OVAL - Phase 1

Great Lunar Expedition for Everyone (GLEE) Lunasat development

Colorado Space Grant Consortium

University of Colorado Boulder Electrical Engineering

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Contents

Project Description

The Luna Sat project is intended to provide a low cost sensor platform with the ability to be deployed to and operate on the lunar surface while providing students with a development board for learning and experimenting through both programming and physical testing.

Elevator Pitch

Previous lunar missions have had to limit data collection to individual probing sites at different time intervals (I.E a rover would drive to a science site, collect data, then drive to a new science site). The Luna Sat's mesh network will spread across 2500m^2 of lunar surface and collect simultaneous real-time data from at least 50 different points of interest. Such a network will improve the resolution and reliability of data collected by averaging values across the network and communicably verifying results.

If our Luna Sat design does not end up being deployed for Lunar exploration, the boards have been designed with students in mind to sponsor open-source development. Each Luna Sat has solder and probing points allowing for the modular addition of programming equipment so students may experiment and learn from the technology within each Luna Sat.

Product Features

The Luna Sat enables planetary scientists to simultaneously gather accelerometer, magnetometer, capacitance, and temperature data from various points of interest across the lunar surface. Each Luna Sat is equipped to operate under the harsh temperature, radiation, and solar-radiance using tested solar-panels with an energy harvesting unit to improve power production and specially selected consumer-grade products. Additionally, each Luna Sat houses a RF transmitter for data transmission up to 60km for communication with a lunar base station (To Be Determined). For more information on the technologies used see 1

Cool technologies

The Luna Sat is a development tool and prototype designed with the ultimate goal of being deployed in quantities of at least 50 individual units on the lunar surface. The Luna Sat's cool factor is that it uses off the shelf components at minimum power draw on a compact footprint. The Luna Sat is intended to survive a wide range of the environments that we expect to see on the region of the lunar surface that we expect to deploy to. The solution that Team Oval is developing will provide the GLEE - Colorado Space Grant team with a solid platform upon which they can perform final environmental studies.

Phase 1 prototype

The phase 1 prototype provided an outlook to how the selected components behave with one-another within our preliminary-design circuit. Our two largest risks within the prototype were the PMICs ability to produce enough voltage and current within the lower range of the solar panels operating limitations and the current-draw from the RF-transmitters. Our phase 1 prototype tested both concerns by proving the PMIC is capable of providing enough power to the circuit provided sufficient input voltage which the Solar Panels can manage to supply.

Test Results

Those are our proof of concept test results for testing RF and PMIC systems

The following section provides a summary and comprehensive description of our test plans that can be found in Appendixes 4-5

Networking Test

During our first Proof of Concept, we tested the following engineering requirements: Sampling the temperature sensor (#5) and using RF to establish a network (#7). Both of these tests were successfully demonstrated and brought light to future considerations.

In the first part of our test we have two microcontrollers, one collecting temperature data and the other transmitting some arbitrary data. Each are connected to a LoRa Module. We used an Adafruit Feather M0 with its own LoRa module to act as our base station and request data from each uniquely identified LunaSat. The setup is shown below.

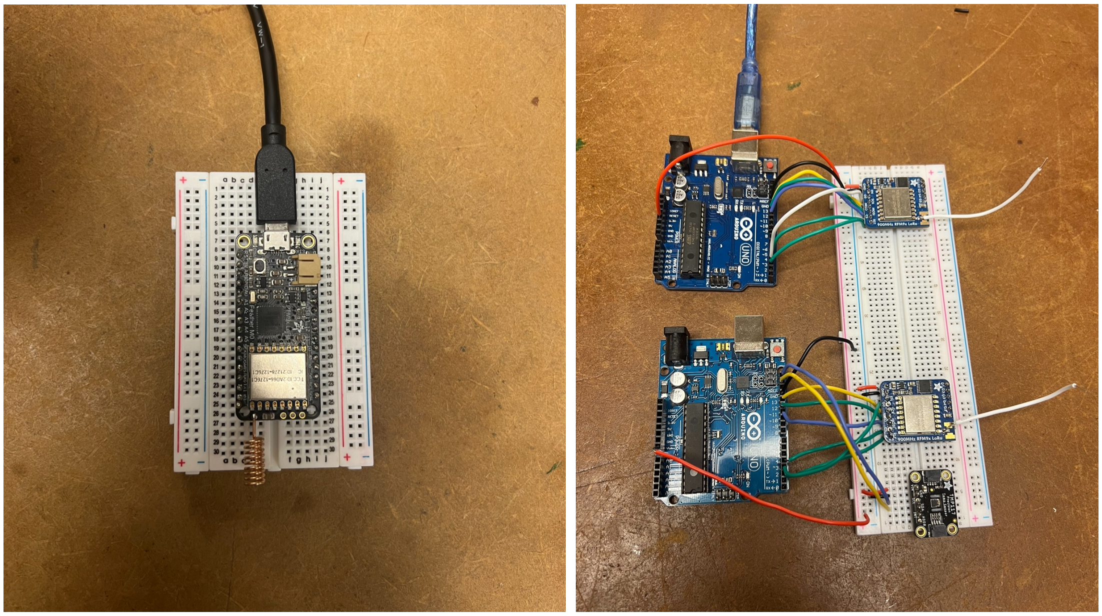


Figure 1: Base Module (left) and mock LunaSats (right)

We successfully demonstrated the ability to request data from a specific LunaSat, send that data back to the base module, function after power is lost and turned back on, and trigger interrupts. Each test resulted in our expected outcome and helped us gain confidence in our approach. We now know we can move forward with specific design techniques such as a unique identity for each LunaSat that can then filter out requests from the base module that were meant for other LunaSats. This approach saves a lot of power on each LunaSat because instead of trying to transmit every so often it will have an interrupt-triggered wake-up that on average will draw a lot less current.

The second part of our test involved measuring the current consumption of a single LunaSat while it is passively waiting for a data request and when it finally receives that request and transmits the data back out. To measure the current consumption we used the INA219 connected to a single LunaSat containing a LoRa module and TMP117 temperature sensor. The TMP117 has a very low current draw on the order of uA so it is practically negligible compared to the current draw of the LoRa module which is on the order of mA. The setup is shown below along with the base module that sent the data requests.

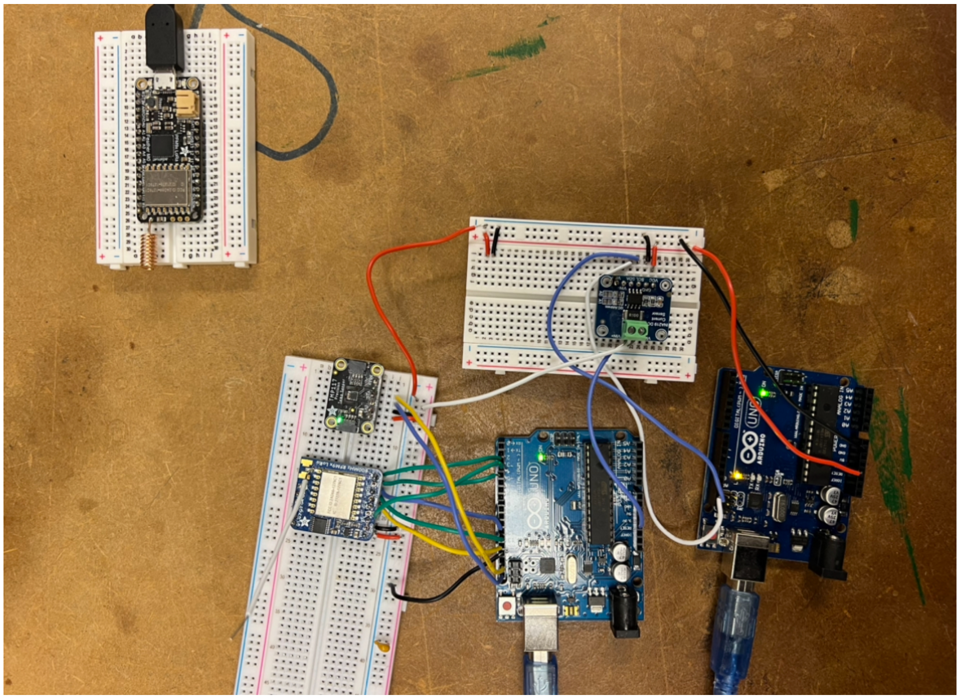


Figure 2: INA219 Measuring Current Consumption of a single LunaSat

Through this test, we were able to verify the LoRa Module's datasheet specs for peak current consumption and learn about how the Received Signal Strength Indicator (RSSI) is affected with distance from base module. From these results, we know we have to operate the LoRa module in a lower transmission mode that would likely only draw 29 mA of current but will have a lower signal boost. This requires custom hardware that will be implemented in our next iteration. We will also need to recharacterize the RSSI vs distance in this new mode.

Figure 3: Test Results of Measuring RSSI at Different Distances

Overall the confidence in our design has drastically increased and we feel comfortable moving forward with our initial plans. We still have some consideration and customization to test with the hardware including PCB layouts and antenna designs, but we feel we have the necessary tools to succeed in this area.

PMIC Test

In our second Proof of Concept test, we focused on evaluating the engineering requirement of Voltage and Current regulation using a PMIC. This particular requirement entailed the PMIC's responsibility to regulate the voltage and ensure maximum power supply for the circuit's operation in energy-deprived conditions on the lunar surface. The test's successful demonstration granted us a deeper comprehension of the necessary modifications and the elements worth preserving.

The primary objective of Test #1 was to assess the cold start functionality of the PMIC in isolation, without any load connected to it. The experimental setup for this test was relatively straightforward. It involved connecting the PMIC to a power supply, while the output of the PMIC was linked to a digital multimeter (DMM). In this test, our anticipated values indicated that once supplied with a voltage of 380mV from the power supply, the PMIC would initiate a cold start process and subsequently generate an output voltage of 3.3V.

Following the increase in the supplied voltage to 380mV, the PMIC failed to produce any output voltage. Consequently, this indicates the failure of test #1, as there was no voltage output from the PMIC, implying that the 380mV was insufficient for the cold start. Prior to conducting the tests, we were aware that certain tests were likely to fail due to the precise and low values being tested, making them susceptible to errors. To account for this, we devised additional tests as contingency measures in the event of a test failure.

This brings us to the second test, where we aim to increase the voltage gradually until the cold start cycle initiates, and then document the precise voltage required for the cold start. The setup remained identical to that of the first test. As the initial voltage of 380mV proved insufficient, we systematically raised the supplied voltage in increments of 10mV until we obtained a response from the PMIC. This process led us to a voltage of 420mV, which was determined to be the minimum voltage necessary to get an output from the PMIC.

Having established that a voltage of 420mV is required for the cold start, we can now proceed to conduct test #3. In this test, the objective was to introduce a load to the PMIC while it was powered off, and increase the voltage to the previously determined value for cold start. The load was a sample circuit designed for this particular test. This circuit was constructed on a breadboard and consisted of our accelerometer, magnetometer, and microcontroller on breakout boards. To ensure the functionality of the microcontroller, we programmed it with a blinky code and incorporated an LED to serve as an indicator. The anticipated outcome of this test was to provide the PMIC with 420mV and enable it to supply the circuit with 3.3V, thereby facilitating the operation of both the microcontroller and the sensors. The test setup remained relatively the same with the breadboard load now connected to the output terminals of the PMIC connected to the top power rail of the load. The figure below shows the setup employed for conducting all tests.

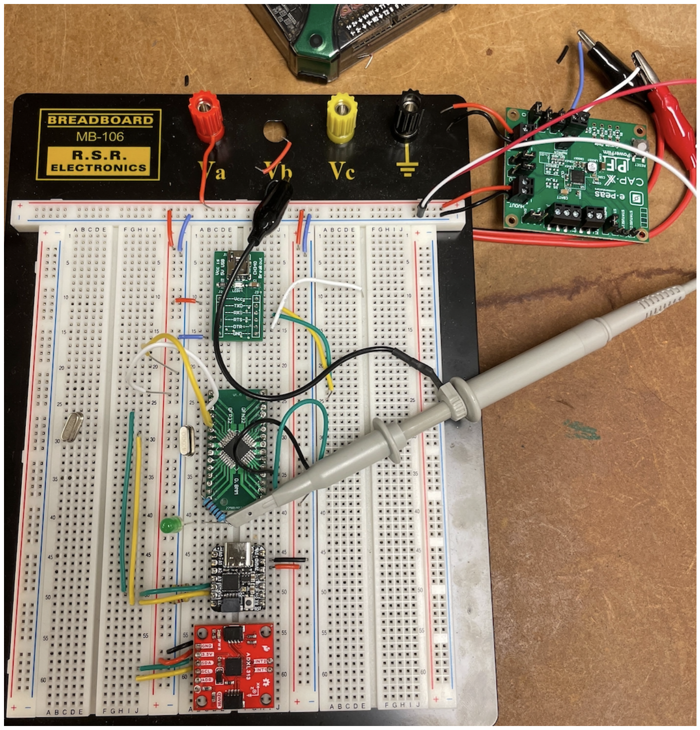


Figure 4: PMIC Test Setup

Upon the completion of test #3, it became apparent that a voltage of 420mV was sufficient for the initial cold start cycle of the PMIC. However, it was observed that the PMIC only produced an output voltage of 1.5V instead of the expected 3.3V, and the current draw was approximately 20mA. Consequently, the LED did not blink, indicating that the microcontroller did not receive an adequate voltage to function properly. Test #4 was to reduce the input/supply voltage to 120mV (the minimum voltage expected for the PMIC to remain functioning) to determine if the PMIC could still deliver the required 3.3V. However, due to the failure of test #3, it was anticipated that test #4 would also yield unfavorable results, as even 420mV proved insufficient to power the circuit. Subsequently, upon decreasing the voltage from 420mV to 120mV, a significant decrease in the output voltage was observed, with the PMIC's output dropping from 1.5V to 0.4V.

This brings us to our final test, which was test #5. This particular test served as an additional measure in case test 4 proved unsuccessful. Test #5 aimed to determine the lowest operational voltage after the cold start. The setup for this test mirrored that of tests 3 and 4. Once again, we gradually increased the voltage by increments of 10mV until we observed the LED initiating its blinking pattern. At this point, we stopped the voltage incrementation and settled on a supply voltage of 850mV. This test conclusion led us to the realization that we required an 850mV supply voltage from the solar panels, surpassing our initial expectations of 380mV or even 420mV. The tests conducted allowed us to form an expected baseline for the voltage requirements of our system. Despite not having all sensors connected to the load, based on data sheets, we can expect a 1-1.2V requirement to power the entire circuit through the PMIC. This new baseline voltage range has confirmed that even under lackluster solar panel operating conditions, with the proper positioning of our array, we will be able to guarantee the boards receive the minimum operating voltages at all times during their deployment.

The future

In phase 2 we begin development of our custom hardware and software.

SX1276 Board

Starting with our own custom design around our RF chip (SX1276). This will allow us to fully utilize the SX1276's lower power transmit mode, which is not accessible on our current test module. This custom SX1276 board will also allow us to characterize antenna performance across different configurations, which will help us when trying to decide our final configuration. Further characterization of RSSI vs distance will be tested along with RSSI vs packet loss. It will be crucial to know the valid RSSI ranges in order to verify the integrity of our data. If needed, some packet correction techniques may be implemented.

I2C Sensor Test Board

We will also be developing an I2C board consisting of all sensors that will be on the final LunaSat. This board will allow us to fully measure the power consumption that the I2C system will require, as well as allow us to begin writing software for our LunaSat. For example, we will need to write I2C drivers for our magnetometer, begin planning on how we will utilize our EEPROM to form packets and develop a schedule/process for sensor polling.

LunaSat V1

After the development and testing of the previously described boards, we will begin designing our first LunaSat board, which should be very similar to our prototype LunaSat with the exception of having all sensors and full functionality. The I2C and RF boards should reduce uncertainty dramatically as they will give us a good foundation for our actual LunaSat design. More specifically, our custom SX1276 board will be a great guide for our RF design decisions.

Challenges

Along the way so far, we have encountered numerous challenges in meeting the initial requirements defined for the project by the Colorado Space Grant.

Energy harvesting

The largest recurring challenge with the system was the ability to power the unit at the lunar latitudes which we expect it to be deployed, within 6 degrees of the lunar pole. The location of deployment means that the configuration of the panels and their orientation had to be adjusted from the original vision presented by our sponsor. This means that we have to sacrifice both mass and volume with increases in both. Through exhaustive analysis of performance and location data we have determined the final solar panel part to be used along with a PMIC and the configuration of this system such that we can guarantee a supply at all targeted times to meet the load as given by the system data-sheets.

Power Minimization

The nature of the intended deployment on the lunar surface limits our power resources to what can be supplied through our solar panels. In order to accommodate this our system needs to take advantage of the low power modes available for our sensors and components. Implementation of all of these operation modes has provided us with ongoing challenges in configuring and setting up all of our systems to operate at these power levels. As we continue into Phase II we will focus particularly on dialing in the Lora communications and ATMega328 microcontroller at a power of 2.1 so we can operate under a maximum power draw of 88 mW.

Microcontroller Bootload

Bootloading the microcontroller proved to be a challenging task because neither of us had any previous experience with this task. It took a lot of research and many failed attempts before we stumbled upon an open-source library that allowed us to configure bootload settings for our microcontroller in an easy and straightforward fashion.

MiniCore library concentrates on ATmega328 microcontroller bootload - `https://github.com/MCUdude/MiniCore/blob/master/README.md`

Conclusion

As a team, we learned a lot during this semester. Whilst there was a lot to learn about microcontroller bootloading, energy harvesting with solar panels and PMIC, different sensors, and RF communication, the most important outcome of this learning experience was working under a sponsor.

As can be seen from Appendix 2, a lot of effort went into understanding and defining the project that was given to us. We learned how to decompose the project into smaller parts and what steps to take in order to fulfill the requirements of the project.

Furthermore, we learned how to appropriately communicate with a project's sponsor in regard to any updates, requesting information, and redefining initial design constraints due impossibility of fulfilling them because of contradicting instructions, time limitations, budget limitations, or any other possible reason.

Overall it was a great semester, and we are proud to work on such an ambitious project!

Appendix

Appendix 1 - Component List

№	Component name	Part reference
1	Microcontroller	*ATmega328pb*
2	Temperature	*TMP117*
3	Magnetometer	*AK09940A*
4	Accelerometer	*ADXL313*
5	Capacitance sensor	*IQS228B*
6	RF Transceiver	*RFM95W LoRa*
7	Solar Panels	*ANYSOLAR SM141K06L*
8	PMIC	*AEM10941*

Table 1: Component list

Appendix 2 - MRD & ERD

1 Revision History

1.1 Revision Date: Sept 21st. 2023

1.2 Revision Date: Dec 15th. 2023

2 Team Roles and Responsibilities

1) Sponsor: **Space Grant**
2) Team number: **14**
3) Team Name: **Oval**
4) Project name: **GLEE LunaSat development**
5) Team members: **Jigme Fritz, Ginn Sato, Caden McVey, Insar Magadeev, Robert Traxler, Saud Almuzaiel**
6) Roles and responsibilities:

Team member	**Lead roles**	**Backup roles and technical responsibility**
Saud	Documentation Manager, Test Engineering Manager	Financial Manager, Assignments Manager
Insar	Project Lead, Assignments Manager	Documentation Manager
Ginn	Morale Manager, Software Manager	User Interface Manager, Test Engineering Manager
Robert	Financial Manager, Power Management Architect	Mechanical Manager, Hardware architect and PCB manager
Jigme	Hardware Architect and PCB manager	Software Manager, Power Management Architect
Caden	User Interface Manager, Mechanical Manager	Morale Manager

3 Defining the product

3.1 In 100 words or less, what will our product do?

The LunaSat will provide a hardware and programming environment suitable for set up and use by students who do not have experience with coding or electronics. The LunaSats will be deployed in groups of hundreds allowing for the collection of geographically distributed data points upon deployment. The LunaSat array will create a self-assembled network of sensor nodes. This network will report back to the deployment module via RF for a period of roughly 7 earth days.

3.2 What is the problem our product will solve? Why is it of value?

The LunaSat will assist students unfamiliar with embedded systems learn the basics, through a board that could have an exciting application of data retrieval from the moon. This is of value as learning embedded systems can be a difficult task, learning with a product that has a very real and exciting use case can help motivate students.

The LunaSat could also solve the issue of producing a lightweight, cheap solution of data procurement on a large surface area on the moon. Sending payloads to space is a costly endeavor, reducing this cost is a worthwhile investment and taking measurements of general conditions on the moon is especially useful to researchers.

3.3 Who is the intended user of the system we will develop?

Students with no electronics or coding experience and possibly Colorado Space Grant.

3.4 What is the value of our product?

A dev board that students can use to learn embedded programming. The scope of the project will also inspire students to dive deeper into their work as it involves achieving a milestone goal of landing technology on the Moon. If our design surpasses expectations, the product will collect valuable data on the Moon for use in aerospace, astrophysical, and planetary sciences. The LunaSats will collect ambient temperature data, surface temperature data, and the regolith dielectric constant data. This data will add to the library of data collected on the Moon and will aid in future astronaut missions and planetary science. Having a good understanding of the surface temperature of the moon and the regolith's dielectric constant can help inspire new techniques for regolith repulsion.

3.5 List and describe at least THREE important or critical behaviors or capabilities of what your product will do and how it will do it. These are the capabilities of the Minimum Viable Product (MVP)

- The boards will be powered by a 50mW solar panel
    - We will manage the embedded system so that we maintain low-power mode and manage power consumption as much as possible
- The boards will communicate with each other and the DM via RF
    - Each board will have a RF transponder with a minimum range of 1-1.5m
- The boards will withstand the extreme radiation experienced on the lunar surface
    - We will use space-grade components to ensure protection against radiation

4 Use Cases

Use Case UC[1]:

1. Primary actor: Colorado Space Grant
2. Stakeholders/interests:
    - Lunar Scientists: Wants accurate data, over the span of six lunar hours.
3. Preconditions:
    - Understanding of what to use the data for.
    - Ability to acquire a spot on a lunar voyage
4. What is a successful outcome:
    - Boards are able to efficiently communicate measurements back to the lander.
    - Boards resting orientation is achieved with good solar exposure and required sensor contacts with regolith.
5. Main success scenario:
    - LunaSats are in a Sleep state until adequate power is provided by solar panels
    - After distribution LunaSats await nominal power availability
    - When adequate power is available, boards begin startup procedure and stage for transmission
    - RF link is established between deployment module and LunaSats
    - Board Statuses are transmitted to deployment module
    - Statuses are relayed to deployment module transceiver, and eventually to lander sat/direct link to earth based transceiver, and eventually to GLEE mission control
    - LunaSats begin sensor readings
    - LunaSats compile packets
    - Then transmitted in a manner similar to board statuses
    - GLEE receives data and data is entered into a GLEE database that everyone can access
6. Special Requirements:
    - Space grade

- Low power
- Measures dielectric of regolith

Use Case UC[2]:

1. Primary actor: Student
2. Stakeholders/interests:
   - Students and Schools: Wants to teach and learn embedded software
3. Preconditions:
   - Computers for students to use
   - LunaSats on hand
   - MCU programmer
4. What is a successful outcome:
   - Students are able to initiate communication between MCU and sensors on boards and are able to extract data measured
5. Main success scenario:
   - Boards come flashed with a basic blinky program that runs when enough power is provided by solar panels or connected by USB?
   - Students use libraries developed by CSG to write code that initiates sensor communication
   - Using serial line students can read sensor measurements
6. Special Requirements:
   - A user interface for students to see measurements
   - Added soldered USB port for easier/cheaper flashing of MCU

Use Case UC[3]:

7. Primary actor: Device/Product (LunaSat)
8. Stakeholders/interests:
   - Students, Schools, Space Grant, and Lunar Scientists: Wants to teach and learn embedded software, Wants accurate data over the span of six lunar hours.
9. Preconditions:
   - Computers for everyone to use
   - Understanding of how to use the LunaSat and what use is the data for
   - Ability to acquire a spot on a lunar voyage
10. What is a successful outcome:
    - Able to initiate communication between MCU and sensors on boards and are able to extract data measured
    - Boards are able to efficiently communicate measurements back to the lander.
    - Boards resting orientation is achieved with good solar exposure and required sensor contacts with regolith.

11. Main success scenario:
    - Boards come flashed with a basic blinky program that runs when enough power is provided by solar panels
    - Students use libraries developed by CSG to write code that initiates sensor communication
    - Using serial line students can read sensor measurements
    - All sensors on the board are able to effectively display correct data
12. Special Requirements:
    - Added soldered USB port for easier/cheaper flashing of MCU
    - Low power
    - Measures dielectric of regolith

5 Marketing Requirements Document (MRD)

#	Marketing req.	Acceptance test notes	Importance
1	PCBA must operate in a space/lunar environment for 6 lunar hours	Create a space-like environment such as a space simulator. Where we can test the lifespan of the PCBA.	Critical
2	Product takes measurements of the magnetic field	Magnetic field readings match existing known magnetic field measurements	High
3	Product takes accelerometer readings	Accelerometer reading matches existing known accelerometer readings	High
4	Product takes capacitance readings	Capacitance reading matches existing known capacitance values	Medium
5	Product takes temperature readings	Temperature readings match other accurate temperature measurements	High
6	Transfer data to main hub	Data is received at the main hub and not altered	Critical
7	Intuitive User Interface	A person with no background in the project could intuitively understand what measurements are being taken and how our network communicates.	Low
8	At least 50 Lunasats will be duplicated from the final result	Design should be designed for mass production (minimize hand soldering required)	High
9	The final payload must be below 2kg	Make sure that the weight times 50 will be less than 2kg	High

6 Engineering Design Requirements (ERD)

Marketing reqs #	Engineering Req.	Justification	Integration test
1	All devices must operate under the following conditions: Temperature range of operation: -35C to 85C	Our device will be deployed on the surface of the moon and must withstand the conditions that are present there. Meanwhile those must be of the shelf products	Test functionality of each device within simulated moon environments
1	34-140 degrees angle of incidence at 85*C with power operation of 88mW	Based off of our product limitations, this is the minimum power production of our board at the maximum survival conditions	Test angle of incidence and temperature performance of power output and board operation at these conditions
1	Voltage and Current regulation using PMIC	The PMIC should regulate the voltage and provide maximum power for the circuit to function under energy deprivation conditions on the lunar surface	Ensure and Measure the voltage and current provided through the PMIC
2	Sample the magnetometer @ 0.3 mHz	Using an electronic sensor is the best way to attain this data.	Ensure the sensor works and produces accurate measurements.
3	Sample the accelerometer @ 16 Hz	We want to know the orientation of the board, as well as deviations in the Moon's orbit.	Ensure the sensor works and produces accurate measurements.
4-5	Sample the capacitance and temperature @ 3 mHz	We want to try to measure the dielectric constant of the regolith and the temperature on the moon	Ensure that sensors work and produce accurate measurements.

6	Use RF in order to establish connection between the main hub and each board up to 60 meters	Communication between boards and the main hub allows data to be synchronized, as well as eventual communication to transceivers that will send data back to Earth.	Ensure boards are able to send information to each other. Ensure a routine that sends measurements to a main transceiver function. Ensure a distance of 60m can be reached
7	Use custom Python code to visualize data using “matplotlib” package	A lot of data will be coming in. To validate it, it needs to be visualized live, while new data is incoming.	Validate that displayed datapoints are identical to the provided data by Lunasats.
8-9	Each board must be weigh less than <40g	To meet the 50-board minimum requirement with a weight budget of 2kg, each board must weigh less than 40g	Ensure all components and PCB weigh less than 40g

7 Design Constraints

7.1 Customer Diver Design Constraints

These are the features that are in the product that do not contribute to the actual functionality of the device but are required because the sponsor says so.

- Mass of one LunaSat less than 5 grams
- Programming Language is Arduino Based
- Power Supply from solar panels
- 6 cm x 6 cm x 1 cm boards
- Cover approximately 300 square meters on lunar surface
- AVR128DB32 Microcontroller
- Continuous ground plane on PCBA
- M24512-DRMN3TP/K EEPROM
- AEM10941 PMIC
- $80-$130 per board
- LunaSats shall overwrite data to a secondary memory location in case the microcontroller data buffers are full

7.2 Industry Based Design Constraints

There are also design constraints that are in place to meet an industry standard, compatibility with existing infrastructure, meet or comply with certain requirements.

- Commercial off the shelf sensors
- I2C, SPI, UART or any low power wired protocol
- Space Rated equipment
- Available RF Frequency ranges on moon surface

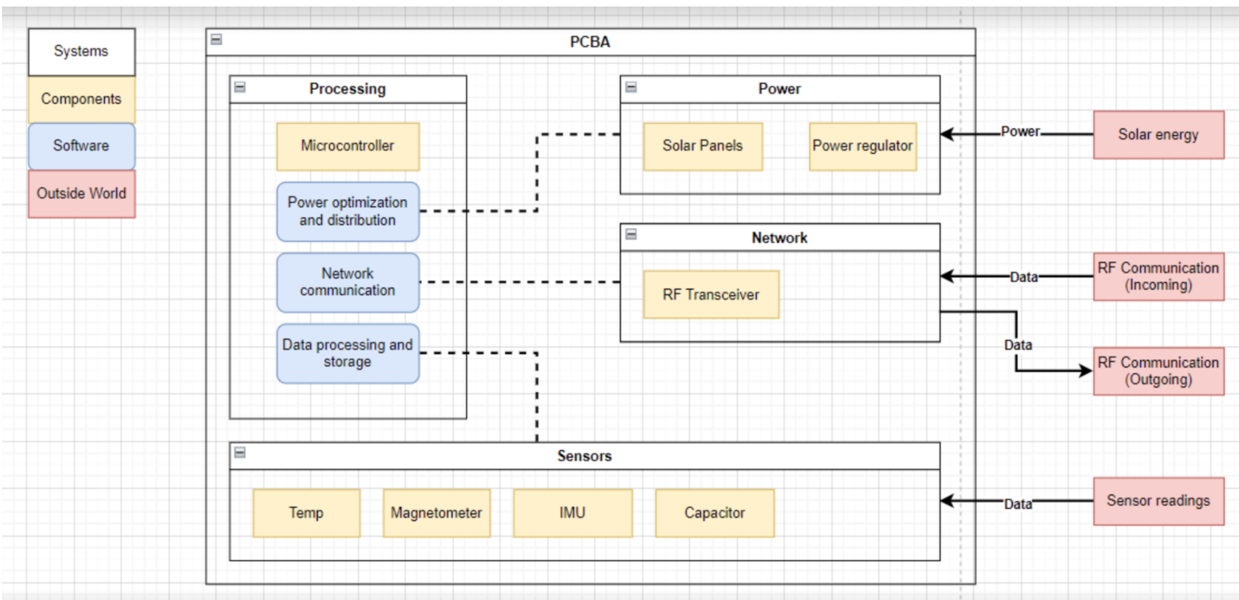
8 Engineering Design Stretch Goals

Radiation dose of operation 110 mSv to 380 mSv (2.5 Earth Days of operation)	Vacuum environment 2x10^-2 torr to 760 torr

Appendix 3 - Product Design

Team Oval
The Initial Product Design and Technology Selection
Draft 3

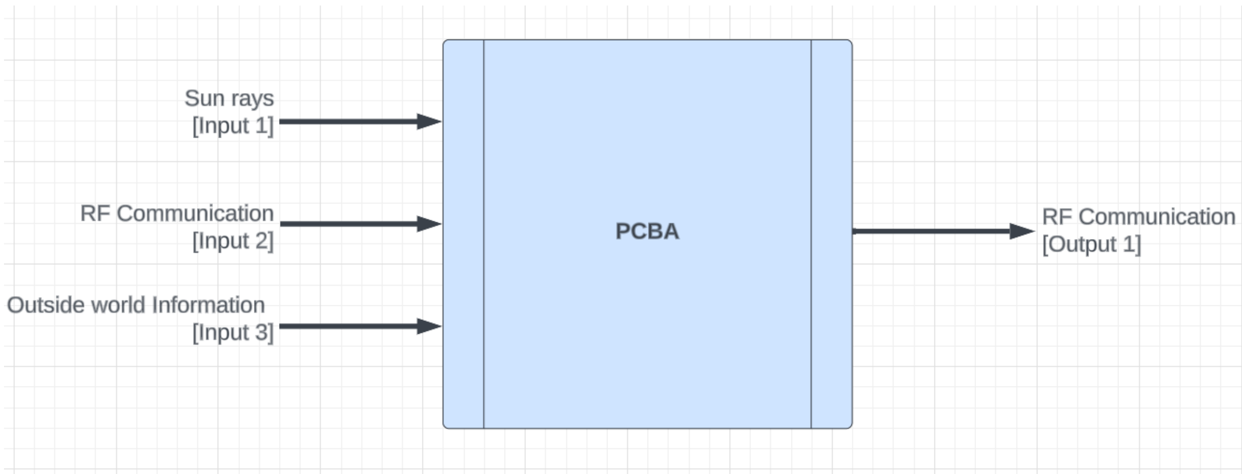
Section 1: Functional Block Diagram



Section 2: Functional Decomposition

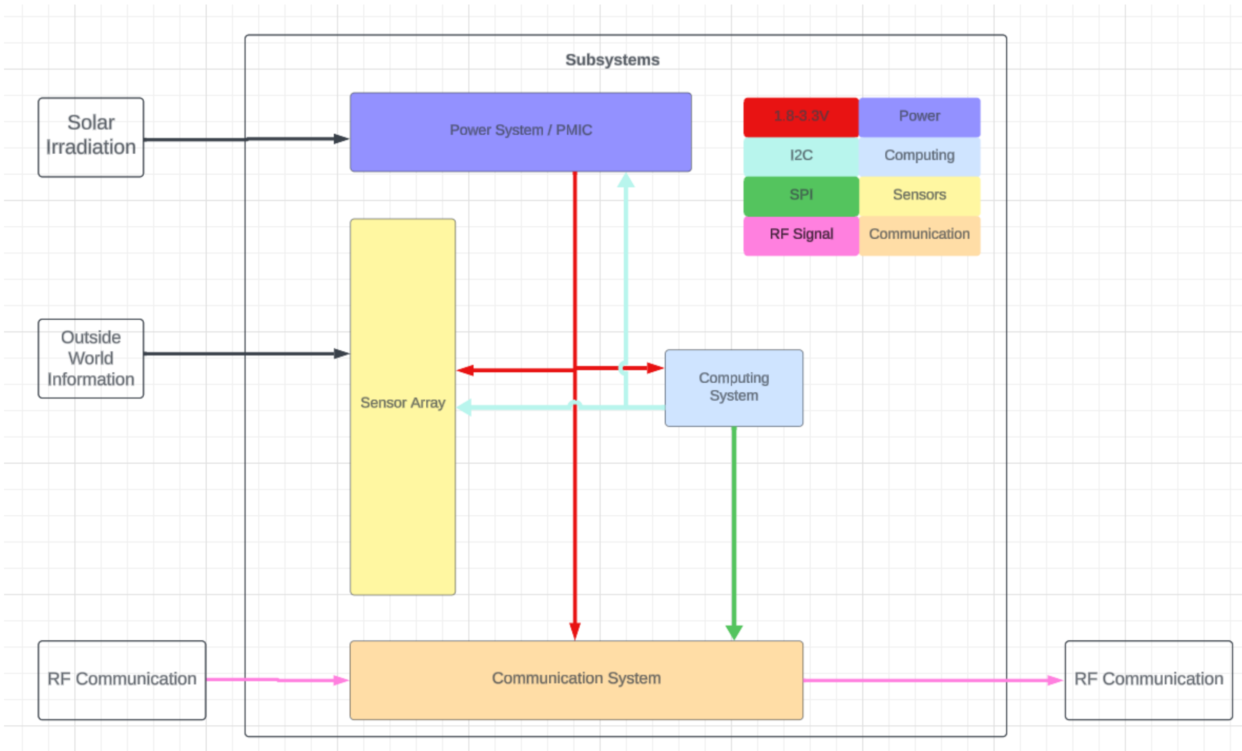
Functional Decomposition Level 0:

[Top Level, Simple Diagram ("black box")]



One block	PCBA
Inputs (energy, information, materials)	[Input 1]: Sun rays (energy to) [Input 2]: Incoming RF data communication [Input 3]: Outside world information: Temperature, Magnetic, Accelerometer, Capacitance Data
Outputs (energy, information, materials)	[Output 1]: Outgoing RF communication
Functionality	[Brief description]: PCBA collects information about the outer world and then communicates the data it has collected to another device. It is powered by solar power.

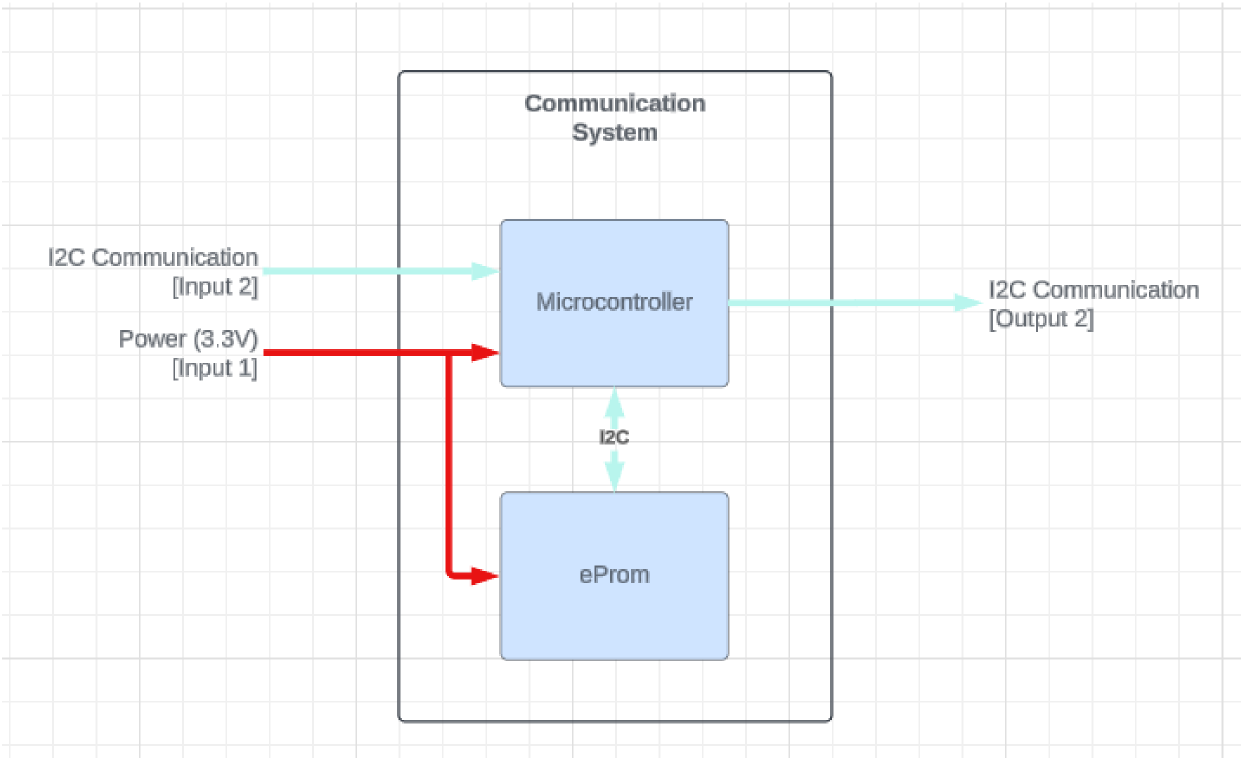
Functional Decomposition Level 1:



Module	Internal PCBA decomposition
Inputs (energy, information, materials)	(Outer world) Solar Irradiation → (Power System) Solar Panels (Outer world) Temperature → (Sensor Array) Temp* (Outer world) Magnetic field → (Sensor Array) Magnetometer* (Outer world) Capacitance → (Sensor Array) Capacitance* (Outer world) Movement → (Sensor Array) Accelerometer* (Outer world) Incoming RF Communication → RF Transceiver
Outputs (energy, information, materials)	[Output 1]: Outgoing RF Communication
Functionality	[Brief description]: The system is powered by solar panels that convert solar irradiation into useful energy. The power line is then stabilized and powers the microcontroller that turns on and configures all of the sensors and RF communication. Data about the outer world is collected by sensors and then sent to the Microcontroller via an I2C bus. The microcontroller then waits for the connection with another device to transfer collected data.

Functional Decomposition Level 2:

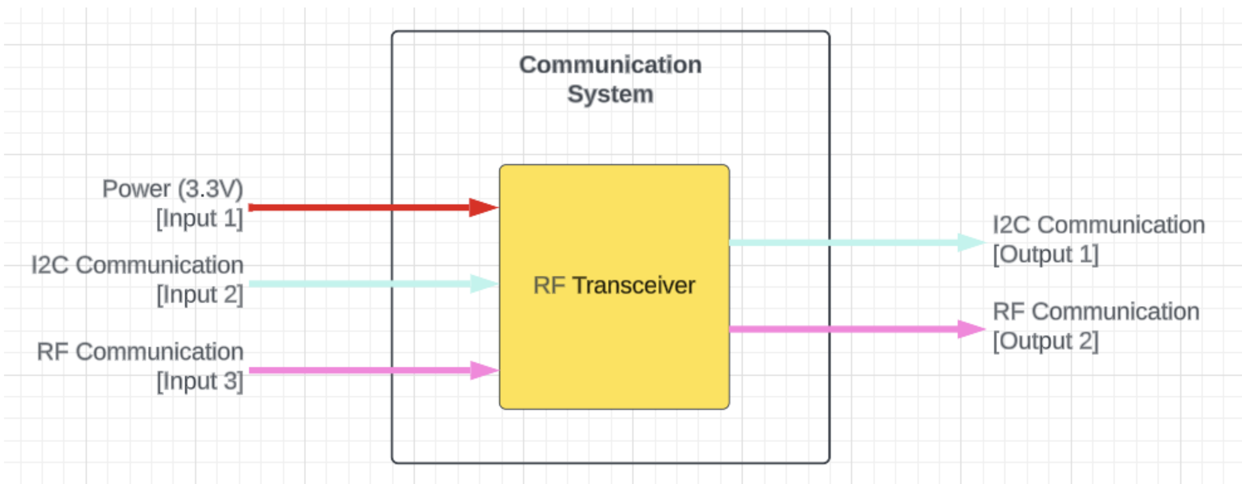
Microcontroller module:



Component/Module	Microcontroller
Inputs (energy, information, materials)	[Input 1]: Power (3.3V) [Input 2]: Incoming I2C communication
Outputs(energy, information, materials)	[Output 1]: Outgoing I2C communication
Functionality	The microcontroller will be what drives the functionality of the entire board. It will communicate with sensors via i2c and packet the measured data. It will communicate with the RF transceiver intermittently, sending packets of data back to a receiver. The data acquired will be stored in eProm until it is sent through RF

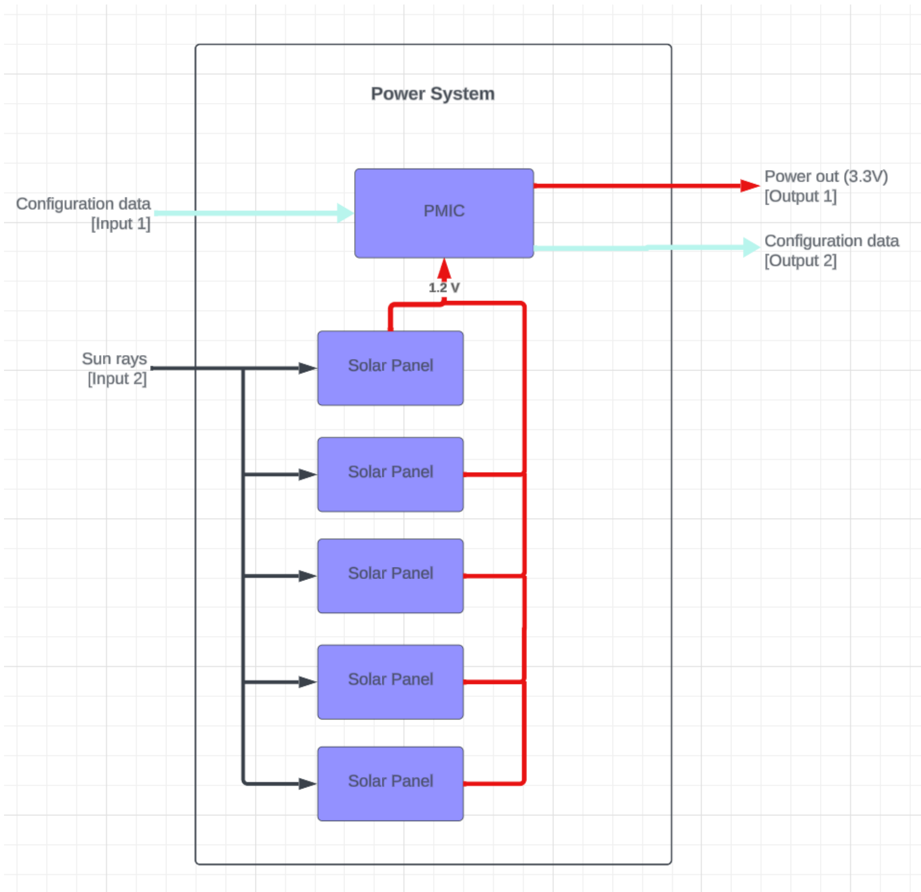
‘

Communication module:



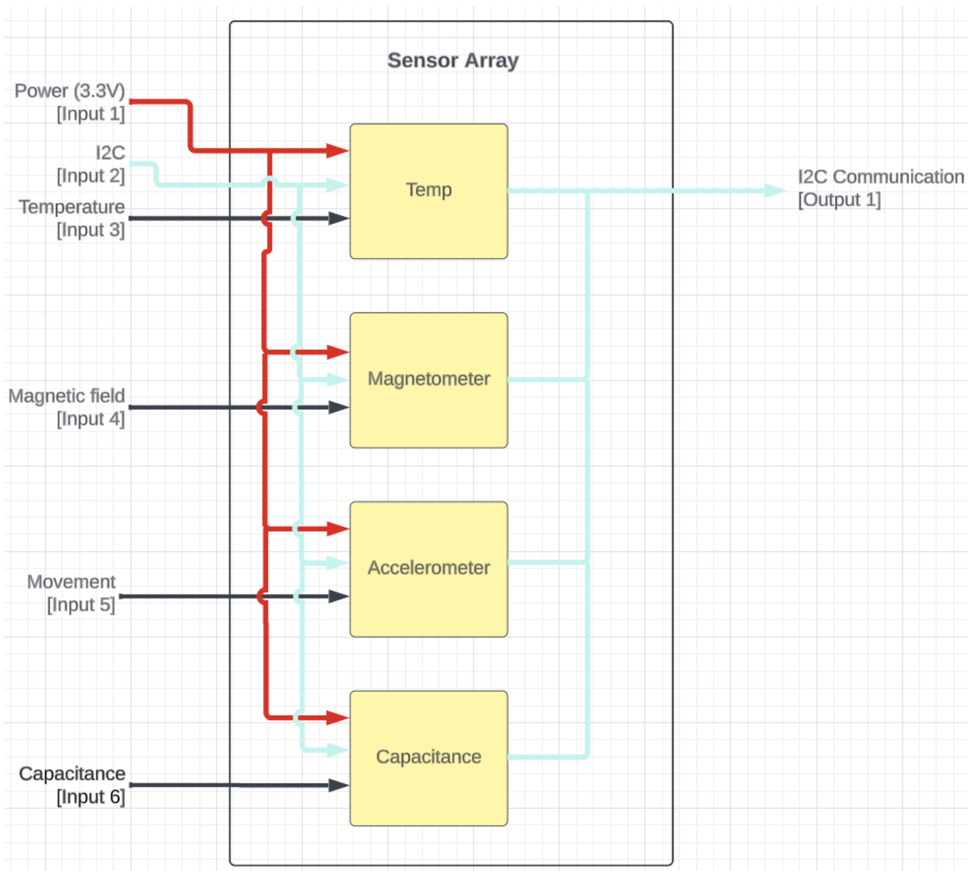
Component/Module	RF Transceiver
Inputs (energy, information, materials)	[Input 1]: Power (3.3V) [Input 2]: Incoming I2C communication [Input 3]: Incoming RF communication
Outputs(energy, information, materials)	[Output 1]: Outgoing I2C communication [Output 2]: Outgoing RF communication
Functionality	RF Transceiver receives and sends data via RF Communication. Directions for what data to send, the data to send, and the received data are transferred through the I2C bus.

Power module:



Component/Module	Power supply
Inputs (energy, information, materials)	[Input 1]: Incoming I2C communication [Input 2-7]: Solar irradiation
Outputs(energy, information, materials)	[Output 1]: Accumulated power [Output 2]: Any data relevant to power regulation NOTE: Final Configuration is not finalized but 6-10 cells (0.5V & 60mA per cell) can be configured to match our final power needs based on energy modes and final devices.
Functionality	Uses solar irradiance to provide power. The wavelength is optimized for use in space and the panel is suitably light-weight and configurable for our application. PMIC stabilizes power output and can be accessed and configured using I2C bus. Voltage boost allows to boost voltage to 3.3V at the cost of some power.

Sponsors module:



Component/Module	Sensors
Inputs (energy, information, materials)	[Input 1]: Power (3.3V) [Input 2]: Incoming I2C Communication [Input 3]: Temperature of the outer world [Input 4]: Magnetic field of the outer world [Input 5]: Movement of the sensor/gravitation field of the outer world [Input 6]: Capacitance of the outer world
Outputs(energy, information, materials)	[Output 1]: Outgoing I2C Communication
Functionality	[Brief description]: Sensors collect data from the outer world and send it through an I2C bus when requested (requests and configuration is also acquired via I2C bus). They all are powered by the same power line.

Section 3: Selecting your microcontroller

The most important features that we were looking for when choosing a microcontroller are:

- High Maturity
- Lowest energy consumption as practically possible
- I2C communication
- SPI communication
- Increased range of operational temperature
- Affordable/cheap

We decided to go with the ATMEGA328PB. We decided to go with this MCU as it is a cheap,well-established chip, with a high capability to minimize power consumption. It can communicate to peripherals via I2C and SPI. Furthermore, the temperature range of operation is on the higher spectrum in comparison to other microcontrollers of the same price category.

We will be ordering a development board, so we can characterize its performance, as well as begin software development for our project.

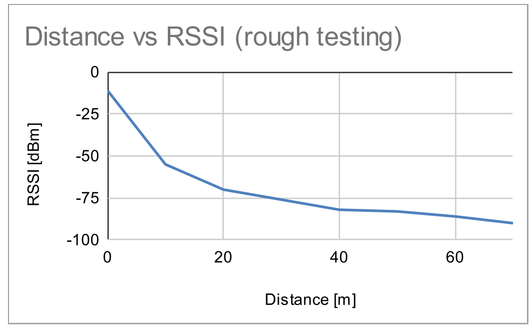
Section 4: Technology options
Fill in the following table:

Technology option	Possible candidate component URL (optional)	Maturity risk (low, medium, high)	Complexity risk (low, medium, high)
Temperature Sensor (TMP117)	Purchase Link	LOW	LOW
Accelerometer (ADXL313)	Purchase Link	LOW	LOW
Magnetometer (AK09940A)	Purchase Link	LOW	MED
Solar Panel (ANYSOLAR SM141K06L)	Purchase Link	MED	MED
Capacitive touch sensor (IQS228B)	Purchase Link	LOW	LOW
Microcontroller	Purchase Link	LOW	MED
PMIC	Purchase Link	MED	MED
LoRa Module(for testing)	Purchase Link	MED	HIGH

Appendix 4 - POC 1 (RF)

Test Writer: Jigme Fritz & Gin Sato			
Test Case Name:	**Proof of Concept Test:** RF Communication	**Test ID #:**	1
Risk Tested:	**<u>Engineering Requirement</u>:** Sample the temperature sensor (#5) and use RF in order to establish a network (#7). **<u>Risk</u>:** Sensor Measurements are important as this is the basis of our entire project. We will need to form packets around this data we collect, when we send it over RF to our main receiver. Having a good RF communication system is an important risk to test for as a poorly designed RF system can result in poor power consumption. Passing this test will ensure that we will have functional boards on the moon.		
Description:	**1. <u>Subsystem</u>:** RF/Communication **2. <u>Inputs and outputs</u>:** Input is enviornmental data and output the numerical values via RF. Measure these values using sensors and transmit via the LoRa Module. **3. <u>Equipment</u>:** LoRa Module Base Station, Temperature Sensor, Current Sensor, LoRa Module LunaSats, Laptops **4. <u>Expected Values</u>:** Expecting the successful transmision of our sensor data. Verify that no data was lost in transmission. **5. <u>Plan if test fails:</u>** Continuously alternating data requests from each LunaSat module. If no data is received, print this out. If signal strength is too weak, print this out. Ensure that hardware connections are secure and valid. Consider BLE if LoRa proves impractical.	**Type:**	Software, RF
Name of Tester:	**Jigme Fritz, Ginn Sato**	**Date:**	12/05/23
Name of Team:	**Oval**	**Time:**	9:30
Setup and Procedure:	**<u>Setup</u>**: 2 Lunasat prototypes with unique identifiers - externally powered breadboards containing Sensors, Microcontroller, and LoRa slaves, are measuring data with sensors. Upon request from a base station, the specific LoRa slave will transmits its data to the master LoRa module. A computer is connected to the microcontrollers using Usart and displays what data is being sent via a Serial monitor. Base station consists of the tranciever and a microcontroller that displays incoming RF communication data. **<u>Procedure</u>**: All of the LunaSat prototypes will be powered. Base station will the also powered on, it will then request data from lunasats using a unique ID system. Lunasat will then send the data point via RF and aslo display sent data on the serial monitor. (Data would contain reading from sensor and would be transmitted in mutiple packages) The aquired data by the base station will then be displayed on a different Serial Monitor.		

Step	Input parameter/Action	Expected Output	Pass	Fail	N/A	Actual Output
1	Two LunaSats reading sensor data while stationary on table. Base module requests data from LunaSat #1.	LunaSat #1 recieves request and sends sensor data to base module. Sensor data is printed by LunaSat on local computer that powers it. Data recieved is printed on Base Module and is identical to data sent.	X			LunaSat #1 recieved request and sent sensor data to base module. Sensor data was printed by LunaSat on local computer. Data recieved was printed on Base Module and was identical to data sent.
2	Base module requests data from LunaSat #2.	LunaSat #2 recieves request and sends sensor data to base module. Sensor data is printed by LunaSat on local computer that powers it. Data recieved is printed on Base Module and is identical to data sent.	X			LunaSat #2 recieved request and sent sensor data to base module. Sensor data was printed by LunaSat on local computer. Data recieved was printed on Base Module and was identical to data sent.
3	Change environment (e.g. temperature) and repeat steps 1 and 2.	Sensor data is printed by LunaSat on local computer that powers it every time data is requested. Data recieved by Base Module is printed and is identical to data sent.	X			Sensor data was printed by LunaSat on local computer every time data was requested. Data recieved by Base Module was printed and was identical to data sent.
4	Power off one of the LunaSats.	No response from corresponding LunaSat. Base station continues alternating requests from each LunaSat.	X			There was no response from LunaSat that was powered off but the BaseStation continued to request data. Base Module indicated that no data was received.
5	Power the LunaSat back on.	Base station recieves data from Lunasat that was initially powered off. Data recieved is identical to data sent.	X			Once the LunaSat was powered back on and a request was recieved, the data sent was the same as data received.
6	Walk down hallway of capstone lab with LunaSat #1. This will weaken the signal below -80 RSSI (Received Signal Strength Indicator) towards the end of the hallway.	When RSSI value < -80 dBm, the Base Module will not consider the data valid and indicate this in a print statement.	X			When RSSI value < -80 dBm, the Base Module would consider the data invalid and print to serial line saying which module was sending a weak signal
7	Walk back towards Oval's Capstone Bench where RSSI will go above -80 dBm.	Base station recieves data from LunaSat withl an RSSI > -80 dBm and data recieved is identical to data sent.	X			Base station began recieving data from LunaSat with an RSSI > -80 dBm again and data recieved was identical to data sent.
8	Receive a data request and send back data	Print 'Interrupt 0 Received' when we recieve a data request and when the data is sent back. Interrupt 0 is triggered on both.	X			Printed correct information upon data recieved and data sent.

9	Receive a data request and send back data	Print out on separate serial monitor the current consumption, current sample # and time interval in uS.	X			Printed the current consumption. Peaked at 120 mA for about 25 ms during the transmission. The passive current when waiting for a transmission request is 10 mA.
10	Request and recieve data from LunaSat at different ranges 0 -70m	Print RSSI on BaseModule Computer. Plot the results.	X			
Overall Test Result: The test results were very successful and each input/ output relation functioned as we expected them to.			X			All tests passed
What was learned: The RF communication is capable of working at distances greater than 50 m however the RSSI depends on our enviornment. The current consumption peaks at around 120 mA during transmission and these current consumption constraints will be a crucial risk factor moving forward. Our idea of scheduling the LunaSats request and using a unique ID will be a viable protocol for communication between LunaSats. After our dicsussion with the Professor Bogatin, the TAs, and our sponsors we realized that a new big risk was getting enough power to our RF system but this risk will mainly be avoided with our custom RF design that enables lower energy modes.						

Appendix 5 - POC 2 (PMIC)

Test Writer: Saud, Caden			
Test Case Name:	**Proof of Concept Test:** Power Output	**Test ID #:**	2
Risk Tested:	**Engineering Requirement:** voltage and current regulation using PMIC (This was not on our EDR because we didnt know at the time of making engineering requirenments that we would need to use the PMIC. However we have now updated our ER and now the voltage and current regulation using PMIC is one of our engineering requirments) **Risk:** Without proper power distribution to the circuit the whole circuit might not function when		
Description:	**1. Subsystem:** Power **2. Inputs and outputs:** Input voltage and current, and output voltage and current (measured using an oscilloscope and multimeter.) **3. Equipment:** Multimeter, Oscilloscope, Breadboard, 10x Probes, 22kohm resistors, Virtual load **4. Expected Values:** The values that were expected are a 380mV input cold start and a 50mV input after the cold start where the PMIC uses maximum power point tracking to output the maximum current possible while stepping the voltage to 3.3V and 2.1V on both of its outputs. **5. Plan if test fails:** If the test fails, that would mean that the PMIC would not be as efficient as we expected. The backup plan would be to use a voltage regulator component and we would decrease the voltage to up the current. The aim of this would be to keep a constant voltage for the circuit to to function. This would not be a complete substitute to replace the PMIC since the PMIC would be much more efficient. However, with the constraints we have it would help replace one of the functions of the PMIC which is to regulate the voltage.	**Type:**	Hardware
Name of Tester:	**Caden, Saud**	**Date:**	TBD
Name of Team:	**Oval**	**Time:**	TBD
Setup and Procedure:	**<u>Setup</u>:** PMIC is connected to a power supply and will have the output connected to a virtual load/actual load set to a similar resistance that we expect from our final design circuit. Voltage supplied will be shown on the power supply, while, output values will be mesured using multimeter. The current from the PSU will not be accurate which is why we would need a current meter. **<u>Procedure:</u>** PMIC will be supplied with 380mV required for a cold start. The output voltage and current values will be verified (getting 3.3V and 1.8V on PMIC outputs, while total current draw under 30mA). Then input voltage will be lowered to 120mV. The output values for votage and total current draw are veriffied.		

Test	Input parameter/Action	Expected Output	Pass	Fail	N/A	Actual Output
1	PMIC with no load is supplied with 380mV	Cold start cycle will begin. PMIC poweres on and starts supplying required voltage values (3.3V and 1.8V).		X		No Output from device
2	If Test 1 failed: raise voltage untill cold start cycle begins and record the voltage needed for cold start	Cold start cycle will begin. PMIC poweres on and starts supplying 3.3V and 1.8V.	X			420 mV gets us to the desired cold start as noted above
3	Load is added to the powered off PMIC. Then voltage risen to the expected load voltage.	Cold start cycle begins at voltage determined by 1 and 2. The output voltages remain at 3.3V and 1.8V and total current draw around 30mA		X		voltage does not meet expectation with load
4	Input voltage lowered to 120mV	The output voltage and total current draw remains the same		X		voltage drops further
5	If test 4 fails, find the lowest operational voltage after coldstart	The output voltage and total current draw remains the same	X			850 mV allows the blinky code to funciton in the circuit.
Overall Test Result: TBD			X			
What was learned: TBD						