PADL-33: A Low Cost Flight Computer for Stratospheric Ballooning and High-Power Rocketry

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Abstract

The "Phully-Adaptive Data Logger" (PADL-33) flight computer is an educational avionics package for stratospheric ballooning and high-power rocketry. The PADL-33 costs $180 and is assembled on a custom printed circuit board (PCB) or solderless breadboard. The PCB version of the PADL-33 gives students a 5.8” by 1.525” platform with which to log general flight data, with the possibility of adding additional sensors to aid in specific research projects. Students can gain even more exposure to coding, system architecture, and wiring by assembling the PADL-33 sensor suite on a solderless breadboard. The PADL-33 is designed around the Arduino Nano 33 BLE Sense Rev2 (BLE-33) that has an onboard 9-degree-of-freedom (DOF) inertial measurement unit (IMU), barometric pressure sensor, and humidity sensor. The PADL-33 has on board power systems that provide 5 volts to the BLE-33 and are powered by a 3.7 volt Lithium-Ion battery or any battery with a voltage of 5 to 24 volts. The PADL-33 flight computer also includes a micro-SD card breakout, a u-blox NEO-M9N/M8N or ZED-F9P GPS breakout, two temperature sensors, four additional indicator LEDs, 2 switches for power, terminal block breakouts for the BLE-33, and a piezo buzzer for error information. The PADL-33 has been flown in student-built payloads on high-power rocket flights and stratospheric balloon flights through classes and by extracurricular groups at the U of MN – Twin Cities and has proved to be a useful teaching tool.

stratospheric ballooning | high-power rocketry | flight computer

1. Introduction

In the summer of 2023, Ashton Posey developed the PADL-33 flight computer with the goal of building a slim and easily modifiable avionics package capable of collecting flight data from stratospheric balloon and high-power rocket flights. The PADL-33 accomplished these goals and was used to educate students, at the U of M – Twin Cities, on the topics of wiring, coding, soldering, and the engineering process in AEM 1305, a high-power rocketry course, and CSE 1012, a stratospheric ballooning course.

The PADL-33 nominally collects atmospheric data and information about the motion of the vehicle such as altitude, pressure, temp, position, velocity, and inertial measurement data with the option of adding extra sensors. The nominal data collected provides a platform for students to devise their own experiments while keeping complexity low enough for beginners. Students can skip the step of developing the baseline data collection systems for their aerial research project and move straight to implementing the sensor required to verify their hypothesis.

In general, assembling the PADL-33 on a PCB has proven to be the most reliable option for either stratospheric ballooning or rocketry because it has stronger mechanical connections between components. But, in the development of course work for this flight computer, an assignment to assemble the PADL-33 on a solderless breadboard offered students more exposure

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to hands on learning with the wiring of a system. Although, when flown, the solderless breadboard version of the PADL-33 has proven unreliable compared to the PCB version due to intermittent wiring. A way to get around this is to have students assemble the breadboard version of the PADL-33 then fly the PCB version. This allows the students the experience of wiring the complete system while also being able to skip the PCB creation process but still end up with a final product of a PCB from their wiring.

2. Technical Details

2.1. Power Systems The PADL-33 handles power in three ways. One way is with a 3.7 volt rechargeable lithium-ion battery. This method utilizes a 3.7 to 5 volt boost converter that can also recharge the battery with a USB-C port. The second way is with any battery with a voltage of 5 or above up to 24 volts. This method utilizes a 24 to 5 volt reducer that can be used with high current batteries such as RC batteries or 9 volt batteries. If this method is used, the reducer must be soldered into the PCB. With this module soldered in, the 3.7v to 5v booster cannot be used. The third way is by plugging a micro-USB cable into the slot on the BLE-33. All three ways will provide 5 and 3.3 volts to the PCB. On the PADL-33 PCB there are 2 switches for the power systems. If a 3.7 volt rechargeable lithium-ion battery is used, both of the switches in the on-position allows power to travel. With one of the switches in the 3.7v position power travels to the booster and then with the 5v switch in the on-position power travels to the microcontroller. The voltage booster requires a momentary switch (button) for activation, 1 press to turn it on and 2 presses to turn it off. If a battery with a voltage above 5 volts is used, the off position on the switches means on. This distinction was made so that a battery would never short with another battery. Two sets of voltage dividers are located underneath the BLE-33 to read the input voltage and the 5v supply of the system. If the input voltage exceeds 12 volts, that voltage reader cannot be used, since it's a 3.3 volt logic system with a three quarter reduced voltage divider.

2.2. Arduino Nano 33 BLE Sense Rev2 (BLE-33) The microcontroller used on the PADL-33 is an u-blox NINA-B306 Wifi/Bluetooth module with an nRF52840 ARM microcontroller outfitted to the exact pinout as an Arduino Nano on a breakout called the Arduino Nano BLE33 Sense Rev2. This breakout has an onboard 9-DOF IMU (BMM150 & BMI270), barometric pressure sensor (LPS22HB) and five LED's that are always used while also including a humidity sensor, gesture/light/proximity/color sensor and a microphone. The input voltage is 5 to 21 volts but works best at 5 volts, so the voltage on the PCB is brought to 5 volts before being sent to the BLE-33. Although it is powered with 5 volts and mimics the Arduino Nano system, the microcontroller has a 3.3 volt operating voltage with 3.3 volt logic. The BLE-33 reduces the input voltage to 5 and 3.3 volts with an available 950 mA available for use at 3.3 volts.

2.2.1. BMM150 & BMI270 The BMM150 is a 3-axis magnetometer that can be used for compass tracking in low magnetic environments. This can be used for tracking the roll rate of the vehicle in post processing. The BMI270 is a combined 3-axis accelerometer and 3-axis gyroscope. These are useful for calculating the pitch of a vehicle as well as its roll. The gyroscope data can be integrated to find the change in angle from a given time stamp to another. The accelerometer saturates at ±16g, which is relatively low for a high-power rocket flight past the H range of motors. To remedy this, the KX134 ±64g 3-axis accelerometer is already coded into the PADL-33 and can attach to a corner of the PCB using a standoff. The gyroscope saturates at 2000 deg/s which, from its flight history, hasn't happened yet.

2.2.2. LPS22HB Barometric Pressure Sensor This pressure sensor is advertised to work from 0.25 to 1.25 ATM. Since stratospheric ballooning flights go to near 0 ATM, ~10 mBar, past 0.25 ATM this pressure sensor overestimates the altitude by a maximum of 10% at 100,000 feet. This was verified using the M9N GPS and by calculating altitude based on the standard atmospheric model. For high-power rocketry flights flying under 10,000 feet, this pressure sensor is reliable.

2.2.3. Humidity/gesture/light/proximity/color/microphone These sensors are all available for use in the system but only the Humidity sensor is coded into the system.

2.3. GPS All GPS options for the PADL-33 output Position Velocity Time (PVT) information from both GGA and NMEA messages. For the GGA messages this includes Latitude, Longitude, Altitude, Satellites in View (SIV), time in MM:DD:YYYY and HH:MM:SS.MS, Ground Speed, Heading, Position Dilution of Precision (PDOP), North East Down (NED) Velocities, and accuracy in both the Horizontal and Vertical directions. From the NMEA messages, ECEF coordinates are stored. In cases where the GPS update frequency is not fast enough for a given project, the PADL-33 can update all other sensors at a faster frequency than the GPS modules. All listed GPS modules already implemented into the code and require only variable changes to switch between them. There is a TX removal pin on the PCB that needs to be shorted to use UART with the GPS. This is so that any other devices can use UART if needed.

2.3.1. u-blox NEO-M9N Sparkfun Breakout This is the preferred GPS module to use with the PADL-33. It is priced at around $90 and requires an antenna. For the cost, this is a very capable GPS module. It offers up to a 25Hz update frequency on I2C, where the accuracy of the GPS increases with the increasing of the frequency. It has an advertised horizontal accuracy of up to 2 meters. This module can use either I2C or UART communication with the BLE-33. I2C is preferred since it is much faster, but this GPS module disrupts itself and other sensors on the same I2C line when multiple are connected. For cases where other I2C sensors are added to the PADL-33 and update frequency isn't required, the UART connection allows up to 8Hz. Using a patch antenna with a U.FL connection this GPS can get up to 4 meters of accuracy sustained throughout a stratospheric balloon flight, with periods of accuracy down to 1 meter. For use in rocketry, an SMA connector version of this GPS is suggested with the use of a helical antenna such as the GNSS Multi-Band L1/L2/L5 Helical Antenna from SparkFun. This antenna should be placed in a hollow nose cone for optimal GPS signal. For cases where GPS doesn't have to be guaranteed in rocketry flights, the patch antenna performs well enough. This GPS is powered by 3.3 volts.

2.3.2. u-blox NEO-M8N breakout This breakout is currently discontinued and is the lowest quality GPS module that is used by the PADL-33. This module limits the update frequency of the PADL-33 to 1Hz. The biggest reason for this is that the M8N used by MnSGC is UART only, an I2C connection would increase its update frequency to 5Hz. The horizontal accuracy of this GPS is advertised as 2.5 meters at optimal conditions. The antenna used on this GPS is not the best possible option and including the dynamics of a vehicle the accuracy drops to 10 to 30 meters. This GPS is powered by 3.3 volts.

2.3.3. u-blox ZED-F9P MIKROE GNSS RTK CLICK breakout This is the most expensive GPS module that the PADL-33 is outfitted to use, with a price of $230. UART and I2C communication are available on the PADL-33 for this GPS module. It can provide solutions with an accuracy of up to 1 meter using a helical SMA antenna at a maximum update frequency of 10Hz. The F9P breakout can be paired with the u-blox NEO-D9S MIKROE LBAND RTK CLICK breakout for 1Hz RTK solutions with centimeter level accuracy, around 10-50cm. This option is heavily restricted in terms of dynamics and has only successfully been used for coordinate surveying where there's zero movement. For this configuration an antenna splitter can be used, such as the SPX-21223, since the L-Band signals are in a range of frequencies very close to standard GNSS messages. Both of these GPS modules are powered by 5 volts on the PCB, but can be powered by 3.3 volts and communicated with using 3.3 volt I2C logic.

2.4. SD Data Logging The PADL-33 uses a 3.3 volt logic micro-SD card reader connected by SPI. Data is logged to a comma separated values (CSV) file for easy data processing in Excel, Sheets, and any programming software such as MatLab or Python. It has a maximum consistent data logging speed of 10Hz, though it can be pushed to 20Hz with more inconstancy in the frequency. The largest problem with the SD logging is that about 500 characters are being sent to the SD card every time data is logged, which requires data management. To solve this issue, the PADL-33 uses a specific micro-SD card made by Micro Center, shown in Table 1, and stores 5 data strings in its internal flash at a time and then logs all 5 at the same time to give the SD card more time to process data. Without this buffer of time, the micro-SD card would have no time to wipe its internal flash and eventually it would stall the code by 100 milliseconds each update. Only up to 16 Gb micro-SD cards can be used.

2.5. Breakouts Terminal blocks are used to attach off board items to the PADL-33. The battery inputs include a location for a 3.7 volt battery to be plugged in and a location for a battery with a voltage greater than 5 volts to be plugged in. It has a location to output 5 volts from any power systems available. The breakouts also includes pins to attach to the BLE-33 I2C line, UART line, the reset pin, the analog reference pin, 3 analog pins, and 2 digital pins. A transistor was added to the PCB attached to pin D9 that can be used as remote activation for an ejection charge or a heater, though poor performance has been seen when using a heater. Use with an ejection charge has been tested and works as intended.

2.6. Piezo Buzzer Error checking is very important in a system like this. The PADL-33 uses a Piezo Buzzer to alert the user of any errors or successes with the system. To alert the user of a problem with the system a long buzz will play that will not stop. If it stops the error has not gone away. To alert the user that all systems are working, two beeps will play every time data has been updated twenty times.

2.7. LED's Five LED's are included on the BLE-33 with an additional 4 on the PADL-33 attached to digital pins. These digital pins can be used for other tasks because all required information is shown on the BLE-33 LED's. On the BLE-33, it has a green LED to indicate it is on, a yellow LED to indicate that SPI is being used, in this case by the micro-SD card, and three programable LED's. The red programable LED on the BLE-33 is used to alert the user of any errors, same as the Piezo Buzzer. The blue programable LED on the BLE-33 is activated when the transistor is active. The green programable LED on the BLE-33 is not yet used. On the PADL-33 PCB, the yellow LED tells the user when data has been updated, the red LED is for error messaging, and blue and green are not used.

2.8. XBee Radios Radio communication allows a user to communicate between payloads or to a ground station during a stratospheric balloon or high-power rocket flights. To accomplish this, both long and short range radios were selected from the XBee family of radios to ensure they were identical in both pin out and almost identical in the code. It is the only component of the PADL-33 placed on the bottom of the PCB.

2.8.1 XBee 3 Short range radios draw lower power and have a quicker response time than longer range radios. The XBee 3 is a short-range radio with a range of 60 meters with a very quick response time. It is connected to the PADL-33 via UART and acts as a UART replacement to another XBee 3 module. It is powered with 3.3 volts.

2.8.2 XBee Pro SX Long range radios are generally used to communicate with a ground station. This radio has an advertised range of 110 kilometers and a max power consumption of 2 Watts. In practice, it has reliable range of 1 mile using poor antenna conditions inside of a high-power rocket. In terms of power, this module draws around 700mA when powered with 3.3 volts and 1100 mA when powered with 5 volts and using a 3.3 volt linear regulator that turns 1.7 volts into heat. The BLE-33 can supply 660 of its available 950 extra milliamps, leaving enough power for additional sensors.

2.8.2 Thermistors 2 10kOhm thermistors are included on the PADL-33 for reading temperature using the variable resistance of a thermistor and a voltage divider between the thermistor and a 10kOhm resistor. One is on the PCB for payload temperature, and one is on the terminal block connections for off board use.

2.9 Arduino IDE The BLE-33 microcontroller is programmed using the Arduino IDE. After downloading the code for the PADL-33 most of the libraries at top of the main sketch file will need to be downloaded from the library manager. The preferred board to download from the board manager is "Arduino Mbed OS Nano Boards."

2.9 Code Architecture Assembling data from many sources requires an architecture for ease of understanding what is being stored, where its being stored, and how to add new data. In the case of the PADL-33, the architecture is one large data string with comma separated values (CSV) stored into a single CSV file. Using this method allows students to interact with the pre-existing variables that are already being stored. Other architectures can be used to store data and work with the pre-existing system. To accommodate students having a limited view of what coding is, the main coding workspace is limited to the libraries, setup, loop, and two global variables, the header for the CSV file and the on state of the buzzer. The only thing inside of the setup, `void setup(){here}`, is a function call that sets up all required systems. Inside of the loop, `void loop(){here}`, is a soft pause, a function call that updates all sensors, the assembly of the data string, and the logic for logging data. This allows easy addition of code, and a high-level view of what the code is doing with all the low-level bits hidden but still accessible in other tabs of the code.

3. PADL-33 Assembly on a PCB

The PADL-33 can be assembled on a PCB using the parts shown in Table 1. The most recent version of the PADL-33 PCB can be found in the PADL-33 Google Drive Folder, along with many other files with documentation on the PADL-33 such as the code, and introductory presentations. The .zip of the PADL-33 PCB files is used to purchase the PCB from any manufacturer, JLCPCB is the manufacturer chosen by MnSGC for PCB's. The PADL-33 PCB is a 2 layer board, and is usually ordered in the color purple, and with a thickness of 1.0 mm. The parts highlighted in orange are not needed for the breadboard version of the PADL-33.

#	Part	Price $	Qty in Order #	Needed #	Total $
1	Battery Voltage Booster	12	10	1	1.2
2	SD Card Reader	3.5	1	1	3.5
3	Smaller Battery 1100 mAh	26	4	1	6.5
4	M9n GPS	70	1	1	70
5	UFL antenna	7	1	1	7
6	BLE33	43.5	1	1	43.5
7	PCB	10	5	1	2
8	Thermistor 10kOhm	3.03	1	2	6.06
9	10kOhm Resistor	0.63	1	8	5.04
10	330 Ohm Resistor	5.99	100	1	0.60
11	Buzzer	0.8	1	1	0.8
12	LED (built-in resistors) (20 pack) (4 colors)	9.95	20	4	1.99
13	HEX STANDOFF M2.5X0.45 ALUM 11MM	0.67	1	4	2.68
14	MACH SCREW PAN SLOTTED M2.5X0.45	0.48	1	4	1.92
15	HEX NUT 0.197" STEEL M2.5	0.18	1	4	0.72
16	male headers strips	1.53	1	2	3.06
17	female header strips	1.09	1	2	2.18
18	8-position terminal blocks	7.48	1	2	14.96
19	Slide switch	0.76	1	2	1.52
20	Micro SD Card 16GB	8.99	2	1	4.495
21	Battery Reducer	10	10	1	1
22	JST Connector	6.99	10	1	0.699
	Total Order Price:	243.56		TOTAL:	181.49

Table 1. Parts list for the PADL-33.

Shown in Figures 1, 2, 3, and 4 are the various diagrams for the PADL-33 custom PCB including an image of the PCB, a schematic for the PCB, the wiring diagram of the PCB, and an assembled PADL-33 PCB. On the left side of the PADL-33 PCB is the BLE-33 microcontroller with terminal blocks on either side. The middle contains the button, power systems, micro-SD card reader, LED's, switches, and the Piezo Buzzer. On the right side are the GPS options and the TX removal short. The PCB has resistor ohm values listed on the PCB for easy assembly.

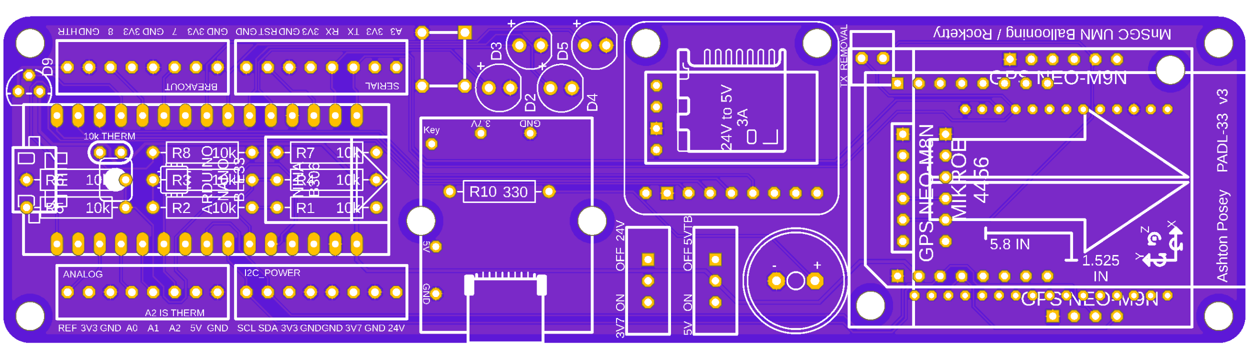

Fig. 1. PADL-33 custom PCB printed image, generated by Fusion 360 Electronics Designer.

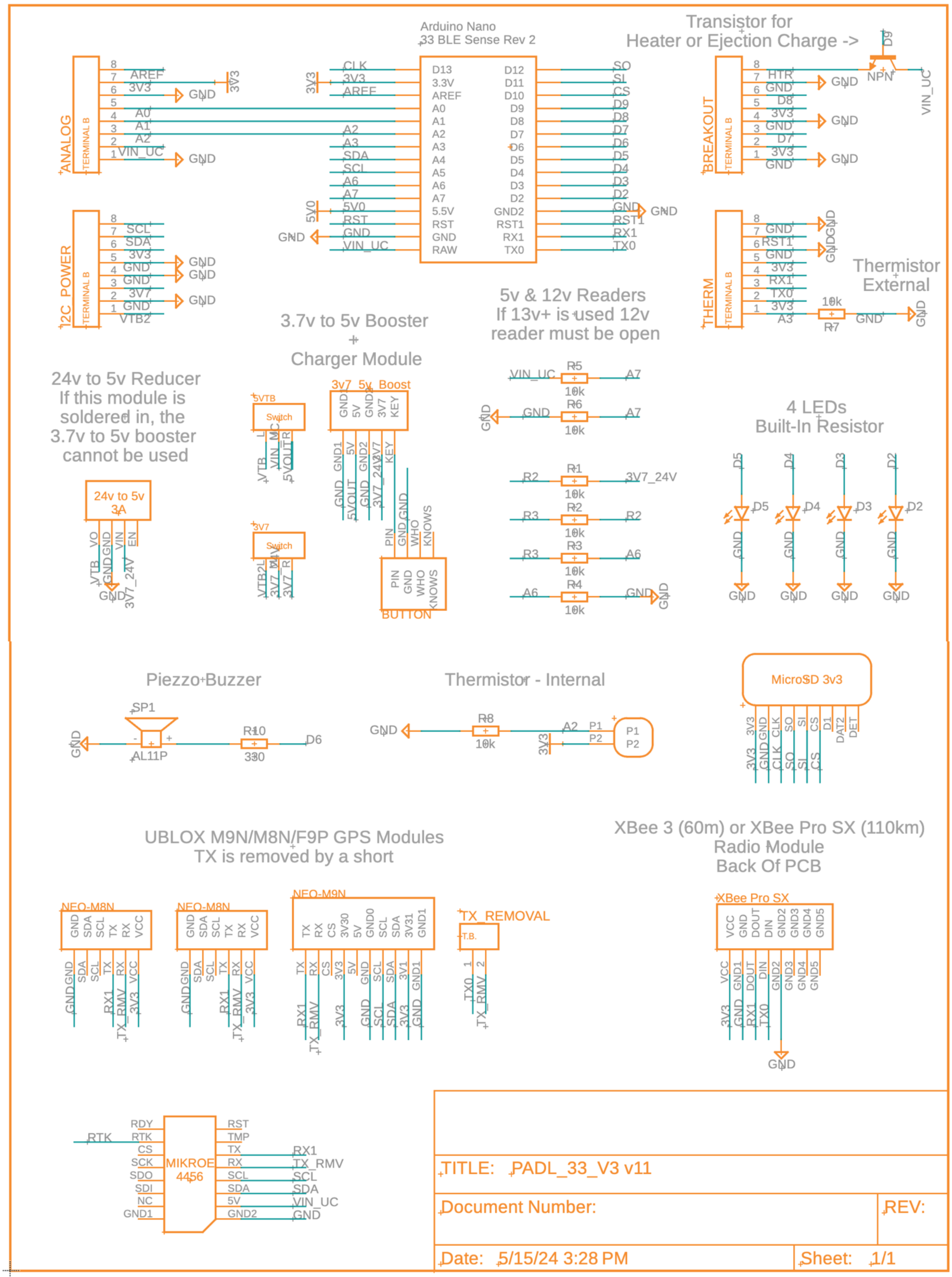

Fig. 2. PADL-33 custom PCB Schematic, drawn with Fusion 360 Electronics Designer.

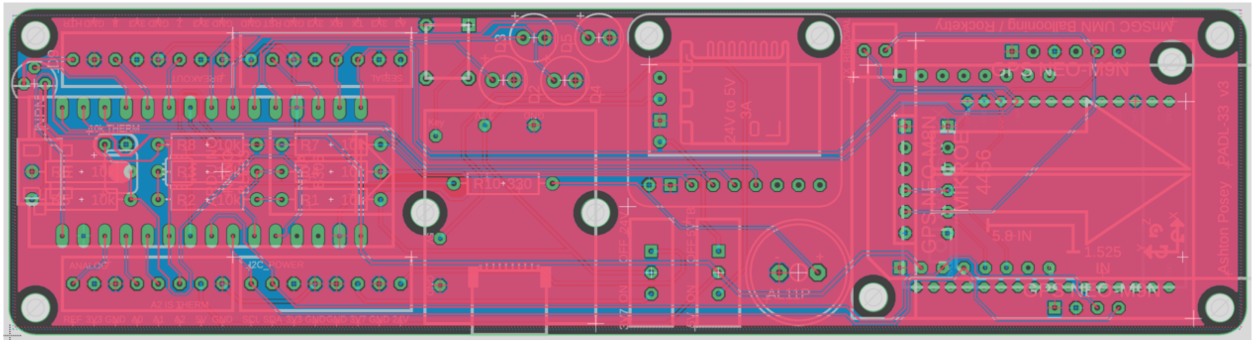

Fig. 3. PADL-33 custom PCB Wiring Diagram, drawn with Fusion 360 Electronics Designer.

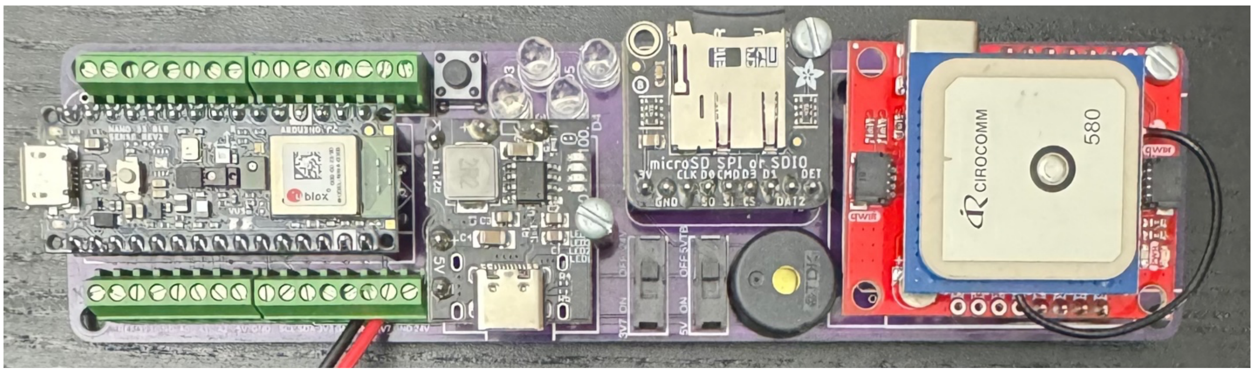

Fig. 4. Assembled PADL-33.

4. PADL-33 Assembly on a Breadboard

The PADL-33 can be assembled on a breadboard using the additional parts shown in Table 2, some parts on the Table 1 parts list are not needed for the breadboard PADL-33 and are highlighted in orange on Table 1. Another option for powering the PADL-33 other than the method shown in this example is by using a rechargeable battery pack, such as the ActionHeat 3000mAh battery in table 3, that plugs into the Micro-USB port on the BLE-33. With this method, the voltage reducer shown in this breadboard example is not needed and is highlighted in orange in Table 2.

#	Part	Price $	Qty in Order #	Needed #	Total $
23	Battery Voltage Reducer	7.59	3	1	2.53
24	LCD-14532 QWIIC MICRO OLED Breakout	18.50	1	1	18.50
25	Solderless Breadboard 830	4.25	1	1	4.25
26	DKS-WK1-ND Wiring Kit	9.61	1	1	9.61
27	9 volt Ultimate Lithium Battery	23.02	2	1	11.51
28	9 volt Battery Jack with Plug	5.99	10	1	0.59
	Total Order Price:	68.90		TOTAL:	46.99

Table 2. Additional Parts needed for the breadboard PADL-33.

One method for wiring the PADL-33 is shown below in Fig. 5. Considering the architecture of the wiring is important for this build. As shown in Fig. 5, not all wires are able to stay on the solderless breadboard when every wire has its own path. Crossing moving wires under devices or wires over wires may be necessary to accomplish this task. An instructional slide show exists, located in the PADL-33 Google Drive folder, that walks students through how to assemble the breadboard version of the PADL-33 with technical details about the system. Instructional documents for adding I2C sensors to the PADL-33 also exist.

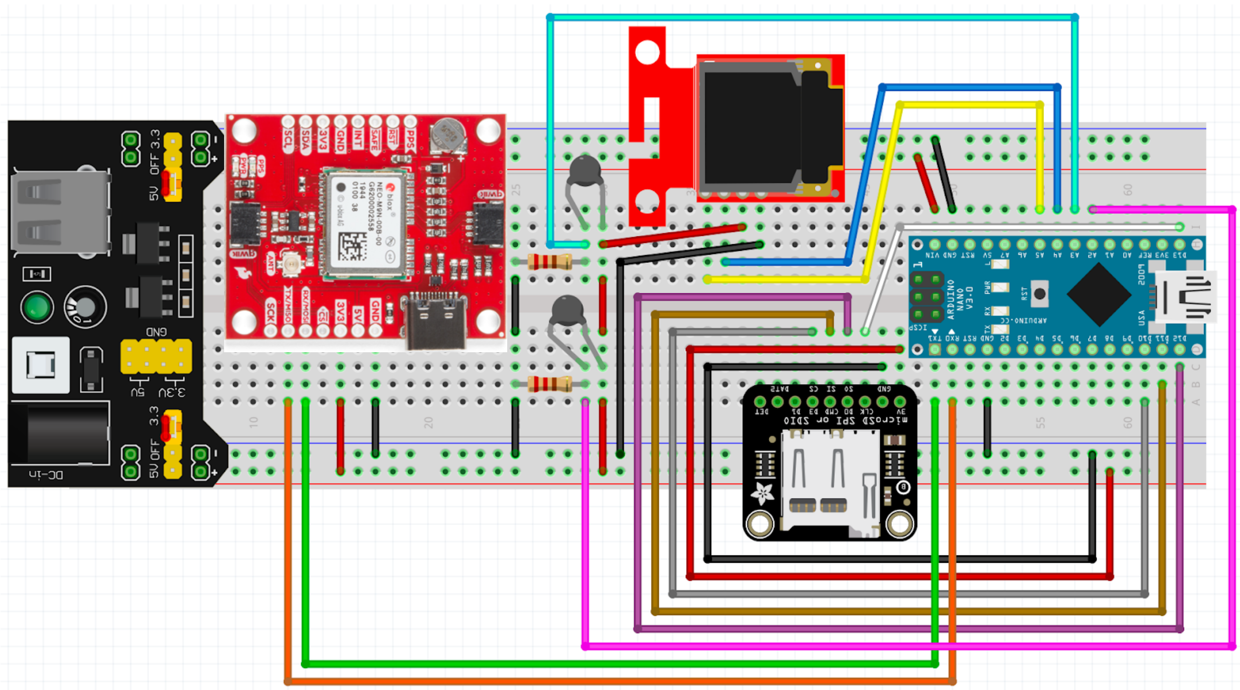

Fig. 5. PADL-33 assembled on a breadboard with the addition of a 9v reducer and an OLED with the reduction of the piezo buzzer. Diagram drawn on Fritzing.

5. Data Analysis and Discussion of Results

The PADL-33 has currently flown on 9 high-power rocket flights and 13 stratospheric balloon flights. Since its creation many issues related to data collection and efficiency have been resolved and continue to be resolved by the MnSGC Stratospheric Ballooning team. Some of the notable modifications are the increase in polling speed, the addition of accuracy measurements, and North East Down (NED) velocities all for the GPS system. With the increased polling speed, it operates optimally at 10Hz. Since this processor is limited to 64MHz the update speed of the system is limited to below the 25Hz maximum of the M9N GPS. This, however, can be achieved using a Teensy 4.1 system such as the PTERODACTYL [1], at a greater cost.

In a few stratospheric balloon flights, issues with temperature turning the system off were observed. The conclusion that temperature was causing issues was drawn after conducting low pressure tests at a constant temperature to rule out pressure. A resistive heat pad attached to the battery and the BLE-33 will solve this issue and greatly increase the PADL-33's chance of success during ballooning flights. This can be accomplished with one 15x5cm resistive heat pad. The Problem with these heat pads is that they draw a lot of current, 700 mA at 5 V. So, attaching a heater to an external battery eliminates the worry of a battery running out and shutting off the PADL-33 as well. As shown in Table 3, parts to accomplish this are listed. 2 ActionHeat battery packs are only necessary if the PADL-33 will also be powered by a battery pack. This battery pack lasts around 2h with a heater attached and much longer with only the PADL-33. It does require a micro-USB cable to be stripped and soldered to the heater, red to red and black to black. This battery pack deals with the dumb load (no data) and doesn't drain itself to the point of never being able to be charged again.

#	Part	Price $	Qty in Order #	Needed #	Total $
29	ActionHeat 3000mAh Battery Pack	49.99	2	2	49.99
30	15x5 cm Resistive Heat Pad	5.50	1	1	5.50
31	Micro-USB cable	1.15	1	2	2.30
	Total Order Price:	**56.64**		**TOTAL:**	**57.79**

Table 3. Additional Parts needed for the success of the PADL-33.

To receive a clear GPS signal, the best practice is to make sure that the GPS antenna is unobstructed, and to not put electrical tape on the antenna. Use a double-sided piece of tape to attach the antenna to the GPS module. Also, make sure the GPS has a lock before the payload is sealed and launched. If there's no lock before flight it usually means the antenna does not have a clear view of enough satellites to form a solution.

Shown in Fig. 6 are plots of the data from the PADL-33 in a stratospheric balloon flight. On this flight, the payload was not heated, and it was flown in an insulation foam payload with a thickness of 0.5". This was a breadboard PADL-33 that was zip tied down and powered with a 9 volt ultimate lithium battery. All the data levels out when the payload reaches the ground, but some steady state error can be seen, especially in the IMU plots. The GPS plots fall perfectly flat after landing because the GPS antenna had popped off during the impact with the ground. All plots other than the positional accuracy plots see an immediate reaction to the burst at apogee.

The altitude versus time graph is required on both stratospheric balloon and high-power rocket flights. It gives the user the most basic information about how high it went and its altitude at any given time. Either of these variables can be used to create comparison charts against any other variable in a research project. Due to its importance, the PADL-33 has two methods to calculate it, both shown on Fig. 6, on two different sensors, pressure, and GPS. The inaccuracy of the pressure sensor at high altitudes can be seen in position Fig. 6 as well.

Pressure and temperature both get very low during a stratospheric ballooning flight and are the cause of most problems with electrical hardware. The plots created by the PADL-33 for pressure and temperature can help diagnose issues related to hardware. The GPS accuracy measurements help diagnose GPS issues and give useful information about how trustworthy your GPS measurements are. The NED velocities and the IMU data give useful information about how the payload was moving. In the NED velocity graph in Fig. 6, the balloon was accelerating in both the North and East directions in the Troposphere and then it began decelerating in the Stratosphere. The Down velocity shows the balloon moving up at about 5 m/s. Then after burst the balloon reached its peak downward velocity and decelerated to around 10 m/s down on impact. The accelerometer agrees that the payload was experiencing accelerations with maximum changes at the same times, specifically at burst. It also shows two gusts of wind that seemed to give it an extra acceleration. The gyroscope shows continuous oscillations about the z axis (yaw), with increased oscillations at the time of the two wind gusts and then a maximum oscillation at the time of burst.

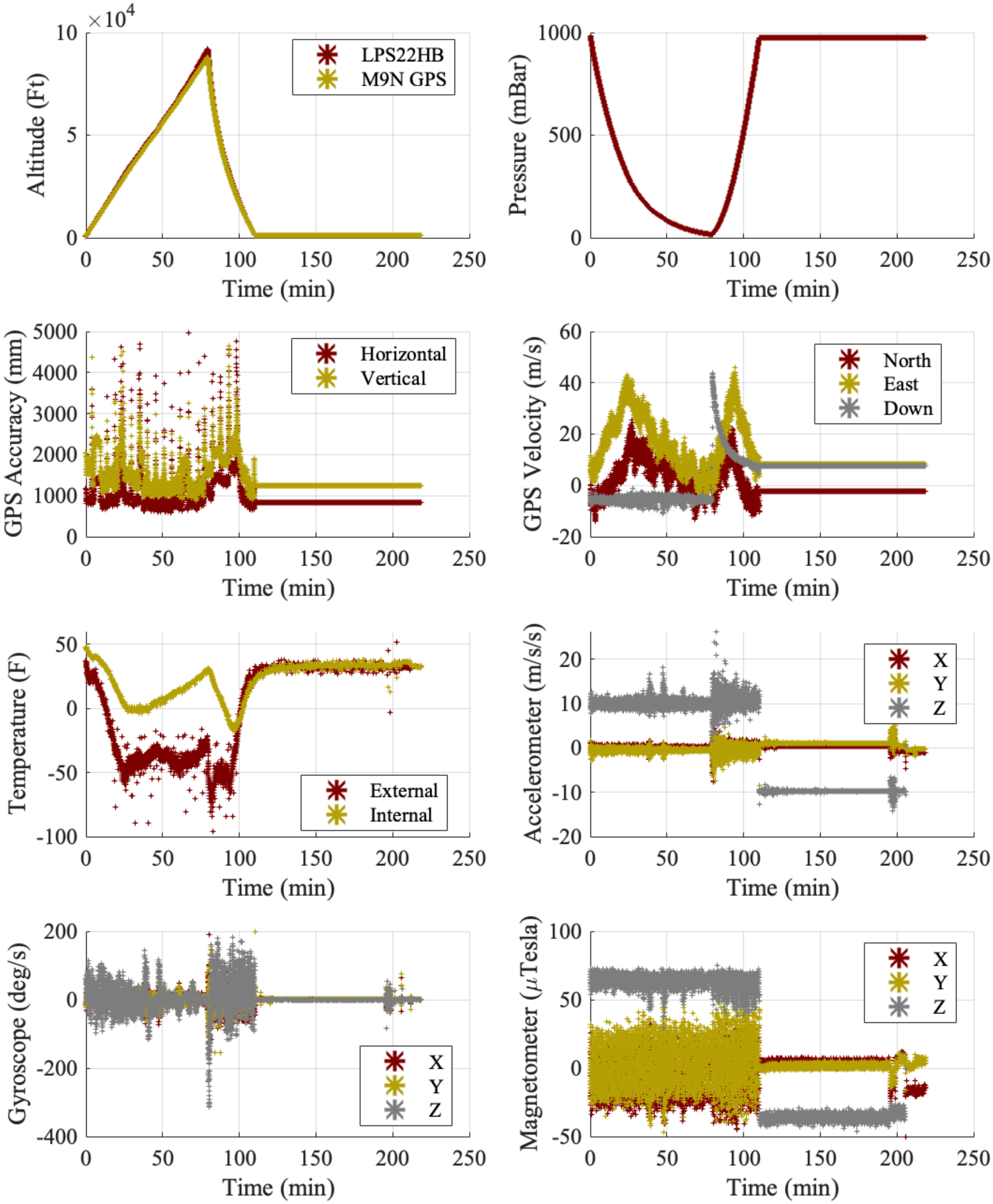

Fig. 6. PADL-33 data from Gopher Launch (GL) 217, on February 11, 2024. This is Ballooning Flight data from the M9N GPS, LPS22HB Pressure Sensor, BMM150 Magnetometer, & BMI270 Accelerometer & Gyroscope. Plots were generated along with plots of all other system information using a MatLab script available in the Google Drive folder.

6. Summary

The PADL-33 is a versatile flight computer for both stratospheric ballooning and high-power rocketry that allows students to conduct research in dangerous and hard to reach environments at a relatively low cost. It gives students a PCB or solderless breadboard platform to log general purpose flight sensor data such as temperature, barometric pressure, 9-DOF IMU, and GPS. Assembly of both the solderless breadboard and PCB versions of the PADL-33 give students exposure to soldering, wiring, coding, and the engineering process. Adding additional sensors and devices is made systematic by the code architecture, available pins on the BLE-33, and instructional documents. The PADL-33 has been used in the classroom to power 3.3 and 5 volt devices and add analog/I2C sensors. It has been used in extracurriculars to log meter-level accurate GPS data and predict a high-power rockets apogee. In total this flight computer has been on 9 high-power rocket flights and 13 stratospheric balloon flights. Through classes and extracurriculars the PADL-33 has proven its ability to accomplish desired research goals.

7. References

[1] Wallo, S., Posey, A., Wehling, P., Van Gerpen, A. & Flaten, J., (2023) "PTERODACTYL: A Versatile Flight Computer for Stratospheric Ballooning", Academic High Altitude Conference 2022(1). doi: https://doi.org/10.31274/ahac.15639