AAE 450/490
TracSat Design Project

Test Readiness Review

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Funded by: General Atomics

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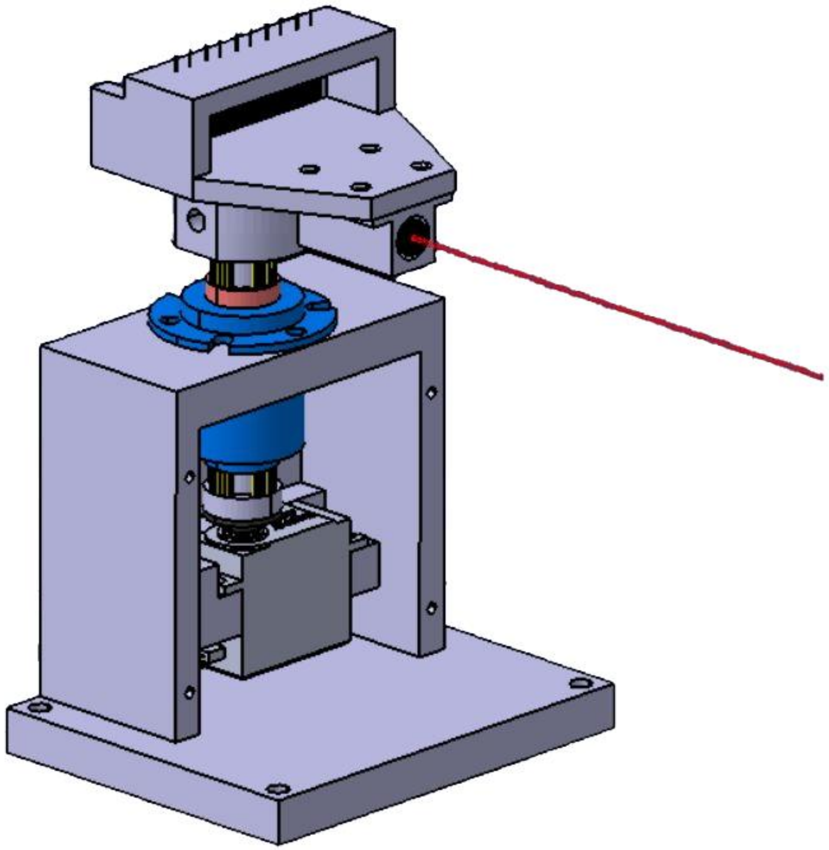


Agenda

- Project Overview
- Laser Link System
- Electronics
- Laser Tracking System
- Hardware and Propulsion
- Questions

Project Overview

- Mission Objectives and Requirements
- Mission Success Criteria
- Original Test Plan

Mission Objectives and Requirements

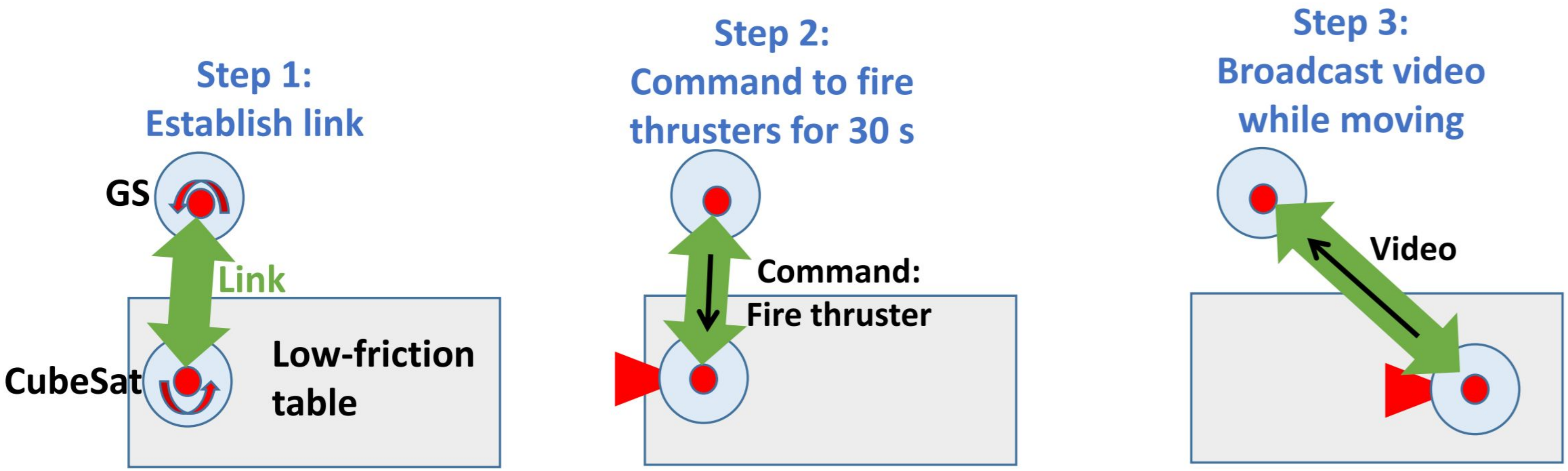
Mission Objectives	
MO 1	Develop a “levitation base” for CubeSat testing and demonstration.
MO 2	Develop CubeSat capable of translational movement.
MO 3	Demonstrate transmission of video between a CubeSat and Ground Station via a 50 kHz tracking laser communication.
MO 4	Maintain communication between CubeSat and Ground Station during movement

System Requirements

System Requirements	
SR 1	LLS must track and maintain link with CubeSat at velocity up to 10cm/s
SR 2	LLS must be able to re-establish link if lost.
SR 3	LLS must be able to transmit data at rate of at least 50kHz
SR 4	PLS air bearings must be able to maintain levitation with less than: 5 degrees of rotational drift and 5cm of translational drift, after 30s of operation
SR 5	PLS thrusters must be able to produce purely translational movement with less than: 10 degrees of rotational drift and 10cm of translational drift, after 8ft.

Original Final Test

- One CubeSat levitating on low-friction table
- Ground Station located away from low-friction surface
- Mission Sequence:
  1. GS and CubeSat establish communication link
  2. GS sends command to CubeSat to fire cold gas thrusters
  3. CubeSat transmits video to GS using laser communications



Laser Link System

- Background
- Hardware
- LLS Architecture
- Test Plans

Purpose & Requirements

Purpose

The purpose of the Laser Link System is to provide a controller, user interface, and system architecture to transmit various telemetry between the CubeSat and Ground Station.

Requirements

- LLS shall provide uninterrupted uplink and downlink communication throughout the movement of the CubeSat
- LLS shall be transmit the data at the rate no less than 50 kHz
- LLS shall transmit live video during downlink

Current Laser

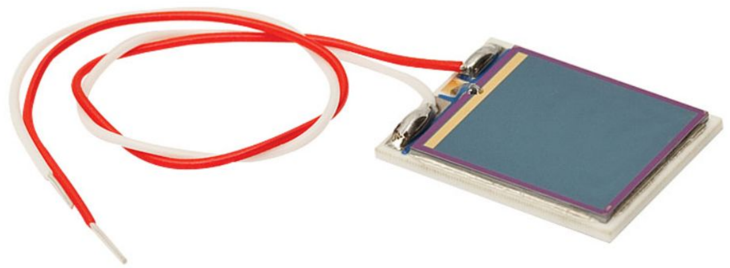
Adafruit TTL Laser Diode

- The laser has the following performance parameters:
  - Max TTL frequency: 50KHz
  - Price: $19
- Useful as a temporary laser to test preliminary data transfer with updated microcontroller.
- Similar dimensions to original laser, so previous structural mechanisms have not changed

Detector

ThorLabs FDS1010 Photodiode

- Requirement: Rise Time must match or exceed frequency at which laser operates
- The photodiode has the following performance parameters:
  - Responsivity: 0.725 A/W
  - Active Area: 100mm^2
  - Rise/Fall Time: 65 ns
  - Wavelength: 350 - 1100 nm
- Five photodiodes will be included in detector array on Ground Station and CubeSat as a part of the LTS system



System Architecture

Important System Requirements:

- Convert data into binary and transmit as pulses through laser (using TTL).
  - Must be efficient and fast — data will often be streamed in real-time.
  - Conversion must occur in phases due to limited storage space for data/bit arrays
- Receive data with minimal loss and convert back to original data.
  - Similar metrics to previous conversion

Error Mitigation:

- Phase shift due to in-program delays:
  - Mitigated by newer algorithm deployed last semester. Required laser/receiver to remain in phase for only 8 bits. Then reset.
  - **Initialization Pulse** removed all phase shift issues.
- Inaccurate delay function from board. Will alter data irreparably.

Telemetry

Level of Complexity	Telemetry Contents	Data Rate Required	Additional Challenges
1	Basic test information (sentence, simple bit string)	< 1 kbps	N/A
2	Commands to CubeSat (translate, stop, send specific data)	~1 kbps	Requires developed Ground Station user interface
3	CubeSat state information (translation speed, rotation rate, power levels, etc.)	~100 kbps	CubeSat must be integrated with primary avionics sending information to LLS
4	Video from CubeSat at varying levels of quality (grayscale → compressed → 480p → 1080p)	> 1 Mbps	Requires little-to-no packet loss and very high data rates.

LLS Test Plan

- Develop a GUI System for Downlink/Uplink
  - Uplink consists of transmitting commands to satellite
  - Downlink consists of receiving data such as acceleration, position, or angular measurements
  - Long-term goal of live video transmission would be implemented here
- Implement existing LaserCom code into PYNQ boards and run tests to improve transmission speeds
  - Some logistical complications from transferring to Python-based microcontroller
  - Eventual goal to achieve 50 kHz transmission rate
  - Additional task of live video to bit-stream data on PYNQ boards

Ground Station Software

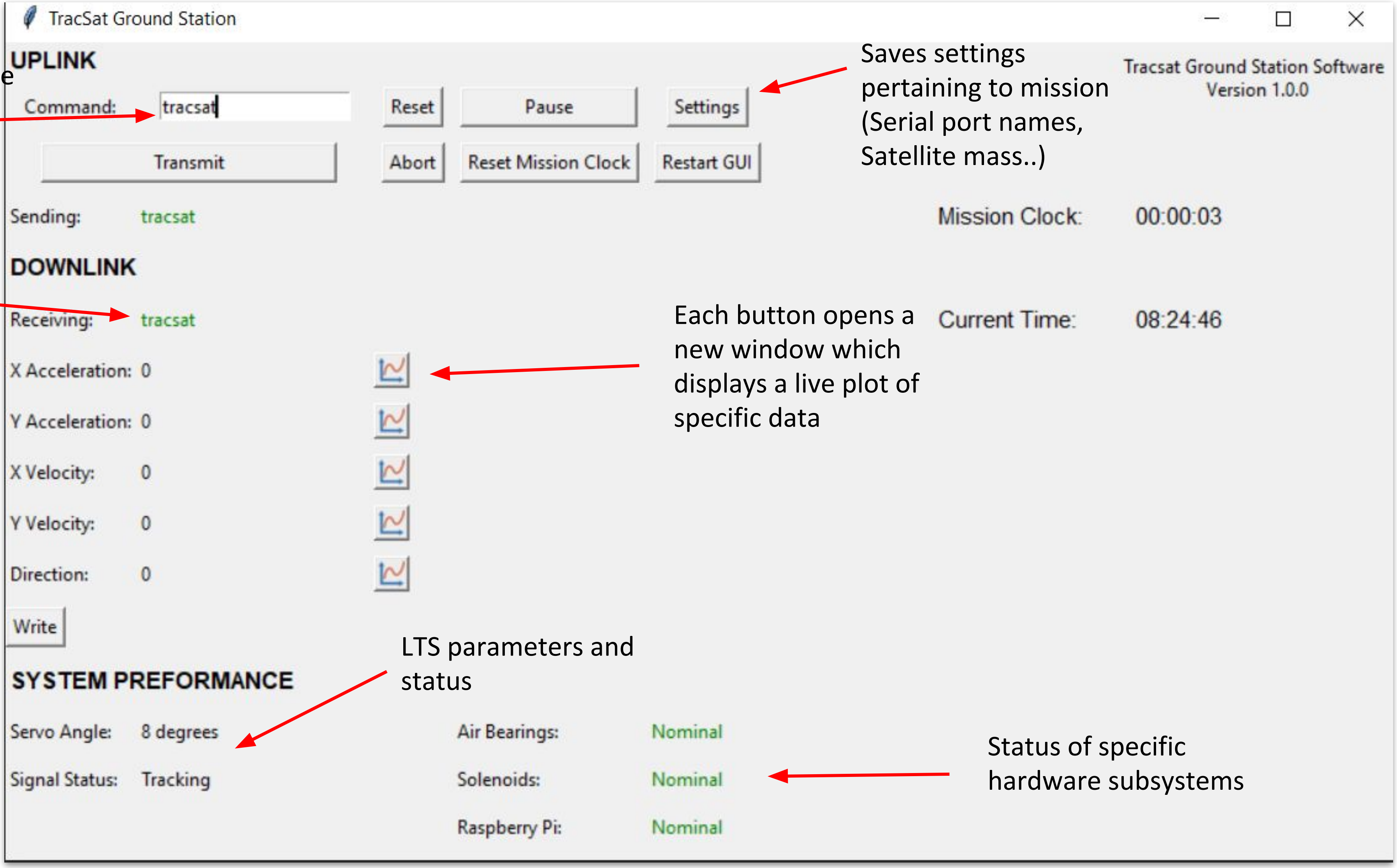
- **Develop ground station software with a GUI**
  - In order to simplify the control and analysis of missions, a ground station GUI will connect the user to the lasercom system
- **Uplink**
  - Allows the user to transmit commands to the satellite and perform other miscellaneous functionality (pause, reset…)
  - Fully Completed.
- **Downlink**
  - Receives live telemetry from the satellite and allows for the live plotting of the data
  - Also receives system performance parameters to monitor status of all systems.
- **Future plans**
  - Live plotting and testing of telemetry needs to be completed.
  - Make the code as versatile and independent as possible, so we can connect different lasercom systems to it with little effort.

Ground Station Software (Cont.)

Easily send short commands to satellite

Currently receiving "Tracsat"

Ability to write all data to an external file.



Saves settings pertaining to mission (Serial port names, Satellite mass..)

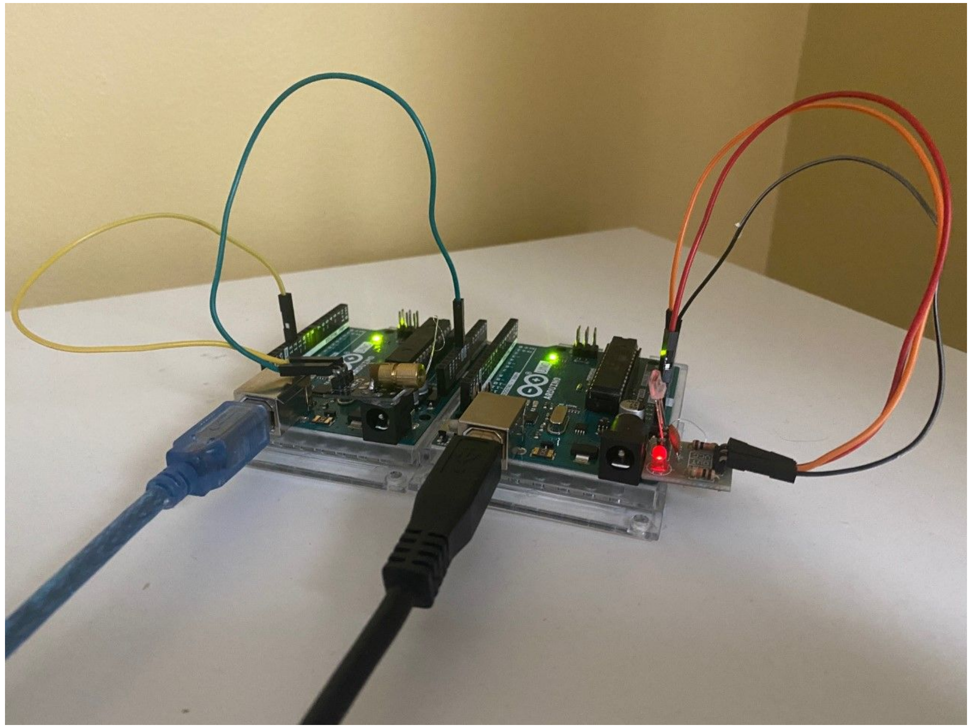
Each button opens a new window which displays a live plot of specific data

LTS parameters and status

Status of specific hardware subsystems

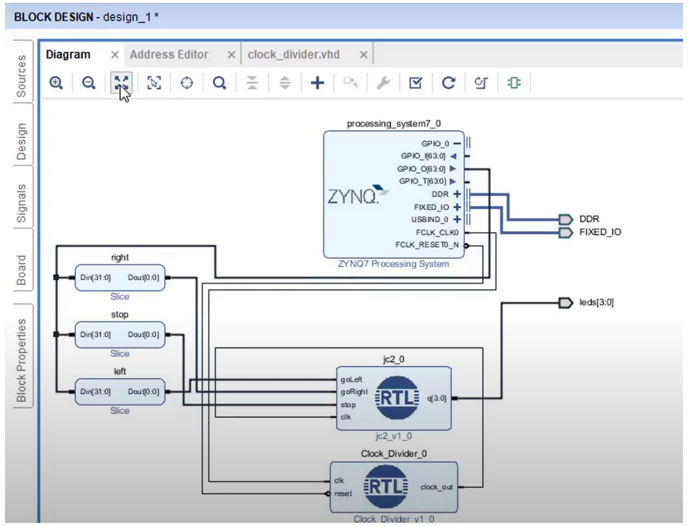
Ground Station Software Testing

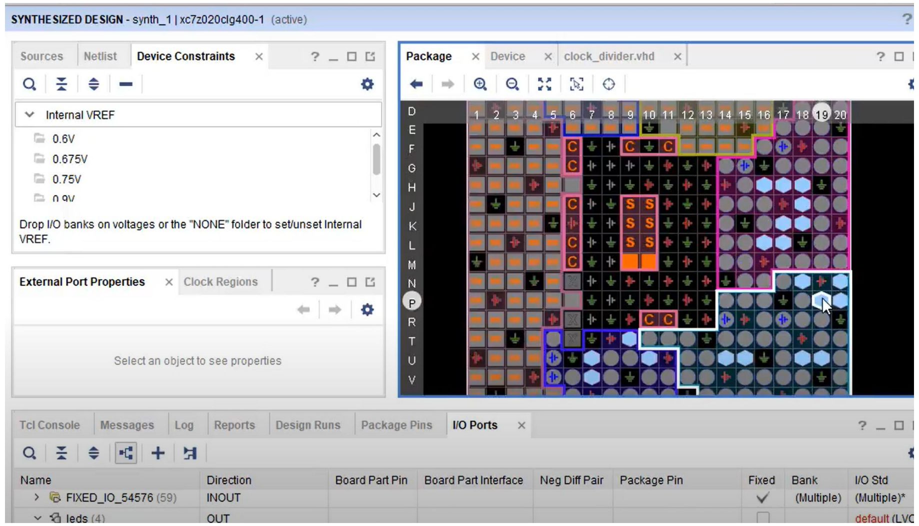
- **Currently testing GUI and ground station with the Arduino system**
  - Already working, and easy to set up.
  - Connected through serial ports, thus allowing them to be replaced with alternative lasercom systems at any time (PYNQ…)
- **Future testing plans**
  - Live telemetry is the biggest challenge
  - Alter the lasercom system to send live data/telemetry (random values).
  - Create functions/algorithms to efficiently receive, analyse and display the several channels of data.
  - Must ensure that all functionality is independent of the Arduino for future compatibility



PYNQ Software

- **To activate GPIO pins, a significant amount of expertise is required**
  - Turning on the GPIO pins will allow us to activate the laser beam
  - Pins, however, are programmed outside of main Jupyter software
- **GPIO pins operate separately with VIVADO software which is programmed in VHDL**
  - Utilize IP integrator block design to individually define pin locations and other necessary standards
  - Contrasts with Arduino where pin locations are inherently defined





PYNQ Software (cont.)

- **Currently testing video transmission capability with pre-recorded videos**
  - Began with converting images to numpy array
  - Worked on video conversion to collection of individual image frames
- **Future testing plans**
  - Try to connect a webcam to PYNQ to convert live video into bit stream data that would be implemented later for video transmission
  - May encounter problems with trying to extract data from webcam similar to turning on GPIO pins
  - Attempt to make more progress with GPIO system, if possible

Electronics

- Microcontroller
- PCB/Power
- Solenoids

Microcontroller

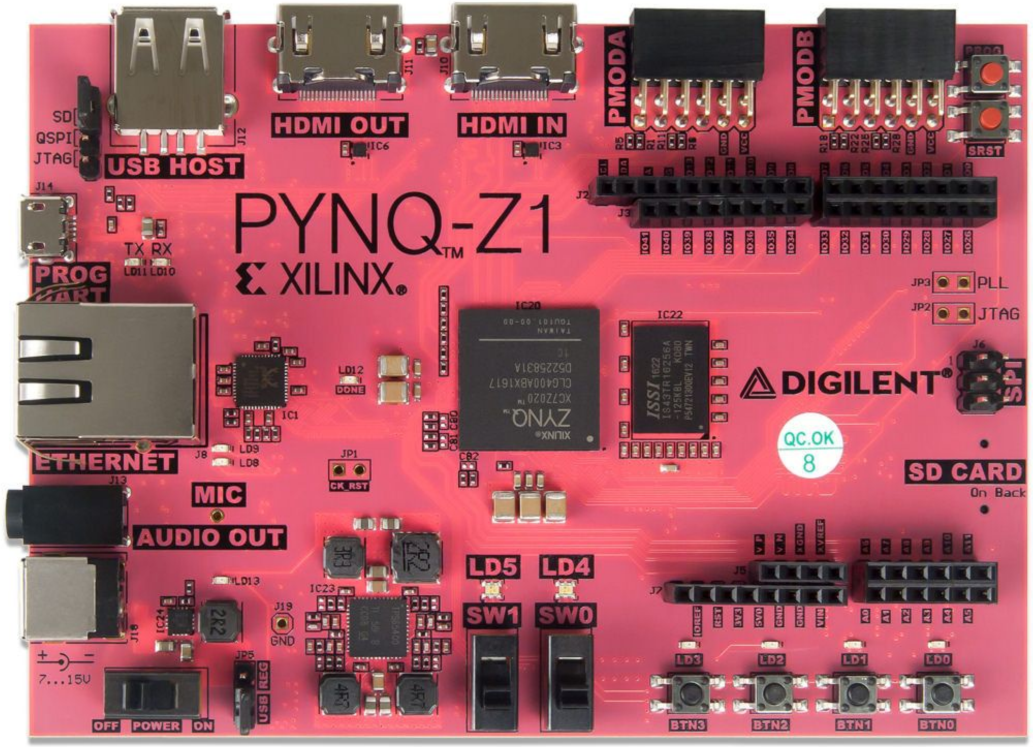
Digilent PYNQ-Z1

Requirements:

- 1 MHz digital input/output speed
- Fit the form factor of the CubeSat
- Programmable with either Python or C/C++
- As many I/O pins as Arduino/Raspberry Pi
- 12 V power to satisfy power budget

Capabilities/Features:

- 8 high-frequency IO PMOD ports
- High frequency Arduino Shield
- Variable power range (7-15 v)



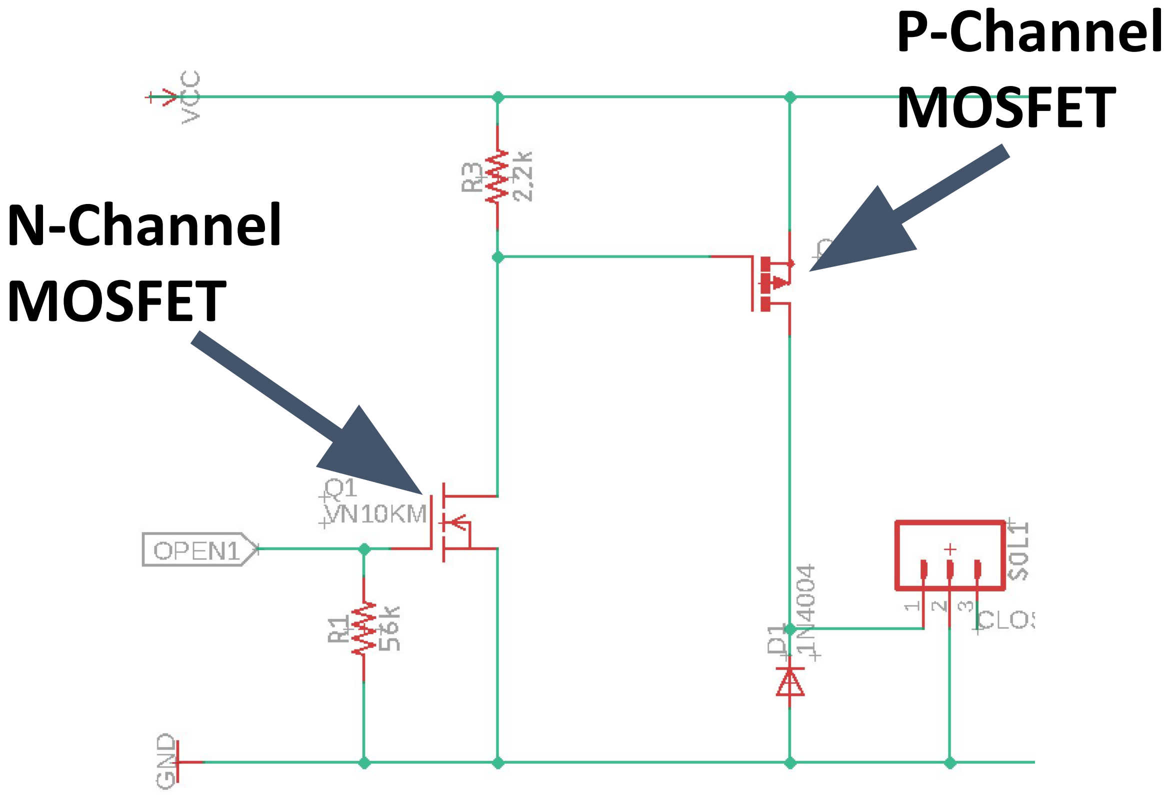
PCB

Requirements:
- Supply power to microcontroller, servo motor, and solenoids
- Allow microcontroller to interface with solenoids to open and close as needed
- Fit CubeSat form factor

Circuit Design Features:
- Uses 1 N-Channel and 1 P-Channel MOSFET
- Accommodates wide array of microcontrollers

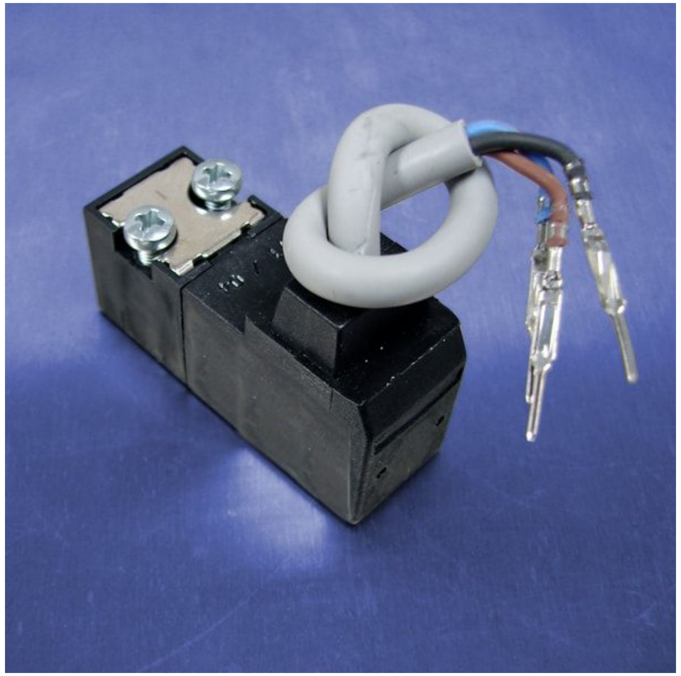
MOSFET 1: On Characteristics	
Minimum	Maximum
0.8 V	3.0 V

MOSFET 2: On Characteristics	
Minimum	Maximum
-2.0 V	-4.0 V



Solenoids

Requirements:
- Easily actuate between open and close
- Compact form factor
- Minimal impact on power budget
- Operate in range of voltages supplied by battery



Selected Component:
- Pneumadyne 2 Way Magnetically Latching Solenoid

Power	Voltage	Voltage Tolerance	Response Time
4 W	12 V	-5% , +10%	10 - 12 ms

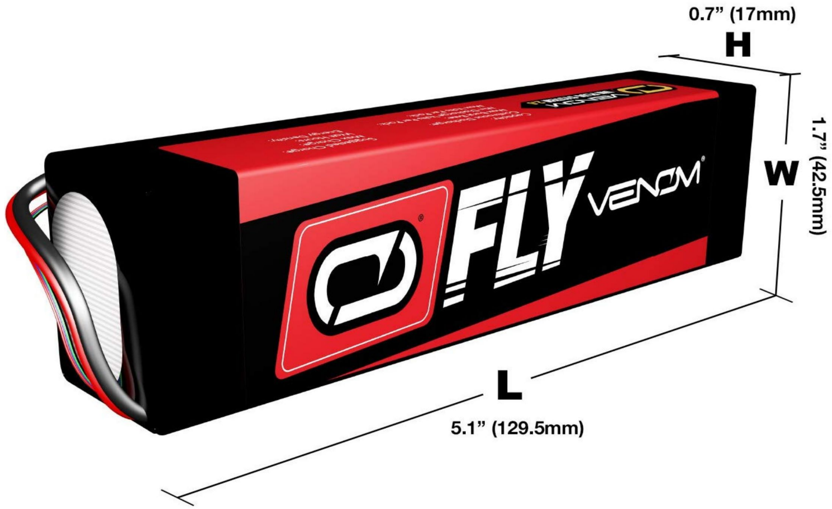
Power Budget and Battery

Requirements:

- Give preliminary estimate of power needs for our system

Selected Component:

- 11.1 V 3 Cell LiPo Drone Battery 3200 mAh
- When fully charged, operates at 12.6 V and steadily decreasing from there towards nominal voltage



Normal Power Use Case (40 Minute Operating Time)						
Item	Amps (Amp)	Voltage (V)	Power (W)	Duty Cycle	Watt-hours	mAh
Microcontroller	0.8	12	9.6	1.0	6.4	533.33
Solenoid (x4)	0.3333	12	4.0	0.022	0.00977	0.814
Servo Motor	0.25	5	1.3	1.0	0.13889	27.78
					Total:	**561.925**

Worst Power Use Case (40 Minute Operating Time)						
Item	Amps (Amp)	Voltage (V)	Power (W)	Duty Cycle	Watt-hours	mAh
Microcontroller	2.5	12	30.0	1.0	20	1666.66
Solenoid (x4)	0.3333	12	4.0	0.220	0.293	24.444
Servo Motor	0.8	5	4.0	1.0	0.444	88.89
					Total:	**1691.11**

Electronics Test Plan

The PCB will be assembled and tested off-site

- The PCB for the four solenoids has been designed and parts have been ordered.
- We now have access to a soldering iron and will attach all components
- Once assembled, the board and solenoids will be tested using the two power sources from 3089.

The plan is to get the solenoid and board to work using the normal battery and raspberry pi.

Laser Tracking System

- Schematic
- Selected Components
- Control Software

Purpose & Requirements

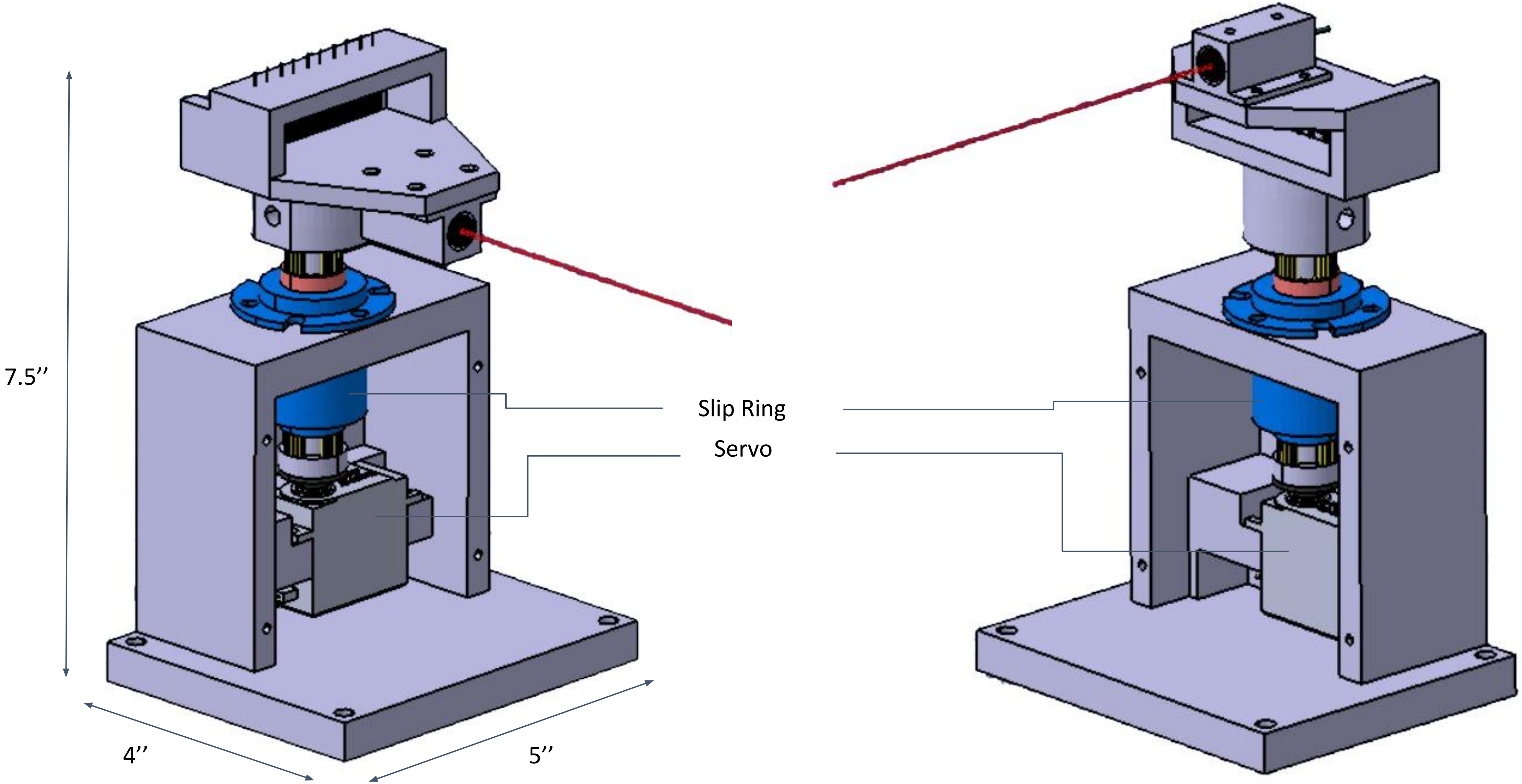
Purpose

The LTS is designed to obtain and maintain laser link between the CubeSat and Ground Station during maneuvering.

Requirements

- The LTS must be able to establish, maintain, and re-establish laser contact between the ground station and CubeSat
- LTS must have motor capable of rotating the LLS at a acceptable speed
- LTS will use the microcontroller selected by the team
- The LTS will be tested before TRR using the testbed purchased last semester

Schematic

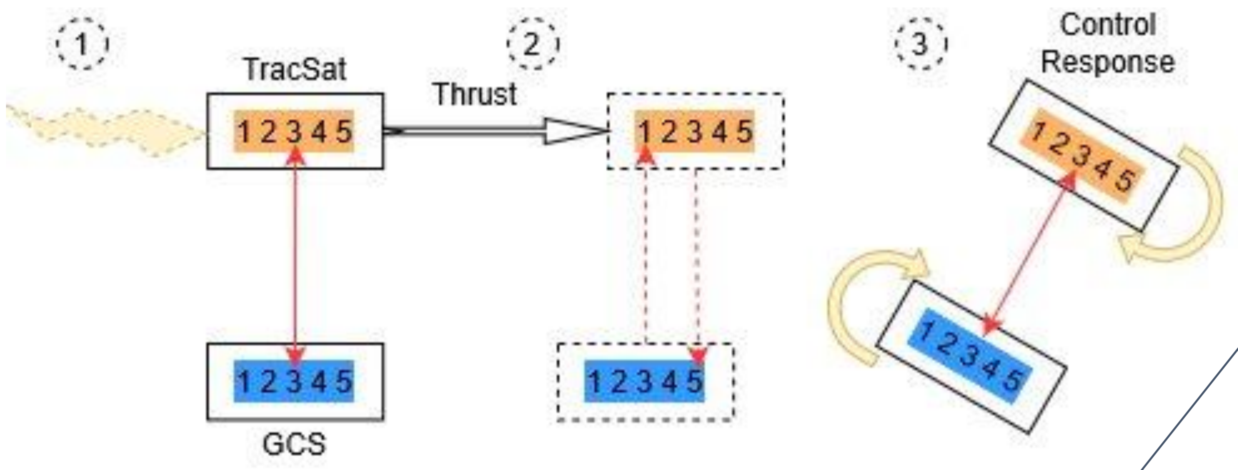


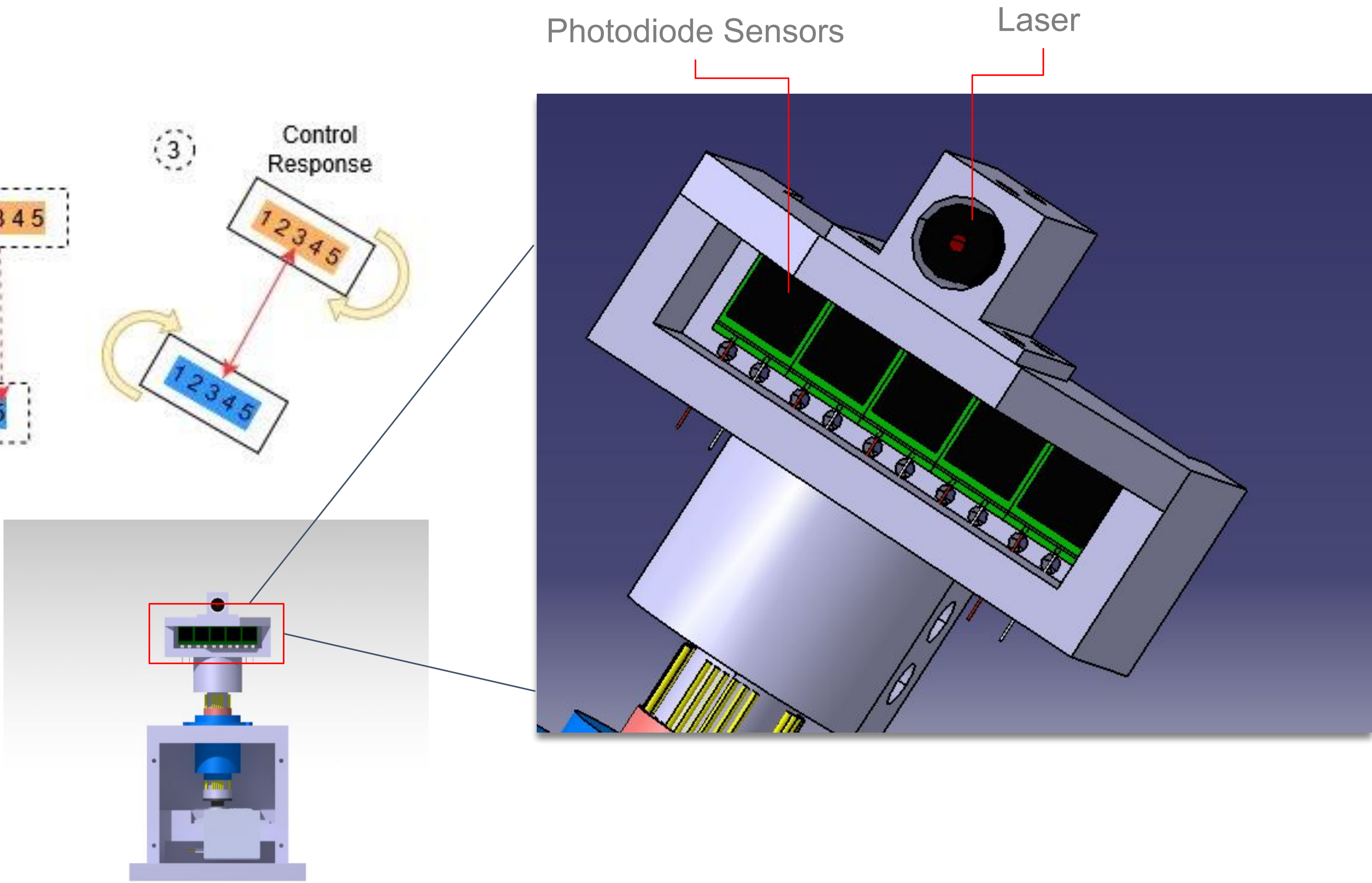
Motor

AR-3606HB Continuous Rotation Servo

- The motor has the following performance parameters:
  - 6.7 kg-cm of torque
  - 71 RPM with no load
  - 4.8V minimum voltage
- Specifications: 4.05 x 2 x 3.8 cm
- CR servo allows for precise speed control with 360 degrees of rotation

Detector Array Set-Up



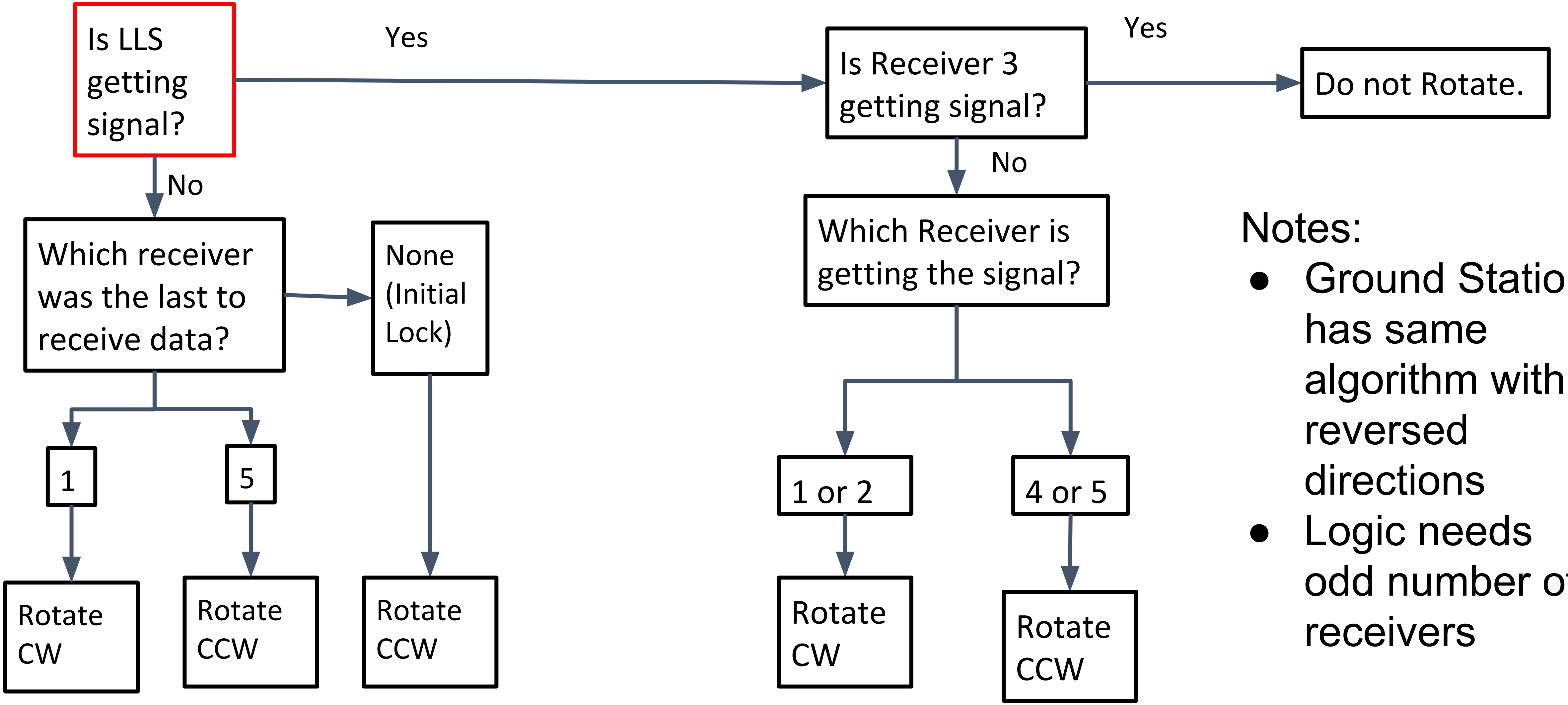


LTS Control Software

LTS Control System is designed to rotate the receivers and laser diode to keep it in constant contact with the Ground Station.

- Control System operates with on-off logic
  - ‘On’: Laser is hitting center laser receiver
    - No Movement
  - ‘Off’: Laser is not hitting center receiver
    - Either hitting an off-center receiver or no signal
    - LTS rotates to get back to center receiver

Control Schematic: CubeSat



Notes:

- Ground Station has same algorithm with reversed directions
- Logic needs odd number of receivers

LTS Test Plan-Post Break

- The Laser Tracking System will be tested using a wheeled robot to simulate CubeSat
  - LLS system simulated with continuous-on laser and laser turret
- Robot is a GoPiGo3 from Dexter Industries
  - Two drive wheels, one caster ball
  - Programmed on a Raspberry Pi 3
  - Servo and laser connect through breakout board
- Testbed moves while laser turret tracks ground station
  - Ground Station turret tracks testbed movement

LTS Test Setup: Post-Break

Initial State:

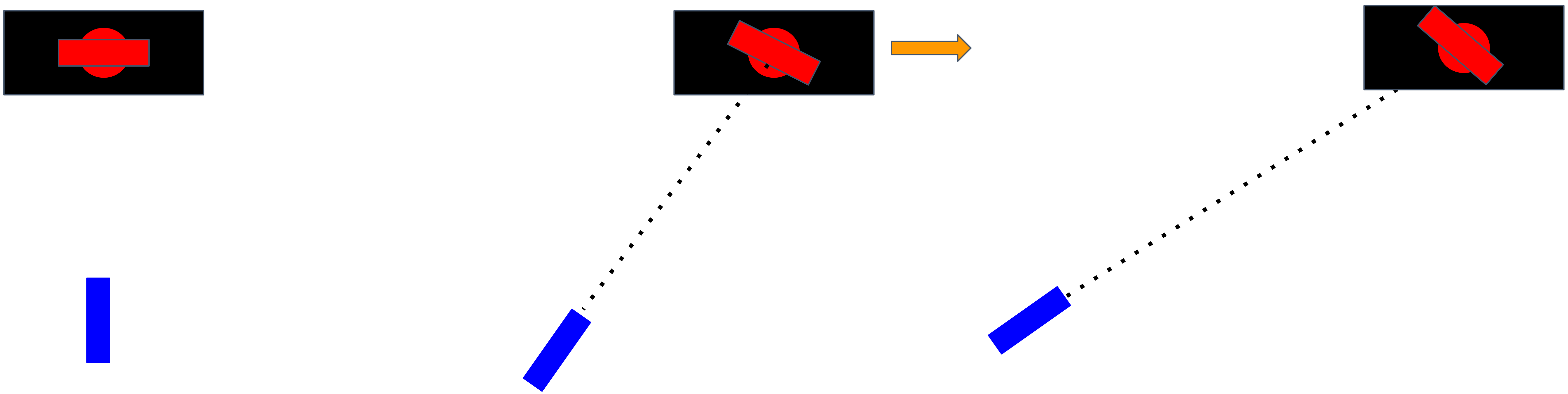
- Testbed (black) is Stationary
- LTS (red) locks manually held laser diode (blue)

Moving State:

- Testbed moves forward
- LTS rotates to maintain signal between handheld diode and testbed

Final State:

- Testbed stops
- LTS stops rotating to maintain laser communication



Hardware and Propulsion

- CubeSat and Base Models
- Final Components
- The Drift Problem
- Experimental Results

Purpose & Requirements

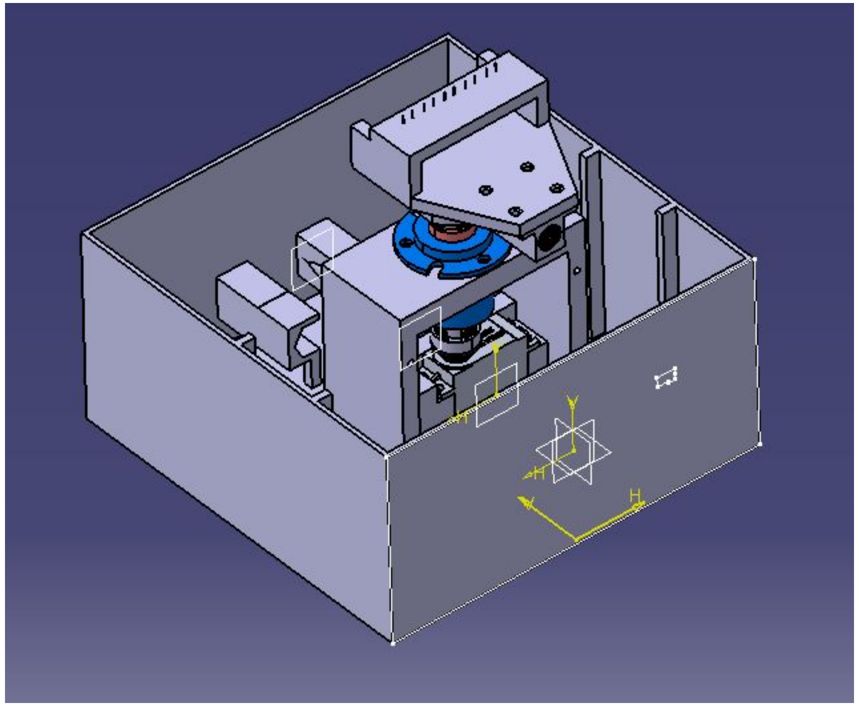
Purpose

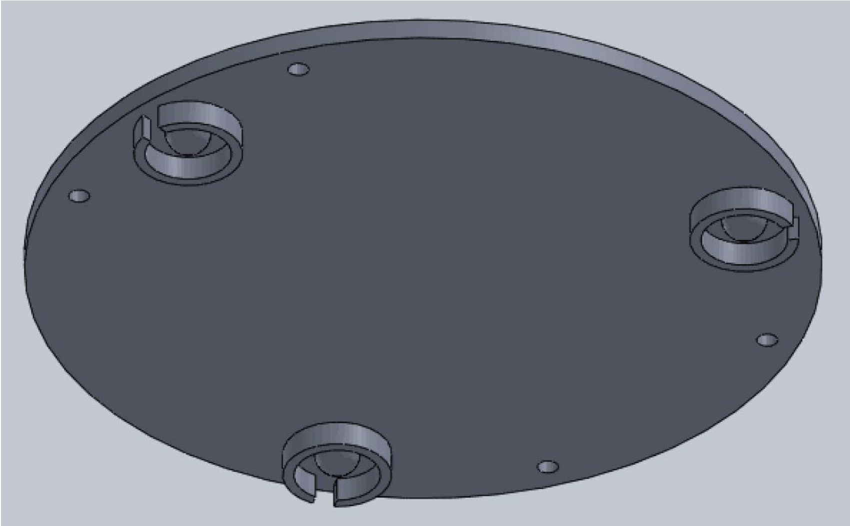
The purpose of the propulsion and levitation system is to provide a low friction space analogue for the cubesat to perform a variety of maneuvers.

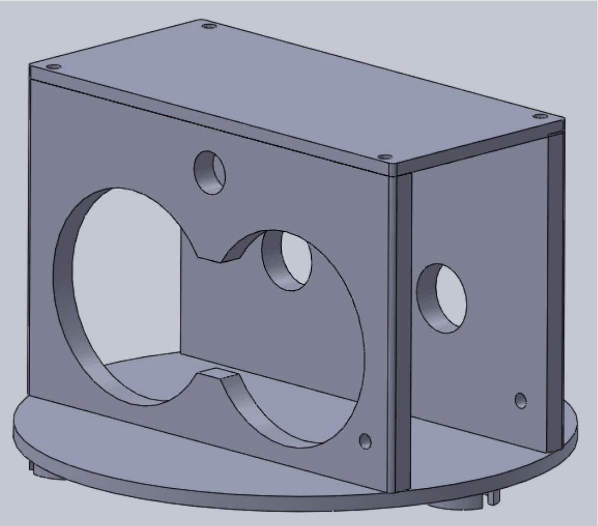
Requirements

- Propulsion and Levitation System must be able to provide free, **one-dimensional** translational motion
- PLS must maintain **steady levitation** with drift less than 5 degrees (rotational) and 5 cm (translational) after 30 seconds of becoming "stationary"
- PLS must move translationally 8 ft with drift less than 10 degrees (rotational) and 10 cm (translational)
- PLS must be precise enough such that the final position must not be more than 5 cm in any direction from the desired final position

CubeSat and Base Models

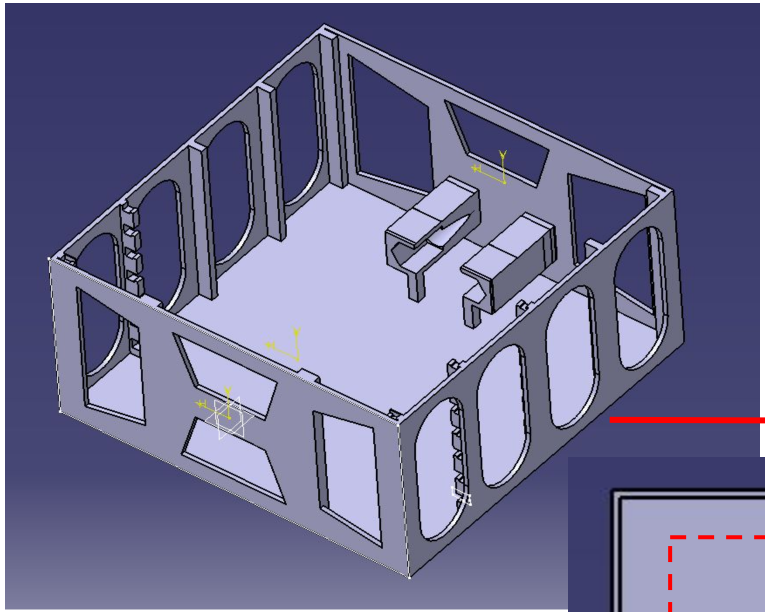


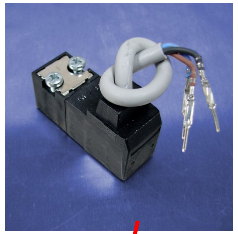


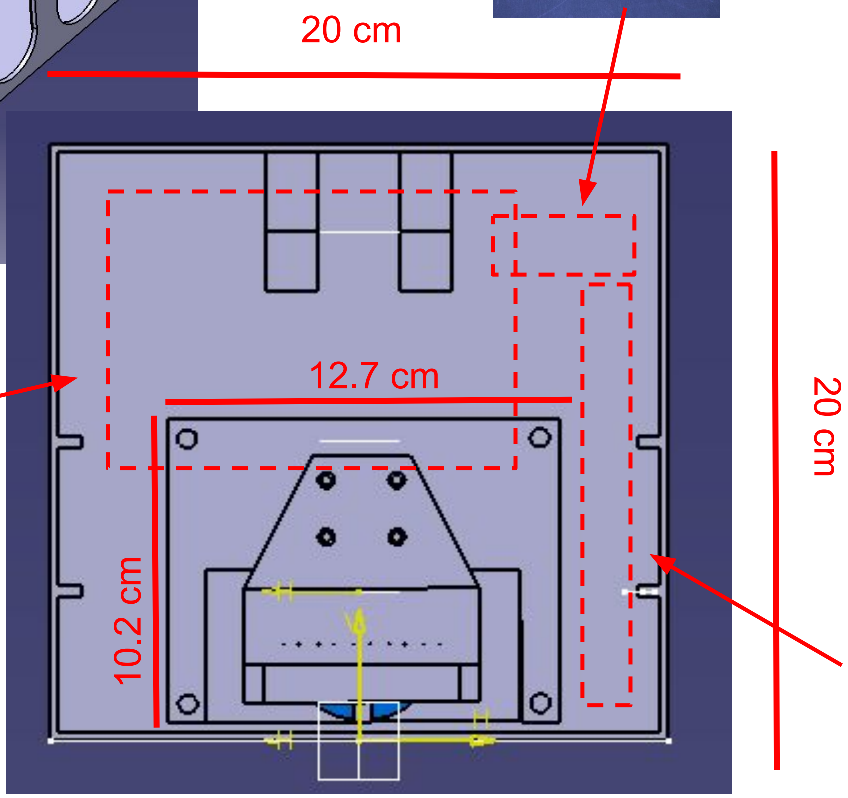


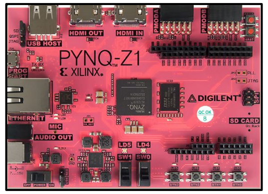
- CubeSat designed with space efficiency, ease of assembly/modification in mind
- Base features cup design with half-sphere “pegs” that precisely point the air bearings towards the surface, helping eliminate drift due to downward thrust deviation
- Base rigidly holds tanks and propulsion system in place, allowing for minimal variability in mass distribution

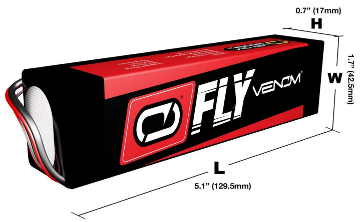
CubeSat Internal Layout





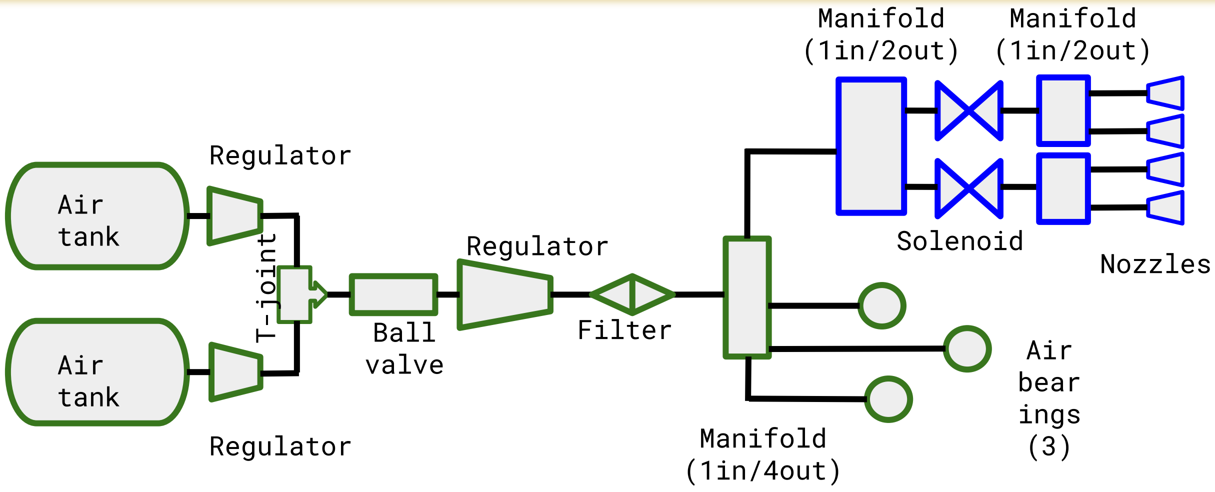


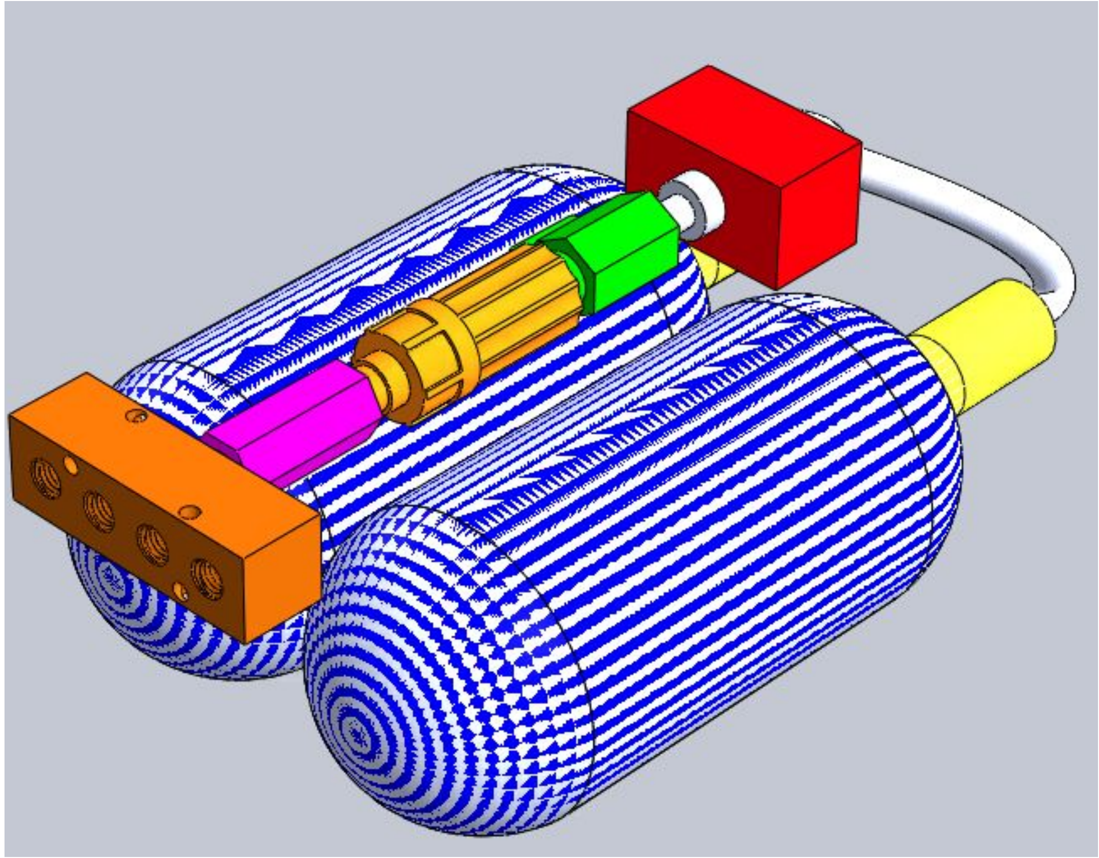




- Size: 4U (20 x 20 x 10 cm)
- “Shelf” system allows for ease of modification
- Secure mounts for nozzles
- Open design allows for ease of assembly
- Mount for laser/receiver on top of CubeSat
    - Future iteration will “Pop up” from inside

Propulsion System Model





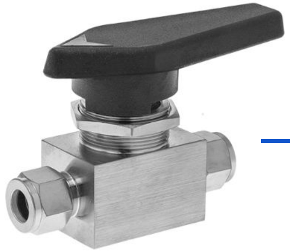
- Two air tanks provide >20 minutes of levitation time (at 2000 psi)
  - Provide ~10 minutes of run time if using nozzles (at 2000 psi)
- 1st stage regulators bring air to 300 psi, which other components can handle
- Ball valve functions as “on/off switch”
- 2nd stage regulator brings air to 80 psi for use in the air bearings and nozzles
- Straight flow manifold delivers air to three air bearings directly, and one manifold for the nozzles
- Once headed for the nozzles, the air passes through the manifold into one of two solenoids and out evenly through two nozzles

Final Components

Air Tanks (x2) (4500 psi)
1st Stage Regulator (300 psi)

T-Joint

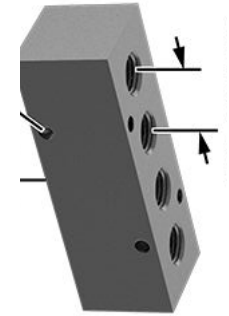
Ball Valve



2nd Stage
Regulator (80 psi)

Air Filter

Straight-Flow
Manifold



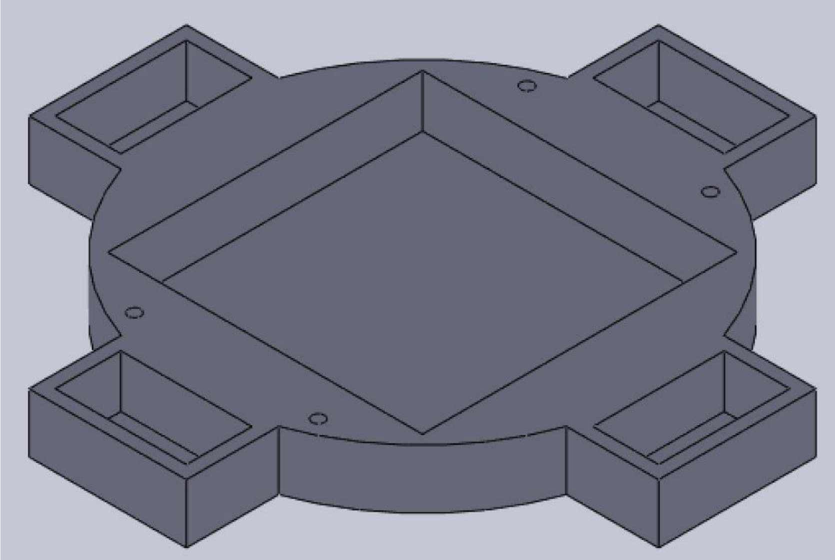
Air Bearings (x3)

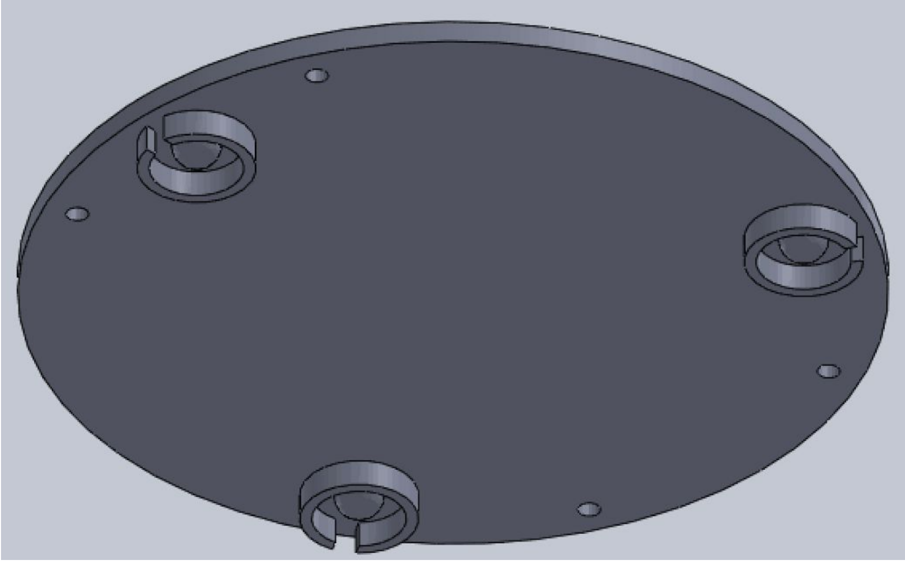
Adjustable Nozzles (x4)

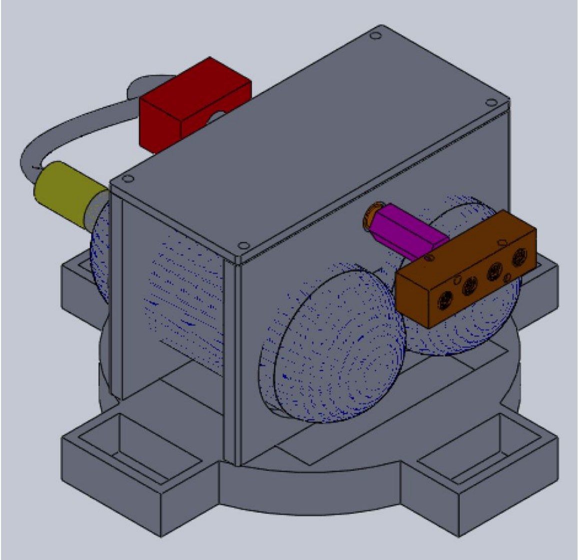
- Air Consumption: 8-26 cfm @ 100 psi
- Airflow Rate: Adjustable
- Max. Inlet Pressure: 150 psi

The Drift Problem

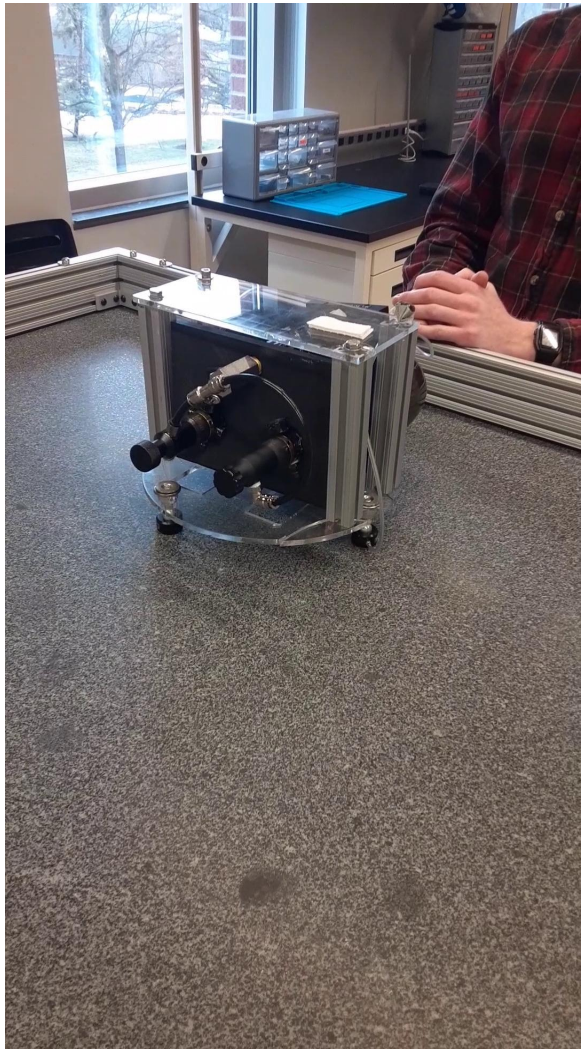
- CubeSat drifts
  - Differing performance of air bearings, length of tubing, base flex, orientation of bearings, weight distribution, table, air currents, initial conditions
- Solutions: cups to hold bearings, same-length tubing, arm to hold CubeSat before testing, pockets for weights







Experimental Results / Best Performance



Original Configuration

Improved Configuration

- Original Configuration
  - Drifted ~15-20 cm in 10 sec
  - Rotate ~10-15 deg counterclockwise in 10 sec
- Improved Configuration
  - Drifted ~2-3 cm in 10 sec
  - Rotated ~2-5 deg counterclockwise in 10 sec
- Differences
  - Length of tubing
  - Weight distribution
  - Orientation of bearings
  - Position of bearings
- Best Performance
  - 2 cm drift in 10 sec
  - 2 deg counterclockwise rotation in 10 sec

Hardware & Propulsion Test Plan

The post break plan is focus on the Hardware CAD and integrate it with the Global CAD.

- The CAD for the propulsion system will be updated and integrated with cubesat
- Global CAD will include updates from other subteams
- Levitation base CAD and troubleshooting of drift problem

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