User Manual CS-XUEPS2-60: FleXU CubeSat Electronic Power System Part #: 01-00732 and 01-01120

Document No.: USM-01-00732

Issue: D

Date: 20/03/2014

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Document Control

Issue	Date	Section	Description of Change	Reason for Change
A	27/01/12	All	First Draft – based on C3D-USM-5023-DLR-EPS2	**N/A**
B	30/1/13	All	Update to reflect hardware update to Rev B.	**Respin of daughterboard PCB to implement improvements from first build**
C	06/09/2013	All	Correction of errors as detailed in ECN 174. Update of TLM equations to match build revision	
D	**20/03/13**	**Table 8-2, Table 8-3, Table 11-5**	**Update Array naming, connector naming and BCR connection to simplify.**	**Customer Request**

Revision Control

Product	Part Number	Build Revision	Notes
FleXU Electronic Power System with 6x12W BCR and 12V regulator	**01-00732**	**D**	

Acronyms and Abbreviations

BCR	Battery Charge Regulator
PCM	Power Conditioning Module
PDM	Power Distribution Module
MPPT	Maximum Power Point Tracker
USB	Universal Serial Bus
ESD	Electro Static Discharge
TLM	Telemetry
EPS	Electrical Power System
EoC	End of Charge
AMUX	Analogue Multiplexer
ADC	Analogue to Digital Converter
AIT	Assembly, Integration and Testing
3U	3 Unit
DEPS	Deployed Electrical Power System
rh	Relative Humidity
DoD	Depth of Discharge
$Kbits^{-1}$	Kilobits per second
Voc	Open Circuit Voltage
Isc	Short Circuit Current

Related Documents

No.	Document Name	Doc Ref.
RD-1	CubeSat Design Specification	CubeSat Design Specification Rev. 12

⚠ Warning ⚠	Risk
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
Ensure switching configuration is implemented correctly before applying power to EPS	If power is applied with incorrect switch configuration, the output of the BCR can be blown, causing failure of the EPS
Observe ESD precautions at all times	The EPS is a static sensitive system. Failure to observe ESD precautions can result in failure of the EPS.
Ensure not to exceed the maximum stated limits	Exceeding any of the stated maximum limits can result in failure of the EPS
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
No connection should be made to H2.35-36	These pins are used to connect the battery to the EPS. Any connections to the unregulated battery bus should be made to pins H2.43-44
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.

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1. Introduction

This document provides information on the features, operation, handling and storage of the Clyde Space FlexU 6-0 EPS. The FlexU 6-0 EPS is designed to integrate with a suitable battery and with a maximum of 12 solar array strings to form a complete power system for use on a CubeSat or NanoSat. Figure 1-1 provides a top level system diagram of the FlexU 6-0 EPS. There are two variations on the FlexU 6-0 EPS, the standard version has Clyde Space part number 01-00732 while the second version contains additional Omnetics connectors for solar array harnessing and is part number 01-01120.

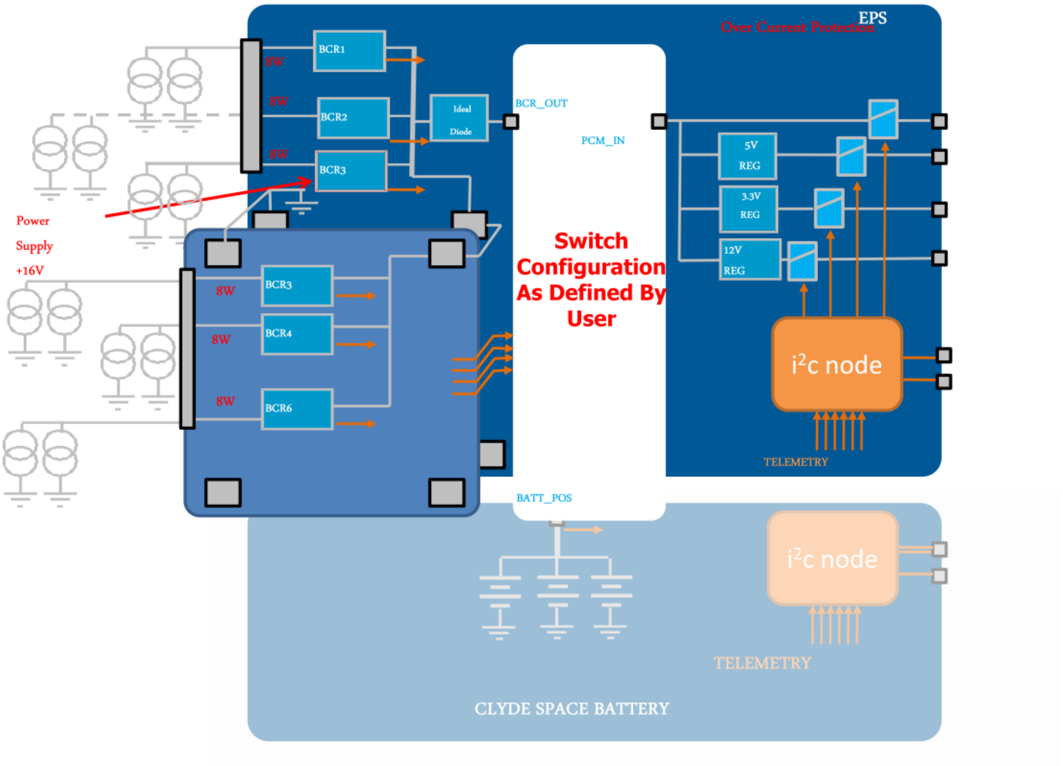


Figure 1-1 System Diagram

1.1 Additional Information Available Online

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

1.2 Continuous Improvement

Clyde Space is continuously improving its processes and products. We aim to provide full visibility of changes and updates. This information can be found at www.clyde-space.com.

1.3 Document Revisions

In addition to hardware and software updates, we also make regular updates to our documentation and online information. Notes of updates to documents can also be found at www.clyde-space.com.

2. OVERVIEW

This is the second generation of Clyde Space CubeSat Electronic Power System (EPS), 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 250 EPS to customers in Europe, Asia and North America. The second generation EPS builds on the heritage gained with the first, whilst adding over 50% additional power delivery capability. Furthermore, we have also implemented an ideal diode mechanism to ensure zero draw on the battery in launch configuration.

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.

3. MAXIMUM RATINGS[(1)]

OVER OPERATING TEMPERATURE RANGE (UNLESS OTHERWISE STATED)				
		BCR	Value	Unit
Input Voltage[(2)]	J1 pins 2&5 or SA1 pins 1&4	BCR1 (12W)	30	V
	J1 pins 8&11 or SA2 pins 1&4	BCR2 (12W)	30	V
	J1 pins 13 or SA3 pins 1&4	BCR3 (12W)	30	V
	J2 pins 11&8 or SA4 pins 1&4	BCR4 (12W)	30	V
	J2 pins 5&2 or SA5 pins 1&4	BCR5 (12W)	30	V
	J2 pins 13 or SA6 pins 1&4	BCR6 (12W)	30	V
	Battery		8.4	V
	5V Bus		5.05	V
	3.3V Bus		3.33	V
	12V Bus		12.12	V
			Value	Unit
Input Current	SA1.1 (BCR1)	@7.4V	1000	mA
	SA1.4 (BCR1)	@7.4V	1000	mA
	BCR1 (total SA1.1 + SA1.4)	@7.4V	1622	mA
	SA2.1 (BCR2)	@7.4V	1000	mA
	SA2.4 (BCR2)	@7.4V	1000	mA
	BCR2 (total SA2.1 + SA2.4)	@7.4V	1622	mA
	SA3.1 (BCR3)	@7.4V	1000	mA
	SA3.4 (BCR3)	@7.4V	1000	mA
	BCR3 (total SA3.1 + SA3.4)	@7.4V	1622	mA
	SA4.1 (BCR4)	@7.4V	1000	mA
	SA4.4 (BCR4)	@7.4V	1000	mA
	BCR4 (total SA4.1 + SA4.4)	@7.4V	1622	mA
	SA5.1 (BCR5)	@7.4V	1000	mA
	SA5.4 (BCR5)	@7.4V	1000	mA
	BCR5 (total SA5.1 + SA5.4)	@7.4V	1622	mA
	SA6.1 (BCR6)	@7.4V	1000	mA
	SA6.4 (BCR6)	@7.4V	1000	mA
	BCR6 (total SA6.1 + SA6.4)	@7.4V	1622	mA
Output Current	BCR1-6	@6.2V	1800	mA
	Battery Bus	@8.26V	4.1	A
	5V Bus	@5V	4.1	A

	3.3V Bus	@3.3V	4.1	A
	12V Bus	@12V	1.1	A
Operating Temperature			-40 to +85	°C
Storage Temperature			-50 to +100	°C
Vacuum			10^{-5}	torr
Radiation Tolerance			15	kRad

Table 3-1 Performance Characteristics of the EPS

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

(2) De-rating of power critical components is in accordance with ECSS guidelines.

4. Electrical Characteristics

Description	Conditions	Min	Typical	Max	Unit
12W BCR (1-6)					
Input Voltage		7.4	--	25	V
Output Voltage		6.2	--	8.26	V
Output Current		0	--	1.2	A
Switching Frequency		140	150	160	KHz
Efficiency	@16.5V input, Full Load	85%	90%	92%	
Unregulated Battery Bus					
Output Voltage		6.2	--	8.26	V
Output Current	Continuous operation	--	--	4.1	A
Operating Frequency		--	--	--	
Efficiency	@8.2V input, Full Load	98.5%	99%	99.5%	
5V Bus					
Output Voltage		4.95	5	5.05	V
Output Current	Continuous operation	--	--	4.1	A
Operating Frequency		470	480	490	kHz
Efficiency	@5V input, Full Load	95%	96%	98%	
3.3V Bus					
Output Voltage		3.276	3.3	3.333	V
Output Current	Continuous operation	--	--	4.1	A
Operating Frequency		470	480	490	kHz
Efficiency	@3.3V input, Full Load	95%	96%	98%	
12V Bus					
Output Voltage		11.88	12	12.12	V
Output Current	Continuous operation	--	--	1.0	A
Operating Frequency		690	700	710	kHz
Efficiency	@12V input, Full Load	90%	94%	96%	
Communications					
Protocol		--	I^2C	--	
Transmission speed		--	100	--	Kbps
Bus voltage		3.26V	3.3V	3.33V	
Node address		--	0x2B	--	Hex
Address scheme		--	7bit	--	
Node operating frequency		--	8MHz	--	
Quiescent Operation					
Power Draw	Flight Configuration of Switches	--	--	0.15	W
Physical		**L**	**W**	**H**	
Dimensions	Height from top of PCB to bottom of next PCB in stack	95	90	15.24	mm
Weight		167g	170g	173g	

Table 4-1 Performance Characteristics of the EPS

4.1 BCR Safe Operating Area

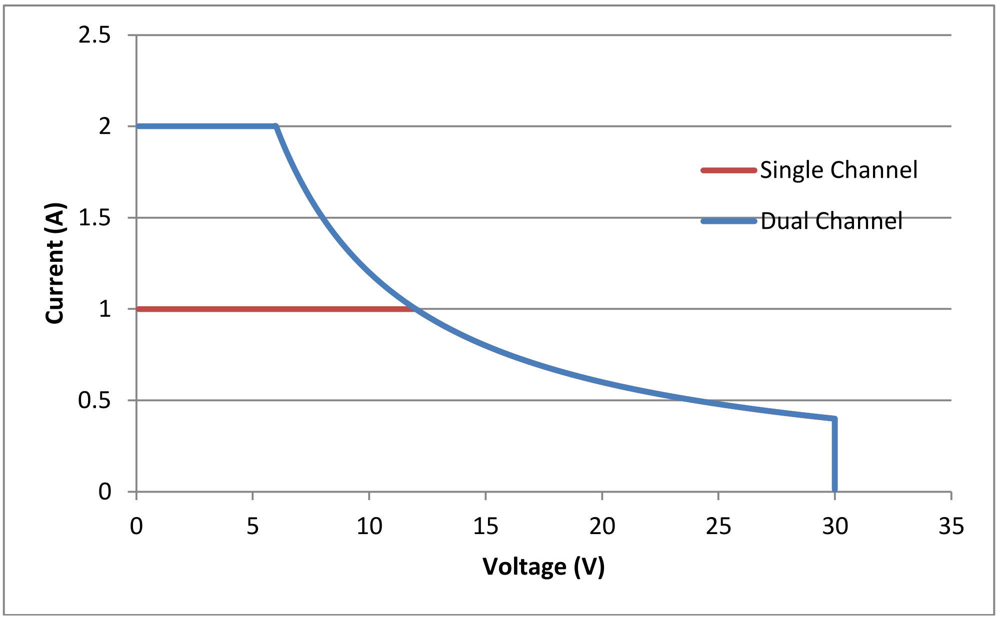


Figure 4-1 BCR Safe Operating Range

The safe operating range of the BCRs is shown in Figure 4-1. Single Channel refers to the maximum power that can be applied to a single pin (e.g. SA1.1). Dual Channel refers to the maximum power that can be applied to two pins connecting to the same BCR (e.g. SA1.1 and SA1.4).

5. Handling and Storage

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

5.1 Electro Static Discharge (ESD) Protection

The EPS incorporates static sensitive devices and care should be taken during handling. Do not touch the EPS 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 EPS is 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 EPS. There are live connections between the battery systems and the EPS on the CubeSat Kit headers. All metal objects (including probes) should be kept clear of these headers.

5.3 Shipping and Storage

The devices are shipped in anti-static, vacuum-sealed packaging, enclosed in a hard protective case. This case should be used for storage. All hardware should be stored in anti-static containers at temperatures between 20°C and 40°C and in a humidity-controlled environment of 40-60%rh.

6. Materials and Processes

6.1 Materials Used

	Material	Manufacturer	%TML	%CVCM	%WVR	Application
1.	Araldite 2014 Epoxy	Huntsman	0.97	0.05	0.33	Adhesive fixing
2.	1B31 Acrylic	Humiseal	3.89	0.11	0.09	Conformal Coating
3.	DC 6-1104	Dow Corning	0.17	0.02	0.06	Adhesive fixing on modifications
4.	Stycast 4952	Emerson & Cuming	0.42	0.17	0.01	Thermally Conductive RTV
5.	PCB material	FR4	0.62	0	0.1	Note: worst case on NASA out-gassing list
6.	Solder Resist	CARAPACE EMP110 or XV501T-4	0.95 or 0.995	0.02 Or 0.001	0.31	-
7.	Solder	Sn62 or Sn63 (Tin/Lead)	-	-	-	-
8.	Flux	Alpha Rosin Flux, RF800, ROL 0	-	-	-	ESA Recommended

Table 6-1 Materials List

Part Used	Manufacturer	Contact	Insulator	Type	Use
DF13-6P-1.25DSA(50)	Hirose	Gold Plated/Pretinned	Polyamide	PTH	Solar Array Connectors and Charging Connector
DF13-6P-1.25H(50)	Hirose	Gold Plated/Pretinned	Polyamide	SMT	Solar Array Connectors
ESQ-126-39-G-D	Samtec	Gold Plated	Black Glass Filled Polyester	PTH	CubeSat Kit Compatible Headers
DF13-6S-1.25C	Hirose	N/A	Polyamide	Crimp Housing	Harness for Solar Arrays (sold separately)
DF13-2630SCFA(04)	Hirose	Gold Plated	N/A	Crimp	Harness for Solar Arrays (sold separately)
A29200-021	Omnetics	COPPER ALLOY PER MIL-DTL-32139, GOLD PLATED	LIQUID CRYSTAL POLYMER (LCP)	SMT	Solar Array Connectors
A29100-021	Omnetics	COPPER ALLOY PER MIL-DTL-32139, GOLD PLATED	LIQUID CRYSTAL POLYMER (LCP)	SMT	Solar Array Connectors

Table 6-2 Connector Headers

6.2 Processes and Procedures

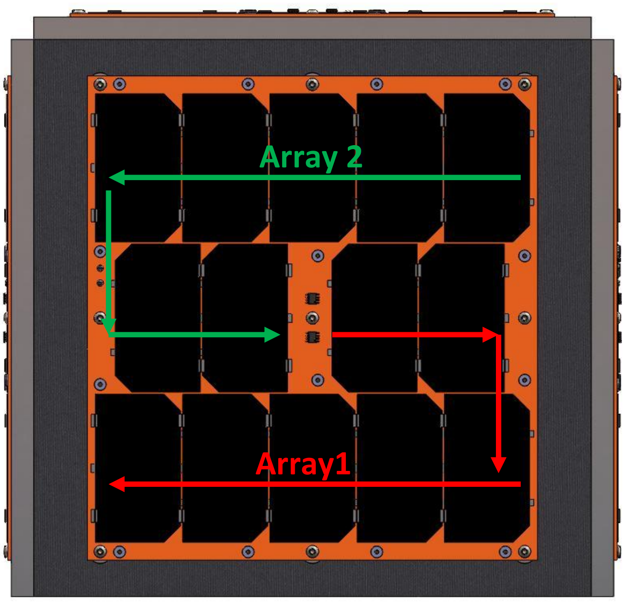
All PCB assembly is carried out and inspected to ESA Workmanship Standards; ECSS-Q-ST-70-08C and ECSS-Q-ST-70-38C.

7. SYSTEM DESCRIPTION

This Clyde Space EPS is optimised for Low Earth Orbit (LEO) missions with a maximum altitude of 850km and is designed for integration with spacecraft utilising up to 12 solar panel strings. Various solar panel configurations can be accommodated including body mounted and deployable panels of various string lengths, and has been designed to be versatile. Please consult our support team if you have specific requirements for connecting the EPS to your spacecraft.

The Clyde Space EPS connects to the solar panels via six independent Battery Charge Regulators (BCRs). Each BCR can be connected to two solar arrays in parallel, provided the connected panels cannot output a combined power greater than 12W. There are a number of possible configurations that can be used, depending on the deployment configuration. An Example is shown in Figure 7-1. Please contact Clyde Space to discuss possible configurations. Each of the BCRs has an inbuilt Maximum Power Point Tracker (MPPT). This MPPT will track the dominant panel of the connected pair (the directly illuminated panel).

The output of the six BCRs are then connected together and, via the switch network, (described in Section 7.2), supply charge to the battery, Power Conditioning Modules (PCMs) and Power Distribution Modules (PDMs). The EPS has an unregulated Battery Voltage Bus, a regulated 5V supply, a regulated 3.3V supply and a regulated 12V supply available on the satellite bus. The EPS also has multiple inbuilt protection methods to ensure safe operation during the mission and a range of telemetry via the I^2C network. These are discussed in detail in Sections 10 and 11 respectively.



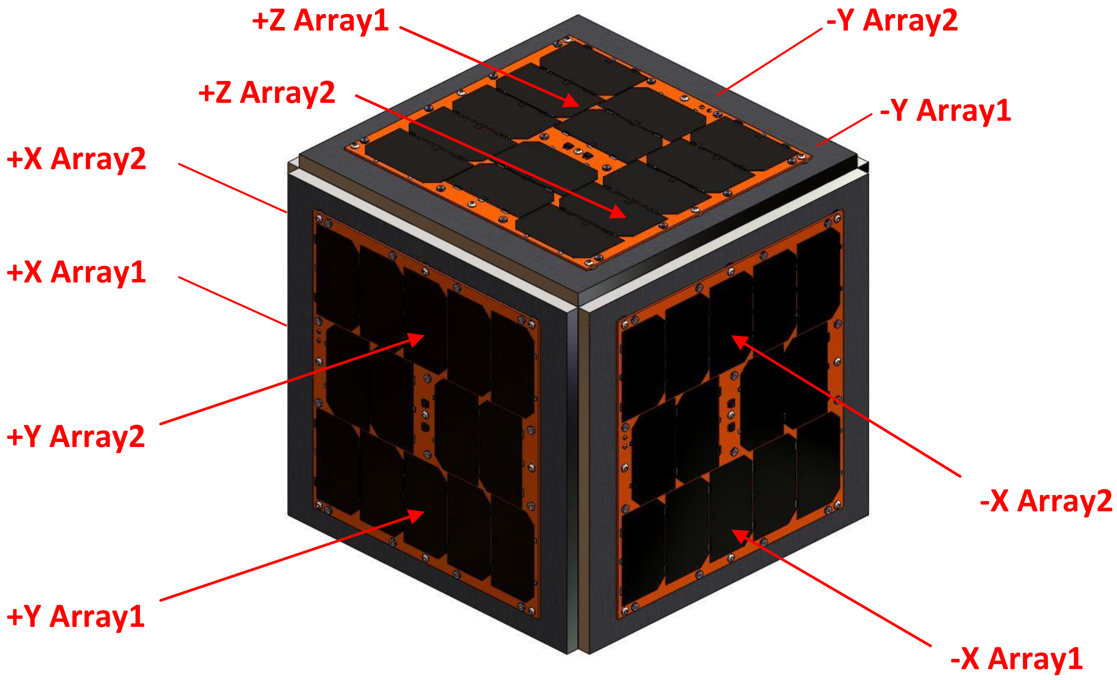


Figure 7-1 Example Array Configuration

7.1 System Overview

Figure 7-2 shows a details block diagram of the EPS.

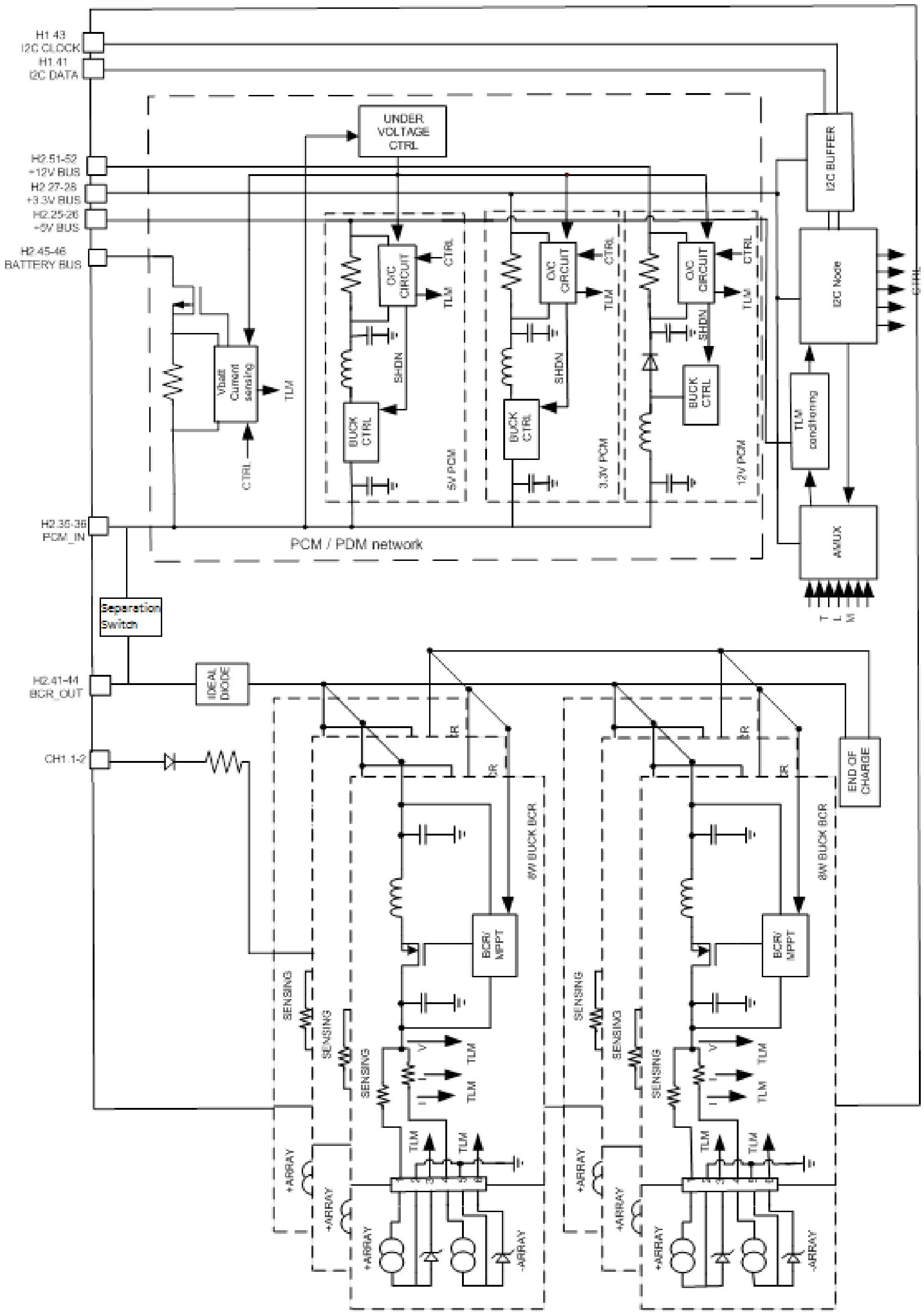


Figure 7-2 Function Diagram

7.2 Autonomy and Redundancy

All BCR power stages feature full system autonomy, operating solely from the solar array input and not requiring any power from the battery systems. This feature offers inbuilt redundancy since failure of one BCR does not affect remaining BCRs. The remainder of the power system is a robustly designed single string.

7.3 Quiescent Power Consumption

The quiescent power consumption of the EPS is ≈0.1W. This number does not include the power used in the control circuitry of the power converters (BCRs and PCMs) as these numbers are included in the efficiency specifications.

7.4 Mass and Mechanical Configuration

The mass of the system is approximately 170g and is contained on a PC/104 size mother card and mounted daughter card, compatible with the Cubesat Kit bus. Other versions of the EPS are available without the Cubesat Kit bus header. Figure 7.3 shows the connector configuration on the PCB.

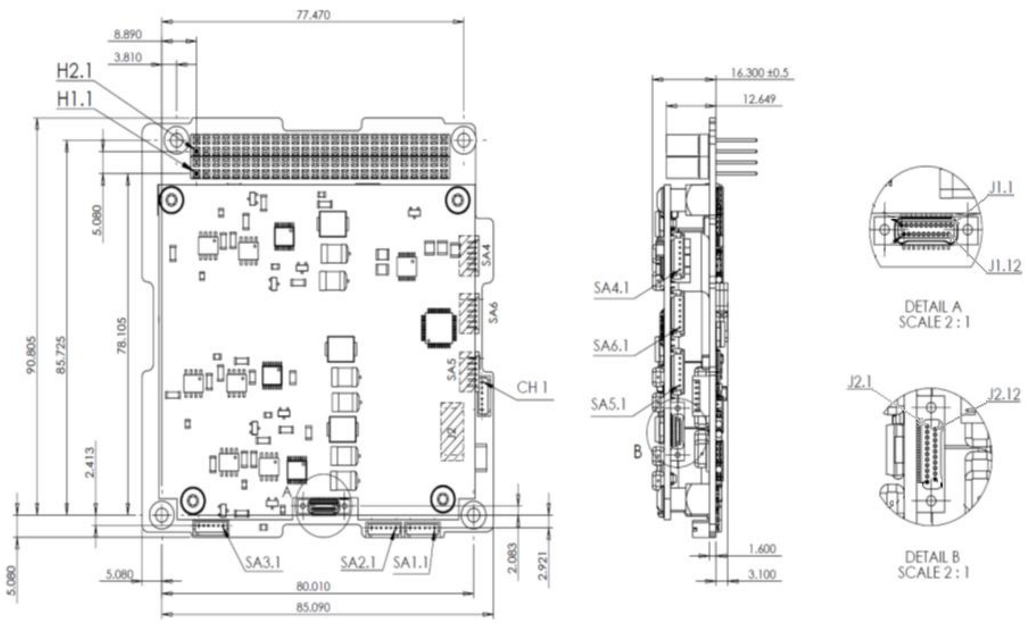


Figure 7-3 Connector layout

8. INTERFACING

The interface to the EPS is outlined in Figure 8-1, including the solar array inputs, connection to the switch configuration, output of the power buses and communication to the I^{2}C node. In the following section it is assumed that the EPS will be integrated with a Clyde Space 3U Battery.

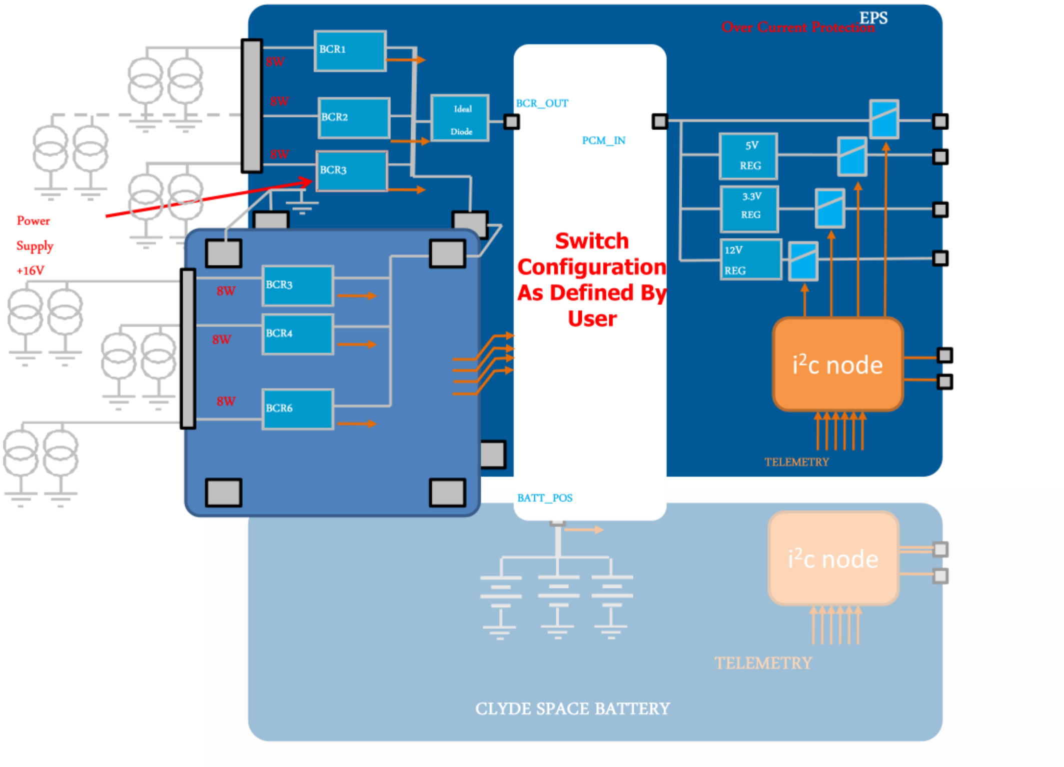


Figure 8-1 Clyde Space EPS and Battery Simplified Connection Diagram

8.1 Connector Layout

The connector positions are shown in Figure 7-3, and described in Table 8.1. Connectors J1 and J2 are only available on the 01-01120 version of the FlexU 6-0 EPS. Connectors SA1 to SA6 are available on both the 01-01120 and 01-00732 versions.

Connector	Function	Connector Type
J1 (only on 01-01120)	Solar Array connector for BCRs 1-3	A29200-021
J2 (only on 01-01120)	Solar Array connector for BCRs 4-6	A29100-021
SA1	Array connector for 12W +/- arrays	DF13-6P-1.25DSA(50)
SA2	Array connector for 12W +/- arrays	DF13-6P-1.25DSA(50)
SA3	Array connector for 12W +/- arrays	DF13-6P-1.25DSA(50)
SA4	Array connector for 12W +/- arrays	DF13-6P-1.25H(50)
SA5	Array connector for 12W +/- arrays	DF13-6P-1.25H(50)
SA6	Array connector for 12W +/- arrays	DF13-6P-1.25H(50)
H1	Cubesat Kit bus compatible Header 1	ESQ-126-39-G-D
H2	Cubesat Kit bus compatible Header 2	ESQ-126-39-G-D
CH1	Ground Charging for batteries	DF13-6P-1.25DSA(50)

Table 8-1 Connector functions

8.2 Solar Array Connection

The standard approach for connecting solar arrays to the 01-00732 and 01-01120 EPS are through the connectors SA1 to SA6. The 01-01120 EPS also has additional interfaces allowing arrays 1 to 3 to be connected through a single harness to J1 and arrays 4 to 6 through a second harness to J2. Both of these interfaces accommodate power inputs from the arrays with temperature telemetry for each. See Section 4.1 for details on limits of safe operation for the BCRs.

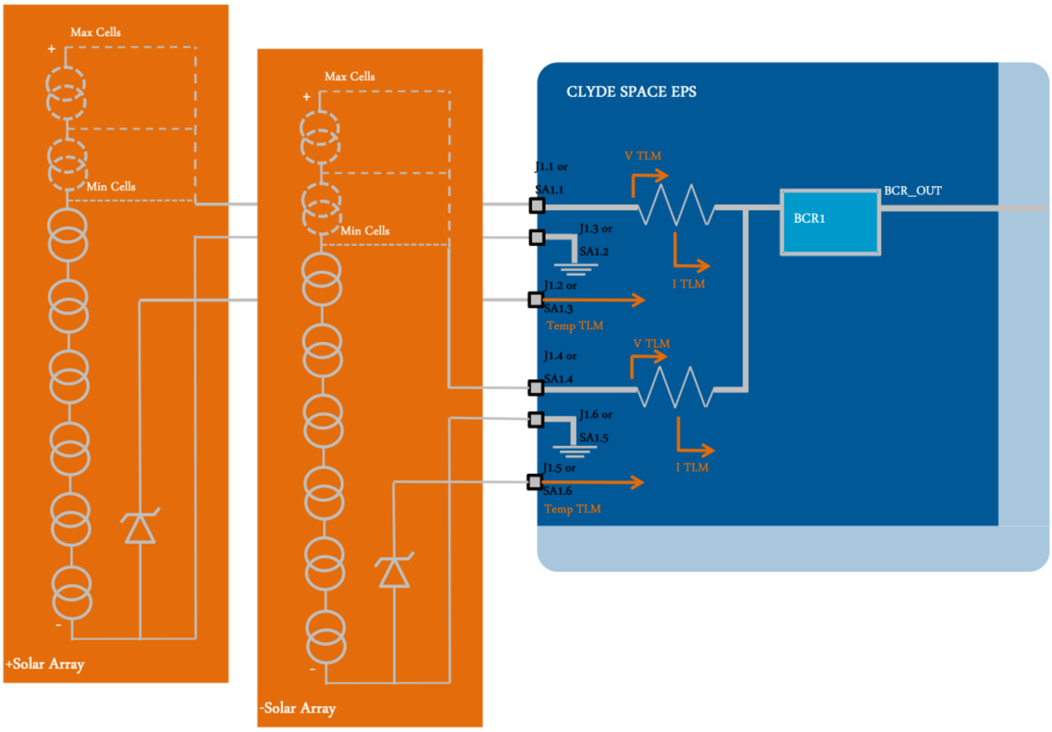


Figure 8-2 Solar Array Configuration

Individual Connectors (01-00732 and 01-01120)

HIROSE DP12-6P-1.25 DSA connector sockets are used on the EPS mother board and HIROSE DP12-6P-1.25H on the daughter board. These are labelled SA1-SA6 and are routed to BCRs1-6. All BCRs are capable of interfacing to 12W panels and should be harnessed to arrays with multiples of 4-8 cell strings. The pinouts of the connectors are shown in Table 8-2 to Table 8-7 with a figure indicating pin 1 of the connector shown in Figure 8-3.

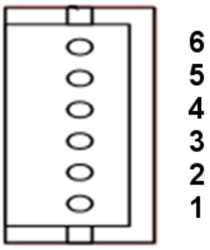


Figure 8-3 Solar Array Pin Numbering

Pin	Name	Use	Notes
1	+ARRAY1 (12W)	+ Power Line	Power
2	GND	Ground Line	Power RTN and GND connection for Temp Sensor
3	+ARRAY1_TEMP_TELEM	+ Array Telemetry	Telemetry
4	-ARRAY1 (12W)	- Power Line	Power
5	GND	Ground Line	Power RTN and GND connection for Temp Sensor
6	-ARRAY1_TEMP_TELEM	- Array Telemetry	Telemetry

Table 8-2 Pin out for Header SA1

Pin	Name	Use	Notes
1	+ARRAY2 (12W)	+ Power Line	Power
2	GND	Ground Line	Power RTN and GND connection for Temp Sensor
3	+ARRAY2_TEMP_TELEM	+ Array Telemetry	Telemetry
4	-ARRAY2 (12W)	- Power Line	Power
5	GND	Ground Line	Power RTN and GND connection for Temp Sensor
6	-ARRAY2_TEMP_TELEM	- Array Telemetry	Telemetry

Table 8-3 Pin out for Header SA2

Pin	Name	Use	Notes
1	+ ARRAY3 (12W)	+ Power Line	Power
2	GND	Ground Line	Power RTN and GND connection for Temp Sensor
3	+ARRAY3_TEMP_TELEM	+ Array Telemetry	Telemetry
4	-ARRAY3 (12W)	- Power Line	Power
5	GND	Ground Line	Power RTN and GND connection for Temp Sensor
6	-ARRAY3_TEMP_TELEM	- Array Telemetry	Telemetry

Table 8-4 Pin out for Header SA3

Pin	Name	Use	Notes
1	+ARRAY4 (12W)	+ Power Line	Power
2	GND	Ground Line	Power RTN and GND connection for Temp Sensor
3	+ARRAY4_TEMP_TELEM	+ Array Telemetry	Telemetry
4	-ARRAY4 (12W)	- Power Line	Power
5	GND	Ground Line	Power RTN and GND connection for Temp Sensor
6	-ARRAY4_TEMP_TELEM	- Array Telemetry	Telemetry

Table 8-5 Pin out for Header SA4

Pin	Name	Use	Notes
1	+ARRAY5 (12W)	+ Power Line	Power
2	GND	Ground Line	Power RTN and GND connection for Temp Sensor
3	+ARRAY5_TEMP_TELEM	+ Array Telemetry	Telemetry
4	-ARRAY5 (12W)	- Power Line	Power
5	GND	Ground Line	Power RTN and GND connection for Temp Sensor
6	-ARRAY5_TEMP_TELEM	- Array Telemetry	Telemetry

Table 8-6 Pin out for Header SA5

Pin	Name	Use	Notes
1	+ARRAY6 (12W)	+ Power Line	Power
2	GND	Ground Line	Power RTN and GND connection for Temp Sensor
3	+ARRAY6_TEMP_TELEM	+ Array Telemetry	Telemetry
4	-ARRAY6 (12W)	- Power Line	Power
5	GND	Ground Line	Power RTN and GND connection for Temp Sensor
6	-ARRAY6_TEMP_TELEM	- Array Telemetry	Telemetry

Table 8-7 Pin out for Header SA6

Ground Charging connector

Connector CH1 is designed to be used as a charging connector. The pinout is shown in Table 8-8.

Pin	Name	Use	Notes
1	+16VCHG	+ Power Line	For Ground charging of battery
2	+16VCHG	+ Power Line	For Ground charging of battery
3	N/C		
4	+16VCHG RTN	Ground Line	Ground Return
5	+16VCHG RTN	Ground Line	Ground Return
6	N/C		

Table 8-8 Pin out for Charging Header CH1

Grouped Connectors (only present on 01-01120 model EPS)

An Omnetics connector, A29200-021, is used on the 01-01120 mother board to route to BCRs 1, 2 and 3, as described in Table 8-9. Similarly, on the 01-01120 daughter board an Omnetics A29100-021 is used to interface to BCRs 4, 5 and 6 as described in Table 8-10. These connectors are only fitted on the 01-01120 model EPS and are not included on the 01-00732.

Pin	Name	Use	Notes
1	-Array1 Temp	Array Telemetry	Telemetry
2	-Array1	+ Power Line	Power
3	+Array1 RTN	Ground Line	Power RTN and GND connection for Temp Sensor
4	+Array1 Temp	Array Telemetry	Telemetry
5	+Array1	+ Power Line	Power
6	-Array2 RTN	Ground Line	Power RTN and GND connection for Temp Sensor
7	-Array2 Temp	Array Telemetry	Telemetry
8	-Array2	+ Power Line	Power
9	+Array2 RTN	Ground Line	Power RTN and GND connection for Temp Sensor
10	+Array2 Temp	Array Telemetry	Telemetry
11	+Array2	+ Power Line	Power
12	N/C		
13	N/C		
14	N/C		
15	+Array1 RTN	Ground Line	Power RTN and GND connection for Temp Sensor
16	-Array3 Temp	Array Telemetry	Telemetry
17	-Array3	+ Power Line	Power
18	-Array3 RTN	Ground Line	Power RTN and GND connection for Temp Sensor
19	+Array3 Temp	Array Telemetry	Telemetry
20	+Array3	+ Power Line	Power
21	+Array3 RTN	Ground Line	Power RTN and GND connection for Temp Sensor

Table 8-9 Pin out for Header J1

Pin	Name	Use	Notes
1	-Array4Temp	Array Telemetry	Telemetry
2	-Array4	+ Power Line	Power
3	- Array4 RTN	Ground Line	Power RTN and GND connection for Temp Sensor
4	+Array4 Temp	Array Telemetry	Telemetry
5	+Array4	+ Power Line	Power
6	+Array4 RTN	Ground Line	Power RTN and GND connection for Temp Sensor
7	-Array5 Temp	Array Telemetry	Telemetry
8	-Array5	+ Power Line	Power
9	-Array5 RTN	Ground Line	Power RTN and GND connection for Temp Sensor
10	+Array5 Temp	Array Telemetry	Telemetry
11	+Array5	+ Power Line	Power
12	N/C		
13	N/C		
14	N/C		
15	+Array5 RTN	Ground Line	Power RTN and GND connection for Temp Sensor
16	-Array6 Temp	Array Telemetry	Telemetry
17	-Array6	Array Telemetry	Power
18	-Array6 RTN	Ground Line	Duplicate Connection
19	+Array6 Temp	Array Telemetry	Duplicate Connection
20	+Array6	+ Power Line	Duplicate Connection
21	+ Array6 RTN	Ground Line	Duplicate Connection

Table 8-10 Pin out for Header J2

8.3 Solar Array Harness

Clyde Space supply harnesses (sold separately) to connect the solar panels to the EPS.

Temperature sensing telemetry is provided for each solar array connected to the EPS. A compatible temperature sensor (LM335M) is fitted as standard on Clyde Space solar arrays. The output from the LM335M sensor is then passed to the telemetry system via on board signal conditioning. Due to the nature of the signal conditioning, the system is only compatible with zener based temperature sensors i.e. LM335M or equivalent. Thermistor or thermocouple type sensors are incompatible with the conditioning circuit. Figure 8-4 provides a block diagram showing the connection of the temperature sensor.

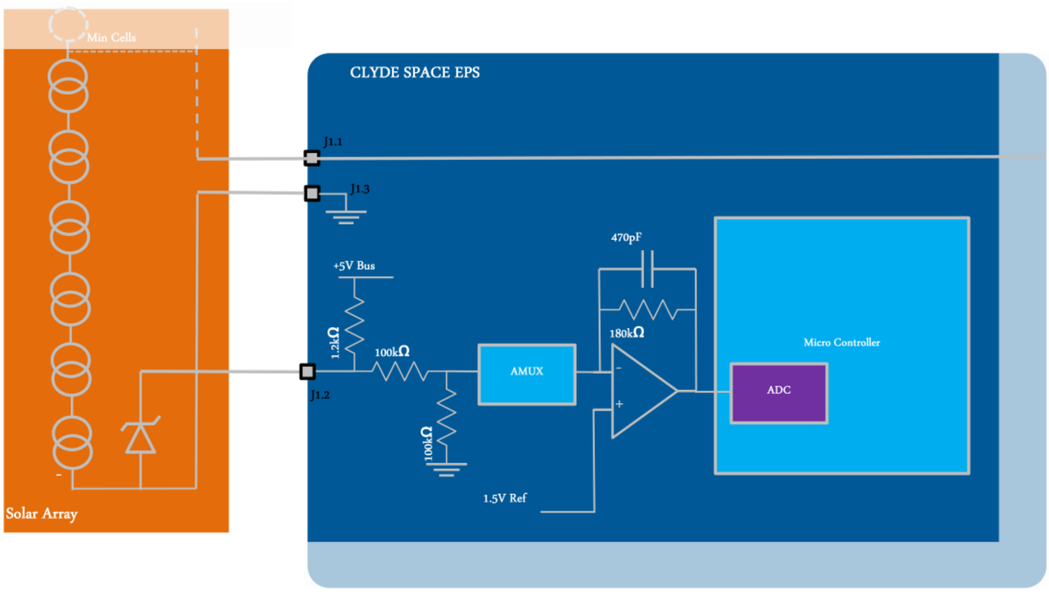


Figure 8-4 Temperature sensor block diagram

8.4 CubeSat Kit Compatible Headers

Connections from the EPS to the buses of the satellite are made via the CubeSat Kit compatible headers H1 and H2, as shown in Figure 8-5.

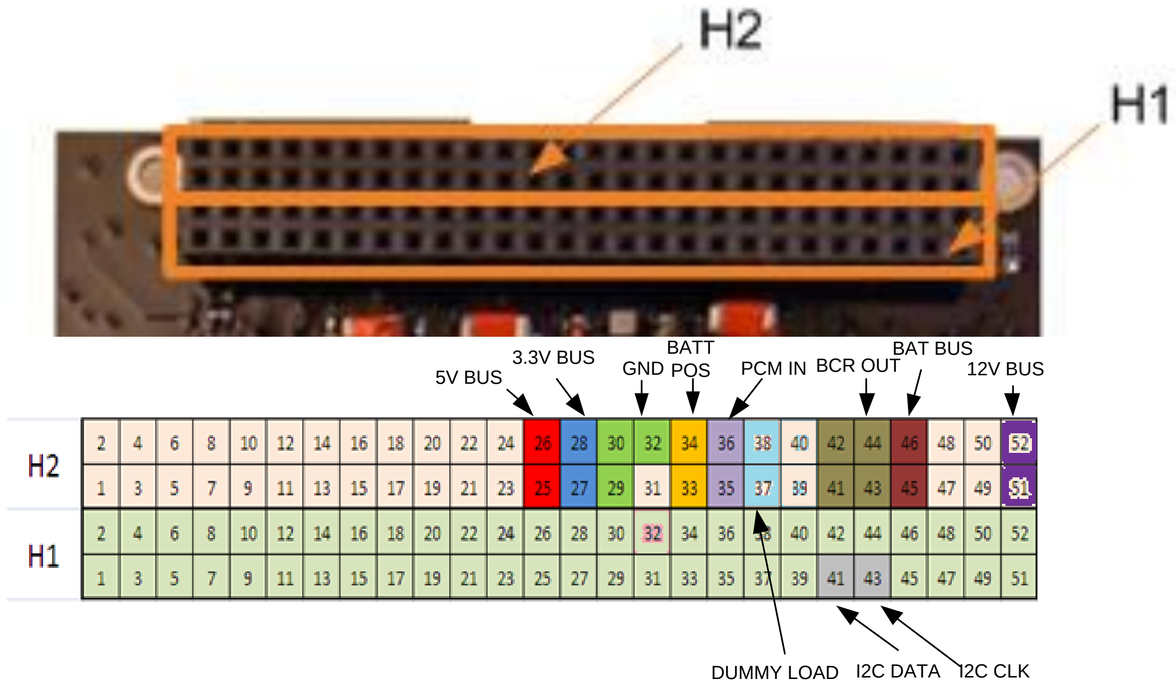


Figure 8-5 EPS Connector Pin Identification

8.5 Cubesat Kit Header Pin Out

HEADER 1				HEADER 2			
Pin	Name	Use	Notes	Pin	Name	Use	Notes
1	NC	Not Connected	Not Connected	1	NC	Not Connected	Not Connected
2	NC	Not Connected	Not Connected	2	NC	Not Connected	Not Connected
3	NC	Not Connected	Not Connected	3	NC	Not Connected	Not Connected
4	NC	Not Connected	Not Connected	4	NC	Not Connected	Not Connected
5	NC	Not Connected	Not Connected	5	NC	Not Connected	Not Connected
6	NC	Not Connected	Not Connected	6	NC	Not Connected	Not Connected
7	NC	Not Connected	Not Connected	7	NC	Not Connected	Not Connected
8	NC	Not Connected	Not Connected	8	NC	Not Connected	Not Connected
9	NC	Not Connected	Not Connected	9	NC	Not Connected	Not Connected
10	NC	Not Connected	Not Connected	10	NC	Not Connected	Not Connected
11	NC	Not Connected	Not Connected	11	NC	Not Connected	Not Connected
12	NC	Not Connected	Not Connected	12	NC	Not Connected	Not Connected
13	NC	Not Connected	Not Connected	13	NC	Not Connected	Not Connected
14	NC	Not Connected	Not Connected	14	NC	Not Connected	Not Connected
15	NC	Not Connected	Not Connected	15	NC	Not Connected	Not Connected
16	NC	Not Connected	Not Connected	16	NC	Not Connected	Not Connected
17	NC	Not Connected	Not Connected	17	NC	Not Connected	Not Connected
18	NC	Not Connected	Not Connected	18	NC	Not Connected	Not Connected
19	NC	Not Connected	Not Connected	19	NC	Not Connected	Not Connected
20	NC	Not Connected	Not Connected	20	NC	Not Connected	Not Connected
21	ALT I^2C CLK	Alt I^2C clock connection	0ohm resistor R265 (must fit to operate)	21	NC	Not Connected	Not Connected
22	NC	Not Connected	Not Connected	22	NC	Not Connected	Not Connected
23	ALT I^2C DATA	Alt I^2C data connection	0ohm resistor R264 (must fit to operate)	23	NC	Not Connected	Not Connected
24	NC	Not Connected	Not Connected	24	NC	Not Connected	Not Connected
25	NC	Not Connected	Not Connected	25	+5V BUS	+5V Power	Regulated 5V bus
26	NC	Not Connected	Not Connected	26	+5V BUS	+5V Power	Regulated 5V bus
27	NC	Not Connected	Not Connected	27	+3.3V BUS	+3V3 Power	Regulated 3V3 bus
28	NC	Not Connected	Not Connected	28	+3.3V REG	+3V3 Power	Regulated 3V3 bus
29	NC	Not Connected	Not Connected	29	GND	Ground connection	System power return
30	NC	Not Connected	Not Connected	30	GND	Ground connection	System power return
31	NC	Not Connected	Not Connected	31	NC	Not Connected	Not Connected
32	NC	Not Connected	Not Connected	32	GND	Ground connection	System power return
33	NC	Not Connected	Not Connected	33	BATT POS	Power line	Pull pin normally connected pin
34	NC	Not Connected	Not Connected	34	BATT POS	Power line	Pull pin normally connected pin
35	NC	Not Connected	Not Connected	35	PCM IN	Power line	Sep SW normally connected pin
36	NC	Not Connected	Not Connected	36	PCM IN	Power line	Sep SW normally connected pin
37	NC	Not Connected	Not Connected	37	DL	Dummy Load Protection	Pull pin normally open pin
38	NC	Not Connected	Not Connected	38	DL	Dummy Load Protection	Pull pin normally open pin
39	NC	Not Connected	Not Connected	39	NC	Not Connected	Not Connected
40	NC	Not Connected	Not Connected	40	NC	Not Connected	Not Connected
41	I^2C DATA	I^2C data	Data for I^2C communications	41	BCR OUT	Power line	Common point PP +SS pins
42	NC	Not Connected	Not Connected	42	BCR OUT	Power line	Common point PP +SS pins
43	I^2C CLK	I^2C clock	Clock for I^2C communications	43	BCR OUT	Power line	Common point PP +SS pins
44	NC	Not Connected	Not Connected	44	BCR OUT	Power line	Common point PP +SS pins
45	NC	Not Connected	Not Connected	45	Batt Bus	Power line	Output to batt bus
46	NC	Not Connected	Not Connected	46	Batt Bus	Power line	Output to batt bus
47	NC	Not Connected	Not Connected	47	NC	Not Connected	Not Connected
48	NC	Not Connected	Not Connected	48	NC	Not Connected	Not Connected
49	NC	Not Connected	Not Connected	49	NC	Not Connected	Not Connected
50	NC	Not Connected	Not Connected	50	NC	Not Connected	Not Connected
51	NC	Not Connected	Not Connected	51	+12V REG	+12 Power bus	Regulated 12 bus
52	NC	Not Connected	Not Connected	52	+12V REG	+12 Power bus	Regulated 12 bus

Table 8-11 Pin Descriptions for Header H1 and H2

NODE	HEADER	CUBESAT KIT NAME	NOTES
+5V BUS	2.25-26	+5V	5V Regulated **Bus** Output
+3.3V BUS	2.27-28	VCC_SYS	3.3V Regulated **Bus** Output
BATT POS	2.33-34	SW0	Positive Terminal of Battery (**not** Battery Bus) **DO NOT CONNECT TO ANYTHING OTHER THAN PULL PIN TERMINAL**
PCM IN	2.35-36	SW1	Input to PCMs and PDMs (Switches ➔)
DUMMY LOAD	2.37-38	SW2	(Switches ➔)
N/C	2.39-40	SW3	(Switches N/C) Unused connection of launch switch closed state
BCR OUT	2.41-44	SW4	Output of BCRs (➔ Switches)
BCR OUT	2.41-44	SW5	Output of BCRs (➔ Switches)
BATTERY BUS	2.45-46	VBATT+	Battery Unregulated **Bus** Output

Table 8-12 Header pin name descriptions relating CubeSat Kit names to CS names

8.6 Switch Options

The Clyde Space EPS 01-00732 has three connection points for switch attachments, as shown in Figure 8-6. There are a number of possible switch configurations for implementation. Each configuration must ensure the buses are isolated from the arrays and battery during launch. The batteries should also be isolated from the BCRs during launch in order to conform to CubeSat standard [RD-1].

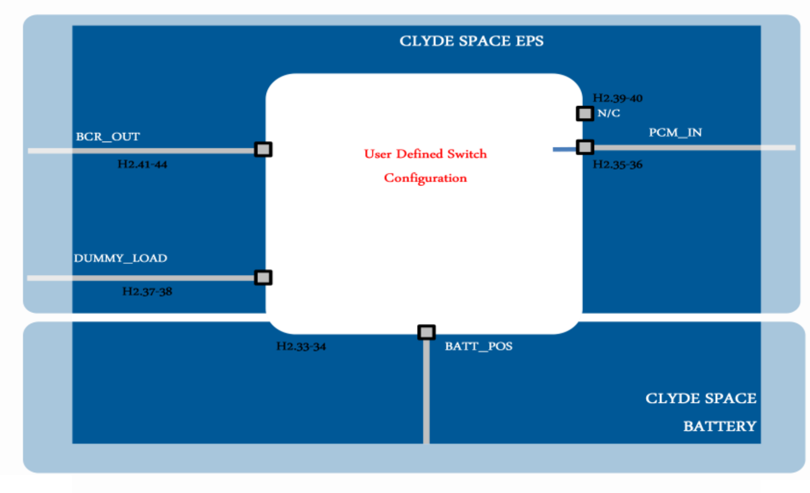


Figure 8-6 Switch Configuration

Options 1 and 2 below are two suggested methods of switch configuration, but are by no means exhaustive. If you wish to discuss other possible configurations please contact Clyde Space.

Option 1

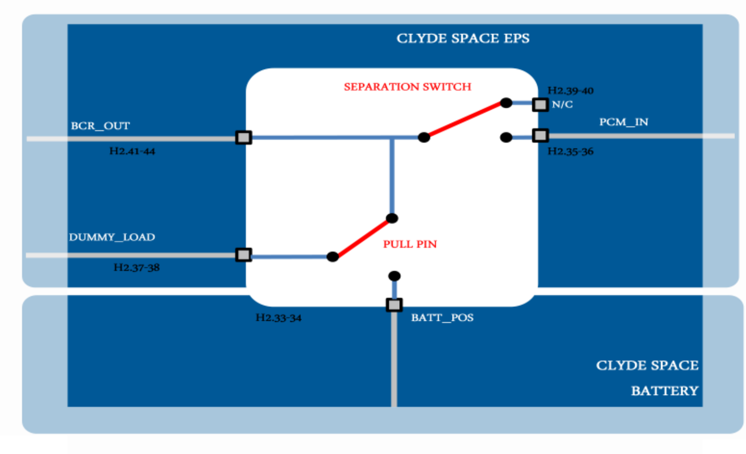


Figure 8-7 Switch Configuration Option 1

Option 1, shown in Figure 8-7, accommodates the CubeSat Kit bus available switches offering two-stage isolation. The separation switch provides isolation of the power buses during the launch. The pull pin may be used for ground based isolation of the batteries, though it does not provide any isolation during launch.

NOTE: The second generation Clyde Space EPS has zero-current draw when the pull pin is removed – i.e. there will be no current drawn from the battery while on the launch vehicle.

When pull pin is inserted, the battery is isolated from the output of the BCRs. Under these conditions, if power is applied to the input of the arrays, or by connecting the USB or charging connector, there is a possibility of damaging the system. In order to mitigate this risk a "Dummy Load" is fitted on the EPS.

Option 2

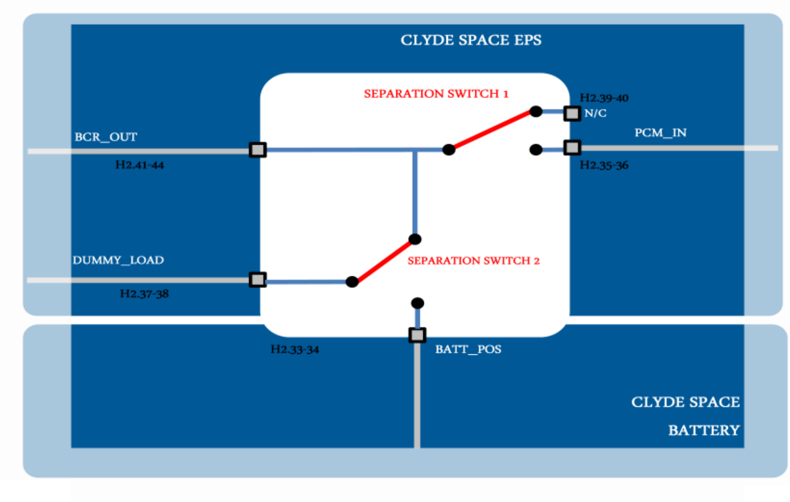


Figure 8-8 Switch Configuration Option 2

Option 2, shown in Figure 8-8, is compatible with structures incorporating two separation switches, providing complete isolation in the launch configuration. In the configuration shown above the dummy load will be in circuit until deployment of separation switch 2.

Care should be taken to ensure that the switches used are rated to the appropriate current levels.

Please contact Clyde Space for information on implementing alternative switch or dummy load configurations.

Dummy Load

The Dummy Load provides an additional ground support protection system, providing a load for the BCRs when the pull pin is inserted using the normally open (NO) connection of the Pull Pin. By connecting this Dummy Load to the NO pin BCR damage can be circumvented. The wiring arrangement for the dummy load is indicated in Figure 8-8.

The load protects the battery charge regulator from damage when the 16V charge or array power is attached and the batteries are not connected. This system is not operational during flight and is only included as a ground support protection.

8.7 Battery connection

Connection of the battery systems on the EPS is via the Cubesat kit bus. 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.

When the battery is connected to the EPS, the battery will be isolated until implementing and connecting a switch configuration, as discussed in Section 8.6. Ensure that the battery is fully isolated during periods of extended storage.

When a battery board is connected to the CubeSat Kit header, there are live, unprotected battery pins accessible (H2.33-34). These pins should not be routed to any connections other than the switches and Clyde Space EPS, otherwise all protections will be bypassed and significant battery damage can be sustained.

8.8 Buses

All power buses are accessible via the CubeSat Kit headers and are listed and described in Table 8-11. These are the only power connections that should be used by the platform since they follow all battery and bus over-current protections.

9. Technical Description

This section gives a complete overview of the operational modes of the EPS.

9.1 Charge Method

The BCR charging system has two modes of operation: Maximum Power Point Tracking (MPPT) mode and End of Charge (EoC) mode. These modes are governed by the state of charge of the battery.

MPPT Mode

If the battery voltage is below the preset EoC voltage the system is in MPPT mode. This is based on a constant current charge method, operating at the maximum power point of the solar panel for maximum power transfer.

EoC Mode

Once the EoC voltage has been reached, the BCR changes to EoC mode, which is a constant voltage charging regime. The EoC voltage is held constant and a tapering current from the panels is supplied to top up the battery until at full capacity. In EoC mode the MPPT circuitry moves the solar array operation point away from the maximum power point of the array, drawing only the required power from the panels. The excess power is left on the arrays as heat, which is transferred to the structure via the array's thermal dissipation methods incorporated in the panels.

The operation of these two modes can be seen in Figure 9-1.

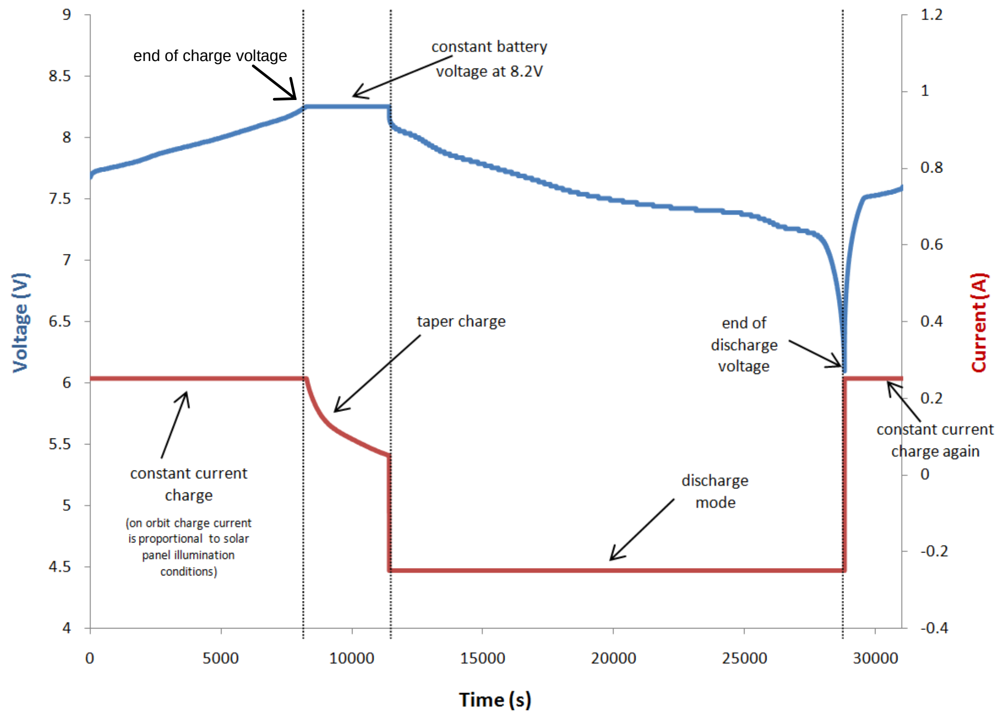


Figure 9-1 Tapered charging method

9.2 BCR Power Stage Overview

As discussed in section 7, the EPS has six separate, independent BCRs, each designed to interface to two parallel solar arrays configured to have a combined output of no greater than 12W (e.g. a seven cell string on one face of the satellite connected to a seven cell string on the opposing face). Each of the 12W BCRs interface to the main body and deployed panels, with up to 7 triple junction cells in series.

The design offers a highly reliable system that can deliver 90% or greater of the power available from the solar array network at full load.

12W BCR power stage

The 12W BCR is a BUCK converter, allowing the BCR to interface to strings with four to seven cells in series. The use of a BUCK converter offers significant increases in efficiency under most conditions over a SEPIC topology. With input voltages between 10V and 24V the design will operate at peak efficiency. If the input voltage drops to between 8.9V and 10V the solar panels will move away from their Maximum Power Point. This is because the converter will reach its maximum allowable duty cycle. The loss in efficiency will only occur under the worst case conditions of hot temperatures at end of life as the solar panel output voltages decrease.

9.3 MPPT

Each of the BCRs can have two solar arrays connected at any given time; only one array can be illuminated by sunlight, although the other may receive illumination by albedo reflection from earth. The dominant array is in sunlight and this will operate the MPPT for that BCR string. The MPPT monitors the power supplied from the solar array, shown in Figure 9-2. This data is used to calculate the maximum power point of the array. The system tracks this point by periodically adjusting the BCRs to maintain the maximum power derived from the arrays. This technique ensures that the solar arrays can deliver much greater usable power, increasing the overall system performance.

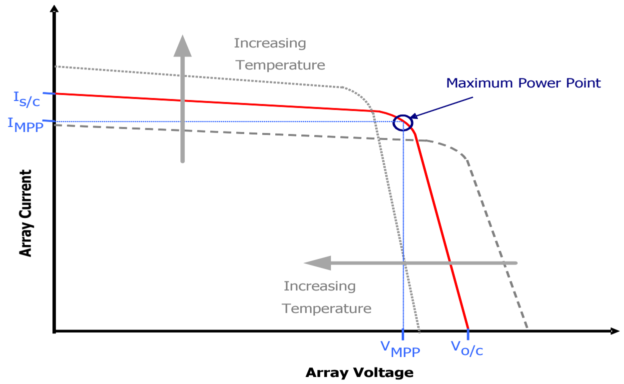


Figure 9-2 Solar Array Maximum Power Point

The monitoring of the MPP is done approximately every 2.5 seconds. During this tracking, the input of the array will step to o/c voltage, as shown in Figure 9-3.

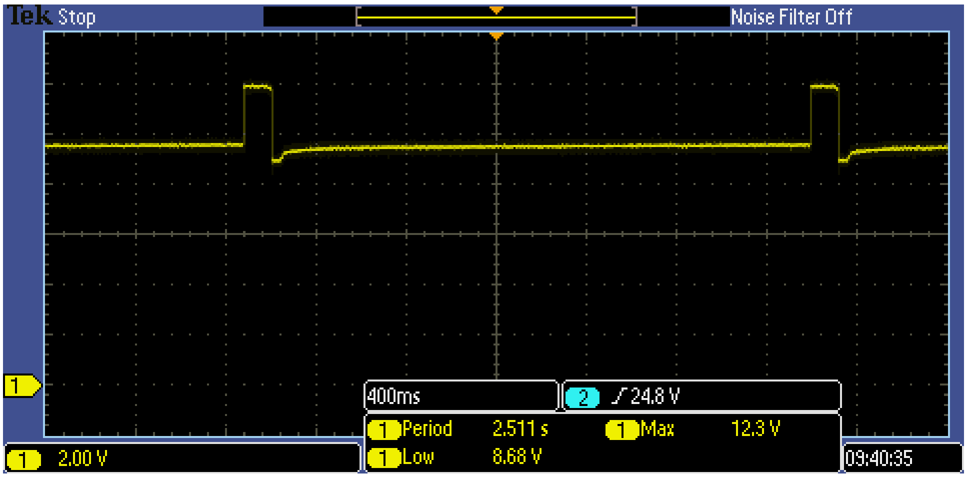


Figure 9-3 Input waveform with Maximum Power Point Tracking

9.4 5V and 3.3V PCM

The 5V and 3.3V regulators both use buck switching topology regulators as their main converter stage. The regulator incorporates intelligent feedback systems to ensure the voltage regulation is maintained to +/- 2% deviation. The efficiency of each unit at full load is approximately 96%. Full load on the 3V3 and 5V regulators have a nominal output current of 4.1A. Each regulator operates at a frequency of 480 kHz.

9.5 12V PCM

The 12V regulator uses a boost switching topology regulator as the main converter stage. The regulator incorporates intelligent feedback systems to ensure the voltage regulation is maintained to +/- 1% deviation. The efficiency at full load is approximately 95%. Full load on each of the regulator have a nominal output current of 1A. The regulator operates at a frequency of 700 kHz.

10. General Protection

The EPS 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 Over-Current Bus Protection

The EPS features bus protection systems to safeguard the battery, EPS and attached satellite sub-systems. This is achieved using current monitors and a shutdown network within the PDMs.

Over-current shutdowns are present on all buses for sub system protection. These are solid state switches that monitor the current and shutdown at predetermined load levels, see Table 10-1. The bus protection will then monitor the fault periodically and reset when the fault clears. This is illustrated by the waveform in Figure 10-1.

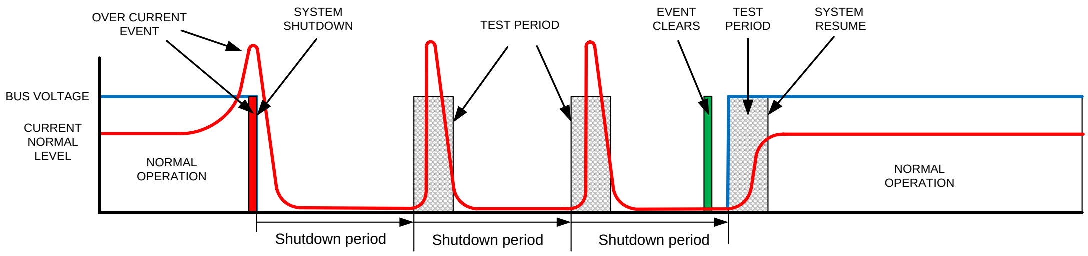


Figure 10-1 Current protection system diagram

Bus		Trip point / trip duration (approximation)
Battery Bus	Shutdown period	750ms
	Test period	60ms
5V bus	Shutdown period	750ms
	Test period	31ms
3.3V bus	Shutdown period	750ms
	Test period	31ms
12V bus	Shutdown period	750ms
	Test period	60ms

Table 10-1 Bus protection data

10.2 Battery Under-voltage Protection

In order to prevent over-discharge of the battery, the EPS has in-built under-voltage shutdown. This is controlled by a comparator circuit with hysteresis. In the event of the battery discharging to≈6.2V, the EPS will shut down the supply buses. This will also result in the I^2C node shutting down. When a power source is applied to the EPS (e.g. an illuminated solar panel) the battery will begin charging immediately. The buses, however, will not reactivate until the battery voltage has risen to ≈7V. This allows the battery to charge to a level capable of sustaining the power lines once a load is applied.

It is recommended that the battery state of charge is monitored by the on board computer of the satellite and loading adjusted appropriately (turning off of non-critical systems) when the battery capacity is approaching the lower limit. This will prevent the hard shutdown provided by the EPS.

11. Telemetry

The telemetry node allows the satellite on board computer (OBC) to monitor the operation of the EPS and reset the power buses if this is required for payload or platform recovery operations.

The telemetry node consists of a microcontroller which interfaces to the various telemetry sensing circuits on the EPS through an analogue multiplexer. The microcontroller is configured to connect through a buffer circuit to the I^{2}C bus of the satellite as a slave node. In response to I^{2}C telemetry requests the microcontroller will configure the analogue multiplexer to connect the desired telemetry channel to the analogue to digital converter (ADC) within the microcontroller before sampling the desired channel and allowing it to be read back over the I^{2}C bus. In response to a telecommand the telemetry node will decode the incoming message and reset the desired power bus.

The key elements of the I^{2}C node are illustrated in Figure 11-1

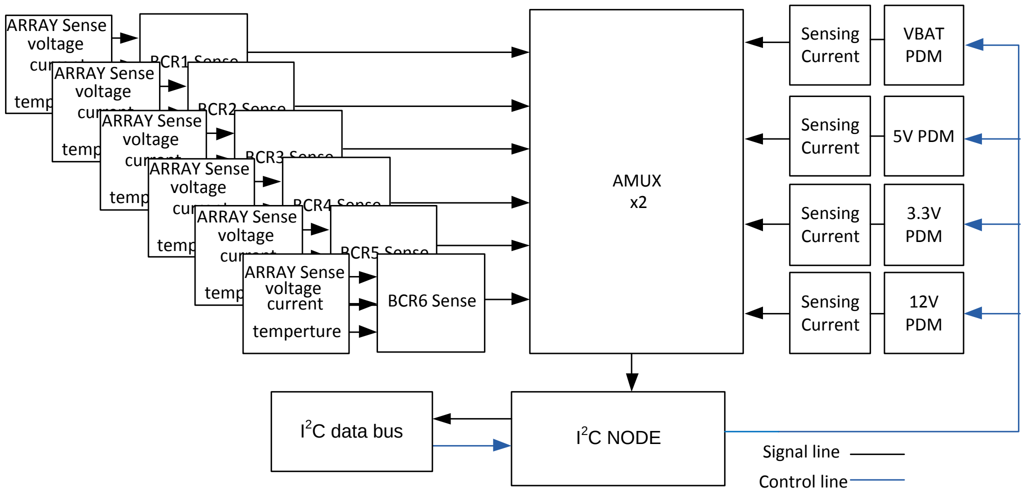


Figure 11-1 Telemetry functional diagram

11.1 I²C Command Interface

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 I^{2}C address of the TTC Node is factory set at 0x2B and the I^{2}C node will operate at up to 100kHz bus clock.

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 two data bytes. When reading data responses both data bytes should be read together. A delay of at least 1.2ms should be inserted between sending a command and reading the telemetry response. This is required to allow the microcontroller to select the appropriate analogue channel, allow it to settle, and then sample the telemetry reading.

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

In 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 being used as the OBC however the user should ensure that this is the case.

The read and write command definitions are illustrated in Table 11-1.

		Address Byte			Byte 1		Byte 2		
Write Command	S	7 bit node address	W	A	Command	A	Parameter	A	
Read Command	S	7 bit node address	R	A	Reply MSB	A	Reply LSB	N	P

S	Start Condition	P	Stop Condition	☐ Transmitted from Master (OBC)
A	Acknowledge	W	Write bit	
N	Not Acknowledged	R	Read bit	■ Transmitted from Slave (TTC node)

Table 11-1 I²C Write and Read command packets

An example of using the read and write commands is provided below. In this example the OBC is requesting a telemetry reading of the solar array 1 input voltage.

		Address Byte Address 0x2B + write flag									Byte 1 Command type 0 - read ADC									Byte 2 ADC Channel 5 - Array 1 V									
Write Command	S	0	1	0	1	0	1	1	0	A	0	0	0	0	0	0	0	0	A	0	0	0	0	0	1	0	1	A	
Delay > 1.2ms																													
		Address 0x2B + read flag									ADC result MSB									ADC result LSB - ADC total = 402									
Read Command	S	0	1	0	1	0	1	1	1	A	0	0	0	0	0	0	0	1	A	1	0	0	1	0	0	1	0	N	P

S	Start Condition	P	Stop Condition	☐ Transmitted from Master (OBC)
A	Acknowledge	W	Write bit	
N	Not Acknowledged	R	Read bit	■ Transmitted from Slave (TTC node)

If a read message which does not have a preceding write message is received by the telemetry node, the value 0xF000 is returned. All bit level communication to and from the board is done by sending the MSB first.

11.2 Command Summary

Table 11-2 provides a list of the commands for the EPS. The parameter that should accompany the commands is included in the table. Descriptions of the commands follow the table.

Command		Parameter	Description
Decimal	**Name**	**Decimal**	
0	ADC	0-33	Read ADC Channel
1	Status	0	Request Status Bytes
2	PDM Off	0-7	Turns off the selected PDM for a short time
4	Version	0	Request Firmware Version
128	Watchdog	0	Causes a soft reset of the microcontroller

Table 11-2 Command Summary

ADC Read

This command is used to read a telemetry value from the EPS. The command accepts a parameter which determines which ADC channel should be read. A list of the ADC channels available is provided in Table 11-5.

The data response to an ADC read command is a 10 bit unsigned value encoded in the two data bytes as shown in Figure 11-2. The first byte received contains the two most significant bits and the second byte received the remaining 8 bits. If the ADC reading is not yet ready 0xF000 is returned

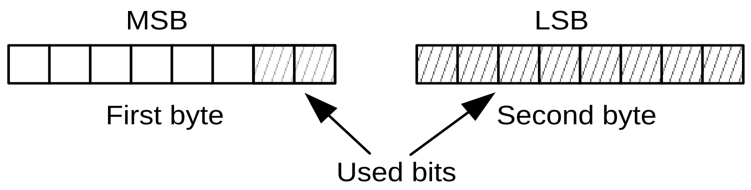


Figure 11-2 ADC 10bit data packet:

The result received should then be entered into the conversion equations, covered in section 11.3, which calculate the requested parameter in physical units. The equations provided in section 11.3 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 board 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 an EPS, however the tailored equations will vary slightly for every EPS manufactured and therefore may be different between flight and engineering model hardware.

Status

The status bytes are designed to supply operational data about the I^2C Node. To retrieve the two bytes that represent the status the command 0x01 should be sent followed by 0x00 as the status command has no parameter associated with it. The meaning of each bit of the status byte is shown in Table 11-2.

Byte	Bit	Description	If Low (0)	If High (1)	Note
1	0	Unknown Command Type	Last command OK	Last Command Unknown	Bit cleared when read
	1	Unknown Command Value	Last Command Value OK	Last Command Value Out of Range	Bit cleared when read
	2	ADC Result Not Ready	ADC Result Ready	ADC Result Not Ready	Bit cleared when read
	3	Not used	-	-	Reads as ‘0’
	4	Oscillator bit	External Oscillator running	External Oscillator failure	-
	5	Watchdog Reset Occurred	No Watchdog Reset	Watchdog Reset Occurred	Bit cleared when read
	6	Power On Reset Occurred	Power On Reset Occurred	No Power On Reset Occurred	Bit cleared when read
	7	Brown Out Reset Occurred	Brown Out Reset Occurred	No Brown Out Reset Occurred	Bit cleared when read
2	0	I^2C Error	No I^2C Errors	I2C Error Occurred	Bit cleared when read
	1	I^2C Write Collision	No I^2C Write Collision	I2C Write Collision Occurred	-
	2	I^2C Overflow	No I^2C Overflow	I^2C Overflow Occurred	-
	3	Received Message to Long	Received Messages Correct Length	Last Message incorrect Length	
	4-7	Not Used	-	-	Reads as ‘0’

Table 11-3 Status Bytes

BUS Off

The user can turn off any of the power buses in the EPS for a short period in order to trigger a hard reset of any connected systems. The command 0x02 is sent followed by a parameter byte which determines which bus should be reset. Details of the bus reset flags are provided in Table 11-4. Setting the appropriate bit to 1 will trigger a reset of the bus. Any combination of buses can be turned off, however it should be noted that if the 3.3V PDM is switched off the I^2C node will be reset.

Bit	Description	If Low (0)	If High (1)
0 (LSB)	Battery Bus Reset Flag	Bus remains active	Bus will be reset
1	5V Bus Reset Flag	Bus remains active	Bus will be reset
2	3V3 Bus Reset Flag	Bus remains active	Bus will be reset
3	12V Bus Reset Flag	Bus remains active	Bus will be reset
4	Not Used	-	-
5	Not Used	-	-
6	Not Used	-	-
7 (MSB)	Not Used	-	-

Table 11-4 Bus Reset Parameter bit functions

Version

The firmware version number can be accessed by the user using this command. Please contact Clyde Space to learn the version number on your board.

WatchDog

The Watchdog command allows the user to force a reset of the I^2C node. If the user detects or suspects an error in the operation of the I^2C node then this command should be issued. When issued the I^2C node will reset and return to an initial state.

11.3 ADC Channels

Each of the analogue channels, when read, returns a number between 0-1023. To retrieve the value of the signal this number represents it is to be entered into an equation. Table 11-5 contains conversion equations for each of the channels. Tailored equations for each individual build will be provided in the test report document supplied with the hardware.

ADC Channel	Signal Name	Connector	Equation	Units
0 (0x00)	+Array1 Current	SA1.1	Current = -0.5431 x ADCcount + 528.5093	mA
1 (0x01)	+Array1 Temp	SA1.3	Temperature = -0.163 x ADCcount + 110.8611	ºC
2 (0x02)	+/-Array1 Voltage	SA1.1/SA1.4	Voltage = -0.0148 x ADCcount + 22.7614	V
3 (0x03)	-Array1 Current	SA1.4	Current = -0.5431 x ADCcount + 528.5093	mA
4 (0x04)	-Array1 Temp	SA1.6	Temperature = -0.163 x ADCcount + 110.8611	ºC
5 (0x05)	+/-Array2 Voltage	SA2.1/SA2.4	Voltage = -0.0148 x ADCcount + 22.7614	V
6 (0x06)	-Array2 Current	SA2.4	Current = -0.5431 x ADCcount + 528.5093	mA
7 (0x07)	-Array2 Temp	SA2.6	Temperature = -0.163 x ADCcount + 110.8611	ºC
8 (0x08)	+/-Array3 Voltage	SA3.1/SA3.4	Voltage = -0.0148 x ADCcount + 22.7614	V
9 (0x09)	+Array3 Current	SA3.1	Current = -0.5431 x ADCcount + 528.5093	mA
10 (0x0A)	+Array3 Temp	SA3.3	Temperature = -0.163 x ADCcount + 110.8611	ºC
11 (0x0B)	+Array2 Current	SA2.1	Current = -0.5431 x ADCcount + 528.5093	mA
12 (0x0C)	+Array2 Temp	SA2.3	Temperature = -0.163 x ADCcount + 110.8611	ºC
13 (0x0D)	-Array3 Current	SA3.4	Current = -0.5431 x ADCcount + 528.5093	mA
14 (0x0E)	-Array3 Temp	SA3.6	Temperature = -0.163 x ADCcount + 110.8611	ºC
15 (0x0F)	+Array4 Current	SA4.1	Current = -0.5431 x ADCcount + 528.5093	mA
16 (0x10)	+Array4 Temp	SA4.3	Temperature = -0.163 x ADCcount + 110.8611	ºC
17 (0x11)	+/-Array4 Voltage	SA4.1/SA4.4	Voltage = -0.0142 x ADCcount + 21.9654	V
18 (0x12)	-Array4 Current	SA4.4	Current = -0.5431 x ADCcount + 528.5093	mA
19 (0x13)	-Array4 Temp	SA4.6	Temperature = -0.163 x ADCcount + 110.8611	ºC
20 (0x14)	+/-Array5 Voltage	SA5.1/SA5.4	Voltage = -0.0142 x ADCcount + 21.9654	V
21 (0x15)	-Array5 Current	SA5.4	Current = -0.5431 x ADCcount + 528.5093	mA
22 (0x16)	-Array5 Temp	SA5.6	Temperature = -0.163 x ADCcount + 110.8611	ºC
23 (0x17)	+/-Array6 Voltage	SA6.1/SA6.4	Voltage = -0.0142 x ADCcount + 21.9654	V
24 (0x18)	+Array6 Current	SA6.1	Current = -0.5431 x ADCcount + 528.5093	mA
25 (0x19)	+Array6 Temp	SA6.3	Temperature = -0.163 x ADCcount + 110.8611	ºC
26 (0x1A)	+Array5 Current	SA5.1	Current = -0.5431 x ADCcount + 528.5093	mA
27 (0x1B)	+Array5 Temp	SA5.3	Temperature = -0.163 x ADCcount + 110.8611	ºC
28 (0x1C)	-Array6 Current	SA6.4	Current = -0.5431 x ADCcount + 528.5093	mA
29 (0x1D)	-Array6 Temp	SA6.6	Temperature = -0.163 x ADCcount + 110.8611	ºC
30 (0x1E)	3V3 Bus Current	H2.27/H2.28	Current = -5.4311 x ADCcount + 4636.0085	mA
31 (0x1F)	5V Bus Current	H2.25/H2.26	Current = -5.4311 x ADCcount + 4636.0085	mA
32 (0x20)	BatV Bus Current	H2.45/H2.46	Current = -5.4311 x ADCcount + 4636.0085	mA
33 (0x21)	12V Bus Current	H2.51/H2.52	Current = -5.4312 x ADCcount + 5285.093	mA

Table 11-5 ADC Channels

12. TEST

All EPS are fully tested prior to shipping, and test reports are supplied. In order to verify the operation of the EPS please use the following outlined instructions.

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

- Battery compatible with Clyde Space EPS (or simulated battery)
- Breakout Connector (with connections as per Figure 12-1)
- Array Input (test panel, solar array simulator or power supply and limiting resistor)
- Oscilloscope
- Multimeter
- Electronic Load
- Aardvark I^2C interface (or other means of communicating on the I^2C bus)

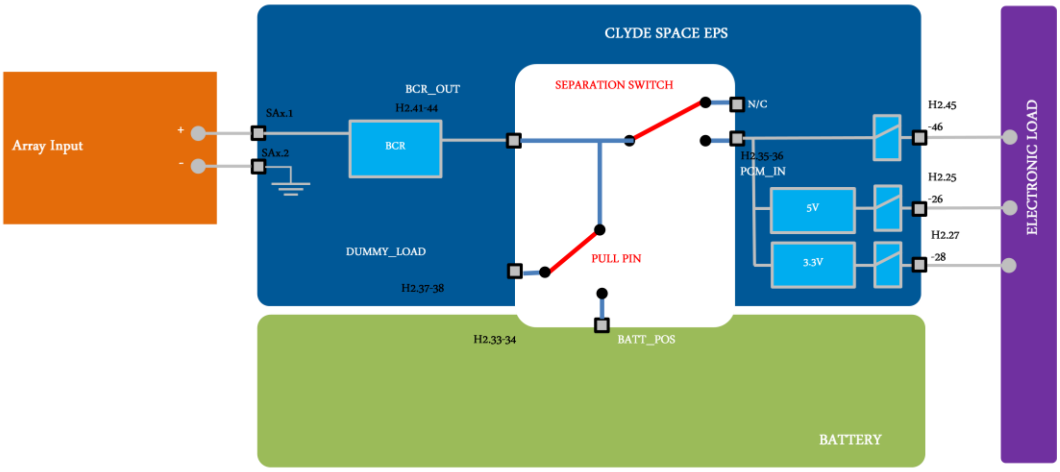


Figure 12-1 Suggested Test Setup

The breakout connector should be wired with the switch configuration to be used under mission conditions.

12.1 Power up/Down Procedure

The test setup should be assembled following the order detailed below:

- Breakout connector assembled with switches set to launch vehicle configuration (as shown in Figure 12-1)
- Fit Breakout connector to EPS
- Connect battery to stack
- Connect electronic load (no load) to buses
- Remove Pull Pin
- Connect array input

When powering down this process should be followed in reverse.

12.2 Battery Setup

The system should be tested with a battery in the system. This can be done using a Clyde Space Battery by stacking the boards, or by using a power supply and load to simulate the behavior of a battery. This setup is shown in Figure 12-2.

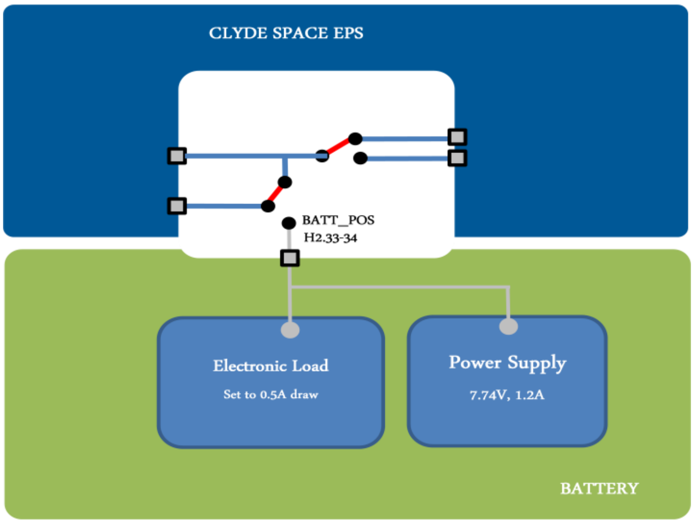


Figure 12-2 Simulated Battery Setup

12.3 Solar Array Input

There are 3 options for the array input section:

- A solar array
- A solar array simulator
- A benchtop power supply with current limiting resistor

When using a solar array or solar array simulator the limits should not exceed those outlined in Table 12-1.

	Voc (V)	Isc (mA)
BCR1	24.5	464
BCR2	24.5	464
BCR3	24.5	464
BCR4	24.5	464
BCR5	24.5	464
BCR6	24.5	464

Table 12-1 solar array limits

When using a power supply and resistor setup to simulate a solar panel the required configuration is shown in Figure 12-3.

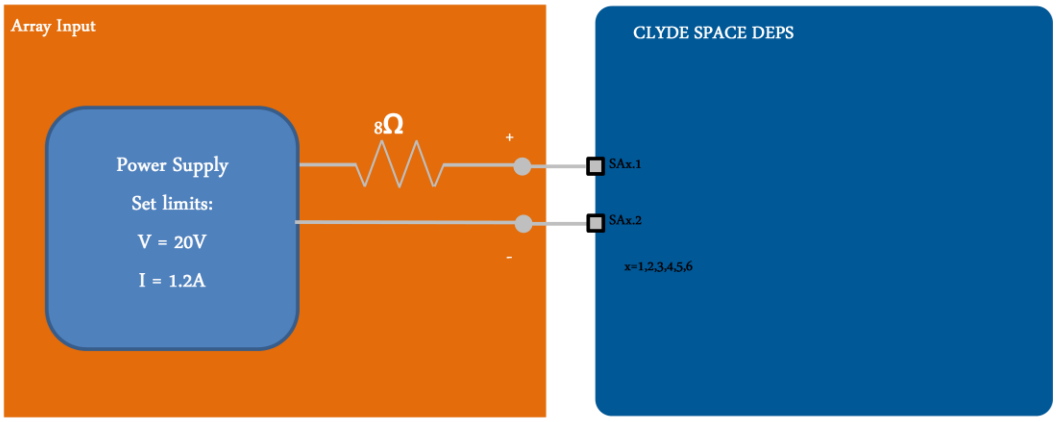


Figure 12-3 Solar Panel using power supply

12.4 Configuration and Testing

The following section outlines the procedure for performing basic functional testing

PCM Testing

In order to test the PCMs connection to a battery source must be implemented. In order to do this the Pull Pin and Separation Switch should be removed, connecting the battery, as shown in Figure 12-4.

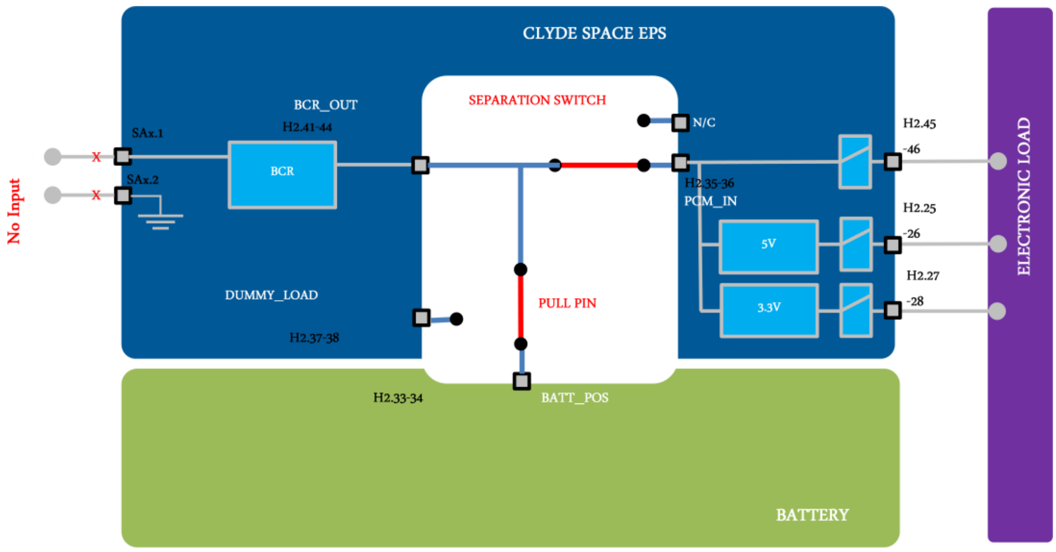


Figure 12-4 Test set-up with Pull Pin Removed

In this configuration all buses will be activated and can be measured with a multimeter.

By increasing the load on each of the buses you will be able to see the current trip points' activation, as discussed in section 10.1.

Undervoltage Protection

When using a simulated battery it is possible to trigger the undervoltage protection. Using the same test setup as detailed in Figure 12-2 and Figure 12-4, if the voltage is dropped to below ≈6.2V the undervoltage will be activated. This can be observed by the buses shutting down.

BCR Testing

In order to test the operation of the BCRs the separation switches and pull pin should be placed in their flight configuration as shown in Figure 12-5. Once this is done the array input can be connected.

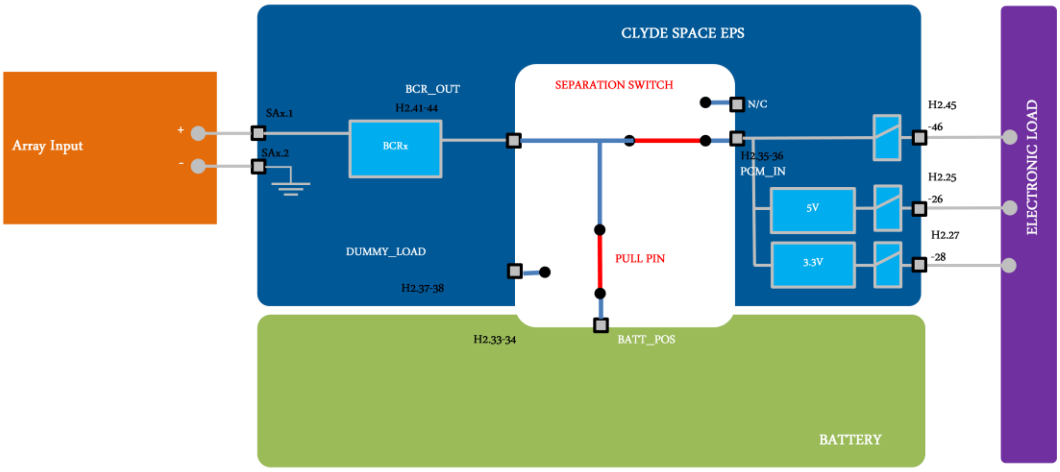


Figure 12-5 Test set-up in Flight Configuration

To check the operation of the BCR/MPPT an oscilloscope probe should be placed at pin 1 of the active solar array connector (not at the power supply). The wave form should resemble Figure 12-6.

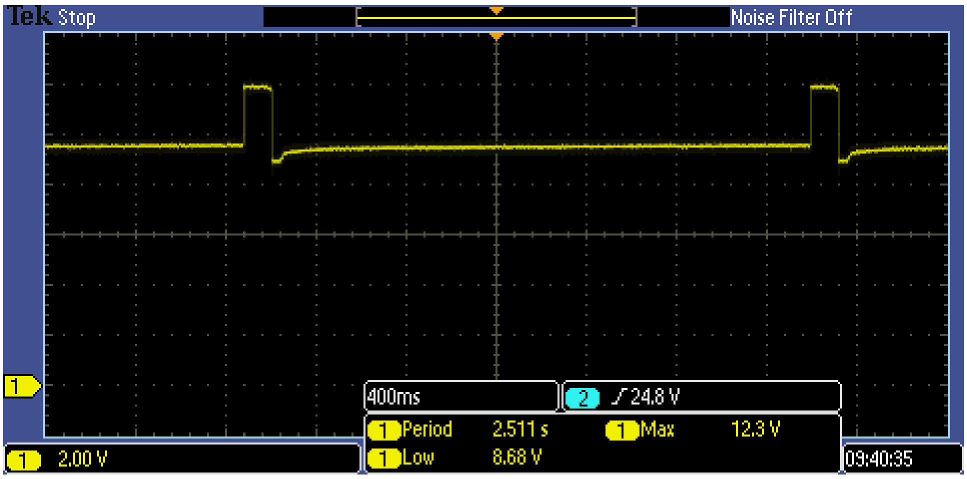


Figure 12-6 Waveform of Solar Array Input

EoC Operation

Using the test setup detailed in Figure 12-5 the EoC operation can be demonstrated. By raising the voltage of the simulated battery above ~8.26V the EoC mode will be activated. This can be observed using an ammeter coming from the Array input, which will decrease towards 0A.

16V Charging

Figure 12-7 shows the test setup for the 16V charging.

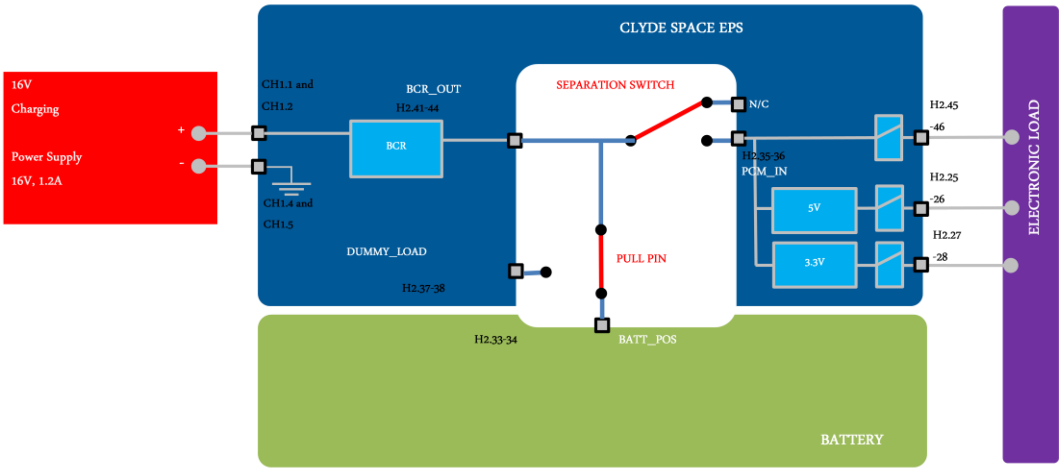


Figure 12-7 +16V charge setup

This setup should only be used for top up charge on the battery, not for mission simulation testing.

13. Developer AIT

AIT of the EPS with other CubeSat modules or subsystems is the responsibility of the CubeSat developer. Whilst Clyde Space outlines a generic process which could be applicable to your particular system in this section we are not able to offer more specific advice unless integration is between other Clyde Space products (or compatible products), see Table 14-1. AIT is at the risk of the developer and particular care must be taken that all subsystems are cross-compatible.

Throughout the AIT process it is recommended that comprehensive records of all actions be maintained tracking each subsystem specifically. Photo or video detailing of any procedure also helps to document this process. Comprehensive records are useful to both the developer and Clyde Space; in the event of any anomalies complete and rapid resolution will only be possible if good records are kept. The record should contain at least;

- Subsystem and activity
- Dates and times of activity (start, finish, key milestones)
- Operator(s) and QAs
- Calibration of any equipment
- Other subsystems involved
- Method followed
- Success condition or results
- Any anomalous behaviour

Before integration each module or element should undergo an acceptance or pre-integration review to ensure that the developer is satisfied that the subsystem meets its specification through analysis, inspection, review, testing, or otherwise. Activities might include:

- Satisfactory inspection and functional test of the subsystem
- Review of all supporting documentation
- Review of all AIT procedural plans, identifying equipment and personnel needs and outlining clear pass/fail criteria
- Dry runs of the procedures in the plan

Obviously testing and analysis is not possible for all aspects of a subsystem specification, and Clyde Space is able to provide data on operations which have been performed on the system, as detailed in Table 13-1.

	Performed on	Availability	
Functional	Module supplied	Provided with module	
Calibration	Module supplied	Provided with module	
Vacuum	Performed on module prototype	In manual	
Thermal	Performed on module prototype	In manual	
Simulation & modelling	Not performed	Not available	

Table 13-1 Acceptance test data

Following this review, it is recommended the system undergoes further testing for verification against the developer's own requirements. An example compliance matrix structure is shown in Table 13-2.

ID	Requirement	Procedure	Result (X)	Success criteria	Compliance (pass / fail)
SYS-0030	The system mass shall be no more than 1 kg	TEST-01	0.957 kg	X < 1 kg	PASS
SYS-0040	The error LED remains off at initialisation	TEST-02	LED flashing	LED off	FAIL
SYS-0050	…	…	…	…	…

Table 13-2 Compliance matrix example

All procedural plans carried out on the EPS should conform to the test setups and procedures covered in Section 0.

During testing it is recommended that a buddy system is employed where one individual acts as the quality assurance manager and one or more perform the actions, working from a documented and reviewed test procedure. The operator(s) should clearly announce each action and wait for confirmation from their QA. This simple practice provides a useful first check and helps to eliminate common errors or mistakes which could catastrophically damage the subsystem.

Verification is project dependant, but should typically start with lower-level subsystem-specific requirements which can be verified before subsystems are integrated; in particular attention should be paid to the subsystem interfaces to ensure cross-compatibility. Verification should work upwards towards confirming top-level requirements as the system integration continues. This could be achieved by selecting a base subsystem (such as the EPS, OBC or payload) and progressively integrating modules into a stack before structural integration. Dependent upon the specific systems and qualification requirements further system-level tests can be undertaken.

When a subsystem or system is not being operated upon it should be stowed in a suitable container, as per Section 5.

14. Compatible Systems

	Compatibility	Notes
Stacking Connector	CubeSat Kit Bus	CubeSat Kit definition pin compatible
	Non-standard Wire Connector	User defined
	Other Connectors	Please contact Clyde Space
Batteries	Clyde Space 3U Battery Systems	10W/hr – 30 W/hr Lithium Ion Polymer
	Lithium Polymer 8.2v	(2s1p) to (2s4p)(1) More strings can be connected in parallel to increase capacity if required
	Lithium Ion 8.2v	(2s1p) to (2s4p) (1) More strings can be connected in parallel to increase capacity if required
	Other Batteries	Please contact Clyde Space
Solar Arrays	Clyde Space 12W solar array	Connects to BCR 1-6
	12W triple junction cell arrays	4-8 in series connection
	Other array technologies	Any that conform to the input ratings for Voltage and Current(2)
Structure	Pumpkin	CubeSat 3U structure
	ISIS	CubeSat 3U compatible
	Other structures	Please contact Clyde Space

Table 14-1 Compatible Systems

(1) Refers to series and parallel connections of the battery cells within the battery system. e.g. 2s1p indicates a single string of two cells in series.
(2) Will require some alteration to MPPT. Please contact Clyde Space.