Project Proposal
Mesh Network Positioning System

— Team 5 —
Peter Giannetos
Noah Breit

— TA —
Michael Gamota

— Date —
13 February 2025

— Course —
ECE 445, Senior Design Laboratory
University of Illinois Urbana Champaign

Table of Contents

1. Introduction

1.1 Background

Spaceshot from the Illinois Space Society is working towards being one of the first collegiate teams to build and launch a completely student designed vehicle 100 kilometers to the edge of space; Also known as the Kármán line. A critical challenge in reaching space is being able to reliably verify launch altitude data, because many commercial systems like Global Positioning Systems (GPS) are not operable in those extreme conditions. Suitable internal inertial navigation systems are cost prohibitive for amateur applications, and for mission critical applications multiple novel redundant methods are highly prefered.

(Spaceshot recently broke the University's 7-year standing altitude record in June of 2024, and is looking to do so again in the summer of 2025. Kairos II Launch)

1.2 Solution

This project aims to create a novel off grid radio positioning system that can be used to track objects. Due to the practicality of testing to 100 km, with the only limitation being link budget, this system will focus on creating the foundational hardware and software to track objects at shorter ranges. In the future better antennas could be used to drastically extend range. Depending on progress this system may be flight tested at a launch in April.

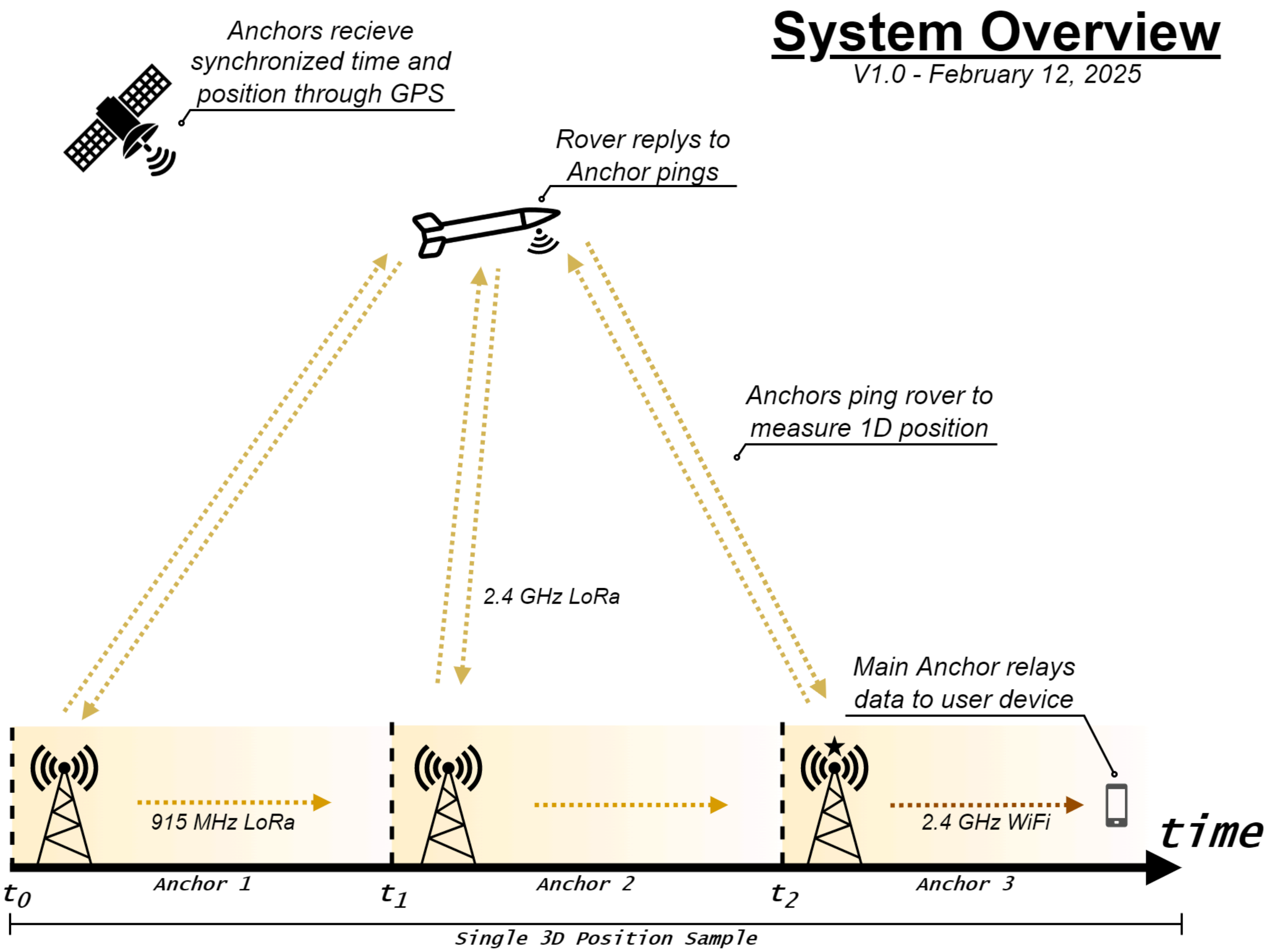
1.2.1 Overview

Timing the round trip call and response of a radio signal, the distance between transceivers can be calculated with the known constant speed of light. Using at minimum 3 ground based "Anchor" nodes with known positions, a moving "Rover" node can be sequentially pinged and its position calculated through trilateration. Rover nodes would be attached to the desired tracking assets of unknown position. Anchor nodes must have synchronized time to allow for Time Division Multiple Access (TDMA) communication with an asynchronous Rover node.

1.2.2 Additional Applications

- Drone tracking
- Warehouse asset & robotics tracking
- Car tracking

1.3 Visual



1.4 High Level Requirements

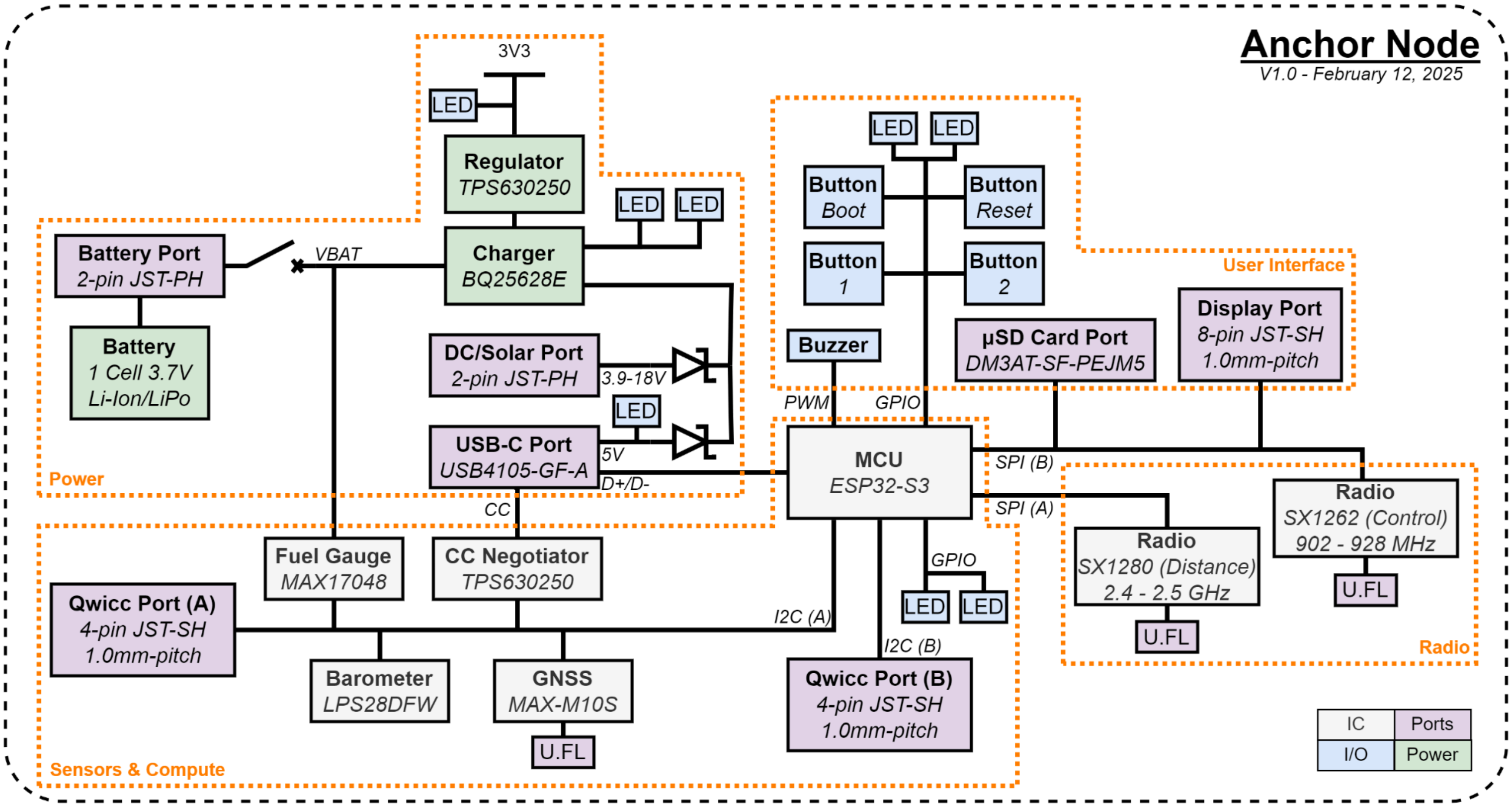
1. Perform 3D trilateration of a Rover node at a minimum distance of 20 meters from at least one anchor node with a sample rate of at most 2 second. Sample rate is defined as the time period a position reading is resolved.

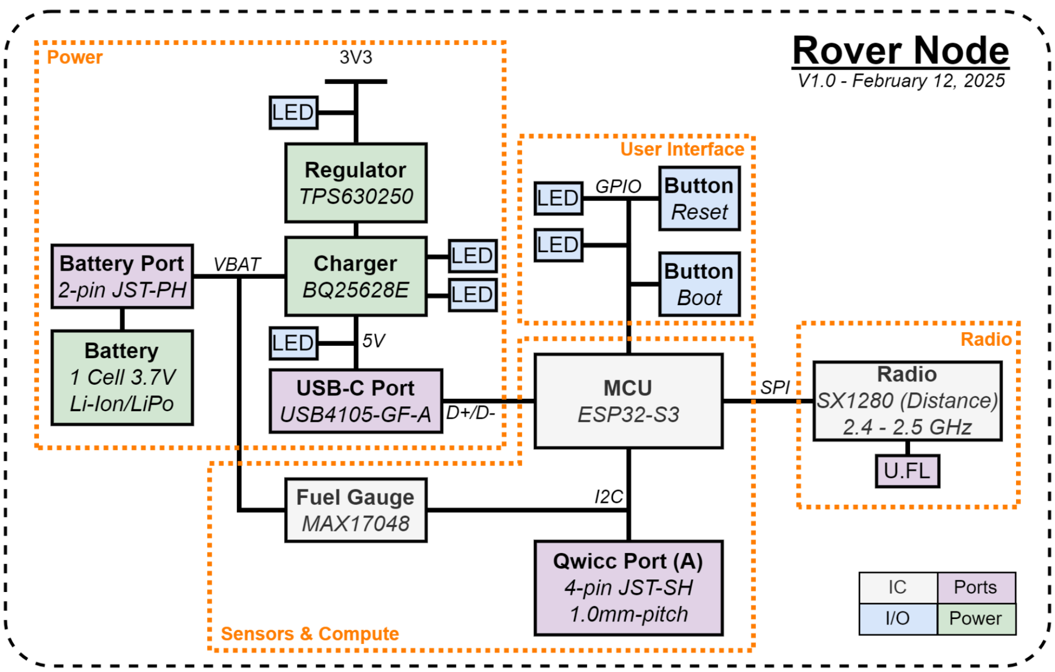
2. Relay barometer, GNSS, and at minimum one other data point to another node in the network with a latency of less than 2 seconds. Latency is defined as the time from an initial sensor reading to reception by another member of the network.

3. Publish real-time position data to a local WiFi network. We define real-time as at most 5 seconds delay between receiving initial sensor or calculated data to receiving on WiFi

2. Design

2.1 Block Diagrams





2.2 Block Descriptions

2.2.1 Anchor

Anchors are reference nodes with synchronized time and fixed positions.

- *Requirement 1: Nodes must have synchronized time and a known position.*

2.2.2 Rover

Rovers are roaming nodes with unknown position or time attached to a tracking asset.

- *Requirement 1: Nodes must automatically respond to Anchor ping requests.*

2.2.3 Power

Each node is battery operated with the option to charge and power the device through a USB-C port. The BQ25628E controls power switching and battery charging. A thermistor is used to ensure the battery does not overheat during charging. For Anchor nodes an additional generic DC input port is available that can be used for solar panels or other power sources. It's able to optimize voltage draw for near maximum power draw and employs a buck-boost convert to ensure it outputs at most 4.5V. The TPS630250 regulates the input voltage to a stable 3.3V for all system components. Additionally a few debug LEDs for 3.3V, 5V, Power Good, and Charging are connected to these circuits. The goal is to enable portable deployments with seamless charging or extended usage in fixed locations.

- *Requirement 1: Voltage regulator must output 3.3V and supply 2A at maximum*
- *Requirement 2: Battery charger must be configurable with GPIO and resistors, or I2C*
- *Requirement 3: Battery charger must accept 1S 3.7V LiPo batteries and automatically switch between USB and battery power sources.*

2.2.4 Radios

Each node contains an SX1280 which has a built in ranging engine that is able to ping another radio and calculate the distance. This is then telegraphed over SPI to the user without the need for extensive timing and tuning of the radio front end. The SX1280's ease of use for ranging is what directly enables this project to maintain a focused and achievable scope. Anchor nodes also contain an SX1262 which serves as a command and control backbone for anchor nodes to share data while not congesting the primary ranging radios. The SX1280 uses 2.4 GHz LoRa and the SX1262 uses 915 MHz LoRa. LoRa enables low power usage yet longer ranges.

- *Requirement 1: Radio systems must use seperate frequency bands to avoid congestion*
- *Requirement 2: Radios must occupy ISM bands for license free operation*
- *Requirement 3: Radios must use SPI or I2C for communication with MCU*

2.2.5 User Interface

Anchor and Rover nodes each contain boot and reset buttons for programming the microcontroller (MCU). However, Anchors which are not at a premium for space have additional buttons and a buzzer for the user to interact with and configure the devices. An optional display can also be added via the display port. Anchors feature a MicroSD card port to allow for long term data logging. Each node also has debug LEDs that are user programmable.

- *Requirement 1: MCU must have SPST buttons to enable programming*
- *Requirement 2: MicroSD card must interface with at most 32GB FAT32 cards*

2.2.6 Sensors & Compute

Each node has a fuel gauge to measure battery charge over time and an ESP32-S3 MCU as the core control unit. These MCUs feature WiFi/Bluetooth connectivity for additional user interaction. Anchor nodes feature a GPS module for precise synchronized timing and deducing their own position. A water resistant barometer is used to further resolve their vertical position. Anchors have a USB-C Configuration Channel (CC) negotiator to ensure proper USB power delivery.

- *Requirement 1: All sensors must communicate over SPI or I2C and draw 3.3V.*
- *Requirement 2: Barometer must output a resolution of at least 1 meter*
- *Requirement 3: GPS module must output 1 Hz time pulse and position within 3 meters*
- *Requirement 4: Fuel gauge must read cell voltage and communicate over SPI or I2C*
- *Requirement 4: MCU have a clock speed greater than 100 MHz and communicate over SPI, I2C, and PWM to interface with all modules.*

2.3 Additional Descriptions

2.3.1 Mechanical Mounting

Each node has M2 mounting holes for easy integration into a case or tracking asset. Anchor nodes have a 3D printed case to protect them during outdoor usage, increase portability, and allow for tripod mounting for field usage. User ports and buttons will mostly remain accessible for ease of use.

2.3.2 Antennas

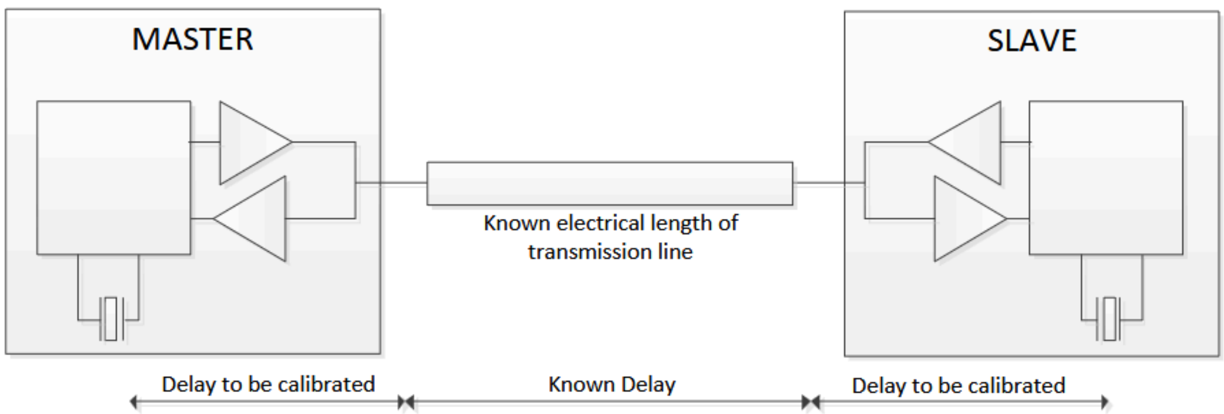
Rover nodes only have one antenna that will require a U.FL connector. Depending on their space constraints patch antennas will most likely be the optimal solution. Anchor nodes also have three U.FL connectors. An internal active patch GPS antenna will be mounted inside the case, while two U.FL to SMA bulkhead adapters will be mounted through the case wall. This will enable the user to switch antennas for their specific needs.

In regular usage omnidirectional antennas for the 915 MHz and 2.4 GHz LoRa radios can be used, but if long range usage is required more directional antennas may be used. The MCU's have an embedded antenna for WiFi/Bluetooth connectivity.

2.4 Tolerance Analysis

One key aspect of our design is ensuring ranging accuracy provided by the SX1280 modules. There are a multitude of ways ranging could be degraded such as multipath reflections and doppler shift caused by high velocity tracking assets. However, calibration of the SX1280 to account for different antenna front ends is the most prevalent for mitigating error.

2.4.1 Calibration



[6] Semtech, Ranging Calibration Setup

Using a coax cable of known length the system delay can be isolated to just the RF front end of the ranging devices. This offset would then be applied to future ranging measurements.

$$D_{uncalibrated} = (RangeResult \times D_{LSB})/2$$
$$D_{calibrated} = (D_{uncalibrated} - D_{cable})/2$$
$$Calibration = D_{calibrated}/D_{LSB}$$

Additionally, outdoor line of sight measurements can be conducted when the nodes are separated at known fixed distances. Their measured vs actual error can be calculated and then applied as a linear offset. More advanced offsets could also be used if you take into account alternate frequencies and LoRa parameters.

2.4.2 Manufacturer Testing

Semtech, the manufacturer of the SX1280, conducted outdoor range testing after calibration at a distance of 170 meters with an estimated error of less than 4 meters for single samples, and less than 1 meter accuracy for larger sample sizes of 70.

2.4.3 External Testing

In 1D testing conducted by Stuart Robinson has revealed an error rate of about 0.2% at 40.65 kilometers [16]. In additional testing Robinson was able to achieve a measured ground distance of 89.237 km [16] with a small directional antenna; Further suggesting this system's potential for ranges in excess of 100 km.

2.4.4 Tolerance Expectations

Ultimately, the team expects to achieve relatively high positional accuracy. However without the ability to test the system they are hesitant to guarantee a specific error tolerance of less than 10%. External testing has revealed the SX1280 can be highly accurate, but it is to be seen if similar accuracy can scale down to shorter distances of around 25 meters for the purposes of a demonstration.

3. Ethics

3.1 FCC Regulations

We will follow all FCC regulations as they concern our RF equipment such as transmit power and spectrum usage.

3.2 Tracking Assets

All assets being tracked will be owned by the team and not another individual without their explicit consent.

3.3 Feedback

As this is an experimental project we plan to maintain an open mind when creating this novel system by listening to ideas given from mentors, course staff, students, and others throughout the project. We will take notes in their lab notebook on any feedback received to ensure it is properly documented and considered.

4. Safety

4.1 Batteries

Following the *Safe Practice for Lead Acid and Lithium Batteries* guidelines all batteries will be charged in their recommended conditions, and stored in a flammables cabinet when not in use. When handling batteries they will be treated with care and monitored for degradation. If disposal is needed batteries will be left in the battery cabinet until proper disposal is available.

5. Citations and References

[1] IEEE, "IEEE Code of Ethics," IEEE, [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html, Accessed: Feb. 10, 2025.

[2] ACM, "ACM Code of Ethics and Professional Conduct," ACM, [Online]. Available: https://www.acm.org/code-of-ethics, Accessed: Feb. 10, 2025.

[3] Semtech, "AN1200.29 Introduction to Ranging with the SX1280 Transceiver", Semtech, [Online]. Available: https://semtech.my.salesforce.com/sfc/p/#E0000000JeIG/a/3n000000l9OZ/Kw7ZeYZuAZW3Q4A3R_IUjhYCQEJxkuLrUgl_GNNhuUo, Accessed: Feb. 11, 2025.

[4] Semtech, "AN1200.80 LoRa Doppler Immunity", Semtech, [Online]. Available: https://semtech.my.salesforce.com/sfc/p/#E0000000JeIG/a/3n000000l9JA/FoIjLVxAx4xpf3Wh5xvvX3B9PWTw.S7R.YPZHazMzBo, Accessed: Feb. 11, 2025.

[5] Semtech, "AN1200.50 SX1280 Ranging Protocol and Result Processing", Semtech, [Online]. Available: https://semtech.my.salesforce.com/sfc/p/#E0000000JeIG/a/2R000000UypY/5mprGH6TIzeLnfosUgj1xK5ftoqDpoCnRk_dzY_jAx4, Accessed: Feb. 11, 2025.

[6] Semtech, "Introduction to Ranging with the SX1280 Transceiver", Semtech, [Online]. Available: https://semtech.my.salesforce.com/sfc/p/#E0000000JeIG/a/44000000MDiH/OF02Lve2RzM6pUw9gNgSJXbDNaQJ_NtQ555rLzY3UvY, Accessed: Feb. 11, 2025.

[7] Jamie Smith, "The Lightspeed Rangefinder," EngrXiv Preprints, Accessed: Feb. 11, 2025. [Online]. Available: https://engrxiv.org/preprint/download/1655/version/2524/3401/2512

[8] u-blox, "MAX-M10S Data sheet," u-blox, Apr. 8, 2024. [Online]. Available: https://content.u-blox.com/sites/default/files/MAX-M10S_DataSheet_UBX-20035208.pdf, Accessed: Feb. 11, 2025.

[9] Espressif Systems, "ESP32-S3-MINI-1 & ESP32-S3-MINI-1U Datasheet," Version 1.3, Espressif Systems, Mar. 7, 2023. [Online]. Available: https://www.espressif.com/sites/default/files/documentation/esp32-s3-mini-1_mini-1u_datasheet_en.pdf, Accessed: Feb. 11, 2025.

[10] Texas Instruments, "BQ25628E I2C Controlled 1-Cell, 2A, Maximum 18V Input, Buck Battery Charger with NVDC Power Path Management," BQ25628E datasheet, Jul. 2023. [Online]. Available: https://www.ti.com/lit/ds/symlink/bq25628e.pdf, Accessed: Feb. 11, 2025.

[11] Texas Instruments, "TPS630250: High-Efficiency Buck-Boost Converter," Texas Instruments, [Online]. Available: https://www.ti.com/product/TPS630250, Accessed: Feb. 15, 2025.

[12] Semtech, "SX1261/2 Datasheet", Semtech, [Online]. Available: https://semtech.my.salesforce.com/sfc/p/#E0000000JelG/a/2R000000Un7F/yT.fKdAr9ZAo3cJLc4F2cBdUsMftpT2vsOICP7NmvMo, Accessed: Feb. 11, 2025.

[13] STMicroelectronics, "LPS28DFW - Dual full-scale, 1260 hPa and 4060 hPa, absolute digital output barometer with water-resistant package," LPS28DFW datasheet, Dec. 2021. [Online]. Available: https://www.st.com/resource/en/datasheet/lps28dfw.pdf, Accessed: Feb. 11, 2025.

[14] Analog Devices, "MAX17048/MAX17049 3μA 1-Cell/2-Cell Fuel Gauge with ModelGauge m3," MAX17048/MAX17049 datasheet, Rev. 5, Jan. 2023. [Online]. Available: https://www.analog.com/media/en/technical-documentation/data-sheets/MAX17048-MAX17049.pdf, Accessed: Feb. 11, 2025.

[15] Texas Instruments, "TUSB320LAI, TUSB320HAI USB Type-C Configuration Channel Logic and Port Control," TUSB320LAI datasheet, May 2017. [Online]. Available: https://www.ti.com/lit/ds/symlink/tusb320lai.pdf, Accessed: Feb. 11, 2025.

[16] Robinson, S. (GW7HPW), "SX1280_Testing: Semtech SX1280 2.4ghz LoRa Ranging Transceivers," GitHub repository, Apr. 2019. [Online]. Available: https://github.com/StuartsProjects/SX1280_Testing, Accessed: Feb. 11, 2025.

[17] ECE 445 Course Staff, "Safe Practice for Lead Acid and Lithium Batteries," University of Illinois, ECE 445: Senior Design Project Laboratory, Rev. D, Apr. 13, 2016. [Online]. Available: https://courses.grainger.illinois.edu/ece445/documents/GeneralBatterySafety.pdf, Accessed: Feb. 11, 2025.