DESIGN AND CONSTRUCTION OF A PATCH ANTENNA

Authors: Project developed as part of a course. Collaborators are not listed here.

1. Introduction

1.1 CST Introduction

CST, a software for electromagnetic antenna simulation, was used to simulate the dipole. It allows precise analysis of the antenna behavior even before production and helps optimize the design, saving time and avoiding the construction of incorrect prototypes. CST also provides the ability to examine environmental conditions and different usage scenarios, evaluating factors such as directivity, impedance, and bandwidth, enabling the design of more efficient and high-performance antennas suitable for specific applications..

1.2 Patch Antenna Introduction

A patch antenna, also known as a microstrip antenna, is a common type of antenna used for transmitting and receiving electromagnetic signals. It consists of a thin metallic conductor, usually rectangular or square, called the patch, mounted on a dielectric substrate. The transmission line theory for a microstrip applies if: $W \ll \lambda$ and $h \ll \lambda$.

When a voltage or current is applied to the patch, electric and magnetic fields are generated and propagate in the surrounding space. The shape and dimensions of the patch, as well as the substrate material, influence the antenna's characteristics and performance. The antenna's resonance frequency is related to the patch size and the substrate material.

2. Objective of the Laboratory Experiment

The design of a patch antenna starts with an analysis of the desired operating specifications. Then, using CST, the behavior of the patch is simulated under different operating conditions, optimizing its geometry and characteristics to achieve the desired performance. CST simulations allow evaluating the effect of various modifications on the antenna's performance, such as size adjustments, materials used, and feeding configurations. This iterative approach helps refine the design to maximize efficiency and optimize bandwidth, ensuring that the patch meets the specific project requirements. Once the design and optimization phase in CST is complete, the construction phase begins, involving the physical realization of the simulated antenna. Attention to detail is essential during this process to ensure that the final product meets the specifications as closely as possible.

Figure 1: *Operating parameters; frequency range from 0 to 4 GHz because a narrower band would not allow an accurate view of all details (less precise). Operating frequency: 2.25 GHz.*

3. Simulation

3.1 Substrate Creation

For the CST patch simulation, the process begins with creating the substrate using the Brick function. As with other components, it is recommended to input values parametrically rather than numerically for greater flexibility in case of data modifications.

Figure 2: *Substrate parameters.*

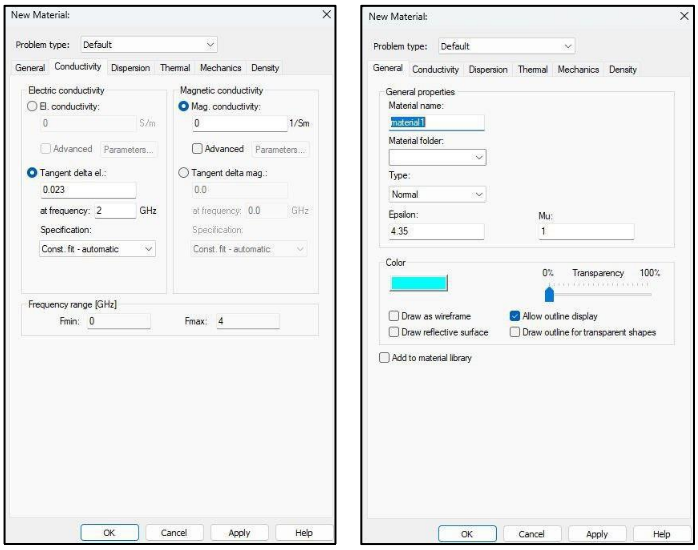

Figure 3: *Substrate material properties (as per datasheet).*

3.2 Ground Plane Creation

After creating the substrate, the next step is the ground plane creation. This layer serves several crucial functions:

1. **Wave reflection:** Acts as a reflective mirror for electromagnetic waves, optimizing overall efficiency.

2. **Interference reduction:** Functions as an electromagnetic shield, reducing external interference and improving signal quality.

3. **Control of undesired radiation:** Limits radiation in unwanted directions, maintaining signal directivity.

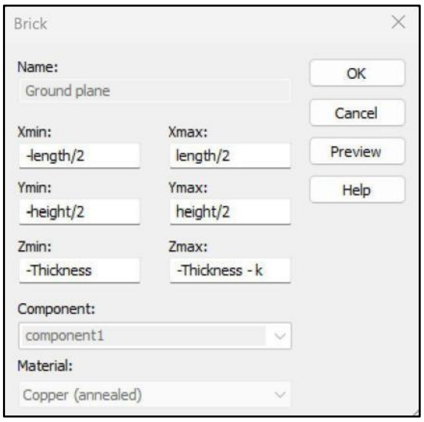

Figure 4: *Ground plane parameters.*

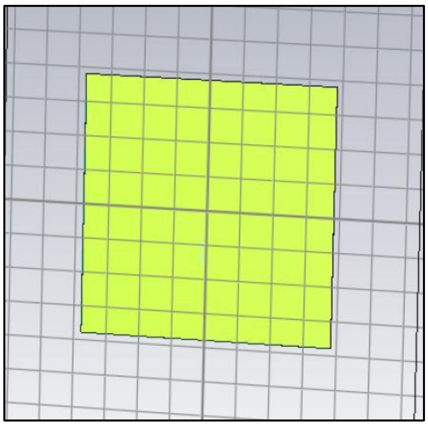

Figure 5: *CST visualization of the ground plane.*

3.3 Patch Creation

Next, the patch itself is created using the Brick function to model new components.

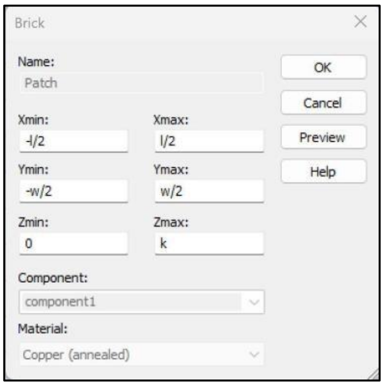

Figure 6: *Patch parameters.*

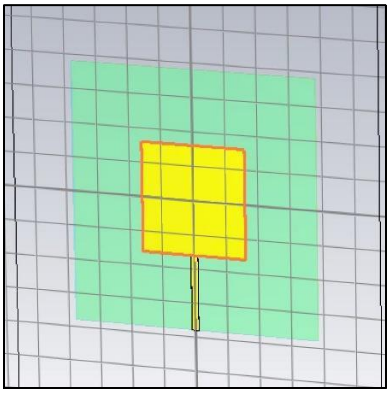

Figure 7: *CST visualization of the patch.*

3.4 Microstrip Creation

To determine the width (W) of the microstrip, the Impedance Calculation tool was used, selecting a “thin microstrip” type at 2.25 GHz, with thickness and permittivity 4.35 (from the datasheet). The microstrip required to feed the patch was then created.

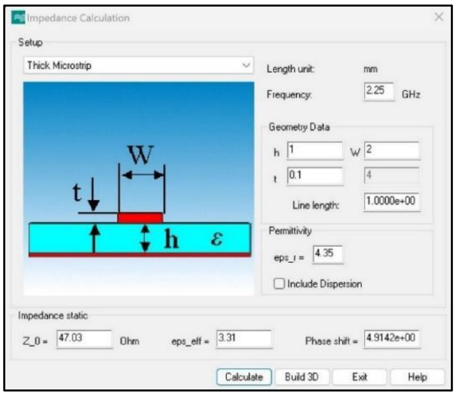

Figure 8: *Automatic microstrip width calculation using* ***Impedance Calculation****.*

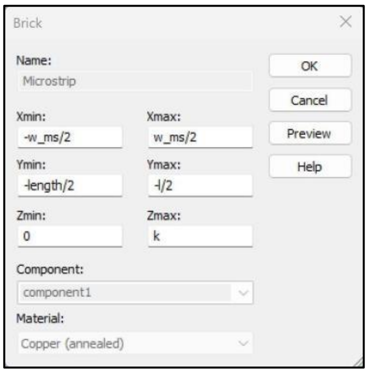

Figure 9: *Microstrip parameters.*

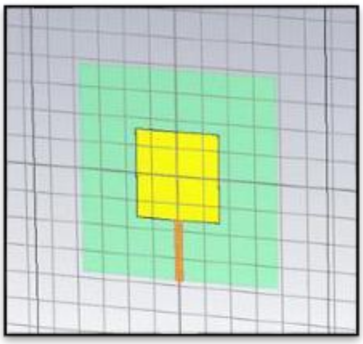

Figure 10: *CST visualization of the microstrip.*

3.5 Port Creation

In CST, the waveguide port is used to connect a waveguide to a simulated electromagnetic structure or device. This port simulates the interface behavior between the waveguide and the device, allowing analysis of the interaction between the propagating electromagnetic waves and the device. Waveguide ports can be configured in terms of size, shape, and propagation mode, enabling accurate simulation of the interaction between the waveguide and the antenna. In this experiment, the waveguide port was used to simulate the interface between the patch antenna and the waveguide. The waveguide port tool in CST was used to create this connection.

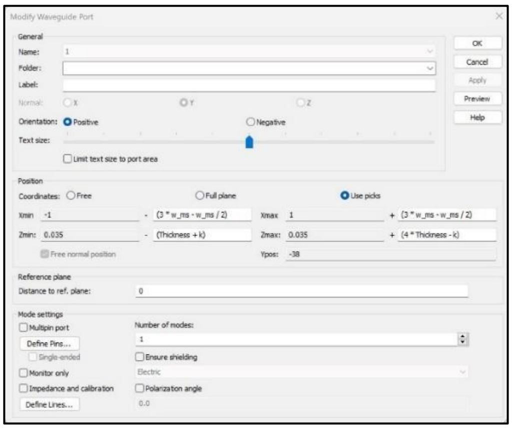

Figure 11: *Port creation.*

3.6 Insertion Creation

After the initial simulation, it was noticed that the attenuation peak was not optimized at the desired frequency. To address this, inserts were added to the patch, which modify the patch geometry and tune the antenna.

Figure 12: *Insert parameters.*

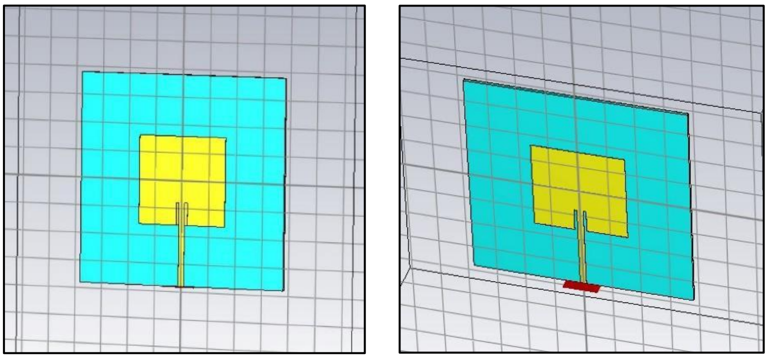

Figure 13: *CST visualization of the patch with inserts and port.*

3.7 Simulation

Finally, the insert dimensions were optimized using the parameter sweep function, allowing multiple simulations to be run automatically while varying the parameters of interest. Intervals and step sizes can be defined.

Once the simulations are complete, results are compared via a graph showing the reflection coefficient S1.1. To improve antenna performance, the geometry, particularly the length of the inserts (“inset dx” and “inset sx”), was adjusted so that the reflection peak shifts from the initial value, identified via the axis marker function, to the desired value. This centers the feeding and improves performance. The curve with the peak closest to the desired frequency and lowest attenuation is selected, and the patch is constructed with inserts of the corresponding size to optimize the antenna performance.

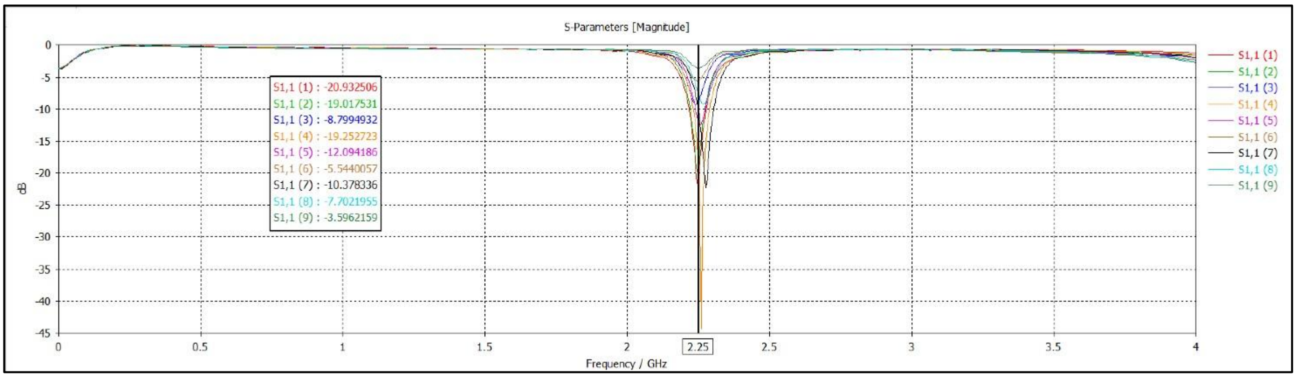

Figure 14: *Graph showing* ***S1.1*** *curves obtained via* ***Parameter Sweep****.*

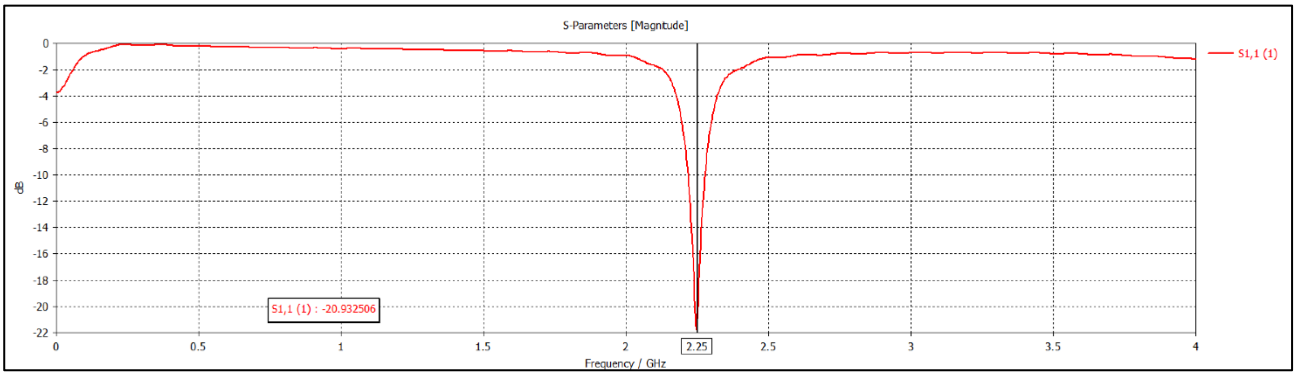

Figure 15: *Selected* ***S1.1*** *curve.*

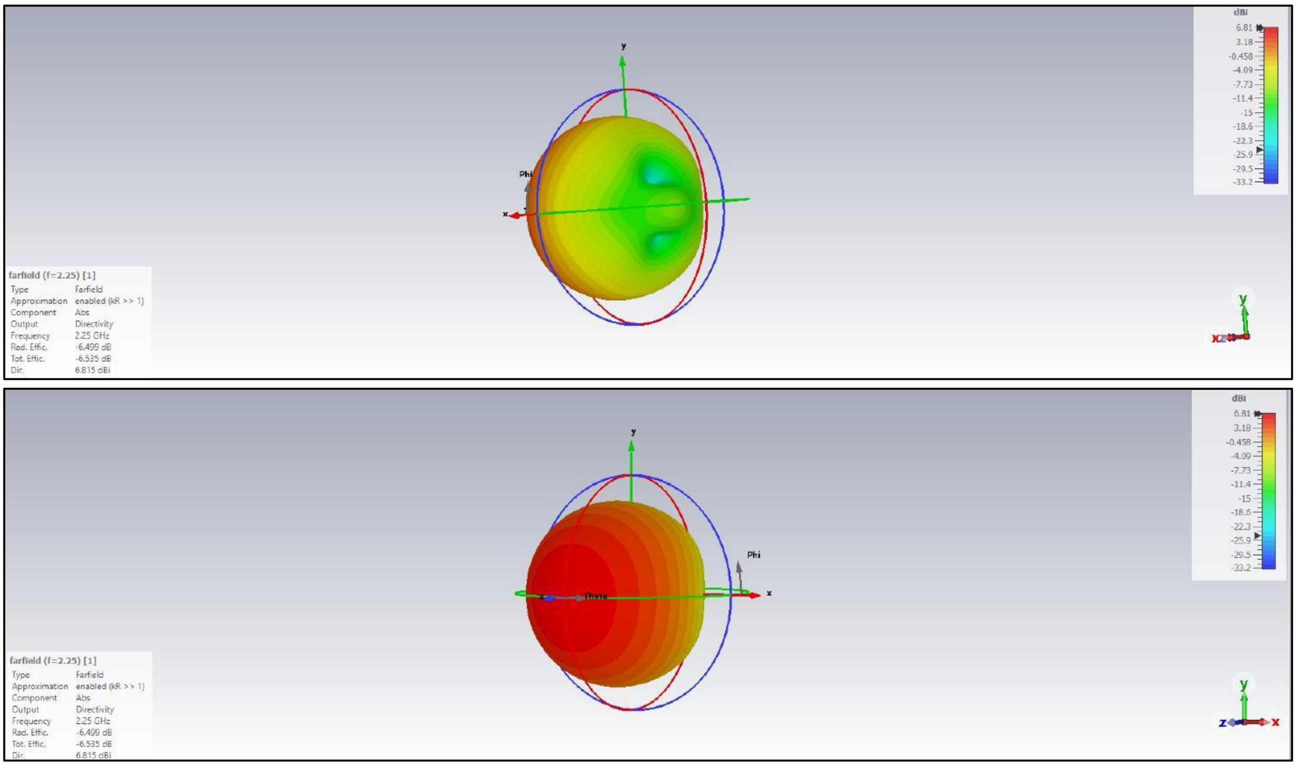

Figure 16: *Farfield graphs of the antenna.*

4. Construction of the Antenna

To build the antenna, an Isola DE104 FR-4 substrate (76x76x1 mm) was provided. Patch dimensions were set according to parameters in Image 17. Using a ruler and cutter, the ground plane was cut from a copper sheet, matching the substrate size, and glued to one side.
The patch and microstrip were then constructed similarly. The microstrip was connected to an SMA female connector via soldering to feed the antenna. To verify antenna functionality, it was connected to a previously calibrated nanoVNA.

Parameter List

Name	Expression	Value	Description
length	= 76	76	
height	= length	76	
Thickness	= 1	1	
k	= 0.035	0.035	
l	= 32	32	
w	= l	32	
w_ms	= 2	2	
x_sweep	= 1	1	
y_sweep	= 8	8	

Figure 17: *Dimensions defining the antenna.*

5. Observations

1. The antenna does not perfectly match the values obtained in simulation, despite using the same parameters. This discrepancy is due to manual tools and non-mechanized cutting procedures introducing inevitable inaccuracies during construction.
2. After initial testing with the nanoVNA, the measured gain was slightly lower than expected from CST simulations. This was likely due to slight errors in cutting the copper components of the patch, reducing gain. To correct this, extra copper was added to the patch to increase surface area and improve gain, as shown in Image 18.

Figure 18: *Copper added to the patch.*

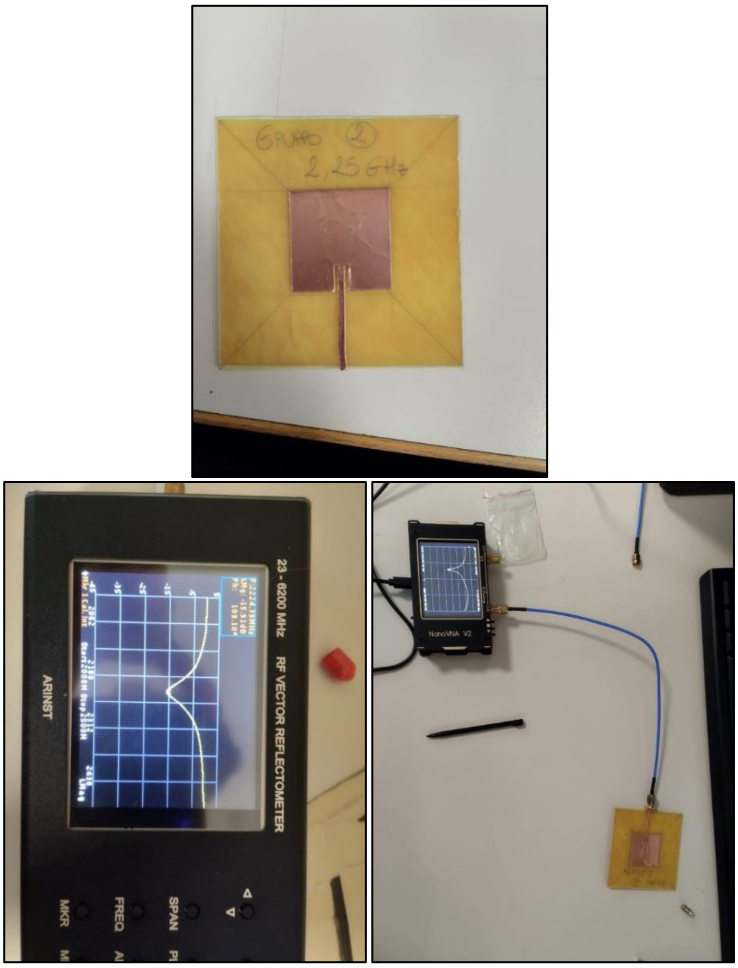

Figure 19: *Practical antenna construction.*

6. Conclusions

This laboratory exercise enhanced skills in using CST and provided deeper understanding of patch antennas and their key characteristics. It also demonstrated the ease of modifying and improving antenna gain using copper, as noted in observation 5.2.