Journal of Engineering Research and Technological Innovations.
[JERTI] Vol. 1, No 1, 25 - 38 (2026)
https://journals.kwasu.edu.ng/index.php/jerti ISSN: 3093-0863

Design and Analysis of a Circular and Rectangular 3.5 GHz Patch Antenna for Wireless Application

S. O. Zakariyya[1], K. O. Osunsanya[2], R. A. Alao[3], B. O. Sadiq[4,5]

[123]Electrical and Electronics Engineering, University of Ilorin, Ilorin, Nigeria, [4]Computer Engineering Department, Ahmadu Bello University, Zaria, Nigeria, [5]Electrical and Computer Engineering, Kampala International University, Uganda

[1]Zakariyya.os@unilorin.edu.ng, [2]Osunsanya.ko@unilorin.edu, [3]alao.ra@unilorin.edu.ng [4]bosadiq@kiu.ac.ug
Corresponding Author: zakariyya.os@unilorin.edu.ng | +234-814-991-3528

ABSTRACT

This work presents the development and performance evaluation of rectangular and circular patch antennas designed for 3.5 GHz wireless communication applications. Both antenna structures were developed using FR-4, a low-cost dielectric material, offering a relative permittivity of 4.3 and a substrate depth dimension of 1.65 mm. The antennas were excited through a quarter-wave transformer and their behavior was examined through CST Microwave Studio. According to the obtained simulation results, the rectangular patch achieves resonance at 3.5 GHz, providing a value of −32.8 dB as the return loss, 1.04 as the VSWR, 115.6 MHz bandwidth, and a value of 7.06 dBi as the directivity gain. In comparison, the circular patch antenna achieves a value of −32.2 dB as the return loss, 1.05 VSWR, 110.28 MHz bandwidth, and a value of 6.92 dBi as the directivity gain. A performance comparison with existing 3.5 GHz antenna designs documented in existing research confirms that the proposed designs offer superior impedance matching and enhanced performance, positioning them as strong candidates for current wireless communication technologies.

Keywords: Patch, Wireless, Substrate, Microstrip, Gain

1. INTRODUCTION

The widespread adoption of wireless devices such as smartphones, tablets, laptops, global positioning system (GPS) units, and radio navigation tools has significantly advanced modern communication technologies. These devices rely on seamless connectivity with service points, enabling efficient data exchange through a radio link with minimal interference (Zakariyya et al., 2025).

At the core of this communication process lies the antenna, which is indispensable for both transmitting and receiving signals. As the number of users and devices continues to grow, the demand for compact antennas has intensified. These antennas must maintain high performance while occupying minimal physical space, thereby meeting the requirements of modern portable and handheld communication systems.

Among the various antenna types, microstrip patch antennas (MPAs) are widely recognized for their simple fabrication process, compact size, and reliable performance. Their low profile, lightweight nature, and ability to deliver wide bandwidths make them highly suitable for modern communication demands (Salami et al., 2017; Zakariyya et al., 2016a; Zakariyya et al., 2016b). When mounted on rigid surfaces, MPAs are particularly advantageous because of their cost-effectiveness, ease of manufacturing, and mechanical adaptability (Rana et al., 2023).

A patch antenna is generally fabricated from a conductive material, commonly gold or copper, and may be shaped into different geometries including rectangular and

Publisher
Faculty of Engineering and Technology,
Kwara State University, Malete. P.M.B. 1530 Ilorin,
Kwara State, Nigeria.

https://doi.org/10.5281/zenodo.18441506

circular among others (Balanis, 2005; Wong, 2004). Both the radiating patch and the feed network are realized on the substrate using standard PCB fabrication methods (Kumar & Ray, 2003; Orban & Moernaut, 2009).

Microstrip patch antennas have become a major focus of research because of their small form factor, straightforward fabrication process, and effective performance in wireless communication applications, particularly in the 3.5 GHz band, which is central to 5G and broadband applications. Various design strategies have been proposed, ranging from modifications in patch geometry to the use of different substrates and feeding mechanisms, directed toward enhancing essential performance indicators, including minimizing return loss, broadening bandwidth, increasing gain, improving efficiency, and ensuring stable radiation. Recent studies have explored innovative layouts, material choices, and antenna arrays to optimize antenna performance for diverse applications including WiMAX, satellite communication, wireless LANs, and wearable technologies. This growing body of work highlights the continued drive to enhance antenna performance while maintaining compactness and cost-effectiveness

Rana et al. (2023) proposed an S-band microstrip antenna for operation around 3.5 GHz using a Rogers RT/Duroid substrate. The design demonstrated favorable simulation results, achieving an acceptable impedance matching and good radiation properties, making it suitable for satellite links. In addition, the antenna exhibited good gain and efficiency, further highlighting its potential for application in radar systems.

A compact wideband microstrip antenna with a partial annular patch as the radiating element for LEO satellite telemetry was proposed in the work of Pushpalatha et al. (2023). Simulation and validated measurements were used to verify the antenna's performance, confirming its wide bandwidth and omnidirectional coverage. Despite this, a modest gain of 1.434 dbi was recorded.

The work of Cirik and Yildirim (2016) focuses on building a better antenna for WiMAX systems that operate at 3.5 GHz. Instead of using extra electronics to boost power, the authors improved the antenna's shape. A basic patch antenna was first created, but it only gave a small signal strength. By placing an extra patch above the main one and slightly raising the ground surface, the antenna's signal strength increased. This shows that simple design changes can make antennas much more powerful and reliable while keeping the system affordable and easy to build.

The work of Rana et al. (2022) built a basic, easy-to-manufacture antenna for wireless communication. They used a well-known Rogers RT/Duroid 5880, which has properties that help handle signals well. By simulating the antenna's behavior on a computer, they checked how well it matched with the signal source and how well it transmitted signals over a range. Their results showed that this simple design performs reliably and could be a smart, budget-friendly choice for building wireless devices.

The work of Singh et al. (2013) proposed an antenna that's easy to build and works well for wireless LANs around 3.5 GHz. The structure is a printed patch with a unique arrow-head cut-out (slot), mounted on a thin and lightweight material. Computer simulations show that it has a good return loss (–31 dB) and is fairly well-matched to its feed (VSWR = 2). It also gives off a nearly circular beam in all directions, which is great for keeping connections steady.

The work of Ferdous et al. (2019) outlines a small, affordable antenna designed for 5G systems working at 3.5 GHz. It uses an oval-shaped copper patch on a common FR-4 board and is fed by a line printed on the same layer. Simulations show the antenna sends and receives signals very efficiently with an input match of –30 dB, and a radiation strength of about 5 dB. The main beam of its radiation pattern points strongly forward, while unwanted side emissions are minimal.

The work of Irfansyah et al. (2021) presents the design of a rectangular microstrip antenna arranged as a 1×2 array for operation at 3.5 GHz. The approach focuses on using multiple patch elements on an FR-4 substrate to improve antenna performance while maintaining a lightweight and easily integrable structure. Simulation-based optimization demonstrated acceptable impedance matching and enhanced radiation characteristics.

The work of Ibrahim et al. (2021) looks at how the type of material underneath a patch antenna affects how well it works for 5G at 3.5 GHz. Three materials were tested: two characterized by low permittivity and one with a mid-range permittivity, each having slightly different thicknesses. By running computer simulations, the authors compared how each design reflected signals, handled voltage standing waves, how wide its bandwidth was, its gain, and its overall efficiency. The key takeaway is that even small changes in the material type and thickness make a big difference in how well the antenna performs.

The work of Gupta et al. (2014) describes building a small antenna that uses air instead of a traditional material underneath the patch to see how well it works at 3.525 GHz. Using computer-based electromagnetic simulation, the authors designed a tiny rectangular antenna mounted on a thin air layer and connected via a standard feed line. They tested for how much signal is reflected back, how wide the operating frequency range is, how well the antenna radiates, and how efficiently it matches electrical impedance. By using air with no dielectric losses, the design promises solid performance for microwave applications without the downsides of conventional substrates.

The work of Prabha, Nataraj, and Jagadeeswari (2022) created a simple patch antenna that works at around 3.5 GHz, for 5G and other wireless systems. Using simulation software, they built a virtual model of the antenna and tested how well it sends and receives signals, how well it's matched with the feeding circuitry, and how wide a frequency range it supports. When compared to other common designs, this antenna showed promising behavior for modern wireless uses.

The work of Chowdhury et al. (2022) introduces a slim, easy-to-make antenna that fits beneath the surface (low-profile) and is specially designed for the lower 5G frequency range (Sub-6 GHz). Essentially, it's a rectangle-shaped cutout in a flat plane (a slot antenna) that's tested using both computer simulations and actual fabrication. The antenna shows good control over how much signal reflects back, how it transfers signals forward, and how well it matches with the electronics that power it. All in all, when compared to similar antennas, this design delivers reliable performance while staying compact, making it a practical choice for 5G wireless setups.

This work of Noordin et al. (2024) explores how to improve the design of a small, flat antenna working at 3.5 GHz. The structure is built on PTFE (a low-loss material), which helps reduce signal distortion. The proposed structure was verified through simulations conducted in CST to validate the design, demonstrating the effectiveness of the approach and offering insights into the optimization of microstrip antennas.

The work of Rengarajan et al. (2025) developed a small, comfortable antenna that can be worn on the body to monitor vital signs. It uses a smart T-shaped layout printed on FR-4 material and works at several key frequencies: 2.5, 3.5, 4.5, and 5.5 GHz—covering many common wireless bands. Simulated in HFSS software, the design shows better signal matching, less energy loss, stronger signal output, and improved coverage compared to typical wearable antennas. Thanks to its clever shape and construction, it remains lightweight and functional for health-monitoring gadgets.

The work of Rana et al. (2023b) design a rectangular patch that operate at 3.5 GHz. Using simulation software, the researchers evaluated its performance. The antenna shows good control over how much signal reflects back, how it transfers signals forward, and how well it matches with the electronics that power it. All in all, when compared to similar antennas, this design delivers good performance.

Exploring antenna geometries that balance size, bandwidth, gain, and ease of fabrication is crucial given the increasing demand for effective and small antennas in present day wireless communication, especially within the 3.5 GHz band used for advanced broadband services. This study addresses the persistent trade-offs among compactness, bandwidth, gain, and return loss in microstrip patch antennas operating at the 3.5 GHz band. Unlike existing FR-4 designs that employ complex or multilayer geometries, the proposed antennas use a simple single-layer structure with a quarter-wave transformer feed to achieve improved impedance matching and radiation efficiency. By comparing rectangular and circular geometries, the work provides valuable insights into their respective performance characteristics in terms of bandwidth and radiation behavior. In addition, a sensitivity analysis highlights the effects of dimensional variations on return loss and VSWR, demonstrating the design's robustness and fabrication tolerance.

2. MATERIALS AND METHODS

2.1 *Antenna Design*

The initial stage of microstrip patch antenna design is guided by three established parameters: the substrate thickness (h), the frequency at which resonance is intended (f_r) and the material's relative dielectric property (ε_r). In this study, FR-4 served as the chosen dielectric medium, selected on account of its economic advantage and common availability. The selected FR-4 material provides ε_r=4.3 and has been modeled with a thickness of h =1.65. The resonant frequency was specified as f_r = 3.5 GHz, which falls within the commonly utilized bands in wireless communication systems.

2.2 *Circular Patch Antenna*

In the case of a circular structure, the effective radius is derived through the cavity model approach. An intermediate factor, denoted as F, is expressed as:

$$F = \frac{8.791 * 10^9}{f_r \sqrt{\varepsilon_r}} \quad (1)$$

Using this constant, the effective radius R of the patch is obtained from (Balanis, 2005):

$$R = \frac{F}{\sqrt{1+\frac{2h}{\pi\varepsilon_r F}[\ln(\frac{\pi F}{2h})+1.7726]}} \quad (2)$$

Here, R stands for patch radius (mm), h represent the dimension of the substrate thickness height (mm) and ε_r characterizes the dielectric constant. This formulation ensures that the designed structure resonates at the specified frequency

2.3 Rectangular Patch Antenna Design

For the rectangular microstrip structure, the microstrip line approximation model is typically used to estimate its dimensions. The design process begins with the patch width W which can be expressed as:

$$W = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \quad (3)$$

In this context, W represents the width of the proposed patch structure, f_r denotes the resonant point, and ε_r represent the substrate material permittivity. Next, the effective dielectric constant (ε_{eff}) is calculated to account for the non-uniform field distribution around the patch. It is modeled as:

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + \frac{12h}{w}\right)^{\frac{-1}{2}} \quad (4)$$

Because of fringing effects at the edge of the patch structure, the antenna's effective length is slightly longer than its physical length. The extension of length on each side, ΔL, is calculated as:

$$\Delta L = \frac{(\varepsilon_{eff} + 0.3)(W/h + 0.264)}{(\varepsilon_{eff} - 0.258)(W/h + 0.8)} \quad (5)$$

By incorporating this adjustment, the patch's true length L_p can be calculated as:

$$L_p = L_{eff} - 2\Delta L \quad (6)$$

Where $L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_{eff}}}$ is effective length of the antenna structure and directly determines the resonant behavior of the antenna.

c is the speed of light in vacuum (m/s).

2.4 Feeding Mechanism

Both antenna designs employed a quarter-wave transformer as the feeding method. This approach provides effective impedance matching between the feed line and the radiating patch, thereby improving power transfer and minimizing reflections at the input port.

The edge impedance $Z_{in} = 90\frac{\varepsilon_r^2}{\varepsilon_r-1}\left(\frac{L}{W}\right)^2$ (7)

The quarter-wave transformer impedance is evaluated as:

$$Z_T = \sqrt{Z_0 Z_{in}} \quad (8)$$

Where Z_T stands for the quarter-wave transformer impedance, Z_0 denotes the impedance of 50 ohms, and Z_{in} is the edge impedance.

2.5 Simulation Setup

The two designs, circular and rectangular, were modeled and analyzed using CST Microwave Studio. The simulation setup enabled the evaluation of performance to compare both antenna structures. In terms of dimensions, the rectangular patch measures 19.25 mm in length and 26 mm in width, while the circular patch has a radius of 11.5 mm. The corresponding CST-MWS simulation model is shown in Figure 1.

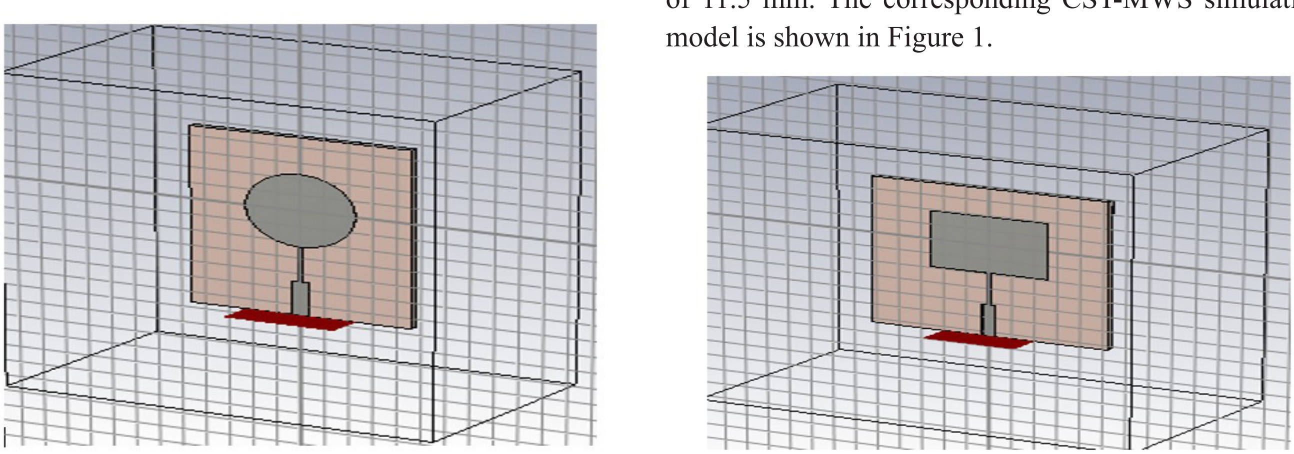
(a) (b)

Figure 1. Structural layouts of the proposed patch antennas: (a) circular patch structure and (b) rectangular patch structure

All simulations were carried out using the time-domain transient solver. The substrate was defined as FR-4 with relative permittivity $\varepsilon_r = 4.3$, loss tangent =0.025 and thickness h=1.65 mm. The patch and feed were modeled as copper with conductivity σ=5.8×10^7 S/m and thickness 30 µm. A hexahedral mesh was employed for spatial discretization, while excitation was provided through a waveguide port with a reference impedance of 50 Ω. Radiation characteristics were obtained using the far-field monitor, and the quarter-wave transformer was modeled with the characteristic impedance and physical dimensions (width and length) specified in Table 1.

Table 1: Parameters of the MPA.

Parameters	Description	Rectangular	Circular
w_p	Width of the patch	26 mm	----
L_p	Length of the patch	19.25 mm	---
w_g	Width of the ground plane	52 mm	52 mm
L_g	Length of the ground plane	49 mm	49 mm
w_f	Width of the feed	2.9 mm	3.3 mm
L_f	Length of the feed	10.8 mm	10.8 mm
w_q	Width of the quarter wave	1 mm	0.7 mm
L_q	Length of the quarter wave	11 mm	11 mm
ε_r	dielectric constants	4.3	4.3
R	patch radius	------	11.5 mm

3. RESULTS AND DISCUSSION

3.1 *Return loss*

S-parameters are fundamental metrics used to characterize the input–output behavior of high-frequency systems, offering valuable insights into how signals interact across different ports. In antenna analysis, a lower S11 value corresponds to a favorable matching and improved radiation competence. For the proposed design, the minimum reflection is observed at −32.8 dB for the rectangular structure and −32.2 dB for the circular patch at 3.5 GHz, both well below the conventional −10 dB threshold typically adopted as a benchmark for acceptable antenna performance, as illustrated in Figures 2 and 3. Accordingly, the rectangular patch achieves an effective impedance bandwidth of 115.63 MHz, spanning 3.445 GHz to 3.5606 GHz, while the circular patch attains a bandwidth of 110.28 MHz, ranging from 3.4431 GHz to 3.5534 GHz. These results confirm the suitability of the proposed antenna designs for 3.5 GHz applications.

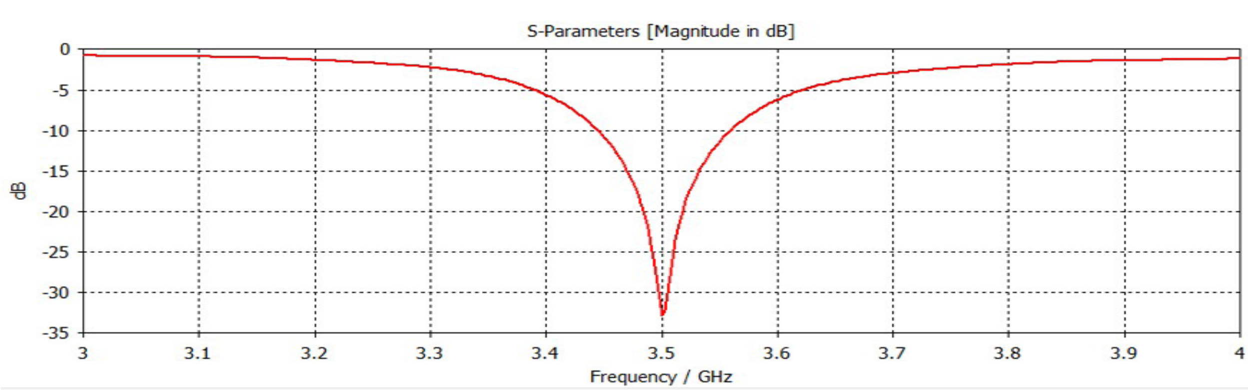

Figure 2: Reflection coefficient (S11) plot for the rectangular patch structure

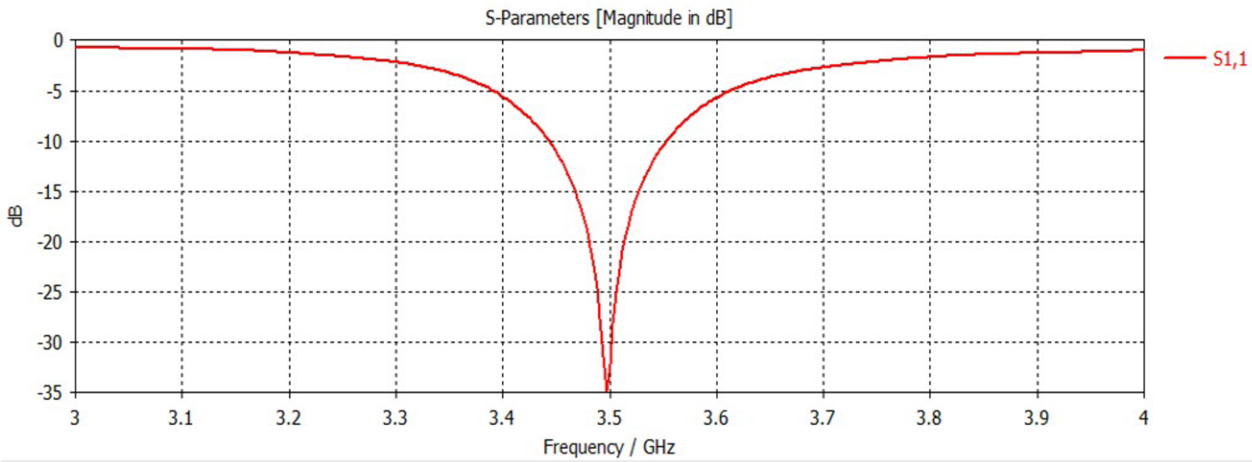

Figure 3: Reflection coefficient (S11) plot for the circular patch structure

3.2 Voltage Standing Wave Ratio

This is another key metrics for evaluating antenna behavior, as it indicates the degree of impedance matching between the antenna and the transmission line. A value of 1.0 denotes an ideal match, while values below 2.0 are generally regarded as acceptable for practical use. For the proposed design, the rectangular structure exhibits a value of 1.04 and the circular structure indicates a VSWR of 1.06 at 3.5 GHz as displayed in Figures 4 and 5. These results, being very close to the ideal case, signify minimal reflection losses and seamless transfer of input power into the antenna. These results further validate the excellent impedance matching characteristics of the proposed antennas at the target frequency.

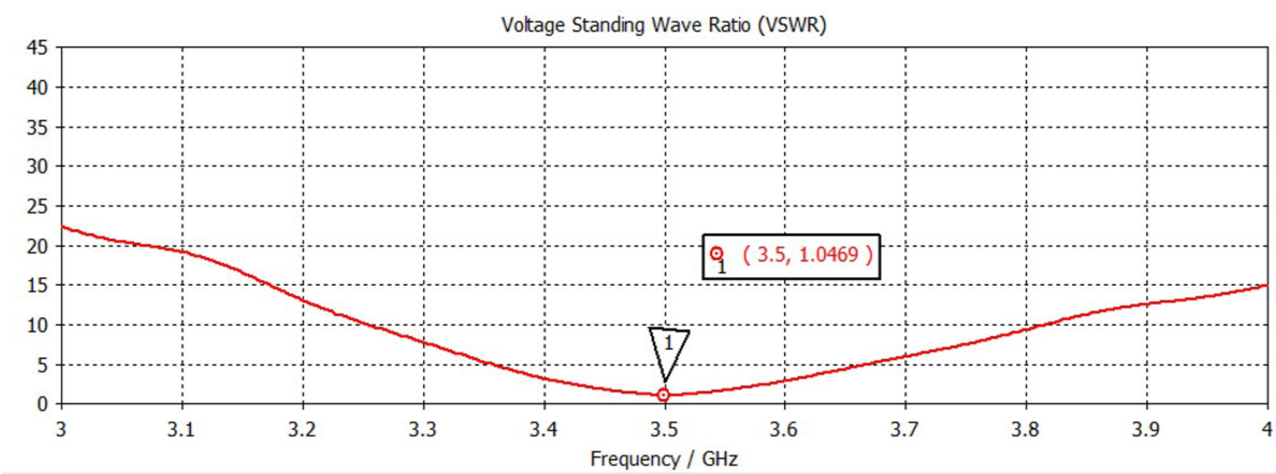

Figure 4: VSWR plot for the rectangular patch antenna

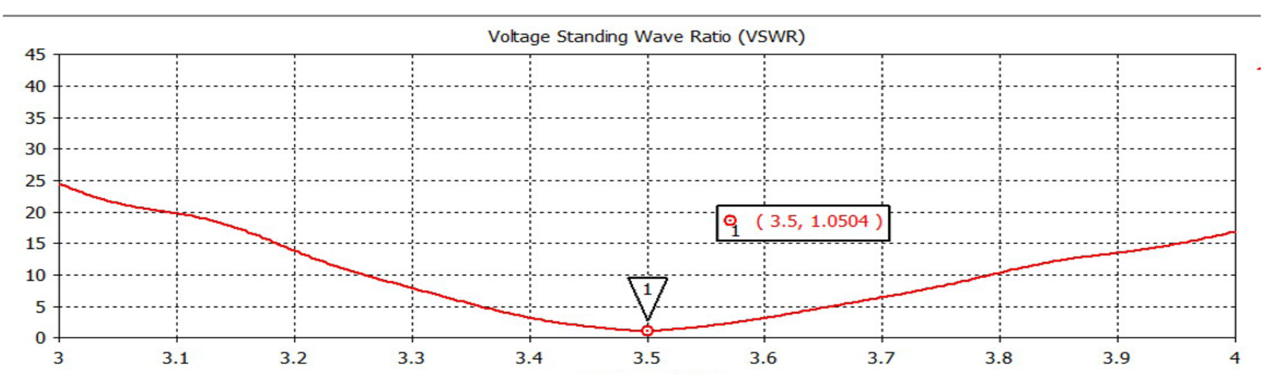

Figure 5: VSWR plot for the circular patch antenna

3.3 Radiation Pattern

An essential parameter in evaluating the performance of a microstrip patch antenna is its radiation pattern, as it provides a clear indication of how efficiently the antenna directs and radiates energy. At the operating frequency of 3.5 GHz, the proposed designs exhibit strong directivity. Specifically, the rectangular patch achieves a directivity of 7.06 dBi, and a radiation efficiency of 41.9%, while the circular patch records a directivity of 6.96 dBi and an efficiency of 38.8%. Figure 6 and 7 illustrates the radiation distributions of the antennas, demonstrating their ability to concentrate radiated power in the desired direction. The relatively moderate efficiencies observed in both designs are attributed to the use of FR4 substrate material, which has a high dielectric loss tangent. This property leads to greater dielectric losses and reduced radiation efficiency compared to low-loss substrates such as Rogers RT/Duroid or Taconic. Nevertheless, these results confirm that both antenna configurations maintain effective radiation performance at the target frequency, making them well-suited for 3.5 GHz applications.

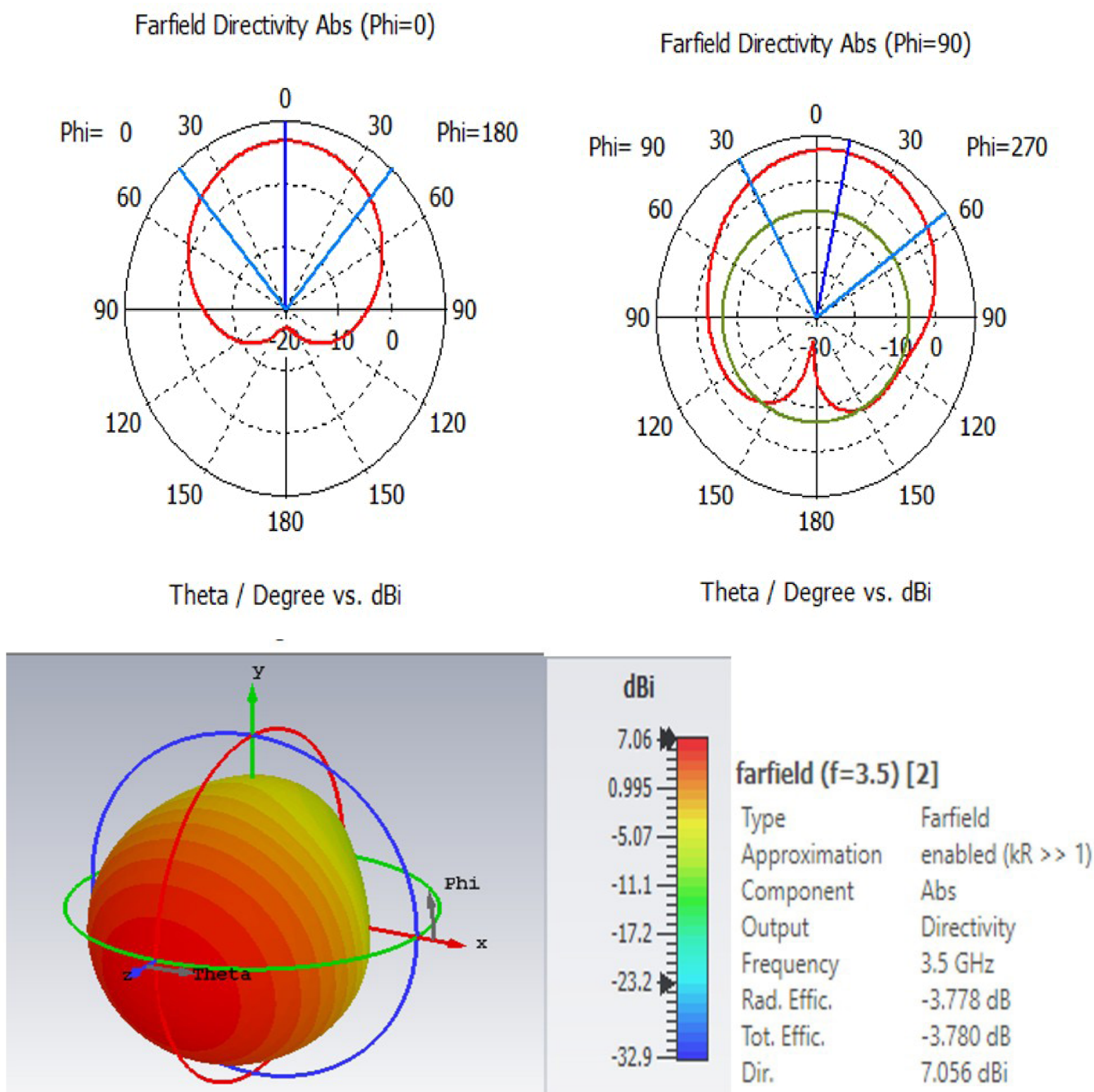

Figure 6: Radiation pattern characteristic of the proposed rectangular antenna

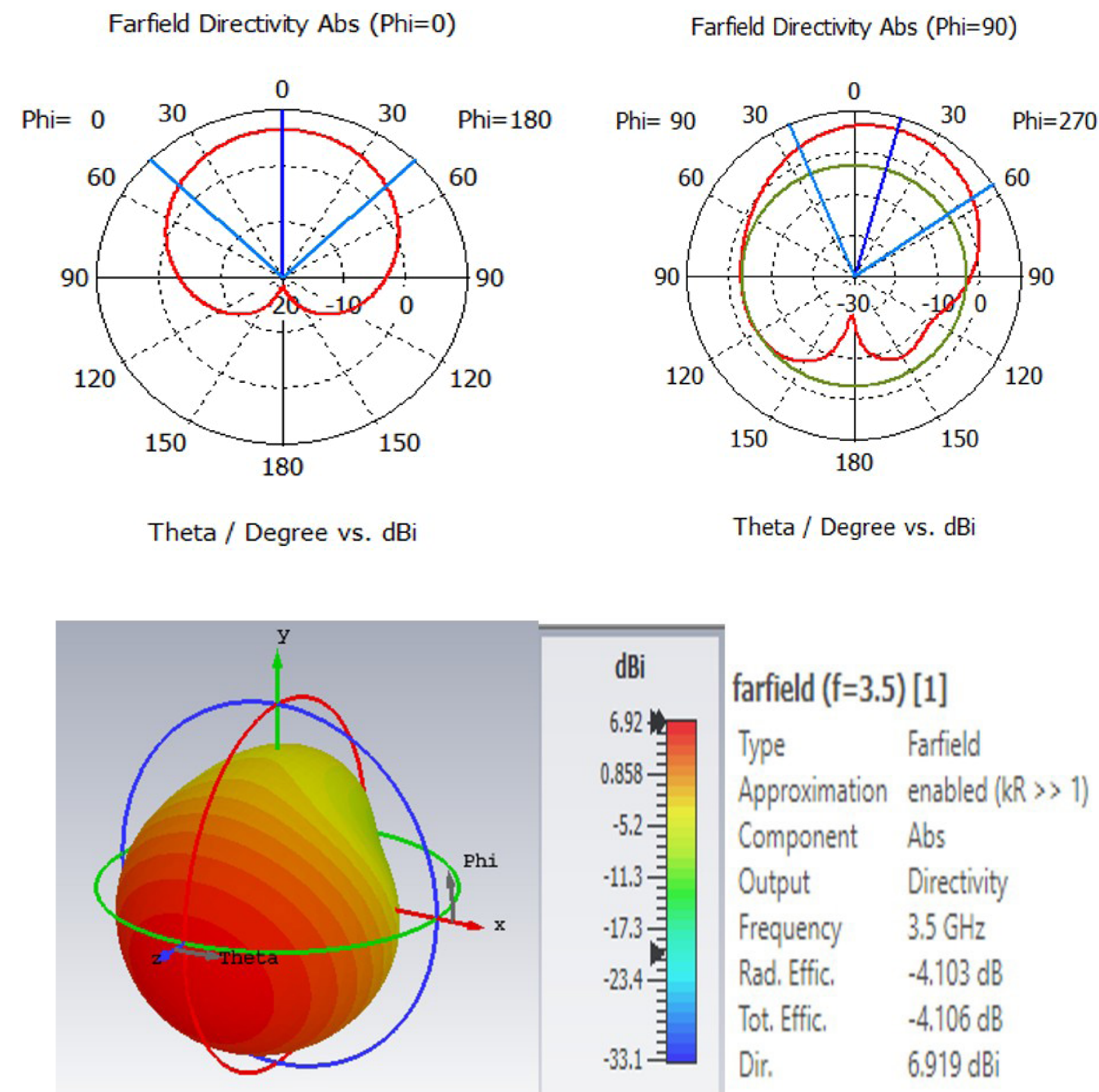

Figure 7: Radiation pattern characteristic of the proposed circular antenna

3.4 Sensitivity Analysis

A sensitivity (parametric) analysis was conducted to examine the effect of dimensional variations on the performance of both the rectangular and circular patch antennas. The analysis focused on how changes in the patch length and width influence the rectangular patch performance, and how variations in the radius affect the circular patch performance. Two key performance metrics were considered: return loss ($|S_{11}|$) and Voltage Standing Wave Ratio (VSWR). The corresponding results are presented in Figures 8–13.

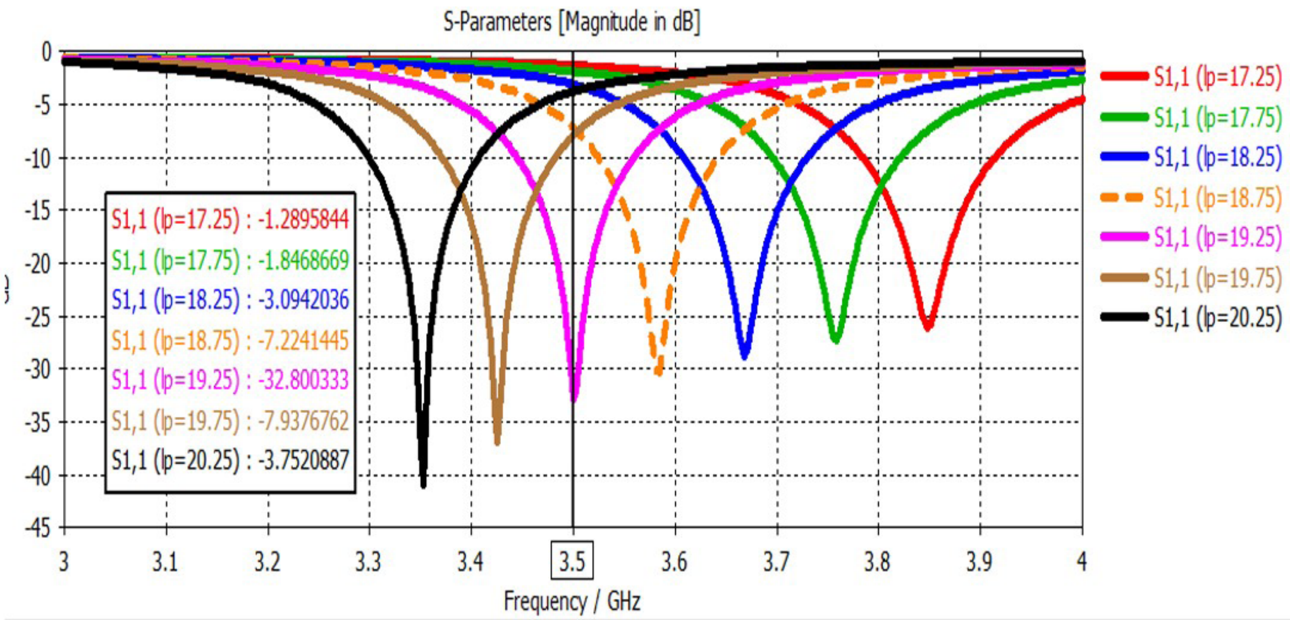

Figure 8: Effect of Patch Length (L_p) Variation on the Return Loss and Resonant Frequency of the Rectangular Patch Antenna.

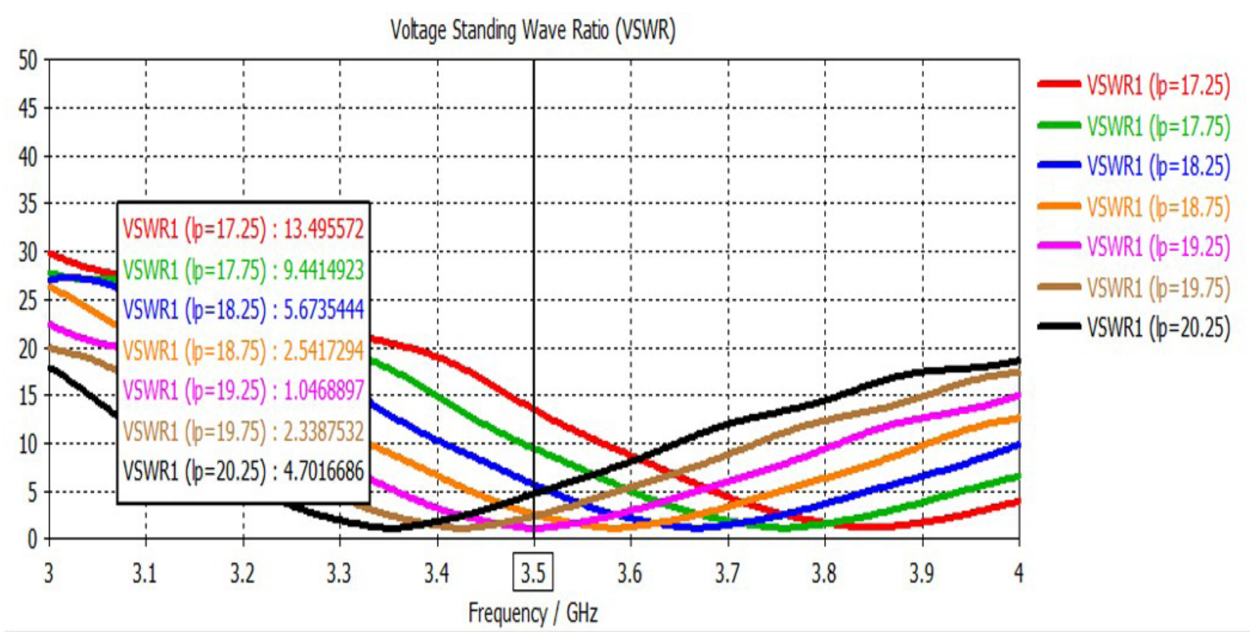

Figure 9: Effect of Patch Length (L_p) Variation on the VSWR of the Rectangular Patch Antenna.

For the rectangular patch antenna, when the patch length was varied across values of 17.25, 17.75, 18.25, 18.75, 19.25, 19.75, and 20.25 mm, the corresponding return loss ($|S_{11}|$) values were −1.28, −1.84, −3.09, −7.22, −32.8, −7.93, and −3.75 dB, while the respective VSWR values were 13.4, 9.4, 5.6, 2.5, 1.04, 2.33, and 4.7. It was observed from Figures 8 and 9 that the optimum performance, indicated by the minimum $|S_{11}|$ and VSWR closest to unity, occurred at Lp = 19.25 mm, which corresponds to the antenna's resonant condition at 3.5 GHz. Deviations from this dimension resulted in significant impedance mismatch and degradation of return loss.

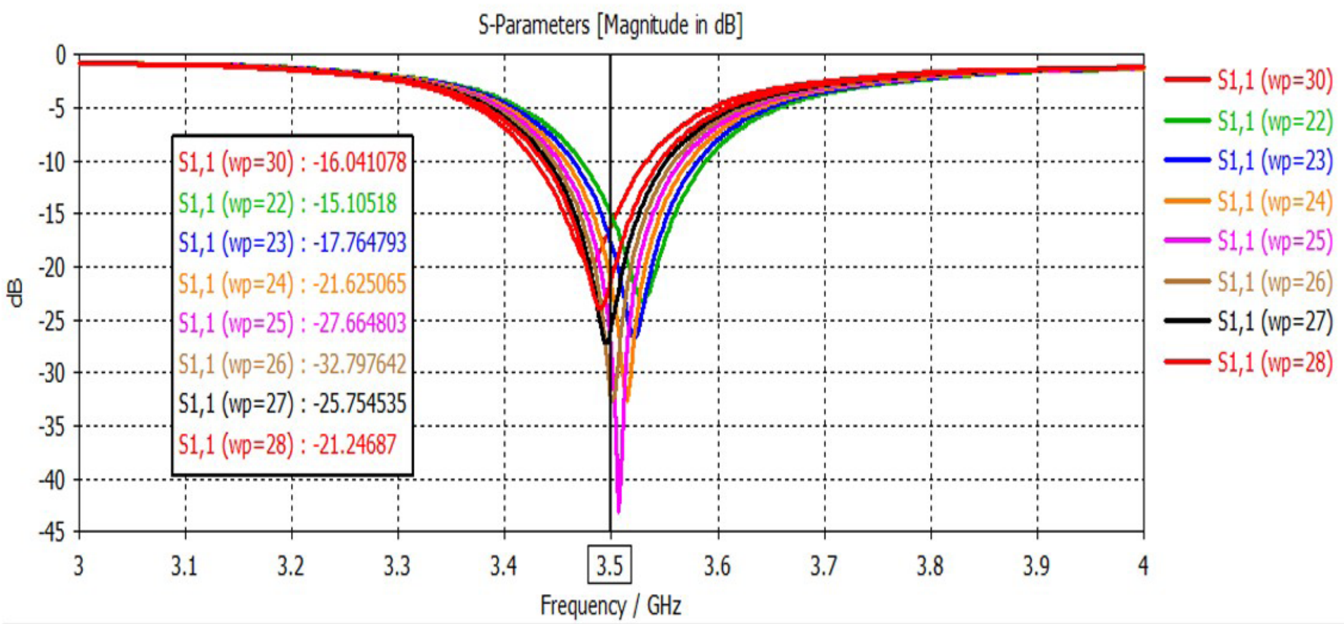

Figure 10: Effect of Patch Width (W_p) Variation on the Return Loss and Resonant Frequency of the Rectangular Patch Antenna.

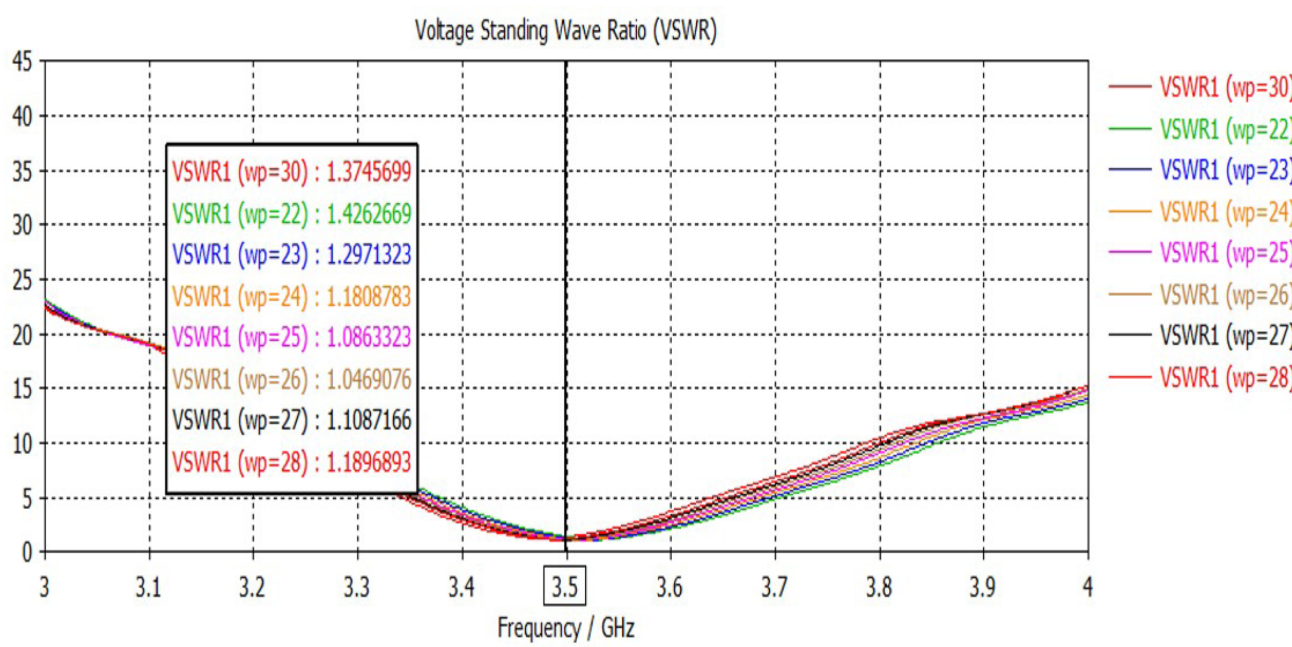

Figure 11: Effect of Patch Width (W_p) Variation on VSWR of the Rectangular Patch Antenna.

Similarly, when the patch width was varied through 22, 23, 24, 25, 26, 27, 28, and 30 mm, the corresponding return loss values were −15.10, −17.76, −21.62, −27.66, −32.79, −25.75, −21.24, and −16.04 dB, with VSWR values of 1.42, 1.29, 1.18, 1.08, 1.04, 1.10, 1.18, and 1.37, respectively. The results show that an optimal width of 26 mm provides the best impedance matching, resulting in a VSWR of 1.04 and return loss of −32.79 dB. Increasing or decreasing the width beyond this value shifts the resonant frequency and degrades impedance matching as illustrated in Figures 10 and 11.

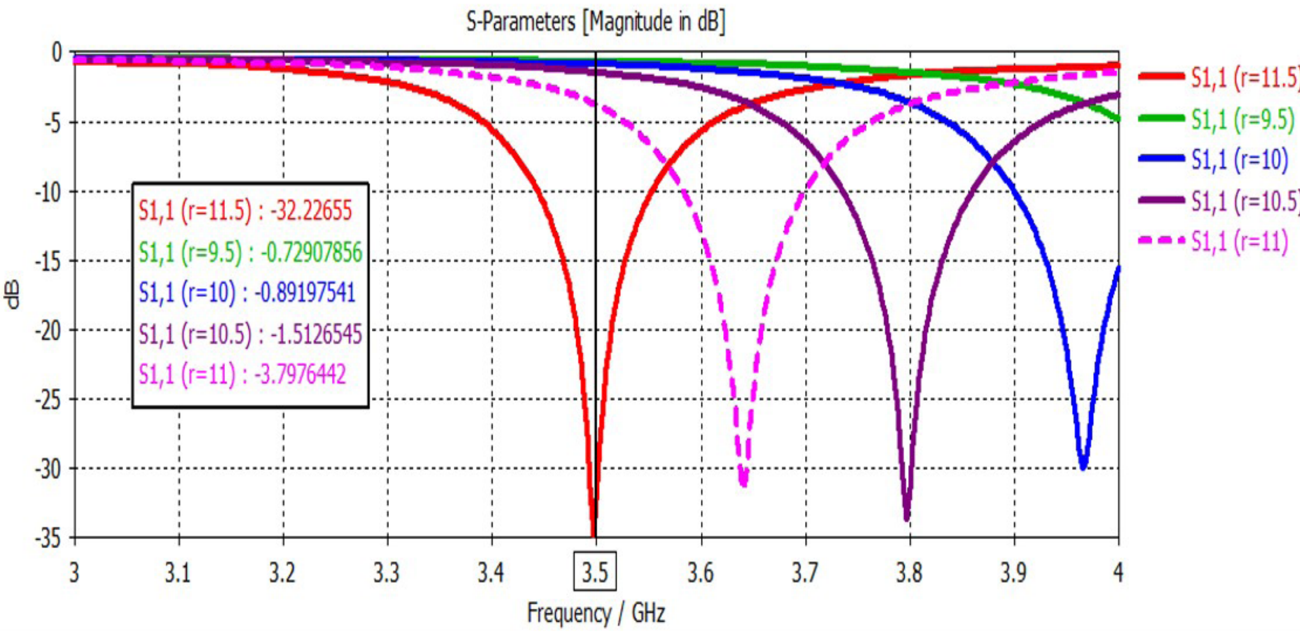

Figure 12: Effect of Patch Radius Variation on the Return Loss and Resonant Frequency of the Circular Patch Antenna.

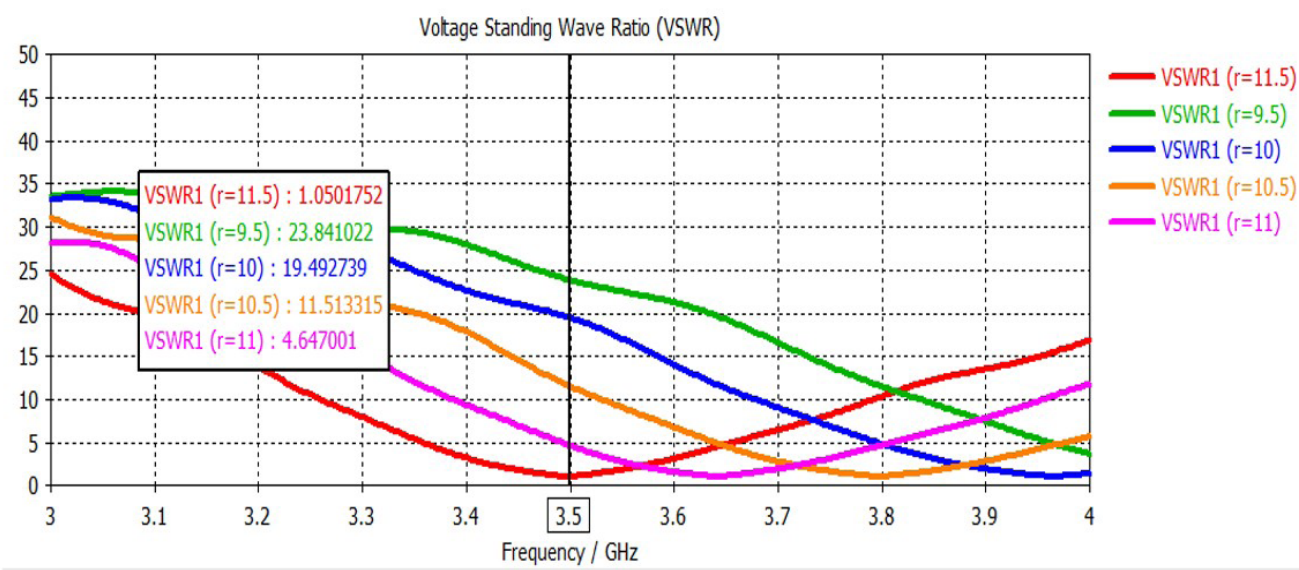

Figure 13: Effect of Patch Radius Variation on the VSWR of the Circular Patch Antenna.

For the circular patch antenna, variations in the patch radius were analyzed for values 9.5, 10, 10.5, 11, and 11.5 mm, yielding corresponding return loss values of −0.72, −0.89, −1.51, −3.79, and −32.2 dB, and VSWR values of 23.84, 19.49, 11.51, 4.64, and 1.05, respectively. The optimal performance was achieved at R = 11.5 mm, where the antenna exhibits a well-matched condition ($|S_{11}| = -32.2$ dB, VSWR = 1.05) at 3.5 GHz as illustrated in Figures 12 and 13.

Overall, the sensitivity results reveal that small deviations in the antenna's physical dimensions significantly affect its impedance matching characteristics. The analysis confirms that maintaining tight fabrication tolerances around the optimized dimensions, Lp = 19.25 mm, Wp = 26 mm, and R = 11.5 mm, is critical for achieving stable resonance and efficient operation. These findings provide valuable insight into the manufacturability and robustness of the proposed antenna designs

3.5 Discussion

Table 2 provides a consolidated summary of the simulated results for the rectangular and circular patch antennas at 3.5 GHz. Both designs exhibit excellent impedance matching, as indicated by return loss values of −32.8 dB for the rectangular patch and −32.2 dB for the circular patch, with corresponding VSWR values of 1.04 and 1.05, respectively, both very close to the ideal value of unity. In terms of bandwidth, the rectangular patch achieves 115.6 MHz, slightly higher than the 110.28 MHz obtained with the circular patch. A similar trend is observed in radiation performance, where the rectangular patch records a directivity gain of 7.06 dBi and an efficiency of 41.9%, compared to 6.92 dBi and 38.8% efficiency for the circular design. Overall, while both antennas demonstrate excellent suitability for 3.5 GHz applications, the rectangular patch offers marginally superior performance in bandwidth, directivity, and radiation efficiency, making it a more favorable option for applications requiring enhanced radiation performance and wider operating bandwidth.

The simulation outcomes from this study reveal a clear performance advantage over several benchmarked microstrip patch antenna (MPA) designs reported in the literature. In particular, the proposed antenna achieves a return loss of −32.8 dB, a VSWR of 1.04, a directivity gain of 7.06 dBi, and a bandwidth of 115.6 MHz at 3.5 GHz. These values surpass the results reported in previous studies (Chowdhury et al., 2022; Irfansyah et al., 2021; Noordin et al., 2024; Rana et al., 2023; Rengarajan et al., 2025), as summarized in Table 3. While Rana et al. demonstrated a slightly wider bandwidth of 144.1 MHz, the proposed design provides a superior balance of return loss, VSWR, and directivity, making it highly efficient and well-suited for modern wireless applications. The comparative analysis in Table 3 underscores the advantages of the present work, confirming its effectiveness for 3.5 GHz communication systems.

Table 2: Simulation results.

	Rectangular Patch	Circular Patch
Return loss (dB)	-32.8	-32.2
VSWR	1.04	1.05
Bandwidth (MHz)	115.6	110.28
Directivity (dBi)	7.06	6.92
Efficiency (%)	41.9	38.8

Table 3: Comparison between the proposed design and benchmarked MPA in the literature.

Reference	S11	VSWR	Directivity(dBi)	Bandwidth
Chowdhury et al. (2022)	-26.5 dB	-	4.2	19 MHz
Noordin et al. (2024)	-22.8 dB	1.15	6.82	60 MHz
Rengarajan et al. (2025)	-27.68 dB	1.55	-	-
Rana et al. (2023)	-30.6 dB	1.06	6.05	144.1 MHz
Irfansyah et al. (2021)	-12.54 dB	1.6	5.5	66.5 MHz
This work	-32.8 dB	1.04	7.06	115.6 MHz

4. CONCLUSION

The design and simulation of rectangular and circular microstrip patch antennas at 3.5 GHz have been successfully carried out, with both structures demonstrating excellent impedance matching, low reflection losses, and stable radiation characteristics. Between the two designs, the rectangular patch antenna exhibits slightly higher directivity and wider bandwidth, indicating better radiation efficiency compared to the circular patch. When benchmarked against similar antennas from the literature, the proposed antennas show clear improvements in return loss, VSWR, and directivity, thereby validating their effectiveness for wireless communication applications. Overall, the results highlight the rectangular patch antenna as a more favorable choice for applications requiring enhanced gain and bandwidth, while the circular patch remains a viable alternative where compactness and design simplicity are prioritized. These findings establish the novelty of the work and its practical relevance to the development of efficient antennas for next-generation wireless networks.

REFERENCES

Balanis, C. A. (2005). Antenna theory: Analysis and design (3rd ed.). Wiley-Interscience.

Chowdhury, M. Z. B., Islam, M. T., Rmili, H., Hossain, I., Mahmud, M. Z., & Samsuzzaman, M. (2022). A low-profile rectangular slot antenna for sub-6 GHz 5G wireless applications. *International Journal of Communication Systems, 35*(17), e5321. https://doi.org/10.1002/dac.5321

Cirik, F., & Yildirim, B. S. (2016). Analysis and design of a 3.5-GHz patch antenna for WiMAX applications. *International Journal of Microwave and Wireless Technologies*, *8*(1), 63–70. https://doi.org/10.1017/S1759078714001238

Ferdous, N., Chin Hock, G., Hamid, H. A. S., Raman, M. N. A., Kiong, T. S., & Ismail, M. (2019, June). Design of a small patch antenna at 3.5 GHz for 5G application. IOP Conference Series: Earth and Environmental Science, 268(1), 012152. https://doi.org/10.1088/1755-1315/268/1/012152

Gupta, M., Sachdeva, S., Swamy, N. K., & Singh, I. P. (2014). Rectangular microstrip patch antenna using air as substrate for s-band communication. *Journal of Electromagnetic Analysis and Applications, 6*(3), 38–41. https://doi.org/10.4236/jemaa.2014.63006

Ibrahim, B., Yang, L., Wang, H., & Tahseen, H. U. (2021). High gain 2×4 rectangular patch antenna array at 3500 MHz for 5G applications. In 2021 International Applied Computational Electromagnetics Society Symposium (ACES-China) (pp. 1–2). https://doi.org/10.23919/ACES-China52398.2021.9581933

Irfansyah, A., Harianto, B. B., & Pambudiyatno, N. (2021). Design of rectangular microstrip antenna 1x2 array for 5G communication. *Journal of Physics:* Conference Series*, 2117*(1), 012028. https://doi.org/10.1088/1742-6596/2117/1/012028

Kumar, G., & Ray, K. P. (2003). Broadband microstrip antennas (1st ed.). Artech House.

Noordin, I. R. M., Hasmizam, M. M., Azmin, A., Fauzi, N. A., Zamri, A. A. M., & Zamani, M. D. N. (2024). Parametric optimization of microstrip patch antenna design for enhanced performance at 3.5 GHz wireless applications. In 2024 IEEE 14th Symposium on Computer Applications & Industrial Electronics (ISCAIE) (pp. 435–439). IEEE. https://doi.org/10.1109/ISCAIE61308.2024.10576301

Orban, D., & Moernaut, G. J. K. (2009). The basics of patch antennas (Updated). Orban Microwave Products, RF Globalnet, 1(9), 1–3.

Prabha, K. R., Nataraj, B., & Jagadeeswari, M. (2022). Design and analysis of microstrip patch antenna for sub-6 GHz applications. In 2022 1st International Conference on Electrical, Electronics, Information and Communication Technologies (ICEEICT) (pp. 1–3). IEEE. https://doi.org/10.1109/ICEEICT53079.2022.9768490

Pushpalatha, M., Namana, N., Navadagi, T. S., & Varun, D. (2023). Design of wide-band microstrip antenna for s-band telemetry applications. Advanced Electromagnetics, 12(1), 70–76. https://doi.org/10.7716/aem.v12i1.2078

Ramli, N., Noor, S. K., Khalifa, T., & Rahman, N. H. A. (2020). Design and performance analysis of different dielectric substrate-based microstrip patch antenna for 5G applications. *International Journal of Advanced Computer Science and Applications,* 11(8), 77–83. https://doi.org/10.14569/IJACSA.2020.0110811

Rana, M. S., Hossain, S., Shuva, S. K. S., Sen, B. K., Islam, S. K. I., & Rahman, M. M. (2022). Design and simulation of microstrip patch antenna for wireless communication systems. In 2022 4th International Conference on Circuits, Control, Communication and Computing (I4C) (pp. 321–325). IEEE. https://doi.org/10.1109/I4C57141.2022.10057931

Rana, M. S., Khurshid, M. N., Joy, S. K., Sourav, M. S. I., Hassan, M. J., & Nazmul, M. J. (2023). A 3.5 GHz microstrip patch antenna design and analysis for wireless applications. *Indonesian Journal of Electrical Engineering and Computer Science,* 32(2), 828–837. https://doi.org/10.11591/ijeecs.v32.i2.pp828-837

Rana, M. S., Sen, B. K., Mamun, M. T. A., Mahmud, M. S., & Rahman, M. M. (2023). A 2.45 GHz microstrip patch antenna design, simulation, and analysis for wireless applications. Bulletin of Electrical Engineering and Informatics, 12(4), 2173–2184.

Rana, M. S., Islam, S. I., Mamun, S. A., Mondal, L. K., Ahmed, M. T., & Rahman, M. M. (2022). An s-band microstrip patch antenna design and simulation for wireless communication systems. *Indonesian Journal of Electrical Engineering and Informatics,* 10(4), 945–954. https://doi.org/10.52549/ijeei.v10i4.4141

Rengarajan, G., Ramalingam, N., & Suriyan, K. (2025). Advanced T-shaped smart antenna architecture for improved mobile network efficiency. *Journal of Industrial Textiles*, 55. https://doi.org/10.1177/15280837251351190

Salami, A. F., Zakariyya, O. S., Sadiq, B. O., & Abdulrahman, O. A. (2017). Evaluative assessment of an X-band microstrip patch antenna for wireless systems. arXiv. https://arxiv.org/abs/1709.00613

Singh, S., Kumar, J., Singh, S., & Gaur, S. (2013). Design of arrow head slotted microstrip patch antenna for WLAN applications. I*nternational Journal of Engineering and Advanced Technology,* 5, 186–188. https://doi.org/10.13140/RG.2.2.33470.72000

Wong, K. L. (2004). Compact and broadband microstrip antennas (2nd ed.). John Wiley & Sons.

Zakariyya, O. S., Sadiq, B. O., Abdulrahman, O. A., & Salami, A. F. (2016). Modified edge-fed Sierpinski carpet miniaturized microstrip patch antenna. *Nigeria Journal of Technology,* 35(3), 637–641.

Zakariyya, O. S., Sadiq, B. O., Olaniyan, A. A., & Salami, A. F. (2016). Dual band fractal antenna design for wireless application. *Computer Engineering and Applications Journal,* 5(3), 101–108.

Zakariyya, S. O., Omole, V. O., Gbadamosi, M. A., Adesina, A. J., Yeketi, A. A., & Sadiq, B. O. (2025). Design, simulation and analysis of a microstrip patch antenna at 2.45 GHz frequency for wireless application. Selcuk *University Journal of Engineering Sciences,* 24(1), 11–17.