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Rocket Telemetry System

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Rocket Telemetry System

Final Design Report

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Table of Contents:

List of Figures:

List of Tables:

1. Problem Statement:

1.1 Need:

(DD & ML) The Akronauts Rocket Design Team gathers limited data on rocket launches. Flight data is needed to locate the rocket after a launch, compare the flight path with an ideal path, and make incremental improvements to the rocket design based on the flight data. Past implementations of recovery systems included the use of a Ham Radio and transmitter. These implementations have provided partial data of the flight path, but not all the data. Data received included the apogee (highest point the rocket reaches) and last known location of the rocket. Additionally, when operating on the Ham Radio band, a license is required to broadcast a signal. Obtaining a license adds a certain level of inconvenience when wanting to test the system, especially if the number of individuals on the team who currently have a license is little to none. These systems are prebuilt and do not have customizable options. This adds complexity or another component to gather another piece of information about the rocket. In other words, there is no common location to gather all the information about the flightpath. The current system only provides maximum altitude data by utilizing altimeters onboard the rocket. The Akronauts Design Team would like to see velocity, acceleration, and altitude data over time. A system which would provide the Akronauts Design Team with real-time data, and also be unobtrusive to innovative designs is needed.

1.2 Objective:

(NW) The proposed solution is a student-built telemetry system that tracks more real time data than the current systems that the Rocket Team uses. The system will collect position and velocity data from the rocket and provide the user with detailed plots and visualizations concerning the flight of the rocket. This low-power system will allow the user to take detailed measurements for long periods of time to compensate for wait times during pre-launch and recovery time in the post-launch phase. The measurement system will fit inside the diameter of the rocket. Off the rocket, the system will process the data into customizable and easy to read plots and visualizations at a ground station. The software will display the flight data nearly in real time, instead of only after the flight.

1.3 Research Survey:

(DD, ML, & NW) Telemetry is the transmission and recording of data from measurement devices. Gathering data from a moving rocket in real time requires a transmitter and a receiver working together to send and receive sensory input from onboard components. To accomplish this task, a processing unit is placed inside the rocket. This processing unit is responsible for gathering data from various sensors located in the rocket and wirelessly transmitting the signal to a ground station. The downlink is an essential portion of a telemetry system. The greater the number of samples taken on the rocket, the better the depiction of the flight path. However, the number of samples must be balanced with other considerations such as size, weight, and power consumption.

At the ground station, data processing takes place. This is where data will be decoded, and the system will display information for the end-user in an easy to use manner. Real-time data is ideal because then data can be accessed immediately. This differs from post flight processing, in which the data is stored onboard and can only be reviewed at a later time [1]. Processing data in real-time provides the end user with information needed to determine if the rocket launch was a success. If a launch is not successful, data from onboard sensors allow engineers to better predict what went wrong, and how to resolve the issue before the next launch. Having flight data readily accessible also provides key information to recover the rocket in the post launch phase. This allows for onboard sensor data to be stored locally on the rocket as a redundant backup of the flight information.

The goal of onboard sensors is to take onboard data measurements from various devices during flight and provide information on different stages of the rocket flight [2]. To accomplish visualization of the rocket’s trajectory, previous designs included an accelerometer (x,y,z), an inertial measurement unit (IMU), a GPS, temperature sensor, and altitude sensor [2]. Compared to previous designs, this project will implement a modular system. Modularity provides the ability to prioritize sensory input in the graphical user interface. In addition, if a sensor is disconnected unexpectedly from launch, data transmission will still occur even if one or multiple sensors is not properly working. In doing such, sensors can be added or removed based on the data of interest needing to be displayed.

Data gathered onboard the rocket can be used to run algorithms and extrapolate additional useful information about the rocket flight, such as the drag coefficient. Real time flight data gathered from the rocket can then be correlated with simulation data to verify the accuracy of simulation results, and to see if the rocket is performing as predicted.

Directly comparing real and simulated data, namely importing simulation results to compare the flight path, sets this design apart from current existing technology. Additionally, software algorithms will save time previously consumed by lengthy hand calculations during the post processing of data phase. These algorithms will only have to be implemented into the software once, while hand calculations have to be performed after each individual launch. Being able to account for such inconsistencies allows for the engineers to make smarter design decisions in a timelier manner.

Transmitting data live from a rocket has been previously accomplished in several ways. One such implementation was the "Simple-1" module. This communication system is composed of two parts, the transmitter onboard the rocket, and the receiver at the ground station [2].

The in-flight portion collects data via sensors (temperature, altitude, acceleration, GPS, and IMU) and processes this data with an Arduino Mini. The collected data uses different protocols, which the Arduino organizes and summarizes. This organized data is sent to the Radiometrix using the RadioTeletype (RTTY) protocol [2]. The in-flight sensors types for this project will be similar to those implemented in the "Simple-1" rocket, but will also allow for expandability of sensory input with the graphical user interface.

On the ground, a software defined radio architecture was used. A HackRF radio recieved the signal, and the DL-FLDIGI software was used to decode the audio signal. Additionally, the DL-FLDIGI is able to export data in order to visualize it [2].

One limitation of the "Simple-1" module is the transmission frequency. In the US, the Industrial, Scientific, and Medical band (ISM Band) are unlicensed bands. Operating on frequencies in the 2.4–2.4835 GHz band or the 902–928 MHz band will not require a license. Additionally, " 2.4-GHz band is a worldwide unlicensed band. This is an important advantage compared to the 902–928 MHz band. The 2.4-GHz band also has a wider bandwidth than the 902–928 MHz band which means more available channels. The disadvantages of the 2.4-GHz band are: increased cost and current consumption of the active components, reduced propagation distance for the same power, and increased band congestion due to such systems as Bluetooth and wireless internet" [3]. Due to inconvenience involved with obtaining a license, the project will utilize a license free operating band.

Another limitation of the "Simple-1" module is that data transmission between the sensors and the microcontroller requires software tasks to consume a large amount of memory. The use of the 8-bit microcontroller have limited the amount of computing capabilities, thus optimization of the libraries is required. Due to the number of tasks required for the RF transmission implementations, a timer controller resource is needed to manage protocol time gaps [2].

Another rocket telemetry system implementation is the "Payload Test Rocket". This system collects acceleration, orientation, and photographic data. Similar to the "Simple-1" implementation, these data are all inputs to a microcontroller (In this particular case, an ATMEGA128). The data is transmitted live using radio frequency to a radio transciever on the ground. Graphs for acceleration of the rocket can be produced, and are clear enough to label the different stages of the rocket's flight (pre-launch, launch, free-fall, parachute release, parachute stabilize) [4].

In addition, different antenna types are available for transmitting telemetry information. A study of compared the performance of three different antenna types: monopole, patch, and wraparound [5]. Position, speed, rotation, acceleration, and temperature were a few of the measurements collected. Electromagnetic waves transferred this information to the ground station, at a frequency of around 2.465 GHz. The paper focused on the fact that an antenna should either be mounted on the surface of the rocket in a way that does not interfere with the aerodynamics of the rocket or placed inside the rocket. The paper concluded that, of the three antennas tested, "the monopole antenna gives better bandwidth performance" [5].

The visualization of transmitted data has been accomplished in several ways in the past. One trajectory visualization of a shuttle launch and a rocket launch used a "GPS Simulator, GPS receiver, lap-top computer, MATLAB software, FUGAWI software, and SATELLITE TOOL KIT (STK) software" to visualize the trajectory [6]. Of most interest is the STK software, which is capable of visualizing position and altitude, including "3D animation capabilities and a 2D map background for visualizing the path of these vehicles over time" [6]. Additionally, the FUGAWI software is "used for visualization of the trajectory of a moving vehicle. This software was used in this research to visualize the ground tracks of an airplane and a rocket" [6].

Another data visualization tool is the ADD (Adaptive Data-driven Design framework). While not aimed at telemetry systems, the ADD framework has mapping and charting capabilities. The ADD framework aims to make interactive data visualization accessible not only on desktop but on mobile applications. The challenge to overcome is the many different types and sizes of mobile devices. The ADD framework achieves this by implementing a responsive design, which incorporates benefits of both D3.js and React. Abilities include charting features and planned support for real-time data streaming without a need to refresh the web page. The ADD framework is an open-source library [7].

There are also existing and patented technologies that may be relevant to the design. The first of these patented technologies is a design for a “collection and distribution system” invented by Peter H. Diamandis, Granger Whitelaw, and Michael R. D'Angelo. Their system was originally designed for rocket-powered, aerial racing. According to the patent description, the system wirelessly collects a first set of geospatial data on one or more aerial vehicles in question, as well as a second set of visual data from a ground station, preferably in real time [8]. Collected data is then processed on computers at the ground station and redistributed “to one or more end-users”. [8]. The information outlined in the patent document describes a similar problem which can be directly applied to the current telemetry project.

Furthermore, this patent is relevant since it was designed for rocket-powered vehicle competitions, but also expands upon how the system would be setup to collect and distribute processed data to many individuals (e.g. a rocket team) both in real and post time. Overall, the patent gives a good design pattern for how such a telemetry system would be set up, and yet leaves much of the implementation of the specific components of the design up to those who would implement their system.

A second patented technology is a design for a “remote asset control system for optimized asset performance under a variety of circumstances” invented by James Higgins, Christopher D. Leidigh, and Jefferey Weiss at ALEKTRONA CORP [9]. In summary, the patent describes an intermediary failsafe system to address when a primary monitoring system experiences issues or exceptions to its primary behavior. Higgins and his team describes the system as being implemented in a "distributed computing network" made up of a server in communication with some monitored systems with the ability to store and issue a set of instructions to the systems via the network [9].

Although the "remote asset control system" patent is not quite as relevant as the data collection and distribution system, it still contains valuable design considerations relevant to this project's rocket telemetry system. Specifically, the patent addresses/minimizes the number of software related problems. Gaps in telemetry measurements are caused by hardware or software failures and the article expands upon the idea and composition of a "multi-tiered telemetry caching and transference mechanism". This mechanism is claimed to "[maximize] the amount of telemetry available for software analytical operations" [9]. These two issues are important since a small difference in measurement precision can make a significant difference when comparing the actual flight path versus the simulated flight path of the rocket.

1.4 Marketing Requirements:

(DD, ML)

1. The system should transmit data reliably over the far range of a rocket’s flight.
2. The system should be transportable in the diameter of a rocket.
3. The system should provide data visualization and comparisons in near real-time.
4. The system should use frequencies that can be operated without a license.
5. The system should operate during preflight plus the duration of the flight without needing recharged.
6. The system should be reusable in multiple rocket flights.

1.5 Objective Tree:

(DD, ML)

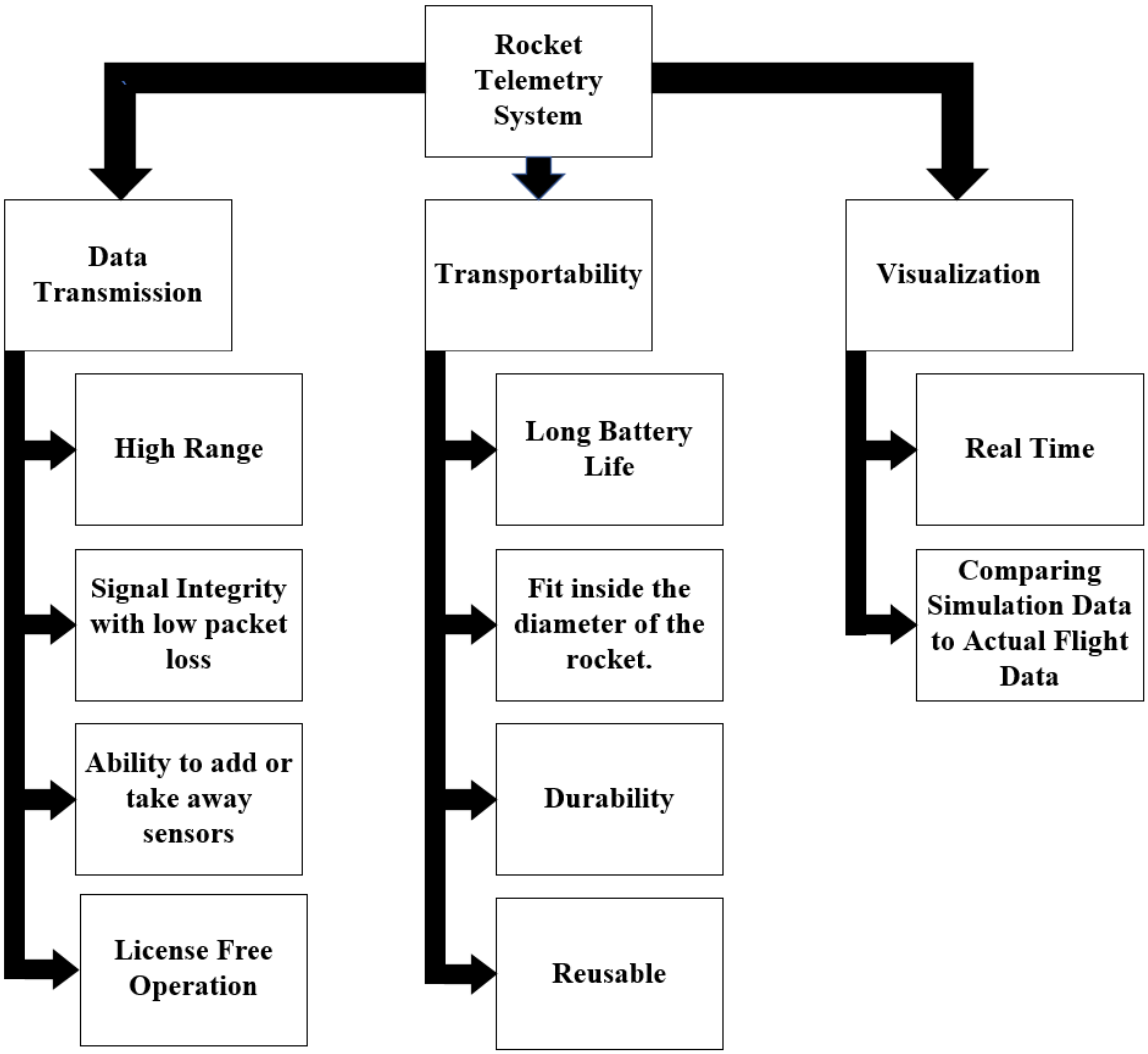

Figure 1: Rocket telemetry system objective tree.

The rocket telemetry system is composed of three main requirements as shown in Figure 1. Data transmission is important in the following areas: long range communication, the ability to receive most if not all the data that is transmitted, to work independent of which sensors are connected, and to operate in a license free frequency range. The transmitter must be able to work while the rocket is at its furthest point from the ground station. The signal must be strong enough at the receiver to avoid loss of data. If a sensor becomes disconnected due to the acceleration of the rocket, then the other information must continue to transmit. The bandwidth of transmission must follow the FCC regulations. Transportability is important in the following areas; have a long battery life since the rocket could be on the stand for up to five hours before launch, be compact and easy to move since there is a payload that must move in and out of the rocket, be able to handle high changes in acceleration, and be usable for multiple launches as long as the rocket operates properly. Visualizations are needed in the following areas: displaying data in an easy to read form such as graphs and directions, comparing to other launches, and determining what changes to the rocket are beneficial for further improvements. Visualizations will be updated in near real-time goal, with software displaying and updating the path of the rocket as it the flight takes place. It is possible for a sensor to become disconnected due to the acceleration of the rocket. If this occurs, then the other sensory information must continue to transmit, without the nonfunctional sensor’s data.

2. Design Requirements Specification:

(CB3, DD, ML)

Table 1: Design Requirements Specification

Marketing Requirement	Engineering Requirements	Justification
2	The system will fit into an 8-inch-high and 6-inch diameter section of the rocket.	This is the area that rocket team has set aside in the rocket for the data transmission system.
4	The system will transmit over the frequencies in the ranges: 2.4–2.4835 GHz or 902–928 MHz.	These frequencies are the unlicensed band. Removes license responsibility from the rocket team.
1, 6	The system must transmit data from up to 6 miles away.	This is the maximum altitude the rocket travels, plus drifting that can occur during descent.
1, 4	The receiver sensitivity should be able to account for path loss of at least 115dB.	The receiver must have a sensitivity to receive signals reliably.
1, 3	The transmission system will support a bandwidth of at least 3.84 kilobits per second.	This bandwidth is necessary to transmit the data frequently enough to obtain precise, real-time calculations.
5	The system will operate for a minimum of 5 hours without needing recharged.	Per the NASA Student Launch Handbook, the system must be capable of remaining in launch-ready configuration for a minimum of 2 hours without losing the functionality of any critical onboard components. The flight itself is approximately 8 minutes, and this allows almost 3 hours for recovery.
1, 3	The system will transmit data wirelessly at a rate of once every 100ms.	The system must transmit data in real-time wirelessly, as opposed to a display after the flight (post-flight processing).
3	The system will store data on-board at a rate of once every 10ms.	They system will store higher-accuracy data on-board in case of extreme packet loss and for in-depth post-flight calculations. (GPS data will not be stored at this frequency because it's purpose is for post-flight rocket location.)
3	The system will be able to store up to 1440 KB of data on-board.	The system will have enough room to store data continuously at the maximum storage rate for the entire life of the system's battery.
3	The sensors must sense the maximum values of each parameter within 1%.	The maximum values for all the sensors are as follows; height = 5500 feet, acceleration = 12 g, and velocity = 790 feet per second, and CEP (circular error probable) = 2000 feet. The error for all the sensors must be less than the following; height = 55 feet, acceleration = 0.12 g, velocity = 7.9 feet per second, and CEP = 20 feet. The minimum ranges of sensitivity are 0.0465 LSB/ft, 0.324 LSB/fps, 21.333 LSB/g, and 0.128 LSB/ft for CEP. The maximum ranges of sensitivity are 4.65 LSB/ft, 32.4 LSB/fps, 2133.3 LSB/g and 12.8 LSB/ft for CEP. (Further explanation in calculations)
Marketing Requirements: 1. The system should transmit data reliably over a far range. 2. The system should be transportable in the diameter of a rocket. 3. The system should provide data visualization and comparisons in near real-time. 4. The system should use frequencies that can be operated without a license. 5. The system should operate during preflight plus the duration of the flight without needing recharged. 6. The system should be reusable in multiple rocket flights.		

3. Accepted Technical Design:

3.1 Mechanical Sketch:

(DD, ML, NW)

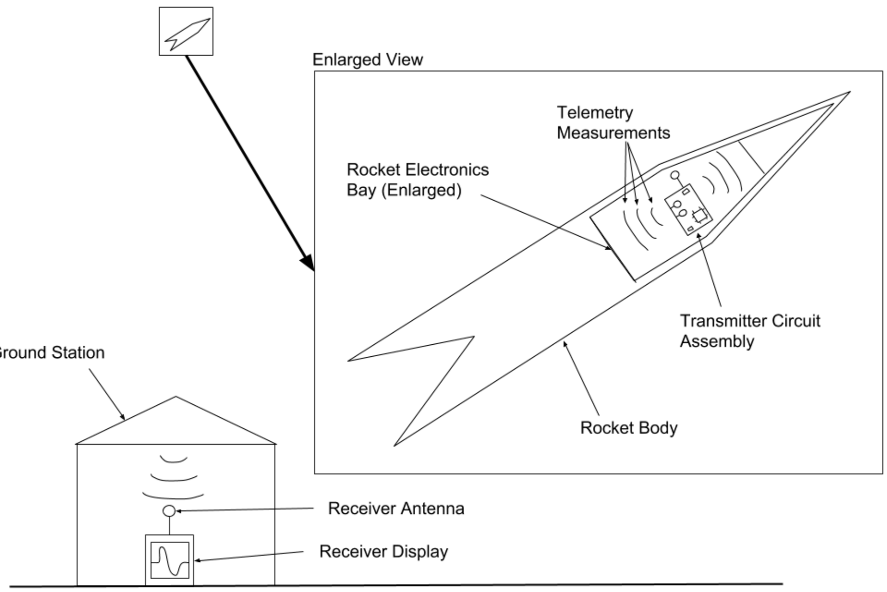

Figure 2: Mechanical sketch of rocket telemetry system.

The mechanical sketch in Figure 2 visualizes the operation of the system. The system senses the acceleration, velocity, altitude, and location of the rocket. That information is transmitted to the ground station and displayed in an easily understandable way.

3.2 Level 0 Block Diagram:

(CB3, DD, ML)

Figure 3: Level 0 rocket telemetry system.

The Level 0 block diagram in Figure 3 depicts the overall functionality the system. The system must take in a DC power, acceleration, velocity, altitude, and GPS data from their respective sensors and display them in an easy to read and understandable fashion.

Table 2: Level 0 Rocket Telemetry System

Module:	Rocket Telemetry System
Designer	David Dalvin Clark Bryant III Monica Lacek Nicholas Wolgamott
Inputs	DC power, acceleration, velocity, position, altitude sensors, GPS
Output	Rocket data visualization
Functionality	Locate and display data

3.3 Level 1 Hardware Block Diagram:

(CB3, DD)

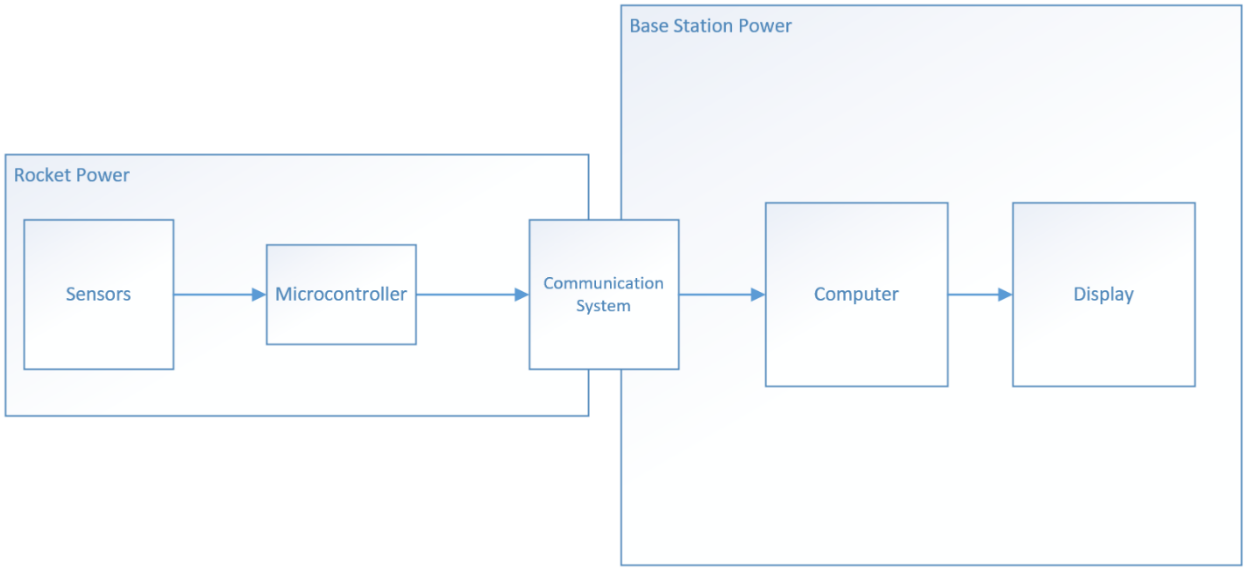

Figure 4: Level 1 fundamental hardware system.

The Level 1 Hardware Diagram shown in Figure 4 is used to determine the hardware function needed from each section of the system. The sensor data is sent to the microcontroller and told when and how to be transmitted. Those transmitted signals are then received and go to a computer that calculates the position, acceleration, velocity, and altitude of the rocket. Those values are then displayed on the display in forms of numbers, graphs, or other various methods.

Table 3: Level 1 Sensors

Module:	Sensors
Designer	David Dalvin Clark Bryant III Monica Lacek Nicholas Wolgamott
Inputs	Physical Changes, Power 5V
Output	Analog sensor signals from physical changes. Output voltage should not exceed 5V
Functionality	Sense the physical properties of the rocket.

Table 4: Level 1 Microcontroller

Module:	Microcontroller
Designer	David Dalvin Clark Bryant III Monica Lacek Nicholas Wolgamott
Inputs	Sensor output, Power 5V
Output	Digital output from sensor data. Output voltage should not exceed 5V Sensor data must be sent in a repeating predetermined routine
Functionality	Determine a priority order for reading and outputting sensor data in a time synchronized process.

Table 5: Level 1 Communication System

Module:	Communication System
Designer	David Dalvin Clark Bryant III Monica Lacek Nicholas Wolgamott
Inputs	Digital Data, Power 5V
Output	Receiver data after the signal is transmitted and received.
Functionality	Modulate, transmit, and receive signal

Table 6: Level 1 Computer

Module:	Computer
Designer	David Dalvin Clark Bryant III Monica Lacek Nicholas Wolgamott
Inputs	Receiver data, power supply
Output	Data for visualization
Functionality	To process receiver data and allow for displaying of information

Table 7: Level 1 Display

Module:	Display
Designer	David Dalvin Clark Bryant III Monica Lacek Nicholas Wolgamott
Inputs	Data for visualization.
Output	Graphical representations of sensor data and direction and distance to the rocket.
Functionality	To show the end user results from the flight path and locate rocket.

3.4 Level 2 Hardware Block Diagram:

(CB3, DD, ML, NW)

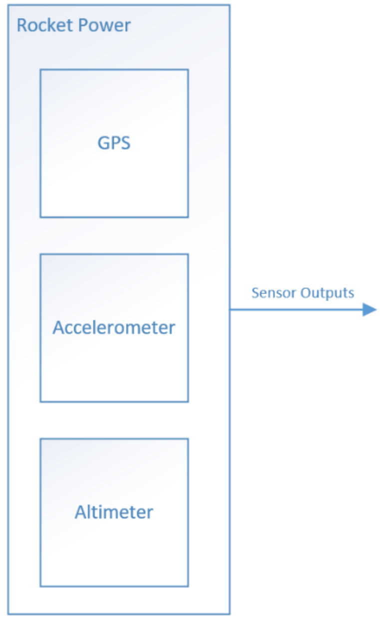

Figure 5: Level 2 Sensors

Table 8: Level 2 Sensors- GPS

Module:	GPS
Designer	David Dalvin Clark Bryant III Monica Lacek Nicholas Wolgamott
Inputs	Satellite Signal, Power 5V
Output	X, Y, and Z digital output. Output voltage should not exceed 5V
Functionality	Determine the X, Y, and Z position of the rocket with respect to a ground station.

Table 9: Level 2 Sensors-Accelerometer

Module:	Accelerometer
Designer	David Dalvin Clark Bryant III Monica Lacek Nicholas Wolgamott
Inputs	Acceleration, Power 5V
Output	Digital output from voltage change. Output voltage should not exceed 5V
Functionality	Determine position, velocity, and acceleration. Calculate distance from launch pad.

Table 10: Level 2 Sensors-Altimeter

Module:	Altimeter
Designer	David Dalvin Clark Bryant III Monica Lacek Nicholas Wolgamott
Inputs	Altitude, Power 5V
Output	Digital output from voltage change. Output voltage should not exceed 5V
Functionality	Detect changes in barometric pressure and calculate altitude. Characterize apogee of rocket.

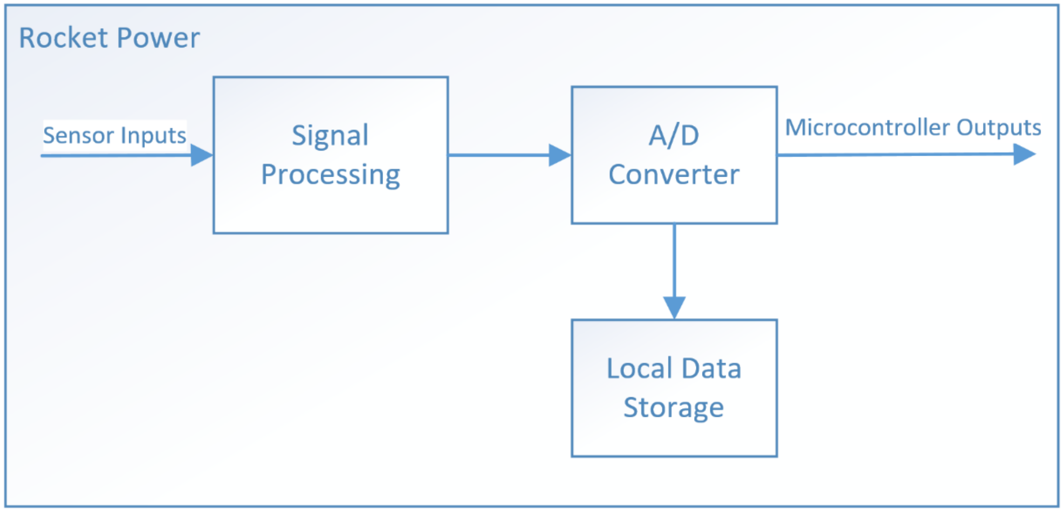

Figure 6: Level 2 Microcontroller

Table 11: Level 2 Microcontroller-Signal Processing Unit

Module:	Signal Processing Unit
Designer	David Dalvin Clark Bryant III Monica Lacek Nicholas Wolgamott
Inputs	Sensor Signal, Power 5V
Output	Sensor signals. Output voltage should not exceed 5V
Functionality	Adjusts the range and bandwidth of the sensor signals before converting.

Table 12: Level 2 Microcontroller-Analog to Digital Converter

Module:	Analog to Digital Converter
Designer	David Dalvin Clark Bryant III Monica Lacek Nicholas Wolgamott
Inputs	Sensor Signal, Power 5V
Output	Digital data from sensor signals. Output voltage should not exceed 5V
Functionality	Change the analog sensor signals to digital signals.

Table 13: Level 2 Microcontroller-Local Data Storage Device

Module:	Local Data Storage Device
Designer	David Dalvin Clark Bryant III Monica Lacek Nicholas Wolgamott
Inputs	Digital Data, Power 5V
Output	Stored digital data. Output voltage should not exceed 5V
Functionality	Store the digital data on the rocket.

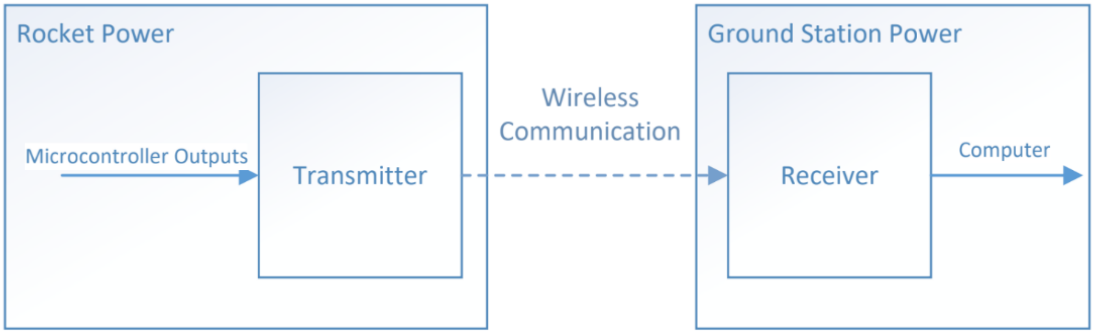

Figure 7: Level 2 Communication System

Table 14: Level 2 Transmitter

Module:	Transmitter
Designer	David Dalvin Clark Bryant III Monica Lacek Nicholas Wolgamott
Inputs	Digital Data, Power 5V
Output	Electromagnetic wave of data Output voltage should not exceed 5V
Functionality	Convert the digital data into analog data, add redundancy to message, modulate the signal, and transmit the electromagnetic wave of data.

Table 15: Level 2 Receiver

Module:	Receiver
Designer	David Dalvin Clark Bryant III Monica Lacek Nicholas Wolgamott
Inputs	Electromagnetic wave of data, Power 5V
Output	Digital data Output voltage should not exceed 5V
Functionality	Receive the electromagnetic wave, demodulate the data, convert analog data to digital data, and perform error correction.

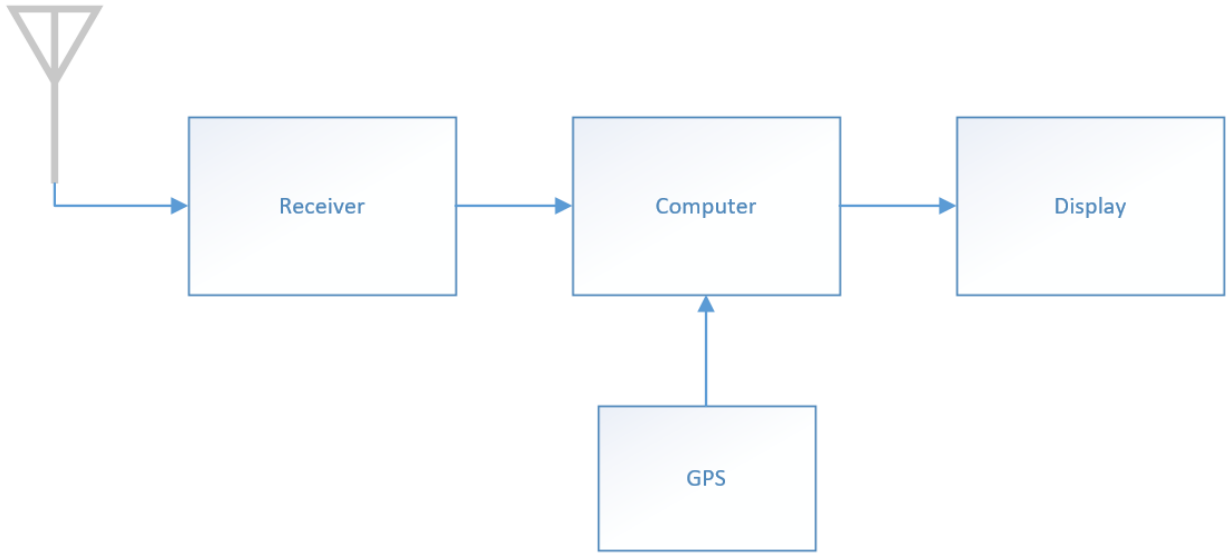

Figure 8: Level 2 Ground Station.

Table 16: Level 2 Receiver

Module:	Receiver
Designer	David Dalvin Clark Bryant III Monica Lacek Nicholas Wolgamott
Inputs	Electromagnetic wave of data, Power 5V
Output	Digital data Output voltage should not exceed 5V
Functionality	Receive the electromagnetic wave, demodulate the data, and convert analog data to digital data.

Table 17: Level 2 Sensors- GPS

Module:	GPS
Designer	David Dalvin Clark Bryant III Monica Lacek Nicholas Wolgamott
Inputs	Satellite Signal, Power 5V
Output	X, Y, and Z digital output. Output voltage should not exceed 5V
Functionality	Determine the X, Y, and Z position of the rocket with respect to a ground station.

Table 18: Level 2 Computer

Module:	Computer
Designer	David Dalvin Clark Bryant III Monica Lacek Nicholas Wolgamott
Inputs	Receiver data, power supply
Output	Data for visualization
Functionality	To process receiver data and allow for displaying of information

Table 19: Level 2 Display

Module:	Display
Designer	David Dalvin Clark Bryant III Monica Lacek Nicholas Wolgamott
Inputs	Data for visualization.
Output	Graphical representations of sensor data and direction and distance to the rocket.
Functionality	To show the end user results from the flight path and locate rocket.

4. Hardware Schematics/ Circuit Diagrams:

(CB3, DD, NW)

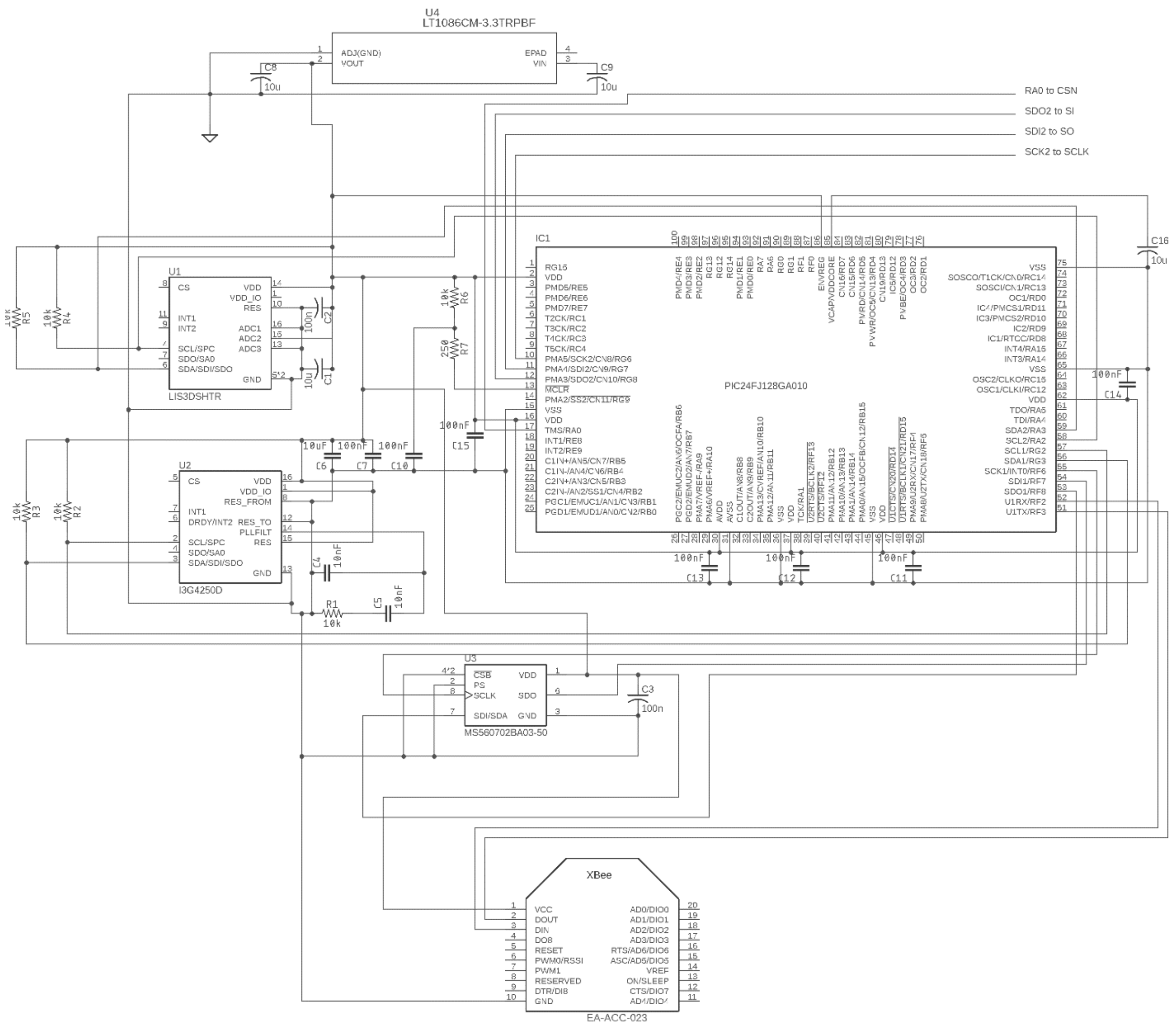

Figure 9: Microcontroller and Sensors Circuit

The microcontroller communicates with four sensors. The accelerometer and gyroscope both communicate via I^2C. The pressure sensor communicates via SPI. The GPS will be connected using the same pin alignment as an Xbee and communicating using UART. The battery will be regulated by 3.3V regulators. There is load capacitors for the rail voltages all respectively close to the respective component that uses the power from the regulator. The microcontroller communicates with the transmitter circuit using SPI. All the communication pins for I^2C and SPI are used on the microcontroller. All information will also be stored on an on-board SD card for post-flight processing in case of packet loss during the flight. The table below helps show all the communication connections.

Table 20: Microcontroller Communication Pins

Microcontroller Pins Numbers	Microcontroller Pin Use	Sensor Pin Number
10	SCK2 to SCLK on Transmitter	1
11	SDI2 to SO on Transmitter	2
12	SDO2 to SI on Transmitter	20
17	RA0 to CSN on Transmitter	7
51	U1TX to DOUT on GPS	2
52	U1RX to DIN on GPS	3
53	SDO1 to SDI on Pressure Sensor	7
54	SDI1 to SDO on Pressure Sensor	6
55	SCK1 to SCLK on Pressure Sensor	8
56	SDA1 to SDA on Gyroscope	3
57	SCL1 to SCL on Gyroscope	2
58	SCL2 to SCL on Accelerometer	4
59	SDA2 to SDA on Accelerometer	6

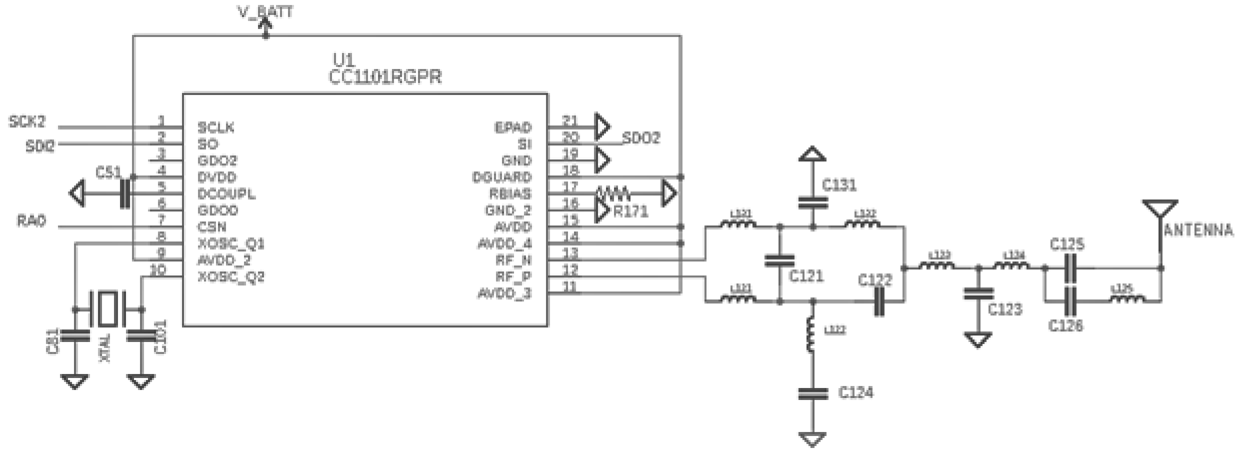

Figure 10: CC1101 Suggested Layout for 868/915MHz Circuit

The CC1101 Circuit shown in Figure 10 was closely modeled after the recommended layout provided by the datasheet. The components and their placement are important to optimize performance. Since the team had no prior experience designing RF boards, the datasheet was a reliable source to reference when creating the schematics. The majority of the support circuitry are of the 0402 size package. The 0402 size are highly desirable due to reducing noise in the overall RF circuitry. The datasheet recommended surface mount components by the manufacturer Murata.

When designing the printed circuit board for the transmitter and receiver chip, the datasheet also offers highly encouraged recommendations to ensure optimal operation of the circuit. The top layer of the PCB is utilized for signal routing, while the open areas are filled with metallization connected to a ground utilizing several vias. Vias offer good thermal performance along with low inductance to grounding. The datasheet suggests using tented vias to reduce the likelihood of defects caused in the reflow process. Decoupling capacitors should be positioned close to the supply pin and connected to power through separate vias. The datasheet stresses the importance of supply power filtering. Other recommendations include avoiding routing sharp edges close to the crystal oscillator. Reasoning behind this is because the pad of the crystal may shift the DC operating point and result in duty cycle variation.

Overall, the datasheet highly recommends following the reference layout of the CC1101DK (Development Kit) with a fully assembled CC1101EM (Evaluation Model).

5. Onboard Software Flowchart:

(ML)

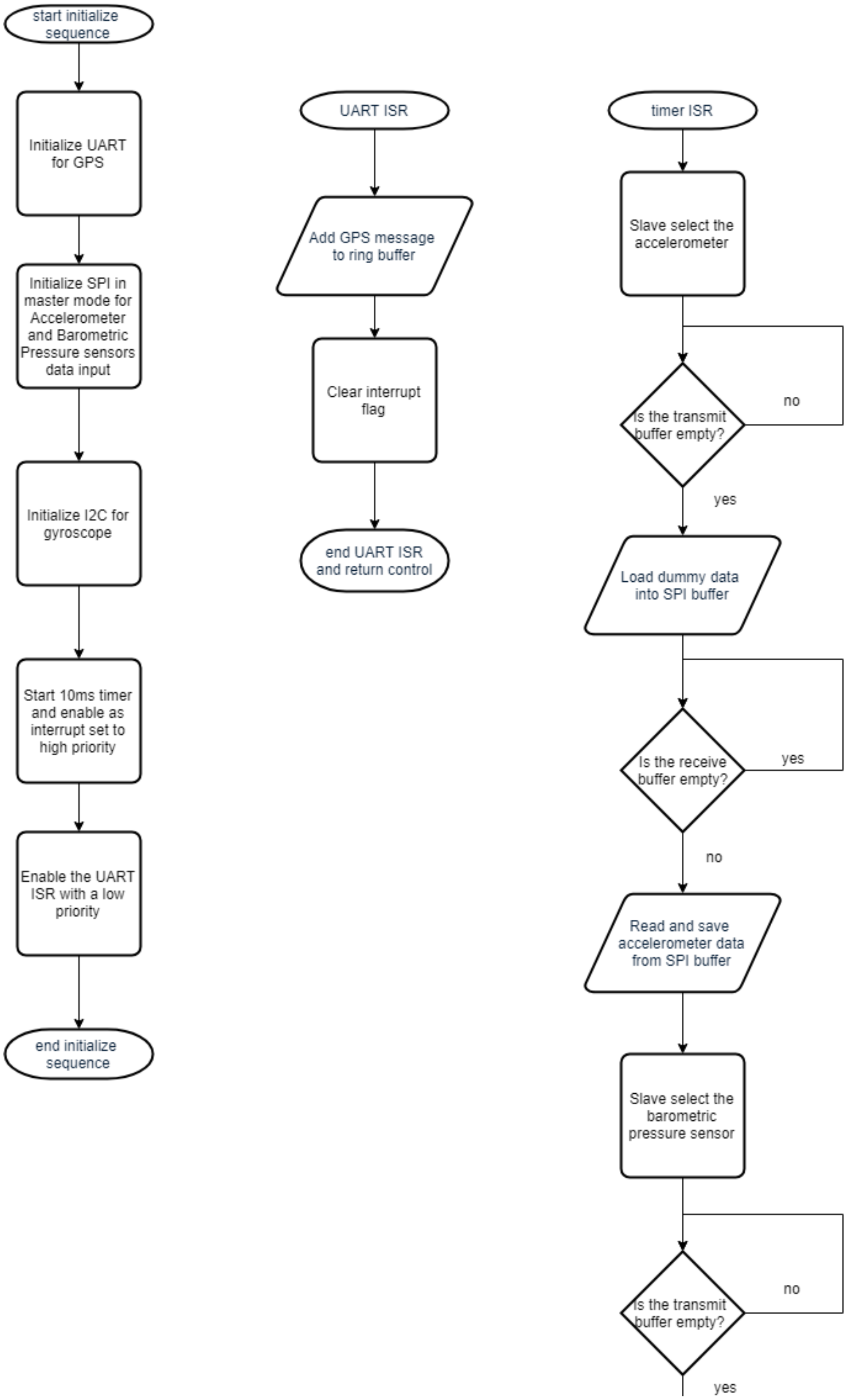

Figure 11: Onboard Microcontroller Software Flowchart Part I

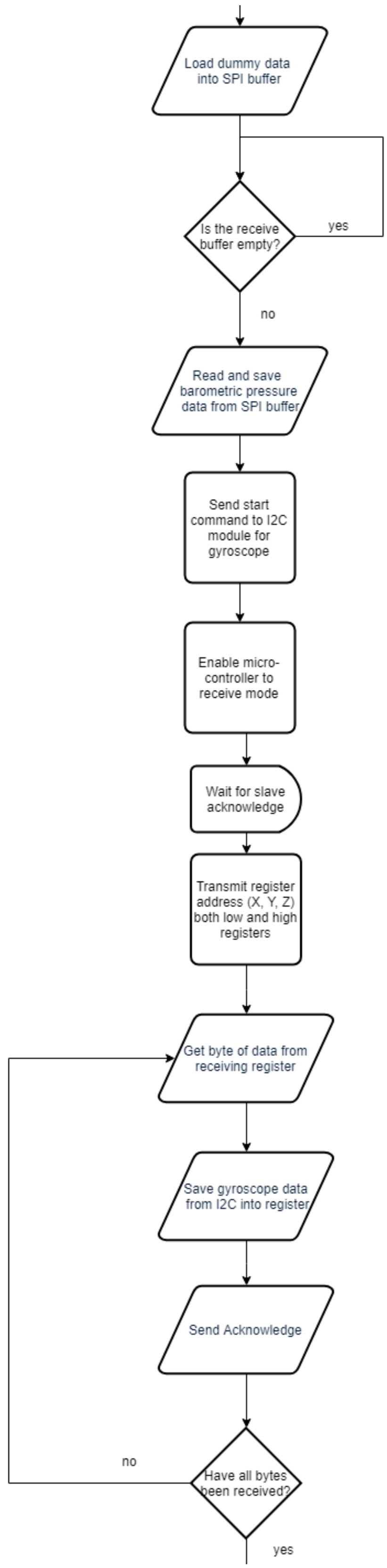

Figure 12: Onboard Microcontroller Software Flowchart Part II

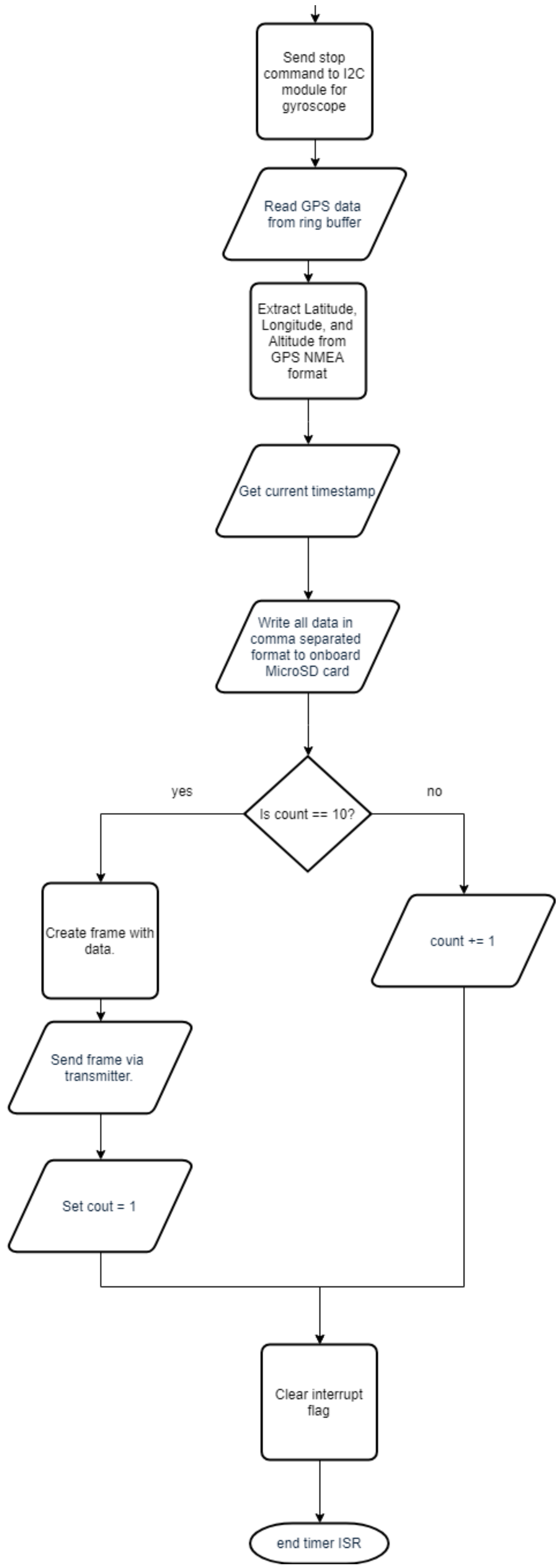

Figure 13: Onboard Microcontroller Software Flowchart Part III

The Onboard Software Flowchart (Figures 11 through 13) shows how the sensory data is collected and transmitted. When the microcontroller is first powered on, it completes a sequence of initializations that do one-time configurations, for example, the UART baud rate. Two Interrupt Service Routines (ISR) are created. One is timer-based, and runs every 10 ms. The other is run when new UART data arrives. The timer-based ISR has a higher priority so it’s operation will not be interrupted. Sensory data in the timer-based ISR is read via SPI and I2C protocols. The accelerometer and the barometric pressure sensor communicate via SPI. The gyroscope communicates via I2C. These protocols are different are require different steps. The most recent GPS data can be read from the ring buffer where it is placed during the UART ISR. At the end of the timer ISR, all the collected data is written to the on-board MicroSD card. Additionally, the count is incremented. When count is 10, that means 100ms have passed. Every 100ms, a frame should be created and sent by the transmitter. Then the count is reset.

6. Ground Station Microcontroller Software Flowchart:

(ML)

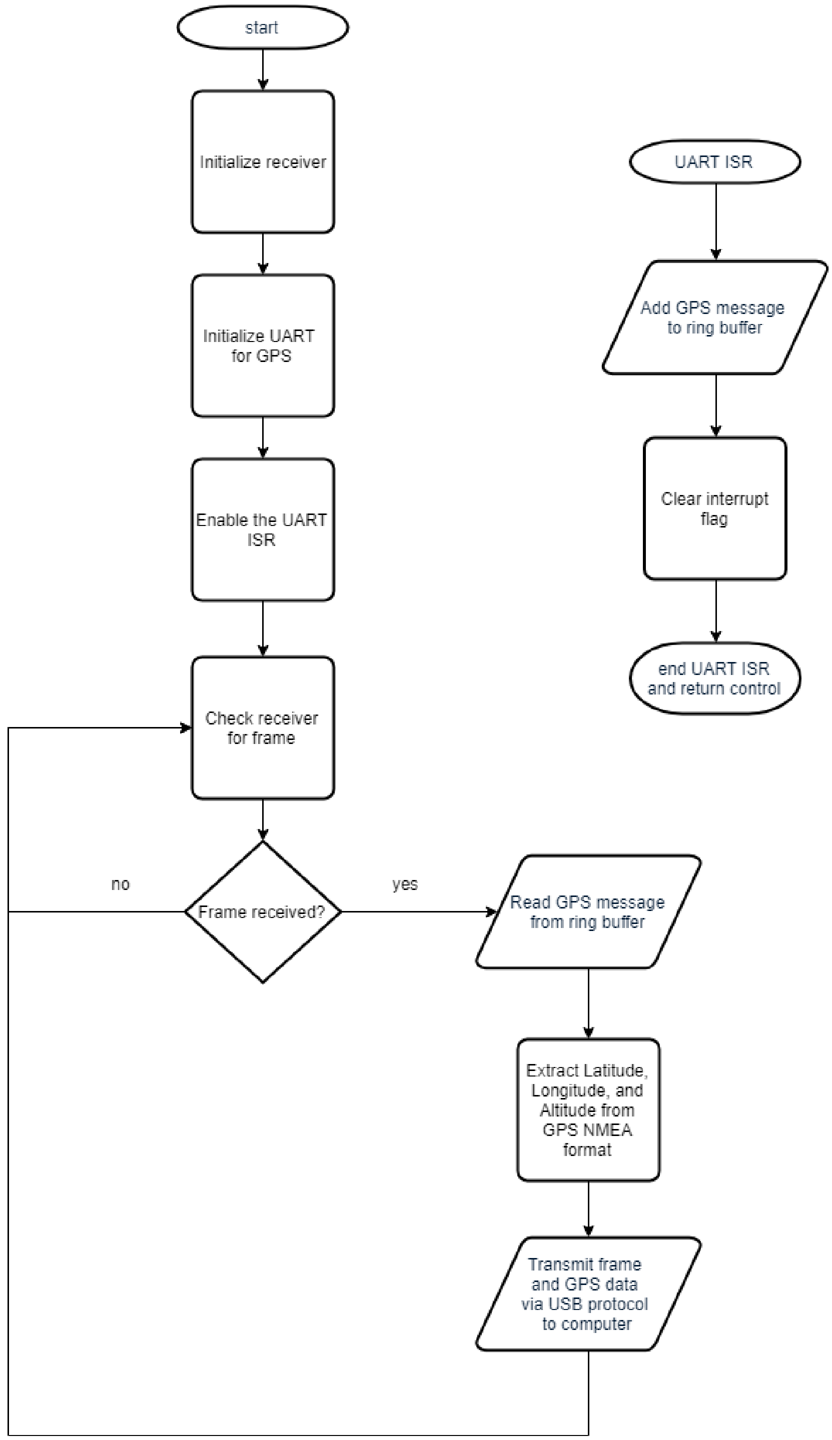

Figure 14: Ground Station Microcontroller Software Flowchart

The software flowchart for the microcontroller located at the ground station is shown in Figure 14. The software for the UART module interfacing with the GPS will be identical to the code for the on-board microcontroller, including the configuration and ISR. The main difference is that the RF module is configured to receive frames. Finally, each frame and additional GPS data is sent via USB protocol to the attached computer.

8. Ground Station Desktop Application Flowchart:

(ML)

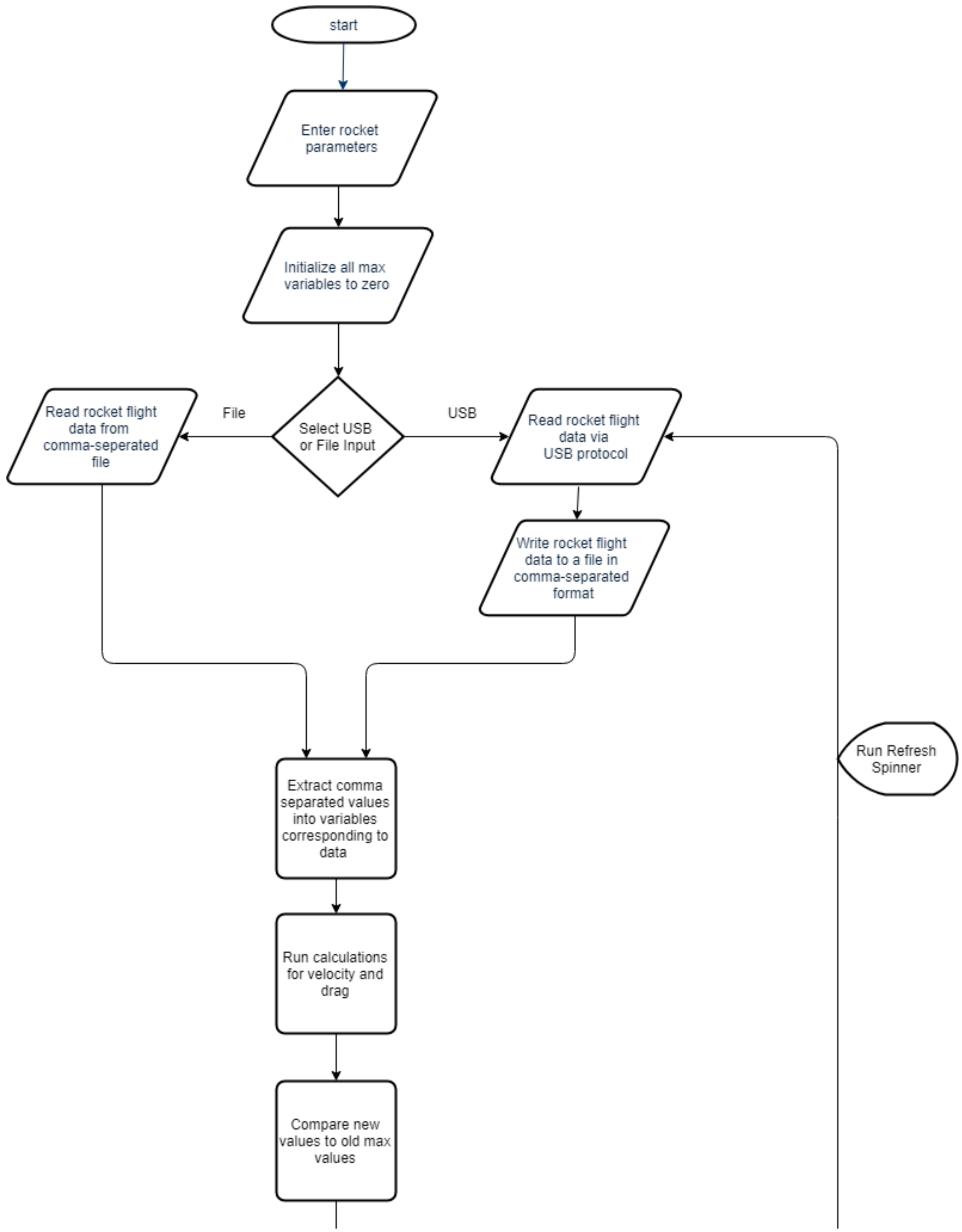

Figure 15: Flight Data Software Flowchart Part I

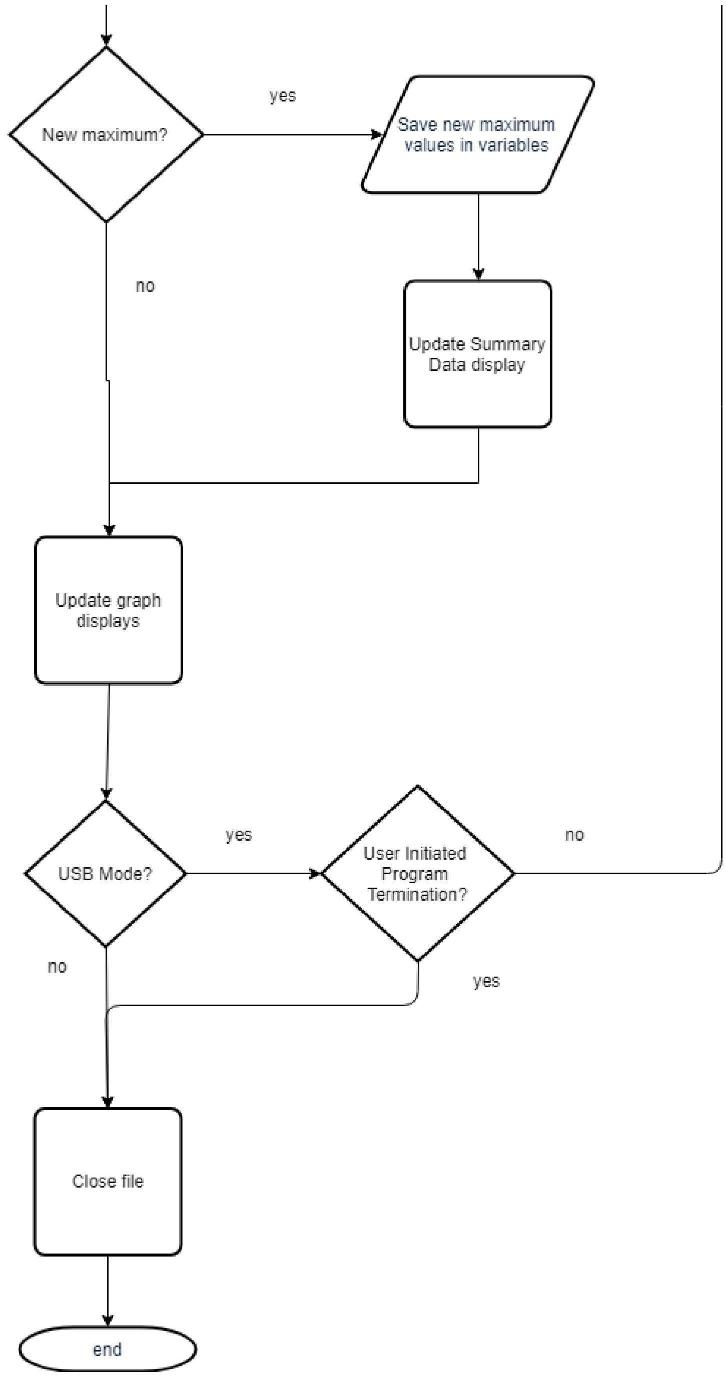

Figure 16: Flight Data Software Flowchart Part II

The software flowchart for the flight data display is shown in Figures 15 and 16. This software sequence starts when the user opens the desktop application. The user will be prompted to enter the rocket parameters, such as mass of the rocket. Then the user will be asked to either select the USB (live data) input, or a file input. If the data is coming in live, part of the USB process is to write the incoming data in comma-separated format to a file for permanent storage. The data is prepared and calculations are performed on the data. The new data is compared to old data to check for the possibility of new maximum values. The summary data and graphs are then displayed or updated. The sequence ends with the user terminating the program, and the file that is in use will then be saved and closed.

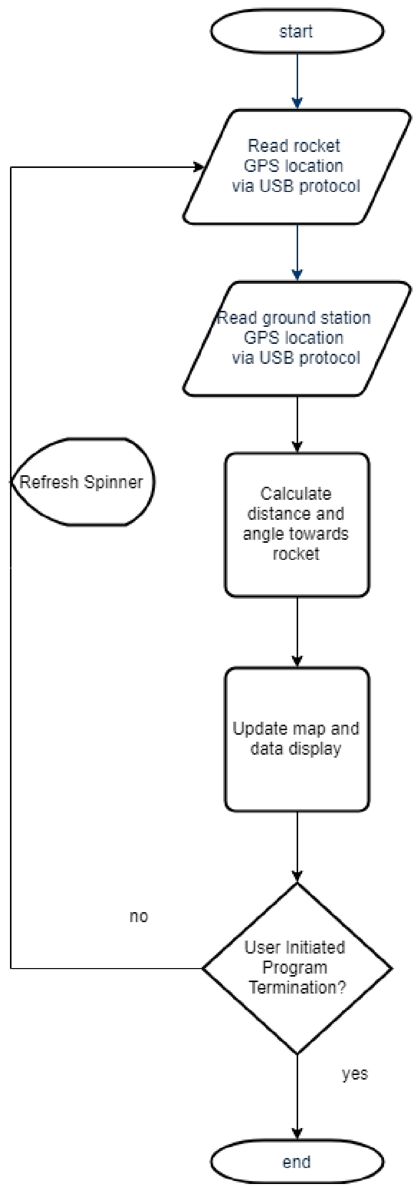

Figure 17: Rocket Locator Software Flowchart

The software flowchart for the rocket locator software is shown in Figure 17. The program starts when the user opens the desktop application. The application requires that the microcontroller be connected and transmitting data via USB protocol. The application can extract the GPS location of the rocket and the ground station, and perform calculations to direct the user what the distance and angle the rocket is from the ground station. Each time new data is received, the display is updated. This process continues until the user ends the program.

9. Level 2 Software Block Diagram:

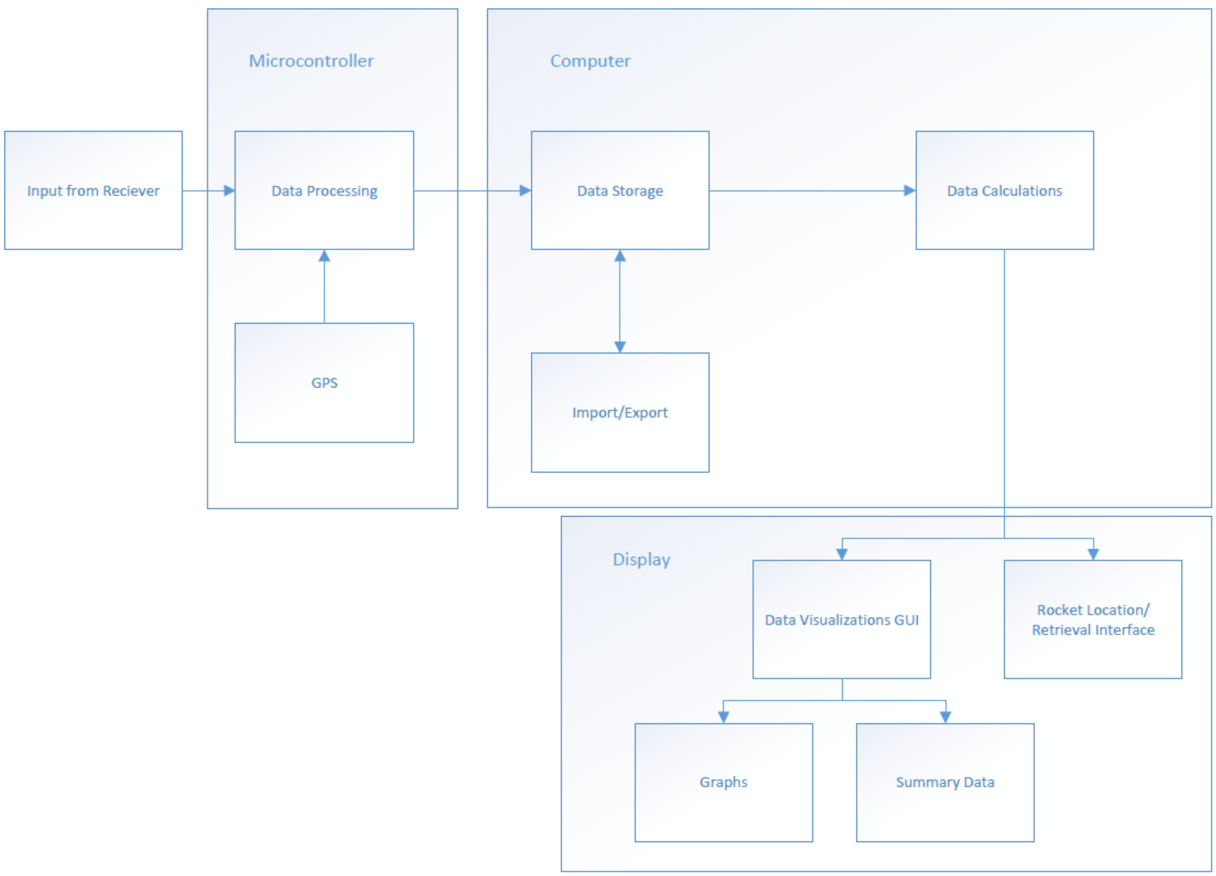

Figure 18: Level 2 Ground Station Software

The Level 2 Software Diagram, shown in Figure 18, shows the flow of data through the ground station software system. Input from the receiver is processed for error correction and to account for lost data. GPS input for the ground station is also collected. The data is saved as it comes in. The data storage method will allow users to import or export data later. Data calculations are performed on the stored data, since the data arrives in near real-time, the calculations will have to be updated at the rate data is received. These calculations are then sent to a graphical user interface (GUI). The GUI has two parts. First, the data visualization area, where graphs and summary data are displayed. This area can be used during the flight, and the data can be imported or referenced hours, days, and weeks after the flight. The second part is a retrieval interface. This interface will aid the team in locating the rocket once it has landed. Based on the rocket’s last known GPS, and the receiver's GPS location, a direction and distance to the rocket will be displayed. This display will only be useful while locating the rocket and will not be necessary when viewing historical launch data.

10. Software User Interface Mockups:

(ML)

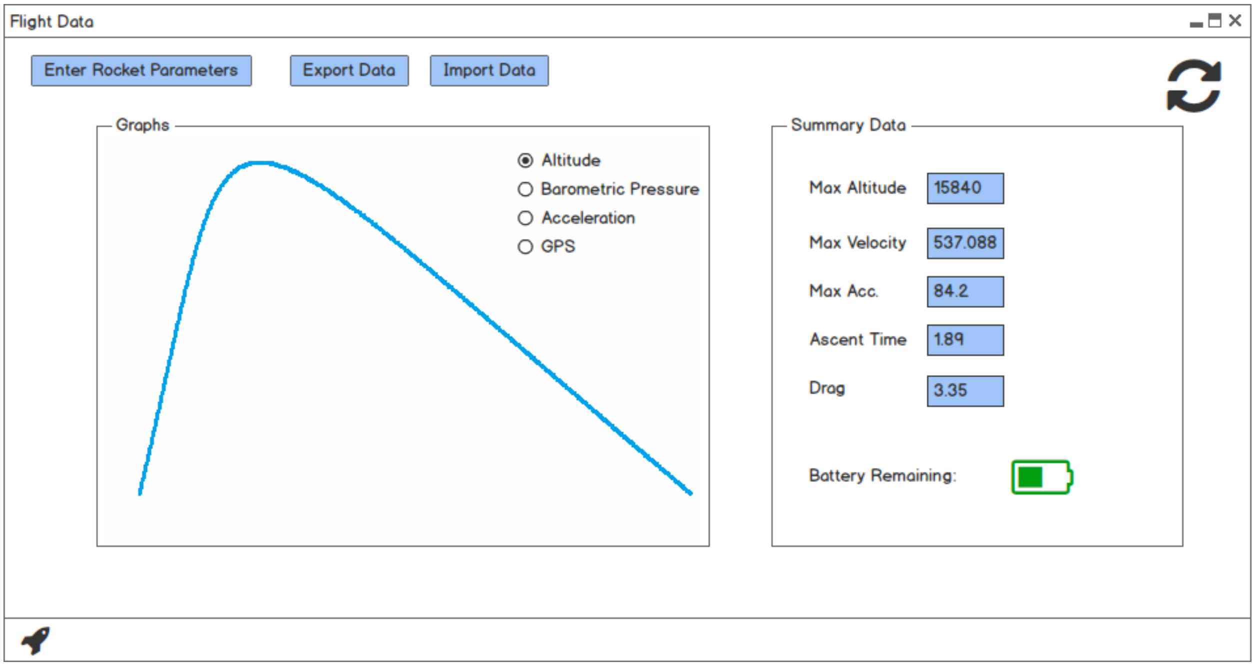

Figure 19: Rocket Data Visualization Interface

The rocket data visualization user interface will resemble the mockup in Figure 19. The "Enter Rocket Parameters" button will allow the user to enter specifics of the rocket that impact calculations, such as the drag calculations. The "Export Data" and "Import Data" will allow the launch data to be saved and allow the user to view saved data from past launches. The graphs section displays a graph based on whichever data type is selected: Altitude, Barometric Pressure, Acceleration, and GPS. The summary data section will display pertinent data calculations from the overall flight. The refresh symbol will appear to notify the user that data is arriving in real time.

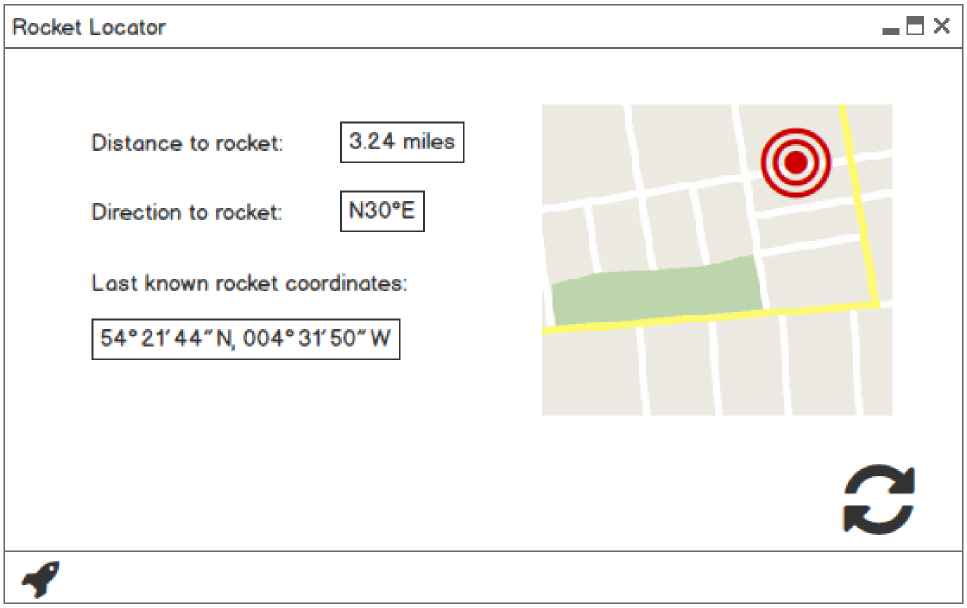

Figure 20: Rocket Retrieval Interface

The rocket locator interface, shown in Figure 20, will be used to locate the rocket after it lands. It displays the distance and direction to the rocket, as well as the last GPS coordinates the rocket transmitted. A map will also be displayed to further aid in recovery. The refresh symbol will notify the user if the data is arriving in real time. The data will be updating based on changes in the rocket's or locator device's position.

11. Software Programming Languages and Technologies:

(ML)

All microcontroller code will be written in the C programming language, this includes the code for the onboard microcontroller as well as the ground station microcontroller. The code for the desktop applications will be written in C#. The graphical user interfaces will be created using Windows Presentation Foundation (WPF). The graphs will be created using a WPF graphing library such as Interactive Data Display or OxyPlot.

12. Engineering Calculations:

(CB3, ML, DD)

Data Transmission and Storage Calculations:

Assuming the following sensor data is transmitted in 4 bytes each: timestamp, altitude, barometric pressure, GPS x-axis, GPS y-axis, GPS z-axis, and acceleration x-axis, y-axis, z-axis, and gyroscope x-axis, y-axis, z-axis, there is a total of 48 bytes of data. Assume the transmitter accounts for error correction and frame overhead. Accuracy with respect to max velocity (0.7 Mach) is as follows:

0.7 Mach = 537.9 miles/hr = 788.9 ft/sec = 0.79 ft/ms

If storing one frame of data per 10ms, at max speed the data will be sampled a minimum of at least once every 7.9 feet. This means the system has the accuracy to detect a change of 7.9 feet at maximum velocity. There must be at least 48 bytes per 10ms or 384 bits per 10ms. Assuming data is stored for the entire battery life of 5 hours, this gives us:

5 hrs x 60 min x 1000ms/10ms x 48 bytes = 1440 KB storage space required.

If transmitting one frame per 100ms, this transmits 384 bits per 100ms = 3.84 kbps of bandwidth.

Signal Strength Calculations:

The path loss for signals in free space is given as FSPL= 20log ($4\pi df/c$), where d is distance between transmitter and receiver, f is the frequency of transmission, and c is the speed of light. The frequency range is around 920MHz, the distance is 10 miles and the speed of light in 186,282 miles/sec. The gain of both antennas must be 0dB to track the rocket in all directions. This gives us a path loss of at least 115dB. Looking at common receivers, the sensitivity of the receiver is about –100dBm = -130dB. Since -130dB is less than -115dB this gives the signal at the receiver a signal within its sensitivity range.

Doppler Signal Shift Calculations:

The Doppler Effect has dependence on speed of object and speed of signal propagation. The following equation is used to find the Doppler effect; $f_r = [(c + v_s)/(c + v_o)] * f_t$

With f_t being the frequency at the transmitter (this is planned to be in the 902-928MHz range), v_s being the velocity of the rocket with respect to the receiver (0.7 Mach = 0.7*343 m/s), v_o is velocity of the receiver (0 m/s), and c being the speed of light (3*10^8 m/s). The f_r is the frequency that is received by the receiver, and the difference between f_r and f_t is the Doppler modulation, which is a maximum of 736 Hz reduced. Adding a factor of safety, 800 Hz is the maximum Doppler modulation needing to design to mitigate.

Power Calculations:

The power of the system with the lowest power consumption parts found is 1 watt, and the components with the most power consumption is 3 watts. Excel is used to generate a table for charge dissipation of the battery with a voltage range from 5 to 9 volts. The charge dissipation is in units of mA per 5 hrs, since the battery must last 5 hours. Table 12 is a portion of the full table.

Table 21: Battery charge dissipation (mA per 5 hrs) matrix

Charge Chart	Voltage (V)	Volts	Volts	Volts	Volts	Volts	Volts
Power (W)		5	5.2	5.4	5.6	5.8	6
Watts	1	1000	961.5385	925.9259	892.8571	862.069	833.3333
Watts	1.1	1100	1057.692	1018.519	982.1429	948.2759	916.6667
Watts	1.2	1200	1153.846	1111.111	1071.429	1034.483	1000
Watts	1.3	1300	1250	1203.704	1160.714	1120.69	1083.333
Watts	1.4	1400	1346.154	1296.296	1250	1206.897	1166.667
Watts	1.5	1500	1442.308	1388.889	1339.286	1293.103	1250
Watts	1.6	1600	1538.462	1481.481	1428.571	1379.31	1333.333

Launch Duration Calculations:

The rocket's engine is completely exhausted after 2.4 seconds. Maximum velocity is achieved at the end of the engine's life. Knowing that the maximum velocity is 0.7 Mach, the rockets velocity will decrease until reaching apogee. In a vacuum the time it takes for the rocket to reach apogee after the engine is exhausted is $0.7(343 \text{ m/s}) - (9.8*t) = 0$. The rocket will reach apogee approximately 24 seconds after the engine is exhausted. Adding the time for the engine to exhaust the launch will take 26.4 seconds. The rocket will not be in a vacuum creating a drag force on the rocket and deaccelerating the rocket much faster than gravity alone. Taking into account the drag from air resistance, the rocket reaches apogee in the range of 10-15 seconds.

Sensor Sensitivity Calculations:

The sensors must operate with errors as low as 55 feet for height, 7.9 fps for velocity, 0.12 g for acceleration, and 20 feet for circular error probable. A sensitivity of 1% is 33mV/LSB. For at least 1% accuracy 7 bits are necessary. Since there are no 7 bit sensors then at least 8 bits of resolution is required for all sensors. The sensitivity should be equal to or greater than 0.6 mV/ft, 4.18 mV/fps, 275 mV/g, and 1.65 mV/ft for CEP (circular error probable). The sensitivity must not be too high or there will be very low SNR. Since there is a transmitter and many digital circuits the noise in the system will be significant. To avoid problems with noise the system should try to avoid sensors with 100 times the lower sensitivity. This means the max sensitivity of 60 mV/ft, 418 mV/fps, 27500 mV/g, and 165 mV/ft for CEP. Since many of the sensors are digital the sensitivities might be in terms of LSB. The minimum ranges are 0.0465 LSB/ft, 0.324 LSB/fps, 21.333 LSB/g, and 0.128 LSB/ft for CEP. The maximum range is 4.65 LSB/ft, 32.4 LSB/fps, 2133.3 LSB/g and 12.8 LSB/ft for CEP.

Transmitter and Receiver Calculations:

Based off the CC1101 being used as both the transmitter and receiver on the rocket, several calculations can be accomplished to determine the distance the CC1101 can transmit. In order to calculate the anticipated range, the information above in conjunction with the TI Datasheet on the CC1101 was used to approximate a theoretical range using principles of the Friis equation [10]. For a transmitter power of 12.589mW, operating frequency of 920MHz, cable loss of 10dB, a transmission rate of 100 milliseconds, and sending 48 bytes of data per frame (the calculation assumes no transmitting antenna gain). The necessary bandwidth can be calculated to be 3.84 kbps which corresponds to a Kbaud rate of 3.75. For different receiver sensitivities, the free space path loss was obtained. For the CC1101, a Kbaud rate of 3.75 in the 868/915MHz range, the anticipated receiver sensitivity is between -112dBm and -104dBm. This result allows for the free space path loss to be calculated in the range of 105dB to 113dB. Converting these values in to meters and then miles, the anticipated range of the CC1101 transceiver chip is between 2.86 miles to 7.20 miles. This value will only improve, as it is a worst-case calculation. The actual coverage distance within this calculation will be closer to the 7.20 miles based off the actual kBaud data rate. A closer approximation to the range anticipated with the CC1101 chip is 4.54 miles.

To help the range requirements, the design team will be using an 11dBi high gain Yagi antenna on the ground station along with a 3dBi gain antenna for the transmitter. With the high gain antenna at the ground station, there should not be any issues meeting the required range. The CC1101 also has a range extender called the CC1190. The CC1190 is a 850MHz – 950MHz range extender which can be used in conjunction with the CC1101 in long range applications. The CC1190 improves the receiver sensitivity and allows for a higher output power [10].

To the amount of Doppler shift the CC1101 can account for can be determined from the CC1101's datasheet. The CC1101 receiver performs frequency offset compensation digitally. According to the datasheet, the receiver can compensate for a shift in the range of ±202 kHz to ±210 kHz, well above the requirements of this system.

13. Parts List:

(DD)

Table 22: Parts List 1

Qty.	Refdes	Part Num.	Description
2	GPS	EA-ACC-023	GPS Chip
1	CC1101 Tx/Rx + CC1190 Range Extender	CC1101CC1190EMK868	KIT EVAL CC1101CC1190868-915
4	Rx CC1101	CC1101RGPR	RF Transceiver Low-Power Sub-1GHz RF Transceiver
4	CC1101Breakout Board	IPC0082	QFN-20 to DIP-24 SMT Adapter (0.5 mm pitch, 4.0 x 4.0 mm body, 2.5 x 2.5 mm pad)
2	Tx/Rx Antenna	A9D3S	Antenna 915MHz OmniDirectional 3dBi w/SMA. GSM ISM 1/4 Wave
2	SMA Cable	OL-2763	RF Coaxial Cable SMA Male to SMA Female 2 Meters
2	Accelerometer	LIS3DSHTR	Accelerometer
1	Accelerometer Breakout Board	IPC0090	LGA-12 to DIP-12 SMT Adapter (0.5 mm pitch, 3.0 x 3.0 mm body)
2	Gyroscope	I3G4250D	Gyroscope
1	Gyroscope Breakout Board	PA0102	LGA-16 to DIP-16 SMT Adapter (0.65 mm pitch, 4 x 4 mm body)
2	Pressure Sensor	MS560702BA03-50	Barometric Pressure Sensor
1	Pressure Sensor Breakout Board	DR127D254P08	Dual Row 1.27mm Pitch 8-Pin to DIP-8 Adapter
2	Battery	Tenergy	Power Supply
1	Charger	Tenergy	Power Supply Charging Station
2	Regulator	LT1086CM-3.6#PBF	Voltage Regulator
2	Microcontroller	PIC24FJ128GA010-I/PF	PIC24FJ128GA010-I/PF-ND Microcontroller Chip
2	Microcontroller Breakout Board	PA0109	TQFP-100 to DIP-100 SMT Adapter (0.5 mm pitch, 14 x 14 mm body)
2	MicroSD Breakout Board	1528-1462-ND	MicroSD Breakout
1	MicroSD Card	MB-ME64GA/AM	Samsung MicroSD Card
1	MicroSD to USB	Sabrent	MicroSD to USB adaptor
2	ProtoBoard		Perfboard for testing without designing and buying a full fledged PCB
2	Regulator	LT1086CM-3.3#PBF	Voltage Regulator

Table 23: Parts List Transmitter and Receiver Support Circuitry

Qty.	Refdes	Part Num.	Description
4	C51	GRM155R62A104KE14D	0.1µF ±10% 100V Ceramic Capacitor X5R 0402 (1005 Metric)
4	C81	GRM1555C2A270JA01D	27pF ±5% 100V Ceramic Capacitor C0G, NP0 0402 (1005 Metric)
4	C101	GRM1555C2A270JA01D	27pF ±5% 100V Ceramic Capacitor C0G, NP0 0402 (1005 Metric)
4	C121	GRM1555C2A1R0CA01D	1pF ±0.25pF 100V Ceramic Capacitor C0G, NP0 0402 (1005 Metric)
4	C122	GRM1555C2A1R5CA01D	1.5pF ±0.25pF 100V Ceramic Capacitor C0G, NP0 0402 (1005 Metric)
4	C123	GRM1555C2A3R3CA01D	3.3pF ±0.25pF 100V Ceramic Capacitor C0G, NP0 0402 (1005 Metric)
4	C124	GRM1555C2A101JA01D	100pF ±5% 100V Ceramic Capacitor C0G, NP0 0402 (1005 Metric)
4	C125	GRM1555C2A120JA01D	12pF ±5% 100V Ceramic Capacitor C0G, NP0 0402 (1005 Metric)
4	C126	GRM1555C2A470JA01D	47pF ±5% 100V Ceramic Capacitor C0G, NP0 0402 (1005 Metric)
4	C131	GRM1555C2A1R5CA01D	1.5pF ±0.25pF 100V Ceramic Capacitor C0G, NP0 0402 (1005 Metric)
4	L121	LQW15AN12NJ0ZD	Fixed Inductors 0402 12nH 0.14ohms 500mA +/-5%
4	L122	LQW15AN18NJ0ZD	Fixed Inductors 0402 18nH 0.27ohms 370mA +/-5%
4	L123	LQW15AN12NJ0ZD	Fixed Inductors 0402 12nH 0.14ohms 500mA +/-5%
4	L124	LQW15AN12NJ0ZD	Fixed Inductors 0402 12nH 0.14ohms 500mA +/-5%
4	L125	LQW15AN3N3G80D	Fixed Inductors 0402 3.3nH 0.030ohms 2A +/-2%
4	L131	LQW15AN12NJ0ZD	Fixed Inductors 0402 12nH 0.14ohms 500mA +/-5%
4	L132	LQW15AN18NJ0ZD	Fixed Inductors 0402 18nH 0.27ohms 370mA +/-5%
4	XTAL	NX3225GA-26MHZ-TI	CRYSTAL 26.0000MHZ 10PF SMD
4	R171	RK73H1ETTP5602F	Thick Film Resistors - SMD 56K OHM 1%

14. Material Budget Information:

(DD)

Table 24: Material Budget Information 1

Qty.	Part Num.	Description	Unit Cost	Total Cost
2	EA-ACC-023	GPS Chip	$38.75	$77.50
1	CC1101CC1190EMK868	KIT EVAL CC1101CC1190868-915	102.50	102.50
4	CC1101RGPR	RF Transceiver Low-Power Sub-1GHz RF Transceiver	3.85	15.40
4	IPC0082	QFN-20 to DIP-24 SMT Adapter (0.5 mm pitch, 4.0 x 4.0 mm body, 2.5 x 2.5 mm pad)	8.39	33.56
2	A9D3S	Antenna 915MHz Omnidirectional 3dBi w/SMA. GSM ISM 1/4 Wave	4.99	9.98
2	OL-2763	RF Coaxial Cable SMA Male to SMA Female 2 Meters	7.98	15.96
2	LIS3DSHTR	Accelerometer	2.01	4.02
1	IPC0090	LGA-12 to DIP-12 SMT Adapter (0.5 mm pitch, 3.0 x 3.0 mm body)	6.29	6.29
2	I3G4250D	Gyroscope	8.09	16.18
1	PA0102	LGA-16 to DIP-16 SMT Adapter (0.65 mm pitch, 4 x 4 mm body)	6.29	6.29
2	MS560702BA03-50	Barometric Pressure Sensor	2.67	5.34
1	DR127D254P08	Dual Row 1.27mm Pitch 8-Pin to DIP-8 Adapter	3.79	3.79
2	Tenergy	Power Supply	9.99	19.98
1	Tenergy	Power Supply Charging Station	17.99	17.99
2	LT1086CM-3.6#PBF	Voltage Regulator	4.11	8.22
2	PIC24FJ128GA010-I/PF	PIC24FJ128GA010-I/PF-ND Microcontroller Chip	4.58	9.16
2	PA0109	TQFP-100 to DIP-100 SMT Adapter (0.5 mm pitch, 14 x 14 mm body)	19.49	38.98
2	1528-1462-ND	MicroSD Breakout	7.50	15.00
1	MB-ME64GA/AM	Samsung MicroSD Card	13.99	13.99
1	Sabrent	MicroSD to USB adaptor	7.99	7.99
2		Perfboard for testing without designing and buying a full-fledged PCB		
2	LT1086CM-3.3#PBF	Voltage Regulator	4.36	8.72
			Total	$436.84

Table 25: Material Budget Information Transmitter and Receiver Support Circuitry

Qty.	Part Num.	Description	Unit Cost	Total Cost
4	GRM155R62A104KE14D	0.1µF ±10% 100V Ceramic Capacitor X5R 0402 (1005 Metric)	$0.10	$0.40
4	GRM1555C2A270JA01D	27pF ±5% 100V Ceramic Capacitor C0G, NP0 0402 (1005 Metric)	0.13	0.52
4	GRM1555C2A270JA01D	27pF ±5% 100V Ceramic Capacitor C0G, NP0 0402 (1005 Metric)	0.13	0.52
4	GRM1555C2A1R0CA01D	1pF ±0.25pF 100V Ceramic Capacitor C0G, NP0 0402 (1005 Metric)	0.10	0.40
4	GRM1555C2A1R5CA01D	1.5pF ±0.25pF 100V Ceramic Capacitor C0G, NP0 0402 (1005 Metric)	0.10	0.40
4	GRM1555C2A3R3CA01D	3.3pF ±0.25pF 100V Ceramic Capacitor C0G, NP0 0402 (1005 Metric)	0.10	0.40
4	GRM1555C2A101JA01D	100pF ±5% 100V Ceramic Capacitor C0G, NP0 0402 (1005 Metric)	0.10	0.40
4	GRM1555C2A120JA01D	12pF ±5% 100V Ceramic Capacitor C0G, NP0 0402 (1005 Metric)	0.13	0.52
4	GRM1555C2A470JA01D	47pF ±5% 100V Ceramic Capacitor C0G, NP0 0402 (1005 Metric)	0.13	0.52
4	GRM1555C2A1R5CA01D	1.5pF ±0.25pF 100V Ceramic Capacitor C0G, NP0 0402 (1005 Metric)	0.10	0.40
4	LQW15AN12NJ0ZD	Fixed Inductors 0402 12nH 0.14ohms 500mA +/-5%	0.24	0.96
4	LQW15AN18NJ0ZD	Fixed Inductors 0402 18nH 0.27ohms 370mA +/-5%	0.24	0.96
4	LQW15AN12NJ0ZD	Fixed Inductors 0402 12nH 0.14ohms 500mA +/-5%	0.24	0.96
4	LQW15AN12NJ0ZD	Fixed Inductors 0402 12nH 0.14ohms 500mA +/-5%	0.24	0.96
4	LQW15AN3N3G80D	Fixed Inductors 0402 3.3nH 0.030ohms 2A +/-2%	0.26	1.04
4	LQW15AN12NJ0ZD	Fixed Inductors 0402 12nH 0.14ohms 500mA +/-5%	0.24	0.96
4	LQW15AN18NJ0ZD	Fixed Inductors 0402 18nH 0.27ohms 370mA +/-5%	0.24	0.96
4	NX3225GA-26MHZ-TI	CRYSTAL 26.0000MHZ 10PF SMD	0.64	2.56
4	RK73H1ETTP5602F	Thick Film Resistors - SMD 56K OHM 1%	0.11	0.44
			Total	$14.28

15. Project Schedule Fall:

(DD, NW)

Task Name	Duration	Start	Finish	Resource Names
SDP1 Fall 2018	**23 days**	**Thu 9/6/18**	**Sun 10/7/18**	**Bryant III,Dalvin,Lacek,Wolgamott**
Project Design	**23 days**	**Thu 9/6/18**	**Sun 10/7/18**	**Bryant III,Dalvin,Lacek,Wolgamott**
Preliminary Report	**11 days**	**Thu 9/6/18**	**Thu 9/20/18**	**Bryant III,Dalvin,Lacek,Wolgamott**
Cover Page	11 days	Thu 9/6/18	Thu 9/20/18	Dalvin
Table of Contents, List of Tables, List of Figures	11 days	Thu 9/6/18	Thu 9/20/18	Dalvin
Need	11 days	Thu 9/6/18	Thu 9/20/18	Bryant III,Dalvin,Lacek,Wolgamott
Objective	11 days	Thu 9/6/18	Thu 9/20/18	Bryant III,Dalvin,Lacek,Wolgamott
Background	11 days	Thu 9/6/18	Thu 9/20/18	Dalvin,Lacek,Wolgamott
Marketing Requirements	11 days	Thu 9/6/18	Thu 9/20/18	Dalvin,Lacek,Wolgamott
Objective Tree	11 days	Thu 9/6/18	Thu 9/20/18	Dalvin,Lacek
Block Diagrams Level 0, 1… With FR tables	**11 days**	**Thu 9/6/18**	**Thu 9/20/18**	**Bryant III,Lacek**
Hardware Modules (Identify Designer)	11 days	Thu 9/6/18	Thu 9/20/18	Bryant III,Dalvin
Software Modules (Identify Designer)	11 days	Thu 9/6/18	Thu 9/20/18	Lacek
Mechanical Sketch	11 days	Thu 9/6/18	Thu 9/20/18	Wolgamott
Team Information	11 days	Thu 9/6/18	Thu 9/20/18	Dalvin
References	11 days	Thu 9/6/18	Thu 9/20/18	Dalvin
Preliminary Parts Request Form	11 days	Thu 9/6/18	Thu 9/20/18	Bryant III,Dalvin,Lacek,Wolgamott
Midterm Report	**23 days**	**Thu 9/6/18**	**Sun 10/7/18**	**Bryant III,Dalvin,Lacek,Wolgamott**
Design Requirements Specification	11 days	Mon 9/17/18	Sun 9/30/18	Dalvin,Lacek
Midterm Design Gantt Chart	11 days	Mon 9/17/18	Sun 9/30/18	Dalvin

Design Calculations	**16 days**	**Mon 9/17/18**	**Sun 10/7/18**	**Bryant III,Lacek,Wolgamott,Dalvin**
Electrical Calculations	**16 days**	**Mon 9/17/18**	**Sun 10/7/18**	**Bryant III,Dalvin,Lacek**
Path Loss	16 days	Mon 9/17/18	Sun 10/7/18	Lacek
Data Transmission	16 days	Mon 9/17/18	Sun 10/7/18	Lacek
Power, Voltage, Current	16 days	Mon 9/17/18	Sun 10/7/18	Bryant III
Doppler Effect	16 days	Mon 9/17/18	Sun 10/7/18	Bryant III,Lacek
Mechanical Calculations	**16 days**	**Mon 9/17/18**	**Sun 10/7/18**	**Bryant III**
Launch Duration	16 days	Mon 9/17/18	Sun 10/7/18	Bryant III
Block Diagrams Level 2 With FR tables and ToO	**6 days**	**Mon 9/17/18**	**Sun 9/23/18**	**Lacek**
Hardware Modules (Identify Designer)	6 days	Mon 9/17/18	Sun 9/23/18	Dalvin,Bryant III
Software Modules (Identify Designer)	6 days	Mon 9/17/18	Sun 9/23/18	Lacek
Midterm Design Presentations Part 1	1 day	Thu 10/11/18	Thu 10/11/18	Bryant III,Dalvin,Lacek,Wolgamott
Midterm Design Presentations Part 2	1 day	Thu 10/18/18	Thu 10/18/18	Bryant III,Dalvin,Lacek,Wolgamott
Project Poster	11 days	Mon 10/8/18	Sun 10/21/18	
Secondary Parts Request Form	16 days	Mon 9/17/18	Sun 10/7/18	
Final Design Report	**38 days**	**Mon 10/8/18**	**Wed 11/28/18**	
Abstract	38 days	Mon 10/8/18	Wed 11/28/18	
Software Design	**23 days**	**Mon 10/8/18**	**Wed 11/7/18**	
Modules 1 …n	**23 days**	**Mon 10/8/18**	**Wed 11/7/18**	
Psuedo Code	23 days	Mon 10/8/18	Wed 11/7/18	
Hardware Design	**23 days**	**Mon 10/8/18**	**Wed 11/7/18**	

Modules 1 …n	**23 days**	**Mon 10/8/18**	**Wed 11/7/18**	
Simulations	23 days	Mon 10/8/18	Wed 11/7/18	
Schematics	23 days	Mon 10/8/18	Wed 11/7/18	
Parts Lists	**38 days**	**Mon 10/8/18**	**Wed 11/28/18**	
Parts list for Schematics	38 days	Mon 10/8/18	Wed 11/28/18	
Materials Budget List	38 days	Mon 10/8/18	Wed 11/28/18	
Proposed Implementation Gantt Chart	38 days	Mon 10/8/18	Wed 11/28/18	
Conclusions and Recommendations	38 days	Mon 10/8/18	Wed 11/28/18	
Final Design Presentations Part 1	1 day	Thu 11/8/18	Thu 11/8/18	
Final Design Presentations Part 2	1 day	Thu 11/15/18	Thu 11/15/18	
Secondary Parts Request Form	10 days	Thu 10/4/18	Wed 10/17/18	
Final Parts Request Form	41 days	Mon 10/8/18	Sun 12/2/18	

16. Project Schedule Spring:

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Task Name	Duration	Start	Finish	Resource Names
SDP2 Spring 2019	**41 days**	**Mon 11/12/18**	**Sat 1/5/19**	**Bryant III,Dalvin,Lacek,Wolgamott**
Project Implementation	**40 days**	**Mon 11/12/18**	**Fri 1/4/19**	**Bryant III,Dalvin,Lacek,Wolgamott**
Hardware Implementation	**41 days**	**Mon 11/12/18**	**Sat 1/5/19**	**Bryant III,Lacek,Wolgamott,Dalvin**
Schematics	15 days	Mon 11/12/18	Fri 11/30/18	Bryant III,Wolgamott
Printed Circuit Boards	15 days	Mon 11/12/18	Fri 11/30/18	Bryant III,Wolgamott
Communication	**25 days**	**Mon 11/26/18**	**Fri 12/28/18**	**Bryant III,Dalvin,Wolgamott**
Breadboard Components	10 days	Mon 11/26/18	Fri 12/7/18	
Transmitter and Receiver Communication	**10 days**	**Mon 11/26/18**	**Fri 12/7/18**	**Bryant III,Dalvin,Wolgamott**
Establish Communication Frequency	10 days	Mon 11/26/18	Fri 12/7/18	Dalvin
Enable Doppler Correction	10 days	Mon 11/26/18	Fri 12/7/18	Dalvin,Wolgamott
Enable Error Correction	10 days	Mon 11/26/18	Fri 12/7/18	Dalvin,Wolgamott
Microcontroller and Tx/ Rx Integration	10 days	Mon 12/10/18	Fri 12/21/18	Dalvin,Wolgamott
Sensors, Microcontroller, and Tx/ Rx Integration	10 days	Mon 12/10/18	Fri 12/21/18	Bryant III,Dalvin,Wolgamott
Reading Sensor Data	15 days	Mon 12/10/18	Fri 12/28/18	Bryant III,Dalvin,Lacek,Wolgamott
Testing Hardware	**6 days**	**Mon 12/31/18**	**Sat 1/5/19**	**Bryant III,Dalvin,Wolgamott**
Verify Tx/ Rx can account for frequency shift	6 days	Mon 12/31/18	Sat 1/5/19	Dalvin,Wolgamott
Verify Wireless Link	6 days	Mon 12/31/18	Sat 1/5/19	Dalvin,Wolgamott
Verify Reading Sensor Data	6 days	Mon 12/31/18	Sat 1/5/19	Bryant III,Wolgamott
Verify Onboard Storage of Information	6 days	Mon 12/31/18	Sat 1/5/19	Lacek,Wolgamott

Software Implementation	**40 days**	**Mon 11/12/18**	**Sat 1/5/19**	**Lacek,Dalvin**
Detailed Flowcharts	10 days	Mon 11/12/18	Fri 11/23/18	Dalvin,Lacek
Programming Microcontroller	**15 days**	**Mon 11/12/18**	**Fri 11/30/18**	**Wolgamott,Lacek**
Rocket	**35 days**	**Mon 11/12/18**	**Fri 12/28/18**	**Lacek,Wolgamott**
Startup Sequence	35 days	Mon 11/12/18	Fri 12/28/18	Dalvin,Lacek,Wolgamott
Establish Communication Channel	35 days	Mon 11/12/18	Fri 12/28/18	Dalvin,Lacek,Wolgamott
Identify Pins to Read Data From	35 days	Mon 11/12/18	Fri 12/28/18	Bryant III,Wolgamott
Transmit Sensor Input	35 days	Mon 11/12/18	Fri 12/28/18	Bryant III,Wolgamott
Onboard Data Storage	35 days	Mon 11/12/18	Fri 12/28/18	Lacek,Wolgamott
Ground Station	**35 days**	**Mon 11/12/18**	**Fri 12/28/18**	**Lacek,Wolgamott**
Startup Sequence	35 days	Mon 11/12/18	Fri 12/28/18	Dalvin,Lacek,Wolgamott
Establish Communication Channel	35 days	Mon 11/12/18	Fri 12/28/18	Dalvin,Lacek,Wolgamott
Identify Pins to Read Data From	35 days	Mon 11/12/18	Fri 12/28/18	Bryant III,Wolgamott
Receive Sensor Input	35 days	Mon 11/12/18	Fri 12/28/18	Bryant III,Wolgamott
Graphical User Interface	**6 days**	**Mon 12/31/18**	**Sat 1/5/19**	**Bryant III,Dalvin,Lacek,Wolgamott**
Options of Programming Languages	6 days	Mon 12/31/18	Sat 1/5/19	Lacek
Analysis of Program Libraries	6 days	Mon 12/31/18	Sat 1/5/19	Bryant III,Lacek
GUI Layout	6 days	Mon 12/31/18	Sat 1/5/19	Bryant III,Dalvin,Lacek,Wolgamott
Importing Data from Display	6 days	Mon 12/31/18	Sat 1/5/19	Bryant III,Lacek,Wolgamott
Export Data to Save Locally	**6 days**	**Mon 12/31/18**	**Sat 1/5/19**	**Bryant III,Lacek,Wolgamott**
Data Format	6 days	Mon 12/31/18	Sat 1/5/19	Lacek,Wolgamott

Plots	6 days	Mon 12/31/18	Sat 1/5/19	Bryant III,Lacek,Wolgamott

17. Design Team Information:

Clark Bryant III, Electrical Engineering.

David Dalvin, Electrical Engineering.

Monica Lacek, Computer Engineering.

Nick Wolgamott, Electrical Engineering.

18. Conclusions and Recommendations:

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The design team believes the rocket telemetry system design is feasible. Due to project timelines, it will be an engineering challenge to build and test the system design before the Akronauts subscale launch in early January. According to section 2.20.1, in the NASA Student Launch Handbook, “All teams will successfully launch and recover their full-scale rocket prior to FRR in its final flight configuration. The rocket flown must be the same rocket to be flown on launch day” [11]. This would require the rocket telemetry system to be completed by January 5th, 2019.

Due to a rushed design process, intricate requirements of the system, and unforeseeable circumstances that may arise, the project may not meet the hard deadlines as outlined above. A scenario in which the deadline cannot be met would require testing the system by other means.

19. Bibliography:

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[2] J. Sebasti and G. Alejandro, "Design , Construction and Testing of a Data Transmission System for a Mid-power Rocket Model," *IEEE Aerosp. Conf.*, 2017.

[3] M. Loy, R. Karingattil, and L. Williams, "ISM-Band and Short Range Device Regulatory Compliance Overview," *Ti*, no. May, pp. 1–17, 2005.

[4] A. Irawan, H. Rizal, S. A. S, and W. Adiprawita, "Payload Test Rocket," pp. 155–160, 2013.

[5] Pattapong Sripho; Suriya Duangsi; Marinda Hongthong, "Comparison of antenna for DTI rocket telemetry system." Defence Technology Institute, Nonthaburi, Thailand, Nonthaburi, Thailand, p. 6, 2016.

[6] D. R. Brown and D. B. Dunn, "Trajectory visualization by using Global Positioning Systems (GPS)," *Proceedings. IEEE SoutheastCon, 2005.* pp. 183–186, 2005.

[7] L. J. Chi, C. H. Huang, and K. T. Chuang, "Mobile-friendly and streaming web-based data visualization," *TAAI 2016 - 2016 Conference on Technologies and Applications of Artificial Intelligence, Proceedings*. pp. 124–129, 2017.

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[10] "student_launch_handbook_2019.pdf." National Aeronautics and Space Administration George C. Marshall Space Flight Center, p. 48, 2018.

20. Appendix:

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Datasheets:	Hyperlink:
GPS Chip	https://www.embeddedartists.com/wp-content/uploads/2018/06/GlobalTop-FGPMMOPA6H-Datasheet-V0A.pdf
CC1101-CC1190EMK Evaluation Board	http://www.ti.com/lit/ml/swru284a/swru284a.pdf
RF Transceiver Low-Power Sub-1GHz RF Transceiver	http://www.ti.com/lit/ds/symlink/cc1101.pdf
QFN-20 to DIP-24 SMT Adapter (0.5 mm pitch, 4.0 x 4.0 mm body, 2.5 x 2.5 mm pad)	http://www.proto-advantage.com/store/datasheets/IPC0082.pdf
Antenna 915MHz OmniDirectional 3dBi w/SMA. GSM ISM 1/4 Wave	https://www.data-alliance.net/antenna-915mhz-omnidirectional-3dbi-w-sma-gsm-ism-1-4-wave/
Accelerometer	https://www.st.com/content/ccc/resource/technical/document/datasheet/23/c3/ea/bf/8f/d9/41/df/DM00040962.pdf/files/DM00040962.pdf/jcr:content/translations/en.DM00040962.pdf
LGA-12 to DIP-12 SMT Adapter (0.5 mm pitch, 3.0 x 3.0 mm body)	http://www.proto-advantage.com/store/datasheets/IPC0090.pdf
Gyroscope	https://www.st.com/content/ccc/resource/technical/document/datasheet/e4/b1/d1/62/1a/e6/44/2f/DM00168691.pdf/files/DM00168691.pdf/jcr:content/translations/en.DM00168691.pdf
LGA-16 to DIP-16 SMT Adapter (0.65 mm pitch, 4 x 4 mm body)	http://www.proto-advantage.com/store/datasheets/PA0102.pdf
Barometric Pressure Sensor	https://www.mouser.com/datasheet/2/418/NG_DS_MS5607-02BA03_B-1134558.pdf
Dual Row 1.27mm Pitch 8-Pin to DIP-8 Adapter	http://www.proto-advantage.com/store/datasheets/DR127D254.pdf
Power Supply	https://www.amazon.com/Tenergy-Rechargeable-Connector-Airplanes-Aircrafts/dp/B001BCOWLY
Power Supply Charging Station	https://www.amazon.com/Tenergy-Universal-Batteries-Compatible-Connectors/dp/B003MXMJX8/ref=pd_bxgy_21_2?_encoding=UTF8&pd_rd_i=B003MXMJX8&pd_rd_r=aa3b68ff-d3ed-11e8-bab7-ab1331cf4c6b&pd_rd_w=p9vG9&pd_rd_wg=X1ECA&pf_rd_i=desktop-dp-

	sims&pf_rd_m=ATVPDKIKX0DER&pf_rd_p=6725dbd6-9917-451d-beba-16af7874e407&pf_rd_r=ZTNSDT1WPHGCXRK6NG43&pf_rd_s=desktop-dp-sims&pf_rd_t=40701&psc=1&refRID=ZTNSDT1WPHGCXRK6NG43
Voltage Regulator	https://www.mouser.com/datasheet/2/609/1086ffs-1268422.pdf
PIC24FJ128GA010-I/PF-ND Microcontroller Chip	http://ww1.microchip.com/downloads/en/DeviceDoc/39768d.pdf
TQFP-100 to DIP-100 SMT Adapter (0.5 mm pitch, 14 x 14 mm body)	http://www.proto-advantage.com/store/datasheets/PA0109.pdf
MicroSD Breakout	https://cdn-learn.adafruit.com/downloads/pdf/adafruit-micro-sd-breakout-board-card-tutorial.pdf
Samsung MicroSD Card	https://www.amazon.com/dp/B06XX29S9Q/ref=sxts_kp_bs_tr_1?pf_rd_m=ATVPDKIKX0DER&pf_rd_p=8778bc68-27e7-403f-8460-de48b6e788fb&pd_rd_wg=rdlPV&pf_rd_r=CMFR6TCGGE2S5DQEGRQA&pf_rd_s=desktop-sx-top-slot&pf_rd_t=301&pd_rd_i=B06XWZWYVP&pd_rd_w=nB8s7&pf_rd_i=micro%2Bsd%2Bcard&pd_rd_r=36126fb1-33f1-4e58-9a82-c991b1256867&ie=UTF8&qid=1541103240&sr=1&th=1
MicroSD to USB adaptor	https://www.amazon.com/Sabrent-SuperSpeed-Windows-Certain-Android/dp/B00OJ5WBUE/ref=sr_1_34?ie=UTF8&qid=1540993592&sr=8-34&keywords=sd+card+to+usb+3.0
Voltage Regulator	https://www.mouser.com/datasheet/2/609/1086ffs-1268422.pdf
0.1µF ±10% 100V Ceramic Capacitor X5R 0402 (1005 Metric)	https://psearch.en.murata.com/capacitor/product/GRM155R62A104KE14%23.pdf
27pF ±5% 100V Ceramic Capacitor C0G, NP0 0402 (1005 Metric)	https://search.murata.co.jp/Ceramy/image/img/A01X/G101/ENG/GRM1555C2A270JA01-01.pdf
1pF ±0.25pF 100V Ceramic Capacitor C0G, NP0 0402 (1005 Metric)	https://www.mouser.com/datasheet/2/281/murata_03052018_GRM_Series_1-1310166.pdf
1.5pF ±0.25pF 100V Ceramic Capacitor C0G, NP0 0402 (1005 Metric)	https://www.mouser.com/datasheet/2/281/murata_03052018_GRM_Series_1-1310166.pdf

3.3pF ±0.25pF 100V Ceramic Capacitor C0G, NP0 0402 (1005 Metric)	https://search.murata.co.jp/Ceramy/image/img/A01X/G101/ENG/GRM1555C2A3R3CA01-01.pdf
100pF ±5% 100V Ceramic Capacitor C0G, NP0 0402 (1005 Metric)	https://www.mouser.com/datasheet/2/281/murata_03052018_GRM_Series_1-1310166.pdf
12pF ±5% 100V Ceramic Capacitor C0G, NP0 0402 (1005 Metric)	https://search.murata.co.jp/Ceramy/image/img/A01X/G101/ENG/GRM1555C2A120JA01-01.pdf
47pF ±5% 100V Ceramic Capacitor C0G, NP0 0402 (1005 Metric)	https://search.murata.co.jp/Ceramy/image/img/A01X/G101/ENG/GRM1555C2A470JA01-01.pdf
Fixed Inductors 0402 12nH 0.14ohms 500mA +/-5%	https://www.mouser.com/datasheet/2/281/c51e-794816.pdf
Fixed Inductors 0402 18nH 0.27ohms 370mA +/-5%	https://www.mouser.com/datasheet/2/281/c51e-794816.pdf
Fixed Inductors 0402 3.3nH 0.030ohms 2A +/-2%	https://www.mouser.com/datasheet/2/281/c51e-794816.pdf
CRYSTAL 26.0000MHZ 10PF SMD	https://media.digikey.com/pdf/Data%20Sheets/NDK%20PDFs/NX3225GA.pdf
Thick Film Resistors - SMD 56K OHM 1%	https://www.mouser.com/datasheet/2/219/RK73H-5715.pdf