User Manual: 3rd Generation CubeSat Battery Family

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Document Control

Issue	Date	Section	Description of Change	Reason for Change
A	15/02/2016	All	First Revision	Based on NanoRacks 3G battery USM
B	19/04/2016	Section 4	Updated weights	See ECN648
		Section 8	Updated grounding description and pinout	
		Section 10	Addition of cell-level protection circuit diagram	
		Section 13	Addition of Launch Provider Information section	
		Section 4	Update integrated battery heights	See ECN710
		Section 5 & 10	Added battery discharge warning if inhibits are not enabled	
C	14/07/2016	Section 2	Add 80Wh to list of products covered	ECN759
		Section 3	Add 80Wh battery maximum ratings	
		Section 0	Add electrical and physical characteristics of 80Wh battery	
		Section 5	Add note about installing inhibits during storage	
		Section 7	Add 80Wh drawing	
		Section 8	Describe interface of 80Wh battery	
		Section 10	Describe inhibit configuration of 80Wh battery	
		Section 12	Correct information error in Table 12-6	
		Section 15	Add reminder to use standoffs with 80Wh battery	
		Section 16	Add 80Wh battery to compatibility matrix	

Related Products

Assembly #	Assembly name	Notes
01-02683	10Wh Standalone Battery	
01-02684	20Wh Standalone Battery	
01-02685	30Wh Standalone Battery	
01-02686	40Wh Standalone Battery	
01-02687	80Wh Standalone Battery	
01-02681	10Wh Integrated Battery	
01-02682	20Wh Integrated Battery	

Related Documents

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No.	Document Name	Doc Ref.
RD-1	3rd Generation EPS No Inhibits User Manual	USM-1335
RD-2	NASA General Environmental Verification Standard	GSFC-STD-7000 April 2005
RD-4	Use of the Clyde Space 3rd Generation CubeSat Battery on manned missions	TN-1404

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Acronyms and Abbreviations

Ah	Ampere Hour
AIT	Assembly, Integration and Testing
BCR	Battery Charge Regulator
DoD	Depth of Discharge
EoC	End of Charge
EPS	Electrical Power System
ESD	Electro Static Discharge
Isc	Short Circuit Current
MPPT	Maximum Power Point Tracker
PDM	Power Distribution Module
rh	Relative Humidity
TTC	Telemetry and Telecommand
Voc	Open Circuit Voltage
Wh	Watt Hour

#	⚠ Warning ⚠	Risk
⚠1	Ensure headers H1 and H2 are correctly aligned before mating boards	If misaligned, battery positive can short to ground, causing failure of the battery and EPS
⚠2	Observe ESD precautions at all times	The battery is a static sensitive system. Failure to observe ESD precautions can result in failure of the battery
⚠3	Ensure not to exceed the maximum stated limits	Exceeding any of the stated maximum limits can result in failure of the battery
⚠4	Ensure batteries are fully isolated during storage	If not fully isolated (by switch configuration or separation) the battery may over-discharge, resulting in failure of the battery. This is particularly important for the integrated battery
⚠5	No connection should be made to H2.35 – H2.36 and H2.41 – H2.44	These unprotected pins are used to connect the battery to the EPS. Any connections to the unregulated battery bus should be made to pins H2.45-H2.46
⚠6	H1 and H2 pins should not be shorted at any time	These headers have exposed live pins which should not be shorted at any time. Particular care should be taken regarding the surfaces these are placed on.
⚠7	Battery should only be operated when integrated with an EPS	The EPS includes a number of protection circuits for the battery. Operation without these protections may lead to damage of the batteries
⚠8	Do not discharge batteries below 6V	If the battery is discharged to a voltage below 6V the cells have been compromised and will no longer hold capacity
⚠9	If batteries are over-discharged DO NOT attempt to recharge	If the battery is over discharged (below 6V) it should not be recharged as this may lead to cell rupture.

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1 INTRODUCTION

This document provides information on the features, operation, handling and storage of Clyde Space manned flight ISS compatible 3G battery family. The manned flight ISS compatible range utilise inhibits included in the battery which allow for efficient and safe battery switching to comply with manned flight and ISS regulations. Several different capacities and form factors are available. The battery family is designed to integrate with a suitable EPS and solar arrays to form a complete power system for a CubeSat.

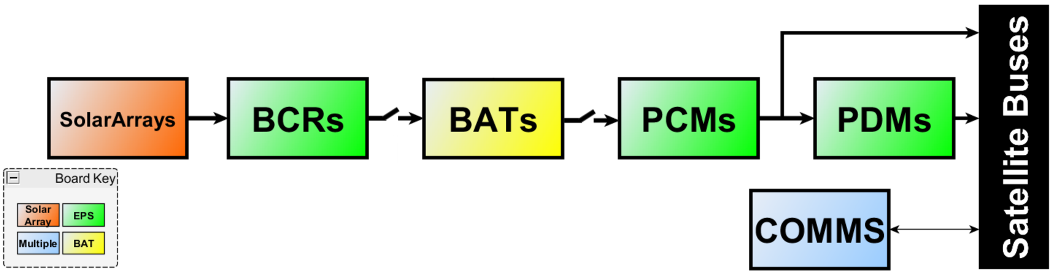

Figure 1-1 Complete Power System Diagram

1.1 Additional Information Available Online

Additional information on CubeSats and Clyde Space Systems can be found at www.clyde.space.

1.2 Continuous Improvement

At Clyde Space we are continuously improving our processes and products. We aim to provide full visibility of the changes and updates that we make, and information of these changes can be found by visiting our website: www.clyde.space.

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2 Overview

The Clyde Space CubeSat Battery range has been developed by our team of highly experienced Spacecraft Power Systems and Electronics Engineers.

Since introducing the first generation in 2006, Clyde Space has shipped over 500 battery systems to customers in Europe, Asia and North America. The batteries utilise Lithium Ion Polymer technology to offer world leading power to mass ratios in a form factor ideally suited to the volume constraints of CubeSats. In addition to this, testing has been carried out by both ESA and NASA.

Clyde Space is the World leading supplier of power system components for CubeSats. We have been designing, manufacturing, testing and supplying batteries, power system electronics and solar panels for space programmes since 2006. Our customers range from universities running student led missions, to major space companies and government organisations.

2.1 Products Covered

Battery	Product Code	Notes
10Wh Standalone	01-02683	The standalone battery interfaces with the EPS within the stack using the standard CubeSat PC104 interface.
20Wh Standalone	01-02684	
30Wh Standalone	01-02685	
40Wh Standalone	01-02686	
80Wh Standalone	01-02687	The 80Wh standalone battery comprises two 40Wh standalone batteries, each of which can be placed anywhere in the stack using the PC104 interface.
10Wh Integrated	01-02681	An integrated battery is mated to a Clyde Space EPS as a daughterboard and uses a single PC104 interface.
20Wh Integrated	01-02682	

3 Maximum Ratings[1]

3

MAX RATINGS OVER OPERATING TEMPERATURE RANGE (UNLESS OTHERWISE STATED)					
				Value	Unit
10Whr	Charge Limits	Voltage	max	8.4	V
		Current	max	2	A
		Current Rate	max	1.53C	Fraction of Capacity
	Discharge Limits	Voltage	min	6.2	V
		Current	max	2	A
		Current Rate	max	1.53C	Fraction of Capacity
20Whr	Charge Limits	Voltage	max	8.4	V
		Current	max	4	A
		Current Rate	max	1.53C	Fraction of Capacity
	Discharge Limits	Voltage	min	6.2	V
		Current	max	4	A
		Current Rate	max	1.53C	Fraction of Capacity
30Whr	Charge Limits	Voltage	max	8.4	V
		Current	max	6	A
		Current Rate	max	1.53C	Fraction of Capacity
	Discharge Limits	Voltage	min	6.2	V
		Current	max	6	A
		Current Rate	max	1.53C	Fraction of Capacity
40Whr	Charge Limits	Voltage	max	8.4	V
		Current	max	8	A
		Current Rate	max	1.53C	Fraction of Capacity
	Discharge Limits	Voltage	min	6.2	V
		Current	max	8	A
		Current Rate	max	1.53C	Fraction of Capacity
80Whr	Charge Limits	Voltage	max	8.4	V
		Current	max	16	A
		Current Rate	max	1.53C	Fraction of Capacity
	Discharge Limits	Voltage	min	6.2	V
		Current	max	16	A
		Current Rate	max	1.53C	Fraction of Capacity

[1] Stresses beyond those listed under maximum ratings may cause permanent damage to the Battery. These are the stress ratings only. Operation of the Battery at conditions beyond those indicated is not recommended. Exposure to absolute maximum ratings for extended periods may affect reliability

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	MAX RATINGS OVER OPERATING TEMPERATURE RANGE (UNLESS OTHERWISE STATED)	Value	Unit
All	Operating Temperature	-10 to 50	°C
	Storage Temperature	1 Year: -20 to +20 3 Months: -20 to +45 1 Month: -20 to +60	°C
	Vacuum	10^{-5}	torr
	Vibration	To [RD-2]	

Table 3-1 Maximum Ratings of Clyde Space Batteries

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4 Electrical and Physical Characteristics

4.1 10Wh Standalone Battery

Description	Notes	Min	Typical	Max	Unit
Charge Conditions					
EoC Voltage		8.22	8.26	8.3	V
Charge Current	Recommended maximum C/2	--	0.65	--	A
Discharge Conditions					
Full Discharge Voltage		6.16	6.2	6.24	V
Discharge Current	Recommended maximum C/2	--	0.65	--	A
Depth of Discharge	Recommended	--	20%	--	N/A
Capacity					
Discharge rate C/15	-20°C	--	1.21	--	Ah
	0°C	--	1.31	--	Ah
	20°C	--	1.35	--	Ah
	40°C	--	1.34	--	Ah
Discharge rate C/10	-20°C	--	1.19	--	Ah
	0°C	--	1.29	--	Ah
	20°C	--	1.34	--	Ah
	40°C	--	1.38	--	Ah
Discharge rate C/5	-20°C	--	1.13	--	Ah
	0°C	--	1.29	--	Ah
	20°C	--	1.34	--	Ah
	40°C	--	1.34	--	Ah
Discharge rate C/2	-20°C	--	0.83	--	Ah
	0°C	--	1.2	--	Ah
	20°C	--	1.26	--	Ah
	40°C	--	1.3	--	Ah
Operating Conditions					
Quiescent Power Consumption	Draw from 3V3 (and negligible power from 5V)	--	--	< 0.1	W
Heater					
Power Draw	Heater active (3V3 powered heater)	--	0.20	--	W
Temperature	Enable heater	--	1	--	°C
	Disable heater	--	6.5	--	°C
Communications					
Protocol		--	I^2C	--	
Transmission speed		--	100	--	$Kbits^{-1}$
Bus voltage		3.26V	3.3V	3.33V	
Node address		--	0x2A	--	Hex
Address scheme		--	7bit	--	
Node operating freq.		--	27MHz	--	
Physical					
Dimensions	Height from top PCB to lowest component		9.95		mm
Mass		115	121	127	g

Table 4-4-1 Performance Characteristics of the 10Wh Standalone Battery (01-02683)

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4.2 20Wh Standalone Battery

Description	Notes	Min	Typical	Max	Unit
Charge Conditions					
EoC Voltage		8.22	8.26	8.3	V
Charge Current	Recommended maximum C/2	--	1.3	--	A
Discharge Conditions					
Full Discharge Voltage		6.16	6.2	6.24	V
Discharge Current	Recommended maximum C/2	--	1.3	--	A
Depth of Discharge	Recommended	--	20%	--	Capacity
Capacity					
Discharge rate C/15	-20°C	--	2.42	--	Ah
	0°C	--	2.62	--	Ah
	20°C	--	2.69	--	Ah
	40°C	--	2.68	--	Ah
Discharge rate C/10	-20°C	--	2.38	--	Ah
	0°C	--	2.59	--	Ah
	20°C	--	2.68	--	Ah
	40°C	--	2.77	--	Ah
Discharge rate C/5	-20°C	--	2.26	--	Ah
	0°C	--	2.58	--	Ah
	20°C	--	2.67	--	Ah
	40°C	--	2.68	--	Ah
Discharge rate C/2	-20°C	--	0.83	--	Ah
	0°C	--	1.2	--	Ah
	20°C	--	1.26	--	Ah
	40°C	--	1.3	--	Ah
Operating Conditions					
Quiescent Power Consumption	Draw from 3V3 (and negligible power from 5V)	--	--	< 0.1	W
Heater					
Power Draw	Heater active (3V3 powered heater)	--	0.40	--	W
Temperature	Enable heater	--	1	--	°C
	Disable heater	--	6.5	--	°C
Physical					
Dimensions	Height from top PCB to lowest component		15.75		mm
Mass		186	196	205	g

Table 4-4-2 Performance Characteristics of the 20Wh Standalone Battery (01-02684)

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4.3 30Wh Standalone Battery

Description	Notes	Min	Typical	Max	Unit
Charge Conditions					
EoC Voltage		8.22	8.26	8.3	V
Charge Current	Recommended maximum C/2	--	1.95	--	A
Discharge Conditions					
Full Discharge Voltage		6.16	6.2	6.24	V
Discharge Current	Recommended maximum C/2	--	1.95	--	A
Depth of Discharge	Recommended	--	20%	--	Capacity
Capacity					
Discharge rate C/15	-20°C	--	3.64	--	Ah
	0°C	--	3.92	--	Ah
	20°C	--	4.04	--	Ah
	40°C	--	4.02	--	Ah
Discharge rate C/10	-20°C	--	3.57	--	Ah
	0°C	--	3.88	--	Ah
	20°C	--	4.03	--	Ah
	40°C	--	4.15	--	Ah
Discharge rate C/5	-20°C	--	3.4	--	Ah
	0°C	--	3.87	--	Ah
	20°C	--	4.01	--	Ah
	40°C	--	4.02	--	Ah
Discharge rate C/2	-20°C	--	2.49	--	Ah
	0°C	--	3.59	--	Ah
	20°C	--	3.78	--	Ah
	40°C	--	3.89	--	Ah
Operating Conditions					
Quiescent Power Consumption	Draw from 3V3 (and negligible power from 5V)	--	--	< 0.1	W
Heater					
Power Draw	Heater active (3V3 powered heater)	--	0.60	--	W
Temperature	Enable heater	--	1	--	°C
	Disable heater	--	6.5	--	°C
Physical					
Dimensions	Height from top PCB to lowest component		21.55		mm
Mass		254	268	281	g

Table 4-4-3 Performance Characteristics of the 30Wh Standalone Battery (01-02685)

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4.4 40Wh Standalone Battery

Description	Notes	Min	Typical	Max	Unit
Charge Conditions					
EoC Voltage		8.22	8.26	8.3	V
Charge Current	Recommended maximum C/2	--	2.6	--	A
Discharge Conditions					
Full Discharge Voltage		6.16	6.2	6.24	V
Discharge Current	Recommended maximum C/2	--	2.6	--	A
Depth of Discharge	Recommended	--	20%	--	Capacity
Capacity					
Discharge rate C/15	-20°C	--	4.85	--	Ah
	0°C	--	5.23	--	Ah
	20°C	--	5.39	--	Ah
	40°C	--	5.36	--	Ah
Discharge rate C/10	-20°C	--	4.76	--	Ah
	0°C	--	5.18	--	Ah
	20°C	--	5.37	--	Ah
	40°C	--	5.53	--	Ah
Discharge rate C/5	-20°C	--	4.53	--	Ah
	0°C	--	5.16	--	Ah
	20°C	--	5.34	--	Ah
	40°C	--	5.36	--	Ah
Discharge rate C/2	-20°C	--	3.32	--	Ah
	0°C	--	4.79	--	Ah
	20°C	--	5.04	--	Ah
	40°C	--	5.19	--	Ah
Operating Conditions					
Quiescent Power Consumption	Draw from 3V3 (and negligible power from 5V)	--	--	< 0.1	W
Heater					
Power Draw	Heater active (3V3)	--	0.80	--	W
Temperature	Enable heater	--	1	--	°C
	Disable heater	--	6.5	--	°C
Physical					
Dimensions	Height from top PCB to lowest component		27.35		mm
Mass		318	335	351	g

Table 4-4-4 Performance Characteristics of the 40Wh Standalone Battery 01-02686)

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4.5 80Wh Standalone Battery

Description	Notes	Min	Typical	Max	Unit
Charge Conditions					
EoC Voltage		8.22	8.26	8.3	V
Charge Current	Recommended maximum C/2	--	5.2	--	A
Discharge Conditions					
Full Discharge Voltage		6.16	6.2	6.24	V
Discharge Current	Recommended maximum C/2	--	5.2	--	A
Depth of Discharge	Recommended	--	20%	--	Capacity
Capacity					
Discharge rate C/15	-20°C	--	9.7	--	Ah
	0°C	--	10.46	--	Ah
	20°C	--	10.78	--	Ah
	40°C	--	10.72	--	Ah
Discharge rate C/10	-20°C	--	9.52	--	Ah
	0°C	--	10.36	--	Ah
	20°C	--	10.74	--	Ah
	40°C	--	11.06	--	Ah
Discharge rate C/5	-20°C	--	9.06	--	Ah
	0°C	--	10.32	--	Ah
	20°C	--	10.68	--	Ah
	40°C	--	10.72	--	Ah
Discharge rate C/2	-20°C	--	6.64	--	Ah
	0°C	--	9.58	--	Ah
	20°C	--	10.08	--	Ah
	40°C	--	10.38	--	Ah
Operating Conditions					
Quiescent Power Consumption	Draw from 3V3 (and negligible power from 5V)	--	--	< 0.2	W
Heater					
Power Draw	Heater active (3V3)	--	1.60	--	W
Temperature	Enable heater	--	1	--	°C
	Disable heater	--	6.5	--	°C
Physical					
Dimensions	Height from top PCB to lowest component		56.94[1]		mm
Mass		636	670[2]	702	g

Table 4-4-5 Performance Characteristics of the 80Wh Standalone Battery (01-02687)

[1] Assumes batteries are stacked as close as possible in the stack, as shown in Section 7.4.5.
[2] Mass excludes any standoffs

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4.6 10Wh Integrated Battery

Description	Notes	Min	Typical	Max	Unit
Charge Conditions					
EoC Voltage		8.22	8.26	8.3	V
Charge Current	Recommended maximum C/2	--	0.65	--	A
Discharge Conditions					
Full Discharge Voltage		6.16	6.2	6.24	V
Discharge Current	Recommended maximum C/2	--	0.65	--	A
Depth of Discharge	Recommended	--	20%	--	Capacity
Capacity					
Discharge rate C/15	-20°C	--	1.21	--	Ah
	0°C	--	1.31	--	Ah
	20°C	--	1.35	--	Ah
	40°C	--	1.34	--	Ah
Discharge rate C/10	-20°C	--	1.19	--	Ah
	0°C	--	1.29	--	Ah
	20°C	--	1.34	--	Ah
	40°C	--	1.38	--	Ah
Discharge rate C/5	-20°C	--	1.13	--	Ah
	0°C	--	1.29	--	Ah
	20°C	--	1.34	--	Ah
	40°C	--	1.34	--	Ah
Discharge rate C/2	-20°C	--	0.83	--	Ah
	0°C	--	1.2	--	Ah
	20°C	--	1.26	--	Ah
	40°C	--	1.3	--	Ah
Operating Conditions					
Quiescent Power Consumption	Draw from 3V3 (and negligible power from 5V)	--	--	< 0.1	W
Heater					
Power Draw	Heater active (3V3 powered heater)	--	0.20	--	W
Temperature	Enable heater	--	1	--	°C
	Disable heater	--	6.5	--	°C
Physical (without EPS)					
Dimensions	Height from top PCB to lowest component		9.95		mm
Mass		81	85	89	g
Physical (with EPS)					
Dimensions	Height from top PCB to lowest component		19.6		mm
Mass		166	171	175	g

Table 4-4-6 Performance Characteristics of the 10Wh Integrated Battery (01-02681)

4.7 20Wh Integrated Battery

Description	Notes	Min	Typical	Max	Unit
Charge Conditions					
EoC Voltage		8.22	8.26	8.3	V
Charge Current	Recommended maximum C/2	--	1.3	--	A
Discharge Conditions					
Full Discharge Voltage		6.16	6.2	6.24	V
Discharge Current	Recommended maximum C/2	--	1.3	--	A
Depth of Discharge	Recommended	--	20%	--	Capacity
Capacity					
Discharge rate C/15	-20°C	--	2.42	--	Ah
	0°C	--	2.62	--	Ah
	20°C	--	2.69	--	Ah
	40°C	--	2.68	--	Ah
Discharge rate C/10	-20°C	--	2.38	--	Ah
	0°C	--	2.59	--	Ah
	20°C	--	2.68	--	Ah
	40°C	--	2.77	--	Ah
Discharge rate C/5	-20°C	--	2.26	--	Ah
	0°C	--	2.58	--	Ah
	20°C	--	2.67	--	Ah
	40°C	--	2.68	--	Ah
Discharge rate C/2	-20°C	--	0.83	--	Ah
	0°C	--	1.2	--	Ah
	20°C	--	1.26	--	Ah
	40°C	--	1.3	--	Ah
Operating Conditions					
Quiescent Power Consumption	Draw from 3V3 (and negligible power from 5V)	--	--	< 0.1	W
Heater					
Power Draw	Heater active (3V3)	--	0.40	--	W
Temperature	Enable heater	--	1	--	°C
	Disable heater	--	6.5	--	°C
Physical (without EPS)					
Dimensions	Height from top PCB to lowest component		15.75		mm
Mass		152	160	168	g
Physical (with EPS)					
Dimensions	Height from top PCB to lowest component		27.41		mm
Mass		238	246	254	g

Table 4-4-7 Performance Characteristics of the 20Wh Integrated Battery (01-02682)

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5 HANDLING AND STORAGE

The batteries require specific guidelines to be observed for handling, transportation and storage. These are stated below. Failure to follow the guidelines may result in damage to the units or degradation in performance.

5.1 Electro Static Discharge (ESD) Protection

The batteries incorporate static sensitive devices and care should be taken during handling. Do not touch the batteries without proper electrostatic protection in place. All work carried out on the system should be done in a static dissipative environment.

5.2 General Handling

The batteries are robust and designed to withstand flight conditions. However, care must be taken when handling the device. Do not drop the device as this can damage the cells. There are live connections between the battery systems and the batteries on the CubeSat Kit headers. All metal objects (including probes) should be kept clear of these headers.

Gloves should be worn when handling all flight hardware.

Flight hardware should only be removed from packaging in a class 100000 (or better) clean room environment.

The exterior surface of the cells is covered with space grade Kapton adhesive tape; this provides insulation for the cells and is not to be removed.

Note: The inhibits must be enabled while the system is not in use to prevent battery discharge – even with no load connected, there is a small current draw from the battery. This is particularly important for the integrated battery as the EPS is always mated to the battery.

5.3 Shipping and Storage

The devices are shipped in anti-static and enclosed in a hard protective case. This case should be used for storage. All hardware should be stored in anti-static containers.

Rate of capacity degradation of lithium polymer cells in storage is dependent on the storage environment, particularly temperature, and cell state of charge. It is recommended that the batteries are stored with voltages approximately 7.6V (50% DoD), at a temperature between -10°C and +10°C and in a humidity-controlled environment of 40-60%rh.

The most serious degradation occurs when cells are stored in a fully charged state.

If batteries are stored for long periods of time, they may over discharge. To prevent this, batteries should be charged periodically to maintain ≈7.6V. It is also recommended that inhibits on the battery or an EPS are left in place/replaced during periods of storage.

The shelf-life of this product is estimated at 5 years when stored appropriately.

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6 Materials and Processes

6.1 Materials Used

Material	Manufacturer	%TML	%CVCM	%WVR	Application
Araldite 2014 Epoxy	Huntsman	0.97	0.05	0.33	Adhesive fixing
Arathane 5750	Huntsman	0.41	0.03	-	Conformal Coating
DC 6-1104	Dow Corning	0.17	0.02	0.06	Adhesive fixing on modifications
Stycast 5952	Emerson & Cuming	1.38	0.62	0.01	Thermally Conductive RTV
Stycast 2850	Henkel Electronics	0.25	0.02	-	IP protective layer
PCB material	FR4	0.62	0	0.1	Note: worst case on NASA out-gassing list
Solder Resist	CARAPACE EMP110 or XV501T-4	0.95 or 0.995	0.02 Or 0.001	0.31	-
Solder	Sn62 or Sn63 (Tin/Lead)	-	-	-	-
Flux	Alpha Rosin Flux, RF800, ROL 0	-	-	-	ESA Recommended

Table 6-1 Materials List

Part Used	Manufacturer	Contact	Insulator	Type	Use	Required Mating Connector
ESQ-126-39-G-D	Samtec	Gold Plated	Black Glass Filled Polyester	PTH	CubeSat Header	Stack Connector
ESQ-126-39-G-D	Samtec	Gold Plated	Black Glass Filled Polyester	PTH	CubeSat Header	Stack Connector
DF13-6P-125DSA	Hirose	Gold Plated	Polyamide	PTH	Programming Header	DF13-6S-1.25C
DF13-2P-125DSA	Hirose	Gold Plated	Polyamide	PTH	Separation Switch	DF13-2S-1.25C
DF13-2P-125H	Hirose	Gold Plated	Polyamide	PTH	Separation Switch	DF13-2S-1.25C
DF13-3P-125H	Hirose	Gold Plated	Polyamide	PTH	RBF	DF13-3S-1.25C
DF13-8P-1.25DSA	Hirose	Gold Plated	Polyamide	PTH	Overvoltage resistor	DF13-8S-1.25C

Table 6-2 Connector Headers

6.2 Processes and Procedures

All assembly is carried out to IPC610 Class 3 standard.

7 System Description

The Clyde Space 3G battery family is optimised for Low Earth Orbit (LEO) missions with a maximum altitude of 850km. The batteries are designed for integration with spacecraft that have an EPS compatible with lithium ion polymer technology.

Clyde Space batteries offer high capacity with low mass and volume. The battery systems all have autonomous integrated heater systems to enhance operation at low temperatures.

The battery heater is an independent analogue circuit which maintains the battery temperature above 0°C. The heater is thermostatically controlled to automatically turn on when the battery temperature falls below 1°C, and switch off again when the temperature rises above 5°C.

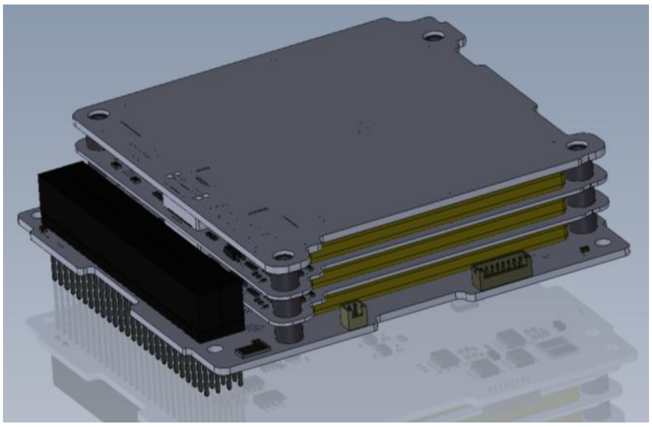

Figure 7-1 3G Standalone Battery Configuration

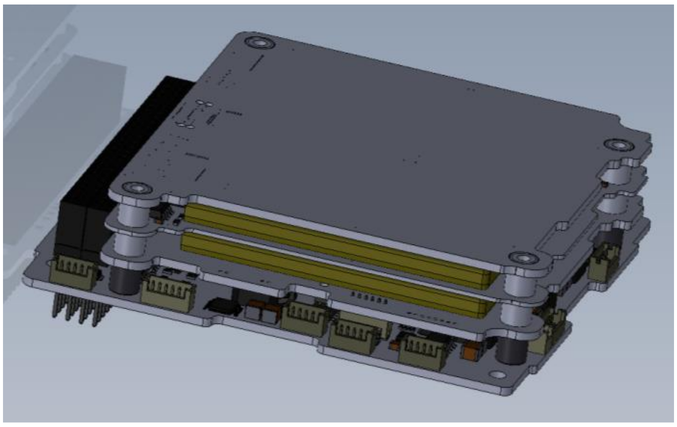

Figure 7-2 3G Integrated Battery Configuration

7.1 3G Battery Family

The 3G manned flight ISS compatible battery family has a variety of different configurations. The two form factors available are the standalone battery and integrated battery. The standalone battery interfaces with the EPS within the stack using the standard CubeSat PC104 interface. The integrated battery is mated to a Clyde Space EPS as a daughterboard. This provides tighter mechanical integration and uses a single PC104 interface for both the EPS and battery.

Battery	Product Code	Notes
10Wh Standalone	01-02683	The standalone battery interfaces with the EPS within the stack using the standard CubeSat PC104 interface.
20Wh Standalone	01-02684	
30Wh Standalone	01-02685	
40Wh Standalone	01-02686	
80Wh Standalone	01-02697	The 80Wh standalone battery comprises two 40Wh standalone batteries, each of which can be placed anywhere in the stack using the PC104 interface.
10Wh Integrated	01-02681	An integrated battery is mated to a Clyde Space EPS as a daughterboard and uses a single PC104 interface.
20Wh Integrated	01-02682	

Table 7-1 3G Battery Manned Flight family configurations

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7.2 Protection and Redundancy

All Clyde Space batteries have as standard multiple protection systems in place at a cell, battery, and system-level which will automatically respond to external fault conditions in order to protect the battery and wider-system from irrecoverable damage.

For a full breakdown of the protection systems associated with this product and their operation refer to section 10 General protection.

7.3 Quiescent Power Consumption

The quiescent power consumption of the battery is ≈ 0.1W. This power is drawn from the 3.3V and 5V available on the header to power the heater control circuitry.

7.4 Dimensions

7.4.1 10Whr Standalone

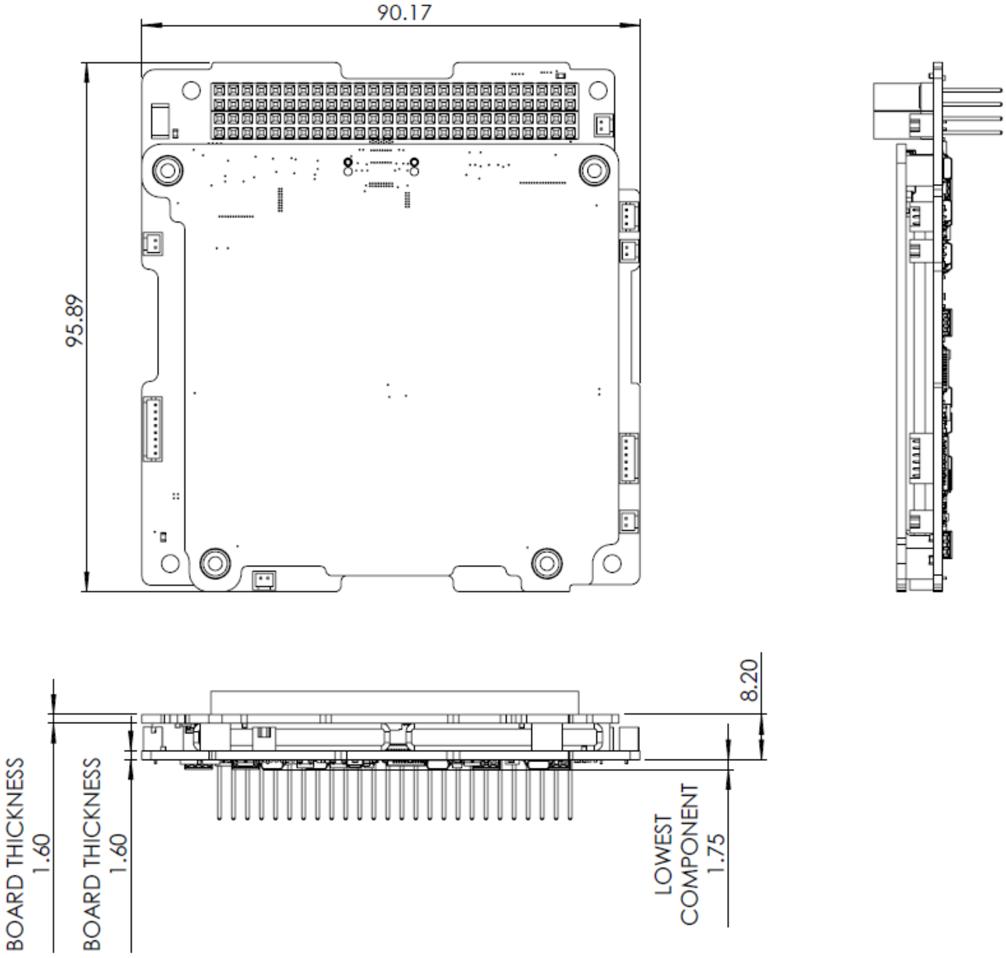

Figure 7-3 10Whr (01-02683) Standalone Battery External Dimensions

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7.4.2 20Whr Standalone

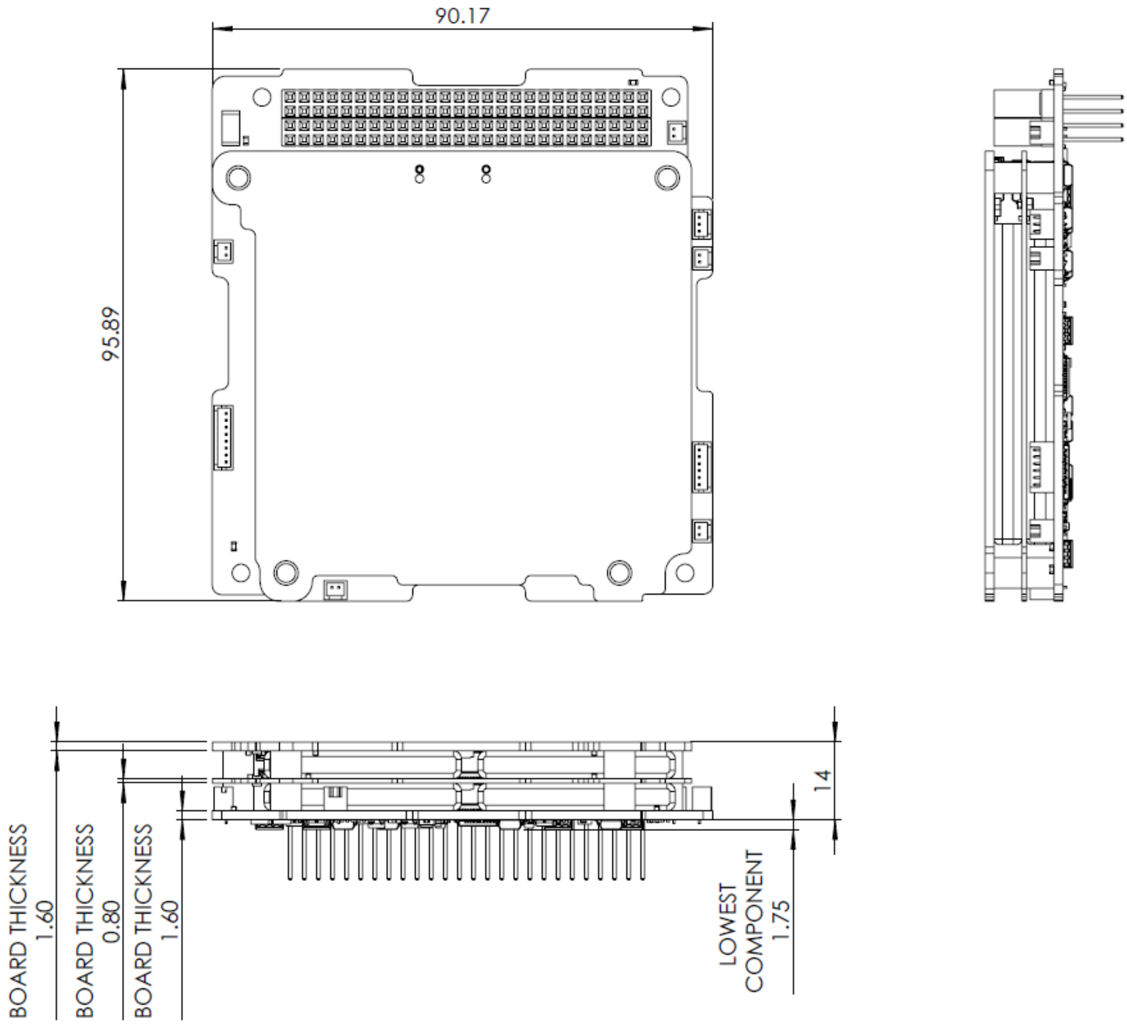

Figure 7-4 20Whr (01-02684) Standalone Battery External Dimensions

7.4.3 30Whr Standalone

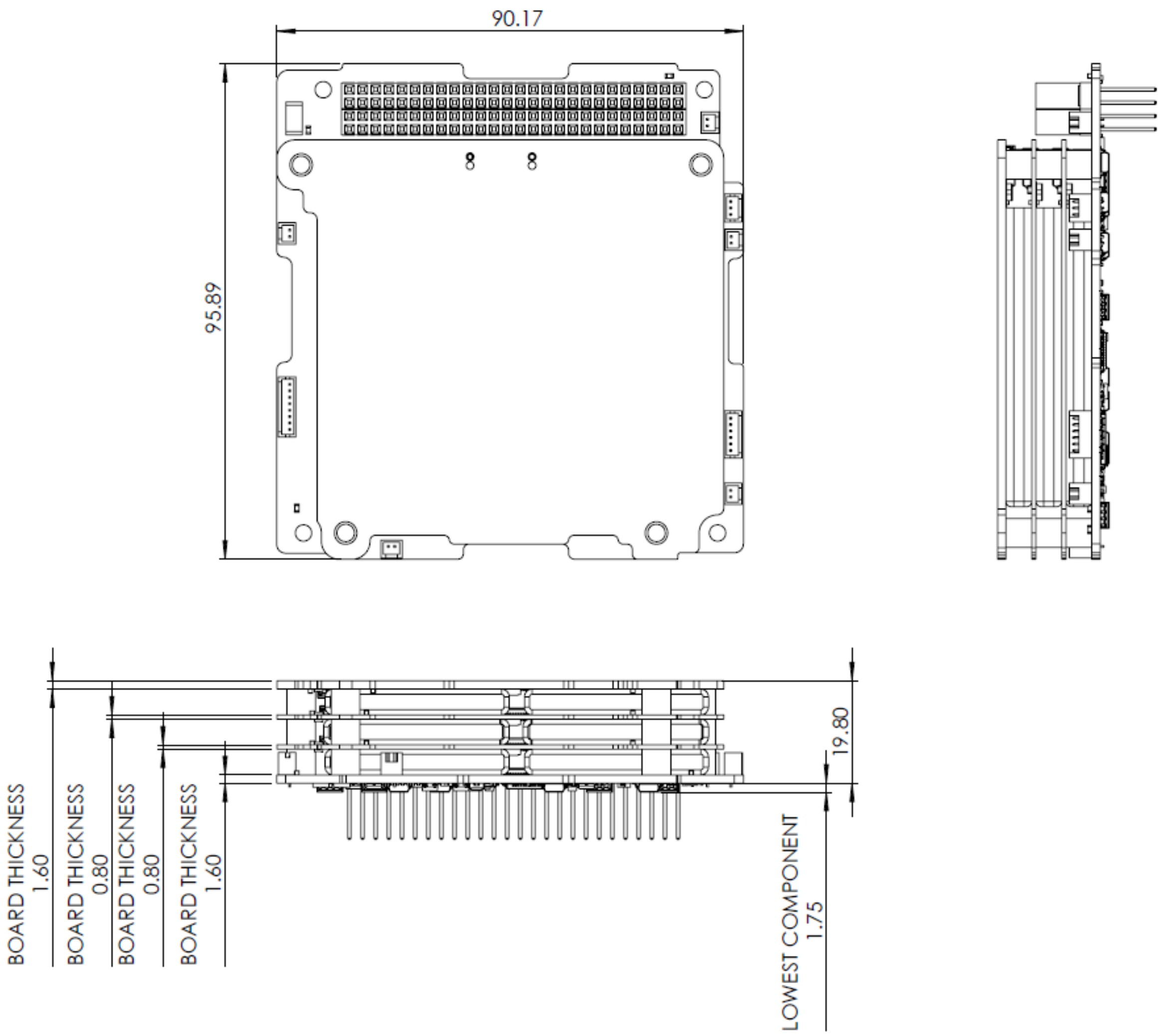

Figure 7-5 30Whr (01-02685) Standalone Battery External Dimensions

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7.4.4 40Whr Standalone

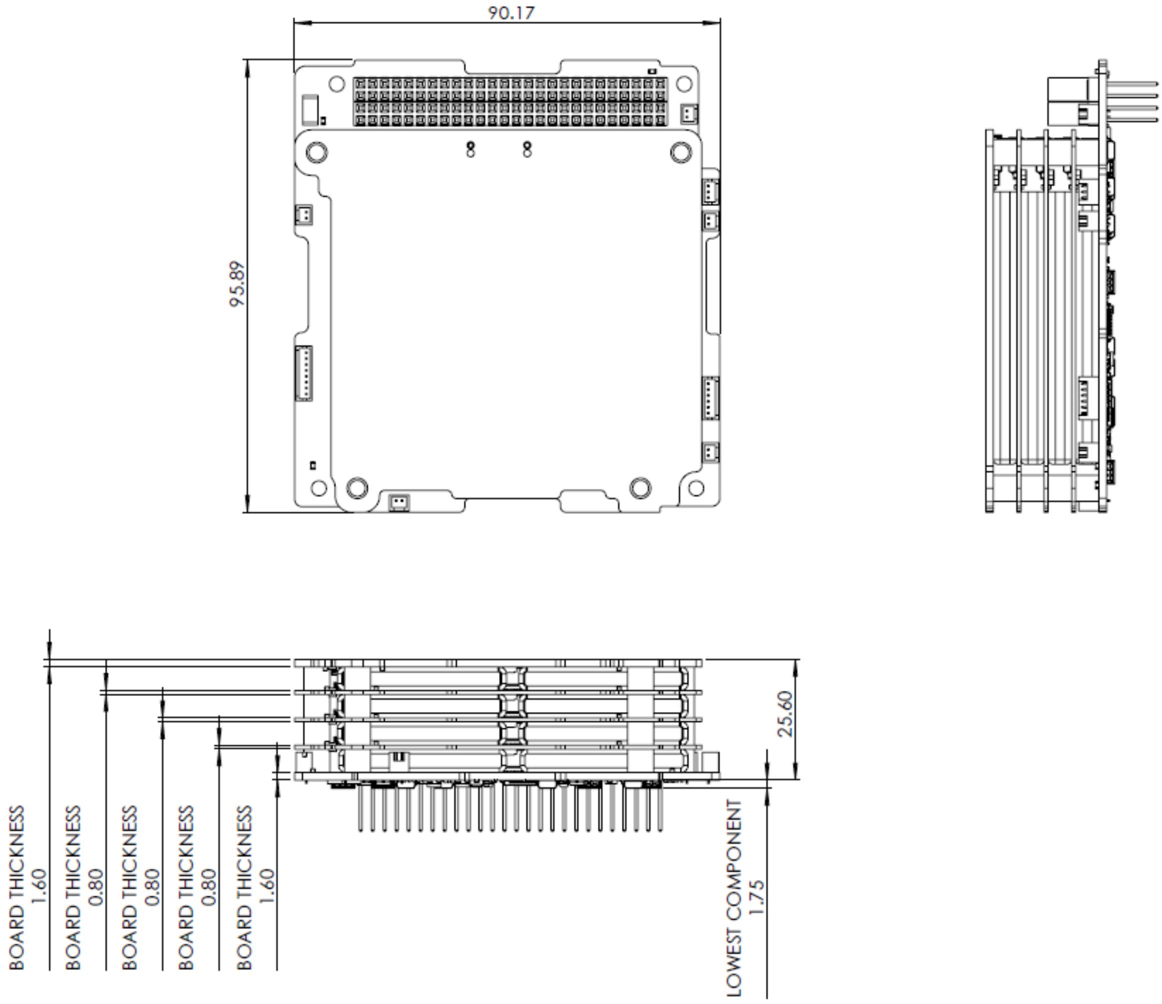

Figure 7-6 40Whr (01-02686) Standalone Battery External Dimensions

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7.4.5 80Wh Standalone

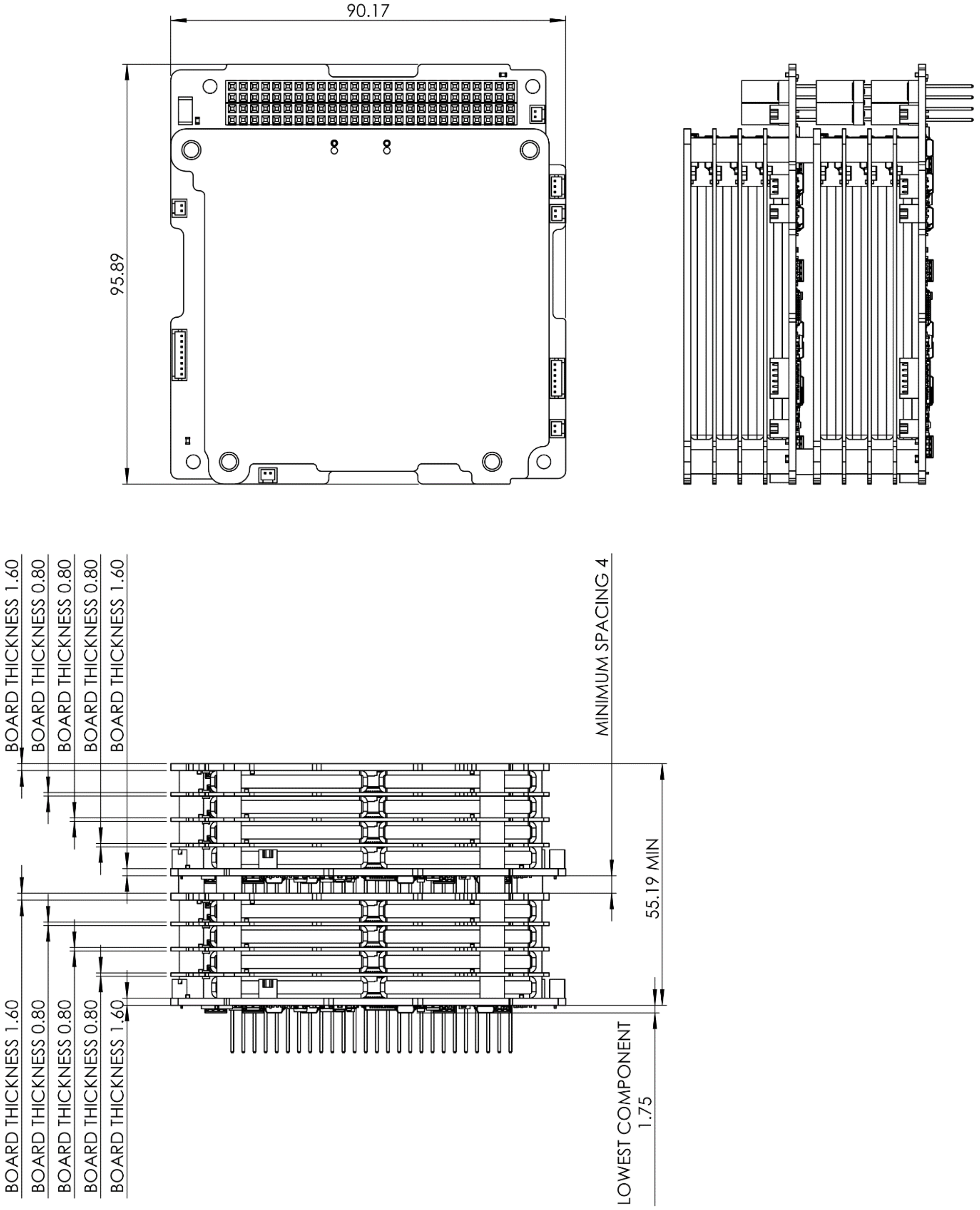

Figure 7-7 80Whr (01-02687) Standalone Battery External Dimensions (Example stack)

The 80Wh battery is supplied as two separate 40Wh batteries, which may be stacked as desired by the customer. A recommended configuration, in which the batteries are stacked adjacent to each other and connected with ESQ-126-38-G-D headers (supplied with the assembly), is shown above. Standoffs are not shown in this drawing as they will vary depending on the design of the satellite, but must be used to space the batteries apart in the stack. Minimum spacing, as governed by

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acceptable distances between boards, is shown here. Maximum spacing is governed by connector insertion depths. Refer to connector datasheets for more information.

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7.4.6 10Whr Integrated

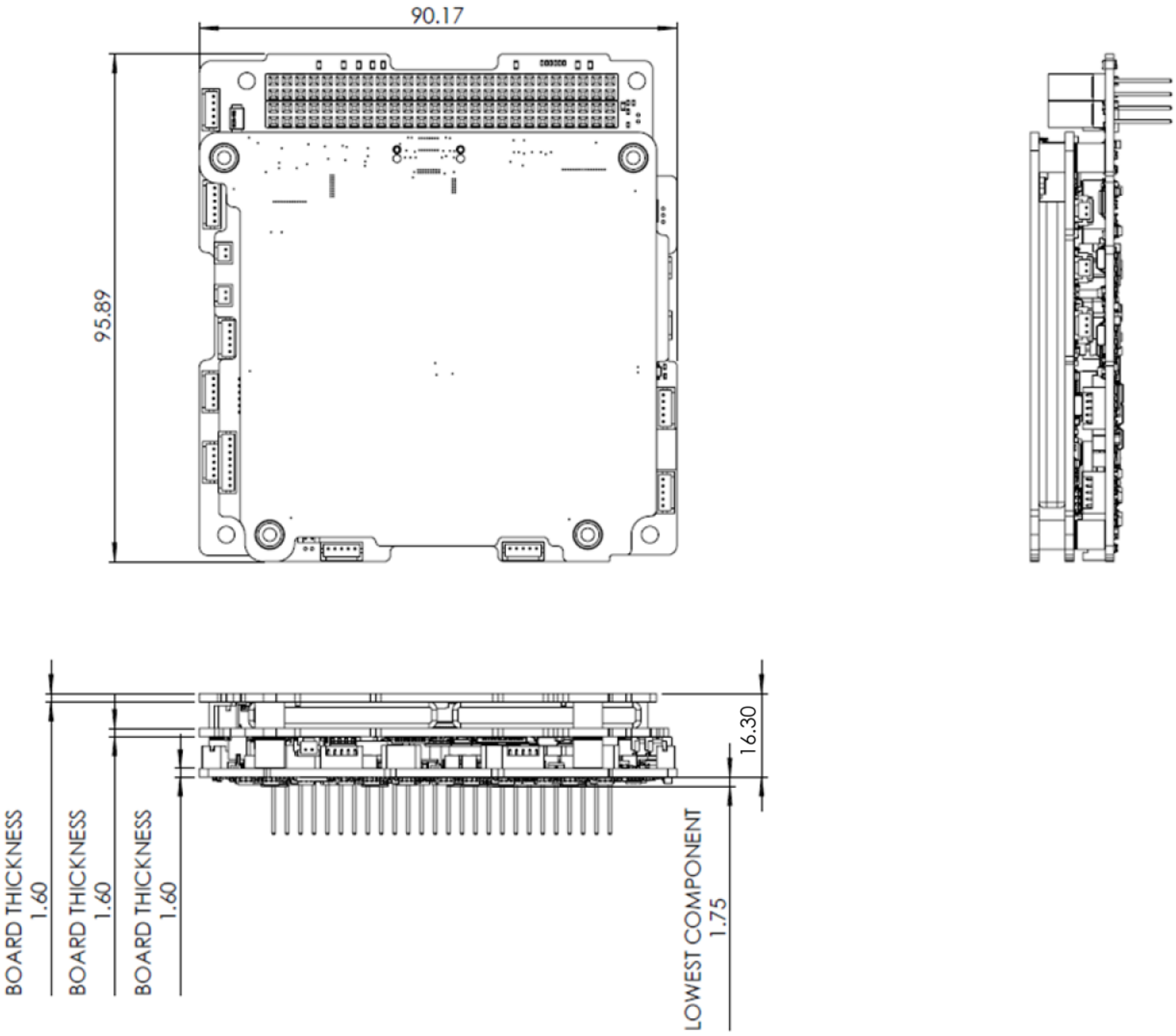


Figure 7-8 10Whr (01-02681) Integrated Battery and EPS External Dimensions

7.4.7 20Whr Integrated

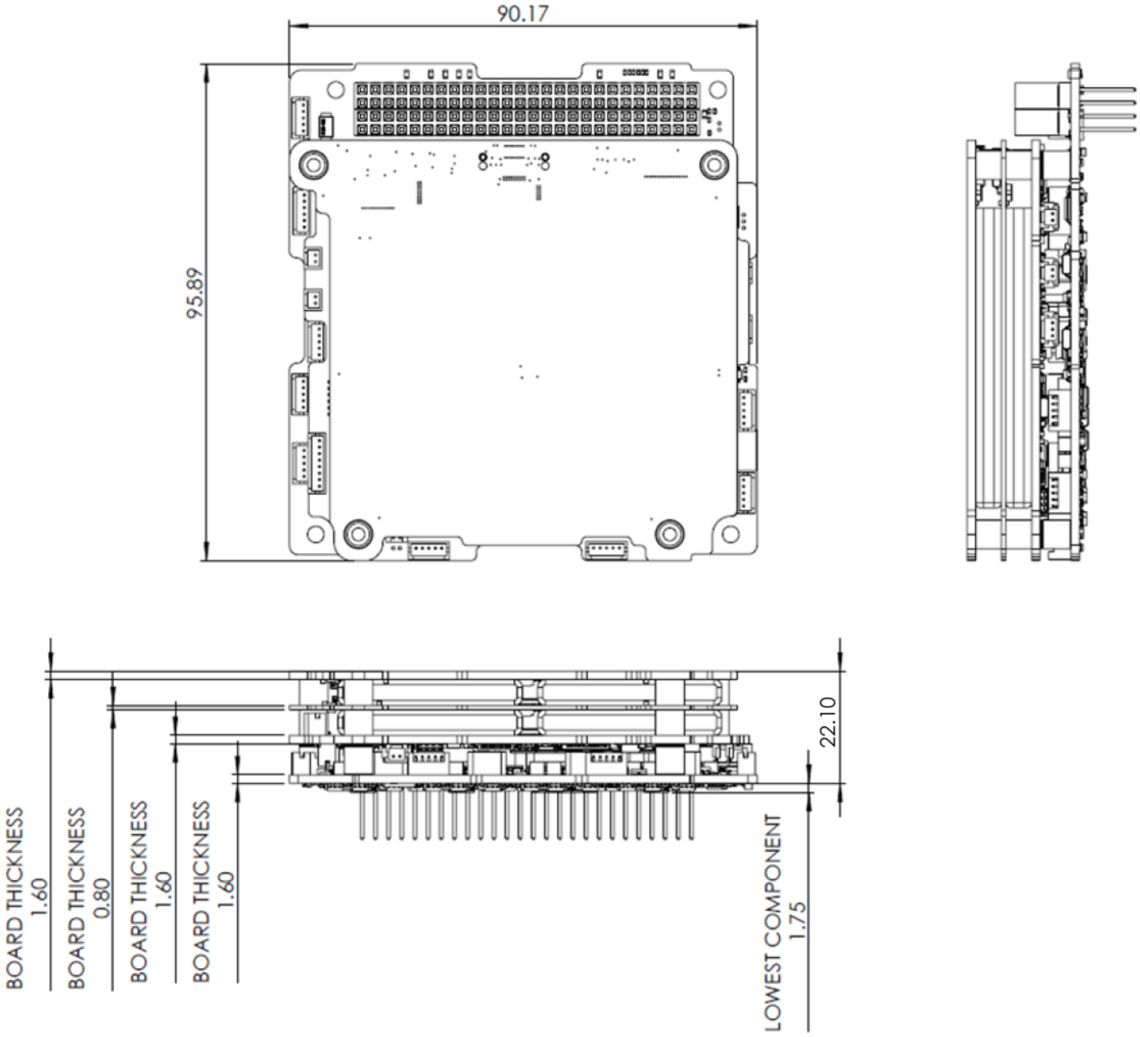
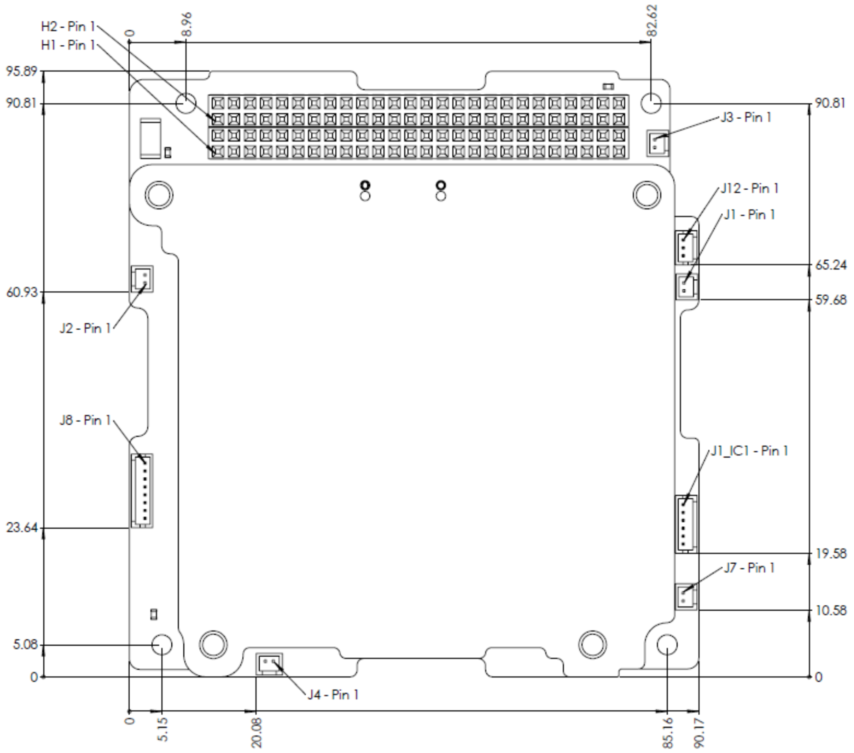


Figure 7-9 20Whr (01-02682) Integrated Battery and EPS External Dimensions

8 INTERFACING

8.1 Standalone Connector Layout and Mounting Locations

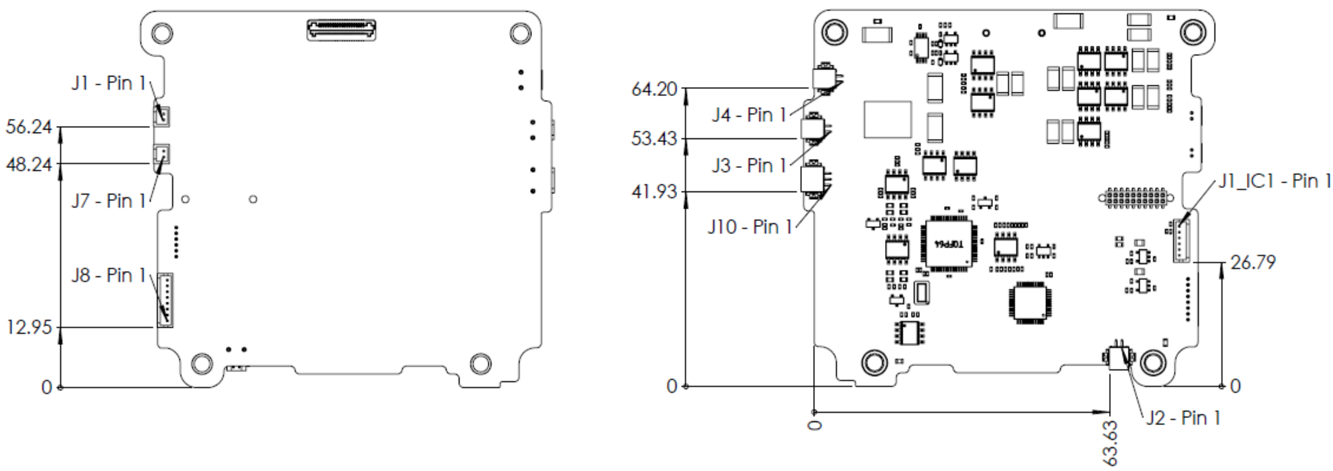


Connector	Function
H2	Main Bus Header
H1	Main Bus Header
J1	High Side Inhibit 1
J2	High Side Inhibit 2
J3	High Side Inhibit 3
J4	High Side Inhibit 4
J7	Low Side Inhibit
J12	Remove Before Flight
J8	Overvoltage shunt resistor interface
J1_IC1	Programming Header – not for customer use

Figure 8-1 Standalone battery external connector layout and functions

8.2 Integrated Battery Connector Layout

The integrated battery must be used in combination with a compatible EPS; for mounting hole locations refer to the applicable EPS user manual.



Connector	Function
J1	High Side Inhibit 1
J2	High Side Inhibit 2
J3	High Side Inhibit 3
J4	High Side Inhibit 4
J7	Low Side Inhibit
J8	Overvoltage shunt resistor interface
J10	Remove Before Flight
J1_IC1	Programming Header – not for customer use
Not shown in this diagram are the EPS connections. These can be found in USM-1335.	

Figure 8-2 Integrated battery external connector layout and functions

(left – battery motherboard top view, right – bottom view)

8.3 3G Standalone Battery Bus Headers

Connections from the battery to the bus of the satellite are made via the CubeSat Kit compatible header H1 and H2.

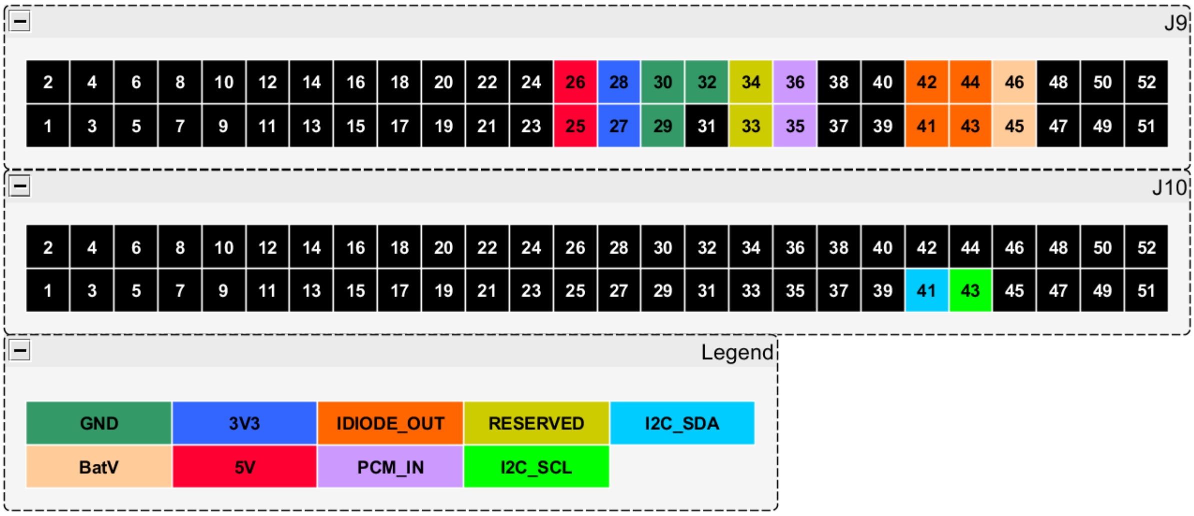


Figure 8-3 CubeSat Kit Header Schematic

Please note that all of J9 pins highlighted in the above diagram are used internally between the EPS and the battery. Placing any other connection on these pins can result in the incorrect operation or terminal failure of the EPS or battery.

In addition to the pins highlighted above there are additional pins allocated on the EPS header which must be taken into account when making connections to the stack header of a combined EPS and standalone battery assembly. For a list of header pin allocations for the EPS refer to the applicable EPS user manual.

8.4 3G Integrated Battery Bus Headers

These can be found in USM-1335.

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8.5 3G Standalone Battery Header Pinouts

H1 - HEADER 1				H2 - HEADER 2			
Pin	Name	Use	Notes	Pin	Name	Use	Notes
1	NC	-	-	1	NC	-	-
2	NC	-	-	2	NC	-	-
3	NC	-	-	3	NC	-	-
4	NC	-	-	4	NC	-	-
5	NC	-	-	5	NC	-	-
6	NC	-	-	6	NC	-	-
7	NC	-	-	7	NC	-	-
8	NC	-	-	8	NC	-	-
9	NC	-	-	9	NC	-	-
10	NC	-	-	10	NC	-	-
11	NC	-	-	11	NC	-	-
12	NC	-	-	12	NC	-	-
13	NC	-	-	13	NC	-	-
14	NC	-	-	14	NC	-	-
15	NC	-	-	15	NC	-	-
16	NC	-	-	16	NC	-	-
17	NC	-	-	17	NC	-	-
18	NC	-	-	18	NC	-	-
19	NC	-	-	19	NC	-	-
20	NC	-	-	20	NC	-	-
21	NC	-	-	21	NC	-	-
22	NC	-	-	22	NC	-	-
23	NC	-	-	23	NC	-	-
24	NC	-	-	24	NC	-	-
25	NC	-	-	25	5VBUS	5V Bus	Power Bus
26	NC	-	-	26	5VBUS	5V Bus	Power Bus
27	NC	-	-	27	3V3BUS	3V3 Bus	Power Bus
28	NC	-	-	28	3V3BUS	3V3 Bus	Power Bus
29	NC	-	-	29	GND	Ground	System Ground
30	NC	-	-	30	GND	Ground	System Ground
31	NC	-	-	31	NC	-	-
32	NC	-	-	32	GND	Ground	System Ground
33	NC	-	-	33	Reserved	Do Not Use	-
34	NC	-	-	34	Reserved	Do Not Use	-
35	NC	-	-	35	PCM_IN	Power Convertor In	Supply to Power Bus Regulators
36	NC	-	-	36	PCM_IN	Power Convertor In	Supply to Power Bus Regulators
37	NC	-	-	37	NC	-	-
38	NC	-	-	38	NC	-	-
39	NC	-	-	39	NC	-	-
40	NC	-	-	40	NC	-	-
41	NC	I^2C SDA	I^2C Data Line	41	IDIODE_OUT	Ideal Diode Output	Solar Array Regulator Output
42	NC	-	-	42	IDIODE_OUT	Ideal Diode Output	Solar Array Regulator Output
43	NC	I^2C SCL	I^2C Clock Line	43	IDIODE_OUT	Ideal Diode Output	Solar Array Regulator Output
44	NC	-	-	44	IDIODE_OUT	Ideal Diode Output	Solar Array Regulator Output
45	NC	-	-	45	BatVBUS	Unregulated Battery Bus	Power Bus
46	NC	-	-	46	BatVBUS	Unregulated Battery Bus	Power Bus
47	NC	-	-	47	NC	-	-
48	NC	-	-	48	NC	-	-
49	NC	-	-	49	NC	-	-
50	NC	-	-	50	NC	-	-
51	NC	-	-	51	NC	-	-
52	NC	-	-	52	NC	-	-

Table 8-1 Pin Descriptions for 3G Standalone Battery Header H1 and H2

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8.6 EPS and Battery Integration

8.6.1 Standalone Battery (10Wh-40Wh)

Connection of the battery systems to the EPS is via the main bus headers. Ensure that the pins are aligned, and located in the correct position, as any offset can cause the battery to be shorted to ground, leading to catastrophic failure of the battery and damage to the EPS. Failure to observe these precautions will result in the voiding of any warranty.

Ensure that the battery is fully isolated during periods of extended storage.

When a battery board is connected to the header, there are live battery pins accessible (H2.35 – H2.36 and H2.41 – H2.44). These pins should not be routed to any connections other than the Clyde Space EPS, otherwise protections will be bypassed and significant battery damage may be sustained.

8.6.2 Standalone Battery (80Wh)

Integration of the 80Wh batteries is as described in section 8.6.1, except that the 80Wh is supplied as two separate 40Wh batteries, each with its own PC104 header. The two batteries can be mounted adjacent in the stack, using the supplied spacing header to connect them -- mechanical spacers/standoffs vary between applications and are thus left as the customer's responsibility. Alternatively, the individual 40Wh units can be placed separately in the stack as desired.

The two batteries should be stored in the same conditions and used together so that degradations of the individual units are matched.

8.6.3 Integrated Battery

The customer will receive an integrated battery already fully integrated with an EPS, however, the battery positive pins on the EPS are still exposed. Failure to isolate the battery will allow the battery to discharge into the EPS and cause battery failure once the battery voltage drops below the minimum value.

Further details about safe handling can be found in the EPS user manual.

8.7 Buses

The 3V3 and 5V power buses must be supplied to the battery from the EPS to power the I^2C node and heater control circuitry.

8.8 Grounding

To ensure optimum operation it is recommended that a star grounding scheme should be used on satellites. Connection of all ground return paths to a single point helps reduce noise emission and reception and reduces any magnetic moments created by uncontrolled current loops. The battery negative terminal is the designated star point. The battery acts as a large capacitance which provides the perfect location for the connection of the star ground point.

The chassis of the satellite should be connected to the power or signal ground only at the star point. System ground is connected to the mounting holes which in turn connects to the chassis. Therefore, the chassis should not be directly connected to any PCBs at any other point in the satellite. This prevents any ground loops or unwanted power return paths. Capacitors may be used to shunt high frequency components to the chassis to provide shielding. This is acceptable as no DC current can pass through the capacitors.

On the 80Wh battery, a DC chassis ground connection is provided only on one of the two 40Wh units.

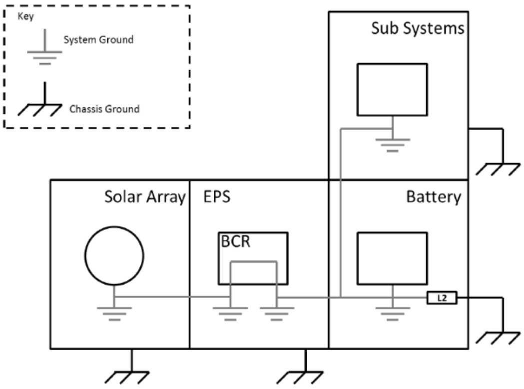

Figure 8-4 Star Grounding Point at Battery Negative Terminal

9 Charge and Discharge Modes

Clyde Space batteries should always be charged using a Clyde Space EPS. The EPS uses a constant current and constant voltage tapered charging regime. Further details about this can be found in the Clyde Space EPS user manual.

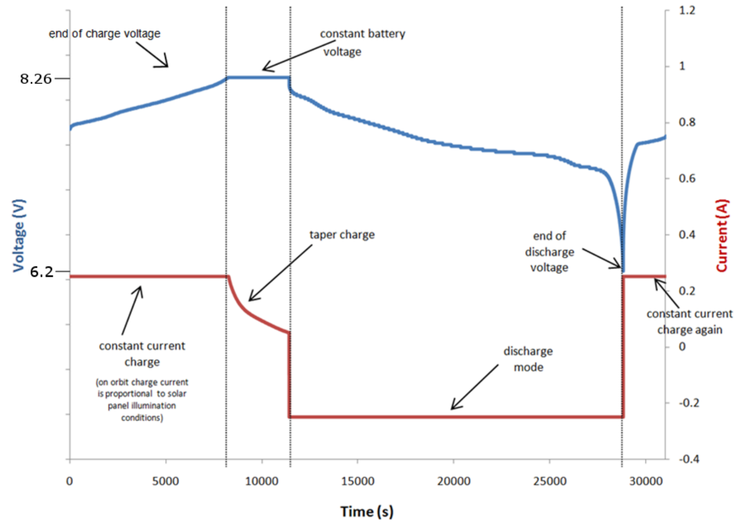

Figure 9-1 Tapered charging method

9.1 Discharge

4 **Figure 9.1** shows the profile of a full discharge of the battery at a C/5 rate. A full discharge cycle is carried out on all Clyde Space batteries prior to shipment to verify their capacity. In order to maximise the cycle life of the battery, it is recommended to discharge the battery to a maximum of 20% DoD.

9.2 Lot Acceptance Testing

In order to determine the cell's suitability for space applications, Clyde Space undertakes an extensive Lot Acceptance Testing regime. An abbreviated set of results is detailed in this section; for a full description of the lot acceptance process and results please contact Clyde Space.

9.2.1 Cell Capacity Variation with Discharge Rate and Temperature

Discharge plots are shown in **Figure 9-2** for rates of C/15, C/10, C/5, C/2 and C at 40°C. In **Figure 9-3,** capacities for each discharge rate are compared for all temperatures. Note that these measurements were carried out per cell. A summary of the results is shown in **Table 9-1**.

	Discharge Rate and Measured Capacity (Ah)			
T (°C)	C/15	C/10	C/5	C/2
-20	1.21	1.19	1.13	0.83
0	1.31	1.29	1.29	1.2
20	1.35	1.34	1.34	1.26
40	1.34	1.38	1.34	1.3

Table 9-1 Measured capacities at different discharge rates and temperatures.

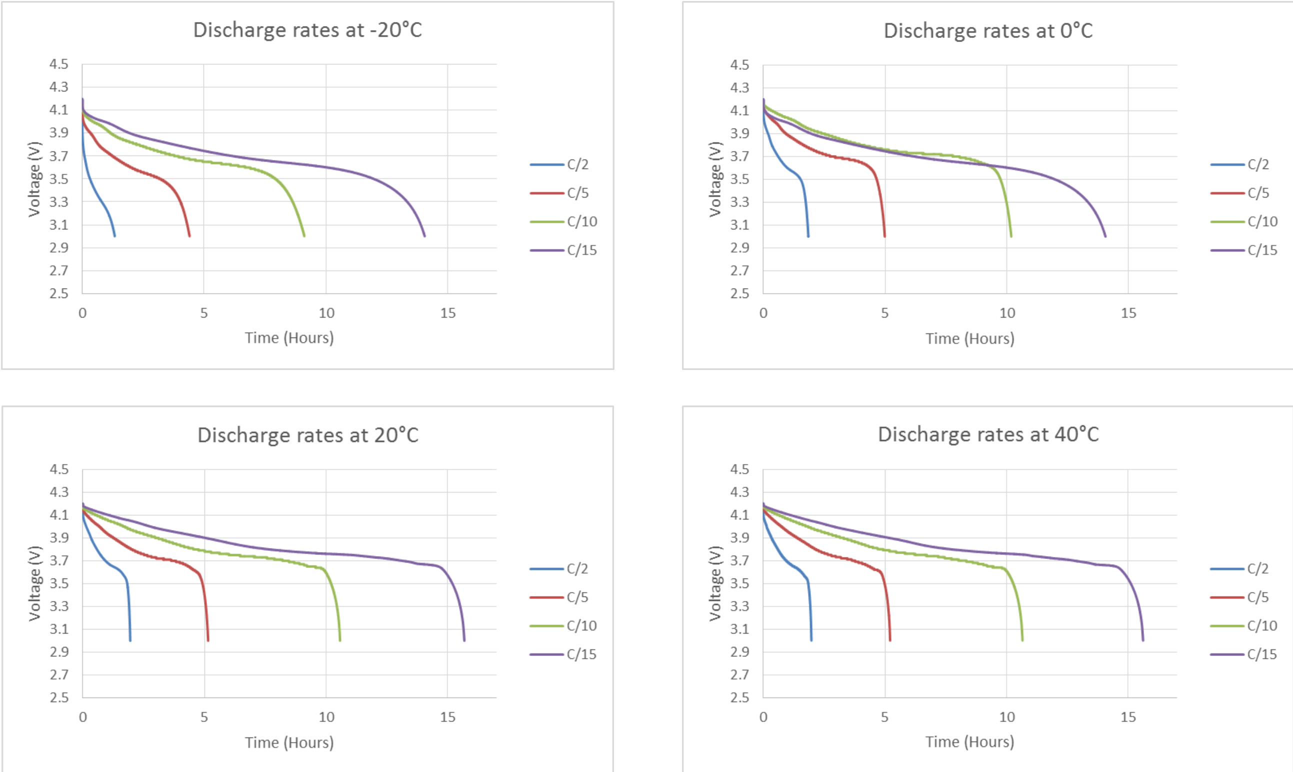

Figure 9-2 Cell discharge rates vs Time

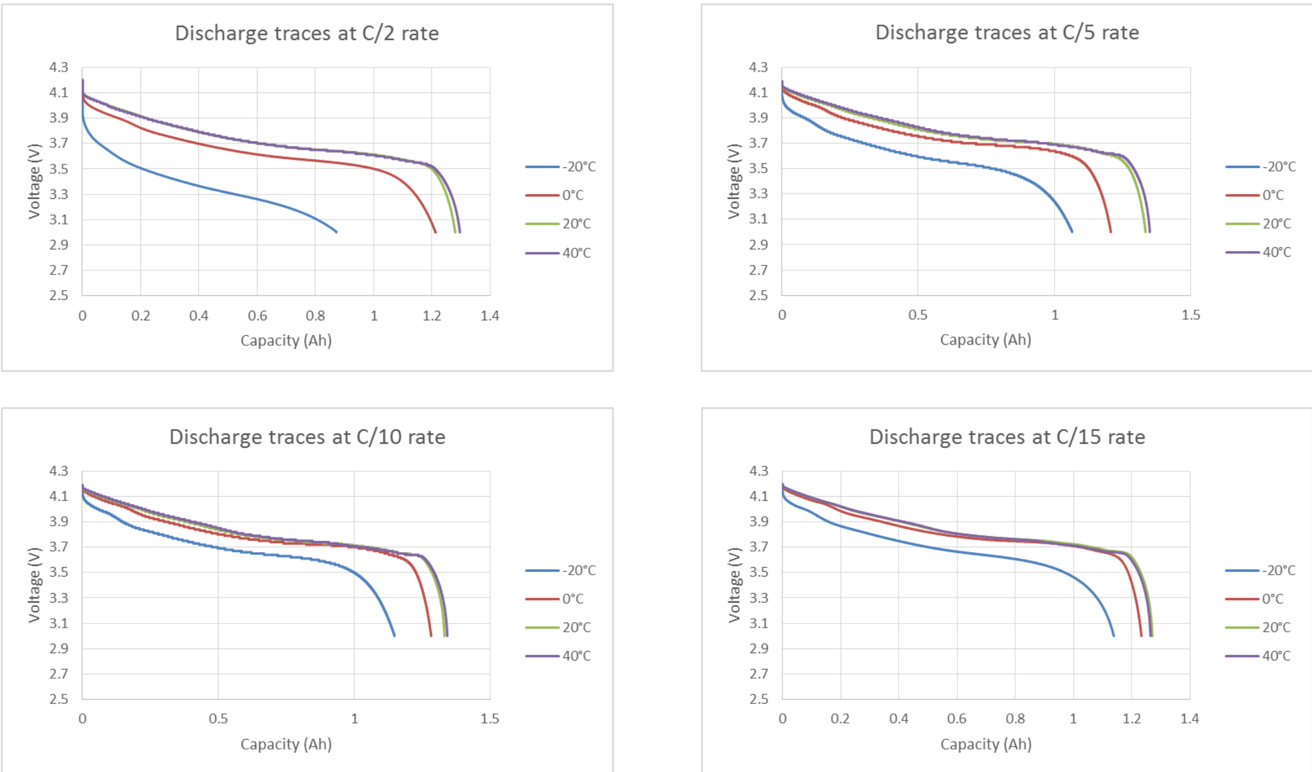

Figure 9-3 Cell discharge rates vs Capacity

9.2.2 Vacuum Cycling

Vacuum cycling was carried out in a chamber at less than 200mbar pressure and at ambient temperature in order to characterise the effects of low pressure on the lithium polymer cell.

Tolerance of a cell to low pressure and vacuum conditions depends on the internal arrangement of the cell electrodes and how well they remain in contact; to make the results more representative of a CubeSat battery under vacuum the cell under test was mechanically constrained as it would be in a battery assembly.

A plot of cell voltage vs. time for 5 cycles is shown in **Figure 9-4**; the cell was discharged at a rate of C/5. Capacity variation with cycle number is indicated in **Table 9-1**.

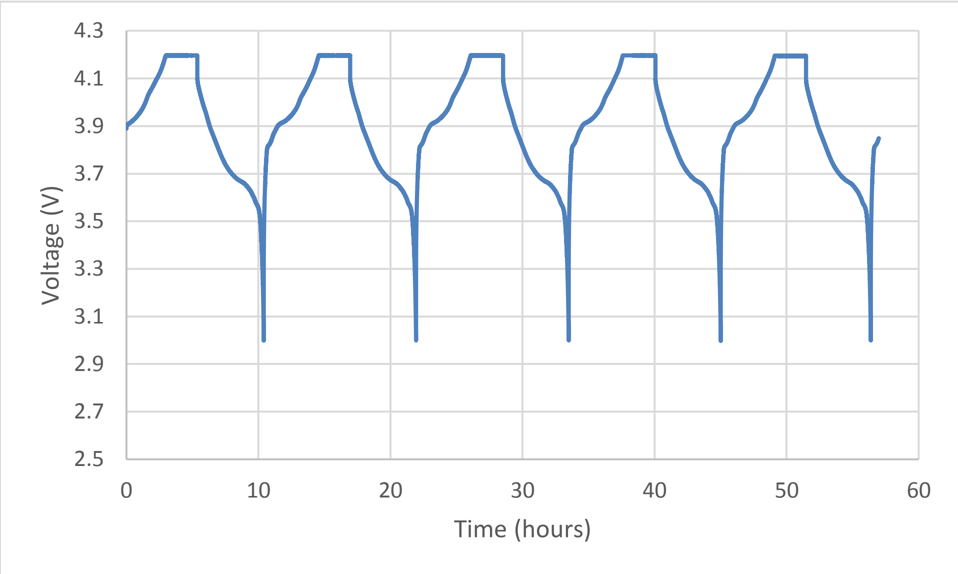

Figure 9-4 Cell cycled at C/5 rate in a vacuum

Cycle number	Cell Capacity (Ah)
1	1.272
2	1.268
3	1.257
4	1.251
5	1.241

Table 9-1 Cell capacity variation with vacuum cycle number

No change in cell mass was observed following the vacuum cycling (masses measured to 2 decimal places), and there was no evidence of any cell leakage, or any unusual behaviour in the cycling profile.

Standard capacity measurements were carried out following the vacuum cycling. Very little difference was seen in the capacity measured before and after vacuum cycling (1.322Ah before, 1.311Ah after). Vacuum cycling therefore did not have any significant detrimental effect on the cell capacity.

Although the cells ‘bulge’ in a vacuum, the spiral wound arrangement of the cell, and use of polymer electrolyte means that there is no separation of cell components in a vacuum, and therefore little effect on the cell cyclability.

9.2.3 EMF vs SoC

Cells were cycled at a slow rate, C/50, in order to minimise the cell internal resistance and therefore measure the cell capacity. This test was carried out at room temperature.

A plot of voltage vs. capacity is shown in **Figure 9-5**.

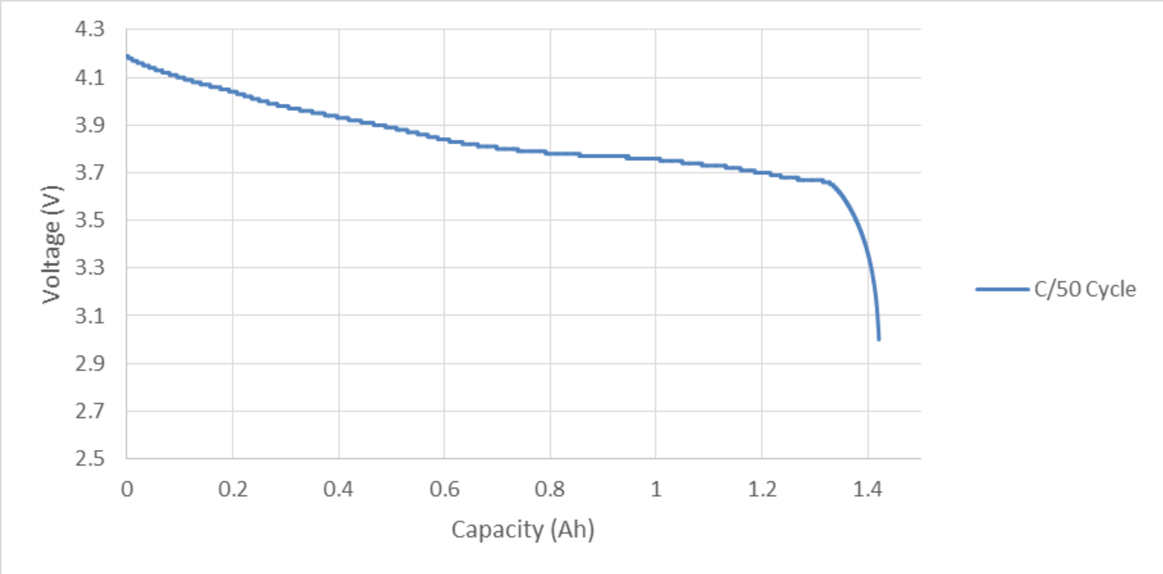

Figure 9-5 Discharge trace at C/50 rate at 20°C.

The capacity of the cell discharged at C/50 was approximately 1.452Ah, which is comparable to capacities at higher discharge rates and indicates the consistency of internal resistance with discharge rate for this particular brand of cell. Internal resistances have been estimated from previous figures at the cross-over point from discharge to charge. For cells cycled between C/2 up to C/50, internal resistances estimates were between 140millihoms up to 190millohms.

In **Table 9-2**, the cell voltage at different depth of discharge is shown for discharge rates of C/5 compared with C/50. It is clear from the table that the voltage remains higher as the discharge progresses at C/50 rate compared to C/5; this is due to the instantaneous effect of cell internal resistance causing a drop at the battery output proportional to the discharge current.

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DoD (%)	Voltage of cell discharged at C/5 (V)	Voltage of cell discharged at C/50 (V)
0	4.2	4.2
5	4.08	4.14
10	4.03	4.07
15	3.98	4.03
20	3.93	3.98
25	3.9	3.95
30	3.86	3.92
35	3.82	3.98
40	3.79	3.95
45	3.77	3.82
50	3.75	3.8
55	3.73	3.79
60	3.72	3.78
65	3.71	3.77
70	3.7	3.76
75	3.69	3.74
80	3.67	3.72
85	3.65	3.7
90	3.61	3.67
95	3.52	3.61
100	3	3

Table 9-2 Voltage variation with DoD at C/5, and at C/50

10 GENERAL PROTECTION

The battery (and wider power system) has a number of inbuilt protections and safety features designed to maintain safe operation of the EPS, battery and all subsystems supplied by the EPS buses.

10.1 Protection Overview

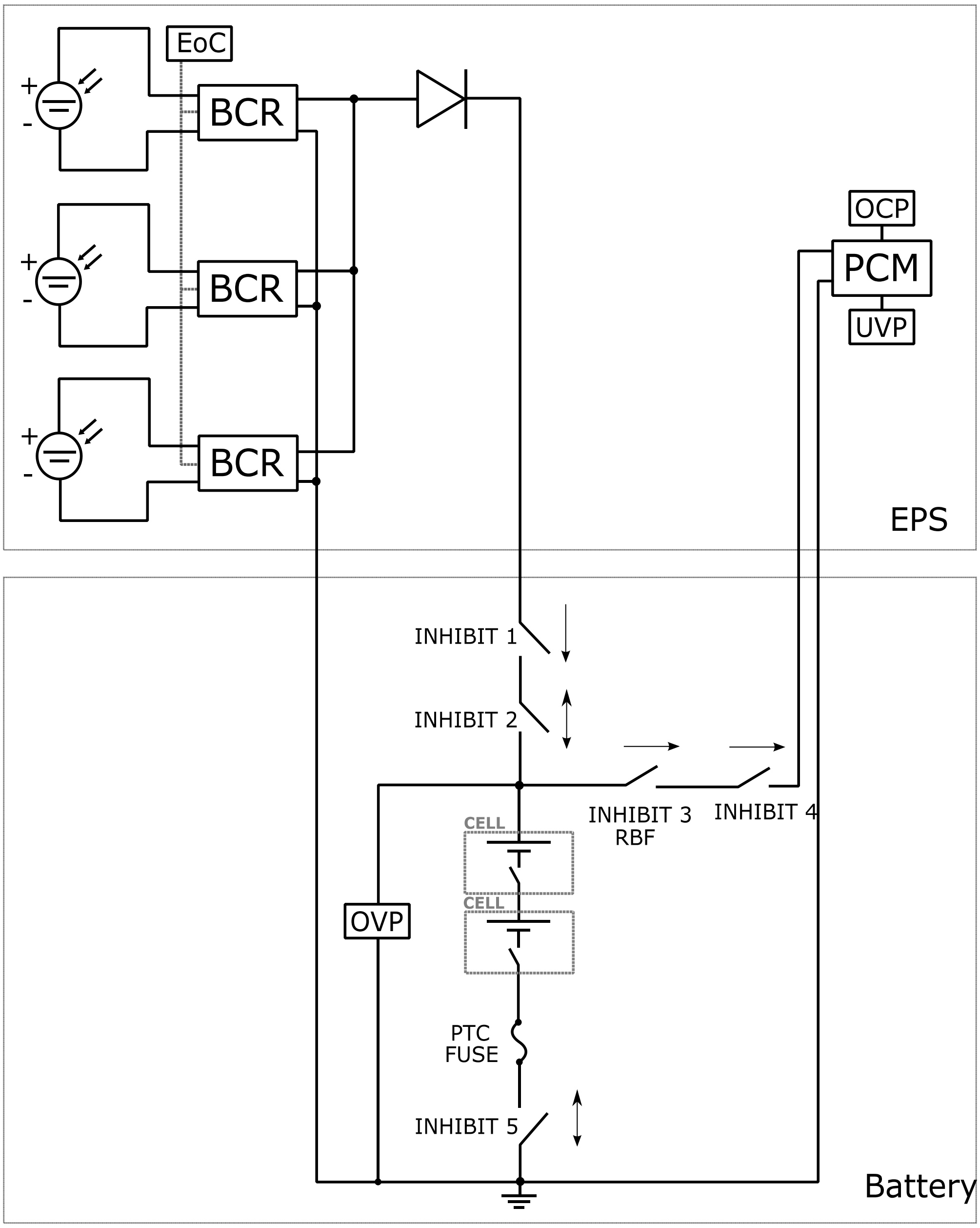

Figure 10-1 Integrated EPS and Battery Protection Architecture

A general overview of the protection systems implemented at both a battery level and EPS level is shown above in Figure 10-1; combined these protections are in place on all standard Clyde Space power systems, using the manned flight configuration.

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10.2 End of Charge

Once the EoC voltage has been reached by the battery, the BCR changes to EoC mode, which is a constant voltage charging regime. Please see Clyde Space EPS user manual for further details.

10.3 Over-Current Bus Protection (OCP)

Over-current protection is carried out on the EPS. Please see Clyde Space EPS user manual for further details.

10.4 Battery Under-voltage Protection (UVP)

Under-voltage protection is carried out on the EPS. Please see Clyde Space EPS user manual for further details.

10.5 Cell Level Protection Circuit

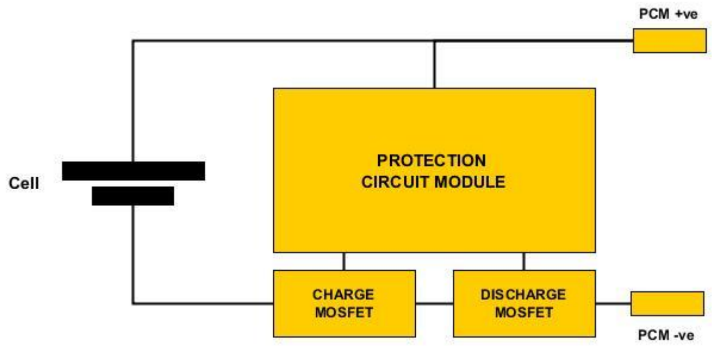

Figure 10-2 Cell level protection circuit schematic

Each cell within a battery assembly has a protection circuit fitted at its terminals – this protection circuit provides four different protection modes that inhibit charge or discharge when a battery is exposed to conditions beyond its rated limits. The protection circuit consists of a control IC with two back to back MOSFETs on the low-side connection.

It is the responsibility of the user to ensure that the electrical characteristics of the battery defined in this manual are not exceeded during normal operation; the cell level protection circuit will only activate when these values are exceeded. This means that consideration must be taken to ensure that a battery is appropriately sized in relation to its solar array and payload configuration for any given application.

Whilst each protection circuit is implemented at a cell level, the activation of a protection mode on any particular cell will have an impact on the entire battery assembly. A protection mode being triggered in one string of a battery will cause the remaining strings in the battery to also trigger as long as the external conditions persist. In this way the activation of multiple individual protections at a cell level will collectively inhibit or allow charge or discharge out of the battery assembly.

The four different protection modes are summarised below.

Protection Mode	Activation	Release
Cell Overcurrent – Charge	Charge current through string >2A for >10ms	Removal of charge via BCRs
Cell Overcurrent – Discharge	Discharge current through string >2A for >10ms	Application of charge and load current <2A
Cell Overvoltage	Cell voltage >4.275V	Removal of charge
Cell Undervoltage	Cell voltage drops below <2.3V	Application of charge via BCRs

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10.5.1 Cell Overcurrent – Discharge

In the event of a discharge current greater than 2A per string within the battery for a period of time greater than 10ms, the protection circuit will activate and will inhibit further discharge to the entire battery assembly. This means that all circuitry downstream of the batteries – power buses, EPS undervoltage monitoring, and I^2C nodes will be completely disabled whilst this protection mode is active.

Discharge protection will be disabled once a charge voltage is applied to the battery via the BCRs. During this time the output voltage measured at the terminals of the battery will not reflect the real battery voltage – care should be taken to distinguish between a battery that has triggered the overdischarge protection mode and a battery that has been physically damaged.

10.5.2 Cell Overcurrent – Charge

In the event of a charge current greater than 2A per string within the battery for a period of time greater than 10ms, the protection circuit will activate and will inhibit further charge to the entire battery assembly. The only way to activate this condition is to supply excessively large amounts of current via the BCRs – it should be ensured that a battery is appropriately sized in relation to any connected panel configuration.

Charge protection will be disabled once a load of any magnitude is applied to the battery.

10.5.3 Cell Overvoltage/Cell Undervoltage

Under normal conditions for a battery integrated with an EPS, the two cell level protection modes overvoltage and undervoltage will always be superseded by the EPS level protections for Undervoltage and End of Charge.

The main protection provided by the overvoltage and undervoltage modes is for the case of batteries in transit or otherwise not integrated with an EPS; for these scenarios the undervoltage and end of charge protection for the battery will not be present as these are based on the EPS. The cell level overvoltage and under voltage modes provide an extra layer of protection for an un-integrated battery, particularly in case of accidental over-discharge for when the battery is left unattended for long periods of time.

Whilst cell undervoltage protection is enabled, the battery voltage may read approximately 0V – as with the overdischarge protection mode, care should be taken to distinguish between a battery that has triggered the protection mode and a battery that has been physically damaged.

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10.6 Over-current Polyswitch Protection

A polyswitch is fitted in line with each string of the battery. This is a resettable fuse, designed to trip when an over-current, either charge or discharge, is observed by the string. The polyswitch should only activate in case of all other protections within the system being bypassed.

Temperature (°C)	Approximate Trip Current (A)
-40	7.0
-20	6.3
0	5.5
20	5.0
40	4.0
60	3.3

Table 10-1 Polyswitch Trip Current Variation with Temperature

The approximate fusing currents are shown in **Table 10-1** above**.** If the cause of the over-current subsequently clears, the fuse will reset, allowing current to flow to and from the battery again.

Once a polyswitch has been fused and reset once the resistance is unknown – as such the efficiency may be degraded following this event. Hence, if a polyswitch is fused during ground testing, it should be replaced.

10.7 Inhibit Operation

There are five separation switch operated inhibits built into the battery motherboard. When pins 1 and 2 of an inhibit connector are shorted together the inhibit is activated and no current can flow through the inhibit. When the pins 1 and 2 of the inhibit connector are open circuited the inhibit is disabled and current can freely flow through it.

As shown in Figure 10-1, there are four high side inhibits to prevent current flowing from the battery and solar arrays to the PCMs, as well as current from solar arrays to the battery. There is a low side inhibit on the battery to completely isolate the battery from the satellite. The RBF (Remove Before Flight) operates using the same circuitry as high side inhibit 3. Both the separation switch and RBF connector pins need to be open circuited before current can flow. Note that the arrows above inhibits in Figure 10-1 indicate the current direction that can be blocked when the inhibit is activated.

The 80Wh battery comprises two 40Wh units, each with independent inhibits. The two 40Wh assembly inhibit connections must be harnessed together. This will ensure that the inhibits of the two units operate together. An example of this harnessing for high side inhibit 1 is shown in Figure 10-3. All other inhibits, including the RBF, should use this same split harnessing.

The inhibits consist of solid state switching circuitry. The switching MOSFETs used have extremely low drain-source resistance for high efficiency. By using MOSFET switches directly on the battery motherboard compared to the conventional approach of wiring the separation switches to the mechanical switches, greater performance can be delivered. The main current loop is much smaller and this provides lower losses and decreases failure points. The electromagnetic interactions between the power system are minimised both internally to subsystems in the satellite and the earth's magnetic field.

Note: When the battery is mated to an EPS, the inhibits must be enabled while the system is not in use to prevent battery discharge. This is particularly important for the integrated battery as the EPS is always mated to the battery.

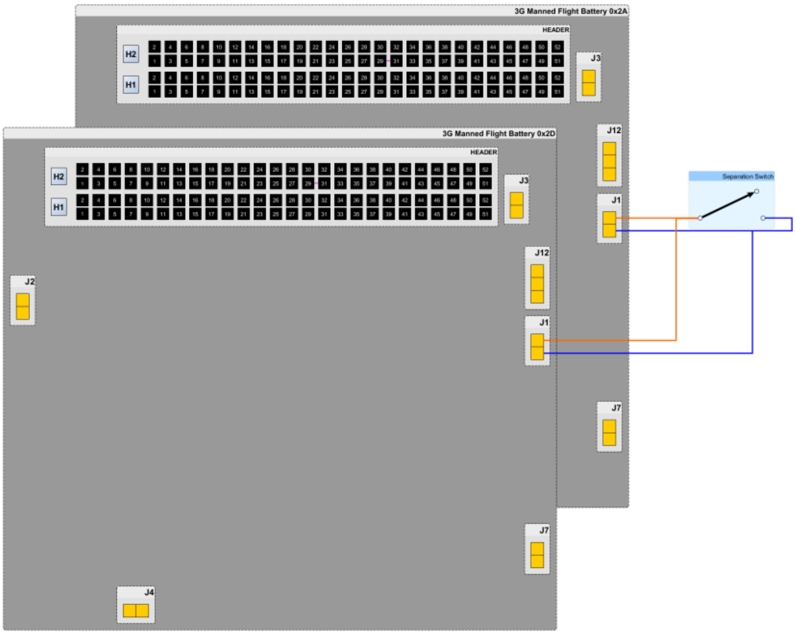

Figure 10-3 - Connection of high side inhibit 1 for 80Wh battery

10.8 Overvoltage protection (OVP)

In addition to the cell level overvoltage protection there is a safety mechanism for dealing with large voltage spikes at the positive terminal of the battery. This feature protects the battery in case of back EMF and other overvoltage events.

The excess energy will be discharged through an off-board shunt resistor that interfaces the battery board through connector J8 (see Section 8 Interfacing). The connector is an 8 pin male header (Hirose DF13-8P-1.25DSA(50)): pins 1-4 connect to one end of the resistor and pins 5-8 connect to the other end.

Shunt resistor requirements:

- 15 Ohms
- 25W rated (e.g. THS2515RJ)
- Mounted to a heat tolerant/dissipative part of the structure

Clyde Space offers a shunt resistor with an integrated harness (27-01472). Please contact Clyde Space for further information.

11 HEATER OPERATION

Each battery string has its own autonomous heater, designed to maintain the temperature of the batteries above 0°C to maximise the capacity of the battery.

The heater is controlled by a thermostat circuit with hysteresis. When the temperature of the board drops below 1°C the heater on each board will switch on, drawing power from the 3V3 Bus (or 5V if configured for it). This can be observed via the heater telemetry. Once the temperature rises above 5°C the heater will switch off.

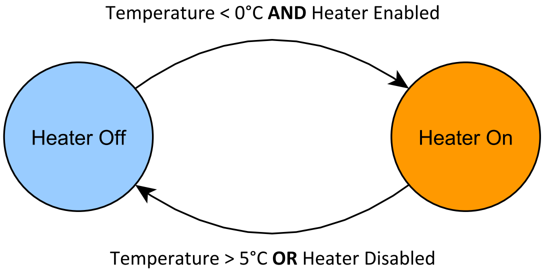

Figure 11-1 Operation of the Heater Control circuitry

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12 TELEMETRY AND TELECOMMAND

12.1 Communications

All communications to the Telemetry and Telecommand (TTC) node are made using an I²C interface which is configured as a slave and only responds to direct commands from a master I²C node - no unsolicited telemetry is transmitted. The 7-bit I²C address of the TTC node is factory set at 0x2A (10-40Wh batteries only) and the I²C node operates at a 100kHz bus clock. For the 80Wh battery, one of the 40Wh units operates on I²C address 0x2A and the other on 0x2D. Refer to the CoC for each unit to determine the I²C address of each.

12.2 Command Protocol

Two message structures are available to the master; a write command and a read command. The write command is used to initiate an event and the read command returns the result. All commands start with the 7 bit slave address and are followed by the data bytes. When reading responses, all data bytes should be read out together. Each command has a delay associated with it, this is required to allow the microcontroller time to process each request.

For a write command the first data byte will determine the command to be initiated. The second byte contains the parameters associated with that command. For commands which have no specific requirement for a parameter the second data byte should be set to 0x00.

For a read command, the first data byte represents the most significant byte of the result and the second data byte represents the least significant byte.

Before sending a command, the master is required to set a start condition on the I²C bus. Between each byte the receiving device is required to acknowledge receipt of the previous byte in accordance with the I²C protocol. This will often be accommodated within the driver hardware or software of the I²C master however the user should ensure that this is the case.

The read and write command definitions are illustrated in **Figure 12-1**.

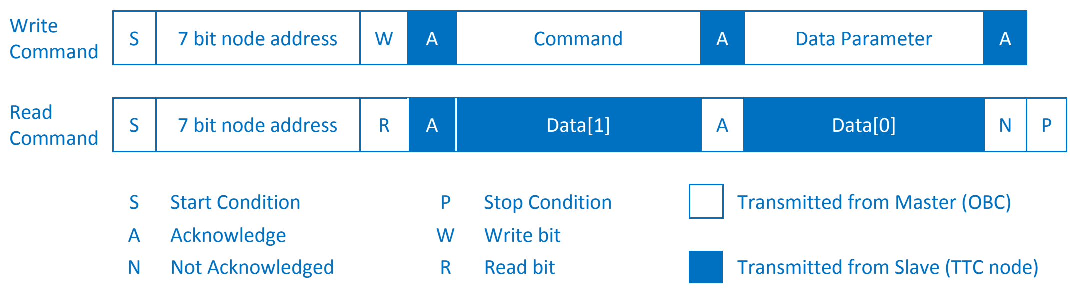

Figure 12-1 I²C Write and Read of 2 byte command packet

If an error has been generated from a command then the return value will be 0xFFFF. If this value is returned it is recommended to either inspect the status bytes or to request the code representing the last error generated on the board as described in **Section 12.4.2**.

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12.3 List of Available Commands

Name	Command	Data[1][1]	Data[0]	Bytes Returned	W/R Delay
Board Status	0x01	NA	0x00	2	< 1
Get Last Error	0x03	NA	0x00	2	< 1
Get Version	0x04	NA	0x00	2	< 1
Get Checksum	0x05	NA	0x00	2	35
Get Telemetry	0x10	*Table 12-8*		2	5
Get Number of Brown-out Resets	0x31	NA	0x00	2	<1
Get Number of Auto Software Resets	0x32	NA	0x00	2	< 1
Get Number of Manual Resets	0x33	NA	0x00	2	< 1
Get Heater Controller Status	0x90	NA	0x00	2	< 1
Set Heater Controller Status	0x91	NA	*Mode*	2	-
Manual Reset	0x80	NA	0x00	0	-

[1] Where a command has Data[1] listed as NA, the command only requires a single data byte to be transmitted. This is given by Data[0].

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12.4 Housekeeping and Status Commands

12.4.1 Board Status (0x01)

Command	Data[0]	Bytes Returned	Delay, ms
0x01	0x00	2	< 1

The status bytes are designed to supply operational data about the I^2C Node. To retrieve the data that represent the status, the command **0x01** should be sent followed by **0x00**. The meaning of each bit of the returned status bytes is shown below. Please note that Data[1] is the first byte returned and Data[0] is the last, this is shown in detail by Figure 12-1.

Data[n]	Bit	Description
0	0	Set **HIGH** if last command not recognised
	1	Set **HIGH** if a watchdog error occurred, resetting the device
	2	Set **HIGH** if the data sent along with the last command was incorrect
	3	Set **HIGH** if the channel passed with the last command was incorrect
	4	Set **HIGH** if there has been an error reading the EEPROM
	5	Set **HIGH** if a Power On Reset error occurred
	6	Set **HIGH** if a Brown Out Reset occurred
	7	Set **HIGH** if Heater Thermostat Circuitry is Active
1	0	Unused
	…	
	7	

Table 12-2 Status bits for 3G Battery

12.4.2 Get Last Error (0x03)

Command	Data[0]	Bytes Returned	Delay, ms
0x03	0x00	2	< 1

If an error has been generated after attempting to execute a user's command the value 0xFFFF is returned. To find out the details of the last error, send the command **0x03** followed by the data byte **0x00**. This will return the code of the last error generated. Details of each error code are given by Table 12-3.

Code	Description
0x10	CRC code does not match data
0x01	Unknown command received
0x02	Supplied data incorrect when processing command
0x03	Selected channel does not exist
0x04	Selected channel is currently inactive
0x13	A reset had to occur
0x14	There was an error with the ADC acquisition
0x20	Reading from EEPROM generated an error
0x30	Generic warning about an error on the internal SPI bus (only if daughterboard is connected)

Table 12-3 List of Clyde Space Error Codes

12.4.3 Get Version (0x04)

Command	Data[0]	Bytes Returned	Delay, ms
0x04	0x00	2	< 1

The version number of the firmware will be returned on this command. The firmware version number is encoded in the following way:

	Data[1]								Data[0]							
Bit	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Value	Battery Firmware Rev				Battery Firmware Number											

Table 12-4 Version Number Breakdown

The revision number returns the current revision of the firmware that is present on the board. The firmware number returns the current firmware on the board.

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12.4.4 Get Checksum (0x05)

Command	Data[0]	Bytes Returned	Delay, ms
0x05	0x00	2	35

This command instructs the node to self-inspect its ROM contents in order to generate a checksum. The value retrieved can be used to determine whether the contents of the ROM have changed during the operation of the device.

	Data[1]								Data[0]							
Bit	7	6	5	4	3	2	1	0	7	6	5	4	3	2	1	0
Value	Firmware Checksum															

12.4.5 Manual Reset (0x80)

Command	Data[0]	Bytes Returned	Delay, ms
0x80	0x00	0	-

If required the user can reset the TTC node using this command. When issued, the board will reset within 1 second. This command will result in the board being brought up in its defined initial condition.

Resetting the board in this fashion will increment the Manual Reset Counter. More details about this counter are found in **Section 12.7.3**.

12.5 Telemetry

The node telemetries allow the satellite's on board computer (OBC) to monitor the operation of the battery.

The telemetry node interfaces to the various sensing circuits on the battery through an analogue multiplexer. In response to I^2C telemetry requests, the microcontroller will configure the analogue multiplexer to connect the desired telemetry channel to the analogue to digital converter (ADC). The microcontroller will sample the desired channel and allow it to be read over the I^2C bus. In response to a telecommand the telemetry node will decode the incoming message and reset the desired power bus.

An abridged example of the I^2C node is illustrated by **Figure 12-1**

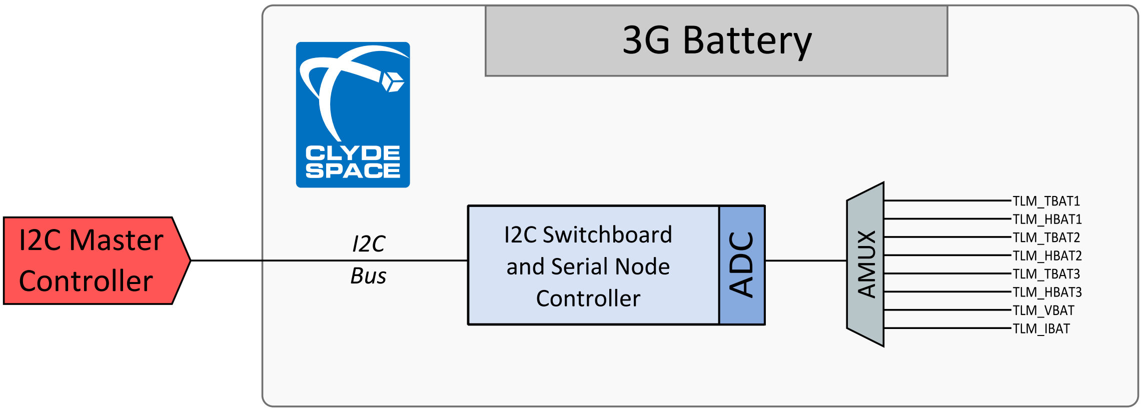

Figure 12-1 Abridged telemetry functional diagram

Each available telemetry is represented by a two byte code. These codes consist of:

- What type of telemetry is requested, i.e. PDM or PCM, analogue inputs, or some other form of sensor.
- The channel being requested.
- The reading to take; whether it's voltage, current, temperature etc.

A break-down of the telemetry structure is given in Table 12-5. The Telemetries which are available for this board are given in **Table 12-8**. If a telemetry is requested which is not available, a Channel Error will be generated.

Data[1]				Data[0]			
Nibble 3		Nibble 2		Nibble 1		Nibble 0	
Family	**Code**	**TLM Type**	**Code**	**Channel**	**Code**	**Attribute**	**Code**
Power Systems	E	Main Power	2	Core Bus Miscellaneous	0 to 7 8 to F	Voltage	0
						Current	A
Power Systems	E	Temperature	3	Main Board	0 to 7	Temperature	8

Table 12-5 Break down of Clyde Space telemetry code structure.

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12.6 Get Telemetry (0x10)

Command	Data[1]	Data[0]	Bytes Returned	Delay, ms
0x10	0xE?	0x??	2	5

As described above, requesting telemetry involves sending the command 0x10 plus a 2 byte telemetry code to the node. Once transmitted, the node will configure itself to read the requested value. The data returned will be in the format shown in Table 12-6.

Data[1]								Data[0]							
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	0	0	0	0	0	ADC Result									

Table 12-6 ADC result return format

The result should then be converted to physical units via the conversion equations in **Table 12-8**. The equations provided in **Table 12-8** are the theoretical equations for the system. If more accurate telemetry results are required, tailored equations are available from the test report for the individual product which will be supplied with the hardware. The advantage of using tailored equations is that they compensate for component tolerances and parasitic losses in an individual build of a battery, however the tailored equations will vary slightly for every battery manufactured and therefore may be different between flight and engineering model hardware.

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Name	TLE Code	Description	Uncalibrated Conversion Equation	Units	Availability[1]			
					10Whr	20Whr	30Whr	40Whr
TLM_VBAT	0xE280	Battery Output Voltage	0.008993 x ADC	V	✓	✓	✓	✓
TLM_IBAT	0xE284	Battery Current Magnitude	14.662757 x ADC	mA	✓	✓	✓	✓
TLM_IDIRBAT	0xE28E	Battery Current Direction	ADC < 512 Charging; Else Discharging	-	✓	✓	✓	✓
TLM_TBRD	0xE308	Motherboard Temperature	(0.372434 x ADC) -273.15	°C	✓	✓	✓	✓
TLM_IPCM5V	0xE214	Current Draw of 5V Bus	1.327547 x ADC	mA	✓	✓	✓	✓
TLM_VPCM5V	0xE210	Output Voltage of 5V Bus	0.005865 x ADC	V	✓	✓	✓	✓
TLM_IPCM3V3	0xE204	Current Draw of 3.3V Bus	1.327547 x ADC	mA	✓	✓	✓	✓
TLM_VPCM3V3	0xE200	Output Voltage of 3.3V Bus	0.004311 x ADC	V	✓	✓	✓	✓
TLM_TBAT1	0xE398	Daughterboard 1 Temperature	(0.397600 x ADC) -238.57	°C	✓	✓	✓	✓
TLM_HBAT1	0xE39F	Daughterboard 1 Heater Status	ADC < 512 Heater Off; Else On.	-	✓	✓	✓	✓
TLM_TBAT2	0xE3A8	Daughterboard 2 Temperature	(0.397600 x ADC) -238.57	°C	-	✓	✓	✓
TLM_HBAT2	0xE3AF	Daughterboard 2 Heater Status	ADC < 512 Heater Off; Else On.	-	-	✓	✓	✓
TLM_TBAT3	0xE3B8	Daughterboard 3 Temperature	(0.397600 x ADC) -238.57	°C	-	-	✓	✓
TLM_HBAT3	0xE3BF	Daughterboard 3 Heater Status	ADC < 512 Heater Off; Else On.	-	-	-	✓	✓
TLM_TBAT4	0xE3C8	Daughterboard 4 Temperature	(0.397600 x ADC) -238.57	°C	-	-	-	✓
TLM_HBAT4	0xE3CF	Daughterboard 4 Heater Status	ADC < 512 Heater Off; Else On.	-	-	-	-	✓

Table 12-7 List of Telemetry Codes for the 3G Battery range

[1] If telemetry is requested from a TLE code which is not available on your battery model, the returned data should be discarded.

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12.7 Watchdogs and Reset Counters

12.7.1 Get Number of Brown-out Resets (0x31)

Command	Data[0]	Bytes Returned	Delay, ms
0x31	0x00	2	<1

This counter is designed to keep track of the number of brown-out resets that have occurred. This counter will roll over at 255 to 0.

12.7.2 Get Number of Automatic Software Resets (0x32)

Command	Data[0]	Bytes Returned	Delay, ms
0x32	0x00	2	< 1

If the on-board microcontroller has experienced a malfunction, such as being stuck in a loop, it will reset itself into a pre-defined initial state. Using this command, **0x32,** it is possible to retrieve the number of times this reset has occurred.

12.7.3 Get Number of Manual Resets (0x33)

Command	Data[0]	Bytes Returned	Delay, ms
0x33	0x00	2	< 1

A count is kept of the number of times the device has been manually reset using the Reset command. Sending the command **0x33** with data byte **0x00** will return the number of times the device has been reset in this fashion.

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12.8 Heater Commands

12.8.1 Get Heater Controller Status (0x90)

Command	Data[0]	Bytes Returned	Delay, ms
0x90	0x00	2	1

Return the current status of the battery heater controller. Return codes listed in **Table 12-8**.

12.8.2 Set Heater Controller Status (0x91)

Command	Data[0]	Bytes Returned	Delay, ms
0x91	*Heater Code*	0	1

Control the operation of the battery heater circuitry. If **enabled** the battery will activate its heater when the cells temperature drops below a predefined value. When **disabled** the heater will remain off regardless of the sensed temperature. An illustration of the heater control operation is shown by **Figure 11-1**

Code	Description
0x00	Thermostat control circuitry **disabled**. Heater will remain off, regardless of conditions.
0x01	Thermostat control circuitry **enabled**. Heater will switch on when on-board thermostat senses it's appropriate.

Table 12-8 Description of heater status byte

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13 LAUNCH PROVIDER INFORMATION

When integrated into suitable platforms the Clyde Space 3rd Generation CubeSat battery family are compatible with a wide variety of launch platforms including manned missions. If you are intending to launch your CubeSat from a manned flight platform please refer to [RD-4] 'TN-1404 Use of the Clyde Space 3rd Generation CubeSat Battery on manned missions' for further information including safety qualification, answers to common launch provider questions and additional acceptance testing required to meet the necessary safety conditions.

15 TEST

All batteries are fully tested prior to shipping, and test reports are supplied. In order to verify the operation of the batteries please use the following instructions. In order to safely test the battery, it should be connected to a Clyde Space EPS.

NOTE: *Any charging and discharging of the battery will reduce the battery capacity, especially large DoD (Depth of Discharge) testing. Consider this when performing any testing of the battery mentioned below. Particular care should be taken not to reduce flight model battery capacity before launch.*

The following is a step by step introduction in how to connect the battery and verify its operation.

In order to test the functionality of the battery you will require:

- EPS
- Array Input (test panel, solar array simulator or power supply with limiting resistor)
- Oscilloscope
- Multimeter
- Electronic Load
- Aardvark I^2C adaptor (or other means of communicating on the I^2C bus)

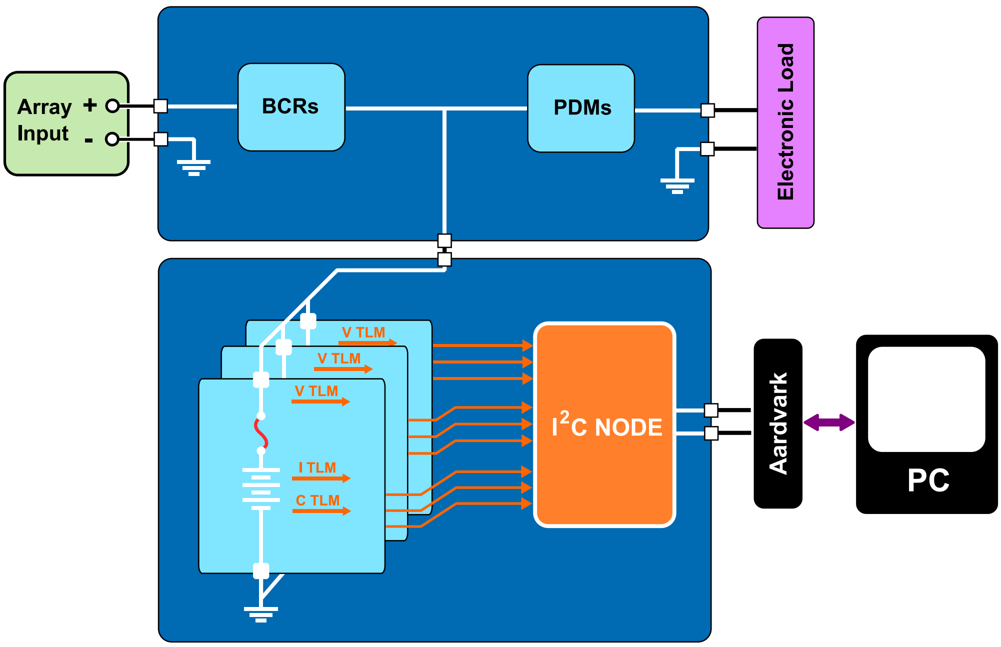

Figure 15-1 Suggested Test Setup

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15.1 Battery Stackup

If using an 80Wh battery, it will have to be stacked up prior to test. Ensure that appropriate standoffs are used to support the battery and ensure that the CSK header is not damaged. Dimensions are shown in section 7.4.5.

15.2 Solar Array Input

Testing should be performed with an EPS. See the appropriate user manual for this product.

15.3 Power Up/Down Procedure

The order of assembly should follow:

- Connect battery to stack
- Connect electronic load to battery bus
- Activate separation and RBF switches to link the connections between BCR_OUT, BAT_POS and PCM_IN to allow current to flow.
- Connect array input

When powering down, this process should be followed in reverse.

15.4 Configuration and Testing

The following section outlines the procedure for performing basic functional testing. An EPS is required to safely test the battery ensuring the EPS protects the battery from being damaged. Therefore some of the following sections mention functions within the EPS necessary for battery testing.

15.4.1 Battery Discharge

Ensure that the separation and RBF switches are not activated. All buses will be activated and can be measured with a multimeter. By increasing the load on the battery bus you will be able to see the battery voltage decrease and battery current show discharge status.

15.4.2 Undervoltage Protection

All testing should be performed in conjunction with a Clyde Space EPS. Please refer to the EPS user manual for further details on performing undervoltage protection testing.

15.4.3 BCR Testing

All testing should be performed in conjunction with a Clyde Space EPS. Please refer to the EPS user manual for further details on performing BCR testing.

15.4.4 EoC Operation

All testing should be performed in conjunction with a Clyde Space EPS. Please refer to the EPS user manual for further details on performing End of Charge testing.

15.4.5 Telemetry Testing

The 3V3 and 5V bus voltage and current telemetry can be queried using the I^2C interfacing shown in the telemetry section of this user manual. This provides information on the current power consumption of the battery I^2C node.

While charging and discharging, the current magnitude and direction telemetry can be read. The voltage of the battery can also be read.

If the battery is used in a thermal chamber to drop the temperature, the heater telemetries can be read to monitor the operation of the heaters for each board in the battery stack. The temperature of each board can also be read.

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16 Compatible Systems

Battery compatibility must take into account the BCR capability provided by the EPS as well as the peak output power provided by the connected solar arrays.

	Stacking Connector	EPS	Arrays	Notes
Standalone 10Whr (01-02683)	CubeSat Kit Bus	25-02451 – 3G EPS (1UB) No Inhibits	Clyde Space -2-3 Cell solar array	Peak battery charge current following BCR stage not to exceed 2A
			N/A - Clyde Space 4-8 Cell solar array	
			Other array technologies[1]	
		25-02452 – 3G EPS (3UA) No Inhibits	Clyde Space 2-3 Cell solar array	Peak battery charge current following BCR stage not to exceed 2A
			Clyde Space 4-8 Cell solar array	
			Other array technologies	
		01-02453 – 3G EPS (XUA) No Inhibits	Clyde Space 2-3 Cell solar array	Peak battery charge current following BCR stage not to exceed 2A
			Clyde Space 4-8 Cell solar array	
			Other array technologies[6]	
Standalone 20Whr (01-02684)	CubeSat Kit Bus	25-02451 – 3G EPS (1UB) No Inhibits	Clyde Space 2-3 Cell solar array	Peak battery charge current following BCR stage not to exceed 4A
			N/A - Clyde Space 4-8 Cell solar array	
			Other array technologies	
		25-02452 – 3G EPS (3UA) No Inhibits	Clyde Space 2-3 Cell solar array	Peak battery charge current following BCR stage not to exceed 4A
			Clyde Space 4-8 Cell solar array	
			Other array technologies	
		01-02453 – 3G EPS (XUA) No Inhibits	Clyde Space 2-3 Cell solar array	Peak battery charge current following BCR stage not to exceed 4A
			Clyde Space 4-8 Cell solar array	
			Other array technologies[6]	
Standalone 30Whr (01-02685)	CubeSat Kit Bus	25-02451 – 3G EPS (1UB) No Inhibits	Clyde Space 2-3 Cell solar array	Peak battery charge current following BCR stage not to exceed 6A
			N/A - Clyde Space 4-8 Cell solar array	
			Other array technologies	
		25-02452 – 3G EPS (3UA) No Inhibits	Clyde Space 2-3 Cell solar array	Peak battery charge current following BCR stage not to exceed 6A
			Clyde Space 4-8 Cell solar array	
			Other array technologies	
		01-02453 – 3G EPS (XUA) No Inhibits	Clyde Space 2-3 Cell solar array	Peak battery charge current following BCR stage not to exceed 6A
			Clyde Space 4-8 Cell solar array	
			Other array technologies[6]	
Standalone 40Whr (01-02686)	CubeSat Kit Bus	25-02451 – 3G EPS (1UB) No Inhibits	Clyde Space 2-3 Cell solar array	Peak battery charge current following BCR stage not to exceed 8A
			N/A - Clyde Space 4-8 Cell solar array	
			Other array technologies	
		25-02452 – 3G EPS (3UA) No Inhibits	Clyde Space 2-3 Cell solar array	Peak battery charge current following BCR stage not to exceed 8A
			Clyde Space 4-8 Cell solar array	
			Other array technologies	
			Clyde Space 2-3 Cell solar array	
			Clyde Space 4-8 Cell solar array	

[1] Any array technologies that conform to the BCR input ratings for Voltage and Current. Consult EPS user manual or contact Clyde Space for more details.

		01-02453 – 3G EPS (XUA) No Inhibits	Other array technologies[6]	Peak battery charge current following BCR stage not to exceed 8A
Standalone 80Whr (01-02687)	CubeSat Kit Bus	25-02451 – 3G EPS (1UB) No Inhibits	Clyde Space 2-3 Cell solar array	Peak battery charge current following BCR stage not to exceed 16A
			N/A - Clyde Space 4-8 Cell solar array	
			Other array technologies	
		25-02452 – 3G EPS (3UA) No Inhibits	Clyde Space 2-3 Cell solar array	Peak battery charge current following BCR stage not to exceed 16A
			Clyde Space 4-8 Cell solar array	
			Other array technologies	
		01-02453 – 3G EPS (XUA) No Inhibits	Clyde Space 2-3 Cell solar array	Peak battery charge current following BCR stage not to exceed 16A
			Clyde Space 4-8 Cell solar array	
			Other array technologies[6]	

	Stacking Connector	EPS	Arrays	Notes
Integrated 10Whr (01-	N/A – Stacking connector present on 1U/3U EPS Motherboard	25-02451 – 3G EPS (1UB) No Inhibits	Clyde Space 2-3 Cell solar array	Peak battery charge current following BCR stage not to exceed 2A
			N/A - Clyde Space 4-8 Cell solar array	
			Other array technologies	
Integrated 20Whr (01-	N/A – Stacking connector present on 1U/3U EPS Motherboard	25-02451 – 3G EPS (1UB) No Inhibits	Clyde Space 2-3 Cell solar array	Peak battery charge current following BCR stage not to exceed 4A
			N/A - Clyde Space 4-8 Cell solar array	
			Other array technologies	