Electronic Power Supply (EPS) Interface Control Document

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University Rover Challenge
RoSE: Instrumentation & Control Subsystem

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Table of Contents

1. Introduction

This document describes the features, operation, handling and storage of the UHM RoSE EPS, designed to integrate with a suitable battery pack to form a complete power system for use on a Rover.

The UHM RoSE Team is continuously improving our processes and products. We aim to provide full visibility of the changes and updates that we make, and updates will be provided via revisions of this document.

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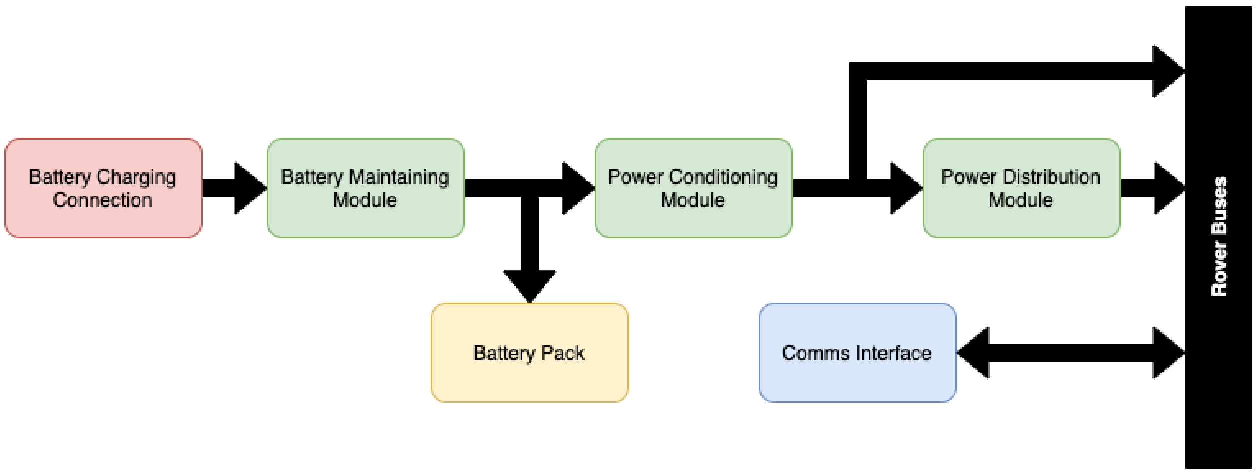

Figure 1-1: System Diagram

2. Overview

This EPS incorporates a number of additional features over and above what is typically offered for open source applications. The main features include:

- 10 commendable power switches
- Improved over-current protection
- 12V regulated bus as a standard
- Solid state circuitry
- Telemetry information
- Communications reset timeout
- Very Low Power MCU using FRAM technology

This EPS has been designed by the Instrumentation & Control Team as a student project. This is completely designed and manufactured by undergraduate students without assistance from UHM faculty or staff. Please submit GitHub issues for any discrepancies or contact opieca@hawaii.edu for any questions.

3. Maximum Ratings[1]

Over Operating Temperature Range (Unless Otherwise Stated)				
		BMM	Value	Unit
Input Voltage[2]	CHRG1	BMM1	25	V
	CHRG2	BMM2	25	V
	CHRG3	BMM3	25	V
	12V Bus		12.12	V
	Batt Bus		8.4	V
	5V Bus		5.05	V
	3V3 Bus		3.33	V
			Value	Unit
Input Current	CHRG1	@16V	2	A
	CHRG2	@16V	2	A
	CHRG3	@16V	2	A
Output Current	12V Bus	@12V	1.5	A
	Batt Bus	@8V26	4.5	A
	5V Bus	@5V	4.5	A
	3V3 Bus	@3V3	4.5	A
Operating Temperature			-40 to 85	℃
Storage Temperature			-50 to 100	℃
Vacuum			10^{-5}	torr
Radiation Tolerance			10	kRad
Vibration			To [RD-3]	

(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
BMM1-3					
Input Voltage		7.4	--	30	V
Output Voltage		6.144	--	8.26	V
Output Current		0	--	1.5	A
Switching Frequency		245	250	225	KHz
Efficiency	@16.5V Input, Full Load	85%	90%	92%	
12V Bus					
Output Voltage		11.88	12	12.12	V
Output Current		--	1.2	1.5	A
Operating Frequency		750	800	850	kHz
Efficiency	@12V Input, Full Load	90%	94%	96%	
Unregulated Battery Bus					
Output Voltage		6.144	--	8.26	V
Output Current		--	4	4.5	A
Operating Frequency		--	--	--	kHz
Efficiency	@8V26 Input, Full Load	98%	99%	99%	
5V Bus					
Output Voltage		4.95	5	5.05	V
Output Current		--	4	4.5	A

Operating Frequency		470	480	490	kHz
Efficiency	@5V Input, Full Load	95%	96%	98%	
3V3 Bus					
Output Voltage		3.267	3.3	3.333	V
Output Current		--	4	4.5	A
Operating Frequency		470	480	490	kHz
Efficiency	@3V3 Input, Full Load	94%	95%	97%	
Communications					
Protocol		--	I^2C	--	
Transmission Speed		--	100	--	$Kbits^{-1}$
Bus Voltage		3.26	3.3	3.33	V
Node Address		--	0x20	--	Hex
Address Scheme		--	7	--	Bit
Node Operating Frequency		--	27	--	MHz
Quiescent Operation					
Power Draw		--	--	<0.2	W
Physical		**L**	**W**	**H**	
Dimensions	Height from top of PCB to bottom of next PCB in stack	95	90	15.24	mm
Weight		84	86	88	g

Table 4-1: Performance Characteristics of the EPS

4.1 Battery Charging Safe Operation

The safe operating range of the BMMs is shown in Figure 4-1 and Figure 4-2 above. Single Channel refers to the maximum power that can be applied to a single pin (e.g. BMM1.1). Dual Channel refers to the maximum power that can be applied to two pins connecting the same BMM (e.g. BMM1.1 and BMM1.4).

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 unit 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 shielding or protection in place. All handling of the system should be done in a static dissipative environment.

5.2 General Handling

The EPS is robust and designed to withstand extreme 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 interconnect headers. All metal objects (including probes) should be kept clear of these headers.

ESD Dissipative Gloves should be worn when handling all hardware.

Hardware, which has not been conformal coated, should only be removed from its packaging in a clean environment.

5.3 Shipping and Storage

The devices are shipped in anti-static 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℃ and 40℃ and in a humidity-controlled environment of 40-60% rh.

The shelf-life of this product is estimated to be 5 years when properly stored.

6. Materials and Processes

6.1 Materials Used

	Material	Manufacturer	%TML	%CVCM	%WVR	Application
1.						

2.						
3.						
4.						
5.						
6.						
7.						

Table 6-1: Materials List

Part	Manufacturer	Contact	Insulator	Type	Use	Required Mating Connector

Table 6-2: Connector Headers

6.2 Processes and Procedures

All assembly is expected to be completed in accordance with IPC and NASA Workmanship Standards; AS9100/ISO9001/NASA-STD-8739.x

7. System Description

7.1 System Overview

This EPS is designed for integration with a Rover unit that allows for tethered charging and removable battery packs. The EPS can accommodate the standard supplied charging cable and connection, but has been designed to be versatile; please consult our support team if you have specific requirements for connecting the EPS to the Battery and Charging Cables in another way.

The Charging Cables connect to the Battery Maintaining Modules (BMMs) via an industrial grade weatherproof connection. The output of the BMMs are then connected together through ideal diodes to supply charge to the battery, Power Conditioning Modules (PCMs) and Power Distribution Modules (PDMs).

The PCM network has an unregulated Battery Voltage Bus, a regulated 5V Supply Bus, a regulated 3V3 Supply Bus, and a regulated 12V Supply Bus. In addition to the main buses, there are 10 commendable power switches:

- (2x) 12V
- (2x) BatV
- (3x) 5V
- (3x) 3V3

The EPS also features multiple inbuilt protection methods to ensure safe operation during the mission and a full range of EPS telemetry via the I^2C network. These are discussed in detail in Sections 10 and 11.

7.2 Quiescent Power Consumption

All power system efficiencies detailed (for BMMs and PCMs) takes into account the associated low level control electronics. As such, these numbers are not included in the Quiescent Power Consumption Figures.

The TTC node is the only circuitry not covered in the efficiency figures, and has a Quiescent Power Consumption of approximately 0.2W, which is the figure for the complete EPS.

7.3 Mass and Mechanical Configuration

The mass of the EPS is approximately 100g (not including the battery) and is contained on a single 4-Layer FR4 PCB.

8. Interfacing

The connector interfaces of the EPS are outlined in Figure 8-1, including the BMM inputs, connection to the disarm switches, output of the power buses and communication to the I^2C Node. In the following section, it is assumed that the EPS will be integrated with a UHM RoSE Battery Pack.

8.1 Battery Charging Connection

The EPS has three connectors for the attachment of the Charging Cable. This interface accommodates inputs from external charging circuits through a weatherproof connection.

XXX connector sockets are used on the EPS and are labeled BMM1-3. These BMMs are capable of interfacing external power circuits to an 8.4V battery pack while charging at 4A. All battery arrays connected in parallel should have the same number of cells.

8.2 Temperature Sensing Interface

Temperature sensing telemetry is provided for each Battery Pack connected to the EPS. A compatible temperature sensor (LM335AM) is fitted as standard on all UHM RoSE Charging Connections and Battery Packs. The output of the LM335AM sensor is 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. LM335AM or equivalent. Thermistor or thermocouple type sensors are incompatible with the conditioning circuit.

The formula for calculating temperature from ADC counts can be found in Table 11-7.

8.3 Header Pinouts

Insert Drawing with pinouts

8.4 EPS to Battery Connection

Connection of the Battery to the EPS is via the Battery Headers. Ensure that the pins are aligned, and located in the correct position, as any offset can cause the battery to be shorted to ground, leading to catastrophic failure of the battery and damage to the EPS.

When a battery board is connected to the Battery Header, there are live, unprotected battery pins accessible (pin #s). These pins should not be routed to any connections other than the UHM RoSE EPS, otherwise all protections will be bypassed and significant damage to the battery can occur.

Failure to observe these precautions will result in voiding of any warranty or guarantee.

9. Technical Description

This section gives a complete overview of the operational modes of the EPS. It is assumed that a complete UHM RoSE EPS System (EPS, Batteries, and Charging Cables) are in operation for the following sections.

9.1 Charge Method

9.2 5V and 3V3 PCMs with Latching Current Limiter

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 +/- 1% deviation. The efficiency of each unit at full load is approximately 96% for the 5V PCM and 95% for the 3.3V PCM. Full load on each of the regulators has a nominal output current of 4.5A. Each regulator operates at a frequency of 480 kHz. The Latching Current Limiter is described in Section 9.7. If an over-current event triggers the Latching Current Limiter a retry circuit will attempt to re-enable the bus as described in section 10.1.

9.3 12V PCM with Latching Current Limiter

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 94%. Full load on each of the regulators have a nominal output current of 1.5A. The regulator operates at a frequency of 800 kHz. The Latching Current Limiter is described in Section 9.7. If an over-current event triggers the Latching Current Limiter a retry circuit will attempt to re-enable the bus as described in section 10.1.

9.4 BatV PCM with Latching Current Limiter

The unregulated BatteryV regulator provides safe access to the battery bus of the rover. The voltage supplied will vary directly with the battery voltage (between 6.144V and 8.26V). The Latching Current Limiter is described in Section 9.7. If an over-current event triggers the Latching Current Limiter a retry circuit will attempt to re-enable the bus as described in section 10.1.

9.5 PDMs with Latching Current Limiter

Ten independently commandable power switches have been included within the current form factor. Each switch has inbuilt overcurrent protection in the form of a latching current limiter (LCL). By utilising an LCL each switch is capable of driving loads with large inrush currents without compromising safety throughout the duration of the mission (this is of particular interest for applications such as transceivers). Once the LCL has activated, turning off the supply of power, the switch will remain off until commanded to switch on again. The switches cover the range of regulated and unregulated voltages provided by the EPS.

In the example system shown above the events are as follows:

1. The payload demands a 3A initial current, however the switch limits the current to 2A. The time this demand is present is less than the latch time of the switch (t_{latch}), so the switch does not switch off.
2. The payload demand drops to 0.5A. This is below the current limit of the switch (ilatch).
3. A fault condition occurs resulting in a demand of 4A. The switch only allows 2A to pass, preventing high current damage to the switch or the payload.

4. The fault remains for longer than tlatch so the switch turns off preventing any current flow.

Switch characteristics at 25°C ambient temperature:

- i_{latch}: The latching current limit is set to allow the maximum safe current the EPS can deliver. This value has been selected based on the fact that, if the current limit is set high to allow a high inrush it will result in a high current limit during normal operation too.
- t_{latch}: The latching has been set to allow for the maximum safe length of time before shutting down the bus, allowing capacitive loads to be charged safely.
- c_{latch}: This is the maximum capacitance that can be charged via the LCL before the switch automatically disables.
- t_{on}: Time delay from switch being commanded to turn on via I^2C node to actual switch turn on.

10. General Protection

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

10.1 Overcurrent Bus Protection

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

Over-current shutdowns are present on all buses and switches for sub system protection. These are solid state switches that monitor the current and shutdown at predetermined load levels. 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 10-2.

The length of time of the test period will depend on the demand caused by the fault condition. Higher current demand results in a shorter test period. All switches and buses are protected against a short circuit fault.

10.2 Battery Under-Voltage Protection

In order to prevent the 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 ~6.144V (slightly above the 6.1V that results in significant battery degradation) 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. Charging Cable) 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 non-critical systems) when the battery capacity is approaching the lower limit. This will prevent the hard shutdown provided by the EPS.

Once the under-voltage protection is activated there is a monitoring circuit used to monitor the voltage of the battery. This will draw approximately 2mA for the duration of shutdown. When ground testing, the battery should be recharged within 40 mins of reaching under-voltage, otherwise permanent damage may be sustained.

11. Telemetry and Telecommand

The telemetry node allows the Rover's 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 analog multiplexer. The microcontroller is configured to connect through a buffer circuit to the I^2C bus of the rover as a slave node. In response to I^2C telemetry requests the microcontroller will configure the analogue multiplexer to connect the desired telemetry channel to the analog to digital converter (ADC) within the microcontroller before sampling the desired channel and allowing it to be read back over the I^2C bus.

11.1 Communications

All communications to the Telemetry and Telecommand, TTC, node are made using an I^2C interface which is configured as a slave and only responds to direct commands from a master I^2C node - no unsolicited telemetry is transmitted. The 7-bit I^2C address of the TTC Node is factory set at 0x20 and the I^2C node will operate at a 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 the data bytes. When reading data responses, both data bytes should be read together. Each command has a delay associated with it, this is required to allow the microcontroller time to process each request.

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

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 I^2C bus. Between each byte the receiving device is required to acknowledge receipt of the previous byte in accordance with the I^2C protocol. This will often be accommodated within the driver hardware or software of the I^2C 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.

Table 11-1: I^2C Write and Read of 2 Byte Command Packet

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

11.2 List of Available Commands

Name	Command	Data[1][1]	Data[0]	Bytes Returned	W/R Delay
Board Status	0x01	NA	0x00	2	<1
Get Last Error	0x03	NA	0x00	2	<1
Get Version	0x05	NA	0x00	2	<1
Get Checksum	0x05	NA	0x00	2	35
Get Telemetry	0x10	Table 11-7		2	5
Get Communications WDT Period	0x20	NA	0x00	2	<1
Set Communications WDT Period	0x21	NA	Period	0	-
Reset Communications WDT	0x22	NA	0x00	0	-
Get Number of Brown-out Resets	0x31	NA	0x00	2	<1

Get Number of Auto Software Resets	0x32	NA	0x00	2	<1
Get Number of Manual Resets	0x33	NA	0x00	2	<1
Get Number of Communication WDT Resets	0x34	NA	0x00	2	<1
Switch ON All PDMs	0x40	NA	0x00	0	-
Switch OFF All PDMs	0x41	NA	0x00	0	-
Get Actual State of All PDMs	0x42	NA	0x00	4	<20
Get Expected State of All PDMs	0x43	NA	0x00	4	<1
Get Initial State of All PDMs	0x44	NA	0x00	4	<20
Set All PDMs to Initial State	0x45	NA	0x00	4	<20
Switch PDM-N “ON”	0x50	NA	N	0	-
Switch PDM-N “OFF”	0x51	NA	N	0	-
Set PDM-N’s Initial State to “ON”	0x52	NA	N	0	200
Set PDM-N’s Initial State to “OFF”	0x53	NA	N	0	200
Get PDM-N’s Actual Status	0x54	NA	N	2	2
Set PDM-N’s Timer Limit	0x60	NA	Limit	0	150
Get PDM-N’s Timer Limit	0x61	NA	N	0	5
Get PDM-N’s Current Timer Value	0x62	NA	N	0	1
PCM Reset	0x70	Table 11-10		0	1
Manual Reset	0x80	NA	0x00	0	-

11.3 Housekeeping and Status Commands

Board Status (0x01)

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

The status bytes are designed to supply operational data about the I^2C Node. To retrieve the data that represent the status, the command 0x01 should be sent followed by 0x00. The meaning of each bit of the returned status bytes is shown below.

<table>
<tr><th>Data[n]</th><th>Bit</th><th>Description</th></tr>
<tr><td rowspan="8">0</td><td>0</td><td>Set HIGH if last command not recognized</td></tr>
<tr><td>1</td><td>Set HIGH if a watchdog error occurred, resetting the device</td></tr>
<tr><td>2</td><td>Set HIGH if the data sent along with the last command was incorrect</td></tr>
<tr><td>3</td><td>Set HIGH if the channel passed with the last command was incorrect</td></tr>
<tr><td>4</td><td>Set HIGH if there has been an error reading the FRAM</td></tr>
<tr><td>5</td><td>Set HIGH if a Power On Reset error occurred</td></tr>
<tr><td>6</td><td>Set HIGH if a Brown Out Reset occurred</td></tr>
<tr><td>7</td><td>Not Used</td></tr>
<tr><td rowspan="3">1</td><td>0</td><td rowspan="3">Not Used</td></tr>
<tr><td>...</td></tr>
<tr><td>7</td></tr>
</table>

Table 11-2: Status Bits for EPS

Get Last Error (0x03)

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

If an error has been generated after attempting to execute a user's command the value 0xFFFF is returned. To find out specifically the details of the last error, send the command 0x03 followed by the data byte 0x00. This will return the code of the last error generated as the byte Data[0]. Details of each error code are given by Table 11-3.

Code	Description
0x10	CRC code does not match data
0x01	Unknown command received
0x02	Supplied data incorrect when processing command
0x03	Selected channel does not exist
0x04	Selected channel is currently inactive
0x13	A reset had to occur
0x14	There was an error with the ADC acquisition
0x20	Reading from FRAM generated an error

Table 11-3: List of UHM RoSE Error Codes

Get Version (0x04)

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

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

<table>
<tr><th></th><th colspan="8">Data[1]</th><th colspan="8">Data[0]</th></tr>
<tr><td>Bit</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td>Value</td><td colspan="4">Revision</td><td colspan="12">Firmware Number</td></tr>
</table>

Table 11-4: Version Number Breakdown

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

Get Checksum (0x05)

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

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

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

Table 11-5: Checksum Breakdown

Manual Reset (0x80)

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

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

Resetting the board in this fashion will increment the Manual Reset Counter. More details about this counter are found in section 11.5.

11.4 Telemetry

The node telemetries allow the Rover on board computer (OBC) to monitor the operation of the EPS and reset the power buses if required for payload or platform recovery operations.

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

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

INSERT FIGURE

Figure 11-2: Telemetry Functional Diagram

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

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

A break-down of the telemetry structure is given in Table 11-5. The Telemetries which are available for this board are given in Table 11-7. If a telemetry is requested which is not available, a Channel Error will be generated.

Get Telemetry (0x10)

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

As described above, requesting telemetry involves sending the command 0x10 plus a 2 byte telemetry code to the node. Once transmitted, the node will configure itself to read the requested value. The data returned will be in the format shown by figure Table 11-X.

Data[1]				Data[0]			
Nibble 3		**Nibble 2**		**Nibble 1**		**Nibble 0**	
Family	**Code**	**TLM Type**	**Code**	**Channel**	**Code**	**Attribute**	**Code**
EPS	E	BMM	1	Channel Number N	N	Voltage A	0
						Current A	4
						Current B	5
						Temperature A	8
						Temperature B	9
EPS	E	Main Power	2	Core Bus Misc	0 to 7 8 to F	Voltage	0
						Current	A
EPS	E	Temperature	3	Mainboard	0 to 7	Temperature	8
EPS	E	PDM	4 to 7	Switch Number N	N mod 16	Voltage	0
						Current	4

Table 11-6: Break Down of Telemetry Code Structure

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

Table 11-7: ADC Result Return Format

The result received should then be entered into the conversion equations, covered in Table 11-8, which calculate the requested parameter in physical units. The equations provided in Table 11-8 are the theoretical equations for the system. If more accurate telemetry results are required, tailored equations are available from the test report for the individual 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 final and engineering model hardware.

Name	TLE Code	Description	Uncalibrated Conversion Equation	Units
VBMM1	0xE110	Voltage Provided to BMM1	0.0249 x ADC	V
IBMM1	0xE114	Current Provided to BMM1	0.0009775 x ADC	mA
VBMM2	0xE120	Voltage Provided to BMM2	0.0249 x ADC	V
IBMM2	0xE124	Current Provided to BMM2	0.0009775 x ADC	mA
VBMM3	0xE130	Voltage Provided to BMM3	0.0249 x ADC	V
IBMM3	0xE134	Current Provided to BMM3	0.0009775 x ADC	mA
IIDIODE_OUT	0xE284	BMM Output Current	14.662757 x ADC	mA
VIDIODE_OUT	0xE280	BMM Output Voltage	0.008993157 x ADC	V
I3V3_DRW	0xE205	3V3 Current Draw of EPS	0.001327547 x ADC	A
I5V_DRW	0xE215	5V Current Draw of EPS	0.001327547 x ADC	A
IPCM12V	0xE234	Output Current of 12V Bus	0.00207 x ADC	A
VPCM12V	0xE230	Output Voltage of 12V Bus	0.01349 x ADC	V
IPCMBATV	0xE224	Output Current of BatV Bus	0.005237 x ADC	A
VPCMBATV	0xE220	Output Voltage of BatV Bus	0.008978 x ADC	V
IPCM5V	0xE214	Output Current of 5V Bus	0.005237 x ADC	A
VPCM5V	0xE210	Output Voltage of 5V Bus	0.005865 x ADC	V
IPCM3V3	0xE204	Output Current of 3V3 Bus	0.005237 x ADC	A
VPCM3V3	0xE200	Output Voltage of 3V3 Bus	0.004311 x ADC	V
VSW1	0xE410	Output Voltage Switch 1	0.01349 x ADC	V
ISW1	0xE414	Output Current Switch 1	0.001328 x ADC	A
VSW2	0xE420	Output Voltage Switch 2	0.01349 x ADC	V
ISW2	0xE424	Output Current Switch 2	0.001328 x ADC	A
VSW3	0xE430	Output Voltage Switch 3	0.008993 x ADC	V
ISW3	0xE434	Output Current Switch 3	0.001328 x ADC	A

VSW4	0xE440	Output Voltage Switch 4	0.008993 x ADC	V
ISW4	0xE444	Output Current Switch 4	0.001328 x ADC	A
VSW5	0xE450	Output Voltage Switch 5	0.005865 x ADC	V
ISW5	0xE454	Output Current Switch 5	0.001328 x ADC	A
VSW6	0xE460	Output Voltage Switch 6	0.005865 x ADC	V
ISW6	0xE464	Output Current Switch 6	0.001328 x ADC	A
VSW7	0xE470	Output Voltage Switch 7	0.005865 x ADC	V
ISW7	0xE474	Output Current Switch 7	0.001328 x ADC	A
VSW8	0xE480	Output Voltage Switch 8	0.004311 x ADC	V
ISW8	0xE484	Output Current Switch 8	0.001328 x ADC	A
VSW9	0xE490	Output Voltage Switch 9	0.004311 x ADC	V
ISW9	0xE494	Output Current Switch 9	0.001328 x ADC	A
VSW10	0xE4A0	Output Voltage Switch 10	0.004311 x ADC	V
ISW10	0xE4A4	Output Current Switch 10	0.001328 x ADC	A
TBRD	0xE308	Board Temperature	(0.372434 x ADC) - 273.15	°C

Table 11-7: List of Telemetry Codes for the EPS Mainboard

11.5 Watchdogs and Reset Counters

Two on-board watchdog timers are used to restart the device if it becomes non-operational due to an error in the microcontroller. The Communications Watchdog is used to reset the device if a designated period passes in which the device receives no data on the I^2C bus. The second watchdog is the on-board Software Watchdog which is used to reset the device if the microcontroller feels it has malfunctioned. If the node determines that an error has occurred, the device is rebooted into its pre-defined initial state.

Both watchdogs have associated counters which can be queried to determine the number of times the device has reset itself through either a lack of communications or a software error. A third counter is also available which maintains a record of how many times the device is reset from a Brown-Out condition.

Set Communications Watchdog Period (0x21)

Command	Data[0]	Bytes Returned	Delay, ms
0x21	0x??	0	--

The Communications Watchdog by default has a value of 4 minutes set as its timeout period. If 4 minutes pass without a command being received, then the device will reboot into its pre-defined initial state. This value of 4 minutes can be changed using the Set Communications Watchdog Period command, 0x21. The data byte specifies the number of minutes the communications watchdog will wait before timing out.

A minimum value of 1 minute or a maximum of 90 minutes can be set. The device will always reboot with a timeout value of 4 minutes set. If an invalid value is specified then the device will generate a Data Error.

Get Communications Watchdog Period (0x20)

Command	Data[0]	Bytes Returned	Delay, ms
0x20	0x00	2	<1

This command provides the user with the current communications watchdog timeout that has been set. The returned value is indicated in minutes.

Get Number of Brown-out Resets (0x31)

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

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

Get Number of Automatic Software Resets (0x32)

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

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

Get Number of Manual Resets (0x33)

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

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

Get Number of Communications Watchdog Resets (0x34)

Command	Data[0]	Bytes Returned	Delay, ms
0x34	0x00	2	<1

As described previously, the device will reset itself if it does not receive any data via I^2C for a predefined length of time. The communications node keeps a count of the number of times such an event has taken place. Sending the command 0x34 along with the data byte 0x00 will return the number of communication watchdog resets.

11.6 PDM Control

On-board power distribution modules can either be controlled via commands which address them individually or all at once. Associated with each module is its attempted status, its actual status and the state it will be initialised with when the board boots.

Switch On All PDMs (0x40)

Command	Data[0]	Bytes Returned	Delay, ms
0x40	0x00	0	--

When this command is issued, all PDMs turn on.

Switch Off All PDMs (0x41)

Command	Data[0]	Bytes Returned	Delay, ms
0x41	0x00	0	--

When this command is issued, all PDMs turn off.

Get Actual State of All PDMs (0x42)

Command	Data[0]	Bytes Returned	Delay, ms
0x42	0x00	4	<20

The PDMs have over current protection built in. As a result, a PDM that is expected to be on may have tripped. This command returns the actual state of all the PDMs. The bits of the bytes returned represent the state of each PDM, with 0 representing off and 1 representing on. The order of bits is shown in Table 11-9.

Bit	7	6	5	4	3	2	1	0
Data[3]								
Data[2]	--	--	--	--	--	--	--	--
Data[1]	--	--	--	--	--	PDM 10	PDM 9	PDM 8
Data[0]	PDM 7	PDM 6	PDM 5	PDM 4	PDM 3	PDM 2	PDM 1	--

Table 11-9: PDM Byte Codes

Get Expected State of All PDMs (0x43)

Command	Data[0]	Bytes Returned	Delay, ms
0x43	0x00	4	<1

The expected PDM state is returned using this command. The command returns the expected state of all the PDMs. The format of the returned data is given by Table 11-9, with 0 representing OFF and 1 representing ON.

Get Initial State of All PDMs (0x44)

Command	Data[0]	Bytes Returned	Delay, ms
0x44	0x00	4	<20

The initial state of the PDMs is returned using this command. The initial state for all the PDMs is returned in response to this command. The bit indication is the same as that in Table 11-9, with a 1 indicating the PDM is selected to be ON at power up or reset.

Set All PDMs to Initial State (0x45)

Command	Data[0]	Bytes Returned	Delay, ms
0x45	0x00	4	<20

This command sets the initial state of the PDMs after rebooting. This includes resetting all timers associated with each PDM (See section 11.7 for more information about PDM Timers).

Switch PDM-N "ON" (0x50)

Command	Data[0]	Bytes Returned	Delay, ms
0x50	Channel #	0	--

This command turns on an individual PDM defined in the data byte, PDM 1 is 0x01, PDM2 is 0x02 etc. If an invalid channel is specified, 0xFFFF is returned and the device will generate an Invalid Channel error.

Switch PDM-N “OFF” (0x51)

Command	Data[0]	Bytes Returned	Delay, ms
0x51	Channel #	0	--

This command turns off an individual PDM defined in the data byte, PDM 1 is 0x01, PDM2 is 0x02 etc. If an invalid channel is specified, 0xFFFF will be returned and the device will generate an Invalid Channel error.

Set PDM-N’s Initial State to “ON” (0x52)

Command	Data[0]	Bytes Returned	Delay, ms
0x52	Channel #	0	200

Using the command 0x52 allows a PDM’s initial status to be set to ON. After a reset or reboot, this PDM channel will be enabled. The channel is specified in the data byte, PDM 1 is 0x01, PDM2 is 0x02 etc. If an invalid channel is specified, 0xFFFF will be returned and the device will generate an Invalid Channel error.

Set PDM-N's Initial State to "OFF" (0x53)

Command	Data[0]	Bytes Returned	Delay, ms
0x53	Channel #	0	200

Using command 0x53 allows a PDM's initial status to be set to OFF. After a reset or reboot, this PDM channel will be disabled. The channel is specified in the data byte, PDM 1 is 0x01, PDM2 is 0x02 etc. If an invalid channel is specified, 0xFFFF will be returned and the device will generate an Invalid Channel error.

Get PDM-N's Actual Status (0x54)

Command	Data[0]	Bytes Returned	Delay, ms
0x54	Channel #	2	2

The PDMs have over current protection, as a result a PDM that is expected to be on may have tripped. This command returns the actual state of the requested PDM specified in the data byte, PDM 1 is 0x01, PDM2 is 0x02 etc. A returned value of 1 indicates the PDM is ON and a returned value of 0 indicates the PDM is OFF.

11.7 PDM Timers

Each Power Distribution Module has a user configurable timer associated which allows the maximum time the PDM can be ON for to be set. Unless there is user intervention, the PDM will switch OFF after this period. This feature can be useful for high power circuitry which could drain a Rover's power supply if not monitored correctly. A minimum duration of 30 seconds can be set and a maximum of 127 minutes.

Through the PDM Timer Control each PDM can be in one of three states:

- **Permanently Disabled:** Any attempt to enable the PDM will fail.
- **Enabled without timer restrictions:** Once switched on, the PDM will remain enabled indefinitely.
- **Enabled with timer restrictions:** Once switched on, the PDM will only remain on for a predefined period of time.

Out of the box, each PDM is setup without timer restrictions. Once configured the timer settings are stored in FRAM and will remain in effect after a reboot.

Theory of Operation

Each PDM timer has two values associated with its control:

PDM Timer Limit: This is the maximum length of time the PDM will remain on for. When set to 0xFF, the timer will remain on indefinitely when enabled. If set to 0x00 the timer will always remain off, regardless of any attempt to enable it. If a command is sent to switch on a disabled channel, the error INACTIVE CHANNEL (0x04) will be generated.

The timer limit is set in multiples of 30 Seconds; therefore supplying a value of 0x0A will set the PDM's enabled duration to 5 minutes.

Associated Commands: Set PDM Timer Limit (0x60) and Get PDM Timer Limit (0x61)

PDM Timer Current Value: The Current Value of the timer is the length of time the timer has been enabled for. Again, its values are in multiples of 30 seconds. Returned values are always rounded down. Therefore if the PDM has been on for 7 minutes and 20 seconds the expected Timer Current Value of 0x0E would be returned.

Associated Commands: Get PDM Current Value (0x62)

If a PDM is enabled and its timer is active, sending a Set PDM On command to the PDM will set its current value to zero, effectively resetting the timer count. This means that from the moment a Set PDM On command is received the PDM will remain active for its full Timer Limit duration.

Set PDM Timer Limit (0x60)

Command	Data[1]	Data[0]	Bytes Returned	Delay, ms
0x60	Channel #	Period	0	150

Set the length of time a channel can remain enabled for. The value supplied gives the duration in increments of 30 seconds, e.g. duration=0x0A would enable the PDM for 5 minutes.

Supplying a value of period=0xFF sets the PDM to remain enabled indefinitely. A value of period=0x00 will permanently disable the PDM until such time that the timer is set to a value greater than 0x00.

If an invalid channel is specified, 0xFFFF will be returned and the device will generate an Invalid Channel error.

If an invalid period is specified, 0xFFFF will be returned and the device will generate an Invalid Data error.

Get PDM Timer Limit (0x61)

Command	Data[0]	Bytes Returned	Delay, ms
0x61	Channel #	2	5

Returns the maximum timer value currently set for the PDM. Durations are returned in increments of 30 seconds, e.g. duration=0x0A would mean the PDM was enabled for a total of 5 minutes.

Get PDM Current Value (0x62)

Command	Data[0]	Bytes Returned	Delay, ms
0x62	Channel #	2	1

Returns the time passed since the PDMs timer was enabled. Durations are returned in increments of 30 seconds, e.g. duration=0x0A would mean the PDM has been enabled for a total of 5 minutes.

11.8 PCM Control

PCM Reset (0x70)

Command	Data[0]	Bytes Returned	Delay, ms
0x70	PCM Channels	0	1

The individual power buses on the EPS can be reset using this command. Table 11-10 provides the breakdown of the data bits to reset a power bus.

Power Bus	Bit String
BatV	0x01
5V	0x02
3V3	0x04
12V	0x08

Table 11-10: Power Bus Breakdown

A combination of the bit strings can also be used. For example to reset the 5V and the Battery V bus, send the data 0x03.

When this command is used, the chosen power bus, or buses, will be held in reset for a period of approximately 500ms. This has the effect of turning off the power bus for this period of time.

It should be noted that when the 3.3V power bus is reset, communication to the TTC node will be lost for the period of time the bus is held in reset. The TTC node will power up in its initial configuration.

12. Test

All EPS units must be fully tested prior to shipping, and test reports available for review. In order to verify the operation of the EPS please use the following outlined instructions.

12.1 Required Equipment

- Charging Cables
- EPS
- Battery Pack
- Battery Inhibit Harness
- Oscilloscope
- Multimeter
- Electronic Load
- Rover OBCS

Battery

During test phases it is not always possible or advisable to use a battery. For example to test End of Charge or undervoltage shutdown operation you may want to alter the battery voltage manually rather than wait for a battery to charge/discharge.

When testing without a battery the system requires a simulated battery to be attached. This can be achieved by using a PSU (to set the battery and supply current when required/discharging) and an electronic load (to simulate the battery taking current/charging) connected in parallel.

The PSU should be set using the voltage as the required battery voltage (V_{psub}) and a current limit of 2C (I_{psub}) (the highest recommended discharge rate of the battery). The electronic load current (I_{eloadb}) setting should be set to approximately 1C of the battery to be used. You must also ensure the eLoad setting is higher than the supplied BMM current, otherwise the BCR will be pushed into EoC.

12.2 Basic System Setup

Before any testing commences all equipment described above should be used with limits set up appropriately.

1. All PSUs should be switched off.
2. Connect the Battery (or simulated battery – Switch on the PSU and eLoad).
3. Verify that the Switches are operating correctly (i.e. there is no power supplied on the buses and no current drawn from the "battery").

13. Compatible Systems

	Compatibility	Notes
Batteries	UHM RoSE Battery System	Lithium Ion Polymer
	Lithium Polymer 8.2V	(2S1P) to (2S3P) More strings can be connected in parallel to increase capacity if required
	Lithium Ion 8.2V	(2S1P) to (2S3P) More strings can be connected in parallel to increase capacity if required
	Other Batteries	Please Contact UHM RoSE