Hardware Design

1. Design Choices

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

Quick Facts Table

Specification	Value
Frequency	868 MHz
Modulation	LoRa
Bandwidth	125 kHz
Maximum output power	22 dBm
Maximum current consumption	118 mA
Effective data rate	537.1 bps
Coding rate	4/5
Spreading Factor	11
Antenna	λ/4 monopole

Table 1: COMMS Quick Facts Table

1.1. Transciever and Technology

It is crucial to consider that the restricted size of the PocketQube will dictate the maximum power of the signal to can transmit. This is both due to the physical space constraints, discarding the possibility of more complex designs and also due to the power constraits of having a small surface area on the lateral boards for energy gathering.

Hence, it requiered to employ technlogies that provide low consumption, small amounts of space as well as the necessary power and range capabilities to meet the mission's requirements.

It is opted for the utilization of LPWANs (Low Power Wide Area Networks), specifically employing the LoRa (Long Range) physical layer technology. The selected **transciever** for the subsystem is the SX1262 LoRa Transciever from Semtech, chosen from a range of options due to its superior output, frequency and lower power consumption in comparison to its counterparts:

Chip	SX1262	SX1261	SX1268	SX1272	SX1276	SX1278
Physical Layer Technology	LoRa	LoRa	LoRa	LoRa	LoRa	LoRa
Frequency range	150 - 960 MHz	150 - 960 MHz	410-810 MHz	860-1020 MHz	137-1020 MHz	137-525 MHz
Bandwidth	7,8 - 500 kHz	7,8 - 500 kHz	7,8 - 500 kHz	7,8 - 500 kHz	7,8 - 500 kHz	7,8 - 500 kHz
Maximum output power	22 dBm	15 dBm	22 dBm	20 dBm	20 dBm	20 dBm
Maximum current consumption	118 mA	25,5 mA	107 mA	125 mA	120 mA	120 mA
Size	4mm x 4mm	4mm x 4mm	4 mm x 4 mm	6 mm x 6 mm	6 mm x 6 mm	6 mm x 6 mm

Table 1: Transciever comparisons and selected transciever in green.

Another factor taken account into the desing choice is the flight heritage of the technlogy as FOSSASAT-1 already practically demonstrated the feasibility LoRa communications in space.

1.2. Switch

The **switch** to be used must fulfill certain requisites established mainly by the transciever. First of all it is important to consider the frequency ranges it'll have to work on, being around 868 MHz in our case. Furthermore the switch is to be controlled by an analogic pin of the SX1262, therefore it must work at voltages as close as possible as 3.3V. The insertion losses are also an important factor, having to be minimized. The commutation control scheme has some flexibility as software can be defined to sort out path chosing.

The switch selected is the BGS12P2L6E6327XTSA1 from Infineon. Previously the BGS12PL6E6327XTSA1 was used but due to availability issues the first one has been selected. The new switch boasts less losses while being feature in the same package as the old one. Both provide low current consumption and fulfill the previous requirements.

1.3. Crystal Oscillator

The COMMS **crystal oscillator** is responsible for providing a stable RF reference signal to the transciever. This signal is to be of a frequency of 32 MHz as established by the transciever manufacturer. It is mandatory that the selected oscillator remains stable enough in a range of temperatures around -20ºC-80ºC.

The selected crystal oscillator is the FA-128_32.0000MF20X-K5 from EPSON due to it's size and appropiate frequency drifts in the temperature ranges expected. This oscillator is also recommended by the transciever manifacturer.

1.4. Antenna Connector

The selected **antenna connector** is the D.FL75-R-SMT-1(40) from Hirose Electric due to it fitting the frequency and thermic requirements as well as being easily mated.

1.5. Antenna

The **antenna** is the part of the communications system that radiates the signals towards the ground station and receives the signals coming from it. There are different kinds of antennas, but not all of them fit the needs and constraints of a PocketQube mission. Derived from the requirements, the antenna needs to have the following features:

- Tuned at 868 MHz (λ = 0.346 m), to use Europe LoRa ISM frequency.
- Foldable within the PocketQube standard maximum dimensions.
- Wide beam width (large θ3dB) to avoid having pointing mismatch with the GS.

Having analyzed the different alternatives of antennas, only wire antennas accomplish the size requirements while keeping an easy method to fold them. A monopole antenna is selected due to the complications that arise from using a dipole design (possible interferences and modification of some features of the radiation pattern) as well as the simplicity to fold it.

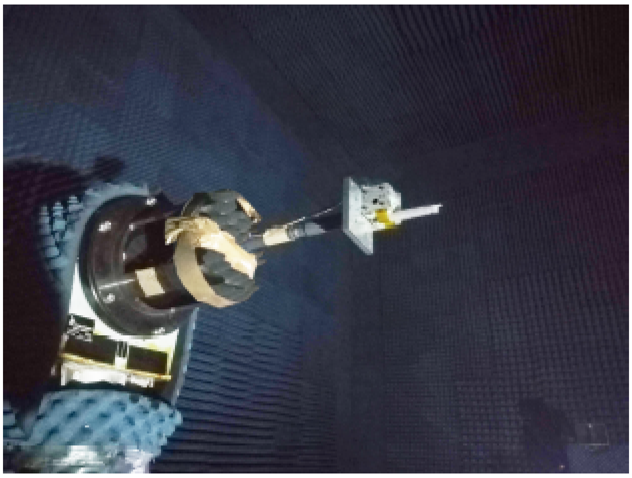
Note that an ideal monopole has an infinite ground plane that, following the image theory for currents, will radiate as if the monopole had another symmetric element on the other side of the ground plane. However, in real life, the ground is neither a perfect conductor which cancels the radiation in the horizontal direction, nor it has an infinite ground plane, which generates some back lobes.

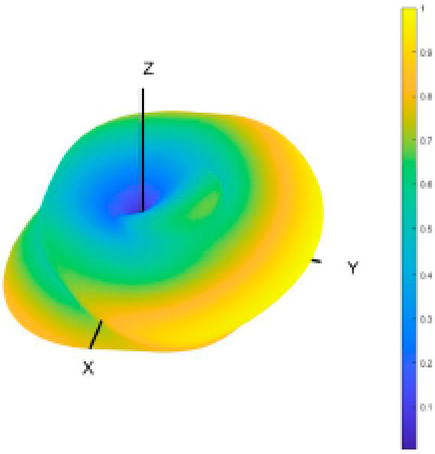
The **antenna** designed then is a piece of metric tape cut at a lenght of around $\lambda/4$ (the frequency being 868MHz). This materials used in these tapes provide proper transmission and reception of EM raditation in our desired frequency range while being resilient to radiation in other parts of the spectrum. It is also a cost-effective solution as well as a proven through flight heritage deisgn. Despite the fact that the length of an ideal monopole is a quarter of the wavelength ($\lambda/4 = c/4f = 3\cdot10^8/4\cdot868\cdot10^6 = 8.64$ cm) depending on the characteristics of the antenna and where it is placed, this length can differ a bit.

To tune the antenna it was connected to a VNA and then cut until the peak was placed at 868 MHz. The obtained length was 9.5 cm, also counting the part of the antenna that is inside the PocketQube.

Radiation pattern

Another important test to determine the gain (or loss) of the antenna and the direction of radiation is the measurement of the radiation pattern. This was done in the anechoic chamber of the department of Signal Theory and Communications. Next a picture of the anechoic chamber is shown, and the follwoing figures provide the results of the radiation pattern.





Figures: UPC anechoic chamber & Normalized radiation pattern

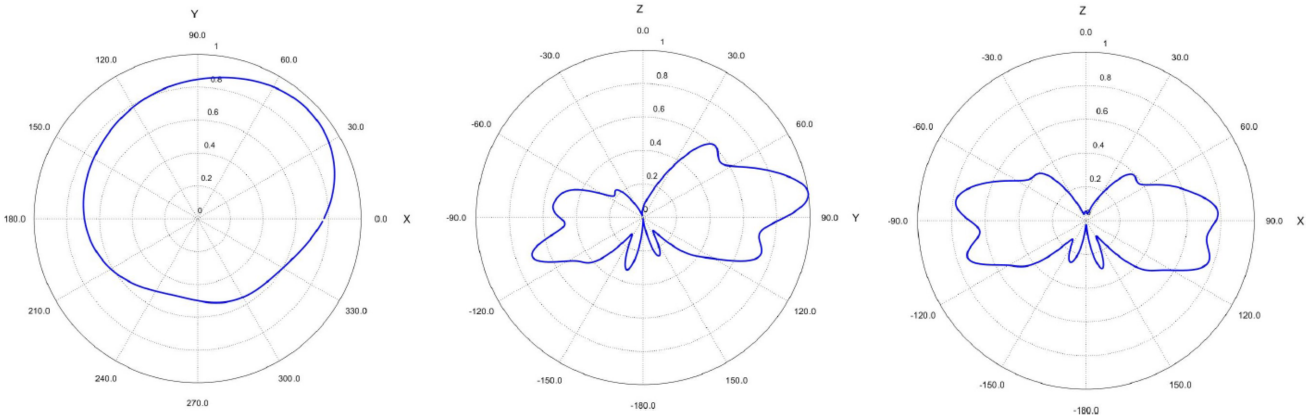


Figure: XY YZ ZX cuts of the normalized RPE

The maximum gain obtained in our case is 1.15 dB, and the directivity is 3.115 dB. The θ−3dB is approximately 60º. Finally, the next figure presents the gain radiation pattern.

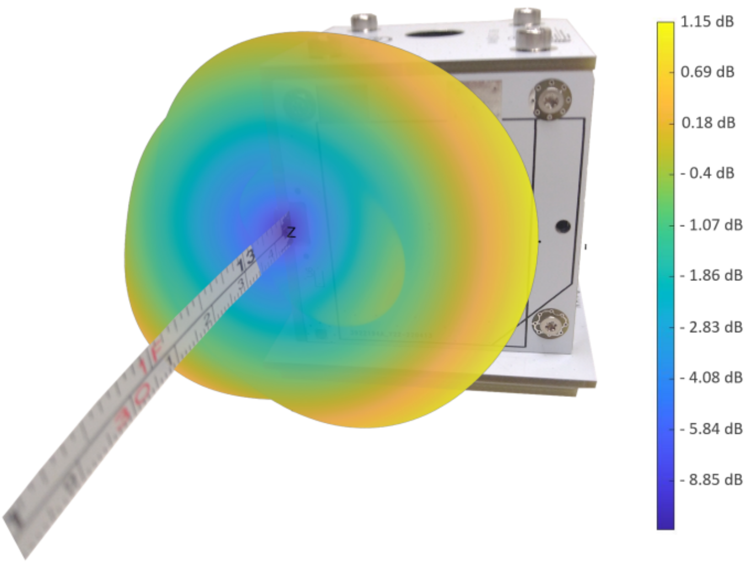


Figure: Gain radiation pattern in dB

2. Schematic Design

The overall design, separated by functional blocks is provided next:

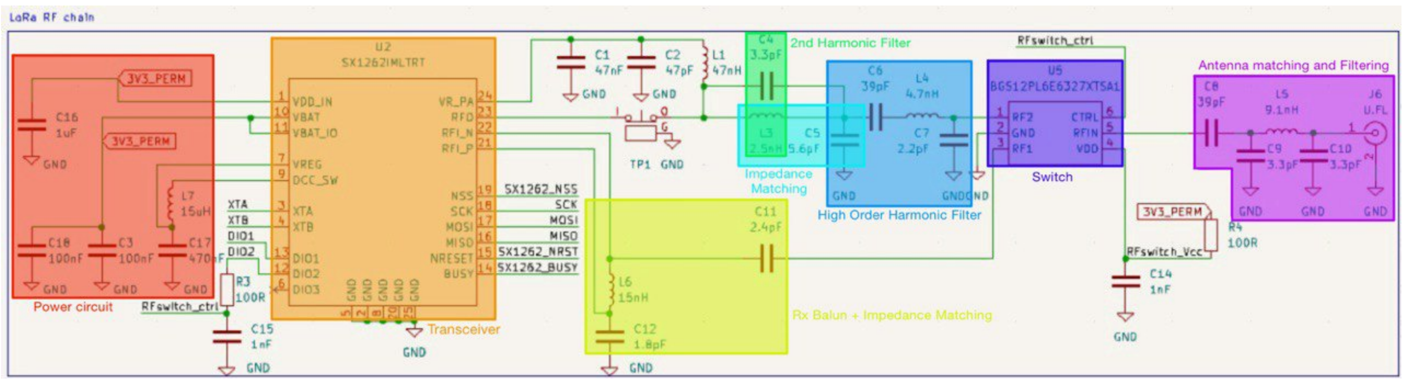


Figure 1: COMMS Colored Schematic. Note that the switch used in this schematic corresponds to the previous version, but no functional changes are presented.

Note that the schematic for the OSC is provided in Figure 4. The 3V3_PERM line arrives through the vertical connectors, from the EPS. Some component value choices justification are provided in the next section (PCB Design), but it can be said that most of them follow the reference design at our selected configuration.

Transciever

The SX1262 allows different set-ups for power distribution, interupt handling, clock reference signals and switch control. The selected power distribution (**power circuit**) uses a DC-DC regulator, reducing the power consumption of the core. A reference schematic from the manufacturer is provided next:

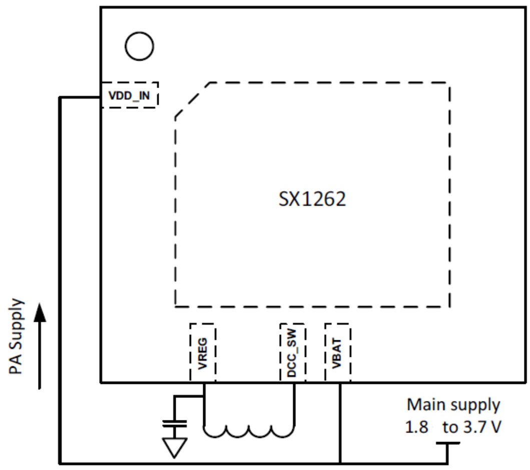


Figure 2: SX1262 DC-DC Power Configuration Schematic

While the SX1262 might be provided of a reference signal by a TCXO (Temperature Compensated Crystal Oscillator) our design involves the use of an on-chip oscillator (OSC). Leaving the DIO3 (PIN 6) unused. The communication between the MCU and the transciever is performed through SPI (PINS 16 to 19) and the DIO 1 line is used to transmit interruption to the OBC.

A table of the function and ID of each PIN of the transciever is provided next:

Pin Number	Pin Name	Type (I = Input, O = Output)	Description
0	GND	-	Exposed Ground pad
1	VDD_IN	I	Input voltage for power amplifier regulator, connected to pin 10
2	GND	-	Ground
3	XTA	-	Crystal oscillator connection, can be used to input external reference clock
4	XTB	-	Crystal oscillator connection
5	GND	-	Ground
6	DIO3	I/O	Multi-purpose digital I/O - external TCXO supply voltage (NOT USED)

Pin Number	Pin Name	Type (I = Input, O = Output)	Description
7	VREG	O	Regulated output voltage from the internal regulator DC-DC
8	GND	-	Ground
9	DCC_SW	O	DC-DC Switcher Output
10	VBAT	I	Supply for the RFIC
11	VBAT_IO	I	Supply for the Digital I/O interface pins (except DIO3)
12	DIO2	O	RF Switch control
13	DIO1	O	Interrupt Output to the MCU
14	BUSY	O	Busy indicator
15	NRESET	I	Reset signal, active low
16	MISO	O	SPI slave output
17	MOSI	I	SPI slave input
18	SCK	I	SPI clock
19	NSS	I	SPI Slave Select
20	GND	-	Ground
21	RFI_P	I	RF receiver input
22	RFI_N	I	RF receiver input
23	RFO	O	RF transmitter output (high power PA)
24	VR_PA	-	Regulated power amplifier supply

Table 1: SX1262 PIN Layout and description

Physically those PINs relate to the following layout in the SX1262:

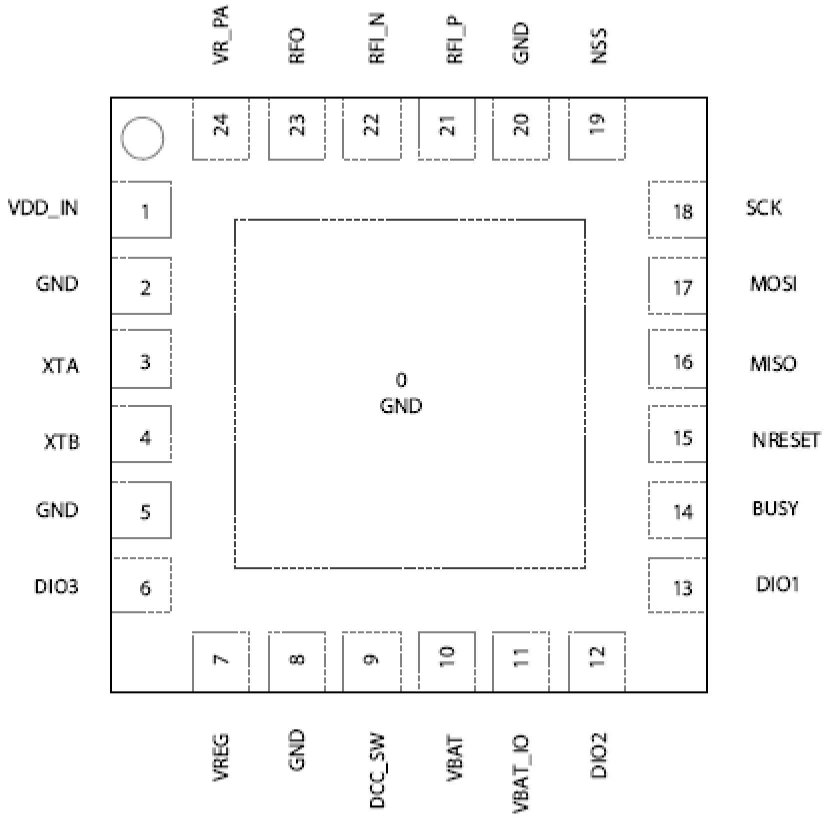


Figure 3: PIN Layout from the SX1262 top view

Crystal Oscillator

The trimming capacitors on the clock may not be connected depending on the clock selection, if it is to be changed. As a matter of fact the transciever offers the possibility of configuring the capacitance of internal capacitors to perform the same task as this ones. On current PoCat design they remain not connected.

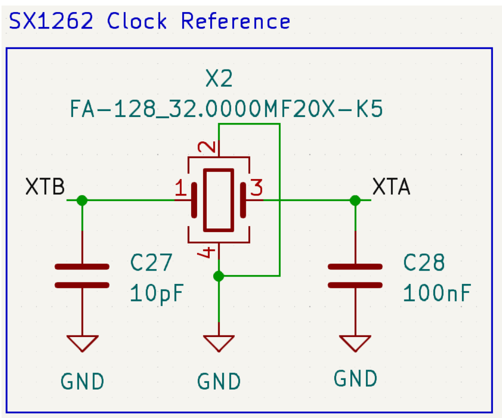


Figure 4: Crystal Oscillator Schematic

Switch

The switch is controlled through the DIO2 (PIN 12) of the SX1262, selecting the RF2 path (transmission line) when the pin rises to high. If it drops, the path selected will then be the RF1 (reception line). It is supplied with 3.3V through the vertical connectors.

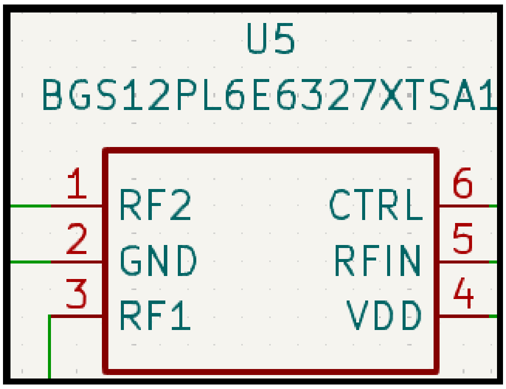
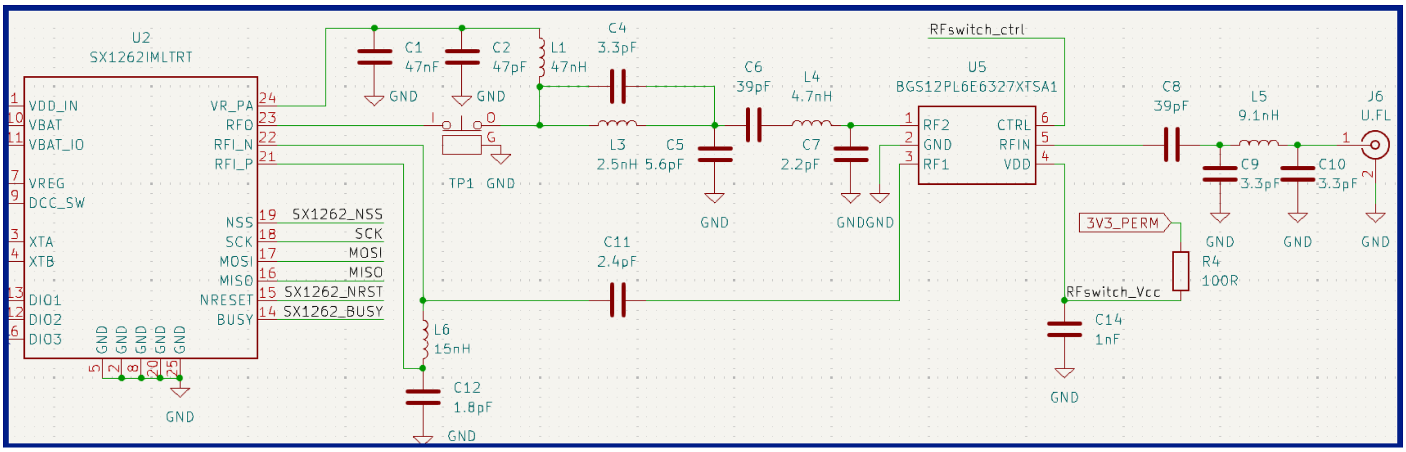


Figure 3: Switch Schematic

Transmission and reception lines

The rest of the design follows the reference schematic provided by Semtech on the SX1262 for usual applications with some changes to optimize space and provide testing capabilities, such as the inclussion of a test probe in the transmission line.

The upper part of the connection between the transceiver and the switch transmits the signal generated in the SX1262 (RFO line), then it is amplified (VR PA line) and the harmonics of second and higher order are filtered. The bottom lines are the ones that take the signal received from the switch to the transceiver. As the transceiver needs a balanced signal and the switch provides an unbalanced one, a balun is added in between to do the unbalanced-balanced conversion. One last important aspect is that all the circuits that connect the main components (transceiver-switch-connector) are matched to 50 Ω.



3. PCB Design

3.1. Overview

The COMMS PCB must support the schematic presented before with a design that minimized losses and interferences. Its tasks correspond to those stablished in the functional description of the system, mainly providing TT&C (Telemetry Tracking an Command) capabilities, as well as P/L data acquisition.

The COMMS subsystem is encapsulated within the OBC-COMMS PCB, sharing space in the same board. In this section the COMMS related lines and components will be explained while the OBC ones remain in their section.

It is interfaced, like the other PCB's in the stack, with the rest of the boards through vertical connectors on each side. Despite this the only relevant inter-board connections in the COMMS case are both the ground plane and voltage line as well as the antenna itself. The later is communicated through a coaxial connector, one in this PCB and another in a lateral board where the antenna is soldered or screwed.

3.2. PCB Layers and Structure

The PCB has 4 internal layers distributed as shown in the next figure:

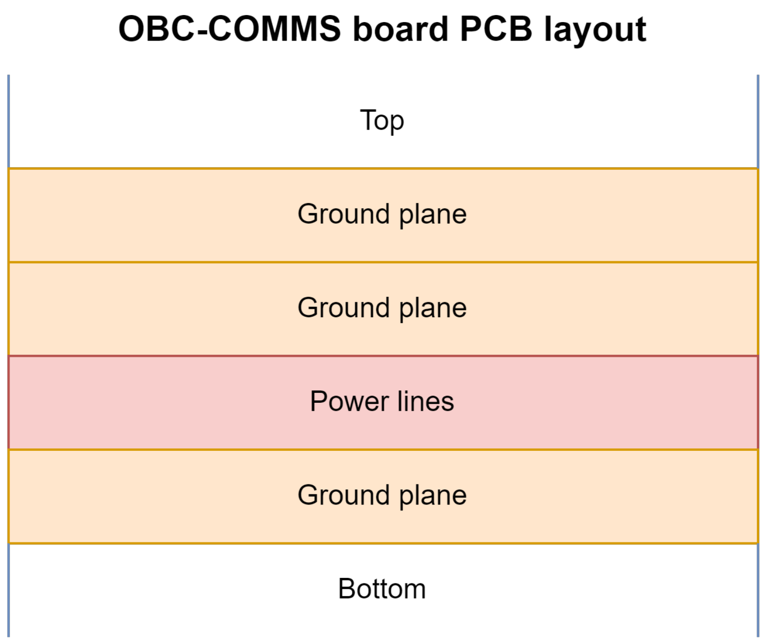


Figure 4: OBC-COMMS PCB Structure

An explanation of the layer distribution is provided next:

Top Layer

- Used for component placement and high-frequency signal routing, especially for LoRa communication circuitry.
- Sensitive to interference.
- Requires a ground plane directly below to maintain controlled impedance for LoRa signals.

First Ground Plane

- Dedicated ground plane that provides a return path for high-frequency signals on the top layer.
- Reduces crosstalk and EMI.
- Forms a microstrip structure with the top layer, ensuring signal integrity.

Second Ground Plane

- Additional grounding layer to enhance isolation between high-frequency signals (top layer) and the power layer below.
- Reduces ground bounce and noise coupling.

Power Lines Layer

- Dedicated layer for power distribution across the board.
- Sandwiched between two ground planes for isolation.

Third Ground Plane

- Provides isolation and noise reduction, serving as a reference plane for the bottom layer. - Adds electromagnetic shielding for the power layer. - Contributes to stable grounding across the board.

Bottom Layer

- Used for additional signal routing or for larger power traces that require less controlled impedance. Redundant oscillators are located on this side as well as PoL controls (OBC).
- Separated from the power layer by a ground plane to reduce interference.

3.3. Key Components

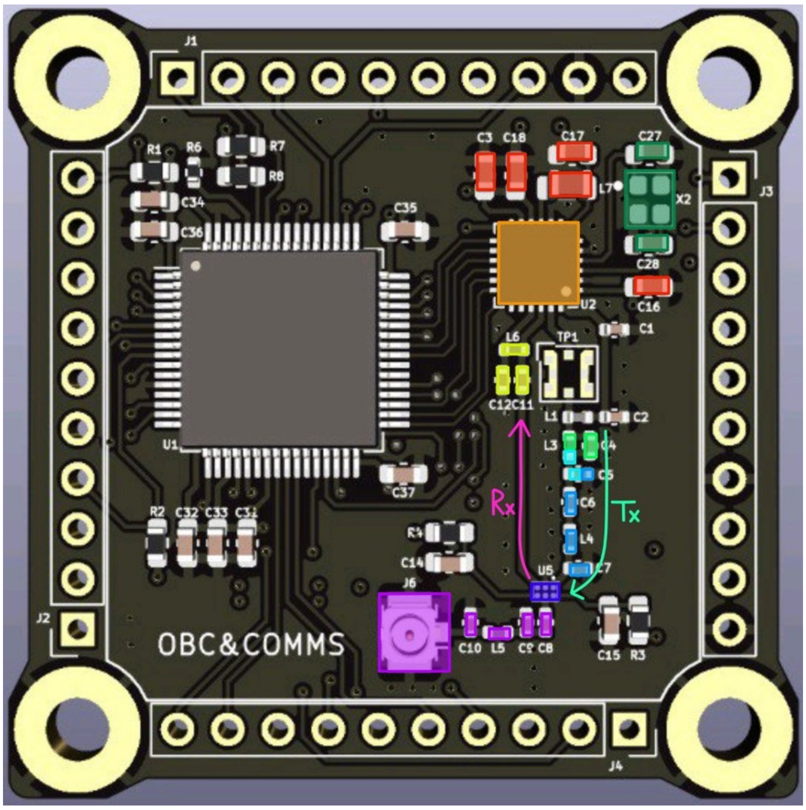


Figure 4: OBC-COMMS PCB With colored blocks

- Power Circuit: This section is tasked with ensuring the proper power supply for the COMMS subsystem. It receives voltage from the EPS Voltage Regulator as well as from the MCU itself.
- Oscillator: The oscillator block is composed by the crystal oscillator itself as well as coupling capacitors to further stabilize the reference signal.
- Transceiver: The main component of the COMMS subsystem.
- Rx Balun & I.M: The balun balances the reception line and impedance matching is performed
- Rx Line: From the switch to the transciver it carries the received RF signals
- Tx Line: From the transciever to the switch it carries the RF signals to be sent.
- Filters & I.M: Two filters provide robustness against high frequencies and maximize voltage at our transmission frequencies. Further information is provided in the following sections.
- Switch: The switch is located between the antenna and it's filtering and the transmission and reception lines. It is controlled by the transciver.
- Antenna / Atenna Matching + Filtering: The antenna is located in a lateral board and can be deployed through the distruction of a dynnema. The received and to be transmitted signals are filtered by a series CC and a LC circuits. The antenna is connected to the board here.

Power Circuit

The power circuit uses the following components:

Capacitors C3/C18 (GRM188R72A104KA35J):

These two capacitors reduce noise to the input voltage of the transciver and avoid undesired voltage peaks.

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 25V	0.1uF	+/-10%	-55 to 125°C	Flow, Reflow

Capacitor C16 (GRM188R61A105KA61D):

This capacitor also avoids coupling from high frecuencies to perturbate the voltage input.

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 10V	1uF	+/-10%	-55 to 85°C	Flow, Reflow

Capacitor C17 (C1608X7R1V474K080AB):

This capacitor is a part required for the DC-DC Configuration of the transciever.

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 35V	0.47uF	+/-10%	-55 to 125°C	Flow, Reflow

Inductor L7 (LQM21DN150M70L):

This inductor is a part required for the DC-DC Configuration of the transciever.

Inductance (μH)	Tolerance	Typ. DC Resistance (Ω)	Max. DC Resistance (Ω)	Self Resonant Frequency (MHz min.)	Rated Current (mA) (Ind Change.)	Rated Current (mA) (Temp Change.)
15	±20%	0.95	1.235	24	140	250

Oscillator:

The oscillator block is comprised by the oscillator itself as well as two decoupling capacitors (C27/C28). As of most current design this capacitors are not connected due to the use of the provided internal capacitors in the SX1262.

Transceiver:

No relevant components are to be explained of the transciever as they are comprised in other parts. The transciver datasheet is attached here DS SX1262.

Rx Balun & I.M + Rx Line:

The impedance is matched considering a 50Ω load in each side of the line. The values are selected following the reference design provided by Semtech as seen on page 27 of the following document: RT/TX Values

Inductor L6 (LQW15AN15NH00D):

Inductance (nH)	Tolerance	Max. DC Resistance (Ω)	Self Resonant Frequency (gHz min.)	Rated Current (mA) (Ind Change.)
15	±3%	0.16	5.0	450

Capacitor C12 (600L1R8BW200T):

Capacitance	Voltage Rating	Tolerance	Temperature Coefficient	Minimum Operating Temperature	Maximum Operating Temperature
1.8 pF	200 V	0.1 pF	0 PPM / C, 30 PPM / C	-55 C	+125 C

Capacitor C11 (600L2R4BW200T):

Capacitance	Voltage Rating	Tolerance	Temperature Coefficient	Minimum Operating Temperature	Maximum Operating Temperature
2.4 pF	200 V	0.1 pF	0 PPM / C, 30 PPM / C	-55 C	+125 C

Filters & I.M + Tx Line:

The transmission line values are also selected following the reference design RT/TX Values and the selected components are the following:

RefDes	Package	Value	Qty	Description	Manufacturer Code
C1	0402	47nF	1	Multilayer ceramic capacitors X7R ±10%, 16V	GRM155R71C473KA01J
C2	0402	47pF	1	Multilayer ceramic capacitors C0G ±5%, 50V	GJM1555C1H470JB01J
C4	0402	3.3pF	1	Silicon RF Capacitor 200V 3.3pF ±0.1pF	600L3R3BT200T
C5	0402	5.6pF	1	Multilayer ceramic capacitors C0G ±0.25pF, 50V	GRM1555C1H5R6CA01D
C6	0402	39pF	1	Multilayer ceramic capacitors C0G ±5%, 50V	GJM1555C1H390FB01D
C7	0402	2.2pF	1	Silicon RF Capacitor 200V 2.2pF ±0.1pF	600L2R2BT200T
L1	0402	47nH	1	Wirewound Inductor ±2%	0402DC-47NXGRW
L3	0402	2.5nH	1	Wirewound Inductor ±0.2nH	LQW15AN2N5C00D
L4	0402	4.7nH	1	Wirewound Inductor ±2nH	0402DC-4N7XGRW

Atenna Matching + Filtering:

The antenna filtering values are also provided on RT/TX Values and the selected components are the following ones:

RefDes	Package	Value	Qty	Description	Manufacturer Code
C8	0402	39pF	1	Multilayer Ceramic Capacitors C0G ±5%, 50V	GJM1555C1H390FB01D
C9	0402	3.3pF	1	Silicon RF Capacitor 200V 3.3pF ±0.1pF	600L3R3BT200T

RefDes	Package	Value	Qty	Description	Manufacturer Code
C10	0402	3.3pF	1	Silicon RF Capacitor 200V 3.3pF ±0.1pF	600L3R3BT200T
L5	0402	9.1nH	1	Wirewound Inductor ±2%	LQW15AN9N1G8 ZD

3.4. Design Considerations

Here are some desing considerations taken into account when designing the COMMS side of the PCB, but take into account that the main priorities in the design are to ensure both the fitting of the components as well as their full functionallity in accord to the requirements. After those conditions are met importance is given to basic good practice design guidelines such as:

- **Component Placement:** Critical components, including inductors (e.g., L6) and capacitors (e.g., C12, C11) in the RF signal chain, are placed close to one another to minimize parasitic effects.
- **Matching Network and Filter:** The components along the RX and TX paths are positioned near the IC and connected through short traces.
- **RF Trace Layout:** The RX and TX paths (marked with pink and green arrows) are straight and avoid sharp angles, improving RF signal integrity.
- **Power Filtering:** The use of capacitors and inductors near power inputs and close to ICs ensures that high-frequency noise is filtered out. The capacitors are also placed close to ground to improve noise reduction.
- **Oscillator Placement:** The oscillator is located away from the RF signal paths, which reduces the risk of interference from clock harmonics.
- **EMC and Via Stitching**: The board includes via stitching in the corners and around the perimeter, and the layout keeps return paths close to the corresponding signal paths.

Overall good practices and PCB Guidelines are also provided by the manufacturer in the following document: PCB Guidelines

4. State of the art

The communication methods employed by other satellites bear a strong resemblance to ours, albeit with some differing aspects such as signal frequency and power. For instance, in the case of Alba Orbital PocketQubes, the transceiver operated within the 145/435 MHz range from the radio amateur band. Additionally, other types of satellites like CubeSats have the flexibility to incorporate power amplifiers, enhancing signal strength, an option not feasible for PocketQubes due to their restricted size and power limitations. Consequently, the power and bandwidth capabilities of signals in other satellites enable them to achieve higher data rates and transmit data of superior quality.

In the general structure, the fundamental principle remains consistent: a transceiver is responsible for both transmitting and receiving signals. These signals undergo filtration in the transmission and reception chains, modulation and demodulation before being distributed to their respective destinations.

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