Open Access Original Article

Design of a Small Slotted Partial Grounded Fifth-Generation Patch Antenna at 3.5 GHz with Improved Performance

Sayed Abdul Hadi [1] , Abu Zafor Muhammad Touhidul Islam [1]

1. Department of Electrical & Electronic Engineering, University of Rajshahi, Rajshahi, BGD

Corresponding author: Abu Zafor Muhammad Touhidul Islam, touhid.eee@ru.ac.bd

Received 11/26/2024
Review began 11/26/2024
Review ended 01/28/2025
Published 01/28/2025

DOI:
https://doi.org/10.7759/s44388-024-02790-8

Abstract

Compact microstrip antennas are critical for 5G applications due to their ability to integrate easily into telecommunication devices, reduce power consumption, and simplify installation in urban environments. These features make them essential for efficient deployment in modern, densely populated areas. In this work, a small rectangular shaped slotted and partial grounded patch antenna has been designed and simulated at 3.5 GHz for 5G wireless applications. The antenna is created on a 30 × 20 mm^2 size FR-4 lossy substrate having 0.8 mm thickness. A 50 Ω microstrip feed line is used for delivering power to the antenna. Key performance parameters are evaluated and the proposed antenna achieved return loss, gain, directivity, and bandwidth of −56 dB, 2.15 dB, 2.69 dBi, and 1040 MHz, respectively. The antenna design is optimized with the incorporation of slotting on the patch plane and partially removed ground plane structure to obtain minimum Voltage Standing Wave Ratio (VSWR) and return loss values while improving gain, directivity, and bandwidth. The comparative studies reveal that the designed antenna outperforms the previously published designs at 3.5 GHz and is suitable for applications in 5G wireless communication systems. The suggested antenna's experimental prototype is built, and the return loss and VSWR measurements and simulation results agree quite well. The results of this study can be used for the development of compact, low-cost, and improved performance 5G antennas for various applications including mobile devices, Internet of Things network coverage, and small-cell deployments in dense urban areas in the future.

Categories: Microwave and RF Engineering, Wireless Communication Systems
Keywords: patch antenna, mobile application, rectangular slot, partial ground, 5g, 3.5 ghz

Introduction

Microstrip patch antennas, introduced in the 1970s, emerged in response to the shrinking size of electronic devices and have since become vital to modern communication systems. Known as the "eyes and ears" of communication technology, these antennas have revolutionized the field of antenna engineering. Especially in the age of miniaturization, microstrip antennas have widely used in various microwave systems, including radar, telemetry, biomedical devices, mobile and satellite communications, worldwide interoperability for microwave access (WiMAX), Global Positioning System, and more, due to their light weight, low profile, low cost, and ease of manufacture [1]. In a standard microstrip patch antenna, the metallic radiating patch rests on a dielectric substrate that is grounded, with rectangular patches being the most common design [2]. These antennas offer flexibility in feed lines, multiple frequency operations, and good bandwidth, making them suitable for demanding applications [3].

The growth of the fifth generation (5G) wireless network offers high-speed data transmission rates with the frequency range at the lower end 3-5 GHz and at the upper end 24-71 GHz [4]. High-gain and low-profile wideband antennas are crucial for maintaining high-speed wireless communication. Microstrip patch antennas are suitable for 5G communication applications. The effectiveness of the patch antenna depends on the thickness of the substrate, size of the patch, and feedline used [5]. In earlier studies, authors used different techniques to improve the antenna's performance, like partial ground plane with slots [6-8], defective ground structures [9,10], and different substrate materials with different dielectric constant [11-14]. In Ridoy et al. [15], microstrip patch antennas were designed at 3.5 GHz applying three distinct substrates FR-4, RT-5880, and TLC-30 and compared their performance. A small rectangular 5G patch antenna was developed in Rana et al. [16] employing the amalgam method and achieved more than 1.2 GHz bandwidth, 2.50 dB peak gain, and 96.25% radiation efficiency.

In Rana et al. [16], a patch antenna is designed to operate at 3.5 GHz for future wireless communications with improved gain and bandwidth. The designed antenna was fabricated to validate the simulation results. They designed and simulated another microstrip patch antenna operating at 3.5 GHz [17] using Rogger RT5880 as the substrate material with a dielectric constant of 4.3 for raising directivity gain and reducing return loss. In addition, the substrate material's dielectric constant is 4.3. This antenna aims to get a standard Voltage Standing Wave Ratio (VSWR), raise its directivity gain, and give it an acceptable bandwidth. In addition, it should reduce its return loss. In addition, the antenna's return loss will decrease. Cirik and Yildirim [18] designed a high-gain microstrip patch antenna for WiMAX application. They incorporated parasitic radiator and elevated ground plane to enhance gain of the antenna operating at 3.5 GHz. A microstrip patch antenna is constructed by Ramli et al. [13] using three different substrate materials that can function at 3.5 GHz using Computer Simulation Technology (CST) Microwave Studio. They simulated the antennas, analyzed and compared the performance of different antenna configurations. A novel 3.5 GHz rectangular patch antenna is designed by Hossain et al. [19] for applications in the S-band. They obtained lower return loss and a wider bandwidth compared to its performance at lower frequencies and the bandwidth is boosted by increasing the thickness of the substrate. In Prabha et al. [20] microstrip patch antennas were investigated, which are operating in the sub-6 GHz frequency region with a frequency of 3.55 GHz and suitable for use in WiMAX wireless communication applications. The reported rectangular patch antenna displayed superior gain and directivity performance.

Although there are a lot of earlier works on antenna design at 3.5 GHz, most of them are simulation-based study and lack from experimental validation. The major limitations of these designed antennas are their large size and narrow bandwidths. The goal of the research is to design a rectangular slotted microstrip patch antenna at 3.5 GHz with a small size and improved performance characteristics required for 5G wireless communication applications. After the simulation, the second objective is to make an experimental prototype of the designed antenna and measure its performance parameters in the laboratories.

The rest of the article is arranged as follows: it begins with an exploration of microstrip patch antenna design principles in the Introduction section. The Materials and Methods section outlines the design approach, which involves utilizing both simulation and experimental validation to realize the desired performance metrics such as gain, bandwidth, and efficiency. The Results section presents the outcomes of the antenna design efforts, highlighting key findings and their implications within the context of current research. This includes an analysis of the antenna's performance characteristics and comparisons with existing designs or theoretical expectations. The Discussion section wraps up the study by summarizing the key takeaways from the simulation and experimental findings.

Materials And Methods

Antenna design

Structure of the Antenna

The design employs a microstrip feed line to deliver power to the radiating patch element of the antenna, with its characteristic impedance matching the feed line to an impedance of 50 Ω. Among the common feeding methods (microstrip line, coaxial cable, proximity-coupled, and aperture-coupled feed) used for the development of microstrip patch antenna, the microstrip line feeding method is chosen for this design because of its smooth surface, lightweight, small volume, cost-effectiveness, and ease of doing fabrication.

Figure *1* depicts the structure of the proposed antenna designed to resonate at 3.5 GHz. A 0.8 mm thick FR-4 lossy material whose dielectric constant 4.4 and loss tangent 0.025 is used as substrate. A slotted patch and partial ground structures are incorporated in the proposed design and the design parameters are optimized to obtain the antenna with improved performance. The optimized various parameter values of the proposed antenna are shown in Table *1*. The patch is placed on the FR4 substrate's upper surface. The size of the patch is 14 mm × 14.5 mm. The dimension of the FR4 substrate is 30 mm × 20 mm. The antenna comprises a right-angle triangular slot (p = q = 3 mm, r = 4.24 mm) and rectangular slots (L_{i1} = 8.75 mm, W_{i1} = 2 mm, W_{i2} = 1.5 mm, L_{i3} = 12.5 mm, W_{i3} = 1 mm). A microstrip feedline having a dimension of 15 mm × 1.47 mm is used to excite the patch. A slotted patch and a partial ground construction are combined in the design for obtaining better performance. A partial ground plane of 20 mm × 14 mm is inserted on the rare side of the dielectric material. Partial grounding converts the patch antenna's narrow band features into wide band properties. It also diminishes back lobe radiation and the energy stored in the substrate. Slots minimize the VSWR, return loss, along with the antenna's overall dimensions. It improves the bandwidth and gain of the antenna. Figure *1a* shows the designed antenna's front view while the rear view is depicted in Figure *1b*.

The microstrip patch antenna was designed, simulated, and analyzed using CST Studio, which is a software that specializes in analyzing 3D and multilayer configurations in various forms. CST is widely employed for designing different types of antennas and facilitates the calculation and visualization of several key performance parameters considered in the analysis.

Parameters	Values (mm)
Width of Substrate, Ws	20
Length of Substrate, Ls	30
Length of Feed, Lf	15
Width of Feed, Wf	1.47
Length of Patch, Lp	15
Width of Patch, Wp	14.50
Width of Ground, Wg	20
Length of Ground, Lg	14
Height of Substrate, h	0.8
Li1	8.75
Wi1	2
Wi2	1.5
Li3	12.5
Wi3	1
P	3
q	3
r	4.24
Parameters	Values (mm)
Width of Substrate, Ws	20
Length of Substrate, Ls	30
Length of Feed, Lf	15
Width of Feed, Wf	1.47
Length of Patch, Lp	15
Width of Patch, Wp	14.50
Width of Ground, Wg	20
Length of Ground, Lg	14
Height of Substrate, h	0.8
Li1	8.75
Wi1	2
Wi2	1.5
Li3	12.5
Wi3	1
P	3
q	3
r	4.24

TABLE 1: Proposed antenna’s optimized parameter values

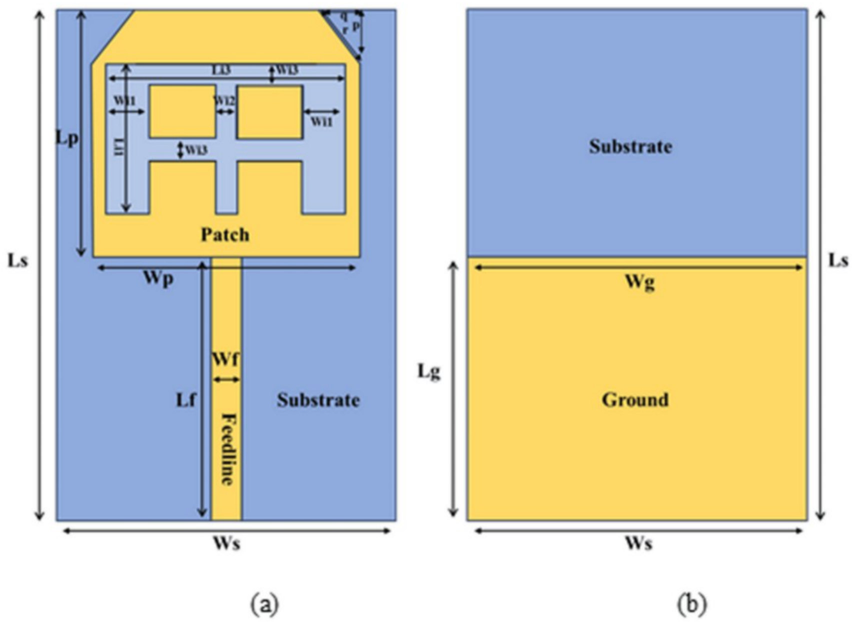

FIGURE 1: Proposed antenna structure (a) front view, (b) rear view

Results

Simulation results

The simulated results of performance parameters of the proposed antenna are discussed here.

Return Loss (S11)

Return loss is an important metric for evaluating how well signals are transferred from the source to the load, particularly if there is an issue with impedance matching or if the load does not receive all of the generated power [14]. It is essential for verifying that impedance matching requirements are satisfied. The S11 parameter, representing return loss, was computed for the antenna design and the results are depicted in Figure *2* as a function of frequency. As seen, the antenna operates at a resonant frequency of 3.5 GHz. The antenna's return loss drops to a minimum of −56 dB at 3.5 GHz, showcasing effective impedance compatibility between the feed line and the patch that radiates. At this frequency, the antenna efficiently radiates maximum power and reflects minimal power. The return loss of −56 dB reflects a reduction of 56 dB in the power reflected compared to the incident power.

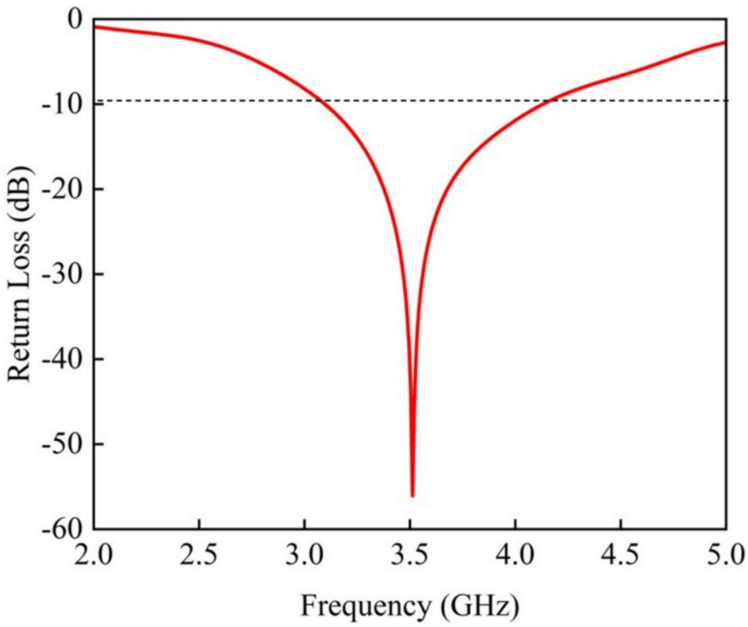

FIGURE 2: Return loss vs frequency of the proposed antenna

Bandwidth

To calculate the antenna’s bandwidth, the return loss graph is employed, which shows the frequency range where the return loss is less than −10 dB, as illustrated in Figure 2. The bandwidth can be further represented as a percentage relative to the band’s center frequency. For the designed antenna, the upper and lower cutoff frequencies are 4.132 GHz and 3.097 GHz, and the bandwidth is 1040 MHz, which is huge enough for used in 5G applications.

VSWR

The VSWR, commonly referred to as the standing wave ratio, is an important indicator of how well the antenna’s impedance matches with the feedline. When VSWR is high, it implies that a substantial amount of the signal is reflected rather than radiated. Ideally, the VSWR should fall between 1 and 2 to minimize reflection losses and ensure efficient operation. When VSWR is lower, it reflects more effective impedance matching between the antenna and its feedline, allowing for more effective power transfer to the antenna. Impedance mismatches between the input and reflected signals within the connector cause signal reflections, affecting VSWR. Figure 3 displays the VSWR versus frequency graph for the designed antenna. The antenna achieves a VSWR of 1.003 at 3.5 GHz, which is below the threshold of 2, demonstrating excellent impedance matching and optimal performance.

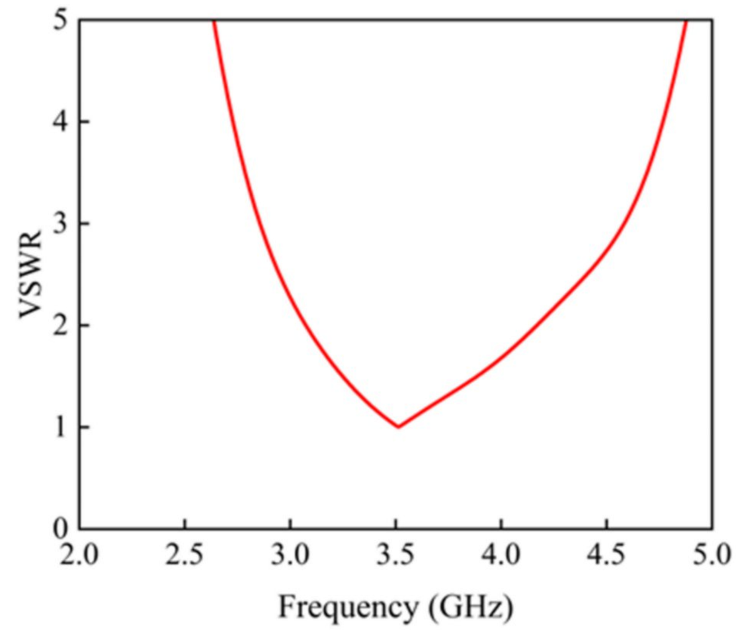

FIGURE 3: VSWR vs frequency of the proposed antenna

VSWR, Voltage Standing Wave Ratio

Efficiency

Antenna efficiency, which represents the ratio of the total energy radiated to the net energy received by the antenna, is a critical performance metric. Figure 4 illustrates the simulated radiation efficiency and total efficiency of the proposed antenna. At the resonant frequency of 3.5 GHz, the antenna achieves a peak value 93.5% for both the radiation and total efficiency. The antenna's radiation efficiencies at the lower frequencies (3.097 GHz) and higher (4.132 GHz) cutoff frequencies are 92.9% and 86.5%, respectively.

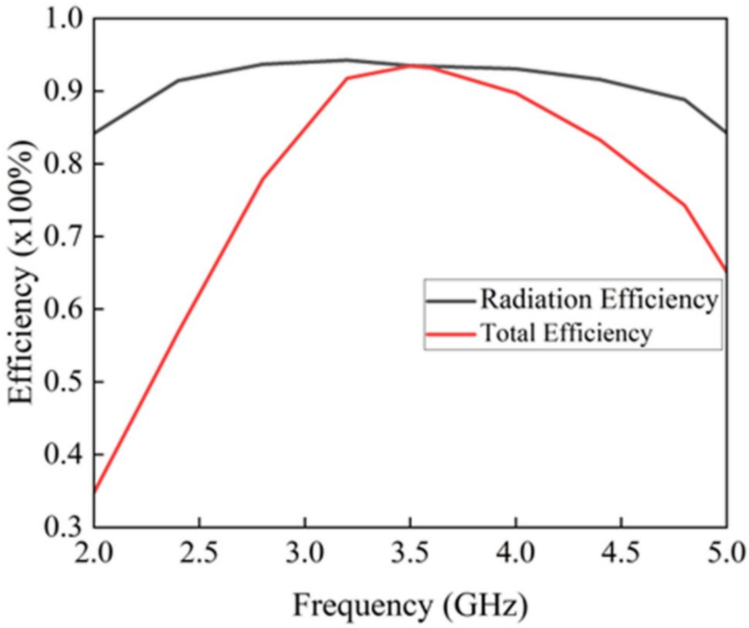

FIGURE 4: Efficiency vs frequency of the proposed antenna

Gain

Antenna gain is a crucial performance parameter, representing the field intensity radiated by the antenna compared to that of a reference antenna. Expressed in decibels (dB), gain indicates the direction of maximum radiation and measures the efficiency with which the antenna transforms electrical energy into radio waves in a given direction. The change of gain of the designed antenna with frequency is shown in Figure *5*. The proposed antenna achieves a gain of 2.15 dB at 3.5 GHz and a peak gain of 2.43 dB between the operating range of 3.097 to 4.132 GHz. A lower gain suggests that the antenna supports signal transmission and reception radio frequency (RF) energy in nearly any direction without requiring precise alignment, while a higher gain focuses more power in a specific direction, reducing reception from other angles. The proposed antenna's gain makes it suitable for various applications, with low gain antennas being ideal for point-to-multipoint and short-range communications, and high gain antennas being better suited for high-speed communication. The 2D polar plot of gain for (a) phi = 0, (b) phi = 90 degrees and the 3D gain pattern of the proposed antenna at 3.5 GHz are shown in Figures *6* and 7, respectively.

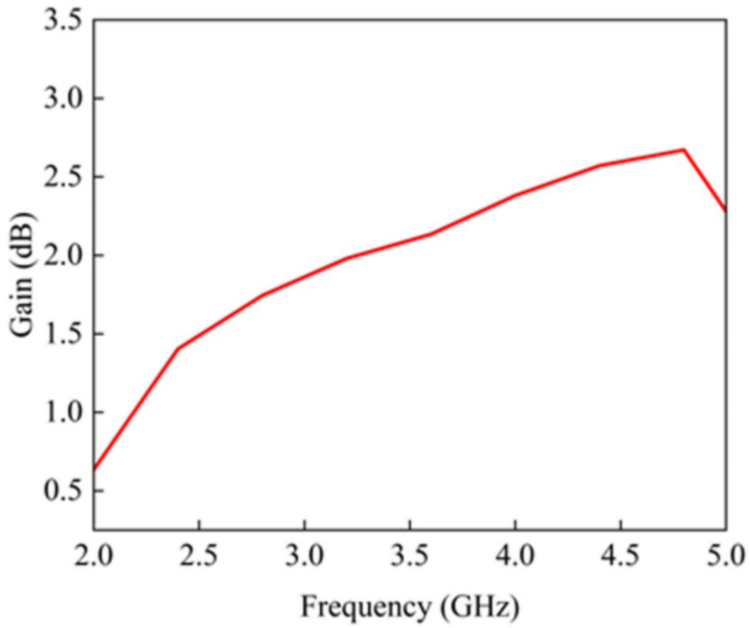

FIGURE 5: Gain vs frequency of the proposed antenna

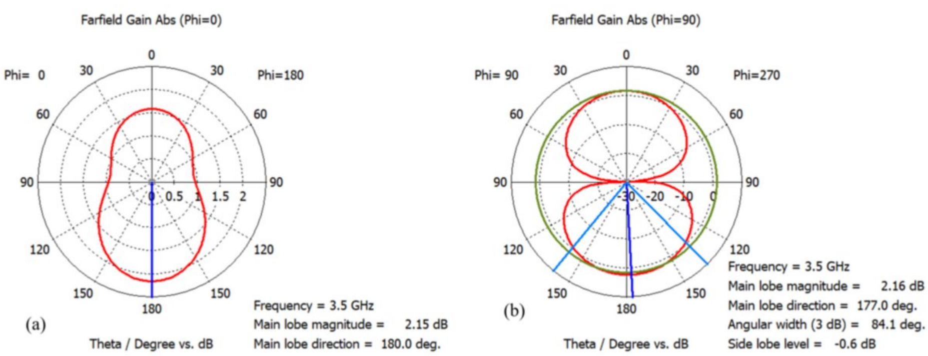

FIGURE 6: Polar plot of gain at 3.5 GHz for (a) phi = 0, (b) phi = 90 degrees

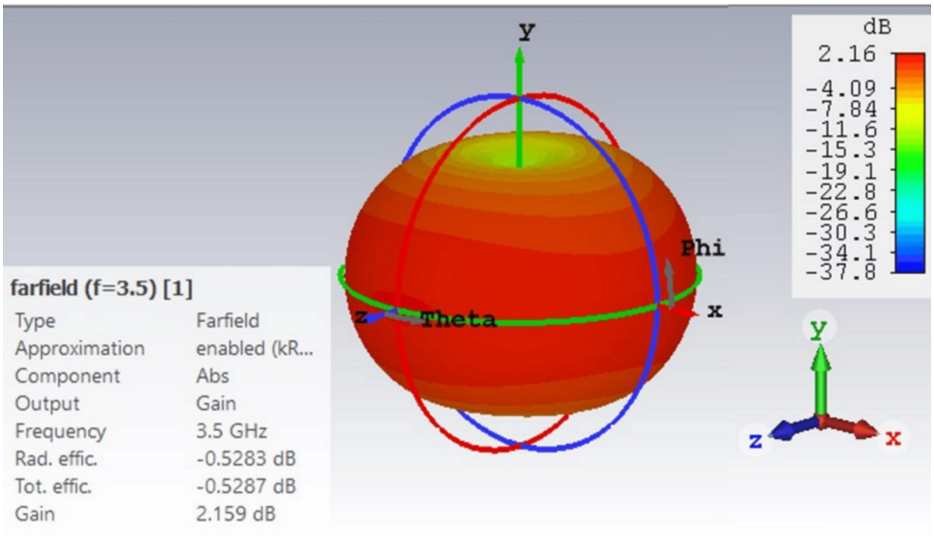

FIGURE 7: The 3D gain pattern of the proposed antenna at 3.5 GHz

While the gain of 2.15 dB is lower than other 5G antenna designs, this trade-off is offset by the antenna's compact size and wide bandwidth of 1040 MHz. These attributes ensure compatibility with applications requiring a small form factor and support high data rates, particularly for short-range or indoor environments such as Internet of Things (IoT) networks and small-cell deployments. This trade-off aligns with the specific performance requirements of modern 5G systems.

Directivity

Maximizing the radiation pattern of an antenna to focus power in a specific direction is essential for effective transmission and reception. This capability reflects the antenna's ability to concentrate EM energy in a certain path. A lower directivity suggests that the antenna distributes RF energy relatively evenly in all directions, while higher directivity means that the antenna focuses energy more precisely in a specific direction. The change of directivity of the designed antenna with frequency is shown in Figure 8. The antenna achieves a directivity of 2.69 dBi at 3.5 GHz and its maximum value of 3.1 dBi is observed within the operating range (3.097-4.132 GHz). The 2D polar plot of directivity for (a) phi = 0, (b) phi = 90 degrees and the 3D directivity pattern of the proposed antenna at 3.5 GHz are shown in Figures 9 and 10, respectively.

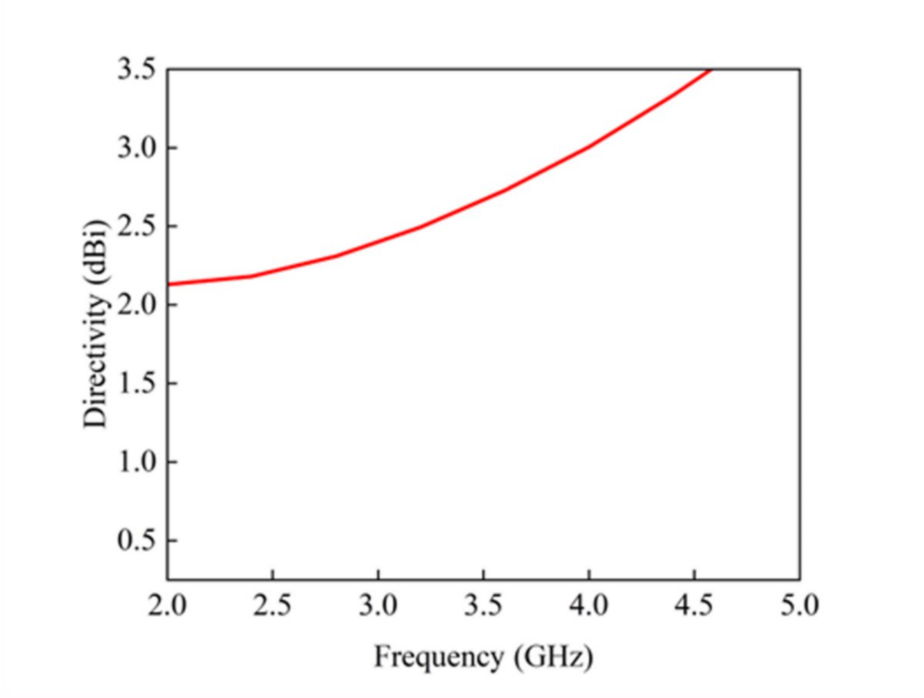

FIGURE 8: Directivity vs frequency of the proposed antenna

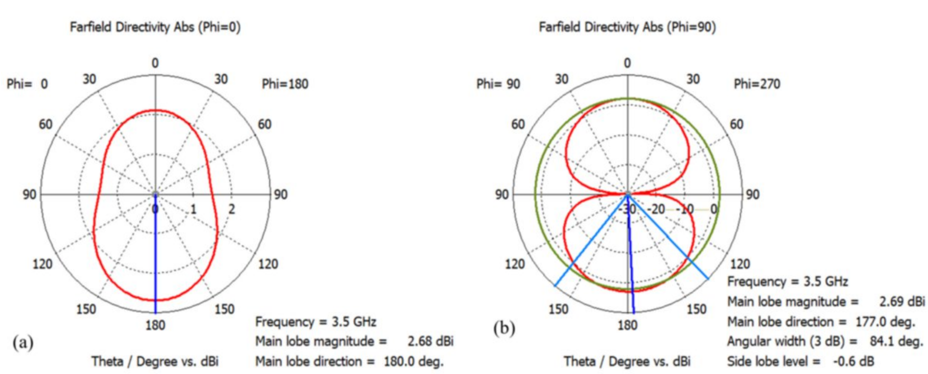

FIGURE 9: Polar plot of directivity at 3.5 GHz for (a) phi = 0, (b) phi = 90 degrees

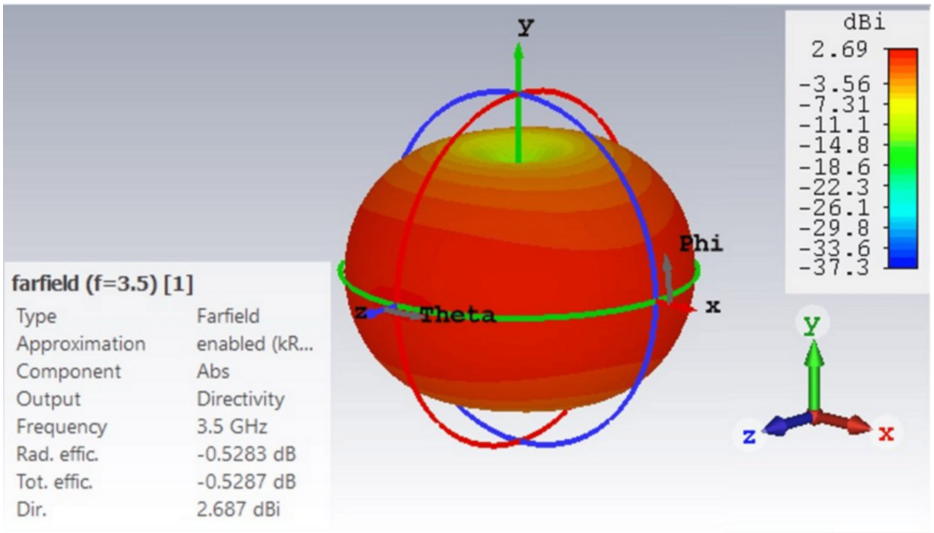

FIGURE 10: 3D directivity pattern of the proposed antenna at 3.5 GHz

Radiation Pattern

Radiation pattern describes the radiation properties of an antenna when measured on the surface of a sphere with a fixed radius. It is analyzed by employing a spherical coordinate system. Figure 11 shows the polar plot of the far-field radiation pattern for the E-field. As seen, at φ = 0 degree, the main-lobe magnitude and main-lobe direction are 16.9 dBV/m and 180 degrees. At φ = 90 degrees, the main-lobe magnitude, main-lobe direction, and angular width are 16.9 dBV/m, 177.3 degrees, and 84.1 degrees, respectively. No significant sidelobes are observed, indicating focused radiation with minimal energy leakage in undesired directions.

Figure 12 shows the polar plot of the far-field radiation pattern for the H-field. The corresponding values at φ = 0 degree, are −34.6 dBV/m and 180 degrees, while at φ = 90 degrees, are −34.6 dBV/m, 177 degrees, and 84.1 degrees. The uniform radiation pattern in the H-plane shows negligible sidelobe presence, supporting omnidirectional performance.

The radiation patterns presented exhibit strong directional characteristics with negligible sidelobe levels and excellent polarization purity. The absence of significant sidelobes ensures minimal interference in adjacent directions, which is essential for improving signal clarity and reducing unintended signal leakage. This is particularly beneficial, such as in 5G networks. These attributes make the antenna suitable for practical 5G applications in environments with high-density communication systems, including directional point-to-point communication and omnidirectional IoT deployments.

Figure 13 depicts the 3D far-field radiation patterns of the proposed antenna. It has been observed that the antenna is showing an omnidirectional radiation patterns at 3.5 GHz resonance frequency. The antenna radiates a maximum power density of 16.9 dBV/m at the resonant frequency of 3.5 GHz.

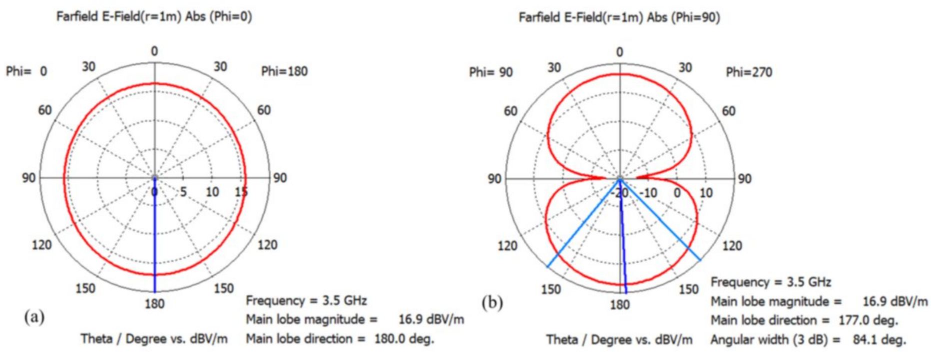

FIGURE 11: Polar plot of E-field pattern for (a) phi = 0, (b) phi = 90 degrees

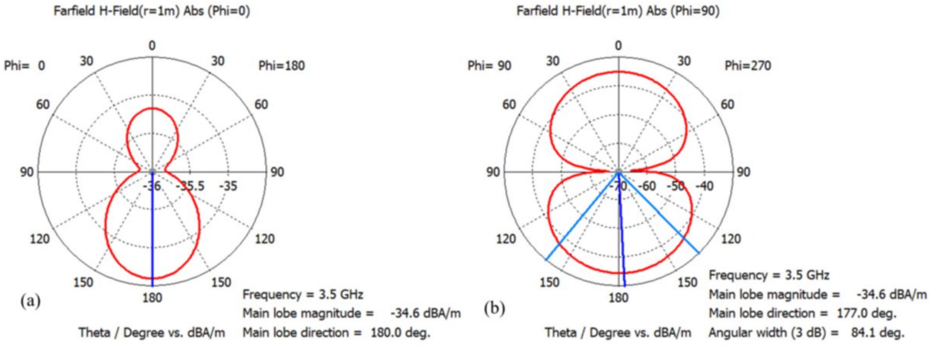

FIGURE 12: Polar plot of H-field pattern for (a) phi = 0, (b) phi = 90 degrees

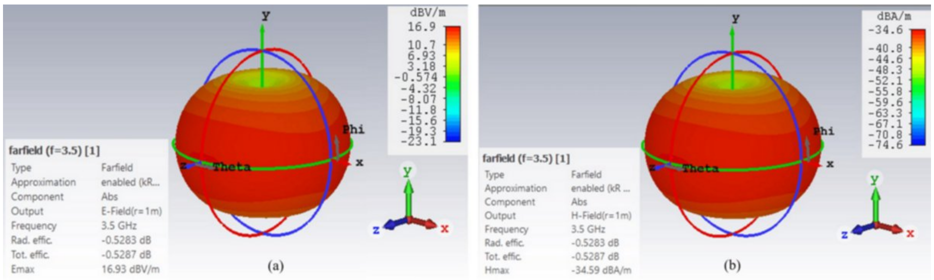

FIGURE 13: 3D far-field radiation patterns of the proposed antenna (a) E-field, (b) H-field

Surface Current Density

The antenna’s current distribution is represented as an electric field for better visualization. As shown in Figure *14*, the current distribution on the patch at 3.5 GHz resonates with a maximum surface current density of 38.3 dBA/m. The figure reveals that the highest current density occurs at the patch’s edges and around the feed line, which typically indicates non-uniform current distribution. Such non-uniformity can happen due to several factors like geometry of the system (layout of the patch and feed line), conductivity variations, edge effects, and electromagnetic fields. Non-uniform current distribution can indeed play a role in improving antenna performance in certain scenarios by reducing losses, enhancing bandwidth and improving directionality or gain in desired directions of 38.3 dBA/m. The figure reveals that the highest current density occurs at the patch’s edges and around the feed line.

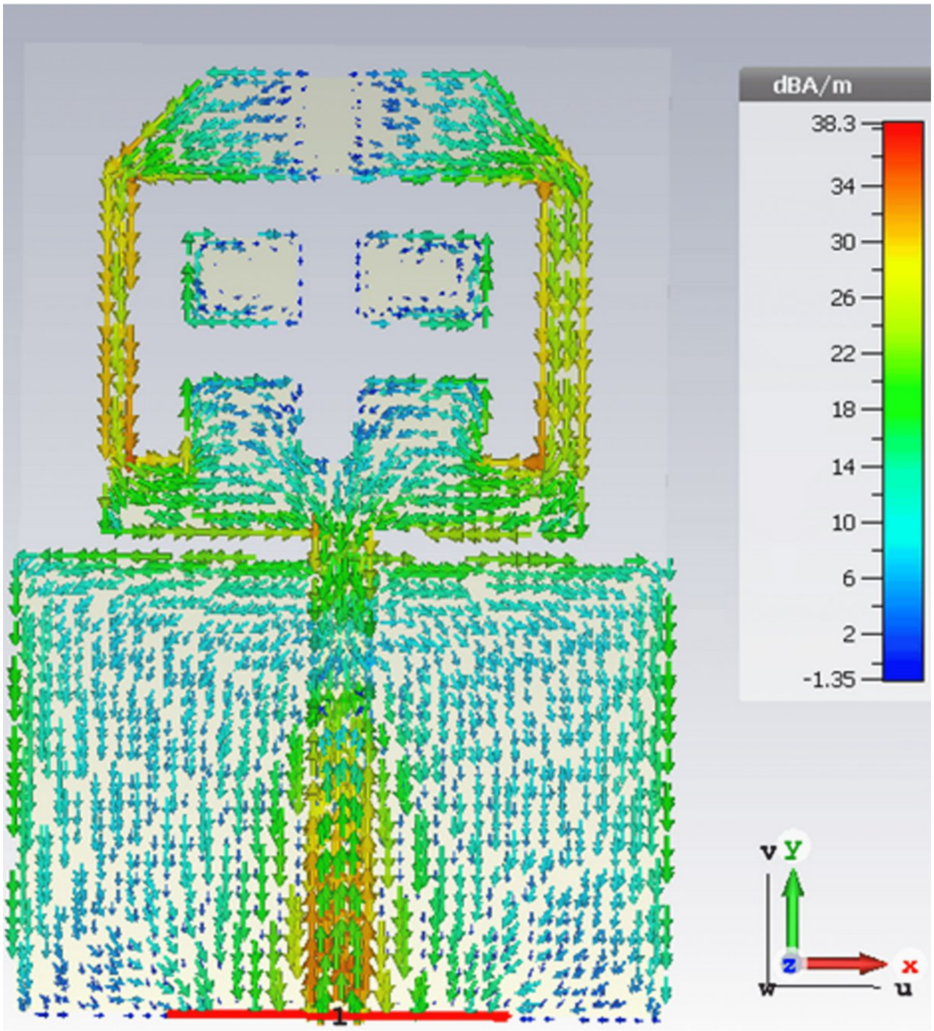

FIGURE 14: Surface current density of the proposed antenna at 3.5 GHz

Discussion

Comparison with recent works

A comparison of the suggested antenna with other referenced antennas is presented in Table *2*. It is evident from the table that the proposed antenna is smaller in size, shows a minimal return loss, and broader bandwidth than many of the referenced antennas. The radiation efficiency of this antenna is reasonable for the targeted 5G applications, while the gain value is lower than most of the ones stated in the references. In spite of having a lower gain, the proposed antenna has a wider bandwidth, which implies an improvement in data transfer rates. Therefore, considering the overall performance, we can conclude that the proposed antenna satisfies the required conditions for 5G wireless communication applications.

Ref. No.	Antenna Size (L × W × h) (mm^3)	Substrate Material/ε_r	Return Loss (dB)	Gain (dB)	BW (MHz)	Radiation Efficiency (%)
[21]	30 × 30 × 1.5	FR-4/4.6	−31.77	1.43	1036	90.75
[22]	71 × 65 × 1.5	FR-4/4.3	−17.264	3.93	116.6	49.99
[17]	20 × 26 × 1.6	FR-4/4.3	−30.66	>5	144	77
[23]	50 × 50 × 1.6	FR-4/4.4	−29.5	3	230	NR
[24]	26 × 20 × 1.6	FR-4/4.3	−30.61	NR	144.1	NR
[25]	26 × 20 × 1.6	FR-4/4.3	−30.61	NR	144.1	NR
[26]	25.2 × 48 × 1.6	FR-4/4.3	−30	5.01	NR	96.67
[27]	43.36 × 35 × 1.575	FR-4/NR	−21.8	6.62	210	89
This Work	30 × 20 × 0.8	FR-4/4.4	−56	2.15	1040	93.5

TABLE 2: Comparison of proposed antenna with other FR-4 based designs at 3.5 GHz

NR, Not Reported

“This Work” stands out with an impressive −56 dB, more negative return loss, indicating very good antenna performance. The highest reported gain is in Ref. [27] with 6.62 dB. Ref. [17] also has a gain greater than 5 dB. “This Work” shows a significant bandwidth of 1040 MHz, which is much wider compared to other references indicating that the antenna can operate more effectively over a wider frequency range. Ref. [21] also has a high bandwidth of 1036 MHz. “This Work” again performs well with 93.5% radiation efficiency indicating better efficiency, while Ref. [21] and Ref. [27] are also relatively high at 90.75% and 89%, respectively. Ref. [22] has the lowest performance in terms of return loss, bandwidth, and radiation efficiency. Ref. [27] has the highest gain but moderate performance in other parameters. “This Work” shows the best overall performance with the lowest return loss, highest bandwidth, and high radiation efficiency.

The proposed FR-4 based patch antenna is smaller in size and offers wider bandwidth, while maintaining reasonable efficiency, cost-effectiveness, and better impedance matching. The reported gain of 2.15 dB, though lower than some designs, is adequate for short-range 5G applications such as IoT devices and small-cell deployments. These scenarios benefit more from wide bandwidth and compact designs than from high gain. The proposed antenna achieves a balance between wide bandwidth, compact size, and acceptable gain. While the gain of 2.15 dB is relatively low, it is justified by the antenna’s ability to support high data rates and its versatility in 5G applications requiring small form factors, such as IoT networks and small-cell deployments. Its compact size and wide bandwidth support high-speed connectivity in mobile devices. The omnidirectional H-plane radiation ensures reliable IoT network coverage, while the focused E-plane pattern and low sidelobe levels make it ideal for small-cell implementations in dense urban areas.

Experimental results of return loss and VSWR

The structure of the proposed antenna is fabricated, and the S11 and VSWR are measured in free space using LiteVNA 64, which has a measurement range of 50 Hz to 6.3 GHz. The glass fiber is used as the substrate during the fabrication due to the unavailability of pure FR-4 material. Figure *15* represents the structure of the fabricated antenna, and Figure *16* illustrates the experimental setup for the measurement of the performance parameters of the manufactured antenna.

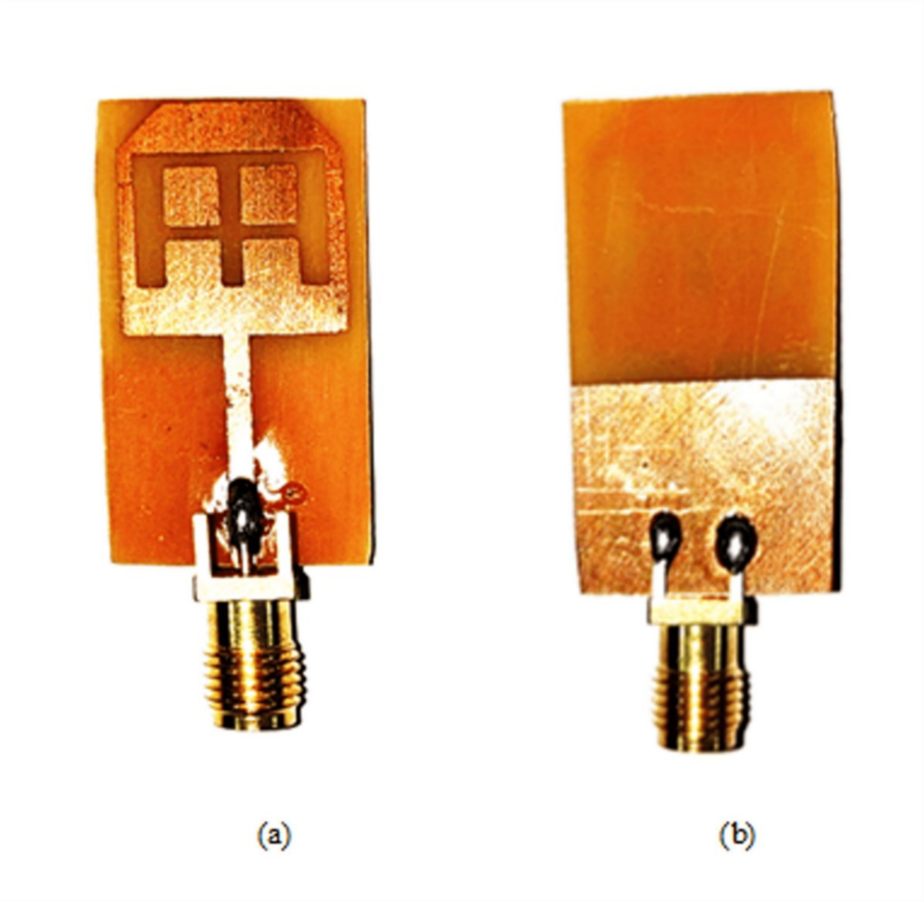

FIGURE 15: (a) Front and (b) back view of the fabricated antenna

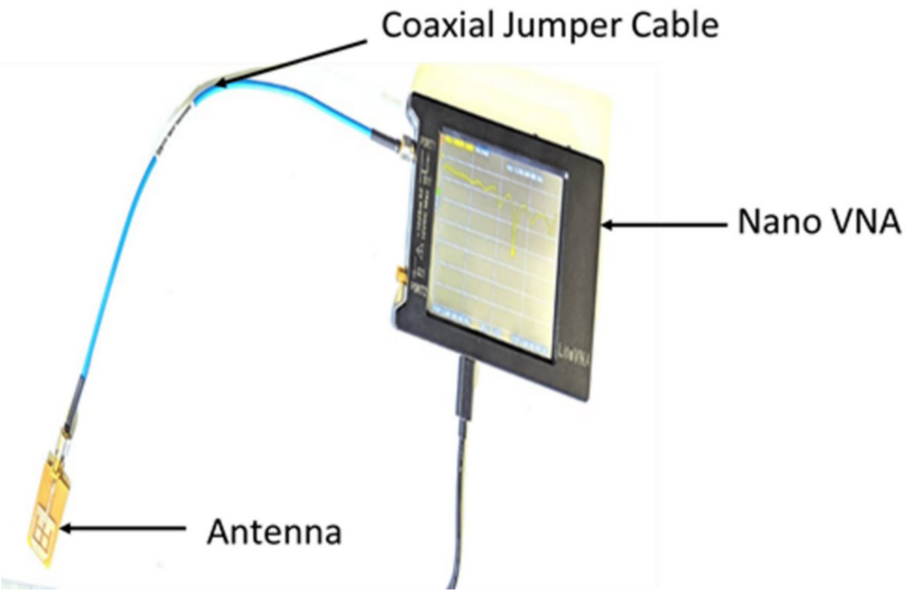

FIGURE 16: Setup for measurement

Figure *17* illustrates the change in return loss (S11) acquired by simulation and measurement versus frequency. As seen, the simulated resonant peak frequency is 3.48 GHz which is close to 3.5 GHz of the designed antenna. The measured value of the return loss at resonant frequency is −43 dB. The antenna's operating bandwidth measured at −10 dB is 1300 MHz (2.95-4.25 GHz) covering the most popular lower 5G (3.33-4.2 GHz) band applications. The variation of the VSWR acquired by simulation and measurement versus frequency is shown in Figure 18. The VSWR values obtained are 1.003 (simulated) and 1.21 (measured), respectively.

The experimental results deviated from the simulated results because of the presence of some manufacturing defects, such as pure FR-4 not being used as substrate, etc. The fluctuations or ripple in the measured data can be introduced by various means, such as material absorption, dispersion, scattering effects caused by the structural defects, or quality of the materials used, connector loss, and so on.

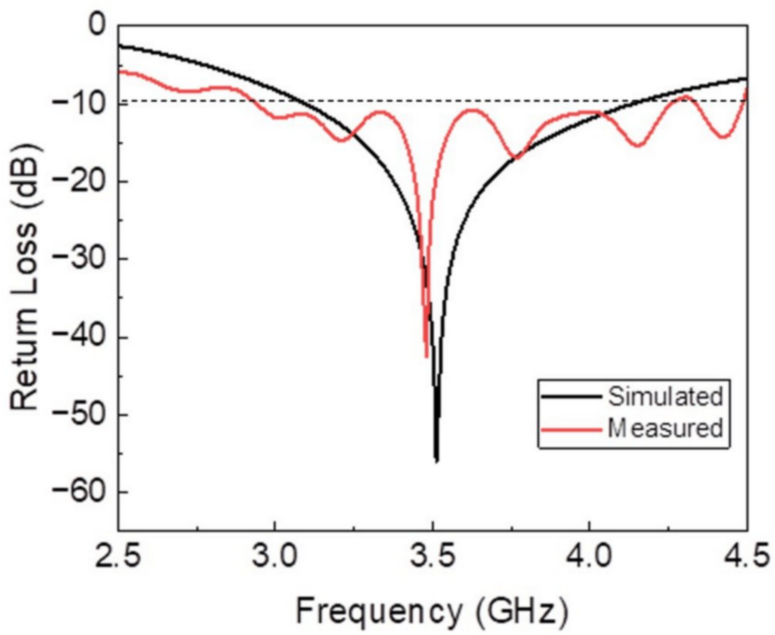

FIGURE 17: Simulated and measured return loss of the proposed antenna

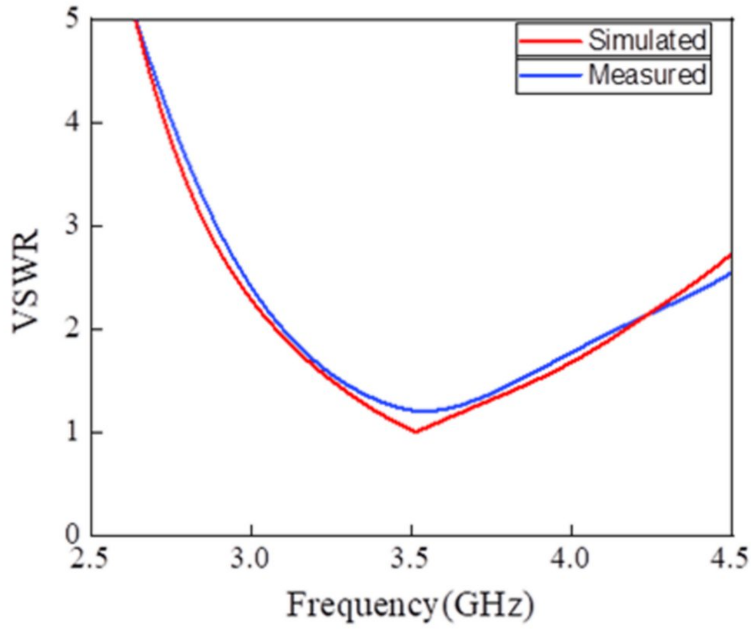

FIGURE 18: Simulated and measured VSWR of the proposed antenna

VSWR, Voltage Standing Wave Ratio

Conclusions

A novel design of a small rectangular slotted partial grounded microstrip patch antenna is provided in this paper for 3.5 GHz 5G wireless technology using CST Microwave Studio. The antenna design is optimized with the incorporation of slotting on the patch plane and partial grounded structure. The proposed antenna is compact in size with the dimensions of 30 × 20 × 0.8 mm^3, and a 50 Ω microstrip feed line is used for delivering power to the antenna. This study analyzed the main performance parameters of the antenna such as return loss, VSWR, bandwidth, gain, directivity, efficiency, current density, and radiation pattern. With a minimum return loss of −56 dB at the resonant frequency of 3.5 GHz, the impedance matching between the feed line and the radiating patch is excellent. The antenna's −10 dB bandwidth is 1040 MHz, and the gain and radiation efficiency at 3.5 GHz are 2.15 dB and 93.5%, respectively. The comparative study of the simulation results obtained in this study reveals that the designed antenna outperforms previously published designs in terms of wide bandwidth, stable gain, and acceptable efficiency and could be a suitable candidate at 3.5 GHz to meet the demands of 5G technology for the advancement of high-speed wireless communication systems. The results for return loss and VSWR from the simulated and measured data of the proposed antenna's experimental prototype exhibit good correspondence. Its compact size and wide bandwidth support high-speed connectivity in mobile devices. The omnidirectional H-plane radiation ensures reliable IoT network coverage, while the focused E-plane pattern and low sidelobe levels make it ideal for small-cell implementations in dense urban areas. This antenna could be deployed, such as in smart cities or automotive communication systems.

In future research work, alternative substrates with better dielectric properties, like low-loss Rogers RT5880, will be used to minimize losses and improve overall performance for high-frequency applications. Additional experiments will be conducted to validate key metrics like radiation efficiency and test the antenna's performance under varied environmental conditions (e.g., temperature, humidity) to ensure its robustness. Instead of using glass fiber, pure FR-4 substrate will be used in the proposed antenna's prototype to align with the simulated setup.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

Concept and design: Abu Zafor Muhammad Touhidul Islam

Acquisition, analysis, or interpretation of data: Abu Zafor Muhammad Touhidul Islam, Sayed Abdul Hadi

Critical review of the manuscript for important intellectual content: Abu Zafor Muhammad Touhidul Islam, Sayed Abdul Hadi

Supervision: Abu Zafor Muhammad Touhidul Islam

Drafting of the manuscript: Sayed Abdul Hadi

Disclosures

Human subjects: All authors have confirmed that this study did not involve human participants or tissue. **Animal subjects:** All authors have confirmed that this study did not involve animal subjects or tissue. **Conflicts of interest:** In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

References

1. Amal KA, Amma S, Joseph S: Compact dual band microstrip patch antenna for Wi-Fi and WiMAX applications. 2015 International Conference on Control Communication & Computing India (ICCC). IEEE, Trivandrum, India; 2015. 474-77. 10.1109/ICCC.2015.7432943
2. Parmar, N, Saxena, M, Nayak, K: Review of microstrip patch antenna for WLAN and WiMAX application. International Journal of Engineering Research and Applications. 2014, 4:168-71.
3. Navneet G, Rituraj R: Selection of microstrip patch antenna substrate for WiMAX application using multiple attribute decision making approach. International Journal of Microwave Science and Technology. 2014, 2014:Article ID 703181. 10.1155/2014/703181
4. Sayidmarie KH, McEwan NJ, Excell PS, Abd-Alhameed RA, See CH: Antennas for emerging 5G systems. International Journal of Antennas and Propagation. 2019, 2019:9290210. 10.1155/2019/9290210
5. Mishra R, Muchhal N, Mishra RS: Multiple T slot compact & ultra wide band microstrip patch antenna for Wimax applications. 2014 IEEE Students' Conference on Electrical, Electronics and Computer Science. IEEE, Bhopal, India; 2014. 1-6. 10.1109/SCEECS.2014.6804494
6. Ahmed F, Kabir H, Islam T: Design of a compact patch antenna with bandwidth and efficiency improvement for UWB applications. Multidisciplinary Science Journal. 2023, 5:2023030.
7. Ashish J, Rao AP: Design and implementation of compact dual band U-slot microstrip antenna for 2.4GHz WLAN and 3.5GHz WiMAX applications. 2019 International Conference on Smart Systems and Inventive Technology (ICSSIT). IEEE, Tirunelveli, India; 2019. 1084-86. 10.1109/ICSSIT46314.2019.8987906
8. Kandewal MK, Kumar BK, Sachin K: Defected ground structure: fundamentals, analysis, and applications in modern wireless trends. International Journal of Antennas and Propagation. 2017, 2017:2018527. 10.1155/2017/2018527
9. Olawoye TO, Kumar P: A high gain antenna with DGS for sub-6 GHz 5G communications. Advanced Electromagnetics. 2022, 11:41-50. 10.7716/aem.v11i1.1670
10. Sajjad H, Sethi WT, Zeb K, Mairaj A: Microstrip patch antenna array at 3.8 GHz for WiMax and UAV applications. 2014 International Workshop on Antenna Technology: Small Antennas, Novel EM Structures and Materials, and Applications (iWAT). IEEE, Sydney, NSW, Australia; 2014. 107-10. 10.1109/IWAT.2014.6958609
11. Pakkiam KT, Mandeep JS: Design of multiband parallel strip patch antenna for DCS/WLAN/WIMAX and RFID applications. 2016 IEEE Industrial Electronics and Applications Conference (IEACon). IEEE, Kota Kinabalu, Malaysia; 2016. 348-53. 10.1109/IEACON.2016.8067403
12. Maheswari T, Sankar VU, Reddy SS, Kumar BP, Rushendrababu K: Design of a microstrip patch antenna for 5G wireless applications. International Journal of Research and Analytical Reviews (IJRAR). 2019, 6:510-15.
13. Ramli N, Noor SK, Khalifa T, Abd Rahman NH: Design and performance analysis of different dielectric substrate based microstrip patch antenna for 5G applications. International Journal of Advanced Computer Science and Applications. 2020, 11:77-83. 10.14569/IJACSA.2020.0110811
14. Ahmed MF, Kabir MH, Islam AZMT: Design of a miniature rectangular patch antenna for 5G applications. ARPN Journal of Engineering and Applied Sciences. 2023, 18:1468-73. 10.59018/0623184
15. Ridoy PM, Elme KM, Shihab R, Saha P, Jawad-Al-Mursalin M, Alam N: A simple design of microstrip patch antenna for WLAN application using 5.4 GHz band. Communications, Signal Processing, and Systems. CSPS 2021. Lecture Notes in Electrical Engineering. Springer, Singapore; 2022. 878:574-81. 10.1007/978-981-19-0390-8_70
16. Rana MS, Islam SI, Mamun SA, Mondal LK, Ahmed MT, Rahman MM: An S-band microstrip patch antenna design and simulation for wireless communication systems. Indonesian Journal of Electrical Engineering and Informatics (IJEECS). 2022, 10:945-54. 10.52549/ijeei.v10i4.4141
17. Rana MS, Hossain S, Shuva SKS, Sen BK, Islam SKI, Rahman MM: Design and simulation of microstrip patch antenna for wireless communication systems. 2022 4th International Conference on Circuits, Control, Communication and Computing (I4C). IEEE, Bangalore, India; 2022. 321-25. 10.1109/I4C57141.2022.10057931
18. Cirik F, Yildirim BS: Analysis and design of a 3.5-GHz patch antenna for WiMAX applications. International

Journal of Microwave and Wireless Technologies. 2016, 8:63-70. 10.1017/S1759078714001238
19. Hossain S, Islam T, Alam S, Munna FS, Mondal T, Jim SK: Design and analysis of 3.5 GHz rectangular patch microstrip antenna for s-band applications. 2023 IEEE International Conference on Integrated Circuits and Communication Systems (ICICACS). IEEE, Raichur, India; 2023. 1-4. 10.1109/ICICACS57338.2023.10100219
20. Prabha KR, Nataraj B, Jagadeeswari M: Design and analysis of microstrip patch antenna for sub-6GHz applications. 2022 First International Conference on Electrical, Electronics, Information and Communication Technologies (ICEEICT). IEEE, Trichy, India; 2022. 1-3. 10.1109/ICEEICT53079.2022.9768490
21. Pushpalatha M, Namana N, Navadagi TS, Varun D: Design of wide-band microstrip antenna for S-band telemetry applications. Advanced Electromagnetics. 2023, 12:70-76. 10.7716/aem.v12i1.2078
22. Rana MS, Rana SB, Islam SKI, Ahamed MT, Rahman H, Hasan MM: Design and performance analysis of S-band microstrip patch antenna for wireless applications. 2022 4th International Conference on Circuits, Control, Communication and Computing (I4C). IEEE, Bangalore, India; 2022. 138-42. 10.1109/I4C57141.2022.10057701
23. Wildan W, Cahyasiwi DA, Alam S, Zakariya MA, Ramza H: Circle microstrip antenna simulation for frequency 3.5 GHz. Journal of Electrical Engineering Acta. 2021, 1:1-4.
24. Asianuba IB, Nwanodim L: Design analysis of 5G microstrip antenna. International Journal of Engineering and Modern Technology (IJEMT). 2022, 8:12-24.
25. Paragya D, Siswono H: 3.5 GHz rectangular patch microstrip antenna with defected ground structure for 5G. ELKOMIKA Jurnal Teknik Energi Elektrik Teknik Telekomunikasi & Teknik Elektronika. 2020, 8:31-42.
26. Ferdous N, Hock GC, Hamid SHA, Raman MNA, Kiong TS, Ismail M: Design of a small patch antenna at 3.5 GHz for 5G application. IOP Conference Series: Earth and Environmental Science. 2019, 268:012152. 10.1088/1755-1315/268/1/012152
27. Ibrahim SK, Jebur ZT: A high gain compact rectangular patch antenna for 5G applications. 2021 International Conference on Communication & Information Technology (ICICT). IEEE, Basrah, Iraq; 2021. 156-60. 10.1109/ICICT52195.2021.9568415