Electromagnetic Fields and Waves II (CIE 338) - Spring 2024

A Hexa-Band Quad-Circular-Polarization Slotted Patch Antenna for 5G, GPS, WLAN, LTE, and Radio Navigation Applications

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Contents

1 Introduction

The aim of this project is to replicate and refine a patch antenna system within CST, based on the optimization strategies outlined in the reference paper. we will primarily attempt to optimize the patch antenna to excite specific modes—TM100, TM110, TM210, and TM220—at frequencies of 0.7, 1.17, 1.57, and 2.4 GHz, respectively, using a single microstrip line for feeding. Outside of antenna engineering, the significance of this work lies in the integration of CP operation within GPS bands, mitigating multipath interference, eliminating polarization mismatch losses, and reducing sensitivity to transmitter/receiver angle discrepancies. In summary, this study contributes to the advancement of antenna design principles, particularly in the context of GPS technology integration.

2 Design Considerations and basic theory

The proposed antenna structure leverages a hexa-band quad-circular-polarization (CP) design, offering versatility across various communication standards. As illustrated in the figures bellow. The antenna comprises a radiating slotted patch antenna fed by a microstrip line. The patch antenna, printed on stacked FR4 substrates, features an inverted s-shaped slot etched into the metal to induce CP operation.

2.1 Resonant Modes Analysis

The patch antenna resonates at LTE, GPS L5/L1, and WLAN bands, namely 0.7, 1.17, 1.57, and 2.4 GHz. The resonance frequencies $f_{r,mnp}$ of the generated modes within the patch antenna are derived from the cavity model, where m, n, and p denote the mode orders, and dx, dy, and dz represent the antenna dimensions. Through fine-tuning using CST MWS, the dimensions are adjusted to achieve resonances at desired frequencies.

Hybrid modes can be excited within the microstrip line when its thickness approaches the guided wavelength. These hybrid modes, designated as EH_n, represent a superposition of TE and TM modes. For the given microstrip line dimensions, three hybrid modes $EH1$, $EH3$, and $EH4$ resonate at 1.3, 3.18, and 3.5 GHz, respectively.

2.2 Performance Evaluation

Simulation results, illustrated in Fig. 2, depict the magnetic field distributions of various resonant modes, including $TM110$, $TM210$, $EH1$, $EH3$, and $EH4$. Additionally, the $S11$ performance of the microstrip line, excluding the patch antenna part, is evaluated to demonstrate the performance of the hybrid modes.

2.3 Design Specifications

The proposed antenna design offers advantages over traditional approaches, including quad-band CP operation across six frequency bands, simplified fabrication using printed circuit board technology, and elimination of external feeding or power divider networks. These attributes position the antenna as a competitive solution for diverse communication standards and applications. After completing the design in CST, the Gerber files were sent for fabrication Figure 1.

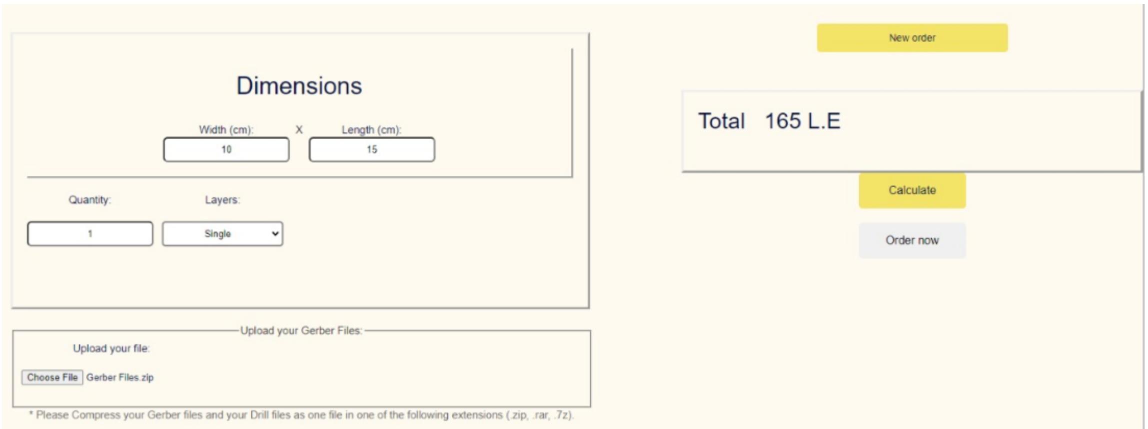


Figure 1: Fabrication Price

> ”For a microstrip line with a metal area of $3.95 \times 19.89\,\text{mm}^2$ and substrate volume of $150 \times 100 \times 19.2\,\text{mm}^3$, three hybrid modes EH1, EH3, and EH4 resonate at frequencies of 1.3, 3.18, and 3.5 GHz, respectively” [1].

Additionally, the dimensions of the antenna structure include:

- Upper substrate volume: $150 \times 100 \times 11.2\,\text{mm}^3$
- Lower substrate volume: $150 \times 100 \times 19.2\,\text{mm}^3$
- Patch metal area: $116.4 \times 83.9\,\text{mm}^2$
- Microstrip line metal area: $3.95 \times 19.89\,\text{mm}^2$
- Microstrip line center distance from the right edge of the lower substrate: 64.08 mm
- Length AB: 106.69 mm
- Length AC: 15.48 mm
- Length CE: 91.2 mm
- Length DE: 3.64 mm
- Slot rotation angle: 300.4° starting from the x-axis [1].

3 Validation and Simulation Results

Figure 2 illustrates the design layout, while Figures 4, 5, 6, and 7 showcase the far-field radiation patterns at different frequencies of 0.7 GHz, 1.17 GHz, 1.57 GHz, and 2.4 GHz respectively. The gain-frequency response is depicted in Figure 8, and a GrebView representation is provided in Figure 3. Additionally, Figures 10a, 11a, 12a, 13a, and 14a present various stages of the project with both GIF and PNG formats for each. The realized gain-frequency characteristics are depicted in Figure 9, while the S11 parameter response is captured in Figure 15a.

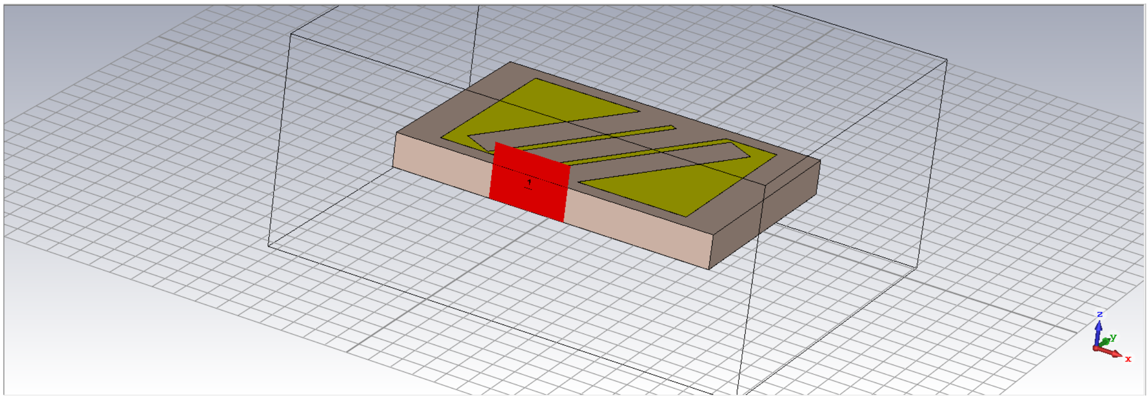


Figure 2: Design Layout

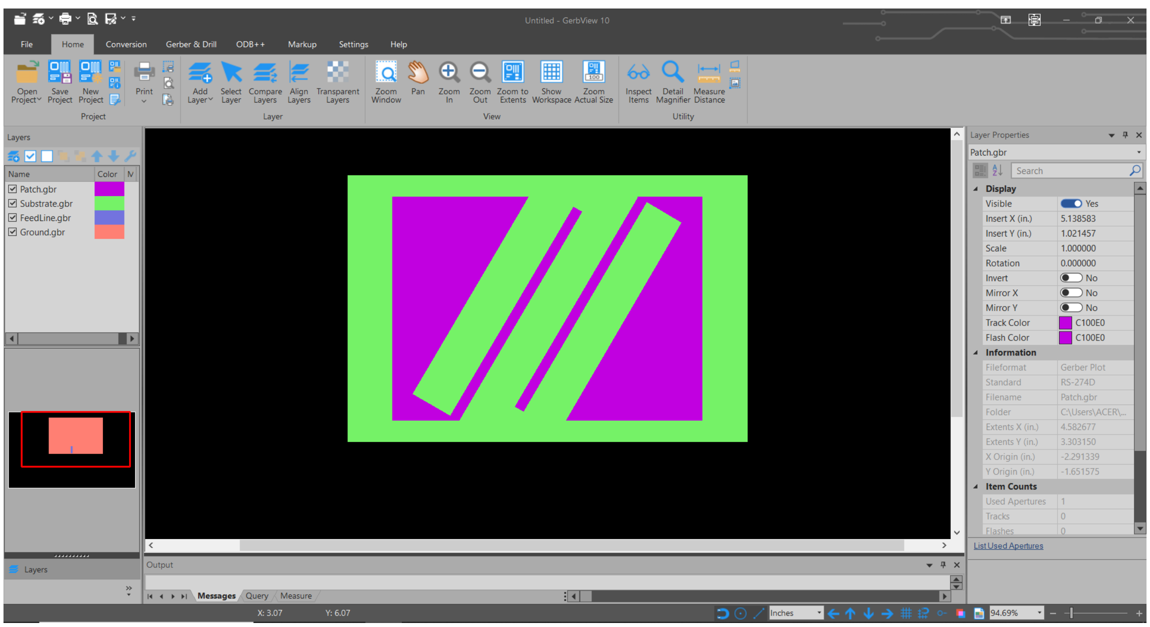


Figure 3: GrebView Representation

3.1 FarField Simulations

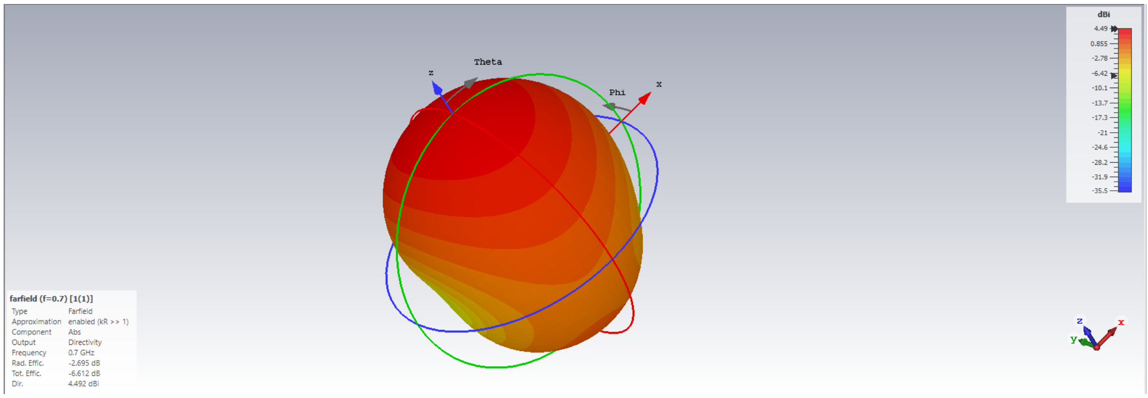


Figure 4: Far-Field Radiation Pattern at 0.7 GHz

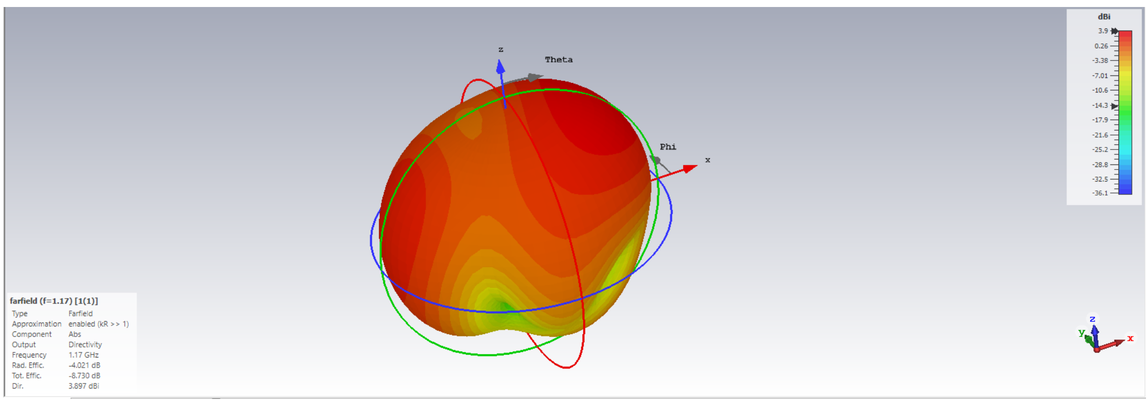


Figure 5: Far-Field Radiation Pattern at 1.17 GHz

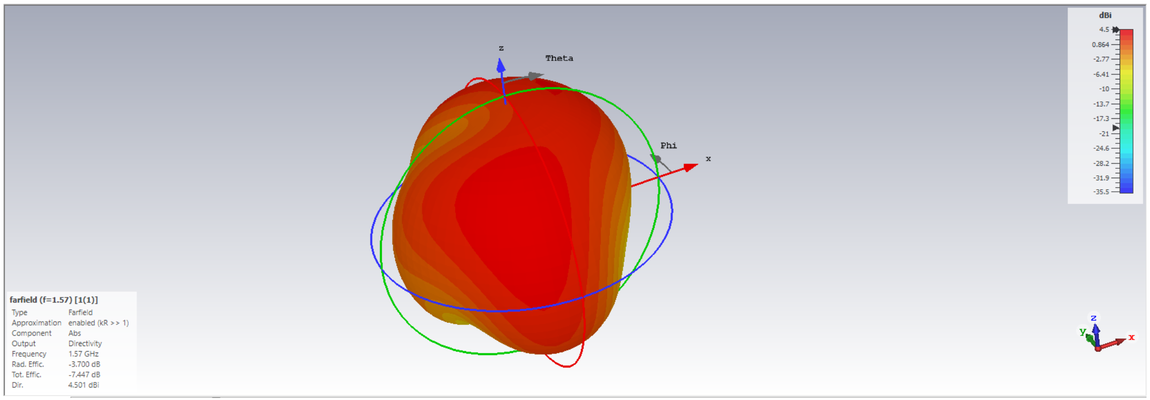


Figure 6: Far-Field Radiation Pattern at 1.57 GHz

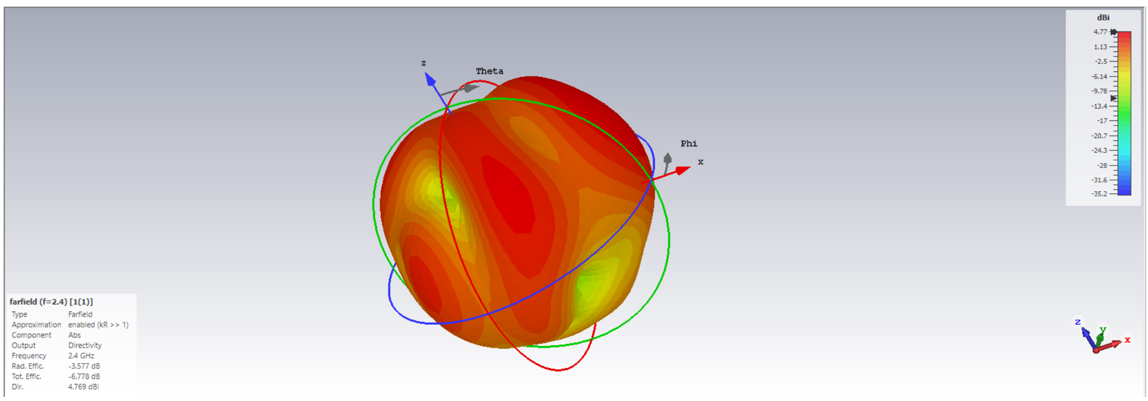


Figure 7: Far-Field Radiation Pattern at 2.4 GHz

3.2 Gain Simulations

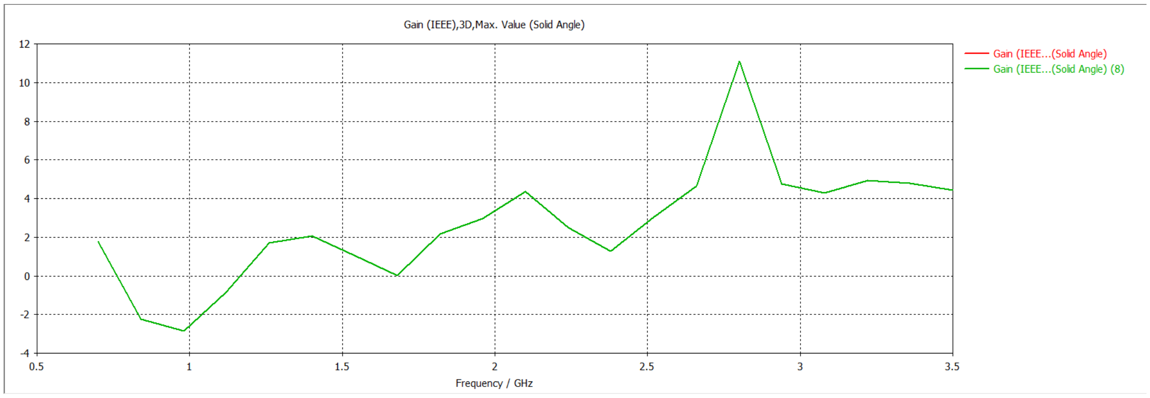


Figure 8: Gain-Frequency Graph

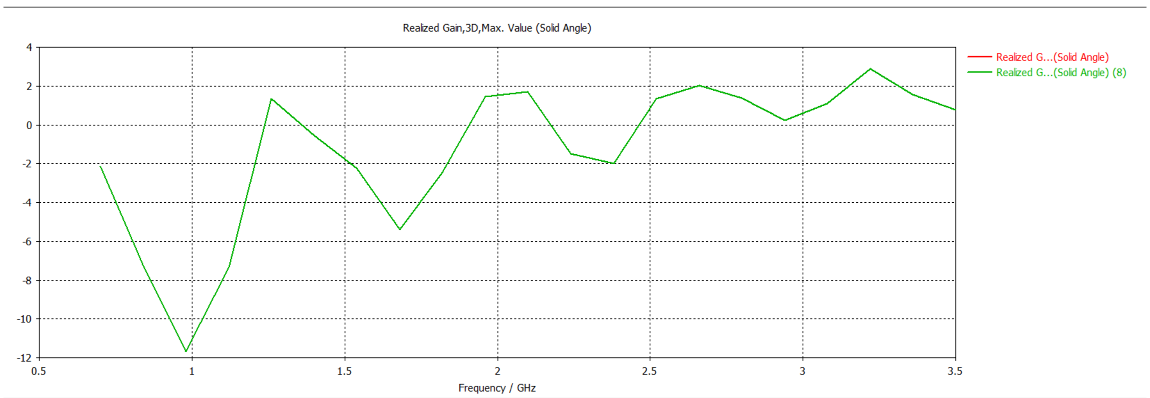
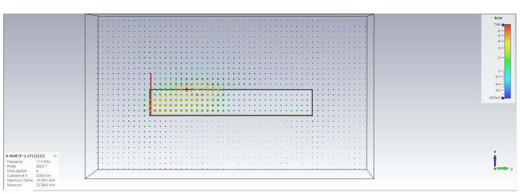
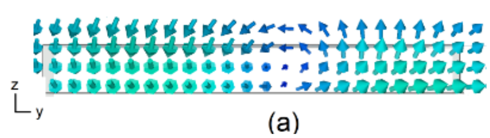


Figure 9: Realized Gain-Frequency Graph

3.3 Magnetic Field Destributions

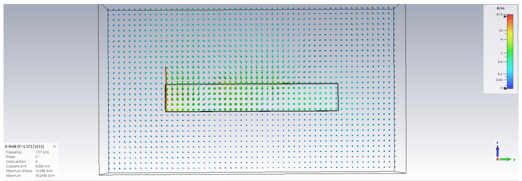


(a) Our Simulation

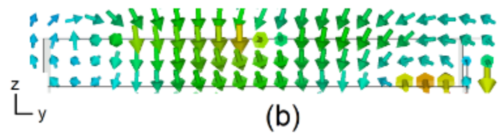


(b) Paper's Simulation

Figure 10: TM_{110} at 1.17 GHz (patch)

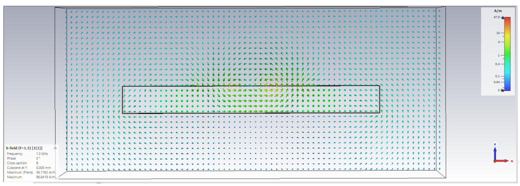


(a) Our Simulation

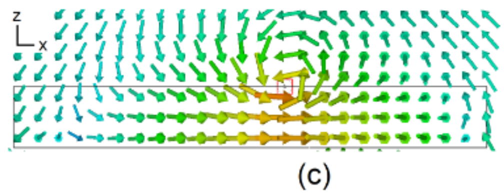


(b) Paper's Simulation

Figure 11: TM_{210} at 1.57 GHz (patch)

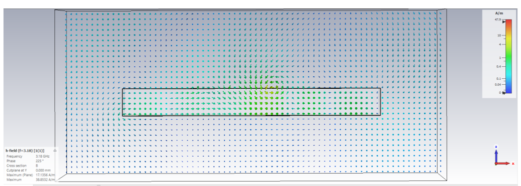


(a) Our Simulation

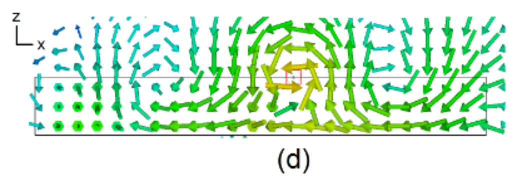


(b) Paper's Simulation

Figure 12: EH_1 at 1.3 GHz (Microstrip)

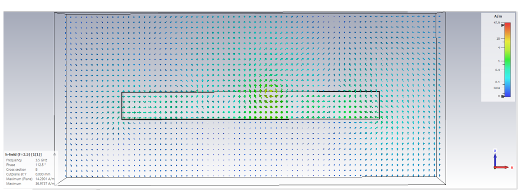


(a) Our Simulation

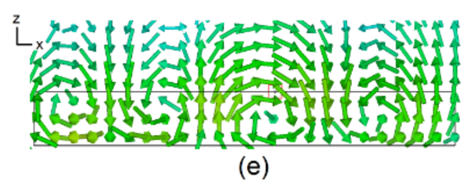


(b) Paper's Simulation

Figure 13: EH_3 at 3.18 GHz (microstrip)

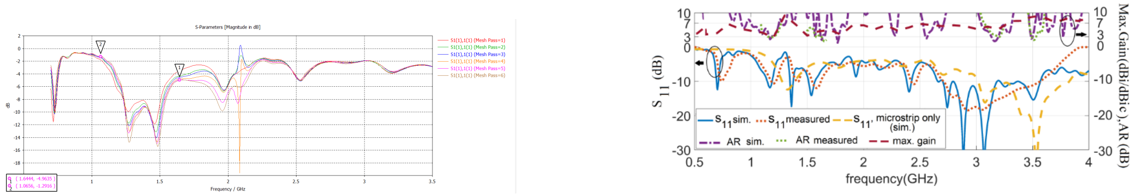


(a) Our Simulation



(b) Paper's Simulation

Figure 14: EH_4 at 3.5 GHz (Microstrip)



(a) Our Simulation

(b) Paper's Simulation

Figure 15: S parameters Plots

4 Improvements

Several enhancements were implemented in the dimensions of the patch antenna. These included alterations in the dimensions of the microstrip line, adjustments in the height of both the lower and upper substrate layers, and modifications in the number of modes generated per simulation. These refinements aimed to redefine the parameters to facilitate radiation across most of the intended frequencies, with the exception of EH3 and EH4 at 3.18 GHz and 3.5 GHz, respectively. Notably, these adjustments resulted in a significant improvement in the excitation of these frequencies, enabling them to radiate at a much higher intensity.

5 Challenges and problems

As for challenges we faced, the dimensions of the microstrip-patch antenna weren't as accurate in the simulation results as in the original paper. The width of the microstrip feedline to the width of the whole substrate thickness wasn't proportionate enough to calculate a port extension coefficient (insert the necessity for the port extension coefficient from ChatGPT). We needed to at least multiply this ratio by 2 to be in the accepted range. We tried both test cases of doubling the width of the microstrip or halving the thickness of the substrate. Doubling the width of the microstrip feedline resulted in a more distorted S11 parameter graph and didn't excite the intended frequencies. On the other hand, when we halved the substrate thickness by two, we could improve the S11 excitation patterns to a much more accurate standard referring to the reference paper. Although we tried as much as we could to interchange multiple parameters, we couldn't excite the last two hybrid modes EH3 and EH4, which took a long time of trial and error and presented a challenge for our output and simulations.

6 Team members' contributions

Name	Responsibilities
Aser Osama	• Extracted the exact measurements from the research paper. • Designed the whole Microstrip-Patch antenna as a CAD model in CST MWS.
Omar Elsayed	• Tested the Microstrip-Patch antenna design. • Introduced changes to the variables for the challenges discussed before. • Simulated and extracted the output data, graphs, and screenshots for the project.
Saifeldin Mohamed	• Exported the entire project into Gerber files. • Reviewed each Gerber file in the Gerbview software. • Registered for the NTI PCB Lab to send the project output Gerber files and made the purchase. • Written the Project's Final Document.

7 Conclusion

In conclusion, we aimed to replicate and improve the given patch antenna system in CST, Focusing on optimizing it excite specific modes. The antenna structure was designed to resonate at LTE GPS L5/L1, and WLAN bands. Simulation results were promising and showed magnetic field distributions of resonant modes. We have validated the antenna's performance through a multitude of CST simulation runs and repetitive tweaking of parameters such as the dimensions of the antenna. Substrate layers improved frequency excitations. Refinements in dimensions, microstrip line configurations, and substrate layers significantly improved frequency excitation, underscoring the antenna's potential for diverse applications in GPS technology integration and beyond.

References

[1] A. Abdalrazik, A. Gomaa, and A. A. Kishk, "A hexa-band quad-circular-polarization slotted patch antenna for 5g, gps, wlan, lte, and radio navigation applications," *Antennas and Wireless Propagation Letters*, vol. 1, 2021.