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EPS 2.0 Documentation

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SpaceLab, Universidade Federal de Santa Catarina, Florianópolis - Brazil

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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.

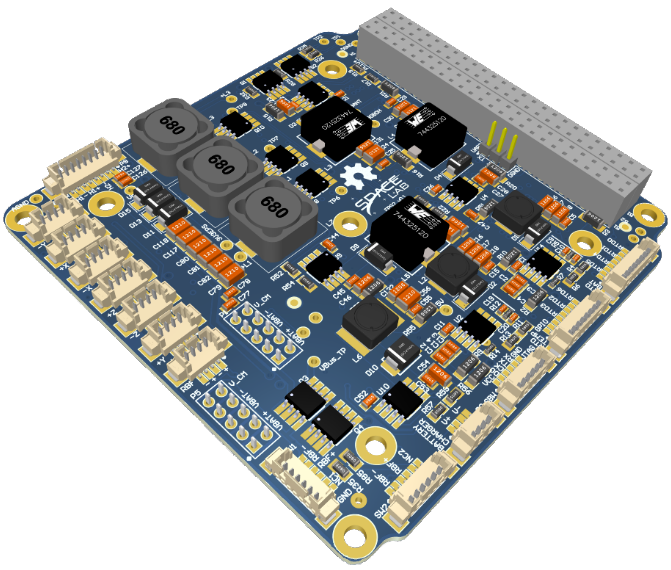

Figure 1.1: 3D view of the EPS 2.0 PCB.

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.

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.

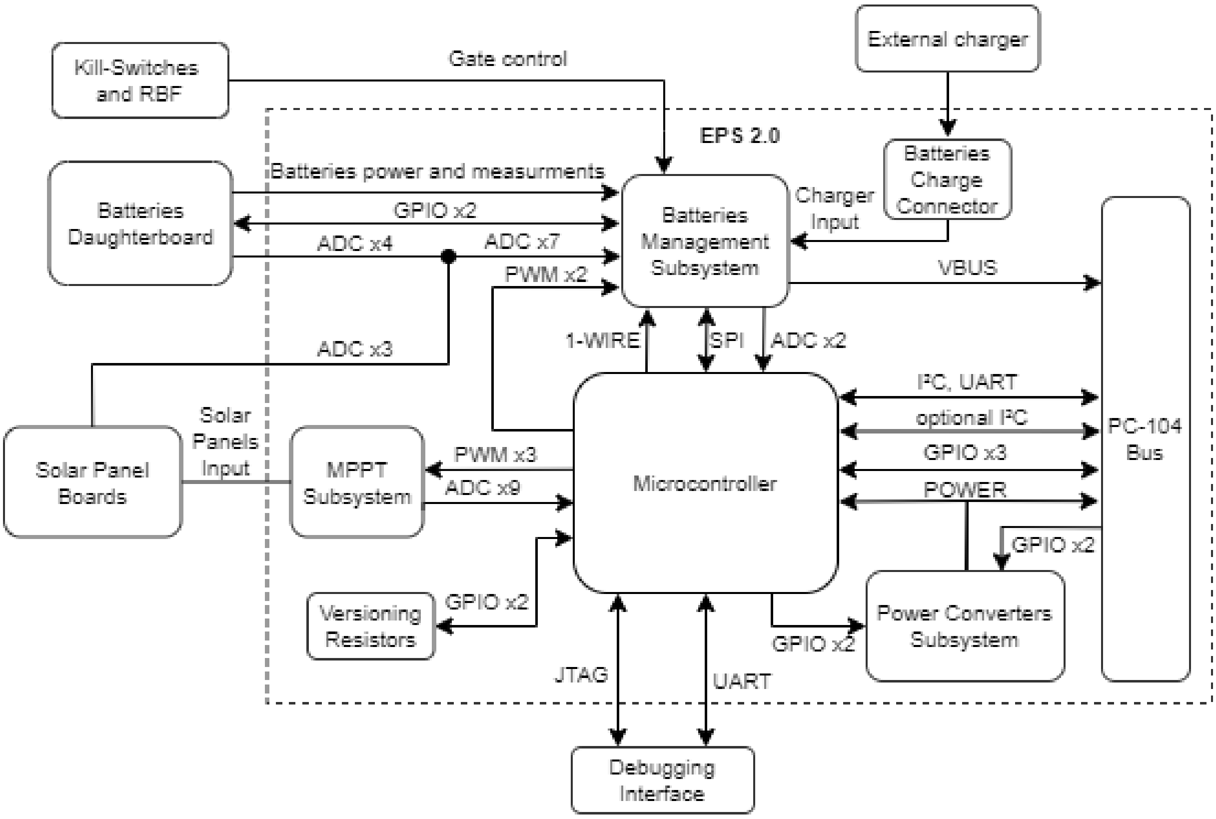

Figure 2.1: EPS 2.0 MCU Block diagram.

2.2 Power Block Diagram

2.3 System Layers

2.4 Operation

2.4.1 Execution Flow

2.4.2 Data Flow

2.4.3 Status LEDs

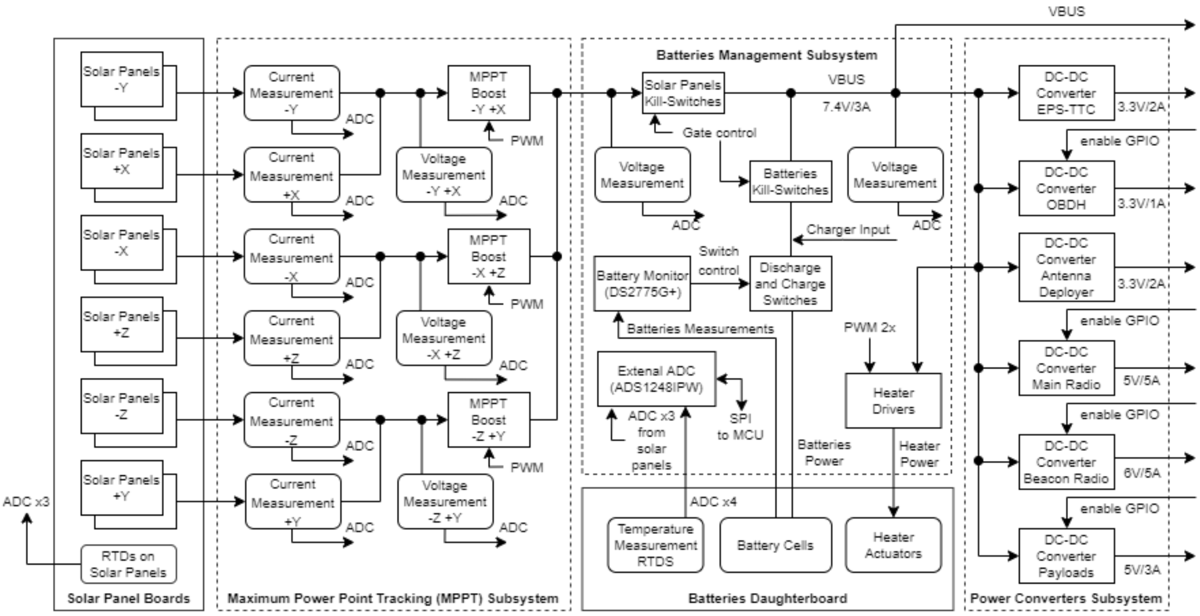

Figure 2.2: EPS 2.0 Power Block diagram.

CHAPTER 3

Hardware

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3.1 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 SI4010dy 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. Finally, the EPS PCB is provided with a LMC555 chip, which is able to generate a fixed PWM for the MPPT circuit in case of EPS 2.0 MCU failures.

3.2 Measurement Circuits

The measurement circuits are used to generate a voltage proportional to the variable being measured, in a range accepted by the MCU internal ADC.

3.2.1 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:

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

3.2.2 Beacon Current

This measurement takes place at the output of the EPS-Beacon 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.

3.2.3 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:

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

3.2.4 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.

3.2.5 Main Power Bus Voltage

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

3.3 Heaters Control Circuit

The batteries operate over a specified temperature range and need active heating to work properly in space. The heaters control circuit is composed of the heaters themselves, RTDs, an external ADC and the drivers.

3.3.1 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.

3.3.2 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.

3.4 Battery Control Circuit

The batteries are monitored by the DS2775 chip. It measures several parameters and sends them to the EPS MCU via one-wire protocol. Also it automatically protects the batteries against short-circuits, overvoltage and undervoltage situations by switching two mosfets (FDS6898AZ).

3.5 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.

3.6 Voltage Regulators

To supply itself and the other modules, the EPS has 6 integrated DC-DC regulators. To supply the Beacon MCU and itself a TPS5420QDRQ1 regulator is used, with and output voltage of 3.3 V and 2 A current capability. This regulator is always on.

To power the payload, a TPS5430QDDARQ1 regulator is used. It has an output voltage of 5 V and 3 A current capability. The EPS can enable/disable this regulator.

OBDH and the main radio are powered by TPS5410QDRQ1 regulator, with an output voltage of 3.3 V and 1 A current capability. The EPS can enable/disable this 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.

Finally, each PA is powered by its own TPS54540QDDARQ1 regulator, with an output voltage of 5 V and 5 A current capabiity. The Beacon MCU controls its PA regulator enable/disable function and the OBDH MCU controls the main radio PA regulator enable/disable function.

3.7 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 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.

3.8 External Connectors

The EPS module is connected to the other modules using the PC-104 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 EPS 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 EPS PCB and a table explaining each pin function.

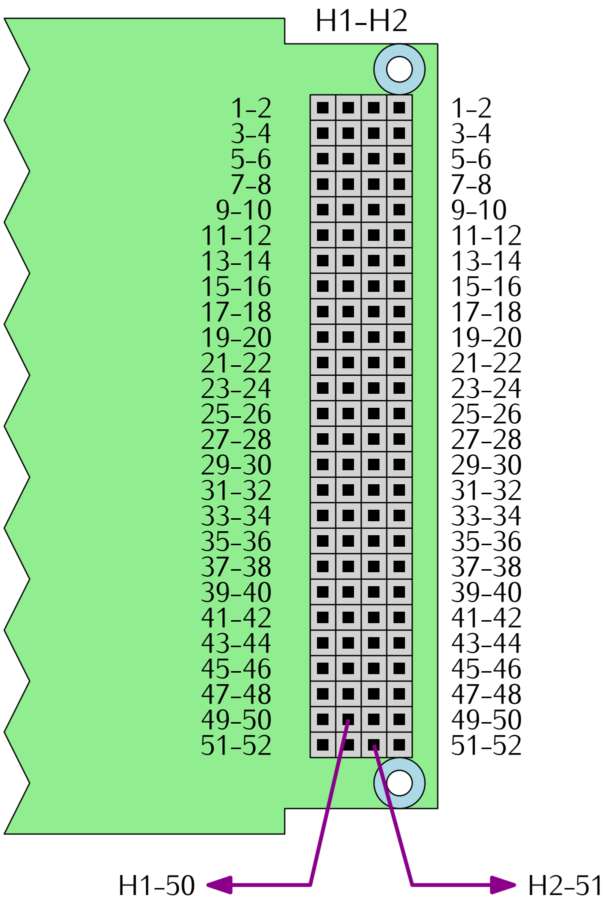

Figure 3.1: Reference diagram of the PC-104 bus.

3.8.1 PC-104

3.8.2 Solar Panels

3.8.3 Kill-Switches

3.8.4 Battery Charge

3.8.5 Remove Before Flight

3.8.6 RTDs

3.8.7 Battery Module

3.8.8 Battery Heater

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.

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

Firmware

4.1 Tasks

A list of the firmware tasks can be seen in the Table 4.1.

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

Table 4.1: Firmware tasks.

CHAPTER 5

Board Assembly

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CHAPTER 6

Usage Instructions

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