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TÍTOL DEL TFC: Design and implementation of a synthetic aperture antenna for a femto-satellite.

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Resumen

El uso de antenas cerámicas es adecuado para condiciones medioambientales difíciles en las que es difícil la transmisión de energía.

El uso de una agrupación de antenas puede hacer que el diagrama de radiación sea mucho más directivo y hacer que la transmisión sea más eficiente.

También existe la posibilidad de modificar la frecuencia y la fase de la señal entre los elementos de la agrupación haciendo que sea posible cambiar la dirección del diagrama de radiación sin ningún tipo de movimiento mecánico.

Esta combinación que se utiliza muy a menudo en los Radares de Apertura Sintética (SAR) es también conveniente para pequeños satélites o para aplicaciones de la Tierra.

Este trabajo final de carrera está dirigido al diseño e implementación de una antena a la que se le podrá aplicar apertura sintética para un femto-satélite.

El desarrollo de la antena se llevará a cabo mediante una herramienta informática llamada EEsof Advance Design System (ADS). La antena será implementada y probada en el laboratorio con el fin de obtener el coeficiente de reflexión, la ganancia y la impedancia en función de la frecuencia y comprobar si los resultados obtenidos en las pruebas reales son iguales a los obtenidos en las simulaciones informáticas.

En este trabajo final de licenciatura, tratamos de comprobar si esta antena puede ser utilizada en una misión real de bajo coste en la que se debe utilizar un femto-satélite (masa menor a 100 gramos).

El desarrollo se llevará a cabo dentro del grupo WikiSat que es un competidor de la N-Prize para lanzar un femto-satélite en órbita LEO, con un coste inferior a 1.000 libras esterlinas.

Palabras clave: Antena de Apertura Sintética, Bajo Coste, Femto-Satélite, N-Prize, ADS, Micro strip.

Title: Design and implementation of a synthetic aperture antenna for a femto-satellite
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Date: April, 4th 2011

Overview

The use of ceramic antennas is suitable for difficult environmental conditions in which it is difficult to transfer.

The use of an antenna array can cause the radiation pattern is much more directive and make the transmission more efficient.

It is also possible to modify the frequency and phase of the signal between elements of the array making it possible to change the direction of the radiation pattern without any mechanical movement.

This combination is very often used in Synthetic Aperture Radar (SAR) are also suitable for small satellites or for applications on Earth.

This final bachelor work is aimed at the design and implementation of an antenna to be implemented with synthetic aperture antenna for a femto-satellite.

The development of the antenna is implemented through a software tool called EEsof Advanced Design System (ADS). The antenna will be deployed and tested in the laboratory to obtain the reflection coefficient, the gain and impedance versus frequency and check the results of actual tests are equal to those obtained in computer simulations.

This final work try to see if this antenna can be used in a low-cost real mission where we must use a femto-satellite (mass less than 100 grams).

The development will take place within the group WikiSat which is a competitor of the N-Prize to launch a femto-satellite in LEO at a cost less than £ 1,000.

Keywords: Synthetic Aperture Antenna, Low cost, Femto-Satellite, N-Prize, ADS, Micro strip.

Dedicated to my family

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INTRODUCTION

In this work, we want to see if Synthetic Aperture Antennas (SAA) are suitable for low cost femto-satellites. The first step will be to define the bases of a ceramic array antenna that works at the same time as a structure for the whole satellite.

In order to design a ceramic antenna array suitable for low cost femto-satellites, this work will discuss the basic theory of antenna arrays, technology oriented in microstrip transmission lines and how they can be used for impedance matching.

The theory of antenna arrays allows for radiation patterns with values of directivity and gain that cannot be achieved with the basics. It depends on the number of elements that form the array and the separation between them. The intention of this work is to provide the basic knowledgement to implement not only an array antenna but also try to implement the synthetic aperture changing the phase.

This is a complete project that will be divided into 4 phases: design, simulation, fabrication and testing. In the design and simulation we will see the most used tools, while in the manufacturing and testing, we will see manual implementations to make real tests.

The chapter 1 is divided into 3 sections. The first describes some concepts of antennas. The second section briefly describes the software used in the design of the antennas will be produced and the last part presents the tools, both software and hardware, for the manufacture of designs.

In chapter 2 I will talk about WikiSat Space Program and how my work is integrated inside this project.

In the third chapter I will explain the whole process of making prototypes. The first part is the design using computer assist tools and their subsequent production of PCBs. In the last part I will talk about the prototypes that are offered the best results in the simulations and I have built.

The fourth chapter explains the process and the tools used to test these prototypes (methodology, measurement equipment, etc.); also I discuss the results obtained in these tests (Graphs, Smith charts, etc.).

In chapter 5 is about environmental impact that this work has generated.

The last chapter is for the final conclusions of the work as well as the possible future works.

We used the Wikipedia as an encyclopedia but we checked its correctness.

Acknowledgements

As a Team, we want be grateful for the collaboration of the WikiSat members, Team FREDNET members and EETAC colleagues.

Special thanks to the *Centre Tecnològic de Telecomunicacions de Catalunya* (CTTC) for the use of their semi-anechoic chamber in Castelldefels - SPAIN.

Finally I want to thank our sponsors and collaborators:

Figure 1 WikiSat partners

ACRONYMS, ABBREVIATIONS AND DEFINITIONS

ADS	Advance Design System
CAM	Computer-Aided Manufacturing
CNC	Computer Numerical Control
EEsof	Electronic Engineering Software
EDA	Electronic Design Automation
EIRP	Equivalent Isotropic Radiated Power
EM	Electromagnetic Moment
EMI	Electromagnetic interference
FA	Array Factor
FR4	Designation for glass reinforced epoxy printed circuit boards
Gerber	Family of file format used by the printed circuit board (PCB) industry to describe the electrical connections of a printed circuit board
GNU	Project that develops free operation systems with the property that is free software
GPS	Global Position System
.GRB	Idem Gerber
LPFK	Enterprise of PCB prototyping, depaneling and processing
NC-Drill	Family of file format used by the printed circuit board (PCB) industry to describe the electrical connections of a printed circuit board
PCB	Printed Circuit Board
RADAR	Radio Detection And Ranging
RF	Radio Frequency
RO4003	Type of substrate fabricated by Rogers Corporation
SAA	Synthetic Aperture Antenna
SAR	Synthetic Aperture Radar
SMA	Subminiature version A connector
SNR	Signal to Noise Ratio
SPI	Serial Peripheral Interface. Bus SPI.
TAP	Testing Antenna Protocol
TL	Transmission line
UWB	Ultra Wide Band
VSWR	Voltage Standing Wave Ratio
WIFI	Wireless Fidelity

CHAPTER 1. SYNTHETIC APERTURE ANTENNAS (SAA)

In this chapter, the first part presents some definitions and some theories that are used in this work. In the second part few tools used in the design are presented and finally, in the third part, there is an exposition of technologies for manufacturing these designs.

1.1 Definitions

1.1.1 Antenna

An antenna [1] is a device designed with the purpose of to transmit or to receive electromagnetic waves or radio frequency (RF) into free space. A transmitting antenna transforms electromagnetic waves and voltages thus a receiver performs the inverse function[1].

There are two basic types of antennas depending on the purpose for which they are made:

- **Omni-directional antenna:** those that need to expand the maximum possible radiated power in all directions.
- **Directive antenna:** those that the power be channeled in one direction.

The antenna characteristics depend on the relationship between their dimensions and the wavelength of the RF signal transmitted or received:

- **Basic:** If the dimensions of the antenna are much smaller than the wavelength.
- **Resonant:** If it has dimensions on the order of half wavelength.
- **Directives:** If its size is much larger than the wavelength has.

1.1.2 Electromagnetic field

When an antenna radiates, there is a different behavior between near field and far field. In near field, the predominant field is electric but in far field, the predominant field is magnetic. The radiation pattern of a given antenna in near field is really complex and electromagnetic interferences (EMI) are an issue.

It is normally accepted [2] that the distance in which the change between near field and far field happens is $\lambda/2\pi$ and λ is the wave length.

[1] WIKIPEDIA – Antena - http://es.wikipedia.org/wiki/Antena (Updated: January 2011)

1.1.3 Aperture Antenna

There are aperture antennas that use surfaces or gaps to address the electromagnetic beam and concentrate the emission and reception in one direction. The most known is the parabolic antenna, used in terrestrial radio and satellite links. The gain in these antennas is related with the surface of the parabola: if it is larger, we have more collimation of beam and it means more directivity.

There are several types of aperture antennas like the horn antenna, the satellite dish, the Doppler Radar satellite dish, etc. but in general all they are reflecting surfaces. A particular type of aperture antenna is the synthetic aperture antenna, generally used in the *Synthetic Aperture Radar (SAR).*

A *SAR* is a radar system that, using algorithms, process the information captured by de radar antenna. This processing wants create a “virtual sweep” combining the information obtained in different previous sweeps[2].

This type of radar illuminates a scene through a series of pulses at a frequency. Part of the energy propagated (all directions) returns to the antenna (echo). A sensor measures the intensity and the delay of the signals emitted and received and form images based on distance from the radar. It operates primarily in the microwave radiation, which makes it independent from external factors such as rain, clouds or fog. It works in discrete domain to sample the signal. Radar images are composed of many dots or elements, called pixels. Each pixel represents a detected return echo.

Finally this system provides the same performance like the radar was an antenna bigger and directive that it has in fact. In its creation, it was done in such a way that the radar was in movement and the targets were immobile (aviation systems). It was used also in remote sensing and cartography applications.

1.1.4 Antenna Array

An antenna array is a set of two or more identical antennas distributed and ordered such a way that, in far field, the group behaves as one antenna with a different radiation pattern of the individual elements [1].

The main feature in antenna arrays is that its radiation pattern is modified according to the desired application. This is achieved by modifying the phase and the amplitude of the signal that exists in each element of the set.

According with the antennas distribution in the array we can make the next classification:

[2] WIKIPEDIA – SAR - http://es.wikipedia.org/wiki/Radar_de_apertura_sint%C3%A9tica (Updated: January 2011)

- **Linear array:** the elements are distributed on a line.
- **Planar array:** the elements are distributed in two dimensions.
- **Formed array:** the elements are distributed in a curved surface.

Other characteristics of antenna array, a part of the radiation beams with more directivity (more gain and more angular selectivity), are:

- **Increased coverage area:** because the gain is bigger than omni-directional or sectorized antennas.
- **Reduction of transmission power:** to have more gain in the antenna allows increasing the sensibility.
- **Reduction of interference level:** the better spatial selectivity of the antenna will allow the receptor to omit interfering users signals. Even we can define an array with a configuration with a primary and a secondary antenna where secondary cancels the interferences.
- **Reduction of multipath propagation**: due to lower angular dispersion of the radiated power, it reduces the number of paths that must follow the signal before arrives to the receptor.

One problem in antenna array is the interference that may arise between them. Therefore it exist simulation software that can help us (in a theoretical way) to see the results obtained as a function of the disposition of the set elements.

Considering an equally spaced distribution antenna, all equals, with the same orientation and identical power distribution, the power in each antenna is determined by a complex excitation coefficient I_n:

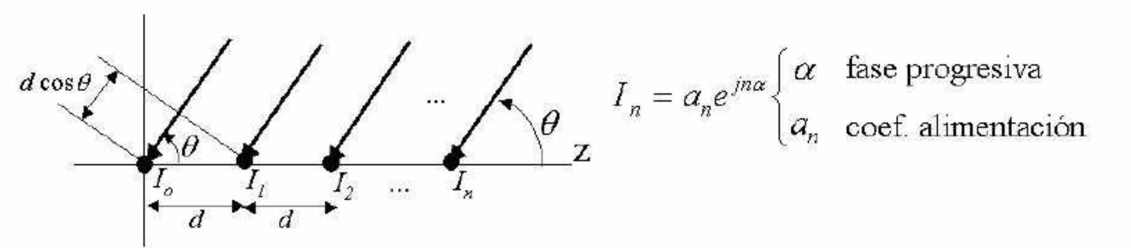

Figure 2 Distribution of equally spaced antennas

If the radiation vector produced by the antenna at the origin and excitation unit is $N_0(r)$, then the radiation array vector is:

$$\vec{N}(\hat{r}) = \vec{N}_0(\hat{r}) \sum_{n=0}^{N-1} I_n e^{jk_z nd} = \vec{N}_0(\hat{r}) \sum_{n=0}^{N-1} a_n e^{jn(kd\cos\theta+\alpha)} = \vec{N}_0(\hat{r}) \sum_{n=0}^{N-1} a_n e^{jn\psi} \quad \textbf{(1.1)}$$

Where:

$$\psi = k_z d + \alpha = kd\cos\theta + \alpha \tag{1.2}$$

Is the electrical angle and represents the gap that occurs in far field due to two consecutive elements. This expression permits us to define the array factor like:

$$FA(\Psi) = \sum_{n=0}^{N-1} a_n e^{jn\Psi} \tag{1.3}$$

And the radiation fields:

$$\vec{E}(\vec{r}) = \vec{E}_0(\vec{r}) \times FA(\Psi) \tag{1.4}$$

With the above equations we can deduce:

- $FA(\psi)$ can be interpreted as the Fourier transform of the discrete sequence an. Therefore, $FA(\psi)$ can be 2π periodic.
- Inversely, an can be watched like the coefficients of the development in Fourier series of $FA(\psi)$.
- If the coefficients an are real and positive, the maximum of $FA(\psi)$ appears for $\psi=0$ (fields are added in phase).
- As $\theta[0,\pi]$ the values of $FA(\psi)$ that belong to the visible range in radiation pattern correspond to $\psi[-kd+\alpha, kd+\alpha]$.
- If the basic antenna is isotropic, then $FA(\theta)$ is the array radiation pattern.
- $FA(\psi)$ only depends of an but the real radiation pattern depends also of kd, α y E .

1.1.5 Impedance Matching

The antenna must be connected to a transmitter or a receiver and radiate the maximum possible power with minimum losses. The antenna and transmitter or receiver must be adjusted for maximum power transfer. Usually the transmitter / receiver is located far from the antenna and the connection is made through a transmission line or wave guide, which also participates in the adaptation, considering its characteristic impedance, its attenuation and length. Therefore, another parameter related to the input impedance is the reflection coefficient ρ, which is given by:

$$\rho = \frac{Z_i - Z_0}{Z_i + Z_0} \tag{1.5}$$

Where Z_i is the impedance of the antenna and Z_0 is the characteristic impedance of the transmission line where is connected the antenna. From this reflection coefficient we can calculate the ratio of stationary wave, better known as *SWR*. This is related to the signal reflected back to the transmitter and it is determined by:

$$SWR = \frac{1 + |\rho|}{1 - |\rho|} \tag{1.6}$$

Considering that the impedance of a receiving antenna is the same as the impedance of the antenna acting as a transmitter, an antenna is adapted to a receiver or a transmission line, when the reflection coefficient ρ is equal to 0 also that input impedance Z_i is equal to the line characteristic impedance Z_0. In this case, the *SWR* will have a value of 1.

Impedance matching is considered by most people who are dedicated to electronics as a difficult and delicate. However, this is a very important aspect, since this adaptation depends on the optimization of transmitters and receivers, influencing therefore the quality of the link. There are several ways to solve the problem but for the moment it is not possible to obtain conclusions in order to say which method is better, because depending on the needs it is more efficient to use one or other. However, whatever the procedure is adopted, numerical results are similar. In general, we try to determine the values of three or four passive components, inductances or capacitances. In radiocomunications, the aim is to transfer the maximum power from a voltage source V_E, with an internal resistance R_G, to a load R_L. The simplified diagram of the figure summarizes the problem:

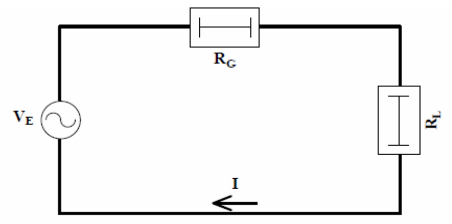

Figure 3 Basic circuit diagram

In the simple case of the figure, the R_G and R_L impedances are pure resistances. Certainly, there can be this hard fact, but usually not very often a real case. Generally, the impedances Z_G and Z_L are complex impedances[3].

Are two impedances Z_G and Z_L. Between the generator and the load is sandwiched an impedance matching network like we can see in the figure.

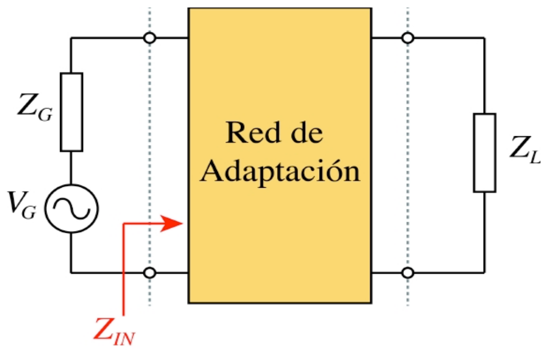

Figure 4 Impedance matching network diagram

The two impedances Z_G and Z_L are generally pure resistances or complex impedances, which can be in the form of series or parallel resistance, with a capacity or an inductance.

The matching networks can be divided into:

- **Non-dissipated:** if the adaptation is made up exclusively with reactive elements, inductors or capacitors.
- **Dissipated:** if the adjustment involves one or more resistors.

There is a lot of adaptive networks depending on the elements used and the disposal of these in it.

In cases of narrow-band applications in order to all the power delivered by the generator arrives to the load is necessary for the network adapter was designed with reactive elements (non-dissipative network.) In this case the condition of adaptation can be imposed at any point in the network. In theory, low frequency circuit networks are studied in L by its simple design and how useful the practical level. A network in L consists of two reactive elements, one connected in series and one in parallel with the load. But conventional inductances and capacitors stop behaving as desired when used for the realization of microwave circuits. On the other hand, the connection elements and encapsulated with

[3] Impedance Matching
http://www.profesores.frc.utn.edu.ar/electronica/electronicaaplicadaiii/Aplicada/Cap11Adaptaciondeimpedancias2008.pdf (Updated: January 2011)

associated parasitic elements complicating the study of these devices in this frequency range.

Inductors and capacitors can be made in order to function properly at microwave frequencies but its structure is very different from the characteristics of low frequency components. There are devices that store electrical and magnetic energy but with very different geometries and compositions that depend on the technology chosen for the circuit to which they are intended for. In our case, we use transmission lines (TL) with micro strip technology[4].

There are several ways to design adaptation networks using TL:

- Design with TL sections ending at open circuit (capacitive behavior) or short circuit (inductive behavior). These elements are called "stubs". In this case the characteristic impedance is a data and we only have to calculate the lengths of the stubs and some of the line sections that are connected to each other and to the rest of the circuit.
- Design with a single section of TL. Assuming the ideal line, the unknowns to calculate are its characteristic impedance and length. To obtain the values Z_C and length d we used the expression:

$$Z_{in} = Z_C \frac{Z_L + jZ_C\, tg\,(\beta d)}{Z_C + jZ_L\, tg\,(\beta d)} \tag{1.7}$$

1.1.6 Micro strip technology

Micro strip is a TL type that can be fabricated using PCB (Printed Circuit Board) and used to transmit microwaves signals[5].

It consists of a conducting strip separated from the mass strip by a dielectric substrate layer. Microwave components such as antennas, couplers, filters, splitters, etc. can be formed from micro strip, doing the component as a metallization on the substrate. The Micro strip is cheaper than the traditional technology of waveguide, besides being lighter and more compact.

[4] Impedance Matching - http://agamenon.tsc.uah.es/Asignaturas/it/tsf/apuntes/Tema2_Parte2.pdf (Updated January 2011)

[5] WIKIPEDIA – Microstrip - http://es.wikipedia.org/wiki/Microstrip (Updated: January 2011)

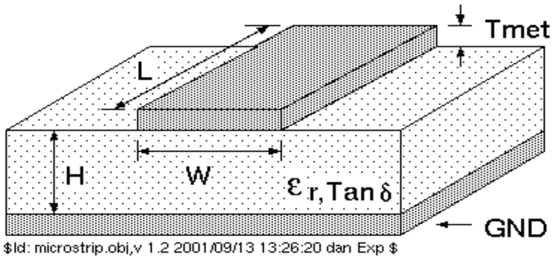

Figure 5 Micro strip features[6]

To cut costs, the micro strip can be built on an ordinary *FR4* substrate (standard PCB). However, we found that the dielectric losses in *FR4* are too high at microwave, and the dielectric constant is not sufficiently well controlled.

Micro strip lines are also used in PCB designs high-speed digital, where signals must be routed from one place to another with minimal distortion as possible, avoiding noise and radiation interference.

The electromagnetic wave carried by a micro strip exists, in part, on the dielectric substrate, and partly in the air above it. In general, the dielectric constant of the substrate is greater than air, so that the wave travels in a non-homogenous. Consequently, the propagation speed is somewhere between the speed of radio waves in the substrate, and the speed of radio waves in the air. This behavior is commonly described by stating the effective dielectric constant (or effective relative permittivity) of the micro strip.

Approximate form of the expression of characteristic impedance of a micro strip:

$$Z_{\text{microstrip}} = \frac{Z_0}{2\pi\sqrt{2(1+\varepsilon_r)}} \ln\left(1 + \frac{4h}{w_{\text{eff}}}\left(\frac{14+\frac{8}{\varepsilon_r}}{11}\frac{4h}{w_{\text{eff}}} + \sqrt{\left(\frac{14+\frac{8}{\varepsilon_r}}{11}\frac{4h}{w_{\text{eff}}}\right)^2 + \pi^2\frac{1+\frac{1}{\varepsilon_r}}{2}}\right)\right) \quad \textbf{(1.8)}$$

1.2 Tools used in design

1.2.1 ADS

Advance Design System (*ADS*) is a design software system produced by *Agilent EEsof EDA*, a unit of *Agilent Technologies*. It provides an integrated design environment to designers of RF electronic products such as mobile phones, pagers, wireless networks, satellite communications, radar systems, and high-speed data links.

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6 Microstrip Features - http://maxwell.ugr.es/innov/visua0506/microstrip.htm (Updated: January 2001)

This software supports every step of the design process (schematic capture, layout, frequency-domain and time-domain circuit simulation, and electromagnetic field simulation) allowing the user to fully characterize and optimize an RF design without changing tools.

Agilent EEsof has donated this tool to many universities and a lot of new engineers have used[7].

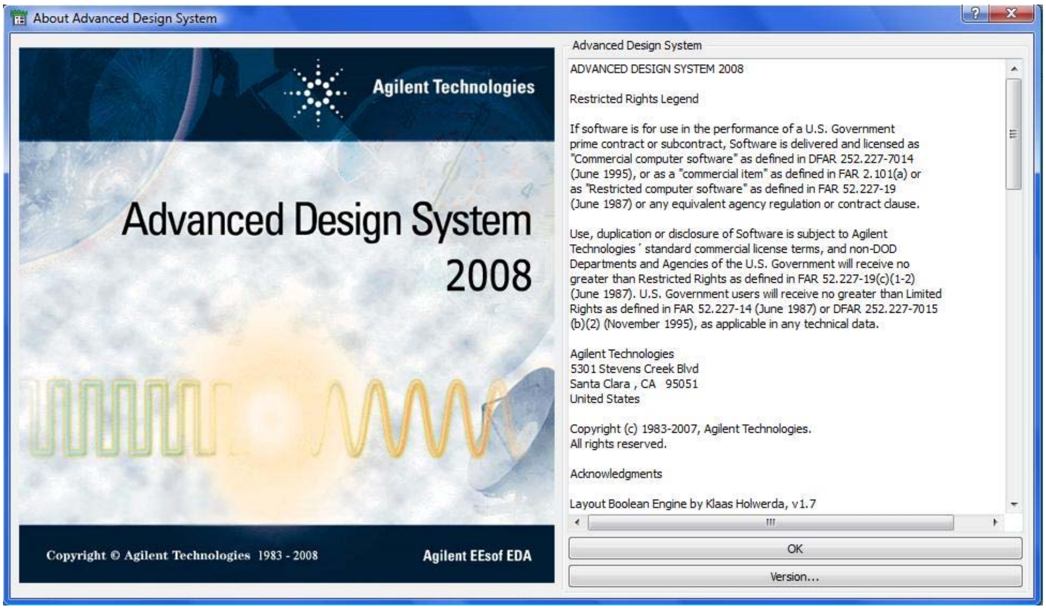

Figure 6 *ADS* information

1.2.2 SuperNec

The *SuperNEC* software uses the method of Electromagnetic Moment (EM) to solve the radiation patterns. It is provided with the easiest ever structure input and model creation tool. The output viewer provides the designer with all the necessary information for proper antenna analysis including features such as 3D & 2D pattern plots, smith chart plots with markers, coupling plots, efficiency plots etc. This tool includes optimized code for Intel processors, various fast solvers and a parallel execution option for extremely large problems.

SuperNEC has a number of predefined antenna assemblies making it easy and quick to design and analyze antennas. Users can also add to this library of antenna types and structures. Some antennas included on it are: Yagi, Log periodic dipole array, Helix, Patch, Dipole antenna, etc.[8]

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[7] ADS http://www.home.agilent.com/agilent/product.jspx?cc=US&lc=eng&ckey=1297113&nid=-34346.0.00&id=1297113 (Update: February 2011)

[8] SuperNec - http://www.supernec.com/ (Update: February 2011)

1.2.3 FreePCB

FreePCB is a printed circuit board design program for Microsoft Windows. It was designed to be easy to learn and easy to use, yet capable of professional-quality work. It allows for up to 16 copper layers, both metric and English units, and export of designs in RS-274X Gerber format. It is free software released under the terms of the GNU General Public License[9].

Basic features:

- 1 to 16 copper layers.
- Board size up to 60 inches by 60 inches.
- Uses English or metric units (i.e. mils or mm) for most functions.
- Footprint libraries courtesy of Ivex Design International, PCB Matrix and the IPC.
- Copper fill areas.
- Footprint Wizard and Footprint Editor for creating or modifying footprints.
- Imports and exports PADS-PCB netlists.
- Exports extended *Gerber* files (RS274X) and *Excellon* drill files.
- Design rule checker.
- Autosave.

Figure 7 *FreePCB* information

1.2.4 Eagle PCB

This freeware tool is, nowadays, one of the most popular programs to design PCB boards in the community. Many of our providers like Sparkfun or Farnell they provide footprint libraries for Eagle. This tool has the capability of to work

9 FreePCB - http://www.freepcb.com/ (Update: February 2011)

with schematics and many tools to put to the limit the design process when we use CNC manufacturing tools.

1.3 Tools used in fabrication

1.3.1 PCB

RO4003 materials are composed of video fiber thermoplastic resin impregnated with a ceramic loaded laminate which produces a rigid, thermally, stable electrical properties suitable for microwave applications. These plates are manufactured by the company *Rogers*. The characteristics of the material that we use to produce these prototypes are[10]:

Table 1.1 Substrate features

Substrate	***εr***	***tanδ***	***t (mm)***	***h (mm)***
RC4003	3.38	0	0.035	1.524

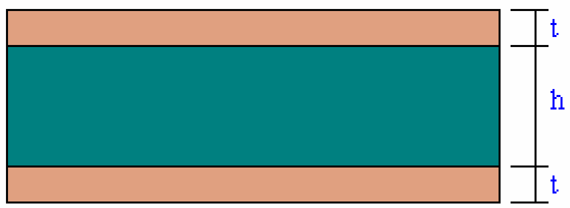

Figure 8 Substrate diagram

The *RO4003C* be the substrate used in this project, since its lower loss tangent will ensure greater efficiency in the design of the TL.

1.3.2 CircuitCAM

CircuitCAM developed for *LPFK* allows us to automatically import list of openings and tools after reading the *Gerber* and *NC-Drill* files. Then is when the software opens up a variety of editing options for modifying the data. The program *CircuitCAM LPKF Lite* is very easy to handle. Individual Adjustment toolbars and import assignments enable you to work especially fast and effective. A program assistant (Wizard) guides the user step by step through the course of the program, from importing PCB data to the generation of channels and contour milling, finishing with the export of production data. In this way,

[10] Rogers Corporation – Microstrip Substrate Features http://www.rogerscorp.com/documents/726/acm/RO4000-Laminates---data-sheet-and-fabrication-guidelines-RO4003C-RO4350B.aspx (Updated: February 2011)

even inexperienced users can quickly and successfully create the data for the milling cutter[11].

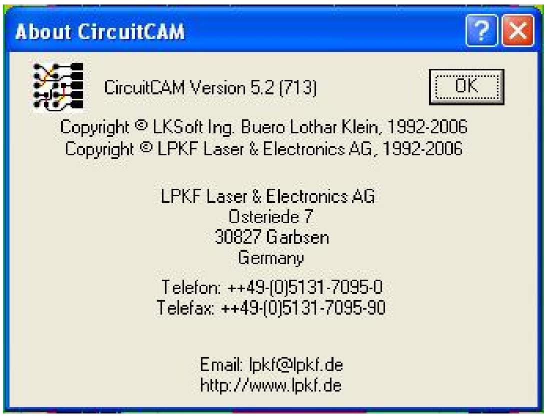

Figure 9 *CircuitCAM* information

1.3.3 BoardMaster

BoardMaster is the software who allows control all *LPKF ProtoMat plotter* systems, and it is available as an upgrade to current *LPKF* plotter owners[12].

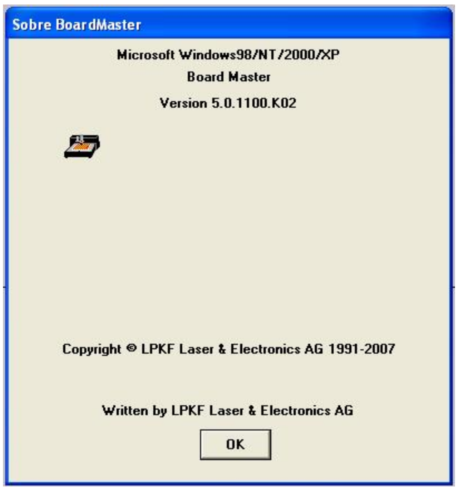

Figure 10 *BoardMaster* information

[11] LPFK – CircuitCAM features http://www.lpkf.es/productos/creacion-rapida-prototipos-pcb/software/circuitcam-lite.htm (Update: February 2011)

[12] LPFK – BoardMaster features http://www.lpkf.es/productos/creacion-rapida-prototipos-pcb/software/boardmaster.htm (Update: February 2011)

1.3.4 LPFK ProtoMat C60

The 60,000 rpm programmable speed motor of this plotter allows the use of an extended range of tools, including small rectangular profiled end-mills with diameters as small as 10 mils. Such tools have superior characteristics for RF and microwave applications and allow maximum precision at minimum penetration into the substrate. The high-speed motor also allows maximum density digital design with track/clearance geometries of 4 mil and 8 mil drill holes[13].

Figure 11 *LPFK ProtoMat C60*

1.3.5 Ceramic antennas

Most ceramic materials are not good electrical conductors. A sub-category is the dielectric insulating behavior. A dielectric material maintains a magnetic field through it, without inducing loss of energy. This is very important in the construction of electrical capacitors and is also useful in an antenna.

The ceramic dielectric is used in two main areas: the first is the progressive loss of high frequency dielectric, used in applications such as microwave ovens and radio transmitters, and second, are the materials with high dielectric constant (ferroelectric). Although the ceramic dielectric is lower compared to other options for most purposes, usually it works very well[14].

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13 LPFK – LPFK ProtoMat C60 - http://www.lpkf.es/_mediafiles/1026-product-catalog-2011.pdf (Update: February 2011)

14 WIKIPEDIA – Technical ceramics - http://es.wikipedia.org/wiki/Cer%C3%A1mica_t%C3%A9cnica (Updated: February 2011)

Ceramic antennas have characteristics of compact size and high performance with a reduced size which helps to reduce the size of the device to be manufactured. The compact size of the component makes it easy to mount on circuit boards. This makes it an ideal solution for devices designed with limited space so this type of antenna is used for handheld devices such as GPS, mobile phones, etc.

Figure 12 Ceramic antenna used in this project[15]

1.3.6 SMA connector

Subminiature version A connector (*SMA*) is a threaded connector type used in microwave coaxial cable, useful up to a frequency of 33 GHz, although often no longer be used from the 18 GHz. There are types designed for 26.5 GHz.

- *Features*: *SMA* connectors are relatively inexpensive alternative to other connectors used in microwave (APC-3.5 for example). They have a characteristic impedance of 50 Ω, leading to a standing wave ratio (*SWR*) as low as 1:1.5 is customary to keep a gold finish to prevent rusting.
- *Types*: There are many variations of this type of connector, for cable or motherboard, departing straight or right angle, finished in gold or steel. Although the standard connector, the male carries the "nut", reverse *SMA* exist, with the nut on the female, they often carry the WIFI antenna (screw jack)[16].

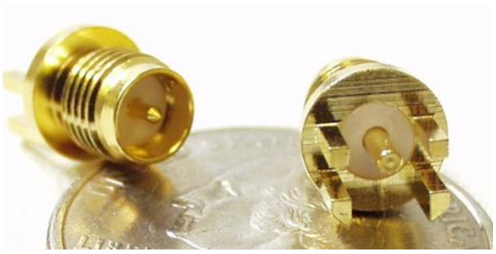

Figure 13 Connector SMA used in this project[17]

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[15] Ceramic antenna photograph - http://www.sparkfun.com/products/9025 - (Updated: February 2011)
[16] WIKIPEDIA – SMA connector - http://es.wikipedia.org/wiki/SMA_%28conector%29 - (Updated: February 2011)
[17] SMA connector photograph - http://www.sparkfun.com/products/592 - (Updated: February 2011)

CHAPTER 2. WIKISAT SPACE PROGRAM

In this chapter I will introduce the space program that this work is part of. We also present the N-Prize contest that motivates this open collaboration activity. The use of high antennas in the three versions of satellites is discussed at the end of this chapter.

2.1 Wikisat Project

2.1.1 *Wikisat space team*

The Wikisat group was started in 2009 like the activity of some engineers and open collaborators that belong to Team FREDNET, a contestant for the Google Lunar X-Prize[18]. A number of teachers and students joined because its open collaboration is suitable for teaching and to involve students that want to have real aerospace experience. Nowadays, Wikisat team is participating in the N-Prize where this Synthetic Aperture Antenna (SAA) work is used.

2.1.2 *N-Prize contest*

The N-Prize challenge[19] is a competition promoted by the British Paul Dear to motivate the creativity, originality and inventiveness in the face of severe odds and impossible financial restrictions. Rules of the contest are simples; we have to put a satellite with a mass of between 9.99 and 19.99 grams, and to prove that it has completed at least 9 orbits around the Earth. The total cost of the launcher cannot exceed in any case the £999.99.

Lots of teachers, students and collaborators are working in a femto-satellite called WikiSat and his rocket, the Wiki-Launcher to participate in the N-prize.

2.2 WikiSat: The femto-satellite

The satellite WikiSat brains the mission. The idea is that the payload has the control of the launcher and takes predefined decisions when needed. This is one of the group statements related to the satellite. For precaution, the satellite will not have receiver. The WikiSat is being designed to fit N-Prize rules.

One of the most restrictive parameters in the satellite will be the mass. A non redundancy policy has been applied and the system must be Single Fault Tolerant.

[18] http://www.googlelunarxprize.org/
[19] http://www.n-prize.com/

2.3 Wiki-Launcher: The mini-launcher

The Wiki-Launcher will be controlled by the WikiSat. There is no available prototype yet but the design is mainly decided. It has lateral nozzles to control the trajectory and it won't have fins. A GPS will be used in the mini-launcher but not in the satellite for tracking purposes.

Current simulations say that will be able to carry a 20 grams payload to an altitude of 250 km. This satellite remains on orbit for few weeks. This tiny satellite is injected to the orbit by a launcher of 1.5 m of length and 35 kg of mass. This launcher uses ACPC (ammonium perchlorate composite propellant) which is an advanced solid propellant.

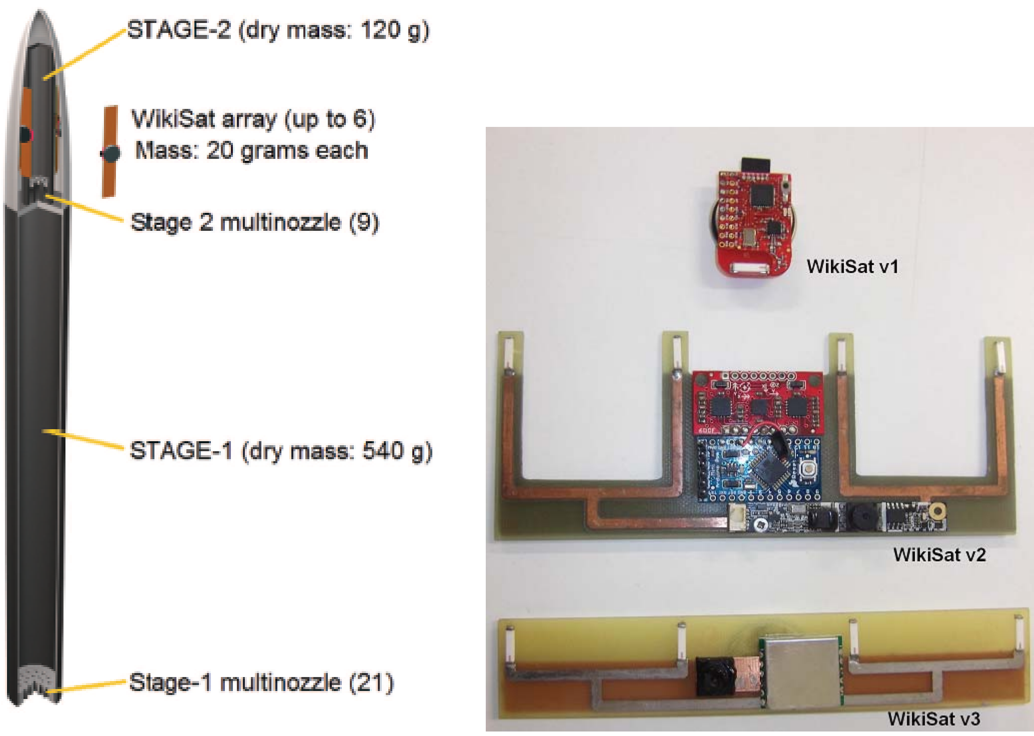

Figure 14 Wiki-Launcher design and three generations of the WikiSat

In the previous figure, three generations of femto-satellites are shown. The first version used a ceramic antenna. Following versions used Antenna Arrays. The version 3 shows a bad design of no more than 6 dB gain antenna.

The idea of to use the Synthetic Aperture Antenna (SAA) was proposed in this third version. Thanks to this PCB technology, many subsystems and electronics components are under a small shield, except for the sensors. Thanks to the present work, current designs achieve up to 23 dB gain antennas.

CHAPTER 3. SAA ON A BOARD

In the different parts of this chapter, I will explain step by step all the tools used to design and fabricate some prototypes of ceramic antenna arrays. First using computer programs to find a good result and then manufacturing them.

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3.1 How to design with ADS

ADS is a software suite with which to design circuits of all kinds but is primarily intended for users working with RF. Thanks to the large number of predefined elements that have (which you can modify the parameters to our liking) is relatively easy to make it work.

Apart from being able to design the schematics of the circuits and do simulations of the same, it allow to obtain the value of the most common measurement parameters such as RF reflection coefficient, impedance...

This section focuses on explaining the steps taken to design prototypes that have been made for this work.

1- When you open the program first and most important is to create a directory named project that will save any schematic that we created. In this project you must specify the units of measurement we will use in its development can choose from four different mils, millimeter, micron or create a new. In our case we choose millimeter.

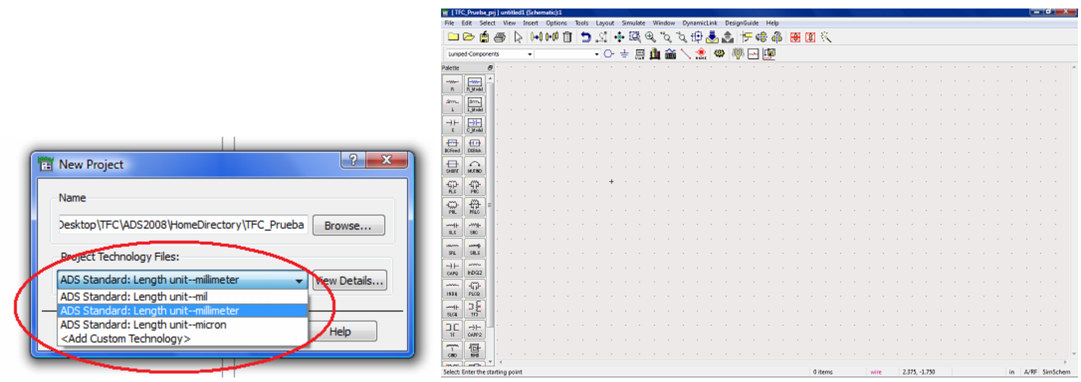

Figure 15 *ADS* - New project window and New schematic window

Once you create this directory by default opens a new schematic window in which to start work.

2- The most important buttons on this screen are located in the toolbar and are:

1- Insert Port.
2- Insert Ground.
3- Variables (allows the introduction of variables rather than fixed numbers as parameters of some elements).
4- Simulate
5- Tuning
6- Palette

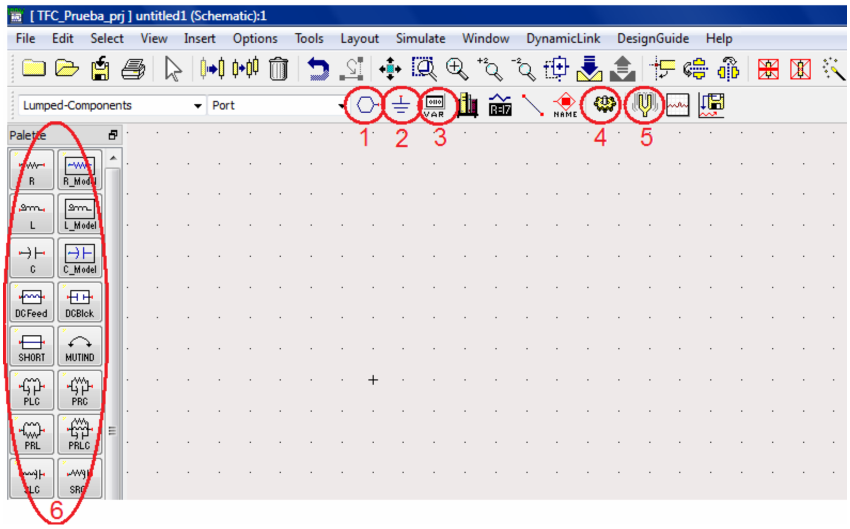

Figure 16 *ADS* - Schematic window most important buttons

On the right is the palette of tools and components that have to be set in the schematic to design the circuits. These components are grouped by type (passive components, active components, power supplies...). Just above the palette there is a drop down list which lists all the groups of elements that can work with this program. In our case, we use two lists:

- "TL Microstrip" to create the tracks.
- "Simulation-S_Param" to simulate the S parameters of the designs.

3- In the list "TL Microstrip " There are many types of components (coils, gaps, coplanar lines ...) but 5 are the items are basically going to use:

- MSUB: essential to define the parameters of the substrate of microstrip line (width of the dielectric, loss tangent ...)

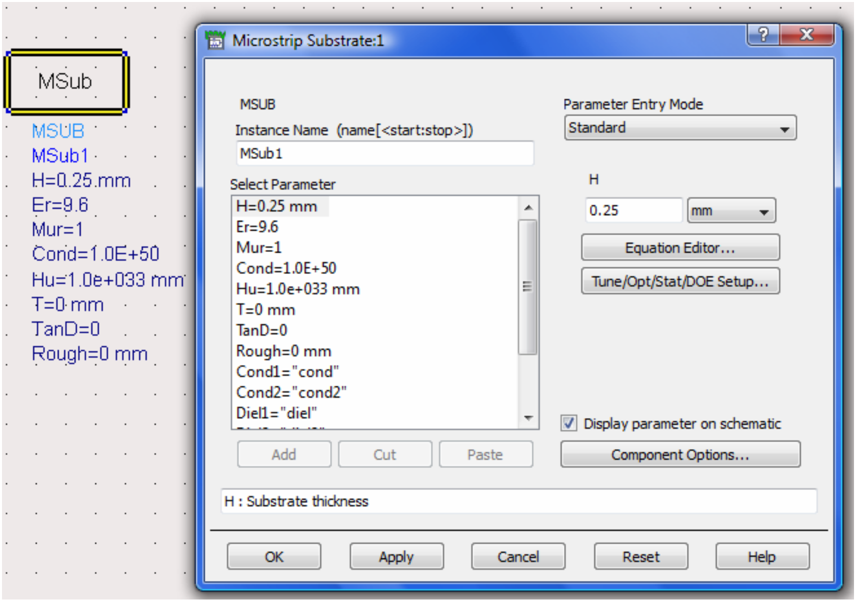

Figure 17 *ADS* - Microstrip Substrate features window

- MC_LIN: piece of microstrip line on which you can choose the width, length and the substrate (which in turn can be variable).
- MSOBND: essential in 90-degree turns.
- MSTEP: imperative for change of track widths.
- MTEE: a must in T junctions.

The use of these elements is essential since in the simulation program takes into account the possible changes in the behavior of RF because any small variation, for example, the width of a track or two tracks as they are united, may introduce significant changes in the outcome.

4- The basic elements in order to make the simulations are the ports where we measure the parameters S. In our case we will need 5 ports: one to represent each of the antennas and the port of entry that will hold the signal.

We must also define the parameters of the simulation. To do this in the list "Simulation-S_Param", you choose the SP button. In the menu that appears you can define all parameters: start frequency, end frequency, frequency hopping, types of parameters to be measured (S, Y, Z, group delay)...

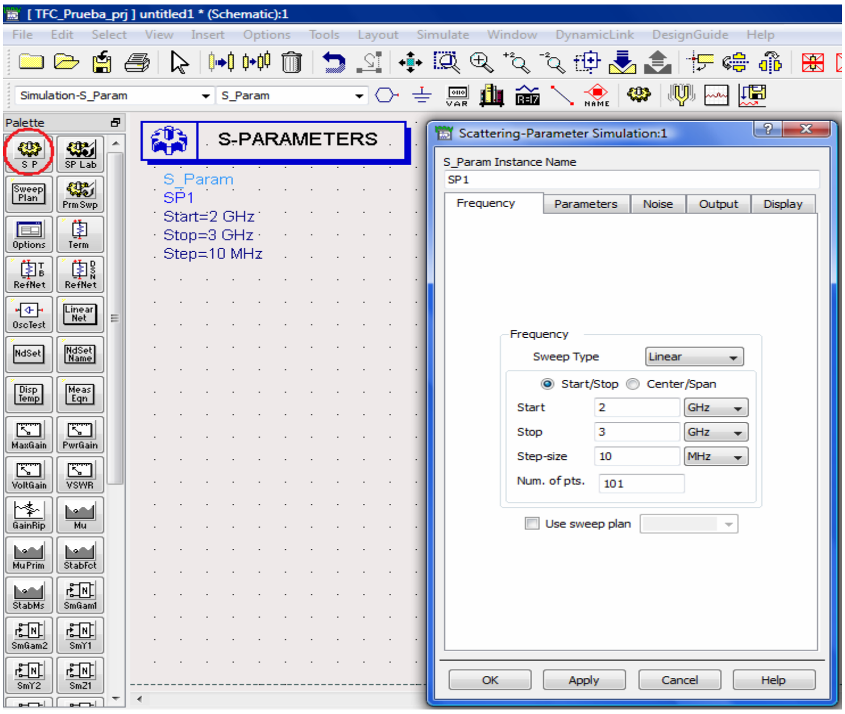

Figure 18 *ADS* - S-Parameters features window

In our case, as the antennas used WIFI working frequency (2.4 GHz - 2.5 GHz), the simulation is between 2 GHz and 3 GHz with a jump of 10 MHz, in order to obtain the best accuracy possible without saturating calculation processor program.

Not must we forget two important parameters such as input impedance of the circuit (all the circuit must be adapted to 50 Ohms) and the VSWR. By default, the program measures these values in S11, but can be changed by double clicking on the item and changing the port that want to get the values.

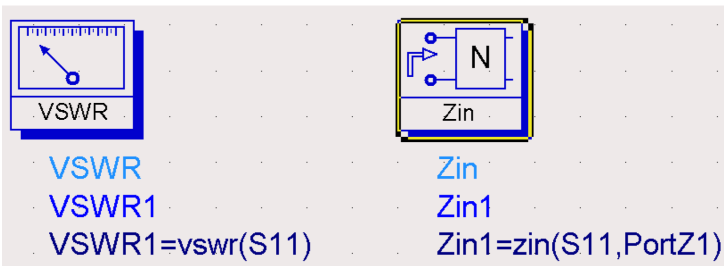

Figure 19 *ADS* - VSWR and Zin measurement elements

5- Once we have all the elements, we can start designing the prototypes. As for the realization of this project was started from an initial model was based on 4 antennas arranged symmetrically, we have followed that line of work.

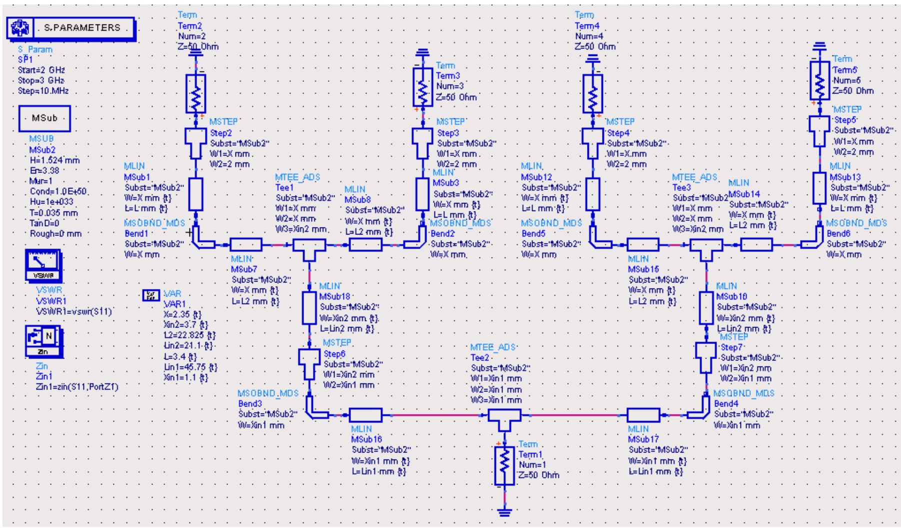

Figure 20 *ADS* – Completed prototype design

6- When we have the design ready and all parameters defined, you can perform the simulation.

When simulating, the program executes a new window where you can visualize as best suits the results. So the program lets you choose how you want to represent the data (Figure 21 (1)) (table of values, graph...), put markers (Figure 21 (2)), etc.

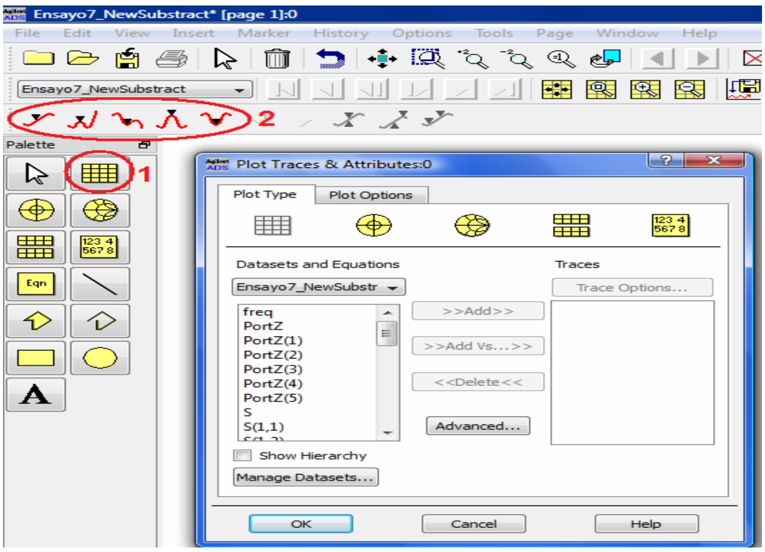

Figure 21 *ADS* – Plot features window

The most interesting results on these prototypes, which are those that are shown, are:

- Zin Vs frequency (in graph and data table).
- VSWR Vs Frequency.
- S11, S21, S31, S41 and S51 Vs frequency.

7- To try to optimize the results of the designs we had used the tool "tuning".

The use of "tuning" is very useful because it allows real-time change the values of variables and instantly to see the result in the simulations.

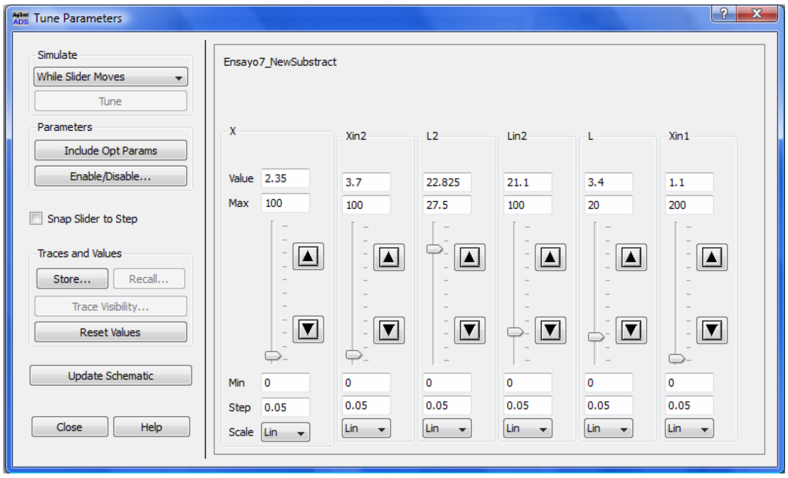

Figure 22 *ADS* – Tune parameters window

It is for this reason that in all the TL, to define the parameters (width and length) variables were used instead of fixed numbers.

Once you have obtained the desired values in the simulation of RF, we can pass to PCB layout program (in our case *FreePCB*).

3.2 How to design with SuperNec

This section explains how they have performed simulations with *SuperNec*. This program allows us to simulate the fields radiated by the antenna array designed in *ADS*.

Of different antennas that provides the software, has chosen the elemental dipole because the dipole radiation pattern is very similar to elementary diagram has ceramic antenna to be used in the prototypes (obtained from the datasheet of the antenna).

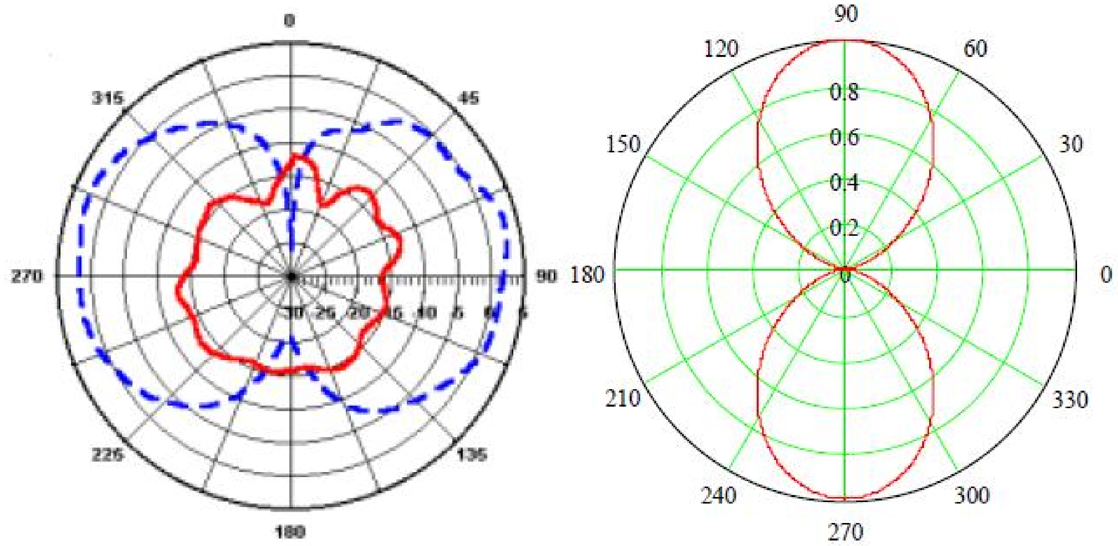

Figure 23 Radiation patterns (ceramic antenna – elemental dipole)

The following explains the steps taken to perform the simulation.

1- When the program is opened we see a screen with a grid in which we represent the three dimensions (X-Y-Z).

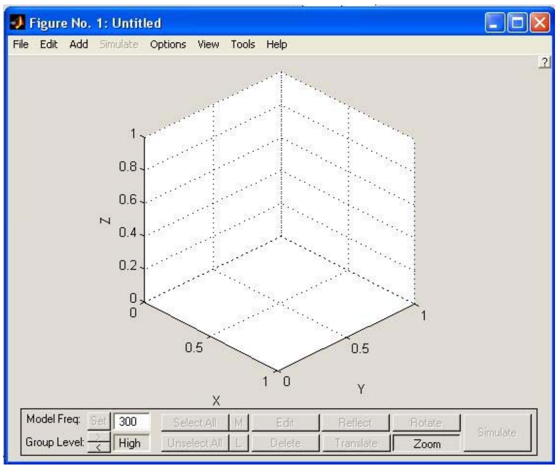

Figure 24 *SuperNec* – New design window

2- As mentioned above, there are many different types of items can be added. For these prototypes have been used elementary dipoles (*sndipole*).

Click in menu *"Add→Assembly→antennas→sndipole"*

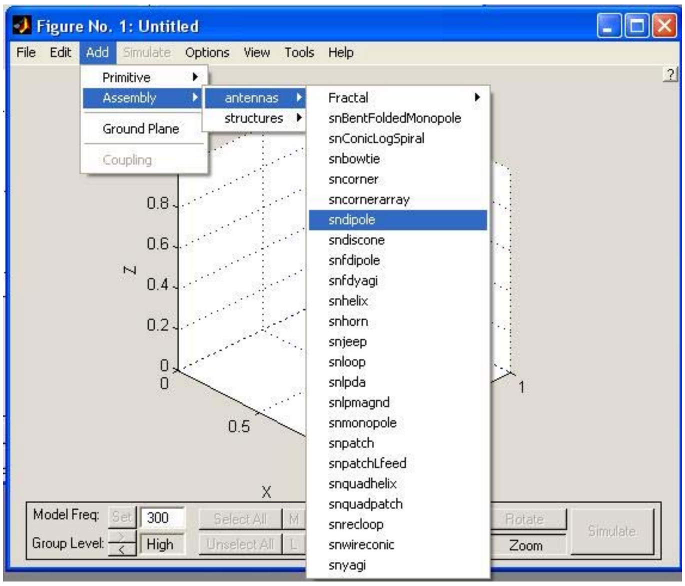

Figure 25 *SuperNec* – Add element route

After selecting the type of item you want to add, a menu is opened in which we must define its characteristics (location, orientation, number of segments...). Important: the coordinate's values must be introduced in meters.

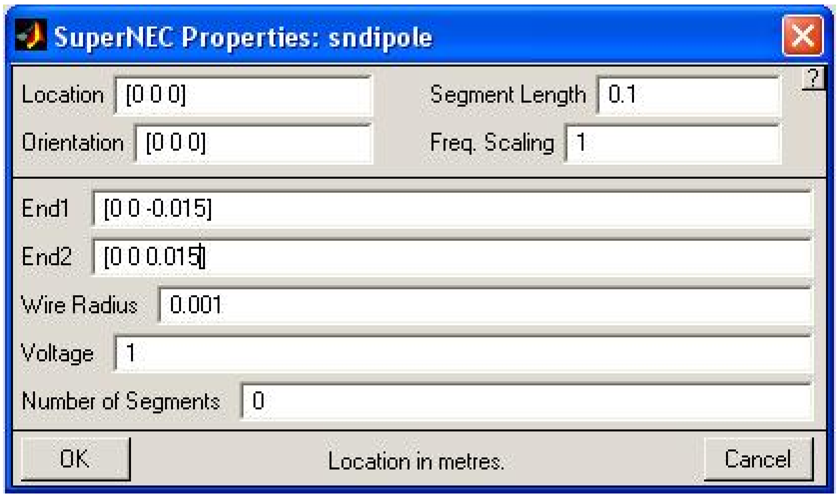

Figure 26 *SuperNec* – Sndipole features

This program works with 3D coordinate what needs to define its location as a vector. For all simulations, has placed the first item in the origin of coordinates. You should also define the size of the dipole with a vector.

After had defined the element features, it appears on the grid.

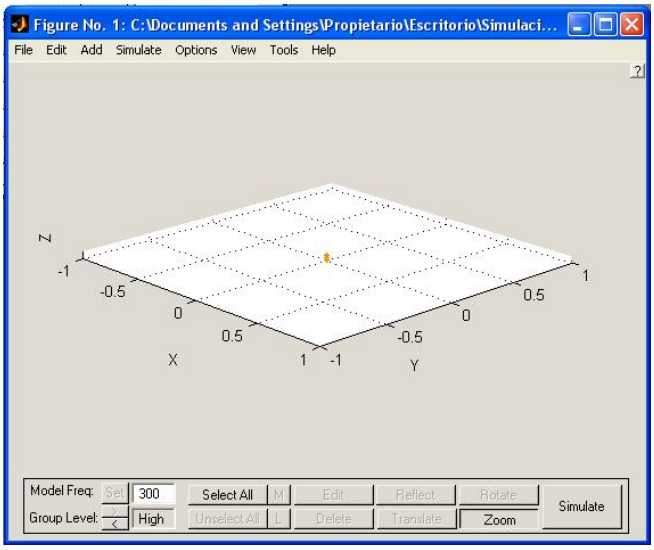

Figure 27 *SuperNec* – One element on the grid

3- As the prototype antenna consists of 4 equal, we must add 3 elements equal to existing. The easiest way to do this is by selecting the item and clicking on the button below "*Translate*". This tool allows us to: "*Move*" or "*Duplicate*". Select "*Duplicate*" and introduce the coordinates in which to copy the item.

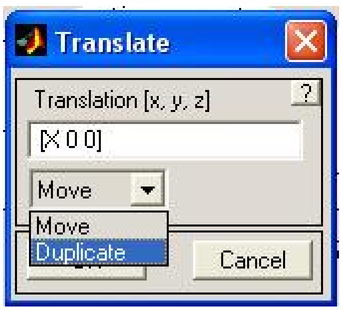

Figure 28 *SuperNec* – Translate window

To calculate the displacement of the copy will use data from *ADS* (is the length of the TL). So it will scroll [X 0 0] (where X is the distance between elements) because we will have the elements along the X axis.

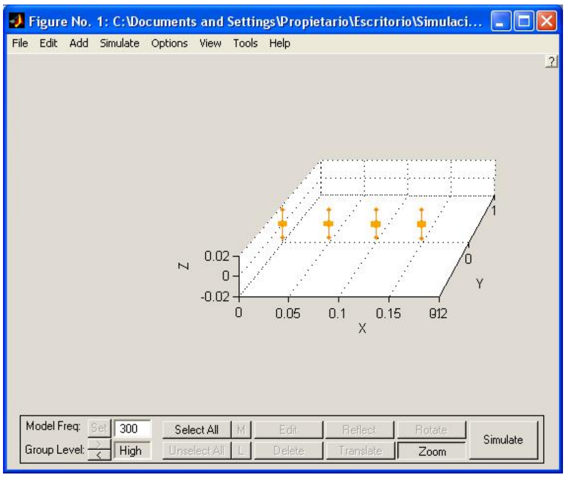

Figure 29 *SuperNec* – 4 elements array

4- Now that you have the 4 elements aligned and separated a distance as the design of *ADS*. Can be passed to simulate.

On the menu *"Edit→Simulation Settings"* you can set all simulation parameters (frequency, what radiation patterns we must draw (modify their angles theta and phi), if we want add an external current source...).

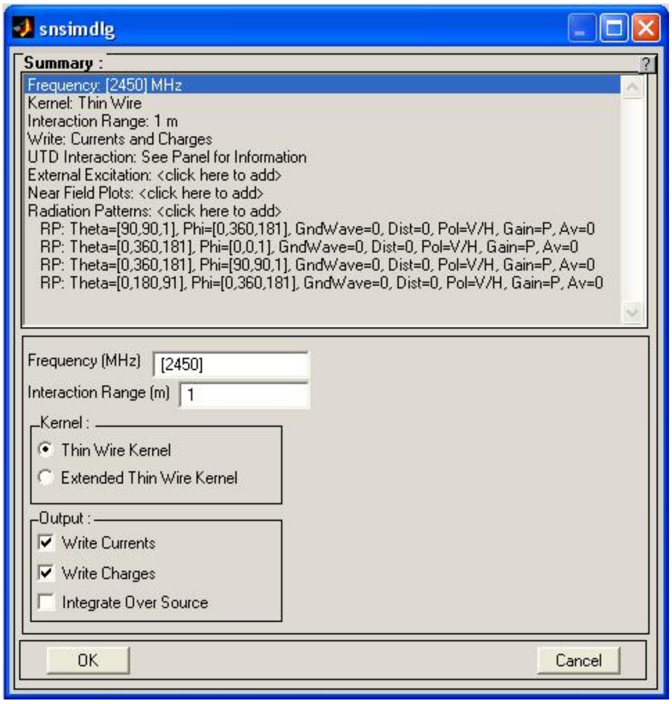

Figure 30 *SuperNec* – Simulation settings window

Once we have all parameters defined, we can click "*Simulate*" on initial window.

After calculations, the program opens a window where you can choose the graphics that we want to be displayed (current distributions, radiation patterns ...). When the graphics want to be drawn are selected, click in "*Plot*" and appears in the screen.

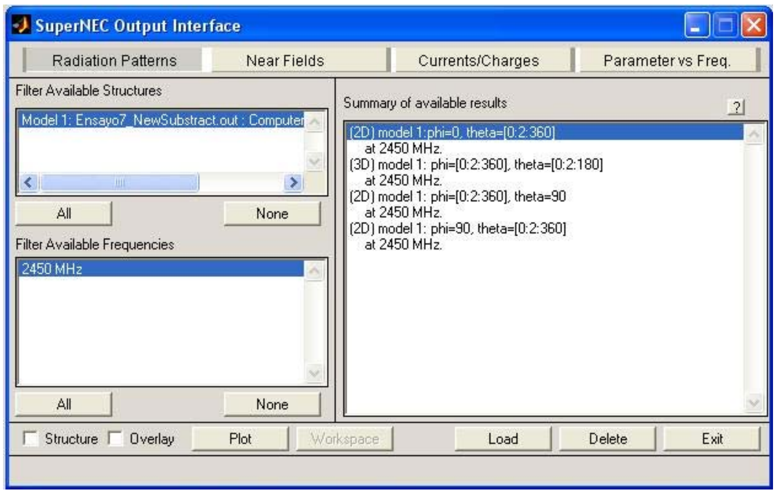

Figure 31 *SuperNec* – Graphics selection window

In this case, it was considered that the most important are radiation patterns and 3 are shown: 3D radiation pattern (it is very useful and provides a color code for identify the gain), azimuth radiation pattern and elevation radiation pattern).

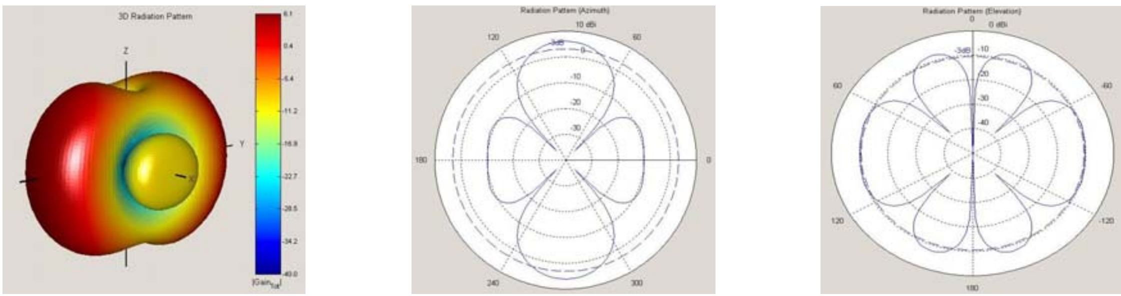

Figure 32 *SuperNec* – Example radiation pattern graphics (3D – Azimuth – Elevation)

3.3 How to design with FreePCB

FreePCB is one of the PCB design software's most widely used due to its easy handling[20].

You can import components lists from other software like EAGLE discussed before so that it will draw the tracks and you can even design their own footprints.

[20] http://code.google.com/p/moon-20/wiki/Tutorials#How_to_build_a_PCB by Lara Navarro

For this project we have to use this software, but regardless of any list of components, because all are transmission lines, the surfaces of the lines are drawn manually.

Considering data from the *ADS* design (length and width of the tracks) make the design is simple but longer, because this software work by coordinates, must be constantly calculating X and Y variables based on the width and the length of each of the tracks.

1- When you open the program in the initial screen can only do two tasks: creating a new project or open an existing one.

   By creating the new project it appears a menu of options that asks the directory where you saved the project and the directory where you saved the library of elements and the number of layers of copper will have.

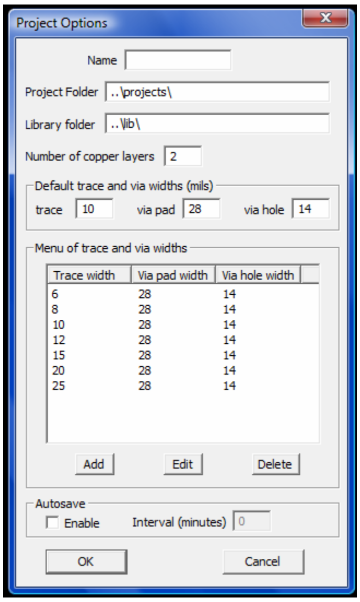

Figure 33 *FreePCB* – Project options window

   In the case of our designs, no library is needed because the tracks are drawn by hand and consist of two layers of copper (these are microstrip lines).

2- After creating the project, displays the grid to start drawing. At the top is a drop-down lists from which you can choose the units of the coordinates (mils or mm) (Figure 34 (1)), the number of grid you see on screen (Figure 34 (2)), the precision of mouse manually drawing (Figure 34 (3))...

   To the right is the color coding of different possible layers that can have both on-screen (Figure 34 (4)) and at the bottom we have the position of the mouse in X, Y (Figure 34 (5)).

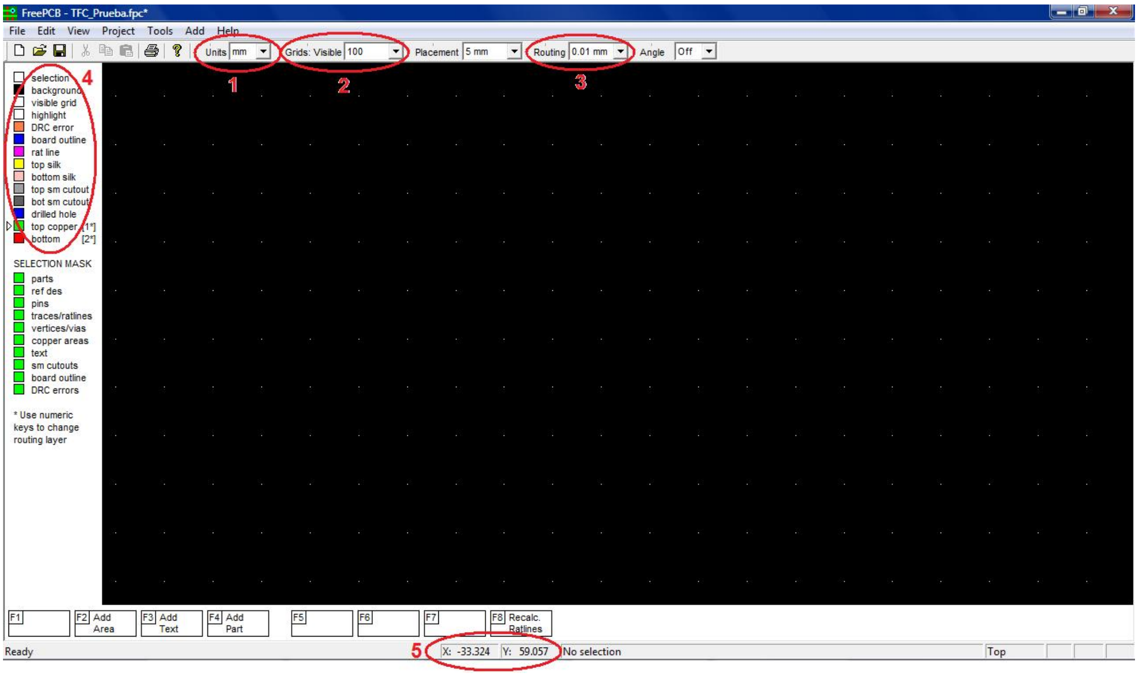

Figure 34 *FreePCB* – Most important parts in the design window

3- To start your track from scratch, you must press F2 ("*Add Area*"). In the menu that appears we have to name the area to be drawn, choose which layer will belong (top or bottom) and the type of fill you want to give the drawing.

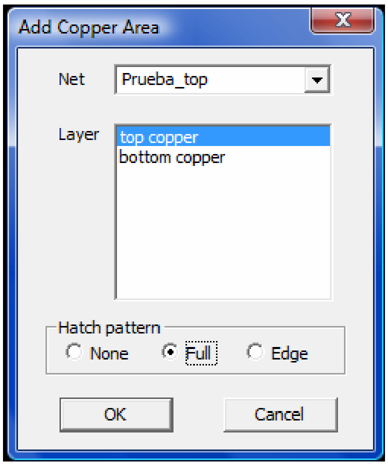

Figure 35 *FreePCB* – Add copper area window

4- Once accepted, the mouse is displayed and you can draw the desired area. Each mouse click will create a vertex. The mouse can move in vertical, horizontal or angled 45 degrees.

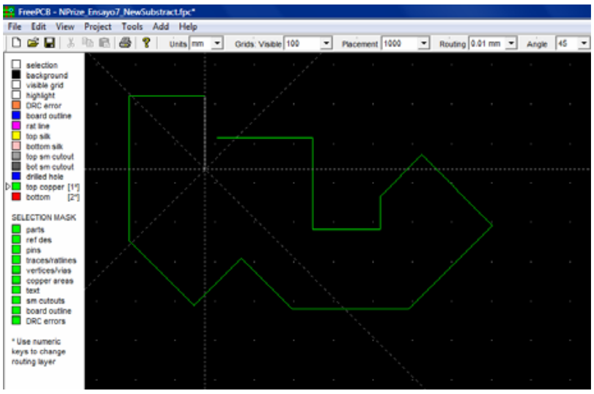

Figure 36 *FreePCB* – Drawing with the mouse

To close the desired area, you must press the "esc" key and the program automatically closes the area since the last vertex to the first.

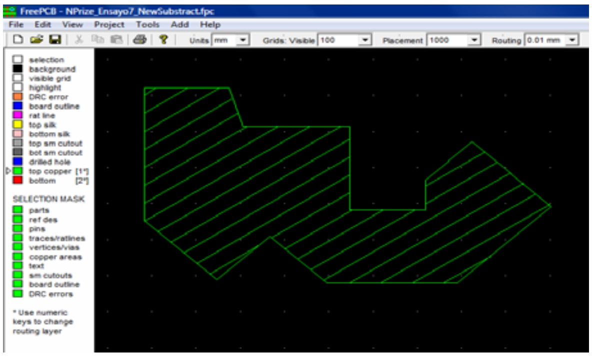

Figure 37 *FreePCB* – Finished cooper area

5- If you select any of the vertices, a menu that allows several operations: "*Set Position", "Move Vertex", "Delete Vertex"* and "*Clear Area*".

The best way to move a vertex position is changing manually the coordinates, because the mouse does not allow as much definition as is necessary in some cases. This operation is done by selecting the top by pressing F1 ("*Set Position*") and entering the desired values in each coordinate.

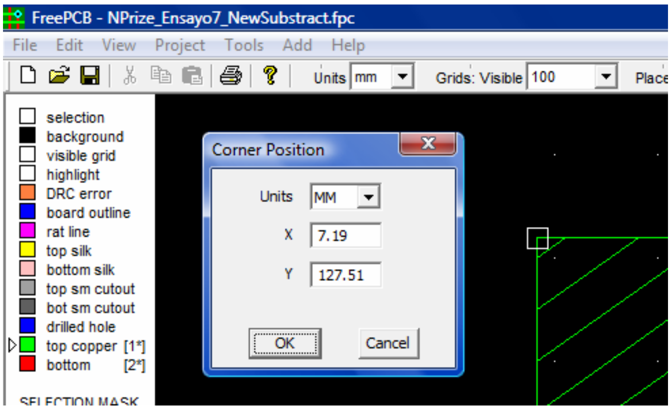

Figure 38 *FreePCB* – Corner position window

The design of all areas is done in the same way. For the designs created in this project, we used 3 layers: a layer of solder (top), ground layer (bottom) and outside of the plate line (border outline).

Because both the lengths and widths obtained in the TL's have several decimal places, the areas in *FreePCB* have made all 4-vertices, having to calculate the coordinates of each based on data from *ADS*.

The following figure shows the result of one of the designs: in green you can see the solder layer (top) in red, the ground layer (bottom) and blue for outside line (border outline).

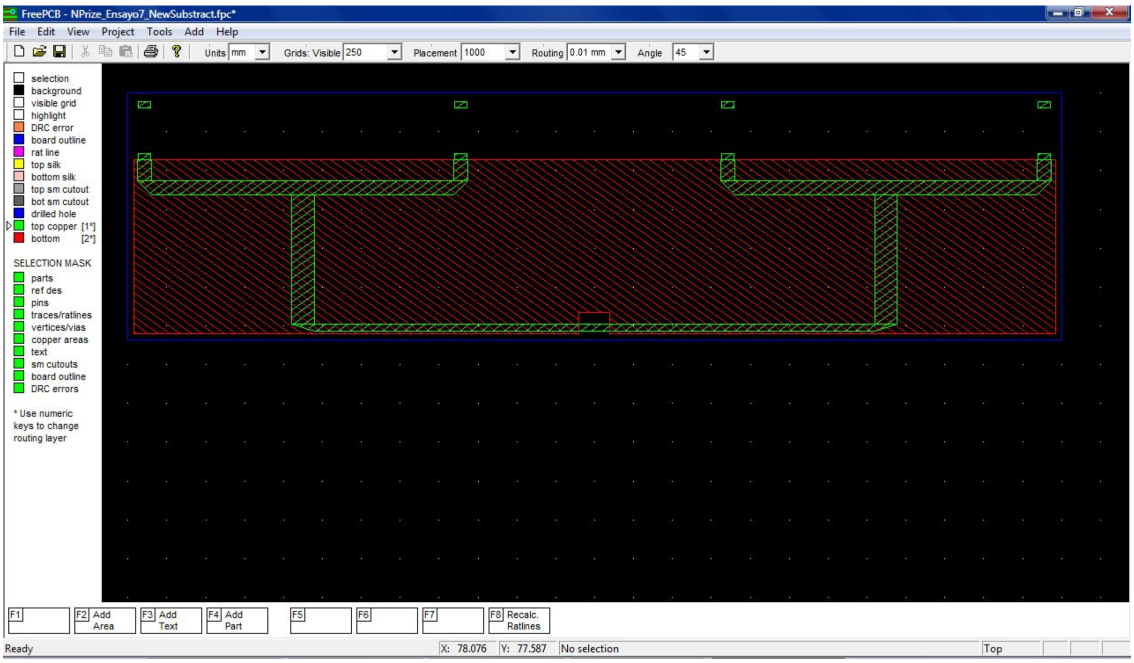

Figure 39 *FreePCB* – Completed prototype design

When the design is finalized, we create *.GRB* files, which are imported to the program *CircuitCAM* for PCB manufacturing.

In the "*File*" menu is selected "*Generate CAM files*". The menu below allows you to select which layers you want to generate *.GRB*, in which units of measurement (mil or mm) and other options (including border line, including text...). In our designs we have created 2 *.GRB* files (one for top and one for bottom) including the border line and measurement in mm.

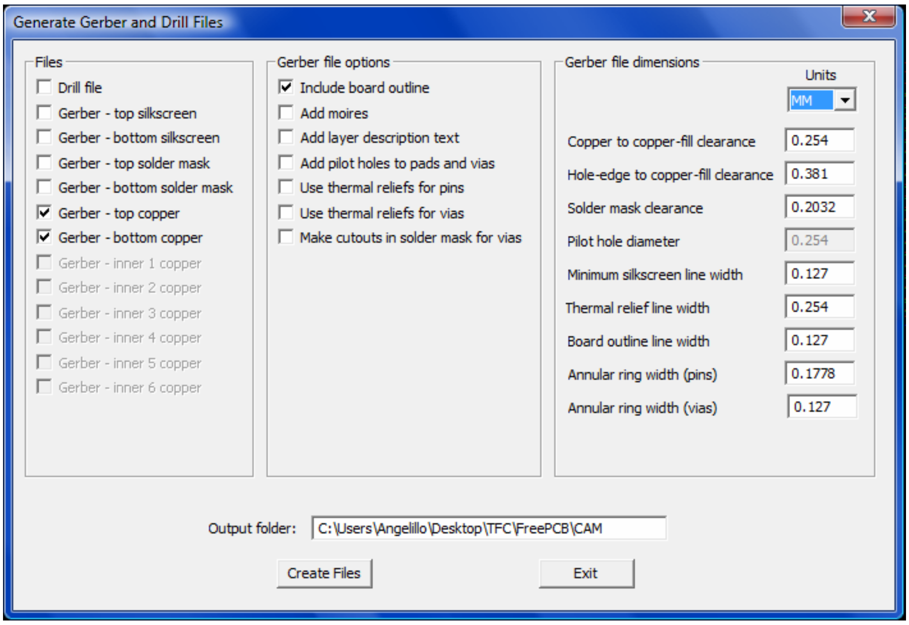

Figure 40 *FreePCB* – Generate Gerber and Drill files window

3.4 Manufacturing

Once you have the design of the copper tracks and you get the files *.GRB* from *FreePCB* or EAGLE programs, the plates can be made. But the program that controls the plotter milling means a type of file called *.LMD*. The way to get this kind of file it is using software that provides the manufacturer of the plotter, in this case *LPFK*. You can find extra information in the Lara Navarro's tutorial[21].

After obtaining this file, which is automatically loaded into the plotter driver program (*BoardMaster*), the machine can be connected and the router will draw the cooper traces.

Finally, only need to weld the components (antennas and *SMA* connector) to perform the tests. The prototype is finished.

[21] http://code.google.com/p/moon-20/wiki/Tutorials#How_to_build_a_PCB by Lara Navarro

3.4.1 The .LMD file creation with CircuitCAM

1- Import .*GRB* files created with *FreePCB*.

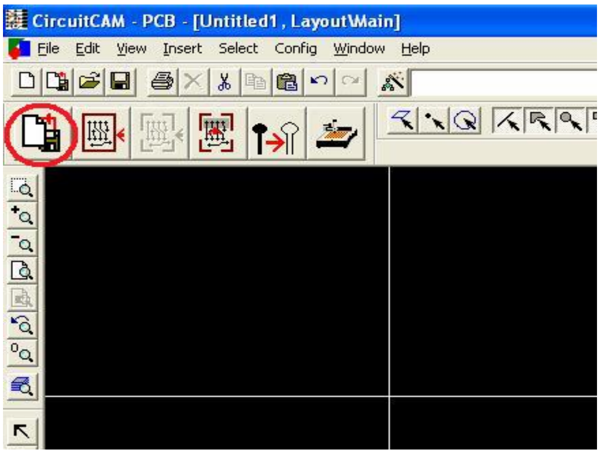

Figure 41 *CircuitCAM* – Import button in new design window

We must select the layer referred to the imported file (top or bottom). In the file selection screen displayed the measures we have our PCB.

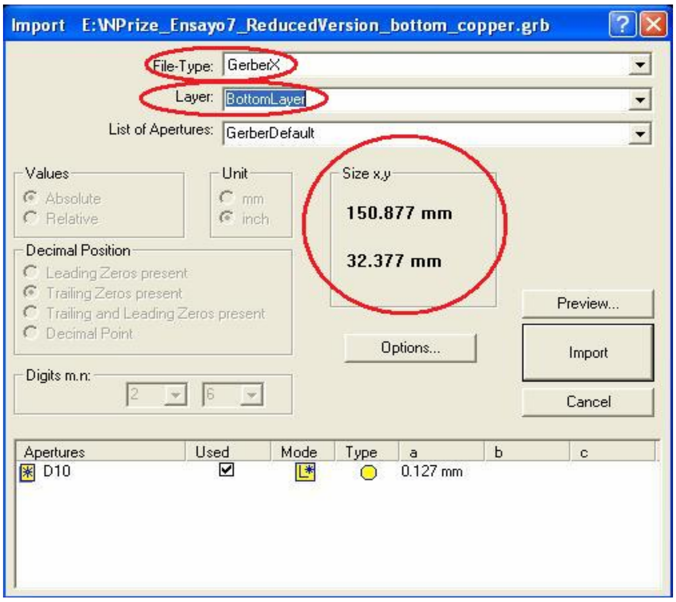

Figure 42 *CircuitCAM* – Import file features window

We do this as many times as layers we are stuck. In the present case will make the operation twice: once for the sealing layer (Top) and one for the ground layer (Bottom).

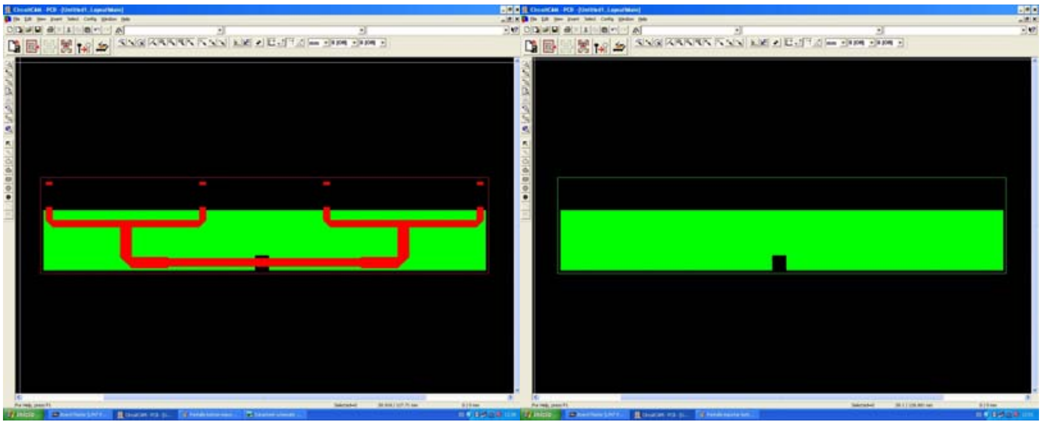

Figure 43 *CircuitCAM* – Top and bottom *.grb* files imported

2- Once you have imported the two layers on the screen, you must do the contour drawing that will be cut by the PCB with the tool *"Contour Routing".*

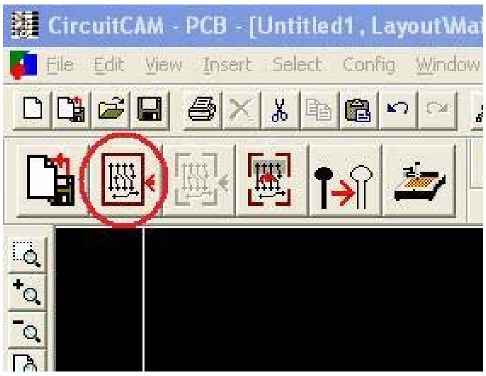

Figure 44 *CircuitCAM* – Contour routing button

In this menu you can select:

- Which of the two layers to obtain the contour line (the relationship with the *"Border Outline"* drawn in *FreePCB*).
- A tool we use to make the cut.
- If you want to make holes that connect the two layers

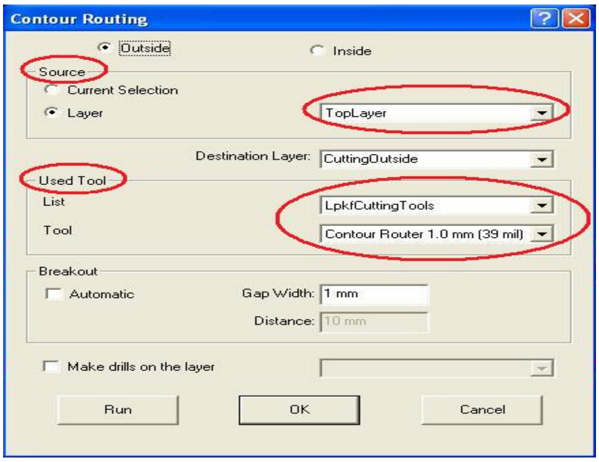

Figure 45 *CircuitCAM* – Contour Routing features window

After selecting the desired fields, press the button "*Run*" and we will see the outline drawn on the screen.

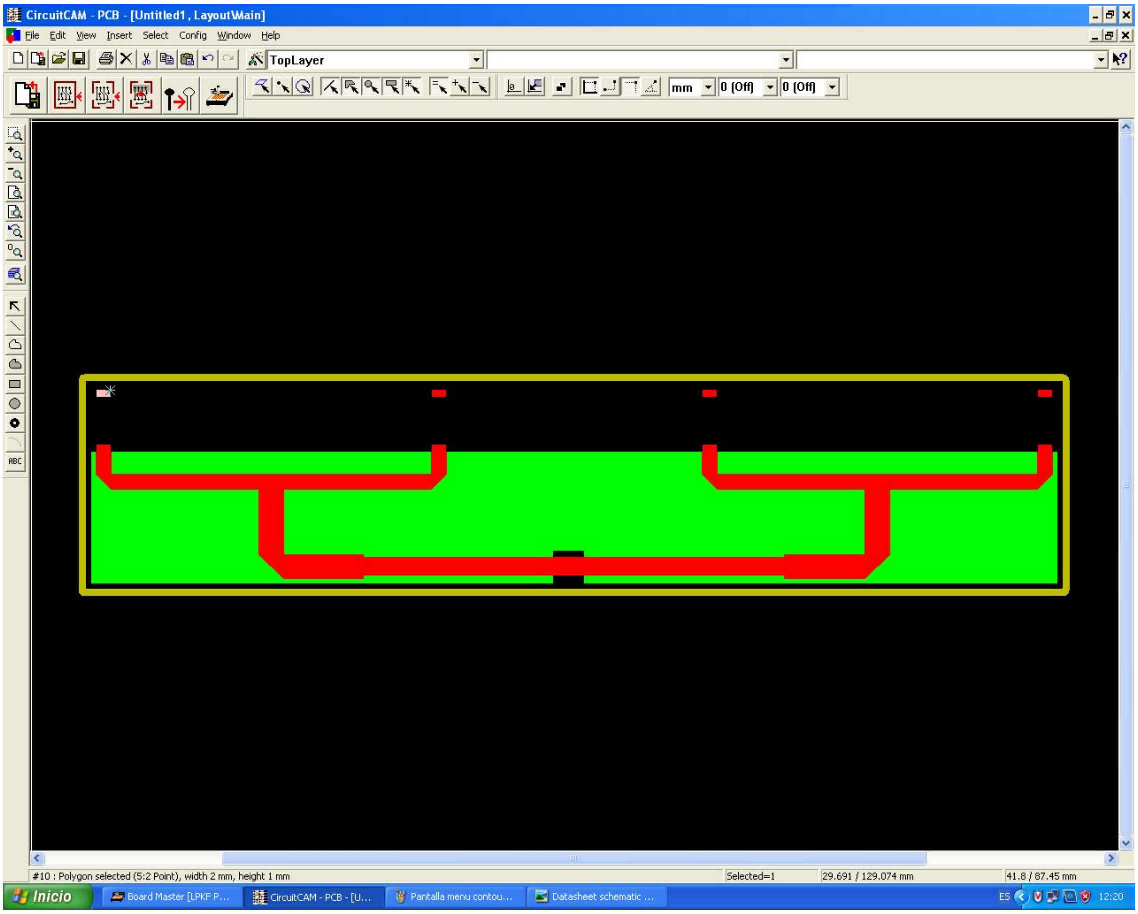

Figure 46 *CircuitCAM* – Design with contour line defined

3- Now you must select the work area in which we want the program to execute the task of drawing the paths to be followed by the machine to manufacture the PCB. For this we use the tool "*Rubout All Layers*".

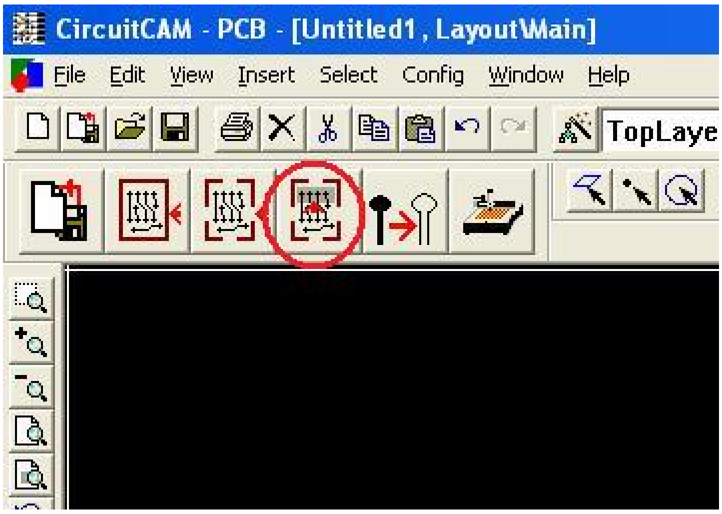

Figure 47 *CircuitCAM* – Rubout All Layers button

4- After selecting the area of work, we must define the parameters that we want the work *LPFKProtoMatC60*. To do this, open the Edit Menu and choose the tool "*Insulate*". Within this menu we have:

- Choose the working layer (top or bottom).
- The tools we use to make this layer.
- The orientation of the lines you want to follow the *ProtoMat* (vertical or horizontal depending on the design).

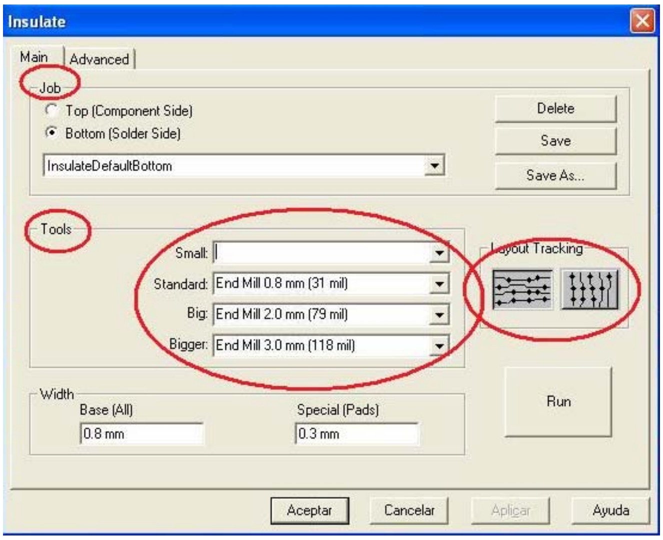

Figure 48 *CircuitCAM* – Insulate features window

Once we have all these parameters selected, press the "*Run*" button and the program will draw the "paths" that follow the *ProtoMat* to make tracks.

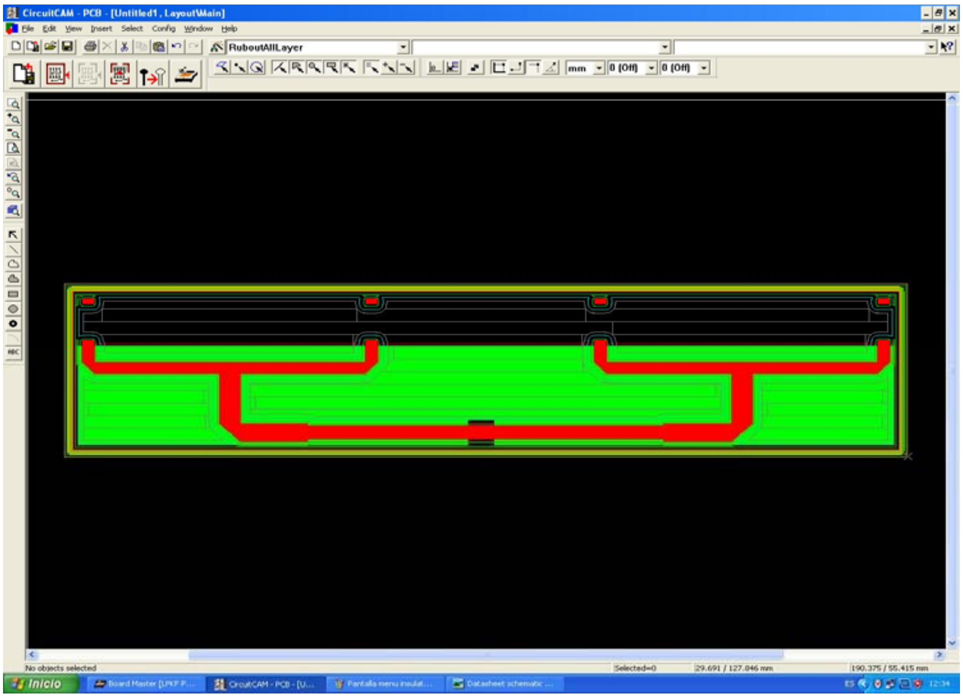

Figure 49 *CircuitCAM* – Finished prototype design

5- Once we have the PCB design with lines that follow the *ProtoMat*, select the button "*Export LPFK Circuit Board Plotter*".

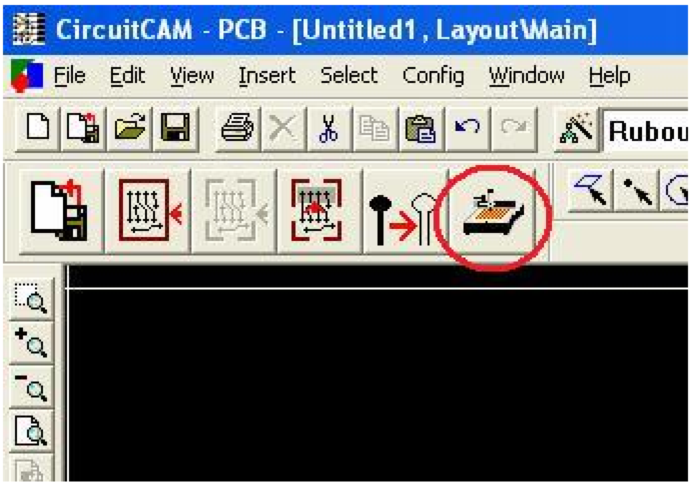

Figure 50 *CircuitCAM* - Export LPFK Circuit Board Plotter button

This tool gives a screen save your work and we generate a file type *.LMD* we exported directly to the *BoardMaster* program.

3.4.2 BoardMaster

CircuitCAM program directly imports the file *.LMD* to the plotter driver.

At the start screen driver software is the image of the leads generated by CircuitCAM. Only we must select the layer want to make (top or bottom) and start the process.

The driver indicated in each time when we change the bit (the size of the bits had been defined already at CircuitCAM).

Once end the milling process, cut and polished to remove any impurities.

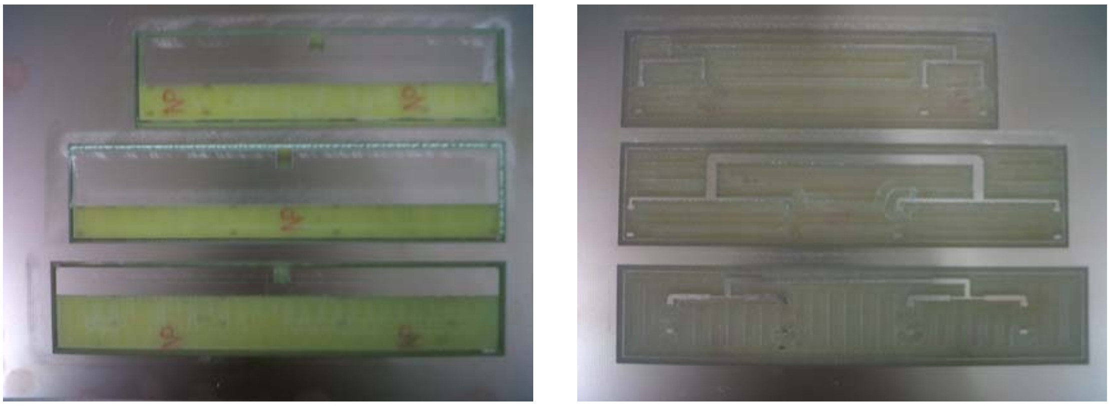

Figure 51 Milling process finished

The PCB is now ready to weld the components.

3.4.3 Welding components

For our prototype we weld two types of components on the board that we manufactured: SMA connector, which will introduce the test signal, and 4 antennas. Use a soldering iron and tin.

To weld the antennas have added two small areas of copper in the design of FreePCB the size specified in the datasheet of the item. It gets a bit of tin in the two areas in which they must put the antenna.

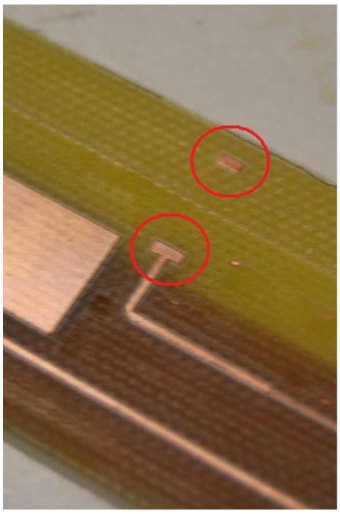

Figure 52 Areas where to weld the antenna

Once the tin is very hot, it is near the antenna and is placed with pliers contacting the pre-tinned surfaces. Within seconds, the solder hardens and the item is secure. This process is repeated for the four antennas.

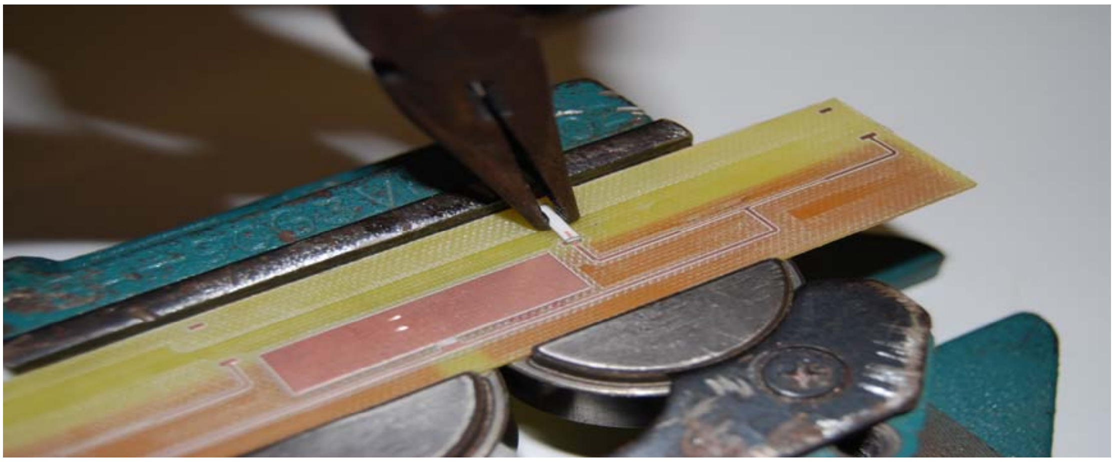

Figure 53 Put the antenna in the position and weld

To add the connector, you should make a hole with the drill to pass the PIN connector and make contact with the TL input. The SMA connector is soldered to the back of the PCB. Legs should be cut to bring the base of the connector to the plate and it touches the ground layer.

It has the connector in position and welded. To make a good soldering tin should be very hot. This shape is very liquid and can be shaped better. In seconds is solidified.

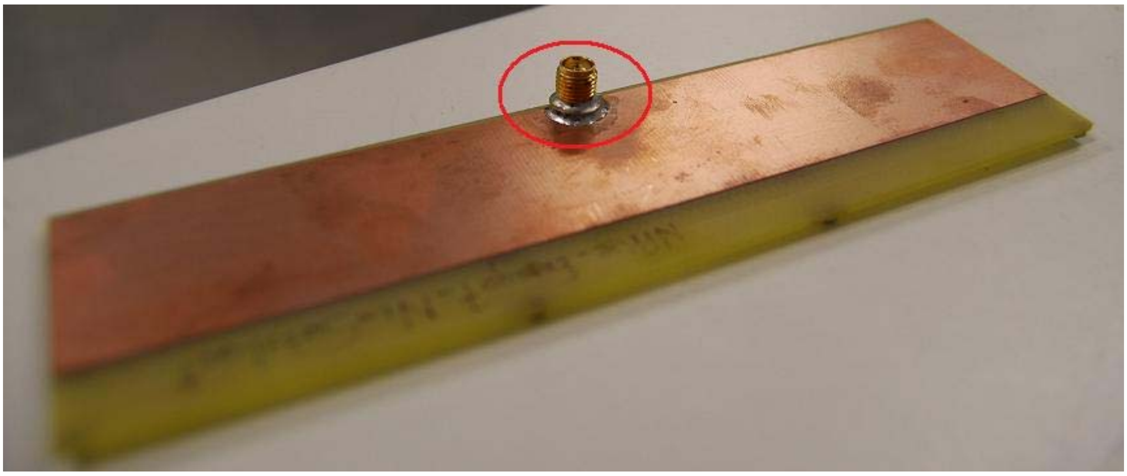

Figure 54 SMA soldered connector

The prototype is ready for power testing.

3.5 Designs manufacturing

We have designed a lot of prototypes. It began by trying to adapt each antenna separately using capacitors and inductors but it was too difficult because the values that were not commercial use should be part of the difficulty that he had to weld these components on the slopes.

Finally we decided to do all the adaptation with micro strip lines. The distribution of the antennas is made symmetrically, so that all the prototypes are very similar, although each of them has any amendment that sets it apart from the rest.

Here are the prototypes that have worked best in the simulations and have been manufactured.

For each of the designs are attached graphs obtained in *ADS* simulations (S-Parameters, VSWR and Z_{in}), simulations of *SuperNec* (distribution and radiation patterns (3D, azimuth and elevation)), an actual photograph of the finished prototype and a brief explanation of the feature that differentiates each other.

3.5.1 NPrize_Array_v2_2_2

The prototype is based on an earlier prototype that seeks to improve the size reduction. It is based on variations in track width. It has a very narrow entry line (0.74 mm) that is transformed into the curve in a wider line (1.49 mm). This performs the same operation in the following turns. With this you can reduce the size.

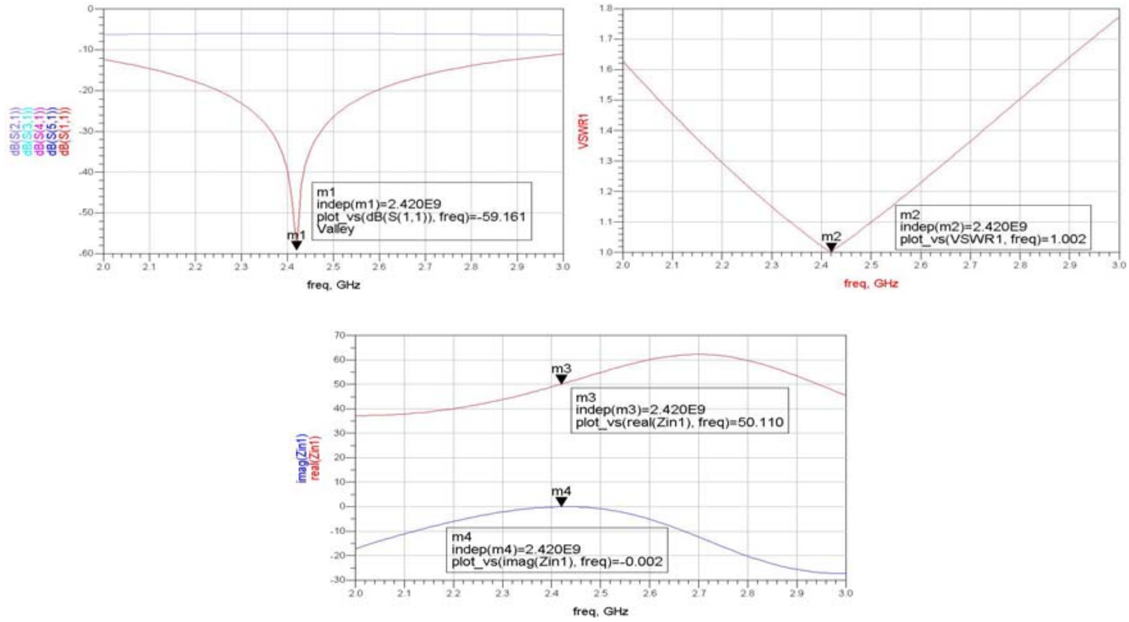

Figure 55 S-Parameters, VSWR and Z_{in} *ADS* graphics

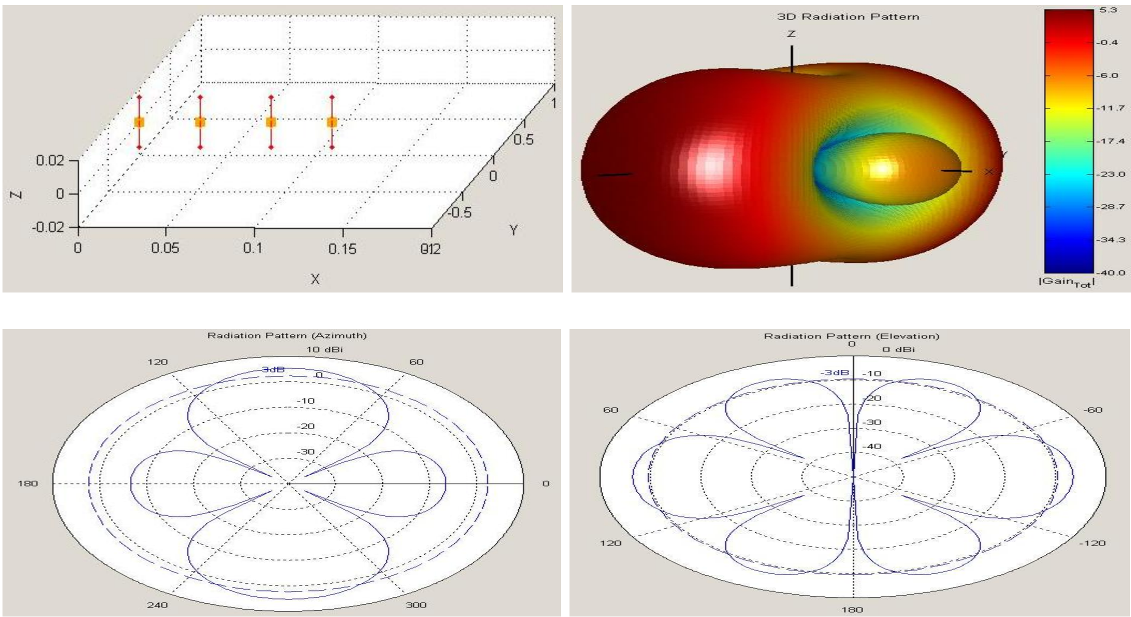

Figure 56 Distribution and Radiation Pattern (3D – Azimuth – Elevation) *SuperNec* graphics

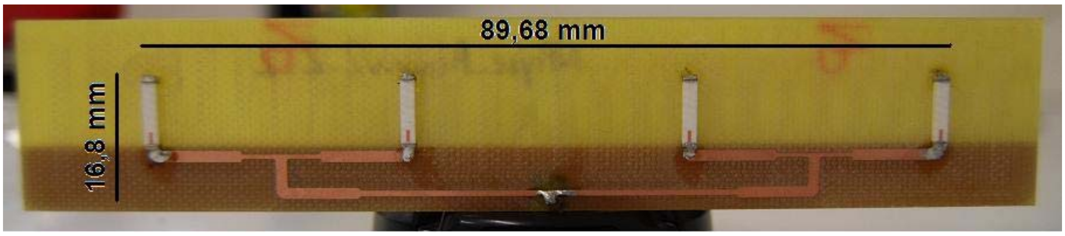

Figure 57 Prototype completed

3.5.2 NPrize_Ensayo5b_DentroMedidas_2_sinLin_2

This prototype differs from others in that the antennas are not equally spaced. We attempted to make two groups of two antennas attached. The width of the TL is constant.

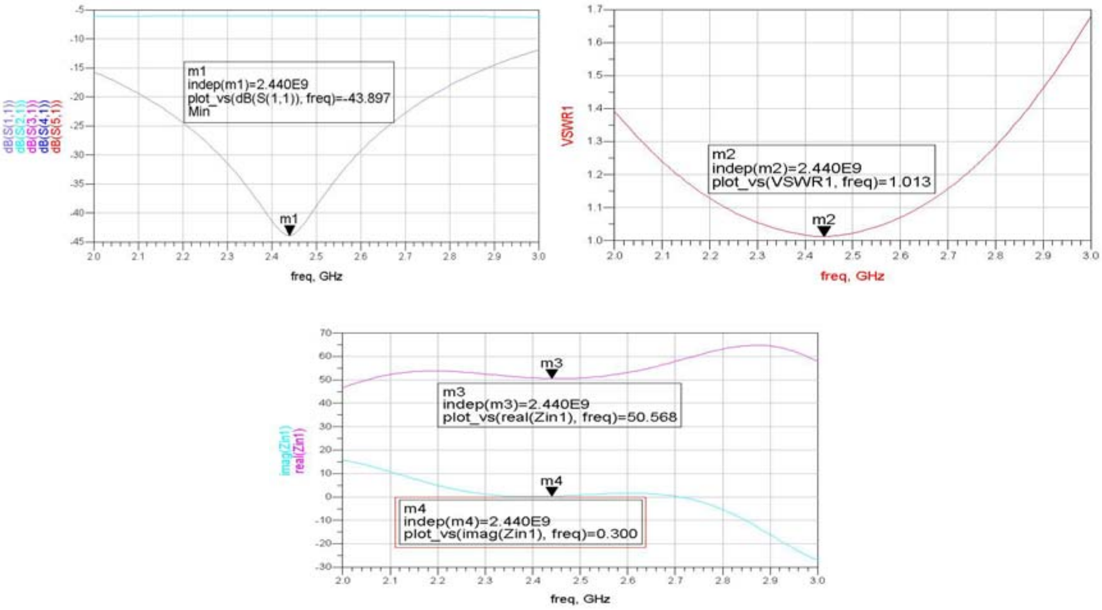

Figure 58 S-Parameters, VSWR and Z_{in} *ADS* graphics

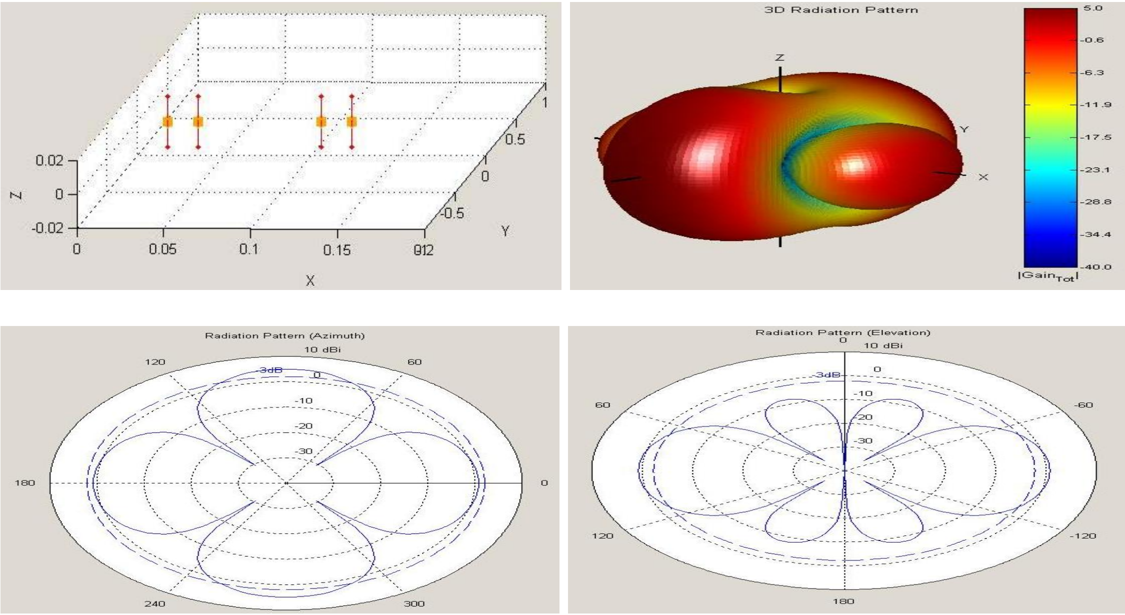

Figure 59 Distribution and Radiation Pattern (3D – Azimuth – Elevation) *SuperNec* graphics

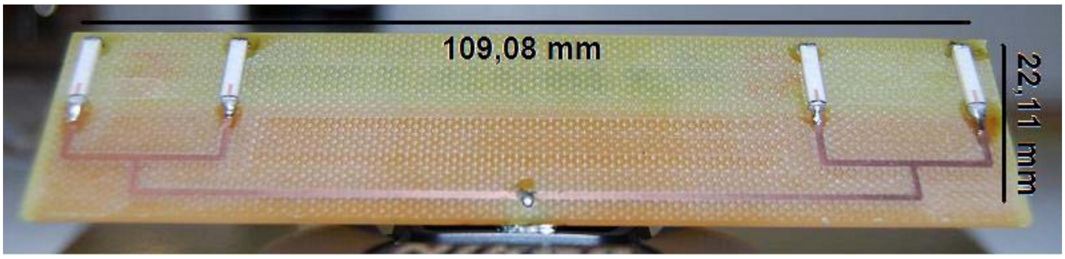

Figure 60 Prototype completed

3.5.3 NPrize_Ensayo7

This design is made with a very wide input line (2.5 mm) which are then narrowed in the last segment (0.9 mm). TL wide provides stability to the circuit and provides a better performance than narrow lines. The antennas are almost equally spaced.

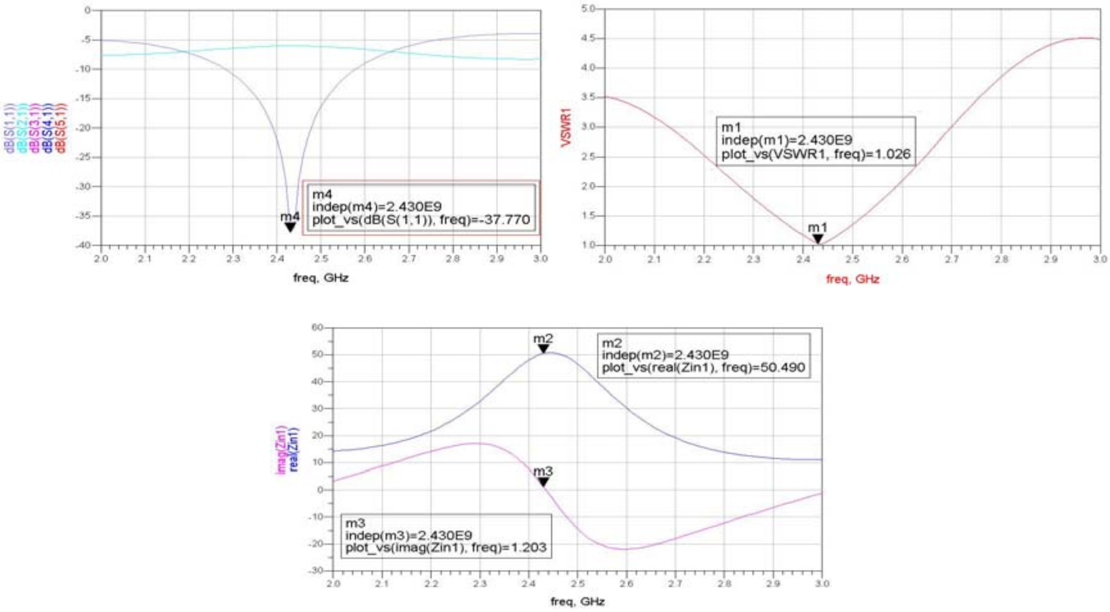

Figure 61 S-Parameters, VSWR and Z_{in} *ADS* graphics

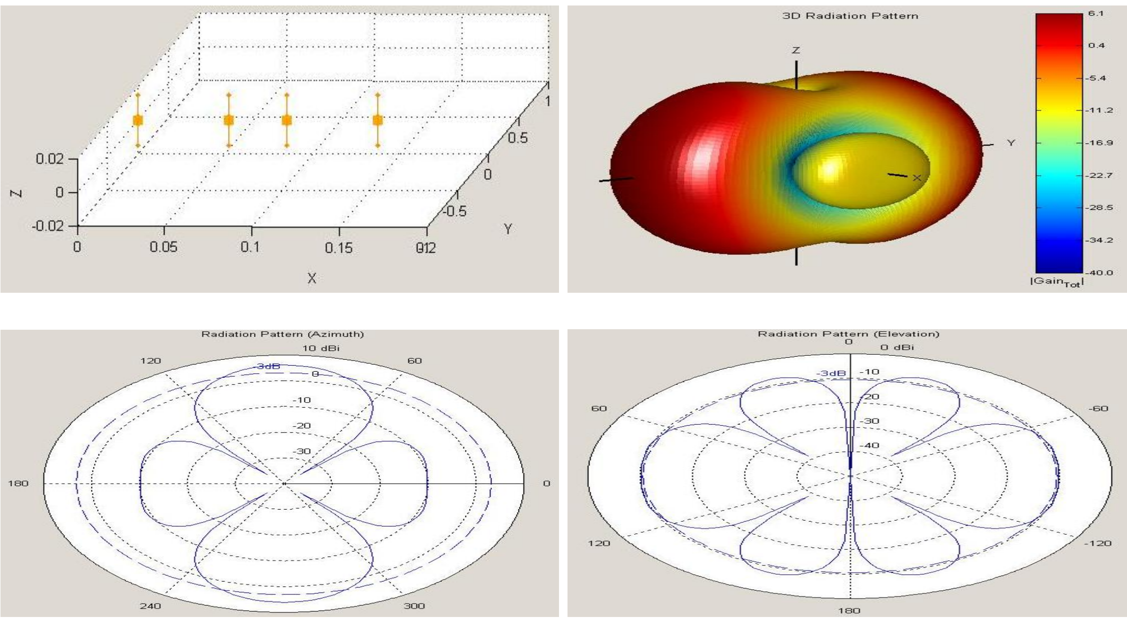

Figure 62 Distribution and Radiation Pattern (3D – Azimuth – Elevation) *SuperNec* graphics

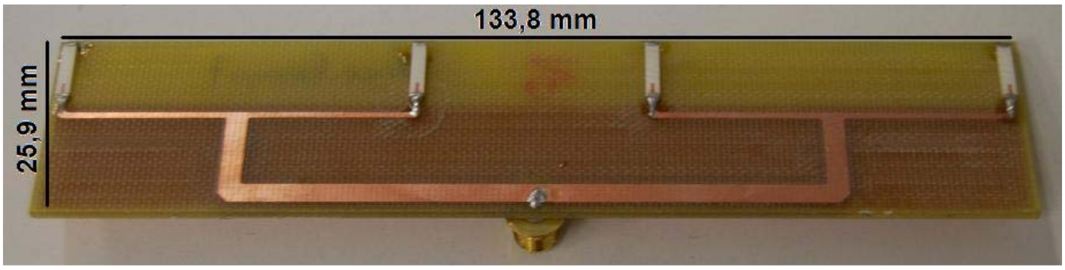

Figure 63 Prototype completed

3.5.4 NPrize_Ensayo11

For this design have been re-test the changes in the width of the TL. But unlike the previous design, we have 3 different widths. The wider the TL input (2.7 mm). This TL is a bit narrow (2 mm) on a section to make the first corner. The last section of TL which is in contact with the antenna is the narrowest (1 mm).

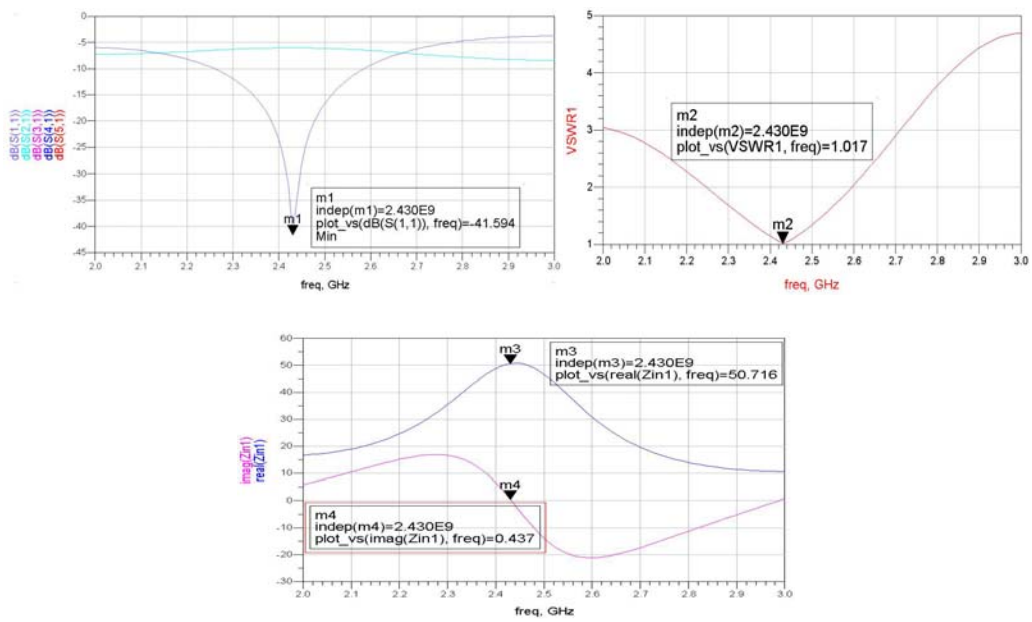

Figure 64 S-Parameters, VSWR and Z_{in} *ADS* graphics

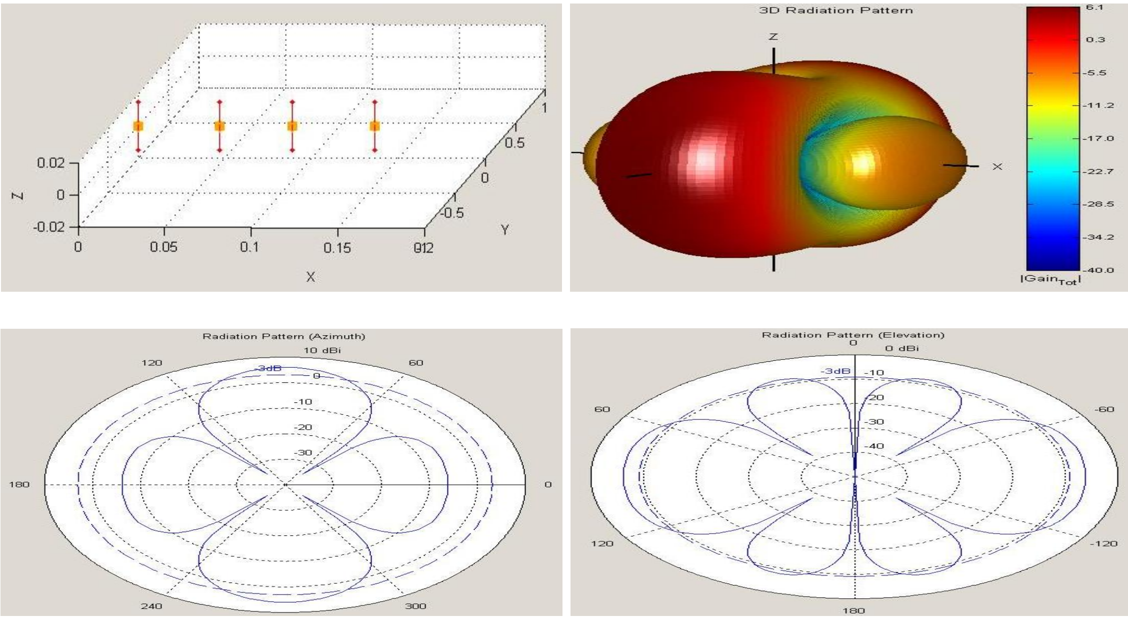

Figure 65 Distribution and Radiation Pattern (3D – Azimuth – Elevation) *SuperNec* graphics

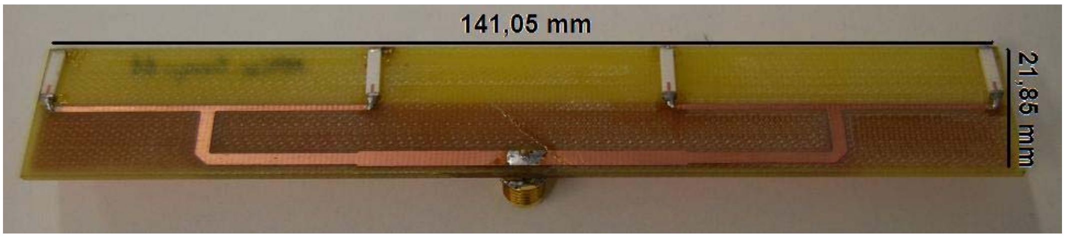

Figure 66 Prototype completed

3.5.5 NPrize_Ensayo13

This prototype has been the most difficult to design. It uses a narrow line with that to have the same impedance as a broad, must be very long. As should meet specifications of size, has had to draw the TL by "S ".

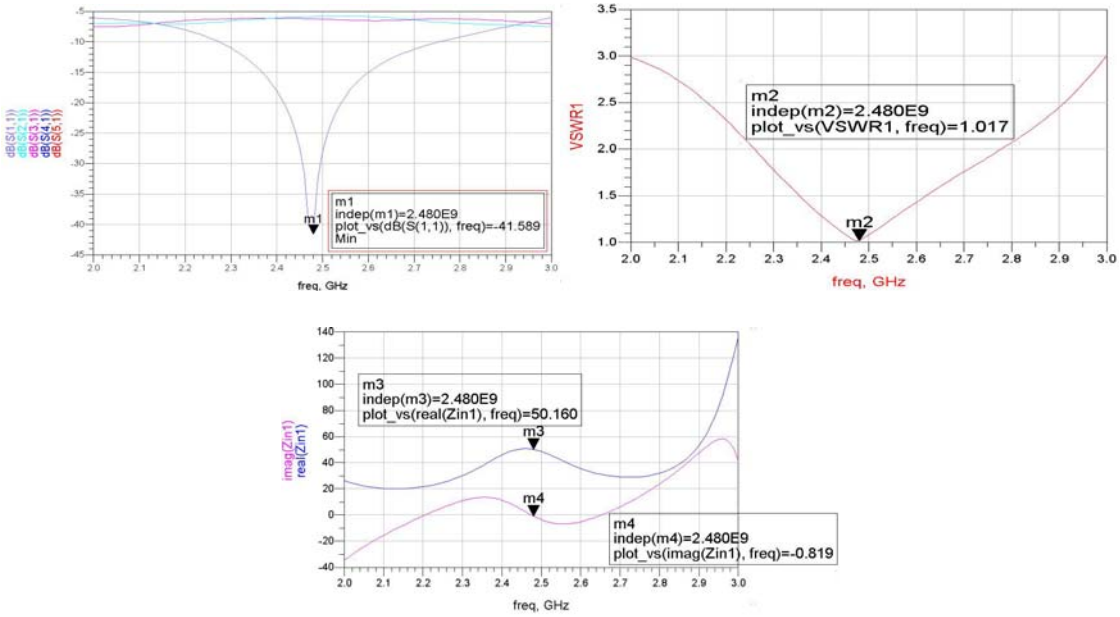

Figure 67 S-Parameters, VSWR and Z_{in} *ADS* graphics

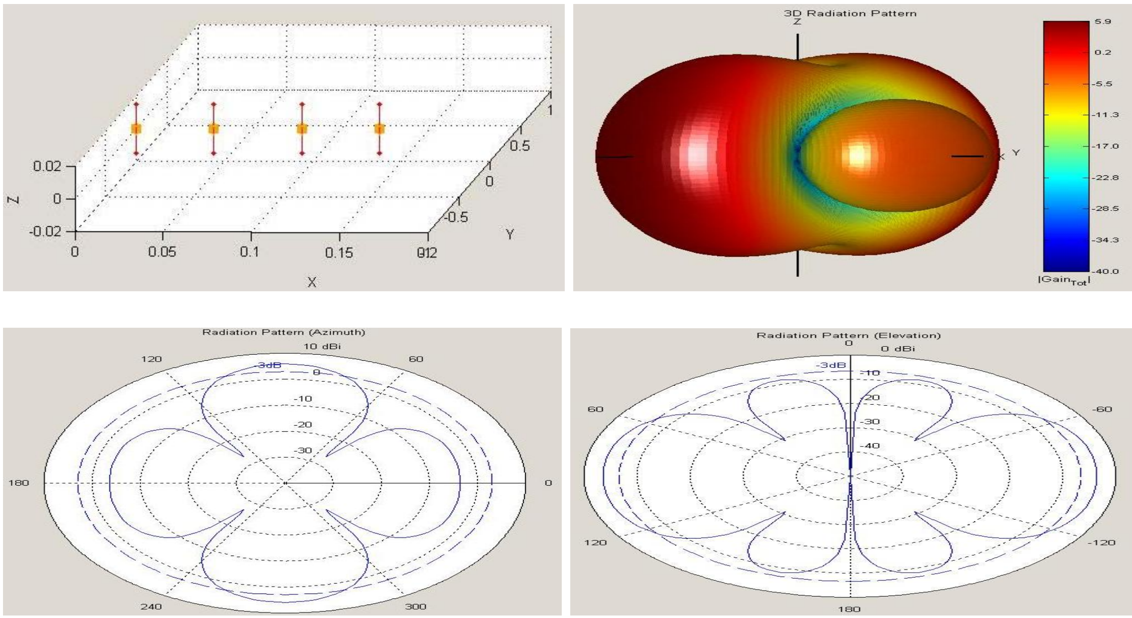

Figure 68 Distribution and Radiation Pattern (3D – Azimuth – Elevation) *SuperNec* graphics

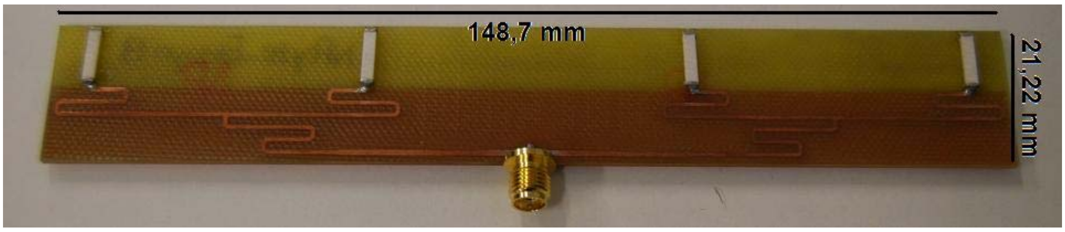

Figure 69 Prototype completed

3.5.6 NPrize_Ensayo7_NewSubstract

This is the latest prototype has been designed and manufactured. It is based on the "NPrize_Ensayo7" (as he was offered the best results in laboratory tests) but changed significantly.

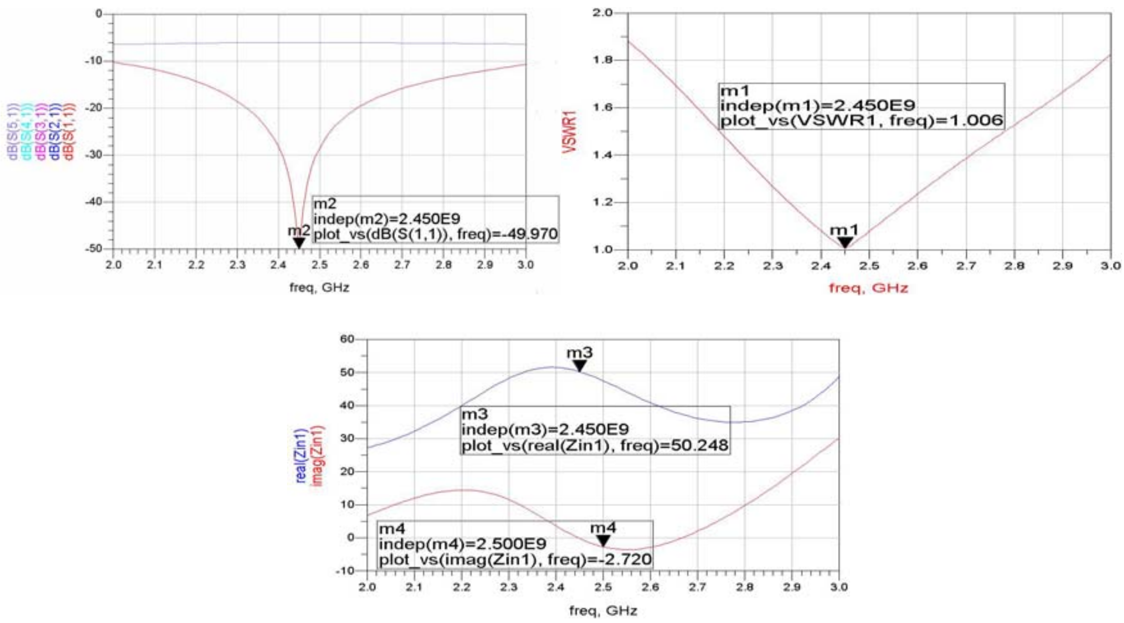

Figure 70 S-Parameters, VSWR and Z_{in} *ADS* graphics

It has redefined the substrate with new values. We have used 3 different track widths: 1.1 mm in the TL input, 3.7 mm in the middle TL and 2.35 mm in the TL that connects to the antenna (that has made the size a little greater).

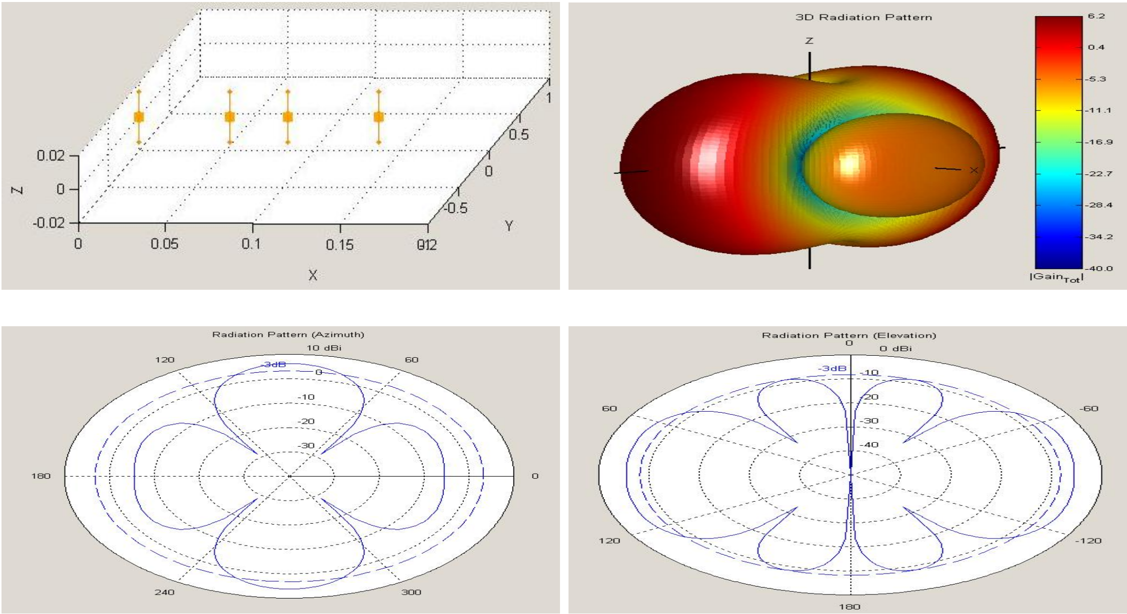

Figure 71 Distribution and Radiation Pattern (3D – Azimuth – Elevation) *SuperNec* graphics

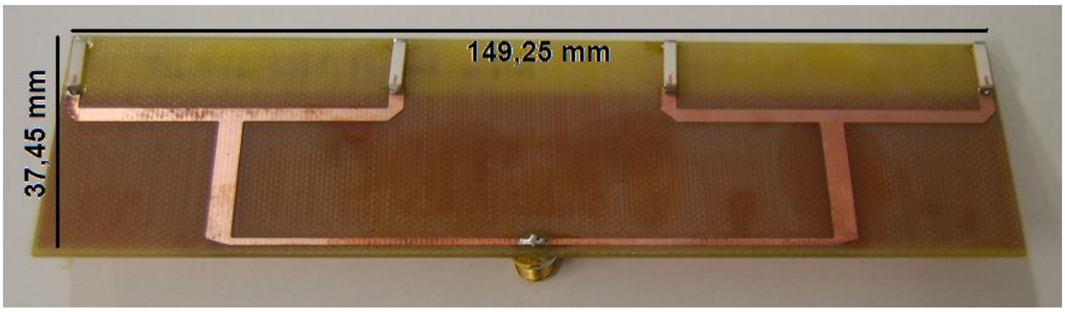

Figure 72 Prototype completed

3.5.7 Results summary

This section represents a summary table with the most interesting results of the simulations.

Different techniques were tested in order to see the effect in the overall radiation pattern. Because the small sizes of this concept, we should deal with the near field. Any small change may change totally the gain of the antenna.

Table 3.1 Simulations results summary

Prototype	Best Freq (GHz)	VSWR	S11 (dB)	Zin_Real (Ohms)	Zin_Imag (Ohms)	Max Gain (dB)
NPrize_Array_v2_2_2	2.42	1.002	-59.161	50.11	-0.002	5.3
NPrize_Ensayo5b_ DentroMedidas_2_sinLin_2	2.44	1.013	-43.897	50.568	0.300	5.0
NPrize_Ensayo7	2.43	1.026	-37.77	50.490	1.203	6.1
NPrize_Ensayo11	2.43	1.017	-41.594	50.716	0.437	6.1
NPrize_Ensayo13	2.48	1.017	-41.589	50.160	-0.819	5.9
NPrize_Ensayo7_NewSubstract	2.45	1.006	-49.97	50.248	-2.720	6.2

The purposes of these series of implementations were to take some background for the telecommunications group inside the Wikisat team. The help of telecom teachers was really decisive during the implementations. Also we achieved the vest results with the help of Serveis Tecnics from the EETAC School that showed us how to use the CNC device.

CHAPTER 4. SAA PROTOTYPING

This chapter explains the methodology used to obtain the actual values of the parameters that were measured in the simulation.

4.1 Equipment Used

In this section a brief presentation of the elements used in the process.

4.1.1 Spectrum Analyzer *Agilent CSA N1996A*

The N1996A is a low cost portable spectrum analyzer with a scalar network analysis personality for general frequency power measurements, stimulus response analysis and spectrum monitoring. The N1996A helps you to easily balance among your multiple test needs, regardless whether your use is on a production line, in a development lab, or at an outdoor site.[22]

Figure 73 *Agilent CSA N1996A*

4.1.2 Spectrum Analyzer *AnritsuMS2034A*

The MS2034A VNA Masters are the first and only truly portable handhelds with integrated 2-port vector network analyzer from 2 MHz to 4 GHz, spectrum analyzer from 9 kHz to 4 GHz, and power meter capabilities in a single instrument.

Ideally suited for aerospace and defense application, the VNA Master offers valuable measurement capabilities that can replace obsolete instruments and

[22] Agilent CSA N1996A
http://www.home.agilent.com/agilent/product.jspx?nid=-536902453.927043.00&lc=eng&cc=US
(Updated: February 2011)

improve operator mobility. In this way, field engineers and technicians can more quickly install, deploy, and maintain RF systems in the field.

VNA Master is also an excellent solution for low-cost manufacturing and other general purpose applications given the broad frequency coverage, excellent performance, and integrated capabilities[23].

Figure 74 *AnritsuMS2034A*

4.1.3 Signal Generator *AgilentE4433B*

This signal generator offers a wide range (250 kHz to 4 GHz) of digital modulation capabilities for research and development, manufacturing or troubleshooting applications.

Providing a comprehensive feature set, the E4433B generates standard and custom digital modulation formats, filtering and burst shapes, as well as versatile analog modulation[24].

Figure 75 *AgilentE4433B*

[23] Anritsu MS2034A - http://www.anritsu.com/en-US/Products-Solutions/Products/MS2034A.aspx
(Updated: February 2011)

[24] Agilent E4433B - http://www.teknetelectronics.com/Search.asp?p_ID=11802&pDo=DETAIL
(Updated: February 2011)

4.1.4 Transmitting antenna *Duck Dipole 2.4GHz*

Antenna with 2.2 dBi with Reverse Polarized - SMA RF connector. It is perfect for prototyping with our RF ICs. It has 50 Ohms impedance[25].

Figure 76 Transmitting antenna

4.1.5 SMA-N Cable

Coaxial cable for antenna connection, using an RP-SMA (Reverse Polarity) male connector on one end and an N-Type connector on the other end. Both connectors are male.

This cable is made with RG-58 coaxial wire, with a nominal impedance of 50 Ohms[26].

Figure 77 SMA-N cable to connect the antenna with de measure equipment

4.1.6 Calibration Items

These elements are necessary to calibrate spectrum analyzers.

The first is a female-female adapter, since the output of the SMA cable is a male and both Load and Short are also male connection.

[25] Transmitting antenna - http://www.sparkfun.com/products/145 - (Updated: February 2011)
[26] SMA-N cable - http://www.datapro.net/products/rp-sma-to-n-type-antenna-cable.html - (Updated: February 2011)

The second is a load of 50 Ohms. Since the circuit has to be adapted to this value, we must use this load to calibrate the equipment.

The third element is a short circuit.

Figure 78 Male-Female adapter – Load (50 Ohms) - Short Circuit

4.2 Process

This part of the chapter explains how to calibrate the measurement equipment and methodology used to measure various parameters of interest: Return Loss, impedance and gain.

4.2.1 Equipment calibration

The first step is to calibrate the two spectrum analyzers. It is very important to calibrate it but the results obtained are not adequate. The calibration process is identical for the two SA, the only difference is the interface of each of the equipment.

Here's the calibration of *Agilent CSA N1996A*.

Turn on the SA and once the system must press the "*Mode*" (Figure 79 (1)). Of the possible modes of operation offered by the equipment, select "*Stimulus / Response*". When already is in this mode, press the button "*Meas*" (Figure 79 (2)) and select "*Return Loss"* (Figure 79 (3)).

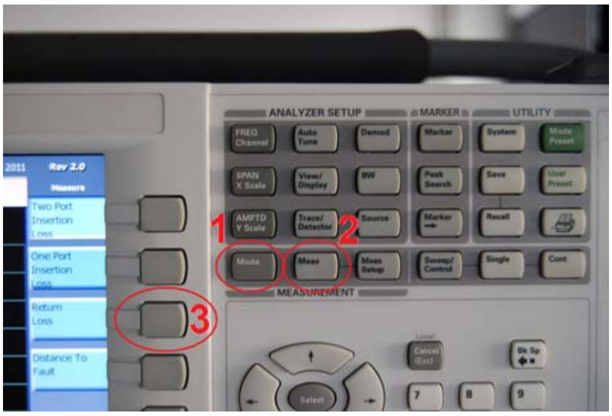

Figure 79 *Agilent CSA N1996A* keypad

On screen we have the graph will show the return loss but the team is not calibrated. For better resolution and we work in a range of frequencies known, select the values of the maximum and minimum range to represent the graph. In this case, as initial frequency use 2 GHz and select final frequency as 3 GHz.

After selecting the frequency range, click on "*Calibrate*" and follow the onscreen instructions. First you must leave the circuit open (do not connect anything in the cable). Secondly you need to connect the piece to simulate the short and end should be wired to simulate the load of 50 Ohms.

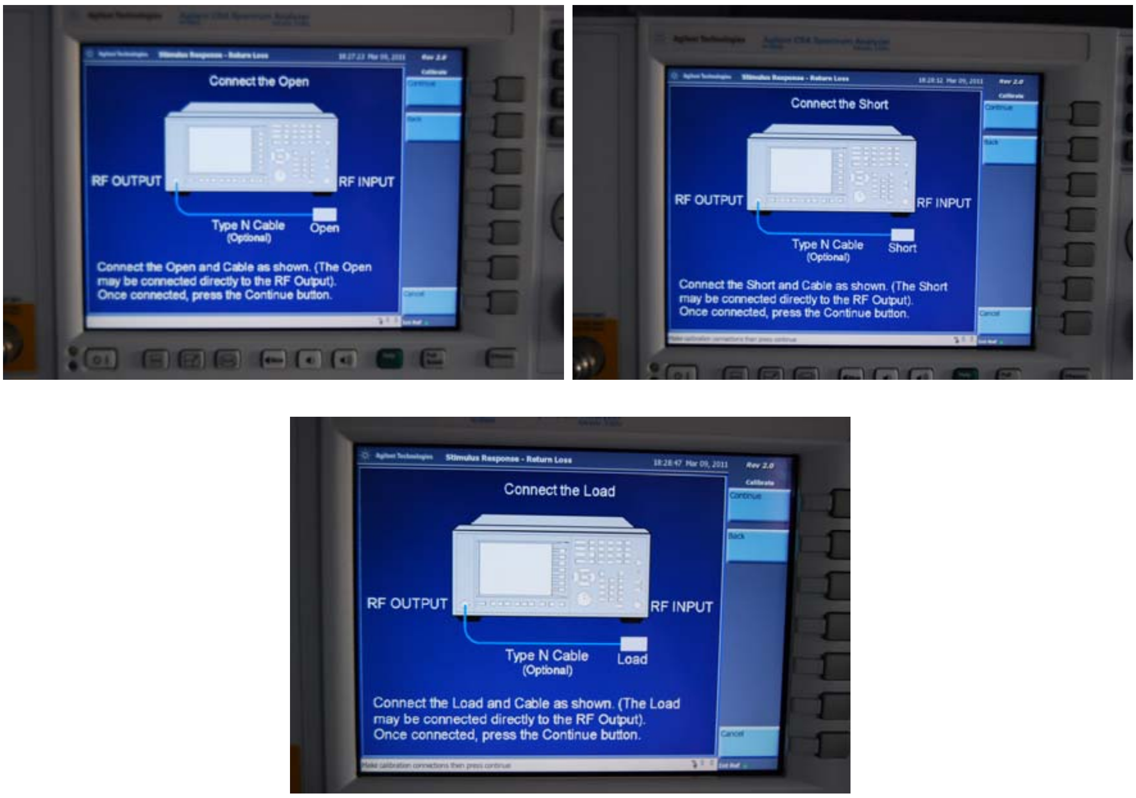

Figure 80 Screenshots for calibrating process (Open – Short – Load)

Now the equipment is already calibrated and ready to connect the prototypes.

In the case of *AnritsuMS2034A* (use to obtain the Smith Chart) once lit, press "*Shift*"→"*Mode*" and has to choose "*Vector Network Analyzer*". From the options listed is to be chosen "*S11 Reflection*" and the submenu be chosen, "*Smith Chart*".

When we have the Smith chart on the screen you should choose the initial and final frequency being represented and calibrate. Appear on-screen steps.

4.2.2 Return Loss measurement

Once we have the SA calibration, can take measurements threading the cable to the antenna. We put the antenna on a stand to try to affect the least possible external factors such as having it caught by hand or our own body can influence the impedance.

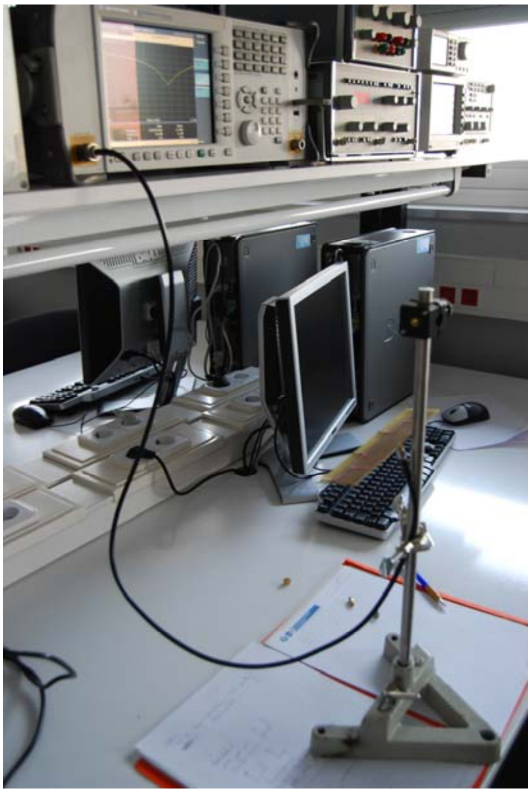

Figure 81 Return Loss measurement

This equipment allows us to take screenshots and save them to USB.

4.2.3 Impedance measurement

The process is the same as in the previous case: connect the antenna cable and put it in the support.

Figure 82 Impedance measurement

When the antenna is connected and displayed the graph, you can enter a "*Marker*" in a precise frequency value to see the impedance at that frequency. In these tests, the frequency value of the "*Marker*" is the same as the frequency for which we obtained the best value for "*Return Loss*".

The AnritsuMS2034A also allows for screen shots and save them on a USB.

4.2.4 Gain measurement

The measurement of the gain of the prototype is done by simulating a full link.

To make this measurement we had used the signal generator *AgilentE4433B*. The output of this generator is connected to the transmitting antenna (specified in section 4.1.4). Desired values are chosen both frequency and signal strength (Figure 83 (1)).

In the SA, select the mode "*Spectrum Analyzer*" and choose the frequency range you want to represent in the graph. You connect the cable to the "*RF in*" on the SA and the antenna in the other side. The antenna is placed in the holder and placed facing the transmitting antenna (Figure 83 (2)). On the display of SA appears the signal received by the prototype that we tested.

Figure 83 Link for received power measurement

If you make a simple power balance:

$$P_{RX} = P_{TX} + G_{TX} - TX_{losses} - \lambda_s + G_{RX} - RX_{losses} \quad \textbf{(4.1)}$$

where P_{RX} is the power received, P_{TX} is the power transmitted, G_{TX} is the gain of transmitting antenna, G_{RX} is the gain of receiving antenna, Tx_{losses} and Rx_{losses} are losses introduced by cables and connectors and λ_s are the space losses defined by:

$$\lambda_s = 10\log\left(\frac{(4\pi d)}{\lambda}\right)^2 \quad \textbf{(4.2)}$$

Where d is the distance between antennas.

To find the value of the gain in reception:

$$G_{RX} = -P_{TX} - G_{TX} + TX_{losses} + \lambda_s + RX_{losses} + P_{RX} \quad \textbf{(4.3)}$$

where all the values are known.

4.3 Practical results

This section shows the screenshots of Return Loss (with *Agilent CSA N1996A*) and Smith Chart (with *AnritsuMS2034A*) for each of the prototypes manufactured.

As the results were not expected, the only prototype that has been tested for gain has been with the NPrize_Ensayo7_NewSubstract. The section of this prototype shows the capture of the received signal and a table of different values of gain as the positioning of the prototype to the transmitting antenna.

4.3.1 NPrize_Array_v2_2_2

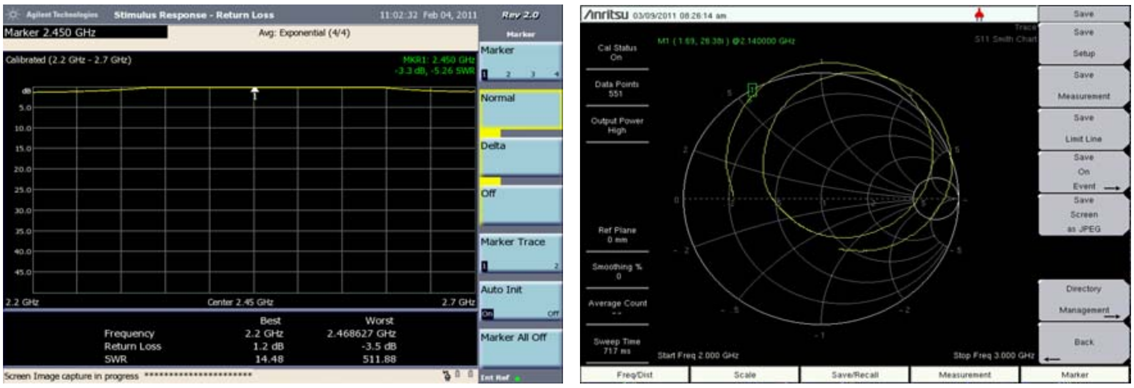

Figure 84 NPrize_Array_v2_2_2 - Return Loss and Smith chart

4.3.2 NPrize_Ensayo5b_DentroMedidas_2_sinLin_2

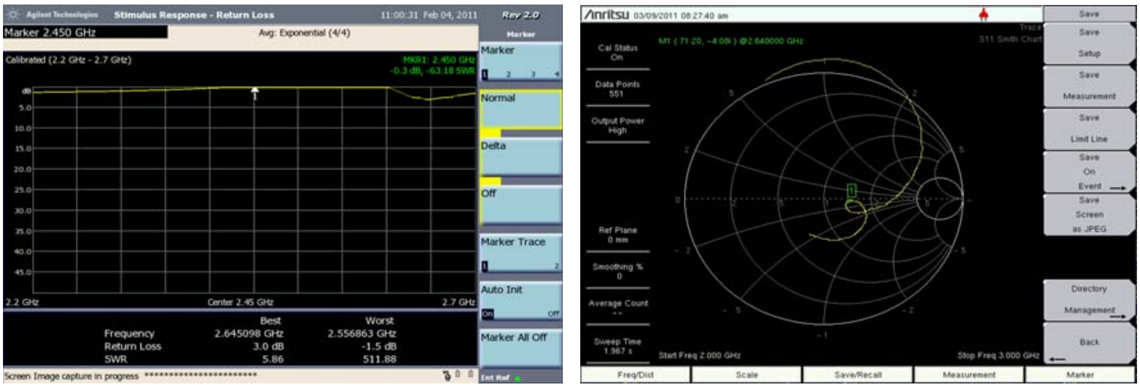

Figure 85 NPrize_Ensayo5b_DentroMedidas_2_sinLin_2 - Return Loss and Smith chart

4.3.3 NPrize_Ensayo7

Figure 86 NPrize_Ensayo7 - Return Loss and Smith chart

4.3.4 NPrize_Ensayo11

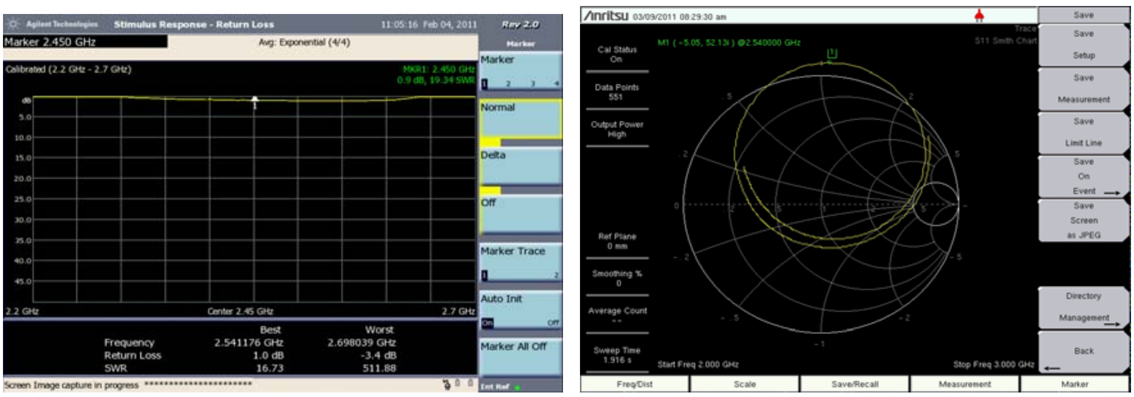

Figure 87 NPrize_Ensayo11 - Return Loss and Smith chart

4.3.5 NPrize_Ensayo13

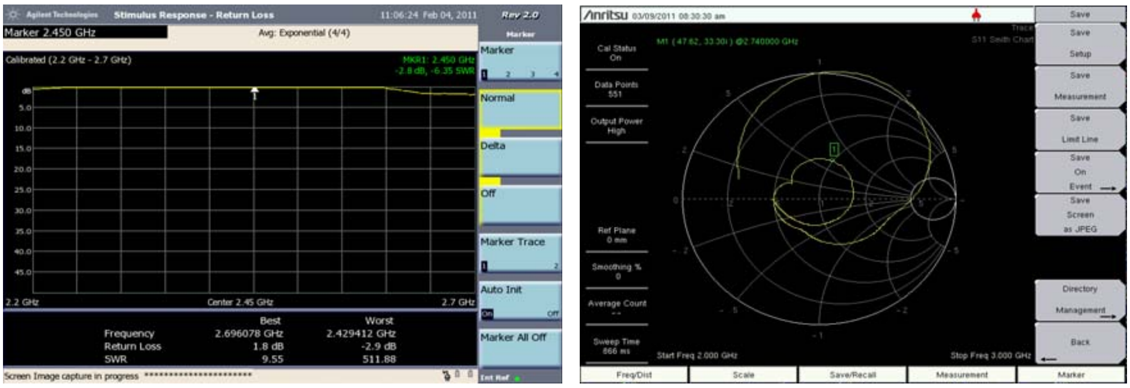

Figure 88 NPrize_Ensayo13 - Return Loss and Smith chart

4.3.6 NPrize_Ensayo7_NewSubstract

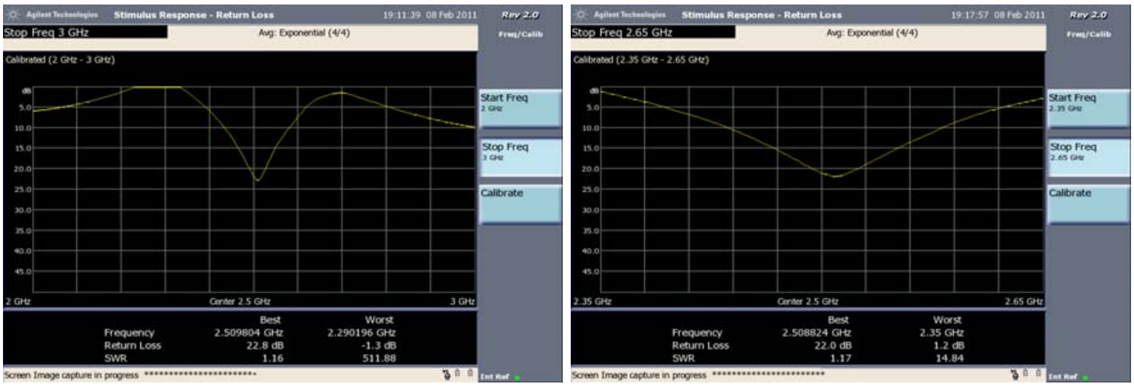

Figure 89 NPrize_Ensayo7_NewSubstract - Return Loss

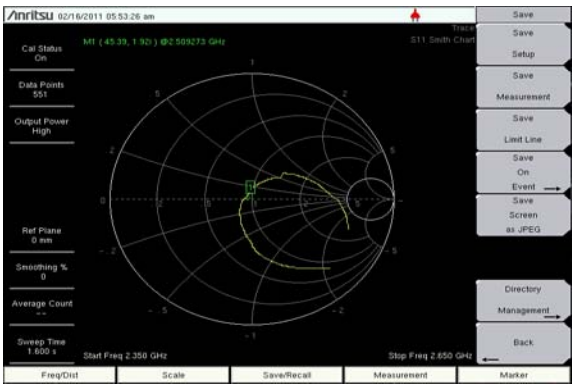

Figure 90 NPrize_Ensayo7_NewSubstract - Smith chart

We have taken several measures of received power for this prototype by moving the support that holds it and turning on the horizontal and vertical angles, obtaining the values shown below.

Table 4.1 Gain results for NPrize_Ensayo7_NewSubstract

Distance (m)	Freq (GHz)	Ptx (dBm)	Θ(°)	Φ(°)	Prx (dBm)
1.05	2.4	0	0	90	-41.1
			0	45	-44.2
			0	0	-38.5
			0	-45	-44.5
			0	-90	-46
			30	0	-43
			-45	0	-52
	2.38		0	0	-43
	2.425		0	0	-43.5
	2.45		0	0	-45
	2.5		0	0	-50
	2.51		0	0	-47
	2.52		0	0	-47

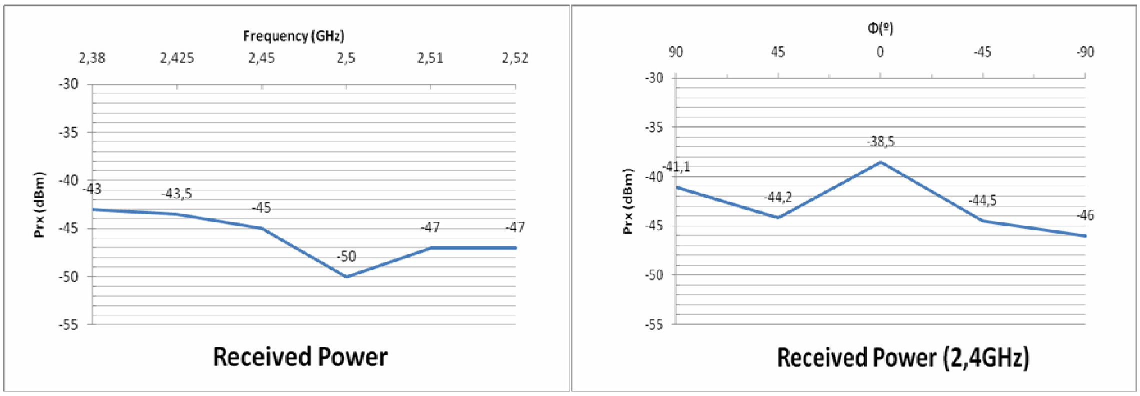

Figure 91 Graphics from NPrize_Ensayo7_NewSubstract (P_{rx} Vs Frequency (for Θ = Φ = 0º) and P_{rx} Vs Φ (for Frequency = 2.4 GHz))

Table 4.2 Best result for NPrize_Ensayo7_NewSubstract

Distance(m)	Freq (GHz)	Ptx (dBm)	Θ(°)	Φ(°)	Prx (dBm)
1.05	2.5	0	10±3	5±2	-33.66

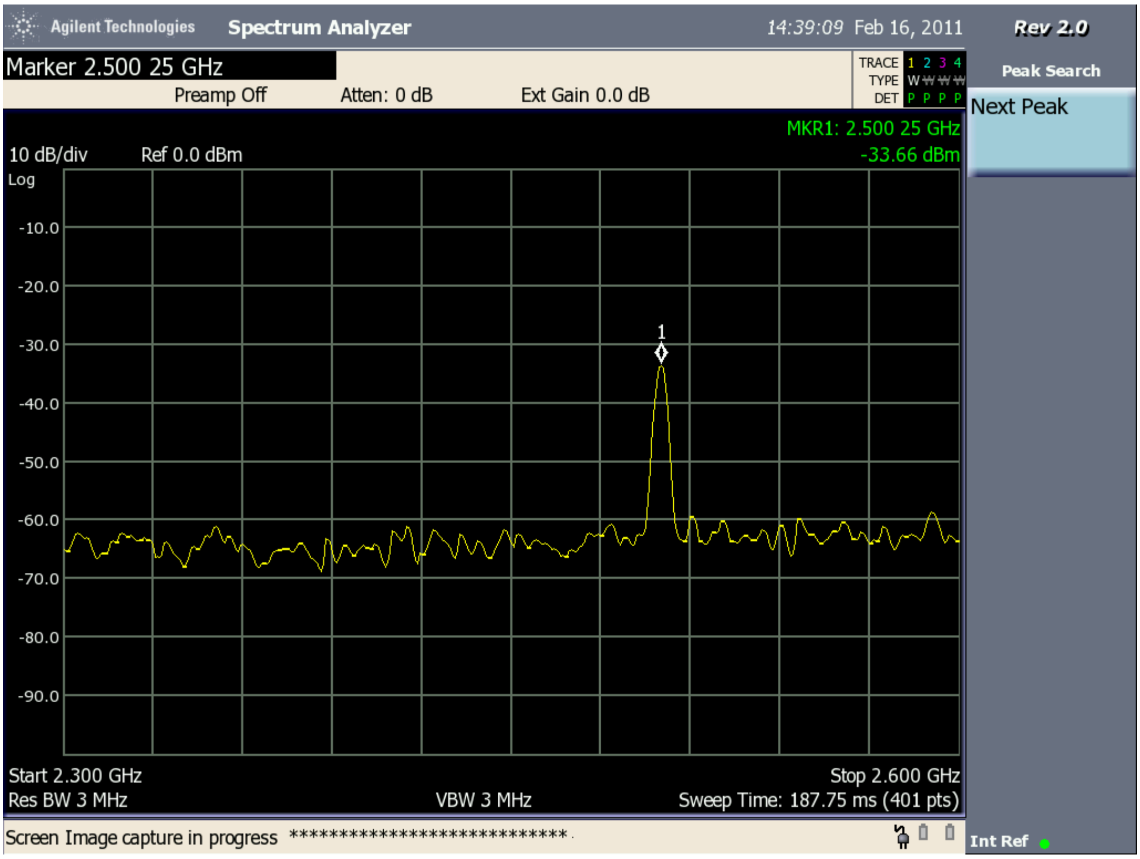

Figure 92 Capture "P_{RX}" from NPrize_Ensayo7_NewSubstract

Using the formula **(4.3)** and replacing all values:

$$G_{RX} = -P_{TX} - G_{TX} + TX_{losses} + \lambda_s + RX_{losses} + P_{RX}$$

G_{RX} = 0 dBm – 2 dBm + 0.5 dB + 40.82 dB + 0.5 dB – 33.66 dBm = **6.16 dB**

4.3.7 Results summary

This section represents a summary table with the most interesting results of the tests.

Table 4.3 Test results summary

Prototype	Best Freq (GHz)	VSWR	S11 (dB)	Z_{in} Real (Ohms)	Z_{in} Imag. (Ohms)	Max Gain (dB)
NPrize_Array_v2_2_2	2.14	13.09	-1.3	1.69	26.38	-
NPrize_Ensayo5b_DentroMedidas_2_sinLin_2	2.64	7.74	-2.3	71.20	-4.08	-
NPrize_Ensayo7	2.45	6.88	-2.5	7.36	52.63	-
NPrize_Ensayo11	2.54	16.23	-1.1	-5.05	52.13	-
NPrize_Ensayo13	2.74	7.43	-2.4	47.62	33.30	-
NPrize_Ensayo7_NewSubstract	2.50	1.16	-22.8	45.9	1.92	6.16

CHAPTER 5. ENVIRONAMENTAL IMPACT

The impact of this type of antennas can be taken in terms of saving power during the life cycle.

Other considerations should be taken into account related to the manufacturing process. Hazard materials are used during the manufacturing process like acids or dangerous powder that is harmful for the environment.

Working conditions should be adequate to the health safety of the operators. Air extractor should be installed and personal protections may be provided for operators.

During the development of this project, low cost materials were used that is transferred in terms of energy saving; avoiding the resource waste.

CHAPTER 6. CONCLUSIONS

6.1 Results analysis

In order to design a ceramic antenna array for a femto-satellite, this work has discussed the basic theory of antenna arrays, technology oriented in microstrip transmission lines and how they can be used for impedance matching.

The theory of antenna arrays allows for radiation patterns with values of directivity and gain that cannot be achieved with the basics. It depends on the number of elements that form the array and the separation between them. The intention of this work is to provide the basic knowledgement to implement not only an array antenna but also try to implement the synthetic aperture changing the phase.

As this is a real project could be divided into 4 phases: design, simulation, fabrication and testing. In the design and simulation the most used tools are software, while in the manufacturing and testing, work is much more manual. Each of these was explained in this work in detail.

We have designed several prototypes on simulation provided very good results but in practice the values obtained were not as good as expected. The reason was the type of microstrip substrate. The substrate characteristics defined in the first prototypes did not match the characteristics of the substrate was produced and this fact is what makes it change the performance.

Finally, the correct use of a proper substrate generated very good results that were tested in the semi-anechoic chamber. We can state that this kind of antennas are suitable for femto-satellites because they will work as Synthetic Aperture Antenna (SAA) and at the same time the work like the structure for the whole satellite.

6.2 Future work

As future research each prototypes could be tested in the anechoic chamber. These tests offer us the results of the real radiation patterns of the prototypes and could be compared with simulations.

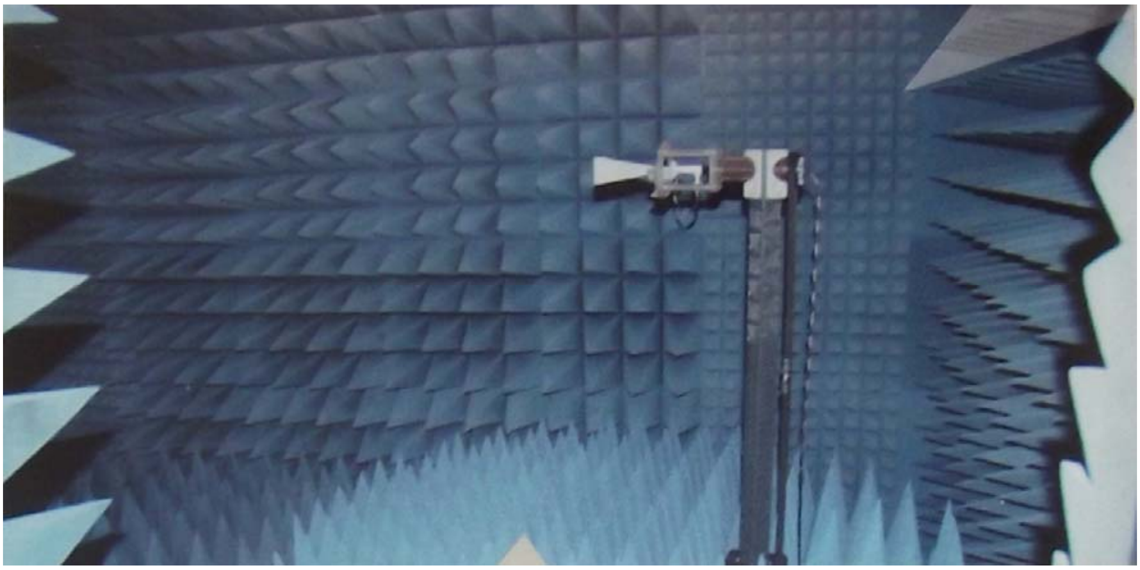

Figure 93 CTTC semi-anechoic chamber

Another possible line of work is the optimization of the final prototype trying to reduce the size, since it is the satellite structure, smaller size means less weight and this in turn means that the effort put into orbit would imply lower costs.

Another purpose of the antenna designed in this project may be to apply it in a radar system. To improve the ability of radar, phase shifters may be implemented in each of the antennas of the array to modify its radiation pattern and make it more directive radiation pattern.

CHAPTER 7. BIBLIOGRAPHY

[1] Cardama, A. et al., *Antenas,* Ediciones UPC, Barcelona, (1998).

[2] Joshua Tristancho, Marcos Quilez et all. *An Electromagnetic Interference Reduction Check List For Unmanned Aircraft System.* 48th AIAA Aerospace Sciences Meeting, (2009)