UNIVERSITAT POLITÈCNICA DE CATALUNYA
BARCELONATECH

L-BAND RADIOMETER FOR A FLEXIBLE MICROWAVE RADIOMETER PAYLOAD

A Degree Thesis

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by

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Abstract

Nowadays the aerospace industry is doing its next step to a new generation of satellites, simplest, smaller and cheaper. The CubeSats are small satellites formed by cube units of 10x10x10 cm^3 and are usually designed to carry devices that have to be tested on space or even scientific payloads.

The NanoSat Lab of the UPC works on these new space platforms. They have developed the ^{3}Cat-1, which it is ready to be launched, and the ^{3}Cat-2, which was already launched. The future projects of this laboratory are the ^{3}Cat-3, in collaboration with the Cartographic and Geologic Institute of Catalonia (ICGC), and the ^{3}Cat-4, the satellite that will carry the payload designed on this thesis.

The ^{3}Cat-4 was born when it comes a call from Fly Your Satellite program from the ESA. This educational program intends to promote the development of CubeSats on the universities, so it selects six universities and it makes the mentoring of the project and also proportionate the launcher.

This thesis intends to design the scientific payload of the ^{3}Cat-4, which will carry two applications of remote sensing and one Automatic Identification System (AIS). The remote sensing applications are a GNSS-Receiver and an L-Band Radiometer. The L-Band Radiometer has the heritage of the work developed on Engineering Advanced Project course (PAE) where the investigations about the implementation of a radiometer on a small platform using a low cost receiver, the RTL-SDR.

Overall, although the main topic of the thesis is the radiometry, the project will be specially focused on the developing of the three experiments integrated on the same payload.

Resum

Actualment la indústria aeroespacial està donant el seu proper pas cap a una generació de satèl·lits més senzills, més petits i més barats. Els CubeSats són petits satèl·lits formats per unitats cúbiques de 10x10x10 cm^3, i normalment estan dissenyats per dur aparells que han de ser testejats al espai o inclús càrregues útils científiques.

Al NanoSat Lab de la UPC es treballa en aquest nou tipus de plataformes espacials. Han desenvolupat el ^{3}Cat-1, que ja està llest per enviar al espai, i el ^{3}Cat-2, que ja es va enviar al espai. Els pròxims projectes que es duran a terme són el ^{3}Cat-3, en col·laboració amb l'Institut Cartogràfic i Geològic de Catalunya (ICGC), i el ^{3}Cat-4, el satèl·lit que portarà la càrrega útil dissenyada en aquest treball.

El ^{3}Cat-4 va néixer quan va arribar la proposta del programa Fly Your Satellite de la ESA. Aquest programa educatiu té com a objectiu promoure el desenvolupament de CubeSats a les universitats, per això selecciona a sis participants i els guia durant el procés i a més proporciona el llançador.

Aquest treball té com a objectiu dissenyar la càrrega útil del ^{3}Cat-4, la qual portarà dos aplicacions de teledetecció i un Sistema d'Identificació Automàtic (AIS). Les aplicacions de teledetecció són un receptor GNSS i un radiòmetre en banda L. El radiòmetre en banda L hereta la feina feta durant el curs de Projecte Avançat d'Enginyeria (PAE), en la que es van dur a terme investigacions sobre la implementació d'un radiòmetre en una plataforma petita i de baix cost, el RTL-SDR.

En general, encara que el tòpic principal d'aquest treball sigui la radiometria, el projecte estarà especialment centrat en el desenvolupament dels tres experiments integrats a la mateixa càrrega útil.

Resumen

Actualmente la industria aeroespacial está dando el próximo paso hacia una generación de satélites más sencillos, más pequeños y más baratos. Los CubeSats son pequeños satélites formados por unidades cúbicas de 10x10x10 cm^3, y normalmente están diseñados para llevar aparatos que tiene que ser testeados en el espacio o incluso cargas útiles científicas.

En el NanoSat Lab de la UPC se trabaja en este nuevo tipo de plataformas espaciales. Han desarrollado el ^{3}Cat-1, que ya está listo para ser enviado al espacio, y el ^{3}Cat-2, que ya se envió al espació. Los próximos proyectos que se llevaran a cabo són el ^{3}Cat-3, en colaboración con el Instituto Cartográfico y Geológico de Catalunya (ICGC), y el ^{3}Cat-4, el satélite que llevará la carga útil diseñada en este trabajo.

El ^{3}Cat-4 nació cuando llegó la propuesta del programa Fly Your Satellite de la ESA. Este programa educativo tiene como objetico promover el desarrollo de CubeSats a las universidades, por ese motivo seleccionan a seis participantes y los guía durante el proceso además de proporcional el lanzador.

Este trabajo tiene como objetico diseñar la carga útil del ^{3}Cat-4, la cual llevará dos aplicaciones de teledetección y un Sistema de Identificación Automático (AIS). Las aplicaciones de teledetección son un receptor GNSS y un radiómetro en banda L. El radiómetro hereda el trabajo realizado durante el curso de Proyecto Avanzado de Ingeniería (PAE), en el que se llevaron a cabo investigaciones sobre la implementación de un radiómetro en una plataforma pequeña y de bajo coste, el RTL-SDR.

En general, aún que el tópico principal de este trabajo sea la radiometría, el proyecto estará especialmente enfocado en el desarrollo de los tres experimentos integrados en la misma carga útil.

Vull dedicar aquest treball al Avi Carles, que sempre va estar molt orgullós dels meus estudis i de la meva feina, i al Iaio Josep, que em va encomanar el seu esperit "enginyeril" de ben petit convertint-me anys més tard en un enginyer. Aquest treball de fi de grau és un petit homenatge. Us estimo molt.

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I would like to thank all of his support to Ricard Castellà, because of the things that I have learned from him from the more theoretical to the simplest hardware tricks and for all of the hours that he have spent with me on the D3 giving me advices or simply giving me support when nothing seemed to work. Thanks partner, I owe you some "E-things".

Arnau Solanellas and Pol Via have been a key piece of this project. They have transmitted to me a lot of knowledge and they have given to me any advice every time I have requested. I have grown a lot as an engineer learning things that are not taught on university courses, and maybe I will not ever learned, and that is because of you, thanks.

I would like to thank to Juan Fran Muñoz for his advices and his predisposition to help whenever I needed it. Noemí Miguélez has been a fundamental part of this thesis for two reasons: this thesis will not exist without her previous studies on RTL-SDR possibilities, and the software that she developed to test the three experiments of the Conditioning Board. She has spent so many hours and she has had a lot of patience while taking measurements many times and including going to the Port of Barcelona by motorbike, thanks for everything.

I have learned a lot about the methods and procedures of an ESA project by the Project Leader of the ^{3}Cat-4, Joan Adrià Ruiz. Thank you for all the support, patience and advices.

Although this project have been carried at UPC, my work partners of Tryo Aerospace have been an important part of this project by giving advices and suggestions, and specially for being comprehensive during all this period, thanks to all.

My family and friends have been an unconditional and unbreakable support. It have been a hard time full of work and personal difficult moments. They have been here helping me with everything that they have, thank you so much.

Finally I would like to thank to my tutor Adriano Camps for giving me the opportunity to work on an interesting thesis and converting it to the payload of the ^{3}Cat-4 on the Fly Your Satellite call from the ESA. Thanks for this opportunity.

This thesis have not been easy, and if now it is working although the one thousand problems that had at the first moments it is thanks to your support.

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1. Introduction

1.1. Project Background

This project has been developed at the Nanosat Lab of the UPC [1]. In this laboratory different graduated and ungraduated students work on space applications designed for small CubeSat satellites (one CubeSat unit is 10x10x10 cm^3).

The students of this laboratory have developed two nanosatellites so far. The first one is the ^{3}Cat-1 (1-unit CubeSat), the first satellite developed in Catalonia that tests an experimental solar cells (“Cellsats”) developed at the Electronic Engineering Department of UPC and a low-resolution CMOS camera; the second one is the ^{3}CAT-2 (6-units CubeSat) which carries the “PYCARO” as the main payload, a dual-band and dual-polarization reflectometer developed at Remote Sensing Lab and NanoSat Lab of UPC. Now they are working on the ^{3}Cat-3 in collaboration with the Cartographic and Geologic Institute of Catalonia (ICGC).

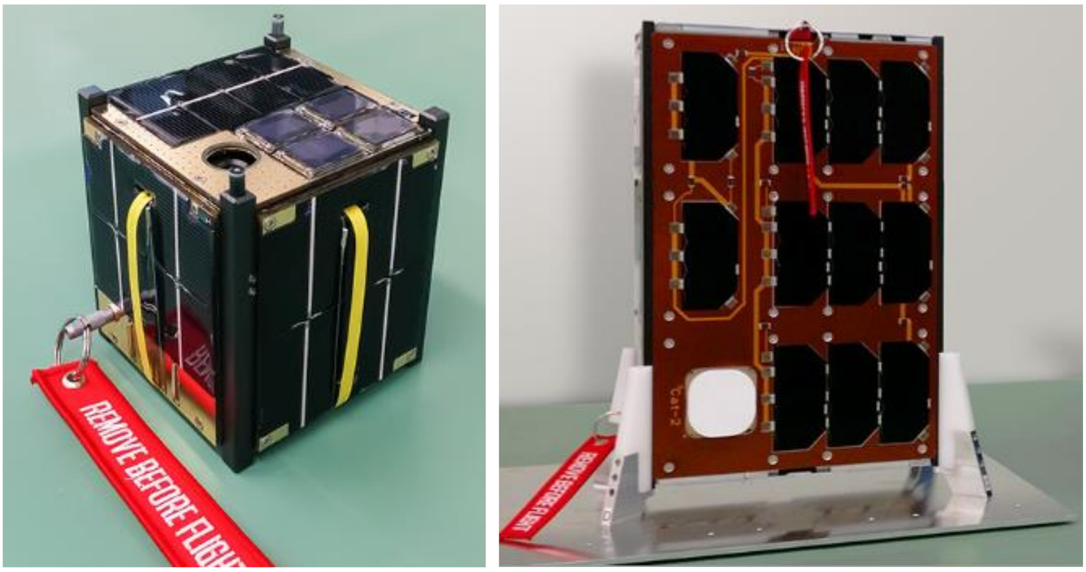


Figure 1-1: (Left) 3Cat-1, (Right) 3Cat-2

At the beginning of this project, as an answer to the call from the European Space Agency (ESA) for the “Fly your satellite” space program, the ^{3}Cat-4 project was conceived as a 1-unit CubeSat with a functions similar to the ^{3}Cat-2. The scientific payload of this satellite will contain a GNSS-Reflectometer, an Automatic Identification System (AIS) and a L-band radiometer. The challenge of this payload is to be developed on a small and simplified board using the studies of Noemí Miguélez Gómez about the use of the RTL-SDR for passive microwave space payloads.

This project has the heritage payloads of the work done in *Advanced Engineering Project (PAE)* course. In this course a payload containing a L-band radiometer was developed using the RTL-SDR technology and the correspondent signal processing on GNURadio platform.

The Radiometer was implemented using two synchronized RTL-SDR that receive the same signal, but phased 180º from each other, and then by using the signal processing on GNURadio was implemented the Radiometer. This typology had some performing problems due to the Automatic Gain Control (AGC) of the RTL-SDR, which at this moment it was not possible to be disabled, and the lack of synchronization of the two devices.

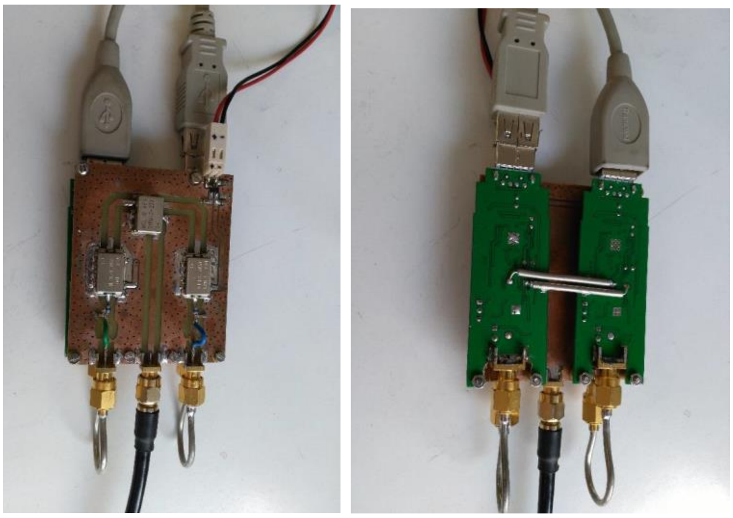


Figure 1-2: (Left) Top Layer, (Right) Bottom Layer

Therefore, due to the previous work during the PAE course and the [3]Cat-4, decisions, in this Degree Thesis there is a need to redesign the L-band Radiometer in a more simplified way with less power consumption and less space and adding also to the same board the AIS and GNSS-R experiments sharing resources in the more optimized way.

1.2. Goals

The project target of this project is the design and implementation of an L-band Radiometer at 1.413 GHz, based on a low-cost software defined radio (SDR), for a flexible microwave payload. Based on this, the goals defined for this Degree Thesis are:

- To find a small, low power consumption and efficient solution to develop the AIS, GNSS-R and Radiometer experiments in a single board.
- To understand an existing design of an OBC expansion board, and replicate it by using and adapting only the necessary parts.

To achieve these objectives, it was necessary to acquire the following knowledge:

- To learn how to route complex Printed Circuit Boards (PCB) of four layers by following design restrictions about placement, RF lines and differential pair lines routing.
- To learn how to weld complex Surface Mount Devices (SMD) components with small and Quad-Flat No-leads (QFN) packages by using different welding techniques.
- To test the payload by using setups that include Vector Network Analyser (VNA), Spectrum Analyser, Noise Figure Meter, Oscilloscope, Signal Generator and voltage sources.

2. State of the art

2.1. GNSS-R

Global Navigation Satellite System Receivers is a passive remote sensing method based on the reception of Global Positioning System (GPS), Global'naya Navigatsionnaya Sputnikovaya Sistema (GLONASS), Galileo and Beidou signals. The performance of this method consists on the comparison between the direct signal received and the reflected on Earth's surface received signal. That remote sensing method needs a large constellation of satellites permanently transmitting signals to the Earth that can be reused.

The emitted signals from the satellites are centred at L-Band, and the recollected data can be used in two different remote sensing purposes.

- **Altimetry:** Measurement of the altitude of a target. By using the time delay from the directed and the reflected signals, the altitude of the target can be deduced. This measurement can also be used to determine the sea state.
- **Reflectometry:** The GNSS Receiver can be interpreted as a bi-static radar, where the transmitter is each satellite of the navigation constellation and the receiver is a single receiver. The main difference with a traditional bi-static radar is that instead of using a dedicated transmitter, it uses Signals of Oportunity (SoOp).

The difference that this thesis intends to make, is to implement a GNSS Receiver on a CubeSat platform by using a low cost and size reduced receiver, the RTL-SDR.

2.2. AIS

The Automatic Identification System is an automatic tracking system orientated to the ships and Vessel Traffic Services (VTS). By sharing periodically data with nearby ships and AIS base stations, they can be automatically tracked.

The implementation of this tracking system using Low Earth Orbit (LEO) satellites consists on the receiving of all vessel's signals, demodulating, decoding and storing on the orbiting satellite and then download to the ground station.

The marine communications' band is the Very High Frequencies (VHF), and the channels assigned for AIS systems' are: AIS-1 (161.975 MHz) and AIS-2 (162.025 MHz).

The difference that this thesis intends to make, is to implement an AIS tracking system on a CubeSat platform by using a low cost and size reduced receiver, the RTL-SDR.

2.3. L-band Radiometer

The Radiometer is a microwave remote sensing passive method that studies the noise temperature of the targets. It has multiple applications depending on the frequency band of study, in the case of the L-Band it is used to measure soil moisture and ocean salinity (e.g. SMOS Mission).

There are various typologies of Radiometer and the one that is implemented is the Total Power Radiometer (TPR). This topology fundamentally consists on an amplifier chain, a square law detector and a low pass filter. Basically it amplifies the power level of the received signal, which because it is noise, it is low, and then a power detector of the received signal.

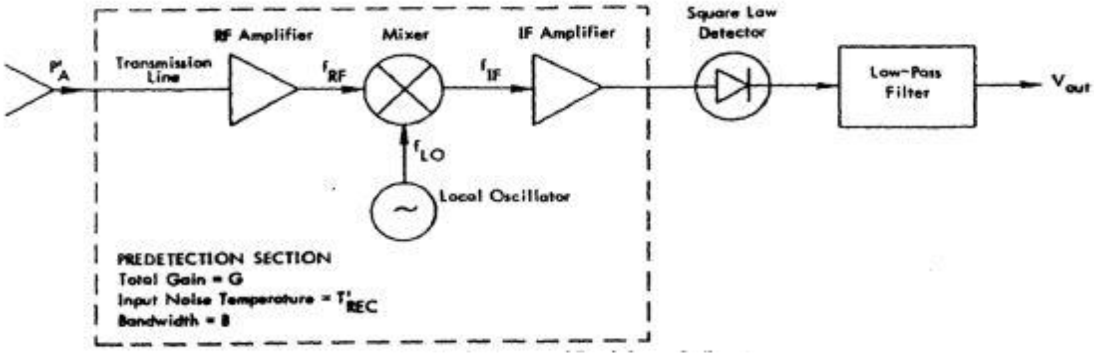


Figure 2-1: Total Power Radiometer block diagram [6]

There are two main parameters on a Radiometer, the radiometer output voltage (V_{out}) and the Radiometric Sensitivity (ΔT), which represents the minimum variation of the measured temperature that the Radiometer is able to detect. For the TPR the expressions are the following:

$$Vout = G(Ta + Trec) \, , \tag{1}$$

and

$$\Delta T = \frac{Ta+Trec}{\sqrt{B\tau}} \, , \tag{2}$$

where G is a radiometer constant, T_a is the equivalent antenna temperature, T_{rec} is the physical temperature of the receiver, B is the receiver's noise bandwidth and τ is the integration tine.

The TPR is one of the simplest topologies and instead of its good performing it have an important limitation, the gain fluctuations. So on the design of a TPR it has to be taken into account that aspect in order to correctly implement the dispositive.

3. Methodology / Project development

3.1. 3Cat-4 Payload

The ^{3}Cat-4 payload is composed by two boards that are assembled together before the integration of the subsystem into the spacecraft structure. The two boards are the Payload Acquisition Board (or motherboard) and the Payload Conditioning Board (or RF daughterboard) which will be located upper the Acquisition Board on an intermediate sublevel between this board and the next level of the satellite structure. Appendix M shows the CAD renders of the ^{3}Cat-4.

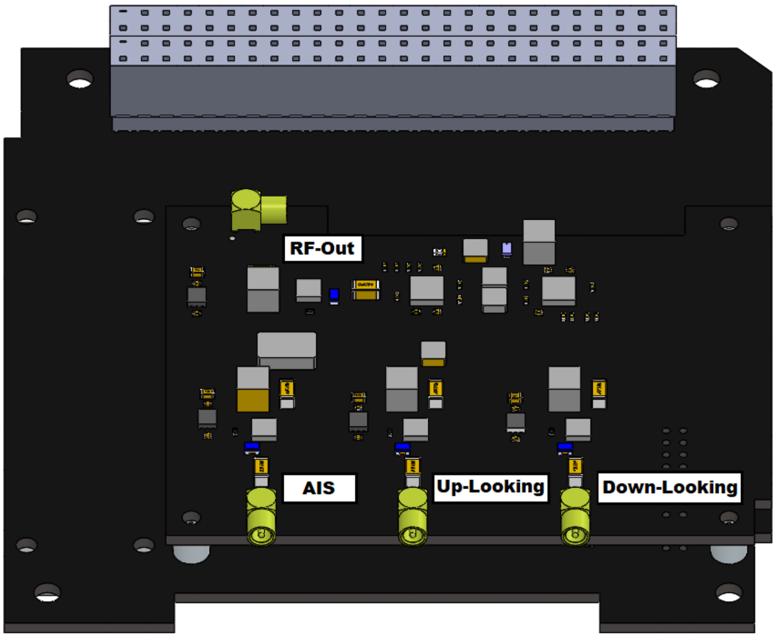


Figure 3-1: Render of the complete Payload. (Top) Conditioning Board, (Bottom) Acquisition Board

3.2. Conditioning Board

3.2.1. System Design

The Conditioning Board contains three RF experiments which are: an L-band GNSS-R, an AIS for vessels and an L-band radiometer. There are three RF inputs:

AIS port: Signal received from the AIS antenna located at the top of the satellite. It is centred at approximately 161 MHz. This RF port contains the AIS messages from the marine communications. It is used for the AIS experiment.

Up-Looking port: Signal received from the L1 GPS antenna located at the top of the satellite. It is centred at approximately 1575 MHz. This RF port contains the direct signal from the GPS satellites. It is used for the GNSS-R experiment.

Down-Looking port: Signal received from the wideband helix antenna located at the bottom of the satellite. Inside the span of this RF signal there are contained three important signals: the reflected signal at L1 band (1575 MHz), the reflected signal at L2 band (1227 MHz) and the Radiometer signal (1420 MHz). It is used for GNSS-R and Radiometer experiments.

The board only has one output that is connected to the RTL-SDR, so the signal from the three RF inputs is combined in the following way:

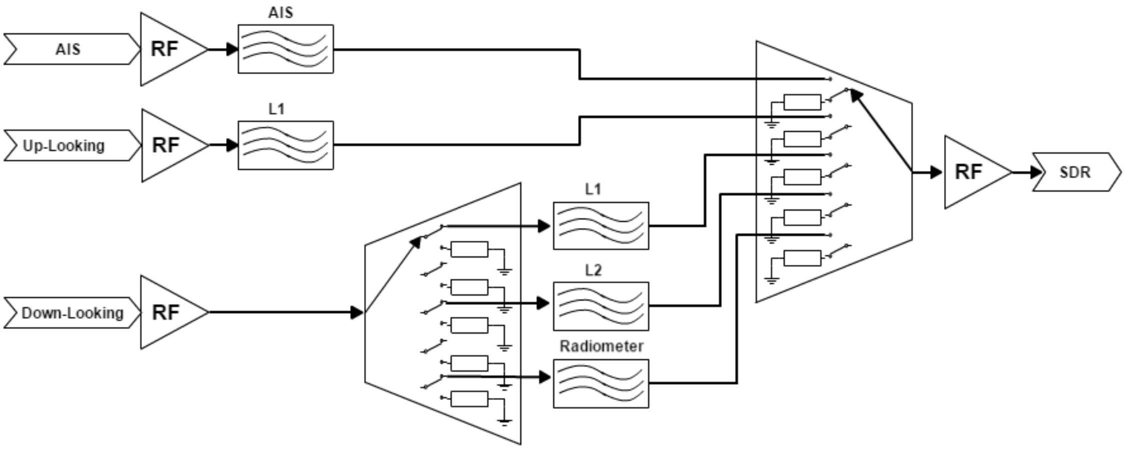


Figure 3-2: Conditioning Board block diagram

The signal from each input port is previously amplified and filtered, but in the case of the Down-Looking port there is a previous stage between the amplifying and the filtering parts where the signal is split into three parts by using a switch and then is filtered on each channel for each application. Once every signal is amplified and filtered, another switch drives one signal at a time to the RTL-SDR. Appendix F shows the main components selected to implement the block diagram and Appendix D shows the complete schematic.

The use of the switch makes it possible to use each experiment individually and sequentially enable the operation of the experiment, while disabling the others. All control signals are independent, so the switches can be configured independently and only the required Low Noise Amplifiers (LNA) can be enabled (for each experiment only two LNA's will be enabled), thus minimizing power consumption. With this configuration the power consumption of the Conditioning board will be ≈ **200 mW**.

Table 3-1: Conditioning Board power budget

Signal Type	*V nominal*	*I nominal*	*P nominal*
Control signals	1.8 V	54 uA	97.2 uW
Power supply	3.3 V	60 mA	198 mW
TOTAL			**198,01 mW**

The board design fulfils the ^{3}Cat-4 requirements document (Appendix B). Appendix G shows the complete list of the control signals used in the board.

Finally, a prototype of the switch circuit (a critical element of the design) was implemented to individually test its performance and learn about the device. The design consists of a simple board with five RF input ports and one RF output port, there is also a debug port with a picoblade connector where the control signals of the switch are introduced.

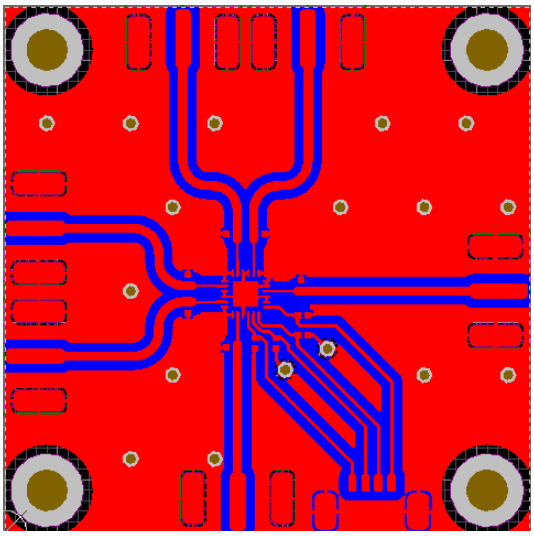


Figure 3-3: Layout of the prototype of the five ports switch

3.2.2. Placement & Routing

The Conditioning Board contains RF signals, so some special design restrictions have to be taken into account. There have to be a layer reserved for RF lines and a layer below it reserved for ground plane. It has been selected the number of layers (in this case four) with two criteria.

- The board has enough control signals to make unfeasible the use of only two layers without interfering the RF lines.
- As a general design constraint, the PCB Thickness has to be 1.6 mm. That represents a routing problem because the necessary width to have the RF line matched at 50 Ω is large (3 mm), so instead of using a substrate height of 1.6 mm, a substrate height of 0.2 mm is used which has a matched RF line width of 0.33 mm. That is possible by using the top layer of the PCB and to locate the ground plane in the first internal layer which has this substrate height.

The Conditioning Board is compliant with the [3]*Cat-4-UPC-DOC-Design_Specification_v1* document.

Table 3-2: Layer Stack Parameters of the Conditioning Board

PCB Thickness	***Copper Thickness***	***Solder Mask Colour***	***Dielectric***	***Surface Finish***
1.6 mm	35um for external layers, 17um for internal layers	Black	FR-4	Lead-Tin

Table 3-3: PCB layers information of the Conditioning Board

Layer	***Signals***	***Components***
Top Layer	RF signals	Allowed
Internal Layer 1	Dedicated RF ground plane	-
Internal Layer 2	Control signals	-
Bottom Layer	Power supply and control signals	Not Allowed

The three RF input connectors have to be at the -Y edge of the board and the RF output connector is located at the +Y edge, but rotated 90º respect the edge of the board. In that direction there is a notch in the PCB that allows to drive the RF cable from the output connector to the input of the RTL-SDR, which it is located under the Conditioning Board. At the -Y, -X corner there is a board-to-board stackable connector (16 pins, 2 rows) that receives the power supply and control signals which are generated by the Acquisition Board (Appendix F). Figure 3.4 shows the position of the input RF connectors position and the RF output connector position aligned 90º from the input connector of the RTL.

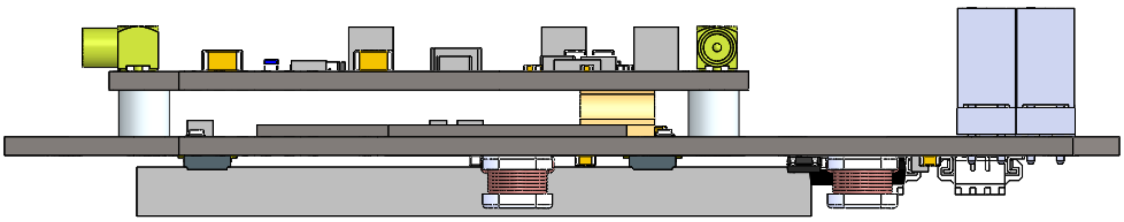


Figure 3-4: Side view of the complete assembled payload

The RF lines have been routed in the more possible straight way and the line bends have been defined by curvatures with a radius equivalent to three times the line width [2]. The complete PCB layout is on Appendix H.

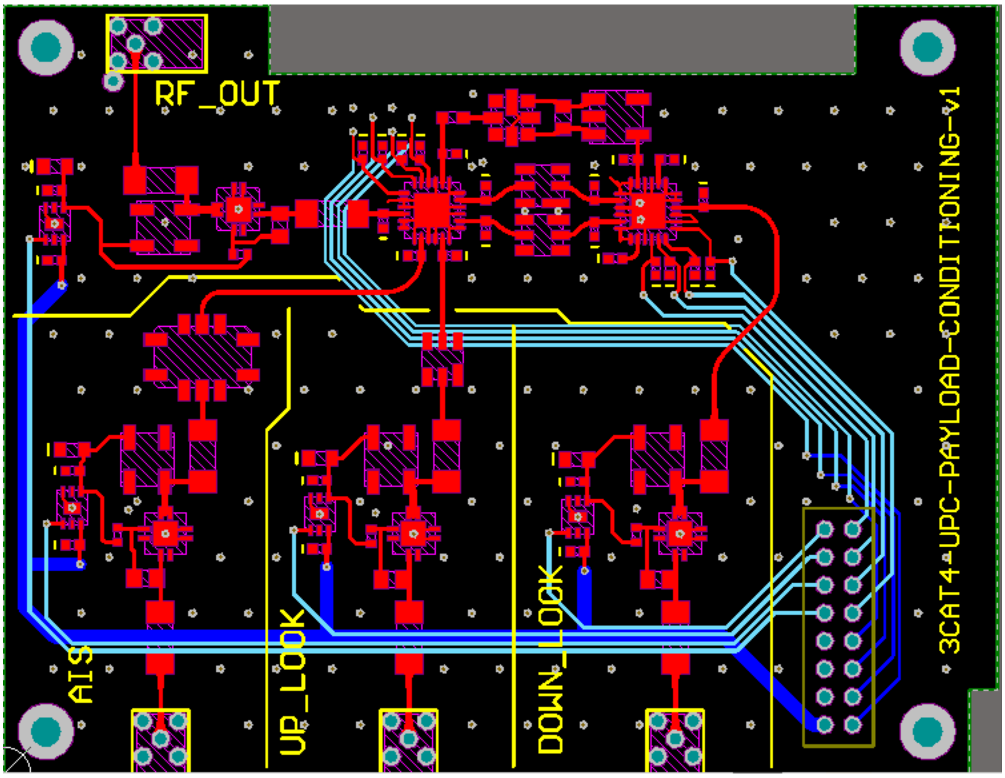


Figure 3-5: Conditioning Board Layout (without ground planes)

3.2.3. Assembly & Test

The Conditioning Board has some components with QFN packages, so the following details have to be taken care of during the welding process. Because of the characteristics of the packages and the available material of the university, the better way to weld the QFN components is using Hot Air (Appendix N). With this procedure it is really important to weld that type of packages firstly and the bigger ones before the smaller ones. That order is necessary because while using hot air the previously welded components can be un-welded because of the heat and even can be thrown away if they are small enough because of the air flow.

The board needs to be power supplied and it also needs the control signals of the two switches and the enables of the Low Dropout Regulators (LDO). The signals come from the Acquisition Board through the 16 pins stackable board to board connector, so in order to test independently the board, a group of test cables have to be used.

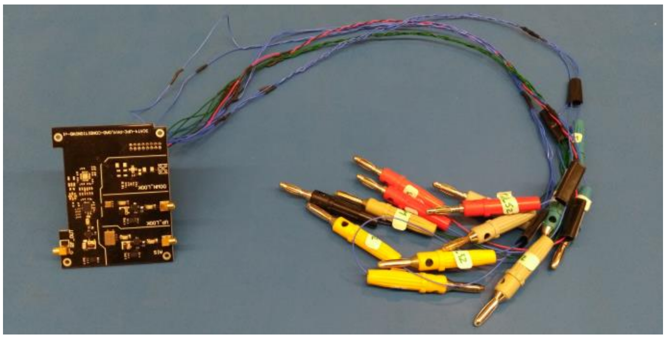


Figure 3-6: Test cables connected to the Conditioning Board by a removable connector

The board is supplied at two different voltages (3.3 V & 1.8 V), so two independent power suppliers are required. There are two groups: the ones that will be connected all the time and the ones that will be connected temporally. In the first group there is the main power supply of the LNA (3,3 V), and the supply ports of the switches, then in the second group there are the control ports of the switches, and the enables of the LDOs that supply the LNAs. Because of datasheet specifications the control ports of the switches cannot be all turned off, so in case of disabling all the control ports have to be pushed up.

The tests, that been designed in order to check the performance requirements of the board are listed below:

Table 3-4: Test plan of the Conditioning Board

Test	*Material*	*Description*
Stability Vd	Power Source	Vary the input voltage of 3.3 V and check that the output is fixed at 3 V.
LNA polarization	Power Source	The LNA must have a current consumption of 0 mA when the LDO is not enabled and 30 mA when it is enabled.
RF Gain	VNA & Power Source	Measure the Gain of each RF chain and validate it with the Line-Up.
Noise Figure	Noise Figure Meter & Power Source	Measure the Noise Figure of each RF chain and validate it with the Line-Up.
Isolation	VNA & Power Source	Measure the S parameters when the Switch is blocking the signal

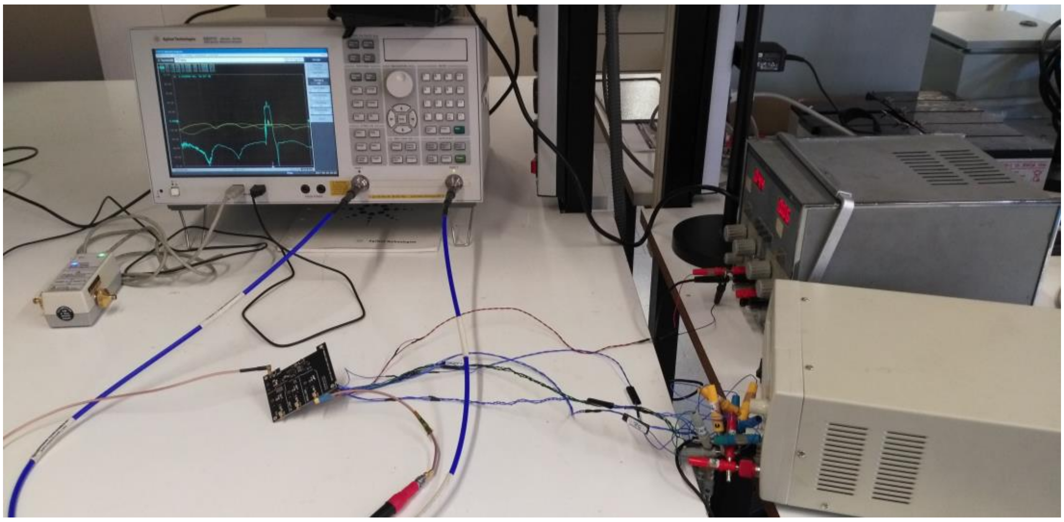


Figure 3-7: Partial Conditioning board’s setup

3.3. Acquisition Board

3.3.1. System Design

The acquisition board contains two devices, the Overo Ironstorm-P [3], and the RTL-SDR NooElec NESDR Nano 2+ [4], and it also contains the Tobi expansion board for Overo [5], but instead of using the original expansion board, it has been analysed, and have been replicated only the necessary parts for the Overo functions that are needed on the 3Cat-4. The parts included in the model are:

- DC/DC converter that regulates the 5 V from the satellite general power supply and converts it to the 3.3 V for Overo power supply.
- DC/DC converter that regulates the 5 V from the satellite general power supply and converts it to the 3.3 V for the Conditioning Board power supply.
- LDO converter that regulates the 3.3 V from the Overo power supply to 1.8 V for the Conditioning Board power supply.
- USB connection circuit for the connectivity with the NooElec.
- Two level shifters that shift up from 1.8 V to 3.3 V the UART ports of the Overo (the external debug port and the internal of the satellite).

In Figure 3.8 there is a block diagram that shows the structure and the connection between the elements of the Acquisition Board.

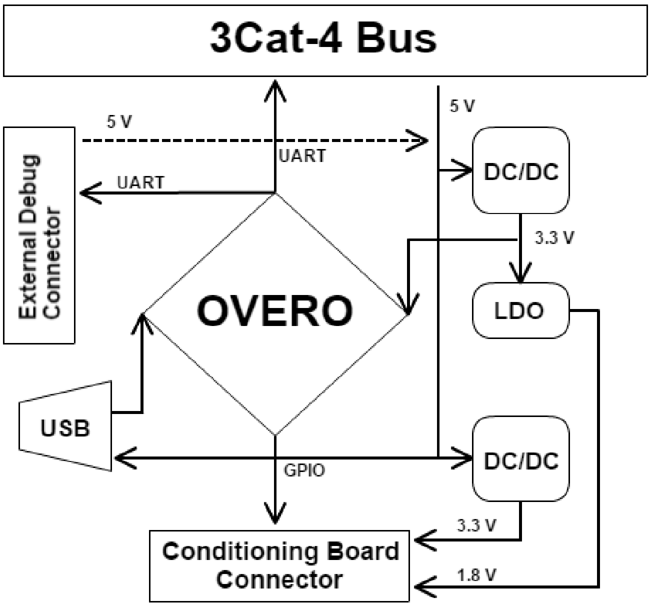


Figure 3-8: Acquisition Board block diagram

3.3.2. Placement & Routing

The Acquisition Board has four layers and it is compliant with the *3Cat-4-UPC-DOC-Design_Specification_v1* document.

Table 3-5: Layer Stack Parameters

PCB Thickness	*Copper Thickness*	*Solder Mask Colour*	*Dielectric*	*Surface Finish*
1.6 mm	35um for external layers, 17um for internal layers	Black	FR-4	Lead-Tin

Table 3-6: PCB layers information

Layer	*Signals*	*Components*
Top Layer	USB differential pair and UART	Allowed below 5 mm height
Internal Layer 1	Dedicated USB circuit ground plane	-
Internal Layer 2	Power supply, control signals and UART	-
Bottom Layer	Power supply, control signals and UART	Allowed on the +X, -X of the board

Although this board has a lot more space than the Conditioning Board (one full CubeSat layer), it has a lot of placement restrictions due to the integration into the satellite. The main ones are:

- The RTL-SDR is attached on the -X edge of the Conditioning Board into a dedicated hole (Figure 3.12).
- On the top layer there are attached two magnetorquers on the +X and +Y edges, so only components under the Conditioning Board are allowed, so the maximum component height must be 5 mm (gap between the two boards).
- Once integrated in the satellite structure, the board is really close to the battery pack of the satellite which is located at the centre of the board. So, on the bottom layer of the board the components are allowed only on the +X, -X edges.
- The debug connectors and the Overo connectors have to be located on the +X edge for satellite structure requirements.

Appendix M shows the renders of the satellite where the commented design restrictions are appreciated.

For the routing criteria, there have been two important aspects that have been taken into account during the design. The first one is the USB differential pair, which has been routed following the recommended design criteria for this type of lines and it has been equalized in order to correct the net length differences on the corners and finally it has been placed a complete ground plane layer below. The second one is the line width of the power supply lines which have been assigned to 1 mm in order to prevent considerable voltage falls in the line. The calculation was carried out with the *Saturn PCB Toolkit* [8] software and by iterating about the obtained values, the permitted voltage falls and the available space in the board, the line width was fixed.

Table 3-7: Expected maximum voltage falls

Line	***I max***	***Voltage fall max (200 mm net length)***
NooElec power supply	0,5 A	0,051 V
Conditioning Board power supply	0,08 A	0,082 V
Overo Ironstorm-P power supply	1 A	0,102 V

Finally, in the case of the DC/DC circuit, it has been taken into account an aspect of the IC datasheet which specifies that the DC/DC circuit have two isolated grounds that are connected in a single point.

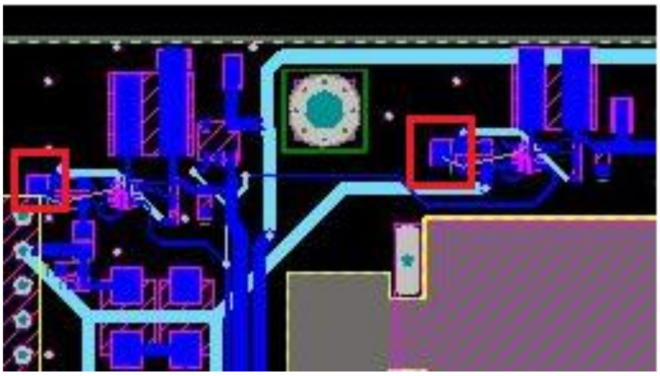


Figure 3-9: Single point ground matching of the DC/DC

Figure 3.10 shows the layout of the Acquisition Board and Appendix I contains the complete PCB layout.

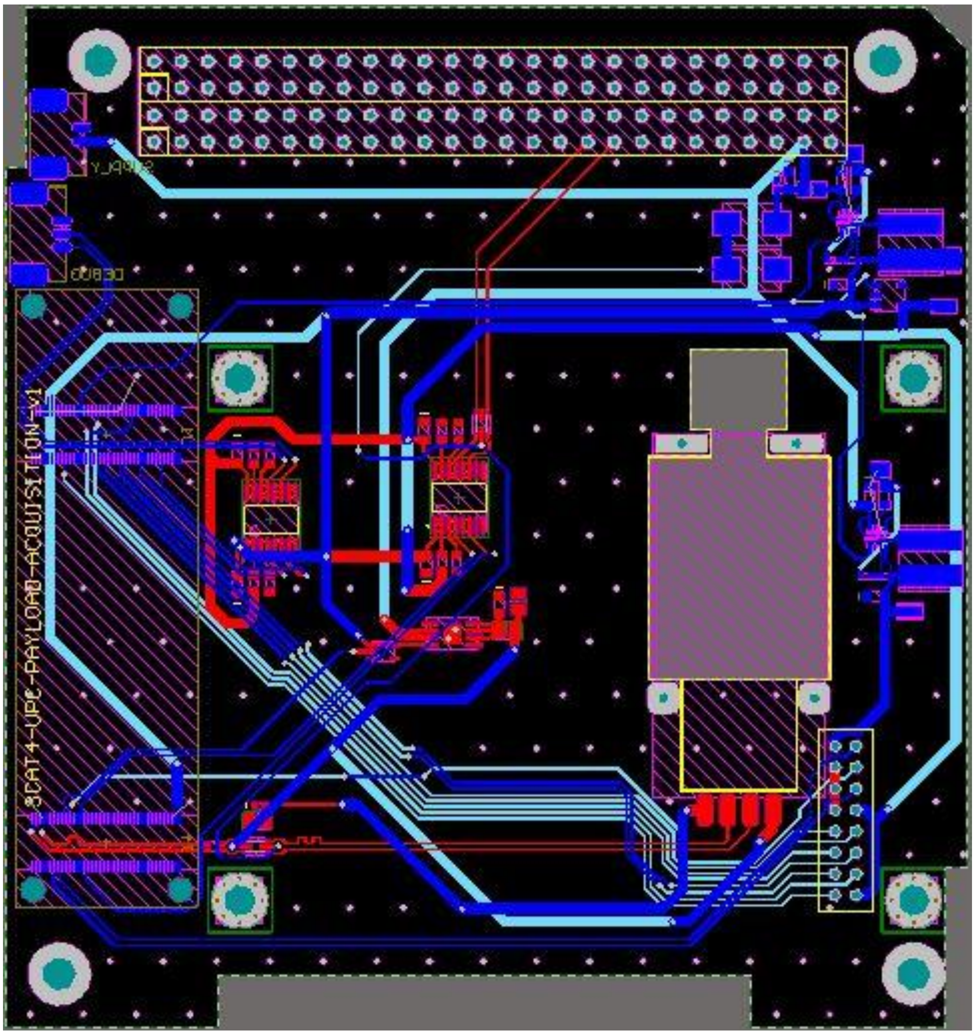


Figure 3-10: Acquisition Board Layout (without ground planes)

Finally, because of the lack of experience on USB differential pairs routing, it have been done a prototype of the RTL-SDR USB’s circuit in order to test the possibility to undo a USB connector (in this case the one from the NooEelec), and then route it through a PCB Board and restore the signal on the other part. The PCB Layout is shown below:

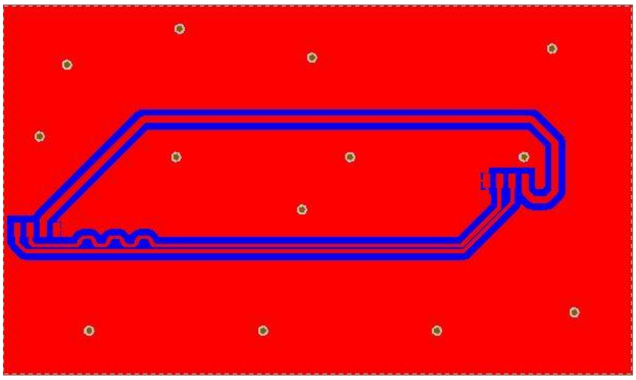


Figure 3-11: Layout of the USB’s circuit prototype

3.3.3. Assembly & Test

The Acquisition board has also QFN packages, so the same considerations apply to the use of Hot Air. Apart from the QFN packages there is another critical element, the Overo connectors have a 0.4 mm pitch. In order to correctly assemble these connectors, one connector have been welded firstly in the oven, and then it has been attached to the Overo, by the two connectors, in order to ensure the correct alignment between them, and the second connector have been welded pin by pin with the soldering iron. Finally the RTL has been attached to the board by tin bridges and the connection of the USB to the correspondent pads have been done by wires.

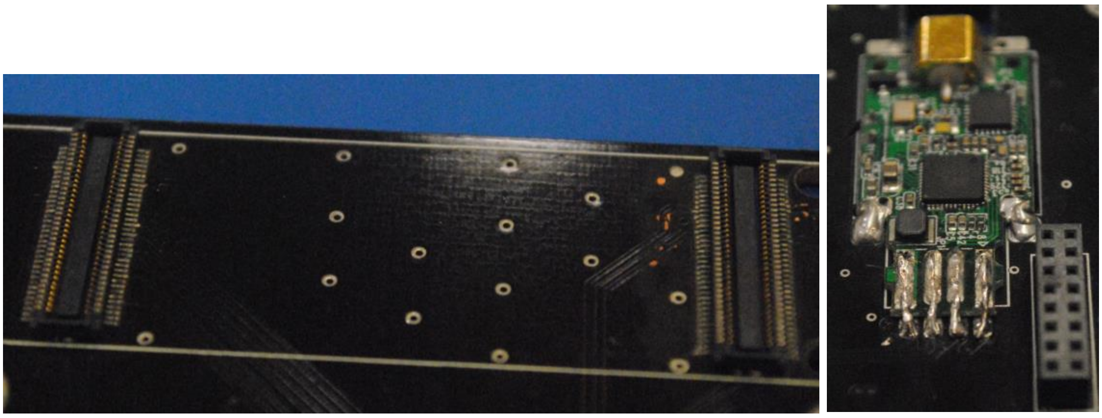


Figure 3-12: (Left) Overo connectors, (Right) NooElec assembled on the Acquisition board

The board is supplied only at +5 V coming from the satellite bus, but in order to debug externally it has a picoblade external connector on the +X edge of the board. For the same reason, there is a picoblade external connector on the +X edge of the board dedicated to export a debug UART.

The tests that have to be designed in order to check the performance requirements of the board are listed below:

Table 3-8: Test plan of the Acquisition Board

Test	***Material***	***Description***
Stability Vout	Power Source	Vary the input voltage of 5 V and check that the output is fixed at 3.3 V on the two DC/DC.
Levels shifted	Power Source	Introduce an external signal of 1.8 V to the level shifters and check that the signal is shifted to 3.3 V
NooElec	-	Check the correct connectivity of the RTL-SDR
Overo	-	Check the correct connectivity of the Overo

4. Results

4.1. Prototypes

4.1.1. Five ports switch prototype

The switch prototype have been used to learn about the polarization characteristics of the dispositive by testing individually. There are two main lessons that have been extracted from this testing.

- Because of an error during the design of the switch circuit, the RF lines had decoupling capacitors, so the signal was being blocked. After discovering that, the modification was included in the Conditioning Board.
- Although there is not any internal connection, if any RF port is short-circuited then all RF ports become short-circuited. For design reasons, there is one port that has a transformer that, by definition, is short-circuiting the port, so firstly a hard connection from GND to RF was done in order to check the theory of all ports short-circuited, and then in order to try to solve this problem it was placed a capacitor cutting the RF line in order to avoid short-circuiting on DC. Finally it was measured with the VNA this approach and it works, so the same modification on the RF lines was included in the Conditioning Board.

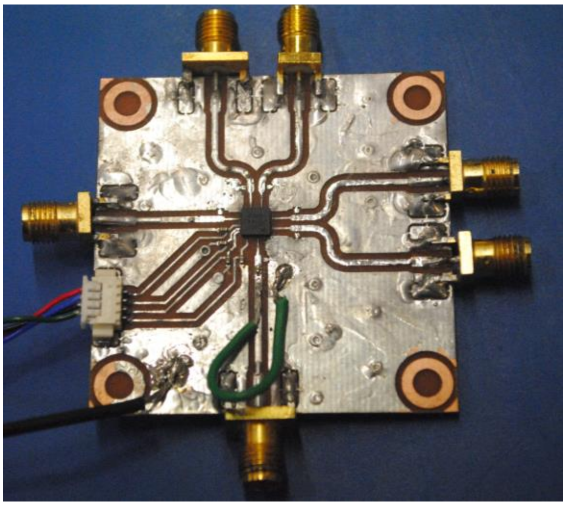


Figure 4-1: Five ports switch prototype

4.1.2. USB differential pair prototype

A RTL-SDR was used to test that is possible to undo a USB connector and route it through a PCB and take the signal with an USB cable on the other extreme of the board. The test was successful, the laptop was able to detect the connected RTL and then by the SDRSharp software was received and correctly demodulated the FM radio.

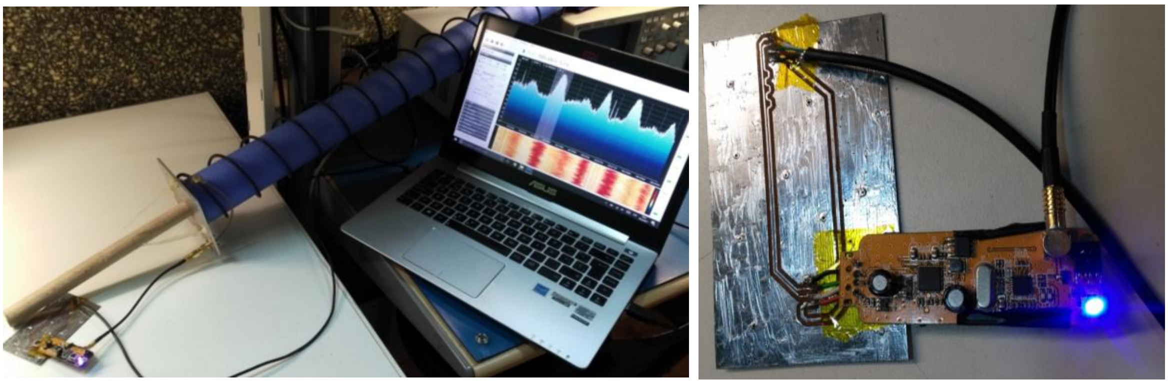


Figure 4-2: (Left) Test setup using an Helix antenna, (Right) RTL-SDR prototype

4.2. Conditioning Board test validation

During the validation process of the Conditioning Board, the tests listed in chapter 3 have been performed:

Stability Vd: The four LDO have a non-variant output fixed at +3 V without ripple.

LNA polarization: The four LNA are correctly polarized at Idrain = 30 mA.

RF Gain: The RF gain has been measured with the Vector Network Analyzer. Figure 4.3 shows in a common graph the obtained values of S21 parameter. On Appendix K there is the full S-Parameters graphs of every RF chain.

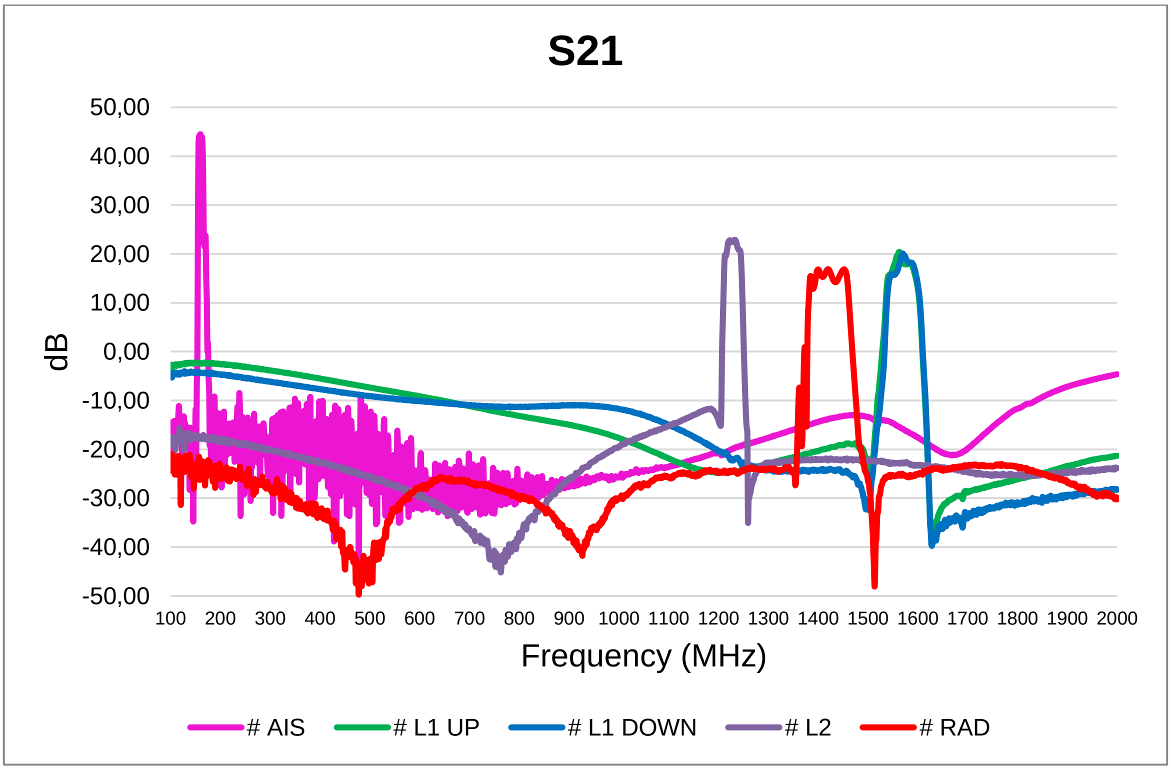


Figure 4-3: S21 of each RF chain with the switch configured

Table 4-1: Theoretical Gain vs Measured Gain

RF Chain	*Theoretical Gain*	*Measured Gain*
AIS	43.20 dB	43.74 dB
L1 Up-Looking	27.72 dB	18.04 dB
L1 Down-Looking	26.92 dB	19.34 dB
L2	30.44 dB	22.47 dB
Radiometer	25.70 dB	16.98 dB

There have not been enough time to work more on the Conditioning Board, so the gain differences have not been corrected. In Chapter 6.2 Future Approach, the approximations and simulations are commented and the planned future approach to solve the gain problem.

Noise Figure: The Noise Figure has been measured with the Noise Figure Meter. Because of the frequency range limitations of the available Noise Figure Meter on the university, the measurement of the L1 band cannot be done. The results of the measurements can be seen on the following images.

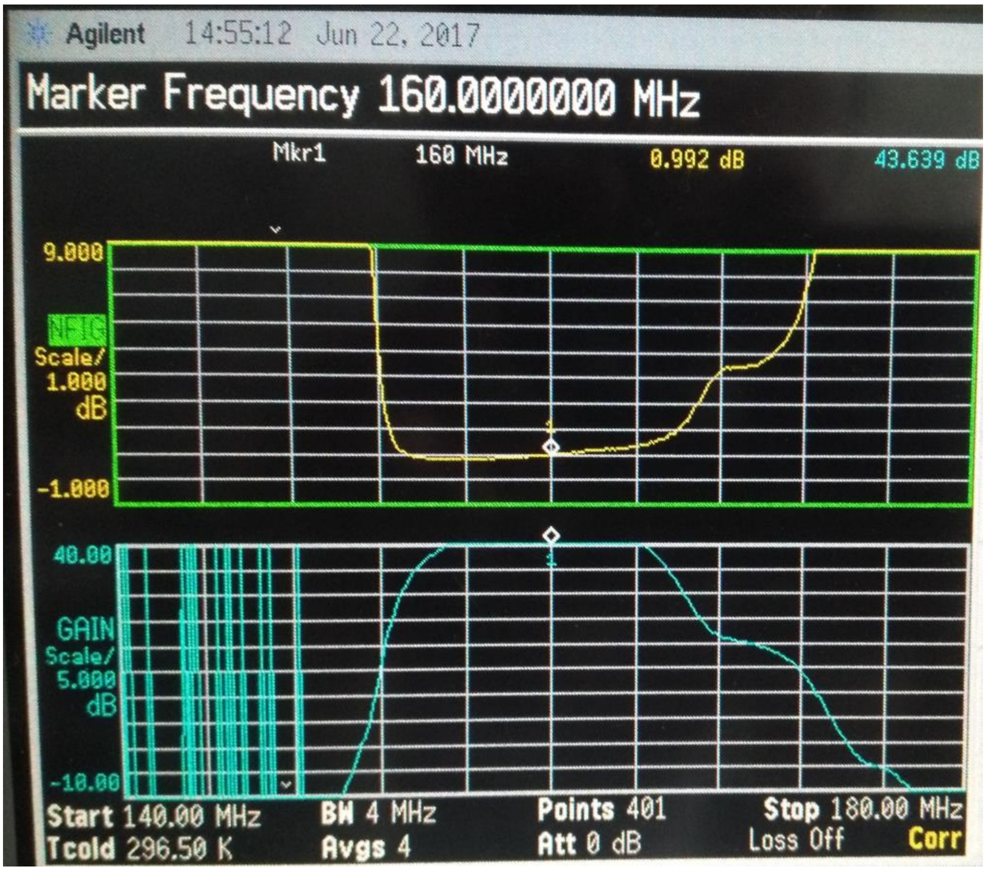


Figure 4-4: Noise Figure of the AIS RF chain

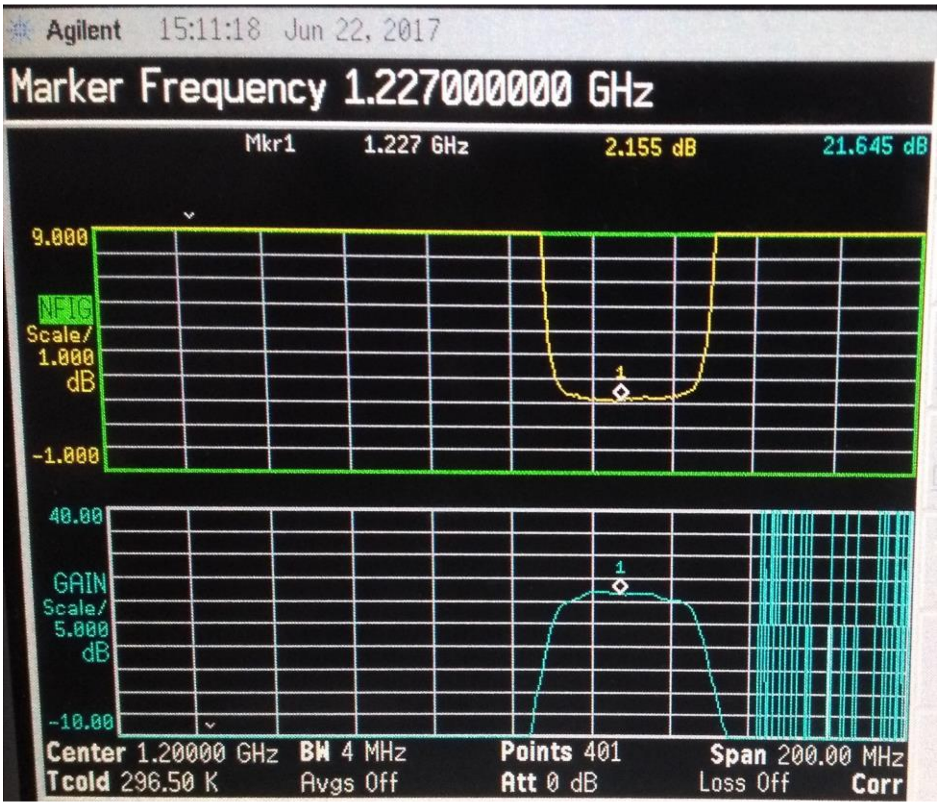


Figure 4-5: Noise Figure of the L2 RF chain

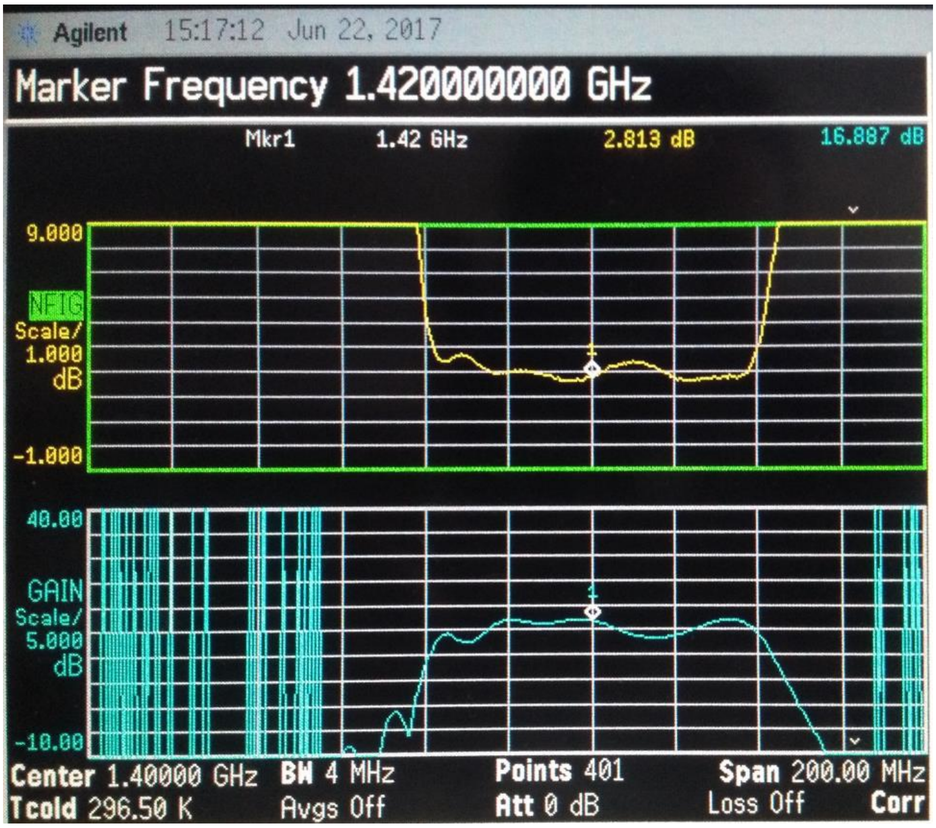


Figure 4-6: Noise Figure of the Radiometer RF chain

Table 4-2: Theoretical NF vs Measured NF

RF Chain	***Theoretical NF***	***Measured NF***
AIS	0.84 dB	0.99 dB
L2	0.99 dB	2.16 dB
Radiometer	1.18 dB	2.81 dB

There is a mismatch between the theoretical Noise Figure and the measured. It is understandable that the RF chains that have mismatches on the results are the ones that have also mismatches on the measured gain results. There are two factors that can increase the Noise Figure of the receptor:

- Internal interferences on the chain related to the shortage of gain because of internal reflected signals.
- Barcelona is a very noisy city, and although the bands analysed are restricted there is still a lot of noisy contamination. So, because the board does not have isolation structure, an important percentage of the ambient noise can be introduced to the board. This effect can be observed on Figures 4.4, 4.5 and 4.6, where at the laterals of the band there is a lot of noise.

<u>Isolation:</u> The isolation between the three different RF experiments of the payload have been measured with the Network Analyser and it turns to be greater than 40 dB for all channels at all frequencies. The following graph represents the attenuation that applies the board to the experiments that are not enabled, or in other terms, the isolation of the active experiment with the disabled ones. There are three groups: the AIS experiment, the L1 Up-Looking chain and the Down-Looking chain which includes L1, L2 and Radiometer.

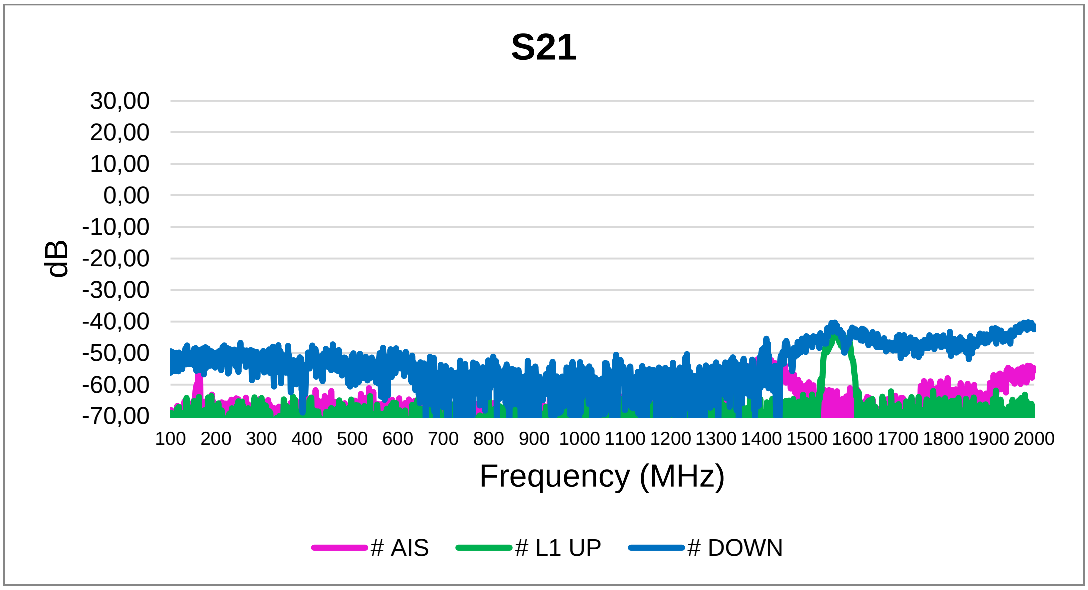


Figure 4-7: S21 of each RF chain with the switch blocking the signal

4.3. Payload performance

4.3.1. AIS experiment

In order to test the AIS experiment it have been used the signal processing software of Noemí Miguélez Gómez thesis. We decided to test the experiment on Campus Nord, where signals from Torre de Collserola were received, and on Barcelona's port where signals from vessels were received. Appendix L shows the full software outputs of the received packets.

```
2017/06/22 13:47:15.610794 gnuais[3742:140298719045824] INFO: A: Received correctly: 13 packets
2017/06/22 13:47:15.610811 gnuais[3742:140298719045824] INFO: B: Received correctly: 12 packets
```

Figure 4-8: AIS software output receiving from Campus Nord

```
2017/06/22 16:57:37.783450 gnuais[3203:139887149635776] INFO: A: Received correctly: 58 packets
2017/06/22 16:57:37.783469 gnuais[3203:139887149635776] INFO: B: Received correctly: 56 packets
```

Figure 4-9: AIS software output receiving from Barcelona's port

Finally, on the following graph, can be seen the maximum peaks of AIS received packets during the reception experiment on Barcelona's port.

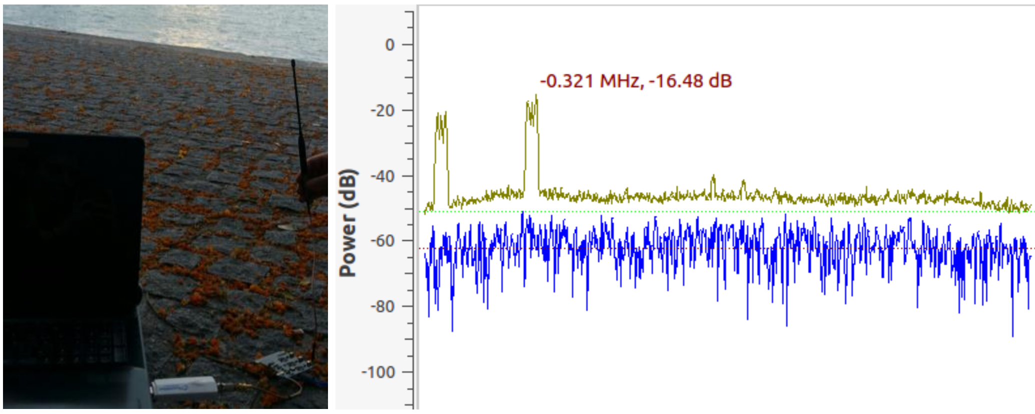


Figure 4-10: (Left) Measuring setup, (Right) Maximum power AIS received packages

4.3.2. GNSS-R experiment

In order to test the GNSS-R experiment it have been used the signal processing software that the [3]Cat-4 software team is developing. We decided to test the experiment on Campus Nord. The output of the GNSS-R software is shown on Figure 4.11.

```
Detectado Satélite #2 en señal directa. SNR = 4.793979.
Detectado Satélite #12 en señal directa. SNR = 6.776585.
Detectado Satélite #14 en señal directa. SNR = 2.832011.
Detectado Satélite #25 en señal directa. SNR = 8.592089.
Detectado Satélite #29 en señal directa. SNR = 8.345580.
Detectado Satélite #32 en señal directa. SNR = 6.131141.
Fin del Procesado de GPS-L1.
```

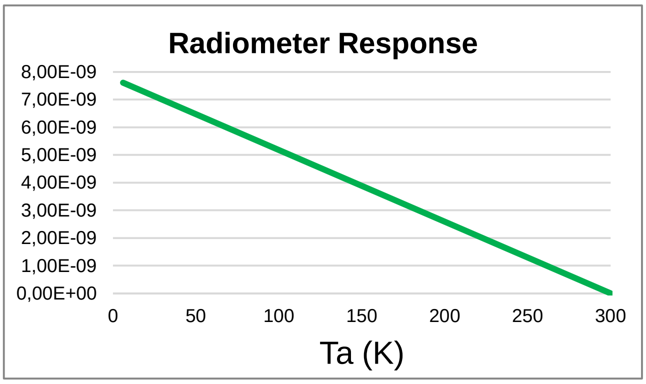
Figure 4-11: GNSS-R software output

4.3.3. Radiometer experiment

The Radiometer implemented on this thesis is a Total Power Radiometer (TPR), and the procedure to calibrate this experiment consists on taking the output measurement at two known points and then, by using the output linearity (1), stablish a linear response.

The known points are a hot load and a cold load. The hot load is a microwave absorber or a matched load, which will have an equivalent temperature of the physical temperature of the receptor, and the cold load can be obtained by pointing to the sky looking to the North of the Earth, which will have an equivalent temperature of 6 K.

The procedure used to calibrate the Radiometer has been the following: point to the sky with an L-Band Helix antenna designed on Engineering Advanced Project (PAE) to obtain a cold load and then switch off the signal to obtain the hot load from the internal matched load of the switch.



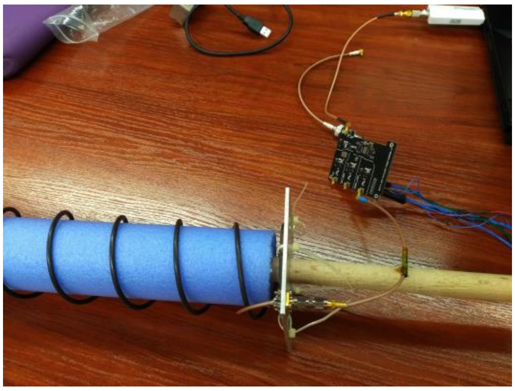


Figure 4-12: (Left) Linear response of the Radiometer, (Right) Measurement Setup

The result was incorrect because the calibration line appears to have inverted slope, and remembering expression (1) ($Vout = G(Ta + Trec)$), it is impossible to obtain a greater value by measuring a low Ta. The first step was to assume that Barcelona is a noisy city and a cold load point the sky cannot be obtained, so the next calibration was done by using an Active Cold Load (ACL) [7] which was previously characterized on the Noise Figure Meter (see Figure 4.13)

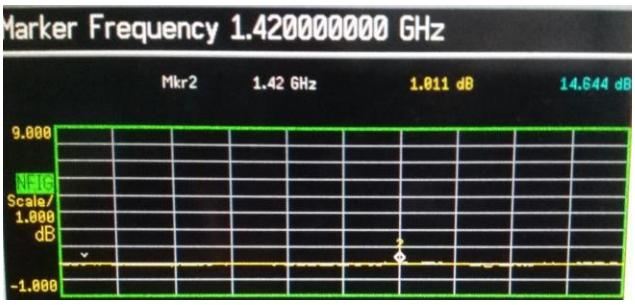


Figure 4-13: Characterization of the SPF-5043Z transistor acting as an ACL

Using the following expression:

$$Teq = To(NF - 1)\ , \tag{3}$$

the Teq of the cold load is **76.01 K.** Although that new procedure, the calibration failed again with an output similar to the first try (Figure 4.12). The explanation is that the block diagram of the Conditioning Board (Figure 3.2) shows that the cold and the hot load measurement points are not located on the same place, so the signal coming from the points goes through different pads. The cold load is placed on the input connector and the hot load can be obtained from any of the two switches. The noise figure of the receiver is 2.81 dB (Table 4.2) and the equivalent temperature of the receiver is **263.86 K**, but measured between the input and the output connectors (the pad that follows the cold load). The problem is that the pad of the hot load, which is shorter, is not characterized in terms of $Trec$, which makes the calibration invalid (See expressions 4, 5, 6)

$$Vcold = G(Tcold + Trec1)\ , \tag{4}$$

$$Vhot = G(Thot + Trec2)\ , \tag{5}$$

and

$$Trec1 \neq Trec2\ , \tag{6}$$

Finally, taking the hot load measurement on the input connector, with a matched load connected to it, the calibration has been completed successfully.

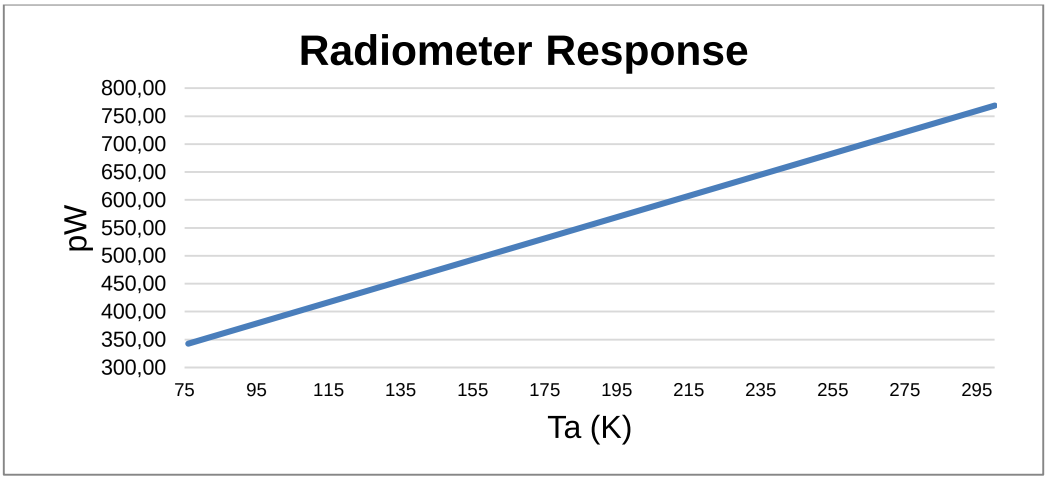


Figure 4-14: Radiometer calibrated response

5. Budget

In this chapter the costs of the project are detailed.

Hardware costs:

Table 5-1: Hardware costs

Components	***Qty***	***Cost/Unit (€)***	***Cost (€)***
Resistors	95	0.163	15.48
Capacitors	335	0.205	68.67
Inductors	58	0.382	22.15
LNA	40	1.56	62.4
RF Choke	20	3.62	72.4
Transformer	20	2.72	54.4
Switch	12	9.01	108.12
IC	67	0.756	50.65
MMCX Connectors	10	5.45	54.5
Stackable Connectors	10	1.18	11.8
Overo Connectors	4	3.02	12.08
Diode	4	0.312	1.24
Power Inductor	12	0.376	4.51
PCB	10	10	100
TOTAL			**638.37**

Measurement and developing tools costs:

Table 5-2: Measuring and developing tools costs

Tool	***Cost/week (€)***	***Weeks***	***Cost (€)***
Network Analyzer	400	4	1600
Spectrum Analyzer	350	4	1400
Oscilloscope	150	4	600
TOTAL			**3600**

Development Costs:

The assigned development cost of a trainee engineer is 8 €/h.

Table 5-3: Development costs

Tool	***Hours***	***Cost (€)***
Design & components selection	60	480
PCB Layout	180	1440
Assembly	240	1920
Test	180	1440
Documentation	60	480
TOTAL		**5760**

6. Conclusions and future development:

6.1. Conclusions

The purpose of this thesis was to develop a flexible microwave payload including three RF experiments: AIS, GNSS-R and L-Band Radiometer based on a low-cost software defined radio (SDR).

So, taking into account the preliminary goals and the obtained results the following conclusions are presented:

- The development of a common RF board, containing AIS, GNSS-R and Radiometer experiments, of 70 x 54 mm.
- The conversion of the commercial Tobi expansion board for Overo into a specially purposed board by the nanosatellite applications.
- The reduction of the power consumption of the Conditioning Board by using control and enable signals.
- I have learned a lot on routing complex PCB of more than two layers and by following design restrictions.
- I have learned a lot ont PCB boards assembly, which includes different welding processes and standards.
- I have learned a lot on the complex measurement instruments in order to test the Conditioning Board.
- Some design errors have been successfully corrected by isolating the problem on a separated prototype and investigating about the design.
- The L-Band Radiometer has been successfully calibrated and operated. The block diagram has been analysed to study the initial calibration problems, and finally the error have been isolated and corrected
- The GNSS-R experiment has been successfully operated by receiving GPS satellite's signals from Campus Nord.
- The AIS experiment has been successfully operated by receiving more than one hundred AIS packets from Campus Nord and Port of Barcelona.

6.2. Future Approach

As a future approach, because of the difficulties that the Conditioning Board has presented, there have not been enough time to work on the Acquisition Board. So the next step into this thesis would be to restore the testing and investigation about the Acquisition Board.

The measurements and the tested performance of the Conditioning Board appears to be good enough for an initial version, but because it is an essential part of the ^{3}Cat-4, it needs to be tested and iterated more time.

The first aspect that it needs to be solved is the mismatching on the Gain measurements and the related mismatching on the Noise Figure measurements. It have been done an ADS simulation using the S-parameters of the used components on the amplifying circuit and it appears to be a decrement of the input matching of the LNA. The next step would be to do an isolated prototype of the LNA and investigate about its behaviour at higher frequencies.

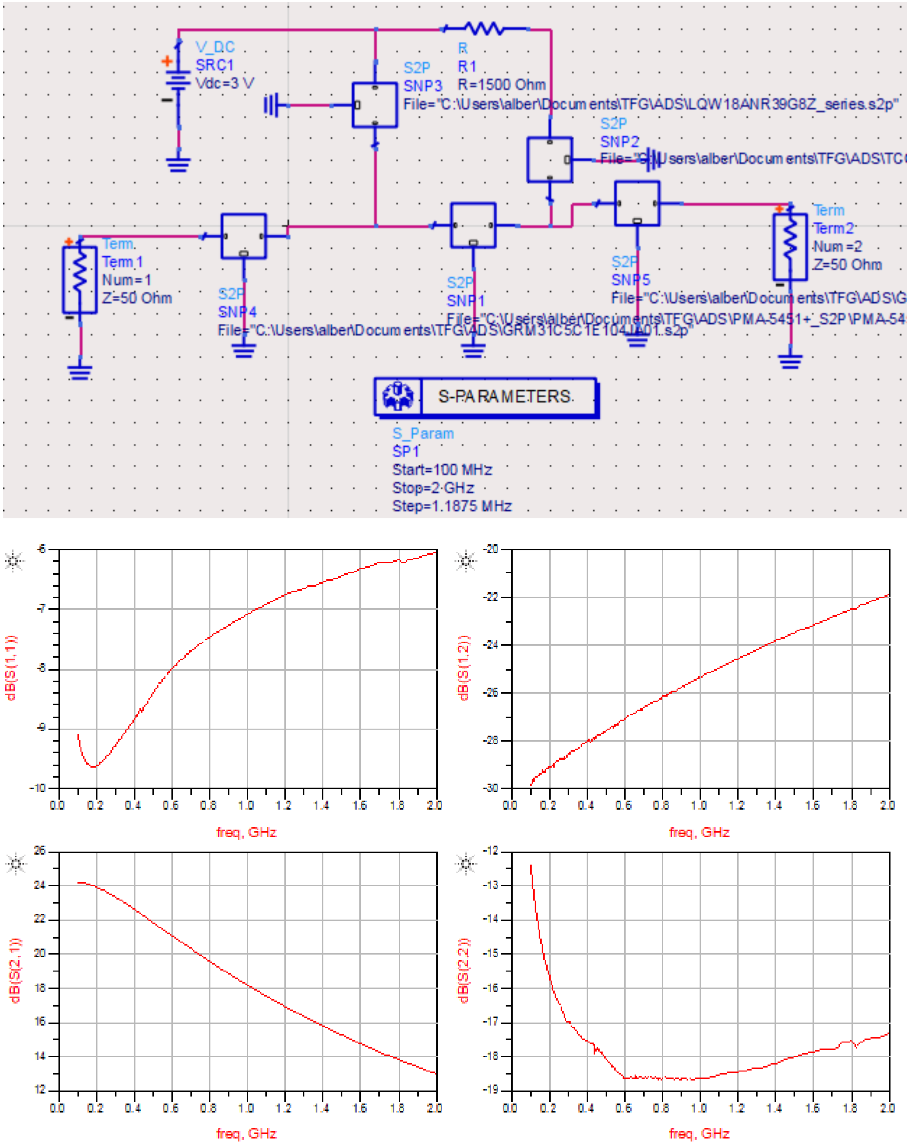


Figure 6-1: (Up) ADS schematic of the LNA circuit, (Down) ADS simulation outputs

Although the correction of the gain mismatch probably positively affects the noise figure mismatch, it cannot be obviated that the board is unprotected from extern signals. Because one of the experiments is a radiometer, which is a very sensible device, it is strongly recommended to redesign the board adding shielding cavities that isolates the board from external signals and between the experiments.

Another important aspect to take into account is the selected LNAs because its wideband it is an advantage for the LNA located before the RF output (where the signal band goes from 160 MHz to 1.57 GHz), but it is a disadvantage for the LNAs located after the RF input where there is not any previous filter apart from the antenna and interferences are also amplified. A next step would be to replace the input wideband LNAs with narrow band ones specific for every RF channel.

Finally, in chapter 4.3.3 (Radiometer calibration) the architecture of the board has been explained. It has an error on the radiometer's calibration. The future approach of this board is to re-design the architecture including the necessary elements to ensure that the signal coming from the radiometer (cold load, hot load and intermedium load) goes through the same pad, and that this pad can be characterized with the Noise Figure Meter.

To finalize, the very useful applications of the Active Cold Load (ACL), that have been used to calibrate the radiometer, gives reasons to implement it on the new architecture by adding a third option to the radiometer chain (antenna, hot load and cold load). In the actual design there is not any cold load calibration and it is assumed that, once calibrated one time, this point does not fluctuate excessively. However taking into account that the radiometer typology is a TPR, which has considerable gain fluctuations, and that the ACL is a simple and small size device, it could fit on the future design of the Conditioning Board.

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[6] *Ulaby, Moore, Funk, "Microwave remote sensing, active and passive", Vols. I,II,III, Addison Wesley i Artech House 1981, 1982, 1986*. Last visited: 15/02/2017

[7] Sten Schmidl Súbjcerg, Jan E. Balling and Niels Skou. *Performance assessment of an LNA used as active cold load*. Last visited 26/06/2017

[8] *Saturn PCB Toolkit Web Page*. URL: http://www.saturnpcb.com/pcb_toolkit.htm . Last visited: 01/05/2017

Appendix A: Gantt Diagram and Work Packages

Project: System Design (Conditioning payload)	WP ref: 1	
Major constituent: Simulation		
Short description: Design of the optimal configuration of the conditioning payload, which contains the RF experiments of the satellite. Consists in a general overview of the different subsystems to combine them in the more efficient way.	Planned start date:15/02/2017 Planned end date: 20/02/2017 Start event:15/02/2017 End event: 25/06/2017	
Internal task T1: General system overview. Design an optimal configuration.	Deliverables: Block Diagram	Dates: 20/02/2017

Project: Components selection (Conditioning payload)	WP ref: 2	
Major constituent: Simulation & Sales		
Short description: Election of the different components of the conditioning payload. The power efficiency, size and cost criteria are applied. Then, each component is purchased and created on Altium platform.	Planned start date: 20/02/2017 Planned end date: 27/02/2017 Start event:15/02/2017 End event: 25/06/2017	
Internal task T1: Select the components applying the criteria listed above. Internal task T2: Contact with the distributors to optimize the purchasing orders. Internal task T3: Create the components on Altium platform to start the design of the PCB.	Deliverables: List of the components.	Dates: 27/02/2017

Project: Placement (Conditioning payload)	WP ref: 3	
Major constituent: Hardware prototype		
Short description: Placement of the hardware parts on the PCB. It has to be matched with the dimension specifications provided by the assembly engineer of the nanosatellite.	Planned start date: 23/02/2017 Planned end date: 02/03/2017 Start event:15/02/2017 End event: 25/06/2017	
Internal task T1: Placement of the components on the PCB.	Deliverables: First iteration of the PCB.	Dates: 02/03/2017

Project: Routing (Conditioning payload)	WP ref: 4	
Major constituent: Hardware prototype		
Short description: Routing of the PCB.	Planned start date: 02/03/2017 Planned end date: 07/04/2017 Start event:15/02/2017 End event: 25/06/2017	
Internal task T1: Routing of the Conditioning payload	Deliverables: PCB v01	Dates: 07/04/2017

Project: Manufacturing (Conditioning payload)	WP ref: 5	
Major constituent: Hardware prototype		
Short description: Welding components to the PCB.	Planned start date: 12/04/2017 Planned end date: 12/06/2017 Start event:15/02/2017 End event: 25/06/2017	
Internal task T1: Welding of the Conditioning payload.	Deliverables:	Dates: 12/06/2017

	PCB v01 manufactured	

Project: System Design (Acquisition payload)	WP ref: 6	
Major constituent: Simulation		
Short description: Design of the optimal configuration of the acquisition payload. The nanosatellite contains a processor which has to be use with an expansion board, which it is too large, so it has to be own designed without the non-necessary parts and fitting it to the nanosatellite hardware specifications.	Planned start date: 27/02/2017 Planned end date: 10/03/2017 Start event:15/02/2017 End event: 25/06/2017	
Internal task T1: General system overview. Design an optimal configuration.	Deliverables: Block Diagram	Dates: 10/03/2017

Project: Placement (Acquisition payload)	WP ref: 7	
Major constituent: Hardware prototype		
Short description: Placement of the hardware parts on the PCB. It has to be matched with the dimension specifications provided by the assembly engineer of the nanosatellite.	Planned start date: 10/03/2017 Planned end date: 31/03/2017 Start event:15/02/2017 End event: 25/06/2017	
Internal task T1: Placement.	Deliverables: First iteration of the PCB.	Dates: 31/03/2017

<table>
<tr><td>Project: Routing (Acquisition payload)</td><td colspan="2">WP ref: 8</td></tr>
<tr><td>Major constituent: Hardware prototype</td><td colspan="2"></td></tr>
<tr><td rowspan="2">Short description:
Routing of the PCB.</td><td colspan="2">Planned start date: 31/03/2017
Planned end date: 27/04/2017</td></tr>
<tr><td colspan="2">Start event:15/02/2017
End event: 25/06/2017</td></tr>
<tr><td>Internal task T1: Routing of the Conditioning payload.</td><td>Deliverables:
PCB v01</td><td>Dates:
27/04/2017</td></tr>
</table>

<table>
<tr><td>Project: Manufacturing (Acquisition payload)</td><td colspan="2">WP ref: 9</td></tr>
<tr><td>Major constituent: Hardware prototype</td><td colspan="2"></td></tr>
<tr><td rowspan="2">Short description:
Welding components to the PCB.</td><td colspan="2">Planned start date: 10/05/2017
Planned end date: 17/05/2017</td></tr>
<tr><td colspan="2">Start event:15/02/2017
End event: 25/06/2017</td></tr>
<tr><td>Internal task T1: Routing of the Conditioning payload.</td><td>Deliverables:
PCB v01 manufactured</td><td>Dates:
17/05/2017</td></tr>
</table>

Project: Testing & Documentation	WP ref: 10	
Major constituent: Hardware prototype		
Short description: Testing and correcting possible errors. Also documentation of the characteristics of the equipment.	Planned start date: 10/05/2017 Planned end date: 10/06/2017	
	Start event:15/02/2017 End event: 25/06/2017	
Internal task T1: Testing.	Deliverables: Payload definitive.	Dates: 10/06/2017

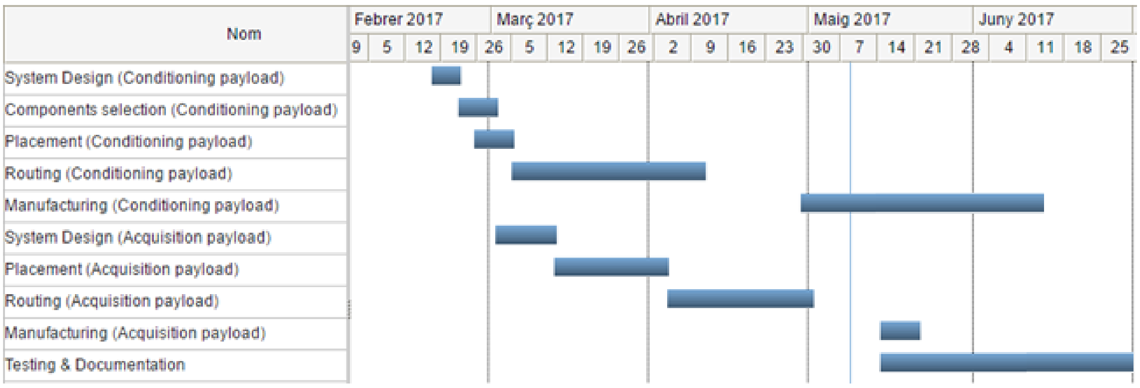

Figure A-1: Gantt Diagram of the thesis

Appendix B: Conditioning's Board Requirements

On this appendix, the Conditioning Board requirements are presented. There are some that are defined in TBD (To Be Defined) terms because they are ones that have implications with the [3]Cat-4 and they are not integrated with the other group requirements or simply they are not defined yet because the design is on a preliminary phase.

Table B-1: Requirements Glossary

Field	**Acronym**	**Description**
Mission	M	Related to the main goal of the system
Space Segment	SS	Related to the space segment of the mission
System	S	Related to both segments
Ground Segment	GS	Related to the ground segment
Type	**Acronym**	**Description**
Functional	FUNC	Related to the function
Configuration	CONF	Related to the configuration
Interfaces	INTER	Related to the interface
Physical	PHY	Related to the physical features
Environmental	ENV	Related to the environment
Quality	QA	Related to the quality
Operations	OPER	Related to the possible operations/actions
Support	SUPP	Related to the project support
Verification	VER	Related to the verification process

Table B-2: Conditioning Board requirements

Field	Type	Description
SS	CONF	AIS, Reflectometer and Radiometer conditioning payload must be implemented into the same board
SS	PHY	Components height must be below TBD mm
SS	PHY	The board maximum width must be TBD mm
SS	PHY	The board maximum lenght must be TBD mm
SS	PHY	The board maximum height must be TBD mm
SS	CONF	The board should be implemented on the rooftop of the Acquisition board
SS	INTER	The board shall be subjected by four spacers at TBD mm located at the position defined by the Acquisition board
SS	INTER	The board must have four MMCX connectors for the three input RF ports and the output RF port
SS	INTER	The three input RF ports should be located at -Y edge of the board
SS	CONF	The components should be placed at the top layer of the Conditioning Board
SS	INTER	The board should have a board to board stackable connector with TBD rows of TBD pins
SS	CONF	The top layer should be reserved for RF lines
SS	CONF	The internal layer below the RF layer must be reserved for ground plane
SS	FUNC	The minimum accepted AIS RF Gain shall be TBD dB
SS	FUNC	The maximum accepted AIS RF NF shall be TBD dB
SS	FUNC	The minimum accepted AIS RF Isolation shall be TBD dB
SS	FUNC	The minimum accepted L1 up-looking RF Gain shall be TBD dB
SS	FUNC	The maximum accepted L1 up-looking RF NF shall be TBD dB
SS	FUNC	The minimum accepted L1 up-looking RF Isolation shall be TBD dB

SS	FUNC	The minimum accepted L1 down-looking RF Gain shall be TBD dB
SS	FUNC	The maximum accepted L1 down-looking RF NF shall be TBD dB
SS	FUNC	The minimum accepted L1 down-looking RF Isolation shall be TBD dB
SS	FUNC	The minimum accepted L2 RF Gain shall be TBD dB
SS	FUNC	The maximum accepted L2 RF NF shall be TBD dB
SS	FUNC	The minimum accepted L2 RF Isolation shall be TBD dB
SS	FUNC	The minimum accepted Radiometer RF Gain shall be TBD dB
SS	FUNC	The maximum accepted Radiometer RF NF shall be TBD dB
SS	FUNC	The minimum accepted Radiometer RF Isolation shall be TBD dB
SS	FUNC	The maximum accepted power consumption is TBD mW
SS	CONF	The board should have independent control signals for the TBD control pins
SS	CONF	The board must have an input power port at minimum Vout+Vdropout of the supply LDOs
SS	CONF	The input power supply of the LNA's should not be greater than TBD V
SS	CONF	The board must have an input power port at minimum 1,8 V
SS	CONF	The input control signals should not be greater than TBD V
SS	CONF	The board shall have a maximum current consumption of 80 mA
SS	QA	The components used must be space qualified

Appendix C: Acquisition's Board Requirements

On this appendix, the Acquisition Board requirements are presented. There are some that are defined in TBD (To Be Defined) terms because they are ones that have implications with the ^{3}Cat-4 and they are not integrated with the other group requirements or simply they are not defined yet because the design is on a preliminary phase..

Table C-1: Requirements Glossary

Field	**Acronym**	**Description**
Mission	M	Related to the main goal of the system
Space Segment	SS	Related to the space segment of the mission
System	S	Related to both segments
Ground Segment	GS	Related to the ground segment
Type	**Acronym**	**Description**
Functional	FUNC	Related to the function
Configuration	CONF	Related to the configuration
Interfaces	INTER	Related to the interface
Physical	PHY	Related to the physical features
Environmental	ENV	Related to the environment
Quality	QA	Related to the quality
Operations	OPER	Related to the possible operations/actions
Support	SUPP	Related to the project support
Verification	VER	Related to the verification process

Table C-2: Acquisition Board requirements

Field	Type	Description
SS	PHY	The board maximum width must be TBD mm
SS	PHY	The board maximum lenght must be TBD mm
SS	PHY	The board maximum height must be TBD mm
SS	PHY	The heigh of the components placed on the top layer should not be greater than TBD mm
SS	INTER	The board must contain a Overo Ironstorm-P
SS	INTER	The Overo Ironstorm-P should be located at the +X edge of the board
SS	INTER	The board must contain a NooElec Nano 2+
SS	INTER	The NooElect Nano 2+ should be attached into the Acquisition Board on a dedicated hole
SS	INTER	The board should contain the common nanosatellite bus connector standard PC-104
SS	INTER	The board should have a board to board stackable connector with TBD rows of TBD pins
SS	CONF	In order to set the supply voltage of the Acquisition Board a DC/DC should be used
SS	CONF	In order to set the supply voltage of the Conditioning Board a DC/DC should be used
SS	INTER	The DC/DC efficiency should be greater than TBD %
SS	CONF	The acquisition board DC/DC maximum consumption should not be greater than 1A
SS	CONF	The acquisition board DC/DC maximum consumption should not be greater than 80mA
SS	CONF	The acquisition board DC/DC must be set at the supply voltage of the Overo Ironstorm-P
SS	CONF	The conditioning board DC/DC should be set at voltage TBD dropout compliant of the supply LDOs of the Conditioning Board

SS	CONF	The UART minimum voltage level should be 3,3 V
SS	CONF	The board should have two UART, general and debug
SS	CONF	The board should contain two debug ports, debug UART and external power supply
SS	CONF	The debug ports should be located at the +X edge of the board
SS	CONF	The internal layer below the differential pair of the USB must be reserved for ground plane
SS	QA	The components used must be space qualified

Appendix D: Conditioning's Board Schematic

On this appendix, the schematic of the Conditioning Board is shown.

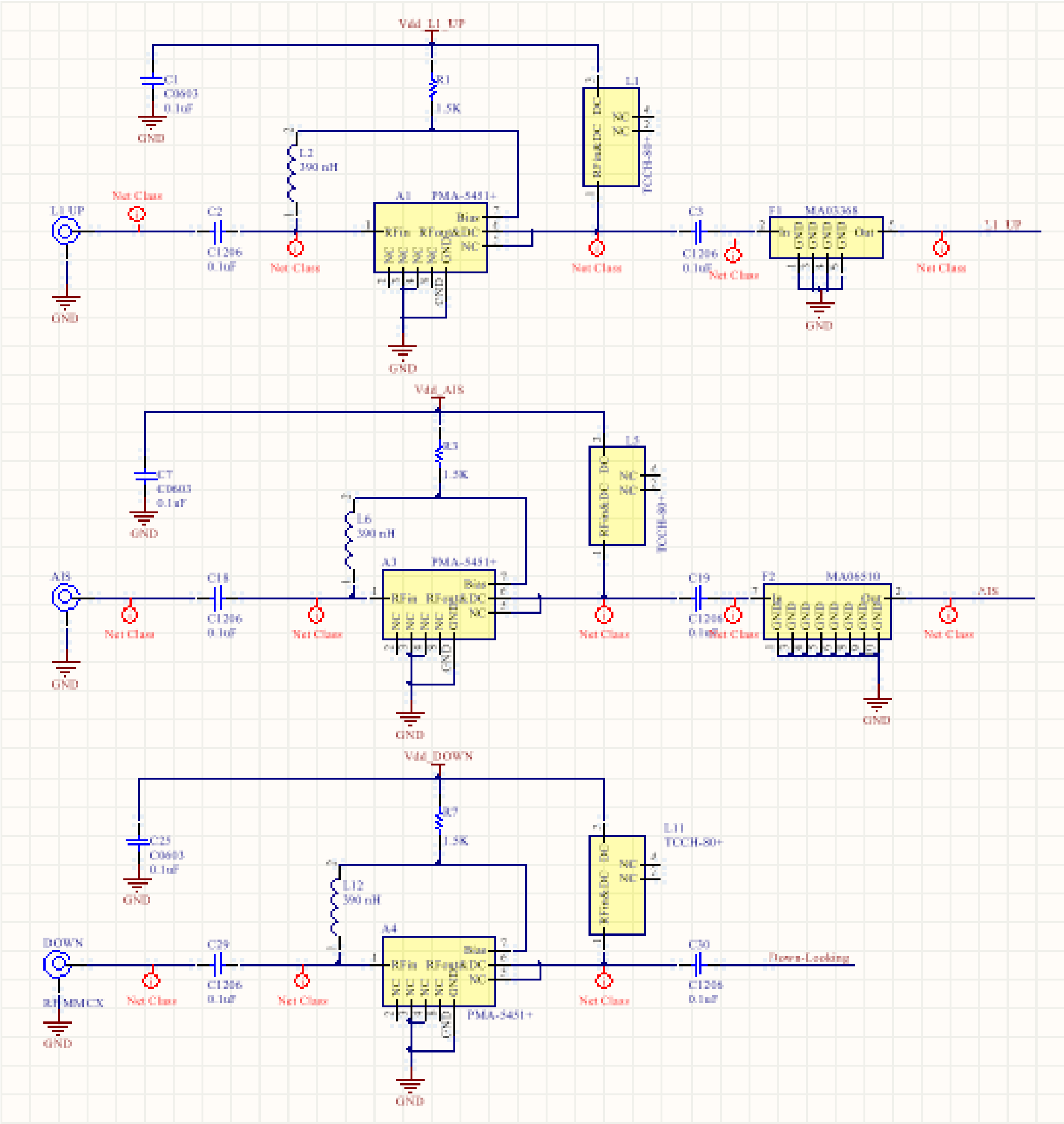

Figure D-1: Input RF amplifying circuit

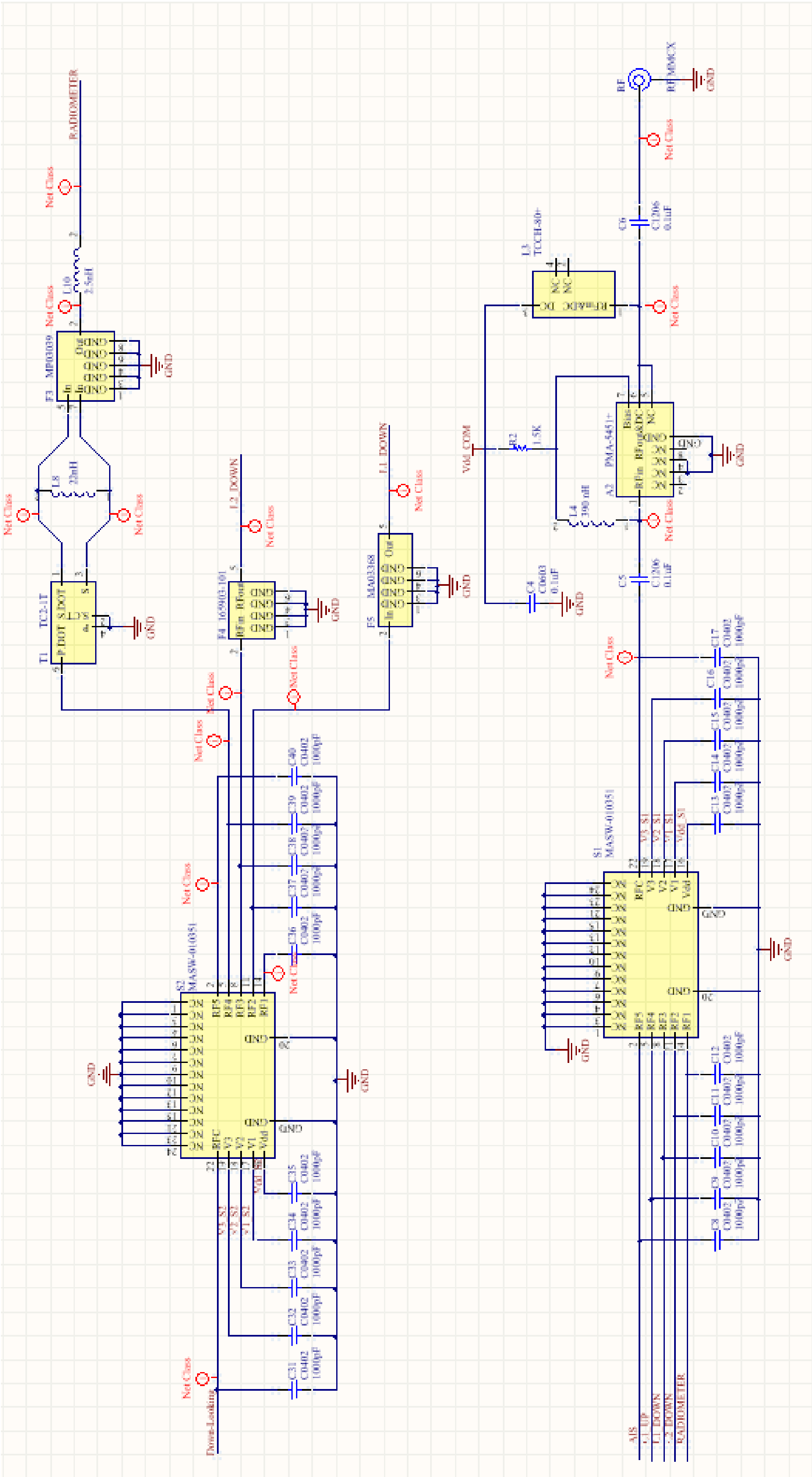

Figure D-2: Switching circuits and output RF amplifying circuit

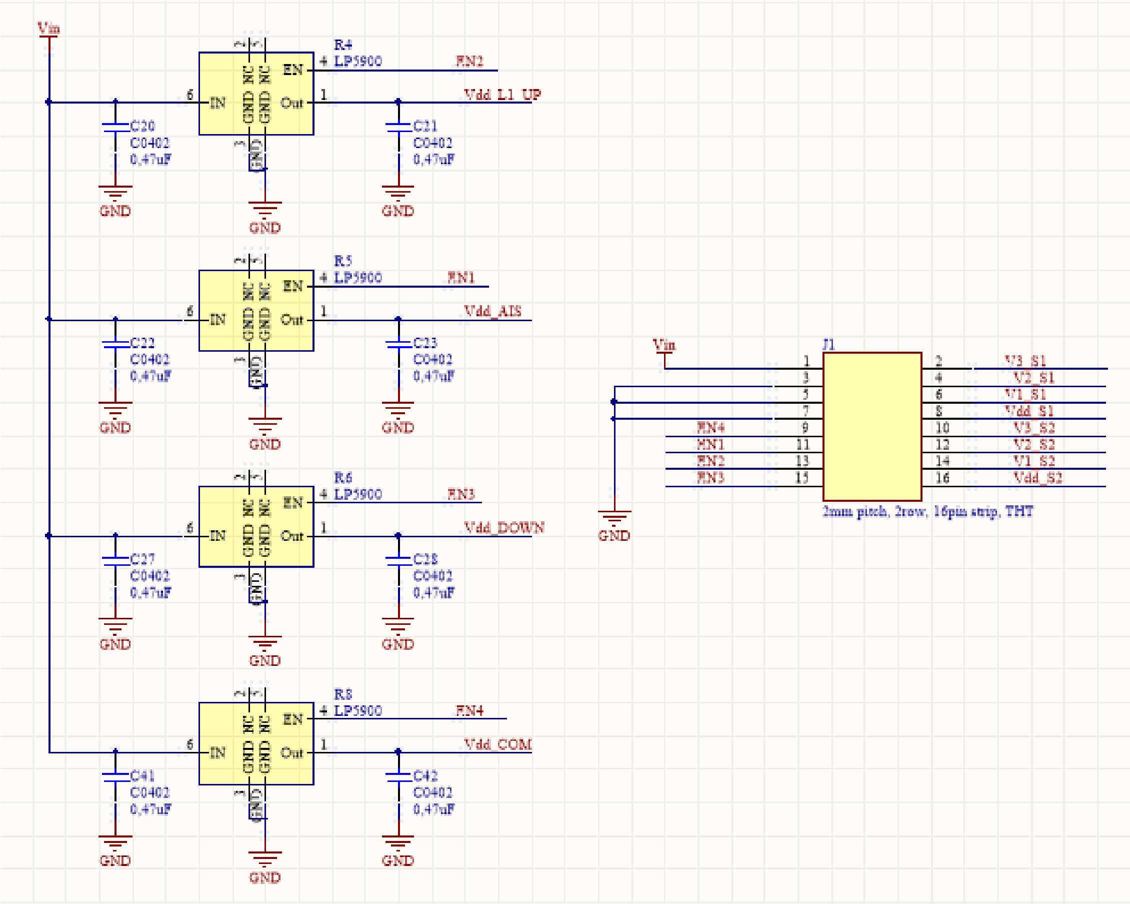

Figure D-3: LDOs and board to board stackable connector

Appendix E: Acquisition's Board Schematic

On this appendix, the schematic of the Acquisition Board is shown.

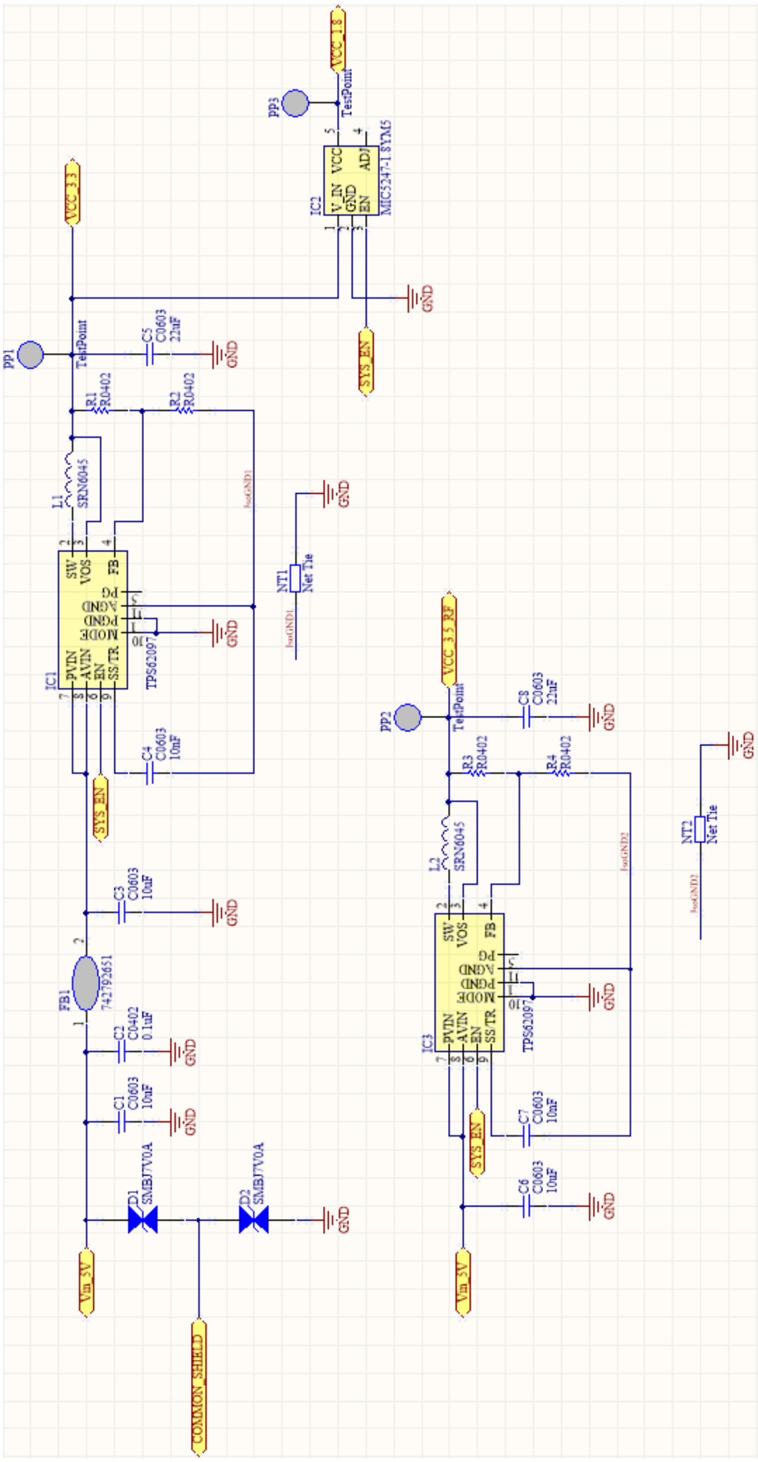

Figure E-1: DC/DC blocks

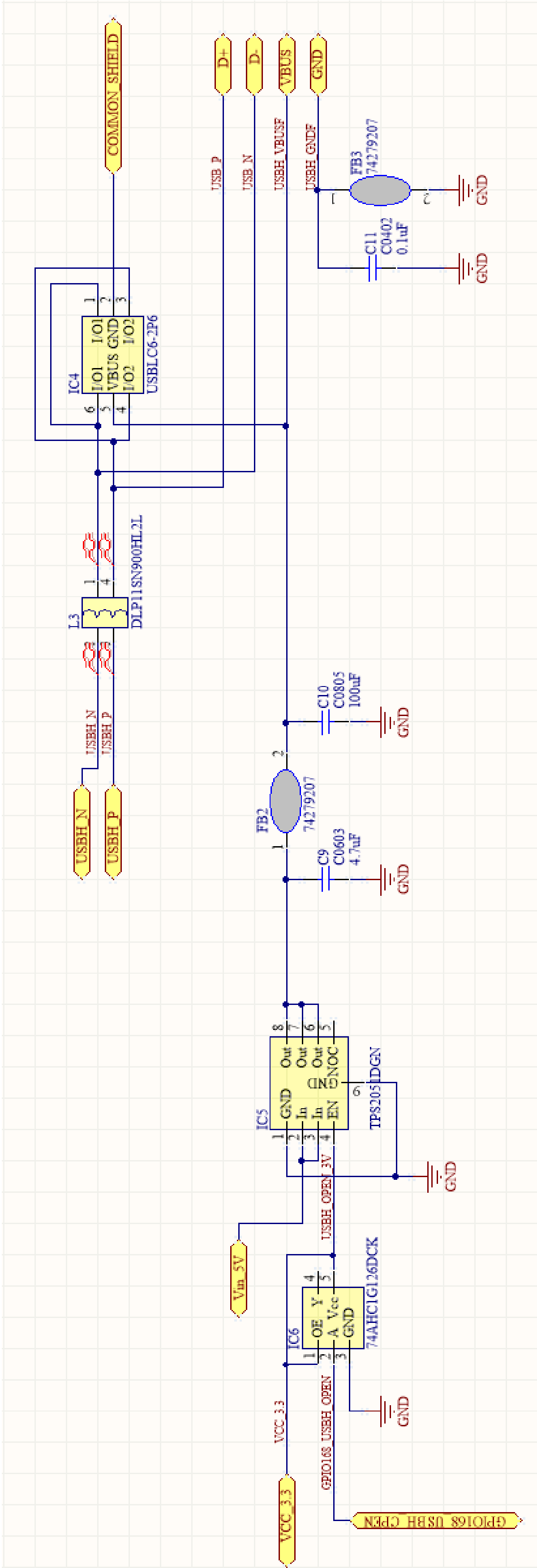

Figure E-2: USB connection circuit

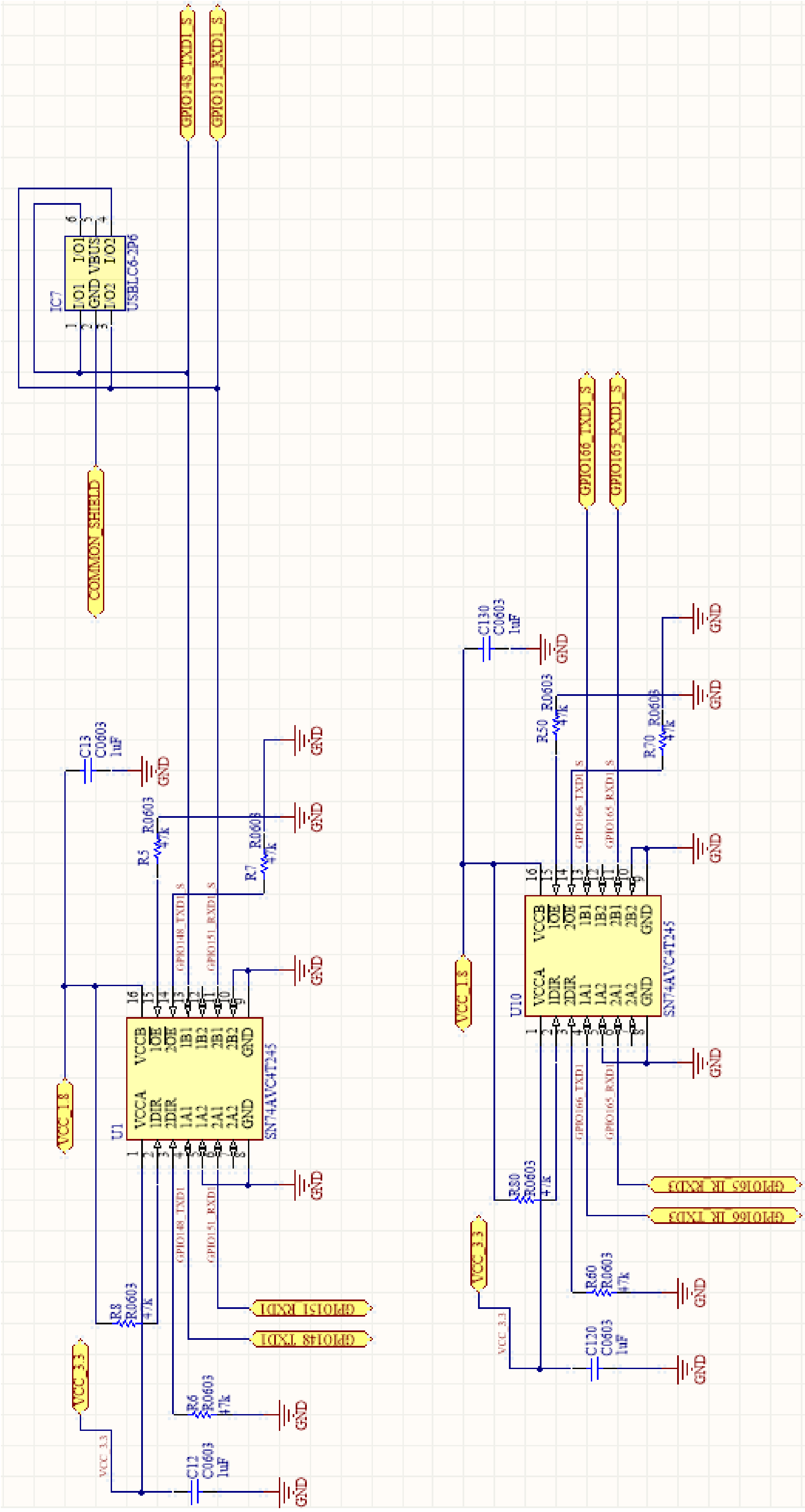

Figure E-3: UART level shifters

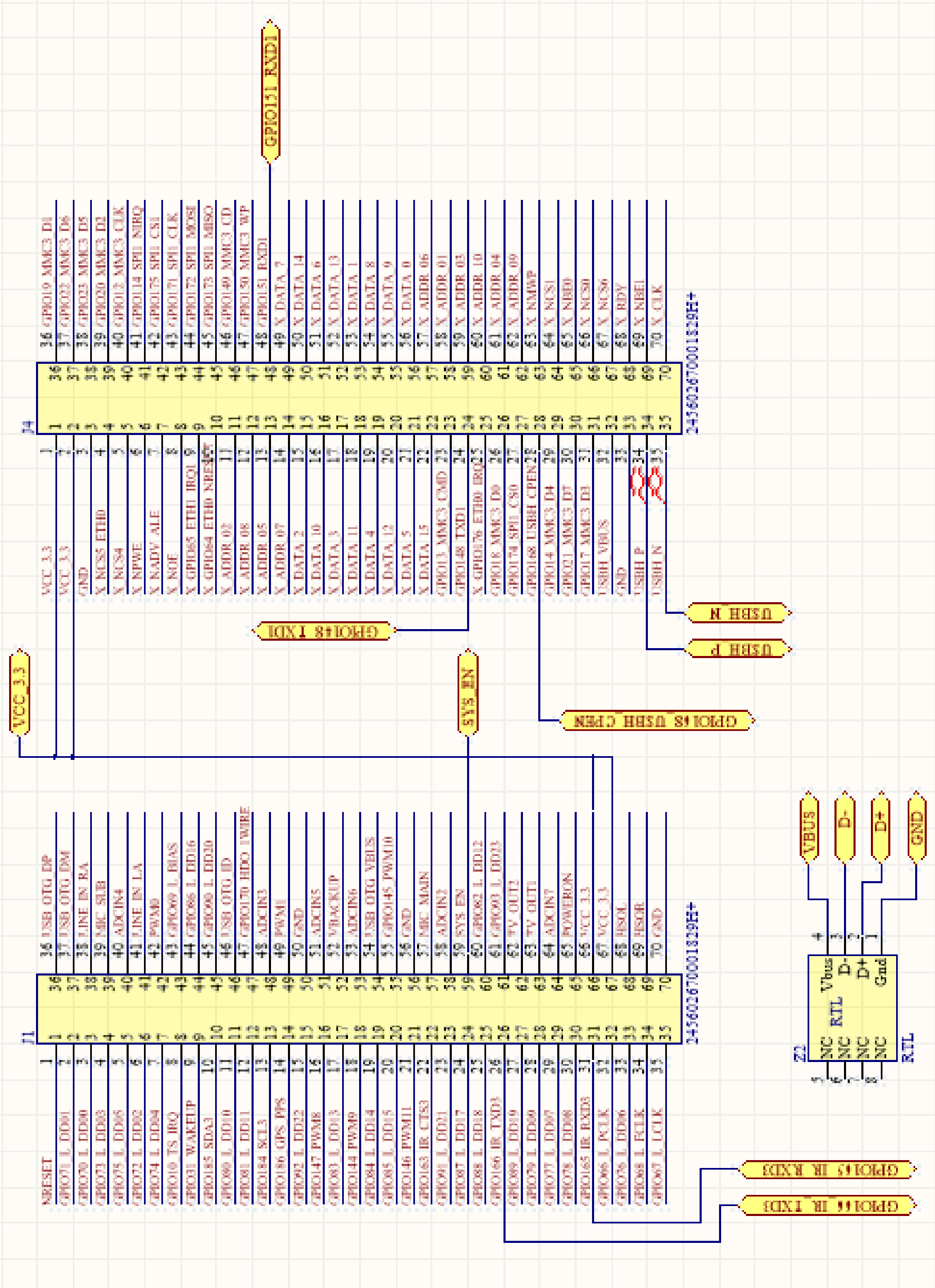

Figure E-4: Overo connectors and RTL

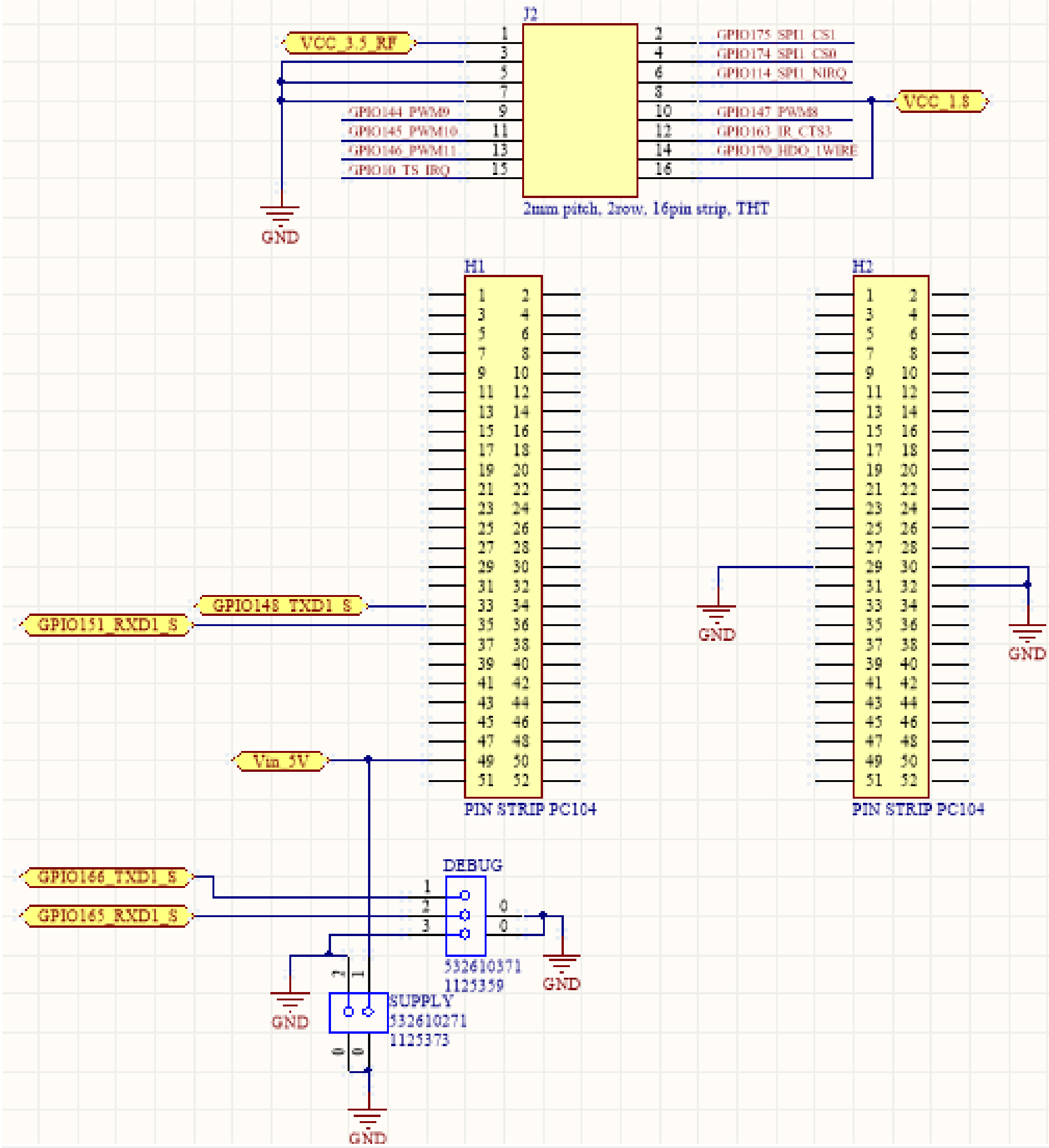

Figure E-5: Board to board stackable connector, satellite bus connectors and external debug connectors

Appendix F: RF Components

On this appendix, the main components of the Conditioning Board related to the RF experiments are listed.

LNA:

The selected LNA is the PMA-5451+ from Minicircuits. It has been selected because its low power consumption (30 mA at 3V) and its wideband.

Table F-1: PMA-5451+ performance

Channel	***Gain (dB)***	***NF (dB)***
AIS	24.4	0.8
L2	17.32	0.85
Radiometer	16.25	0.79
L1	15.26	0.9

Figure F-1: PMA-5451+

Saw Filters:

The selected type of filter is the SAW because of its good bandpass performance and the previous experience working with this filters on Advanced Engineering Project course.

Table F-2: Saw Filters performance

Channel	***Filter***	***IL (dB)***	***Fc (MHz)***
AIS	MA06510	3.8	159.16
L2	MP01601	2.2	1227.6
Radiometer	MP03039	5	1420
L1	MA03368	2	1575.42

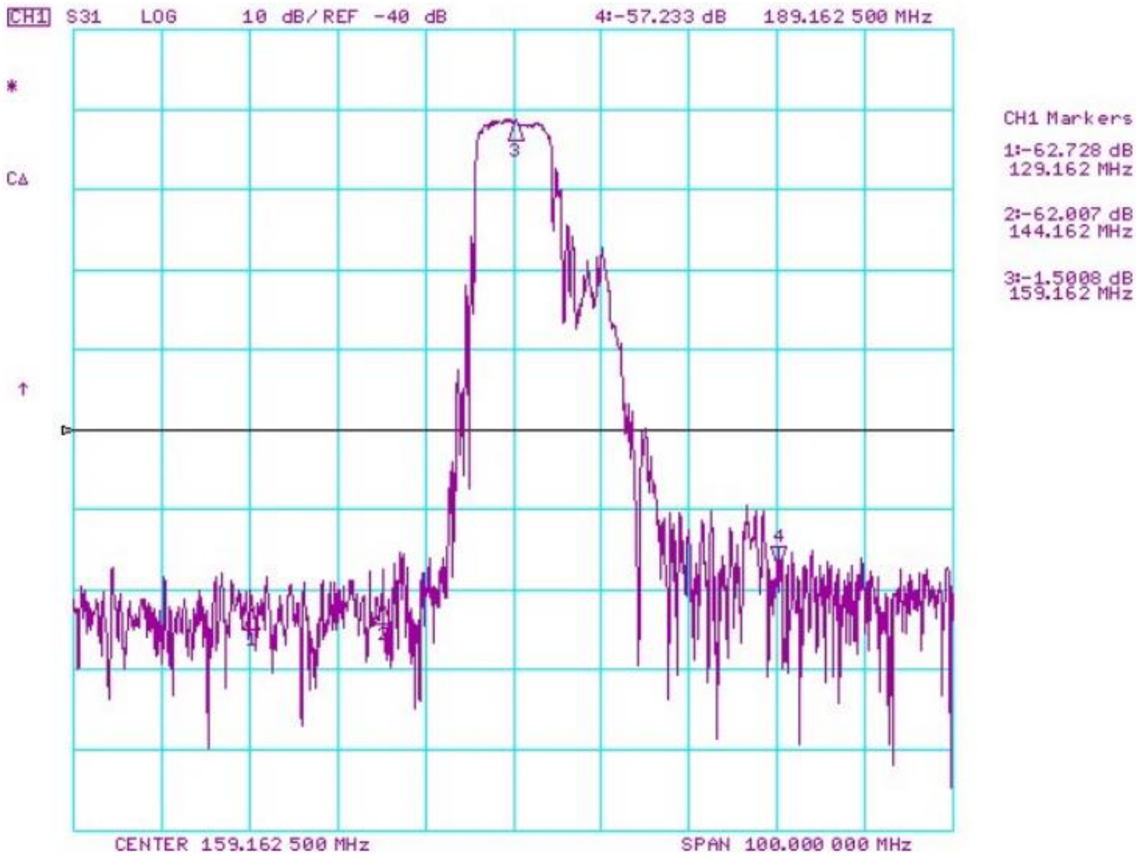

Figure F-2: MA06510 frequency response

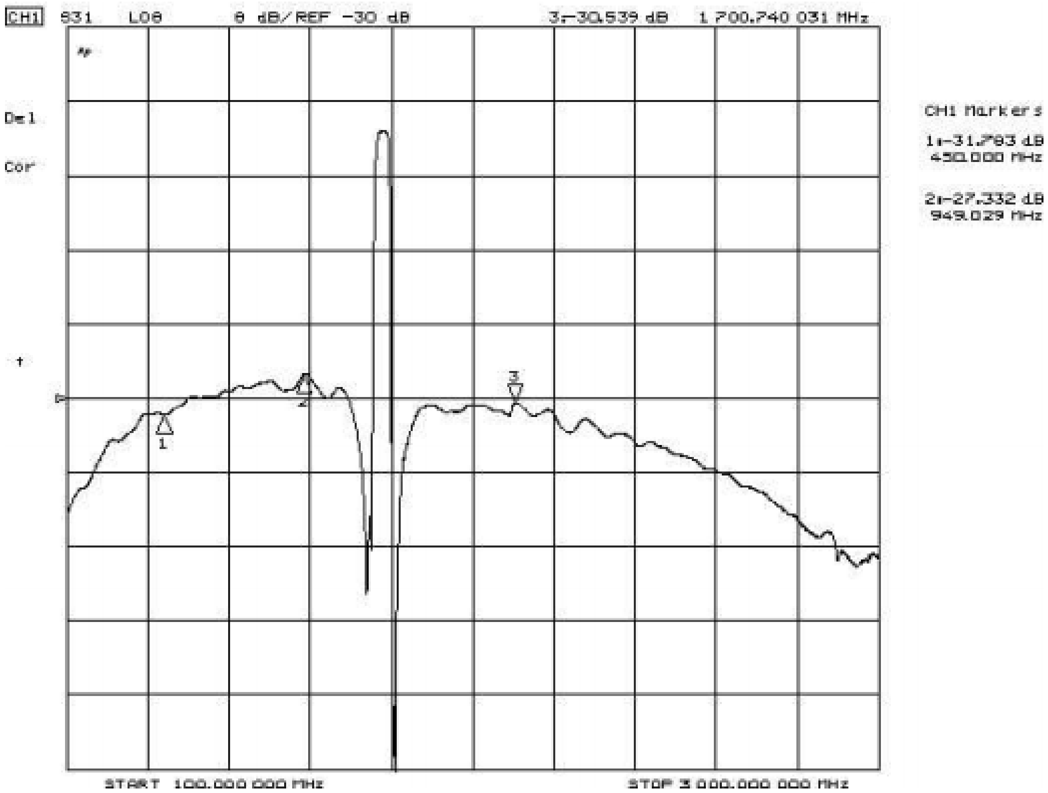

Figure F-3: MP01601 frequency response

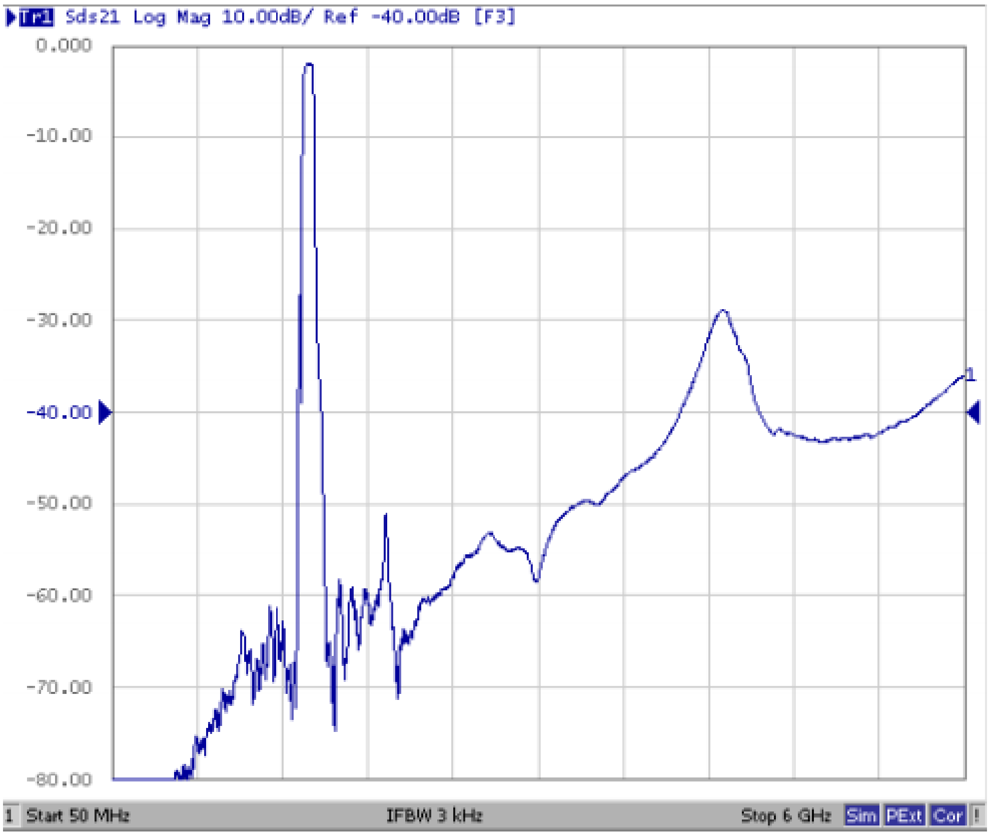

Figure F-4: MP03039 frequency response

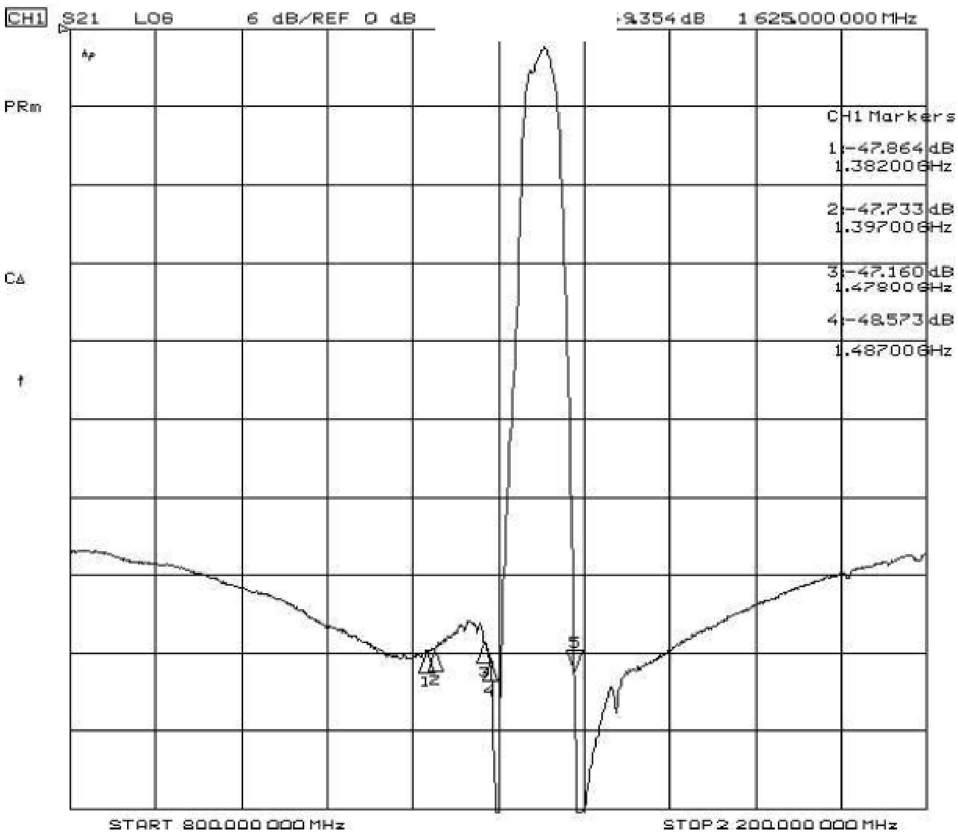

Figure F-5: MA03368 frequency response

Switch:

The selected switch is the MASW-010351 from MACOM. It have a five ports to one configuration with an absorptive typology. Can be polarized at 1.8 V (GPIO of Overo voltage level) and transmit ones at the same supply voltage.

Table F-3: MASW-010351 insertion losses

Channel	***IL (dB)***
AIS	1.8
L2	1
Radiometer	0.9
L1	0.8

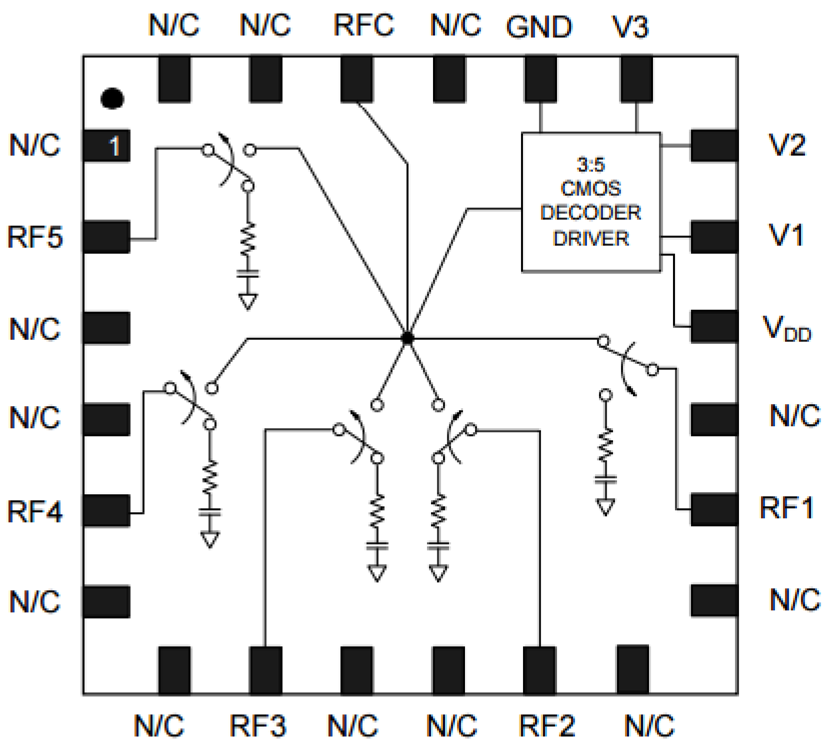

Figure F-6: Functional diagram of the MASW-010351

Appendix G: Payload's Control Signals

On this appendix, the control signals used on the Conditioning Board are listed. All signals are generated on the Acquisition Board and transmitted to the Conditioning Board by the board to board stackable connector.

Table G-1: Control signals of the payload

Part	*Signal*	*V nominal*	*I nominal*
LDO (LNA1)	EN1	1.8 V	5.5 uA
LDO (LNA2)	EN2	1.8 V	5.5 uA
LDO (LNA3)	EN3	1.8 V	5.5 uA
LDO (LNA4)	EN4	1.8 V	5.5 uA
Switch 1	Vdd_S1	1.8 V	1 uA
	V1_S1	1.8 V	5 uA
	V2_S1	1.8 V	5 uA
	V3_S1	1.8 V	5 uA
Switch 2	Vdd_S2	1.8 V	1 uA
	V1_S2	1.8 V	5 uA
	V2_S2	1.8 V	5 uA
	V3_S2	1.8 V	5 uA

Appendix H: Conditioning's Board Layout

On this appendix de PCB layout of the Conditioning Board is shown.

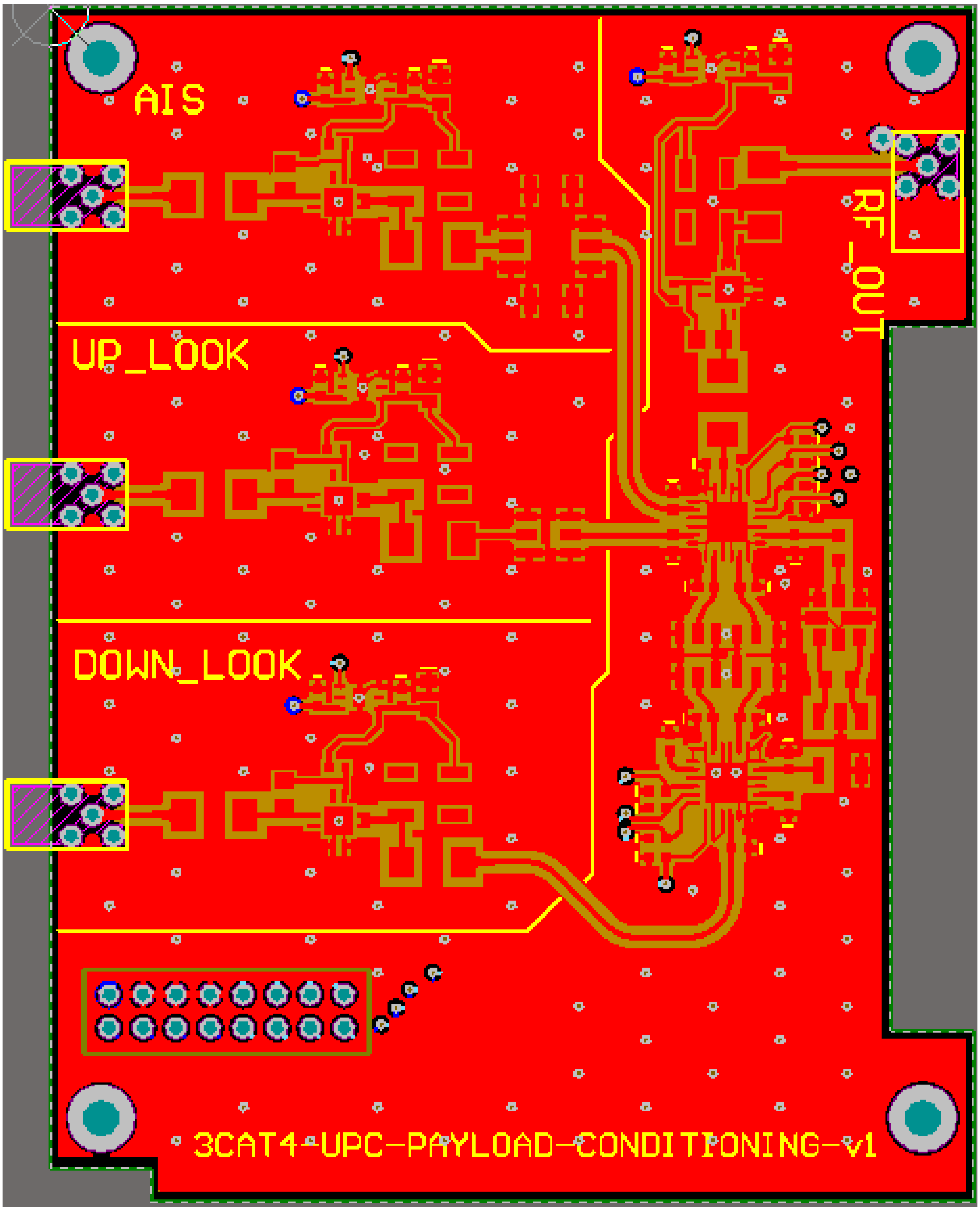

Figure H-1: Top Layer of the Conditioning Board

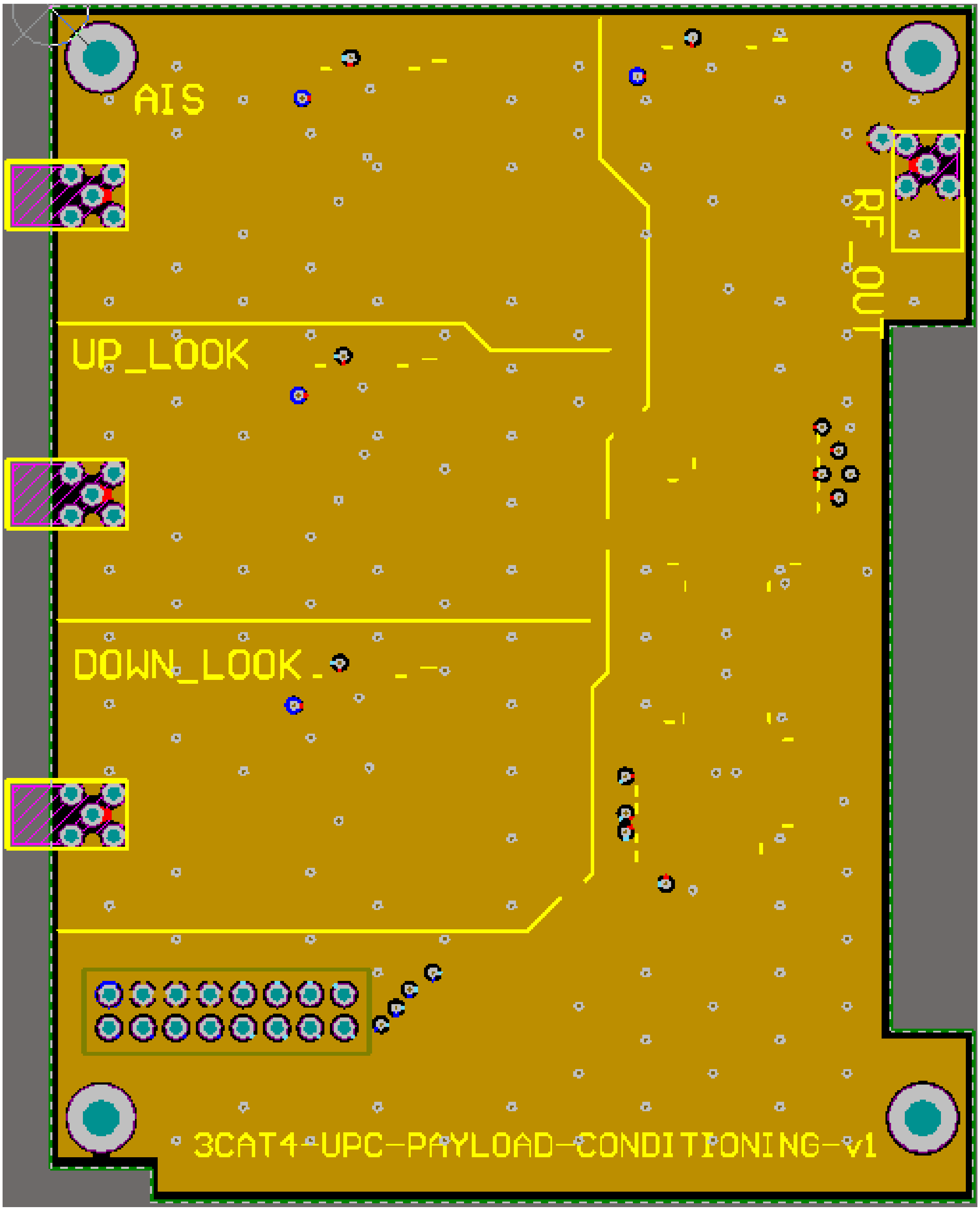

Figure H-2: Internal Layer 1 of the Conditioning Board

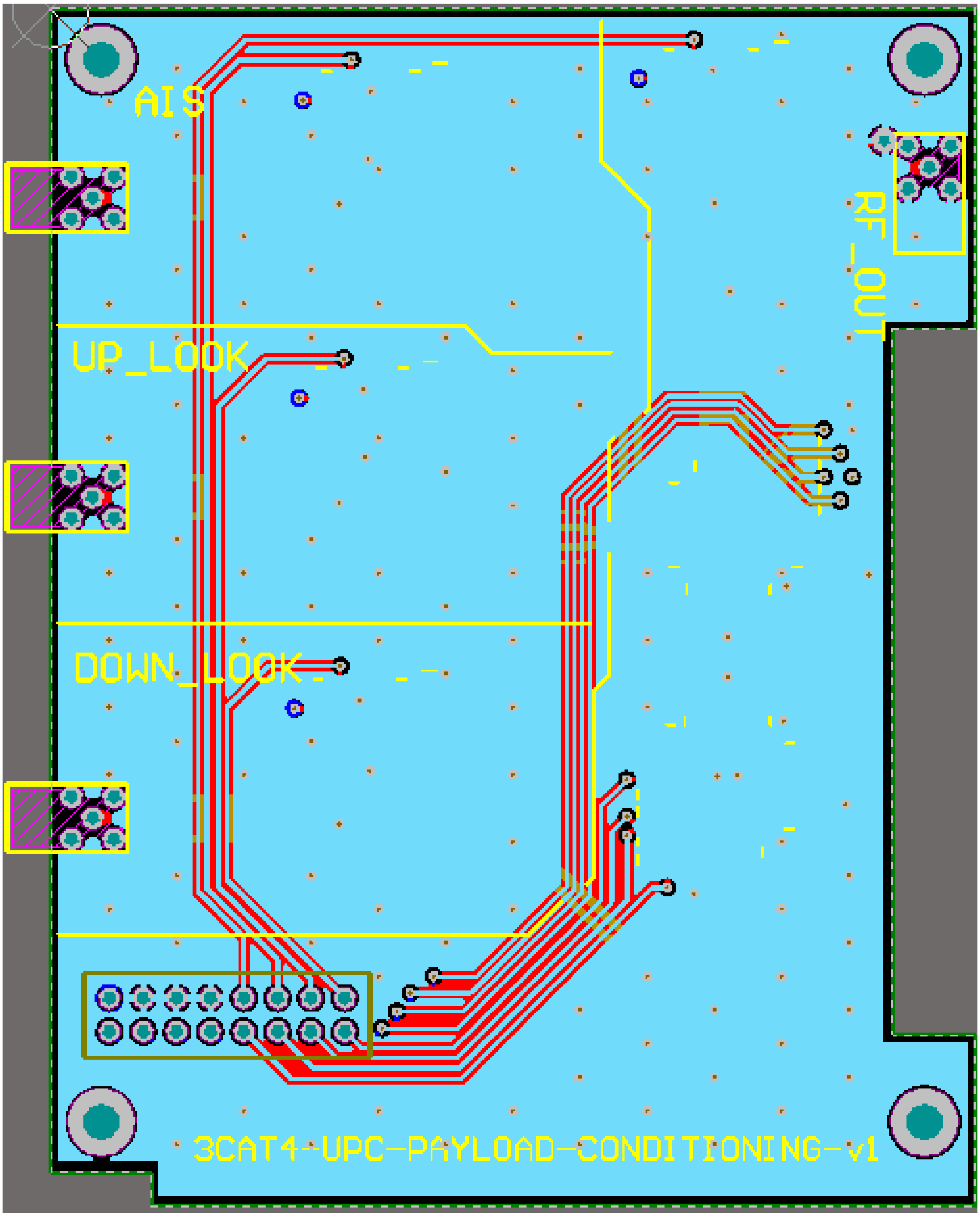

Figure H-3: Internal Layer 2 of the Conditioning Board

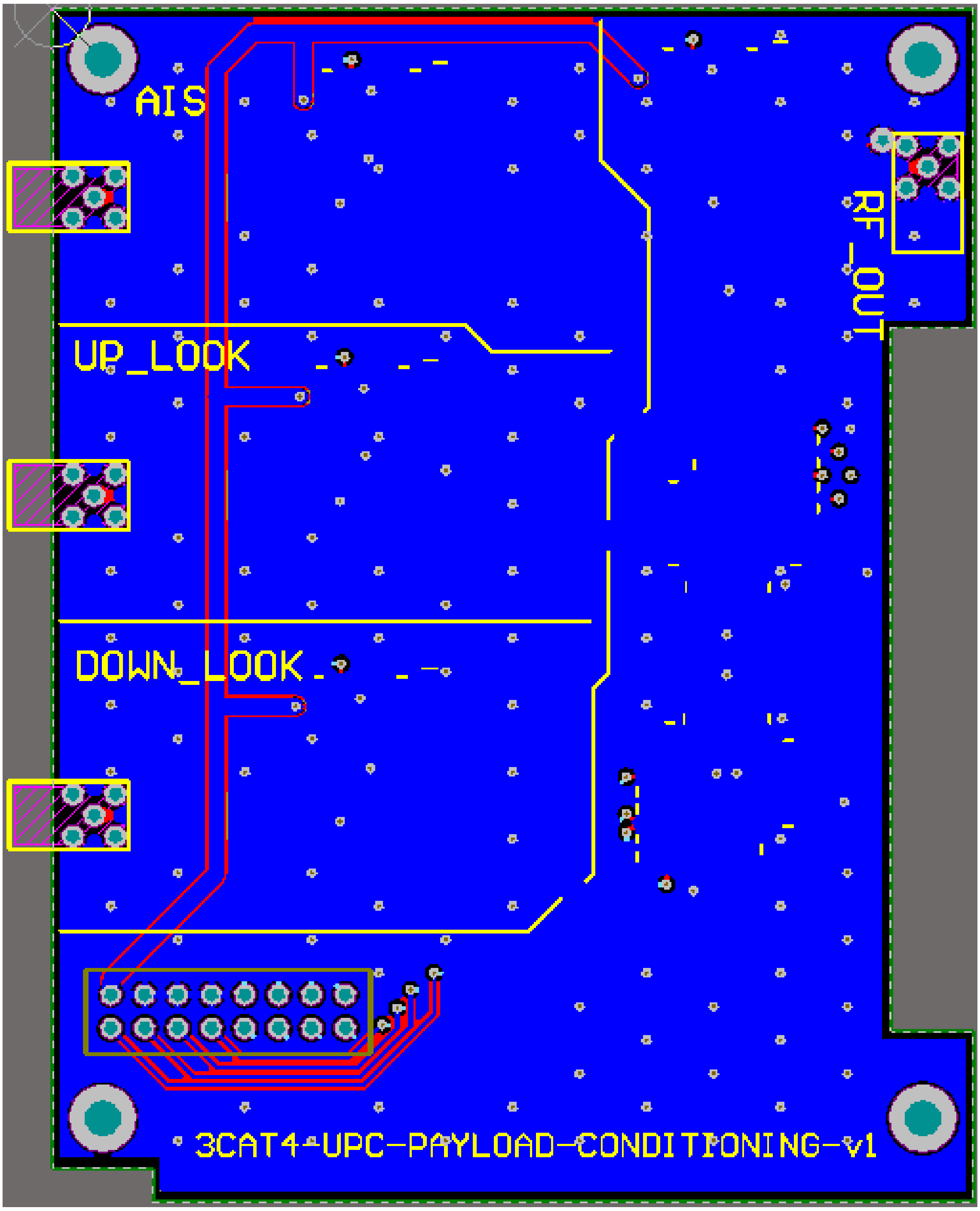

Figure H-4: Bottom Layer of the Conditioning Board

Appendix I: Acquisition's Board Layout

On this appendix, the PCB layout of the Acquisition Board is shown.

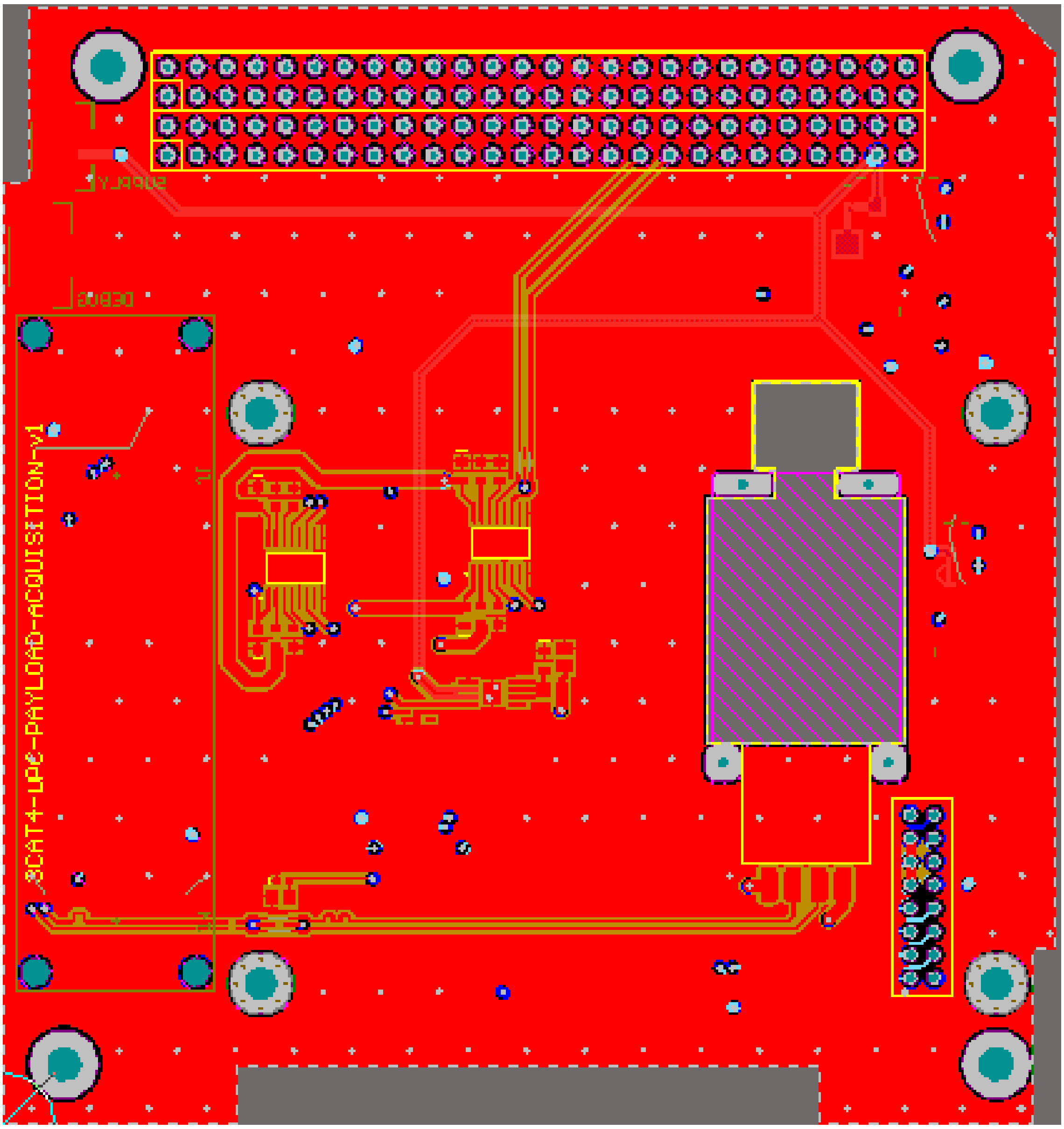

Figure I-1: Top Layer of the Acquisition Board

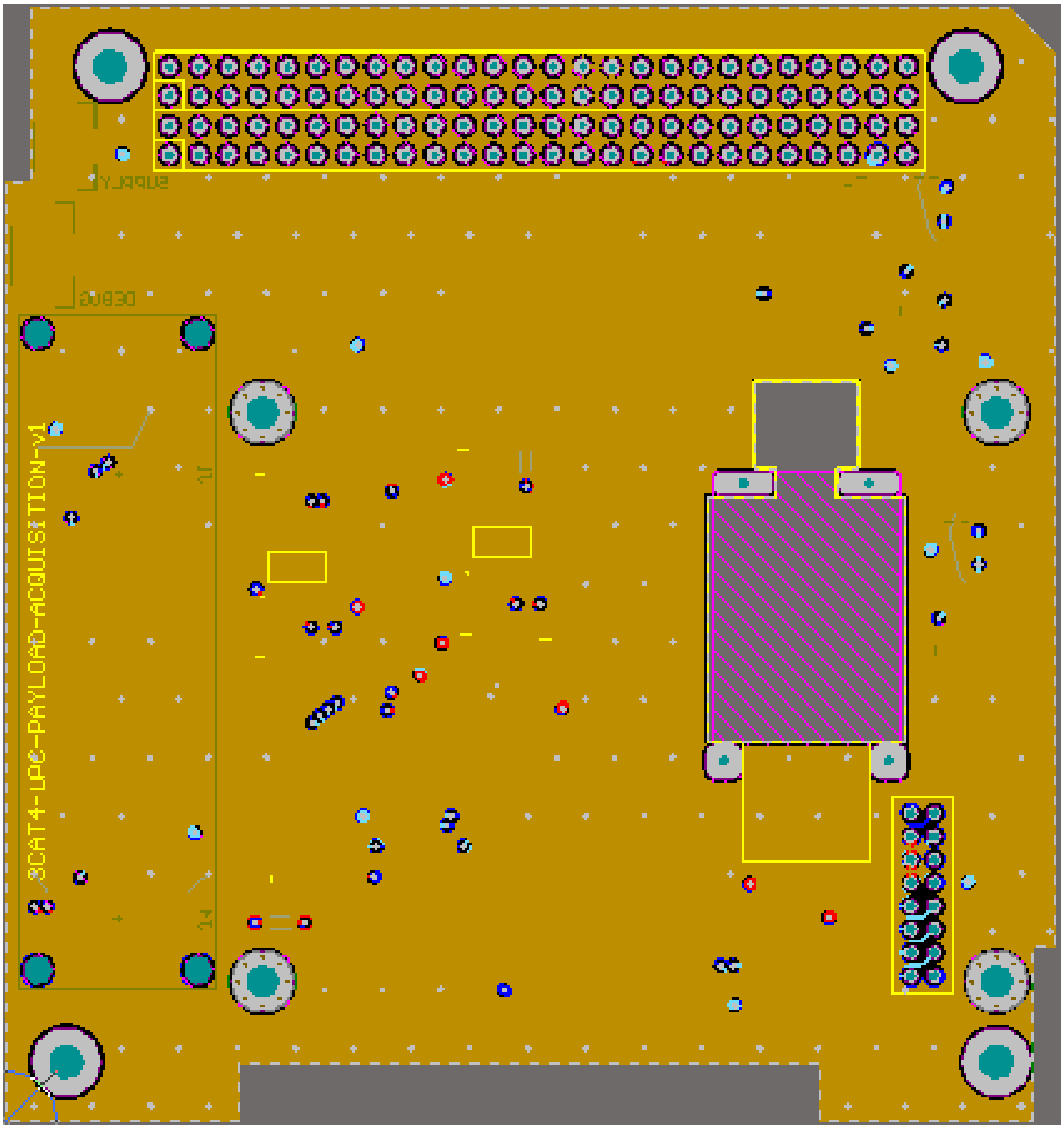

Figure I-2: Internal Layer 1 of the Acquisition Board

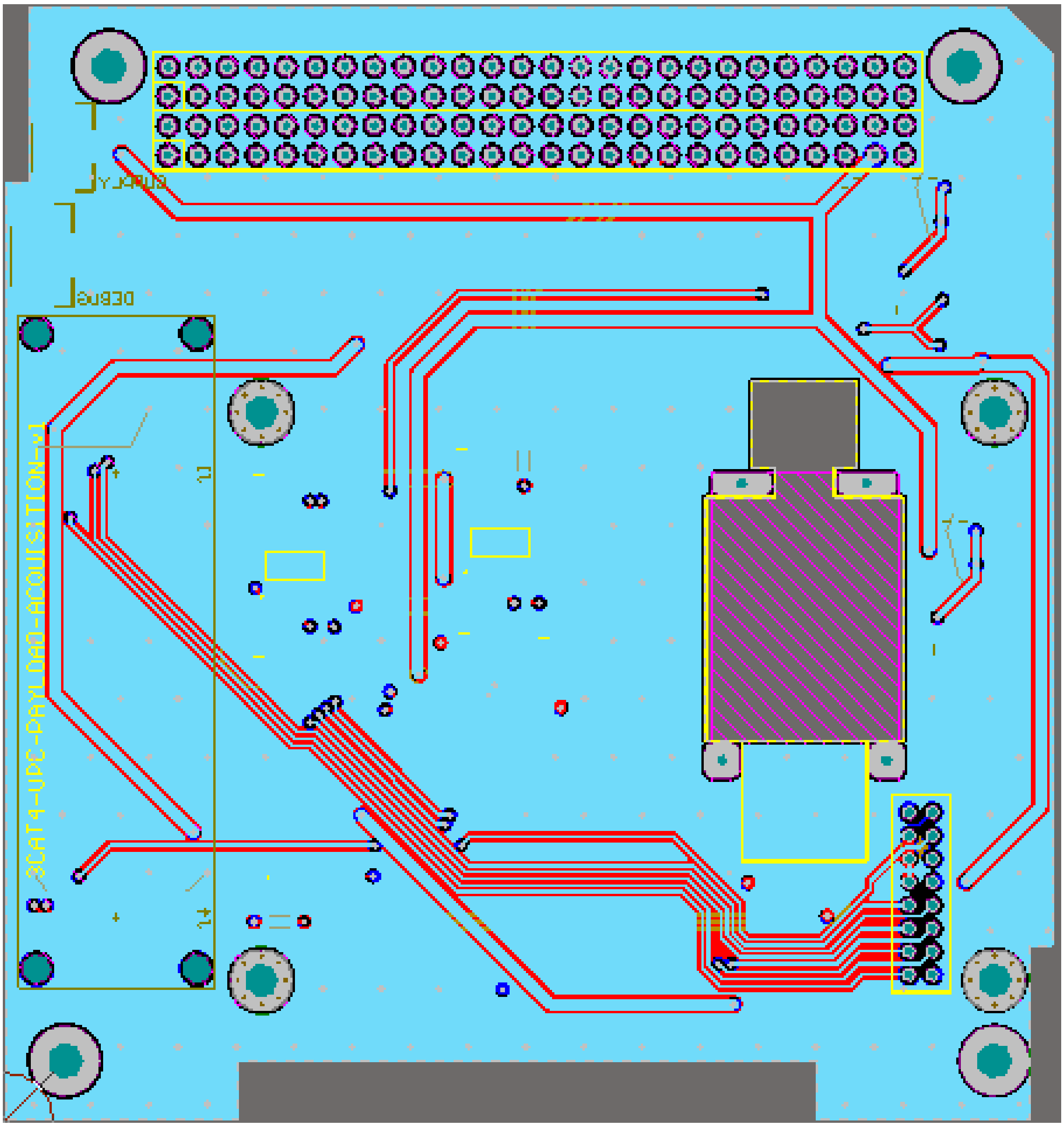

Figure I-3: Internal Layer 2 of the Acquisition Board

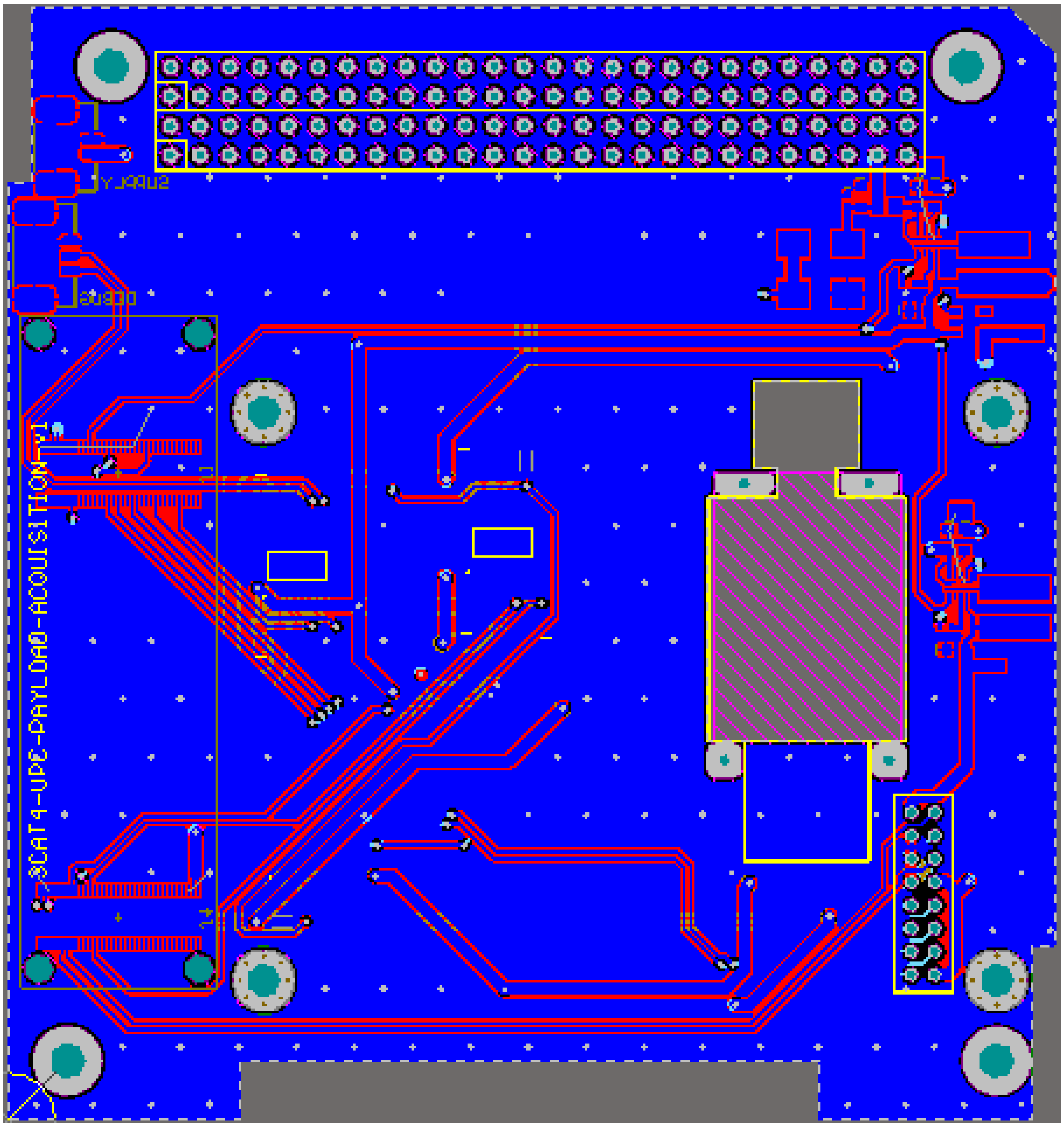

Figure I-4: Bottom Layer of the Acquisition Board

Appendix J: Payload images

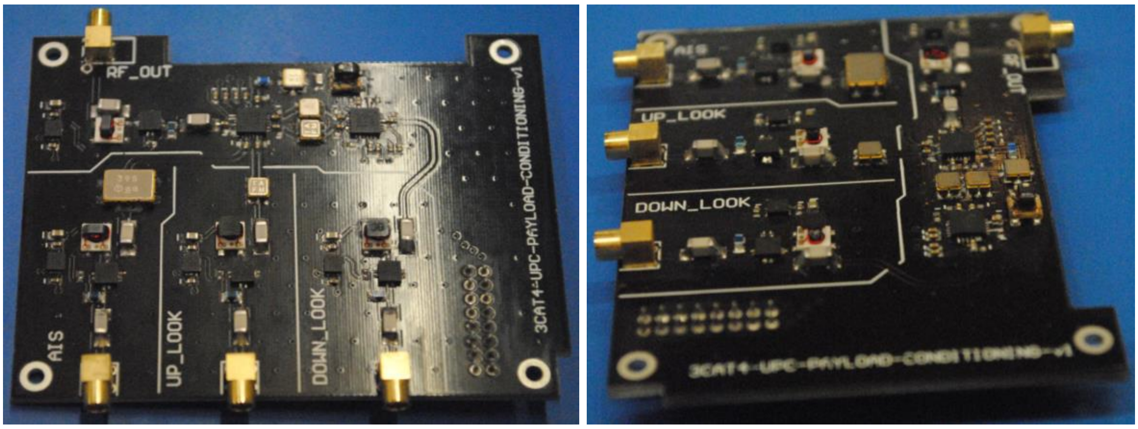

Figure J-1: (Left) Conditioning Board up sight, (Right) Conditioning Board lateral sight

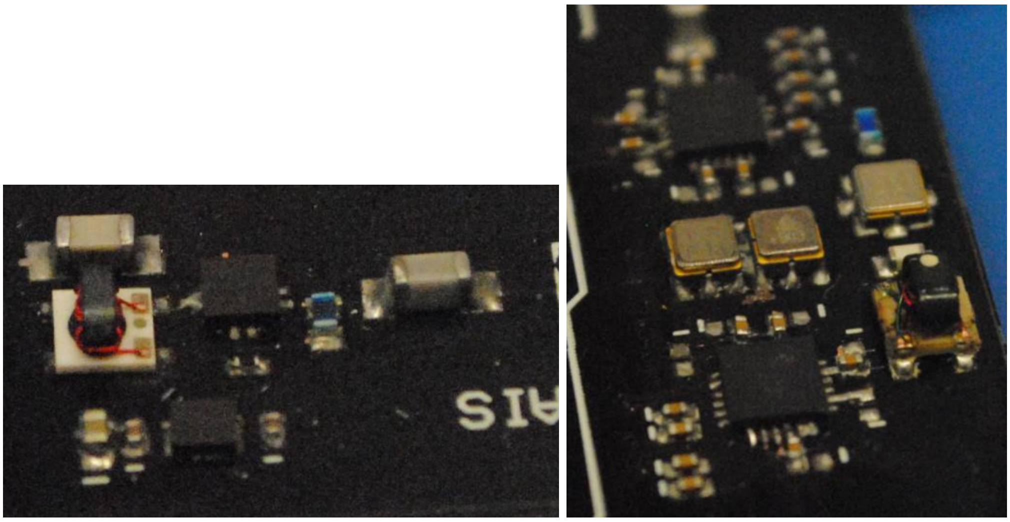

Figure J-2: (Left) Amplifying circuit, (Right) Switching circuit

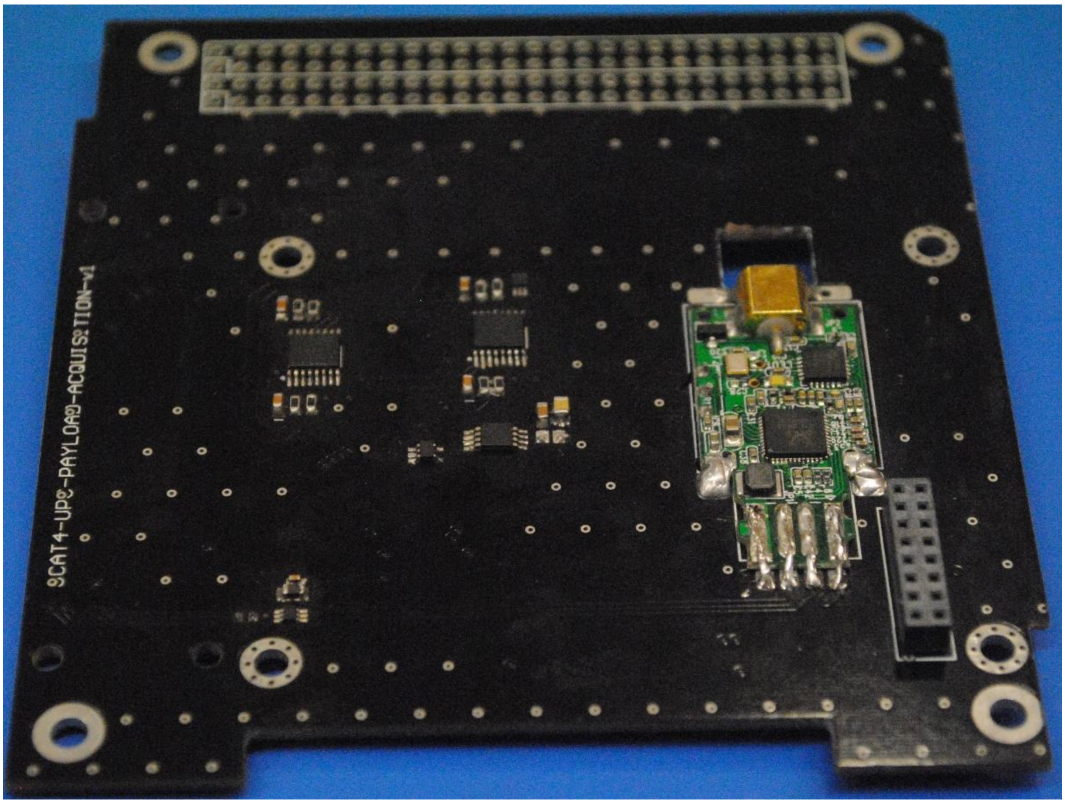

Figure J-3: Top Layer of the Acquisition Board

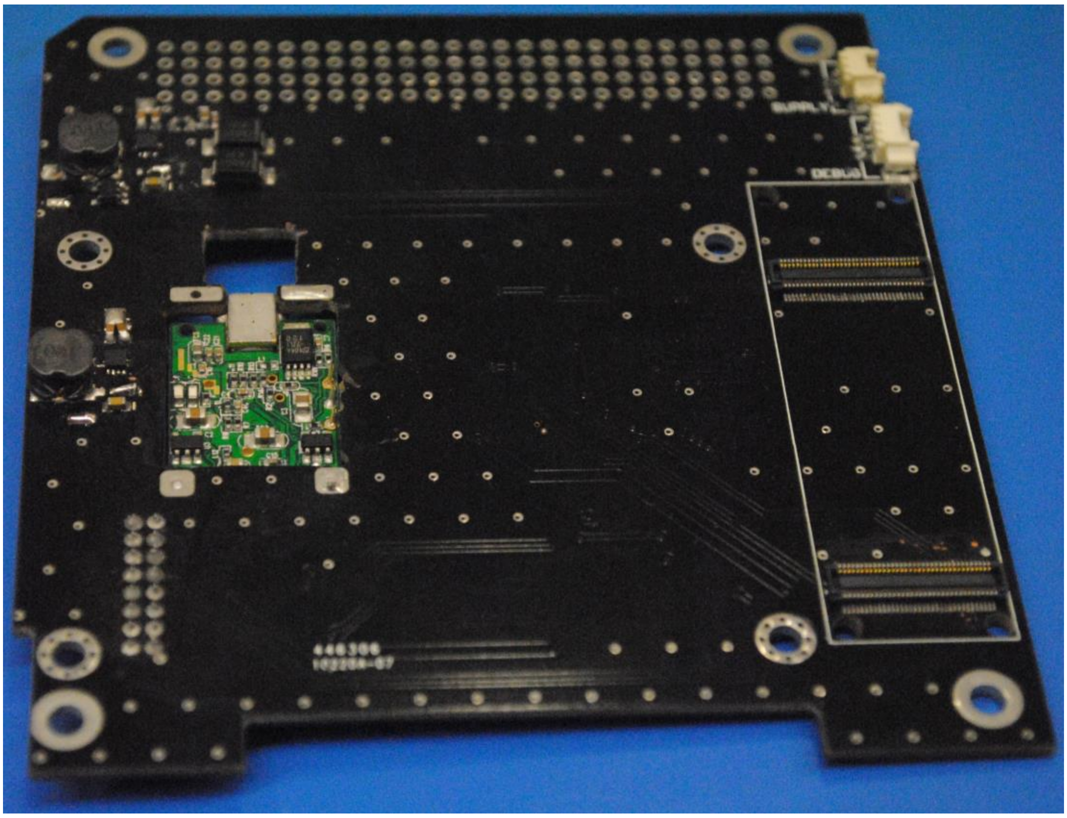

Figure J-4: Bottom Layer of the Acquisition Board

Figure J-5: Overo Ironstorm-P connected

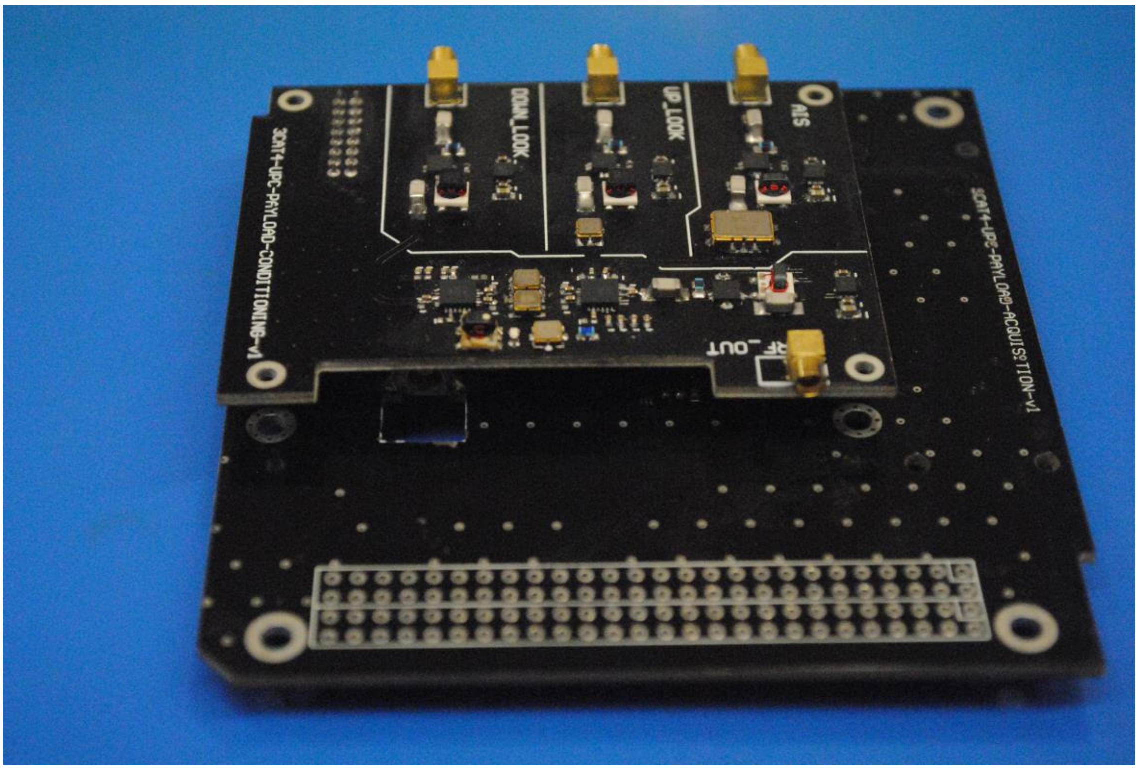

Figure J-6: Complete Payload

Appendix K: Conditioning's Board S-Parameters

In this Appendix, the S-Parameters of every RF chain are shown.

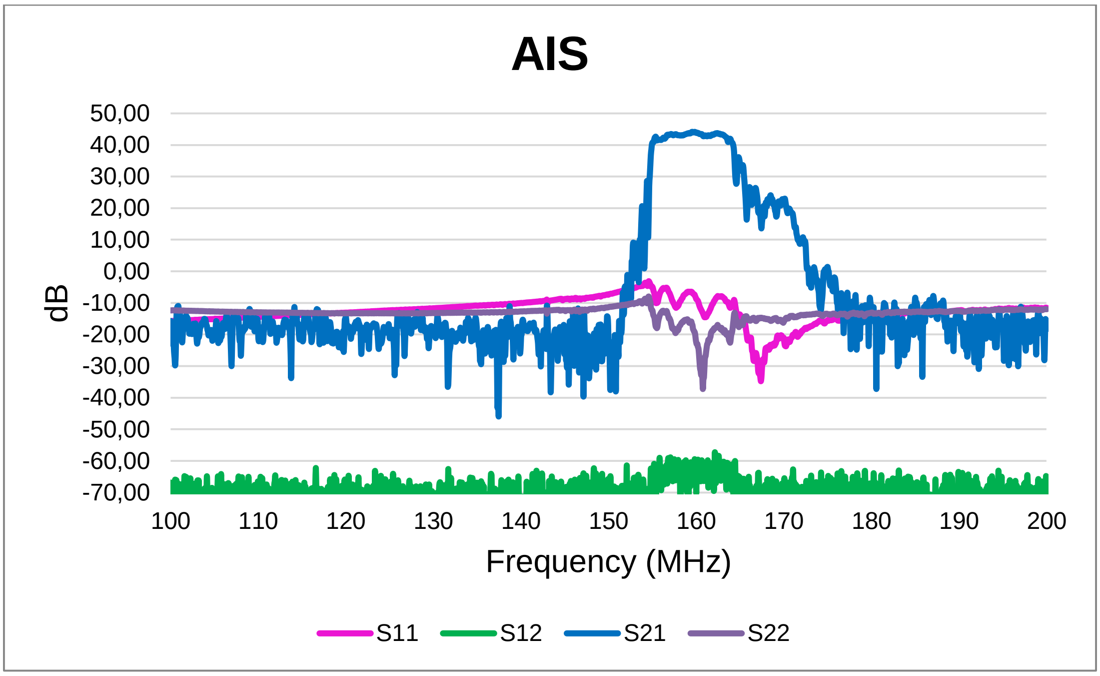

Figure K-1: AIS RF chain S-Parameters

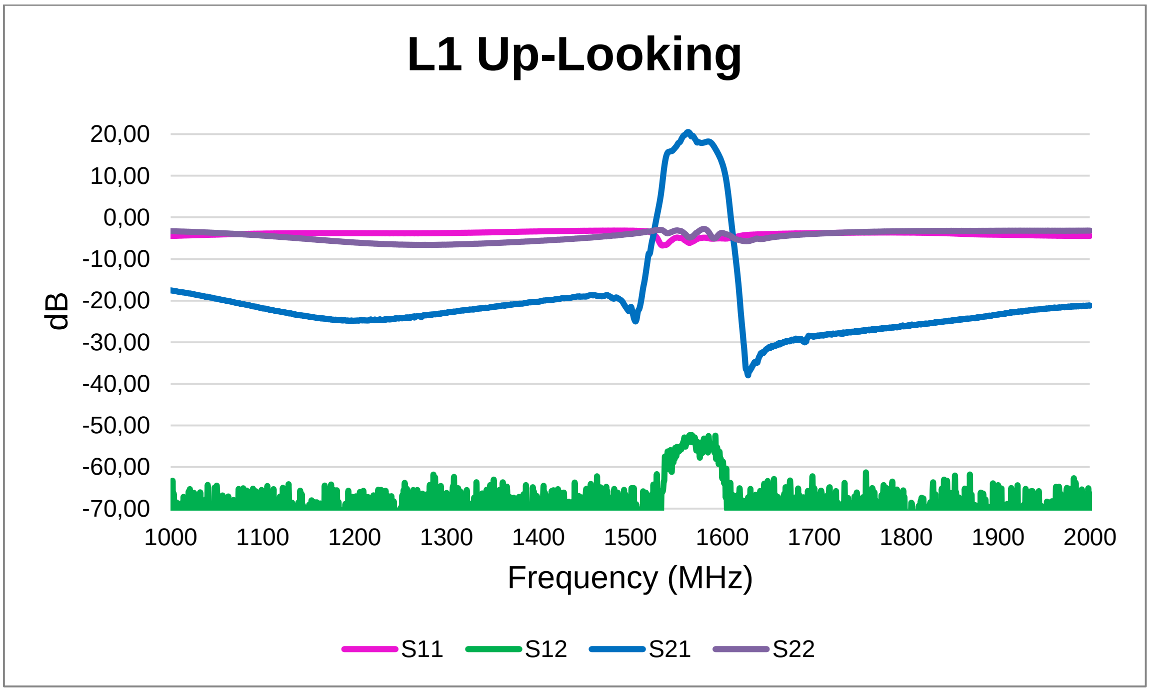

Figure K-2: L1 Up-Looking RF chain S-Parameters

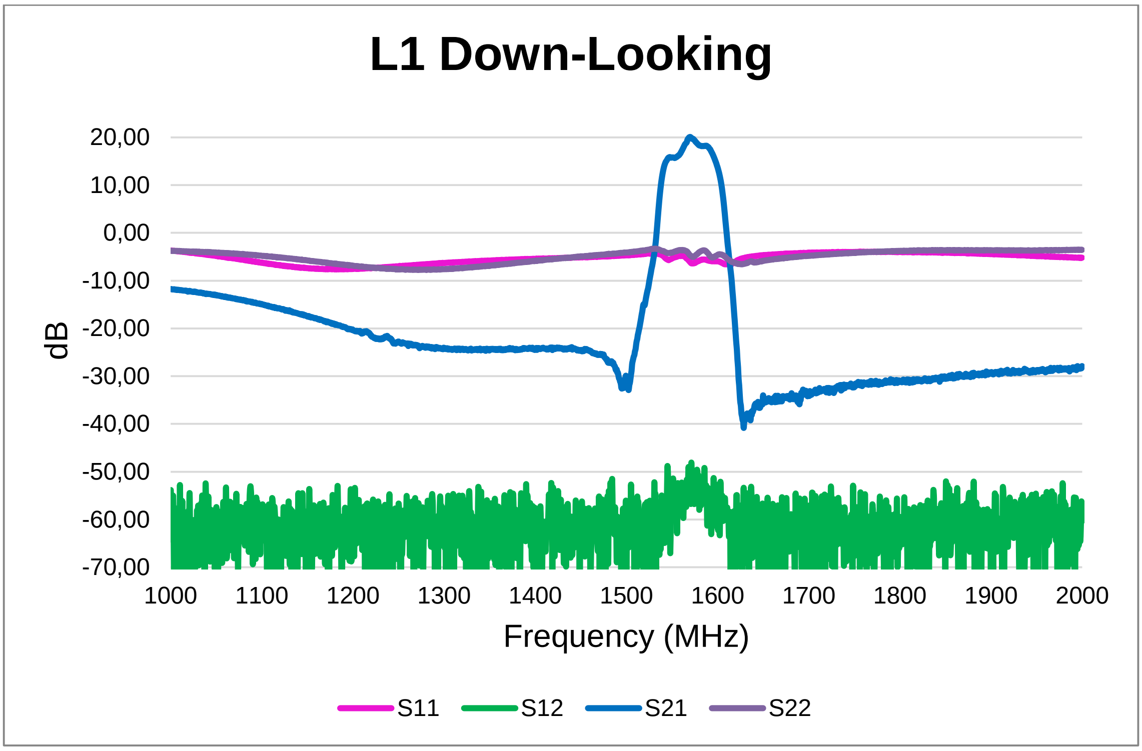

Figure K-3: L1 Down-Looking RF chain S-Parameters

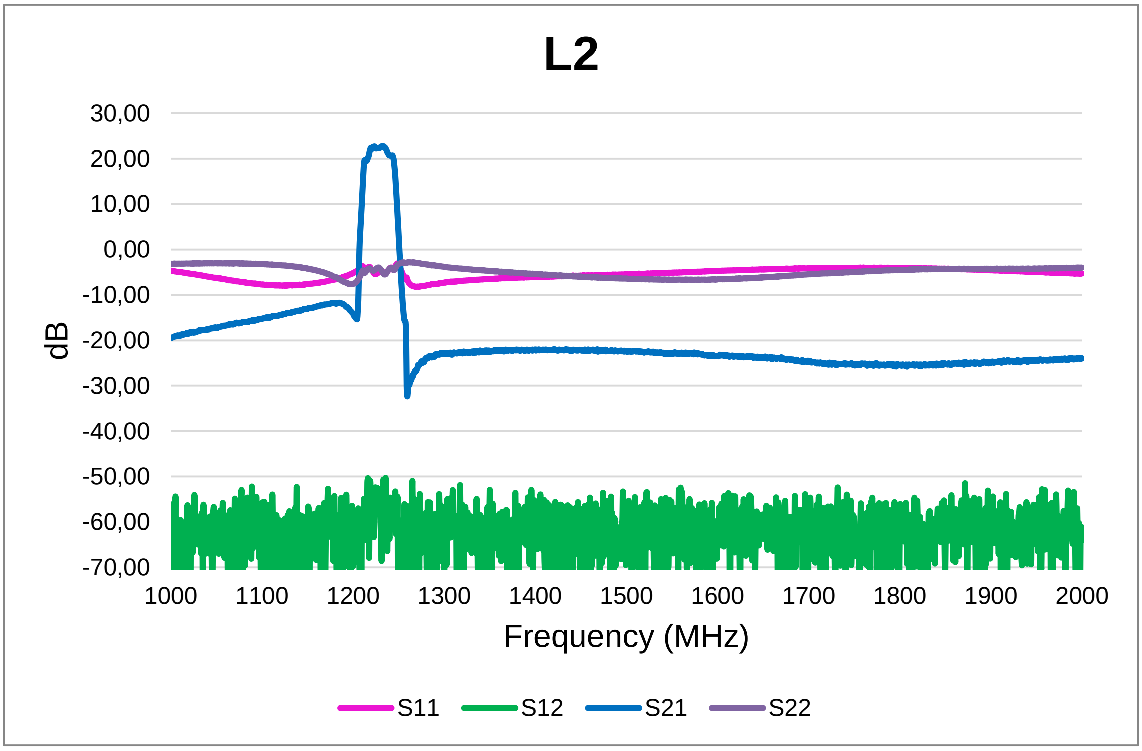

Figure K-4: L2 Down-Looking RF chain S-Parameters

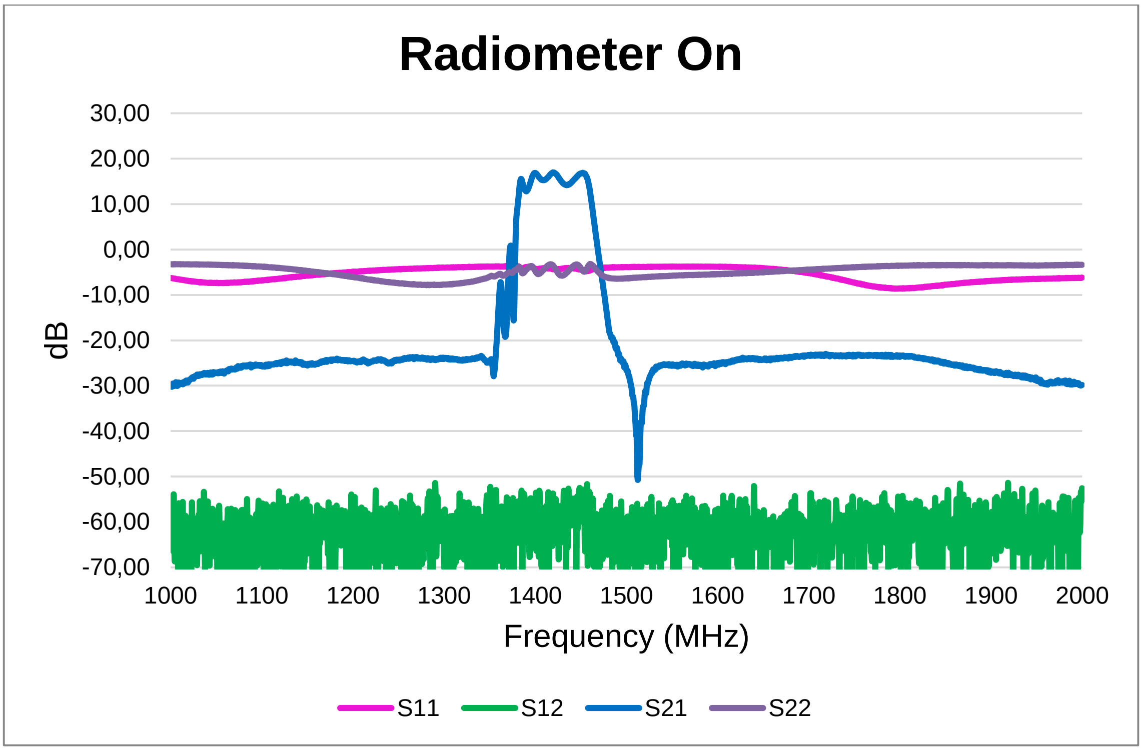

Figure K-5: Radiometer RF chain S-Parameters

Appendix L: AIS Received Packets

In this appendix, the output of the AIS software with the data about the packets received is shown.

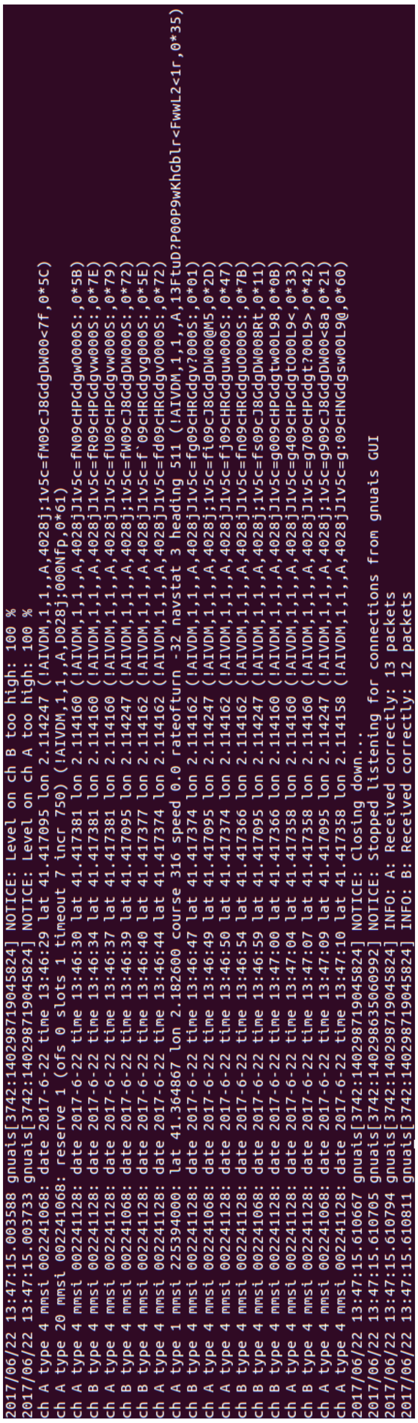

Figure L-1: AIS received packets of Torre de Collserola at Campus Nord

Figure L-2: AIS received packets of vessels at Port of Barcelona

Appendix M: 3Cat-4 Renders

On this appendix the CAD renders of the ^{3}Cat-4 are shown so a more detailed of the payload integration on the satellite can be obtained.

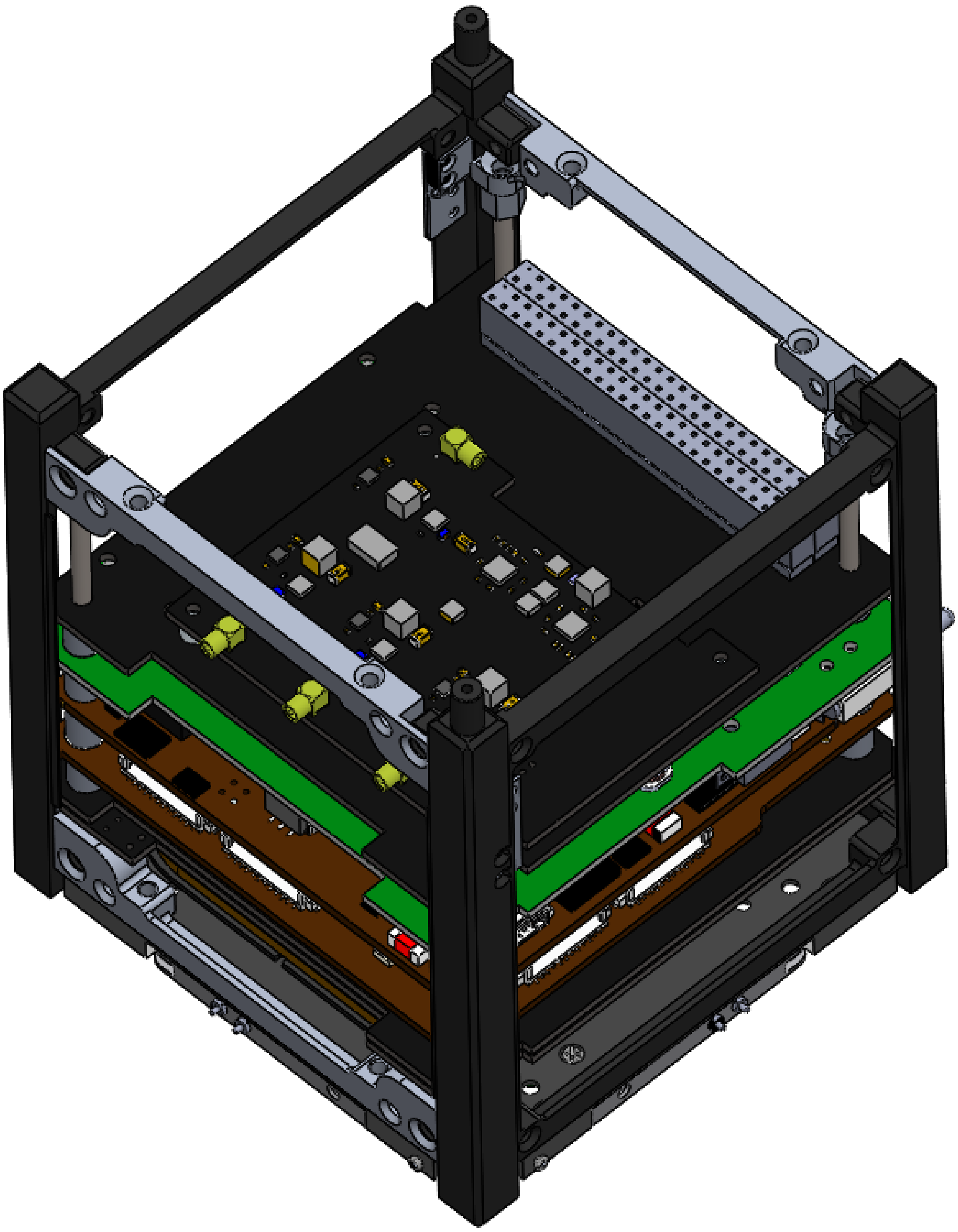

Figure M-1: 3Cat-4 mid-up sight without solar panels

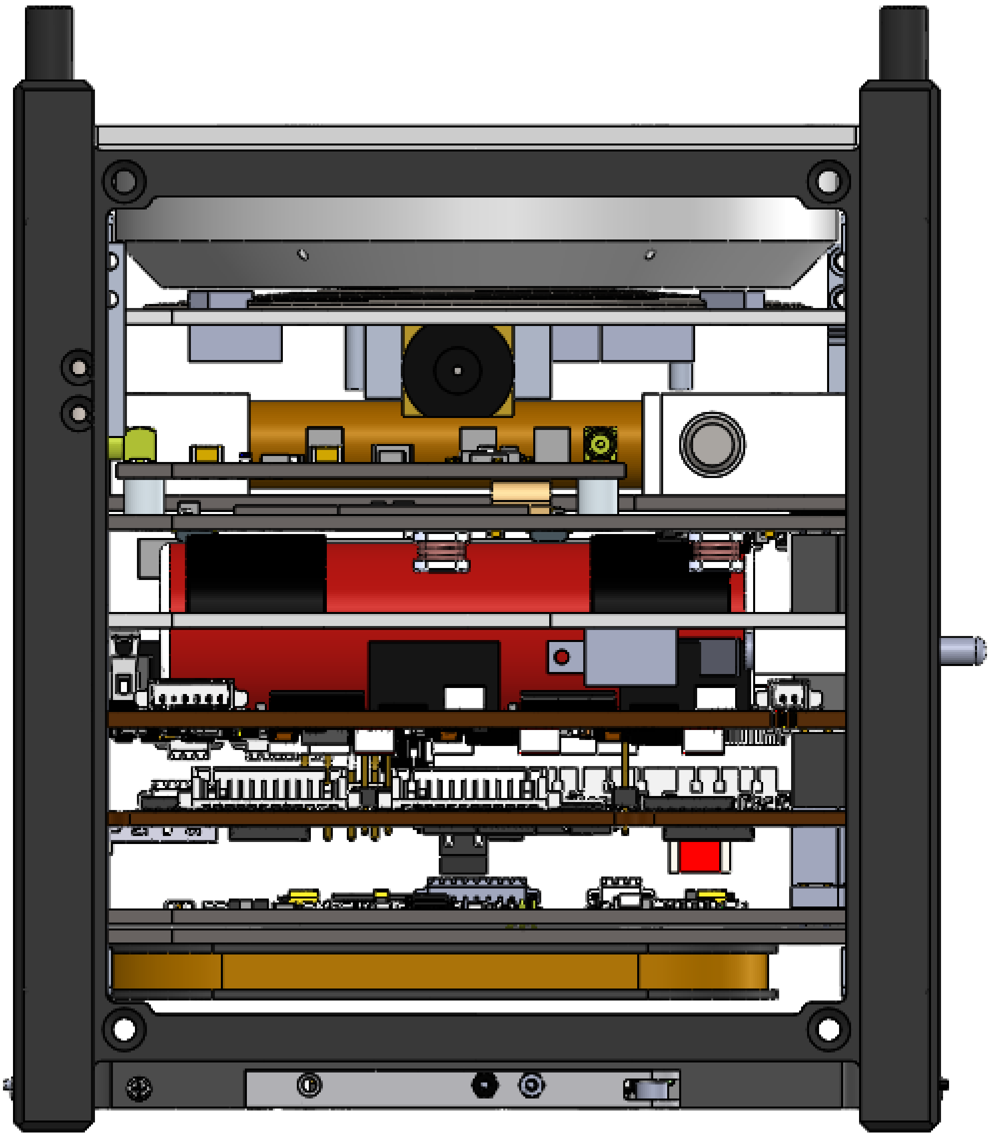

Figure M-2: 3Cat-4 lateral sight without solar panels

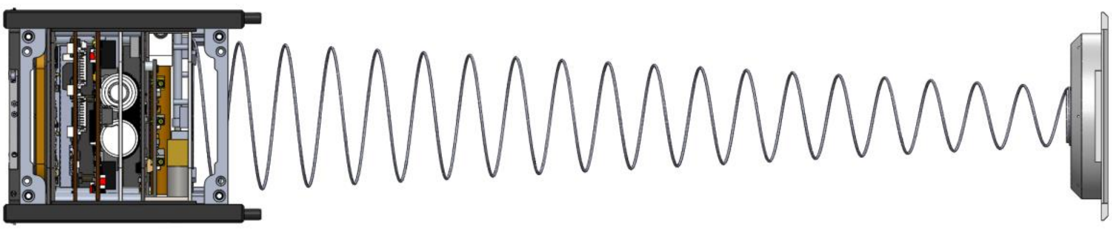

Figure M-3: 3Cat-4

Appendix N: Hot Air Welding Procedure

In this appendix the hot air welding procedure is explained.

Step 1: Cover the footprint with a thin layer of tin using the soldering iron.

Figure N-1: Footprint of the TPS62097

Step 2: Repeat the same step on the pads of the component. The nominal temperature of the soldering iron have to be reduced to maximum 300 ºC in order to avoid damaging the component.

Figure N-2: Bottom layer of the TPS62097

Step 3: Configure the hot air machine at a temperature between 350 ºC and 400 ºC and the air flow at the minimum level. Apply heat until the thin layer of tin applied on step 1 starts to melt.

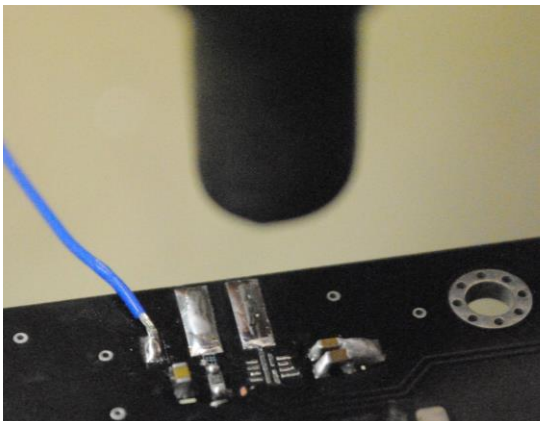

Figure N-3: Applying heat to the footprint

Step 4: Once the tin surface of the footprint starts to melt, place the component over the footprint while the heat is still applied. On this step, once the tin layer of the component and the layout melt both, a tension between the liquid tin drops is created and it helps to align the component into the pads position.

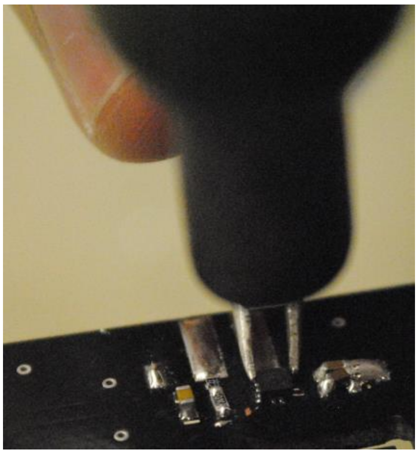

Figure N-4: Placing the component over the footprint

Step 5: Once the pads are correctly aligned with the footprint, press very softly the component in order to ensure that it is completely supported over the PCB and finally stop applying the heat in order to finalize the welding. During this step, if there is some extra tin on the pads of the component, some drops of liquid tin may be spit outside. In case of need to clean the pads of the component because of the extra tin, after the welding it can be extracted by using the soldering iron pad by pad.

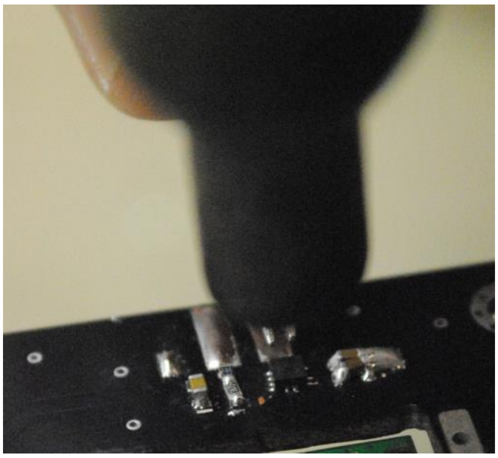

Figure N-5: Pressing the component before stop applying heat