IRISHSAT

PASSION. DRIVE. EXCELLENCE.

Proposal: Senior Design × NearSpace Launch

11/21/24

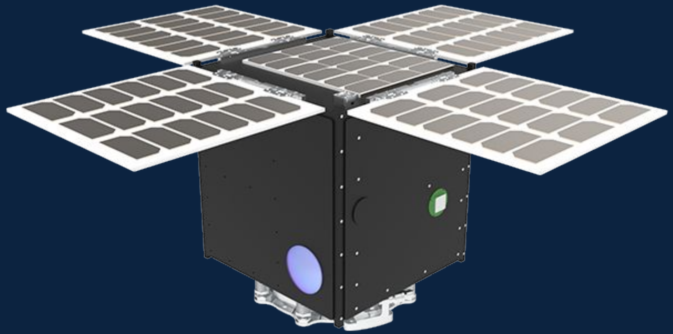
Introduction

Satellites

Why are satellites important/useful?

- Enable:
  - Global Communication
    - Internet, TV, phone
  - Earth Observation:
    - Climate, research
  - Navigation:
    - Location, timing services

to make life on Earth easier and better, provide security, and enable worldwide connectivity



Problem Description

The Problem:
The Challenge of Small Satellite Attitude Control

Initial Problem:

- LEO satellites accumulate significant angular velocity ω_0 on all three axes (*tumble*) upon deployment, rendering satellites unusable:
  - No stable communication
  - Inefficient solar charging
  - Inaccurate sensing and imaging
- Once *detumbled*, precise pointing is required for operations (e.g. alignment with Sun, Earth, etc)

The Solution: Attitude Determination & Control Systems (ADCS)

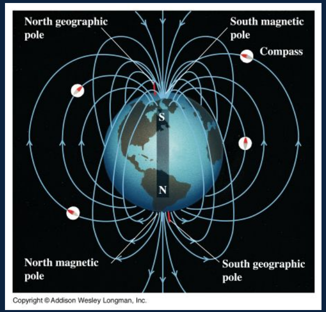
- Current ADCS Solutions are Not Ideal for Small Satellites
  - Large: Reaction wheels
  - Power hungry: Ion thrusters
  - **Expensive**: Both!

Small satellites require a compact, low-power, cost-efficient ADCS solution that does not yet exist!

Proposed Solution

CHARMSat ☘️

Innovative ADCS Module for Small Satellites!



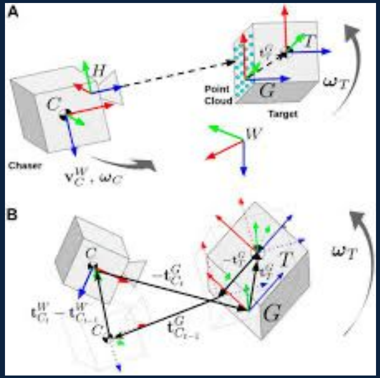
Compact → Compatible with 0.5U satellites (10cm × 10cm × 5cm)

High-**A**ccuracy → Main function: fast detumbling and pointing

Reduced-power → Complete detumbling in <7Wh (wow!)

Magnetorquer → Passive actuators (efficient, small)

Satellite → Completely local (no GPS or downlink needed)



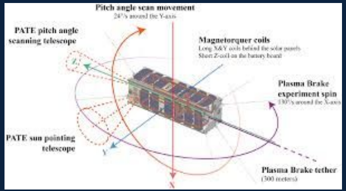
GPS-Free Magnetorquer-Only ADCS

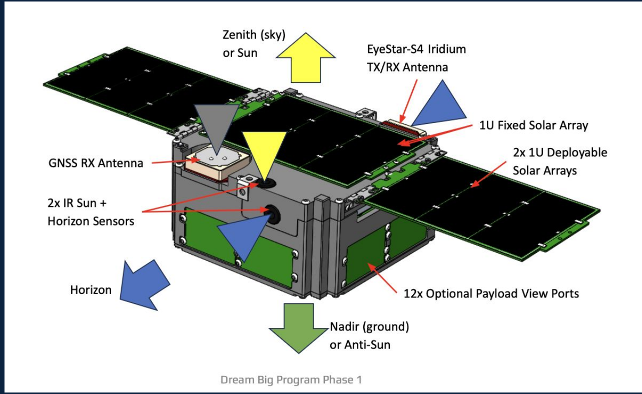
Goal: **Plug-and-Play ADCS Scalable Module**

(user provides only power and requests, system alerts when action completed)

Five Subsystems:

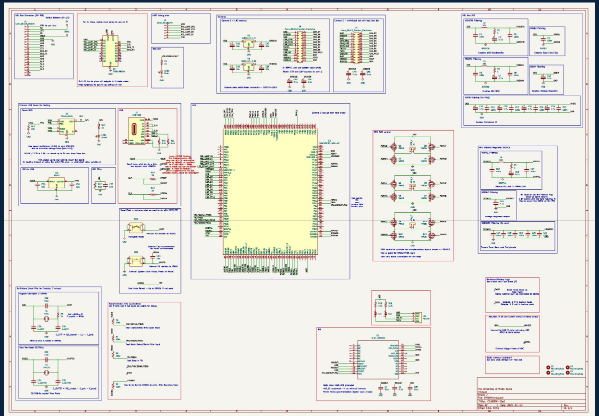
1. PCB, Sensor Suite, and Circuit Design
2. Magnetorquer Design
3. Controls Software
4. Firmware
5. Structures and Thermal

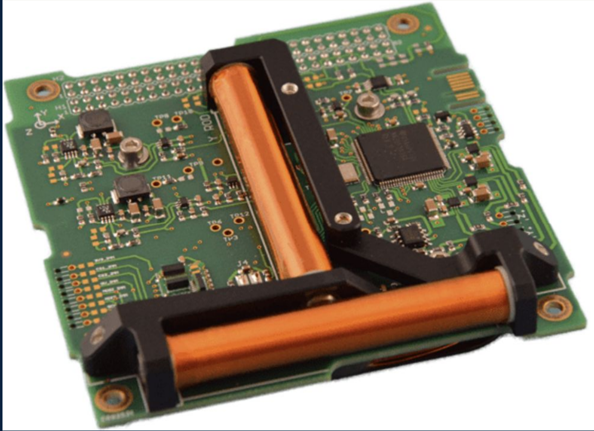




1. PCB, Sensor Suite, and Circuit Design

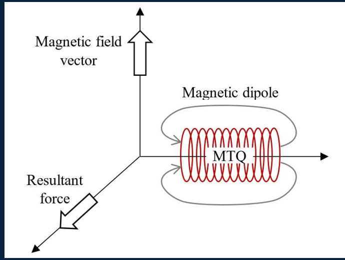
- **Two Infrared imaging cameras**:
  - Horizon sensing
  - *Where are we pointed?*
  - Captures images for processing to determine satellite’s orientation relative to Earth
- **Inertial measurement unit (IMU)**:
  - Measures angular velocity & acceleration
  - *How are we spinning?*
  - Uses accelerometer and gyroscope data to monitor rotational motion + magnetometer data
- **Rad-tolerant MCU:**
  - RTOS task management and central hub
  - *How do we best control the satellite?*
  - Uses sensor and bus data to make decisions
- **Bus Power Input:**
  - 3.3V 1A, 5v 1A, 6-9V 2A





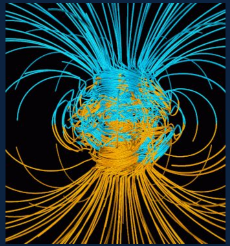
2. Magnetorquer Design

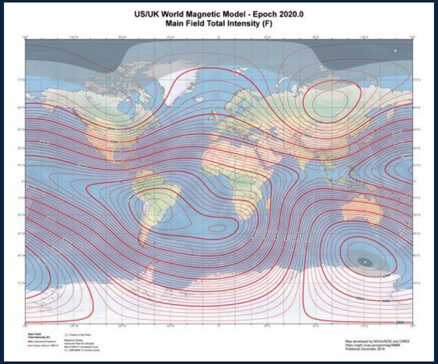
Magnetorquer: Wire wrapped in coils around some geometry with properties that result in solenoid model physics.



$$\mathbf{m} = nI\mathbf{A},$$

$$\boldsymbol{\tau} = \mathbf{m} \times \mathbf{B},$$





Magnetometer: Reads surrounding magnetic field. Determines satellite's environment and provides data for magnetorquer controls.

Current through solenoid creates magnetic dipole which interacts with Earth's magnetic field to generate torque

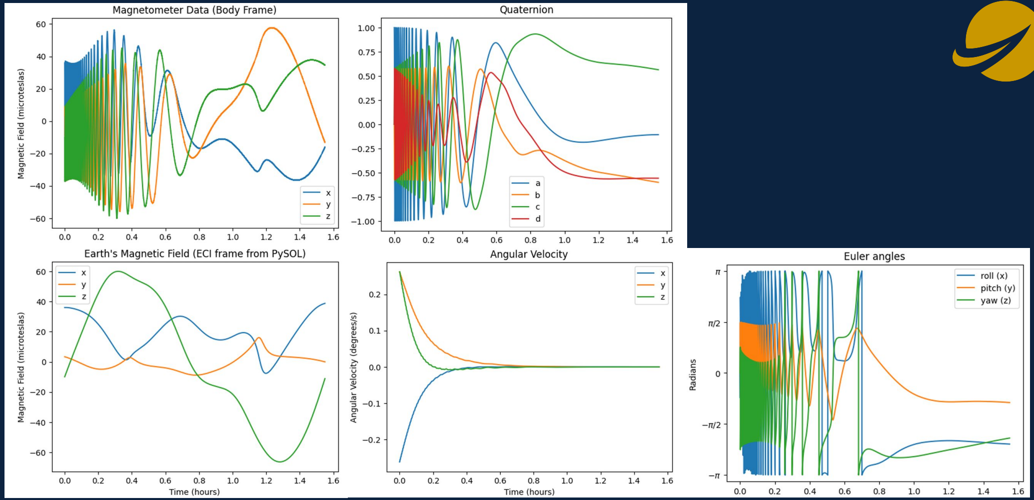
Why magnetorquers?

- Smaller, cheaper, and lower power than alternative actuators
- Aligned along x, y, z planes
- Completely passive (with fewer failure points)

3. Controls Software

What does it need to do?

- Process sensor data to filter and combine raw inputs into actionable data
- Generate control signals to act as commands for magnetorquers
- Enable data exchange to ensure reliable communication with sat bus
- Design and produce a compact PCB with all necessary compute and interfaces on board



How?

- Control Algorithms
  - B-dot, PID, Kalman filter
- Sensor Data Processing
  - Collection, persistent storage, transmission
- System Reliability
  - Watchdogs, voting, parity

4. Firmware

What is it?

- Custom NSL Packet structure interfacing
- Communications signaling
- Sending Requests to sat bus and decoding uplinks

Why is it important?

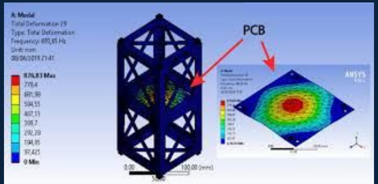
- Allows for proper integration of bus and payload to carry out information transfer
- Allows our payload to downlink data to Earth

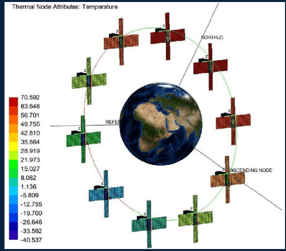
```
Payload Initialized!
Functional Command Received: F5
0x50 50 50 F5 30 60 6A FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
0xAA 05 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
ACK received from NSL :)
Functional Command Received: F4
0x50 50 50 F4 30 60 6A FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF FF 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
0xF5 18 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
```

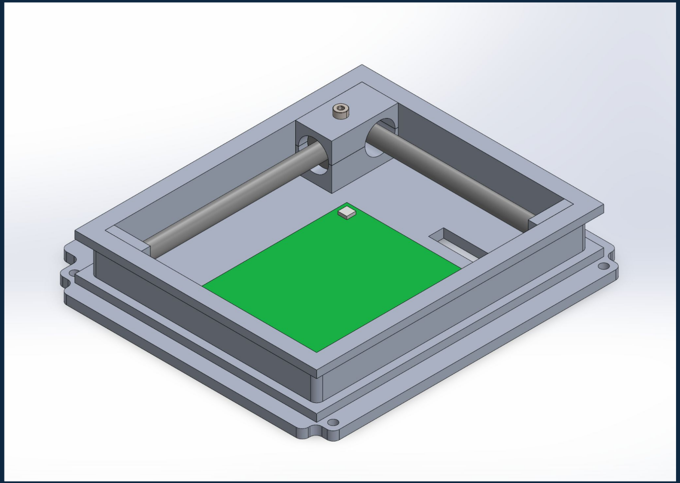
5. Structural and Thermal

What does this team do?

- Matching the structural interface given to us by NSL
- Integrating payload into physical housing
- Protecting electronics and payload from harsh launch and space conditions
- Performing critical thermal analysis
- Implementing essential thermal mitigation for operation in LEO with understanding of sensor temperature limitations
- Magnetorquer wrapping and potting







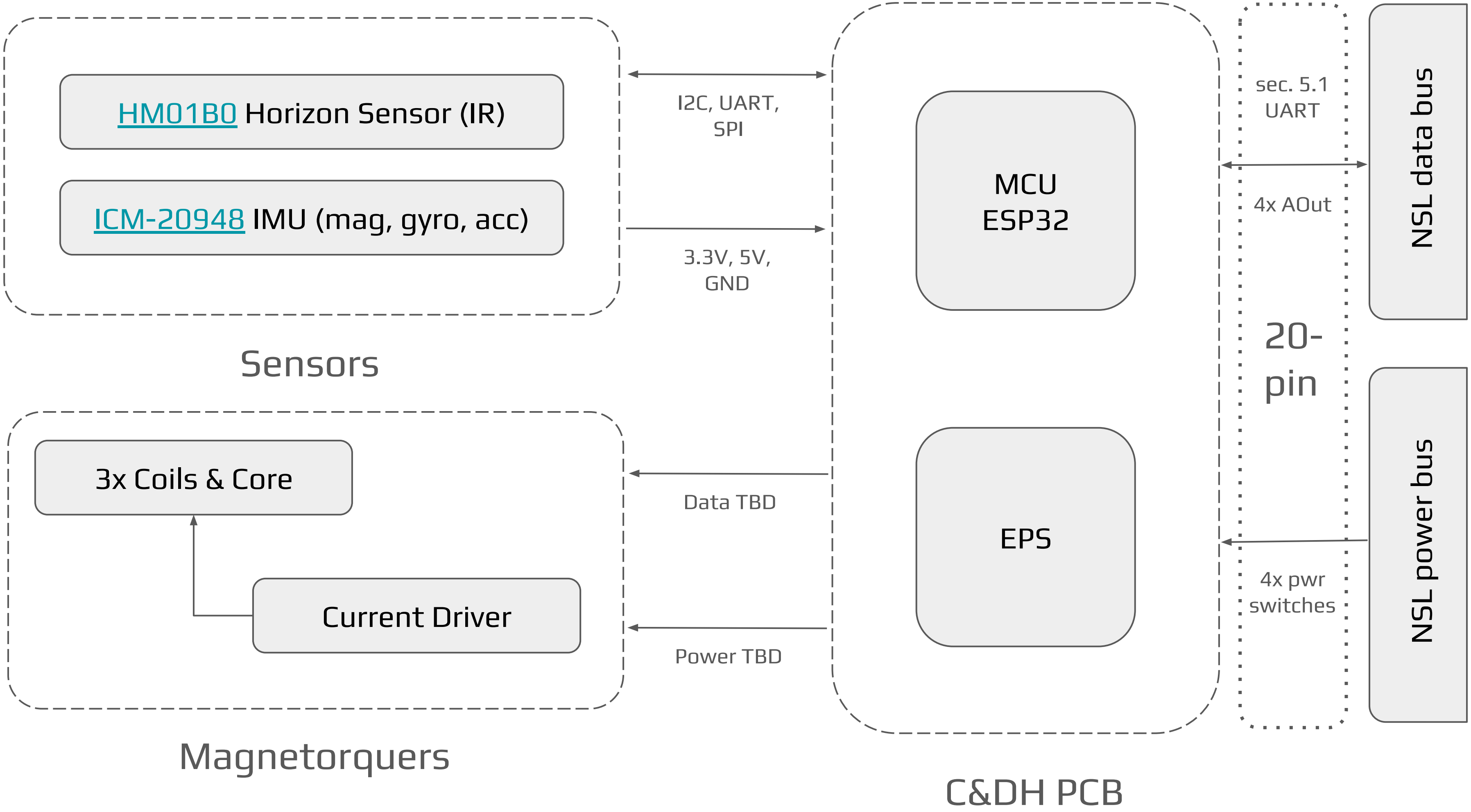
Demonstrated Features

March Integration & Demonstration

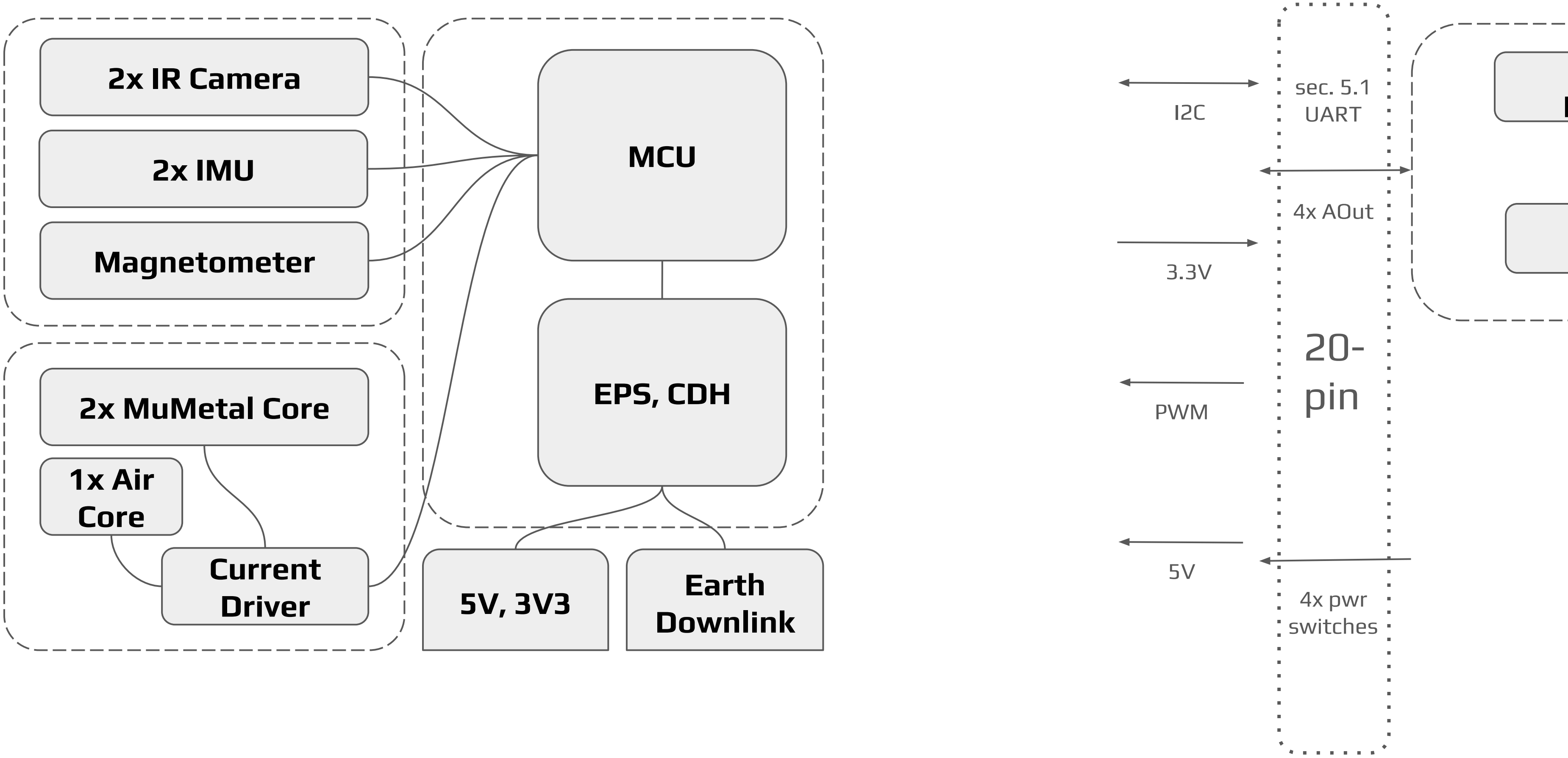
1. **Perform detumbling** when released from the rocket, ω_o <0.5 deg/s on x,y,z
2. Complete detumble and any **arbitrary attitude control** in <7 Wh.
3. Calculate the necessary magnetorquer control signals with **in-house designed algorithms**.
4. **Interface with NSL's satellite bus**, including uplink to an existing constellation (then communication back to Earth).
5. **Process camera inputs** to detect the horizon and conduct search for control directions

Will then get launched on Falcon 9 and operate in space!

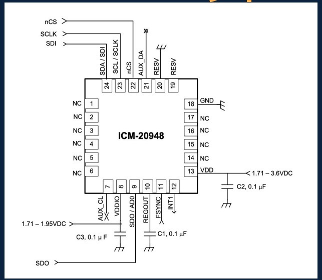
Available Technologies



HM01B0 Horizon Sensor (IR)
ICM-20948 IMU (mag, gyro, acc)
I2C, UART, SPI
3.3V, 5V, GND
Sensors
MCU ESP32
EPS
sec. 5.1 UART
4x AOut
20-pin
4x pwr switches
NSL data bus
NSL power bus
3x Coils & Core
Current Driver
Data TBD
Power TBD
Magnetorquers
C&DH PCB

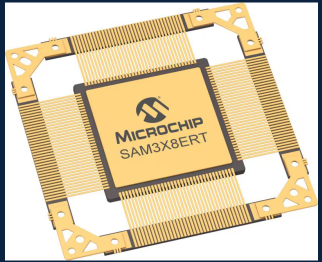

2x IR Camera
2x IMU
Magnetometer
MCU
EPS, CDH
2x MuMetal Core
1x Air Core
Current Driver
5V, 3V3
Earth Downlink
I2C
3.3V
PWM
5V
sec. 5.1
UART
4x AOut
20-pin
4x pwr switches

ICM-20948



Super low power consumption (3mW). Hermetically sealed so no helium leakage

SAM3X8ERT

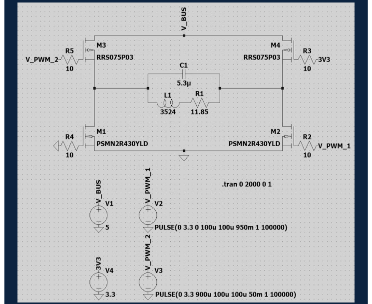


Radiation tolerant, 130mW max draw, Regular 3-20MHz clock, sleep clock 32.768kHz

HM01B0

4mW power consumption. Small (<5mm^2). High res enough for our algorithm (324x324)

H-Bridge



Bidirectional MTQ control (H bridge)

Engineering Content

General Engineering - Project Stages

1. Brainstorming and ideation
2. **Understanding requirements and specifications**
3. Defining mission success
4. System design and subsystem planning
5. **Preliminary Design Review**
6. Subsystem design and analysis
7. **Critical Design Review**
8. Prototype production
9. **Prototype testing**
10. Prototype test analysis and improvements
11. **Final system production and integration**
12. Final system testing
13. Final system analysis

Subsystem Engineering Tasks

1. **PCB, Sensor Suite, and Circuit Design**
   - Schematic and Layout Design, Component Selection, Comms Protocols
2. **Magnetorquer Design**
   - Material and Parameter Optimization, Power and Torque Characterization
3. **Controls Software**
   - Attitude determination and control, sensor data acquisition, PID controller, Kalman Filtering, EOM determination, Horizon Tracking, RTOS
4. **Firmware**
   - ICD requirements, packet construction, send requests and receive info
5. **Structures and Thermal Systems**
   - NSL structural integration, component thermal analysis, potting, magnetorquer wrapping

Preliminary Designs and Optimization

Design Optimization

Overall Best Magnetorquer Configuration given Time Constraint of 60 s:

Relative Permeability: 74000

Rod Radius: 0.32 cm

Number of Turns: 1719

Number of Layers: 9

Total Resistance: 11.369588927335636 Ohms

Total Wire Length: 34.562545737733466 m

Magnetic Dipole: 0.9202410185697143 A·m²

Inductance: 135.99715080399375 H

Time Constant: 11.961483539393319 s

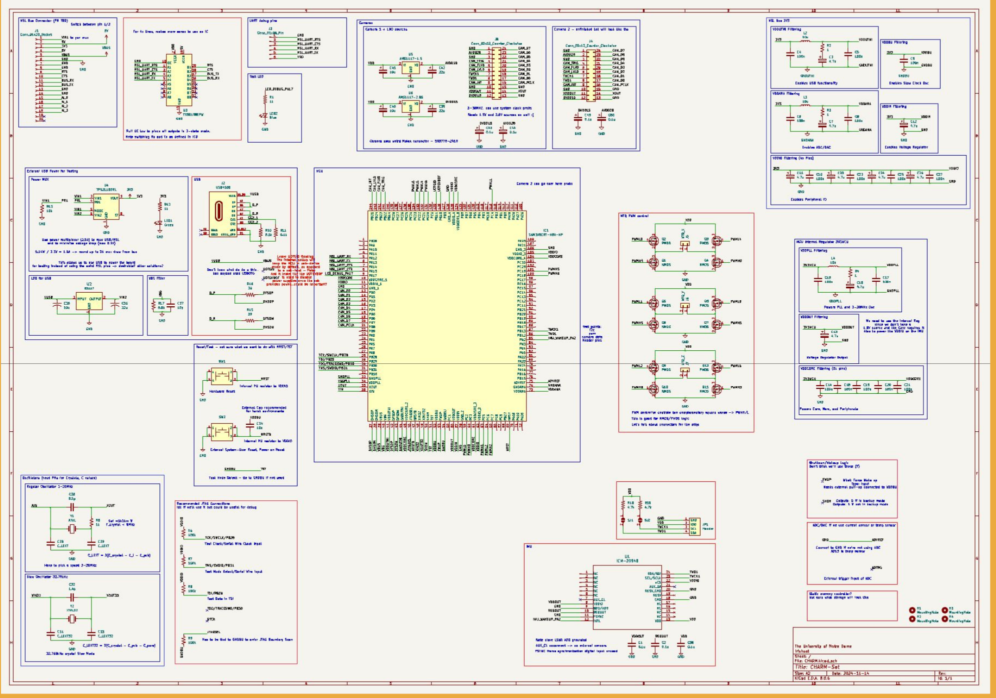
Switching Time: 59.807417696966596 s

Maximum Torque: 2.760723055709143e-05 N·m

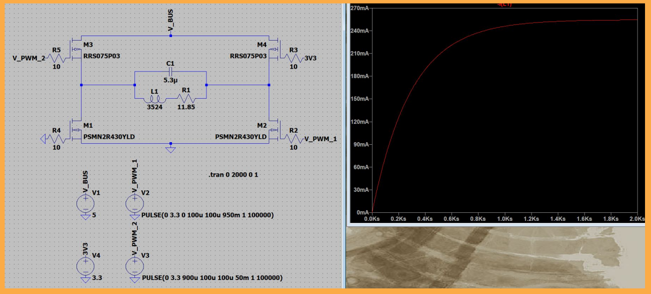
Maximum Current: 0.4 A

Time to Full Current: 55.084667375801416 s

Schematic Design



SPICE Simulation



Preliminary 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.

Preliminary Test Planning for Payload

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
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.

Conclusion

Conclusion

- Attitude Determination and Control Systems (ADCS) are **essential**.
- **There exists no ADCS** that is fully autonomous *and* "plug-and-play".
- CHARMSat delivers a **compact, low-power** 0.5U system with **precise** attitude control and detumbling
- Brings ADCS functionality to **small, low-power, low-complexity** satellites

CHARMSat represents a critical step toward democratizing space by enabling small satellite developers to achieve reliable, high-performance stabilization and control.