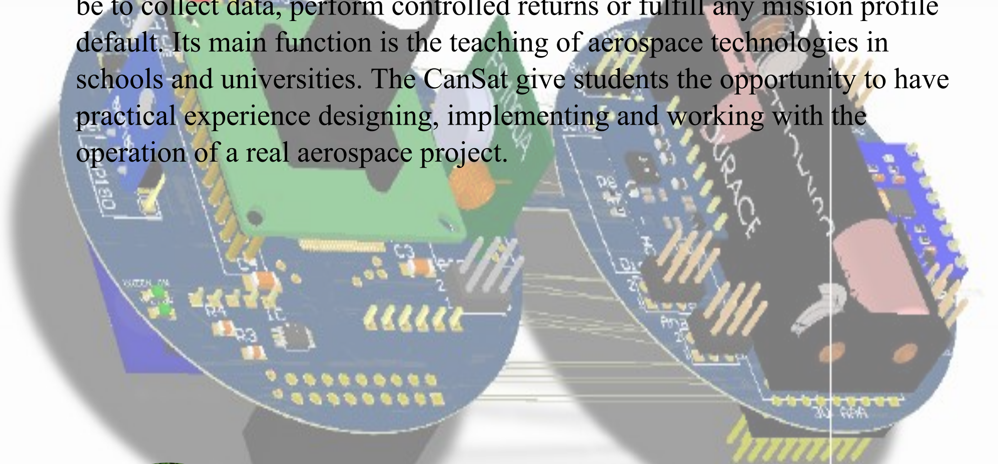


The aim of this project is the design and building of a CanSat motherboard that connect plug and play, which facilitates the installation to novice users. The CanSat is a device or system the size of a soda can with a mission may be to collect data, perform controlled returns or fulfill any mission profile default. Its main function is the teaching of aerospace technologies in schools and universities. The CanSat give students the opportunity to have practical experience designing, implementing and working with the operation of a real aerospace project.

Francisco Jesús Lázaro Lorente is a telecommunication engineer from Andújar, Jaén, Spain. He finished his Bachelor's Studies in 2016 at University of Granada. He starts working with GranaSAT Team in 2015, where I started to work on the project of a CanSat which is the one presented in this report.

Andrés María Roldán Aranda is the Academic Head of the GranaSAT Development Team, and the tutor of this project. He is professor in Electronics and Computer Technology Department in the University of Granada.

FINAL DEGREE PROJECT

Mechanical, Electronic Design and Implementation of a CanSat

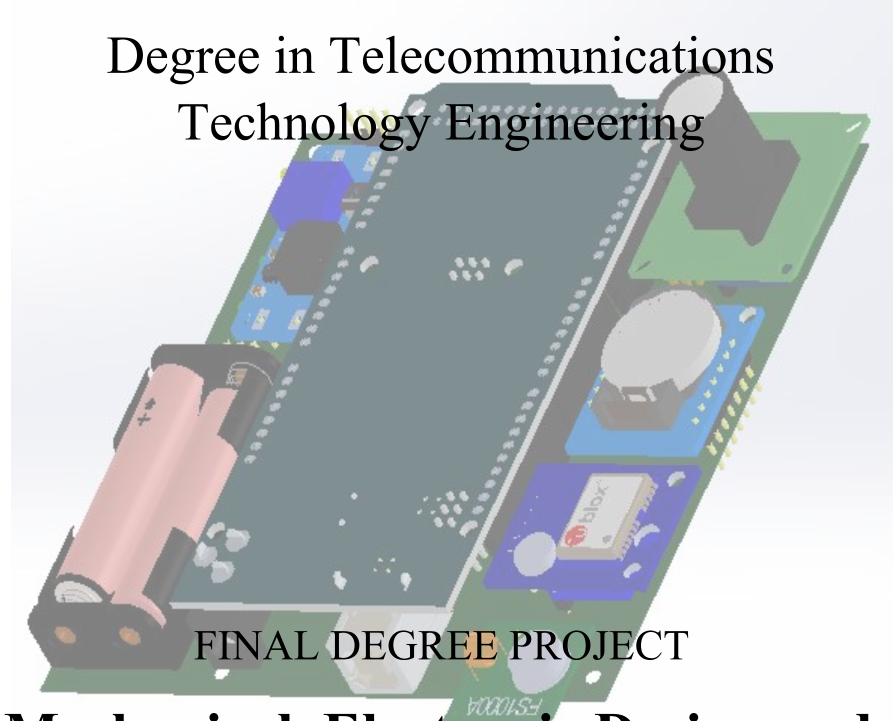
Francisco J. Lázaro Lorente

TELECOMMUNICATIONS ENGINEERING

2015/16

UNIVERSITY OF GRANADA

Degree in Telecommunications Technology Engineering



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Tutor: Andrés María Roldán Aranda

GRADO EN INGENIERÍA DE
TECNOLOGÍAS DE TELECOMUNICACIÓN

TRABAJO FIN DE GRADO

“Mechanical, Electronic Design and Implementation of a CanSat”

CURSO: 2015/2016

Francisco Jesús Lázaro Lorente

GRADO EN INGENIERÍA DE TECNOLOGÍAS DE TELECOMUNICACIÓN

“Mechanical, Electronic Design and Implementation of a CanSat”

REALIZADO POR:

Francisco Jesús Lázaro Lorente

DIRIGIDO POR:

Andrés María Roldán Aranda

DEPARTAMENTO:

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D. Andrés María Roldán Aranda, Profesor del departamento de Electrónica y Tecnología de los Computadores de la Universidad de Granada, como director del Trabajo Fin de Grado de D. Francisco Jesús Lázaro Lorente,

Informa:

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“Mechanical, Electronic Design and Implementation of a CanSat”

ha sido realizado y redactado por el mencionado alumno bajo nuestra dirección, y con esta fecha autorizo a su presentación.

Granada, a 12 de Septiembre de 2016

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Fdo. Francisco Jesús Lázaro Lorente

Fdo. Andrés María Roldán Aranda

Mechanical, Electronic Design and Implementation of a CanSat

Francisco Jesús Lázaro Lorente

PALABRAS CLAVE:

CanSat, picosatélite, GranaSAT, arduino, acelerómetro, magnetómetro, lowcost, MATLAB, solidworks, altium, giróscopo, análisis, ESA, mecánica, diseño, electrónica, PCB.

RESUMEN:

Los CanSat dan a los estudiantes la oportunidad de tener una experiencia práctica diseñando, implementando y trabajando con la operación de un proyecto aeroespacial real. El objetivo de este trabajo es el diseño y construcción de un CanSat de bajo coste. Este tipo de satelites, basados en sistemas de bajo coste, tienen muchas aplicaciones como competicones a grandes escalas patrocinadas por la Agencia Espacial Europeacoste, además para el equipo GranaSAT nos ofrece una alternativa para futuros proyectos relaciones con los picosatelites. Se podría decir que el desarrollo del CanSat sería como una placa de pruebas para testear diferentes dispositivos que seran utilizados en proyectos muchos mas grandes y fiables.

El CanSat es un aparato o sistema del tamaño de una lata de refresco cuya misión puede ser recoger datos, efectuar retornos controlados o cumplir algún perfil de misión predeterminado. Su principal función es la enseñanza de tecnologías aeroespaciales en escuelas y universidades. Si bien se los denomina "satélites", no lo son en el sentido estricto de su definición como cuerpo que gira alrededor de un planeta. Estos aparatos normalmente deben ser completamente autónomos y pueden recibir o transmitir datos.

KEYWORDS:

CanSat, GranaSAT, arduino, accelerometer, magnetometer, lowcost, MATLAB, solidworks, altium, gyroscope, analysis, design, mechanics, electronic, PCB.

ABSTRACT:

The CanSat give students the opportunity to have practical experience designing, implementing and working with the operation of a real aerospace project. The aim of this work is the design and construction of a low cost CanSat. This type of satellites, based on low cost systems have many applications such as large competitions sponsored by the European Space Agency scales, in addition to the GranaSAT team offers an alternative for future relations with pico-satellites projects. You could say that the development of CanSat would be like a breadboard to test different devices that will be used in many larger and reliable projects.

The CanSat is a device or system the size of a soda can with a mission may be to collect data, perform controlled returns or fulfill any mission profile default. Its main function is the teaching of aerospace technologies in schools and universities. Although called "satellites", they are not in the strict sense of its definition as a body that revolves around a planet. These devices typically must be completely autonomous and can receive or transmit data.

Dedicado a

Mis padres, Francisco y Rosa María, y mis hermanos Marisol y Jorge, porque sin ellos y sin su apoyo, llegar hasta aquí hubiera sido imposible.

Agradecimientos:

En primer lugar, me gustaría agradecer a mis padres Franciscp y Rosa María, y a mis hermanos Marisol y Jorge su apoyo durante mi periodo universitario, y en general, durante toda mi vida. Hubiese sido imposible conseguir lo que he conseguido hasta ahora sin su incondicional apoyo y compañía en cada momento. Con este proyecto, cierro mi etapa universitaria, pero abro otra en la que seguiréis siendo los principales protagonistas.

También quiero agradecer a mis compañeros y amigos de Teleco, quiénes me han ayudado en cada momento que lo he necesitado en mis años universitarios., y cada amigo que dió su mejor apoyo hacia mi persona en toda mi vida. Pero especialmente me gustaría agradecer a mi gran amigo Jose Manuel por su apoyo y buenos consejos cuando más lo he necesitado.

Por último, agradezco a todo el equipo de desarrollo de GranaSAT su colaboración, pero en especial a mi tutor, Andrés María Roldán Aranda por su tiempo dedicado, y comentarios intructivos, no sólo para este proyecto, sino para mi futura vida profesional.

Acknowledgments:

Firstly, I would like to thank my parents Francisco y Rosa María,my sister Marisol and my brother Jorge for their support during my university period and, in general, my whole life. It would have been impossible to achieve what I achieved without their unconditional support and company in every moment. With this project, I close my university stage, opening up a new one in which you will also be main characters.

I want to thank to my Teleco's colleagues and friends too, who help me in every moment that I need in my university years, and each friend who do their best support to my person in my whole life. But specially I would also thank to my great friend Jose Manuel for their support and good advice when I most needed.

Finally, I would like to thank to the GranaSAT Development Team, but particulary my advisor, Andrés María Roldán Aranda for his provided timely and instructive comments, not only for this project, but for my future professional life. I hope you will never change.

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GLOSSARY

Altium Altium Designer is an electronic design automation software package for printed circuit board, FPGA and embedded software design, and associated library and release management automation. It is developed and marketed by Altium Limited of Australia.

AX.25 AX.25 +is a data link layer protocol derived from the X.25 protocol suite and designed for use by amateur radio operators. It is used extensively on amateur packet radio networks. AX.25 v2.0 and later occupies the data link layer, the second layer of the OSI model. It is mainly responsible for establishing connections and transferring data encapsulated in frames between nodes and detecting errors introduced by the communications channel. As AX.25 is a pre-OSI-model protocol, the original specification was not written to cleanly separate into OSI layers. This was rectified with version 2.0 (1984), which assumes compliance with OSI level 2..

CanSat CanSat is a simulation of an integrated volume and shape of a soda actual satellite (355 ml.) with an approximate mass of 500 grams whose mission may collect data or perform controlled returns. The word CanSat comes from Can (soft drink can) and Sat (contraction satellite).

GranaSAT GranaSAT is an academic project from the University of Granada consisting of the design and development of a picosatellite (Cubesat). Coordinated by the Professor Andrés María Roldán Aranda, GranaSAT is a multidisciplinary project with students from different degrees, where they can acquire and enlarge the necessary knowledge to front a real aerospace project. `http://granasat.ugr.es/`.

MicroSD MicroSD is a non-volatile memory card format developed by the SD Card Association (SDA) for use in portable devices.

NMEA The National Marine Electronics Association (NMEA) has developed a specification that defines the interface between various pieces of marine electronic equipment. The standard permits marine electronics to send information to computers and to other marine equipment. GPS receiver communication is defined within this specification. Most computer programs that provide real time position information understand and expect data to be in NMEA format. This data includes the complete PVT (position, velocity, time) solution computed by the GPS receiver.

Servomotor A servomotor is a rotary actuator or linear actuator that allows for precise control of angular or linear position, velocity and acceleration. It consists of a suitable motor coupled to a sensor for position feedback. It also requires a relatively sophisticated controller, often a dedicated module designed specifically for use with servomotors. Servomotors are not a specific class of motor although the term servomotor is often used to refer to a motor suitable for use in a closed-loop control system.

Solidworks SolidWorks (stylized as SOLIDWORKS) is a solid modeling computer-aided design (CAD) and computer-aided engineering (CAE) computer program that runs on Microsoft Windows. SolidWorks is published by Dassault Systèmes. The program allows modeling of parts and assemblies and extract from them as much technical drawings and other information necessary for production. It is a program that works based on new modeling techniques with CAD systems. The process involves transferring the mental idea to the CAD system designer, "building virtually" the part or assembly. Subsequently all extractions (plans and swap files) are made fairly automated.

ACRONYMS

3D 3 Dimensions.

ADS Attitude Determination System.

APRS Automatic Packet Reporting System.

CMOS Complementary MOS.

DC Direct Current.

DLR Deutsches Zentrum für Luft- und Raumfahrt.

ECTD Electronics and Computer Technology Department.

EEPROM Electrically Erasable Programmable Read Only Memory.

ESA European Space Agency.

GPS Global Positioning System.

GS Ground Station.

I2C Inter-Integrated Circuit.

ICSP In Circuit Serial Programming.

LED Light Emitting Diode.

LEO Low Earth Orbit.

LNA Low Noise Amplifier.

MEMS Microelectromechanical Systems.

MHz Megahertz.

PC Personal Computer.

PCB Printed Circuit Board.

PL Payload.

RF Radio Frequency. Radiofrecuencia.

SCH Schematic.

SMD Surface Mount Devices.

SNSB Swedish National Space Board.

SSC Swedish Space Corporation.

THT Through-Hole Technology.

UGR University of Granada.

VGA Video Graphic Array.

CHAPTER

1

INTRODUCTION

The following final degree project completed the studies of the Degree in Telecommunications Technology Engineering. The aim of this project was the design and implementation of a CanSat, GranaSAT.

GranaSAT, whose logo is shown in figure 1.1, is an aerospace project, carried out in the University of Granada, which aims to build a Cubesat by the student's final projects degree. This project is coordinated by the professor Andrés María Roldán Aranda and it allows to the students acquire knowledge about the aerospace field and a real experience in this area. The equipment needed for that project and the laboratories for the student's projects are located in the Sciences Faculty of the University of Granada.

Figure 1.1 – *Logo GranaSAT*

GranaSAT was involved in the BEXUS/REXUS programme defined in its webpage as a programme realized between the German Aerospace Center (DLR) and the Swedish National Space Board (SNSB), and a collaboration with the European Space Agency (ESA) [36]. In the case of GranaSAT, the choice was BEXUS, the part of this programme where the students use an stratospheric balloon to test their systems.

GranaSAT used BEXUS to prove the system which will be included in the future Cubesat. During one year, the team (the author of this document was part of this team) designed an Attitude Determination System (ADS) based on three different methods: a Horizon Sensor, a Magnetometer and a Star Tracker [33].

The experiment was launched in October 2014 in Kiruna (Sweden), where the Esrange Space Center(SSC) is located and the result of this launch for GranaSAT Team was successful. In the Figure 1.2, is shown the launch of this project.

Figure 1.2 – *BEXUS19 Launch*

In order to test all over systems for the Cubesat, a testbed is needed, a simulation platform designed for the test of a aerospace system, in this case, the GranaSAT's subsystems. This platform will imitate the frictionless environment of the space scenario and it will take the measurements to analyze this scenario with some sensors.

1.1 What's a CanSat?

CanSats in Europe is an initiative of the European Space Agency (ESA), which also supports national CanSat events with the help of local organisations. These organisations are collaborating to increase the support for CanSat activities in Europe.

A CanSat is a simulation of a real satellite, integrated within the volume and shape of a soft drink can. The challenge for the students is to fit all the major subsystems found in a satellite, such as power, sensors and a communication system, into this minimal volume. The CanSat is then launched to an altitude of a few hundred metres by a rocket or dropped from a platform or captive balloon and its mission begins: to carry out a scientific experiment and achieve a safe landing.

CanSats offer a unique opportunity for students to have a first practical experience of a real space project. They are responsible for all aspects: designing the CanSat, selecting its mission, integrating the components, testing, preparing for launch and then analysing the data.

1.2 Motivation

The motivation of the implementation of this project is to facilitate and familiarize students in the world of electronics for mini-satellites. The idea is that anyone can build a CanSat with very cheap components and sensors that can be purchased easily online.

This project will facilitate the GranaSAT development team test the different sensors and components to be used for future implementations and projects related to aerospace.

1.3 Project Objectives

In order to get a successful result for that final degree project, the following objectives have to be fulfill.

- Design a PCB where you can interconnect the various sensors normally used in satellites and easy electronic purchasing by anyone, for bringing the aerospace world to everyone:
    - Used in the design of PCB sensors in different modules constructed so by different manufacturers.
    - Implementation of an optimal software that provides all the functionality users CanSat.

1.4 Project Structure

In this project, each chapter is directly related with the system engineering process concerned. In the flow diagram of the figure 1.3 there is a scheme of this process.

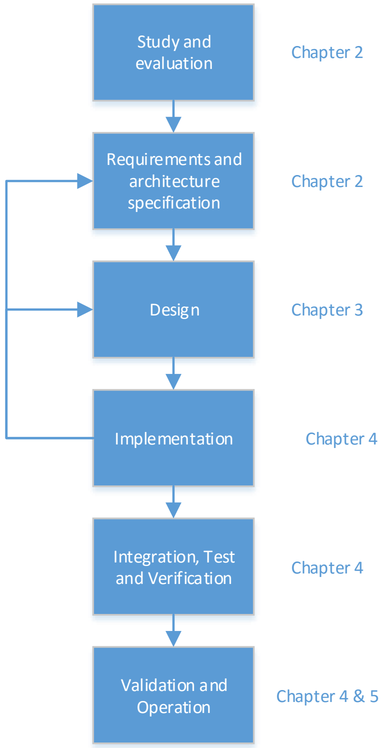


Figure 1.3 – *Flow of the project process*

- **Chapter 2 and 3: Background and Analysis:** in this chapter, we will analyze how a CanSat is studied, the different subsystem that it should include, and the theoretic questions that it has to develop.
- **Chapter 4: System Design** in this chapter, we will describe the design of the whole system, electronics and mechanical subsystems chosen for the GranaSAT Testbed. Moreover, the software design will be studied in this chapter too.
- **Chapter 5: Integration, test and verification** in this chapter, we will explain the test and verification procedures followed to prove the whole system, and the followed integration to ensure its correct operation.
- **Chapter 6: Validation and Operation**: the conclusions of the project and the operational working process. We also describe briefly the possible improvements and

future work related with this project.

CHAPTER

2

BACKGROUND STUDY

As we have previously said the Cansat project is intended to meet the different subsystems used in nano-satellites. The CanSat project consists of 3 parts mainly:

- **Launch system.** We can use small rockets or a helium balloon to get our CanSat get the maximum height possible. In our case the option is designed helium balloon that is less expensive and simpler to implement.

(a) *Example of a rocket launch* **(b)** *Example of Helium balloon*

Figure 2.1 – *Launch system [22]*

- **Telemetry System.** This part is everything related to electronics such as temperature, pressure, gyroscopes sensors or even GPS and cameras. We must also emphasize communication systems to send such data telemetry.

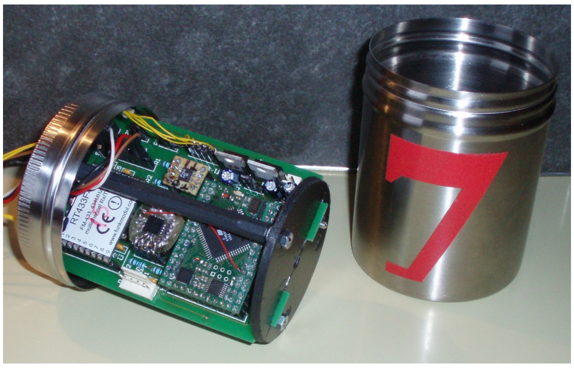


Figure 2.2 – *Example of a CanSat [2]*

- **Landing system.** Once the system reaches its highest point in the sky, landing system which consists of a parachute with a size and shape specified to ensure that the CanSat not damaged.

Figure 2.3 – *Example of a parachute.[30]*

2.1 CanSat introduction

A CanSat is a simulation of a real satellite, integrated within the volume and shape of a soft drink can. The challenge for the students is to fit all the major subsystems found in a satellite, such as power, sensors and a communication system, into this minimal volume. The CanSat is then launched to an altitude of a few hundred metres by a rocket or dropped from a platform or captive balloon and its mission begins: to carry out a scientific experiment and achieve a safe landing.

The CanSat concept was first introduced in the midnineties by the American professor, Robert Twiggs. The idea behind the project was to let students be able to deal with some of the same challenges in building a satellite, but at the same time it had to be done over a much shorter period of time and with small expenses. Typically, a number of student teams come together to launch their CanSats during the course of a day, competing for prizes. The rules and objectives can vary depending on the country where it is developed the competition.[14]

The main purpose of CanSat for GranaSAT team is able to use it as a testbed for the various subsystems are developed for more complex projects such as nano- cubesat or where the GranaSAT team is involved. The CanSat may be a first initial test to see how these subsystems behave a few meters above the ground and to sudden changes in temperature and pressure.

2.2 Types of CanSat

There are mainly two types of CanSats, though a third category is usually added for those machines that do not fit in the two first:

- **Telemetry**. This is the one whose primary purpose is to collect and transmit data from the flight and weather conditions in real time to be processed by a Ground Station (GS). CanSats in this category do not use a steering system since its objective is not to fall at a particular point but to collect data while the descent (which is not usually controlled). Of the systems mentioned in the previous sections the most used are: barometer, thermometer, GPS and camera.

- **ComeBack**. The main task of these is to land in a controlled manner as close as possible to a target marked by GPS coordinates. These devices can be guided by GPS. This position is sent to the microprocessor which compares the position of the target from the analysis of these data to calculate the angle at which it should turn to address the target and gives appropriate instructions to the steering system. This process is repeated continuously to make corrections. Such devices also store data on the flight but since the number of sensors that accompany them is less, information is more scarce than in the previous type. A ComeBack CanSat always carries a steering system that allows it to maneuver, to orient and to move towards the target. Normally such a mechanism is actuated by one or more actuator(s) controlled by the microprocessor so that the Servomotor rotates to one side or the other and so rotating CanSat. There are two main types depending on whether CanSat incorporates a parachute or glider or a rotor and wings.

  - **CanSats with parachutes or paragliders**. These devices generally have a steering system consisting of threads that move asymmetrically so as to generate a difference in lift of the longitudinal axis so the CanSat rotates in one way or another. It uses fairly simple mechanics. These devices are difficult to govern due to the generally low rate of descent and the large surface area lifts it.

  - **CanSats with wings or rotors**. Mechanically more complex and less vulnerable to weather conditions that CanSats with parachute or gliders. This kind of gadgets are much more harsh to govern and require an electronic system able to perform many more corrections per second due to its higher rate of descent.

- **Openclass**. In this category, any robot that is not included in any of the previous two categories can be submitted. Most CanSat presented in this category are robots testing new systems or new designs that have not yet been tested (technology demonstrators).[26] [6]

2.3 Defining the mission

The design of the entire CanSat system is based on the definition of the mission that it will develop. Depending on the CanSat competition each team must plan their mission and adapt them to the requirements established. The major competitions CanSat are held in Japan, United States and Europe where they are led by ESA.[11]

In these competitions it is considered the fact that the CanSat will be released to a temperature, pressure, height and location: certain height, measuring basic atmospheric parameters and is defined position. These parameters are measured during the development of the mission, from launch to the decline. The main objectives of the mission can be summarized as follows:

- The CanSat shall collect temperature and pressure data and calculate the height during the flight path.
- Another point to consider is to transmit the data to the base station during flight especially the important thing is location data of the device.
- Finally one of the main mission is to get new becoming cheaper and more viable than we currently subsystems. Ultimately to test different hardware and software designs.[14]

2.4 Segment flight

If we refer to the elements that form a CanSat can be grouped into two main sections: the platform and payload (PL).

- **Payload**. The PL refers to the set of sensors, experiments, processes and all that is part of the system responsible for carrying out the mission, ie, the part that flies and is supported by the other subsystems segment flight or spaceship and develops the objective of the mission. For example, satellite systems in the payload corresponds to the antennas, amplifiers, waveguides, frequency converters and other elements that receive and send RF signals on the satellite. In the case of the CanSat in question, this subsystem will consist of pressure sensors, temperature and GPS receiver, which is responsible for making the respective measurements. The subsystems that can be found within the PL are as shown below:

  - **Transmission and communications subsystem (telemetry)**. This system is made up of the antenna or antennas transmit and receive (telemetry and command) and the stages responsible for encoding and sending radio signals. For our case a transmitter module that works in the band 144.800 MHz because the GS GranaSAT team the receiver operates in this frequency band.

  - **Power subsystem**. This subsystem is responsible for providing power to all other subsystems of the CanSat as are the transmitter, sensors and the GPS receiver. In the case of our design we have a pack of batteries 3V representing the energy source and the stages of voltage regulation and power that will operate on all circuits.

  - **Data Management Subsystem**. This is the system responsible for managing all information from the various sensors or actuators containing both the part of the platform and the payload. Is a subsystem that directly manages the physical "bus" along which data from different subsystems and software associated with it. For the simplicity of the design of a CanSat, the flight computer is part of this subsystem (control software) and does not require separate treatment, although in missions more complex, it is common to treat the flight computer independently.

  - **Mechanical support subsystem and containment structure**. This subsystem is made up of mechanical containment structure and the entire platform and payload CanSat. It consists of the can itself and the adjustments made to allow conveniently and safely accommodate all stages of the different subsystems. A correct design and a favorable performance largely ensure safety and life of the mission.

  - **Ground Station**. Where telemetry system for storage and deployment is received. It consists of:

    - **Transceiver**, consisting of an antenna and the device that decodes the RF signal.
    - **Conversion system and communication with PC**, giving information and send commands (although this feature is not required) that are received by the antenna and the transceiver.
    - PC with software deployment and data analysis.

- **Platform**. The satellite platform refers to the structure that supports with support elements to perform the function that is allocated a CanSat. It consists of a series of specialized subsystems on a specific task as are the electrical subsystem, communications subsystem or data management subsystem. Unlike the payload, the platform may contain sensors that are used, not to carry out the mission, but to allow the payload to operate properly and the mission can be accomplished.

2.5 System Requirements

As we have described before, the design of PCB CanSat hould facilitate the implementation and development of a CanSat any user as already discussed in the Section 1.3 of the Chapter 1. The main idea is that the motherboard available the maximum possible sensors so that each user choose our design starts from the sensors to be used in its mission. A possible structure of the different subsystems that make up the CanSat can be shown in the diagram below:

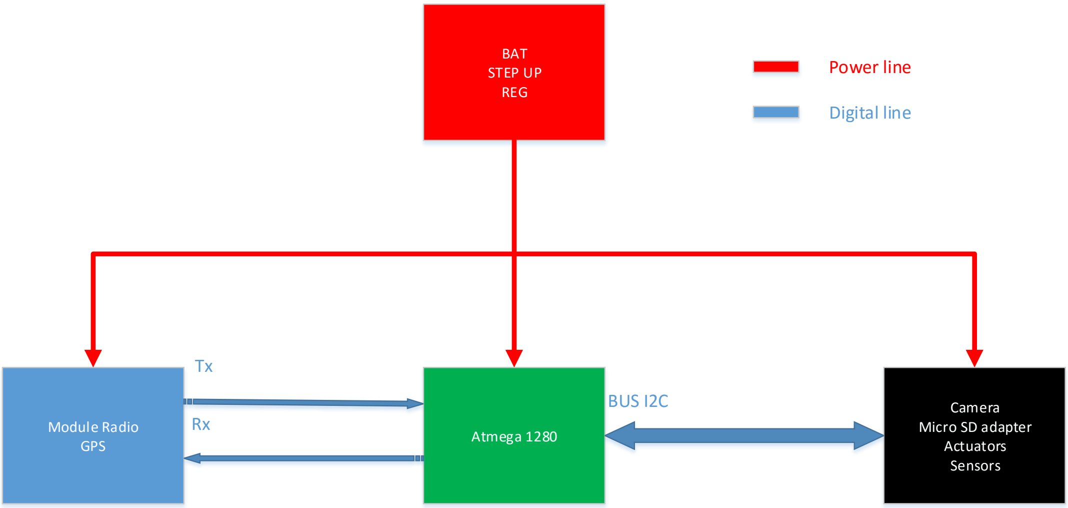


Figure 2.4 – *Block diagram of the subsystems of the CanSat.*

2.5.1 Hardware requirements

The system should meet some hardware requirements. In this section, the hardware requirements will be divided in differents subsystems: communication system, actuators, sensors.

2.5.2 Communication System

It is required a link between the Ground Station and CanSat. This link should have the following characteristics:

- Bidirectional option. It is necesary the communication between the GS and the Satellite in two ways because the use of the telemetry (transmission of the data from the sensors in the Satellite to the PC) and the telecontrol (orders transmission from the GS to the CanSat's actuators).
- Bandwidth. The communication device should provide the sufficient bandwith to transfer the data, taking into account the rules CanSat competitions, these rules may vary depending on the country.
- Reliability and efficiency. The CanSat requires a efficiency communication system, which enhance the efficiency in the power consumption too.
- The parameters measured with the sensors should be represented in the GS in real time.

2.5.3 CanSat PCB and electronic devices

The designed PCB should have some requirements for a correct operation. That PCB will include the sensors, a microprocessor, the actuators and the power system.

- The PCB power system should provide the required voltages to supply every system on it.
- That power system, will be battery powered because the CanSat is a wireless system, without any cable.
- The battery must have the maximum capacity to turn on the system as long as possible, in the minimum size conceivable.
- The sensors have to offer the maximum accuracy for the measurements, and a compatible communication with the microprocessor.
- The microprocessor ought to permit a correct communication with the GS, and it should have the necessary ports for every sensors, actuators, etc.
- The PCB should have the minimum consumption of energy as possible, because the power supply is a battery and it have to save as much as it can. Moreover, the cost have to be reduced to the minimum possible too.
- The PCB have to fit with the size of soft drink can taking into account that the weight have to be as light as possible, because it will enhance the possibility of the proper functioning and to get the highest altitude in flight.

2.5.4 Mechanical parts

In this project, one of the most important parts is the mechanical design and implementation, because we have to adapt to the volume of a can of soda or even specifications imposed in the CanSat competition. The main requirements are:

- We have to take advantage of the volume of the can to the fullest, to place all possible electronic components. We must place the heavier elements criterion for this system stable in flight.
- The design and placement of parachutes in the CanSat must be taken into account for everything to work properly at the time of the flight.
- Another aspect in the mechanical design are the thermal problems. The design must be optimal in order to dissipate heat properly.

2.5.5 Software

It is necessary a software that allows the functions of telemetry and telecontrol for the CanSat. So, the software design has three subsections: telemetry, telecontrol and software on board.

2.5.5.1 Telemetry

- Port control in the GS to receive the data.
- Divide and decode the paquets received to organise the data in the PC of the GS.
- An error algorithm to ensure that every data is received correctly.
- Real time display of the data received.
- The option of save or load (from a previous session) the data received.
- The system shall provide appropriate viewers for the user to read the data collected (use of graphics, for example).

2.5.5.2 Telecontrol

The system should be prepared for the telecontrol from the GS to the CanSat. That option should be optional, to optimize the data transmission bidirectionally. It will have the same characteristics and requirements than telemetry if we used the same protocol to upload and download the data. The telecontrol must operate to the software on board to change the desired parameters as well as enable or disable the camera to capture images.

2.5.5.3 Software onboard

- In order to have measurements in real time, the algorithm should be as efficient as possible.
- The microprocessor will have to read the data and calculate the outputs for the actuators in the minimum necessary time.

CHAPTER

3

SYSTEM ANALYSIS

In this chapter, it will be analysed the most relevant parts of the CanSat related with this project. A comparative study will be done in order to select the best option for each part, as much to electronics as to mechanical design. That chapter will be essential to have a proper design, presented in chapter 4.

The first part that will be studied is the CanSat Technology, in order to choose the best design keeping in the way of possible minimum price and dimensions. Later, the electronics parts will be analysed and finnally some issues for the mechanical part, and a resumme of the communication system.

3.1 CanSat Technology

Nowadays, the CanSat technology are in a constant growth driven by CanSat competitions that are made in different countries. The technology used should be limited by the mission imposed by the various competitions as mentioned above. Sensors, actuators and various electronic components must meet the specifications set by the competition.

Figure 3.1 shown below you can see an example of designing a CanSat. In this example it was decided to put 3 PCBs placed one above the other to maximize space as far as possible.

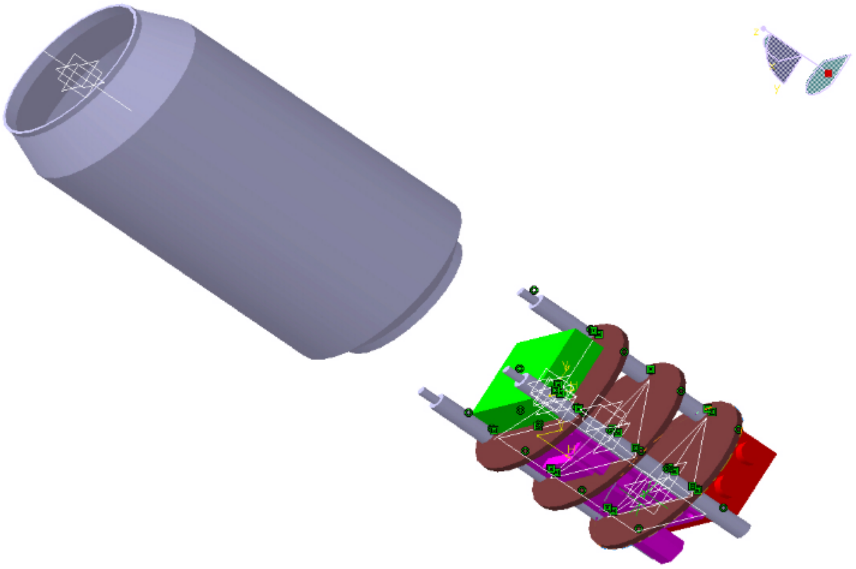


Figure 3.1 – *Virtual model of a CanSat[10]*

In contrast, in figure 3.2 we can see another design in which only uses a PCB because the size of its components are better suited in this way.

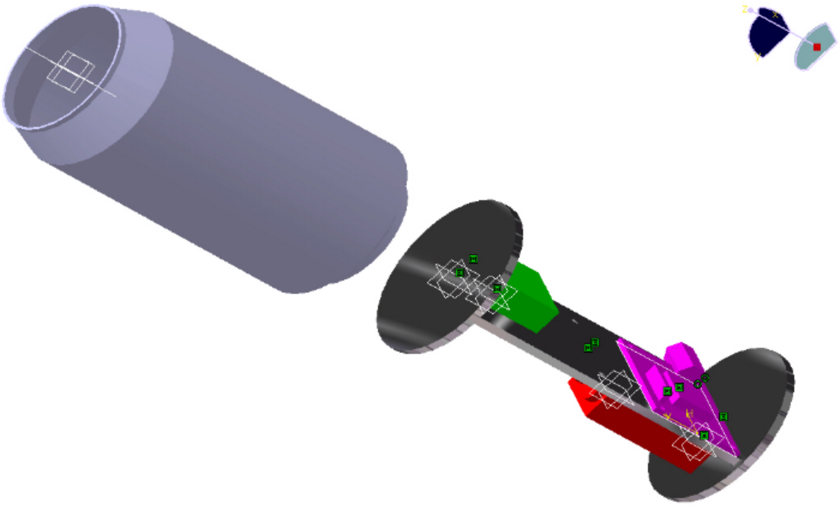


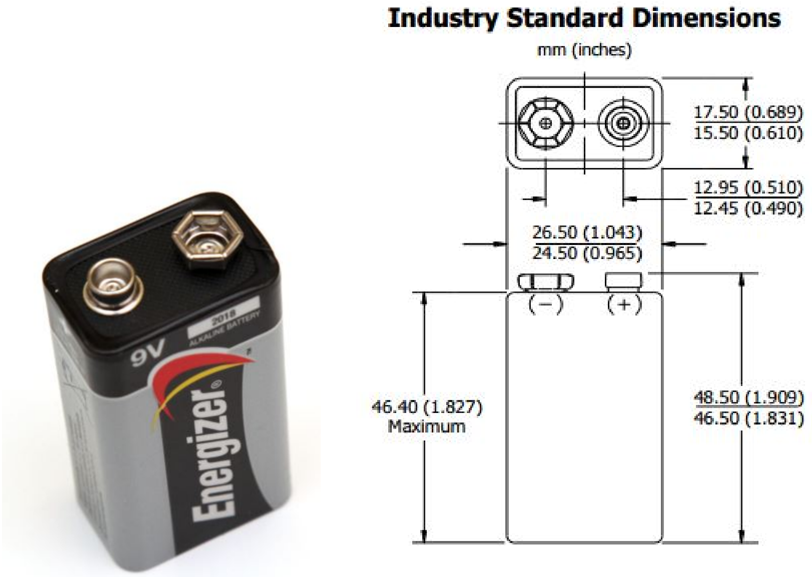
Figure 3.2 – *Virtual model of a CanSat[10]*

3.2 Power systems

This part is the one that supplies power to all other components to make the PCB work properly. In our design we need different values of voltage to power these sensors, specifically need 3,3V and 5V. Apart from the need to feed the sensors, the supply system has to ensure some autonomy to perform its functionality for a long time.

For our project we must choose between two alternatives, such alternatives will be analyzed below:

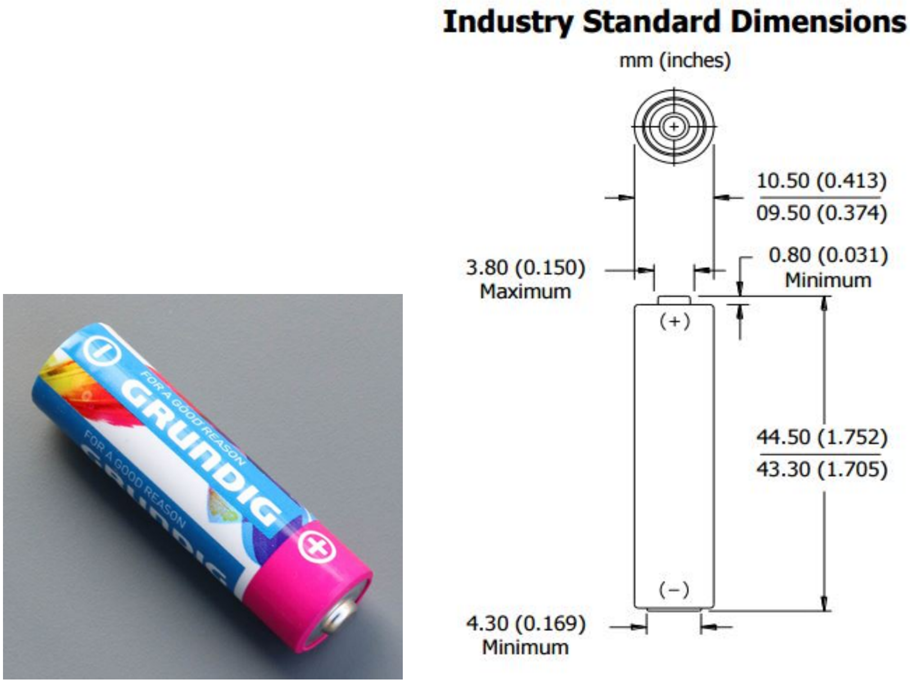
- **Battery 9V**. This battery can be one of the alternatives to power supply our PCB, for that we should also use a step down or regulators to lower the voltage of 9V to 5V and 3,3V (In chapter 4 will be explained in more detail). This solution ensures very good autonomy but has a disadvantage is its size and weight as seen in figure 3.3.



(a) *9V Battery* (b) *Dimensions of a 9V battery*

Figure 3.3 – *Photo and dimensions of a 9V battery [24]*

- **Battery AAA of 1,5V**. This type of battery is the other option, for it will need at least two batteries in series to obtain at least a 3V. In this case also we need a regulator or step up to raise the voltage of 3V to 5V and 3.3V.



(a) *AAA Battery* **(b)** *Dimensions of a AAA battery*

Figure 3.4 – *Photo and dimensions of a AAA battery [25]*

At first glance you can see that the 9V battery will be bigger and heavier than the other two batteries together, however we will show a figure 3.5 with 3D models made in Solidworks where we can compare these characteristics. In addition to 3D models of batteries we've added their holders, saying that these 3D models are made with exact measurements of the actual components.

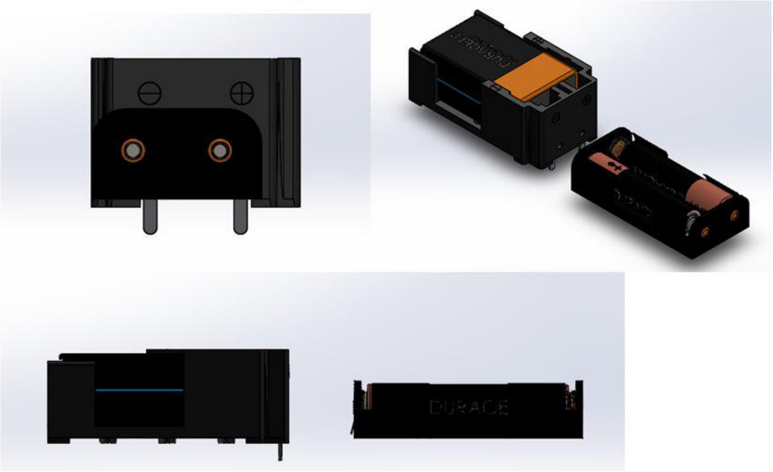


Figure 3.5 – *Comparison of 3D models of batteries*

Choice between different batteries		
	2 Battery AAA + holder	Battery 9V + holder
Width (mm)	24.4	21.36
Length (mm)	51.9	29.97
high (mm)	12.9	54.94
Battery weight (g)	11.5	45
Holder weight (g)	3.65	8.32
Total weight (g)	**26.65**	**53.32**

Table 3.1 – *Comparison weight and size of power supplies [24] [25]*

Based only on the mechanical characteristics the best option is to use as power supply because two AAA batteries as shown in the table 3.1 this option weighs half as the 9V battery. But this is not all, we also have to keep in mind when choosing the power supply can have autonomy and if the best option in the mechanical aspect is also good choice in the technical aspect and this will be discussed in more detail in chapter 4.

3.3 Sensors for the CanSat

As explained in the previous chapter the CanSat mission is to take data from temperature, pressure, etc, therefore these parameters need for sensors that are able to collect this data.

- **Magnetometer**. It is a sensor which measures the Earth's field. In Low Earth Orbit LEO, where the magnetic field of the Earth is the sufficient strong and 3D magnetometer will provide a proper attitude determination. there are three types: fluxgate, magneto-resistive and magneto-inductive. They should be well calibrated in order to have the control about the field generated within the CanSat. If the sensor is perfectly calibrated, that option is one of the best because of its good accuracy.

- **Accelerometer**. It is a inertial sensor, and measure translatory accelerations. The MEMS inertial accelerometers consists of a mass-spring system in a vacuum. When it is exercised an acceleration on the sensor, the mass in the spring system is displaced. The description of that functionality is shown in the figure 3.6, a sensor capacitive with MEMS technology. When the mass is moved of its original position, the capacitance changes and, then, the voltage too.

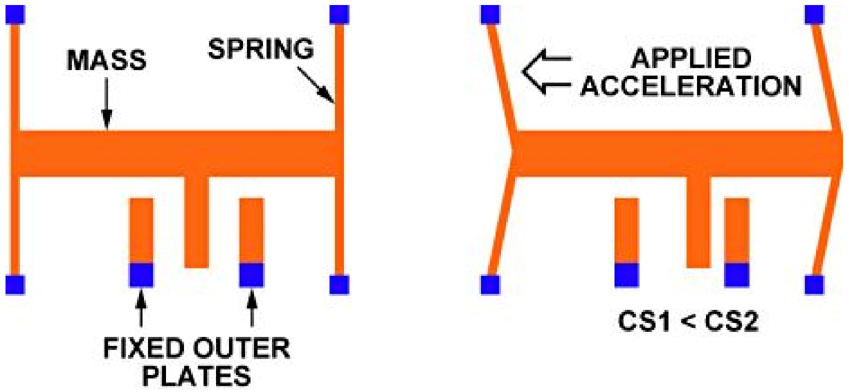


Figure 3.6 – *MEMS accelerometer [37]*

The following table 3.2 presents the comparison of four different 3D accelerometer MEMS technology that can be found on the market:

Parameter	**LSM303**	**MPU6050**	**ADXL345**	**LIS302DL**
Magnetometer incorporated	yes	no	no	no
Gyroscope incorporated	no	yes	no	no
Temperature range (ºC)	-40 to 85	-40 to 85	-40 to 85	-40 to 85
Voltage Supply (V)	2.16 to 3.6	5	2 to 3.6	2.16 to 3.6
Output data rate (Hz)	0.75-220	4-8000	6-3200	100-400
Communication protocol	I2C	I2C	I2C	I2C
Consumption at 3.3V (mA)	1.1	3.9	0.4	1.2

Table 3.2 – *Comparison of accelerometer [28] [44] [40] [43]*

We opted for the LSM303 of between four options we have shown in the table 3.2, the features that have not been compared are practically the same values. We have chosen this option because in one system incorporate both an accelerometer and magnetometer, can also save on space within the PCB layout. As consumption is another important factor it is within a fairly acceptable range.

- **Gyroscope**. That kind of sensor will measure the angular velocity of the body about a specified axis of rotation, in this case the CanSat, without the need of a external reference. Vibrating structure gyroscopes are simpler and cheaper than conventional rotating gyroscopes of similar accuracy.

  The gyroscope is not one of the essential missions sensors in a CanSat since it is not very common for actuators or motors are placed to control its descent. In our project we will use it as a compass to send to the GS localization coordinates and can capture pictures with the camera when the lens of the camera pointing toward Earth.

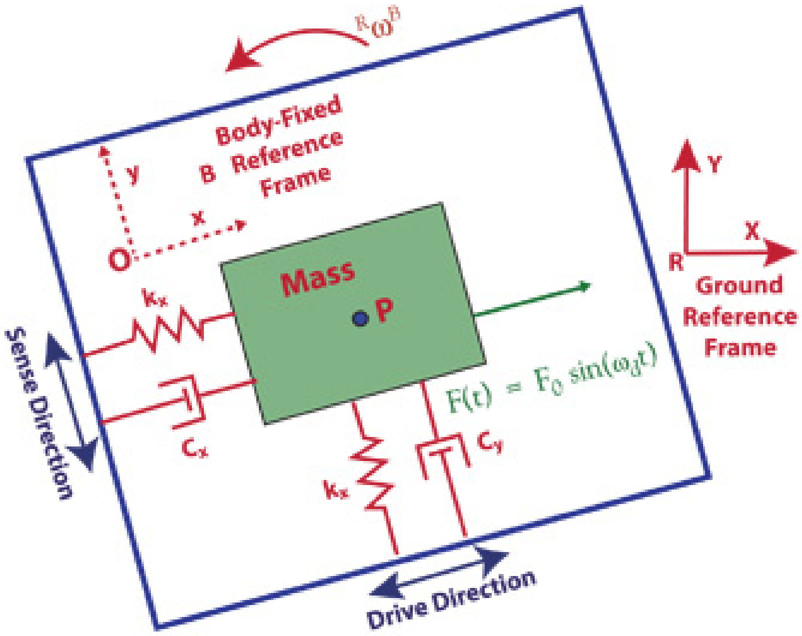


Figure 3.7 – *MEMS gyroscope [20]*

The figure 3.7 shows a physical model of a typical MEMS vibratory gyroscope designed to measure the angular velocity of the body about the Z-axis of the ground reference frame.

Below we will make another feature comparison between the best MEMS vibratory gyroscope often used for these purposes (you can be seen in the table3.3) in order to select the best for our system.

Parameter	**L3G4200D**	**MPU6050**	**L3GD20H**
Accelerometer incorporated	No	Yes	No
Voltage Supply[1](V)	5	5	5
Temperature range (ºC)	-40 to 85	-40 to 85	-40 to 85
Sensitivity (mdps/digit)	8.75, 17.50, 70	7.6, 15.2, 30.4, 60.8	8.75, 17.50, 70.00
Output data rate (Hz)	100-800	4-8000	11.9-757.6
Communication protocol	I2C	I2C	I2C
Consumption at 3.3V (mA)	6.1	3.9	5

Table 3.3 – *Comparison of gyroscopes [28][31][32]*

Each sensor will be used in MEMS technology, in order to have the smallest size possible and because of the CanSat limitations in size and weight, our choice for this sensor will be the MPU6065 board.

- **Thermometer**. The temperature sensors are devices that convert temperature changes into changes in electrical signals that are processed by electric or electronic equipment. Usually in the missions of the CanSat one of the objectives it is to obtain temperature measurements along the flight time, and then make a further analysis of these measurements and obtain the appropriate conclusions.

- **Barometer**. Barometer is a sensor that measures pressure, so a sensor of this type fructaciones pressure captures and converts them into voltage signals and sends them to the microcontroller to be interpreted.

  Obtaining pressure measurements also usually one of the requirements of the missions CanSat competitions.

Parameter	**SCP1000**	**MPL115A2**	**BMP180**
Thermometer incorporated	yes	yes	yes
Temperature range (ºC)	-20 to 70	-40 to 105	-40 to 85
Voltage Supply (V)	2.4 to 3.3	2.4 to 5.5	2 to 3.6
Measuring range (kPa)	30-120	50-115	30-110
Communication protocol	SPI	I2C	I2C
Consumption at 3.3V (μA)	4	5	5

Table 3.4 – *Comparison of barometer [42] [41] [38]*

The GranaSAT team has used in other projects the sensor BMP180 therefore will choose this option because it can be helpful in future projects undertaken in the GranaSAT team also as we can see in the table 3.4 the features that have been compared are practically the same values.

3.4 Other electronic components

Besides sensors also a CanSat is formed by communication systems such as radio transmitters, location systems (GPS receiver) imaging systems (cameras) or data storage systems (MicroSD adapter).

- **GPS receiver**. Currently, the inclusion of this receptor in the CanSat is not a mandatory requirement of the competition, although many teams do since it provides very useful data sent in real time by telemetry to the Ground Station (GS) and also facilitates the location of the device after the landing a explained in the section 4.1.1.1.5 of chapter 4.

  For our project will use the GPS NEO-6M of the company U-blox, (for more information in [8]), equipped on a PCB. This device consists of an EEPROM with factory settings, a button battery to maintain the configuration data in EEPROM, an LED and a ceramic antenna.

- **Radio module**. It is the system used for communication between CanSat and GS as we have discussed above. In our design we will use a radio transmitter whose function will send telemetry data during flight of the CanSat, as already mentioned in section 2.5.2 of chapter 2. In the table 3.5 we can see a comparison of the two transmitters used in our project:

Parameter	**Radiometrix HX1**	**FS1000A**
Transmit power (mW)	300	10
Operating frequency (MHz)	144.390 - 144.800 - 169.4125	315 - 418 - 433 - 915
Voltage Supply (V)	5	5
Consumption at 5V (mA)	140	4
Dimensions (mm)	43 x 15 x 5	19 x 19
Price (€)	39,24	2,71

Table 3.5 – *Comparison of radio module [35] [12]*

  In the first stage of the design process prototype CanSat, we use the module Radiometrix HX1 because it uses a high power transmission and this module is much more standardized to the field of tracking with GPS. But the final choice was the FS1000A module because its dimensions are much smaller and the price is much lower, although this module is a bit more limited performance. In the next chapter 4 will discuss in more detail.

- **Camera**. This component is not indispensable in the missions performed in the CanSat competitions in our project but we thought it would be a good idea to capture a few images during such missions. One of the main objectives as discussed in the section 1.3 was the low cost of the product to reach the maximum potential users, so we chose the cheapest camera that we found on the market we can see in the section 4.1.1.1.7 of chapter 4.

- **Data storage systems**. All data obtained by different sensors is advisable to store them in a memory to have a safe copy because it can happen that system radio to send data fails for any reason. As in previous elections, our approach will be smaller, lower cost, so our storage system will be an MicroSD adapter.

3.5 On-board microprocessor selection

In order to use the libraries provided by the sensors suppliers, we decided to use Arduino code, but instead of use a complete board of Arduino, the decision was take only the microprocessor AVR chip and the needed circuit components to work with it. Now, it is needed the selection of which microprocessor of Arduino is the best for our project, so the best way to select is comparing the main characteristics of some of them (see table 3.6).

Model	**ATmega1280-16AU**	**ATmega8-16AU**	**ATmega328P-AU**
SRAM (KB)	4	1	2
ROM (KB)	128	8	32
EEPROM (B)	4096	512	1024
IO Pins	86	23	23
Speed (MHz)	16	16	20
ADC-Bits	10-bit	10-bit	10-bit
PWM	8	3	6
Min Supply Volts (V)	1.8	2.7	1.8
Timers Counters	6	3	3
SPI	5	1	2
TWI (I2C)	1	1	1
UART	4	1	1
ADC channels	16	8	8
Ext Interrupts	32	2	24
Price (€)	8,71	3,72	3,41

Table 3.6 – *Comparison of microprocessors [18]*

The best option for the CanSat project is the ATMEGA1280-16AU, because it has the necessary analog and digital pins and it is the cheapest one. That microprocessor is used in THT model in Arduino MEGA, but we will use the SMD model to save weight and space in the PCB.

CHAPTER

4

SYSTEM DESIGN

In this Chapter of the project will be specified the details of the design of every subsystem. In the design of each part, we should apply the requirements given in the Chapter 2, in the Section 2.5. In order to have the best solution for every subsystem, in chapter 3 we have done an Analysis of other projects with different ideas.

The Block diagram shown in the Chapter 2, in the figure 2.4, shows every subsystem that the GranaSAT CanSat has. Now, we will see the design of the whole system, and the specifications of each part.

4.1 Electronic Design

The PCB of the CanSat will have the objective of connect the sensors, the microprocessor that controls everything, and the power supply part. That PCB was designed in Altium Designer 14, a PCB design tool which include the Schematics design, PCB design and 3D model of the PCB. Last option is very useful for the study of the dimension of that PCB, because it can be used to prove if the design fits with the 3D model of the mechanical parts.

Before making the final design of CanSat made a small prototype for conducting tests and to go drawing conclusions.

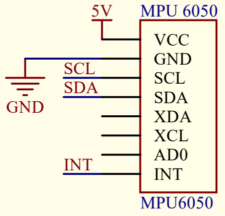
4.1.1 Prototype Shield CanSat

The prototype will consist of a PCB where easily connect and disconnect the sensors and other components that will be used in the final PCB. In the prototype we will not consider anything mechanical design and also we will use the Arduino MEGA, because this plate contains the same microprocessor that will use us in the final design of the CanSat.

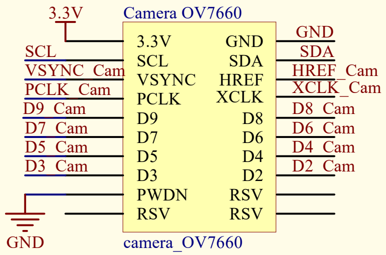
4.1.1.1 Electronic Schematics and components descriptions

In the following pages is shown the schematic of the PCB, with every subsystem included on it. In this project we have two schematics, one corresponding to the different sensors and the other corresponds to power systems with microprocessor.

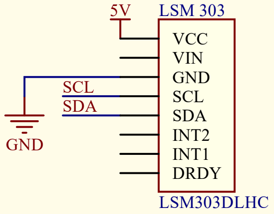
The MPU6050 sensor contains a MEMS accelerometer and a MEMS gyroscope in a single chip.



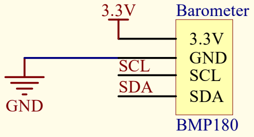
The OV7660 camera module is a low cost 0.3 mega pixel CMOS color camera module, that can output 640×480 VGA resolution image at 30fps.



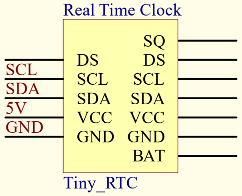
The LSM303 combines a digital 3-axis accelerometer and 3-axis magnetometer into a single package that is ideal for making a tilt-compensated compass.



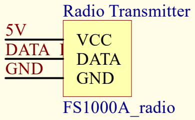
The BMP180 is barometric pressure sensor measure the absolute pressure of the air around him. This pressure varies with both the weather and altitude.



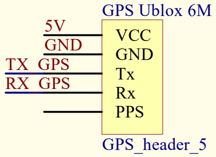
Real Time Clock has dual ports I2C bus (SCL, SDA) and power (VCC, GND).



RF transmitter working frequency of 433Mhz.



GPS ublox NEO-6M



Designer's signature

Supervisor's signature

Sheet title: **Sensors Schematics**

Project title: **PCB_Shield_Project_v02.PrjPcb**

Desginer: **Francisco Jesús Lázaro Lorente**

Date: * Revision: * Sheet * of *

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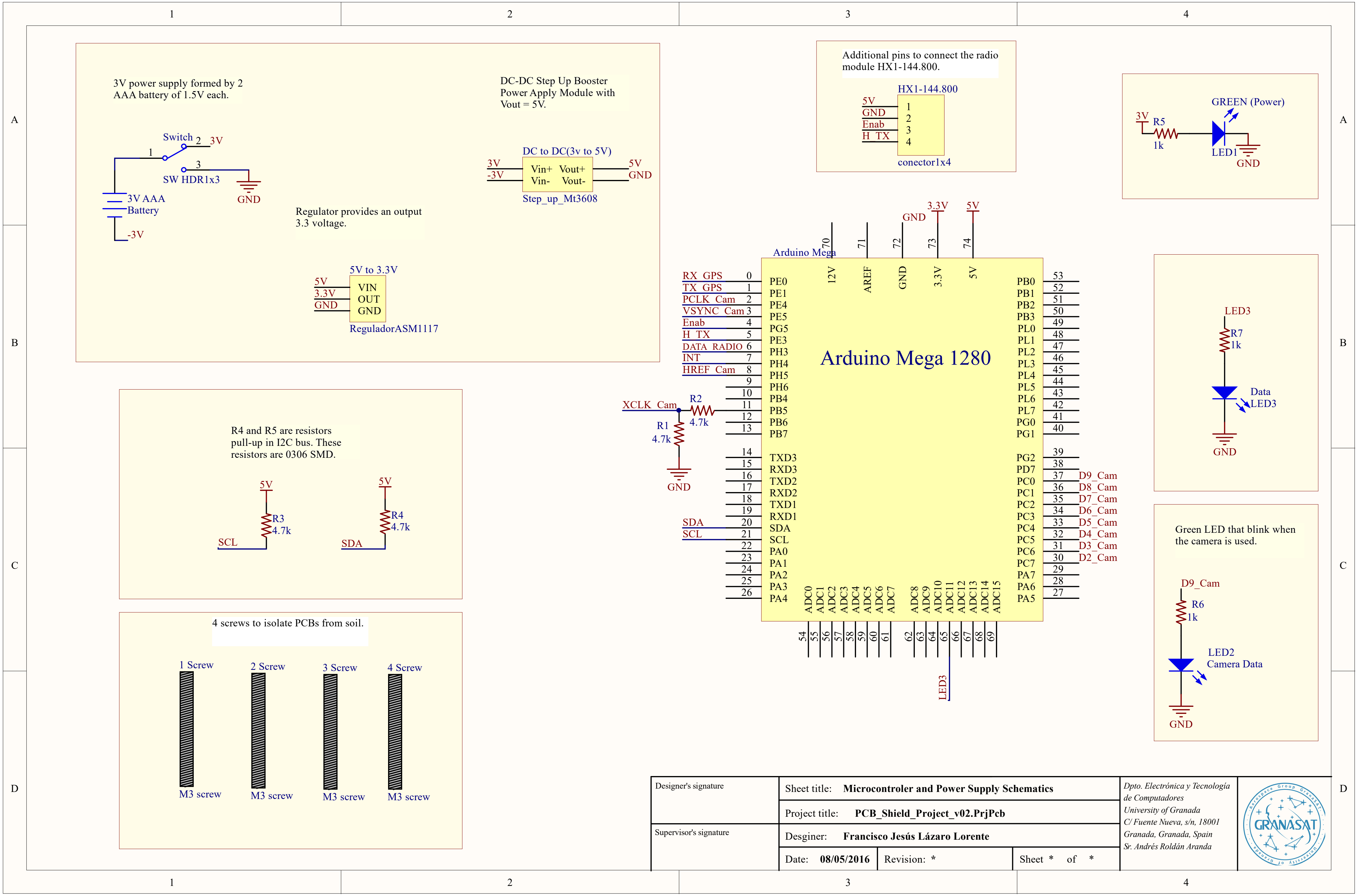

3V power supply formed by 2 AAA battery of 1.5V each.

DC-DC Step Up Booster Power Apply Module with Vout = 5V.

Regulator provides an output 3.3 voltage.

Additional pins to connect the radio module HX1-144.800.

R4 and R5 are resistors pull-up in I2C bus. These resistors are 0306 SMD.

4 screws to isolate PCBs from soil.

Green LED that blink when the camera is used.

Designer's signature

Supervisor's signature

Sheet title: **Microcontroler and Power Supply Schematics**

Project title: **PCB_Shield_Project_v02.PrjPcb**

Degsiner: **Francisco Jesús Lázaro Lorente**

Date: **08/05/2016** Revision: * Sheet * of *

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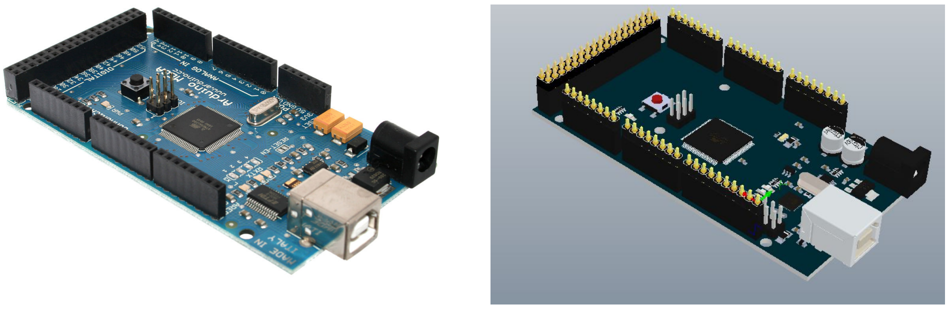
Then, we will see every part of the schematic designed in more detail.

4.1.1.1.1 Microprocessor

CanSat Shield for the microprocessor will be Arduino MEGA board because this board uses the same microprocessor we have chosen for the CanSat board (see figure 4.1).



(a) *Real board* **(b)** *3D models (Altium)*

Figure 4.1 – *Arduino Mega board [15]*

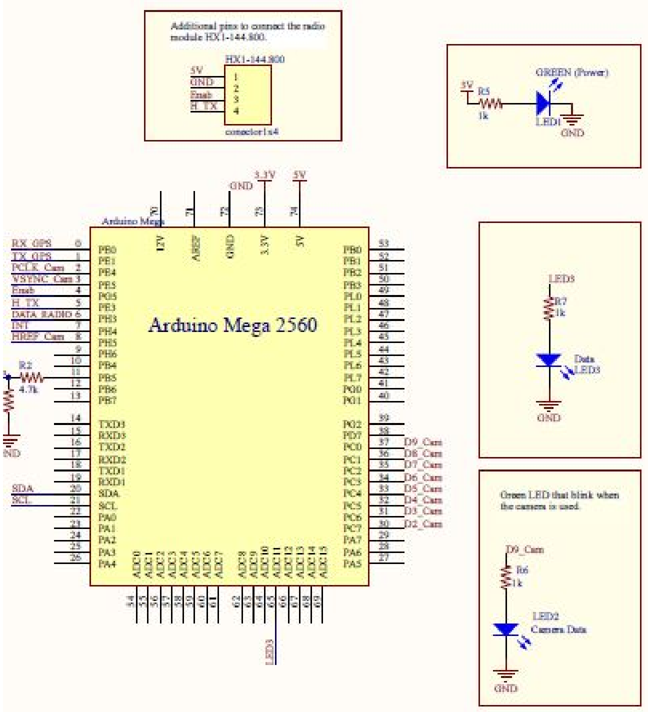


Figure 4.2 – *Schematics for Arduino Mega*

Figure 4.2 shows the schematic of the Arduino Mega, where we can see the different pins and labels that have connections with all elements of the project. The symbol at the top corresponds to the pins to use an external radio module, namely the module HX1-144.800 which we discussed in section 3.4 of chapter 3. Finnaly, the right part of the schematic of the Arduino Mega is the SMD LEDs notificators:

- LED Power (red color): One of the most common LEDs in an Arduino Board is the LED Blink, a LED connected to the pin number 13 of the Arduino. It is very useful for the tests of the microprocessor, to show how it is working in each moment when a problem appears. In our Arduino board we can't see this LED because it is hidden, so we have put the LED Power in another part of the design that makes the same function.

- LED Data (red color): This LED indicates if the I2C bus is sending data or not. In our design almost all sensors communicate with the microcontroller via the I2C bus, so it is a way of testing any communication problems.

- LED Camera (red color): As the name suggests, this LED tells us when the camera is capturing photographs or when running in recording mode.

The resistors value used for these LEDs was calculated measuring the voltage and current consumption of each one:

	LED Power	**LED Data**	**LED Camera**
Operating Voltage (V)	1.8	1.8	1.8
Datasheet Current (mA)	6	6	6
Measured Current (mA)	4.2	4.5	4.1
Theoretic Value Resistor (Ω)	761.67	716.11	780.48
Normalized Value Resistor (Ω)	1000	1000	1000

Table 4.1 – *Calculations of the resistor for the LEDs*

The Equation 4.1.1 was used for these calculations.

$$R = \frac{V_{dd} - V_{LED}}{I_{LED}} \tag{4.1.1}$$

Where V_{dd} is the voltage supply for the LED and the resistor (5V), V_{LED} is the voltage that the LED supports for a correct operation (1.8V), and I_{LED} is the current consumption that the LED have had in the measurements.

4.1.1.1.2 Magnetometer and Accelerometer Sensor

The magnetometer sensor chosen is the LSM303DLHC model (Figure 4.3), of STMicroelectronics as discussed in Section 3.3 of Chapter 3. The datasheet of this sensor is found on the reference [44].

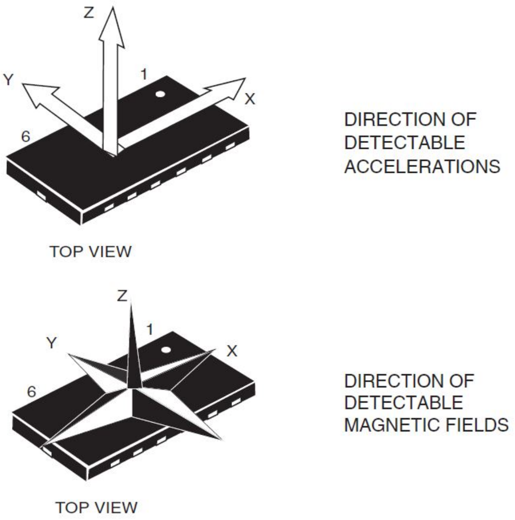


Figure 4.3 – *LSM303DLHC chip [44]*

In order to have an easier soldering process, a test board (GY-511) for this sensor has been used. (see figure 4.4 and 4.5 for the schematic of this test board). That sensor has a 3D digital linear acceleration sensor and a 3D digital magnetic sensor. The following table shows the main characteristics.

Figure 4.4 – *Photo of the the test board for LSM303DLHC*

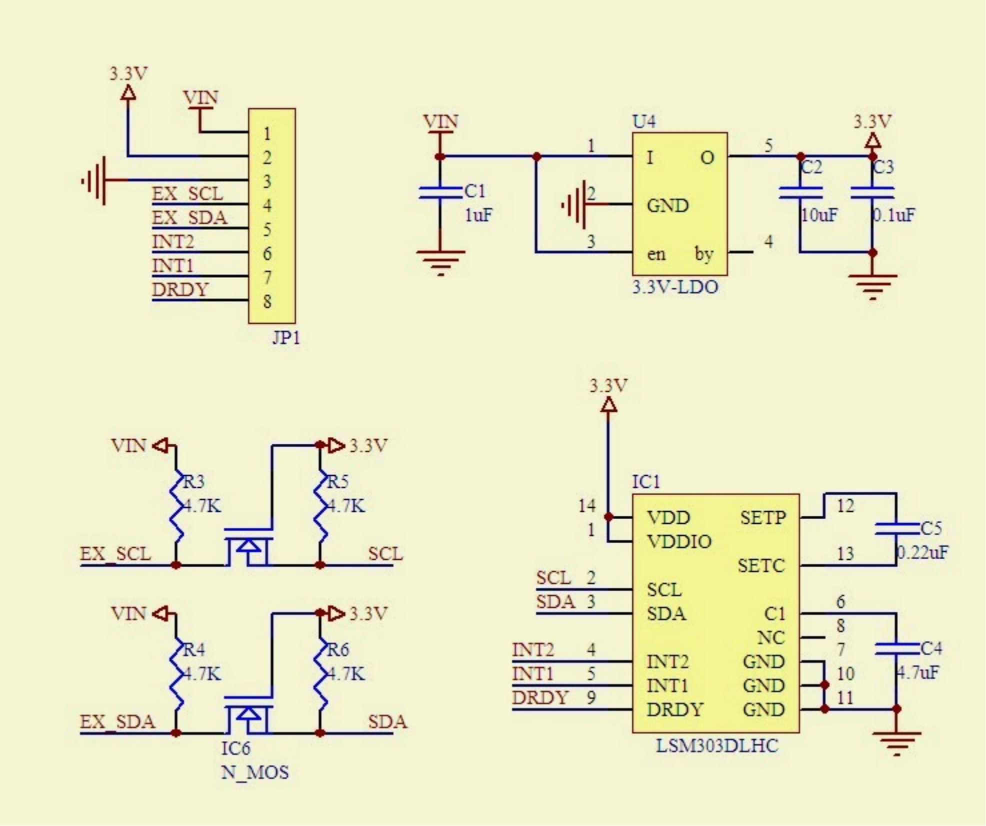


Figure 4.5 – *Schematic of the test board for LSM303DLHC [23]*

Number of channels	3 x accel + 3 x magnet
Magnetic field scale (gauss)	±1.3/±1.9/±2.5/±4.0/±4.7/±5.6/±8.1
Linear acceleration scale (G)	±2/±4/±8/±16
Data output (bits)	16
Interface	I2C
Analog supply voltage for the sensor (V)	2.16-3.6
Analog supply voltage for the board (V)	5
Temperature range (°C)	-40 to +85

Table 4.2 – *LSM303DLHC Specifications [44]*

The schematic symbol that this sensor has is shown in figure 4.6. It has 8 pins through hole, to place the test board shown in figure 4.4.

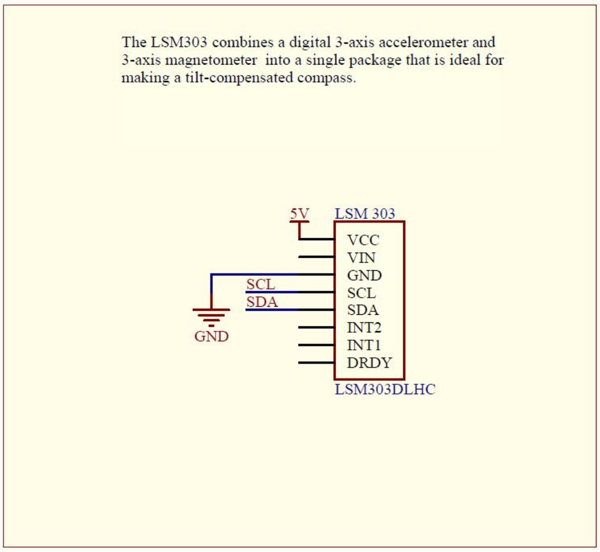


Figure 4.6 – *Schematic symbol for Shield CanSat Board for LSM303DLHC*

4.1.1.1.3 Gyroscope and Accelerometer Sensor

In order to have the gyroscope sensor on the Shield CanSat PCB, we have include the MPU6050 sensor, which includes an gyroscope and an accelerometer. The MPU-6050 devices mixes a 3-axis gyroscope (3D) and a 3-axis accelerometer on the same chip. In addition, it includes Digital Motion Processor™ (DMP™), which processes complex 6-axis MotionFusion algorithms. [17] As the LSM303DLHC sensor (see previous section 4.1.1.1.2), we have used a test board for this sensor, GY-521 board in that case (see Figure 4.7). It allow us a better soldering process and an easier prototype version to prove the different subsystems. The schematic of this board is shown in Figure 4.8, where is represented the circuit necessary for the correct operation oh that chip, the MPU6050 sensor.

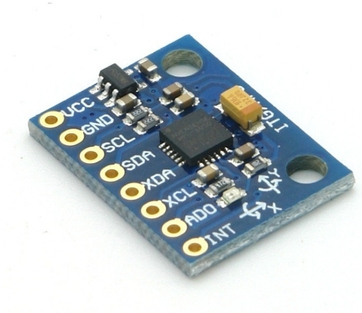


Figure 4.7 – *Photo of the test board for MPU6050 [3]*

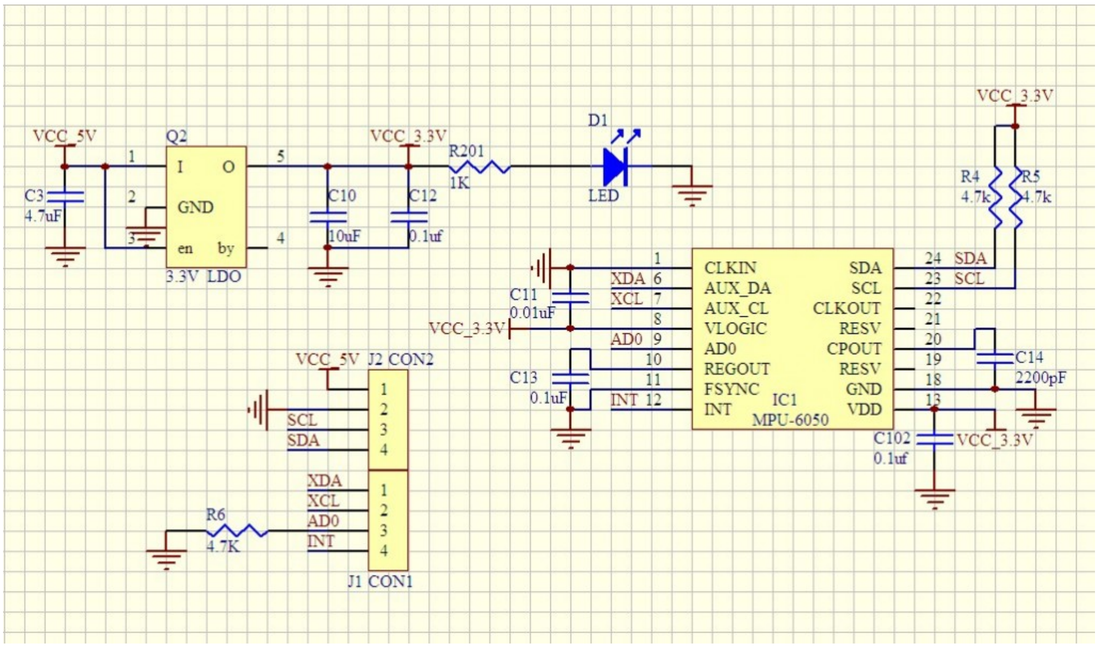


Figure 4.8 – *Schematic of the test board for MPU6050 [16]*

And finally, the same as LSM303DLHC, it is placed on the Shield CanSat PCB an 8 pins schematic symbol (see figure 4.9), for the placement of the test board shown in the Figure 4.7.

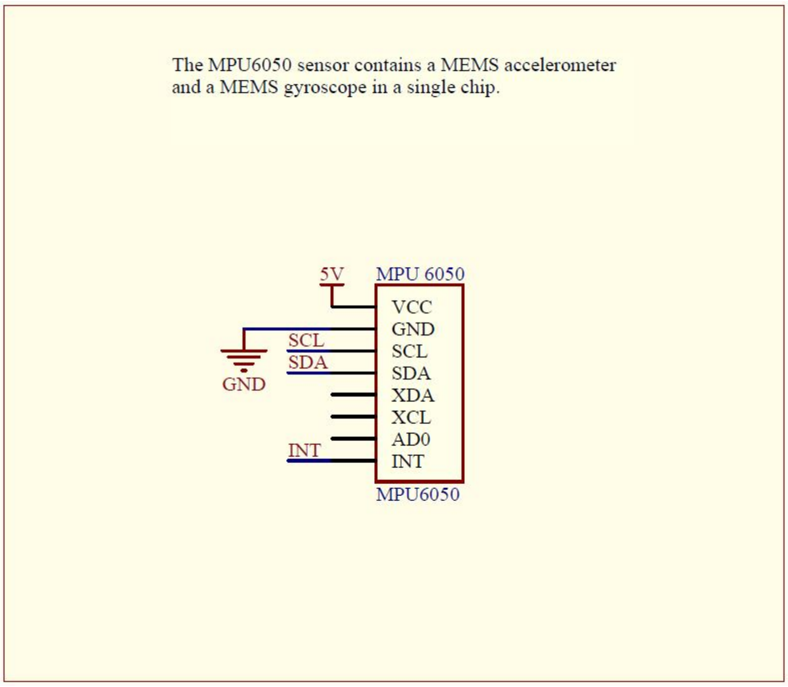

The MPU6050 sensor contains a MEMS accelerometer and a MEMS gyroscope in a single chip.

Figure 4.9 – *Schematic symbol for Shield CanSat board for MPU6050*

The main characteristics of this sensor are the following:

Number of channels	3 x accel + 3 x gyro
Gyroscope scale (º/sec)	±250 ±500 ±1000 ±2000
Linear acceleration scale (G)	±2/±4/±8/±16
Data output (bits)	16
Interface	I2C
Analog supply voltage for the sensor (V)	2.375–3.46
Analog supply voltage for the board (V)	5
Logic supply voltage (V)	1.71 to VDD (5)
Temperature range (°C)	-40 to +85

Table 4.3 – *MPU6050 Specifications [28]*

For the communication with the microprocessor, I2C protocol is used, connected in parallel with the LSM303DLHC and the LCD described before. In the Figure 4.10 is shown how this connection is done and the directions that each device has.

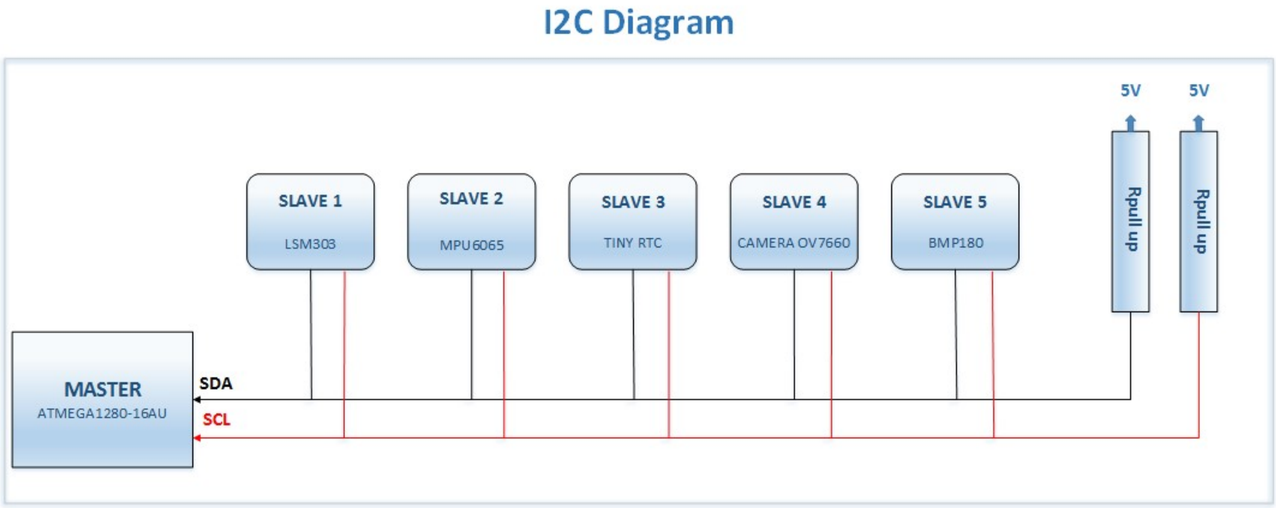


Figure 4.10 – *I2C diagram of the system*

4.1.1.1.4 Barometer and Thermometer Sensor

For this sensor we will use the test board GY-68 (see figure 4.11) similar to the above sensors. This test board includes an thermometer sensor too, as you can see in the schematic of figure 4.12 and as we saw in the previous sensors also communicates with the microprocessor by the bus I2C (see diagram in figure 4.10).

Figure 4.11 – *Photo of the test board for BMP180 [7]*

A great advantage of the GY-68 board is its small size, which allows facilitate the design on the PCB Shield CanSat and thus we can reduce a lot the size of our final design.

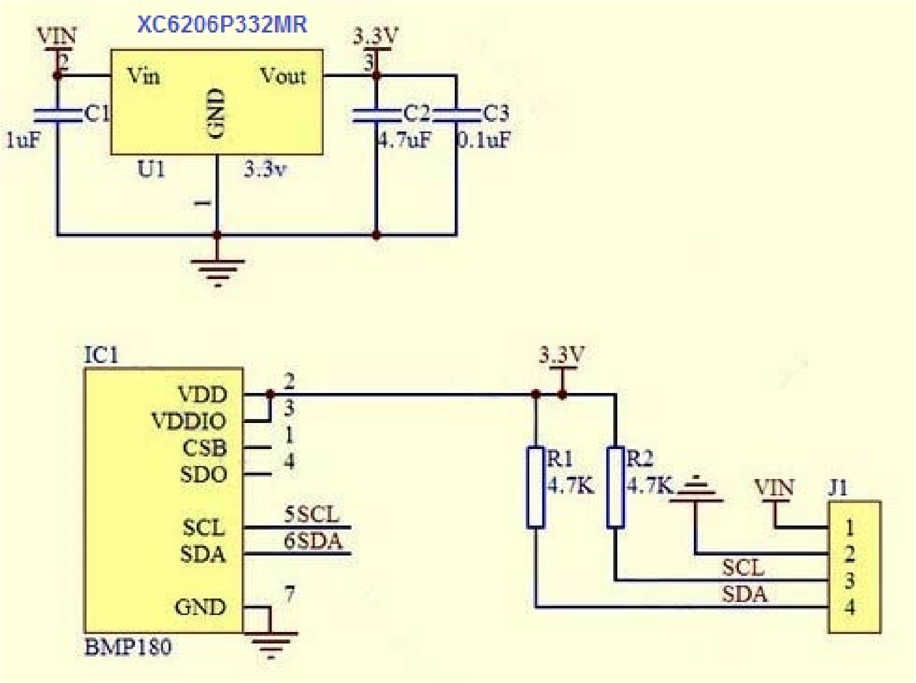


Figure 4.12 – *Schematic of the test board for BMP180 [5]*

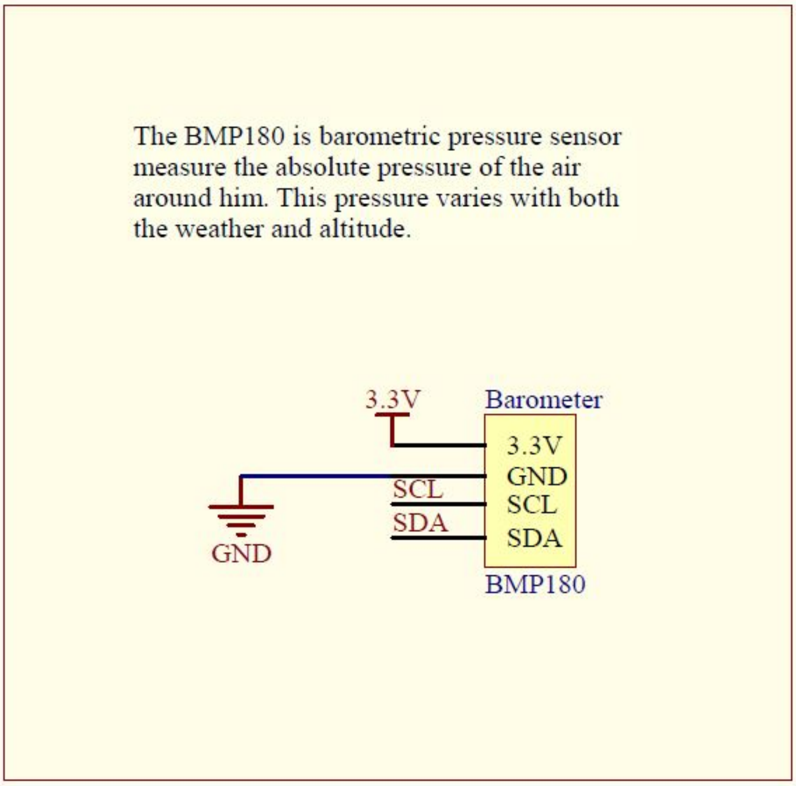


Figure 4.13 – *Schematic symbol for Shield CanSat board for BMP180*

The symbol show in figure 4.13 is the schematic of the GY-68 board on our Altium design, which consists of four pins, the first two are supply (3.3V and ground) and the other two are the communication bus I2C.

4.1.1.1.5 GPS Module

For the GPS module we opted for the chip U-blox family, namely the NEO-6M model which is mounted on a test board called GY-NEOMV2. This board consists of an electronic to adapt the supply voltage, an external battery, some acrshortLEDs and an antenna as see in figure 4.15.

The GY-NEOMV2 board can operate with a supply voltage in the range of 3V to 5V, while the signals entering and leaving are 3.3 voltage, so a converter levels is required if a arduino or microcontroller will communicate (transmit) to the GPS module (arduino use 5V). If you only want to receive NMEA data simply connect the pin TX with RX arduino and receive the data sent by the module, in this case, no need to level conversion by the arduino recognizes the 3.3V as high [8].

In our design we use only the GPS receiver module and therefore do not need a converter voltage levels as you can see in the schematic of figure 4.16.

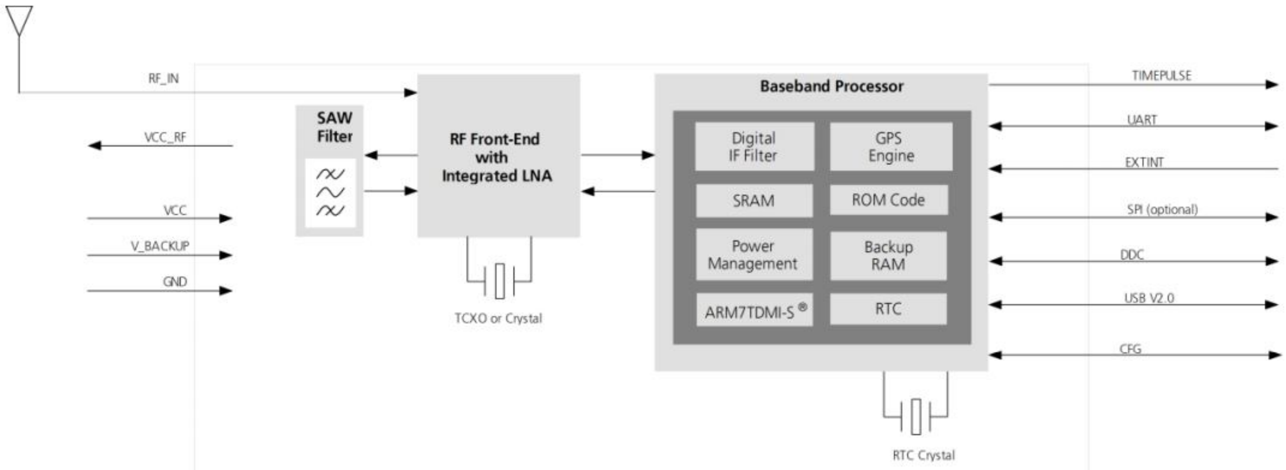


Figure 4.14 – *Blocks diagram of the NEO-6M module [8]*

Figure 4.14 shows a block diagram of NEO-6M chip company U-BLOX, where we can see the different parts comprising such displays three large blocks that are saw filter, RF with integrated LNA and the last main block Baseband Processor where we can find the different memories and internal oscillators.

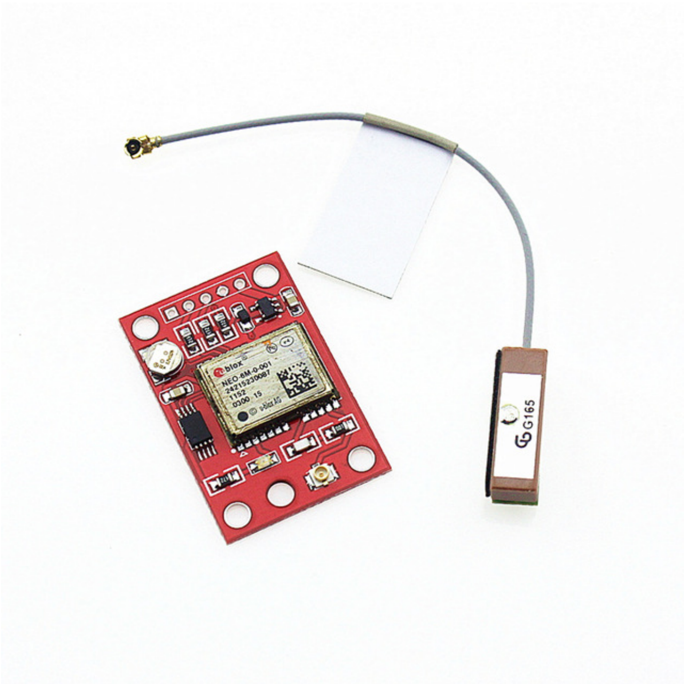


Figure 4.15 – *Photo of the test board for GY-NEOMV2*

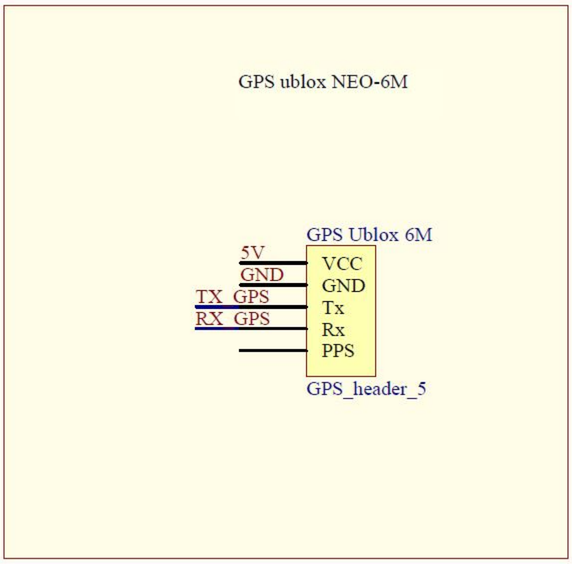


Figure 4.16 – *Schematic symbol for Shield CanSat board for GY-NEOMV2*

The symbol of the schematic shown in figure 4.16 corresponds to the GY-NEOMV2 where we can see it has 5pins, two power supply, two for serial communication (UART interface TX and RX) and finally another pin called PPS. The PPS (Pulse Per Second) pin is used for synchronization with other elements or devices, if you want to use the module in transmission mode instead of reception.

4.1.1.1.6 Radio Module

Now let's talk radio FS1000A module that has the form you can see in figure 4.17, is a very small module and also very cheap that as we saw in section 3.3 of Chapter 3 its features are somewhat limited. This module works at several frequencies (see section 3.3) but we will use the operating frequency of 433 Mhz in AM modulation,

The emitter usually has 3 pins (VCC->5V, GND, DATA), with a few variants that expose the fourth pin for connecting an external antenna to increase the range.

Figure 4.17 – *Photo of the test board for FS1000A [12]*

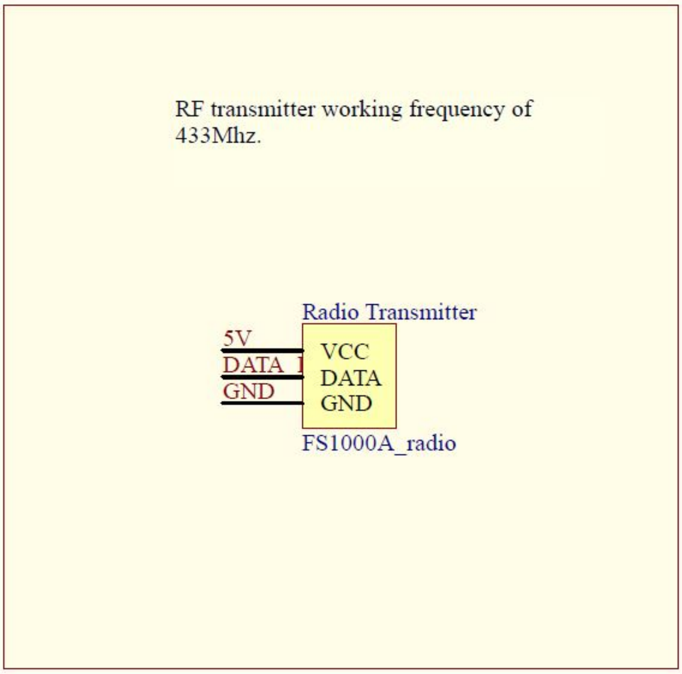


Figure 4.18 – *Schematic symbol for Shield CanSat board for FS1000A*

As radio module has only three pins its schematic symbol in Altium is quite simple as you can see in figure 4.18. Two pins are for power supply and the rest is the data pin. The data pin goes directly to the pin 6 Arduino Mega and using a simple library radio module operation is quite easy.

Comment on the Radio module FS1000A comes with your radio receiver as you can see in Figure 6, but in our project we will not use because we have an ICOM receiver in the GS team GranaSAT that is capable of receiving and demodulating said frequency.

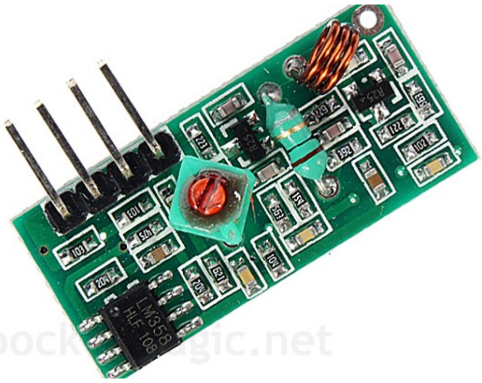


Figure 4.19 – *Photo of Receiver FS1000A board citeFS1000A*

4.1.1.1.7 CMOS OV7660 Camera Module

The camera that we use in the project is called OV7660 (you can see in figure 4.20) is a low voltage CMOS image sensor that provides the full functionality of a single-chip VGA camera and image processor in a small footprint package. The OV7660 provides full-frame, sub-sampled or windowed 8-bit images in a wide range of formats, controlled through the Serial Camera Control Bus (SCCB) interface. This product has an image array capable of operating at up to 30 frames per second (fps) in VGA with complete user control over image quality, formatting and output data transfer. All required image processing functions, including exposure control, gamma, white balance, color saturation, hue control and more, are also programmable through the SCCB interface [34].

Figure 4.20 – *Photo of Camera OV7660 board [34]*

The following schematic diagram of figure 4.21 we will see an example of blocks by connecting the camera to host (in our host will be the Arduino Mega). The camera module is powered from a single 3.3V power supply. An external oscillator provide the clock source for camera module XCLK pin. With proper configuration to the camera internal registers via I2C bus, then the camera supply pixel clock (PCLK) and camera data (Data[9:0]) back to the host with synchronize signal like HREF and VSYNC.

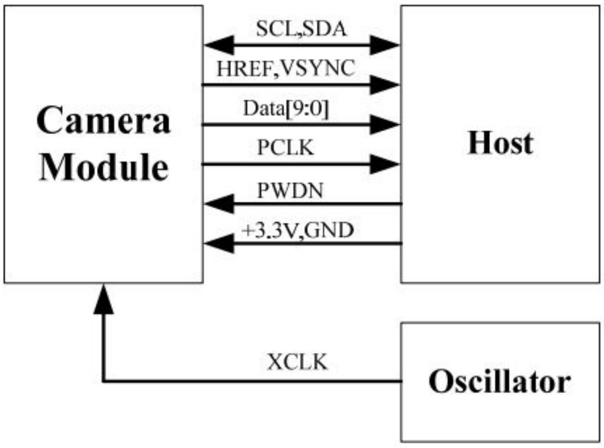


Figure 4.21 – *Schematic Diagram of Camera OV7660 board [34]*

The main characteristics of this camera are the following:

Power Supply (V)	2.45 to 5
Temperature range (ºC)	-30ºC to 70ºC
Output Formats (8-bit)	YUV/CbCr 4:2:2 RGB565/555 GRB 4:2:2 Raw RGB Data
Transfer Rate (fps)	30 for VGA
Array Element (VGA)	640 x 480
SNR (dB)	3.65
Power Requirements (μA)	>20

Table 4.4 – *Camera OV7660 Specifications [34]*

In the schematic shown in figure 4.22 is the one that we use in the design of our project, which we can see that the supply voltage is 3.3V, use two pins for I2C bus communication, eight pins for sending data, two pins for clock signals PCLK and XCLK are bigger and VSYNC and HREF pins that are signals for synchronizing data for each image.

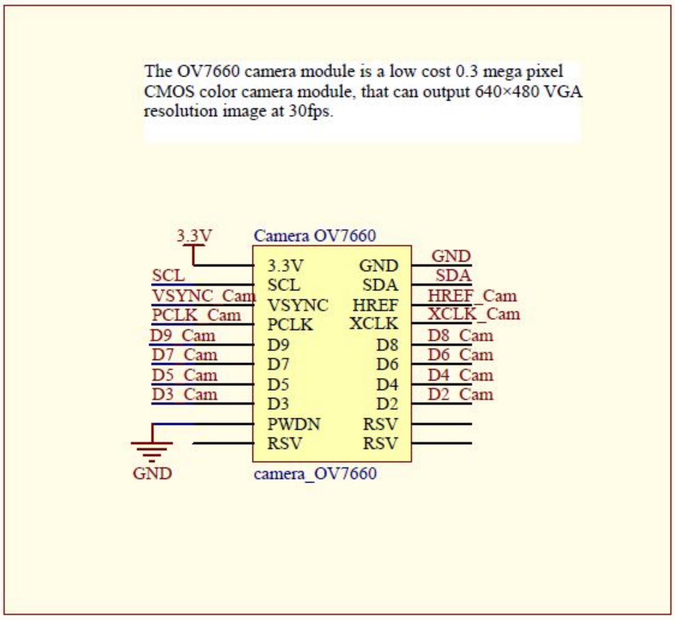


Figure 4.22 – *Schematic symbol for Shield CanSat board for Camera OV7660*

4.1.1.1.8 Tiny RTC Clock

The test board Tiny RTC system will use as reference system that gives us the date and time although our system is power off because it consists of an external battery. This board is formed by the DS1307 and AT24C32 components as you can see in figure 4.23.

- **DS1307**. It is a very interesting solution when you need to work with events that require timeliness and accuracy over time. This small integrated circuit is one of the most popular RTC (Real Time Clock) market watches for its ease of use and its long-term reliability. Address and data are transferred serially via a 2-wire, bi-directional bus. The clock/calendar provides seconds, minutes, hours, day, date, month, and year information. The end of the month date is automatically adjusted for months with fewer than 31 days, including corrections for leap year. The clock operates in either the 24-hour or 12-hour format with AM/PM indicator. The DS1307 has a built-in power sense circuit that detects power failures and automatically switches to the battery supply [21].

- **AT24C32**. It is a programmable memory (EEPROM) provides 32 at 536 bits of serial electrically erasable and programmable read only memory organized as 8192 words of eight bits each. The device's cascadable feature allows up to eight devices to share a common two wire bus. The device is optimized for use in many industrial and commercial application where low power and low voltage operation are essential [19].

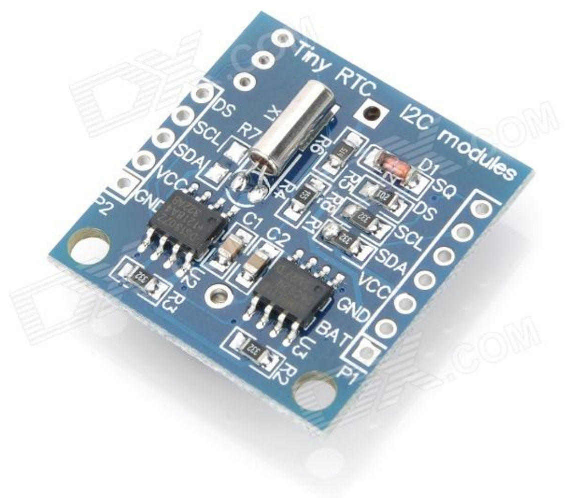


Figure 4.23 – *Photo of the test board for Tiny-RTC [4]*

In the schematic of figure 4.24 is the one that corresponds to the design of the Tiny RTC board, where we can see the different connections between the DS1307 and AT24C32 components.

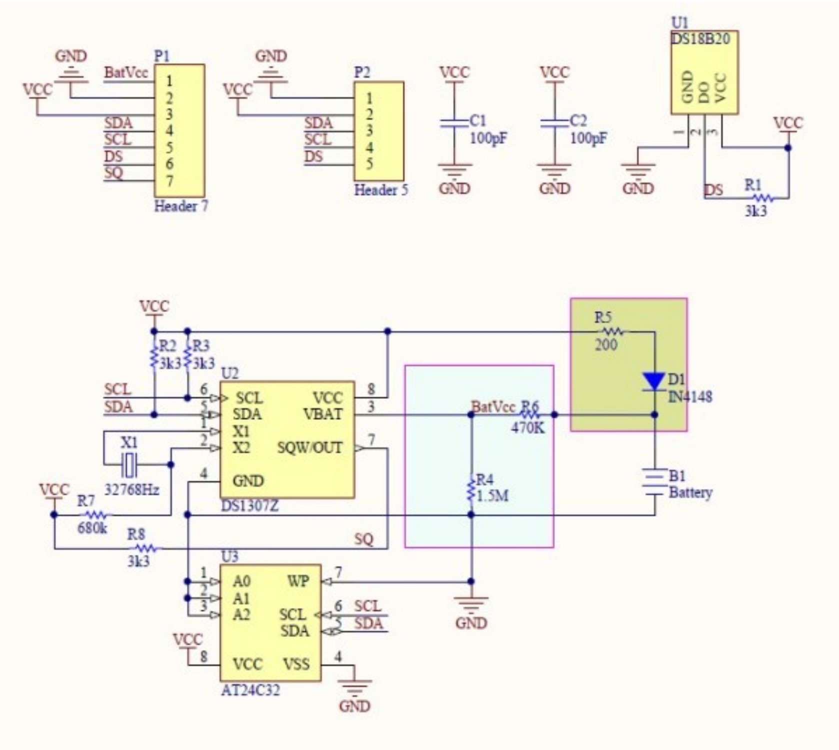


Figure 4.24 – *Schematics of the test board for Tiny-RTC [4]*

The schematic symbol that this sensor has is shown in figure 4.25. It has 12 pins through hole, to place the test board in Shield CanSat PCB, on the left side there are 5-pin and 7-pin right. In our project we will use only 4 of the 12 having the Tiny RTC board, two for power supply and other two for the bus I2C.

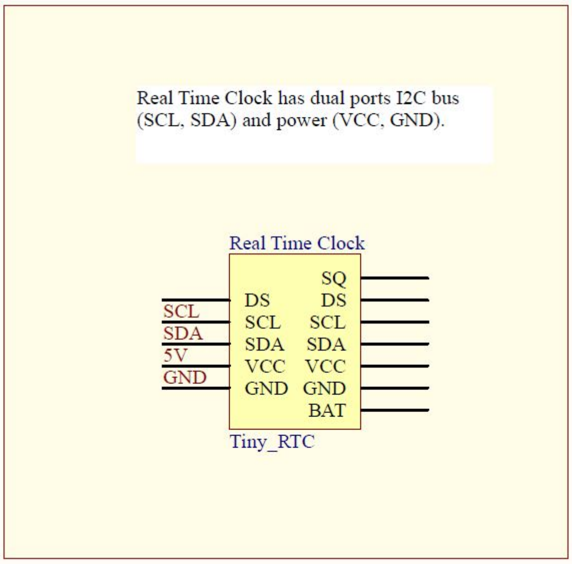


Figure 4.25 – *Schematic symbol for Shield CanSat board for Tiny-RTC*

4.1.1.1.9 Power system

The last section of the Schematic design for the Shield CanSat PCB of GranaSAT project, is the power system. Schematics are shown in figure 4.26.

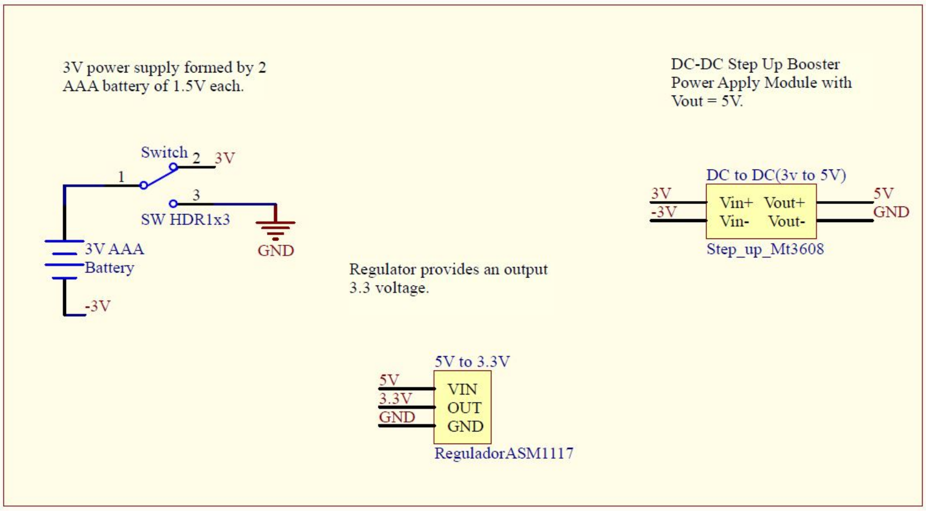


Figure 4.26 – *Schematics for the power system of Shield CanSat*

In the power system we can distinguish three main parts. The symbol on the left of the schematic (figure 4.26) corresponds to the battery formed by two AAA batteries 1,5V each providing more or less a total voltage of 3V. The symbol which is below corresponds to a voltage regulator that sets the voltage 3,3V and the last symbol corresponds to a DC-DC converter, which converts the battery 3V to 5V.

4.1.1.1.9.1 Battery

The first part that is represented in the schematic is the battery with a switch. The switch is responsible for giving energy to the PCB and we will use a switch to the design of the final CanSat but in the case of design PCB prototype will use a jumper as you can see in the figure 4.27.

Figure 4.27 – *Jumper used in the Shield CanSat PCB*

As we discussed in section 3.2 of chapter 3 we choose as power supply two AAA batteries observing the mechanical characteristics as seen in table 3.1.

To check if the battery chosen will have sufficient capacity to supply the entire Shield CanSat PCB we have done an analysis of consumption of all sensors have as can be seen in table 4.5.

List of components	**Average consumption (mA)**
NEO-6 GPS ublox	74
MPU6050	1.55
LSM303	1.52
Tiny RTC	0.74
BMP180	1.34
FS1000A radio	4
Camera OV7660	13.2
Total consumption	**96.35**

Table 4.5 – *Consumption list of all sensors*

As shown in table 4.5, we have average consumption of all devices is 96.35 (mA) and according to figure 4.28 one AAA battery to a 1.2V voltage can have an autonomy of three hours with a consumption of 100 (mA). We should note that our battery has two AAA batteries in series so that the battery can say meets the requirements of autonomy of the CanSat mission.

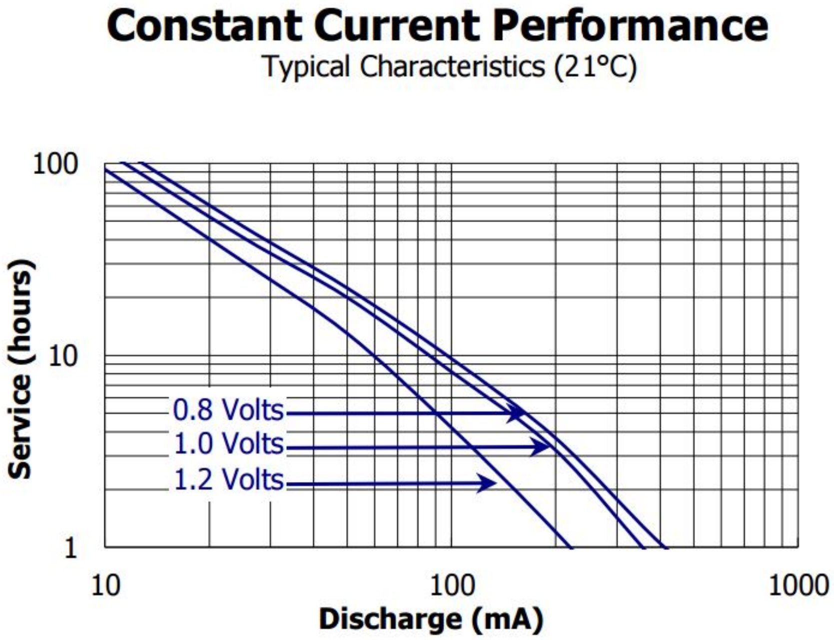


Figure 4.28 – *Graphic discharge 1,5V AAA battery [25]*

4.1.1.1.9.2 DC-DC converters

Figure 4.29 – *Photo of the test board for Step up Mt3806*

The power system has the voltage converter, in order to have 5V output with the 3V nominal input voltage from the battery. The converter that is used Mt3608, which is at a test board as shown in figure 4.29. That step-up switching controller provides 93% of efficiency over a 30mA to 2A load [13]. It will be used a potentiometer that is placed on the test board (see figure 4.29) to adjust the output voltage to 5V.

The main characteristics of this Mt3608 are the following:

Maximum output current (A)	2
Input voltage (V)	2 to 24
Maximum output voltage (V)	5 to 28
Efficiency (%)	93
Operating Temperature (ºC)	-40 to 85

Table 4.6 – *Main characteristics of test board Mt3608 [13]*

Figure 4.30 shows the schematic symbol in we used for the converter is shown. You can see that input will 3V from the battery and the output corresponds to 5V.

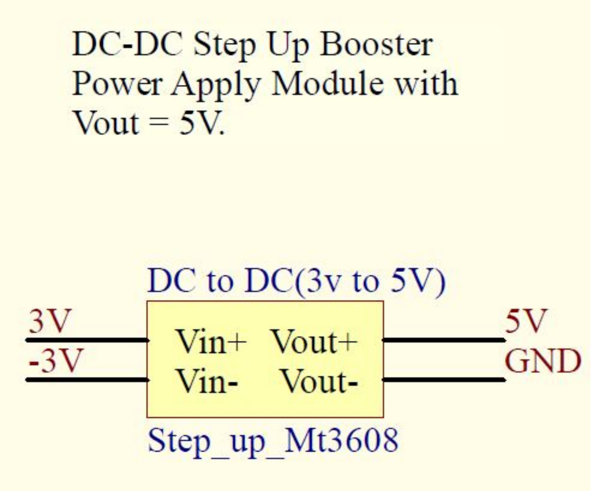


Figure 4.30 – *Schematics of Step up Mt3806*

We also need a voltage of 3.3V for this we will use the ASM1117 regulator. The role of the regulator is to convert 5V step-up to 3.3V to power certain sensors. As convert Mt3608, the ASM1117 is also placed on a test board as can be seen in figure 4.31.

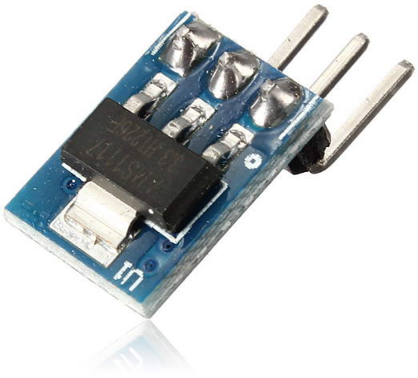


Figure 4.31 – *Photo of the test board for ASM1117 [46]*

Finally show in figure 4.32 the symbol we use for this controller where we can see it has three pins that are input, output and ground.

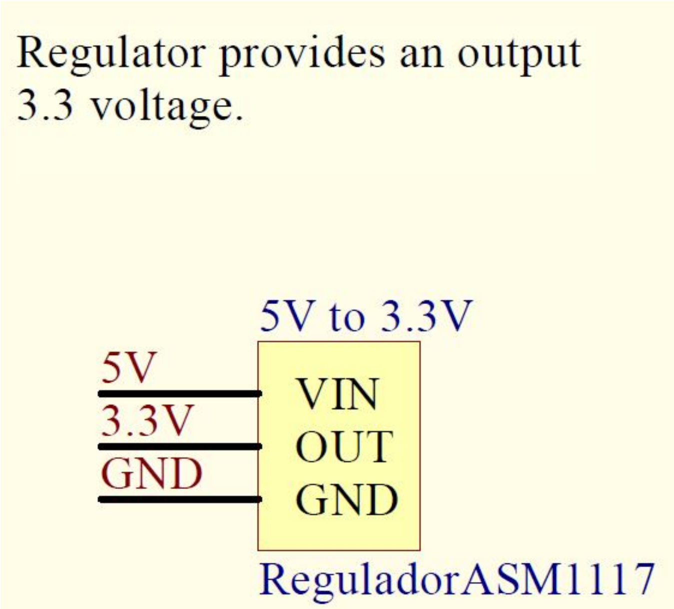


Figure 4.32 – *Schematics of ASM1117 regulator*

4.1.1.2 PCB Design

In this section, it will be presented the design process for the PCB design of the circuit that has been explained in the section 4.1.1.1. For the PCB design, I have used Altium Designer, the same as the Schematic Design. That tool allows connect the schematic and

PCB, linking every component that you place on it. That design has some relevant steps which have to be followed in the right order for a proper PCB design:

- **PCB production Technology**. The first step that you have to take into account when build a PCB is the production technology that you have available for the project. In my case, a prototyping PCB machine was available thanks to the ECTD (LPFK ProtoMat S62 [29]) for the PCB production. So, the solution that we have available is a copper plate with the tracks, holes and vias made with drilling tools. One of the most important features with this technology is the easy PCB production in both sides, top and bottom layer and the drilling facilities that it has to make the holes and vias. The figure 4.33 present the LPFK ProtoMat S62 that we have in the laboratory of the Faculty of Science of the University of Granada.

Figure 4.33 – *LPFK ProtoMat S62*

- **Mounting technology**. Once we know what type of technology is available for the PCB production, we have to decide what mounting technology is the best solution for our design. The first issue that we have to consider is the minimum weight for the PCB, because is one of the requirements (see section 2.5), so the SMD technology is the best solution. There are some devices which are not available in SMD, so the PCB will have SMD and THT technology.

- **Package types**. Depending on the device chosen, different packages have been selected, trying to choose the smallest one because of the weight constraint. For the passive devices (resistors, capacitors, etc), in the majority of the cases, the size chosen was 0805 and 0603, but there are some 1206 and 0402, subject to the power consumption of each resistor and the maximum voltage for the capacitors.

- **PCB Library**. As soon as we have selected the components and their package it is time to make the PCB library. The library will include the footprints of every component placed on the PCB and it will be created with the packages found in other libraries or made by the designer (measuring the device with a caliber or taking the measurements from the datasheet information).

- **Transfering the components from the SCH to the PCB**. When the PCB library was finished, the schematic should have every component linked to its footprint. The next step is transfer that information to a PCB, in order to start with the placing and the routing of the footprints. That step will create the netlists for the PCB, which will indicate the connections between the components in order to facilitate the next step.

- **Placing and routing the PCB components**. First, a good placing will facilitate the routing of the components(trace the tracks that connect the components).

- **Verify the PCB design rules and connections**. Altium Designer has a really useful tool: *Design Rule Check* (see figure 4.34). That tool have the objective of test if the rules for the design are being fulfilled. That rules will be explained in the section 4.1.1.2.1.

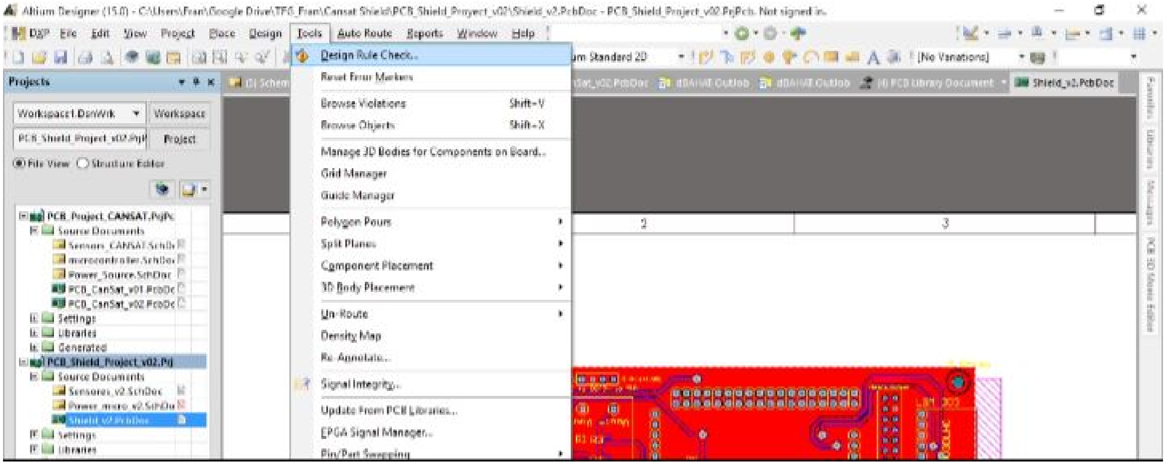


Figure 4.34 – *Design Rule Check - Altium Designer*

4.1.1.2.1 Design rules PCB

The ProtoMat S62 (PCB prototype machine) has some mechanical requirements that we have to take into account. The affected PCB characteristics for that requirements are:

- **Track**. In every moment, the best option was the maximunm width possible for the tracks, in order to reduce the resistance of the track and allow a better operation for the

PCB, overall, for the power tracks. The minimum width for the tracks has been 15 mils, because of the operation mode that has the plotter, in order to have a minimum final width of the 10 mils, so the production phase reduces 5 mils approximately from the design. Moreover, it should be avoid the 90º angles, and the shortest tracks possible.

- **Clearance**. The clearance is the minimum spacing between the tracks on a PCB. The clearance should be as minimum 10 mils, in order to avoid the short-circuit between the tracks, because of the production errors that it can exist. Anyway, once the PCB was ended, with a cutter tool you can remark the tracks in order to avoid the shavings generated by the production phase.

- **Hole size**. The constraint of the hole size is imposed by the available drilling tools that we have in the laboratory. The minimum size fixed was 0.6 mm, and the available tools were: 0.6, 0.7, 0.8, 0.9, 1, 1.1, 1.3 y 1.5 mm. The biggest holes were made with a milling cutter drilling the perimeter of the hole.

- **Annular ring**. The annular ring is the copper portion between the hole and the perimeter of the pad. That rule is the same for the vias and THT pads. The minimum diameter of the annular ring is 80 mils, in order to have a good support for the soldering of this lead or via.

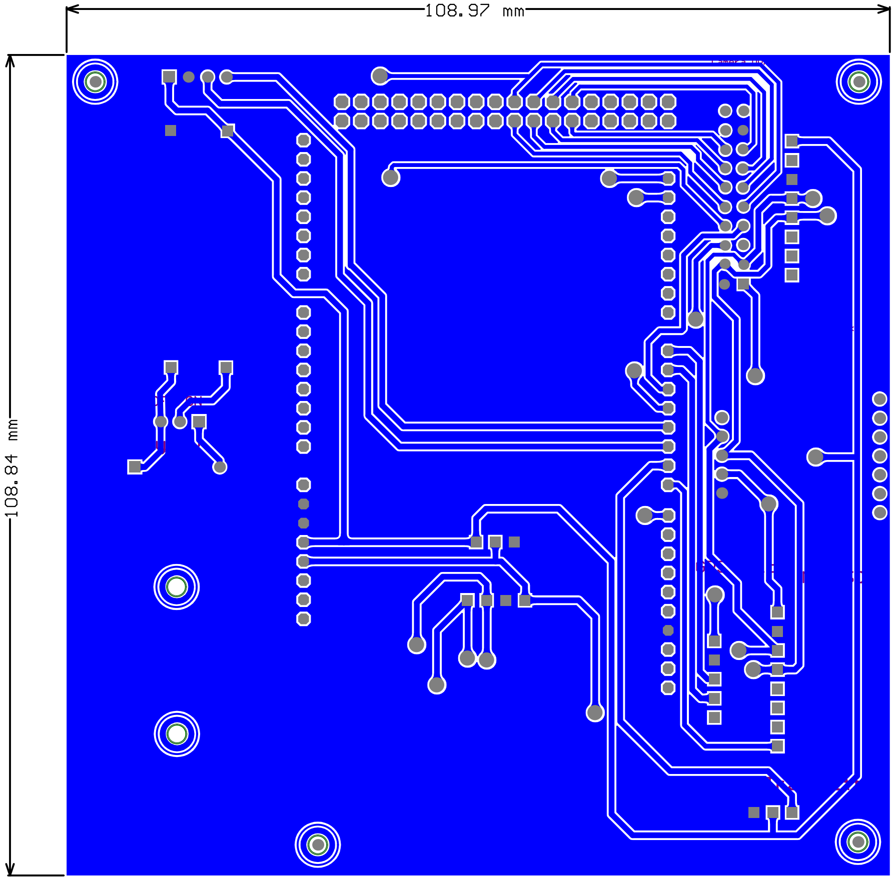
- **Text layer**. The production type that we have available has not the silkscreen process. With the intection to give more information of the PCB, a text tool (in both sides) has been created, on the ground plane, to avoid the short-circuits and the errors in the tracks.

- **Board Outline**. One of the most important things of the PCB is its dimension and shape. Because the PCB had to have circular shape, and the dimension was designed taking into account that goes into a can soda.

4.1.1.2.2 2D view of the PCB Design

The dimensions of the Shield CanSat PCB are arbitrary, adapting to the dimensions of the different sensors and especially the Arduino Mega which is the largest element in our PCB.

In the following pages will be located the PCB Design Schematics, where is described the tracks, vias, holes, footprints, and the position of each component. The first schematics is bottom layer of Shield CanSat and next schematics is top layer in red color.



Designer's signature:

Supervisor's signature:

Sheet title: Shield CanSat

Project title: GranaSAT-I

Designer: Francisco J. Lazaro Lorente

Supervisor: Andres Roldan Aranda

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University of Granada
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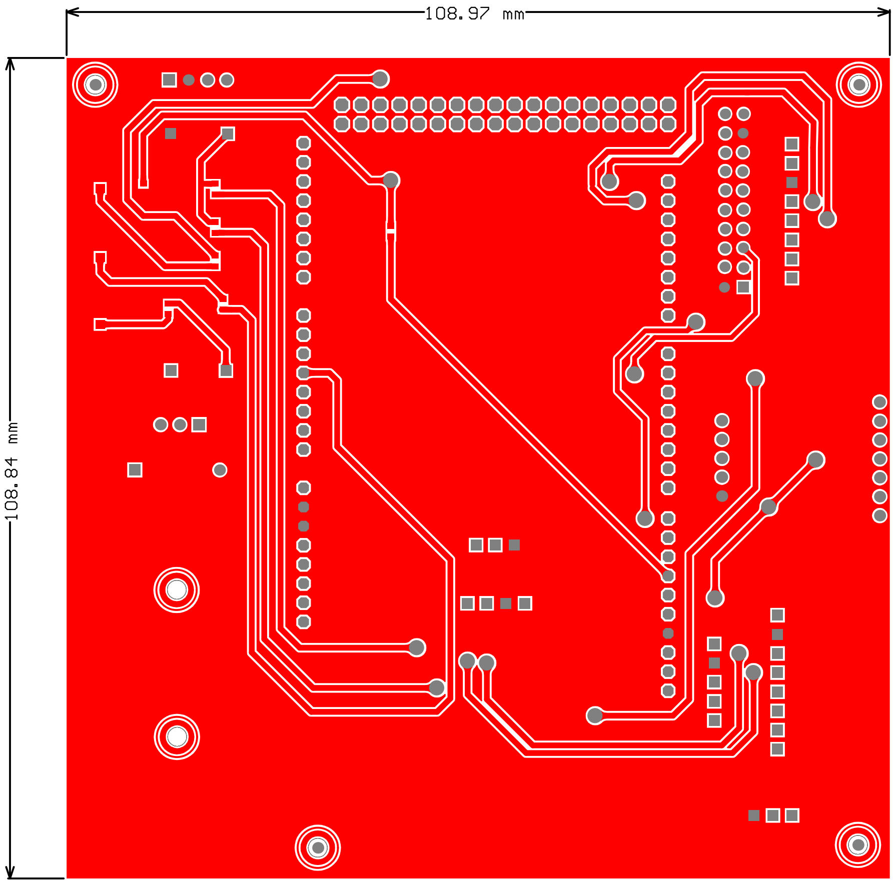
Sr. Andres Roldan Aranda

Date: 01.03.2015 Revision: 1
Sheet 1 of 10



Designer's signature:

Supervisor's signature:

Sheet title: Shield CanSat

Project title: GranaSAT-I

Designer: Francisco J. Lazaro Lorente

Supervisor: Andres Roldan Aranda

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Date: 01.03.2015 Revision: 1
Sheet 1 of 10

4.1.1.2.3 3D view of the PCB Design

In this section, the PCBs shown in the section 4.1.1.2.2 will be represented in 3D view. That models will be used as reference in order to have an idea of the real size and aspect of the final PCB implementation.

That task has been carried out linking each footprint to a 3D model. The 3D models have been downloaded from `http://www.3dcontentcentral.es/` but some of then have been designed for the author of this project in Solidworks.

The figure show the 3D model of this project, one from each side of the PCB.

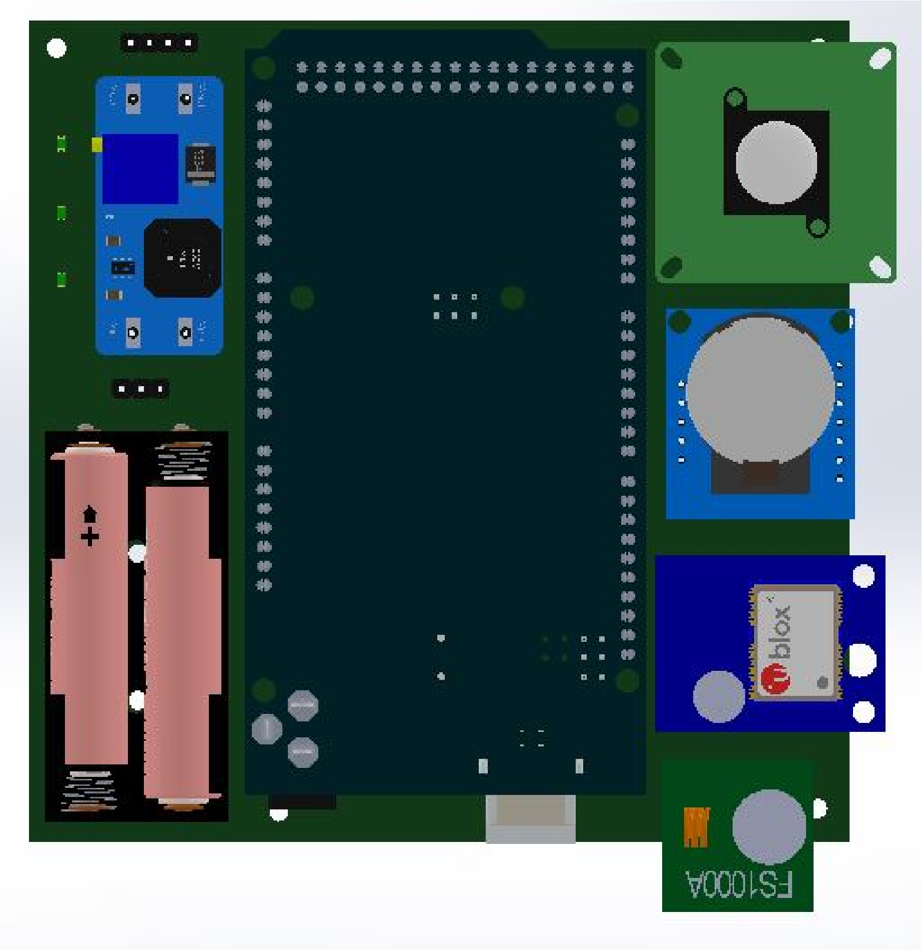


Figure 4.35 – *3D View of the top side*

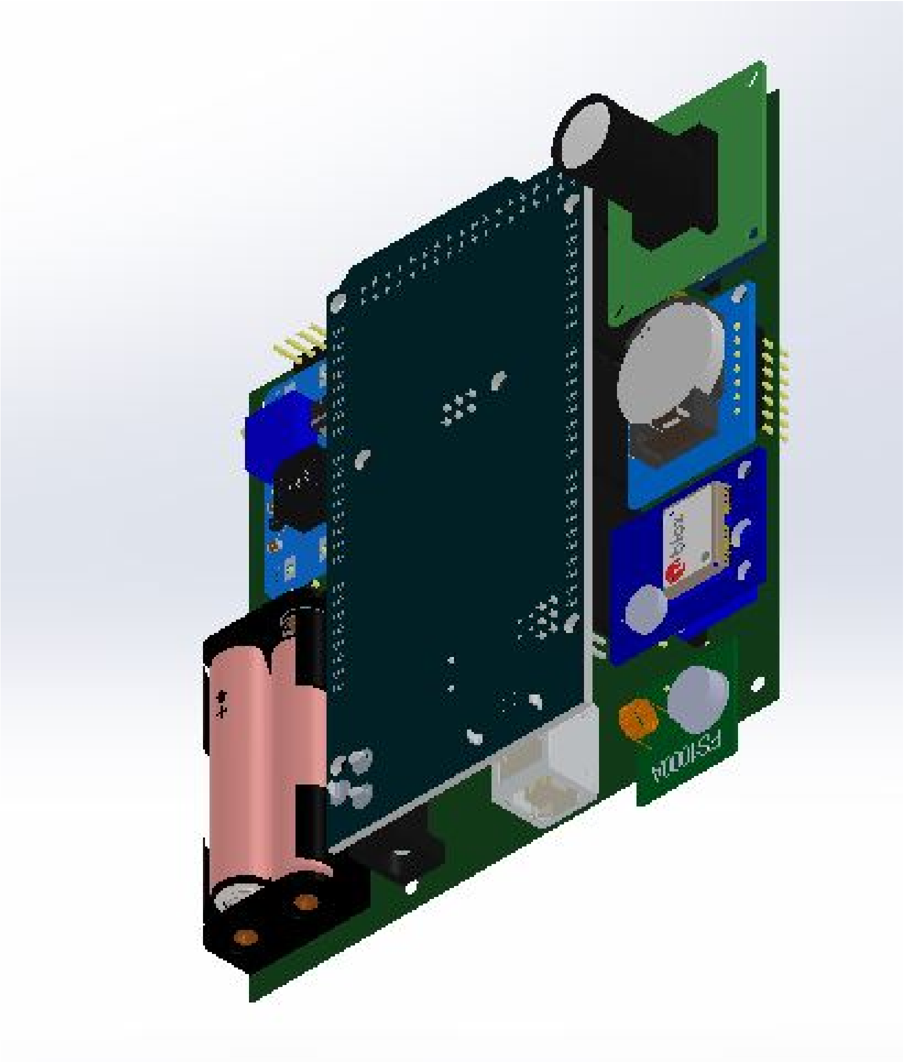


Figure 4.36 – *3D View of the vertical side*

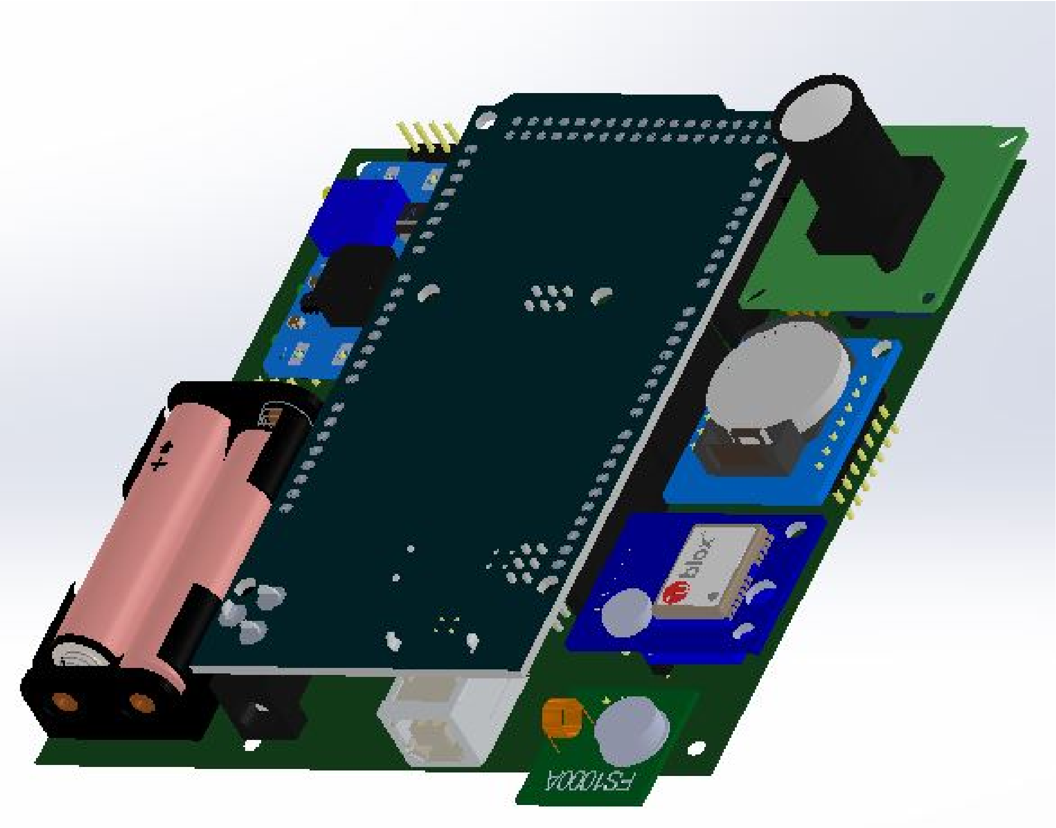


Figure 4.37 – *3D View of the right side*

Now we will show how it turned our Shield PCB:

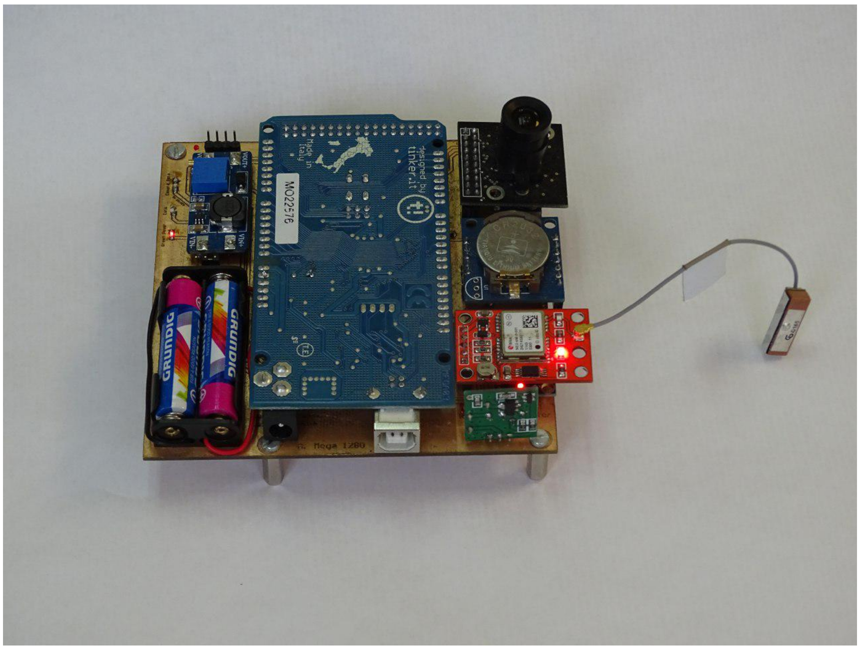


Figure 4.38 – *Shield CanSat PCB*

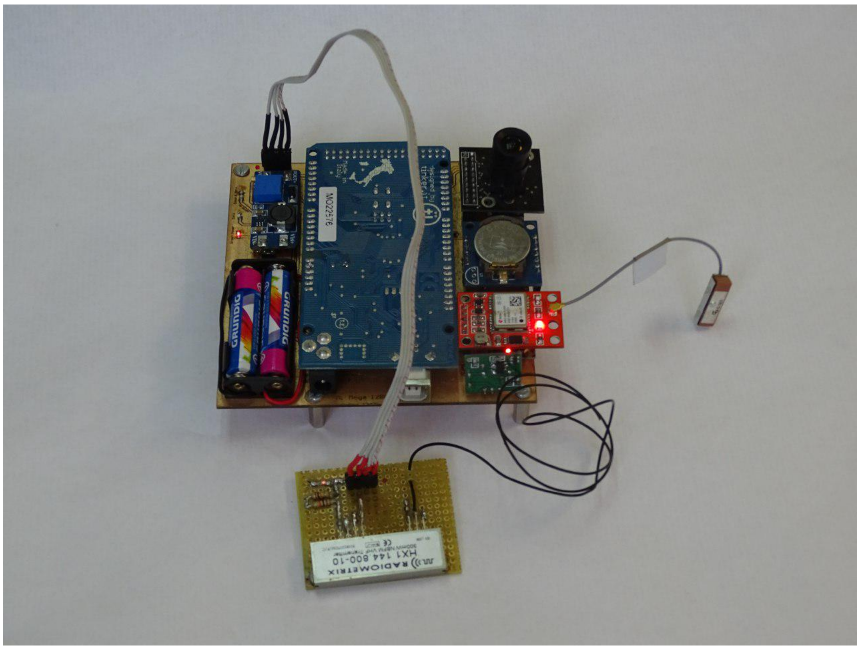


Figure 4.39 – *Shield CanSat PCB with module HX1-144.800*

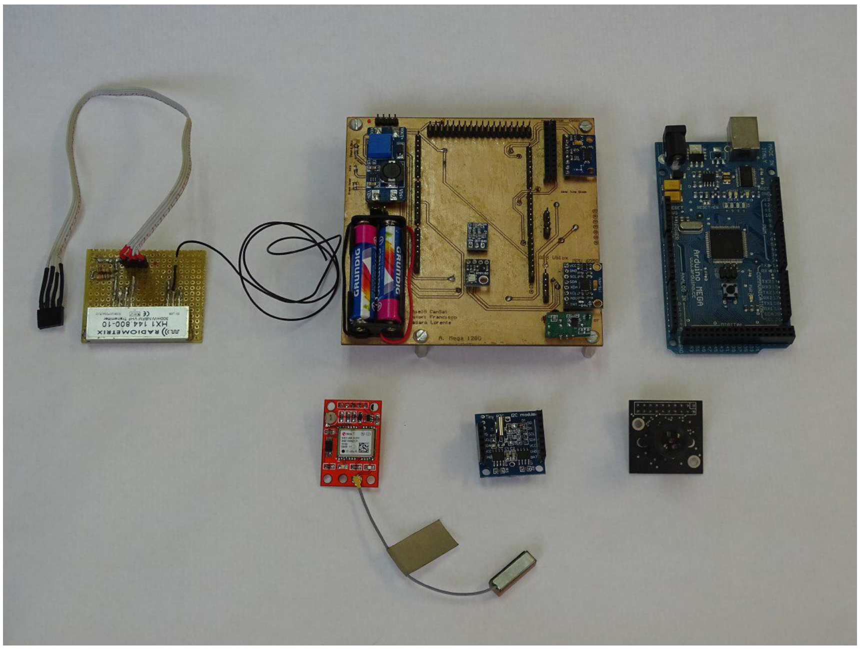
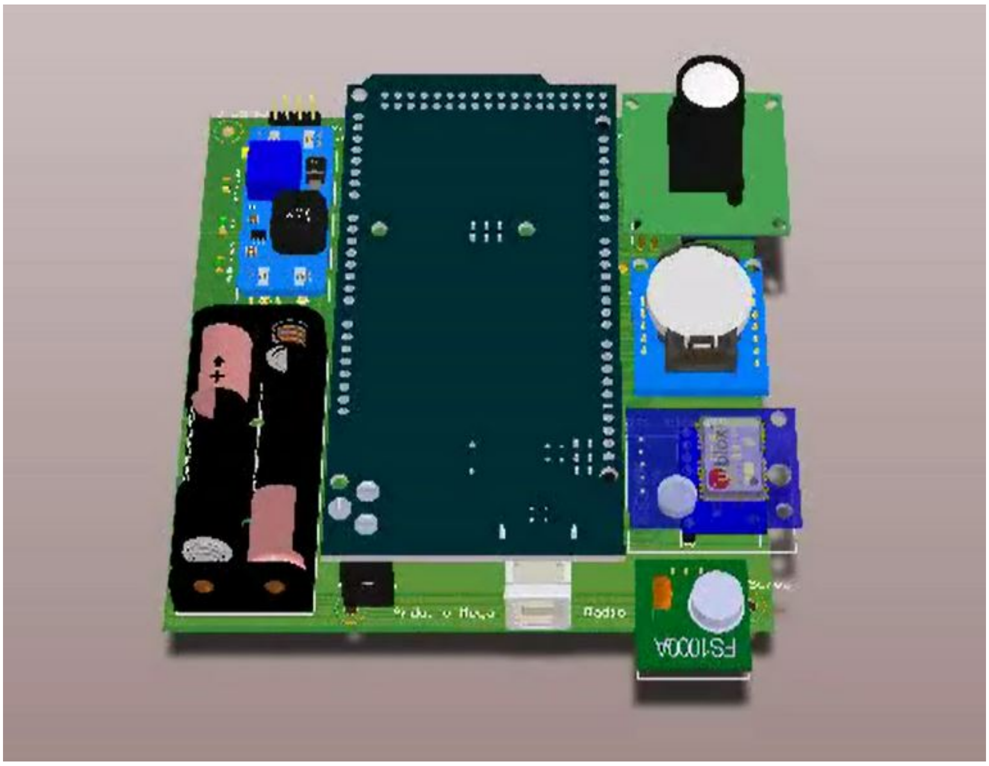


Figure 4.40 – *Disassemble Shield CanSat PCB*

Next we show a video of the 3D model of the PCB:

Video 4.1 3D view of the PCB

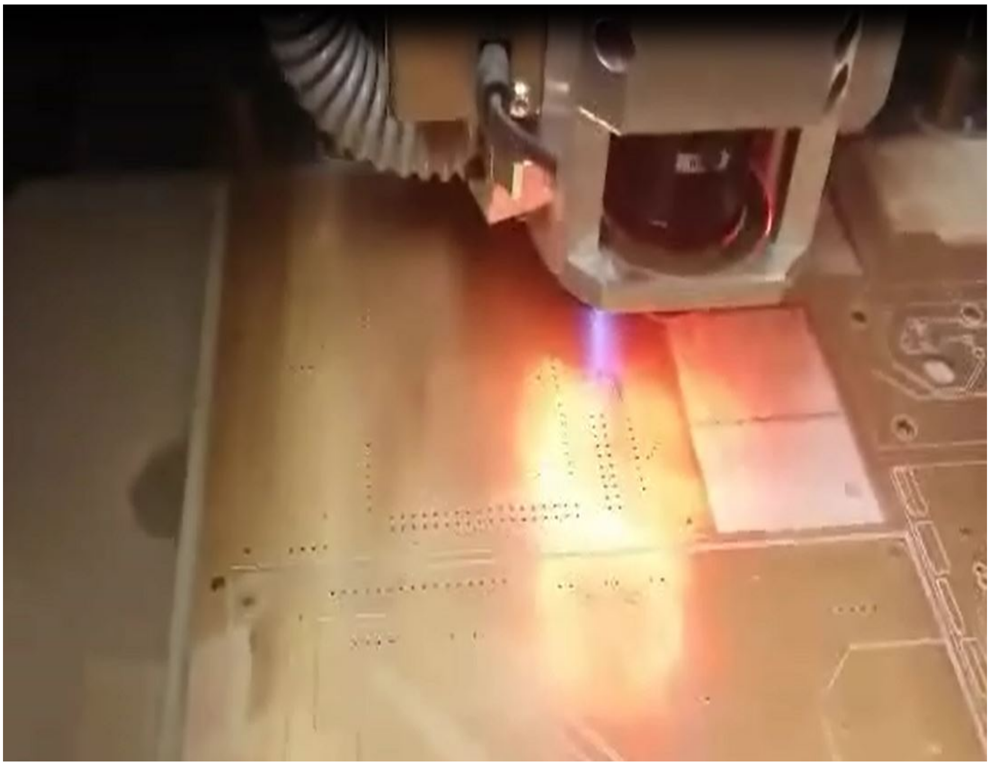


4.1.1.2.4 Manufacture of the PCB

sssec:manufacture)

As we said in section 4.1.1.2 for the manufacture of PCB use the technology LPFK ProtoMat S62 and below show a video during the manufacture of the CanSat Shield PCB (see 4.2) [29].

Video 4.2 Manufacture of the PCB



After manufacture had to apply a varnish to protect the PCB future oxidations and corrosions. The varnish realized by us with a resin and acetone as shown in the following figures:

Figure 4.41 – *Varnishing process*

In figure 4.41 we can see the manufacturing process of the resin.

Figure 4.42 – *Disassemble Shield CanSat PCB*

In figure 4.42 we can see the application process of the varnish.

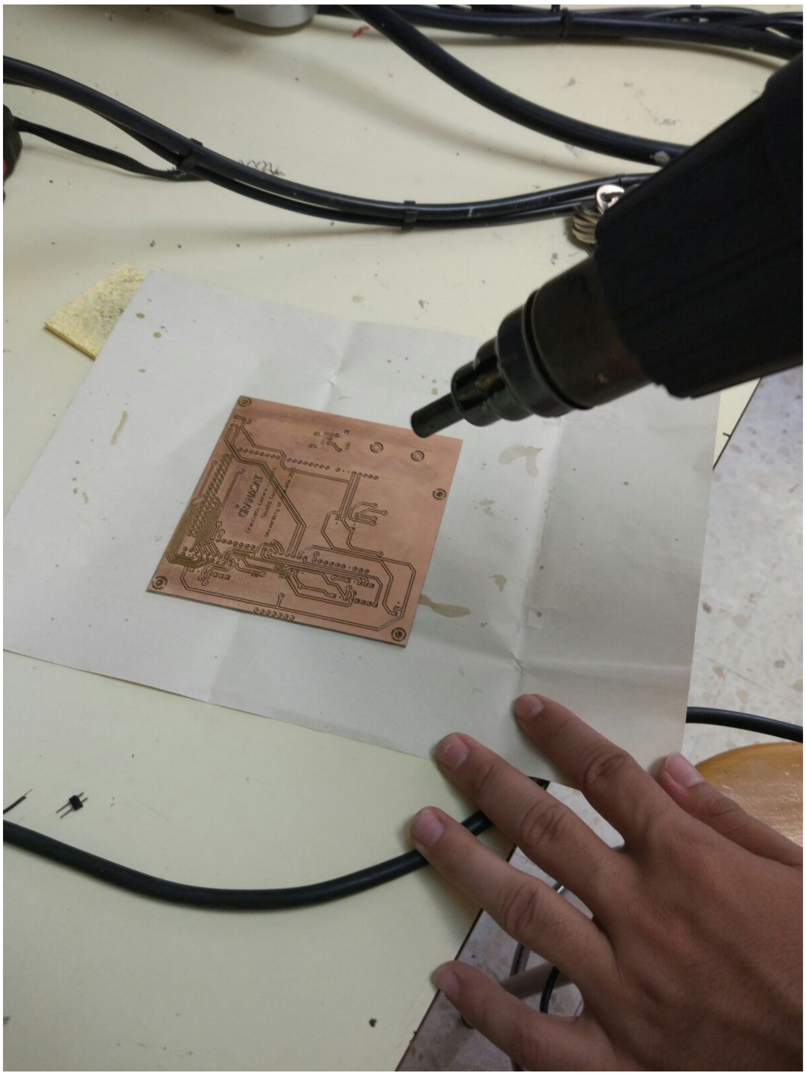


Figure 4.43 – *Disassemble Shield CanSat PCB*

In figure 4.43 we can see the drying process of varnish

4.1.2 Final Product CanSat

In this section we will see the final design of the CanSat where the dimensions of the PCB is adapted to the dimensions of the soda can. The elements described in Section 4.1 will be the same as used in this design, there are only three major differences:

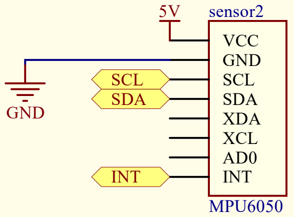
- **Microprocessor**. Instead of using the Arduino Mega board in the design of the prototype, in this case we will use the encapsulation of the microprocessor with its corresponding electronics.

- **Tiny RTC**. In this design we will not use the test board Tiny RTC, instead we will use only the encapsulated DS1307.
- **MicroSD adapter**. As I discussed in section 3.4 in chapter 3 we will have a storage system based on an SD memory by using MicroSD adapter.

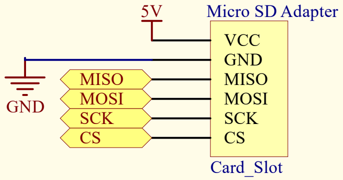
4.1.2.1 Electronic Schematics and components descriptions

In the following page is shown the schematic of the PCB, with every subsystem included on it.

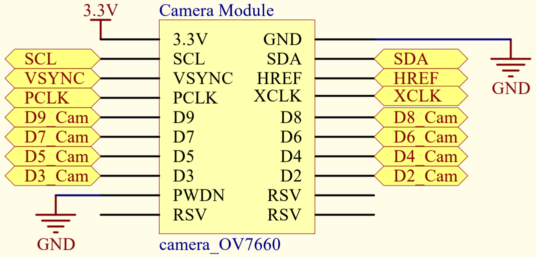
The MPU6050 sensor contains a MEMS accelerometer and a MEMS gyroscope in a single chip.



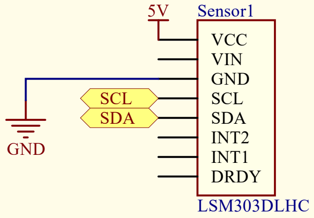
The micro SD adapter can be powered by 5V or 3.3V.



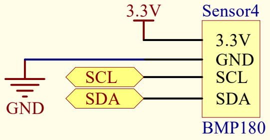
The OV7660 camera module is a low cost 0.3 mega pixel CMOS color camera module, that can output 640×480 VGA resolution image at 30fps.



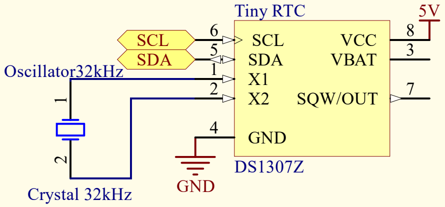
The LSM303 combines a digital 3-axis accelerometer and 3-axis magnetometer into a single package that is ideal for making a tilt-compensated compass.



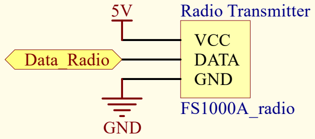
The BMP180 is barometric pressure sensor measure the absolute pressure of the air around him. This pressure varies with both the weather and altitude.



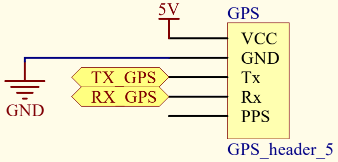
Real Time Clock has dual ports I2C bus (SCL, SDA) and power (VCC, GND).



RF transmitter working frequency of 433Mhz.



GPS ublox NEO-6M



Designer's signature

Supervisor's signature

Sheet title: **Diferentes sensores CANSAT**

Project title: **PCB_Project_CANSAT.PrjPcb**

Desginer: **Francisco Jesús Lázaro Lorente**

Date: **24/05/2016** Revision: * Sheet * of *

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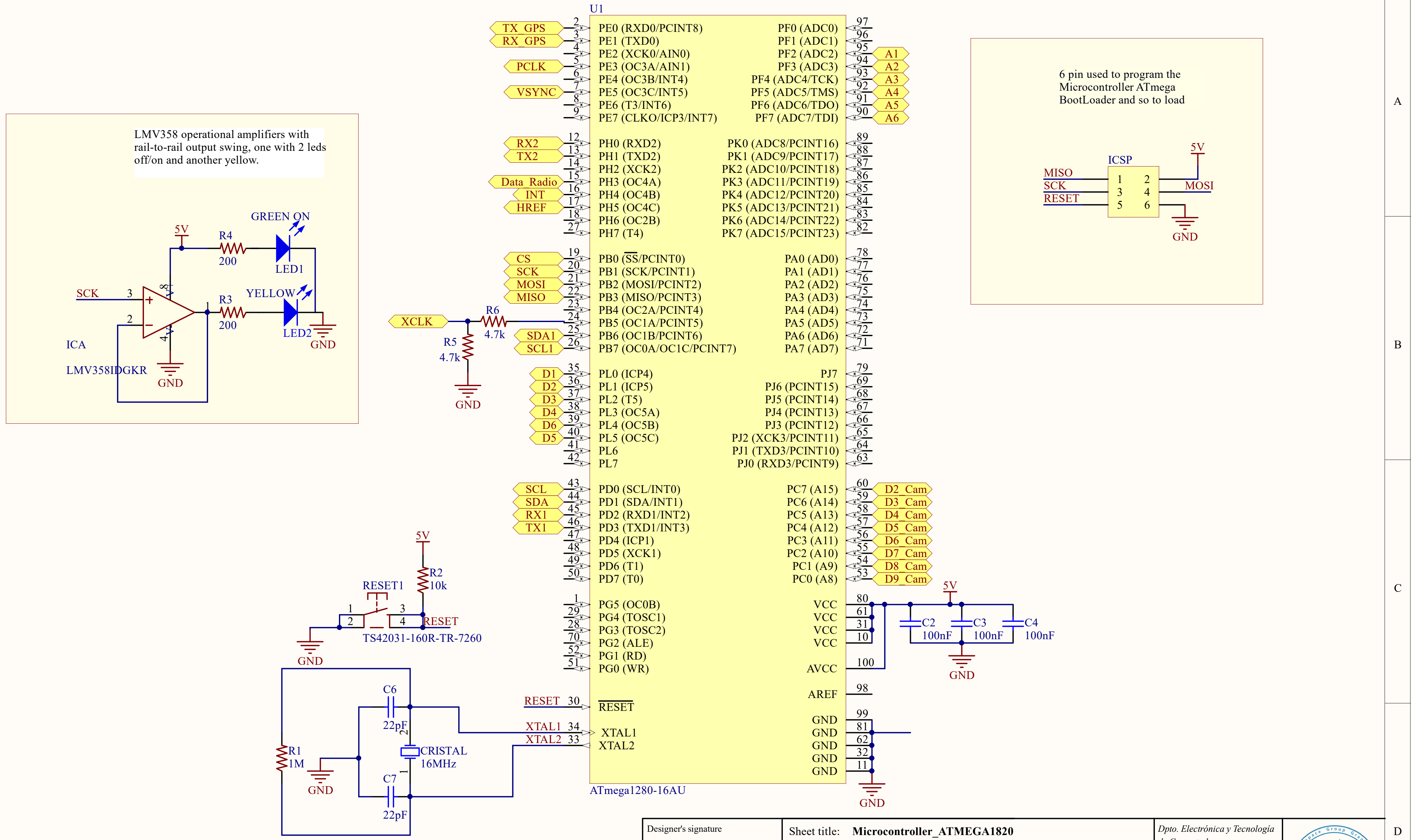
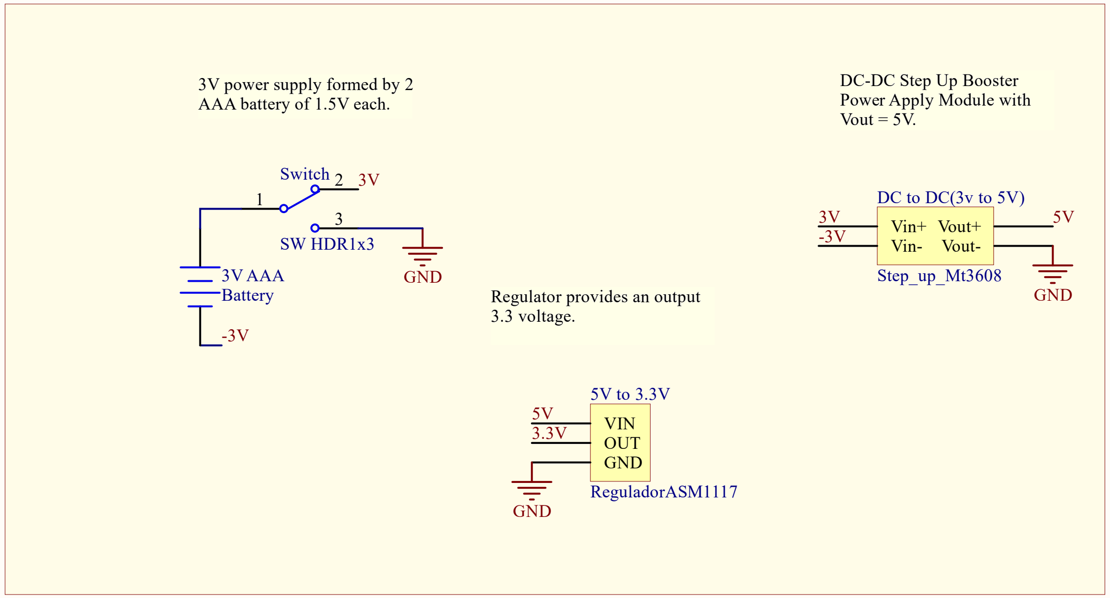
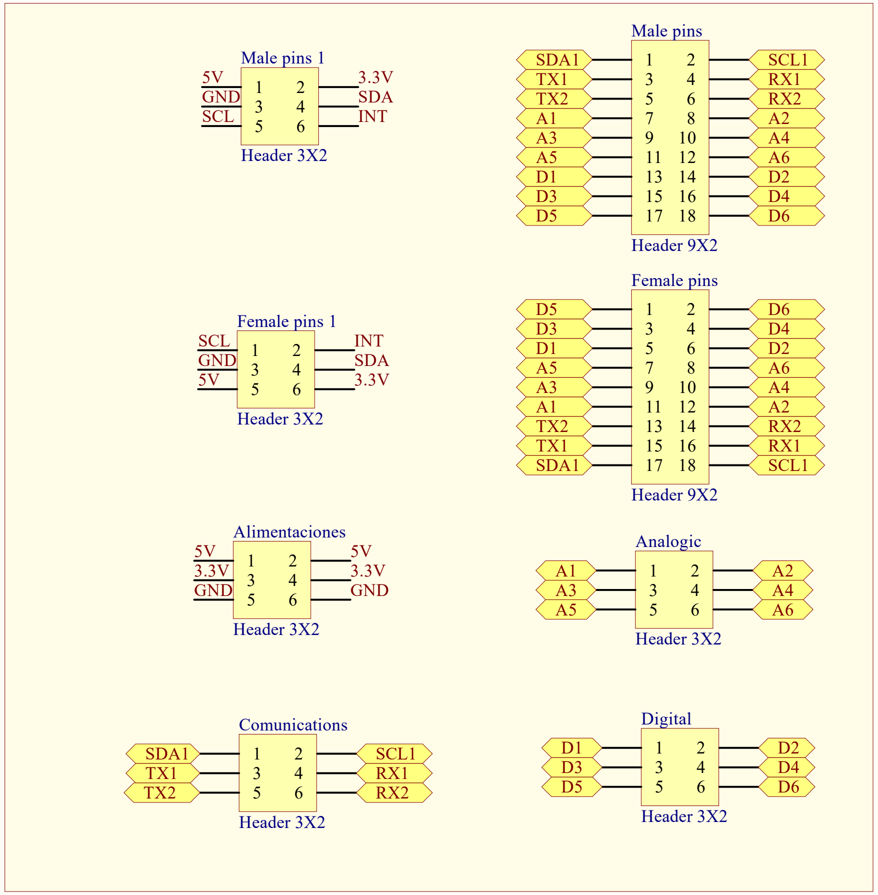
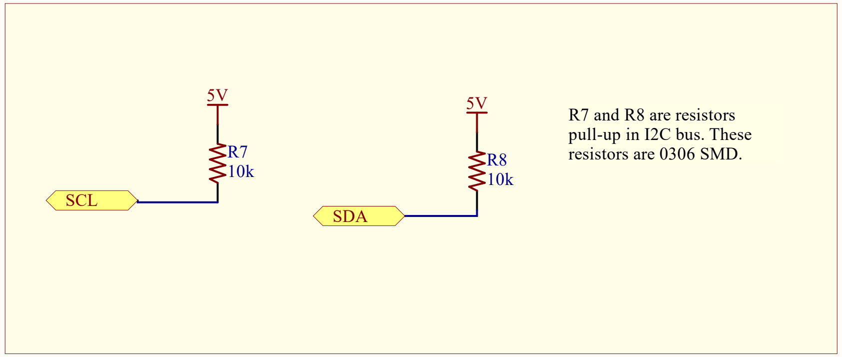
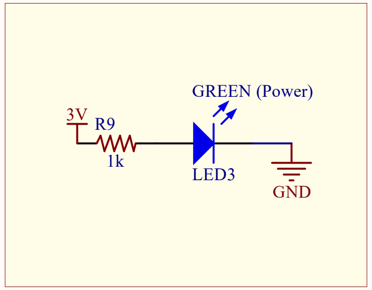


Designer's signature	Sheet title: **Microcontroller_ATMEGA1820**	*Dpto. Electrónica y Tecnología de Computadores* *University of Granada* *C/ Fuente Nueva, s/n, 18001* *Granada, Granada, Spain* *Sr. Andrés Roldán Aranda*
	Project title: **PCB_Project_CANSAT.PrjPcb**	
Supervisor's signature	Desginer: **Francisco Jesús Lázaro Lorente**	
	Date: **24/05/2016** Revision: * Sheet * of *	









Designer's signature	Sheet title: **Power Supply**	*Dpto. Electrónica y Tecnología de Computadores* *University of Granada* *C/ Fuente Nueva, s/n, 18001* *Granada, Granada, Spain* *Sr. Andrés Roldán Aranda*
	Project title: **PCB_Project_CANSAT.PrjPcb**	
Supervisor's signature	Desginer: **Francisco Jesús Lázaro Lorente**	
	Date: **02/06/2016** Revision: * Sheet * of *	

4.1.2.1.1 Microprocessor

Unlike the prototype design in the CanSat we use the same microprocessor, but in the SMD mode to save space and weight for the PCB. The microprocessor is from Atmel Corporation, model ATMEGA1280-16AU as see in the figure 4.44.

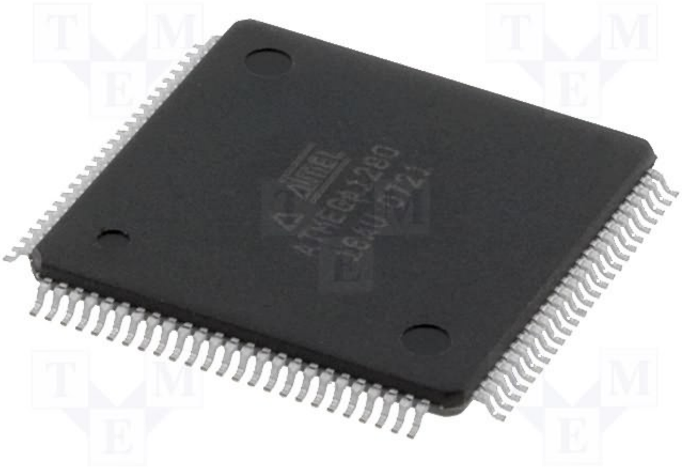


Figure 4.44 – *Pinout ATMEGA1280-16AU*

The schematic designed for the control of the microprocessor is shown in Figure 4.45.

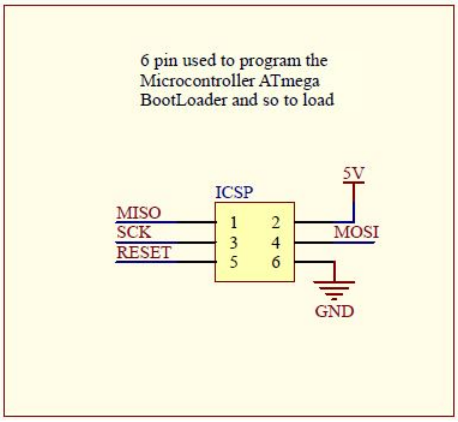


Figure 4.45 – *Schematic of ICSP for ATMEGA1280-16AU*

The symbol that we can see in the picture 4.45 is the ICSP port. That port is used for the communication between a programmer and the microprocessor, with the objective of program it.

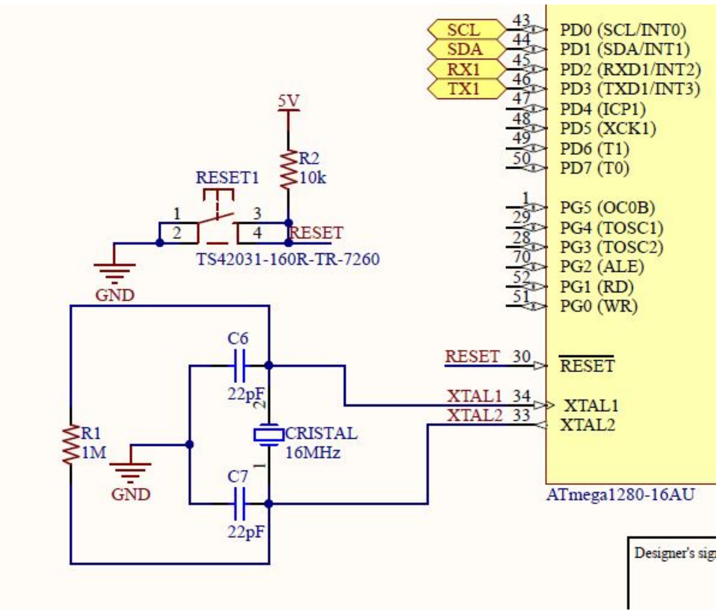


Figure 4.46 – *Schematic of oscilator for ATMEGA1280-16AU*

The microprocessor is programmed for use it as an Arduino Mega, so the external clock installed is of 16MHz. That clock is made with a crystal oscillator and their capacitors connected to the pins ROSC1 and TOSC2 of the ATMEGA1280-16AU (see figure 4.47).

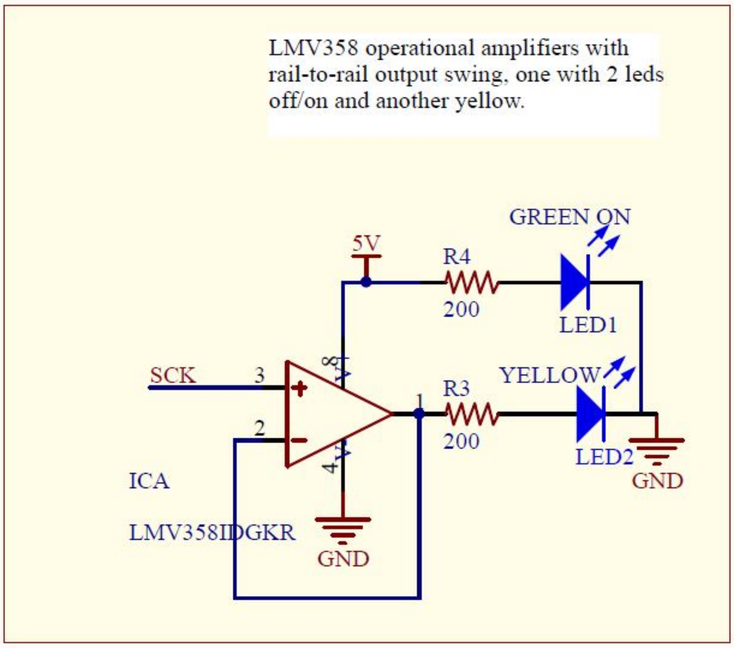


Figure 4.47 – *Schematic of LVM358 for ATMEGA1280-16AU*

The device that controls the Blink LED (LMV358IDGKR) is an operational amplifier used as a comparator to turn ON/OFF the LED. [27].

Moreover, to reset the testbed, there is a button (shown in figure 4.48) with a pull-up resistor of $10k\Omega$.

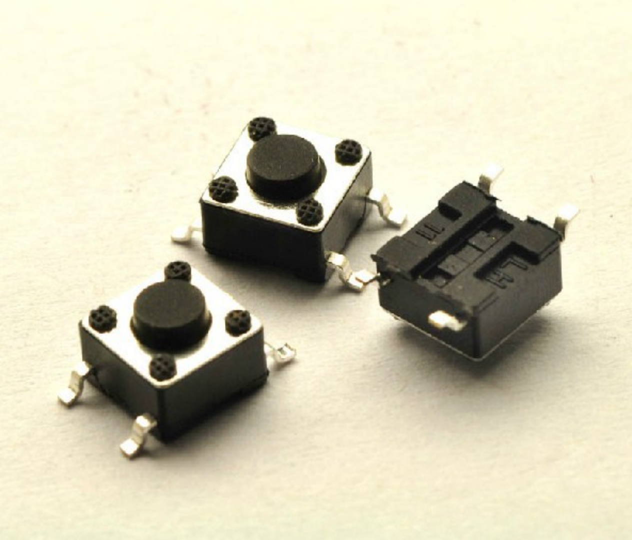


Figure 4.48 – *Reset button*

4.1.2.1.2 Substitution Tiny RTC

We will replace the test board Tiny RTC by package SMD of DS1307 to save space and weight for the PCB. In the next figure 4.49 you can see this SMD package:

Figure 4.49 – *SMD package of DS1307 (Serial Real Time Clock)*

For the perfect operation of this module we will need an external 32kHz oscillator as we can see in the schematic of figure 4.50:

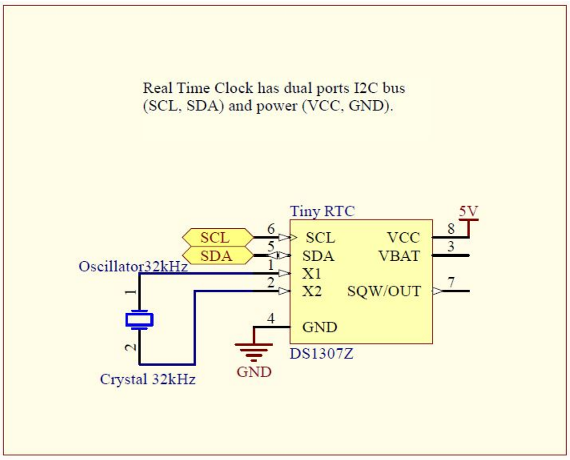


Figure 4.50 – *Schematic of DS1307*

4.1.2.1.3 MicroSD adapter

This storage system we have incorporated into the design of the final PCB because as you can see in section 4.1.1.1 doesn't speak any of MicroSD adapter. In this case we will also have a test board that is able to read and write to MicroSD cards (see figure 4.51). Actually the data will store on a memory as you can see in figure 4.52, and the test board adapter will handle the MicroSD write data telemetry to save.

Figure 4.51 – *Photo of test board of MicroSD Card Adapter*

Figure 4.52 – *Photo of MicroSD Card [39]*

The adapter board communicates with the microprocessor through the ICSP communication, so in the schematic of figure 4.53 we see that there are four pins (MISO, MOSI, SCK and CS).

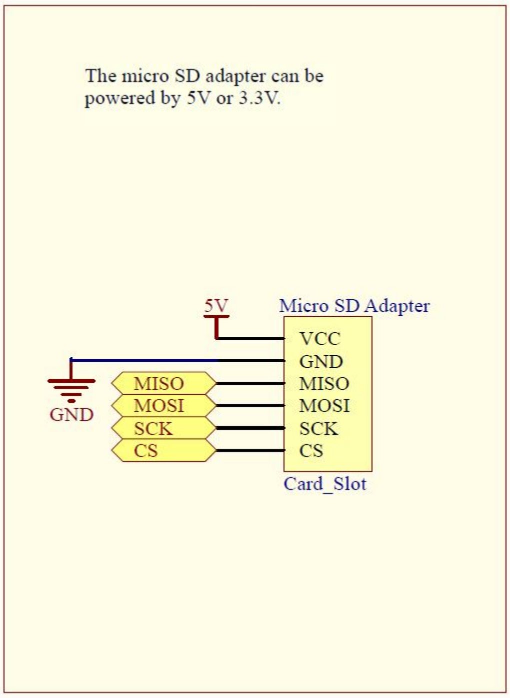

The micro SD adapter can be powered by 5V or 3.3V.

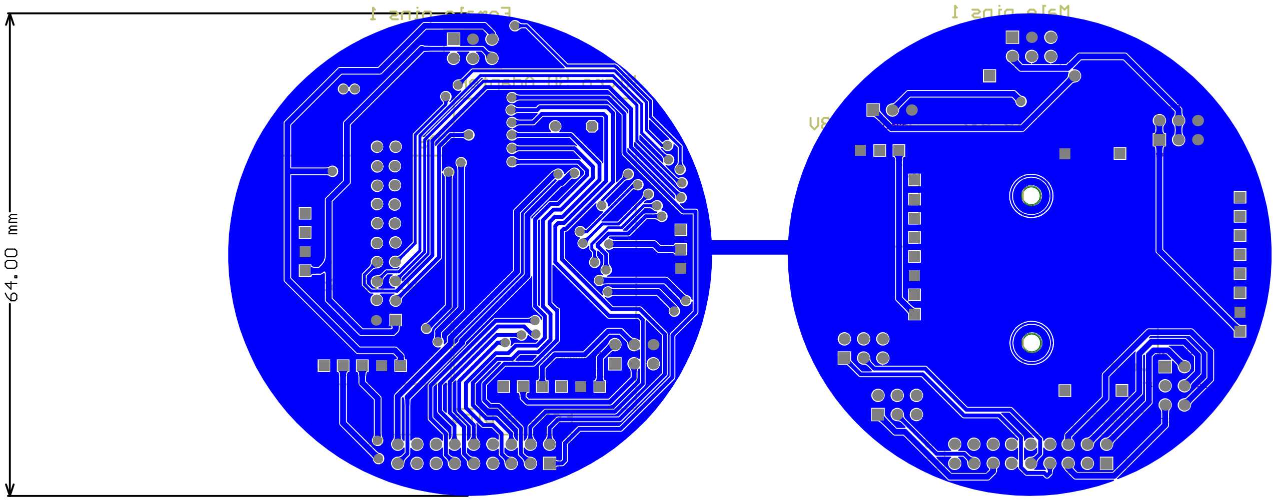
Figure 4.53 – *Schematics of MicroSD Card Adapter*

4.1.2.2 PCB Design

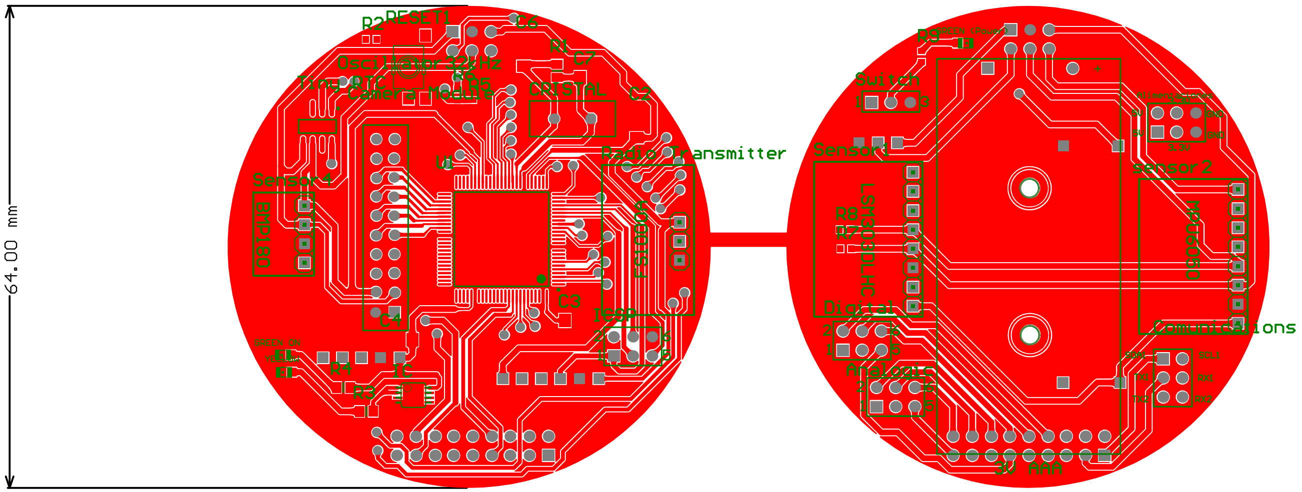
The design process PCB CanSat identical to the prototype is done, seen above in section 4.1.1.2.

4.1.2.2.1 2D viwe of the CanSat PCB Design

In this section we will show the dimensions CanSat PCB design where we can see it has a rounded shape for adapting to the size of a soda can. In the following schematic we will mostar the top and the bottom layer but we can see that there are two circular plates joined by a small segment, this is due to practices when working with Altium issues. The right way would have been each of the board on a single sheet but this issue seriously hampered its realization.



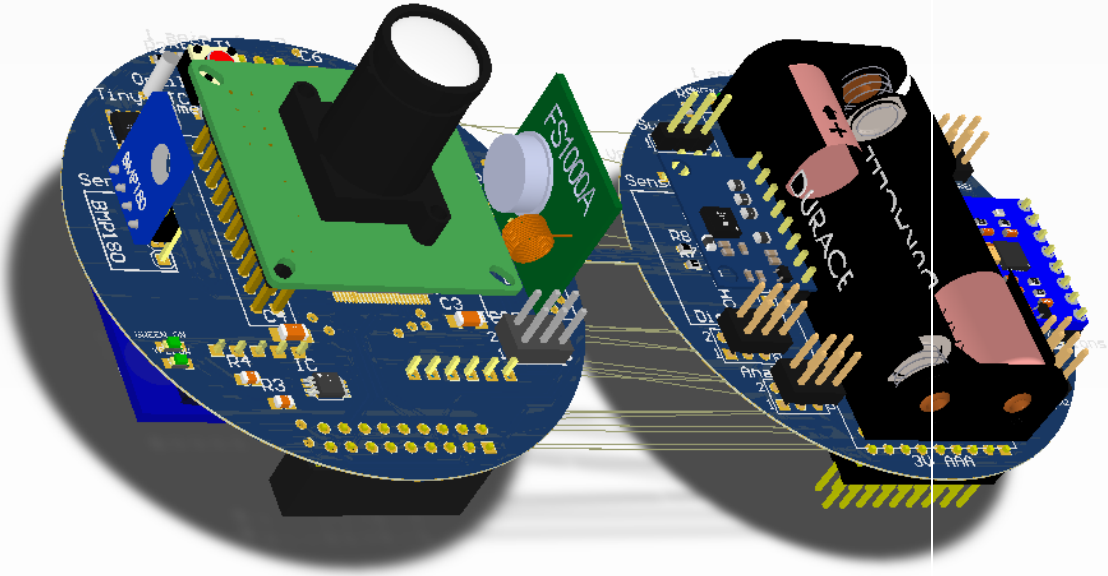
Designer's signature:	Sheet title: Double PCB CanSat	Dpto. Electronica y Tecnologia de Computadores University of Granada C/ Fuente Nueva, s/n, 18001 Granada, Granada, Spain Sr. Andres Roldan Aranda	
	Project title: GranaSAT-I		
Supervisor's signature:	Designer: Francisco J. Lazaro Lorente		
	Supervisor: Andres Roldan Aranda	**Date: 01.03.2015 Revision: 1** **Sheet 1 of 10**	



Designer's signature:	Sheet title: Double PCB CanSat	Dpto. Electronica y Tecnologia de Computadores University of Granada C/ Fuente Nueva, s/n, 18001 Granada, Granada, Spain Sr. Andres Roldan Aranda
	Project title: GranaSAT-I	
Supervisor's signature:	Designer: Francisco J. Lazaro Lorente	
	Supervisor: Andres Roldan Aranda	**Date: 01.03.2015 Revision: 1** **Sheet 1 of 10**

4.1.2.2.2 3D viwe of the CanSat PCB Design

In this section, the PCBs shown in the section 4.1.1.2.2 will be represented in 3D view. That models will be used as reference in order to have an idea of the real size and aspect of the final CanSat PCB implementation. The two board are placed one above the other as if it were a sandwich. The PCB is on the left (which contains the camera) and the other containing the battery is to be put up.


FS1000A
BMP180
C6
C3
R4
R3
R8
Sens
Ser
DURACE
3V AAA

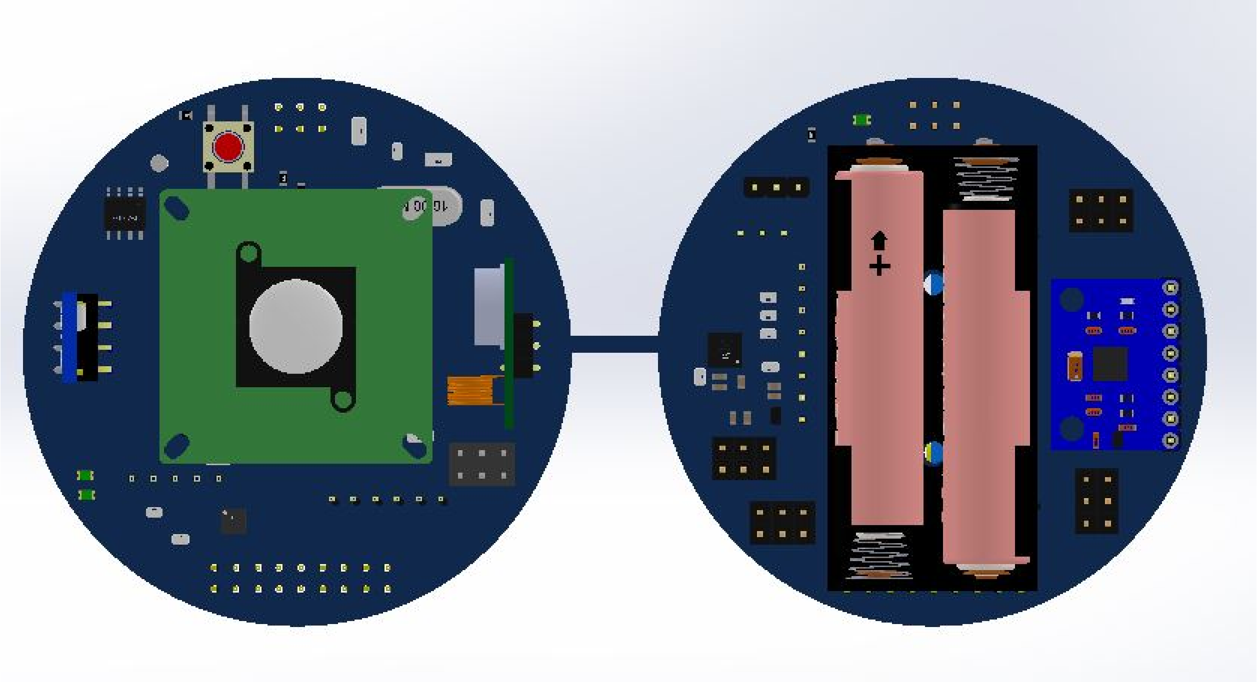


Figure 4.54 – *3D View of the top side*

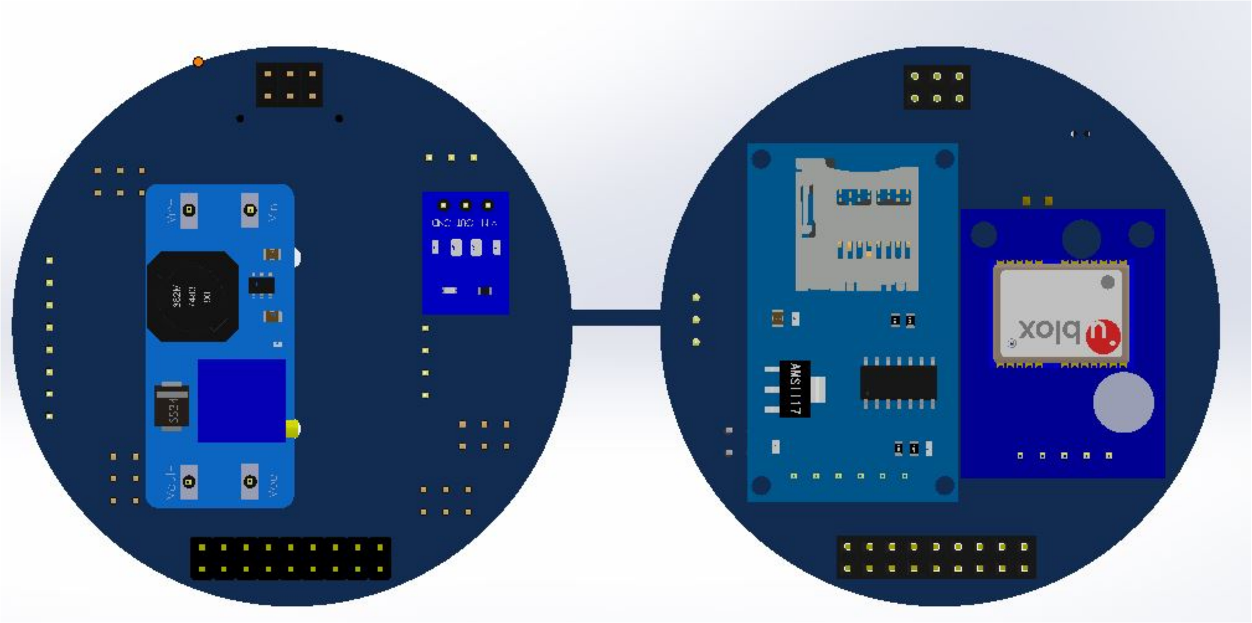
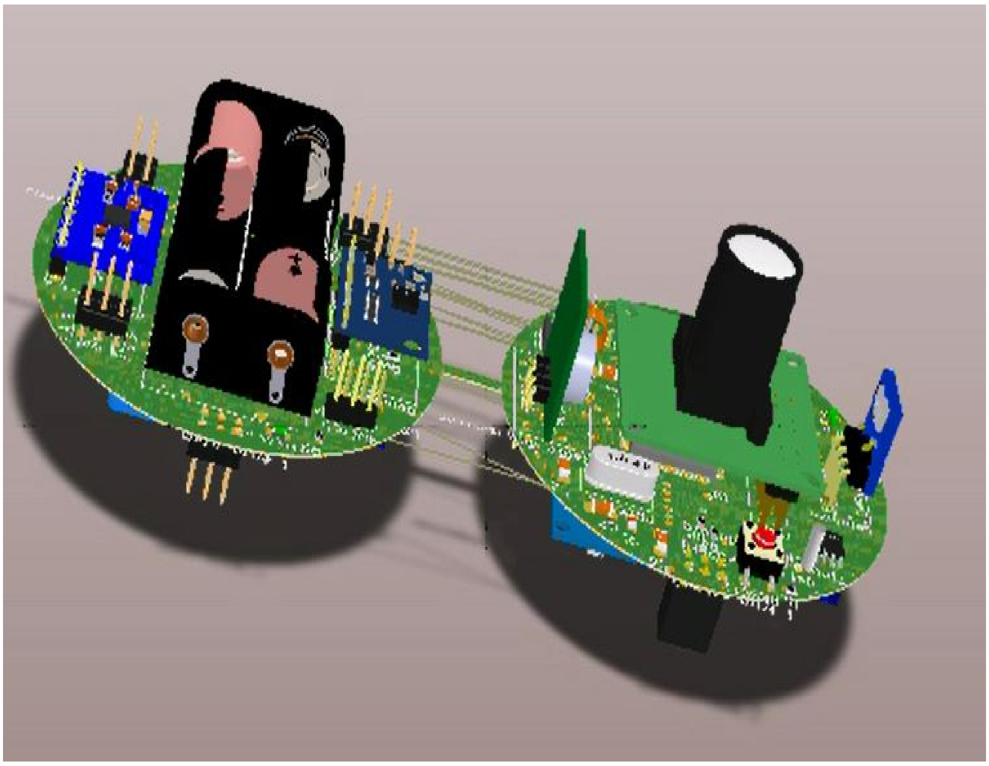


Figure 4.55 – *3D View of the bottom side*

Next we show a video of the 3D model of the PCB

Video 4.3 3D view of the CanSat PCB



4.2 Software Design

In this section will be studied the necessary software design for the system, note that this section of the project works and not very developed due to certain problems of time but we will explain what is the idea to develop for our CanSat perform the desired functions. That design has two parts: the onboard software, and the GS software.

4.2.1 On-board software

On-board Software is controlled by the microprocessor in the Testbed PCB and it has the following functions:

- Read the data sensors.
- Make a backup of telemetric data periodically.
- Transmit the data to the GS with radio module.

In order to have a more clear description of the software design, the state diagram of the on-board software is shown in the figure 4.56.

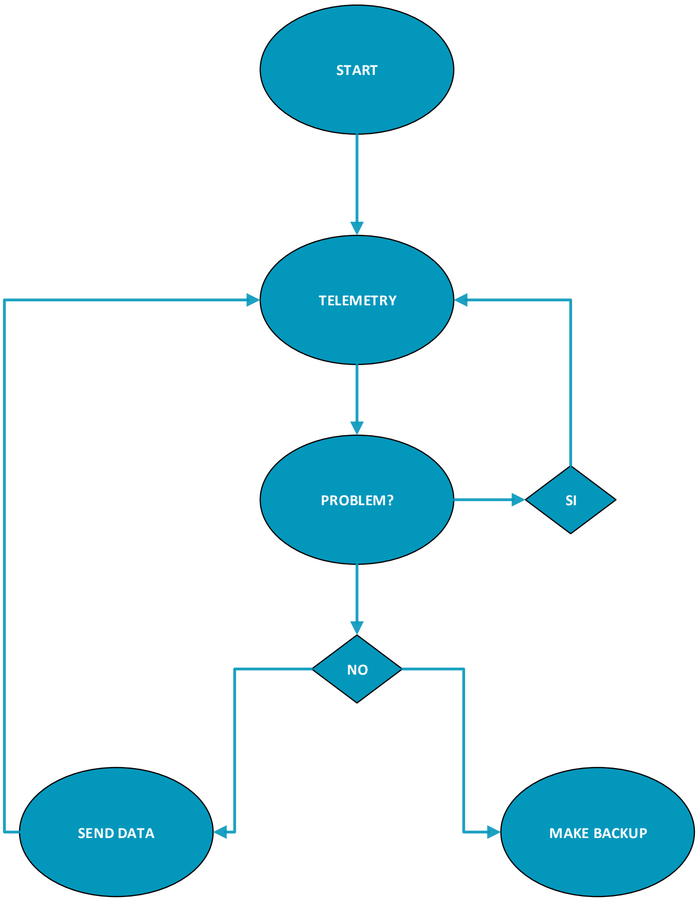


Figure 4.56 – *On-board State diagram*

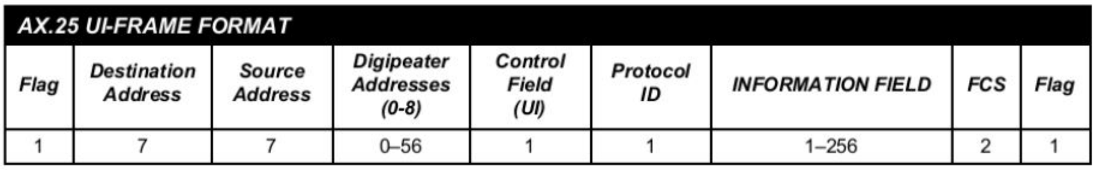
In that state diagram we have five different states, which are going to be described now:

- **START**. In that state, the system is waiting to be turned on. It will only be occupied the first one time.
- **TELEMETRY**. When the system is in that state, it will be measuring the data from the sensors until the reading process is ended.

- **PROBLEM?**. In this state we will see that most of the sensors are working and get consistent values, especially we focus more on the GPS to always have located the device. If all goes well we turn to the following states and if not then return to the state TELEMETRY.
- **SEND DATA**. In this state we build the APRS frames along with telemetry data and send the frame captured by radio.
- **MAKE BACKUP**. Finally, when the error is calculated, that state is the responsible for the control of the actuators. It will send the necessary commands and the system will come back to the TELEMETRY state, making a loop.

For packaging data we will use APRS using the AX.25 protocol. Basically the result of the programming is responsible for sending a general lock beacon every ten minute and a frame format synchronized telemetry three minutes after each transmission of the overall mark. Let's run APRS offline mode, so the AX.25 frames are transmitted without waiting for any response, and the reception at the other end is not guaranteed so we use data storage systems [1].

Let's now see the structure of the information sent:



AX.25 UI-FRAME FORMAT

Flag	Destination Address	Source Address	Digipeater Addresses (0-8)	Control Field (UI)	Protocol ID	INFORMATION FIELD	FCS	Flag
1	7	7	0–56	1	1	1–256	2	1

Figure 4.57 – *AX.25 UI-frame format [45] [1]*

In the figure 4.57 we can see the different field have the AX.25 frames and we will use the INFORMATION FIELD field to enter a frame with the telemetry information [45].

4.2.2 GS software

As I said in the beginning of this section is not part of the implementation of this software but the ideas is that our proyect will have a graphic interface, a dashboard, showing the telemetry values received from the CanSat and sending the telecontrol commands there. For example, that graphic interface will be developed with Matlab, where the values will be shown in different tabs where the data will be organized and the configuration for the radio link can be changed.

CHAPTER

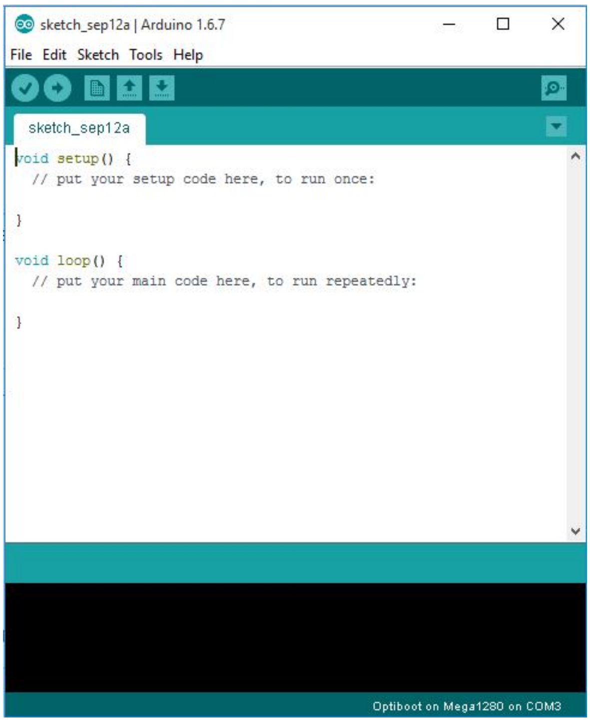
5

INTEGRATION, TESTS AND VERIFICATION

In this chapter, we will see the integration phase of this project, how each subsystem works with each other. Moreover, we will see a tracking of GPS running through the graphical interface of the website http://es.aprs.fi/.

5.1 Monitoring data

For different tests communication between sensors we use the software development Arduino as can be seen in figure 5.1. The main thing is that the clock signal communication I2C run smoothly, for it using the oscilloscope we can see result.



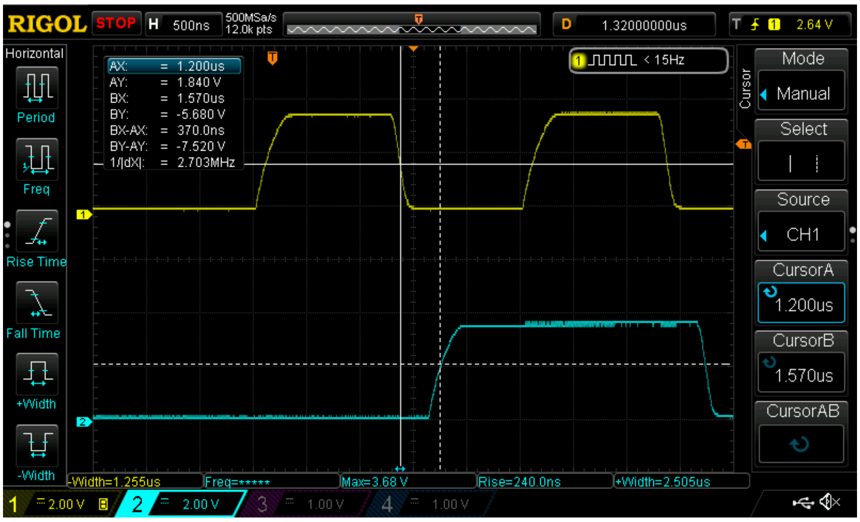
```
void setup() {
  // put your setup code here, to run once:

}

void loop() {
  // put your main code here, to run repeatedly:

}
```

Figure 5.1 – *Software development Arduino*

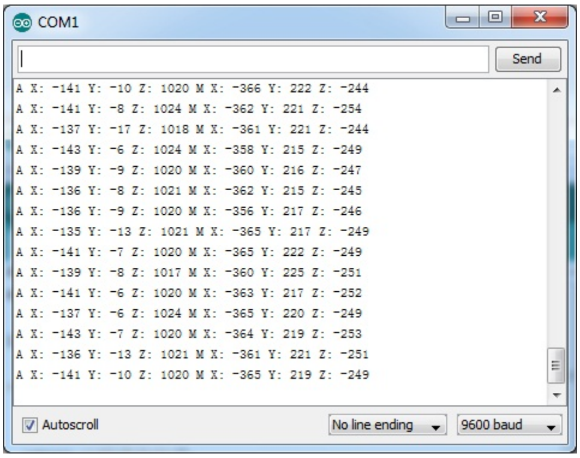


```
AX:      =  1.200us
AY:      =  1.840 V
BX:      =  1.570us
BY:      =  -5.680 V
BX-AX:   =  370.0ns
BY-AY:   =  -7.520 V
1/|dX|:  =  2.703MHz
```

```
-Width=1.255us  Freq=*****  Max=3.68 V  Rise=240.0ns  +Width=2.505us
```

Figure 5.2 – *CLK is the yellow signal and blue signal SDA*

An example of the communication bus shown in figure 5.2, we can observe the clock signal yellow color and blue data signal corresponding to the bus I2C. This is an example of communication only to LSM303 connecting a mega arduino sensor.



```
A X: -141 Y: -10 Z: 1020 M X: -366 Y: 222 Z: -244
A X: -141 Y: -8 Z: 1024 M X: -362 Y: 221 Z: -254
A X: -137 Y: -17 Z: 1018 M X: -361 Y: 221 Z: -244
A X: -143 Y: -6 Z: 1024 M X: -358 Y: 215 Z: -249
A X: -139 Y: -9 Z: 1020 M X: -360 Y: 216 Z: -247
A X: -136 Y: -8 Z: 1021 M X: -362 Y: 215 Z: -245
A X: -136 Y: -9 Z: 1020 M X: -356 Y: 217 Z: -246
A X: -135 Y: -13 Z: 1021 M X: -365 Y: 217 Z: -249
A X: -141 Y: -7 Z: 1020 M X: -365 Y: 222 Z: -249
A X: -139 Y: -8 Z: 1017 M X: -360 Y: 225 Z: -251
A X: -141 Y: -6 Z: 1020 M X: -363 Y: 217 Z: -252
A X: -137 Y: -6 Z: 1024 M X: -365 Y: 220 Z: -249
A X: -143 Y: -7 Z: 1020 M X: -364 Y: 219 Z: -253
A X: -136 Y: -13 Z: 1021 M X: -361 Y: 221 Z: -251
A X: -141 Y: -10 Z: 1020 M X: -365 Y: 219 Z: -249
```

Figure 5.3 – *Acceleration data of the 3 axes of LSM303*

Through Arduino serial port we can display on the monitor that collects values such as sensor LSM303 (see section 4.1.1.1.2) as shown in figure 5.3.

To achieve the functioning of communication with all the sensors had to perform this procedure one by one until once worked and so begin communication with all together.

When we connect all sensors on the I2C bus had big problems, because our input impedance was very large and therefore did not have high voltage levels (see figure fig:marra).

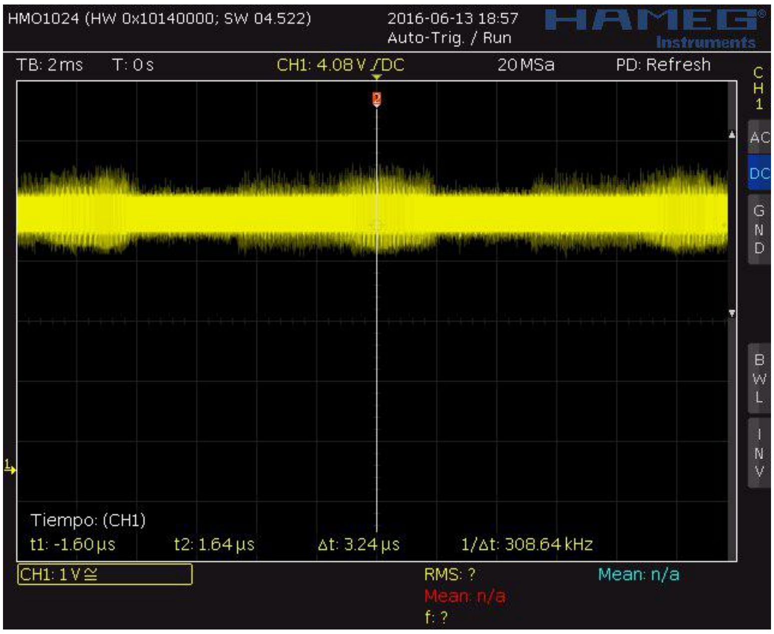


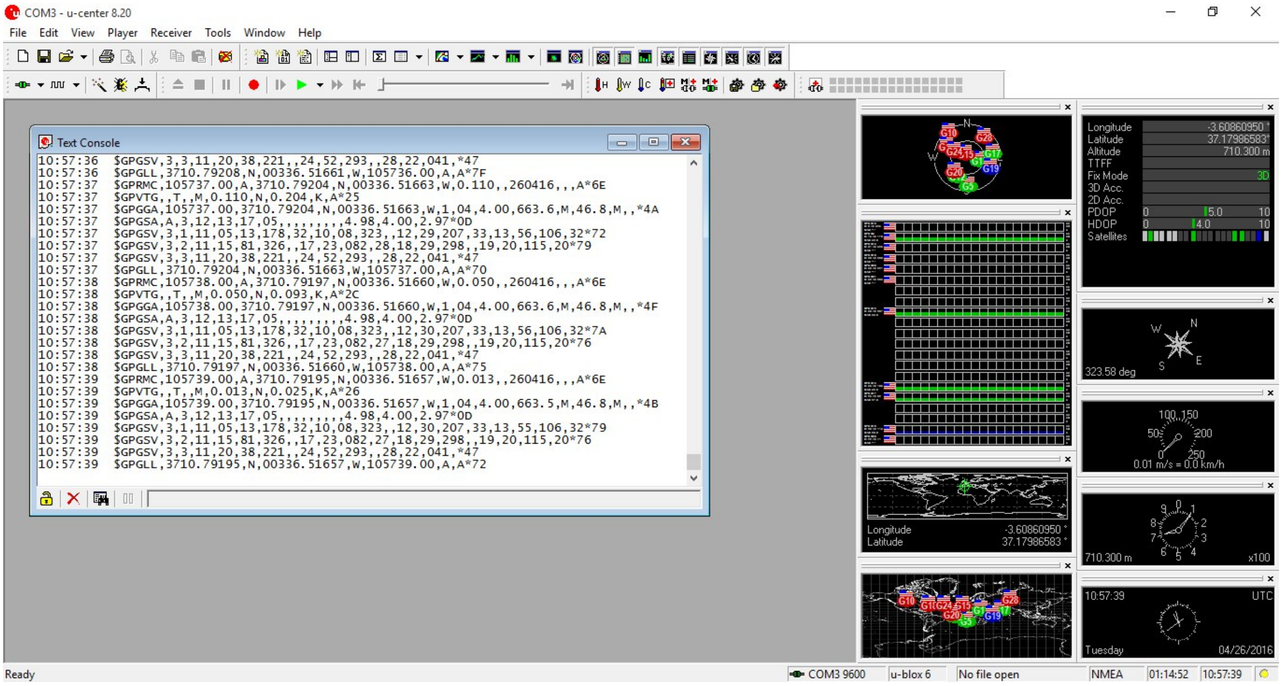
Figure 5.4 – *Clock signal when all sensors connected to the bus i2C*

As shown in figure 5.4 only noise and a very distorted signal is, this occurred because each board testing the different sensors has a resistance pullup therefore the sum of all to a very large impedance attenuates and distorts the signal. The solution was to remove every pull-up resistor of each of the plates and leave only two at the end of bus as shown in figure 4.10.

5.2 Monitoring tracking with GPS

In this section we will show how well the APRS but only sending frames GPS location (data) and we will be able to follow in real time thanks to the graphical interface of the web: http://es.aprs.fi/ the tracking by the science faculty.

To do this test we used an application of the company U-BLOX (u-center 8.20 [9]) is the GPS modules to configure and check that the frames are correct as seen in figure 5.5.



```
10:57:36   $GPGSV,3,3,11,20,38,221,,24,52,293,,28,22,041,*47
10:57:36   $GPGLL,3710.79208,N,00336.51661,W,105736.00,A,A*7F
10:57:37   $GPRMC,105737.00,A,3710.79204,N,00336.51663,W,0.110,,260416,,,A*6E
10:57:37   $GPVTG,,T,,M,0.110,N,0.204,K,A*25
10:57:37   $GPGGA,105737.00,3710.79204,N,00336.51663,W,1,04,4.00,663.6,M,46.8,M,,*4A
10:57:37   $GPGSA,A,3,12,13,17,05,,,,,,,,,4.98,4.00,2.97*0D
10:57:37   $GPGSV,3,1,11,05,13,178,32,10,08,323,,12,29,207,33,13,56,106,32*72
10:57:37   $GPGSV,3,2,11,15,81,326,,17,23,082,28,18,29,298,,19,20,115,20*79
10:57:37   $GPGSV,3,3,11,20,38,221,,24,52,293,,28,22,041,*47
10:57:37   $GPGLL,3710.79204,N,00336.51663,W,105737.00,A,A*70
10:57:38   $GPRMC,105738.00,A,3710.79197,N,00336.51660,W,0.050,,260416,,,A*6E
10:57:38   $GPVTG,,T,,M,0.050,N,0.093,K,A*2C
10:57:38   $GPGGA,105738.00,3710.79197,N,00336.51660,W,1,04,4.00,663.6,M,46.8,M,,*4F
10:57:38   $GPGSA,A,3,12,13,17,05,,,,,,,,,4.98,4.00,2.97*0D
10:57:38   $GPGSV,3,1,11,05,13,178,32,10,08,323,,12,30,207,33,13,56,106,32*7A
10:57:38   $GPGSV,3,2,11,15,81,326,,17,23,082,27,18,29,298,,19,20,115,20*76
10:57:38   $GPGSV,3,3,11,20,38,221,,24,52,293,,28,22,041,*47
10:57:38   $GPGLL,3710.79197,N,00336.51660,W,105738.00,A,A*75
10:57:39   $GPRMC,105739.00,A,3710.79195,N,00336.51657,W,0.013,,260416,,,A*6E
10:57:39   $GPVTG,,T,,M,0.013,N,0.025,K,A*26
10:57:39   $GPGGA,105739.00,3710.79195,N,00336.51657,W,1,04,4.00,663.5,M,46.8,M,,*4B
10:57:39   $GPGSA,A,3,12,13,17,05,,,,,,,,,4.98,4.00,2.97*0D
10:57:39   $GPGSV,3,1,11,05,13,178,32,10,08,323,,12,30,207,33,13,55,106,32*79
10:57:39   $GPGSV,3,2,11,15,81,326,,17,23,082,27,18,29,298,,19,20,115,20*76
10:57:39   $GPGSV,3,3,11,20,38,221,,24,52,293,,28,22,041,*47
10:57:39   $GPGLL,3710.79195,N,00336.51657,W,105739.00,A,A*72
```

Longitude -3.60860950 °
Latitude 37.17986583°
Altitude 710.300 m
TTFF
Fix Mode 3D
3D Acc.
2D Acc.
PDOP 0 5.0 10
HDOP 0 4.0 10
Satellites

323.58 deg

0.01 m/s = 0.0 km/h

710.300 m x100

10:57:39 UTC
Tuesday 04/26/2016

Figure 5.5 – *Showing NMEA frames using App u-center*

In figure 5.5 we can see on the left a box with different frames and on the side of the right are several tables showing data of interest as to how many satellites communicates or that part of the world are those satellites which is asking for information localization.

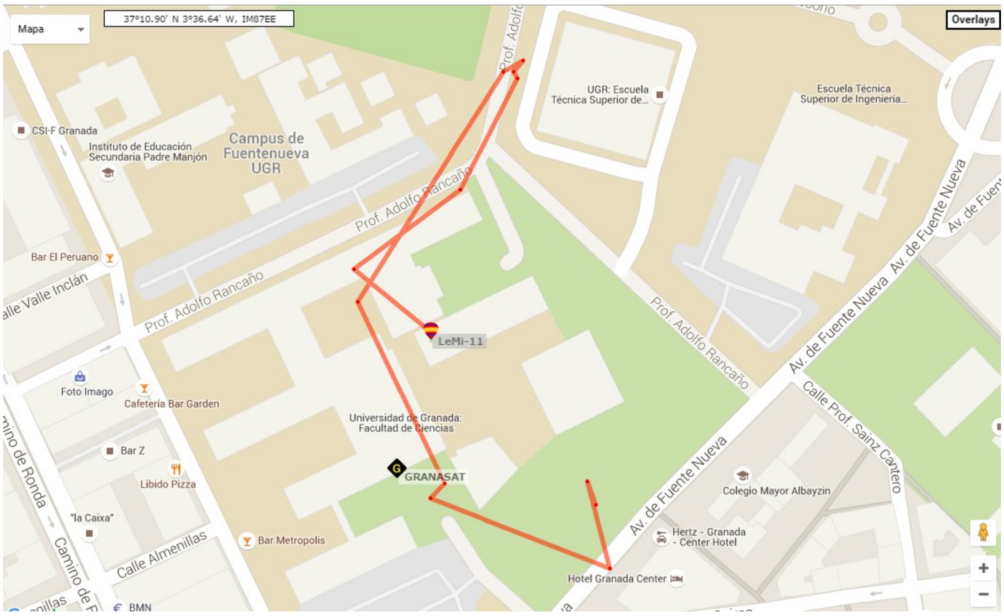


Figure 5.6 – *Tracking Shield CanSat with app of Google*

Finally we just need to use our ICOM 9100 receiver we have in the GS of GranaSAT Team computer and search the google app (http://es.aprs.fi/) the identification name (our case that had left the default "Lemi-11"). In figure 5.6 we can see marked in red the route taken by the faculty of sciences.

Due to lack of time and the non-realization of the complete software we could make all the appropriate tests and consequently the optimal functioning of the CanSat.

CHAPTER

6

CONCLUSIONS AND FUTURE LINES

In this document, we have presented the development of CanSat from prototype to final design through the different stages that entails. We have managed to obtain and understand the concepts of aerospace world that previously didn't know. For a Telecommunication Engineering student as the author of this document is it was arduous to get used to all the attitude concepts, the tracking, electronic design and manufacture of PCB and its implementation to make then efficient and reliable.

Not only the academic problems affected the development of this work, in our case, the budget restriction was also a main bone of contention. It affected all the stages of the project because it was inexpensive our main requirement to be met in this design. In spite of that, the whole team is proud of the work carried out. We have proven that the greatest hits can be achieved with effort rather than a huge budget.

In this entire year working in an aerospace project, we have learnt a little of about this industry works, its standards and how important a good documentation is, as well as we have learnt how to work in teams. Students usually tend to think that they can work in groups, however, we all realised that it was an illusion but after spending several months in the science lab with other partners one can say that the ability to work in groups has been learnt.

The CanSat developed is yet far from being implemented, as it is still a student desgin nano-satellite. However, we think we have lain the groundwork for this purpose. The hardware developed has proven to be quite robust but you can always improve as there is a very large range of components for each sensor or power system.

As software development is where this project more weak due to the lack dedication that has had as we focus more on hardware development so leave a little off the topic of software.

A large future work could be done with this work as a basis. Based on this hardware could be spent on only the implementation of a software that can communicate in real time with the base station and not as in our case that is shaped beacon, where the device emits only without expecting any response.

Another major point to consider in future improvements would stage CanSat flight, you can explore better options for that flight. For example the use of rocket can fairly improve the measurements obtained since it could reach greater heights.

We would like to conclude by saying that it has been quite an enriching experience developing this project, and we did not expect us to have this ability to adapt to the problems and difficulties encountered along a project of this type.

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APPENDIX

A

PROJECT BUDGET

A.1 Electronics costs

For the electronics implementation, we have used the financial contribution of our main sponsor, the ECTD, which paid us the electronics devices shown in the table A.3. Furthermore, the PCB, has been build in the machine LPFK, which belong to the ECTD too. That PCB had a cost of fabrication of 40€, whose breakdown is shown in table A.1.

Item	**Cost(€)**
Copper Plate	10€
Human Resources	25€
Machine working	5€
TOTAL	**40€**

Table A.1 – *PCB building cost*

Therefore, the total cost of the PCB implementation is broken down in the table A.2

Item	**Cost(€)**
PCB Build	40
Electronic devices	62.4075
TOTAL	**102.4075**

Table A.2 – *Total cost of the PCB implementation*

Table A.3 – *Budget for the electronics devices on PCB*

Item	Description	Bought items(Used)	Cost/unit(€)	Bought Cost(€)	Used cost(€)
Microcontroller	ATMEGA328P-AU	2(1)	2.55	5.1	2.55
Operat.amplifier	LMV358IDGKR	3(1)	0.832	2.496	0.832
Push button	B3S-1000P	5(1)	0.353	1.765	0.353
Terminal PCB	3.81mm	5(3)	0.952	4.76	2.856
Red LED	LSR976	4(1)	0.271	1.084	0.271
Green LED	2012CGCK	4(3)	0.106	0.424	0.318
Yellow LED	2012SYCK	5(2)	0.199	0.995	0.398
Crystal	16MHz	1(1)	0.77	0.77	0.77
Crystal	32KHz	1(1)	0.77	0.77	0.77
Capacitor	22pF 0603 50V	2(2)	0.0071	0.0142	0.0142
Capacitor	4.7uF 0603 16V	5(2)	0.0382	0.191	0.0764
Capacitor	220uF 2917 16V	1(1)	3.24	3.24	3.24
Capacitor	47pF 0603 16V	1(1)	0.0243	0.0243	0.0243
Capacitor	2.2uF 0805 6.3V	1(1)	0.0752	0.0752	0.0752
Capacitor	10uF 1206 16V	1(1)	0.504	0.504	0.504
Capacitor	100pF 0805 50V	1(1)	0.0382	0.0382	0.0382
Capacitor	10nF 0805 25V	3(2)	0.237	0.711	0.474
Capacitor	100nF 0805 100V	2(2)	0.128	0.256	0.256
Resistor	0805 4.7kΩ	2(2)	0.0305	0.061	0.061
Resistor	0805 200Ω	2(2)	0.0393	0.0786	0.0786
Resistor	0805 1MΩ	1(1)	0.0948	0.0948	0.0948
Resistor	0805 10kΩ	2(2)	0.021	0.042	0.042
Resistor	0805 2.2Ω	3(3)	0.02	0.06	0.06
Resistor	0805 267kΩ	2(2)	0.0121	0.0242	0.0242
Resistor	0805 160kΩ	1(1)	0.013	0.013	0.013
Resistor	0805 100kΩ	2(2)	0.0289	0.0578	0.0578
Resistor	0805 200kΩ	4(4)	0.0289	0.1156	0.1156

Continued on next page

Table A.3 – continued from previous page

Item	**Description**	**Bought items(Used)**	**Cost/unit(€)**	**Bought Cost(€)**	**Used cost(€)**
Resistor	0805 178kΩ	1(1)	0.0719	0.0719	0.0719
Resistor	0805 470kΩ	1(1)	0.0181	0.0181	0.0181
Resistor	0805 340kΩ	1(1)	0.471	0.471	0.471
Resistor	0805 60.4kΩ	1(1)	0.017	0.017	0.017
Resistor	0805 15kΩ	1(1)	0.039	0.039	0.039
Resistor	0805 0.1Ω	1(1)	0.395	0.395	0.395
Resistor	0805 56Ω	1(1)	0.018	0.018	0.018
Resistor	0805 68Ω	2(2)	0.0132	0.0264	0.0264
Resistor	0805 75Ω	1(1)	0.015	0.015	0.015
Inductor	22uH SMD	2(2)	0.26	0.52	0.52
Inductor	10uH SMD	1(1)	0.258	0.258	0.258
DC-DC Converter	Mt3608 board	1(1)	7.66	7.66	7.66
Regulator	ASM1117	2(1)	1.658	3.316	1.658
Sensor Accel+Gyros	MPU6050	1(1)	2.67	2.67	2.67
Sensor Accel+Magn	LSM303DLHC	1(1)	4.76	4.76	4.76
Camera	OV7660	1(1)	4.76	4.76	4.76
GPS	GY-NEOMV2	1(1)	6.76	6.76	6.76
Module Radio	FS1000A	1(1)	1.6	1.6	1.6
Barometer	GY-68	1(1)	1.3	1.3	1.3
MicroSD	MicroSD Adapter	1(1)	3	3	3
Holder	Holder Battery AAA	1(1)	3.2	3.2	3.2
Battery	Type AAA	4(2)	2.10	8.40	4.20
Real Time Clock	Tiny RTC	1(1)	4	4	4
				TOTAL	**62.4075**

A.2 Software

In the following table is shown how the licenses of the software were adquired:

Software	**Owner of the license**	**Cost(€)**
Altium Designer 14.3	GranaSAT	Free (sponsorship)
SolidWorks 2014	GranaSAT	Free (sponsorship)
Microsoft Visio 2013	UGR	Free (DreamSpark)
Microsoft Project 2013	UGR	Free (DreamSpark)
Arduino IDE	Francisco Lázaro	Free license
AtmelStudio 6.2	Francisco Lázaro	Free license
U-Center 8.20	Francisco Lázaro	Free license
TeXnicCenter	Francisco Lázaro	Free license
Miktex	Francisco Lázaro	Free license
SumatraPDF	Francisco Lázaro	Free license
	TOTAL	0

Table A.4 – *Software cost*

A.3 Human Resources

In this project, in every stage, a junior engineer was working for eight months approximately. If we fix the salary for the junior engineer in Spain about 10€/h and senior engineer about 50€/h (proyect supervison), the total salary related to the human resources in every stage is:

	Junior Engineer		**Senior Engineer**	
Stage	**Hours**	**Cost(€)**	**Hours**	**Cost(€)**
Study and evaluation of the system	300	3000	25	2500
System Design	300	3000	25	2500
System Implementation	100	1000	10	1250
Integration, test and validation of the system	100	1000	10	1250
Sum	**800**	**8000**	**70**	**3500**
TOTAL				**11500**

Table A.5 – *Human resources cost*

A.4 Total Project Cost

Adding the cost of all sections (A.1, A.2, A.3) have a total budget:

Section	**Cost(€)**
Electronics costs	102.4075
Software	0
Human Resources	11500
TOTAL	**11602.4075**

Table A.6 – *Final budget*