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JOURNAL`S UNIVERSITY OF BABYLON FOR ENGINEERING SCIENCES (JUBES)

مـــجلــة جـــامعة بـــــابـل للعلـــــوم الهندسية

Vol. 32, No. 3. \ 2025 ISSN: 2616 - 9916

Design and Analysis of Wideband RHC Polarization Edge Truncated Square Patch Antenna Array for 28 GHz Communication

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Received:	4/6/2025	Accepted:	25/6/2025	Published:	29/6/2025

Abstract

This article presents the design, simulation, and analysis of a high gain, compact size, circularly polarized antenna array operating at 28 GHz frequency in response to the growing needs of 5G networks for small, low profile, high gain, and high-performance antennas. Four identical square patch antennas with two truncated corners make up the antenna array. The patch antennas are powered by a corporate feeding network, which also provides a wide axial ratio bandwidth and enhances the antenna gain. Using Altair FEKO software, antenna simulations revealed an antenna gain of 20.4476 (13.1 dB) and a radiation efficiency of around 99%. The reflection coefficients (S11) were approximately -19 dB throughout a broad bandwidth from 27.25 GHz to 31.75 GHz. Throughout the 27.7 GHz to 28.3 GHz bandwidth, the antenna axial ratio is less than 3dB. As per the outcomes of the calculations, the suggested antenna is appropriate for millimeter-wave communications, particularly for 5G applications that function at frequencies of 28 GHz.

Keywards: Antenna array, Circular polarization, 5G communications, Patch antenna

1. Introduction

5G networks are introduced worldwide as the new communication system that will essentially connect everyone and everything on the planet. Devices, objects, and even machines are included in this connection; consequently (to this connection), a significant frequency spectrum will be needed because of the enormous volume of traffic and high data rates produced by these new device connections. Millimeter waves should be considered for the operation of the 5G systems to gain much more bandwidth to handle the huge volume of data traffic, as the current 5G wireless communication infrastructure is ill-equipped to handle this rapid growth in traffic demand. Because of the severe congestion in the frequency bands below 20 GHz, there is an inevitable shift to the upper part of the spectrum. 28, 38, 64 GHz are the main center frequencies for the millimeter waves used for the promising 5G cellular communications. Certainly, this frequency shift will add more challenges to the antenna designers to develop an antenna system that is strong enough to handle these necessary bandwidths. [1], [2], [3]

A lot of work has recently gone into designing wideband, high gain, circular polarization antenna systems for 5G wireless networks that use the 28 GHz frequency range [4]. In [5] a circularly polarized antenna with a gain of 2.6 dBi, and an axial ratio of 3 dB has been obtained from a triangular monopole antenna with a rectangular slotted ground plane. The antenna achieves return losses (S11) of less than -10 dB in the central frequency of 3.5 GHz with a bandwidth of 2 GHz. The Particle Swarm Optimization method has been adopted in the research [6] to obtain the optimal dimensions of an irregular six-edge polygon-shaped antenna. The proposed antenna shows left-hand circular polarization LHCP with an antenna gain of 2.88 dBi at 2.4 GHz resonant frequency, making it suitable for WLAN communications. A device-to-device antenna has been proposed in [7], where it consists of a compact center disk loaded with a square loop structure. The antenna uses a 6.15 relative permittivity constant with a height of 1.5 mm. LHCP has been achieved over the frequency range 27.3 – 28.6 GHz, making it suitable for 5G mm-waves communications. A multilayer PCB structure has been adopted in [8] to implement a 2×2 truncated patch antenna array, where each patch antenna is excited via a slot coupled to a substrate-integrated gap. 4.3 substrate constant was used to build up the antenna. An impedance bandwidth of more than 6 GHz is obtained (the return losses less than -10 dB) by the proposed antenna from 22.2 GHz to 28.8 GHz, with an axial ratio of 3 dB over the range and a gain 11.53 dB. These results make the designed antenna suitable for 5G communications. The authors in [9] proposed an antenna array for low earth orbit (LEO) satellite communications. The proposed array is composed of 4 × 4 truncated patches printed on Rogers RT6006 material with dielectric constant $\varepsilon r = 6.15$ and material thickness of 1.27 mm to be operated in 8.12 GHz frequency. The proposed array exhibits LHCP with a peak radiation gain of 15.5 dBi and an axial ratio of 3 dB over 700 MHz. A reflection coefficient is less than -10 dB over a bandwidth of 600 MHz. A two-element patch antenna array is introduced in [10] with corner truncation and modified microstrip line and T junction. The antenna shows good response at 28 GHz resonant frequency with a maximum gain of 15.3 dB and 3 dB axial ratio over a bandwidth of 0.35 GHz, which proves that the antenna has a circular polarization attitude. A circular-shaped microstrip patch antenna is presented in [11], where it consists of two concentric circles with a radius of 2.5 mm, and 1 mm printed on Rogers RT Duroid 5880 with Dielectric Constant (εr) equal to 2.2 and height of 0.5 mm. The proposed antenna shows triple band behavior at the resonant frequencies 41, 47.4, and 54.4 GHz with a maximum gain of 9.82 dB (at 47.4 GHz) with a bandwidth of 222 MHz. A 2×2 circular-shaped microstrip patch antenna array to be used for 28 GHz 5G mobile stations is introduced in [12]. The patch antenna array has circular polarization due to its circular shape; the patch elements are fed employing an inset-fed microstrip line. The proposed array shows -32 dB return losses at the resonance frequency 27.9 GHz with 12.7 dB gain and 700 MHz bandwidth. A 1×2 antenna array based on a circular-shaped patch antenna is illustrated in [13]. The antenna array exhibits good performance in the 30 GHz resonance frequency with an approximate bandwidth of 1 GHz and a maximum gain of 9.125 dB. The antenna array uses an inset feed microstrip line to enhance the impedance matching. The authors in [14] proposed a new circular-shaped microstrip patch antenna with a tapered feeding technique. The antenna structure is loaded by capacitance loads by using slots in its structure. The proposed structure has a gain of 8.4 dBi and an axial ratio of 0 dB at the resonance frequency (28 GHz), with a bandwidth of 2 GHz. The antenna has pure right-hand circular polarization (RHCP) at the resonance frequency due to the 0 dB axial ratio. The design of a circular patch antenna with a coaxial probe feed technique is presented in [15]. The proposed antenna has been subjugated to many optimizations to get the proper feeding location. The antenna achieves –57 dB returns losses with a maximum gain of 7.56 dB. The design of a novel circular patch antenna with a new cavity pattern is presented in [16], the antenna exhibits LHCP at the resonance frequency (28 GHz), where the axial ratio is approximately 0.5 dB. A 7.3 dB has been achieved as an antenna gain with a reflection coefficient of -35 dB. In this paper, the design, simulation, and analysis of compact size, low profile, circular polarization, and patch antenna array are introduced. The designed antenna is based on a square patch antenna with truncated corners. The antenna is printed on 0.5 mm thickness Roger Duroid material with a permittivity constant of 2.2.

This article's remaining sections are arranged as follows. The design process for the antenna (radiating patch, feed line, and array design) is presented in Section 2. For both single elements and antenna arrays, the antenna geometry and the intended parameters are explained in Section 3. In Section 4, the outcomes and accomplishments are discussed. In Section 5, the findings of this study are presented.

2. Antenna Design Methodology

The design methodology of the proposed antenna array is presented in this section divided into three partitions, which are: radiating patch element design, quarter-wavelength transmission line calculations, and the antenna array design procedure.

2.1. Radiating Patch

The radiating patch's design is one of the most important parts of creating an antenna array; typically, two parameters are used to create a standard radiating patch antenna: the patch's width and length. Equations 1 through 5 describe how the length and breadth are first determined using the theoretical formulas, and the optimal values are then obtained using the software's optimization process. [17]

$$Wp = c/(2f\sqrt{((\varepsilon_r + 1)/2)}) \tag{1}$$

$$Lp = L_{eff} - 2\Delta L \tag{2}$$

$$\Delta L = 0.412 * \frac{\varepsilon_{eff}+0.3\left(\frac{Wp}{h}+0.264\right)}{(\varepsilon_{eff}-0.258(\frac{Wp}{h}+0.8))} \tag{3}$$

$$L_{eff} = c/(2f\sqrt{(\varepsilon_{eff})}) \tag{4}$$

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1 + 12\frac{h}{Wp}\right]^{-\frac{1}{2}} \tag{5}$$

2.2. Feed-Line

An important factor influencing the input port's impedance and, consequently, the reflection coefficient S11 is the width of the feed line that transmits power from the input port to the radiating patch. The width and impedance of that transmission line can be calculated using the formulas in 6 and 7.[18]

$$Z_0 = \frac{60}{\sqrt{\varepsilon_{eff}}}\ln\left(\frac{8h}{W_L} + \frac{W_L}{4h}\right) \qquad for \quad {W_L}/{d} \leq 1 \tag{6}$$

$$Z_0 = \frac{120\pi}{\sqrt{\varepsilon_{eff}}(\frac{W_L}{h}+1.393+0.667\ln(\frac{W_L}{h}+1.444))} \qquad for \quad {W_L}/{d} \geq 1 \tag{7}$$

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Equation 8 can be used to compute the quarter wavelength microstrip line for impedance matching.; also see Fig. 1. [19]

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

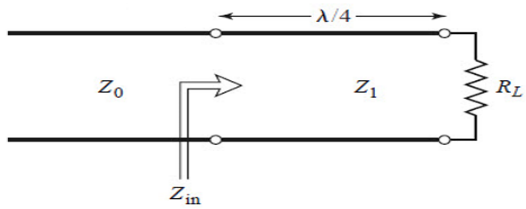

Figure 1 Impedance matching line with Quarter Wave length

2.3.Antenna Array

Since it affects the antenna gain, the radiating element spacing is the most crucial consideration when building an antenna array system. The ideal distance between the patches is 2λ, which will maximize the radiation gain; however, this distance will result in an antenna array that is quite large, which is not desirable. To achieve a satisfactory trade-off between antenna size and gain, FEKO software has been used to perform numerous optimization processes. This array will employ 0.665 λ mm as the spacing that offers this acceptable trade-off.

3. Antenna Geometry and Design Parameters

The first step in designing an antenna array system is the design of a single-element antenna that will be used in the array system as a standard structure. The radiating element is designed theoretically using the formulas in 1 through 8. Then the calculated antenna element will be modeled using FEKO software that uses the Method of Moment numerical method to estimate the design performance accurately, several optimization processes will be carried out to obtain the optimal dimensions that generate the desired response at the desired resonance frequency 28 GHz.

3.1.Single Antenna Element

The radiating antenna is constructed from a square patch with truncated corners (to achieve the circular polarization) printed on dielectric substrate material known as Roger Duroid with a dielectric permittivity constant of 2.2 and height of 0.5 mm. The antenna feeder is also designed and attached to the radiating element structure as shown in figure 2. Table 1, shown below illustrates all the dimensions of the antenna structure including the feeder line. These dimensions are calculated theoretically first, and then the modeled antenna based on these dimensions is optimized through the FEKO simulator to get the optimal values that yield the required response.

Table 1 Design parameters of single-element patch

Antenna Design	W_P (mm)	L_P (mm)	W_{f1} (mm)	W_{f2} (mm)	L_{f1} (mm)	L_{f2} (mm)	Tc (mm)
Square patch	3.2853	3.2853	0.189719	0.44812	2.0499	2.0187	0.827315

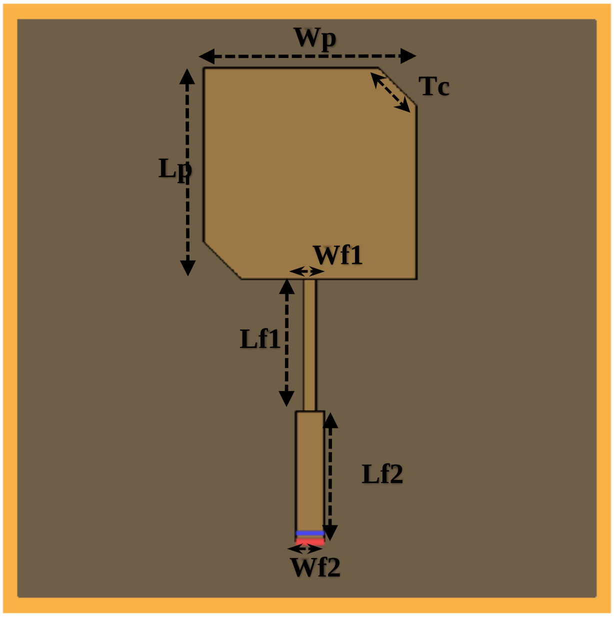

Figure 2 Single Antenna Element

3.2.Antenna Array

The radiating antenna element designed in section (3.1) will be adopted and utilized to design the required antenna array. The antenna array is demonstrated in Figure 3 shown below. Table 2 summarizes the dimensions of the proposed antenna array system.

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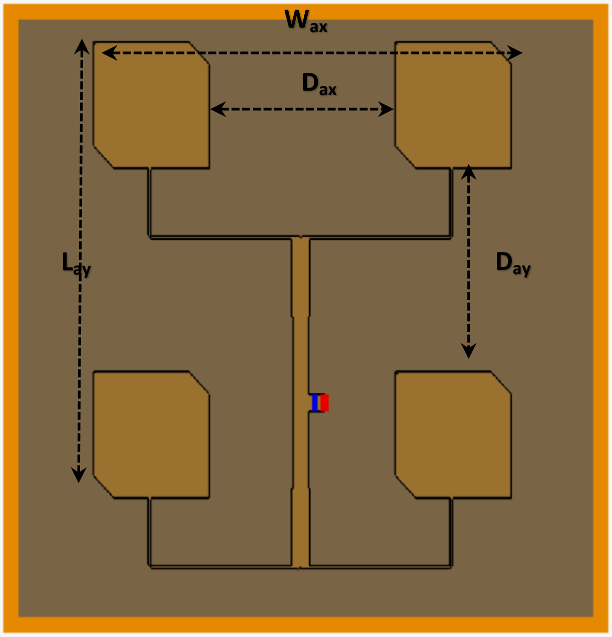

Figure 3 Structure of the antenna array system

Table 2 Array system design parameters

Proposed array	Wax (mm)	Lay (mm)	D_{ax} (mm)	D_{ay} (mm)
2×2 antenna array	11.8508675254	11.85086752552	5.2801300746	5.2801300746

4. Results Analysis and Discussion

The results of the proposed antennas are presented in this section, where return losses, radiation gain, axial ratio, and impedance bandwidth are illustrated for the proposed antennas. On the other hand, a comparison with previous works is also presented in this section.

4.1. Reflection Coefficients

Antenna performance can easily be examined using the return loss parameter (S11), where the return loss parameter measures the amount of the reflected power from the antenna radiating patch towards the input port. The lower S11 level indicates better antenna behavior. From the return loss graph vs frequency, useful information can be obtained, such as the operating frequency, and the antenna bandwidth. Figure 4 shown below illustrates the return loss of the single antenna element as well as for the antenna array. From the return loss vs frequency graph, it is clear that both antennas have good response at the 28 GHz resonance frequency, which proves that the design can be used for the 5G mm-wave mobile station. A single antenna element provides a bandwidth of 1.456 GHz, while the array provides 4.5 GHz, which means the antenna array exhibits wideband behavior.

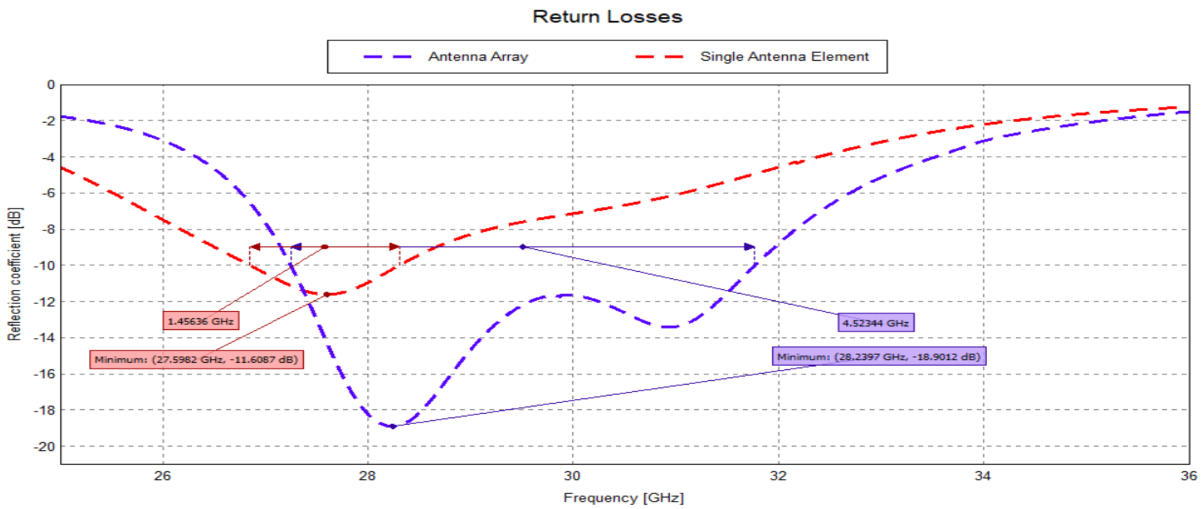

Figure 4 Return Losses graph

4.2. Antenna Radiation Pattern

The near field as well as the far field graphs illustrates the radiational pattern of the proposed antennas, and describe the way in which the antenna radiate the input power. The radiation pattern graph contains a wealth of information about the antenna parameters, including antenna gain/directivity, axial ratio (AR), and half-power beam width. Figure 5 shows the radiation patterns of a single antenna element and an antenna array.

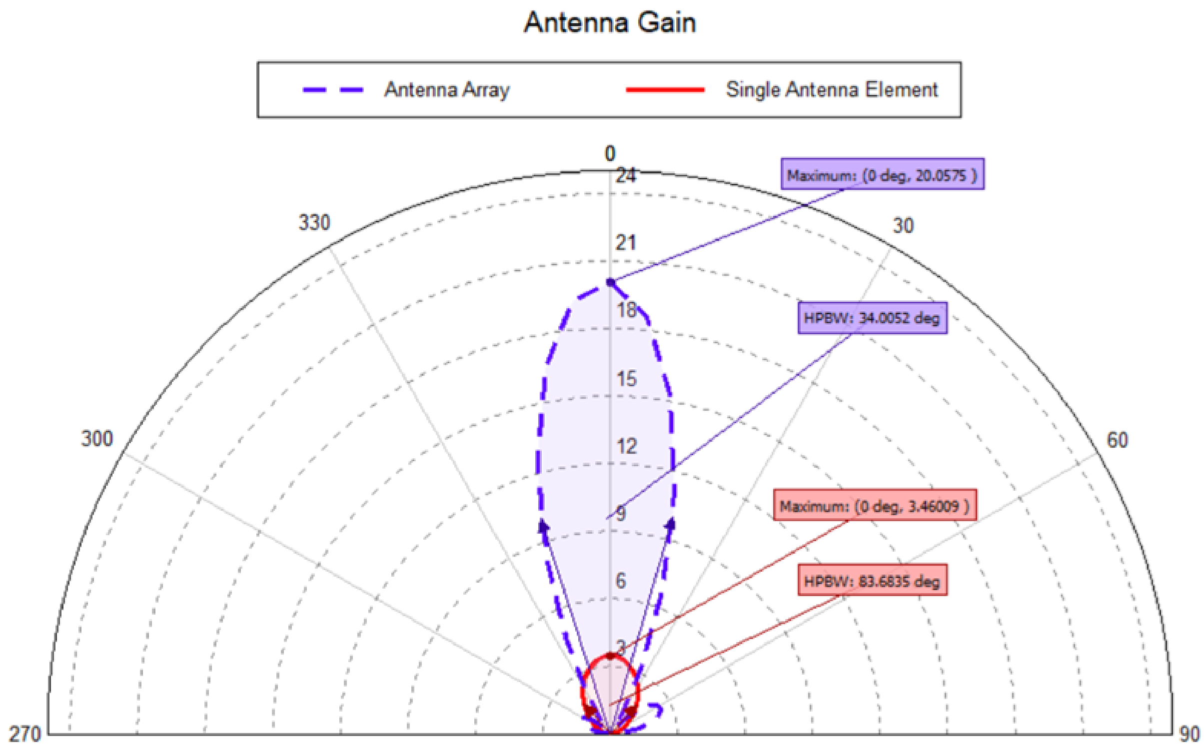

Figure 5 Antenna Gain

The single element has a low gain level (as shown in the figure) of around 3.5 dB with half power beam width of 83 degrees which is undesirable behavior, especially with 5G communications. On the other hand, the antenna array achieves 20 dB gain concentrated in beamwidth of 34 degrees, and this is a very good improvement.

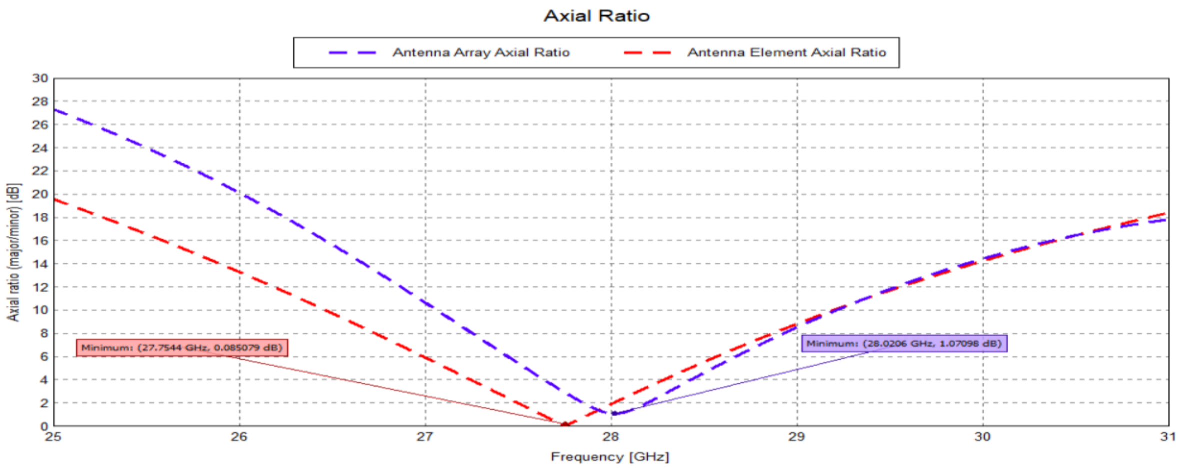

Figure 6 Axial Ratio Graph

Also, the proposed antenna supports circular polarization, an essential feature for the 5G communication systems, where single antenna elements as well as the array system achieve less than 2 dB axial ratio in the resonance frequency which means that the proposed antennas operate in circular polarization purely. Circular polarization has been achieved in the designed antennas due to the cutting corners presented in the radiating patches. Table 3 provides a comparison of the proposed antenna array to similar past works. The table illustrates that the suggested antenna outperforms the other works in several aspects, including gain, HPBW, and bandwidth.

Table 3 Proposed antenna vs. previous antenna similar works

Reference	Antenna size (mm×mm×mm)	Antenna type	Resonance freq. (GHz)	Gain (dB)	S11 (dB)	Bandwidth (GHz)	Beamwidth (Degree)	AR (dB)
[12]	18.2×13.1×0.5	2×2 circular patch	27.979	12.7	-32	0.7	36.2°	3
[14]	6×6×0.13	Circular patch	28	8.4	-30	2	NA	0
[16]	2.93×2.93×0.25	Circular patch	28	7.3	-35	1	NA	0.5
[17]	17.16×61.97×0.8	2×4 Rectangle patches	28	13.6	-40	3.53	30°–40°	Linear
[Present]	11.85×11.85×0.5	2×2 Square patch	28.2	20.05	-19	4.523	34 °	1.07

5. Conclusions

This article introduces the design, simulation, and analysis of an antenna array composed of 2×2 planar patch antennas with corner cuts to provide circular polarization. The antenna array has been designed for 5G cellular communications systems. The proposed antenna achieves an axial ratio of less than 2 dB at the resonance frequency with a wide bandwidth of approximately 4.5 GHz. The return losses achieved by the array system are around -19 dB and a radiating gain of 20 dB radiated with a relatively narrow beam width around 34 degrees. Finally, this part concludes that the proposed array is suitable for the use in the 5G communication networks due to the sepurior performance presented in the results above over the previos works.

Acknowledgment

A particular thanks goes to the engineering staff in the College of Engineering at the University of Al-Qadisiyah for their assistance in finishing this research.

References

[1] D. A. Sehrai *et al.*, "Design of high gain base station antenna array for mm-wave cellular communication systems," *Sci Rep*, vol. 13, no. 1, Dec. 2023, doi: 10.1038/s41598-023-31728-z.

[2] P. Loktongbam, D. Pal, A. K. Bandyopadhyay, and C. Koley, "A Brief Review on mm-Wave Antennas for 5G and Beyond Applications," 2023, *Taylor and Francis Ltd.* doi: 10.1080/02564602.2022.2121771.

[3] K. S. Vinay Kumar, V. Shravani, G. Spoorthi, K. S. Udith, T. M. Divya, and V. Muniswamy, "Design, Modeling and Analysis of 2×2 Microstrip Patch Antenna Array System for 5G Applications," in *2023 4th International Conference for Emerging Technology, INCET 2023*, Institute of Electrical and Electronics Engineers Inc., 2023. doi: 10.1109/INCET57972.2023.10170308.

[4] M. M. Soliman, A. Z. M. Imran, and K. S. Ullah, "Highly Efficient 2×2 Antenna Array at 28 GHz and 38 GHz for 5G Applications," in *ICIET 2019 - 2nd International Conference on Innovation in Engineering and Technology*, Institute of Electrical and Electronics Engineers Inc., Dec. 2019. doi: 10.1109/ICIET48527.2019.9290692.

[5] Y. M. Cai, K. Li, Y. Z. Yin, and W. Hu, "Broadband circularly polarized printed antenna with branched microstrip feed," *IEEE Antennas Wirel Propag Lett*, vol. 13, pp. 674–677, 2014, doi: 10.1109/LAWP.2014.2314317.

[6] M.-C. Chang and W.-C. Weng, "A Broadband Circularly Polarized Polygon Slot Antenna Design by Particle Swarm Optimization."

[7] Qing Nie, Zhi-ya Zhang, and Guang Fu, *A Compact Omnidirectional Circularly Polarized Antenna for 5G Communication System*. Shaanxi: 978-1-5386-2416-6/18/$31.00 ©2018 IEEE, 2018.

[8] C. Ma, Z. H. Ma, and X. Zhang, "Millimeter-Wave Circularly Polarized Array Antenna Using Substrate-Integrated Gap Waveguide Sequentially Rotating Phase Feed," *IEEE Antennas Wirel Propag Lett*, vol. 18, no. 6, pp. 1124–1128, Jun. 2019, doi: 10.1109/LAWP.2019.2910657.

[9] M. Elahi, S. Trinh-Van, Y. Yang, K. Y. Lee, and K. C. Hwang, “Compact and high gain 4 × 4 circularly polarized microstrip patch antenna array for next generation small satellite,” *Applied Sciences (Switzerland)*, vol. 11, no. 19, Oct. 2021, doi: 10.3390/app11198869.

[10] M. Laribi, T. Elkarkraoui, and N. Hakem, “Hight-Gain Circular Polarised Patch Antenna Array at 28 GHz,” in *2020 IEEE International Symposium on Antennas and Propagation and North American Radio Science Meeting, IEEECONF 2020 - Proceedings*, Institute of Electrical and Electronics Engineers Inc., Jul. 2020, pp. 1571–1572. doi: 10.1109/IEEECONF35879.2020.9330481.

[11] M. M. S. Altufaili, A. N. Najaf, and Z. S. Idan, “Design of circular-shaped microstrip patch antenna for 5G applications,” *Telkomnika (Telecommunication Computing Electronics and Control)*, vol. 20, no. 1, pp. 19–26, Feb. 2022, doi: 10.12928/TELKOMNIKA.v20i1.21019.

[12] S. A. Hasan, A. M. Ahmed, M. N. Abdulqader, and Y. S. Dawood, “Design and Simulation of 2 × 2 Micro Strip Circular Patch Antenna Array at 28 GHz for 5G Mobile Station Application,” *International Journal of Electronics and Telecommunications*, vol. 68, no. 4, pp. 721–729, 2022, doi: 10.24425/ijet.2022.143878.

[13] V. K. Tulasi, D. P. Mallikarjuna Rao, and M. Tech, “DESIGN AND PERFORMANCE ANALYSIS OF MULTIBAND CIRCULAR PATCH ANTENNA AND ANTENNA ARRAY FOR MILLIMETER WAVE APPLICATIONS,” 2022. [Online]. Available: www.ijcrt.org

[14] M. A. El-Hassan, A. E. Farahat, and K. F. A. Hussein, “Circularly Polarized 28 GHz Compact Patch Antenna for 5G Mobile Communications,” in *2021 International Telecommunications Conference, ITC-Egypt 2021 - Proceedings*, Institute of Electrical and Electronics Engineers Inc., Jul. 2021. doi: 10.1109/ITC-Egypt52936.2021.9513891.

[15] S. Z. Mohd Hamzah, N. F. Abdul Malek, S. Y. Mohammad, F. N. Mohd Isa, and M. R. Islam, “Design of circular patch antennas at mmWave,” in *Proceedings of the 8th International Conference on Computer and Communication Engineering, ICCCE 2021*, Institute of Electrical and Electronics Engineers Inc., Jun. 2021, pp. 144–149. doi: 10.1109/ICCCE50029.2021.9467213.

[16] R. R. Elsharkawy, K. F. A. Hussein, and A. E. Farahat, “Circularly-polarized 28-GHz antenna for next generations of communication systems,” *Sci Rep*, vol. 15, no. 1, p. 5745, Dec. 2025, doi: 10.1038/s41598-025-86236-z.

[17] Melvin C Jose, S. Radha, B S Sreeja, and Pratap Kumar, “DESIGN OF 28 GHz HIGH GAIN 5G MIMO ANTENNA ARRAY SYSTEM,” in *IEEE Region 10 Conference (TENCON 2019)*, IEEE, 2019, pp. 1913–1916.

[18] A. Irfansyah, B. B. Harianto, and N. Pambudiyatno, “Design of Rectangular Microstrip Antenna 1x2 Array for 5G Communication,” in *Journal of Physics: Conference Series*, IOP Publishing Ltd, Dec. 2021. doi: 10.1088/1742-6596/2117/1/012028.

[19] Muhammad Mostafa Amir Faisal, Mohammad Nabil, and Md. Kamruzzaman, “Design and Simulation of a Single Element High Gain Microstrip Patch Antenna for 5G Wireless Communication,” in *Innovations in Science, Engineering and Technology (ICISET)*, IEEE, Oct. 2018.

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Vol. 32, No. 3. \ 2025 ISSN: 2616 - 9916

تصميم وتحليل هوائي مصفوفة من الرقع المربعة ذات الحواف المقطوعة مستقطب دائريًا واسع النطاق الترددي مخصص للاتصالات ذاة التردد 28 غيغاهرتز

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الخلاصة

تُقدم هذه المقالة تصميم ومحاكاة وتحليل لمصفوفة هوائيات ذات استقطاب دائري، مدمجة الحجم ومرتفعة الكسب، تعمل عند تردد 28 غيغاهرتز استجابةً للحاجة المتزايدة في شبكات الجيل الخامس (5G) إلى هوائيات صغيرة، منخفضة الارتفاع، عالية الكفاءة وعالية الكسب. تتكوّن المصفوفة من أربعة هوائيات رقعية مربعة الشكل ذات زاويتين مقطوعتين. يتم تغذية الهوائيات من خلال شبكة تغذية مركزية (corporate feeding network) تعمل على توفير عرض نطاق محوري واسع (axial ratio bandwidth) وتحسين كسب الهوائي. أظهرت محاكاة الهوائي باستخدام برنامج Altair FEKO أن كسب الهوائي بلغ 20.4476 (ما يعادل 13.1 ديسيبل)، وكفاءة إشعاعية بلغت حوالي 99%. كما بلغت معاملات الانعكاس (S11)حوالي −19 ديسيبل عبر نطاق ترددي واسع من 27.25 غيغاهرتز إلى 31.75 غيغاهرتز. أما نسبة المحور axial ratio)فكانت أقل من 3 ديسيبل ضمن نطاق التردد من 27.7 غيغاهرتز إلى 28.3 غيغاهرتز. ووفقًا لنتائج الحسابات، فإن الهوائي المقترح مناسب تمامًا للاتصالات في نطاق الموجات المليمترية، وخصوصًا لتطبيقات الجيل الخامس التي تعمل عند تردد 28 غيغاهرتز.

الكلمات الدالة:-مصفوفة هوائيات، الاستقطاب الدائري، اتصالات الجيل الخامس، الهوائي الرقعي

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