The principal aim of this proyect is the development of low cost radiocommunication systems. More particularly, these are systems based on long distance satelite communications. Herein is presented the analisys, design, simulation and building of some of this systems as well as the improve of the Ground Station of the GranaSAT project.

Miguel Ángel del Río Ruíz is a telecommunication engineer from Granada, Spain. He finished his Master Studies in 2016 at University of Granada. He starts working with GranaSAT Team in 2015, involved in the Ground Station improvement proyect, and continued with his final project degree designing, developing and testing low cost systems for satellite image reception.

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FINAL MASTER PROJECT

Design, development and testing for low cost systems for satellite image reception

Miguel Ángel del RioRuiz

TELECOMMUNICATIONS ENGINEERING

2015/16

UNIVERSITY OF GRANADA

Master in Telecommunications Engineering

FINAL MASTER PROJECT

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Academic year 2015/2016

Tutor: Andrés María Roldán Aranda

Tutor:Ignacio F. Sanchez García

Universidad de Granada

MASTER EN INGENIERÍA DE TECNOLOGÍAS DE TELECOMUNICACIÓN

TRABAJO FIN DE MASTER

“Design, development and testing for low cost systems for satellite image reception”

CURSO: 2015/2016

Miguel Ángel del Río Ruíz

Universidad de Granada

MASTER EN INGENIERÍA DE TECNOLOGÍAS DE TELECOMUNICACIÓN

"Design, development and testing for low cost systems for satellite image reception"

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Informan:

que el presente trabajo, titulado:

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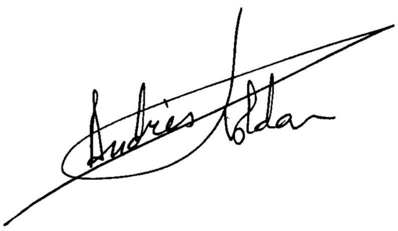

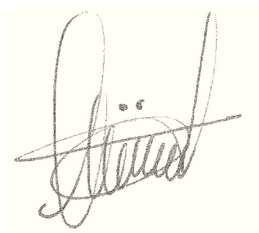

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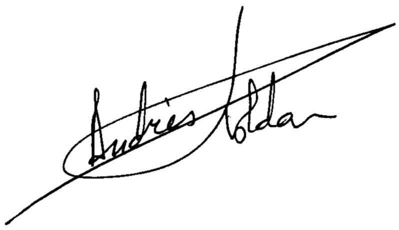

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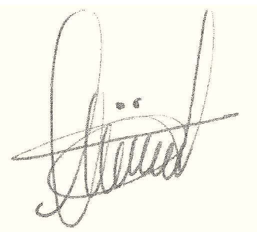

Fdo. Ignacio F. Sanchez García

Design, development and testing for low cost systems for satellite image reception

Miguel Ángel del Río Ruíz

PALABRAS CLAVE:

Antena, Estacion Terrena, satelite, señal, CubeSat, GranaSAT, Solidworks, CST, PCB

RESUMEN:

El principal objetivo del presente trabajo de fin de máster es diseñar sistemas de radiocomunicación de bajo coste capaces de establecer comunicaciones satelitales de larga distancia y que puedan aportar al alumno nuevas capacidades en el campo de las telecomunicaciones así como cumplir los requisitos especificados por el cliente.

El enfoque del proyecto ira orientado a una metodología comercial, de manera que se utilizaran técnicas y herramientas de diseño utilizadas en la industria de las telecomunicaciones de manera de que este trabajo pueda ser útil en el ámbito comercial y los dispositivos aquí fabricados puedan ser replicados para su comercialización. Se ha tratado de dar, además, de un enfoque multidisciplinar a fin de desarrollar y ampliar las capacidades y conocimientos aprendidos durante la titulación de Máster en Ingeniería de Telecomunicación de la Universidad de Granada.

Además del enfoque comercial y multidisciplinar se ha tratado este trabajo de fin de máster de manera que el alumno realice un aprendizaje de dificultad incremental en el que se abordan algunas tareas introductorias y de complejidad cada vez más elevada de modo que sea capaz de comprender y manejar íntegramente tanto el proceso de diseño como las herramientas software y hardware utilizadas.

Cabe destacar también que este trabajo está integrado en el marco del proyecto GranaSat y que las tareas realizadas sirven para cumplir requisitos de este extenso proyecto.

KEYWORDS:

Antenna, Ground Station, Satellite, signal, CubeSat, GranaSAT, solidworks, CST, PCB

ABSTRACT:

The principal aim of this final master work is to design low cost radiocommunications systems able to establish long distance satellite communications which can provide the student new capacities and knowledge in the field of telecommunications and satisfy the client requirements.

The approach of the project will be guided to a commercial methodology, by this way, telecommunications industry tools and techniques will be used in order to this work can be useful in the commercial ambit and the devices that we build can be replicated for its commercialization. We have tried to give a multidisciplinary focusing in order to improve and develop skills and knowledge learned during the telecommunications engineering master degree in the university of Granada.

Added to that, we have tried this Final master work with the objective the student have a incremental difficulty learning in which some introductory task of increasingly high complexity are approach by the student with the objective he can be able to understand and manage as well the whole design process as the software and hardware tools used.

Is noteworthy that this final master work is integrated into GranaSAT project, so, the task performed serves to satisfy some requirements of this extensive project.

Dedicado a

Mi madre, porque sin su apoyo, llegar hasta aquí no habría sido posible. A mis compañeros de GranaSAT, por hacerlo todo un poco más ameno y fácil. A mis amigos, por haberme ayudado en la medida de lo posible. Y por último, a aquellos que no pudieron verlo.

Agradecimientos:

En primer lugar, me gustaría agradecer a mi madre, y a mi familia, 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.

También quiero agradecer a mis compañeros de Teleco y amigos, 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.

Por último, agradezco a todo el equipo de desarrollo de GranaSAT su colaboración y ayuda, mención especial a mi tutor, Andrés María Roldán Aranda por su tiempo dedicado y por preocuparse por nuestra vida profesional.

Acknowledgments:

Firstly, I would like to thank my mother and my family 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.

I want to thank to my Teleco's colleagues and friends, 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.

Finally, I would like to thank to the GranaSAT Development Team, with especial mention to my advisor, Andrés María Roldán Aranda for his provided timely and to care for my professional life.

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GLOSSARY

ADS Advanced Design System (ADS) is an electronic design automation software system produced by Keysight EEsof EDA,[1] a division of Keysight Technologies. It provides an integrated design environment to designers of RF electronic products such as mobile phones,[2] pagers, wireless networks, satellite communications, radar systems, and high-speed data links [Wikipedia, 2016a].

CST MWS CST MICROWAVE STUDIO® is a specialist tool for the 3D EM simulation of high frequency components.

Cubesat Cubesat is a type of miniaturized satellite for space research that is made up of multiples of 10×10×11.35 cm cubic units. CubeSats have a mass of no more than 1.33 kilograms per unit, and often use commercial off-the-shelf (COTS) components for their electronics and structure. CubeSats are most commonly put in orbit by deployers on the International Space Station, or launched as secondary payloads on a launch vehicle.

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/.

Ground Station A ground station is a terrestrial radio station designed for extraplanetary telecommunication with spacecraft (constituting part of the ground segment of the spacecraft system), or reception of radio waves from astronomical radio sources.

LNA A LNA (Low Noise Amplifier) is an electronic amplifier that amplifies a very low-power signal without significantly degrading of its signal-to-noise ratio.

LNB A low-noise block downconverter (LNB) is the receiving device mounted on satellite dishes used for satellite TV reception, which collects the radio waves from the dish. Also called a low-noise block, low-noise converter (LNC), or even low-noise downconverter (LND).

SolidWorks 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.

Touchstone Touchstone is a format of ASCII file used to define electronic devices properties.

UHF UHF (Ultra High Frequency) is the lowest frequency in amateur UHF band. It defines frequencies between 420 MHz and 450 MHz.

VHF VHF (Very High Frequency) is the band defined between 420 MHz and 450 MHz frequencies.

VNA A VNA (Vector Network Analyzer) is an instrument that measures the network parameters of electrical networks. Nowadays, network analyzers commonly measure s–parameters because reflection and transmission of electrical networks are easy to measure at high frequencies, but there are other network parameter sets such as y-parameters, z-parameters, and h-parameters. Network analyzers are often used to characterize two-port networks such as amplifiers and filters, but they can be used on networks with an arbitrary number of ports.

X-Quad The X-Quad is an improved design of the well known multi element quads. They are especially designed for amateur radio.

ACRONYMS

AMSAT Radio Amateur Satellite Corporation.

AoS Arrival of Signal.

ARISS Amateur Radio on the International Space Station.

ESA European Space Agency.

HF High Frequency.

ISS International Space Station.

LoS Lost of Signal.

OEM Onda electromagnetica.

QHA Quadrifilar Helix Antenna.

SWR Standing wave ratio.

CHAPTER

1
INTRODUCTION

This final master project completed the studies of the Master in telecommunications technology engineering. The aim of this is to design, develop and test low cost systems for satellite image and video reception. This project is part of GranaSAT program.

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 based on the students degree and master final project. This project is coordinated by the professor Andrés María Roldán Aranda and it allows students to acquire knowledge about the aerospace field and a real experience in this area. The equipment needed for that project and the laboratories for the students projects are located in the Sciences Faculty of the University of Granada.

Figure 1.1 – *Logo GranaSAT*

The ARISS program is an initiative of AMSAT along with amateur radio organizations. Their main intention is to approach the aerospace world to young students providing an educational opportunity for students, teachers and the general public to learn about space exploration, space technologies and satellite communications [ARISS, 2016]. GranaSAT is a learning program too, therefore, in order to approach the aerospace world to Spanish primary student, we are going to develop the radio system necessary for ISS video contact.

Additionaly, for the purpose of studying Cubesat radiation systems and making communication tests, we are going to develop an antenna. The aim is to contact with two new cubesat which ESA has launched recently (AAUSAT4 and E-st@r-II Cubesats).

1.1 Problem Statement

The development of a radio system able to contact with the ISS is not an easy task for a college organization.

There are some radio systems provided by RF HAMDESIGN enterprise [HAMDESIGN, 2016] for ISS HAM TV contact purposes, but the price of this radiation systems is quite high (approximately, system shown in figure 1.2, parabolic dish and helix dish feed, without LNA, costs 400 €). For this reason, the aim of this project is to design and build a low cost system for satellite video reception.

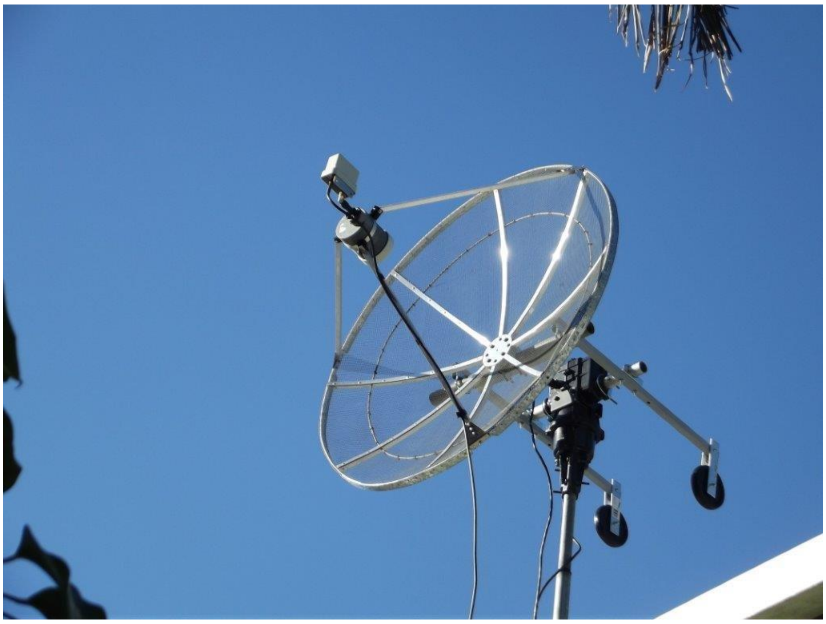


Figure 1.2 – *RF HAMDESIGN parabolic dish and helix dish feed. [HAMDESIGN, 2016]*

Furthermore, due to the fact that the space available on Ground Station antenna tower of GranaSAT is not enough for another antenna, we have to design a low cost fixed antenna for Cubesats mentioned on the introduction of this chapter. One more time, there are some radio systems provided by particular enterprises for Cubesats signal reception. Our objective is to reduce the cost and improve some features of the commercial antennas.

1.2 Motivation

The design and building of a low cost radio system will provide the possibility to have a video contact with ISS to many schools and, in this way, children coursing primary studies could be involved in the scientific world at earlier stages.

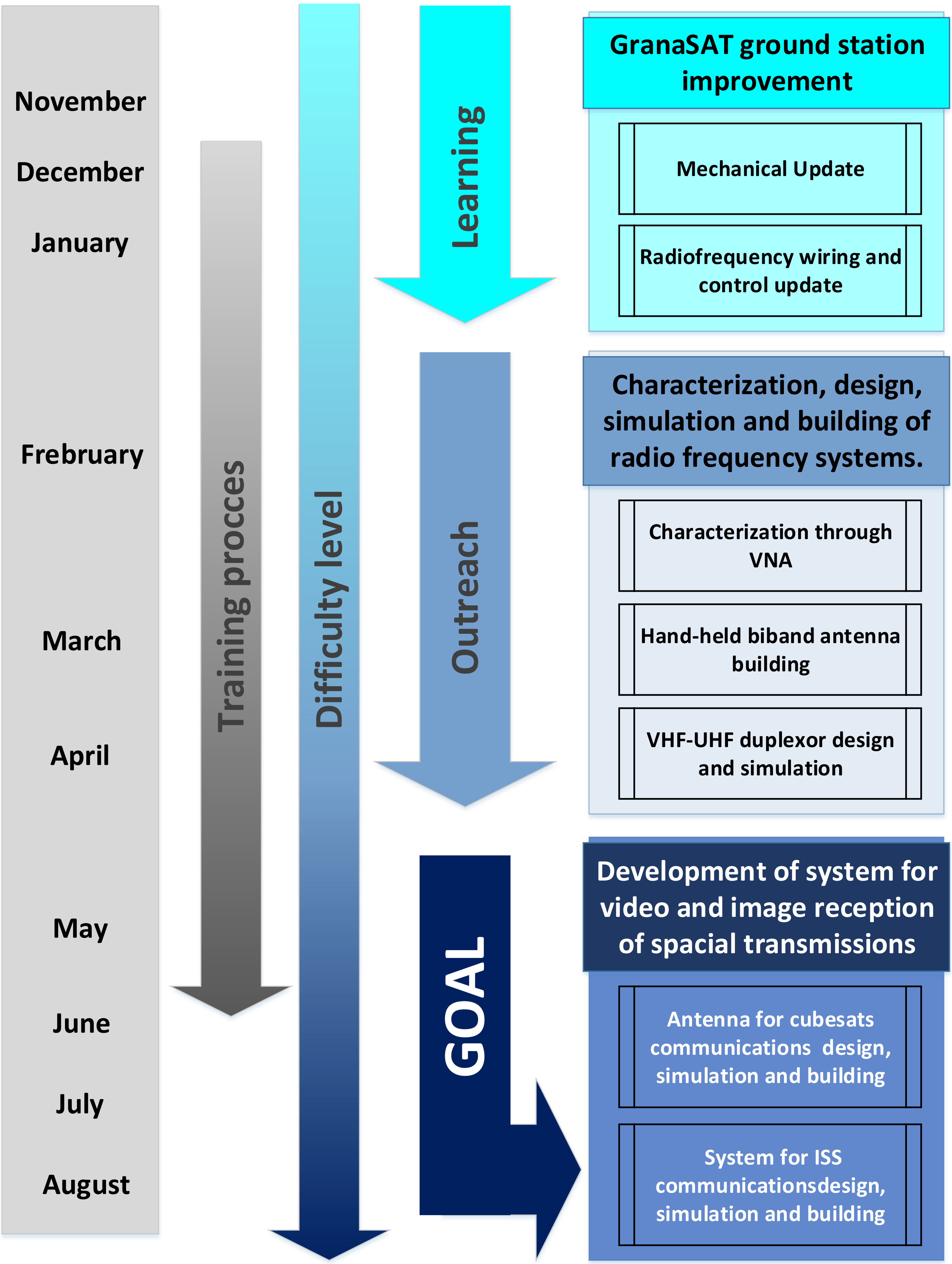
Apart from that, as we saw on chapter 1, the main objective in GranaSAT is to design a Cubesat. Within the aerospace field, it is necessary to be sure that radio systems are working properly. In this line, we are going to design and test the antenna for the GranaSAT Cubesat signal reception. As it is impossible to test the antenna with our own satellite (in real conditions, before launching it to space) we will design the antenna to test it with the AAUSAT4 and E-st@r-II Cubesats.

In order to obtain the necessary knowledge to develop this system, we are going to make some previous tasks directly related with radio frequency field. This will additionally result in an enhancement of the GranaSAT project. Also, the whole project will provide the student the scientific background to process engineering procedure.

1.3 Project Objectives

The objectives of this final master project could be divided into two categories:

- Primary goals: These goals has been explained in previous sections and include the development of radiation system for video and image reception of spacial transmissions:
  - Antenna for Cubesat communications design, simulation and building.
  - System for ISS communications design, simulation and building.
- Secondary goals: These goals helps the student to acquire the knowledge necessary to carry out primary goals and include the improvement of GranaSAT Ground Station and the characterization, design, simulation and building of radio frequency systems.
  - GranaSAT Ground Station improvement.
    - Mechanical update.
    - Radio frequency wiring and control update.
  - Characterization, design, simulation and building of radio frequency systems.
    - Characterization through VNA.
    - Hand-held biband antenna building.
    - VHF-UHF duplexor design and simulation.


November
December
January
Frebruary
March
April
May
June
July
August
Training proces
Difficulty level
Learning
Outreach
GOAL
GranaSAT ground station improvement
Mechanical Update
Radiofrequency wiring and control update
Characterization, design, simulation and building of radio frequency systems.
Characterization through VNA
Hand-held biband antenna building
VHF-UHF duplexor design and simulation
Development of system for video and image reception of spacial transmissions
Antenna for cubesats communications design, simulation and building
System for ISS communicationsdesign, simulation and building

1

1.4 Project Structure

In this project we have followed the system engineering procedure with a previous learning process which allows the student to address the primary goals mentioned on section 1.3. Chapters in this documents are ordered temporally:

- **Chapter 2: GranaSAT ground station improvement:** in this chapter, we will analyse the update of the radiation system of GranaSAT. We will explain the previous state of the ground station and the improvements that we have done. This work helps the student to learn about operation of radiation system on a ground station.
- **Chapter 3: Characterization, design, simulation and building of radio frequency systems:** in this chapter we will do the characterization of radiation parameters of a QHA antenna. We will additionally explain the building of a Hand-held biband antenna and the design and simulation of a VHF and UHF duplexor will be also described.
- **Chapter 4: Antenna for Cubesat communications design, simulation and building:** in this chapter we will see the design, simulation, building and testing procedures followed to develop the antenna.
- **Chapter 5: System for ISS communications design, simulation and building:** in this chapter, we will describe the design, simulation, building and testing procedures followed to develop the radiation system for ISS communications.
- **Chapter 6: Conclusions and future work:** the conclusions of the project and the operational working process will be explained on this chapter. We will also describe briefly the possible improvements and future work related with this project.

CHAPTER

2 GRANASAT GROUND STATION IMPROVEMENT

The GranaSAT Ground Station is located in the Faculty of Sciences in Granada. This Ground Station is composed of two differentiated systems: radiation and control. Radiation system consists of the antennas, the tower, the rotor, the antenna switch, the LNAs and the whole wiring. Control system includes the transceiver,the rotor control system and the antenna switch control system. See figure 2.1.

The Radiation System is placed on the roof of the Faculty of Sciences and the control system is placed on the basement of the same building.

In this chapter we are going to explain the improvement of this Ground Station. First of all, we will introduce the initial state of the whole system before the update our group has carried out. Then, we will see how it could be improved. Finally, we will describe the steps followed for the update of the GranaSAT Ground Station.

2.1 Ground Station previous status

The radiation system was composed of a tower of antennas with two X-Quad antennas, a rotor which is able to orient the antennas where is needed and two LNAs. The control system was composed of a receiver/transceiver and the controller of rotor.

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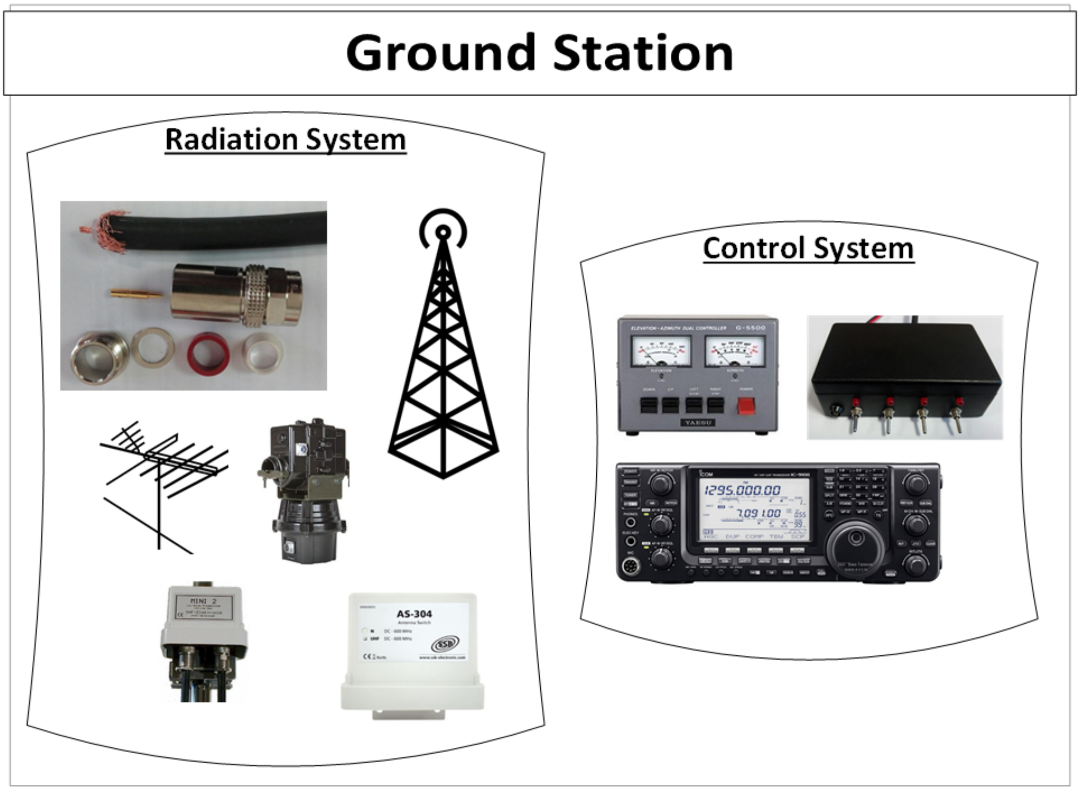


Figure 2.1 – *breakdown of Ground Station system.*

2.1.1 Radiation system previous status

In this subsecction we will do a breakdown of the radiation system elements.

- Antennas: There was two X-Quad antennas. One for 2 m (145 MHz) and another for 70 cm (435 MHz). The polarisation of these antennas is switchable, but it was configured as right hand circular polarization (RHCP) [WIMO, 2016]. add to that, there was one biband antenna (144 MHz and 430MHz) Diamond X-200-N. X-Quad antennas are shown in figure 2.2.

- Rotor: This rotor model G-5500 [YAESU, 2016] was developed by Yaesu company and it allows us to move the antennas in order to orient them to satellites that we need to contact. See figure 2.3.

- LNAs: The LNAs used are MVV 432/2 and Mini 2 of WIMO company. The MVV 432/2 is for 435 MHz and so, it is connected to 2 m X-Quad. The mini 2 amplifier is for 135 MHz and is connected to 70 cm X-Quad. see figure 2.4.

(a) *X-Quad for 2 m* (b) *X-Quad for 70 cm*

Figure 2.2 – *X-Quad antennas on GranaSAT Ground Station before improvement.*

Figure 2.3 – *C rotor.*

(a) *MVV 432/2 LNA* (b) *Mini 2 LNA*

Figure 2.4 – *LNAs on GranaSAT Ground Station before improvement.*

- Tower: The tower is used to aggregate X-Quad antennas, Rotor and LNAs systems in a unique structure. See figure 2.5.

In figures 2.6a and 2.6b we can observe the whole radiation system before the improvements were done.

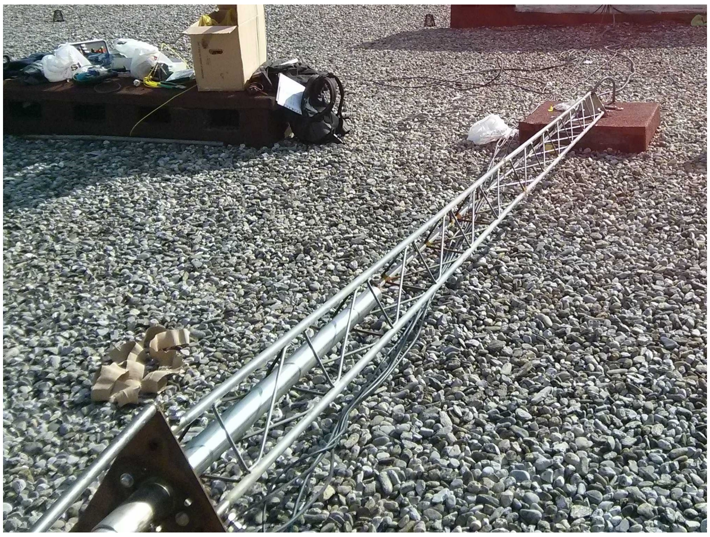


Figure 2.5 – *Antenna tower of GranaSAT.*

(a) *Wimo antennas on tower* **(b)** *complete radiation system*

Figure 2.6 – *Radiation system before improvements.*

2.1.2 Control system previous status

In this subsection we will do a breakdown of the control system elements.

- Transceiver: The Icom IC-9100 works on HF, VHF and UHF bands. It has two independent receivers. see figure 2.7

Figure 2.7 – *Icom IC-9100 transceiver.*

- Rotor controller: The rotor controller used in GranaSAT is the Yaesu G-5500. see figure 2.8.

Figure 2.8 – *Yaesu G-5500 controller.*

A diagram of the whole Ground Station system before its update is shown on figure 2.9.

2.2 Ground Station improvements

The aim of this section is to update the Ground Station system with new antennas in the communications tower. For this purpose, we need to increase the tower capacity and to include a switch which allows us to choose the antenna needed. The steps followed for this update to be completed are listed below.

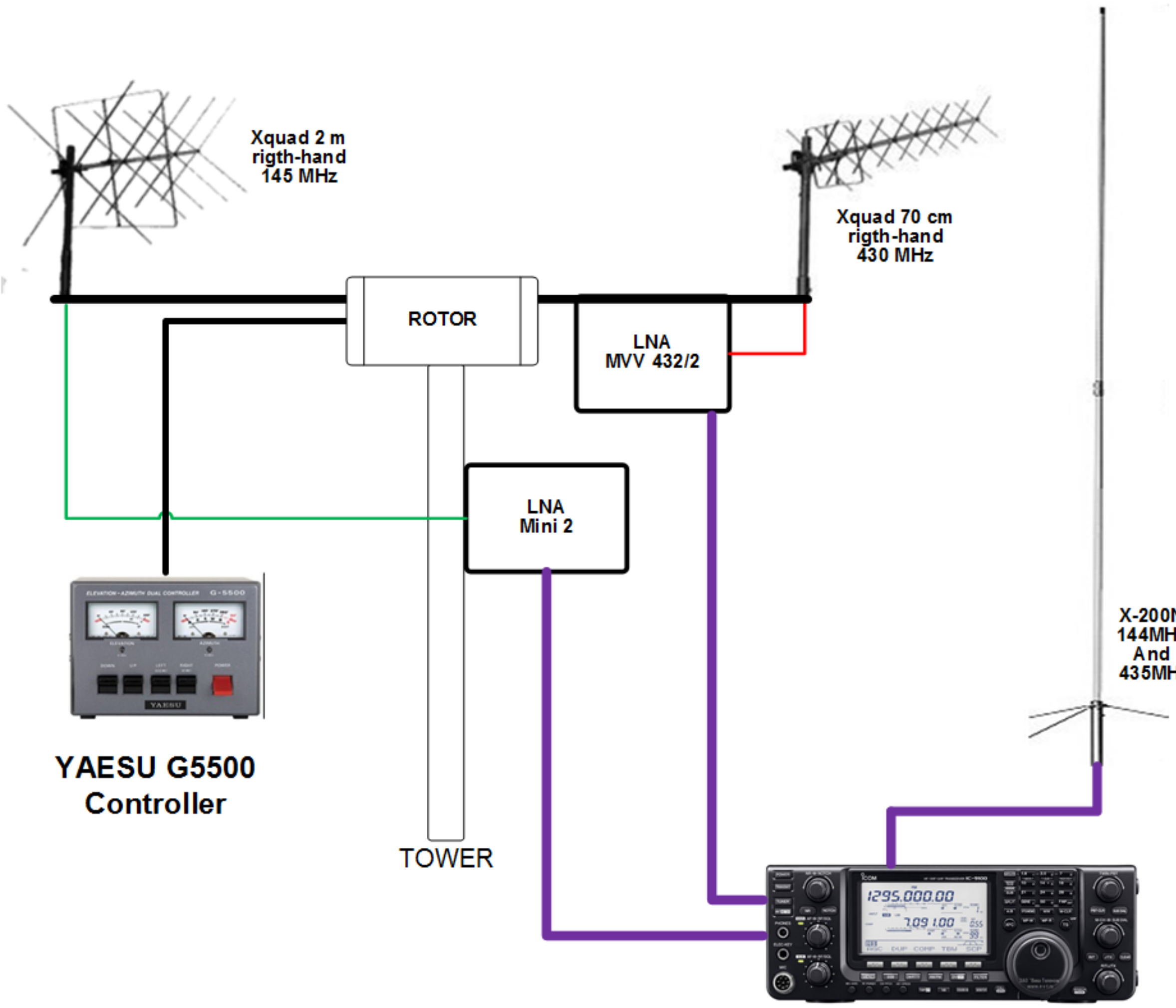


Figure 2.9 – *Old ground station system diagram.*

- Commercial antennas assembly.
- Tower expansion.
- Balance weigh system.
- Wiring sanitation.
- Electronic antenna switch inclusion.
- Manual antenna selector building.

Each one of the mentioned steps will be detailed in the following subsections.

2.2.1 Commercial antennas assembly

Five new antennas are going to be added to the tower in addition to the two already existing X-Quad (previously mentioned on section 2.1.1). Moreover, we will assembly two fixed antennas too.

- Tower antennas.
  - 2 m X-Quad with left hand circular polarization (LHCP) configuration.
  - 70 cm X-Quad with left hand circular polarization (LHCP) configuration.
  - 13 cm helix. This antenna is an helical antenna witch 40 turns and a gain of 16 dB. Its works in 2300 MHz - 2450 MHz frequency range. See figure 2.10.

Figure 2.10 – *2300 MHz - 2450 MHz helical antenna.*

  - 23 cm helix array. This antenna consist of an array of 4 helical antennas in 1250 MHz - 1300 MHz frequency range. The array has a gain of 16 dB. It is shown in figure 2.11.
  - 70 cm helix antenna. It is a helical antenna with 7 turns at 430 MHz - 440 MHz and has a gain of 9.5 dB. This antenna can be seen in 2.12
- Fixed antennas.
  - Parabolic dish. This dish has been assembled and fixed to the wall and it will be

2

Figure 2.11 – *1250 MHz - 1300 MHz helical antenna array.*

Figure 2.12 – *430 MHz - 440 MHz helical antenna.*

used to focus the direction of an helical antenna we will do. It will be explained on chapter 5. The parabolic dish can be seen in figure 2.13

– D3000N Super Discone Antenna. The D3000N Super Discone Antenna is an ultra-wideband antenna covering amateur radio, commercial 2-way, cellular, air traffic control and various utility frequency bands (25 to 3000 MHz receive, 50-1200 MHz transmit). See figure 2.14.

Figure 2.13 – *Parabolic dish.*

Figure 2.14 – *D3000N Super Discone Antenna.*

2.2.2 Tower expansion

As we are going to increase the number of antennas on the tower, we need to expand its capacity.

2

Before the tower was improved, it had a unique steel tube mast of 4 cm diameter. There were two antennas on this mast, as we explained in section 2.1.1, one antenna on each end of the steel tube. From this point, we want to incorporate 5 additional antennas to the tower. To do this, we are going to include two 4 cm diameter steel tubes more to the existing structure creating a new "H" Structure. See figures 2.15, 2.16 and 2.16b to understand the update process.

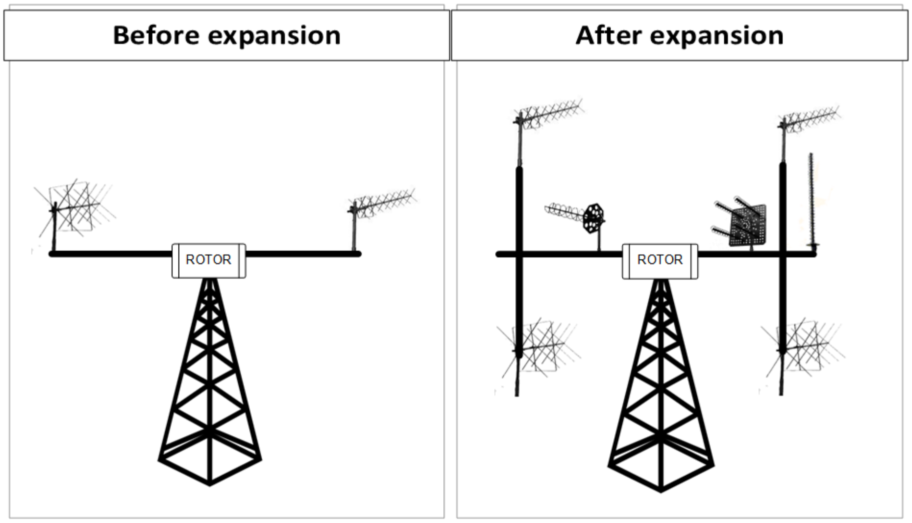
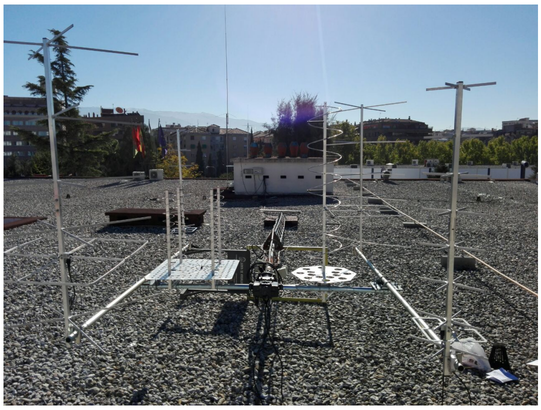


Figure 2.15 – *Tower expansion diagram.*

(a) *"H structure"*



(b) *"H structure whith antennas"*

Figure 2.16 – *Balance steel tubes fixing.*

2.2.3 Balance weigh system

Rotor yaesu G-5500, viewed on section 2.1.1, is able to move two X-Quad antennas without its gears being damaged. however, due to extension of antenna capacity on the tower, the weight of the whole system has been increased and we must design a balance weigh system.

Our design comprises two weights added to the end of another two 4 cm of diameter steel tube placed on the joins which forms de "H" explained before. It should compensate the weight of 7 antennas situated on the tower. We decided to set up two steel roods with bags of different weights placed at the end of these roods until the mast was balanced. In figure 2.17 we can see the structure designed to hold the steel roods.

Figure 2.17 – *Balance system fixing.*

Also, in figure 2.18 we can see the bags used to calculate the weight which equilibrated the mast of antennas.

Figure 2.18 – *Mechanical calculation for the weight required.*

As a result of this process of mechanical calculations we obtained that two bags (5 kg each one) were needed.

To increase the strength of the structure, 4 cm of diameter steel tubes were added covering the steel roods. In figure 2.19 we can see the structure designed to hold the steel tubes.

2

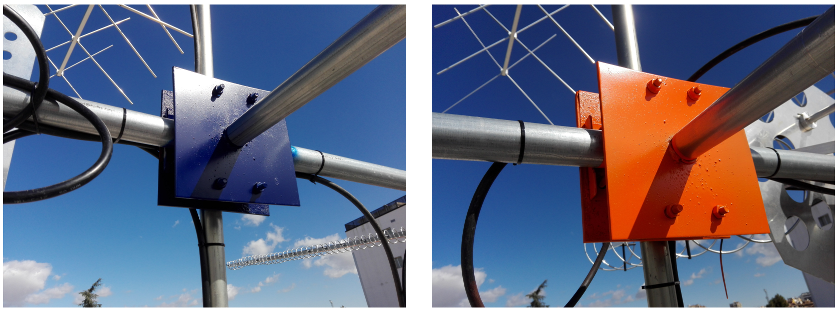


Figure 2.19 – *Balance steel tubes fixing.*

Finally, we replaced the bags with weights. The final result of the balance weight system is shown in figure 2.20.

Figure 2.20 – *Complete balance weight system.*

2.2.4 Wiring sanitation

For the radio frequency wiring, RG-213/4 coaxial wire was used. This coaxial has a characteristic impedance of 50 Ω and is a low loss wire. We made the wiring of all connections on radiation system and control system.

We use N male connectors for all connexions between antennas, LNAs, Switch and the transceiver. The mount of a N male connector is shown graphically on figure 2.21.

Figure 2.21 – *Male N connector mounting.*

2.2.5 Electronic antenna switch inclusion

As we saw on section 2.1.1, there were two antennas on the radiation system previous to the update and two coaxial wires between the control system (on the basement of science faculty building) and the radiation system (on the roof of science faculty building) to connect antennas and the transceiver. After updating the ground station, with 7 antennas on tower, we needed to extend 5 additional RG-213/4 coaxial wires. Knowing that the distance between the radiation system and the control system is about 30 m, we needed 150 m of this wire. As we can see on `http://es.rs-online.com/web/p/cables-coaxiales/2228660/` the price of this wire is about 200€ each 50 m.Therefore, we needed about 600€ to connect all antennas directly to the transceiver.

As an alternative, we decided to buy a switch of antennas which costs 179 € and let us change between 4 antennas. The other antenna can be connected to MVV 432/2 LNA shown on figure 2.4 which has the possibility to switch between 2 UHF antennas. By doing this, we only need one additional wire of 30 m long. The cost of this whole system is about 299 €. The switch we bought was AS-304 (WIMO company) and it can be seen in figure 2.22.

(a) *AS-304 switch* **(b)** *DIN connector*

Figure 2.22 – *AS-304 switch and DIN connector.*

The switch AS-304 is controlled electrically. The remote control connector on the AS-304 is a 4 pin DIN socket. The according antenna is selected by simply putting the operation voltage of 12 V DC to one of the three Plus-PINs of the DIN-connector. PIN distribution is shown on figure 2.22b . The pin assignment of the AS-304 are:

- Antenna 1 : Is switched to voltage-free conditions.
- Antenna 2 : Is switched with +12 V at PIN 3.
- Antenna 3 : Is switched with +12 V at PIN 2.
- Antenna 4 : Is switched with +12 V at PIN 1.

2.2.6 Manual antenna selector building

As we saw previously in section 2.2.5, we need to change pin voltage on the switch to choose the antenna we want to use.

Added to that, on MVV 432/2 LNA, we can also change between two antennas changing the supply on the MVV 432/2 LNA connector PINs. Putting 0 V on PIN 2 we switch to the antenna 1 and Putting the voltage of 12 V DC on pin 2 we switch to the antenna 2. PIN 4 must be always to 12 V DV voltage. Ground is on PIN 3.

To aggregate the whole switching system on a device, we have designed a manual antenna switch which will control the PIN Voltage on MVV 432/2 LNA and AS-304 switch.

This device has 4 buttons. With the first button we switch between the 70 cm X-Quad with left hand circular polarization (LHCP) and the 70 cm X-Quad with Right hand circular polarization (RHCP). Second, third and fourth buttons switch between the 13 cm, 23 cm and 70 cm helix antennas. This device has also 4 red leds which shows the buttons positions and one yellow led which shows if the manual switch is connected to the supply power.

The manual antenna selector is placed on the basement of the Faculty of Sciences and it is connected to the MVV 432/2 LNA, mini2 LNA and AS-304 switch by a control wire with six independent conductors, this manual switch is able to put +13 V on conductors 2,3,4 and 5 of control wire. The conductor 1 is always to +13 V and the conductor labelled by GND is always on 0 V. see diagram of figure 2.23.

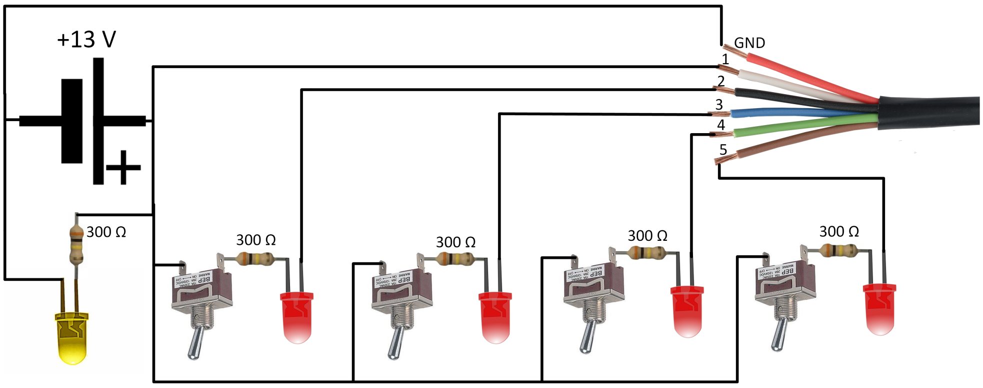


Figure 2.23 – *Connection diagram of manual switch.*

This design has been included into an electric project case junction box. The complete Design of this device is shown on figure2.24.

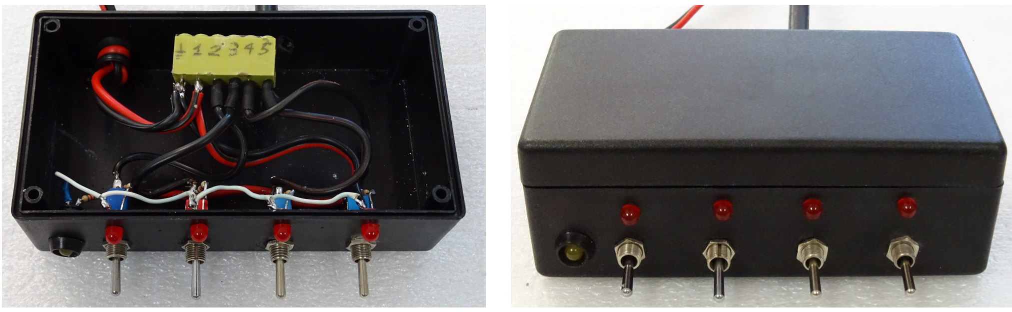


Figure 2.24 – *Manual antenna selector.*

A table with the buttons positions of manual selector for switching each antenna is shown on table 2.1

The switching system of the GranaSAT Ground Station is shown in figure 2.25

Antennas	switch 1	switch 2	switch 3	switch 4
Xquad 70cm RHCP	OFF	-	-	-
Xquad 70cm LHCP	ON	-	-	-
Helix 13cm (2.3GHz)	-	OFF	OFF	OFF
Helix 23cm - 4 (1.3GHz)	-	ON	OFF	OFF
Helix 70cm (430MHz)	-	OFF	ON	OFF
Future antenna	-	OFF	OFF	ON

Table 2.1 – *Buttons position for manual antenna switch*

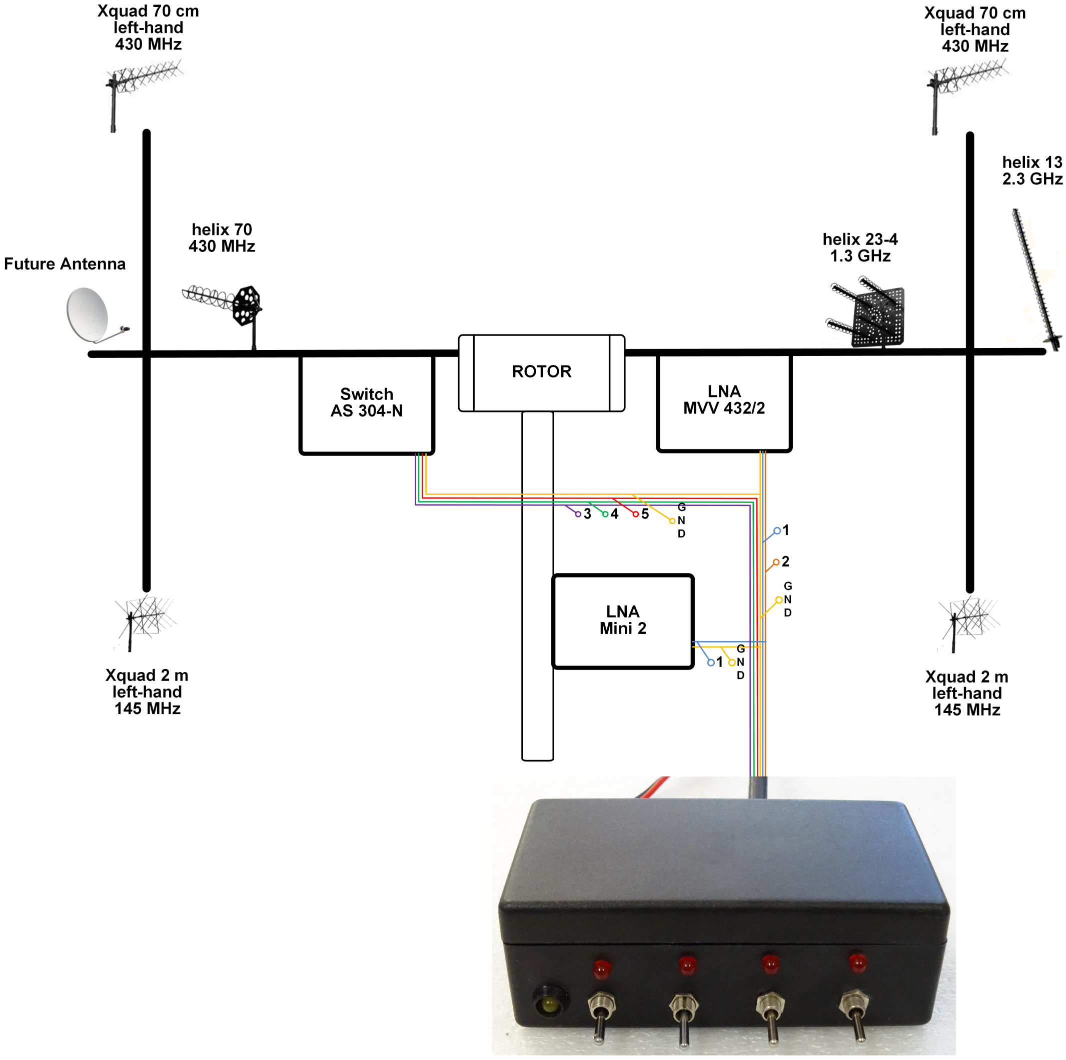


Figure 2.25 – *GranaSAT Ground Station switching system diagram.*

CHAPTER

3

CHARACTERIZATION, DESIGN, SIMULATION AND BUILDING OF RADIO FREQUENCY SYSTEMS.

The aim of this part is to have an outreach with the design of radio frequency system in order to gain the knowledge necessary for developing antennas proposed as one of the primary goals of this project. Firstly, we are going to characterize some parameters of a QHA antenna to learn the VNA functioning. After that, we will build a hand-held biband antenna and we will design a duplexor for this antenna. Once we have finished this task, we will be qualified to tackle primary goals.

3.1 Characterization through VNA

In the GranaSAT laboratory we have a VNA of Agilent technologies company, model E5071C. It allows us to make multiport measurements between 100 KHz and 8.5 GHz. More specifications on `http://www.keysight.com/en/pdx-x202270-pn-E5071C/ena-series-network-analyzer?nid=-32496.1150429&cc=ES&lc=spa&pm=ov`. See figure 3.1.

Also, at the electromagnetic Department of the UGR there are other VNA of the Keysight Company, model N9912A fieldfox. This device supports multiport measurements

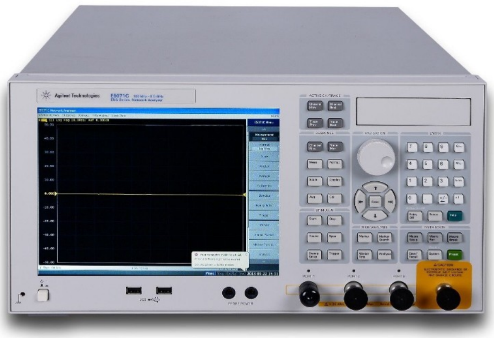


Figure 3.1 – *E5071C vector network Analyzer*

too and the frequencies range of operations is between 2 MHz to 6 GHz. More specifications can be found on http://www.keysight.com/en/pdx-x201745-pn-N9912A/fieldfox-handheld-rf-analyzer-4-ghz-and-6-ghz?nid=-32495.1150124&cc=ES&lc=spa&pm=ov&state=9. See figure 3.2.

Figure 3.2 – *N9912A vector network Analyzer*

We are going to characterize $|S_{11}|$ and $|Z_{11}|$ of a QHA antenna. It comprises two bifilar helical loops oriented in a mutual orthogonal relationship on a common axis. The terminals of each loop are fed in anti-phase and the currents in the two loops are in phase quadrature [STV, 2016]. See the antenna in the figure 3.3.

As the objective of this part is to learn how to characterize antennas through VNA, we are going to compare results obtained on measurements with fieldfox N9912A VNA and Agilent E5071C VNA.

Figure 3.3 – *QHA antenna*

3.1.1 QHA antenna measurement with Fieldfox N9912A

In order to obtain accurate measurements it is important to make a calibration of the VNA to remove wire and connectors undesirable effects. We used the calibration kit 85032F of Agilent and we did an OSL (Open, Short and Load) calibration. In OSL calibrations the Open, Short and Load devices of the kit Agilent 85032F are attached to the end of the coaxial wire that we use to connect the antenna to VNA. We specify that we are going to make a one port calibration. After that, the VNA will be calibrated. See the kit 85032F of Agilent photography on figure 3.4.

Figure 3.4 – *Agilent 85032F calibration kit*

The results obtained on the measurement of the QHA antenna are shown on figures 3.5 and 3.6.

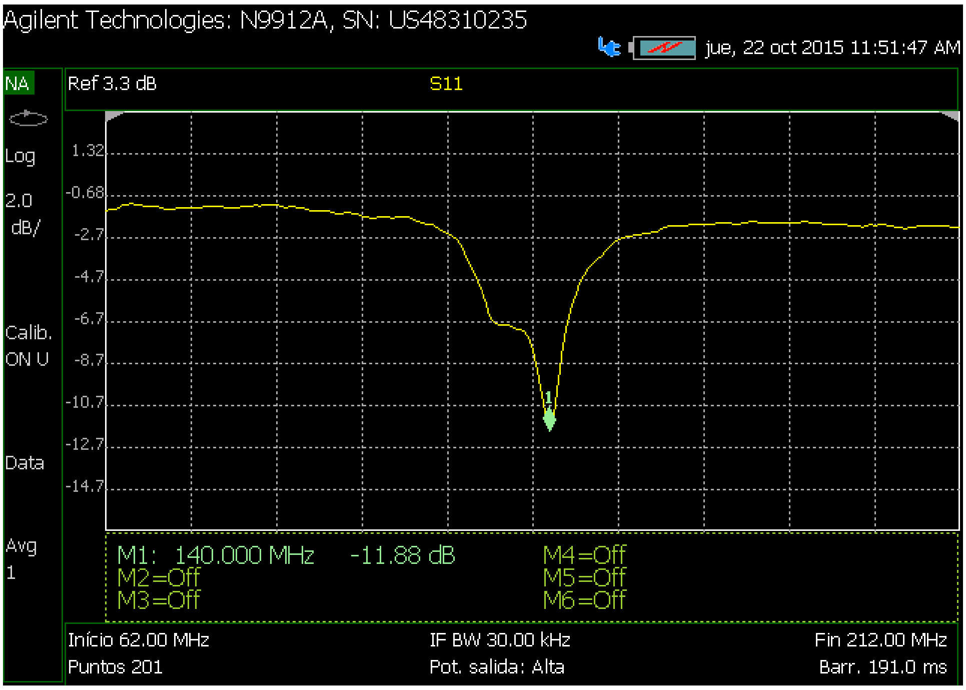


Figure 3.5 – *$|S_{11}|$ parameter for QHA antenna measured with Fieldfox N9912A*

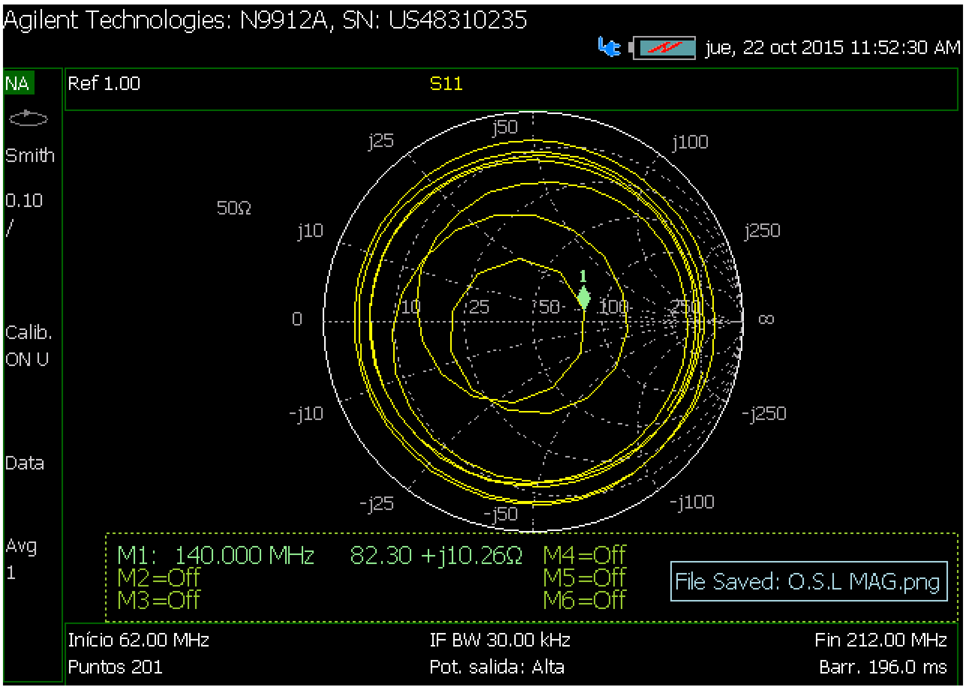


Figure 3.6 – *$|Z_{11}|$ parameter for QHA antenna measured with Fieldfox N9912A*

In figure 3.5 we can see the $|S_{11}|$ parameter of the antenna is -11.88 dB at frequency of 140 MHz. Also, the smith chart of $|Z_{11}|$ parameter is shown in figure 3.6 and we can see the impedance of the QHA antenna at 140 MHz frequency is (82.30 + 10.26j) Ω.

3.1.2 QHA antenna measurement with Agilent E5071C

Using again the Agilent 85032F calibration kit with Agilent E5071C VNA, we measured $|S_{11}|$ and $|Z_{11}|$ of a QHA antenna and the results are shown in figure 3.7.

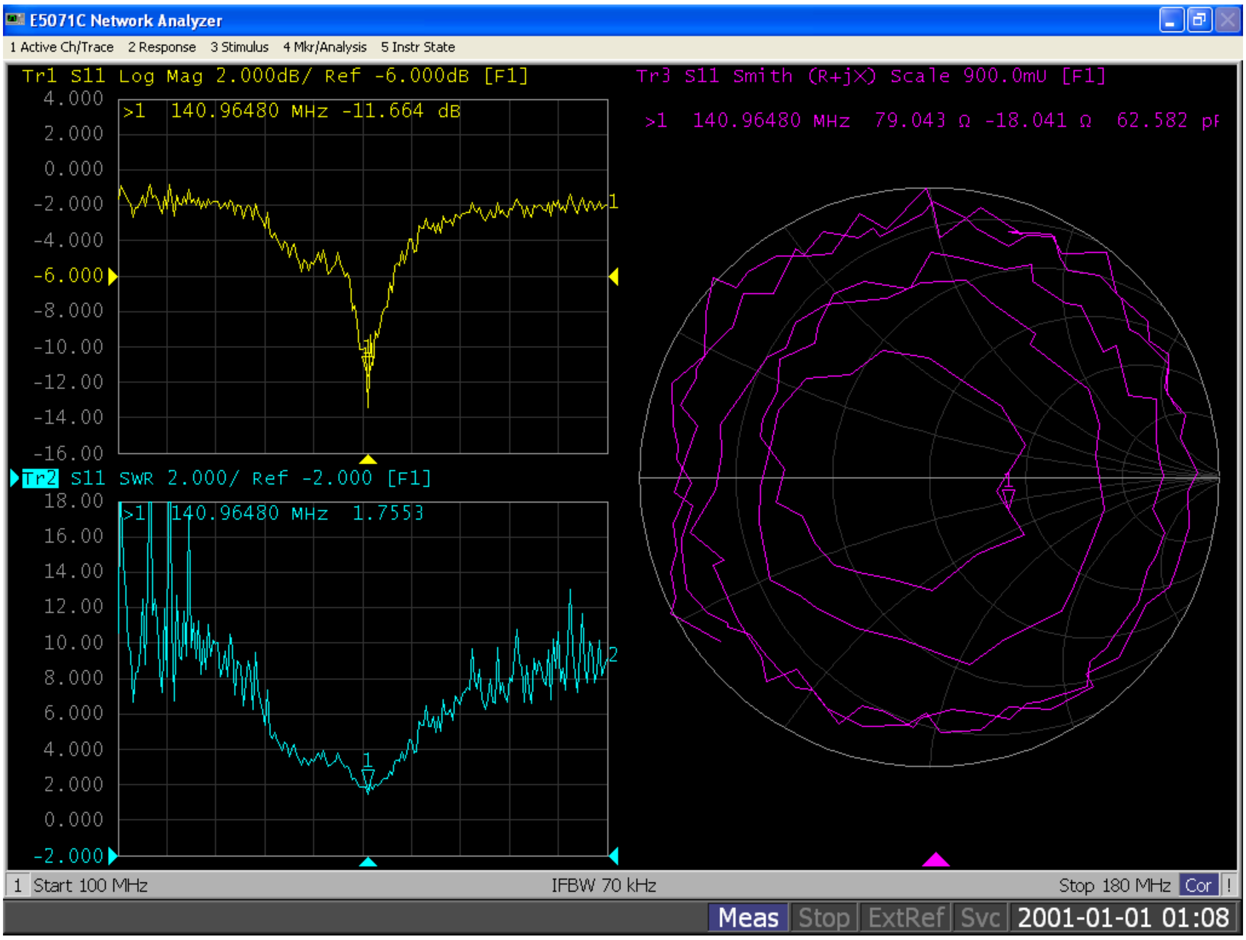


Figure 3.7 – *$|S_{11}|$, $|Z_{11}|$ and SWR parameter for QHA antenna measured with Agilent E5071C*

In figure 3.7 we can see that the $|S_{11}|$ parameter of the antenna is -11.66 dB at frequency of 140 MHz. Also, the smith chart of $|Z_{11}|$ parameter shows that the impedance of the QHA antenna at 140 MHz frequency is (79.04 + 18.04j) Ω.

The results obtained with the Fieldfox N9912A VNA and the Agilent E5071C VNA are very similar, it is an indicator that the measurements are correct.

From now on, we will take the measurements with the Agilent E5071C VNA.

3.2 Hand-held bibanda antenna building

In order to continue with the progress learning about the design of the radio frequency system, we are going to build a hand-held antenna for VHF and UHF frequency bands. The design followed during the construction was obtained from `http://ve2zaz.net/Arrow_Ant/Arrow_Style_Ant.htm` web page. We have chosen this antenna because it is cheap and easy to build.

For the antenna building we only need a PVC pipe and steel rods. We used an evacuation class B PVC pipe of 32 mm which purpose was to fix the 4 mm diameter steel rods.

Before building the antenna simulated it with CST MWS program. We decided to use SolidWorks for the 3D computer-aided design (CAD) and import the design to CST MWS for the electromagnetic simulation. The 3D model designed in CST can be seen on figure 3.8a

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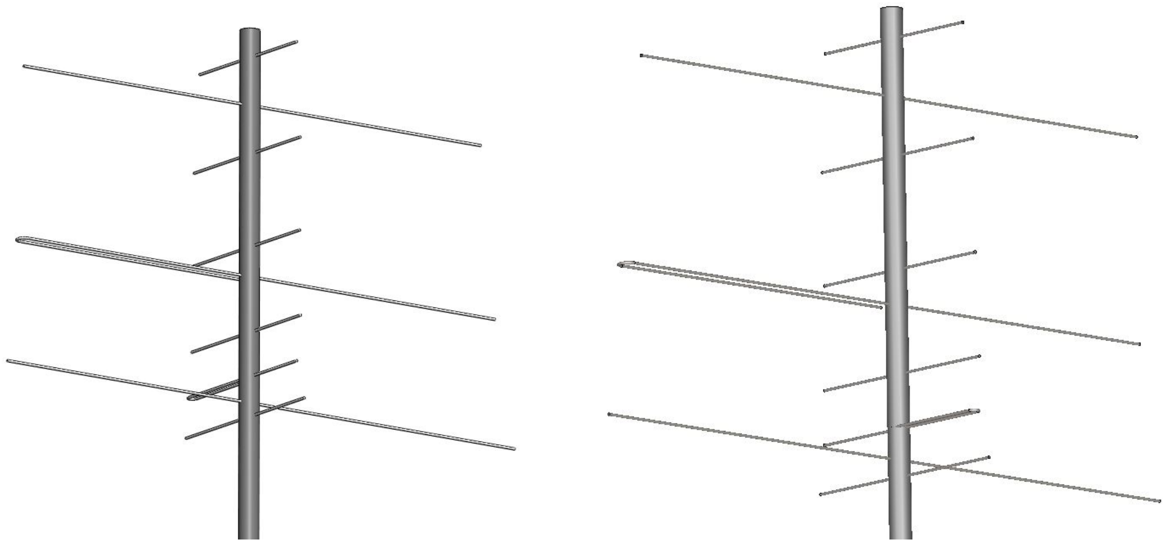

(a) *Design in SolidWorks of biband antenna* **(b)** *Biband antenna imported to CST MWS*

Figure 3.8 – *3D design of hand-held biband antenna.*

In the simulation results we observed that the antenna is perfectly tuned to the centre of the VHF frequency band (140 MHz) and the UHF frequency band (435 MHz). As the results obtained on the simulation verify that the dimensions of the design are correct, we are ready to build the antenna.

We follow the procedure of the web page mentioned at the beginning of this section 3.2. The antenna built is shown on figure 3.9.

The measurements taken with VNA are (shown in figures 3.10 and 3.11) are very similar to the simulation results. In general, these results were expected and in concordance with an antenna of this conditions.

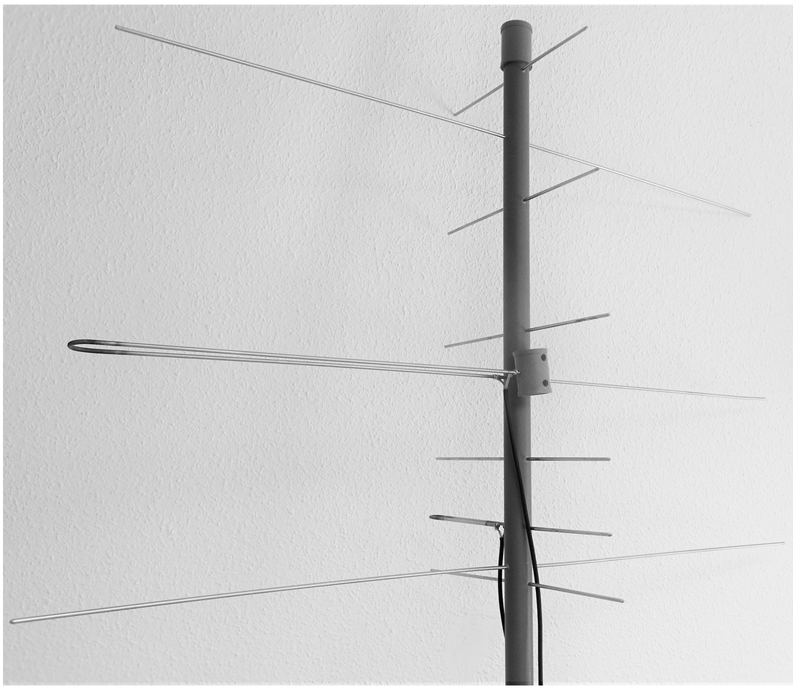

Figure 3.9 – *Hand-held bibanda antenna built.*

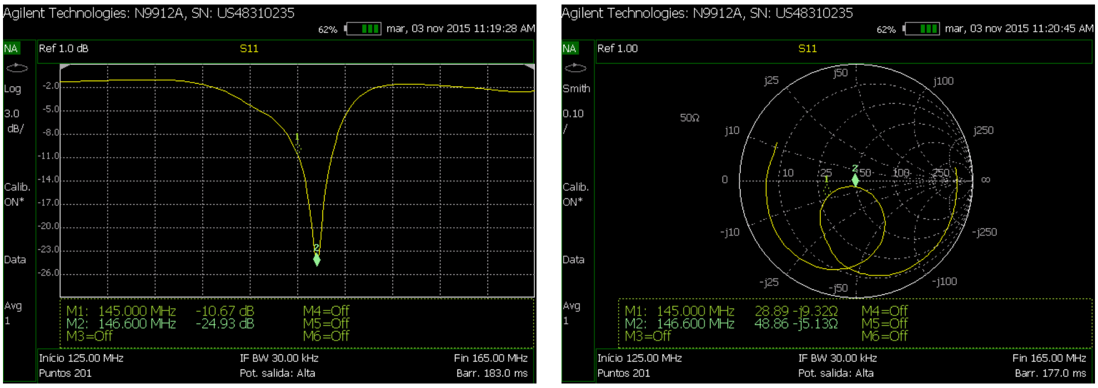

Figure 3.10 – *VHF antenna measurement results.*

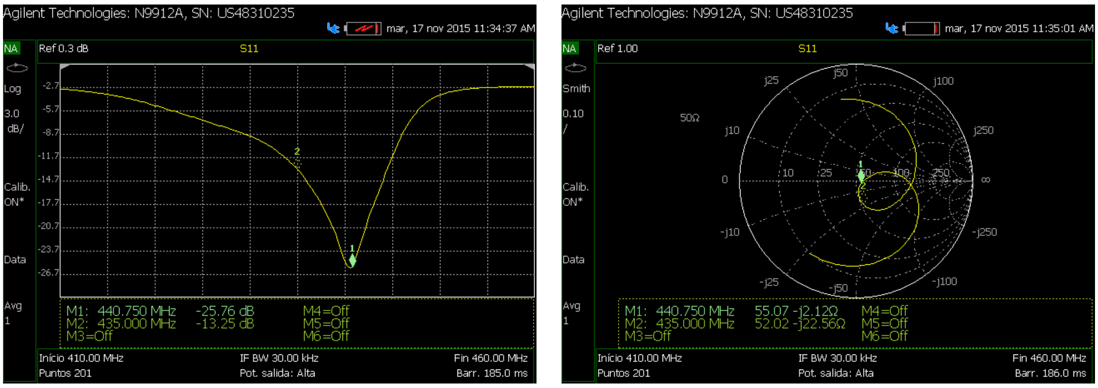

Figure 3.11 – *UHF antenna measurement results.*

3

3.3 VHF-UHF duplexor design and simulation

One important task in the development of a radio system is the associated electronic. It includes a downconverter, a LNA, duplexors, diplexers and other electronic system. In order to learn about this system before setting to work on a development of a complete radio system we are going to design a diplexer for the antenna explained on the previous section 3.2.

A diplexer is a passive device that implements frequency-domain multiplexing. Two ports (e.g., 1 and 2) are multiplexed onto a third port (e.g., 3). The signals on ports 1 and 2 occupy disjoint frequency bands. Consequently, the signals on 1 and 2 can coexist on port 3 without interfering with each other.

Typically, the signal on port 1 will occupy a single low frequency band and the signal on port 2 will occupy a higher frequency band. In that situation, the diplexer consists of a lowpass filter connecting ports 1 and 3 and highpass filter connecting ports 2 and 3. Ideally, all the lowband signal power on port 1 is transferred to the port 3 and vice versa. All the highband signal power on port 2 is transferred to port 3 and vice versa. Ideally, the separation of the signals is complete. None of the low band signal is transferred from the 1 port to the 2 port. In the real world, some power will be lost, and some signal power will leak to the wrong port [Wikipedia, 2016b].

We are going to use ADS software for the design of the duplexer. On the web page mentioned on section 3.2 there is a design of a diplexer which can be included into the PVC pipe structure of the antenna. This diplexer consist of two filters of fifth order. The diplexer board layout is available on the mentioned web page, so in order to adapt our design to this board layout, we are going a simulate and optimize on ADS the diplexer. See the diagram of the desired design on figure 3.12.

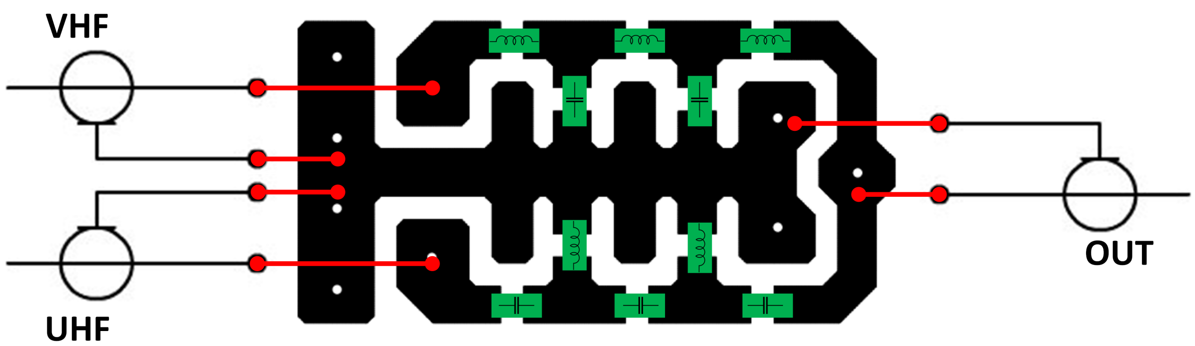

Figure 3.12 – *Diagram of diplexor.*

We are going to design two independent filters, one for the VHF frequency band and another one for the UHF.Later, both filters will be integrated in the same circuit. After that, we will use the optimization tool of ADS program to decrease the interference between two filters.

3.3.1 VHF filter design

We decided to design a low pass chebishev filter. As the space available on the pcb board for each filter is of five smd components, we need to make a fifth order filter. The ripple in the passband may be of 0.5 dB, the cut-off frequency of 220 MHz and the impedance may be 50 Ω due to our antenna impedance is 50 Ω. We use a web calculator (http://www.changpuak.ch/electronics/chebyshev_lowpass.php) to calculate the value of the components instead of calculate it manually. The values for capacitor and inductor for the VHF filter obtained with web filter calculator are shown on figure 3.13.

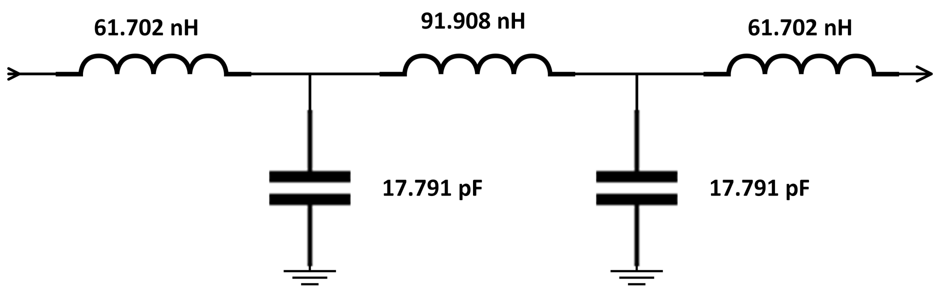

Figure 3.13 – *VHF 5 order chebishev filter.*

The ADS Schematic of this circuit is shown on figure 3.14 and the results of such schematic simulation are shown on figure 3.15.

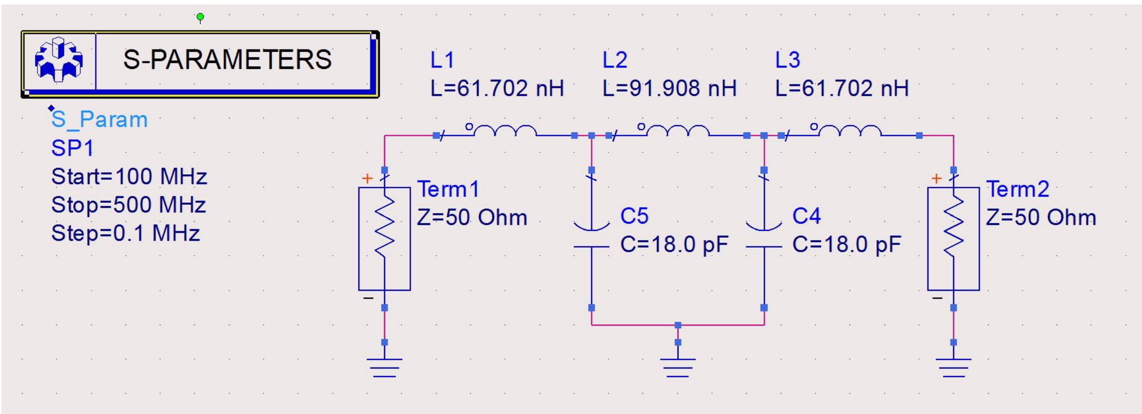

Figure 3.14 – *VHF 5 order chebishev filter ADS schematic.*

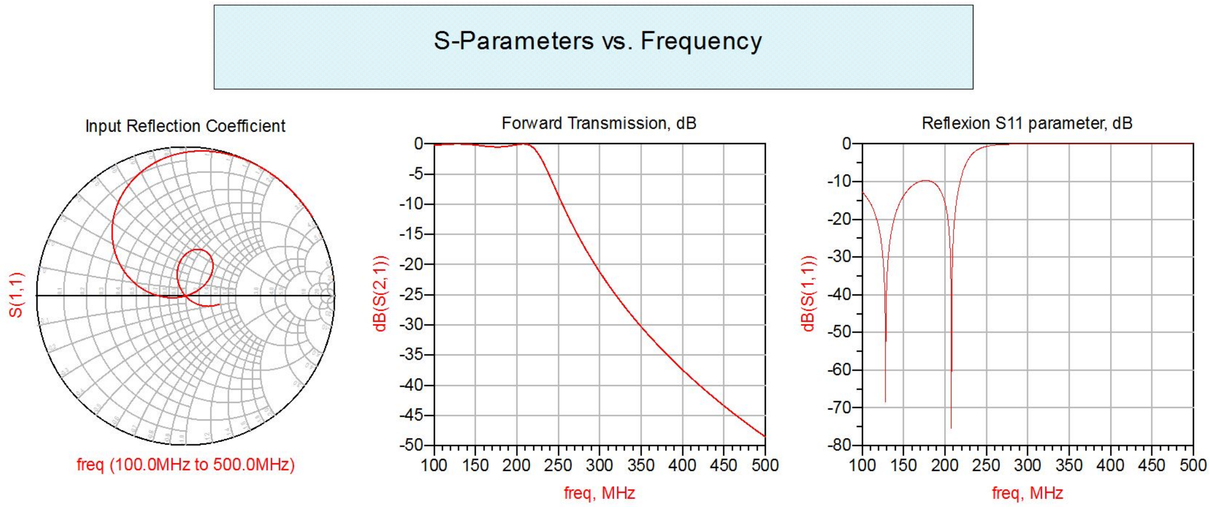

Figure 3.15 – *VHF 5 order chebishev filter ADS schematic.*

3.3.2 UHF filter design

For the design of filter for the UHF frequency band we will use the same procedure we used on previous section 3.3.1. The specifications for this filter are:

- Highpass chebishev of fifth order.
- Passband Riple of 0.5 dB.
- Impedance of 50 Ω.
- Cut off Frequency of 380 Mhz.

The values for capacitor and inductor for UHF filter obtained with web filter calculator are shown on figure 3.16

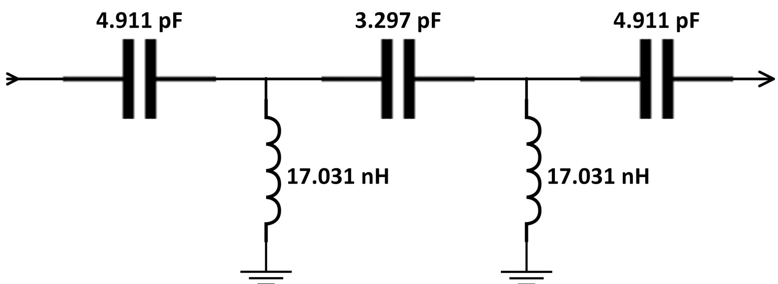

Figure 3.16 – *UHF 5 order chebishev filter.*

The ADS Schematic of this circuit is shown on figure 3.17 and the results of such schematic simulation are shown on figure 3.18.

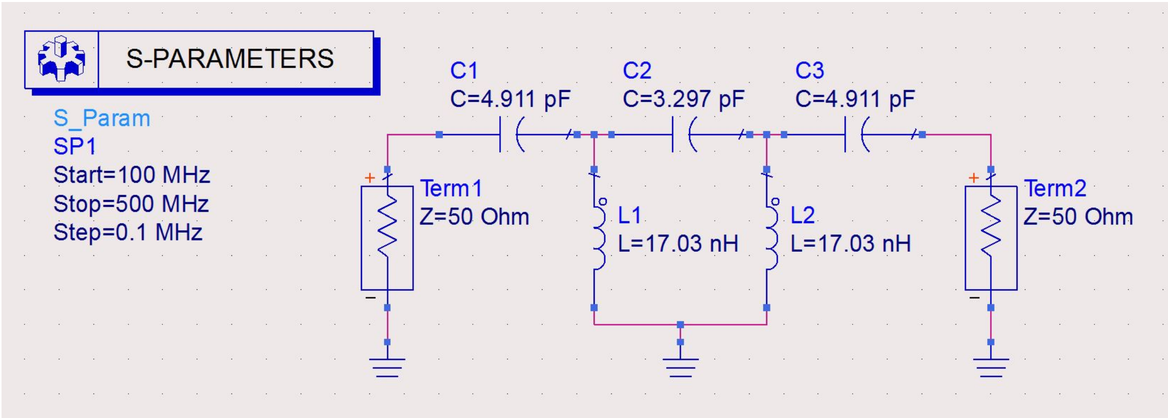

Figure 3.17 – *UHF 5 order chebishev filter ADS schematic.*

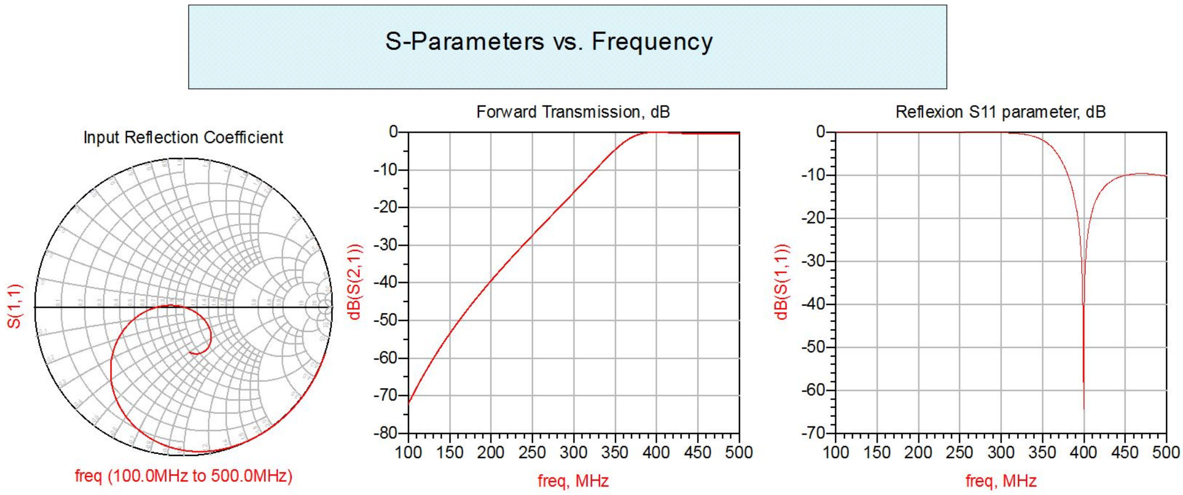

Figure 3.18 – *UHF 5 order chebishev filter ADS schematic.*

3.3.3 VHF and UHF filter integration

Now, we are able to integrate the circuits designed in sections 3.3.1 and 3.3.2 in the PCB board obtaining the structure shown on figure 3.12.Circuits on the same PCB can interfere with each other. It will be solve using the optimization tool of ADS.

In order to obtain a circuit specific for our antenna we are going to capture $|S_{11}|$ parameters for UFH band and VHF band of our antenna and use its on ADS. We will capture it with Agilent E5071C VNA and obtain a file on format ".s1p".Then we could simulate its with the inclusion of S1P blocks. See the new schematic on figure 3.19.

As we can see on results shown on figure 3.20, both filters interfere one with the other and due to that, minimums of S11 parameter are not in the correct places. The goal of this Diplexor is to obtain a minimum in 147 Mhz and other in 435 MHz. In section 3.3.4, we will explain how to use the optimization tool of ADS for achieve these goals.

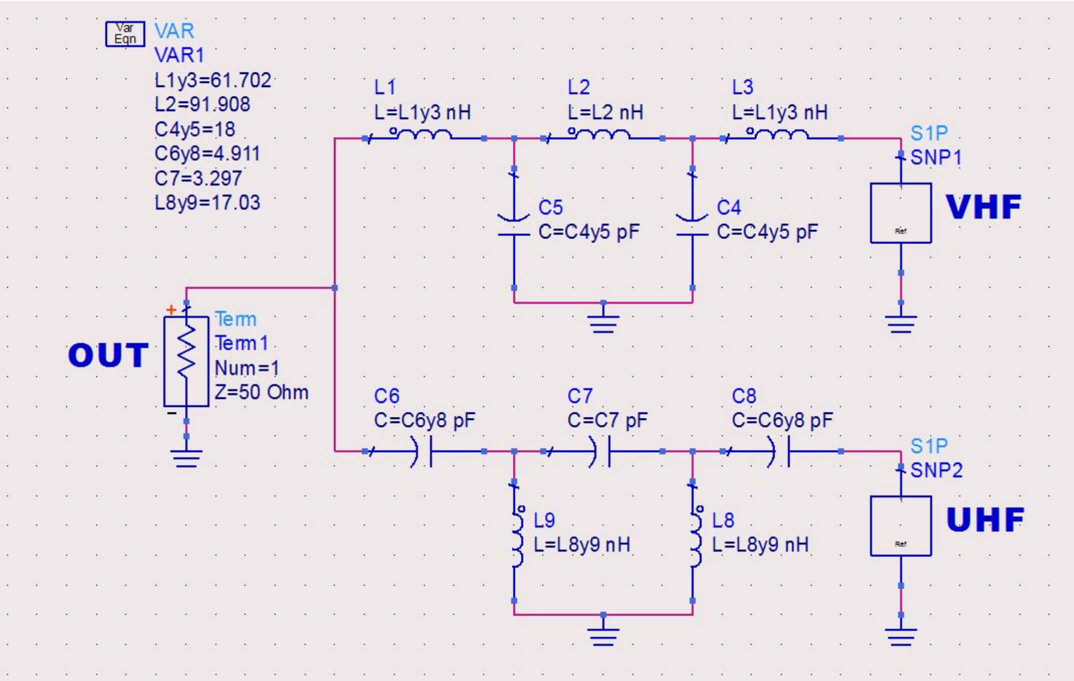

Figure 3.19 – *Diplexor ADS schematic before optimization.*

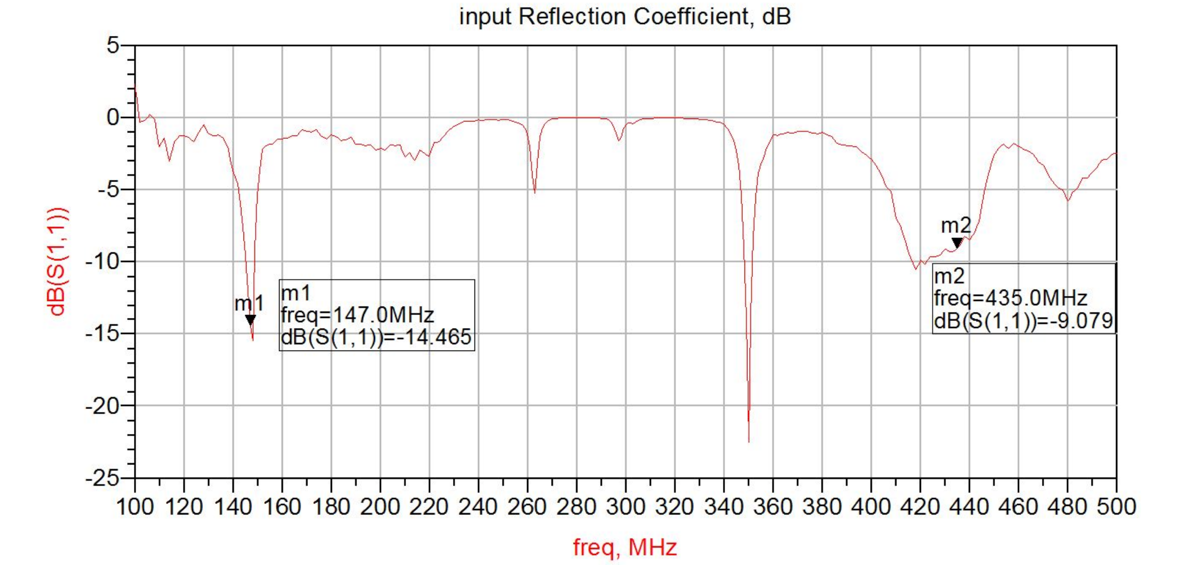

Figure 3.20 – *Diplexor ADS simulation results before optimization.*

3.3.4 ADS optimization

First, to optimize our design, we are going to include two new blocks in ADS schematic, "OPTIM" block and "GOAL" block. "OPTIM" block is used for optimization parameters definition and "GOAL" block is used to define the goals the optimizer have to found. In

"GOAL" block we define to goals, One for each desired minimum on $|S_{11}|$ parameter. see figure 3.21.

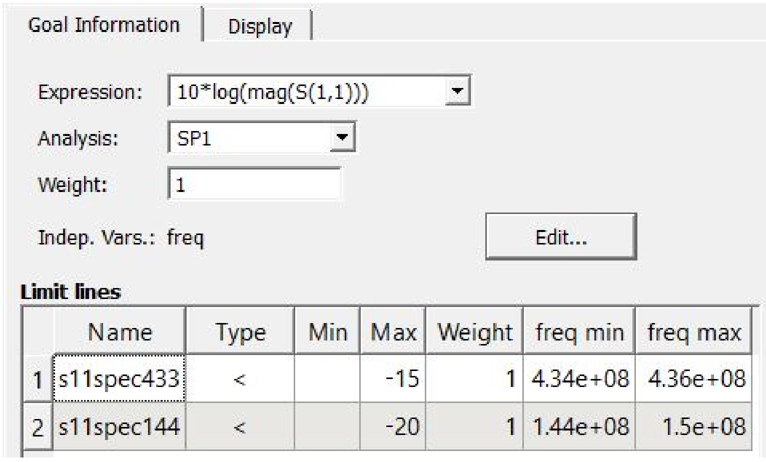

Figure 3.21 – *Goals window definition of ADS "GOAL" block.*

Also, we need to define a range of values for each component on "VAR" block. After that, we are ready for run optimization. The simulation results after this optimization are shown on figure 3.22.

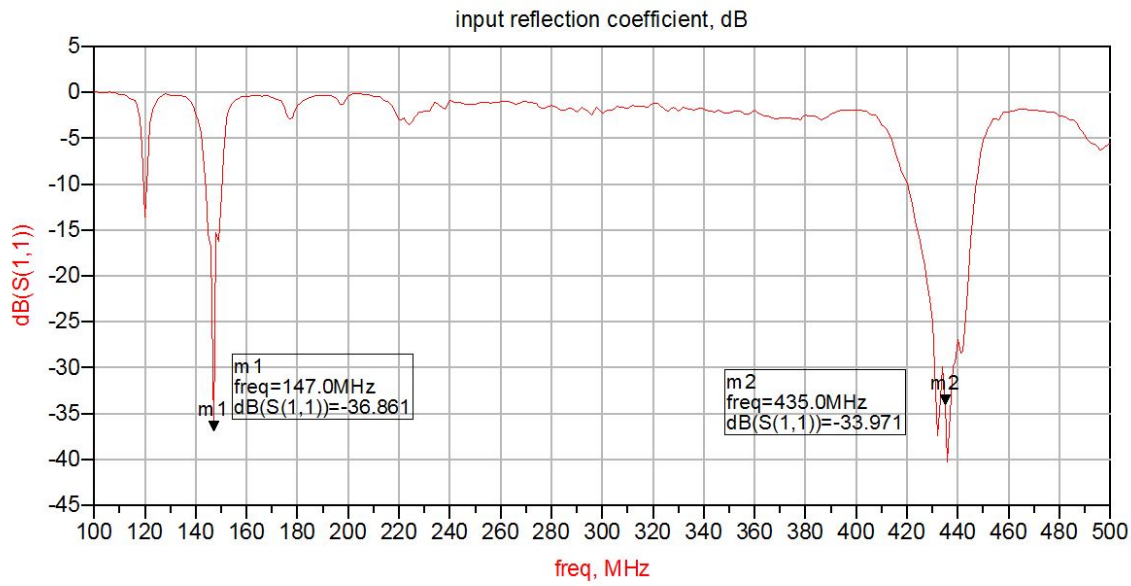

Figure 3.22 – *Diplexor ADS simulation results after optimization.*

Now, as we can see on figure 3.22, the minimums of the $|S_{11}|$ parameter are in the correct frequencies. The values the optimizer has found are shown on figure 3.23.

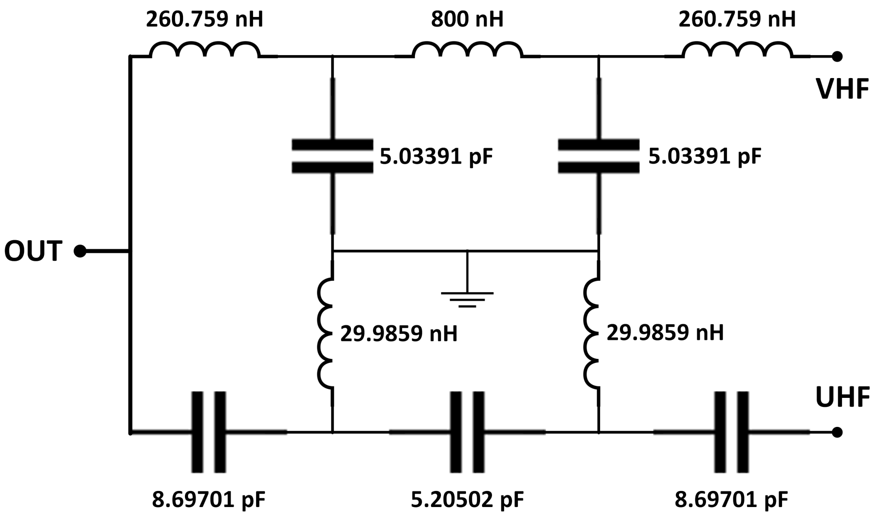

Figure 3.23 – *Diplexor schematic design with optimization values for components.*

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The values obtained on simulation are not commercial values for capacitors and inductor, so, we are going to replace these values for commercial values. The procedure followed consist on changing the value of one of the values of the capacitor or inductor and make a new optimization of the new circuit without optimize the changed value. On this way, the schematic circuit obtained with commercial values for all components is shown on figure 3.24.

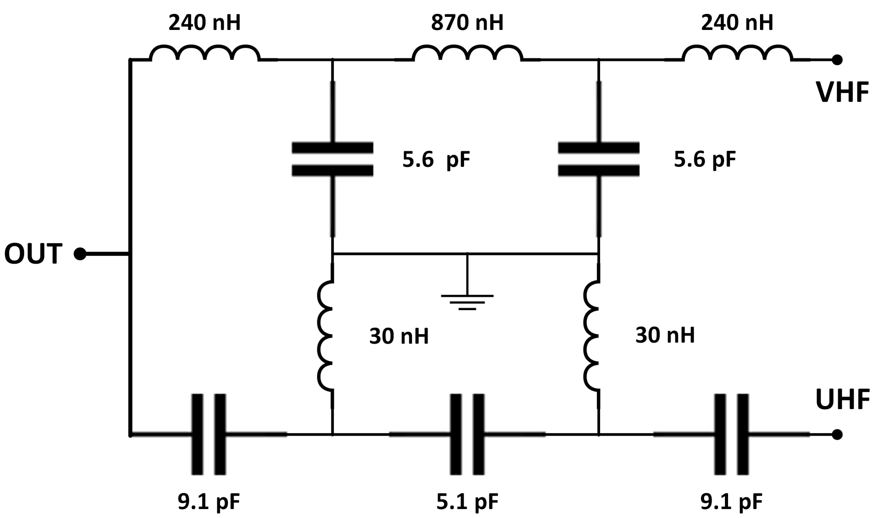


Figure 3.24 – *Diplexor schematic design with optimization commercial values for components.*

The input reflection parameter ($|S_{11}|$) of the final circuit is shown on figure 3.25. As we can see on this figure the minimums of this parameter is just in the desired frequencies, so, our filter design is finished.

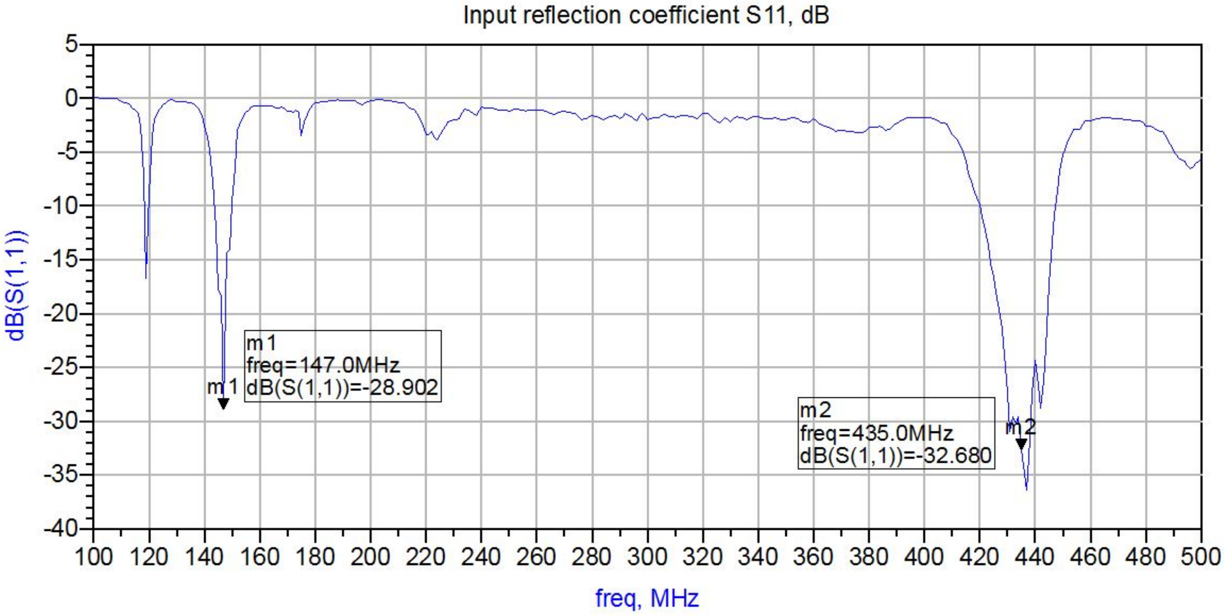


Figure 3.25 – *Diplexor ADS simulation results after optimization with commercial values.*

3

CHAPTER

4

EGBEATTER ANTENNA

In this chapter we are going to explain the development of an antenna for CubeSat reception. To approach this task, we are going to divide the work in four phases. In the first phase we will try to define the requirements of our antenna. During the second phase we will attempt to design the antenna and define its physical characteristics. The impedance adaptation, the systematization and the circular polarization will take part in third phase. Finally, the building of the designed antenna will be done in the fourth phase.

4.1 Antenna requirements

Given that we are going to use this antenna for CubeSat reception, it will be tuned on 435 MHz with an impedance of 50 Ω and a right hand circular polarization. In this section we will explain why we need this requirements.

4.1.1 Frequency

The ESA has launched three low orbit and polar orbit CubeSat which can be received with amateur radio equipment. Two of this CubeSat emit on UHF frequency Band [AMSAT-UK,].

- AAUSAT4 : 437.425 MHz.
- E-st@r-II : 437.485 MHz.

As we can see on [Butler,], the UHF band is between 420 and 450 MHz. Consequently, the center frequency of our antenna must be in 435 MHz and must have a span of 30 MHz.

4.1.2 Polarization

When the radio signals pass through the ionosphere, appears a particular effect named Faraday effect. This effect causes a rotation on the polarization plane of the wave proportional to the square of the wavelength. In the 435 MHz frequency, it occurs 1.5 rotations of the polarization plane in the signals passing through the ionosphere [Wikipedia,].

As circular polarization is not affected by Faraday Effect, most of satellite communications which have to cross the ionosphere do it with circular polarization. A graphic example of Faraday Effect is shown in figure 4.1.

4

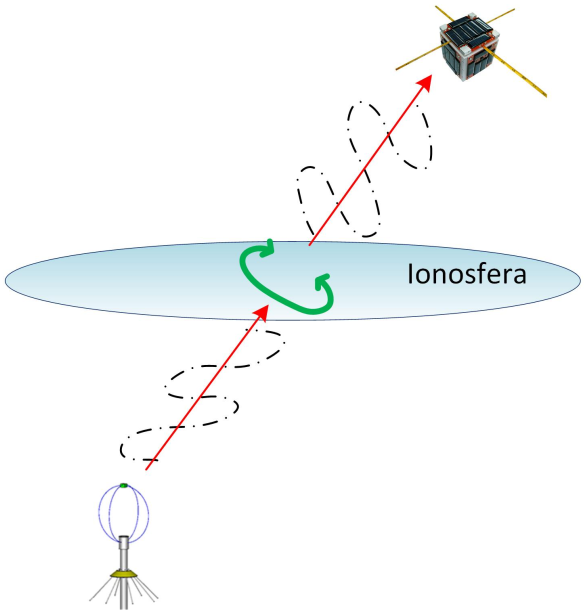


Figure 4.1 – *Faraday rotation effect on ionosphere.*

4.1.3 Radiation pattern

Our objective is to receive the signal of the CubeSats mentioned in section 5.2.1 with a fixed antenna. The orbits of these CubeSats are at a height of 650 Km. For these reasons, the radiation pattern must be sectorial on the vertical plane and omnidirectional on the horizontal plane. The radiation pattern desired is shown in figure 4.2.

Our aim is that the antenna will be able to receive the signal from the point you can see on the horizon (AoS) until it is no longer visible on the opposite side (LoS).

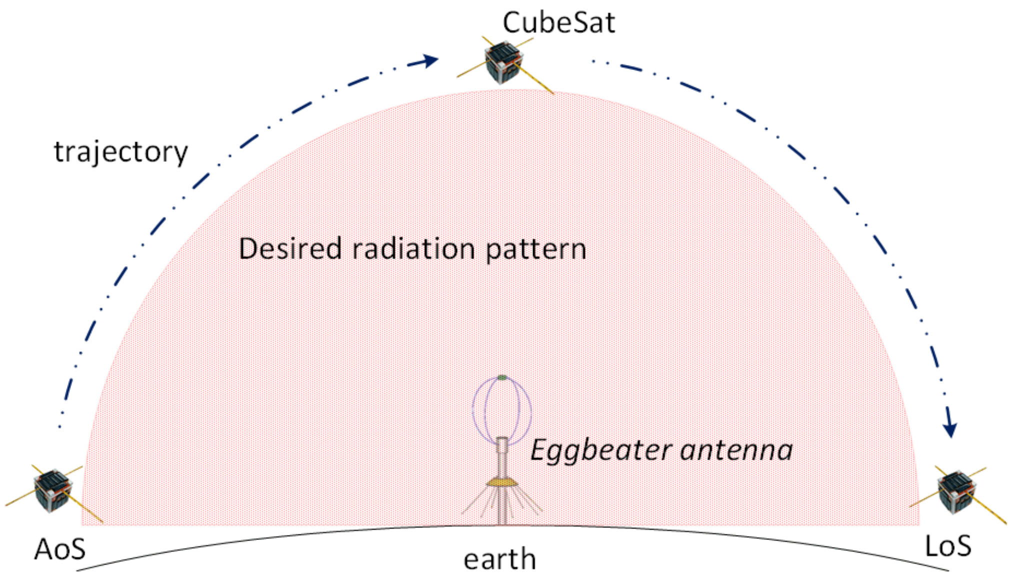


Figure 4.2 – *Desired radiation pattern.*

4.1.4 Impedance

Due to the fact that most of the signal reception and measure equipment works with an impedance of 50 Ω, our antenna impedance will be also 50 Ω.

4

4.2 Antenna design

When the requirements were defined, we analysed different antennas (turnstyle, helix, Quadrifiliar), with the objective to find one which satisfied the requirements. After the analysis were done, we determined that eggbeater antenna is able to meet all requirements that we defined on section 5.2.

4.2.1 Physical specifications

The eggbeater antenna is formed from two circular loops perpendicular to each other and a ground plane formed by radials. See figure 4.3.

In this antenna the perimeter length of each loop is of λ, the length of the radials which form the ground plane is of $\lambda/4$ and the distance between loops and ground plane is $\lambda/8$.

$$\lambda = \frac{c}{f} \tag{4.2.1}$$

According to the physical specifications and the equation 4.2.1 which defines the wavelength for a certain frequency, we can obtain the dimensions of eggbeater antenna

Figure 4.3 – *Antenna eggbeater.*

4

elements for a frequency of 435 MHz.

- Loops perimeter : 68.96 cm.
- Radials length: 17.24 cm.
- Distance between radials and loops: 8.62 cm.

4.2.2 Simulation

According to the physical specifications which we obtained on previous section 2.2.1 and considering the available materials, we created a 3D model of the antenna with the Electromagnetic Simulation program CST. We tried to make a low-cost antenna, so, the materials used in this design are cooper for loops and stainless steel for ground plane.

The energy from the transceiver is simulated in CST through an access port to the antenna. As we have two loops, we have defined one port for each loop.

The feed through this ports in CST is supposed to be symmetric. To enter the ports in CST, the loops are not completely closed. There is a cut in the bottom of the loops which generates a space of 2 cm on each loop. Although, for the simulation of de-phasing, we indicated on post-processing tab that the ports have got an offset of 90º. The resultant 3D model is shown in figure 4.4.

In figure 4.5 it can be seen the module of the reflection parameter $|S_{11}|$ obtained in the simulation. This parameter is the reflection coefficient at input when the output ends on matched load. This is, Z_l=Z_0 (The load impedance and the line characteristic impedance are equals) [Guerrero, 0216] .

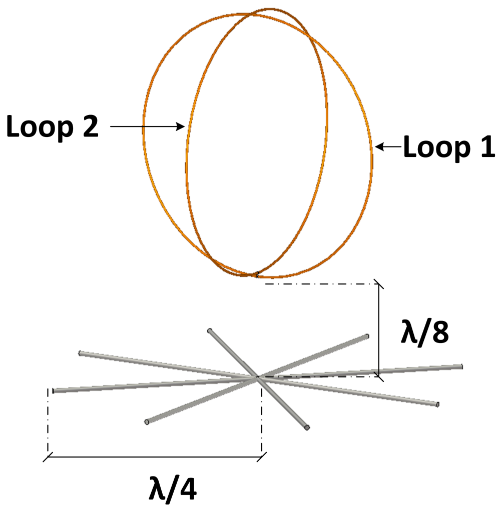


Figure 4.4 – *First 3D model of eggbeater antenna.*

In figures 4.5, 4.6, 4.7 y 4.8 are shown the results obtained after the simulation of one loop supposing the other excited. The results are the same for both loops.

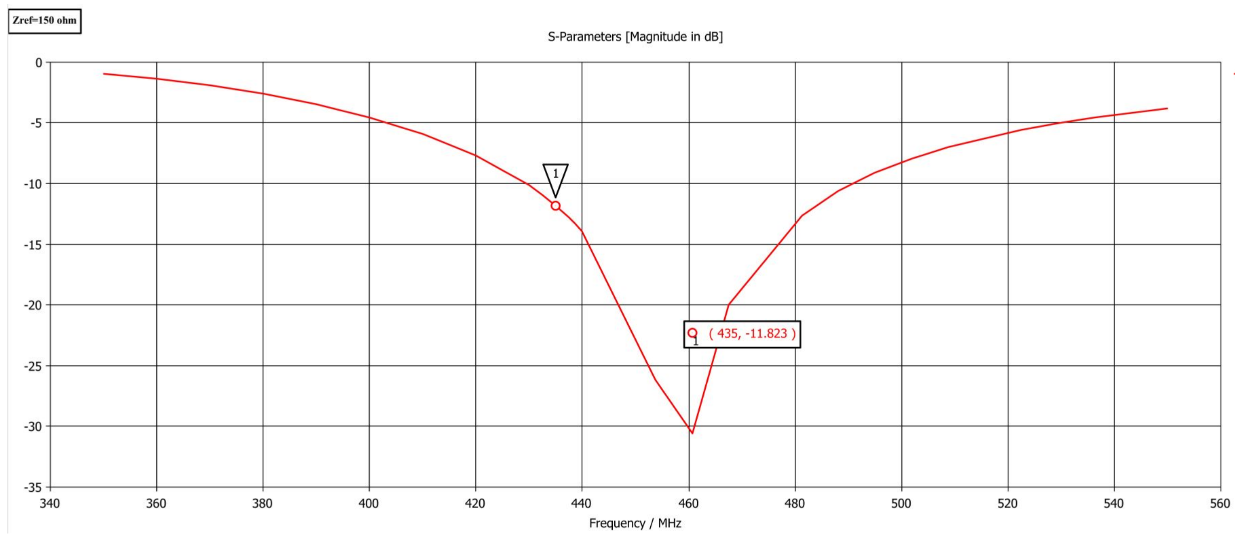


Figure 4.5 – *$|S_{11}|$ parameter [dB].*

As shown in figure 4.5 our antenna is not perfectly tuned at frequency of 435 MHz (minimun in $|S_{11}|$ is not in 435 MHz). Later we will correct this with optimization in CST program.

As we can see in figures 4.7 and 4.8 the radiation pattern obtained on simulation resembles the radiation pattern that we explained on section 5.2.3

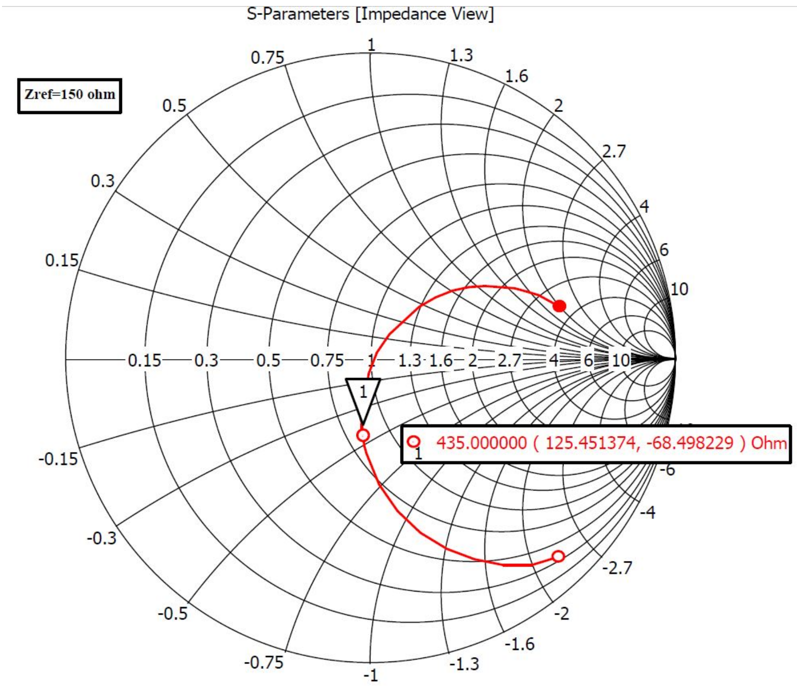


Figure 4.6 – $|Z_{11}|$ *parameter [Ω] (Smith chart).*

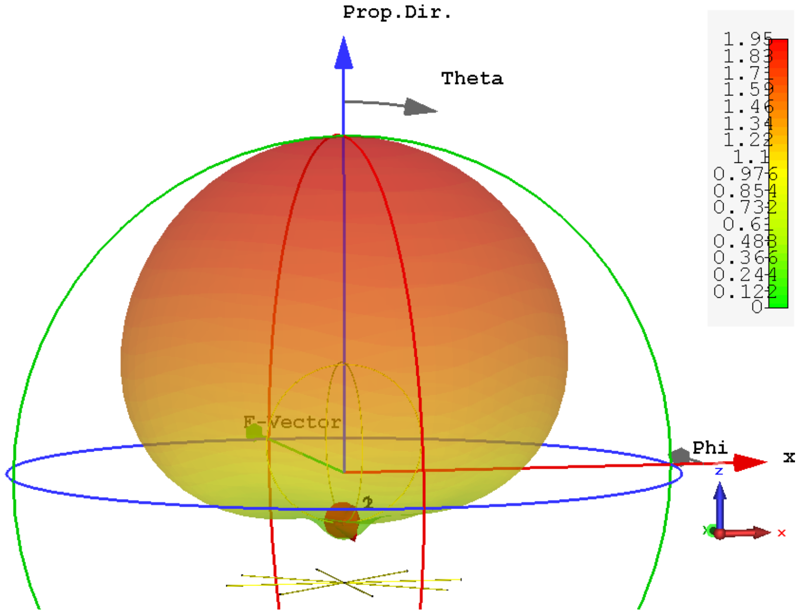
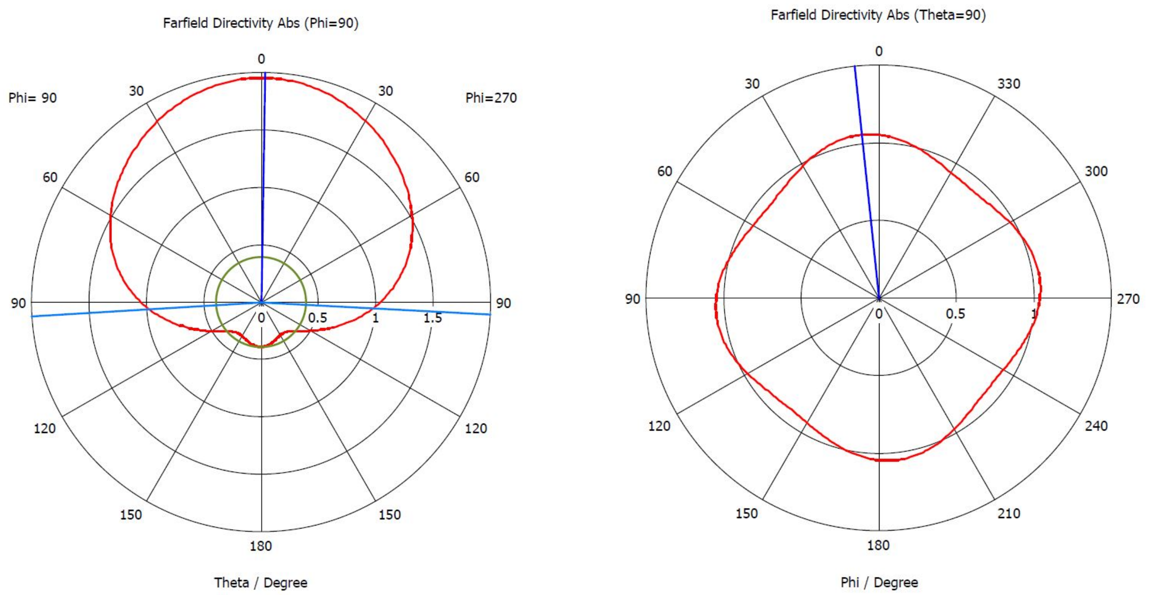


Figure 4.7 – *3D radiation pattern.*

4.2.3 optimization in CST

We have used the optimization tool of CST to adjust the length of the loop perimeter to obtain the minimum of the $|S_{11}|$ parameter at the frequency of 435 MHz. Also, we are going to change the inclination of the steel rod from the ground plane to see the effect produced on the radiation pattern. We can see the result of the simulation after optimization on figures



(a) *vertical plane (1)* **(b)** *horizontal plane (2)*

Figure 4.8 – *Radiation pattern polar coordinates*

4.10, 4.11, 4.12 y 4.13.

The angle (α) was varied between 0 and 60 degrees and the value which optimized the radiation pattern was 45 degrees. The new 3D model simulated in CST is shown in figure 4.9.

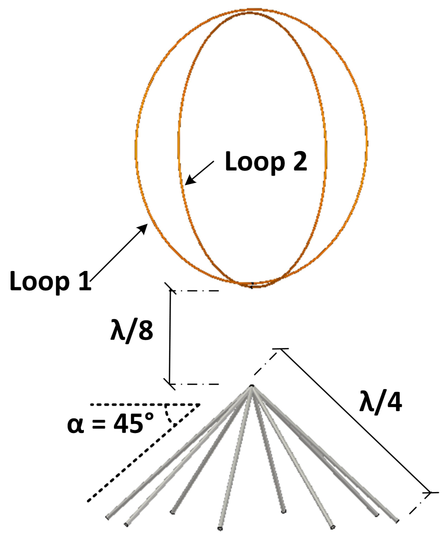


Figure 4.9 – *Second 3D model of eggbeater antenna.*

In figure 4.10 we can see that the new $|S_{11}|$ parameter is now tuned at 435 MHz.

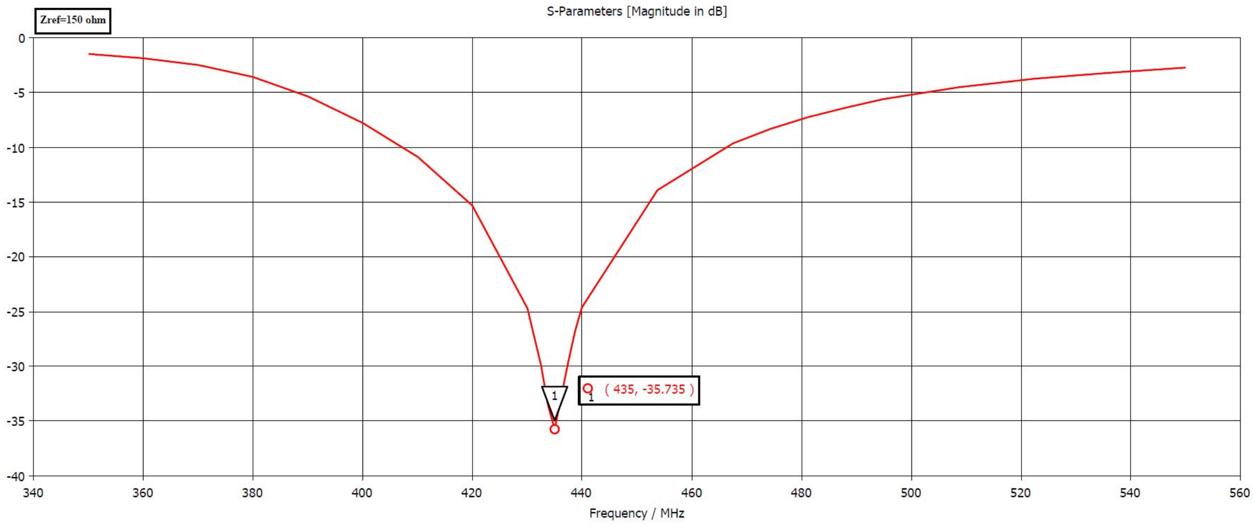


Figure 4.10 – */S_{11}/ parameter [dB] (after optimization).*

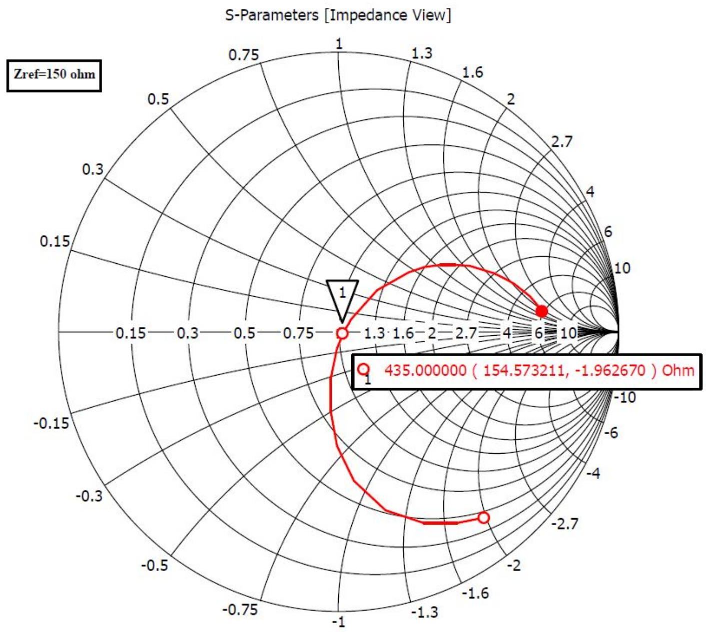


Figure 4.11 – */Z_{11}/ parameter [Ω] (Smith chart, after optimization).*

Due to the propagation the of OEM which travels parallel to the horizontal plane suffers more attenuation than the OEM which travel perpendicularly to the horizontal plane, the diagrams shown on figures 4.12 and 4.13 are more suitable for our antenna application.

Notice that after optimization, the maximum radiation direction form an angle near 45 degrees with horizontal plane and before optimization the maximum direction of radiation formed an angle near 90 degrees with horizontal plane. According to that, we will try to adapt our design to the design seen after optimization 4.9.

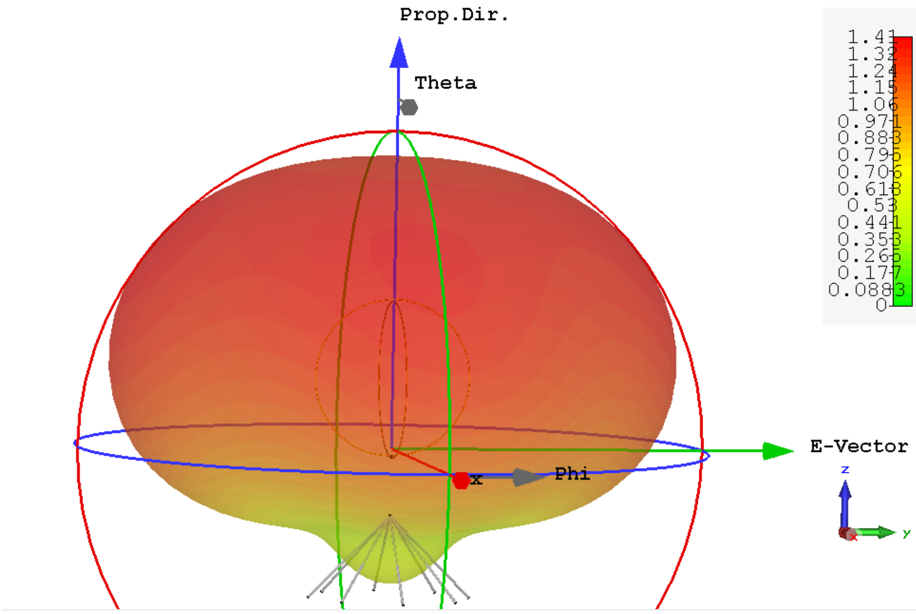
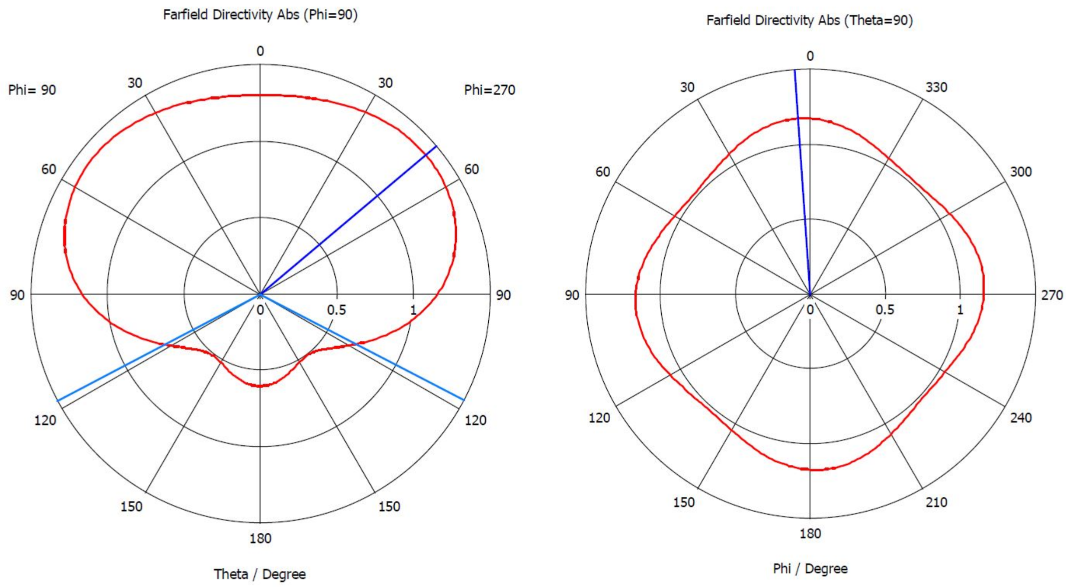


Figure 4.12 – *3D radiation pattern (after optimization).*



(a) *vertical plane (1)* **(b)** *horizontal plane (2)*

Figure 4.13 – *Radiation pattern polar coordinates (after optimization)*

We have included on our simulation mechanic elements which provide the stiffness and realism to our design, these are: A PVC pipe which hold the loops above the ground plane, a piece of ABS designed in SolidWorks and printed on a 3D pinter to hold the inclined steel rods, a PCB board which handles for make the electrical connection between all the steel rods and a part printed on 3D printer with ABS which handles to hold the loops in the upper part. The result is shown in figure 4.14.

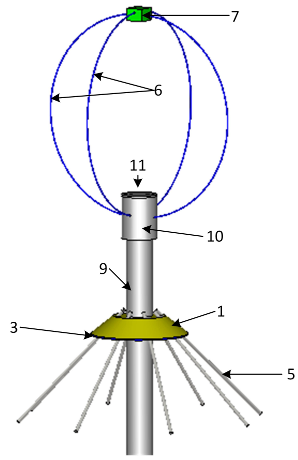


Figure 4.14 – *constructive design of eggbeater Antenna. parts listed on figure are explained in section 4.2.3.*

The results obtained after the simulation of the antenna shows in figure 4.14 did not change quantitatively the results obtained after optimizing. This is because the materials used for provide the stiffness to the system are electromagnetically transparent (ABS has an ϵ_R of 2.9 and PVC has an ϵ_R of 3.2 at this frequency).

4

4.3 Feeding system design

In this section we are going to explain the design of the feeding system including the symmetrization system, the impedance adaptation system and the de-phasing system. We can have an overview of the complete feeding system viewing the figures 4.15 and 4.16.

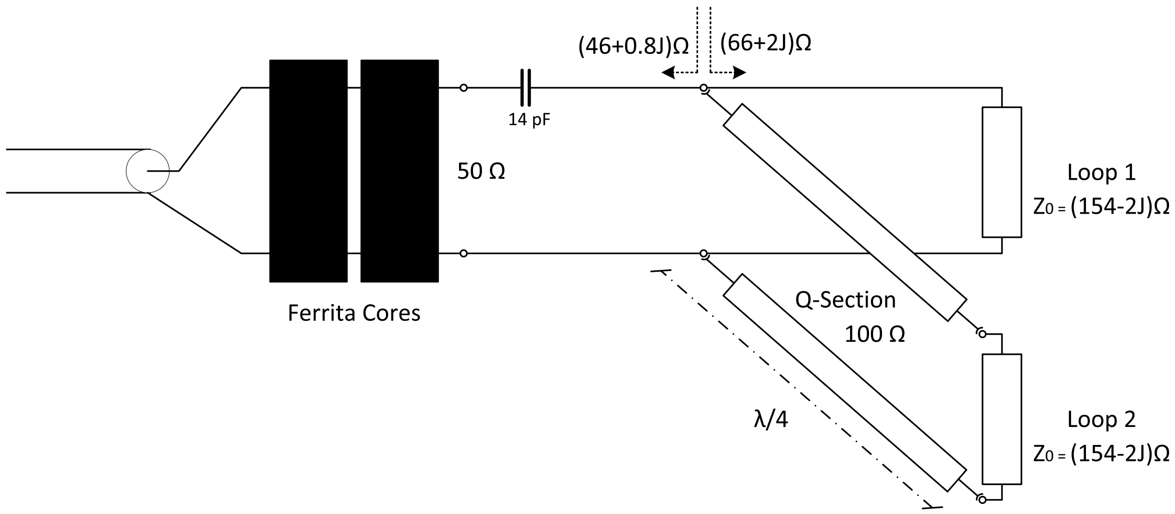


Figure 4.15 – *Transmision line Diagram of eggbeater antenna.*

In the figure 4.15 we can see a transmission line diagram in which the system of impedance adaptation, symmetrization and de-phasing are included. In figure 4.16 a connexion diagram of the whole antenna is shown. This diagram can be separated in different parts listed bellow.

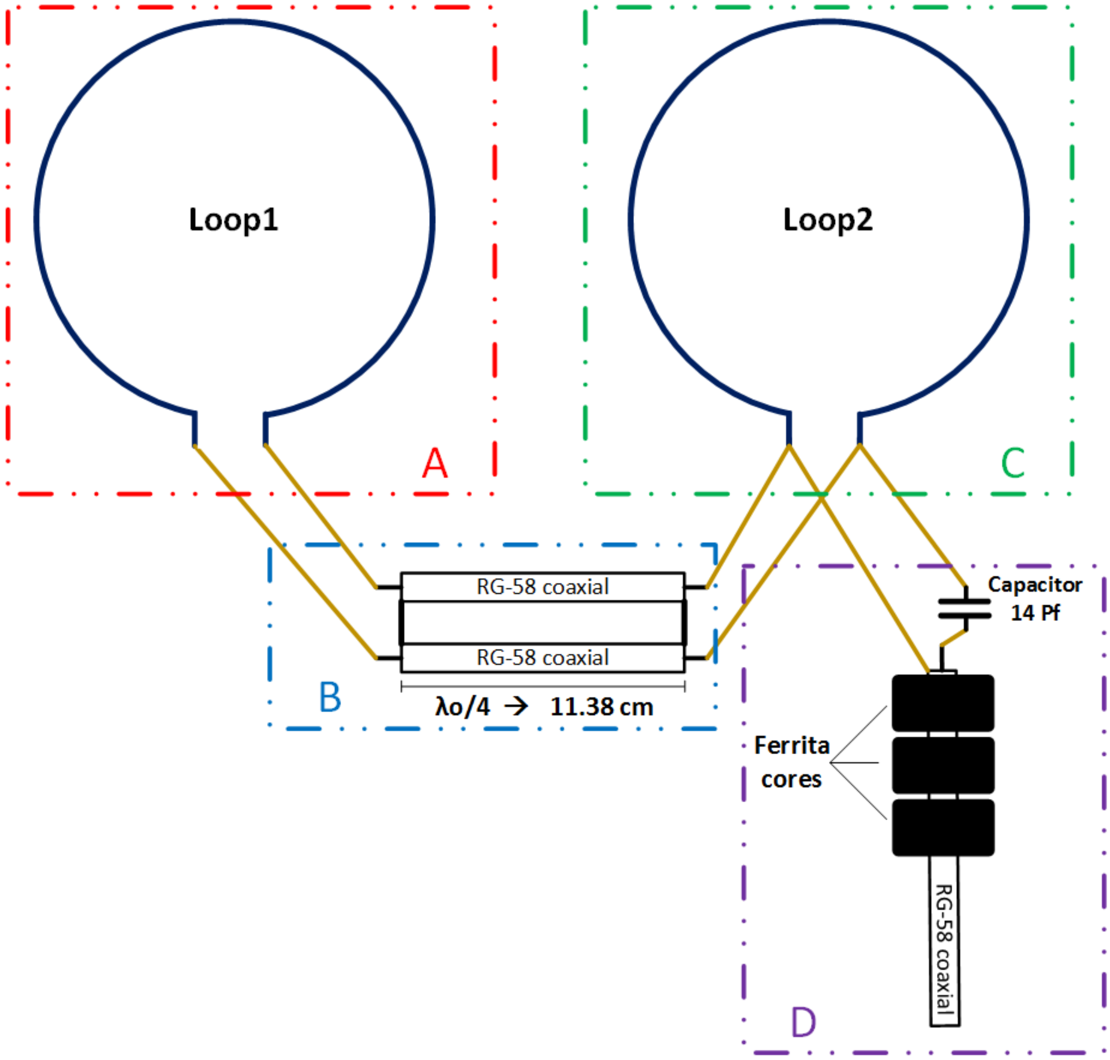


Figure 4.16 – *General overview of connexion diagram of eggbeater antenna.*

- A and C: This section correspond to the antenna loops. These loops have a perimeter of λ (69 cm) and 68 cm after simulation. As it can see in figure 4.11, the impedance of one loop(supposing both loops fed) is (154 -2j) Ω.

- B: In this section we can find the Q-Section transmission line. This Q-section has a length of $\lambda/4$. We will analyse this in section 4.3.1.

- D: In this section take place the symmetrization of coaxial wire and the impedance adaptation. We will see that in sections 4.3.2 and 4.3.3.

4.3.1 Phasing line

The circular polarization is produced by the radiation of two loops with a feeding of 0j and 90j. A transmission line of $\lambda/4$ produces a offset of 90 degrees between both loops.

To obtain the necessary offset between booth loops, we are going to use a Q-section build in RG-58 coaxial with a length of $\lambda/4$. It is shown in figure 4.17. This Q-section will have double impedance that the characteristic impedance of the coaxial wire used to build it.

Figure 4.17 – *Q-section made with RG-58 coaxial.*

As our coaxial wire has a characteristic impedance of 50 Ω, our Q-Section will have an impedance of 100 Ω.

It is important to take account that the propagation speed of the OEM on coaxial wire is not the same than the propagation speed of the OEM on air. So the length of the transmission line is given by the equation 4.3.1.

$$\lambda = \frac{c * V_f}{f} \tag{4.3.1}$$

Where V_f is the propagation speed factor of the coaxial wire. In our case V_f is 0.66 for RG-58 coaxial. Making mathematical calculations, the length of the Q-section will be 11.37 cm.

4.3.2 Impedance adaptation

As we see on figure 4.11, the impedance of one loop (suposing fedding on both loops) is (154-2j) Ω.

We are going to analyse the effect that Q-Section produces when we move the impedance of the loop a distance of $\lambda/4$ on a Smith chart. In the knowledge that the characteristic impedance of Q-Section is 100 Ω, as we saw on section 4.3.1. The result of this analysis is shown in figure 4.18.

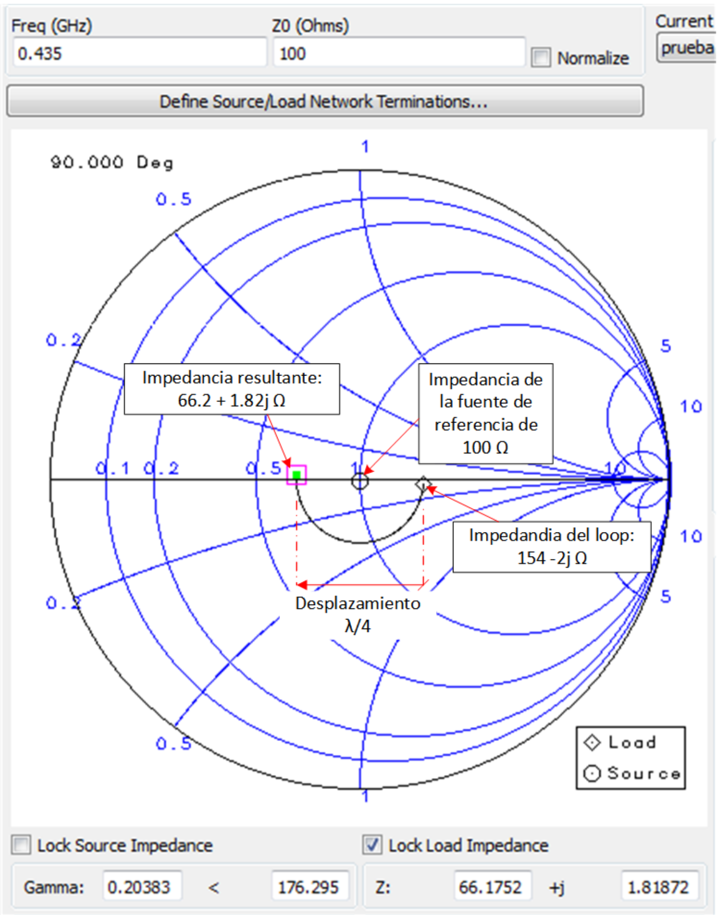


Figure 4.18 – *Movement of λ/4 on loop impedance.*

As we can see on previous analysis, the impedance of the set of loop 1 (section A on figure 4.16) and Q-section (section B on figure 4.16) is (66.2+1.82j) Ω. After This structure, we have the set of loop 1 and Q-section in parallel to the loop 2 (section C on figure 4.16). Doing the parallel between section C with set of sections A and B trough equation 4.3.2 we will obtain the impedance of the complete set.

$$Z_{tot} = \frac{1}{\frac{1}{(154-2j)\Omega} + \frac{1}{(66.2+1.82j)\Omega}} = (46 + 0.8j)\Omega \quad (4.3.2)$$

We can made the same analysis with ADS tool. To do this, we will export the $|S_{11}|$ parameter on Touchstone format from the simulation of one loop that we did in CST tool and we import with a S1P block in ADS. Q-section of RG-58 coaxial has been included on the ADS design and the set has been simulated. The schematic design of ADS is shown in figure 4.19.

Seeing impedance shown on figure 4.20, We can confirm that the results obtained in ADS simulation are very similar to analytical results that we obtained on equation 4.3.2.

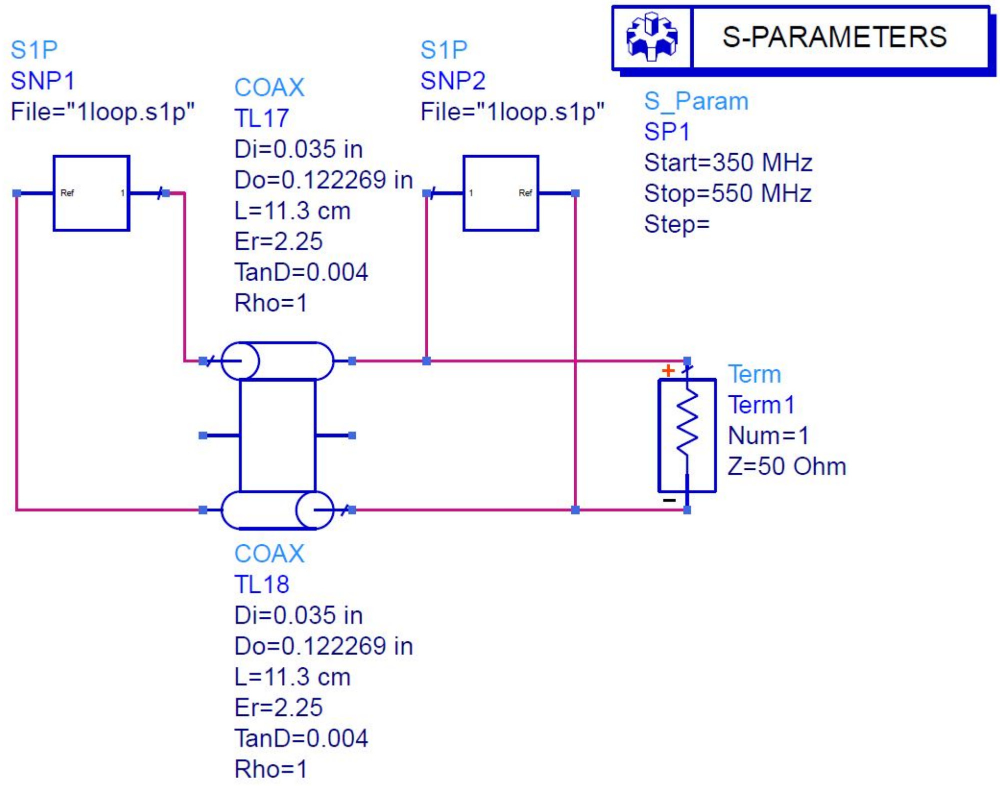


Figure 4.19 – *Schematic of the complete simulation of antenna in ADS.*

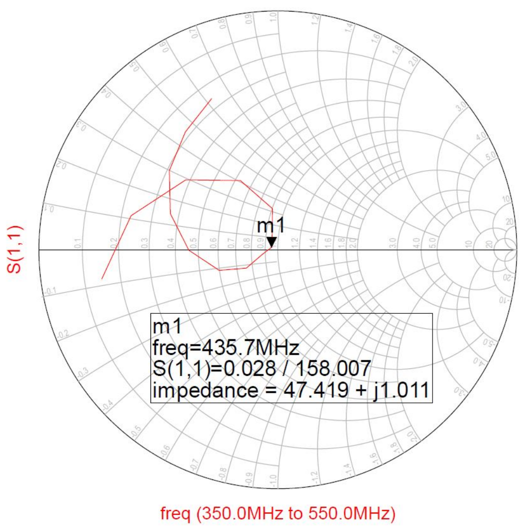


Figure 4.20 – *Smith Chart of $|Z_{11}|$ parameter of antenna simulation in ADS.*

In real measurement of Antenna we obtained an impedance of (47+26j) Ω. This variation on reactance between real measurements and simulation can be caused by the inclusion of N conector, the utilization of unbalanced coaxial wires or by building imperfections.

We decided to include one capacitor to adjust the reactive part of the impedance, it is shown on Section D of figure 4.16. The calculations needed to know the value of the capacitor necessary to correct the reactive part of +26j Ω are shown on equation 4.3.3.

$$C = \frac{1}{2\pi * f * Im(Z)} \tag{4.3.3}$$

Where Im(Z) is the reactance that we want to correct. The value obtained for the capacitors is 14 pF. The SMD capacitor we used has 0805 encapsulation. We are going to use this antenna only for reception signal, in another case, we will have to take into account the potency transmitted for the transceiver and the potency supported for the capacitor.

4.3.3 symmetrization

When a folded dipole or a loop (balanced line) is connected to a coaxial (non balanced line), occurs the situation shown on figure 4.21, where we see that one of the arm of the folded dipole is connected to earth directly and the other is conected to inner conductor of coaxial. As can be seen, the path of the currents for each arm of the dipole is not the same. This imbalance on the currents on arms of folded dipole affect to radiation pattern and impedance.

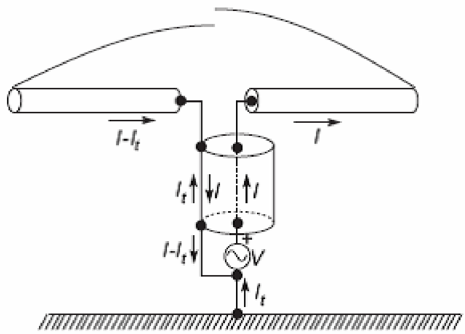


Figure 4.21 – *Unbalanced feed on dipole [Ricalde, 2015].*

As we can see on section D of figure 4.16, RG-58 specific toroidal ferrites has been included on the design to solve the problem of symmetrization. These ferrites causes that currents which travel on coaxial mesh on wrong direction disappears .The toroidal ferrites used are model 2661540002 of Fair-Rite Products Corp. These have an impedance of 370 Ω at frequency of 500 MHz.

4.3.4 Building

On figure 4.22 are shown the parts used on building phase of eggbeater antenna.

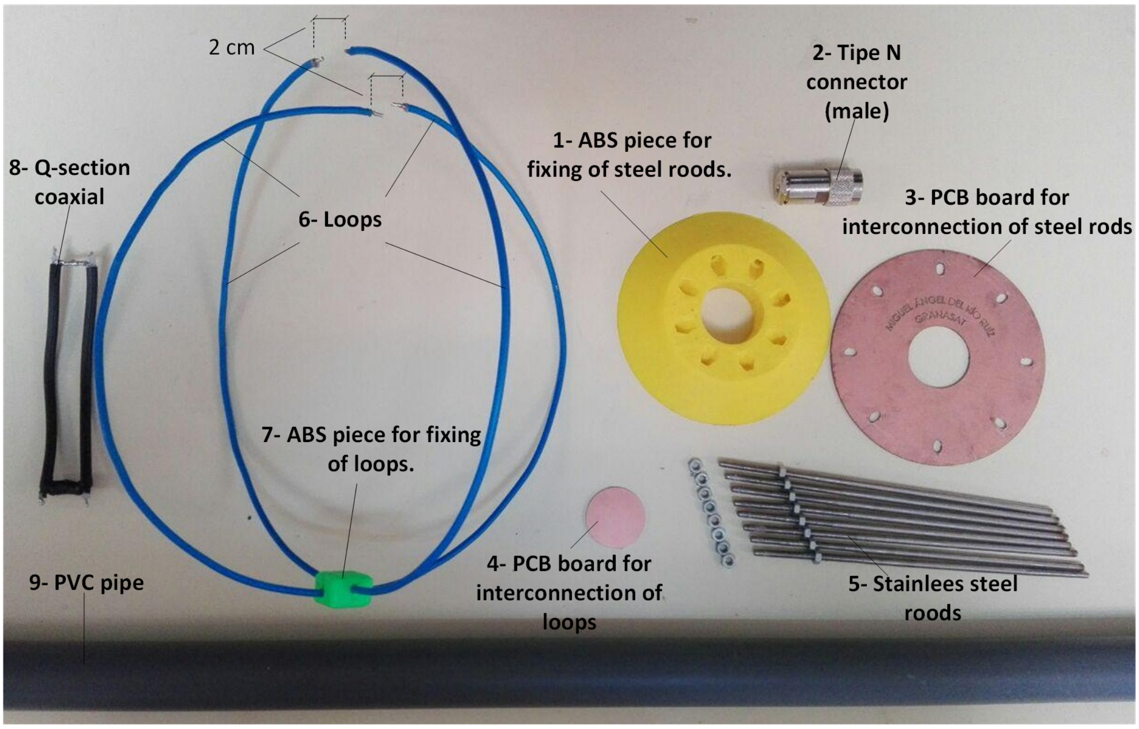


Figure 4.22 – *breakdown of eggbeater parts.*

4

1. ABS piece for fixing of steel roods: This part has been designed in SolidWorks and printed in laboratory of GranaSAT in a 3D printer. As it is shown in figure 4.23, we have extruded gaps for nuts with the purpose of fix the steel roods to the ABS piece.

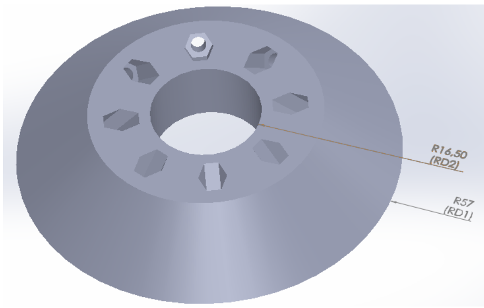


Figure 4.23 – *Design in SolidWorks of an ABS piece for roods fixing.*

2. Aerial type N connector for RG-58 coaxial wire.

3. PCB board for interconnection of steel roods: This piece made the electrical connection between stainless roods which form the ground plane. It has been designed in SolidWorks and build on LPKS S-62 milling machine for PCB of GranaSAT prototyping laboratory.

4. PCB board for interconnection of loops: This component serves to connect loops, feeding wire, Q-Section and capacitor. We have pulled out the cover cooper of some

parts of the PCB board with a cutting tool. see figures 4.26a, 4.27 and 4.28.

5. Stainless roods: These roods form the inclined ground plane. The length may be of $\lambda/4$ and they are threaded whit M4 metric at one end for fixing them whit nuts to pieces 1 and 3. Each one of eight roods has a length of 17.24 cm ($\lambda/4$), so we needed approximately 1.5 m of stainless rood. the price of this stainless roods of 4 mm of diameter is about 1.5 €/m.

6. Loops. Its has been built with cooper rigid wire of 2.5 mm^2 of section. Its have a perimeter of 68 cm (obtained through optimization in CST). The price of the wire is about 0.5 €/m.

7. ABS piece for fixing the loops: This part has been designed in SolidWorks and printed in the laboratory of GranaSAT in a 3D printer for the purpose of fix the loops on their upper part. As it is shown in figure 4.24, this ABS piece is a cube of 2 cm of large and 1.5 cm of heigh.

4

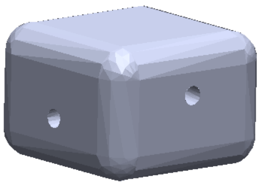


Figure 4.24 – *Design in SolidWorks of an ABS piece for loops fixing.*

8. Q-Section coaxial: This piece has been explained on section 4.3.1. It has been built on RG-58 coaxial wire and its connexions has been isolated with self amalgamating sealing tape.

9. PVC pipe: This is a evacuation class B PVC pipe of 32 mm and its purpose is to join and fix all the whole. Also, an PVC adapter to include the Q-section into the structure and a closing cap to avoid that rain water get into the structure has been included (pieces 10 and 11 in figure 4.25).

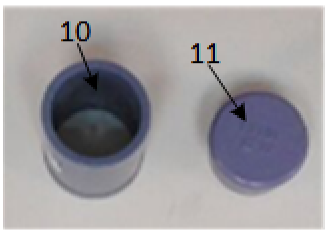
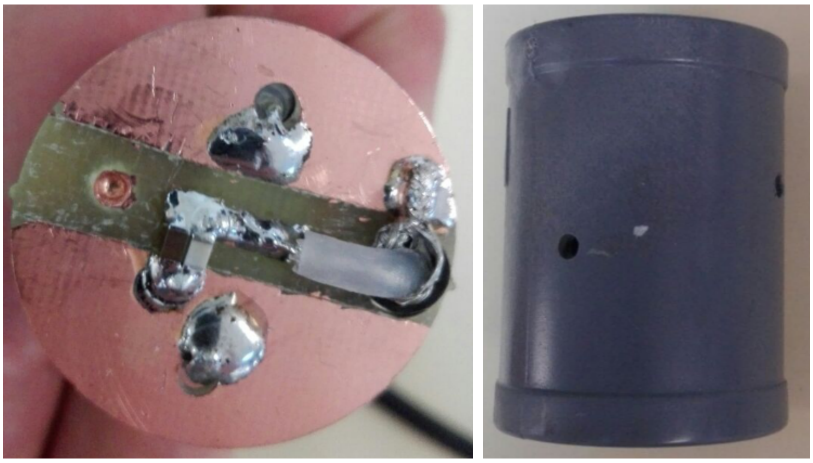


Figure 4.25 – *PVC adapter (left) and PVC closing cap (rigth).*

4.3.5 Assembly

At the beginning, the holes are drilled in the PVC adapter (piece 10) to introduce the loops wires. The holes should be perpendiculars.

Also, we carve the piece 4 with a cutting tool and a hole is drilled for routing the feed coaxial wire. A slot of various mm is provided on piece 4 to integrate the SMD capacitor and two Islets of cooper for loops soldering has been done. This procedure is shown in figure 4.26



(a) *Piece 4 modified* **(b)** *Piece 10 modified*

Figure 4.26 – *Pieces 4 and 10 modified for loops, capacitor and Q-Section assembly*

Now, we have welded the Q-section to the backside of the piece 4 which has been carved too in order to connect the loops. Then, we have introduced the piece 4 with Q-section, the feeding coaxial wire and capacitor into the PVC adapter (piece 10) and we have welded the loops, previously introduced on the holes of adapter, to the piece 4 . this procedure can be seen in figures 4.27 and 4.28.

Now, we are going to proceed with the ground plane system, for that, we are going to introduce the stainless roods (piece 5) into the ABS piece for rood fixing (piece 1) and we are going to thread the nuts to the roods fixing the set as we can see in figure 4.29. The nuts are introduced on a conformed cavity on piece 1 to avoid use a double tool to tighten it.

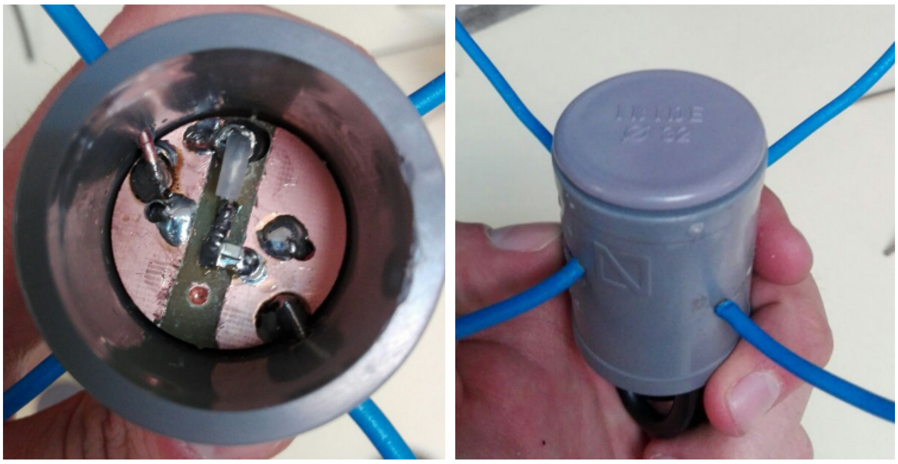
Then, we join two assembled systems (ground plane and radiation system) with the PVC pipe (piece 9) and mount the N type connector (pieza 2) at the end of the feeding coaxial wire.

As shown on figure 4.30, two toroidal ferrites has ben included in order to made a balanced system and symmetrize the feeding wire as we saw on section 4.3.3.

(a) *Piece 4 with Q-Section welded.*

(b) *Side view of set of piece 4, piece 10, feeding wire, Q-section, Capacitor and loops.*

Figure 4.27 – *Assembly of feeding, adaptation, and phasing systems.*



(a) *Assembly on top view*

(b) *Assembly with closing cap*

Figure 4.28 – *Assembly of feeding, adaptation, and phasing systems*

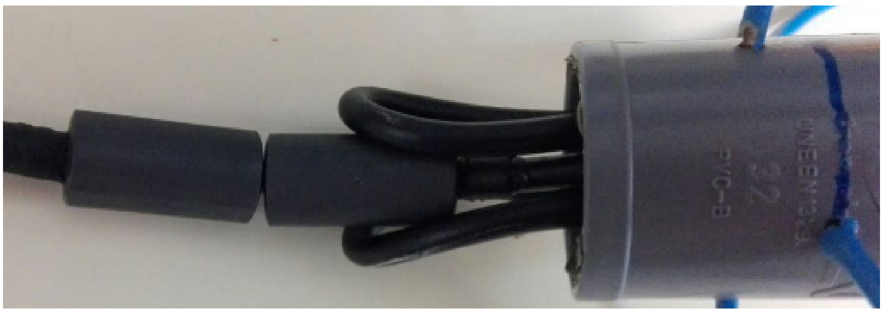
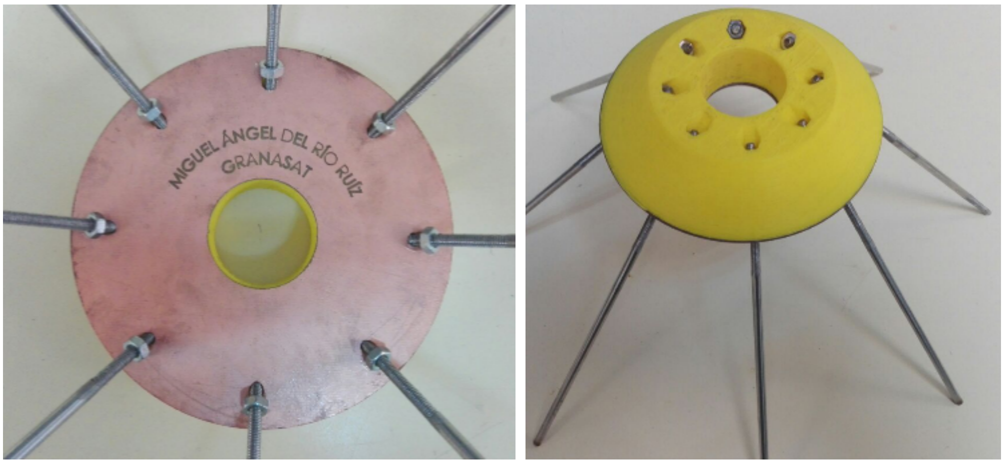


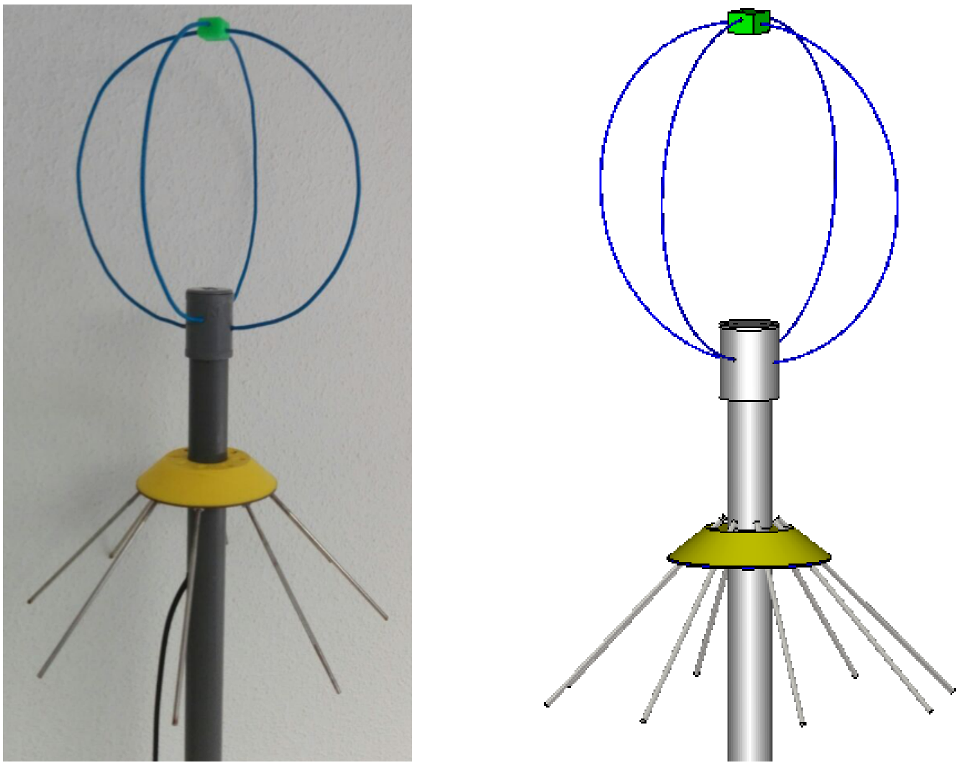
Figure 4.30 – *Assembly of symmetrization system.*



(a) *Side view of Assembly of ground plane* **(b)** *Top view of Assembly of ground plane*

Figure 4.29 – *Assembly of ground plane.*

At the end, we fix the ground plane to the pvc pipe through a clamping flange avoiding the movement of the ground plane. The final result is shown on figure 4.31. As we can see, we have tried to give total realism to simulated model in order to have maximum accuracy on the final results.



(a) *Real antenna built* **(b)** *Simulated antenna*

Figure 4.31 – *comparison betwen real model and simulated model*

4.4 Measurements

Finally, we have done measurements of reflection $|S_{11}|$ parameter, the antenna impedance and the SWR. The results are shown on figures 4.32 and 4.33.

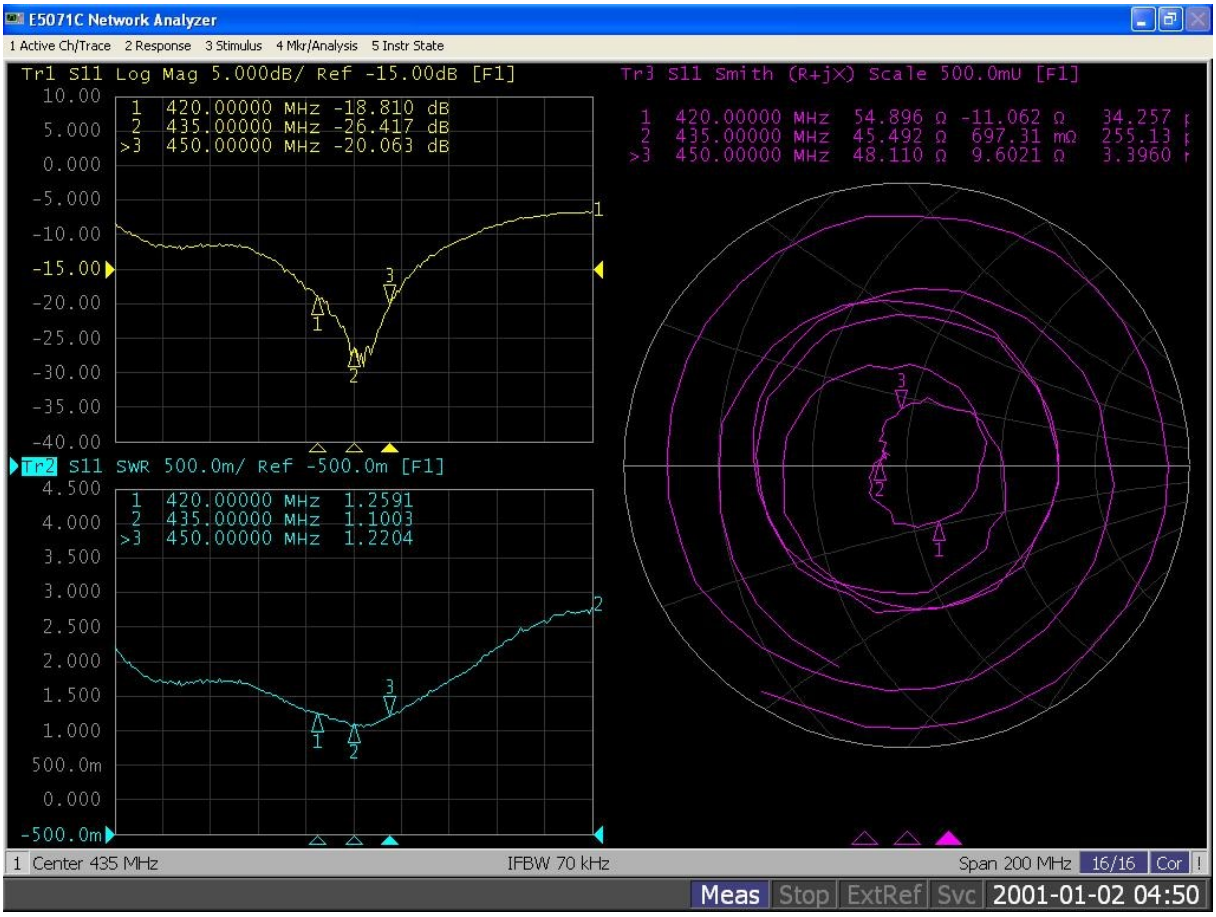


Figure 4.32 – *$|S_{11}|$ (left, up), SWR (left, down) and $|Z_{11}|$ (rigth). 335 MHz - 535 MHz*

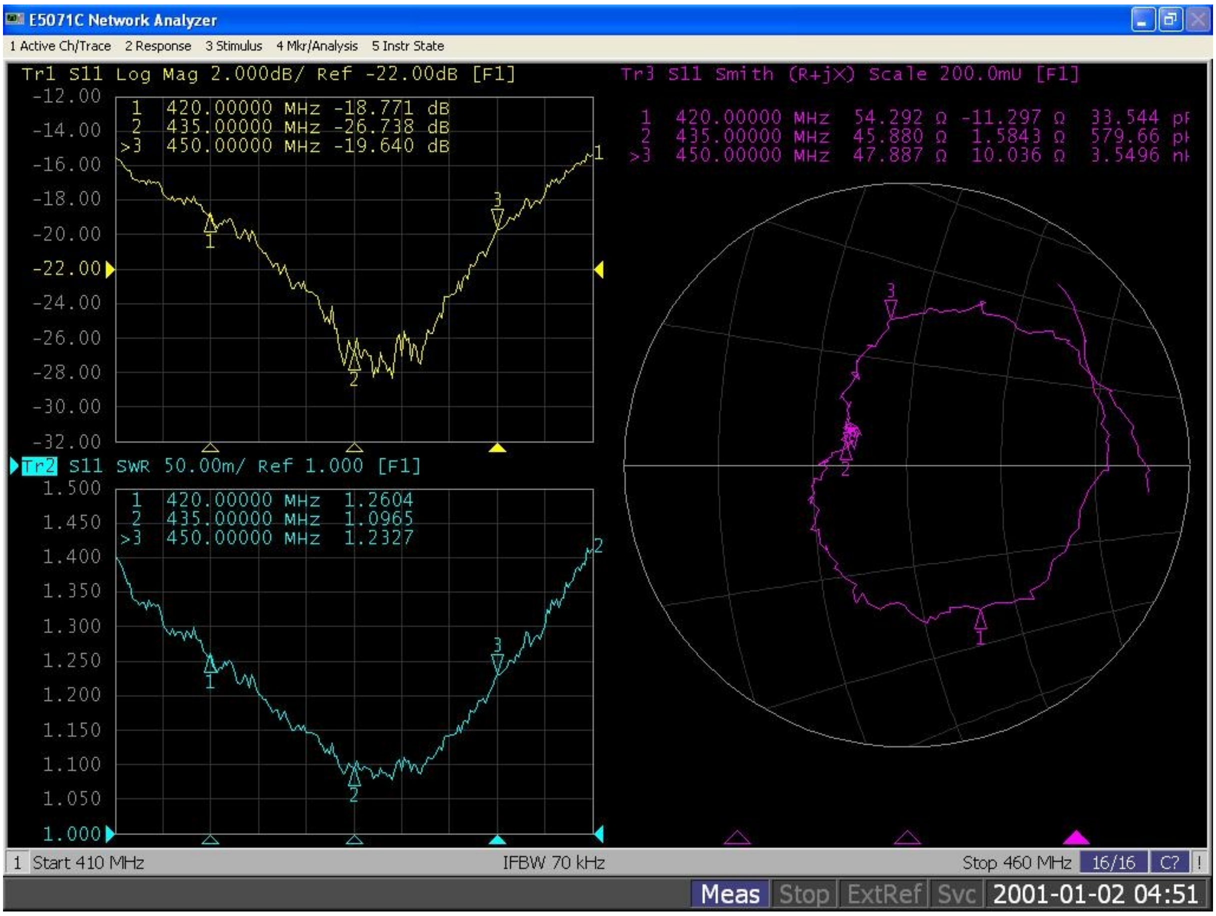


Figure 4.33 – $|S_{11}|$ *(left, up),* *SWR* *(left, down) and* $|Z_{11}|$ *(rigth). 410 MHz - 460 MHz*

CHAPTER

5

SYSTEM FOR ISS COMMUNICATIONS DESIGN, SIMULATION AND BUILDING

The aim of this chapter is the design, simulation and building of a system able to contact whit the ISS. The ARISS program tries to approach scientific world to children coursing primary studies by an experience based on video contacts with the international space station astronauts.

As we will see in the section 5.2, the developing of a radio system for ISS contact is a hard task. Due to that, the systems available on market are to expensive and many schools can not buy them. Our objective is to develop a home made and low cost radio system able to made video streaming with the ISS.

5.1 System description

The system will be able to receive the signal, process it, and show the video image and sound. In order to visualize the video with a common TV or projector, we are going to adapt the video signal to a conventional DVD-S decoder. We should adapt the satellite signal for a conventional DVB-S decoder receptor, as most of the DVB-S receivers can receive signal at 1600 MHz, we will design a down-converter which transform the frequency of the signal of ISS to 1600 MHz. Added to that, we will need a antenna for signal reception.

In this protect we will design the antenna.

5.2 System requirements

Our system should work on 2,4 GHz, it will have an impedance of 50 Ω and right hand circular polarization, also, the system should be very directive. In the following subsections, we will explain why we need this requirements.

5.2.1 Frequency

As we can se on https://amsat-uk.org/satellites/hamtv-on-the-iss/, The transmitter which is installed in the Columbus module can transmit DVB-S signals on 2369 MHz, 2395 MHz, 2422 MHz or 2437 MHz, so our system will be tuned to 2.4 GHz and a bandwidth of 100 MHz.

5.2.2 Polarization

As we explained on previous chapter, the Faraday effect produces a change of polarization angle on signal which pass through the ionosphere, so space communications will often be with circular polarization. In this case, the ISS transmit with RHCP(Right hand circular polarization), so our system should have RHCP too.

5.2.3 Radiation pattern

Due to the distance between the earth and the ISS is about 400 Km, our system must be very directive, so, the antenna of our system should have a very directional radiation pattern.

5.2.4 Impedance

Due to most of the signal reception and measure equipment works with an impedance of 50 Ω, we will seek that the antenna of our system have a impedance of 50 Ω.

5.3 Antenna design

There are many kinds of antennas which can be tuned to 2,4 GHz with an impedance of 50 Ω, but, in this system we also need a RHCP and very directive antenna, so, we decided to design an helix antenna and made it more directive with a reflector.

As the aim of this project is to develop a low cost system which schools can use without spend a lot of money, we decided to design an adapter for mounting the helix antenna we are going to build in any commercial reflector.

5.4 Antenna physical specifications

A helical antenna is an antenna consisting of a conducting wire wound in the form of a helix. In most cases, helical antennas are mounted over a ground plane. The feed line is connected between the bottom of the helix and the ground plane. Helical antennas can operate in one of two principal modes, normal mode or axial mode.

In the normal mode or broadside helix, the dimensions of the helix (the diameter and the pitch) are small compared with the wavelength. The antenna acts similarly to an electrically short dipole or monopole, and the radiation pattern, similar to these antennas is omnidirectional, with maximum radiation at right angles to the helix axis. The radiation is linearly polarised parallel to the helix axis. These are used for compact antennas for portable and mobile two-way radios, and for UHF television broadcasting antennas.

In the axial mode or end-fire helix, the dimensions of the helix are comparable to a wavelength. The antenna functions as a directional antenna radiating a beam off the ends of the helix, along the antenna's axis. It radiates circularly polarised radio waves. These are used for satellite communication [Wikipedia, 2016c] .

For knowing the approximate dimensions of the antenna elements, we decided use an online calculator for helix antennas and then optimize the design with CST MWS. In the online calculator used (`http://www.qsl.net/on6jc/ant/helix/helixcalc.html`), we deffine the entry parameters as:

5

- frecuency: 2400 MHz. This is the center frecuency of our antenna
- Numbers of turns: 3. Our anntena is designed for being mounted in front of a reflector, so, we are limited by the length of the antenna.
- length of turns (in wavelength): 0,25. This parameter and the numbers of turns defines the total length of the antenna. With 3 trusn and a length of 0.25 λ for each turn. The total length of the antenna is 93,7 mm.

The results are shown on figure 5.1.

We can´t meet all the physical specifications of the results shown on figure 5.1 in our design. The conductor diameter in the calculator results is 2,5 mm, but we only dispose rigid wire of 1.78 mm of diameter (2.5 mm^2 of section). Added to that, the radius of the ground plane calculated is of 7,75 cm and it is too big for mounting the antenna in a reflector.

After this analysis we determine that the physical dimensions of the antenna components should be:

Resultados		
Largo de onda	Diámetro (interno) ideal	Ganancia
125 mm	D=42.1 mm	8.27 dBi
Diámetro del conductor	Paso de la hélice (entre centros)	Separación de la sección de adaptación
d=2.5 mm	S=31.2 mm	a=1.2 mm
Largo total conductor	Diámetro (mínimo) reflector	Largo total antena
408.4 mm	R=77.5 mm	L=93.7 mm

Figure 5.1 – *results for online calculation for helical dimensions .*

- Internal diameter of coil: 21,05 mm.

- Conductor diameter: 1,78 mm.

- spacing between coils: 31,2 mm.

- total length of the antenna: 93.7 mm.

- ground plane reflector diameter: 50 mm. This is because we are going to cover it with evacuation class B PVC pipe of 110 mm.

With this changes we need to optimize our design with CST. This procedure will be explained in the subsection 5.5.

5.5 Antenna simulation

We design the antenna in CST with the dimensions explained on previous section. We added to the design a mount female N connector to give all possible realism to simulation. Also, we added a thin cooper sheet to the beginning of the cooper wire in order to adapt the antenna to 50 Ω. In the figure5.2 you can see the 3D model of the antenna designed on CST.

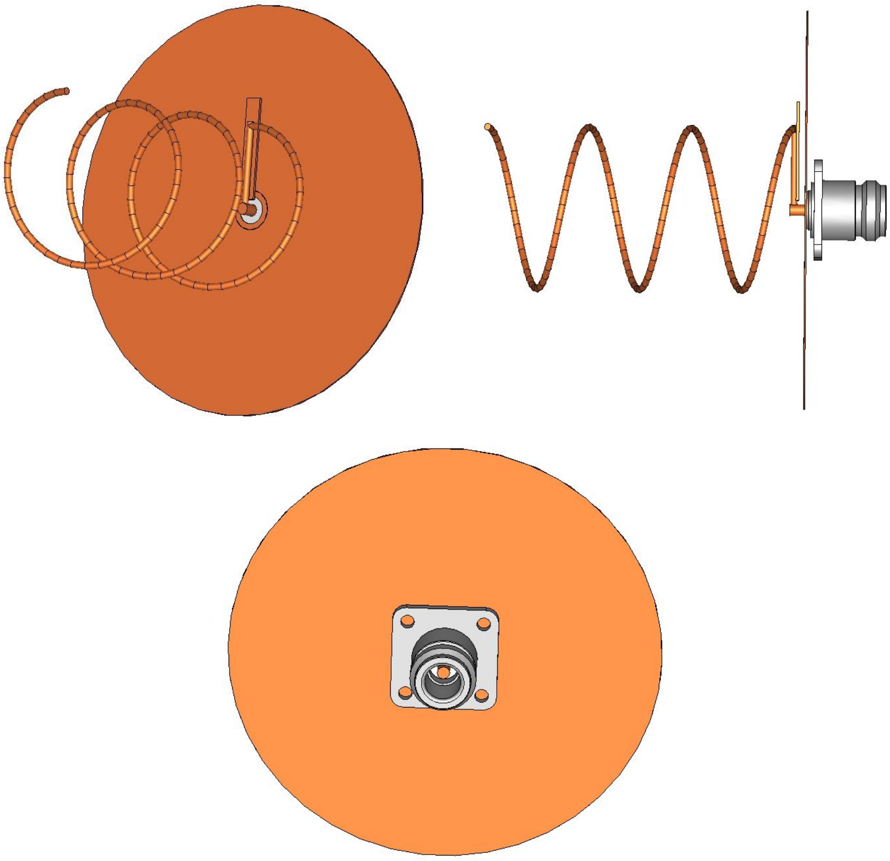


Figure 5.2 – *3D model of the helix antenna.*

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We run the optimization tool for Impedance adaptation calculation. in such a way, the dimensions of the cooper sheet calculated are shown in figure 5.3.

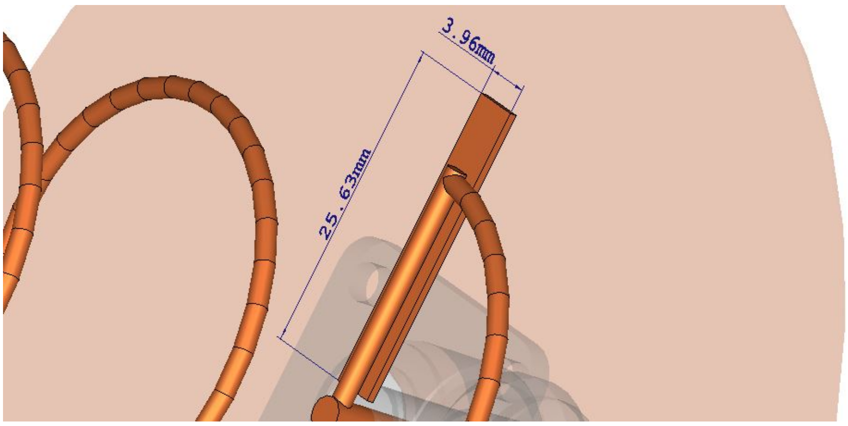

Figure 5.3 – *cooper sheet for impedance adaptation dimensions.*

Simulation results are shown in figure 5.4 and 5.5.

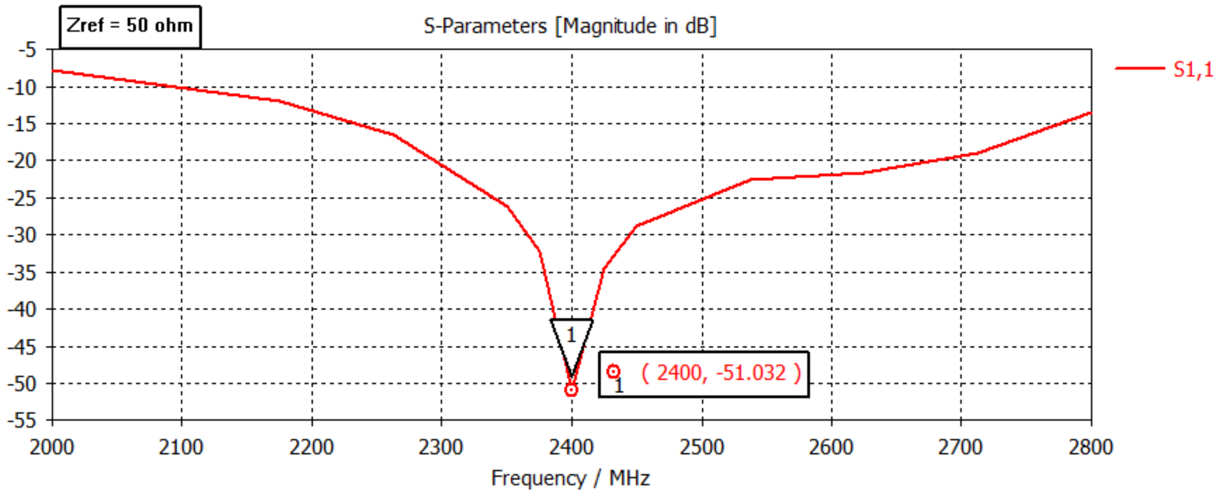

Figure 5.4 – *$|S_{11}|$ parameter [dB].*

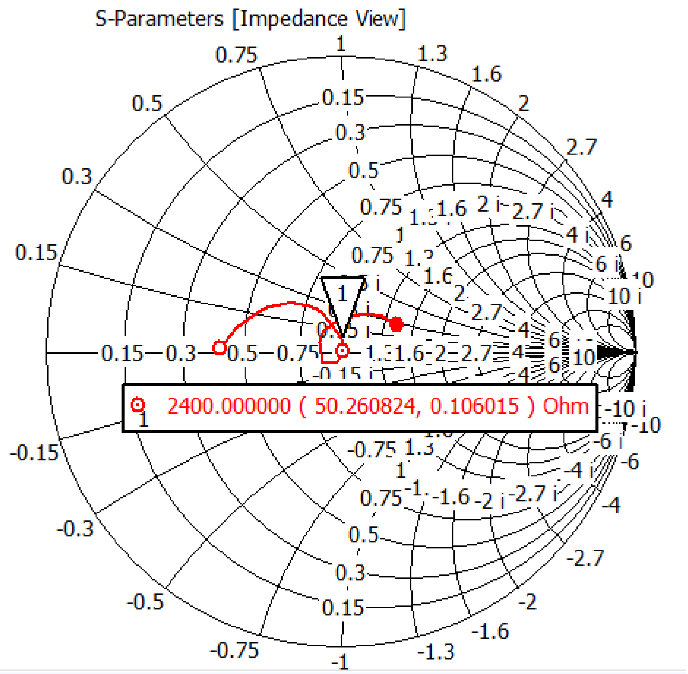

Figure 5.5 – *$|Z_{11}|$ parameter [dB]*

As we can see, our antenna is perfectly tuned to 2400 MHz and its impedance is about 50 Ω.

The 3D radiation pattern obtained on the simulation is shown in figure 5.6.

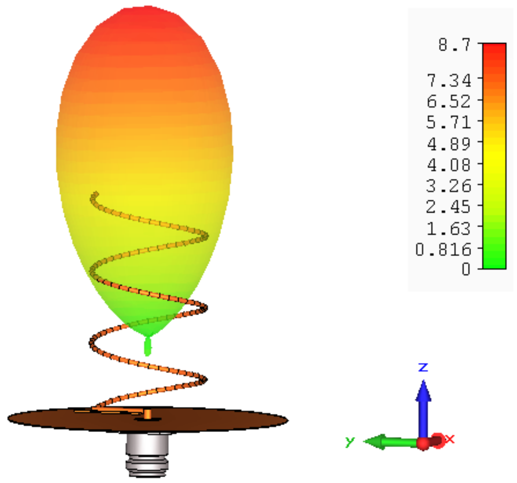

Figure 5.6 – *radiattion pattern of helix antenna.*

In this radiation pattern we can confirm that our antenna is working in the axial mode and our antenna is as directive as expected. The gain of the antenna is 8.7 dBi.

5.6 Building

In order to protect the antenna of adverse weather conditions, we are going to introduce it into a PVC structure formed for one PVC pipe and two PCV caps. We choose PVC because it is cheap, resistant and electromagnetically transparent.

The building procedure begin with the ground plane and PVC cap drilled. We did four holes to screw the N connector to the ground plane plate and the PVC cap. Also, we do other central hole to pass the inner conductor of the connector trough the PVC cap and the ground plane. see figure 5.7

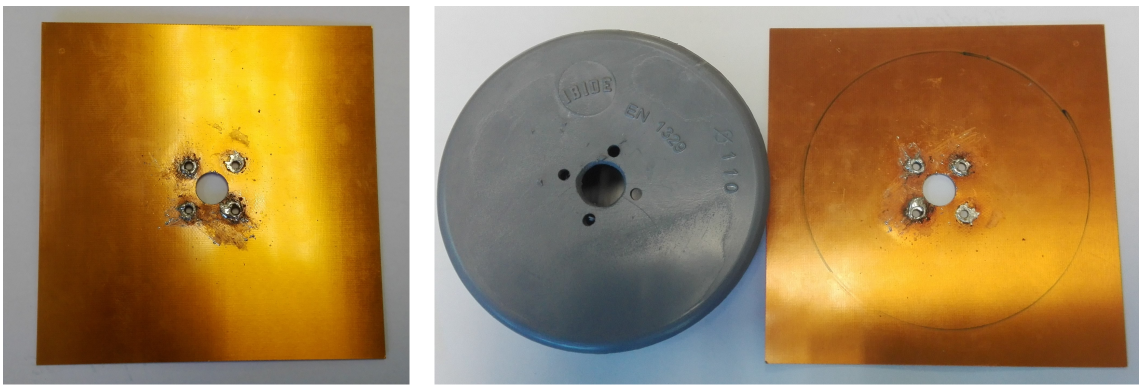

Figure 5.7 – *drilled of PVC cap and PCB board.*

Second step is to cut the ground plane, which was built with a PCB board. We cut this PCB with a electric saw in a way that the PCB can be introduced into the PVC cap. see figure 5.8.

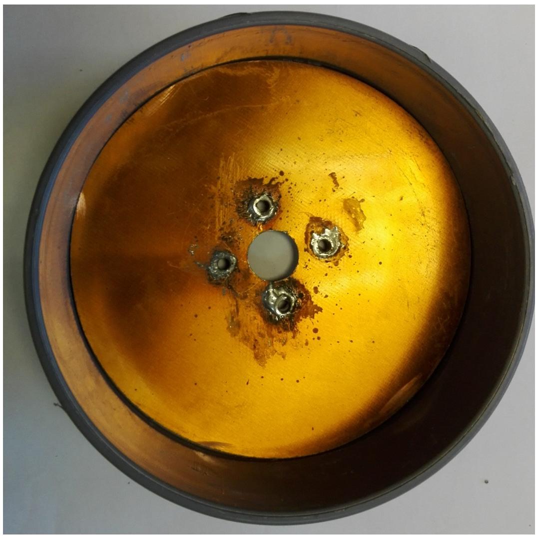

Figure 5.8 – *cutting of PCB ground plane.*

Third step is to join the N connector whit the PCB gorund plane and the PVC cap. To do this, we used through-bolt and fixed its with nuts. The result is shown in the figure bellow 5.9.

Figure 5.9 – *N connector, ground plane and PVC cap mounting.*

Next step is to build the helix with the cooper wire. for that task we use a 4 cm of diameter PVC pipe. We moulded the rigid wire until the desired helix with 3 turns an a total length of 9.37 cm was obtained. Then, the cooper sheet with the dimensions obtained on simulation was soldered with tin as can be seen in the figure 5.10.

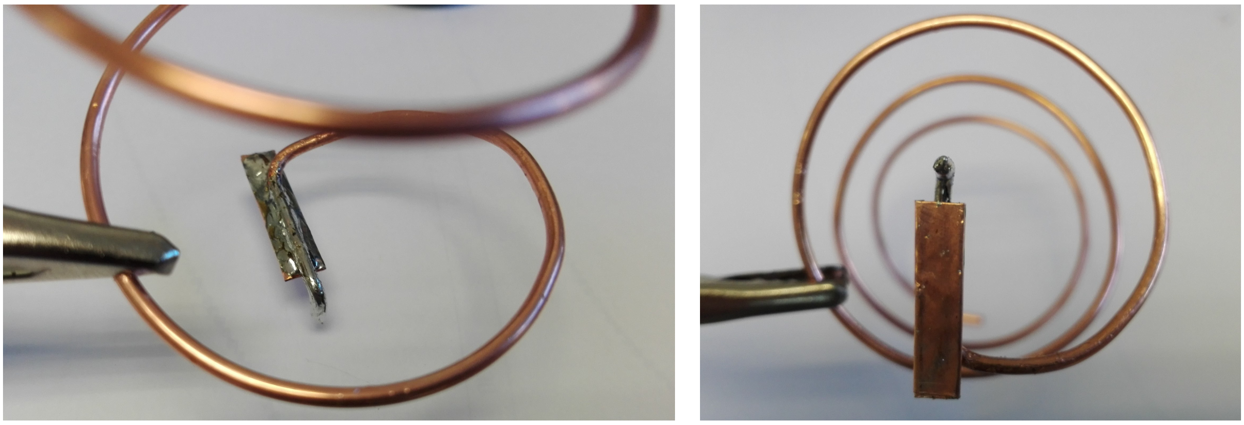

Figure 5.10 – *helix and adaptation system building.*

Then, we soldered the two parts joining the inner conductor of N connector to the beginning of the helix of rigid cooper. To provide stiffness to the mount, we introduce a small piece of foam board between the cooper sheet and the PCB. The result is shown in figure 5.11.

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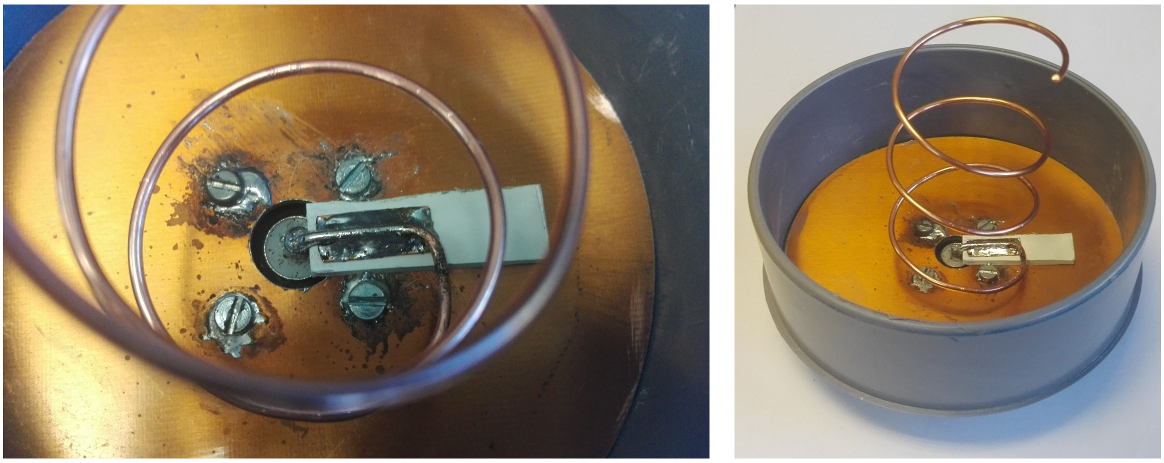


Figure 5.11 – *joining of two parts and fixing of helix.*

The last step is to cover the whole system with the PVC pipe and the upper PVC cap. The PVC Cap was cut with a circular saw and it length is of 12 cm. For more details see figure 5.12.

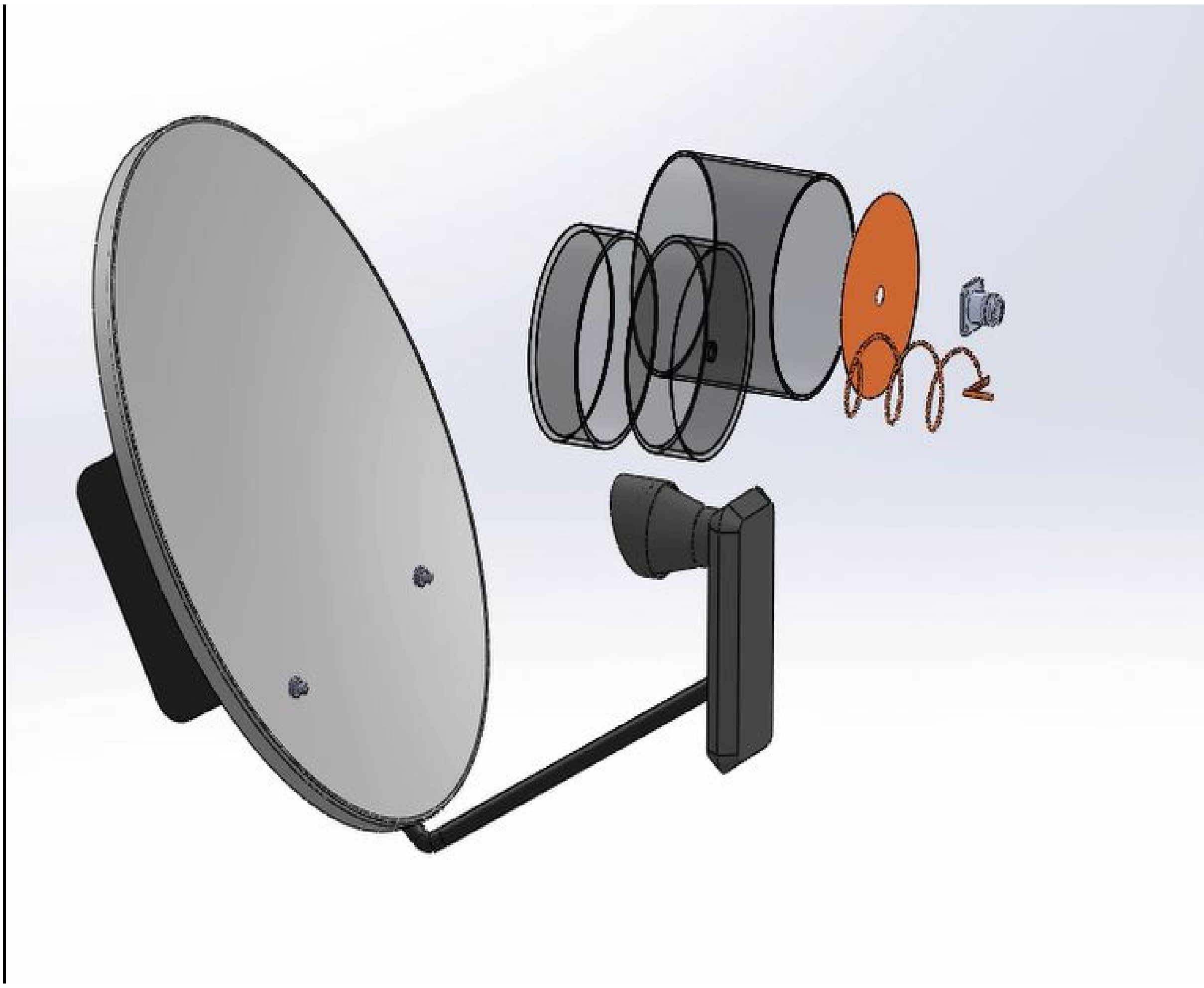
Figure 5.12 – *Antenna finished with PVC protection.*

5.6.1 Design of antenna holding piece

In order to adapt the antenna to a parabolic dish, we have done two holes on the antenna according two the LNB holder of the antenna. the result is shown in figure 5.13

Figure 5.13 – *Antenna fixed on parabolic dish.*

Bellow you can see a video of the assembly of the whole system. Click two times the image for viewing the video 5.1



Video 5.1 – *Helicoidal antenna on parabolic dish*

As we explained in section 5.3, we decided to design an adapter for mounting the helix antenna in any commercial parabolic reflector. Most of reflector have a LNB holder like shown in the figure 5.14.

Figure 5.14 – *Universal LNB holder.*

We designed a piece on SolidWorks which allow us to fix our helicoidal antenna to the universal holder of parabolic dish. The 3d model of the piece we have designed is shown in figure 5.15.

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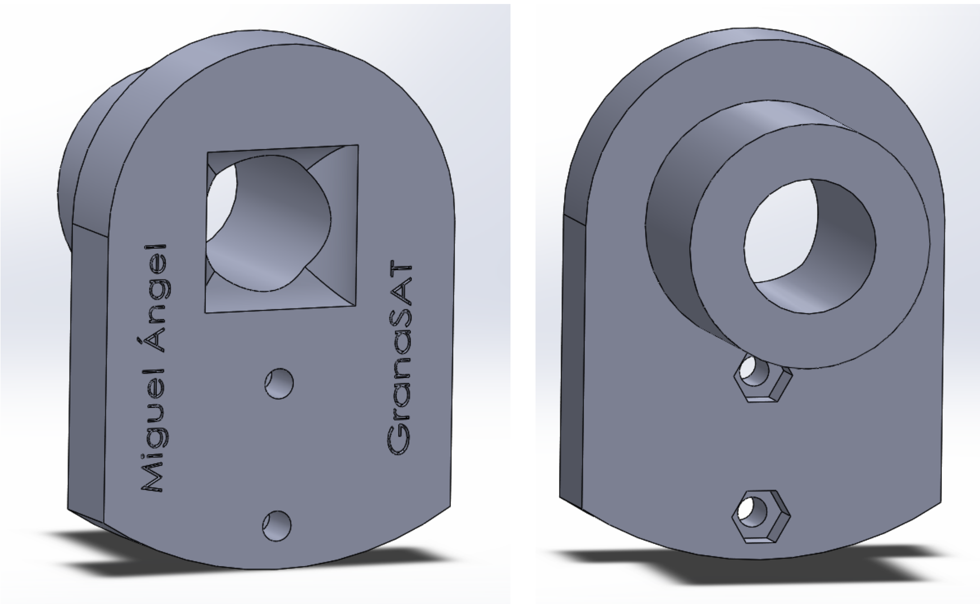

Figure 5.15 – *3d model of universal antenna holder piece.*

This piece is specifically built for this antenna design and have two hexagonal holes to fix the antenna to the piece with two metric 4 nuts.

We make the piece with the 3d printer on ABS plastic and we mounted it in a parabolic dish. the result is shown on figure 5.16

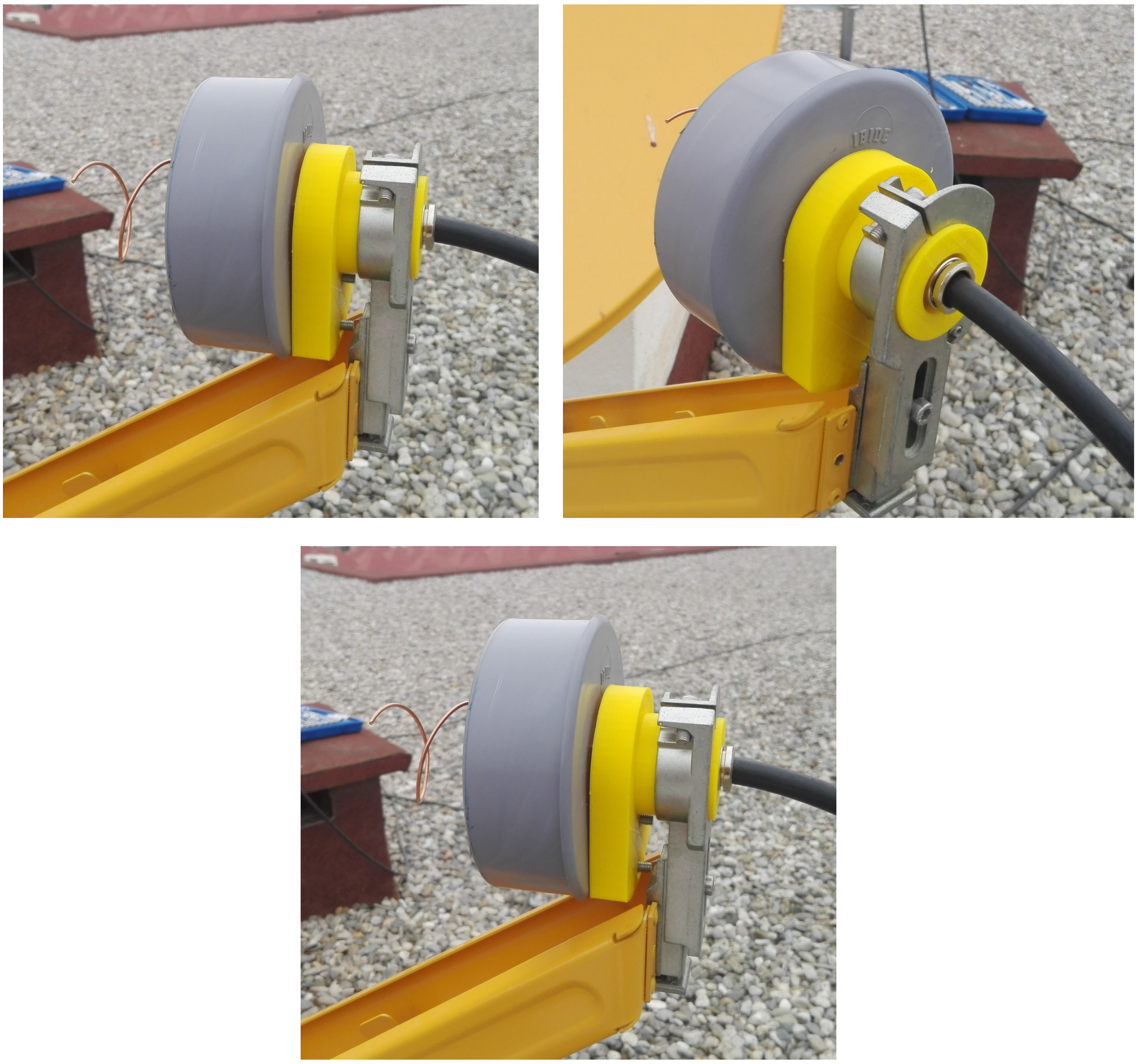

Figure 5.16 – *Antenna holder piece.*

5.7 Measurement

Using again the Agilent 85032F calibration kit with Agilent E5071C VNA, we measured $|S_{11}|$ and $|Z_{11}|$ of the helix antenna and the results are shown in figure 5.17.

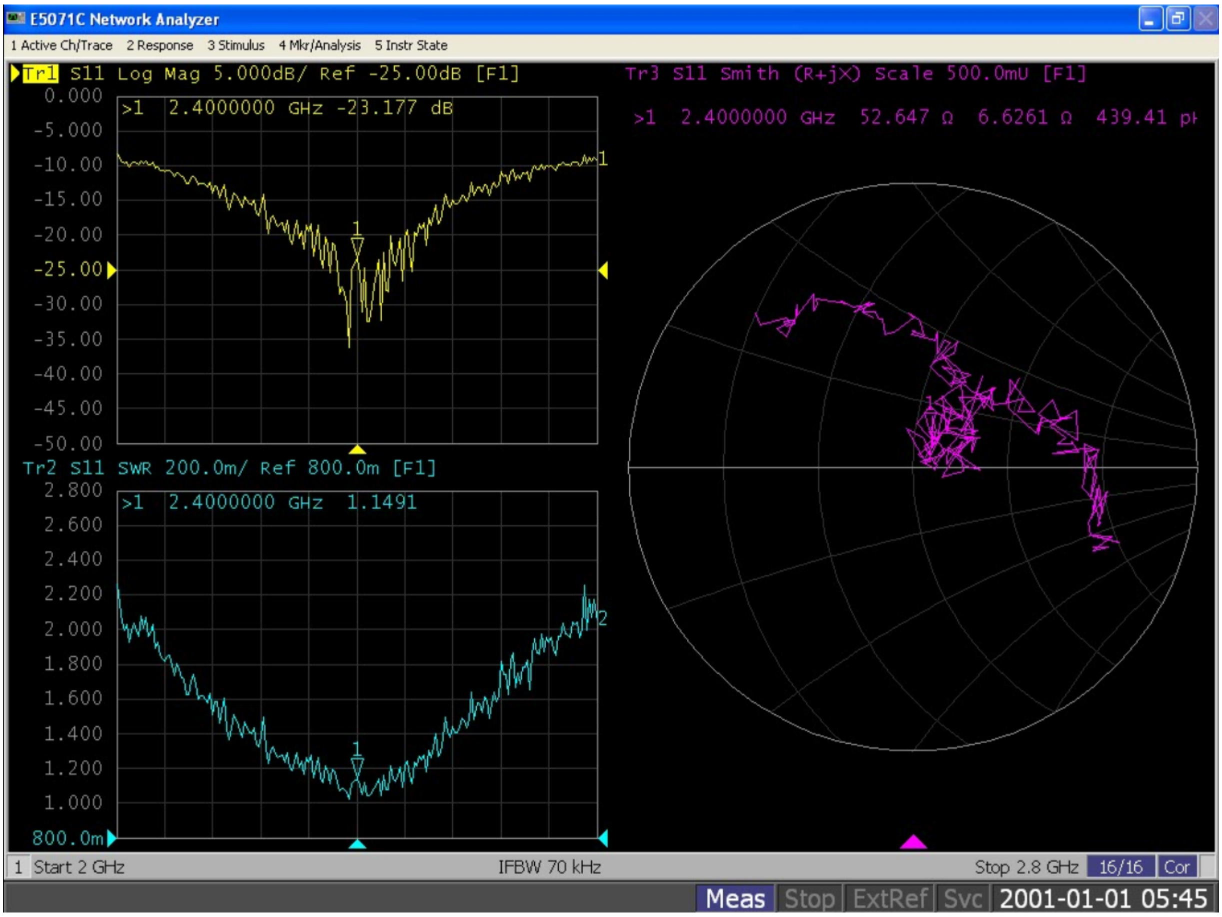

Figure 5.17 – *Antenna fixed on parabolic dish.*

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We can see as the results obtained on measurements are very similar to the results obtained on simulation that twe saw on section 5.5 and our antenna is perfectly tuned to 2,4 GHz with an impedance of 50 Ω.

CHAPTER

6 CONCLUSIONS AND FUTURE LINES

In this document, we have presented the development of some radiation systems for satellite communications as well as a improvement of the GranaSAT Ground Station. For a Telecommunication engineer it is a challenge to deal with aerospace field, so, the students who writes this document is very proud of the knowledge, experience and skills obtained during this work.

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. Only after getting involved in such a demanding project as the GranaSAT, one can say that the ability to work in groups has been learnt.

Also, the student has learned and improved to talk in public due to the conferences related with GranaSAT that the student has done during this project. Added to that, in this moment the GranaSAT team is involved in the publication of some articles in scientific magazines.

Although the client requirements has been achieved, the student think that there are many future work lines that can provide a added value to the systems developed:

- Downconverter for helix antenna: In order to stablish video contact with the

International Space Station (ISS), the development of a Downconverter which convert the frequency of the signal received for the helix antenna in 2,4 GHz to a low frequency signal. By this way the signal could be decoded by a commercial dvb-s receiver.

- LNA for the helix antenna: The signal received for the helix antenna has to travel 50 m on the coax wire to reach the basement. Its produces a noteworthy attenuation in the signal, so, build a LNA specific for this antenna would fix this problem.
- Radiation pattern meter: It would be interesting to have the possibility to have measurements of the antennas we have built. It is possible to design a radiation pattern meter with a Arduino or Raspberry module, a signal receiver, a controlled USB signal transmitter, a calibrated antenna and a mechanical structure to rotate the antenna.

As final conclusion, It is important to note that the student is very proud of the knowledge, skills and experience obtained during this project and appreciates the opportunity that the University and the project GranaSAT has offered him.

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APPENDIX

A

BUDGET

A.1 Elements Cost

In this section, the cost related with the elements used in the built of the antennas are detailed.

In the table A.1 are listed the cost associated to the electronic component used in the antennas including costs of the labour of the built.

Element	Cost (€)
copper wire	7.00 €
SMD capacitor	0.02 €
Coaxial Wire RG58 (5m)	4.22 €
Coaxial Wire RG213/U (60m)	300.00 €
N-connector RG213/U (22)	110.00 €
N-connector mount	7.00 €
N-connector RG58 (3)	9.00 €
Ferrita cores (3)	9.00 €
copper substrate	10.00 €
human resources	50.00 €
PCB milling machine time	5.00 €
TOTAL	**511.24 €**

Table A.1 – *Electronic cost.*

In the table A.2 are detailed the cost associated to the mechanic component used in the antennas including costs of the labour of the built.

Element	Cost (€)
PVC pipe (different types)	20.00 €
Stainless steel rod(8m)	10.00 €
Stainless steel threaded rod(3m)	2.50 €
ABS plastic (different types)	5.00 €
steel pipe (6m)	45.00 €
human resources	50.00 €
3D printer machine time	5.00 €
TOTAL	**137.50 €**

Table A.2 – *Mechanical cost.*

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by this way, in the table A.3 the cost of the elements used in the built of the antennas and the Ground Station improvement are of 864.27 €

ITEM	Cost (€)
electronic elements	511.24 €
mechanical elements	137.50 €
TOTAL	**648.74 €**

Table A.3 – *Elements cost.*

A.2 Software

Then, the cost associated to license of the software used is detailed in the table A.4

Software	**Dueño de la licencia**	**Coste (€)**
Altium Designer	UGR	Free license
CST	Miguel Ángel del Río Ruíz	Demo license
Solidworks	UGR	Free license
ADS	UGR	Free license
TeXnicCenter	Miguel Ángel del Río Ruíz	Free license
Miktex	Miguel Ángel del Río Ruíz	Free license
SumatraPDF	Miguel Ángel del Río Ruíz	Free license
Lnkscape	Miguel Ángel del Río Ruíz	Free license
	TOTAL	0 €

Table A.4 – *software costs.*

A.3 Human resources cost

For this project the recruitment costs for two persons has been assumed.

One of them is a junior engineer (6€/h) working on part time during eight months. The other person is the manager of the project with the salary of a senior engineer (50€/h) with a availability of five hours a week.

The total cost of human resources are detailed on table A.5.

Cargo	**Horas**	**Coste(€)**
junior engineer	1280	7680.00 €
senior enginee	160	8000.00 €
TOTAL		**15680.00 €**

Table A.5 – *Human resources costs.*

The total cost estimated of this project is 16328.74 €