# User Manual: Standalone 30Wh Battery

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| | Name | Date | Signed |
|---|---|---|---|
| **Author** | **Vicki McLaren** | **28/04/2010** | V. McLaren |
| **Approved** | **John Charlick** | **28/04/2010** | John Charlick |

**Clyde Space Ltd.**
Helix Building, Kelvin Campus,
West of Scotland Science Park,
Glasgow G20 0SP, UK.
t: + 44 (0) 141 946 4440

e: enquiries@clyde-space.com
w: www.clyde-space.com

Registered in Scotland No. SC285287
at 123 St Vincent Street Glasgow G2 5EA

SOLUTIONS FOR A NEW AGE IN SPACE

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## Document Control

| Issue | Date | Section | Description of Change | Reason for Change |
|---|---|---|---|---|
| A | 21/04/10 | All | First Draft | |
| | | | | |
| | | | | |

## Revision Control

| Product | Part Number | Revisions covered | Notes |
|---|---|---|---|
| CubeSat 1U Battery | | | |
| CubeSat 3U Battery | | | |
| CubeSat Remote Battery | | | |

## Acronyms and Abbreviations

| | |
|---|---|
| Wh | Watt Hour |
| Ah | Ampere Hour |
| 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 |
| rh | Relative Humidity |
| DoD | Depth of Discharge |
| $Kbits^{-1}$ | Kilobits per second |
| Voc | Open Circuit Voltage |
| Isc | Short Circuit Current |

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## Related Documents

| No. | Document Name | Doc Ref. |
|---|---|---|
| RD-1 | Clyde Space EPS User Manual | Dependant on EPS |
| RD-2 | Solar Panel User Document | Dependant on Solar Panels |
| RD-3 | CubeSat Design Specification | CubeSat Design Specification Rev. 12 |
| RD-4 | NASA General Environmental Verification Standard | GSFC-STD-7000 April 2005 |
| RD-5 | CubeSat Kit Manual | UM-3 |
| RD-6 | Power System Design and Performance on the World's Most Advanced In-Orbit Nanosatellite | As named |
| | | |

| # | 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 | 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 and subsequent damage to the battery |
| 3 | 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 |
| 4 | Ensure not to exceed the maximum stated limits | Exceeding any of the stated maximum limits can result in failure of the battery |
| 5 | 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 |
| 6 | 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 |
| 7 | 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. |
| 8 | 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 |
| 9 | 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 |
| 10 | **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 Batteries. The batteries are configured in a 2s3p configuration (two cells in series, with three pairs in parallel), and are designed to integrate with a suitable EPS and solar arrays to form a complete power system for a CubeSat.

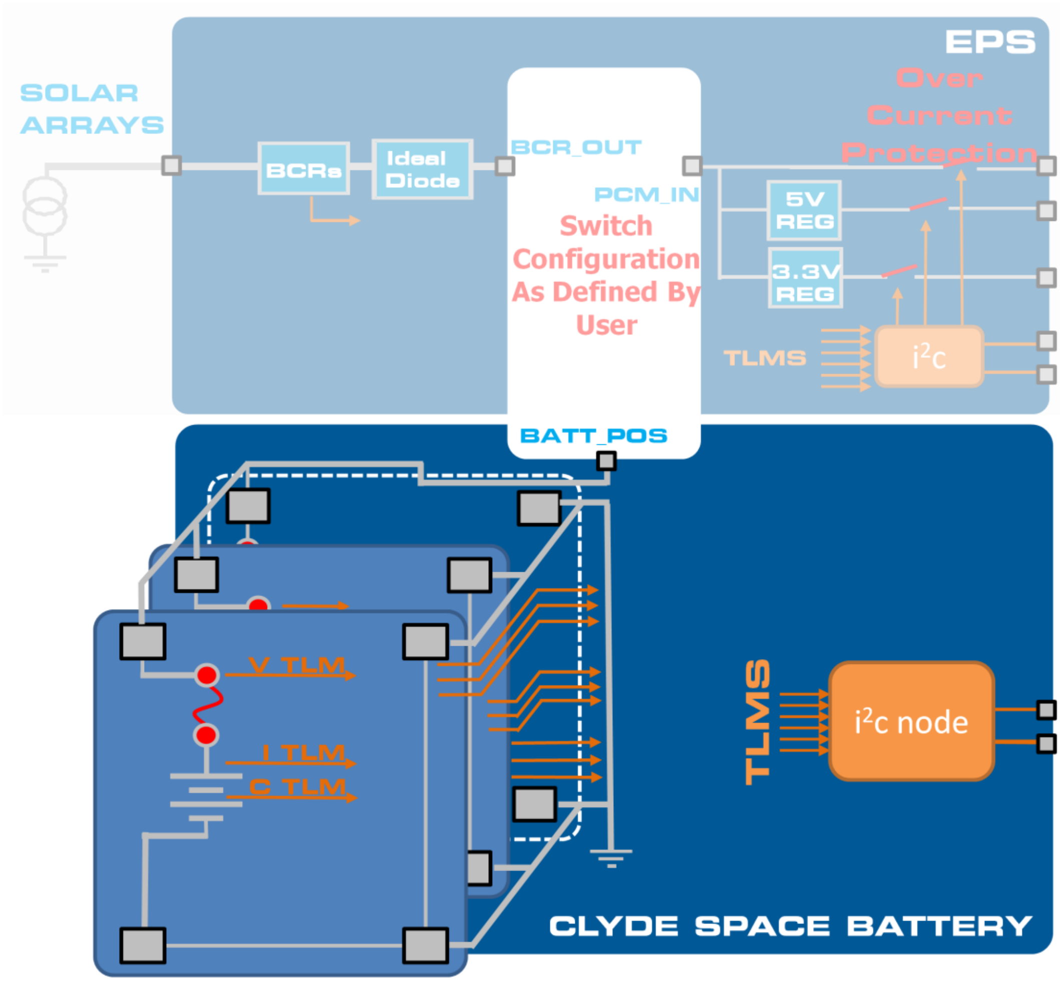


**Figure 1-1 System Diagram**

## 1.1 Additional Information Available Online

Additional information on CubeSats and Clyde Space Systems can be found at www.clyde-space.com. A login is required to access certain documents on our website.

## 1.2 Continuous Improvement

Clyde Space is continuously improving its processes and products. We aim to provide full visibility of changes and updates, and this information can be accessed by logging in to www.clyde-space.com.

## 1.3 Document Revisions

In addition to hardware and software updates, we also update 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

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 120 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, and the batteries have been cleared for launch on NASA manned flights.

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.

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# 3. MAXIMUM RATINGS(1)

| MAX RATINGS OVER OPERATING TEMPERATURE RANGE (UNLESS OTHERWISE STATED) | | | | |
|---|---|---|---|---|
| | | BCR | Value | Unit |
| Charge Limits | Voltage | max | 8.4 | V |
| | Current | max (C) | 3.75 | A |
| | Current Rate | max | C | Fraction of Capacity |
| Discharge Limits | Voltage | min | 6.0 | V |
| | Current | max (C) | 3.75 | A |
| | Current Rate | max | C | Fraction of Capacity |
| | | | | |
| Operating Temperature | | | -10 to 50 | °C |
| Vacuum | | | $10^{-5}$ | torr |
| Radiation Tolerance | | | (TBC) | |
| Shock | | | (TBC) | |
| Vibration | | | (TBC) | |

**Table 3-1 Performance Characteristics of the 30Wh Battery**

(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

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# 4. Electrical Characteristics

| Description | Notes | Min | Typical | Max | Unit |
|---|---|---|---|---|---|
| **Charge Conditions** | | | | | |
| EoC Voltage | | 8.22 | 8.26 | 8.30 | V |
| Charge Current | Recommended maximum C/2 | -- | 1.875 | -- | A |
| **Discharge Conditions** | | | | | |
| Full Discharge Voltage | | 6.16 | 6.2 | 6.24 | V |
| Discharge Current | Recommended maximum C/2 | -- | 1.875 | -- | A |
| Depth of Discharge | Recommended | -- | 20% | -- | Capacity |
| **Capacity** | | | | | |
| Discharge rate C/15 | -20°C | -- | 3.165 | -- | Ah |
| | 0°C | -- | 4.074 | -- | Ah |
| | 20°C | -- | 4.503 | -- | Ah |
| | 40°C | -- | 4.419 | -- | Ah |
| Discharge rate C/10 | -20°C | -- | 2.742 | -- | Ah |
| | 0°C | -- | 3.882 | -- | Ah |
| | 20°C | -- | 4.290 | -- | Ah |
| | 40°C | -- | 4.305 | -- | Ah |
| Discharge rate C/5 | -20°C | -- | 1.704 | -- | Ah |
| | 0°C | -- | 3.483 | -- | Ah |
| | 20°C | -- | 3.828 | -- | Ah |
| | 40°C | -- | 3.849 | -- | Ah |
| Discharge rate C/2 | -20°C | -- | 0.132 | -- | Ah |
| | 0°C | -- | 2.148 | -- | Ah |
| | 20°C | -- | 3.678 | -- | Ah |
| | 40°C | -- | 3.624 | -- | Ah |
| Discharge rate C | -20°C | -- | 0.078 | -- | Ah |
| | 0°C | -- | 0.546 | -- | Ah |
| | 20°C | -- | 3.435 | -- | Ah |
| | 40°C | -- | 3.513 | -- | Ah |
| **Communications** | | | | | |
| Protocol | | -- | $I^2C$ | -- | |
| Transmission speed | | -- | 100 | 400 | $Kbits^{-1}$ |
| Bus voltage | | 3.26V | 3.3V | 3.33V | |
| Node address | | -- | 0x2A | -- | Hex |
| Address scheme | | -- | 7bit | -- | |
| Node operating frequency | | -- | 8MHz | -- | |
| **Quiescent Operation** | | | | | |
| Power Draw | Draw from TLM node | -- | -- | <0.1 | W |
| **Physical** | | | | | |
| Dimensions | Height from top of motherboard PCB | | 20.44 | | mm |
| Weight | | 252 | 256 | 260 | g |

**Table 4-1 Performance Characteristics of the 30Wh Battery**

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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 batteries. 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.

## 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.

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 7.4V (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 ~7.4V. It is also recommended that the Pull Pin is left in place/replaced during periods of storage.

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

# 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<br>or 0.995 | 0.02<br>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 |
|---|---|---|---|---|---|
| ESQ-126-39-G-D | Samtec | Gold Plated | Black Glass Filled Polyester | PTH | CubeSat Kit Compatible Headers |

**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 30Wh Battery is optimised for Low Earth Orbit (LEO) missions with a maximum altitude of 850km. The battery is designed for integration with spacecraft that has an EPS compatible with lithium ion polymer technology.

Clyde Space batteries offer high capacity with low weight and volume. The battery systems all have integrated heater systems to enhance operation at low temperatures, with control via the $I^2C$ node. There is over current protection incorporated to protect the cells in the event of a power line fault; further battery protection is provided when integrated with a Clyde Space EPS.

In addition to this, each battery provides telemetry information for the voltage, current and temperature of each board, accessible via the $I^2C$ node.

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 0°C, and switch off again when the temperature rises above 5°C. The heater can also be switched off by $I^2C$ command for power conservation.

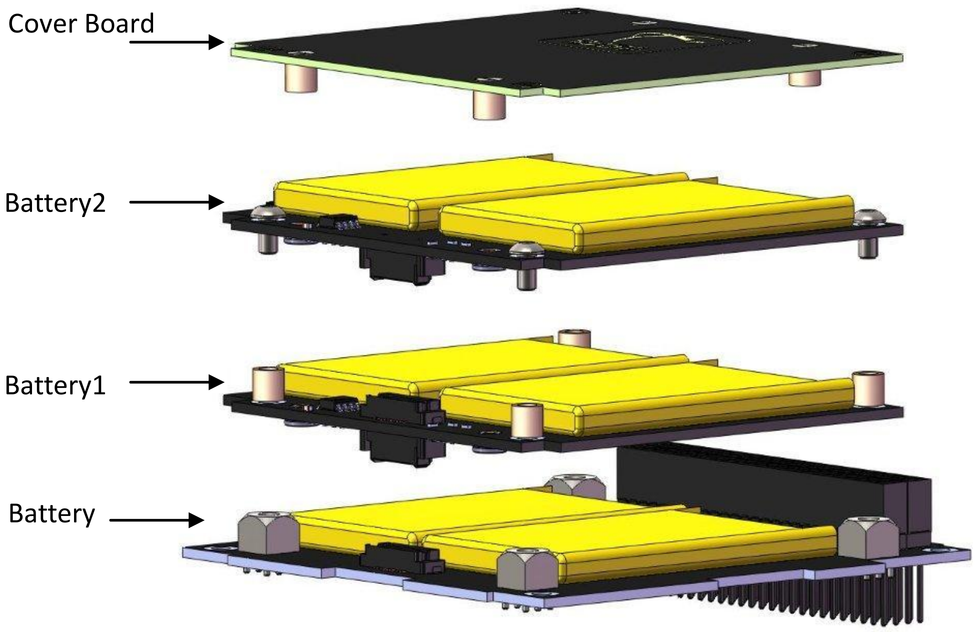


**Figure 7-1 Battery Configuration**

## 7.1 System Overview

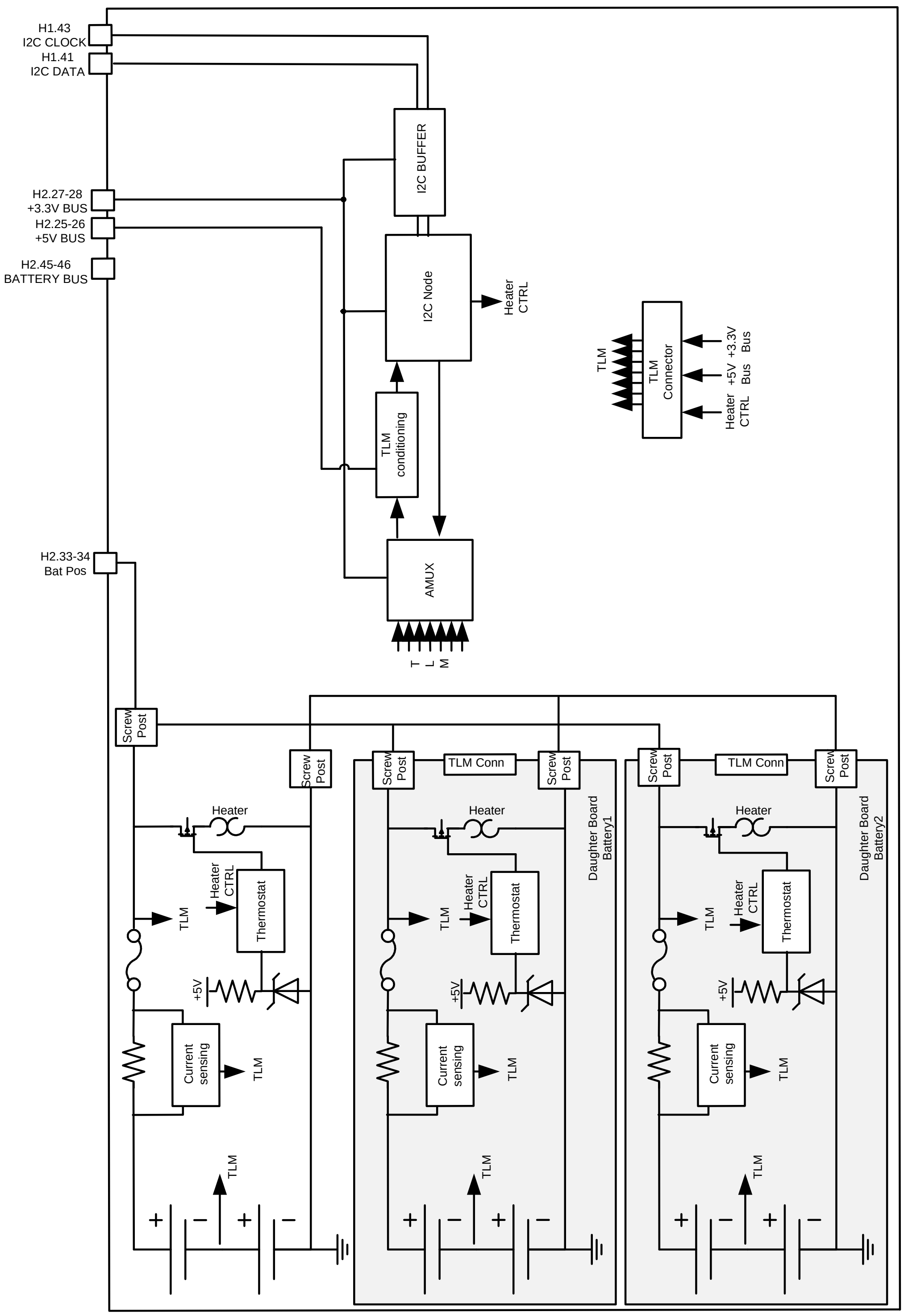


**Figure 7-2 Function Diagram**

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## 7.2 Protection and Redundancy

All batteries have integrated over current protection. This is achieved by using polyswitches which are designed to trip when an over current event occurs. To protect the battery and satellite from power faults, such as over current or under voltage, a system of monitoring and shutdown is required. The system must be able to detect and shutdown any power line which has encountered a fault.

When the battery systems are integrated with a Clyde Space EPS, these protection protocols are inbuilt and will fully protect the whole EPS and battery systems.

The loss of one pair of cells, (i.e. one battery in the stack) will not affect the performance of the remaining batteries – power will continue to be supplied to the system.

## 7.3 Quiescent Power Consumption

The quiescent power consumption of the battery will be ≈0.1W. This power is drawn from the 3.3V, 5V and battery busses, available on the CubeSat header to power the $I^2C$ node and TLM circuitry.

## 7.4 Mass and Mechanical Configuration

The mass of the system is approximately 256g and is contained on a PC/104 size motherboard and two smaller daughterboards, compatible with the CubeSat Kit bus. Other versions of the batteries are available without the CubeSat Kit bus header.

The dimensions of the battery, including the connector locations, are given in Figure 7-3.

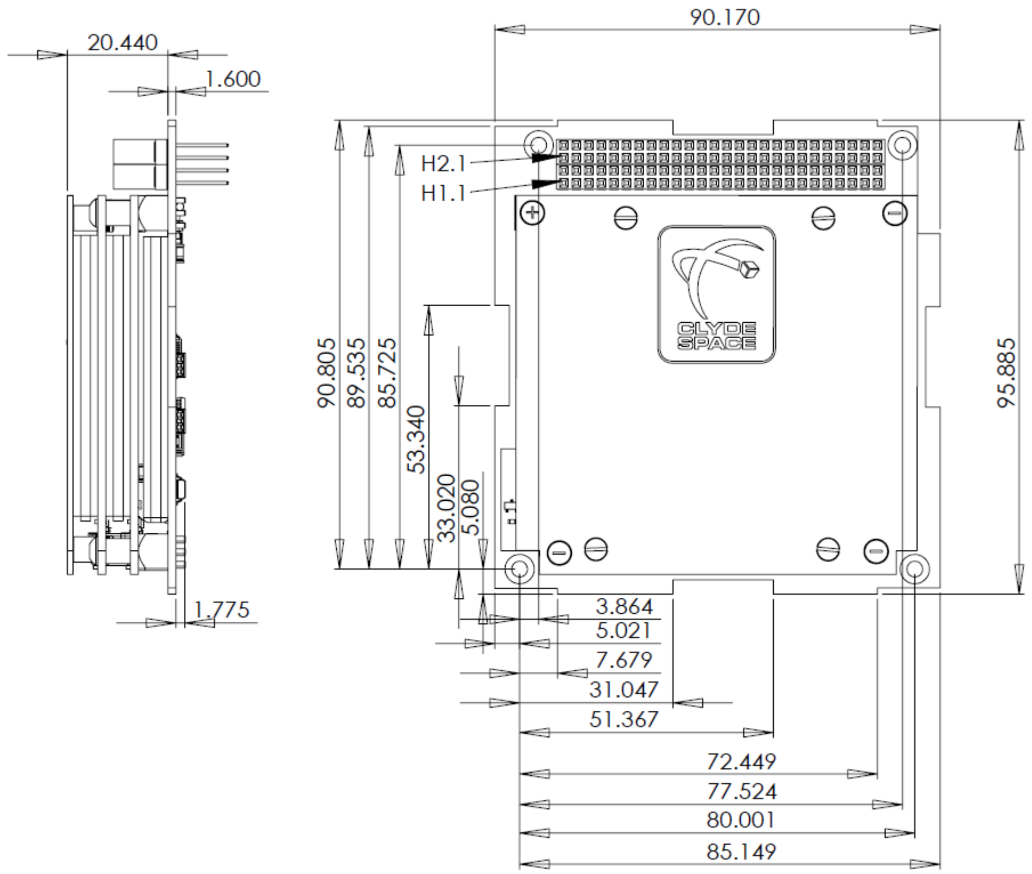


**Figure 7-3 Board dimensions (mm)**

# 8. INTERFACING

The interfacing of the battery is outlined in Figure 8-1, including the solar arrays, EPS, connection to the switch configuration, output of the power buses and communication to the I²C node. In the following section it is assumed that the battery will be integrated with a Clyde Space EPS.

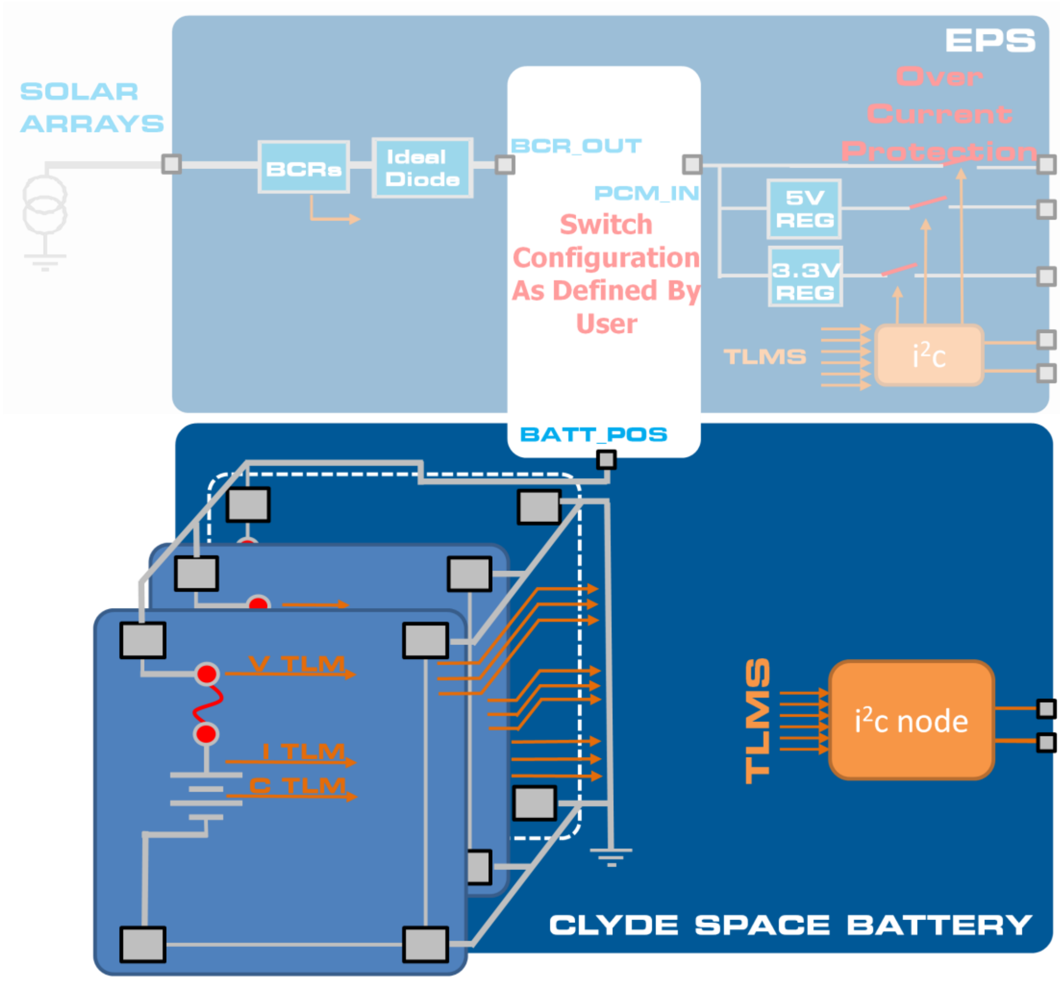


**Figure 8-1 Clyde Space EPS and Battery Simplified Connection Diagram**

## 8.1 Connector Layout

1

The connector positions are shown in Figure 7-3, and described in Table 8.1.

| Connector | Function |
|---|---|
| H1 | Cubesat Kit bus compatible Header 1 |
| H2 | Cubesat Kit bus compatible Header 2 |

**Table 8-1 Connector functions**

## 8.2 CubeSat Kit Compatible Headers

Connections from the EPS to the bus of the satellite are made via the CubeSat Kit compatible headers H1 and H2, as shown in Figure 8-2.

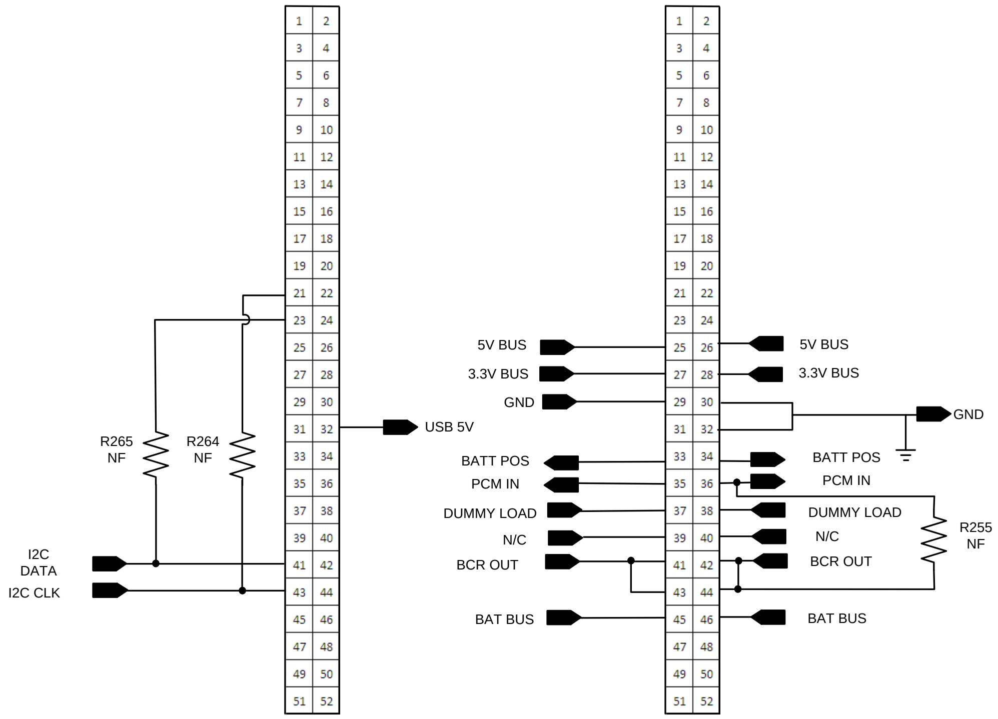


**Figure 8-2 CubeSat Kit Header Schematic**

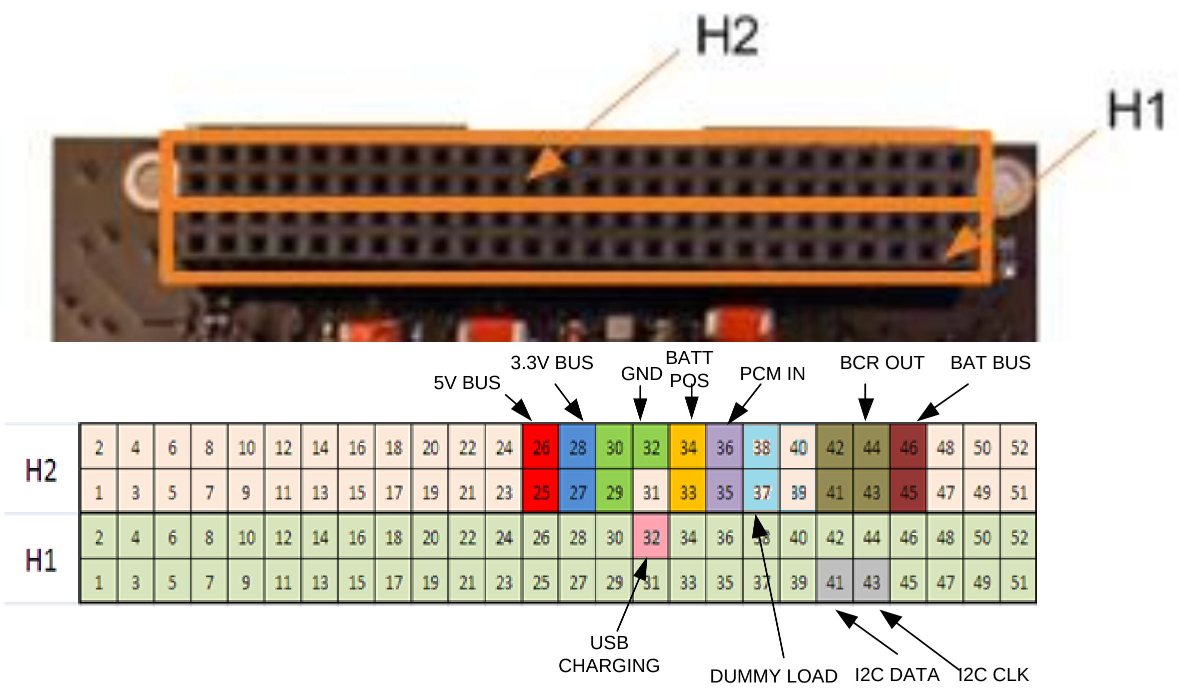


**Figure 8-3 EPS Connector Pin Identification**

## 8.3 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 | ON_I2C | Selection pin for $I^2C$ | Alternative $I^2C$ clock | 24 | NC | Not Connected | Not Connected |
| 25 | NC | Not Connected | Not Connected | 25 | +5V BUS | +5V Power bus | Regulated 5V bus |
| 26 | NC | Not Connected | Not Connected | 26 | +5V BUS | +5V Power bus | Regulated 5V bus |
| 27 | NC | Not Connected | Not Connected | 27 | +3.3V BUS | +3V3 Power bus | Regulated 3V3 bus |
| 28 | NC | Not Connected | Not Connected | 28 | +3.3V REG | +3V3 Power bus | 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 | USB_5 | USB 5+v | Use to charge battery via USB | 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 | Battery Bus | Power line | Output to battery bus |
| 46 | NC | Not Connected | Not Connected | 46 | Battery Bus | Power line | Output to battery 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 |

| HEADER 1 | | | | HEADER 2 | | | |
|---|---|---|---|---|---|---|---|
| Pin | Name | Use | Notes | Pin | Name | Use | Notes |
| 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 | NC | Not Connected | Not Connected |
| 52 | NC | Not Connected | Not Connected | 52 | NC | Not Connected | Not Connected |

**Table 8-2 Pin Descriptions for Header H1 and H2**

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| 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)<br>**Should only be connected between EPS and Battery** |
| PCM IN | 2.35-36 | SW1 | (Switches →)<br>Input to PCMs and PDMs |
| DUMMY LOAD | 2.37-38 | SW2 | (Switches →) |
| N/C | 2.39-40 | SW3 | (Switches N/C)<br>Unused connection of launch switch closed state |
| BCR OUT | 2.41-44 | SW4 | Output of BCRs<br>(→ Switches) |
| BCR OUT | 2.41-44 | SW5 | Output of BCRs<br>(→ Switches) |
| BATTERY BUS | 2.45-46 | VBATT+ | Battery Unregulated **Bus** Output |

**Table 8-3 Header pin name descriptions relating CubeSat Kit names to CS names**

## 8.4 Switch Options

The Clyde Space EPS has three connection points for switch attachments, as shown in Figure 8-4. 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-3].

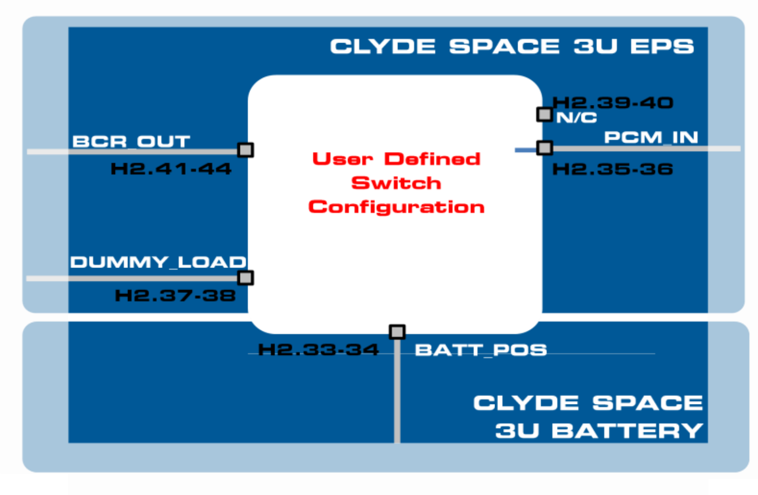


**Figure 8-4 Switch connection points**

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.

### Dummy Load

The Dummy Load is available as 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 USB 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.

The Clyde Space Dummy Load system has been a standard feature from revision D of the EPS onwards. If the Dummy Load is required for an earlier revision please contact Clyde Space for fitting instructions.

Option 1

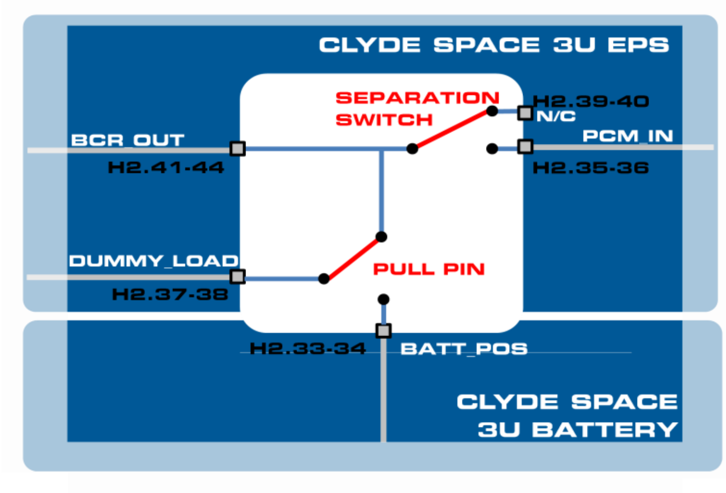


**Figure 8-5 Switch Configuration Option 1**

Option 1 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, there is a possibility of damaging the system. In order to mitigate this risk a "Dummy Load" is fitted on the EPS.

Option 2

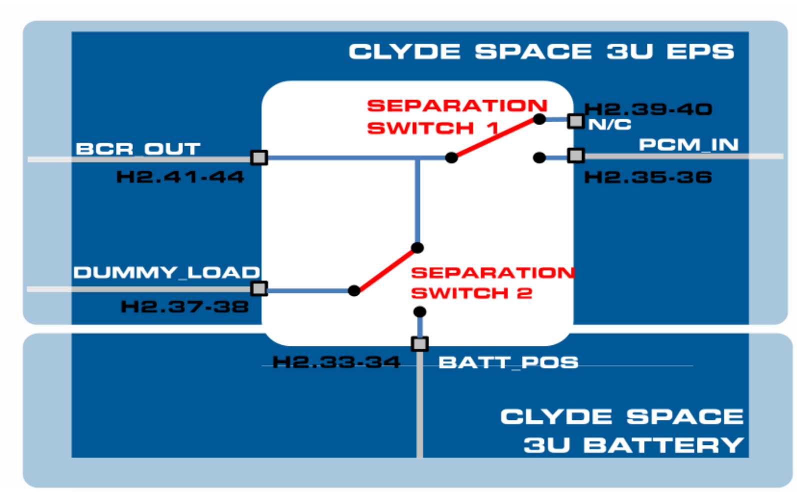


**Figure 8-6 Switch Configuration Option 2**

Option 2 is compatible with structures incorporating two separation switches, providing complete isolation in the launch configuration. The dummy load is not activated in this configuration.

Care should be taken to ensure that the switches used are rated to the appropriate current levels. An alternative solid-state switch can be installed.

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

## 8.5 EPS and Battery Integration

Connection of the battery systems on the 3U 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 fully isolated until implementing and connecting a switch configuration, as discussed in Section 8.4. 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.

## 8.6 Buses

All power buses are accessible via the CubeSat Kit headers and are listed and described in Table 8-2. These buses must be supplied to the battery board to allow $I^2C$ communications and telemetry readings to be made. These are the only power connections that should be used by the platform since they follow all battery and bus over-current protections.

The only connection to the battery positive pins (H2.33 and H2.34) should be to the EPS to allow full protection of the battery to be implemented. Any direct connections to these pins may result in over-discharge of the battery.

All $I^2C$ communications are accessible via the CubeSat kit header. See Section 11.

# 9. TECHNICAL DESCRIPTION

This section gives a complete overview of the operational modes of the battery and the testing undertaken to ensure their suitability for space. It is assumed that a Clyde Space EPS is used for the charging and discharging of the batteries.

## 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 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.

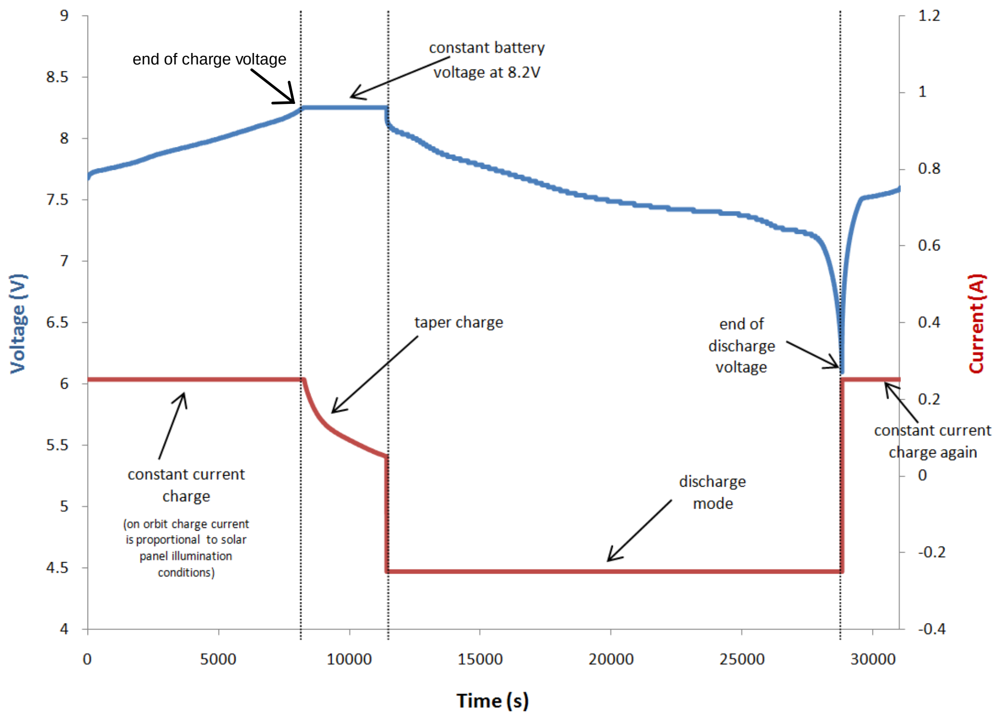


**Figure 9-1 Charge/Discharge Cycle**

The application of constant current/constant voltage charge method on a spacecraft is described in more detail in RD-6. In this document there is on-orbit data showing the operation and how the current fluctuates with changing illumination conditions and orientation of the spacecraft with respect to the Sun.

## 9.2 Discharge

The central section in Figure 9.1 shows the profile of a full discharge of the battery at a C/5 rate (0.25A for a 2s1p battery). 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.

## 9.3 Lot Acceptance Testing

In order to determine the cell's suitability for space applications, Clyde Space undertakes an extensive Lot Acceptance Testing regime. The process is detailed in this section.

### DPA

Destructive Physical Analysis (DPA) of the cell reveals a stacked cell architecture, as shown in Figure 9-2.

The cell is hermetically sealed in a plastic coated foil casing. The cell 'stack' (pictured on the left hand side of the photograph in Figure 9-2) consists of 12 layers. The top layer is shown separated as far as possible in the figure. The individual components are well adhered (confirming the presence of a polymer electrolyte) but can be separated into; current collectors, separators, and active materials. The active material can be removed with a scalpel to reveal the copper electrode.

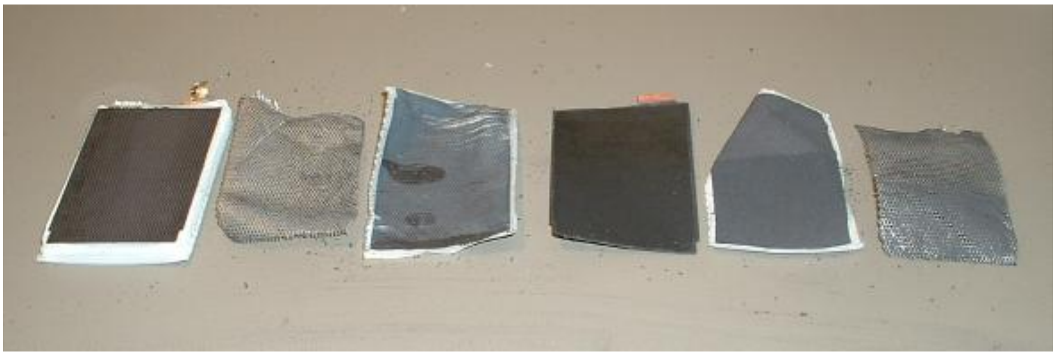

**Figure 9-2 DPA showing separated cell components**

### Capacity Variation with Discharge Rate and Temperature

Discharge plots are shown in Figures 9-3 to 9-6 for rates of C/15, C/10, C/5, C/2 and C at 40°C (Figure 9-3), 20°C (Figure 9-4), 0°C (Figure 9-5), and -20°C (Figure 9-6). In Figures 9-7 to 9-11, 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.

| T (°C) | Discharge Rate and (measured capacity (Ah)) | | | | |
|---|---|---|---|---|---|
| 40 | C/15 (1.437) | C/10 (1.435) | C/5 (1.283) | C/2 (1.208) | C (1.171) |
| 20 | C/15 (1.501) | C/10 (1.430) | C/5 (1.276) | C/2 (1.226) | C (1.145) |
| 0 | C/15 (1.358) | C/10 (1.294) | C/5 (1.161) | C/2 (0.716) | C (0.182) |
| -20 | C/15 (1.055) | C/10 (0.914) | C/5 (0.568) | C/2 (0.044) | C (0.026) |

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

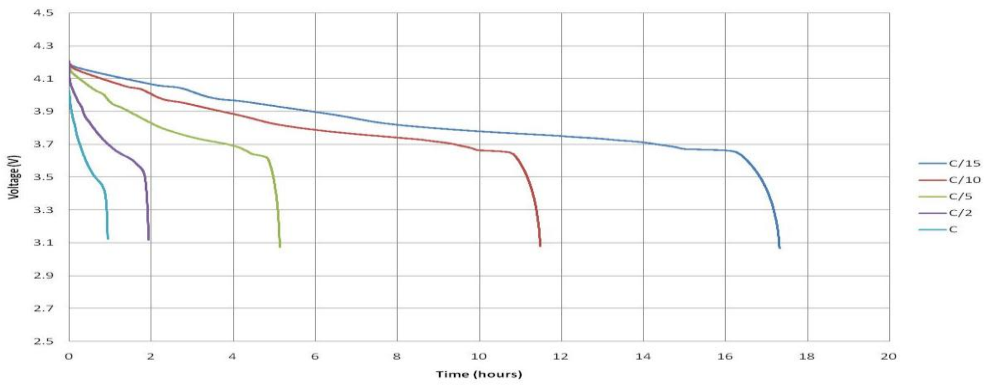


**Figure 9-3 Discharge traces at 40°C at C/15, C/10, C/5, C/2, and C rates**

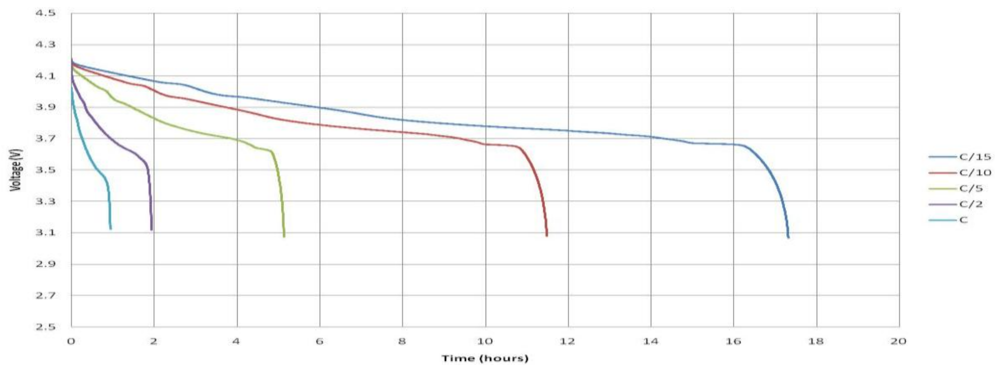


**Figure 9-4 Discharge traces at 20°C at C/15, C/10, C/5, C/2, and C rates**

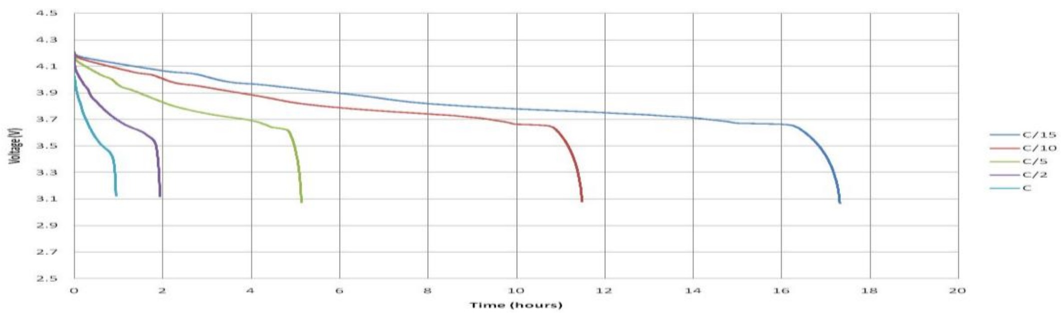


**Figure 9-5 Discharge traces at 0°C at C/15, C/10, C/5, C/2, and C rates**

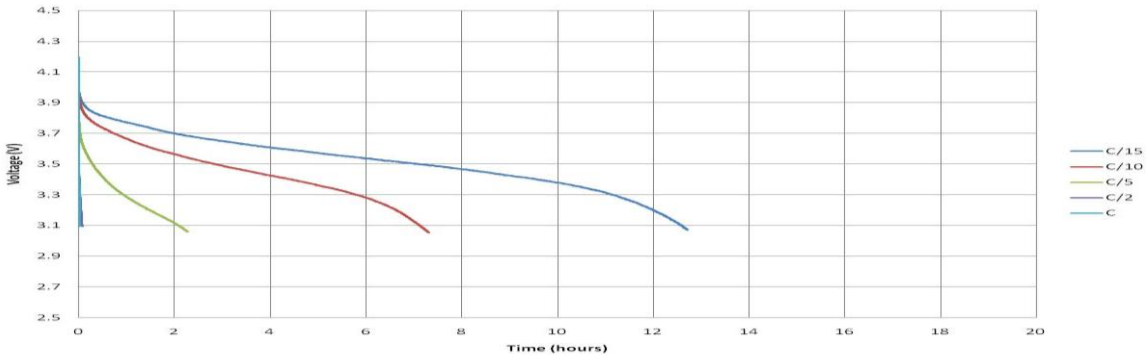


**Figure 9-6 Discharge traces at -20°C at C/15, C/10, C/5, C/2, and C rates**

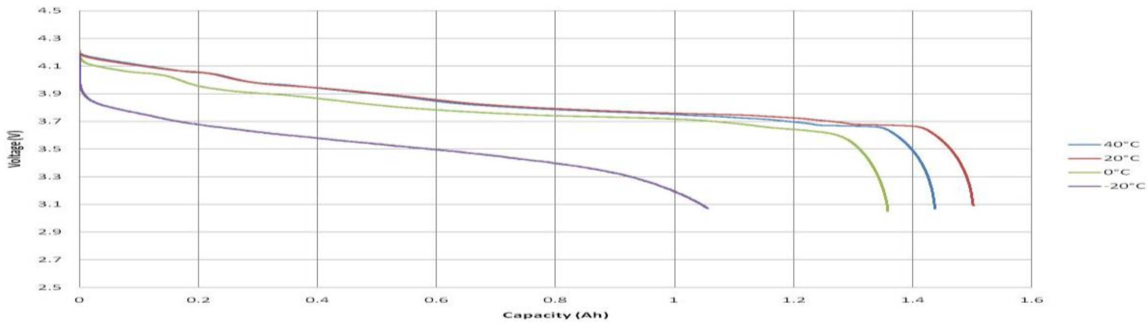


**Figure 9-7 Discharge traces at C/15 rate, at different temperatures.**

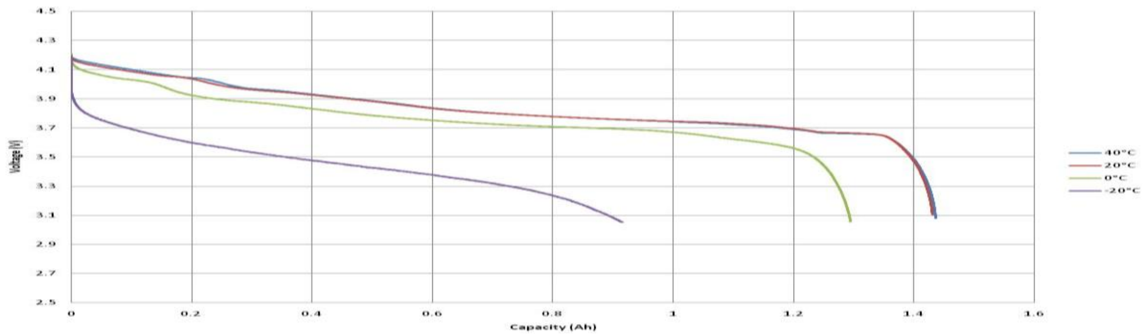


**Figure 9-8 Discharge traces at C/10 rate, at different temperatures.**

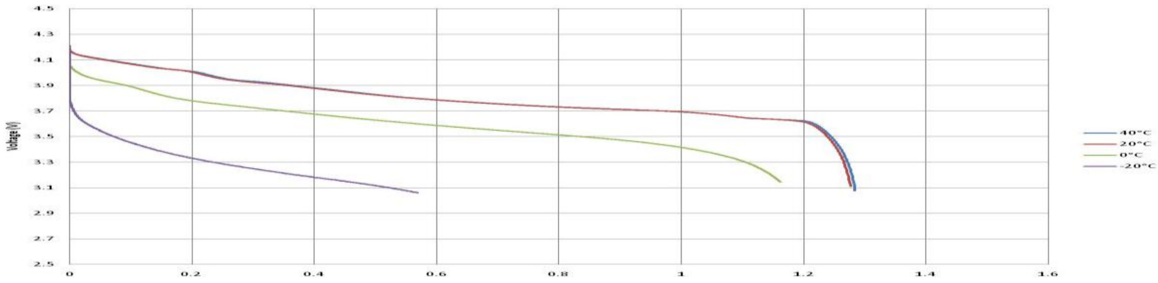

**Figure 9-9 Discharge traces at C/5 rate, at different temperatures**

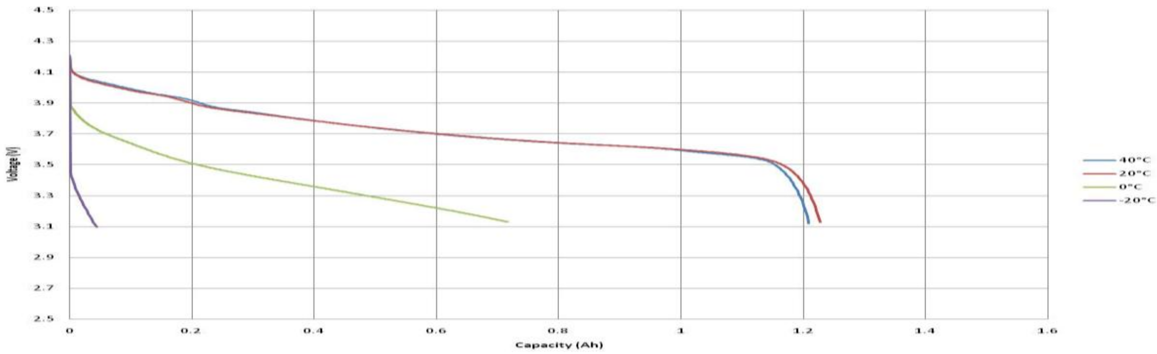


**Figure 9-10 Discharge traces at C/2 rate, at different temperatures.**

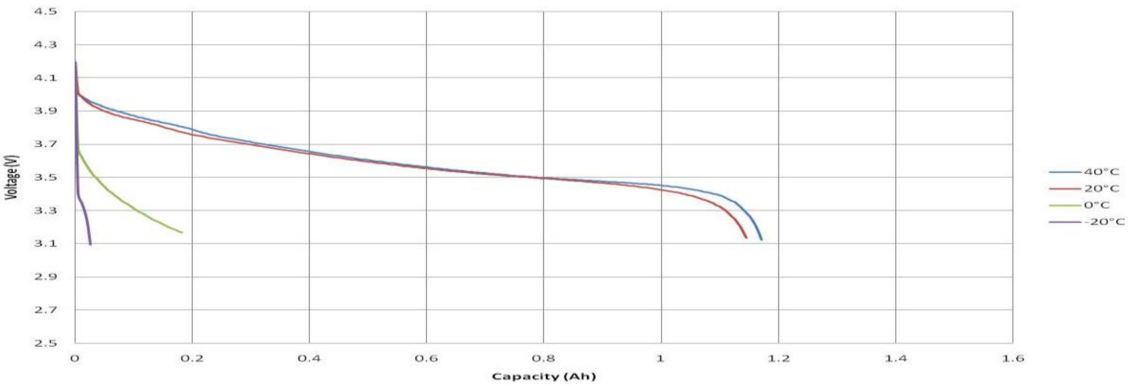


**Figure 9-11 Discharge traces at C rate, at different temperatures.**

## Self Discharge/Optimum Storage Condition

Optimum storage conditions were examined at different temperatures and depths of discharge. The results indicated that the best conditions in which to maintain the cell, and therefore battery capacity, are to store at a depth of discharge around 50% (~7.4V), and at temperatures between -10°C and +10°C. It is therefore recommended that when not in use, batteries are stored in a refrigerator, or similar.

## Vacuum Cycling

Vacuum cycling was carried out in a chamber at 19mbar pressure and at ambient temperature. A plot of cell voltage vs. time for 10 cycles is shown in Figure 9-12. Capacity variation with cycle number is indicated in Table 9-2.

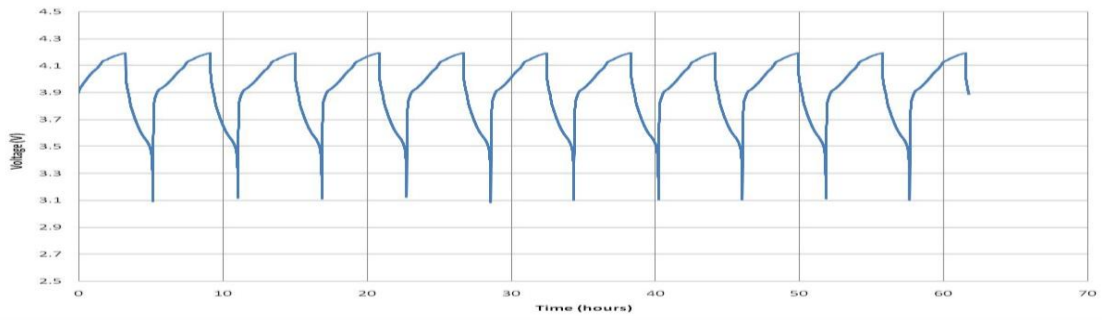


**Figure 9-12 Cell cycled at C/2 rate in a vacuum of 19mbar**

| Cycle number | Capacity (Ah) |
|---|---|
| 1 | 1.193 |
| 2 | 1.193 |
| 3 | 1.172 |
| 4 | 1.200 |
| 5 | 1.198 |
| 6 | 1.190 |
| 7 | 1.197 |
| 8 | 1.195 |
| 9 | 1.190 |
| 10 | 1.187 |

**Table 9-2 Cell capacity variation with vacuum cycle number**

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

The cell capacity varied slightly with subsequent cycles with a decrease of 0.5% in the measured capacity between cycle 1 and cycle 10.

Standard capacity measurements were carried out following the vacuum cycling. Very little difference was seen in the capacity measured before and after vacuum cycling (1.257Ah before, 1.243Ah after). Vacuum cycling therefore did not have any significant detrimental effect on the cell capacity.

Although the cells 'bulge' in a vacuum, the stack 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.

### 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 9-13.

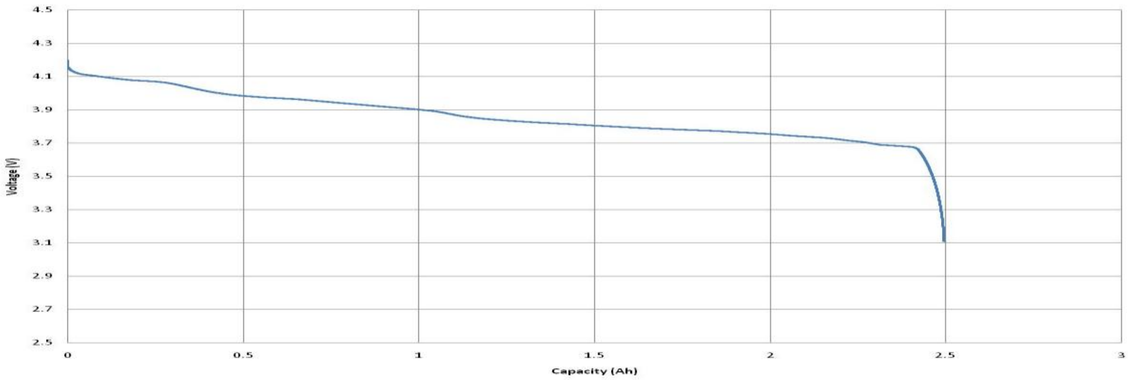


**Figure 9-13 Discharge trace at C/50 rate at 20°C.**

The capacity of the cell discharged at C/50 was 2.495Ah, which is almost double the cell nameplate capacity and indicates the effect of internal resistance on the cell capacity. Internal resistances have been estimated from previous figures at the cross-over point from discharge to charge. Cells cycled at C/2 have an estimated internal resistance of ~0.525ohms, and at C/5 an estimated internal resistance of ~0.412ohms. These figures show that the cell internal resistance increases as the charge/discharge rate also increases.

In Table 9-3, 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.

| DoD (%) | Voltage of cell discharged at C/5 (V) | Voltage of cell discharged at C/50 (V) |
|---|---|---|
| 0 | 4.200 | 4.200 |
| 5 | 4.078 | 4.091 |
| 10 | 4.030 | 4.069 |
| 15 | 3.994 | 4.022 |
| 20 | 3.918 | 3.983 |
| 25 | 3.890 | 3.967 |
| 30 | 3.861 | 3.946 |
| 35 | 3.829 | 3.923 |
| 40 | 3.799 | 3.902 |
| 45 | 3.775 | 3.862 |
| 50 | 3.756 | 3.835 |
| 55 | 3.738 | 3.820 |
| 60 | 3.722 | 3.805 |
| 65 | 3.709 | 3.791 |
| 70 | 3.700 | 3.780 |
| 75 | 3.692 | 3.769 |
| 80 | 3.676 | 3.754 |
| 85 | 3.646 | 3.736 |
| 90 | 3.627 | 3.710 |
| 95 | 3.581 | 3.682 |
| 100 | 3.000 | 3.000 |

**Table 9-3 Voltage variation with DoD at C/5, and at C/50**

# 10. General Protection

The Battery has inbuilt over-current protection and when combined with a Clyde Space EPS utilises a number of other protection circuits and safety features designed to maintain safe operation of the EPS, battery and all subsystems supplied by the complete power system.

## 10.1 Over-current Polyswitch Protection

A polyswitch is fitted in line with each string of the battery. This is a resettable fuse, designed to blow when an over-current, either charge or discharge, is observed by the string. The approximate fusing currents are shown in Table 10-1

| 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**

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.

## 10.2 Over-Current Bus Protection

Additional over-current protection is available on the EPS to safeguard the battery, EPS and attached satellite sub-systems. This is achieved using current monitors and a shut down network within the PDMs.

Over-current shutdowns are present on all buses for sub system protection. These are solid state switches which monitor the current and shutdown at predetermined load levels, see Table 10-2. The bus protection will then monitor the fault periodically and reset when the fault clears. The fault detection and clear is illustrated in the waveform in Figure 10-1.

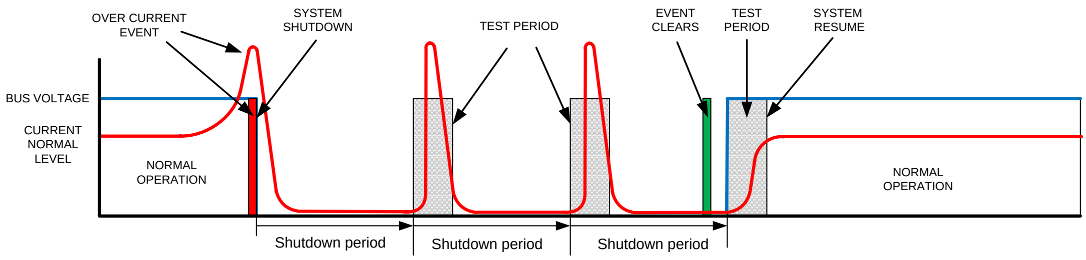


**Figure 10-1 Current protection system diagram**

| Bus | Trip point / trip duration (approximation) |
|---|---|
| Battery bus | |
| Shutdown period | 648ms |
| Test period | 60ms |
| 5v bus | |
| Shutdown period | 584ms |
| Test period | 31ms |
| 3.3v bus | |
| Shutdown period | 524ms |
| Test period | 31ms |

**Table 10-2 Bus protection data**

## 10.3 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 (slightly above the 6.0V, below which significant battery degradation will occur), the EPS will shutdown the supply buses. This will also result in the I$^2$C 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 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 system monitors certain stages of the battery and allows a small degree of control over the heater operation. The telemetry system transfers data via an I²C bus. The telemetry system operates in slave mode and requires an I²C master to supply commands and the clock signal.

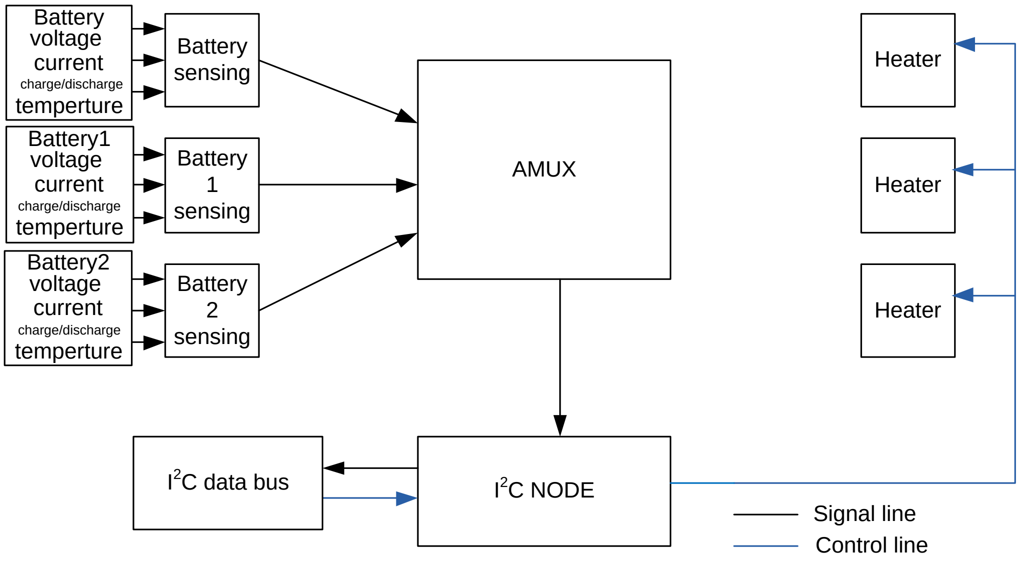


**Figure 11-1 Telemetry functional diagram**

## 11.1 I²C Node

The I²C Node is based on the Microchip PIC16F690. The device node is configured to act as a single channel analogue to digital converter. The microcontroller controls the analogue multiplexer that routes the signals from the sensors. The PIC16F690 program is designed to operate as a slave sensor node on the I²C bus. The program will select and then convert the desired signal data from the telemetry network on demand. There is also a control feature that can shutdown the heater operation.

The following sections briefly describe the hardware that is used.

### Analogue Multiplexer

A 32 channel analogue multiplexer is used for selecting the correct sensor signal. The multiplexer is controlled from the microcontroller.

### Additional Hardware

Further required hardware includes an oscillator and an I²C bus extender. The oscillator provides a robust clock signal for the microcontroller. The bus extender provides greater robustness to signal noise on the I²C bus during integration and operations.

## 11.2 I²C Command Interface

All communications to the Telemetry and Telecommand (TTC) Node are via an I²C interface. The TTC Node is configured as a slave and only responds to direct commands from a master I²C node. No unsolicited telemetry is transmitted. A maximum 400Kbits$^{-1}$ bus speed is supported, with typical bus speeds of 100Kbits$^{-1}$. The address of the TTC Node is factory set. The address is 0x2A. This can be changed on request.

Helix Building, WSSP,
Glasgow G20 0SP, UK

### Message Formats

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. The first data byte should be the command. The second byte represents the data that is used as part of the command. An example of the data is the analogue to digital channel to read.

An example of a read command would be:

- The master transmits the slave address with write flag, command type (0x00) and data (ADC channel)
- The slave acts on the commands, sets the correct channel and reads the analogue to digital converter
- The master transmits the slave address with read flag
- The slave responds with a two-byte value

If a read message does not have a preceding write message, the value 0xF000 is returned. All bit level communication to and from the board is done by sending the MSB first. If both bytes are not read then the system may become unstable.

### ADC

The $I^2C$ node acts as a multi channel analogue to digital convertor which allows the board to supply sensor data to the user. When the command is received, a delay, approximately 1.2ms, is inserted to allow the analogue reading to settle. After this delay the result can be retrieved. The result is a 10 bit value with the first byte received containing the two most significant bits and the second byte received the remaining 8 bits.

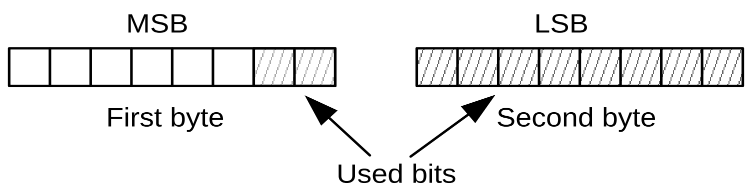


**Figure 11-2 ADC 10bit data packet**

To retrieve a sensor reading the following procedure should be used:

Send 0x00 followed by 0x0$X$, where $X$ represents the channel number in Hex format. This instructs the $I^2C$ node that the user wishes to retrieve a sensor value and which sensor to take the reading from.

After a small delay, approximately 1.2ms, the user can issue a read command and the result will be transmitted. The most significant byte is sent first followed by the least significant byte.

The result received should then be entered into the conversion equations, covered in a further section, which calculates the requested parameter.

If the reading is not yet ready 0xF000 is returned

This process should be followed for all ADC channels.

## 11.3 Command Summary

Table 11-1, below, provides a list of the commands for the EPS. The data that should accompany the commands is included in the table. Descriptions of the commands follow the table.

| Command Type | | Command Value Range | Description |
|---|---|---|---|
| Decimal | Name | Decimal | |
| 0 | ADC | 0-31 | Read ADC Channel |
| 1 | Status | N/A | Request Status Bytes |
| 4 | Version | N/A | Request Firmware Version |
| 5 | Heater | 0-1 | Force Heater Off |
| 6 | Forced Heater Status | N/A | Request the status of the force heater command |
| 128 | Watchdog | N/A | Causes a soft reset of the micro |

**Table 11-1 Command Summary**

### 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. The meaning of each bit of the status byte is shown in Table 11-2.

### Heater Off

The user may wish to turn off the heater, e.g. to conserve power. To carry this out the command 0x0600 is sent. The response is a two byte reply with the LSB representing the Forced Heater Status. If the user has forced the heater off then reply is 0x0001, otherwise the reply is 0x0000.

### 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.

| Byte | Bit | Description | If Low (0) | If High (1) | Note |
|---|---|---|---|---|---|
| 0 | 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 |
| 1 | 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 11-2 Status Bytes**

## 11.4 ADC Channels

| ADC Channel | Signal | Units |
|---|---|---|
| 0 | Battery Current Direction | *High = Discharge, Low = Charge* |
| 1 | Battery Current | *mA* |
| 2 | Cell Voltage | *V* |
| 3 | Battery Voltage | *V* |
| 4 | Battery Temperature | *°C* |
| 5 | Battery1 Current Direction | *High = Discharge, Low = Charge* |
| 6 | Battery1 Current | *mA* |
| 7 | Cell1 Voltage | *V* |
| 8 | Battery1 Voltage | *V* |
| 9 | Battery1 Temperature | *°C* |
| 10 | Batter2 Current Direction | *High = Discharge, Low = Charge* |
| 11 | Batter2 Current | *mA* |
| 12 | Cell2 Voltage | *V* |
| 13 | Battery2 Voltage | *V* |
| 14 | Battery2 Temperature | *°C* |
| 15 | GND | *N/A* |
| 16 | GND | *N/A* |
| 17 | GND | *N/A* |
| 18 | GND | *N/A* |
| 19 | GND | *N/A* |
| 20 | GND | *N/A* |
| 21 | GND | *N/A* |
| 22 | GND | *N/A* |
| 23 | GND | *N/A* |
| 24 | GND | *N/A* |
| 25 | GND | *N/A* |
| 26 | GND | *N/A* |
| 27 | GND | *N/A* |
| 28 | GND | *N/A* |
| 29 | GND | *N/A* |
| 30 | GND | *N/A* |
| 31 | GND | *N/A* |

**Table 11-3 ADC Channels**

## 11.5 Conversion Equations

Each of the analogue channels, when read, returns a number between 0-1023. To retrieve the value of the analogue signal this number, ADC, is to be entered into an equation. When the equation is used, the value calculated is the value of the input analogue signal. Table 11-4 contains example equations of the conversions of each of the channels. To obtain more accurate equations, a full calibration test should be conducted.

| ADC Channel | Conversion Equation | Units |
|---|---|---|
| 0 | *High = Discharge, Low = Charge* | *N/A* |
| 1 | -3.49185 x ADC + 3173.465 | *mA* |
| 2 | -0.00483 x ADC + 4.852724 | *V* |
| 3 | -3.49185 x ADC +3173.465 | *V* |
| 4 | -0.163 x ADC + 4.753 | *°C* |
| 5 | *High = Discharge, Low = Charge* | *N/A* |
| 6 | -3.49185 x ADC + 3173.465 | *mA* |
| 7 | -0.00483 x ADC + 4.852724 | *V* |
| 8 | -3.49185 x ADC +3173.465 | *V* |
| 9 | -0.163 x ADC + 4.753 | *°C* |
| 10 | *High = Discharge, Low = Charge* | *N/A* |
| 11 | -3.49185 x ADC + 3173.465 | *mA* |
| 12 | -0.00483 x ADC + 4.852724 | *V* |
| 13 | -3.49185 x ADC +3173.465 | *V* |
| 14 | -0.163 x ADC + 4.753 | *°C* |
| 15 | N/A | |
| … | | |
| 31 | N/A | |

**Table 11-4 ADC Channel Equations**

# 12. Test

8

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 outlined instructions. In order to safely test the battery, it should be connected to a Clyde Space 3U EPS.

The following is a step by step intro of how to connect and verify operation.

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

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

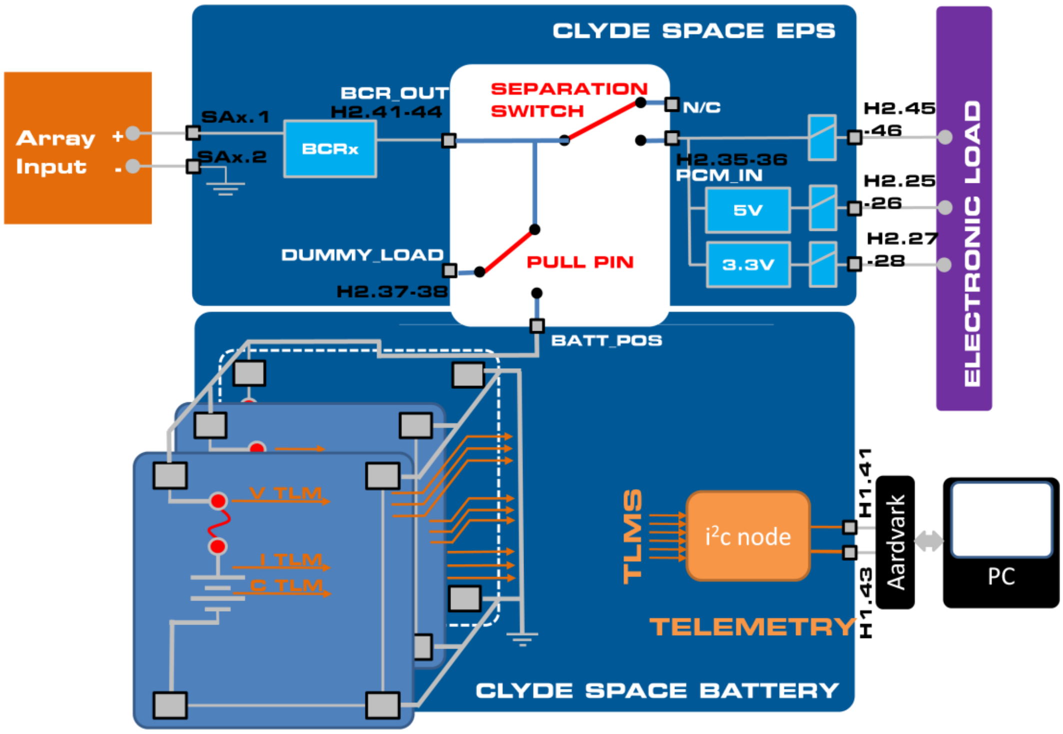


**Figure 12-1 Suggested Test Setup**

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

## 12.1 Power up/Down Procedure

1

The order of assembly should follow 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 to battery bus
- Remove Pull Pin

- Activate Separation Switch
- Connect array input

When powering down this process should be followed in reverse.

## 12.2 Solar Array Input

There are 3 options for the array input section:

- A solar array
- A solar array simulator
- A bench top 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 (SA1)** | 24.5 | 464 |
| **BCR2 (SA2)** | 24.5 | 464 |
| **BCR3 (SA3)** | 6.13 | 464 |

**Table 12-1 solar array limits**

When using a power supply and resistor setup to simulate a solar panel the required setup is shown in Figure 12-2.

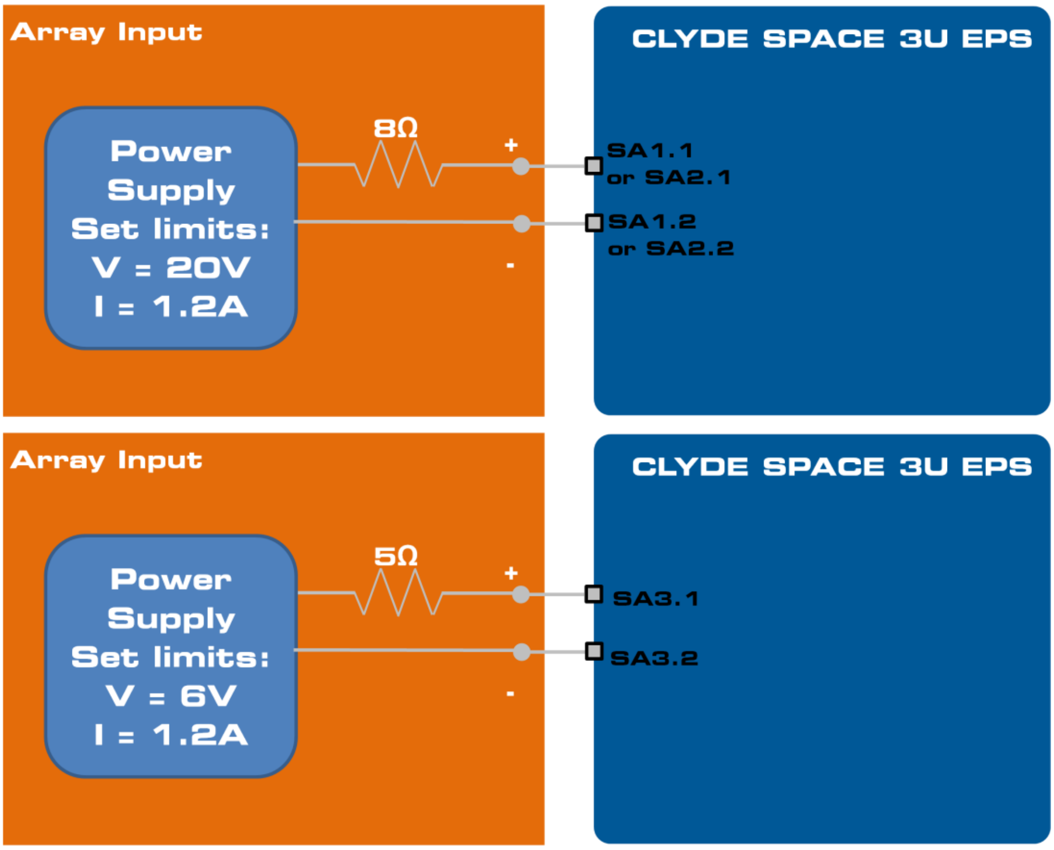


**Figure 12-2 Solar Panel using power supply**

## 12.3 Configuration and Testing

The following section outlines the procedure for performing basic functional testing

### PCM Testing/Battery Discharge

In order to test the PCMs power must be applied to the PCM_IN connection. In order to do this the "Pull Pin" should be removed, connection the battery, as shown in Figure 12-3.

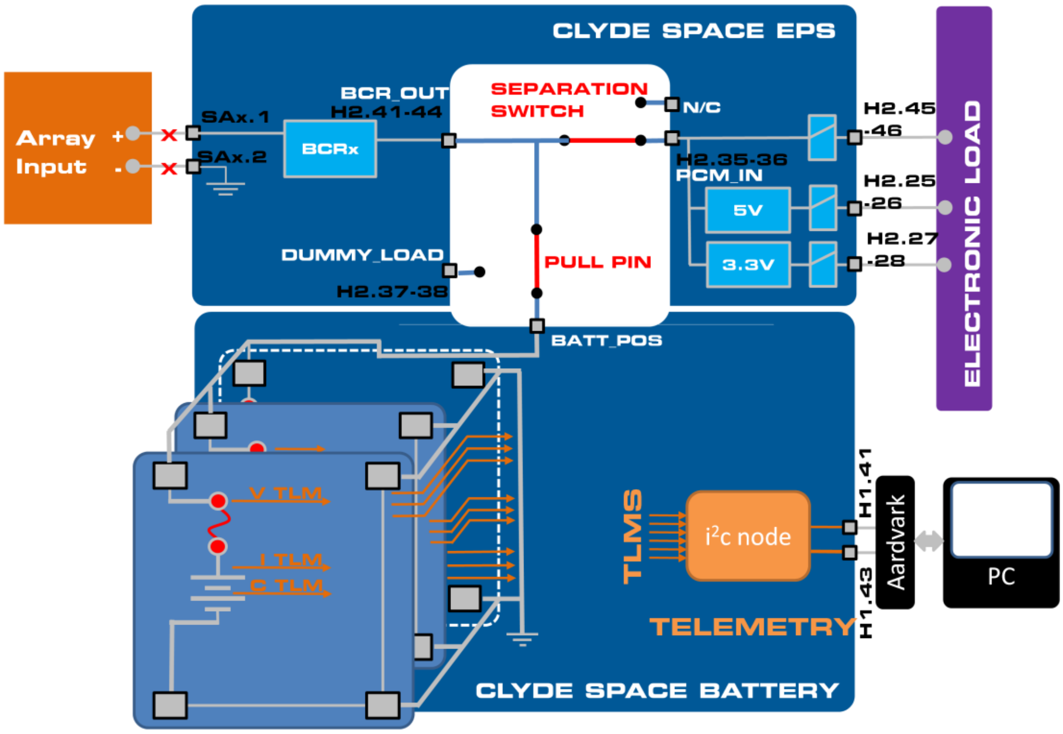


**Figure 12-3 Test set-up with Pull Pin Removed**

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

By increasing the load on the battery bus you will be able to see the battery voltage decrease and battery current showing discharge status.

### Undervoltage Protection

It is possible to trigger the undervoltage protection. Using the same test setup as detailed above, if the voltage is dropped to below ~6.2V (by continuous discharge) the undervoltage will be activated. This can be observed by the power buses shutting down.

**Note:** This test takes the battery to 100% DoD and should always be followed by a charge cycle.

### BCR Testing

In order to test the operation of the BCRs the separation switches should be moved to flight configuration, as shown in Figure 12-4, (with the pull pin still removed). Once this is done the array input can be connected.

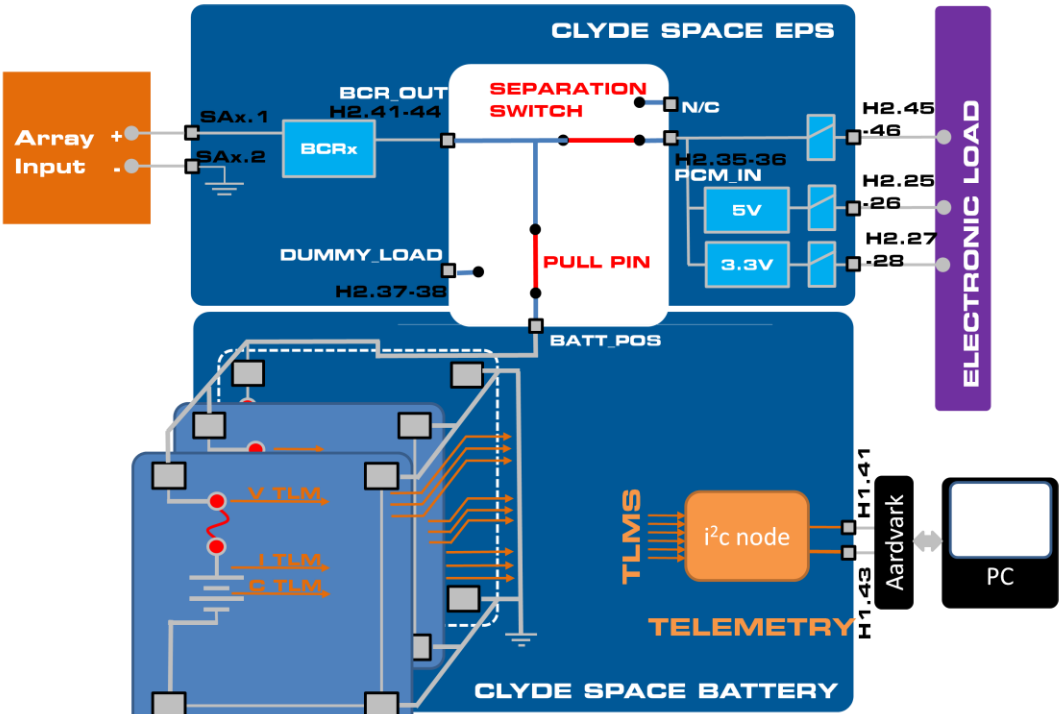


**Figure 12-4 Test set-up in Flight Configuration**

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 12-5.

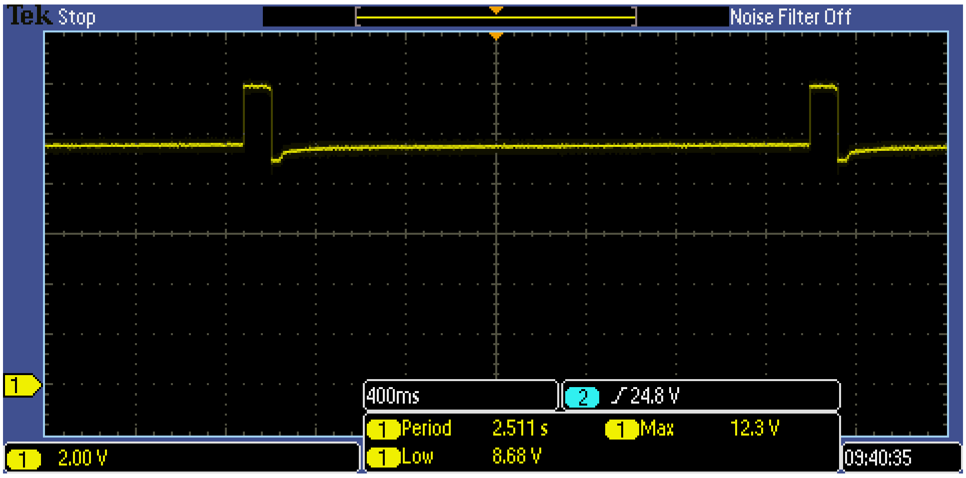


**Figure 12-5 Waveform of Solar Array Input**

## 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.

## 5V USB Charging

Figure 12-6 shows the test setup for the 5V USB charging.

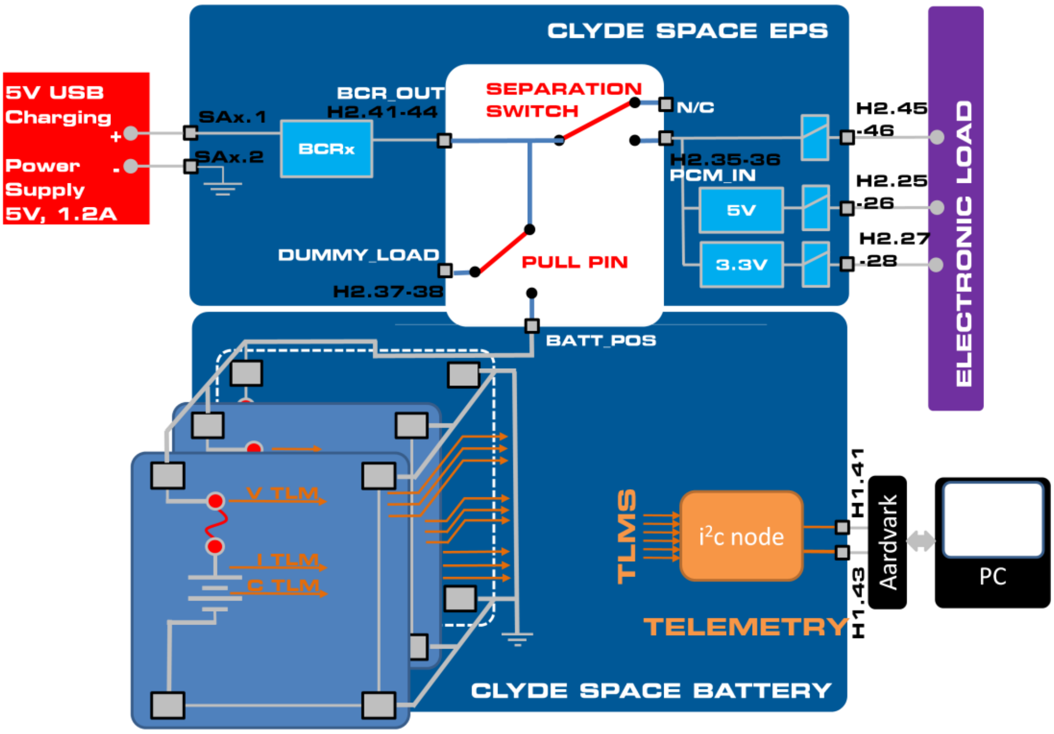


**Figure 12-6 Waveform of Solar Array Input**

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

Helix Building, WSSP,
Glasgow G20 0SP, UK

# 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 those of 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. Commonly requirement compliance is presented in a compliance matrix, as shown in Table 13-2.

| 13.1 ID | 13.2 Requirement | 13.3 Procedure | 13.4 Result (X) | 13.5 Success criteria | 13.6 Compliance<br>13.7 (pass / fail) |
|---|---|---|---|---|---|
| 13.8 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 12.

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 |
| EPS | Clyde Space EPS Systems | 1U, 3U and DEPS variants |
| Solar Arrays | Clyde Space 3W solar array | Connects to BCR 3 via SA3 |
| | Clyde Space 8W solar array | Connects to BCR 1/2 via SA1/2 |
| | 3W triple junction cell arrays | 2 in series connection |
| | 8W triple junction cell arrays | 6-8 in series connection |
| | Other array technologies | Any that conform to the input ratings for Voltage and Current |
| Structure | Pumpkin | CubeSat 3U structure |
| | ISIS | CubeSat 3U compatible |
| | Other structures | Please contact Clyde Space |

**Table 14-1 Compatibilities**