

Design of a Multiple-Beam 8×8 Phased Array Microstrip Antenna for 28 GHz 5G mmWave Applications

Bassey Ndifreke G., Isiyaku Ya'u, Habeeb Bello, E.E Agbon, S. A. Mikail, Abdulmumin Idris
Department of Electronics and Telecommunications Engineering,
Ahmadu Bello University, Zaria, Nigeria

ABSTRACT

This study presents the design and simulation of a multiple-beam phased array microstrip antenna optimized for 28GHz 5G millimeter-wave (mmWave) applications. The phased array consists of 64 rectangular patch elements, each measuring 4.24 mm in width and 3.47 mm in length, arranged in an 8×8 configuration, linearly polarized along X and Y planes. Rogers RT/Duroid 5880 substrate material having dielectric constant of 2.2 and low loss tangent of 0.0009 was used due to its high performance at high frequency and low signal losses, to enhance high radiation efficiency and accurate beamforming. The overall dimension of the antenna array is 42.8mm × 42.8mm. Radius bends were introduced at all feed corners to minimize signal loss, impedance mismatch, and unwanted corner radiation. Hybrid beamforming technique that combines both corporate feed network and digital beamforming was utilized to produce 32 separately steerable beams. CST Studio Suite 2025 was utilized for the antenna modeling and simulation, while optimization of parameters was performed using Genetic Algorithm (GA) and Particle Swarm Optimization (PSO), implemented in MATLAB R2024b and dynamically tuned in CST. The design achieves a gain of 17.94 dBi, a return loss below -32.462192dB, a bandwidth of 564.5MHz, and beam steering in the range of ±35° azimuth and ±25° elevation.

ARTICLE INFO

Article History

Received: November, 2024

Received in revised form: January, 2025

Accepted: February, 2025

Published online: June, 2025

KEYWORDS

5G, Phased Array Microstrip Antenna,
mmWave, Hybrid Beamforming, Radiation
Efficiency

INTRODUCTION

The fifth-generation (5G) mobile network represents a transformative shift in wireless communication, promising to deliver ultra-high-speed data transmission, significantly reduced latency, and vastly expanded network capacity. Unlike its predecessors, 5G leverages the underutilized millimeter-wave (mmWave) frequency spectrum, particularly bands within 24–100 GHz, to achieve unprecedented performance levels. Among these, the 28GHz band stands out as a globally allocated frequency for 5G deployment due to its favorable trade-off between propagation loss and bandwidth availability. The mmWave spectrum enables wide bandwidth channels of up to several gigahertz, which directly translates into high data rates and massive user capacity essential for applications such as ultra-

high-definition streaming, autonomous vehicles, augmented reality, and the Internet of Things (ITU, 2023). To meet such demanding communication requirements, advanced antenna systems capable of supporting high-gain, directional transmission at these frequencies is essential.

Despite the bandwidth advantages, mmWave signal propagation presents several technical challenges. High path loss, atmospheric absorption, and limited ability to penetrate solid objects significantly degrade signal strength, especially over longer distances and in non-line-of-sight conditions. These drawbacks necessitate the use of advanced antenna technologies to ensure reliable and efficient communication links. Phased array antennas (PAAs) have emerged as a powerful solution, offering features such as beamforming, beam steering, and multi-beam

Corresponding author: Bassey Ndifreke G.

✉ ndifrekeb@gmail.com

Department of Electronics and Telecommunications Engineering, Ahmadu Bello University, Zaria, Nigeria.

© 2025. Faculty of Technology Education. ATBU Bauchi. All rights reserved



generation. These capabilities allow the antenna to dynamically adapt to user locations and overcome signal blockages by directing energy precisely toward intended receivers while minimizing interference (Maggi et al., 2022). The capacity of PAAs to generate multiple simultaneous beams is particularly advantageous for dense urban environments and multi-user scenarios, where signal reliability and spectral efficiency are critical. Moreover, electronic beam steering enabled by PAAs ensures rapid tracking of mobile users without mechanical movement, making them an essential element of 5G infrastructure (Ali et al., 2022).

Among various antenna types, the microstrip patch antenna has gained significant interest for 5G mmWave applications due to its favorable structural and electromagnetic properties. Consisting of a radiating patch etched on a dielectric substrate above a ground plane, this antenna type offers numerous benefits including compactness, low profile, ease of fabrication, low cost, and straightforward integration with active electronic components (Yang & Zhang, 2022). These attributes make microstrip patch antennas ideal for array configurations where multiple radiating elements are required for directional beam control and gain enhancement (Aliu & Abubakar, 2023). Furthermore, the use of high-performance substrates such as Rogers RT/duroid 5880, with low dielectric loss and excellent thermal stability, contributes to improved radiation efficiency and impedance matching in mmWave applications. When configured in phased arrays, these antennas support both analog and digital beamforming architectures, facilitating precise control over radiation patterns while addressing mmWave challenges such as narrow beamwidths and increased free-space losses.

Previous works have demonstrated phased arrays for 5G, yet achieving optimal performance at 28GHz with multiple-beam capability and minimized side-lobe levels remains a challenge. For instance, Prasad et al. (2021) developed an 8×8 multibeam phased array with six independently steerable beams, achieving a maximum gain of 17.02dBi and beam steering

over $\pm 35^\circ$ in azimuth and $\pm 25^\circ$ in elevation. However, the system was constrained by limited bandwidth (400MHz), lacked detailed performance metrics such as radiation efficiency and returns loss, and was not scalable for large MIMO configurations. Similarly, other designs exhibited challenges including narrow scanning ranges, limited number of beams, or the absence of optimization algorithms for performance enhancement (Nigam & Mathur, 2023; Mandloi et al., 2022). These limitations highlight the need for a more robust and high-gain antenna solution.

This research aims to address these gaps by developing an 8×8 multiple-beam phased array microstrip antenna specifically designed for 28 GHz mmWave 5G applications. The proposed antenna integrates hybrid beamforming techniques with advanced optimization algorithms such as Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) to dynamically improve critical performance parameters such as gain, side lobe level (SLL), radiation pattern, and bandwidth. The optimized design seeks to enhance spectral efficiency, support simultaneous multi-user links, and serve as a scalable architecture for future smart city and autonomous system deployments. The remaining section of the paper is organized as follows. Section II gives methodology of the designed antenna; results of the simulations is discussed in section III and the paper is concluded in section IV.

METHODOLOGY

This section describes the approach adopted for the development of the proposed antenna. Rectangular microstrip patch antenna structure was chosen due to its ease of integration into array configurations, and predictable radiation characteristics at mmWave frequencies. Its geometry is well-suited for compact array implementations at 28GHz, where wavelength constraints demand electrically small but effective radiating elements. The patch is modeled on Rogers RT5880 substrate with a dielectric constant (ϵ_r) of 2.2, loss tangent of 0.0009, and a thickness of 0.254 mm.

Corresponding author: Bassey Ndifreke G.

✉ ndifrekeb@gmail.com

Department of Electronics and Telecommunications Engineering, Ahmadu Bello University, Zaria, Nigeria.

© 2025. Faculty of Technology Education. ATBU Bauchi. All rights reserved

The patch dimensions are determined using standard microstrip patch equations based on a center frequency of 28GHz as follows:

i. Wavelength λ_0 :

$$\lambda_0 = \frac{c}{f_0} \quad (1)$$

$$\lambda_0 = \frac{3 \times 10^8}{28 \times 10^9}$$

$$\lambda_0 = 10.71\text{mm}$$

ii. The patch width (W_p):

$$W_p = \frac{c}{2f_0 \sqrt{\left(\frac{\epsilon_r + 1}{2}\right)}} \quad (2)$$

$$W_p = \frac{3.0 \times 10^8}{2 \times 28 \times 10^9} \times \sqrt{\left(\frac{2}{2.2 + 1}\right)}$$

Width of patch, $W_p = 4.24\text{mm}$

iii. Effective dielectric constant (ϵ_{eff}):

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left(1 + 12 \frac{h}{W_p}\right)^{-1/2} \quad (3)$$

$$\epsilon_{eff} = \frac{2.2 + 1}{2} + \frac{2.2 - 1}{2} \left(1 + 12 \frac{0.000254}{0.00424}\right)^{-1/2}$$

Effective Dielectric Constant $\epsilon_{eff} = 2.06$

iv. Fringing length (ΔL)

$$\Delta L = .412h \frac{(\epsilon_{reff} + 0.3) \left(\frac{W_p}{h} + 0.264\right)}{((\epsilon_{reff} - 0.258)) \left(\frac{W_p}{h} + 0.8\right)} \quad (4)$$

$$\Delta L = 0.412 \times 0.000254$$

$$\frac{(2.06 + 0.3) \left(\frac{4.24}{0.000254} + 0.264\right)}{((2.06 - 0.258)) \left(\frac{4.24}{0.000254} + 0.8\right)}$$

$$\Delta L = 0.133\text{mm}$$

v. Patch length (L_p):

$$L_p = \frac{c}{2f\sqrt{\epsilon_r}} - 2\Delta L \quad (5)$$

$$L_p = \frac{3.0 \times 10^8}{2 \times 28 \times 10^9 \sqrt{2.06}} - 2(0.000133)$$

$$\text{Patch length, } L_p = 3.47\text{mm}$$

vi. Radius bend (R):

$$3W_T \leq R \quad (6)$$

$$R = 2.4\text{mm}$$

where:

c is the speed of light (3.0×10^8)

f_0 refers to the operating frequency (28GHz)

ϵ_r denotes the relative permittivity of the substrate material (2.2)

h stands for the thickness of substrate (0.254 mm)

W_T denotes the width of transmission line (0.79mm)

Table 1: Proposed Antenna Design Specification

Parameter	W_p	L_p	h	$W_s = L_{sp}$	R	W_T	$d_x = d_y$
Dimension	4.24mm	3.47mm	0.254mm	42.8mm	2.4mm	0.79mm	5.35 mm

The proposed antenna array is formed by replicating a single rectangular microstrip patch element of width 4.24 mm and length 3.47 mm to form an 8×8 planar array configuration of 32 1×2 sub-arrays with inter-element spacing ($d_x = d_y$) of $\lambda/2$ in CST Studio Suite 2025, to achieve multiple beam performance. The antenna array is fed through a corporate feeding network and excited using waveguide ports assigned to each sub-array for excitation to ensure proper signal distribution and minimize reflection; the feed lines are tapered and bent at corners with a radius of 2.4 mm as shown in the antenna configuration in Figures 1.

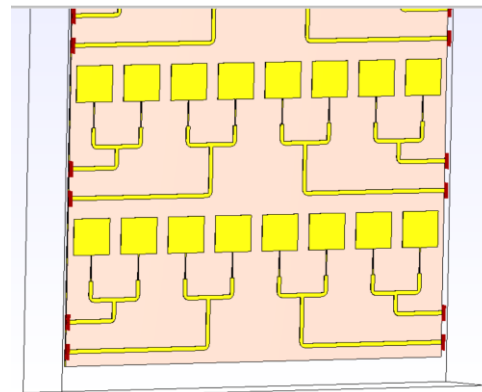


Figure 1: The Simulated Phased Array Antenna

Corresponding author: Bassey Ndifreke G.

ndifrekeb@gmail.com

Department of Electronics and Telecommunications Engineering, Ahmadu Bello University, Zaria, Nigeria.

© 2025. Faculty of Technology Education. ATBU Bauchi. All rights reserved

SIMULATION RESULT AND DISCUSSION

The antenna model was initially simulated in CST Studio Suite using the time domain solver to evaluate the antenna performance. To enhance the antenna performance, the design was optimized using Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) techniques implemented in MATLAB R2024b. The optimization targeted improvements in gain, and return loss.

The simulation results before and after optimization is presented in figure 2 through figure 6. After optimization, the antenna achieved an S11 value of -32.462192dB at 28GHz, corresponding to 0.0565% of power reflected, and over 99.9435% is transmitted by the antenna,

indicating excellent impedance matching with minimal reflection, which significantly enhances power transfer and overall radiation efficiency. The 3D far-field radiation pattern at 28 GHz before and after optimization is shown in Figure 4 and figure 5 respectively. The realized gain of the antenna array reached a peak value of 17.9dBi, indicating a significant enhancement compared to the pre-optimization gain value of -4.42dBi. The simulated -10dB impedance bandwidth of the designed antenna spans from 27.65569GHz to 28.22027GHz, resulting in a total bandwidth of approximately 564.5MHz as presented in figure 6. This corresponds to a fractional bandwidth of 2.02% around a center frequency of 27.94GHz

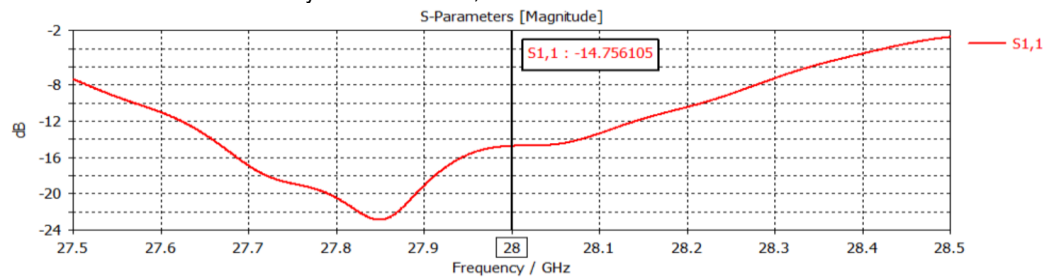


Figure 2: Return Loss before Optimization

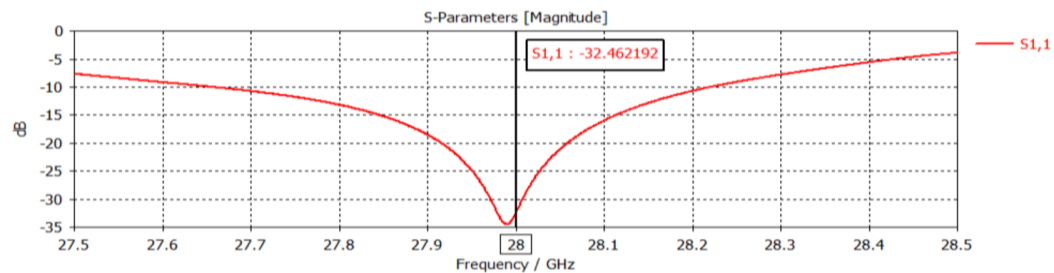


Figure 3: Return Loss after Optimization

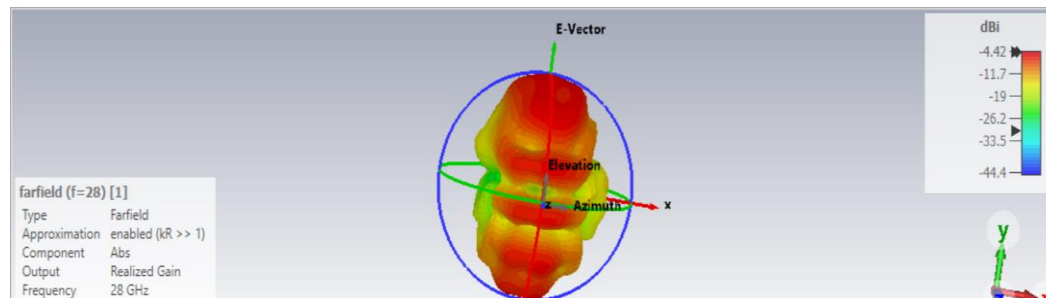


Figure 4: Realized Gain before Optimization

Corresponding author: Bassey Ndireke G.

ndirekeb@gmail.com

Department of Electronics and Telecommunications Engineering, Ahmadu Bello University, Zaria, Nigeria.

© 2025. Faculty of Technology Education. ATBU Bauchi. All rights reserved

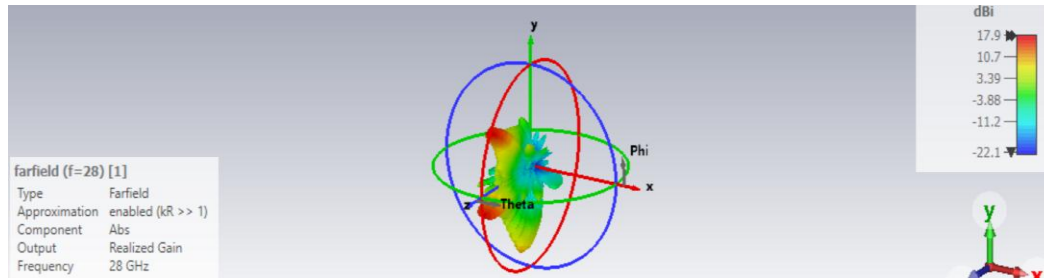


Figure 5: Realized Gain after Optimization

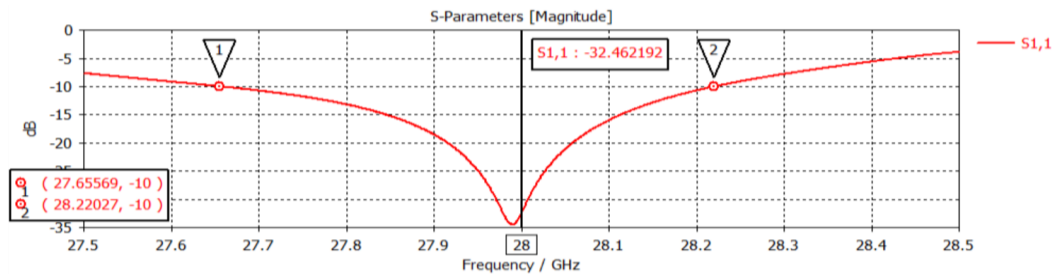


Figure 6: Simulated -10dB impedance bandwidth

Table 2: Summary of the simulated results

Antenna Parameter	S11 at 28GHz	Gain (dBi)	Bandwidth
Results	-32.462192dB	17.94 dBi	567.01Mhz

CONCLUSION

In this paper, an 8×8 multiple-beam phased array microstrip antenna is proposed and designed for 28GHz 5G mmWave wireless applications. The antenna employs a hybrid beamforming technique combining corporate feed network and digital control to generate 32 independently steerable beams. Design optimization using both Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) significantly improved return loss (−32.46 dB), realized gain (17.94 dBi), and bandwidth (564.5 MHz). The incorporation of radius bends at feed corners helped reduce impedance mismatch and signal loss, and the antenna maintained a scanning range of $\pm 35^\circ$ in azimuth and $\pm 25^\circ$ in elevation. The proposed antenna is highly suitable for high-capacity 5G systems, smart cities, and autonomous platforms. Future work will focus on dynamic beam adaptation and scalability in large MIMO environments.

REFERENCES

- Abdul Ghani, F., Najafabadi, A. M. A., Saleh, H., Yapici, M. K., & Tekin, I. (2024). Wide scan angle multibeam conformal antenna array with novel feeding for mm-wave 5G applications. *Microelectronic Engineering*, 294, 112261.
- Ali, S. A., Wajid, M., Kumar, A., & Alam, M. S. (2022). Design challenges and possible solutions for 5G SIW MIMO and phased array antennas: A review. *IEEE Access*, 10, 88567–88594. <https://doi.org/10.1109/ACCESS.2022.3197226>
- Aliu, D., & Abubakar, U. (2023). Development of a Dot Matrix Display Billboard for Edo State University Uzairue, Nigeria. *ATBU Journal of Science, Technology and Education*, 11(2), 384-395.
- Didi, S. E., Halkhams, I., Es-Saqy, A., Fattah, M., Balboul, Y., Mazer, S., & Bekkali, M. E. (2023). New microstrip patch antenna array design at 28 GHz millimeter-wave

Corresponding author: Bassey Ndifreke G.

ndifrekeb@gmail.com

Department of Electronics and Telecommunications Engineering, Ahmadu Bello University, Zaria, Nigeria.

© 2025. Faculty of Technology Education. ATBU Bauchi. All rights reserved



- for fifth-generation application. *International Journal of Electrical and Computer Engineering (IJECE)*, 13(4), 4184–4193.
<https://doi.org/10.11591/ijece.v13i4>
- Hamdoun, A., Medjdoub, F., Himdi, M., Zegaoui, M., & Lafond, O. (2024). Continuously beam-steered phased array antenna using GaN varactors for millimeter-wave applications. *Electronics*, 13(23), 4698.
<https://doi.org/10.3390/electronics13234698>
- International Telecommunication Union (ITU). (2023). *Recommendation ITU-R M.1036-7: Frequency arrangements for implementation of the terrestrial component of International Mobile Telecommunications in the bands identified for IMT in the Radio Regulations*. Retrieved from <https://www.itu.int/pub/R-REC/en>
- Jabbar, A., Kazim, J. U. R., Shawky, M. A., Imran, M. A., Abbasi, Q., Usman, M., & Ur-Rehman, M. (2024). High performance 5G FR-2 millimeter-wave antenna array for point-to-point and point-to-multipoint operation: Design and OTA measurements using a compact antenna test range. *arXiv preprint arXiv:2407.09944*.
- Jain, R., Ranjan, P., Singhal, P. K., & Thakare, V. V. (2022, December). Estimation of s11 values of patch antenna using various machine learning models. In *2022 IEEE Conference on Interdisciplinary Approaches in Technology and Management for Social Innovation (IATMSI)* (pp. 1–4). IEEE.
<https://doi.org/10.1109/IATMSI56455.2022.10119256>
- Jin, G., Sun, Y., Liao, S., & Xue, Q. (2023). Millimeter-wave wide-angle scanning phased array antenna based on heterogeneous beam elements. *IEEE Transactions on Antennas and Propagation*, 71(6), 5463–5468.
- Maggi, M., Hidri, S., Marnat, L., Ettore, M., Orozco, G., Margalef-Rovira, M., ... & Haddadi, K. (2022). Millimeter-wave phased arrays and over-the-air characterization for 5G and beyond: Overview on 5G mm-wave phased arrays and OTA characterization. *IEEE Microwave Magazine*, 23(5), 67–83.
<https://doi.org/10.1109/MMM.2022.3148328>
- Mandloi, M. S., Gupta, P., Parmar, A., Malviya, P., & Malviya, L. (2022). Beamforming MIMO array antenna for 5G millimeter-wave applications. *IEEE Transactions on Microwave Theory and Techniques*, 70(4), 345–352.
<https://doi.org/10.1109/TMTT.2022.3156768>
- Mohammed, J. R. (2023). Optimizing multiple beam patterns for 5G mmWave phased array applications. *Periodica Polytechnica Electrical Engineering and Computer Science*, 67(4), 369–375.
<https://doi.org/10.3311/PPee.22111>
- Najafabadi, A. M. A., Ghani, F. A., & Tekin, I. (2022). Low-cost multibeam millimeter-wave array antennas for 5G mobile applications. *IEEE Transactions on Vehicular Technology*, 71(12), 12450–12460.
- Naqvi, A. H., & Lim, S. (2018). Review of recent phased arrays for millimeter-wave wireless communication. *Sensors*, 18(10), 3194.
<https://doi.org/10.3390/s18103194>
- Nigam, H., & Mathur, M. (2023). Design and analysis of multiple beams phased array microstrip antenna for 5G applications. *Engineering Research Express*, 5(3), 035011.
- Prasad, S., Meenakshi, M., Adhithiya, N., Rao, P. H., Krishna Ganti, R., & Bhaumik, S. (2021). mmWave multibeam phased array antenna for 5G applications. *Journal of Electromagnetic Waves and Applications*, 35(13), 1802–1814.
- Yang, G., & Zhang, S. (2022). Dual-polarized wide-angle scanning phased array antenna for 5G communication systems. *IEEE Transactions on Antennas and Propagation*, 70(9), 7427–7438.

Corresponding author: Bassey Ndifreke G.

✉ ndifrekeb@gmail.com

Department of Electronics and Telecommunications Engineering, Ahmadu Bello University, Zaria, Nigeria.

© 2025. Faculty of Technology Education. ATBU Bauchi. All rights reserved