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Inset Fed Microstrip Patch Antenna Design For 5G Application At 28 Ghz

Md. Abdullah-Al-Mamun[1], Md. Arifur Rahman[2], Md. Kisour Chowdhury[3]

[1]Department of Electrical and Electronic Engineering, Bangladesh Army International University of Science and Technology, Cumilla, Bangladesh
[2]Department of Electrical and Electronic Engineering, First Capital University of Bangladesh, Chuadanga
[3]Department of Electrical Engineering, American International University-Bangladesh
mamunal59@gmail.com, uzzalruapee@gmail.com, ckisour@gmail.com
Corresponding Author: Md. Abdullah-Al-Mamun. E-mail: mamunal59@gmail.com

Abstract— This study describes the design, modelling, and performance assessment of an inset fed microstrip patch antenna (MPA) operating at a center frequency of 28 GHz that was created especially for 5G millimeter-wave (mmWave) applications. Key performance characteristics are significantly improved by the suggested antenna's strategic use of an inset feed mechanism to increase impedance matching and reduce reflection losses. According to thorough calculations carried out using HFSS software, the inset-fed antenna achieves a return loss of –29.8997 dB, demonstrating good impedance matching. Additionally, the design successfully covers the target frequency range needed for high-speed 5G communication systems with a large impedance bandwidth of 1135 MHz (27.47-28.605 GHz). A peak gain of 7.1328 dBi is another feature of the antenna that is necessary to provide adequate signal strength and coverage in small wireless devices. A comparison study is conducted against a traditional non-inset feeding MPA of comparable size in order to highlight the advantages of the inset-fed method. Findings validate the efficacy of the feeding approach by demonstrating that the inset-fed structure provides much increased radiation performance, a wider bandwidth, and dramatically enhanced return loss. Because of its small size, simplicity of construction, and effective radiation properties, the antenna is ideal for incorporation into systems and devices that will support 5G in the future. The feasibility of using inset-fed MPA for high-frequency wireless communication in the millimeter-wave range is confirmed by this work.

Keywords—5G applications; Inset fed; Return loss; Bandwidth; Gain.

I. INTRODUCTION

Fifth-generation (5G) networks, which require high data rates, ultra-low latency, and improved connectivity for applications like augmented reality (AR), driverless cars, and the Internet of Things (IoT), have been deployed as a result of the rapid evolution of wireless communication technologies [1]. Because of its large accessible bandwidth and potential for high-speed data transmission, 5G systems use millimeter-wave (mm-wave) frequency bands, especially the 28 GHz spectrum, to achieve these needs. However, there are many obstacles to overcome when building effective antennas at these high frequencies, such as increased path loss, air absorption, and strict miniaturisation requirements [2], [3]. Because of its low profile, lightweight design, simplicity of manufacture, and compatibility with integrated circuits, MPAs are the most popular antenna type for 5G applications [4]. However, performance at mm-wave frequencies is deteriorated by typical non-inset fed MPAs, which often have limited bandwidth, poor impedance matching, and surface wave losses [5]. A number of feeding strategies, including aperture coupling, inset feeding, and coaxial probe feeding, have been studied in order to get around these restrictions [6]. Because it may increase impedance matching without the

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need for extra matching networks, inset feeding has become one of these promising techniques, increasing radiation efficiency and bandwidth [7].

Rahman and Hasan [8] developed an equilateral triangular MPA that is appropriate for 5G application technologies and operates at 28GHz. Inset feeding approaches are taken into consideration throughout the design process, and both CST and HFSS are implemented in order to evaluate their performance by computing antenna parameters. Using both CST and HFSS techniques, the results show that the S11, VSWR, gain, and bandwidth are -26.24 and -14.60dB, 1.102 and 1.53, 5.39 and 5.94dBi, 0.708 and 0.503GHz, respectively. As a final benefit, the suggested antenna design is smaller than the majority of previous designs and satisfies a 5G technology need. Didi et al. [9] used the microstrip line approach for feeding in their analysis and design of a rectangular MPA with a rectangular slot operating at 28 GHz that is used as 5G wireless applications. This antenna is constructed has a loss tangent of 0.0009, a height of h = 0.5mm, and a relative permittivity of 2.2. These simulations yielded the following results: a gain of 7.5dB, a bandwidth of 1.06GHz, a frequency of 27.97GHz, and a RL of -20.95 dB. As a result, this antenna should meet the requirements for applications using 5G wireless communication. For upcoming 5G millimeter-wave applications, Zhang et al. [10] suggested a MIMO DRA with inhenced isolation. On a substrate, two rectangular (DRs are positioned. The 28 GHz spectrum given to 5G applications by the Federal Communications Commission is covered by the proposed antenna's simulated impedance bandwidth, which spans from 27.25GHz to 28.59GHz. CP inset-fed MPA suitable for 5G wireless systems operating at 28 GHz was reported by Goyal et al. [11]. The 28 GHz frequency spectrum for 5G wireless applications was satisfied by the simulation result. With a RL of -18.25dB, an antenna gain of 6.72dB, and a VSWR < 2, the results viewed that the antenna at 28 GHz has the least amount of reflection. A 28GHz operating frequency MPA for 5G mobile communication was presented by Li [12]. With a BW of 280MHz, a gain of 2.2dBi, a RL of -24dB, and a VSWR of 1.24, the suggested antenna resonates at 28 GHz. The 50 transmission line impedance is matched using the inset feed method. The Rogers RT5880 substrate and copper ground are used in the design. In conclusion, 5G mobile communications may make use of the suggested antenna.

Although the research currently in publication highlights the advantages of inset-fed MPAs, a thorough comparison of inset-fed and non-inset-fed systems operating at 28 GHz is not available. A thorough design and performance study of an inset-fed MPA tailored for 5G applications are presented in this research to close this gap. In order to provide suggestions for future mm-wave antenna designs, the research also looks into how inset width and depth affect impedance matching.

This paper's remaining sections are organized as follows: The antenna design process, including parametric analysis and substrate selection, is covered in Section II. Simulation results are shown in Section III. The comparison analysis with non-inset-fed MPAs is covered in Section IV, and the conclusion is covered in Section V.

II. ANTENNA DESIGN PROCEDURE

A MPA is a lightweight, low-profile antenna made out of a ground plane on one side and a metallic patch printed on a dielectric substrate. [13[, [14]. An inset-fed MPA is particularly constructed for 5G applications at 28 GHz in this study. The inset feed approach is employed to minimise return loss and increase impedance matching. Establishing the design requirements, which include the operating frequency (28 GHz), substrate material (Rogers RT/Duroid 5880 with $\varepsilon_r = 2.2$), and required characteristics like bandwidth and gain, is the first step in the technique. Proper resonance and 50 Ω impedance matching are achieved by calculating the patch's length and breadth as well as the inset feed location using conventional transmission line model formulae. Fig. 1 shows the perspective view of the proposed antenna and Table I shows the dimensions of the antenna. Equations for the antenna design are provided in [15], [16].

Step 1: The patch's width

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

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Step 2: One of the most important parts of antenna design is figuring out the substrate's effective dielectric constant and effective length.

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1 + 12\frac{h}{Wp}\right)^{-0.5} \quad (2)$$

$$Leff = \frac{Co}{2f_r\sqrt{\varepsilon_{reff}}} \quad (3)$$

Step 3: Calculating an antenna's length extension

$$\Delta L = 0.412h\frac{(\varepsilon_{reff}+0.3)\left(\frac{Wp}{h}+0.264\right)}{(\varepsilon_{reff}-0.258)\left(\frac{Wp}{h}+0.8\right)} \quad (4)$$

Step 4: One of the most important calculations in antenna design is determining the antenna's length.

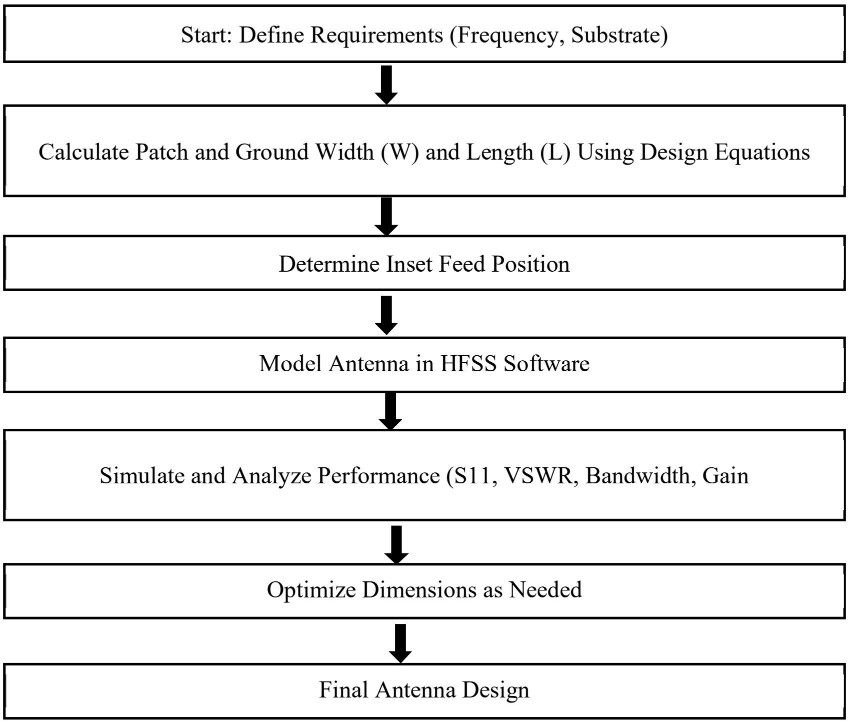
$$Lp = L_{eff} - 2\Delta L \quad (5)$$

Step 5: Following that, the ground plane's length and breadth, as well as the dimensions of the rectangular microstrip patch, may be computed using equations (6) and (7).

$$Lg = 6h + L \quad (6)$$

$$Wg = 6h + Wp \quad (7)$$

Using HFSS software, the antenna is modelled and simulated in order to assess performance parameters such as radiation pattern, bandwidth, gain, and return loss (S11). The required performance is attained by repeatedly optimising the design parameters. The suggested antenna's perspective view is shown in Figure 1, and Table 1 lists the antenna's measurements. The following flowchart presents the methodology.



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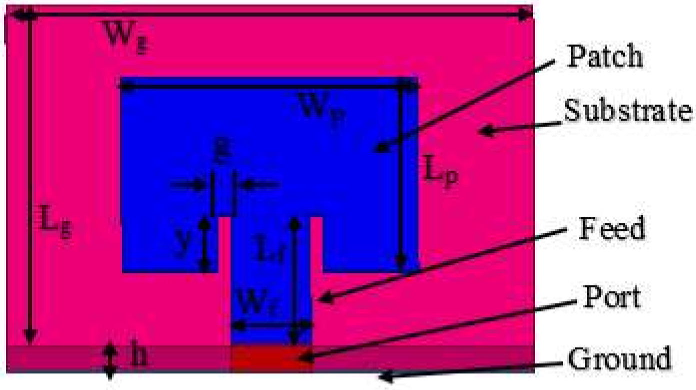

Fig. 1: Perspective view of Inset fed microstrip antenna

Table I: Dimensions of optimized antenna

Substrate height, h	0.5 mm
Ground width, Wg	8.5 mm
Ground Length, Lg	8.5 mm
Patch width, Wp	4.5 mm
Patch length, Lp	4.5 mm
Dielectric constant	2.2 mm
Feed width, Wf	1.21 mm
Feed length, Lf	3.05 mm
Inset depth, y	1.3 mm
Inset width, g	0.195 mm

III. RESULTS AND ANALYSIS

In wireless systems, antennas are essential parts that allow electrical impulses to be converted into electromagnetic waves and vice versa. Antenna performance has a major impact on wireless communication's strength, clarity, and dependability. Engineers look at return loss, bandwidth, gain, and directivity, among other technical criteria, to determine how well an antenna works. These elements assist assess the antenna's suitability for different technical applications and provide a thorough grasp of its capabilities.

A. Return Loss (RL)

Return loss is a crucial antenna design metric that shows how well the antenna matches the feeding network or transmission line. The power that is reflected back as a result of impedance mismatches is measured and is measured in decibels (dB). More effective signal transmission results from improved impedance matching and less reflection, which are represented by a more negative return loss value [17], [18]. The return loss and bandwidth of the inset fed and without inset fed antenna are viewed in Fig. 2 and Table II. The inset-fed MPA in this investigation demonstrated good impedance matching at the target frequency of 28 GHz, with a considerably decreased return loss of –29.8997 dB. The same antenna without the inset feed design, on the other hand, had a return loss of only –13.1938 dB, suggesting worse matching and more signal reflection. Additionally, the inset-fed design resonated precisely at 28 GHz, whereas the non-inset-fed variant resonated slightly lower at 27.85 GHz. The inset-fed design offered a broader bandwidth of 1135 MHz (27.47-28.605 GHz) as opposed to 935 MHz (27.415-28.35 GHz) for the non-inset-fed antenna. These findings demonstrate that the inset feeding method improves the antenna's bandwidth, frequency accuracy, and return loss.

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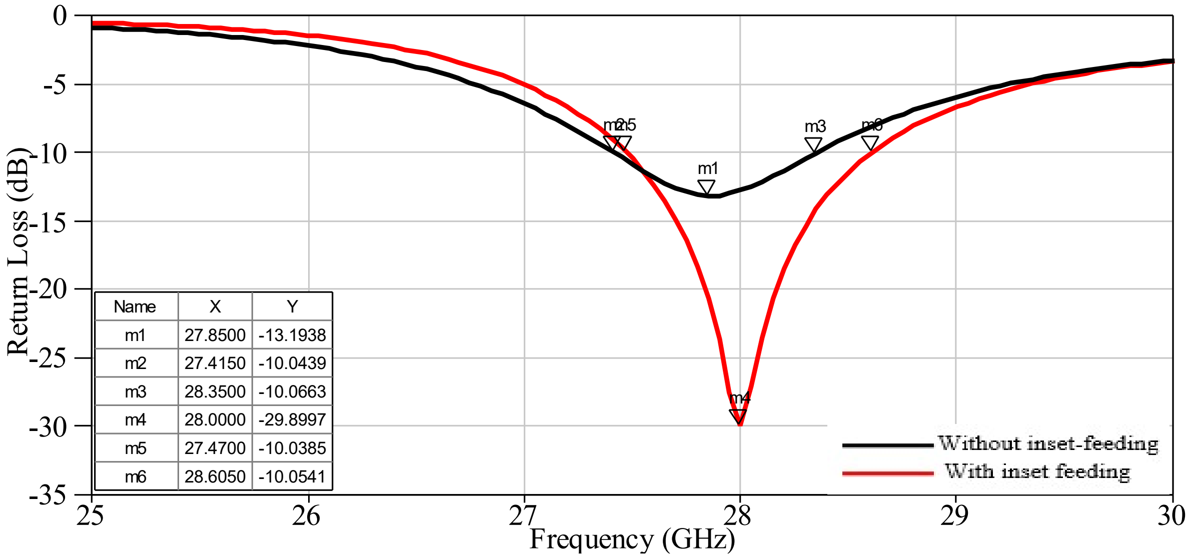

Fig. 2: Return loss plot

Table II: Comparison of inset feeding and without inset feeding antenna

Parameters	Without inset feeding antenna	Inset feeding antenna
Operating frequency (GHz)	27.85	28.00
Return loss (dB)	-13.1938	-29.8997
VSWR	1.5606	1.0661
Bandwidth (MHz)	935 (27.415-28.35 GHz)	1135 (27.47-28.605 GHz)
Gain (dBi)	6.2934	7.1328

B. *VSWR*

A crucial factor in antenna design, the “voltage standing wave ratio (VSWR)” measures how well power is transmitted from the feed line to the antenna. It measures how well the antenna and transmission line match in terms of impedance; a lower VSWR value indicates greater matching and less signal reflection. Perfect matching is ideally represented by a VSWR of 1.0 [19]. The inset-fed MPA in this work demonstrated near-perfect impedance matching and very effective power transmission with an outstanding VSWR of 1.0661 at 28 GHz. A greater VSWR of 1.5606 is observed in the identical antenna without the inset feeding structure, indicating a less effective match and more power being reflected back toward the source. The VSWR plot of those antenna is viewed in Fig. 3 and Table II. This comparison shows that the inset-fed arrangement is better appropriate for high-frequency 5G applications since it greatly enhances impedance matching and overall antenna performance.

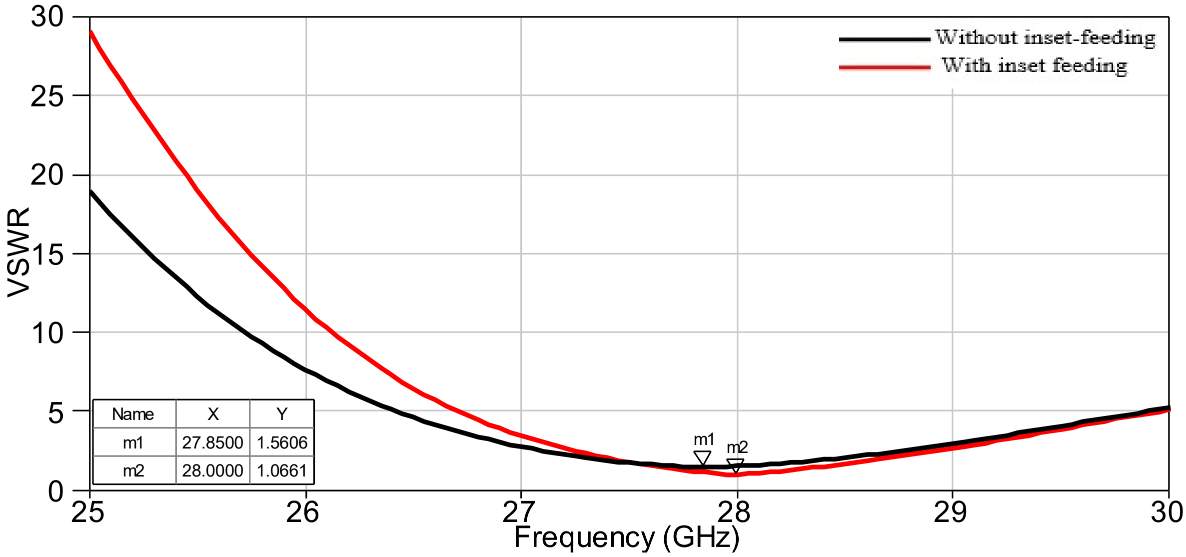

Fig. 3: VSWR plot

C. Antenna Gain

An antenna's 3D gain plot helps evaluate its directional features and peak radiation performance by offering a thorough visual representation of the energy it radiates in all directions. It is an essential tool for assessing how well antenna designs work, especially for high-frequency applications like 5G [20], [21]. The inset-fed MPAs 3D gain plot in this research displays a well-defined directional radiation pattern with a peak gain of 7.1328 dBi at 28 GHz, suggesting effective radiation and a stronger signal in the intended direction. By contrast, the identical antenna without the inset feed has a lower peak gain of 6.2934 dBi, indicating less concentrated radiation and less efficiency. Fig. 4 and Table II displays such antennas' three-dimensional gain plot. This discrepancy demonstrates the value of the inset feed approach, which not only promotes impedance matching but also improves the antenna's energy-directing capabilities. High gain and concentrated radiation are necessary for dependable communication in 5G mmWave applications, which the inset-fed design's enhanced gain validates.

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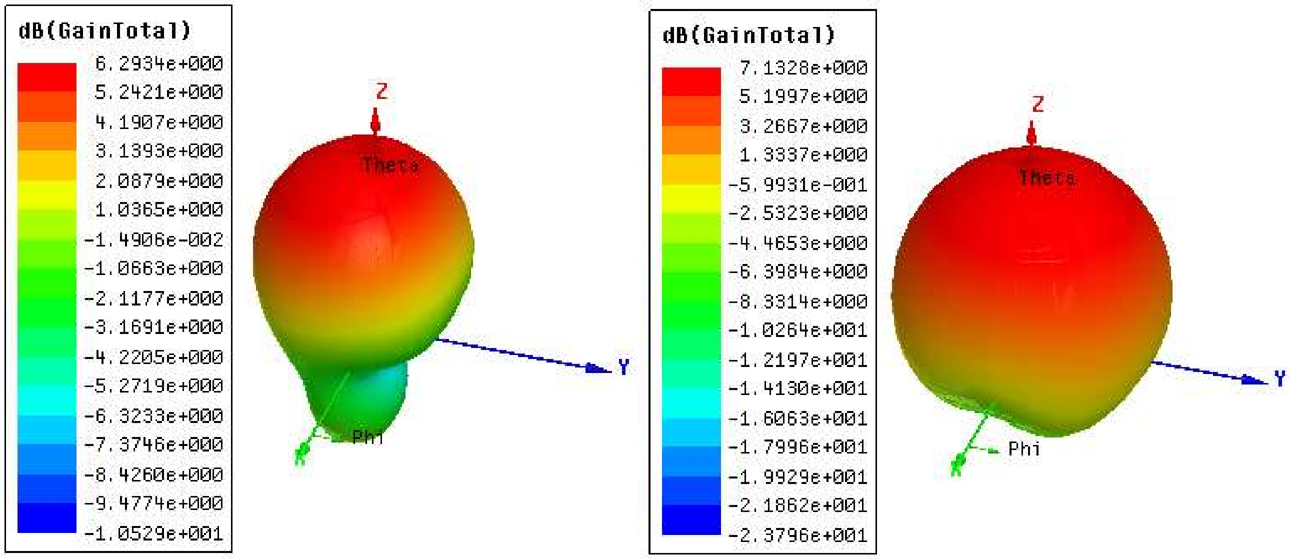

(a) (b)

Fig. 4: 3D Gain Plot at (a) without inset fed (b) with inset fed

IV. Comparative Results with relevant papers

A comparison with previous pertinent research articles has been done in order to evaluate the performance and uniqueness of the suggested inset-fed microstrip patch antenna design for 5G applications at 28 GHz. RL, bandwidth, and gain are the main performance metrics that are assessed since they have a direct impact on the effectiveness, dependability, and signal quality of antennas that operate in the millimeter-wave spectrum. The suggested antenna has a broad bandwidth of 1135 MHz, a peak gain of 7.1328 dBi, and a return loss of -29.8997 dB, showing outstanding impedance matching. The suggested design distinguishes itself from other recent efforts in the literature by combining superior performance with structural simplicity. Wide bandwidth or high gain are achieved by many current devices, although they often call for more intricate geometries or multilayer setups. The suggested antenna's competitive advantage and adaptability for small and effective 5G communication systems are shown in Table III below, which compares it to a few current developments.

Table III: Comparative results with recent relevant paper

Ref.	Operating frequency (GHz)	Return loss(dB)	Bandwidth (MHz)	VSWR	Gain (dBi)
[8]	28	-14.60 -26.24	503 708	-- --	5.94 5.39
[9]	27.97	-20.95	1060	1.197	7.5
[10]	28.1	-19.3	900	1.24	7.02
[11]	28	-18.25	1100	1.278	6.72
[12]	28	-24	280	1.14	2.2
Proposed	28	-29.8997	1135	1.0661	7.1328

V. Conclusion

This work successfully built and optimized a 28 GHz inset-fed MPA for 5G millimeter-wave applications. With a gain of 7.1328 dBi, a bandwidth of 1135 MHz, and a RL of -29.8997 dB, the antenna exhibits outstanding performance in terms of bandwidth, gain, and RL. In comparison to the identical antenna without the inset feed, which demonstrated a gain of 6.2934 dBi, a narrower bandwidth of 935 MHz, and a RL of just –13.1938 dB, the inclusion of an inset feed structure greatly enhanced impedance matching and radiation efficiency. Patch size and feed location were precisely calculated using known equations as part of the design technique. Performance was then optimized by full-wave simulations. The suggested antenna provides a good compromise between simplicity, compactness, and high performance, as shown by the findings, which also showed favorable comparisons with current research in the literature. Because of these features, the antenna is ideal for incorporation into contemporary 5G communication systems, where bandwidth, efficiency, and space are crucial. To further improve the performance for beamforming and massive MIMO applications in 5G networks, future research may investigate the combination of array designs with cutting-edge materials.

References

[1] A. N. Uwaechai, N. M. Mahyuddin,"A Comprehensive Survey on Millimeter Wave Communications for Fifth-Generation Wireless Networks: Feasibility and Challenges," *IEEE Access*, vol. 8, 2020.

[2] J. G. Andrews et al, "What Will 5G Be?," *IEEE Jsac Special Issue On 5g Wireless Communication Systems*, vol. 32, no. 6, 2014.

[3] W. roh et al, "Millimeter-Wave Beamforming as an Enabling Technology for 5G Cellular Communications: Theoretical Feasibility and Prototype Results," *IEEE Communications Magazine*, vol. 52, no. 2, 2014.

[4] O. Darboe et al, "A 28 GHz Rectangular Microstrip Patch Antenna for 5G Applications," *International Journal of Engineering Research and Technology*, Vol. 12, no. 6, 2019.

[5] K. A. Fante, M. T. Gemeda, "Broadband microstrip patch antenna at 28 GHz for 5G wireless applications," *International Journal of Electrical and Computer Engineering (IJECE),* Vol. 11, No. 3, June 2021.

[6] M. A. A. Mamun, S. Datto, M. S. Rahman, "Performance Analysis of Rectangular, Circular and Elliptical Shape Microstrip Patch Antenna using Coaxial Probe Feed," *2nd International Conference on Electrical & Electronic Engineering (ICEEE),* 27–29 December 2017.

[7] M. Z. Rahman et al, "Performance Analysis of an Inset-Fed Circular Microstrip Patch Antenna Using Different Substrates by Varying Notch Width for Wireless Communications," *International Journal of Electromagnetics and Applications*, vol. 10, no. 1, 2020.

[8] B. A. Rahman and S. O. Hasan, "Simulation Design of Low-Profile Equilateral Triangle Microstrip Patch Antenna Operating at 28 GHz," *Int. J. Commun. Antenna Propag.*, vol. 12, no. 2, p. 74, Apr. 2022.

[9] S. E. Didi, I. Halkhams, M. Fattah, Y. Balboul, S. Mazer, and M. El Bekkali, "Design of a microstrip antenna patch with a rectangular slot for 5G applications operating at 28 GHz," *TELKOMNIKA (Telecommunication Comput. Electron. Control.*, vol. 20, no. 3, p. 527, Jun. 2022.

[10] Y. Zhang, J.-Y. Deng, M.-J. Li, D. Sun, and L.-X. Guo, "A MIMO Dielectric Resonator Antenna With Improved Isolation for 5G mm-Wave Applications," *IEEE Antennas Wirel. Propag. Lett.*, vol. 18, no. 4, pp. 747–751, Apr. 2019.

[11] R. K. Goyal and U. Shankar Modani, "A Compact Microstrip Patch Antenna at 28 GHz for 5G wireless Applications," in *2018 3rd International Conference and Workshops on Recent Advances and Innovations in Engineering (ICRAIE)*, Nov. 2018.

[12] Y. Li, "A microstrip patch antenna for 5G mobile communications," *J. Phys. Conf. Ser.*, vol. 2580, no. 1, p. 012063, Sep. 2023.

[13] C. A. Balanis, "Antenna Theory: Analysis and Design", John wiley & sons 3rd Edition. 3rd ed., *Wiley-Interscience*, 2015.

[14] M. A. A. Mamun et al, "Performance Analysis of Line Feeding Microstrip Patch Antenna Using Different Layers of Substrate Materials for Terahertz (THz) Applications," *IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE),* vol. 14, no. 5, 2020.

[15] D. Mathur, S. K. Bhatnagar, and V. Sahula, "Quick estimation of rectangular patch antenna dimensions based on equivalent design concept," *IEEE Antennas and Wireless Propagation Letters*, vol. 13, pp. 1469–1472, Jan. 2014.

[16] H. Werfelli, K. Tayari, M. Chaoui, M. Lahiani, and H. Ghariani, "Design of rectangular microstrip patch antenna," 2nd International Conference on Advanced Technologies for Signal and Image Processing (ATSIP), Mar. 2016, pp. 798-803.

[17] T. S. Bird, "Definition and misuse of return loss," *IEEE Antennas and Propagation Magazine*, vol. 51, no. 2, pp. 166–167, Apr., 2009.

[18] M. S. Rana and M. M. R. Smieee, "Design and analysis of microstrip patch antenna for 5G wireless communication systems," *Bulletin of Electrical Engineering and Informatics*, vol. 11, no. 6, pp. 3329–3337, Dec. 2022.

[19] M. S. Rana and M. Rahman, "Study of Microstrip Patch Antenna for Wireless Communication System," in *2022 International Conference for Advancement in Technology, ICONAT 2022*, pp. 1–4, Jan. 2022.

[20] W. L. Stutzman, "Estimating Directivity and Gain of Antennas," *IEEE Antennas and Propagation Magazine*, vol. 40, no. 4, pp. 7–11, 1998.

[21] N. Kaur, M. Kumar, and J. Singh, "Design of Miniaturized Stair Case Fractal Geometry Based Planar Monopole Antenna for Multiband Wireless Communication Applications," *International Journal of Mechanical Engineering*, vol. 7, pp. 641–648, 2022.