

# Hardware Design

## 1. Design Choices

Up next is provided a table including the most important information of the OBC. In the following sections is found information about each one of them as well as the overall design of the system.

### Quick Facts Table

Component	Value
<b>Microcontroller</b>	STM32L476RG
<b>Core</b>	ARM Cortex-M4
<b>Generation</b>	STM32L4 Series of ultra-low-power MCUs
<b>Flash Memory</b>	1 MB
<b>SRAM</b>	128 KB

Table 1: OBC Hardware Quick Facts Table

### 1.1. Microcontroller Unit (MCU)

The selected microcontroller unit is the STM32L476RG. Among its main features one can find outstanding processing performance, fast interrupt handling, low gate count and ultra-low-power consumption. Some of the reasons that back up this choice are provided next:

- Common industry use, therefore there is a lot of documentation about it on STMicroelectronics' website, but also a significant amount of online tutorials which showcase how this device could be used for a multitude of tasks.
- Size of the flash memory and efficiency of SRAM, paired up with the 32 KB of hardware parity check, enabling the creation a buffer for important data to be safely stored in.
- The availability of a wide array of peripheral communications including I2C, USART, SPI, and SWPM create a very flexible environment for trying out several methods of setup and communication. This is also relevant considering the modular approach to the
- The number of internal and possible external clocks with a capacity of oscillating to 80 MHz allows the satellite to operate under multiple different modes, each with different clock settings well-suited to power management applications.

The microcontroller hosts an overall 4 GByte memory area, at addresses ranging between 0x0000 0000 and 0xFFFF FFFF. Accessible for our use are two SRAM memories providing a total sum of 128KB and a Flash memory with an storage capacity of 1MB.

Memory	Addresses	Storage Capacity	Boot Area	Application Code
SRAM1	0x2000 0000 - 0x2003 FFFF	96 KBytes	NO	NO
SRAM2	0x1000 0000 - 0x1000 7FFF	32 KBytes	NO	NO
Flash	0x0800 0000 - 0x080F FFFF	1 MByte	YES	YES

Table 2: Embedded Memories information

The flash memory is also divided in two 512KBytes banks, enabling read-while-write operations. The embedded SRAM can be accessed in read/write at CPU clock speed with 0 wait states.

## 1.2. Clocks

The MCU is provided with internal clocks but a pair of external clocks are accommodated for clock configuration. This is due to the fact that the speed of the MCU will be slow down depending on the state of the battery as well as due to the necessity of high speeds by the K-Band payload.

These two external clocks will provide redundancy and a stable reference signal to the OBC ensuring proper timings. One of this clocks is a 32.768KHz SMD Low Profile Crystal (ABS09-32.768KHZ-7-T), providing a lower speed signal while the other clock, a ECX-32 SMD CRYSTAL(ECS-120-18-33-JEM-TR3), provides a high speed signal at a frequency 32 MHz. Both were selected due to their temperature operative ranges as well as package size, while also considering availability.

## 1.3. PoL Controls

While the PoL Controls do not belong to the OBC subsystem in on of itself they are located in the OBC-COMMS board and controlled by the MCU. These are required to easily shutdown parts of the system as well as ensuring voltages in critical points. Even though this task could moreless be performed by transistors, the use of PoL IC improves reliability and offers a safer alternative.

The selected IC for this task is the BD2232G-GTR due to it being equipped with the functions of over-current detection, thermal shutdown and under-voltage lockout. The package size and thermal properties also match the system requirements.

# 2. Schematic Design

## 2.1. MCU

The MCU is undoubtedly the most complex piece of the OBC-COMMS PCB in terms of connectivity. It communicates with the rest of the system using DACs, ADCs, UART, I2C (to a great extent), SPI and GPIOs. The schematic of the MCU is provided next:

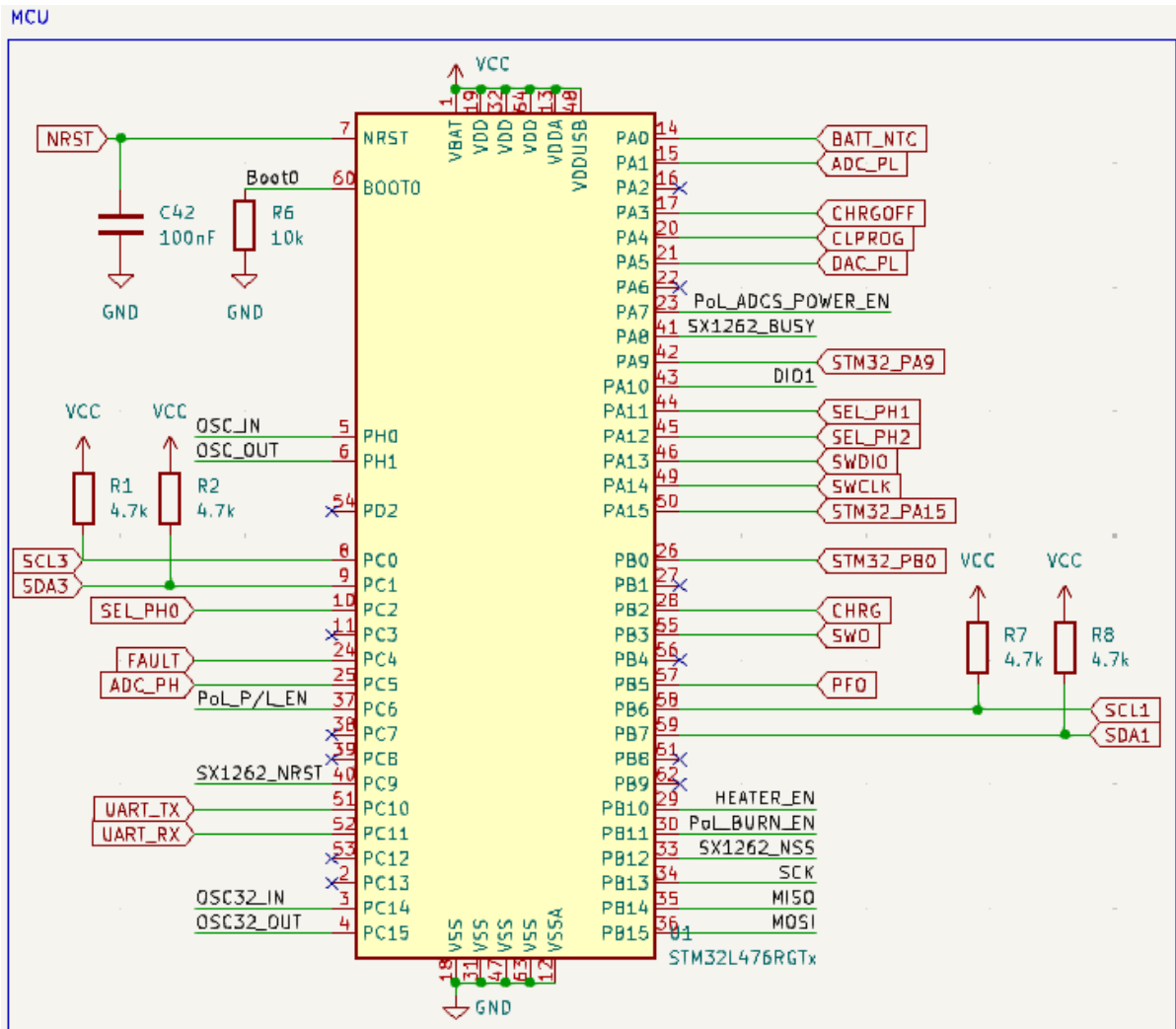


Figure 1: MCU Schematic

In order to avoid high frequency interference with the voltage supply of the MCU seven capacitors are placed in parallel before the input resulting in the following configuration.

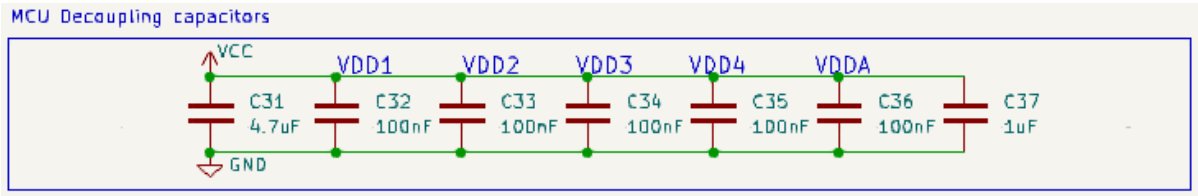


Figure 2: MCU Decoupling Capacitors Schematic

Now a table with some information about each one of the PINs of the MCU is given and most relevant explanations are provided later:

Pin Number / Name	PCB Pin Name	Type	Description
1/VBAT	VCC	Power	General Power line at 3.3V
2/PC13	NC	-	-
3/PC14	OSC32_IN	Input	32 kHz Oscillator Input
4/PC15	OSC32_OUT	Output	32 kHz Oscillator Output
5/PH0	OSC_IN	Input	12 MHz Oscillator Input
6/PH1	OSC_OUT	Output	12 MHz Oscillator Output
7/NRST	NRST	Digital Input	STM32 Reset Pin
8/PC0	SCL3	I2C	I2C3 Clock Bus
9/PC1	SDA3	I2C	I2C3 Data Bus
10/PC2	SEL_PH0	Digital Output	Selector for Photodiode Multiplexer
11/PC3	NC	-	-
12/VSSA	GND	Power	Ground
13/VDDA	VCC	Power	General Power line at 3.3V
14/PA0	BATT_NTC	Analog Input	Battery Temperature NTC Sensor
15/PA1	ADC_PL	Analog Input	ADC Input
16/PA2	X	NC	Unused Pin for Future or No Use
17/PA3	CHRGOFF	Digital Output	Battery Charging Enable Pin
18/VSS	GND	Power	Ground
19/VDD	VCC	Power	General Power line at 3.3v
20/PA4	CLPROG	Analog Output	Charge Current Programming Output
21/PA5	DAC_PL	Analog Output	DAC Output for Payload

Pin Number / Name	PCB Pin Name	Type	Description
22/PA6	X	Not connected	Unused Pin for Future or No Use
23/PA7	PoL_ADCS_POWER_EN	Digital Output	Point of Load Control for ADCS
24/PC4	FAULT	Digital Input	Battery Charging Fault Status Pin
25/PC5	ADC_PH	Analog Input	Photodiode Array Output
26/PB0	STM32_PB0	GPIO	Connected to STM32 PB0, User Defined
27/PB1	X	Not connected	Unused Pin for Future Use
28/PB2	CHRG	Digital Input	Battery Charging Monitoring Pin
29/PB10	HEATER_EN	Digital Output	Heater Enable Pin
30/PB11	PoL_BURN_EN	Digital Output	Point of Load Control for Antenna Deployment
31/VSS	GND	Power	Ground
32/VDD	VCC	Power	General Power line at 3.3V
33/PB12	SX1262_NSS	SPI Chip Select	SX1262 Chip Select
34/PB13	SCK	SPI Clock	SX1262 SPI Clock
35/PB14	MISO	SPI MISO	SX1262 SPI Master-In Slave-Out
36/PB15	MOSI	SPI MOSI	SX1262 SPI Master-Out Slave-In
37/PC6	PoL_P/L_EN	Digital Output	Point of Load Control for Payload
38/PC7	X	Not connected	Unused Pin for Future or No Use
39/PC8	X	Not connected	Unused Pin for Future or No Use
40/PC9	SX1262_N_RST	Digital Input	SX1262 Reset
41/PA8	SX1262_BUSY	Digital Output	SX1262 Busy Indicator
42/PA9	STM32_PA9	GPIO	Connected to STM32 PA9, User Defined
43/PA10	DIO1	Digital Input	SX1262 Interrupts
44/PA11	SEL_PH1	Digital Output	Selector for Photodiode Multiplexer

Pin Number / Name	PCB Pin Name	Type	Description
45/PA12	SEL_PH2	Digital Output	Selector for Photodiode Multiplexer
46/PA13	SWDIO	Serial Wire I/O	STM32 Debug Port
47/VSS	GND	Power	Ground
48/VDDUSB	VCC	Power	General Power line at 3.3V
49/PA14	SWCLK	Serial Wire	STM32 Debug Port
50 /PA15	STM32_PA15	GPIO	Connected to STM32 PA15, User Defined
51/PC10	UART_TX	UART (Output)	UART TX Bus to P/L
52/PC11	UART_RX	UART (Input)	UART RX Bus to P/L
53/PC12	X	Not connected	Unused Pin for Future or No Use
54/PD2	X	Not connected	Unused Pin for Future or No Use
55/PB3	SWO	Serial Wire	STM32 Debug Pin
56/PB4	X	Not connected	Unused Pin for Future or No Use
57/PB5	PFO	Power	Power Fault Output
58/PB6	SCL1	I2C	I2C1 Clock Bus
59/PB7	SDA1	I2C	I2C1 Data Bus
60/BOOT0	Boot0	Boot	Boot Pin
61/PB8	X	Not connected	Unused Pin for Future or No Use
62/PB9	X	Not connected	Unused Pin for Future or No Use
63/VSS	GND	Power	Ground
64/VDD	VCC	Power	General Power line at 3.3V

Table 3: MCU PINs

## 2.2. PoL Control

The Point-of-Load (PoL) control provides powering of critical components of the system, those being the P/L, ADCS, Thermal Knife and the Battery Heater. The IC is powered by the 3.3V line and the schematic follows the manufacturers reference design, with EN/EN# pin being controlled by the OBC with GPIOs (as MCU Outputs).

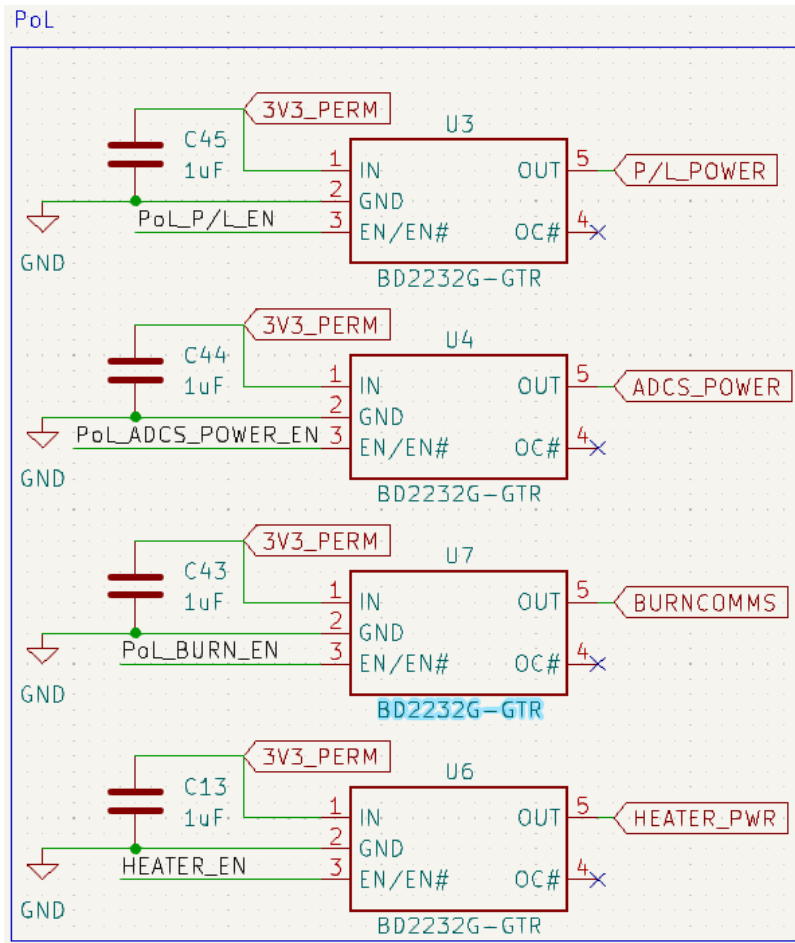


Figure 3: PoL Controls Schematic

The outputs of these PoL is connected to the vertical connectors on the sides of the PCB.

## 2.3. External Clocks

The OBC external clocks are provided with decoupling capacitors to minimize any noise that might affect the reference signals. The schematics are provided next:

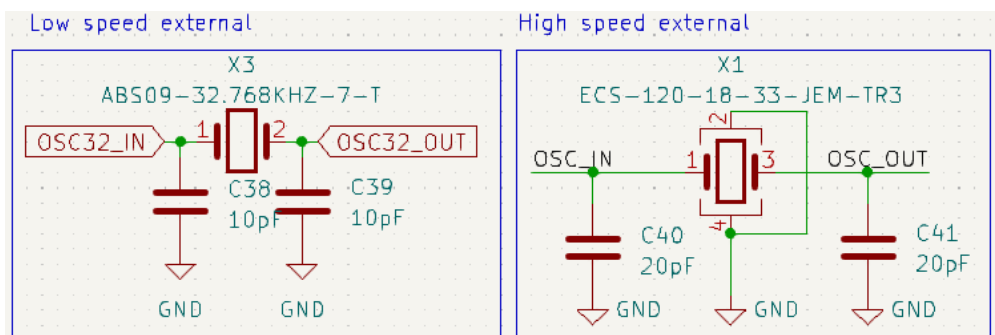


Figure 3: External Clocks Schematic

Capacitors are placed at the extremes of the clocks to reduce the gain of higher harmonics produced by the crystals themselves.

# 2.4. Overall Schematic

A schematic of the whole system is provided now, highlighting the parts with different colours:

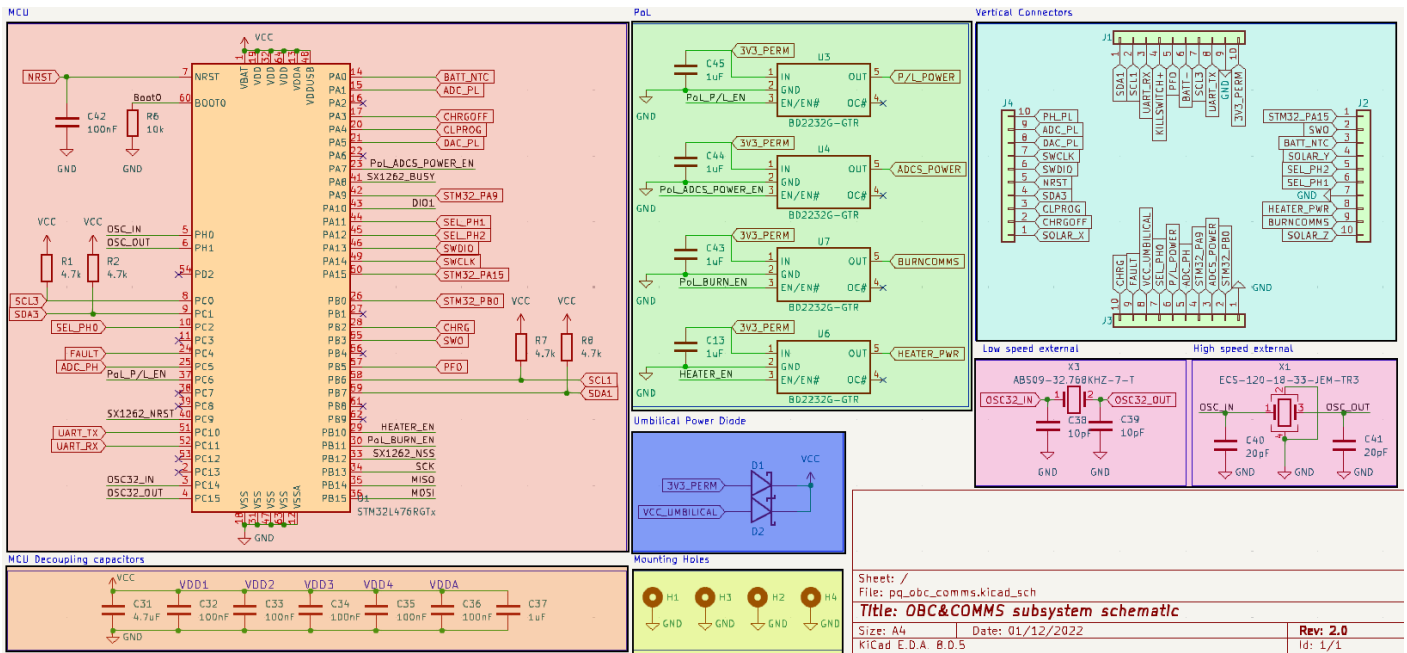


Figure 4: Overall OBC Schematic

- **Red:** The MCU itself, coupled with the pull-up resistors and capacitors it needs for its pins.
- **Green:** The 4 power switch ICs which can switch several pin outputs to zero (more specifically: P/L\_POWER, ADCS\_POWER, BURNCOMMS, and HEATER\_PWR).
- **Light blue:** The outside lateral connectors used for system power and data connectivity.
- **Dark blue:** The Umbilical Power Diode used to protect the circuit from reflections while being directly powered .
- **Pink:** The 2 external oscillators (Low speed and High speed) used as redundant clocks for the OBC circuit.
- **Orange:** The MCU's decoupling capacitors used to reduce and filter out noise caused by sudden changes in power demand from a device or component.
- **Yellow:** The mounting holes for the PCB, which will be used to fixate all the PCB in place with a long screw and give them a common GND pin.

# 3. PCB Design

Next an explanation of the OBC side of the OBC-COMMS PCB is given. Information related to the COMMS side is in its respective section. A render of the PCB is provided in the next figure:

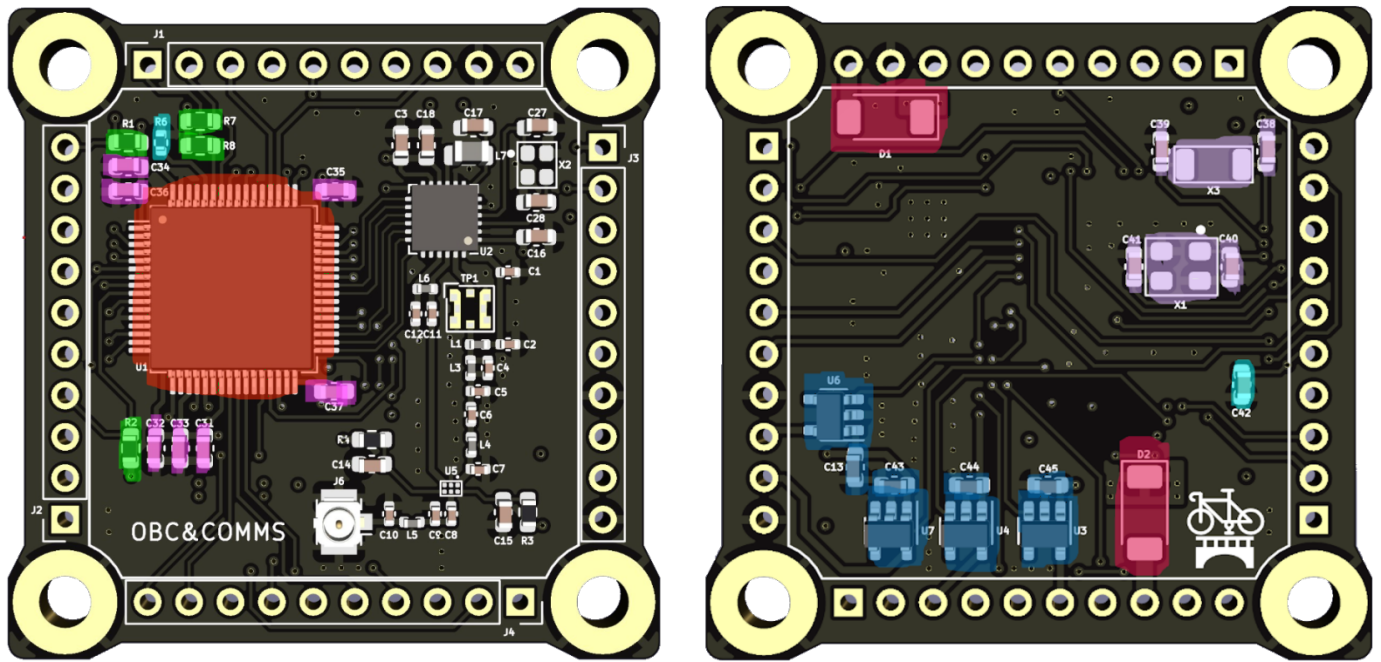


Figure 5: OBC-COMMS PCB with OBC Components highlighted

- **Light red:** MCU.
- **Green:** Pull-up resistors for I2C.
- **Pink:** Decoupling capacitors.
- **Dark blue:** Power switch ICs (PoL Control) and their respective input capacitor.
- **Purple:** Crystal oscillators and their respective coupling capacitors.
- **Crimson red:** Umbilical diode and connector.
- **Light blue:** Input capacitor and resistor for NRST and Boot0 respectively.

The **MCU** is located at the top layer of the PCB, placed at the left side of the board to keeping most power distribution as far away as possible from the COMMS side of the PCB to minimize interference. This distribution also keeps the I2C pins close to the vertical connectors which helps reduce noise from the PCB. The **Decoupling capacitors** are placed throughout the board on the STM32 voltage pins.

The **I2C Pull-up resistors** are simply placed as close as possible to the corresponding pins. This decision also happens to minimize the length of the lines as the PINs are close to the vertical connectors. This same philosophy applies to the **input capacitor and resistor for NRST and Boot0**.

All this components are besides the NRST capacitor are on the top layer. On the bottom layer we find the **Power switch ICs (PoL Control)** which are once again located as close as possible to the vertical connectors where their outputs match in order to minimize power losses, keep lines short and avoid interferences with COMMS. On the same side are the **Crystal oscillators** which are located at the top right corner as the MCU is then located straight on top of them. This is fundamental as the harmonics generated by these clocks are dangerous to the COMMS subsystem, so keeping them as far as possible from the RF lines and transceiver minimizes risk of coupling.

The last piece of the OBC PCB are the **Umbilical diode and connector**, also on the bottom layer and, once again, close to the vertical connectors for the same reasons as before.

A list of the components as well as some information for each part is provided next:

## Microcontroller Unit (MCU)

The table containing the MCU information:

Characteristic	Description
Microcontroller	STM32L476RGT7
MCU Manufacturer	ST
Core	ARM Cortex M4
Word Length	32-bit
Frequency (MHz)	80
Architecture	RISC
FPU	Yes
Consumption	9.6mA
Interfaces	x3 I2C, x3 SPI, x2 UART, x3 USART, x8 GPIO
ADC	3
DAC	2
Flash	1MB
RAM	128KB

Table 4: MCU Information

## Decoupling capacitors

Capacitor C31 is a 4.7uF ceramic capacitor (GRT188R61E475KE13D) with the following characteristics:

Temp. coeff. or Cap. Change	Temp. Range	Ref. Temp.	Rated Voltage	Capacitance	Capacitance Tolerance	Operating Temp. Range	Mounting Method
-15 to 15 %	-55 to 125°C	25°C	DC 100V	4.7uF	+/-10%	-55 to 85°C	Flow, Reflow

Table 5: GRT188R61E475KE13D (C31) Relevant Values

Capacitors C32 to C36 are all 100nF ceramic capacitors (GRM188R72A104KA35J) with the following characteristics:

Temp. coeff. or Cap. Change	Temp. Range	Ref. Temp.	Rated Voltage	Capacitance	Capacitance Tolerance	Operating Temp. Range	Mounting Method
-15 to 15 %	-55 to 125°C	25°C	DC 100V	0.1uF	+/-10%	-55 to 125°C	Flow, Reflow

Table 6: GRM188R72A104KA35J (C32, C33, C34, C35, C36) Relevant Values

Capacitor C37 is a 1uF ceramic capacitor (GRM188R61A105KA61D) with the following characteristics:

Temp. coeff. or Cap. Change	Temp. Range	Ref. Temp.	Rated Voltage	Capacitance	Capacitance Tolerance	Operating Temp. Range	Mounting Method
-15 to 15 %	-55 to 85°C	25°C	DC 10V	1uF	+/-10%	-55 to 85°C	Flow, Reflow

Table 7: GRM188R61A105KA61D (C37) Relevant Values

## I2C Pull-up resistors

The I2C PU Resistors (R1, R2, R7, R8) are all 4.7k thick film resistors (CRCW06034K70JNEAC):

Resistance	Power Rating	Tolerance	Temp. Coefficient	Min. Operating Temp.	Max. Operating Temp.	Voltage Rating
4.7 kOhms	100 mW (1/10 W)	5%	200 PPM / °C	-55 °C	+155 °C	75 V

Table 8: I2C PU Resistors Values (R1, R2, R7, R8)

## Crystal Oscillators

The Crystal oscillators present the following capacitors to filter harmonics:

RefDes	Package	Value	Qty	Description	Manufacturer Code
C38, C39	0402	10pF	1	Multilayer ceramic capacitors C0G ±2%, 50V	06035A100GAT2 A

RefDes	Package	Value	Qty	Description	Manufacturer Code
C40, C41	0402	3.3pF	1	Multilayer Ceramic Capacitors C0G ±5%, 100V	GCM1885C2A200 JA16D

Table 9: Crystal Oscillators Capacitors Values

## Umbilical diode (RBS1LAM40ATR)

The umbilical connector boasts two diodes, which are the same component:

Type	Configuration	Technology	If	Vrrm	Vf	Ifsm	Ir	Vr	Max Op. Temp.
Schottky Diodes	Single	Si	1 A	40 V	340 mV	40 A	150 µA	20 V	+125 °C

Table 10: Umbilical Diodes Values

## Input C&R for NRST and Boot0

NRST and Boot0 make use of the following components:

- The resistor R6 (CRCW040210K0FKEDC):

Resistance	Power Rating	Tolerance	Temp. Coefficient	Min. Operating Temp.	Max. Operating Temp.	Voltage Rating
10 kOhms	63 mW (1/16 W)	1%	100 PPM / °C	-55 °C	+155 °C	50 V

Table 11: R6 Values

- The capacitor C42 (GRM188R72A104KA35J) is the same as the capacitors C32 to C36 **decoupling capacitors** .

## Power switch ICs Capacitors

The power switch capacitors are the same as the C37 **decoupling capacitor** .

## PCB Layers

The OBC-COMMS layers are explained on the COMMS section of hardware-

# 4. State of the art

The Due to the novel nature of the satellite, research in this area is somewhat restricted. Most of the currently deployed spacecraft are primarily the outcome of educational initiatives and an emerging market. Considering all this, the assessment is focused on three enterprises currently offering market solutions, the already introduced Alba Orbital and FOSSA Systems, along with Citadel Space Systems. It is worth mentioning that the products of the latter company, still do not have experience in space. The 3 reference PocketQubes are Unicorn-2, FOSSASat-2 and Scquire, developed by Alba Orbital, FOSSA Systems and, Citadel Space Systems respectively.

The analysis breakdown of their microcontrollers on-board is performed in table 2.1. The underlying purpose of this comparison is to identify the technology that best meets the requirements of our On-Board Computer. In this regard, the research is focused on the relevant features of the microcontroller selected to fly towards space, such as word length, maximum frequency, architecture among others.

Organization	Alba Orbital	FOSSA Systems	Citadel Space Systems
PocketQube	Unicorn-2	FOSSASat-2	Squire
Microcontroller	MSP430	STM32L4	TMS570
MCU Manufacturer	TI	ST	TI
Core	CPU	ARM Cortex M4	ARM Cortex R5F
Word Length	16-bit	32-bit	32-bit
Frequency (MHz)	16	80	300
Architecture	RISC	RISC	RISC
FPU	No	Yes	Yes
Consumption	6.72mA	9.6mA	990mA
Interfaces	x1 I2C, x1 SPI, x1 UART	x3 I2C, x3 SPI, x2 UART, x3 USART, x8 GPIO	x2 I2C, x5 SPI, x4 UART, x16 GPIO
ADC	8	3	2
DAC	-	2	-
Flash	16KB	1MB	4MB
RAM	512B	128KB	512KB

Table x: State of the art comparison

According to the previous table, the microcontroller selected by the emergent picosatellite companies are Texas Instruments (TI) and STMicroelectronics (ST). Regarding the processor core, it is common for the microcontrollers to be based upon a processor manufactured by another enterprise. In this case, the STM32L4 and the TMS570 are based on ARM Cortex M4 and ARM

Cortex R5F respectively, both developed by Arm. However, TI has opted to develop the Central Processing Unit (CPU) core themselves. Furthermore, the critical features that significantly impact microcontroller per-On-board computer software development for PocketQubes formance are frequency and word length.

On the one hand, the frequency establishes the speed of the CPU, expressed in Hertz or MegaHertz represents the number of clock cycles per second. In our scenario, the TMS570 is the fastest in terms of intruccion execution with 300 MHz, followed by the STM32L4 with 80 MHz and finally, the slowest being MSP430 at 16 MHz. On the other hand, the word length determines the width of the processor registers and the bus data width. Consequently, the memory space, data and instruction handling, and data precision are dependent on this parameter. For this reason, the processing performance of the 32-bit microcontroller from FOSSA Systems and Citadel Space Systems is more powerful, than the 16-bit selected by Alba Orbital.

However, performance comes together with power consumption so adjusting the system functioning to its requirements is key. In this context, the assessment should focus on the optimum trade-off between performance and power consumption where the battery capacity plays a critical role. The only parameter that the application writer can tune in order to regulate the power consumption is the clock frequency. For the sake of simplicity, the maximum power consumption of each microcontroller has been analyzed at their respective maximum frequencies (16 MHz, 80 MHz, and 300 MHz). As anticipated, the microcontroller operating at the highest frequency exhibits the highest power consumption, measuring 990 mA. This value is over ten times larger than the power consumption of the STM32L4, which consumes 9.6 mA, and the STM32L4, in turn, consumes twice the power of the MSP430 at 6.72 mA.

Furthermore, the system can reap advantages from the inclusion of a Floating Point Unit (FPU), which is specifically designed to handle floating-point operations. While the CPU is capable of performing such operations, the FPU executes them not only faster, but also with higher precision. Interestingly, Alba Orbital made the decision not to incorporate this component, whereas FOSSA Systems and Citadel Space Systems opted to implement it.

One thing in common among the pioneering entities is the architecture of the MCU. Based on Reduced Instruction Set Computing (RISC), the processing focuses on the use of simple instructions that can be executed in a clock cycle. In general, RISC architecture when compared to Complex Instruction Set Computing (CISC), is much faster, less resource consuming and more power-efficient, which is ideal for embedded systems. Even though CISC reduces the number of memory access since more operations can be done with a single complex instruction, pipelining in RISC also accelerates the memory access process.

Regarding interfaces, it is the part that depends the most on the overall system architecture. In other words, it depends on which are the devices that the microcontroller has to communicate with and which is the protocol required to do so. The system governing FOSSASAT-2 and Squire is more complex since they feature a wide variety of serial peripheral interfaces such as I2C, SPI, UART, USART and GPIO. On the contrary, Unicorn-2 looks somewhat simpler with only one I2C, one SPI and one UART peripheral interfaces required. In addition, FOSSASat-2 accomodates three ADCs, Scquire features two of them and MSP430 has up to 8 ADC channel available. In terms of DAC,

STM32L4 is the only one having this feature, with 2 DACs.

Last but not least, the discussion concerning memory storage is given. As stated before it is directly dependent on the word length, since the more addresses we can use the larger the memory can be. Memory needs to have enough room for both data and the program itself. The three introduced PocketQubes accomodate a Flash memory along with a RAM memory whose sizes are determined according to the system needs.

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