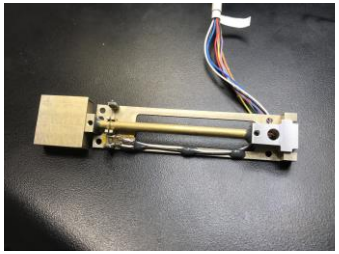
- Responsibilities
  - Develop high-level ADCS operational architecture
    - CubeSpace ADCS → ADCS specific to this mission
  - Plan ADCS acceptance tests
    - Execute ADCS on-board computer (OBC) health check

- ADCS components (excluding coarse sun sensors)

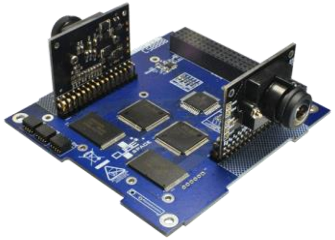
Reaction wheels



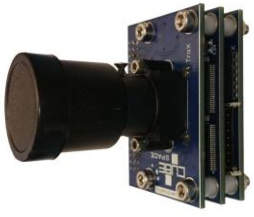
Magnetorquers



Magnetometer



Fine sun/Nadir sensor

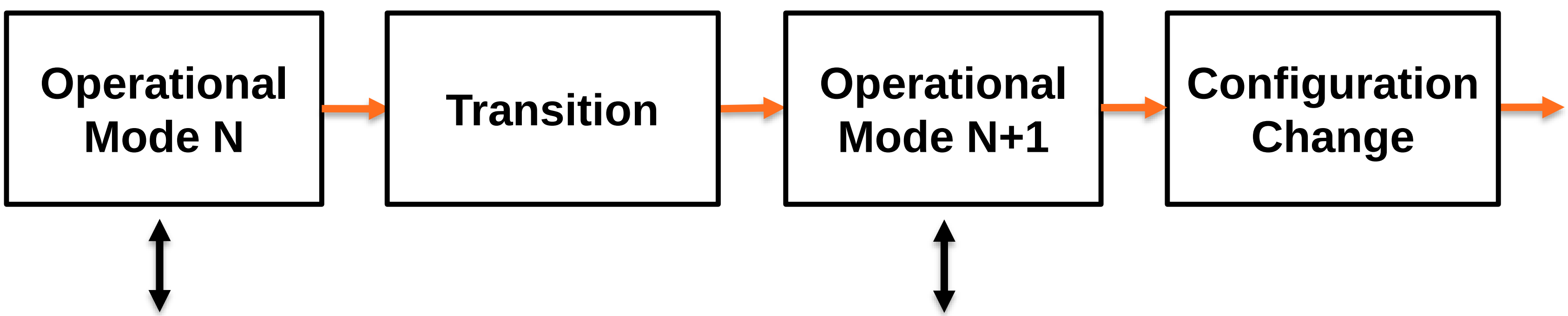


Star tracker

ADCS Operational Architecture

Goal: Architect operational modes and commands to ADCS

- We developed:
  1. Mapping from ADCS operational modes to CubeSpace ADCS
  2. Software architecture for ADCS operational mode transitions
  3. Available sensors in each AAReST configuration
  4. Software architecture for AAReST configuration change



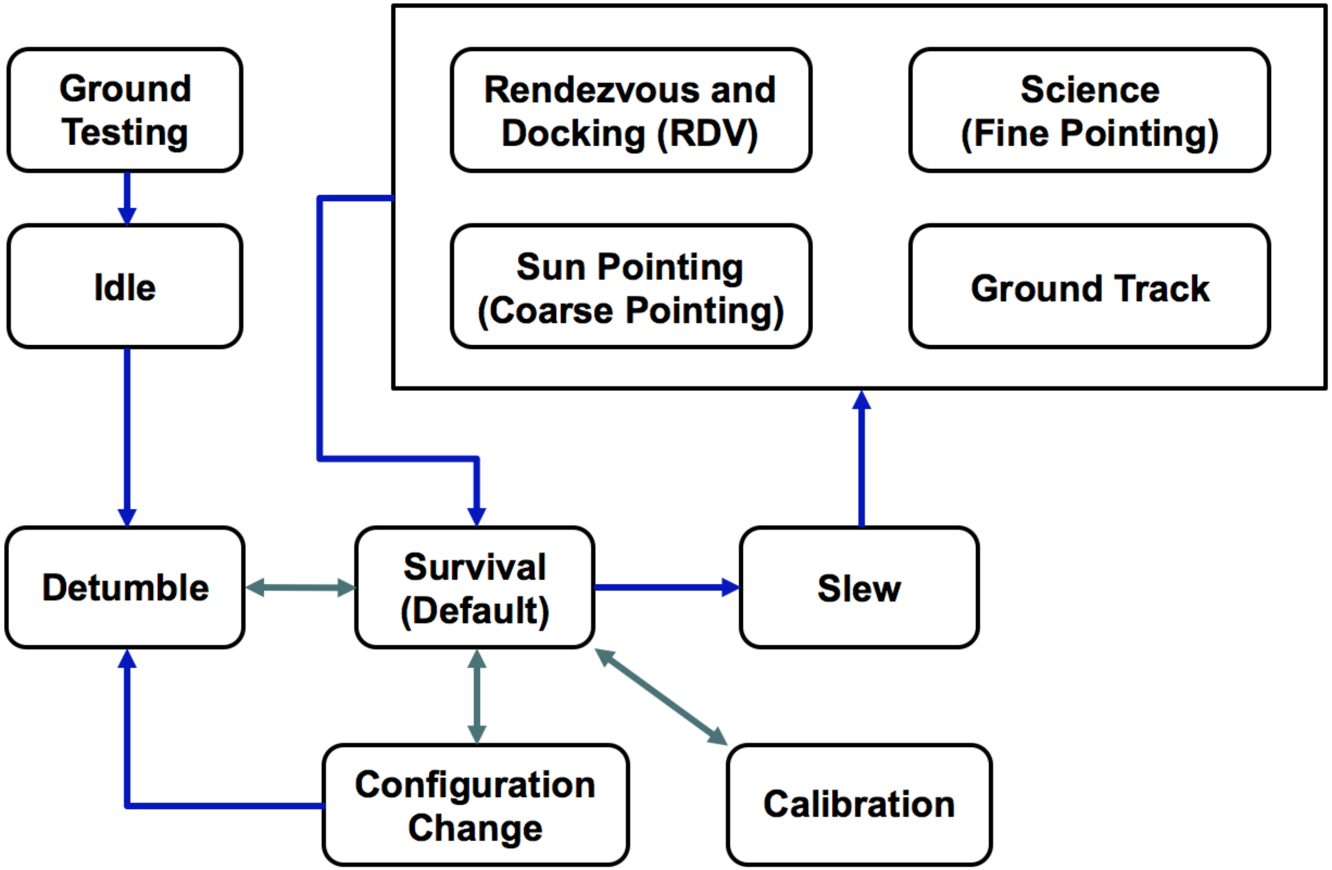
Operational Mode N:

- Control modes
- Estimation modes
- Sensors available

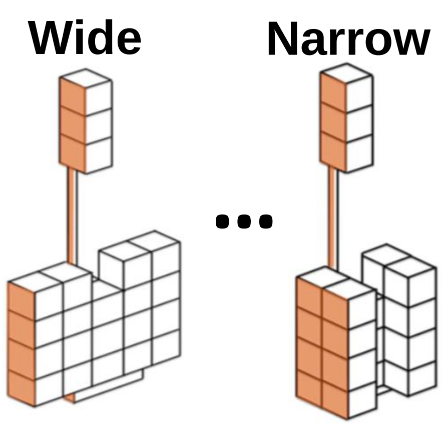
Operational Mode N+1:

- Control modes
- Estimation modes
- Sensors available

Summary of ADCS Operational Modes and Configurations

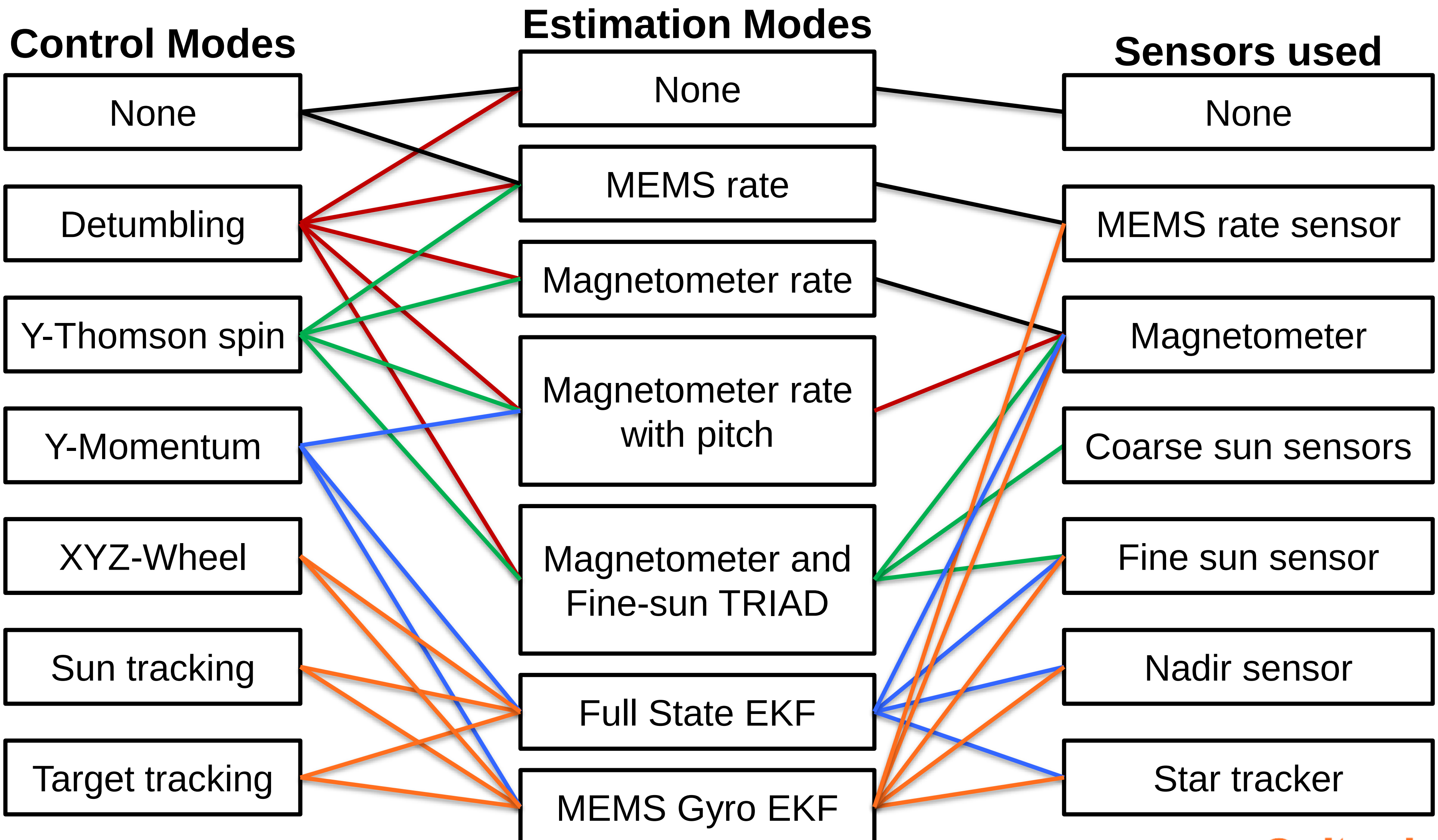


Operational Modes



Configurations

Summary of CubeSpace ADCS



1. Mapping from Operational Modes to CubeSpace ADCS

Operational Mode N → **Transition** → **Operational Mode N+1** → **Configuration Change** →

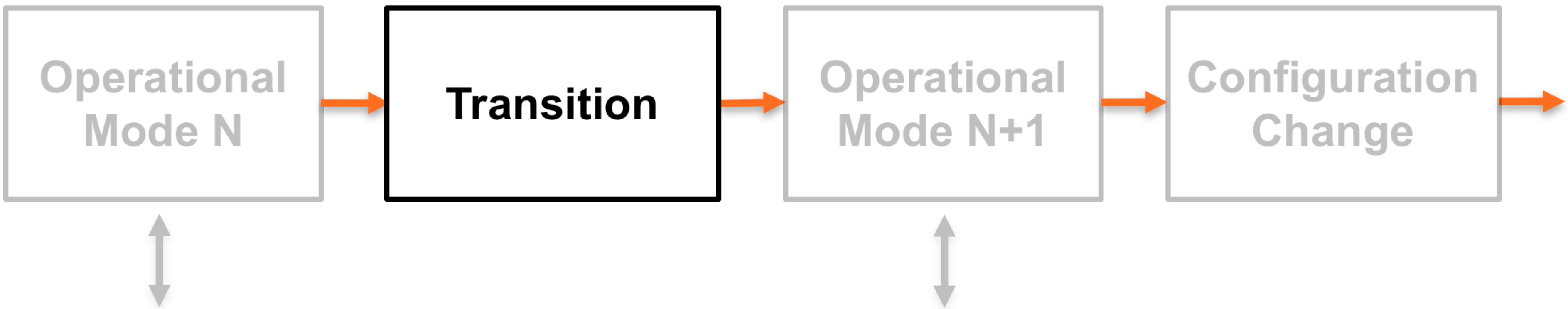
- Control modes
- Estimation modes
- Sensors available

- Control modes
- Estimation modes
- Sensors available

Mapping from Operational Modes to CubeSpace ADCS

Operational mode	Control mode	Estimation mode
Idle	None	None
Detumble	Detumbling control & Y-Thomson spin	MEMS rate & Magnetometer rate
Slew	XYZ-Wheel control	MEMS Gyro EKF
Rendezvous and Docking (RDV)	XYZ-Wheel control	MEMS Gyro EKF
Sun Pointing (Coarse Pointing)	Sun tracking control	Full State EKF
Science (Fine Pointing)	Target tracking control	MEMS Gyro EKF
Ground Track	Target tracking control	MEMS Gyro EKF

2. Software Architecture for Operational Mode Transition



- Control modes
- Estimation modes
- Sensors available

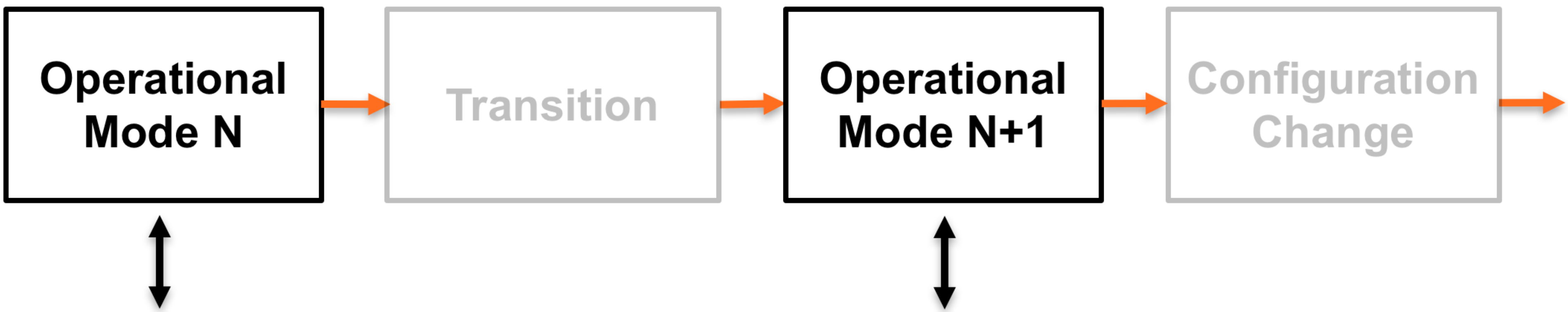
- Control modes
- Estimation modes
- Sensors available

Software Architecture for Transition

Mapping from Required Actions to Commands

Actions	Command Name	ID
1. Check & clear errors	Clear Errors	12
2. Enable ADCS	ADCS Run Mode	10
3. Set control gains	Set CONTROL NAME Parameters	38, 39, 40, 54
4. Set target reference	Tracking Controller Target Reference	55
5. Set control mode	Set Attitude Control Mode	13
6. Distribute power	ADCS Power Control	11
7. Set estimation mode	Set Attitude Estimation Mode	14
8. Set estimation noise and sensor mask	Set Estimation Parameters 1 & 2	43, 44
9. Perform control	Trigger ADCS Loop	18

3. Available Sensors in Each AAReST Configuration



- Control modes
- Estimation modes
- Sensors available

- Control modes
- Estimation modes
- Sensors available

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Sensor Obstructions

- Table shows obstructions by component configuration and impact on sensors
  - Available estimation modes depend on available sensors

Star tracker must be moved slightly to avoid obstructions

Reduced sensor performance – **further analysis required for CSS**

Sensor obstructed – not needed during corresponding mission phases

Mask nadir obstructions in software

Sensor unobstructed

Component	Boom			Antenna		MirrorSat		
Configuration	Stowed	Partially Deployed	Fully Deployed	Stowed	Deployed	Wide	One wide/ one narrow	Narrow
Fine sun sensor								
Star tracker								
Nadir sensor								
$-X_{CAD}$ CSS								
$+Z_{CAD}$ CSS								

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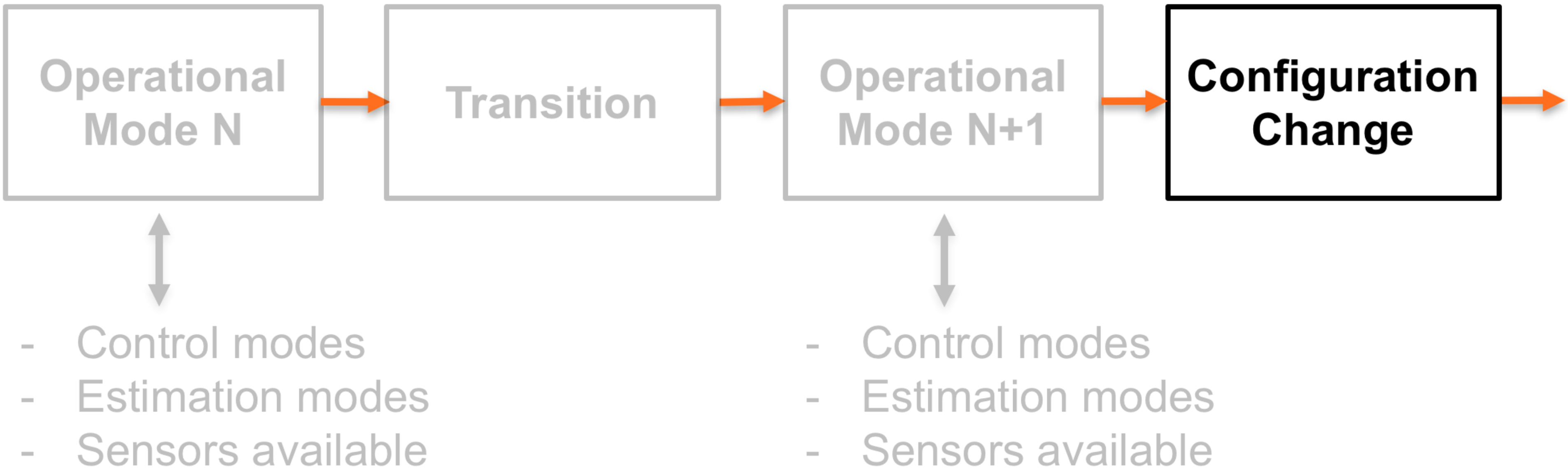
4. Software Architecture for Configuration Change



Architecture for Configuration Change Event

- Designed ADCS operational architecture for configuration change
- Applies to boom deployment and frangibolt breakage

Check satellite state

- Deployment state
- Battery SOC
- Attitude & spin (telecommand (TC) 146 &147)
- Reaction wheel spin rate (TC 156)

Safety checks before deployment

- Attitude rates below threshold
- SOC > 80%
- Reaction wheel rates below threshold

Turn off attitude control

- Set to uncontrolled (TC 13)
- Set constant reaction wheel speed (TC 17)
- Attitude estimation continues

Deployment

- Deploy component
- Wait for deployment completion

Update system parameters

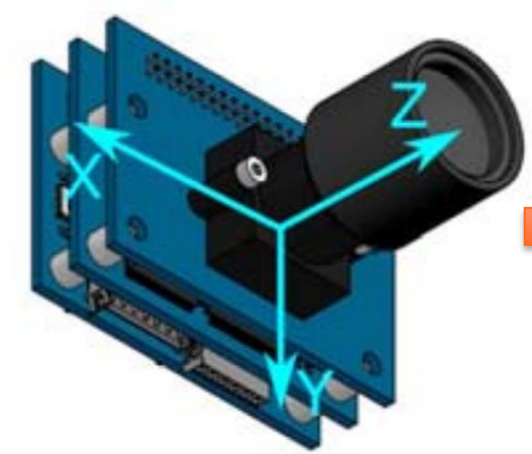
- S/C inertias (TC 41,42)
- Control gains (TC 38-40)
- Estimator parameters (TC 43-44)
- Nadir sensor FOV mask (TC 28-32)
- Ignore obstructed sensors in EKF (TC 44)
- Update available control and estimation modes

Reinitialize control system

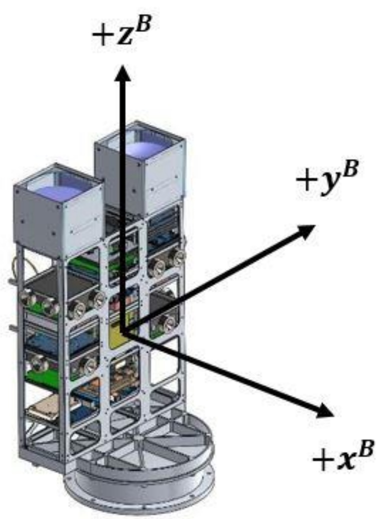
Return to survival mode

ADCS Configuration Sheet

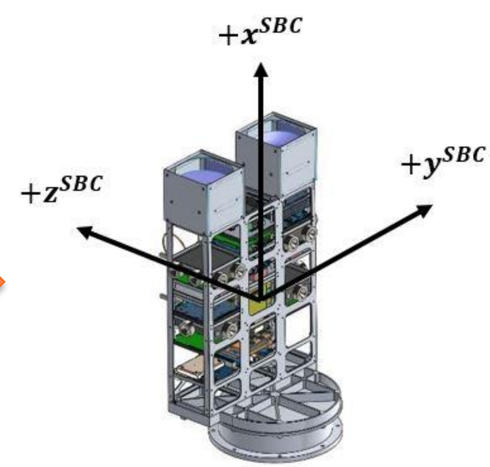
- Goal: Identify ADCS component orientation relative to S/C body frame
- Required by CubeSpace for initial firmware delivery
- Completed configuration sheet and delivered it CubeSpace
- To be updated after final S/C integration and assembly



Component frame



CAD frame



S/C body frame

Acceptance Test Methodology & Setups

Acceptance Test: Overview

- Needed to verify proper functioning of CubeSpace ADCS components
- Developed test plans and setups
- Test philosophy

  - Health check
  - Polarity test
  - Primarily verifying trends in data
  - Not verifying performance quantitatively

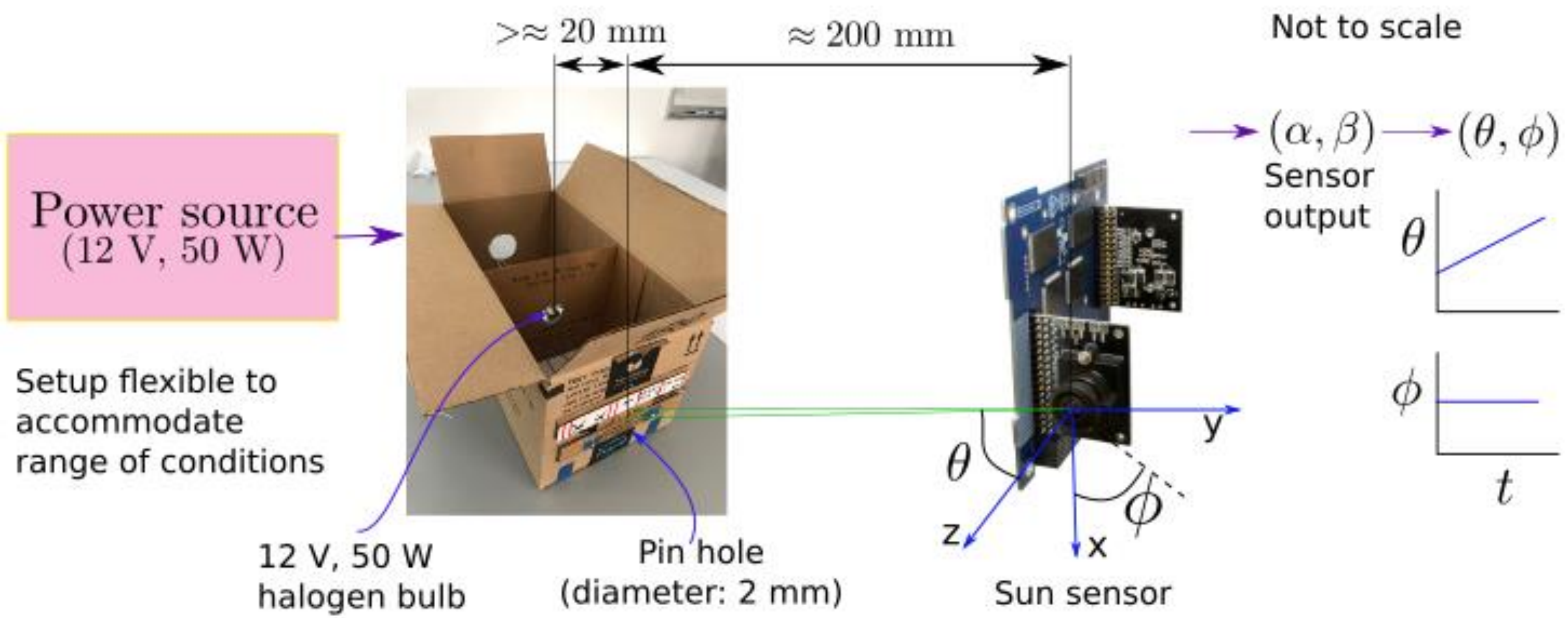
Summary of Test Setups

Component	Test Setup
All components: voltage/current/power	Shunt resistance circuit
Sun sensor	Halogen lamp- pinhole setup
Mangetorquer	Polarity: suspend magnetorquer Functional: determine magnetic moment
Reaction wheel	Polarity: suspend reaction wheel Functional: angular rate data from software
Nadir sensor	Earth and space movie on laptop screen using Celestia
Star tracker	Star-field images on laptop screen using Celestia
Gyroscope	Swivel table
Magnetometer	Earth magnetic field, mobile app for magnetic field measurement

Sun Sensor

- Setup designed to match sun's:
  - Angular diameter
  - Radiation flux density
  - Radiation spectrum

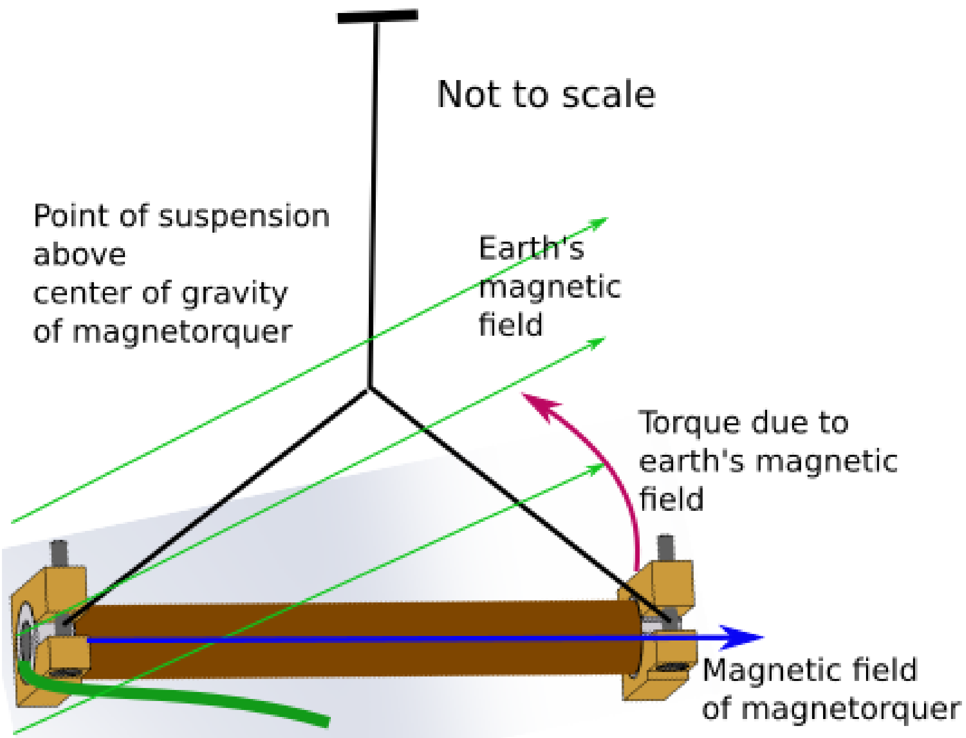
- Test: compare trend in data



Magnetorquer

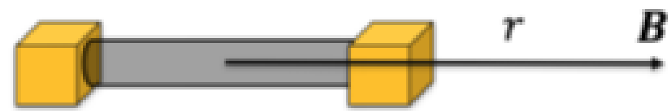
Polarity test

- Setup designed to reduce counter torque on magnetorquer
- Test: magnetorquer should align with earth's magnetic field



Functional test

- Setup designed to calculate magnetic moment, ***m***
- Test: compare ***m*** with specification sheet



$$\boldsymbol{B} = \frac{\mu_0}{4\pi r^3}\boldsymbol{m}$$

$$\|\boldsymbol{m}\| = m = NIA$$

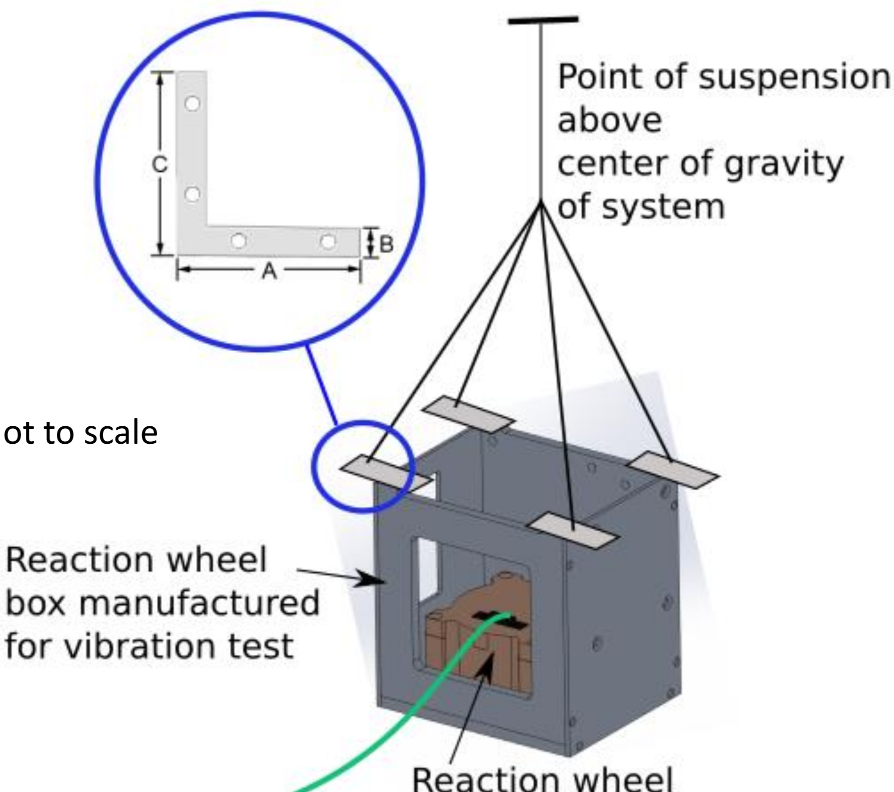
$\boldsymbol{B}$: magnetic field
$\boldsymbol{m}$: magnetic moment
r : distance from rod center
μ_0 : absolute permeability of free space
I : current
N : number of wire turns
A : loop area

Reaction Wheel

Polarity test

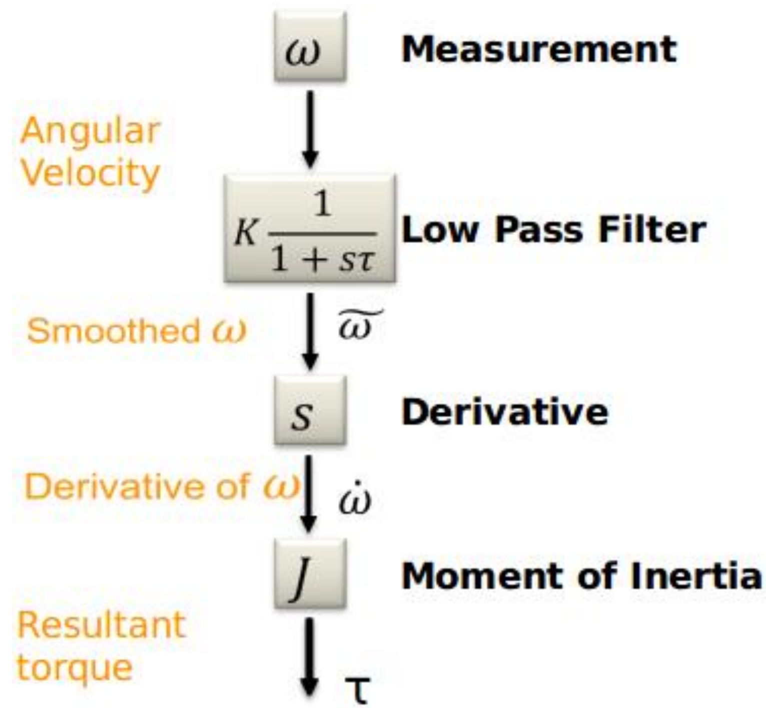
- Setup designed to reduce counter torque on reaction wheel box
- Test: rotation of reaction wheel box should match desired direction

Not to scale



Functional test

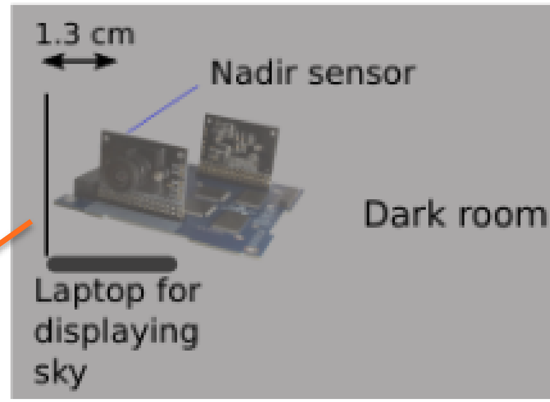
- Obtain angular speed data from software
- Compute torque; compare with specification sheet

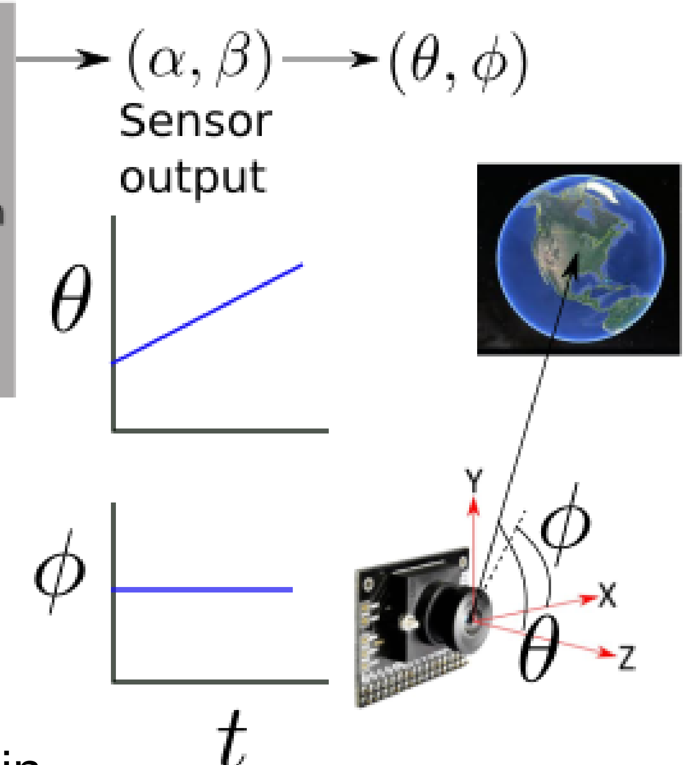


Nadir Sensor

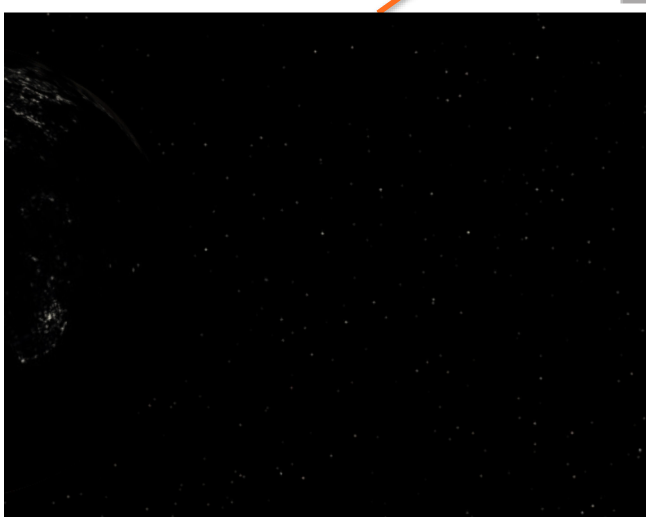
- Setup designed to match earth's angular diameter
- Not addressing earth/space luminance explicitly

Not to scale





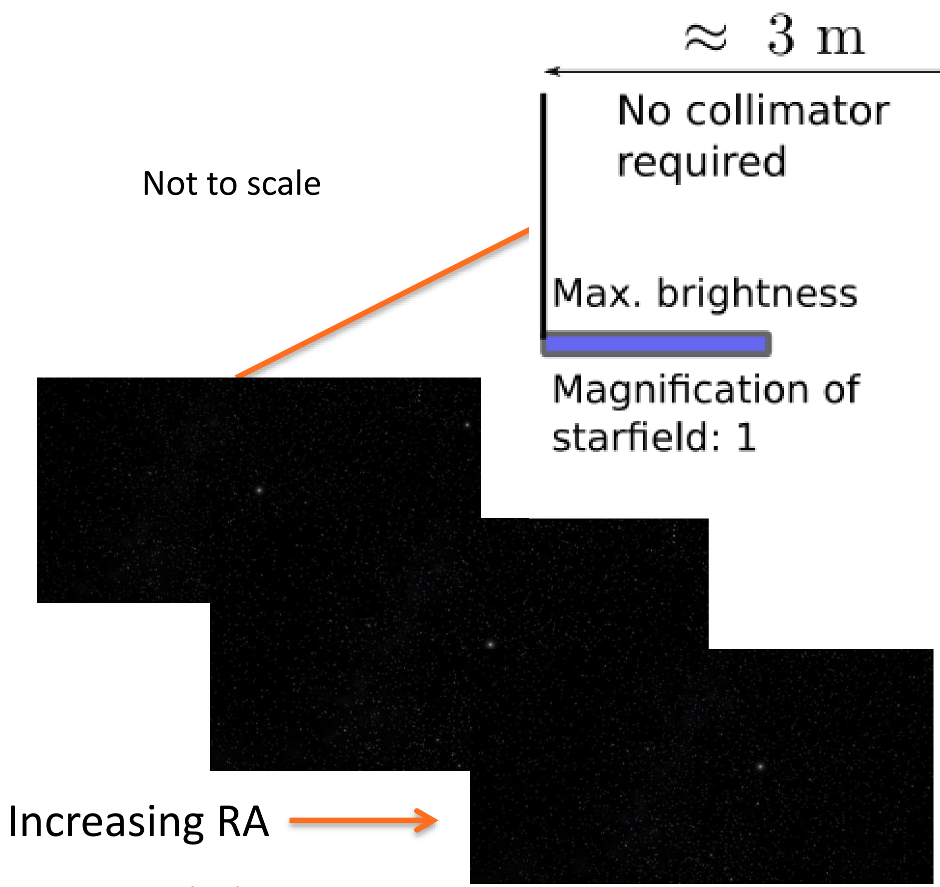
Diameter of earth in image: about 15 cm

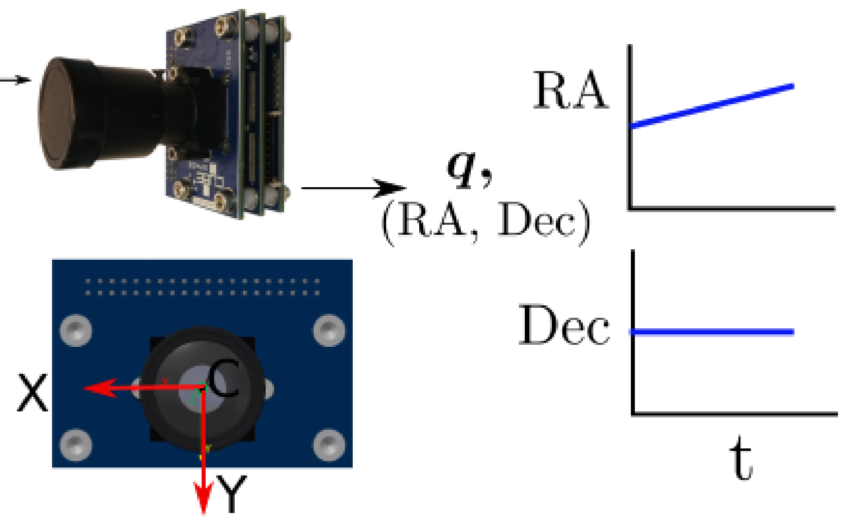


- Test:
  - Show earth images/video (Celestia)
  - Compare trend in data

Star Tracker

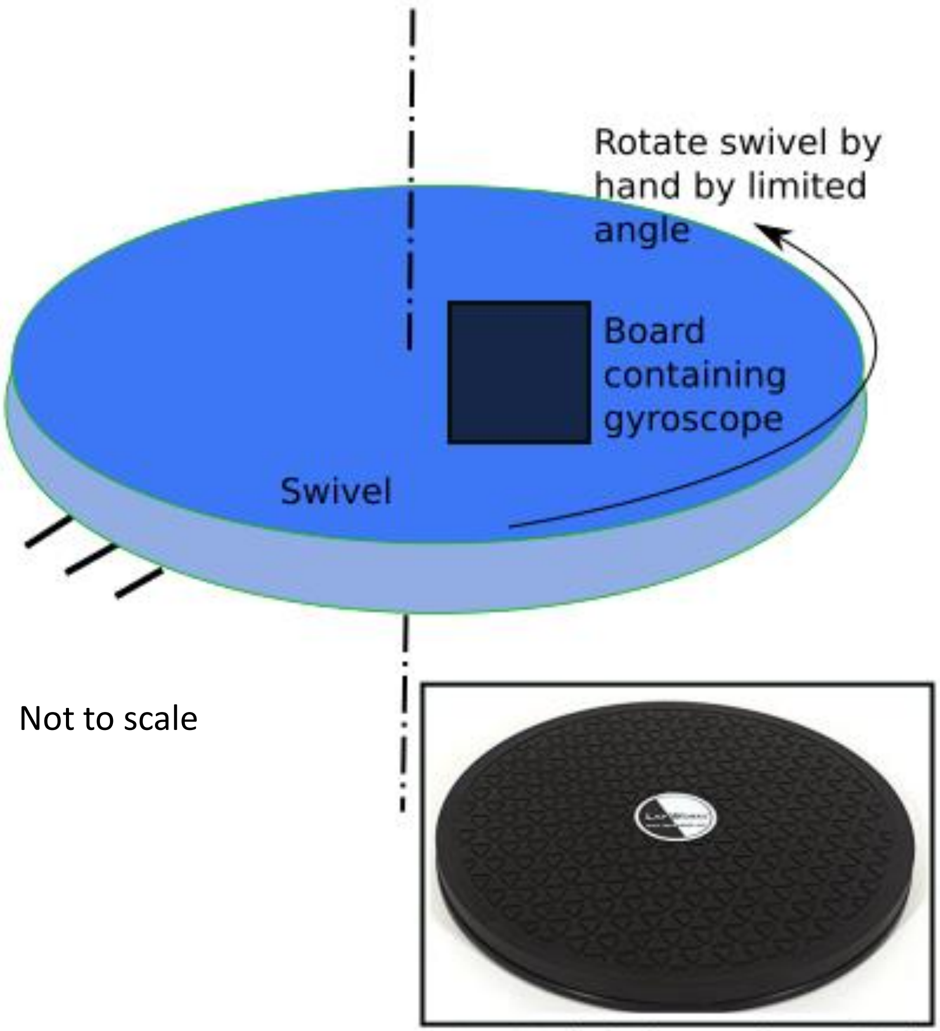
- Setup designed to match:
  - Angular separation of stars - Parallel rays
- Not addressing magnitude of stars (algorithm makes no distinction)





- Test:
  - Show starfield images/video (Celestia)
  - Compare trend in data

Gyroscope



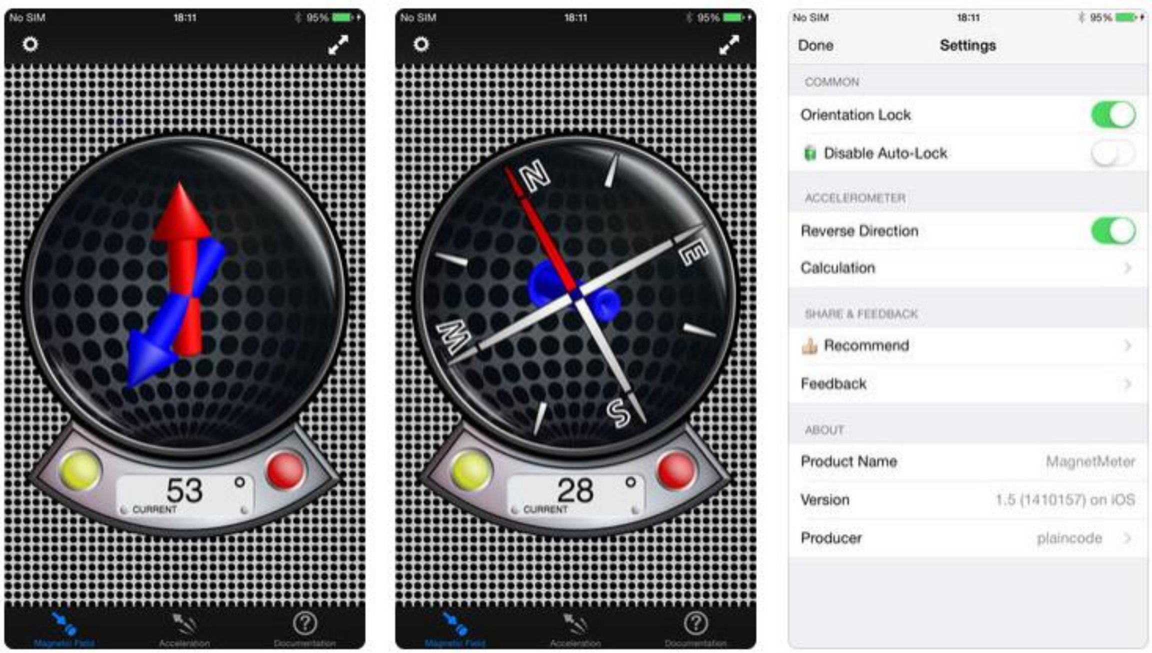
LapWorks 8'' heavy duty swivel

- Setup designed to rotate gyro at an angular rate

- Test:
  - Rotate swivel at about 2˚/s
  - Compare polarity and value of gyro reading

Magnetometer

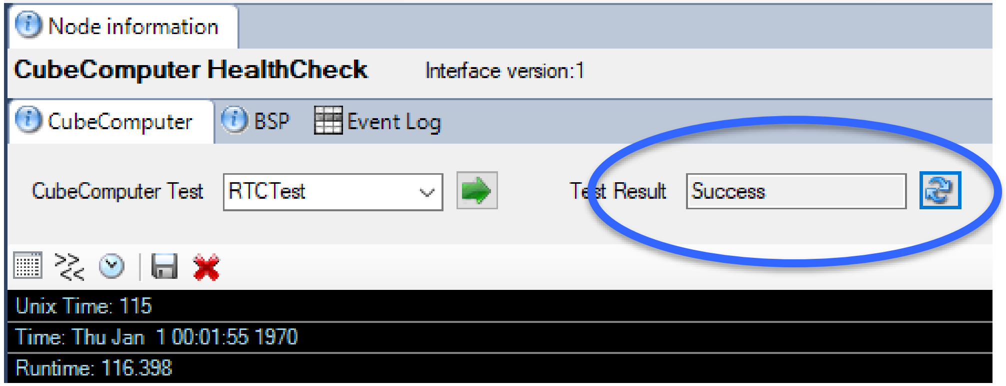
- Test:
  - Place magnetometer in earth magnetic field on ground
  - Compare magnetometer readings with *MagnetMeter* app



MagnetMeter app on App Store (Apple) to compare magnetometer readings

OBC Health Check

- Confirmed basic OBC functions working upon delivery
- Health check procedure provided by CubeSpace
- All health checks successful
  - Watch dog tests displayed failure due to glitch in interface program, CubeSpace reviewed log files and confirmed test was successful



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Conclusion

- Responsibilities
  - Develop high level ADCS operational architecture
  - Plan ADCS component acceptance tests
  - Perform OBC health check
- Completed
  - Mapping between operation modes, sensor obstructions, and available estimation and control modes
  - ADCS command flow for operation mode transition and configuration change
  - Procedure, setup, and parts required for ADCS component acceptance tests
  - Performed OBC health check
- Going forward
  - Perform ADCS component acceptance tests
  - Develop ADCS software around outlined architecture

Questions?

Thermal Team

Jonah Krop Henry Steiner

Mentor: Daniel Türk

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Thermal Overview

Objectives:

- Identify components in danger of exceeding operational and survival temperatures
  - Document and determine critical components
  - Update previous thermal model and run numerical simulations
  - Identify critical components that exceed thermal requirements
- Design passive thermal control system
  - Recommend optical coatings and/or pointing restraints
- Determine impact on mechanical architecture (boom thermal expansion)

Presentation Layout

1. Spacecraft requirements and critical components
2. Model description
   a. Physical model
   b. Orbits and experimental cases
3. Results
   a. Mirrors
   b. CoreSat
   c. Camera
   d. Boom
4. Conclusions
5. Future Work

Critical Thermal Requirements

Component	Survival Min. (°C)	Operational Min. (°C)	Operational Max. (°C)	Survival Max. (°C)
Deformable Mirrors	-60	-15	+20	+50
ADCS hardware	-50*	-10	+60	+100*
Camera	-100	-20†	+20†	+100

- Critical components were identified from list of spacecraft components based on narrowest operational temperature limits and initial simulations

(*) Estimated survival temperatures
(†) Theoretical operational temperatures (experimental data has suggested operational limits are larger)

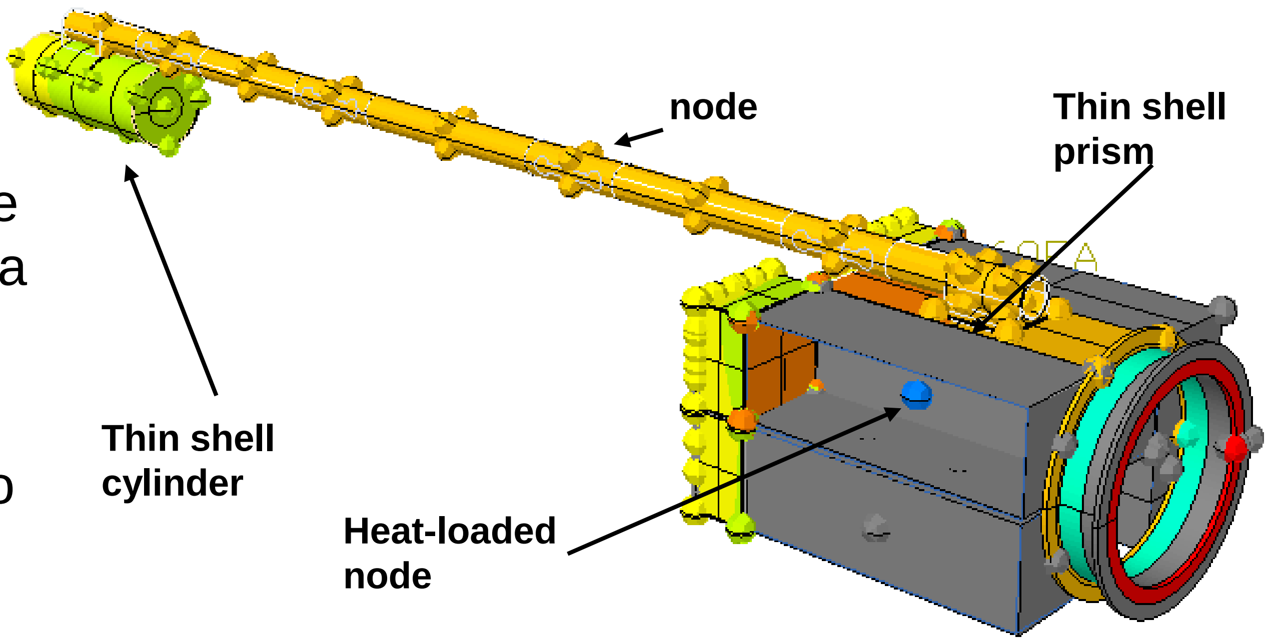
Boom Requirements

Error Source	Min	Max
Boom deflection: translation (mm)		
X translation	-0.625	+0.625
Y translation	-0.625	+0.625
Z translation (Axial)	-0.127	+0.127
Boom deflection: rotation (°)		
Tip	-0.04	+0.04
Tilt	-0.04	+0.04

(Boom requirements provided by Daniel Türk)

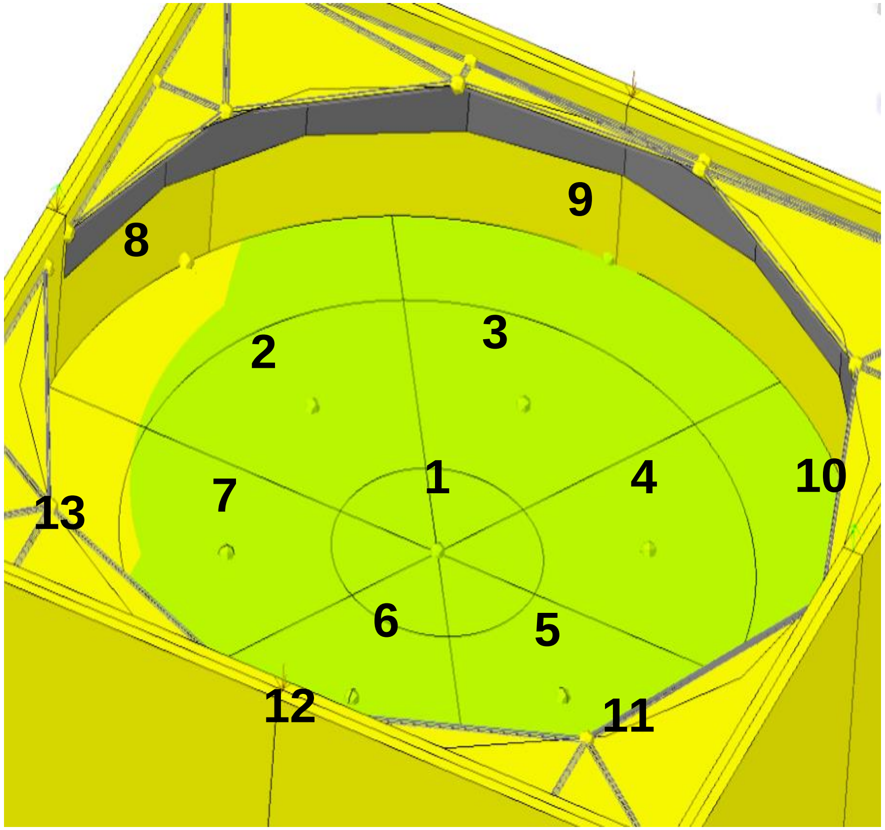
ThermalDesktop Model

- 4 W heat load applied to outside surface of camera
- 30 W applied to internal nodes of Coresat (split into 10 W per stack)
- 6 W applied to outside surfaces of MirrorSats



Mirror Modelling

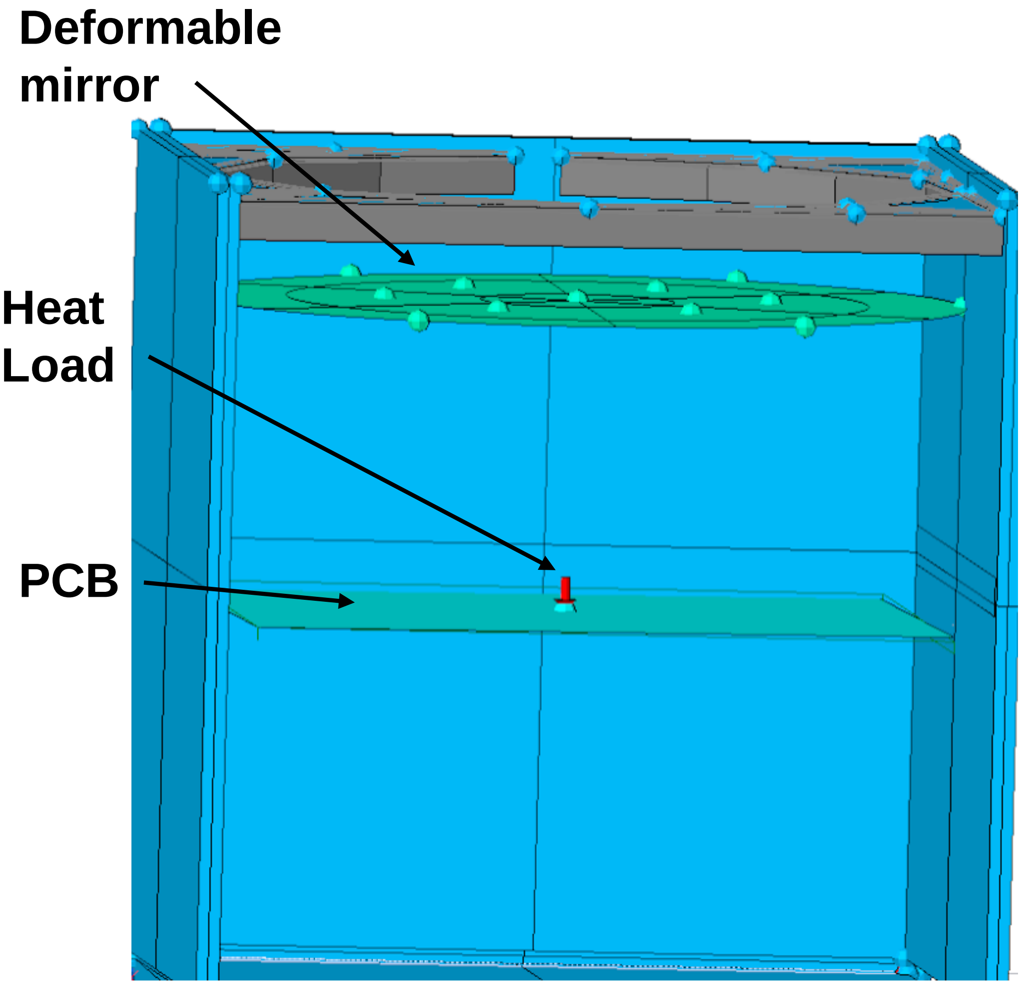
- Deformable mirrors are made of borosilicate glass
- Mirror is modelled as thin shell cylinder, 0.508mm thick
- Mirror is coated with polished aluminum on the front and black paint on the back
- 1 central node, 6 anterior nodes, and 6 edge nodes



Mirror with labeled nodes

Mirror Modelling

- PCB added below deformable mirror to examine the effects of power dissipation on mirror
- Mirror actuation requires 3 W for 10 minute science period



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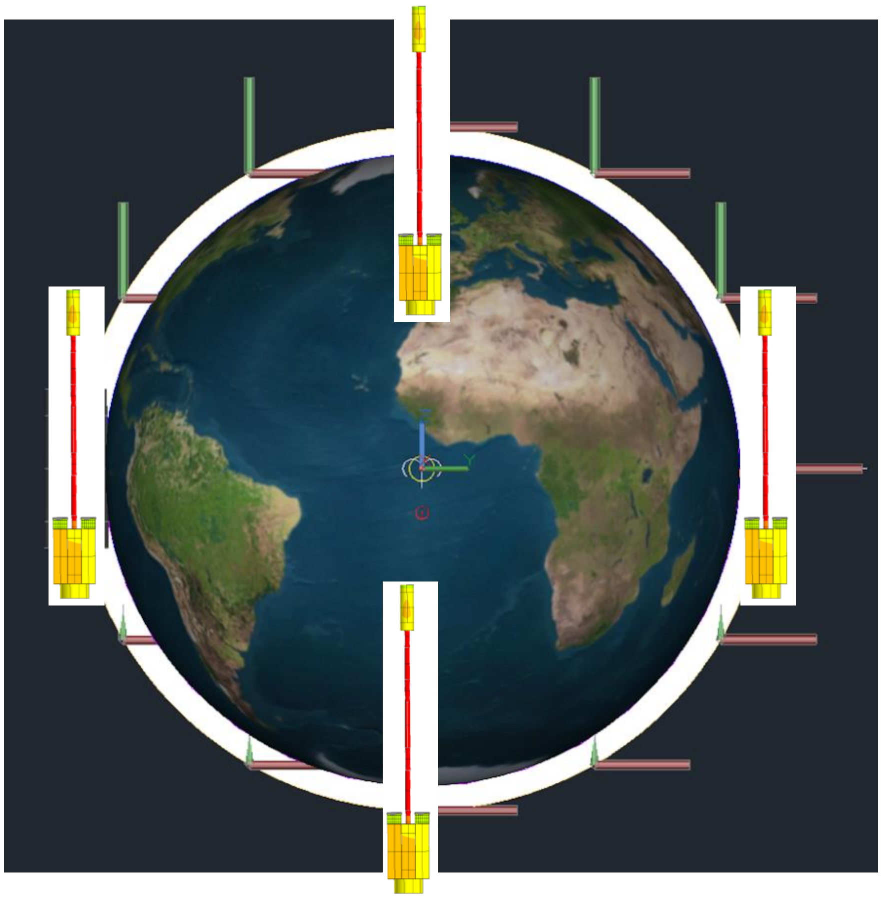
ThermalDesktop Model

- Model contains a mix of solid prisms and thin shells to model different components
  - Each element has material and optical thermal properties assigned to it
  - Each element is composed of a set of nodes at which radiation calculations are computed
- Model incorporates solar radiation, earth radiation, earth albedo

Spacecraft Hot Case

Hot Case: No eclipse period (Ω = 90°)

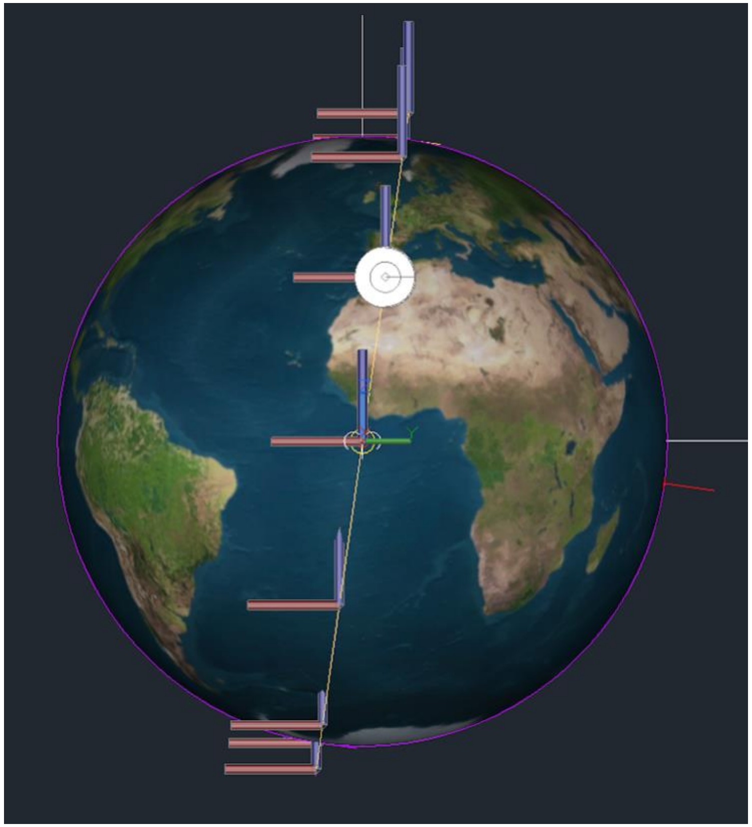


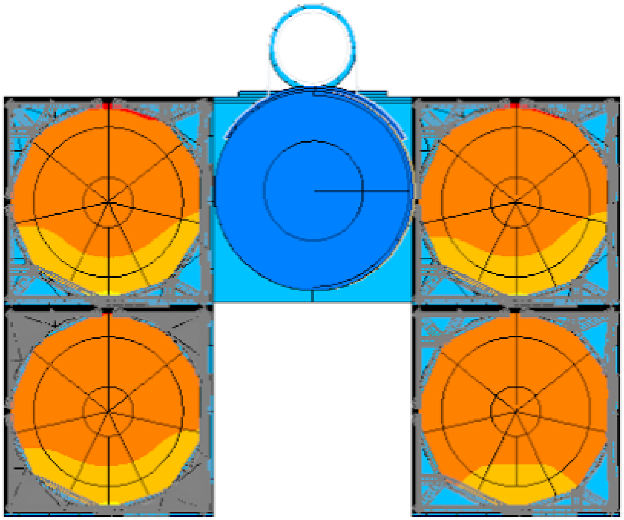
As viewed from sun

Caltech

Spacecraft Cold Case

Cold Case: Eclipse period ($\boldsymbol{\Omega}$ = 180°)

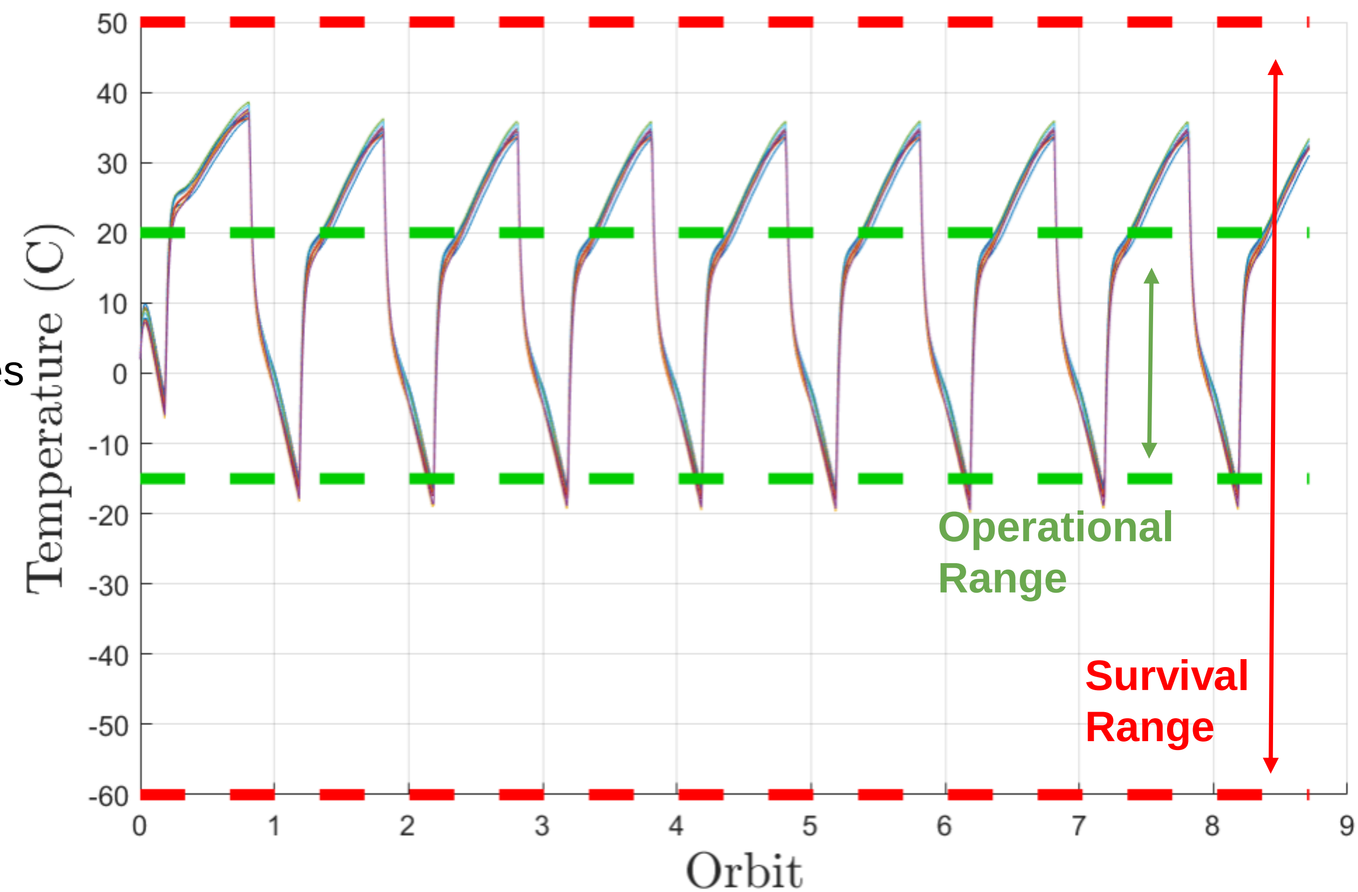




As viewed from sun

Deformable Mirrors, Spacecraft Cold Case

- Mirrors are in direct sunlight, experience eclipse
- Displays irregular temperature jumps, but confidence in min. and max. values due to convergence when tilted towards cold case
- **>90% of eclipse period within operational range**



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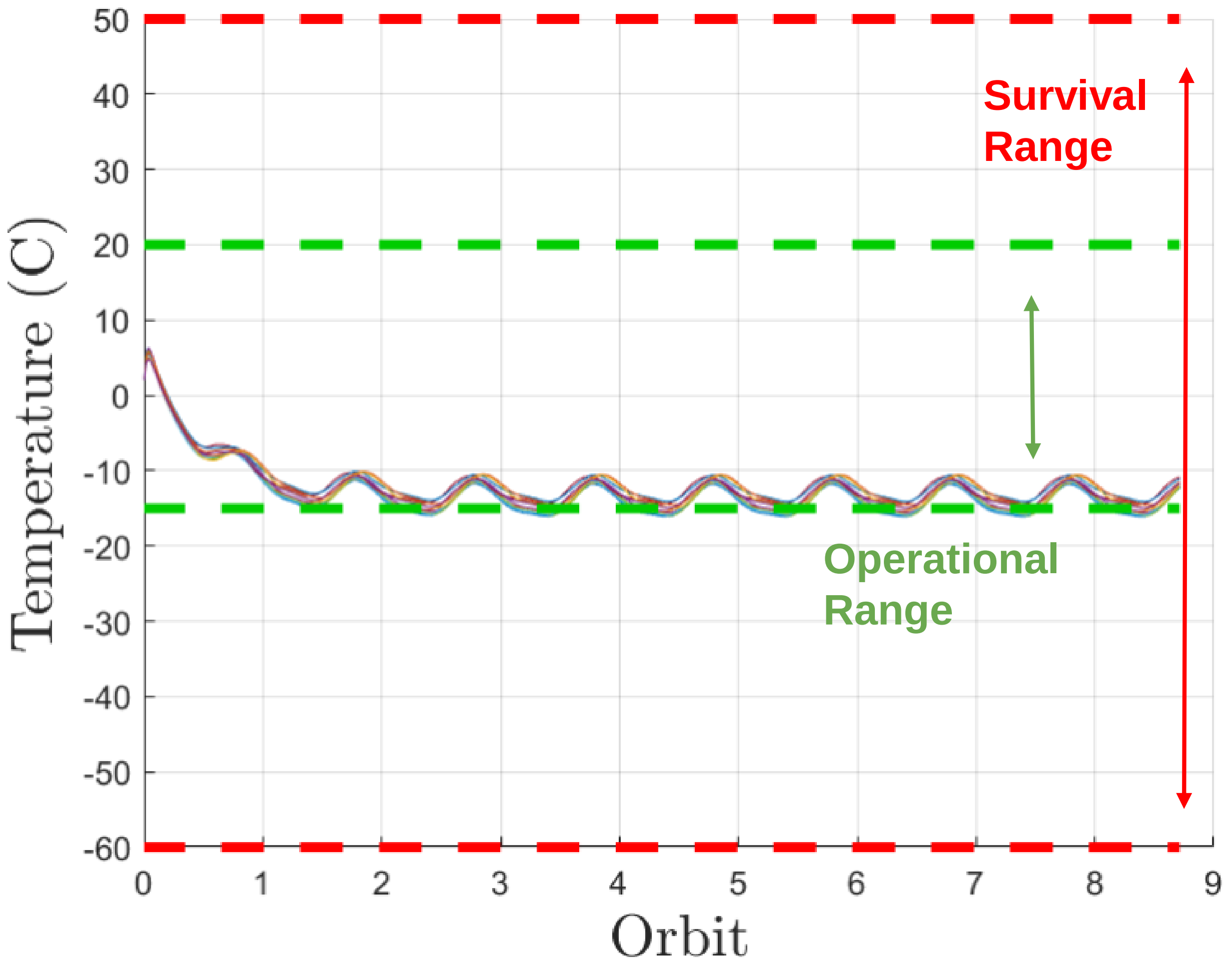
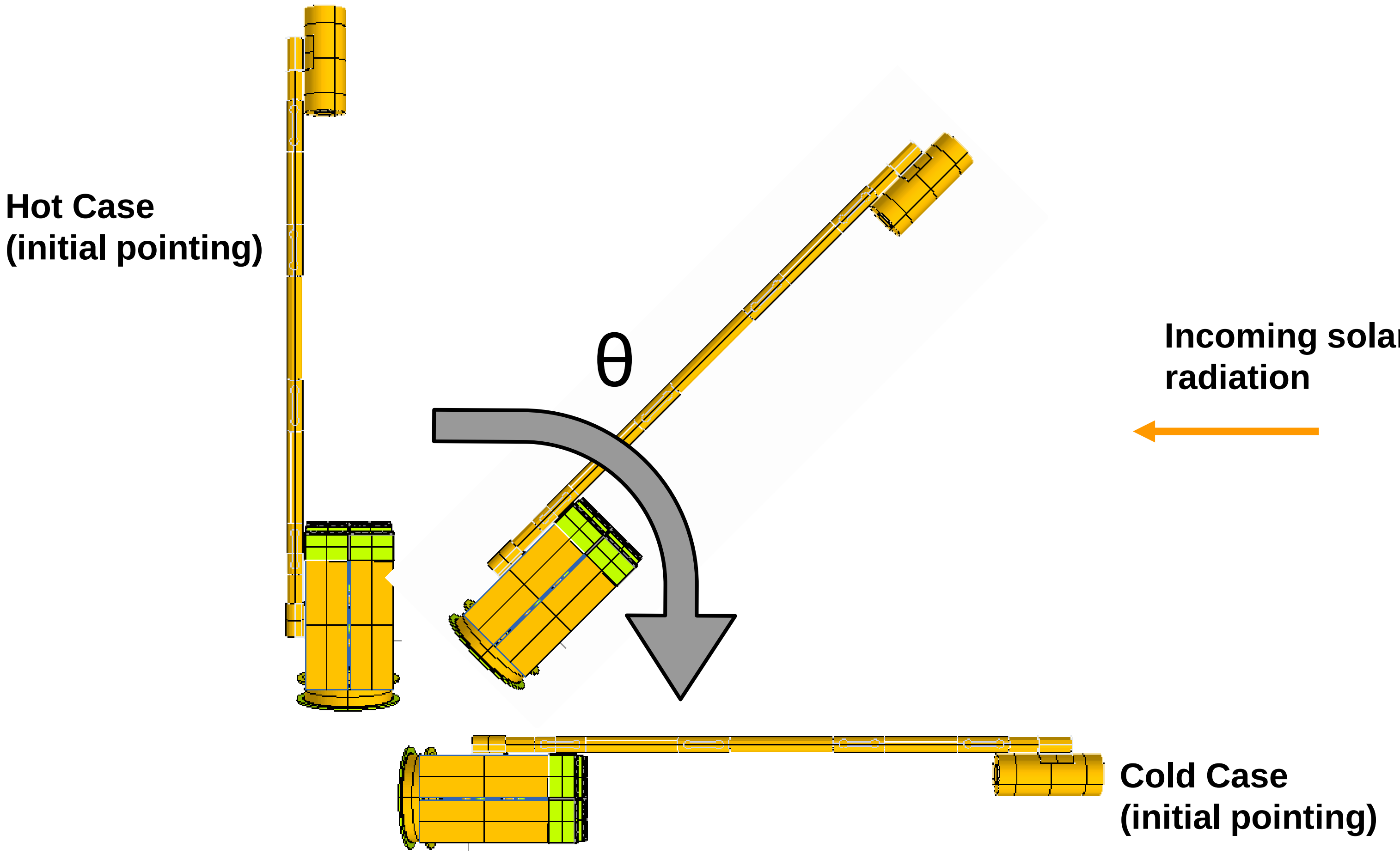
Deformable Mirrors, Spacecraft Hot Case

- Mirrors receive no direct sunlight
- ~5℃ temperature variations due to Earth radiation and albedo reaching mirrors
- **>95% of orbit within operational limits, PCB heat during science brings mirrors within limits**



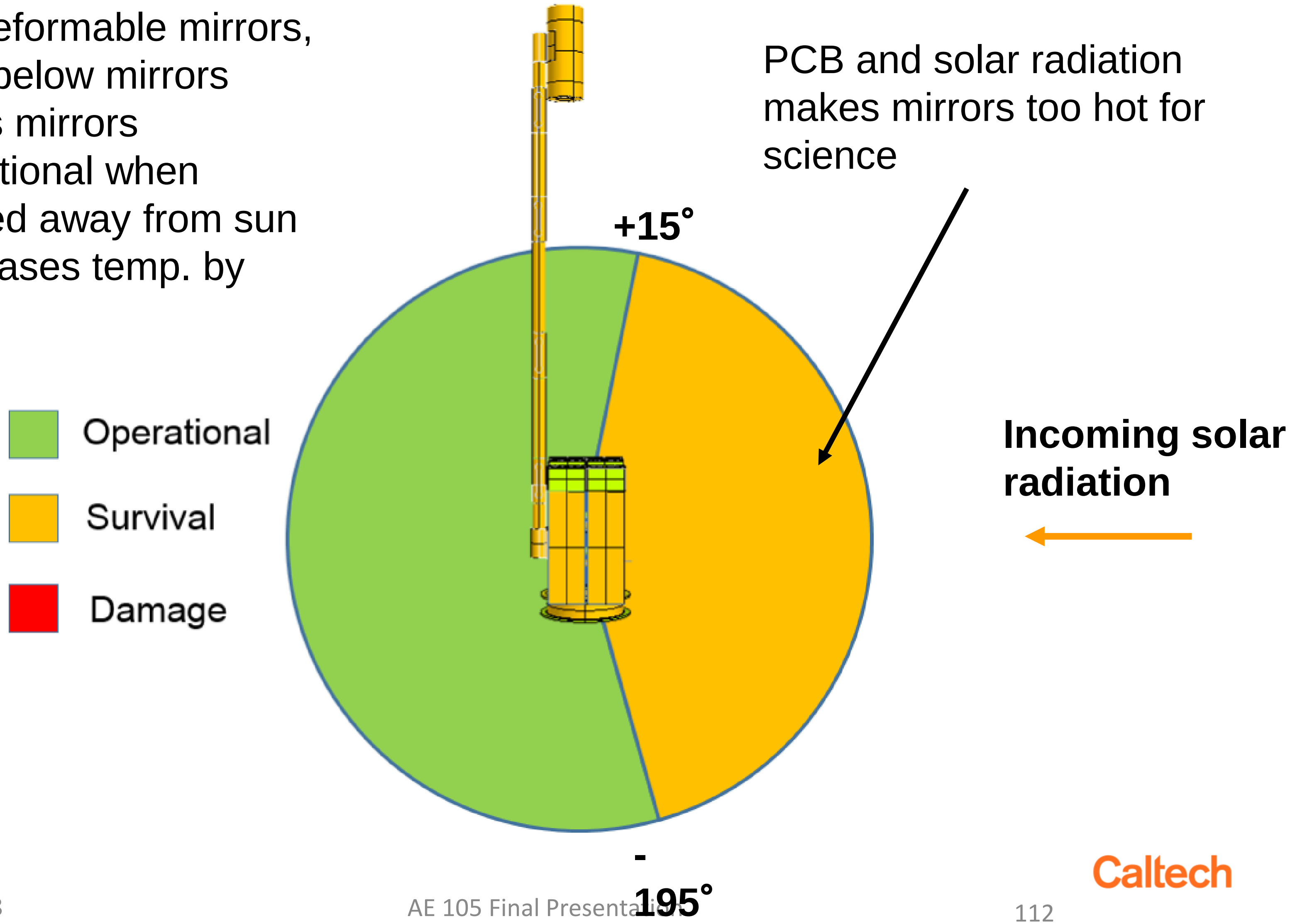
Spacecraft Pointing Considerations

Considering the mirror thermal requirements, what elevation angles of AAReST are permitted and where can science be performed in each case?



Pointing Restrictions: Hot case

- For deformable mirrors, PCB below mirrors keeps mirrors operational when pointed away from sun (increases temp. by 10℃)



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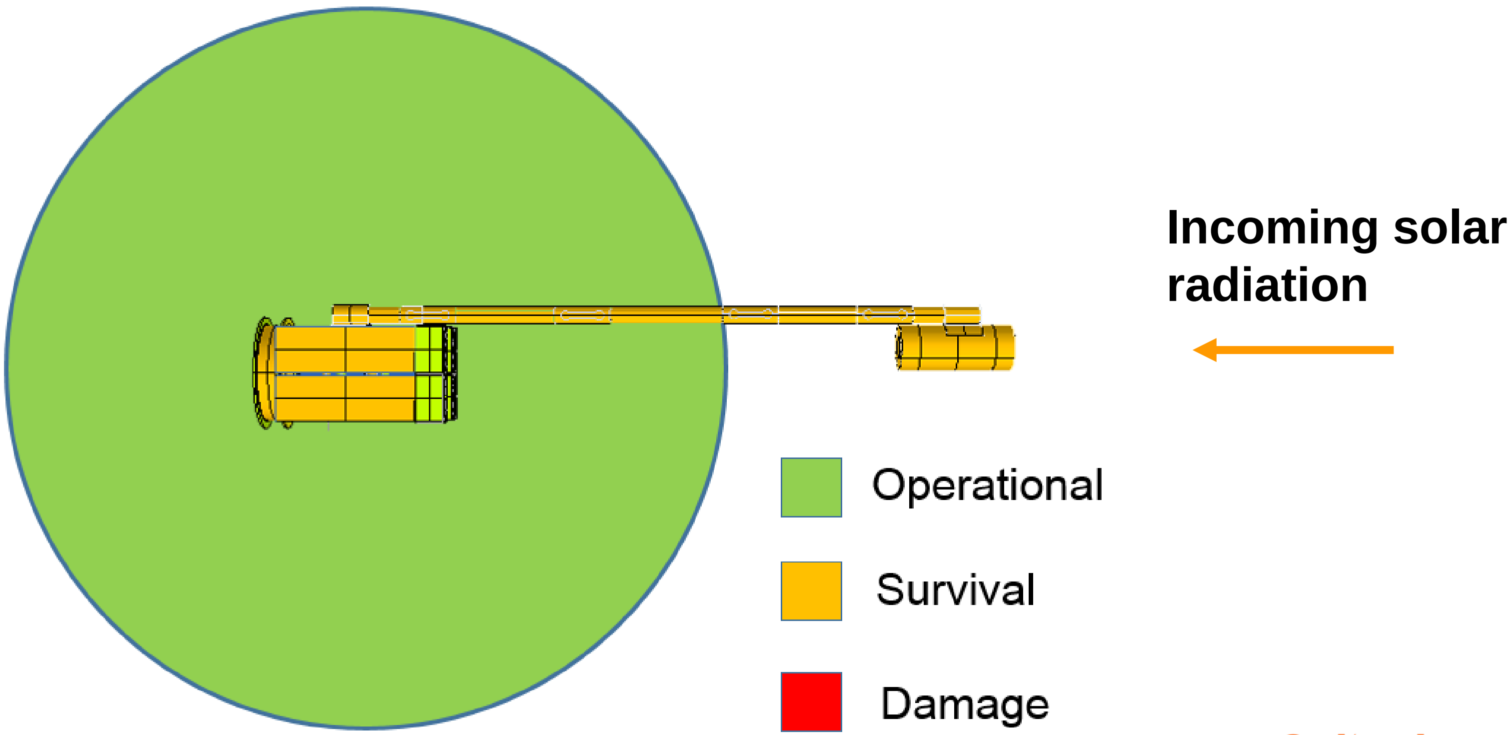
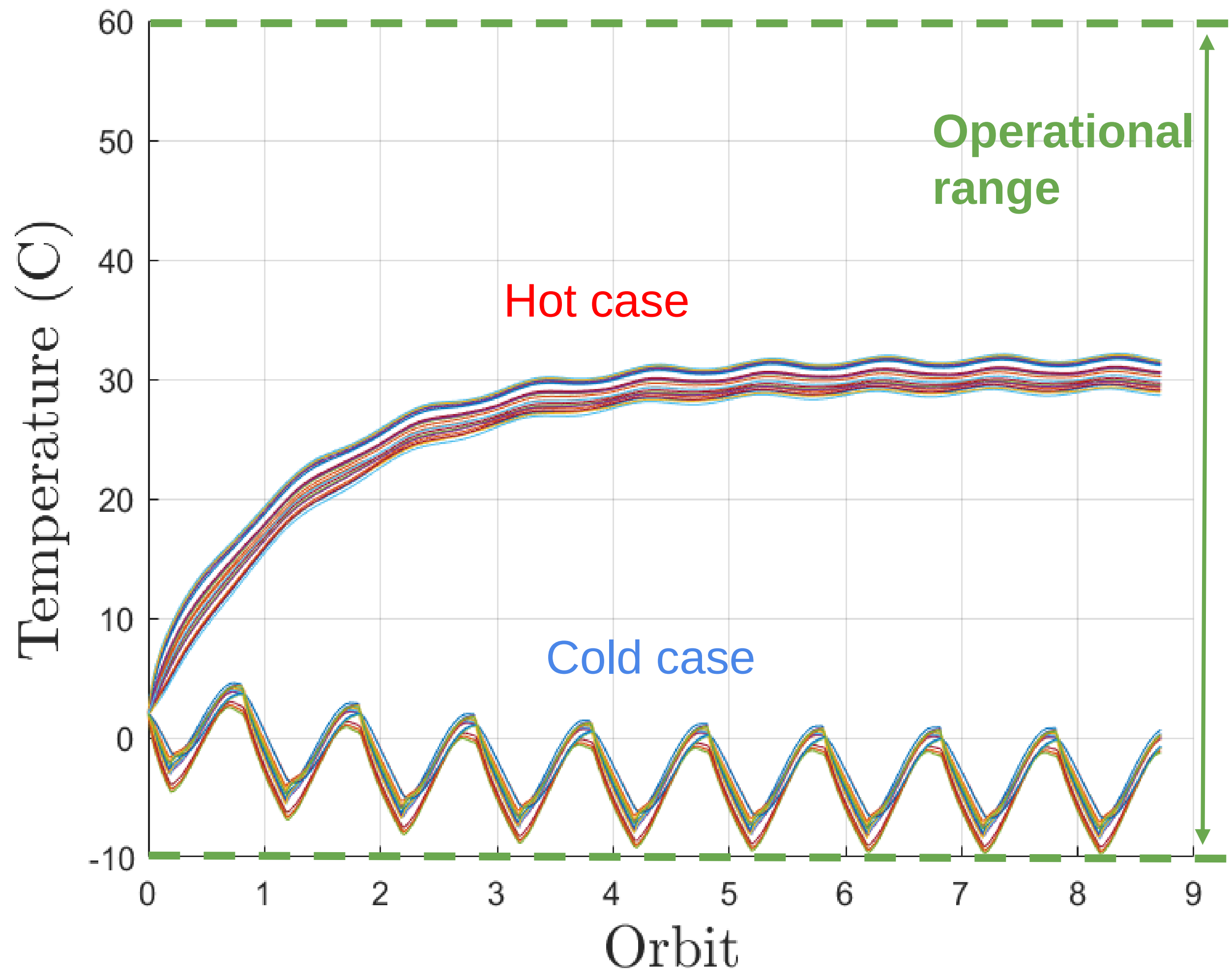
Pointing Restrictions: Cold case

- When pointed towards sun (< +/- 30° **)**, science must be performed towards end of eclipse period
- When pointed away from sun (> +/- 30° **),** science must be performed towards end of sunlight period



CoreSat: ADCS

- **50% margin below hot limit**
- **Cold case reaches exactly lower limit**
- Has heat load applied according to internal power



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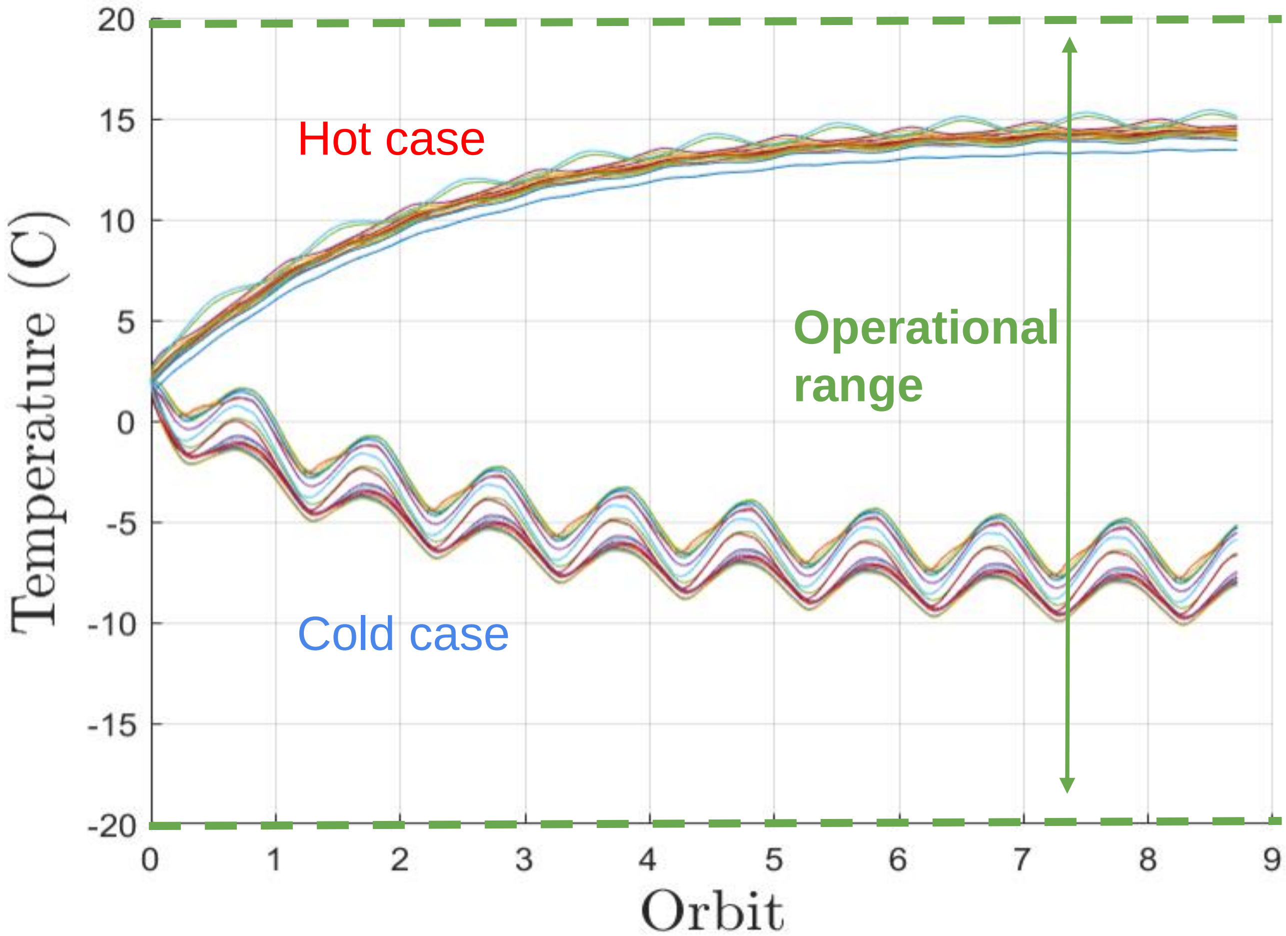
Camera Coating: Chromic Paint Covers All Cases

- **~25% margin below hot temp, ~50% margin above cold temp**
- Camera coated in chromic paint (α=0.44, ε=0.56)
- Camera is running in the cold case (4 W load)

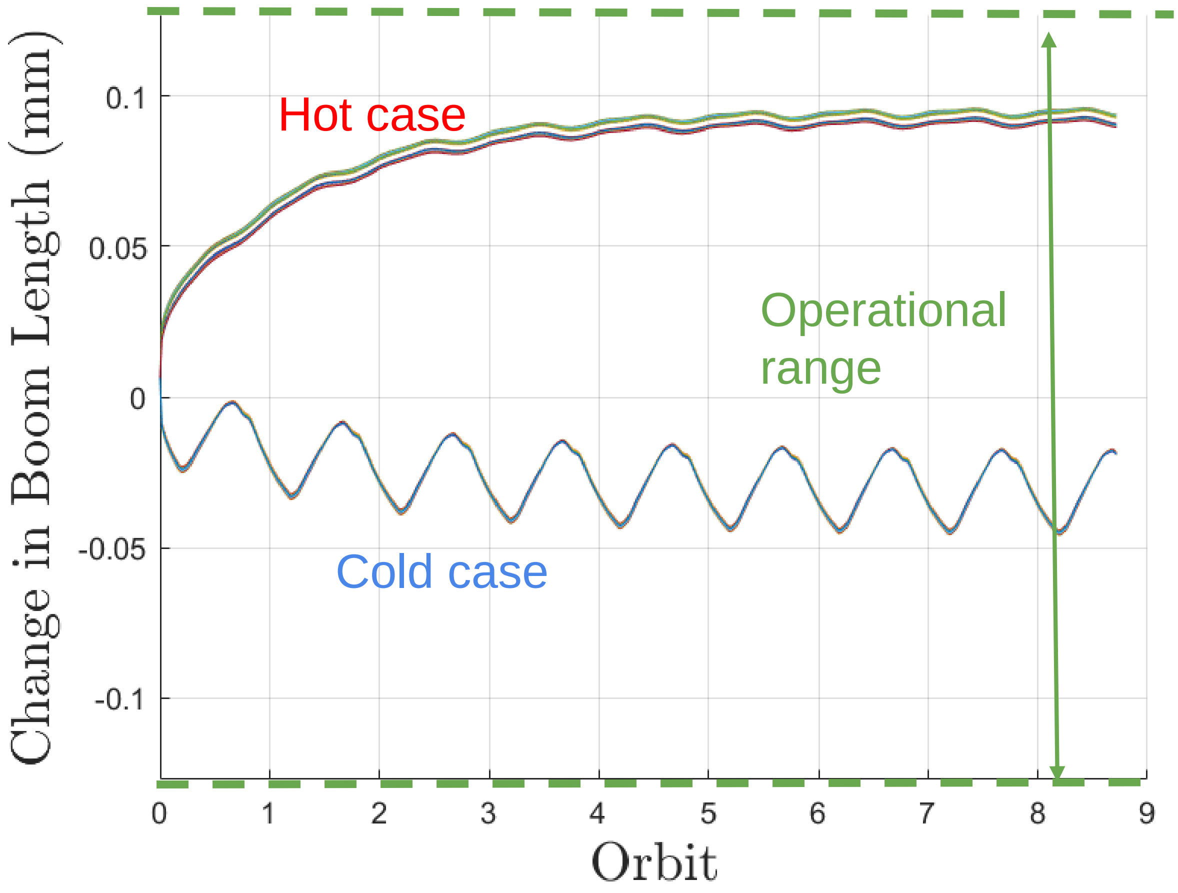


Boom Thermal Distortion

- Changes in temperature cause physical expansion or contraction of materials
- Will consider two problems of thermal distortion
  - Axial expansion (or contraction) as temperature changes
  - Translation as a result of temperature differences between sides of the boom (hot case only)
  - Camera tilt as a result of temperature differences between sides of the boom (hot case only)

Boom Distortion Req. Met

- **~25% margin before reaching upper limit, ~65% margin above lower limit**
- Difference of ~5 μm between sides of the boom at steady temperature in hot case, causes camera tilt of ~0.02°



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Comparing to Requirements

AAReST Component	Operational Restriction	Survival Restriction	Results	Smallest Margin
CoreSat/ADCS System	-10/+60°C	-50/+100°C	-15/+45°C	0%
Deformable Mirrors	-15/+20°C	-60/+50°C	-15/+45°C	20%*
Boom	±0.127 mm (axial) ±0.625 mm (translation)		-0.03/+0.09 mm (axial) 0.005 mm (translational)	25%†
Camera	±20°C	±100°C	-8/+15°C	25%†

* margin to survival temps.
† margin to operational temps.

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Conclusion

- Deformable mirror temperatures remain within operational limits long enough to perform science and do not exceed survival temperatures
- ADCS remains within operational limits (no margin in cold case)
- Boom distortion is within requirements
- Camera can be coated to keep it in operational requirements, but might need to run while in cold scenarios

Future Work

- Refine camera model
- Improve internal modelling complexity to simulate internal temperature profile more accurately
- Experiment with azimuthal angles for pointing considerations
- Extend analysis and adapt model for wide configuration

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Questions?

Onboard Software

Lucas Benoit-Maréchal

Jean-Sébastien Spratt Alexander Wen

Mentor: Fabien Royer

Caltech

Presentation Overview

• Team Overview	Lucas
• Software Development Process	Lucas
• Hardware Test Setup Development	Alexander
• Testing Process	Jean
• Conclusion	Jean

Project Responsibilities and Scope

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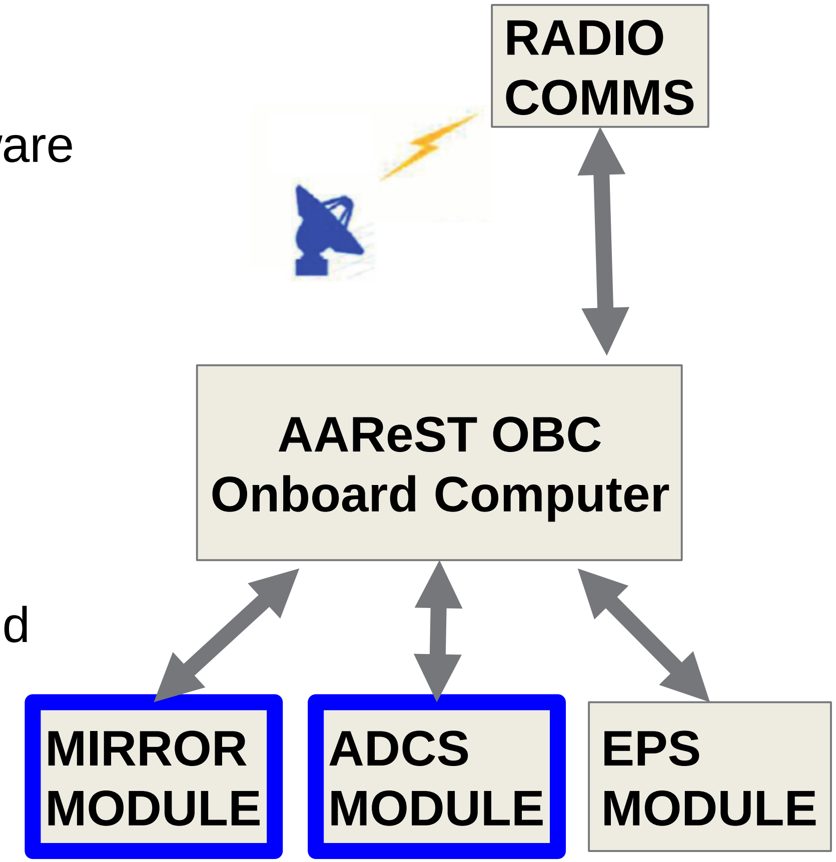
Scope and responsibilities

- **OBC responsible for communication between AAReST subsystems**
  - Interface with existing subsystem software through I2C
- **Main focus: two modules**
  - Mirror
  - ADCS
- **Software:**
  - Driver files that implement telecommand and telemetry requests
  - C Language
  - Communication channel I2C
- **Hardware:**
  - EFM32 board to emulate OBC
  - Arduino to emulate modules



Deliverables

- **Code for Mirror + ADCS functions**
  - 75% of functions written (290/390)

- **Documentation on functions' writing process**
  - Compilable file template
  - Documented pitfalls and solutions

- **Hardware development and test setup**
  - Software configuration for emulators (EFM32 and Arduino boards)
  - Hardware modifications

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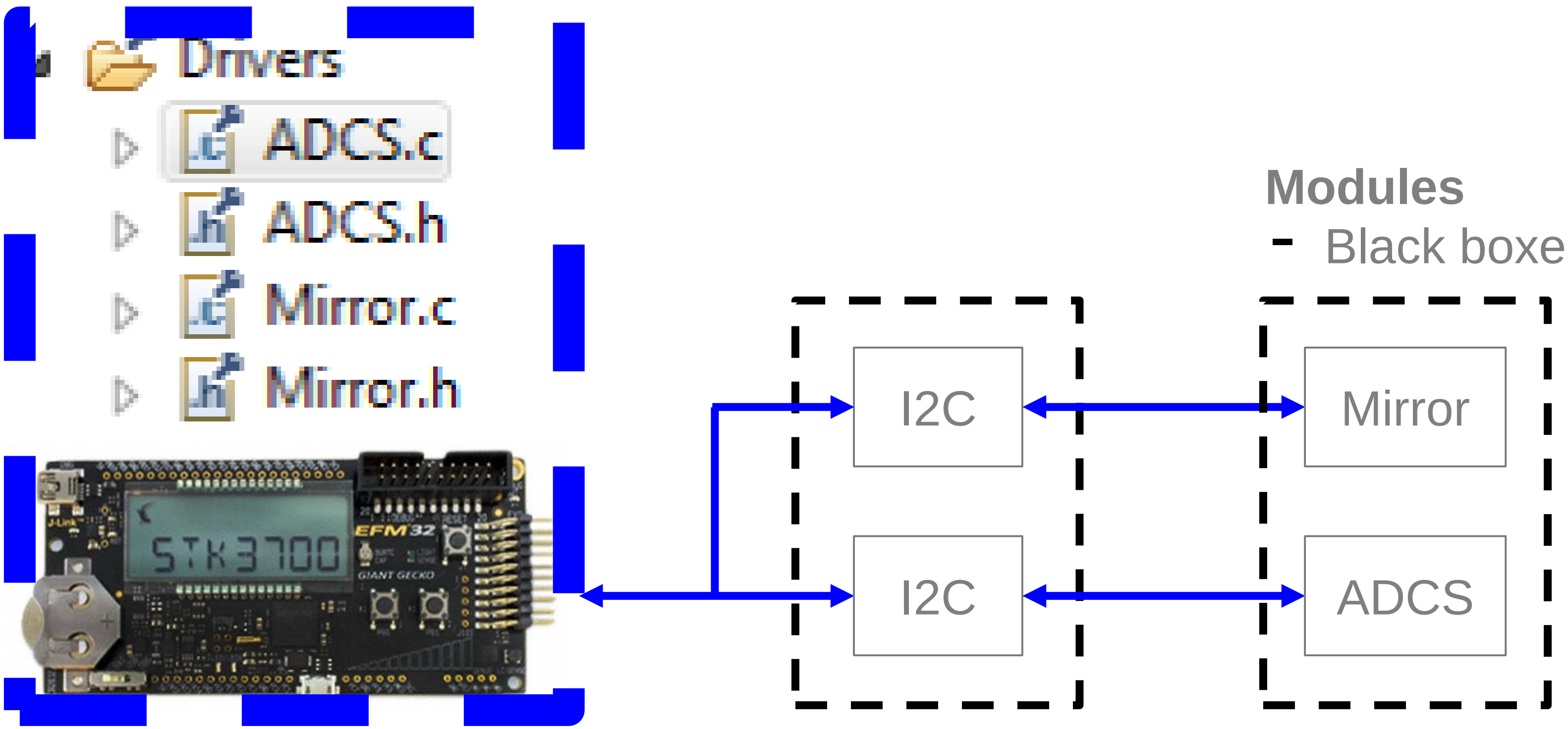
Module Development

Software architecture



EFM32 board
- emulates OBC

Hardware Abstraction Layer (HAL)
- Takes care of communication

- **Source file .c**
  - Functions: format and transmit messages
- **Header file .h**
  - Variables and functions declaration

Anatomy of a telecommand

```c
I2C_TransferReturn_TypeDef USR_ADCS_I2C_SGP4OrbitEccentricity(double eccentricity){
    uint8_t txBuffer[9] = {0};
    I2C_TransferReturn_TypeDef result;

    txBuffer[0] = 47;    // Command ID
    txBuffer[1] = eccentricity;
    result = HAL_i2c_Transmit(ADCS_I2C_Port, 77<<1, bspI2cWrite, txBuffer,9,0,0);

    return result;

}
```

- Creating Message
- ID Number
- Data Byte
- Writing

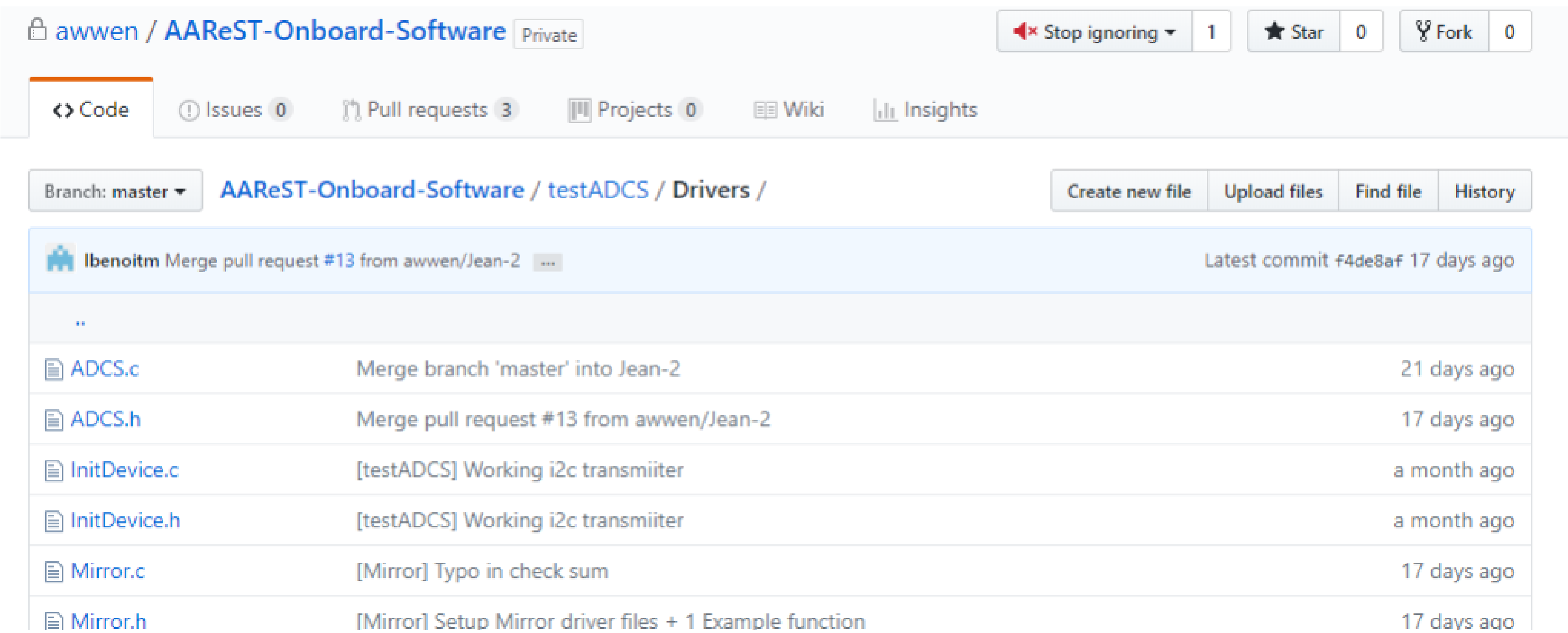
- Interface Control Document (ICD) example:

Table 64: Set SGP4 Orbit Eccentricity Command Format

ID	47		**Parameters Length (bytes)**	8
Description	Set SGP4 Orbit Eccentricity			
Parameters	**Offset (bits)**	**Length (bits)**	**Name**	**Data Type**	**Description**
	0	64	Eccentricity	DOUBLE	Eccentricity

Work organization

- Multi developer configuration management: GitHub platform
  - Code reviews
  - Clear GUI
  - Homogenized nomenclature



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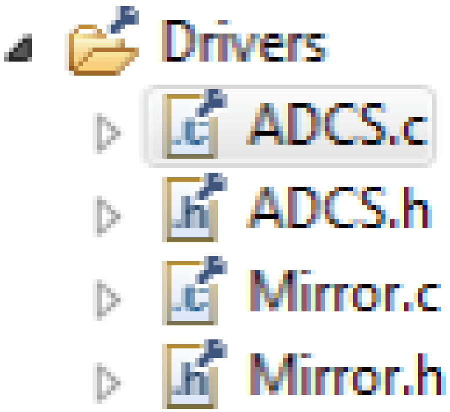
Test Setup Development

Additional work is needed to make driver functions run and execute on the development board



Module Functions | **Additional Work** | **Working I2C Setup**

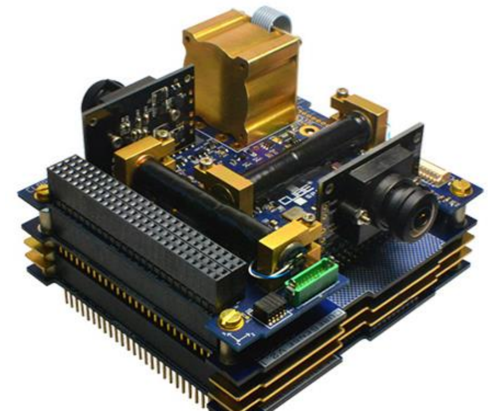
Caltech

We Developed Test Setups That Simulate Flight Config

ADCS Flight Config

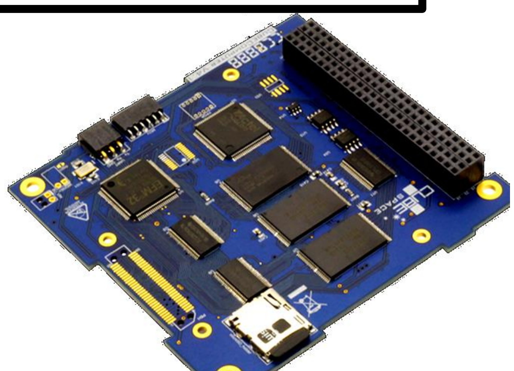
CubeSpace OBC

I2C



CubeSpace ADCS

Mirror Flight Config

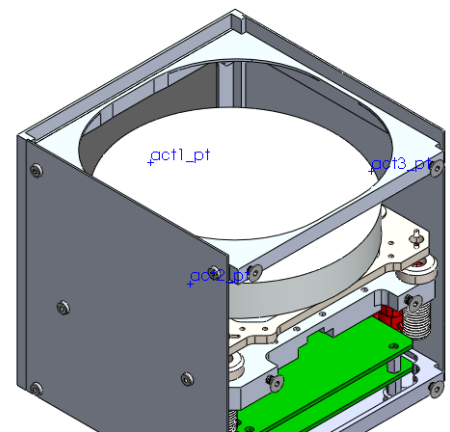


CubeSpace OBC

I2C

I2C - UART Bridge

UART



Mirror Box

We Developed Test Setups That Simulate Flight Config

ADCS Simulator

EFM 32 STK3700

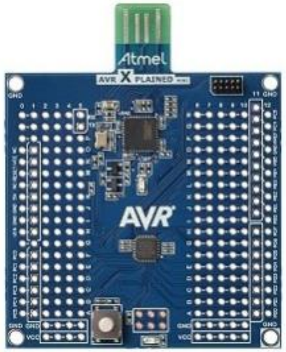
I2C

ADCS Simulator

Mirror Simulator

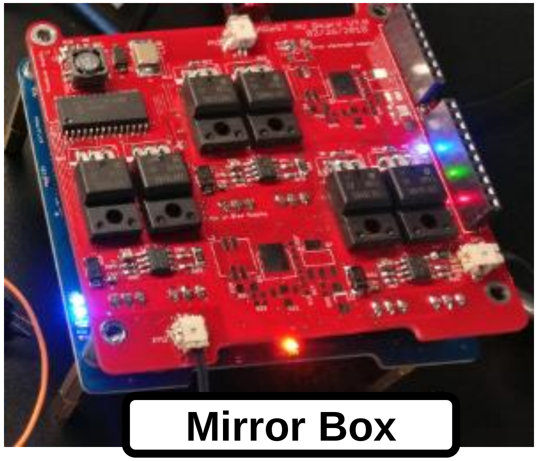
EFM 32 STK3700

I2C



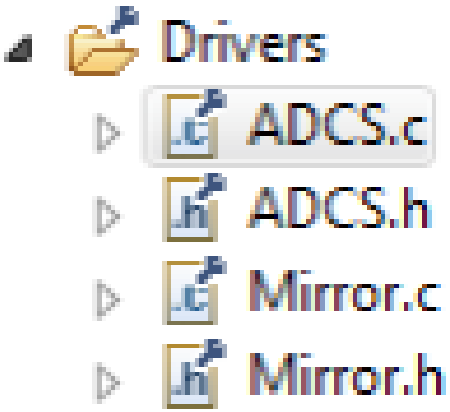
I2C - UART Bridge

UART



Mirror Box

More Software Needed: Development Board Requires Drivers and GPIO Config Files to Setup for I2C



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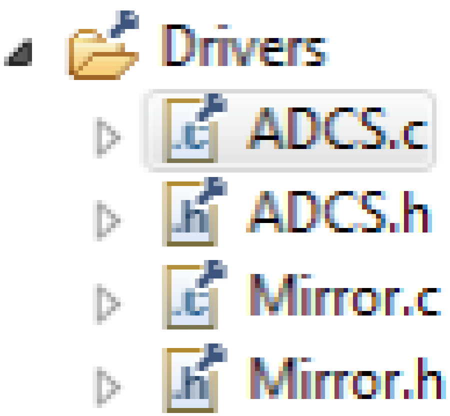
Module Functions

Dev Board Software

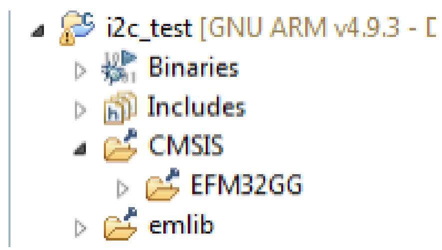
Working I2C Setup

Caltech

More Software Needed: Development Board Requires Drivers and GPIO Config Files to Setup for I2C



Board Drivers



Configuration Files

```
/* Pin PD6 is configured to
GPIO->P[1].MODEH = (GPIO->P

/* Pin PD7 is configured to
GPIO->P[1].MODEH = (GPIO->P
// [Port D Configuration]$
```

Module Functions

Dev Board Software

Working I2C Setup

Even with all of the software configured, some hardware modifications needed as well

Rework Procedure

Required Tools:

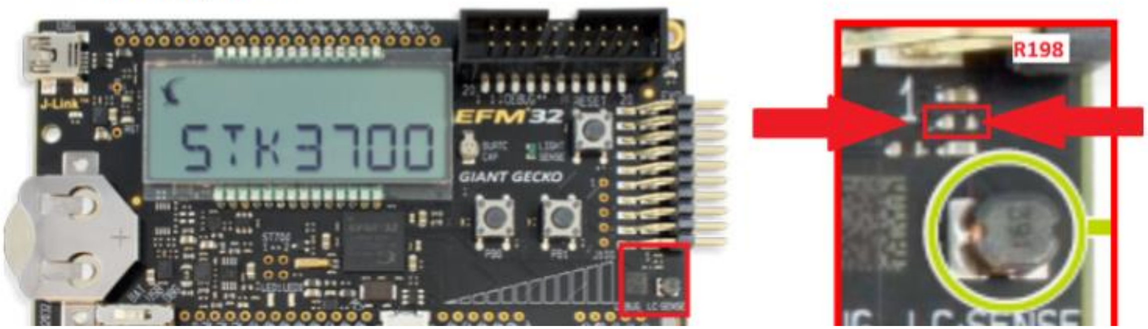
- Soldering Iron

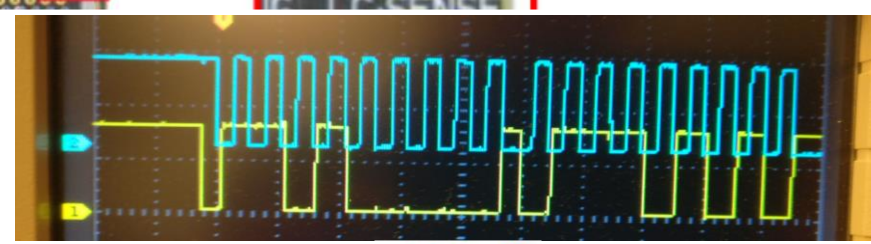
Rework Instructions:

- Remove the 0 ohm resistor R198 of the LC-Sense Circuit.

Notes:

The location of the resistor is indicated below. It is the center, black package component in a column of three components.





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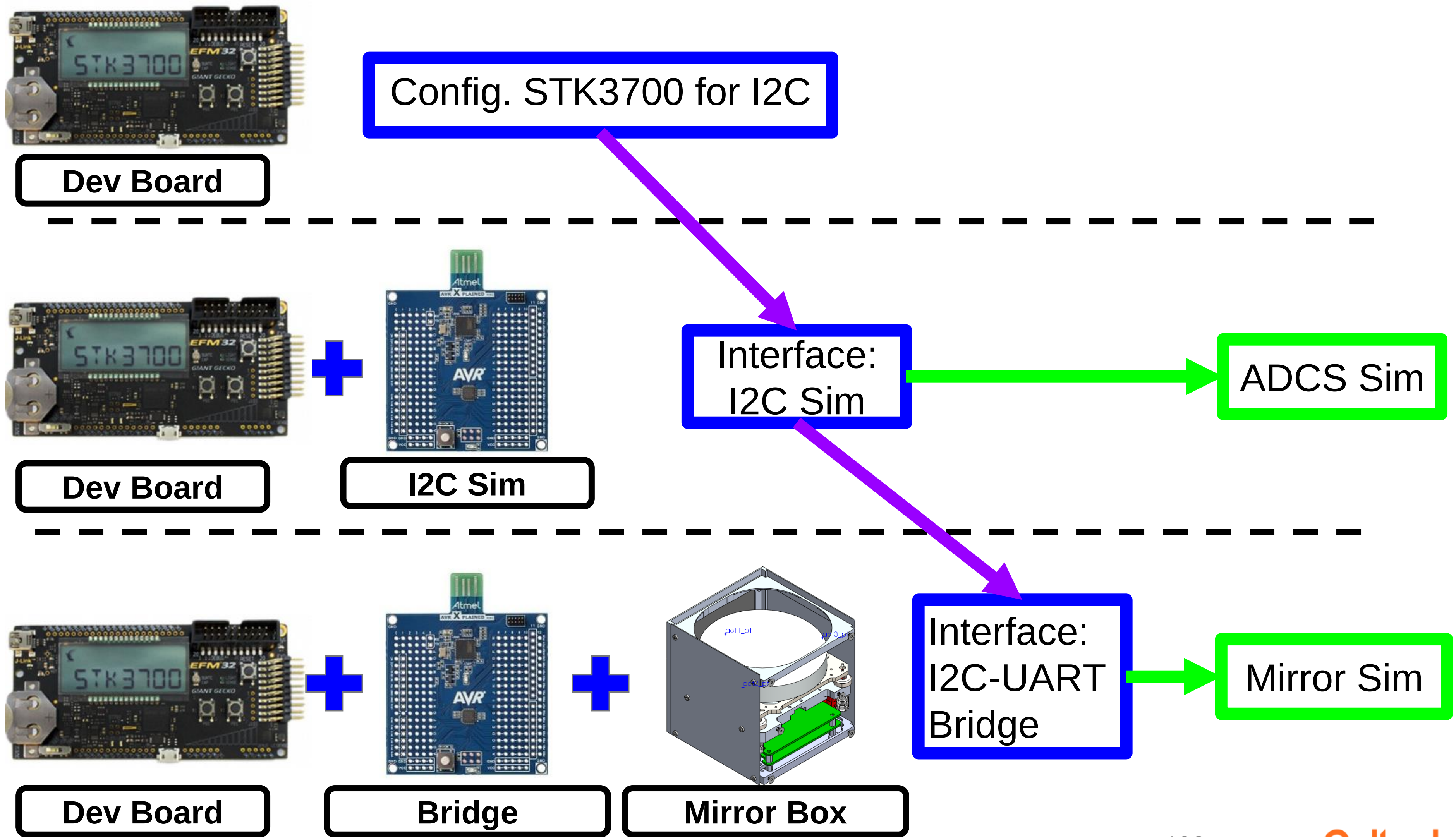
We Built our Test Setups Incrementally: Easy to Debug, Leverage previous work at all stages



ADCS Simulator: Working Final Setup

```
set_led(0,1);
uint16_t value = i2c_read_register(117);
// Set an LED on the Starter Kit if success
if (value == DEVICE_ID)
{
    set_led(1,1);
}
```

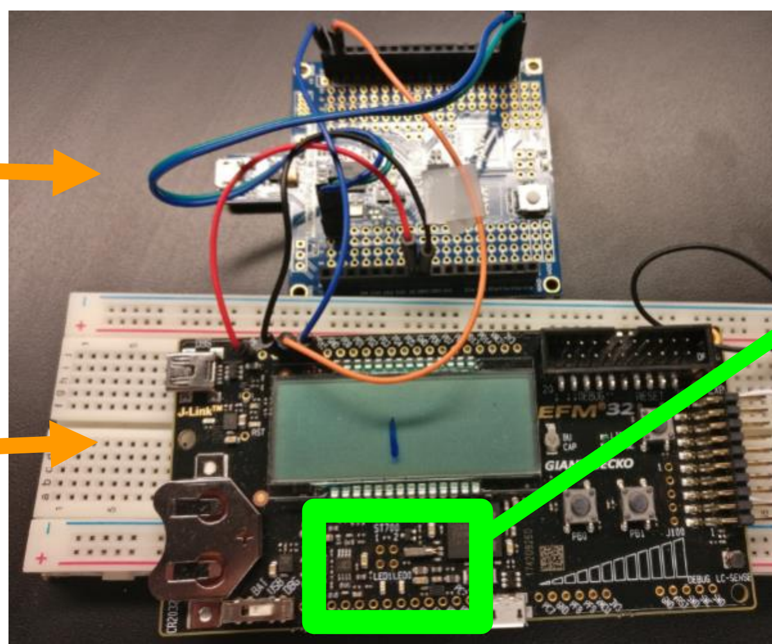
1 — I2C Read from device

2 — If device read correct, turn on LED

ADCS Simulator Setup

ADCS Sim

Dev Board



Two lights = working

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Mirror Simulator: Working Final Setup

```
USR_Mirror_I2C_Start_App();
USR_Mirror_I2C_Move_Pico2(100000);
```

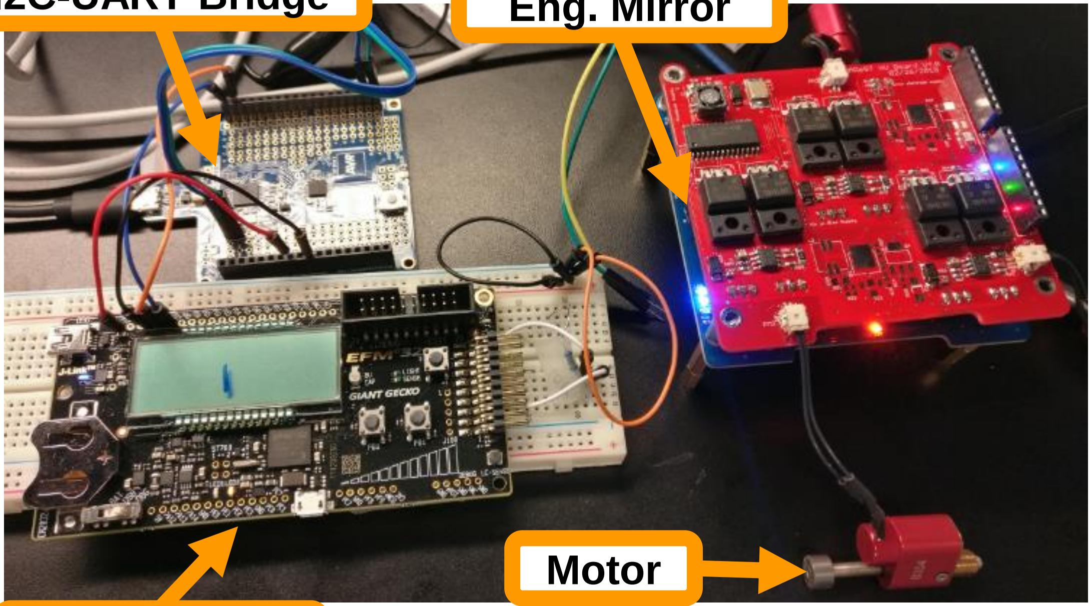
1

Move PicoMotor 2

Mirror Sim Setup

I2C-UART Bridge

Eng. Mirror



Motor

Dev Board

Button press commands motor to turn

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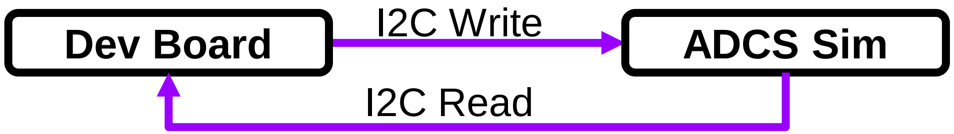
Testing Process

Test Flow

1. Independent visual code review
2. Telecommand Testing (Write only)

3. Telemetry Request Testing (Write and Read)



4. Integration Testing

2. Telecommand Testing

- Create test inputs for each data type

```
// Test values:
uint8_t testu8 = 170;
uint16_t testu16 = 43690;
uint32_t testu32 = 2863311530;
uint8_t testbool = 1;
uint8_t testenum = 2;
```

- Write a list of expected messages using the Interface Control Document (ICD) and test inputs

Command ID	Expected Message
1	1 90
2	2 170 170 170 170 170 170
3	3 1
⋮	⋮

- Run commands and check obtained message

```
// Calling functions with test values inputs:
USR_ADCS_I2C_Reset(); //1
USR_ADCS_I2C_CurrentUnixTime(testu32, testu16); //2
USR_ADCS_Cache_Enable_State(testbool); //3
```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Compiling Expected Message list

Table 10: Reset Command Format

<table>
<tr><td>ID</td><td colspan="2">1</td><td colspan="2">Parameters Length (bytes)</td><td>1</td></tr>
<tr><td>Description</td><td colspan="5">Perform a reset</td></tr>
<tr><td rowspan="2">Parameters</td><td>Offset (bits)</td><td>Length (bits)</td><td>Name</td><td>Data Type</td><td>Description</td></tr>
<tr><td>0</td><td>8</td><td>Magic number</td><td>UINT</td><td>Magic number to make sure it is a valid reset command. Should equal 0x5A</td></tr>
</table>

Message:

1	90

Repeat for each command (ADCS Example):

Command ID	Expected Message
1	1 90
2	2 170 170 170 170 170 170
3	3 1
4	4
⋮	⋮

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Run Commands and Read Message

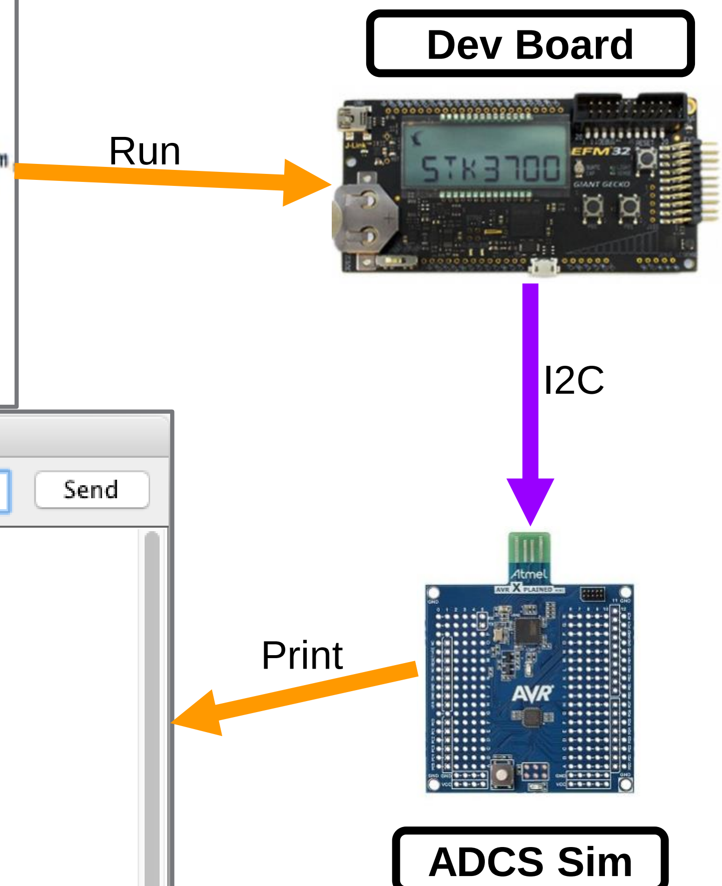
```
// Calling functions with test values inputs:
USR_ADCS_I2C_Reset(); //1
USR_ADCS_I2C_CurrentUnixTime(testu32, testu16); //2
USR_ADCS_Cache_Enable_State(testbool); //3
USR_ADCS_Reset_Log_Pointer(); //4
USR_ADCS_I2C_DeployMagnetometerBoom (testu8); //7
USR_ADCS_I2C_AdcsPowerControl(testenum, testenum, testenum, testenum,testenum
USR_ADCS_I2C_ClearErrors(testbool, testbool); //12
USR_ADCS_I2C_SetAttitudeControlMode(testenum , testbool, testu16); //13
USR_ADCS_I2C_SetAttitudeEstimationMode(testenum); //14
USR_ADCS_I2C_CommandedAttitudeAngles(testi16, testi16, testi16); //15
USR_ADCS_I2C_SetMagnetorquerOutput(testi16, testi16, testi16); //16
USR_ADCS_I2C_SetWheelSpeed(testi16, testi16, testi16); //17
USR_ADCS_I2C_TriggerADCSLoop(); //18
```

/dev/cu.usbmodemFD121 (Arduino/Genuino Uno)

Send

```
1 90
2 170 170 170 170 170 170
3 1
4
7 170
11 170 170 128
12 192
13 2 1 170 170
14 2
15 170 170 170 170 170 170
16 170 170 170 170 170 170
17 170 170 170 170 170 170
18
```

Autoscroll | No line ending | 9600 baud | Clear output



Compare to Expected Messages

Developed test excel spreadsheet

Command ID	Expected Message	Message	Result
1	1 90	1 90	TRUE
2	2 170 170 170 170 170 170	2 170 170 170 170 170 170	TRUE
3	3 1	3 1	TRUE
4	4	4	TRUE
7	7 170	7 170	TRUE
11	11 170 170 128	11 170 170 128	TRUE
12	12 192	12 192	TRUE
13	13 2 128 170 170	13 2 128 170 170	TRUE
14	14 2	14 2	TRUE
15	15 170 170 170 170 170 170	15 170 170 170 170 170 170	TRUE
16	16 170 170 170 170 170 170	16 170 170 170 170 170 170	TRUE
17	17 170 170 170 170 170 170	17 170 170 170 170 170 170	TRUE

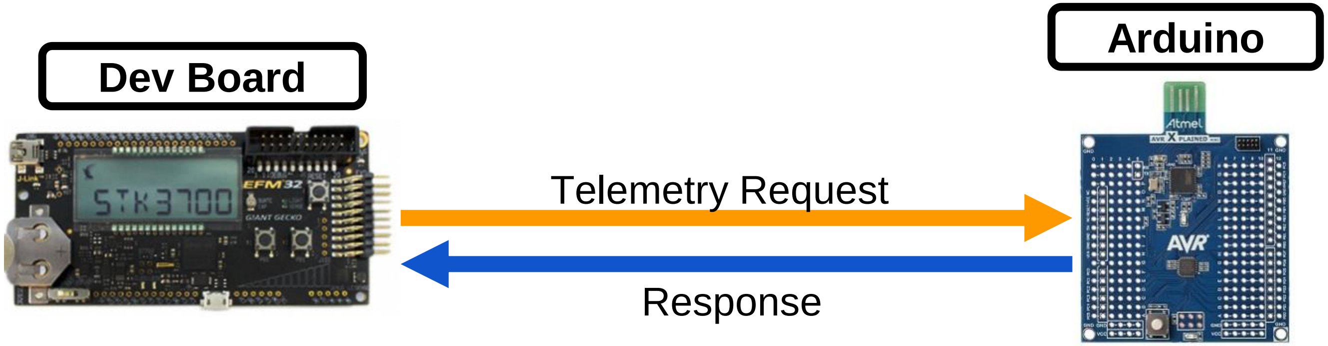
Expected

Obtained

True if messages match

3. Telemetry Request Testing

- Set up Arduino to respond with test register
- Set up dev board test to check responses
- Run commands and check stored values



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Additional Testing Code

Dev Board

Telemetry Request

Response

ADCS Sim

Run Command:

```
USR_ADCS_I2C_GetEstimatedAttitudeAngles(); //146
```

Simulate Command response:

```
// USR_ADCS_I2C_GetEstimatedAttitudeAngles
if (register_address == 146)
{
Wire.write(simulated_registers,6);
Serial.print("146 Transmitted");
Serial.print("\n");
}
```

Test Response:

```
//146
if (TCVal_ADCS.estimated_roll_angle != testi16)
{
    set_led(1,1);
    errors = errors + 1;
}
if (TCVal_ADCS.estimated_pitch_angle != testi16)
{
    set_led(1,1);
    errors = errors +1;
}
if (TCVal_ADCS.estimated_yaw_angle != testi16)
{
    set_led(1,1);
    errors = errors + 1;
}
```

LED stays off: SUCCESS!

4. Integration Testing

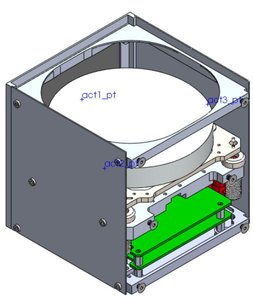
- ADCS: Hardware was received too late
- Mirror Module:

1. MATLAB Function Testing on Module
2. Telecommand Testing

Mirror Box Telecommand Testing

Dev Board

I2C - UART Bridge



Mirror Box

Run Command (example):

```
USR_Mirror_I2C_Move_Pico2(100000);
```

I2C

I2C to UART Conversion code*

UART

- Observe Mirror Box
- Probe Mirror Directly

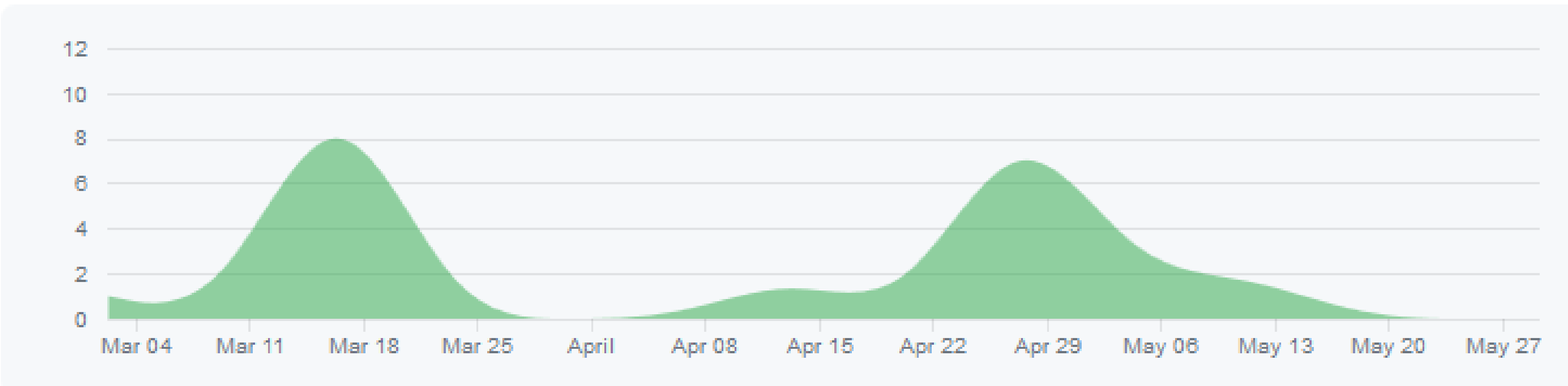
*Provided by Thibaud Talon

Work Accomplished

Mar 4, 2018 – May 31, 2018

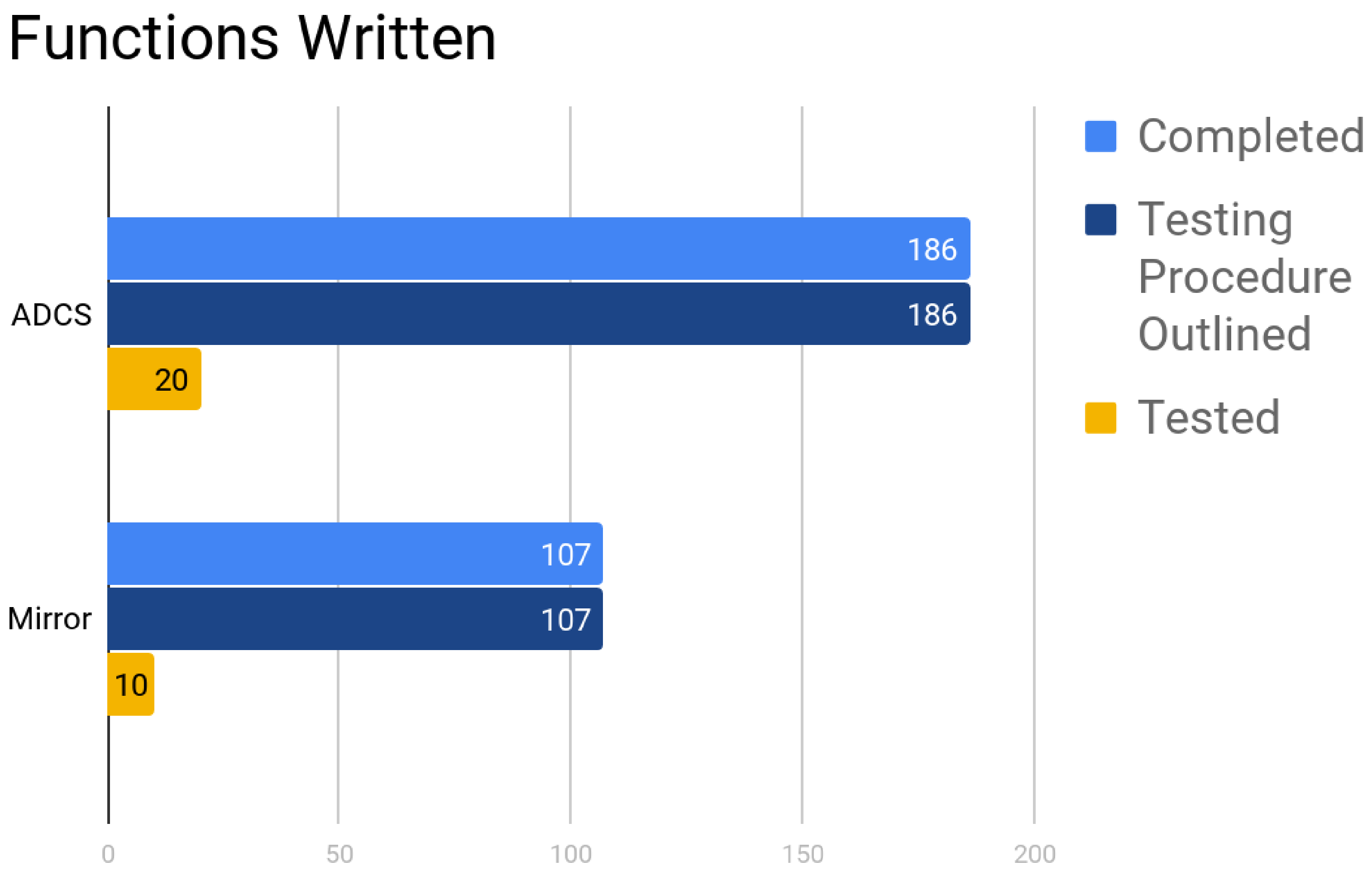
Contributions: Commits

Contributions to master, excluding merge commits



293 Functions written

Work Accomplished



Conclusion

Accomplishments:

- Coded all planned ADCS and Mirror functions
- Developed test setup for the ADCS and Mirror modules
- Performed unit testing on representative functions, and laid out testing procedure for the rest
- Performed integration testing of a few functions on the Mirror module, and laid out the procedure for full integration testing

Future Work:

- Code other modules using documented coding procedure as template
- Finish testing of ADCS and mirror module using the developed test setup and documented testing procedure
- Use testing template to test other modules

QUESTIONS?

Telecom Subsystem

Kai Matsuka , Conor Martin, Edward Chu

Mentors:
Michael Marshall, Maria Sakovsky

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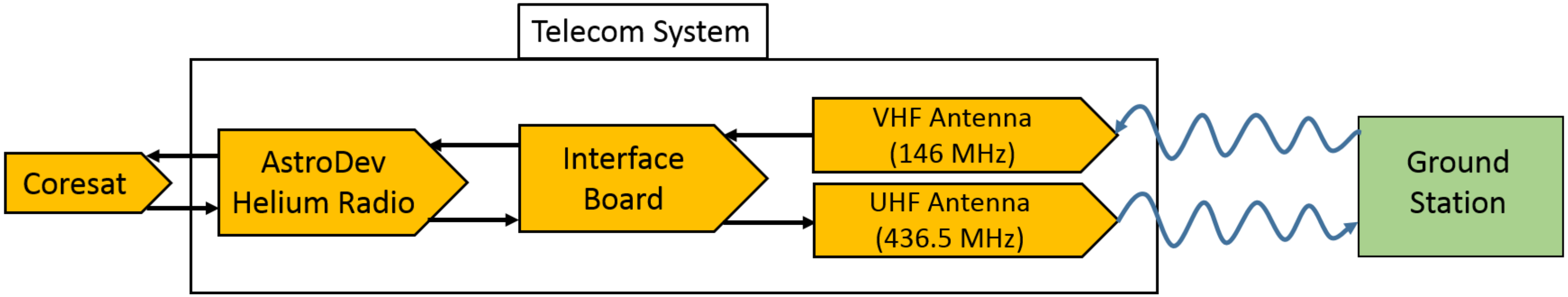
AAReST Telecom Overview

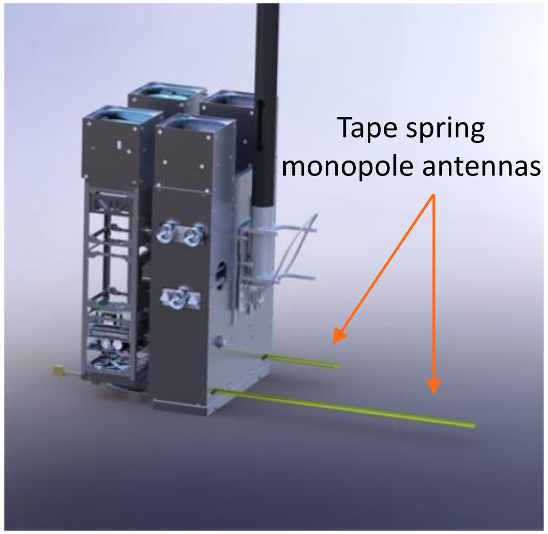


Previous Ae105 classes:

- Selected desired frequencies
- Selected transceiver and designed antennas
- Tested antenna deployment mechanisms

Our primary Ae105 tasks:

- Configure and test the AstroDev radio
  - ➔ Verify functionality of radio
- Experimentally characterize the antennas
  - ➔ Validate antenna design and optimize transmitted power



Telecom Team Objectives

Antenna Responsibilities (Kai, Edward)

1. Perform sensitivity analysis via antenna simulation
2. Fabricate antenna assemblies
3. Fabricate EM-representative spacecraft model
4. Characterize antenna performance

➔ End goal: Test and validate the antenna design

Radio Responsibilities (Conor)

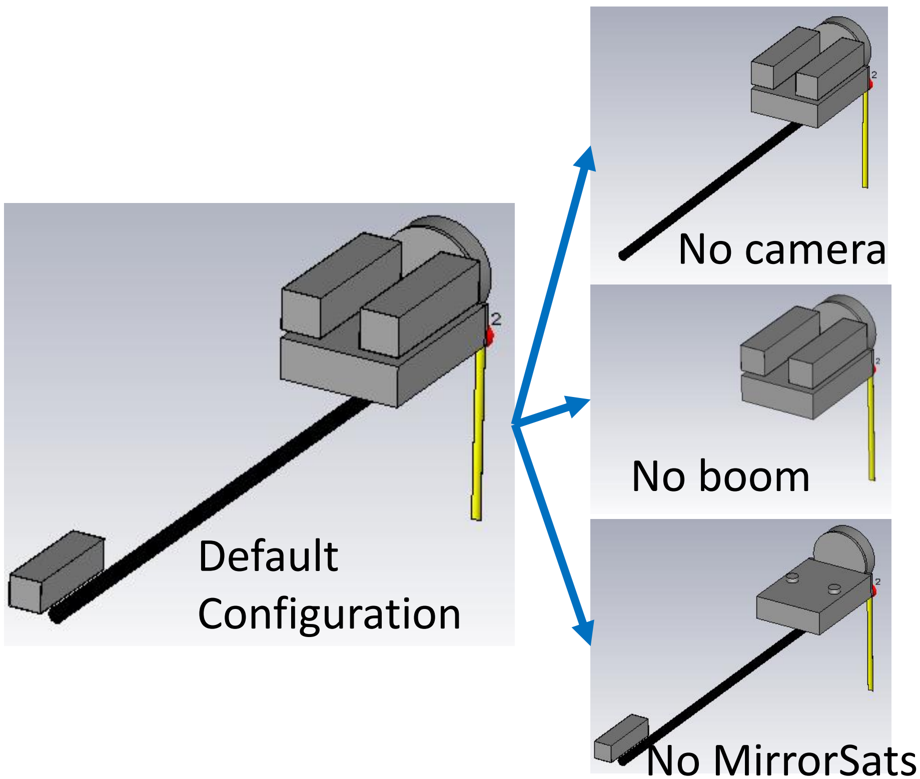
1. Test radio commands
2. Configure the radio
3. Plan power tests

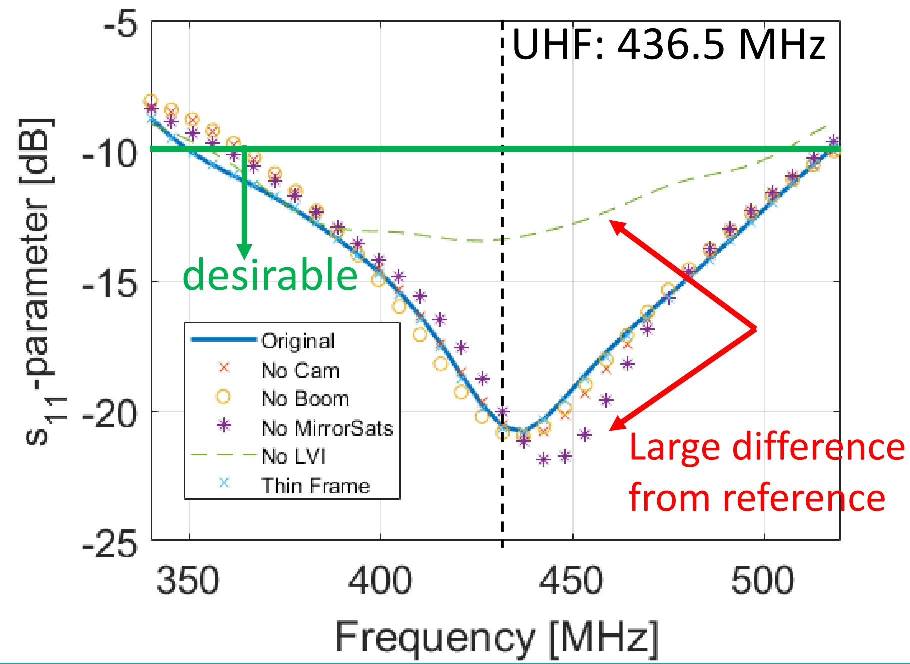
➔ End goal: Test and verify functionality of the radio

Antenna Sensitivity Analysis

- Need to build EM-representative AAReST model for antenna experiments
- Need to determine which components to include in model

➔ Vary geometry in simulation and compare the antenna characteristics





Conclusion:

- Camera/boom not required
- Frame thickness not important
- Coresat, MirrorSats, Launch Vehicle Interface (LVI) required

EM-Representative SC Model

Background:

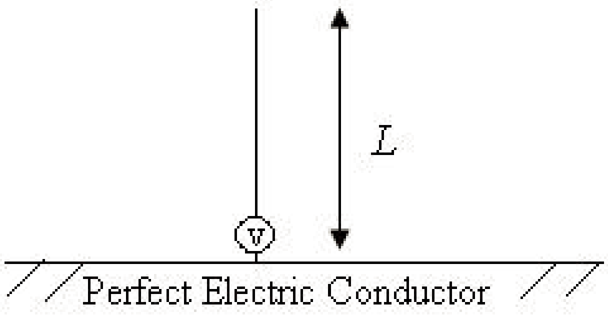
- Ideal monopole antenna assumes infinitely large “ground plane”
- Spacecraft chassis acts as ground plane

Objective: Build EM-representative model for antenna experiments

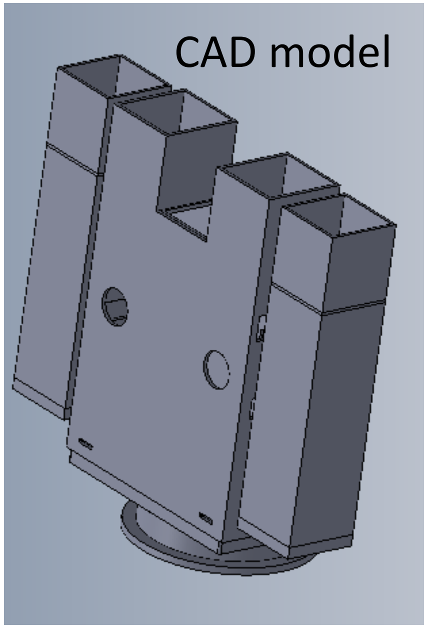
Approach: Simple but sufficiently representative of model

- Used sensitivity analysis results to design model
- Waterjetted 1/16” thick aluminum plates with foam core
- Used vibration test LVI

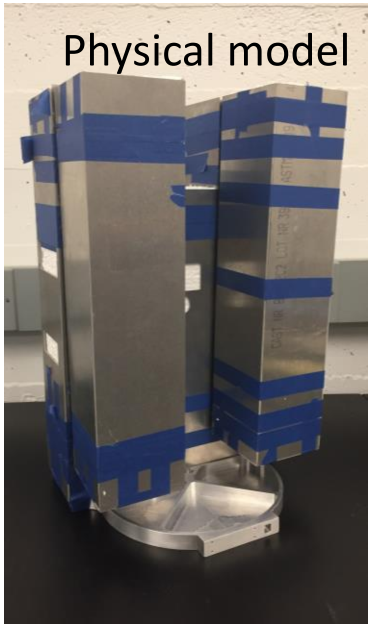
Ideal monopole antenna



CAD model



Physical model



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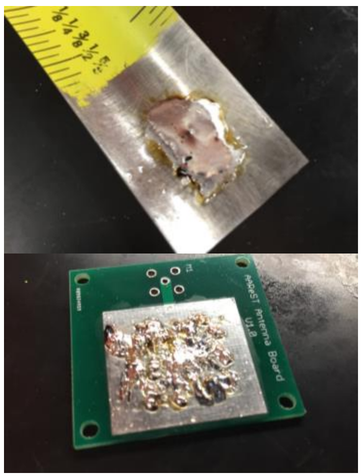
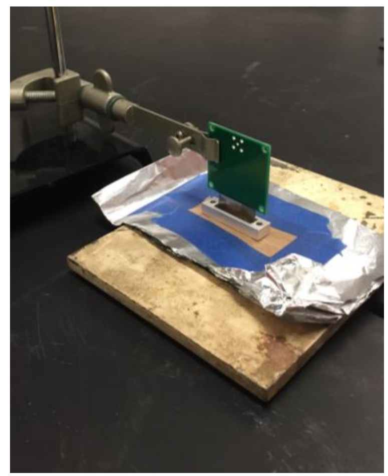
Antenna Fabrication

Objectives:

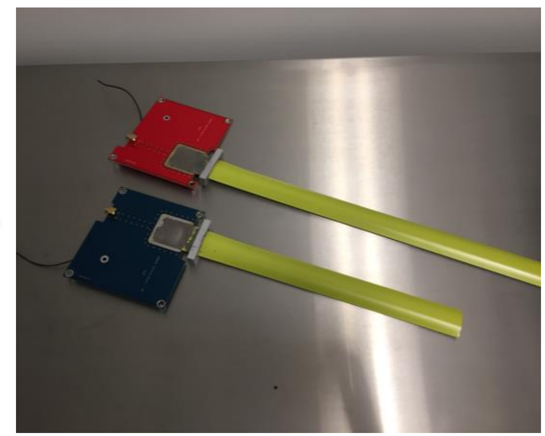
- Develop the antenna fabrication procedure
- Fabricate antenna assemblies for testing



Soldering



Potting



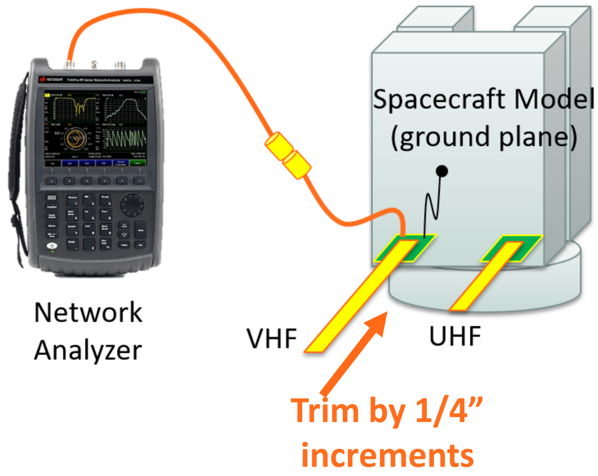
Finished Assembly

Results:

- Fabricated 6 antennas, including 2 flight-like antennas
- Iterated, refined, and documented fabrication procedure

Antenna Experiment Setup

Objective: Find the antenna length that minimizes s_{11} at the desired frequency

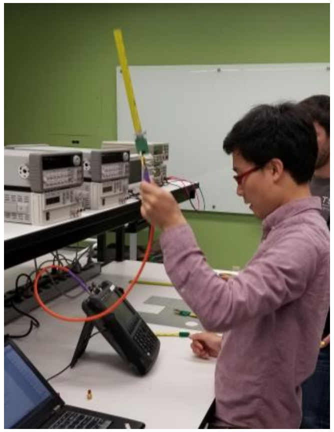


Procedure:

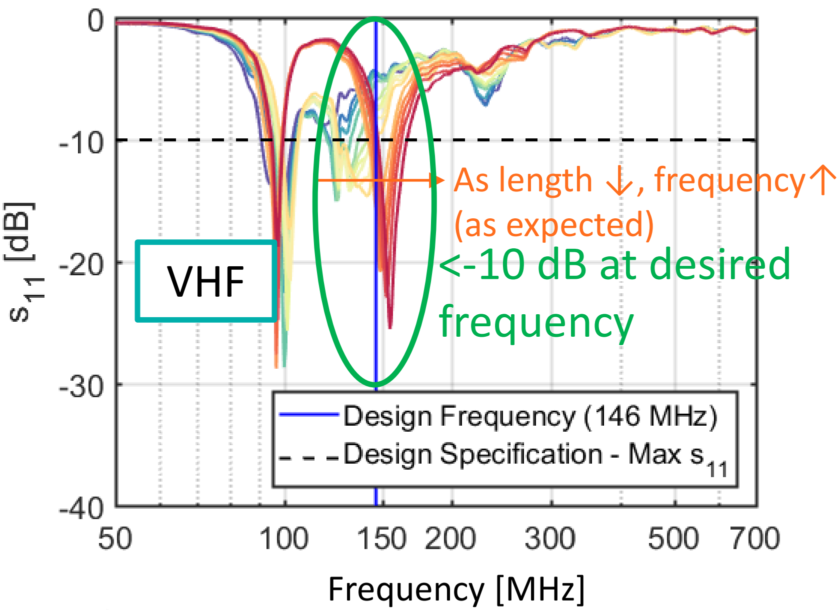
1. Calibrate the Network Analyzer (NA)
2. Measure s_{11} vs. frequency
3. Trim the antenna in ¼” increments
4. Repeat 2 and 3

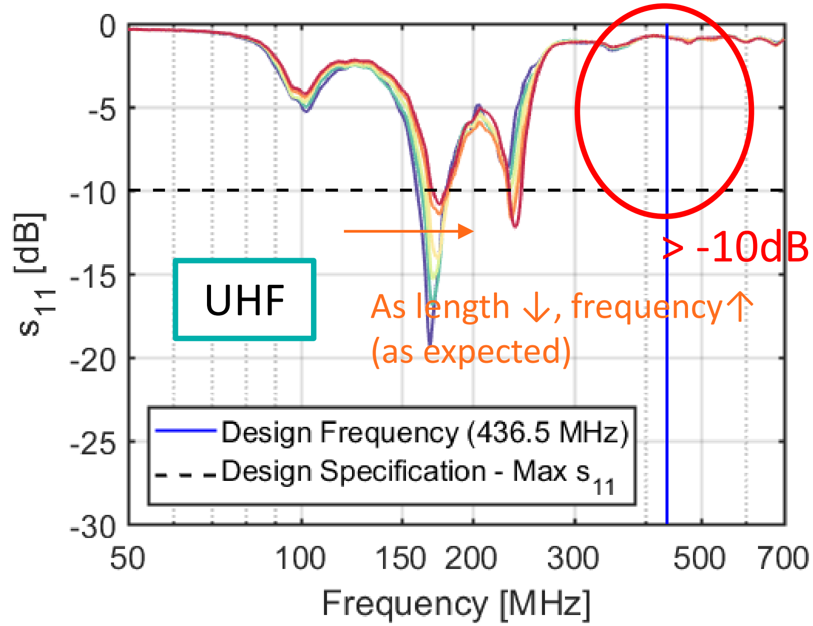
Experiment Parameters:

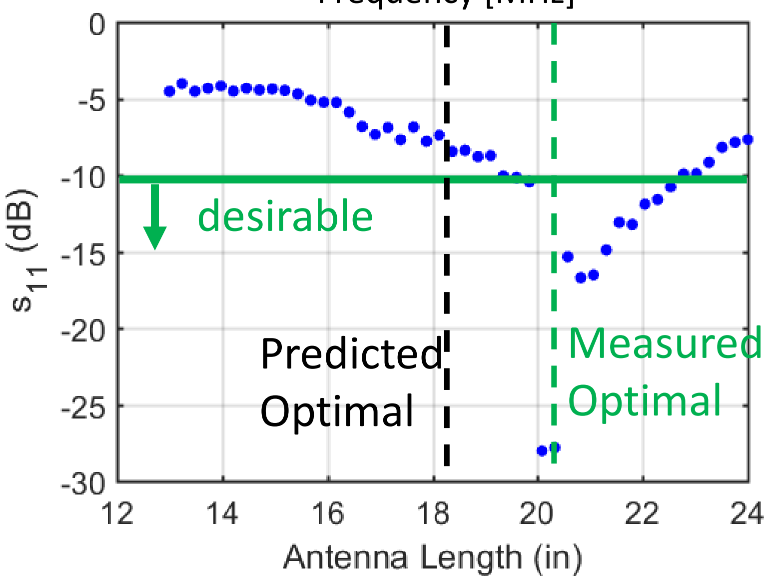
AAReST Comm Freq:	146MHz (VHF), 436.5 MHz (UHF)
Meas. Freq. Range:	50 – 700 MHz
Predicted Lengths:	18.1 in (VHF), 5.7 in (UHF)
Varied Length Range:	12.5-24 in (VHF), 6-10 in (UHF)



Antenna Experiment Results







Results:

- Experimentally determined the optimal VHF antenna length
- Observed expected trend for minimum s_{11} vs frequency
- Unexpected s_{11} values for UHF case → future task is troubleshooting

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Telecom Team Objectives

Antenna Responsibilities (Kai, Edward)

1. Perform sensitivity analysis via antenna simulation
2. Fabricate antenna assemblies
3. Fabricate EM-representative spacecraft model
4. Characterize antenna performance

➔ End goal: Test and validate the antenna design

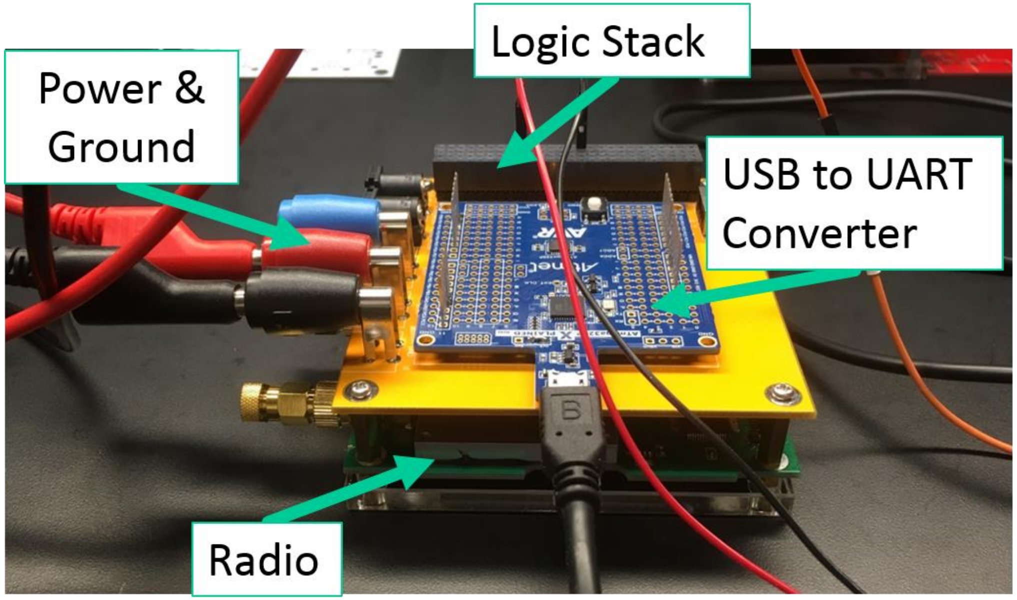
Radio Responsibilities (Conor)

1. Test radio commands
2. Configure the radio
3. Plan power tests

➔ End goal: Test and verify functionality of the radio

Radio Test Plan

1. Testing and configuration
   – Create program to send test commands
2. Power input
   – Measure voltage and current in receiving and transmitting operating modes
3. Power output
   – Measure RF output power



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4. Inrush current
5. Functional test with telecom system
   – Verify radio communication with mock ground station

Future Work

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Radio Commands for Testing

- Known commands and expected responses
- 15 total commands
  - 5 with no payload
  - 10 different payload sizes

0x1001	No-Op	-	0	No-op command. Increments command processing counter.
0x2001	No-Op Ack	-	0	No-op Acknowledge.
0x1002	Reset	-	0	Reset radio processors and systems.
0x2002	Reset Ack	-	0	Reset Acknowledge.
0x1003	Transmit	Bytes	N	Send n number of bytes to radio board.
0x2003	Transmit Ack	-	0	Transmit Acknowledge.
0x2004	Received Data	Bytes	N	Received n number of bytes AX.25 packet
0x1005	Get Transceiver Configuration	-	0	Read radio configuration.
0x2005	Transceiver Configuration	Configuration Structure [2]	N	Radio configuration structure.
0x1006	Set Transceiver Configuration	Configuration Structure	N	Set radio configuration.
0x2006	Set Transceiver Configuration Ack	-	0	Set radio configuration Acknowledge.
0x1007	Telemetry	-	0	Query a telemetry frame.
0x2007	Telemetry	Telemetry Structure	N	Telemetry frame.[3]
0x1008	Write Flash	16 Byte MD5	16	Write Flash with MD5 Checksum
0x2008	Write Flash Ack	-	0	Write Flash Acknowledge
0x1009	RF Configure	RF Structure	N	Low Level RF Configuration
0x2009	RF Configure Ack	-	0	RF Configuration Acknowledge
0x1010	Beacon Data	Bytes	N	Set Beacon Contents
0x2010	Beacon Data Ack	-	0	Ack Set Beacon Contents
0x1011	Beacon Configure	Beacon Structure	N	Set beacon configuration
0x2011	Beacon Conf. Ack	-	0	Ack Beacon Configuration
0x1012	Read Firmware Rev	-	0	Read radio firmware revision.
0x2012	Firmware Rev	Bytes	4	Firmware number, float 4 byte
0x1013	DIO Key Write	Bytes	16	DIO Key Write
0x2013	DIO Key Write Ack	-	0	Ack DIO Key Write
0x1014	Firmware Update	16 Byte MD5	16	Firmware Update Command
0x2014	Firmware Update Ack	-	0	Firmware Update Ack
0x1015	Firmware Packet	Bytes	TBD	Firmware Packet Write
0x2015	Firmware Packet Ack	-	0	Firmware Packet Ack
0x1020	Fast Set PA	Byte	1	Power Amplifier Level Set High Speed
0x2020	Fast Set PA Ack	-	0	Power Amplifier Set Ack

Radio commands and responses

Radio Commands for Testing

- Known commands and expected responses
- 15 total commands
  - 5 with no payload
  - 10 different payload sizes

0x1001	No-Op	-	0	No-op command. Increments command processing counter.
0x2001	No-Op Ack	-	0	No-op Acknowledge.
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0x1005	Get Transceiver Configuration	-	0	Read radio configuration.
0x2005	Transceiver Configuration	Configuration Structure [2]	N	Radio configuration structure.
0x1006	Set Transceiver Configuration	Configuration Structure	N	Set radio configuration.
0x2006	Set Transceiver	-	0	Set radio configuration Acknowledge

Generic message structure

Header (8 Bytes)	Payload (0 to 255 Bytes)	Payload Check Sum A (1 Byte)	Payload Check Sum B (1 Byte)

Figure 1--Packet structure for the Command and Data Interface (CDI).

Sync Characters (2 Bytes)	Command Type (2 Byte)	Payload Size (2 Bytes)	Header Check Sum A (1 Byte)	Header Check Sum B (1 Byte)

Figure 2--Description of the packet header used in the CDI.

Radio commands and responses

Radio Commands for Testing

- Known commands and

0x1001	No-Op	-	0	No-op command. Increments command processing counter.
0x2001	No-Op Ack	-	0	No-op Acknowledge.

"Set Configuration" message structure

```
uint_1 interface_baud_rate;   //Radio Interface Baud Rate (9600=0x00)
uint_1 tx_power_amp_level;    //Tx Power Amp level (min = 0x00 max = 0xFF)
uint_1 rx_rf_baud_rate;       //Radio RX RF Baud Rate (9600=0x00)
uint_1 tx_rf_baud_rate;       //Radio TX RF Baud Rate (9600=0x00)
uint_1 rx_modulation;         //(0x00 = GFSK);
uint_1 tx_modulation;         //(0x00 = GFSK);
uint_4 rx_freq;               //Channel Rx Frequency (ex: 45000000)
uint_4 tx_freq;               //Channel Tx Frequency (ex: 45000000)
unsigned char source[6];      //AX25 Mode Source Call Sign (default NOCALL)
unsigned char destination[6]; //AX25 Mode Destination Call Sign (default CQ)
uint_2 tx_preamble;           //AX25 Mode Tx Preamble Byte Length (0x00 = 20 flags)
uint_2 tx_postamble;          //AX25 Mode Tx Postamble Byte Length (0x00 = 20 flags)
uint_2 function_config;       //Radio Configuration Discrete Behaviors
uint_2 function_config2;      //Radio Configuration Discrete Behaviors #2
```

Radio commands and responses

Radio Interface Program

- Wrote interface program (MATLAB)
  - Enabled serial communication
  - Created user prompt
- Tested 8 important commands
  - Also tested external reset pin

```
%% Define preset list of commands, expected outputs
    %%% Define all possible commands (no checksums)
    commands(1,:)=[72; 101; 16; 2; 0; 0]; %'Reset'
    commands(2,:)=[72; 101; 16; 3; 0; 0]; %'Transmit' -need payload
    commands(3,:)=[72; 101; 16; 6; 0; 0]; %'Set Configuration' -need payload
    commands(4,:)=[72; 101; 16; 32; 0; 0];%'Fast Set PA' -need payload
    commands(5,:)=[72; 101; 16; 5; 0; 0]; %'Get Configuration'
    commands(6,:)=[72; 101; 16; 7; 0; 0]; %'Get Telemetry'
    commands(7,:)=[72; 101; 16; 16; 0; 0]; %'Set Beacon Data' -need payload
    commands(8,:)=[72; 101; 16; 17; 0; 0]; %'Set Beacon Configuration'-need payload
    commands(9,:)=[72; 101; 16; 1; 0; 0]; % 'No-Op'
    commands(10,:)=[72; 101; 16; 8; 0; 0]; %'Write Flash' -need payload
    commands(11,:)=[72; 101; 16; 9; 0; 0]; %'RF Configure' -need payload
    commands(12,:)=[72; 101; 16; 18; 0; 0]; %'Read firmware revision'
    commands(13,:)=[72; 101; 16; 19; 0; 0]; %'DIO Key Write' -need payload
    commands(14,:)=[72; 101; 16; 20; 0; 0]; %'Firmware Update' -need payload
    commands(15,:)=[72; 101; 16; 21; 0; 0]; %'Write Firmware Packet' -need payload
```

Command Window

```
Radio Test Comm Program:

(1)  Reset
(2)  Transmit
(3)  Set Transceiver Configuration
(4)  Fast Set Power Amplifier
(5)  Get Transceiver Configuration
(6)  Get Telemetry
(7)  Set Beacon data
(8)  Set Beacon Configuration
(9)  No-Op
(10)  Write Flash
(11)  RF Configure (RF Structure)
(12)  Read Firmware revision #
(13)  DIO Key Write
(14)  Firmware Update
(15)  Write Firmware Packet

fx Which command to send (1-15)?
```

Power Requirements

Capabilities:

- Radio can draw up to **16 W** and transmit up to **7 W**

Requirements:

- Power budget: **2 W input** for UHF transceiver allocated
- Link budget: 0.8 W RF output power
  - Requires ~2.5 W RF input power

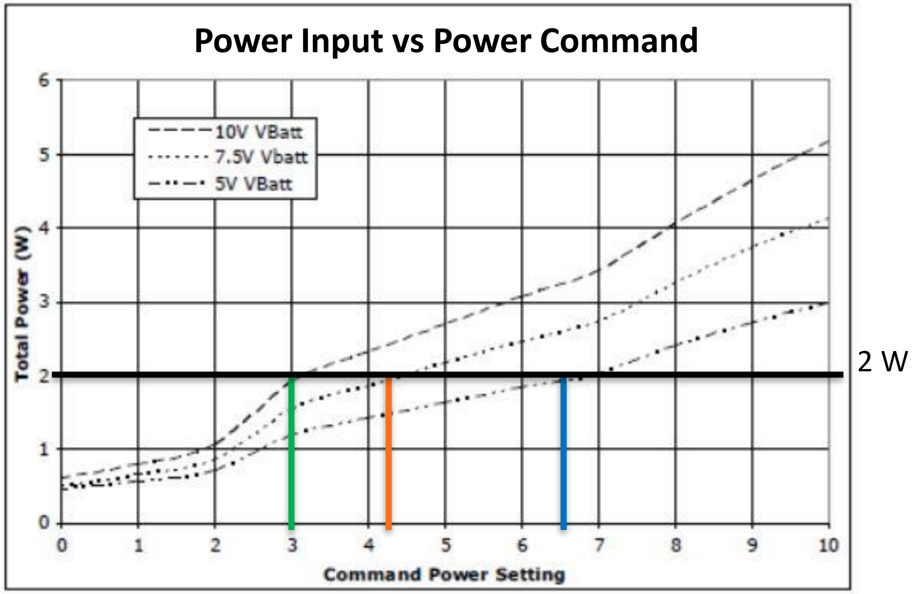

Figure 3 – Power Consumption vs. Power Setting.[2]

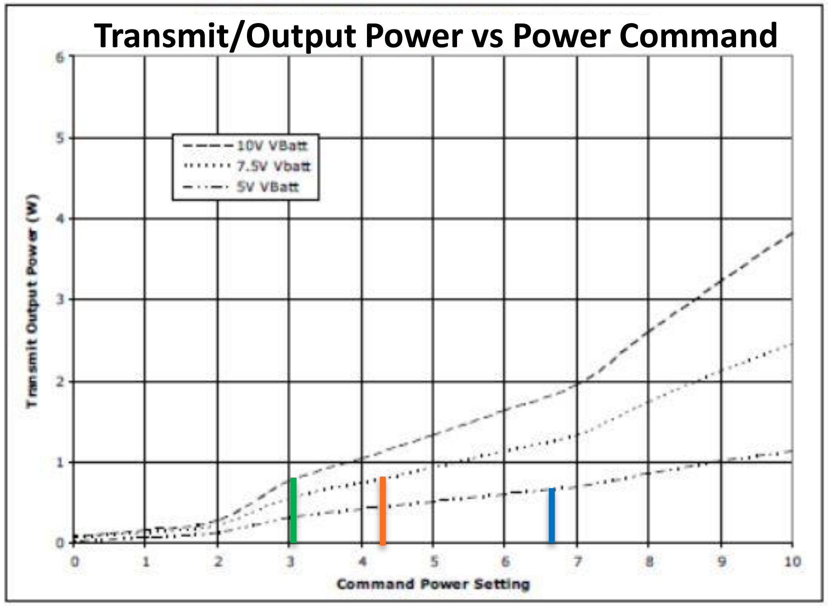

Figure 2 – Output Power vs. Power Setting.[2]

Representative plots for AstroDev radios

Power Requirements

Capabilities:

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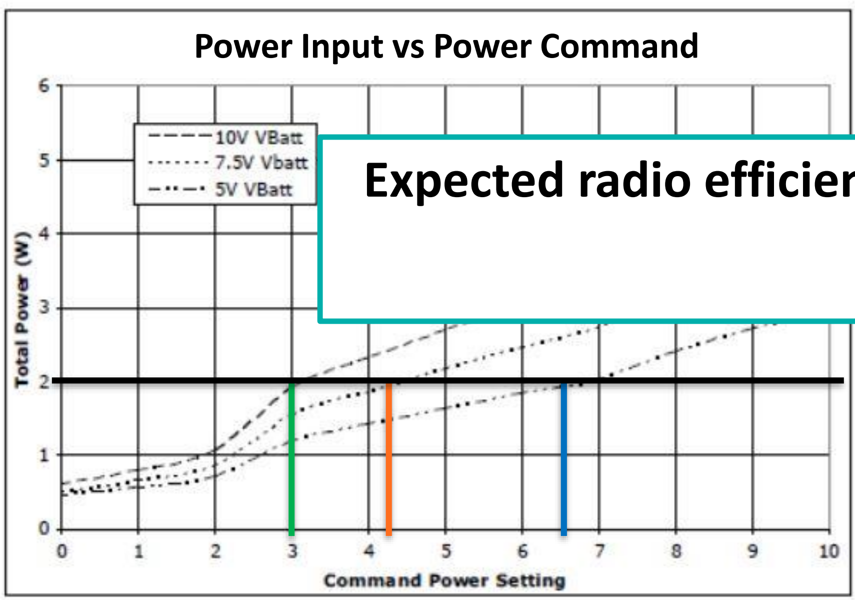


Figure 3 – Power Consumption vs. Power Setting.[2]

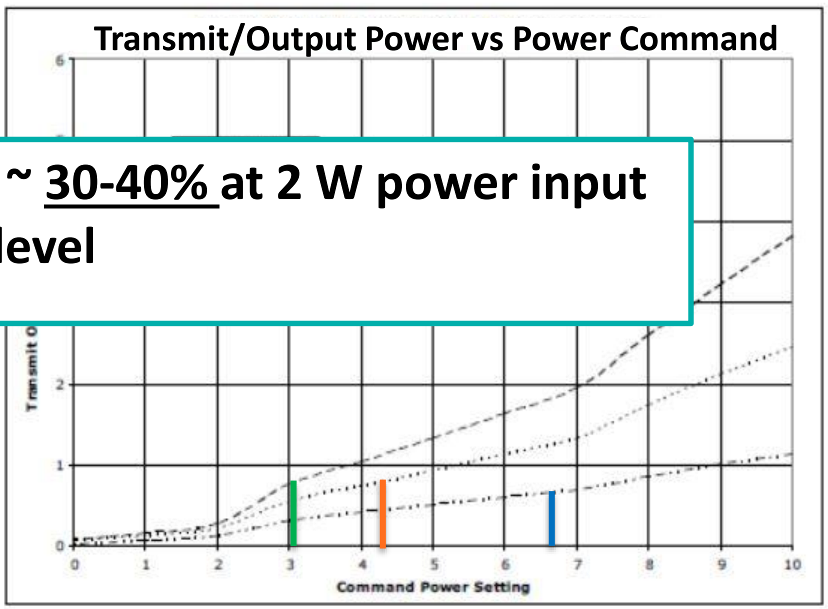


Figure 2 – Output Power vs. Power Setting.[2]

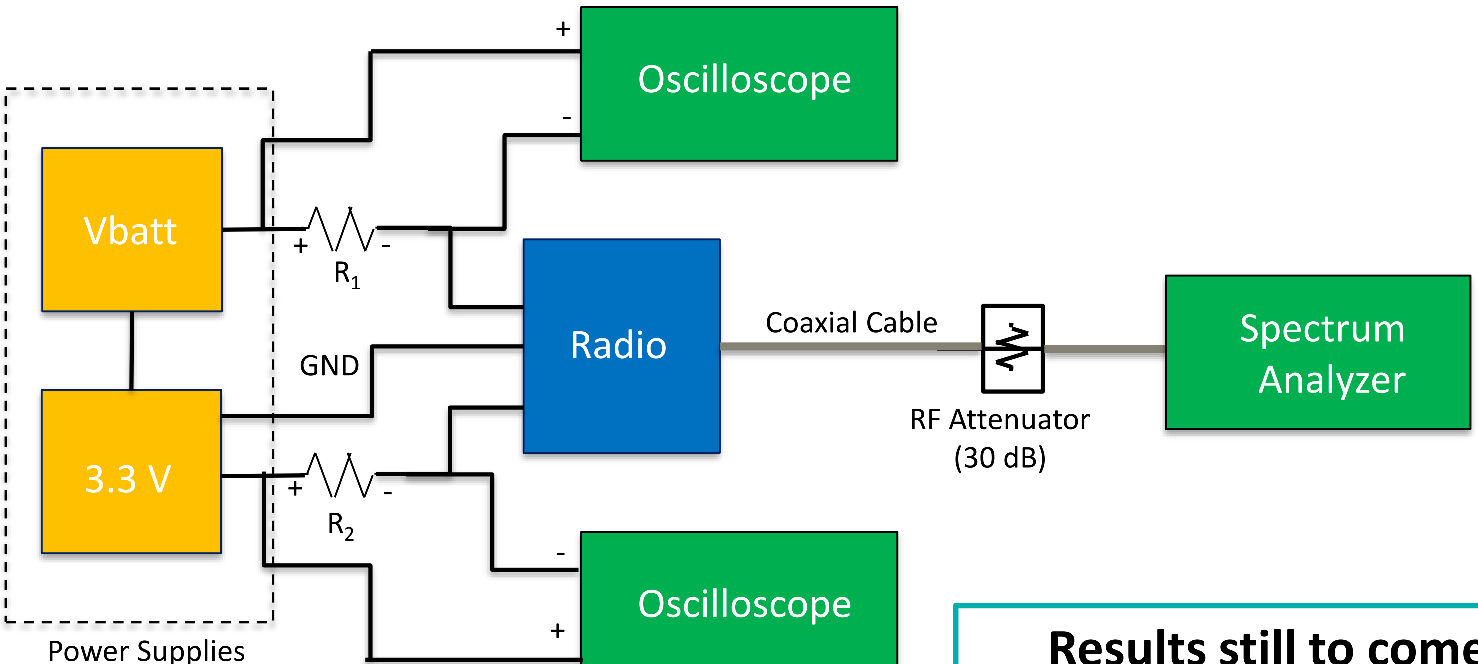
Expected radio efficiency ~ <u>30-40%</u> at 2 W power input level

Representative plots for AstroDev radios

Radio Power Test Setup

Simultaneous input and output power test

- Measure output power with spectrum analyzer
- Measure input power with shunt resistors: R_1 and R_2



Results still to come!

Conclusions

Antenna:

- Fabricated antennas and improved fabrication procedure
- Delivered EM-representative spacecraft model
- Performed preliminary antenna tests
  - Partially confirmed the simulation results

Radio:

- Created interface program for serial radio communication
  - Verified functionality of relevant commands
- Evaluated power requirements
- Developed power test plan
  - Purchased components (attenuators, shunt resistors)

Future Work

Antenna:

- Identify why UHF antenna has unexpected s_{11}
- Measure s_{11} parameter with different spacecraft configurations (e.g. wide configuration)

Radio:

- Conduct radio power tests
- Complete telecom system functional test
  - Simulate ground station
  - Send and receive signals to radio via RF

Questions?

Avionics

Kira Headrick
Daniel Jamison
Lewis Jones
Zoey Flynn
Thibaud Talon
Ashish Goel

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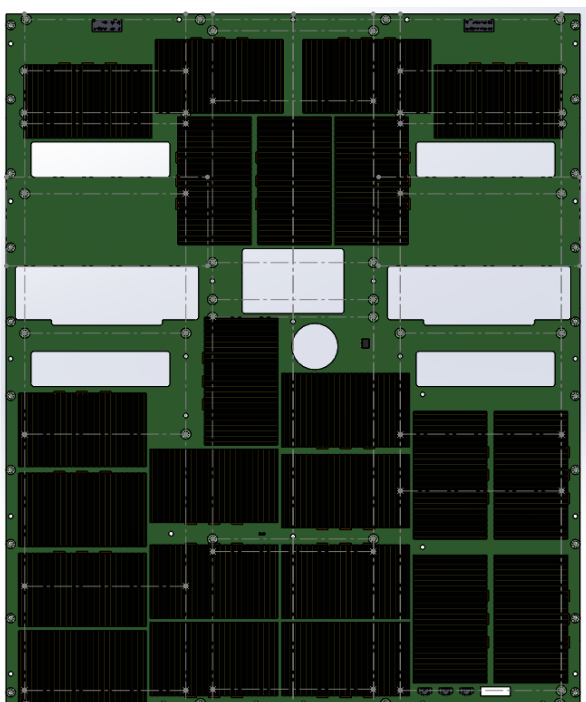
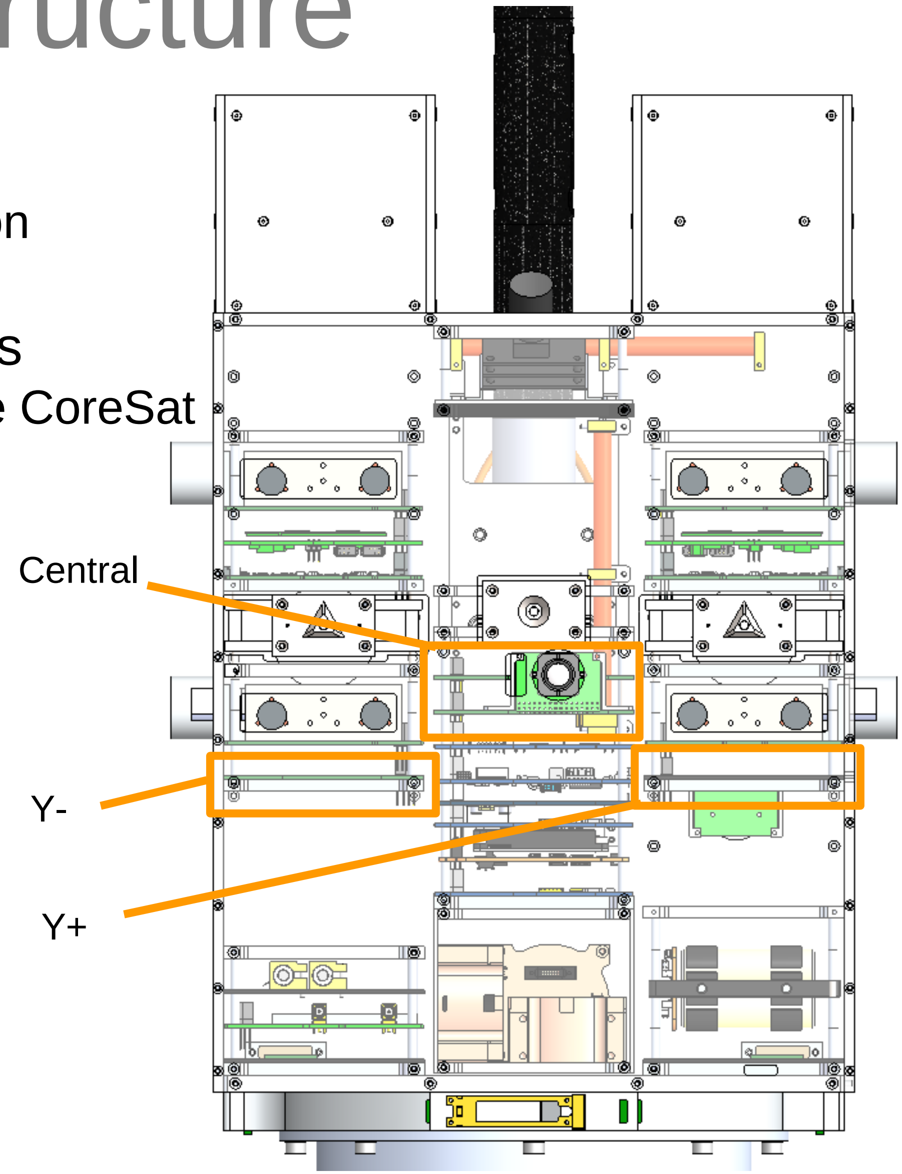
Team Structure

- Kira - Solar panels
  - Generate power from solar radiation
- Lewis, Dan, Zoey - Interface boards
  - Route power and signals within the CoreSat





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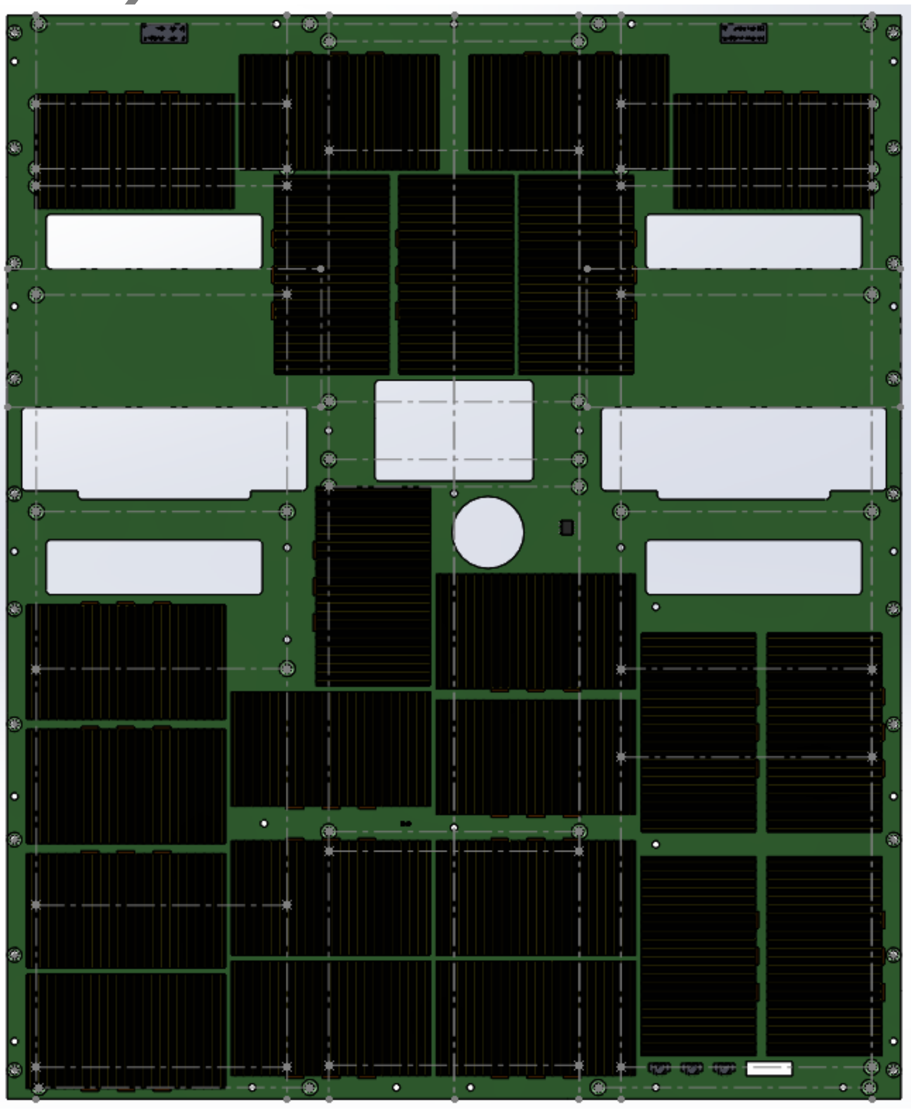
Solar Panel (SP) Overview

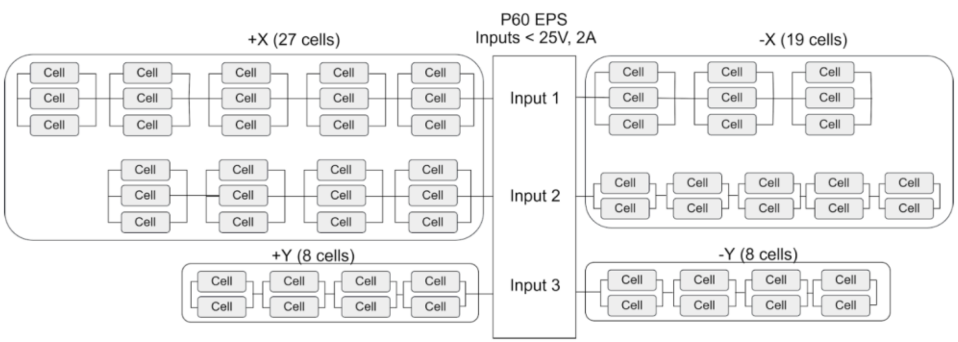
- Solar Panel Responsibilities
- Cell Placement
- PCB Wiring
- Conclusion



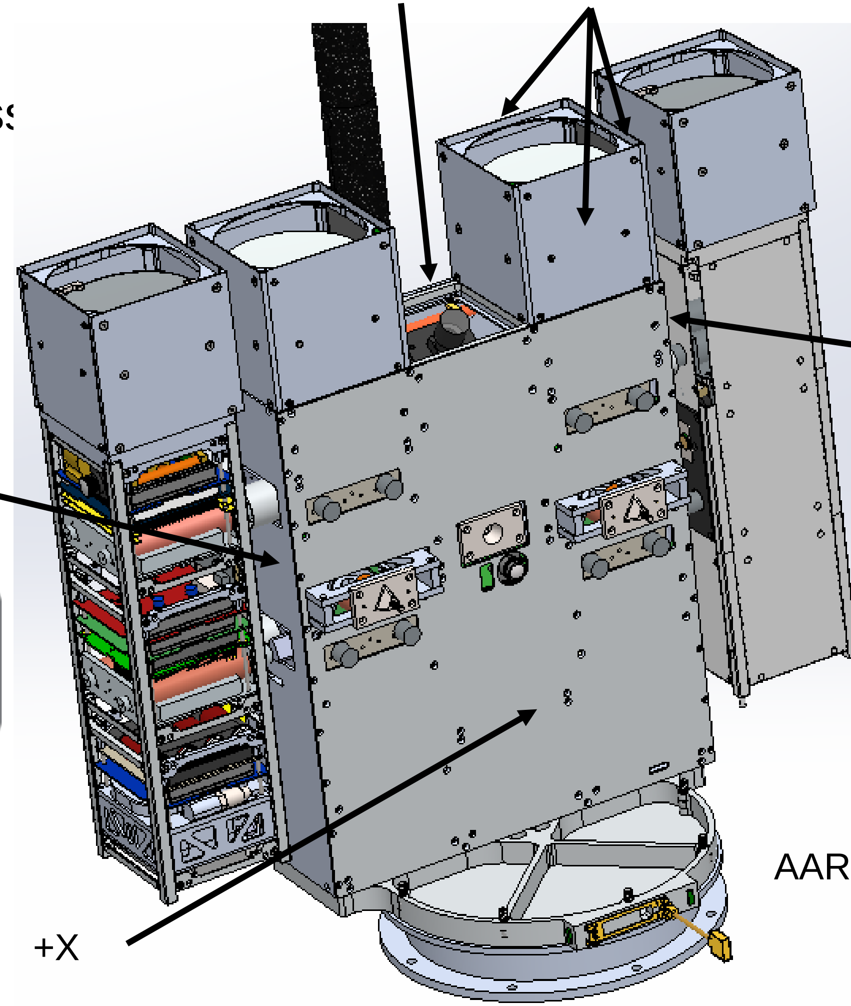
+X Face

SP Responsibilities

- Solar Cell Placement
  - Fit as many solar panels as poss
  - Finalize PCB design
- PCB Wiring
  - Create wiring architecture
  - Create PCB in Eagle

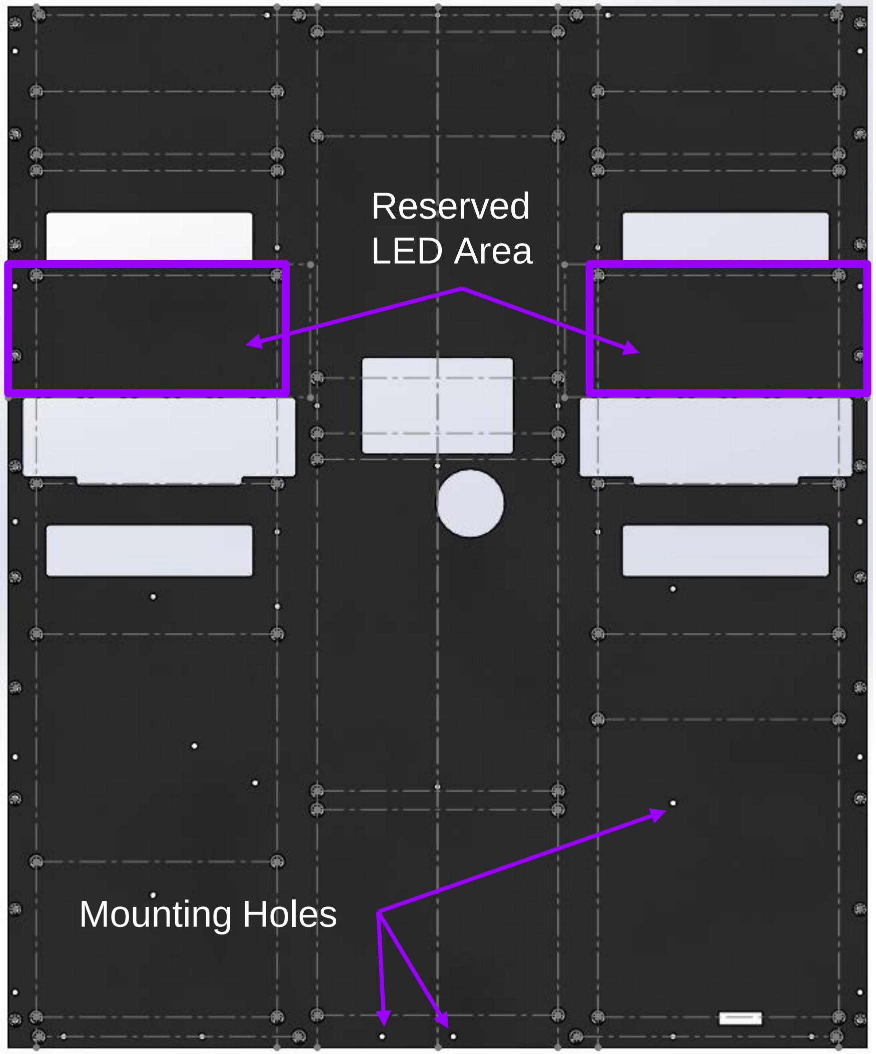


Cell Wiring Diagram (last year)



SP Work: Overview

- Place solar cells
  - Majority of work
  - Changes made on rolling basis
- Place additional components
  - Temp. sensor
  - Sun sensor
  - Connectors
  - Access holes
  - Mounting screws
- Holes for mounting PCB to coresat
  - Number, Clearance
- Avoid reserved areas
- Match number of cells from last year
  - Revisit power consumption studies



+X Face

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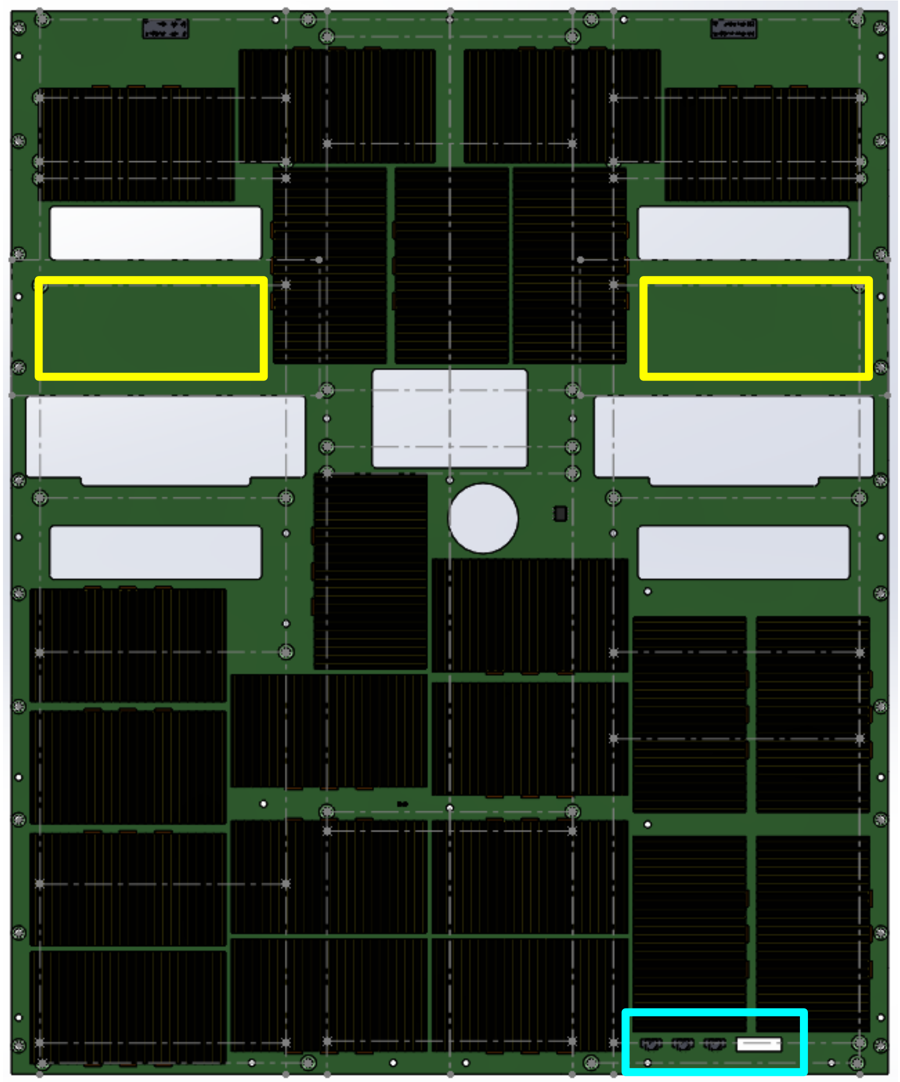
SP Work: +X

- Solar cells: 23

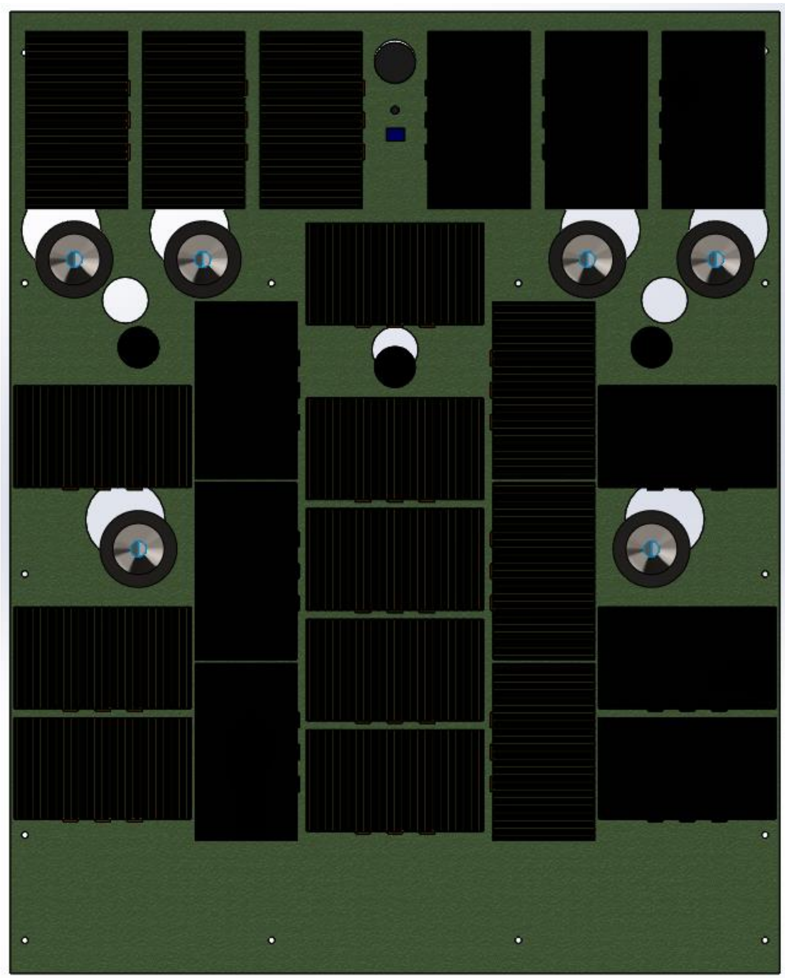
Challenges

- Placement of additional components prevented horizontal symmetry
- Reserved Area for LEDS

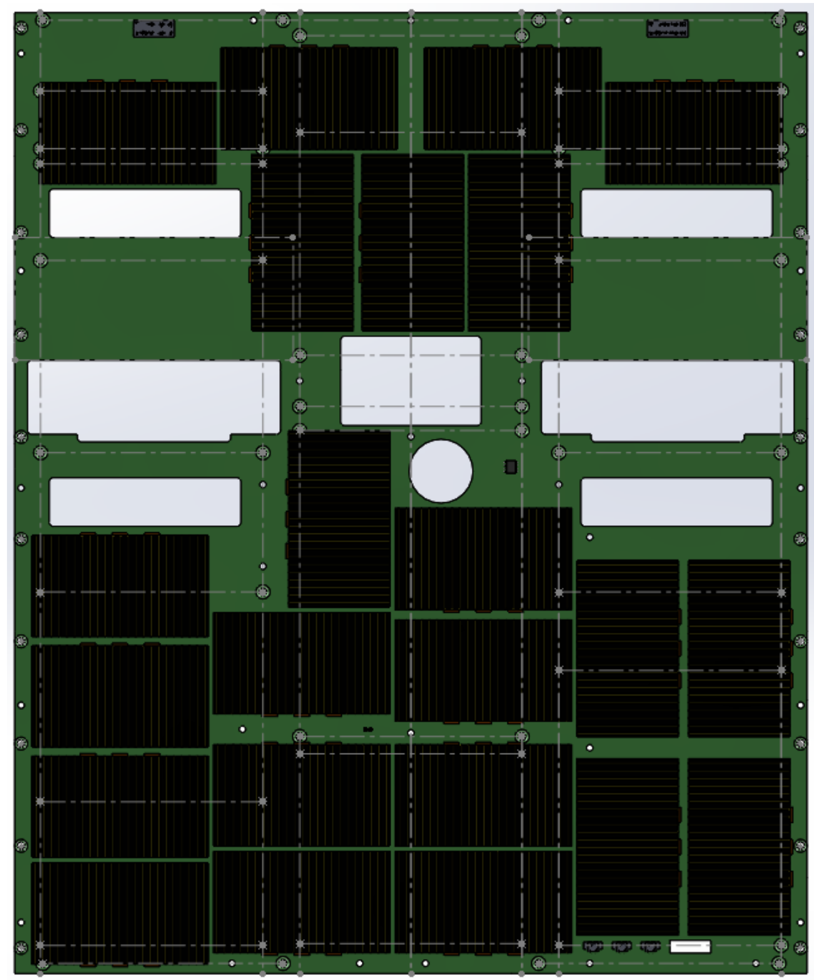


SP Work: +X

Last Year (23 cells)



Current (23 cells)

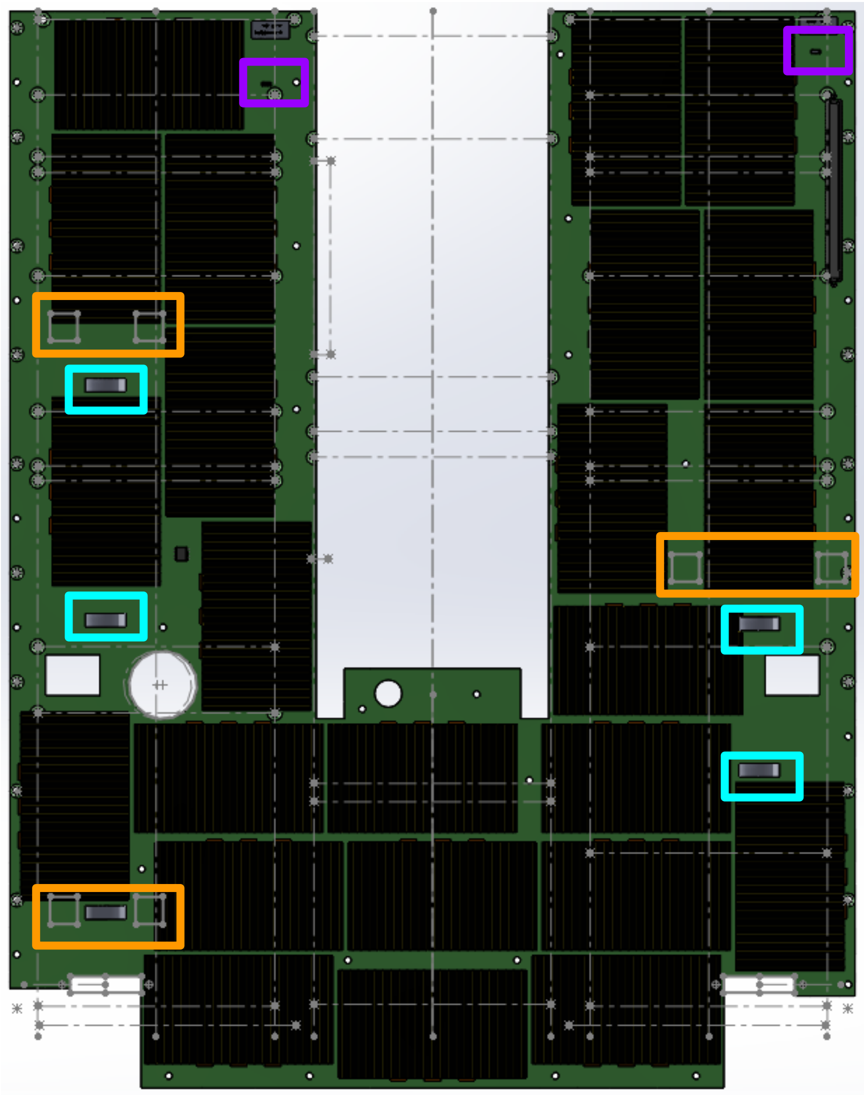


SP Work: -X

- Solar cells: 24
  - Primary power generating face
  - 1 more cell than last year

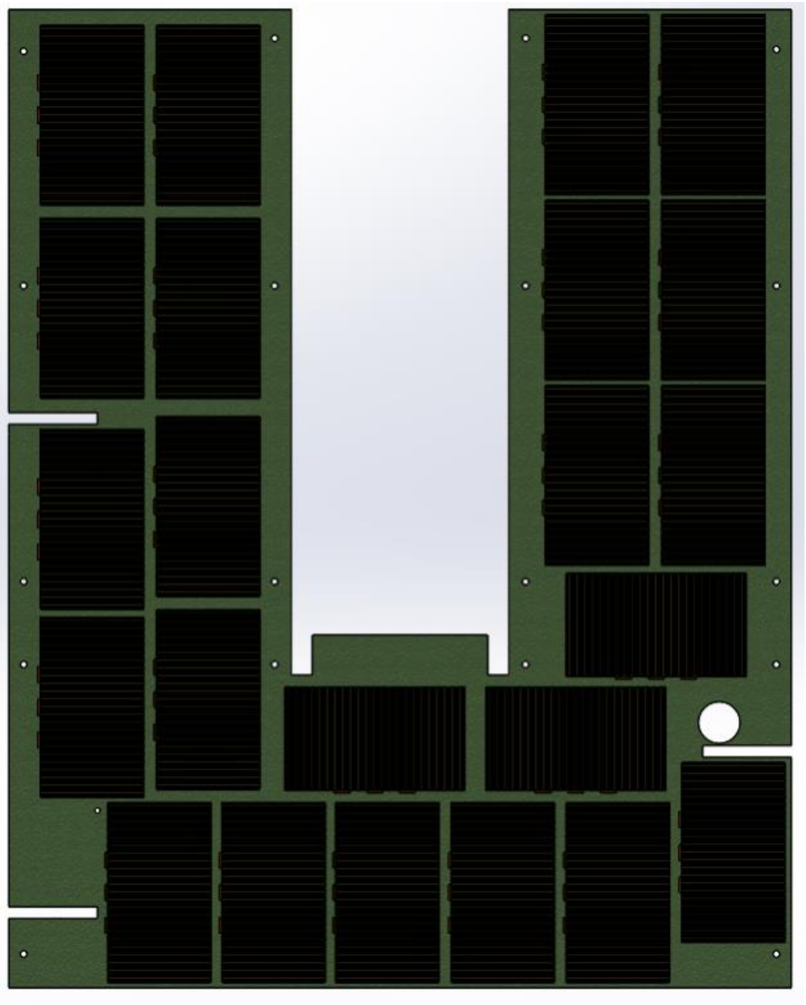
Challenges

- Placement of additional components
  - Cannot overlap with solar cells
  - Spacers for antenna
  - Burn wire screws
- Coarse sun sensors moved
  - Greater field of view for ADCS

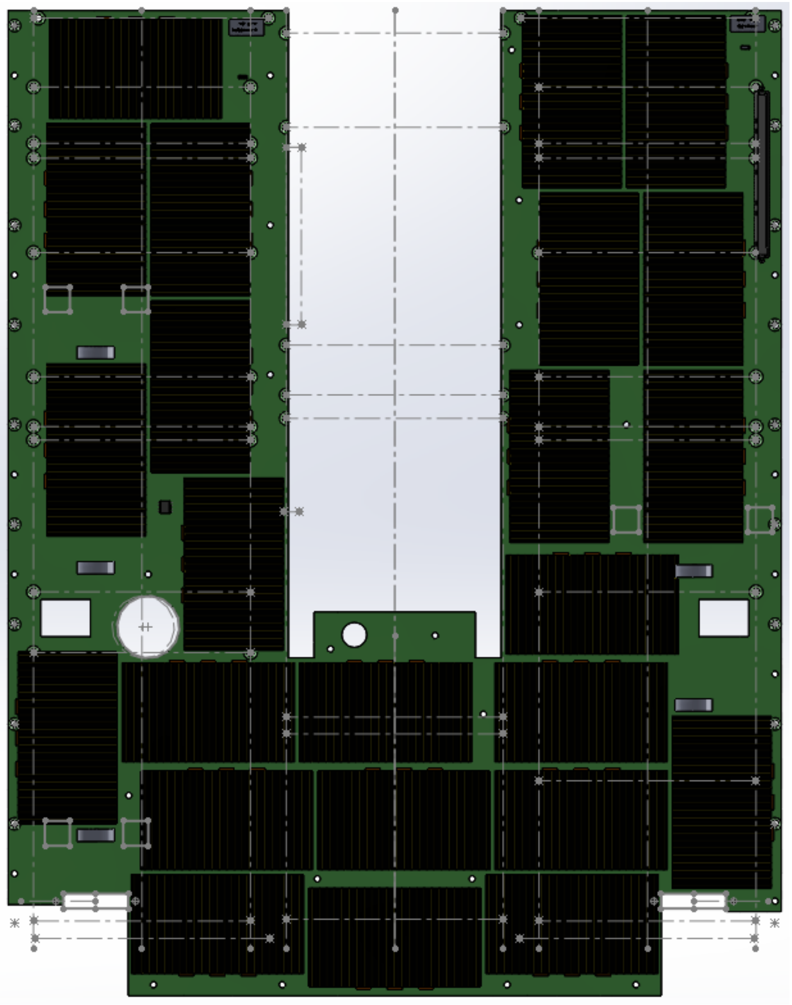


SP Work: -X

Last Year (23 cells)



Current (24 cells)

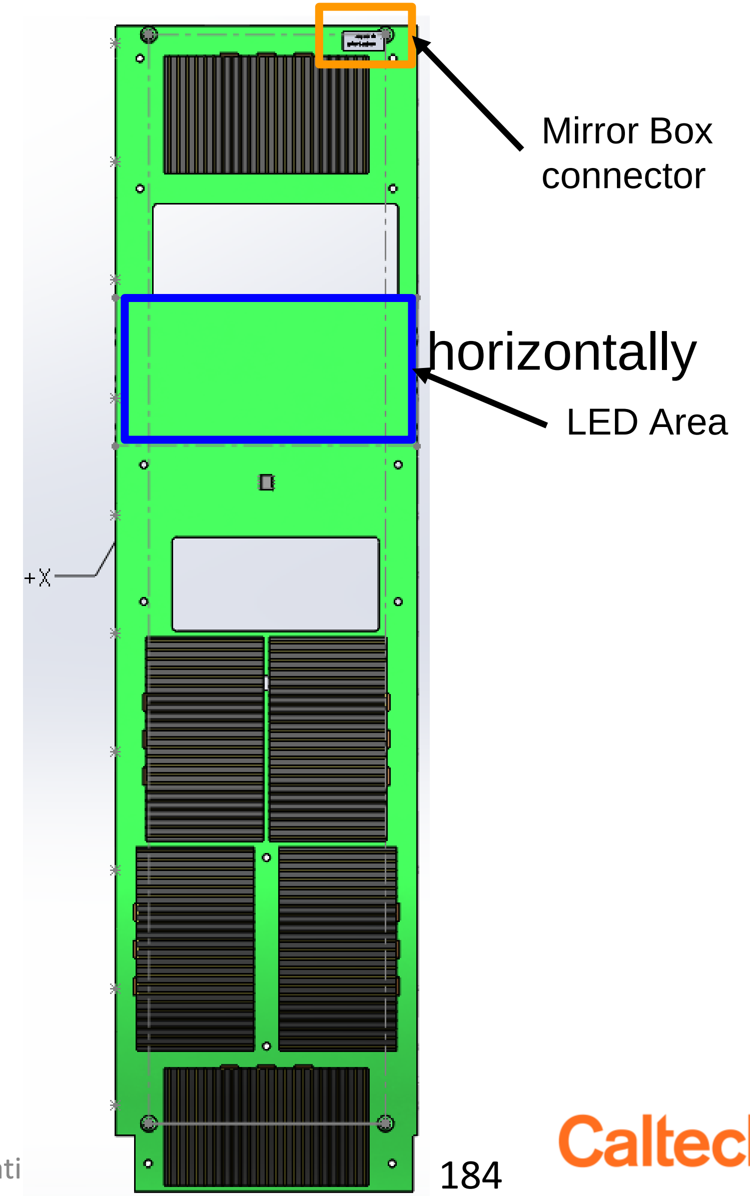


SP Work: +/-Y

- Solar cells: 6

Challenges

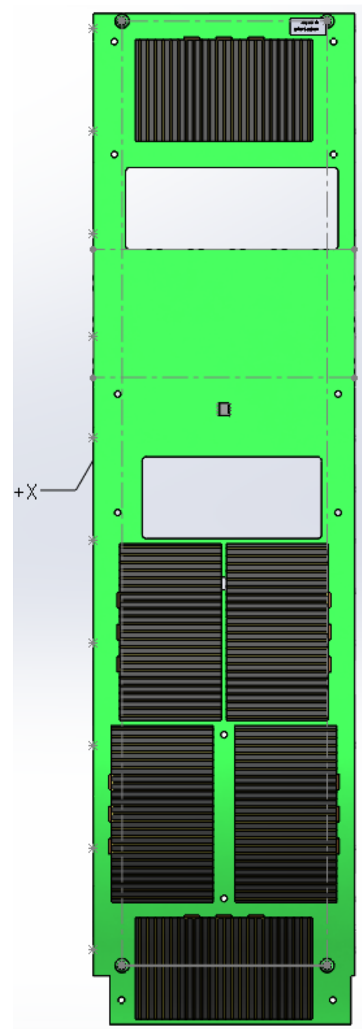
- Reserved area for LEDs
- Mirror Box connector placed horizontally
  - Prevent line twisting



SP Work: +/-Y

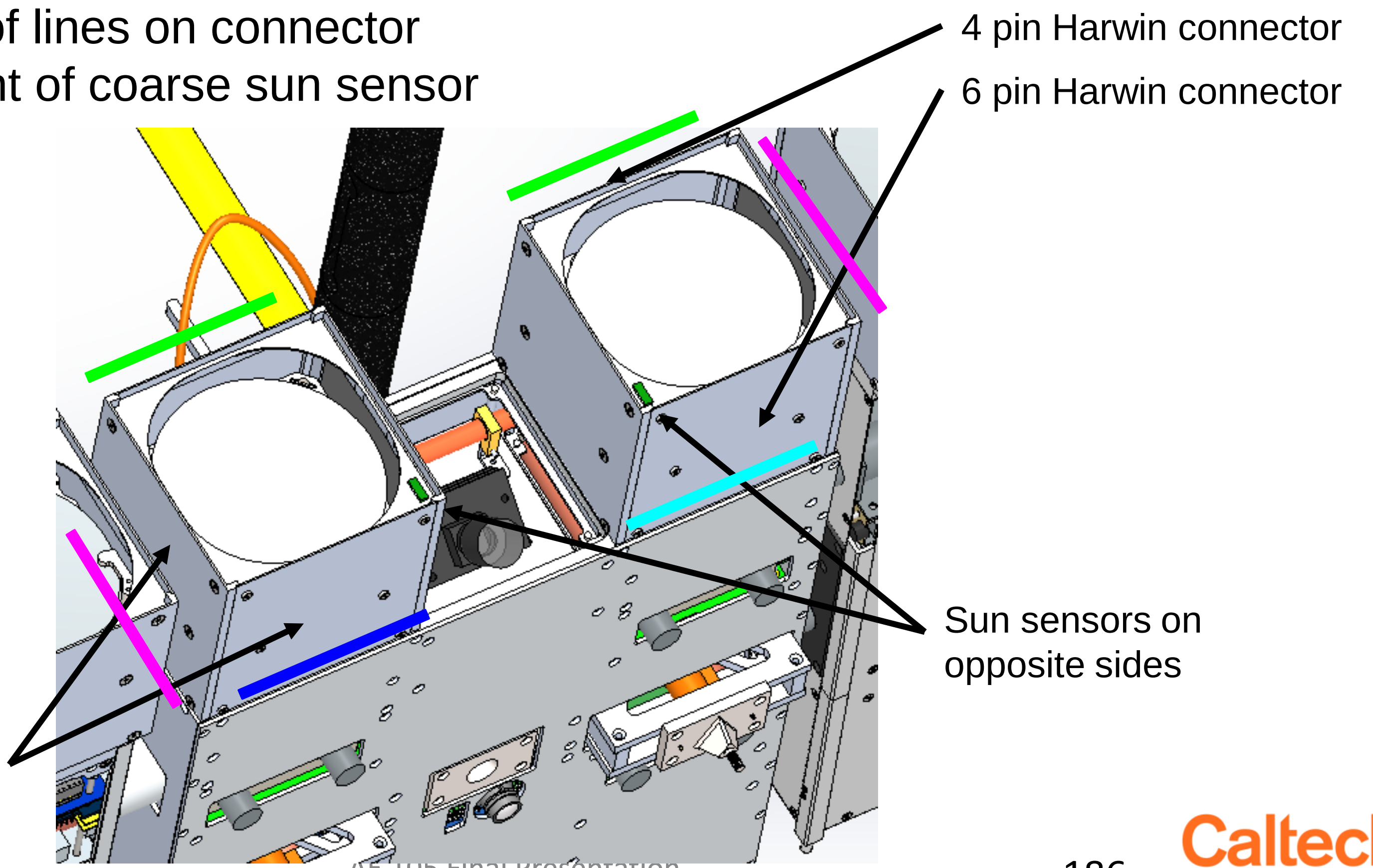
Last Year (6 cells)

Current (6 cells)



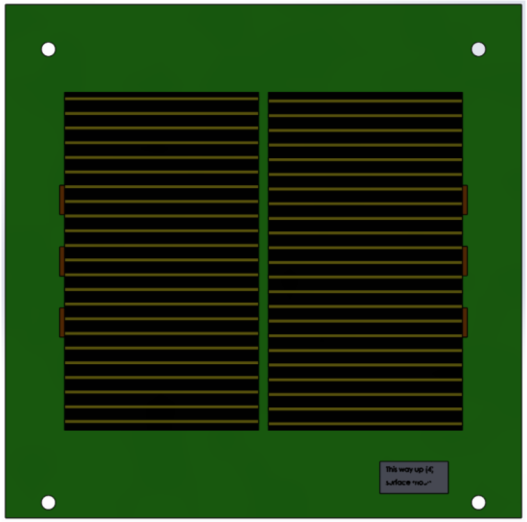
SP Work: Mirror Box

- Solar cells: 2
- 4 styles of mirror box PCB:
- Due to changes in
  - Screw size
  - Number of lines on connector
  - Placement of coarse sun sensor

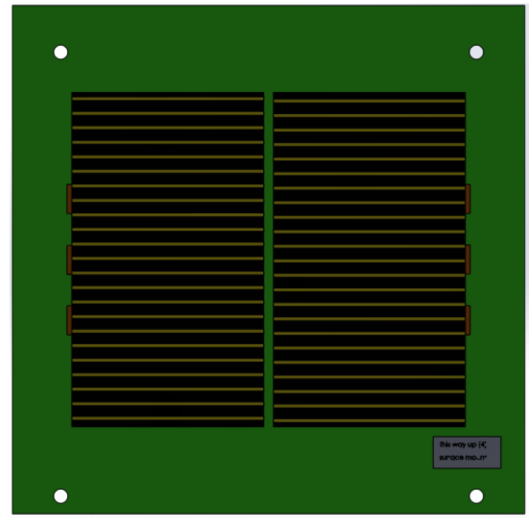


SP Work: Mirror Box

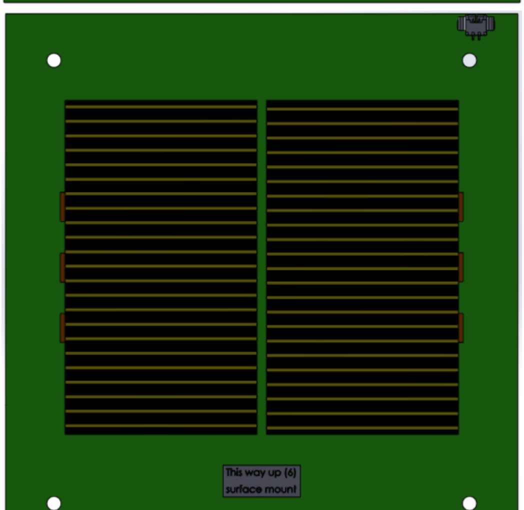
- 4 styles of Mirror Box PCB



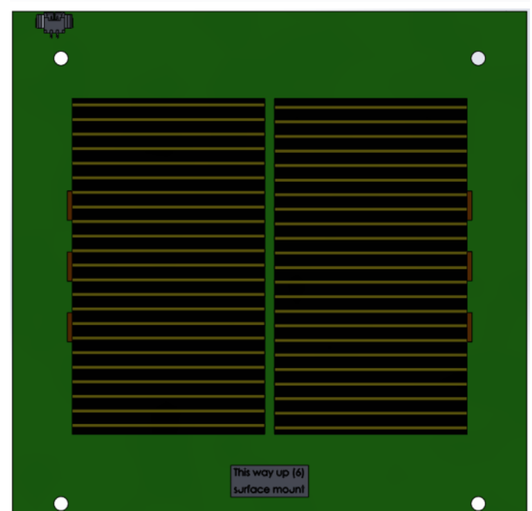
MB on Y Faces



MB on X- Face



MB on X+ Face
Left Side



MB on X+ Face
Right Side

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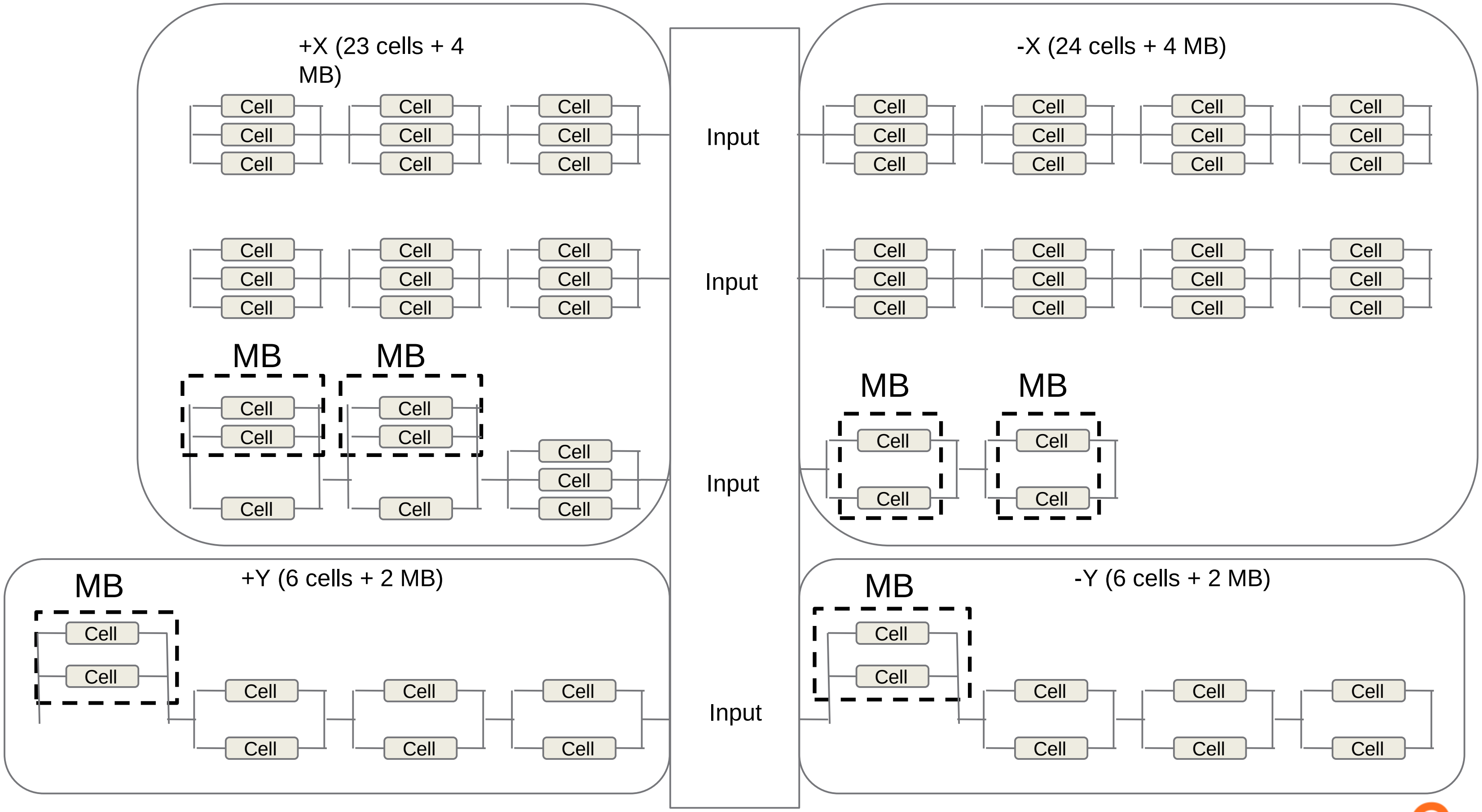
Cell Wiring Diagram

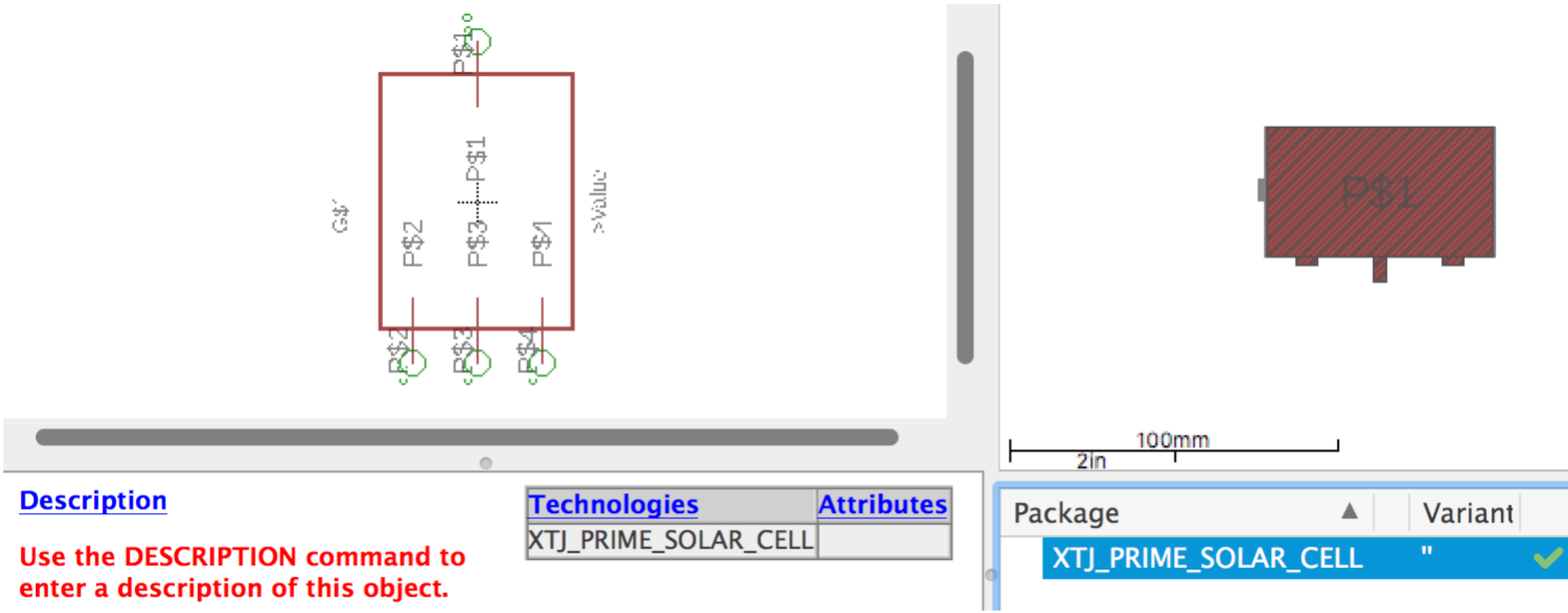
- Per cell: 2.7V, 0.5A
- Per input channel: 16V, 2A
- Combine +/-X and +/- Y channels for geometric reasons



Caltech

Eagle: Solar Cell Component

- Eagle: Software to make PCBs
- No physical datasheet for Solar Cell
  - Cell measured to create component

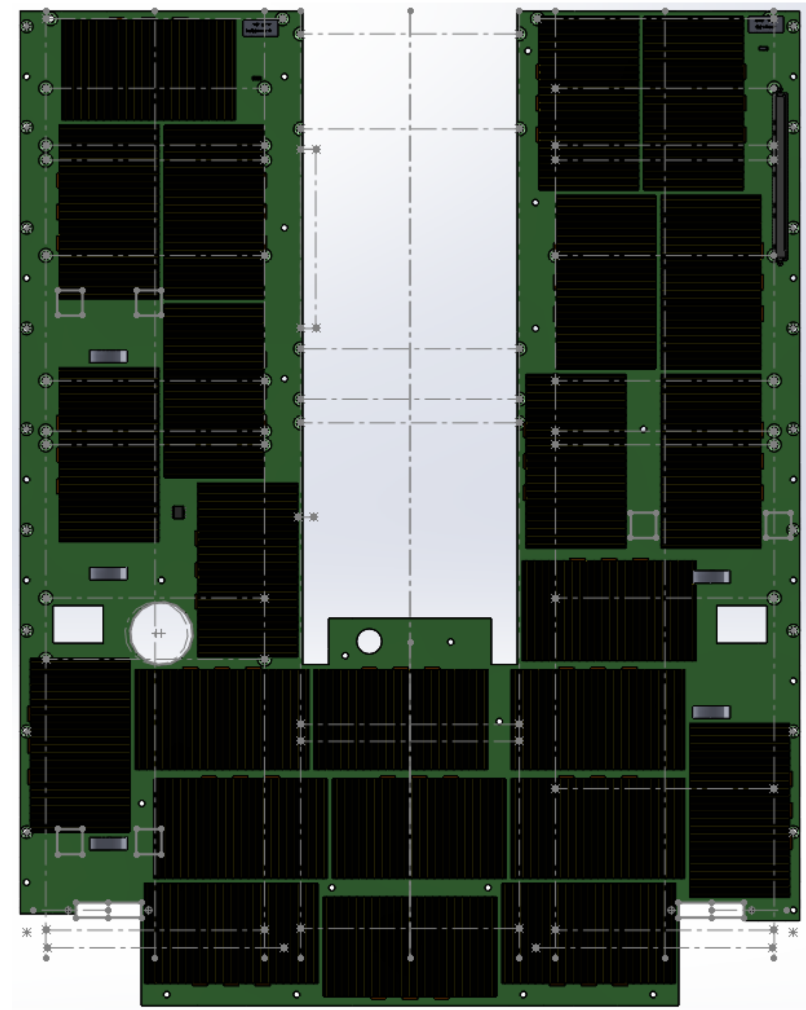


Caltech

SP Conclusion & Future Work

- Solar Cell PCBs
  - Sufficient number of cells per face
  - Primary power face (-X) has one more cell than last year
- Wiring (Eagle)
  - PCB wiring architected
  - Component libraries created
- Future Work
  - Wire PCBs in Eagle

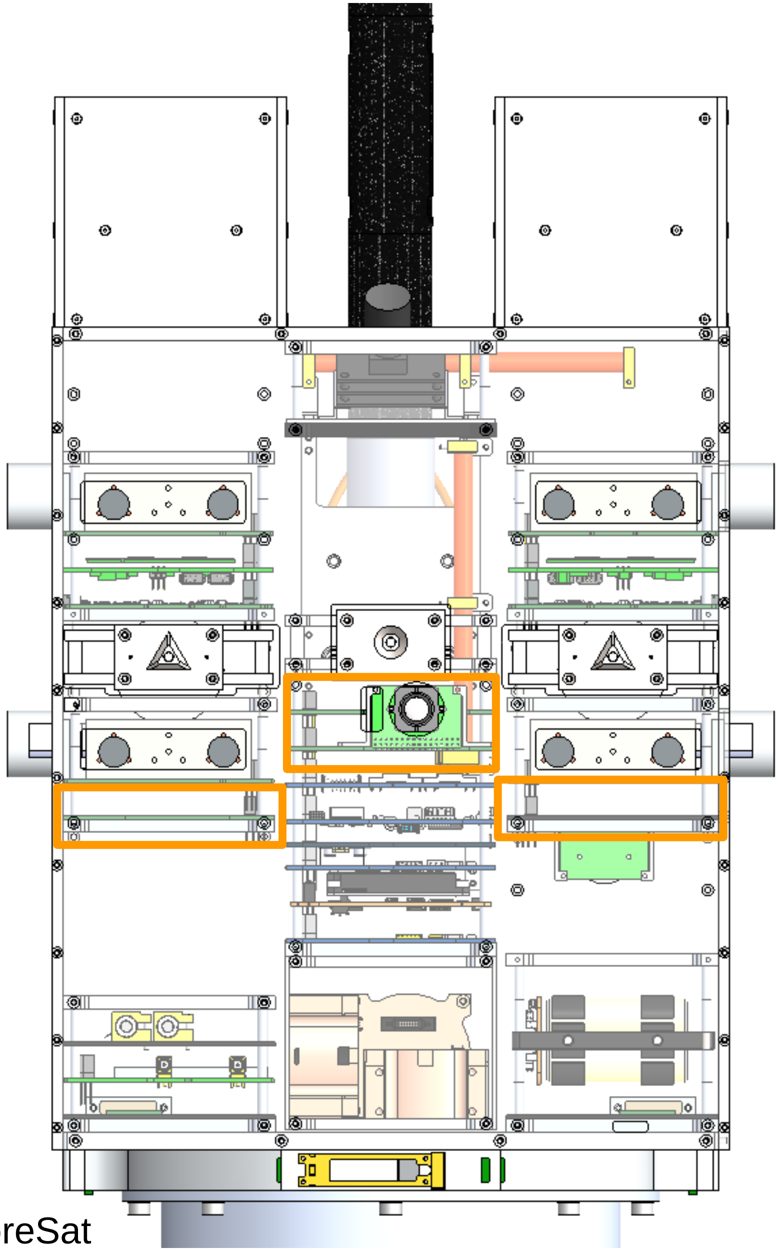
6 Pin Harwin Connector in Eagle



-X Face

Interface Boards

- Project Overview and Progress
- Y+ Interface Board
- Development Process
- Central Interface Board
- Flight Preparation Panel
- Y- Interface Board
- Conclusion



CoreSat

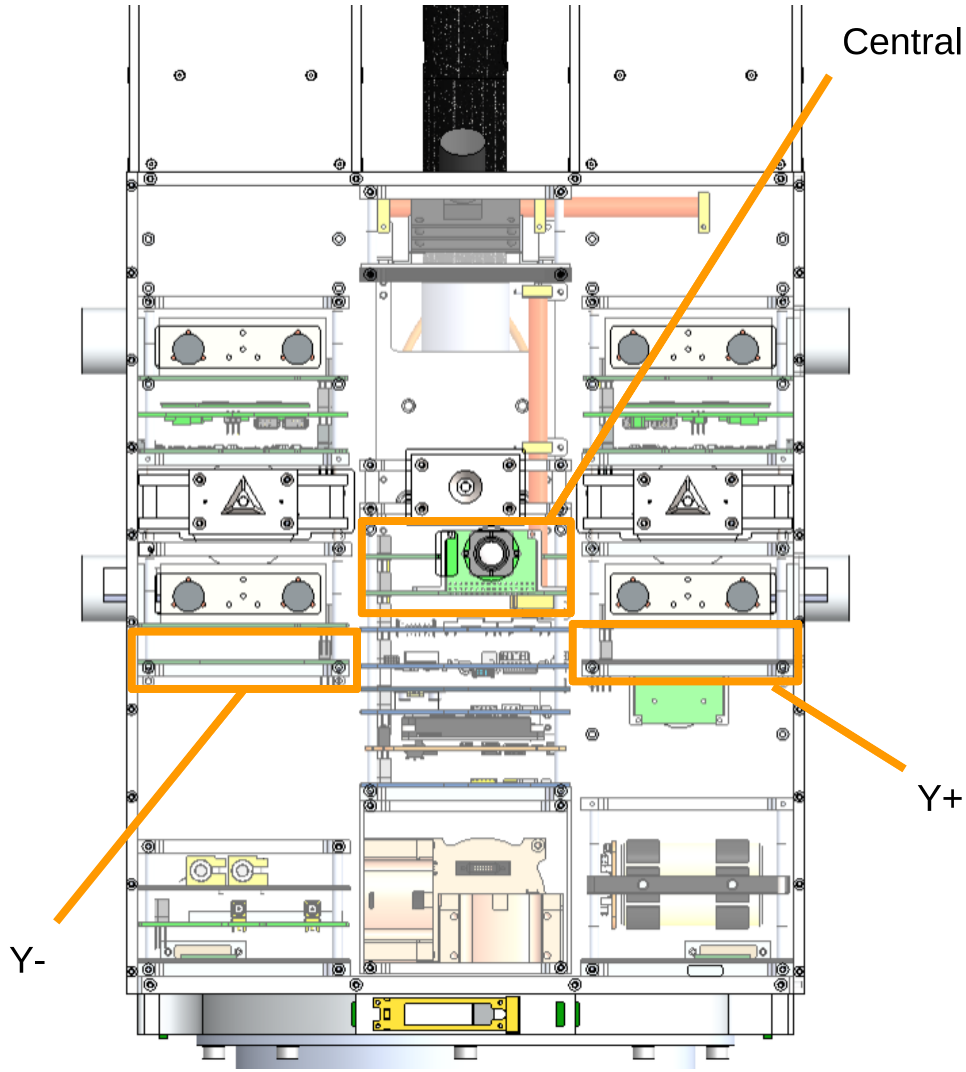
Interface Boards Overview

Objectives:

- Design, manufacture, and test four separate interface boards: Y-, Y+, and two Central

Interface Board Responsibilities:

- Routes connections
  - Solar panels power
  - Sensor signals
  - Power, ground
  - I2C, UART, CAN
  - Payload
  - Radio
- Provide Switching
  - Frangibolts
  - Burn wires
  - Inter-satellite power link
  - Power lines
- Provide voltage conversion
- Analog-digital conversion
  - Temperature sensors



CoreSat (View from X+ Face)

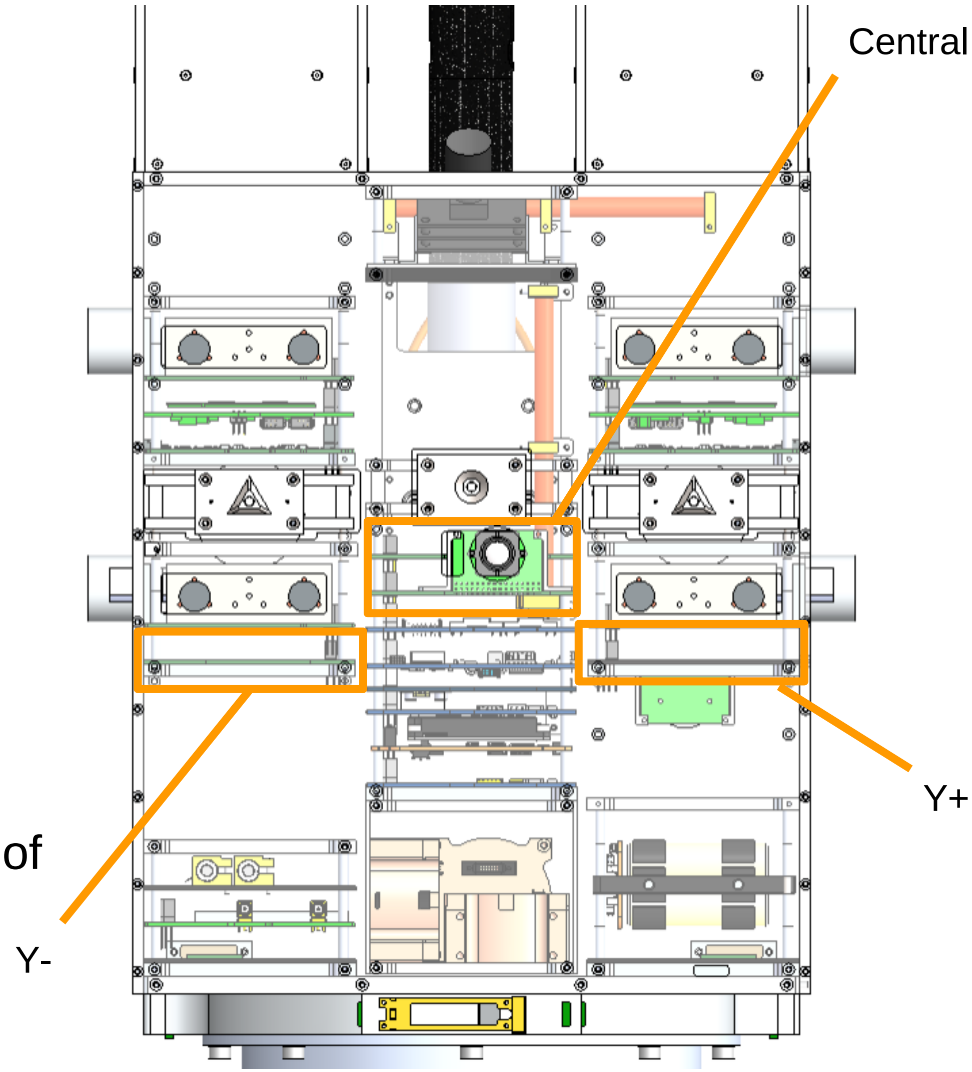
Interface Boards Progress

Completed:

- Routing diagrams
- Connector/component selection
- Schematics
- Layouts
- Hardware assembly for some boards

Current Status:

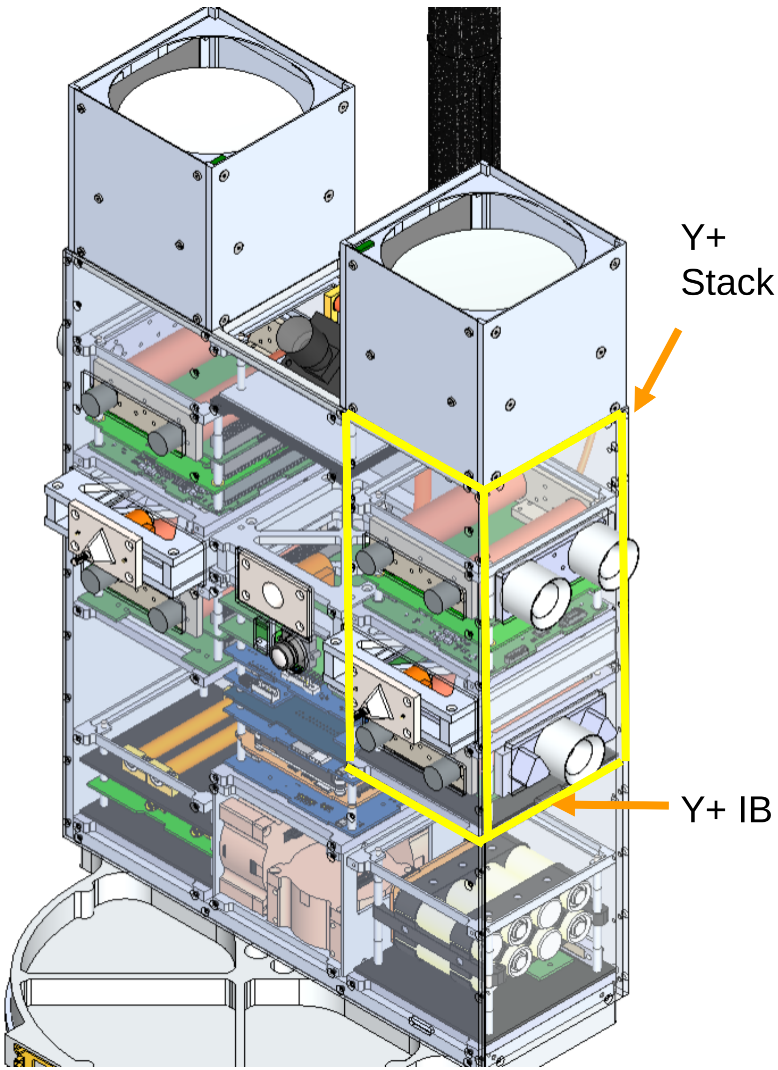
- Y+ Interface Board Assembled
- Central Interface Boards Being Assembled
- Y- Interface Board In Final Stages of Layout



CoreSat (View from X+ Face)

Caltech

Y+ Interface Board



CoreSat (X+ and Y+ Faces)

Y+ Interface Board Responsibilities:

Routing:

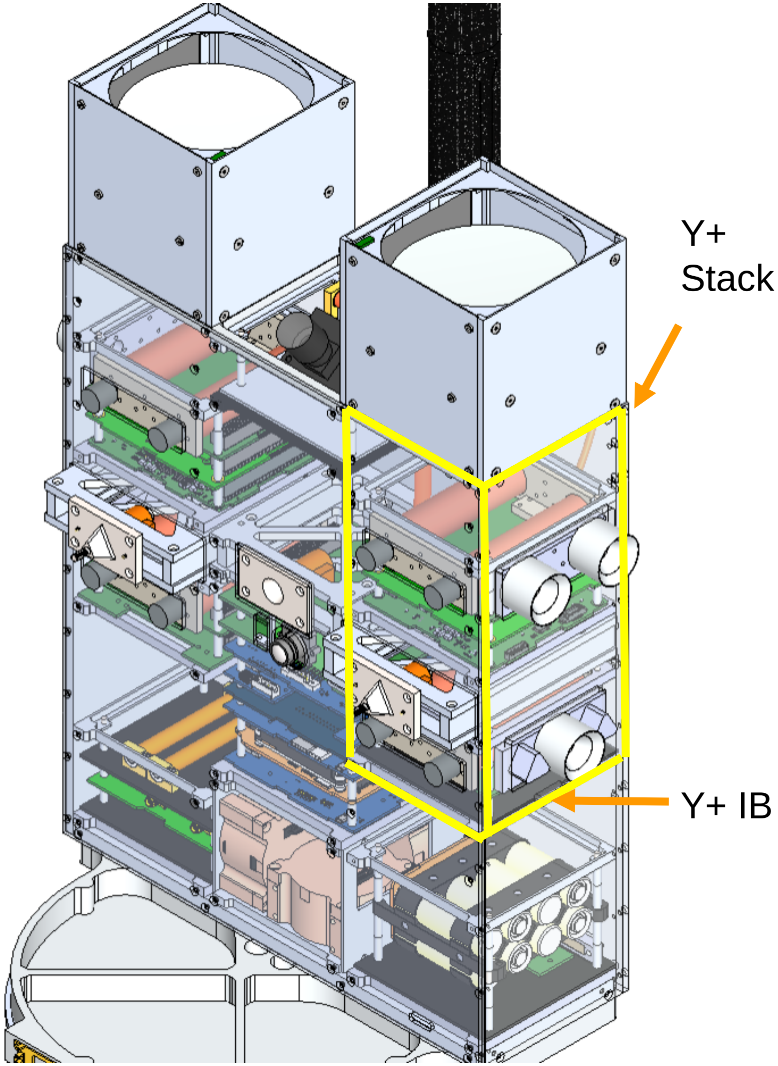
- Route all power and signal between central and Y+ electronics stacks of CoreSat
- Interface with Y+, X+, and X- solar panels
- Route all solar panel power to EPS
- Route all Coarse Sun Sensor (CSS) signals to ADCS

Signal Conversion/Switching:

- Convert analog signals from solar panel temperature sensors to digital
- Perform switching for Inter-Satellite Power Link (ISPL), which allows CoreSat to transfer power to MirrorSat

Provide mounting for antenna burnwire

Y+ Interface Board Progress

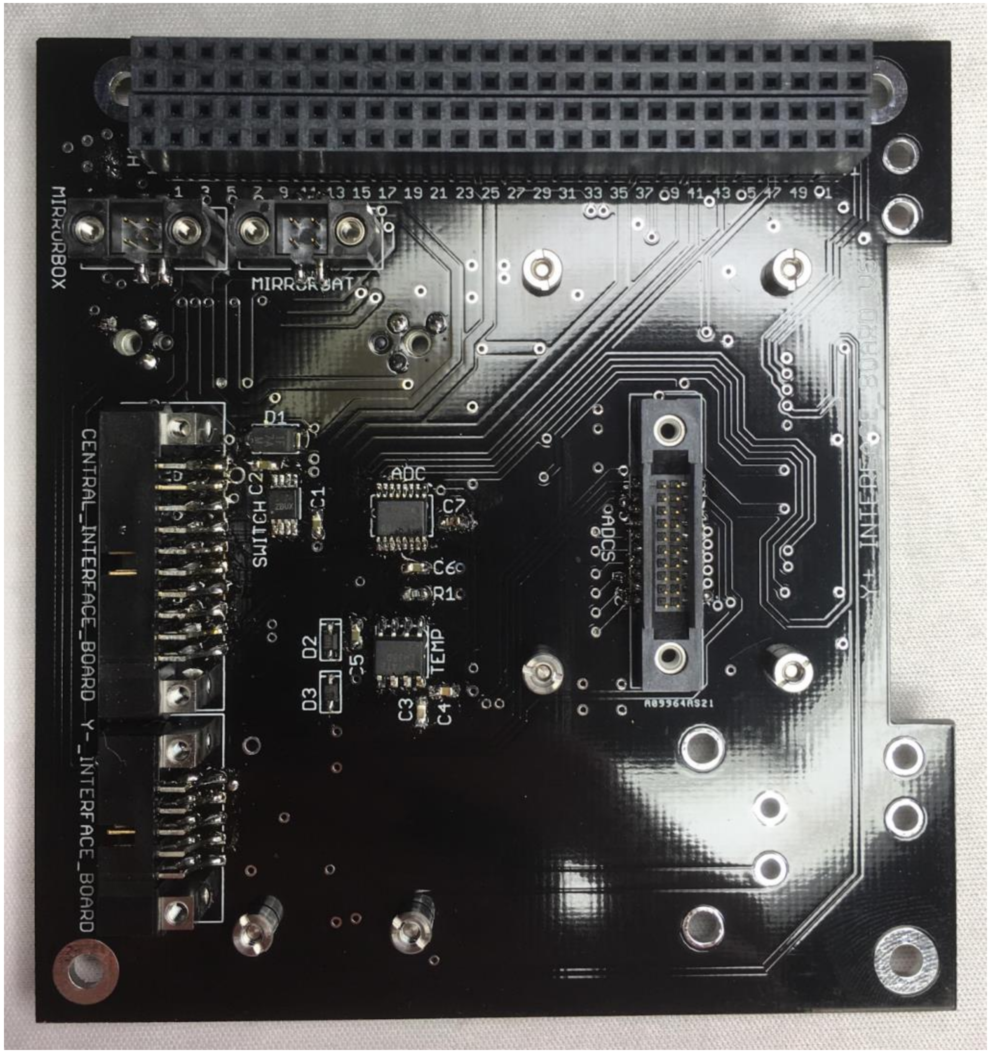


CoreSat (X+ and Y+ Faces)

Completed:
- Schematic
- Design/Layout
- Fabrication
- Assembly

Ready for:
- Verification Testing

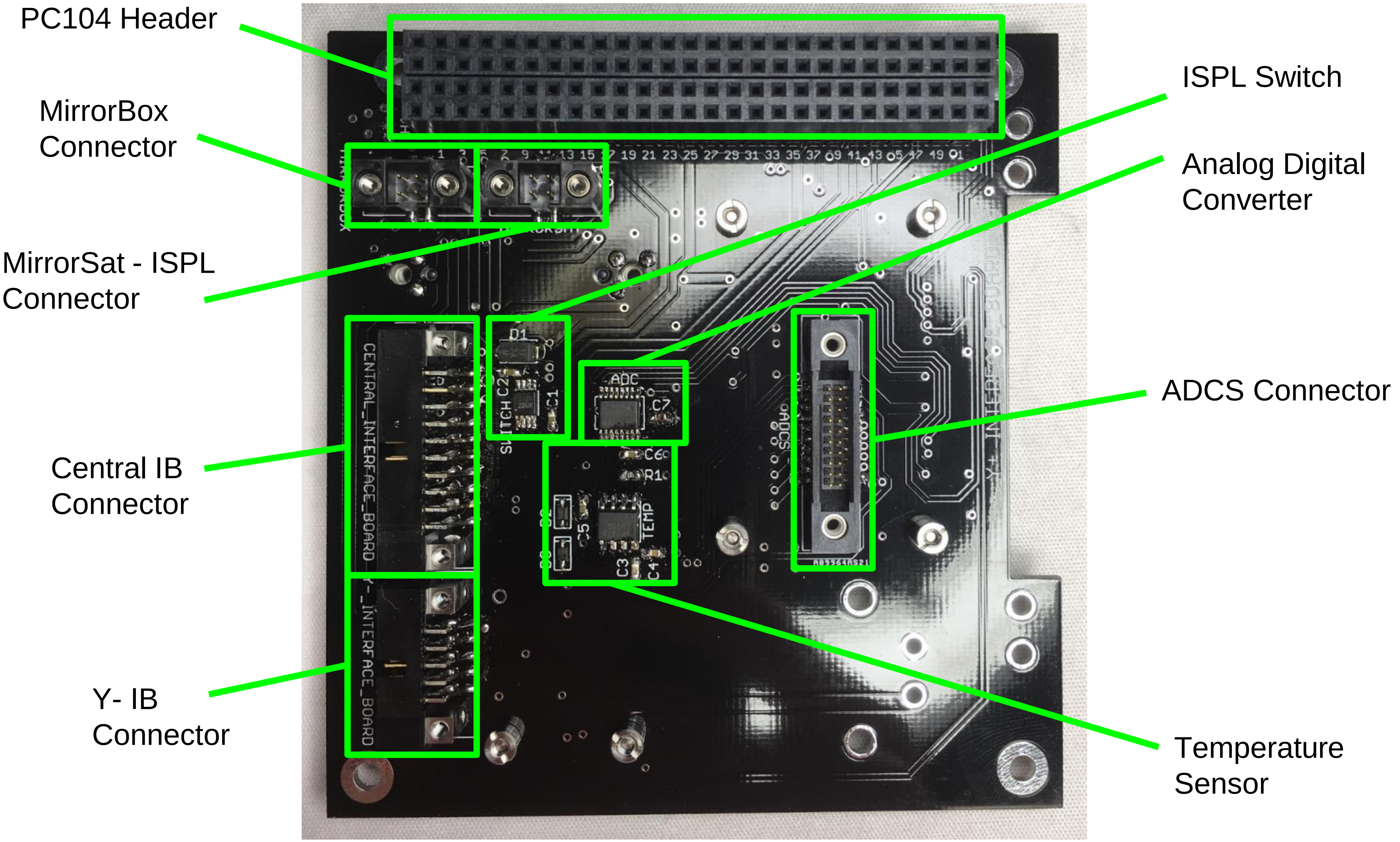
Assembled Y+ Interface Board



Y+ IB, Top Face

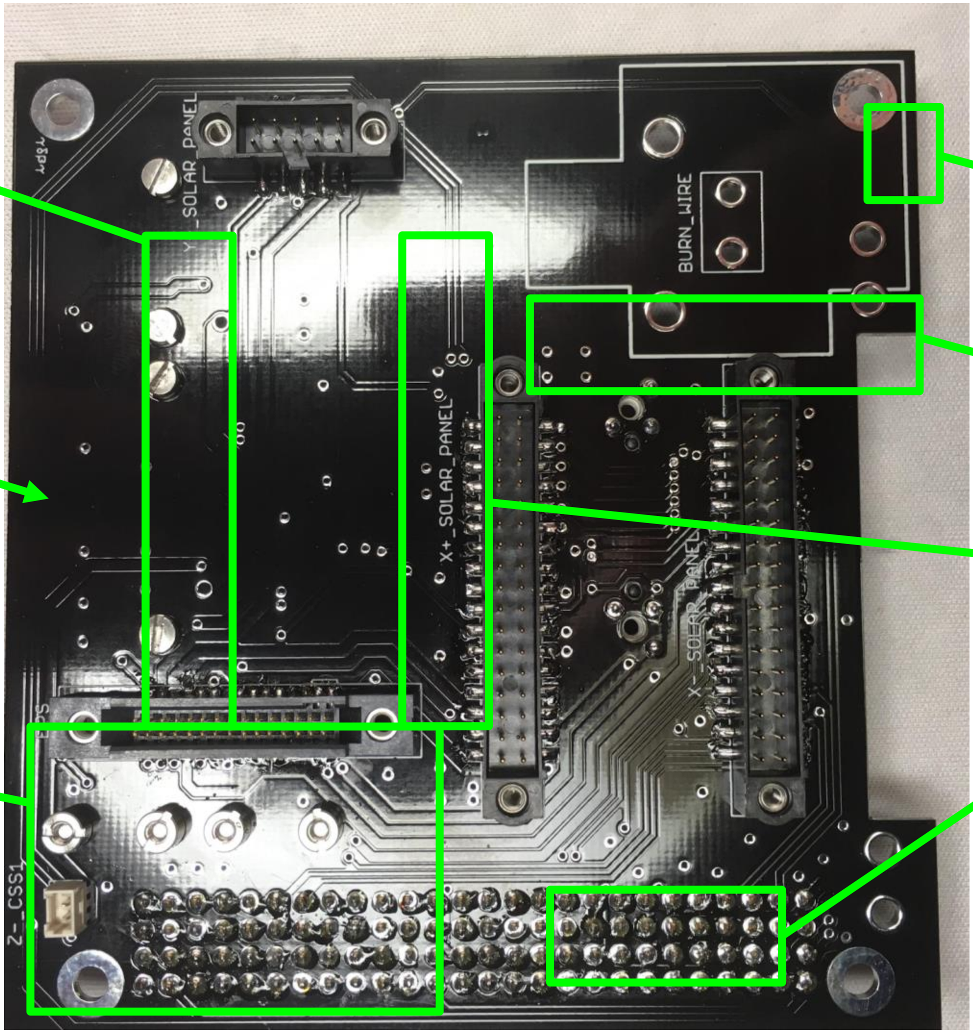
Caltech

Assembled Y+ Interface Board



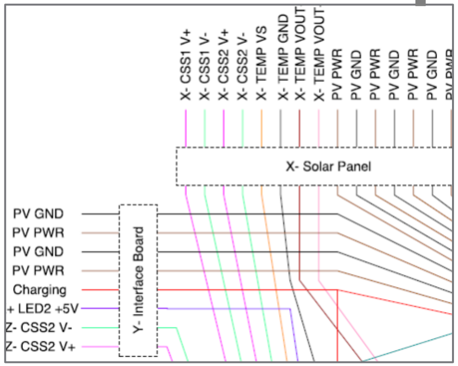
Y+ IB, Top Face

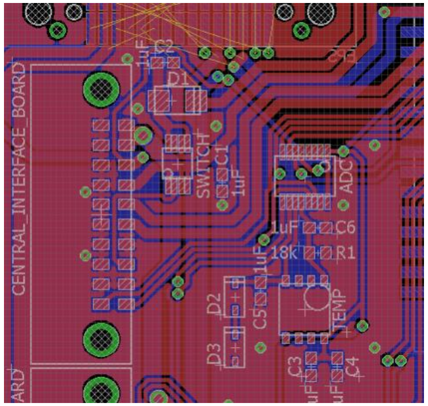
Assembled Y+ Interface Board

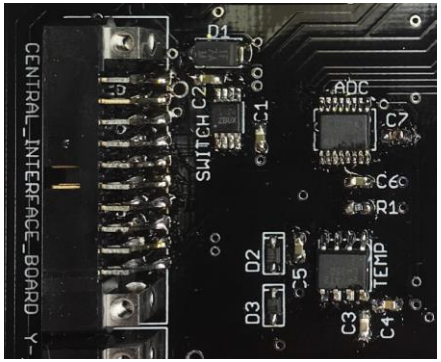


Y+ IB, Bottom Face

Development Process





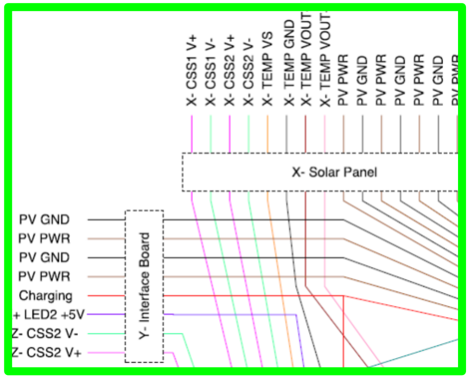


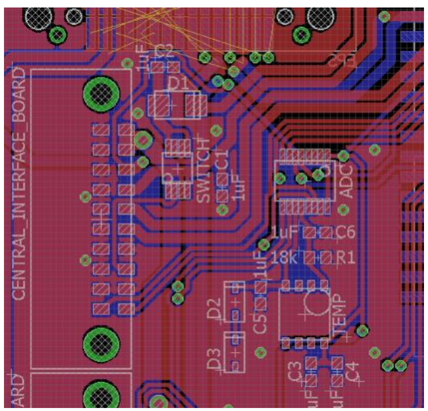
Routing Diagrams

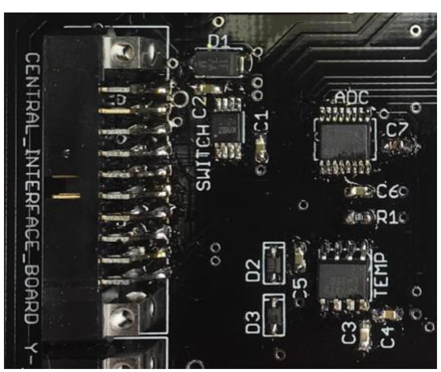
Schematic/Layout

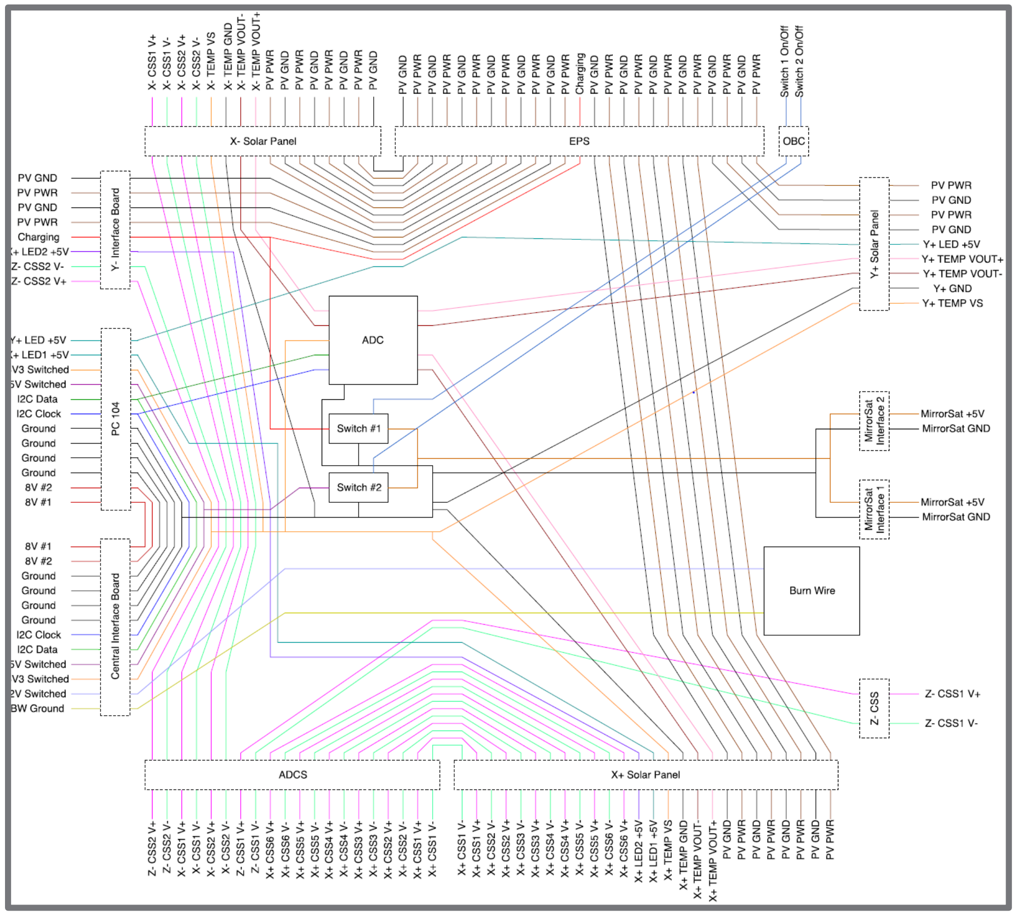
PCB Fabrication/Assembly

Routing Diagram









Routing Diagram of Y+ IB

Objectives:
- Assign Pins
- Select Connectors and Components

Timeline:
Week 1 - 7

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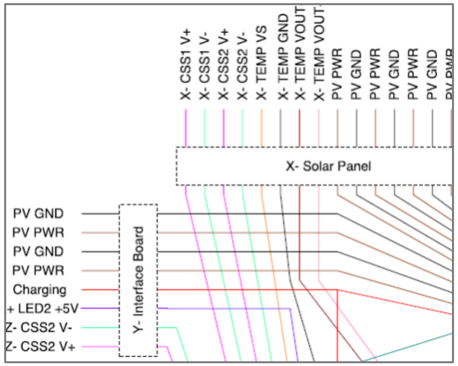
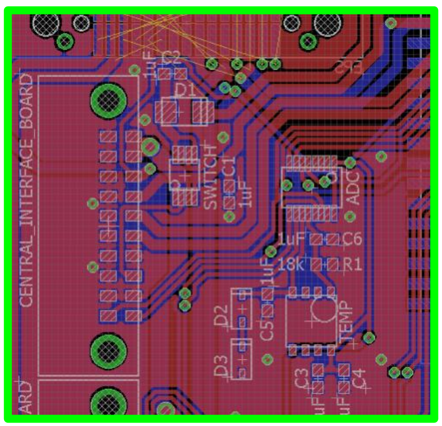
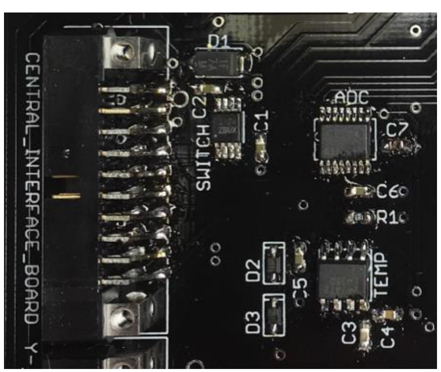
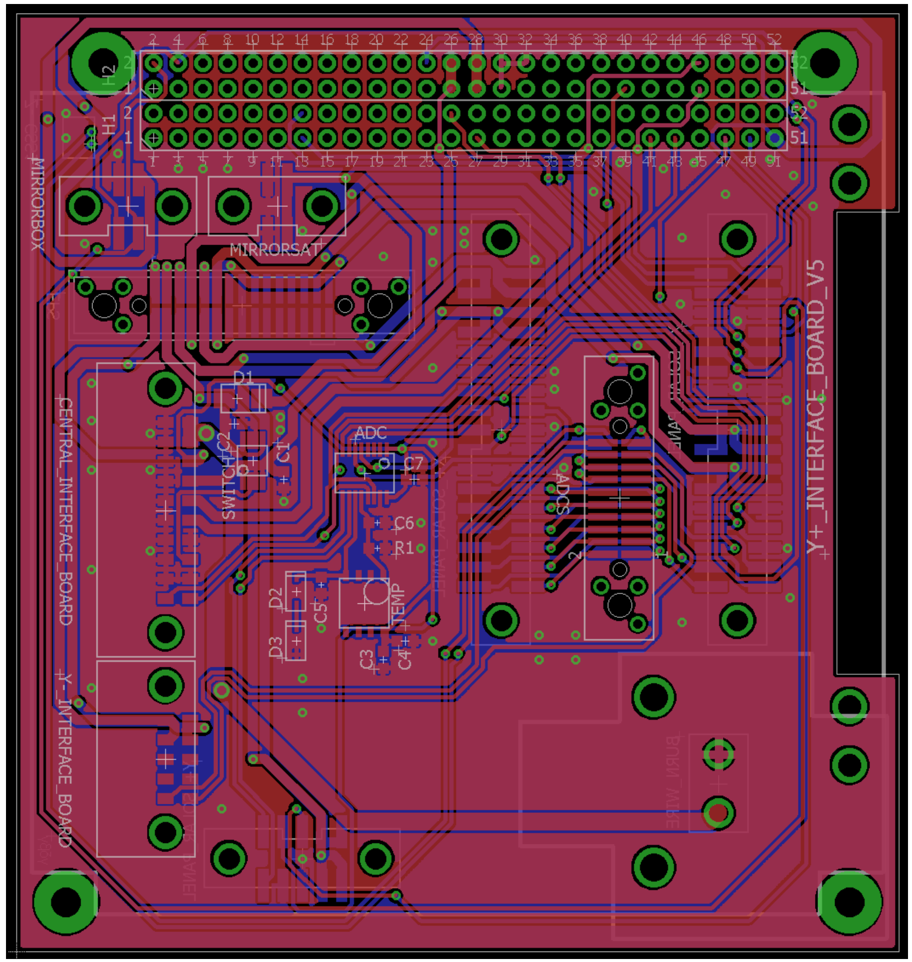
Schematic/Layout









5th Iterations of Y+ Interface Board Layout

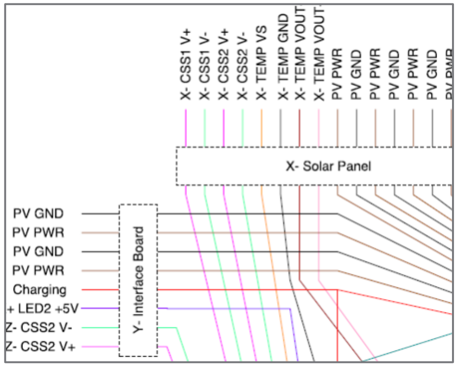
Objectives:

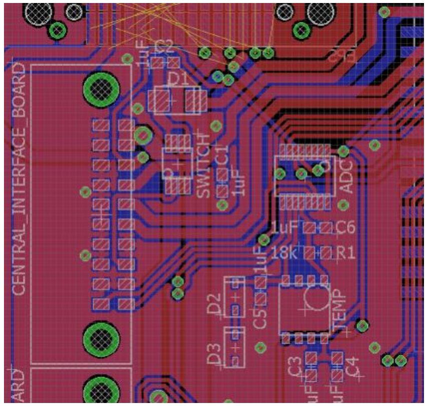
- Place components and connectors
- Route connections

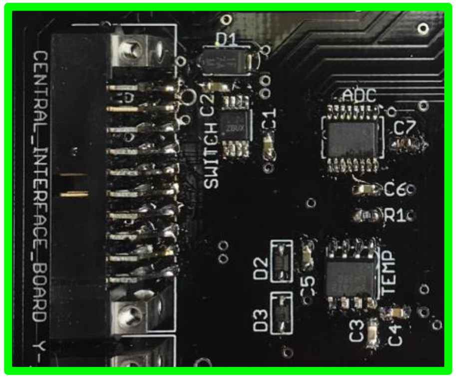
Timeline:

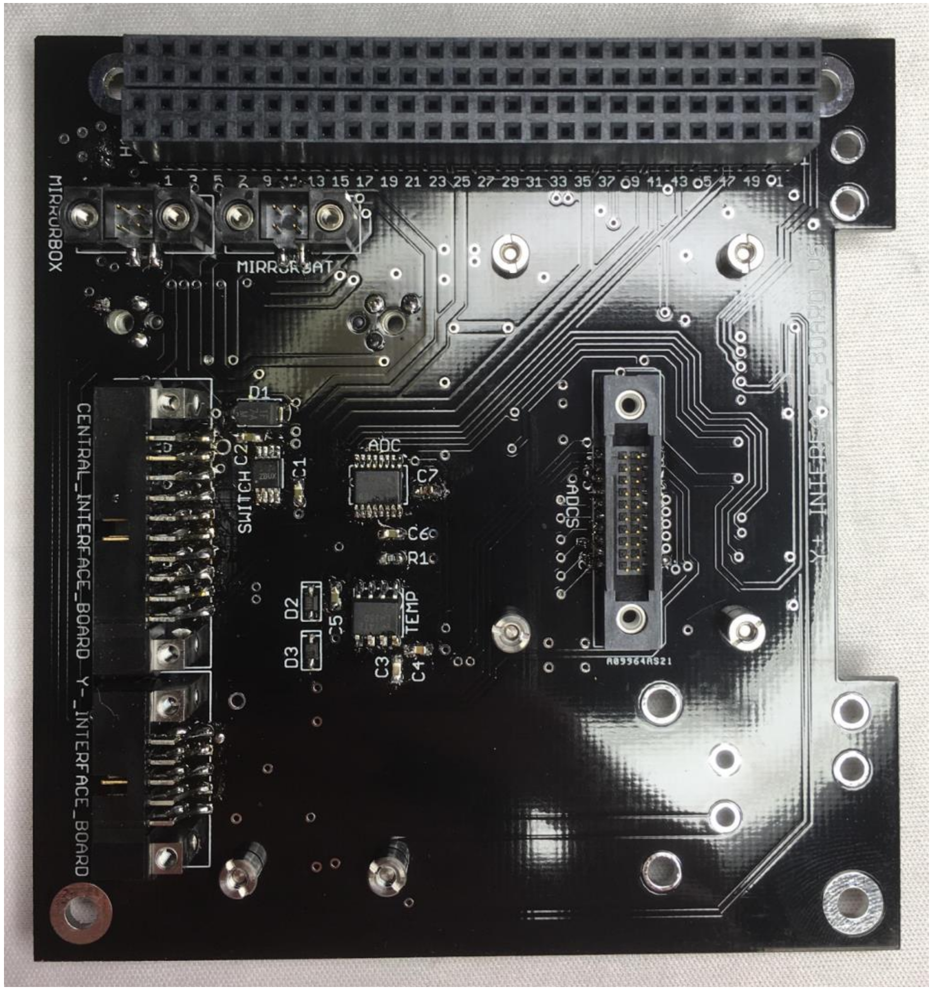
Week 8 - 12

PCB Fabrication/Assembly









Assembled Y+ IB

Objectives:

- Send design for fabrication
- Place orders for components
- Assemble (solder) in clean room

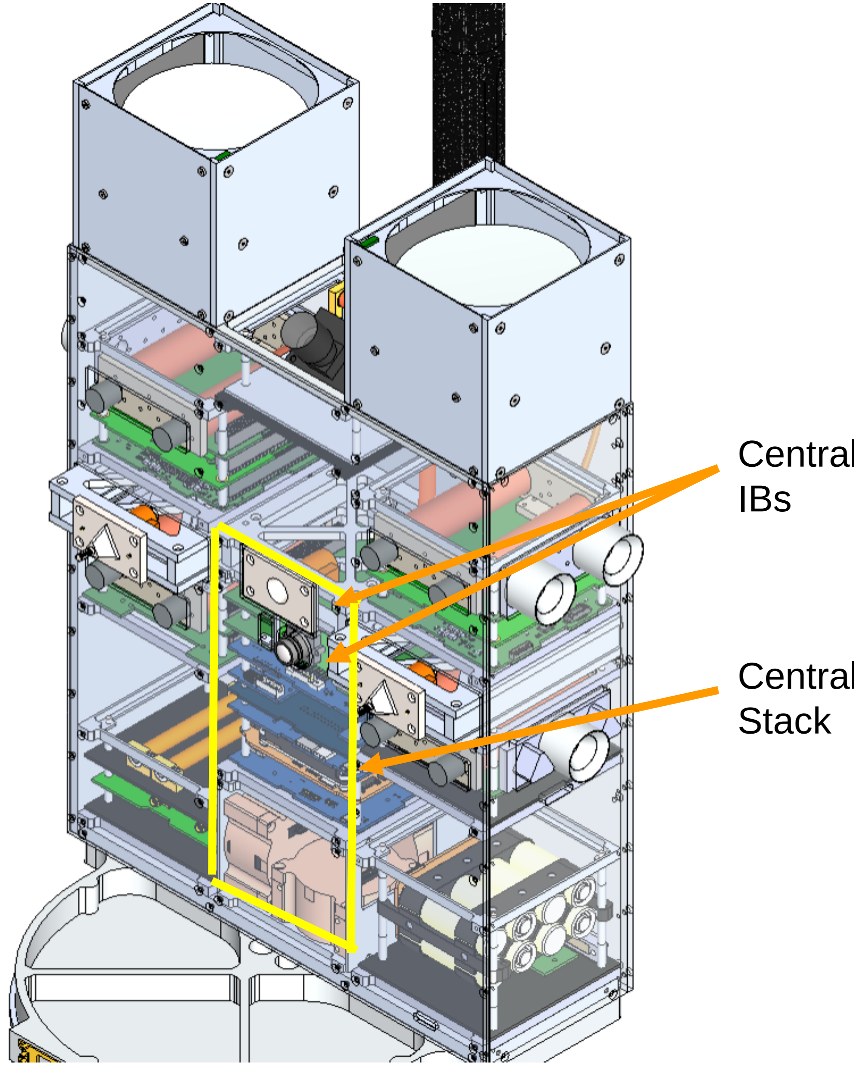
Timeline:

Week 12-14

Central Interface Boards

Central IB Responsibilities:

- Provide interface between the central stack and science instruments, Y+ and Y- interface boards
- Provide power, switching, and data circuitry for the burn wires and frangibolts
- Provide mounting points for fine sun sensor and magnetometer



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Central Interface Boards

Completed:

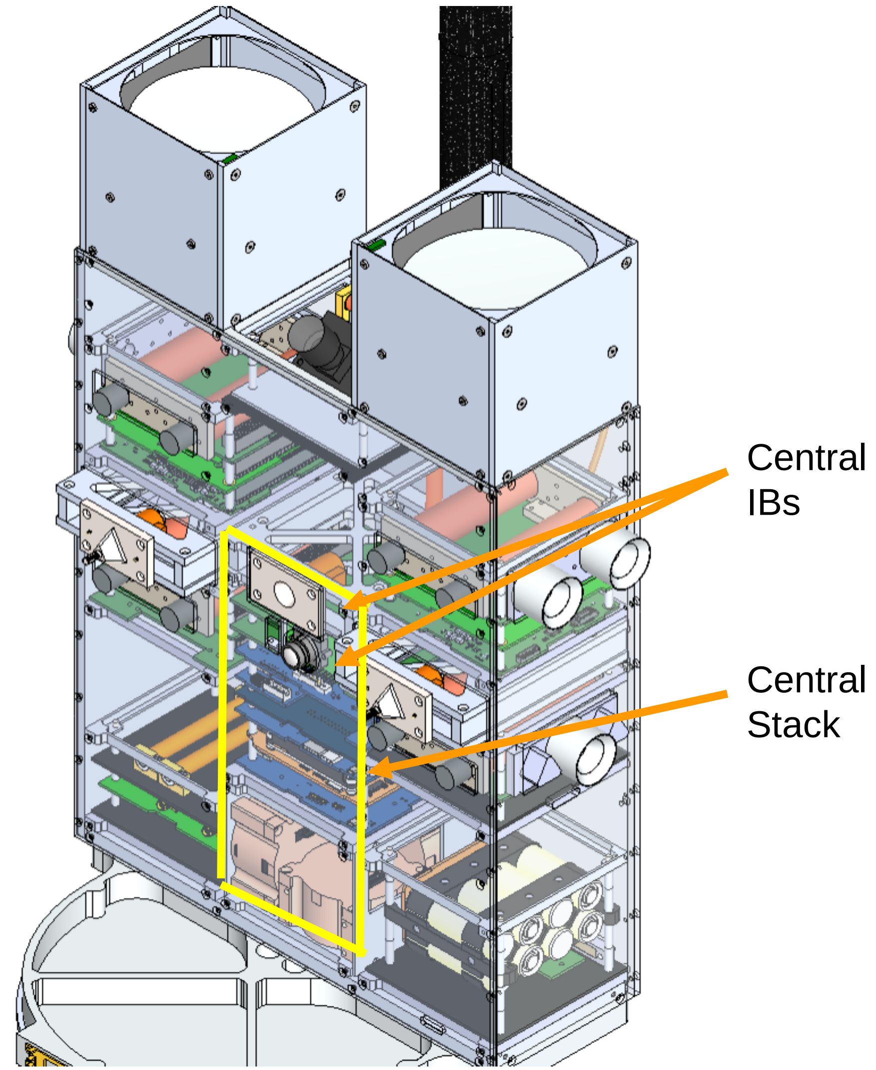
- Schematic
- Design/Layout
- Fabrication

In Progress:

- Assembly

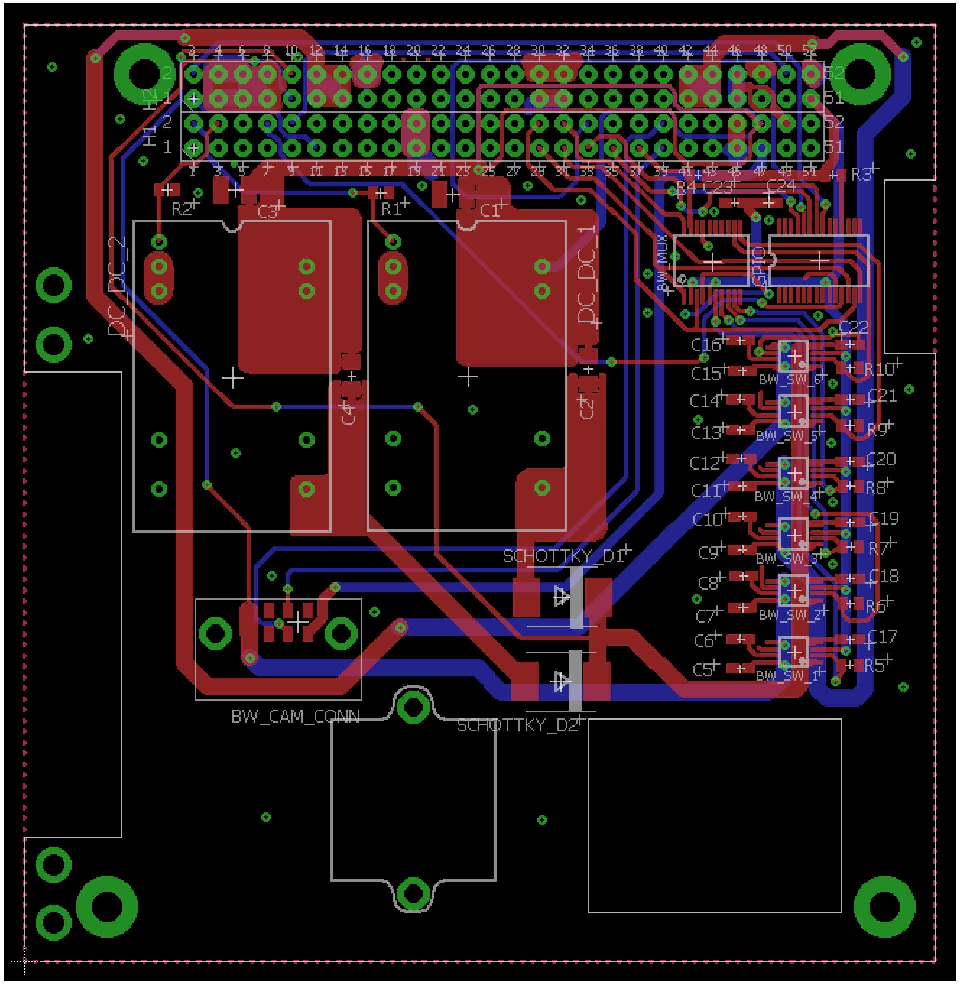
Future steps:

- Verification Testing



Bottom Central Interface Board

- Purpose: power management, burn wire circuitry, camera connector, mounting points for fine sun sensor and magnetometer



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Bottom Central Interface Board

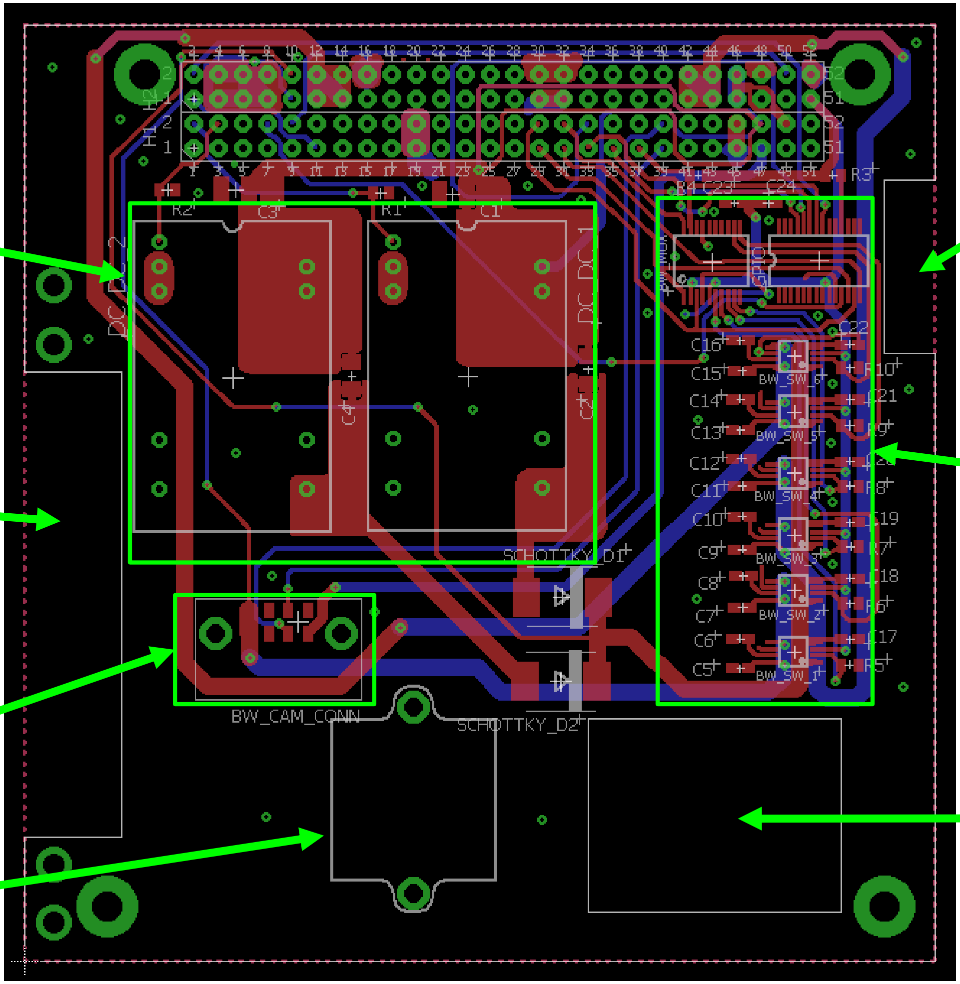
- Purpose: power management, burn wire circuitry, camera connector, mounting points for fine sun sensor and magnetometer

Burn Wire DC/DC Converters

Fine Sun Sensor Mount

Burn Wire and Camera Connector

Magnetometer Mount



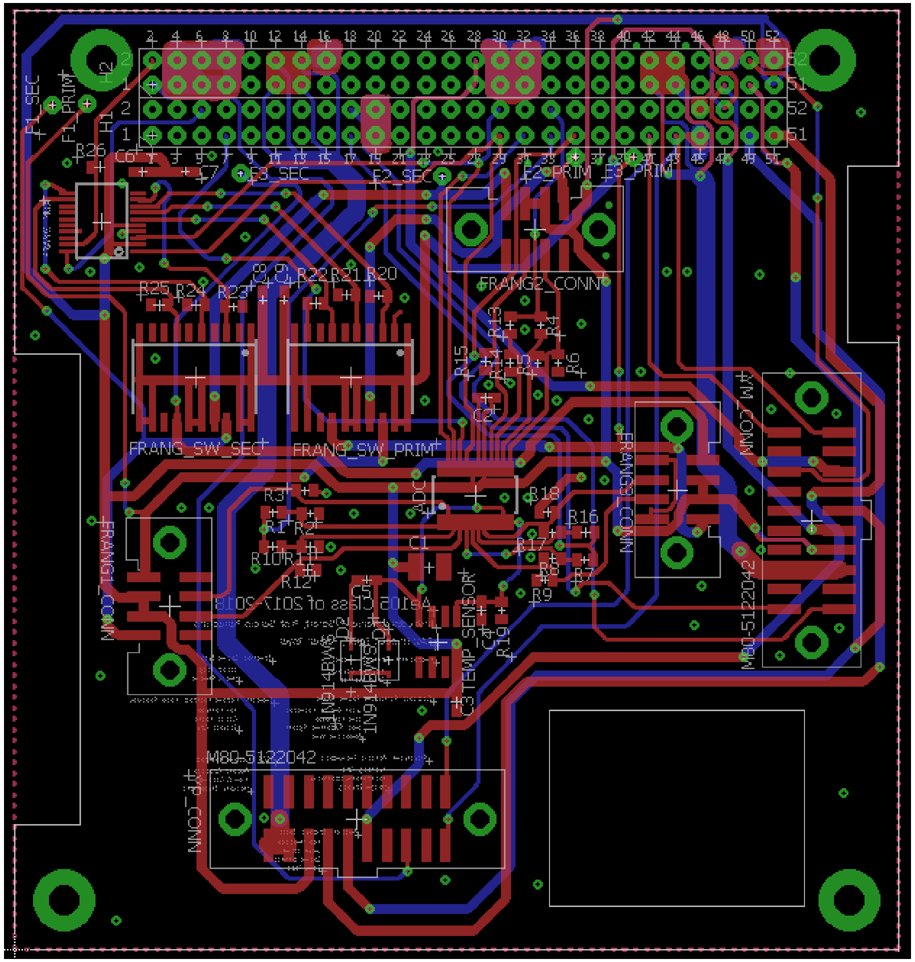
Camera Notch

Burn Wire Switches

Magnetorquer Hole

Top Central Interface Board

- Purpose: Y+ and Y- interface board connectors, frangibolt circuitry, temperature sensor



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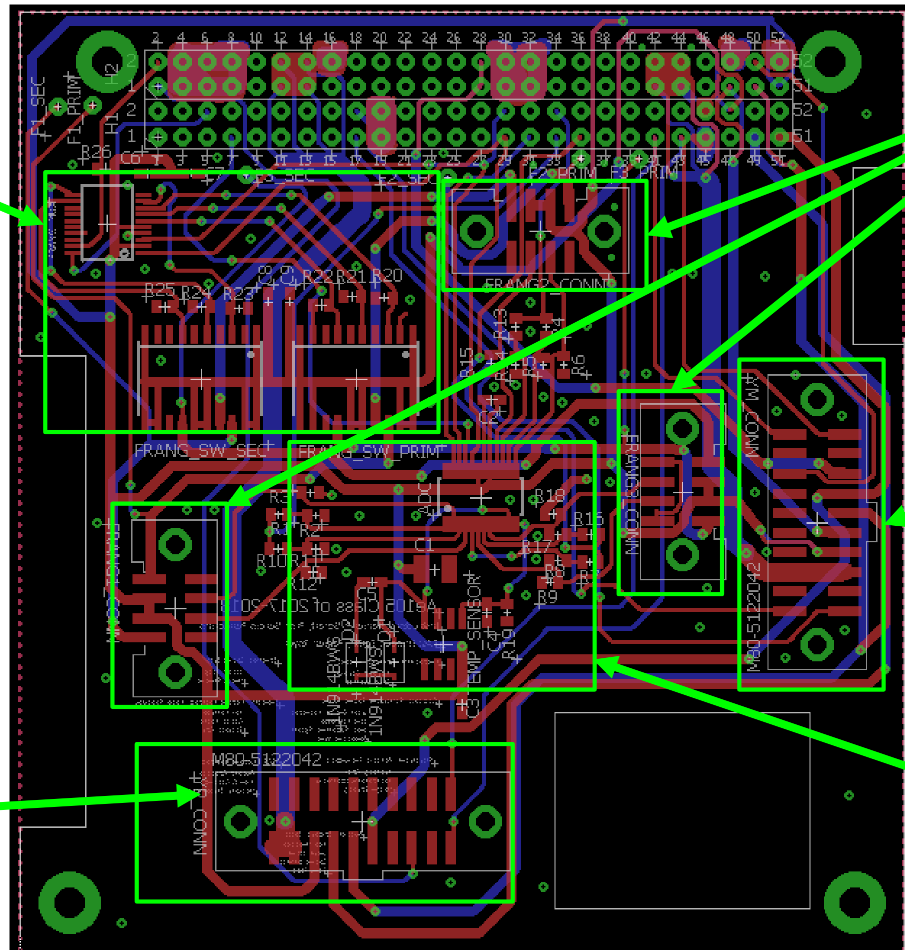
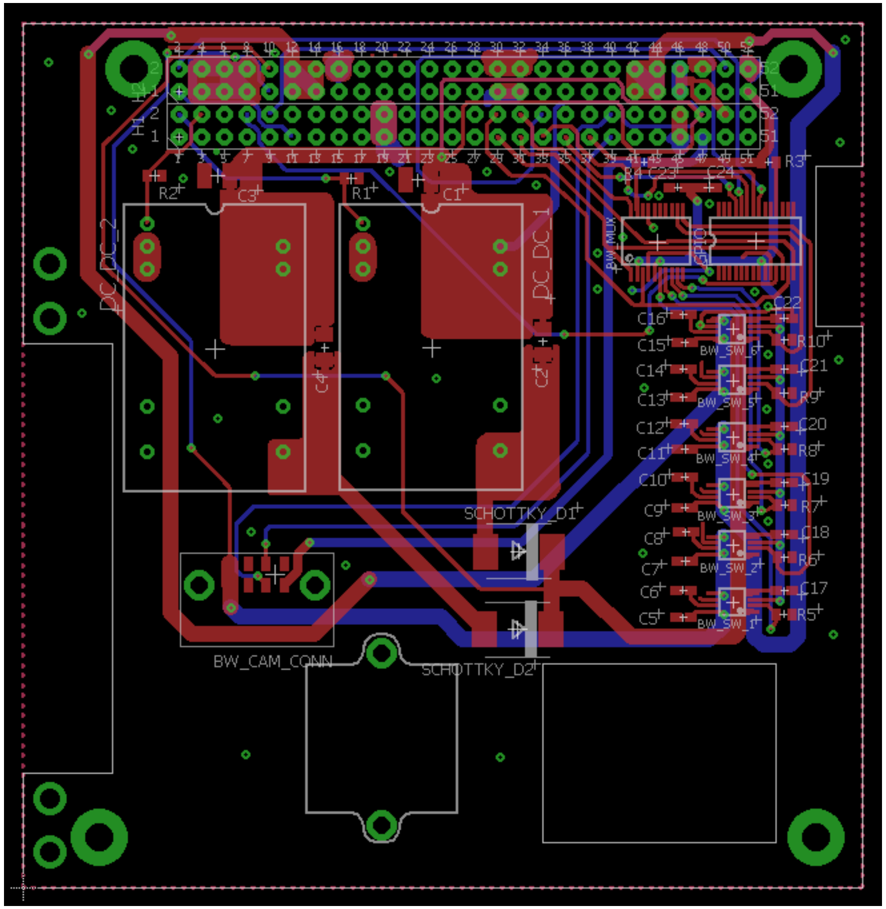
Top Central Interface Board

- Purpose: Y+ and Y- interface board connectors, frangibolt circuitry, temperature sensor

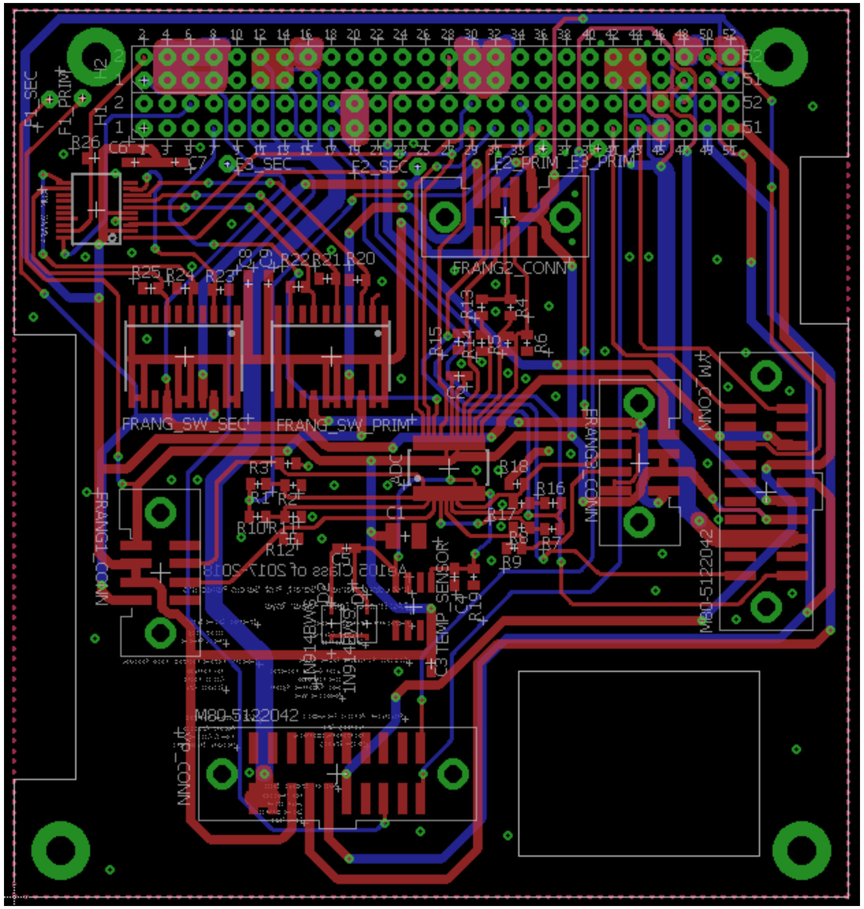


Central IB Layout

Bottom Board:



Top Board:



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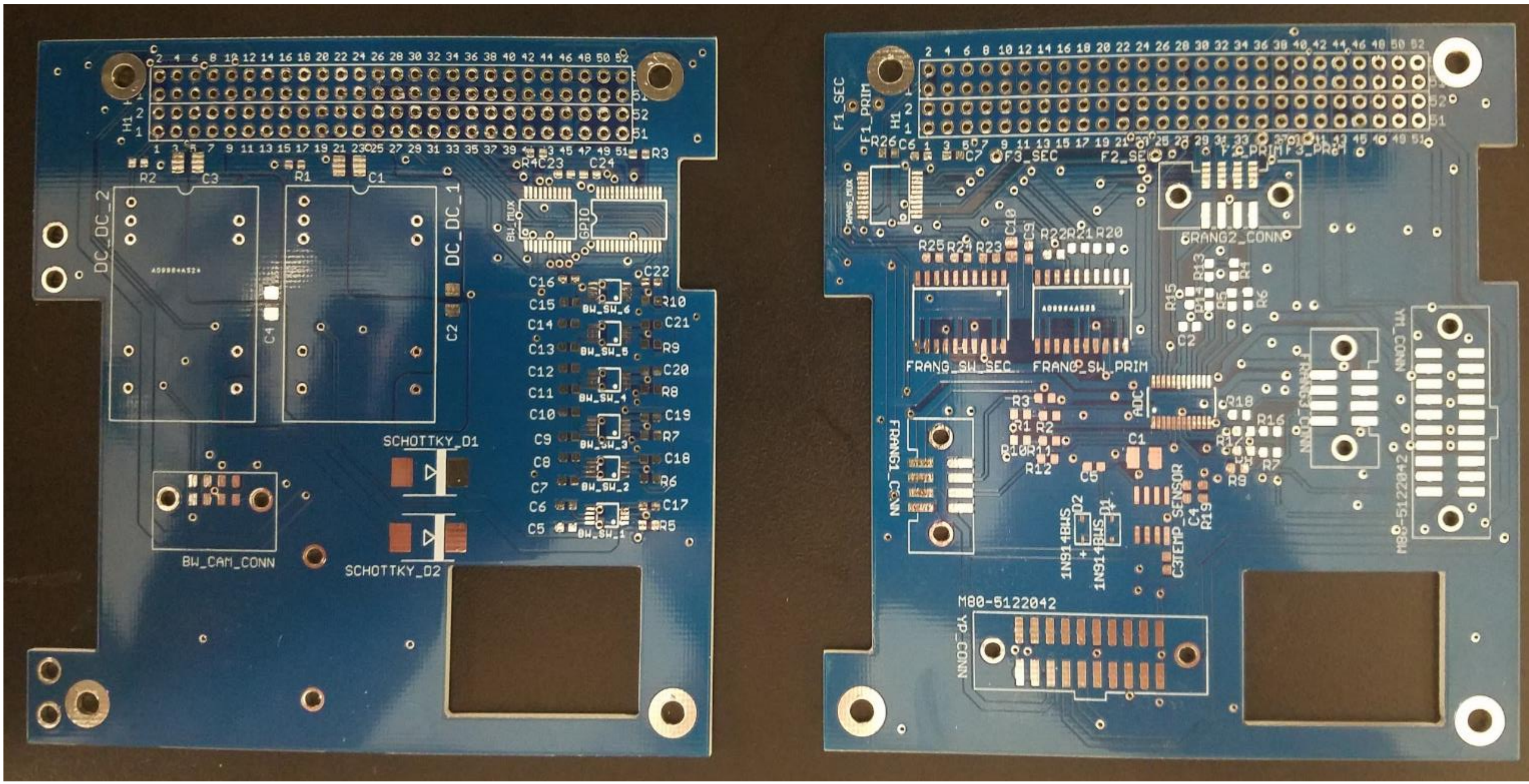
Central IB Fabricated PCBs

Bottom Board: Top Board:



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Flight Preparation Panel

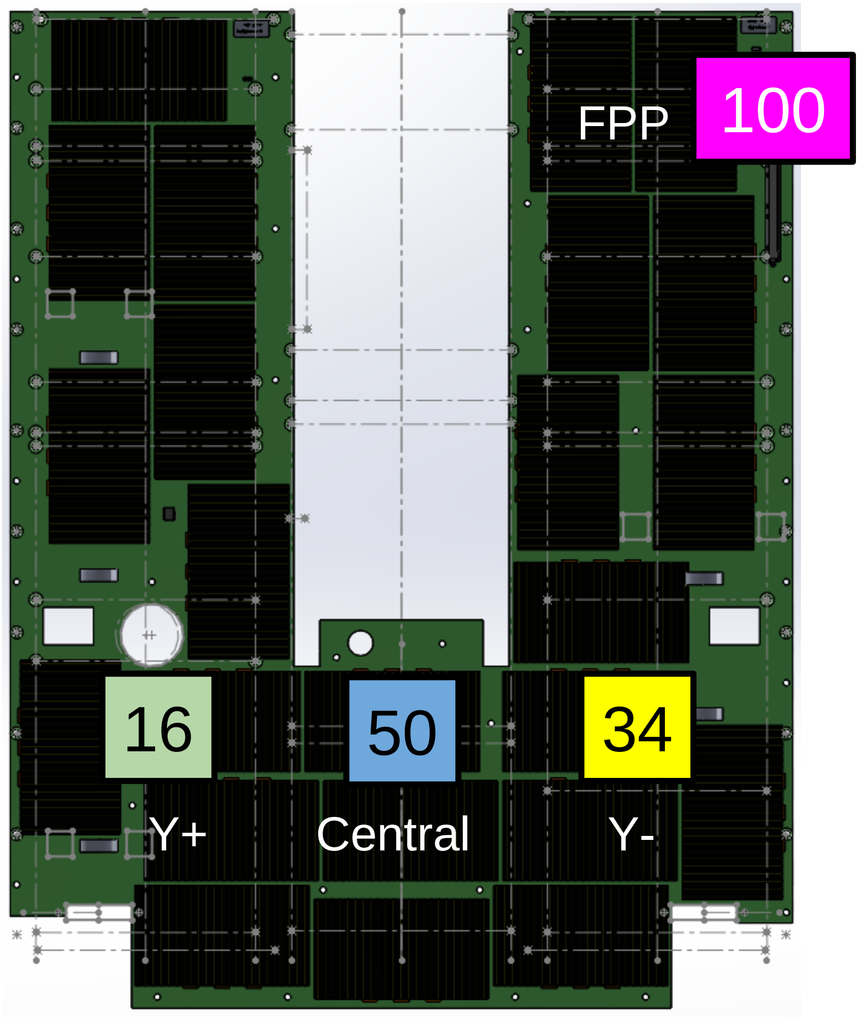
Purpose:

- Allows system to be tested thoroughly after assembly and before flight

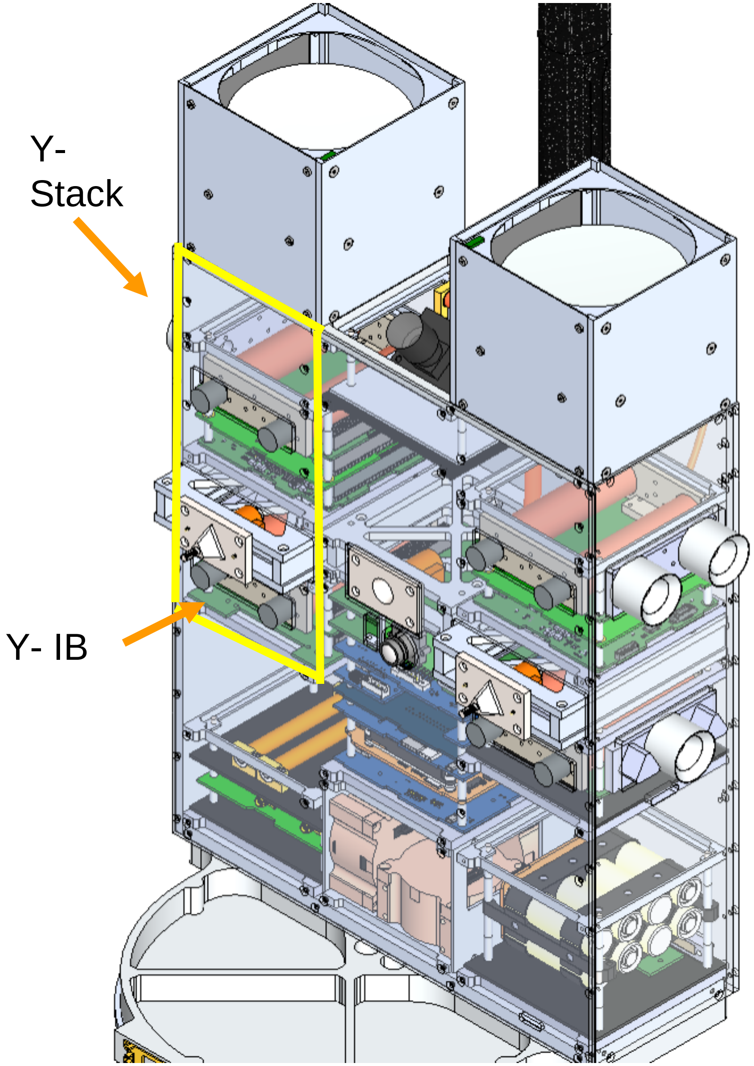
Design:

- Interfaces with all critical power and signal lines and also remove before flight, kill switch, and charging lines
- Consists of 100 lines that route to the interface boards
  - 16 lines to Y+ IB
  - 34 line to Y- IB
  - 50 lines to Central IB

X- Face



Y- Interface Board

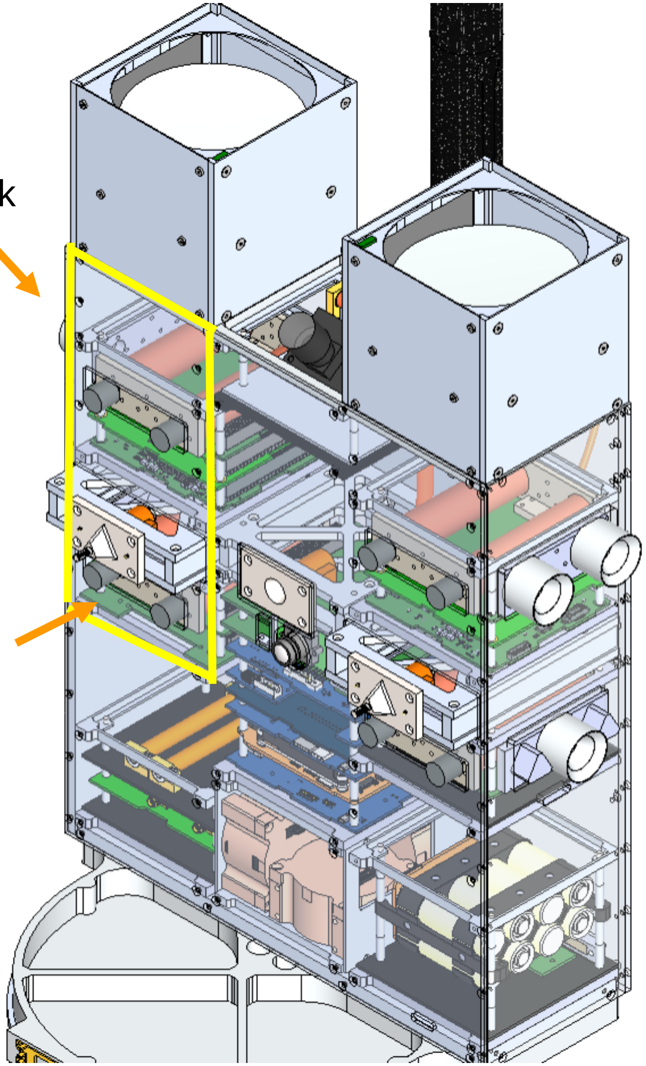


CoreSat

Y- IB Responsibilities:

- Route connections between the Y- stack
- Interface with the Central and Y+ interface boards
- Provide power and data circuitry for the radio
- Connect FPP to EPS

Y- Interface Board Progress

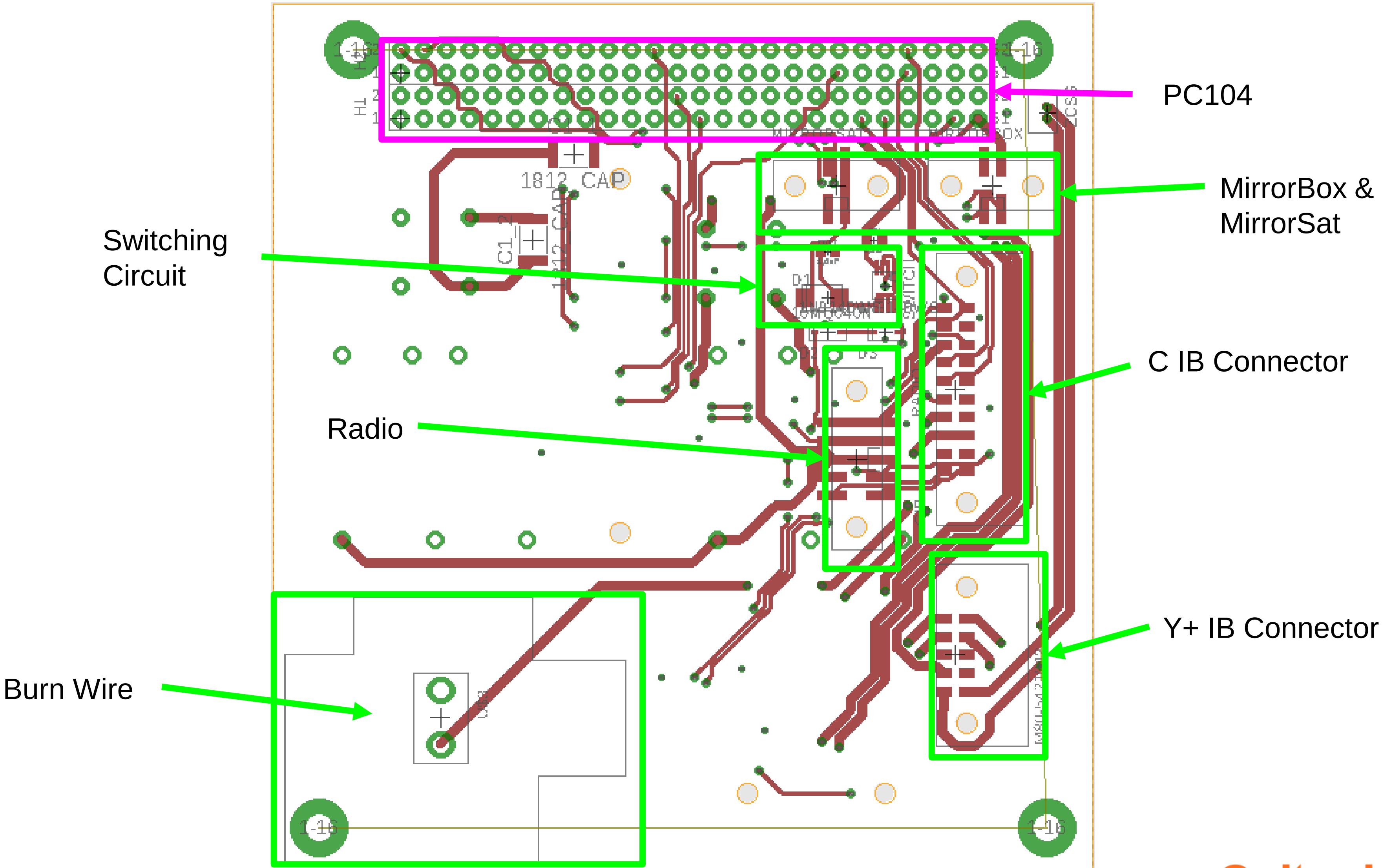


Completed:
- Schematic
- Multiple iterations of design/layout

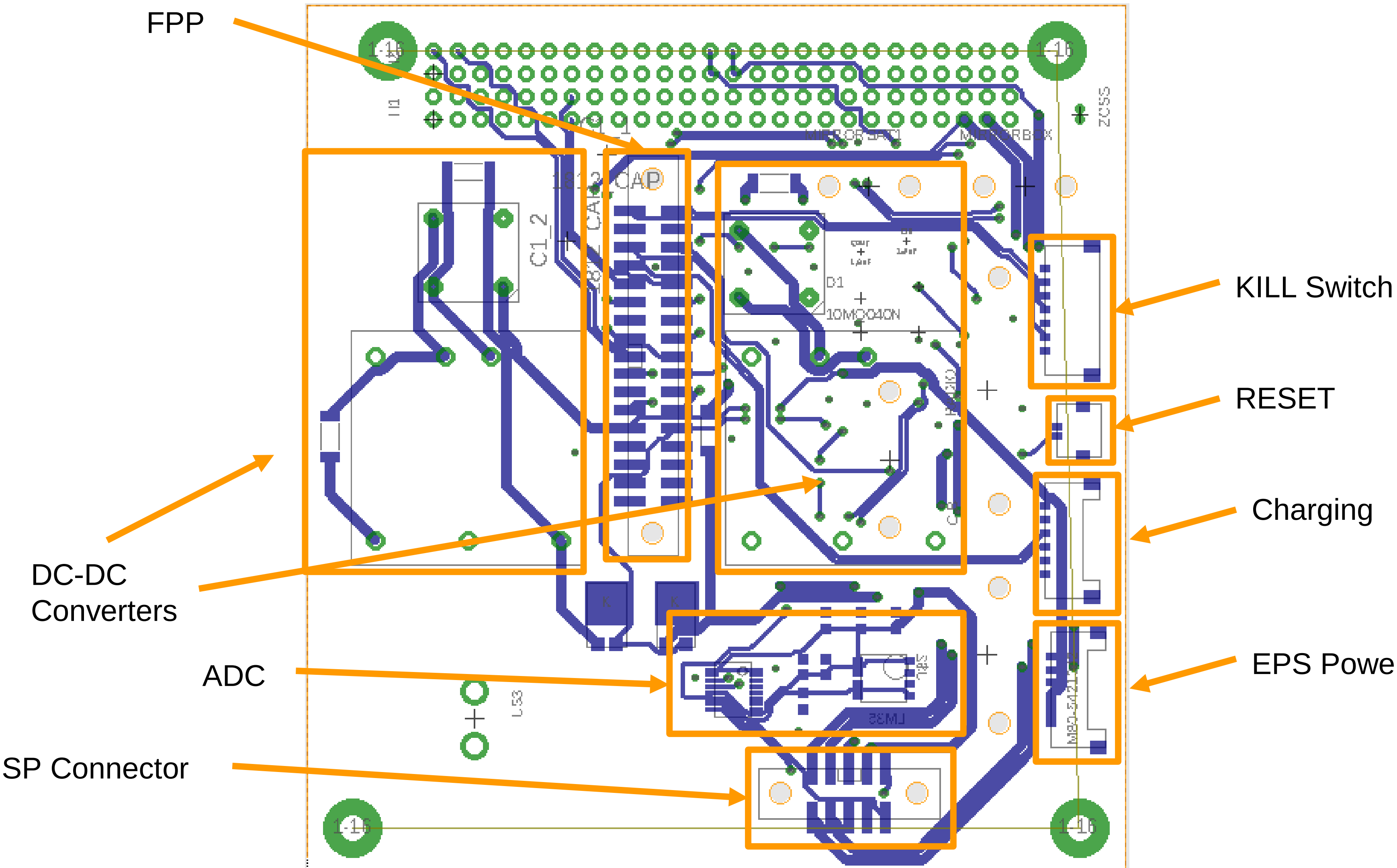
In Progress:
- Final layout

Future Steps:
- Final checks

Y- Board Top


PC104
MirrorBox &
MirrorSat
Switching
Circuit
C IB Connector
Radio
Y+ IB Connector
Burn Wire
1812 CAP

Y- Board Bottom



Conclusion & Future Work

- Y+ Board complete
- Central Board assembly in progress
- Y- Board awaiting final checks
- Future Work
  - Finalize Y- layout
  - Complete Central Board assembly
  - Order remaining parts

Thank You!

Caltech