PATCH ANTENNA AND DIRECTIONAL COUPLER DESIGN AND CONSTRUCTION

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

1. Introduction

1.1 Introduction to AWR

AWR is a software designed for the analysis, design, and optimization of antenna systems and wireless devices, widely used to develop and optimize wireless transmission and reception solutions. The software provides an integrated environment to simulate and evaluate antenna and wireless device performance under different operating conditions, enabling the design of efficient, high-performance antennas tailored to specific application requirements. With AWR, detailed analyses can be performed on parameters such as radiation, gain, radiation pattern, impedance, bandwidth, and many others, allowing designers to refine and optimize antenna designs for the best possible performance. Additionally, AWR offers an intuitive user interface and powerful visualization tools, simplifying the design and analysis of antennas and wireless systems.

1.2 Introduction of Directional Coupler

A directional coupler is a fundamental component in radio-frequency (RF) applications, allowing controlled splitting and combining of signals. This device distributes signal energy across multiple channels or combines signals from different sources without significantly compromising overall system performance. The directional coupler operates using passive components such as transmission lines, electromagnetic couplers, and hybrid networks, ensuring efficient signal splitting or combining with minimal power loss. Directional couplers come in various configurations, including microstrip couplers, waveguide couplers, cavity couplers, and hybrid couplers, each offering specific advantages in terms of performance, size, bandwidth, and insertion loss.

In this specific case, two transmission lines were used. This type of coupler has four ports and exploits the coupling effect obtained by bringing two lines close together. The coupling factor indicates the fraction of input power coupled to the output port. Directivity measures the coupler's ability to isolate forward and backward traveling waves (i.e., coupled and uncoupled ports). Isolation measures the power delivered to the uncoupled port.

2. Laboratory Objective

The design process of a directional coupler begins with a detailed analysis of the desired performance specifications. Using the TXLine tool in AWR, simulations are performed to evaluate the coupler's behavior under different operating conditions, optimizing its geometry and characteristics to achieve the desired performance. Iterative simulations allow refinement of the design to maximize efficiency, ensuring that the coupler meets the project's specific requirements. Once design and optimization in AWR are completed, the practical construction phase begins, requiring careful attention to detail to ensure that the final product closely matches the desired specifications.

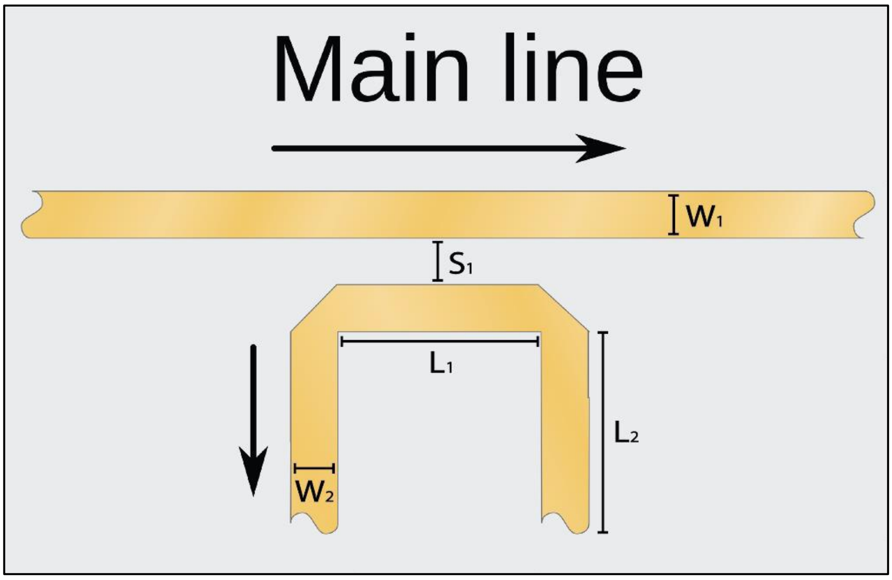


Figure 1: *Schematic of the directional coupler.*

3. Circuit Design

For this laboratory exercise, an ISOLA DE104 substrate (ε_r = 4.35, tan(δ) = 0.023, *Thickness* = 1 mm) was used with an operating frequency of 2.2 GHz. Before implementing the schematic in AWR, the wavelength of the field propagating in the substrate (effective wavelength λ_{eff}, which is smaller than the wavelength in free space) was calculated.

$$\lambda_0 = \frac{c}{f} = \frac{3 * 10^8 \ m/s}{2.2 * \ 10^9 \ Hz} = 0.136 \, m$$

$$\lambda_{eff} = \frac{\lambda_0}{\sqrt{\varepsilon_r}} = \frac{0.136 \ m}{\sqrt{4.35}} = 0.0652 \ m$$

$$L_1 = \frac{\lambda_{eff}}{4} = \frac{0.0652 \ m}{4} = 0.0163 \ m$$

During circuit creation, components were inserted using the electrical function. Parameters were entered in parametric form to allow later modifications and optimizations, declared in Global Definitions via the Equation command.

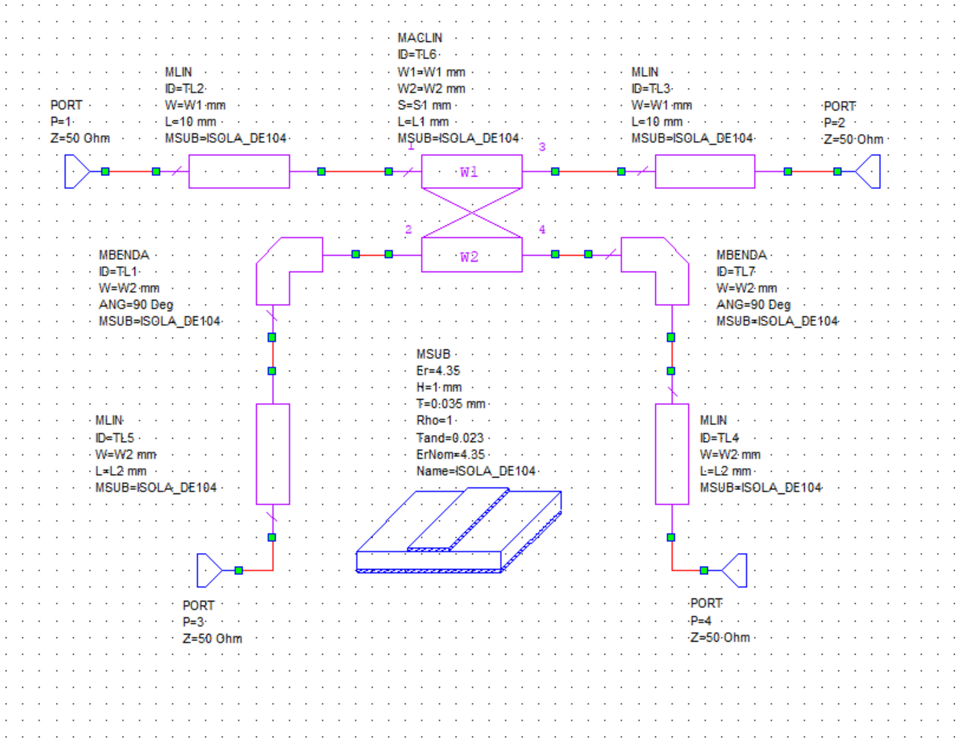


Figure 2: *Directional coupler circuit.*

Four ports were added to the circuit for simulation measurements. The substrate was added according to project specifications. Using the **TXLine** tool, the optimal conductor width (W) was calculated.

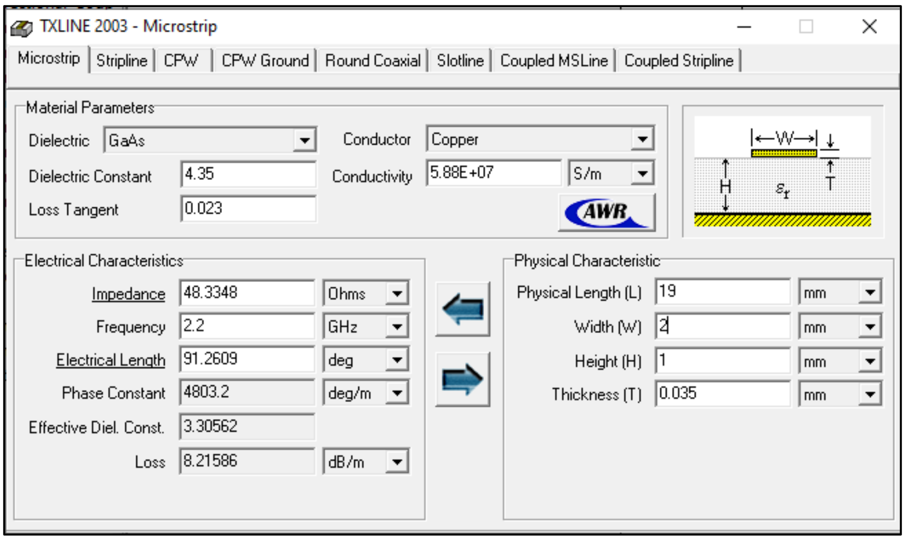


Figure 3: *TXLine tool for W calculation.*

4. Simulation

A new graph was created (Graphs -> New Graph -> Rectangular) and S_{11}, S_{21}, S_{31}, S_{41} parameters were added using Add Measurement. After the first simulation, S_1 was optimized using the Tuner.

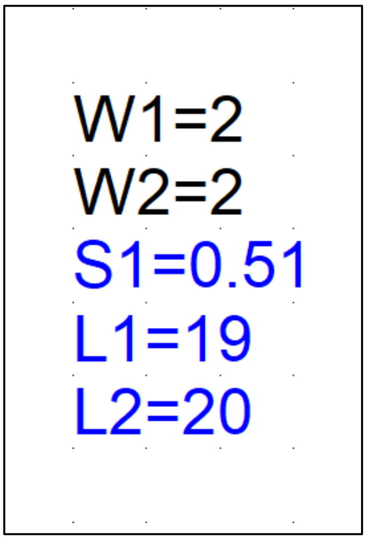


Figure 4: *Optimized parameters.*

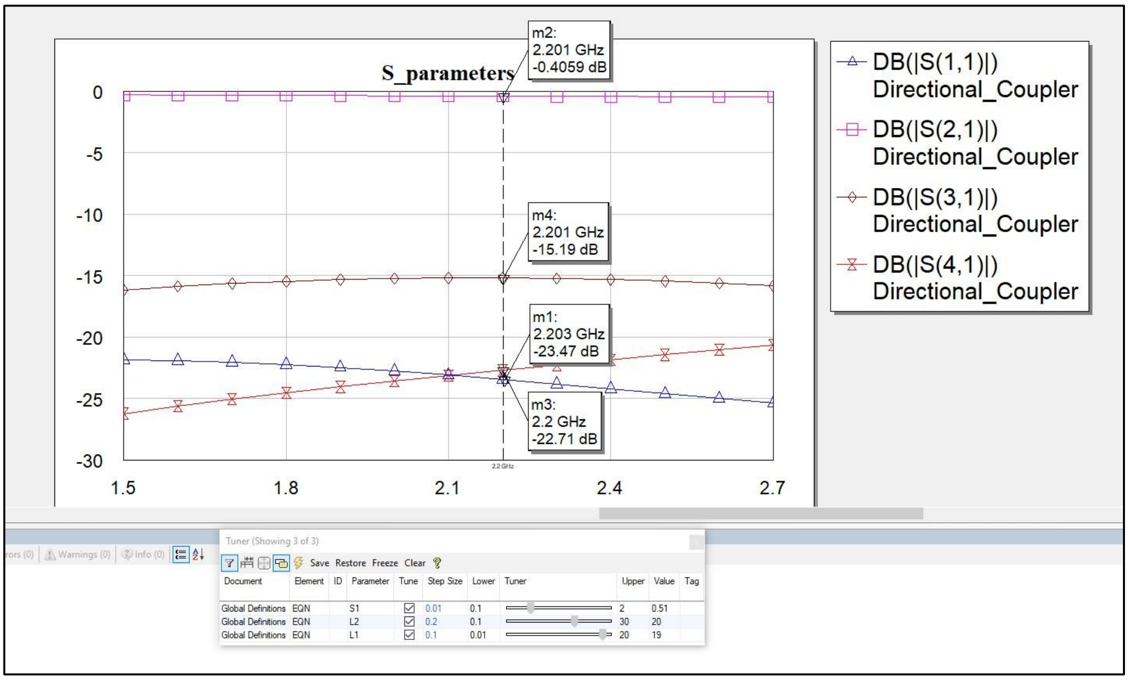


Figure 5: *S-parameters graph.*

A new measurement was then created to analyze the reflected power at each port.

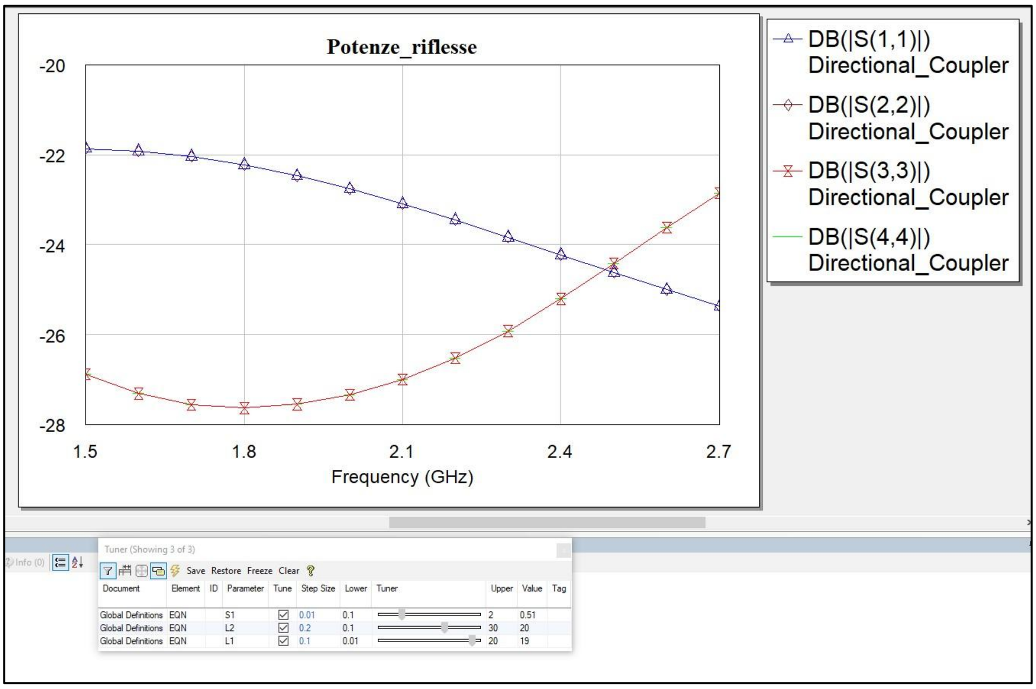


Figure 6: *Reflected power graph of the four ports (S_{11} and S_{22} overlapping; S_{33} and S_{44} overlapping).*

5. Construction

The directional coupler was built on an Isola DE104 FR-4 substrate. Using rulers and a cutter, the ground plane and coupler were cut from a copper sheet, keeping the same substrate dimensions for the ground plane and the calculated dimensions for the coupler.

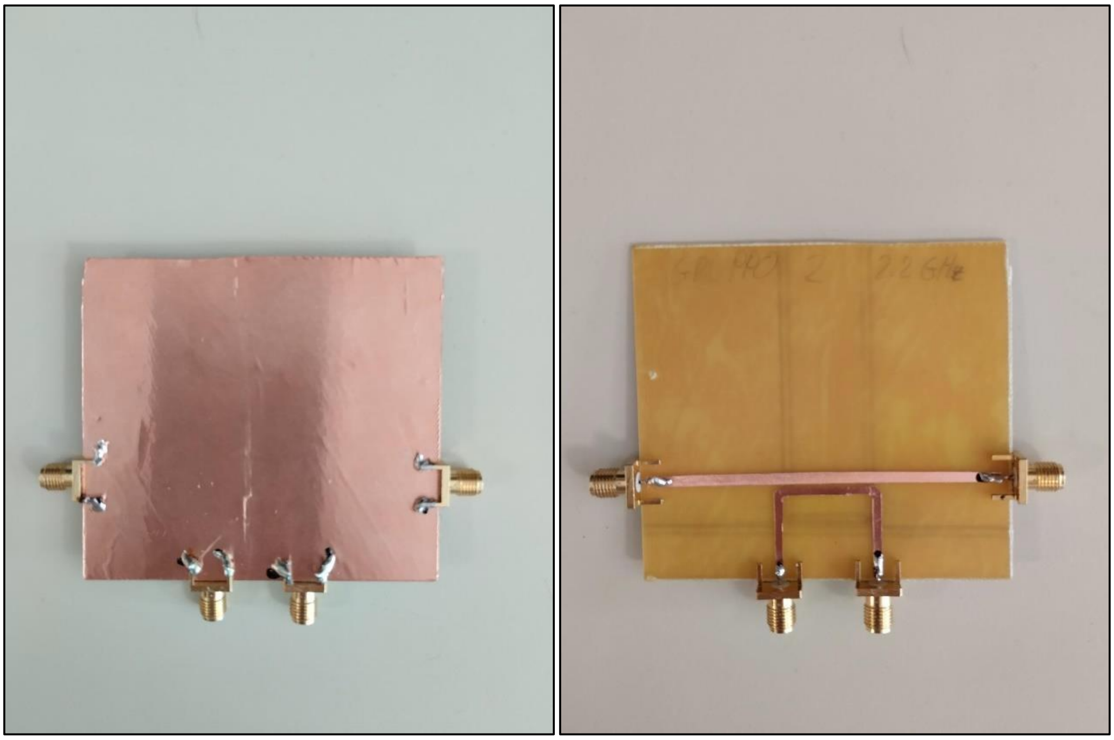
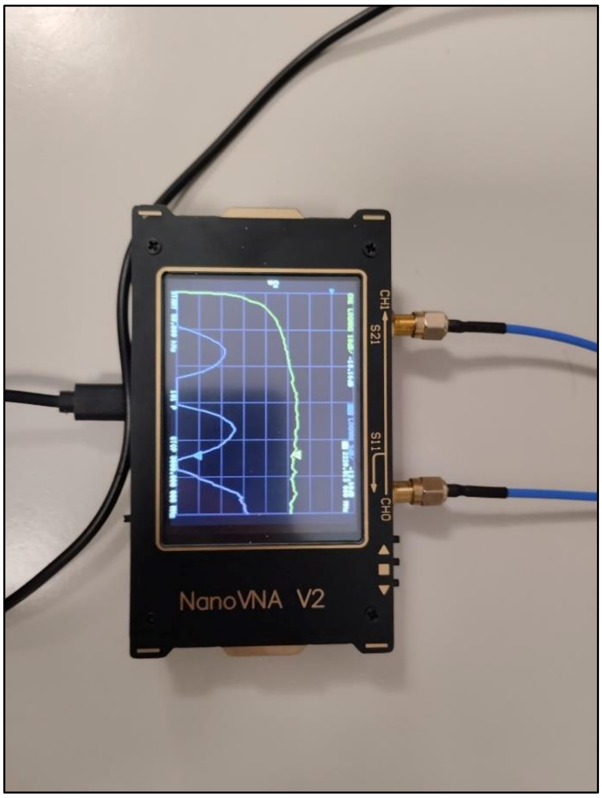


Figure 7: *Directional coupler.*

SMA female connectors were soldered, and measurements were performed using a calibrated nanoVNA.



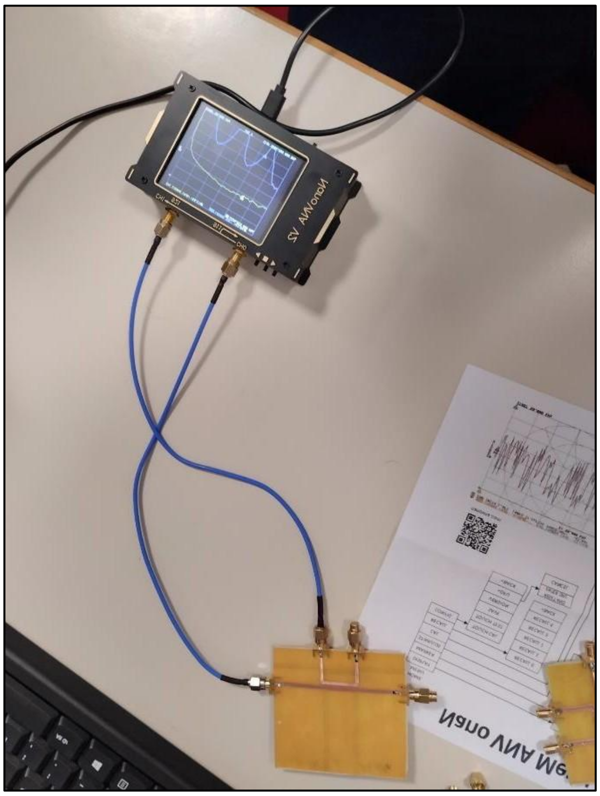


Figure 8: Laboratory measurements.

6. Observations

1. To minimize radiation effects (and thus power loss and interference), sharp corners were avoided by beveling right angles.
2. The length L_2 does not affect coupler characteristics; therefore, the main line was placed toward the substrate edge to avoid interference and copper waste.

3. Conclusions

This laboratory exercise provided valuable insight into the design and construction of a directional coupler. The integrated approach combining AWR simulation and practical construction using adhesive copper proved highly effective. Simulation offered precise guidance during the design phase, allowing exploration of different configurations and performance optimization. The practical phase allowed hands-on evaluation of the proposed solutions. Using adhesive copper facilitated an accessible and cost-effective construction process.