EEE-452: ANTENNA ENGINEERING PROJECT ANALYSIS REPORT

YAGI-UDA ANTENNA

Zeynep Nalçakan (22203100) / Tuna Şahin (22201730) / Berkay Özer (22202119)

Recap of Design Proposal: As a team, we proposed a Yagi-Uda Antenna, a linearly (horizontally) polarized antenna for our term project. We considered two different types of Yagi-Uda Antenna in our proposal, as 3-D and Quasi, to choose one of them during the process and avoid manufacturing and pattern problems that we may encounter. We aim to design the antenna to operate at 3 GHz (wavelength of 10 cm), achieve a matching impedance, and consequently, $|S_{11}| < -10$ dB, with an expected HPBW of 40–60°. The 3-D method is expected to have a maximum directivity of 8-10 dBi. The quasi method is expected to have a maximum directivity of 3-5 dBi. We will use a 50Ω SMA connector and a 6-element topology.

Design Process and Obtained Results: We designed the two Yagi-Uda configurations mentioned above using CST.

- **Quasi Yagi-Uda Design Process**

Firstly, the Quasi Yagi-Uda is designed on CST, following the dimensions and optimisations used by Berkay Atabay [1]. After the pattern was obtained in a similar shape to the expected results of Atabay [1],[2], the next step in the design process was matching. The resonant frequency is found to be dependent mostly on the driver length. Therefore, the driver length was optimised to bring the resonant frequency to 3 GHz. As explained in the proposal, we expected a directivity of 3-5 dBi and an HPBW of 40-60 degrees. We obtained a directivity of 5.3 dBi, and the HPBWs are found to be 60° and 150°. The final design features 1 reflector, 1 driven element, and 5 directors. Overall, we used a 7-element topology, as opposed to the proposed 6-element topology.

- **3-D Yagi-Uda Design Process**

Firstly, the 3-D Yagi-Uda antenna is designed on CST, following the instructions given in NBS Technical Notes [3]. This design has 6 elements, namely: 1 reflector, 1 driven element (dipole) and 4 directors as previously mentioned in the proposal. After acquiring the pattern cuts as the same as the NBS Technical notes, by using optimizer and parameter sweep techniques, the matching was done [3]. Therefore, the driver length was optimised to bring the resonant frequency to 3 GHz. As explained in the proposal, we expected a directivity of 8-10 dBi and an HPBW of 40-60 degrees. We have acquired a -18.15 dB matching at 3 GHz. The resonant frequency is mostly dependent on the driver length. But the parasitic effects of the Yagi-Uda shift the frequency to the left, i.e, to lower frequencies. To compensate for this, the wavelength was decreased, changing the overall dimensions, to get a better matching at 3 GHz. The directivity of the antenna is found to be 11.6 dBi, which is slightly higher than expected. This is due to the fact that we have used PEC for simulating the antenna's behavior. The HPBWs are found to be at 44.2°, and 51.8°.

Bill of Materials (BoM): The following materials are planned for use in the manufacturing process.

Method 1: 3-D Antenna

1) Director, Reflector, Driven Elements
- Bicycle wheel spokes (Aluminum)
- Umbrella frames
- Clothes hanger

2) Boom
- Wand-like cat toy (broken)
- Wooden plate from old projects

Method 2: Quasi Antenna

1) Director, Reflector, Driven Elements
- Milk box
- Metal beverage can
- Aluminium foil from old projects

2) Boom
- Old cardboard box
- Cellulose acetate sheets from old spiral notebooks

Simulation Results of Proposed Design:

- **Quasi Yagi-Uda Simulations**

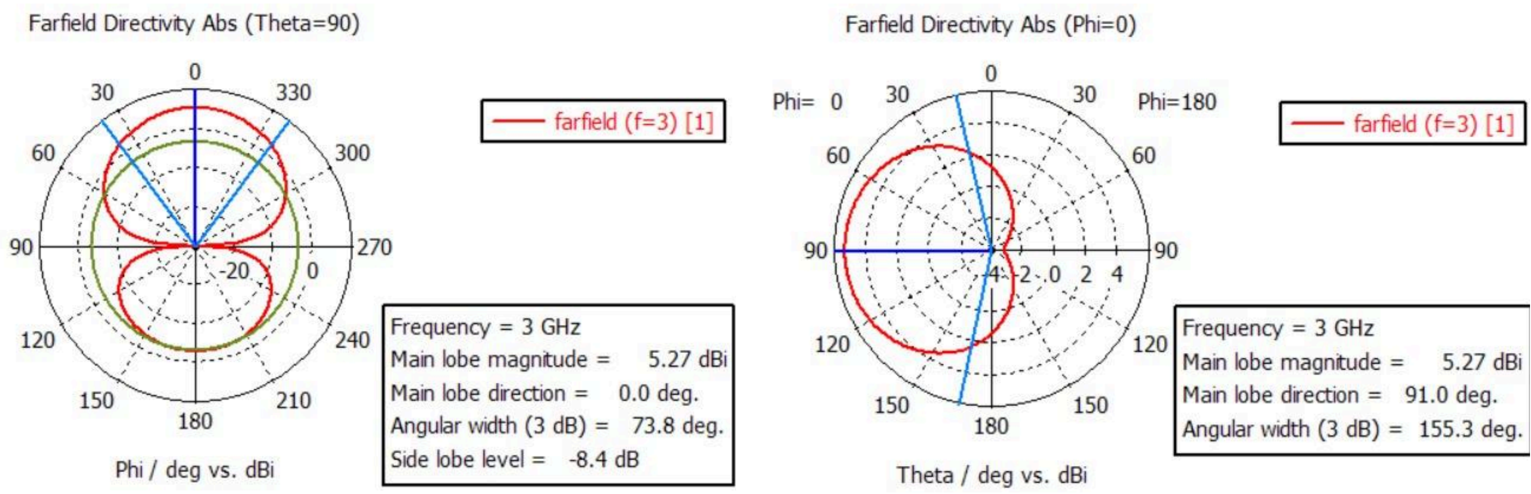


Figure 1.1: Field Patterns of Quasi Yagi-Uda

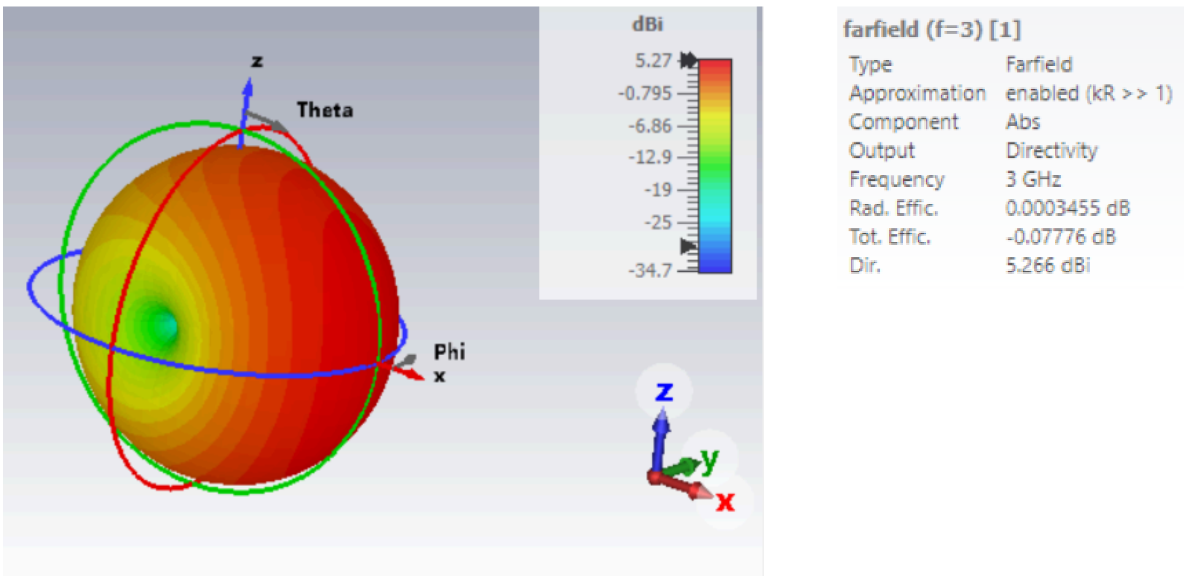


Figure 1.2: Directivity of Quasi Yagi-Uda

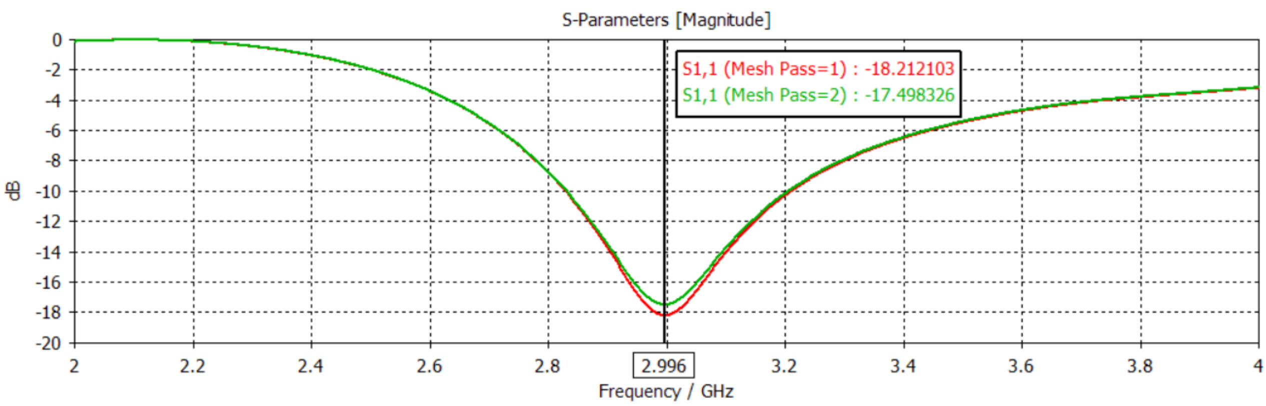


Figure 1.3: S_{11} parameter of Quasi Yagi-Uda

- **3-D Yagi-Uda Simulations**

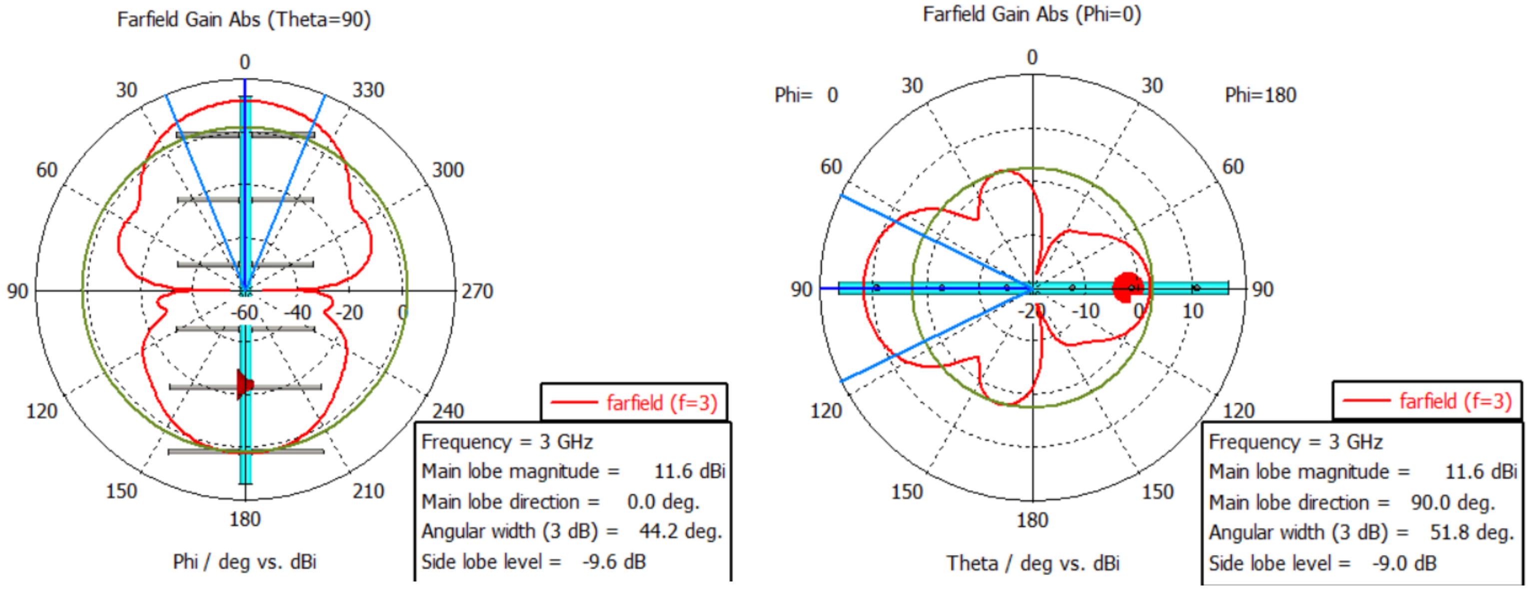


Figure 2.1: Field Patterns of 3-D Yagi-Uda

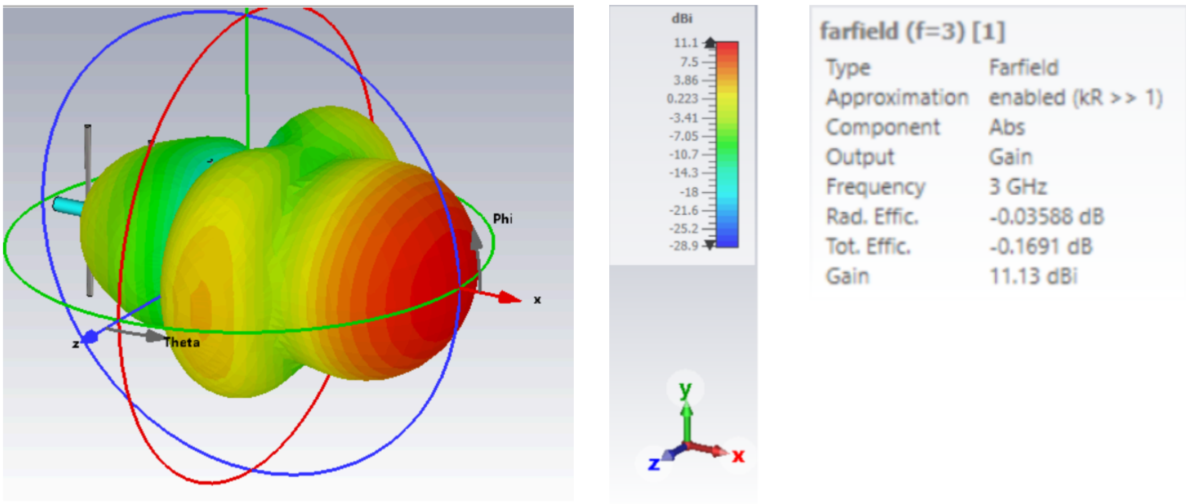


Figure 2.2: Directivity of 3-D Yagi-Uda

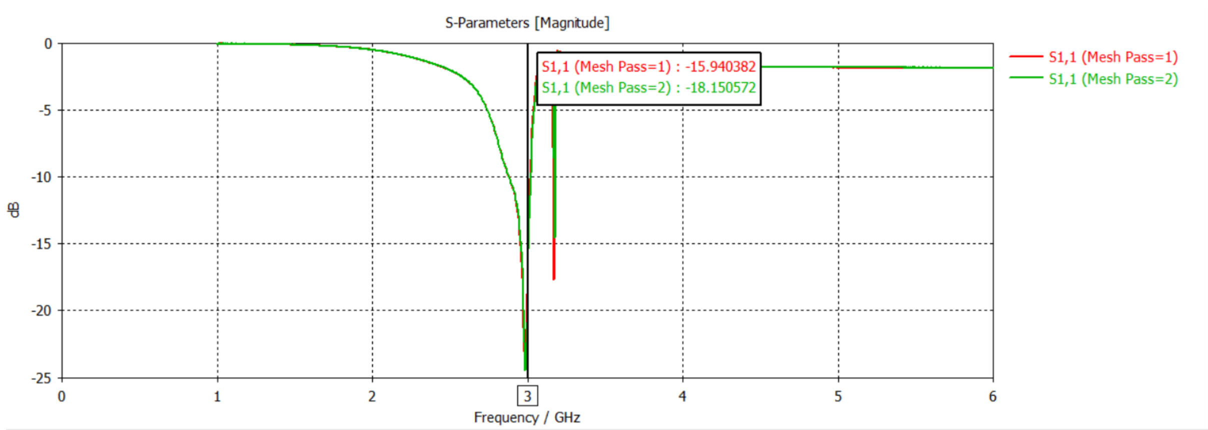


Figure 2.3: S_{11} parameter of 3-D Yagi Uda

Simulation Parameters, Dimensions, and Material Properties:

- **Quasi Yagi-Uda Simulation Parameters:**

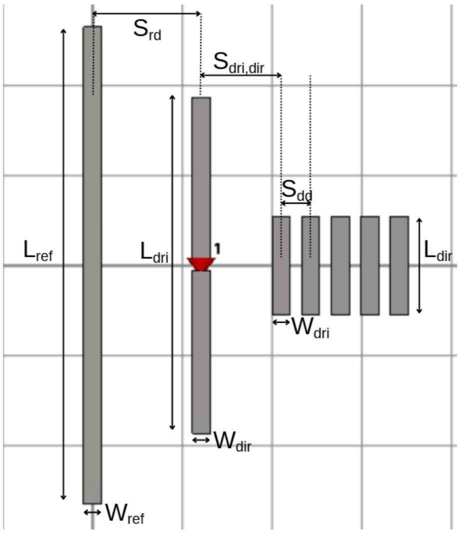
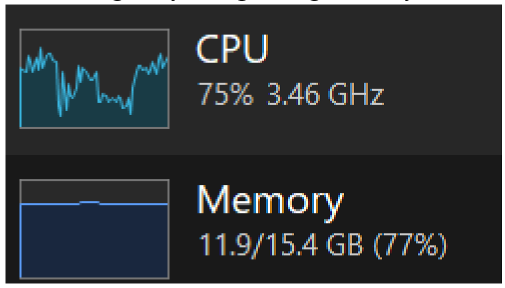
Geometry of the Antenna	Dimensions	Simulation Parameters
	$\lambda = 100mm$ $S_{rd} = 0.121\lambda$ $S_{dri,dir} = 0.089\lambda$ $S_{dir,dir} = 0.033\lambda$ $L_{ref} = 0.53\lambda$ $L_{dri} = 0.37\lambda$ $L_{dir} = 0.11\lambda$ $W_{dir} = 0.02\lambda$ $W_{ref} = 0.02\lambda$ $W_{dri} = 0.02\lambda$ Thickness = 0.01λ $\epsilon_{r,dielectric} = 2.7$	- Adaptive Mesh Refinement - [2,4]GHz Frequency Range - %75 CPU, %80 RAM(16GB) Usage - 340k Meshes - 148 seconds run time for meshing and simulating only the given geometry. 

Figure 3.1: Quasi Yagi-Uda Parameters

- **3-D Yagi-Uda Simulation Parameters:**

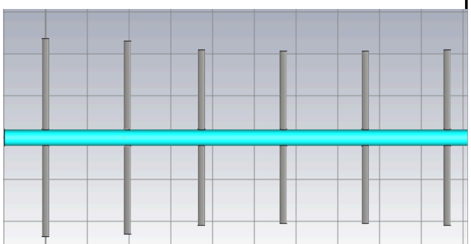
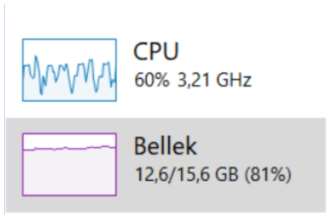
Geometry of the Antenna	Dimensions		Simulation Parameters
	$S_{rd} = 0.2\lambda$ $S_{dri,dir} = 0.18\lambda$ $S_{dir,dir} = 0.2\lambda$ $L_{ref} = 0.482\lambda$ $L_{dri} = 0.471\lambda$ $L_{dir1,4} = 0.428\lambda$	$\lambda = 98mm$ $L_{dir2,3} = 0.420\lambda$ $D_{dir} = 0.0085\lambda$ $D_{ref} = 0.0085\lambda$ $D_{dri} = 0.0085\lambda$ $\epsilon_{r,boom} = 1.74$	-Adaptive Mesh Refinement -[1,6]GHz Frequency Range -%60 CPU, %81 RAM (16GB) Usage -387k Meshes -15 minutes and 32 seconds run time for simulation and meshing. 

Figure 3.2: 3-D Yagi-Uda Parameters

EEE-452: ANTENNA ENGINEERING FINAL REPORT
YAGI UDA ANTENNA DESIGN

Tuna Şahin (22201730) | Berkay Özer (22202119) | Zeynep Nalçakan (22203100)

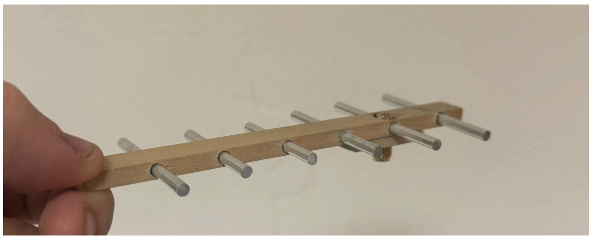


Figure 1: Antenna's Hardware Implementation

1. Recap of the Project:

As a team, we proposed implementing a Yagi-Uda antenna for our term project, as it would be easier to access recycled materials. Additionally, we considered that tuning the antenna can be achieved by adjusting the length of the conducting rods, which allows us to make adjustments without redesigning the antenna from scratch, which made this choice viable. Our group researched and simulated two different types of Yagi-Uda antennas: conventional and quasi-Yagi-Uda antennas. Comparing the S_{11} values, we believed it would be easier to match the conventional Yagi-Uda, as it has a much lower S_{11} value and features a narrower bandwidth. We expected the quality factor to drop in the hardware implementation due to the lossy nature of the components, which will result in a wider band and a lower S_{11} value. The conventional Yagi-Uda design offers a greater margin for error. Therefore, in the hardware implementation, we decided to implement a conventional Yagi-Uda.

Manufacturing Process and Bill of Materials (BOM):

- A short wooden stick was repurposed from scraps of old projects and used as the boom of the antenna.
- For the conductive elements, an aluminum rod with a diameter of roughly 3mm was used, which was obtained from broken camping tents.
- The SMA connectors were provided by Ufuk Tufan at EE-102, Bilkent.

Since all of the materials were acquired from scraps, the project cost is 0₺.

The dimensions of these newly acquired items (i.e., the radius of the aluminum rod and the dimensions of the boom) were entered into CST to compensate for the changes. The dimensions of the remaining components were scaled by a factor of 0.96. The diameter of the elements was reduced from 4 to 3. The elements were cut using a handsaw and inserted into holes on the boom, which were cut using a hand drill. The antenna is visible in Figures 1 and 2.2.

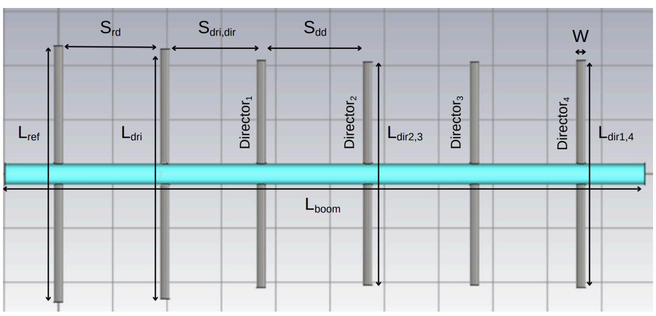


Figure 2.1: Antenna's Design

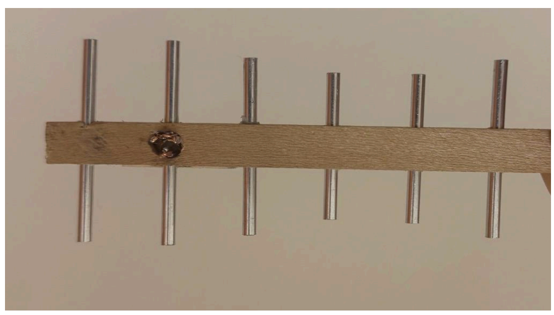


Figure 2.2: Antenna's Hardware

$\lambda = 94mm$	$\epsilon_{r,boom} = 1.74$	$W_{ref} = W_{dir} = W_{dri} = 3\text{mm}$		$L_{boom} = 1.1\lambda$	$L_{dir2,3} = 0.420\lambda$
$S_{rd} = 0.2\lambda$	$S_{dir,dir} = 0.2\lambda$	$L_{dir1,4} = 0.428\lambda$	$L_{dri} = 0.471\lambda$	$L_{ref} = 0.482\lambda$	$S_{dri,dir} = 0.18\lambda$

Table 1: Dimensions of the antenna

	Simulation	Physical Implementation
Boom	Wood $\epsilon_r = 1.74$	Wood
Conductive Elements	Aluminium	Aluminium

Table 2: Materials of Antennas

2. Further Simulation Results:

The E and H planes were determined. The H-plane is the plane bisecting the antenna. The E-plane is the plane where the elements are located.

The cross-polarization and co-polarization of the antenna were also measured in addition to the results in the analysis report.

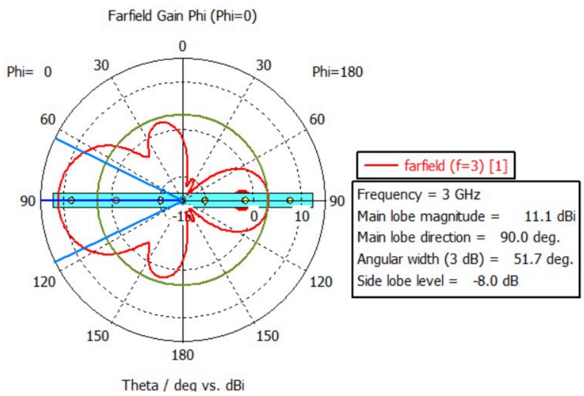


Figure 2.1.1: Co-Polarization (H plane)

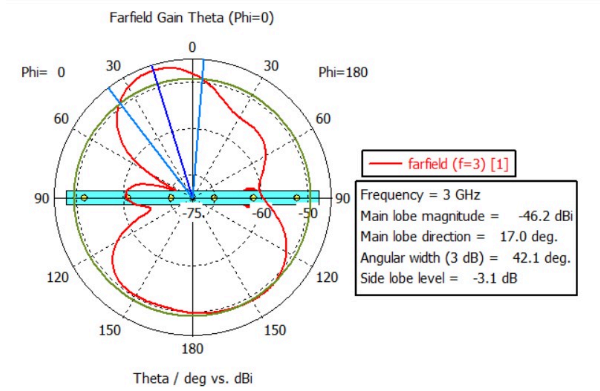


Figure 2.1.2: Cross-Polarization (H plane)

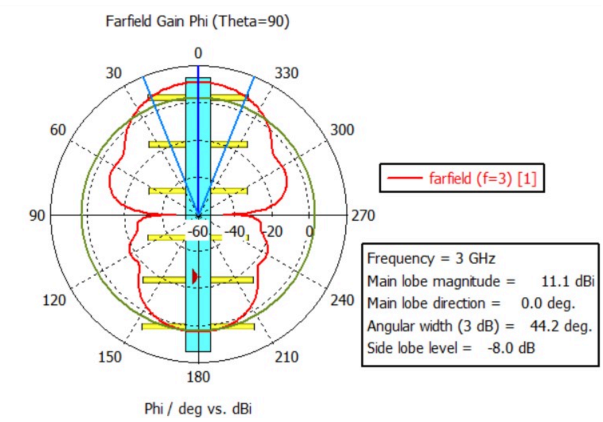


Figure 2.2.1: Co-Polarization (E plane)

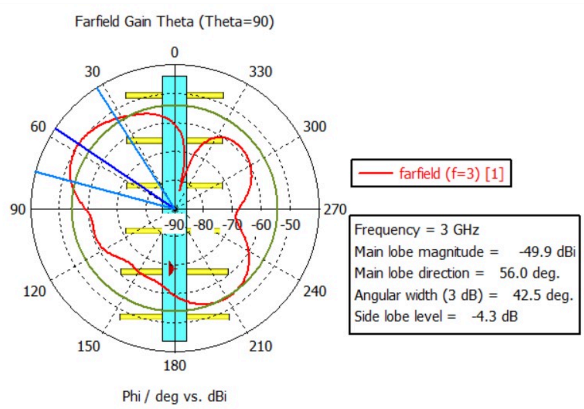


Figure 2.2.2: Cross-Polarization (E plane)

3. **Experimental Results and Procedure:**

The matching was adjusted by scaling the elements and changing the dielectric constant of the boom. The resulting S_{11} results were obtained after tuning the antenna to 3GHz. For the S_{11} measurements, the VNA in EEE 315 was used. The calibration of the network analyzer was achieved by opening the file:

"D:\sobhan\300KHZ_4GHZ_10KHZ_2PORT_ECAL.-S11=S21STA.STA"

Then the S_{11} measurement was obtained, and when compared with the simulation results, it is observed that the S_{11} got broader due to the increasing loss in the hardware implementation, which decreases the quality factor (Q), as expected.

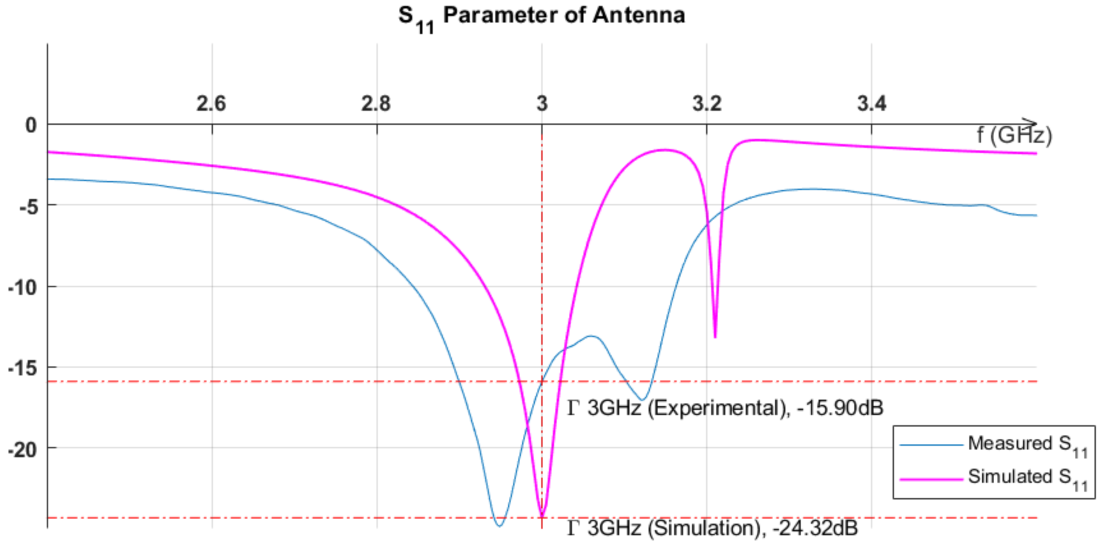


Figure 3.1: Experimental S_{11} Measurements

After the impedance measurement, the antenna's pattern was measured at METEKSAN Defence's facilities. The measurements were performed in an anechoic chamber using near-field measurement methods. AUT was used as a receiver antenna, and as a transmitting antenna, a wide-band (1-20 GHz) ridged horn antenna was used. The system was calibrated using a horn antenna whose gain is known, and the gain of the measured antennas was determined by comparing the amplitude with that of the calibration horn antenna (gain comparison method). The distance between the antennas was set to be 1m, and the AUT was mounted on a plastic bracket on a rotator. Pattern measurements were completed in approximately 12 minutes. The following measurements were obtained.

	E-Plane HBPW (degrees)	H-Plane HBPW (degrees)	Maximum Directivity (dBi)	Radiation Efficiency (dB)	Θ_{max} (degrees)	ϕ_{max} (degrees)	SLL E-Plane (dB)	SLL H-plane (dB)
Experimental 2.9GHz	33.75	51.32	12.651	-3.5	-11	-0.74	-11	-8.5
Experimental 3GHz	52.73	52.73	11.49	-3	-11	-1	-9.6	-9
Experimental 3.1GHz	46.40	57.65	11.51	-3.9	-10	0.7	-7.6	NaN
Simulated 3GHz	44.2	51.8	11.6	-0.5	0	0	-9.6	-9
Theoretical Expectations	30-55	40-60	10-11	~	0	0	~	~

The simulation used lossy materials to make the simulation as close to the physical implementation as possible.

Table 3: Simulated and Measured Antenna Parameters

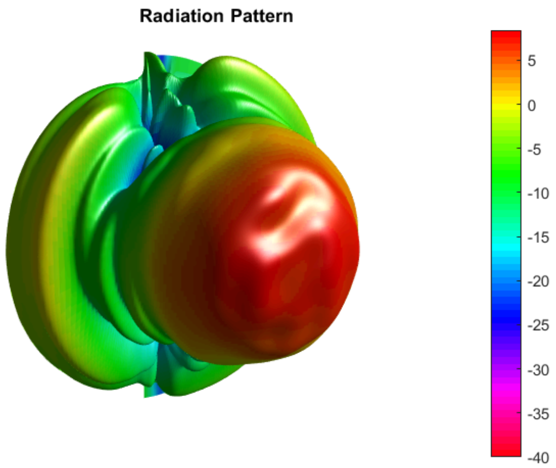


Figure 3.2.1: Measurement of Antenna's 3D Pattern at 3GHz

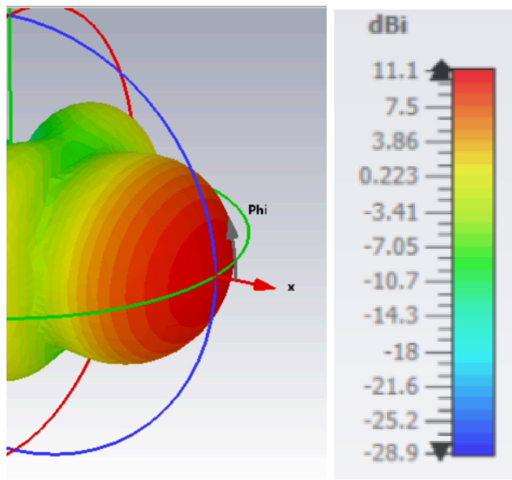


Figure 3.2.2: Simulation of Antenna's 3D Pattern at 3GHz

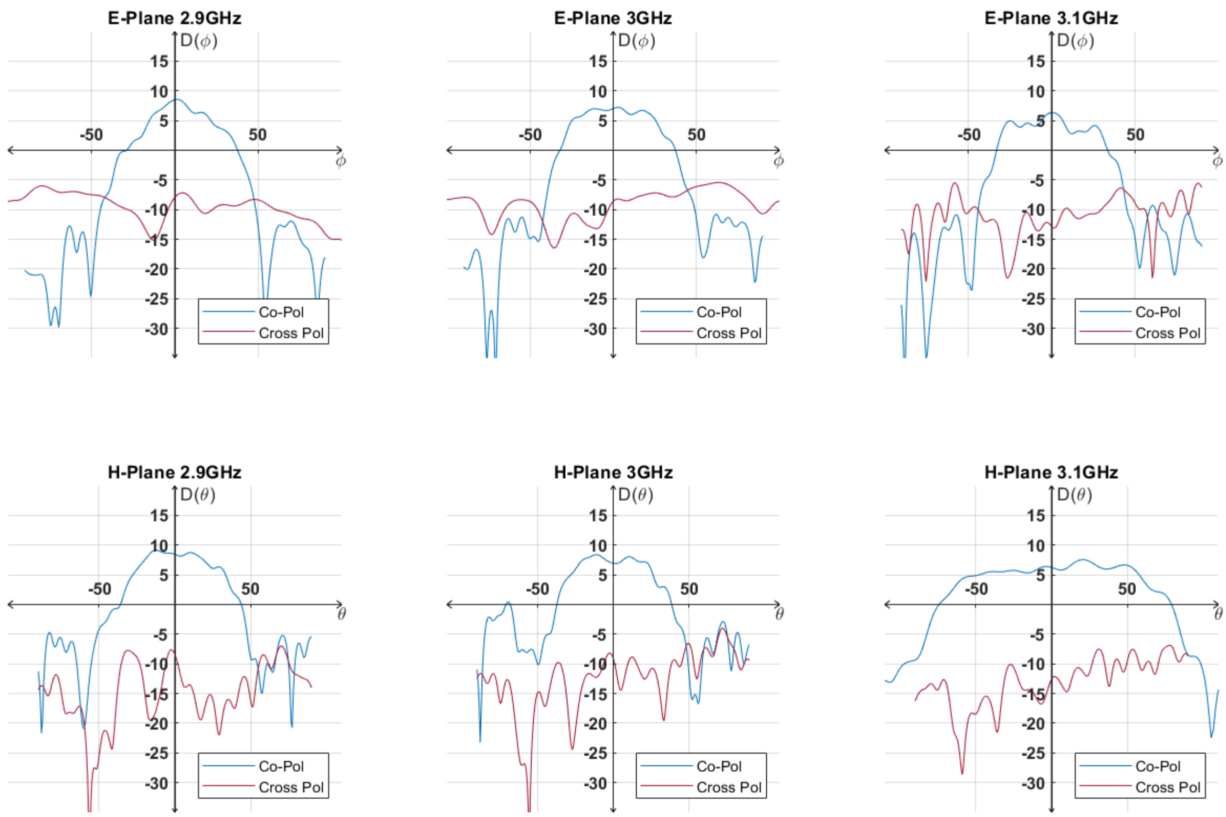


Figure 3.3: Cross and Co-Polarization Gain Patterns for Different Frequencies

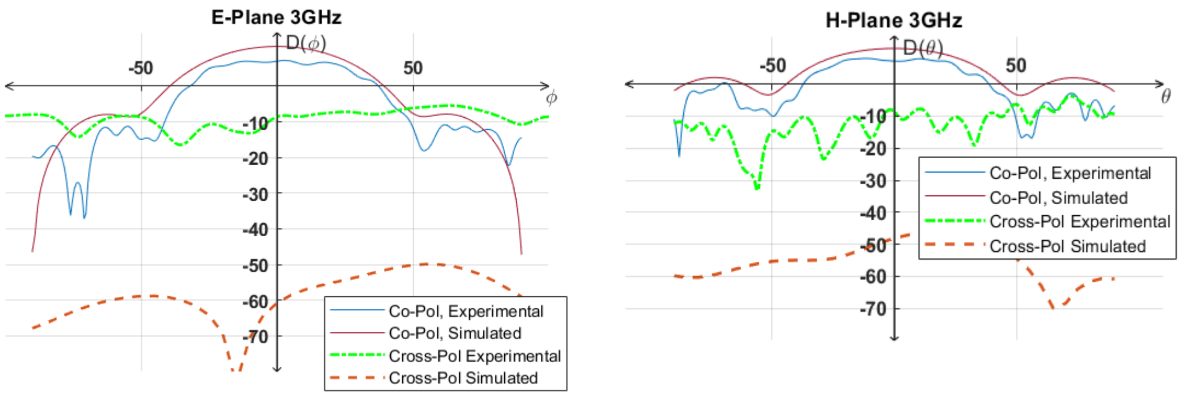


Figure 3.4: Cross and Co-Polarization Comparison at 3GHz

4. Conclusion

- The experimental results generally align with the simulation results. Values for SLL, HPBW, directivity, co-polarized pattern, and S_{11} parameter all align with the simulations, with a slight shift in the resonance frequency for the S_{11} parameter.

- The measurement only measured azimuth values in the range of [-90, 90]. This angle covers half of the solid angle 4π, which underestimates the value of P_{rad} when calculating the directivity. Therefore, this leads to higher directivity and worse radiation efficiency, which account for the discrepancy between directivity and gain. This effect is especially present when the AUT features a significant backlobe, which is the case for our Yagi-Uda. So the actual directivity is lower, and the efficiency is higher than the measured value.

- The direction of maximum radiation was shifted by 10° in the elevation plane. This is due to the dielectrics used to mount the antenna and the additional wooden piece that is used to mechanically reinforce the feeding network.

- Radiation efficiency dropped significantly compared to the simulation, even when the simulation used lossy components. This drop may be due to feedline loss or loss at the connection between the dipole and the SMA connector.

- The measured cross-polarized pattern was much higher than the simulated pattern. One reason for this is the reflections from the backlobe, which causes co-pol leakage, considering the simulated backlobe of the antenna was significant. Also, the finite polarization purity of the receiver antenna will make accurate measurements difficult. Another reason is the possible misalignment of the antennas during installation, which may cause co-polarized leakage. The noise floor will also be significant when measuring values around -70dBi.

REFERENCES:

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Tissues," Applied Sciences, May 2023. [Online]. Available: https://www.mdpi.com/2076-3417/13/11/6678

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[4] C. A. Balanis, *Antenna Theory: Analysis and Design*, 2nd ed. New York, NY, USA: John Wiley & Sons, 1997.

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