Dream Big CDR

Emerging Technology for manufacturing & entrepreneurship of Student payloads

CHARM-Sat

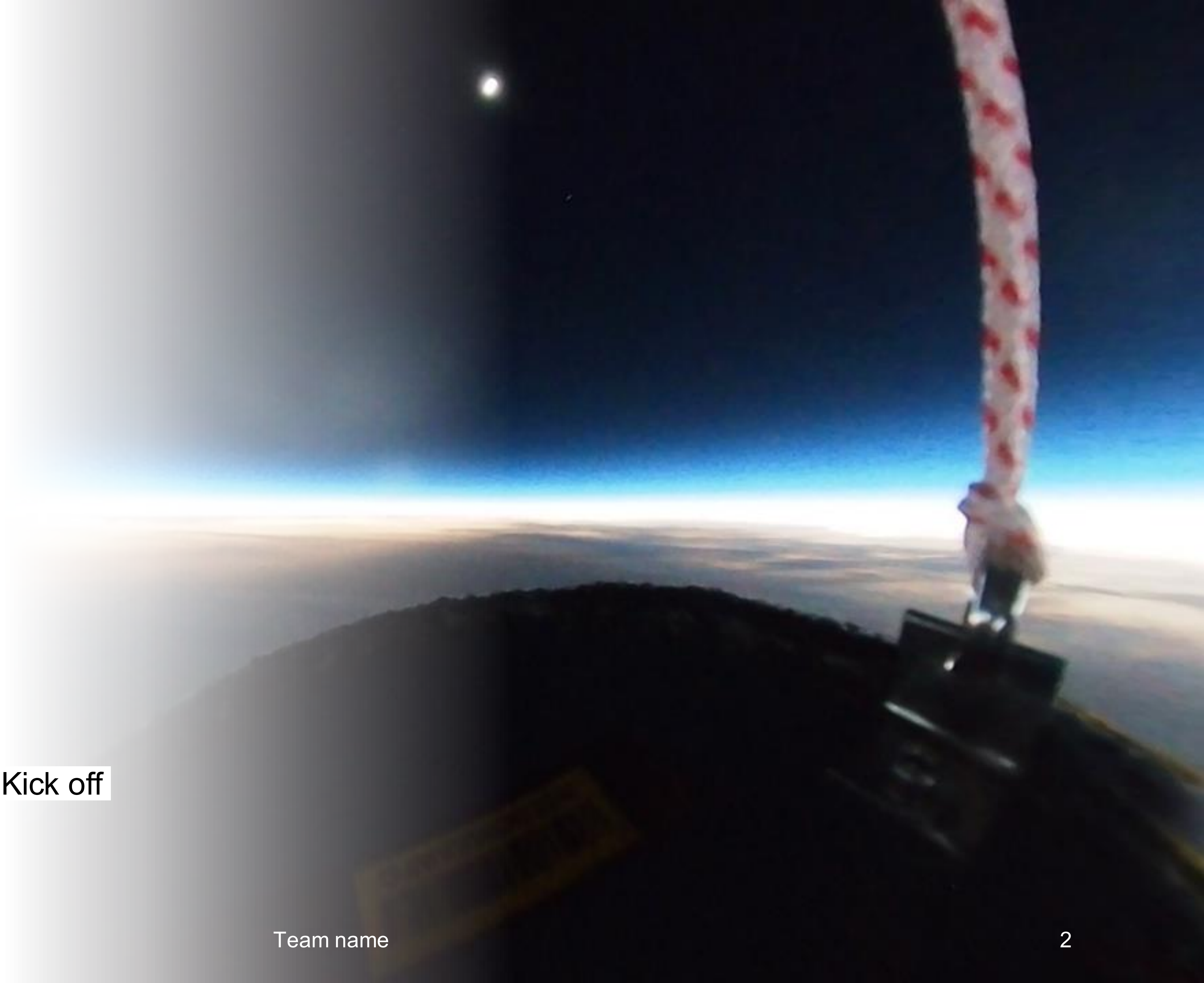
(Control of Hardware Attitude using Reliable Magnetorquers) 🍀 ✨

University of Notre Dame

IrishSat

Agenda

- Program Overview (skipped)
- Outreach Plan/results
- Objectives of Team Mission
- Schedule
- Payload specifications
    - CAD
    - System block diagram
    - PCB Design and Fab
    - Software Operation
        - RTOS Design
        - Firmware
        - Controls
    - Magnetorquer Design
    - Power
    - Test
    - BOM
    - Risk
- Deliverables for IRR and Spring Kick off meeting in Spring 2025
- Questions and Feedback



Outreach Plan

- Groups
  - St. Adalbert Elementary School
  - Robinson Community Center
  - Success Academy
- Level of Involvement
  - Presentations
  - HAB experiment
- Current Status
  - Working with Success Academy on dates for HAB launch
  - Presentation at Success Academy, one planned for St. Adalbert, one getting set up at Robinson Community Center
- Spring Plan
  - First launch around end of Feb
  - Next launch middle/end of March
  - Last launch middle of April

Team Project Overview

Objectives of Team Mission

Executive Summary

- Develop Innovative Technology:
  - Design and implement a modular Magnetorquer-Only ADCS system, providing a low-power, scalable solution for CubeSat autonomous pointing and stabilization.
- Educate Students:
  - Offer hands-on experience in space systems development, enhancing interdisciplinary problem-solving and real-world application of engineering skills.
- Contribute to the Advancement of Space Tech:
  - Advance CubeSat technology by developing a cost-effective, reliable ADCS system using magnetorquers only control with reduced sensor data requirements.
- Benefit the IrishSat Organization:
  - Strengthen IrishSat's technical capabilities and reputation through successful execution of a challenging space mission.
- Bring Recognition to the University of Notre Dame:
  - Showcase Notre Dame's student leadership and excellence in space innovation and research through the University's first successful in-orbit mission.
- Impact the Youth Community through Outreach:
  - Inspire and engage younger generations through outreach activities, promoting STEM education and interest in aerospace.

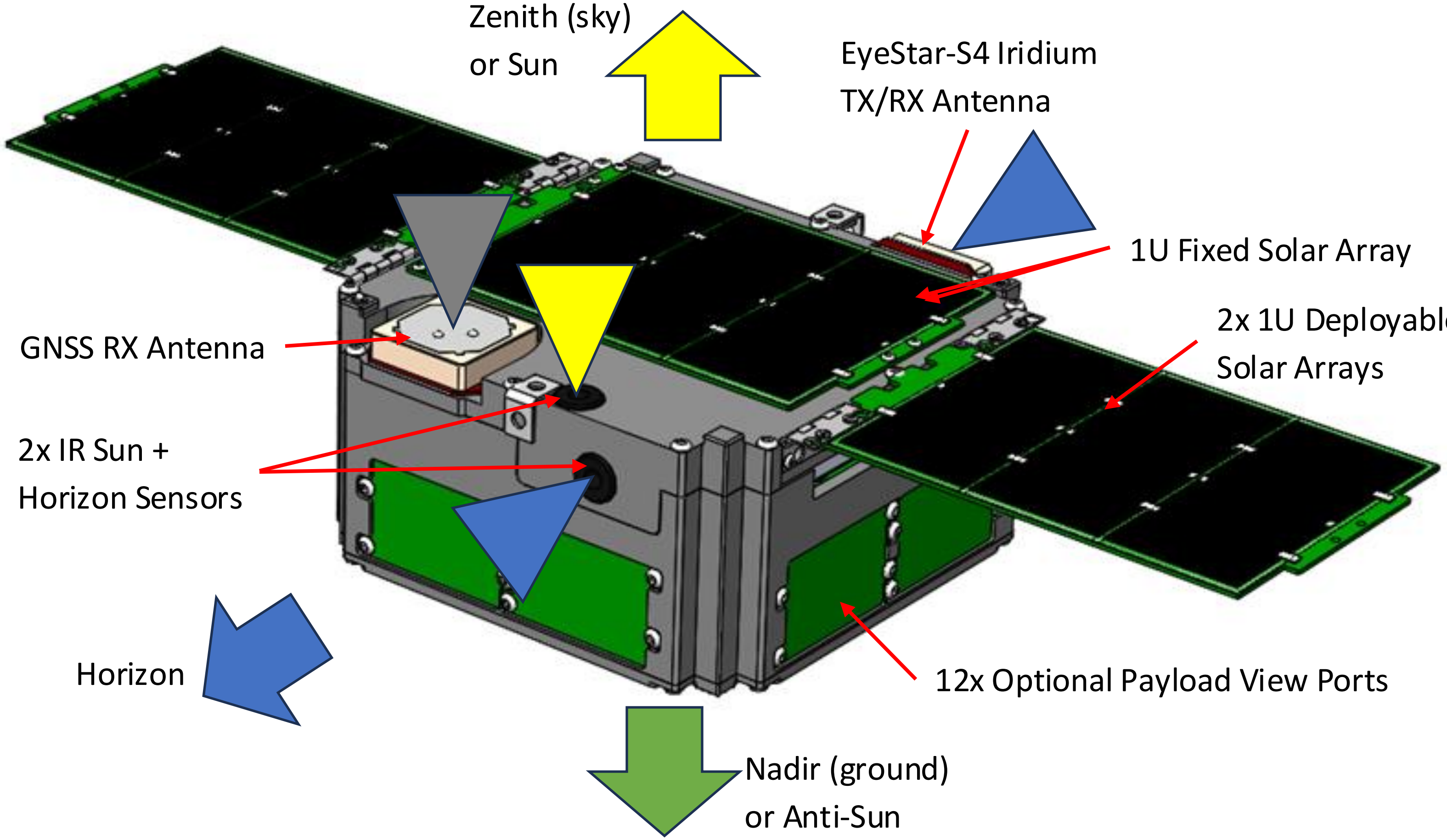
Gantt Chart

Project:			
Mid-project Revamp Date:		Nov-24-24	

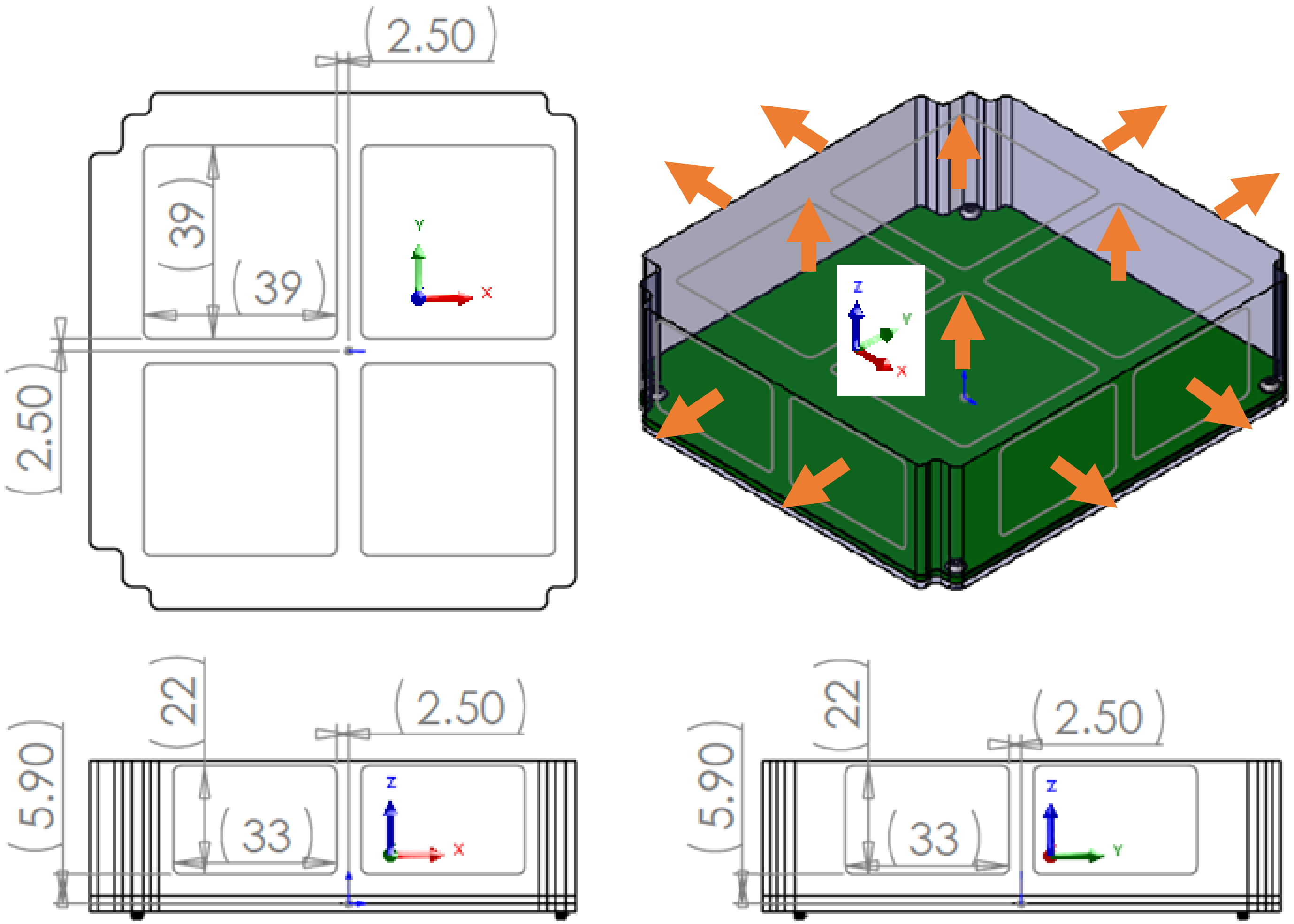
TASKS		START	END
Controls Software:	Need by CDR?	20-Nov	26-Apr
Tune Bdot simulation to have accurate mission parameters like accurate current/power limitations and expected torque values ("gain").		24-Nov	9-Dec
Compare general attitude control plan (UKF? etc.) to computational abilities of available/chosen MCUs		24-Nov	9-Dec
Finalize plan for general control.		24-Nov	9-Dec
Write Bdot in C		24-Nov	9-Dec
Plan out image processing scripts.		2-Dec	21-Dec
Implement plan for general control and test through simulation.	Stretch	8-Dec	12-Jan
Implement image processing scripts and test using images of the Earth online.		15-Dec	12-Jan
Test controls scripting using real hardware and testing setups. Refine algorithms.		13-Jan	1-Feb
Integrate controls scripting with firmware scripts and sensor data acquisition scripting. Test upload onto payload FC.		20-Jan	8-Feb
PCB:	Need by CDR?	20-Nov	26-Apr
Identify backup sensors and MCU in case we need to use something other than selected parts (i.e. we have trouble interfacing and controlling a new MCU).		24-Nov	9-Dec
Complete design review for schematic and finalize circuit design.		24-Nov	9-Dec
Complete layout and ensure that physical layout interfaces with NSL pin connections and fits with allowed payload space.		24-Nov	9-Dec
Order PCB and parts for fabrication.		24-Nov	21-Dec
Fabricate and test first iteration of the board.	Stretch	21-Dec	25-Jan
Refine board design, order/fabricate second iteration of the board.		19-Jan	1-Feb
Upload final code and prepare for final demonstration and full system testing.		1-Feb	15-Feb
Magnetorquers:	Need by CDR?	20-Nov	26-Apr
Complete design review for optimization script so that a final design can be set.		24-Nov	9-Dec
Decide final magnetorquer design		24-Nov	9-Dec
Order materials for fabrication (multiple options including mu-metal, iron, others? Order all of them.)		24-Nov	9-Dec
Complete magnetorquer wrapping setup.		24-Nov	9-Dec
Fabricate 2+ different types of torquerod magnetorquers for empirical testing (mu-metal, iron, any other material we decide). Fabricate air core magnetorquer as well to characterize empirical peroformance.		15-Dec	18-Jan
With empirical data, decide which material is best and fabricate final magnetorquer design.	Stretch	12-Jan	1-Feb
Fabricate final magnetorquer design and integrate with PCB to begin full system testing.		19-Jan	8-Feb
Firmware:	Need by CDR?	20-Nov	26-Apr
Debug current code implementation so that the serial line no longer crashes.		24-Nov	9-Dec
Make high-level coding decisions about architecture. Move from superloop implementation to interrupt-based system?		24-Nov	9-Dec
Send commands using functions instead of serial interface on Arduino IDE.		24-Nov	9-Dec
Complete all expected request functions so that all commands that can be sent to NSL bus are covered. Right now, only F5 and F4 are working properly.		24-Nov	12-Jan
Integrate all software into one script.		1-Feb	15-Feb
Structures + Thermal:	Need by CDR?	20-Nov	26-Apr
Compile all temerature requirements from sensor and MCU to understand temperature control requirements.		24-Nov	9-Dec
Research thermal environment. Find the extremes... what is the hottest the satellite will get? What is the coldest it will get? Add 10% margin to design for (for example, if the hottest we will get is 100 C, design for 110 C).		24-Nov	14-Dec
Simulate Thermal Flow from payload with magnetorquers in Solidworks		24-Nov	21-Dec
3D print NSL-side structural interface to test IrishSat-side structural interface after integration.		12-Jan	1-Feb
Begin creating a potting mold for the magnetorquers so that in the Spring we can carry out the potting process. Does this affect magnetorquer performance? Is this a bad idea?		12-Jan	1-Feb

Satellite Payload Specifications

ThinSat 0.5U Design



Available Payload Viewports



Payload CAD and Structural Specifications

Initial Payload CAD Details

- Mass: 430.35 grams
  - We know this is over R1.11 specs, plan to reduce mass on next slide
- Volume: 104.5 x 98 x 28.1mm
- Center of Gravity in Bus Assembly: -0.09” X, 0.38” Y, -0.03” Z

Plan to Reduce Mass to Meet R1.11

Heaviest parts →

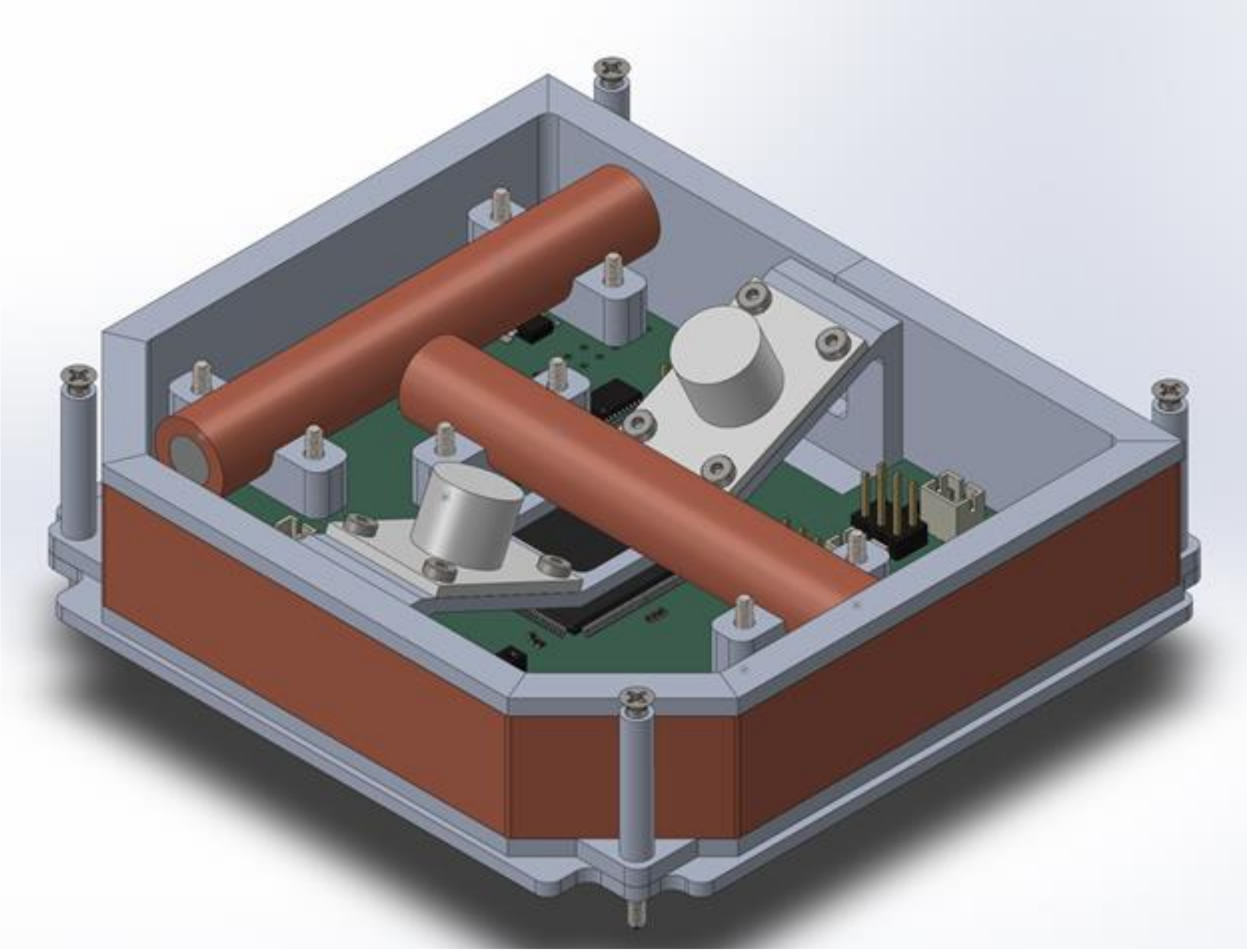
- Magnetorquer wire wrappings
- Aluminum casing/air core frame, top/bottom plates

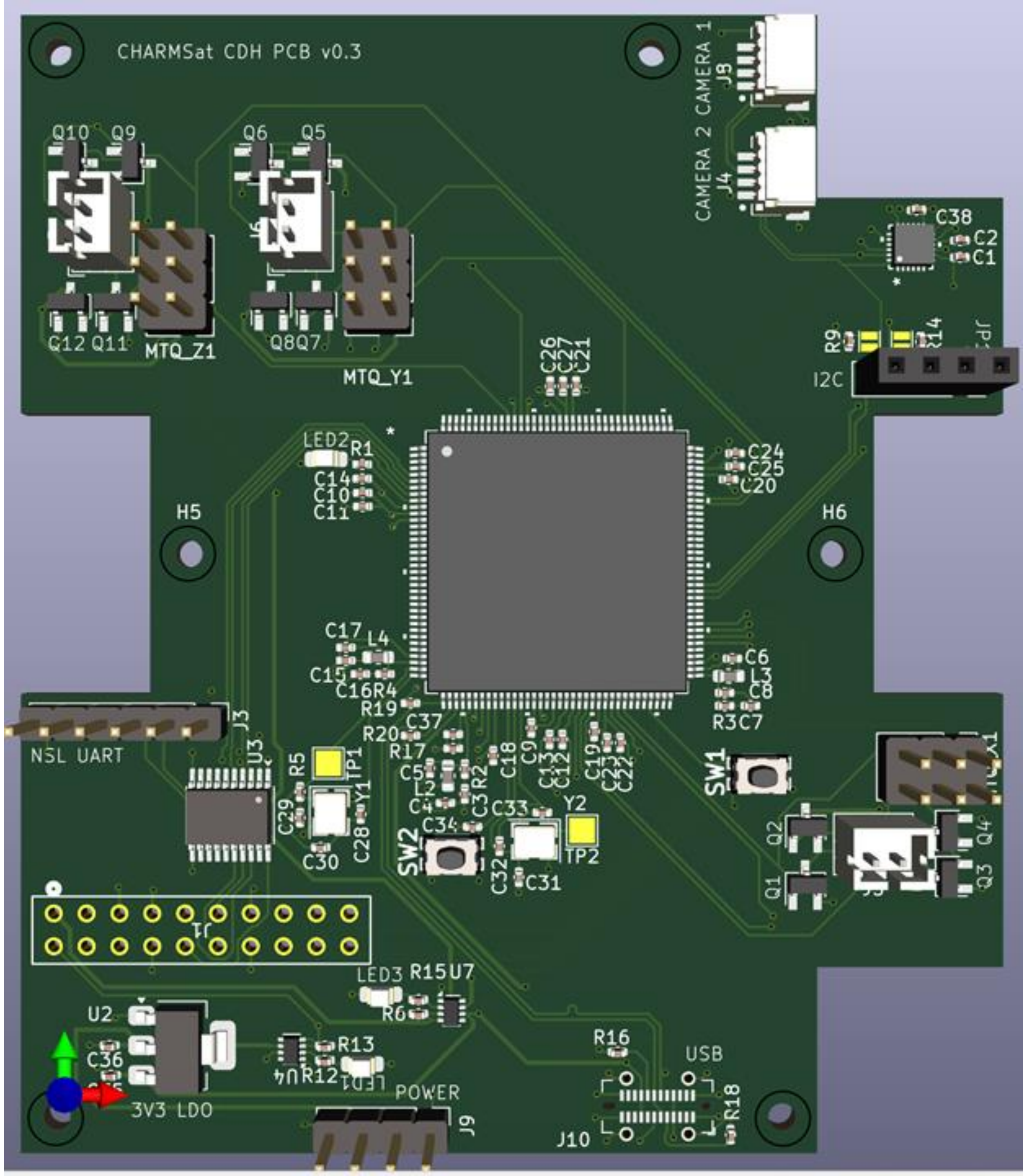
Plan →

- Reduce wire gauge from 30 to 32, reducing cross sectional area and mass by 40%
- Change solid aluminum structures to 40% fill (machine out unnecessary aluminum) reducing mass by 60%
- Reduce wire loops by 10%

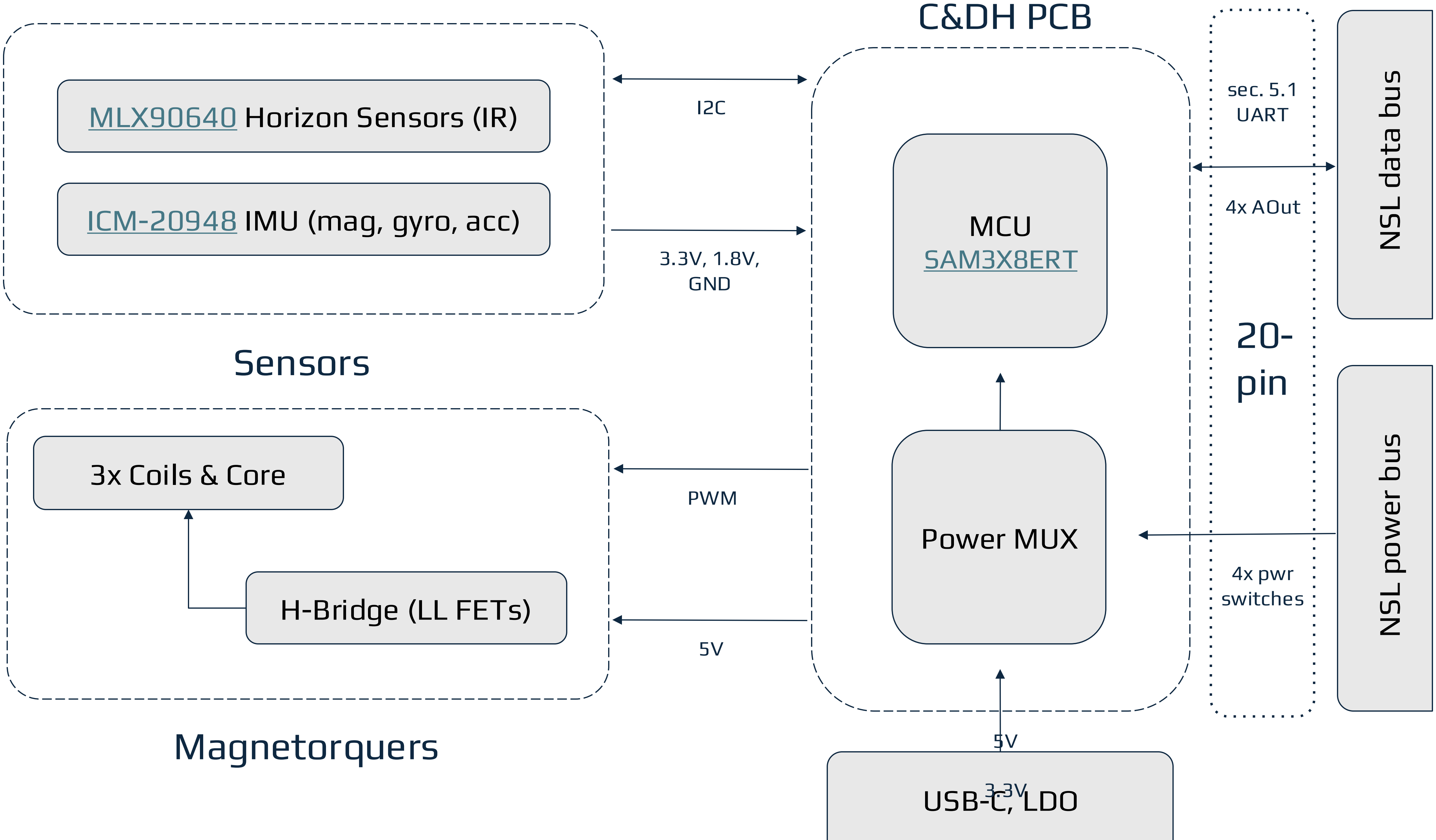
New Projected Mass → 248 grams

Walkthrough

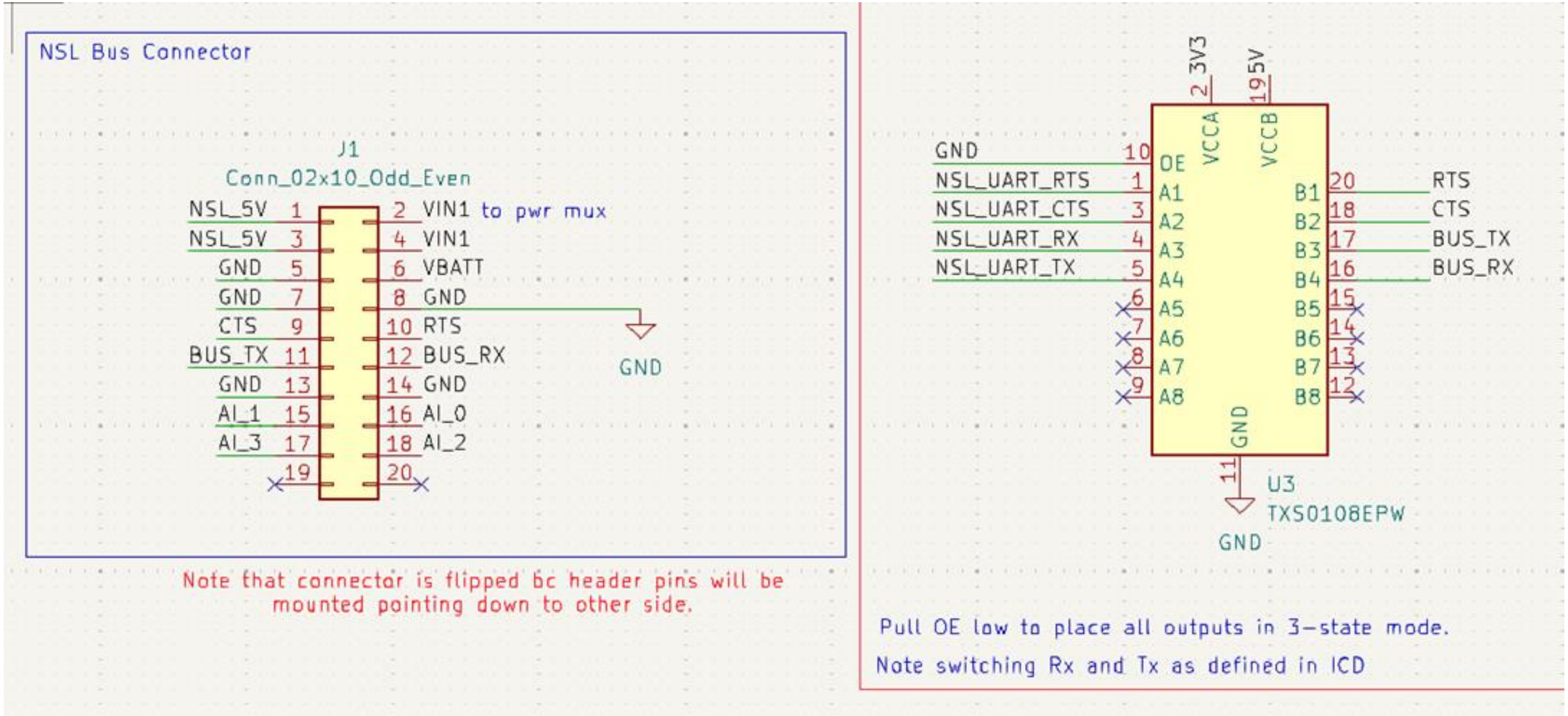




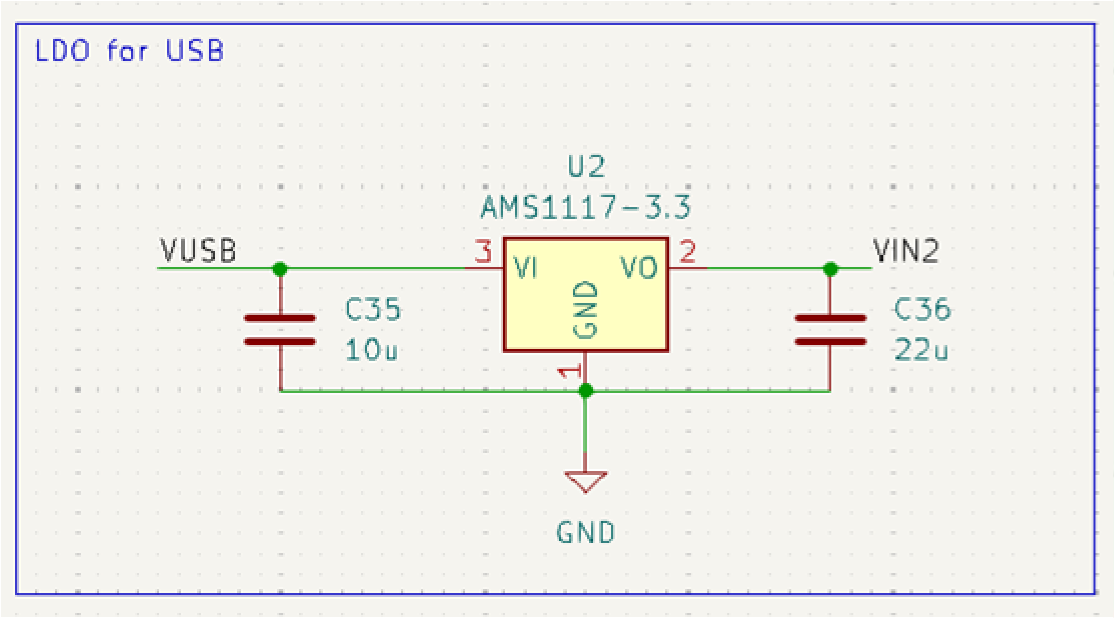
Payload Block Diagram and PCB Schematic/Layout

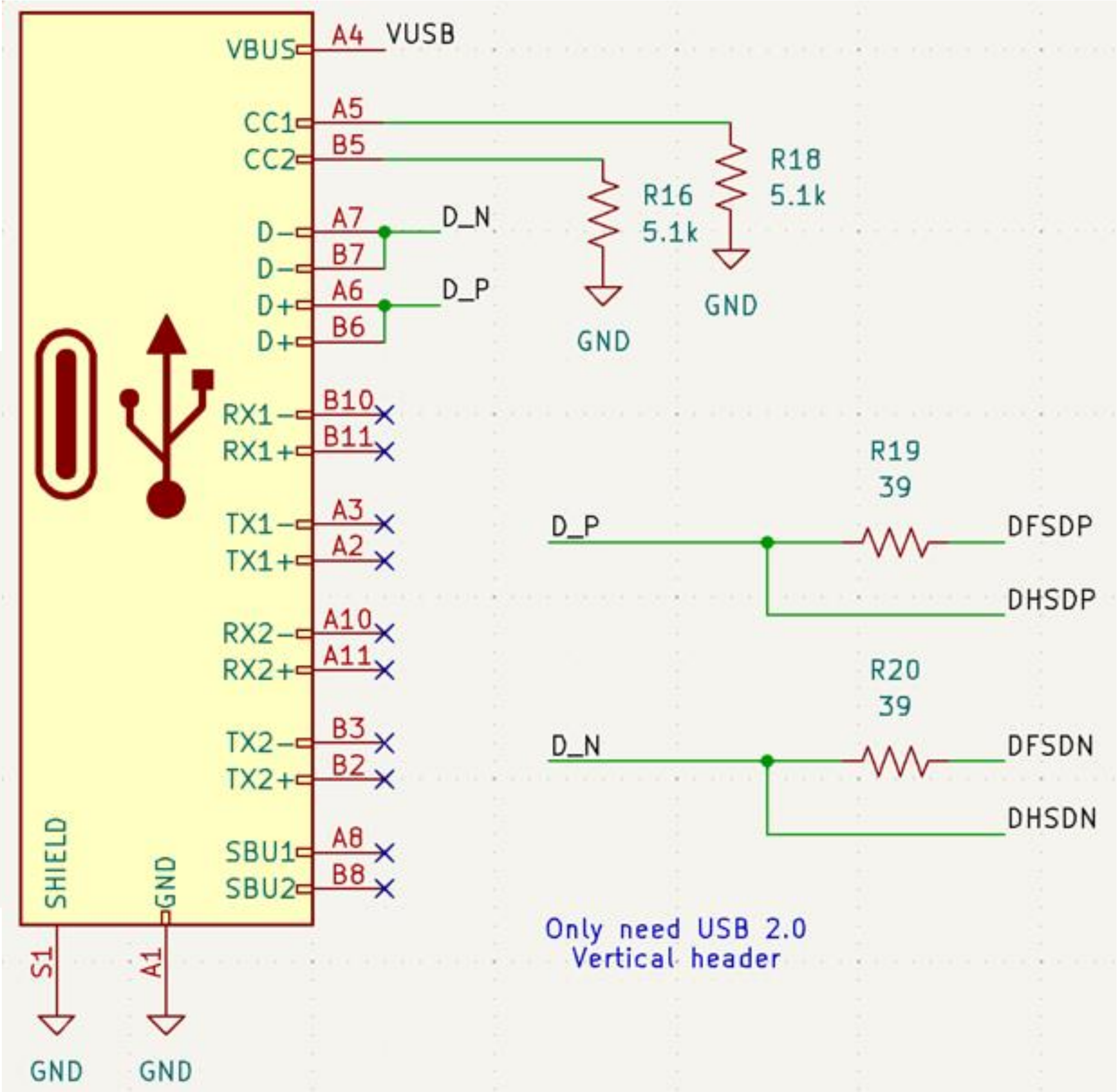

C&DH PCB
MLX90640 Horizon Sensors (IR)
ICM-20948 IMU (mag, gyro, acc)
Sensors
I2C
3.3V, 1.8V, GND
MCU
SAM3X8ERT
Power MUX
sec. 5.1 UART
4x AOut
20-pin
4x pwr switches
NSL data bus
NSL power bus
3x Coils & Core
H-Bridge (LL FETs)
Magnetorquers
PWM
5V
5V
3.3V
USB-C, LDO

Level Shifting -> 5V to 3.3V

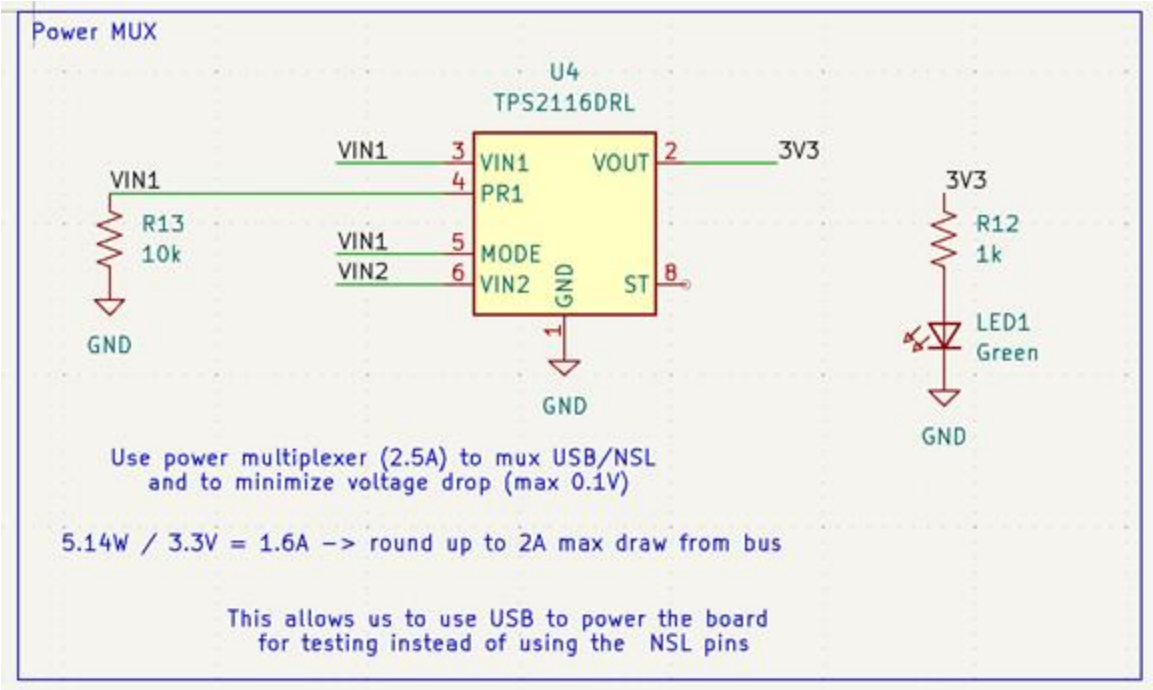


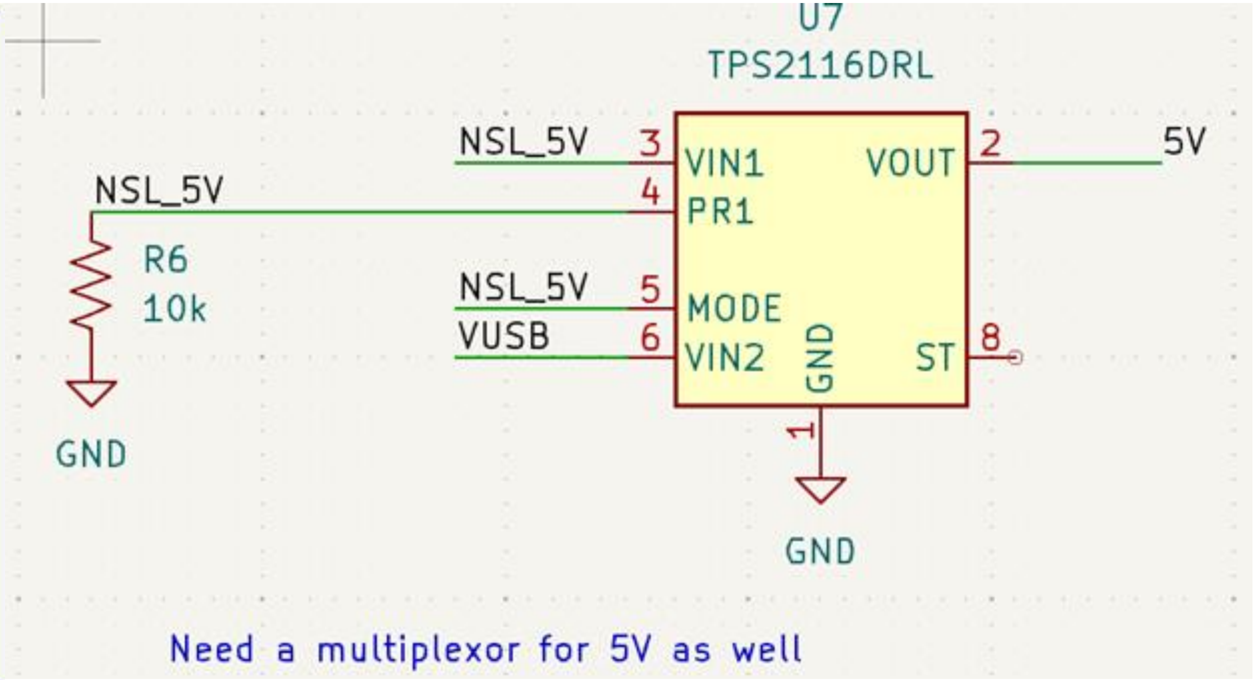
USB 5V, 3.3V


LDO for USB
U2
AMS1117-3.3
VUSB
3
VI
VO
2
VIN2
GND
C35
10u
C36
22u
1
GND

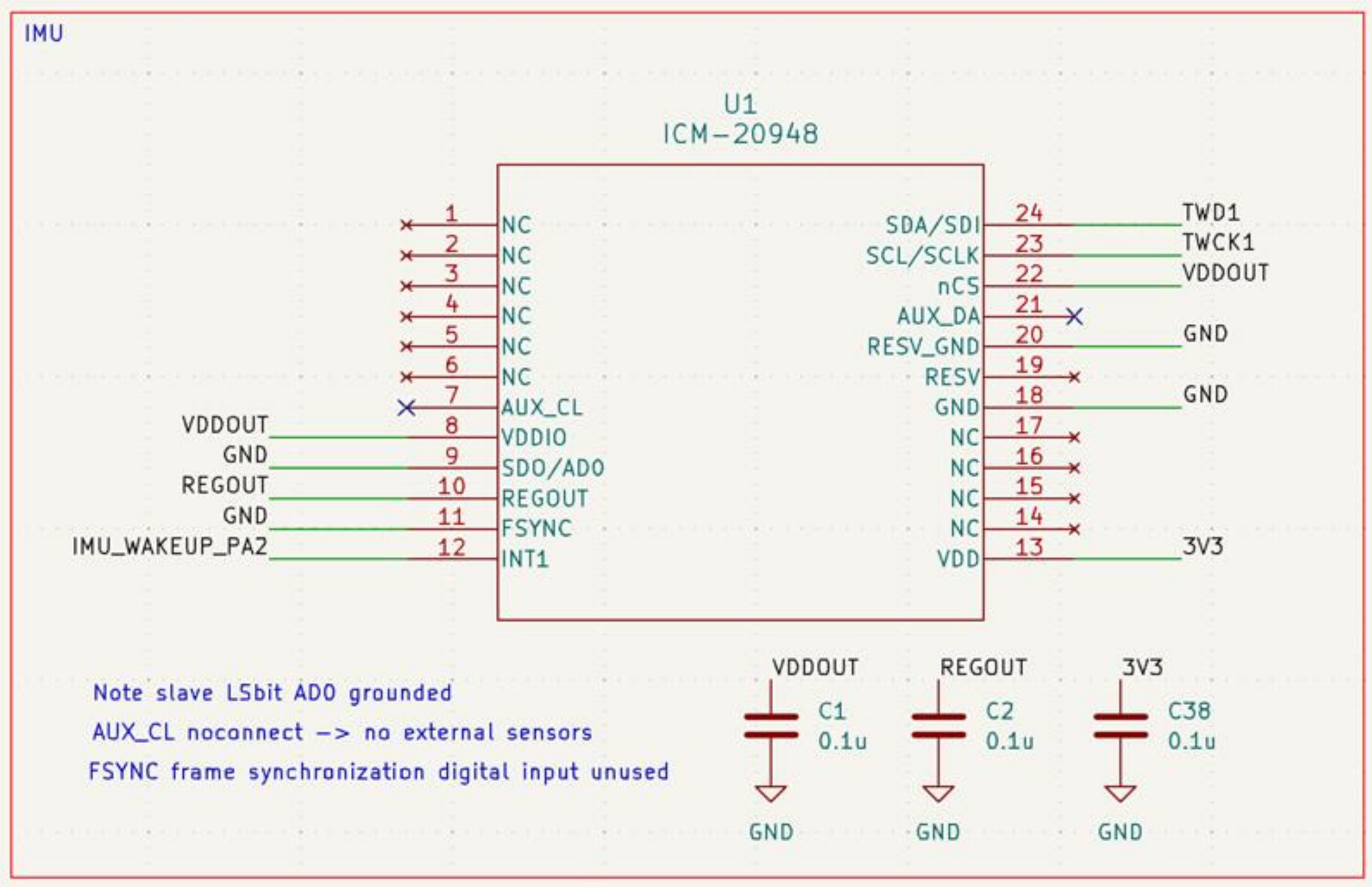

VBUS
A4
VUSB
CC1
A5
CC2
B5
R18
5.1k
R16
5.1k
D-
A7
D_N
D-
B7
D+
A6
D_P
D+
B6
GND
GND
RX1-
B10
RX1+
B11
TX1-
A3
TX1+
A2
RX2-
A10
RX2+
A11
TX2-
B3
TX2+
B2
SBU1
A8
SBU2
B8
SHIELD
GND
S1
A1
GND
GND
R19
39
D_P
DFSDP
DHSDP
R20
39
D_N
DFSDN
DHSDN
Only need USB 2.0
Vertical header

Power Multiplexing

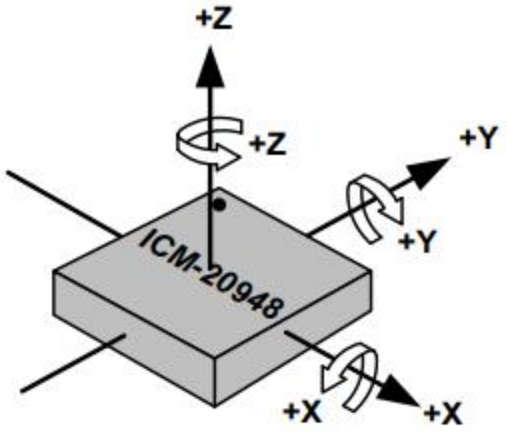




IMU

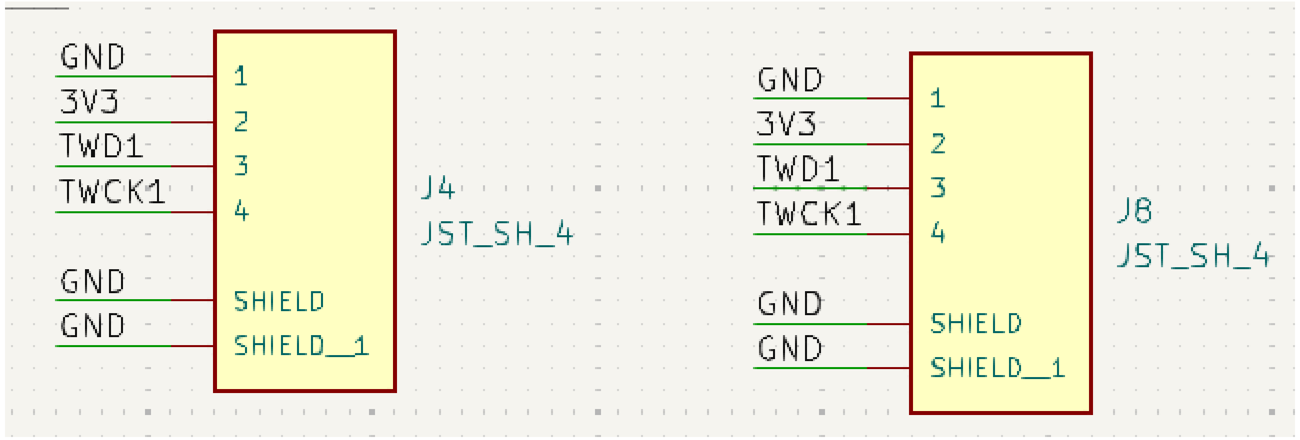


IMU
U1
ICM-20948
NC
NC
NC
NC
NC
NC
AUX_CL
VDDIO
SDO/AD0
REGOUT
FSYNC
INT1
SDA/SDI
SCL/SCLK
nCS
AUX_DA
RESV_GND
RESV
GND
NC
NC
NC
NC
VDD
VDDOUT
GND
REGOUT
GND
IMU_WAKEUP_PA2
TWD1
TWCK1
VDDOUT
GND
GND
3V3
VDDOUT
REGOUT
3V3
C1
0.1u
C2
0.1u
C38
0.1u
GND
GND
GND
Note slave LSbit AD0 grounded
AUX_CL noconnect -> no external sensors
FSYNC frame synchronization digital input unused

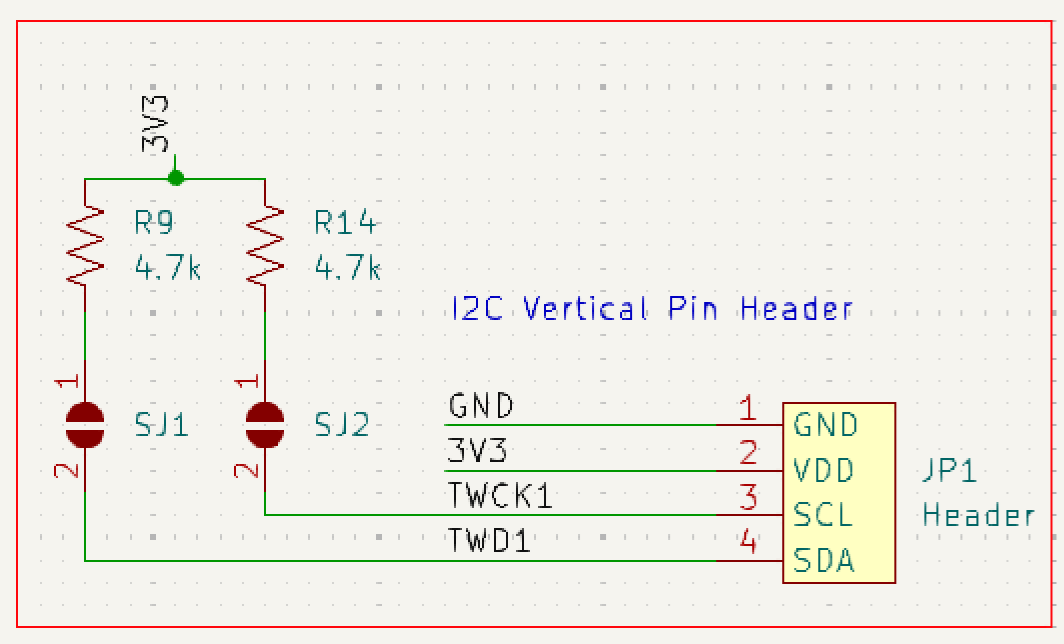


+Z
+Z
+Y
+Y
ICM-20948
+X
+X

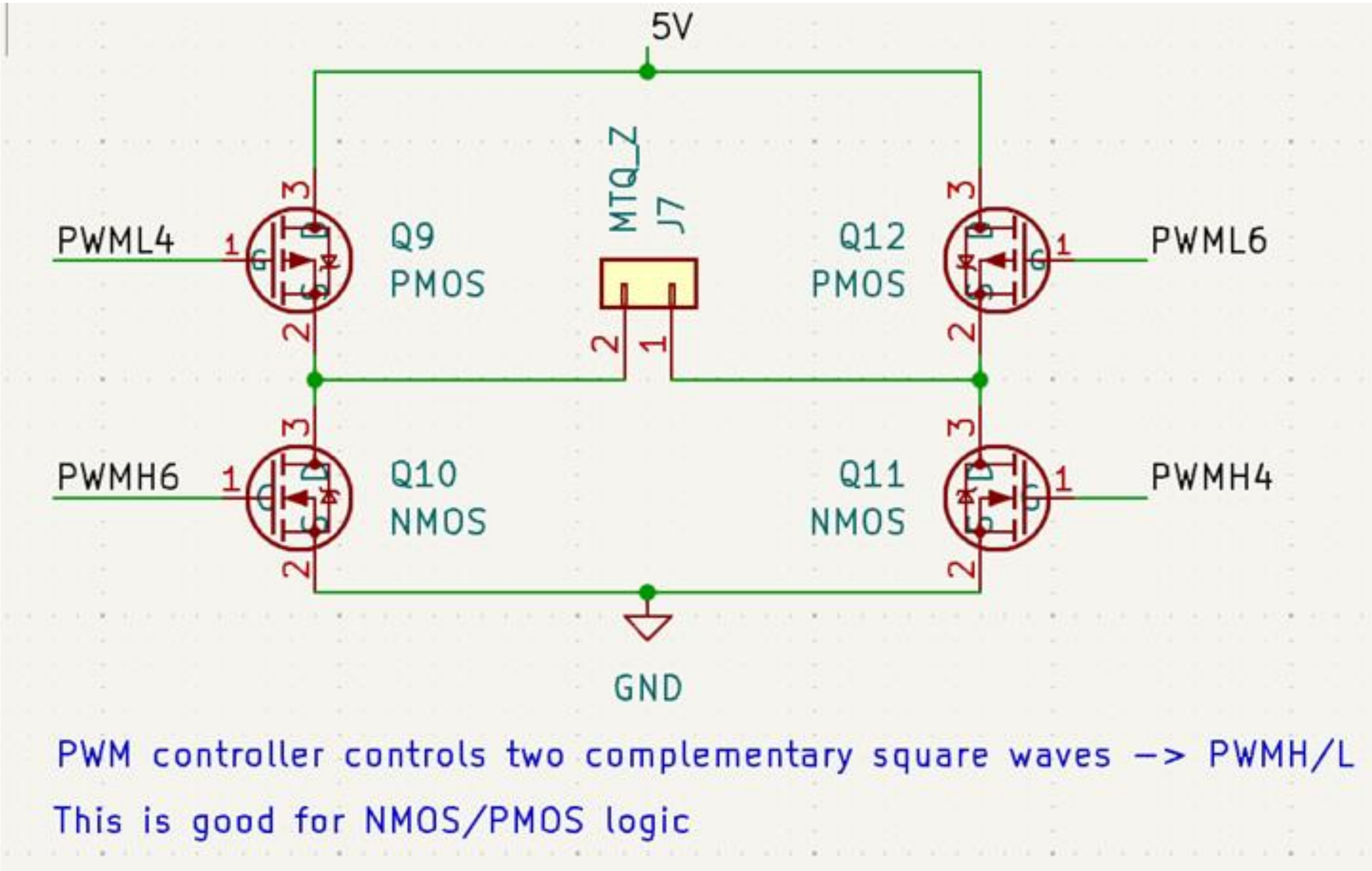
Cameras

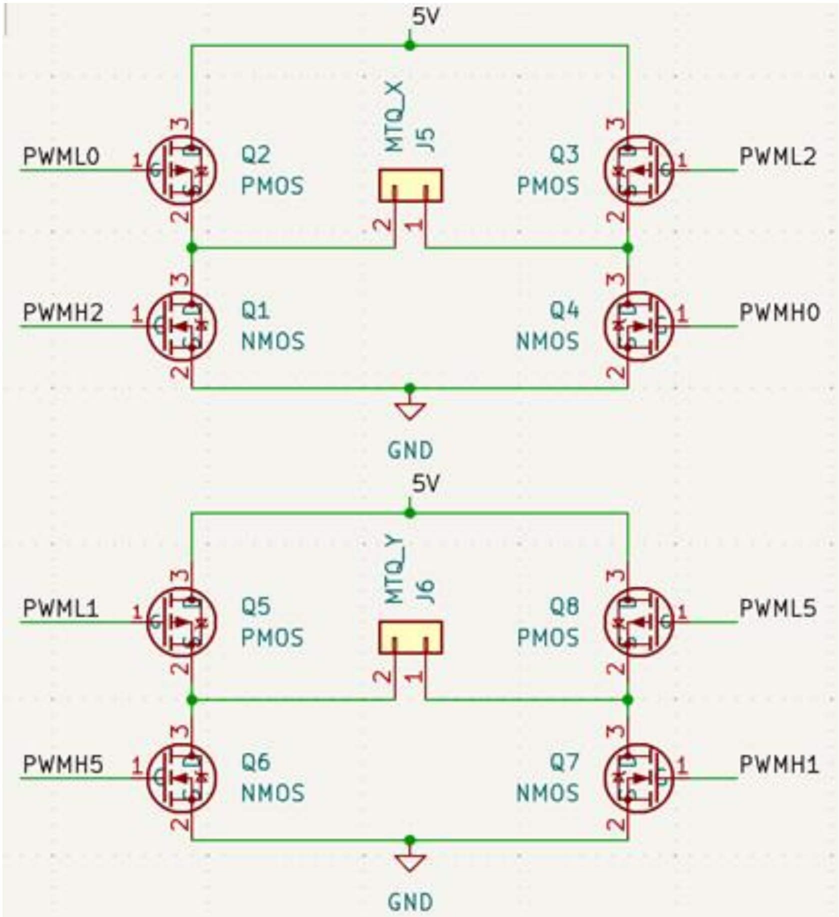

GND
3V3
TWD1
TWCK1
GND
GND
1
2
3
4
SHIELD
SHIELD__1
J4
JST_SH_4
GND
3V3
TWD1
TWCK1
GND
GND
1
2
3
4
SHIELD
SHIELD__1
J8
JST_SH_4


MLX90640
Thermal Camera
VIN
3Vo
GND
SCL
SDA
E336755
GC-2X94V-0

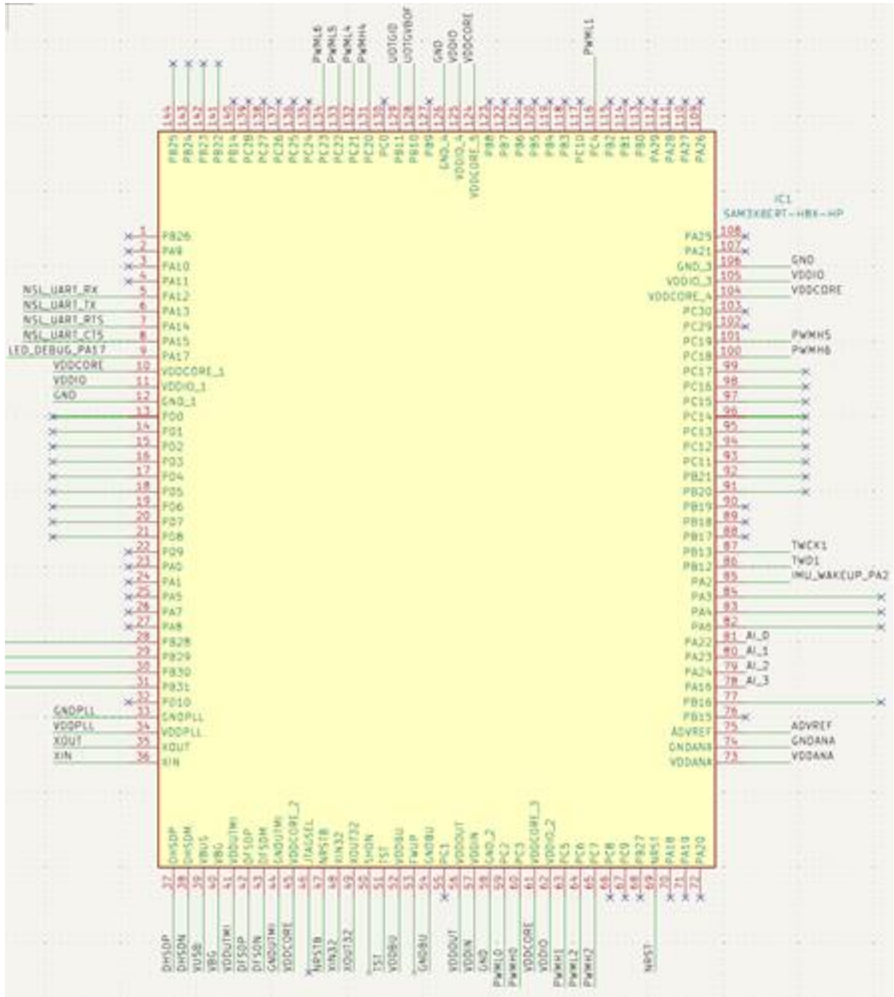

3V3
R9
4.7k
R14
4.7k
I2C Vertical Pin Header
SJ1
SJ2
GND
3V3
TWCK1
TWD1
1
2
3
4
GND
VDD
SCL
SDA
JP1
Header

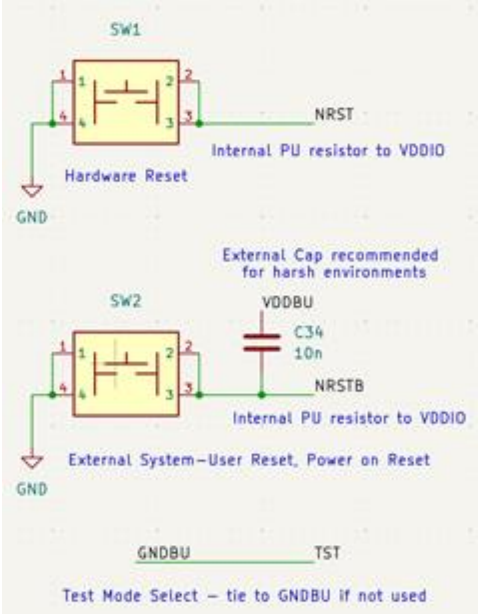
H-Bridge Circuit



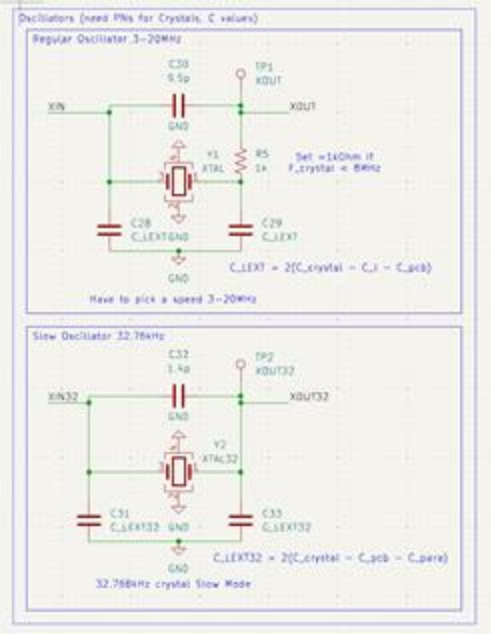


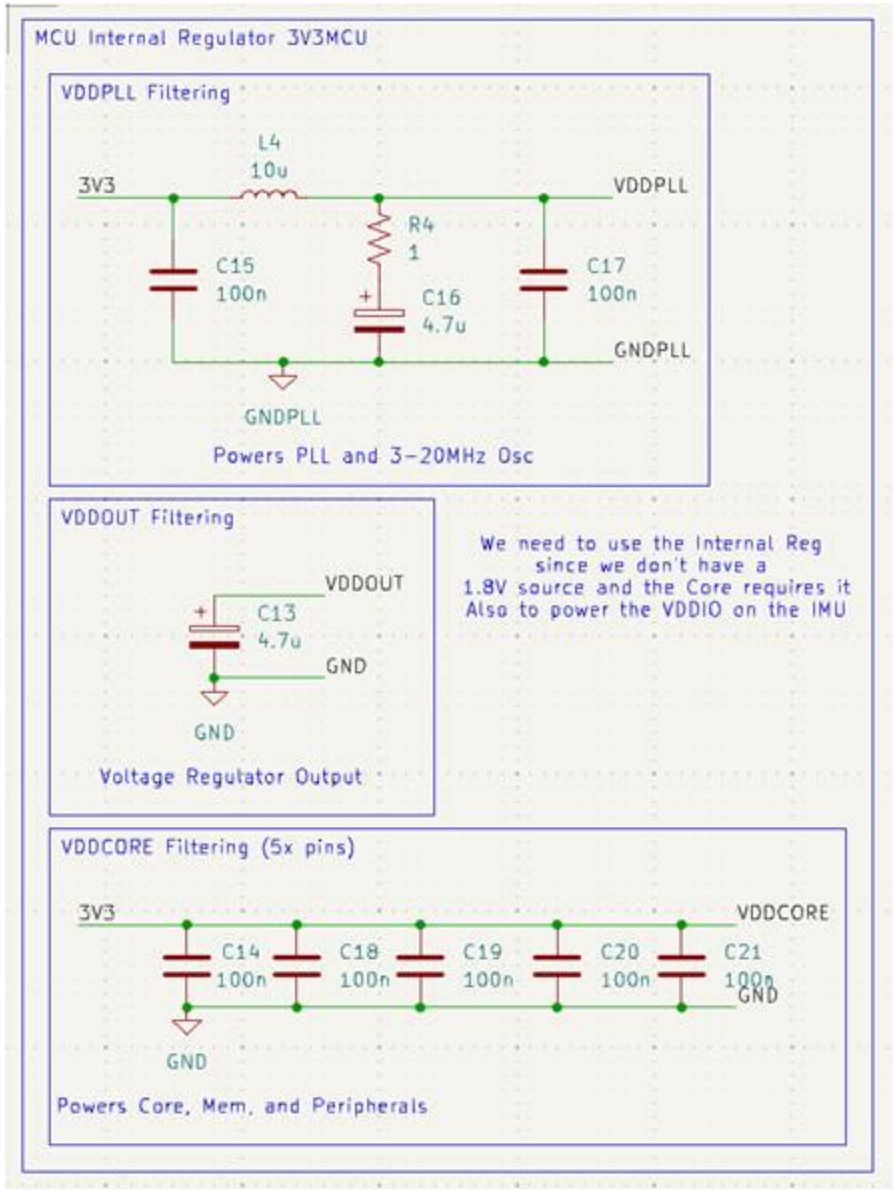
MCU





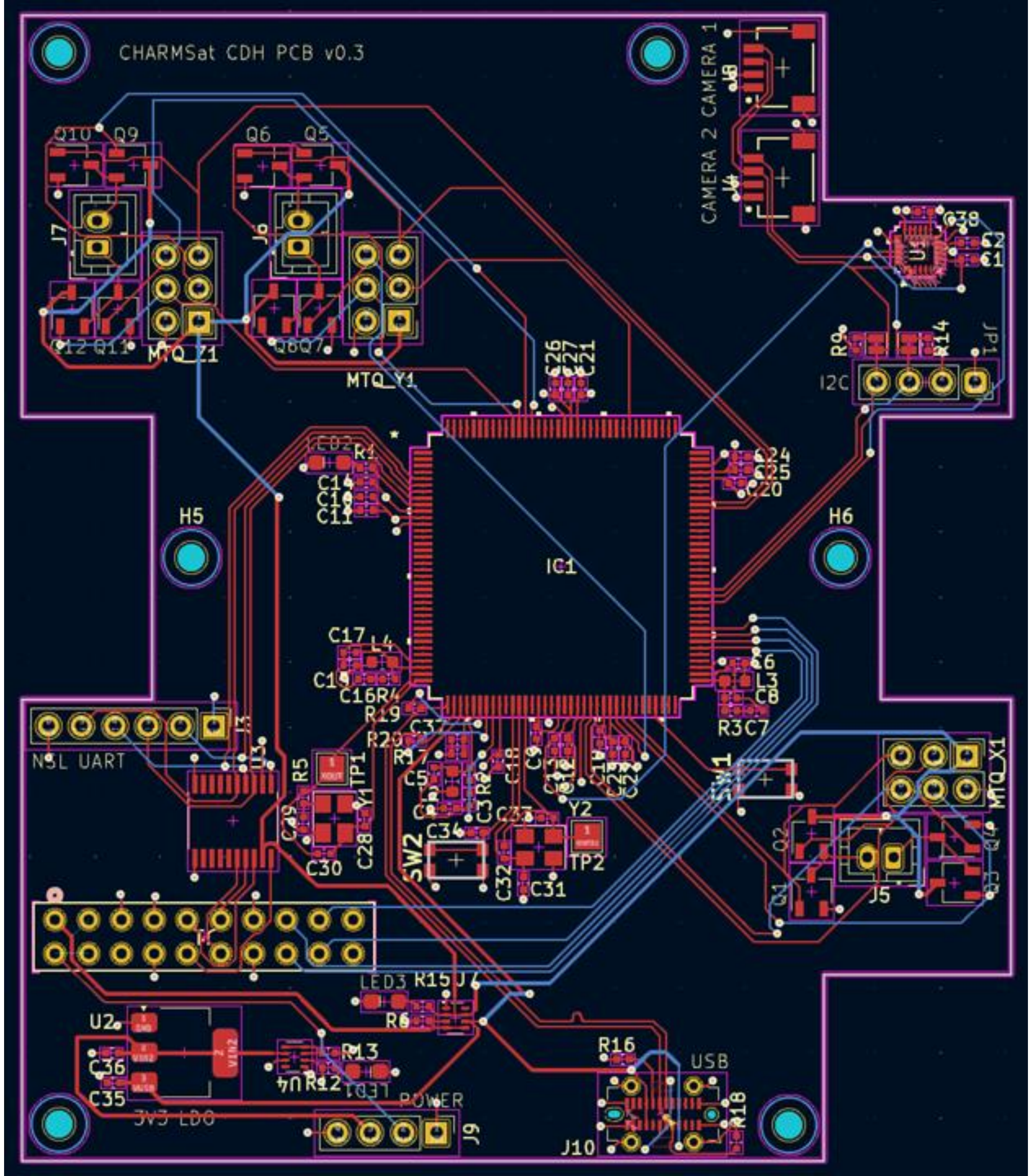
SW1
NRST
Internal PU resistor to VDDIO
Hardware Reset
GND
External Cap recommended for harsh environments
SW2
VDDBU
C34
10n
NRSTB
Internal PU resistor to VDDIO
GND
External System–User Reset, Power on Reset
GNDBU
TST
Test Mode Select – tie to GNDBU if not used





MCU Internal Regulator 3V3MCU
VDDPLL Filtering
L4
10u
3V3
VDDPLL
R4
1
C15
100n
C16
4.7u
C17
100n
GNDPLL
GNDPLL
Powers PLL and 3-20MHz Osc
VDDOUT Filtering
VDDOUT
C13
4.7u
GND
GND
Voltage Regulator Output
We need to use the Internal Reg since we don't have a 1.8V source and the Core requires it Also to power the VDDIO on the IMU
VDDCORE Filtering (5x pins)
3V3
VDDCORE
C14
100n
C18
100n
C19
100n
C20
100n
C21
100n
GND
GND
Powers Core, Mem, and Peripherals

PCB Layout



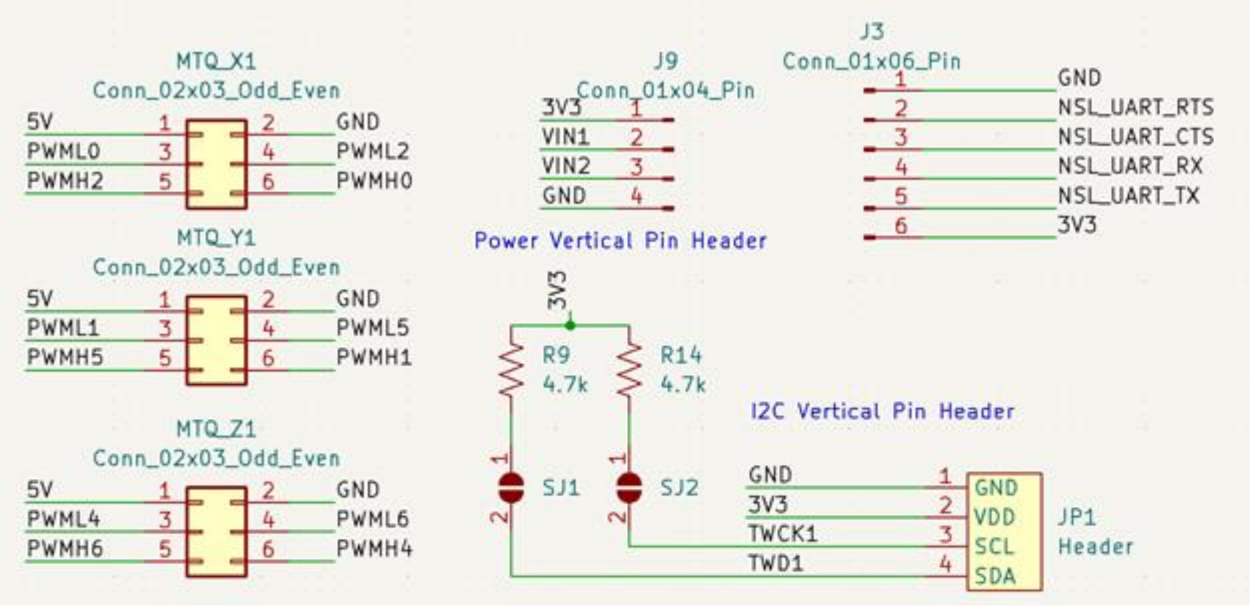
PCB Bringup & Test

Parallel development -> ESP32 board and SAM3 board

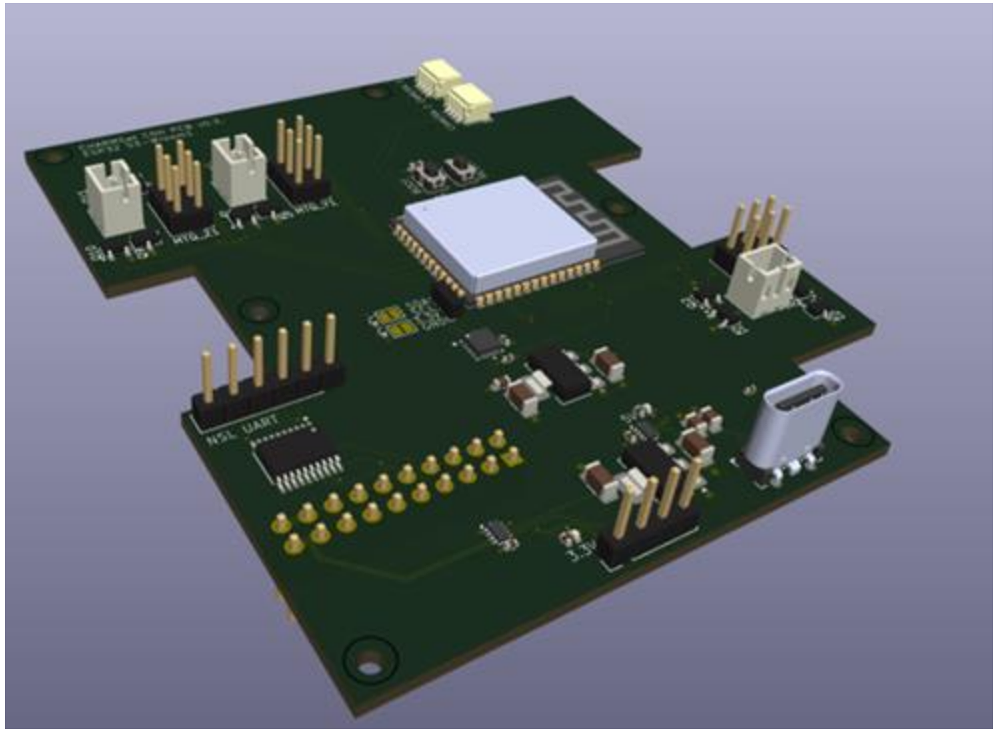
Assembly in EIH / JLC

Debug LED -> “blinky”

Header pins for debug & test



PCB Testing Plan



Substitute SAM3X8ERT for ESP32-S3-Wroom1
105 parts down to 59 (44% reduction)

1. Visual and Power-on test, probing for LDO and Power-Mux performance (LEDs will light)
2. Firmware Upload for ESP32 with “blinky”, IMU, H-Bridge programs
3. Signal Integrity check with oscilloscope under various bus-loading conditions
4. Stress testing: Vibration (in-house), Thermal and Vacuum (on campus) testing

Software Design: RTOS

High-level Software Overview

State Machine

Mode Selection, Command Generation

ADCS Tasks

Controls Tasks

B-cross Task

Nadir point Task

Supporting Tasks

Sensor Data Acquisition Polling Task

Image Processing Task

Firmware Tasks

Comms Tasks

Send and ACK Detection Task

Monitor Uplink Task

Interpret Uplink Task

Software Design: Firmware

Firmware Operation

- Types of data
  - Operational Data
    - Current through magnetometers, correlated magnetometer reading, gyro reading over time (are we slowing down our rotation)
  - Final State Data
    - Sun and Horizon sensor readings (are we pointing where we wanted to)
- Amount of Data
  - 10, 200-byte packets a day, maximize our available transmissions
- Data integrity
  - Redundant data storage external to MCU. No other planned mitigations.
- Bus request used
  - Send Payload Data to Ground, Set ADCS Mode, Request and Change S4 params, Check Buffer for Uplink Data, Request H&S + EPS H&S
- Checkin
  - Check Uplink Buffer command every 1 minute

Firmware RTOS Elements

Tasks

- Allow for time-splicing and task prioritization for more efficient software operations.
- Similar to functions in C, but have extra functionality and protections.
- "**Monitor Commands**", "**Send and ACK Detection**", "**Monitor Uplink**", "**Interpret Uplink**"

Queues

- Allow for the sharing of information between tasks, including controlling when tasks run or don't run.
- Information is securely saved and persistent between function calls and tasks.
- "**Command Queue**", "**Downlink Queue**", "**Uplink Queue**"

Firmware RTOS Operation

1. Monitor Commands

- Monitors “**Serial 1**” line for commands
  - Will receive commands in **“Command Queue”** from other RTOS tasks
- Decodes command, constructs packet, and writes packet to **“Downlink Queue”**

2. Send and ACK Detection

- Monitors **“Downlink Queue”** and sets **RTS pin HIGH** when ready to send.
- Writes packet over “Serial 3” line and waits for **ACK** or **NACK** from NSL
- If **NACK**, retransmit. max 3 retransmissions.

3. Monitor Uplink

- Monitors **“Serial 3” RX** for transmissions.
- If available, write transmission to the **“Uplink Queue”** for interpretation.

4. Interpret Uplink

- Monitors **“Uplink Queue”** for messages that are not **ACK**s or **NACK**s and interprets the data.
- Extracts the **Function Byte** to understand what to do, interpret the uplinked data.

Firmware RTOS Demo

Needed Hardware:

- Two Arduino Megas
  - Eventually will have emulator on Mega and our software on ESP32 or SAM3 MCU
  - Pin connections b/w CTS (3), RTS (2), TX→RX (14, 15)

Needed Files:

- “IrishSat_NSL_FreeRTOS_Try_3.ino” [Most recent version as of 12/7/2024]
- “dream_big_emulator_arduino_mega_v6.ino” [Most recent version as of 12/7/2024]

Software Design: Controls

Controls Software - B-dot Overview

Our B-Dot controller follows 3 basic steps:

Read Sensor Data	Compute Desired Magnetic Moment	Convert To and Output Control Voltages

Use the onboard magnetometer and gyroscope to determine the current magnetic field in CubeSat's body frame and its angular velocity.

Find moment to oppose angular velocity using:

$$\mathbf{m}_{\text{desired}} = -\frac{k}{||\mathbf{B}||^2}(\mathbf{B}_{\text{body}} \times \mathbf{w}_{\text{sat}})$$

Backup: if gyroscope is unreliable, use:

$$\mathbf{m}_{\text{desired}} = -k\frac{\Delta\mathbf{B}}{\Delta t}$$

A control voltage is outputted to our magnetorquers to create the actual magnetic moment. This voltage is given by:

$$V_{\text{in},i} = R_i \cdot \frac{\mathbf{m}_{\text{desired},i}}{n_i A_i \epsilon_i}$$

Controls Software - B-dot Simulation

Goal

- Test magnetorquer specifications
- Estimate controller gain
- Evaluate detumbling methods
- Prepare infrastructure for nadir point simulation

Method

Each iteration:

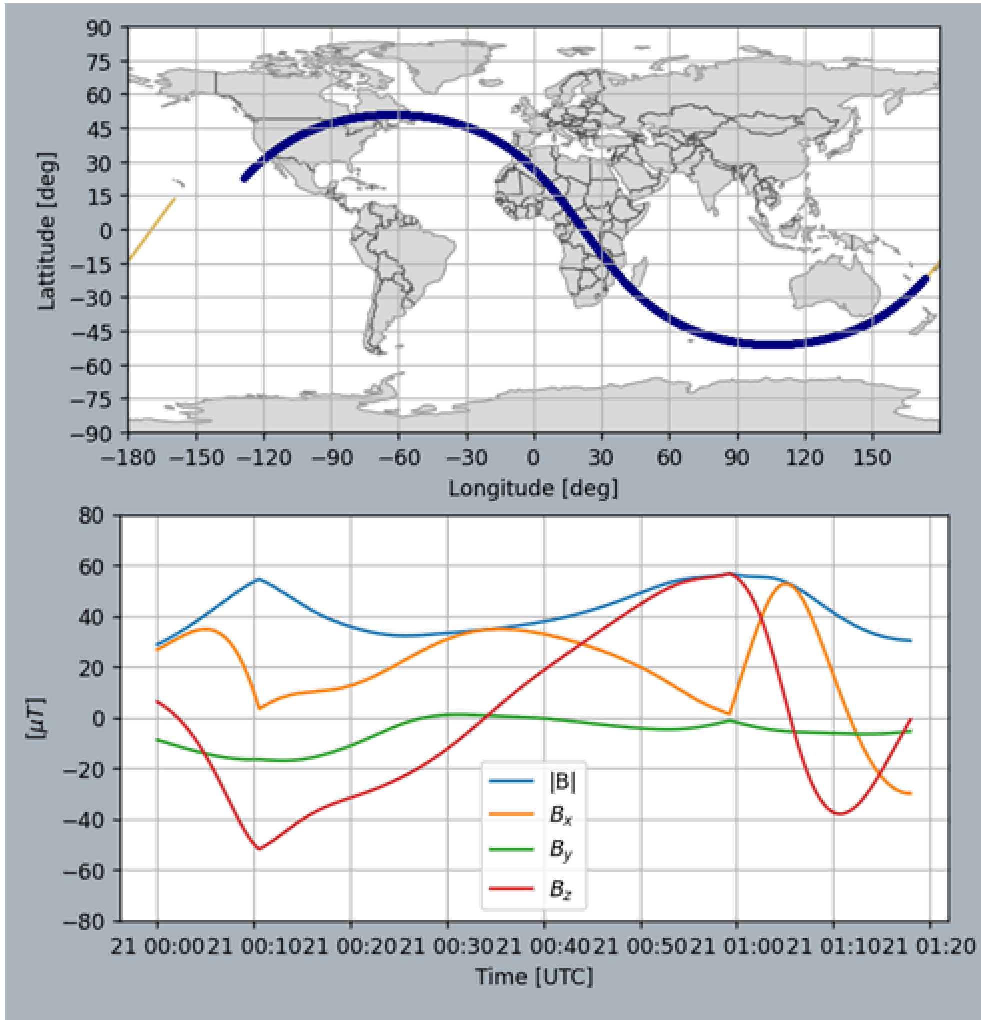
1. Generate sensor data based on GPS data + physics prediction

1. Run b-dot controller

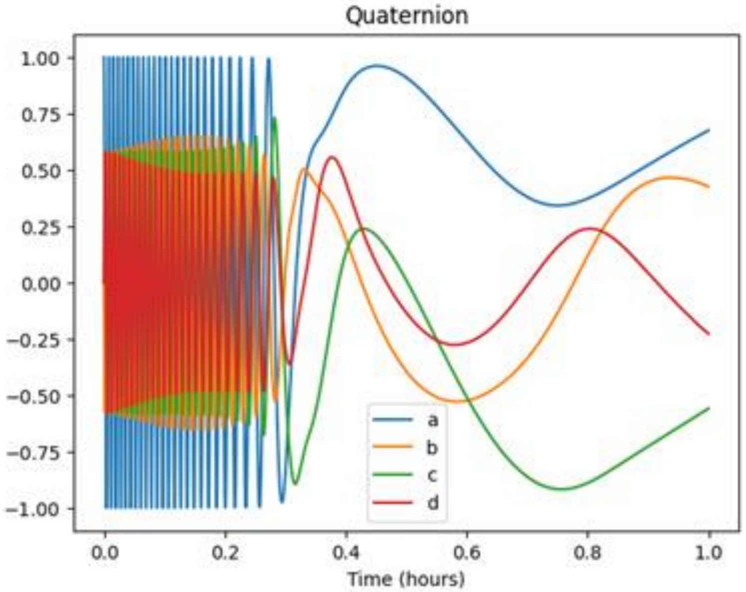
1. Simulate state propagation using Equations of Motion and physics-based modeling of our magnetorquers.

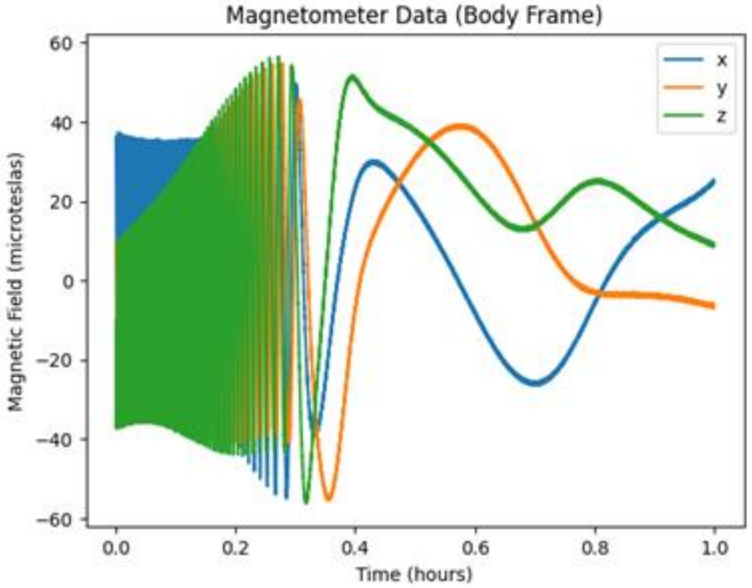
Simulator object tracks actual orientation/velocity and power consumption

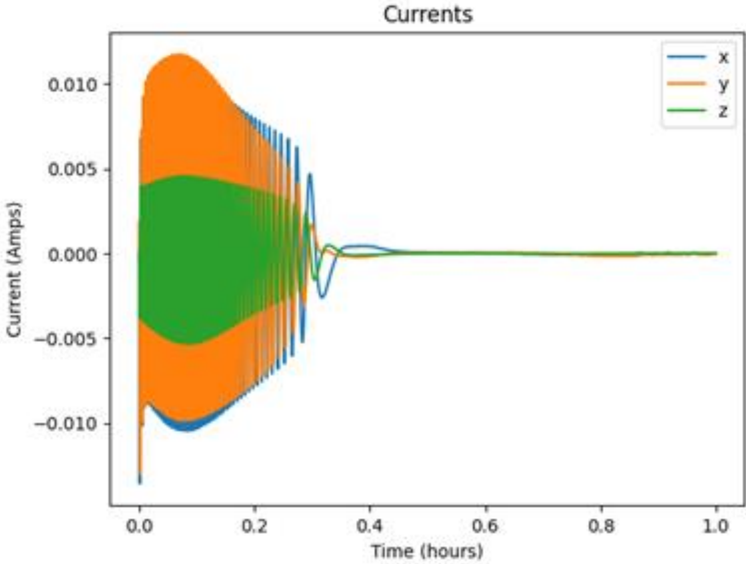
Orbital simulation yields true earth magnetic field (convert to body frame + noise for mag data)

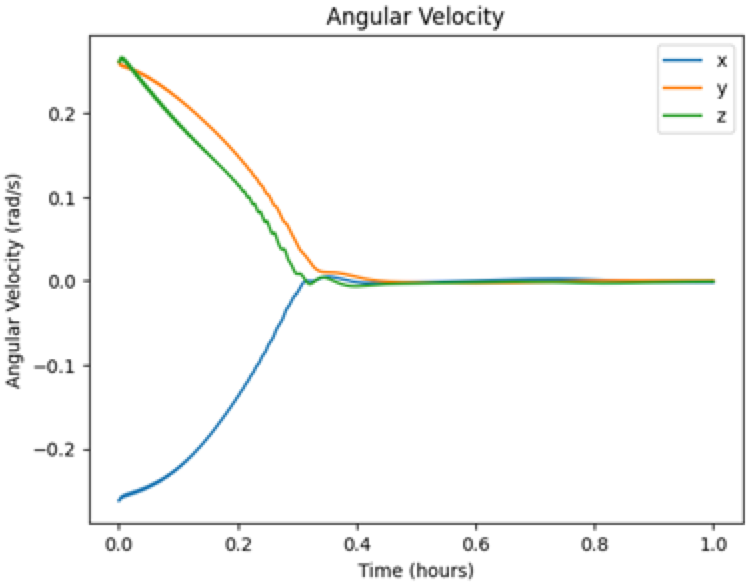


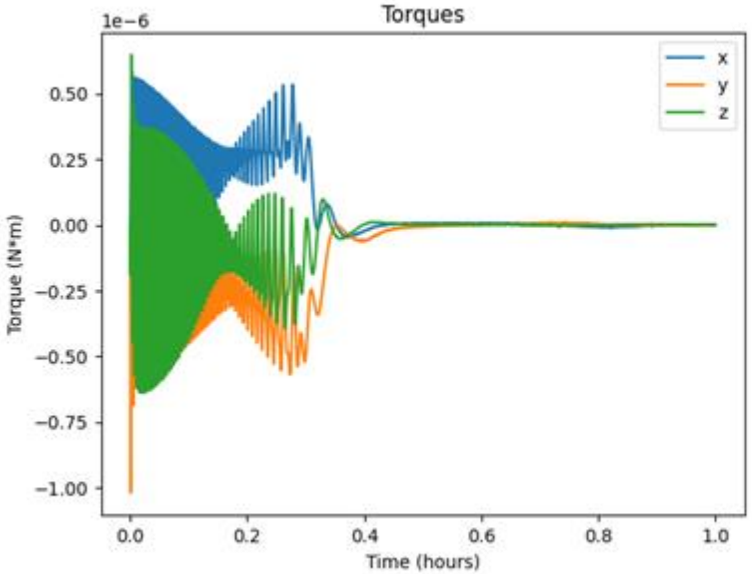
Controls Software - B-dot Results

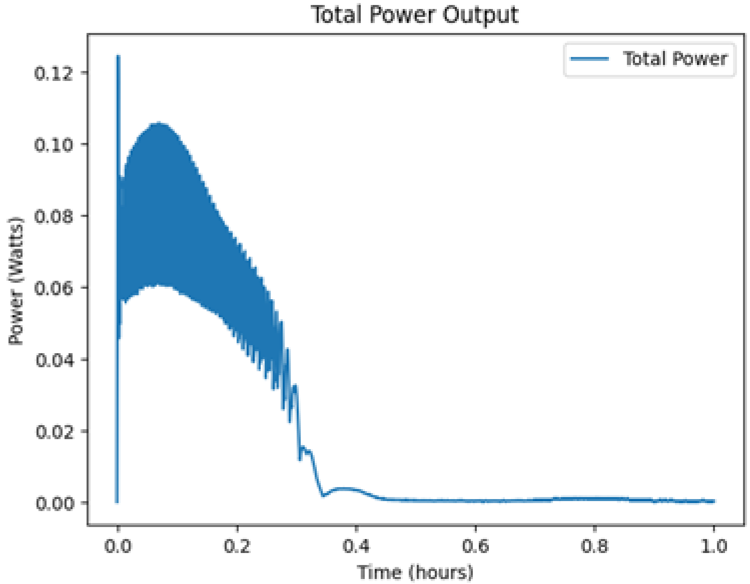




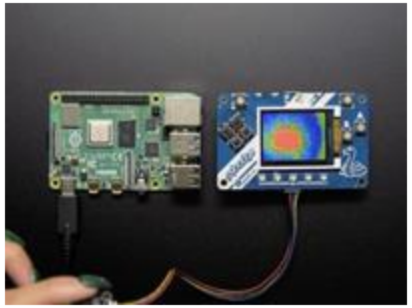








Controls Software - Nadir Pointing (1 sensor)



We are looking at two primary parameters:

- Alpha: The percentage of our horizon sensor filled with Earth versus space
- Phi: The angle of the horizon with the x-axis of our sensor image

1. **Find Horizon In Sensor**
   Rotate along an axis until horizon is spotted in sensor
2. **Align Horizon properly to move to Nadir**
   By setting phi to 0 and Alpha to Alpha desired (a precalculated percentage), we can get to Nadir with 1 sensor
3. **Discern Alpha Dot and Phi Dot**
   By completely turning off controls, we can calculate our derivatives with respect to time to determine how far we are from RAM
4. **Go back to Nadir with our face aligned with RAM**
   With knowing what our derivatives are, we can rotate to have our satellite aligned with RAM while nadir pointing
5. **Maintain Nadir and RAM pointing**
   With all this information, it is very simple to Nadir point while facing the RAM vector as well.

Controls Software - Nadir Pointing (2 Sensors)

1. **Center IR Cameras on both Horizons**
   Rotate until both IR cameras contain the same percentage of earth in their image,
2. **Adjust angle of horizon in sensors**
   Once the angle of the horizon is perfectly flat, we will be nadir pointing
3. **Maintain positioning in sensors**
   Adjust the angle we are at which will change as we rotate; do as best we can with 2 axis control.

Advantages: No constants based on assumption needed, and is much simpler overall in implementation.

Controls Software - Progress and Plan

Completed: B-Dot algorithm, simulation, skeleton PID code, nadir concept planning

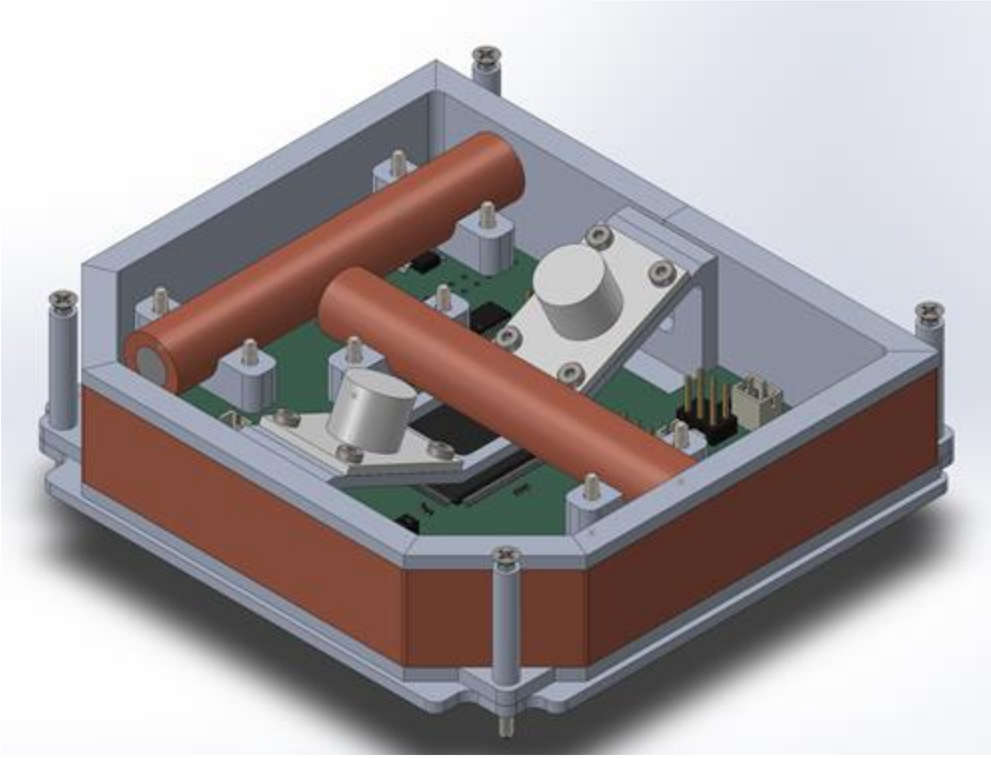
In Progress:

- 3D modelling (Maya) script to generate Earth Horizon Sensor (EHS) images
- Image processing (finding the horizon)
- Conversion from Python to C

Goal: full hardware/software integration by January/early February

Software Design: Magnetorquer Design

Magnetorquer Design



Metal Core Magnetorquer:
- Two cylindrical magnetorquers oriented in X and Y configurations
- High-permeability core material to enhance magnetic field generation

Air Core Magnetorquer:
- Wrapped around the ThinSat walls, leveraging a rectangular geometry for space efficiency

Key Performance Metrics:
- Magnetic Dipole Moment:
  - Optimized for effective torque generation in LEO
- Power Efficiency:
  - Minimized power dissipation to stay within the satellite's power budget
- Switching Time:
  - Ensured rapid response within operational constraints
- Physical Integration:
  - Compact designs tailored for ThinSat payload dimensions

Magnetorquer Design - Optimization

Objective: Maximize magnetic dipole moment while adhering to power, size, and switching constraints

Core Magnetorquer:

- Optimized rod radius, number of turns, and permeability to achieve effective torque with reasonable switching times
- Calculations done balanced resistance, inductance, and demagnetizing effects

Air-Core Magnetorquer:

- Iterated over wrapping configurations to maximize dipole while maintaining manageable power dissipation
- Analyzed layer density, coil resistance, and dimensions for optimal performance

Simulation for optimization done via Python scripts for parameter sweeps and validation of design constraints

Magnetorquer Design - Design Constraints

Inherent Constraints:

- Magnetic Field: Earth's magnetic field strength in LEO (30 μT).
- Power Budget: 5V and 0.4A limits from the satellite's electrical system.
- Space Constraints: Size limited to ThinSat payload dimensions.
- Thermal Management: Power dissipation must not cause overheating.

Chosen Constraints:

- Switching Time: Maximum of 60 seconds for full magnetic dipole reversal.
- Core Length: 7.0 cm for cylindrical cores; 8.5x9.7 cm for rectangular air-core.
- Wire Gauge: 30 AWG selected for wrapping due to size and resistance balance.
- Torque Optimization: Aim to maximize dipole moment while staying within thermal and power limits.

Magnetorquer Design - Final Values Chosen

Core Magnetorquer:

- Relative Permeability: 10,000
- Rod Radius: 0.32 cm
- Number of Turns: 1,845
- Total Resistance: 2.60 Ω
- Magnetic Dipole: 1.06 $A \cdot m^2$
- Switching Time: 37.85 seconds
- Maximum Torque: 3.17×10^{-5} N·m

Air-Core Magnetorquer:

- Number of Layers: 9
- Total Turns: 594
- Total Resistance: 14.26 Ω
- Magnetic Dipole: 1.67 $A \cdot m^2$
- Switching Time: 7.32e-04 s
- Maximum Torque: 4.99×10^{-5} N·m

Magnetorquer Design - Impacts of Design Choices

Core Magnetorquer:

- Advantages:
  - High Magnetic Dipole Moment: Achieves a magnetic dipole of 1.06 $A \cdot m^2$ with a relatively low resistance (2.60 Ω), making it effective for torque generation.
  - Lower Resistance: Enables efficient current flow, reducing power loss and improving overall energy efficiency.
  - Compact Design: The cylindrical geometry with a rod radius of 0.32 cm allows for nice integration in space-constrained systems and upon our board.
- Disadvantages:
  - Manufacturing Complexity: Precise alignment and handling of the core material add to the production challenges.
  - Switching Time: While within constraints, the switching time of 37.85 seconds is slower compared to the air-core design, potentially limiting responsiveness.

Air-Core Magnetorquer:

- Advantages:
  - Higher Magnetic Dipole Moment: Achieves a dipole of 1.67 $A \cdot m^2$, outperforming the core design in terms of torque generation.
  - Fast Switching Time: Extremely fast switching time of 0.73 milliseconds ensures rapid, efficient responsiveness, critical for agile attitude adjustments and long term survival.
  - Simplified Design: Absence of a core material reduces manufacturing complexity and avoids the need for specialized materials.
- Disadvantages:
  - Higher Resistance: Total resistance of 14.26 Ω increases power dissipation (2.28 W at maximum current).
  - Wire Length: Requires significantly more wire (203.74 meters) compared to the core magnetorquer.
  - Integration Challenges: The larger, more complex footprint and wrap-around configuration may complicate payload wrapping and system integration.

Magnetorquer Design - Core Real Testing

Objective: Compare and evaluate the performance of magnetorquers using three core materials:

1. Iron Core (Low Permeability): Cost-effective, short switching time, lower torque generation.
2. Ferrite Core (10,000–20,000): Lightweight, mid-range permeability, good thermal properties.
3. High-Permeability Core (80,000): Maximum torque potential, high material cost, longer switching time, and higher impedance.

Testing Approach:

Fabrication:

- Construct three sets of magnetorquers, each using one of the specified materials.
- Ensure consistent dimensions and design parameters for direct comparison.

Performance Metrics:

- Magnetic Dipole Moment: Measure torque-generating capability under identical current and voltage.
- Switching Time: Assess responsiveness for real-time attitude adjustments.
- Power Dissipation: Evaluate energy efficiency under operational conditions.
- Thermal Behavior: Monitor heat generation and dissipation during sustained operation.

Outcome:

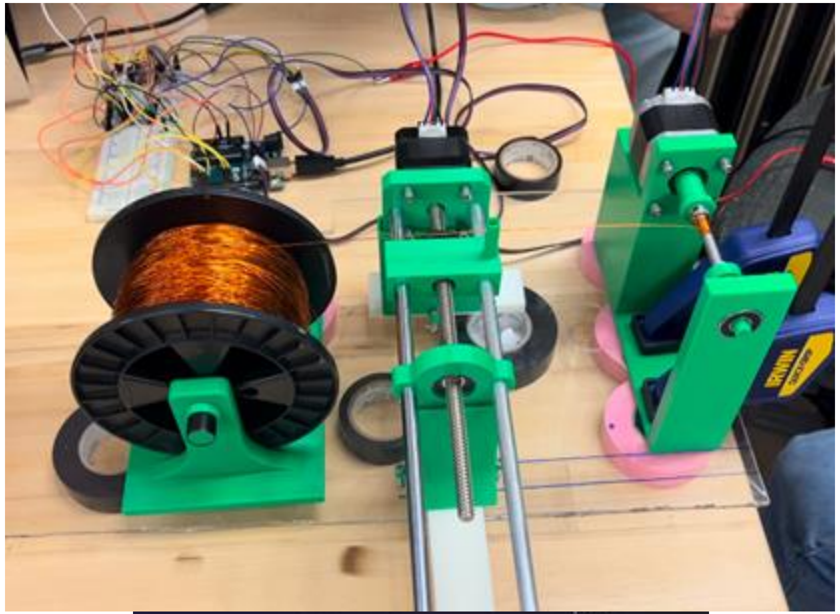
- Identify the optimal core material based on evidence-driven performance data, prioritizing:
- Maximum torque generation.
- Fast and reliable switching time.
- Low power consumption and efficient thermal management.
- Cost-effectiveness and manufacturability.

Implement the best-performing material into the final ThinSat ADCS system.

Magnetorquer Fabrication - Wrappers + EIH

Components:

- Rotating magnetorquer core driven by stepper motor (right)
- Threaded guide driven by linear actuator (middle)
- Free spinning coil of wire (left)



Process:

- Rotating core initiates the motion of the machine pulling the wire from the free spinning coil (keeping tension while doing so)
- The wire goes through the threaded guide system which moves over 1 diameter of the wire for everyone rotation of the core
- The guide goes back and forth reversing direction once the end of the core is reached until the magnetorquer is fully wrapped (all run through arduino code and motor drivers)

Results:

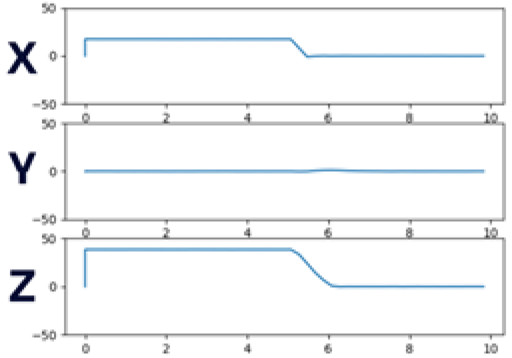
- One test core has been wrapped with 200 efficiently packed turns of wire (shown to the right)
- Adjustments will be made to accommodate for different sized wire and cores

Magnetorquer Testing and Measurement

Objective: Verify the performance and optimize the design of magnetorquers under controlled and simulated operational conditions.

Testing Tools and Facilities:

1. Helmholtz Cage:
    - Precisely control and measure magnetic fields to test torque generation and field cancellation.
    - Features:
        - Programmable PWM for magnetic field adjustments.
        - Calibration for accurate magnetic field readings.
        - Integration with PySol for orbit simulation.
2. Structural Testing Apparatus:
    - Nylon String Test:
        - Allows one-axis rotational testing of ADCS performance with minimal interference.
        - Suspends ADCS system using a 56" nylon string attached to a 3D-printed test bed.
    - Air Bushing Test:
        - Provides a frictionless platform for unidirectional magnetorquer evaluation.
        - Features a custom-fabricated air bearing for precise ADCS motion assessment.
3. Sun Simulation Cage:
    - Simulates solar charging and orientation using blackout fabric and dimmable LEDs.
    - Evaluates magnetorquer and ADCS system's ability to align with or away from a light source.



Performance Metrics:

- Torque Generation: Measured using controlled magnetic fields in the Helmholtz cage.
- Switching Time: Evaluated to ensure responsiveness in attitude control scenarios.
- Power Dissipation and Heat Management: Monitored under operational loads.
- Thermal Performance: Observed using thermal imaging during sustained operation.

Power Analysis + Operation

Power - Limitations

NSL Power Limitations

0.4 A/torquer

Total Watts Drawn →
- Maximum Power Draw, Magnetorquers = 4 W
- Bus Power Draw, no ADCS = 1 W
- Sensor + MCU = 181 mW

Total = 5.181 W

Available Power = 7 Wh

$$\frac{7\ \text{Wh}}{5.181\ \text{W}} = 1 \text{ hour } 21 \text{ minutes at full power}$$

Power

Stay within the bus power restrictions

- 3.3V (sensor and MCU) and 5V rail (Magnetorquers), max 1 A each

Our power nominal requirements

- Sensors + MCU → IMU - 2.5 mW, IR Cam - 23 mW, MCU - 132.56 mW
- Magnetorquer will take the rest of the available power

Power Mode	Power Needed
Lowest/Idle (magnetorquers off)	181.06 mW
During Operation (Two magnetorquers maximally active)	3.531 W
Maximum (All torquers full power)	5.181 W

FOM	Calculation
Minimum Time to Detumble (Ideal)	25.12 seconds
Realistic Time to Detumble	23 mins 21 secs
Ideal Power Consumption	0.000278 Wh
Realistic Power to Detumble	0.289 Wh

Ideal Power Calculations

angular momentum

$$\tau = \frac{\Delta L}{\Delta t}$$

ΔL = Moment of Inertia (I) * Δ Angular Velocity (ω)

$\tau_{max} = 5 \times 10^{-5}\ N \cdot m$ $\quad$ Δ Angular Velo. $= (15^\circ/s)*(3\text{ axes}) = 45^\circ/s$

$\omega = 0.785$ rads/s

$$|I| = \sqrt{(3.02)^2 + (4.13)^2 + (1.96)^2}$$

$$|I| = 5.48\ lbs \cdot in^2 = 0.0016\ kg \cdot m^2$$

$$5 \times 10^{-5}\ N \cdot m = \frac{(0.0016\ kg \cdot m^2)(0.785\ rads/s)}{\Delta t_{min}}$$

$$\boxed{\Delta t_{min} = 25.12 \text{ seconds}}$$

Power Calculations - Realistic Adjustments

1. Ideal case assumed ideal cross product on three axes with Earth’s B-field. Adjustment assumes **50% cross product efficiency.**
2. Ideal case assumes that there is no charge time of the magnetorquers. Max torque not be reached for 60 seconds of full current draw. Adjustment assumes **25% torque efficiency**.
3. Ideal case assumes that satellite is always oriented in a way that allows all 3 axes to be torqued at once. Adjustment assumes an **extra 20 minutes of Idle time** for 3rd axis to align for torquing.

cross prod. efficiency

$$(5\times10^{-5}\ N\cdot m)(0.5)(0.25) = \frac{(0.0016\ kg\cdot m^2)(0.785\ rads/s)}{\Delta t}$$

torque efficiency

$\Delta t \approx 200$ seconds $=$ 3 minutes 21 seconds

Time to detumble $= \Delta t + 20$ min Idle $= 23$ mins

Test Planning and Risk Mitigation

Test Planning - Launch Environment

Potential pre-testing → design a balloon demo/testing platform using our Iris system!

1. Image processing demo with IR cameras? Test in-flight emulator communication?

Pre-environmental testing:

1. Test all operational modes of the satellite
   a. Sun-pointing control, Earth-pointing control, Detumble control, Induce Tumble, System off
2. Interface with **emulator** and test data interface with bus in all modes

TVAC testing:

1. Use **on-campus TVAC system**, run our payload through TVAC cycling meeting ICD testing requirements
   a. 60 degrees celsius , 1E-4 Torr, 6 hours (Bake out)
2. Run TVAC thermal cycling test
   a. -30 degrees to 60 degrees celsius, 1 hour dwell at each extreme, 4 cycles

Vibration testing:

1. Use NASA GEVS Qual levels (14.1 GRMS) on EM units and Acceptance levels (10.0 GRMS) on FM units
   a. Utilize **Near Space Launch vibration table or GOAT Lab vibration table** for testing

Radiation testing (if possible):

1. [Plan TBD, need to find facility with these capabilities, MIL-STD-461 RE102]

Post-environmental testing:

1. After all other testing, make sure the system still functions. Repeat pre-environmental testing.

BOM and Thermal Considerations

BOM and Thermal Considerations

Reference	Value	Datasheet	Footprint	Qty	DNP	Min t	Max
C1,C2,C38	0.1u	https://www.mouser.com/datasheet/2/40	Capacitor_SMD:C_0402_1005Metric	3		-55	125
C3,C7,C11,C12,C13,C16,	4.7u	https://www.mouser.com/datasheet/2/40	Capacitor_SMD:C_0402_1005Metric	9		-55	125
C4,C5,C6,C8,C9,C10,C14	100n	https://www.mouser.com/datasheet/2/40	Capacitor_SMD:C_0402_1005Metric	16		-55	125
C28,C29	C_LEXT	https://www.mouser.com/datasheet/2/40	Capacitor_SMD:C_0402_1005Metric	2		-55	125
C30	9.5p	https://www.mouser.com/datasheet/2/39	Capacitor_SMD:C_0402_1005Metric	1		-55	125
C31,C33	C_LEXT32	https://www.mouser.com/datasheet/2/40	Capacitor_SMD:C_0402_1005Metric	2		-55	125
C32	1.4p	https://www.mouser.com/datasheet/2/28	Capacitor_SMD:C_0402_1005Metric	1		-55	125
C34	10n	https://www.mouser.com/datasheet/2/40	Capacitor_SMD:C_0402_1005Metric	1		-55	125
C35	10u	https://www.mouser.com/datasheet/2/40	Capacitor_SMD:C_0402_1005Metric	1		-55	105
L2,L3,L4	10u	https://www.mouser.com/datasheet/2/28	Inductor_SMD:L_0603_1608Metric	3		-55	125
C36	22u	https://www.mouser.com/datasheet/2/39	Capacitor_SMD:C_0402_1005Metric	1		-55	105
C37	10p	https://www.mouser.com/datasheet/2/39	Capacitor_SMD:C_0402_1005Metric	1		-55	125
IC1	SAM3X8ERT-H8X-HF	http://ww1.microchip.com/downloads/er	MCU:144L-2SB_MCH	1		-40	105
J1	Conn_02x10_Odd_E	https://www.digikey.com/en/products/de	NSL-20-pin:CON20_2X10_TU_TSW_SAI	1		-55	125
J3	Conn_01x06_Pin	https://www.digikey.com/en/products/de	Connector_PinHeader_2.54mm:PinHeader_1x	1		-40	105
J4,J8	JST_SH_4	https://www.jst-mfg.com/product/pdf/en	StockLib:JST04_1MM_RA	2		-25	85
J5	MTQ_X	https://www.digikey.com/en/products/de	Connector_JST:JST_PH_B2B-PH-K_1x02_P2.00	1		-25	80
J6	MTQ_Y	https://www.digikey.com/en/products/de	Connector_JST:JST_PH_B2B-PH-K_1x02_P2.00	1		-25	80
J7	MTQ_Z	https://www.digikey.com/en/products/de	Connector_JST:JST_PH_B2B-PH-K_1x02_P2.00	1		-25	80
J9	Conn_01x04_Pin	https://www.digikey.com/en/products/de	Connector_PinHeader_2.54mm:PinHeader_1x	1		-40	105
J10	USB_C_Receptacle	https://www.usb.org/sites/default/files/d	USB_C_Receptacle_GCT_USB4115-03-C	1		-25	85
JP1	Header	https://mm.digikey.com/Volume0/opasd	StockLib:1x4 Socket	1		-40	105
LED1,LED3	Green	https://optoelectronics.liteon.com/uploa	StockLib:LED_0805	2		-20	80
LED2	Blue	https://mm.digikey.com/Volume0/opasd	StockLib:LED_0805	1		-55	85
MTQ_X1,MTQ_Y1,MTQ_Z1	Conn_02x03_Odd_E	https://www.digikey.com/en/products/de	Connector_PinHeader_2.54mm:PinHeader_2x	3		-40	105
Q1,Q4,Q6,Q7,Q10,Q11	NMOS	https://www.diodes.com/assets/Datashe	StockLib:SOT23	6		-55	150
Q2,Q3,Q5,Q8,Q9,Q12	PMOS	https://www.diodes.com/assets/Datashe	StockLib:SOT23	6		-55	150
R1,R5,R12,R15	1k	https://www.jst-mfg.com/product/pdf/en	Capacitor_SMD:C_0402_1005Metric	4		-55	125
R2,R3,R4	1	https://vishay.com/docs/20024/dcrcwife	Capacitor_SMD:C_0402_1005Metric	3		-55	155
R6,R13	10k	https://www.vishay.com/docs/28952/mc	Capacitor_SMD:C_0402_1005Metric	2		-55	175
R9,R14	4.7k	https://www.vishay.com/docs/28705/mc	Capacitor_SMD:C_0402_1005Metric	2		-55	125
R16,R18	5.1k	https://www.vishay.com/docs/28705/mc	Capacitor_SMD:C_0402_1005Metric	2		-55	125
R17	6.8k	https://industrial.panasonic.com/cdbs/w	Capacitor_SMD:C_0402_1005Metric	1		-55	155
R19,R20	39	https://www.rohm.com/datasheet?p=SFF	Capacitor_SMD:C_0402_1005Metric	2		-55	150
SJ1,SJ2	DNP	N/A	StockLib:Jumper_NO_Small	2	DNP		
SW1,SW2	~	https://www.mouser.com/datasheet/2/24	StockLib:KMR_2	2		-40	85
TP1	XOUT	N/A	TestPoint:TestPoint_Pad_2.0x2.0mm	1	DNP		
TP2	XOUT32	N/A	TestPoint:TestPoint_Pad_2.0x2.0mm	1	DNP		
U1	ICM-20948	https://invensense.tdk.com/wp-content/	IMU:QFN24_3X3X0P9_IVS	1		-40	85
U2	AMS1117-3.3	http://www.advanced-monolithic.com/pc	Package_TO_SOT_SMD:SOT-223-3_TabPin2	1		-40	125
U3	TXS0108EPW	www.ti.com/lit/ds/symlink/txs0108e.pdf	Package_SO:TSSOP-20_4.4x6.5mm_P0.65mm	1		-40	85
U4,U7	TPS2116DRL	https://www.ti.com/lit/ds/symlink/tps211	Package_TO_SOT_SMD:SOT-583-8	2		-40	105
Y1	XTAL	https://www.mouser.com/datasheet/2/40	Crystal:Crystal_SMD_3225-4Pin_3.2x2.5mm	1		-40	85
Y2	XTAL32	https://www.mouser.com/datasheet/2/3/	Crystal:Crystal_SMD_3225-4Pin_3.2x2.5mm	1		-40	85
QT cables for camera				2			
usb-c cable							
male jst headers for mtqs							

Some components only rated -20C -> resistive heating

All parts in stock now (some on hand in ND's EIH)

Sourcing for SAM3… RFQd Microchip, still waiting

Risk analysis and mitigation

Risk	Potential Effect	Mitigation Measure
MEMS Sensor Helium Effect	Sensor performance drift or failure due to helium permeation	Use helium-resistant packaging options or select alternative sensors less susceptible to helium exposure. Test and monitor sensor performance during environmental testing.
3 Sensors with No Redundancy	Each sensor could be a single point of failure	Implement watchdog timers for resetting faulty sensors, using software-based fault detection and safe mode reinitialization for recovery from sensor failures.
Structural Integrity	Physical damage to board, connections, or magnetorquers during launch or operation	Conduct extensive FEA, vibration, thermal, and shock testing to aerospace standards. Use robust design and secure mounting techniques to avoid physical breakage.
Circuitry Incorrectness	Non-functional or suboptimal performance limiting mission success	Validate circuits through SPICE modeling, breadboarding, logic analyzers, and in-depth testing with test pads before final assembly to ensure performance.
Overconsuming Power	Exceeding power budget leading to mission failure	Perform detailed power budgeting, implement low-power modes, power cycling, and optimize component usage to stay within mission power constraints.
Cosmic Radiation	Hardware damage or bit flips in data	Use radiation-tolerant or rad-hardened components, apply error-correction coding (ECC), and implement redundant systems such as Triple Modular Redundancy (TMR) for reliability.
Thermal Management Failure	Overheating or undercooling of critical components	Incorporate thermal modeling and design thermal dissipation systems (heatsinks, radiators). Use temperature monitoring to enable active thermal management.
Sensor Data Inaccuracy	Inaccurate sensor readings affecting ADCS performance	Apply sensor calibration before flight, and implement filtering algorithms (e.g., Kalman filters) to validate sensor data in real-time.
Software Bugs	Unexpected software behavior leading to mission degradation	Thorough testing of software in simulation and HIL environments
Communication Failure	Loss of data link between payload and bus	Implement redundant communication channels and periodic communication checks. Include software-based reconnection protocols for link recovery.

Next Deliverables

Integration readiness review work sheet

- Review Payload testing worksheet
  - Add payload specific test draft
- This will be completed during IRR and signed at delivery

Deliverables For Spring Kickoff Meeting

- Updates to Share with the Dream big group
- Contact info to share with other groups for questions
- 10 min sharing

Deliverables For IRR

- Payload testing worksheet completed
  - PPT with results
- functional testing payload sheet
- Payload Built
- Flown on Balloon early enough in the semester to make repairs

- Bus config worksheet

Questions and Comments