This document explains the function of the Battery Charger, its schematic level design, and its board level design.

Battery Charger

Battery Charger Design

Revision: 1.0.0

Zachary Harrington

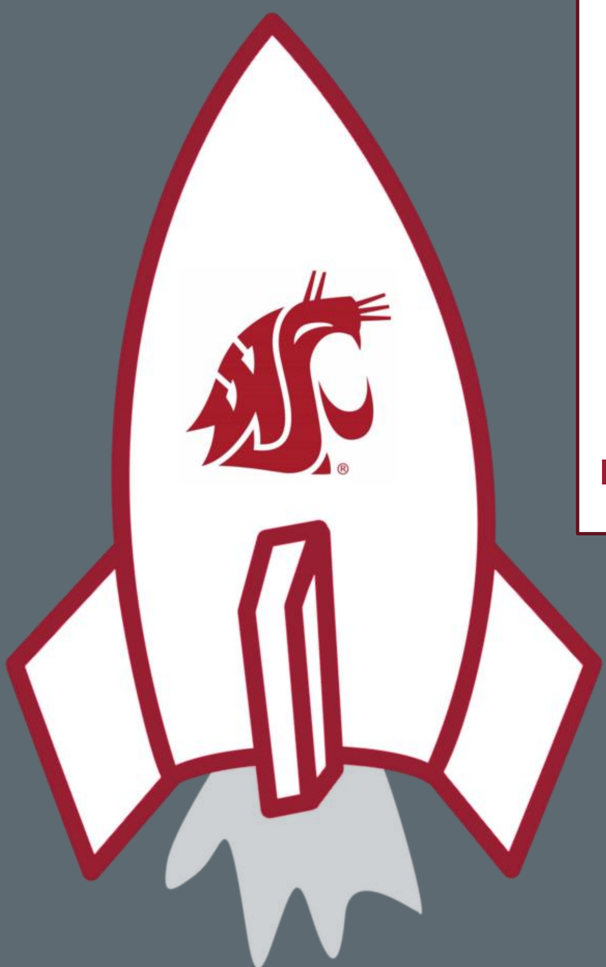

Table of Contents

1 Introduction

This document explains how the Battery Charger will fulfill the following Functions and conform to the following Requirements. This document refers to the Battery Charger version 1.0.

1.1 Functions

The Battery Charger is responsible for the following:

- Charging up to three batteries on Earth
- Monitoring the charge status of each battery

1.2 Requirements

1. Provide 4.2V 1.6A battery charging to up to three batteries in any order
2. Provide temperature and charge monitoring for each battery

2 Detailed Description

This section refers to the Battery Charger schematic. Page numbers will be listed and may have coordinates listed (number and letter combination found around the frame).

2.1 Functional Block Diagram

This section explains the high-level workings of the Battery Charger. The block diagram can be found on the first page of the schematic.

2.1.1 Battery Charger

The charger IC regulates charging sourced from a 5V 3A wall adapter and charges lithium-ion batteries to 4.2V.

2.1.2 Switching

Three ideal diodes control the flow of charge based on the charge status of each connected battery. The battery with the lowest voltage receives all the charging current until it is equal in voltage to another battery. Charging current is then split proportionally between all batteries of equal voltage, with higher charging currents being sent to batteries with higher capacities[1].

2.1.3 Batteries

Each battery is connected to a protection IC that protects against the following faults:

- Overcharge
- Over-discharge
- Charge overcurrent
- Discharge overcurrent
- Load short-circuit

The PENIC also monitors temperature through a thermistor next to each battery.

2.1.4 USB to UART

The USB to UART IC is powered externally by the connected USB device. It provides USB to serial UART conversion to program and communicate with the PENIC.

2.1.5 PENIC

The Performance and Error Notification IC (PENIC) is the microprocessor monitoring the status of the Battery Charger. The PENIC controls three programmable LEDs for visual feedback on the current charge status of each battery. Individual I/O pins read the status of the charger IC, each ideal diode,

[1] LTC4411 (Page 7)

and each thermistor. Charge is cancelled for temperature faults through a direct connection to the charger IC.

A 3.3V 1A linear regulator steps down the 5V input to power the PENIC and all 3.3V references. All unused I/Os on the PENIC also connect to pins headers allowing for additional external sensors and components be monitored or ran by the PENIC. Four pin headers also connect to ground, 3.3V, and 5V to power external components. Each voltage rail supports a combined maximum of 0.5A. This maximum is not regulated and only defined by the available current not in use.

2.1.6 Programmable LEDs

Three programmable LEDs display the current charge status of each battery. The color of each LED is defined by the PENIC and reflects the status of the respective battery[2].

2.1.7 External Control

Five physical switches serve as charge toggles. Three correspond to the three batteries, and two operate in unison to activate the charger itself. The PENIC is always active when connected to power and cannot be physically switched off.

2.2 Schematic

This section explains the chosen circuit implementations and notable changes. The schematic drawings are found on pages two through five of the schematic.

2.2.1 Battery Charger

The battery charger is implemented using the BQ24650[3] battery charger IC (page 2, C2). This IC is designed with Maximum Power Point Tracking (MPPT), for use in variable voltage systems such as solar powered charging situations. It is implemented in this constant voltage system to gain experience designing with it and because the chips are already on-hand.

The battery charger sources power from the 5V 3A connector. At this input voltage the charger has an efficiency of between 80 and 90%.

Unless otherwise stated, the typical application layout from the BQ24650 IC documentation is used in this design. Notable changes are detailed below.

No single thermistor is used in this design because of the presence of three batteries. Rather, three thermistors are independently monitored by the PENIC, which is directly connected to the TS pin. During charging the TS pin voltage is kept between 2.43V and 1.485V, the high and low thresholds. In the event of a temperature fault, the TS pin is set to ground, 0V, and charge is cancelled

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[2] LED truth table
[3] BQ24650

until the TS pin is released or set to a voltage between 2.43V and 1.57V. Even with this protection, it is still recommended to not leave the batteries charging for long periods of time.

The output capacitance is the same, but on the schematic one of the capacitors can be seen moved slightly (page 2, C6) from the spot on the typical application (page 2, C5). Because it is connected to the same node, this has no net effect on the circuit and simply fits better on the schematic.

The inductor value is chosen to be $10\mu\text{H}$ to keep the LC resonant frequency between the recommended 12kHz to 17kHz, where the best stability occurs, as seen below:

$$f_o = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{10\mu H * 14.7\mu F}} = 13.1kHz \quad (1)$$

The sense resistor is chosen to be $25\text{m}\Omega$ to facilitate a charge current of 1.6A as seen below:

$$I_{charge} = \frac{40mV}{R_{SR}} = \frac{40mV}{25m\Omega} = 1.6\text{A} \quad (2)$$

This current satisfies the maximum charge current of 1.625A required by the NCR168650B[4] lithium-ion batteries that this charger is designed for. When more than one battery is being charged, a current less than this per battery is still acceptable.

The voltage divider between the output and VFB pin sets the max output voltage to 4.2V using $10\text{k}\Omega$ resistors as seen below:

$$V_{bat} = 2.1V * \left[1 + \frac{R_2}{R_1}\right] = 2.1V * \left[1 + \frac{10k\Omega}{10k\Omega}\right] = 4.2\text{V} \quad (3)$$

0Ω resistors are added to this voltage divider in the event extra precision or different values is needed.

One of the external control switches replaces the Charge Enable (CE) MOSFET from MPPSET to ground. When not actively switched to ground, MPPSET is held near 1.5V by the voltage divider, allowing the power to be unlimited. Any voltage over 1.2V effectively turns off MPPT, which is not needed in this constant voltage system.

D1 is implemented with a LTC4411[5] ideal diode and serves as a redundancy to protect against reverse current from the batteries. It also is used for its control and status pins allowing the charge status to be monitored and controlled. In

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[4] NCR168650B
[5] LTC4411

this case the control pin is connected to another external control switch and serves as an ON/OFF switch for the charger.

2.2.2 Charge Switching

Switching is implemented using three LTC4411 ideal diodes (page 3, col 2). These diodes are connected in a parallel type of connection where any ratio of charge current can be passed to the three batteries. When any one battery has less voltage, and thus less charge than the rest, only that diode is biased and all the charging current flows to that battery. When instead multiple batteries have similar voltages, the corresponding diodes are all biased and the total charge current is split.

Input and output capacitors are added to each diode to reduce noise. While the input capacitors could be substituted with just one, given the nature of the high frequency switching in the charger IC and the possibility of the diodes not being in a central place on the board, one per diode is used.

A $475\mathrm{k}\Omega$ equivalent resistance is connected from each status pin to $3.3\mathrm{V}$ so that the PENIC pin reads high when the diode is conducting, and thus the corresponding battery is charging. This resistance is considered to be an acceptable equivalent to the $470\mathrm{k}\Omega$ resistance recommended by the diode datasheet. It is also created from components already on-hand.

2.2.3 Protection Circuits

Individual protection circuits for each battery are implemented using the BQ27900[6] protection IC (page 4, A5, B5, & D3). While the charger IC contains protection circuits, the nature of switching between multiple batteries creates a need for individual protection ICs.

Unless otherwise stated, the typical application layout from the BQ29700 IC documentation is used in this design. Notable changes are detailed below.

The recommended $5\mathrm{M}\Omega$ resistors from COUT to ground and DOUT to VSS are implemented with $4.75\mathrm{M}\Omega$ resistors. This is considered to be an acceptable resistance and the resistors are already on-hand.

2.2.4 USB to UART

A USB to UART serial data converter is implemented using the CP2102N[7] IC (page 4, B3). This eliminates the need for an external converter to program the PENIC and creates a more user-friendly experience.

The IC sources power and programming data through the micro-USB cable connecter. This ensures the IC is powered only while data transfer is in

[6] BQ27900
[7] CP2102N

progress. The use of a micro-USB connector helps differentiate between power and programming connections and matches with the current standard.

The CP2102N is capable of more than just USB to UART data conversion and thus no typical application was followed. Instead, unless otherwise stated, the diagram from PCB ARTISTS[8] was used in this design. Notable changes are detailed below.

The 28-pin variant of the CP2102N is used for the TXT and RXT pins, which allow LEDs to be connected to visually display the TXD and RXD serial data transmission. $10\text{k}\Omega$ resistors connect to each LED for similar brightness levels throughout the circuit.

An additional $4.7\mu\text{F}$ capacitor is added to the VDD pin as recommended by the datasheet.

As recommended, a 1ms RC time constant is added to the EN, and thus reset, pin. This is achieved using a $10\text{k}\Omega$ resistor and 100nF capacitor (page 5, B2). The time constant ensures the IO0 pin has time to register LOW before the PENIC is toggled back on, telling it to boot in programming mode.

2.2.5 PENIC and 3.3V Voltage Regulation

The Performance and Error Notification IC (PENIC) is an ESP32-S2-MINI-1[9] microprocessor (page 5, C4). It was chosen for its low cost, integrated WI-FI antenna, and club members familiarity with programming it.

The IC sources power through the LD1117A[10] (page 5, A1), a 3.3V 1A linear regulator which itself sources power through the 5V 3A connector. All I/O pins thus have a voltage level of 3.3V and any inputs must be stepped down to this.

The schematic application layout from the LD1117A datasheet is used in this design for 3.3V voltage regulation.

The peripheral schematics layout from the ESP32 documentation is used in this design for the RESET button, input voltage capacitors, and RC time constant discussed in the USB to UART section. Otherwise, all I/O pins are directly connected to their respective components, and a $10\text{k}\Omega$ volage divider (page 5, C2) is used to read the thermistor data.

The NTCS0603E3T[11] thermistor used has a room temperature resistance of $10\text{k}\Omega$, and a $B_{25/85}$ value of 3960K. When the thermistor equation (4) is rearranged (5) the resistance at $85°\text{C}$ is found to be $1.08\text{k}\Omega$.

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[8] PCB ARTISTS diagram
[9] ESP32-S2-MINI-1
[10] LD1117A
[11] NTCS0603E3T

$$B_{T1/T2} = \left[\frac{T_2 * T_1}{T_2 - T_1}\right] * \ln\left(\frac{R_1}{R_2}\right) \tag{4}$$

$$R_2 = R_1 / e^{\left(B_{T1/T2} / \frac{T_2 * T_1}{T_2 - T_1}\right)} \tag{5}$$

Temperatures in this equation are in Kelvin, though the B value may be denoted by the Celsius values. From these two values, an equation for the resistance of the thermistor vs. temperature can be obtained.

$$R = -148.65 * T(°C) + 13716.4\Omega \tag{6}$$

The batteries are rated between $10°C$ and $45°C$ during charging, making the acceptable voltage divider voltage range between $1.36V$ and $1.81V$.

2.2.6 Programmable LEDs

Three programmable LEDs are implemented using SK6812[12] LEDs (page 5, A6 & B6). These LEDs require a $5V$ voltage level, and thus a bi-directional MOSFET level shifter[13] (page5, A5) is implemented to step up the signal from the $3.3V$ ESP32 pin.

Without getting to detailed, see Electronics Hub[14] for a full explanation, this level shifter circuit is implemented with a n-channel MOSFET containing a drain-substrate diode to ensure proper operation. Although this is not strictly necessary for this application of shifting to a higher voltage, it is still good practice and the NMOS is on-hand.

The typical application layout from the SK6812 datasheet is used in this design. Programming specifications are also located in the datasheet.

2.2.7 Isolated Grounds

Three isolated grounds are used on this schematic. Power ground (PGND) is directly connected to the $5V$ $3A$ USB-C power connector ground. The other grounds are shorted to PGND through 0Ω resistors rated up to $2A$. Digital ground (DGND) connects to the CP2102N circuitry and the micro-USB connector. Chassis ground (CHASSIS) is connected to the mechanical features including the shields of the connectors.

2.2.8 Connectors

There are three connectors, ways to add electrical input, on this device. Two are the $5V$ $3A$ USB-C power connector, and micro-USB programming connector. The other is the breakout pin headers for the PENIC (page 5, C2 & C5). All unused I/O pins are connected to a respective pin header in the event further

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12 SK6812
13 Hackaday - level shifters
14 Electronics Hub – level shifters

monitoring or devices are added. Additionally, two PGND headers, a 3.3V 0.5A header, and a 5V 0.5A header are implemented to power these devices.

2.2.9 External Control

The five control switches were implemented with large DPDT switches. This choice is simply for aesthetic and ergonomic reasons.

2.3 Board

This section explains the chosen board layout and notable changes. The board layout is found in the Eagle board file. The board shall be double layered with 1 oz copper and ENIG finish. The board has no dimension constraints and is 165mm x 75mm.

2.3.1 Layout Constraints

Unless specified in the following subsections, all signals shall use the default parameters below. Signals in the following subsections do not include their sense signals unless otherwise specified. Trace width can be broken if a trace needs to bottleneck down to a pin, the bottleneck shall be minimized.

Trace width:	0.17mm
Vias:	∅0.35mm, unlimited count
Separation:	0.17mm
Length:	unlimited

Devices with specific placement and routing considerations are called out on the schematic, see "CAD Note:"

2.3.1.1 Charger Power Traces - 5.0V, D1_OUT, BQ24650_[PH, SR_P], CHARGER, D[3:5]_OUT, BQ29700[1:3]_VSS, PGND

5.0V applies to between the input connector and input diode. BQ24650_PH applies to between the switching MOSFETs and inductor. BQ24650_SR_P applies to between the inductor and sense resistors. CHARGER applies to between the sense resistors and switching diodes. PGND applies to between the input diode and the three protection circuit MOSFETs.

Trace Width:	0.78mm

2.3.1.2 Pin Header Power Traces - 5.0V, PGND

5.0V applies to between the input diode, 3.3V regulator, and pin header. PGND applies to between the input connector and pin headers.

Trace width:	0.621mm

2.3.1.3 USB Differential Pair - D+, D-

Length:	Length match ±1.0mm
Gap width:	0.375mm

2.3.1.4 3.3V Regulator – 3.3V, PGND
3.3V applies to between the 3.3V regulator, pin header, and ESP32. PGND applies to between the 3.3V regulator and ESP32.

Trace width: 0.391mm

2.3.2 Battery Charger
The layout guidelines from the BQ24650 charger IC datasheet are followed in this design.

2.3.3 External Control
The external control switches are all placed next to each other for aesthetic and ease of use purposes. Although they are far from what they are controlling, since they are simply DC components, any noise or interference picked up on the traces isn't an issue.

2.3.4 DRC
Unless otherwise specified, all design rules checked by the DRC command were followed. Four clearance errors were approved for overlapping pads on the inductor footprint. Ten dimension errors were approved for the connectors needing to be in close proximity to the board edge. Four width errors were approved for the signature footprint.

3 Testing

All tests shall be performed at room temperature and will not be performed under vacuum since the battery charger PCB will not be included on the actual satellite. If any modifications are performed, take note. Include enough information to understand circuit behavior and for others to replicate the results. Include any software written to execute the test and link it to the test notes section. Save all software, waveforms, etc. in a subfolder of the board's test folder for each test. When testing, keep the following guidelines in mind:

- Waveforms shall be captured whenever appropriate
- Have the event take fill the screen (for fast events, zoom in, for slow events, zoom out)
- Label each channel accurately
- Only have bandwidth limiting if necessary for the test (this applies to the oscilloscope and probe settings)
- If ringing or overshoot occurs, use a ground spring or differential probe

Common test instructions can be found on the wiki.

3.1 Before First Power-On Check

Configuration: Battery Charger V1.0.0

This test is required to be executed before batteries are attached and before any external power is applied to the Battery Charger.

3.1.1 Test Instructions

Measure the resistance of various points in reference to PGND located at test point 13 (TP13).

3.1.2 Test Data

The data for this test will be recorded into the table below.

Node	Resistance		Node	Resistance
5.0V (TP1)			TEMP_B (TP8)	
CHARGER (TP2)			TEMP_C (TP9)	
TS-ESP (TP3)			USB_VDD (TP10)	
D3_OUT (TP4)			CP2102N_VDD (TP11)	
D4_OUT (TP5)			3.3V (TP12)	
D5_OUT (TP6)			PGND (TP13)	N/A
TEMP_A (TP7)			D1_OUT (TP14)	

3.2 3.3V Regulator

Results: Pass/Fail

Configuration: Battery Charger V1.0.0

This test evaluates the circuit described in PENIC and 3.3V Voltage Regulation.

3.2.1 Test Instructions

Connect a $5V$ $3A$ USB-C wall adapter to the board with all switches off.

3.2.2 Test Data

Measure the voltage at the 3.3V test point (TP12)		
Voltage	Passing Criteria	Pass / Fail
	$3.432V < V < 3.168V$	

3.3 Charging Voltage

Results: Pass/Fail
Configuration: Battery Charger V1.0.0

This test evaluates the circuit described in Battery Charger.

3.3.1 Test Instructions

Connect a $5V$ $3A$ USB-C wall adapter to the board with all switches on. Apply various loads to the output and then measure the output voltage at the output connector.

3.3.2 Test Data

Voltage should be measured at the charger test point (TP2)			
Load	Voltage	Passing Criteria	Pass / Fail
No load		$4.1V < V < 4.2V$	
500mA		$4.1V < V < 4.2V$	

3.4 Charging Current

Results: Pass/Fail
Configuration: Battery Charger V1.0.0

This test evaluates the circuit described in Battery Charger.

3.4.1 Test Instructions

Apply an increasing load to the output until the current no longer increases.

3.4.2 Test Data

Measure the current at one of the battery connectors		
Max current	Passing Criteria	Pass / Fail
	$1500mA < I < 1625mA$	

3.5 Battery Insertion

Results: Pass/Fail
Configuration: Battery Charger V1.0.0

This test evaluates the circuit described in Charge Switching.

3.5.1 Test Instructions

Charge or discharge a battery to $3.7\mathrm{V}$ before this test. Turn off all switches so no charge is flowing. Insert the battery into each connector and measure the voltage at the charger test point (TP2).

3.5.2 Test Data

Voltage should be measured at the charger test point (TP2)			
Battery	Voltage	Passing Criteria	Pass / Fail
A		$V < 100\mathrm{m}V$	
B		$V < 100\mathrm{m}V$	
C		$V < 100\mathrm{m}V$	

3.6 Battery Charging

Results: Pass/Fail
Configuration: Battery Charger V1.0.0

This test evaluates the circuit described in Battery Charger.

3.6.1 Test Instructions

Charge or discharge the batteries to $3.7\mathrm{V}$ before this test. Connect a $5\mathrm{V}\ 3\mathrm{A}$ USB-C wall adapter to the board with all switches on. Insert all batteries and measure the change in voltage after $30\ \mathrm{minutes}$ to validate all batteries are charging.

3.6.2 Test Data

Measure the change in voltage after $30\ minutes$					
Battery	Initial Voltage	Final Voltage	ΔV	Passing Criteria	Pass / Fail
A				$\Delta V > 20mV$	
B				$\Delta V > 20mV$	
C				$\Delta V > 20mV$	

3.7 External Control

Results: Pass/Fail
Configuration: Battery Charger V1.0.0

This test evaluates the circuit described in External Control.

3.7.1 Test Instructions

Charge or discharge the batteries to $3.7V$ before this test. Connect a $5V$ $3A$ USB-C wall adapter to the board with all switches on. Insert all batteries and measure the change in voltage in 30-minute intervals. For each interval only use one of the following configurations.

- Only Batt A On
- Only Batt B On
- Only Batt C On
- Batt A and B On
- Batt B and C On
- Batt C and A On

3.7.2 Test Data

Measure the change in voltage every $30\ minutes$					
Battery Configuration	Initial Voltage	Final Voltage	ΔV	Passing Criteria	Pass / Fail
A				$\Delta V > 20mV$	
B				$\Delta V > 20mV$	
C				$\Delta V > 20mV$	
A, B				$\Delta V > 20mV$	
B, C				$\Delta V > 20mV$	
C, A				$\Delta V > 20mV$	

3.8 Charge Switching

Results: Pass/Fail
Configuration: Battery Charger V1.0.0

This test evaluates the circuit described in Charge Switching.

3.8.1 Test Instructions

Charge or discharge the batteries to $3.7V$, $3.6V$, and $3.5V$ respectively before this test. Connect a $5V$ $3A$ USB-C wall adapter to the board with all switches on. Insert all batteries and measure the change in voltage in 30-minute intervals. Validate only the batteries at the lowest voltage are charging at any given point.

3.8.2 Test Data

Measure the voltages every $30\ minutes$					
Duration	Batt A Voltage	Batt B Voltage	Batt C Voltage	Passing Criteria	Pass / Fail
30 minutes				Only lowest charging	
60 minutes				Only lowest charging	
90 minutes				Only lowest charging	

3.9 Battery Protection

Results: Pass/Fail
Configuration: Battery Charger V1.0.0

This test evaluates the circuit described in Protection Circuits.

3.9.1 Overcharge

3.9.1.1 Test Instructions

Charge or discharge the batteries to $4.1V$ before this test. For each battery, apply a $4.1V$ $100mA$ source to the input while increasing voltage until COUT transitions low. Remove the source and apply a 20Ω resistive load until COUT transitions high again. Measure the battery voltage, COUT, and DOUT. Ensure the external control switches are configured to the correct battery.

Note: The overvoltage protection delay is typically 1.25s

3.9.1.2 Test Data

Apply a $4.1V, 100mA$ source to the umbilical input with an increasing voltage until COUT transitions low				
Battery	Capture battery voltage, COUT, DOUT	Trigger Voltage	Passing Criteria	Pass / Fail
A			$4.265V < V < 4.285V$	
B			$4.265V < V < 4.285V$	
C			$4.265V < V < 4.285V$	

During overvoltage protection, apply a 20Ω resistive load until COUT transitions high				
Battery	Capture battery voltage, COUT, DOUT	Trigger Voltage	Passing Criteria	Pass / Fail
A			$4.145V < V < 4.205V$	
B			$4.145V < V < 4.205V$	
C			$4.145V < V < 4.205V$	

3.9.2 Over-discharge

3.9.2.1 Test Instructions

Charge or discharge the batteries to $3.0V$ before this test. For each battery, apply a 20Ω resistive load to VBATT until DOUT transitions low. Remove the load and apply a $4.1V$ $100mA$ source to the input until DOUT transitions high again. Measure the battery voltage, COUT, and DOUT. Ensure the external control switches are configured to the correct battery.

Note: The undervoltage protection delay is typically 144ms

1.1.1.1 Test Data

Apply a 20Ω resistive load to VBATT until DOUT transitions low				
Battery	Capture battery voltage, COUT, DOUT	Trigger Voltage	Passing Criteria	Pass / Fail
A			$2.75V < V < 2.85V$	
B			$2.75V < V < 2.85V$	
C			$2.75V < V < 2.85V$	

During undervoltage protection, apply a $4.1V, 100mA$ source to the umbilical input until DOUT transitions high				
Battery	Capture battery voltage, COUT, DOUT	Trigger Voltage	Passing Criteria	Pass / Fail
A			$2.8V < V < 3.0V$	
B			$2.8V < V < 3.0V$	
C			$2.8V < V < 3.0V$	

3.9.3 Charge Overcurrent

3.9.3.1 Test Instructions

Charge or discharge the batteries to $3.7V$ before this test. For each protection circuit, insert the battery apply a $4.1V$ source to the power inputs with increasing current until COUT transitions low. Decrease the current until COUT transitions high again. Measure the battery current, COUT, and DOUT. Ensure the external control switches are configured to the correct battery.

Note: Connect all the power inputs together to share the overcurrent.

3.9.3.2 Test Data

Apply a $4.1V$ source to the power inputs with an increasing current until COUT transitions low				
Battery	Capture battery current, COUT, DOUT	Trigger Current	Passing Criteria	Pass / Fail
A			$3A < I < 5A$	
B			$4A < I < 5A$	
C			$4A < I < 5A$	

Decrease the current from the previous source until COUT transitions low				
Battery	Capture battery current, COUT, DOUT	Trigger Current	Passing Criteria	Pass / Fail
A			$I < 4A$	
B			$I < 4A$	
C			$I < 4A$	

3.9.4 Discharge Overcurrent

3.9.4.1 Test Instructions

Charge or discharge the batteries to $3.7V$ before this test. For each protection circuit, insert the battery and apply an increasing load to VBATT until DOUT transitions low. Decrease the load until DOUT transitions high again.

Measure the battery current, COUT, and DOUT. Ensure the external control switches are configured to the correct battery.

Note: Connect all the power outputs together to share the overcurrent.

3.9.4.2 Test Data

Apply an increasing load to PR_BATT outputs until DOUT transitions low				
Battery	Capture battery current, COUT, DOUT	Trigger Current	Passing Criteria	Pass / Fail
A			$3.5A < I < 5.4A$	
B			$3.5A < I < 5.4A$	
C			$3.5A < I < 5.4A$	

Decrease a high load on PR_BATT outputs until DOUT transitions high				
Battery	Capture battery current, COUT, DOUT	Trigger Current	Passing Criteria	Pass / Fail
A			$I < 3.5A$	
B			$I < 4A$	
C			$I < 3.5A$	
B			$t < 1s$	

3.9.5 Load Short Circuit

3.9.5.1 Test Instructions

Charge or discharge the batteries to $3.7V$ before this test. For each protection circuit, insert the battery and apply a short between VBATT until DOUT. Then remove this short and measure the battery current, COUT, and DOUT. Ensure the external control switches are configured to the correct battery.

3.9.5.2 Test Data

Apply a short between VBATT and PGND				
Battery	Capture battery current, COUT, DOUT	Trigger Delay	Passing Criteria	Pass / Fail
A			$125\mu s < t < 375\mu s$	
B			$125\mu s < t < 375\mu s$	
C			$125\mu s < t < 375\mu s$	

Remove the short between VBATT and PGND				
Battery	Capture battery current, COUT, DOUT	Trigger Delay	Passing Criteria	Pass / Fail
A			$t < 1s$	

3.10 USB to UART Programming

Results: Pass/Fail
Configuration: Battery Charger V1.0.0

This test evaluates the circuit described in USB to UART.

3.10.1 Test Instructions

Connect a $5V$ $3A$ USB-C wall adapter to the board with all switches on. Upload a test code to the PENIC to turn on an LED and communicate information back.

3.10.2 Test Data

Upload code through the USB to UART converter		
Code Uploaded	Passing Criteria	Pass / Fail
	LED turns on	
	Communication achieved	

3.10.3 Test Notes

Replace this text with the test code used.

3.11 Temperature Monitoring

Results: Pass/Fail
Configuration: Battery Charger V1.0.0

This test evaluates the circuit described in PENIC and 3.3V Voltage Regulation.

3.11.1 Test Instructions

Upload a test code to the PENIC to read the temperature from each thermistor voltage divider. Use either serial communication with the PENIC, or the LEDs for visual feedback. Use hot air to validate the voltage changes with temperature.

3.11.2 Test Data

Upload code for reading the thermistor voltages			
Thermistor	Voltage	Passing Criteria	Pass / Fail
A		$1.36V < V < 1.81V$	
B		$1.36V < V < 1.81V$	
C		$1.36V < V < 1.81V$	

3.11.3 Test Notes

Replace this text with the test code used.