DESIGN AND CONSTRUCTION OF AN ELECTROMAGNETIC DIPOLE

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

1. Introduction

1.1 CST Introduction

CST was used to simulate the dipole, a software for electromagnetic antenna simulation that allows precise analysis of antenna behavior even before production. This helps optimize the design, save time, and avoid constructing incorrect prototypes. CST also allows examination of environmental conditions and different use scenarios, evaluating parameters such as directivity, impedance, and bandwidth, enabling the design of more efficient and high-performance antennas tailored to specific applications.

1.2 Electromagnetic Dipole Introduction

The electromagnetic dipole is a common radiating element used for transmitting or receiving electromagnetic waves. It consists of two conductors of finite length, spaced appropriately and fed by a signal source. When current is applied to the dipole conductors, electric and magnetic fields are generated that propagate through space, creating an electromagnetic wave that can be radiated externally. The dimensions of the dipole—its length and conductor thickness—directly influence its performance. The dipole length is related to the desired operating frequency (2.15 GHz). The optimal length can be calculated using theoretical formulas and verified through electromagnetic simulations.

$$\lambda_0 = \frac{c}{f}$$

$$l_{arm} = \frac{\lambda_0}{4}$$

A longer dipole is more efficient at lower frequencies, while a shorter dipole is more efficient at higher frequencies. Dipole optimization also considers:

1. Feed impedance;
2. Bandwidth;
3. Directivity: influenced by dipole geometry and position relative to the ground and surrounding objects. Dipole orientation should be optimized to maximize directivity and radiated power.

2. Laboratory Objective

Designing an electromagnetic dipole begins with analyzing the desired operational specifications. Using CST, the dipole behavior is simulated under different operating conditions, optimizing geometry and characteristics to achieve target performance. CST simulations allow evaluation of the effect of modifications on dipole performance, such as size adjustments, materials, and feed configurations. This iterative approach refines the design to maximize efficiency and bandwidth, ensuring compliance with project requirements. Once design and optimization in CST are complete, the dipole is physically constructed. Attention to detail is crucial to ensure the final antenna matches the desired specifications as closely as possible.

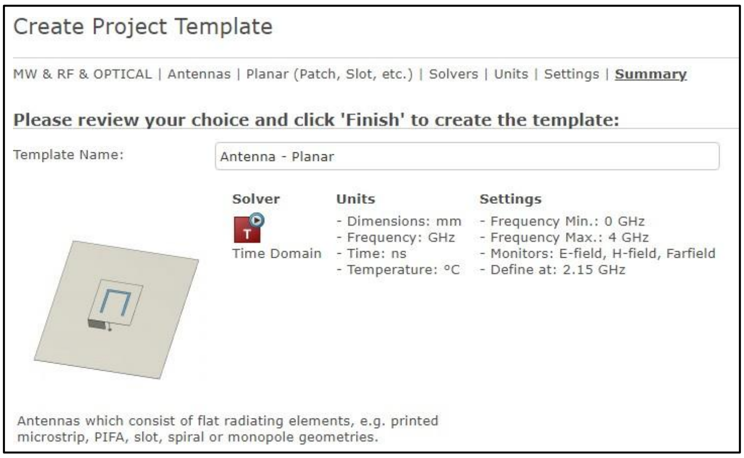

Figure 1: *Operational parameters; bandwidth 0–4 GHz to allow accurate observation of all details.*

3. Simulation

3.1 Substrate Creation

The simulation begins by creating the substrate using the Brick function in CST. Parameters are entered parametrically rather than numerically for flexibility in case of modifications.

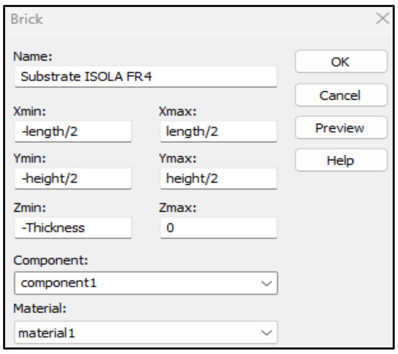

Figure 2: *Substrate parameters.*

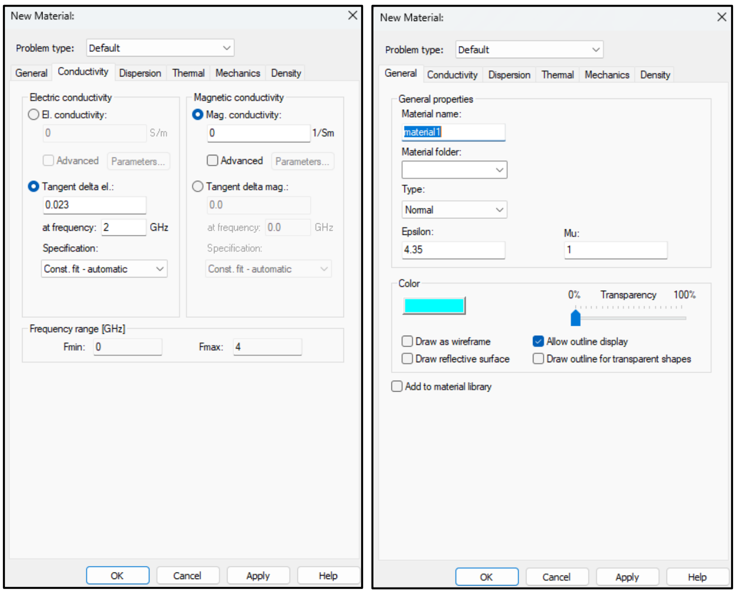

Figure 3: *Material properties of the substrate (data from datasheet).*

3.2 Arm Creation

After the substrate, the two arms of the antenna are created. Correct positioning relative to the substrate and SMA feed connector is critical, as the connector must be soldered directly to the copper.

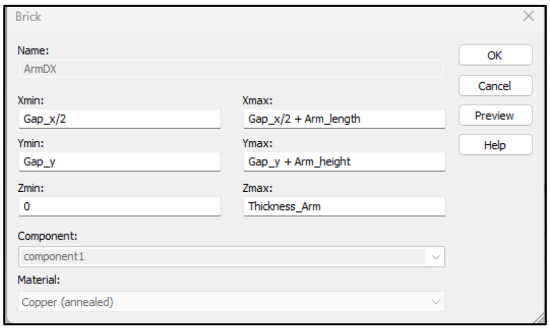

Figure 4: *Parameters of the right arm.*

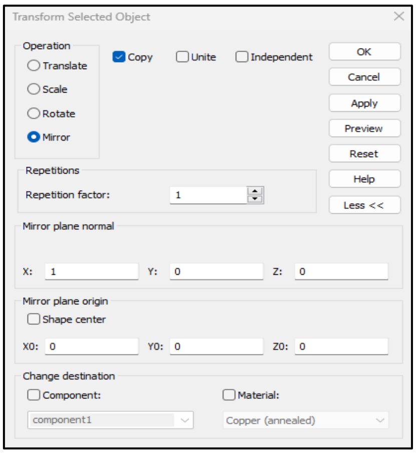

Figure 5: *Creation of the left arm via a mirroring process.*

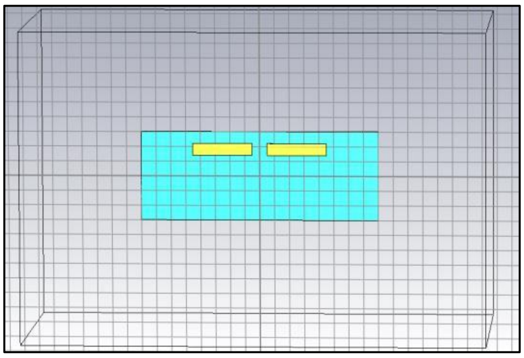

Figure 6: *Substrate with both arms.*

3.3 Copper Connections Between Arms and SMA Connector

Two additional bricks (solid1 and solid2) simulate the connector contacts. Theoretical behavior remains the same if separate, but visually they are combined using: Modeling → Boolean → select armDX → Add → select solid1 → Enter, and similarly for armSX and solid2.

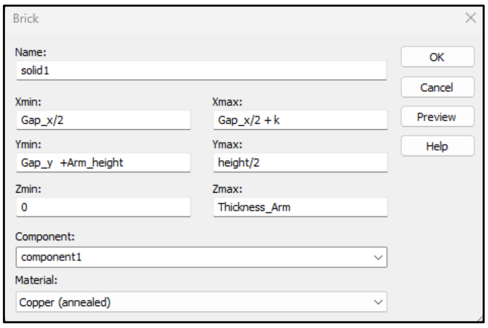

Figure 7: *Copper connection parameters between the right arm and the connector.*

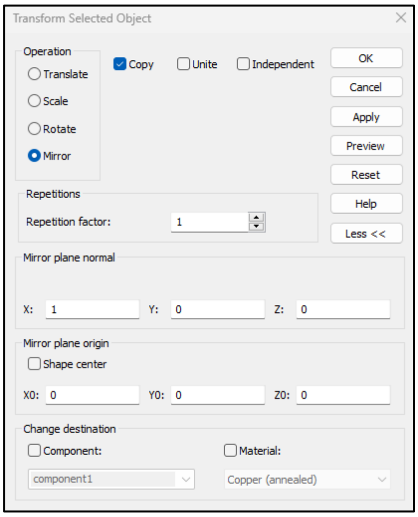

Figure 8: *Creation of the left connection (Solid2) via mirroring.*

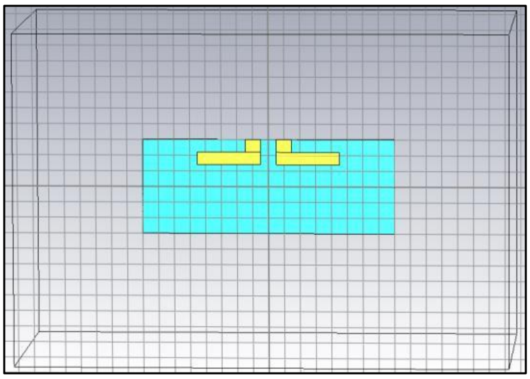

Figure 9: *Complete antenna assembly.*

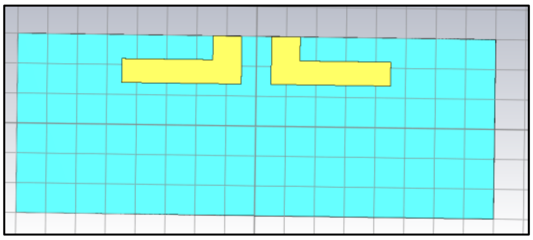

Figure 10: *Blocks after merging procedure.*

3.4 Discrete Port Creation

The concept of a “discrete port” in CST refers to the use of discrete-parametric models to represent components that cannot be directly modeled by the continuous simulation of Maxwell's equations inside the simulator. This allows accurate modeling of the complete circuit behavior, including both discrete components and continuous geometry.

In an electromagnetic dipole, a discrete port represents a feed (voltage or current signals). The use of a discrete port in CST is crucial for accurate and realistic simulation, enabling proper modeling of both continuous and discrete parts of the electromagnetic circuit. Discrete ports are typically represented by a wire segment with an arrow at the center. The wire ends, considered perfect conductors, are connected to the desired points on the model, while the central arrow represents the voltage or current source.

To create the port, the Pick End Point function was used, allowing selection of individual points belonging to the created components. In this case, points were selected at vertices in contact with the substrate on bricks solid1 and solid2. A Discrete Edge Port was then created, positioned midway between the selected points.

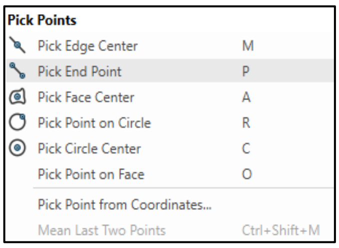

Figure 11: *Pick End Point function.*

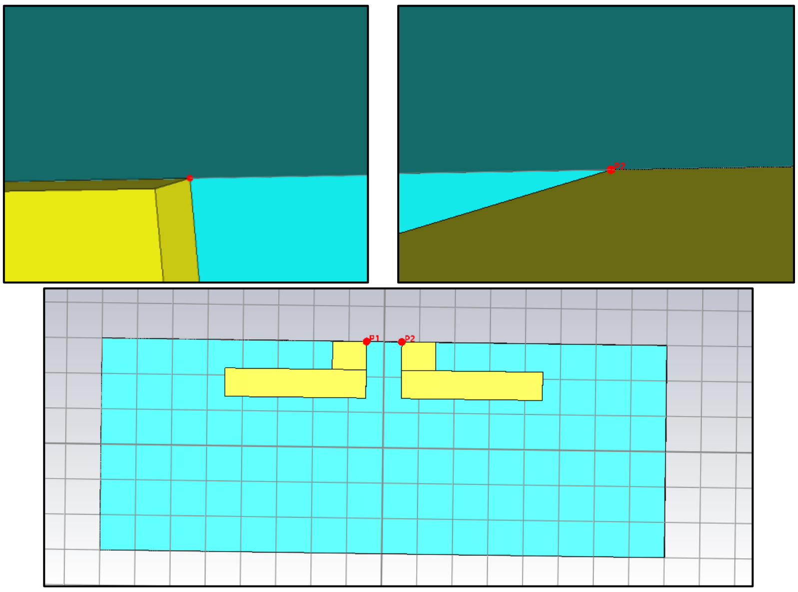

Figure 12: *Selection of points P1 and P2.*

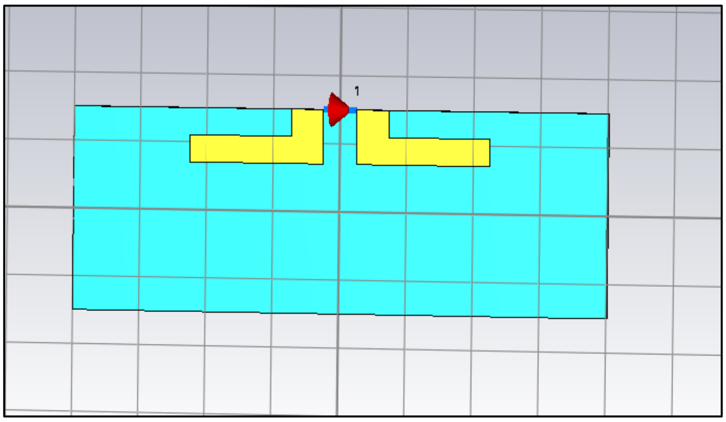

Figure 13: *Discrete port creation.*

3.5 Simulation and Conclusion

Arm dimensions were optimized using a parameter sweep, which automatically performs multiple simulations varying parameters of interest, specifying intervals and steps. Once simulations were complete, results were compared using a graph of the S1.1 reflection coefficient. To improve antenna performance, the arm length (Arm_length) is adjusted so that the reflection peak moves from its initial value (found using the axis marker function, which may not correspond to the correct frequency) to the desired frequency. Among the results, the curve with the peak closest to the desired frequency and minimal attenuation is selected. Arms are then fabricated according to the dimensions corresponding to this curve. The same procedure is applied to the width (Arm_height) for further optimization. Simulations showed that width can remain unchanged, as it does not significantly affect performance.

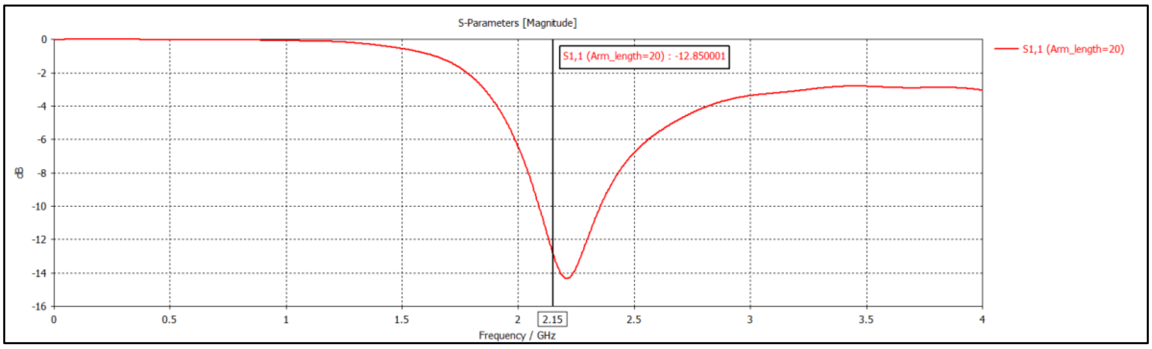

Figure 14: *S1.1 parameter curve with initial arm length.*

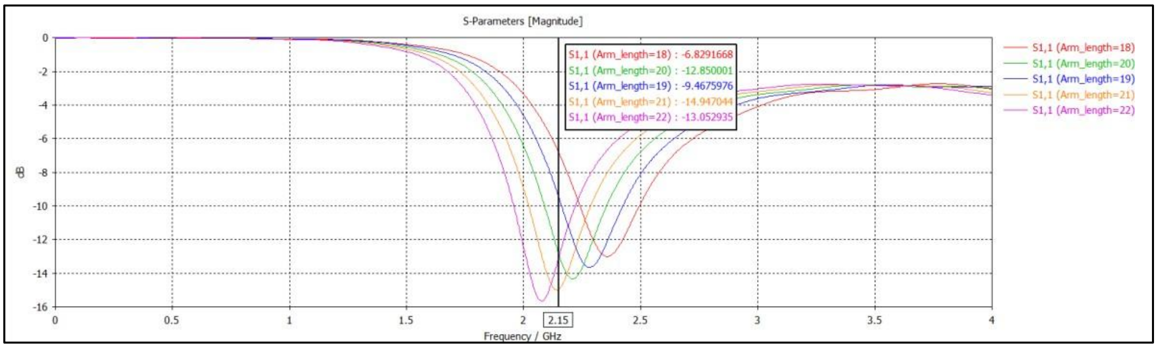

Figure 15: *S1.1 curves after parameter sweep.*

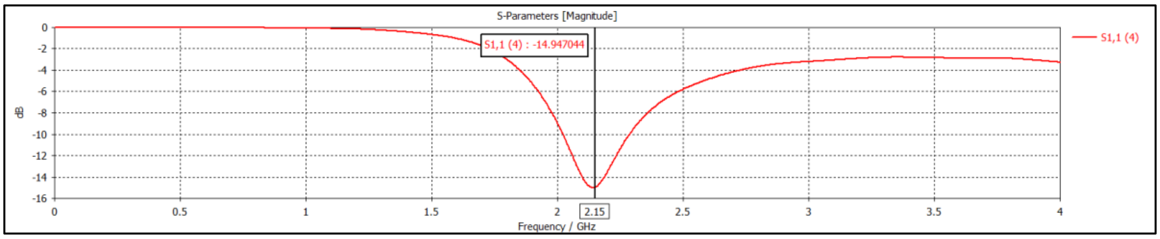

Figure 16: *S1.1 curve with optimized arm length (21 mm) obtained from simulation.*

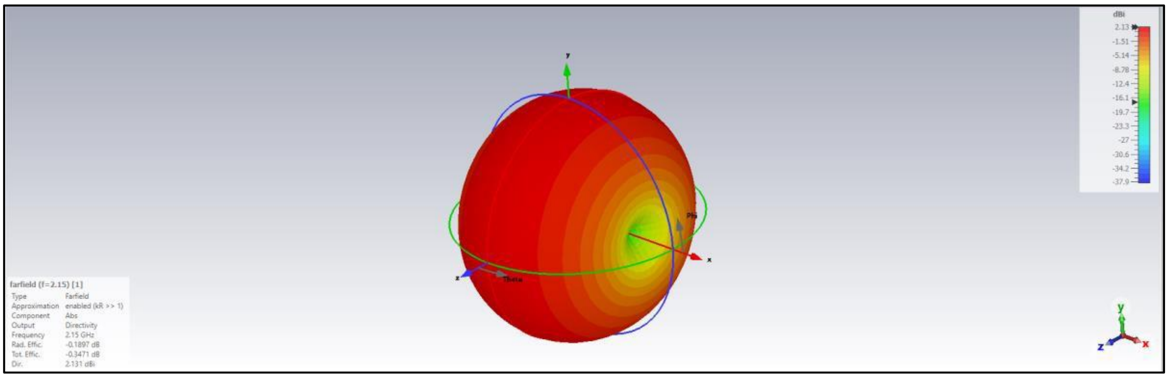

Figure 17: *Antenna far-field pattern.*

4. Practical Construction

To build the dipole, a 73×30×1.54 mm Isola DE104 FR-4 substrate was provided. Using rulers, the arms were drawn on adhesive copper and cut with a cutter. They were then placed on the substrate according to the specified distances. To feed the antenna, the arms were soldered to an SMA female connector. The antenna was tested using a calibrated nanoVNA to verify proper operation.

Parameter List

Name	Expression	Value
length	= 73	73
height	= 30	30
Thickness	= 1	1
Gap_x	= 5	5
Arm_length	= 21	21
Gap_y	= 7	7
Arm_height	= 4	4
Thickness_Arm	= 0.036	0.036
k	= 4.8	4.8

Figure 18: *Antenna dimensions and placement parameters.*

5. Observations

1. The physical antenna does not exactly match simulation values due to manual procedures and non-mechanized tools introducing minor inaccuracies.

2. The substrate initially used FR4 lossy material; creating a material based on datasheet properties did not change results (unlike planar patch antennas).

3. Arm height could be slightly adjusted to fine-tune performance, but this increases construction difficulty due to the small size.

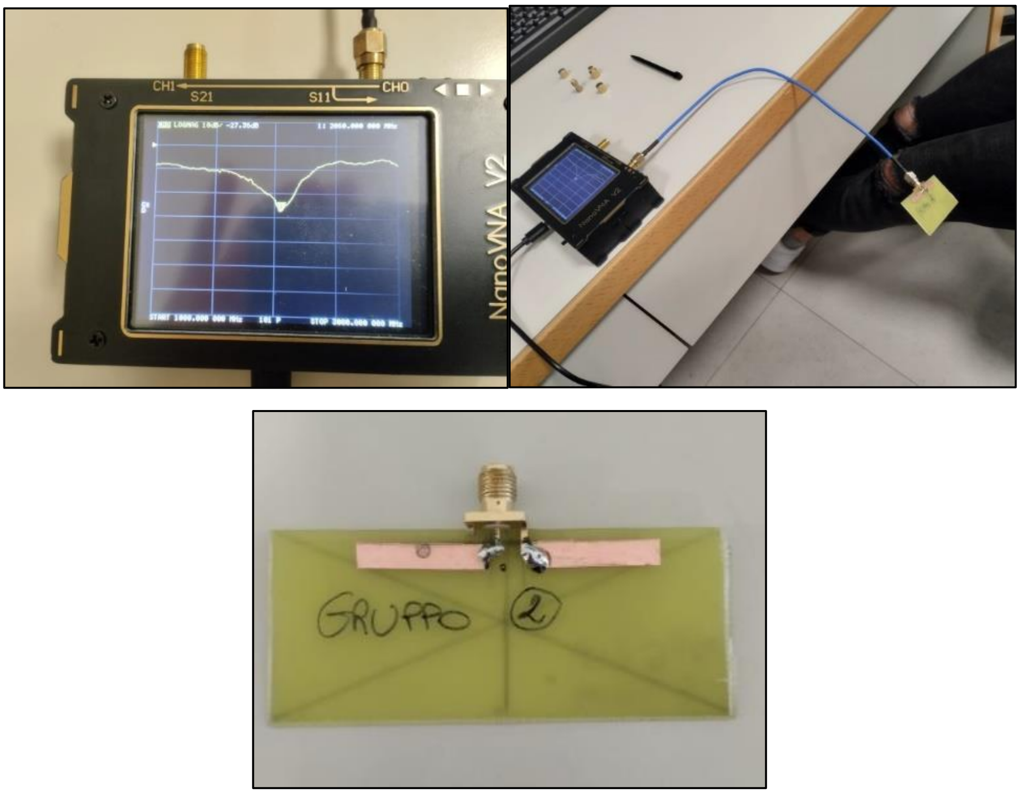

Figure 19: *Physical antenna realization and testing with nanoVNA.*

6. Conclusions

This laboratory experience provided familiarity with the design and fabrication of a planar dipole antenna. CST Studio Suite guided the design, while practical construction using adhesive copper proved effective and accessible. This experience highlights the importance of combining virtual simulations with hands-on experimentation in antenna engineering and telecommunications.