Laboratory for Atmospheric and Space Physics
University of Colorado **Boulder**

Boulder Unmanned Sensor for Transport Events and Repositioner

Test Readiness Review

Presenters: Charlie LaBonde, Ted Zuzula, Leina Hutchinson, Reidar Larsen

Team: Alex St. Clair, Christine Reilly, Gabe Castillo, Jeff Jenkins, Rachel Tyler, Robert Hakulin, Ryan Aronson

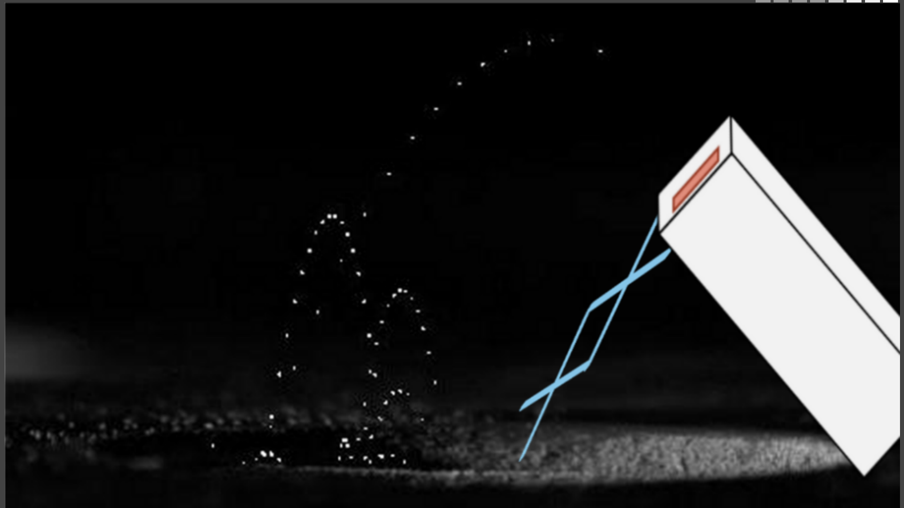
Customer: Dr. Xu Wang, Dr. Zoltan Sternovsky

Advisor: Dr. Torin Clark

Overview

Project Motivation

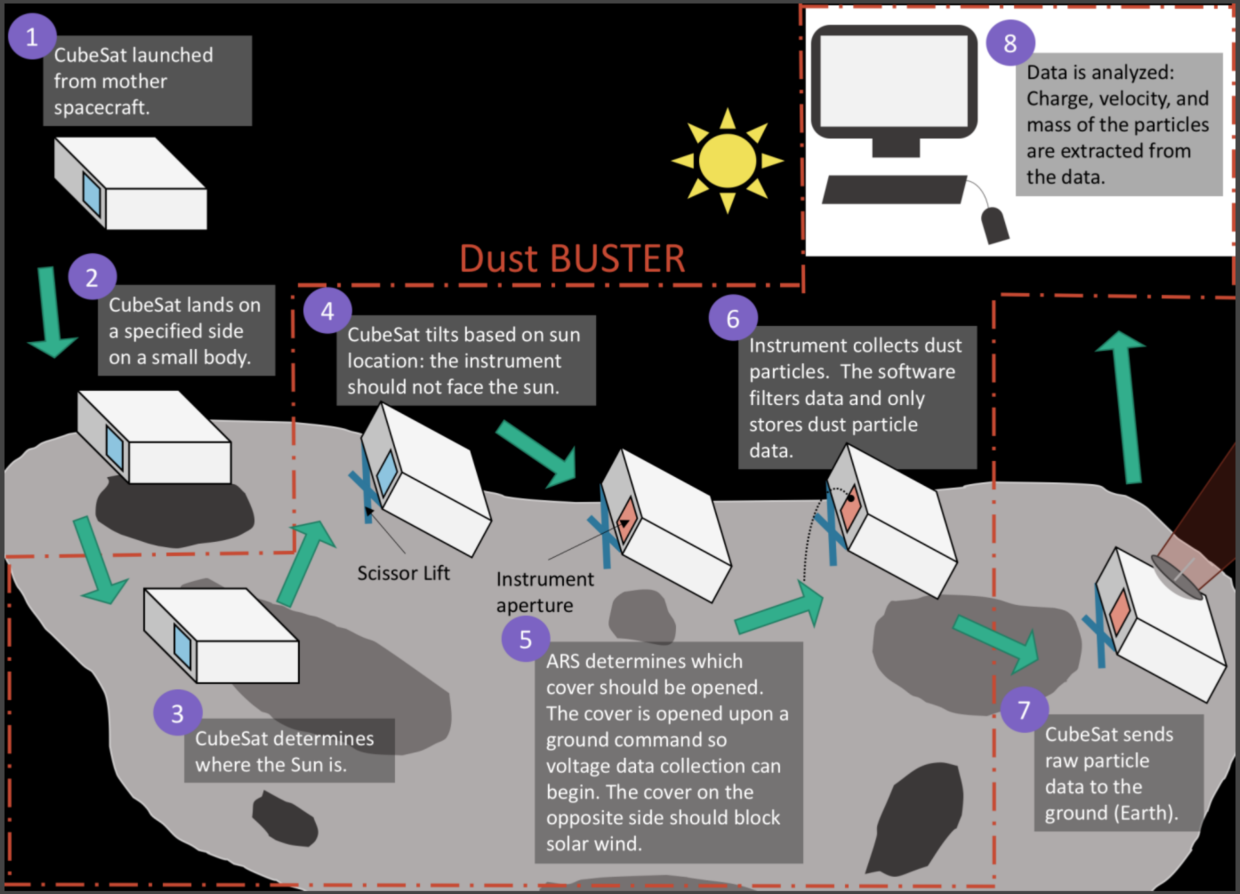
- Dr. Wang's research at LASP suggests that charged particles could be lifted by Coulomb force
  - **Dust transport events**: micron-sized dust particles are charged by various sources in space and ejected from the surface of low-mass bodies
- Current instrument is too large for a space application in low-gravity
- **Data could be collected with a smaller instrument in a CubeSat form factor, for a potential mission to an asteroid**



Project Statement

- Dust BUSTER will miniaturize, manufacture, and test a **Technology Readiness Level (TRL) 4** dust instrument to characterize dust transport events similar to those that occur on asteroids
- To aid the instrument, the team will also design and test an **Autonomous Repositioning System (ARS)** to tilt a 6U CubeSat to a specified angle for dust collection

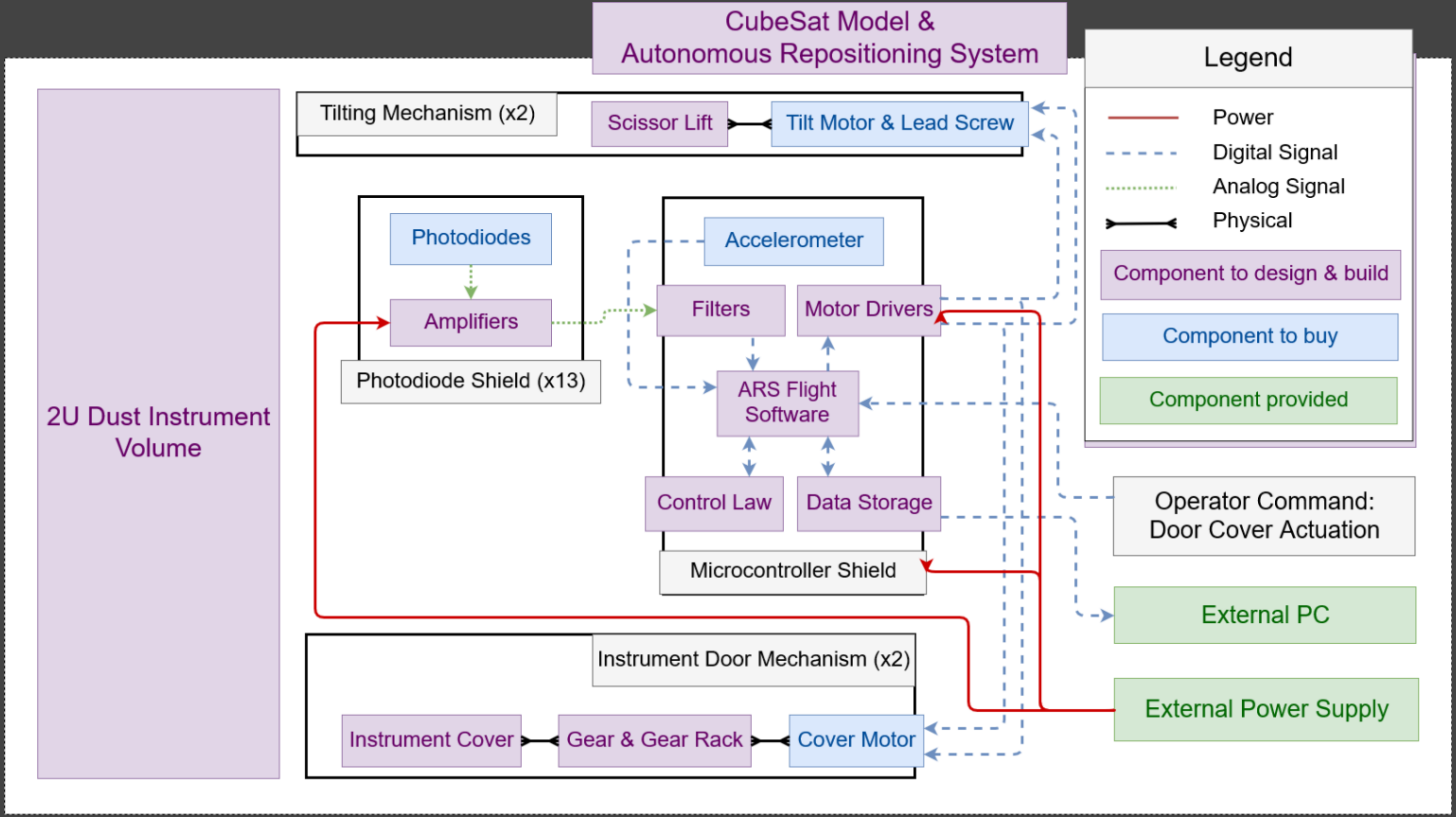
Overall Mission ConOps



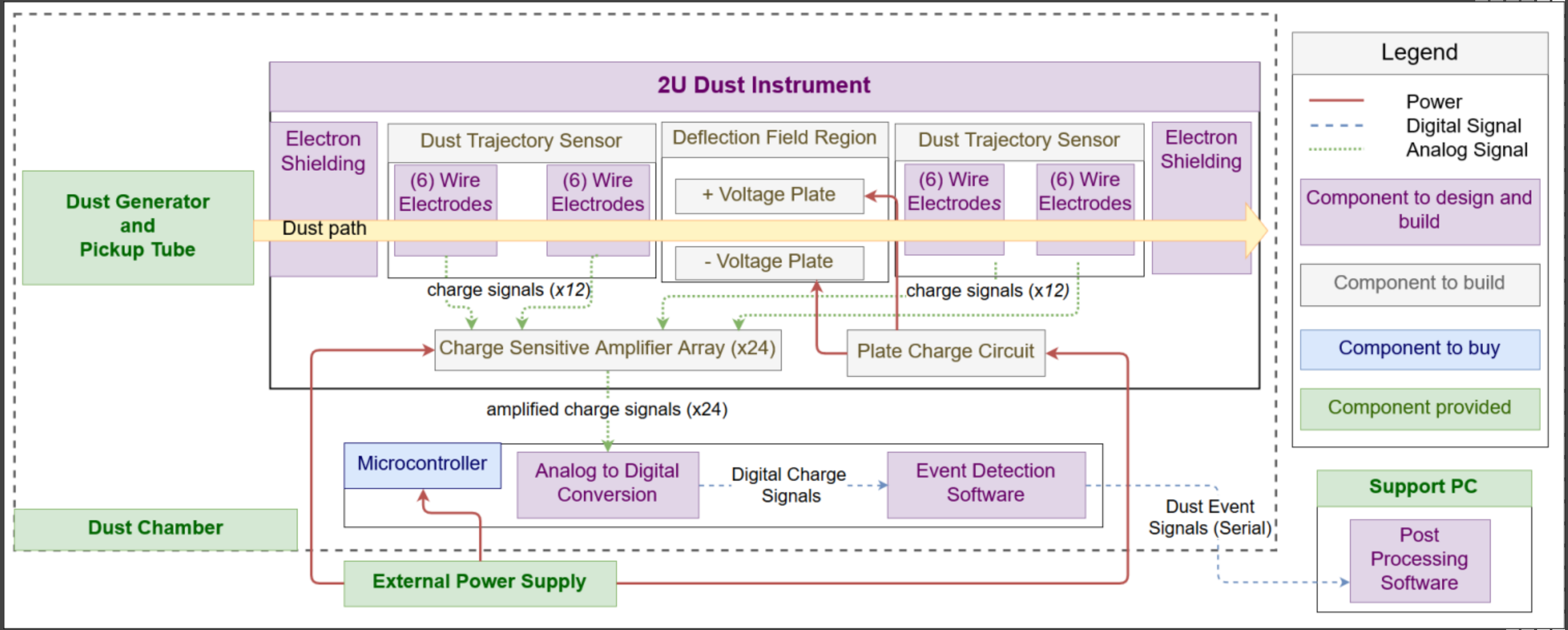
Levels of Success

	Level 1	Level 2	Level 3
Instrument	- 2U TRL 4 dust instrument - Operates in vacuum chamber - Interfaces mechanically with CubeSat	- Wire electrodes remain intact upon 10 m/s impact	-
CubeSat/ ARS	- Construct 6U CubeSat model - Tilt CubeSat model up to 45 degrees on a flat surface - Determine which side of the CubeSat has the least sun	- Open loop autonomous tilt with 5° accuracy - Operates on sandy surface	- Closed loop tilt with 1° accuracy - Instrument cover opens once under operator command
Software	- Detect dust via external trigger - Send dust data over serial - Post processing algorithm extracts mass, velocity, charge	- Self-triggering dust detection algorithm	- Determine uncertainty in mass, velocity, and charge

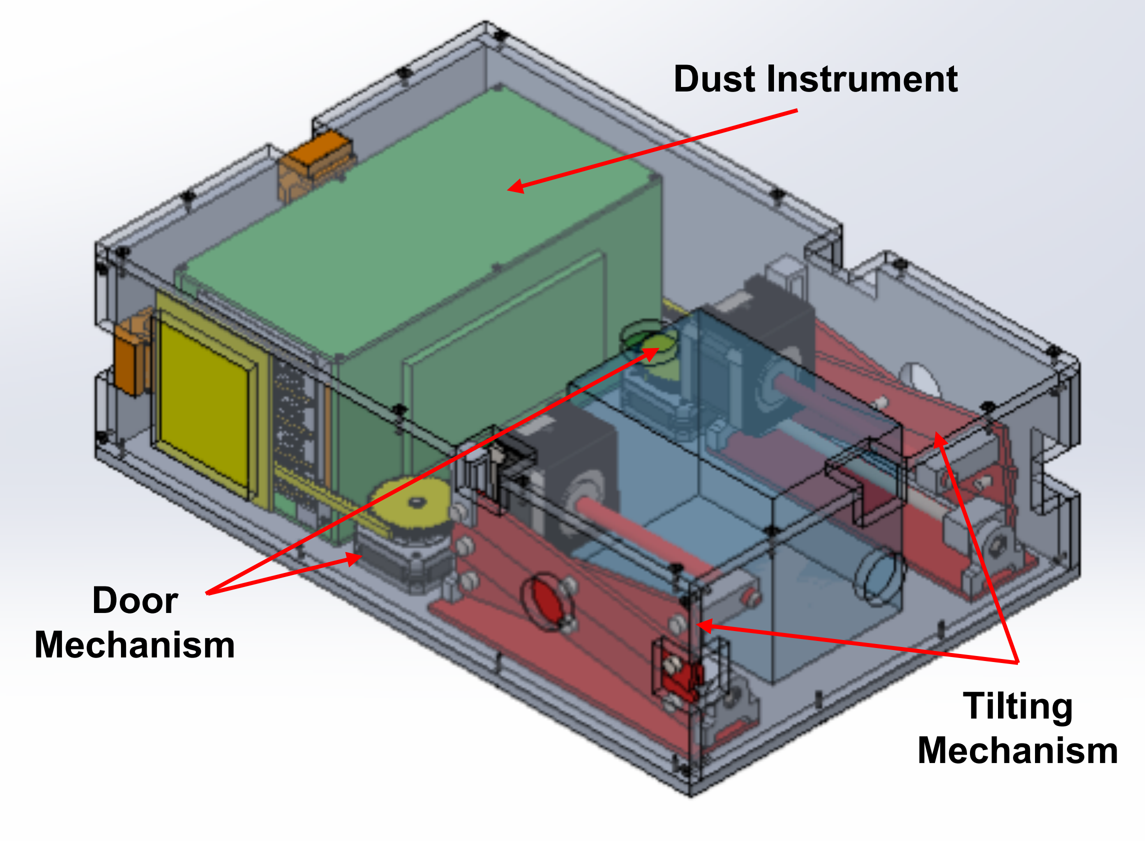
Autonomous Repositioning System FBD



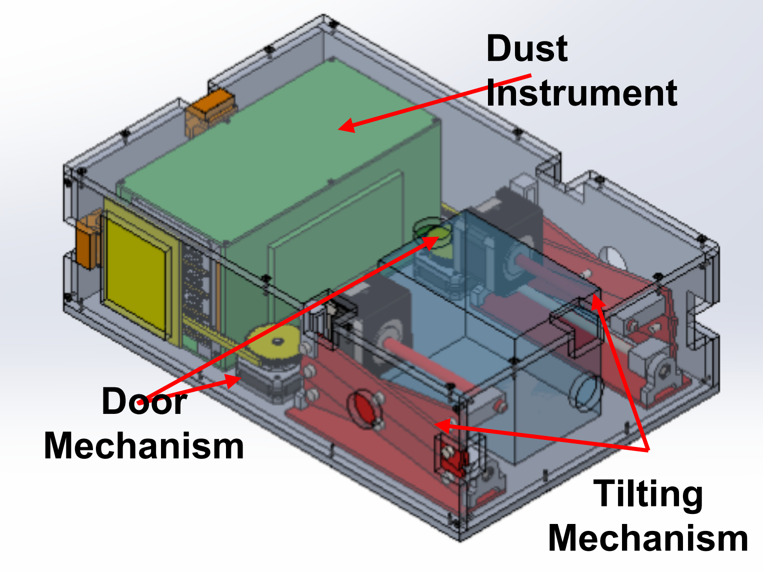
Instrument Functional Block Diagram

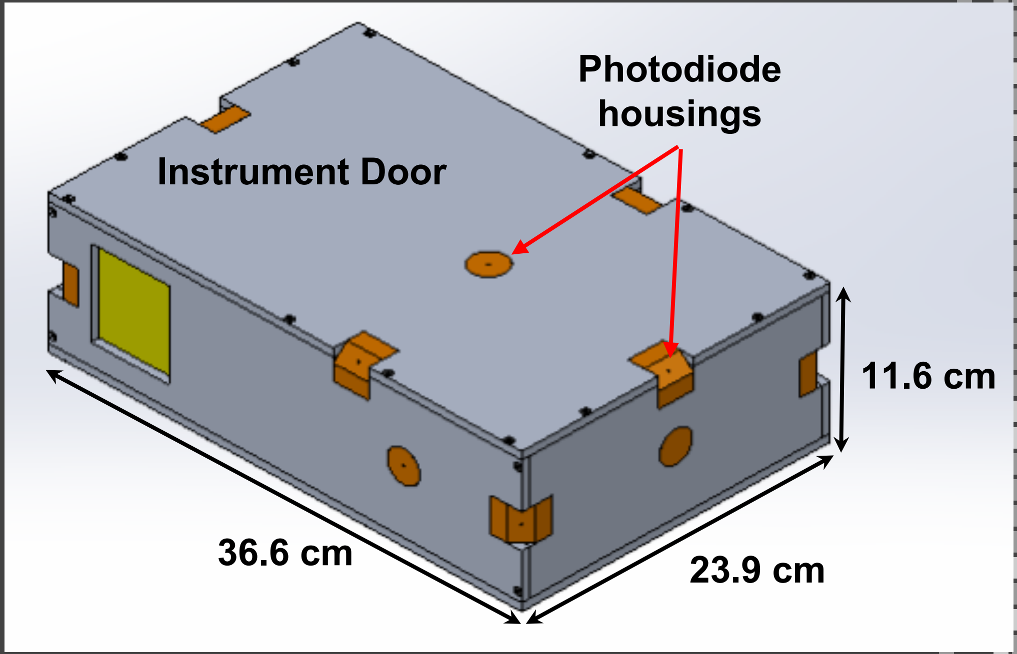


Design Recap

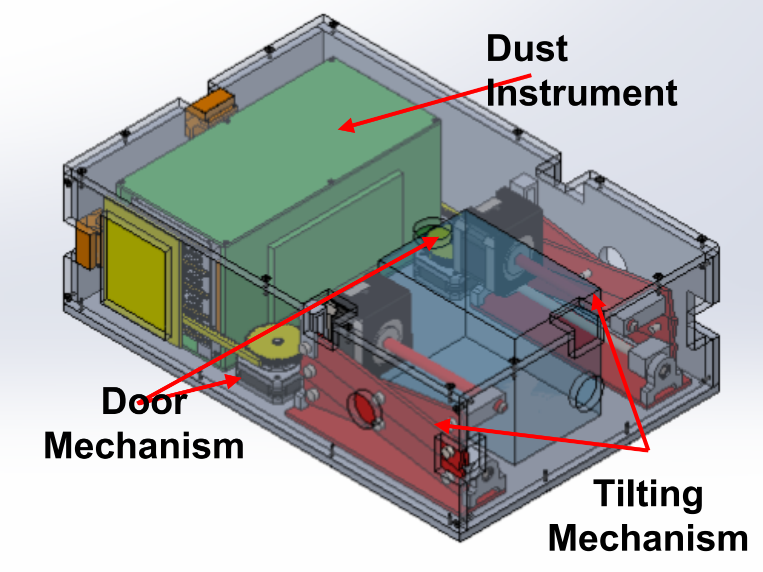


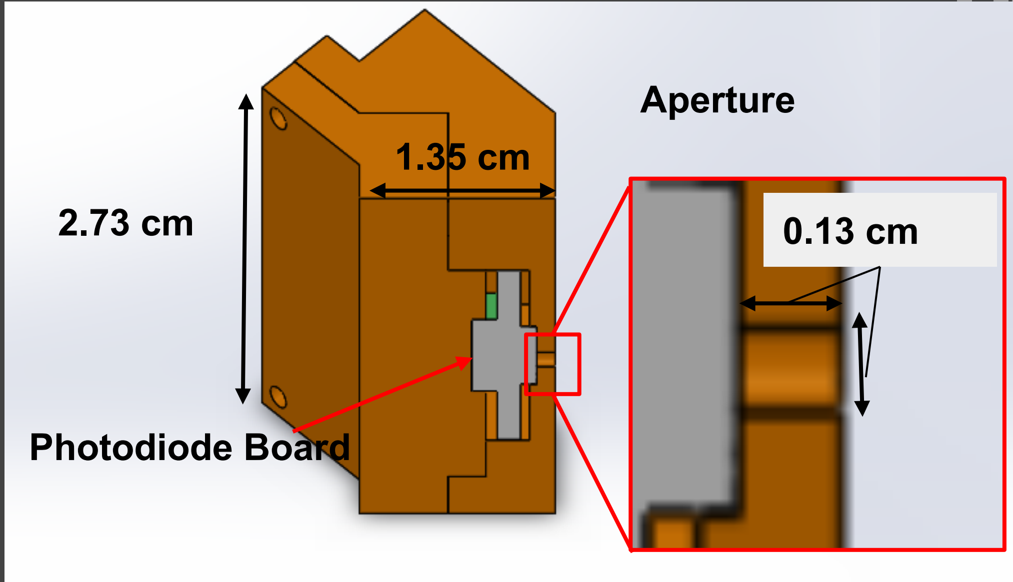
Design Recap -CS Model & Photodiodes





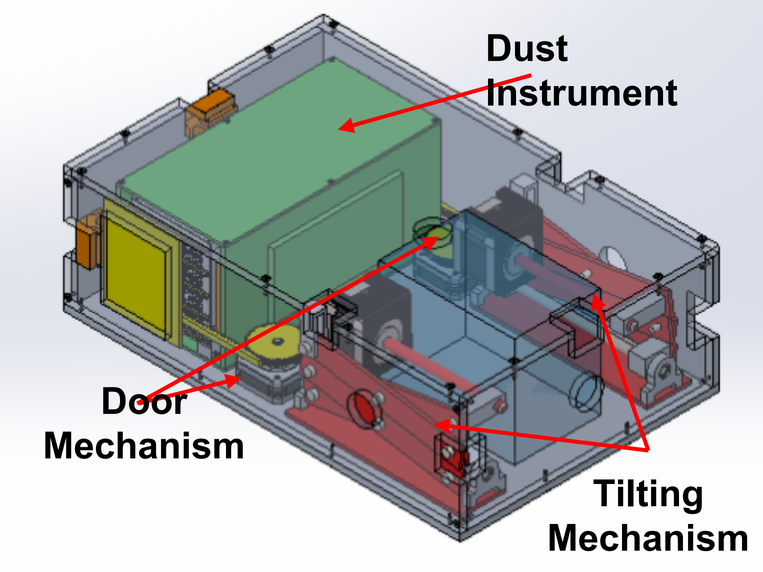
Design Recap - Photodiodes

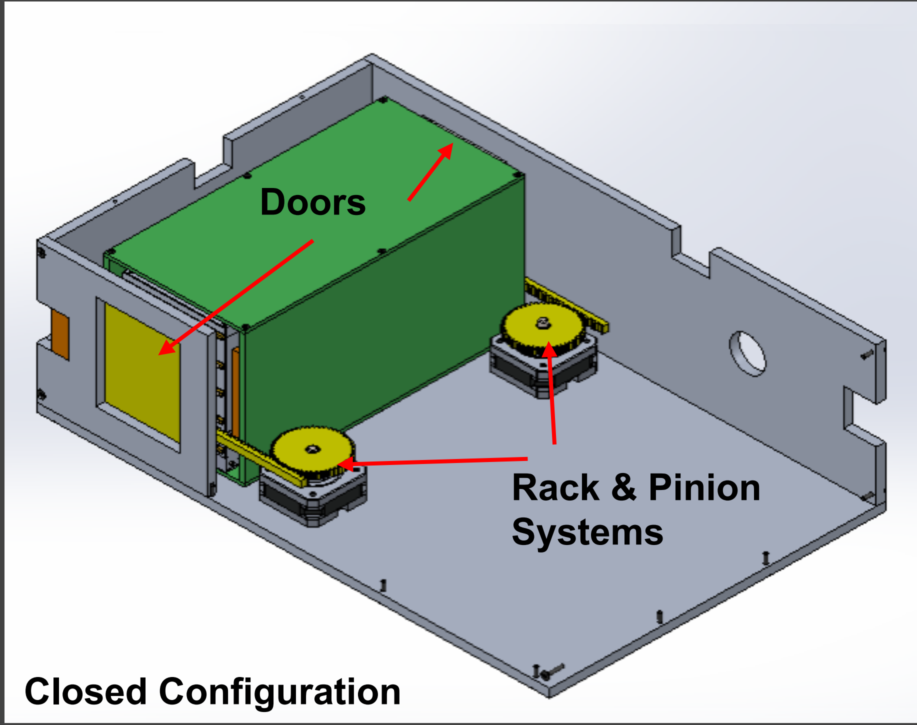




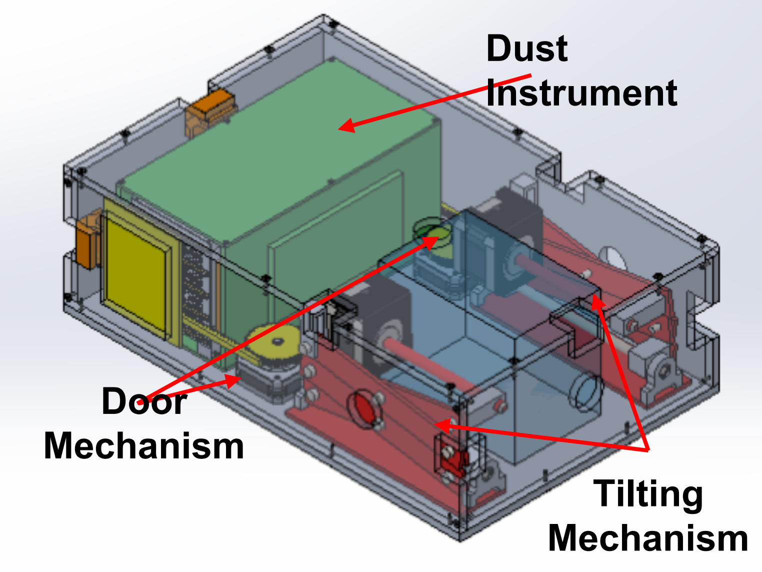
Photodiode Structure

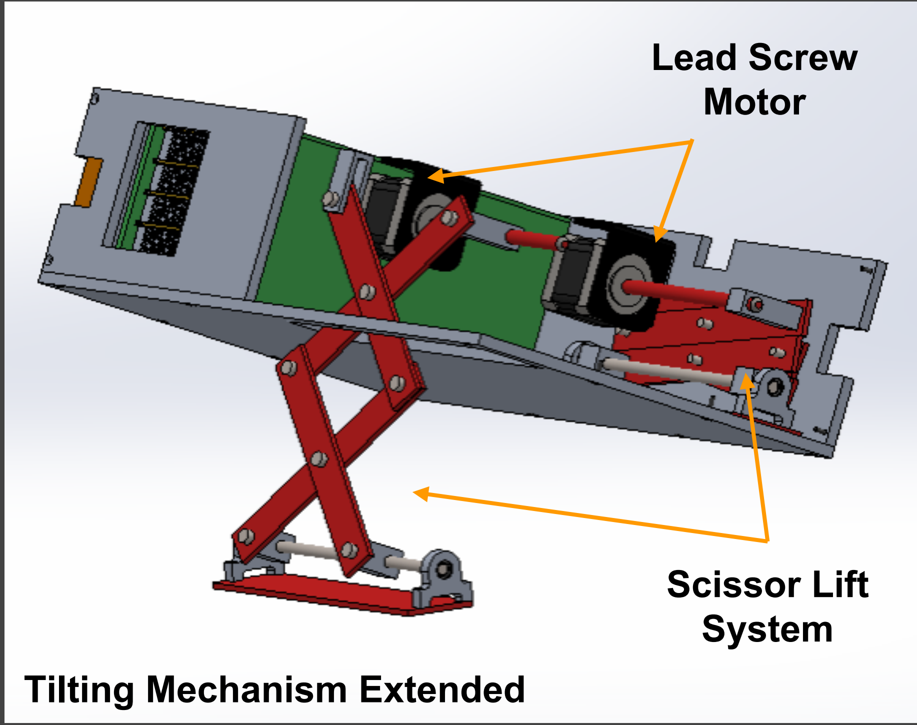
Design Recap -Door Mechanism



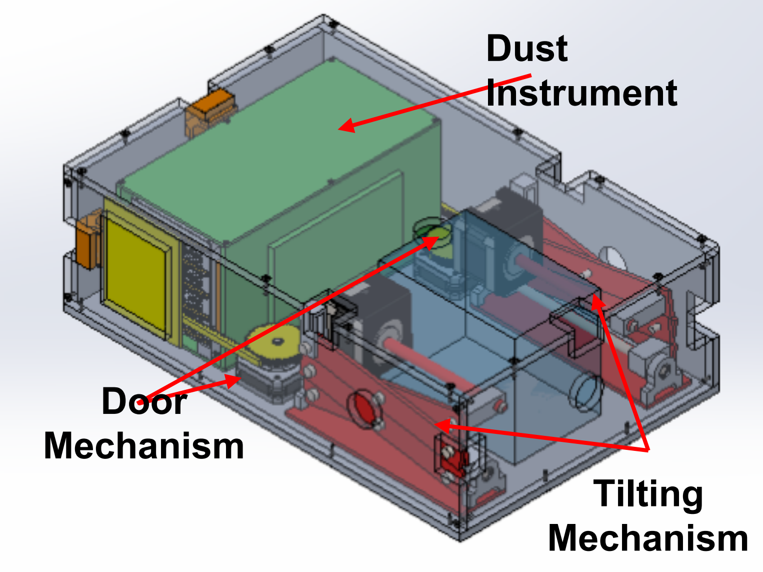


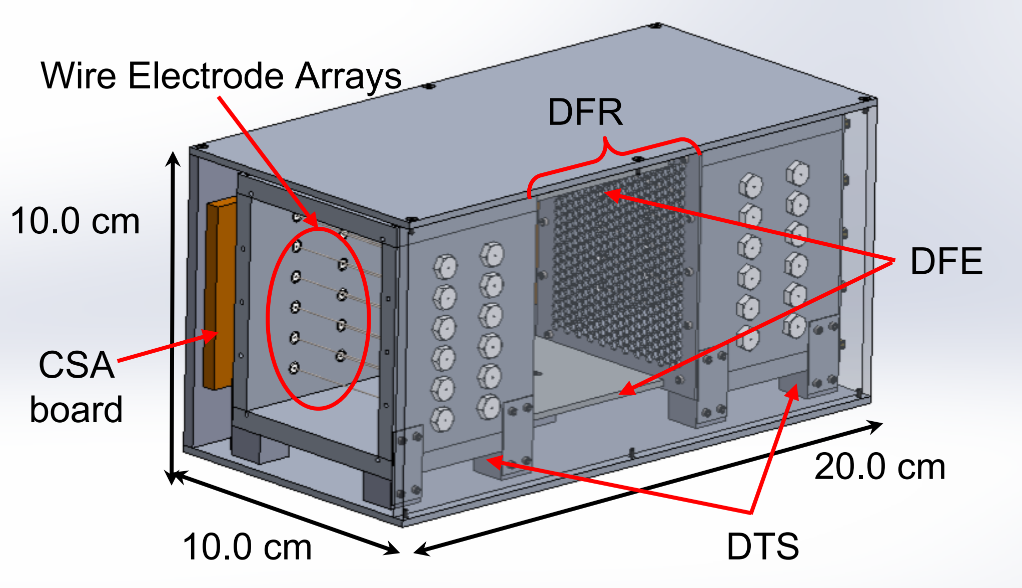
Design Recap -TIlting Mechanism





Design Recap -Dust Instrument





Critical Project Elements

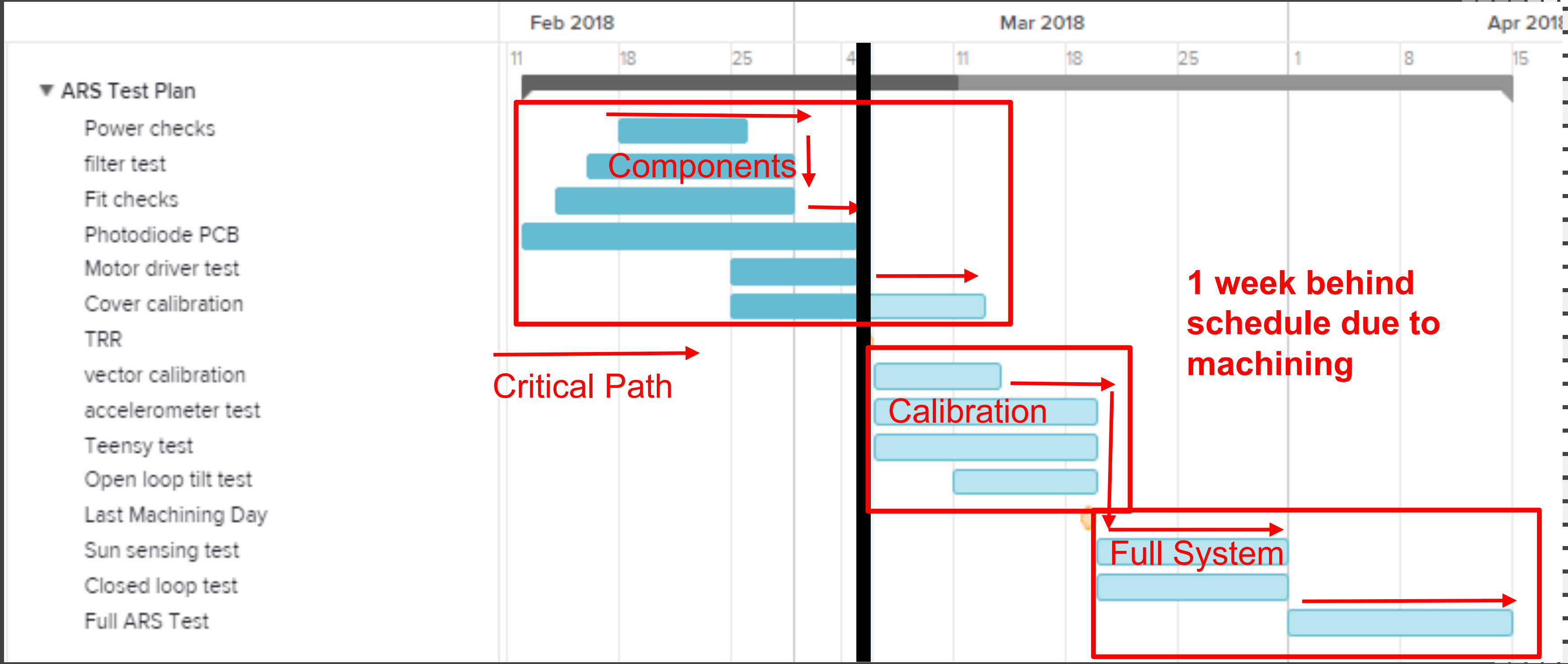
Critical Project Element	Relation to Testing
Sun determination	Full sky accuracy, closed-loop autonomous tilt
Tilting mechanism	Tilt actuation accuracy, closed-loop autonomous tilt
Surviving Impact	Instrument Dust Trajectory Sensor (DTS) and wire electrode impact testing
Real-time event detection	Analog electronics, DTS, electron shield, trigger algorithm, dust detection

Scheduling

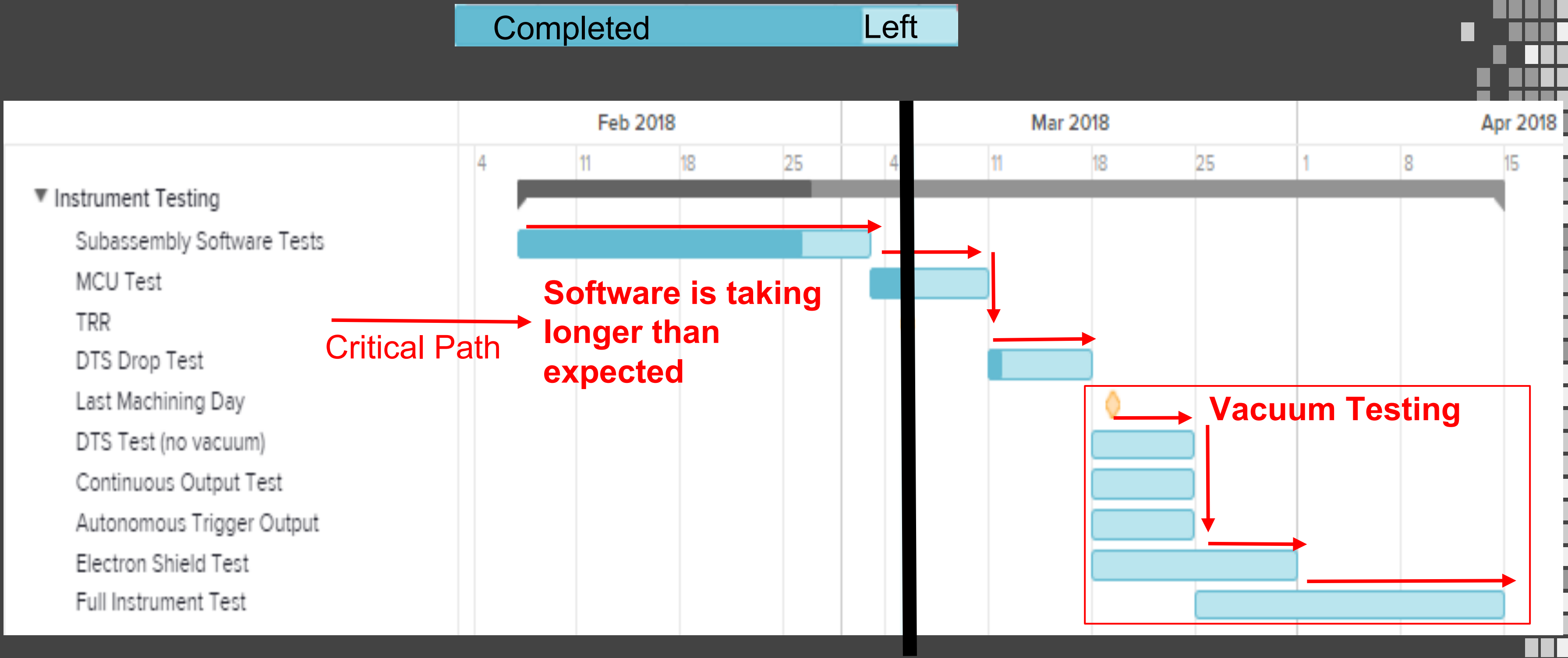
Overview | Schedule | Instrument Test | ARS Test | Budget

ARS Test Schedule

Completed | Left



Instrument Test Schedule



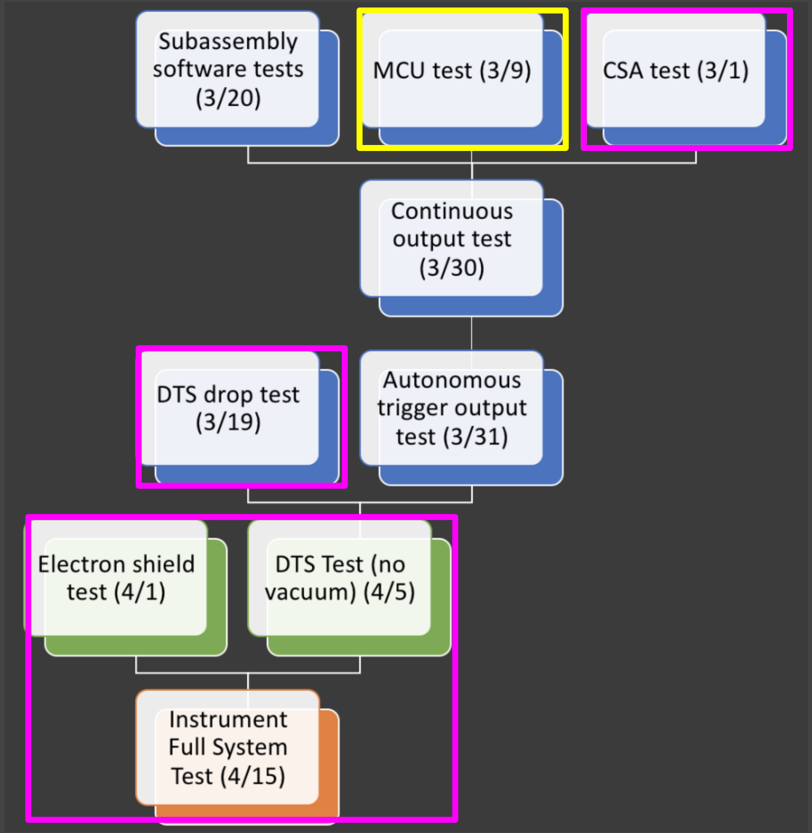
Instrument Test Readiness

Instrument Testing Flow

Complete

In Progress

CPE Milestone



Analog Electronics: Charge Sensitive Amplifier

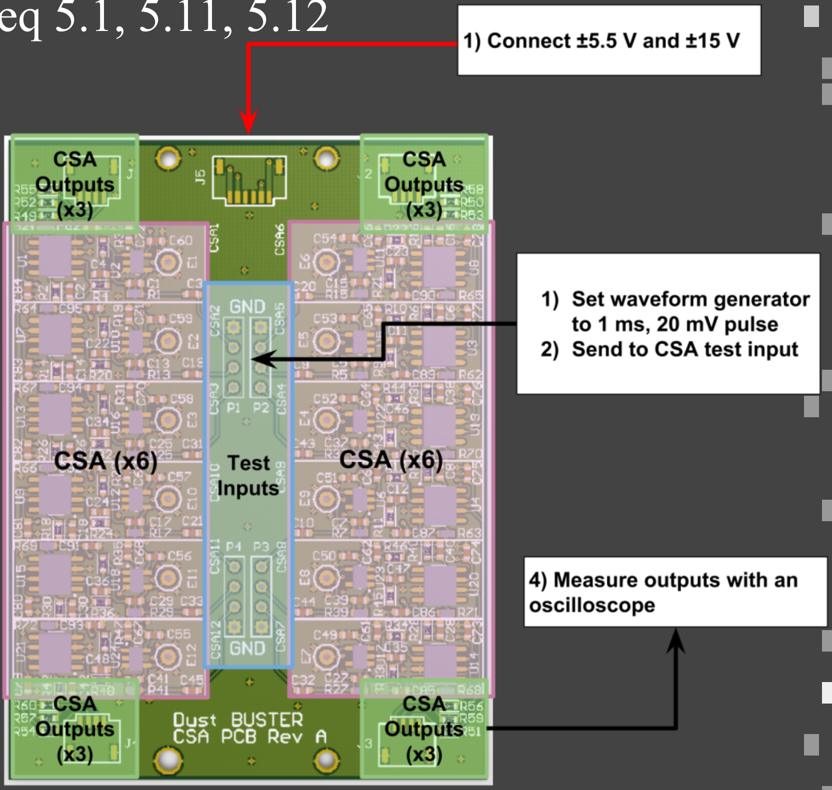
Verify our implementation of customer's design for a charge sensitive amplifier, Req 5.1, 5.11, 5.12

Purpose: Measure each CSA's amplification of a simulated dust event.

Facility: Electronics Lab

- Power supply (±5V & ±15V)
- Waveform generator
- Oscilloscope & probe
- ESD mat/straps
- Assembled CSA PCB

Measurement: voltage of the amplified signal (expected test gain = 100)



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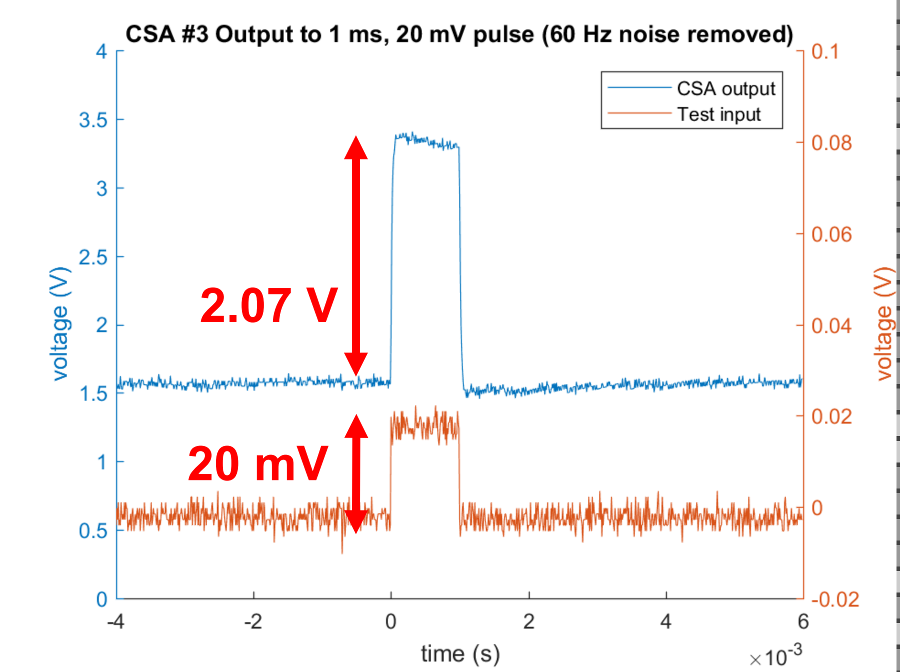


Impact Testing

Verify that Wire Electrodes can withstand 10 m/s impact (Req 2.5.1)

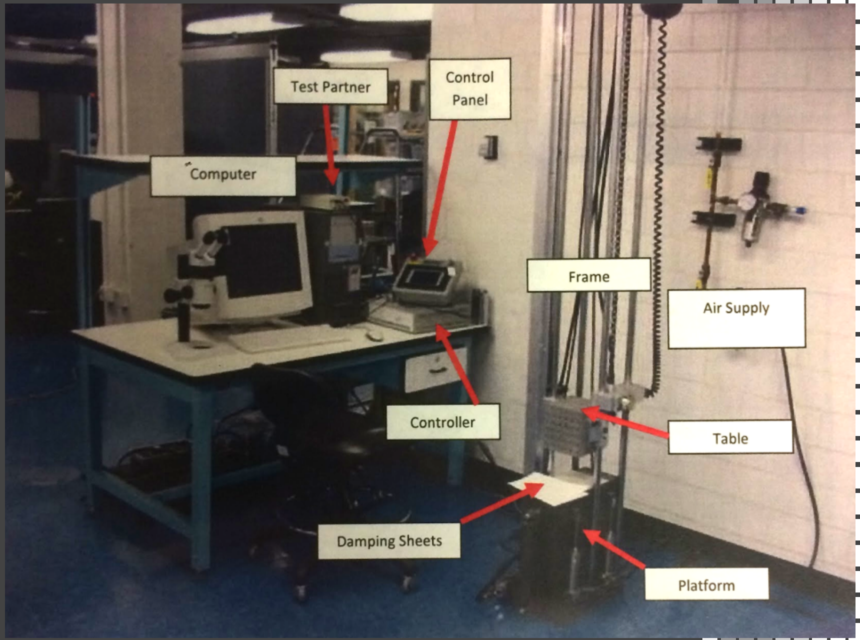
Purpose: Drop a DTS at successively larger impact velocities to characterize failure (when wire electrode becomes free to move)

Facility: Idea Forge

- Lansmont 15D Shock Test Machine
- One DTS unit
- Accelerometer

Procedure:

- Mount DTS to drop test table
- Raise table up to desired height and drop
- Visually inspect wire electrodes for broken or freely moving wires
- Drop again at new height



Impact Testing

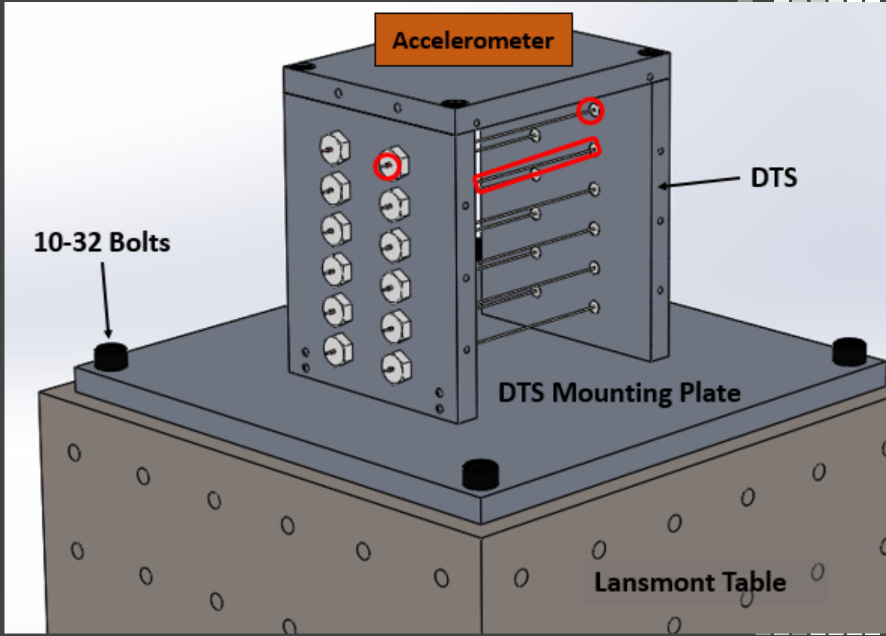
Verify that Wire Electrodes can withstand 10 m/s impact (Req 2.5.1)

Testing Set-up:

- Preliminary drops without DTS to determine drop height vs velocity relationship
- Wire electrodes installed as rigid bar (no slack) with no requirement for tension
- Analyzing for failure (wires free to move) at 3 locations after each test

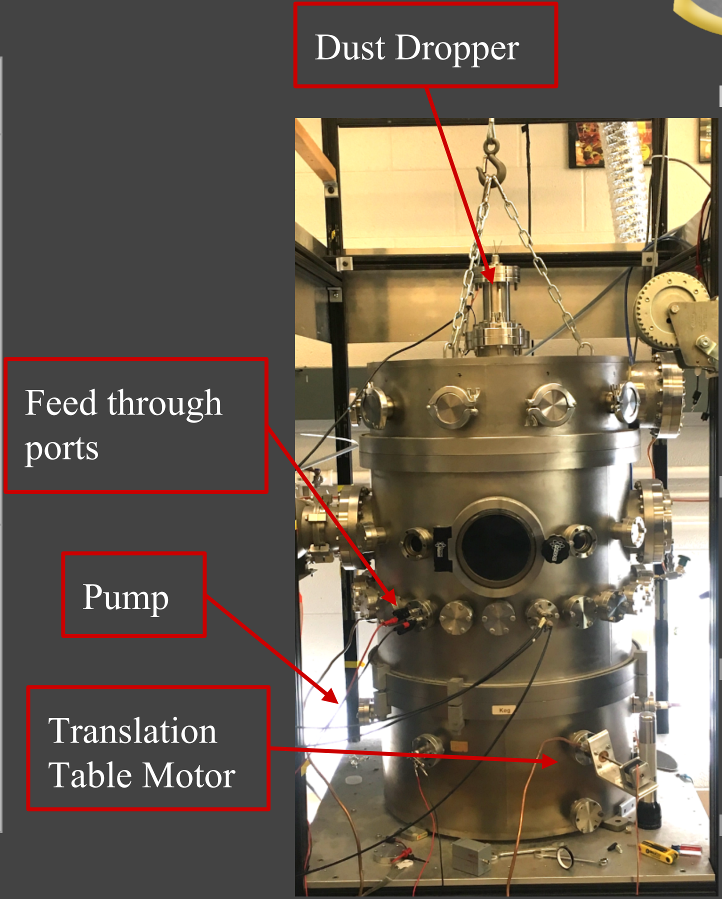
Limitations:

- Only 1 DTS to test
- Material deformations are difficult to analyze



Intro to facilities and data

Location	IMPACT Lab (CU East Campus)
Equipment (Customer Provided)	● Vacuum chamber (w/ pump) ● Vacuum wall cable interfaces ● Dust dropper ● Free electron emitter ● Power supplies (±5V, +3.4V, ±15V, ±5kV) ● Data acquisition ○ 8-channel voltage DAQ ○ Lab computer & software ● Translation table
Data Out	● Analog voltages ○ DTS Stand-alone ○ Electron Shield ● Voltage data file to calculate charge, mass, and velocity ○ MCU/Trigger Software ○ Full Instrument Test



DTS Stand-alone

Verify wire electrode and CSA correctly respond to dust event

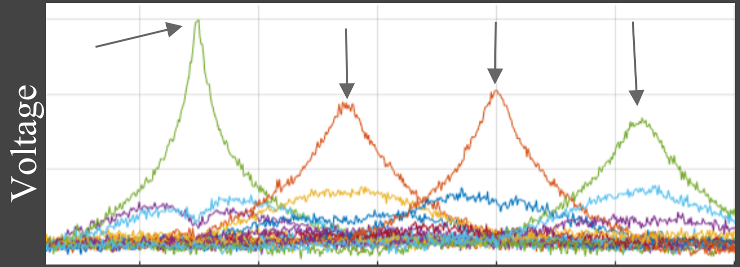
Purpose: Confirm the wire electrode connections and CSA conversion from charge to voltage, and signal amplification

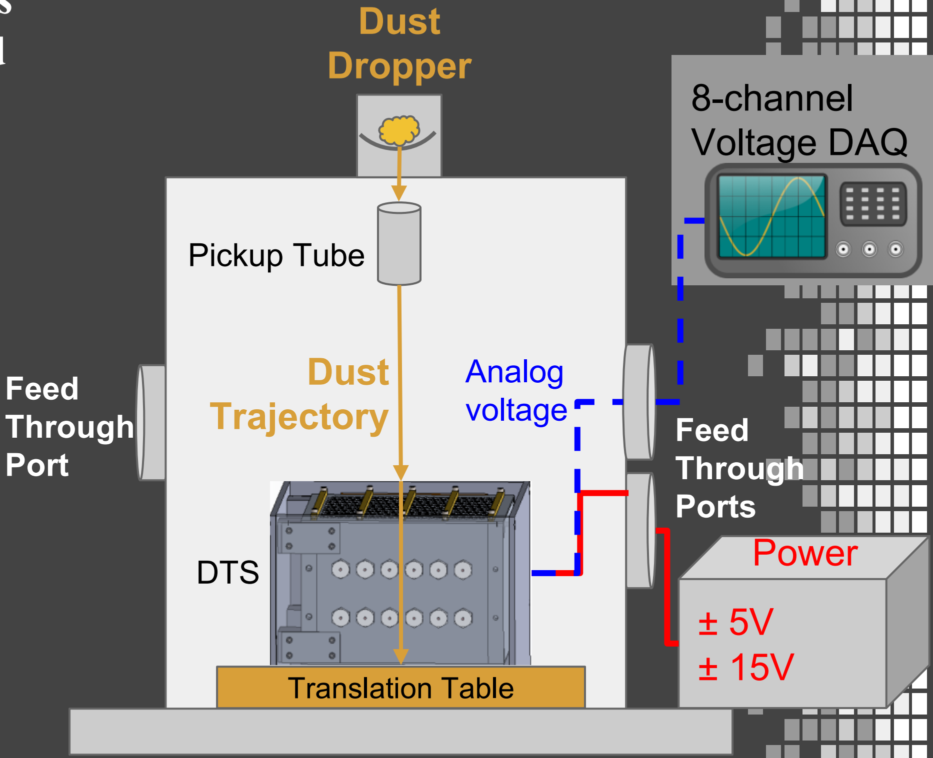
Facility: IMPACT no vacuum

Measure: Live analog voltage output from CSA board (8 wires at a time)

Success: Signal roughly matches expected shape and voltage magnitude (~2 V)

Sample Shape:



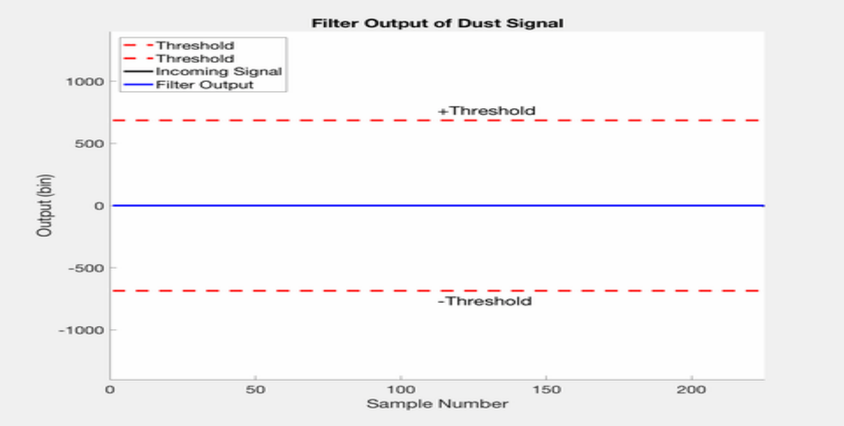


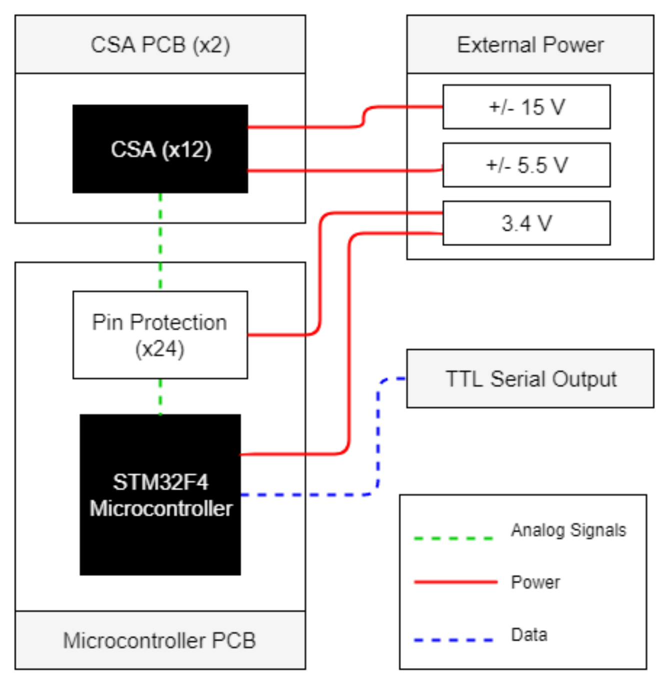
MCU/Trigger software

Verify trigger threshold and MCU data processing

Purpose: Test the ability of the trigger to correctly identify dust events and MCU's ability to process and send data over serial

Facility: IMPACT no vacuum
Output: CSA digital voltage over serial





Electron Shield

Verify that electrons are repelled in TRL4 environment

Purpose: Verify magnetic shield blocks electrons up to 100 eV of energy which would cause noise on the wire electrodes

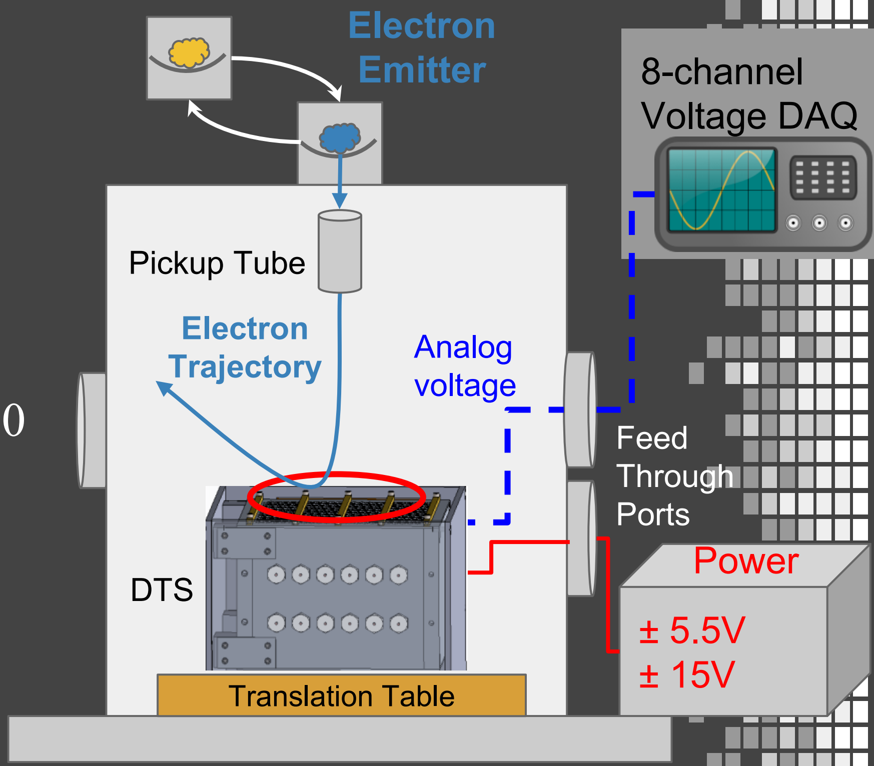
Facility: IMPACT vacuum (for free electrons)

Procedure:

- Replace dust dropper with electron emitter
- Apply set voltage to emit electrons up to 100 eV of energy
- Measure response from CSA over test duration (1 min)

Measure: Digital Voltage

Success: Null Voltage (random noise)



Full Instrument Test

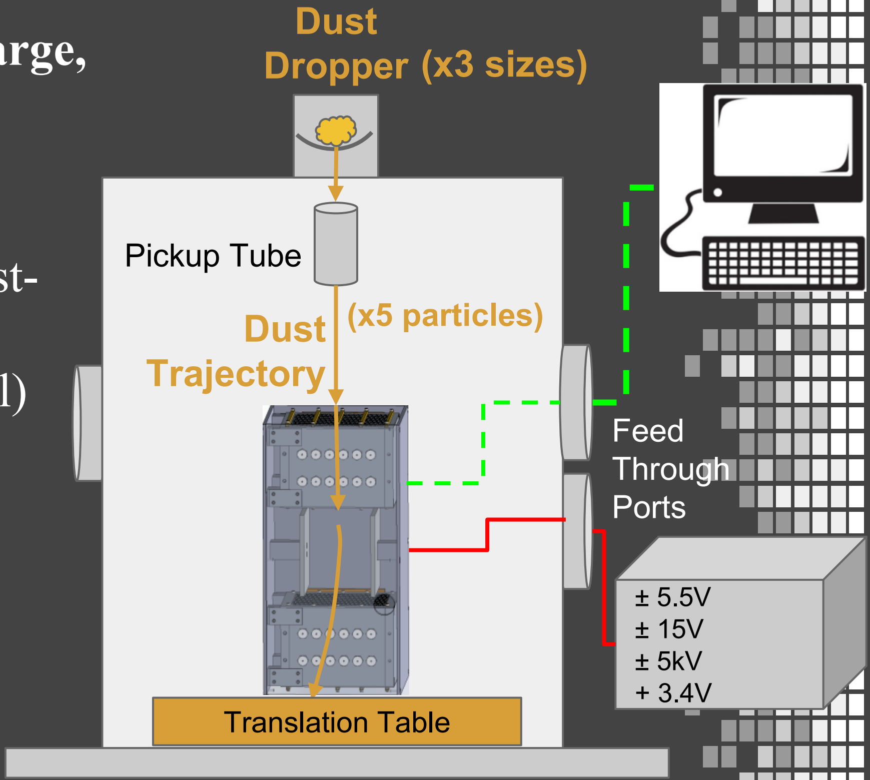
Verify that instrument detects dust particles that enter the instrument.
Req 2, 5, 6

Purpose: Detect a dust event and extract the charge, mass, and velocity of the particle.

Facility: IMPACT vacuum

Measure: Output digital voltage in a data file to post-processing software, calculate charge, mass and velocity distribution in 6 positions (~90 events total)

Data Type	Expected Range
Charge (*Q*)	1 - 160 fC
Mass (*m*)	50-150 µg
Velocity (*v*)	1 - 2 m/s



ARS Test Readiness

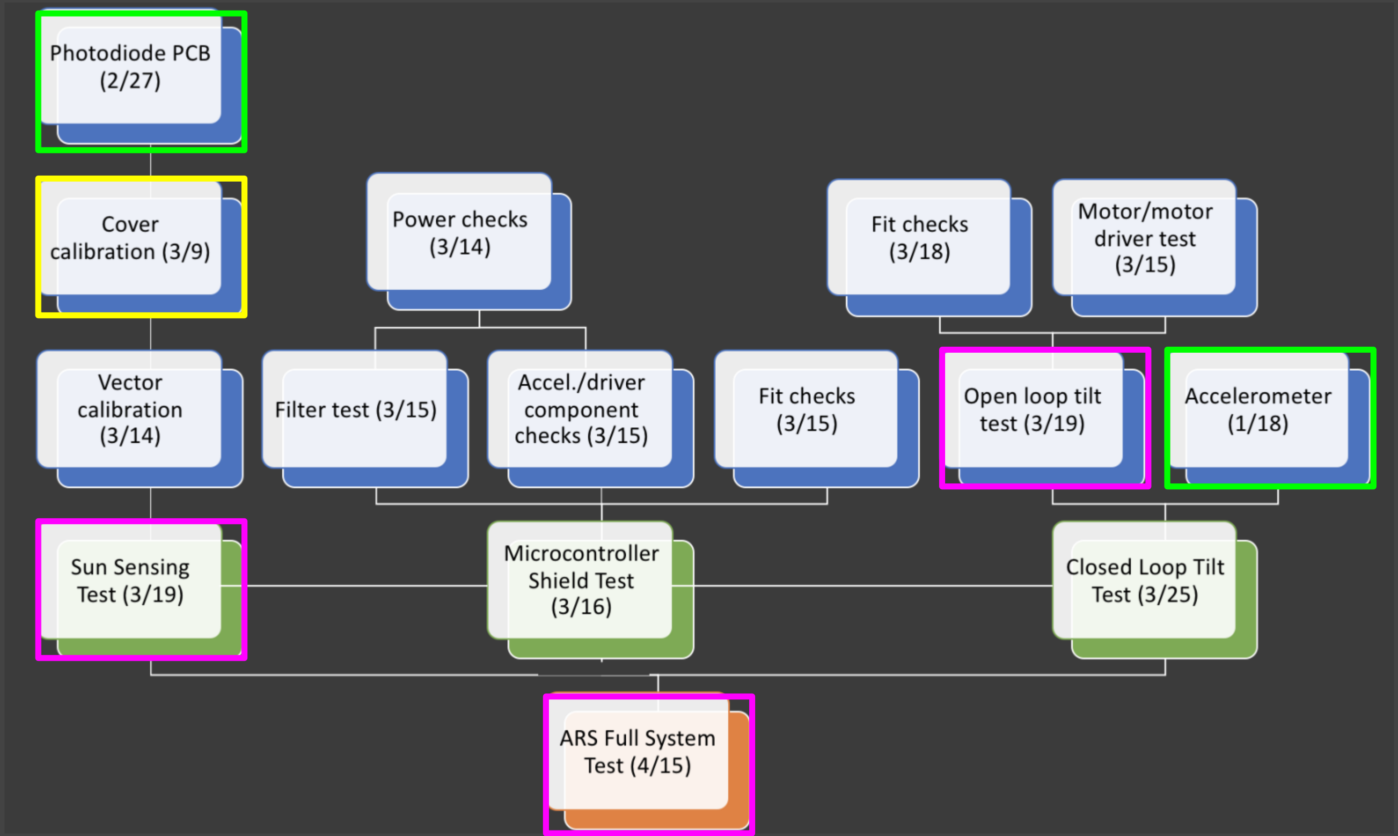
Overview
Schedule
Instrument Test
ARS Test
Budget

ARS Testing Flow

Complete

In Progress

CPE Milestone



Characterization of Sun-sensing

Verify the system can find the sun to within 1° over the full sky.

Requirements 3.21 and 3.22

Purpose: Characterize the accuracy of the photodiodes, covers, and algorithm across the sky.

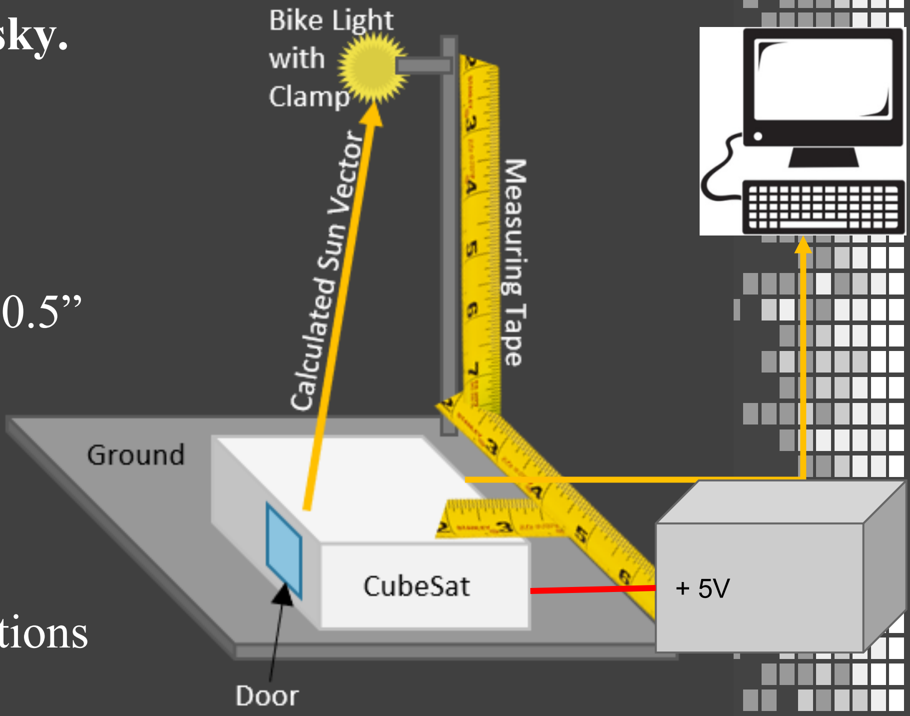
Facility: Bobby's Lab with overhead lights off

Measurements:

- Measured light source position
  - 5ft distance to source, know position to 0.5" for 0.5°
- CubeSat calculated sun vector
  - Based on photodiode measurements

Full sky characterization:

- 32 locations that use all photodiode combinations



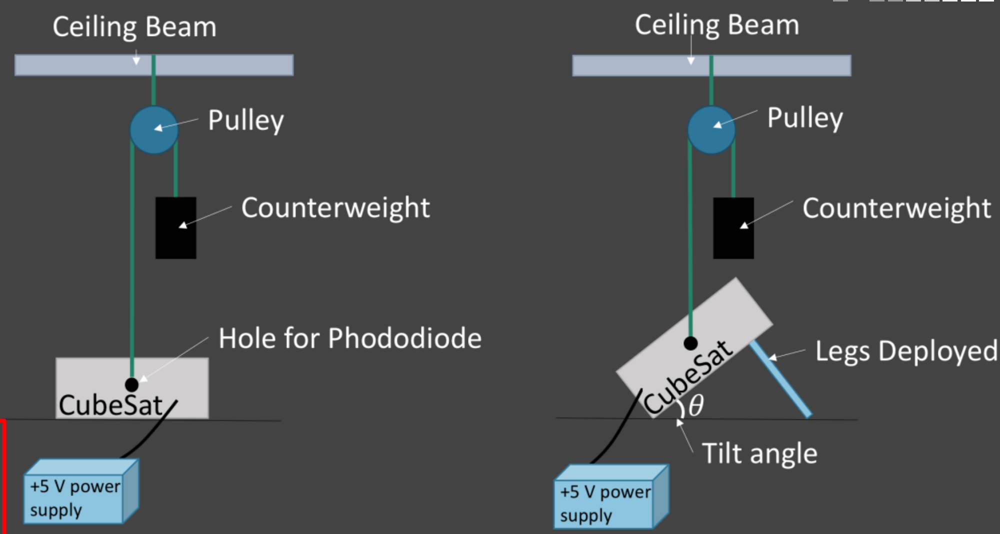
Open Loop Tilt Testing

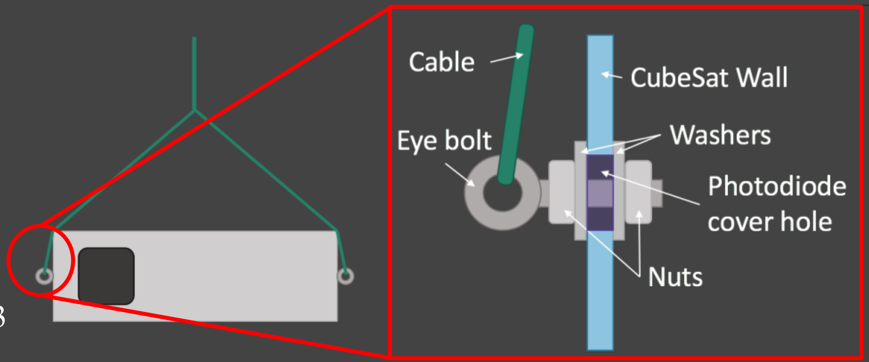
Verify the tilting mechanism can tilt the instrument up to 45° in 1° increments (+/- 0.5° accuracy) - Requirements 4.12,4.121

Purpose: Measure the tilt angle of the Cubesat relative to level ground in 1° increments

Facility: Senior Project Depot

Measurements: Tilting angle of the CubeSat using accelerometer



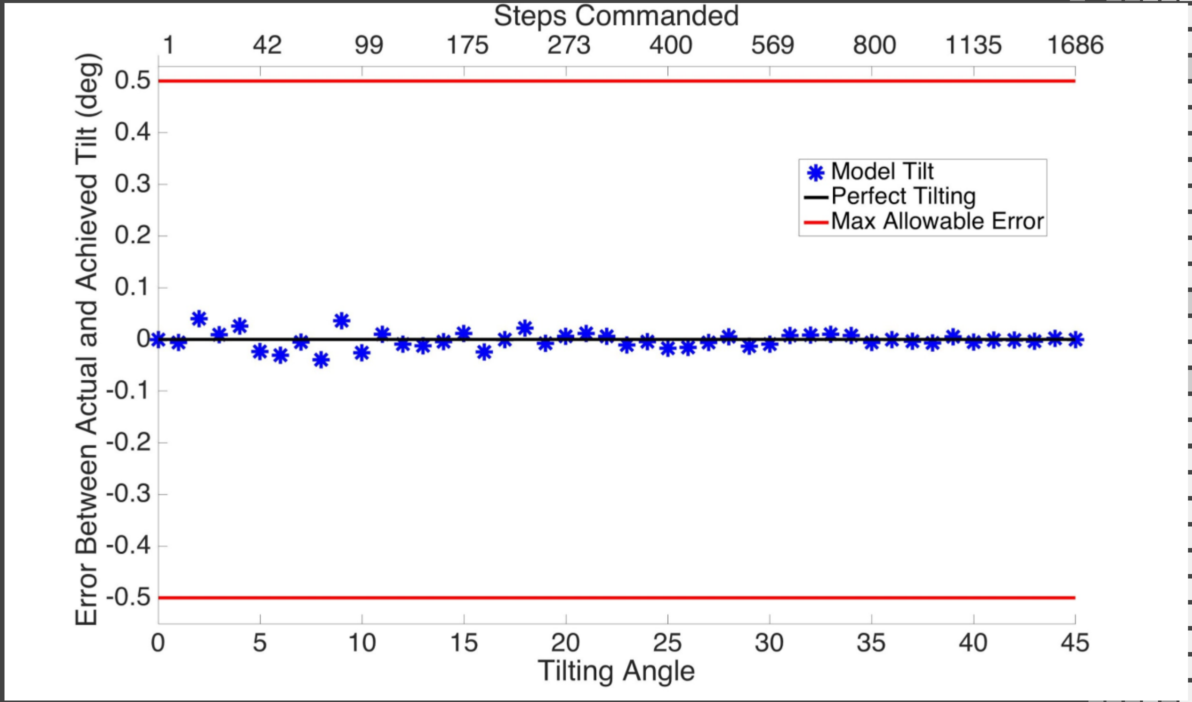


Tilt Testing

Verify the tilting mechanism can tilt the instrument up to 45° in 1° increments (+/- 0.5° accuracy) - Requirements 4.12,4.121

Angle measurements from test will be compared to our tilting model

- If within the allowable error, requirement is satisfied
- Accelerometer has an ¼ degree resolution with ¼ degree accuracy



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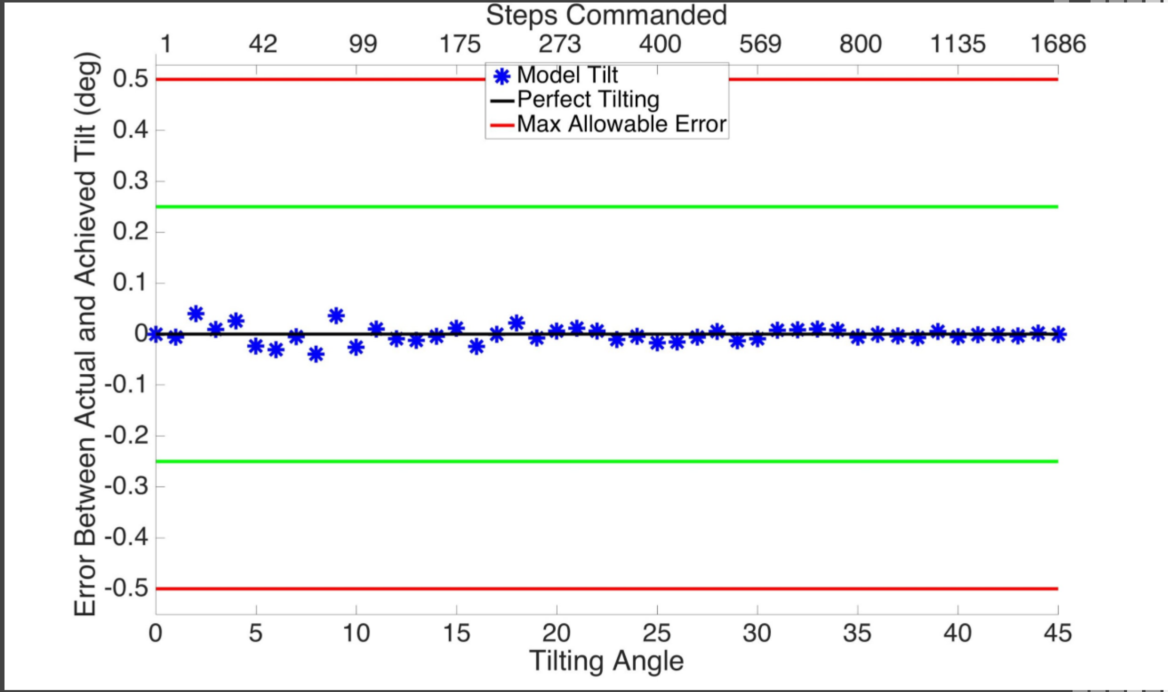
- Accelerometer has an ¼ degree resolution with ¼ degree accuracy
- Expected Values from Accelerometer



Integrated Tilting and Sun-sensing

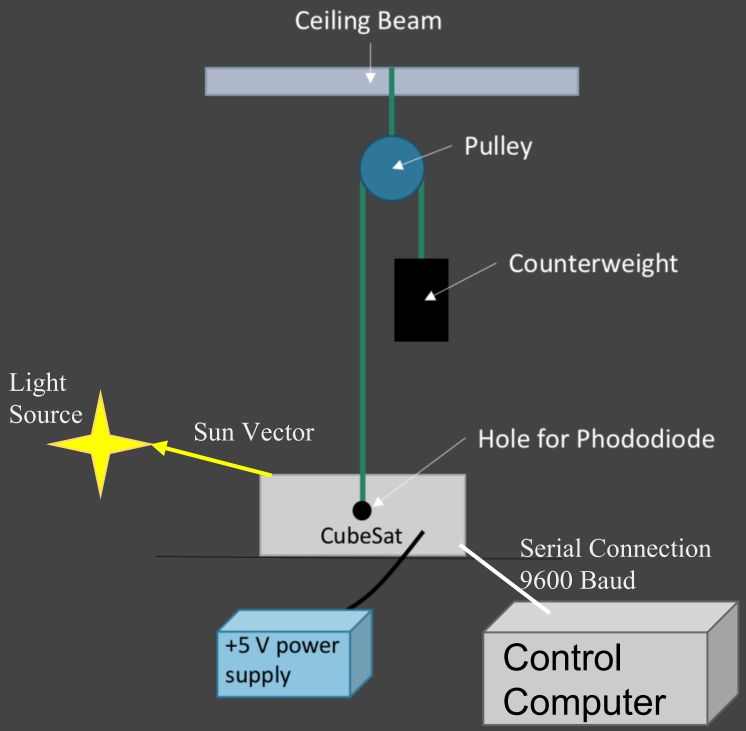
Verify integration of tilting mechanism, door, and sun sensing for 1° accuracy and closed-loop tilting - Requirements 3 and 4

Purpose: Measure the tilt angle of the Cubesat as it responds to light locations

Facility: Senior Project Depot

Measurements:

- Tilting angle of the cubesat using accelerometer - compare to calculated ideal tilt based on actual light source position



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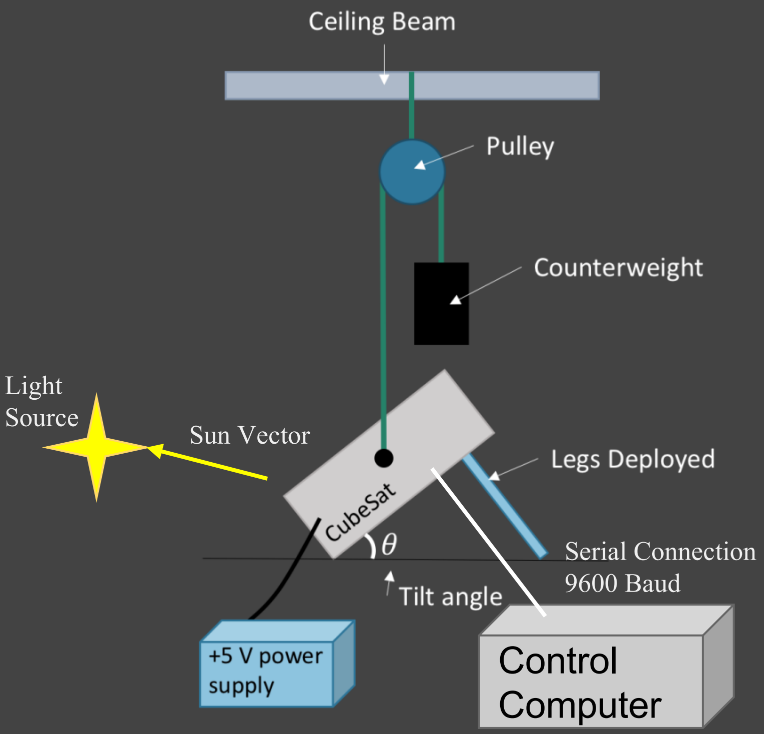


Budget

Overview

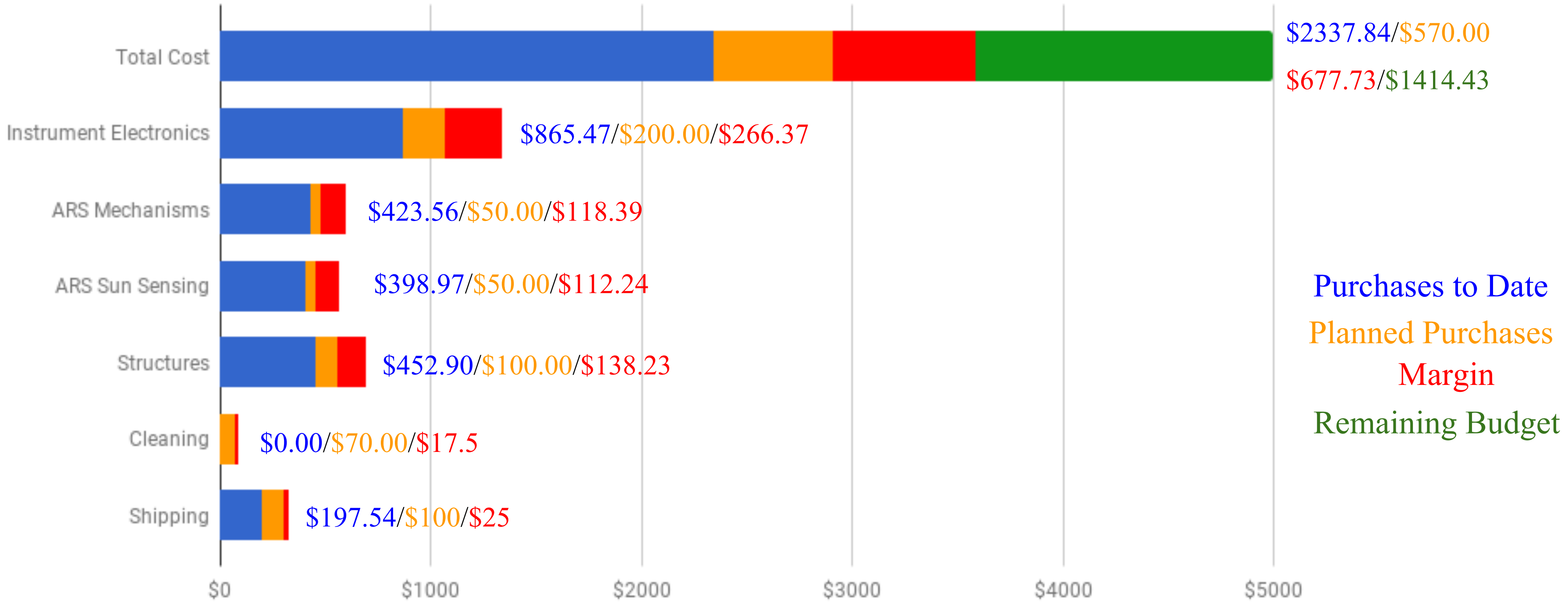
Schedule

Instrument Test

ARS Test

Budget

Cost Plan


Total Cost
Instrument Electronics
ARS Mechanisms
ARS Sun Sensing
Structures
Cleaning
Shipping
$2337.84/$570.00
$677.73/$1414.43
$865.47/$200.00/$266.37
$423.56/$50.00/$118.39
$398.97/$50.00/$112.24
$452.90/$100.00/$138.23
$0.00/$70.00/$17.5
$197.54/$100/$25
$0
$1000
$2000
$3000
$4000
$5000
Purchases to Date
Planned Purchases
Margin
Remaining Budget

Thank you!

Feedback?

Slide Directory

Photodiode Cover Calibration

Verify the photodiodes can measure the sun angle to within 0.5° over the 60° field of view. Requirements 3.21 and 3.22

Purpose: Provide a calibration for the photodiode output to sun angle

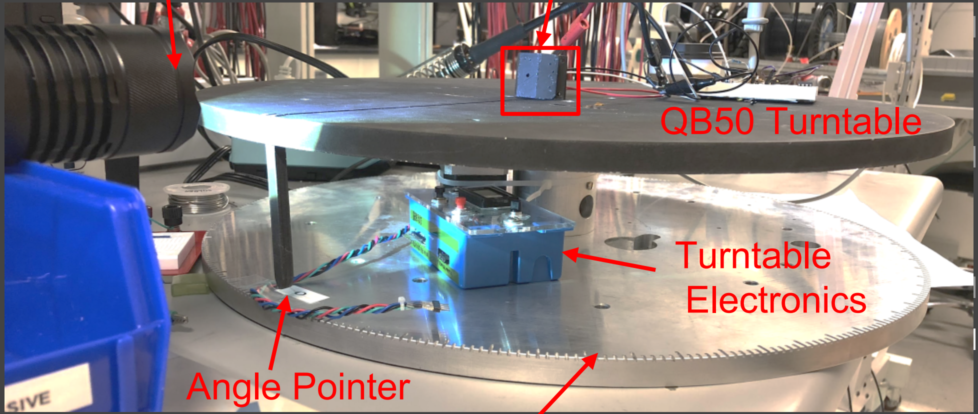
Facility: Bobby's Lab

- Cubesat
- QB50 Turntable
- Light Source (bike light)
- 5V Power Supply

Measurements: Output voltage to oscilloscope

Procedure:

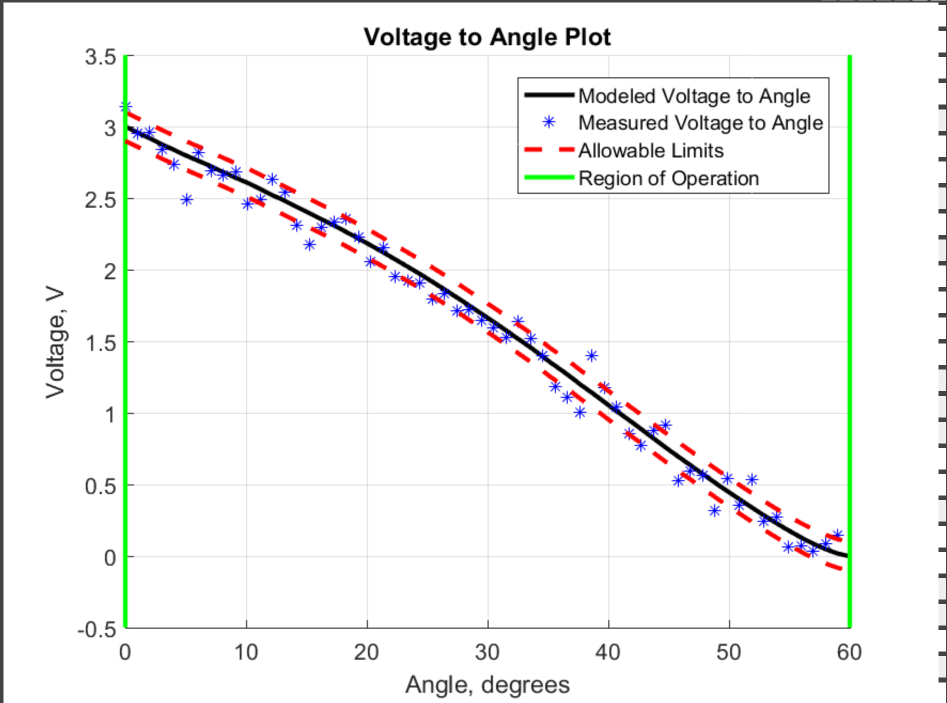
- Set up turntable and photodiode
- Turn 1° increments, measure voltage



Photodiode Cover Calibration

Verify the photodiodes can measure the sun angle to within 0.5° over the 60° field of view. Requirements 3.21 and 3.22

- Current comparison of model and true voltage as measured with the oscilloscope
  - Actual measurements will be done with microcontroller
- Random noise of ~0.1 V is higher than anticipated during design
- Mitigating with an active filter to remove noise
- All points will fall inside the allowable limits



Photodiode Vector Calibration

Verify the pointing of each individual photodiode. Requirements 3.21 and 3.22

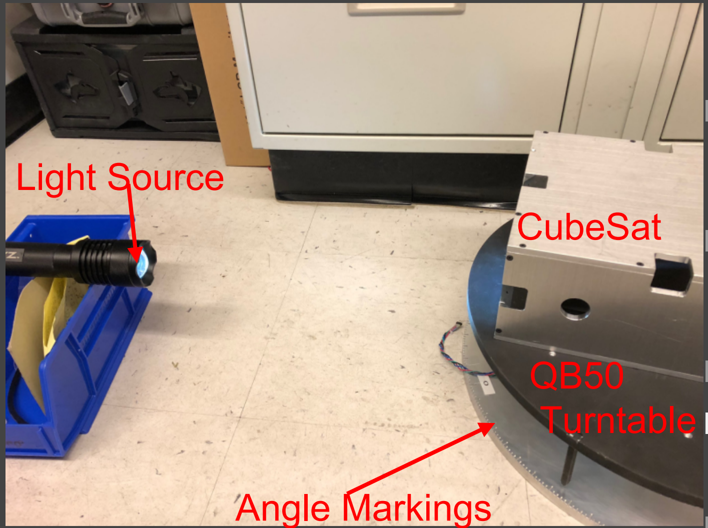
Purpose: Provide a calibration for the pointing of each photodiode on the CubeSat

Facility: Bobby's Lab

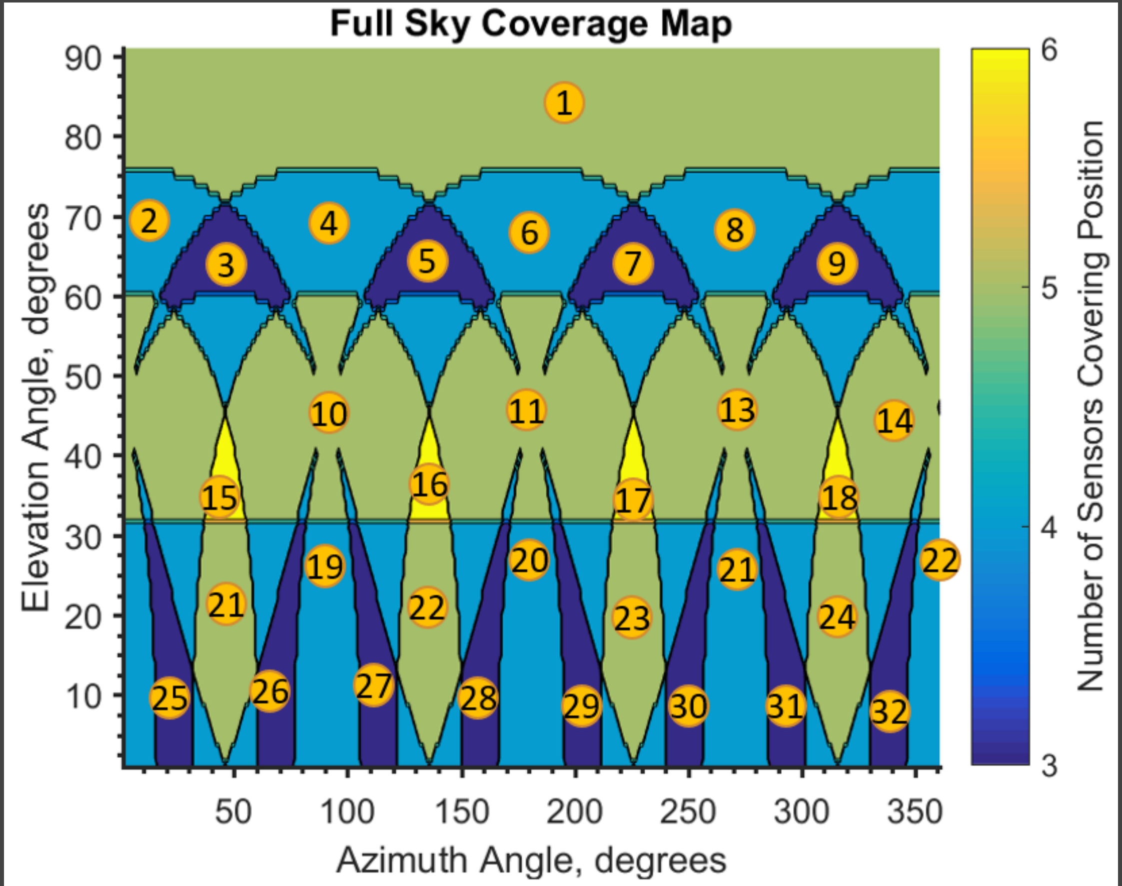
- Cubesat
- QB50 Turntable
  - 1 increments, 0.25" to within 0.005"
- Light Source (bike light)
- 5V Power Supply

Measurements: Output voltage

to microcontroller, resulting sun angles



Sun Sensing Characterization Locations



Accelerometer Testing

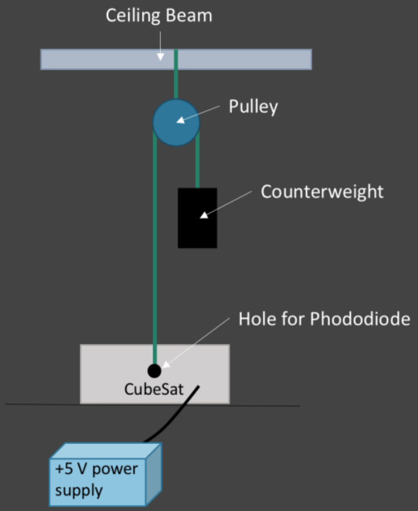
Verify that accelerometer can resolve less than 0.5 degree tilt angle

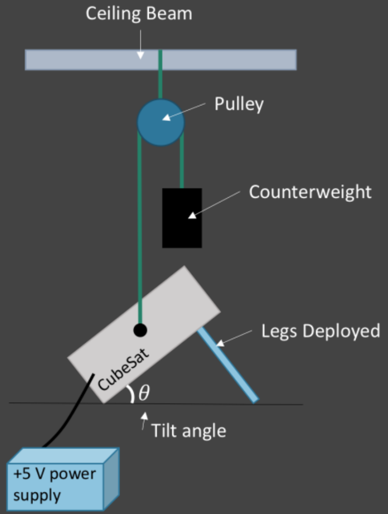
- Characterization of noise levels of digital output
- Machine Shop
  - ADXL345 Triple Axis Accelerometer
  - CNC
  - Accelerometer mount
- Procedure (this can also be a diagram)
  - Calibrate accelerometer
  - Take data at level (0 deg tilt) (10 s)
  - Move CNC known amount
  - Take data at tilt (10s)
  - Compare measure to computed
  - Repeat

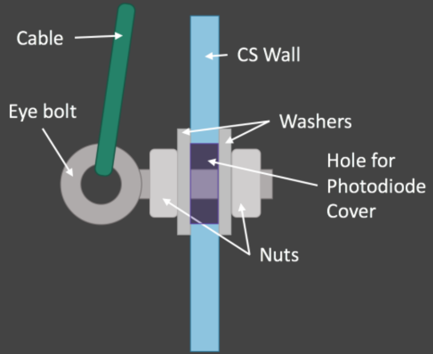
Vacuum Chamber Preparations

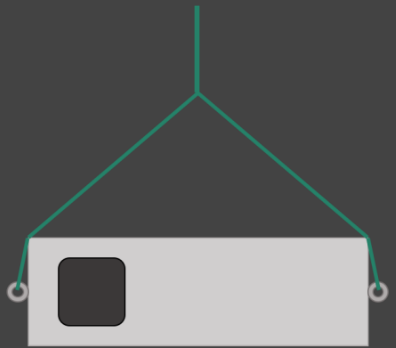
- Cleaning
  - Alcohol/flux remover cleaning for PCBs
  - Acetone and ethanol cleaning in ultrasonic bath for machined components
  - Cleaned instrument stored in ESD bag for transport
- Proper Material Selection
  - Low outgassing materials: aluminum, PEEK, Delrin
  - Vented Bolts

Tilt Testing Procedure









- Procedure
  - Suspend pulley from roof support
  - Attach Rope to Pulley
  - Attach one end of rope to cubesat fixtures
  - Attach other end to counterweight
  - Begin Tilting
  - Measure Tilting
  - Repeat last 2 steps

Door Testing

Purpose: Ensure the Door Opens Correctly

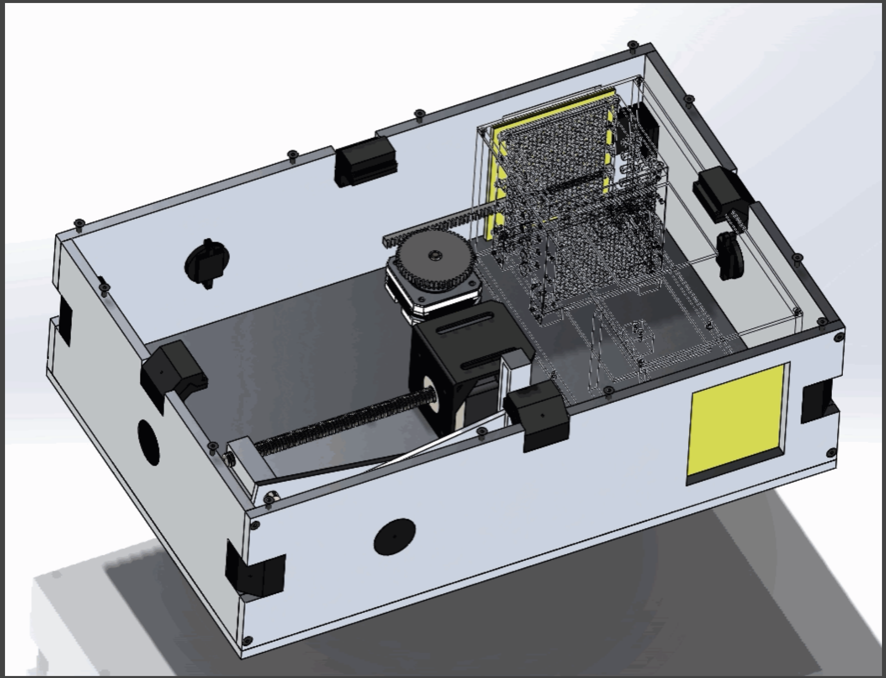
Facility: Senior Project Depot

Measurements:

- Does the door protect this instrument

Procedure:

- Attach door to power supply and Teensy
- Activate door mechanism at level and tilting platform



Photodiodes Boards

Verify functionality of PCB and overall design

- Voltage relative to intensity of light
- Electronics lab
  - Power supply (5V)
  - Oscilloscope/multimeter

- Procedure
  - Connect PCB to power supply and measuring device
  - Turn on and check readout in ambient light
  - In a dark room, position light source 5ft away and check readout at different angles

Instrument Test

Test will must be done 90 times:

- 6 different translation table positions
- 3 different sized dust particles
- 5 recorded events for each particle size in each position

= 90 total events

These numbers are customer specified.

Teensy Shield Test (backup)

Verify functionality of PCB and filter design

- Fit check, verify all components are powered correctly and outputting information
- Electronics lab
  - Power supply (5V)
  - Oscilloscope
  - Multimeter
- Procedure
  - Fit check all COTS boards (do not solder on yet)
  - Connect to power supply and check proper power distribution
  - Connect photodiode and check output after filter
  - Solder on COTS boards one at a time and check functionality of each

Impact Testing Models

- Rigid Bar Statics Model
  - Wire's fail at 4 N impact force
  - Unable to correlate impact velocity to impact force without impact time
- Solidworks Model
  - Proper Material Selection
  - 10 m/s impact results show stresses not exceeding failure stress

Impact Testing Model

Assumptions

- Entire DTS is bonded
- Landing on rigid surface
- Perfectly inelastic collision

Stainless steel 304 wire electrodes

- Ultimate Tensile Strength: 505 MPa

Solder Stoppers

- Length (~ 2.2 mm) designed to shear at 520 MPa normal stress
- Wire will fracture before solder joint shears off