SLB-EPS2-DOC-v0.2

EPS 2.0 Documentation

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SpaceLab, Universidade Federal de Santa Catarina, Florianópolis - Brazil

February 2021

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February, 2021

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Revision Control:

Version	Author	Changes	Date
0.1	G. Marcelino	Document creation	2020/11/05
0.2	Y. Azeredo, A. Vassoler	TBD	TBD

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Nomenclature

1-Wire	*One-Wire.*
ADC	*Analog-to-Digital Converter.*
BAT4C	*Battery Module 4 Cells.*
EPS	*Electric Power System.*
GPIO	*General Purpose Input/Output.*
I2C	*Inter-Integrated Circuit.*
IDE	*Integrated Development Environment.*
JTAG	*Joint Test Action Group.*
LED	*Light-Emitting Diode.*
MCU	*Microcontroller.*
MPPT	*Maximum Power Point Tracking.*
NC	*Normally closed.*
NO	*Normally open.*
PCB	*Printed Circuit Board.*
PWM	*Pulse Width Modulation.*
RBF	*Remove Before Flight.*
RTD	*Resistance Temperature Detector.*
RTOS	*Real Time Operating System.*
SPI	*Serial Peripheral Interface.*
UART	*Universal Asynchronous Receiver/Transmitter.*
XCVR	*Transceiver.*

Contents

CHAPTER 1

Introduction

The EPS 2.0 is a PCB designed to harvest, store and distribute energy for a nanosatellite. It is one of the service modules developed for FloripaSat-2 CubeSat Mission [1]. The energy harvesting system is based on solar energy conversion through ten solar panels attached to the 2U CubeSat structure. The EPS 2.0 is designed to operate the solar panels at their maximum power point (MPPT). The board is also responsible for measuring solar panels current, voltage and the temperature of the panels and batteries. The harvested solar energy is stored in the Battery Module 4C [2] connected to the EPS. The energy distribution is done by several integrated buck DC-DC converters. The full EPS system is composed of the solar panels, the EPS 2.0 PCB and the battery module. The module is capable to measure its power consumption and operate in a lower energy state if needed. A general view of the EPS 2.0 board can be seen in Figure 1.1.

The module is a direct upgrade from the EPS of FloripaSat-1 [3], which grants a flight heritage rating. The improvements focus on providing a cleaner and more generic implementation in comparison with the previous version, more reliability in software, and adaptations for the new mission requirements. All the project, source and documentation files are available freely on a GitHub repository [4] under its respective licenses.

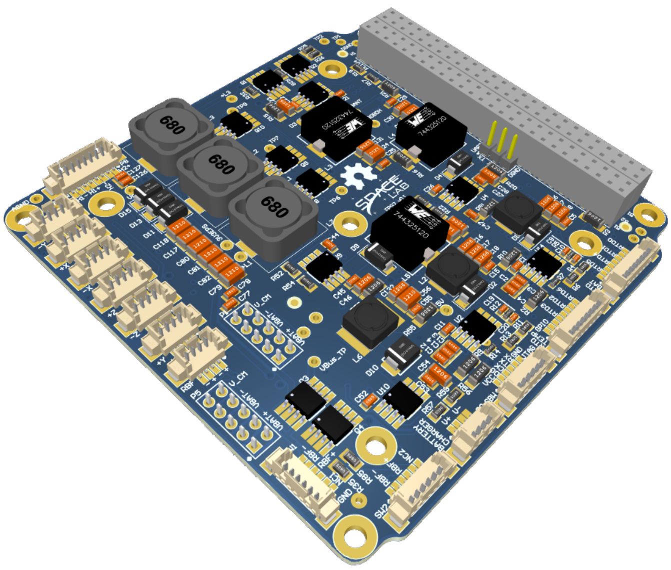

Figure 1.1: 3D view of the EPS 2.0 PCB.

CHAPTER 2

System Overview

The board has a MSP430 low-power MCU that runs the firmware application intended to control and comunicate with its peripherals, subsystems and other modules. The programming language used is C and the firmware was developed using the Code Composer Studio IDE (a.k.a. CCS) for compiling, programming and testing. The module has many tasks, such as interfacing internal peripherals and communicating with other boards, over distinct protocols and time requirements. Then, in order to improve predictability, a Real Time Operating System (RTOS) is used to ensure that the deadlines are observed, even under a fault situation in a routine. The RTOS chosen is the FreeRTOS (v10.2.1), since it is designed for embedded systems applications and it was already validated in space applications. The firmware architecture follows an abstraction layer scheme to facilitate higher level implementations and allow more portability across different hardware platforms, see section 2.3 for more details.

The EPS 2.0 is compatible with GOMspace Solar Panels or with panels of similar characteristics. Algorithms are implemented for MPPT improving power generation, also through measurements the load output can be regulated for a more efficient power distribution to the nanosattelite.

2.1 MCU Block Diagram

The Figure 2.1 presents a simplified view of the module subsystems and interfaces though the microcontroller perspective. The MCU has a programming JTAG, a dedicated UART debug interface and 4 communication buses, divided in 4 different protocols (I2C, SPI, 1-Wire and UART).

There is a I2C buffer to allow secure and proper communication with the OBDH 2.0 module [5]. The SPI protocol is used for controling and retriving data from a additional ADC IC that measures temperature sensors (RTDs) on the batteries board and solar panels. The 1-Wire protocol measures several parameters from the Batteries Managment Subsystem and sends them to the EPS 2.0 MCU. The UART bus that goes to the PC/104 is used for basic telemetry to be sent to the beacon microcontroller within the TTC module. Besides this channels, there are GPIO connections for enabling and disabling power buses, for hard code PCB versioning and some optional GPIOs that can be added and used though the PC/104 interface.

The MCU makes meassuments of current and voltage of the solar panels from its ADC ports for the MPPT Subsystem, also from this data the MPPT is controled by the microcontroller through PWM signals.

A external charger is used for charging the batteries and kill-switches for powering off the EPS 2.0 module during test phase, for flight the kill-switches are also connected to the button switches present on a CubeSat structure.

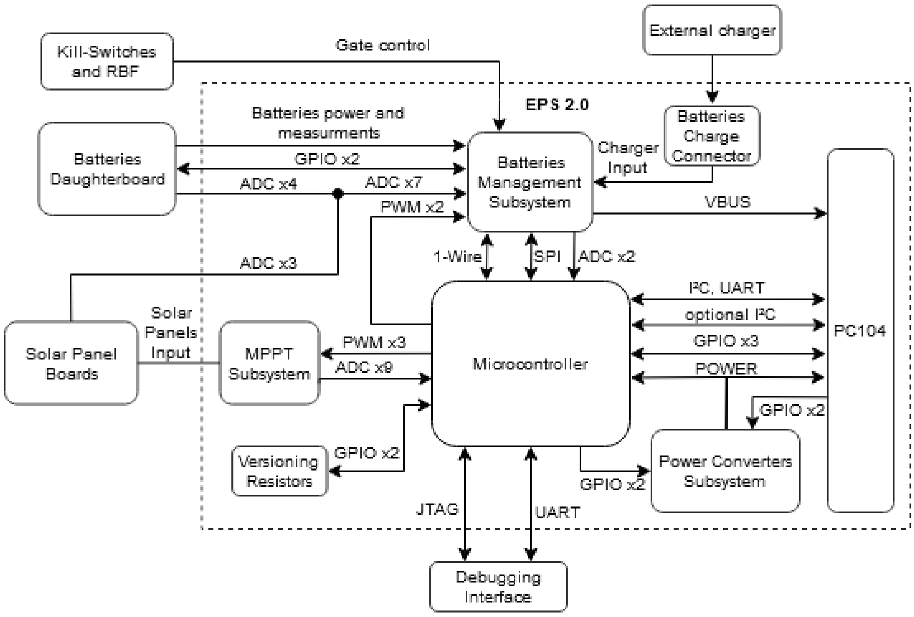

Figure 2.1: EPS 2.0 MCU Block diagram.

2.2 Power Block Diagram

The Figure 2.2 presents a more detailed view of the power subsystems that complements the MCU Block Diagram. More details and descriptions about these hardware components and interfaces are provided in the chapter 3.

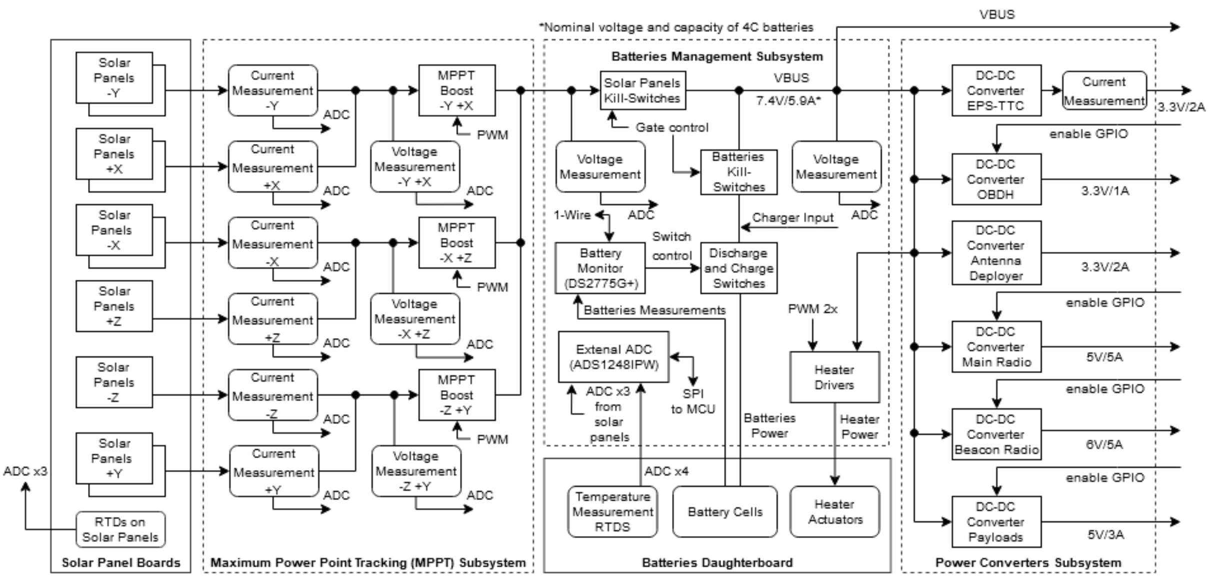

Figure 2.2: EPS 2.0 Power Block diagram.

2.3 System Layers

2.4 Operation

The system operates through the sequencial execution of routines (tasks in the context of the operating system) that are scheduled and multiplexed along the time. Each routine has a priority and a periodicity, which determine the following execution, the set of functionalities currentely running, and the memory usage management. Besides this deterministic scheduling system, the routines have communication channels with each other through the usage of queues, which provides a robust synchorization scheme. In the chapter 4 the system operation and the internal nuances are described in detail. Then, this section use a top view user perspective to describe the module operation.

2.4.1 Execution Flow

2.4.2 Data Flow

2.4.3 Status LEDs

On the development version of the board, there are nine LEDs that indicates some behaviours of the systems. This set of LEDs can be seen on Figure 2.3.

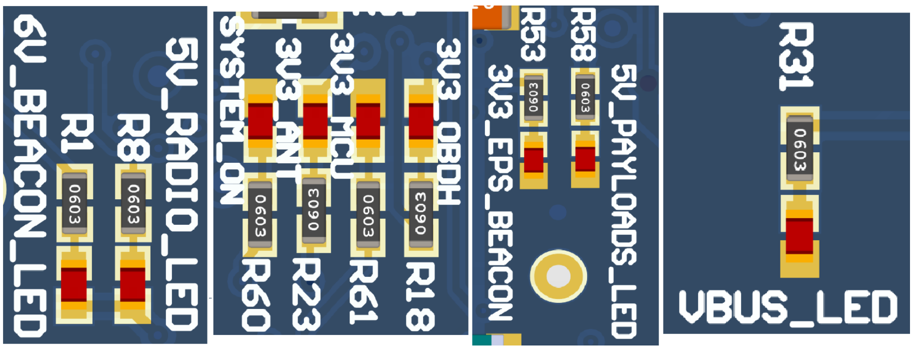

Figure 2.3: Available status LEDs.

A description of each of these LEDs are available below:

- **6V_BEACON_LED**: Indicates that the beacon transceiver 6V power is being sourced.
- **5V_RADIO_LED**: Indicates that the radio transceiver 5V power is being sourced.
- **SYSTEM_ON**: Heartbeat of the system. Blinks at a frequency of 1 Hz when the system is running properly.
- **3V3_ANT**: Indicates that the antenna deployer 3.3V power is being sourced.
- **3V3_MCU**: Indicates that the EPS2 MCU 3.3V power is being sourced.
- **3V3_OBDH**: Indicates that the OBDH module 3.3V power is being sourced.
- **3V3_EPS_BEACON**: Indicates that the EPS2 board and beacon MCU 3.3V power is being sourced.

- **5V_PAYLOADS_LEDS**: Indicates that the payloads 5V power is being sourced.
- **VBUS_LED**: Indicates that the main power bus from the batteries is being sourced.

These LEDs are not mounted in the flight version of the module.

CHAPTER 3

Hardware

The EPS2 is a 4 layer 1.6mm thick PCB with FR-4 dieletric. The module doesn't have any impedance control requirements, for this reason the layer stackup has 1oz (0.0347mm) thickness in inner and outer copper layers. In the following sections, the hardware design, interfaces, and standards are described in detail. Section are devided by subsystem blocks, following the diagrams present on Figure 2.1 and Figure 2.2. The Figure 3.1, Figure 3.2 and Figure 3.3 presents the 3D rendered images of the top, bottom and side views of the board, respectively.

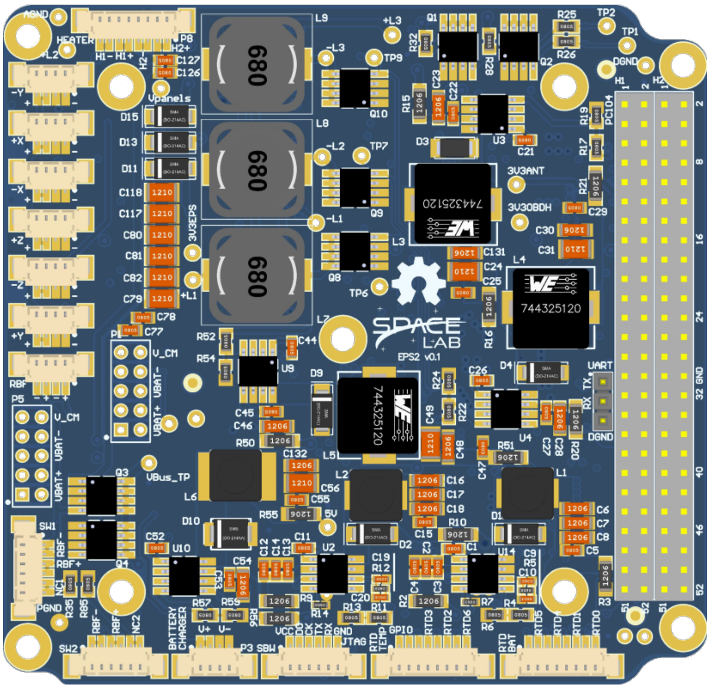

Figure 3.1: Top side of the PCB.

3.1 Interfaces

The Figure 3.4 presents the board interfaces, which consists of communication with other modules, debug access points, and internal peripherals. From the perspective of the microcontroller, there are 4 individual communication buses and the JTAG interface (Spy-Bi-Wire), in the Table 3.1: A1-SPI (dedicated for RTD analog readings with ADS1248);

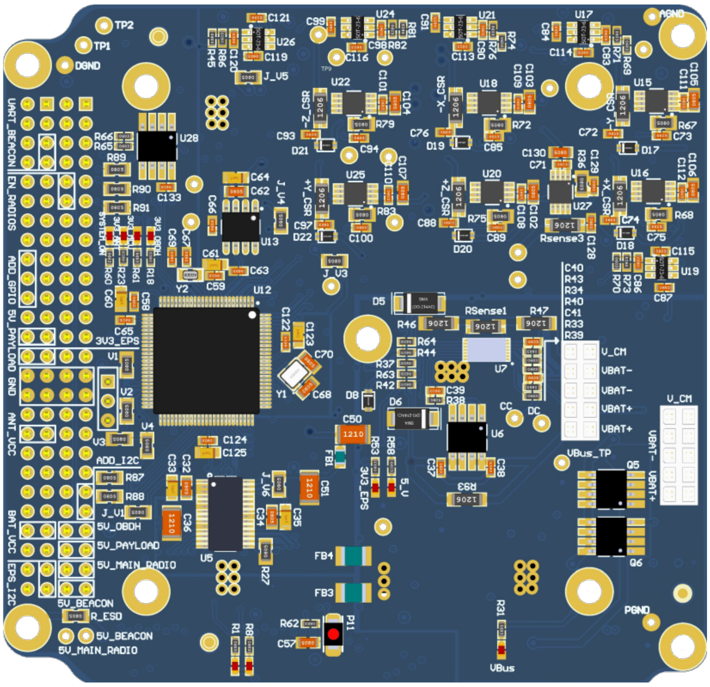

Figure 3.2: Bottom side of the PCB.

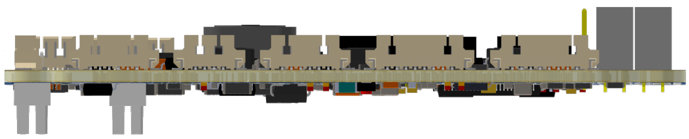

Figure 3.3: Side view of the PCB.

A0-UART (dedicated for Beacon Radio); A2-UART (dedicated for debug); B2-I2C (dedicated for OBDH); From the External Interface (IIP) can be acquired UART log messages for debbuging via USB without the use of an external UART to USB converter. The SPI comunicaton bus it actually an dedicated internall channel for the EPS MCU (master) to the ADS1248 (slave) ADC IC, the analog readings from BAT4C module (a.k.a Battery DaughterBoard) were also represented to show where the RTDs readings come from. Table 3.3 shows the interfaces configuration.

Peripheral	USCI	Protocol	Comm. Protocol
ADS1248	A1	SPI	-
Beacon Radio	A0	UART	-
PC (log messages)	A2	UART	ANSI messages
OBDH	B2	I^2C	FSP
External Interface	-	JTAG	Spy-Bi-Wire

Table 3.1: Boards interfaces.

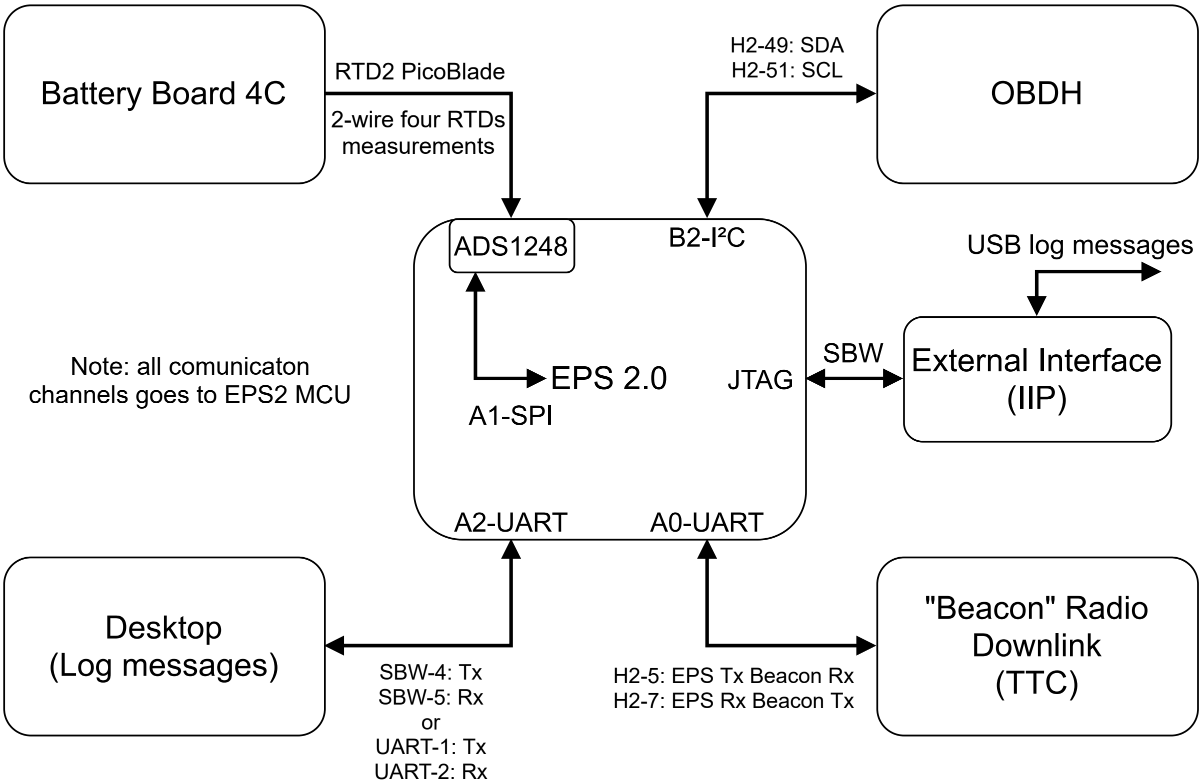

Figure 3.4: EPS interfaces diagram.

3.2 Microcontroller

The MCU consists of a CPU, RAM Memory and Flash Memory (used for program storage and non-volatile status registers). The chosen MCU is a low power 16-bit RISC (*MSP430F6659IPZR*) from Texas Instruments[6]. The Table 3.2 presents a summary of the main available features and Figure 3.5 shows the internal subsystems, descriptions, and peripherals. The microcontroller interfaces, configurations, and auxiliary components are described in the following topics.

Flash	*SRAM*	*Timers*	*USCI*	*ADC*	*DAC*	*GPIO*
512KB	64KB	2	6 (SPI / I2C / UART)	12	2	74

Table 3.2: Microcontroller features summary.

3.2.1 Interfaces Configuration

The microcontroller has 6 Universal Serial Communication Interfaces (USCI) that can be configured to operate with different protocols and parameters. The Table 3.3 describes each interface configurations.

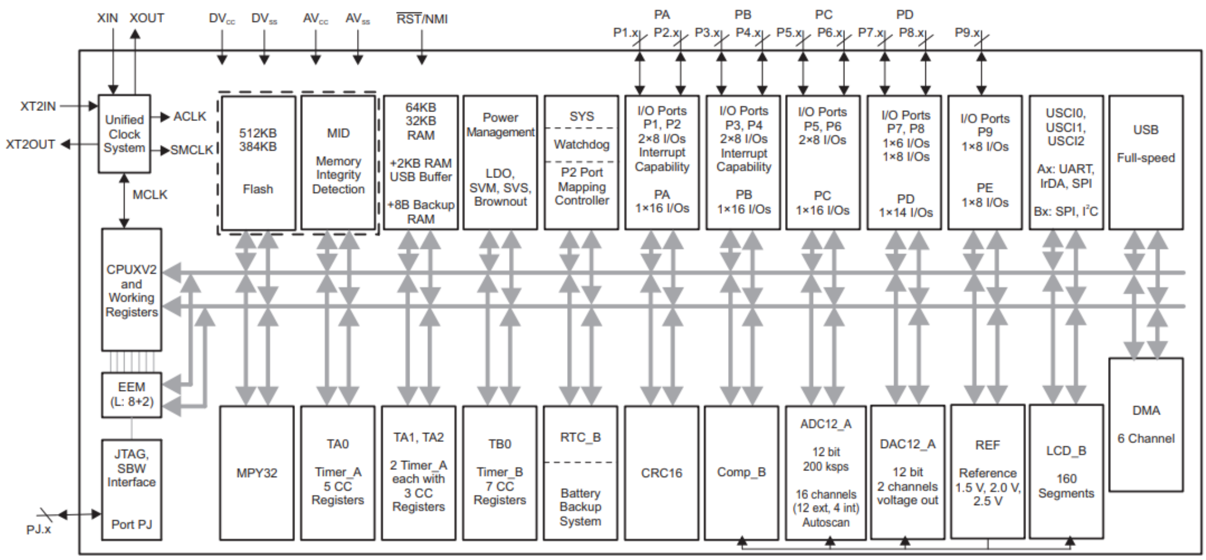

Figure 3.5: Microcontroller internal diagram.

Interface	*Protocol (Index)*	*Mode*	*Word Length*	*Data Rate*	*Configuration*
USCI_A0	UART0	-	8 bits	9600 bps	Stop bits: 1 Parity: None
USCI_A1	SPI	Master	8 bits	TBD	Phase: High Polarity: Low
USCI_A2	UART1	-	8 bits	9600 bps	Stop bits: 1 Parity: None
USCI_B2	I2C2	Slave	8 bits	100 kbps	Address value: 0x36

Table 3.3: USCI configuration.

3.2.2 Voltage Reference

To generate the 3 volts reference for the MCU internal ADC the EPS uses a *595-REF5025AQDRQ1* chip.

3.2.3 Clocks Configuration

Besides the internal clock sources, the microcontroller has two dedicated clock inputs for external crystals: the main clock and the auxiliary clock inputs. There are a 32MHz (*ABM8X-102-32.000MHZ-T*) and a 32.769kHz (*ECS-.327-12.5-34S-TR*) crystals connected to these inputs, respectively. The first source is used for generating the Master Clock (MCLK) and the Subsystem Master Clock (SMCLK), which are used by the CPU and the internal peripheral modules. The second source is used for generating the Auxiliary Clock (ACLK) that handles the low-power modes and might be used for peripherals.

3.2.4 Pinout

An illustration of the microcontroller pinout positions can be seen in the Figure 3.6. The Table 3.4 presents all the EPS 2.0 microcontroller pins assignment.

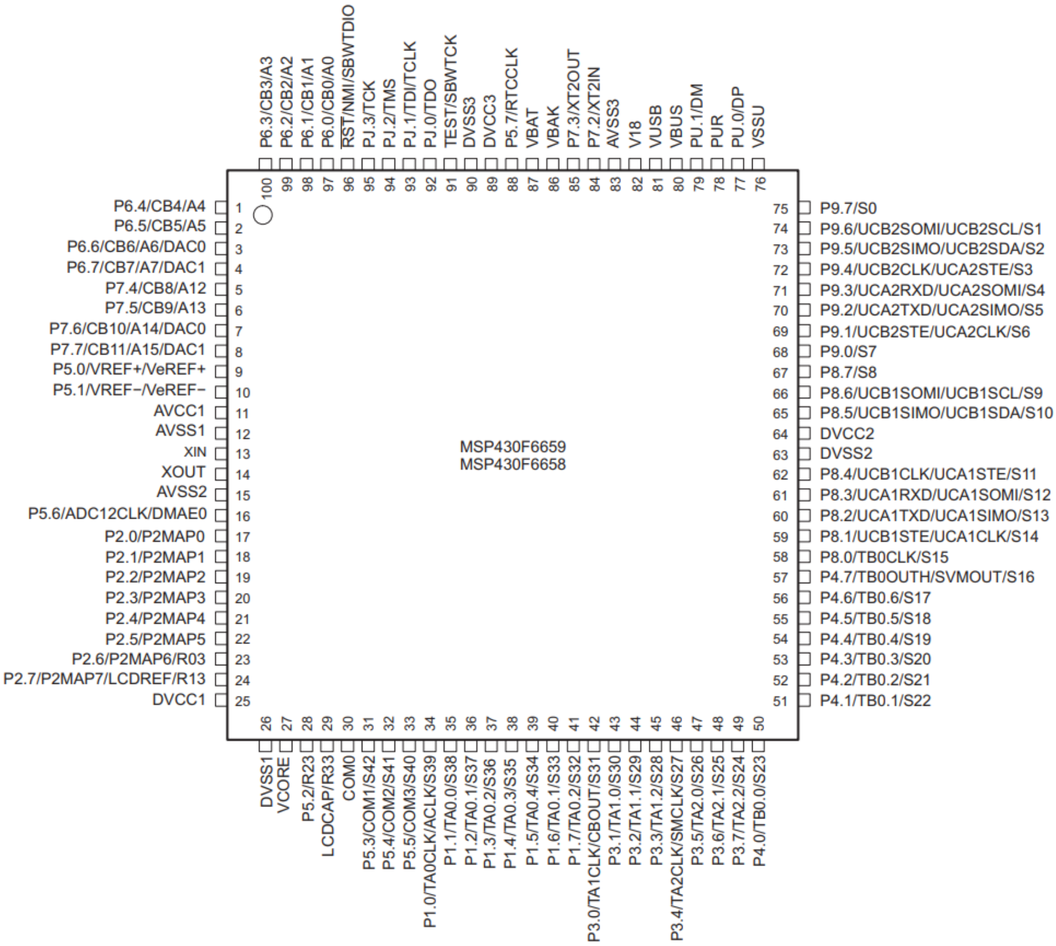

Figure 3.6: Microcontroller pinout positions.

Pin Code	*Pin Number*	*Signal*
P1.0	34	-
P1.1	35	-
P1.2	36	EN_3V3_OBDH
P1.3	37	EN_5V_PAYLOADS
P1.4	38	-
P1.5	39	BAT_GPIO1
P1.6	40	BAT_GPIO2
P1.7	41	-
P2.0	17	-
P2.1	18	PC104_GPIO0
P2.2	19	PC104_GPIO1
P2.3	20	PC104_GPIO2
P2.4	21	UART_EPS_TX_BEACON_RX
P2.5	22	UART_EPS_RX_BEACON_TX
P2.6	23	-
P2.7	24	-

P3.0	42	-
P3.1	43	-
P3.2	44	HEATER2_PWM
P3.3	45	HEATER1_PWM
P3.4	46	VERSION_BIT0
P3.5	47	VERSION_BIT1
P3.6	48	-
P3.7	49	-
P4.0	50	-
P4.1	51	MPPT_PWM_1
P4.2	52	MPPT_PWM_2
P4.3	53	MPPT_PWM_3
P4.4	54	-
P4.5	55	-
P4.6	56	-
P4.7	57	-
P5.0	9	VREF
P5.1	10	AGND
P5.2	28	-
P5.3	31	-
P5.4	32	SYSTEM_LED
P5.5	33	-
P5.6	16	-
P5.7	88	-
P6.0	97	ADC1_+Y_SOLAR_PANEL_CURRENT
P6.1	98	ADC2_+X_SOLAR_PANEL_CURRENT
P6.2	99	ADC3_−X_SOLAR_PANEL_CURRENT
P6.3	100	ADC4_+Z_SOLAR_PANEL_CURRENT
P6.4	1	ADC5_−Z_SOLAR_PANEL_CURRENT
P6.5	2	ADC6_+Y_SOLAR_PANEL_CURRENT
P6.6	3	ADC7_EPS_TTC_XCVR_CURRENT
P6.7	4	ADC_MAIN_POWER_BUSS_VOLTAGE
P7.2	84	XT2_N
P7.3	85	XT2_P
P7.4	5	ADC1_−Y_+X_SOLAR_PANEL_VOLTAGE
P7.5	6	ADC2_−X_+Z_SOLAR_PANEL_VOLTAGE
P7.6	7	ADC3_−Z_+Y_SOLAR_PANEL_VOLTAGE
P7.7	8	ADC_SOLAR_PANELS_TOTAL_VOLTAGE
P8.0	58	-
P8.1	59	RTD_SCLK
P8.2	60	RTD_DIN
P8.3	61	RTD_DOUT
P8.4	62	RTD_RESET
P8.5	65	RTD_CS
P8.6	66	RTD_START
P8.7	67	RTD_DRDY

P9.0	68	PIO
P9.1	69	1-WIRE
P9.2	70	UART0_TX
P9.3	71	UART0_RX
P9.4	72	I2C2_EN
P9.5	73	I2C2_SDA
P9.6	74	I2C2_SCL
P9.7	75	I2C2_READY
PJ.0	92	-
PJ.1	93	-
PJ.2	94	-
PJ.3	95	-
-	13	XT1IN
-	14	XT1OUT
-	96	JTAG_TDO_TDI
-	91	JTAG_TCK

Table 3.4: Microcontroller pinout and assignments.

3.3 Batteries DaughterBoard

Due to size restrictions the 4 cell batteries of the EPS2 were allocated to a dauhter-board named Battery Module 4 Cells, a.k.a BAT4C[2]. Both boards 3D models are assembled together in a EDA tool as seen in Figure 3.7. BAT4C is connected below EPS2 in a board-to-board connector, the female counterpart (*BAT4CIPS1-105-01-S-D*) present on the EPS is seen in Figure 3.8 with it pinout present on Table 3.5. For compability with the older version of the battery module the same connector pads are present near the middle section of the PCB. If the BAT4C is to be used, the connector for these pads must not be soldered, more detail on chapter 5. Also external connectors are used for temperature measurement and control with RTDs and heaters, more details can be seen on ?? and ??.

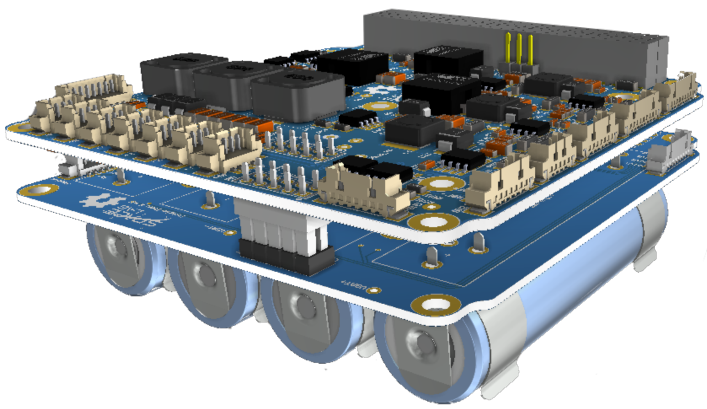

Figure 3.7: EPS2 and BAT4C 3D models assembled.

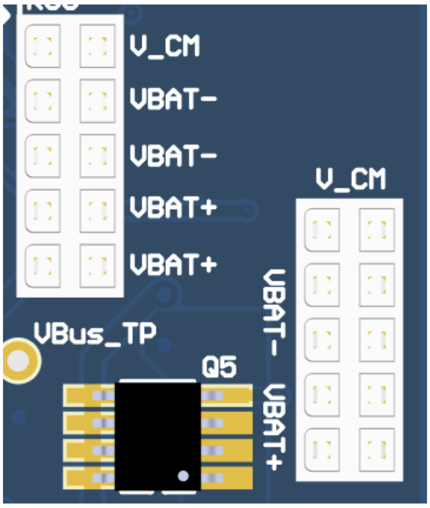

Figure 3.8: EPS2 battery connectors.

Pin	*Row*
1	+Vbat
2	+Vbat
3	+Vbat
4	+Vbat
5	−Vbat
6	−Vbat
7	−Vbat
8	−Vbat
9	Vbat_Common
10	Vbat_Common

Table 3.5: Battery connector pinout.

3.4 Solar Panels

The energy harvesting system is based on solar energy conversion through ten solar panels attached to a 2U CubeSat structure. The solar panels are connected through six 4 pin PicoBlade connectors *0533980471*. Because the EPS2 module has only six input connectors four pairs of solar panels will be connected in paralel. The connection scheme of the solar panels is visible in Figure 3.9. The input connectors for the solar panels power are described in subsection 3.8.2.

3.5 MPPT Subsystem

On the MPPT subsystem the main components are the MPPT boost converters, solar panels voltage and current sensors. These measurement circuits are used to generate a voltage proportional to the variable being measured, in a range accepted by the MCU internal ADC.

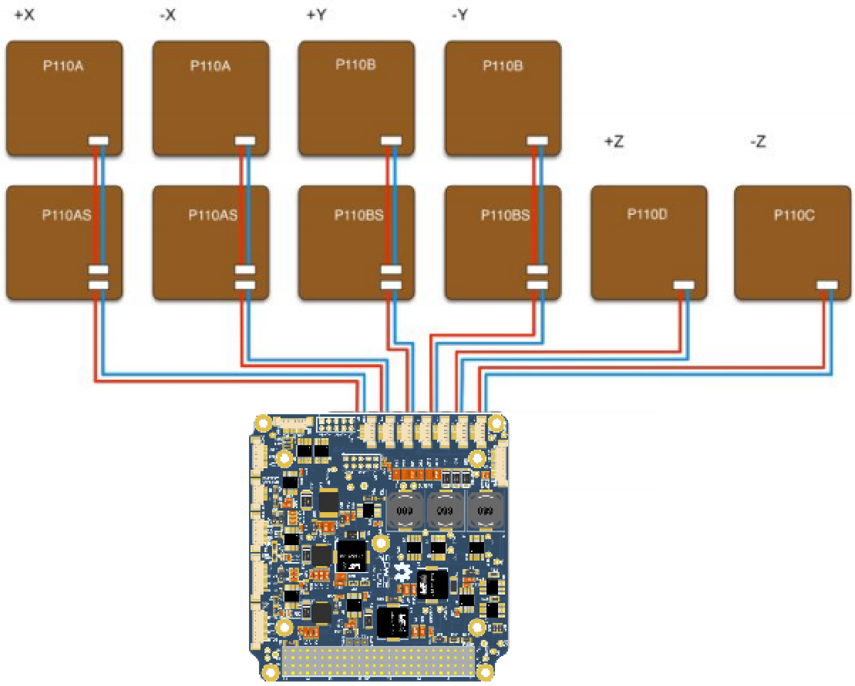

Figure 3.9: Solar panels connection to EPS2.

3.5.1 MPPT Boost Converters

There are three boost converters in the system, one for each couple of solar panels in parallel connection. Each one is a discrete boost with a *HC9-220-R* inductor, a *SI4166DY* mosfet as the switch and a *B340LA-13-F* diode. There are six *GRM32ER1E226KE15L* capacitors and two *GRM216R71H103KA01D* capacitors connected in parallel in the boost output. The output filter is the same for all the converters as their outputs are tied together. The control PWM signals are generated by the MCU at a frequency of nearly 500 kHz. One of the MPPT boosters circuit schematic can be seen in Figure 3.10 and location of all three at the PCB in Figure 3.11.

3.5.2 Solar Panels Current

The main component of the solar panels currents measurement circuit is the *MAX9934TAUA+* current sense amplifier. It generates an output current proportional to the differential input voltage. The gain is 25 μA/mV. To make the measurements possible, the current goes through 50 mΩ, 0.5 % resistors, connected to the inputs of the amplifier, and the outputs are connected to 3.3 kΩ resistors. The output voltage of the circuit is given by:

$$V_{out} = I_{sense} \cdot R_{sense} \cdot G \cdot R_{out} \tag{3.1}$$

In total there are six of these current measurement circuits for the six sides of the CubeSat. Two of the inputs of the solar panels circuit schematic can be seen in Figure 3.12 and location of all six at the PCB in Figure 3.13.

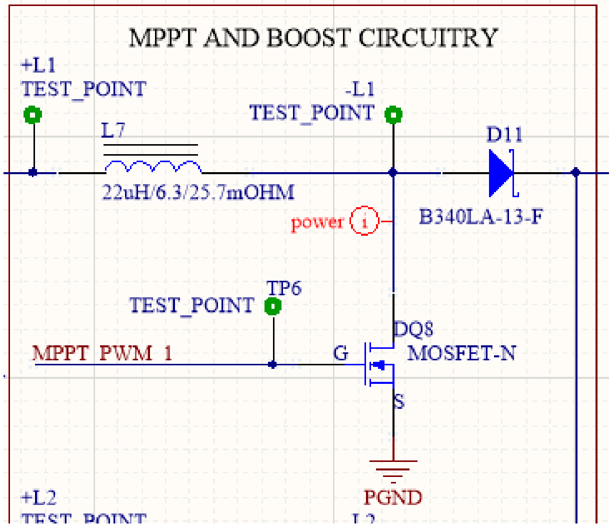

Figure 3.10: One of the MPPT boosters schematic circuit.

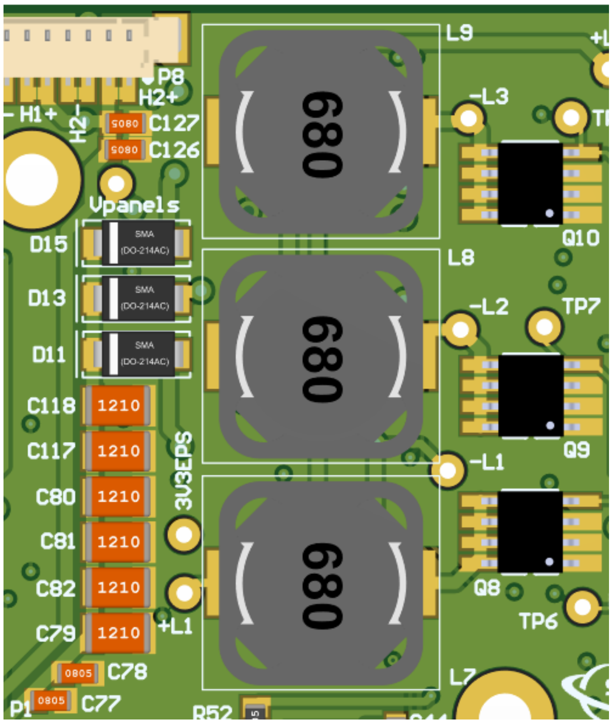

Figure 3.11: MPPT boost converters circuit on the PCB.

3.5.3 Solar Panels Voltage

The solar panels voltage measurement circuit is composed by a voltage divider and an op-amp in a buffer configuration. The voltage divider is composed of a 93.1 kΩ resistor and an 100 kΩ resistor. The op-amp is a *TLV341AIDBVR* chip. The output voltage is given by:

$$V_{out} = V_{sp} \cdot \frac{R_2}{R_1 + R_2} \tag{3.2}$$

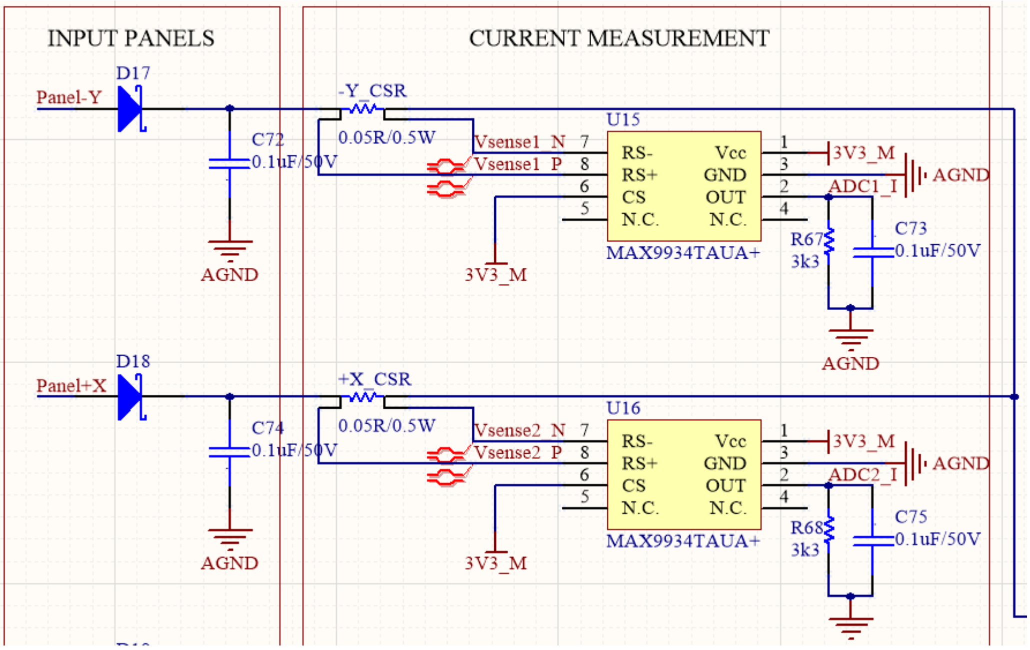

Figure 3.12: Solar panels −Y and +X input circuit schematic.

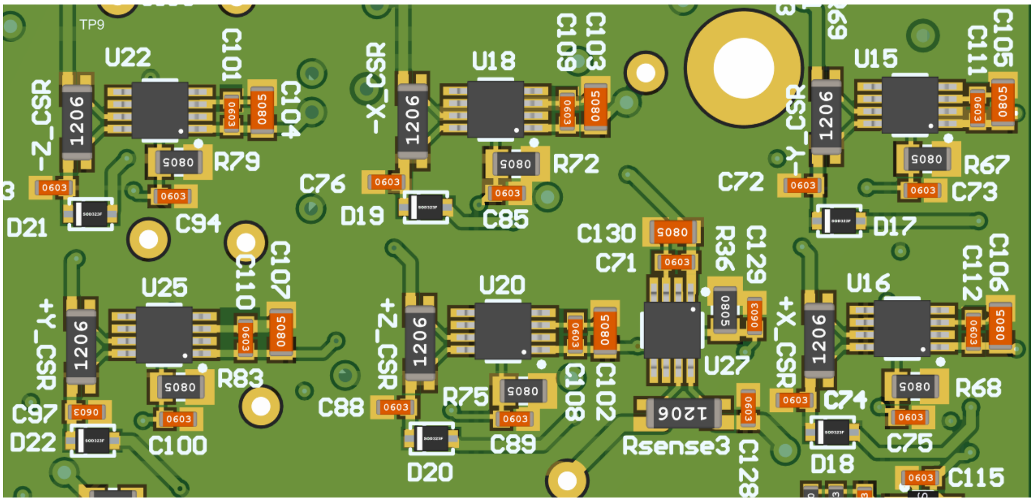

Figure 3.13: Solar panels current measurement circuits on the PCB.

In total there are three of these voltage measurement circuits, the solar panels sides that are meassured together are: −Y with +X, −X with +Z and −Z with +Y. One of the voltage measurement circuit schematic can be seen in Figure 3.14.

3.6 Batteries Managment Subsystem

On the batteries managment subsystem the main components are the battery control circuit, external ADC chip, solar panels and batteries kill-switches, heater drivers and voltage sensors for the boosters output and main power bus.

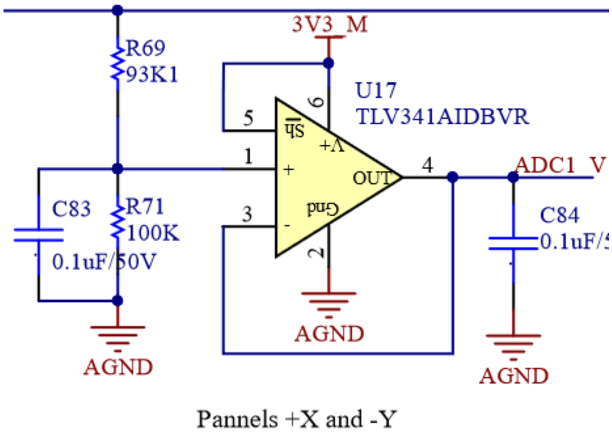

Figure 3.14: Solar panels −Y and +X voltage measurement circuit schematic.

3.6.1 Boost Converters Output Voltage

The boost converters output voltage measurement circuit is very similar to the solar panels voltages measurement circuit, with the exception that the voltage divider is composed by a 300 kΩ resistor and an 100 kΩ resistor. The schematic for the voltage measurement circuit of the solar panels can be seen again for reference in Figure 3.14.

3.6.2 Kill-Switches and Remove Before Flight

These switches are used to separate the solar panels and the batteries from the load during pre-flight and launch. Each one is composed of two *SI4403-CDY-T1-GE3* P-channel mosfets in parallel, as a redundancy. The Kill-Switches and RBF are interfaced on the EPS board via external PicoBlade cables to its respective external mechanisms. RBF functions by simply short circuting the pins of the pin header present on an external interface[7], and for the kill-switches it is required to press the spring buttons on the CubeSat structure, this is naturally done when the nanosatellite in integrated into the deployer. On subsection 3.8.3 and subsection 3.8.4 it is showed the pinouts and locations for these connectors.

3.6.3 Battery Control Circuit

The batteries are monitored by the *DS2775* chip. It measures several parameters and sends them to the EPS2 MCU via one-wire protocol. Also it automatically protects the batteries against short-circuits, overvoltage and undervoltage situations by switching two *FDS6898AZ* mosfets. Its circuit schematic can be seen in Figure 3.15 and location on the PCB in Figure 3.16.

3.6.4 Main Power Bus Voltage

The main power bus voltage measurement circuit is identical to the boost converters output voltage measurement circuit. The schematic for the voltage measurement circuit of the solar panels can be seen again for reference in Figure 3.14.

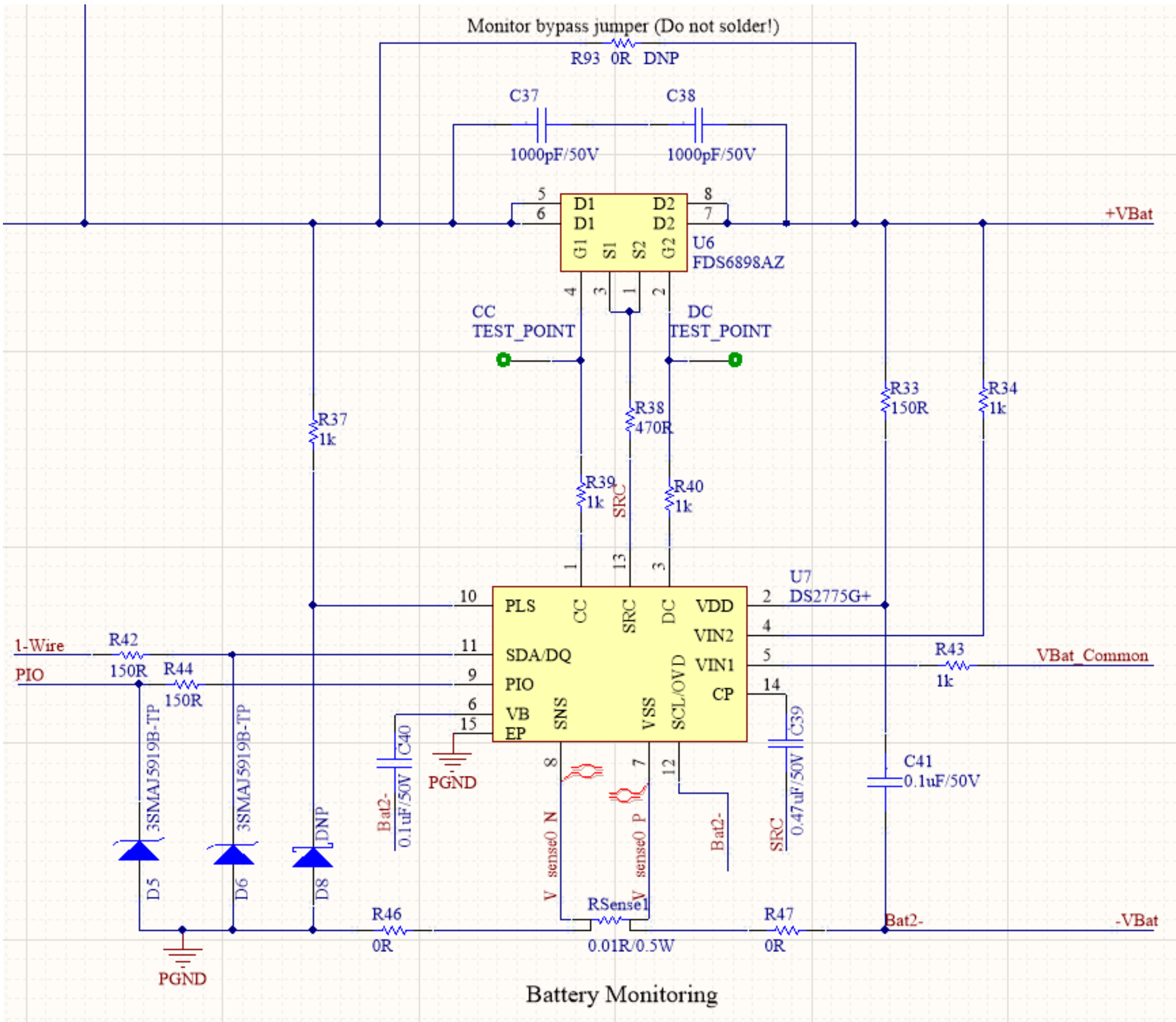

Figure 3.15: Battery monitor circuit schematic.

3.6.5 External ADC

The *ADS1248* chip generates a precise reference current to the RTDs, and samples the voltage proportional to the temperature established over the sensors. This voltage is converted to digital data and sent to the MCU via SPI protocol. The location the IC and its subcircuitry can be seen in Figure 3.17.

3.6.6 Heaters Drivers

The drivers are chopper converters controlled by the MCU, with a PWM frequency of 50 kHz. The switches of the chopper converters are *Si4010DY* mosfets. Its circuit schematic can be seen in Figure 3.18 and location on the PCB in Figure 3.19.

3.7 Power Converters Subsystem

The EPS2 has 6 integrated buck DC-DC regulators, all these are powered from the main power bus. Some regulators are always enabled, others are can be enabled or

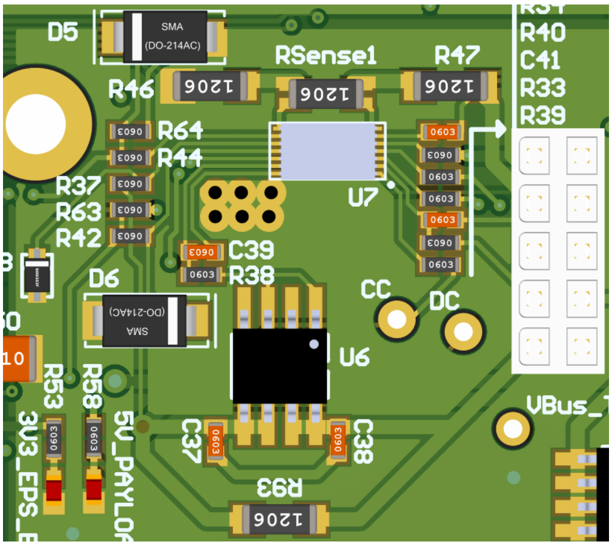

Figure 3.16: Battery monitor circuit on the PCB.

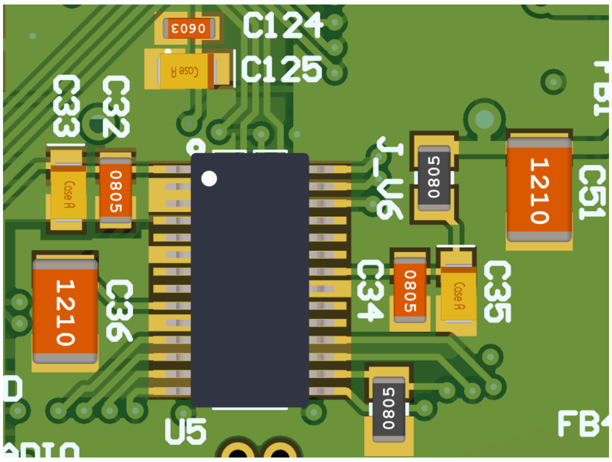

Figure 3.17: ADS1248 circuit on the PCB.

disabled by the EPS2 or other module.

3.7.1 EPS/TTC Regulator

To supply the TTC MCU (also called "Beacon MCU") and EPS2 MCU and its subcircuits a *TPS5420QDRQ1* regulator is used, with and output voltage of 3.3 V and 2 A current capability. This regulator is always on. The EPS/TTC circuit location on the PCB can be seen in Figure 3.20.

There is also a current measurement at the output of the EPS/TTC regulator. It also uses a *MAX9934TAUA+* current sense amplifier, but with a shunt resistor of 75 mΩ, 0.5 % and the output connected to a 4.02 kΩ resistor. The circuit schematic is almost the same as Figure 3.12 only changing the resistors and capacitor values, its location on the PCB is the labeled U27 IC and its passive components in Figure 3.13.

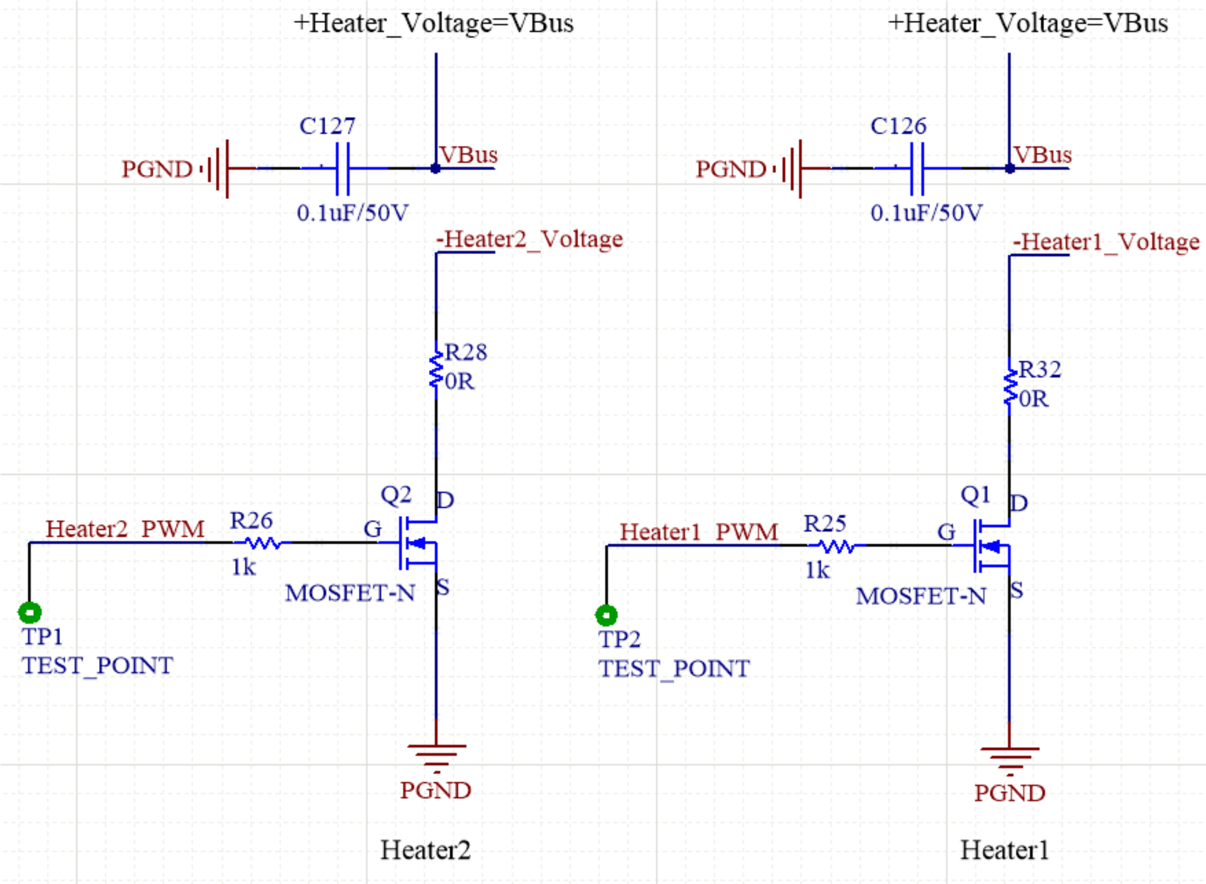

Figure 3.18: Hearter drivers circuit schematic.

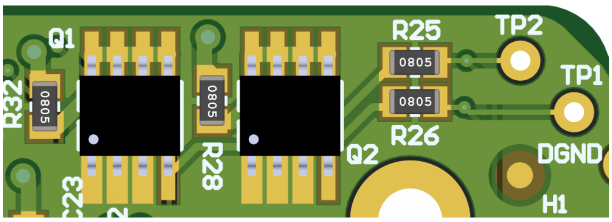

Figure 3.19: Hearter drivers circuit on the PCB.

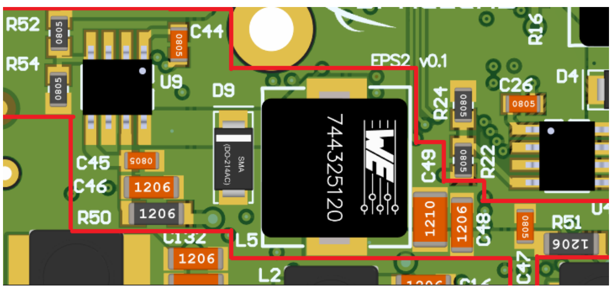

Figure 3.20: EPS/TTC regulator circuit on the PCB.

3.7.2 OBDH Regulator

The OBDH is powered by a *TPS5410QDRQ1* regulator, with an output voltage of 3.3 V and 1 A current capability. The EPS2 can enable/disable this regulator. Its location on the PCB can be seen in Figure 3.21.

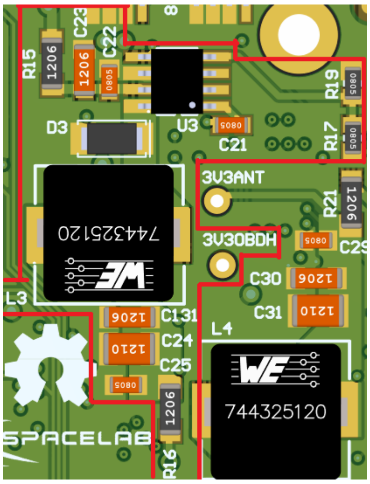

Figure 3.21: OBDH regulator circuit on the PCB.

3.7.3 Antenna Deployer Regulator

The antenna deployment system has a dedicated regulator *TPS5420QDRQ1*, with 3.3 V output voltage and 2 A current capability. This regulator is always on. Its location on the PCB can be seen in Figure 3.22.

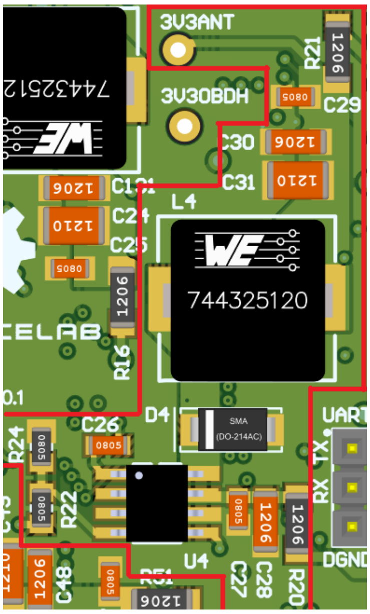

Figure 3.22: Antenna deployer regulator circuit on the PCB.

3.7.4 Main Radio Transceiver Regulator

The main radio XCVR responsible for the Downlink/Uplink of the CubeSat is powered by a *TPS54540QDDARQ1* regulator, with an output voltage of 5V and 5A campability.

The OBDH can enable/disable this regulator. Its location on the PCB can be seen in Figure 3.23.

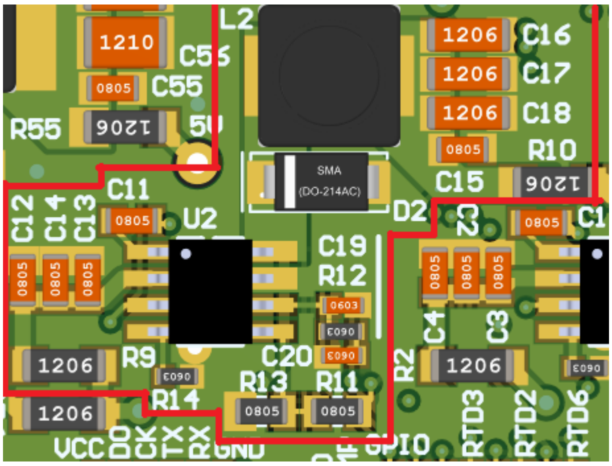

Figure 3.23: Main radio transceiver regulator circuit on the PCB.

3.7.5 Beacon Transceiver Regulator

The Beacon XCVR is powered by a regulator *TPS54540QDDARQ1* regulator, with 6V output voltage and 5A campability. The Beacon MCU can enable/disable this regulator. Its location on the PCB can be seen in Figure 3.24.

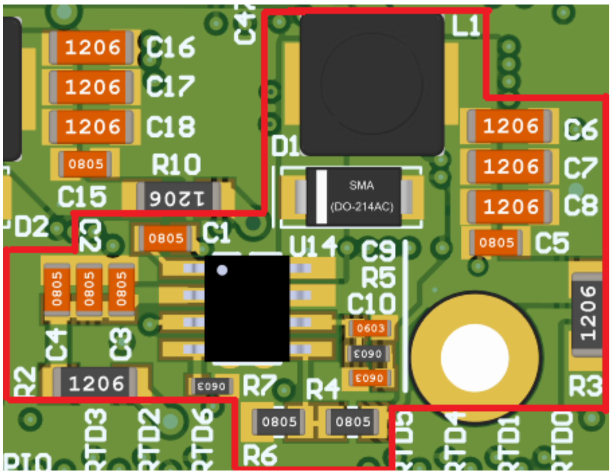

Figure 3.24: Beacon radio transceiver regulator circuit on the PCB.

3.7.6 Payloads Regulator

To power the payloads a *TPS5430QDDARQ1* regulator is used. It has an output voltage of 5 V and 3 A current capability. The EPS2 can enable/disable this regulator. Its location on the PCB can be seen in Figure 3.25.

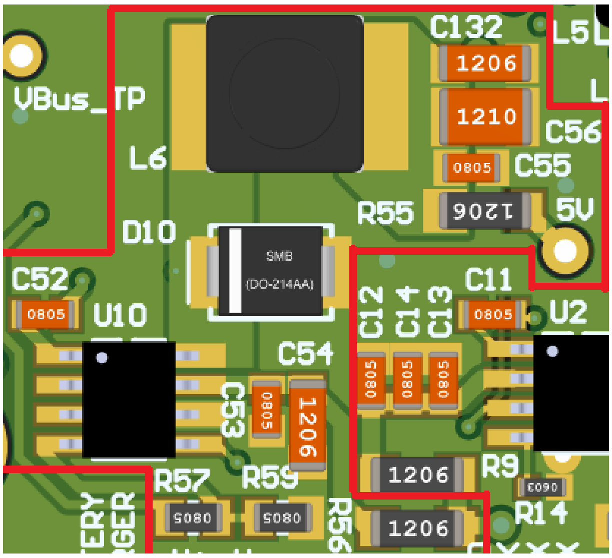

Figure 3.25: Payloads regulator circuit on the PCB.

3.8 External Connectors

The EPS2 module is connected to the other modules using the PC104 bus. The solar panels, the kill-switches, the remove before flight, the RTDs, the heater, the batteries charger connector and the JTAG pins are connected using Molex PicoBlade connectors. The EPS2 module also has a jumper that connects the MCU VCC to the JTAG VCC and a header to debug the board via UART protocol. In the following sections each connector is detailed, with a picture showing the location on the EPS2 PCB and a table explaining each pin function.

3.8.1 PC104

The connector referred as PC-104 is a junction of two double row 28H headers (*SSW-126-01-G-D*). These connectors create a solid 104-pin interconnection across the different satellite modules. The Figure 3.26 shows the PC-104 interface from the bottom side of the PCB, which allows visualize the simplified label scheme in the board. Also, the Table 3.6 provides the connector pinout[1] for the pins that are connected to the module.

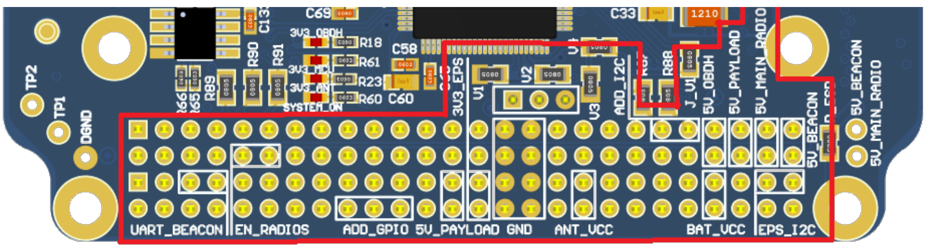

Figure 3.26: Bottom view of PC-104 and simplified labels.

[1] This pinout is simplified since additional interfaces were omitted. Refer to *option sheet* in chapter 5.

Pin [A-B]	*H1A*	*H1B*	*H2A*	*H2B*
1-2	-	-	-	-
3-4	-	-	-	-
5-6	-	-	UART_RX	-
7-8	-	-	UART_TX	-
9-10	-	EN_PWR_5	-	-
11-12	-	EN_PWR_6	-	-
13-14	-	-	-	-
15-16	-	-	-	-
17-18	-	-	-	-
19-20	-	-	-	-
21-22	-	-	-	-
23-24	-	-	-	-
25-26	-	-	PWR_4_5V	PWR_4_5V
27-28	-	-	PWR_7_3V3	PWR_7_3V3
29-30	GND	GND	GND	GND
31-32	GND	GND	GND	GND
33-34	-	-	-	-
35-36	-	-	PWR_1_3V3	PWR_1_3V3
37-38	-	-	-	-
39-40	-	-	-	-
41-42	-	-	-	-
43-44	-	-	-	-
45-46	PWR_2_3V3	PWR_2_3V3	PWR_3_BAT	PWR_3_BAT
47-48	PWR_4_5V	PWR_4_5V	-	-
49-50	PWR_5_5V	PWR_5_5V	I2C_SDA	-
51-52	PWR_6_6V	PWR_6_6V	I2C_SCL	-

Table 3.6: PC-104 connector pinout.

3.8.2 Solar Panels PicoBlades

There are six PicoBlade connectors that can be connected to solar panels. Each one of them is to be used with its respective positive or negative cartesian axis reference label: X, Y or Z. Note that the total current for each individual PicoBlade pin must not exceed 1000mA, this means that the maximum current per connector is 2000mA. Their pinout is showed in Table 3.8 and position on the PCB in Figure 3.27.

3.8.3 Kill-Switches PicoBlades

There are two PicoBlade connectors to be connected to two separete kill-switch spring button mechanisms, one of the mechanism is ilustrated in Figure 3.28. The connection is done by manually soldering and isolating with a heat shrink tube, the other end of the cable goes to PicoBlades of the EPS, their pinout is showed in Table 3.9 and position on the PCB in Figure 3.29.

Signal	**Pin(s)**	**Description**
GND	H1-29, H1-30, H1-31, H1-32, H2-29, H2-30, H2-31, H2-32	Ground reference
PWR_1_3V3	H2-35, H2-36	Power bus 1, 3.3 V, 2 A max.
PWR_2_3V3	H1-45, H1-46	Power bus 2, 3.3 V, 1 A max.
PWR_3_BAT	H2-45, H2-46	Power bus 3, battery terminals (+)
PWR_4_5V	H1-47, H1-48, H2-25, H2-26	Power bus 4, 5 V, 3 A max.
PWR_5_5V	H1-49, H1-50	Power bus 5, 5 V, 5 A max.
PWR_6_6V	H1-51, H1-52	Power bus 6, 6 V, 5 A max.
PWR_7_3V3	H2-27, H2-28	Power bus 7, 3.3 V, 2 A max.
I2C_SDA	H2-49	Primary communication bus (data signal)
I2C_SCL	H2-51	Primary communication bus (clock signal)
UART_RX	H2-5	Secondary communication bus (RX)
UART_TX	H2-7	Secondary communication bus (TX)
EN_PWR_5	H1-10	Enable signal of the power bus 5
EN_PWR_6	H1-12	Enable signal of the power bus 6

Table 3.7: PC-104 bus signal description.

Pin	*Row*
1	Panel [side reference] positive input
2	Panel [side reference] positive input
3	PGND
4	PGND

Table 3.8: Solar panels PicoBlades pinout.

Pin	*Row*
1	Common
2	Common
3	NO
4	NO
5	NC
6	NC

Table 3.9: Kill-switches PicoBlades pinout.

3.8.4 RBF PicoBlade

The RBF PicoBlade interconects the separation switches circuit present on the EPS to be acessed in a external interface. Its pinout is showed in Table 3.11 and position on the PCB in Figure 3.30.

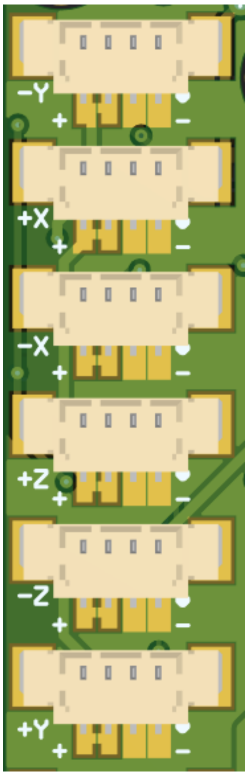

Figure 3.27: Solar panels power input connectors on the PCB.

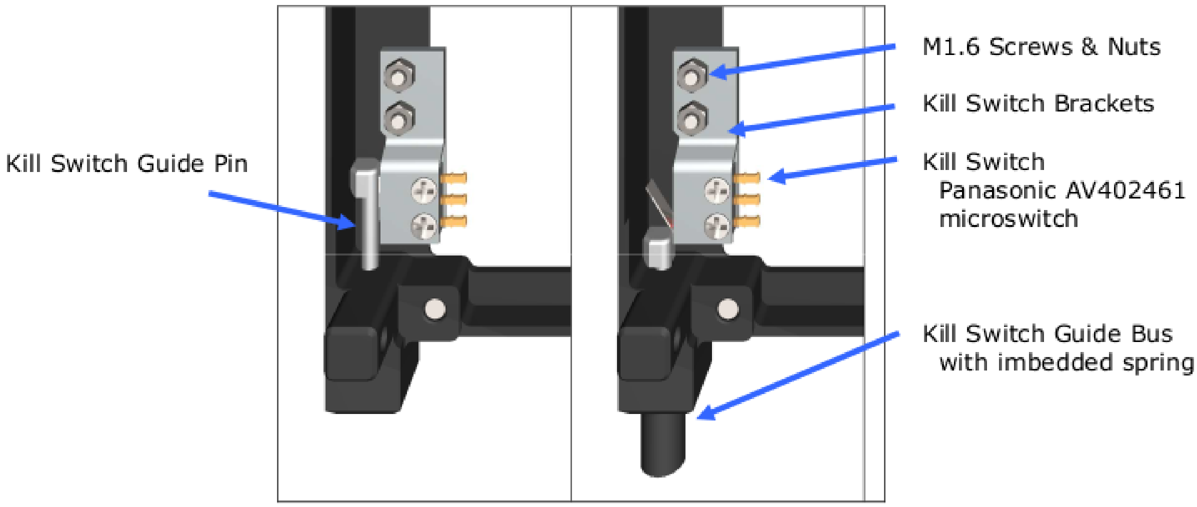

Figure 3.28: Kill-switch spring button mechanism.

3.8.5 RTDs PicoBlade

EPS reads temperature from RTDs present in the BAT4C module with a external PicoBlade cable conected betweem both boards. The two connectors RTD1 and RTD2 pinouts are showed in Table 3.11 and positions on the PCB in Figure 3.31.

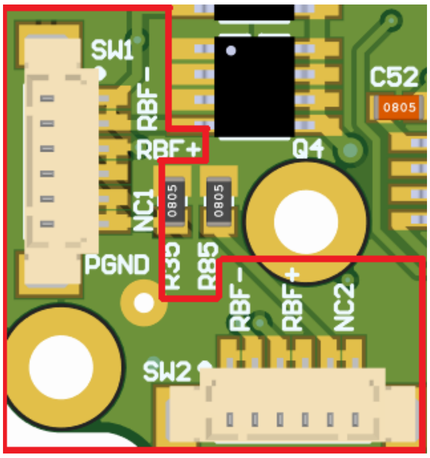

Figure 3.29: Kill-switches PicoBlade connectors on the PCB.

Pin	*Row*
1	+RBF
2	−RBF
3	+RBF
4	−RBF

Table 3.10: RBF PicoBlade pinout.

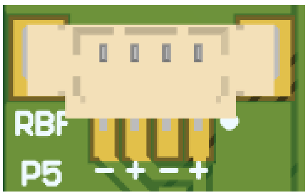

Figure 3.30: RBF PicoBlade connector on the PCB.

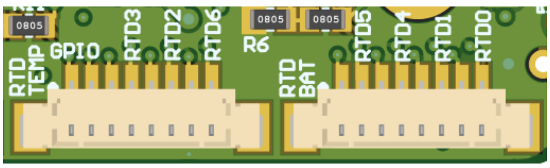

Figure 3.31: RTDs PicoBlade connectors on the PCB.

3.8.6 Heater PicoBlade

The PWM signals that control the heaters present on the BAT4C module is also brought by a external PicoBlade cable. The connector pinout is showed in Table 3.12 and positions on the PCB in Figure 3.32.

Pin	*Row*
RTD1 PicoBlade	
1	BAT_GPIO1
2	BAT_GPIO2
3	RTD_Common
4	RTD_RTD3
5	RTD_Common
6	RTD_RTD2
7	RTD_Common
8	RTD_RTD6
RTD2 PicoBlade	
1	RTD_Common
2	RTD_RTD5
3	RTD_Common
4	RTD_RTD4
5	RTD_Common
6	RTD_RTD1
7	RTD_Common
8	RTD_RTD0

Table 3.11: RBF PicoBlade pinout.

Pin	*Row*
1	−Heater1_Voltage
2	−Heater1_Voltage
3	VBUS
4	VBUS
5	−Heater2_Voltage
6	−Heater2_Voltage
7	VBUS
8	VBUS

Table 3.12: Heater PicoBlade pinout.

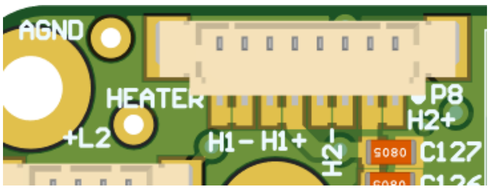

Figure 3.32: Heaters PicoBlade connector on the PCB.

3.8.7 External Batteries Charger PicoBlade

When the EPS and BAT4C are assembled together the batteries can be charged from a PicoBlade connector on which is acessed in a external interface. The same current restriction as for the solar panels connectors is apllied here, the external batteries charger PicoBlade must not exceed 2000mA. The connector pinout is showed in Table 3.13 and position on the PCB in Figure 3.33.

Pin	*Row*
1	V_Charging_Batteries
2	V_Charging_Batteries
3	PGND
4	PGND

Table 3.13: External batteries charger PicoBlade pinout.

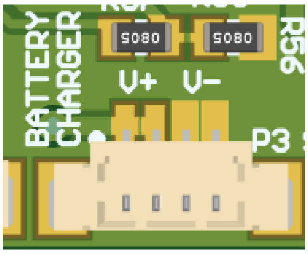

Figure 3.33: External batteries charger PicoBlade connector on the PCB.

3.8.8 JTAG PicoBlade

The EPS module can be programed and debugged through its JTAG PicoBlade connector, see chapter 6 for more information regarding right use of this interface. The connector pinout is showed in Table 3.14 and position on the PCB in Figure 3.34.

Pin	*Row*
1	3V3_MCU
2	TDO
3	TCK
4	UART_Debug_Tx
5	UART_Debug_Rx
6	DGND

Table 3.14: JTAG PicoBlade pinout.

3.8.9 Debug UART Pin Header

For debugging via UART using log messages during test phase a pin header can be easily acessed with jumper wires. This connector is not meant to be soldered in the flight model of the EPS. The connector pinout is showed in Table 3.15 and position on the PCB in Figure 3.35.

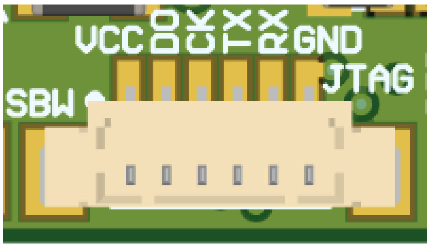

Figure 3.34: JTAG PicoBlade connector on the PCB.

Pin	*Row*
1	UART_Debug_Tx
2	UART_Debug_Rx
3	DGND

Table 3.15: Debug UART pin header pinout.

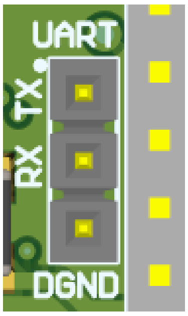

Figure 3.35: Debug UART pin header connector on the PCB.

CHAPTER 4

Firmware

4.1 Sensors and Peripherals Variables

A list of all the variables of EPS with their identification number (ID) and variable type that can be read from the sensors and peripherals is seen in the Table 4.1.

ID	Name/Description	Type
0	Time counter in millseconds	uint32
1	Temperature of the μC in K	uint16
2	EPS circuitry and Beacon MCU current in mA	uint16
3	Last reset cause: - 0x00 = No interrupt pending - 0x02 = Brownout (BOR) - 0x04 = RST/NMI (BOR) - 0x06 = PMMSWBOR (BOR) - 0x08 = Wakeup from LPMx.5 (BOR) - 0x0A = Security violation (BOR) - 0x0C = SVSL (POR) - 0x0E = SVSH (POR) - 0x10 = SVML_OVP (POR) - 0x12 = SVMH_OVP (POR) - 0x14 = PMMSWPOR (POR) - 0x16 = WDT time out (PUC) - 0x18 = WDT password violation (PUC) - 0x1A = Flash password violation (PUC) - 0x1C = Reserved - 0x1E = PERF peripheral/configuration area fetch (PUC) - 0x20 = PMM password violation (PUC) - 0x22 to 0x3E = Reserved	uint8
4	Reset counter	uint16
5	-Y and +X sides solar panel voltage in mV	uint16
6	-X and +Z sides solar panel voltage in mV	uint16
7	-Z and +Y sides solar panel voltage in mV	uint16
8	-Y side solar panel current in mA	uint16
9	+Y side solar panel current in mA	uint16
10	-X side solar panel current in mA	uint16
11	+X side solar panel current in mA	uint16

12	-Z side solar panel current in mA	uint16
13	+Z side solar panel current in mA	uint16
14	MPPT 1 duty cycle in %	uint8
15	MPPT 2 duty cycle in %	uint8
16	MPPT 3 duty cycle in %	uint8
17	Main power bus voltage in mV	uint16
18	RTD0 temperature in K	uint32
19	RTD1 temperature in K	uint32
20	RTD2 temperature in K	uint32
21	RTD3 temperature in K	uint32
22	RTD4 temperature in K	uint32
23	RTD5 temperature in K	uint32
24	RTD6 temperature in K	uint32
25	Batteries voltage in mV	uint16
26	Batteries current in mA	uint16
27	Batteries average current in mA	uint16
28	Batteries accumulated current in mA	uint16
29	Batteries charge in mAh	uint16
30	Battery monitor IC temperature in K	uint16
31	Battery monitor status register	uint8
32	Battery monitor protection register	uint8
33	Battery monitor cycle counter	uint8
34	Battery monitor Remaining Active-Absolute Capacity (RAAC) in mAh	uint16
35	Battery monitor Remaining Standby-Absolute Capacity (RSAC) in mAh	uint16
36	Battery monitor Remaining Active-Relative Capacity (RARC) in %	uint8
37	Battery monitor Remaining Standby-Relative Capacity (RSRC) in %	uint8
38	Battery heater 1 duty cycle in %	uint8
39	Battery heater 2 duty cycle in %	uint8
40	Hardware version	uint8
41	Firmware version (ex.: "v1.2.3"' = 0x00010203)	uint32

Table 4.1: Variables and parameters of the EPS 2.0.

4.2 Tasks

A list of the firmware tasks can be seen in the Table 4.2.

Name	Priority	Initial delay [ms]	Period [ms]	Stack [bytes]
Startup (boot)	Highest	0	Aperiodic	500
Watchdog reset	Lowest	0	100	128
System reset	High	0	36000000	128
Battery Heater Control	TBD	0	TBD	TBD
Read sensors	Medium	0	60000	128
CSP Server	Lowest	0	500	1024
MPPT	TBD	TBD	TBD	TBD
Beacon package	TBD	TBD	TBD	TBD

Table 4.2: Firmware tasks.

CHAPTER 5

Board Assembly

5.1 PCB Fabrication

The board is not designed to be fabricated without a solder mask, but if possible a Class 3 fabrication is recommended. A list with the fabrication specifics can be seen in Table 5.1 and layer stack up can be seen in Table 5.2.

Parameter	**Value**
Size	86.26 $\times$ 92.13 mm
Layers	4
Thickness	1.6 mm
Minimum Hole Size	0.254 mm
Maximum Hole Size	3.2 mm
Silkscreen Color	White
Surface Finish	HASL with lead
Via Process	Tenting vias
Material	FR-4: TG150
Minimum Track/Spacing	6/6 mil (0.1524/0.1524 mm)
Solder Mask Color	Green
Gold Fingers	No
Impedance Control	No
Fiducials	3 on top and bottom layers already placed
Finish Copper	Outer and inner copper 1 oz (35 μm Cu)

Table 5.1: PCB fabrication specifics.

Layer	**Material**	**Thickness mm**
Top Layer	Cooper	0.035
Dielectric 1	Prepreg	0.12
Signal Layer 1	Cooper	0.035
Core	FR-4: TG-150	1.2
Signal Layer 2	Cooper	0.035
Dielectric 2	Prepreg	0.12
Bottom Layer	Cooper	0.035

Table 5.2: PCB stack up.

CHAPTER 6

Usage Instructions

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