Master's Degree in Space and Aeronautical Engineering

UNIVERSITAT POLITÈCNICA DE CATALUNYA

Design and implementation of a single On-Board Computer for CubeSats

Author: Carlos Molina Ordóñez

Director: Miquel Sureda Anfres

Co-director: Adriano José Camps Carmona

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NANOSAT LAB

UNIVERSITAT POLITÈCNICA DE CATALUNYA
BARCELONATECH
Escola Superior d'Enginyeries Industrial, Aeroespacial i Audiovisual de Terrassa

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Abstract

This document reports the process of design, implementation, and testing of an On-Board Computer for CubeSats in a single 1U-sized CubeSat PCB. The aim is to design a modular, cheap, efficient and flexible product than could be easily reproduced and implemented in forthcoming CubeSats missions. The document describes all the hardware design phases, from the selection of components to the creation of the circuits and blocks, following with the physical design of the layout in two stackable boards, and finally the actual integration and subsequent electrical test of the components.

The project ended successfully with a prototype of the OBC allowing the boot of a Linux operative system from a µSD card, and the documentation needed to reproduce the work and manufacture new products.

Resumen

En este documento se describe el proceso de diseño, implementación y verificación de un Ordenador de a bordo (OBC) para CubeSats en una única placa de tamaño estándar 1U. El objetivo es diseñar un producto modular, barato, eficiente y flexible con la idea de que pueda ser fácilmente reproducido e implementado para próximas nuevas misiones espaciales usando CubeSats. En el documento se detallan todas las fases de diseño del hardware, desde la selección de componentes, a la creación de los circuitos y bloques, siguiendo con el diseño físico del layout de 2 placas apilables, y finalmente la integración y posterior verificación eléctrica de los componentes.

El proyecto fue terminado satisfactoriamente con la fabricación de un prototipo de OBC que permite arrancar un sistema operativo Linux desde una tarjeta µSD, junto a toda la documentación necesaria para reproducir y fabricar nuevas unidades.

Acknowledgement

First of all I would like to thank my tutor Adriano for all the help, advise and motivation during the whole project. Also thanks to Miquel for recommend me working with the NanoSat lab team and all his enthusiasm with me and the project.

I also have to mention other members of the NanoSat lab team like Juan Fran, for his help and advise on the design and debug of the OBC, Marc and Albert for teaching me to solder and all the help with the practical hardware part, Lara for helping me with the Altium software and Joan Adrià for the general knowledge he transmitted to me on CubeSats systems and architecture. Finally I have to thank my college Isaac, who developed the software that would run this OBC, for helping me with the definition of the system and the days in the lab debugging the set-up of the software. I hope seeing this Linux running on the OBC very soon.

Also thanks to the friends I made during this year in the Master for all the support, advise and good times together. And, at last, I have to thank my family, my parents and my sister for being there, even in the distance, always encouraging me to continue working and give my best in what I'm doing.

Abbreviations

- **ADC:** Analog-to-digital converter
- **ADCS:** Attitude Determination and Control System
- **COMM:** Communications subsystem
- **COTS:** Commercial Off-The-Shelf
- **CPU:** Central Processing Unit
- **DC:** Direct Current
- **EPS:** Electrical Power System
- **GPIO:** General Purpose Input/Output
- **GS:** Ground Segment
- **IC:** Integrated Circuit
- **IMU:** Inertial Measurement Unit
- **LDO:** Low-DropOut
- **LED:** Light Emitting Diode
- **LSB:** Least Significant Bit
- **MCU:** Micro-Controller Unit
- **MMC:** MultiMediaCard
- **MPU:** Micro-Processor Unit
- **OBC:** On-Board Computer
- **PCB:** Printed Circuit Board
- **PWM:** Pulse Width Modulation
- **RAM:** Random Access Memory
- **ROM:** Read-Only Memory
- **SC:** Spacecraft
- **SD:** Secure Digital
- **SMD:** Surface Mounted Device
- **SoM:** System-On-Module
- **SPI:** Serial Peripheral Interface
- **TBD:** To Be Defined
- **UART:** Universal Asynchronous Receiver-Transmitter
- **USB:** Universal Serial Bus

Chapter 1

Introduction

1.1 Object of the project

The purpose of the work developed during this final master project is to design, implement and test an unified platform that integrate in a single board, the on-board computer of a CubeSat, in order to reduce costs, power and space.

The proposed OBC shall be able to accomplish the tasks of an on-board computer for satellites, manage the communications between subsystems, process and store information, monitor the status of the spacecraft and its onw, and be able to reset or reboot any subsystem or the OBC itself, receiving commands from a user communicating with the computer.

To do this, this project will face the phases of design, implementation, and testing of the hardware of this OBC, what will be developed along with the design of an embedded GNU/Linux environment for the software of this OBC. The result of this project would be a product that may be replicated and re-built for future CubeSats missions.

1.2 Project description

1.2.1 CubeSats overview

A satellite is an artificial object that is intentionally placed in orbit around some celestial object in order to perform a series of tasks, as, for example scientific measurements, monitoring and observation or to serve as a communications relay between other satellites and/or Earth based

Table 1.1: Satellites categorized by mass

Name	Mass (kg)
Large satellite	> 1000
Medium satellite	500 to 1000
Mini satellite	100 to 500
Micro satellite	10 to 100
Nano satellite	1 to 10
Pico satellite	0.1 to 1
Femto satellite	< 0.1

stations or devices.

Traditionally, the satellites were quite large and expensive, and they could be launched just by international agencies like NASA or ESA or big companies. The cost of designing, manufacturing and launching was huge. However, during the last decade, it has been popularized the use of smaller, cheaper satellites that actually are changing the space exploration and exploitation. Nowadays, a new era is beginning. And it has been proven that a small, cheap satellites may perform very well, providing quite good scientific data, creating communications links that support the traditional means or allowing the test of new technologies in space at much less the price of the old big satellites. Of course, those big satellites are still useful when the quality and the importance of the mission requires the best solution.

CubeSats are just one type of these new smaller satellites. The table 1.1 categorizes the satellites according to its mass.

A CubeSat is a particular kind of nanosatellite that has some specific constraints. The size of the satellite is defined by multiples of 10 cm × 10 cm × 10 cm cubic units, and its mass should not exceed 1.3 kg. The CubeSat standard started in 1999 when the effort of Prof. Jordi Puig-Suari of California Polytechnic State University and Bob Twiggs of Stanford University, both in the United States, proposed this kind of small satellites and succesfully worked in the definition of this standard with the aim of giving graduate students the option to really design, build, test and operate a spacecraft in a similar way as big, traditional satellites.

The first satellite was launched on 2003, and since then, the number of satellites per year has been continuously rising, as seen in figure 1.1. During 2019, the overall number of CubeSats launched exceeded the thousand.

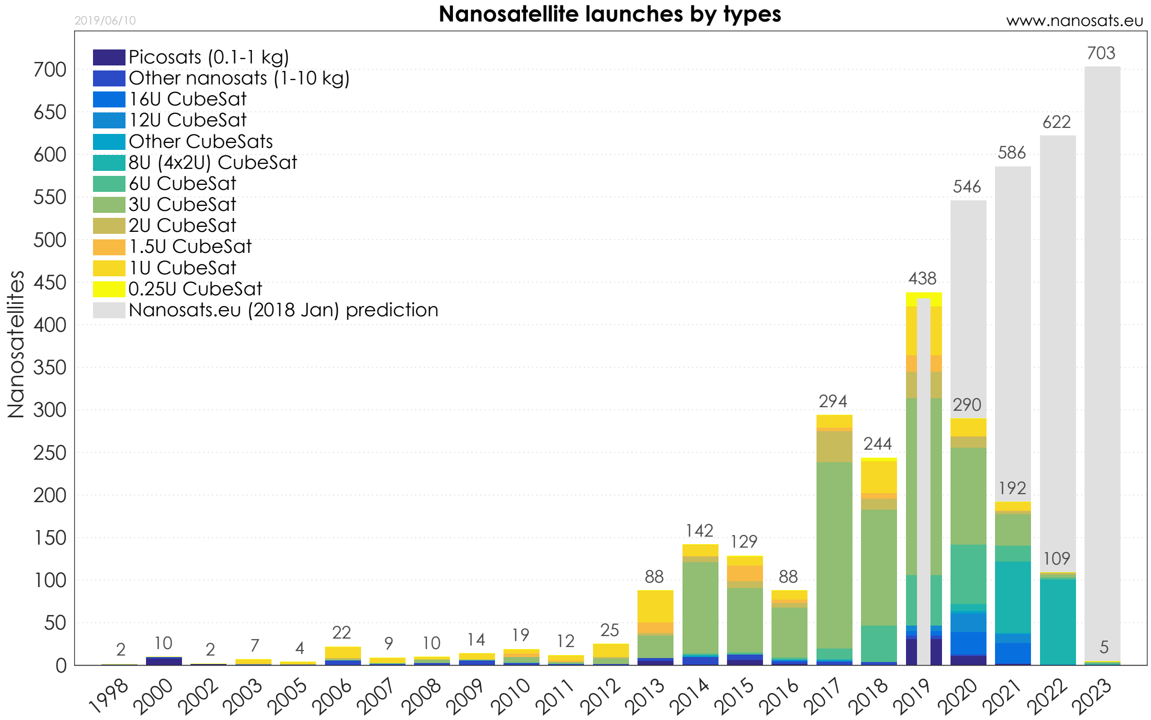


Figure 1.1: Number of nanosatellites launched per year and type by June 2019. "Erik Kulu, Nanosats Database, www.nanosats.eu" [5]

CubeSats are usually manufactured with cheap commercial off-the-shelf (COTS), components for its electronics and mechanics. Also, recently, many companies have begun to work in this field. Both in the manufacturing and design of CubeSats and components, and also in the exploitation and control of these new products.

Focusing now on the design and manufacture of a CubeSat, it must be analysed what are the needs of an spacecraft, and how are they usually faced.

A spacecraft is a vehicle that would fly through the space in orbit, typically around the Earth, but it could be another celestial body. In this case we are focusing on unmanned vehicles, so it needs to provide its own energy, and should be able to communicate with ground stations in order to send payload data back, or upload commands to the SC. This is not something new, created for CubeSats, in essence is the same as the way that traditional satellites work. The common way to manage these tasks is by the definition of subsystems that would be in charge of certain aspects of the SC operation.

1.2.2 Subsystems overview

1.2.2.1 EPS

The Electrical Power System (EPS) is the one in charge of generate, accommodate, store and distribute the electrical power to the rest of subsystems. This is usually made by means of the solar radiation that generates power using some solar panels. Then, the energy is regulated and stored, while distributed to the rest of components.

The use of batteries to store the power is usually needed because during its orbit around the Earth, it could exists some periods of shadow; so if you want to keep the SC working during this time, you need to have generated enough energy during the day period and have stored it in batteries.

1.2.2.2 COMMS

The COMMunicationS subsystem should enable the SC to send and receive information from ground stations in order to command the SC, receive data acquired by the satellite and even send updates or repair part of the on-board software.

It is done usually using antennas and an electronic circuit that generates and amplifies the signal that wants to be transmitted and received. Usually, when transmitting, it is one of the subsystems that demands most energy from the EPS.

1.2.2.3 OBC

The On-Board Computer (OBC) is the main control unit in the SC, that should be able to command and monitor the rest of subsystems and manage the communications between them and with the Ground Segment (GS).

It usually consists of a computer with interfaces to control every subsystem and some amount of storage for the on-board software and the data that may be stored on-board and that is managed by the, sometimes called, On-Board Data Handling (OBDH) subsystem.

1.2.2.4 ADCS

The Attitude Determination and Control System is the one in charge of learning the actual position and orientation of the SC and the actuation on its state by physical apply of torques. The way that the attitude of the satellite is controlled is mission-dependant and it can change during the mission itself. Sometimes what is needed is to keep pointing in a certain direction to take pictures, measure something, or communicate with the ground station. Sometimes, what is needed, is that the spacecraft is rotating at certain rate, or not rotating at all.

The determination of the attitude is usually made using sensor, that could take advantage of the Sun and stars positions, the magnetic field or the electromagnetic signals coming from ground stations. This system also measures the rate of rotation of the SC with gyroscopes, and using some algorithms it is able to determine the overall attitude state.

The attitude control is made by using mechanical action of reaction wheels or by using the existing magnetic field with magnetorquers.

1.2.2.5 TCS

The Thermal Control System is the one in charge of monitoring and controlling the temperature of subsystems and components within the SC. In space, there is not air, but the heat could still propagate though radiation and conduction along the structure of the satellite. Given that the SC could live in sunlight and shadow for some periods, the temperature of its part may vary quite a lot with time. All the components, electrical and mechanical have a margin of temperatures to properly work. So the aim of the TCS is to keep its temperature within its limits.

To do that, the TCS uses temperature sensors to monitor the temperature and heaters or dissipation devices to regulate the heat flow in the SC.

1.3 Justification and needs of the project

This project has been done in the context of the UPC NanoSat Lab[6], a laboratory of CubeSats and nanosatellites, part of the Universitat Politècnica de Catalunya (UPC), Barcelona Tech.

In this laboratory a team of engineers and some equipment work on the design, manufacture, and testing of nanosatellites and payloads. The laboratory owns a class 7 clean room to allow the integration of components that are intended to be launched into space. It also has a vacuum and thermal chamber, and a shake table. Also there is electronic equipment to test and manufacture the electrical boards and systems.

Part of the team is currently manufacturing a satellite that will be launched in 2020 as part of the ESA program "Fly Your Satellite", that is named "**3CAT-4**" [7]. Also there is other projects running as the creation of a ground station and operation centre.

Also, in parallel with the current missions there exists a project, commonly named "**3CAT-NXT**", that accounts for an innovation project where new solutions are investigated and tested. During this year it have been developed some projects under this label with the aim of design a set of subsystems to, in the end, build a full functional satellite by our own, not relying in external suppliers. The justification to this approach is, first of all, reducing the economical cost of buying the subsystems and components to external suppliers, but also, a partial reduction on the risks by the fully understand on the product used. Also, doing our own technology it can be more easily changed or adapted to our real needs.

In this context, some projects were initiated. One must be in charge of the EPS subsystem, designing all the components to properly generate, regulate, store and distribute electrical power to the CubeSat.

My project has been the design of the on-board computer module. The main purpose of that is to try to substitute the use of external suppliers, which is the case of some current missions like 3CAT-4. In order to accomplish that task, I was asked to develop the hardware of this brand new OCB and my college Isaac Montsech was in charge of designing a new embedded Linux Operative System to run on it, allowing the desired functionality. All the work he has been doing from January to June 2019, is covered in his final degree project [8], which I will use as a reference in many points because lots of aspects of my project may be affected by software factors, and viceversa.

1.4 State of the art

As the field of CubeSat is a very active one, despite its relatively recent birth, it can be found many references on developed on-board computers both in the technical literature as also in the market.

In a work from the Norwegian University of Science and Technology, (Normann 2015 [9]), exposes an extensive review of the requirements of an OBC system for CubeSats looking for solutions to an existing OBC developed for his "NUTS" satellite, discussing how to improve the microcontroller and the memories.

In a study of the Manipal Institute of Technology (India)[10], they describe a CubeSat formed by a main platform and a payload were they used 2 on-board computers connected by I2C. The one used for the platform is a Texas Instrument MSP430 microcontroller, which communicates with the ADCS subsystem and COMMS. This MCU has a very low power consumption of 0.022 W at nominal operation. The second microcontroller consists a STM32F207 ARM processor which is in charge of the image processing as part of the payload. Due to the limited RAM and ROM storage that this MCU has, an external SRAM and Flash memory has been used.

Additionally, many commercial options are available in the market. One of them is the one used for 3CAT-4 mission in the laboratory, the GOMSpace®NanoMind™A3200 [11]. This OBC consists in a single, stackable board that measures ($65 \times 40 \times 7.1$ mm), and weights 24 g.

Another example is the OBC developed by the Dutch company ISISpace®, "*iOBC*" [12], that already has flight heritage, with a cost starting from 4400 €, it integrates a 400MHz 32-bit ARM9 processor with FreeRTOS operative system and 512 KB of FRAM (non-volatile storage) and 64MB of SDRAM. This system is integrated in a single CubeSat-sized board of (96 mm $\times$ 90 mm $\times$ 12.4 mm), and it provides I2C, SPI, 2×UART, GPIOs, 8×ADC, 6×PWM and JTAG interfaces.

Finally, "*CubeComputer*" [13] an OBC from CubeSpace®, is a general purpose nanosatellite computer with a built-in 32-bit ARM Cortex-M3 MCU at 4-48MHz, with 256 KB of EEPROM, 4MB flash for code storage, 2×1MB SRAM storage, and µSD socket for external storage up to 2GB. As interfaces, it has 2× I2C ports, 1× debug UART, 1 CAN bus up to 1Mbps, 4×PWM, 4×ADC, and SPI.

1.5 Environmental impact

This project, given that its purpose is to design a part of the hardware for a possible future spacecraft, it has the environmental impact as every space mission.

One of the major environmental impacts of spacecrafts is the contamination of the space surrounding the Earth, both by the satellite itself, and the possible, not desirable, unattached parts due to failures in the design or the operation, or maybe, after a catastrophe like a collision in orbit. Also, sometimes, as a consequence of the launch, some stages of the main launcher vehicle or parts of it, may stay in orbit, at least for some time. All this concern is what is called **space debris**, and it is a very worrying topic, which is becoming more important during the last decades as the act of launching objects into space has become cheaper and more accesible to more countries and companies every day.

Several decades ago, the only objects in space were just a few, big, expensive satellites and probes launched by big agencies and a limited number of countries. Nowadays, it is relatively easy and cheap to create something able to orbit the Earth, and lots of new countries, institutions and companies are launching technology into space. This has a fascinating lecture in terms of improving the technology and disseminate the knowledge around the globe, which would also contribute in better understanding of our own planet and a positive impact in our lives.

But, in contrast, the proliferation of these cheap technologies to access space may become a problem. The problem is the massification of near space around the Earth with small and every-day, less controlled satellites. This is due to the large number of satellites and the difficult coordination between nations, companies and institutions to settle the basis of a legal international frame to regulate the space traffic and establish clear decommission guidelines for every object put in orbit.

Regarding this aspect, this project consists in an specific type of spacecraft that has its own distinctive properties, a CubeSat. CubeSats use to be orbiting the Earth in Low Earth Orbits (LEO), with altitudes around 300 km to 500 km. The size of the spacecraft is well defined according to the standard of CubeSats and also its weight. And usually, they do not make use of active propulsion systems Taking into account that, the atmospheric drag is not negligible, and that is the main cause of deorbiting for these satellites. They use to stay in orbit less than 7 years [14], for 1U, 2U or 3U CubeSats in orbits around 500km.

Also, given the small size of the satellite, and the huge re-entry speeds, in the end all the mechanical and electrical components use to deintegrate and burn in the atmosphere.

Another environmental impact of space missions is the pollution of the launch itself, both in terms of atmospheric pollution with combustion result gases, but also with acoustic pollution, both harmful for the fauna and flora of the launch pad environment.

Chapter 2

Development of the project

2.1 The on-board computer

The main objective of this project, as justified in section 1.3, is the manufacture of and On-Board Computer, briefly introduced in 1.2.2.3. So, from now, the document would try to describe all the work done to accomplish this task. First of all, it is needed a more in depth description of what an OBC is, but in particular, on what this OBC is intended to do.

The OBC is the main brain of the satellite, and it may be able to control and/or communicate with all other subsystems. The user of the satellite, in general would want to communicate with the satellite, sending and receiving commands and data; and all this information would have to be managed by the OBC. Some of these functions are summarized in the next diagram of functions (table 2.1), which would translate, the functions that the user may want to to do, to functions that the OBC would have to implement.

These functions have to be implemented by the OBC as a system, sometimes they are more related to software functions, but other are also mixed with the hardware architecture. What is clear is that software and hardware has to follow very close ways and both has to be consequent with these functions.

Table 2.1: Diagram of functions

User	OBC
Formatting/partitioning a non-volatile memory	Formatting/partitioning an SD card
Send/receive commands to the OBC	Communicate with COMMS subsystem
Flash the kernel Flash the user code Read microcontroller registers Change configuration	Read/write memory
Reboot the OBC	Reboot himself
Monitor OBC status	Monitor himself: CPU load RAM usage Disk usage System temperature
Power on/off other subsystems Switch between operational modules Send commands to other subsystems	Communicate with other subsystems
Execute tasks in real time Load time into the clock	Store a real-time clock

2.2 Project organization

2.2.1 Project plan

The project started in the beginnings of February 2019 in the NanoSat Lab, as an idea to reduce the cost of externally provided OBC modules, as mentioned in the previous chapter 1.3. At the same time, Isaac Montsech begun his parallel project that tries to develop the linux-based software that would be implemented on this OBC. Since that moment, we had weekly meetings with our supervisor Adriano Camps and other colleges involved in the context of 3CAT-NXT projects.

The full project lasted from February 2019 to September 2019, when a first version of the resultant OBC was tested working as expected. The project plan with detailed tasks and its schedule is reported at the end of the document in the Appendix C using a Gantt diagram.

2.2.2 Requirements

To start defining the OBC module, it is mandatory to write down a list of requirements that the product shall accomplish. These requirements are derived from the diagram of functions presented in previous chapter 2.1, taking them and creating a more precise definition of the tasks and design aspects that the system must have. After that, these requirements will translate into design decisions, and the work would start by designing a schematic circuit that satisfies them. Table 2.2 lists the requirements of this project.

These requirements uses a naming convention to identify them that is as follows: ⟨Field⟩-⟨Type⟩-⟨ID_num⟩, where ⟨field⟩ refers to the subsystem involved, and ⟨type⟩ could be FUNC (Functional), DCP (Design, Configuration & Physical), or PERF (Performance).

Table 2.2: Table of OBC requirements

ID	Description	Test method
OBC-FUNC-001	The OBC shall be able to monitor the status of each sub-system	Functional testing
OBC-FUNC-002	The OBC shall be able to reboot other sub-systems	Functional testing
OBC-FUNC-003	The OBC shall be able to control and command all the devices in the spacecraft through its interfaces	Functional testing
OBC-DCP-001	The OBC shall include at least 1 temperature sensor on its board	By design
OBC-PERF-001	The temperature sensors shall have an accuracy of at least ± 2 ºC	Electrical testing
OBC-FUNC-004	The OBC shall include the following interfaces: - I2C - UART - RS-422 - SPI - SD-MMC	By design
OBC-DCP-002	The maximum number of I2C connections shall be 8	By design
OBC-DCP-003	The maximum number of UART connections shall be 8	By design
OBC-DCP-004	The maximum number of RS-422 connection shall be 8	By design
OBC-DCP-005	The OBC shall include a SD card memory storage of at least 32 Gb	By design
OBC-PERF-002	The OBC shall consume less than 500mW	Electrical testing

Table 2.2 – continued from previous page

ID	Description	Test method
OBC-DCP-006	The OBC shall be integrated in one board that fits the Laboratory Standard: - Width: 90.2 mm - Length: 95.9 mm	Mechanical testing
OBC-DCP-007	The components that could generate electromagnetic interferences shall be shielded	Electromagnetic testing
OBC-ENV-001	The OBC board shall withstand vibration tests	Mechanical testing

2.3 Schematic design

The first task to accomplish in the creation of the proposed On-Board Computer is to start designing the hardware components that it will use. This task is performed by following the guidelines imposed by the requirements described in section 2.2.2.

The schematic design phase of the project should take the functions and requirements of the defined system and translate them into a real electronic circuit. This process comprises several tasks that must be followed in order and sometimes they may be iterated.

The first step to start the hardware design is to define a number of major blocks to perform main tasks of the OBC. In our case, the complete schematic of the OBC may be organized in the following parts or blocks:

1. Core
2. Power generation
3. Interfaces
4. Extra functionalities

Each of them has a specific task in the complete system, and they depend on the others. After defining these blocks, the next point is to design exact circuits and sub-circuits, and at the same time select which components would be used. This is done by carefully analysing the initial requirements and ensuring they are achieved.

A first approach to how the global schematic would be like was created before starting the actual design, and can be schematized in the block diagram shown in figure 2.1.

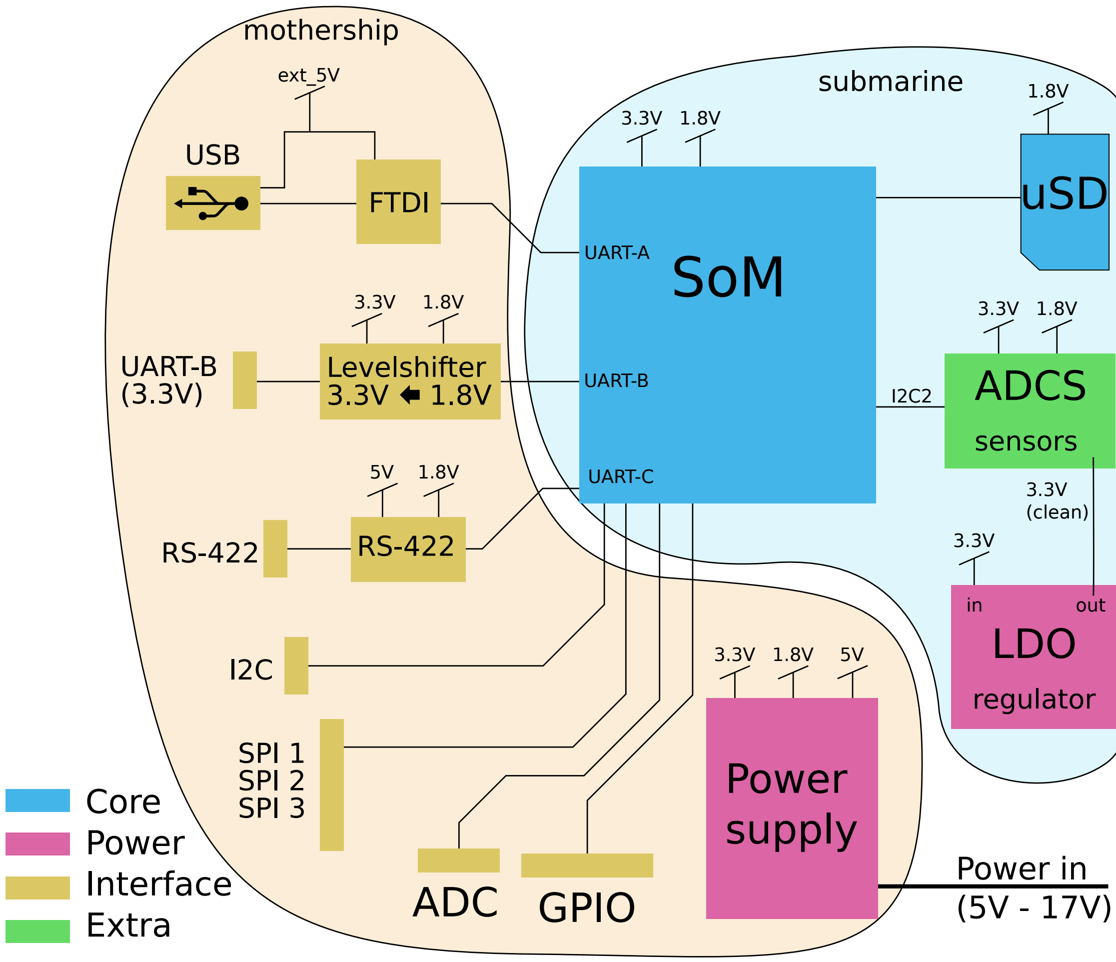


Figure 2.1: Block diagram for the whole OBC design

2.3.0.1 Altium project

To start designing both schematic and layout of the PCB, the EDA software Altium™ [15] is used. This EDA (Electronic Design Automation) tool allows the creation of a project where a library of components can be managed, an schematic created and then, its implementation into the layout of a PCB.

At first instance, after component selection, a library of symbols and footprints was created for the Integrated Circuits, passive components and connectors, including the ones that interface the Torpedo SoM, which was manually created. Other footprints where downloaded from supplier websites and, afterwards, double checked, looking for discrepancies or errors between the dimensions specified in the datasheets.

Once the library was completed, the creation of the proposed schematic started, organizing the full schematic in multiple sheets and creating some hierarchy between them. This hierarchy of files and libraries is shown in figure 2.2.

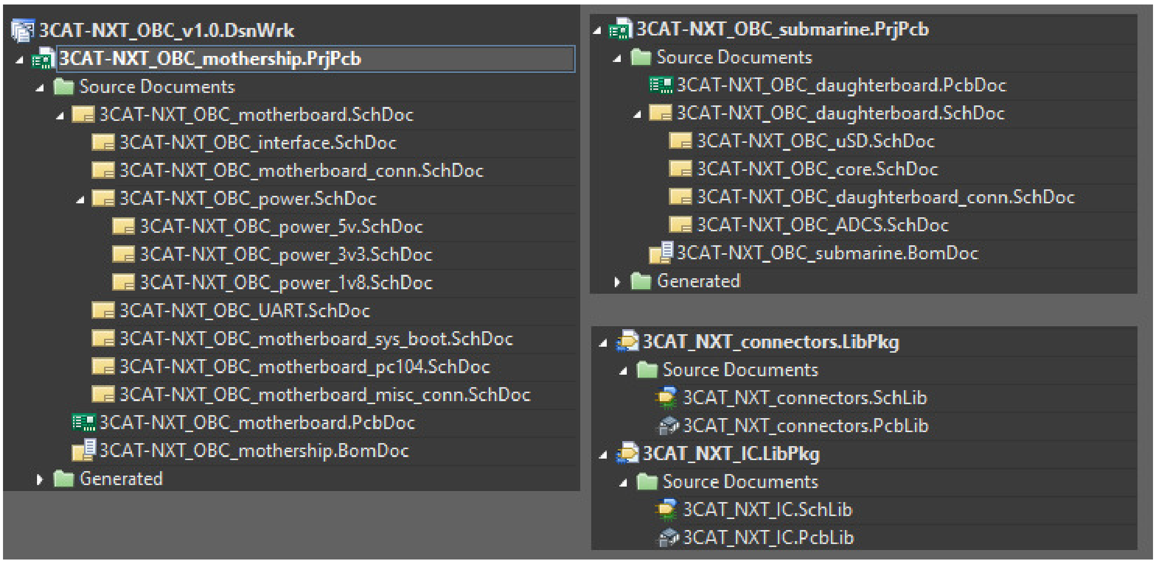


Figure 2.2: Altium workspace created for the project. The left column is the Mothership project, which includes the schematic files organized in sheets and sub-sheets, and the PCB layout.
The right part is the Submarine project and the two libraries created especially for this project: connectors and ICs

2.3.1 Core

The main component to take into account is the core of the OBC, that is the microcontroller (MCU), or microprocessor (MPU) that will be used. Due to the requirements of the OBC in terms of processing power and software requirements, it was decided to use a MPU. The proposed architecture is to use an integrated mini-computer given by an external manufacturer which includes all the basic components of a computer, CPU, ROM and RAM, with several interfaces to communicate with it.

Initially, there were some options considered for that purpose. One option was to use an STM32F4 System-on-Module, as it was used previously in NanoSat Lab to design a prototype of an on-board computer [16]. This consisted of a board that includes:

- Microcontroller: STMicroelectronics STM32F429
- 16 MB NOR Flash: Spansion S29GL128S10DHI010
- 32 MB SDRAM: ISSI IS42SM16160K-6BLI
- Ethernet controller
- External crystal oscillators

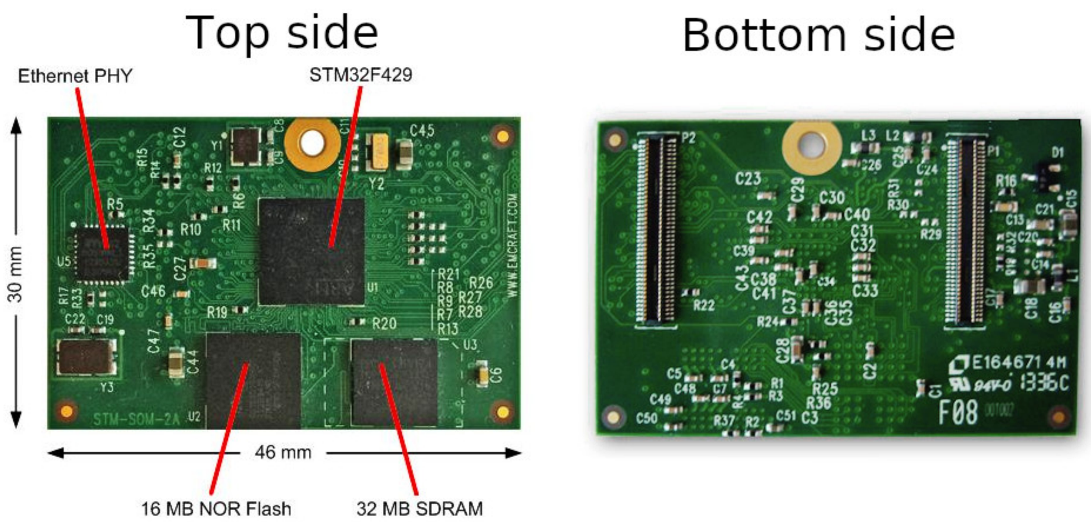


Figure 2.3: STM32F4 System-on-module board

This System-on-module is integrated in a 30mm x 46mm board and is connected by two 100-pin Hirose DF40 series 0.4 mm-pitch board-to-board connectors [17].

Finally, this module was discarded because, for wider possibilities in the future, a more powerful central computer was preferred, bringing more options to even control others subsystems like COMMS, EPS, ADCS. Using a more powerful processor and building a full capable Linux operative system, may have great advantages for future CubeSats missions, allowing more processing load for tasks like communications, attitude and orbit determination and control or any other on-board processing.

The alternative for this module was a microprocessor integrated into a System-on-Module, named as DM3730/AM3703 Torpedo™SoM, commercialized by Logic PD®.

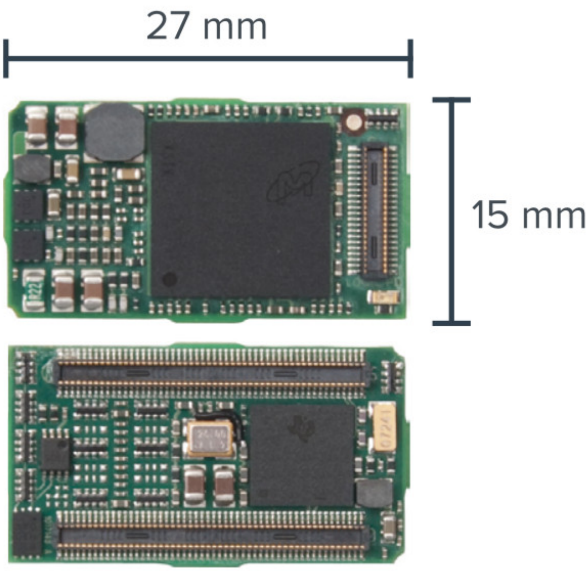


Figure 2.4: Torpedo™SoM

The specifications of the Torpedo SoM are [18]:

- Texas Instrument DM3730 up to 1GHz ARM®Cortex™-A8
- 256MB SDRAM / 512MB NAND Flash memory
- Android, Linux, Windows Embedded CE support
- Industrial temperature (−40 °C to 85 °C)
- 3xUART, 2xMcBSP, 3xSD/MMC, 3xSPI, 2xI2C
- Parallel camera interface
- Ultra-compact form factor (15 × 28 × 3.8 mm)
- Hirose DF40 series 2 × 100 pin 0.4 mm-pitch connectors [17]

The Torpedo SoM has in total 200 pines to connect. Of course, not all of them are of interest for this project. Some of them are used to interface a LCD screen, or to use the external memory interface through GPMC (General Purpose Memory Controller), along with many others. In conclusion, just around 60 signals plus the power supplies are actually connected. The schematic of the connection with to SoM can be seen in figure 2.5.

Also, a circuit that must be mentioned here, related with the Torpedo SoM, is the configuration circuit for the software booting process. The DM3730 includes some signals within its inputs that configures the booting devices priority. These signals are SYS_BOOT[6:0]. Only 0, 1, 3, 4

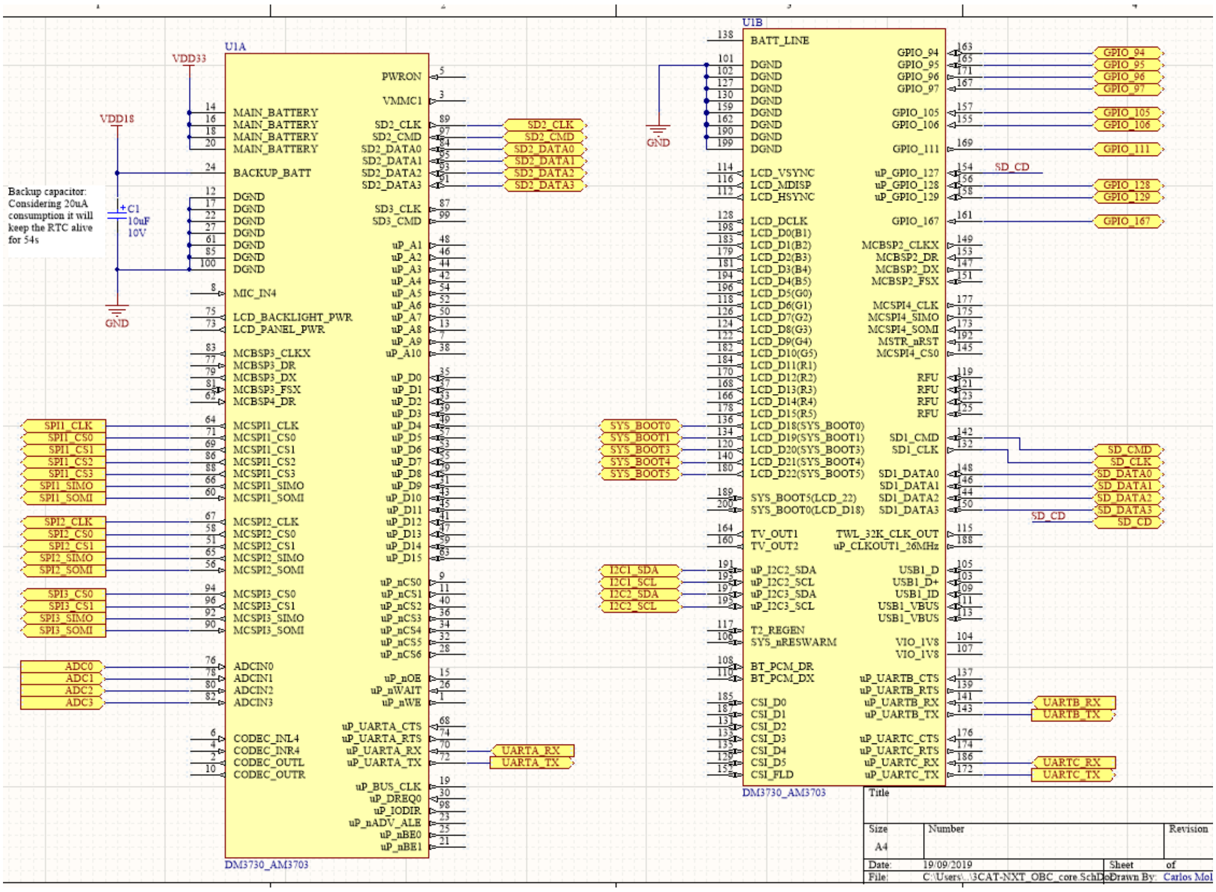


Figure 2.5: Schematic of Torpedo SoM connectors

and 5 are available off-board. Setting them as LOW or HIGH digital values, the boot method can be configured, as described in table 2.3.

This configurability was made accessible to the user by outputting these signals and giving the possibility of shorting them with GND or digital VDD, with 0 Ohm resistors. The schematic in figure 2.6 shows how this is done.

Additionally, around the Torpedo, the OBC needs some components in order to extend and improve the performance of the OBC. Most of them are just a way to interface the outputs and inputs of the board to the CubeSat standard.

2.3.2 Power generation

The SoM and other components in the circuit need a power supply to run. One approach is that the EPS would bring the OBC module the voltages it needs, but this one has the problem

Table 2.3: Configuration signals for boot devices priority

DM3730 processor pins	Boot method
SYS_BOOT[6:0] = 1101111	USB, UART3, MMC1, NAND
SYS_BOOT[6:0] = 1001111	NAND, USB, UART3, MMC1
SYS_BOOT[6:0] = 1001110	XIPwait, DOC, USB, UART3, MMC1
SYS_BOOT[6:0] = 1000110	MMC1, USB

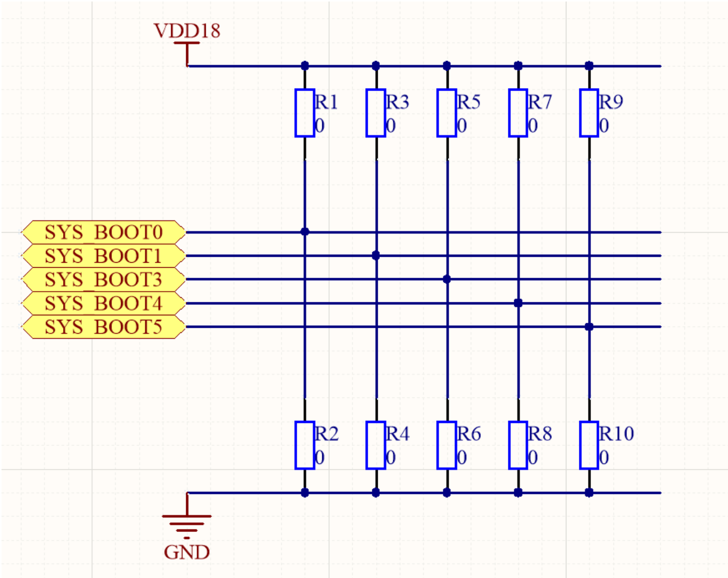


Figure 2.6: Schematic of SYS_BOOT configuration pull up/down resistors

that the EPS would depend too much on the specifications of the OBC, and if they change, the EPS would have to be modified.

The preferred approach is to generate the voltage rails needed just using one input voltage from the EPS. It also has the advantage of being better isolated from external disturbances and noise in the voltage that could be produced by external devices connected to the general power bus.

The main power supply for the SoM is at 3.3V, but it is also needed to generate others points of load at 1.8V and 5V for other devices, as shown in the table 2.4.

The way to obtain these points of load is by using three DC/DC voltage converters that takes the input voltage line from EPS at a certain voltage and outputs the three voltages. The circuit architecture used is a step-down (or buck) converter. So that imposes that the input voltage from the EPS has to be higher than 5V.

Table 2.4: Devices classified by voltage needs

Point of load	Device that uses it
1.8V	RTC Clock of Torpedo SoM Digital supply of ADCS sensors (for I2C) microSD supply Digital input for UART levelshifters
3.3V	Main battery of Torpedo SoM Main power of ADCS sensors Output levelshifters for UART-B
5V	RS-422 output levelshifters for UART-C UART to USB converter for UART-A (debug USB)

Table 2.5: TLV62130 specifications [1]

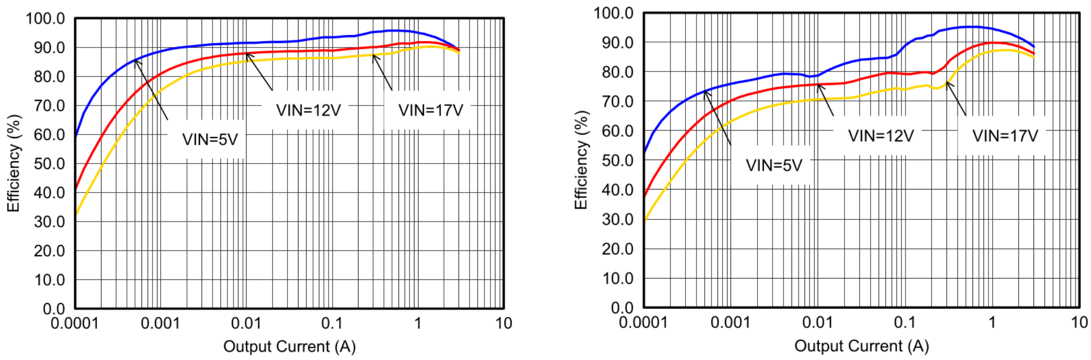
Specification	Value
Input voltage range	3 V to 17 V
Max output current	3 A
Configurable Output Voltage	0.9 V to 5.5 V
Operating junction temperature	−40 °C to 125 °C

The DC/DC voltage converter circuit is based in the Texas Instrument IC TLV62130 [1].

This architecture based on DC/DC buck converters is a good approach for spacecrafts because the efficiency is generally quite high, which is very important in term of the power budget of a mission. This particular IC has the efficiency curves shown in figure 2.7 for the two possible PWM frequencies. It is observed that efficiency is higher for 1.25 MHz, but in the first version of the circuit it was set to the default frequency 2.5 MHz.

So the overall power generation circuit for this OBC was made using the following circuits shown in figures 2.8, 2.9 and 2.10.

Placed before each DC/DC converter, a current limiting and short circuit protection circuit was added using the IC MIC2005-05YM6. This circuit would shutdown the output if the current exceeds 0.5A and also if temperature exceeds 145 °C. The input maximum voltage for the circuit



(a) At 1.25 MHz (b) At 2.5 MHz

Figure 2.7: Efficiency of DC/DC Buck converter TLV62130 for 3.3V output as a function of the output current and different input voltages [1]

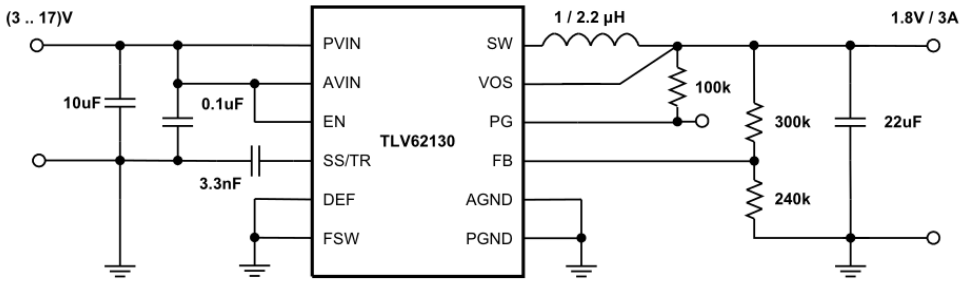


Figure 2.8: DC/DC buck converter for 1.8V rail

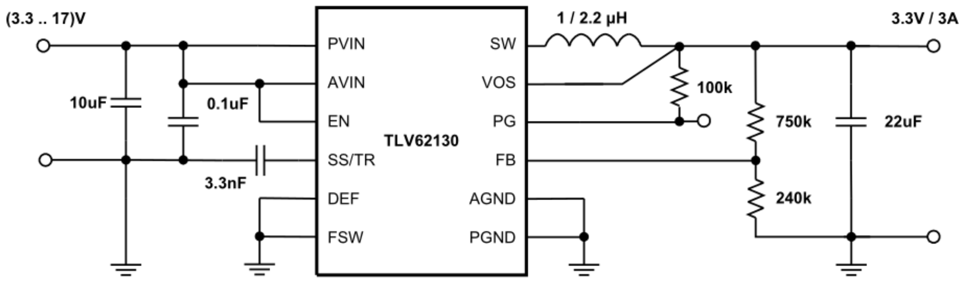


Figure 2.9: DC/DC buck converter for 3.3V rail

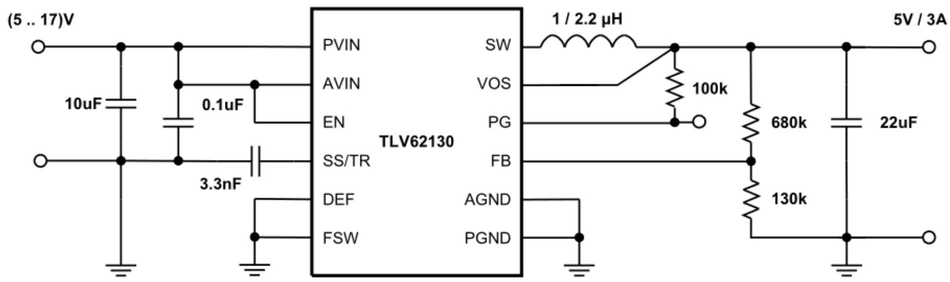


Figure 2.10: DC/DC buck converter for 5V rail

is 5.5V [19]. This is a problem that is discussed in last section ??.

Finally, each branch of power generation (1.8V, 3.3V and 5V) have an schema similar to the one shown in figure 2.11. It has been added a LED to indicate the status of the output, that should be used just with debug purposes, and may be removed for real space missions to reduce power consumption.

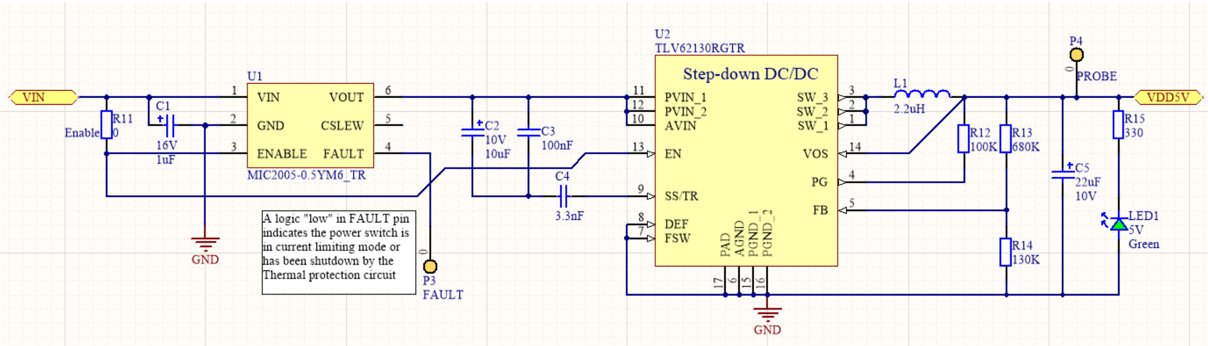


Figure 2.11: Final schematic for 5V power generation

Another remarkable aspect is that, for the power supply of the FTDI chip that converts the UART to USB (as shown in table 2.4), it was used the 5V power rail coming from the external USB connect to the board. By doing this, if there is no USB host connected, there will be no power consumption from the on-board 5V generation. This circuit is depicted in the next section in figure 2.13

2.3.3 Interfaces

As said before, one of the key aspects of the surrounding circuit of the OBC is to serve as an interface for the outputs and inputs of the SoM. In total there are 7 types of interfaces in this OBC, listed in table 2.6:

2.3.3.1 SD/MMC

SD cards (Secure Digital) or MMC (MultiMediaCard) are both digital solid-state storage devices that can be used to write and read information. In our case they can be used to increase the limited storage capacity of the built-in NAND memory of the SoM Torpedo. It can also be used to store the kernel and operative system that the computer will run, so you can easily change

Table 2.6: List of interfaces

Interface type	Quantity	Description
SD/MMC	2	MMC1 (Debug SD card) MMC2 (Optional SD card)
USB 2.0	1	Debug through UART-A
UART	2	UART-B @ 3.3V UART-C to RS-422 @5V
SPI	3	SPI1 (up to 4 Chip Select) SPI2 (up to 2 CS) SPI3 (up to 2 CS)
I^2C	2 (1 external)	I2C1 I2C2 (internal use for attitude sensors)
ADC	4	ADC0 (max 1.5V) ADC1 (max 1.5V) ADC2 (max 2.5V) ADC3 (max 2.5V)
GPIO	10	GPIO_94 GPIO_95 GPIO_96 GPIO_97 GPIO_105 GPIO_106 GPIO_111 GPIO_128 GPIO_129 GPIO_167

the code and recompile it externally, and then test the software running from the SD/MMC card.

The DM3730 allows up to 3 SD/MMC cards [18, 20]. In this prototype of the design, only two would be available. The first one, MMC1, is the debug card, and it is explicitly connected using a µSD slot in the PCB (figure 2.12). The second card has its nets available in the schematic but not connected to any hardware slot. If this is needed in the future, it is just routing these nets until a place to put the connector.

The option of a third card was discarded at first instance because some of the nets to control it actually collide with others, for example, SPI signals. As it will be seen, this is something usual in this SoM, so a trade-off would have to be found in the design, prioritizing some functionalities over others. In this case, it was prioritized having more SPI signals than SD cards –assuming that 2 SD cards are enough for this project.

The schematic of this MMC1 card is just connect each net to the corresponding signal in the SoM and add pull-up resistors for the signals that requires it. This card is powered by the 1.8V voltage

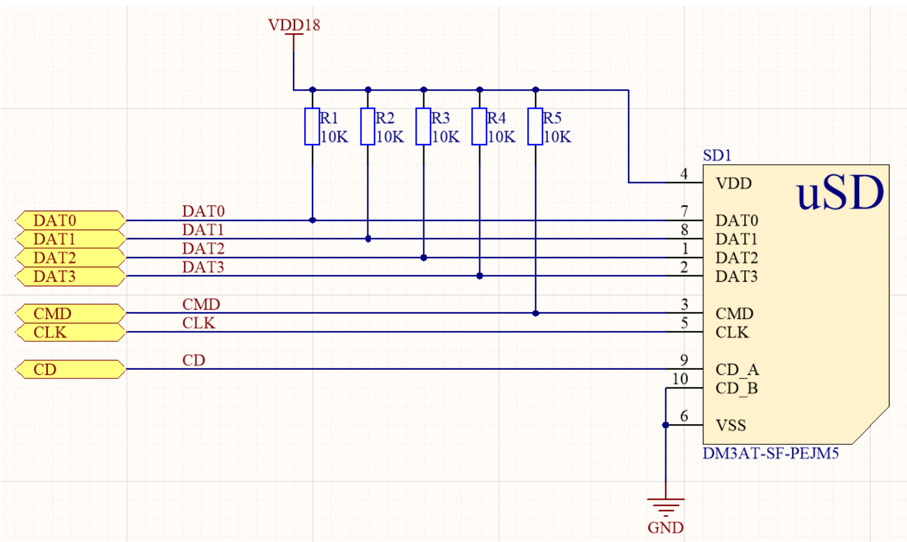


Figure 2.12: Schematic connection of the SD/MMC card

2.3.3.2 USB

The USB is driven from the TX/RX lines of UART-A, which is the one configured by default as debug UART for the SoM Torpedo. These signals have to be translated to 5V by a levelshifter and then the IC FT232RQ [21] does the conversion from UART to USB serial protocol, resulting in a pair of differential nets (USB_P, USB_N) that must be routed to the connector with an impedance less than 90 Ohm.

The power supply is taken from the USB connector 5V rail, which would be generated by the external device connected to the OBC. The overall schematic of this module is depicted in figure 2.13.

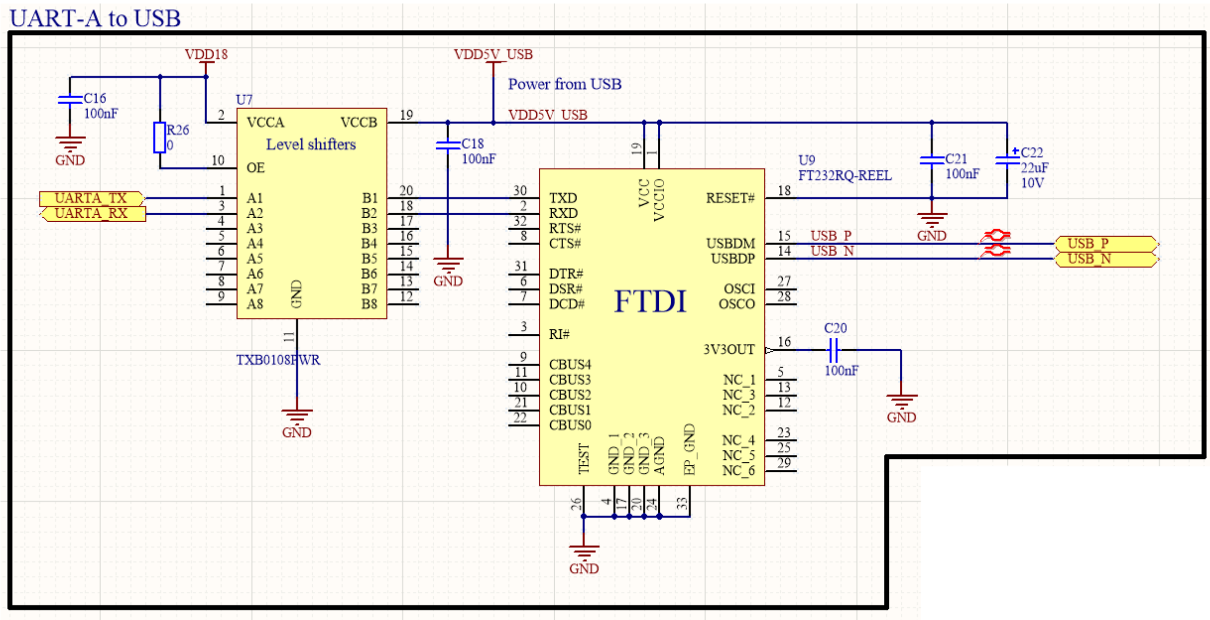
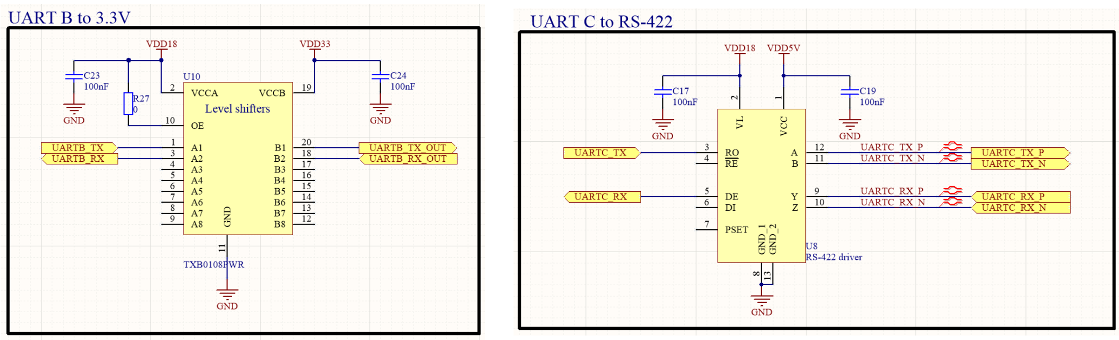


Figure 2.13: UART-A to USB circuit using FT232RQ

2.3.3.3 UART

The other UART interfaces have been also made available to use. UART-B is directly translated into 3.3V using a levelshifter, as shown in figure 2.14a. And UART-C is converted into full-duplex RS-422 serial protocol, that implements differential signalling, helping reducing noise and interferences. This is done by using the IC MAX22502EATC+ [22], which has to be powered by 1.8V in the UART side, and 5V in the RS-422 side, because the differential signal goes at +5V/-5V. The circuit is shown in figure 2.14b.



(a) UART-B translated into 3.3V (b) UART-C converted into RS-422

Figure 2.14: Interface circuits for UART-B and UART-C

2.3.3.4 SPI

Three SPI interfaces are output directly by picoblade connectors, as shown in figure 2.15. One thing to take into account is that the pin SPI_CS3 is configured by default as the SPI3_CLK, so it should have been connected to J10 connector, along with the other SPI3 pines.

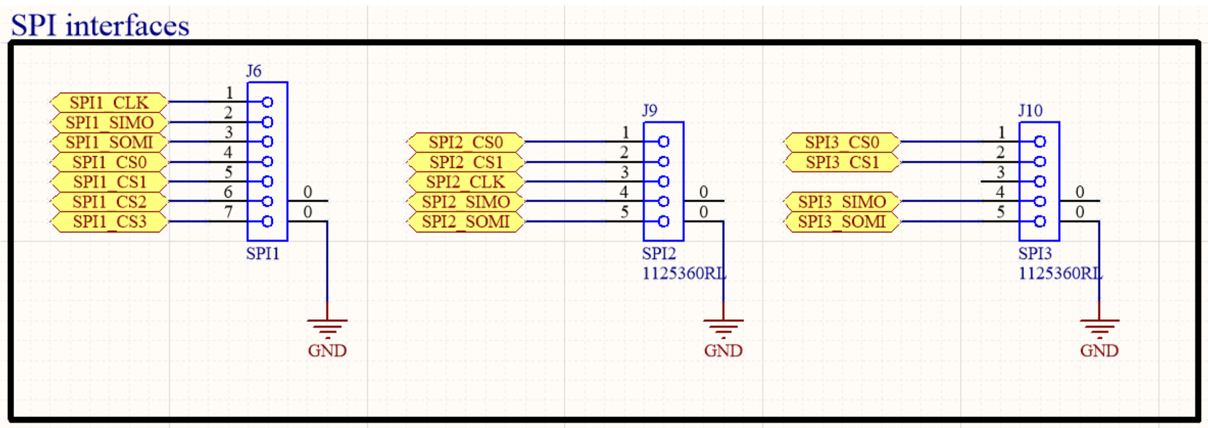


Figure 2.15: SPI interfaces

2.3.3.5 I2C

The SoM has two I2C interfaces. In this version of the hardware, one of them (I2C2) is used internally to communicate with the three attitude sensors, that would be treated in section 2.3.4. So, that means that externally only I2C1 is available with a picoblade connector.

One advantage of the I2C protocol is that it uses just a line for data and another one for the clock, and, it does not use one additional net for each connected device (as does the SPI), so it may allow many devices just using a pair of wires. The only limit is the capacitance of the whole line, that should not exceed 400pF. This capacitance depends on the length of the wires and the number of devices holding from the line.

2.3.3.6 ADC

The SoM provides 4 internal 10-bits ADCs up to 1.5V and 2.5V [20] as specified in table 2.6. If there is a need of having better and/or more ADC inputs, an external ADC chip may be used and connected through one of the available interfaces (SPI, I2C,...).

2.3.3.7 GPIO

10 GPIOs are routed in this version of the hardware. They could be configured, by software, as inputs or outputs, and may be used to control or monitor any signal of interest. More GPIOs would be available from the SoM (see Torpedo hardware specifications document [18]).

2.3.4 Extra functionalities

Finally, it has been implemented other functionalities that every CubeSat mission may use, as a basics. This is a set of attitude sensors. These sensor include a 3-axis gyroscope to measure angular velocity and a 3-axis magnetometer, to measure the magnetic field in the position of the satellite. Additionally it has been added another IC that is a complete IMU (Inertial Measurement Unit), that integrates a gyroscope, magnetometer and accelerometer. The idea of this chip is to have a redundant device that can be used to calibrate the other two, or support the measurement operation.

The specific ICs selected for these tasks were selected together with the attitude team in the lab, taking into account, the attitude related specifications as resolution, range and noise density, but also the interface protocol, voltage range and power consumption.

In terms of power supply, it was preferred 3.3V and the interface could be SPI or I2C. In the end I2C was preferred because, the three sensors could be connected with the same bus and also it was decided that this I2C bus were used only for these ICs, limiting the length of the I2C line to reduce the risk.

As it will be seen in the next paragraphs, these three sensors, may share the power supply at 3.3 V, so they will use the same point of load generated for the main power of the Torpedo SoM. Furthermore, to reduce the noise in the power rail of the sensors, that may be produced by the operation of the Torpedo, or couplings with commutating signals, the supply of these sensors was isolated using a LDO (low-dropout) regulator. It consist a DC linear voltage regulator that has less efficiency of commuting DC/DC converters but is much simpler to connect and also, the power consumption of the sensors is small enough to neglect the losses. The LDO regulator used is the LP5907MFX-3.3 [23], that regulates the output voltage to 3.3V.

The full schematic of this block is shown in figure 2.16.

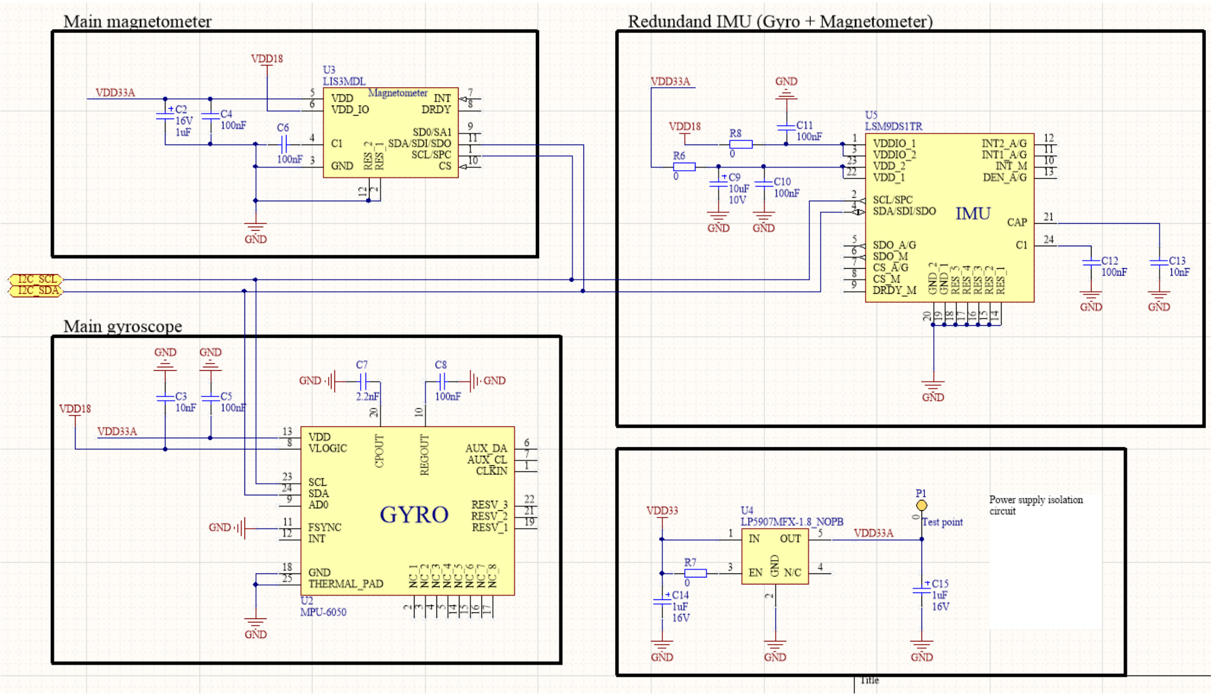


Figure 2.16: Schematic of the ADCS sensors

The following paragraphs give more details of each sensor used.

2.3.4.1 Main gyroscope

The gyroscope selected was the MPU-6050™ from InvenSense®. It has digital output for angular rate in the three axis with user programable full-scale range of ±250, ±500, ±1000 and ±2000 °/s.

Table 2.7: Gyroscope MPU-6050 main specifications [2]

Parameter	Min	Typ	Max
Main power supply	2.375 V	3.3 V	3.46 V
Logic power supply		1.8 V	
Angular rate			±2000 °/s
Resolution		16 bits	
RMS noise @ 100Hz		0.05 °/s rms	
Noise spectral density @ at 10Hz		$0.005\,°/s/\sqrt{Hz}$	
Gyroscope sample rate			8 kHz
Temperature sensor	−40 °C		85 °C
Temperature sensitivity		340 LSB/°C	
Operating temperature	−40 °C		85 °C
Current consumption (only gyroscope)		3.6 mA	

This IC can be controlled by both SPI and I2C, so this last one is the used. The table 2.7 list the main specifications of this sensor.

2.3.4.2 Main magnetometer

The magnetometer selected is the LIS3MDL. This IC implements a low-power high-performance three-axis magnetic sensor. The sensor range covers from ±4 to ±16 gauss. It also includes both SPI and I2C interfaces, this last one at standard and fast modes (100kHz and 400kHz). The table 2.8 summarizes the main specifications of this sensor.

2.3.4.3 Redundant magnetometer + gyroscope

Finally, an ST®Inertial Measurement Unit (IMU), LSM9DS1, was included in the design, to prevent in case of failure of one of the other sensors, or to have a second measurement to compare, calibrate or improve the precision. This IMU has integrated acceleration, angular rate and magnetic field measurements in the three axis. As the other two ICs, it may be commanded by both SPI and I2C. The next table 2.9 details the main specifications.

Table 2.8: Magnetometer LIS3MDL main specifications [3]

Parameter	Min	Typ	Max
Main power supply (Vdd)	1.9 V	3.3 V	3.6 V
Logic power supply	1.71 V	1.8 V	Vdd + 0.1V
Measurement range (FS)	±4 G		±16 G
Resolution		16 bits	
RMS noise (FS= ±12G) XY axis		3.2 mG	
RMS noise (FS= ±12G) Z axis		4.1 mG	
Temperature sensor	−40 °C		85 °C
Temperature sensitivity		8 LSB/°C	
Operating temperature	−40 °C		85 °C
Current consumption (ultra-high resolution mode)		270 µA	
Current consumption (low-power mode)		40 µA	

Table 2.9: IMU LSM9DS1 main specifications [4]

Parameter	Min	Typ	Max
Main power supply (Vdd)	1.9 V	3.3 V	3.6 V
Logic power supply	1.71 V	1.8 V	Vdd + 0.1V
Acceleration range	±2 g		±16 g
Magnetic field range	±4 G		±16 G
Angular rate range	±245 °/s		±2000 °/s
Resolution		16 bits	
Temperature sensor	−40 °C		85 °C
Temperature sensitivity		16 LSB/°C	
Operating temperature	−40 °C		85 °C
Current consumption (accelerometer + magnetic sensor)		600 µA	
Current consumption (gyroscope)		4 mA	

2.4 PCB design

A PCB (Printed Circuit Board), is the typical way of physically implement an electric circuit. It provides mechanical support for the components and also electrical connection between them. A typical PCB is made of a non-conductive substrate, which usually is a composite material, and some layers of some conductive material, usually copper, which is distributed in layers.

During the fabrication of the PCB, the conductive material is etched leaving copper just in the tracks and nets that would be connected together. Also, in order to properly route every net in the circuit, holes are needed to connect different layers of copper. In the technology used in this project, that holes connect all the layers together.

2.4.1 CubeSats constraints

Given that this OBC module is intended to be used in CubeSats missions, it must follow a certain number of constraints related with the size of the board, the connections and interfaces with other modules, the mechanical structure to hold the board.

In terms of the size of the board, every board must fit inside the volume of a CubeSat. Typical 1U, 2U or 3U are elongated and the boards are arranged perpendicular to the long axis of the CubeSat, so the size of the board should fit in the $10 \times 10\,\mathrm{cm}^2$ area section.

Nevertheless, it is also possible to design smaller boards that could connect to a full-sized, square board. One advantage of this is that the same model of circuit could be connected to different baseboards that shares the same interface, which is interesting from the point of view of standardization and unification of the OBC subsystem.

This was the approach when designing this OBC module; a small PCB for the core block and a large PCB for interfaces and power supply. The usual way of naming these type of boards is *Mothership* for the bigger one and *daughterboard* for the smaller. But for my project I personalized this names as "**Submarine**" for the board that holds the Torpedo SOM and "**Mothership**" for the one that connects to the Submarine.

2.4.2 Submarine

At first instance, the Submarine PCB was designed to integrate only the core components (SoM Torpedo and µSD). The Torpedo board size is 15×28 mm, and the µSD connector is around 14×21 mm. The connector between Mothership and Submarine was estimated to have around 80 pines, and a specific connector was selected, explained in next chapter 2.4.4.

Knowing the size of everything included in the board, a estimation of its dimensions was done. The board could measure around 45×65 mm. Then, observing that these dimensions could allow to place two of these boards on top of the standard size of a CubeSat board [24], the definitive dimensions were adjusted to 40×66 mm. Reducing the horizontal length from 45 mm to 40 mm, two boards can be placed together with a small separation, not exceeding the standard width of 90.17 mm.

A sketch of the disposition of these components in the Submarine is shown in figure 2.17. Finally, it was decided to also include the attitude sensors in the same board, because there was enough place for them and also to keep one of the I2C ports in the Submarine board, without using pines of the inter-board connector.

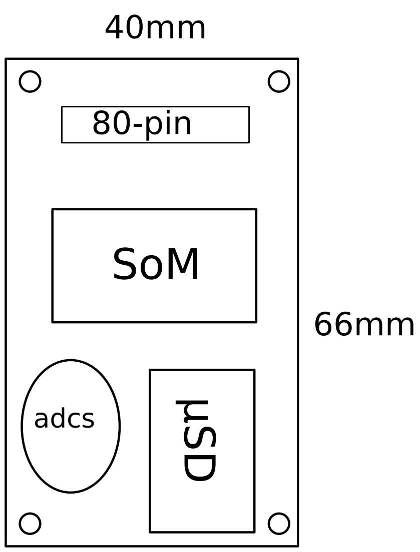
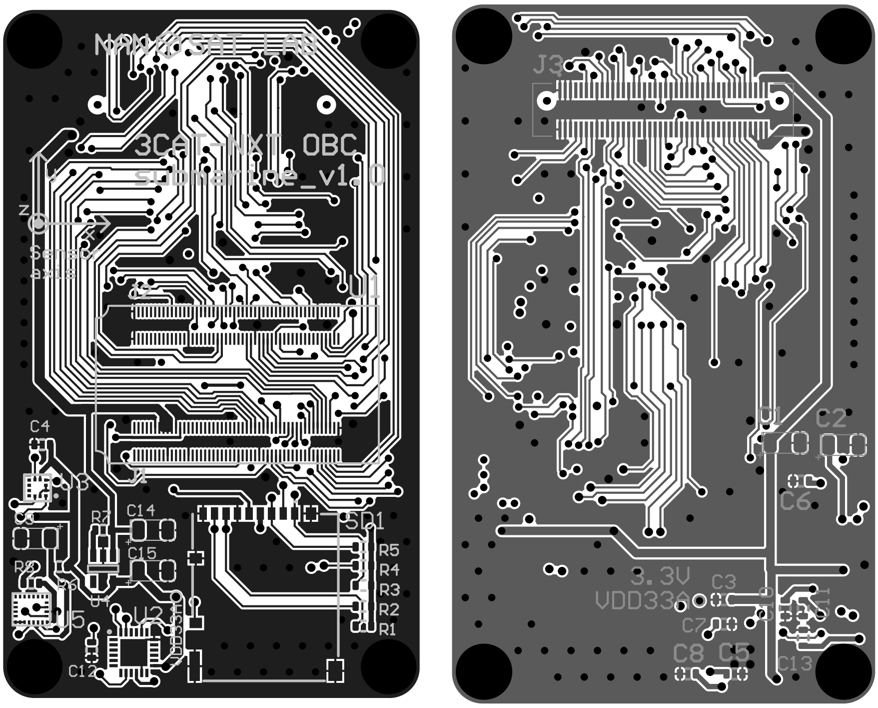


Figure 2.17: Estimation of area for Submarine board

After the area estimation, the process of placing and routing started. Was during this time that I realized that the board would have to be with 4 layers, not just 2 (top and bottom). This was due to that the high congestion of pines of some components like the Torpedo SoM and also the

80-pin connector, did not allow to route them without using more layers.

Finally, the board was completely routed, and the result can be seen in figure 2.18, just the top and bottom layers. Layers 2 and 3 have just some lines. All the areas where there is not a net, where filled by a polygon connected to ground (GND), that also helps improving the ground connection.



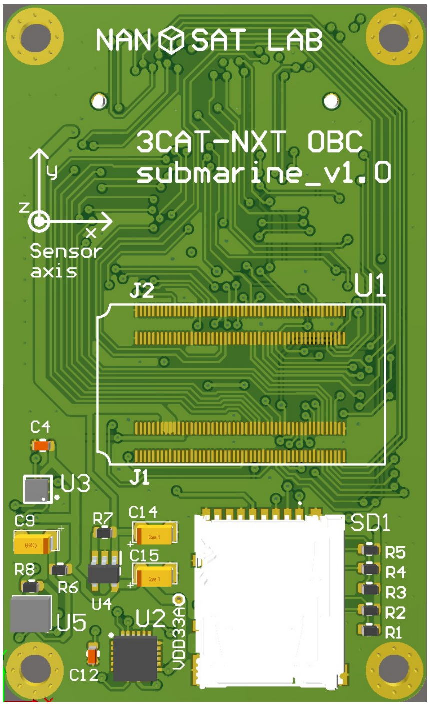
(a) Top side (b) Bottom side

Figure 2.18: Submarine PCB layout

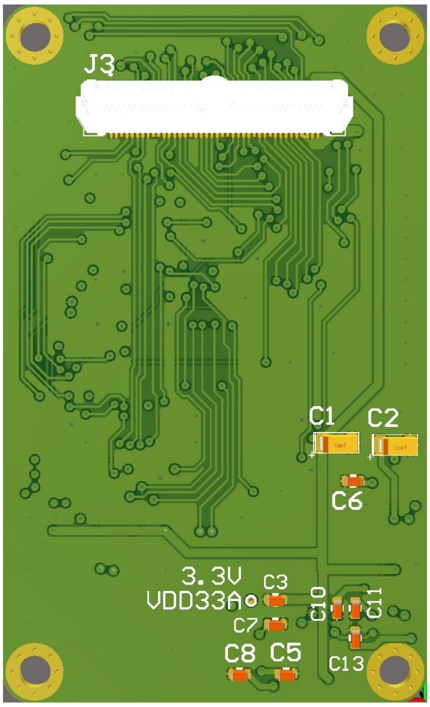
Also, with the aim of providing a global 3d model of the system and also detecting possible collisions between components, the 3d model of each component was added to the footprint, so Altium can take them into account. A 3d view of this board is shown in figure 2.19.

On top of the board was also added some overlay text indicating the name and version of the board, and the name and position of every component to help the soldering of the components. And also was noted the axis in which the attitude sensors were arranged, taking care of orienting them in the same way to simplify the posterior analysis of data measured.

The magnetic sensors has both the axis oriented in a way that the x-axis is the short length of the board (positive to the right), and the y-axis is the long one (positive to the top), leaving the z-axis positive perpendicular to the board plane through the top side. In the case of the



(a) Top side



(b) Bottom side

Figure 2.19: 3D view of the Submarine PCB

gyroscopes, they both share the z-axis, positive in the anti-clockwise direction seen from top, following the vector product $\vec{\imath} \times \vec{\jmath}$. But for x and y-axis the two sensors has the same direction but oposite signs. The one that follows the right-hand rule of vector product is U2 (the main gyroscope MPU-6050), this is, the positive x angular rate is following the vector product $\vec{\jmath} \times \vec{k}$, and the positive y measurement $\vec{k} \times \vec{\imath}$. This can be visuallized in figure 2.20

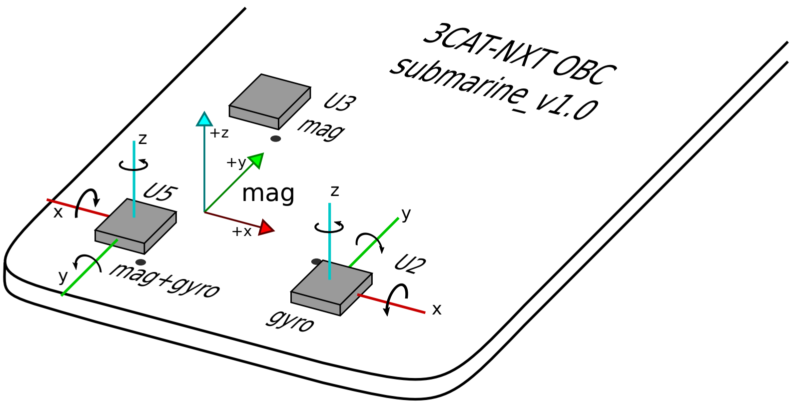


Figure 2.20: Sensor axis visualization. The two magnetic sensors share the same directions indicated with positive axis arrows. The two gyroscopes measure positives angular rates in the sense indicated by the arrows. Note that U5 and U2 have oposite sign for its x and y-axis

2.4.3 Mothership

The Mothership has the size and shape of standard CubeSat boards [24]. This includes the dimensions, number an position of structural holes and the position of the standard CubeSat connector, PC104. The size of the board is 90.17 mm × 95.89 mm with one hole in each corner as depicted in figure 2.21. The full specifications document is attached in appendix D.

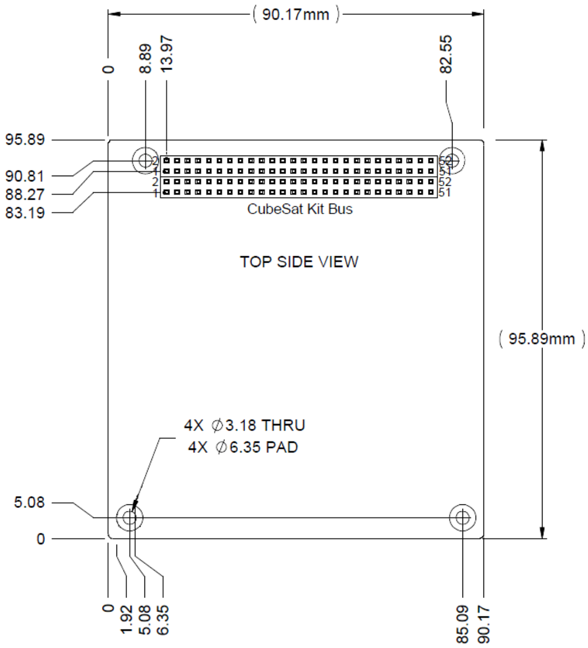
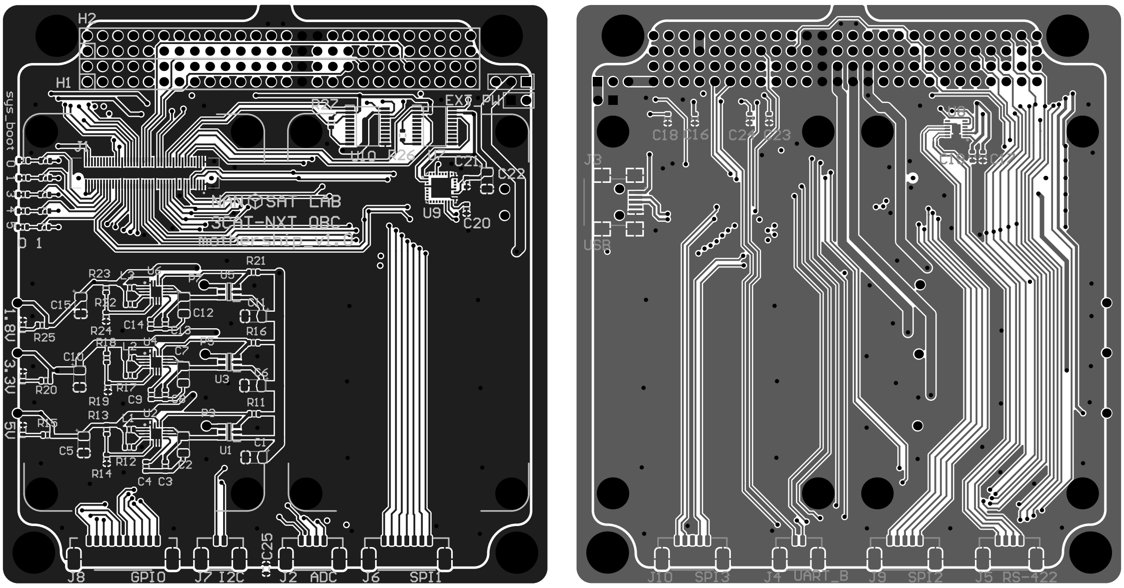


Figure 2.21: Dimensions of the Mothership board according to PCB CubeSat Standard [24]

This board integrate the power generation circuits, all the external interfaces and its associated circuits. The board also supports two Submarine-sized boards on top of it, with the holes to fix them, and the connector for the Submarine. In this version, only in the left side was placed the 80-pin connector, because, in this moment the use of the other board is unknown.

This board started with some constraints: the position of the two daughterboards, the inter-board connector, the main PC-104 CubeSat bus and the holes for structural screws, both for the Mothership structure and for the two daughterboards attached to it. Having the pc-104 connector in the north side of the board, the rest of interfaces were placed in the south side by using 90-degree PicoBlade connectors.

The power generation circuits were place in the left side of the board, under the Submarine slot. And the USB for debug was placed in the bottom face, in the right side. Also in this board were placed the configuration signals for the boot priority selection, as explained in the schematic section. This board is somehow simpler than the Submarine, but, despite that, the high density of nets interfacing with the 80-pin connector, made mandatory to use 4 layers too. The complete layout of this board is shown in figure 2.22.



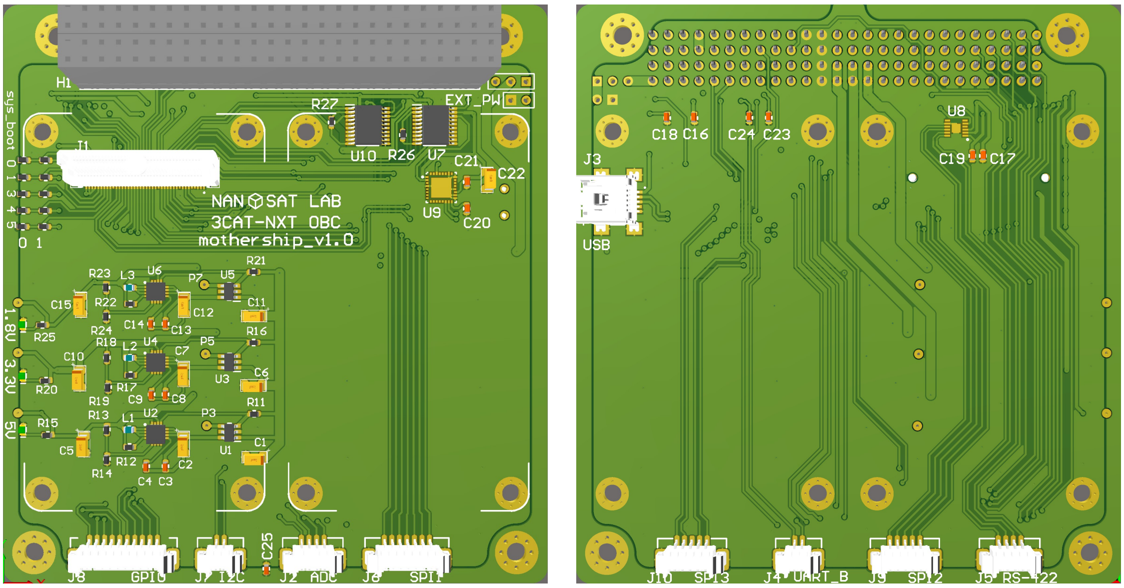
(a) Top side (b) Bottom side

Figure 2.22: Mothership PCB layout

In the same way as for the Submarine, also the 3d model of this board was created and is shown in figure 2.23.

As can be seen in the top side of the board in figure 2.23a, or, with better detail in 2.24, the input power may be selected to come from the pc-104 bus or from the a dedicated extra pin labelled as 5V_EXT. This is done by selecting the position of a jumper in the the 3-pin connector shown in figure 2.24. This input, as explained in the 2.3.2, ranges from 5 V to 17 V.

As mentioned previously, 3D models of every component and the board itself was exported to a CAD software to made a simulation of the integration looking for possible collisions between components. An image of this is shown in figure 2.25.



(a) Top side (b) Bottom side

Figure 2.23: 3D view of the Mothership PCB

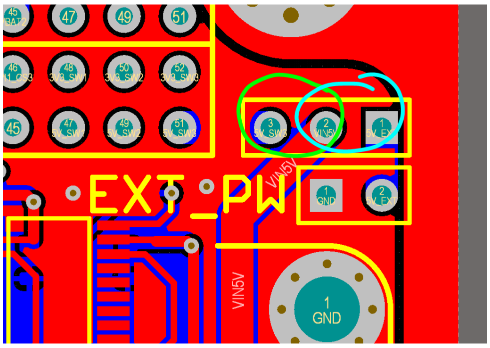


Figure 2.24: Detail of external power input. If the jumper shorts the two left positions the input would came from the pc-104 bus. In the right position the input is taken from EXT_PW connector (where square pin is the GND).

2.4.4 Inter-board connector

In order to communicate the two boards (Mothership and Submarine), a 80-pin inter-board connector. The physical component selected is a SAMTEC High Speed Hermaphroditic Strip LSHM Series [17]. The position of the 80 pines of the Submarine board used to interface with the Mothership, is shown in figure 2.26.

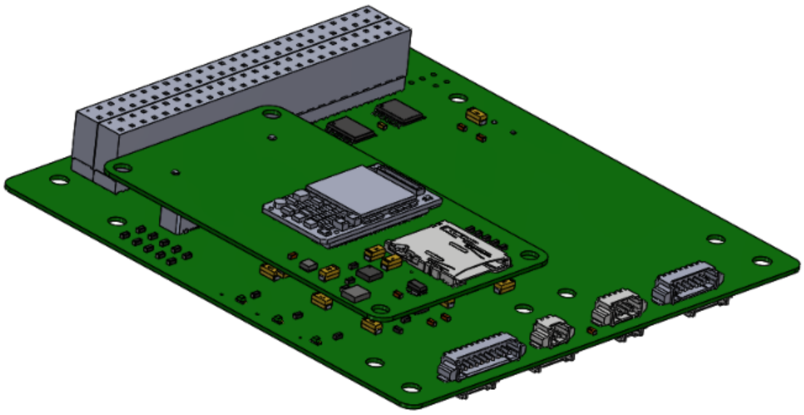


Figure 2.25: A 3D model of the integration of the two boards (Submarine and Mothership) together using a CAD software to check possible collisions between components

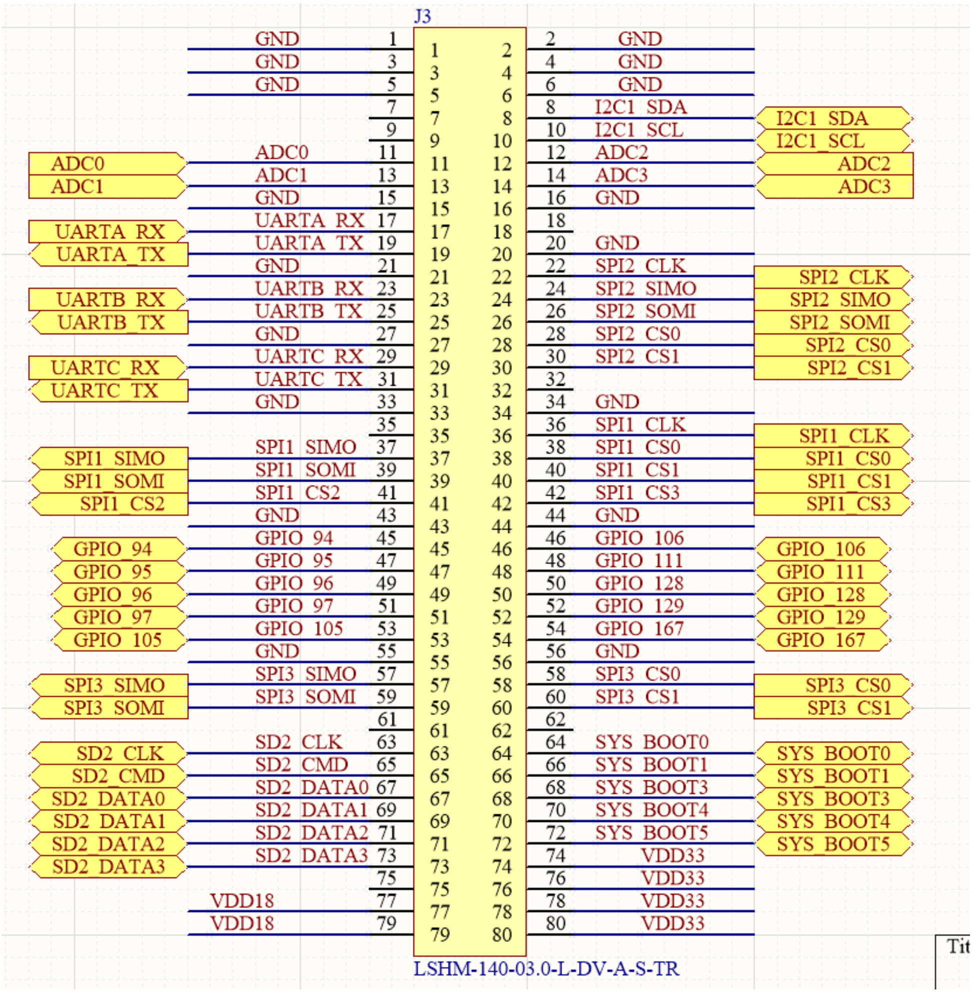


Figure 2.26: Submarine inter-board connector pinout

2.5 Integration phase

The two boards were ordered in a same panel together to reduce costs. The minimum amount of copies were two, so that was the number of boards ordered, which also allows to have a second chance in case of failures and damages in the board. This was also the case for electric components and connectors, they were always ordered, at least 2 or 3 more, depending on the price and the risk of failure.

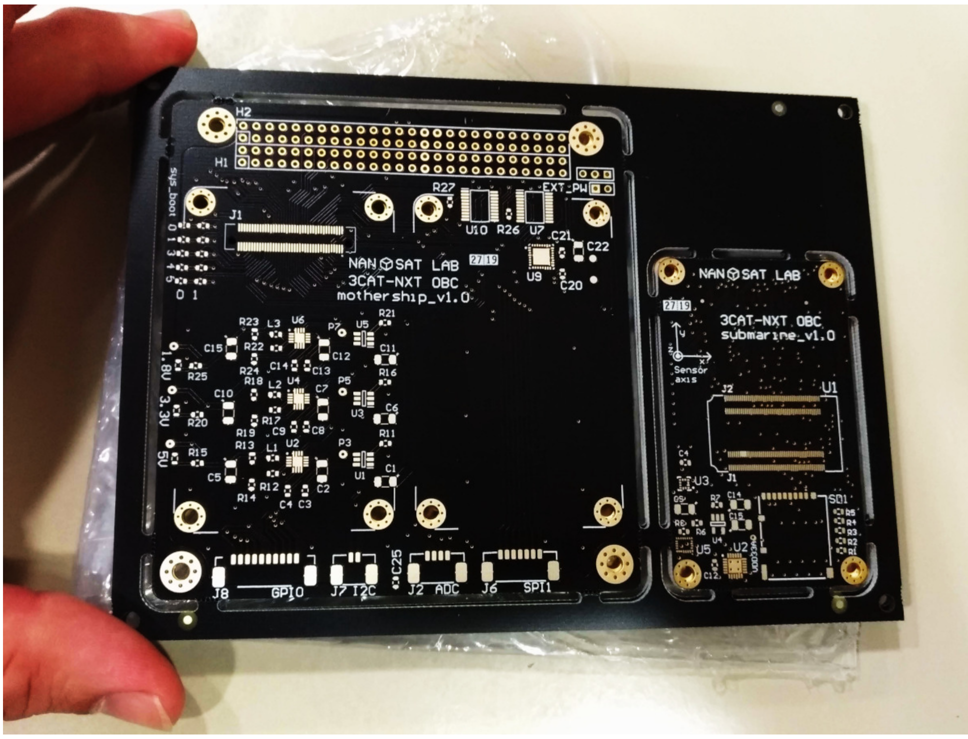


Figure 2.27: The two PCB boards just arrived from the manufacturer in a same panel

When the boards (figure 2.27) and also the electrical components arrived, the integration process started. This process followed the standard used in the NanoSat Lab [25], and can be synthetized in the following points:

1. Check that all the components ordered were received and verify its model name and quantity.
2. Visual inspection of the boards and also first electrical test of main nets, checking for continuity in a same line and ensuring there is no shorts between different lines.
3. Check mechanical fit of the two boards using spacers.
4. Create a sorted list for soldering components:

(a) Components that must be soldered inside a furnace (if existing)
(b) ICs that must be soldered using the hot air gun
(c) Other ICs
(d) The rest of passive components (capacitors, inductors and resistors)
(e) Connectors, starting with smaller

5. Check electrical connections, continuity and no shorts after every soldering.

The first visual inspection concluded that some holes were missed in the board. In particular, the micro USB had holes for two plastic attachments, and so for the 80-pin connectors. The solution for this first version, was to cut the plastic pieces on both connectors.

After that, a mechanical test of integration of the two boards with spacers was done, as seen in picture 2.28.

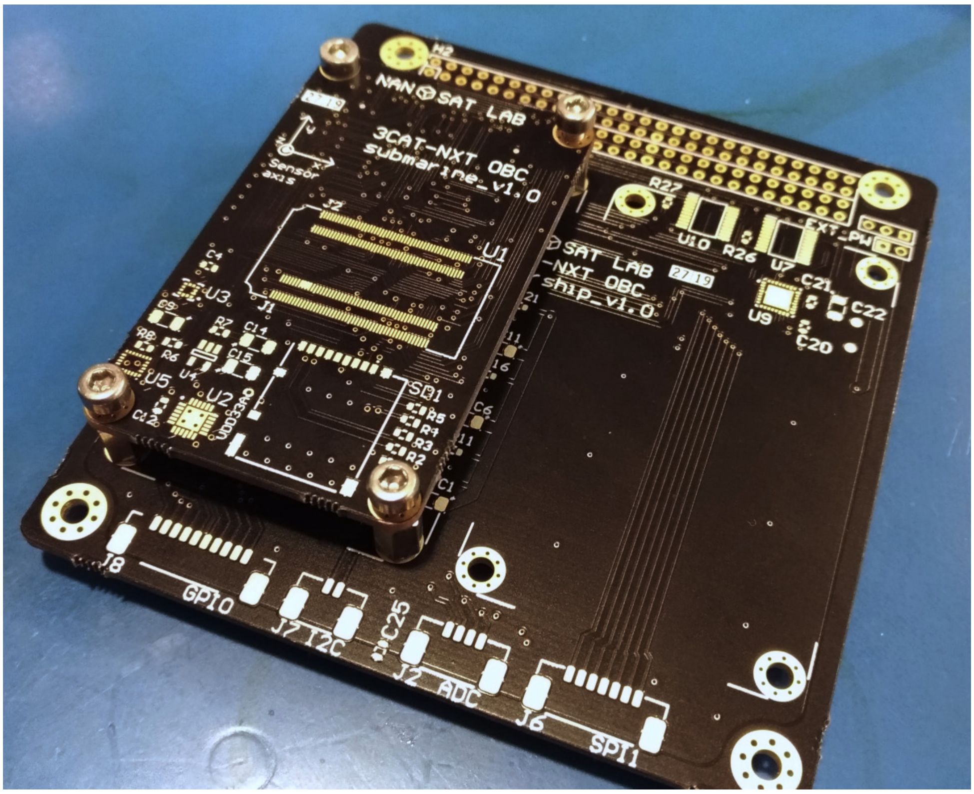


Figure 2.28: Mechanical check of matching boards

As a first try, the 80-pin connector, was soldered manually, without using hot air gun nor furnace. After several tries and checks, it was decided to try the connector in the second board with the furnace, and the result was a bit better, just with some shorts between some pines that were corrected with some manual work.

Also in this development version, the pc-104 pin connector was not integrated, because, before that, it was preferred to check the basic working of the whole system.

Next images shown the process of soldering of the Submarine board, where it can be seen the 100-pin connectors manually soldered (figure 2.29), the full board after being completely soldered (figure 2.30), and both sides of the board with main blocks indicated (figure 2.31).

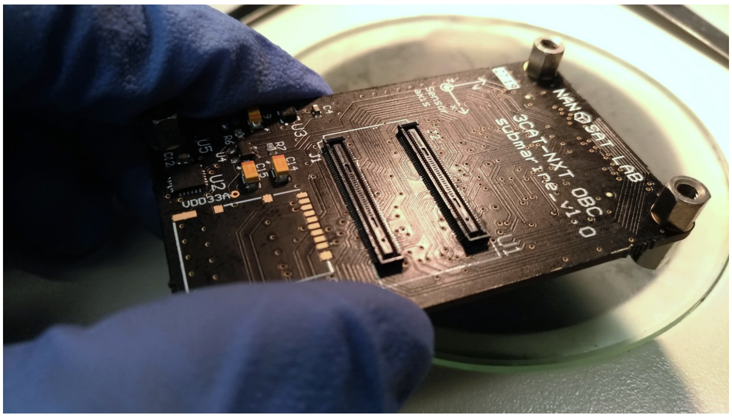


Figure 2.29: Both 100-pin connector soldered

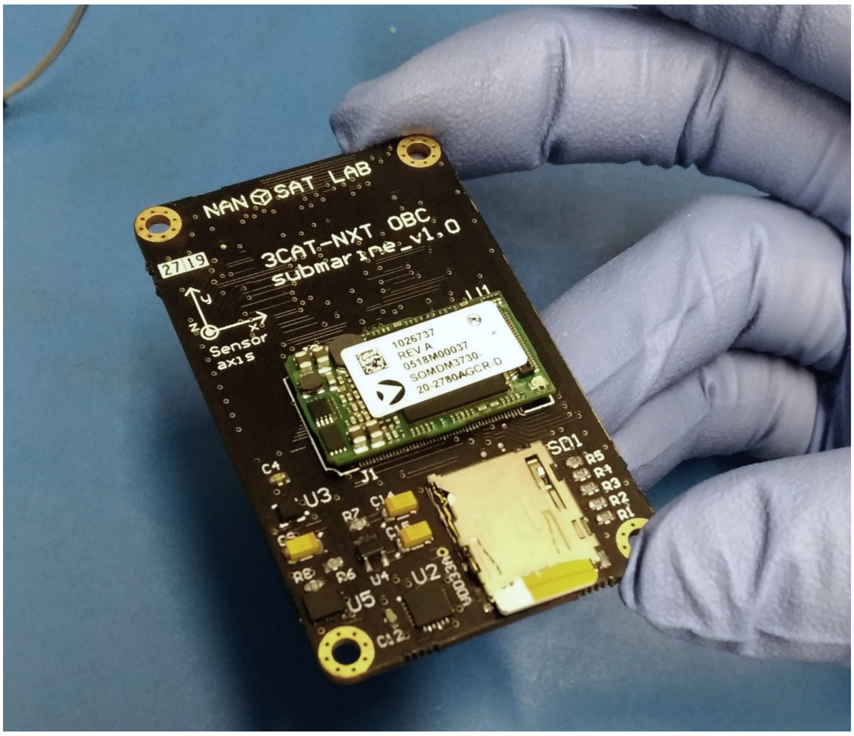


Figure 2.30: Submarine PCB finished with all the components soldered and the Torpedo SoM and µSD plugged

Also, in parallel, the integration of the Mothership board was done by soldering the electrical

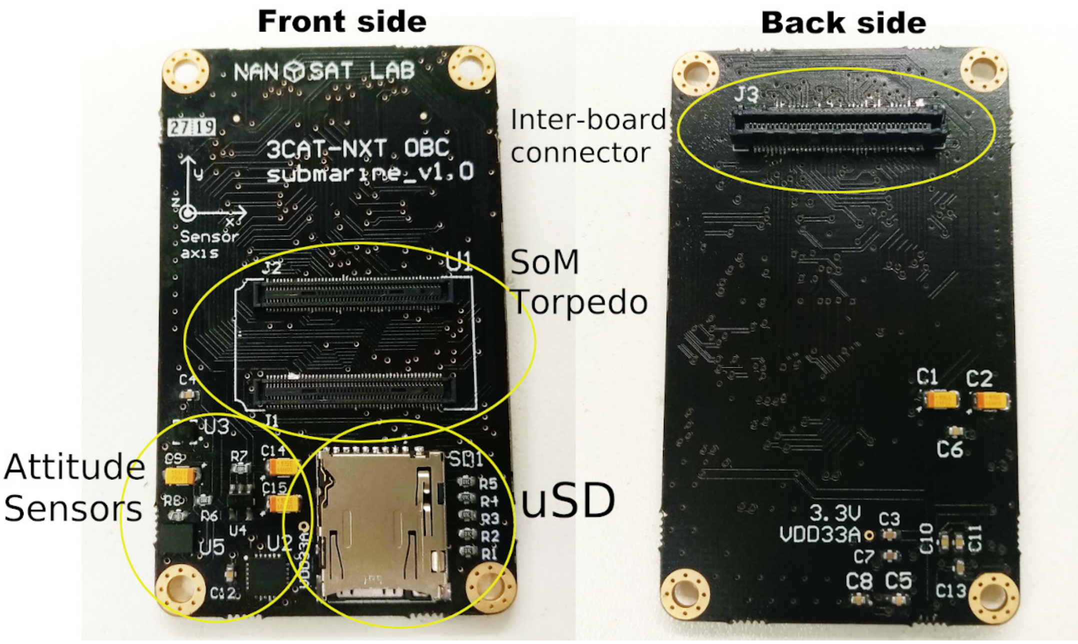


Figure 2.31: Submarine board soldered, indicating the position of main blocks

components and some connectors, as seen in figure 2.32. Not all the connectors were soldered in this current version because they are not still used. For example, it was not soldered the PC-104 bus nor the PicoBlade external interfaces.

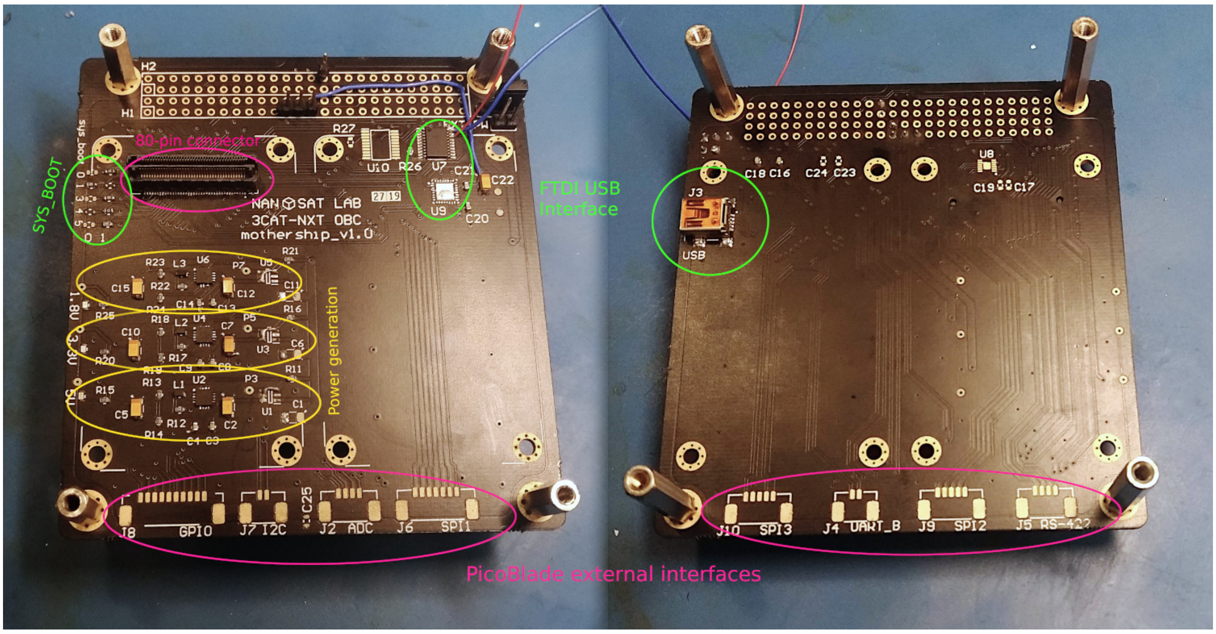


Figure 2.32: Mothership soldered, indicating the position of main blocks

2.6 Test and verification phase

The test and verification steps consist in check that the components soldered in the boards functions as expected and also to verify is the schematic or layout design were correct. This is done step by step, and sometimes it is mandatory to come back to the integration phase because there is something to correct, re-solder or make a major correction of the design.

The steps that where mainly followed were:

1. Check electrical continuity and the no existence of shorts due to soldering
2. Check power generation, one voltage branch at a time, without other ICs and components, and without connecting the Submarine.
3. When all voltages are OK, check the correct propagation of these voltages to the Submarine board (without connecting the Torpedo SoM).
4. When the voltages that supply the SoM are OK, try to power on the Torpedo module. To be able to learn when it is on, the communication though the debug UART with an external computer is needed. Check that the Toperdo powers on, without any µSD card. It should appear the logic PD bootloader.
5. After correct operation, try booting from the µSD, with the same firmware loaded in the card as used when debugging the software in the Torpedo development board.
6. After correct Linux start-up, check other interfaces and functionalities as external, I2Cs and SPIs interfaces or attitude sensors readings.

The test to check that all power supply voltages were correctly working is shown in picture 2.33. The LEDs are used to help the debug process; if they are on, the output is up. They do not check if the voltage is within the correct range, just if they are higher than the voltage that polarizes on the diode. That is one of the design mistakes in the case of the 1.8V point of load. The selected LED has a threshold voltage higher than 1.8V, so it never goes on, even having correct voltage.

After testing correct working of power supplies and its distribution to the Submarine board without any shorts, the Torpedo board was connected to try to communicate with it. For that, the FTDI chip was used to convert the UART signal from the OBC to the USB to con-

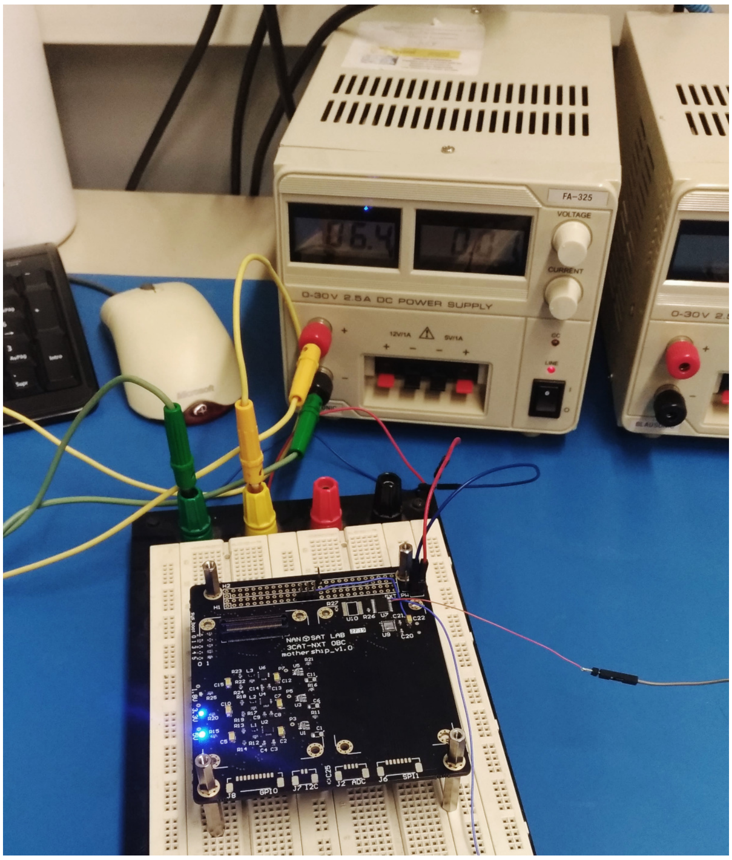


Figure 2.33: Electrical test of power supply voltages working. The three points of load where giving proper lectures of voltage for different input voltage values from 5 V to 17 V, in this case 6.4 V.
As explained, the 1.8V LED does not light even having correct voltage.

nect with the external PC. Doing that, at first instance, without any µSD inserted in the slot, it was observed correct start-up of the firmware, and the debug terminal shown that the LogicLoader™ started correctly, waiting for a memory to boot from any device. The boot configuration used was the first (default) in table 2.3: (USB, UART3, MMC1, NAND). As there was no bootable image any of them, the process stopped.

The next step was to repeat the process after inserting the µSD card, expecting booting from it. At this point something went wrong because the system could not read the SD card. The error was found to be a schematic design mistake which is explained later in chapter 3.2.

Chapter 3

Results of the project

3.1 Product developed

The main objective and result of this project was to develop an OBC as a product to be used in future missions. I consider that this work was archived just with some errors and mistakes during the design and integration phases that would be analysed in subsequent chapter 3.2, with the intention of correcting and, in some cases, improve the result with a second version of the product, as detailed in next chapter 4.2.

The product that was created is an On-Board Computer, that it is able to run an embedded Linux operative system and communicate/command other subsystems in the spacecraft with the use of several available interfaces. A summary of the main specifications of this OBC is shown in table 3.1. And a summary of the external interfaces of the OBC is shown in table 3.2.

Table 3.1: Summary of 3CAT-NXT OBC specifications

Specification	Value	Units	Observations
Dimensions	$90.17 \times 95.89 \times 17.8$	mm	All boards stacked
Mass	52.2	g	Mothership + Submarine
Input voltage range (V_{in})	5 to 17	V	
Rest current consumption	≈ 150	mA	Idle processor at bootloader @ $V_{in} = 6\,\text{V}$
Operating temperature	-40 to 85	°C	
Processor frequency (max)	1	GHz	ARM Cortex-A8
Volatile memory	256	MB	SDRAM
Non-volatile storage	512 (+ SD)	MB	NAND Flash memory

Finally, just as a reference, this OBC module may be comparable with some commercial options like the GOMSpace®NanoMind™A3200 [11], which is an OBC specially designed for CubeSats with the following specifications:

Hardware features

- High-performance AVR32 MCU with advanced power saving features
- 512 KB build-in flash
- 128 MB NOR flash (On two dies of 64 MB each)
- 32 kB FRAM for persistent configuration storage
- 32 MB SDRAM
- RTC clock
- On-board temperature sensors

Interfaces

- I2C, UART, CAN-Bus
- 8 external ADC channels that can also be used as GPIO
- External SPI with 3 chip selects
- Cubesat Space Protocol (CSP)

Table 3.2: List of 3CAT-NXT OBC interfaces

Interface type	Quantity	Description
USB 2.0	1	Debug through UART-A
UART	2	UART-B @ 3.3V UART-C to RS-422 @5V
SPI	3	SPI1 (up to 4 Chip Select) SPI2 (up to 2 CS) SPI3 (up to 2 CS)
I2C	1	I2C1 I2C2 (internal use for attitude sensors)
ADC	4	ADC0 (max 1.5V) ADC1 (max 1.5V) ADC2 (max 2.5V) ADC3 (max 2.5V)
GPIO	10	GPIO_94 GPIO_95 GPIO_96 GPIO_97 GPIO_105 GPIO_106 GPIO_111 GPIO_128 GPIO_129 GPIO_167

- GOSH interface for check-out

ADCS features

- 3-Axis magneto resistive sensor
- 3-Axis gyroscope
- 3 bidirectional PWM outputs with current measurements
- I2C interface for GomSpace Sensor Bus (GSSB)

3.2 Errors and difficulties encountered

During the project, mainly during the testing phase, several error were detected and, in some cases, corrected with a temporal solution. A second version of the OBC would try to correct all of them with a design update, and also other improvements that are not real failures or mistakes. These improvements would be discussed in next chapter 4.2.

3.2.1 Power switch

This error concerns the schematic design of the three power supplies, one per point of load. In order to understand the problem, remembering what was mentioned in chapter 2.3.2, before each DC/DC converter circuit there was a power switch (MIC2005) intended to cut the output if there is a short-circuit after if, which is detected by an sudden increase in the current. It would also cut the output in case of an over-temperature.

The problem is that the input voltage of this component is from 2.5 V to 5.5 V [19], when the expected input could be higher. This is limiting the maximum input voltage of the DC/DC buck converter [1], that is 17 V. If the input voltage needs to be higher than 5.5 V, this power switch should be removed or substituted by an equivalent one with higher input range. If the input is restricted to a maximum of 5.5 V, this IC would not be a problem.

3.2.2 µSD power supply

The power supply that the µSD card was designed to use is the 1.8V that comes from the power generation block in the Mothership board. The problem was found to be that this interface may operate at two voltages, 1.8V or 3.0V. As explained in the Texas Instrument AM37x processors wiki [26]:

> "*The ROM code supports booting from MMC1, but only at 3.0V. If using a TPS659xx power companion chip* –in our case this is integrated in the SoM Torpedo–, *the ROM will command this chip to output 3.0V on VMMC1 when attempting to boot from MMC1. If you are not using a TPS659xx, you must ensure 3.0V is present when the ROM attempts to boot from MMC1.*"

This problem was corrected cutting the PCB track that powered the µSD with 1.8V and soldering a wire from this net to the VMMC1 pin of the Torpedo connector. After that, the ROM code seemed to detect the card better than before, when the card was supplied at 1.8V, but still the Linux kernel could not boot. This is the current point to start working on, as mention in the next chapter 4.2.

3.2.3 Adjust DC/DC working frequency

The current design uses a switching frequency of 2.5MHz in the buck topology converter. According to the datasheet of the current IC, the efficiency is better for every current consumption when the frequency is 1.25MHz instead of 2.5MHz [1], as observed in figure 2.7 for 3.3V. That is similar also for 1.8V and 5V output voltages.

3.2.4 Debug-USB not working

The FTDI integrated circuit is the one used to convert the UART-A port to USB-2.0. The problem detected here comes from the schematic design, where one of the ports, the input pin 18, called "RESET#", was attached to GND, setting a low input there. This port is an **active**

low reset, that can be used by an external device to reset the FT232R. If not required, it can be left unconnected or pulled up to VDD.

As this point is crucial to stablish a communication with the SoM and debug the software, the workaround used was to remove the IC and externally connect the two UART signals (TX and RX) to an external FTDI converter, in particular, the one that uses the STM32F4 board. The solution was successful and the debug interface could be read.

In a following version of the PCB, this pin would be left floating, or maybe with the possibility of grounding it to reset the USB interface.

3.2.5 SPI corrections

As exposed in chapter 2.3.3.4, and the figure 2.15, the default configuration for pin J1.88 of the Torpedo SoM is to be the SPI3_CLK but it can also be the SPI1_CS3. The problem is that, currently, this pin is routed along with the SPI1 signals, to the same PicoBlade connector J6, which is the corresponding to SPI1, but, as the default configuration is as SPI3_CLK, it should be routed to the Picoblade connector J11, with the rest of SPI3 signals.

3.2.6 SYS_BOOT labels

This is just a labelling error. In the picture 3.1 can be seen the actual PCB board and labelling of the SYS_BOOT configuration resistors. The problem here is that the labels of this bits are reversed. The one labelled as 0 is the 5, the 1 is the 4 and so on. The solution is simply inverting the order of the labels.

3.3 Budget estimation

In this project there is two main costs. One of them is the cost of physical material and equipment used during the project, including components and instrumentation. The list of components to manufacture the boards is listed in table 3.3.

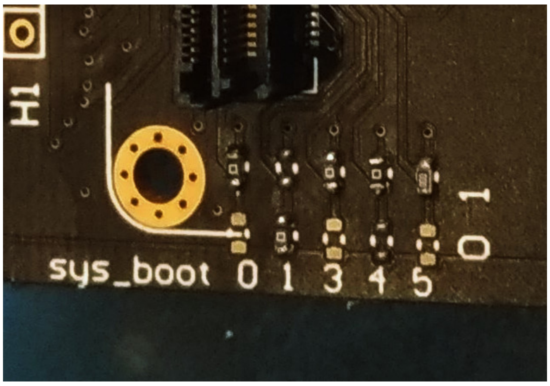


Figure 3.1: Detail of SYS_BOOT pull up/down resistors

Table 3.3: Electric components budget

Value	Description	Manufacturer ID	Qty	Price (€)	Total (€)	Seller
	micro USB connector	10033526-N3212MLF	1	0.518	0.518	Farnell
	Series DF40, 100-pin connector 0.4 mm	DF40C-100DS-0.4V(51)	2	1.25	2.5	Farnell
	Power switch	MIC2005A-1YM6-TR	4	0.249	0.996	Farnell
	Samtec series LSHM Razor Beam Male	LSHM-140-06.0-L-DV-A-N-K-TR	1	9.66	9.66	RS
	Samtec series LSHM Razor Beam Male	LSHM-140-03.0-L-DV-A-N-K-TR	1	8.83	8.83	RS
	Gyroscope	MPU-6050	1	7.25	7.25	Farnell
	Magnetometer	LIS3MDLTR	1	1.39	1.39	Farnell
	Inertial measurement Unit	LSM9DS1TR	1	6.09	6.09	Farnell
	LDO regulator	LP5907MFX-3.3/NOPB	1	0.445	0.445	Farnell
10uF	Tantalum capacitor 10V	TPSA106K010R0900	10	0.398	3.98	Farnell
1uF	Tantalum capacitor 10V	TAJA105K025RNJ	9	0.461	4.149	Farnell
22uF	Tantalum capacitor 10V	TAJA226K010RNJ	7	0.355	2.485	Farnell
100nF	Ceramic multilayer capacitor	06031C104KAT2A	20	0.164	3.28	Farnell

Table 3.3 – continued from previous page

Value	Description	Manufacturer ID	Qty	Price (€)	Total (€)	Seller
3.3nF	Ceramic multilayer capacitor	06035C332KAT2A	3	0.0969	0.2907	Farnell
2.2nF	Ceramic multilayer capacitor	06035C222KAT2A	1	0.108	0.108	Farnell
10nF	Ceramic multilayer capacitor	06035C103KAT4A	1	0.0777	0.0777	Farnell
10K	Resistor 0603	MCWR06X1002FTL	5	0.0059	0.0295	Farnell
0	Resistor 0603	MCWR06X000 PTL	17	0.0051	0.0867	Farnell
330	Resistor 0603	MCWR06X3300FTL	6	0.0057	0.0342	Farnell
100K	Resistor 0603	MCWR06X1003FTL	6	0.0059	0.0354	Farnell
680K	Resistor 0603	MCWR06X6803FTL	2	0.0059	0.0118	Farnell
130k	Resistor 0603	MCWR06X1303FTL	2	0.0056	0.0112	Farnell
750k	Resistor 0603	MCWR06X7503FTL	2	0.0059	0.0118	Farnell
240k	Resistor 0603	MCWR06X2403FTL	4	0.0058	0.0232	Farnell
330k	Resistor 0603	MCWR06X3303FTL	2	0.0057	0.0114	Farnell
2.2uH	Power inductor	PFL1609-222MEU	6	1.15	6.9	Farnell
100uF	Tantalum capacitor 6.3V	TLJA107M006R0800	1	1.25	1.25	Farnell
	Picoblade 7 pin	53261-0771	1	1.1	1.1	Farnell
	Picoblade 2 pines	53261-0271	3	0.678	2.034	Farnell
	Picoblade 4 pin	53261-0471	2	0.858	1.716	Farnell
	Picoblade 10 pin	53261-1071	1	1.34	1.34	Farnell
	Picoblade 5 pin	53261-0571	2	0.952	1.904	Farnell
	Micro SD connector	DM3AT-SF-PEJM5	1	1.83	1.83	Farnell
	DC/DC buck converter	TLV62130RGTR	5	1.844	9.22	RS
	Levelshifter 8bits	TXB0108PWR	4	1.49	5.96	Farnell

Table 3.3 – continued from previous page

Value	Description	Manufacturer ID	Qty	Price (€)	Total (€)	Seller
	Full-duplex RS-422 high-speed receiver-transceiver	MAX22502EATC+	2	4.79	9.58	Farnell
	FTDI USB to serial UART interface	FT232RQ-REEL	2	4.05	8.1	Farnell
	3CAT-NXT OBC PCB board panel		2	250.31	500.62	2cisa
					603.86	

The instrumentation used for the project, in this case, is provided by the laboratory, but an estimation of its cost is summarized in the next table 3.4.

Table 3.4: Budget estimation for instrumentation and tools used

Instrument	Price
Multimeter	60 €
Oscilloscope	300 €
Microscope	1000 €
Power supply	80 €
One-year Altium license	7000 €
Total	8440 €

The second main cost is the job salary of an engineer during the time of the project, and the support of the laboratory technician during the integration phase. This is estimated in the next table 3.5.

So, the final estimation of the whole project cost is around 28500 €. Also it can be estimated the price of manufacturing a new OBC product assuming that all the equipment and licenses are already available, and the budget in this case would be 20100 €.

Table 3.5: Budget estimation for engineers salary

Position	Salary per month	Number of months	Total
Hardware engineer	2500 €	7	17500 €
Laboratory technician	2000 €	1	2000 €
			19500 €

Chapter 4

Conclusions and future work

4.1 Conclusions

This project has supposed a great challenge as it was a difficult and long task, where the design was not clear at the beginning and the specifications were sometimes changed during the development of the project. The scope of the work was ambitious from the beginning. It included not only the design, but also the integration and the test of the product developed. All these tasks where archived until the point of first working tests, with some work still to do in this aspect, as mentioned in previous chapters.

From a personal point of view, the project as also been quite challenging but also very attractive and stimulating. With my background as a physicist who worked in the microelectronics industry I had some knowledge about electronics, communication protocoles and layout design, but I had never worked with PCB design at this level of precision. During the time working in the NanoSat Lab, I learned by myself, and with the help of other colleges there, how to design a project like this using Altium, creating a Bill of Materials to buy and then integrate them. I also learned how to solder, both SMD components and chips with the hot air gun and the furnace. And finally how to create a test campaign, being exhaustive with method and care.

Also during the project, I felt motivated with the idea of creating a real product that, eventually, could be launched in orbit around the Earth. Since the beginning of this Master's Thesis I wanted to do something "real", something that would be useful in the future, not a simple theoretical work. And after this time I think I've archived my objective of, at least, prepare the way to continue improving and using this OBC. I also felt motivated in the environment of the laboratory because they engaged me to continue working on this, letting me know their interest in using my work in future opportunities.

The product created I think would not stop here and would be improved or adapted to future missions because when it will be fully functional, it would be a better option than some commercial options, with the advantage of being cheaper and also created by us, letting us know the complete features and limitations of the design. Also my work will not stop here. If I can, I would continue giving support to the future users of this OBC and it is also my purpose to advise in the design of the next version of the board, if I'm not the one actually doing it.

4.2 Future work and improvements

This project had an overall successful result, obtaining a full design and physical implementation that actually worked fine. But this result were reached because, in some points, some errors or mistakes in the design were partial or totally corrected, as detailed in previous section 3.2.

The idea of the work that has been done, is to not stop here but keep debugging, correcting and improving the design to give this board the possibility of being used in actual future designs and even been tested in orbit, which is its original purpose.

So, at first instance, the work to be done is identifying which are the critical errors (if existing), that does not allow to continue the debug. At this point, the state of the debug process is that the bootloader can not load the Linux image from the SD card. Maybe is related with the problem of the power supply explained in the previous section, even having being done the change in the power supply, substituting the 1.8V with the VMMC1 power coming from the SoM with an external wire. Or, maybe, it could be a software problem related with the kernel image and the bootloader.

Once we can successfully boot the Linux environment, there is still work to do with debugging all the interfaces (SPI, I2C, UART, ADCs, GPIO), temperature readings, attitude sensors communication, SD card read/write.

So, the idea is to continue debugging as much as we can, since we found something really impossible to overcome without changing the schematic/PCB. In this moment, all the corrections and improvements mentioned during these chapters would be applied.

4.2.1 Other minor improvements

The next lines accounts for some minor changes that are not critical for the proper work of the OBC but that would somehow improve the use of the OBC, and the overall result of the project.

Change voltage supply of attitude sensors. As explained in the chapter 2.3.4 when talking about the attitude sensors, it was mentioned that a LDO regulator has been used to stabilize and adapt the power supply of these sensors, also reducing possible digital noise coming from the SoM, as they use the same 3.3V point of load.

The improvement here is to change the voltage in which these sensors are supplied from 3.3V to 3.0V, as the LDO would work better if the input is higher than the output, ideally, the specifications of this LDO regulator advises 1V of difference. In this case that is not possible because the higher input voltage for one of the sensors is 2.375V. But just using the 3.3V may be enough to effectively increase the PSRR (Power Supply Rejection Ratio) of the regulator, and obtain a cleaner power supply for the sensors, probably improving its performance.

Add more text indications on the PCB. Sometimes it was found during the integration and test phases that some labels and indication were missed to have a better understand of the board. The idea is to design a board that any future user could understand and use it without lot of study of the board documentation.

In this way, for example it was missed a label for the input power pines polarity. Maybe it can also be added a protection circuit in case of switching the polarity.

Reduce stacking height. The current stacking height of the Submarine on top of the Mothership is a bit larger than needed. None of the components on both faces are near to touch between them. The work to do here is to calculate the minimum stacking distance possible, and taking into account the available inter-board connector heights and giving a security margin, stablish a new smaller stacking height in order to reduce the overall volume of the system.

Consider alternative inter-board connector. During the soldering phase, as mentioned in previous chapter, one of the components that resulted more difficult to properly solder was the SAMTEC LSHM series 80-pin connector. This point relates with the previous one as the connector used would impact in the stacking height of the Submarine board.

Adding availability for a second SD Card. During the schematic design section, it was mentioned that there are some nets on the sumbarine-SoM interface that are not routed, and that allows the possibility of connecting a second SD/MMC card. This would imply new 7 signals that might be routed to the Mothership board, which may imply a redesign of the inter-board connector, to increase the number of pines. This update is something to discuss, considering the real need of increasing the storage capacity of the OBC.

Consider adding a connector interface for the second un-used daughterboard The space left for a second Submarine-like board is almost empty of components and routing, but it misses the possible connector to interface this board. The work to do here is to study the viability of using the same connector as the Submarine or using a different approach.

Adding support for other interfaces Other interfaces could be added to the OBC if required. For example it could be interesting to add a PWM controller for actuate on magnetorquers or reaction wheels. And also interesting would be to add more, more precise ADC inputs to read external sensors with better precision than the 10-bits that internal SoM Torpedo provides.

4.2.2 Future use of the design

This design is intended to be used as the main brain for future CubeSats missions and the idea is to fully re-use it, with just minor adaptations. The most adaptable features are the interfaces ports. Some of they may be removed or substituted by others, sometimes just with software tricks using the available signals (see Torpedo SoM documentation for that).

Also, in the Mothership board it was planned an empty space to attach a second Submarine-like board, that may be used to integrate another subsystem or payload. One of the possible ideas is to use it to design a COMMS module that directly communicates with the OBC intelligence.

References

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Appendices

C Gantt Diagram

The following pages shown the project plan followed in this project a Gantt diagram.

3CAT-NXT OBC design

Sep 17, 2019

NanoSat Lab

http://

Project manager	Carlos Molina
Project dates	Feb 11, 2019 - Sep 20, 2019
Completion	96%
Tasks	20
Resources	2

Tasks

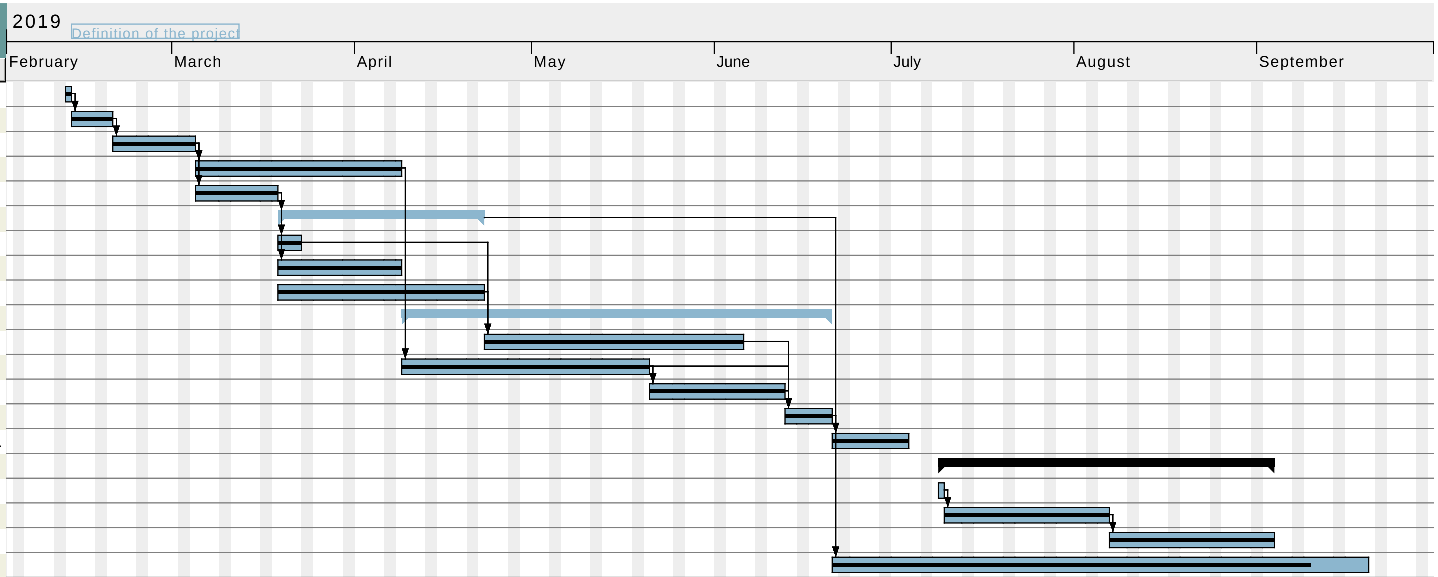
Name	Begin date	End date	Duration	Resources
Start of the project	11/02/2019	11/02/2019	1	Carlos Molina
Definition of the project	12/02/2019	18/02/2019	5	Carlos Molina
Requirements definition	19/02/2019	04/03/2019	10	Carlos Molina
Search of components	05/03/2019	08/04/2019	25	Carlos Molina
Area estimation	05/03/2019	18/03/2019	10	Carlos Molina
Schematic design	19/03/2019	22/04/2019	25	Carlos Molina
Altium project creation	19/03/2019	22/03/2019	4	Carlos Molina
Design of power supply	19/03/2019	08/04/2019	15	Carlos Molina
Design of interfaces	19/03/2019	22/04/2019	25	
PCB design	09/04/2019	20/06/2019	53	
Routing submarine board	23/04/2019	05/06/2019	32	Carlos Molina
Routing mothership	09/04/2019	20/05/2019	30	Carlos Molina
Re-design of board with CubeSat standard	21/05/2019	12/06/2019	17	Carlos Molina
Preparation of fabrication files	13/06/2019	20/06/2019	6	Carlos Molina
PCB manufacturing period	21/06/2019	03/07/2019	9	PCB manufacturer
Hardware integration	09/07/2019	03/09/2019	41	
Manufactured PCB arrives	09/07/2019	09/07/2019	1	Carlos Molina
Soldering components	10/07/2019	06/08/2019	20	Carlos Molina
Electrical tests	07/08/2019	03/09/2019	20	Carlos Molina
Writing report	21/06/2019	19/09/2019	65	Carlos Molina

Resources

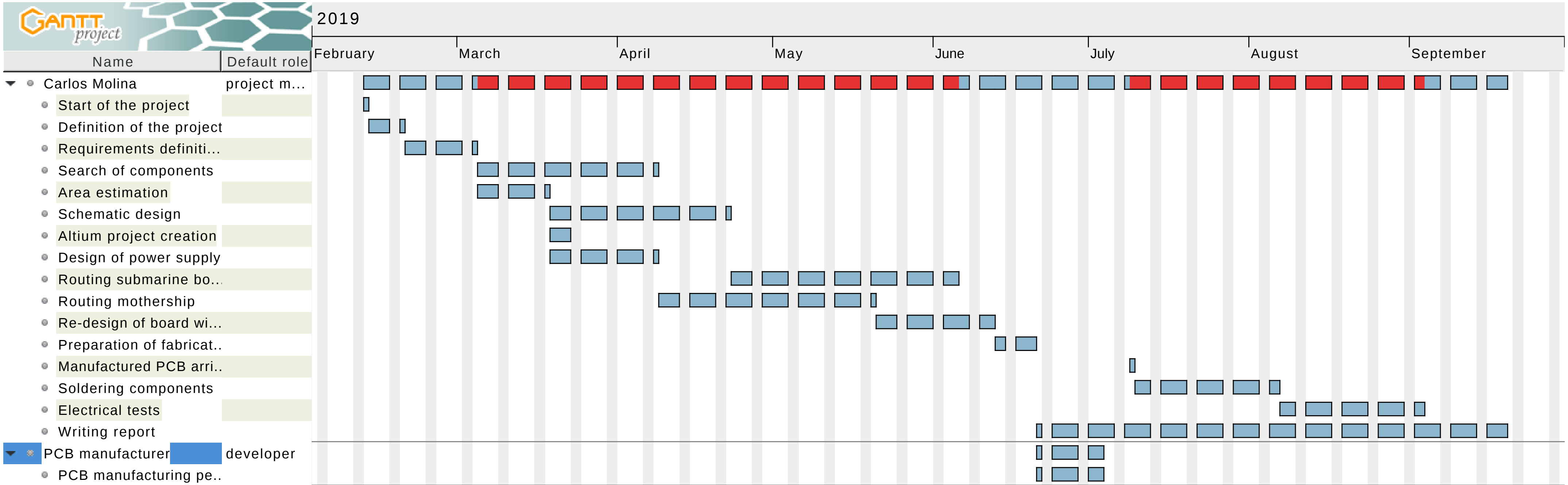
Name	Default role
Carlos Molina	project manager
PCB manufacturer	developer

Gantt Chart

Name	Begin date	End date	Duration	Resources
Start of the project	11/02/2019	11/02/2019	1	Carlos Molina
Definition of the project	12/02/2019	18/02/2019	5	Carlos Molina
Requirements definition	19/02/2019	04/03/2019	10	Carlos Molina
Search of components	05/03/2019	08/04/2019	25	Carlos Molina
Area estimation	05/03/2019	18/03/2019	10	Carlos Molina
Schematic design	19/03/2019	22/04/2019	25	Carlos Molina
Altium project creation	19/03/2019	22/03/2019	4	Carlos Molina
Design of power supply	19/03/2019	08/04/2019	15	Carlos Molina
Design of interfaces	19/03/2019	22/04/2019	25	
PCB design	09/04/2019	20/06/2019	53	
Routing submarine board	23/04/2019	05/06/2019	32	Carlos Molina
Routing mothership	09/04/2019	20/05/2019	30	Carlos Molina
Re-design of board with C..	21/05/2019	12/06/2019	17	Carlos Molina
Preparation of fabrication..	13/06/2019	20/06/2019	6	Carlos Molina
PCB manufacturing period	21/06/2019	03/07/2019	9	PCB manufactu...
Hardware integration	09/07/2019	03/09/2019	41	
Manufactured PCB arrives	09/07/2019	09/07/2019	1	Carlos Molina
Soldering components	10/07/2019	06/08/2019	20	Carlos Molina
Electrical tests	07/08/2019	03/09/2019	20	Carlos Molina
Writing report	21/06/2019	19/09/2019	65	Carlos Molina



Resources Chart



D CubeSat PCD Standard

REVISION HISTORY				
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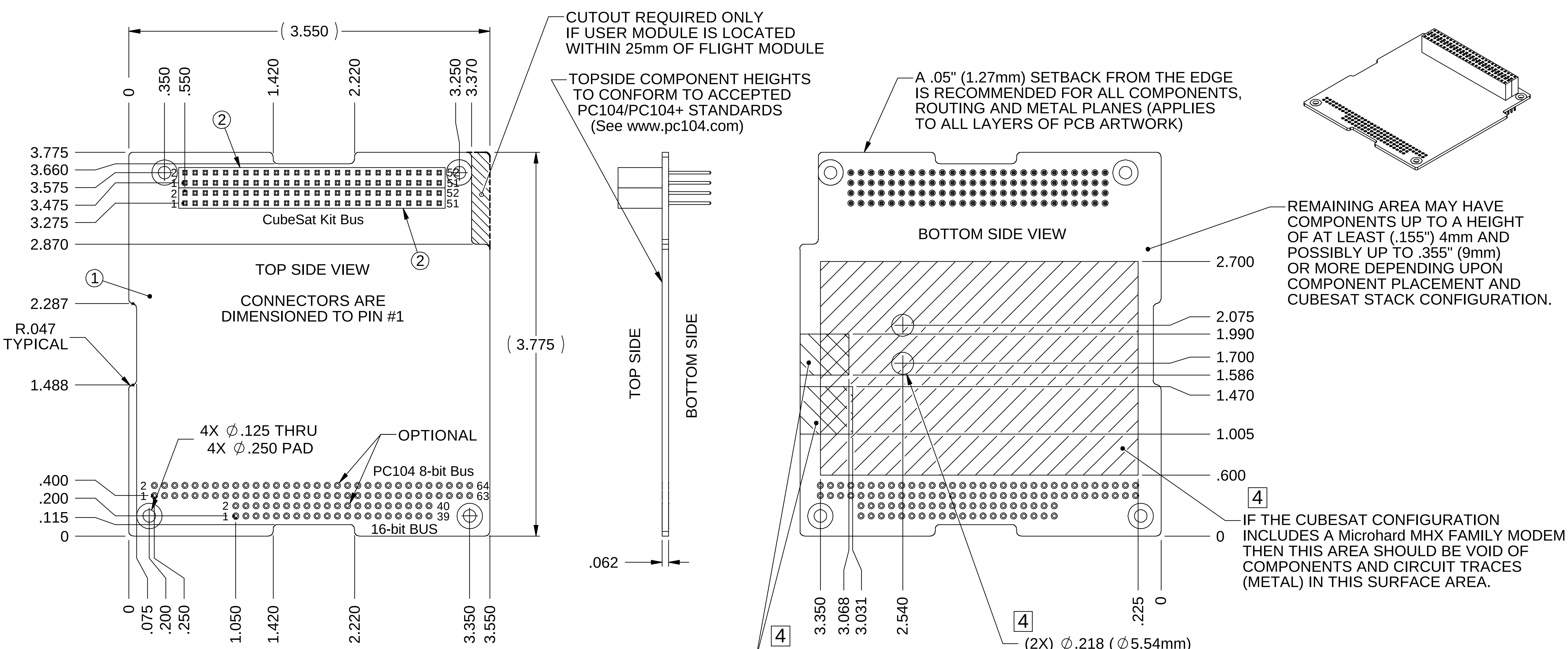

ITEM	QTY	PART NUMBER	DESCRIPTION	MANUFACTURER
1	1	PC104 Spec PCB	User	User
2	2	ESQ-126-39-G-D	2x26 Stack-Through	Samtec.com

NOTES:

1) Connectors shown are .10" x .10" spacing, .025" square pin.

2) Samtec part numbers listed are low insertion force versions.

3) In the case where a 25mm gap will exist above the User Slot an additional connector should be used to gap the extra 10mm distance, plugged into the main connector. Use part SSQ-1XX-22-G-D where "XX" is the # of contacts per row.

4 These comments apply to situations where the User Module (Slot 1) is directly above the FlightModule (Slot 0).

MATERIAL: FINISH: HEAT TREAT: WEIGHT:

PUMPKIN INCORPORATED

744 Naples - San Francisco - CA 94112
(415) 584-6360 ph - (415) 585-7948 fax
info@pumpkininc.com

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ARE:
FRACTIONS DECIMALS ANGLES
.X = ± .040
.XX = ± .020 ± 0° 30"
.XXX = ± .010

APPROVALS		DATE
DRAWN	AWR	09/26/03
CHECKED		
QUAL ENG		

TITLE
CubeSat Kit PCB Specification

SIZE B | DWG. 810-00253 | REV A5

CAD GENERATED DRAWING, DO NOT MANUALLY UPDATE

DO NOT SCALE DRAWING

SCALE 1 : 1 | SHEET 1 OF 3

METRIC DRAWING

REVISION HISTORY				
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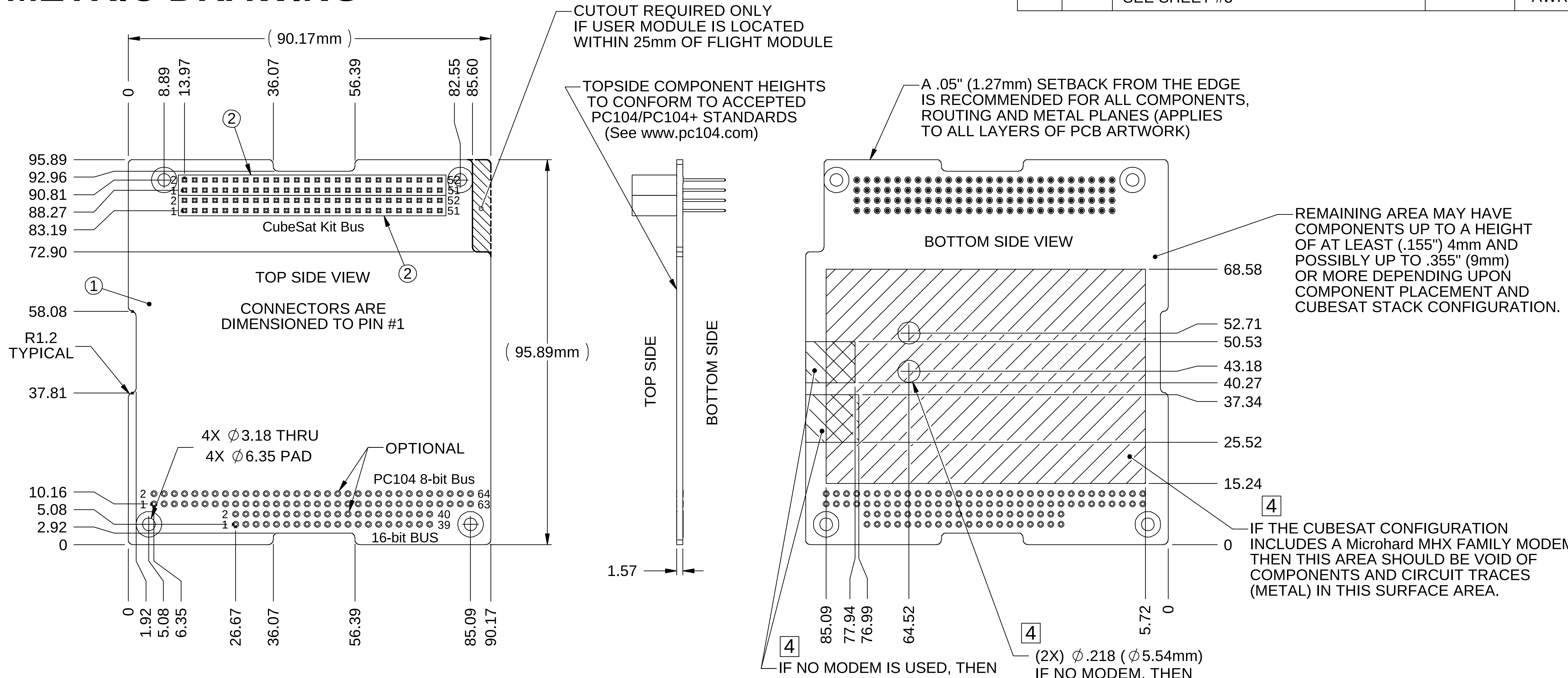
		SEE SHEET #3		AWR



ITEM	QTY	PART NUMBER	DESCRIPTION	MANUFACTURER
1	1	PC104 Spec PCB	User	User
2	2	ESQ-126-39-G-D	2x26 Stack-Through	Samtec.com

NOTES:

1) Connectors shown are .10" x .10" spacing, .025" square pin.

2) Samtec part numbers listed are low insertion force versions.

3) In the case where a 25mm gap will exist above the User Slot an additional connector should be used to gap the extra 10mm distance, plugged into the main connector. Use part SSQ-1XX-22-G-D where "XX" is the # of contacts per row.

4 These comments apply to situations where the User Module (Slot 1) is directly above the FlightModule (Slot 0).

MATERIAL: | FINISH: | HEAT TREAT: | WEIGHT:

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(415) 584-6360 ph - (415) 585-7948 fax
info@pumpkininc.com

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN MILLIMETERS TOLERANCES ARE:
FRACTIONS | DECIMALS X. = ± 1.0, .X = ± .50, .XX = ± .25 | ANGLES ± 0° 30"

APPROVALS		DATE
DRAWN	AWR	09/26/03
CHECKED		
QUAL ENG		

CAD GENERATED DRAWING, DO NOT MANUALLY UPDATE — DO NOT SCALE DRAWING

TITLE ***CubeSat Kit PCB Specification***

SIZE B | DWG. 810-00253 | REV A5

SCALE 1 : 1 | SHEET 2 OF 3

REVISION HISTORY				
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A1	C4	UPDATED LOCATION OF USB & POWER KEEP OUT ZONES	06/01/2004	AWR
A1	A8	ADDED NOTE #5	06/01/2004	AWR
A2	C7	ADDED CUTOUTS FOR EG SOLAR CONN	01/26/2006	AWR
A2	B7/D7	CHANGED 2x20 HEADER TO 2x26	01/26/2006	AWR
A3	C6	ADDED CUTOUT NOTES FOR SWITCH	02/06/2006	AWR
A4	D8/D6	ADDED CORNER CUTOUTS - ADCS	03/20/2007	AWR
A4	B8/B6	ADDED CORNER CUTOUTS - ADCS	03/20/2007	AWR
A4	C8	ADDED R.047 OUTSIDE CORNER NOTE	03/20/2007	AWR
A4	C6	ADDED .180" x .905" SW CUTOUT	03/20/2007	AWR
A4	C6	CHANGED DRAWING TITLE	03/20/2007	AWR
A4	- -	ADDED METRIC DRAWING (SHEET #2)	03/20/2007	AWR
A5	- -	ADDED NOTATIONS TO SHEET 1 & 2	06/19/2007	AWR

MATERIAL:	FINISH:	HEAT TREAT:	WEIGHT:

PUMPKIN™ INCORPORATED

744 Naples - San Francisco - CA 94112
(415) 584-6360 ph - (415) 585-7948 fax
info@pumpkininc.com

APPROVALS		DATE
DRAWN	AWR	09/26/03
CHECKED		
QUAL ENG		

TITLE
CubeSat Kit PCB Specification

SIZE B | DWG. *810-00253* | REV A5

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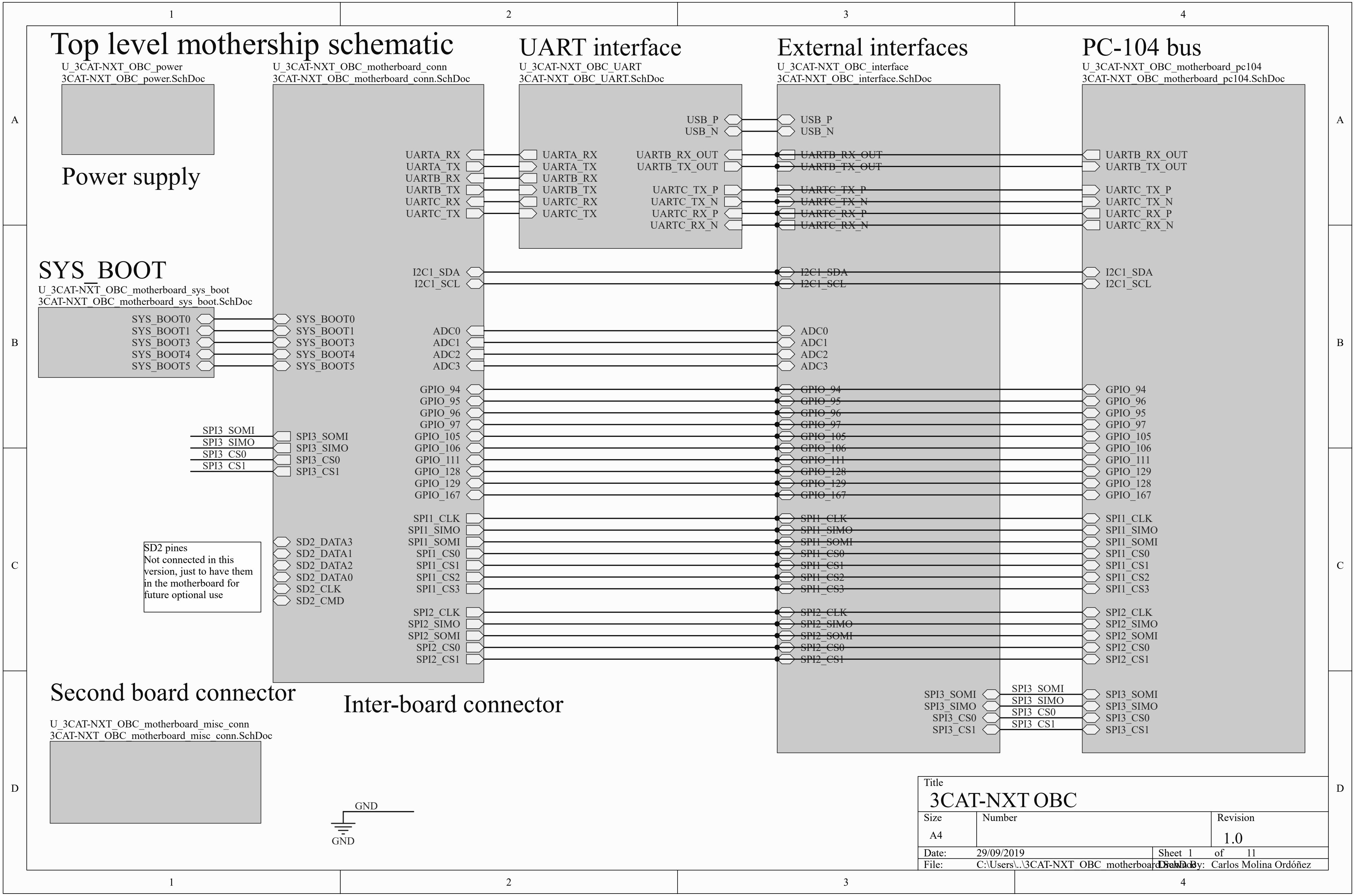
DO NOT SCALE DRAWING

SCALE : NONE | SHEET 3 OF 3

E Project schematics

E.1 Mothership schematic


Top level mothership schematic
U_3CAT-NXT_OBC_power
3CAT-NXT_OBC_power.SchDoc
Power supply
U_3CAT-NXT_OBC_motherboard_conn
3CAT-NXT_OBC_motherboard_conn.SchDoc
UART interface
U_3CAT-NXT_OBC_UART
3CAT-NXT_OBC_UART.SchDoc
External interfaces
U_3CAT-NXT_OBC_interface
3CAT-NXT_OBC_interface.SchDoc
PC-104 bus
U_3CAT-NXT_OBC_motherboard_pc104
3CAT-NXT_OBC_motherboard_pc104.SchDoc
USB_P
USB_N
UARTA_RX
UARTA_TX
UARTB_RX
UARTB_TX
UARTC_RX
UARTC_TX
UARTB_RX_OUT
UARTB_TX_OUT
UARTC_TX_P
UARTC_TX_N
UARTC_RX_P
UARTC_RX_N
SYS_BOOT
U_3CAT-NXT_OBC_motherboard_sys_boot
3CAT-NXT_OBC_motherboard_sys_boot.SchDoc
SYS_BOOT0
SYS_BOOT1
SYS_BOOT3
SYS_BOOT4
SYS_BOOT5
I2C1_SDA
I2C1_SCL
ADC0
ADC1
ADC2
ADC3
GPIO_94
GPIO_95
GPIO_96
GPIO_97
GPIO_105
GPIO_106
GPIO_111
GPIO_128
GPIO_129
GPIO_167
SPI3_SOMI
SPI3_SIMO
SPI3_CS0
SPI3_CS1
SPI1_CLK
SPI1_SIMO
SPI1_SOMI
SPI1_CS0
SPI1_CS1
SPI1_CS2
SPI1_CS3
SD2 pines
Not connected in this version, just to have them in the motherboard for future optional use
SD2_DATA3
SD2_DATA1
SD2_DATA2
SD2_DATA0
SD2_CLK
SD2_CMD
SPI2_CLK
SPI2_SIMO
SPI2_SOMI
SPI2_CS0
SPI2_CS1
Second board connector
Inter-board connector
U_3CAT-NXT_OBC_motherboard_misc_conn
3CAT-NXT_OBC_motherboard_misc_conn.SchDoc
GND
GND
Title
3CAT-NXT OBC
Size
A4
Number
Revision
1.0
Date: 29/09/2019
Sheet 1 of 11
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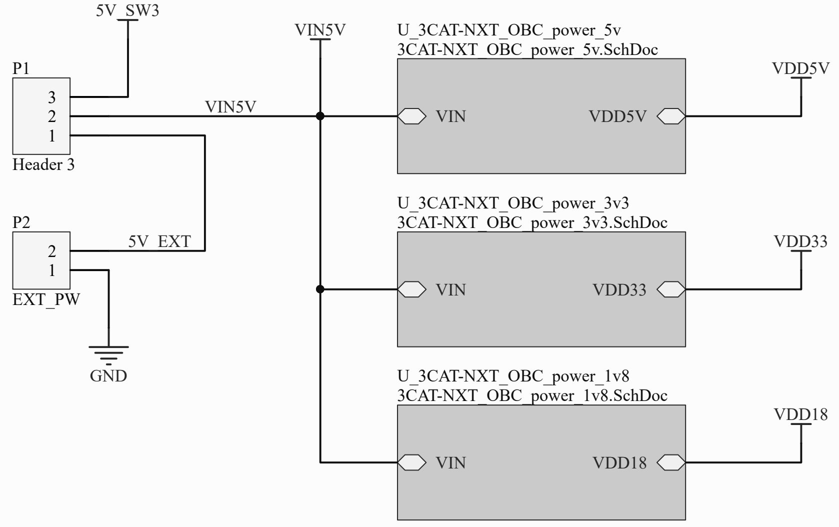
Drawn By: Carlos Molina Ordóñez

Top level power supply



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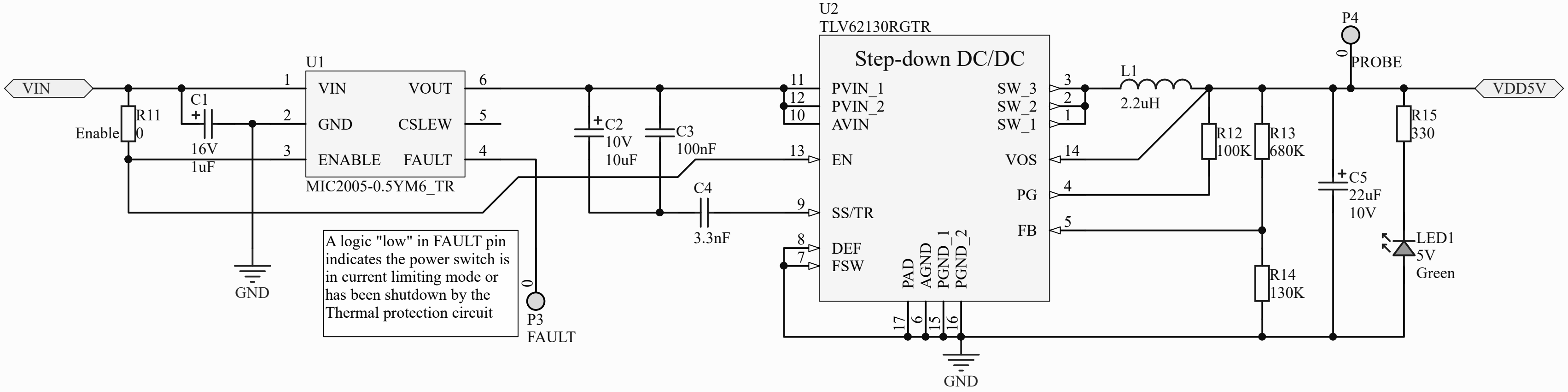
5V Power supply



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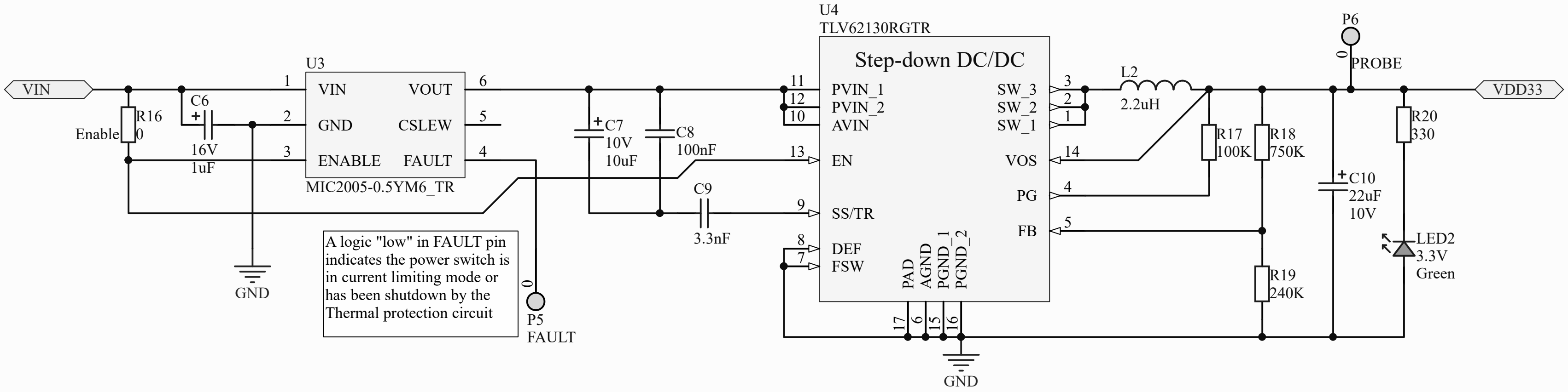
3.3V Power supply



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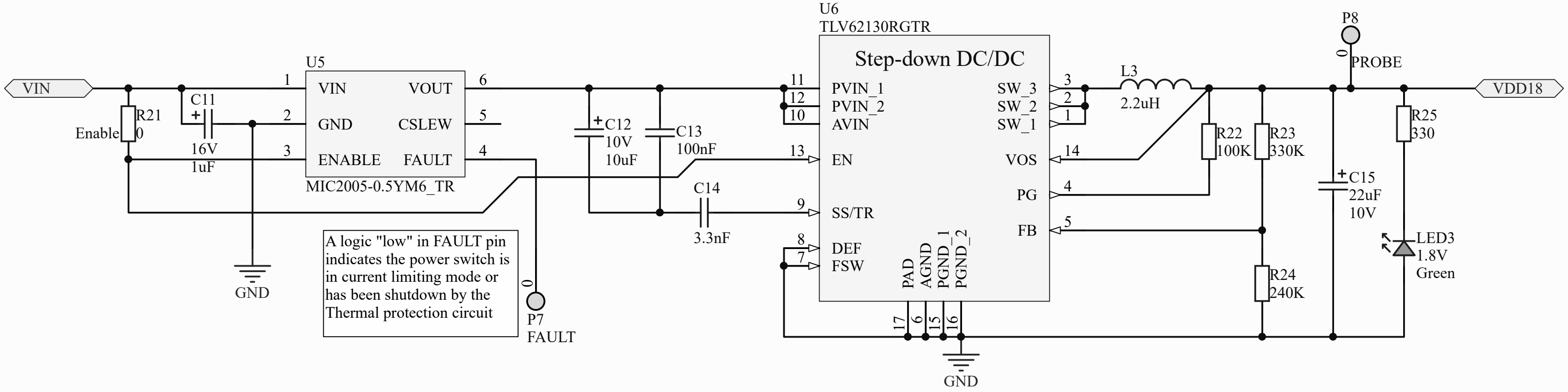
1.8V Power supply



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Size: A4	Number		Revision: 1.0
Date: 29/09/2019		Sheet 5 of 11	
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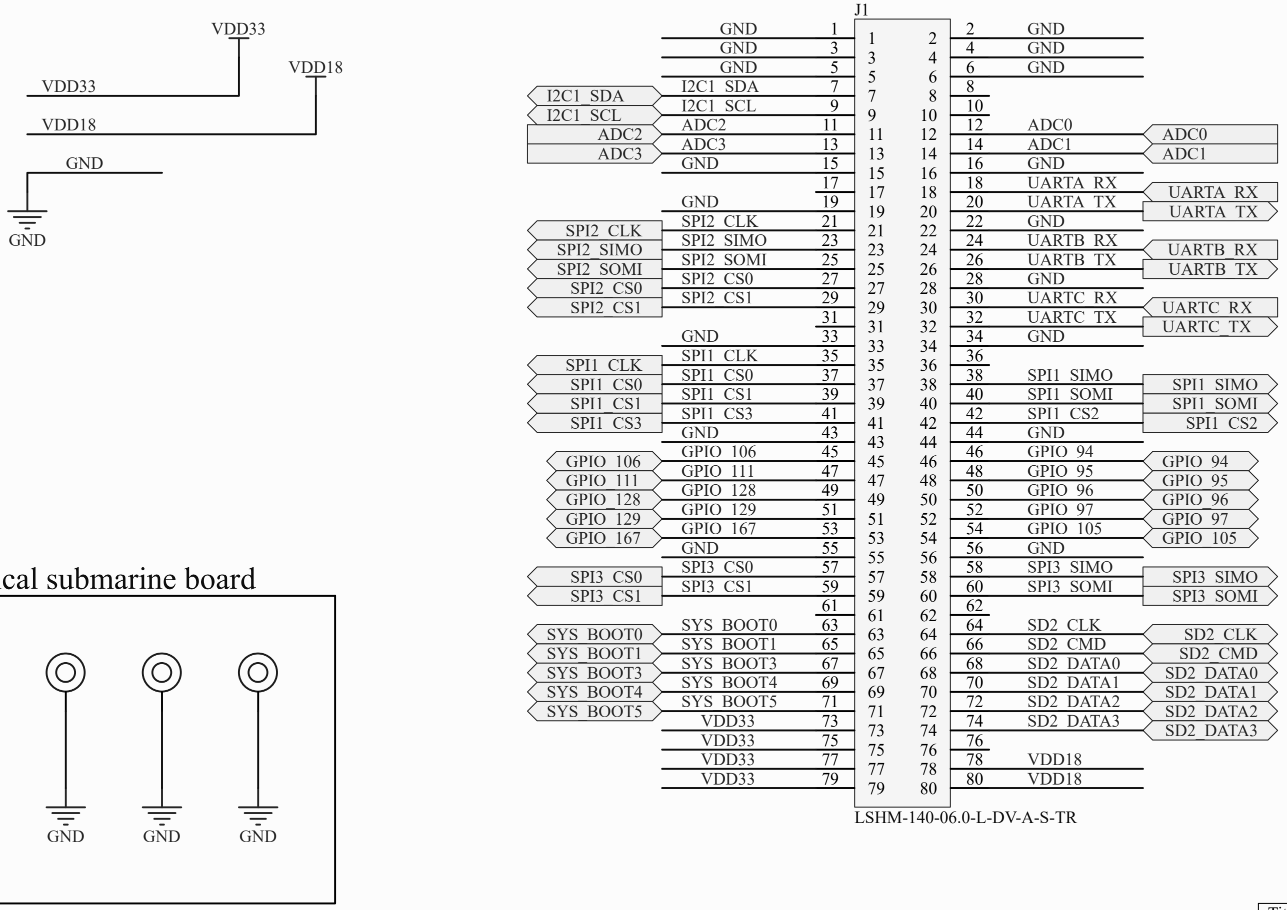
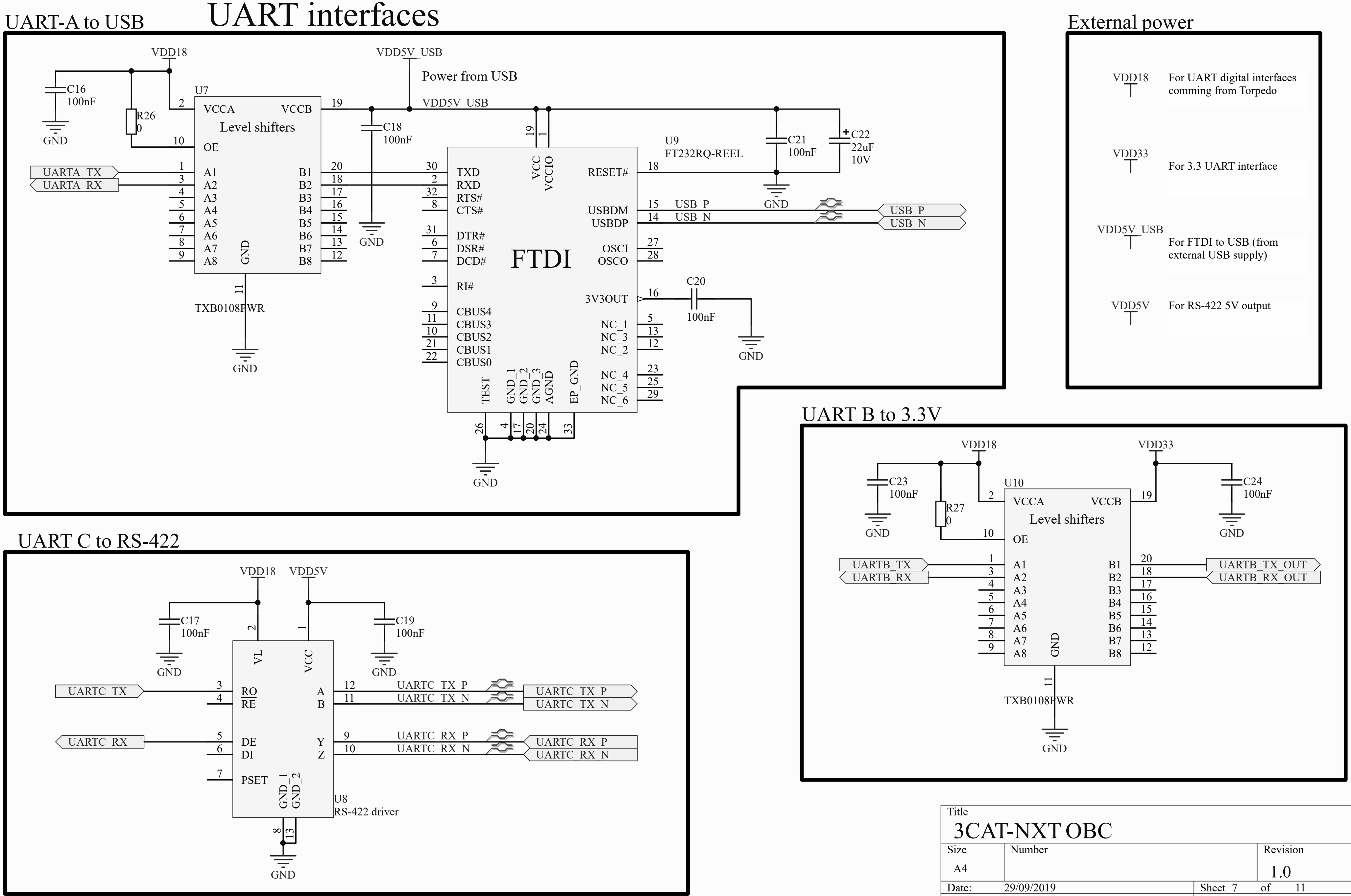
Inter-board connector



Title	3CAT-NXT OBC		
Size	A4	Number	Revision 1.0
Date:	29/09/2019	Sheet 6 of 11	
File:	C:\Users\..\3CAT-NXT OBC motherboard	Drawn By: Carlos Molina Ordóñez	

UART interfaces



Title			
3CAT-NXT OBC			
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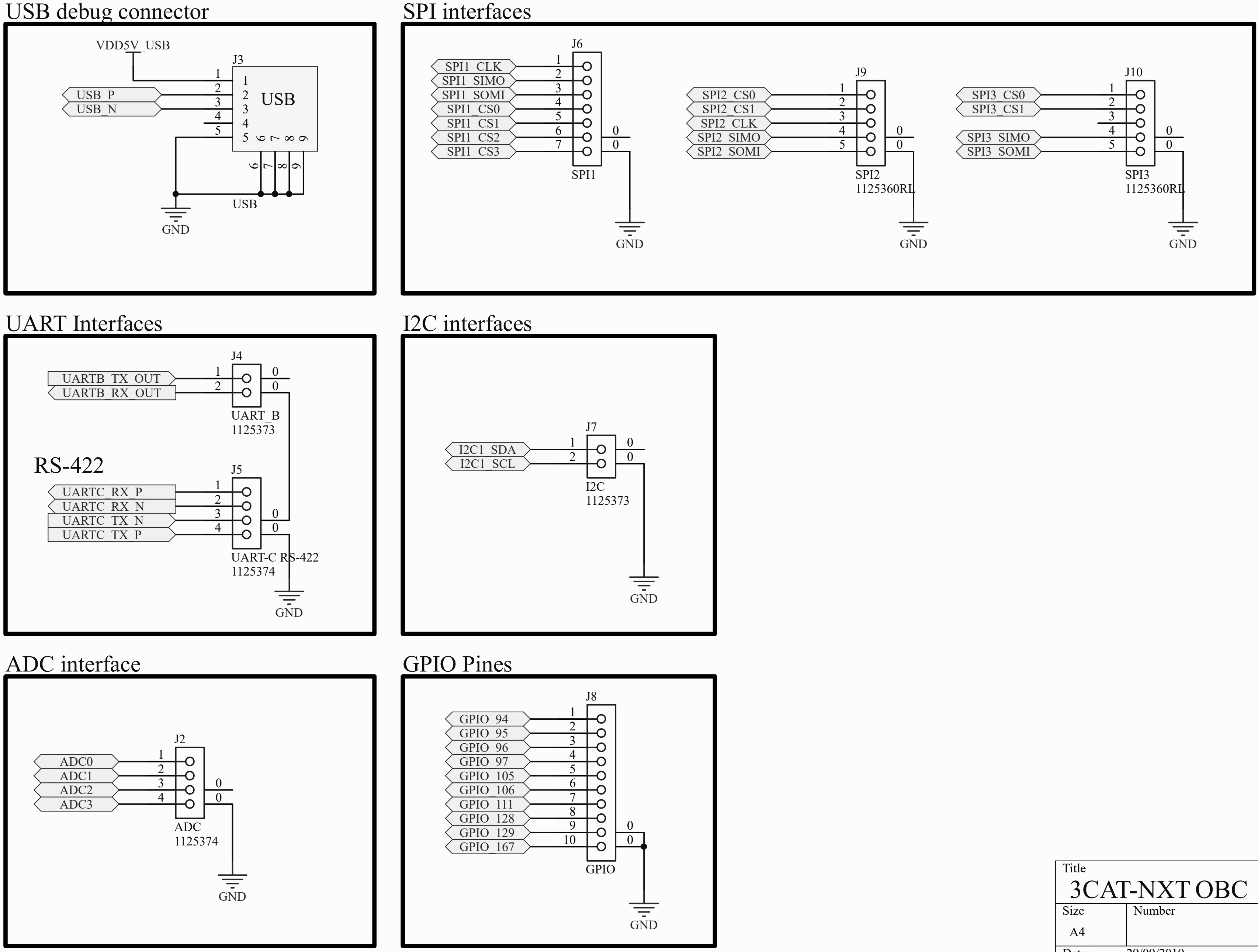
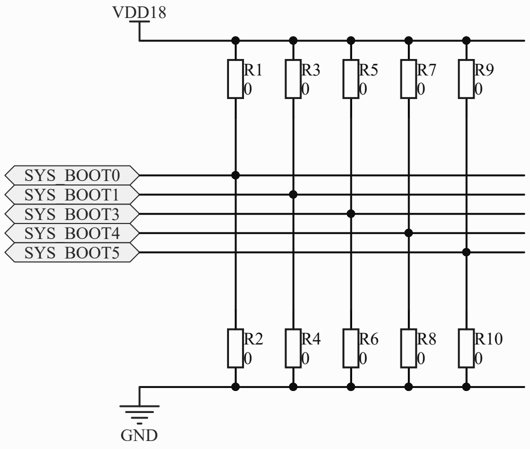
File: C:\Users\..\3CAT-NXT_OBC_UART.SchDoc		Drawn By: Carlos Molina Ordóñez	

External interfaces



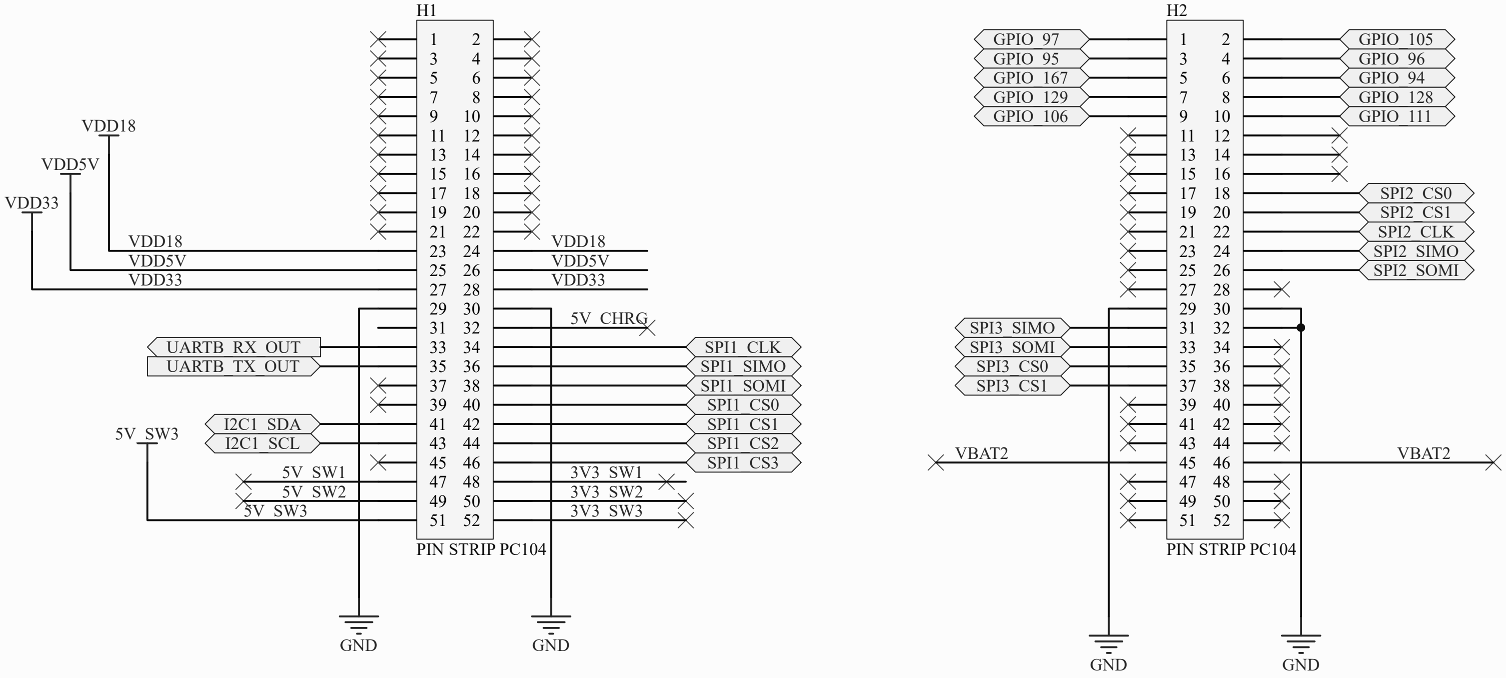
Title		
3CAT-NXT OBC		
Size: A4	Number	Revision: 1.0
Date: 29/09/2019	Sheet 8 of 11	
File: C:\Users\..\3CAT-NXT OBC interface.SchDoc	Drawn By: Carlos Molina Ordóñez	

SYS_BOOT configuration bits

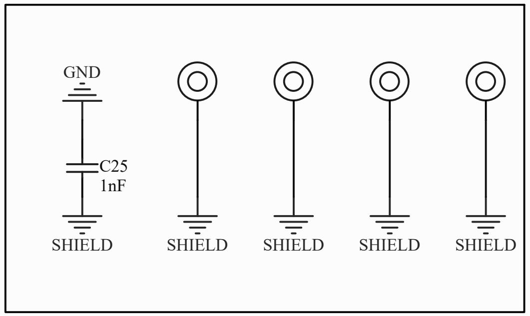


Title			
3CAT-NXT OBC			
Size: A4	Number		Revision: 1.0
Date:	29/09/2019	Sheet 9 of 11	
File:	C:\Users\..\3CAT-NXT_OBC_motherboard_sys_boot.SchDoc	Drawn By: Carlos Molina Ordóñez	

PC-104 interface bus



Mechanical standard 3CAT-NXT



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Revision: 1.0
Date: 29/09/2019
Sheet 10 of 11
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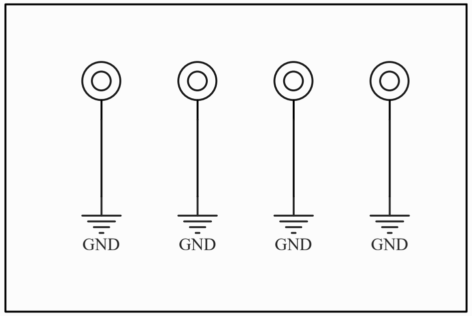
Drawn By: Carlos Molina Ordóñez

Second board connector

Mechanical miscelanoeus board



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Size	Number		Revision
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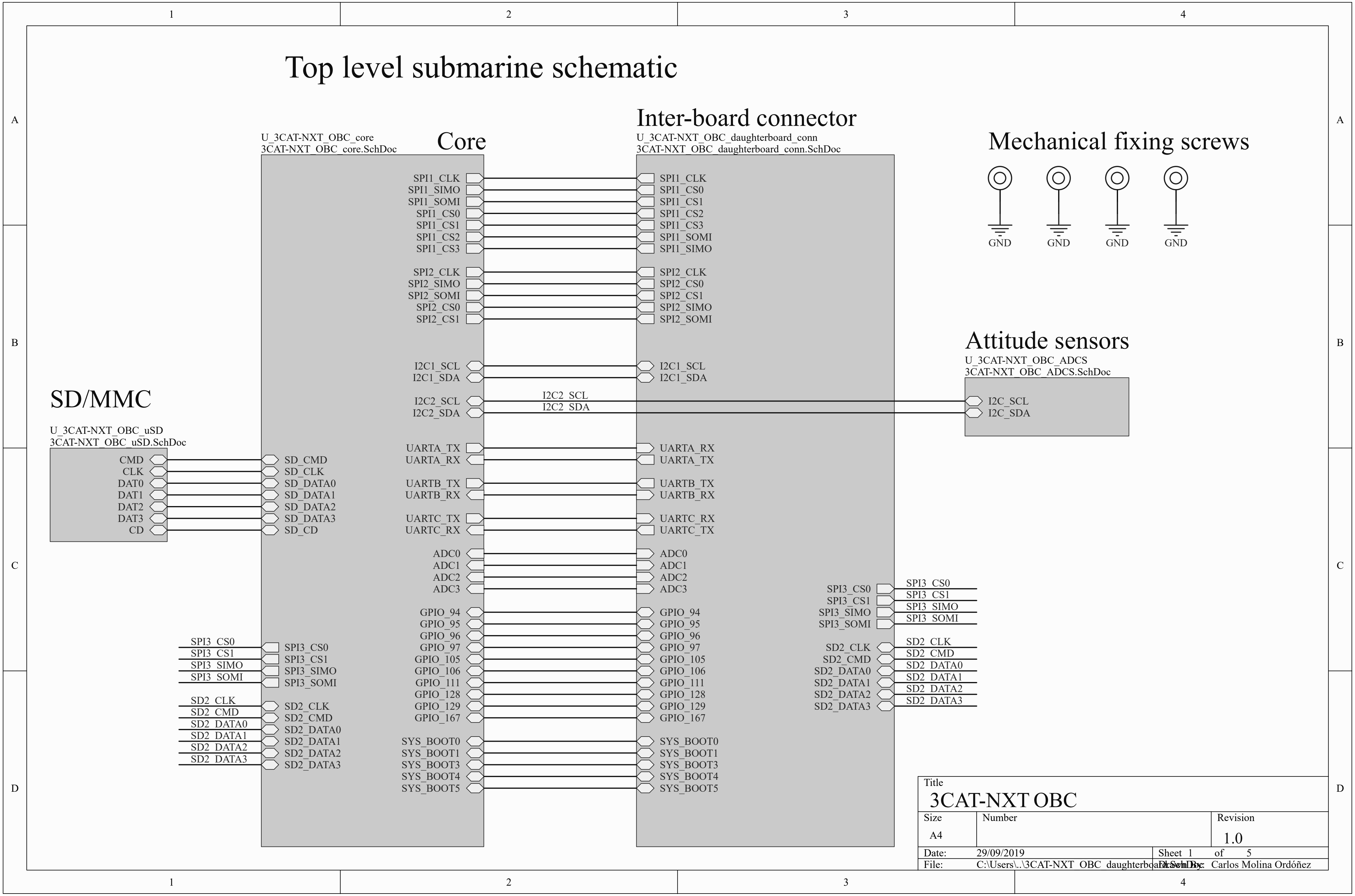
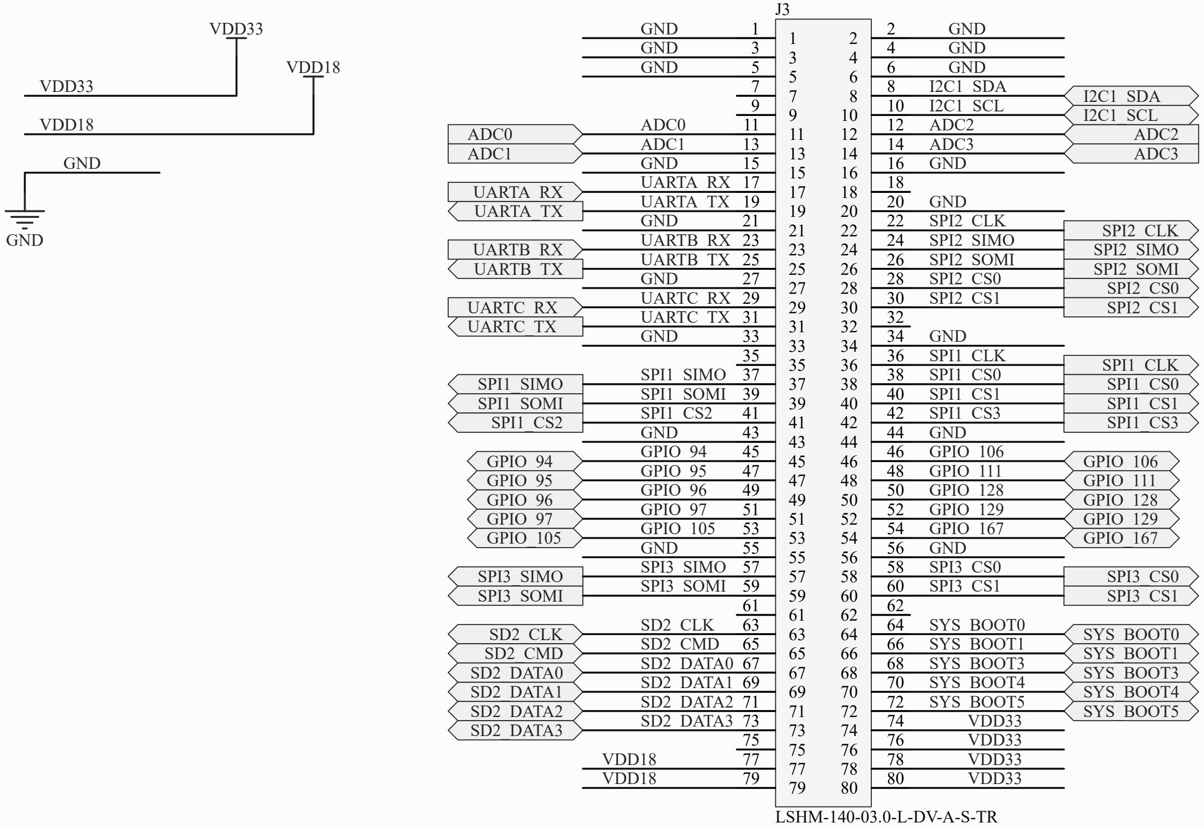
E.2 Submarine schematic


Top level submarine schematic
Core
U_3CAT-NXT_OBC_core
3CAT-NXT_OBC_core.SchDoc
Inter-board connector
U_3CAT-NXT_OBC_daughterboard_conn
3CAT-NXT_OBC_daughterboard_conn.SchDoc
Mechanical fixing screws
GND
GND
GND
GND
SPI1_CLK
SPI1_SIMO
SPI1_SOMI
SPI1_CS0
SPI1_CS1
SPI1_CS2
SPI1_CS3
SPI2_CLK
SPI2_SIMO
SPI2_SOMI
SPI2_CS0
SPI2_CS1
I2C1_SCL
I2C1_SDA
I2C2_SCL
I2C2_SDA
UARTA_TX
UARTA_RX
UARTB_TX
UARTB_RX
UARTC_TX
UARTC_RX
ADC0
ADC1
ADC2
ADC3
GPIO_94
GPIO_95
GPIO_96
GPIO_97
GPIO_105
GPIO_106
GPIO_111
GPIO_128
GPIO_129
GPIO_167
SYS_BOOT0
SYS_BOOT1
SYS_BOOT3
SYS_BOOT4
SYS_BOOT5
SD_CMD
SD_CLK
SD_DATA0
SD_DATA1
SD_DATA2
SD_DATA3
SD_CD
SPI3_CS0
SPI3_CS1
SPI3_SIMO
SPI3_SOMI
SD2_CLK
SD2_CMD
SD2_DATA0
SD2_DATA1
SD2_DATA2
SD2_DATA3
SPI1_CLK
SPI1_CS0
SPI1_CS1
SPI1_CS2
SPI1_CS3
SPI1_SOMI
SPI1_SIMO
SPI2_CLK
SPI2_CS0
SPI2_CS1
SPI2_SIMO
SPI2_SOMI
I2C1_SCL
I2C1_SDA
UARTA_RX
UARTA_TX
UARTB_TX
UARTB_RX
UARTC_RX
UARTC_TX
ADC0
ADC1
ADC2
ADC3
GPIO_94
GPIO_95
GPIO_96
GPIO_97
GPIO_105
GPIO_106
GPIO_111
GPIO_128
GPIO_129
GPIO_167
SYS_BOOT0
SYS_BOOT1
SYS_BOOT3
SYS_BOOT4
SYS_BOOT5
SPI3_CS0
SPI3_CS1
SPI3_SIMO
SPI3_SOMI
SD2_CLK
SD2_CMD
SD2_DATA0
SD2_DATA1
SD2_DATA2
SD2_DATA3
Attitude sensors
U_3CAT-NXT_OBC_ADCS
3CAT-NXT_OBC_ADCS.SchDoc
I2C_SCL
I2C_SDA
SD/MMC
U_3CAT-NXT_OBC_uSD
3CAT-NXT_OBC_uSD.SchDoc
CMD
CLK
DAT0
DAT1
DAT2
DAT3
CD
Title
3CAT-NXT OBC
Size
A4
Number
Revision
1.0
Date: 29/09/2019
Sheet 1 of 5
File: C:\Users\..\3CAT-NXT_OBC_daughterboard.SchDoc
Drawn By: Carlos Molina Ordóñez

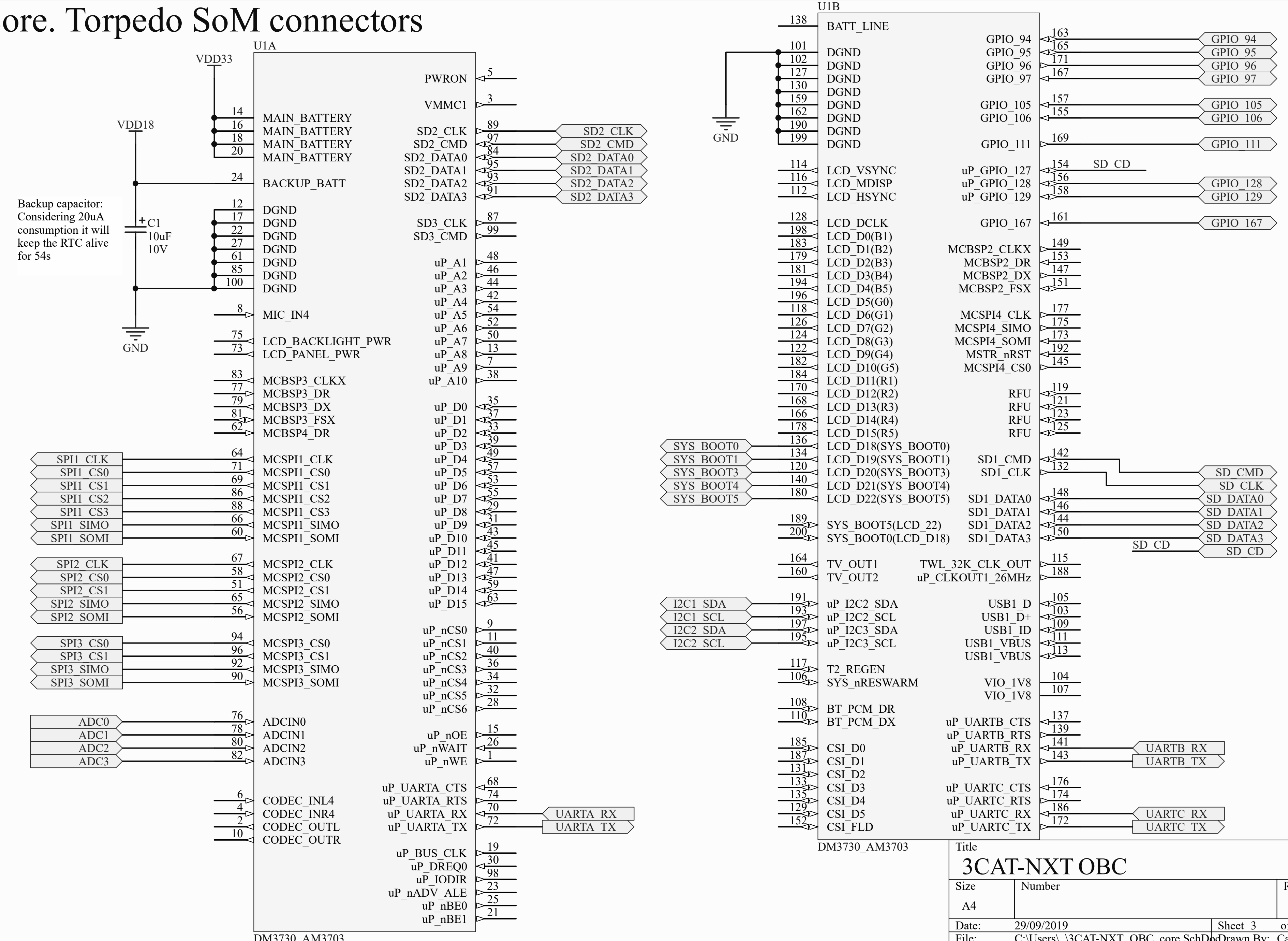
TextText
Text

Inter-board 80-pin connector



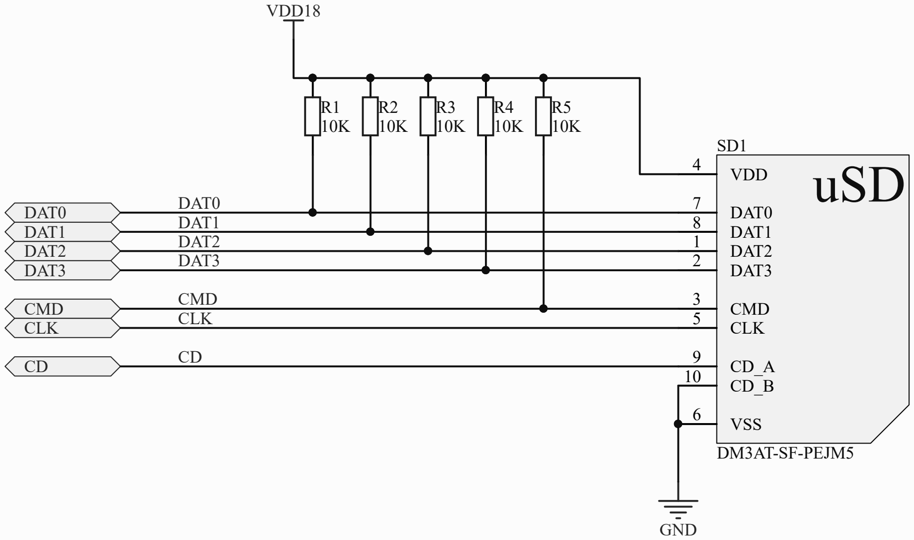
Title: 3CAT-NXT OBC			
Size: A4	Number:		Revision: 1.0
Date: 29/09/2019		Sheet 2 of 5	
File: C:\Users\..\3CAT-NXT OBC daughterboard.SchDoc		Drawn By: Carlos Molina Ordóñez	

Core. Torpedo SoM connectors

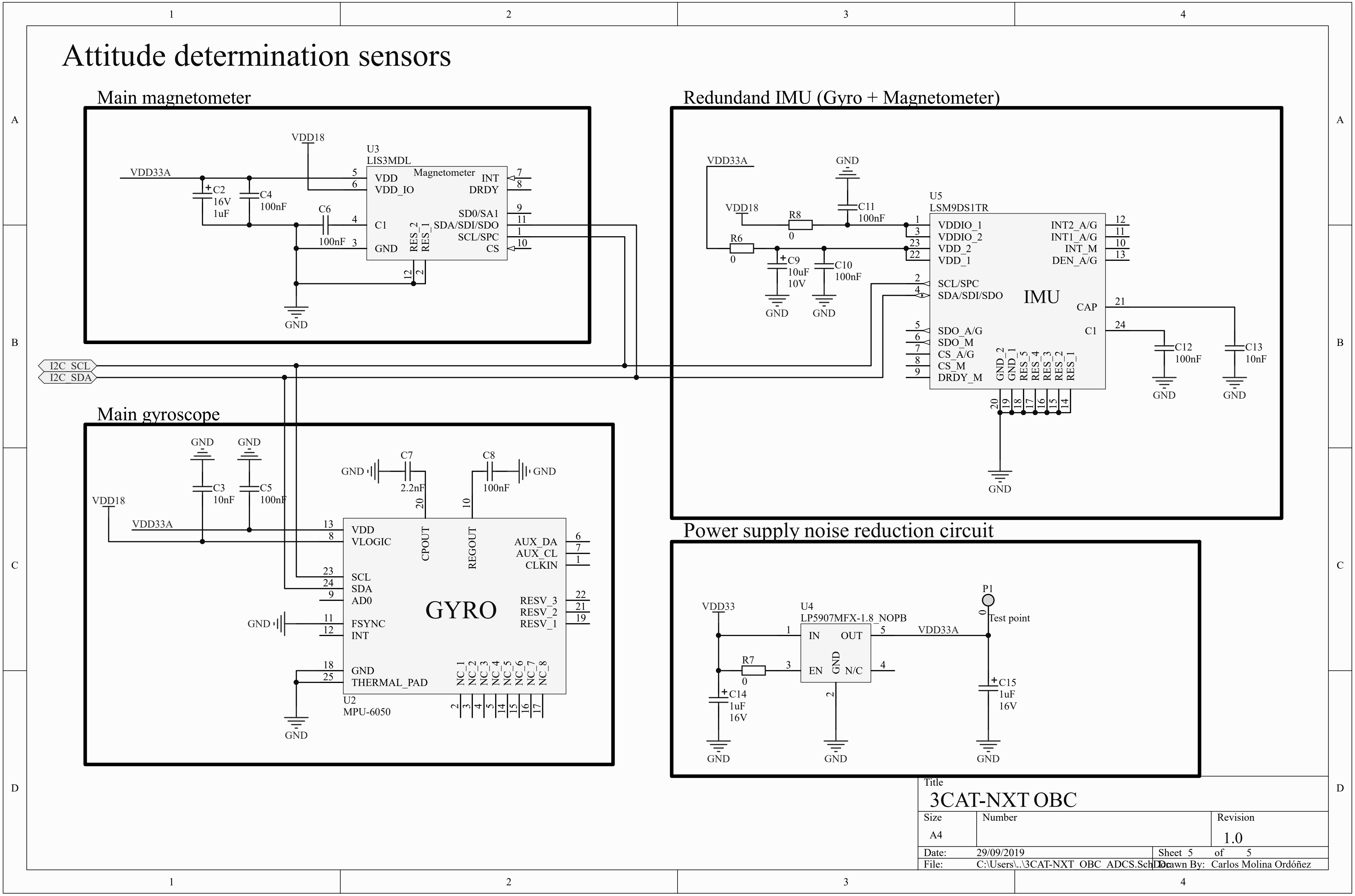


Title		
3CAT-NXT OBC		
Size: A4	Number	Revision: 1.0
Date: 29/09/2019	Sheet 3 of 5	
File: C:\Users\..\3CAT-NXT_OBC_core.SchDoc	Drawn By: Carlos Molina Ordóñez	

SD/MMC card connector



Title: 3CAT-NXT OBC			
Size: A4	Number:		Revision: 1.0
Date: 29/09/2019		Sheet 4 of 5	
File: C:\Users\..\3CAT-NXT_OBC_uSD.SchDoc		Drawn By: Carlos Molina Ordóñez	



Attitude determination sensors
Main magnetometer
VDD18
U3
LIS3MDL
VDD33A
Magnetometer
VDD
VDD_IO
C1
GND
INT
DRDY
SD0/SA1
SDA/SDI/SDO
SCL/SPC
CS
RES_2
RES_1
C2 16V 1uF
C4 100nF
C6 100nF
GND
Redundand IMU (Gyro + Magnetometer)
VDD33A
GND
VDD18
R8 0
R6 0
C11 100nF
C9 10uF 10V
C10 100nF
U5
LSM9DS1TR
VDDIO_1
VDDIO_2
VDD_2
VDD_1
SCL/SPC
SDA/SDI/SDO
SDO_A/G
SDO_M
CS_A/G
CS_M
DRDY_M
INT2_A/G
INT1_A/G
INT_M
DEN_A/G
IMU
CAP
C1
GND_2
GND_1
RES_5
RES_4
RES_3
RES_2
RES_1
C12 100nF
C13 10nF
I2C_SCL
I2C_SDA
Main gyroscope
GND
C3 10nF
C5 100nF
VDD18
VDD33A
C7 2.2nF
C8 100nF
VDD
VLOGIC
SCL
SDA
AD0
FSYNC
INT
GND
THERMAL_PAD
CPOUT
REGOUT
GYRO
AUX_DA
AUX_CL
CLKIN
RESV_3
RESV_2
RESV_1
NC_1
NC_2
NC_3
NC_4
NC_5
NC_6
NC_7
NC_8
U2
MPU-6050
Power supply noise reduction circuit
VDD33
U4
LP5907MFX-1.8_NOPB
IN
OUT
EN
GND
N/C
VDD33A
P1
Test point
R7 0
C14 1uF 16V
C15 1uF 16V
Title
3CAT-NXT OBC
Size
A4
Number
Revision
1.0
Date: 29/09/2019
Sheet 5 of 5
File: C:\Users\..\3CAT-NXT_OBC_ADCS.SchDoc
Drawn By: Carlos Molina Ordóñez