College of Engineering & Applied Science
UNIVERSITY OF COLORADO **BOULDER**

ECEN4610 PoC Report

WATTS UP - JPL

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Elevator Pitch:

We are developing a low-cost, high-impact-survivable Mars hard lander that operates as a fixed environmental sensor node. After impact, it powers up autonomously, collects localized environmental data, stores it redundantly, and transmits it to the Mars relay network on a scheduled basis. Because it removes the complexity and cost of soft-landing hardware, this architecture is inherently scalable, repeatable, and deployable as a distributed sensor network for long-duration Martian science.

1. Major Risk Sites for PoC:

Risk Site 1 - Battery Endurance (Will the batteries last more than 2 sols ?)

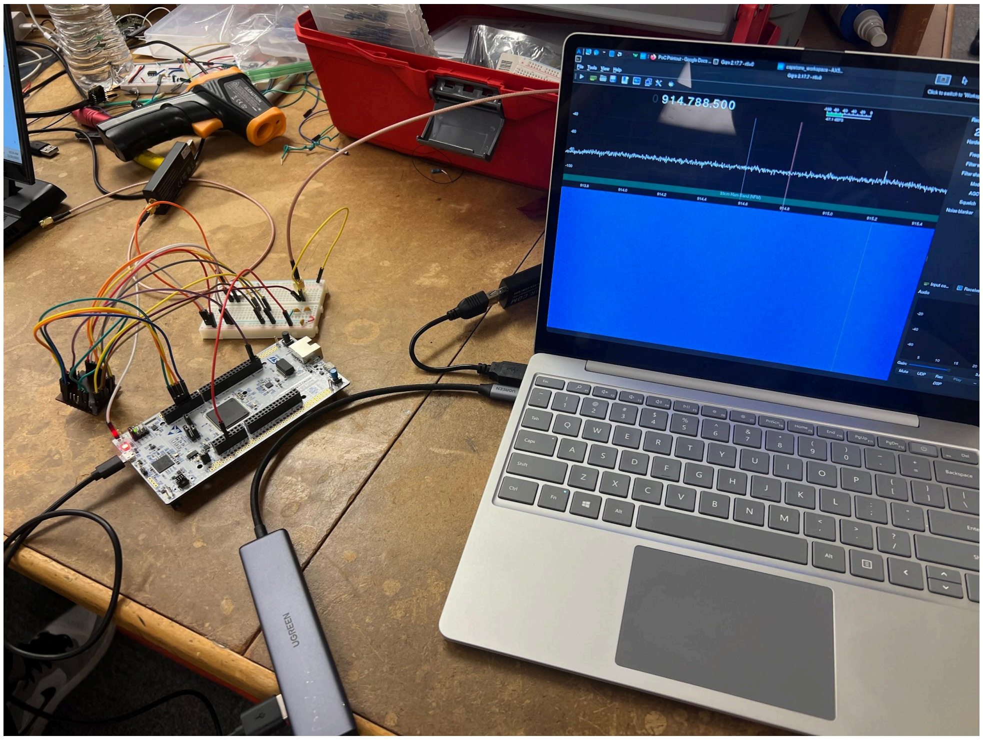
- Risk Statement:
  - We do not yet know if our 3S3P Li-ion battery pack, operated at our expected duty cycle, will provide sufficient energy to power the system for more than 2 Martian sols (49.2 hours).
- Impact if it fails:
  - System dies early → mission failure (no data after deployment), rescope needed for power budget, duty cycle, or pack capacity.

Risk Site 2 - RF Link Reliability (Will the transceiver transmit raw bits?)

- Risk Statement:
  - We ordered AX5043 transceivers from an untrusted source and needed to troubleshoot the transceiver in order to verify if we can implement it into our RF design.
- Impact if it fails:
  - If the transceiver cannot pass raw-bit communication tests, we cannot verify UHF data transmission and we will not be able to implement or test CCSDS packet protocols. Further testing or selecting an alternative transceiver could be next steps.

2. PoC Test 1 (Live) - Raw Bit RF Link (TX/RX)

Risk Addressed: Risk 2 - Transceiver raw-bit link.

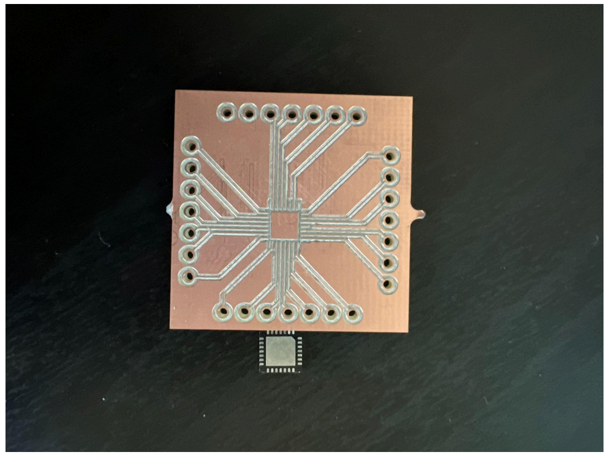


2.1 Objective

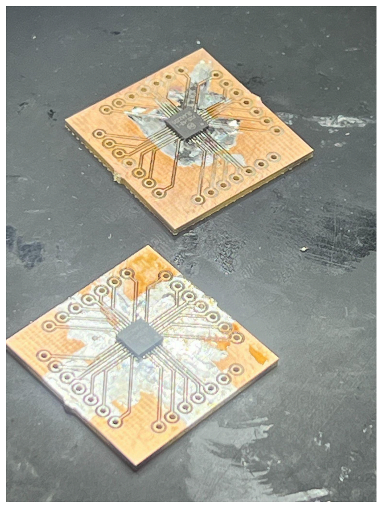
Verify that the AX5043 can transmit raw unformatted bits over RF during a cabled test in a controlled benchtop environment. Demodulate raw-bits from BPSK waveform and measure data rate of transmitted bits.

2.2 Test Setup

- AX 5043 transceiver
- STM32H7 uC development board
- RTLSDRv4
- 20 dB attenuator
- GNU Radio Companion demodulation flowgraph
- GQRX/SDR++ for initial spectrum monitoring



Transceiver assembly



Transceiver Board Fabricated

2.3 Procedure

1. Assemble testing environment
    a. Connect H7 development board, AX5043 transceiver, and RTLSDRv4 together
2. Configure AX5043 registers for data transmission tests
    a. Set frequency, transmission rate, output power, etc.
3. Microcontroller sends 238 bytes to transceiver over SPI, Transceiver transmits in BPSK.
4. Receive transmission on SDR using GQRX
5. Record transmission with GQRX
6. Demodulate signal into raw bytes using GNU Radio Companion

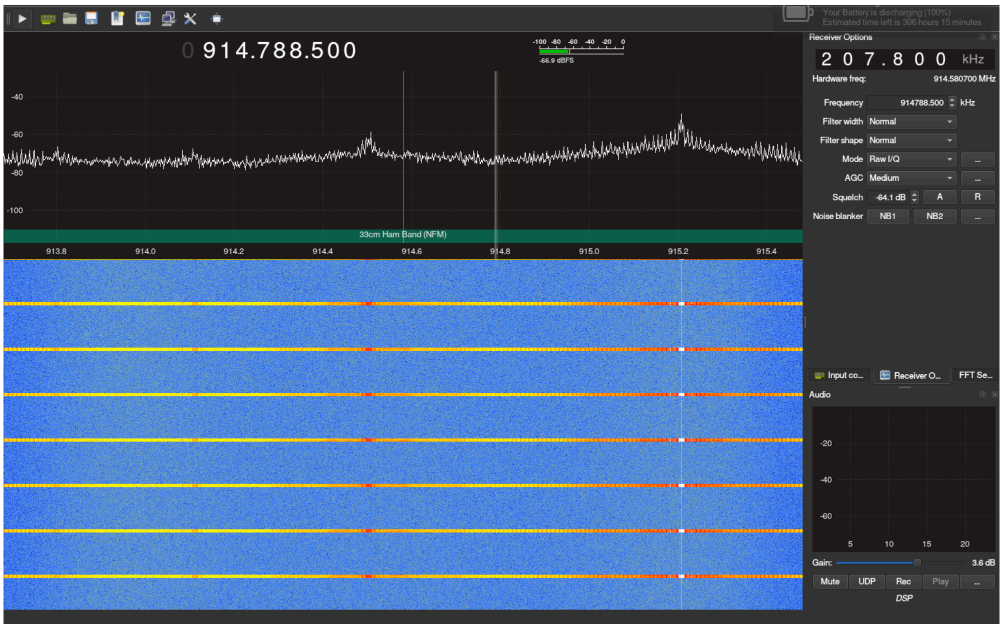
2.4 Success Criteria

Signal should be BPSK modulated and have a measured data rate at a minimum of 4.5 kbps in order to be able to transmit 1 month's worth of sensor data (estimated 0.27MB) to the mars relay network within our

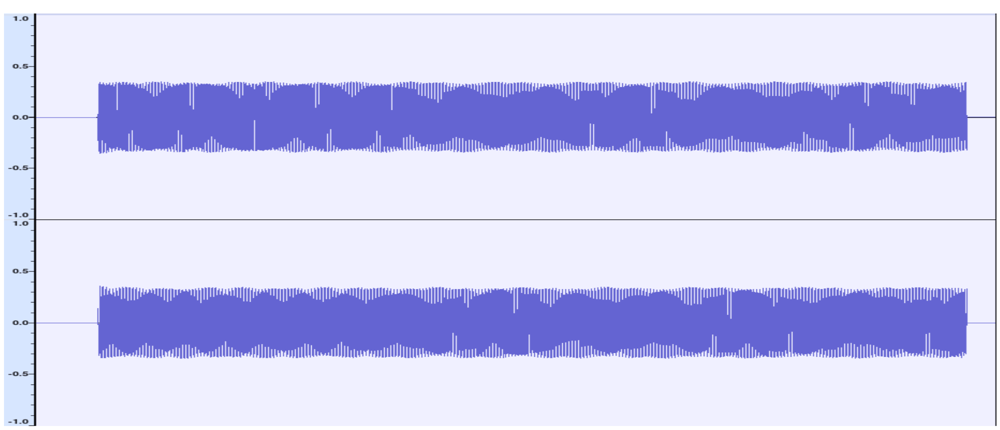
8 minute transmission window. The recorded waveform can be demodulated in GNU Radio to retrieve bytes.

2.5 Results

During PoC testing, we successfully configured the AX5043 transceiver to transmit using the STM32H7. But, we were unable to demodulate the transmitted signal.



Using the RTLSDRv4 and GQRX, we confirmed real-time RF output and verified that the AX5043 was indeed transmitting energy at the correct frequency. Once the signal was verified in the spectrum view, we recorded the signal in raw and .wav formats.



If we take the time it took to transmit the signal (0.200 seconds) and divide the time by the amount of bytes sent (238 bytes), we get an estimated data rate of 9520bps. This is expected because the configuration of our AX5043 transmitter should deliver a ~9600bps data rate, but this is only an estimate because we were unable to demodulate the signal after recording with the SDR. Because we were unable to demodulate our signal, our data rate test failed, and we need to take measures in the future to make sure we are able to transmit properly.

2.6 So What?

1. The point of the test was to confirm the modulation and measure the data rate such that our measured data rate is greater than our minimum required rate.
2. Because our test failed, we need to spend more time testing with this transceiver to see if we are able to get our minimum required data rate consistently.
3. If we are unable to reach our minimum spec consistently with this transceiver, and if the instability of the transceiver is too great a problem, we will need to consider alternative options and look into replacing the transceiver.

3. PoC Test 2 (Documented) - Battery Endurance > 2 Sols

Risk Addressed: Risk 1 - Battery Endurance

3.1 Objective

To test the longevity of the batteries under load for an extended period of time. Characterize and understand the discharge curve in order to determine if our battery life will last longer than ~50 hours.

3.2 Test Setup

For the procedure, we first began by estimating our average current based off of duty cycle. For this estimation we took into account all relevant inefficiencies. This current came out to be **95mA**

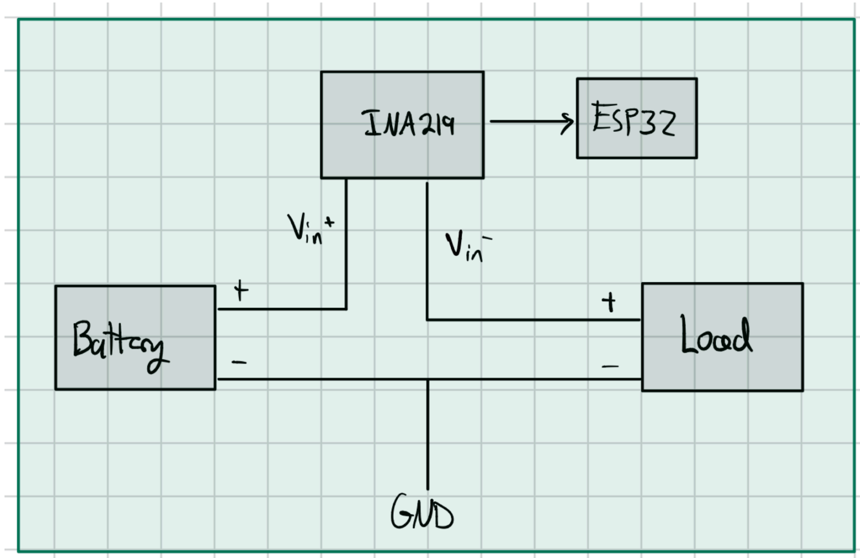
POWER (W)	W		POWER/DUTY CYCLE	AVERAGE POWER
P_3.3	4.001		P_3.3 with D_cycle	0.5848333333
P__5	3.575		P_5 with D_cycle	0.02482638889
P_12	10.992		P_12 with D_cycle	0.2912666667
P_tot	18.568			
P_tot with losses	20.73559862		P_tot with loss & D_cycle	1.129932084

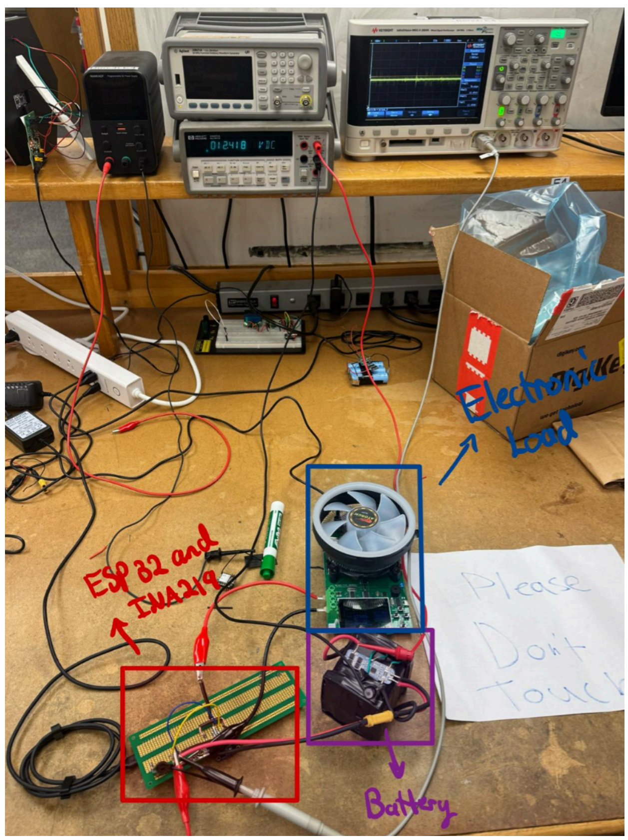
CURRENT	I		CURRENT/DUTY CYCLE	AVERAGE CURRENT
Current with losses	1.727966551		Current with loss & D_cycle	0.09416100698

Once we have obtained average current draw estimate we setup a test in the following manner:

1. Ensure battery pack is fully charged ~12.6v
2. Connect battery to a load that draws a stable current at ~100mA
3. Gather data of the battery voltage decreasing over time
4. Plot the voltage versus capacity and observe

In order to accurately measure the current, voltage, and duration of the test, we sought to automate the test by using an electronic load connected to the battery with an INA219 current sensor in series. The IOT sensor was then read by an ESP32, which then uploaded the data to Thingspeak. The schematic and setup can be seen below.

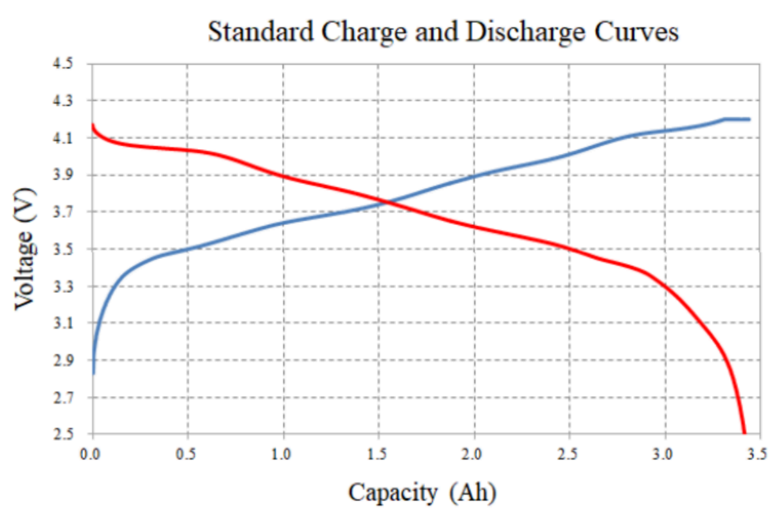

INA219
ESP32
V_{in}^+
V_{in}^-
Battery
Load
GND


Electronic Load
ESP32 and INA219
Battery
Please Don't Touch

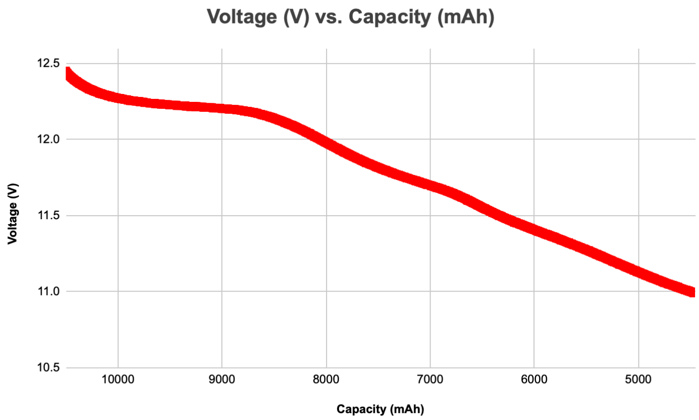
3.3 Procedure and Results

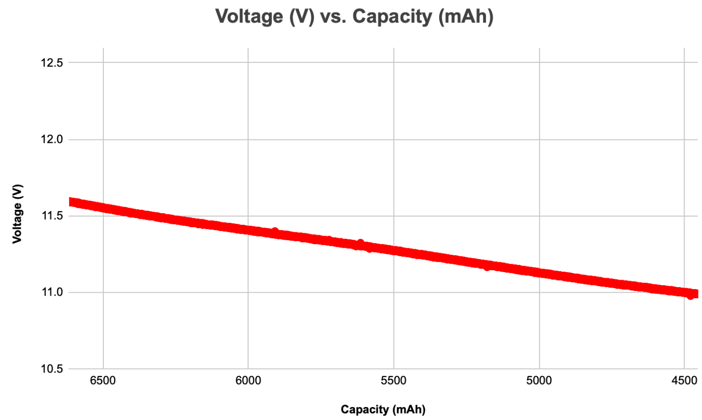
The goal of this PoC experiment was to reduce the risk that our battery pack would not meet the "> 2 Martian Sols of operation" requirement. Rather than guessing from the datasheets, we built a dedicated measurement setup to characterize how our 3S3P Li-ion pack behaves under load and how its terminal voltage varies as a function of delivered capacity and state of charge (SoC).

Our expectations for what the Voltage-vs-Capacity curve should look like come directly from the EVE 18650 datasheet. **Plot 1** in the datasheet provides the standard discharge characteristic for a single Li-ion cell, showing the gradual voltage decline, long mid-range plateau, and the steep end-of-discharge "knee." By referencing this manufacturer curve, we established a baseline prediction of how our own 3S3P battery pack would behave under load. The datasheet curve therefore serves as the theoretical reference against which we compared our measured discharge results in the subsequent plots.



EVE 18650 Datasheet Plot 1: Voltage Discharge vs Capacity (V) (Red)





Plot 2: Voltage (V) vs. Capacity (mAh)

Plot 3: Voltage (V) vs. Capacity (mAh) Zoomed in

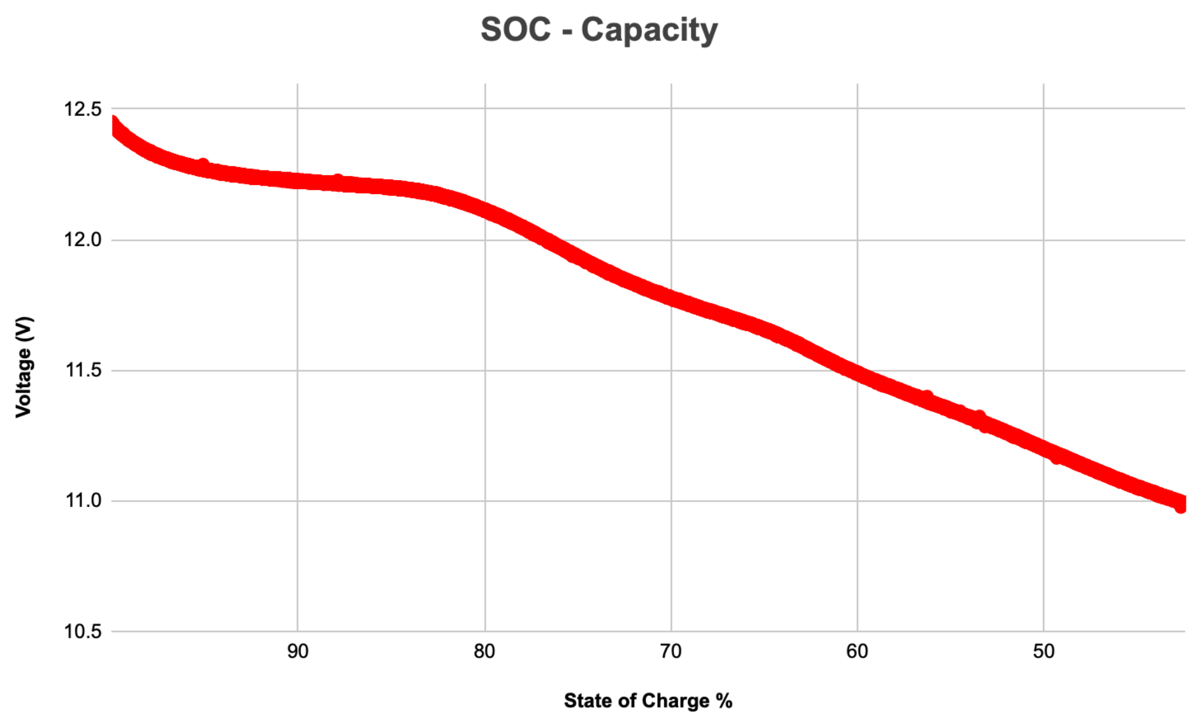
What the plot 1, 2 shows:

This plot represents the discharge curve of our 3S3P Li-ion battery pack, where terminal voltage is plotted against the cumulative delivered capacity measured during the PoC discharge test. The Horizontal axis increases as the battery delivers current over time, and the vertical axis shows the real-time voltage recorded by the INA219 voltage sensor.

Technical interpretation:

At the beginning of the discharge, the voltage is at its fully charged level (12.470 V).
Very quickly, the voltage settles into the primary Li-ion discharge plateau, showing a slow and steady decrease as more capacity is drawn.
This plateau region is crucial because it corresponds to the majority of the battery's usable energy, where voltage remains relatively stable while the pack delivers constant current.

As capacity approaches roughly 50-60% of its usable range, the voltage begins to curve downward more noticeably, that is because we didn't fully discharge the entire capacity yet. We have been running this battery test for 60 hours straight and we still have not reached the discharge cutoff.



Plot 4: Voltage V vs. State of Charge %

From Plot 3, The plot maps the measured battery voltage to its state of charge SoC, computed by integrating the real current over time and normalizing the capacity.

Technical Interpretation:

At high SoC levels (100-85%), the curve is very flat, voltage changes very little even though capacity is being consumed. This is normal for li-ion cells.

In the mid range - SoC (85 - 60 %), voltage begins to decline more noticeably. This region corresponds to the middle portion of the capacity where the system will operate for the longest duration.

Below 60% SoC, the pack slowly approaches the Li-ion “knee” where voltage becomes more sensitive to remaining capacity.

The tail end shows the steeper slope where a small decrease in SoC produces large voltage drop. This is where the cutoff voltage must be chosen carefully to avoid overdischarge.

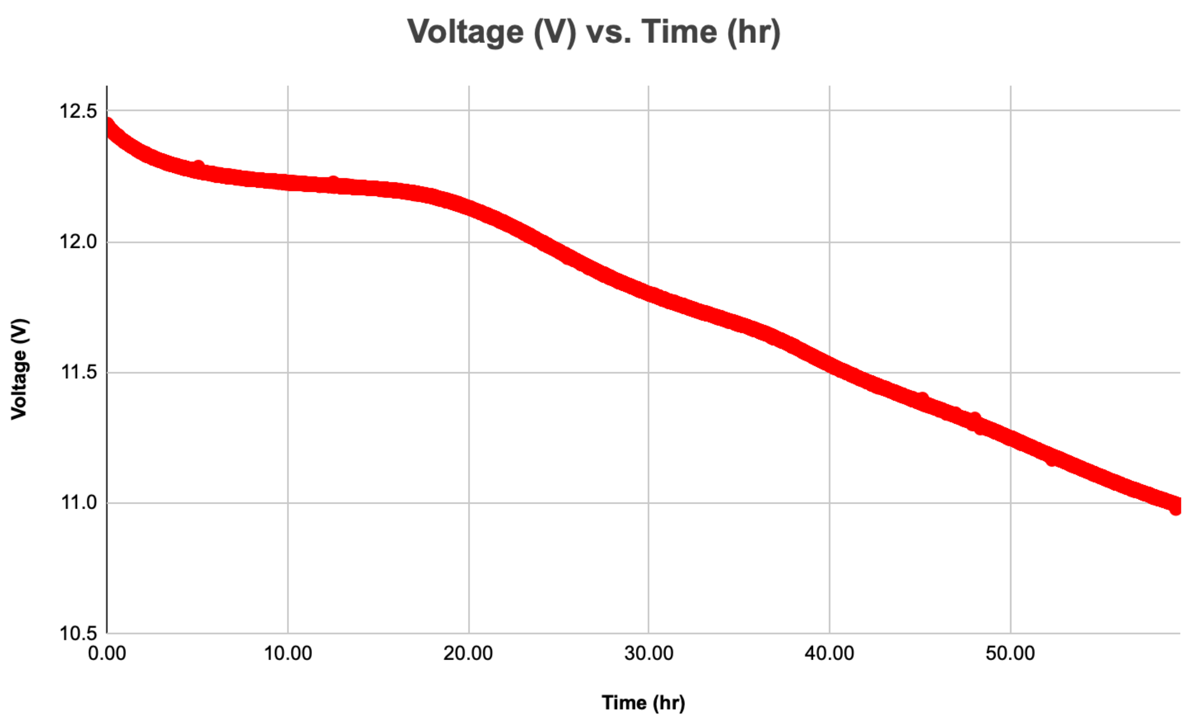
Why this plot matters:

This SoC voltage curve acts as a calibration map for future on system SoC estimation. Because we performed a full discharge experiment with a real mission-like current draw, this empirical curve is more accurate than datasheet estimates. This allows us to later estimate remaining runtime using only measured pack voltage, without needing a dedicated fuel gauge IC.

3.4 So What?

What was the point of this test? The point of this test is to prove that:

1. Our system battery pack can comfortably last 2 Sols, and hit the 50 hour mark.
2. Our test is not yet concluded and still ongoing, we have proved that our battery has lasted at least 50 hours, therefore, we will continue to use this battery design moving forward, unless some other vital reason arises.



Plot 5: Voltage (V) vs. Time (hr)