Bandwidth enhancement of millimeter-wave microstrip patch antenna array for 5G mobile communication networks

Umar Musa, Suleiman Babani, Suleiman Aliyu Babale, Abubakar Sani Ali, Zainab Yunusa, Sani Halliru Lawan
Department of Electrical Engineering, Faculty of Engineering, Bayero University Kano, Kano, Nigeria

Article Info

Article history:

Received Aug 30, 2022
Revised Dec 16, 2022
Accepted Jan 11, 2023

Keywords:

Arrays
Microstrip patch antenna
Millimeter-wave antennas
Slit

ABSTRACT

This paper proposed enhancing the bandwidth of a millimeter wave microstrip patch antenna (MPA) and its array for a 5G mobile communication network. The proposed antenna is designed and fabricated on a Rogers RT Duroid 5,880 substrate with a standard thickness of 0.5 mm, a relative dielectric constant of 2.2, and a tangent loss of 0.0009. With a center frequency of 28 GHz, a measured return loss of -21.37 dB, a bandwidth of 1.14 GHz, and a gain of 6.27 dBi, the proposed single element operates in the local multipoint distribution service band. The proposed antenna is designed and manufactured as an array of 1×2 and 1×4 elements. The 2-element MPA array has a measured bandwidth of 1.207 GHz and a gain of 7.76 dBi, higher than that of a single element. The 4-element MPA array achieved a measured bandwidth of 2.685 GHz and a gain of 9.87 dBi, which is higher than the 2-element and single-element arrays at 28 GHz. This demonstrates that the array of antennas improves gain and bandwidth significantly. Hence, the proposed antenna and array are suitable for 5G mobile communication networks due to their small size.

Corresponding Author:

Umar Musa
Department of Electrical Engineering, Faculty of Engineering, Bayero University Kano
Kano, Nigeria
Email: umusa.ele@buk.edu.ng

1. INTRODUCTION

The requirement for extremely high throughput and more effective communication technology had already resulted in a significant expansion of wireless communication over time. When comparing fifth-generation (5G) base stations to their fourth-generation (4G) counterparts, for example, mobile devices require higher bandwidth [1]. Improved antenna systems are needed to meet the flexibility standards of designs, high gain, and enhanced bandwidth of operation for 5G [1], [2]. Since 5G communications require higher bandwidth, many frequency bands, including 28 GHz, 38 GHz, V band, and E band (71-76 GHz, 81-86 GHz, and 91-93 GHz), can be utilized [3].

A new age of technical development is being ushered in by 5G. The need for communication is shifting globally, and 5G has the potential to revolutionize civilization. It can be used for applications in autonomous driving, robotics, aviation, and the medical field owing to its data transmission rates of more than 1 Gbps [4], [5]. The pioneering spectrum bands for the 5G deployment have been identified as 680 MHz, 3.5 GHz, and 26/28 GHz [5]. To that end, many techniques that can enable 5G communication have been proposed in the literature. The slots technique, antenna array technique, defective ground plane structure, and metamaterial have all been applied to enhance performance parameters to satisfy the demands of 5G technology [6]–[8]. The millimeter-wave (mm-Wave) antenna is an important element of the 5G communication system microstrip antennas have been widely used to date due to their advantages of being compact, lightweight, and simple to integrate which are a good fit for usage in a range of wireless applications, including those for aviation, satellite communication, missiles, and medical applications [9]–[13]. Moreover, it comes with the disadvantage of lower bandwidth which can be enhanced utilizing various designed methods [14], [15] and losses caused by the surface wave; numerous works have been performed to utilize it. Even so, these techniques significantly increase complexity and cost [16]. Similarly, for mm-wave 5G applications, several printed antennas were proposed employing various techniques [17]–[20]. The feeding technique is one of the significant characteristics used to increase impedance bandwidth. However, the feeding method varies depending on antenna fabrication, price, and working mechanism with additional radiation, together with impedance matching [21].

Recently, most researchers presented various antenna design techniques for 5G applications. Antenna arrays designed for the mm-wave band were implemented on mobile handsets, but their structures all seem to be three-dimensional, creating incorporation challenges [22]–[24]. Array antennas, such as patch, slot, Vivaldi, and quasi-Yagi antennas were designed in a variety of configurations in [25]–[28]. Aghoutane *et al*. [12] proposed a broadband square slotted 2×1 slotted patch antenna array for 5G cell phone applications at 30 GHz. Similarly, Hasnaoui and Mazri [1] designed and simulated a rectangular patch array antenna for mm-wave applications. Likewise, Zafar *et al*. [4] proposed a spherical beam steering antenna design for next-generation mobile devices. According to Sohail *et al.* [29], an array of 1×4 antennas are presented utilizing Rogers RT/duroid5880 material, the results of the proposed arrays obtained indicate that the linear array has greater gain than the planar array, however, the planar array has superior bandwidth and return loss. Bangash *et al.* [30] proposed a patch antenna array for mm-wave applications.

Following this trend, to support 5G wireless communication, this paper proposes using a variant of the microstrip patch antenna (MPA) array at 28 GHz. With improved bandwidth and gain. The proposed MPA array would be capable of handling high data bit rates and high-frequency spectrum speeds.

2. ANTENNA DESIGN METHOD

The antenna employs Rogers RT 5,880 with εr=2.2, tan δ=0.0009 and thickness, h=0.5 mm. As shown in Figure 1(a), the MPA employs a slit square-shaped antenna with a transmission line. The antenna was designed and fabricated at 28 GHz. The array is used to improve the bandwidth and gain of the proposed antenna. The designed array has been completed using an array approach as shown in Figure 1(b) and (c) array of 1×2 and 1×4 elements a microstrip feeding method is used for the design antennas. The fabricated prototype of the single-element, an array of 1×2 and 1×4 of the proposed antenna is shown in Figures 1(d)-(f) respectively. Theoretical calculations are used to determine the actual size of the rectangular patch antenna. In (1)–(4) of the transmission and cavity model of the MPA are used in the design of the antenna [31]–[33].

Specifically, the patch length is below *λ/2* in other to allow the fundamental TM_{10} mode. Where *λ* is the wavelength expressed as $\lambda o/\sqrt{\varepsilon\ reff}$ and *λo* which demonstrates free space wavelength while εreff indicates effective dielectric substrate. The length and width of the patch are increased on each end by a distance Δ*L*, expressed as (1):

$$\Delta L = 0.412h \frac{(E_{eff}+0.3)\left(\frac{W}{h}+0.264\right)}{(E_{eff}-0.264)\left(\frac{W}{h}+0.8\right)} \tag{1}$$

Where h expressed the thickness of the substrate and W indicates the patch width. The patch effective length, Leff is expressed as (2):

$$Leff = L + 2\Delta L \tag{2}$$

Where *L* represents the patch length. Moreover, for a resonance frequency, f_o the patch effective length is expressed as (3):

$$L_{eff} = \frac{C}{2f_o\sqrt{E_{eff}}} \tag{3}$$

Likewise, patch width antenna is expressed as (4):

$$W = \frac{C}{2f_o\sqrt{\frac{E_r+1}{2}}} \tag{4}$$

where c=3×10^8 m/s is the speed of light.

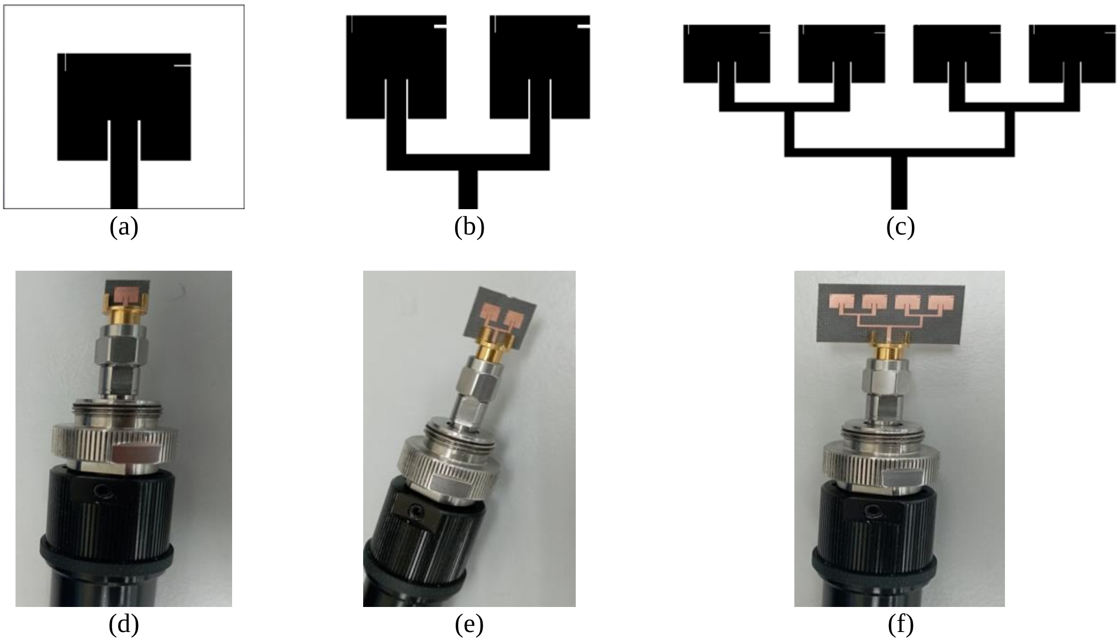

Figure 1. Design and prototype of the proposed MPA at 28 GHz (a) single element MPA, (b) MPA array of 1×2 elements, substrate size is 10.3×14.2 mm, (c) MPA array of 1×4 elements, substrate size is 14.3×26.2 mm, (d) prototype of single element, (e) prototype of 1×2 elements, and (f) prototype of 1×4 elements

The dimensions of the MPA are substrate width=7.24 mm, substrate length=6.3 mm, patch width=4 mm, patch length=3.3 mm, substrate thickness=0.5 mm, patch thickness=0.035 mm, feed length=3.1 mm, feed width=0.8 mm, slit width=0.1 mm, slit length=2.95 mm.

3. EXPERIMENTAL RESULTS AND DISCUSSION

The proposed antenna array was modeled using CST microwave studio. The simulation was validated by comparing the results obtained after fabrication to the measured results. The parameters under consideration are reflection coefficient, surface current distribution, radiation pattern and gain.

3.1. Single element MPA

The simulated and measured reflection S_{11} of the single element MPA at 28 GHz is shown in Figure 2. According to the figure, the proposed antenna operates at 28 GHz and has a simulated reflection coefficient (S_{11}) of -23.7 dB. The resonant frequency of the fabricated antenna is measured at 27.5 GHz with S_{11} of -21.37 dB and a bandwidth of 1.14 GHz that ranges from 26.96 GHz to 28.1 GHz. The difference between measured and simulated resonant frequencies can be attributed to fabrication tolerances and cable losses. Likewise, the radiation patterns of the single-element MPA have been simulated at 28 GHz. Figure 3 shows the radiations patterns of the single-element MPA in the E-plane and H-plane at 28 GHz. From Figure 3(a), it can be observed that the radiation patterns at the resonant frequency of 28 GHz in directional in the E-plane and omnidirectional in the H-plane as shown in Figure 3(b). Furthermore, Figure 4 depicts the surface current distribution of the single-element MPA at 28 GHz. It can be seen that at 28 GHz, the maximum surface current is directed around the edges of the patch, feedline and vertical slit. However, the antenna achieved a high gain of 6.27 dBi.

3.2. MPA array of 1×2 elements

Figure 5 shows the simulated and measured S_{11} for 2-element array MPA, showing above 28 GHz with simulated S_{11} of -31.07 dB. The resonant frequency of the fabricated antenna is measured at 28.5 GHz with S_{11} of -22.37 dB and a bandwidth of 1.207 GHz that ranges between 27.84 GHz to 29.05 GHz. This demonstrates that the bandwidth of the 2-element MPA array exceeds that of the single element throughout the frequency range. The gain with a 1×2 MPA array is 7.76 dBi, which is a gain increase of 1.51 dBi. Furthermore, the radiation patterns of the single-element MPA have also been simulated. Figure 6 depicts the radiation patterns of a 2-element MPA array in the E-plane and H-plane at 28 GHz. The radiation patterns at the resonant frequency of 28 GHz are directional in the E-plane as shown in Figure 6(a) and omnidirectional in the H-plane as shown in Figure 6(b). This demonstrates an increased bandwidth and gain over the single-element MPA. Moreover, Figure 7 depicts the surface current distribution of the proposed 1×2 MPA array at 28 GHz. It can be seen that at 28 GHz, the maximum surface current is directed around the edges of the patch, feedline and vertical slit.

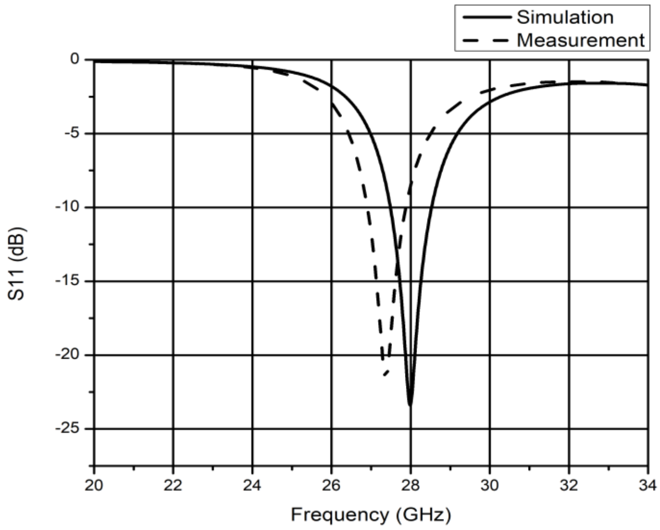

Figure 2. Simulated and measured S_{11} of the single element MPA

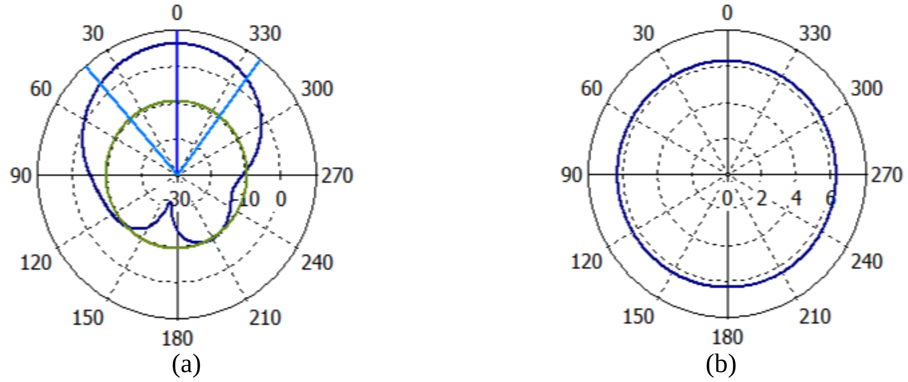

Figure 3. Radiation patterns of the single element MPA (a) E-plane and (b) H-plane

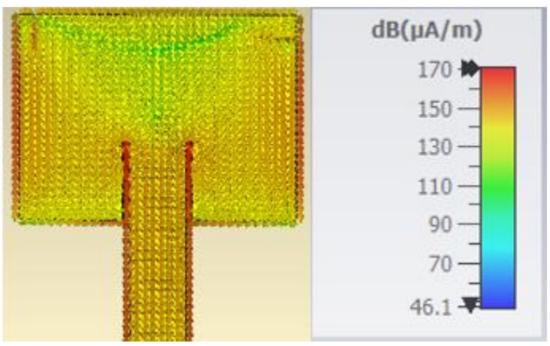

Figure 4. Surface current distribution of the single element MPA

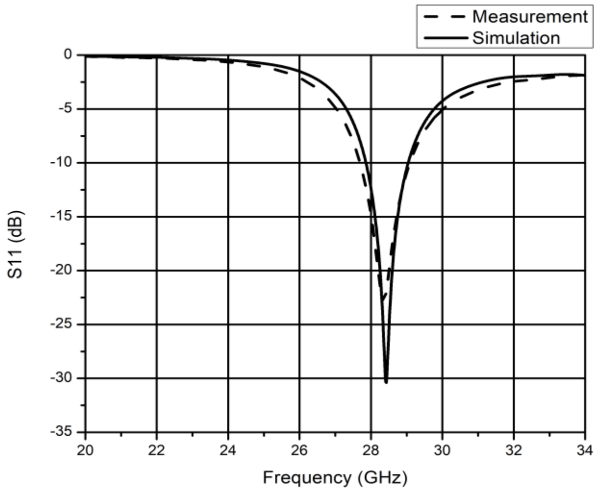

Figure 5. Simulated and measured S_{11} of the MPA array of 1×2 elements

(a) (b)

Figure 6. Radiation patterns of the MPA array of 1×2 elements (a) E-plane and (b) H-plane

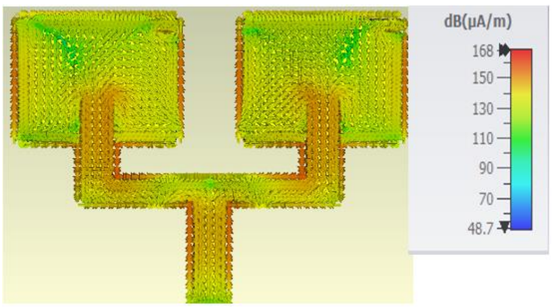

Figure 7. Surface current distribution of the MPA of 1×2 elements

3.3. MPA array of 1×4 elements

Figure 8 shows a comparison of simulated and measured reflection coefficients for the 4-element array MPA, the proposed antenna resonates at 28 GHz and with a simulated S_{11} of -30.71 dB. The fabricated antenna has a resonant frequency of 27.8 GHz, with a measured S_{11} of -19.37 dB, and a bandwidth of 2.685 GHz, which ranges between 26.66 GHz and 29.35 GHz. At 28 GHz, the bandwidth of the 4-element MPA array is greater than that of the 2-element and single-element MPA arrays. The single-element MPA has a gain of 6.27 dBi and the 2-element MPA array has a gain of 7.76 dBi. The gain with a 1×4 MPA array is 9.87 dBi, which is a 2.11 dBi increase over a 1×2 MPA array. Furthermore, the radiation patterns of the single-element MPA have also been simulated. Figure 9 depicts the radiation patterns of a 4-element MPA array in the E-plane and H-plane at 28 GHz. It is observed that the radiation patterns at the resonant frequency of 28 GHz are directional in the E-plane as shown in Figure 9(a) and omnidirectional in the H-plane as shown in Figure 9(b). Similarly, this design has demonstrated an increased bandwidth and gain over the single-element MPA and 12 MPA arrays. As a result, when compared to the 2-element patch antenna and the single patch antenna, the directivity and gain are significantly increased. Moreover, Figure 10 depicts the surface current distribution of the proposed 1×4 MPA array at 28 GHz. It can be seen that at 28 GHz. This demonstrates the suitability of this antenna design for use in 5G applications.

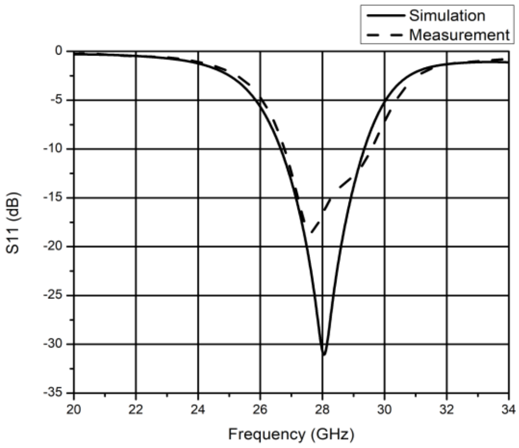

Figure 8. Simulated and measured S_{11} of the MPA array of 1×4 elements

(a) (b)

Figure 9. Radiation patterns of the MPA array of 1×4 elements (a) E-plane and (b) H-plane

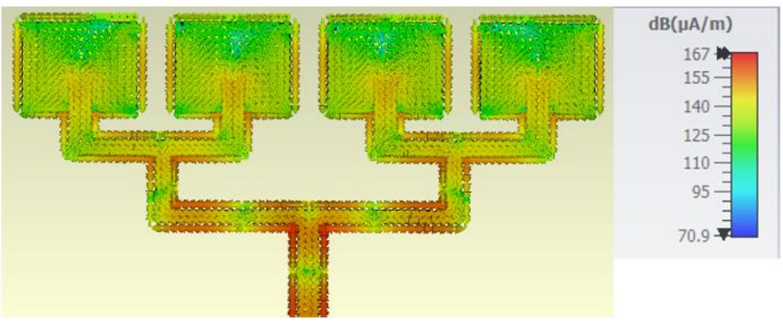

Figure 10. Surface current distribution of the MPA of 1×4 elements

In addition, Table 1 summarizes the measured bandwidth and directivity values at 28 GHz for the MPA 1, 2, and 4 rectangular parallel feed arrays. According to the table, increasing the number of elements increases gain, bandwidth and directivity implying that the four-element patch antenna has high characteristics. When the results were compared to the previous work, which is illustrated in Table 2, the following conclusions were reached: first, there is no fabrication or validation of their design between simulation and measurement. Second, the proposed array antenna achieves better results in terms of bandwidth, reflection coefficient and directivity; and finally, the measured values obtained are comparable to those obtained at 28 GHz and provide high bandwidth (2.685 GHz).

Table 1. Summary results of single element, 1×2 and 1×4 array MPA

Antenna design	Measured S_{11} (dB)	Measured bandwidth (GHz)	Directivity (dBi)
Single element	-21.37	1.14	6.27
1×2 MPA	-22.37	1.207	7.76
1×4 MPA	-19.37	2.685	9.87

Table 2. Comparison with previous work of different 1×4 array MPA

Ref	Resonance frequency (GHz)	S_{11} (dB)	Bandwidth (GHz)	Directivity (dBi)
[29]	28.00	-16.66	0.94	10.00
[30]	27.09	-42.6	1.63	10.95
[1]	28.00	-35.6	2.2	12.87
[4]	28.00	-17.00	-	6.9214
This work	28.00	-30.71	2.685	9.87

4. CONCLUSION

MPA with increased performance in terms of speed, size, data rate, and efficiency are required for mm-wave applications. As a result, enhancement methods are required. This study proposes a new antenna array design for the 5G mobile communication network at 28 GHz. A four-element antenna array's bandwidth and directivity increased when compared to single-element and two-element array antennas, as demonstrated by the simulated and measured results comparison. The 5G antenna and array can be used for future 5G mobile communications due to their compactness and small size.

ACKNOWLEDGEMENTS

The Nigerian Communication Commission (NCC) Research and Development Department funded this work with grant number NCC/R&D/BUK/010.

REFERENCES

[1] Y. E. Hasnaoui and T. Mazri, “Study, Design and Simulation of an Array Antenna for Base Station 5G,” in *2020 International Conference on Intelligent Systems and Computer Vision (ISCV)*, Jun. 2020, doi: 10.1109/iscv49265.2020.9204261.
[2] D. Muirhead, M. A. Imran, and K. Arshad, “A Survey of the Challenges, Opportunities and Use of Multiple Antennas in Current and Future 5G Small Cell Base Stations,” *IEEE Access*, vol. 4, pp. 2952–2964, 2016, doi: 10.1109/access.2016.2569483.
[3] W. A. Awan, “Very small form factor with ultra wide band rectangular patch antenna for 5G applications,” in *2018 International Conference on Computing, Mathematics and Engineering Technologies (iCoMET)*, Mar. 2018, doi: 10.1109/icomet.2018.8346395.
[4] T. Zafar, A. Noor, T. Ahmed, N. M. J. Piya, and A. K. M. A. M. Azad, “Development and Study of 28GHz Antenna for Different Shapes and Work on Antenna Transparency for Celluler Devices,” in *2020 IEEE Region 10 Symposium (TENSYMP)*, 2020, doi: 10.1109/tensymp50017.2020.9230779.
[5] U. Musa, S. Babani, Z. Yunusa, and A. S. Ali, “Bandwidth Enhancement of Microstrip Patch Antenna Using Slits for 5G Mobile Communication Networks,” in *2020 International Symposium on Antennas and Propagation (ISAP)*, Jan. 2021, doi: 10.23919/isap47053.2021.9391151.
[6] E. S. M. U. Noor and M. I. Khattak, “Design and Analysis of Dual-Band Microstrip Patch Antenna Array for 5G Cellular Communication Networks with Improved Radiation Characteristics,” in *2019 Second International Conference on Latest trends in Electrical Engineering and Computing Technologies (INTELLECT)*, Nov. 2019, doi: 10.1109/intellect47034.2019.8954981.
[7] M. Nahas, “A Super High Gain L-Slotted Microstrip Patch Antenna For 5G Mobile Systems Operating at 26 and 28 GHz,” *Engineering, Technology &amp$\mathsemicolon$ Applied Science Research*, vol. 12, no. 1, pp. 8053–8057, Feb. 2022, doi: 10.48084/etasr.4657.
[8] V. A. A. Filho and A. L. P. S. Campos, “Performance optimization of microstrip antenna array using frequency selective surfaces,” *Journal of Microwaves, Optoelectronics and Electromagnetic Applications*, vol. 13, no. 1, pp. 31–46, Jun. 2014, doi: 10.1590/s2179-10742014000100003.
[9] L. Ge, J. Wang, M. Li, T.-Y. Shih, and S. Chen, “Antennas and Circuits for 5G Mobile Communications,” *Wireless Communications and Mobile Computing*, vol. 2018, pp. 1–2, Jun. 2018, doi: 10.1155/2018/3249352.
[10] K. H. Sayidmarie, N. J. McEwan, P. S. Excell, R. A. A-Alhameed, and C. H. See, “Antennas for Emerging 5G Systems,” *International Journal of Antennas and Propagation*, vol. 2019, pp. 1–3, Jul. 2019, doi: 10.1155/2019/9290210.
[11] P. S. Naik and H. G. Virani, “1×4 Microstrip Patch Slotted Array Antenna for 5G C-Band Access Point Application,” in *2020 International Conference on Electronics and Sustainable Communication Systems (ICESC)*, Jul. 2020, doi: 10.1109/icesc48915.2020.9156015.

[12] B. Aghoutane, H. E. Faylali, S. Das, and M. Elghzaoui, "Design of a high gain 2 1 patch array for fifth generation wireless applications," in *2019 7th Mediterranean Congress of Telecommunications (CMT)*, Oct. 2019, doi: 10.1109/cmt.2019.8931351.
[13] N. M. Nadzir, M. K. A. Rahim, N. A. Murad, and M. Himdi, "Millimeter Wave Microstrip Antenna with CSRR for 5G Application," in *2020 International Symposium on Antennas and Propagation (ISAP)*, Jan. 2021, doi: 10.23919/isap47053.2021.9391130.
[14] M. S. Rabbani and H. G-Shiraz, "Simple methods for enhancing bandwidth of a rectangular microstrip patch antenna," in *2nd IET Annual Active and Passive RF Devices Seminar*, 2014, doi: 10.1049/ic.2014.0184.
[15] C. Wu, K. L. Wu, Z. Q. Bi, and J. Litva, "Accurate characterization of planar printed antennas using finite-difference time-domain method," *IEEE Transactions on Antennas and Propagation*, vol. 40, no. 5, pp. 526–534, May 1992, doi: 10.1109/8.142627.
[16] E. Hussein and N. Qasem, "Design and optimization of rectangular microstrip patch array antenna using frequency selective surfaces for 60 GHz," *International Journal of Applied Engineering Research*, vol. 11, pp. 4679–4687, Nov. 2016.
[17] Y. Jandi, F. Gharnati, and A. O. Said, "Design of a compact dual bands patch antenna for 5G applications," in *2017 International Conference on Wireless Technologies, Embedded and Intelligent Systems (WITS)*, Apr. 2017, doi: 10.1109/wits.2017.7934628.
[18] L. G. Ayalew and F. M. Asmare, "Design and optimization of pi-slotted dual-band rectangular microstrip patch antenna using surface response methodology for 5G applications," *Heliyon*, vol. 8, no. 12, p. e12030, Dec. 2022, doi: 10.1016/j.heliyon.2022.e12030.
[19] M. I. Khattak, A. Sohail, U. Khan, Z. Barki, and G. Witjaksono, "Elliptical slot circular patch antenna array with dual band behaviour for future 5g mobile communication networks," *Progress In Electromagnetics Research C*, vol. 89, pp. 133–147, 2019, doi: 10.2528/pierc18101401.
[20] M. Anab, M. I. Khattak, S. M. Owais, A. A. Khattak, and A. Sultan, "Design and analysis of millimeter wave dielectric resonator antenna for 5g wireless communication systems," *Progress In Electromagnetics Research C*, vol. 98, pp. 239–255, 2020, doi: 10.2528/pierc19102404.
[21] S. Sharma, C. C. Tripathi, and R. Rishi, "Impedance Matching Techniques for Microstrip Patch Antenna," *Indian Journal of Science and Technology*, vol. 10, no. 28, pp. 1–16, Feb. 2017, doi: 10.17485/ijst/2017/v10i28/97642.
[22] N. Ojaroudiparchin, M. Shen, S. Zhang, and G. F. Pedersen, "A Switchable 3-D-Coverage-Phased Array Antenna Package for 5G Mobile Terminals," *IEEE Antennas and Wireless Propagation Letters*, vol. 15, pp. 1747–1750, 2016, doi: 10.1109/lawp.2016.2532607.
[23] K. M. Morshed, K. P. Esselle, M. Heimlich, D. Habibi, and I. Ahmad, "Wideband slotted planar inverted-F antenna for millimeter-wave 5G mobile devices," in *2016 IEEE Region 10 Symposium (TENSYMP)*, May 2016, doi: 10.1109/tenconspring.2016.7519403.
[24] H. Zhou, "Phased array for millimeter-wave mobile handset," in *2014 IEEE Antennas and Propagation Society International Symposium (APSURSI)*, Jul. 2014, doi: 10.1109/aps.2014.6904795.
[25] J. Bang and J. Choi, "A SAR Reduced mm-Wave Beam-Steerable Array Antenna With Dual-Mode Operation for Fully Metal-Covered 5G Cellular Handsets," *IEEE Antennas and Wireless Propagation Letters*, vol. 17, no. 6, pp. 1118–1122, Jun. 2018, doi: 10.1109/lawp.2018.2836196.
[26] I. Syrytsin, S. Zhang, G. F. Pedersen, and A. S. Morris, "User-Shadowing Suppression for 5G mm-Wave Mobile Terminal Antennas," *IEEE Transactions on Antennas and Propagation*, vol. 67, no. 6, pp. 4162–4172, Jun. 2019, doi: 10.1109/tap.2019.2905685.
[27] X. Chen, M. Abdullah, Q. Li, J. Li, A. Zhang, and T. Svensson, "Characterizations of Mutual Coupling Effects on Switch-Based Phased Array Antennas for 5G Millimeter-Wave Mobile Communications," *IEEE Access*, vol. 7, pp. 31376–31384, 2019, doi: 10.1109/access.2019.2902951.
[28] H. Li, Y. Cheng, and Z. Ling, "Design of Distributed and Robust Millimeter-Wave Antennas for 5G Communication Terminals," *IEEE Access*, vol. 8, pp. 133420–133429, 2020, doi: 10.1109/access.2020.3010527.
[29] A. Sohail, H. Khan, U. Khan, M. I. Khattak, N. Saleem, and J. A. Nasir, "Design and Analysis of a Novel Patch Antenna Array for 5G and Millimeter Wave Applications," in *2019 2nd International Conference on Computing, Mathematics and Engineering Technologies (iCoMET)*, Jan. 2019, doi: 10.1109/icomet.2019.8673490.
[30] K. Bangash, M. M. Ali, H. Maab, and H. Ahmed, "Design of a Millimeter Wave Microstrip Patch Antenna and Its Array for 5G Applications," in *2019 International Conference on Electrical, Communication, and Computer Engineering (ICECCE)*, Jul. 2019, doi: 10.1109/icecce47252.2019.8940807.
[31] C. A. Balanis, *Antenna Theory: Analysis and Design*. Wiley; 4th edition, 2016. [Online]. Available: https://www.wiley.com/en-us/Antenna+Theory%3A+Analysis+and+Design%2C+4th+Edition-p-9781118642061 (accessed: Dec. 07, 2022).
[32] P. Subbulakshmi and R. Rajkumar, "Design and characterization of corporate feed rectangular microstrip patch array antenna," in *2013 IEEE International Conference ON Emerging Trends in Computing, Communication and Nanotechnology (ICECCN)*, Mar. 2013, doi: 10.1109/ice-ccn.2013.6528560.
[33] Q. Deng, W. Zhang, and J. Jiang, "Design and simulation of the microstrip antenna for 2.4 GHz HM remote control system," in *Proceedings of the 2nd International Conference On Systems Engineering and Modeling*, 2013, doi: 10.2991/icsem.2013.44.

BIOGRAPHIES OF AUTHORS

Umar Musa obtained his bachelor's degree in Electrical Engineering from Bayero University Kano, Nigeria, in 2012, and M. Eng. Electronic and Telecommunication Engineering in 2016 from Universiti Teknologi Malaysia (UTM), Malaysia. He is currently a Ph.D. student in the Department of Communication Engineering, Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia (UTHM). He is currently a lecturer in the Department of Electrical engineering at Bayero University Kano, Nigeria and, he is a member of the Council for the Regulation of Engineering of Nigeria since 2019. His area of research includes, but is not limited to, the design of RF and microwave devices, and active antennas measurement. He can be contacted at email: umusa.ele@buk.edu.ng.

Suleiman Babani received his bachelor's degree in Electrical Engineering from Bayero University Kano, Nigeria in the year 2008, and M. Eng. Electronics and Telecommunication Engineering in the year 2014 from Universiti Teknologi Malaysia UTM, Malaysia. He is currently a Ph.D. student in Advanced Materials, Antenna Design at Universiti Putra Malaysia UPM. He has published many local and international journals and conference proceedings on the design and development of R.F. and nanomaterials for electronic applications and the development of microstrip patch antennas for certain applications. He is currently a lecturer in the Department of Electrical engineering at Bayero University Kano and, he is a corporate member of the Nigerian Society of Engineers and a member of the Council for the Regulation of Engineering of Nigeria since 2014 and 2015. His main interests include R.F and microwave devices and applications, Nanomaterials for electronic applications, antenna design and applications. He can be contacted at email: sbabani.ele@buk.edu.ng.

Suleiman Aliyu Babale received his bachelor's degree in Electrical Engineering from Bayero University Kano, in 2005, and his master's degree in Electrical Engineering from Ahmadu Bello University Zaria, in 2012. In 2018, he earned a Ph.D. in electrical engineering with a major in Telecommunications from Universiti Teknologi Malaysia. He is a member of staff with BUK and has over 30 journals and conference papers on telecommunications. Since 2011, he has been a registered member of COREN. He can be contacted at email: sababale.ele@buk.edu.ng.

Abubakar Sani Ali received his bachelor's degree in electrical engineering from Bayero University Kano, in 2014, and an MSc in Communications and Signal Processing from the University of Leeds. He is currently a Ph.D. student at Khalifa University and also a lecturer in the Department of Electrical engineering at Bayero University Kano, Nigeria. His area of research includes low-power wireless communications, machine learning, and artificial intelligence. He can be contacted at email: asali.ele@buk.edu.ng.

Zainab Yunusa received her bachelor's degree in Electrical Engineering from Bayero University Kano, Nigeria in the year 2003, and M. Eng. in Electrical Engineering in the year 2010 from Bayero University Kano, Nigeria. She then received her Ph.D. in sensor technology engineering from Universiti Putra Malaysia in 2015. She has published many local and international journals and conference proceedings on the design and development of R.F and microwave sensors, nanomaterials for electronic applications and the development of microstrip patch antennas for certain applications. She is currently a Senior lecturer in the Department of Electrical engineering at Bayero University Kano and an Assistant professor in the Department of Electrical Engineering University of Hafr Al Batin, Kingdom of Saudi Arabia. She is a corporate member of the Nigerian Society of Engineers and a member of the Council for the Regulation of Engineering of Nigeria since 2011. Her main interests include R.F and microwave devices and applications, nanomaterials for electronic applications, gas sensors, antenna design and applications. She can be contacted at email: zyyusuf.ele@buk.edu.ng.

Sani Halliru Lawan received the B.Eng. and M.Eng. degrees in electrical engineering from Bayero University Kano, Kano, Nigeria, in 2006 and 2013, respectively, and the Ph.D. degree in electrical engineering (photonics) from Universiti Teknologi Malaysia, in 2019. He has been working as a Lecturer at Bayero University Kano since 2009. His research interests include fiber propagation, optical and wireless communication systems, passive optical networks, and electrical engineering services. He can be contacted at email: shlawan.ele@buk.edu.ng.