SPACELAB

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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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 GOLDS-UFSC 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.
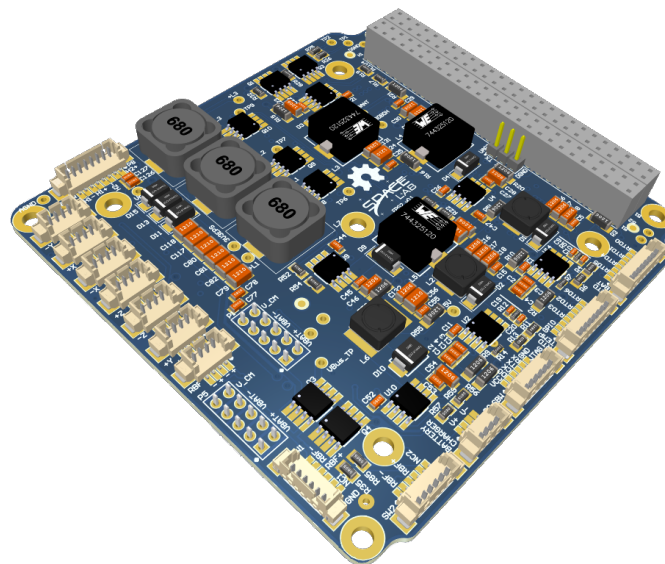

Figure 1.1: 3D view of the EPS 2.0 PCB.

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.
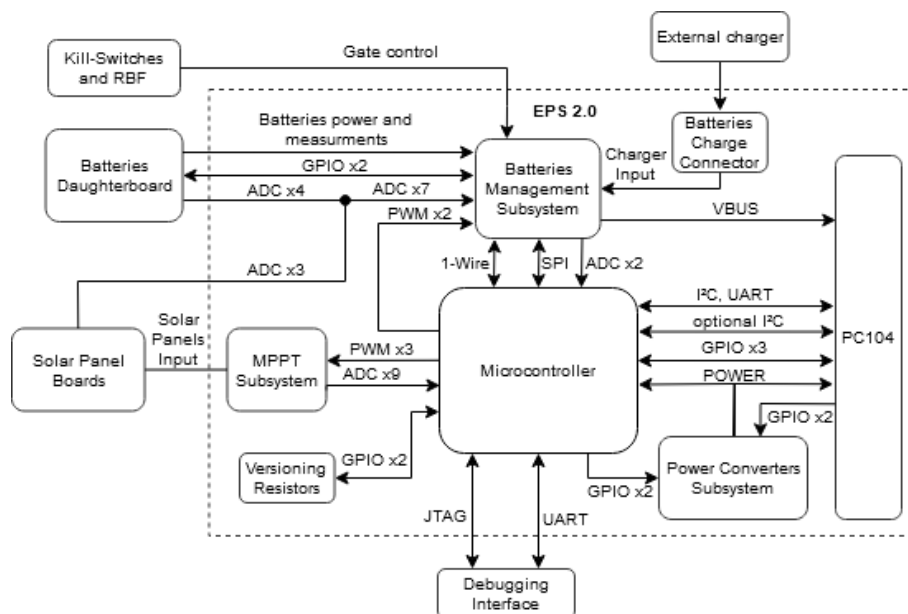

Figure 2.1: EPS 2.0 MCU Block diagram.

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.
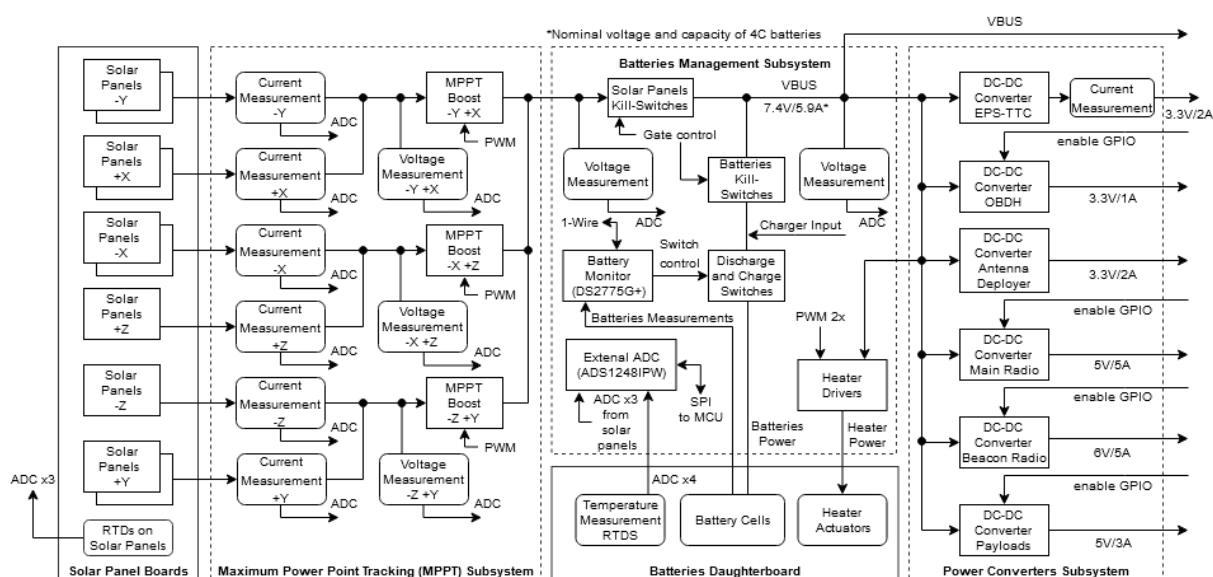

Figure 2.2: EPS 2.0 Power Block diagram.

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 currently 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.
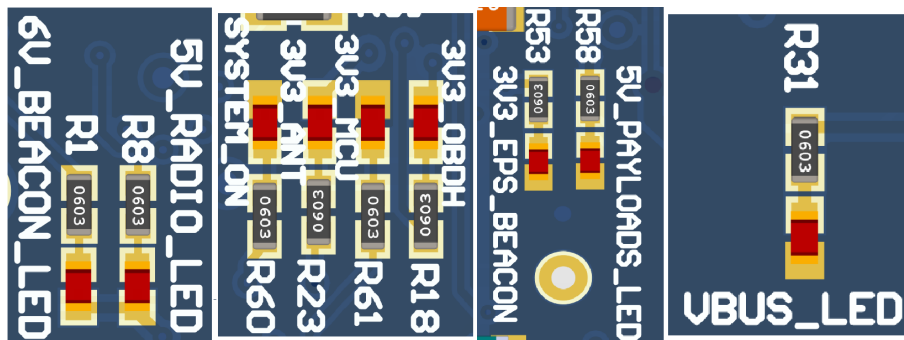
Figure 2.3: Available status LEDs.

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.
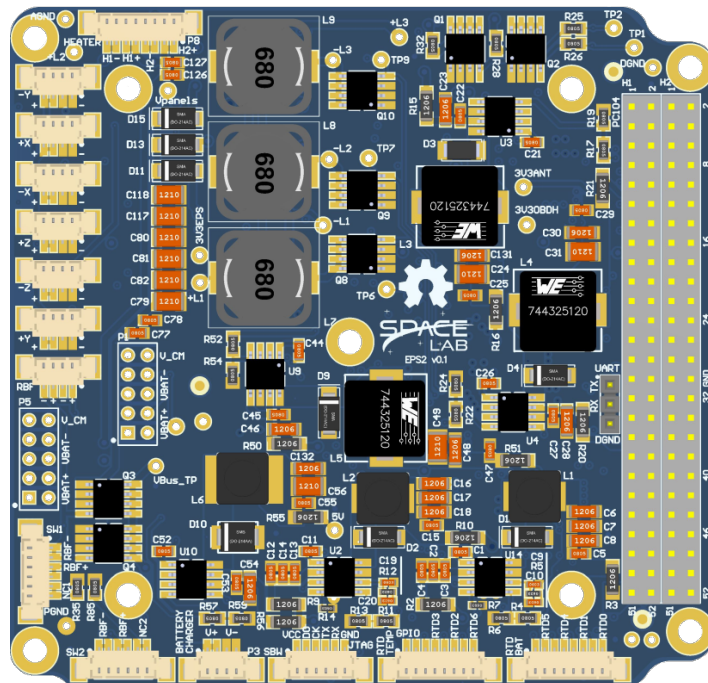
Figure 3.1: Top side of the PCB.

3.1 MCU

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. It contains seven power consumption operation modes, four 16-bit timers, 12-bit ADC and DAC, six universal serial communication
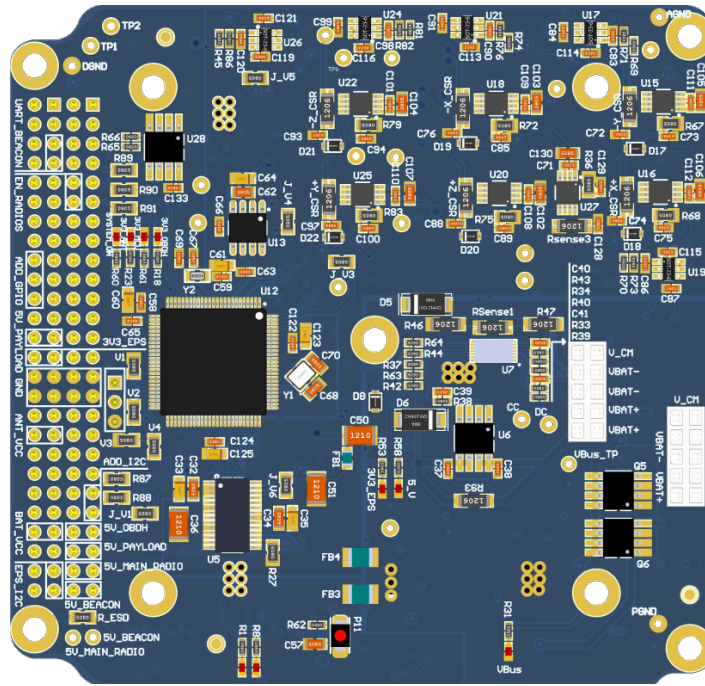
Figure 3.2: Bottom side of the PCB.
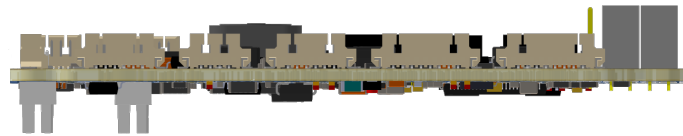
Figure 3.3: Side view of the PCB.

interfaces (USCIs), a real–time clock (RTC) block and up to 74 I/O pins. It uses a *ECS–.327–12.5–34S–TR* 32.768 kHz external crystal and a *ABM8X–102–32.000MHZ–T* 32 MHz external crystal. To generate the voltage reference for the MCU internal ADC the EPS uses a *595–REF5025AQDRQ1* chip.

3.2 Batteries DaughterBoard

3.3 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 3.3.
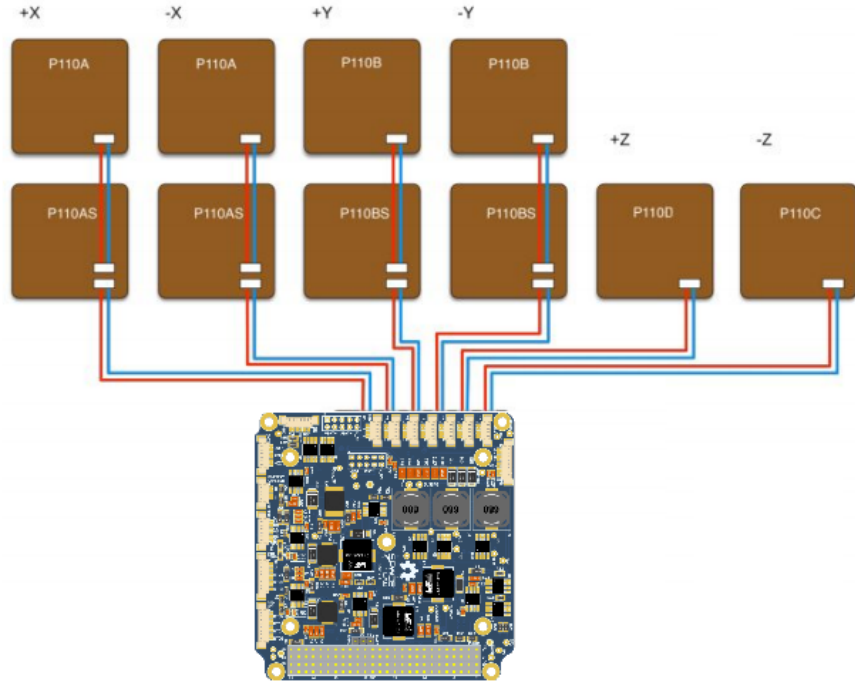
Figure 3.4: Solar panels connection to EPS2.

3.4 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.

3.4.1 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.

3.4.2 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:

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

3.4.3   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:

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

3.5   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.

3.5.1   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.

3.5.2   Kill-Switches

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. When either the RBF is in place or the kill-switches are pressed, the mosfets disconnect the loads from the sources.

3.5.3   Remove Before Flight

3.5.4   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.

3.5.5   Main Power Bus Voltage

The main power bus voltage measurement circuit is identical to the boost converters output voltage measurement circuit.

3.5.6   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.

3.5.7 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.

3.6 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 disabled by the EPS2 or other module.

3.6.1 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.

There is 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.

3.6.2 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.

3.6.3 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.

3.6.4 Main Radio Transceiver Regulator

The main radio transceiver 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.

3.6.5 Beacon Transceiver Regulator

The Beacon transceiver is powered by a regulator *TPS54540QDDARQ1* regulator, with 6V output voltage and 5A campability. The Beacon MCU can enable/disable this regulator.

3.6.6 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.

3.7 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.

3.7.1 PC104
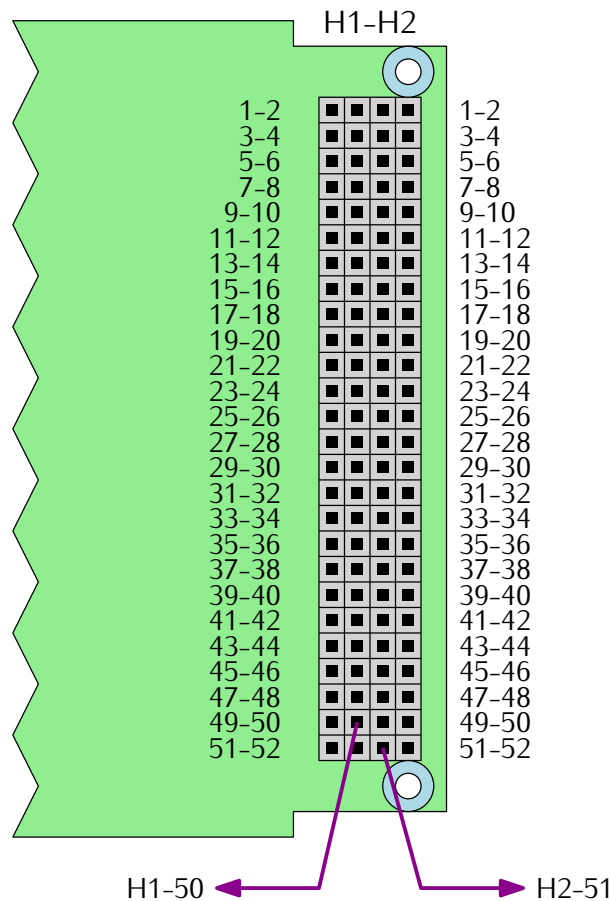
Figure 3.5: Reference diagram of the PC-104 bus.

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 3.1: PC–104 connector pinout.

3.7.2 Solar Panels PicoBlades

3.7.3 Kill–Switches PicoBlades

3.7.4 RBF PicoBlade

3.7.5 RTDs PicoBlade

3.7.6 Heater PicoBlade

3.7.7 External Batteries Charger PicoBlade

3.7.8 JTAG PicoBlade

3.7.9 Debug UART Pin Header

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 3.2: PC–104 bus signal description.

CHAPTER 4

<div align="right">

Firmware

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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	Main power bus voltage in mV	uint16
15	Batteries RTD1 temperature in K	uint32
16	Batteries RTD2 temperature in K	uint32
17	Batteries RTD3 temperature in K	uint32
18	Batteries RTD4 temperature in K	uint32
19	Batteries voltage in mV	uint16
20	Batteries current in mA	uint16
21	Batteries average current in mA	uint16
22	Batteries accumulated current in mA	uint16
23	Batteries charge in mAh	uint16
24	Battery monitor IC temperature in K	uint16
25	Batteries monitor status register	uint8
26	Batteries monitor protection register	uint8
27	Batteries monitor cycle counter	uint8
28	Batteries monitor remaining active absolute capacity register	uint16
29	Batteries monitor remaining standby absolute capacity register	uint16
30	Batteries monitor remaining active relative capacity register	uint8
31	Batteries monitor remaining standby relative capacity register	uint8

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 × 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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