QB50 CubeSat MSR

Satellite Testbed for Attitude Response

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Problem Statement

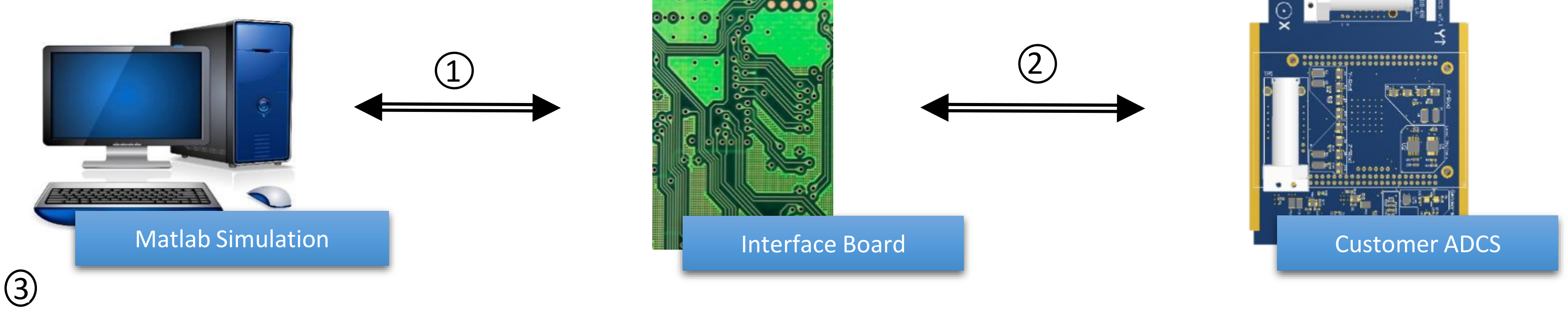
Develop a **test suite** that will allow for the **validation and calibration** of the QB50 Attitude Determination and Control System based (**ADCS**) on simulated mission environment.

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.

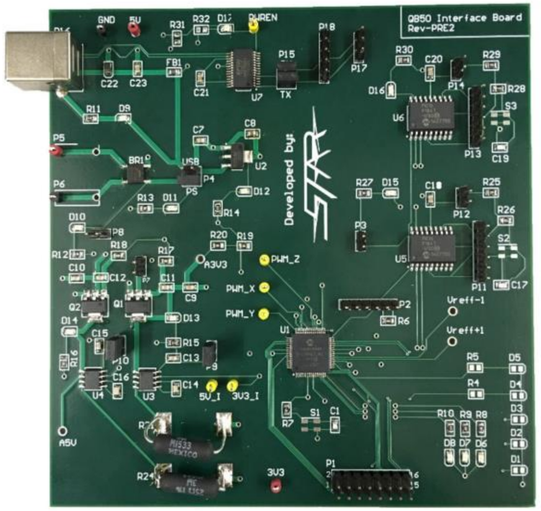
Interface Board

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
- Minor changes from CDR

Levels of Success

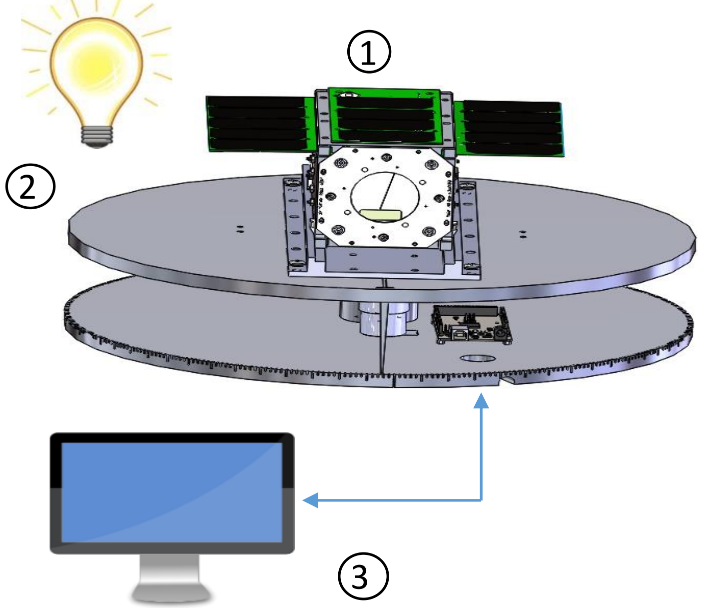
- Level 3 – Implement GUI to disable sensors

Critical Project Elements

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

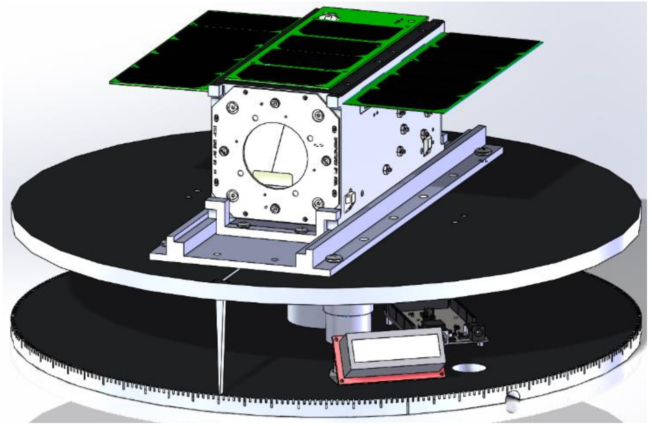
Sun Sensor Turntable

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

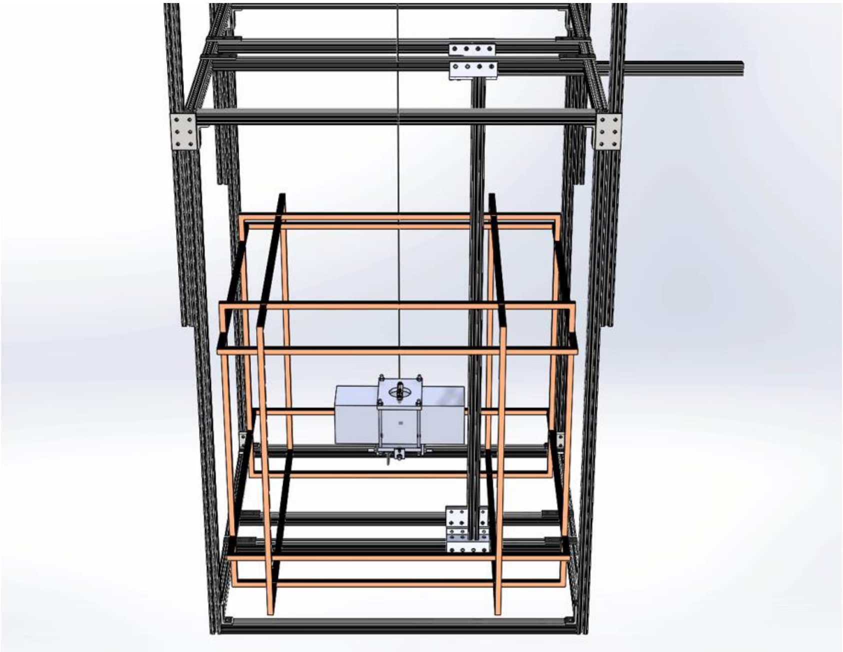
- Level 1 – Rotate with ±0.5 degrees accuracy

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 2 – Verify functionality of magnetorquer

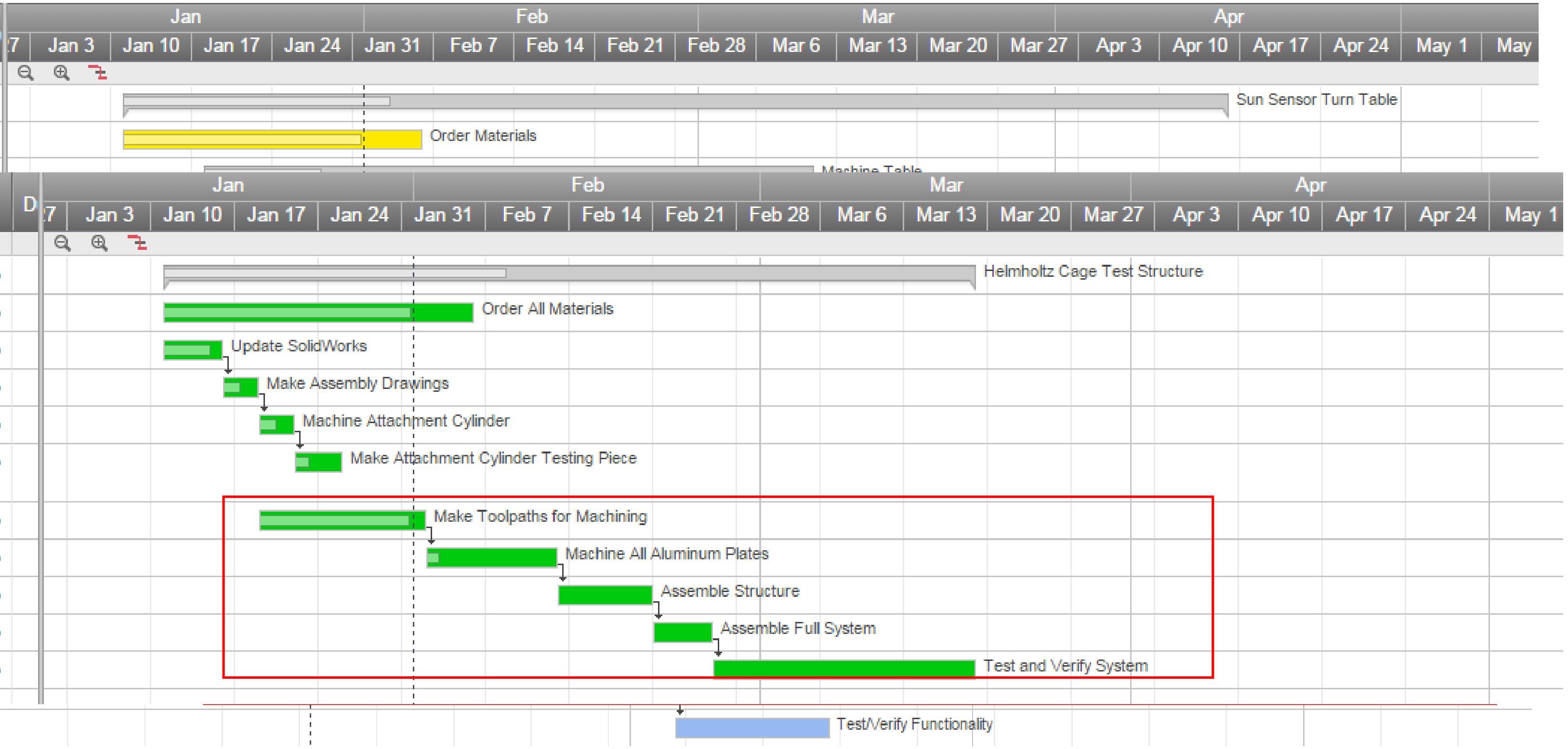
Critical Project Elements

- Minimize torque on line

Schedule

	Task Name	Start Date	End Date	% Com...
1	⊟ Sun Sensor Turn Table	01/11/16	04/15/16	24%
2	Order Materials	01/11/16	02/05/16	80%

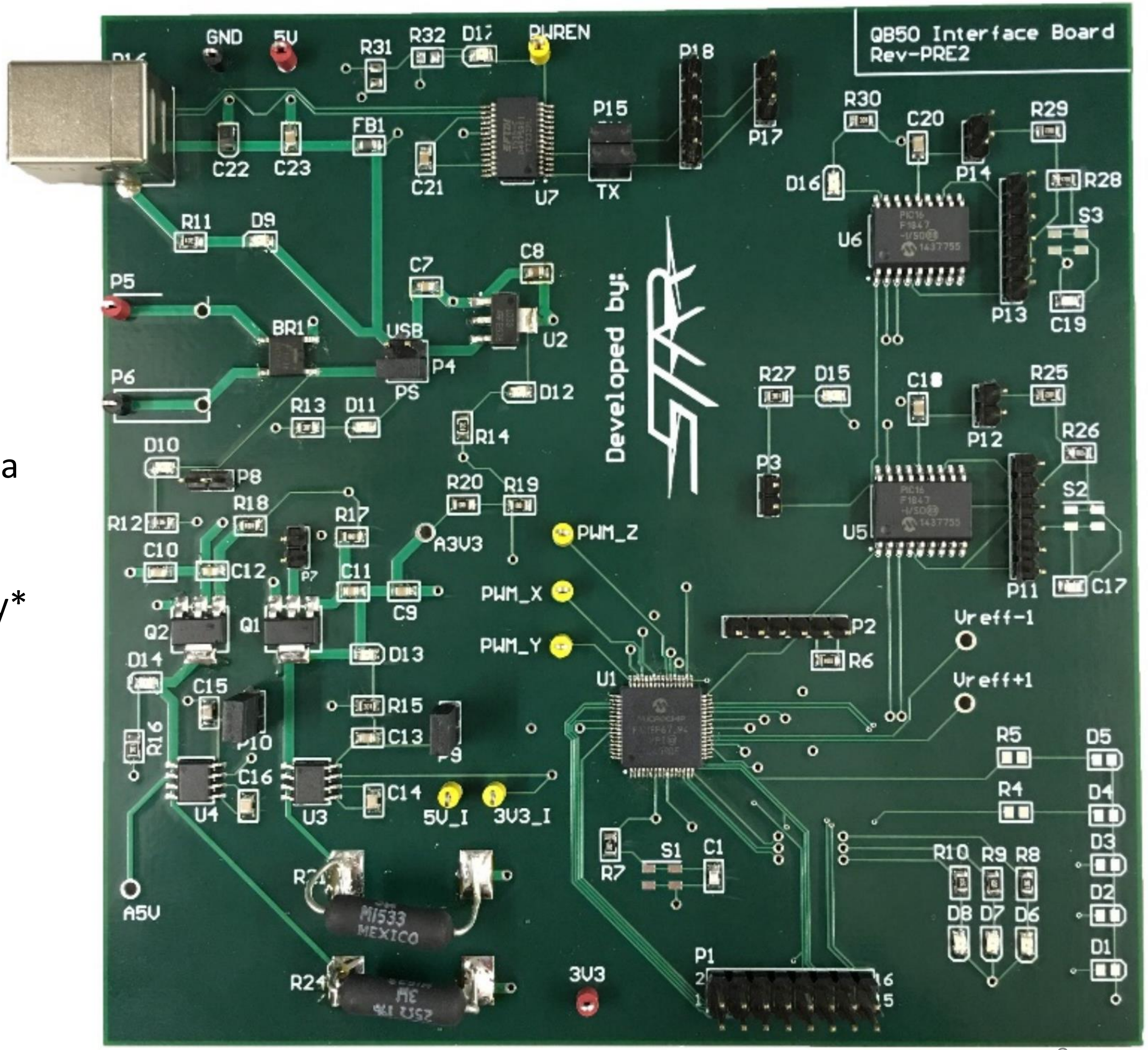
	Task Name	Start Date	End Date	% Com...
1	⊟ Helmholtz Cage Test Structure	01/11/16	03/18/16	42%
2	Order All Materials	01/11/16	02/05/16	80%
3	Update SolidWorks	01/11/16	01/15/16	80%
4	Make Assembly Drawings	01/16/16	01/18/16	50%
5	Machine Attachment Cylinder	01/19/16	01/21/16	50%
6	Make Attachment Cylinder Testing Piece	01/22/16	01/25/16	30%
7	Make Toolpaths for Machining	01/19/16	02/01/16	90%
8	Machine All Aluminum Plates	02/02/16	02/12/16	10%
9	Assemble Structure	02/13/16	02/20/16	0%
10	Assemble Full System	02/21/16	02/25/16	0%
11	Test and Verify System	02/26/16	03/18/16	0%
30	Test/Verify Functionality	03/05/16	03/18/16	0%



Interface Board

Current Status

PRE2 Development Board



Major Tasks Completed

- ✓ Board Fully populated
- ✓ Power (5V & 3.3V) is functional
- ✓ FTDI connects to computer and transmits data
- ✓ Master microcontroller is programmable
- ✓ ADCS power switches (MOSFETs) work
- ✓ Current sensors work and measure accurately*

*With caveat discussed later

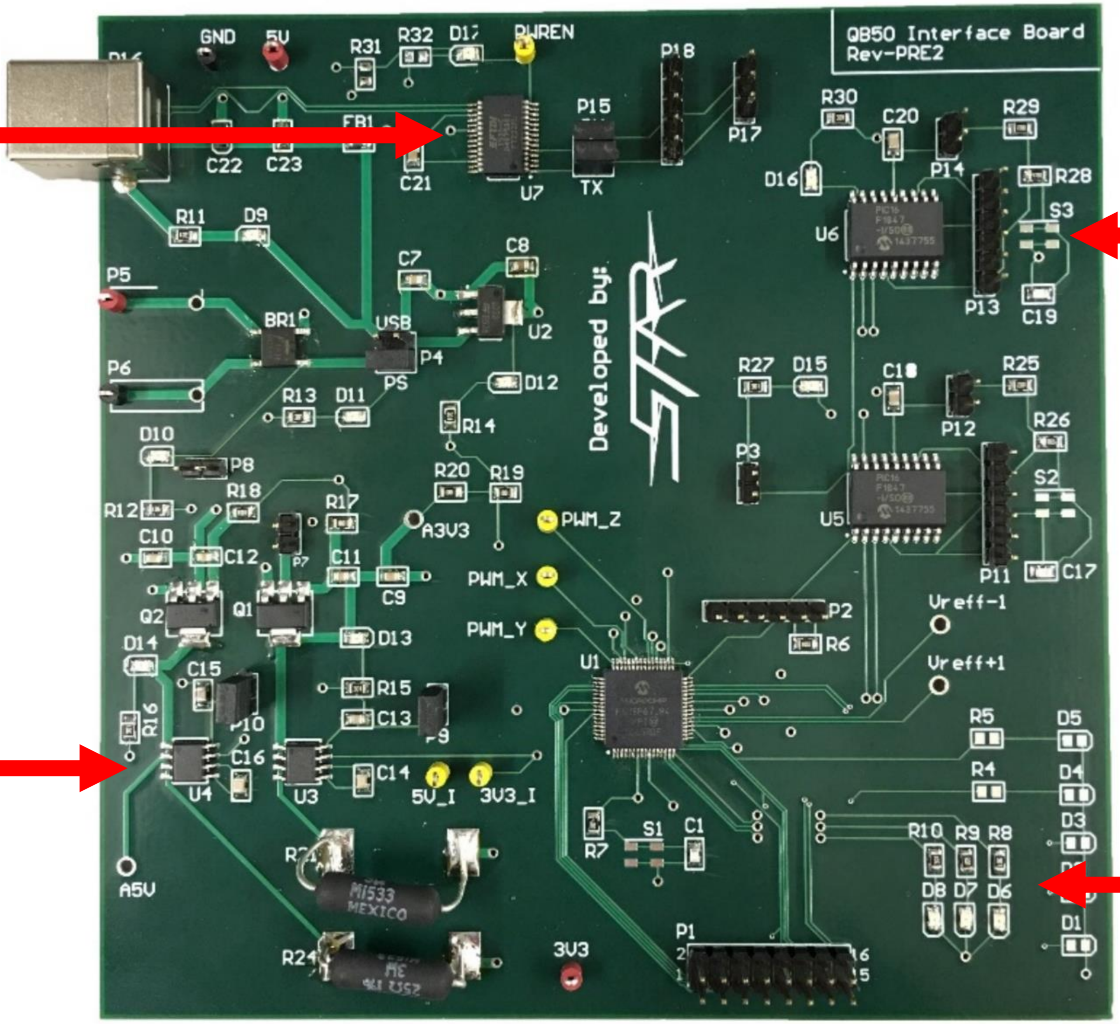
Major Tasks to Complete

- ❑ Functionally test slave microcontrollers
- ❑ Test full data communication between USB and microcontrollers
- ❑ Begin next board revision

Changes to Board

*Found in Errata

FTDI chip has power enable glitch *



Incorrect footprint size

Current sensor power voltage isn’t stable enough

Use of Incorrect I/O pins *

FTDI Power Enable Glitch

What was discovered:

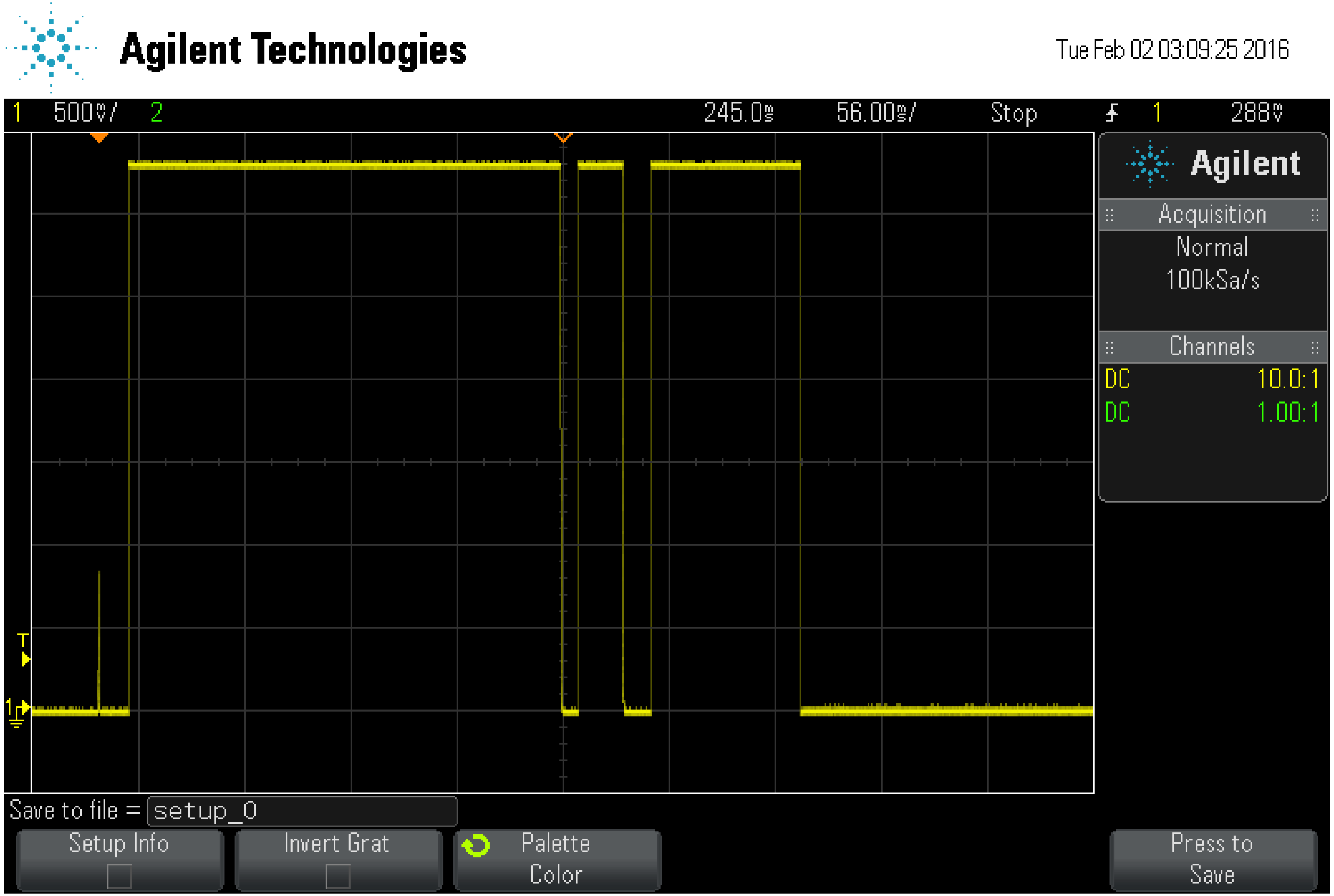
- ~13ms periods of enable that shouldn't occur
- Known glitch outlined in device errata

Why it's an issue:

- Will cause the interface board to draw to much current when not suppose to

Solution:

- Use a different FTDI chip (FT230X)
  - Does not contain glitch
  - Functionally the same chip
  - Smaller pin count/package

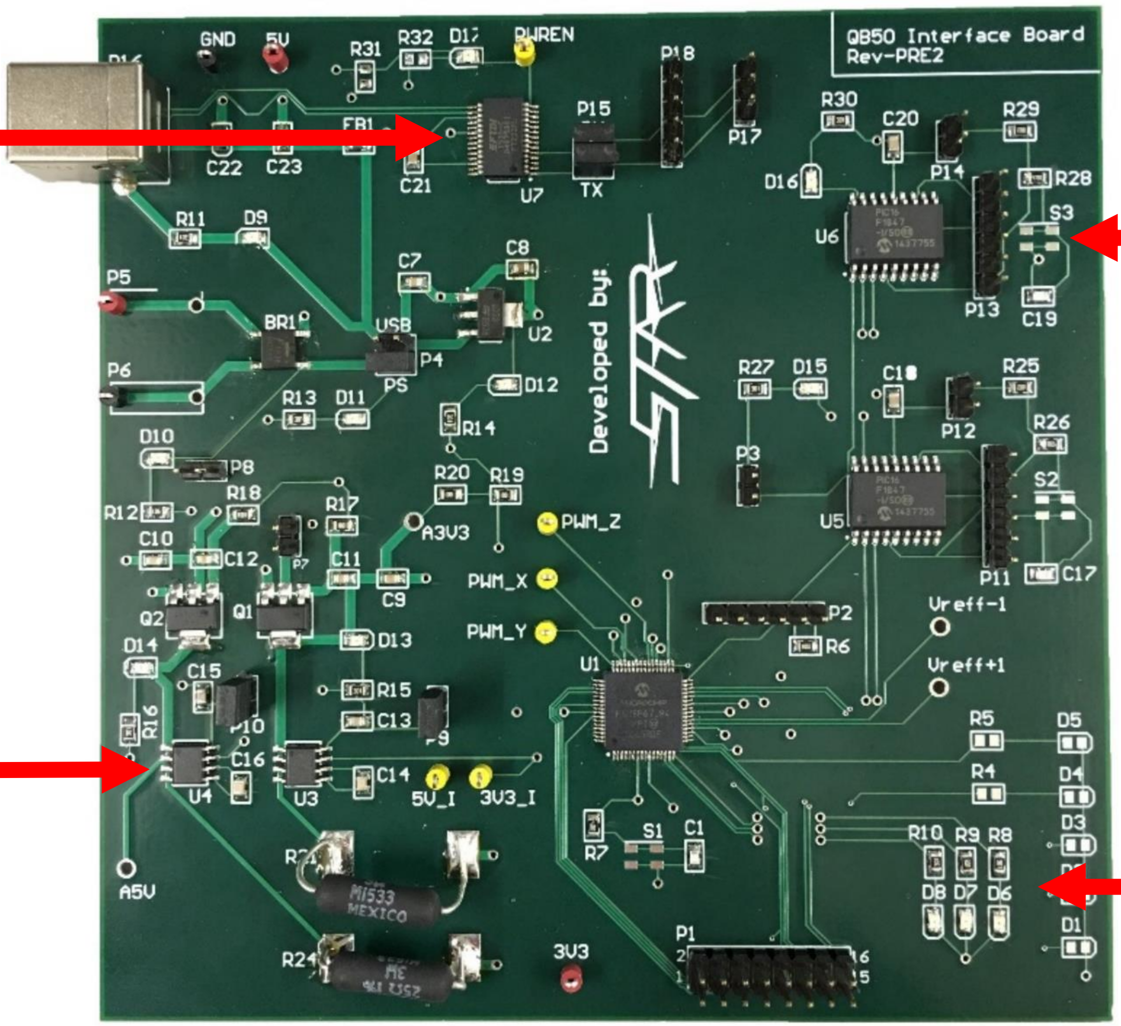


Changes to Board

*Found in Errata

FTDI chip has power enable glitch *

Change base sizes/locations



Current sensors supply voltage isn't consistent enough

Use of Incorrect I/O pins *

Current Sensors

What was known:

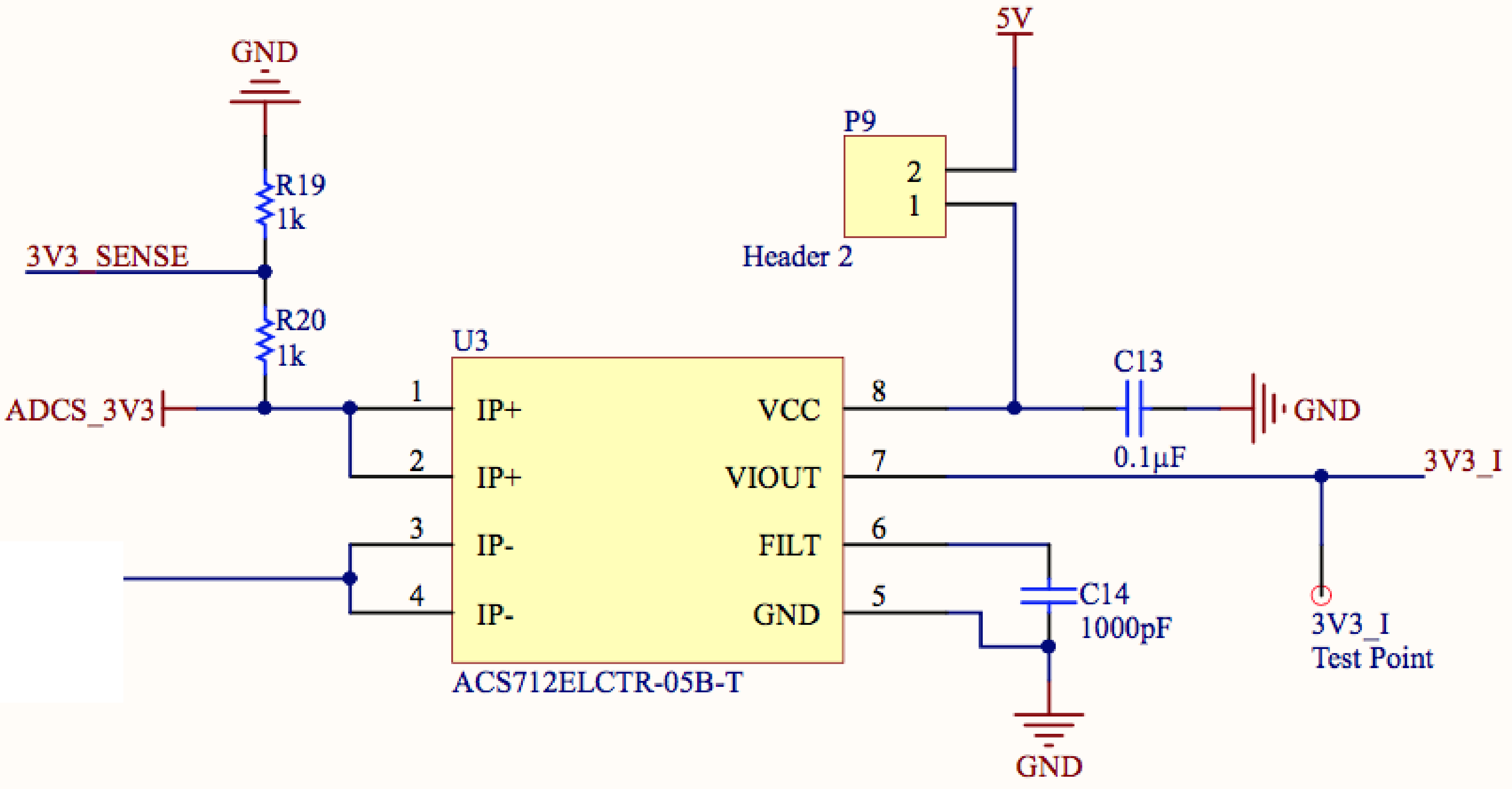
- Sensors are powered by 5V
    - Specified operating range from 4.5V to 5.5V
- Interface board 5V plane varies as much as 300mV depending on load

What was discovered:

- Sensor measurement output changes with sensor supply voltage by a ratio of ~1/2

Solution:

- Power sensors with a more stable 5V (exact method of doing so unknown at this point)

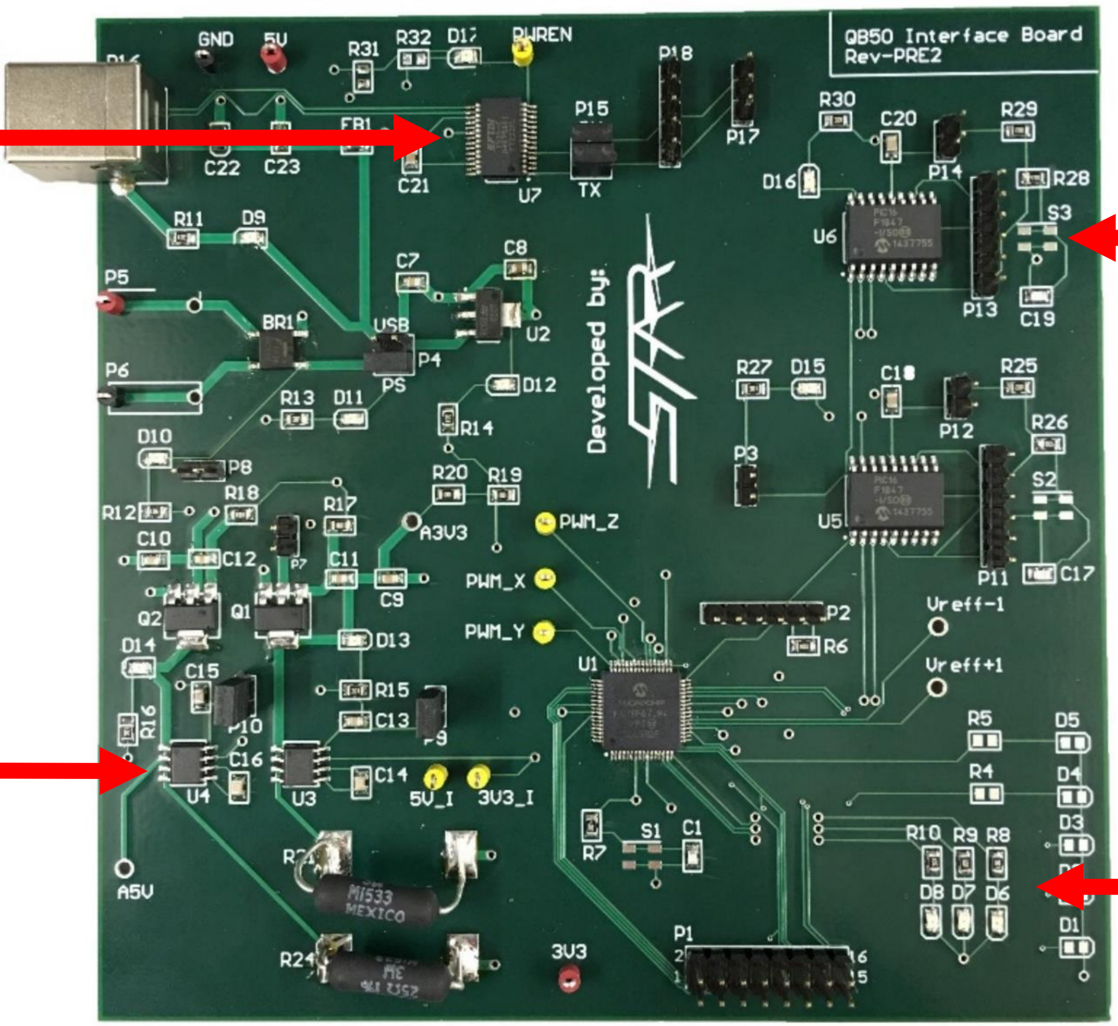


Changes to Board

*Found in Errata

FTDI chip has power enable glitch *

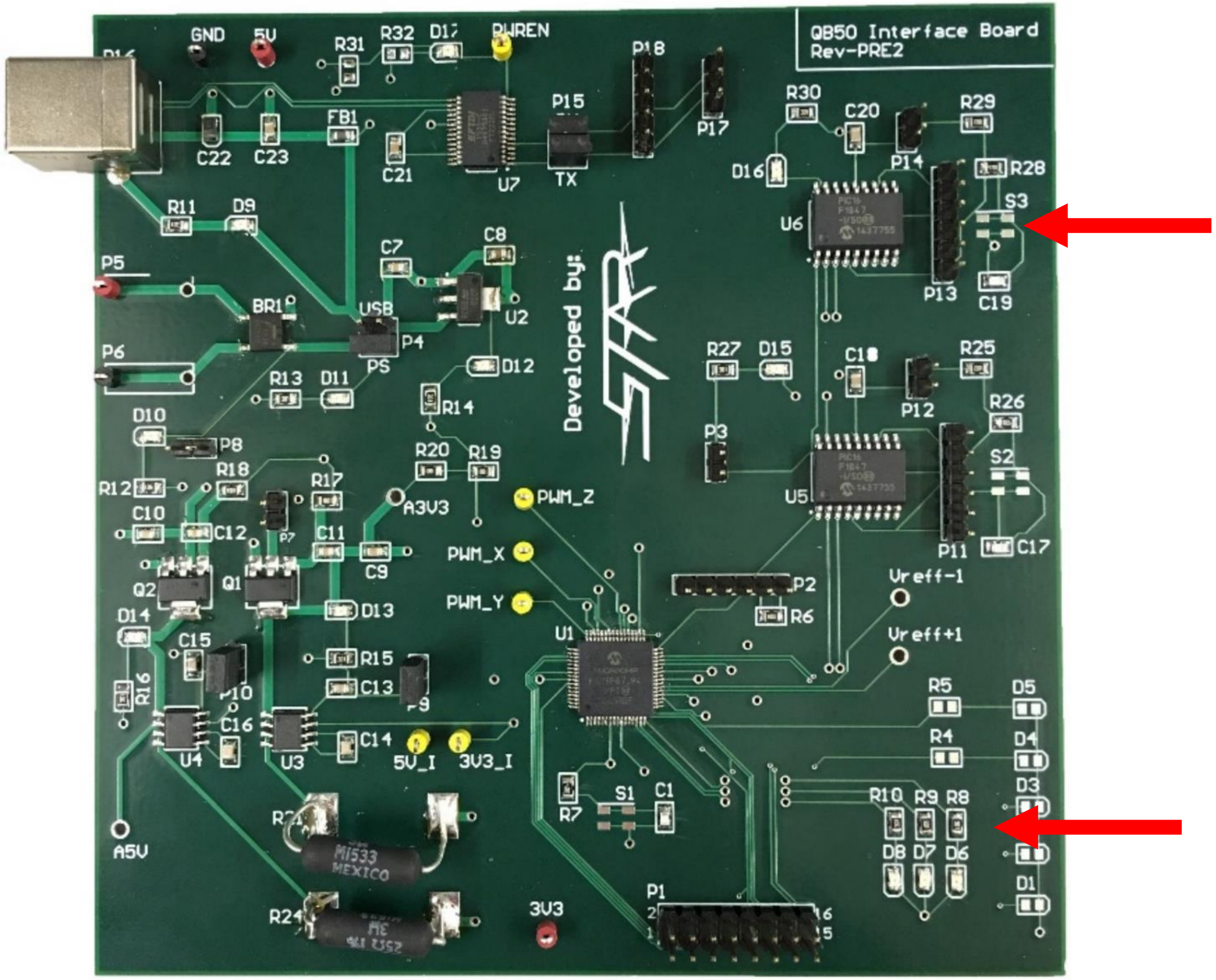
Change base sizes/locations



Current sensors supply voltage isn’t consistent enough

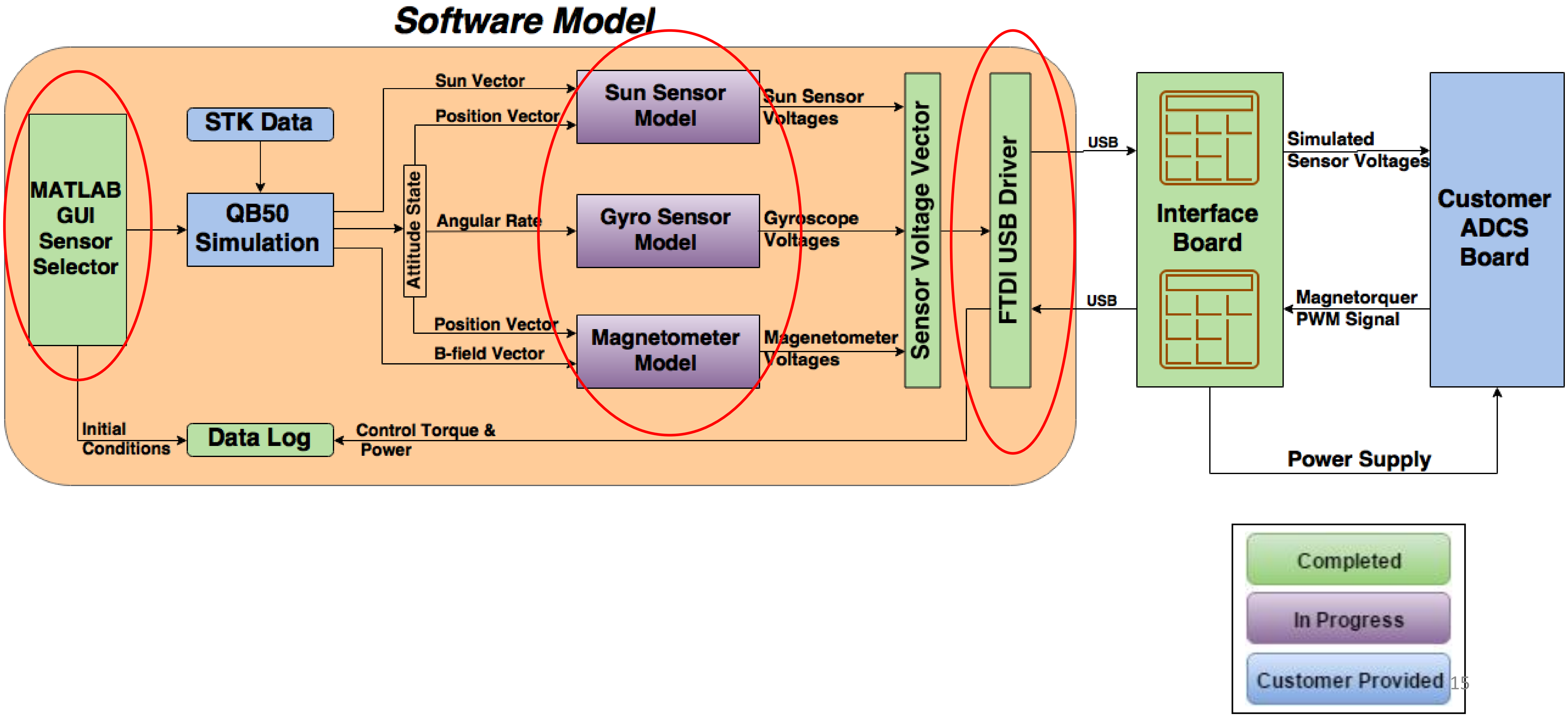
Use of Incorrect I/O pins *

General Board Layout Changes



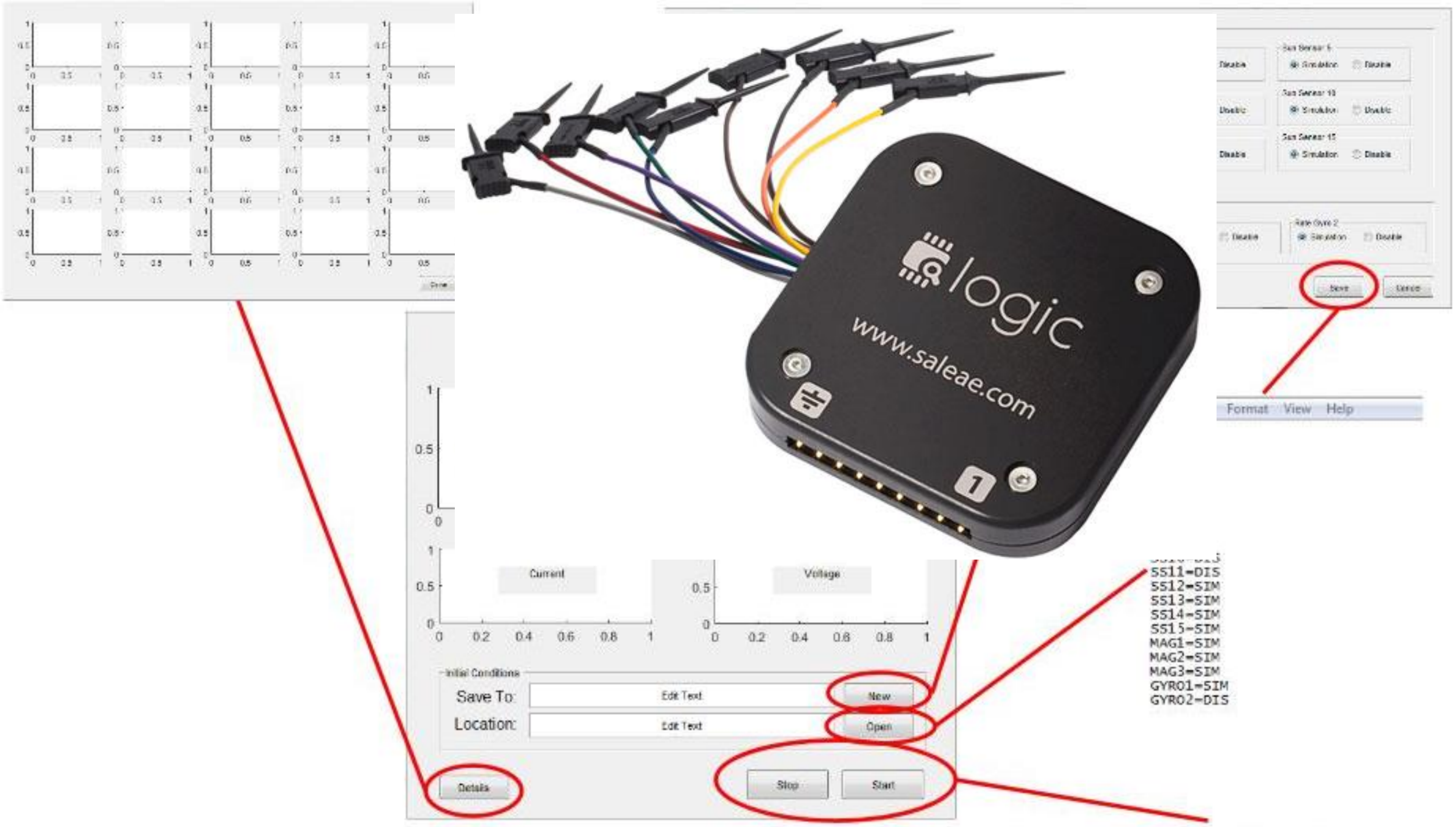
- Microcontroller reset button footprints to small
- 2 of 3 LEDs connected to master microcontroller don’t work
  - Connected to I/O pins incorrectly labeled as such in datasheet

Software Flow Diagram



Software Current Status

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

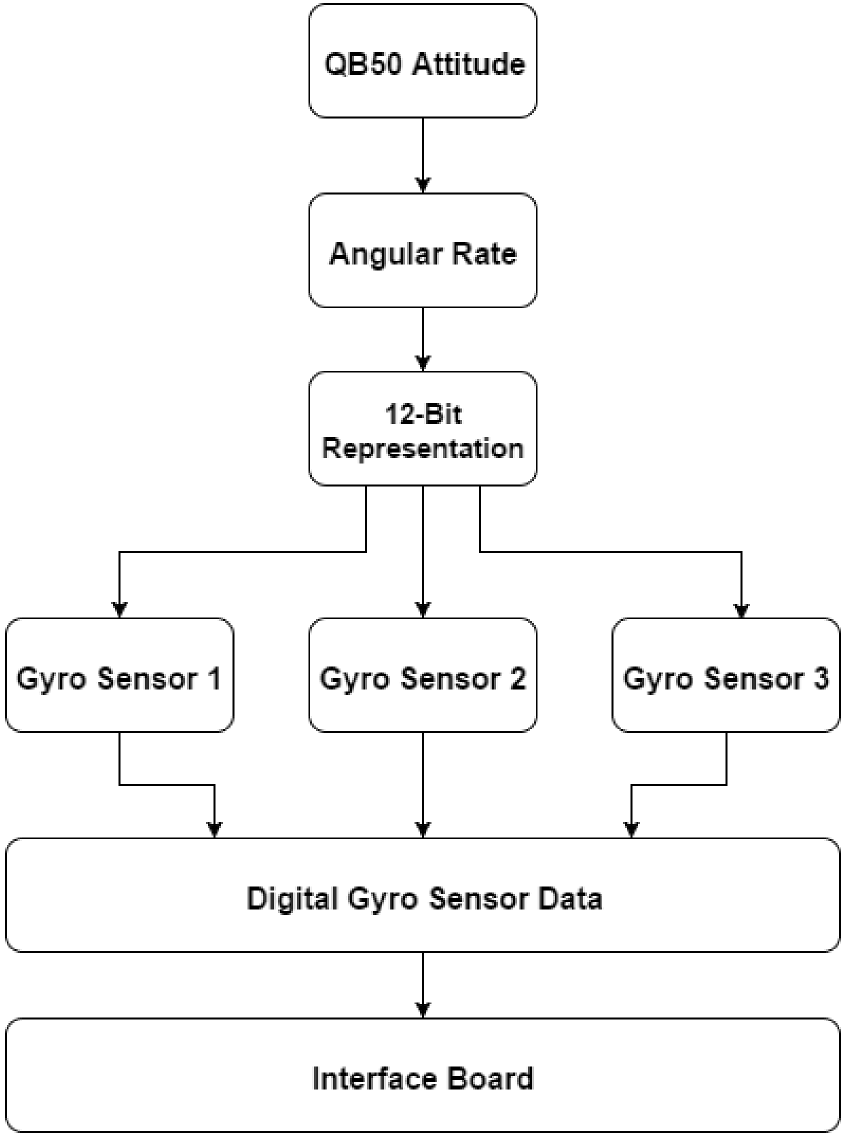


Start and Stop Simulation

Software Future Work

- Execute basic test program on Interface board
- Development of calibrated magnetometer and gyro models
- Compile sun-sensor data.
- Transmit simulated sensor data to Interface Board
- GUI Implementation
- Compute Control Torque from PWM signal
- Log Control Torque and Power consumption data.
- Full Software system test

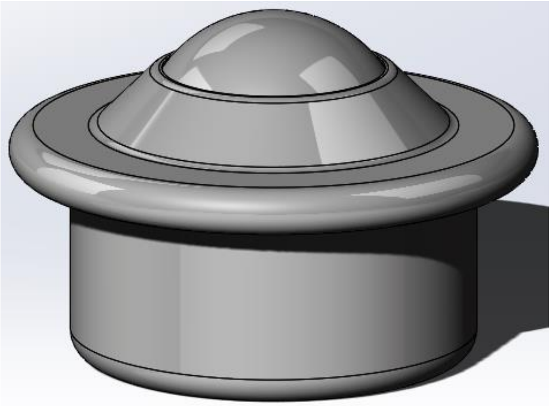
Sensor Model Calibration



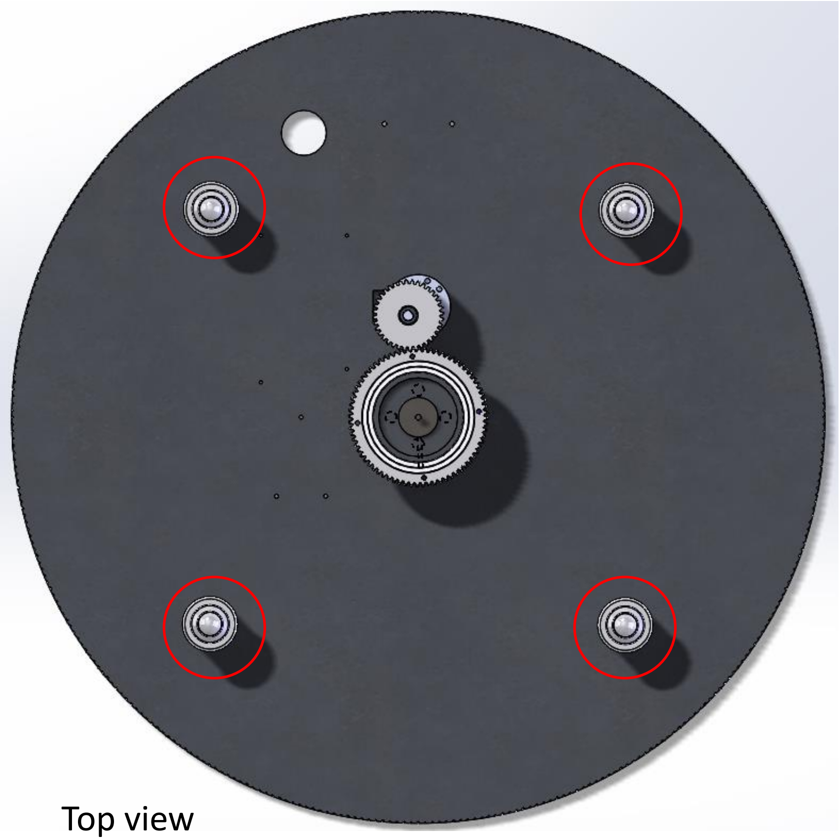
Sun Sensor Turntable

Turntable – Design Update

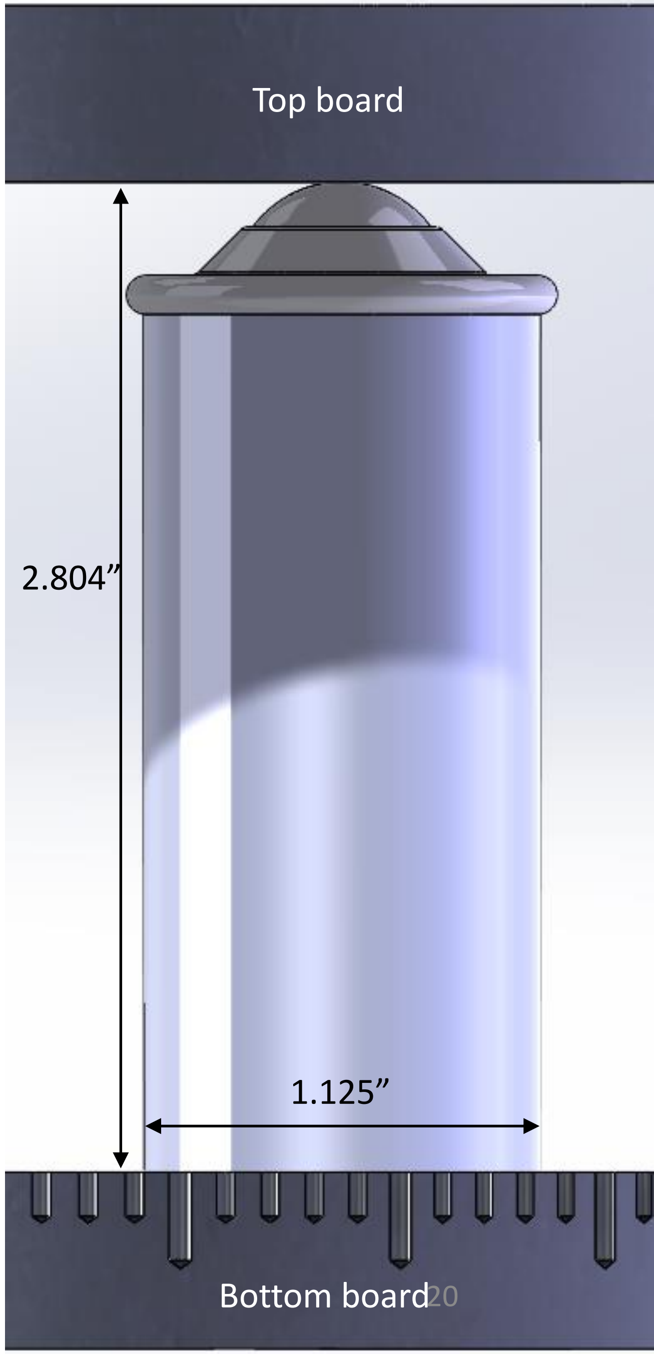
- Prevent precession of board
- Addition of 4 posts with ball transfers
    - Ball transfer friction fit into aluminum post



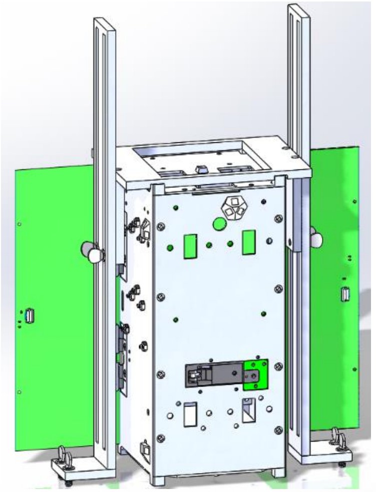
Bearing
$10.50 each



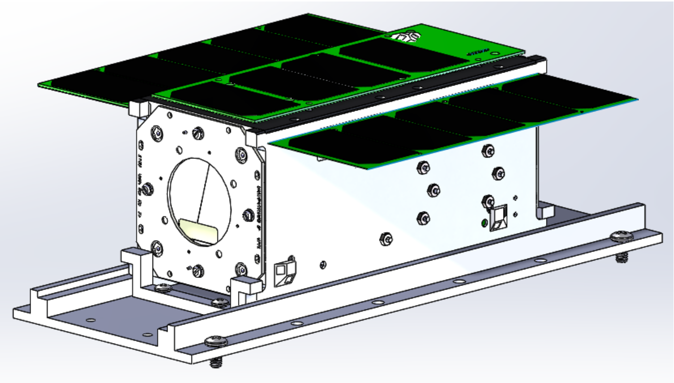
Top view



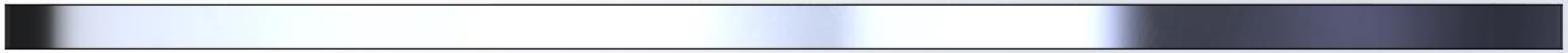
Turntable – Major Components Overview



1. Vertical Clamp



2. Horizontal Clamp



3. Top Board

4. Shaft

5 major parts we are manufacturing

5. Bottom Board

Turntable – Major Components Overview

Part	Materials Ordered	Manufacturing in Progress	Complete
1. Vertical Clamp • 2x slider plate • 2x base plate • 2x inner plate • 1x feet clamp	X		
2. Horizontal Clamp	X	X	X
3. Top Board	X	X 4 hours remaining	
4. Shaft	X		
5. Bottom Board	X		

- All final machining processes will be computer controlled

- Standard 0.005” CNC tolerances are fine for all parts

  - Several friction fit components

- Bottom board will be most difficult to machine

  - Same or simpler process for remaining parts

Turntable - 5. Bottom Board

Purpose

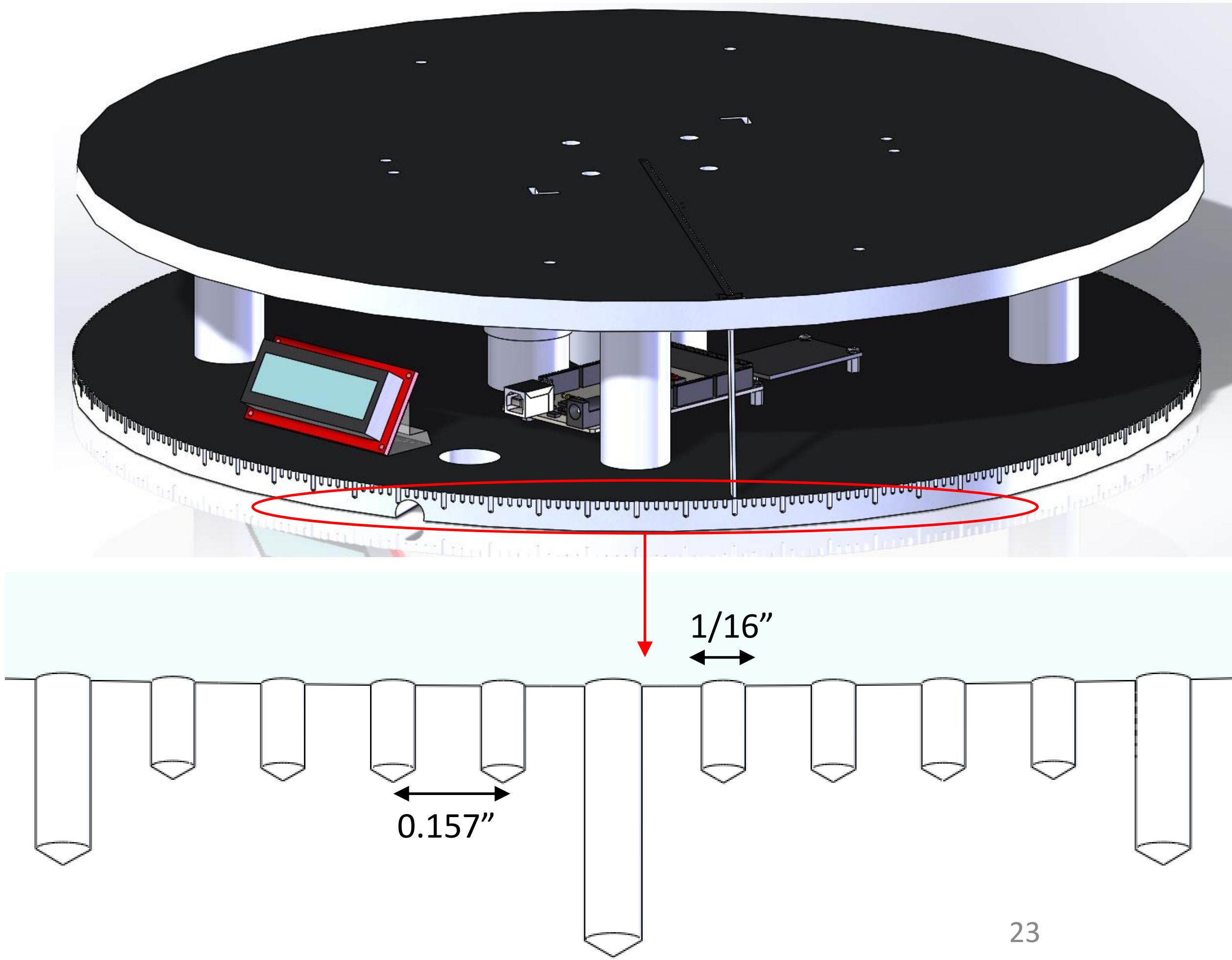
- Support and prevent tilting of top board
- Angle etchings
- House electronics

Manufacturing

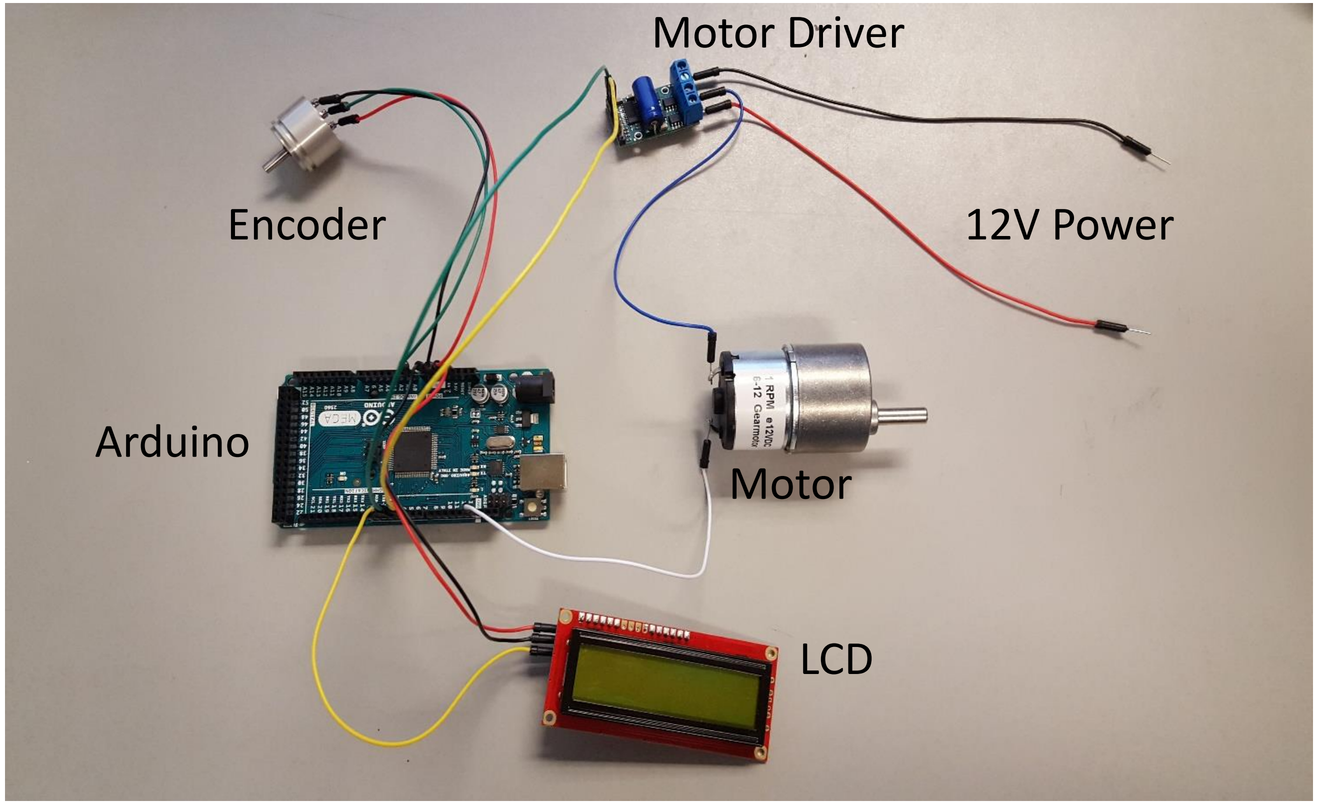
- Mill aluminum disc circumference to dimension
- Drill and tap holes

Angle etchings

- Will be used to satisfy ±0.5° accuracy requirement
- Drill with 1/16” bit around circumference
- Tolerance = 0.0785”



Turntable – Electronics



Current Status

	Ordered	Functionally Tested	Performance Tested
LCD	X	X	N/A
Encoder	X	X	
Motor	X	X	

Changes

- Arduino Mega to Arduino Due
  - 10 bit ADC to 12 bit ADC

HelmHoltz Cage

HelCaTS Parts

Parts Purchased (Red)

Extruded Aluminum

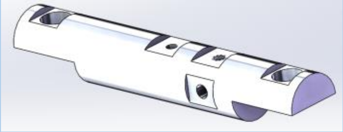
Screws / Nuts

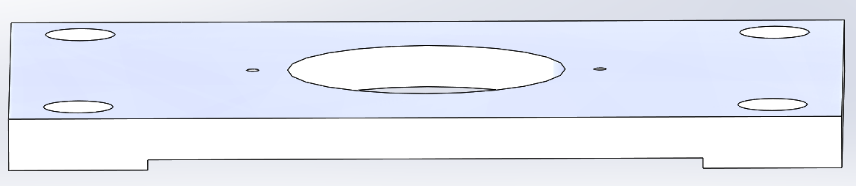
Threaded Rod

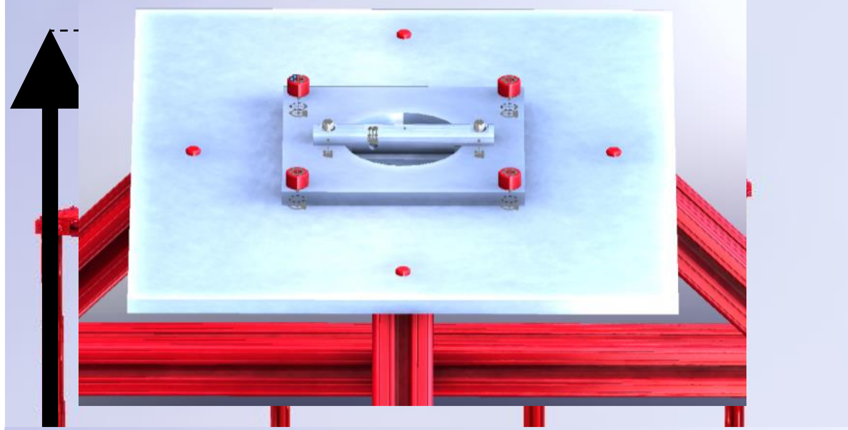
Parts Provided by Customer (Green) Satellite

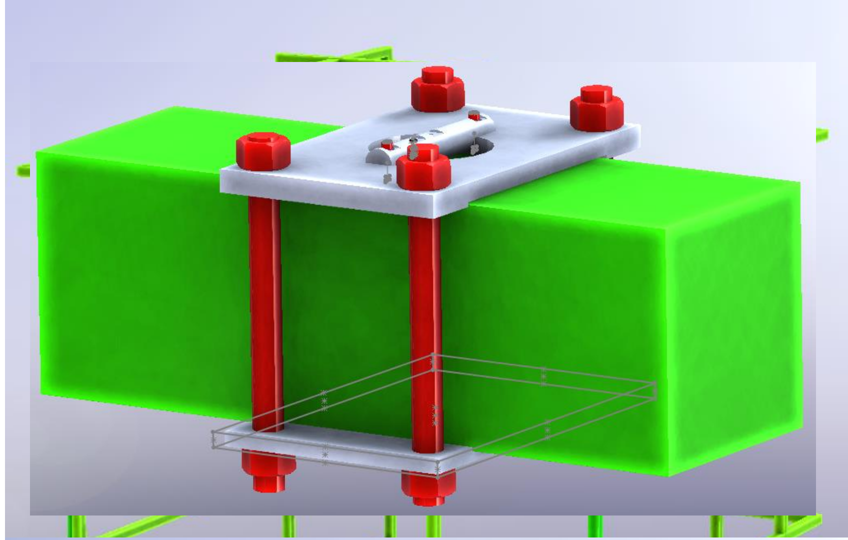
Helmholtz Cage

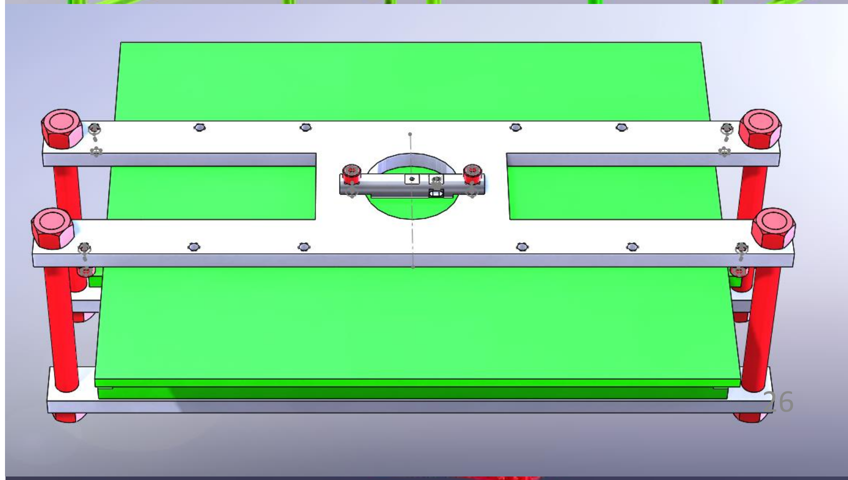
Parts Machined by STAR Attachment Cylinders Attachment Plates





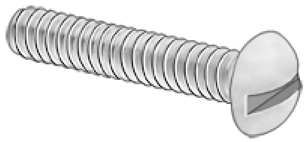


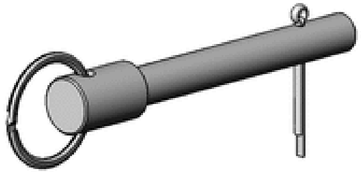




HelCaTS Purchased Parts

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

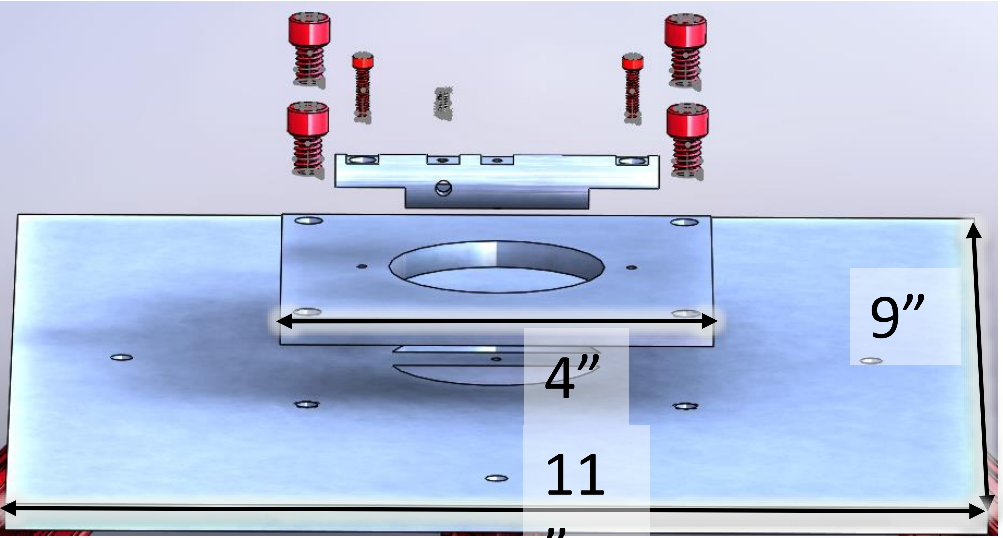


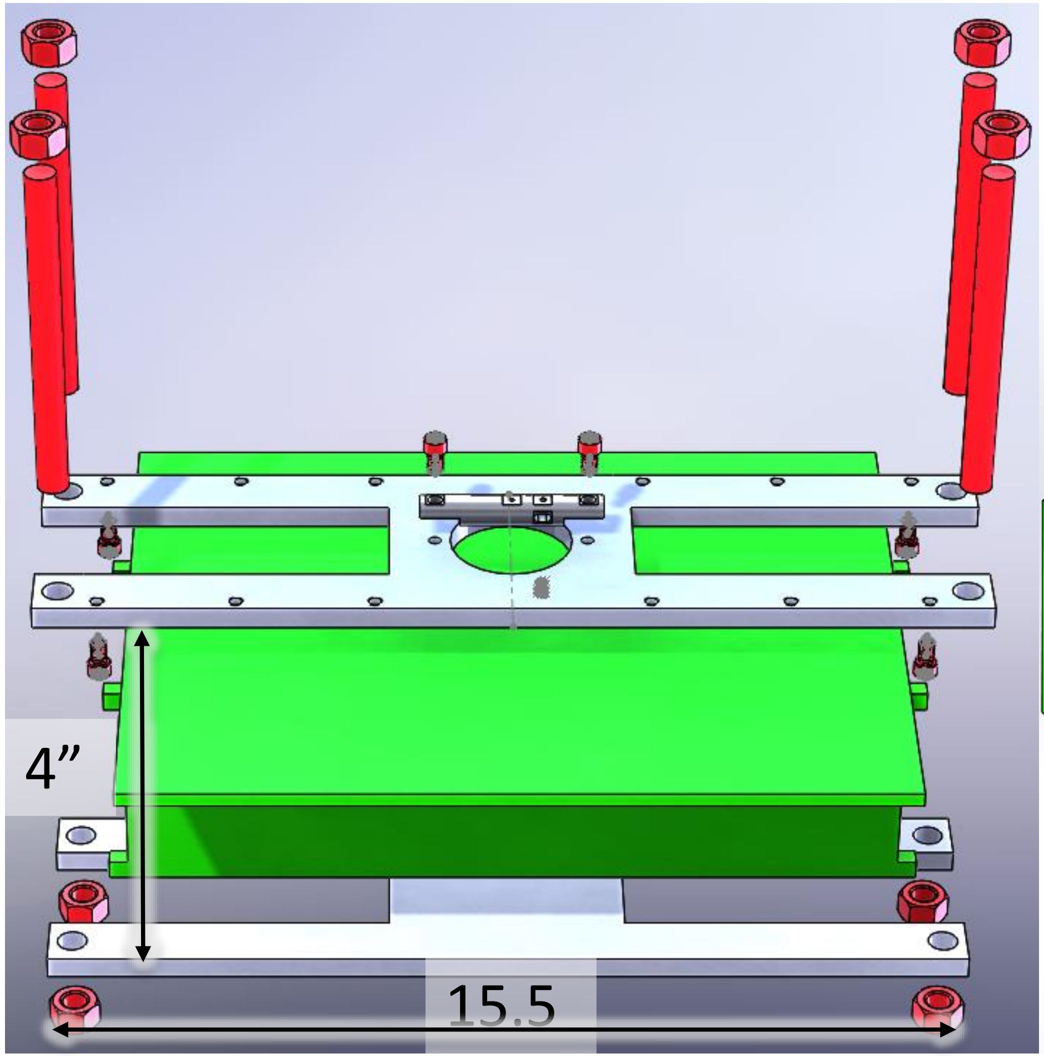


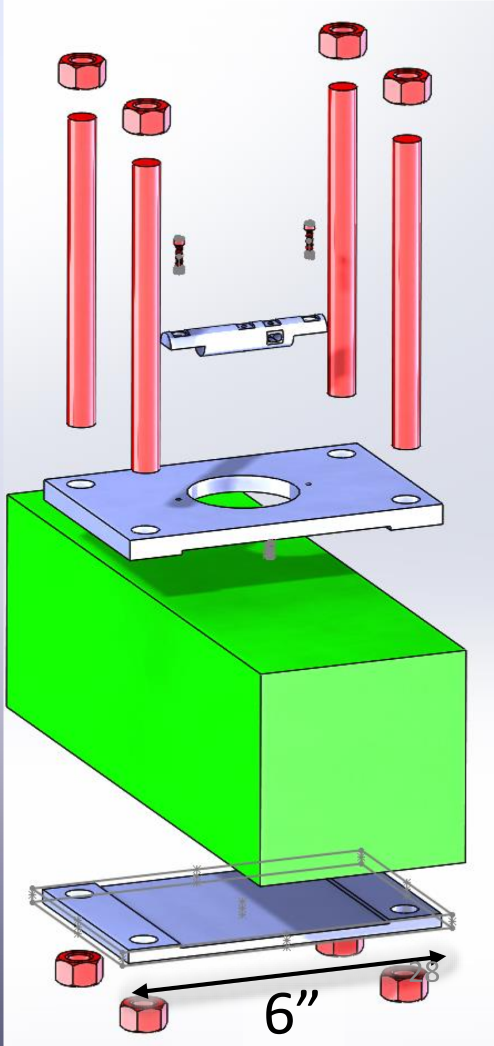
- Stainless Steel T-Nuts for attachment to extruded Aluminum
- Extruded Aluminum Bars (machined by 8020)
  - Cut to size 48” ,45.7”, 33”, 31”, 24” (+/- 0.015”)
  - Some Ends Tapped
  - Through holes drilled to pin the sliding mechanism (location accurate to +/- 0.03 in long direction +/- 0.01 in short direction)


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





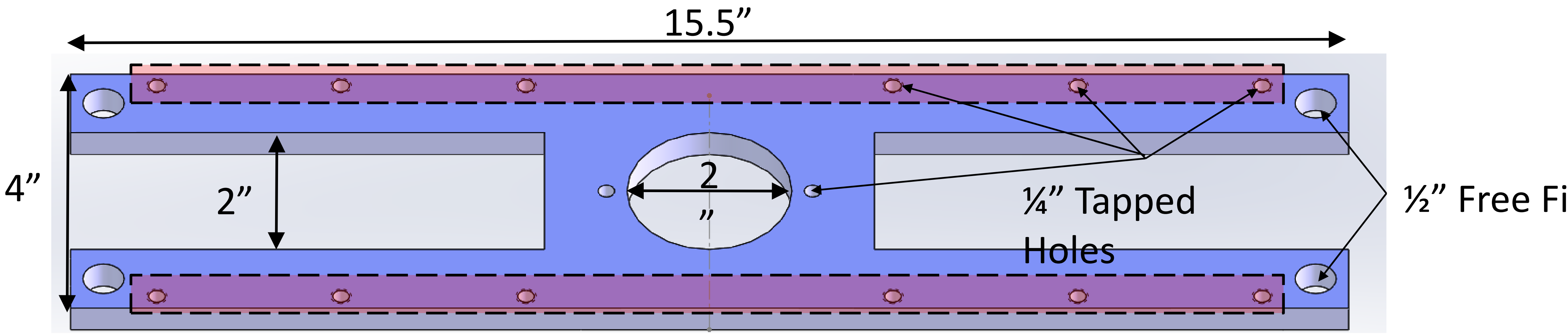


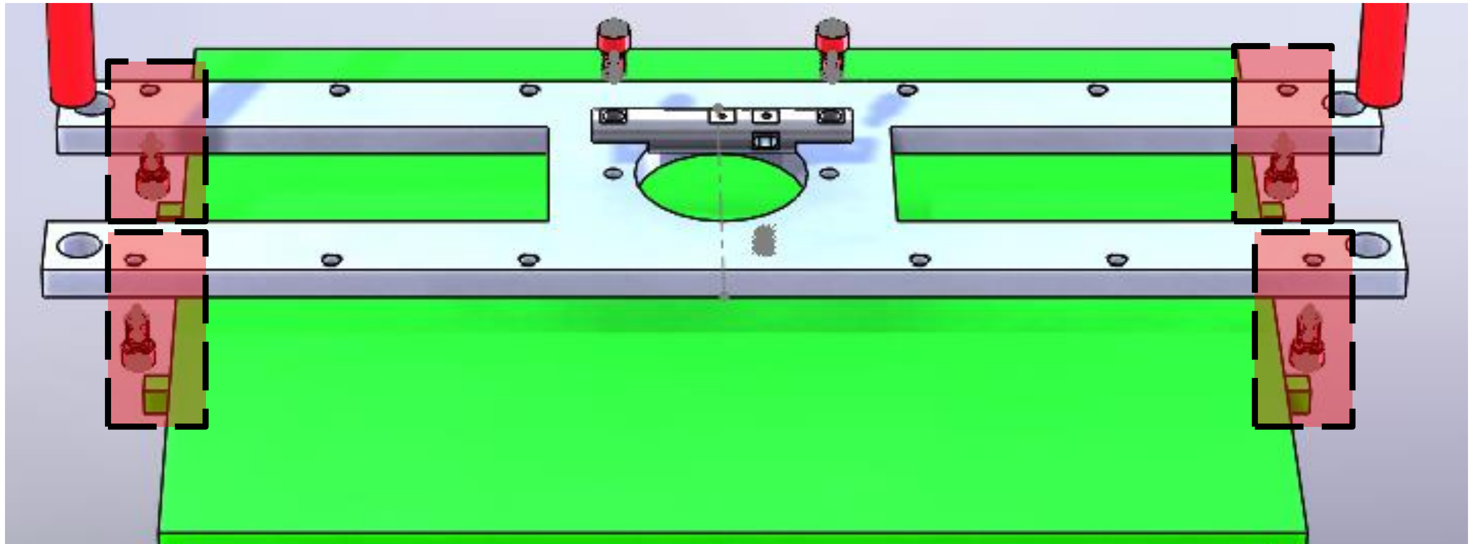
HelCaTS Manufactured Parts - Overview

Part	Materials Ordered	Manufacturing in Progress	Complete
1. Small Clamp • Top Plate • Bottom Plate	X	x	1 of 2
2. Large Clamp • Top Plate • Bottom Plate	X	X	
3. Structure Attachment Plates • Big Plate • Small Plate	X		
4. Attachment Cylinders	X		1 of 2

HelCaTS Design Updates

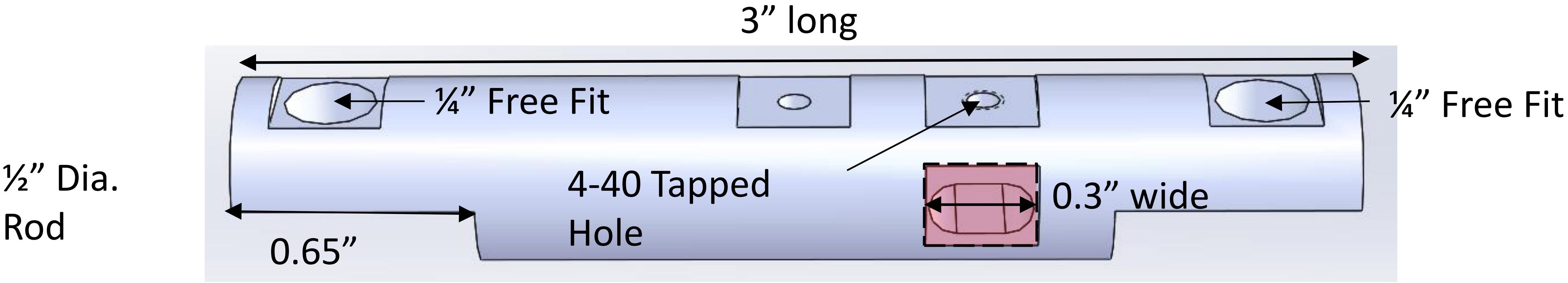
- Large Clamp Top Plate - Added holes to clamp on satellite feet





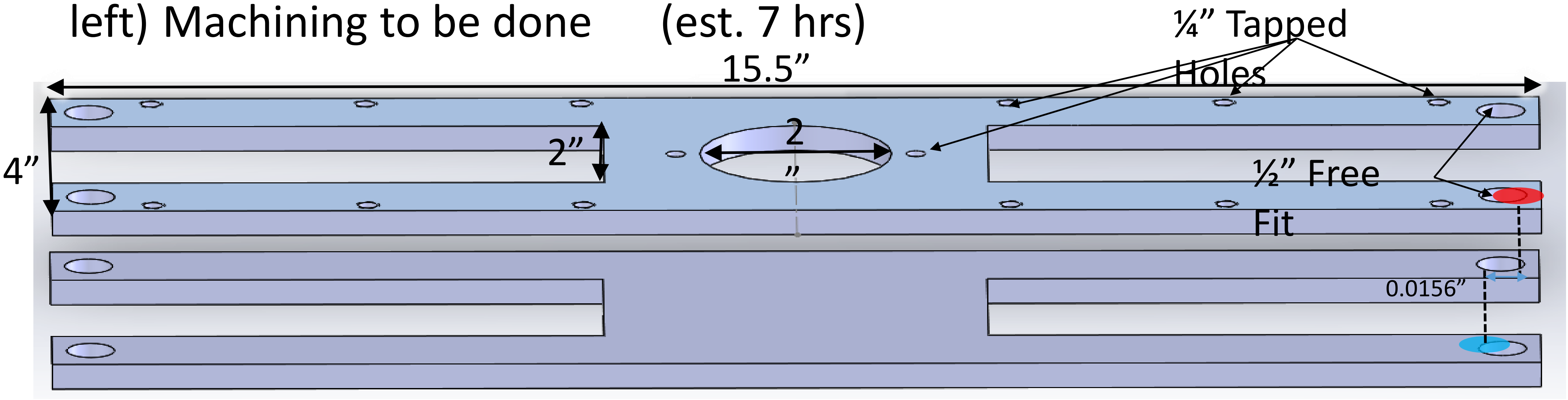
HelCaTS Design Updates

Attachment Cylinder – Slotted hole to allow for more tolerance (from 0.001" to 0.0675")



HelCaTS Large Clamp Machining - In Progress

Status: Toolpaths 80% Written (20 minutes left) Machining to be done (est. 7 hrs)



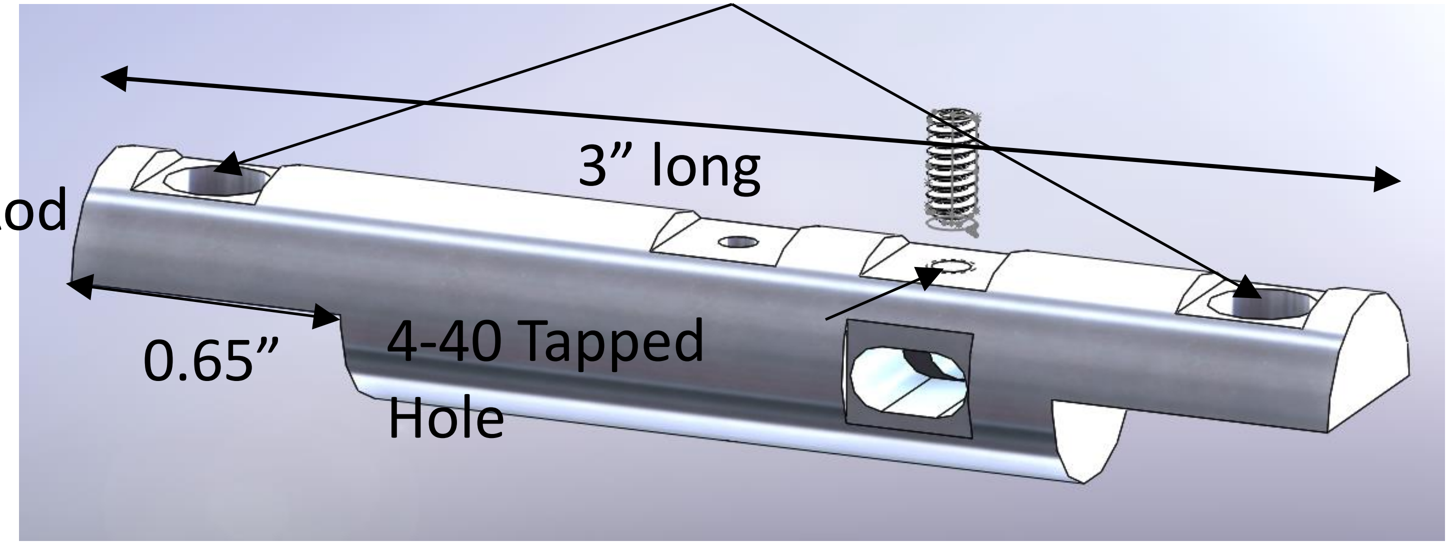
Machining Tolerance: 0.005”

Critical Dimensions:

- spacing of ½” holes must be accurate to +/- **0.0156”** in each direction
- spacing of tapped ¼” center holes must be accurate to +/- **0.008”** in each direction
- spacing of attachment holes must be accurate to **+/- 0.15”** in each direction

HelCaTS Manufactured Parts - Attachment Cylinder

Status: 1 of 2 Machined



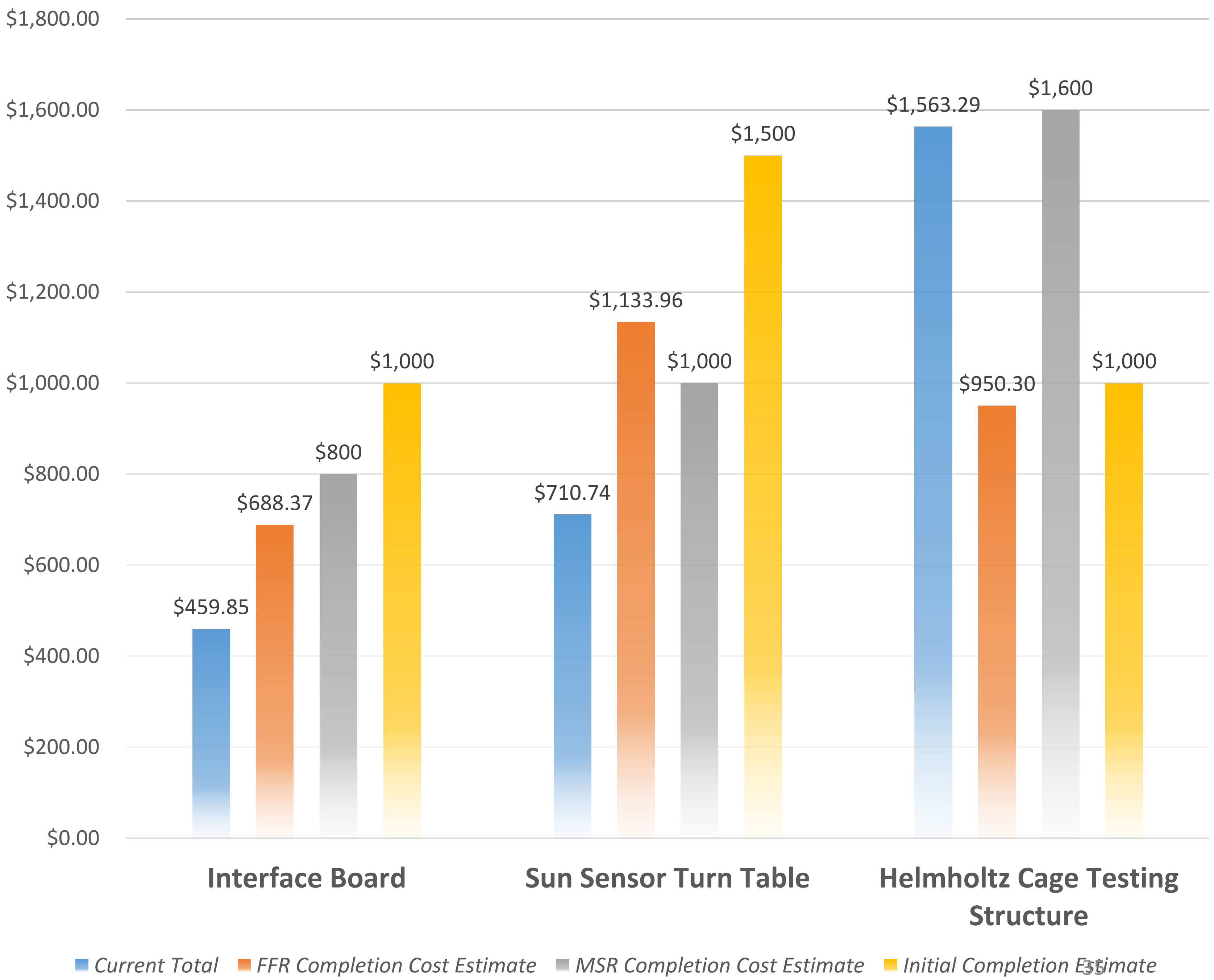
Critical Dimensions:

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

Budget

Budget

- Total Budget: **$5,000**
- Total Spent: **$2,805.77**
- FFR Completion Cost Projection: **$3,072.63**
- MSR Completion Cost Projection: **$3,700**
    - **Need: IB revisions**
- Δ ≈ +**$700** from FFR
- Current *Estimated* Completion Margin: **26%**
    - FFR Margin Est.: **39%**



Backup Slides

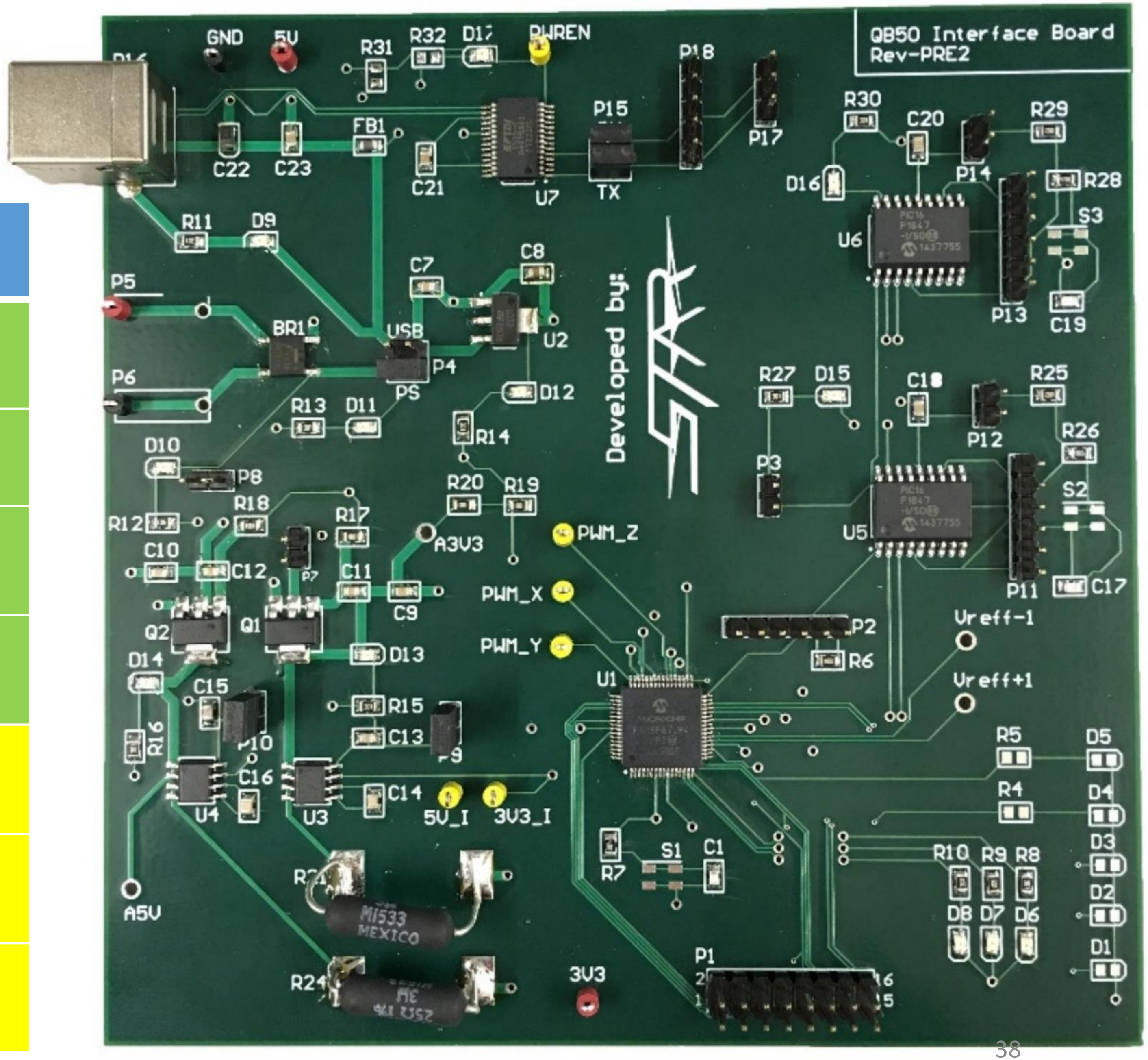
Interface Board Timeline

Completed
Margin
Continuous
Goal

Project STAR Gantt Chart – Interface Board				January				February				March				April				May	
	Start Date	Achieved Complete Date	Expected Finish Date	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2
Interface Board																					
Hardware	**9/16/2016**		**4/25/2016**																		
Acquire Necessary Components	12/16/2015	1/8/2016																			
Assemble Test Board	1/22/2016	1/21/2016																			
Integrate with Software	1/12/2016		2/19/2016																		
Complete Altium Board Revisions	2/1/2016		2/5/2016																		
Final Board Order	N/A		2/12/2016																		
Populate Revised Board	N/A		2/26/2016																		
Test/Verify Functionality	N/A		3/25/2016																		
Software	**9/15/2015**		**4/25/2015**																		
Develop GUI Architecture	1/11/2016		2/26/2016																		
Simulation Development	1/3/2016		3/11/2016																		
Verify Simulation Functionality and Results	2/5/2016		3/18/2016																		
Validate Sensor Models/Update Models	2/5/2016		3/18/2016																		
Test Program for Simulation-IB Datalink	1/20/2016		2/12/2016																		
Full Simulation Model Implementation	2/5/2016		3/25/2016																		

Interface Board Status: Hardware

Item	Status	Next Step
Component Acquisition	Complete	Order REV0
Soldering	Complete	Acquire REV0
Header installation	Complete	Acquire REV0
PIC MμC Programmable	Complete	Develop code
PIC SμC Programmable	Incomplete	Investigate Code Configurator GUI
REV0 Design/Order	Incomplete	Continue development
REV0 Population	Incomplete	Acquire REV0



Interface Board Status: Software for MμC

Item	Status	Next Step
Switch between compilers (C18 →XC8)	Success	Continue to use XC8 libraries
#pragma config	Success	Add more if needed
Initial / Configuration	Success	Update as needed
Main Loop	Success	Add in interrupt logic
USART Configuration (Tx/Rx)	In Progress	Verify code against hardware
PWM Configuration	In Progress	Further Develop Code
ADC Configuration	In Progress	Investigate current sensors *(future slide)*

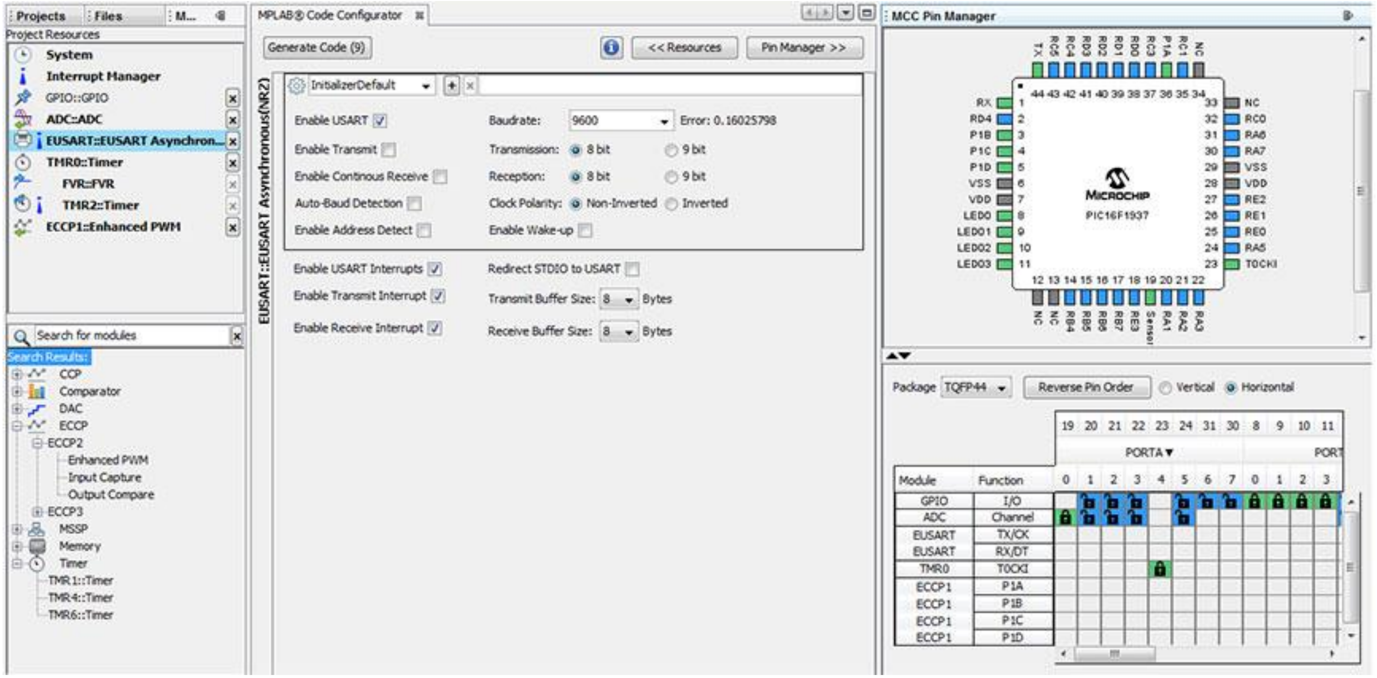
```
/******************************************************************************
 * Initial()
 *
 * This subroutine performs all initializations of variables and registers.
 ******************************************************************************/
void Initial() {
    //ANCON = 0x0F;
    CM1CON = 0x00;
    CM2CON = 0x00;
    CM3CON = 0x00;
    ANCON1 = 0x00;
    ANCON2 = 0x00;
    ANCON3 = 0;
    UCONbits.USBEN = 0;
    // Goal: Configure USART connections, PWM, FTDI, ADC connections

    // PWM Configuration:
    // X = CCP4/RP7/RB3
    // Y = CCP5/RP8/RB0
    // Z = CCP6/RP10/RA7

     TRISA = 0b11111111; //
          // A0 = 5V_I
          // A1 = 5V_Sense
          // A2 = VReff-1 Test Point
          // A3 = Vreff+1 Test Point
          // A4 = 3V3_I
          // A5 = 3V3_Sense
          // A6 = (not used)
          // A7 = PWM_Z
     TRISB = 0b00001101;
          // B0 = PWM_Y
          // B1 = N/A
          // B2 = FTDI_RX
          // B3 = PWM_X
          // B4 = N/A
          // B5 = N/A
          // B6 = ISCP_CLK_M
          // B7 = ISCP_DAT_M
     TRISC = 0b00000000;
          // C0 = ADCS_GPS_3V3_EN
          // C1 = ADCS_GPS_EN
          // C2 = ADCS_5V_EN
          // C3 = FTDI_TX
          // C4 = ADCS_3V3_EN
          // C5 = ADCS_BOOT
          // C6 = N/A
          // C7 = Master TX
```

Interface Board Status: Software for SμC

Item	Status	Next Step
Switch to XC8 Compiler	Complete	Continue to use XC8 libraries
Pin Mapping	Complete	Move on to REV0 mappings
Code Configurator	In Progress	Enhance Understanding of GUI tool
Ability to program	In Progress	Create functioning code



Code Configurator: Plug-In to MPLAB X IDE

-Allows GUI configuration of PIC

-Automatic module creator

Example of Progress – Flashing LEDS

Test Component	Hardware/Software	Demonstrating
Board Population	Hardware	Soldering success
Basic Pin Configuration	Software	Pins are mapped correctly
Header Installation	Hardware	Wires/lines can be probed
PIC can be programmed	Hardware	PIC is properly functioning
USB Power	Hardware	Board has proper power supply
FTDI Chip	Hardware	Successful communication between the computer and the PIC

Power Measurements – PS @ 6.76V

25Ω Load (~400mA total current draw)

- 5V
  - Power Plane = 5.02V
  - A5V = 4.995V
  - @ load = 4.993V
- 3.3V
  - Power Plane = 3.311V
  - A3V3 = 3.292V
  - @ load = 3.291V

No Load

- 5V
  - Power Plane = 5.2V
- 3.3V
  - Power Plane = 3.312V

Power Measurements – USB Power

25Ω Load (~400mA total current draw)

- 5V
  - Power Plane = 4.89V
  - A5V = 4.865V
  - @ load = 4.860V
- 3.3V
  - Power Plane = 3.311V
  - A3V3 = 3.293V
  - @ load = 3.291V

No Load

- 5V
  - Power Plane = 5.059V
- 3.3V
  - Power Plane = 3.312V

Current Sensor Measurements

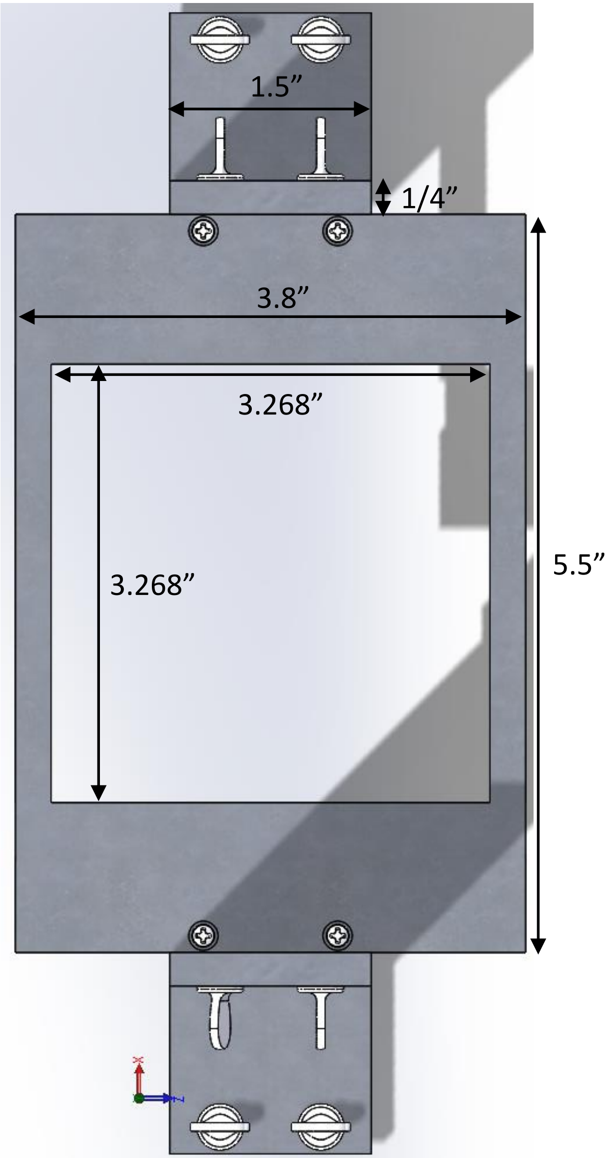
- Board powered by power supply, supply voltage was adjusted so that the current sensors always received 5V power
- Measurements taken with Fluke multimeters
- Sensor sensitivity is 185mV/A
- $I = \frac{V_{Out} - V_{Zero}}{Sensitivity}$

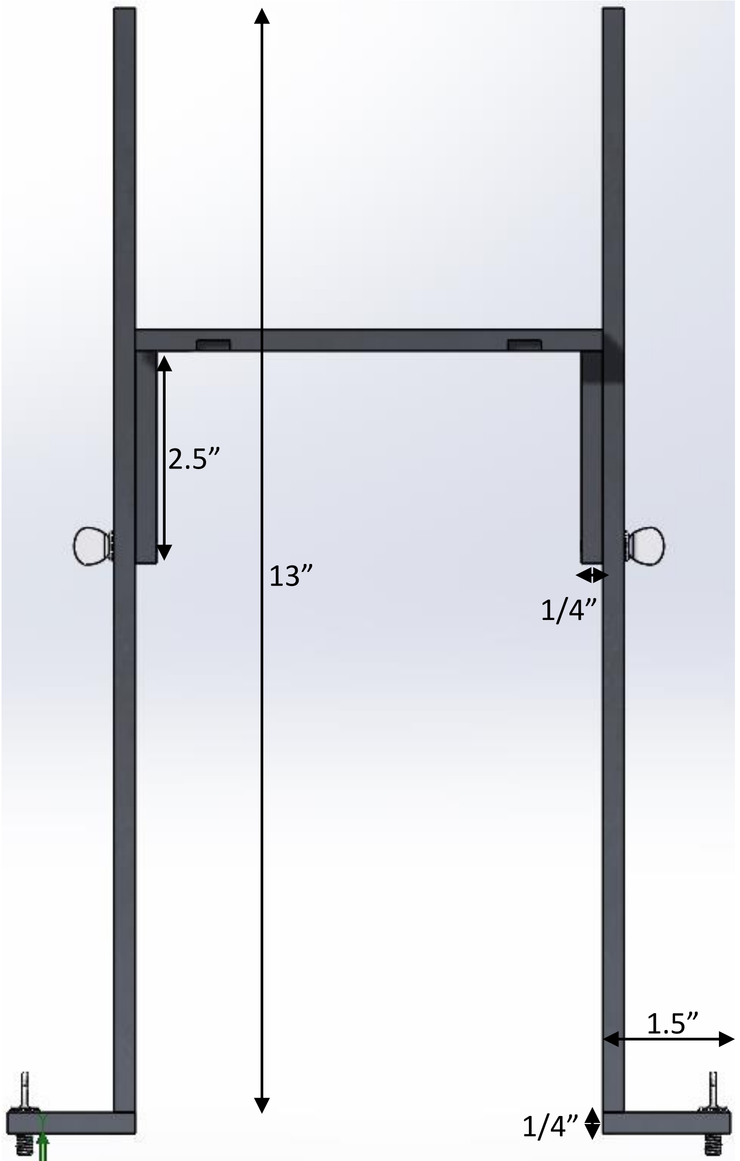
- Currents measured by Fluke
  - 5V = 204mA
  - 3V3 = 139mA
- 0A voltage output
  - 5V = 2.515V
  - 3V3 = 2.51V
- Sensor output under load
  - 5V = 2.553V → 216mA
  - 3V3 = 2.538V → 146mA

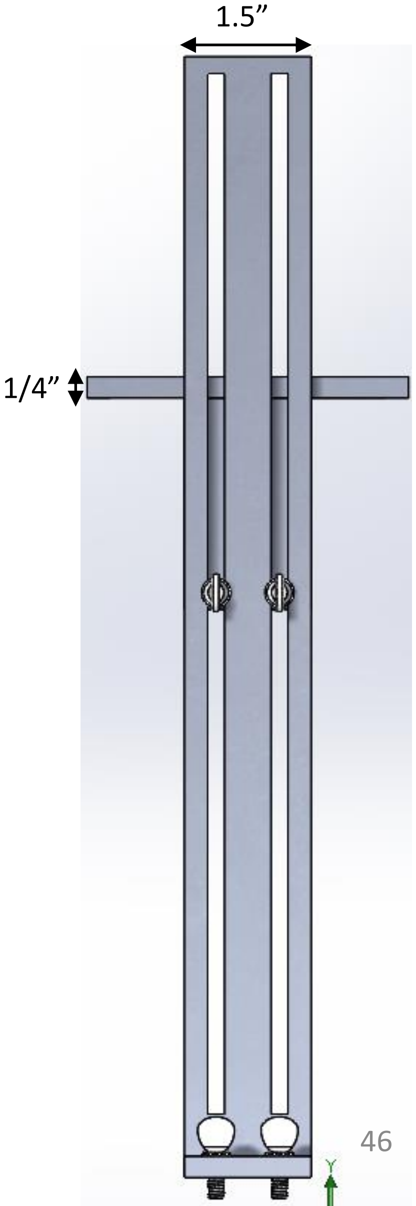
Turntable - 1. Vertical Clamp

- Purpose
  - Secure and align CubeSat in vertical orientation
- Status
  - Material in transit
- Manufacturing
  - All 5 sub parts made from ¼” thick aluminum plate
  - Mill aluminum plate and bars to dimension
  - Drill and tap holes
  - Bead blast at BioServe lab (decrease reflectance to 15-20%)
- Most difficult component
  - 1-2 weeks machining

Turntable - 1. Vertical Clamp



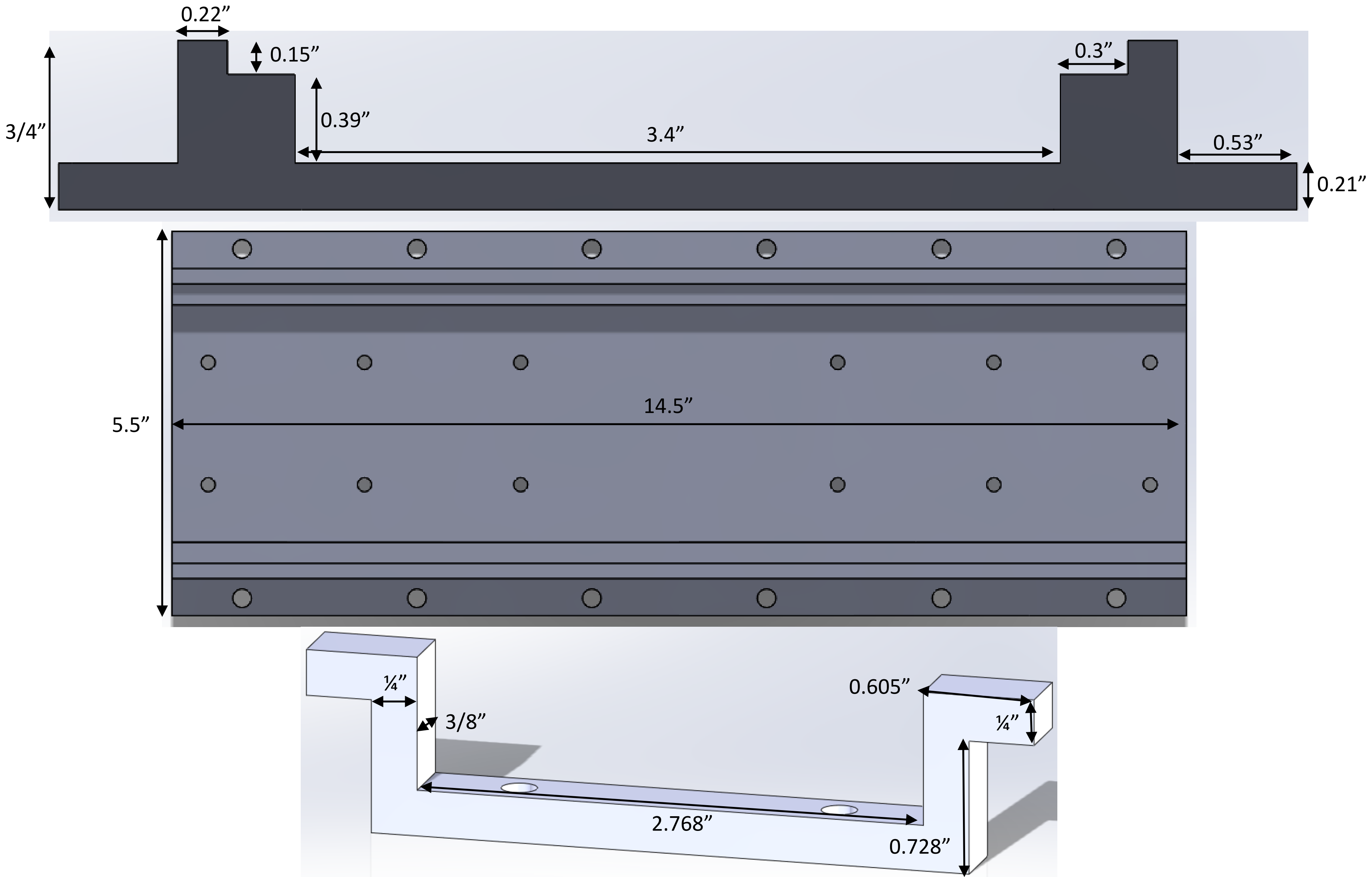




Turntable - 2. Horizontal Clamp

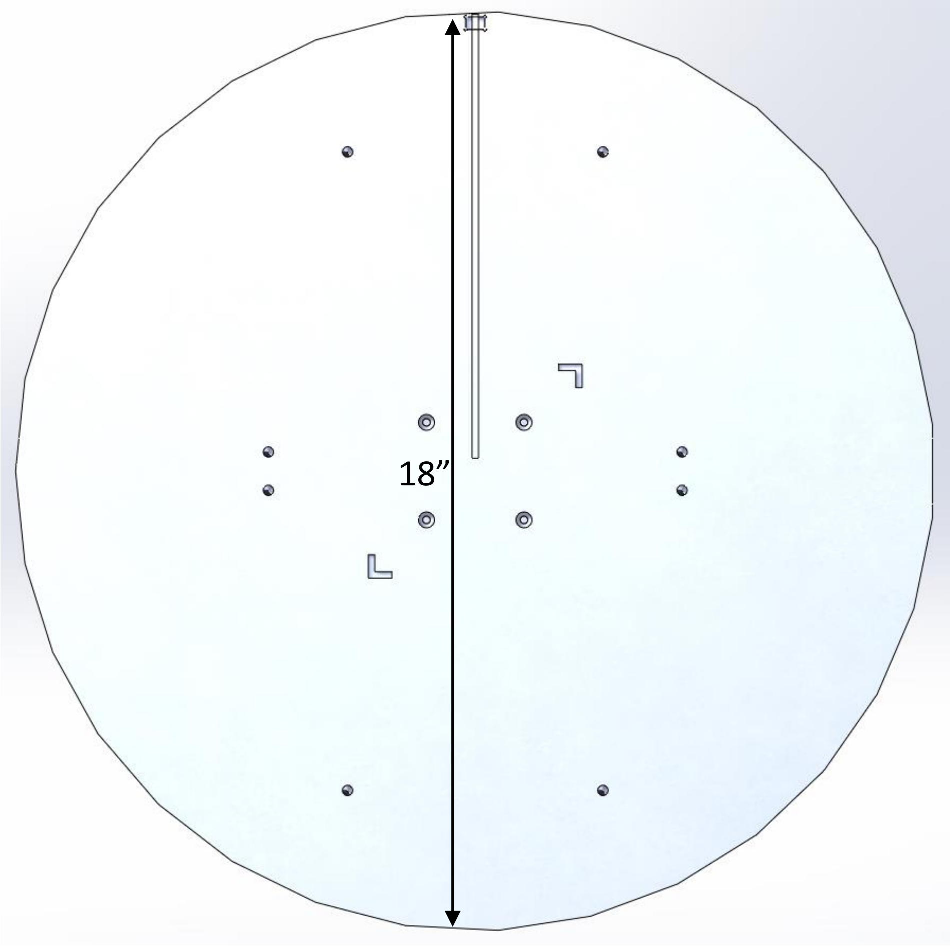
- Purpose
  - Secure and align CubeSat in horizontal orientation
- Status
  - Complete
- Manufacturing
  - Mill aluminum plate to dimension
  - Drill and tap holes
  - Bead blast at BioServe lab (decrease reflectance to 15-20%)
- Most difficult component
  - Manufacturing time

Turntable - 2. Horizontal Clamp



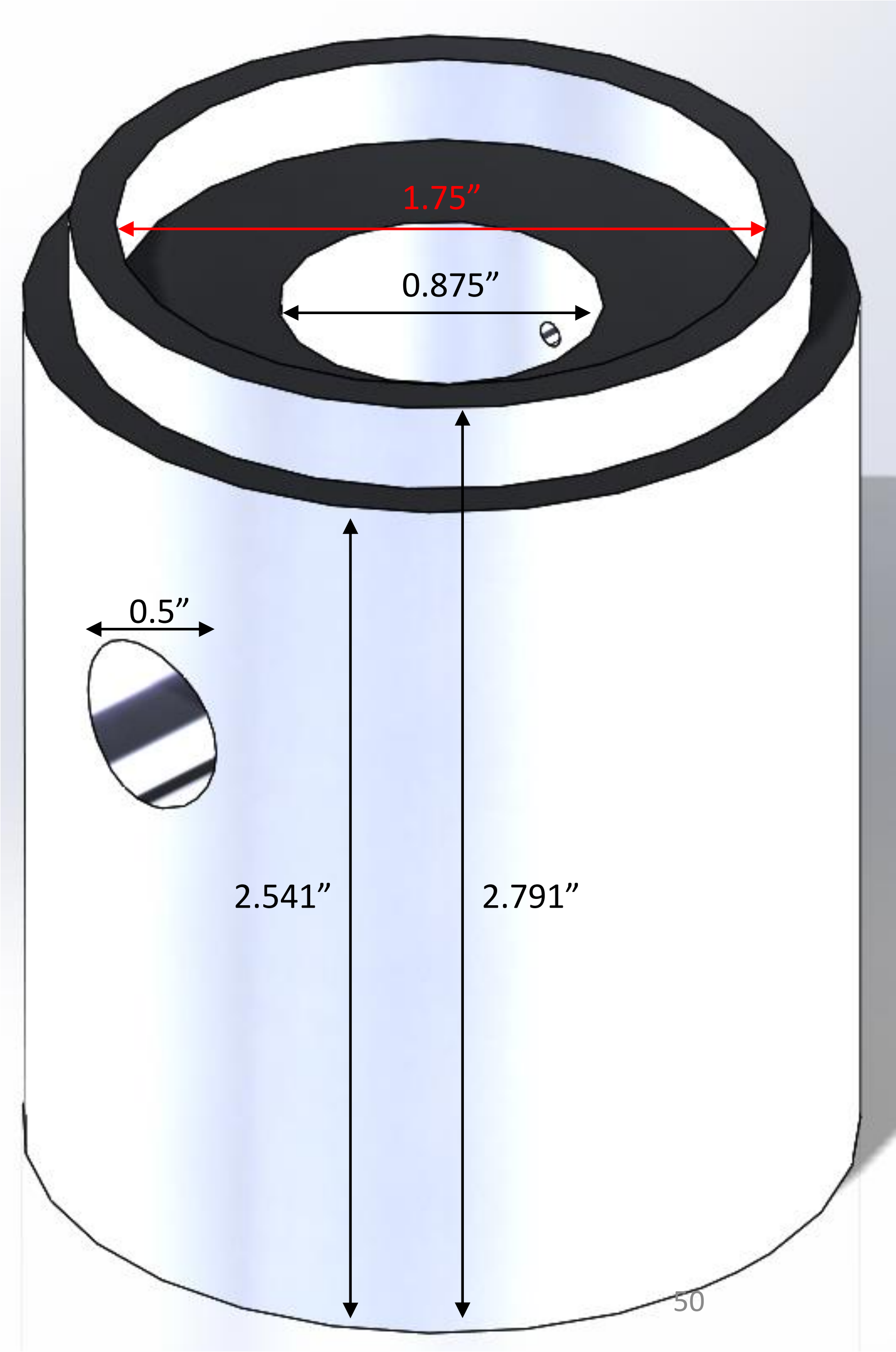
Turntable - 3. Top Board

- Purpose
  - Rotate CubeSat for Sun sensor calibration
  - Point towards physical angle etchings
- Status
  - Machining in progress
- Manufacturing
  - ½” thick aluminum disc
  - Mill aluminum disc circumference to dimension
  - Drill and tap holes
- Critical component
  - Low reflectance coating (2-3 weeks turn around)



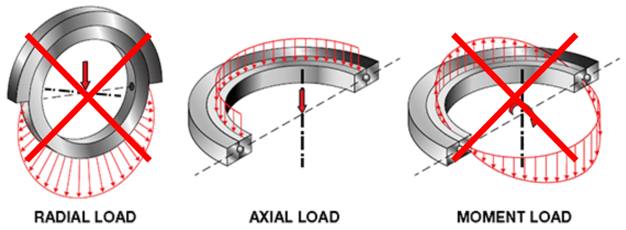
Turntable - 4. Shaft

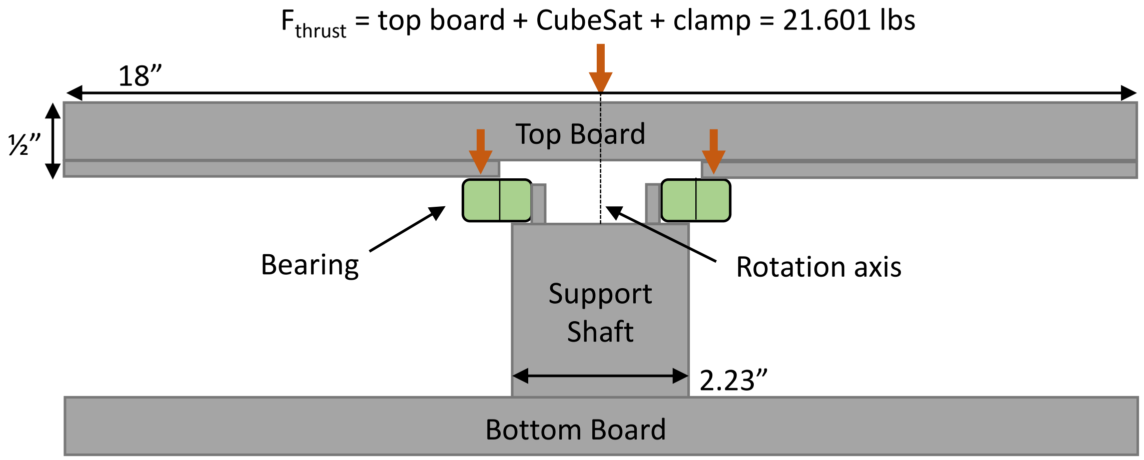
- Purpose
  - Support load and allow gears to rotate top board
  - House encoder for angle measurement
- Status
  - Material in transit
- Manufacturing
  - Mill aluminum rod
    - Encoder housing
    - Friction fit bearing ring
  - Drill and tap holes
- Most difficult component
  - Manufacturing time (1-2 weeks)

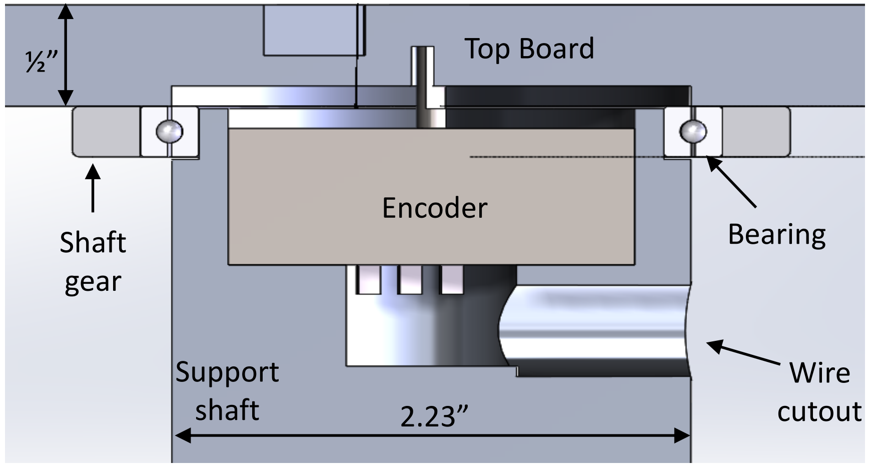


Turntable - Force and Moment Analysis

- CG of CubeSat is in 0.4” sphere of geometric center
- Geometric center aligned with rotation axis of board and within diameter of support shaft = no moments produced
- Combination ball-thrust bearing supports axial load
  - Thrust load capacity = 790 lbs
  - Moment load capacity = 430 in*lbs
  - Board can roughly support 45 lbs point load on perimeter





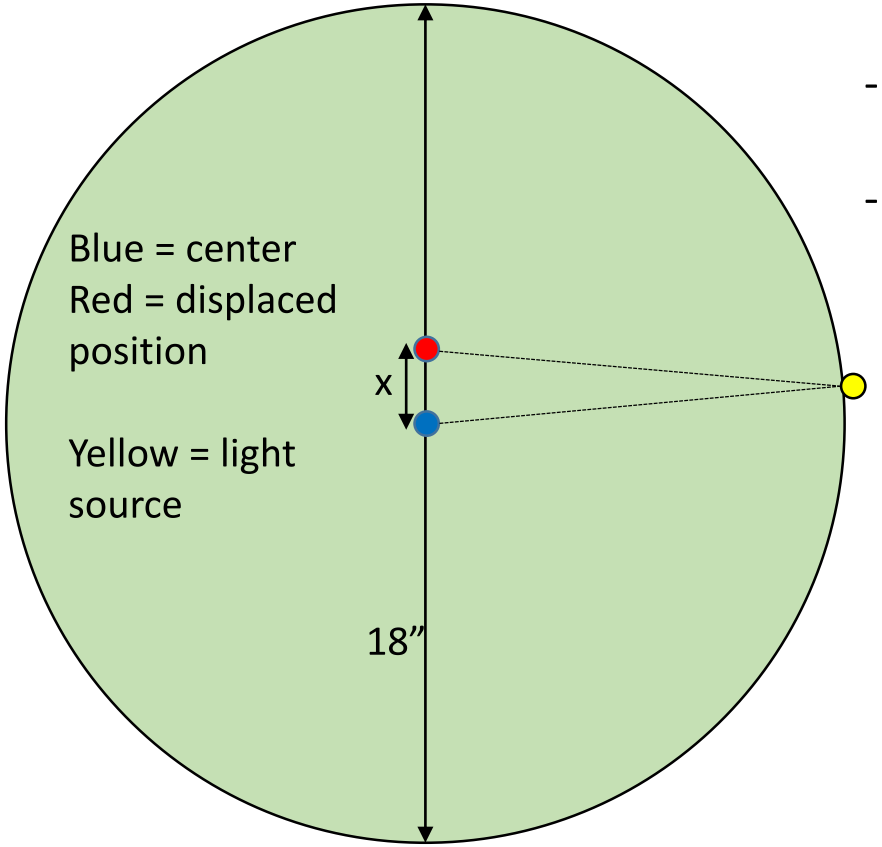


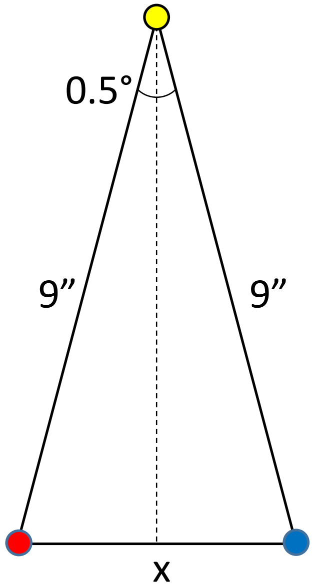
Turntable - Tolerance Stack Angle Analysis

Max displacement satellite can be from center of board to maintain 0.5° accuracy

Worst case scenario, assume:

- Light source is at perimeter of board, 9” away
- Light source is between center and displaced positions
- Distance ‘x’ can be approximated by isosceles triangle





sin(0.25°) = (x/2)/9”

x = 0.0785”
Can easily be achieved with 0.005” CNC tolerance

Turntable - Sub Parts

These parts require very little or no manufacturing

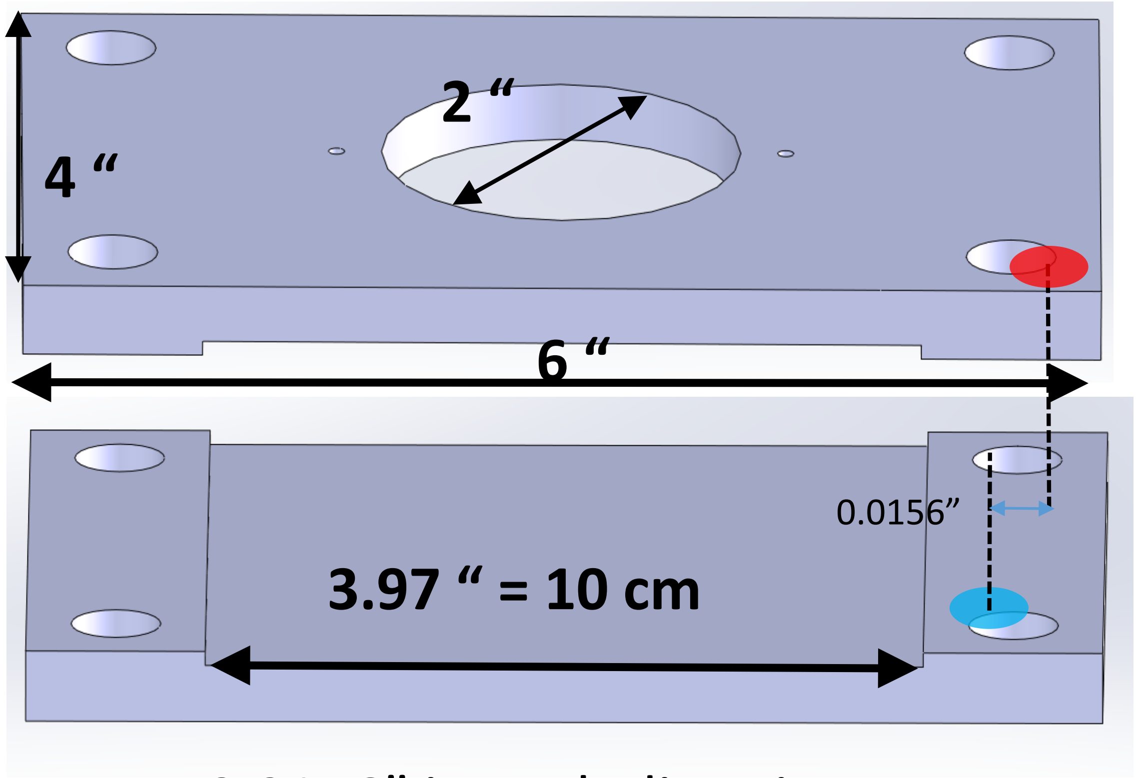
Part	Materials Ordered	Manufacturing in Progress	Complete
Bearing	X	~	X
Shaft gear		~	
Motor gear			
Precession shafts (4x)	X		
Precession bearings (4x)		~	
Encoder shaft coupling		~	
Angle etching needle	X		
Screws		~	
Acrylic spacers		~	
Acrylic screws		~	

HelCaTS Small Clamp Machining – Backup

Status: Top Plate Finished

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

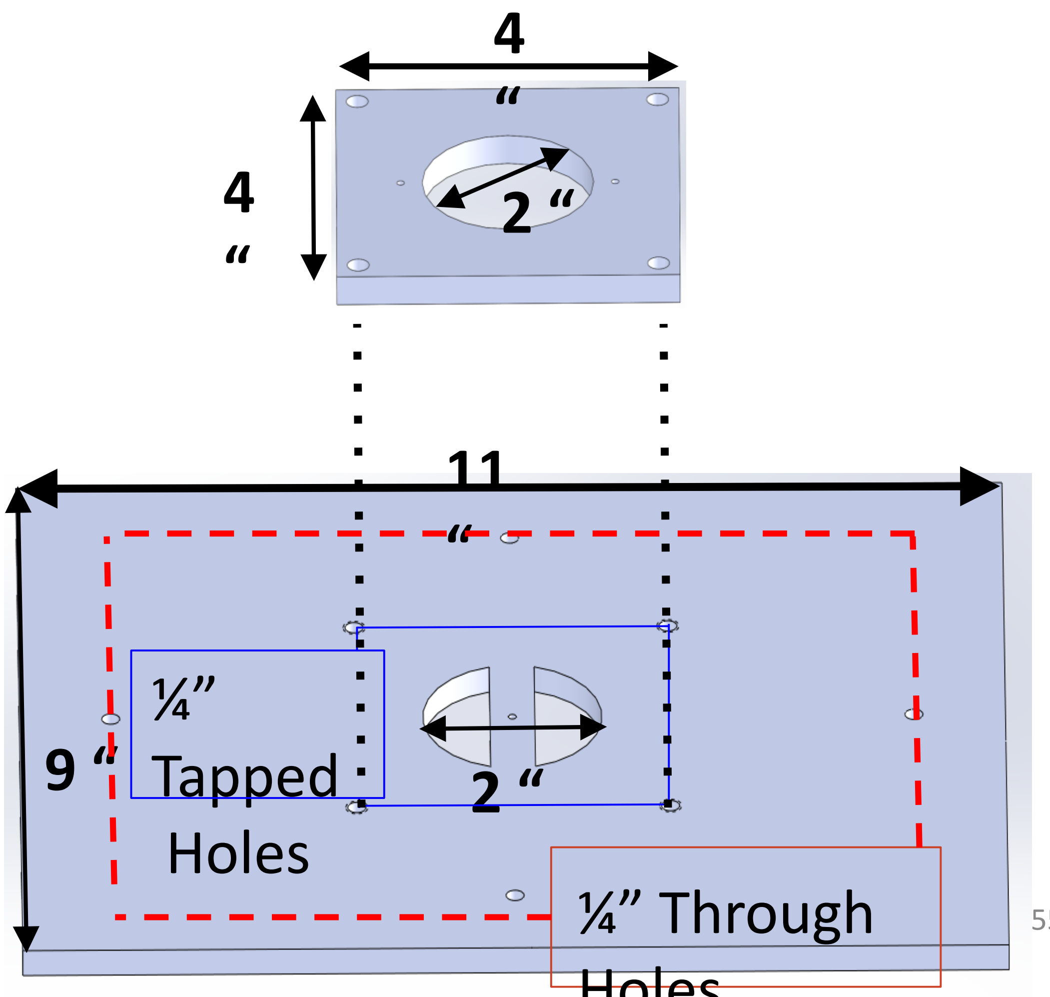
HelCaTS Attachment Plate Machining - To be done

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”

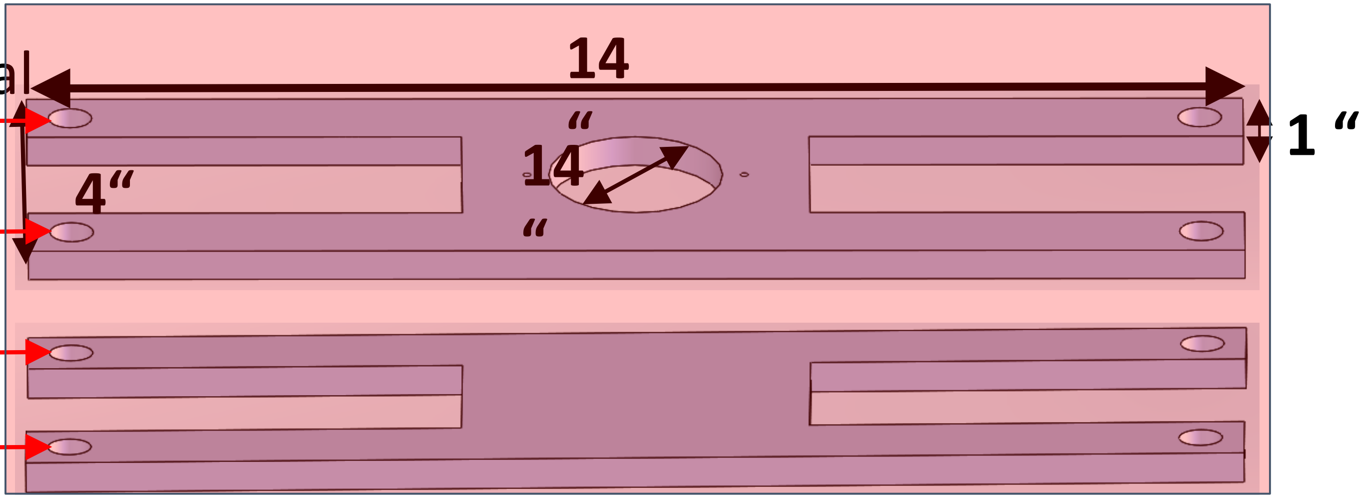


HelCaTS Manufactured Parts - Backup

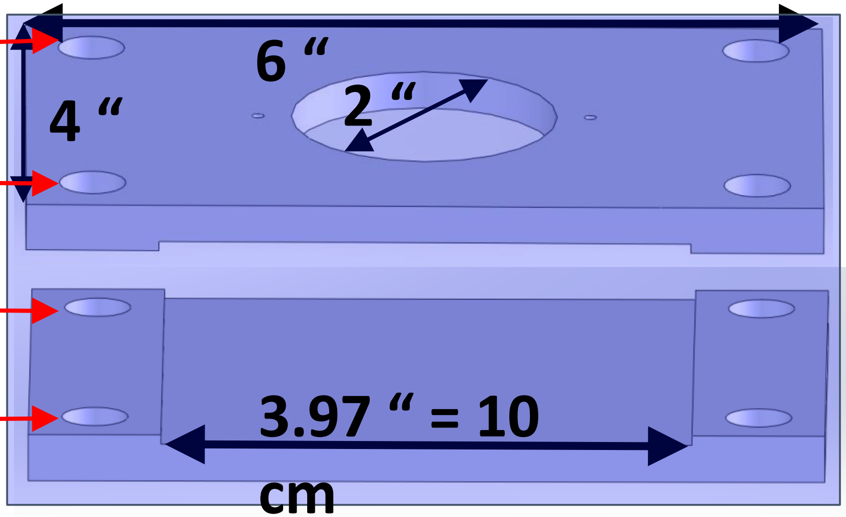
HelCaTS Manufactured Parts - Backup

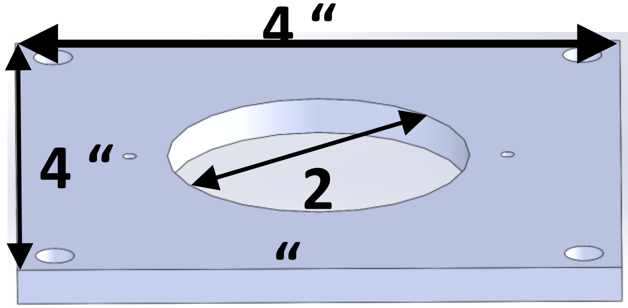
Similar colors = similar dimensions
All plates are 0.25” thick and will be machined with the CNC

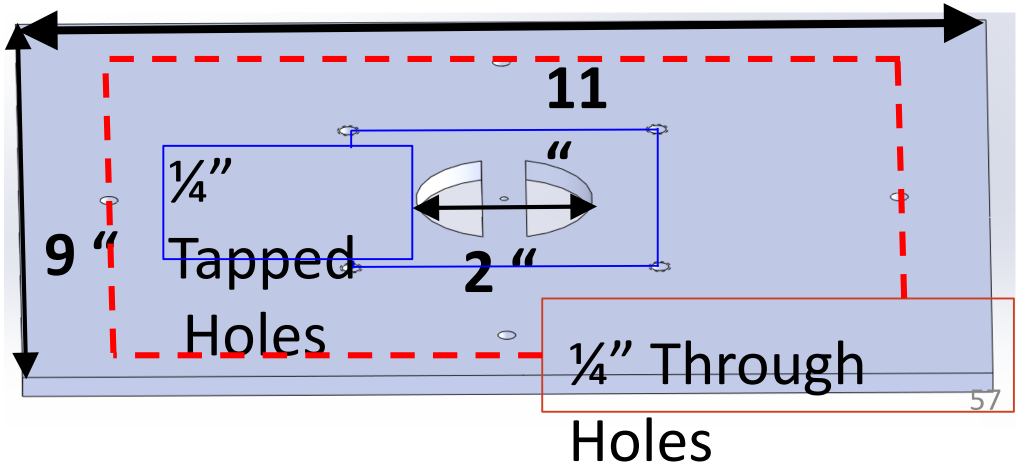
8 Pieces in Total



½” Through Holes

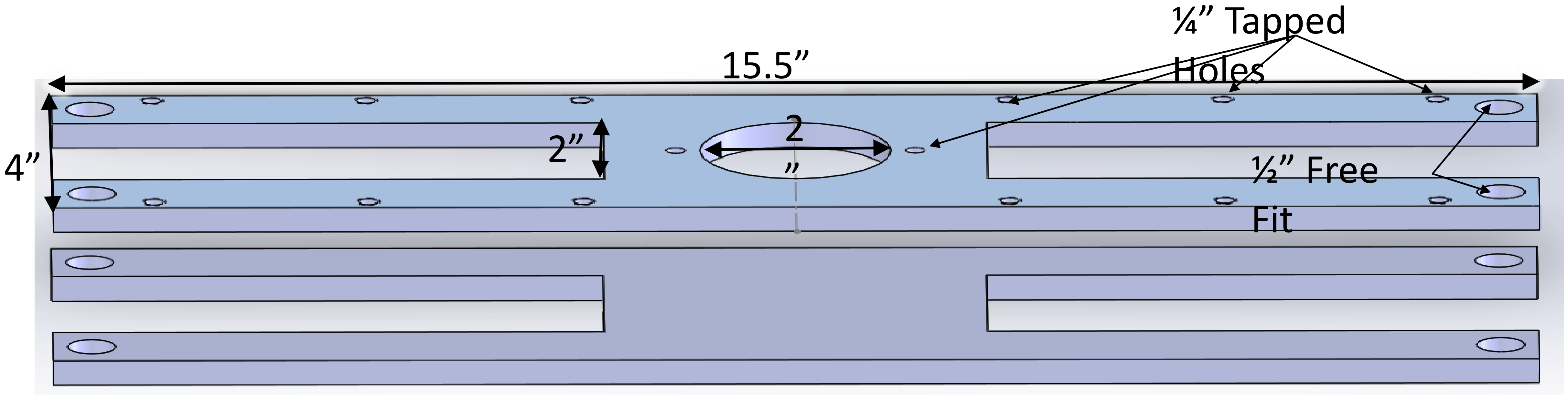




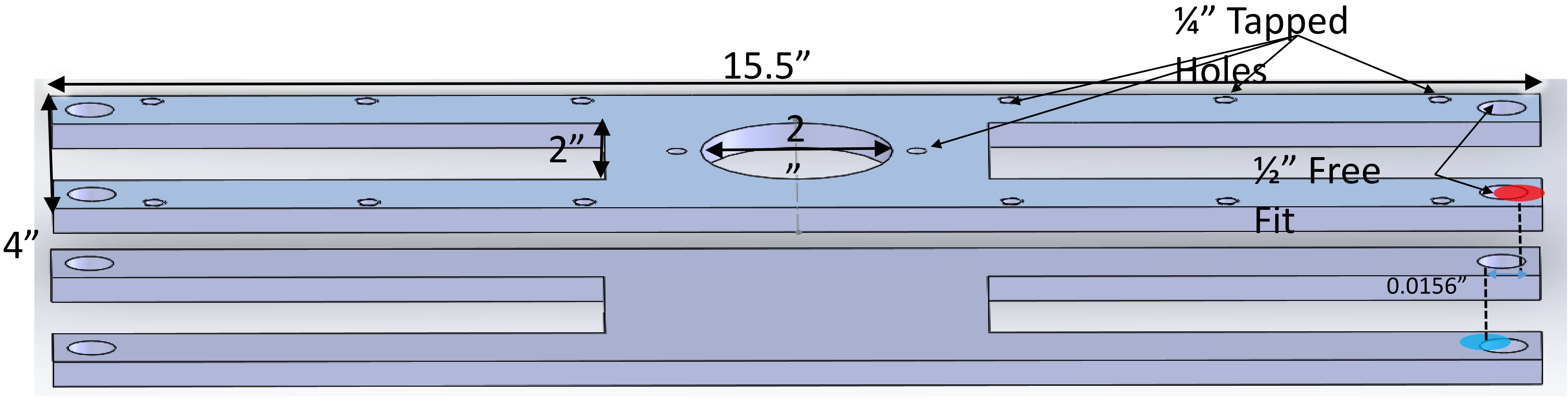


HelCaTS Large Clamp Machining - In Progress

Status: Toolpaths 80% Written (20 minutes left) Machining to be done (est. 7 hrs)



HelCaTS Large Clamp Machining

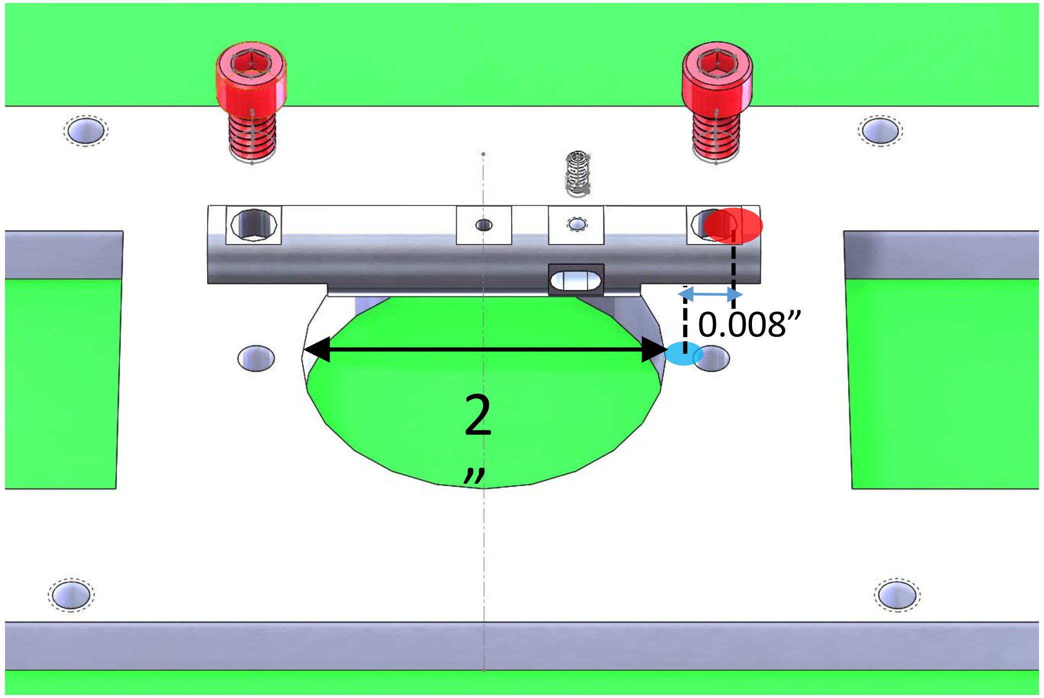


Machining Tolerance: 0.05”

Critical Dimensions:

- spacing of ½” holes must be accurate to +/- **0.0156”** in each direction

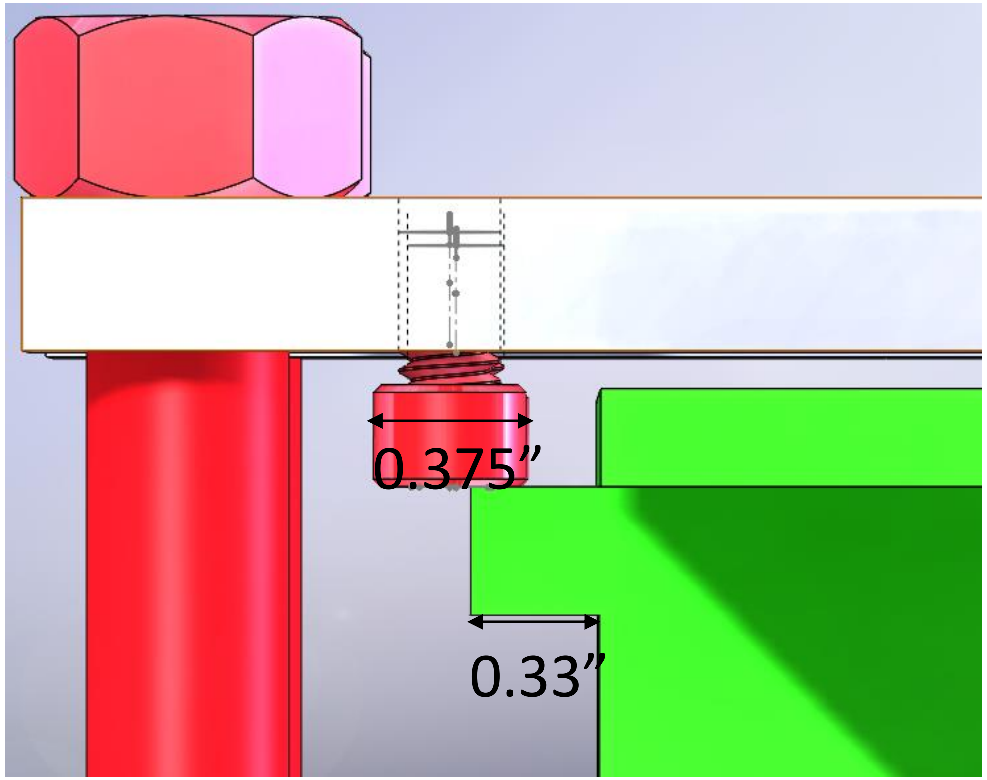
HelCaTS Large Clamp Machining

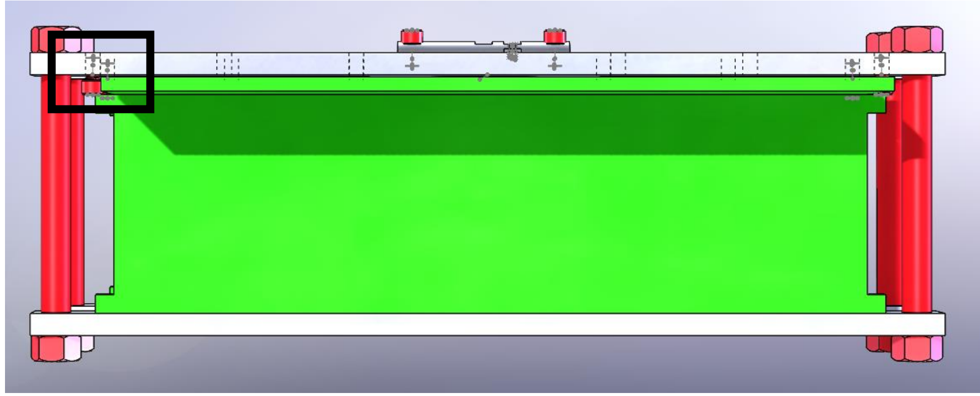


Machining Tolerance: 0.05”

Critical Dimensions: - spacing of tapped ¼” center holes must be accurate to +/- **0.008”** in each direction

HelCaTS Large Clamp Machining - In Progress

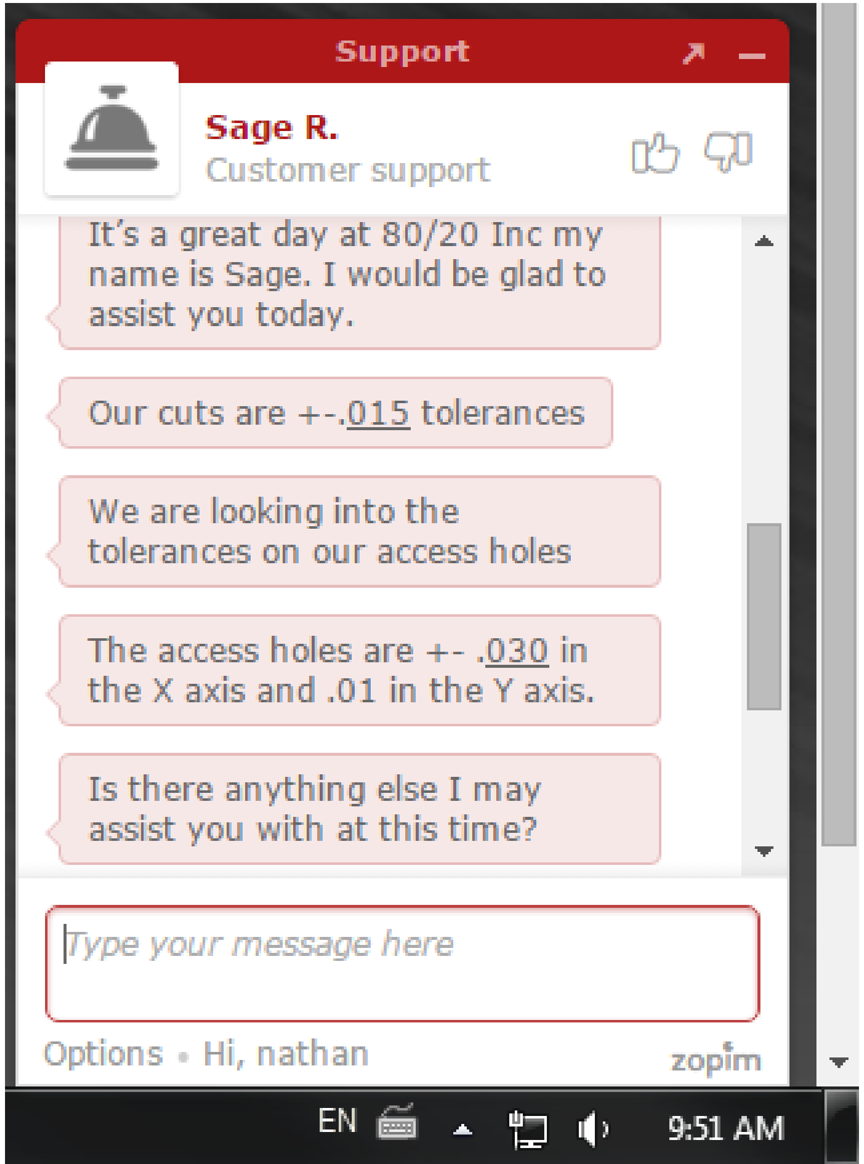




Critical Dimensions:

- spacing of attachment holes must be accurate to **+/- 0.1"** in each direction

Tolerance Confirmation - Backup

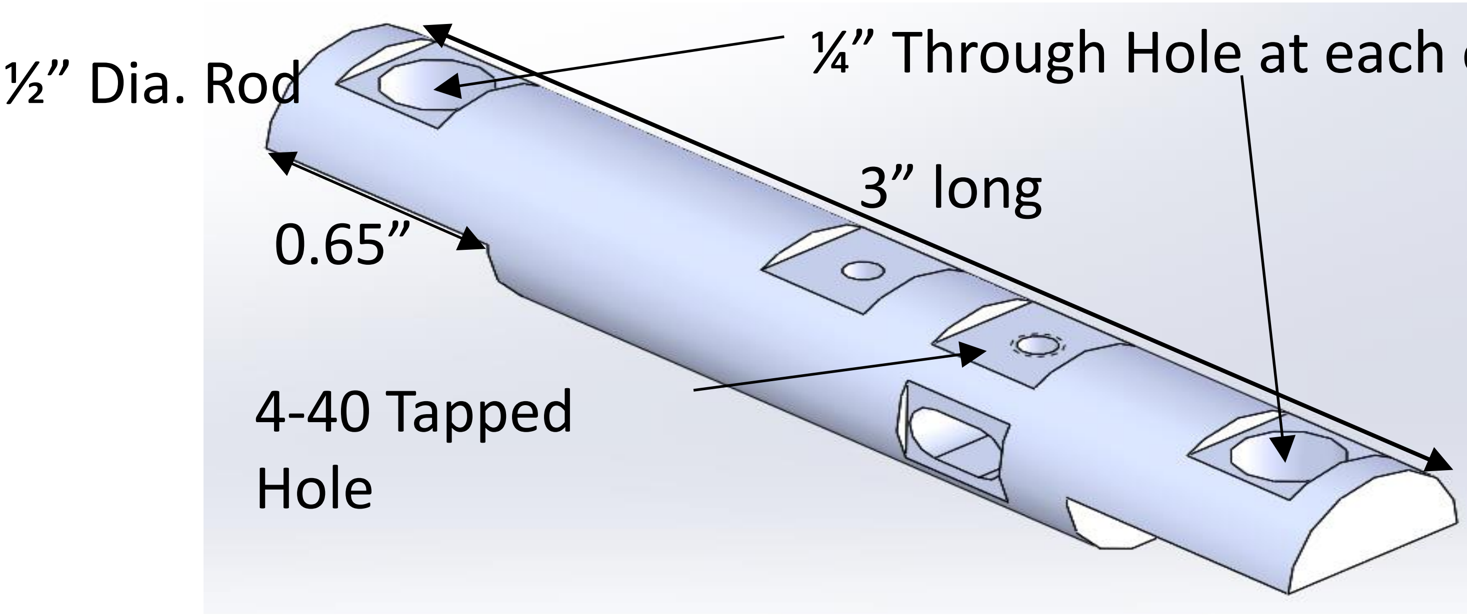


HelCaTS Manufactured Parts - Attachment Cylinder

Status: 1 of 2 Machined

Machining Order:

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



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