AMPTS FTA Avionics Design

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v1.2

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1 Introduction

This document outlines the initial design of electrical hardware that will support the flight test article (FTA) being developed for the NASA Flight Opportunities *Additive Manufacturing of Thermal Protection Systems* (AMTPS) project. This project is a collaboration between several NASA facilities including JSC and Langley as well as other research institutions namely the University of Kentucky and Oak Ridge National Laboratories. Figure 1 shows a general overview of the various components that are expected to be a part of the flight test article (referred to as 'the capsule') based on current requirements.

Capsule hardware must be capable of robust data acquisition in order to characterize the thermal, pressure, and overall heating environment of supersonic reentry. In addition to collecting multiple data channels, the hardware must be capable of transmitting its location as it touches back down to Earth. The multi-channel data acquisition system must also save flight data for further analysis after it touches back down. Timing the deployment of a parachute before touchdown is also a requirement of the hardware in order to lessen the force of impact.

This document is organized as follows: Section 2 discusses needed capabilities in the form of technical and logistical requirements set by the NASA project design document (rev. E). Section 3 displays the preliminary designs and testing hardware for the various subsystems of the capsule. This includes data acquisition, logging, and vehicle-to-ground communication for recovery operations. Section 5 contains in-work project considerations as well as an approximate schedule. Appendix A contains schematics for PCBs that have been prototyped. Appendix B contains images of testing hardware that has been developed along with initial experimental results.

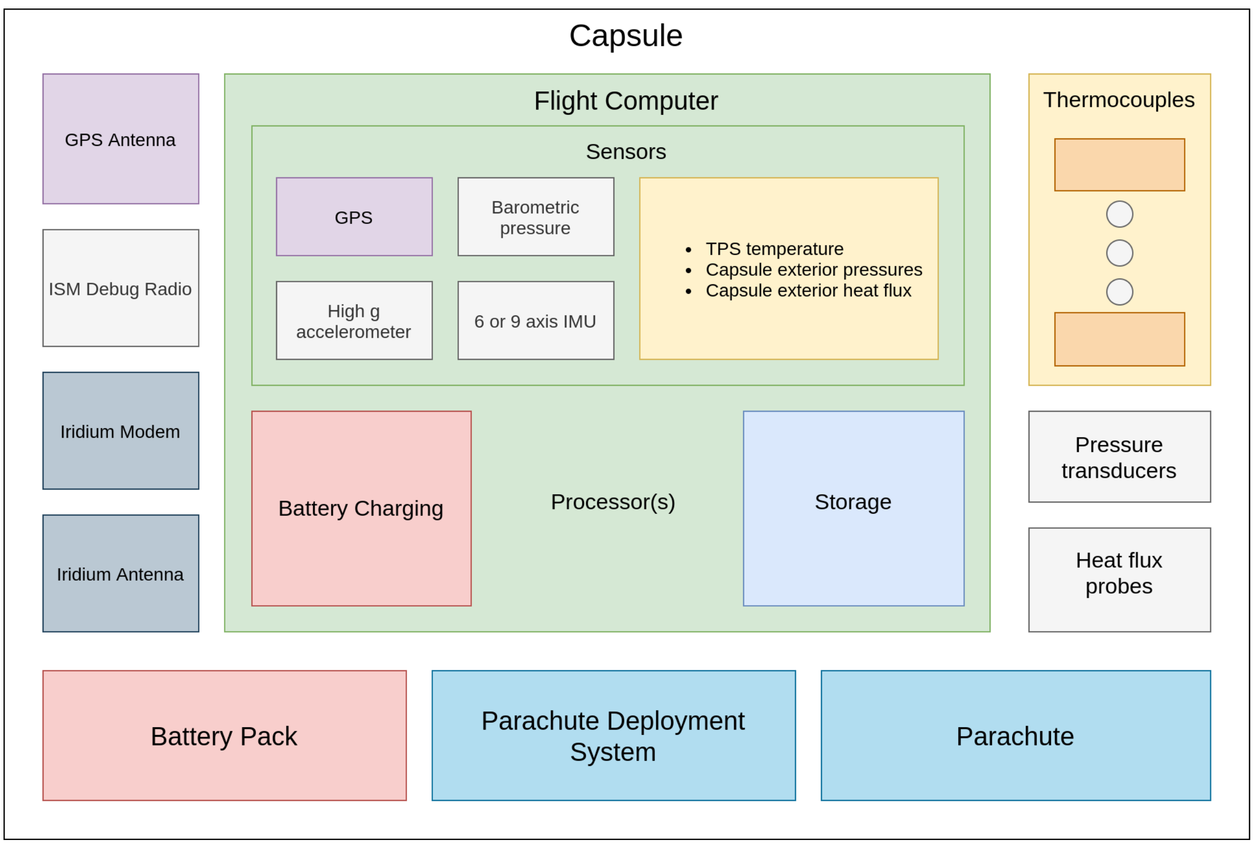

Figure 1: Capsule component overview, showing the various functional blocks.

2 Requirements

Based off of the most recent revision (E) of the flight test requirements document.

1. Instrumentation and telemetry
   (a) Shall support betwen 8 and 20 thermocouples of varying type
   (b) Shall support up to 6 absolute pressure sensors
   (c) Shall support at least 1 intertial measurement unit (IMU)
   (d) Should support 1 heat flux sensor
   (e) Shall contain a GPS for recovery operations, accurate to with 100m
   (f) Capsule shall contain an internal barometric pressure sensor
   (g) Telemetry data shall be collected at a minumum of 10Hz
   (h) Telemetry data shall be stored to onboard nonvolatile memory that will survive landing
   (i) Location telemetry shall be transmitted through a vehicle-to-ground system (e.g. Iridium satellite, Xbee)
   (j) Recovery location should be broadcasted at least once every 5 minutes post-flight
2. Activation and flight sequencing
   (a) Shall be powered through the duration of the flight
   (b) Shall support continuous operation between -20 deg C and 80 deg C
   (c) Shall support pre-launch activation on the ground; should support low power mode prior to deployment
   (d) Shall detect and/or sense when deployment has occurred via interfacing with the launch vehicle
   (e) Shall transmit in-flight telemetry with position information
   (f) In-flight telemetry should contain capsule velocity
   (g) Shall trigger parachute deployment at a specified time
3. Physical properties
4. Avionics hardware shall weigh under or around 0.5kg
5. Shall cost under $3,000

3 Subsystem Design

3.1 Main command and data handling

Using off the shelf processors for convenience, and also to avoid bottlenecks in prototyping due to unpredictable chip shortages. Currently, two development boards from Adafruit are being used to prototyping and are listed below in Table 1[1][2]. The diagram in Figure 2 provides a general overview of the organization of electronic hardware within the capsule.

[1]TPM: Temperature and Pressure Measurement
[2]CDH: Command and Data Handling

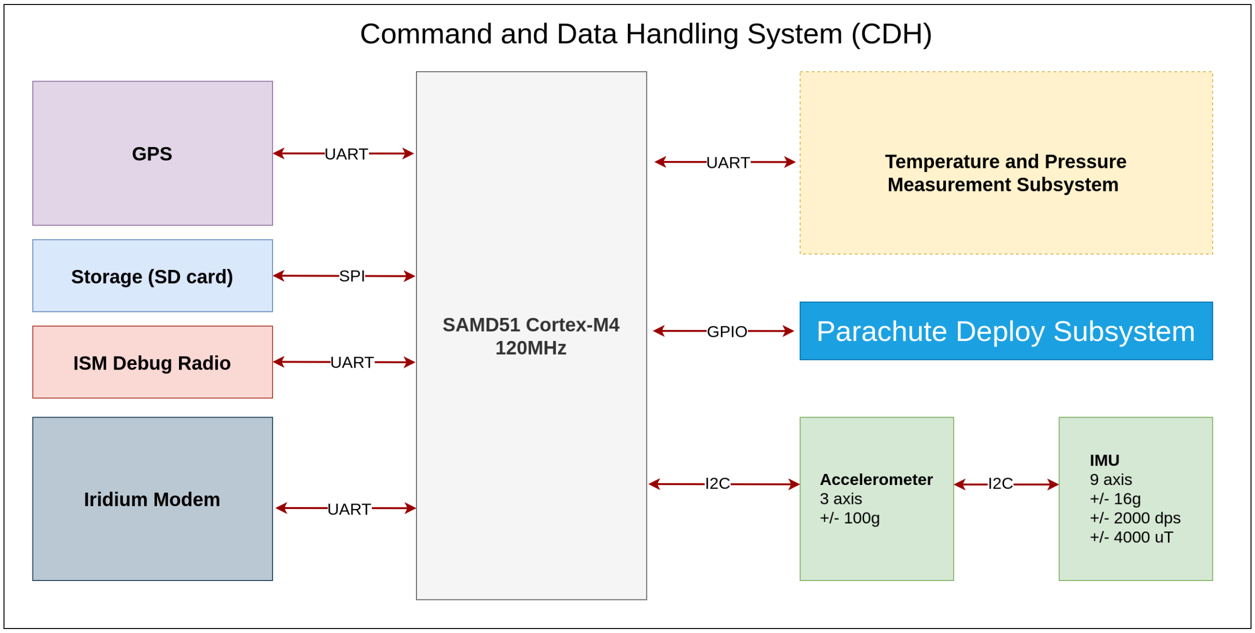

Figure 2: Main functional components of the capsule and the communication buses between them.

Table 1: List of processors used and their capabilities.

Part	Description	Role	Product Link
(2) Feather M0 Basic Proto	Cortex-M0 @ 48 MHz	TPM and IMU processor	https://www.adafruit.com/product/2772
Feather M4 Express	Cortex-M4 @ 120Mhz	CDH Processor	https://www.adafruit.com/product/3857

3.2 Temperature and Pressure Measurement

The temperature and pressure measurement (TPM) Subsystem (TPMS) supports collection of several data-points needed for recreating the heating environment of reentry. The diagram in Figure 3 shows an overview of the temperature and pressure monitoring subsystem. Images of prototyping the TPMS are shown in Appendix B.

In order to support the large number of TCs required in the capsule, a breakout board supporting 6 of the MCP9600T-E/MX series TC to digital converter was designed. This TC converter chip was selected due to its support for a wide variety of TC types (K, J, T, N, S, E, B and R)[3], as well as its chainable I^2C interface, allowing more sensing elements to connected with less wiring (similar SPI based conversion chips have a chip select line per chip that would restrict the number of pins available for other capsule functionality).

For pressure meausrement, Honeywell sensing solutions temperature compensated absolute digital pressure sensors were selected and are shown in Table 2. These single port absolute pressure sensors are available with a variety of sensitivities, allowing a different sensor to be exchanged later on in the design process if it is determined that the current predicted pressure environment is no longer accurate.

[3] https://www.digikey.com/en/products/detail/microchip-technology/MCP96L00T-E-MX/9606988

Table 2: List of pressure sensors and their capabilities

Part	Measurement Range	Product Link
SSCSRNN015PA3A3	0-103.42 kPa	https://www.digikey.com/en/products/detail/honeywell-sensing-and-productivity-solutions/SSCSRNN015PA3A3/2416212
SSCSRNN1-6BA7A3	0-160 kPa	https://www.digikey.com/en/products/detail/honeywell-sensing-and-productivity-solutions/SSCSRNN1-6BA7A3/2416214

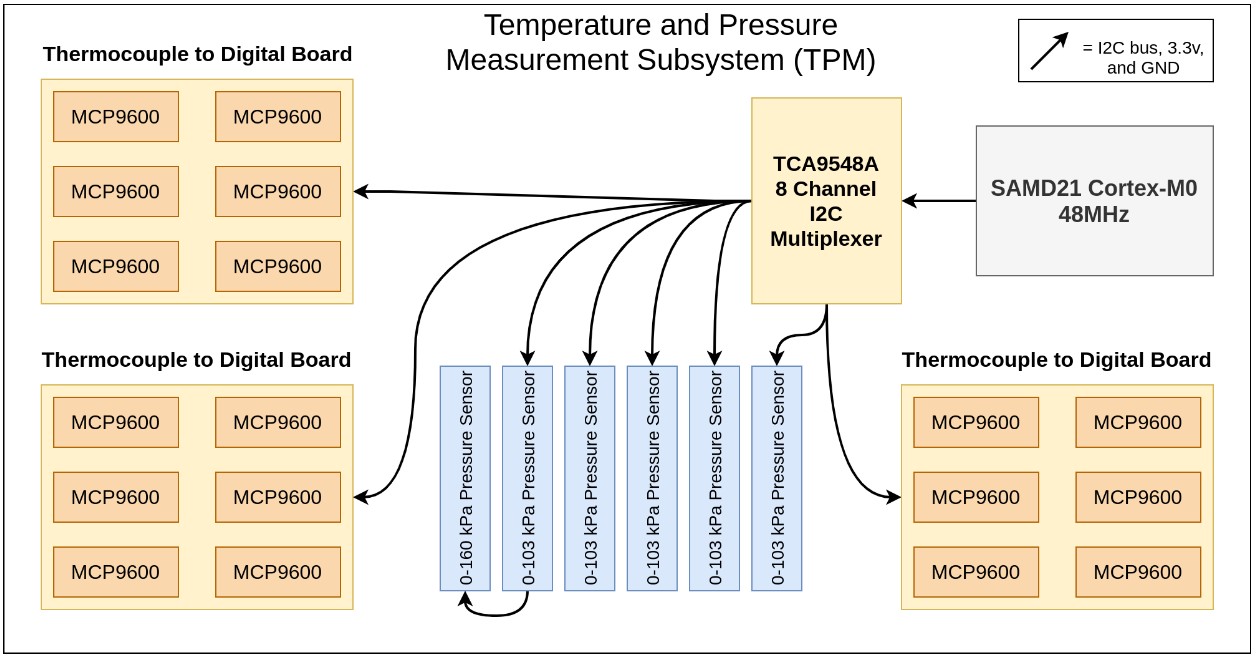

Figure 3: Functional decomposition of the TPMS.

3.3 Inertial Measurement

A breakout board for the H3LIS100DL [4] +/- 100g accelerometer has been designed to help in the evaluation of this IC as an effective way to measure acceleration loads on the capsule. The ADXL377 is another potential high-g 3-axis acceleromter [5], but has analog output and higher cost since it is currently only available in a pre-assembled breakout board.

In addition to a high-g 3-axis accelerometer, a lower dynamic range 6 axis acceleromter+gyroscope chip will also be included in the capsule (such as a ICM-20949 or MPU6050).

3.4 Telemetry

Iridium modem to send GPS coordinates for recovery operations. University of Kentucky has an Iridium modem available to use, with an account providing message credits. Discussion on the use of this modem is yet to have happened. Additional vehicle-to-ground telemetry would be reassuring as the Iridium network can be unreliable for short periods of time. It is unclear whether this would be achievable with a COTS radio link (such as XBee or LORA) that would not require FCC certification. This requires coordination

[4] https://www.digikey.com/en/products/detail/stmicroelectronics/H3LIS100DL/7313278
[5] https://www.adafruit.com/product/1413

with launch site for tracking with a directional antenna and other hardware setup. The appeal of the Iridium is we get an email with the GPS coordinates of the capsule and we can tell the recovery crew the location of the capsule from anywhere.

3.5 Parachute Deployment

Main parachute deployment will use a CO_2 cartridge puncture system which has a servo actuated trigger. Servo control signal pins are allotted on the main CDH processor and configured in software to trigger when necessary. Current plans to decide correct deployment time are to use capsule internal barometric pressure, possibly in combination with one of the external pressure sensors.

3.6 Storage

On board non-volatile storage is required to log in-flight telemetry data for post processing. Due to the high vibrational loads expected during launch, an SD card might be unreliable (spring loaded contacts could separate from card). For this reason, solid state flash integrated circuits are being explored that can store just as much information as an SD card. Exporting logged data from the capsule would then be done via cabled connection to a computer after capsule recovery.

3.7 Power

To power the capsule avionics, a lithium polymer battery will be used. Most likely a 2 cell (in series) with a high quality switching step down regulator to provide a 5 volt system bus. A single cell approach (with no 5v regulator) eases charging but might cause system electronics to be unreliable during low battery voltage scenarios. No matter what cell configuration is chosen, a battery protection IC will be used for added safety from shorts and battery depletion.

3.8 Durability

Syntactic foam may be used. Consisting of glass microballoons with epoxy resin, it can encase electronics to protect from very high acceleration loads during ascent. Currently working with NASA JSC to get glass microballoons to UK for testing.

4 Subsystem Software

Capsule operation sequence is planned as follows:

1. Low power state prior to launch
2. Activate main operation loop upon separation from launch vehicle
3. Begin logging all telemetry to internal storage and periodically transmitting Iridium packets with position and velocity information for recovery operations
4. At a specified capsule internal barometric pressure, trigger the CO_2 release servo to release the drogue and main parachute.

Currently, verified functionalities include logging of accelerometer, pressure, thermocouple, and GPS data to internal storage. Next steps include adding sending of Iridium modem packets with current position and velocity as well as integrating the IMU logging functionality (currently waiting on parts to be delivered).

Software for the capsule is under version control at `http://github.com/krups/amtps-fta-software`. This is a private repository; if anyone would like access, please send an email to matthew.ruffner@uky.edu with their Github username and they will be given access.

5 Project Logistics

5.1 Cost

According the the most recent revision of the project outline, NASA has alotted $3,000 towards the avionics design. Currently the University of Kentucky has not used any of these funds in the prototyping of capsule hardware.

5.2 Schedule

Figure 4 shows an approximate schedule for assembly and evaluation of test hardware over the later half of 2021. The project is current slightly ahead of schedule with subsystem testing occurring roughly a month earlier than expected.

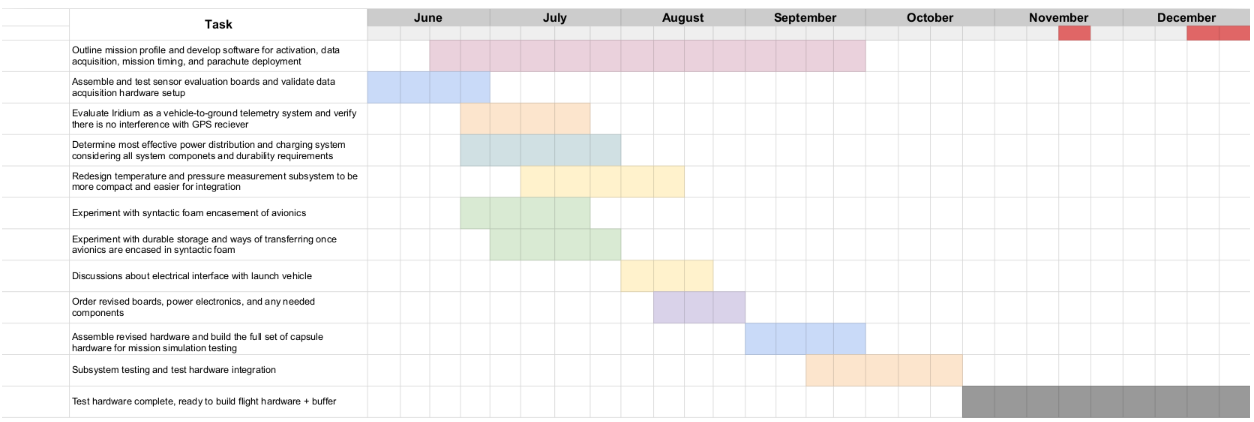

Figure 4: Approximate schedule for completion of test hardware.

A Schematics

A.1 Pre-made processor breakout boards

For the TPM board, CDH board, and IMU logger board, existing processor breakouts will be used due to shortages of bare chips.

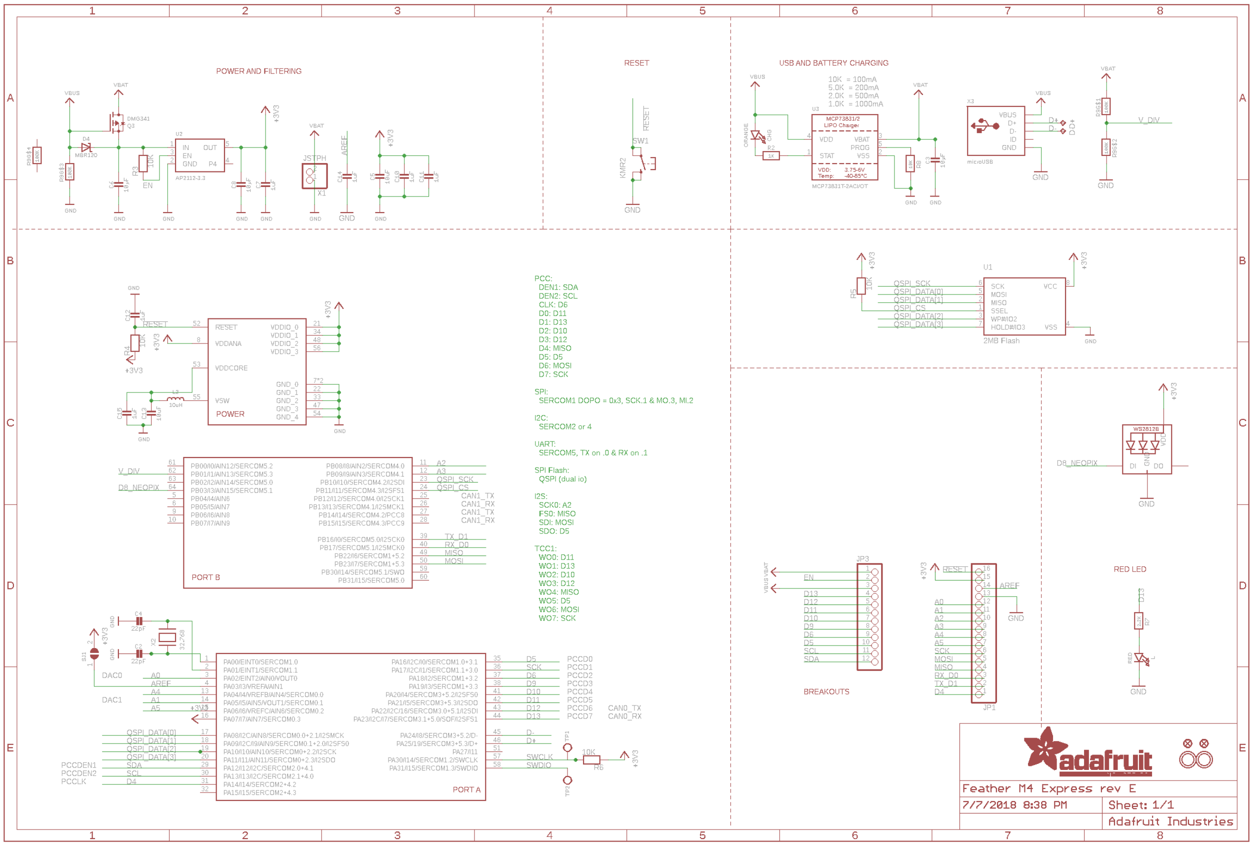

Figure 5: Feather M4 Express schematic, used in the main CDH board.

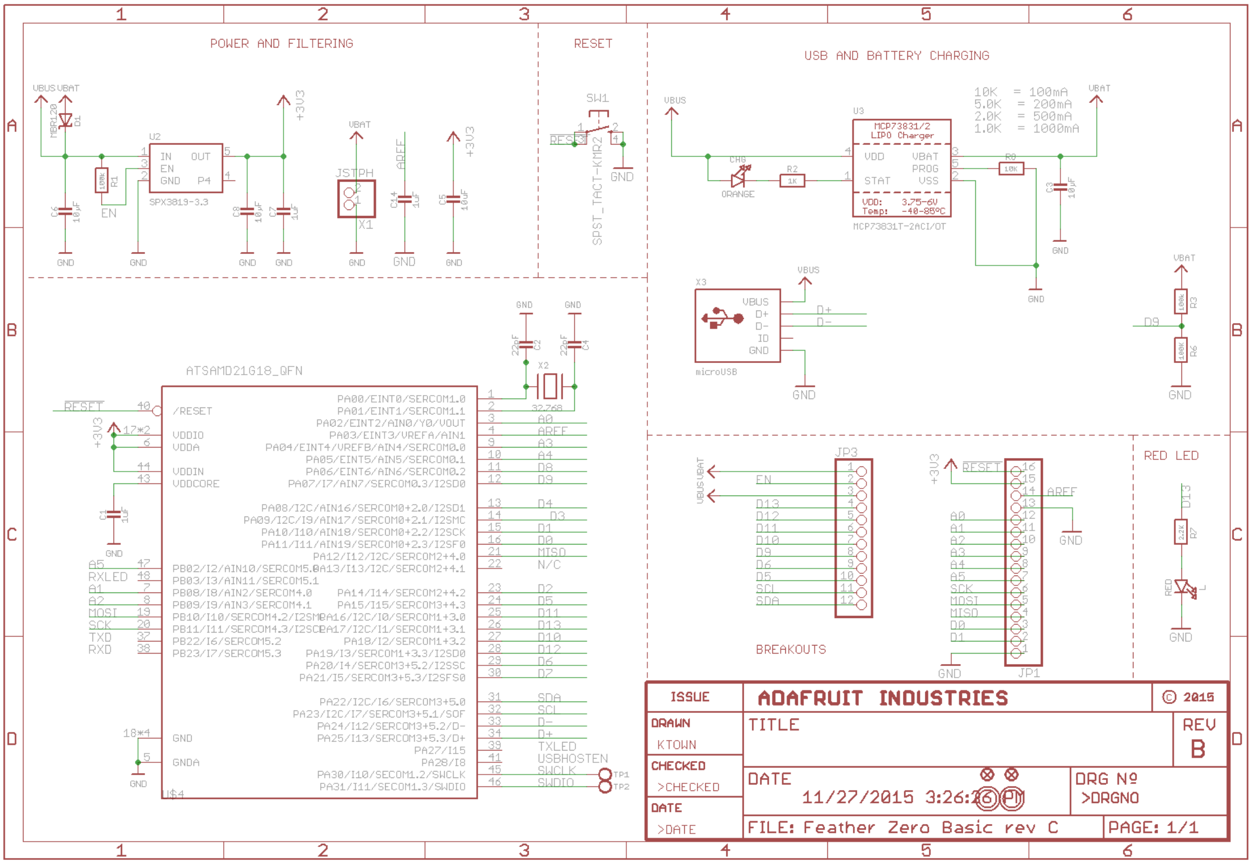

Figure 6: Feather M0 schematic, used in the IMU logger and TPM boards.

A.2 TC to Digital Schematics

Figures 7 and 8 show the schematics of the 6 channel TC to digital converter breakout board.

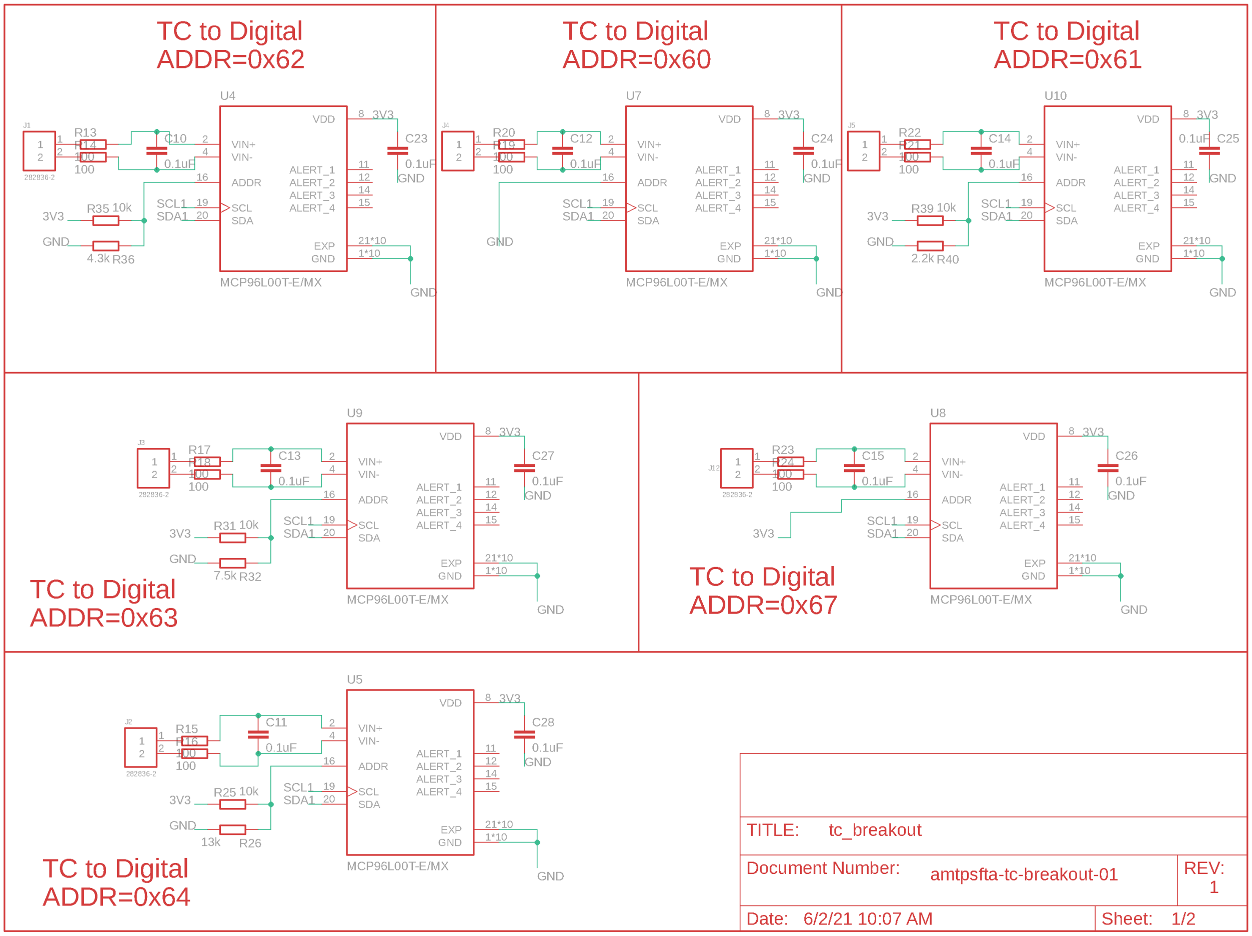

Figure 7: TC to digital schematics, page 1/2

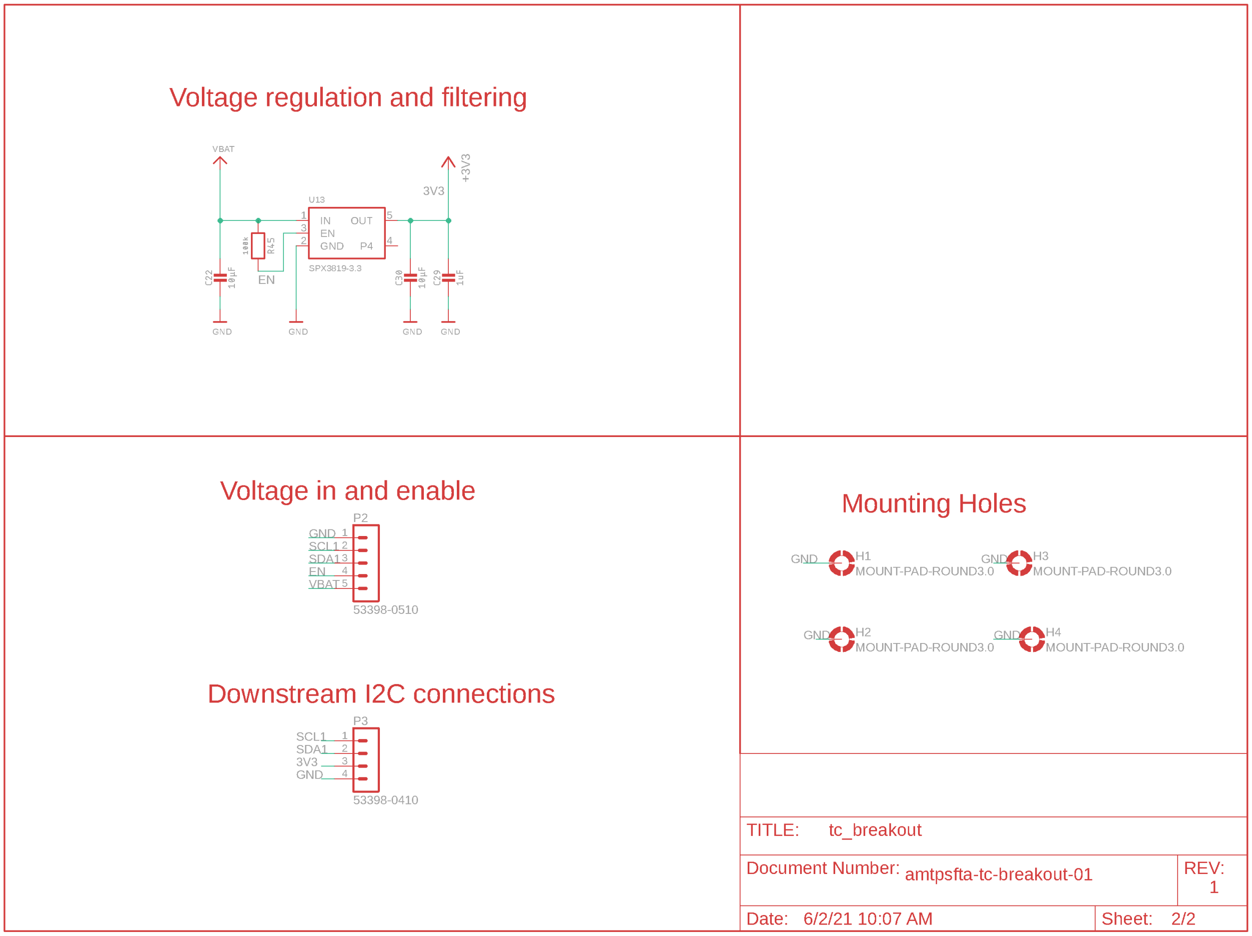

Figure 8: TC to digital schematics, page 2/2

A.3 Main CDH Schematics

Figures 9 and 10 show the schematics of the main CDH PCB.

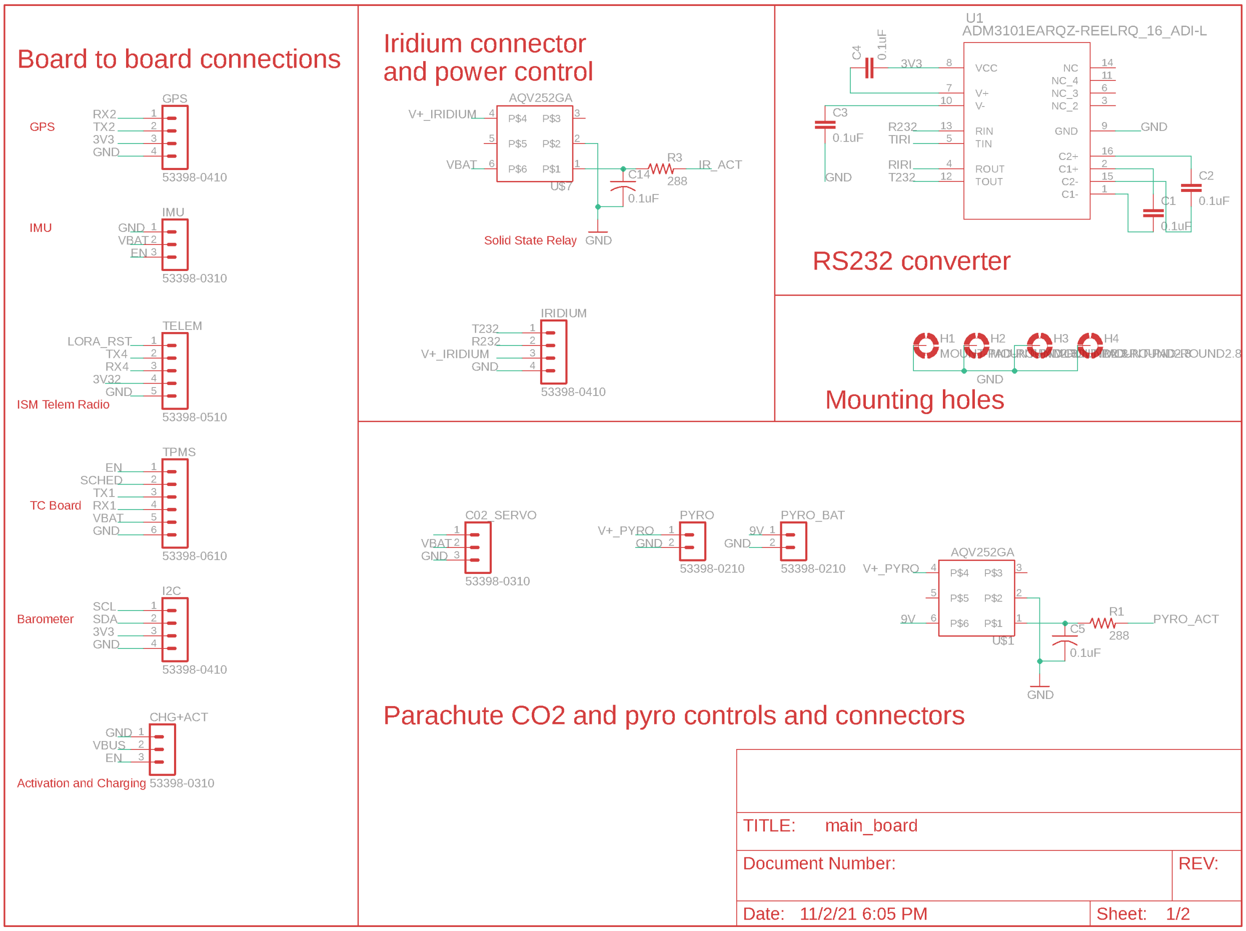

Figure 9: Main CDH schematics, page 1/2

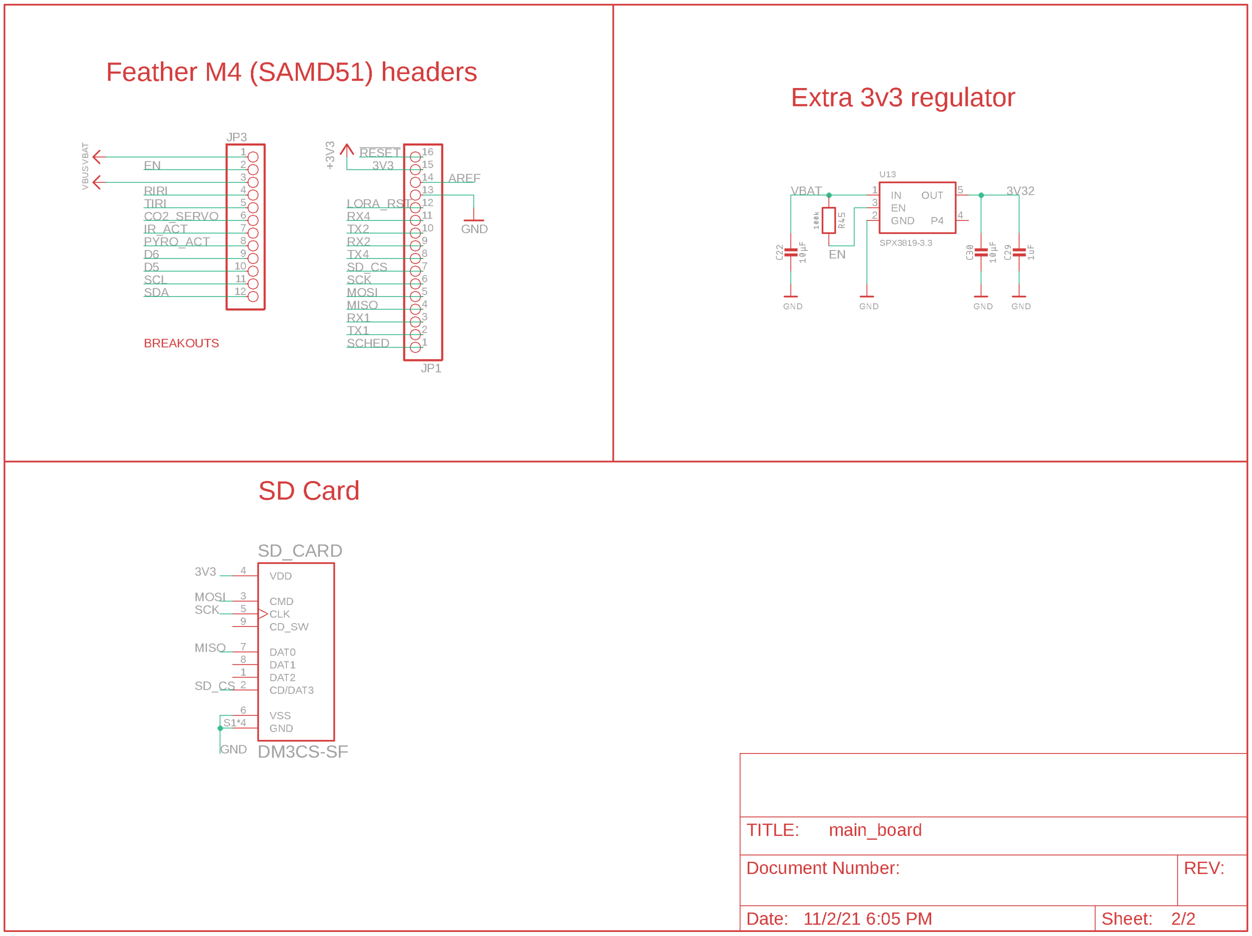

Figure 10: Main CDH schematics, page 2/2

A.4 TPM Schematics

Figures 11 and 12 show the schematics of the TPM subsystem PCB.

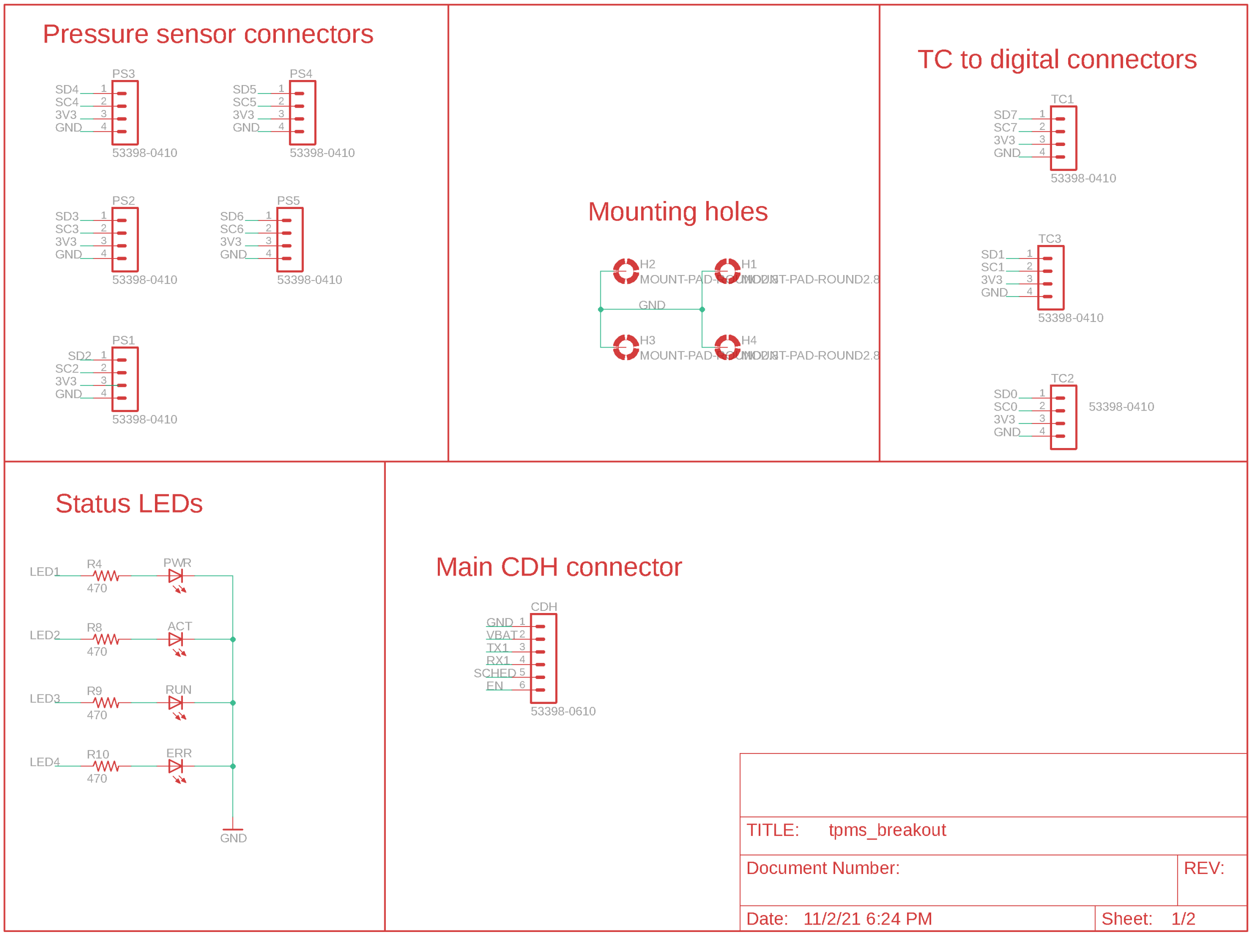

Figure 11: TPM schematics, page 1/2

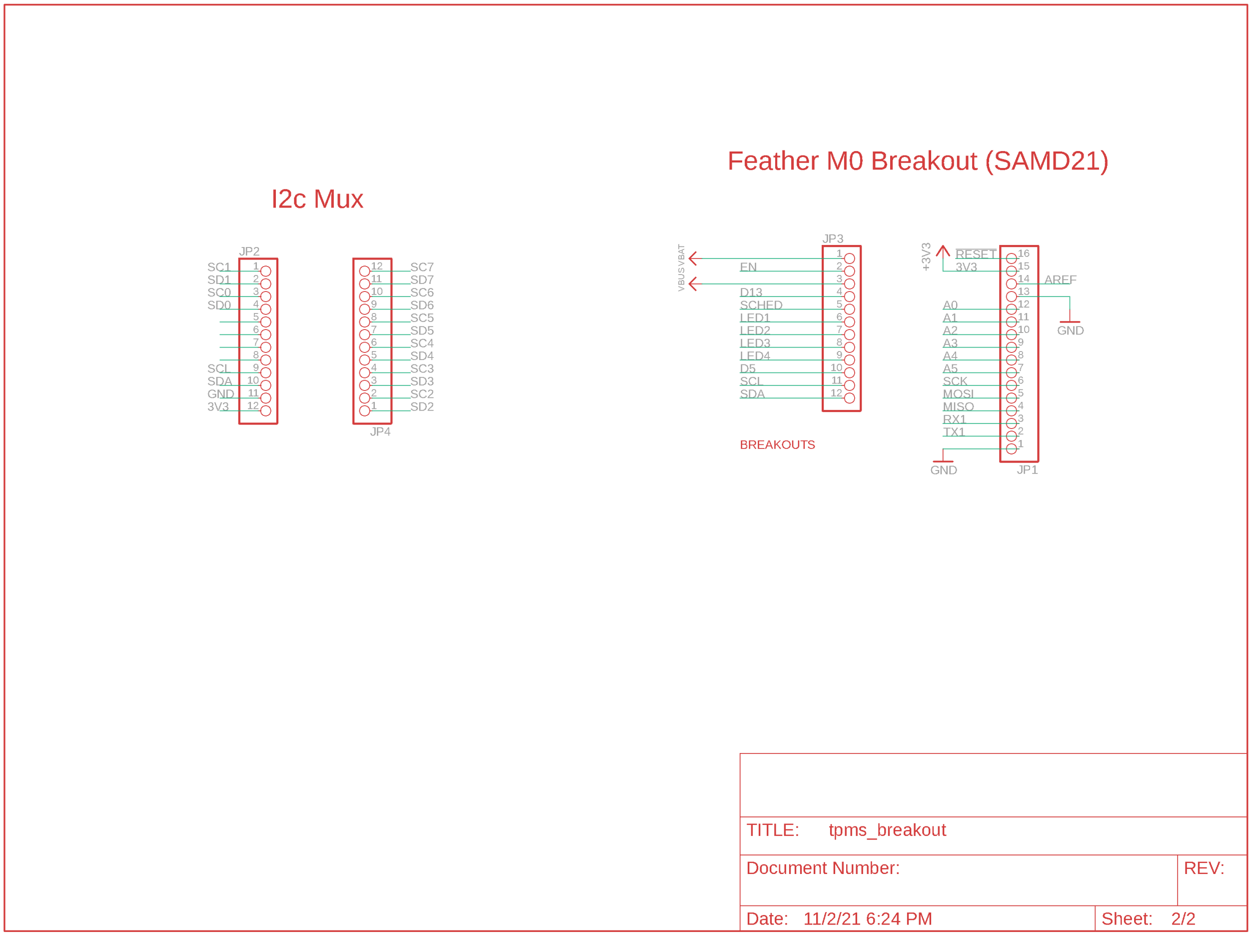

Figure 12: TPM schematics, page 2/2

A.5 IMU Logger Schematics

Figures 13, 14, and 15 show the schematics of the IMU logger PCB.

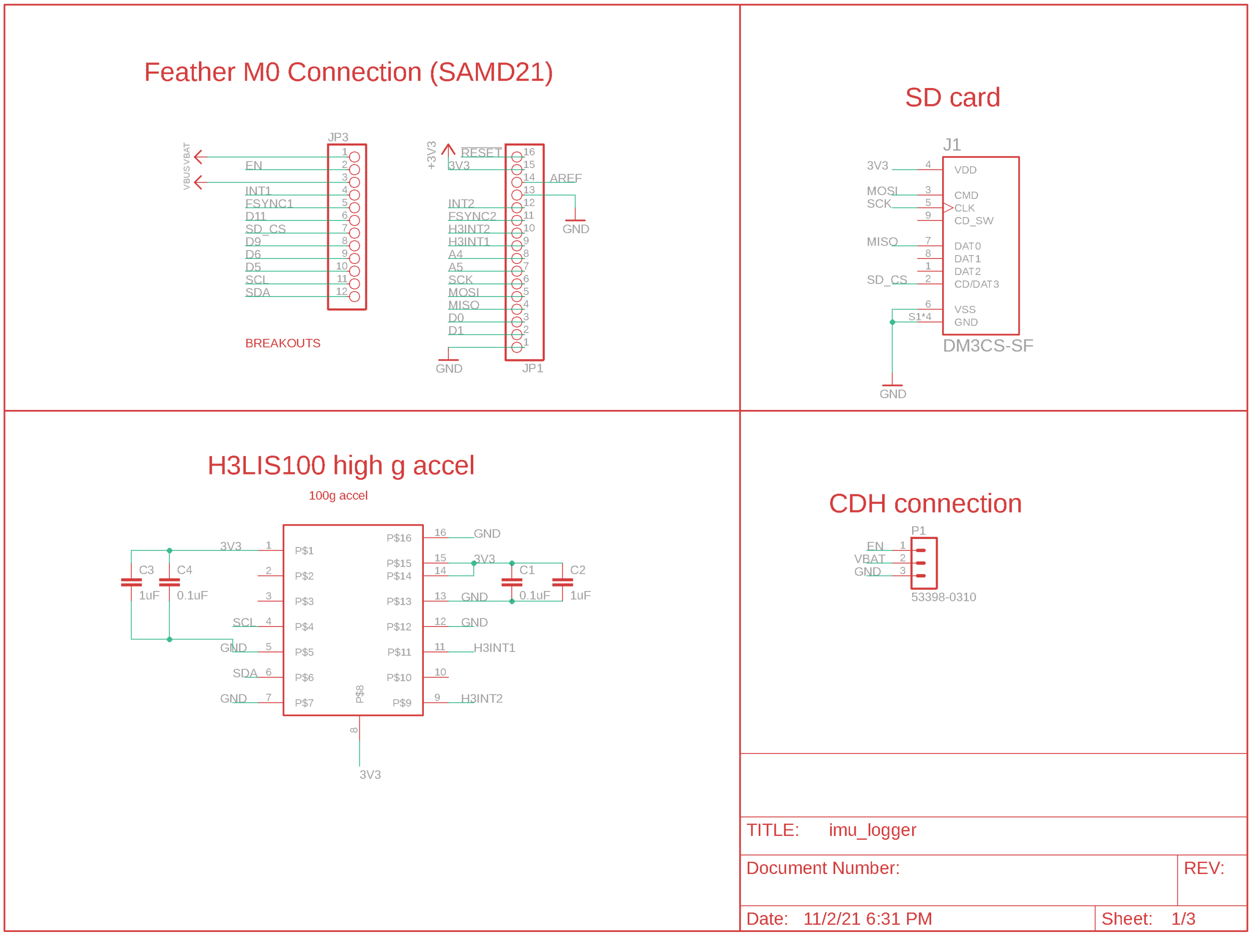

Figure 13: IMU logger schematics, page 1/3

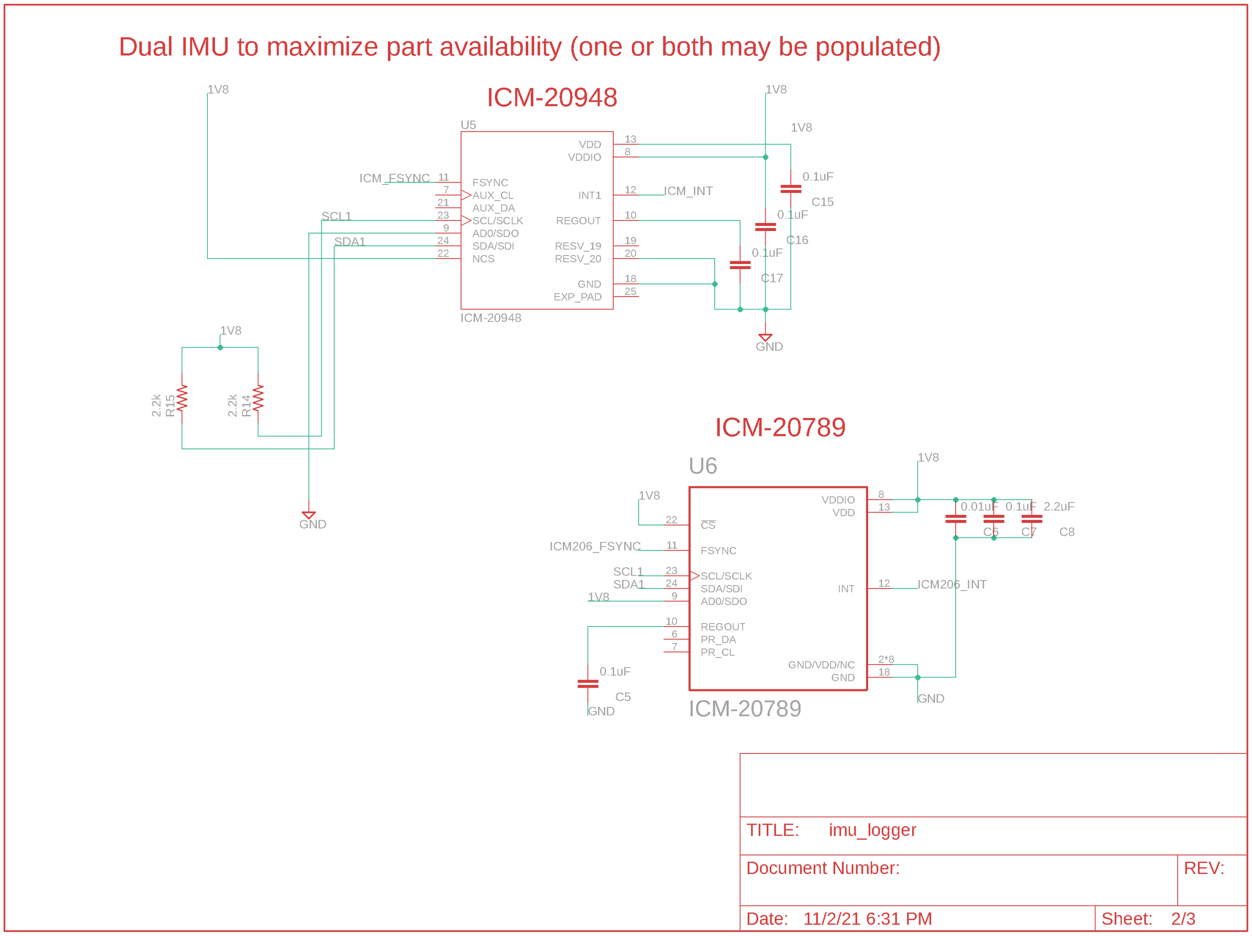

Figure 14: IMU logger schematics, page 2/3

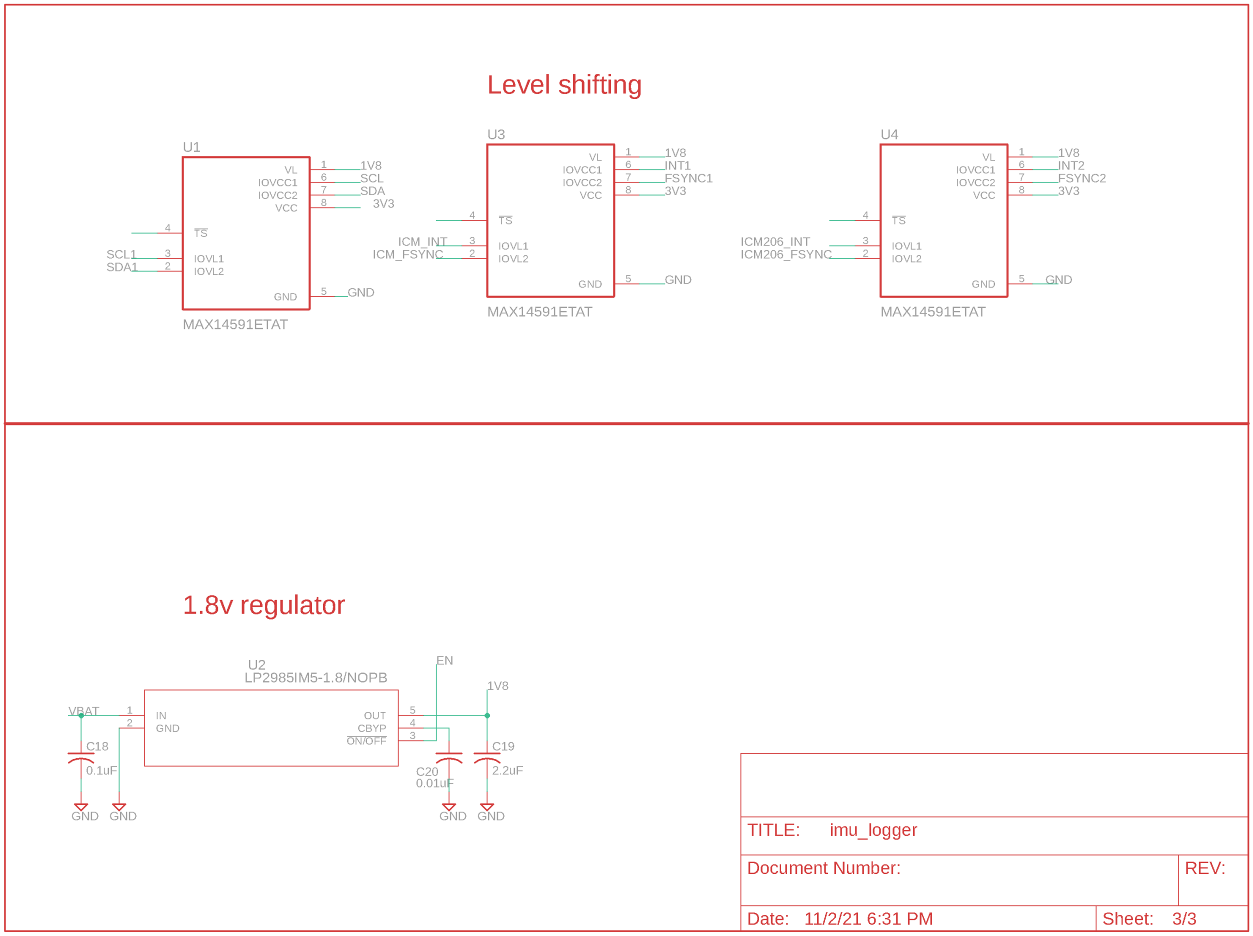

Figure 15: Page 3/3

B Subsystem Testing

Testing hardware is assembled and is currently being used for software development. CAD models of capsule avionics have been integrated into the capsule mechanical CAD (with the exception of wiring) to verify physical fit.

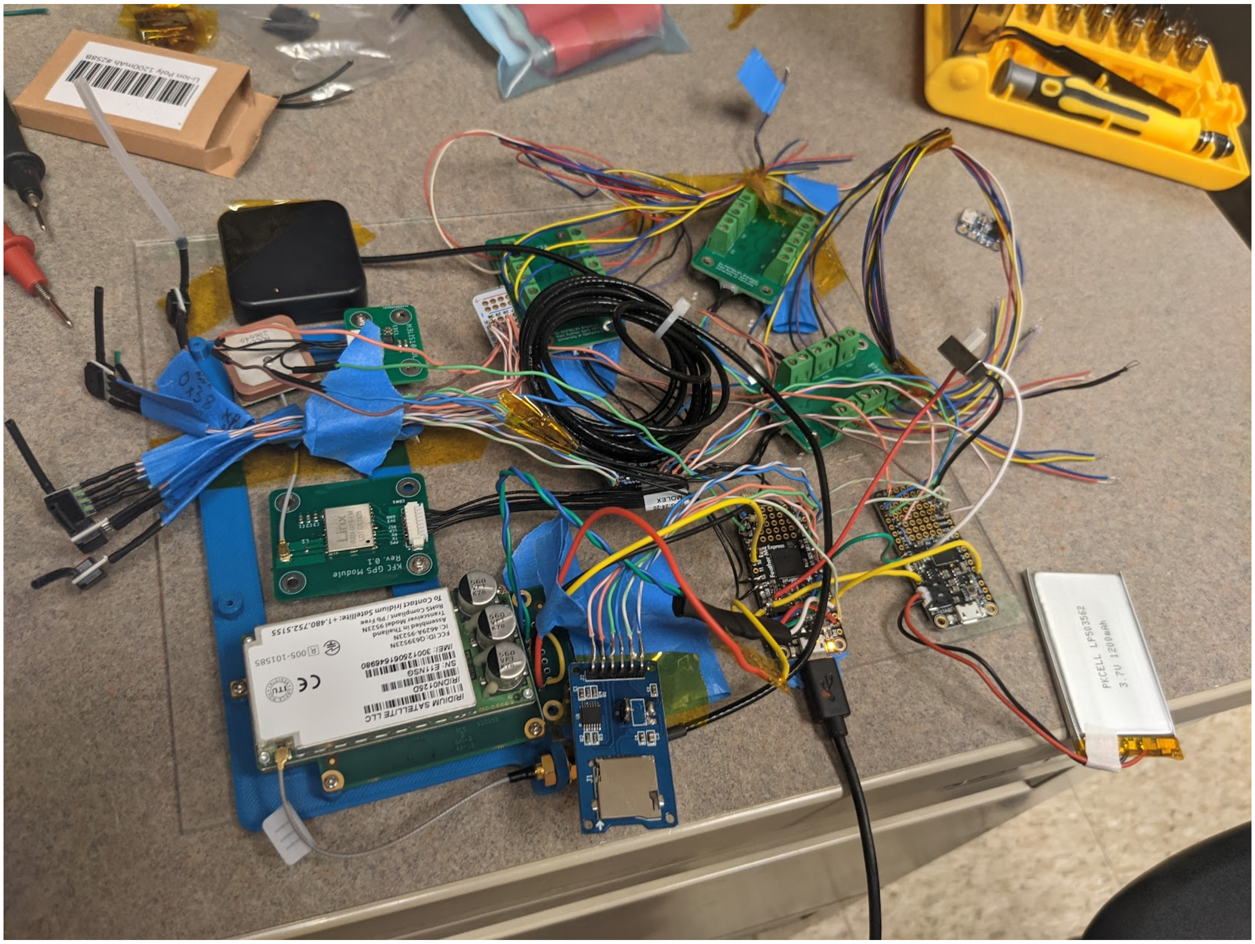

Figure 16: Initial build of subsystem testing hardware. Shown here: Top right: 18 temperature and 5 channel TPM subsystem connected to main CDH subsystem (bottom right). SD card logging and GPS receiver and antenna also shown (top left). Bottom left: Iridium satellite modem.

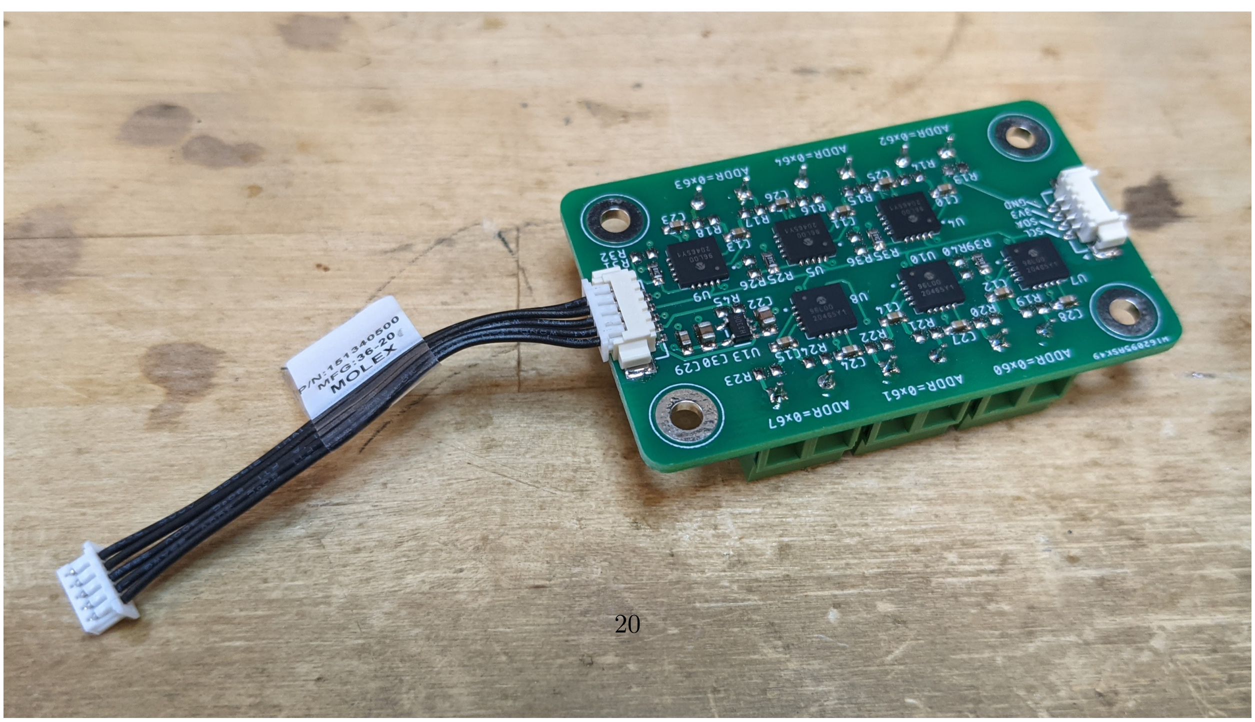

Figure 17: Bottom of V1 Evaluation board for MCP9600 TC to digital converter

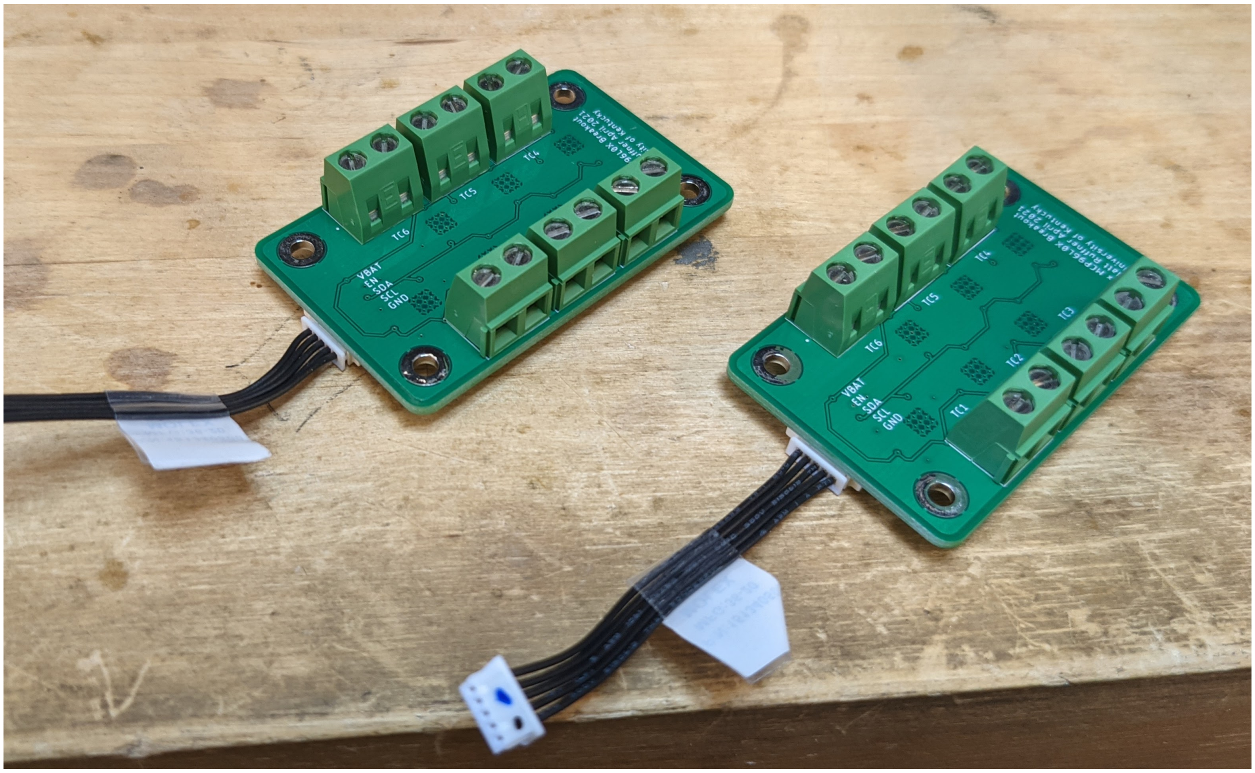

Figure 18: Top of V1 Evaluation board for MCP9600 TC to digital converter

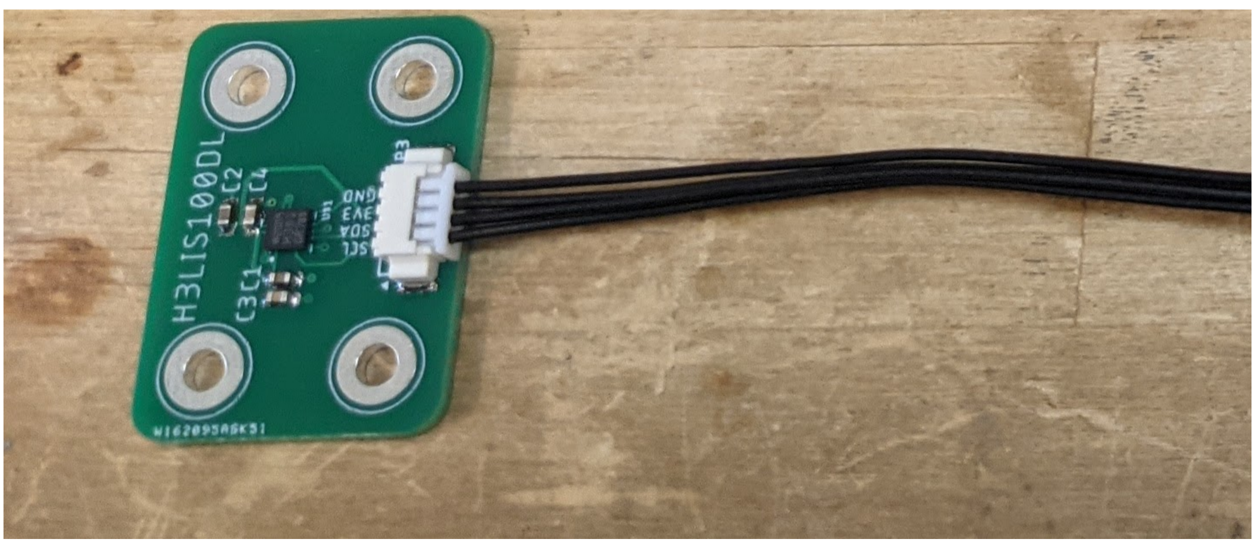

Figure 19: High g accelerometer testing PCB.

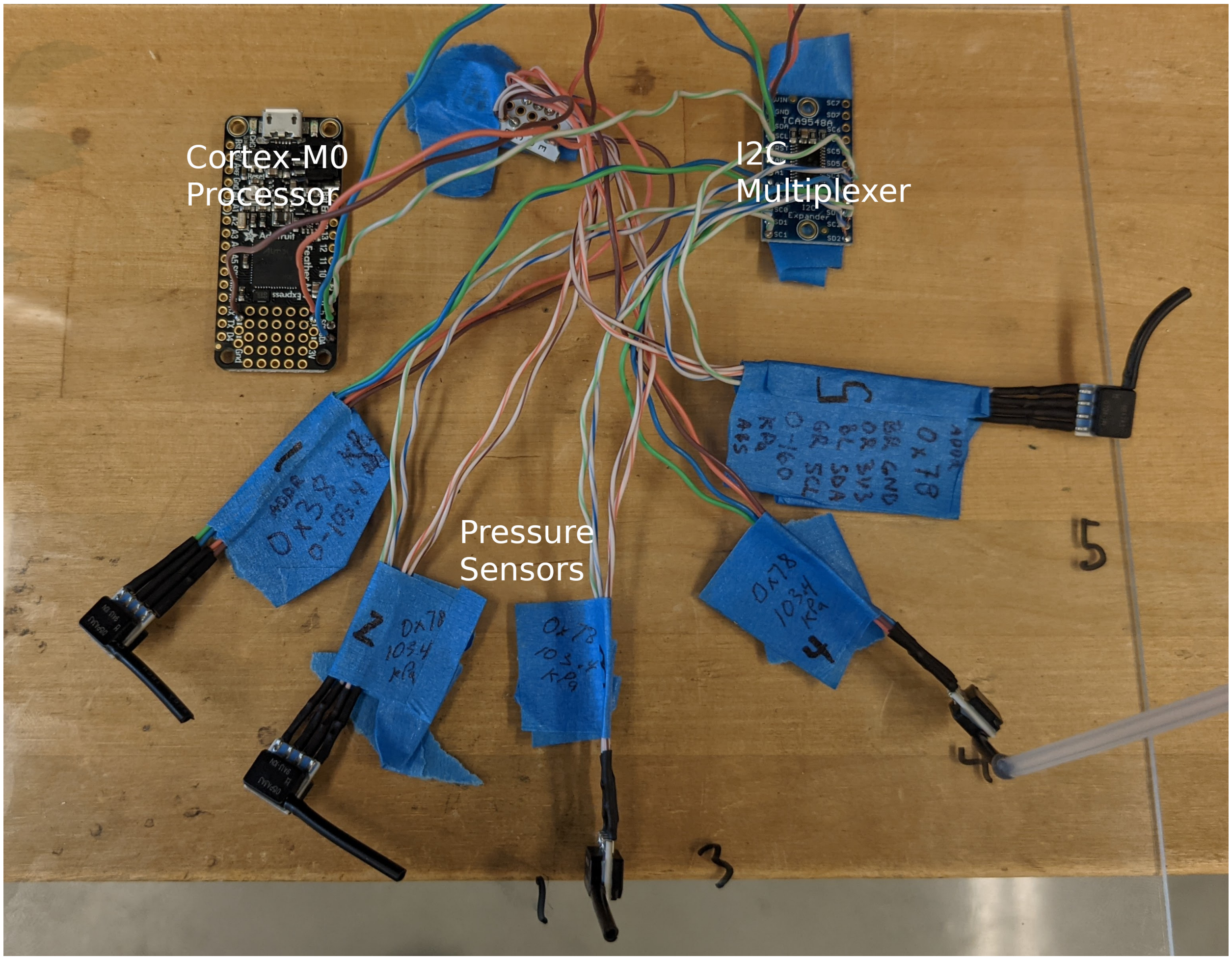

Figure 20: Testing setup for the pressure sensors.

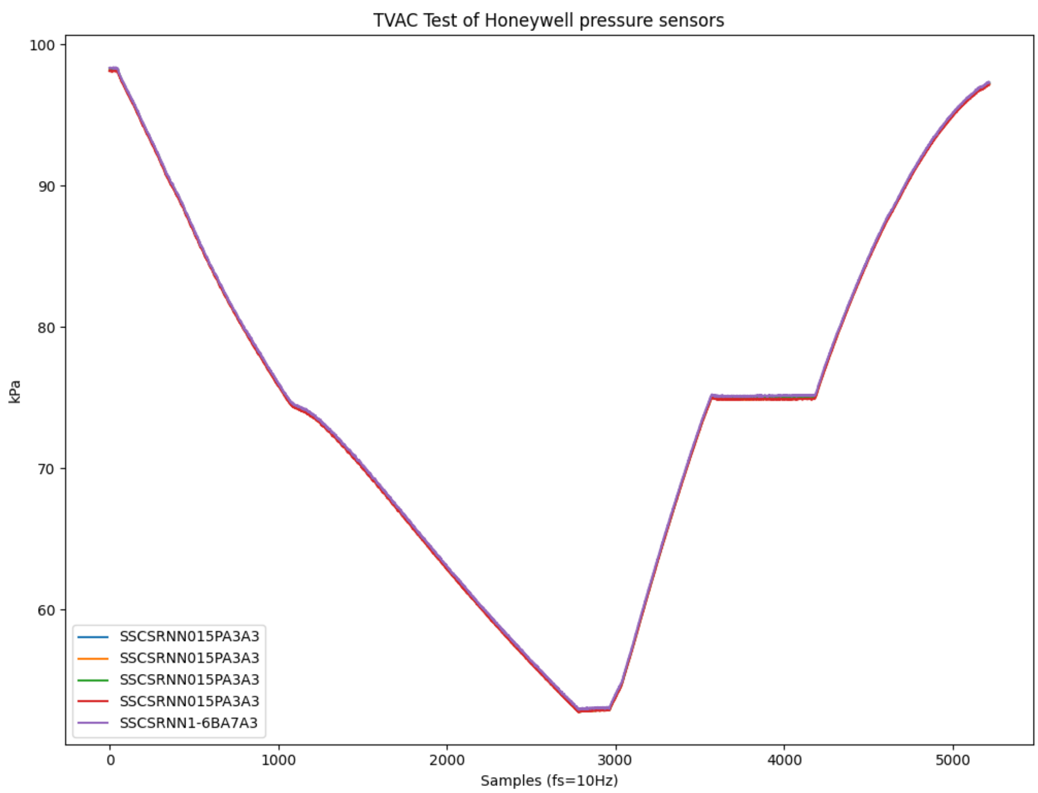

Figure 21: Pressure readout from 5 Honeywell sensors over an 8 minute session in a thermal vacuum chamber. Not only were the Honeywell sensors all very close to each other, these values closely matched the pressure readout on the TVAC chamber.