QB50 CubeSat TRR

Satellite Testbed for Attitude Response

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Problem Statement

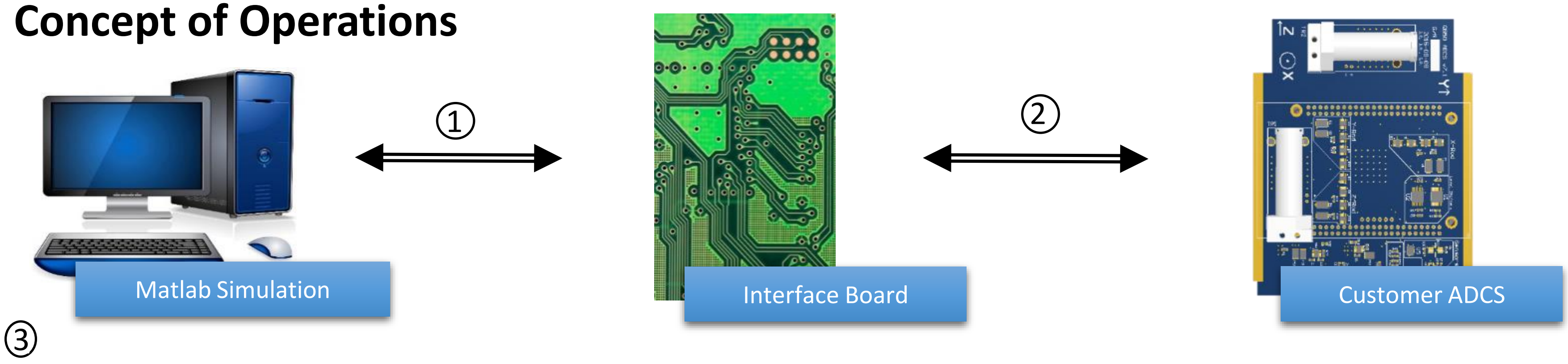
Develop a **test suite** that will allow for the **validation and calibration** of the QB50 Attitude Determination and Control System based (**ADCS**) on simulated mission environment.

Project Objectives

- Develop an ***interface board*** that will allow for a hardware-in-the-loop simulation by running a simulation on the ADCS board.
- Develop a ***turn-table*** apparatus for Sun sensor calibration.
- Develop ***test apparatus*** for conducting Helmholtz cage test.

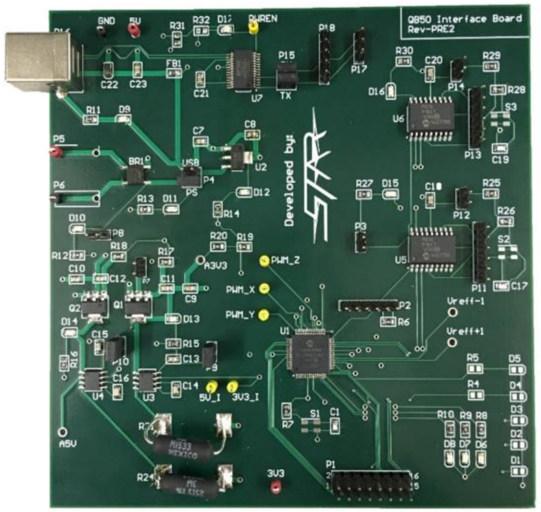
Interface Board

Concept of Operations



1. **Send simulation data to interface board**
2. **Emulate sensor readings to ADCS board**
3. **Run simulation and log necessary data**

Baseline Design



- 4 layer printed circuit board
- PIC microcontroller to program
- Implemented changes since MSR

Levels of Success

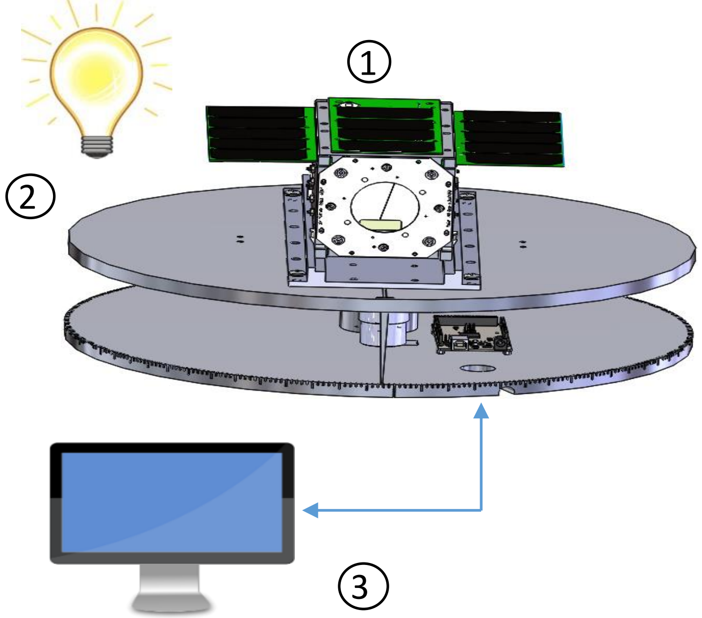
- Level 1 – Send sensor data at 10 Hz
- Level 2 – Log magnetorquer output
- Level 3 – Implement GUI to enable/disable sensors

Critical Project Elements

- Communicate at correct frequency
    - ADCS runs at 10Hz, Simulation runs much faster
    - Store simulation data, stream at desired rate

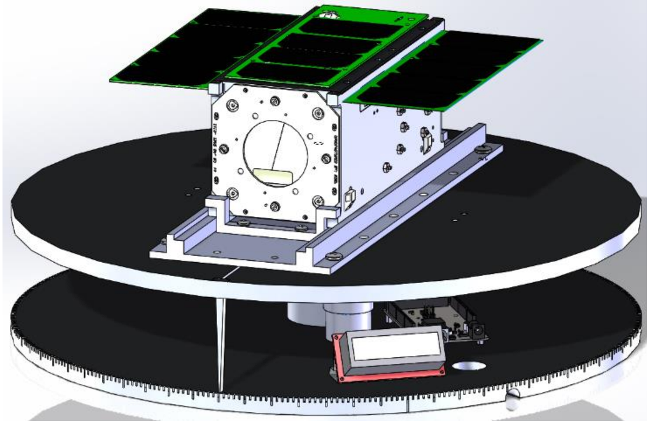
Sun Sensor Turntable

Concept of Operations



1. **Integrate CubeSat**
2. **Rotate turntable**
3. **Compare table angle to angle reported by CubeSat**

Baseline Design



- Aluminum plates, DC motor, magnetic encoder
- Arduino to program
- Allow for 2 orientations
- No major changes from CDR

Levels of Success

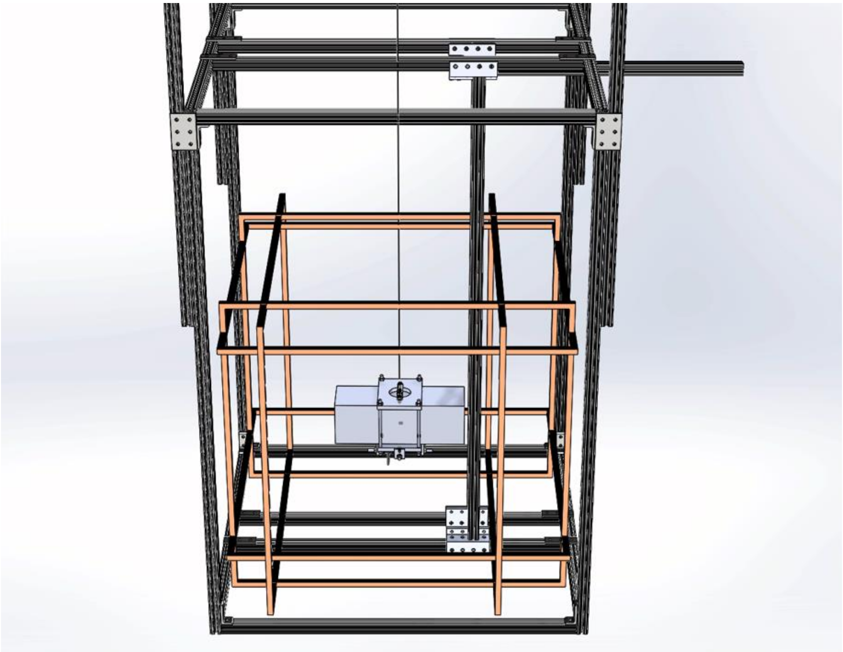
- Level 1 – Rotate with ±0.5 degrees accuracy
- Level 2 – Motorize turntable
- Level 3 – Implement automatic control

Critical Project Elements

- Top plate reflectance < 5%
  - 2-3 weeks to get coated

HelmHoltz Cage

Concept of Operations



1. **Integrate CubeSat**
2. **Rotate CubeSat without magnetorquer**
3. **Rotate CubeSat with magnetorquer**
4. **Compare results**

Baseline Design

- Extruded Aluminum
- Braided nylon, 30lbs load
- No major changes from CDR

Levels of Success

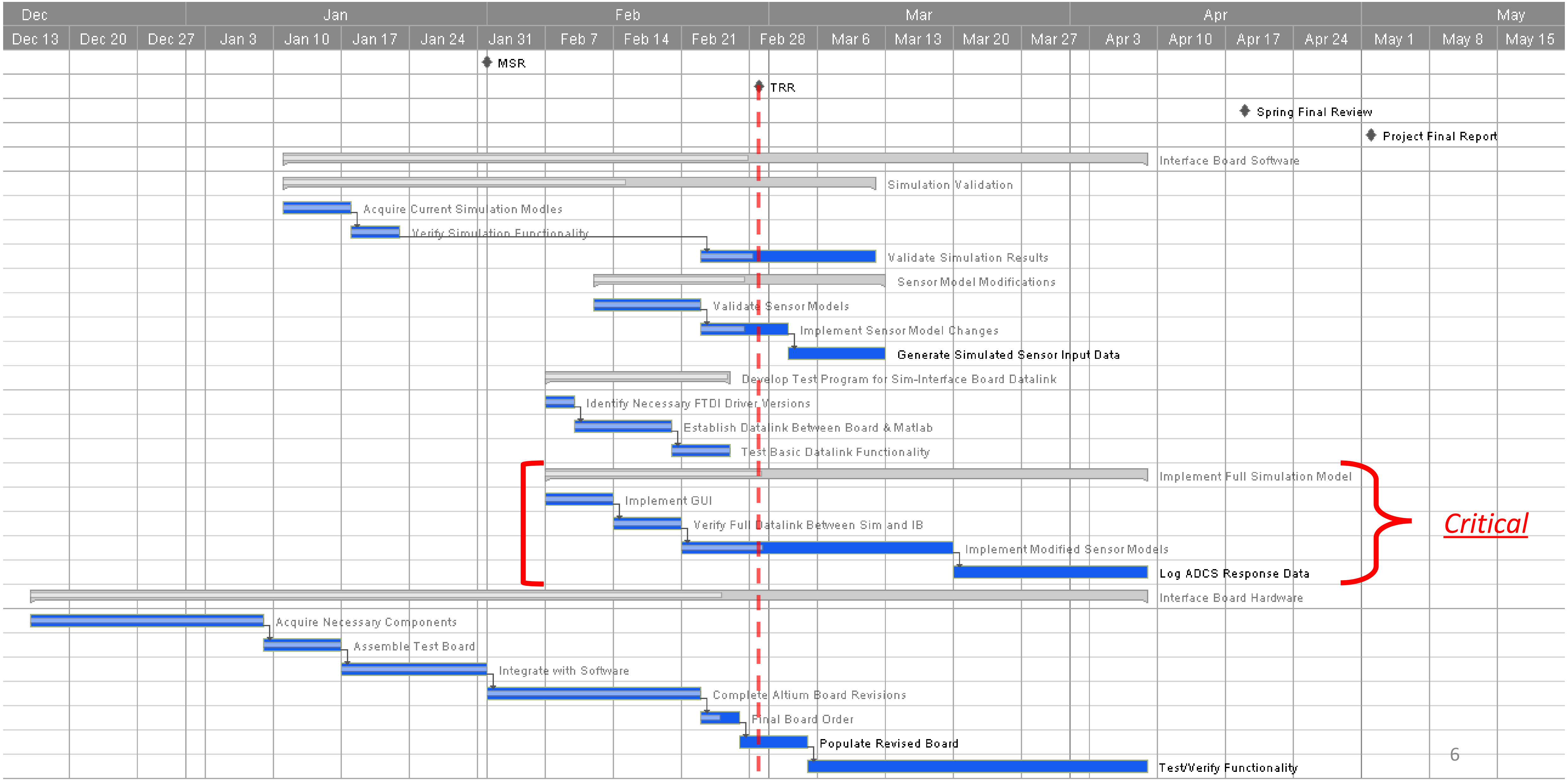
- Level 1 – Verify functionality of magnetorquers

Critical Project Elements

- Minimize torque on line

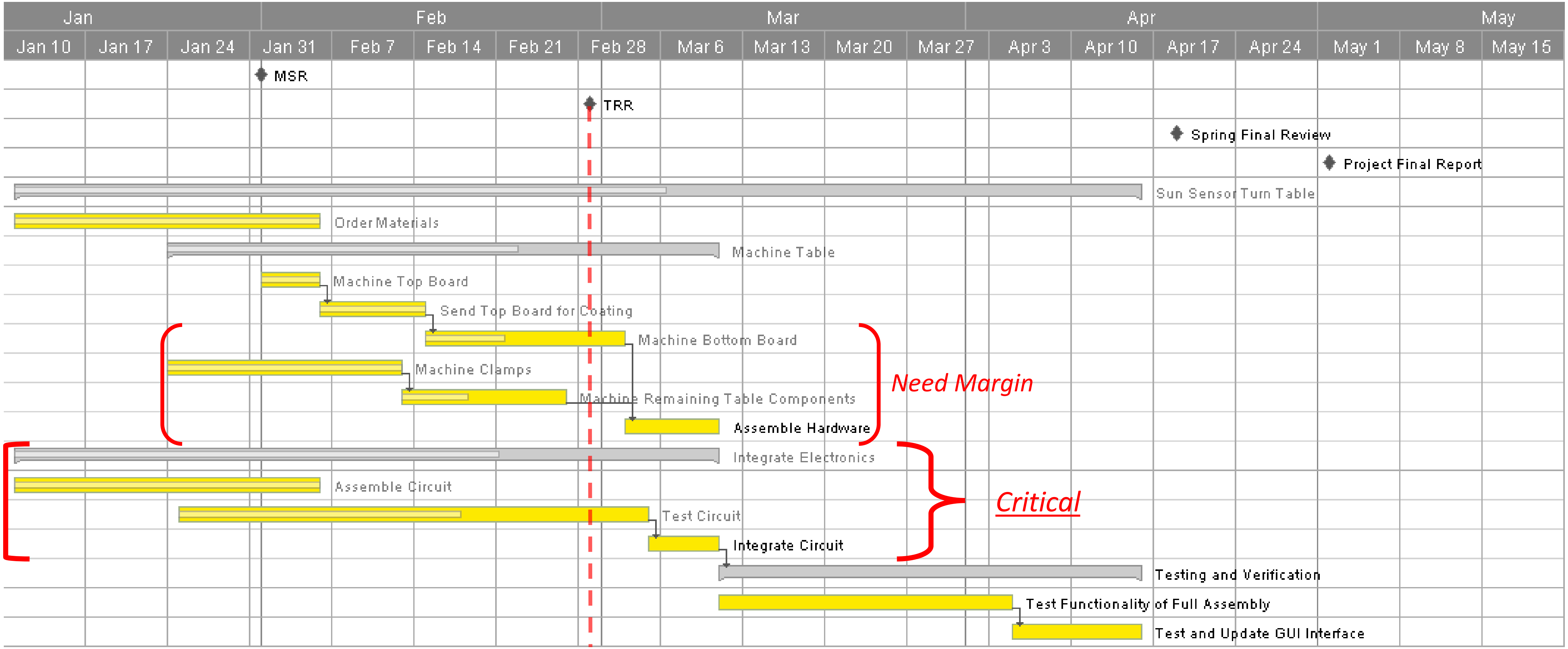
Interface Board Schedule

*no major changes



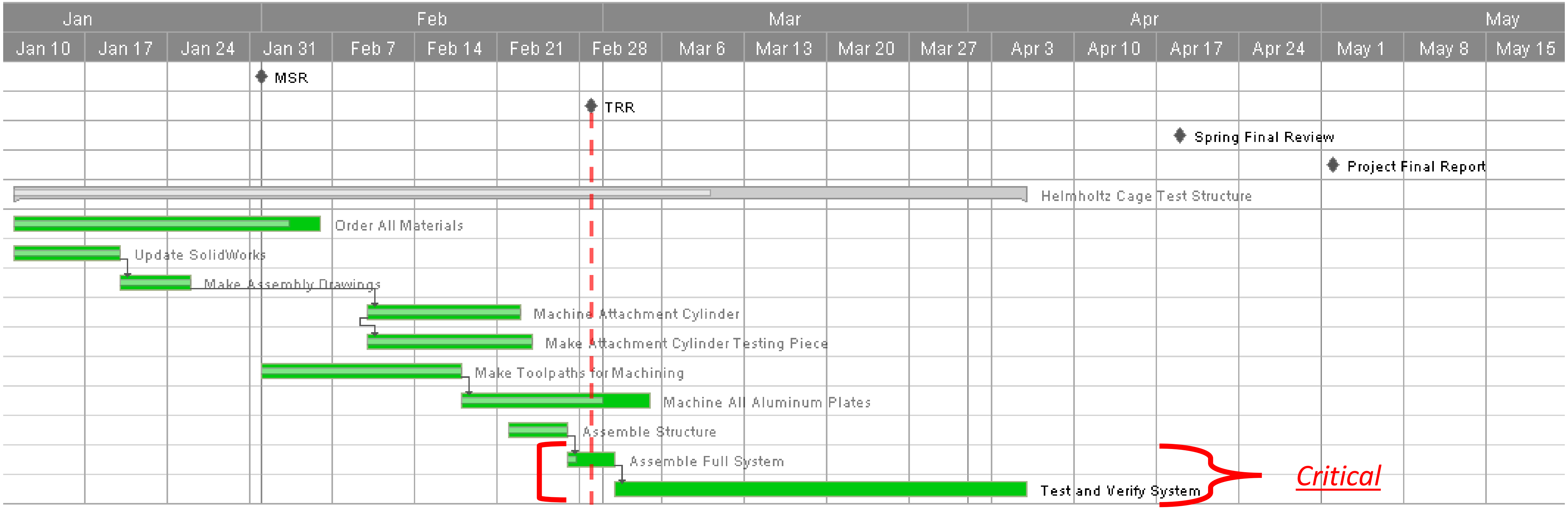
Sun Sensor Turn Table Schedule

*no major changes

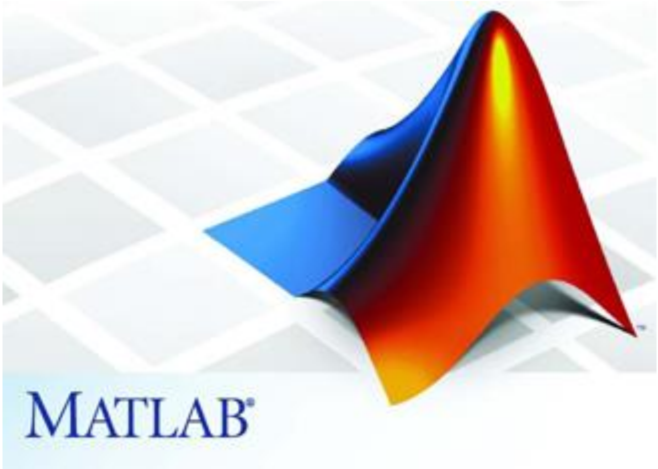


Helmholtz Cage Testing Structure Schedule

**no major changes*

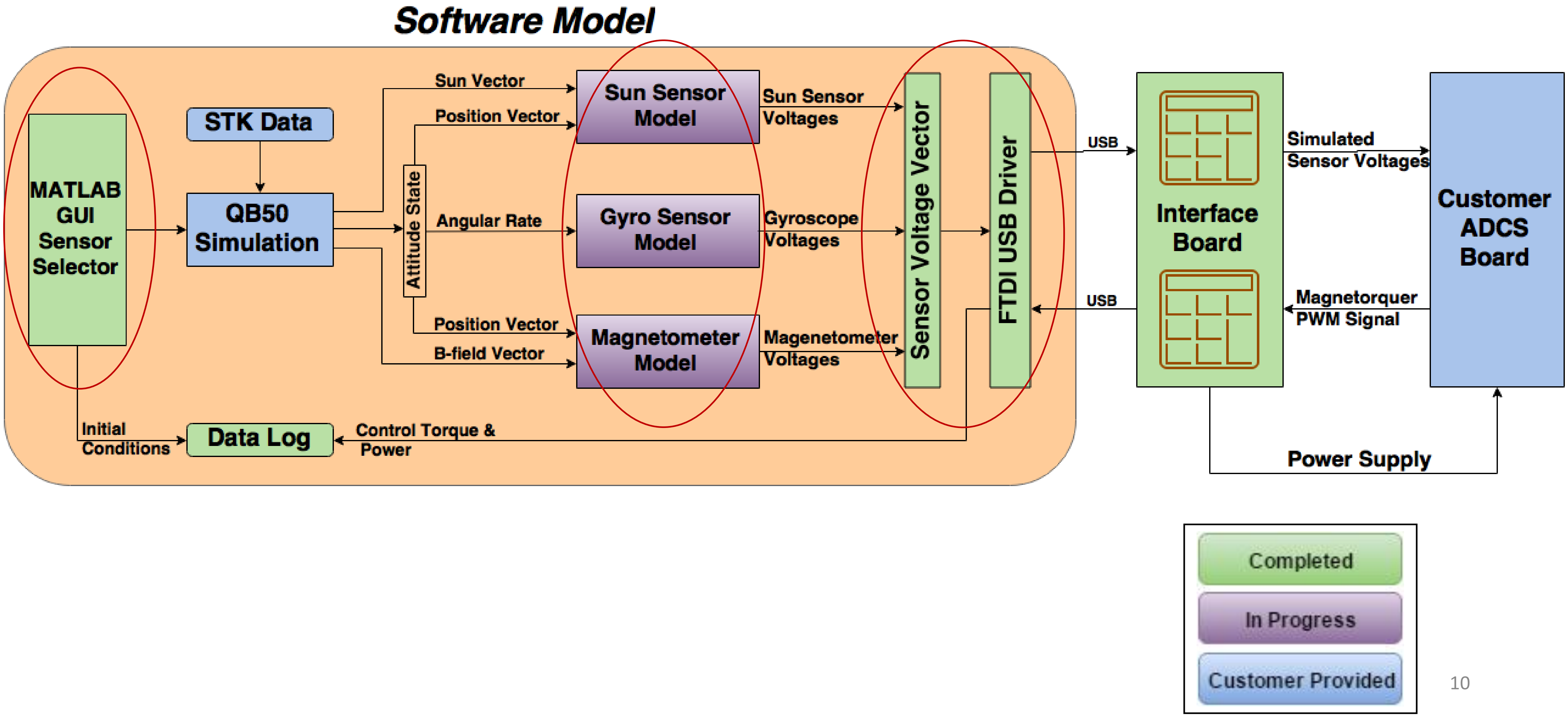


Matlab Simulation



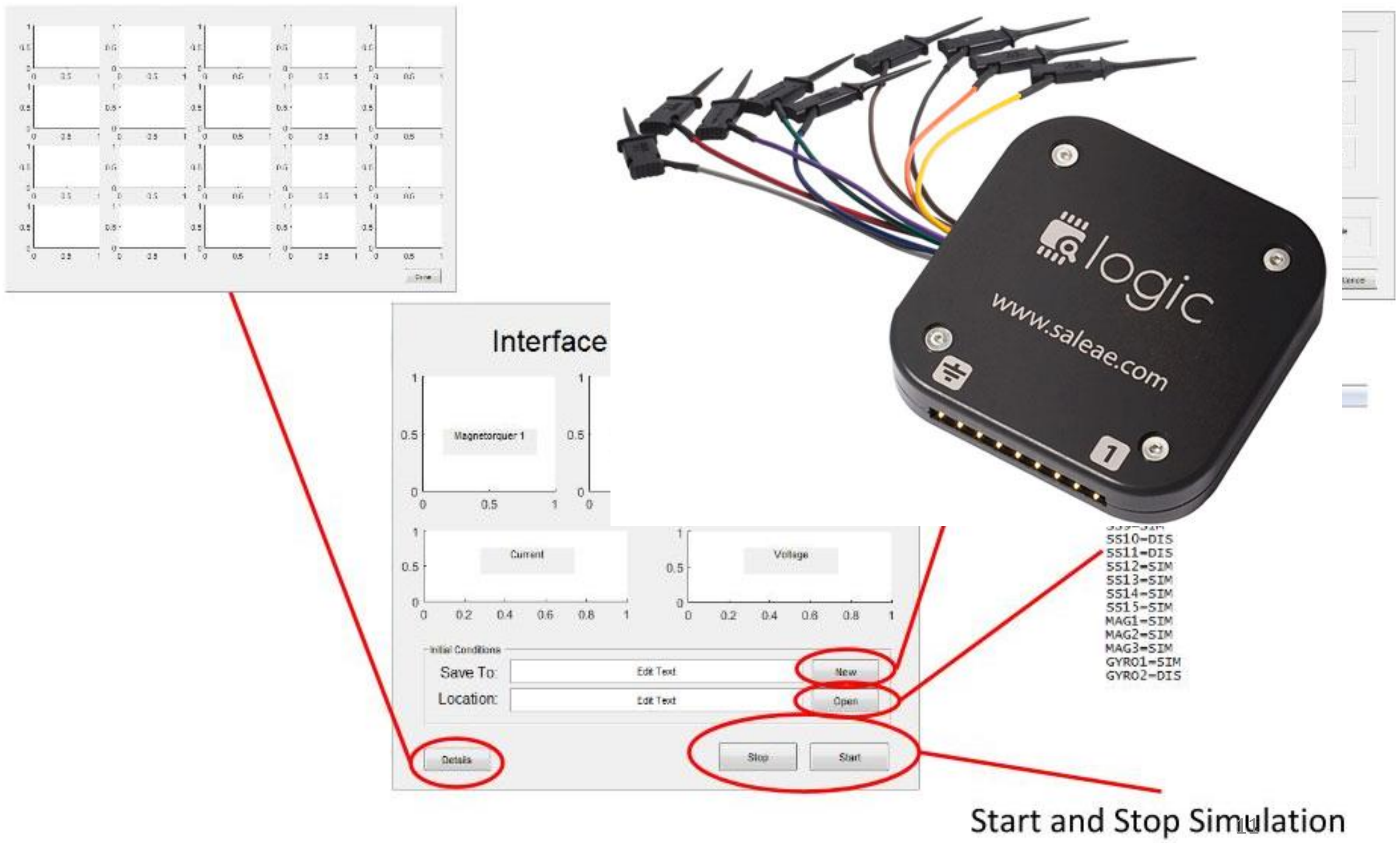

```
function ye = kalmanf(A,B,C,Q,R,u,t,yv) %#eml
P = B*Q*B';                          % Initial error covariance
x = zeros(size(B));                  % State initial condition
ye = zeros(length(t),1);
errcov = zeros(length(t),1);
for i=1:length(t)
  % Measurement update
  Mn = P*C'/(C*P*C'+R);
  x = x + Mn*(yv(i)-C*x);            % x[n|n]
  P = (eye(size(A))-Mn*C)*P;         % P[n|n]
  % Compute output
  ye(i) = C*x;
  errcov(i) = C*P*C';
  % Time update
  x = A*x + B*u(i);                   % x[n+1|n]
  P = A*P*A' + B*Q*B';                % P[n+1|n]
end
```

Software Flow Diagram

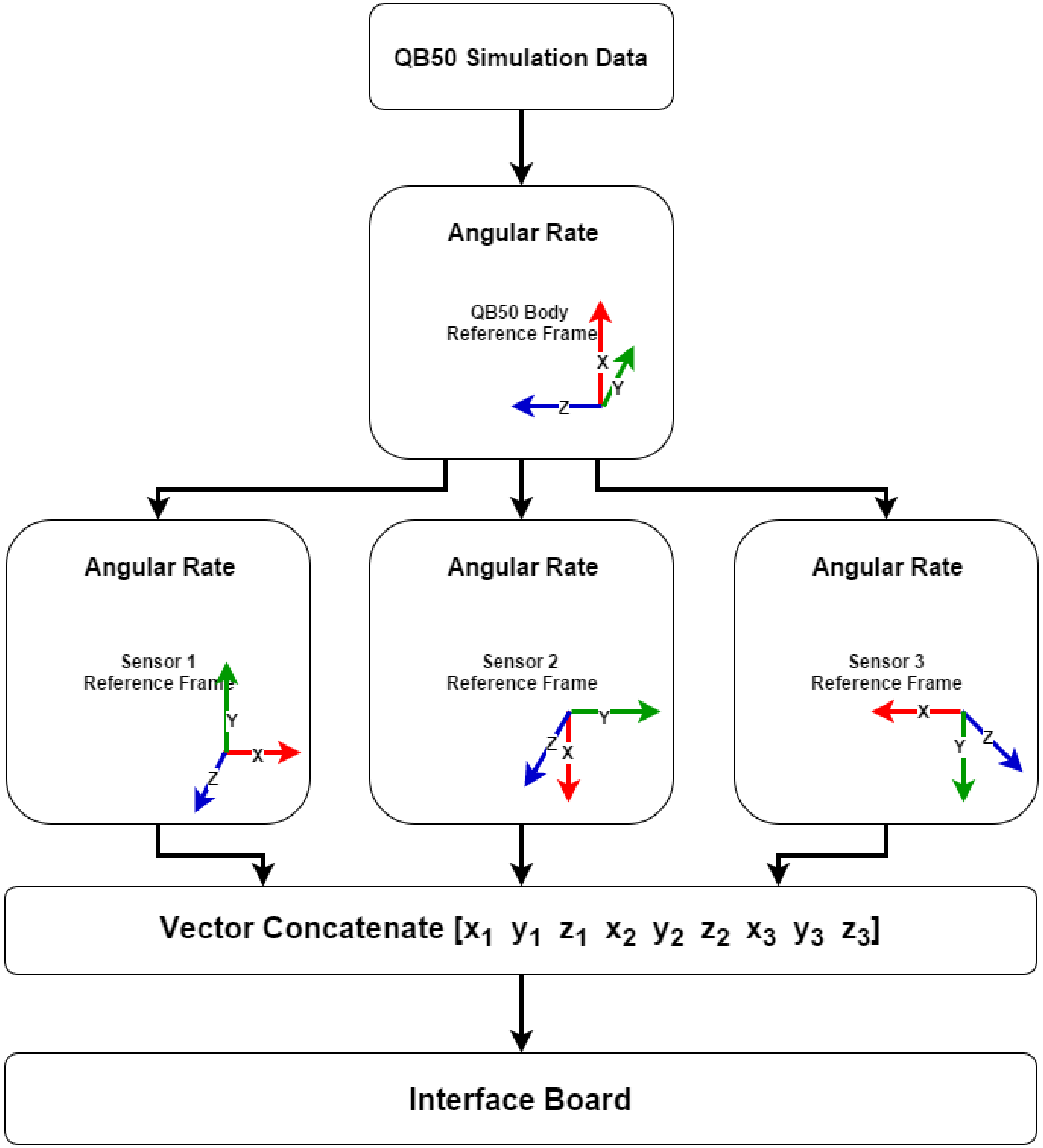


Software Current Status

- ✓ GUI Interface Bu
- ✓ FTDI Drivers veri
- ✓ Code developme
- ✓ Acquired QB50 G



Software Changes



Software – FTDI Driver Test

Purpose: Confirm data link with interface board

Test equipment:

- Interface Board
- PC or Mac
- MATLAB® Software
- FTDI Drivers

Procedure:

- Establish communication with FTDI Drivers
- Pass data to interface board
- Verify data received with digital logic analyzer

Validation:

- Verify MATLAB® can communicate with interface board

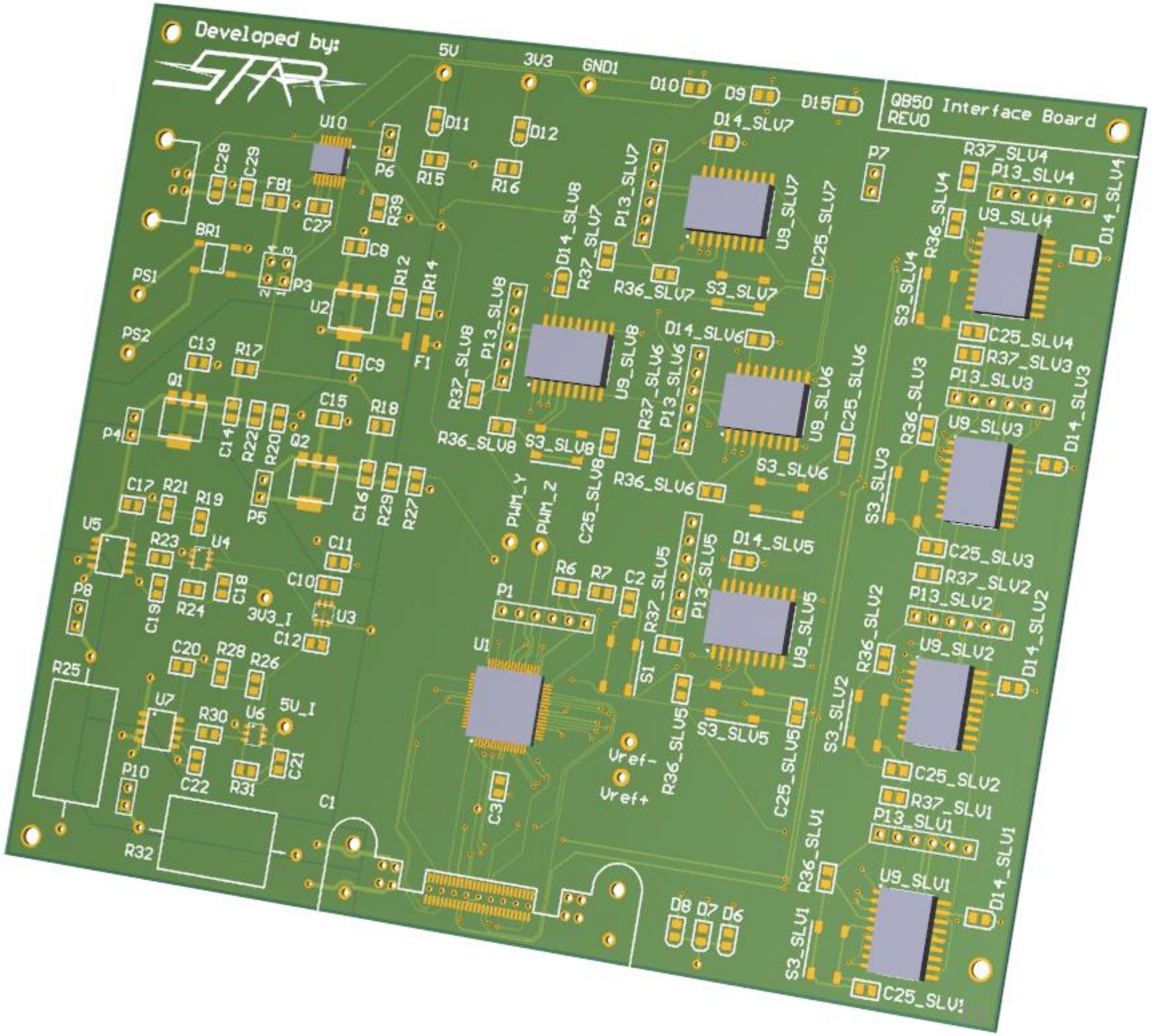
Risk Reduction:

- Confirms communication datalink

Software Future Work

Task	Estimated Time (Hours)	Margin (Hours)
Development of calibrated sensor models	25	15
Execute basic test program on Interface board	5	2
Transmit simulated sensor data to Interface Board	5	2
GUI Implementation	3	1
Compute Control Torque from PWM signal	3	1
Log Control Torque and Power Consumption Data	3	1
Full Software System Test	20	10
TOTAL	**64**	**32**

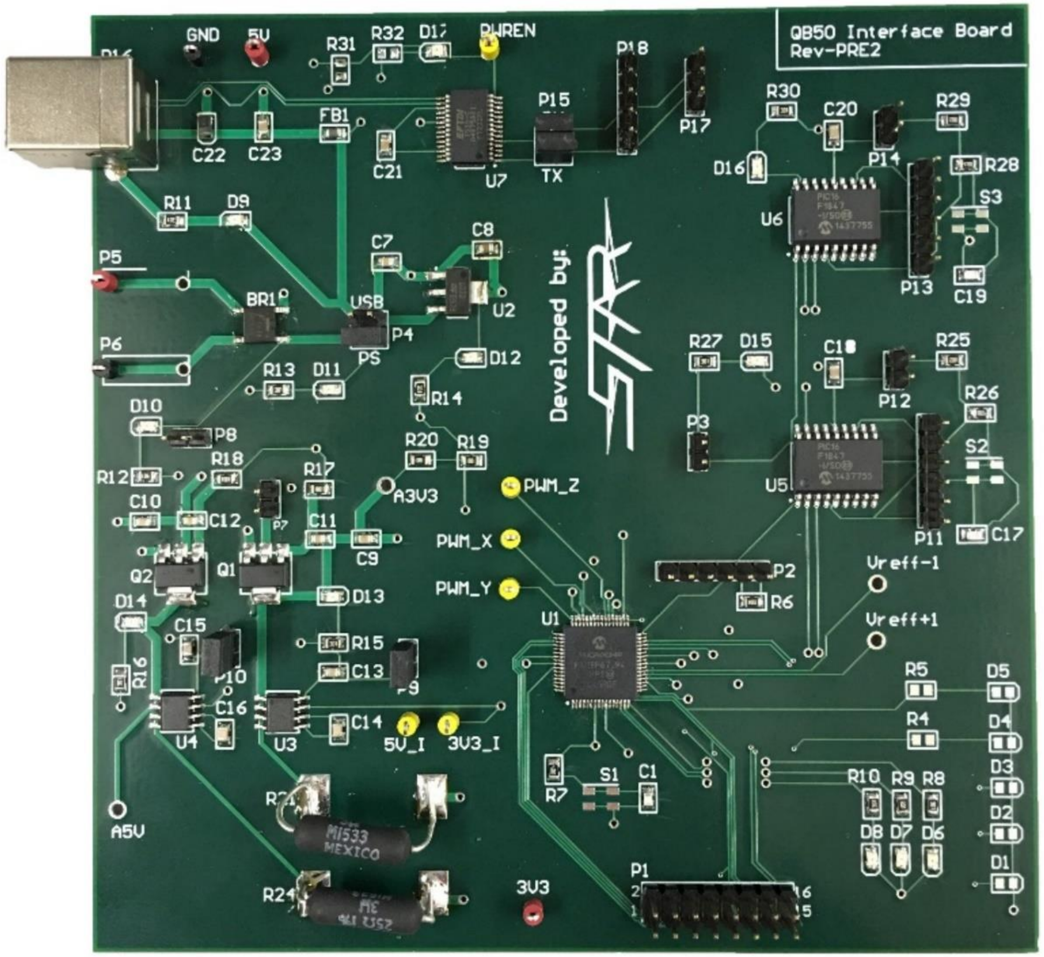
Interface Board



Currently Completed Tasks

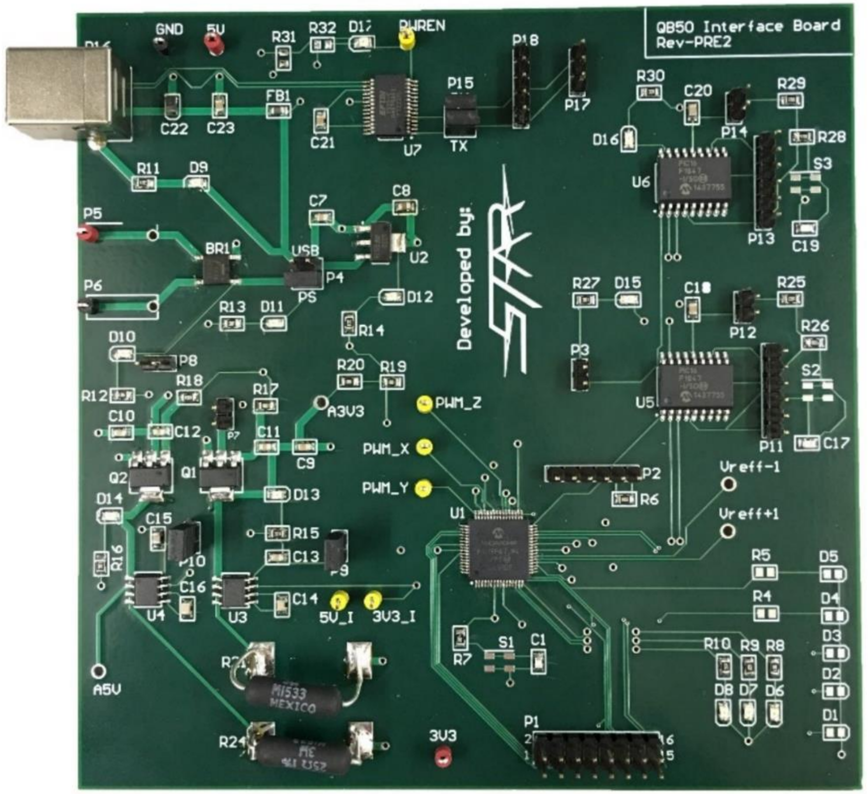
- FTDI Chip
  - USART Transmitting (from PC into Master)
  - USART Receiving (from Master into PC)
- Master Microcontroller
  - Programmable
  - I/O Pins Verified
  - Receiving USART Data
  - Transmitting USART Data
- Slave Microcontroller
  - Programmable
  - I/O Pins Verified
- Board
  - Testing Board Fully populated
  - Power (5V & 3.3V) is functional
  - ADCS power switches (MOSFETs) work
  - Current sensors work and measure accurately

PRE2 Testing Board

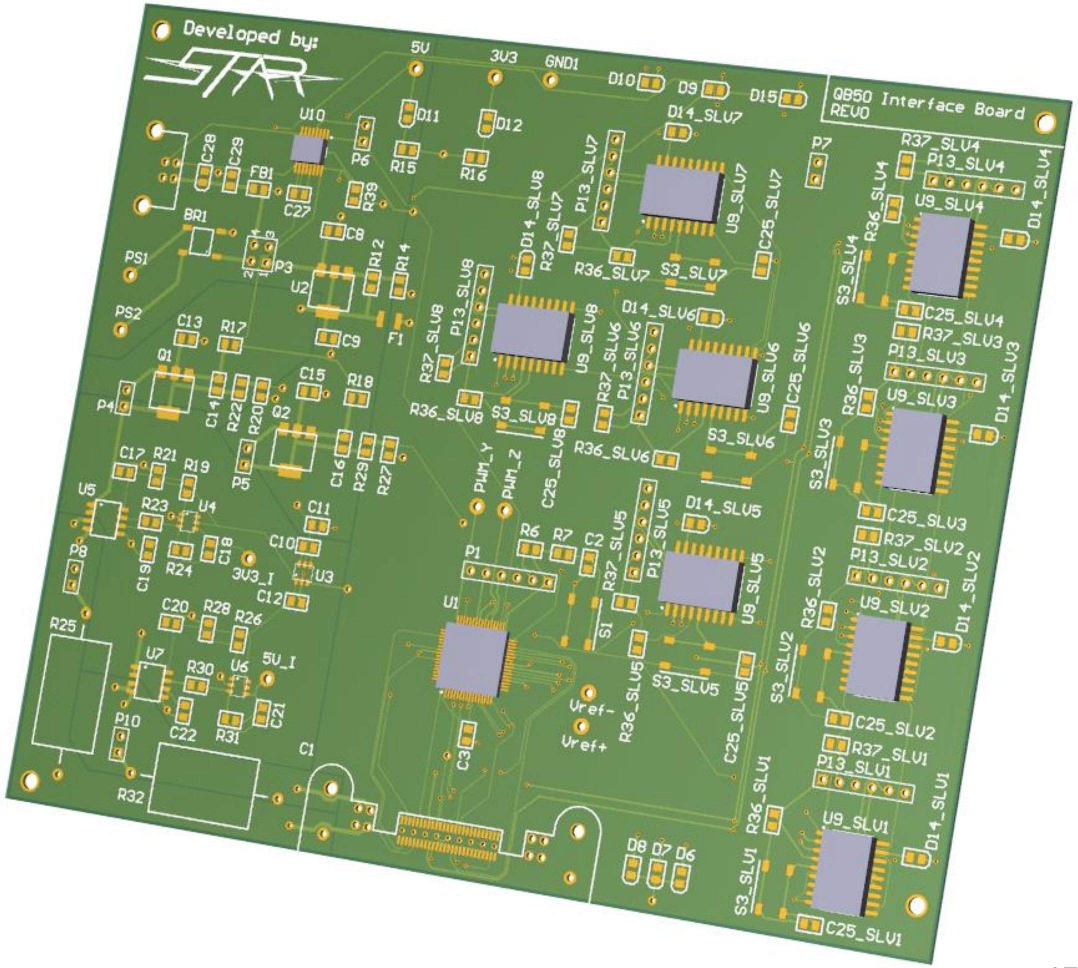


Board Revision

PRE2 Testing Board



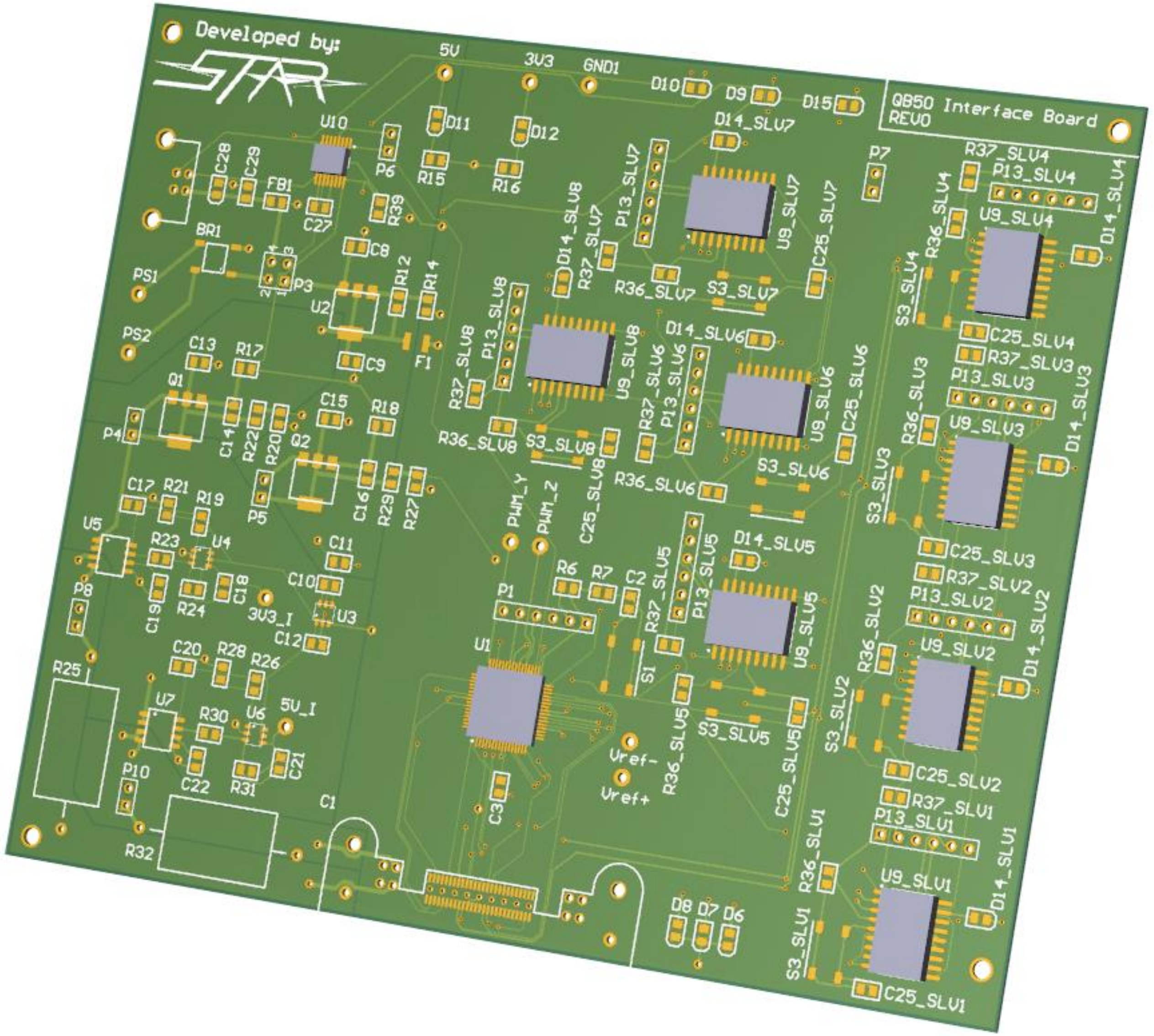
REV0 Production Board



Implemented Fixes since MSR

- FTDI Chip
  - Switched to FT230X
    - Will fix power enable glitch (discussed in MSR)
- Master Microcontroller
  - Board design changed I/O pins
    - Fixed issues discovered in Errata
- Slave Microcontroller
  - Board now fully populated with all 8 controllers
- Board
  - Small changes to board layouts
    - Soft Reset button footprints corrected
- ADCS Sensors
  - Added step-up/step-down converters, preventing inaccurate measurements
    - Issue discussed in MSR

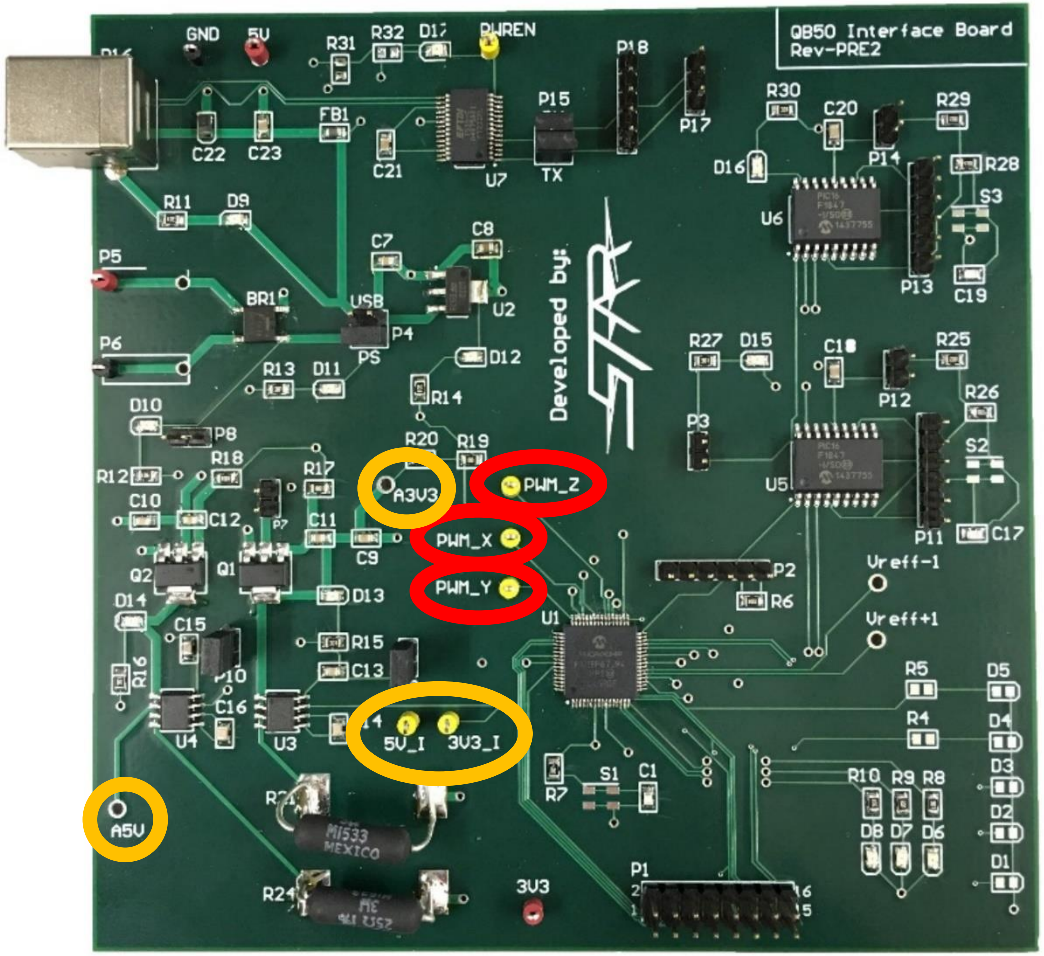
REV0 Production Board



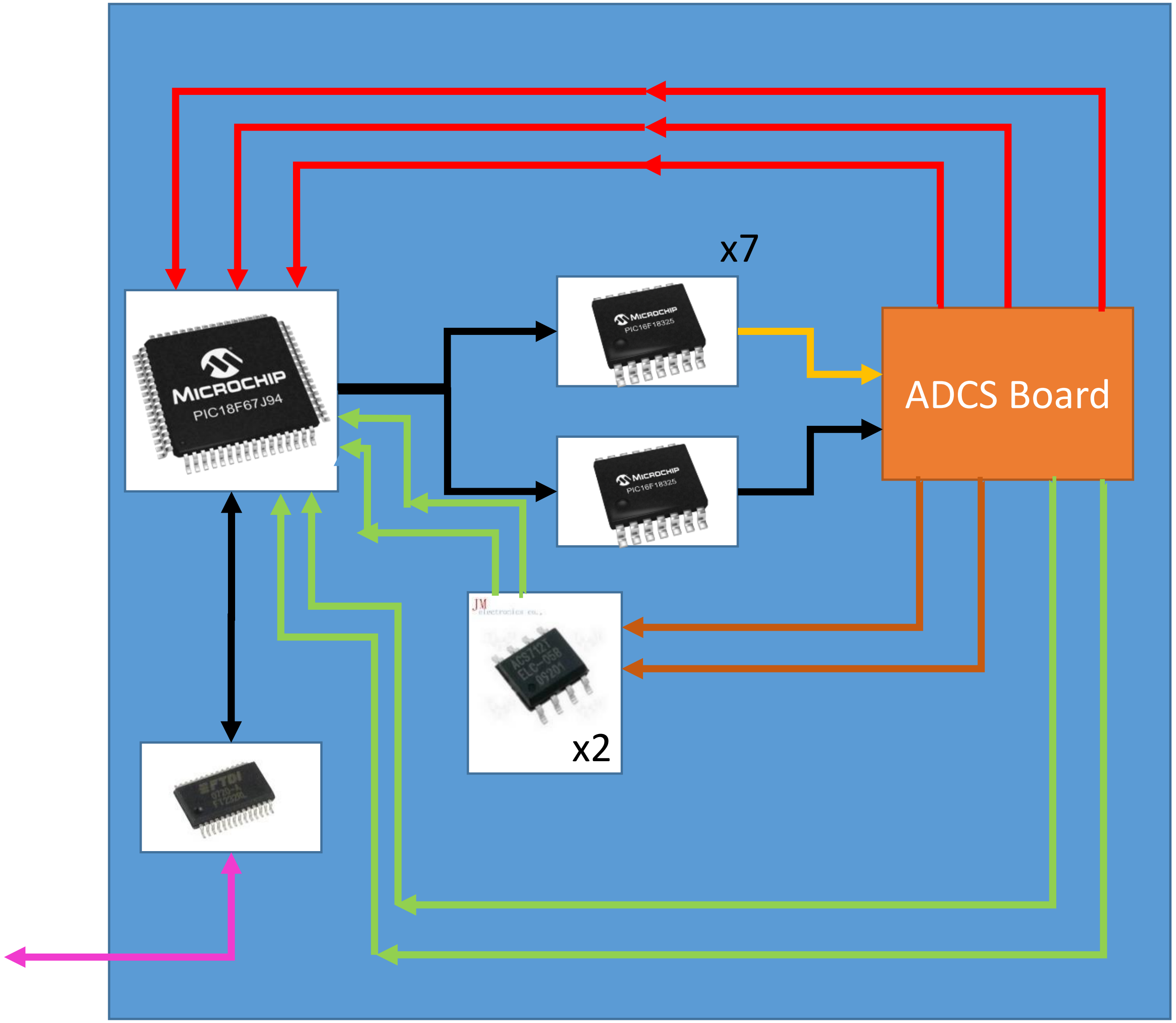
Remaining Tests

- Master to Slave Controllers
  - Transmit line to be verified via Logic Analyzer
- Slave to ADCS
  - Transmit/Receive Line verified via Bus Pirate
  - Address mapping received from graduate students
- PWM Capture
  - Capture times for each magnetorquer signal
  - Transmit data over USART
- Voltage/Current Sensors
  - Configure ADC channels
  - Transmit data over USART

PRE2 Testing Board



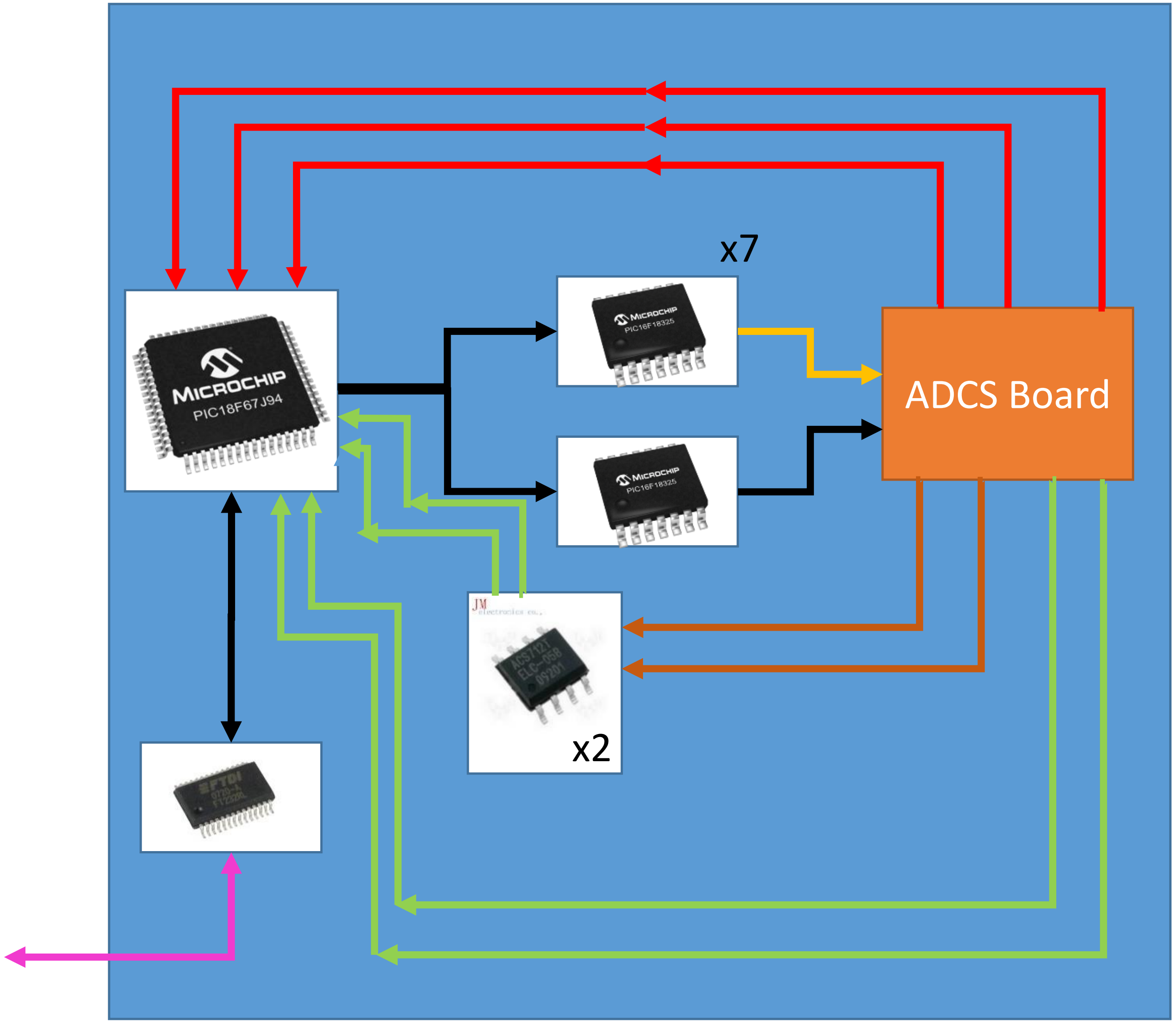
Full Board Design (Block Diagram)



Legend:

- = USART
- = I^2C
- = FTDI – USB
- = FTDI Chip
- = PIC18F67J94 (Master)
- = PIC16F1874 (Slave)
- = PWM Signals (X,Y,Z)
- = Voltage
- = Current
- = Current Sensor

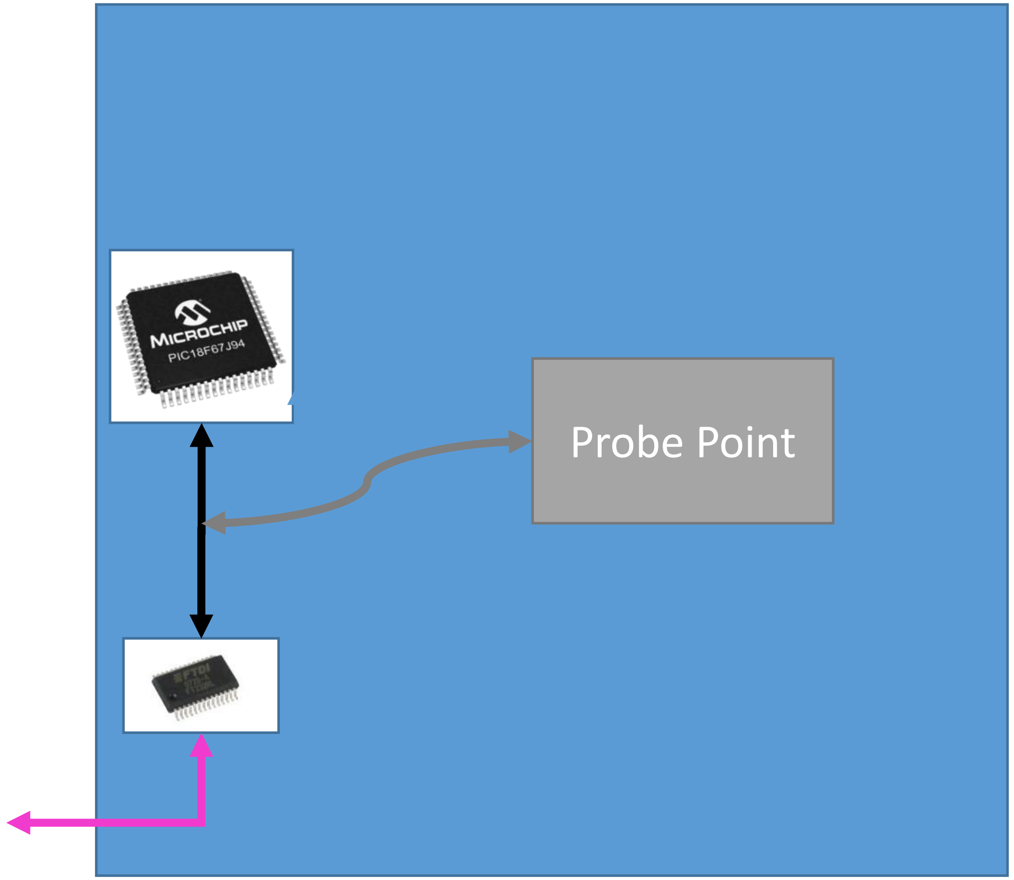
Overall Required Functionality



- Send simulated sensor data into ADCS Board, measure power draw and magnetorquer response

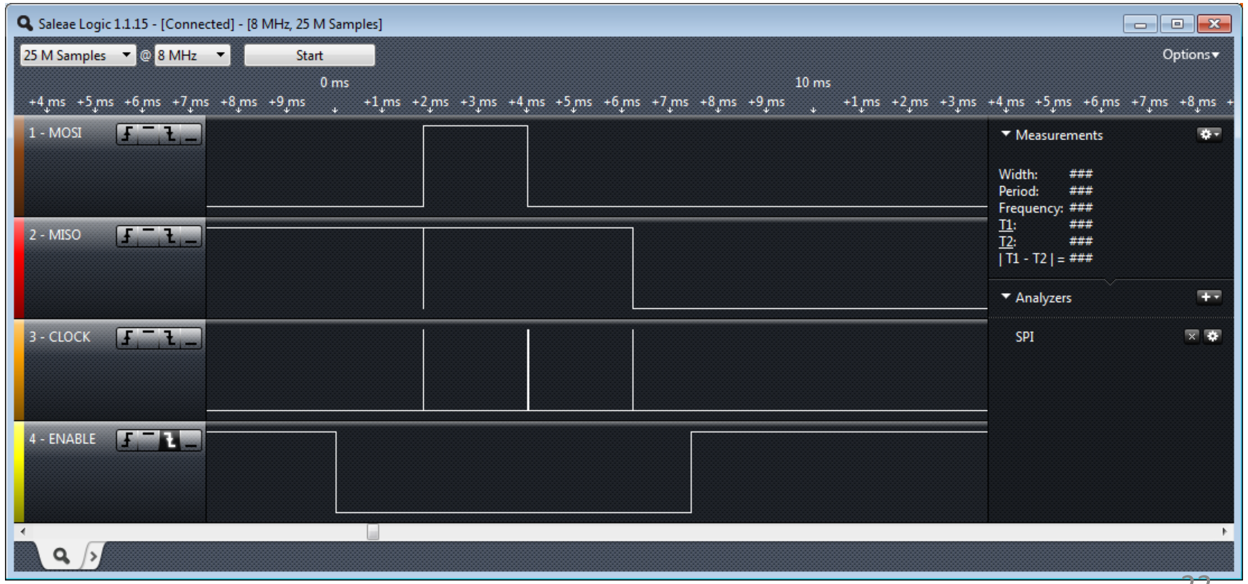
Transmitted Data	Sensor	Sent Over
	Sun Sensors (x15)	I^2C
	GPS (X,Y,Z)	USART
	Magnetometers (X,Y,Z)	I^2C
	Rate Gyros (X,Y,Z)	I^2C
Received Data		
	Magnetorquer Response as PWM Signal (X,Y,Z)	
	3.3V line voltage	
	3.3V line current	
	5V line voltage	
	5V line current	

Overall Required Functionality

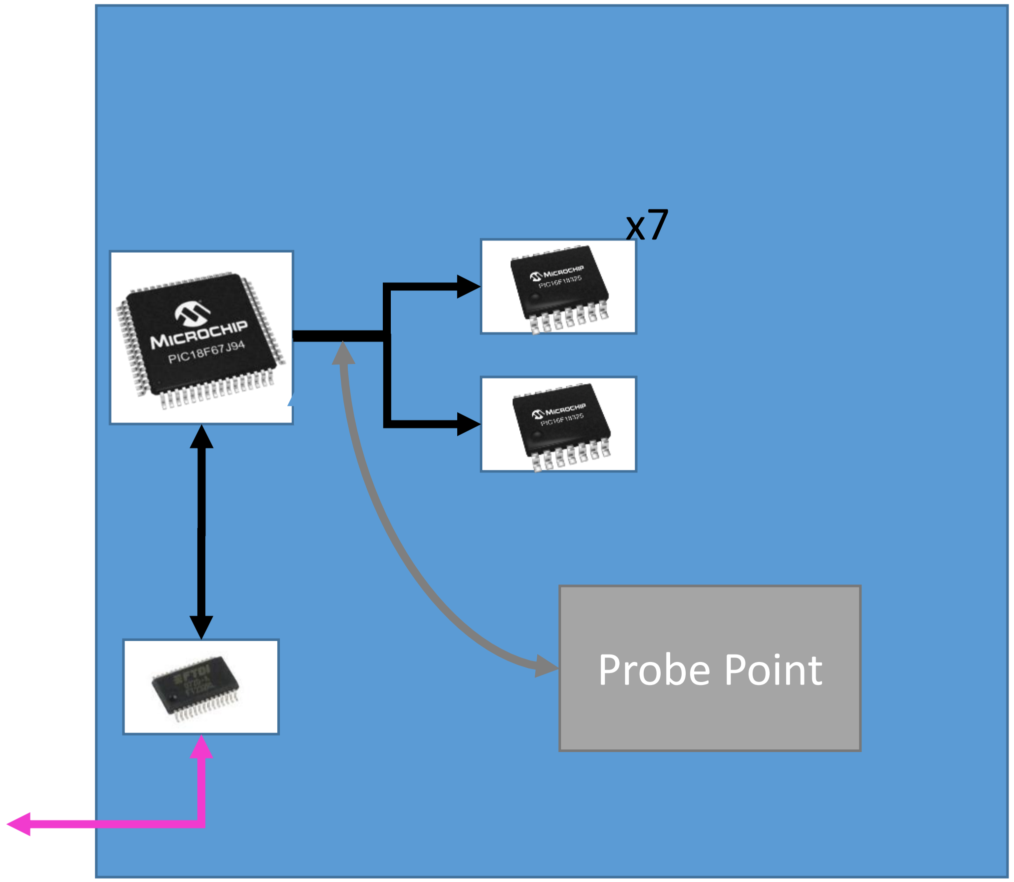


- PC → FTDI → Master µC (µC → Microcontroller)
  - Use Digital Logic Analyzer to verify correct data transfer

- Digital Logic Analyzer (DLA)
  - -USART communication
  - -ASCII recognition

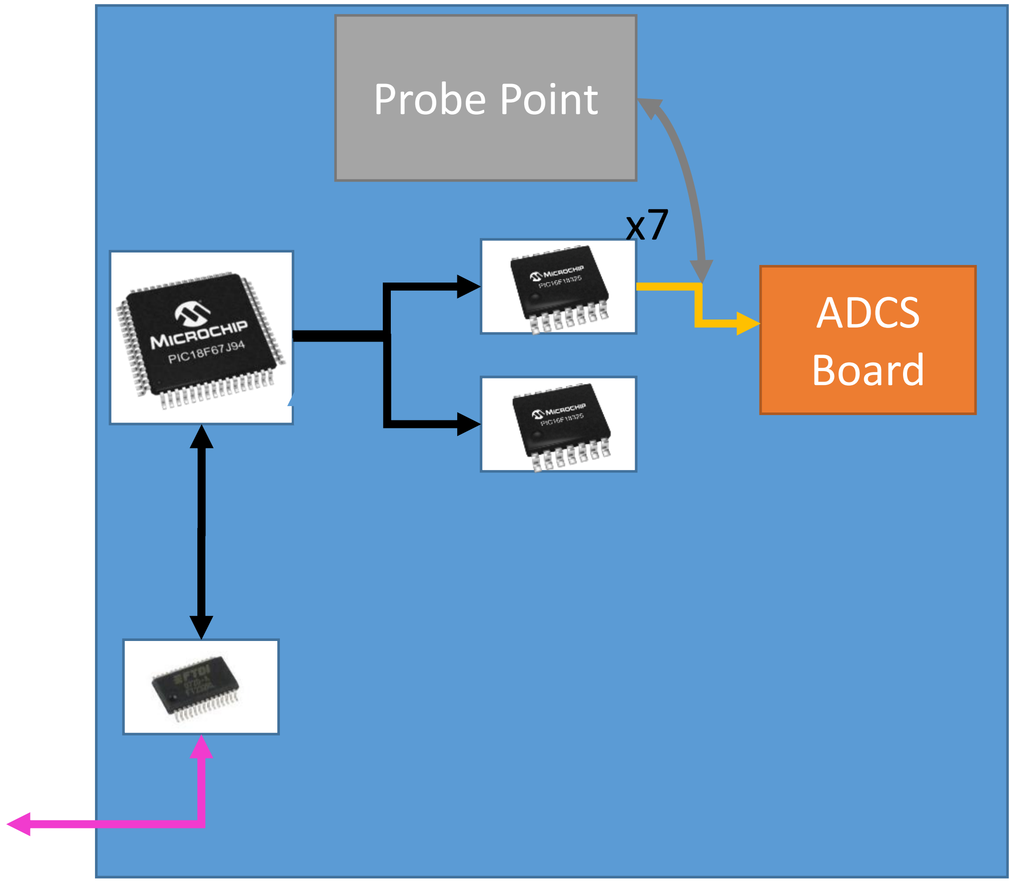


Overall Required Functionality



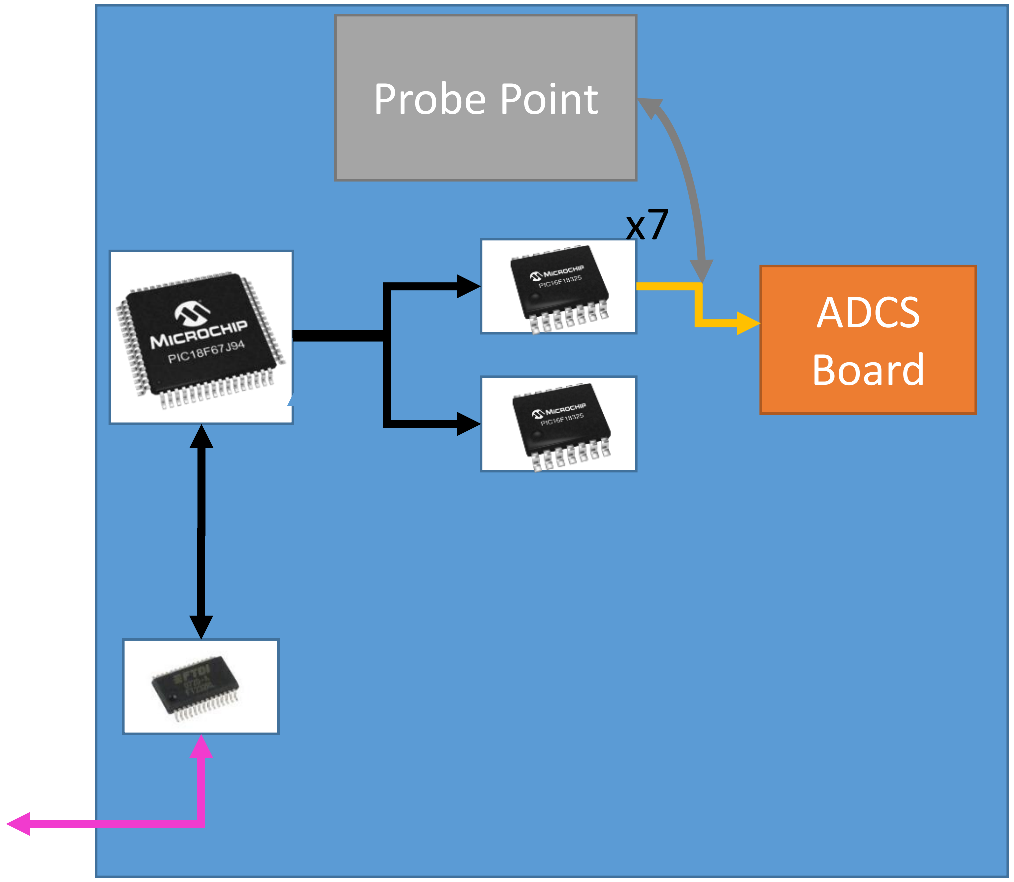
- PC → FTDI → Master µC
  - Use Digital Logic Analyzer to verify correct data transfer
- Master µC → Slave µCs
  - Use DLA to verify transmitted data
  - Light LEDs when data is recognized

Overall Required Functionality

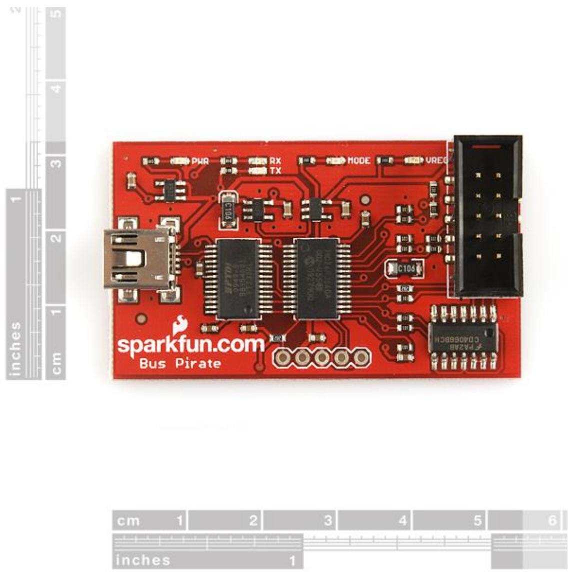


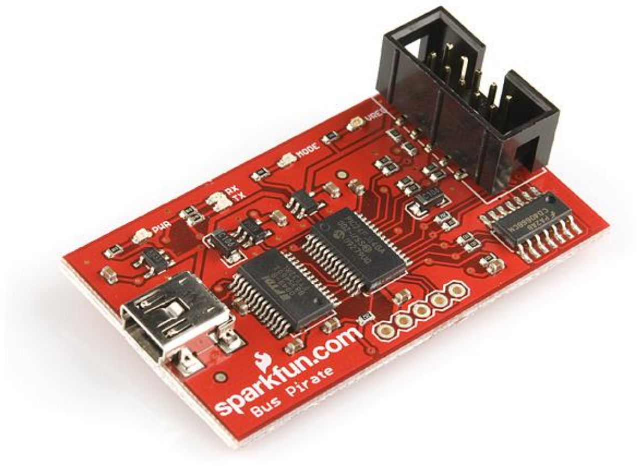
- PC → FTDI → Master µC
  - Use Digital Logic Analyzer to verify correct data transfer
- Master µC → Slave µCs
  - Use DLA to verify transmitted data
  - Light LEDs when data is recognized
- Slave µCs → ADCS
  - Query, verify transmission over I^2C line via Bus Pirate

Overall Required Functionality



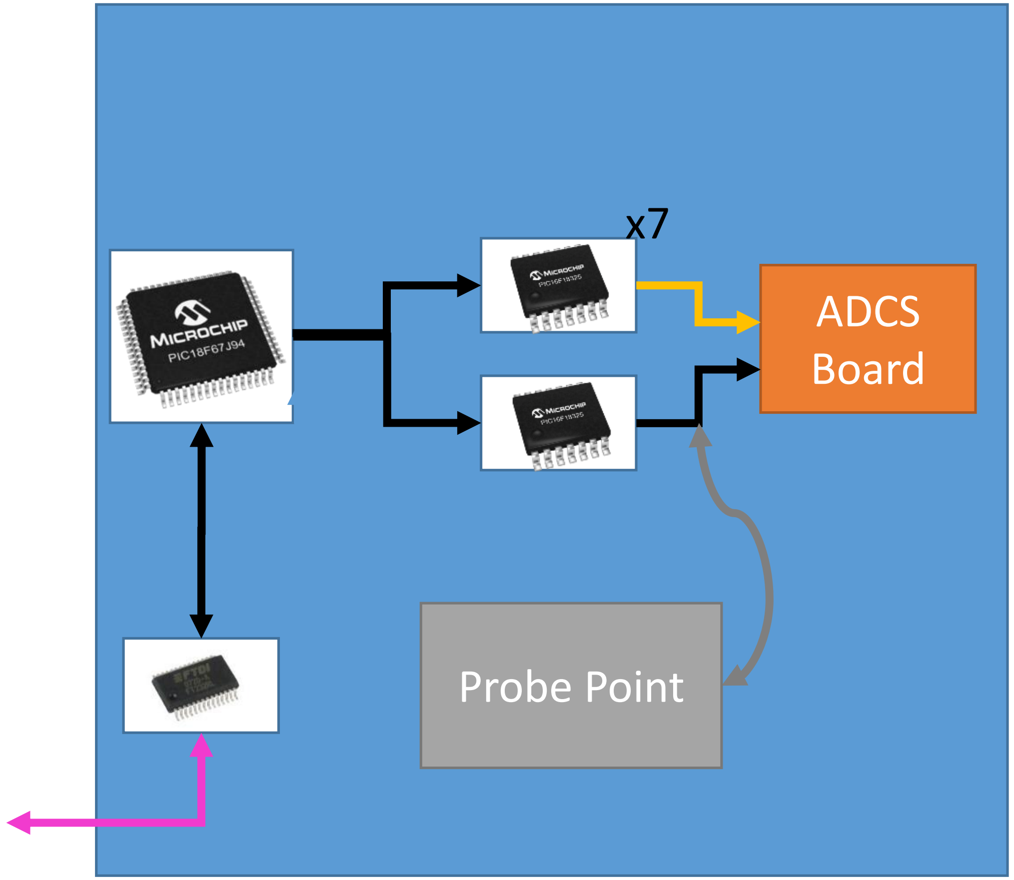
- Bus Pirate
  - Functionally similar to DLA
  - Includes I^2C Communication
  - Can send and receive data





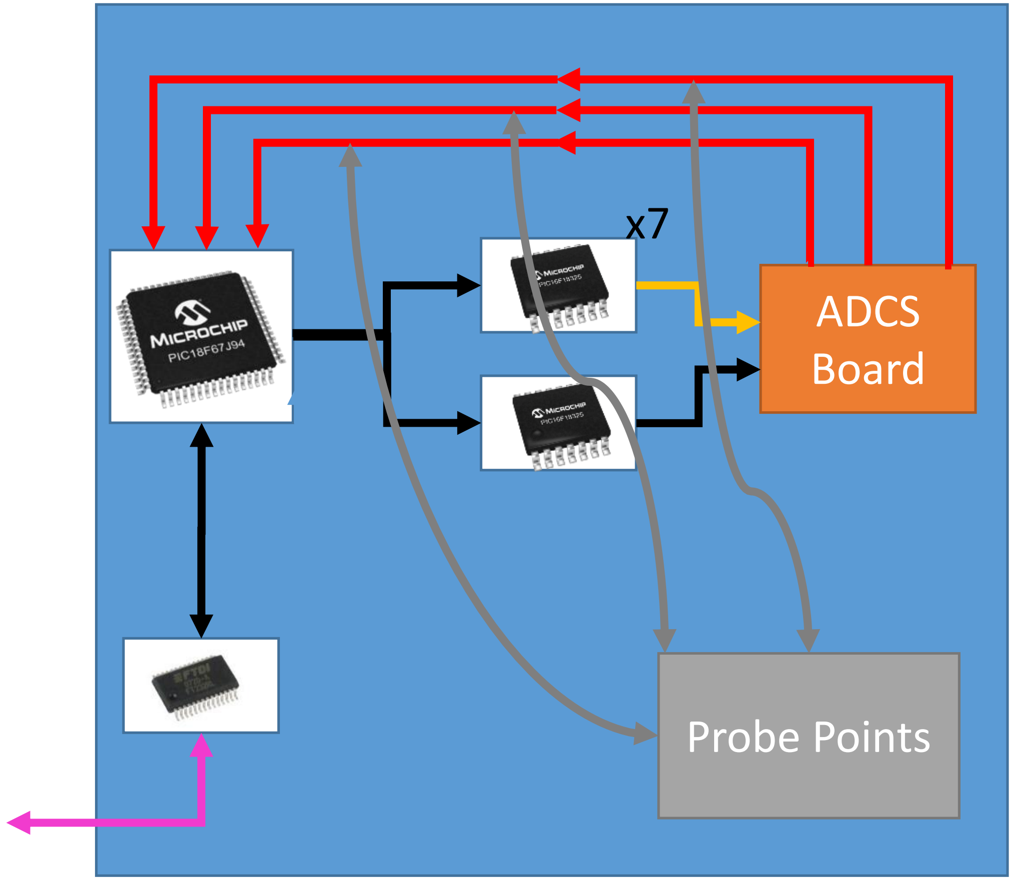
- Slave µCs → ADCS
  - Query, verify transmission over I^2C line via Bus Pirate

Overall Required Functionality

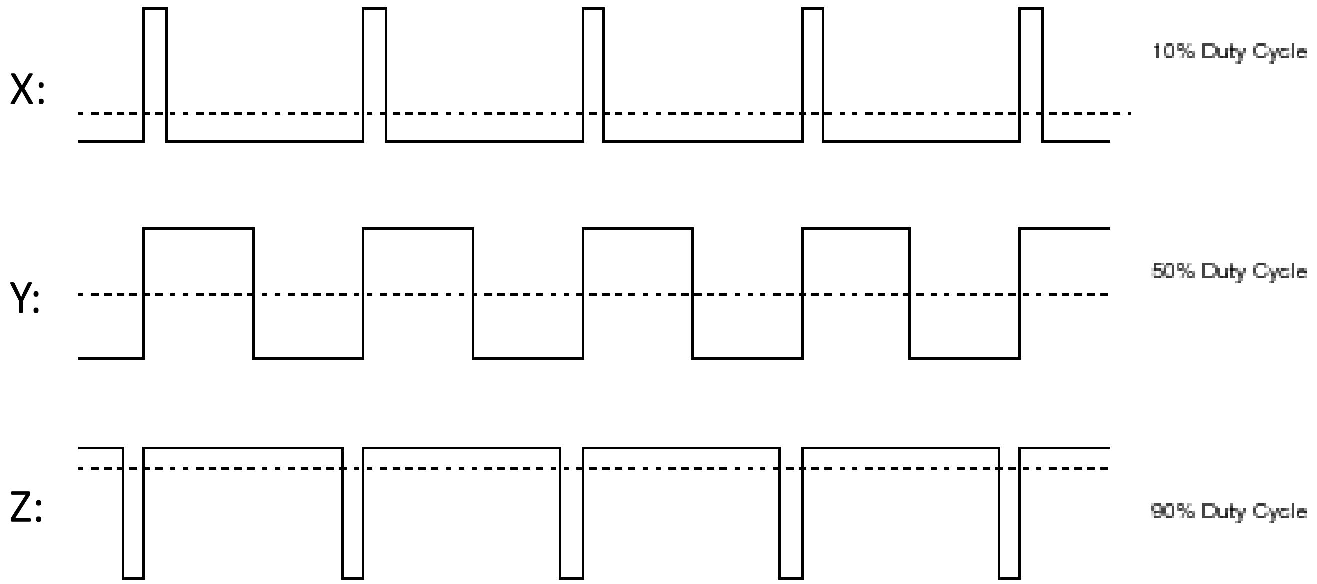


- PC → FTDI → Master µC
  - Use Digital Logic Analyzer to verify correct data transfer
- Master µC → Slave µCs
  - Use DLA to verify transmitted data
  - Light LEDs when data is recognized
- Slave µCs → ADCS
  - Query, verify transmission over I^2C line via Bus Pirate
  - Verify USART line with DLA

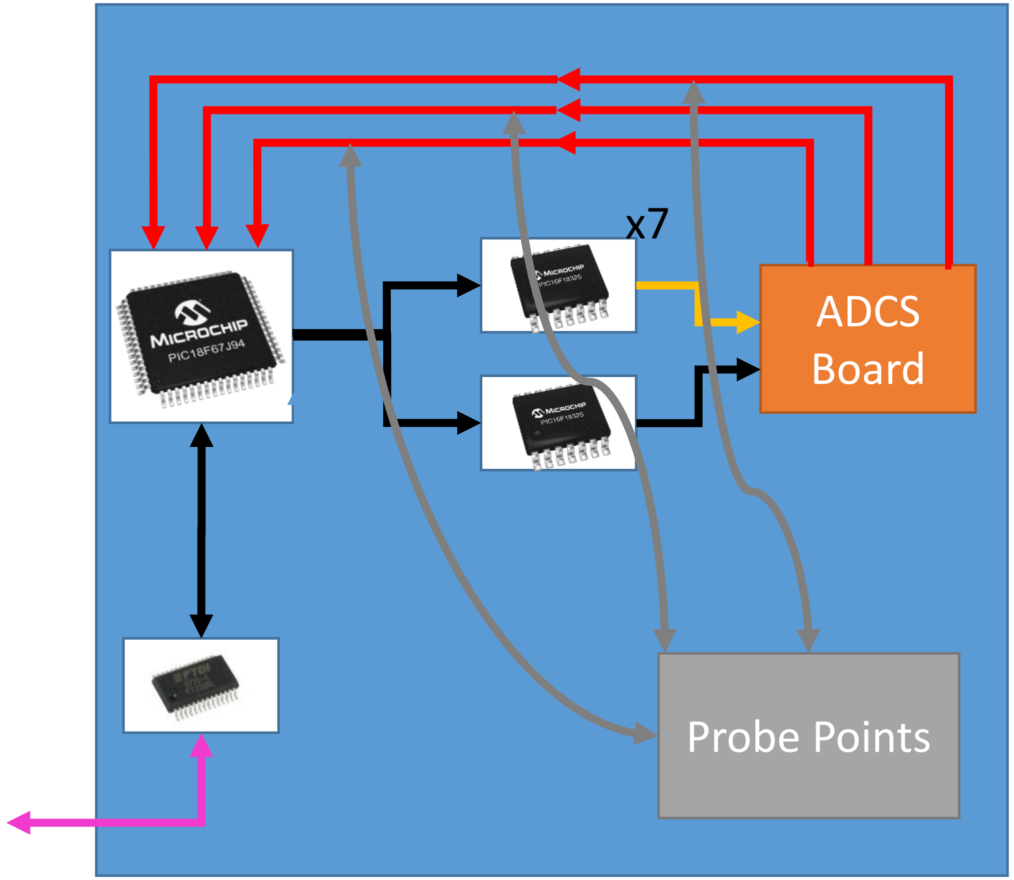
Overall Required Functionality



- Magnetorquer PWM → Master µC
  - Use function generator as base
  - Use oscilloscope to verify



Overall Required Functionality



- Magnetorquer PWM → Master µC
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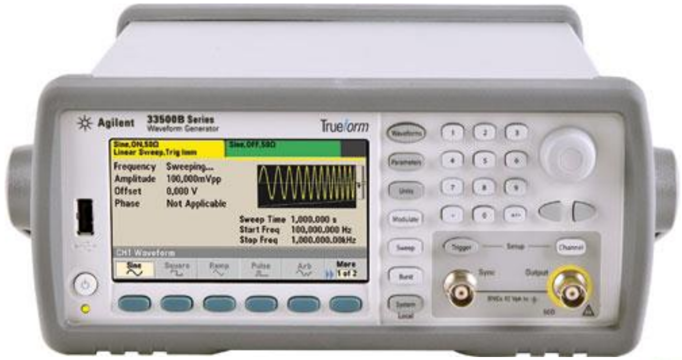
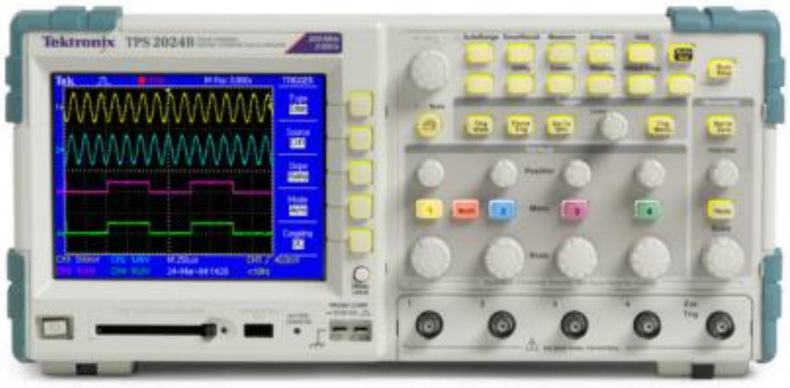
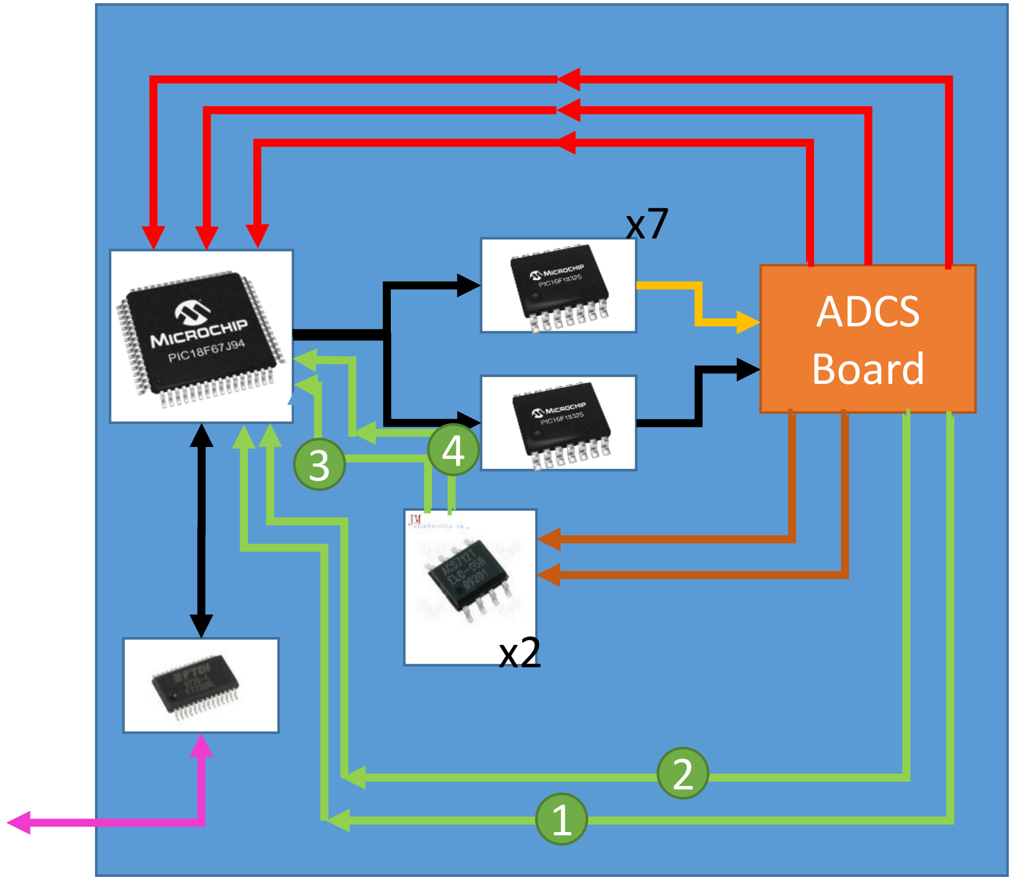


- Function Generator
  - Mimic the X, Y, and Z magnetorquer PWM signals
    - Frequency
    - Voltage range

- Oscilloscope
  -Live feed of voltages



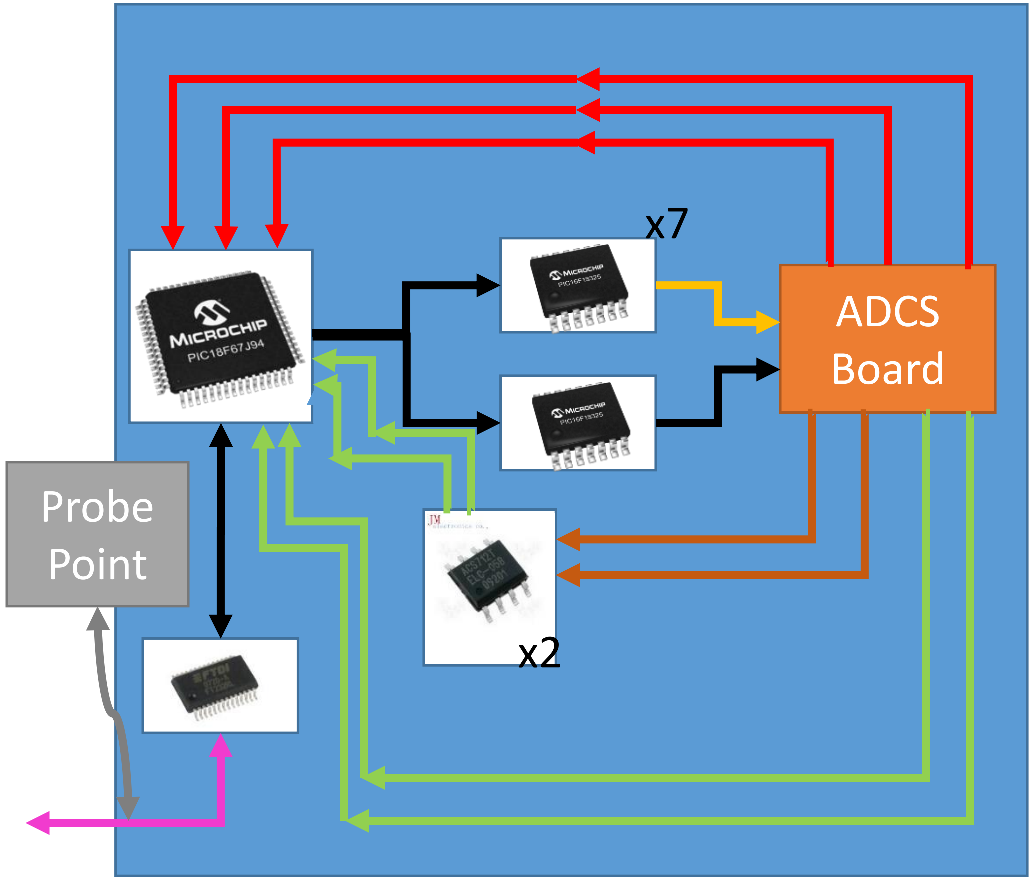
Overall Required Functionality



- Magnetorquer PWM → Master µC
  - Use function generator as base
  - Use oscilloscope to verify
- Power draw → Master µC
  - Use oscilloscope to verify voltages

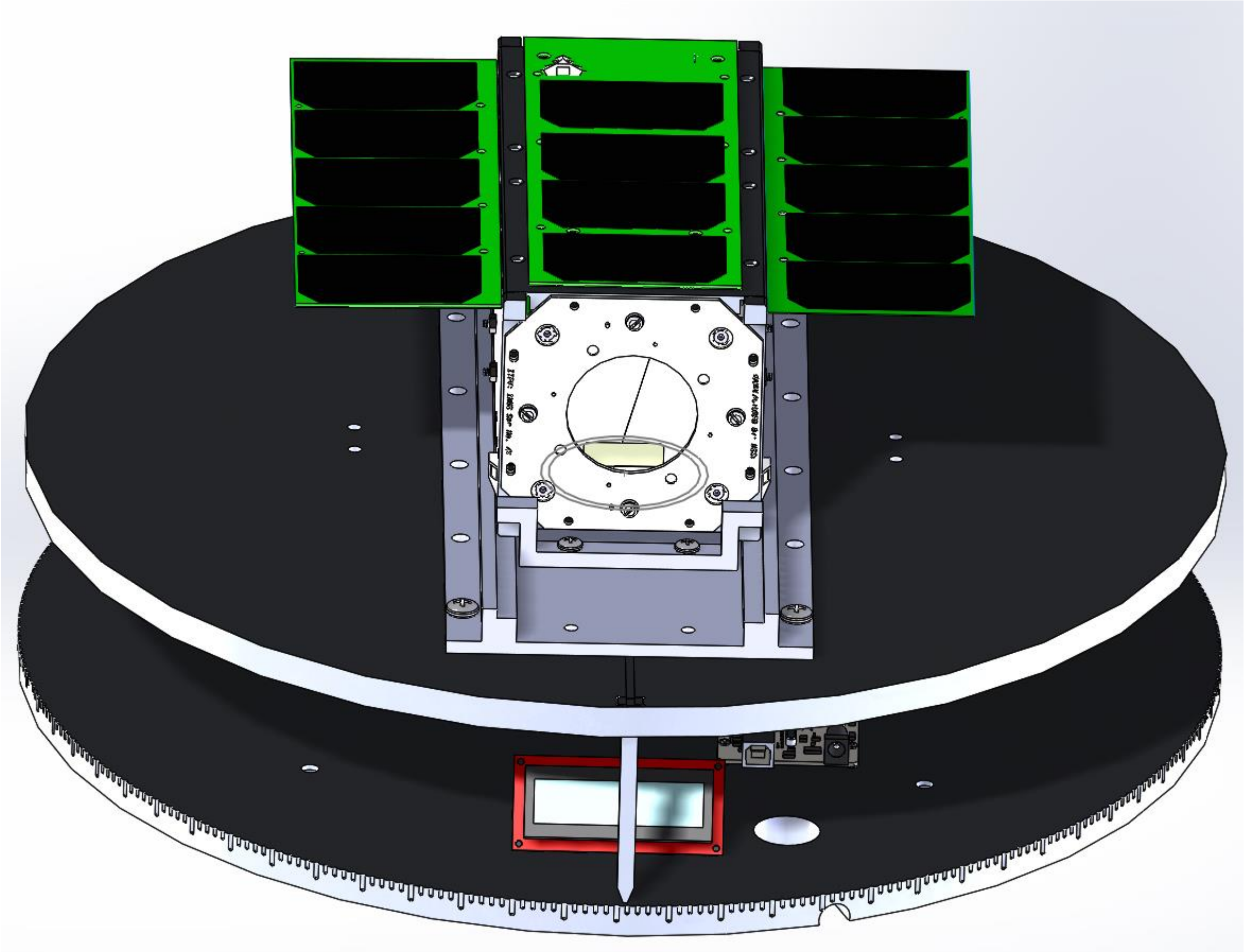
Point	Line	Measuring
1	3.3V line Raw Voltage	Voltage [V]
2	5V line Raw Voltage	Voltage [V]
3	3.3V line Current	Current [A]
4	5V line Current	Current [A]

Overall Required Functionality



- Magnetorquer PWM → Master μC
  - Use function generator as base
  - Use oscilloscope to verify
- Power draw → Master μC
  - Use oscilloscope to verify voltages
- Data (on Master μC) → PC
  - Use DLA to analyze received data
  - Compare sent data to received data on Matlab

Sun Sensor Turntable

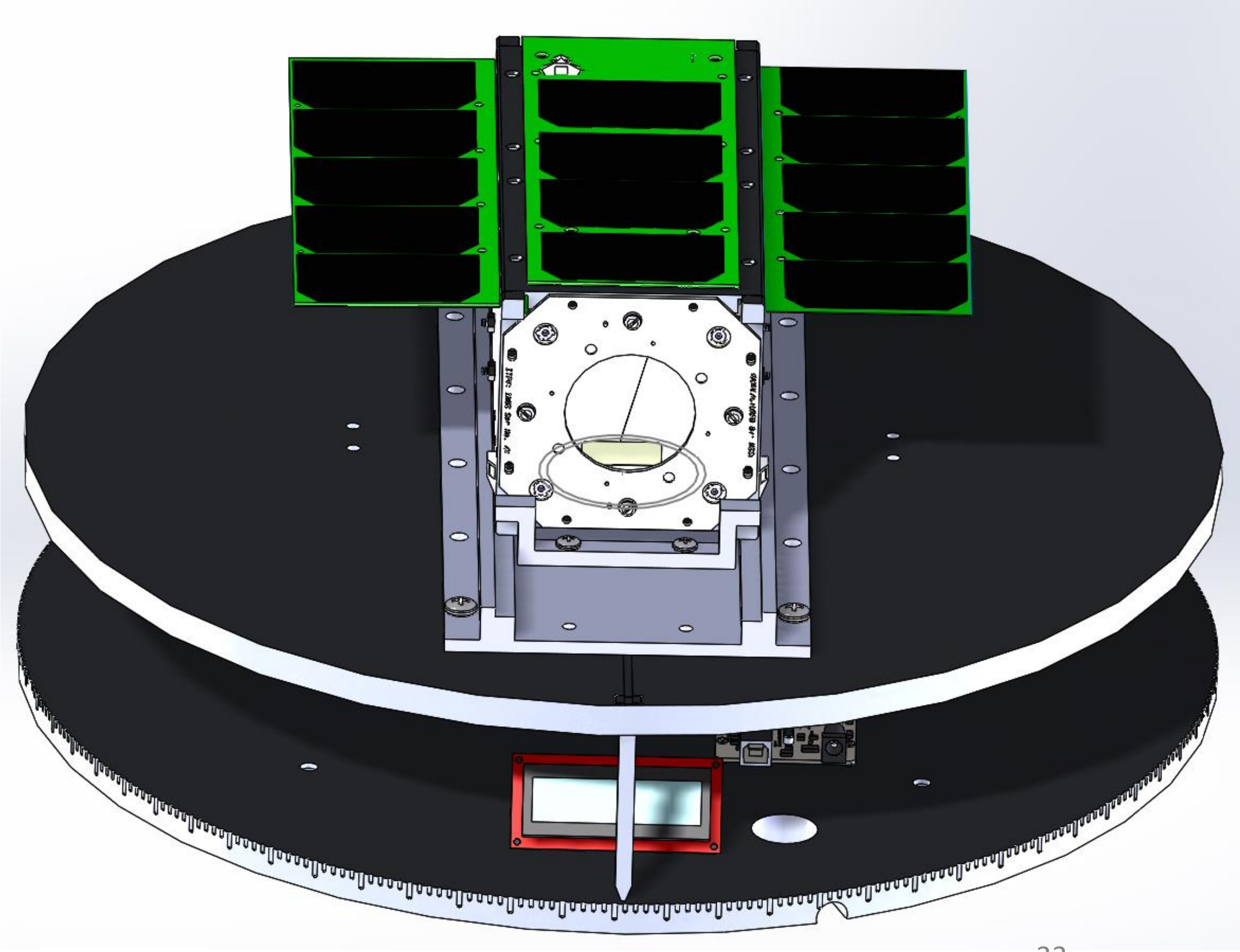


Status Update

- Manufacturing
  - Completed
    - Horizontal Clamp
    - Top Board – Shipped for coating
  - Remaining components
    - Shaft (0%, 4 Hours remaining)
    - Bottom Board (15%, 4 Hours remaining)
    - Vertical Clamp (85%, 2 Hours remaining)
- Electronics
  - Encoder – 340 degree range (20 – 360)
    - Multi-turn encoders would have less than required ±0.5° resolution

Turntable – Test Overview

1. Match angle etchings with encoder reading
2. Rotate at constant angular rate
3. Point to commanded angle



Turntable – Angle Accuracy Test

Purpose: Confirm angle etchings match angle displayed on LCD

Procedure:

- Zero encoder
- Manually rotate turntable to each angle etching
- Compare physical and electronic an

Test equipment:

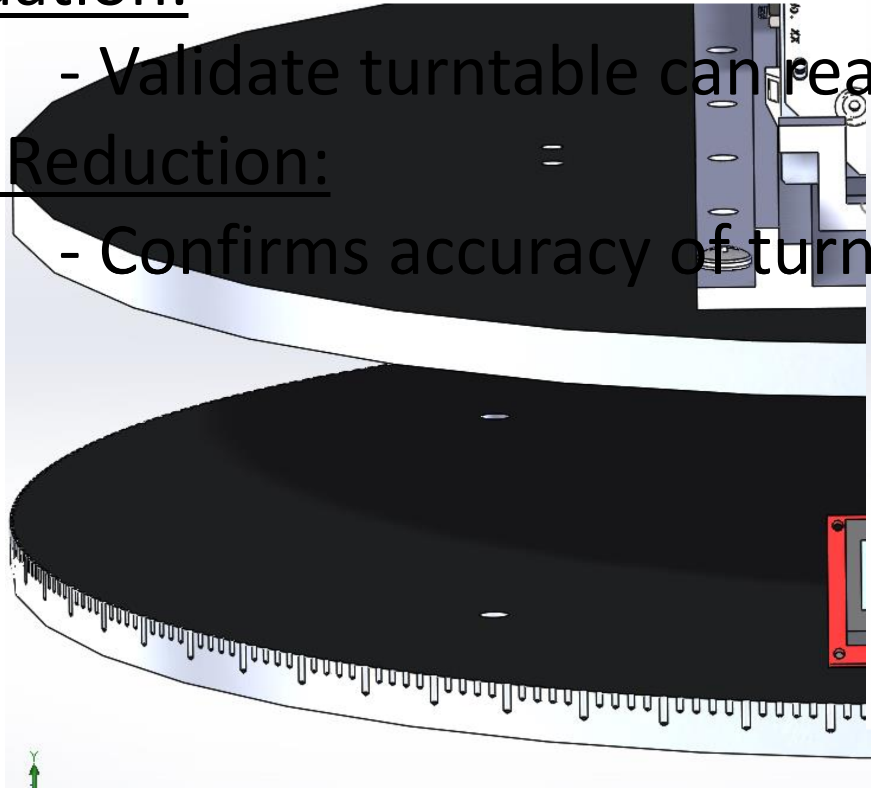
- Power supply
- Assembled turntable

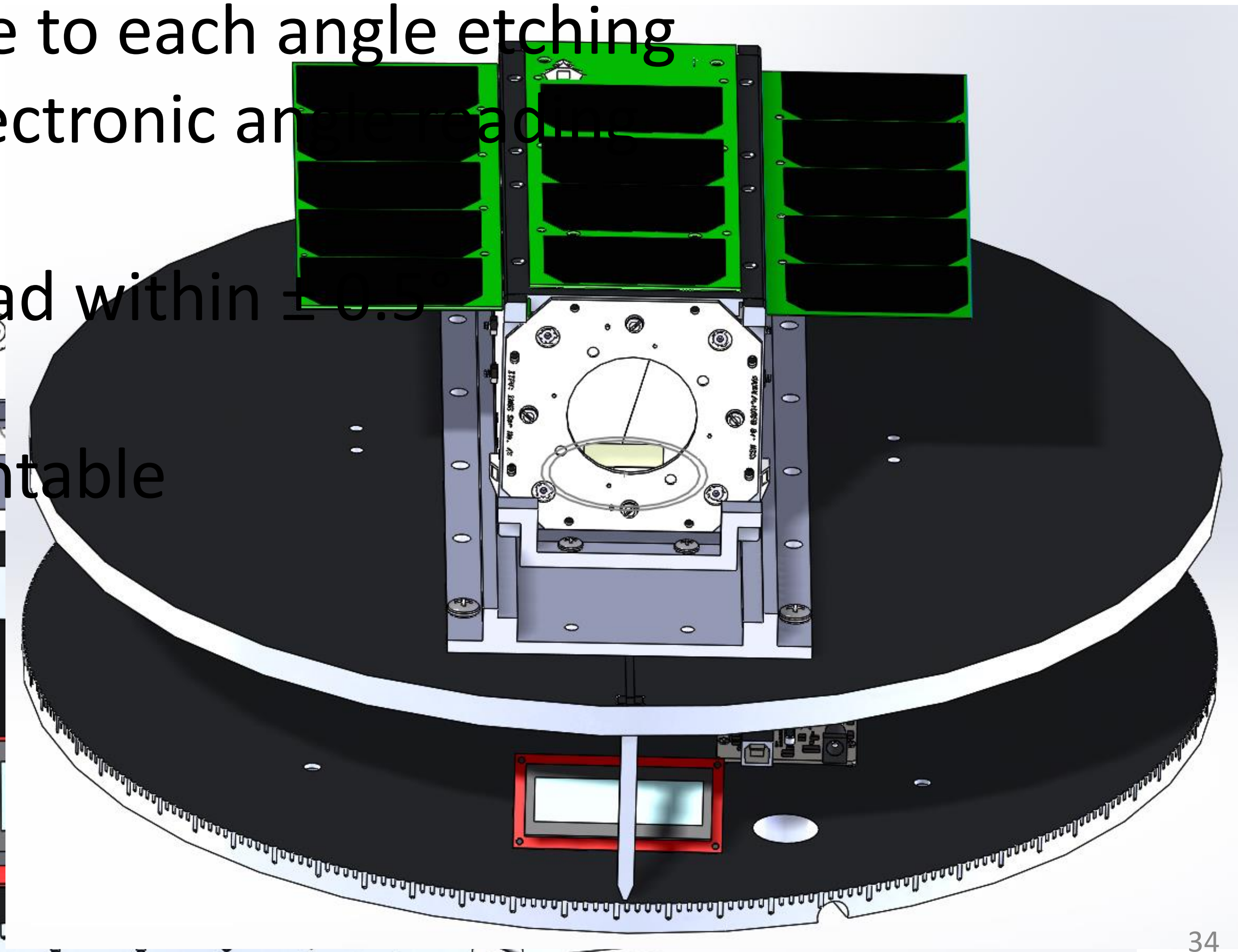
Validation:

- Validate turntable can read within ± 0.5

Risk Reduction:

- Confirms accuracy of turntable





Turntable – Sweep Mode Test

<u>Purpose:</u> Confirm rotation of board at constant angular rate (0.15 – 0.5) RPM

<u>Test equipment:</u>

- Stopwatch
- Power supply
- Assem

<u>Procedure:</u>

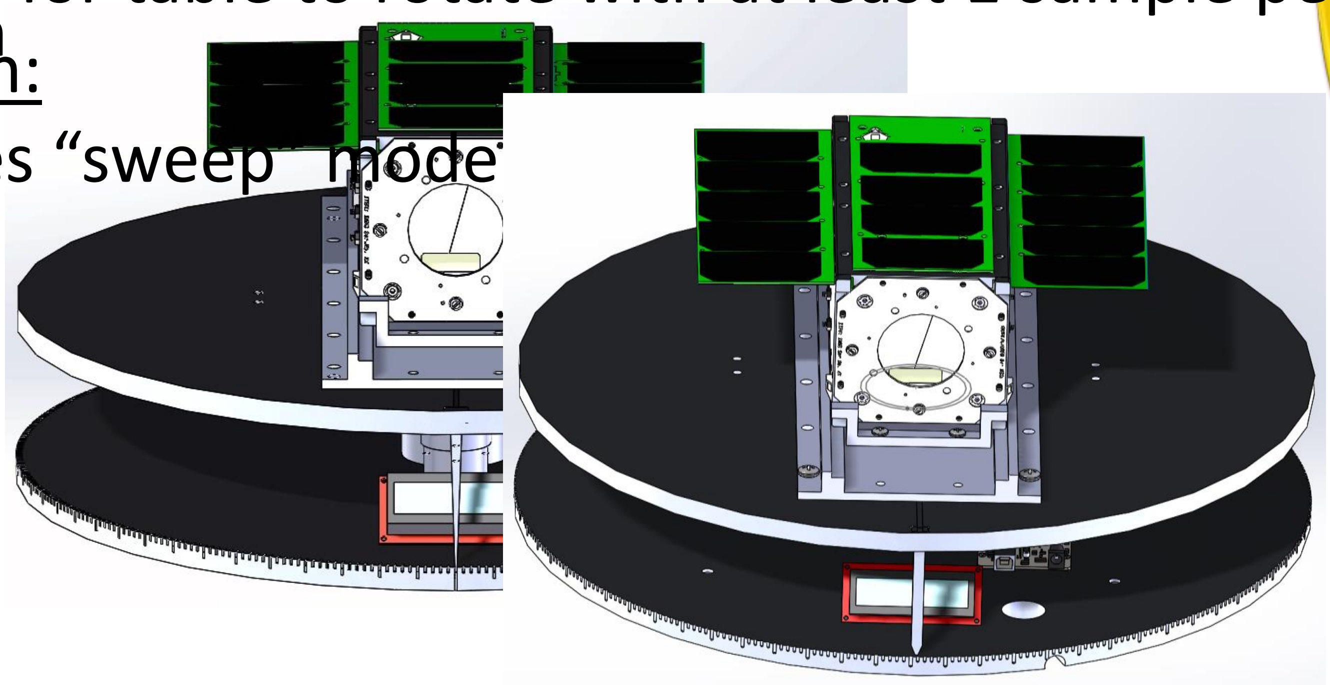
- Set table to rotate at desired RPM in GUI
- Measure time for full rotation
- Compare desired and measured RPMs

<u>Validation:</u>

- Ability for table to rotate with at least 1 sample per degree

<u>Risk Reduction:</u>

- Verifies “sweep” mode



Turntable – Point Mode Test

Purpose: Confirm turntable is pointing to desired angle

Procedure:

- Set table to rotate to desired angle in GUI
- Wait for turntable to stop rotation
- Check accuracy of final angle
- Compare theoretical model to exp

Test equipment:

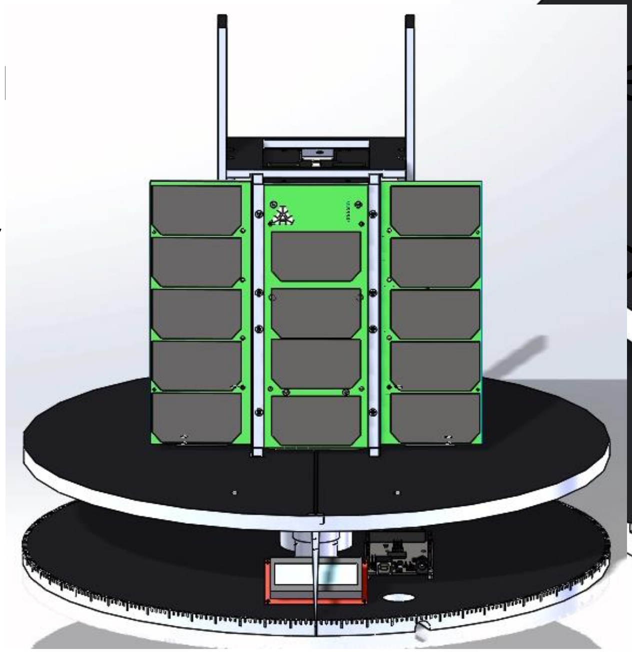
- Power supply
- Assembled turntable

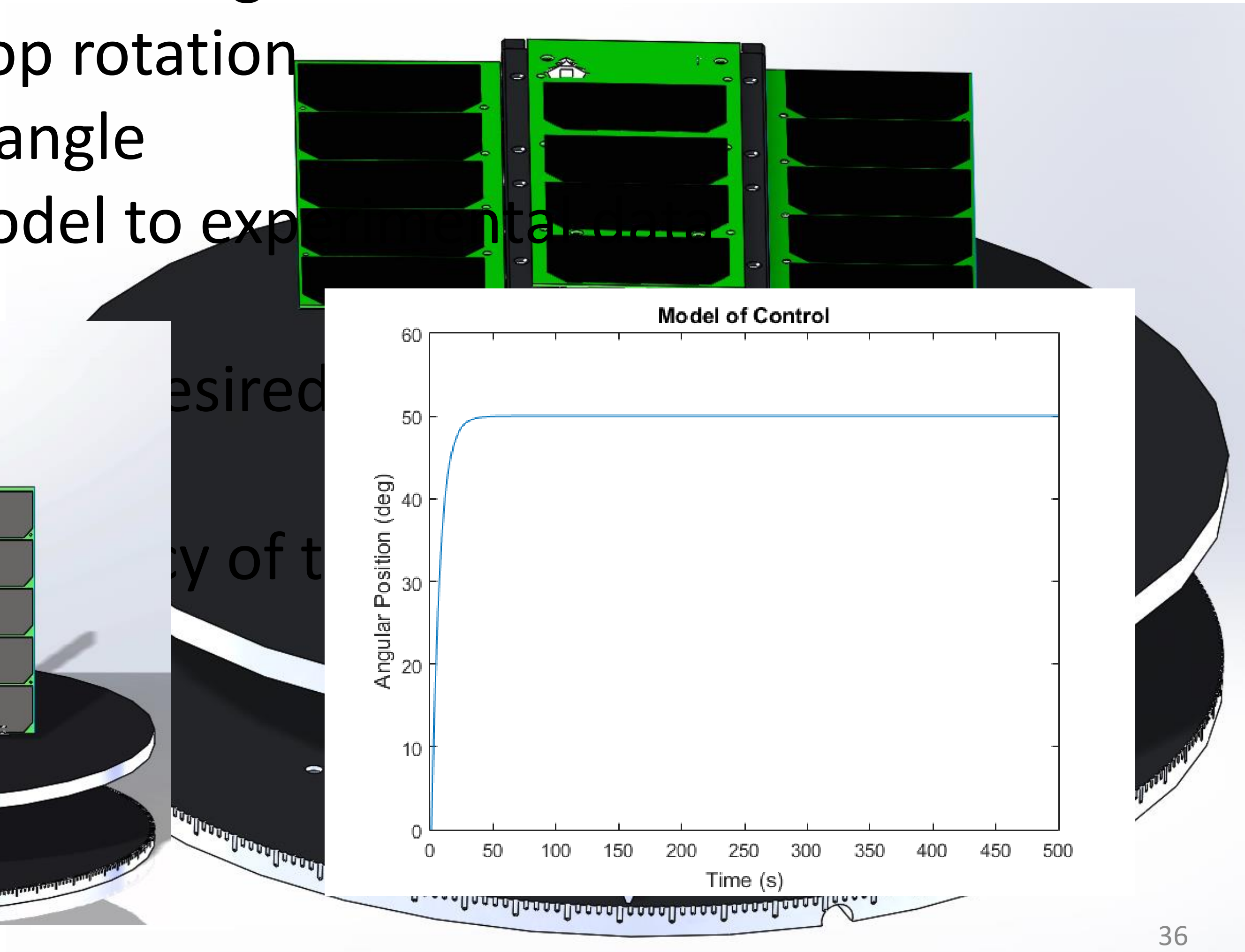
Validation:

- Ability fo esired

Risk Reduction:

- Verifies “ cy of t





HelCaTS

Helmholtz Cage Testing Structure

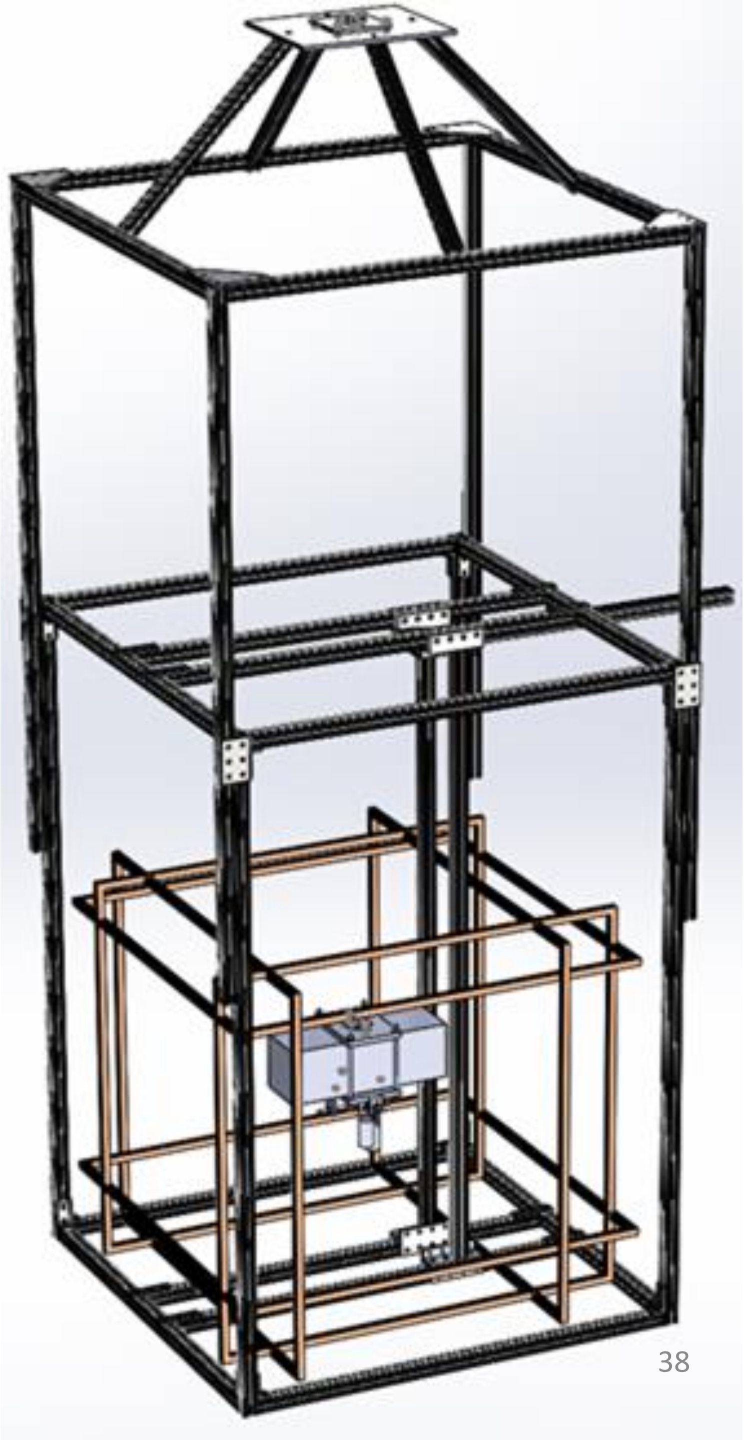
HelCaTS Testing Overview

Validation Testing

- Test time to rotate of a satellite mass model
  - Also tests the repeatability of the release mechanism
- Perform test with the QB50 satellite and its magnetorquers
  - (Includes Graduate Team)

Safety Testing

- Test Strength of Line and Attachment Mechanism



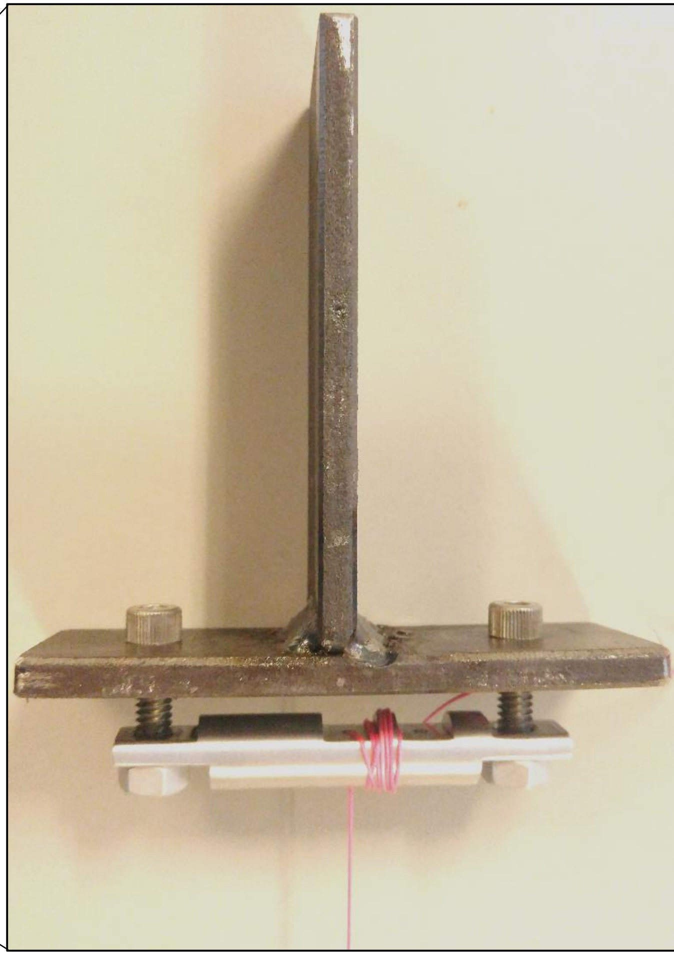
Strength of Line and Attachment

Test Objective:

- Validate the manufacturer's claims that the line can withstand 27 lbs
- Validate that the attachment mechanism will withstand at least 27 lbs

General Procedure:

- Line is attached to attachment cylinders and plates at each end
- Plates placed in the Instron tensile testing machine.
- Test done to failure of the line.



Strength of Line and Attachment

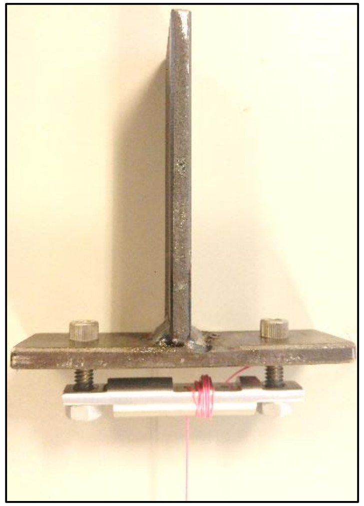
Data Gained:
- Maximum load of the braided nylon line
- Lower limit of attachment mechanism maximum load

Expected Results:
- The line, not the attachment mechanism, will fail above 27 lbs

Resources Used:
- Instron Tensile Testing Machine
- Attachment Cylinder x 2
- Testing Clamp x 2
- Line

Status:
- Will take ~2 man-hours
- All STAR provided materials are on hand
- Schedule time with the Instron Tensile Testing Machine

Risk Reduction
- Provides confidence in line strength



X 2

Time to Rotate of Satellite Mass Model

Test Objective:

- Validate the time to rotate model

Data Gained:

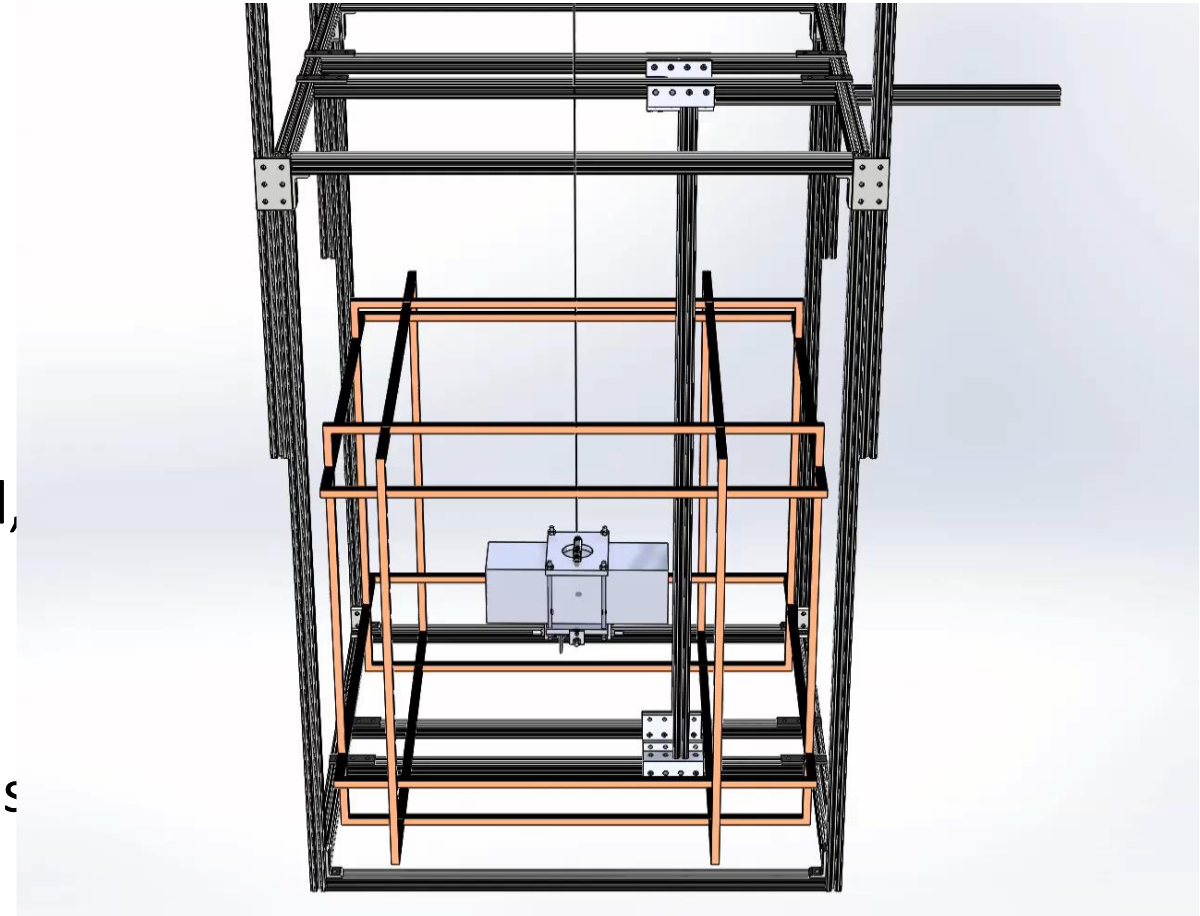
- Time needed for satellite to rotate
- Variation in time to rotate produced by release mechanism compared to hand-release

General Procedure:

- Rotate the satellite 360º
- Measure the time it takes to rotate back through 0º
- Perform multiple trials releasing by hand, with the release mechanism

Expected Results:

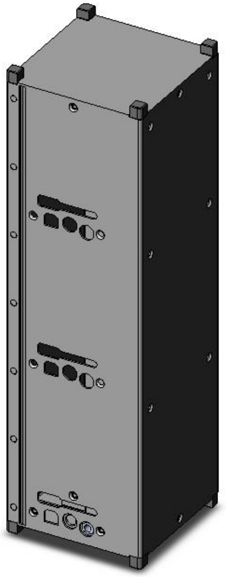
- Time to Rotate ~ 4 minutes 30 seconds
- Slight variation between clockwise and counter-clockwise dependent on the twis the line.
- The release mechanism will remove any significant variation in time to rotate.



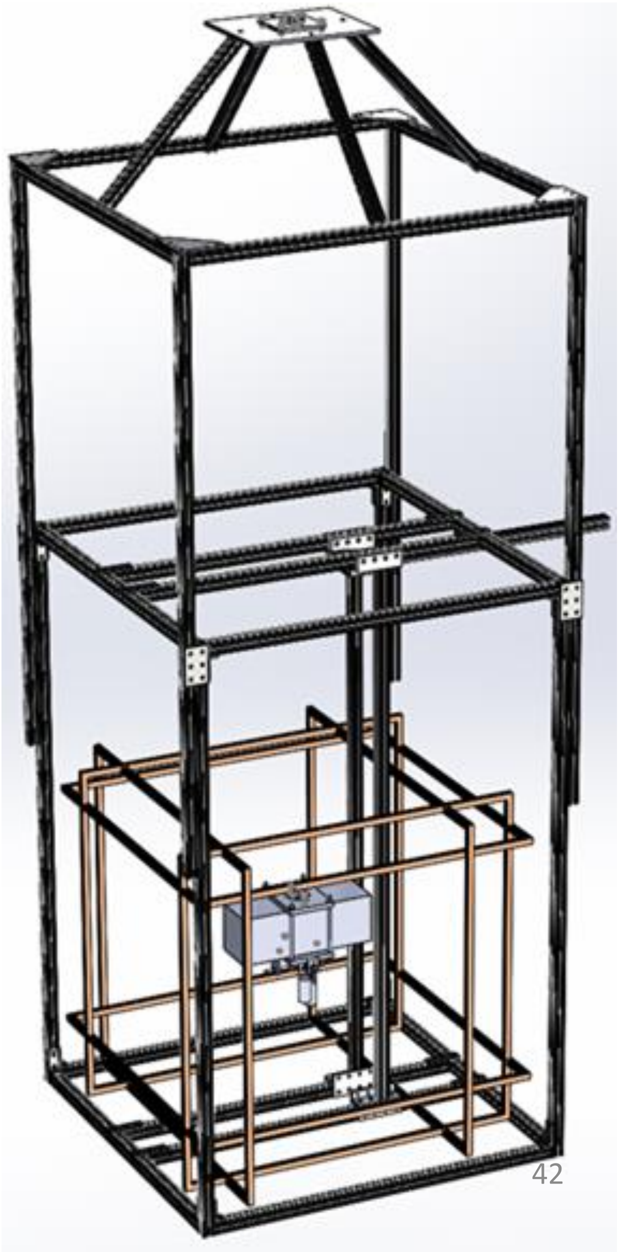
Time to Rotate of Satellite Mass Model

Resources Used:
- HelCaTS Structure
- Satellite Mass Model
- Cell Phone - video recording

Status:
- Will take ~ 14 man-hours
- Very similar test done in the Fall



3U CubeSat Mass Model

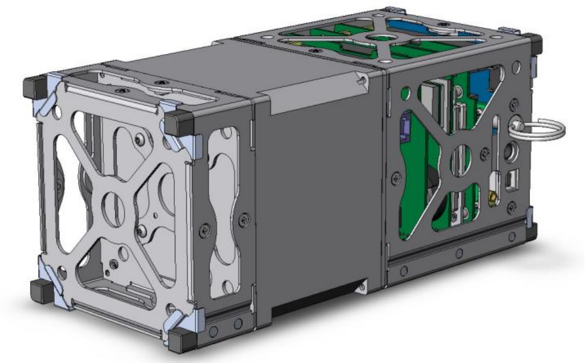


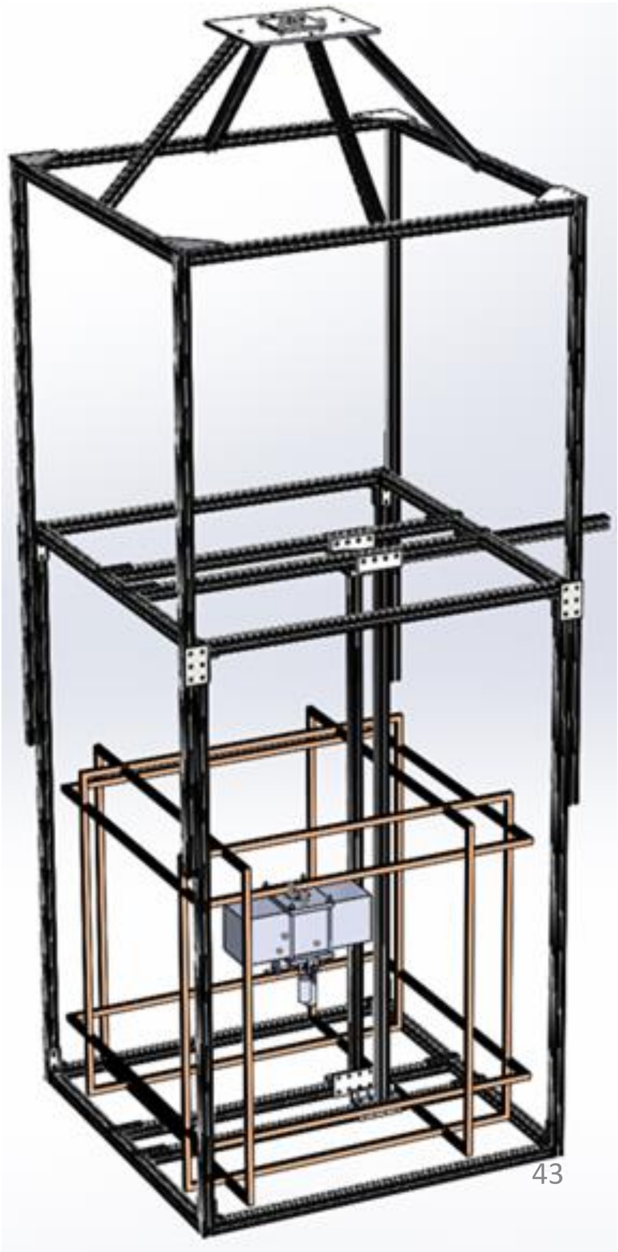
Performance Test with Satellite and Magnetorquers

Test Objective:
- To validate the time to rotate model with and without magnetorquers

Changes from Previous Test:
- Requires the assembled QB50 cubesat
- Time to rotate with and without magnetorquers is compared

Data Gained:
- Impact of magnetorquers on time to rotate [Critical Project Element]





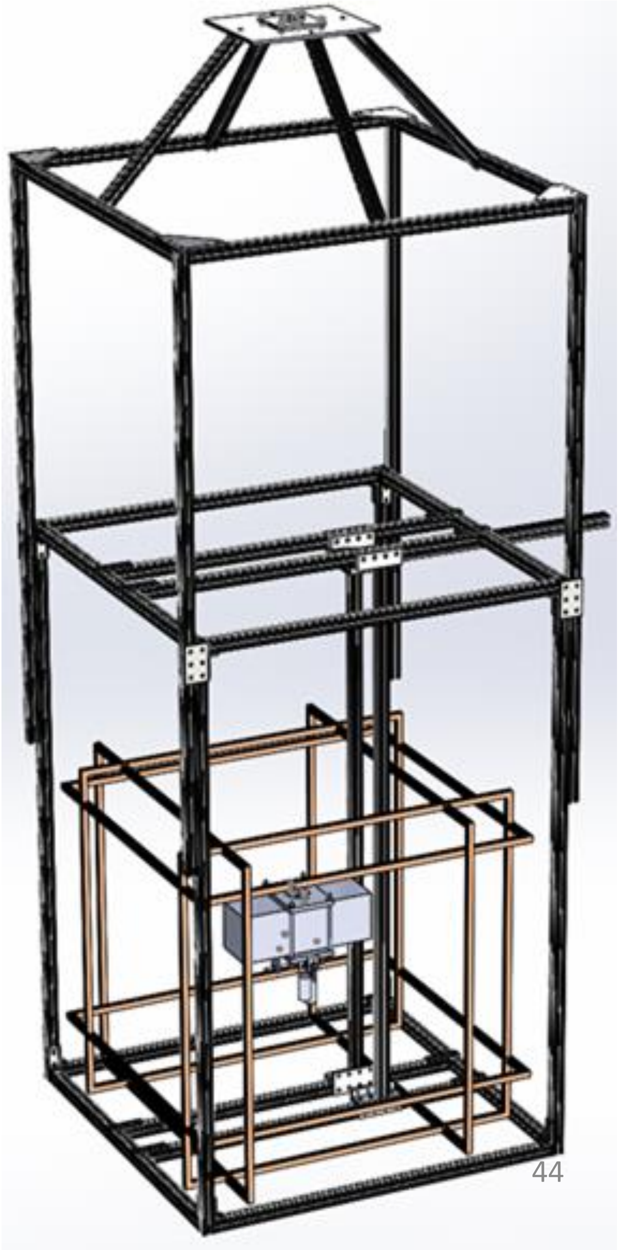
Performance Test with Satellite and Magnetorquers

Status:
- Will take ~5 man-hours
- Completed by 5 April with the STAR and grad student teams

Expected Results

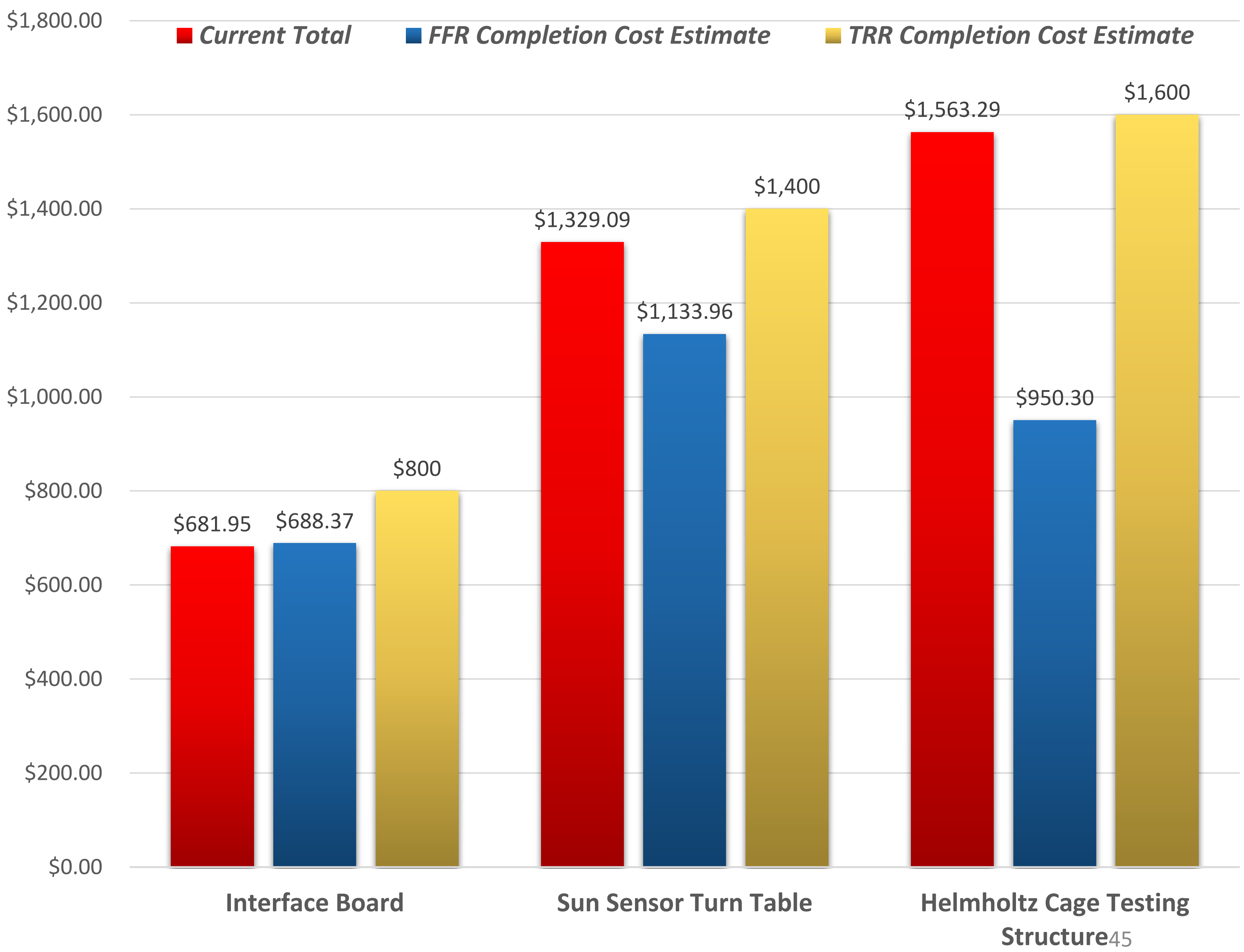
Acting Torque (τ)	Time to Rotate	Change in Time to Rotate
τ_{Line}	4 min 30 sec ± 7.5 sec	0
$\tau_{Line} + \tau_{Sat}$	3 min 50 sec	-40 seconds
$\tau_{Line} - \tau_{Sat}$	5 min 35 sec	+60 seconds

The success of this test will demonstrate the validity of the HelCaTS design

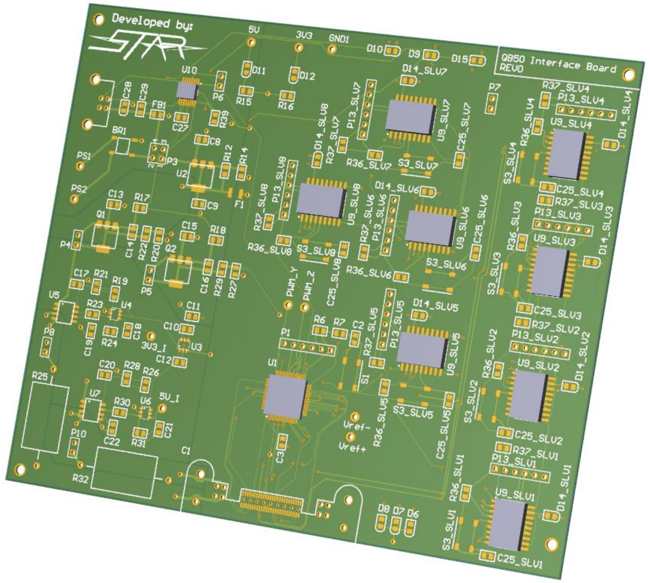


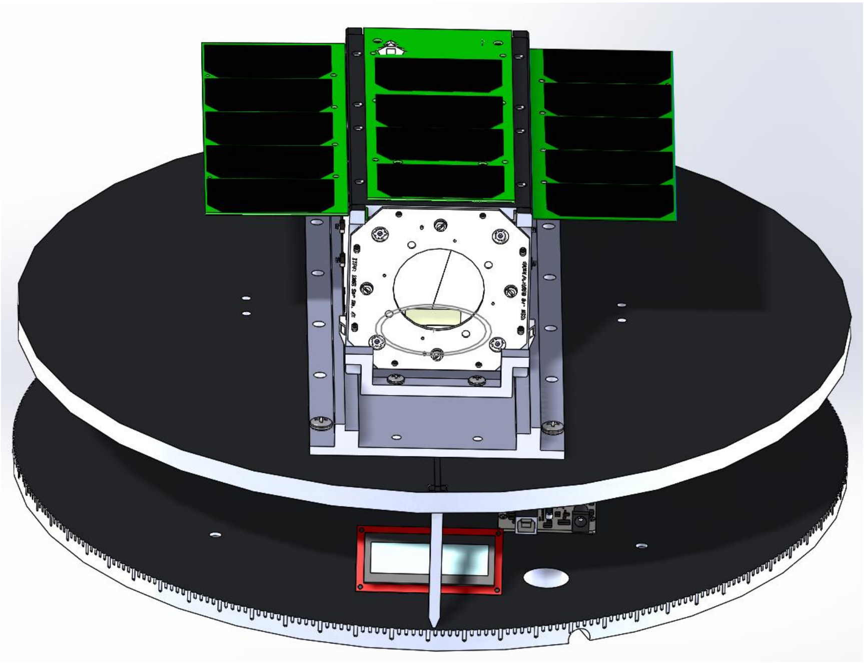
Budget

- Total Budget: **$5,000**
- Total Spent: **$3,607.96**
- FFR Completion Cost Projection: **$3,072.63**
- TRR Completion Cost Projection: **$3,800**
  - **Need: Final IB Revision Population- $120.00**
  - **Need: SS Top Board Return Shipping- $50.00**
- Δ ≈ +**$800** from FFR
- Current *Estimated* Completion Margin: **24%**
  - FFR Margin Est.: **39%**



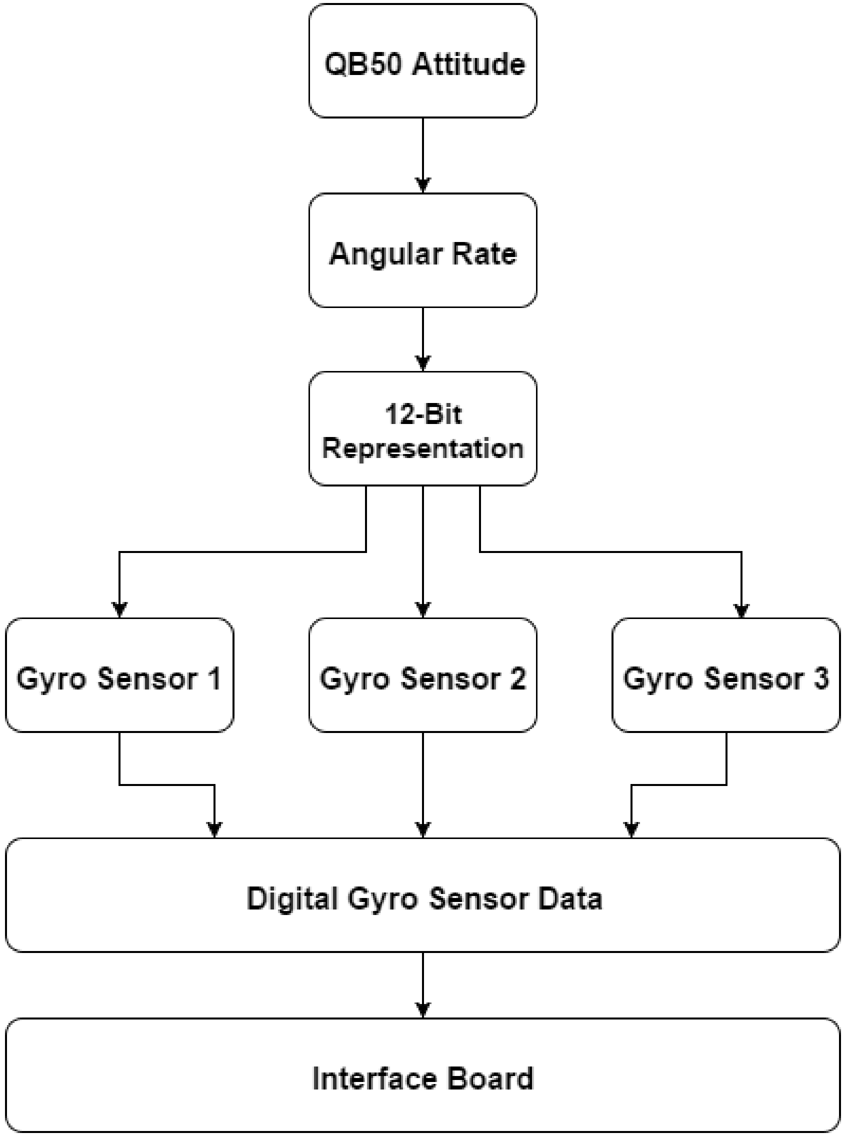
Questions?



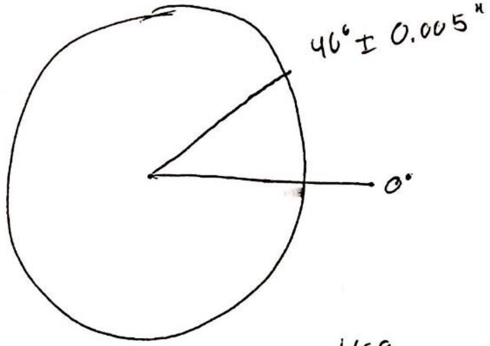


Backup Slides

Sensor Model Calibration



Tolerance



$dia = 18''$

$C = \pi d = 56.54867$

$$\frac{40^\circ}{360^\circ} = \frac{x}{56.54867} \longrightarrow x = 6.28318''$$

$$X \pm 0.005'' \longrightarrow \measuredangle \pm 0.5^\circ$$

$$\frac{\theta}{360^\circ} = \frac{6.28318 \pm 0.005''}{56.54867}$$

$$\theta = 40.0318^\circ$$

$\hookrightarrow$ **0.0318° max error**

Test Strength of Attachment and Line

Test Objective: Validate the manufacturer's claims that the line can withstand 30 lbs

Validate the assertion that the attachment mechanism will withstand at least 30 lbs

General Procedure: Line is attached to attachment cylinders at each end, which are attached to testing clamps, and are placed in the Instron tensile testing machine. Test done to failure of the line.

Data Gained: Maximum load of the braided nylon line

Lower limit of attachment mechanism maximum load

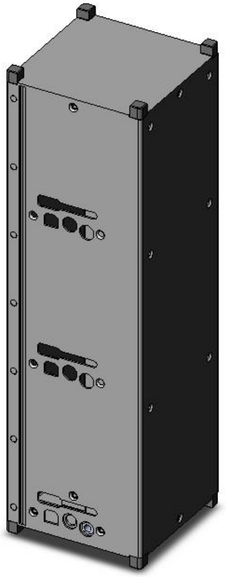
Resources Used: Instron Tensile Testing Machine || Attachment Cylinders || Testing Clamps || Line

Test Time to Rotate of Satellite Mass Model

Resources Used:
- HelCaTS Structure
- Satellite Mass Model
- Cell Phone - video recording

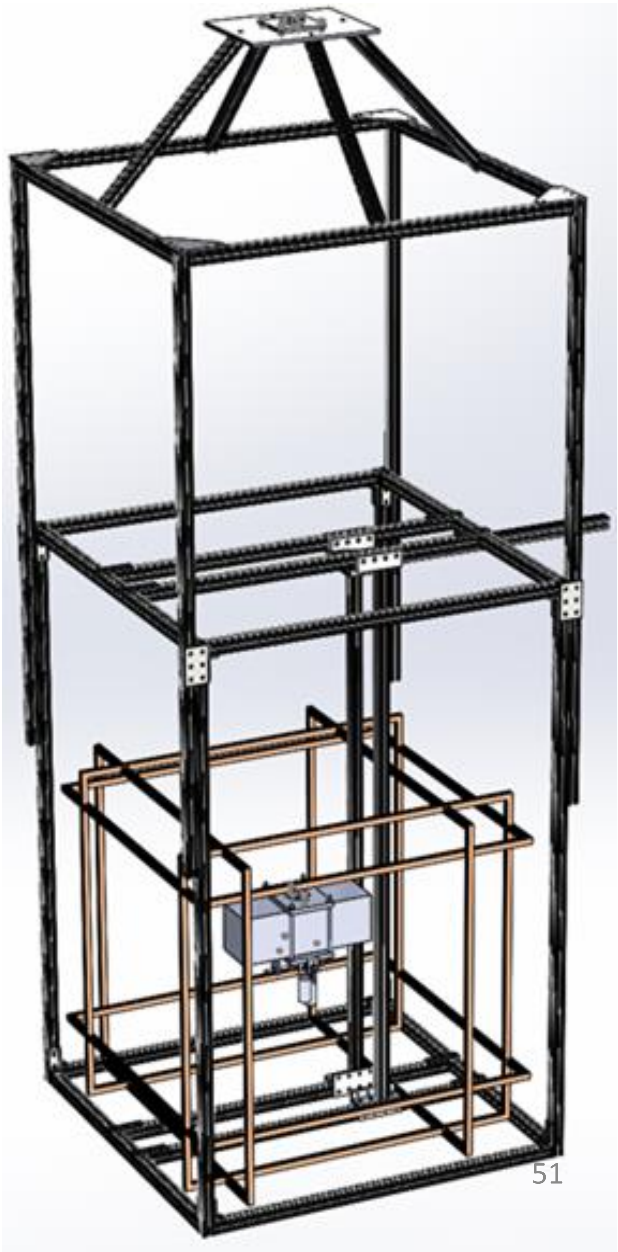
Risk Reduction:
- Provides confidence that the test will perform as intended (reduces risk that initial data was faulty, or that the satellite cannot rotate in a reasonable amount of time)

Status:
- Will be completed 2 weeks after the structure is finished (1 week after the previous two tests).
- Very similar test done in the Fall



3U CubeSat Mass Model

Cell Phone



Test Time to Rotate of Satellite

Test Objective: Validate the time to rotate model

General Procedure: Rotate the satellite 360^{o} and measure the time it takes to rotate back to 0^{o}

Perform multiple trials releasing by hand, and with the release mechanism

Data Gained: Time for satellite to rotate clockwise, counter-clockwise

Variation in time to rotate produced by release mechanism compared to hand-release

Resources Used: HelCaTS Structure, Satellite Mass Model, Cell Phone - video recording

Risk Reduction: Provides confidence that the test will perform as intended (reduces risk that initial data was faulty, or that the satellite cannot rotate in a reasonable amount of time)

Test 5: Performance Test with Satellite and Magnetorquers

Test Objective: To validate the time needed to rotate with the magnetorquers acting with and against the direction of twist.

General Procedure: Rotate the satellite 360^{o}, Turn on the magnetorquers, Measure the time taken to return to 0^{o}, Ensure that the magnetorquers were acting in the direction they were measured

Data Gained: Impact of magnetorquers on time to rotate [Critical Project Element]

Resources Used: HelCaTS Structure || QB50 Satellite including magnetorquers and control software

Test 1: Test Satellite Impact into Foam

Test Objective: To verify that the satellite will not endure more than ?? G's if it falls.

General Procedure: Drop satellite mass model with attached phone from 1' onto foam. Repeat multiple times to obtain confidence

Data Gained: X, Y, and Z Peak acceleration during impact (recording frequency 200 Hz = sample every 0.005 s)

Resources Used: HelCaTS Structure, Cell Phone, Acceleromate PRO, Foam

Risk Reduction: Provides confidence in the foam used to account for satellite impact (reduces risk of satellite breaking if it does fall)

Expected Results: The foam will reduce the satellite's impact acceleration from ??? to

Test 4: Test Effects of Over-Tightening Rods

Test Objective: To find the number of turns, or torque required, to tighten the clamping rods such that
the satellite will not slip, but will also not be damaged by the compression.

General Procedure: Place Pumpkin in clamps and measure compression force

Data Gained: Compression force provided as nuts are tightened

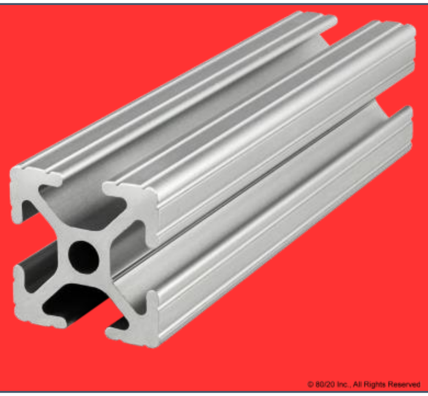
Resources Used: Attachment Clamps || Wrench || 4 Load Cells || Data aquisition software

Risk Reduction: Provides confidence that the satellite will not be damaged by over-tightening the rods (reduces risk of satellite damage by over-tightening rods)

HelCaTS Parts

Parts Purchased (Red)

- Extruded Aluminum
- Screws / Nuts
- Threaded Rod

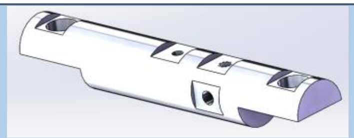


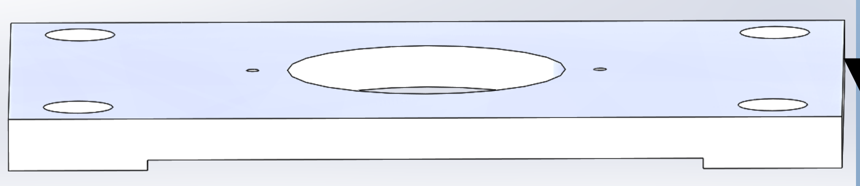
Parts Provided by Customer (Green)

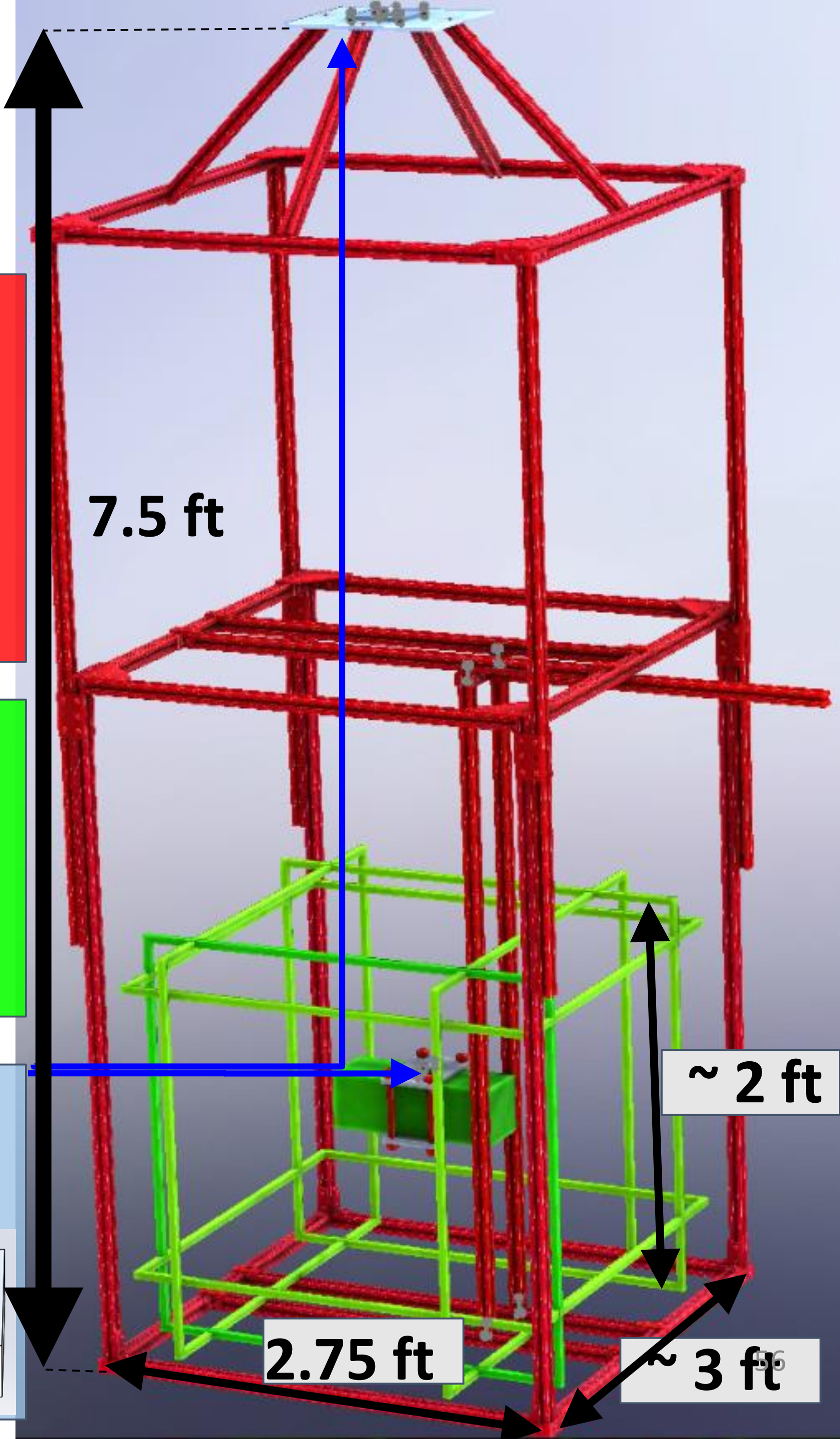
- Satellite
- Helmholtz Cage

Parts Machined by STAR

- Attachment Cylinders
- Attachment Plates

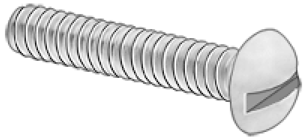


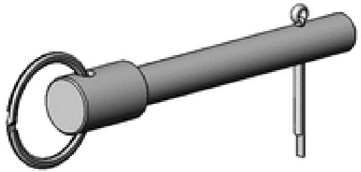




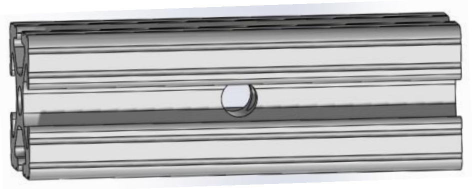
HelCaTS Purchased Parts

- Various Screws, Nuts, and Clevis Pins (all aluminum)





- S[illegible]teel [illegible] for a[illegible] extruded Aluminum
- Extruded Aluminum Bars (machined by 8020)
  - Cut to size 48” ,45.7”, 33”, 31”, 24”
    - (+/- 0.005”)
  - Some Ends Tapped
  - Through holes drilled to pin the sliding mechanism

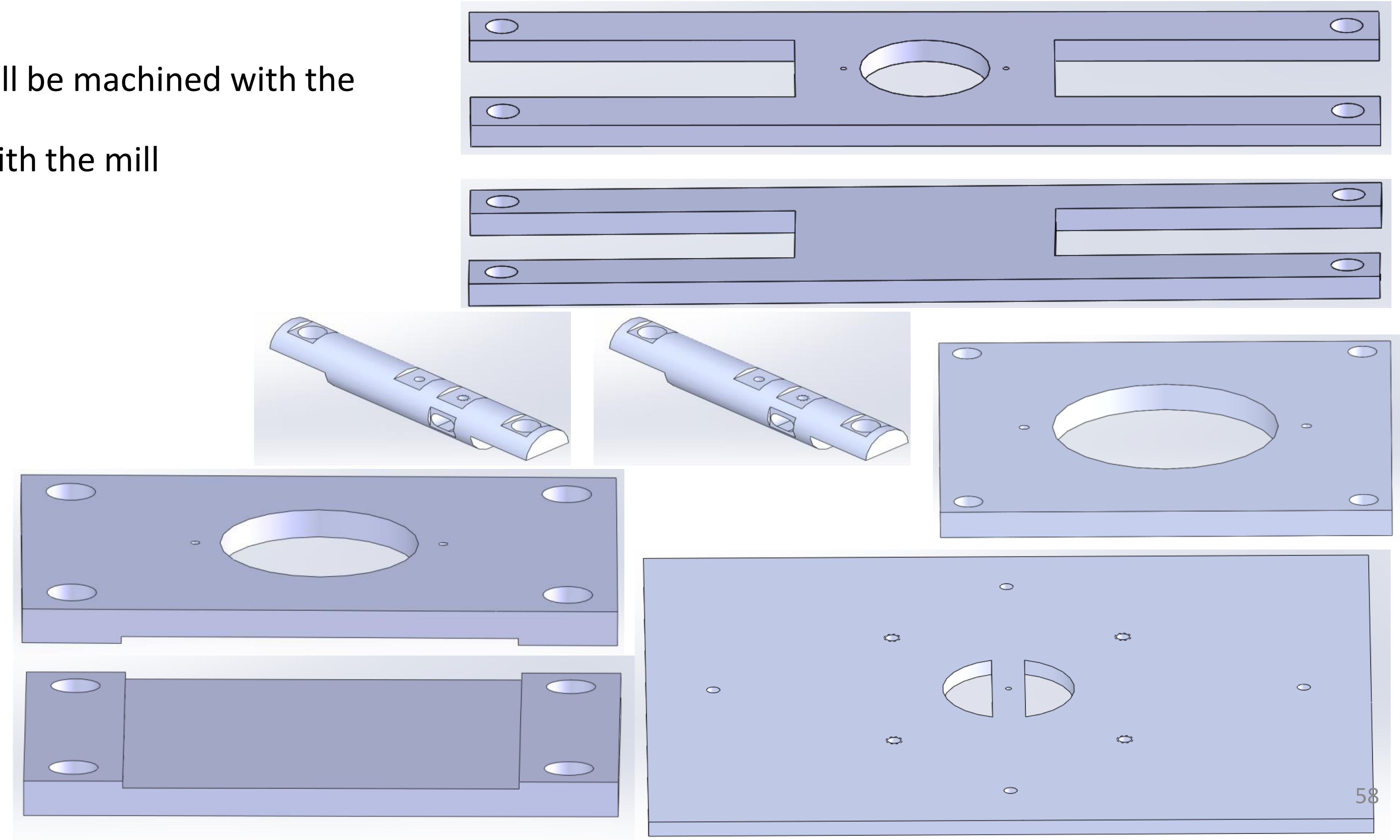




HelCaTS Manufactured Parts - Overview

8 Pieces in total

All plates are 0.25” thick and will be machined with the CNC

Cylinders are made manually with the mill

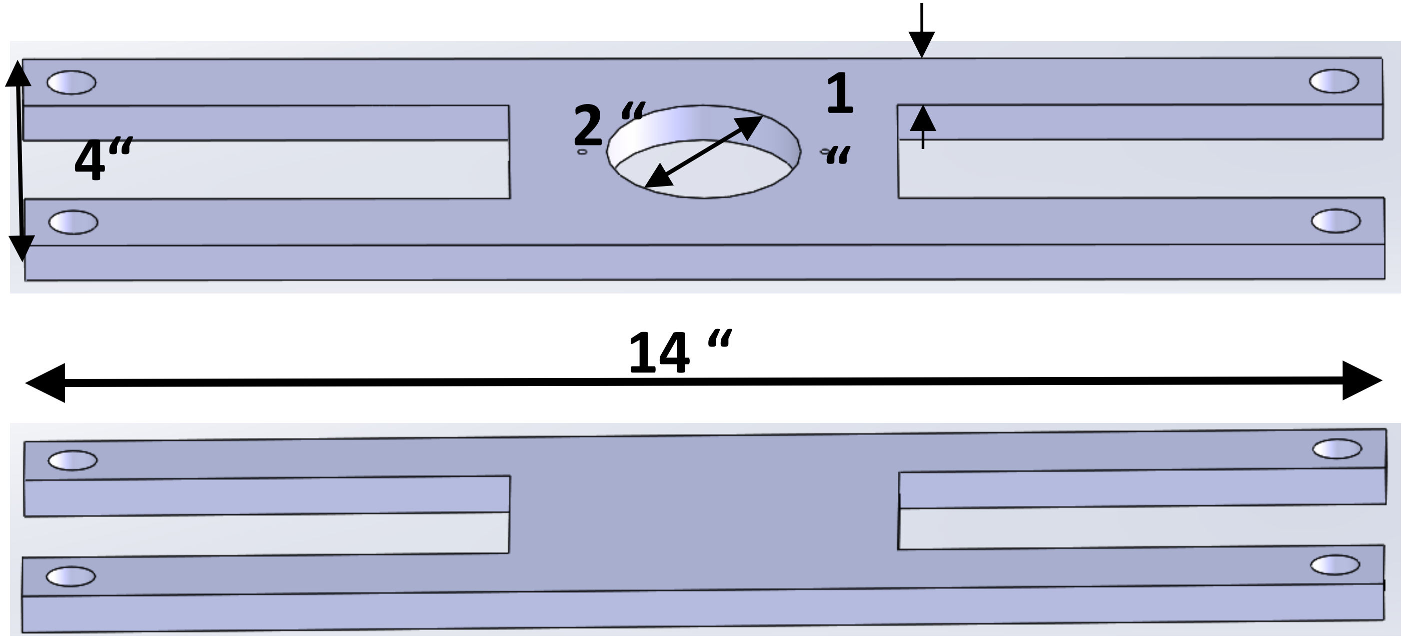


HelCaTS Large Clamp Machining - In Progress

Status: Toolpaths 80% Written
Machining to be done

Machining Order:

- cut out legs
- cut out center hole
- drill holes
- clean outer dimensions



Critical Dimension:

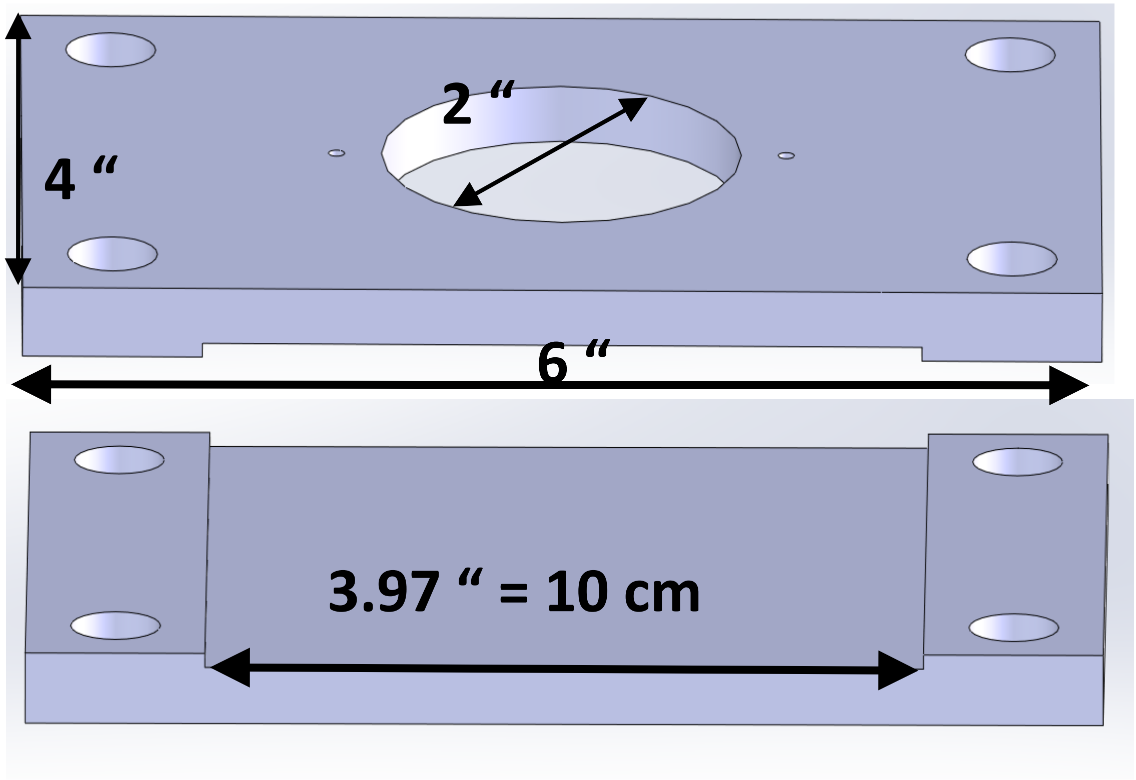
- spacing of ½" holes must be accurate to 0.0156" in each direction
- spacing of tapped ¼" holes must be accurate to 0.008" in each direction

HelCaTS Small Clamp Machining - Finished

Status: Machining Done (will be done Friday)

Machining Order:

- cut out center hole
- drill holes
- clean outer dimensions
- flip over and take down center



Critical Dimension:

- spacing of ½" holes must be accurate to 0.0156" in each direction
- spacing of tapped ¼" holes must be accurate to 0.008" in each direction

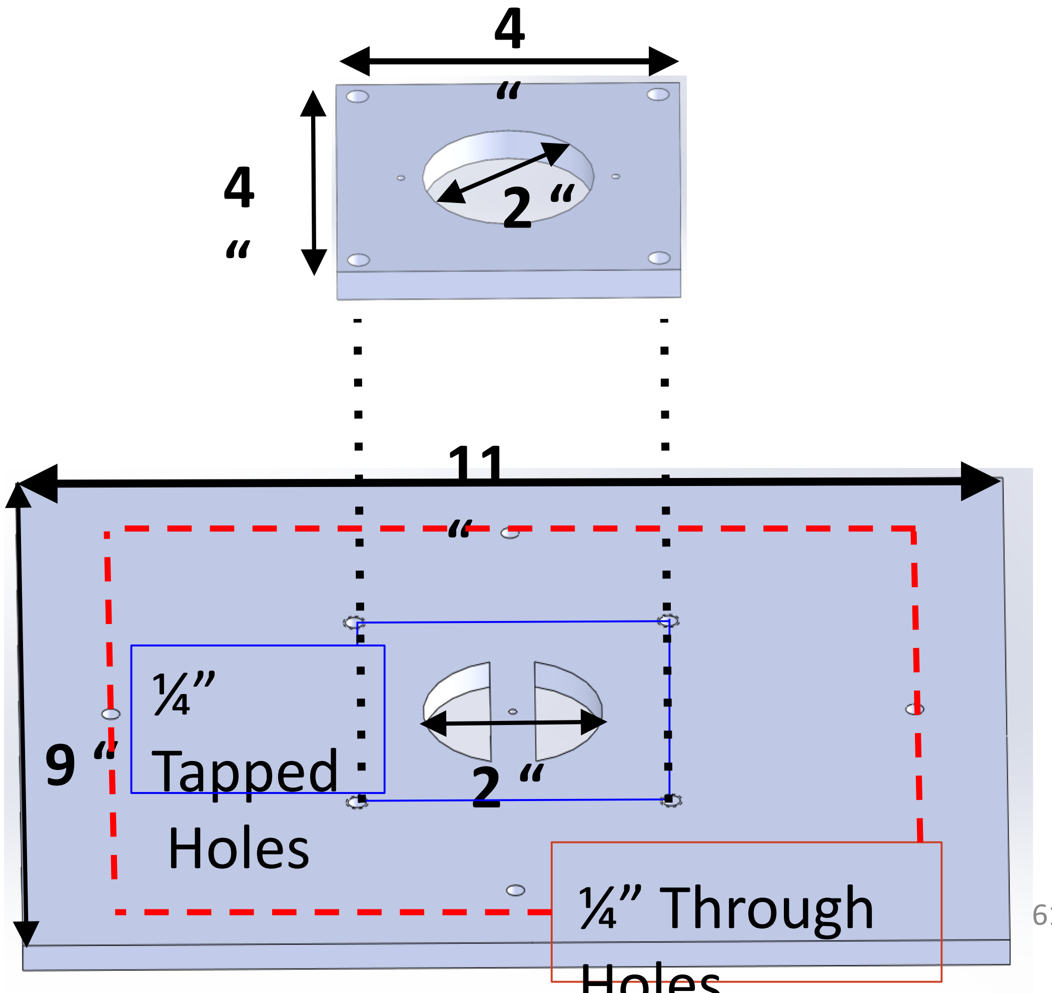
HelCaTS Attachment Plate Machining - To be done

Machining order:

- Take out center holes
- Drill holes
- Clean outer dimensions

Critical Dimensions:

- Plate-to-plate holes must be accurate to 0.008”
- ¼” Tapped holes on top plate must be accurate to 0.1”

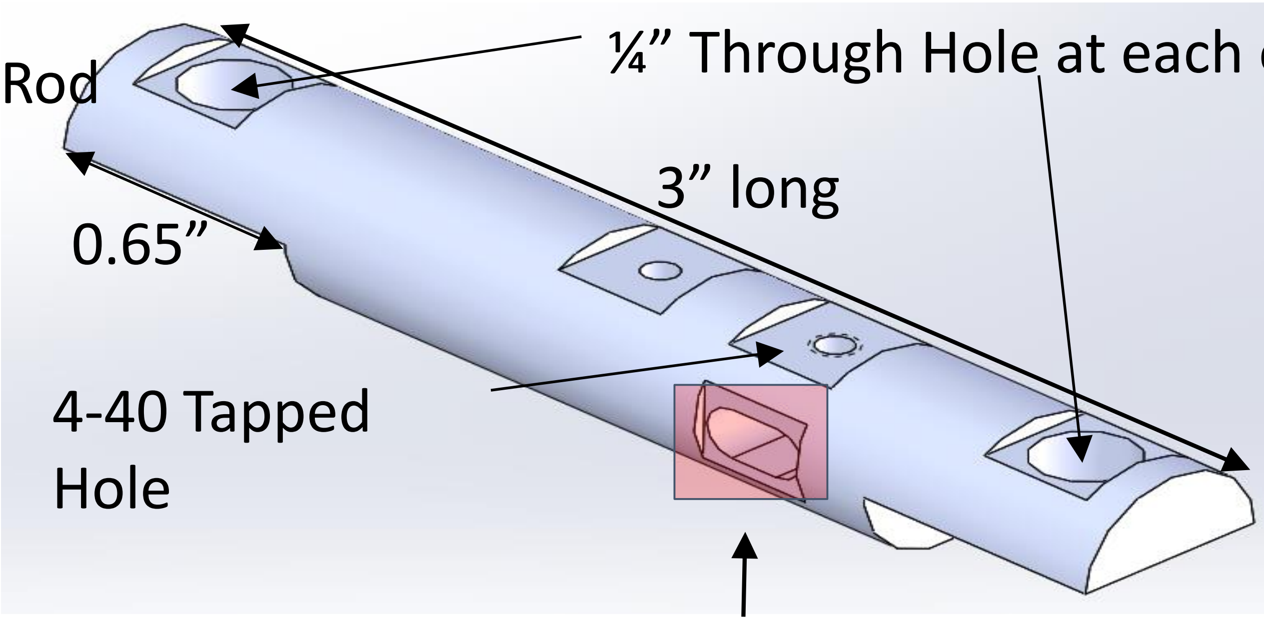


HelCaTS Manufactured Parts - Attachment Cylinder

Status: 1 of 2 Machined

Machining Order:

- Mill Shoulders
- Make slots for hole drilling
- Drill holes
- Slot necessary hole



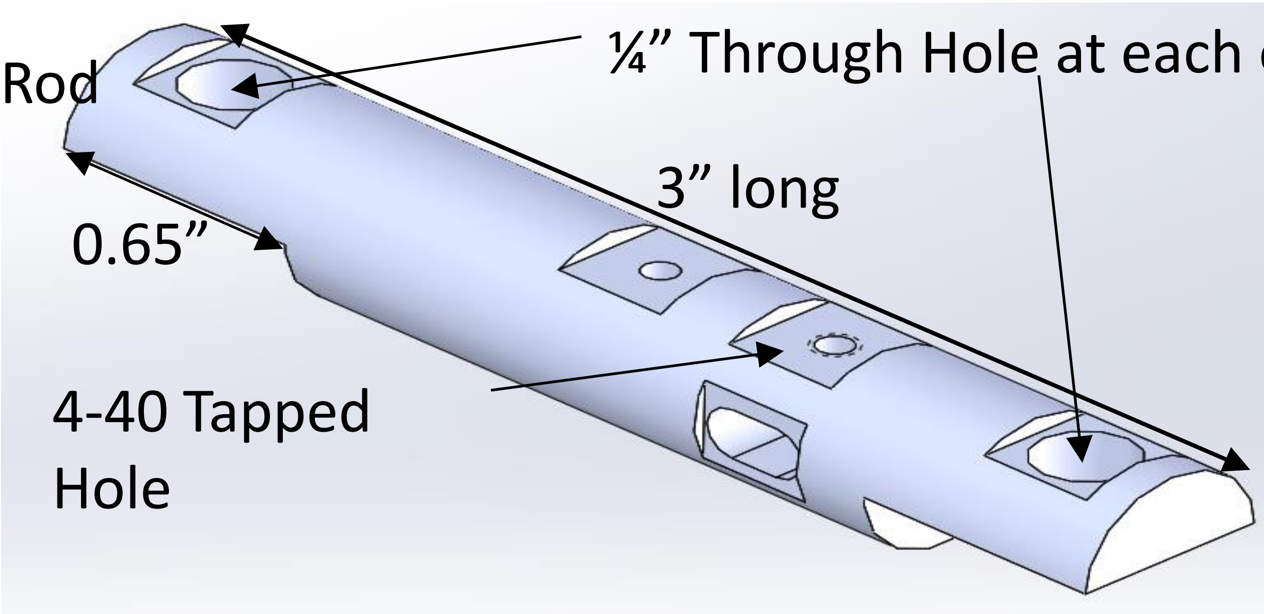
Change: hole now slotted

Slotted hole made by:
- drilling with a #25 bit (0.1495”)
- using a 9/64” end mill (0.1406”) to slot the hole

HelCaTS Manufactured Parts - Attachment Cylinder

Critical Dimensions:

- End holes must be accurate to 0.008”
- Set screw hole and slotted hole must be accurate to within 0.0675



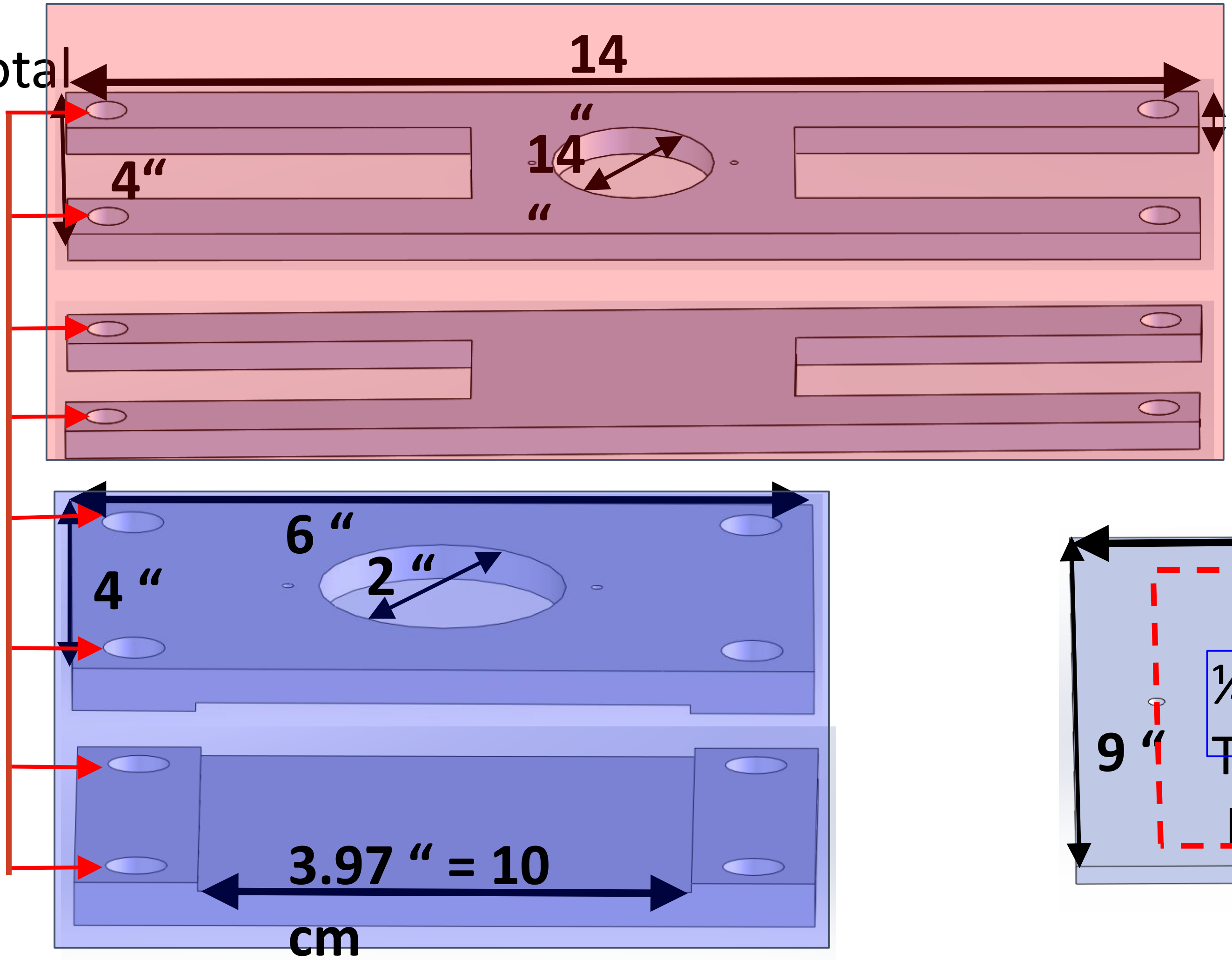
HelCaTS Manufactured Parts - Backup

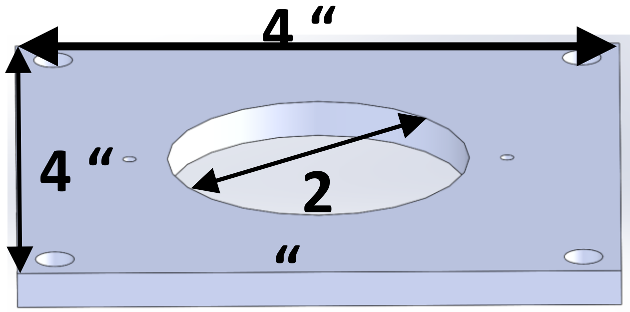
HelCaTS Manufactured Parts - Backup

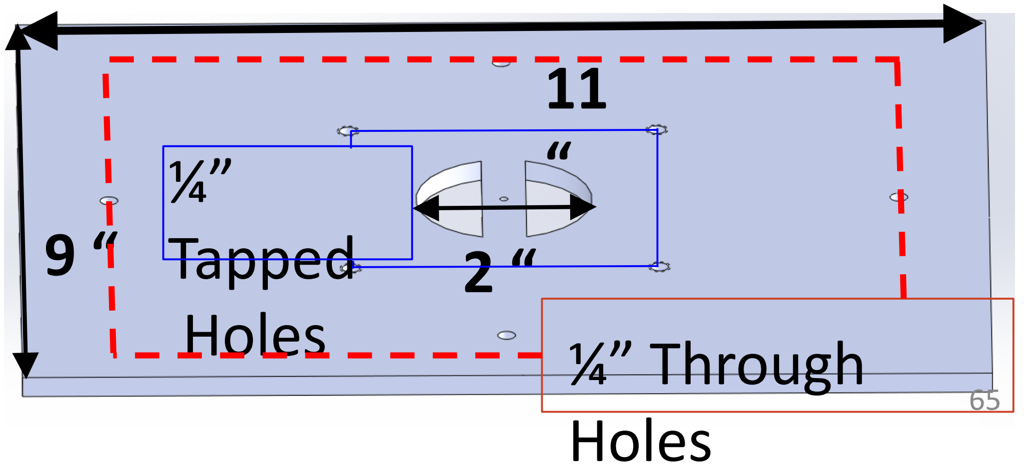
Similar colors = similar dimensions
All plates are 0.25” thick and will be machined with the CNC

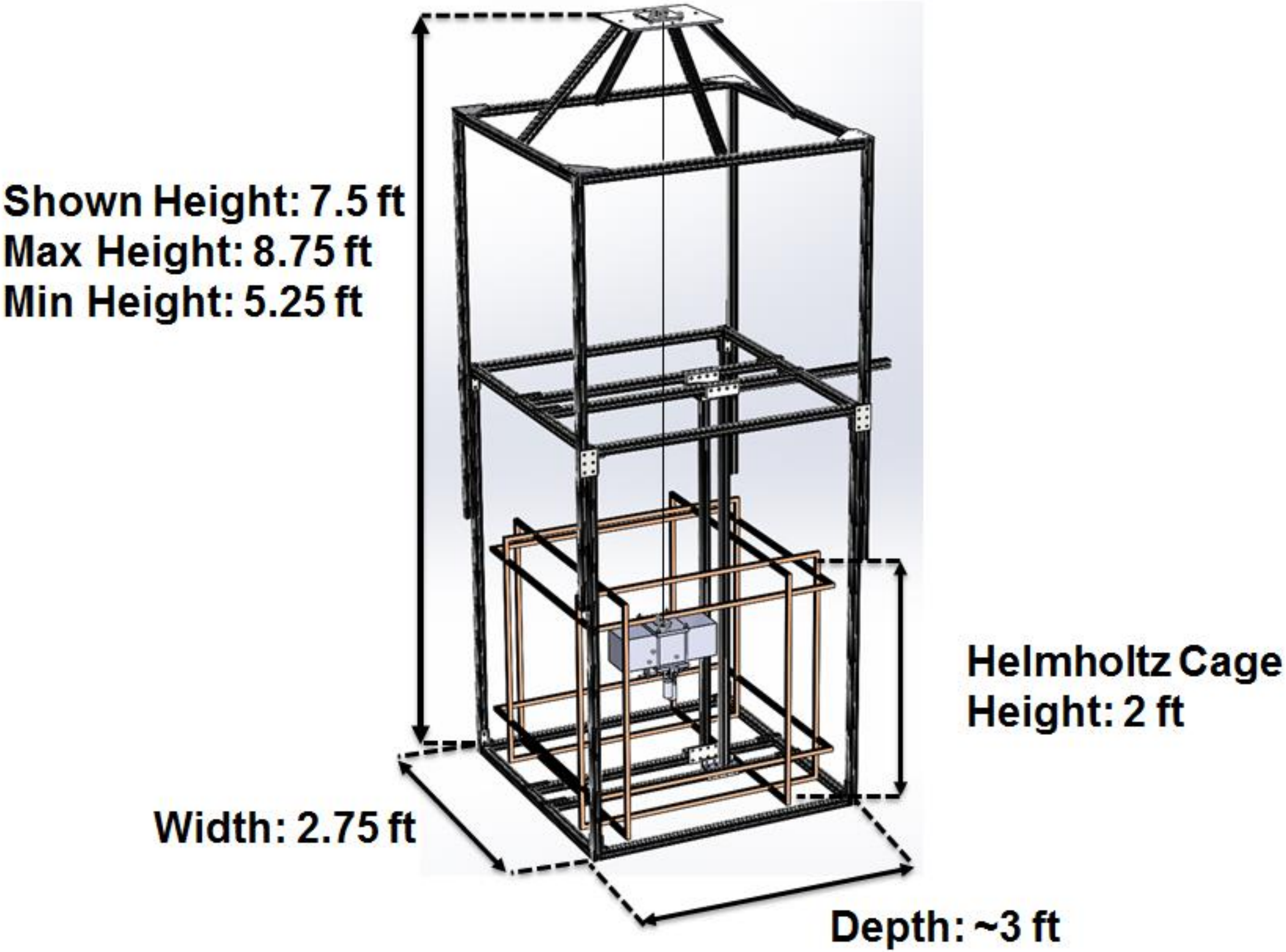
8 Pieces in Total

½” Through Holes








Shown Height: 7.5 ft
Max Height: 8.75 ft
Min Height: 5.25 ft
Helmholtz Cage
Height: 2 ft
Width: 2.75 ft
Depth: ~3 ft