USER MANUAL

Electrical Power System (EPS I & EPS I Plus)

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This user manual details the applications, features and operation of EnduroSat's Electrical Power System (EPS I and EPS I Plus).

Please read this manual before unpacking and using the module to ensure safe and proper use.

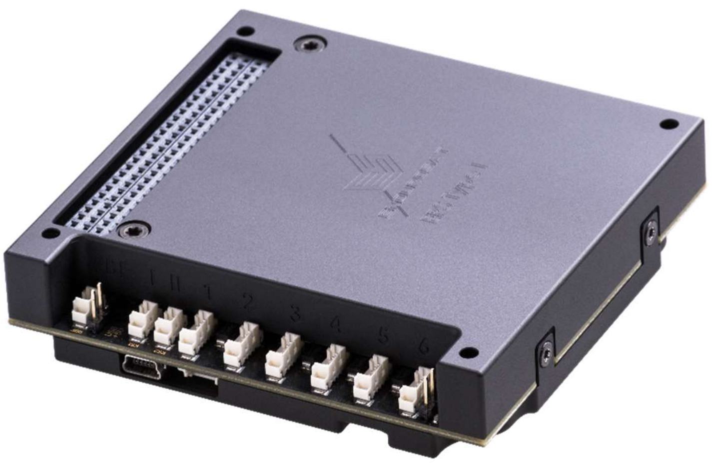

Figure 1: EnduroSat's Electrical Power System (EPS I and EPS I Plus)

1 CHANGE LOG

Date	Version	Note
21/11/2018	Rev 1.0	Initial
20/12/2018	Rev 2.0	Technical writing enhancements
10/03/2020	Rev 2.1	7. Electrical Characteristics – Heater power Consumption of EPS I+ (two battery packs) is added. 6.7.1 JMP1 – All reset parameters are described.

2 ACRONYMS LIST

BCR	Battery Charger Regulator
EMC	Electromagnetic Compatibility
EOC	End of Charge
EPS	Electrical Power System
ESD	Electrostatic Discharge
CC	Constant Current
CV	Constant Voltage
JMP	Jumper
I2C	Inter Integrated Circuit
Li-Po	Lithium Polymer Battery
LUP	Latch-up Protected
MPPT	Maximum Power Point Tracking
PCM	Protection Circuit Module
RBF	Remove Before Flight
RTC	Real Time Clock
UART	Universal Asynchronous Receiver/Transmitter
USB	Universal Serial Bus
LDO	Low Dropout Regulator
MCU	Microcontroller
VCP	Virtual COM Port

3 HIGHLIGHTED FEATURES

- ✓ Three Solar Panel Channels (one for each CubeSat axis: x, y and z)
- ✓ Input voltage (per Solar Panel Channel): up to 5.5 V
- ✓ Input current (per Solar Panel Channel): up to 1.8 A
- ✓ Six connectors for the solar panels
- ✓ Integrated blocking diode for each solar panel connector
- ✓ Battery pack power: 10.2 Wh (20.4 Wh for two battery packs)
- ✓ Battery pack voltage: 3.7V nominal
- ✓ Very low power consumption in normal operation: 20mA @3.7V battery
- ✓ Stackable battery packs: up to 8A
- ✓ Output power buses: 3.3V, 5V, BCR (5Vmax) and 'battery raw'
- ✓ 3.3V and 5V latch-up protected outputs
- ✓ Interfaces: UART, I2C, USB (Virtual COM Port)
- ✓ Two deployment and one Remove Before Flight (RBF) switches can be connected
- ✓ Six general purpose outputs for shutdown/reset of external modules
- ✓ USB debug & battery charger
- ✓ Weight: EPS I = 208g (includes 1 battery pack)
- ✓ Weight: EPS I Plus = 292g (includes 2 battery packs)

4 SYSTEM DESCRIPTION

EnduroSat's EPS I and EPS I Plus modules are ideal for 1U, 1.5U and 2U CubeSat satellites.

The EPS I module has one integrated Li-Po battery pack with a capacity of 10.2Wh. The maximum output power from all power buses combined is 10W.

The EPS I Plus module has two integrated Li-Po battery packs connected in parallel with a total capacity of 20.4Wh. The maximum output power from all power buses combined is 20W.

The aluminum housing of the EPS modules improves the thermal capabilities of the whole system, reduces the EMC, and protects the electronics from radiation particles.

A CubeSat has three axes: x, y and z, and each axis has two sides: + and -. The EPS has three Solar Panel Channels, one for each axis. Each Solar Panel Channel on the EPS has two connectors, one for each side of the axis. Therefore, in total the EPS has six solar panel connectors (as a CubeSat has six sides). Each Solar Panel Channel has a DC-DC step-up converter with Maximum Power Point Tracking (MPPT). The output energy for each solar panel is monitored. All three Solar Panel Channels are in parallel and can work at the same time. Therefore, the generated energy is a sum of all solar panels.

Each Solar Panel Channel has the following features:

- Precision current and voltage measurement
- Overcurrent protection
- Overvoltage protection
- Overtemperature protection
- ESD protection
- Solar panel reverse insertion protection

The Solar Panel Channels can handle input voltages up to 5.5V and the current maximum threshold for overcurrent protection is set to 1.8A. The operating temperature range is from -40°C to +150°C and the overtemperature threshold is set to +155°C (the module will turn off if this threshold is reached and restart automatically when the temperature decreases to +130°C). The efficiency of the step-up convertors is up to 95%.

The step-up convertor turns OFF if the input voltage is lower than $V_{F\ \mathrm{blocking\ diode}}$ + 0.27V (under voltage lockout) and restarts when the voltage exceeds $V_{F\ \mathrm{blocking\ diode}}$ + 0.34V. A hysteresis is implemented to avoid unpredictable ON-OFF switching. However, the minimum input voltage threshold for boosting is $V_{F\ \mathrm{blocking\ diode}}$+0.5V.

The step-up convertors work at 100kHz fixed frequency. The duty cycle is controlled by the MPPT algorithm. The boosted output voltage can be accessed through the PC/104 connector for additional functionality such as charging of the external battery pack, super capacitors, etc.

The battery charger operates in both linear and quasi-pulse modes and this happens according to the Constant Voltage and Constant Current rules. The advantage of the quasi-pulse charging method is that it allows the energy from weakly illuminated solar cells to be very efficiently harvested. Four different charging current modes can be selected according to the solar panel configuration used on the CubeSat. The efficiency of the battery charger is around 90%.

The EPS includes firmware and hardware battery protection. A single battery pack consists of 2 Li-Po battery cells connected in parallel. Each battery cell within each battery pack has an integrated Protection Circuit Module (PCM) which prevents over-current, over-charge and over-discharge.

EnduroSat have developed a firmware algorithm to protect the batteries from short circuit, deep discharge and overheating (see Figure 2).

As an additional safety feature, the battery packs also have hardware protection against over-current, over-charge and over-discharge. If the PCMs are triggered (i.e. the battery cells are disconnected from the EPS), then all power bus outputs from the EPS are turned off. In this case the following occurs:

i) Over-current: the PCMs automatically reset themselves and reconnect the battery pack to the EPS.
ii) Over-charge: the PCMs automatically reset when the charging voltage drops below 4.275V.
iii) Over-discharge: the PCMs automatically reset when the battery cell voltage goes above 2.3V

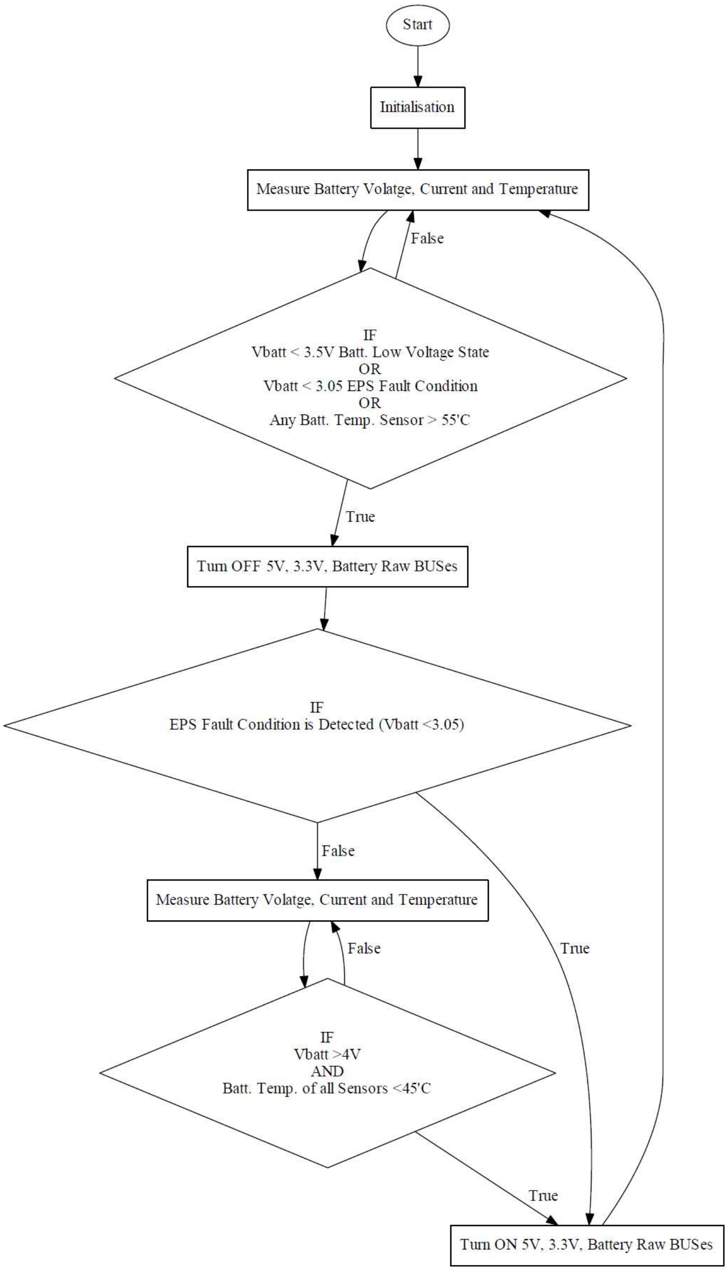

Figure 2: Algorithm for protection of the batteries from short circuit, deep discharge and overheating.

Each battery pack has three independent heaters to prevent charging below 0 ^{0}C. A special algorithm optimizes the heater power consumption in relation to the temperature (see Figure 3).

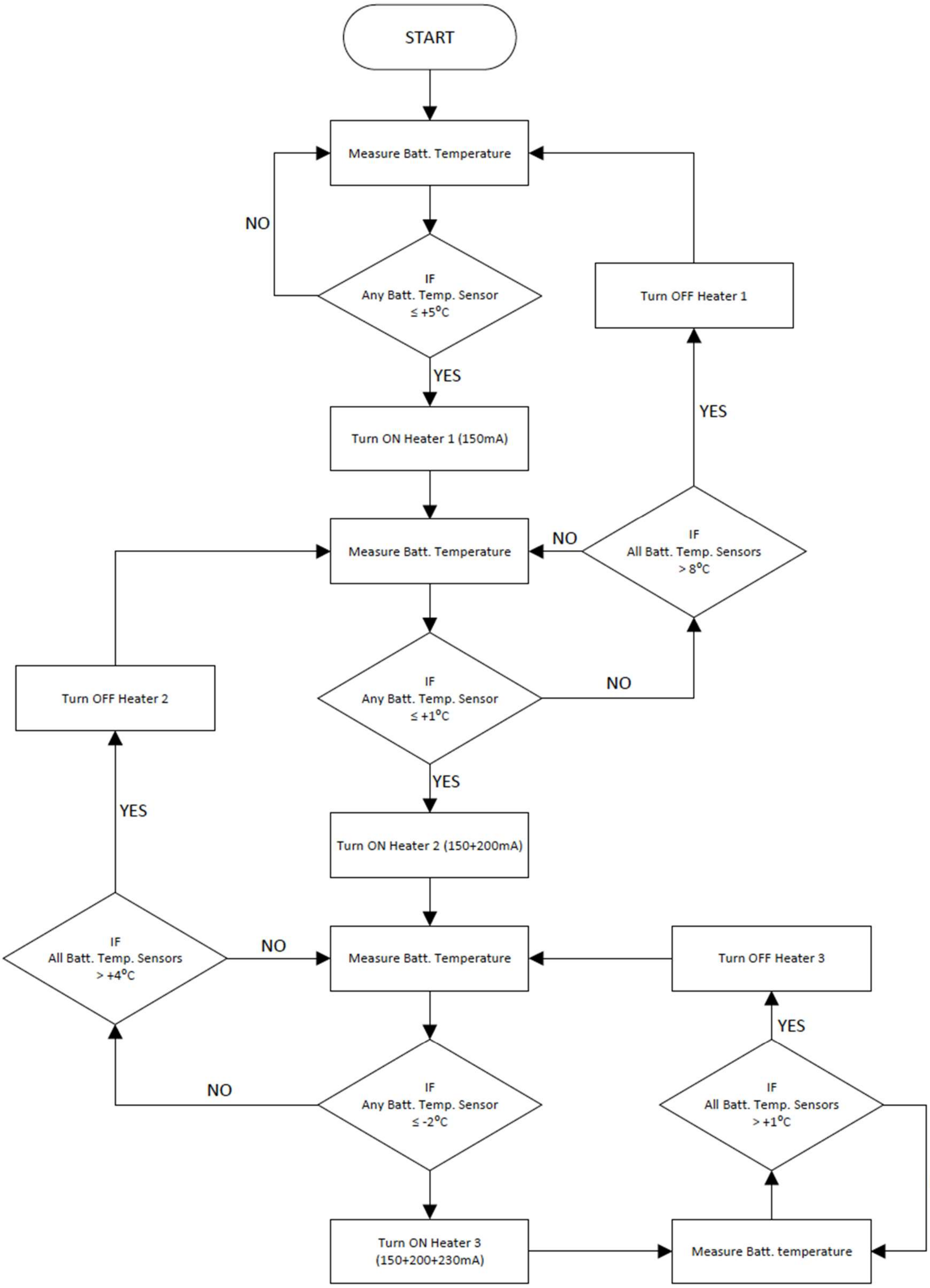

Figure 3: Algorithm for the optimization of the heater power consumption

A CubeSat has two deployment switches located at two opposite corners of the CubeSat structure, in accordance with the CubeSat design specification. These two deployment switches should be connected to the dedicated deployment connectors on the EPS module.

A CubeSat also has a Remove-Before-Flight (RBF) switch located on the side of the CubeSat structure, in accordance with the CubeSat design specification. The Remove-Before-Flight (RBF) switch should be connected to the dedicated Remove-Before-Flight (RBF) connector on the EPS module.

When the RBF pin is plugged in or both deployment switches are pressed, the EPS module is inactive. In order to activate the EPS module, it is necessary that the RBF pin is unplugged and at least one deployment switch is released. The deployment switches and the RBF switch are peripheral circuits to the EPS module and control high impedance internal MOSFET switches in the EPS which connect/disconnect the internal battery pack(s) from the EPS module.

Once the EPS module is turned on, then the self-locking functionality is activated, and the power supply cannot be stopped by resetting the deployment switches or the Remove Before Flight(RBF) pin. For ground test purposes, the self-lock functionality can be stopped using the PC software via the USB port or from the dedicated jumper JMP1.

The incoming power along with the energy stored in the batteries is used to feed all the main buses: 3.3V@3A, 5V@2A and 'battery raw'@4A (specifications are for EPS I with 1 Battery Pack).

There are two Latch-Up Protected (LUP) outputs: one internally connected to the 5V BUS (H1-48) and one internally connected to the 3.3V BUS (H1-51). The trip current threshold is 2A for both LUP outputs. If the trip current threshold is reached the LUP output is disconnected. An auto retry mechanism is implemented and every 15ms the LUP outputs check if the current is below the trip threshold for normal operation to continue. This trip condition can be reported to an external module such as the OBC.

When the EPS is turned on a special 3.3V output power bus ($V_{RTC\ BUS}$) from the EPS supplies an external Real Time Clock (RTC) in EnduroSat's OBC. This $V_{RTC\ BUS}$ cannot be shut off even when a low battery state occurs. The current on this $V_{RTC\ BUS}$ is limited with a 1kΩ serial resistor. Please note, when the satellite is turned off and ready for deployment in the P-Pod then the $V_{RTC\ BUS}$ is also off. This means that the Real Time Clock (RTC) is also off and must be set in orbit after the satellite has been deployed.

In case of a problem the EPS MCU can be reset by pin H1-28 of the PC/104 connector by pulling it low (GND) to logical level 0.

4.1 EPS Module Monitoring

There is built-in firmware in the EPS module for monitoring, which can report (via the external interfaces) the following parameters:

- ✓ Voltage and current generated by each solar panel. N.B. the voltage measurements are made after the solar panel integrated blocking diode.
- ✓ Combined voltage and current of all three Solar Panel Channels
- ✓ Output current of each power bus (5V BUS, 3.3V BUS, Battery BUS and BCR BUS)
- ✓ Battery pack(s) voltage, current and temperature (one temperature sensor per battery cell)
- ✓ Up to three external temperature sensors
- ✓ Critical flag status: power cycle, low voltage, EPS fault conditions, over temperature, and minimum and maximum temperatures reached for each battery cell.
- ✓ On/Off status of the output power buses
- ✓ On/Off status of all six general-purpose outputs of the EPS module
- ✓ Charge mode status
- ✓ Self-lock function status
- ✓ Battery heater status

The EPS module measures the current from each solar panel, and the Solar Panel Channel voltage. The total output voltage of the three Solar Panel Channels is also monitored. Each Solar Panel Channel has a step-up converter with MPPT.

The EPS module measures the output current of all the power buses: 5V, 3.3V, 'battery raw' and BCR Out. When the 5V and 3.3V BUS is within 5% of the required voltage then its status flag is set to PASS(1), and when the voltage is outside 5% then its status flag is set to FAIL(0) .

The EPS module monitors the instantaneous temperature of every battery cell. It also monitors the minimum and maximum temperature of every battery cell (since the EPS module was switched on).

On the first battery pack there is a single connector for an additional three external temperature sensors. The temperature sensors can be mounted anywhere with the satellite.

4.2 EPS Module Control:

The firmware provides control (via the external interfaces) of the following features:

- ✓ On/Off state of the self-lock function
- ✓ On/Off state of the power BUS': BCR, 3.3V, 5V and 'battery raw'
- ✓ On/Off state of the 3.3V and 5V LUP outputs
- ✓ On/Off state of the six general-purpose outputs
- ✓ Set the battery charge mode (4 different options/currents)
- ✓ On/Off state of the battery heaters

The EPS module has six general purpose outputs. Every output can be switched between 2.7V and ground. All outputs are protected with diodes and 10k pull-down resistors, which enable other modules to control them at the same time. Diode OR gates can be realized on these outputs.

5 BLOCK DIAGRAM

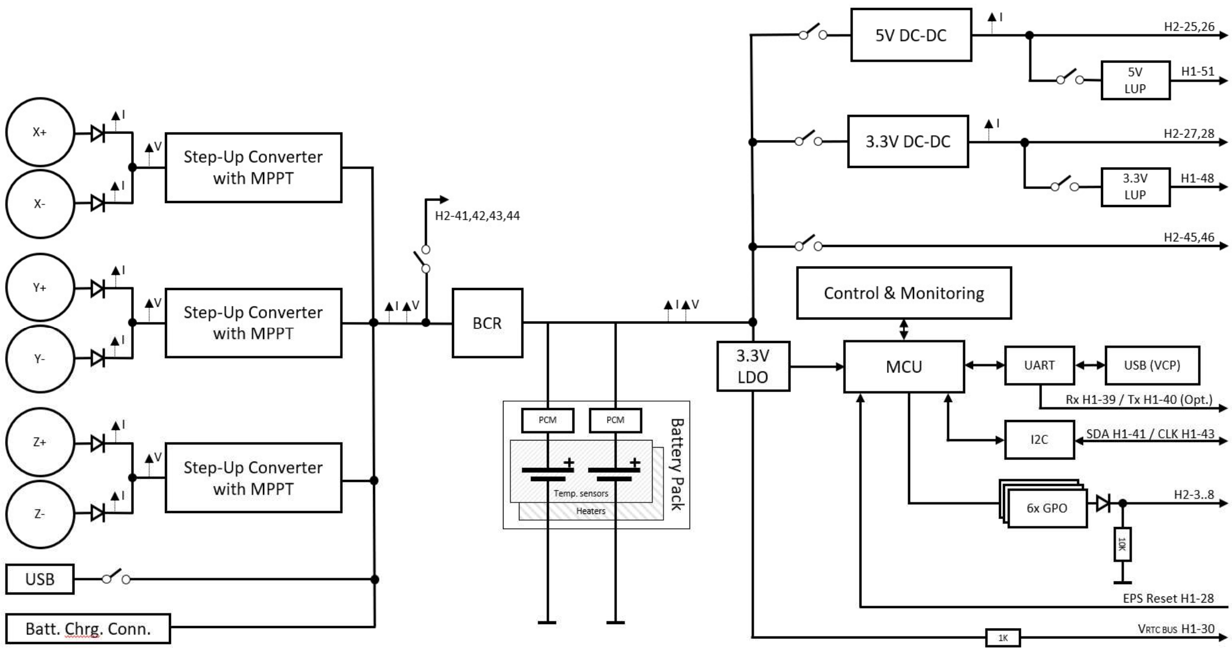

Figure 4: Block diagram of the EPS Module

6 CONNECTOR PINOUT

6.1 Location of Connectors

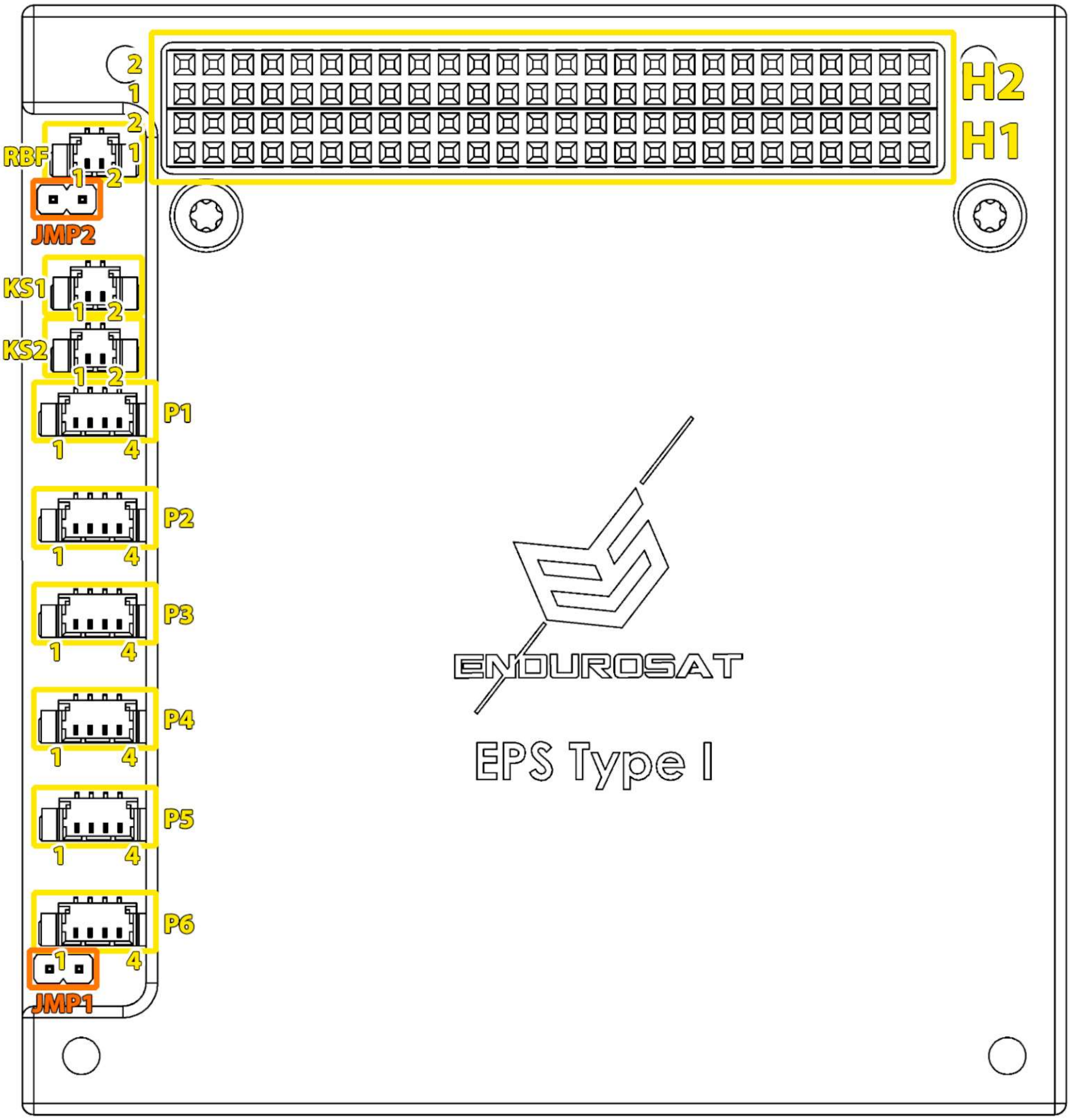

Figure 5: Location and Pinouts of Top Side Connectors

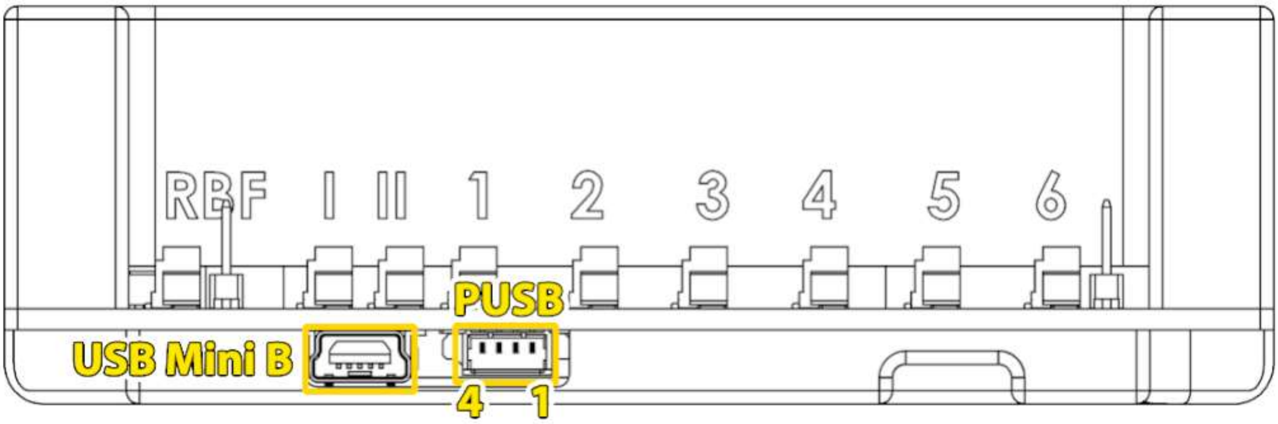

Figure 6: Location and Pinouts of Bottom Side Connectors

6.2 H1 & H2 - PC/104 Stack Connector

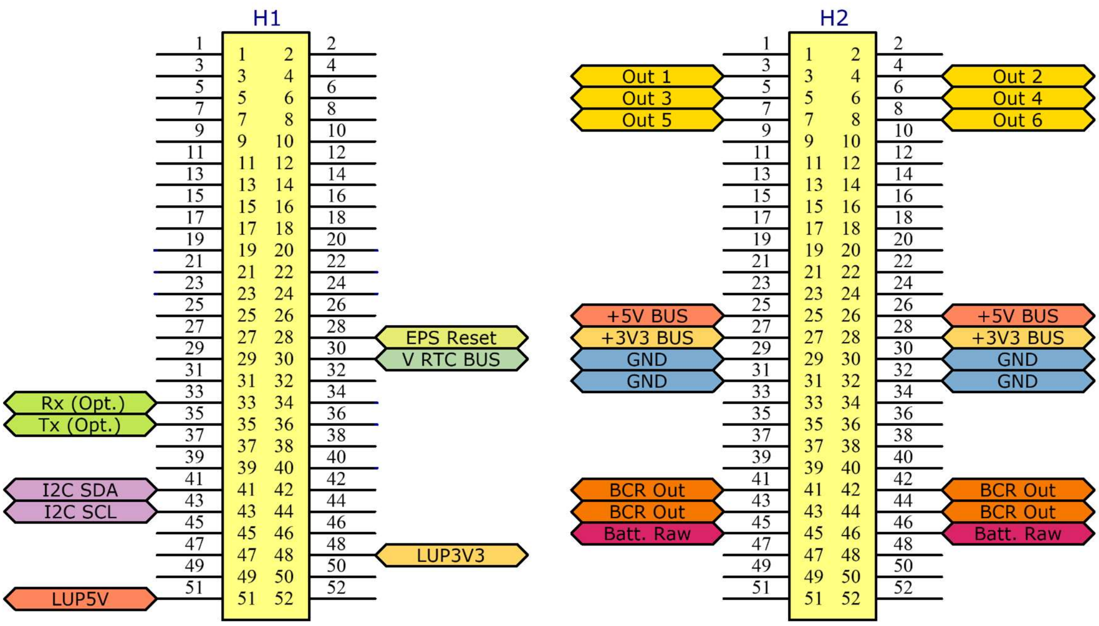

Figure 7: Pinouts of PC/104 Stack Connector

6.2.1 H1 – Stack Connector

Pin	Mnemonic
H1-28	EPS Reset
H1-30	V_{RTC} BUS
H1-39	UART RX[1]
H1-40	UART TX[1]
H1-41	I2C SDA
H1-43	I2C CLK
H1-48	LUP1 3.3V
H1-51	LUP2 5V

[1] Optional – Hardware Customizable

Table 1: Pinouts: H1 of PC/104 Stack Connector

6.2.2 H2 – Stack Connector

Pin	Mnemonic
H2-3	OUT1
H2-4	OUT2
H2-5	OUT3
H2-6	OUT4
H2-7	OUT5
H2-8	OUT6
H2-25	5V BUS
H2-26	5V BUS
H2-27	3.3V BUS
H2-28	3.3V BUS
H2-29	GND
H2-30	GND
H2-31	GND
H2-32	GND
H2-41	BCR Out
H2-42	BCR Out
H2-43	BCR Out
H2-44	BCR Out
H2-45	VBATT BUS
H2-46	VBATT BUS

Table 2: Pinouts: H2 of PC/104 Stack Connector

6.3 P1 to P6 - EPS Solar Panel Connectors

The EPS module has six solar panel connectors from P1 to P6, and they are 4 pin MOLEX Picoblade 53398-0471. EnduroSat's recommended configuration is as follows:

EPS Solar Panel Connector	Axis
P1	Z+
P2	Z-
P3	Y+
P4	Y-
P5	X+
P6	X-

Table 3: EPS Solar Panel Connectors and Associated Axis

This configuration can be modified, taking in to account that the pairs: P1 and P2, P3 and P4, P5 and P6 should be connected to the solar panels on opposite sides of the same axis.

The pinouts for an EPS Solar Panel Connector is the same for each of the 6 connectors (P1 - P6):

Pin	Mnemonic	Description
1	-	Negative
2	-	Negative
3	+	Positive
4	+	Positive

Table 4: Pinouts of each EPS Solar Panel Connector

6.4 KS1 and KS2 – Deployment Switches

KS1 and KS2 connectors are Deployment Switch 1 and Deployment Switch 2, respectively. Both are 2 pin MOLEX Picoblade 53398-0271 connectors.

6.5 RBF – Remove Before Flight

RBF is the Remove Before Flight connector. It is a 2 pin MOLEX Picoblade 53398-0271 connector.

6.6 USB Connectors

6.6.1 USB mini B – can be used for monitoring and control of the EPS module. When the JMP2 is inserted the internal batteries can be charged though this connector.

6.6.2 PUSB – Secondary USB connector. PUSB is connected electrically in parallel to the USB mini B. The purpose of this connector is so the user can access the EPS module when the satellite is fully assembled. When the satellite is fully assembled the USB mini B and PUSB connectors may not be physically accessible. Therefore, a custom USB cable can be connected from the PUSB connector to the Satellite Communication Interface Connector (SCIC) on the bottom side of EnduroSat's X/Y RBF Solar Panel. This Satellite Communication Interface Connector(SCIC) is also accessible from the top side of the Solar Panel and this allows the user to easily configure and monitor the EPS module as well as charge the batteries.

Pin	Mnemonic	Description
1	+5V	+5Vdc USB Input
2	USBN	Data Negative
3	USBP	Data Positive
4	GND	Ground

Table 5: Pinouts of PUSB Connector

6.7 Jumpers

6.7.1 JMP1

When the jumper is inserted the Self-Lock functionality is turned OFF. This also can be done by graphic user interface software. The whole satellite can be switched OFF with the insertion of the RBF pin or by pressing both of the deployment switches together. When the jumper is inserted it resets all of the EPS module system logs (Power Cycles; Low Voltage States; Short Circuit States; Over Temperature States; Minimum and Maximum Temperatures of each Battery Cell). In the EPS module with software version older than 1601 the default output conditions are also reset: Output from 1 to 6; LUP3.3V & LUP5V; Fast Charge Mode.

6.7.2 JMP2

When the jumper is inserted the batteries can be charged from the USB Mini B connector.

7 ELECTRICAL CHARACTERISTICS

Parameter	Unit	Condition	Min	Typ	Max
Battery Capacity					
Capacity	mAh	EPS with 1 battery pack	2640	2800	
	mAh	EPS with 2 battery packs	5280	5600	
	Wh	EPS with 1 battery pack		10.4	
	Wh	EPS with 2 battery packs		20.8	
Battery Charger					
EOC voltage	V		4.08	4.1	4.12
Charge current	mA	Charge Mode 4	755	815	875
	mA	Charge Mode 3	540	580	620
	mA	Charge Mode 2 (by default)	430	460	490
	mA	Charge Mode 1	215	230	245
Battery Discharge					
Over Discharge Detection	V	Limited by PCM	2.24	2.3	2.36
Over Current Detection	mA	EPS with 1 battery pack (limited by PCM)		4000	9000 (8 to 16ms)
	mA	EPS with 2 battery packs (limited by PCM)		8000	16000 (8 to 16ms)
Exp. Cycle Life	mAh	Discharge @ 0.5/1C, 23 ±2^{0}C;	500 Cycles ≥ 2196 mAh		
Unregulated Battery Bus					
Output voltage	V	Firmware defined	3.5		4.12
Output current	mA	EPS with 1 battery pack (limited by PCM)		4000	9000 (8 to 16ms)
	mA	EPS with 2 battery packs (limited by PCM)		8000	16000 (8 to 16ms)
+5 V Bus					
Output voltage	V		4.88	5	5.15
Output current	mA	EPS with 1 battery pack			2000
	mA	EPS with 2 battery pack			4000

Operating frequency	kHz		500	535	560
Efficiency		V_{batt} = 4; I_{5VBUS} = 2A	82%	84%	86%
+3.3 V Bus					
Output voltage	V		3.3	3.38	3.45
Output current	mA	EPS with 1 battery pack			3000
	mA	EPS with 2 battery pack			4000
Operating frequency	kHz		465	495	525
Efficiency		V_{batt} = 4V; $I_{3.3VBUS}$ = 2A	72%	76%	78%
Module Consumption					
Power Consumption	mW	Normal Operation. LUP5V & LUP3V3 are OFF		75	
	mW	Low Voltage or High Temperature State. All Buses are OFF		43	
Current Consumption	mA	Batt. Low State @3.3V		13	
	mA	Normal Operation @3.7V		20	
	mA	LUP3V3 & LUP5V	3.9		5
	mA	Heater 1 - 1x Battery Pack	90	100	115
	mA	Heater 2 - 1x Battery Pack	140	150	170
	mA	Heater 3 - 1x Battery Pack	185	200	225
	mA	Heater 1 - 2x Battery Packs	180	200	230
	mA	Heater 2 - 2x Battery Packs	280	300	340
	mA	Heater 3 - 2x Battery Packs	370	400	450
Fault Current Threshold (auto retry every 15ms)	A	LUP3V3 & LUP5V	1.75		2.2
Solar Panels Input					
Voltage	V	@25^{0}C	0	4.66	5.5
Current	mA	@25^{0}C		517	1800
Power	W	@25^{0}C		2.6	
Integrated blocking diode forward voltage ($V_{F\ BLOKING\ DIODE}$)	V	@1A & 25^{0}C		0.325	
		@0.5A & 25^{0}C		0.275	

Table 6: Electrical Characteristics of the EPS I & EPS I Plus Module

8 MECHANICAL DRAWING

The following pictures show the external dimensions of a fully assembled EPS module. The EPS module, as already mentioned, has 2 configurations: EPS I with one battery pack, and EPS I Plus with two battery packs. The bottom side of the module has two openings, which can be used for routing cables within the satellite. The top view is the same for both configurations (see Figure 8).

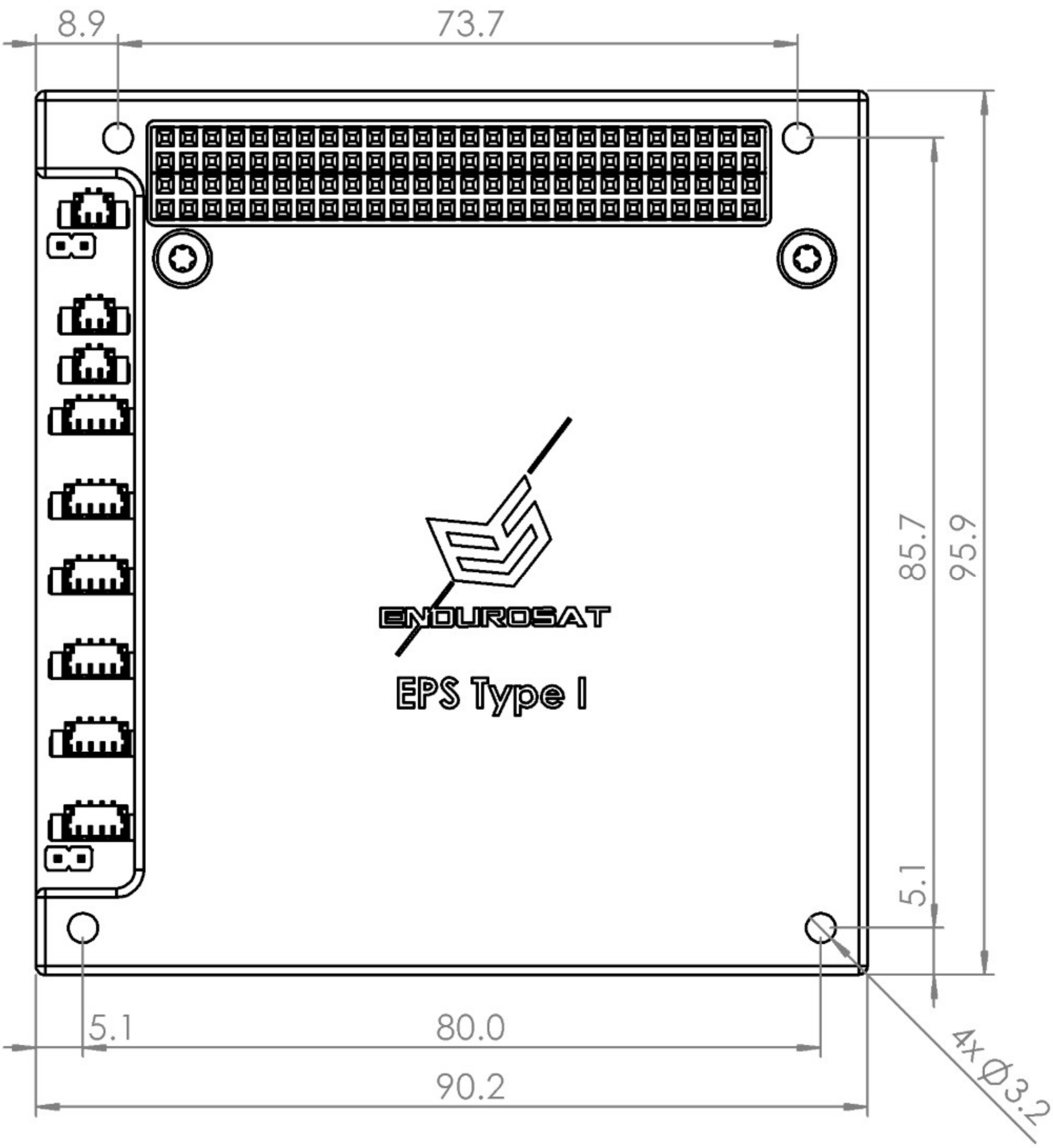

Figure 8: EPS Module - Top View (all dimensions are in mm)

The bottom part of both the EPS I and the EPS I Plus module are the same. There are two openings to assist in routing cables within the satellite (see Figure 9, Figure 10 and Figure 11).

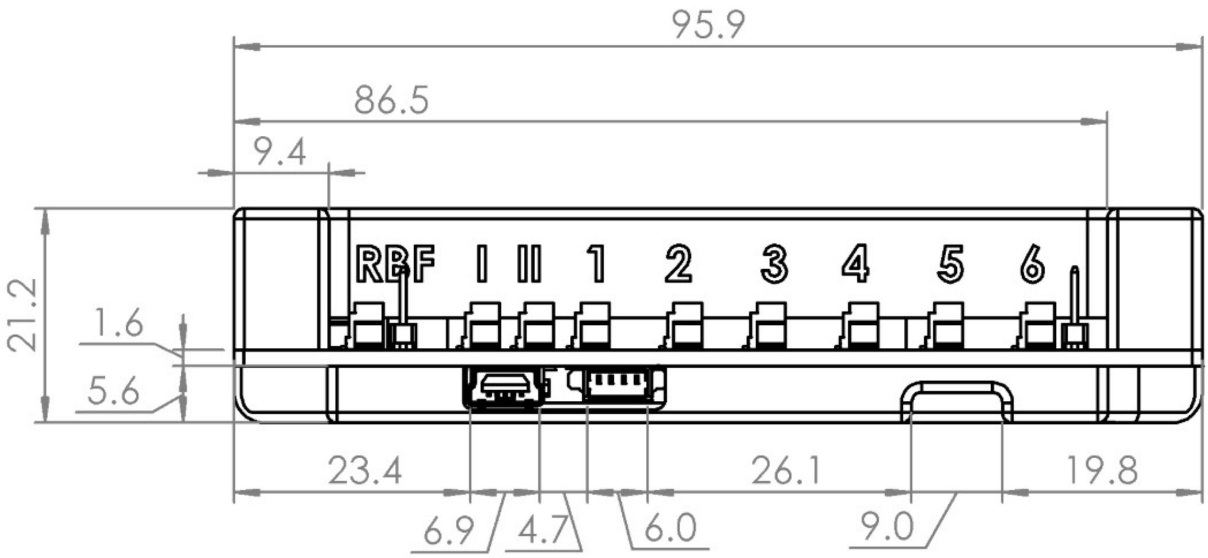

Figure 9: EPS I Module with one Battery Pack – Side View

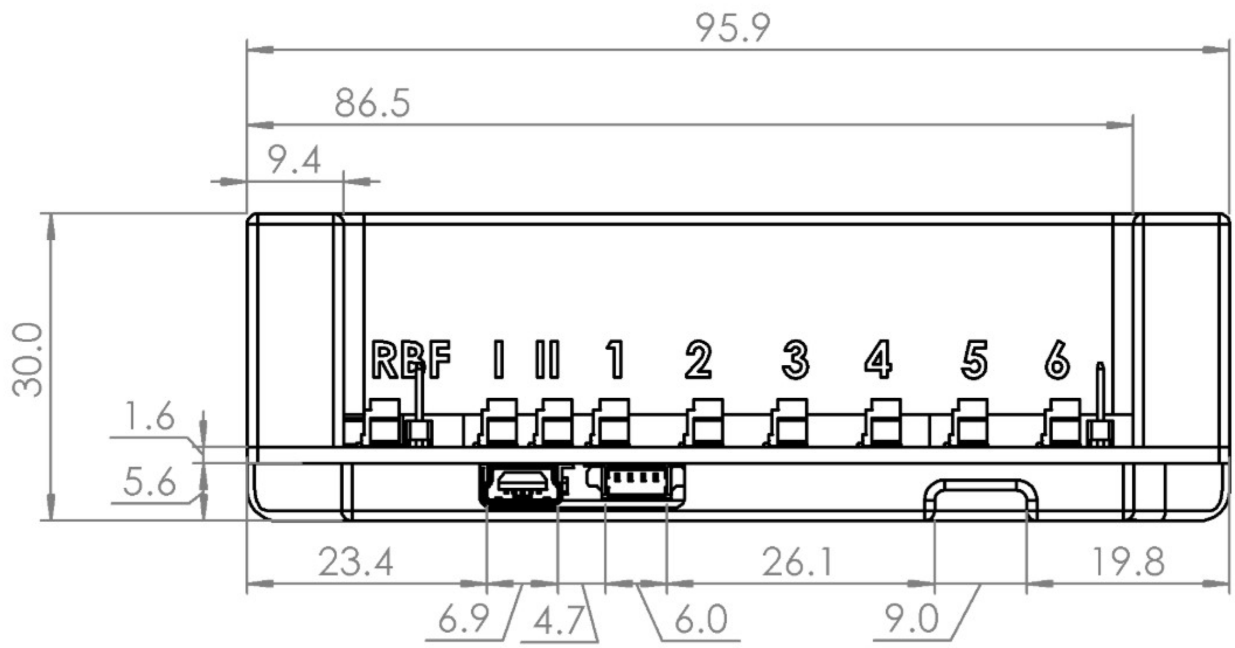

Figure 10: EPS I Plus Module with two Battery Packs – Side View

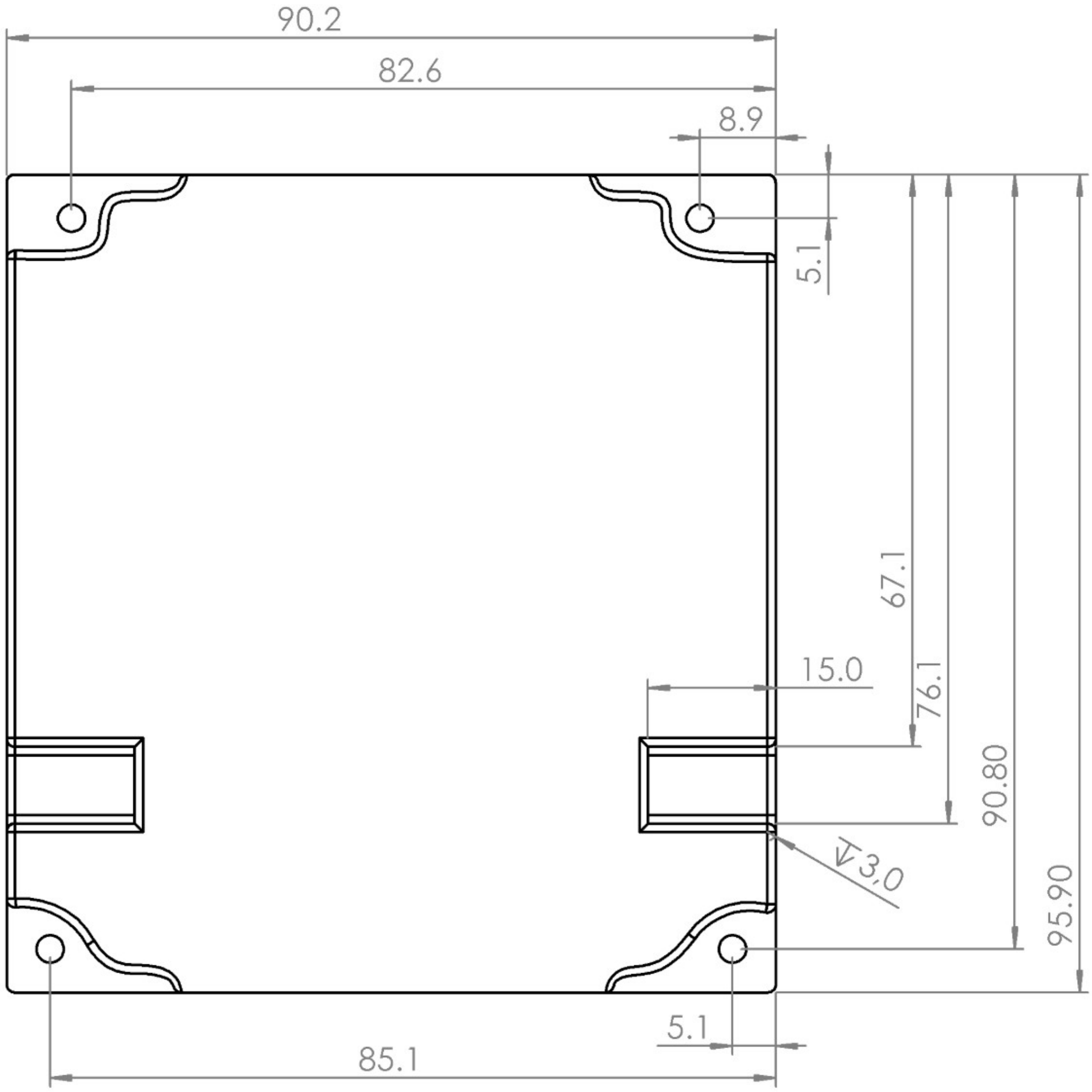

Figure 11: EPS Module - Bottom View with Openings

9 ENVIRONMENTAL AND MECHANICAL TEST

A full campaign of qualification tests were performed on the qualification engineering model The qualification test levels and duration follow the ESA standard ECSS-E-ST-10-03C and GEVS: GSFC-STD-7000A. The tests performed were:

- Thermal Cycling
- Thermal Vacuum
- Random Vibration
- Sine Vibration
- Shock Test
- Total Ionizing Dose

A test report can be provided upon request.

10 HANDLING AND STORAGE

Particular attention shall be paid to the avoidance of damage to the EPS during handling, storage and preservation. The handling of the EPS module should be performed in compliance with the following instructions:

- Handle using PVC, latex, cotton (lint free) or nylon gloves.
- The environment where the EPS module will be handled shall meet the requirements of a Class 100,000 environment. It shall be free of contaminants such dust, oil, grease, fumes and smoke from any source.
- Store in such a manner as to exclude stress and prevent damage.
- To prevent the deterioration of the power module, it must be stored in a controlled environment, i.e. the temperature and humidity levels shall be maintained in the proper ranges:
  - Ideal storage temperature range: 15ºC to 27ºC
  - Ideal storage humidity range: 30% to 60% relative humidity (RH)

11 WARNINGS

This product uses semiconductors that can be damaged by electrostatic discharge (ESD). Observe precautions for handling

Sensitive electronic device. Do not ship or store near strong electrostatic, magnetic, electromagnetic, or radioactive fields.

LITHIUM ION RECHARGEABLE BATTERY
Caution! May explode if disposed of in fire

- Do not incinerate or place near an open flame
- Do not drop, crush, puncture or disassemble battery
- Do not short terminals
- Do not expose to temperatures above 140°F/60°C
- Do not replace by a battery other than that specified by the manufacturer