SHIELD AI

Nova 2 Battery Pack

Datasheet

4/1/2020

Version History

Implemented By	Release Date	Changes
Alex Fields	5/29/2020	

Table of Contents

1 Overview

1.1 Description

The Nova 2 battery pack utilizes the Texas Instruments BQ40Z50-R3 Fuel Gauge. The purpose of the battery pack is to provide safety protections and power for the Nova 2 robot and collect lifetime statistics on the battery cells. The battery pack consists of 4 main components housed together in a single device:

1. Battery Cells:
    a. Murata US18650VTC6 Lithium Ion batteries configured in 3S3P configuration. These batteries are the power supply for the Nova 2 robot and provide 9Ah of capacity. There are 3 thermistors thermally coupled to the cells, and 4 voltage sense lines kelvin connected to each cell in the stack.
2. Battery Pack board:
    a. This board contains the BQ40Z50-R3 fuel gauge, the MCU that controls the pack, and the circuitry to enable and disable the pack. It also serves as the interface to any device in which the battery pack is inserted. The Ground and Batt+ power rails are soldered directly from the cells to this board.
3. HRI board:
    a. The HRI board contains 8 RGB LEDs (24 LEDs total) and the User Interface pushbutton. It acts as the HRI (Human-Robot-Interface) between Nova 2 and the end user. The user can issue multiple commands based on the length of their button push. The LEDs can give status on battery life, pack mode, charging status, etc.
4. Flex Cable:
    a. The flex cable connects the battery pack board to the HRI board, providing power and communication to the HRI board.

NOTE: Due to parameter limitations of the fuel gauge, the sense resistor used is half the value of the fuel gauge programmed value. Because of this, every data point the fuel gauge reports with regards to current or capacity (mA, mW, mAh, mWh) is half of the actual current or capacity. The settings described below use the “real world” current and capacity values.

1.2 Key Features

The key features of the battery pack are summarized below:

1. Fuel gauge for safety protections, power management, lifetime statistics, etc.
2. Pack output cannot be enabled until it is inserted into a known Nova 2 device.
3. Facilitate human-robot interface with the quad, charger, and backpack.
4. When the battery is placed in the charger or a quad with an alternate power supply, the pack output is enabled without waiting for a button press.
5. When the battery pack is connected to an unpowered Nova 2, it detects the insertion, identifies the Nova 2 bot, powers it, and allows Nova 2 to auto-boot without the need for a button press.
6. Deep sleep shipping mode for ultra low self power consumption. Exits deep sleep when mated to a charger
7. Sleep mode when disconnected from Nova 2 device for low self power consumption
8. Capable of detecting and identifying up to 16 different hosts such as:
    a. Nova 2 1.0
    b. Nova 2 Charger 1.0
    c. Backpack 1.0
    d. Factory Nova 2 1.0
    e. Nova 2 Factory charger 1.0
9. The fuel gauge and the microcontroller can be updated remotely over I2C when plugged into Nova 2.
10. Facilitates a production test and calibration solution.
11. Exposed interfaces are ESD protected.
12. Conformally coated PCB.
13. Permanent failure is enabled for extreme operating points (like cell undervoltage).
14. Contains a button board with 8 RGB LEDs and an I2C controllable LED driver.

2 Specifications

NOTE: Charging currents are taken to be positive and discharge currents are taken to be negative.

2.1 Electrical Characteristics

This section provides the electrical characteristics of the individual battery cells.

Parameter	Description	Typ	Units
Battery Type	Individual battery cell description	US18650VTC6	-
Battery Manufacturer	The manufacturer of the individual cells	Murata	-

Battery Chemistry	Chemistry utilized in the individual cells	$LiMn_2O_4$ (Lithium Manganese Oxide)	-
Pack Capacity	Total capacity of the battery pack (3S3P configuration)	9000	mAh
Pack Energy Capacity	Total energy of the battery pack (3S3P configuration)	97.2	Wh
Pack Capacity @ -30A DSG	Capacity of battery pack @ -30A continuous discharge	8100	mAh
Pack Internal Resistance	Typical internal resistance of the battery pack	18	m**Ω**
~~Pack Energy Density~~	~~Energy density of battery pack, measured in Watt-hours / kilograms~~	~~631~~	~~Wh/l~~
Pack Voltage	Nominal voltage of battery pack (3S3P configuration)	10.8	V

2.2 Nominal Performance Characteristics

This section details the expected performance characteristics of the pack under typical use cases.

The characteristics related to charging assume the Nova 2 battery pack is being charged by either the Nova 2 robot connected to a USBC adapter, or the Nova 2 tabletop charger.

The characteristics related to discharge assume the pack is supplying power to a Nova 2 robot during a typical flight mission.

Parameter	Description	Typ	Units
Charging			
Fully Charged Voltage, V_{Pak}	Pack input (V_{J4+}-V_{J4-})	12.6	V
Charge Current, I_{CHG} 0°C < $T_{Avg, Cells}$ < 12°C	Charging Current when 0°C < $T_{Avg, Cells}$ < 12°C	3	A
Charge Current, I_{CHG} 12°C < $T_{Avg, Cells}$ < 45°C	Charging Current when 12°C < $T_{Avg, Cells}$ < 45°C	6	A
Charge Current, I_{CHG} 45°C < $T_{Avg, Cells}$ < 60°C	Charging Current when 45°C < $T_{Avg, Cells}$ < 60°C	5	A
Robot Charge Current, I_{RCHG} 0°C < $T_{Avg, Cells}$ < 60°C	Charging Current when charging through Nova 2 when 0°C < $T_{Avg, Cells}$ < 60°C	3	A

Peak Charge Current 1 $I_{CHG,Peak1}$	Peak charging current allowed for a duration of 6 seconds	13	A
Peak Charge Current 2 $I_{CHG,Peak2}$	Peak charging current allowed for a duration of 3 seconds	15	A
Max Temperature in Charge	Temperature above which the pack will disable charging	60	℃
Min Temperature in Charge	Temperature below which the pack will disable charging	0	℃
Charge Time, Nova 2 Charger	Nominal charge time utilizing Nova 2 tabletop charger	1.65	h
Charge Time, Nova 2 Robot	Nominal charge time charging through the robot connected to USBC adapter	3.3	h
Discharging			
Discharge Current, I_{DSG}	Nominal pack discharging current for Nova 2	-30	A
Nominal Power Draw P_{Draw}	Nominal supplied power to Nova 2 during flight	-324	W
Max Sustained Current: 2 minutes $I_{MAX,2m}$	Max current the pack will sustain for 2 minutes	-64	A
UV Auto-land, V_{UVAL}	Pack voltage below which Nova 2 will auto land	7.5	V
UVLO threshold, V_{UVLO}	The single cell voltage below which will disable the pack output until put on a charger	2	V
Max Temperature in Discharge	Temperature above which Nova 2 will auto land	80	℃
Min Temperature in Discharge	Temperature below which the pack will disable discharging	-40	℃

2.3 Recommended Operating Conditions

This section provides the recommended conditions for operation and storage of the battery pack.

Parameter	Description	Min	Max	Units
Operating				
Battery Voltage, V_{Batt}	Battery input (V_{M1}-V_{M2})	7.5	12.6	V
Average Cell Temperature in Discharge, $T_{Avg, DSG}$	Average temperature of the 3 thermistors thermally coupled to each cell in discharge	-20	75	℃

Average Cell Temperature in Charge, $T_{Avg, CHG}$	Average temperature of the 3 thermistors thermally coupled to each cell in charge	12	45	°C
Time on Charger	Amount of time the pack should remain on the charger after completing a full charge		9	h
Storage				
Long Term Storage SoC	the State of Charge the battery pack should be stored if stored for long periods of time	20	60	%
Recommended Storage Temperature	The ambient temperature the pack should be stored	0	35	°C
Storage Humidity	The humidity of the storage environment for the pack		50	%

2.4 Absolute Maximum Ratings: Safe Operation

These absolute maximum ratings are the voltage, current, and temperature limits above which can result in undefined behavior of the pack, and the potential for safety hazards including, but not limited to, fire. For the safety of the operator, these values should never be exceeded.

Parameter	Description	Min	Max	Units
Battery Input Voltage, V_{Batt}	Battery input (V_{M1}-V_{M2})	6.0[1]	12.75	V
Charging Voltage, V_{Pak}	Pack input (V_{J4+}-V_{J4-})	V_{Batt}[2] -0.3[3]	12.75	V
Pack Charge Current, I_{CHG}	Peak Pack Charging Current		6	A
Average Cell Temperature in Discharge, $T_{Avg, DSG}$	Average temperature of the 3 thermistors thermally coupled to each cell in discharge	-20	80[4]	°C
Average Cell Temperature in Charge, $T_{Avg, CHG}$	Average temperature of the 3 thermistors thermally coupled to each cell in charge	0	60	°C

[1]Nova 2 will Auto Land at pack voltage of 7.5V

[2]If pack output is enabled

(3)If pack output is disabled

(4)Nova 2 will Auto Land when cell temperature reaches 80C

2.5 Absolute Maximum Ratings: Permanent Failure

These absolute maximum ratings are based on the voltage, current, capacity and temperature limits before the fuel gauge permanently disables the pack, specified in greater detail in Section 3.3. They are shown here for quick reference.

Parameter	Description	Min	Max	Units
Battery Input Voltage, V_{Batt}	Battery input (V_{M1}-V_{M2})	5.1	13.5	V
Charging Voltage, V_{Pak}	Pack input (V_{J4+}-V_{J4-})	V_{Batt} (1) -0.3(2)	13.5	V
Pack Charge Current, I_{CHG}	Peak Pack Charging Current		17	A
Average Cell Temperature, T_{Avg}	Average temperature of the 3 thermistors thermally coupled to each cell		91	℃
Capacity Degradation	The fully charged capacity the pack must degrade to before it is considered EOL and permanently disabled	4500		mAh
Voltage Imbalance at Rest	The max difference in rest voltage between the highest and lowest voltage cell	500(3)		mV

(1)If pack output is enabled

(2)If pack output is disabled

(3)Only valid if min cell voltage is > 3500mV

(4)Only valid if min cell voltage is > 3700mV

3 Fuel Gauging

3.1 Settings

This section describes many of the settings the fuel gauge uses to ensure optimal charging & discharging of the battery pack, along with the monitoring of the cells over their lifetime.

NOTE: Due to parameter limitations of the fuel gauge, the sense resistor used is half the value of the fuel gauge programmed value. Because of this, every data point the fuel gauge reports with regards to current or capacity (mA, mW, mAh, mWh) is half of the actual current or capacity. The settings described below use the "real world" current and capacity values.

Parameter	Description	Value	Units
Advanced Charge Algorithm			
Temperature Ranges			
T1 - T2	Low Temperature	0 - 12	°C
T2 - T5	Standard Low Temperature	12 - 20	°C
T5 - T6	Recommended Temperature	20 - 25	°C
T6 - T3	Standard High Temperature	25 - 45	°C
T3 - T4	High Temperature	45 - 60	°C

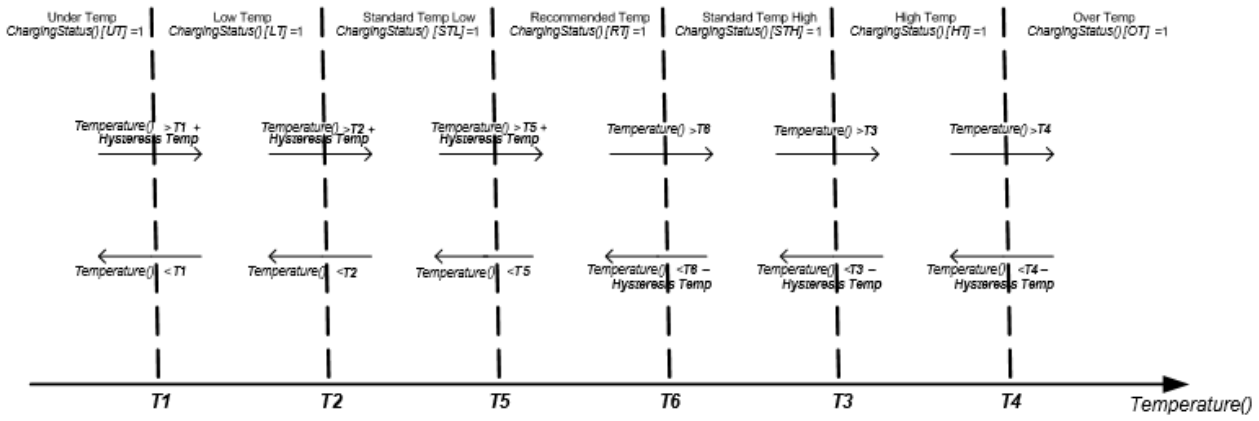

Fig: Graphical Representation of Temperature Ranges

Charging Current/Voltage Requests @ Various Temperatures and SoC			
CC_{LT}	Charging Current: Low Temperature	3	A
[1]CV_{LT}	Charging Voltage: Low Temperature	4200	mV
CC_{SLT}	Charging Current: Standard Low Temperature	6	A
[1]CV_{SLT}	Charging Voltage: Standard Low Temperature	4200	mV
CC_{RT}	Charging Current: Recommended Temperature	6	A
[1]CV_{RT}	Charging Voltage: Recommended Temperature	4200	mV
CC_{SHT}	Charging Current: Standard High Temperature	6	A
[1]CV_{SHT}	Charging Voltage: Standard High Temperature	4200	mV
CC_{HT}	Charging Current: High Temperature	5	A
[1]CV_{HT}	Charging Voltage: High Temperature	4100	mV
PCHG Current	Pre-charging Current	900	mA
PCHG Start Voltage	Voltage above which Pre-charging is enabled	2000	mV
Charge Term Taper Current	Current below which a valid charge termination will occur	300	mA
Charge Term Voltage Offset	4200mV per cell - this value will still result in a valid charge termination	150	mV
Cell Balancing in Charge			
Bal Time/mAh Cell 1	Balance time per mAh imbalance in cell 1	63	s/mAh
Bal Time/mAh Cells 2-3	Balance time per mAh imbalance in cells 2-3	65	s/mAh
Min Start Balance Delta	Minimum cell differential voltage to begin balancing	3	mV
Power			
Shutdown			
[1]Shutdown Voltage	Voltage below which the FG will shutdown to conserve power	1900	mV

PF Shutdown Voltage	Voltage below which the FG will shutdown to avoid a SUV PF	1750	mV
Charger Present Threshold	Voltage on V_{pak} above which will wake the Fuel Gauge from Shutdown mode	3000	mV
Sleep			
Bus Timeout	Time SMBus must be low to enter sleep mode	5	s
Voltage Time	Fuel gauge will wake up from sleep every x seconds to take a voltage measurement	5	s
Current Time	Fuel gauge will wake up from sleep every *x* seconds to take a current measurement	20	s
Ship[2]			
FET Off Time	Time for FETs to turn off after Shutdown command is issued off production line	5	s
Delay	Delay between Shutdown command and the actual device shutting down	10	s
IATA[3]			
Communications			
SBS Configuration			
Remaining AH Cap. Alarm	Alarm flag is set when this much capacity remains	500	mAh
Remaining WH Cap. Alarm	Alarm flag is set with this much capacity (in cWh) remains	432	cWh
Remaining Time Alarm	Alarm flag is set with this much time remaining for the pack (assuming CC)	2	min
Serial Number	Serial number of the pack	0001[4]	-
Manufacturer	Manufacturer of the pack	SAI (subject to change)	-
Manufacture Date	Date of pack manufacture	1/1/1980 (subject to change)	-
Gas Gauging			

Design Capacity	Capacity of the pack in mAh	9000	mAh
Design Voltage	Full stack voltage of the pack	10800	mV
Cycle Count Percentage	DoD % at which a CHG/DSG “Cycle” is counted	90	%
FD Set Voltage Threshold	Fully Discharged cell voltage threshold	2000	mV
FD Clear Voltage Threshold	Cell voltage threshold to clear FD flag	2200	mV
FD Set % RSOC Threshold	RSOC % to set FD flag	0	%
FD Clear % RSOC Threshold	RSOC % to clear FD flag	5	%
FC Set Voltage Threshold	Fully Charged cell voltage threshold	4200	mV
FC Clear Voltage Threshold	Cell voltage threshold to clear FC flag	4100	mV
FC Set % RSOC Threshold	RSOC % to set FC flag	100	%
FC Clear % RSOC Threshold	RSOC % to clear FC flag	95	%
TD Set Voltage Threshold	Terminate Discharge cell voltage threshold	2100	mV
TD Clear Voltage Threshold	Cell voltage threshold to clear TD flag	2200	mV
TD Set % RSOC Threshold	RSOC % to set TD flag	3	%
TD Clear % RSOC Threshold	RSOC % to clear TD flag	5	%
TC Set Voltage Threshold	Terminate Charge cell voltage threshold	4200	mV
TC Clear Voltage Threshold	Cell voltage threshold to clear TC flag	4100	mV
TC Set % RSOC Threshold	RSOC % to set TC flag	100	%
TC Clear % RSOC Threshold	RSOC % to clear TC flag	95	%
Load Mode	Current or Power based gauging	Power	-

Load Select	Type of power gauging	Present Average Discharge Power	-

(1)Per cell
(2)NOTE: Auto ship is disabled. Battery pack manufacturer must place fuel gauge in Shutdown Mode prior to shipping by sending 0x21
(3)NOTE: IATA is disabled in this pack. It is incumbent on the manufacturer that each pack conforms to IATA specifications before shipping (i.e. < 30% SoC)
(4)NOTE: The manufacturer should increment the serial number by 1 each new pack

3.2 Protections

The protections listed below will disable the pack output and are designed to be last resort efforts to protect the cells and robot from damage.

There are multiple algorithmic approaches employed by the battery pack MCU, charger IC, and robot CPU to avoid reaching these drastic limits (e.g. the robot will perform an automatic landing when the pack voltage reaches 7.5V). However, in the case that a protection is tripped, the pack output will be disabled until the recovery conditions are met.

Name	Description	Value	Unit	Justification
Cell Undervoltage (CUV)				
CUV:Threshold	The cell voltage that will disable the pack after *CUV:Delay* seconds	2000	mV	Want a very low value, should rely on flight controller disabling before battery disable
CUV:Delay	The time cell voltage must be < *CUV:Threshold* before disabling the pack	2	s	
CUV: Recovery	The cell voltage needed to re-enable the pack	2500	mV	Cells must be charged a decent amount before re-enabling the pack
Cell Undervoltage Compensated (CUVC)				
CUVC:Threshold	The compensated cell voltage (by taking battery internal resistance*current into account) that will disable the pack after *CUVC:Delay* seconds	2000	mV	See above, compensated for IR voltage drop
CUVC:Delay	The time compensated cell voltage must be < *CUVC:Threshold* before disabling the pack	2	s	
CUVC:Recovery	The cell voltage needed to re-enable the pack	2500	mV	
Cell Overvoltage (COV)(1)				

COV:Threshold Low Temp	The cell overvoltage threshold when: *T1 < pack temperature < T2*	4250	mV	prevent overcharge by capping cell voltage to 50mV above spec
COV:Threshold Standard Low Temp	The cell overvoltage threshold when: *T2 < pack temperature < T5*	4250	mV	
COV:Threshold Standard High Temp	The cell overvoltage threshold when: *T6 < pack temperature < T3*	4250	mV	
COV:Threshold High Temp	The cell overvoltage threshold when: *T3 < pack temperature < T4*	4150	mV	Max cell voltage we charge to in high temperature conditions is 4100, so we keep the 50mV difference
COV:Threshold Rec Temp	The cell overvoltage threshold when: *T5 < pack temperature < T6*	4250	mV	
COV:Delay	The time cell voltage must be > *COV:Threshold *Temperature Range** before disabling the pack	2	s	
COV:Recovery Low Temp	The recovery cell voltage threshold when: *T1 < pack temperature < T2*	4100		want to make sure the cells are fully recovered from overvoltage
COV:Recovery Standard Temp Low	The recovery cell voltage threshold when: *T2 < pack temperature < T5*	4100		
COV:Recovery Standard Temp High	The recovery cell voltage threshold when: *T6 < pack temperature < T3*	4100		
COV:Threshold High Temp	The recovery cell voltage threshold when: *T3 < pack temperature < T4*	4100		
COV:Threshold Rec Temp	The recovery cell voltage threshold when: *T5 < pack temperature < T6*	4100		
Overcurrent in Charge (OCC)				
OCC: Threshold 1	The charging current (sustained for *OCC1 Delay* seconds) threshold to disable the pack	13000	mA	max charging current spec'd for the cells is 4A per cell. so 12A max, thus

				we can allow for short duration currents 0.33A per cell above spec
OCC1: Delay	The time charging current must be > *OCC Threshold 1* to disable the pack	6	s	want to make sure the overcurrent is not sustained for long
OCC: Threshold 2	The charging current threshold (sustained for *OCC2: Delay* seconds) to disable the pack	15000	mA	secondary threshold for shorter duration high current
OCC2: Delay	The time charging current must be > *OCC Threshold 2* to disable the pack	3	s	
OCC Recovery Threshold	The current threshold (sustained for *OCC Recovery Delay* seconds) required to re-enable the pack	-25	mA	need slight discharge current to recover
OCC Recovery Delay	The time *OCC Recovery Threshold* current must be sustained before re-enabling the pack	5	s	
Overcurrent in Discharge (OCD)				
OCD Threshold 1	The discharging current threshold (sustained for *OCD1: Delay* seconds) to disable the pack	-64000	mA	Nova 2 can expect 30-40A continuous currents, and up to 80A peak currents. 64A for 2 minutes protects the hardware without nuisance tripping
OCD1 Delay	The time discharging current must be > *OCD: Threshold 1* to disable the pack	120	s	we shouldn't see 60+A currents sustained for 2+ minutes
OCD Threshold 2	The discharging current threshold (sustained for *OCD2: Delay* seconds) to disable the pack	-65535	mA	
OCD2 Delay	The time discharging current must be > *OCD:Threshold 2* to disable the pack	120	s	
OCD Recovery Threshold	The current threshold (sustained for *OCD Recovery Delay* seconds) required to re-enable the pack	200	mA	need modest charging current to recover
OCD Recovery Delay	Time that current must be > *OCD Recovery Threshold* to re-enable the pack	5	s	
OCD Latch Limit	Counter threshold to latch[(2)]	0	counts	If an OCD event occurs, the DSG FET will latch, and can be recovered by a LOW-HIGH-LOW transition on PRES pin

Overtemperature in Charge (OTC)				
OTC Threshold	The average cell temperature threshold (sustained for *OTC Delay* seconds) during charging above which will disable the pack	60	℃	We have additional protections of charge suspend and charge inhibit at 50C, so this is a last resort protection in charge
OTC Delay	The time the average cell temperature must be > *OTC Threshold* during charging to disable to the pack	2	s	
OTC Recovery	The average cell temperature threshold to re-enable the pack	55	℃	5C hysteresis to re-enable the pack
Over Temperature in Discharge (OTD)				
OTD Threshold	The average cell temperature threshold (sustained for *OTD Delay* seconds) during discharging above which will disable the pack	85	℃	We have additional protections in the Planning and Controls of the robot to safely land in an OT condition, so this is a last resort protection
OTD Delay	The time the average cell temperature must be > *OTD Threshold* during discharging to disable to the pack	2	s	
OTD Recovery	The average cell temperature threshold under which will re-enable the pack	80	℃	5C hysteresis to re-enable the pack
Under Temperature in Charge (UTC)				
UTC Threshold	The average cell temperature threshold (sustained for *UTC Delay* seconds) during charge under which will disable the pack	0	℃	The spec for charging is 0C, so below this temperature we cannot charge the cells
UTC Delay	The time the average cell temperature must be > *UTC Threshold* during discharging to disable to the pack	2	s	
UTC Recovery	The average cell temperature threshold above which will re-enable the pack	5	℃	5C hysteresis to re-enable the pack
Under Temperature in Discharge (UTD)				
UTD Threshold	The average cell temperature threshold (sustained for *UTD Delay* seconds) during discharge under which will disable the pack	-40	℃	There is no safety hazard in discharging the cells at -40C, thus we allow discharge at that temperature
UTD Delay	The time the average cell temperature must be > *UTD Threshold* during	2	s	

	discharging to disable to the pack			
UTD Recovery	The average cell temperature threshold above which will re-enable the pack	-30	℃	
Pre-charge Timeout (PTO)				
PTO Threshold	The pre-charging current threshold to begin the charge timer	800	mA	Precharge current is set to 900mA, so this value is below that
PTO Suspend Threshold	The precharging current threshold under which will suspend the charge timer	700	mA	
PTO Delay	PTO timer must be > *PTO Delay* seconds to inhibit charge	1800	s	We should not be precharging for more than half an hour
PTO Recovery	The precharging current threshold under which will re-enable the pack	2	mAh	
Charge Timeout (CTO)				
CTO Threshold	The charging current threshold to begin the charge timer	1250	mA	We want a reasonable charge current before beginning the timer
CTO Suspend Threshold	The charging current threshold under which will suspend the charge timer	1000	mA	
CTO Delay	CTO timer must be > *CTO Delay* seconds to inhibit charge	21600	s	If charger is taking more than 60 hours something is wrong and the charge should be suspended
CTO Recovery	The charging current threshold under which will re-enable the pack	4	mAh	
Overcharge (OC)				
OC Threshold	The calculated capacity above the max pack capacity to disable charging the pack	450	mAh	Overcharging the pack is a safety concern, and 5% overcharge is a rule of thumb
OC Recovery	The calculated capacity above the max pack capacity to re-enable the pack	2	mAh	
RSOC OC Recovery	The calculated relative state of charge under which the pack will re-enable	90	%	
Charger Overvoltage (CHGV)				
CHGV Threshold	The charger voltage threshold (sustained for *CHGV Delay* seconds) above *ChargingVoltage()* to disable charging the pack	500	mV	We want to ensure we aren’t charging the cells over 4.4V

CHGV Delay	The time the charger output voltage must be > *COV Threshold* + *CHGV Threshold* to disable charging the pack	30	s	
CHGV Recovery	The charger voltage threshold under *COV Threshold* required to re-enable the pack	-500	mV	cells should be discharged to a reasonable value before re-enabling charge
Charger Overcurrent (CHGC)				
CHGC Threshold	The charger current threshold (sustained for *CHGC Delay* seconds) above *ChargingCurrent()* to disable charging the pack	500	mA	We want to prevent overcurrent in the cells, and 167mA per cell is reasonable
CHGV Delay	The time the charger output current must be > *CHGC Threshold* + *ChargingCurrent()* to disable charging the pack	60	s	
CHGV Recovery	The charger current threshold required to re-enable the pack	0	mA	Must be discharging to re-enable the pack
Pre-charger Overcurrent (PCHGC)				
CHGC Threshold	The charger current threshold (sustained for *CHGC Delay* seconds) above *ChargingCurrent()* to disable charging the pack	500	mA	
CHGV Delay	The time the charger output current must be > *CHGC Threshold* + *ChargingCurrent()* to disable charging the pack	60	s	
CHGV Recovery	The charger current threshold required to re-enable the pack	0	mA	
Analog Front End (AFE) Hardware Protections				
Overload in Discharge (AOLD)				
AOLD Latch Limit	Number of AOLD events before latch occurs[(2)]	0	counts	Want to latch immediately after OLD condition
AOLD Counter Decrement Delay	Time after *AOLD Latch Limit* before decrementing number of counts	10	s	
AOLD Recovery	Recovery time after overload event	5	s	
AOLD Reset	Time to reset *AOLD Latch Limit* counter after *AOLD Recovery*	15	s	
AOLD Threshold	Hex value that sets “Over Load” current value and duration	ba	hex	-77.76 mV across 0.5mOhm is -155.52A for 21ms

Short Circuit in Charge (ASCC)				
ASCC Latch Limit	Number of ASCC events before latch occurs[2]	0	counts	Want to latch immediately after SCC condition
ASCC Counter Decrement Delay	Time after *ASCC Latch Limit* before decrementing number of counts	10	s	
ASCC Recovery	Recovery time after short circuit in charge event	5	s	
ASCC Reset	Time to reset *ASCC Latch Limit* counter after *ASCC Recovery*	15	s	
ASCC Threshold	Hex value that sets the “Short Circuit” current value and duration	70	hex	44mV across 0.5mOhm is 88A for 427us
Short Circuit in Discharge (ASCD)				
ASCD Latch Limit	Number of ASCD events before latch occurs[2]	0	counts	Want to latch immediately after SCD condition
ASCD Counter Decrement Delay	Time after *ASCD Latch Limit* before decrementing number of counts	10	s	
ASCD Recovery	Recovery time after short circuit in discharge event	5	s	
ASCD Reset	Time to reset *ASCD Latch Limit* counter after *ASCD Recovery*	15	s	
ASCD Threshold	Hex value that sets the “Short Circuit” current value and duration	72	hex	-88.81mV across 0.5mOhm is -177.6A for 427us

[1]The Cell Overvoltage protections are dependent on the temperature of the pack, Please see temperature ranges in the Advanced Charging Algorithm section of 3.1

[2]All latch protections can be reset by a LOW-HIGH-LOW transition of the PRES pin.

3.3 Permanent Failure

The protections listed below will permanently disable the pack output and are designed to be a last resort safety protection when the pack reaches current, voltage, or temperature levels that render the pack permanently unusable. If a permanent failure is tripped, the pack cannot be recovered and must be sent back for safe disposal.

Name	Description	Value	Unit	Justification
Safety Undervoltage (SUV)				
SUV:Threshold	The cell undervoltage that will permanently disable the pack after *SUV:Delay* seconds	1700	mV	Want a very low value, should rely on flight controller disabling before battery disable
SUV:Delay	The time cell voltage must be <	5	s	

	SUV:Threshold before permanently disabling the pack			
Safety Overvoltage (SOV)				
SOV:Threshold	The cell overvoltage that will permanently disable the pack after *SOV:Delay* seconds	4500	mV	
SOV:Delay	The time cell voltage must be > *SOV:Threshold before permanently disable the pack*	5	s	
Safety Overtemperature (SOT)				
SOT Threshold	The average cell temperature threshold (sustained for *SOT Delay* seconds) during charging above which will disable the pack	91	℃	Want to permanently disable the pack before the typical “fire hazard” temperatures of lithium ions at 100C
SOT Delay	The time the average cell temperature must be > S*OT Threshold* during charging to disable to the pack	5	s	
Open Thermistor				
Open Thermistor Threshold	Temperature threshold for open thermistor	-50	℃	If an open thermistor is detected, the pack should permanently disable as temperature safety will be impeded
Open Thermistor Delay	The time the *Open Thermistor Threshold* is reached before permanently disabling the pak	5	s	
Voltage Imbalance: Rest (VIMR)				
Check Voltage	Minimum voltage to check for imbalance	3500	mV	See above
Check Current	Minimum current to check for imbalance	5	mA	
Delta Threshold	Voltage imbalance threshold	500	mV	
Cell Degradation (CD)				
CD Threshold	Capacity degradation for permanent fail	4500	mAh	If the pack capacity drops to 50% its initial value, it is considered EOL
Delay	Number of cycles at *CD Threshold* before permanent fail	2	cycles	
Charge FET Damage (CFET)				
OFF Threshold	Current threshold when CFETs are off	10	mA	If >10mA is being drawn

	above which will permanently disable the pack			when FETs are off, the FETs are damaged and the pack will permanently disable
OFF Delay	Time for *OFF Threshold* to be exceeded to permanently disable the pack	5	s	
Discharge FET Damage (DFET)				
OFF Threshold	Current threshold when DFETs are off above which will permanently disable the pack	-10	mA	See above
OFF Delay	Time for *OFF Threshold* to be exceeded to permanently disable the pack	5	s	

3.4 Lifetime Data Collection

This section lists and describes the lifetime data collection of the pack, which provides valuable information on the aging cycle of the pack including cell degradation and impedance over lifetime.

Name	Description	Unit
Voltage		
Cells 1-3 Max Voltage	Max voltage of each cell	mV
Cells 1-3 Min Votlage	Min Voltage of each cell	mV
Max Delta Cell Voltage	Maximum cell voltage imbalance	mV
Current		
Max Charge Current	Maximum charging current the pack experienced	mA
Max Discharge Current	Maximum discharging current the pack experienced	mA
Max Avg Dsg Current	Maximum average discharge current the pack experienced	mA
Max Avg Dsg Power	Maximum average discharge power the pack experienced	cW
Temperature		
Max Temp Cell	Maximum temperature an individual cell experienced	℃
Min Temp Cell	Minimum temperature an individual cell experienced	℃
Max Delta Cell Temp	Maximum difference between cell temperatures the pack experienced	℃
Safety Events		
No of COV Events	Number of cell overvoltage events	events
Last COV Event	Number of cycles since the last COV event	cycles

No of CUV Events	Number of cell undervoltage events	events
No of CUV Events	Number of cycles since the last CUV event	cycles
No of OCD1 Events	Number of overcurrent in discharge 1 events	events
Last OCD1 Event	Number of cycles since the last OCD1 event	cycles
No OCD2 Events	Number of overcurrent in discharge 2 events	events
Last OCD2 Event	Number of cycles since the last OCD2 event	cycles
No of OCC1 Events	Number of overcurrent in charge 1events	events
Last OCC1 Event	Number of cycles since the last OCC1 event	cycles
No of OCC2 Events	Number of overcurrent in charge 2 events	events
Last OCC2 Event	Number of cycles since the last OCC2 event	cycles
No of AOLD Events	Number of Analog Over Load in Discharge events	events
Last AOLD Event	Number of cycles since the last AOLD event	cycles
No of ASCD Events	Number of Analog short circuit in discharge events	events
Last ASCD Event	Number of cycles since the last ASCD event	cycles
No of ASCC Events	Number of Analog short circuit in charge events	events
Last ASCC Event	Number of cycles since the last ASCC event	cycles
No of OTC Events	Number of overtemperature in charge events	events
Last OTC Event	Number of cycles since the last OTCevent	cycles
No of OTD Events	Number of overtemperature in discharge events	events
Last OTD Event	Number of cycles since the last OTD event	cycles
Charging Events		
No Valid Charge Terms	Number of times a valid charge termination condition was reached	events
Last Valid Charge Term	Number of cycles since last charge termination condition was reached	cycles
Gauging Events		
No QMax Updates	Number of times QMax has been updated	
Last QMax Update	Number of cycles since last QMax update	
No of RA Updates	Number of times RA table has been updated	
Last RA Update	Number of cycles since last RA update	
No of RA Disable		
Last RA Disable		
PowerEvents		
No of Shutdowns	Number of times the fuel gauge has been shutdown	

Cell Balancing		
Cb Time Cell 1	Time spent balancing Cell 1	
Cb Time Cell 2	Time spent balancing Cell 2	
Cb Time Cell 3	Time spent balancing Cell 3	
Time		
Total FW Runtime	Total time the FW has been running	
Time Spent in UT RSOC A		
Time Spent In UT RSOC B		
Time Spent In UT RSOC C		
Time Spent in UT RSOC D		
Time Spent In UT RSOC E		
Time Spent In UT RSOC F		
Time Spent in UT RSOC G		
Time Spent In UT RSOC H		
Time Spent in LT RSOC A		
Time Spent In LT RSOC B		
Time Spent In LT RSOC C		
Time Spent in LT RSOC D		
Time Spent In LT RSOC E		
Time Spent In LT RSOC F		
Time Spent in LT RSOC G		
Time Spent In LT RSOC H		
Time Spent in SlT RSOC A		
Time Spent In LT RSOC B		
Time Spent In SLT RSOC C		
Time Spent in SLT RSOC D		
Time Spent In SLT RSOC E		
Time Spent In SLT RSOC F		
Time Spent in SLT RSOC G		
Time Spent In SLT RSOC H		
Time Spent in SLT RSOC A		
Time Spent In SLT RSOC B		
Time Spent In SLT RSOC C		
Time Spent in SLT RSOC D		

Time Spent In SLT RSOC E		
Time Spent In SLT RSOC F		
Time Spent in SLT RSOC G		
Time Spent In SLT RSOC H		
Time Spent in RT RSOC A		
Time Spent In RT RSOC B		
Time Spent In RT RSOC C		
Time Spent in RT RSOC D		
Time Spent In RT RSOC E		
Time Spent In RT RSOC F		
Time Spent in RT RSOC G		
Time Spent In RT RSOC H		
Time Spent in STH RSOC A		
Time Spent In STH RSOC B		
Time Spent In STH RSOC C		
Time Spent in STH RSOC D		
Time Spent In STH RSOC E		
Time Spent In STH RSOC F		
Time Spent in STH RSOC G		
Time Spent In STH RSOC H		
Time Spent in HT RSOC A		
Time Spent In HT RSOC B		
Time Spent In HT RSOC C		
Time Spent in HT RSOC D		
Time Spent In HT RSOC E		
Time Spent In HT RSOC F		
Time Spent in HT RSOC G		
Time Spent In HT RSOC H		
Time Spent in OT RSOC A		
Time Spent In OT RSOC B		
Time Spent In OT RSOC C		
Time Spent in OT RSOC D		
Time Spent In OT RSOC E		
Time Spent In OT RSOC F		

Time Spent in OT RSOC G		
Time Spent In OT RSOC H		

3.5 Device Security

The fuel gauge is sealed and can be unsealed with the following password:

Unseal: 49215341

Unseal Full Access: FFFFFFFF