Journal of Engineering Science and Technology Review 17 (5) (2024) 81-86

Research Article

JOURNAL OF
Engineering Science and Technology Review

www.jestr.org

A Novel Structured Antenna with Microstrip Line Fed for Low-Band 5G Applications

Prachi Gupta and Brijesh Mishra*

Department of Electronics and Communication Engineering, School of Engineering and Technology, CMR University, Bengaluru, India

Received 22 March 2024; Accepted 15 September 2024

Abstract

With a focus on sub-6 GHz band, this paper introduces a unique axe-shaped antenna design for 5G communication applications. A 1.6 mm-thick antenna patch is carefully etched over a FR4 substrate with a dielectric constant of ε_r= 4.3 and fed via a line feed method. By using a defected ground construction method, the radiator's mirror image is finely etched onto the ground plane. The total size of the suggested design, which was modeled with CST Microwave Studio, is 48.5 × 24.5 × 1.6 mm³. Several performance factors have been closely monitored in this study, including Surface current distributions, S-Parameter, Antenna Gain and Radiation patterns. The antenna shows great benefits for 5G communication applications with a stable gain of 4.6 dB at the resonating frequency of 3.5 GHz and a simulated and measured bandwidth of 470 MHz (13.4 % fractional bandwidth) and 489 MHz (14.1% fractional bandwidth), respectively. The resonating band is within the mid-band frequency range assigned for 5-Generation networks. A prototype of suggested antenna was characterized using a Vector Network Analyzer (VNA-N5247A) to confirm its effectiveness for 5G, and the findings showed a strong degree of agreement with the simulations.

Keywords: 5G mid-band, DGS (Defective Ground Structure), axe-shaped antenna, elliptical arc.

1. Introduction

The demand for dependable and fast wireless communication has increased recently due to the growing use of smartphones, tablets, and other mobile devices. The fifth generation (5G) wireless communication technology is expected to dramatically improve data rates, lower latency, and increase network capacity over existing 4G systems [1]. The availability of a significant frequency spectrum is a prerequisite for 5G networks in order to accommodate the high data rates and capacity. The latest research and development in 5G antenna design has concentrated on enhancing gain, bandwidth, and compactness to fulfill the high data rate and low latency demands of the upcoming networks. To improve signal strength and coverage, researchers have looked into cutting-edge methods including beamforming, multiple-input multiple-output (MIMO) systems, and integrating millimeter-wave (mmWave) technology. In order to maximize performance while minimizing antenna size, metamaterials and defective ground structure (DGS) are also being utilized. Compact, high-performance antennas appropriate for 5G applications in mobile phones, base stations, and Internet of Things devices are being developed as a result of these developments.

Two different frequency bands for 5G New Radio (NR) have been identified by the Third Generation Partnership Project (3GPP). These are referred to as FR1 (which is in the sub-6GHz range of 450 MHz - 6GHz) and FR2 (which is in the mm-wave range of 24.2 - 52.6 GHz) [2]. These bands include both newly designated 5G wide bands and traditional frequencies. The sub-6 GHz frequency bands have been designated as the major frequency ranges for 5G deployment due to their ability to balance capacity and coverage.

The 5G bands in India have been determined by the Telecom Regulatory Authority (TRAI) in compliance with the International Mobile Telecommunications (IMT)/5G framework [3]. Microstrip antennas have become very popular choices for sub-6 GHz antennas because of their small profile, lightweight construction, affordability, and simplicity in wireless system integration.

The 5G bands in India have been determined by the Telecom Regulatory Authority (TRAI) in compliance with the International Mobile Telecommunications (IMT)/5G framework [3]. Microstrip antennas have become very popular choices for sub-6 GHz antennas because of their small profile, lightweight construction, affordability, and simplicity in wireless system integration. The performance parameters of sub-6 GHz microstrip antennas for 5G applications have been refined in recent studies, with an emphasis on increasing gain, expanding bandwidth, and reducing cross-polarization [4]. To improve the performance of microstrip antennas, techniques including utilizing metamaterials, artificial magnetic conductors (AMC), and defective ground structures (DGS) have been suggested.

One study [2], for example, examines a rectangular patch antenna with proximity-coupled feeding and DGS that operates at 3.5 GHz and has enhanced impedance bandwidth. Using the Rogers RT/Duroid5880 as a substrate, a different researcher suggested a multiband antenna design for 5G mobile applications that spans 3.5 GHz to 12 GHz [5]. Furthermore, a small patch antenna designed for 5G purposes by another researcher [6] has a gain higher than 5 dB.

Expanding upon previous research, [7] describes the design of a flexible co-planar waveguide patch antenna that operates at sub-6 GHz frequencies by using polyethylene terephthalate as a substrate. Other novel designs that employ methods like slotting, DGS, TGS, and array topologies [8–14]

*E-mail address: brijesh.mishra0933@gmail.com
ISSN: 1791-2377
doi:10.25103/jestr.175.11

have also been thoroughly investigated in the context of 5G applications, expanding the range of available antenna options. Several 5G antennas such as for textile, mobile and reconfigurable applications have also been reported in recent works [15-17].

In this paper, we present a small axe-shaped antenna designed with the Defective Ground Structure (DGS) method, which is positioned underneath the antenna to reduce its size and improve its bandwidth. The International Telecommunication Union (ITU) has designated the critical frequency spectrum for 5G applications, which the suggested design resonates at: 3.5 GHz. A thorough examination of the antenna's properties is outlined in multiple parts in the foregoing sections, providing a detailed explanation of its performance characteristics.

2. Antenna Geometry

Making the right substrate choice is a crucial first step in building antennas that are customized for certain uses. The height, loss tangent, and effective permittivity of the substrate have a big impact on important parameters like impedance matching and bandwidth. First, the antenna was built using a traditional elliptical patch design, which was based on Equation [1]. This first strategy did not, however, meet the specified criteria, such as bandwidth and operating frequency, which required additional improvement of other important aspects.

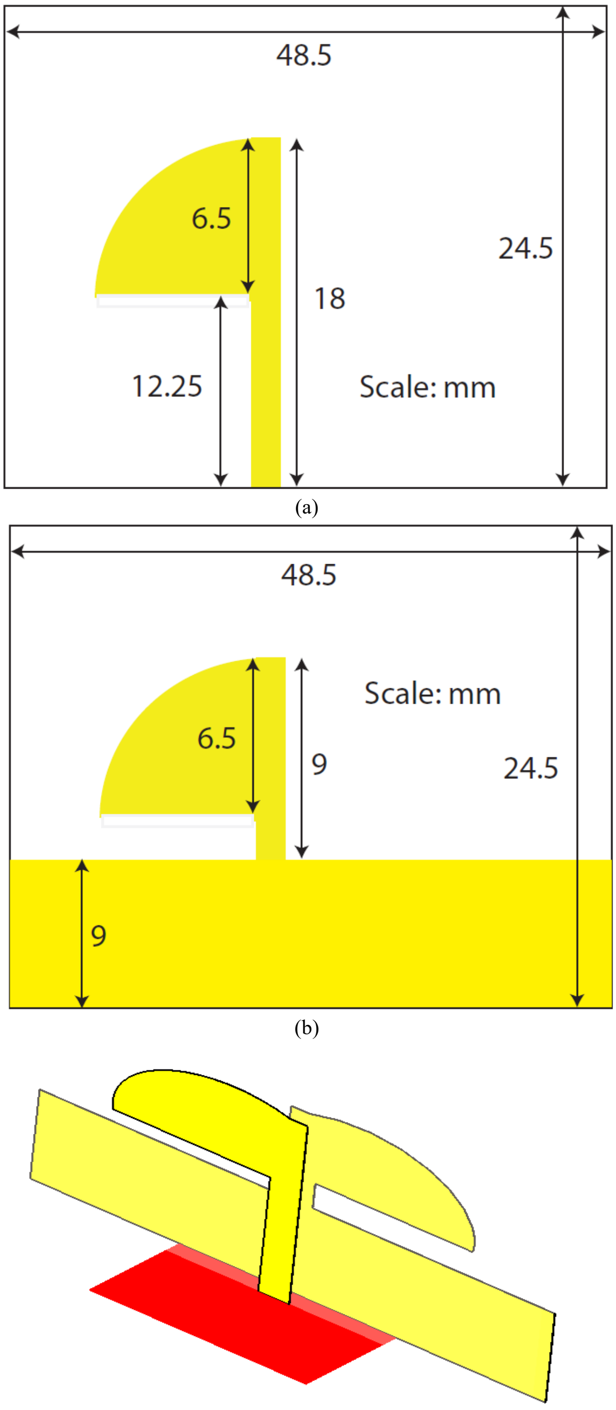
In order to overcome these constraints, the radiator of the antenna was significantly altered, becoming an axe-shaped patch arrangement by means of calculated adjustments. The radiator was cleverly mirrored on the ground plane by utilizing the Defective Ground Structure (DGS) approach. The ability of the axe-shaped structure to produce an optimal current distribution and improved radiation properties led to its selection for the antenna design. Improved impedance matching and a more uniform emission pattern are the results of the axe shape's excellent connection between the antenna's many components. Additionally, this design helps to reduce the antenna's overall size while preserving desired performance metrics. By interfering with the ground plane current, which alters the effective inductance and capacitance, the Defective Ground Structure (DGS) was added to increase bandwidth and gain. This method contributes to the antenna's overall compactness and enhanced performance by increasing bandwidth and decreasing undesired electromagnetic interference. Line feed technology was used to make sure that the excitation was optimized with an impedance of 50Ω as per standard. Equations (1) & (2) was carefully used to determine the patch's radius, allowing for exact modifications to be made in order to satisfy the antenna's performance goals and design requirements. The actual arc dimension of an elliptical patch can be computed after equations (1) & (2) as given below:

$$R_p = \frac{F}{\sqrt{1+\frac{2h}{\pi\varepsilon F\left[ln\left(\frac{F\pi}{2h}\right)+1.7726\right]}}} \quad (1)$$

Where,

$$F = \frac{8.791\times 10^9}{f\sqrt{\varepsilon}} \quad (2)$$

Radius of patch is represented by Rp, height of substrate is represented by h, f is the resonant frequency and Ɛ is the effective dielectric constant of substrate. The physical dimensions are well labelled in Fig. 1, and it is enumerated in the table. 1 with corresponding name. The front view, bottom view and side view geometry of the proposed antenna are portrayed in Figs. 1 (a), (b) and (c), respectively. According to antenna theory and simulated results, the proposed antenna geometry is fabricated and tested and illustrated in Figs. 2 (a) & (b). The simulated and measured results are discussed in the foregoing sections.



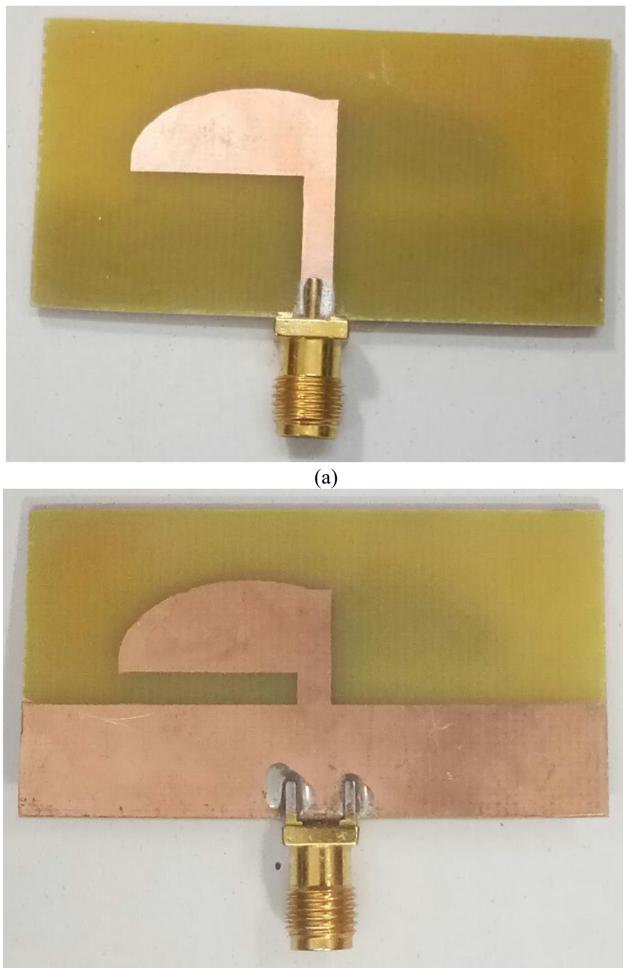
(c)

Fig. 1. Antenna geometry (a) Front view (b) Bottom view (c) Side view

The surface current distribution for the 3.5 GHz microstrip patch antenna shown in Fig. 3 highlights an important aspect of its operation. The concentration of current at the ground plane, stripline, and radiating patch edges, in particular, indicates that the antenna shape plays an important role in steering electromagnetic waves. This concentration pattern is consistent with the TM01 mode, in which the y-axis direction is the primary direction of current flow. This alignment indicates effective radiation use of the patch's surface area, which is essential for the best possible antenna performance. The surface current achieves a maximum intensity of 100 A/m at the resonance frequency of 3.5 GHz, indicating that the antenna can withstand significant power levels at this frequency. As a result, the observed current distribution not only highlights the antenna's applicability for modern wireless communication needs but also offers insightful information about how the antenna functions.

Table 1. Antenna parameters

Parameters	Dimensions (mm)	Parameters	Dimensions (mm)
Length of Ground	48.5	Minor Axis of ellipse	13
Width of Ground	9	Height of Substrate	1.6
Length of Substrate	48.5	Length of Feedline	18
Width of Substrate	24.5	Width of Feedline	2.9
Major Axis of ellipse	22	Size of DGS	9×48.5



(a)

(b)

Fig. 2. Fabricated prototype of the proposed Antenna (a) Front view (b) Bottom view

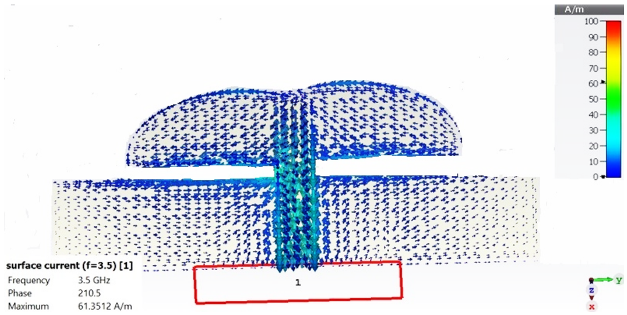


Fig. 3. Surface current distribution of the proposed antenna at 3.5 GHz

3. Results and discussions of simulated and measured results

The suggested antenna was created on a FR-4 substrate with a dielectric constant of 4.4 utilizing a conventional photolithography technique. To guarantee the integrity of the axe-shaped structure and Defective Ground Structure (DGS) parts, precision etching was required during the fabrication process. A vector network analyzer (VNA-N5247A) was used for measurements in order to evaluate the gain, bandwidth, and return loss of the antenna. To guarantee precise impedance measurements, calibration was carried out using a conventional short-open-load-through (SOLT) technique. In an anechoic chamber designed to reduce reflections and outside interference, the radiation pattern of the antenna was tested. We have also talked about possible causes of inaccuracy that were reduced by several testing cycles and meticulous calibration, like small fabrication flaws or outside influences during measurements.

The performance study of the proposed antenna is carried out in this section in terms of reflection coefficient, VSWR, radiation patterns, 3D-antenna gain, directivity, and surface current distributions. Figure 4 depicts the simulated and measured reflection coefficient performance of the proposed antenna, and it is fairly seen that the antenna resonates at 3.5 GHz frequency. The resonating frequency of the proposed antenna conforms with the electrical dimension (λ/2) of the antenna. The suggested antenna resonantly operates at 3.506 GHz and 3.475 GHz, exhibiting a 13.4% simulated and 14.1% measured fractional bandwidth. There is, however, a little difference between the simulated and measured results, which can be related to things like defects in the fabrication process, inconsistent soldering, and the precision of the measuring instruments' calibration. An image of reflection coefficient measurement during antenna testing by means of N5247A VNA (Vector Network Analyzer) was taken and portrayed in Fig. 5. It is evident from Fig. 4 and Fig. 5 that both confirm the correctness and consistency of the simulated and experimental results.

A comparative overview of the proposed work and recently reported works is presented in Table 2. Compared to the antennas reported in [2], [18], and [20], which offer bandwidths of 6.6%, 0.26%, and 4.1%, respectively, the proposed antenna exhibits a much greater bandwidth of 13.4% (simulated) and 14.1% (measured). The incorporation of the Defective Ground Structure (DGS) technology, which increases bandwidth by altering the effective inductance and capacitance, is credited with this enhancement. Although antenna [19] has a slightly broader bandwidth of 18.3%, its usefulness in tiny devices is limited by its huge physical size (2430.2 mm³). On the other hand, our design achieves a more compact size while preserving good bandwidth performance, which makes it more appropriate for contemporary applications with limited space. Furthermore, the compactness and gain balance offered by our antenna design is essential for real-world implementation in wireless communication systems. The suggested design is more inventive and efficient than previous ideas, as seen by its broader bandwidth and better gain while being compact in size, the suggested approach is more efficient and is appropriate for contemporary, space-constrained applications.

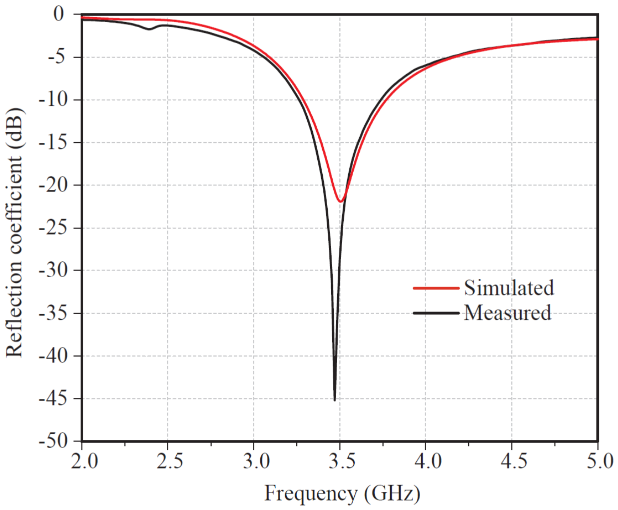


Fig. 4. Reflection coefficient Vs frequency plot of proposed design at 3.5 GHz

The proposed antenna was evaluated at a far field using an anechoic chamber and a measuring setup with the testing antenna and a reference horn antenna, as shown in Fig. 6. Through the synchronization of measurement and experimental data at 3.5 GHz, a comparative study of radiation patterns was produced that included the co- and cross-polarization properties of the suggested antenna. The resulting 3.5 GHz radiation patterns reveal different behaviors, as shown in Figs. 7(a) and (b) for the E-plane and H-plane, respectively. In particular, the E-plane patterns have a structure like the digit eight, which suggests trends in directed radiation. On the other hand, the omnidirectional character of the H-plane patterns points to a high directivity antenna. The cross-polarization levels are significantly lower than the co-polarization levels, highlighting the antenna's effectiveness as a 3.5 GHz radiator. This discovery is consistent with the principles of antenna design in physics, whereby reduced cross-polarization and optimized radiation patterns lead to improved signal integrity and performance in communication systems.

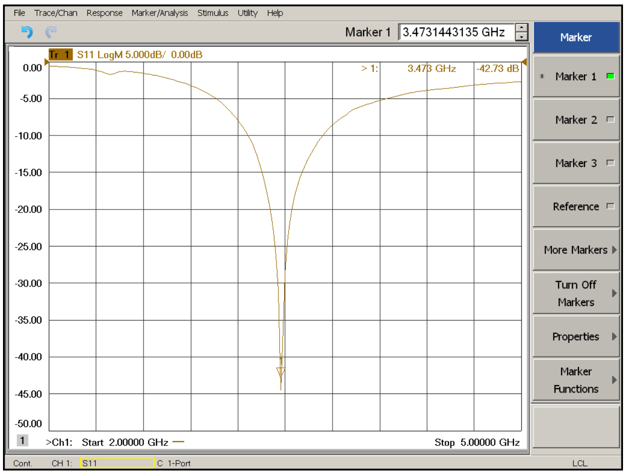


Fig. 5. Experimental photograph through VNA of the reflection coefficient

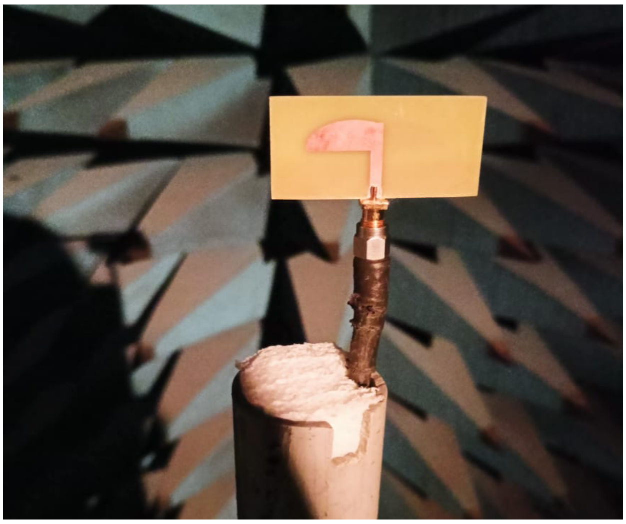
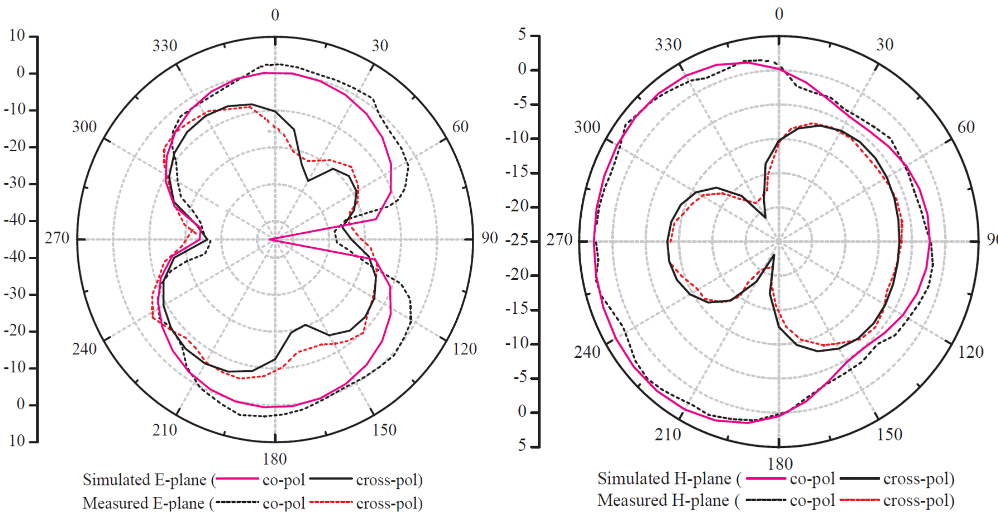


Fig. 6. Measurement setup of the proposed antenna in anechoic chamber

Table 2. Comparison between proposed design [*] and reported designs [2, 18-20].

Ref.	**Frequency (GHz)**	**Antenna size (mm^3)**	**Substrate specification SN, DC, LT, H**	**Gain (dB)**	**BW (MHz)**	**Fractional BW %**
[2]	3.5	45×35×1.6=2520	FR4, 4.4, 0.02, 1.6 mm	3.6	233.2	6.6
[18]	3.4	34×34×3.2=3699.2	FR4, 4.3, 0.02, 3.2 mm	3.8	9.11	0.26
[19]	3.5	44.1×35.1×1.57=2430.2	Rogers RT5880, 2.2, 0.0009,1.57mm	3.68	641.2	18.3
[20]	3.5	40×40×1.65=2640	FR4, 4.3, 0.0005, 0.5 mm	6.05	144.1	4.1
[*]	3.5 S 3.47 M	48.5×24.5×1.6=1901.2	FR4, 4.3, 0.025, 1.6 mm	4.6 S 4.8 M	470 S 489 M	13.4 S 14.1 M

Legends: [*]-Proposed work, S-Simulated, M-Measured, SN-Substrate name, DC-Dielectric constant, LT-Loss of tangent, H-Substrate height



(a) (b)

Fig. 7. Radiation patterns in terms of co and cross polarization at 3.5 GHz (a) E-Plane (b) H-Plane

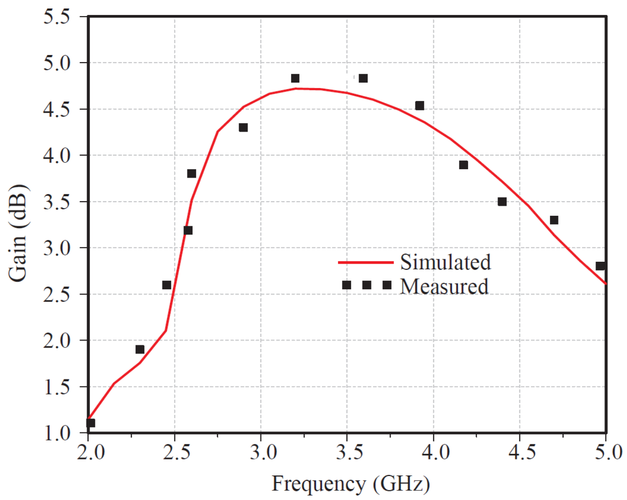


Fig. 8. Simulated and measured antenna gain plot of the proposed antenna.

The results of antenna gain are derived from radiation patterns data with horn antenna power and finally Friis equation [21] is used to calculate the measured antenna gain. A simulated and measured antenna gain plot of the proposed antenna is illustrated in Fig. 8. The gain of the proposed antenna shows a stable behavior in the operating band and a gain of 4.6 dB (simulated) and 4.8 dB (measured) is obtained at resonating frequency. The gain of the intended antenna (4.8 dB) is better than the antennas 3.6 dB [2], 3.8 dB [18], and 3.68 dB [19] as reported in Table 2. However, the antenna [20] exhibits a high gain of 6.05 dB as compared to the proposed antenna gain but it was obtained after the penalty of large antenna size (2640 mm^3).

The axe-shaped antenna's distinctive design, which enables effective current distribution and impedance matching over a broad frequency range, results in consistent gain. Gain variations are lessened by this geometry's reduction of resonant peaks and troughs. Compared to other documented antenna designs, the axe-shaped construction also improves surface current flow and offers a bigger effective aperture, which results in improved radiation efficiency and steady performance.Owing to the above discussion, the proposed antenna has established a good trade-off between the antenna parameters and makes the antenna a good choice among all the reported antennas in Table 2.

4. Conclusion

An important improvement in antenna design has been made with the creation of the planned sub-6 GHz band antenna for 5G applications. The antenna achieves remarkable performance characteristics by using a special axe-shaped patch structure that is enhanced with a mirror image patch on the ground plane by using the Defective Ground structure technique. It is noteworthy that at the important sub-band frequency of 3.5 GHz, which is essential for 5G communication, it achieves a fractional bandwidth of 470 MHz with 13% efficiency. Line feed is used to guarantee the perfect matching, which improves performance even further. Built on an FR4 substrate measuring only 48.5 × 24.5 × 1.6 mm^3, the manufactured design provides an impressive 489 MHz bandwidth at 3.5 GHz. Its effectiveness is confirmed by the agreement between simulated and measured outcomes, making it a strong contender for 5G applications. Important characteristics like gain, radiation efficiency, and reflection coefficient are all well within permissible bounds, indicating that the design is suitable for the rigorous demands of 5G networks. This highlights the design approach's inventiveness as well as its ability to make a substantial contribution to the advancement of wireless communication systems.

References

[1] T. S. Rappaport *et al.*, “Millimeter Wave Mobile Communications for 5G Cellular: It Will Work!,” *IEEE Access*, vol. 1, pp. 335–349, May 2013, doi: 10.1109/ACCESS.2013.2260813.

[2] D. Paragya and H. Siswono, “3.5 GHz rectangular patch microstrip antenna with defected ground structure for 5G,” *ELKOMIKA J. Tek. Energi Elektr. Tek. Telekomun. Tek. Elektron.*, vol. 8, no. 1, Art. no. 31, Jan. 2020.

[3] "Auction of Spectrum in frequency bands identified for IMT/5G"." Telecom Regulatory Authority of India, Nov. 30, 2021. [Online]. Available: https://www.trai.gov.in/sites/default/files/CP_30112021.pdf
[4] M. Li and K.-M. Luk, "Low-cost wideband microstrip antenna array for 60-GHz applications," *IEEE Trans. Antennas Propag.*, vol. 62, no. 6, pp. 3012–3018, Mar. 2014.
[5] P. Elechi and P. O. Richard-John, "Improved Multiband Rectangular Microstrip Patch Antenna for 5G Application," *J. Telecommunic., Electron. Comp. Engin.*, vol. 14, no. 2, pp. 7–14, Jun. 2022.
[6] N. Ferdous, G. Chin Hock, S. Hamidah A.Hamid, M. N. A. Raman, T. Sieh Kiong, and M. Ismail, "Design of a small patch antenna at 3.5 GHz for 5G application," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 268, no. 1, Art. no. 012152, May 2019.
[7] A. Desai, T. Upadhyaya, J. Patel, R. Patel, and M. Palandoken, "Flexible CPW fed transparent antenna for WLAN and Sub-6 GHz 5G applications, Microw," *Microw. Opt. Technol. Lett*, vol. 62, no. 5, pp. 2090–2103, Feb. 2020.
[8] Paul, L.C.; Das, S.C.; Rani, T.; Muyeen, S.M.; Shezan, S.A.; Ishraque, M.F, "A slotted plus-shaped antenna with a DGS for 5G Sub-6GHz/WiMAX applications", *Heliyon,* vol. 8, no. 12, Art. no. e12040, Dec. 2022.
[9] Prachi and T. K. Mandal, "Dual frequency millimeter-wave perturbed ring patch antenna array for 5G applications," *IETE J. Res.*, vol. 69, no. 9, pp. 2709-2725, Nov. 2022.
[10] M. I. Khattak, "Elliptical Slot Circular Patch Antenna Array with Dual Band Behaviour for Future 5G Mobile Communication Networks*", Prog. Electrom. Res. C.,* vol. 89, pp. 133-147, Jan. 2019.
[11] S. Agarwal, "High gain linear 1×4X-slotted microstrip patch antenna array for 5G mobile technology," *J. Telecommunic. Inform. Techn.,* vol. 1, pp. 50–55, Jan. 2020.
[12] P. Gupta and V. Gupta, "Thinned 8 × 8 planar antenna arrays with reduced side lobe levels for 5Gapplications," *Wirel. Pers. Commun.*, vol. 119, pp. 639–655, Feb. 2021.
[13] P. Gupta and V. Gupta, "Linear 1 × 4 microstrip antenna array using slotted circular patch for 5G communication applications," *Wirel. Pers. Commun.*, vol. 127, no. 4, pp. 2709–2725, Jun. 2022.
[14] M. Sohel Rana, S. Hossain, S. Biswas Rana, and M. Mostafizur Rahman, "Microstrip patch antennas for various applications: a review," *Indones. J. Electr. Eng. Comput. Sci.*, vol. 29, no. 3, Art. no. 1511, Mar. 2023.
[15] P. Jha, A. Kumar and A. De, "Two-port miniaturized textile antenna for 5G and WLAN applications," *Int. J. Microw. Wirel. Technol.,* vol. 15, no. 8, pp. 1443–1452, Oct. 2023.
[16] M. Hu and Y. Li, "Wideband Back Cover Microstrip Antenna With Multiple Shorting Vias for Mobile 5G MIMO Applications," *IEEE Trans. Antennas Propag.,* vol. 71, no. 10, pp. 8290–8295, Oct. 2023.
[17] S. T. Al-Hadeethi, T. A. Elwi, and A. A. Ibrahim, "A Printed Reconfigurable Monopole Antenna Based on a Novel Metamaterial Structures for 5G Applications," *Micromachines*, vol. 14, no. 1, Art. 131, Jan. 2023.
[18] Y. Al-Yasir, A. Abdullah, N. Ojaroudi Parchin, R. Abd-Alhameed, and J. Noras, "A new polarization-reconfigurable antenna for 5G applications," *Electronics (Basel)*, vol. 7, no. 11, Art. no. 293, Nov. 2018.
[19] M. F. Rafdzi, S. Y. Mohamad, A. A. Ruslan, N. F. A. Malek, M. R. Islam, and A. H. A. Hashim, "Study for Microstrip Patch Antenna for 5G Networks," in *2020 IEEE Student Conference on Research and Development (SCOReD)*, Batu Pahat, Malaysia: IEEE, Sep. 2020, pp. 524–528. doi: 10.1109/SCOReD50371.2020.9251037.
[20] M. S. Rana, M. N. Khurshid, S. K. Joy, M. S. I. Sourav, M. J. Hassan, and M. J. Nazmul, "A 3.5 GHz microstrip patch antenna design and analysis for wireless applications," *Indonesian J. Electr. Engin. Comp. Sci.*, vol. 32, no. 2, Feb. 2023.
[21] K. Chang, Ed., *Encyclopedia of RF and microwave engineering*. Hoboken, N.J: John Wiley, 2005.