AMPTS FTA Electronic Hardware Design

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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 including the University of Kentucky and Oak Ride 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 about to touch back down to Earth. The multichannel data acquisition system must also save flight data for 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 set by the NASA project design document (rev. E) that are relevant to the avionics hardware. 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. Appendix A contains schematics for PCBs that have been prototyped. Appendix B contains images of testing hardware that has been developed.
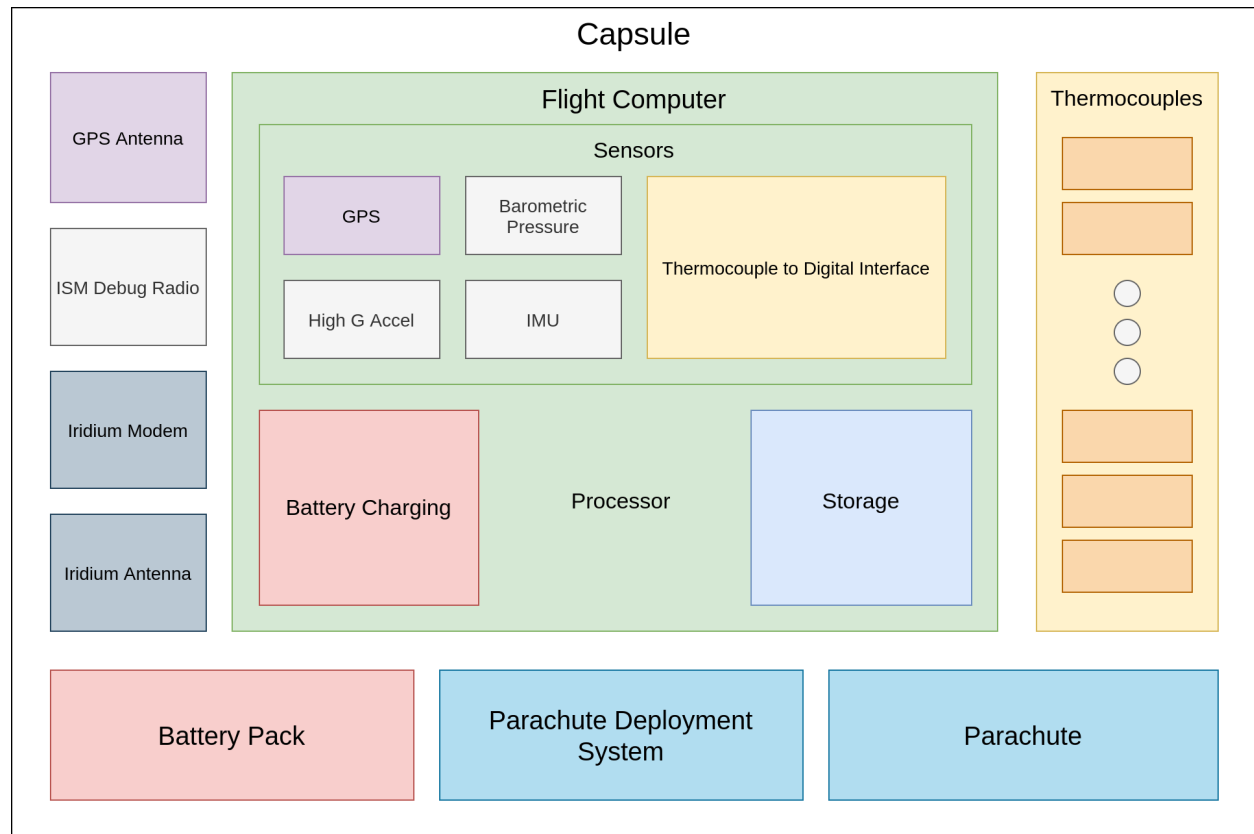

Figure 1: Capsule component overview, showing the various functional blocks.

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

   (f) Telemetry data shall be collected at a minumum of 10Hz

   (g) Telemetry data shall be stored to onboard nonvolatile memory that will survive landing

   (h) Location telemetry shall be transmitted through a vehicle-to-ground system (e.g. Iridium satellite, Xbee)

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 depoyment has occurred via interfacing with the launch vehicle

   (e) Shall trigger parachute deployment at a specified time.

3 Preliminary 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].

Table 1: List of processors used and their capabilities.

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

The diagram in Figure 2 provides a general overview of the organization of electronic hardware within the capsule.

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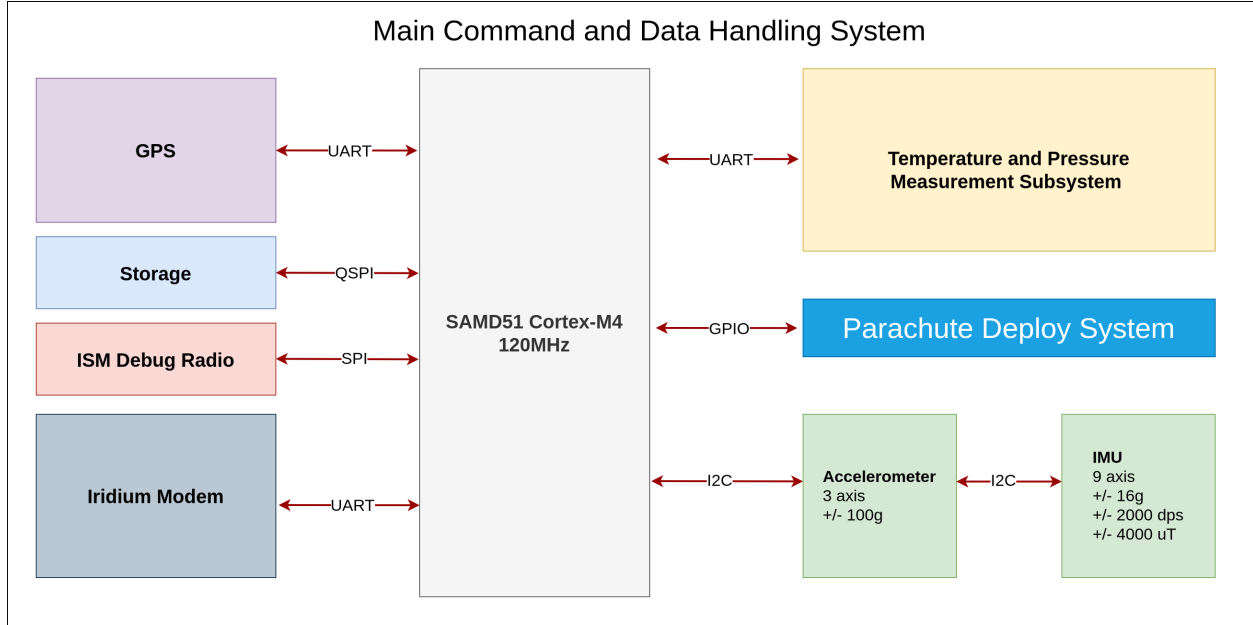[2]CDH: Command and Data Handling

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

3.2   Temperature and Pressure Measurement

The temperature and pressure measurement (TPM) Subsystem (TPMS) supports collection of several datapoints needed for recreating the heating environment of reentry.

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^{2}C 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).

A breakout board was designed with 6 MCP9600 converter chips to serve as an initial design for a t ewill be done on a breakout

For pressure meausrement, Honeywell sensing solutions temperature compensated absolution 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.

A picture of the preliminary pressure sensor evaluative setup in shown in Appendix B, Figure 7.

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

Finally, Figure 3 shows an overview of the temperature and pressure monitoring subsystem

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

Temperature and Pressure Measurement Subsystem

Thermocouple to Digital Board

MCP9600	MCP9600
MCP9600	MCP9600
MCP9600	MCP9600

TCA9548A 8 Channel I2C Multiplexer

SAMD21 Cortex-M0 48MHz

= I2C bus, 3.3v, and GND

Thermocouple to Digital Board

MCP9600	MCP9600
MCP9600	MCP9600
MCP9600	MCP9600

0-160 kPa Pressure Sensor
0-103 kPa Pressure Sensor
0-103 kPa Pressure Sensor
0-103 kPa Pressure Sensor
0-103 kPa Pressure Sensor
0-103 kPa Pressure Sensor

Thermocouple to Digital Board

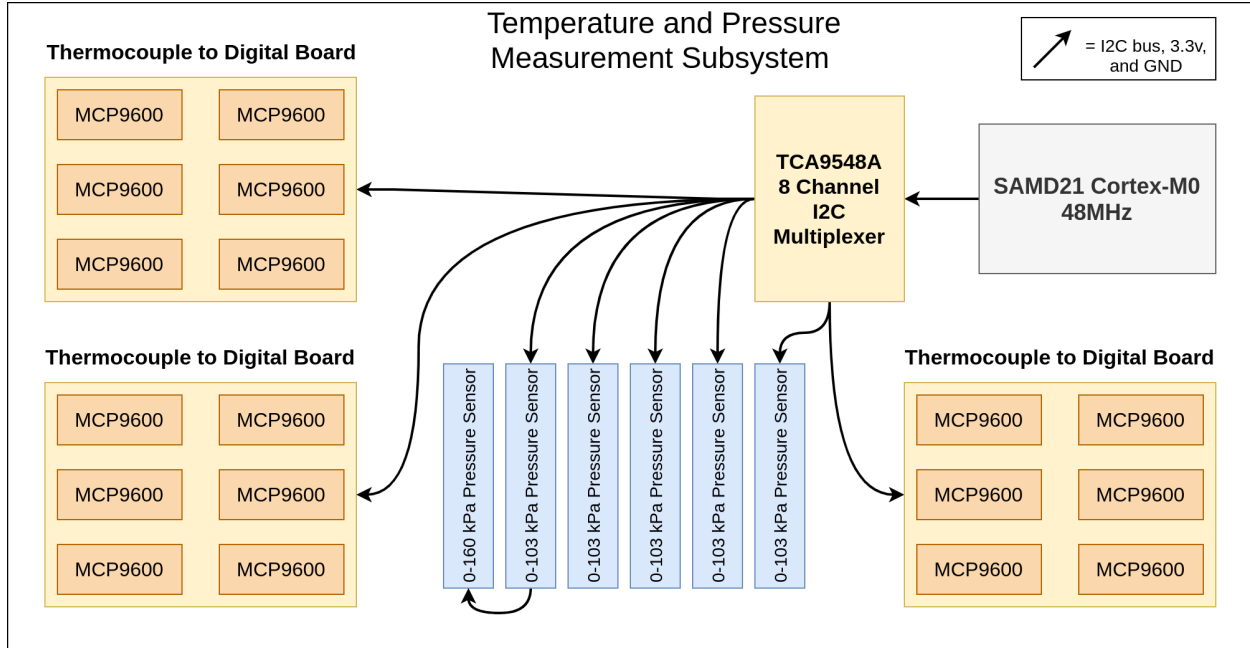| MCP9600 | MCP9600 |
| MCP9600 | MCP9600 |
| MCP9600 | MCP9600 |

Figure 3: Overview 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 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 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.

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

Exporting logged data from the capsule would then be done via cabled connection to a computer after capsule recovery.

4   Other Considerations

4.1   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.

4.2   Cost

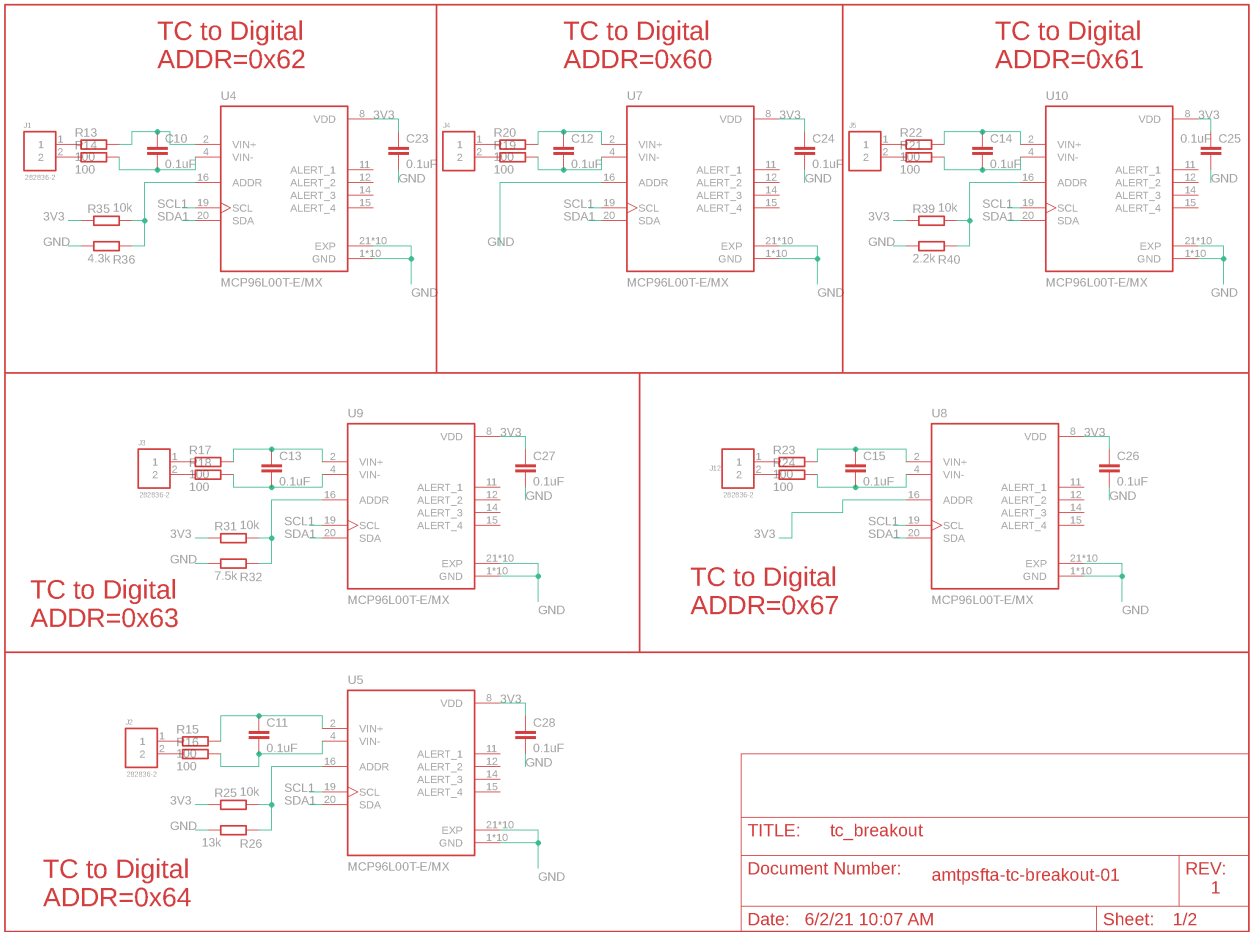According the the most recent revision of the project outline, NASA has alotted $3,000 towards the avionics design. Currently the University of Kentucky has not used any of these funds in the prototyping of capsule hardware.
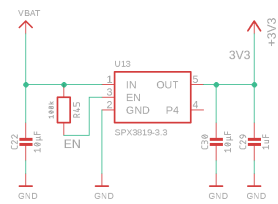
A   Schematics

A.1   Command and Data Handling

Schematics for the Cortex-M0/M4 development boards are available from the links provided to the Adafruit product pages.
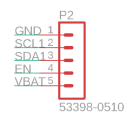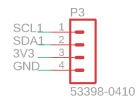
A.2 TC breakout board

TC to Digital
ADDR=0x62

TC to Digital
ADDR=0x60

TC to Digital
ADDR=0x61

TC to Digital
ADDR=0x63

TC to Digital
ADDR=0x67

TC to Digital
ADDR=0x64

U4 VDD 8 3V3 C23 0.1uF GND
VIN+ VIN- ADDR ALERT_1 ALERT_2 ALERT_3 ALERT_4 11 12 14 15
SCL1 19 SDA1 20 SCL SDA
EXP GND 21*10 1*10 GND
R13 R14 100 C10 2 4 0.1uF 16
3V3 R35 10k GND 4.3k R36
J1 1 2 282836-2
MCP96L00T-E/MX

U7 VDD 8 3V3 C24 0.1uF GND
VIN+ VIN- ADDR ALERT_1 ALERT_2 ALERT_3 ALERT_4 11 12 14 15
SCL1 19 SDA1 20 SCL SDA
EXP GND 21*10 1*10 GND
R20 R19 100 C12 2 4 0.1uF 16
GND
J6 1 2
MCP96L00T-E/MX

U10 VDD 8 3V3 0.1uF C25 GND
VIN+ VIN- ADDR ALERT_1 ALERT_2 ALERT_3 ALERT_4 11 12 14 15
SCL1 19 SDA1 20 SCL SDA
EXP GND 21*10 1*10 GND
R22 R21 100 C14 2 4 0.1uF 16
3V3 R39 10k GND 2.2k R40
J5 1 2
MCP96L00T-E/MX

U9 VDD 8 3V3 C27 0.1uF GND
VIN+ VIN- ADDR ALERT_1 ALERT_2 ALERT_3 ALERT_4 11 12 14 15
SCL1 19 SDA1 20 SCL SDA
EXP GND 21*10 1*10 GND
R17 R18 100 C13 2 4 0.1uF 16
3V3 R31 10k GND 7.5k R32
J3 1 2 282836-2
MCP96L00T-E/MX

U8 VDD 8 3V3 C26 0.1uF GND
VIN+ VIN- ADDR ALERT_1 ALERT_2 ALERT_3 ALERT_4 11 12 14 15
SCL1 19 SDA1 20 SCL SDA
EXP GND 21*10 1*10 GND
R23 R24 100 C15 2 4 0.1uF
3V3
J12 1 2 282836-2
MCP96L00T-E/MX

U5 VDD 8 3V3 C28 0.1uF GND
VIN+ VIN- ADDR ALERT_1 ALERT_2 ALERT_3 ALERT_4 11 12 14 15
SCL1 19 SDA1 20 SCL SDA
EXP GND 21*10 1*10 GND
R15 R16 100 C11 2 4 0.1uF 16
3V3 R25 10k GND 13k R26
J2 1 2 282836-2
MCP96L00T-E/MX

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Document Number: amtpsfta-tc-breakout-01
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Date: 6/2/21 10:07 AM Sheet: 1/2

8

Voltage regulation and filtering

VBAT

+3V3
3V3

U13
1 IN OUT 5
3 EN
2 GND P4 4
SPX3819-3.3

C22
10µF

R45
100k

EN

C28
1µF

C29
1µF

GND GND GND GND

Voltage in and enable

P2
GND 1
SCL1 2
SDA13
EN 4
VBAT 5
53398-0510

Downstream I2C connections

P3
SCL1 1
SDA1 2
3V3 3
GND 4
53398-0410

Mounting Holes

GND H1
MOUNT-PAD-ROUND3.0

GND H3
MOUNT-PAD-ROUND3.0

GND H2
MOUNT-PAD-ROUND3.0

GND H4
MOUNT-PAD-ROUND3.0

TITLE: tc_breakout

Document Number: amtpsfta-tc-breakout-01

REV: 1

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B   Testing setup
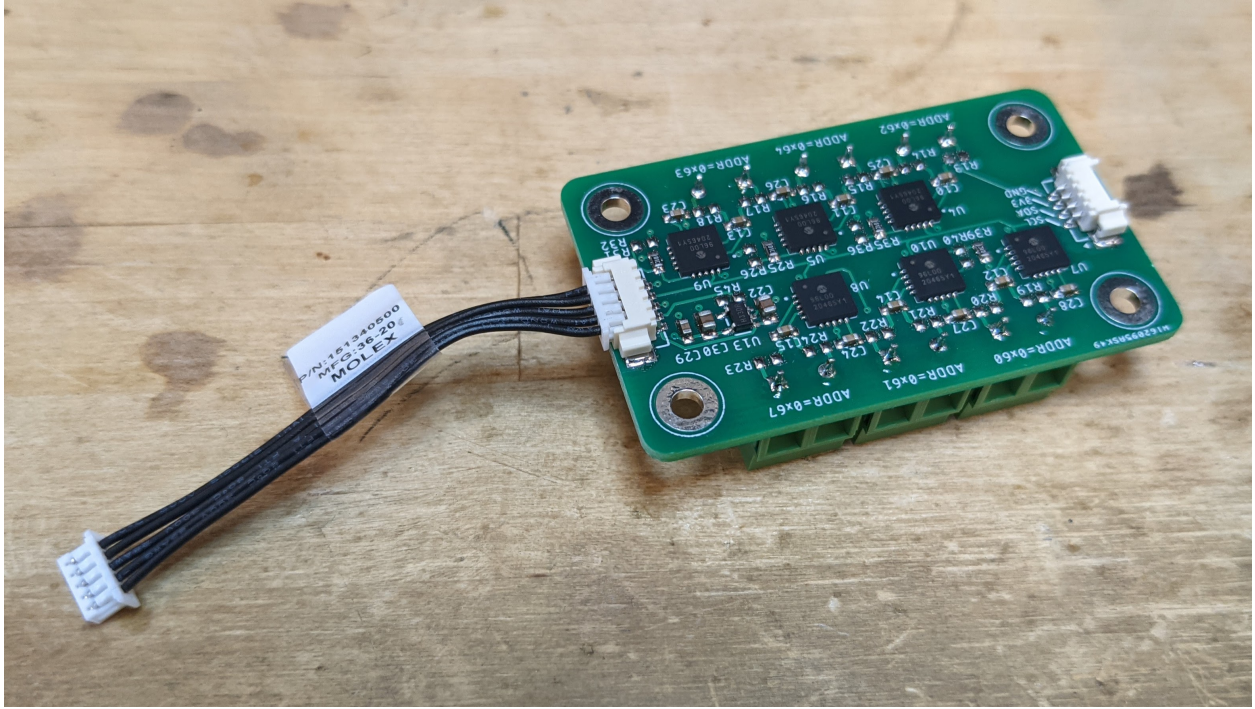
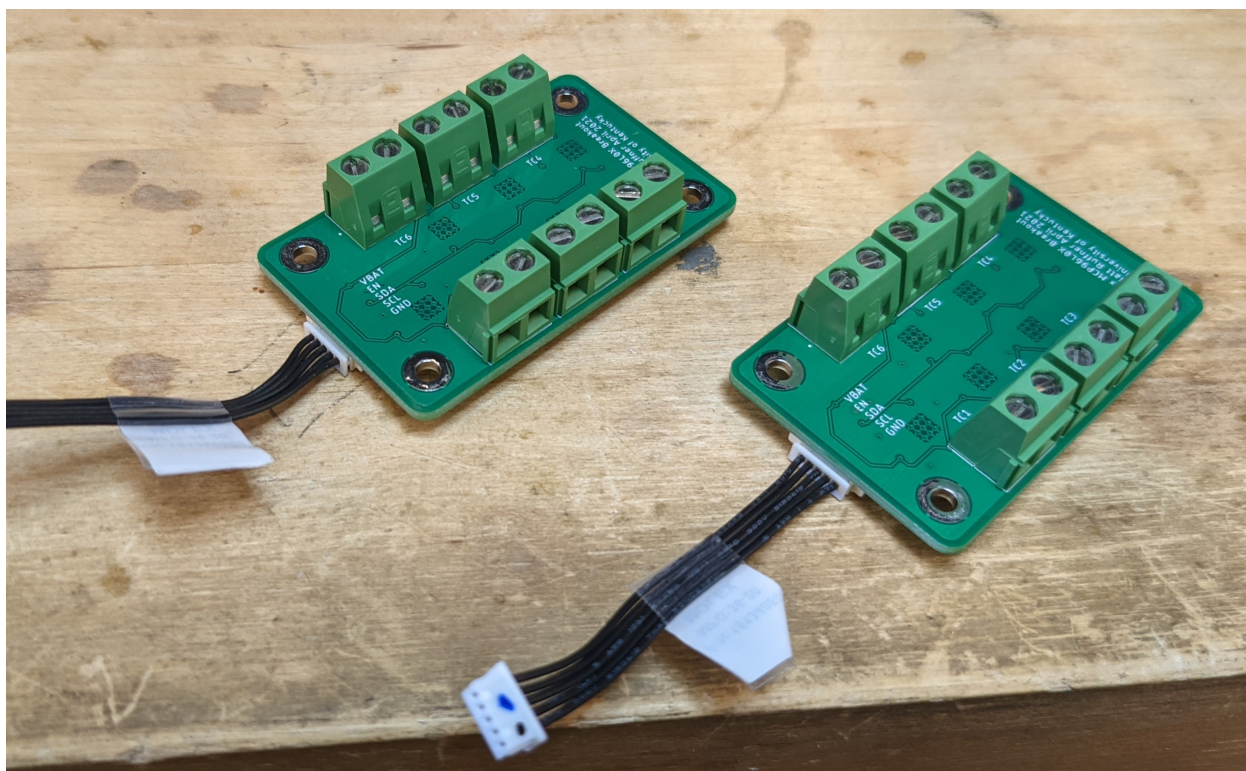Figure 4: Bottom of V1 Evaluation board for MCP9600 TC to digital converter

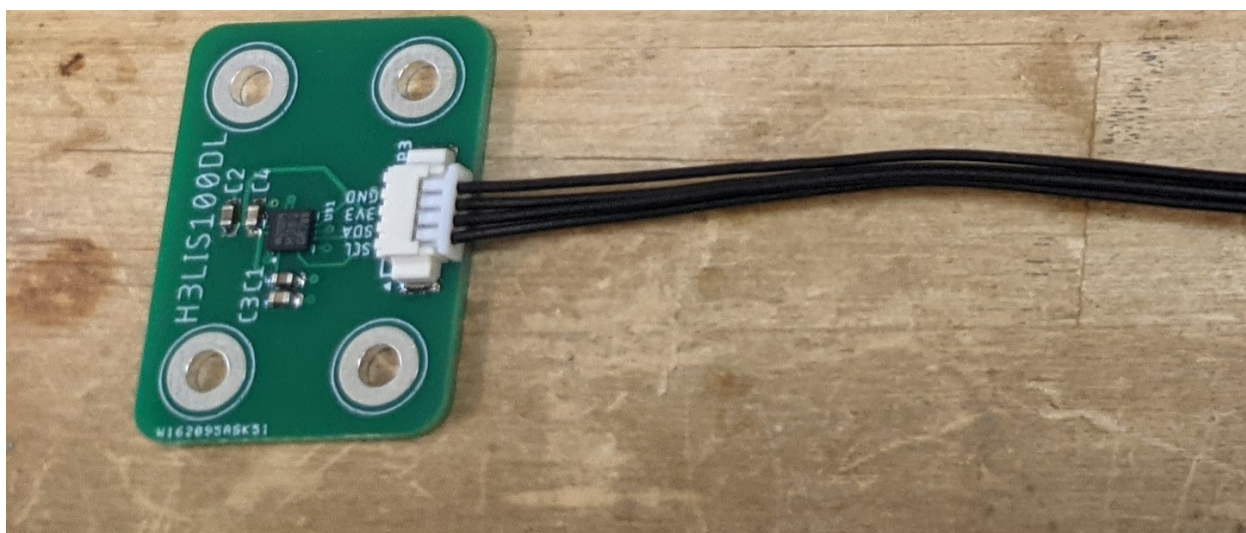Figure 5: Top of V1 Evaluation board for MCP9600 TC to digital converter
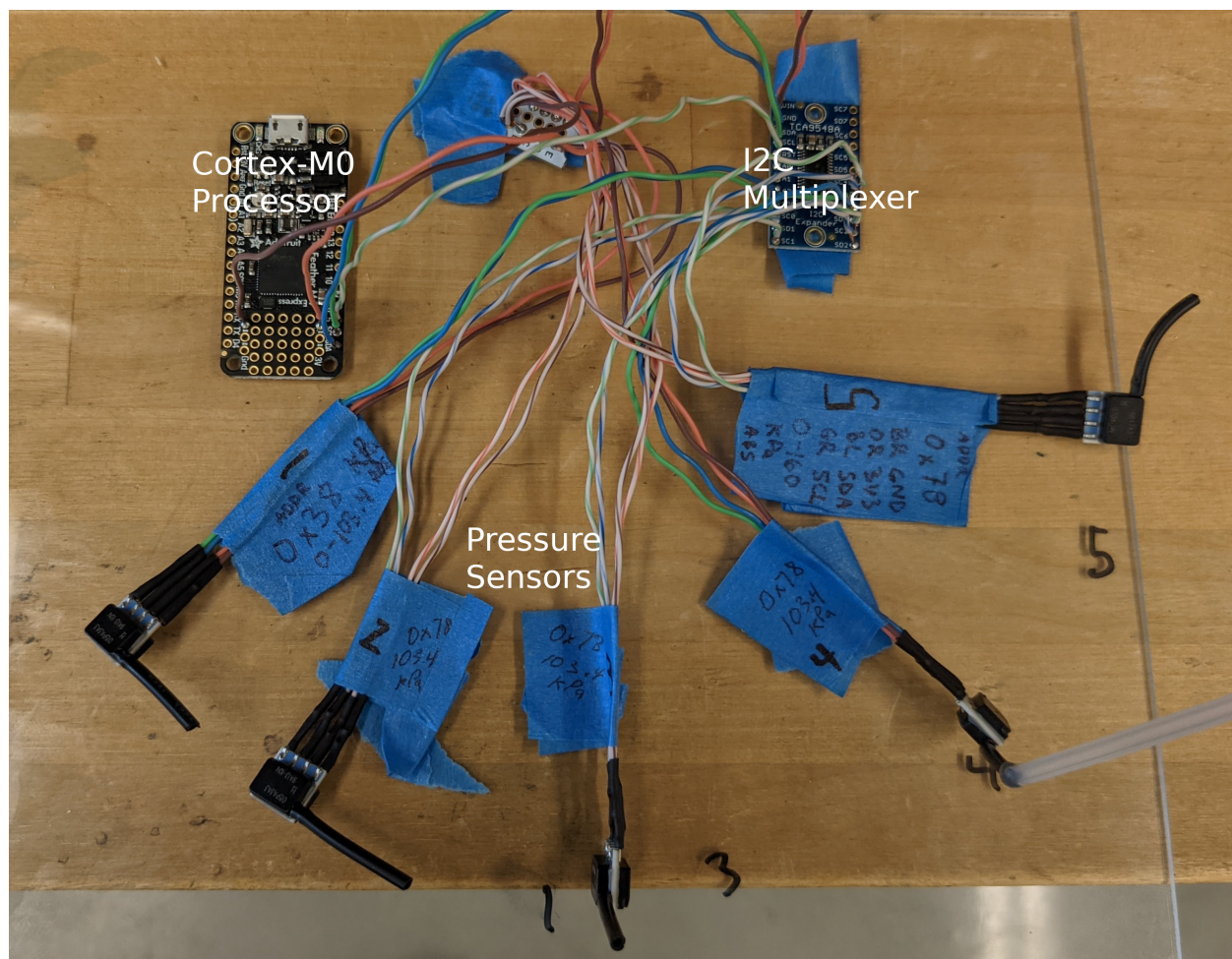

Figure 6: High g accelerometer testing PCB.

Figure 7: Testing setup for the pressure sensors.