C.H.A.N. - O.S.M.

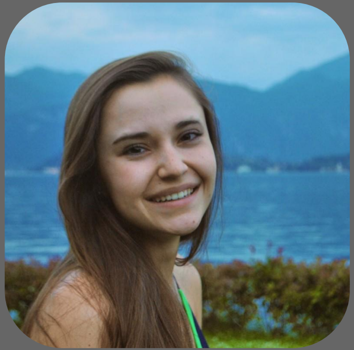
Climatic High-Altitude Navigator for Optical Signal Measurement

Critical Design Review: Group 2

Michael “Zion” Franz · Jake “Dorf” Dorfman · Lily “Oculus” Sigg · Hector “Diesel” Parra · Sean “Shaggy” Rego

Meet The Team

Jacob Dorfman
Electrical Engineering (BS)
2025



Lily Sigg
Photonics Engineering (BS)
2025

Sean Rego
Chemistry (BS)
2018
Electrical Engineering (BS)
2025

Hector Parra
Electrical Engineering (BS)
2025

Michael Franz
Electrical Engineering (BS)
2025

1. System Overview
2. Hardware & Software
3. PCB & Software Design
4. Testing
5. Administrative Content

1. System Overview
2. Hardware & Software
3. PCB & Software Design
4. Testing
5. Administrative Content

Problems & Motivation

Educational Problems

- **There are not enough high altitude STEM kits.**
  - Almost all kits are a collection of COTS parts sold as a package.
  - There are no integrated “plug ‘n play” kits available.

Ecological Problems

- **There is a disconnect between terrestrial and atmospheric fire models.**
  - Satellites in orbit cannot monitor one area for an extended period of time.
  - Satellites struggle to detect fire/smoke through cloud cover.
  - Satellites cannot determine what type of vegetation is burning.
- **Not every country can afford satellite wildfire monitoring.**
  - Fire-monitoring balloons could take the place of satellites.
  - Much cheaper to launch a myriad of balloons vs one satellite.

ECE Goals & Objectives

- **Basic Goals: Design a Balloon Payload that can….**
  - Measure atmospheric conditions such as temperature, humidity, pressure.
  - Determine its velocity, altitude, and coordinates.
  - Transmit data to a receiver & record data that can be clearly interpreted.
- **Advanced Goals:**
  - Create a base station that receives live data and displays it in a clear manner.
  - Design a GUI for graphically displaying data collected by the payload.
- **Stretch Goals:**
  - Reach an apogee of 100,000+ feet.
  - Recover the payload.

OSE Goals & Objectives

- **Basic Goals: Design a Balloon Payload that can....**
  - Characterize flame spectra to determine levels of and ratio between potassium and sodium with the spectrometer.
- **Advanced Goals:**
  - Detect the concentration of green, unburnt vegetation from the data captured by the photodiode.
- **Stretch Goals:**
  - Obtain the absorbance spectra of burnt vegetation (carbon deposits) using the spectrometer.

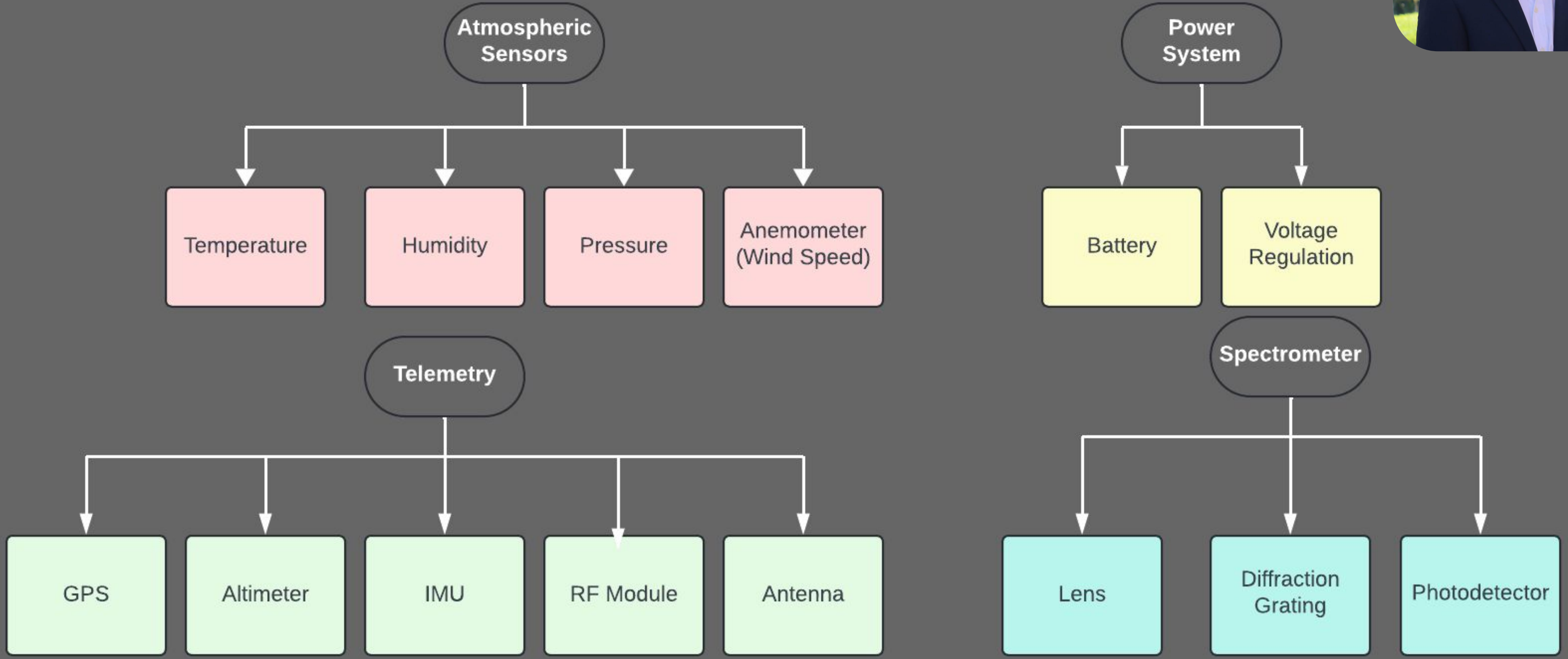
Engineering Requirements

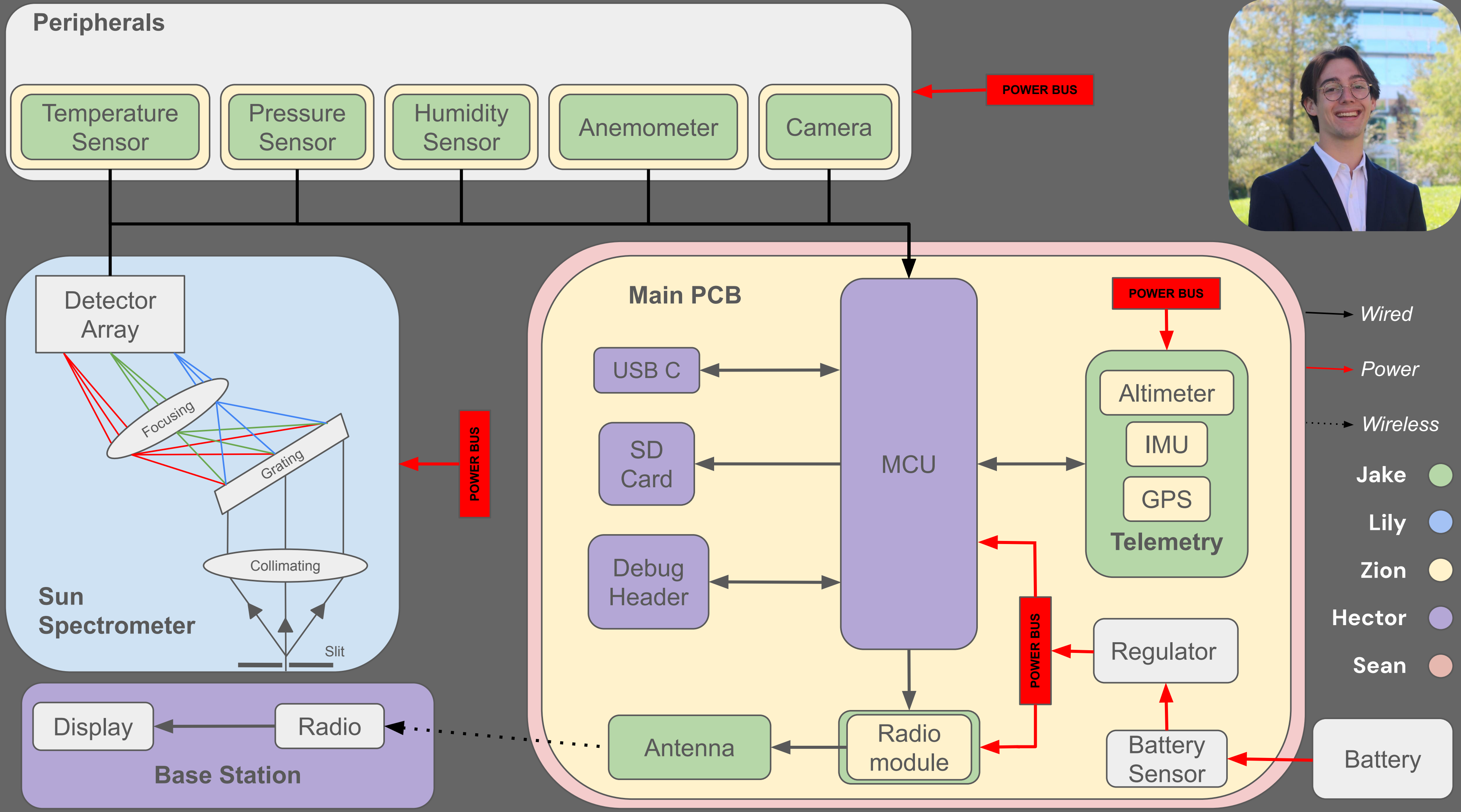
Electrical Specifications		
Component	**Parameter**	**Specification**
Radio	Communication Range	100 feet
Anemometer	Measurement Range	5 – 25 mph
Temperature Sensor	Accuracy	+/– 10 °C
Humidity Sensor	Accuracy	+/– 10% RH
Pressure Sensor	Accuracy	+/– 10 mbar
Altimeter	Vertical Accuracy	+/– 2 meters
GNSS System	Horizontal Accuracy	+/– 10 meters
IMU	Bias Instability	6 deg/hr
Camera	Frames Per Second	24+ FPS
System	Power Consumption	< 10 W

Optical Specifications		
Component	**Parameter**	**Specification**
System	Detection Distance	> 1 foot
	Weight	< 2.5 kg
Detector	Wavelength Range	430 nm – 1100 nm
	Accuracy	+/– 10 nm
Electrical System	Temperature Range	–50 °C – 30 °C
Housing	Size	10 x 10 x 10 cm
Light Source	Required Intensity	> 10,000 mcd

1. System Overview
2. **Hardware & Software**
3. PCB & Software Design
4. Testing
5. Administrative Content

Subsystems


Atmospheric Sensors
Temperature
Humidity
Pressure
Anemometer (Wind Speed)
Power System
Battery
Voltage Regulation
Telemetry
GPS
Altimeter
IMU
RF Module
Antenna
Spectrometer
Lens
Diffraction Grating
Photodetector


Peripherals
Temperature Sensor
Pressure Sensor
Humidity Sensor
Anemometer
Camera
POWER BUS
Detector Array
Focusing
Grating
Collimating
Slit
Sun Spectrometer
POWER BUS
Main PCB
USB C
SD Card
Debug Header
MCU
POWER BUS
Altimeter
IMU
GPS
Telemetry
POWER BUS
Regulator
Antenna
Radio module
Battery Sensor
Battery
Display
Radio
Base Station
Wired
Power
Wireless
Jake
Lily
Zion
Hector
Sean

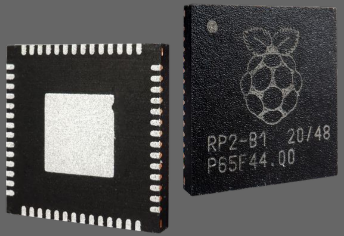
System Architecture

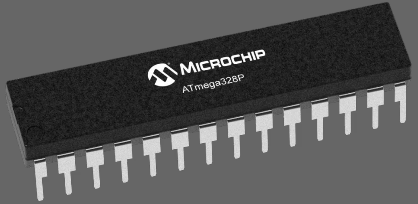
	Microcontroller	**FPGA**
Power Consumption	Preferred	Acceptable
Parallelization	Acceptable	Preferred
Peripheral Support	Preferred	Acceptable
Programmability	Preferred	Acceptable

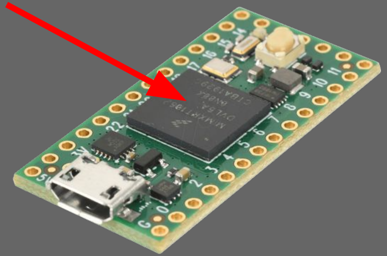
- We chose a microcontroller
  - Application does not need heavy computing power
  - Power consumption, peripheral support, and programmability are key to mission success.

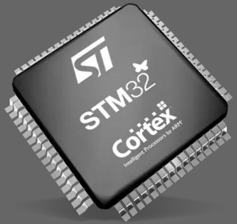
Microcontroller Selection

- Important Metrics:
  - Onboard Flash Size
  - Programmability (Arduino IDE)
  - Solderability (Pin Pitch)
  - Low Power Consumption
- Top Competitors:
  - RP2040
  - ESP32 (Wroom Series)
  - ATmega328P
  - i.MXRT1062
  - STM32F446









Microcontroller Selection

		RP2040	ESP32	ATmega328P	i.MX RT1062	STM32F446
2nd Highest	**CoreMark**	NA	994.26	NA	2314	608
	Dhrystone	NA	NA	0.0127	NA	225
Highest	**Flash Size (Onboard)**	0 kB	4 MB	32 kB	0	512 kB
2nd Highest	**RAM Size**	256 kB	520 kB	2 kB	1 MB	128 kB
Easiest (Tie)	**Programmability**	Medium	Easy	Easy	Medium	Difficult
Easiest (Tie)	**Solderability**	Medium	Easy	Easy	Difficult	Medium
3rd Lowest	**Power Consumed (mA/MHz)**	9.4	0.28	0.375	0.123	0.2
2nd Lowest	**Cost Per Unit ($)***	0.7	1.00 - 6.79	1.52 - 3.03	12.56 - 18.79	7.23 - 11.48

*Prices on Digikey as of 7/21/2024

Legend
1st Place
2nd Place
3rd Place
4th Place

Atmospheric Sensor Suite

Humidity Sensor Technology Selection

Technology	Accuracy	Resolution	Operating Range	Response Time	Cost
Capacitive	Great	Best	Best	Best	Great
Resistive	OK	Great	Great	Great	Best
Thermal	Good	Good	Good	Good	Good
Gravimetric	Best	OK	OK	OK	OK

Legend
1st Place
2nd Place
3rd Place
4th Place

Atmospheric Sensor Suite

Capacitive Humidity Sensor Selection

Sample->

Component	Accuracy	Resolution	Response Time	Power Consumption	Cost
HTU21D(F)	5% RH	0.04% RH	5 sec	450uA	FREE
HS3003	1.5% RH	0.01%RH	6 sec	24.4uA	$4.58
HTU31	2% RH	0.01% RH	3 sec	414uA	$4.76

Legend
1st Place
2nd Place
3rd Place
4th Place

Atmospheric Sensor Suite

Pressure Sensor Technology Selection

Technology	Accuracy	Resolution	Operating Range	Cost	Temperature Resistance
Mercury	Average	Average	Limited	Great	OK
Aneroid	Good	Average	Limited	Best	OK
Piezo (E/R)	Best	Great	Great	OK	Best
Capacitive	Great	Best	Best	Great	Great

Legend
1st Place
2nd Place
3rd Place
4th Place

Atmospheric Sensor Suite

Capacitive Pressure Sensor Selection

Component	Accuracy (Pa)	Resolution (Pa)	Pressure Range (mbar)	Cost ($)
ICP-10101	+/-1	0.01	30-1100	$3.67
MS560702BA01-50	+/-0.8	0.01	10-1200	N/A Bulk
MS580301BA01-00	+/-0.8	0.01	10-1200	FREE

Sample->

Legend
1st Place
2nd Place
3rd Place
4th Place

Atmospheric Sensor Suite

Anemometer Technology Selection

Cost is Crucial

Technology	Accuracy	Resolution	Response Time	Cost
Cup Type	Good	OK	Good	Best
Hot Wire	Good	Good	Best	OK
Sonic	Best	Great	Great	Bad
LiDAR	Great	Best	Great	Bad

Legend
1st Place
2nd Place
3rd Place
4th Place

Atmospheric Sensor Suite

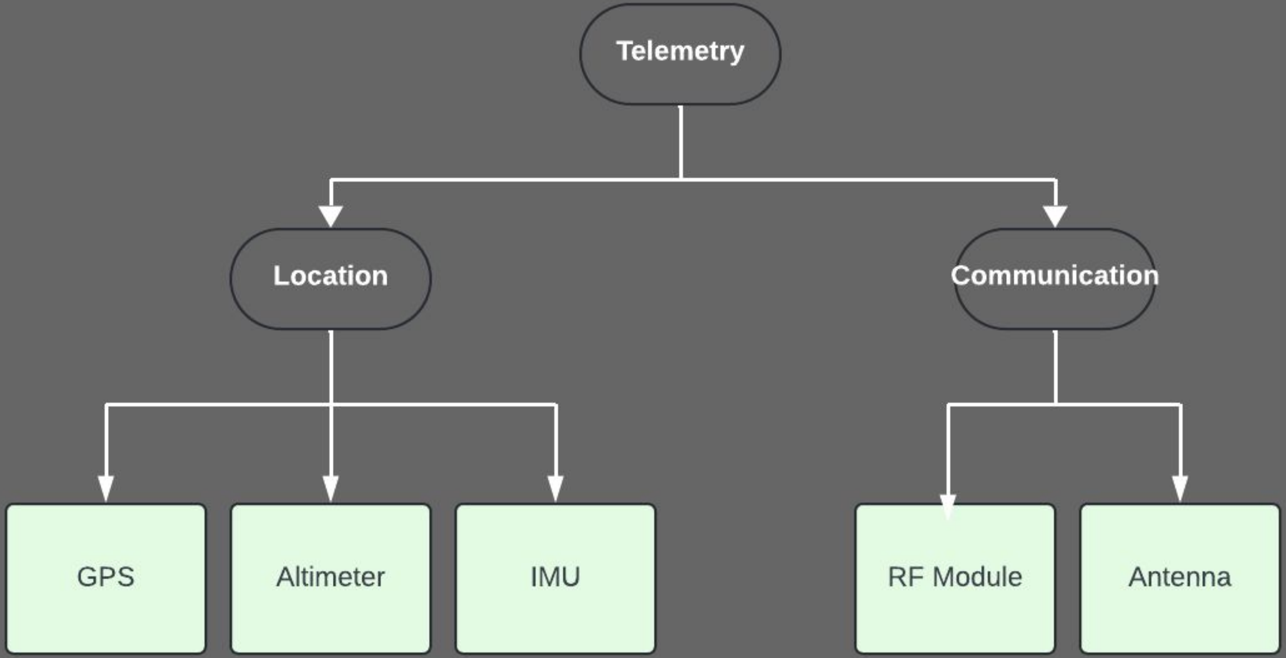
Anemometer Part Selection

Component	Accuracy	Size (in)	Operating Range (mph)	Cost
1733	+/- 0.3 mph	4.1x4	Up to 150	$44.95
Inspeed	+/- 1.0 mph	9x6x6	3 - 200	$69.00
NPN Pulse	+/- 0.2 mph	6.3x6.3	Up to 150	$19.80

Highest Operating Range

Legend
1st Place
2nd Place
3rd Place
4th Place

Telemetry Peripherals



Telemetry Peripherals

IMU Technology Choice

	FOG	MEMS
Bias Instability	Up to 0.0001°/hr.	Up to 0.1°/hr.
True North Positioning	Yes	No
Footprint	Large	Small
Weight	Heavy	Light
Cost (Vs competitor)	10X More	10X Less

Legend
1st Place
2nd Place
3rd Place
4th Place

Telemetry Peripherals

IMU Part Choice

	ICM20948	BNO086	ISM330DHCX
Gyro Drift over Temperature (dps/°C)	+/- 0.05	N/A	+/- 0.005
Acc. Drift over Temperature (mili-g/°C)	0.8	N/A	0.1
Gyroscope Update Rate (Hz)	9000	1000	6667
Accelerometer Update Rate (Hz)	4500	500	6667
Cost Per Unit ($)*	8.64	16.85	9.60

Legend
1st Place
2nd Place
3rd Place
4th Place

Telemetry Peripherals

Altimeter Technology Selection

Technology	Range	Accuracy	Ease of Implementation	Cost
Barometric	Best	Okay	Best	Best
GPS	Great	Good	Great	Great
Radar	Okay	Great	Okay	Good
Laser	Good	Best	Good	Okay

Legend
1st Place
2nd Place
3rd Place
4th Place

Telemetry Peripherals

Altimeter Part Selection

Altimeter	Range	Operating Temp	Accuracy	Cost
MS5611-01B A03	30 – 110 kPa	-40 °F to 185° F	±0.150 kPa	$12
LPS28DFW	26 – 406 kPa	-40 °F to 185° F	±0.05 kPa	$16
MPL311A2	50 – 110 kPa	-40 °F to 185° F	±0.400 kPa	$10

Cost is Crucial

Legend
1st Place
2nd Place
3rd Place
4th Place

Telemetry Peripherals

GPS Technology Selection

	Accuracy	Service Area	Legality	Cost
GNSS	Best	Best	Best	Free
Cellular Network	Not Best	Not Best	Not Best	Based on plan

Legend
1st Place
2nd Place
3rd Place
4th Place

Telemetry Peripherals

GNSS Part Selection

	MAX-M10S	NEO-F10N	ZED-F9P	SAM M8-Q
Altitude Ceiling (m)	80,000	80,000	80,000	50,000
Positional Accuracy (m)	1.5	1	0.01	2.5
Velocity Accuracy (m/s)	0.5	0.5	0.5	0.05
Heading Accuracy (°)	0.3	0.3	0.3	0.3
I2C	Yes	No	Yes	Yes
Multiband	No	Yes	Yes	No
Antenna on Chip	No	No	No	Yes
Cost Per Unit ($)*	21.00	49.00	129.00 - 138.00	31.00

Legend
1st Place
2nd Place
3rd Place
4th Place

Important

Telemetry Peripherals

RF Module Technology Selection

Framework	Data Access	Ease of Implementation	Cost
APRS	Best	Good	Best
LoRa	Good	Best	Good
Iridium	Worst	Worst	Worst

Legend
1st Place
2nd Place
3rd Place
4th Place

Telemetry Peripherals

Antenna Technology Selection

Antenna	Gain	Radiation Pattern	Ease of Implementation
Dipole	Okay	Best	Best
J pole	Great	Great	Great
Yagi	Best	Worst	Okay
Skew Planar	Worst	Good	Good
Iridium Satellite	Good	Okay	Worst

Legend
1st Place
2nd Place
3rd Place
4th Place

Power Supply

Battery Technology Choice

Battery	Energy Density	Temperature Stability	Cost
Lithium Ion	Great	Great	Good
Lithium Polymer	Good	Good	Great
Lithium Iron Phosphate	Okay	Okay	Good
Alkaline	Worst	Worst	Best
Lithium Sulfur Dioxide	Best	Best	Worst

Legend
1st Place
2nd Place
3rd Place
4th Place

- **Failure of this system means an almost certain loss of product**
- **Temperature & Capacity were the most important parameters**

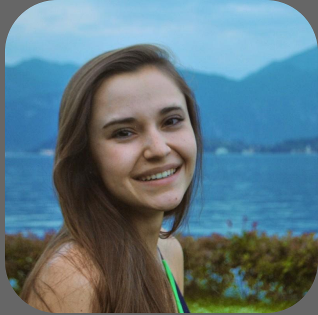
Power Supply

Voltage Regulator Part

Operation Mode	Supply Voltage (V)	Operating Temp. (C)	Current Draw (uA)	Cost (USD)
LT1242CS8	10-25	0-100	7	$9
LT1339CSW	12	0-70	14	$14
TSP62142	3-17	-40-125	17	$2

Legend
1st Place
2nd Place
3rd Place
4th Place

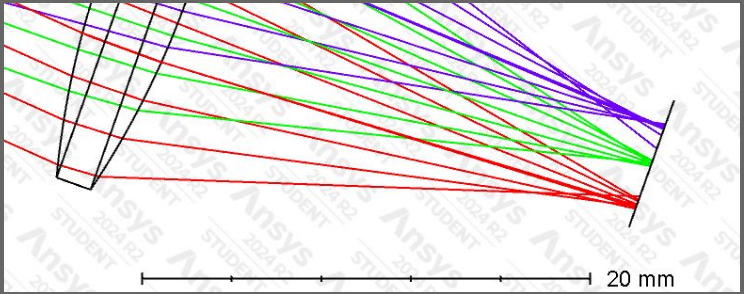
Optical Emission Spectrometer



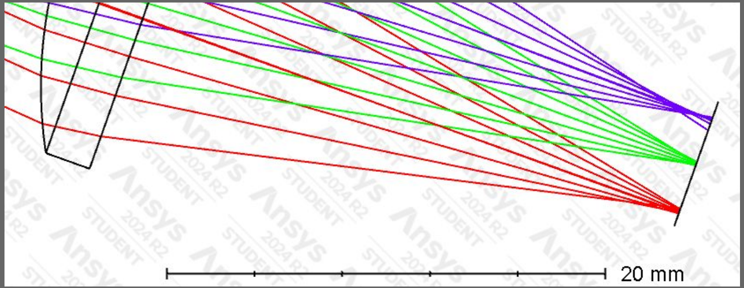
Lens Design Selection

Component	Average Cost	Wavelength Range (nm)	Applicability
Bi-Convex	$37	350 - 2200	moderate
Bi-Concave	$30	350 - 2200	low
Plano-Convex	$28	350 - 2200	high
Plano-Concave	$35	400 - 2200	low

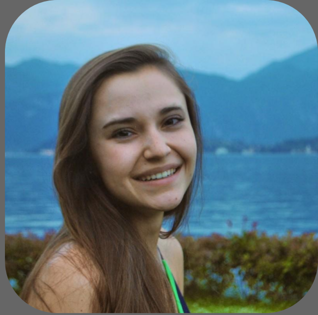
This option is the cheapest on average, within the preferred wavelength range, and as shown on the right, is more precise compared to the bi-convex lens.



Bi-Convex



Plano-Convex

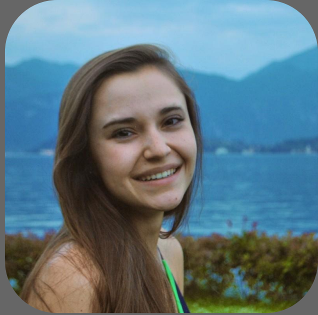


Optical Emission Spectrometer

Diffraction Grating Selection

Type	Spectral Range	Cost	Groove Density
Ruled	Best in ultraviolet or specified singular wavelengths	~$15 (education-grade) ~$150 (industry-grade)	best below 600 lines/mm
Holographic	Best in ultraviolet into visible	~$15 (education-grade) ~$150 (industry-grade)	best below 600 lines/mm

The resolution tends to be generally better and the project specifications call for UV into VIS range.



Optical Emission Spectrometer

Detector Selection

Component	Wavelength Range (nm)	Peak Wavelength (nm)	Cost	Radiant Sensitive Area (mm^2)
Si Pin Photodiode	430 – 1100	800	$50	18.6
IR Photodiode (C10439-03)	190 – 1100	960	$907	100
InGaAs Photodiode	900 – 1700	1550	$100	6.45

Legend
1st Place
2nd Place
3rd Place
4th Place

The silicon option is not only the cheapest but also falls within the proper wavelength range. The range of wavelengths being detected are between 460nm and 768 nm, so the peak of 800nm falls the closest.

ESP32 IDE/Software Selection

- Important metrics:
  - Language Complexity
  - IDE/Software Compatibility and Flexibility
  - External Support
  - Ease of Use

- Possible Options:
  - Arduino IDE
  - ESP-IDF
  - Simulink
  - MicroPython

ESP32 IDE/Software Selection

IDE/Software	Language Complexity	Compatibility and Flexibility	External Support	Ease of Use
Arduino IDE (C/C++)	Good	Good	Best	Best
ESP-IDF (C/C++)	Good	Best	Good	Good
Simulink (MATLAB)	Bad	Worst	Bad	Bad
MicroPython (Python)	Best	Bad	Bad	Worst

Legend
1st Place
2nd Place
3rd Place
4th Place

Data Processing/GUI Software Selection

- Important metrics:
  - Capabilities
  - External Support
  - Ease of Use

- Possible Options:
  - C#
  - Python
  - MATLAB

Data Processing/GUI Software Selection

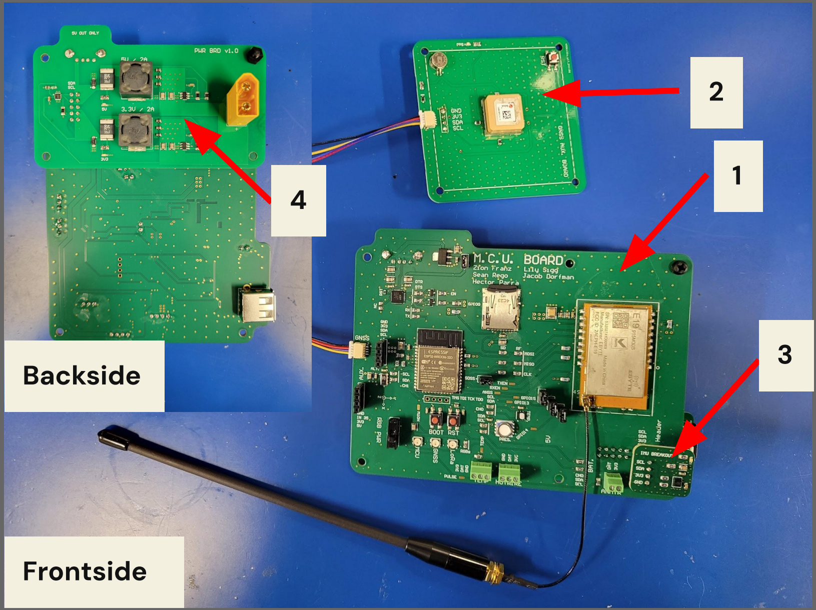
Software	Capabilities	External Support	Ease of Use
C#	Best	Good	Worst
Python	Good	Best	Best
MATLAB	Bad	Bad	Good

Legend
1st Place
2nd Place
3rd Place
4th Place

The Balloon Payload System (B.P.S.)

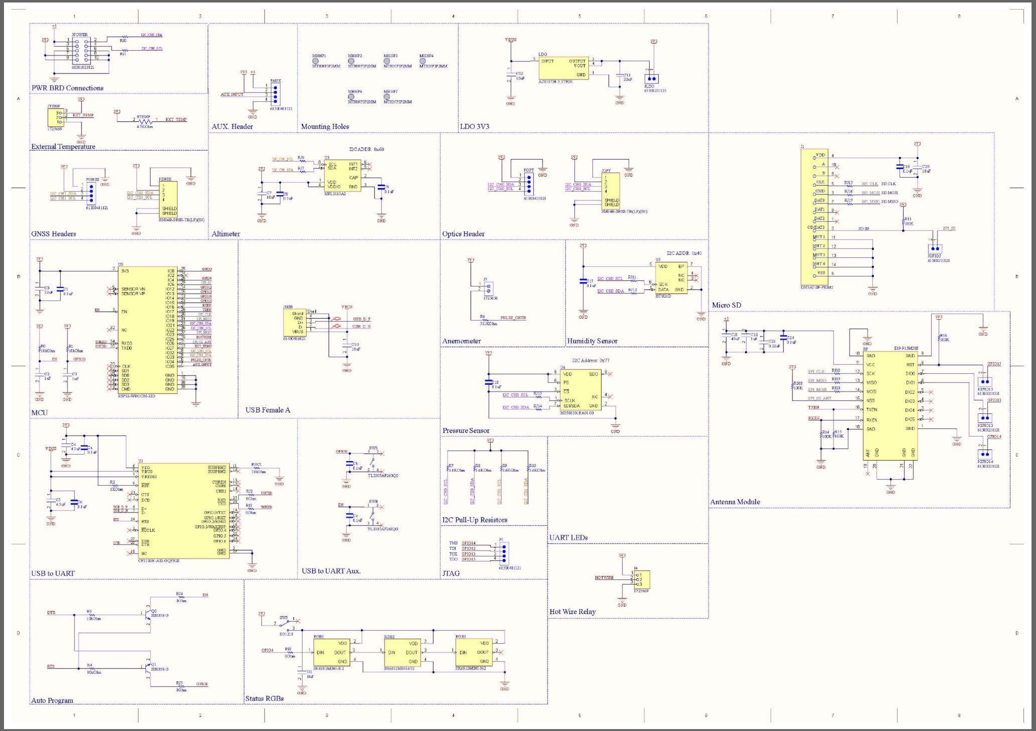
- Consists of Four Boards:
  - MCU Board (1)
  - GNSS Board (2)
  - IMU Board (Frontside MCU Board) (3)
  - Power Board (Backside MCU Board) (4)

- Provides a backbone for a variety of experiments.
  - Power & I2C supplied over auxiliary headers.
  - External temperature sensor support.
  - Rapid Deflation Device (RDD) support.



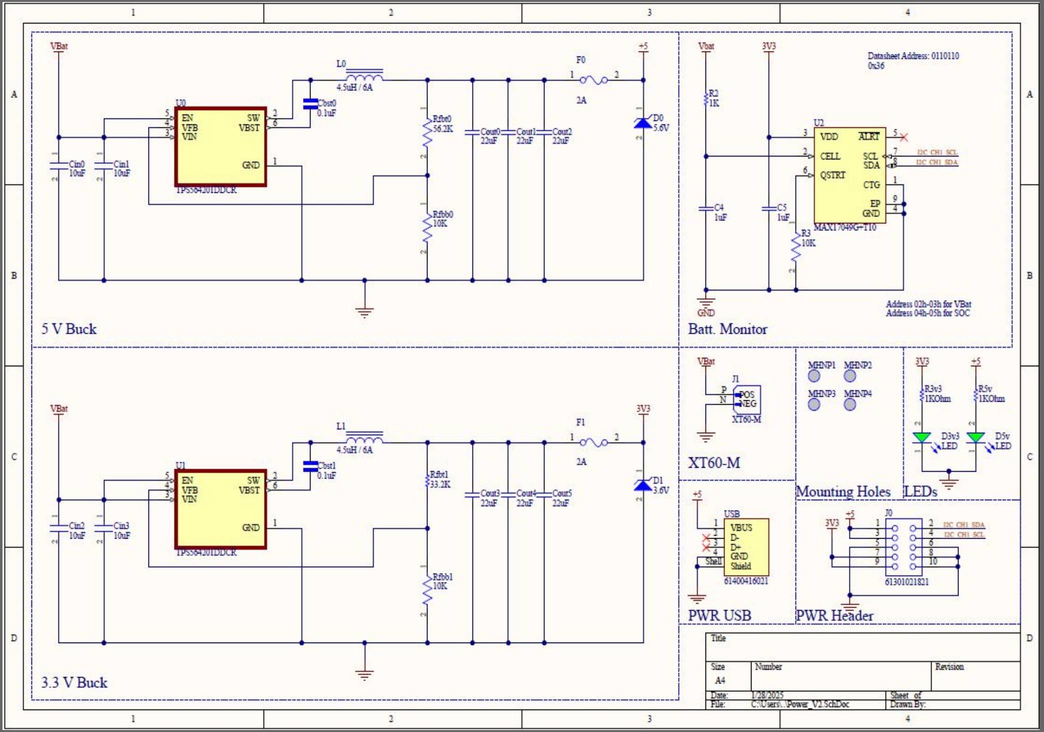
MCU Board Overall Schematic

- Contains all atmospheric & telemetry peripherals except:
  - GNSS
  - IMU
  - Anemometer
- GNSS module is on a seperate board due to its special ground plane and shielding requirements.
- IMU is mounted on a seperate board for ease of solderability due to high pin density.
- Anemometer interfaces via screw terminals.

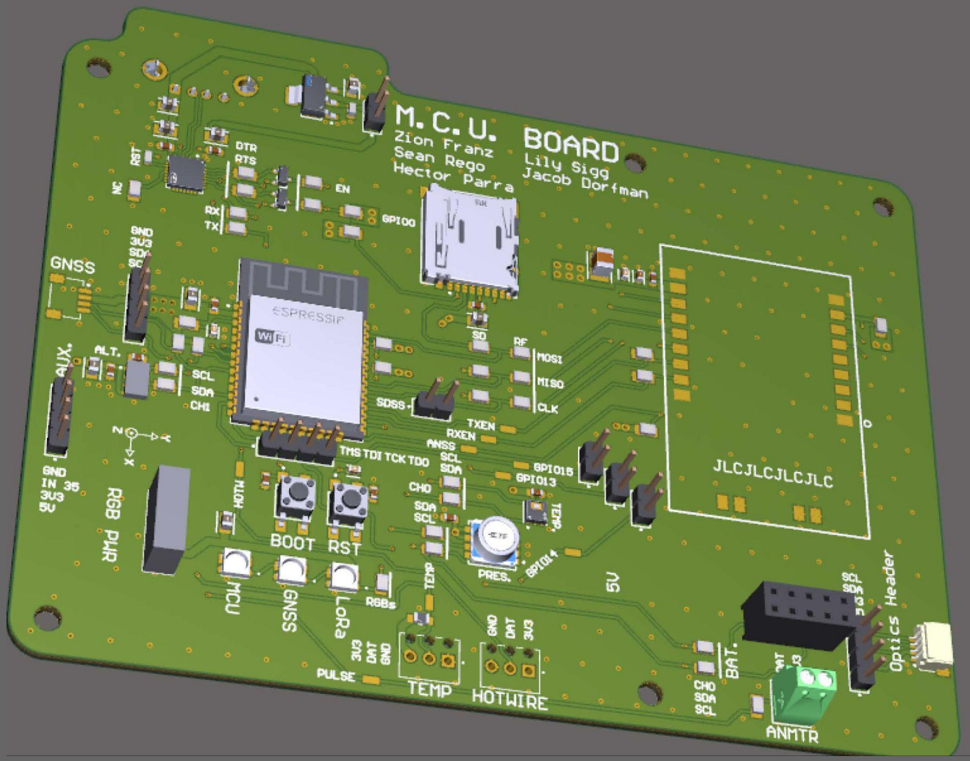


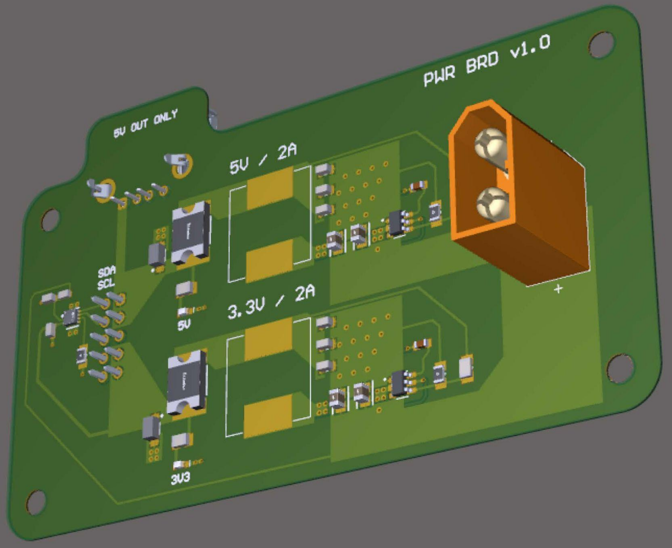
Power Board Schematic

- Buck Converter Topology
- 3.3 V & 5.0 V.
- Low switching frequency (~500 KHz).
- Outputs protected via zener diodes & fuses.
- 2 Cell Lipo Battery State of Charge monitor.

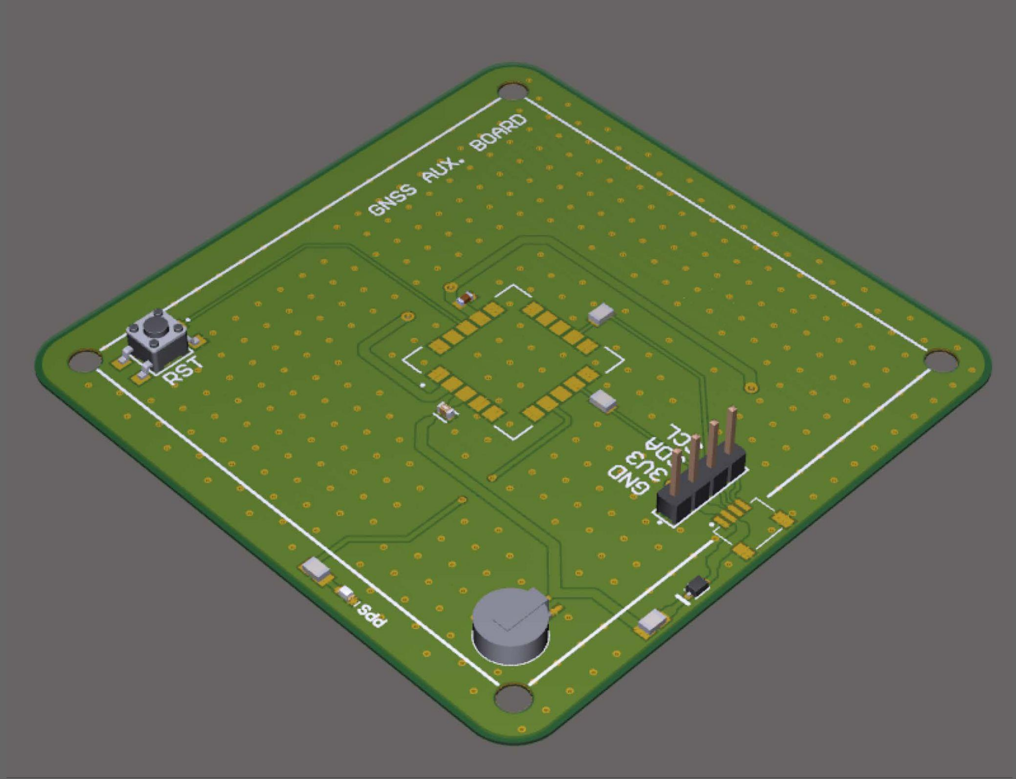


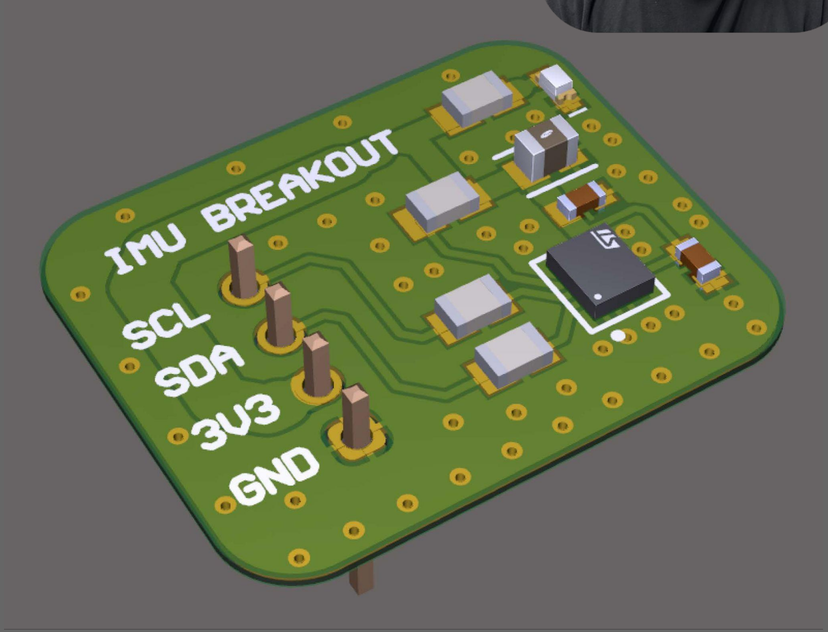
MCU & Power Boards



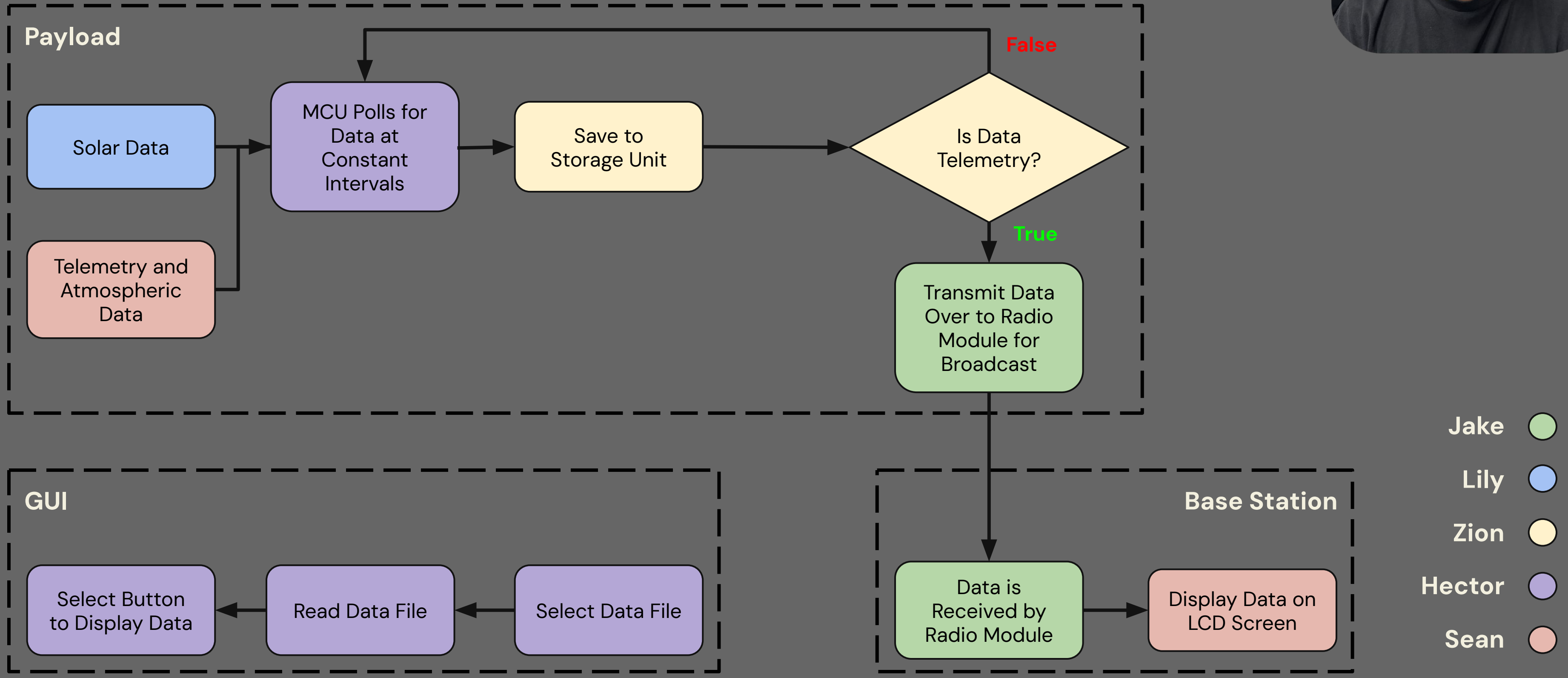


GNSS & IMU Boards



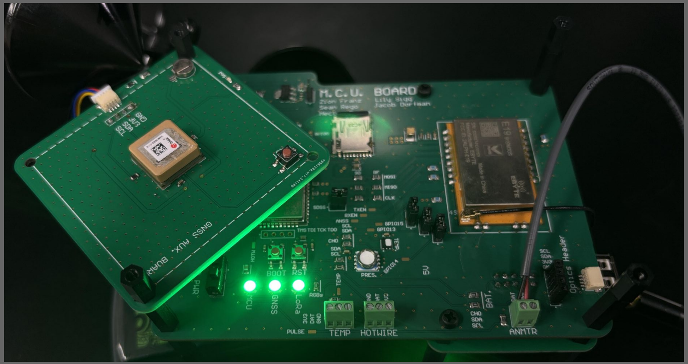


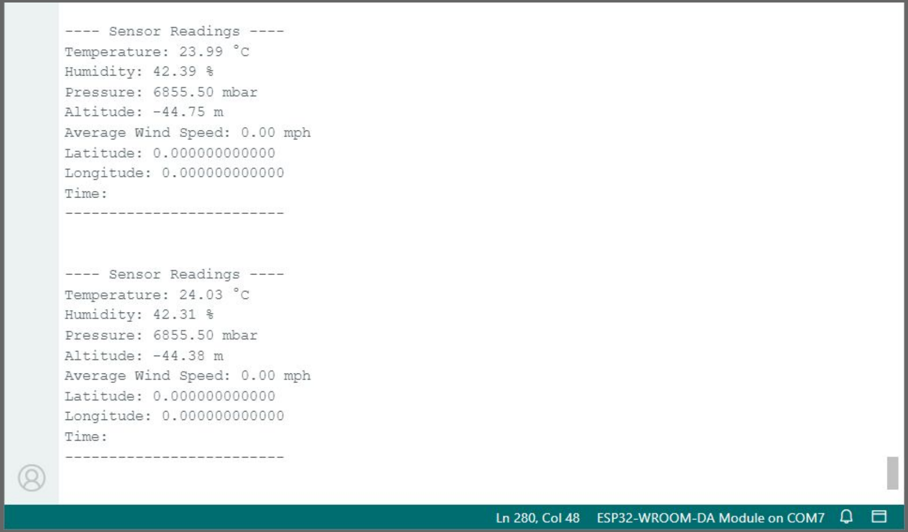
Software Diagram



Payload

- Important tasks:
    - Poll Data at Constant Intervals (15s).
    - Save and Organize Data in a CSV File.
    - Transmit Data Via Radio To Base Station.
    - Give Status Lights for Important Modules (MCU, GPS and Radio)



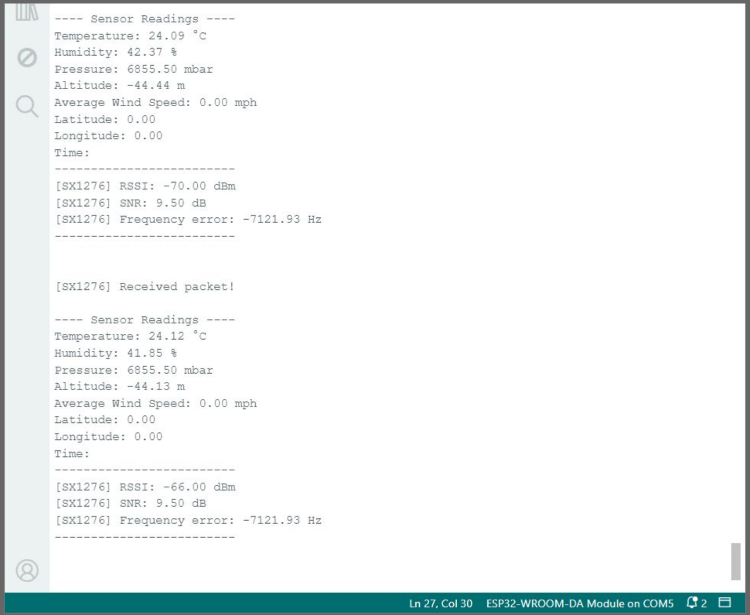


```
---- Sensor Readings ----
Temperature: 23.99 °C
Humidity: 42.39 %
Pressure: 6855.50 mbar
Altitude: -44.75 m
Average Wind Speed: 0.00 mph
Latitude: 0.000000000000
Longitude: 0.000000000000
Time:
-------------------------


---- Sensor Readings ----
Temperature: 24.03 °C
Humidity: 42.31 %
Pressure: 6855.50 mbar
Altitude: -44.38 m
Average Wind Speed: 0.00 mph
Latitude: 0.000000000000
Longitude: 0.000000000000
Time:
-------------------------
```

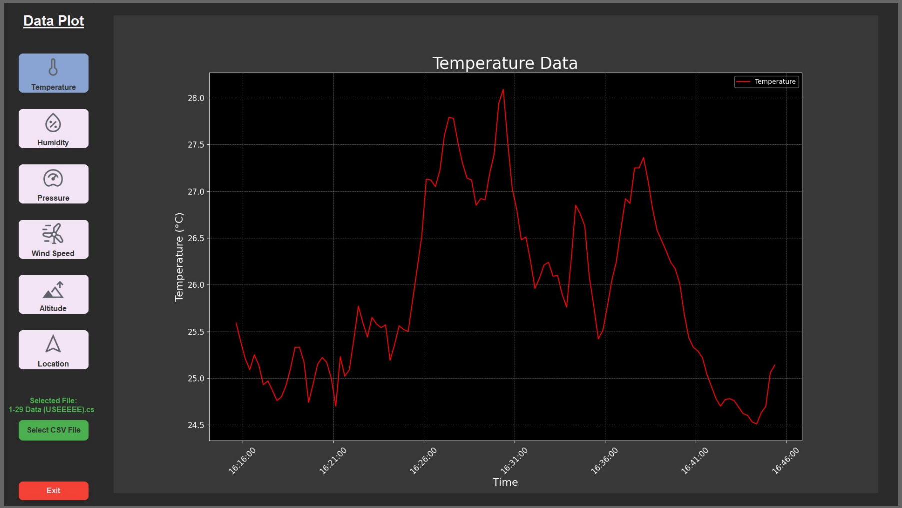
Base Station

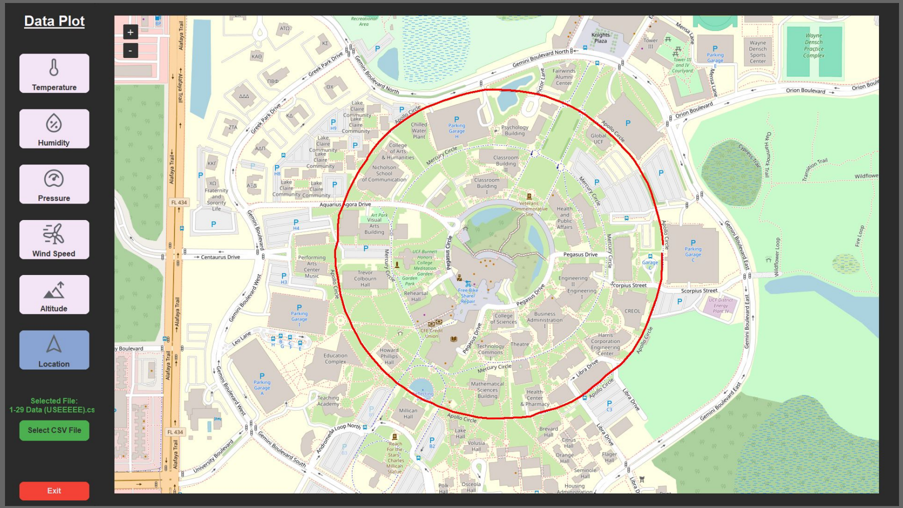
- Important tasks:
  - Receive Data Transmitted from Payload.
  - Show Received Data Using LCD Screen.
  - Use Buttons to Toggle Through Data Being Displayed



GUI

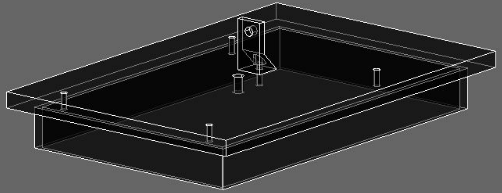
- Important tasks:
  - Prompt User to Select Data File (CSV File).
  - Toggle Through Plotted Data By Using Buttons.





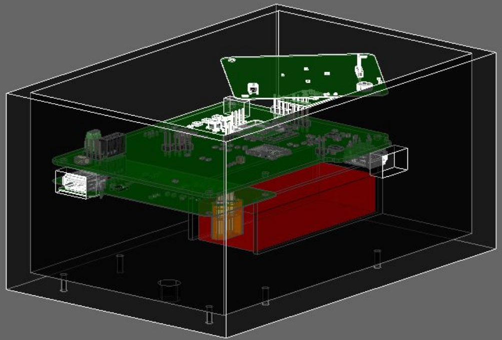
Mechanical Systems

- Several enclosure iterations were designed and 3D printed.



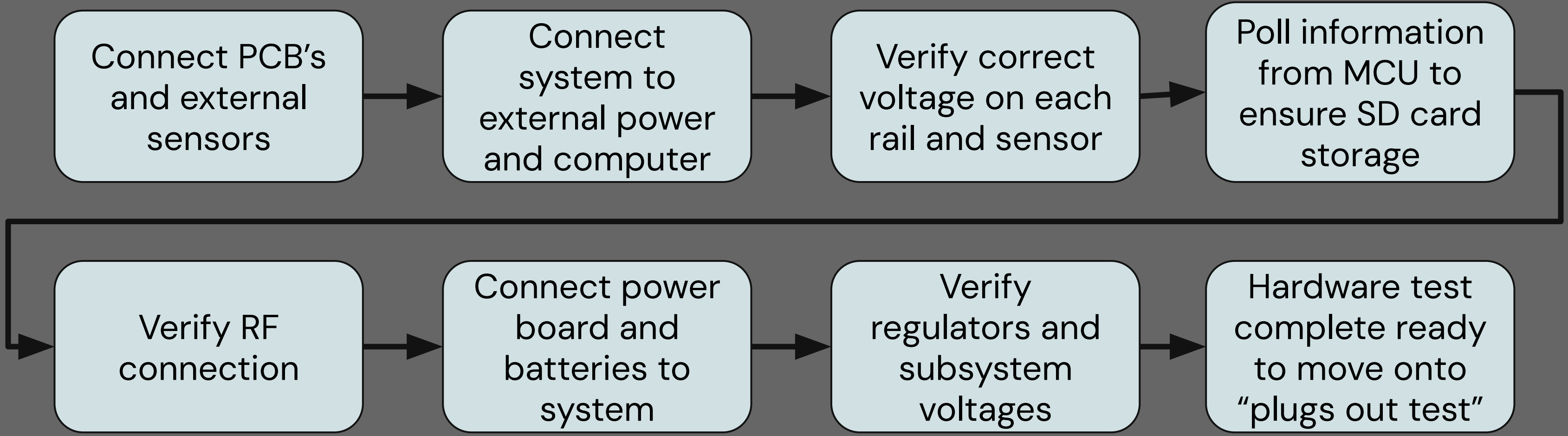
- One box encases the entire payload.

- Another specially made black box was fabricated to shield the spectrometer from unwanted ambient light.



1. System Overview
2. Hardware & Software
3. PCB & Software Design
4. **Testing**
5. Administrative Content

Hardware Testing



Software Testing

Connect PCB's and external sensors → Connect system to external power and computer → Run script to poll each sensor → Verify data received from sensor → Compare data to second reliable source → Verify full RF transmission and storage of sensor data → Software test complete ready to move onto "plugs out test"

Plugs Out Test / Performance Evaluation

- Demonstrate all systems and operational procedures in as near a flight configuration as is practical and to verify their capability in a simulated launch
- During this test, showcased in our SD1 Mini Demo, we verify all subsystems and power work together to gather, transmit and store data in a full system level launch simulation test.

Component	Parameter	Specification	Met / Not Met
Radio	Communication Range	100 feet	Met
Anemometer	Measurement Range	5 – 25 mph	Met
Temperature Sensor	Accuracy	+/- 10 °C	Met
Humidity Sensor	Accuracy	+/- 10% RH	Met
Pressure Sensor	Accuracy	+/- 10 mbar	Met
Altimeter	Vertical Accuracy	+/- 2 meters	Met
GNSS System	Horizontal Accuracy	+/- 10 meters	Met
IMU	Bias Instability	6 deg/hr	Met

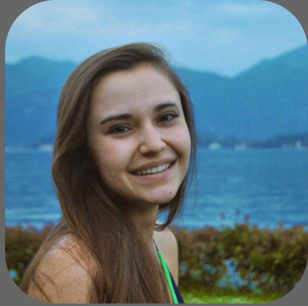
Successes and Challenges

SUCCESSES

- Achieved an on ground communication range of approximately 600 feet
- Full systems test complete
- Data interacts interacts and displays on GUI

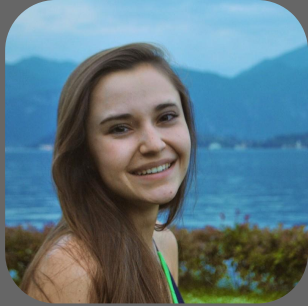
CHALLENGES

- Difficulties familiarizing ourselves with the equipment and verifying data
- Cooked RF Module during soldering
- Error in PCB text resulting in some confusion



Optical Testing

Simulation is run in Zemax → Components are aligned on an optical table → Collimated halogen lamp is used to prove the concept → 3D component holder is designed in CAD & printed → Components are mounted in 3D model → Collimated halogen lamp is used to prove model concept → Model is tested with Na & K flame → Model is tested with artificial sun source → Revisions made as needed

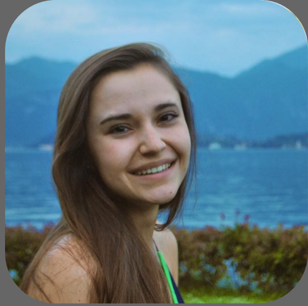


Performance Evaluation

- Using various types of greenery and the Na & K metals, the spectrometer was tested for the parameters below
  - Roughly 1.25 ft detection distance
  - 20,000+ mcd light source
  - Wavelength range and accuracy are proper
- Further testing and evaluation is underway

Optical Specifications			
Component	**Parameter**	**Specification**	**Met/Not Met**
System	Detection Distance	> 1 foot	Met
Detector	Wavelength Range	430 nm – 1100 nm	Met
	Accuracy	+/- 10 nm	Almost Met
Light Source	Required Intensity	> 10,000 mcd	Met

Successes and Challenges



SUCCESSES

- Resolving a full visible spectrum
- Collecting adequate light
- Stable optical containment
- Concept is generally proved

CHALLENGES

- Wavelength accuracy is slightly off
- Diffraction grating is extremely scratched, meaning fuzzy lines
- Full system is heavier than anticipated

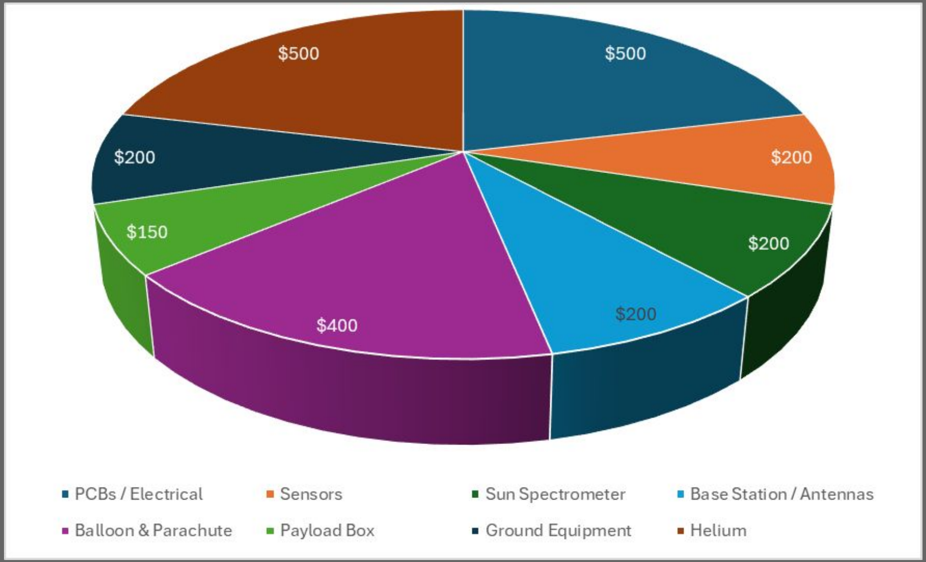
GOING FORWARD

- CMOS needs calibration
- New diffraction grating needs to be found/ordered
- Thinner interior structure on the 3D prints to accommodate for the heavy lenses

1. System Overview
2. Hardware & Software
3. PCB & Software Design
4. Testing
5. **Administrative Content**

Budget

Sub-System	**Cost**
PCBs / Electrical	$500
Sensors	$200
Sun Spectrometer	$200
Base Station / Antennas	$200
Balloon & Parachute	$400
Payload Box	$150
Ground Equipment	$200
Helium	$500
Total	**$2,350**



Condensed Work Distribution

Zion Franz	MCU Design
	GNSS/IMU
	Launch Coordinator
Jake Dorfman	Power Design
	Communications Design
Lily Sigg	Spectrometer
Hector Parra	Software
	Base Station Design
Sean Rego	Temperature, Air Pressure, Altimeter Design
	Anemometer, Humidity

Progress Report

Milestones