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Orthogonally Placed 2-Port MIMO Antenna System for 5G mm-wave Application

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***Abstract*—**This paper presents a compact MIMO antenna of 2-port having placed orthogonally for upcoming 5th generation mm-wave application. The single unit cell of the proposed MIMO antenna system consists of an elliptical patch as a radiator with a dimension of 2.1 x 1.1 mm^2 (a x b) using a microstrip feed line of 50-ohm for impedance matching. Roggers RT5880 is used as a substrate material with a standard thickness of 0.254 mm and a total dimension of 9 x 8 mm^2 (Lx W). It is observed from the simulation that a single antenna element operating from 29.6—44.2 GHz, wide impedance bandwidth of 14.6 GHz, and -25.8 dB return loss at a central frequency of 38.7 GHz. Furthermore, a 2-port MIMO antenna system is utilized for increased channel capacity and high diversity polarization. For MIMO transformation, the same single unit cells are arranged orthogonally for mitigating mutual coupling. The total geometry of the proposed design is 8 x 15 mm^2 having a compact size and offering a wide impedance bandwidth of 16 GHz, low isolation coefficient of -17 dB, high gain, efficiency, low ECC, and high diversity gain. However, all the simulated outcomes for the proposed design are valid and consider good candidate

The overall geometry of the proposed MIMO

***Keywords*—** MIMO, Elliptical-shaped, orthogonal, next-generation, ECC.

I. Introduction

In the realm of mobile communication, there is a rapidly growing demand for data transfer at high speeds and with bigger channel capacities. An expanding number of internet users are connecting to the internet at an exponential rate, driven by the use of many wireless devices by individual users. This trend necessitates high data transmission rates with minimal latency. Furthermore, current wireless communication systems face additional difficulties because of the growing need for smaller devices.[1] Moreover, the existing band spectrum is congested due to multiple technologies utilizing overlapping frequencies. [2]Because of this, the wireless system and the band spectrum might not be able to deal with the issues that are currently being faced.[3] In light of this, academics have begun investigating new technologies, such as the millimeter-wave (mm-wave) band spectrum, which extends from 30 to 300 GHz, and 5G, as a potential answer to the problems that have recently arisen. [4] Many different band spectrums could be used for future applications involving millimeter waves, the 28 GHz band is important because it has a low absorption rate and a large amount of unlicensed spectrum. [5, 6]. Also, any communication system must have this mandatory module. I.e. additional restrictions that counteract the aforementioned difficulties should be incorporated into the design of the antenna [7]. One of the most essential elements of 5G wireless communication networks is the technique known as multiple-input-multiple-output antennas, or MIMO. Through the utilization of this technology, spectrum efficiency, cost efficiency, and energy efficiency are all improved. Increasing channel capacity by a large amount is a common application of MIMO, which is employed in a wide variety of systems. As a result, experts in the field are devoting more time and energy to creating new antenna designs specifically for mm-wave applications. Hence, 28 GHz was the primary focus of most of the published mm-wave antenna designs, and it led to the development of a wide variety of antenna designs for applications such as smartwatches, smartphones, portable devices, and dongle devices[8]. Due to low atmospheric attenuation, which is one of the most significant and non-negotiable challenges in mm-wave communication, and because of this, it has garnered a considerable lot of interest from the research community. [9, 10] Because these types of attenuations lead the signal to become faint as it moves from the transmitter to the reception side, resulting in the user receiving a signal of poor quality and low intensity.[11, 12]An antenna with a high gain and Multiple Input Multiple Output (MIMO) configuration can address these problems and enhance user communication by utilizing the multi-path characteristic.[13-16]

Several antennas that are suitable for use in mm-wave applications have been described in the published literature. An antenna for 5G that has a MIMO design and a wide response of 23–40 GHz has been reported in a study [17]. The proposed design has an area of 80 x 80 mm^2. The MIMO architecture that has been proposed is capable of achieving a very wide bandwidth; nevertheless, the size of this bandwidth has been observed to be fairly enormous. A circular, polarized MIMO antenna with 4 ports is presented in [18], to enhance the radiation properties, an antenna element is positioned within the center of a large number of parasitic elements. On the other hand, the utilization of parasitic elements contributes to an increase in the complexity of the MIMO design that has been proposed. The authors of Reference [19]describe a single antenna element that has a maximum gain of 6.59 dB and an overall dimension of 10 × 6 mm^2. Despite the fact that the antenna element is capable of achieving sufficiently high gains, electromagnetic band-gap structures (EBG) are being implemented. The coupling problems are becoming more severe, but the fabrication work is becoming more complicated. Also, in [20], it is suggested to use array antennas at two different frequency bands: 28 GHz and 38 GHz. Although the stated antenna has a significant gain, it does not have the MIMO capability.

Reference [21] proposes an 8 x 8 MIMO setup with a total volume of 31.2 × 31.2 × 1.57 mm^3, resonating at 25.2 GHz with a peak gain of 8.7 dB, In spite of the fact that the suggested antenna radiation response shows a significant number of back and side lobes. An antenna that is designed for use in 4G and 5G applications is provided in Reference [22]. This antenna has a resonance frequency of 28 GHz and spans a total area of 75 × 85 mm2. In the mm-wave spectrum, the gain is 5.13 dB, and the radiation response has many side and back lobes. Due to these factors, the suggested antenna is not suitable for use in mm-wave communication. Similarly, a design for a millimeter-wave antenna that has a structure of T-shaped using cpw feed and covers the frequency band that is approximately between 25.1-- 37.5 GHz is proposed in [23]. The reported design achieved a gain of 9.86 dBi at 36.8 GHz but it has a limitation of MIMO system and complex design with bulky shape. An antenna system that is multi-band and four-port is described in Reference [24]. The system has an overall size of 158 × 78 mm^2, achieving a gain of 5.1 dB at 28 GHz. Through the use of the mm-wave antenna, three distinct resonances were produced at frequencies of 28 GHz, 37 GHz, and 39 GHz. However, each antenna has its unique dimensions, the board can only accommodate a maximum of four antennas. An innovative T slot four-element antenna system that is comprised of two element-feed networks is shown in Reference [25]. The suggested design operating in two bands .i.e. sub-6 GHz and mm-wave range (24-- 29), achieving a gain of 5 dBi with an impedance bandwidth of 5 GHz. Despite the fact that having a bigger dimensions of ground plane assembly and radiating elements prevents the structure from being employed with a greater number of elements.

Based on the aforementioned literature as discussed above, this research work focuses on developing a MIMO antenna system with reduced decoupling for 38 GHz mm-wave application, keeping in mind the demand for compact devices. The single unit cell was further utilized for a 2-port MIMO antenna system, arranged orthogonally without any complex decoupling techniques, achieving a high gain and wider impedance bandwidth. Keeping all essential MIMO parameters and pattern diversity, the proposed design is valid and can be considered a good candidate for the 5G application.

II. Antenna Design

A. Single Unit Cell

Based on the MIMO antenna design, the proposed single antenna element is depicted in Figure 1. Figure 1(a) shows the top view of the proposed design while Figure 1(b) indicates the bottom view having truncated ground. The optimized dimensions are listed in Table 1. Truncated ground with a slot having a length of 1.38mm and width of 1.3 mm is utilized for wider impedance bandwidth while an elliptical resonator is for impedance matching. Roggers RT5880 is used as a substrate material with a standard thickness of 0.254 mm. The overall geometry of the proposed single antenna element is 8 x 9 mm^2, using a 50-ohm microstrip line for impedance matching having a 5.6 mm length and 0.9mm width. For impedance enhancement, the elliptical resonator is optimized to one end.

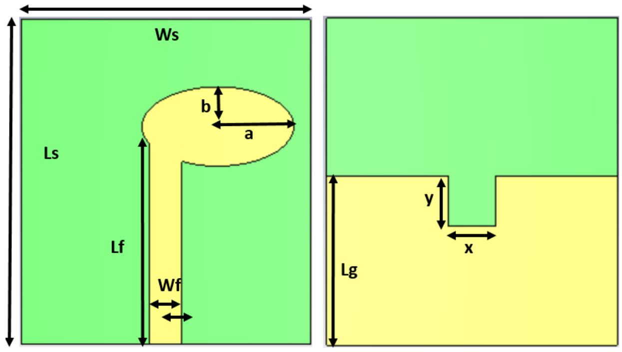


Figure 1. Proposed single antenna Element

TABLE I. Parameters of Single Unit Cell

Description	*Parameters*	*Values (mm)*
Substrate Length	L_s	*9*
Substrate Width	W_s	*8*
Substrate Thickness	H_s	0.254
Elliptical Length	a	2.1
Elliptical width	b	1.1
Length of feed	L_F	5.6
Width of feed	W_f	0.9

B. MIMO Configuration

As illustrated in Fig. 2, the proposed design is transformed into a 2-port MIMO system. The overall dimensions of the proposed design are 8 x 15mm^2. Each radiating element in the MIMO system was positioned at an angle of 90^0 from each other, keeping a distance of 5 mm between center-to-center.

Such arrangements of MIMO configuration are essential for less coupling effect and improved spatial and pattern diversity. The optimized dimensions of the proposed array are listed in Table 2.

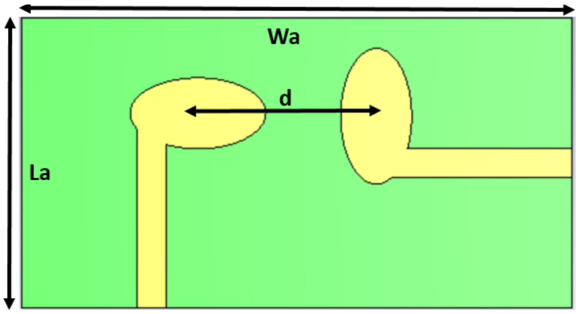


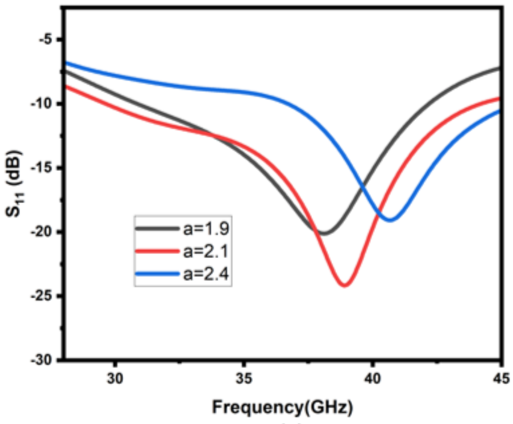
Figure 2. Proposed 2-port MIMO antenna system

TABLE II. PARAMETERS OF SINGLE UNIT CELL

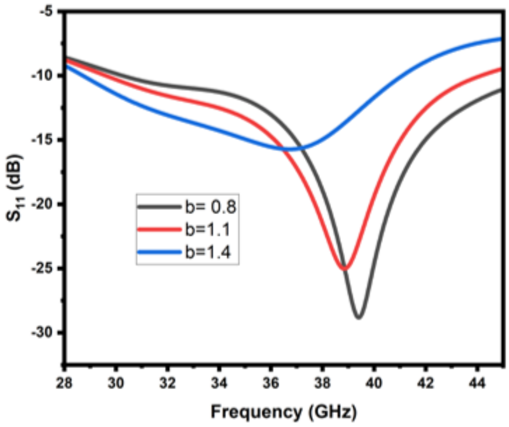
Description	Parameters	Values (mm)
Length of array	L_a	*15*
Width of array	W_a	*8*
Separation distance	d	5

III. PARAMETRIC STUDY

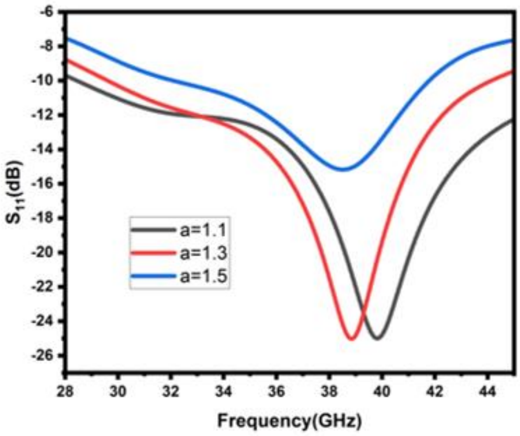
Figure 3 illustrates the impact of different factors on the proposed MIMO antenna, such as the length and width of the elliptical radiator, and the ground slot effect as depicted in Figure 3. Fig 3(a) shows the effect of radiator length, which also confirms the theoretical concept that increasing length will decrease the frequency and at 2.1 mm length it gives much improved impedance having a central frequency of 38.5 GHz with wide impedance. Figure 3 (b) shows the effect of width on the reflection coefficient. By increasing the width its impedance shifts to a lower frequency but impedance degrades. Figure 3 (c) illustrates the width effect of the ground slot, having better impedance at 1.3mm achieved at the desired 38 GHz frequency.



(a)



(b)



(c)

Figure 3. Effect of various parameters on proposed unit cell (a) Elliptical length (b) Elliptical width (c) width of ground slot

IV. RESULTS AND DISCUSSION

A. Single Unit cell

An important parameter that describes the impedance-matching characteristics and bandwidth of the antenna elements is termed the reflection coefficient (S_{11}). The simulated scattering parameters of the proposed single antenna element having resonance less than 10 dB are depicted in Figure 4. From the figure, it can be observed that single-unit cells are operating from 29.6—44.2 GHz having a wide impedance bandwidth of 14.6 GHz, and a return loss of -25.8 dB at a resonance of 38.7 GHz.

The simulated 2-D far-field radiation pattern (E & H) of the suggested design is illustrated in Figure 5 (a). The radiation patterns are simulated at a central frequency of 38.7 GHz, achieving a peak gain of 4.56 dBi at 40.7 GHz and 4.24 dBi at 38-8 GHz. Figure 5(b) shows the gain vs frequency plot of the suggested design. The simulated radiation efficiency of the suggested design is depicted in Figure 5 (b). From the figure, it can be noticed that it has an overall radiation efficiency of more than 95 % across the operating band and 96.6 % at a central frequency.

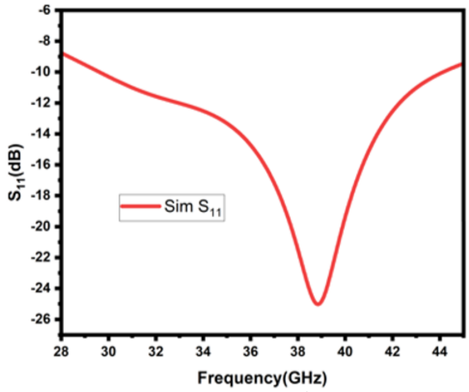
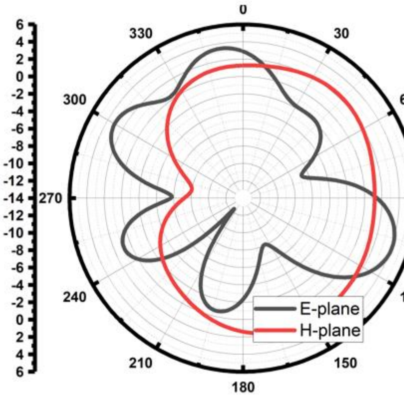
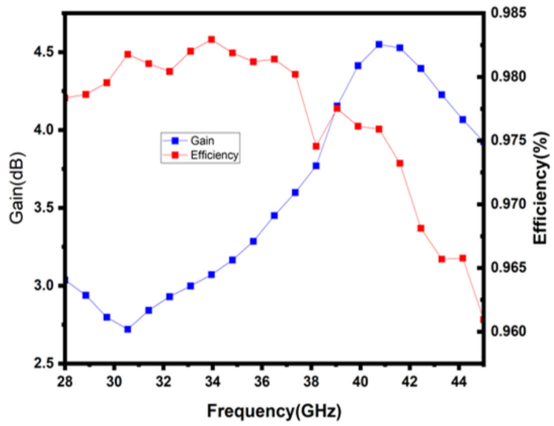


Figure 4. Simulated s-parameter of the proposed single antenna element



(a)



(b)

Figure 5. Simulated results of single antenna element (a) 1D far field (b) Gain vs frequency & Rad Efficiency

B. *MIMO configuration*

By maintaining center–a center-to-center distance of 5mm, the simulated return loss of the proposed 2-port MIMO system is depicted in Figure 6. From the figure, it can be observed that the return loss of port-1 has a slight shift toward higher frequency due to unsymmetrical geometry, maintaining a bandwidth of 16.1 GHz (28.1—44.2). The isolation coefficient of the proposed design is noticed below the standard value. i.e. -15 dB, throughout the operating band, validating the design performance. Figure 7(a) illustrates the simulated 2D far-field radiation pattern and 7(b) indicates gain vs frequency and efficiency. From the figure, it can be shown that it has a peak gain of 5 dBi at 38 GHz with an overall efficiency of more than 96 % throughout the operating band.

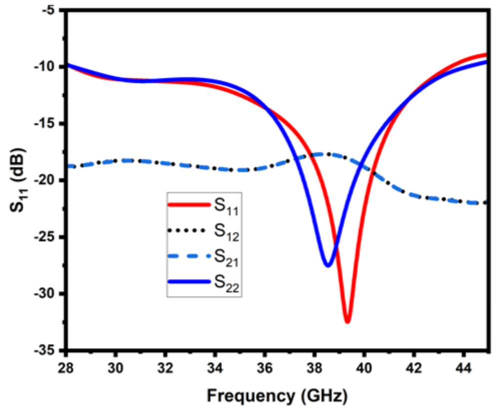
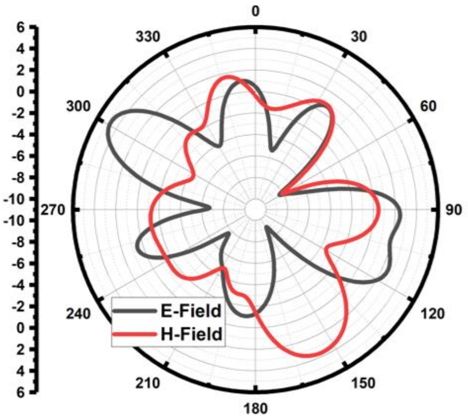
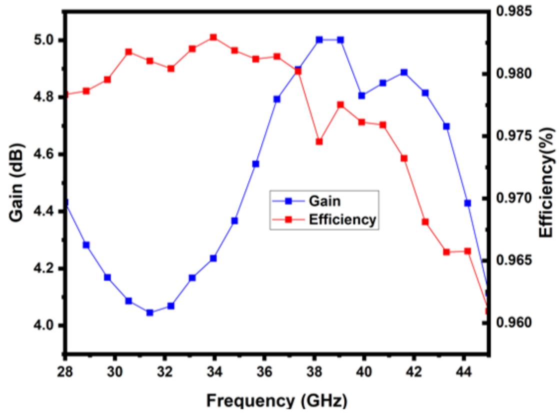


Figure 6. Simulated results of the proposed MIMO system



(a)

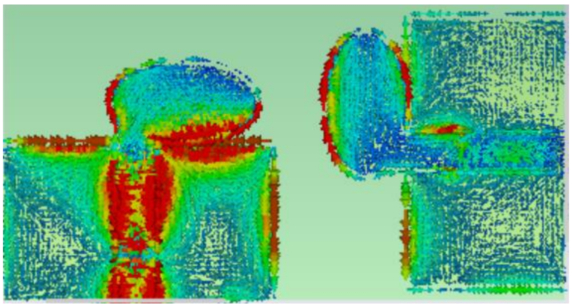


(b)

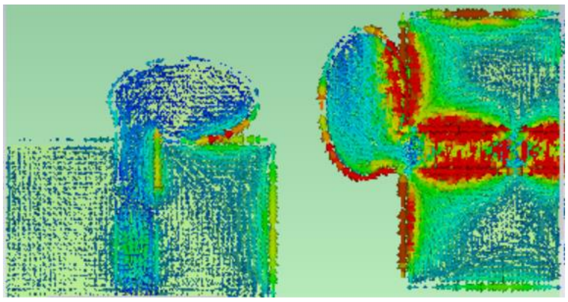
Figure 7. Simulated results of proposed MIMO antenna system (a) Far-field radiation pattern at 38 GHz (b) Gain vs frequency and efficiency

C. *Current distribution*

Figure 10 shows a representation of the surface current distribution that was simulated for the suggested 2-port MIMO antenna, representing both ports respectively. It is worth mentioning that both the antenna's components share a maximum current distribution pattern that centers on the feed line, radiating structure, and truncated ground plane. Therefore, it is possible to assert that the truncated ground and elliptical resonator is an essential component in the process of achieving a wideband response.



(a)



(b)

Figure 8. Current distribution of 2-port MIMO antenna at 38 GHz (a) Port-1 (b) Port-2

D. *MIMO Parameters*

1) *Envelop correlation coefficient (ECC)*

One of the most essential parameters that is utilized in the process of evaluating the performance of the MIMO antenna is the envelope correlation coefficient (ECC). It determines if the branch signals received by the various MIMO-antenna elements are correlated with one another or isolated from one another. The ECC should have a value of zero to provide the highest possible level of inter-element isolation. However, an ECC of a value less than 0.5 is almost good enough for enhanced diversity performance. [26] Figure 9 indicates the simulated ECC of the proposed design. From the figure, it can be shown the ECC has a value of less than 0.007 throughout the operating band, which indicates design validity and enhanced performance.

2) *Diversity Gain (DG)*

The diversity gain (DG) is another key metric that is used to measure the performance of the MIMO antenna. Using DG in the MIMO system gives details about gain enhancement and gives diversity effects on wireless links. Using equation 1, it can be calculated.[26]. Figure 10 illustrates the simulated DG of the proposed MIMO design, which has a value of 9.9 dB throughout the operating band.

$$DG = \sqrt{1 - ECC^2} \qquad (1)$$

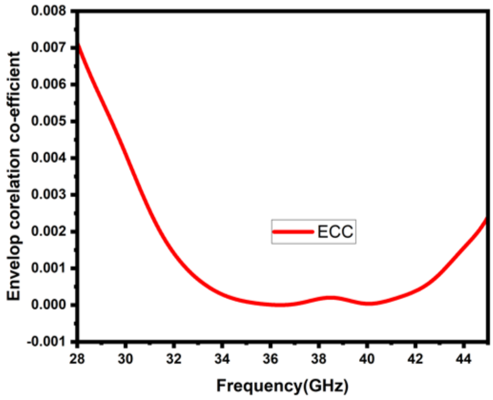
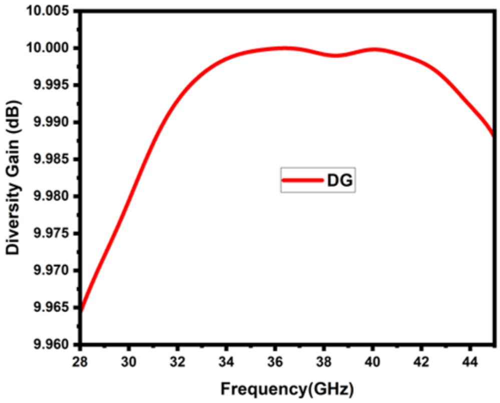


Figure 9. Simulated ECC of proposed MIMO antenna



V. CONCLUSION

In this paper, a compact 2-port MIMO antenna for an mm-wave communication system is presented. The single unit cell of the proposed work is configured to elliptical resonator of truncated ground and slot. The total dimensions of a single element are 8 x 8 mm^2 offering a compact size. The single antenna operates from 29.6—44.2 GHz, covering a wide impedance bandwidth of 14.6 GHz, and a peak gain of 4.24 dBi. The single antenna element is further transferred to a two-port MIMO system of compact size. The overall dimensions of the proposed 2-port MIMO are 8 x15 mm^2. To mitigate mutual coupling, MIMO antennae are arranged orthogonally, achieving a high isolation of less than 15 dB, ECC below 0.001, and DG of 9.9 dBi. Therefore, the proposed single and MIMO antenna offers a very compact size and high performance, resulting in a good candidate for 5G mm-wave application.

REFERENCES

[1] J. G. Andrews et al., "What will 5G be? " vol. 32, no. 6, pp. 1065-1082, 2014.

[2] W. A. Awan, A. Zaidi, N. Hussain, A. Iqbal, A. J. M. Baghdad, and O. T. Letters, "Stub loaded, low profile UWB antenna with independently controllable notch‐bands," vol. 61, no. 11, pp. 2447-2454, 2019.

[3] M. Hussain, S. M. Rizvi, A. Abbas, A. Nadeem, I. Alam, and A. Iftikhar, "A wideband antenna for V-band applications in 5G communications," in 2021 International Bhurban Conference on Applied Sciences and Technologies (IBCAST), 2021, pp. 1017-1019: IEEE.

[4] W. A. Awan, A. Zaidi, and A. Baghdad, "Patch antenna with improved performance using DGS for 28GHz applications," in 2019 international

conference on wireless technologies, embedded and intelligent systems (WITS), 2019, pp. 1-4: IEEE.

[5] N. Hussain, M.-J. Jeong, J. Park, and N. J. I. A. Kim, "A broadband circularly polarized fabry-perot resonant antenna using a single-layered PRS for 5G MIMO applications," vol. 7, pp. 42897-42907, 2019.

[6] A. N. U. Rehman, R. Jamil and I. Jamil, "Effect of Different BER Performance Comparison of MAP and ML Detection", World Academy of Science Engineering and Technology, vol. 8, no. 9, pp. 1524-1527,2014.

[7] M. Hussain and N. Nadeem, "A co-planer waveguide feed dual band antenna with frequency reconfigurability for WLAN and WiMax systems," in 2019 International Conference on Electrical, Communication, and Computer Engineering (ICECCE), 2019, pp. 1-5: IEEE.

[8] M. Khalid et al., "4-Port MIMO antenna with defected ground structure for 5G millimeter wave applications," vol. 9, no. 1, p. 71, 2020.

[9] E. J. J. W. P. S. NetWorld, "5g: Challenges, research priorities, and recommendations," 2014.

[10] I. Shayea, T. A. Rahman, M. H. Azmi, and M. R. J. I. A. Islam, "Real measurement study for rain rate and rain attenuation conducted over 26 GHz microwave 5G link system in Malaysia," vol. 6, pp. 19044-19064, 2018.

[11] H. Aliakbari, A. Abdipour, A. Costanzo, D. Masotti, R. Mirzavand, and P. Mousavi, "Performance investigation of space diversity for a 28/38 GHz MIMO antenna (applicable to mm-wave mobile network)," in 2016 Fourth International Conference on Millimeter-Wave and Terahertz Technologies (MMWaTT), 2016, pp. 41-44: IEEE.

[12] Rehan Jamil et al., Case Study of Wireless Networking for Small Business, Int.J Engineering works, Vol. 1, PP. 20-25, Sept. 2014

[13] J. Zhang, X. Ge, Q. Li, M. Guizani, and Y. J. I. W. c. Zhang, "5G millimeter-wave antenna array: Design and challenges," vol. 24, no. 2, pp. 106-112, 2016.

[14] F. Wang, Z. Duan, X. Wang, Q. Zhou, Y. J. I. J. o. A. Gong, and Propagation, "High isolation millimeter-wave wideband MIMO antenna for 5G communication," vol. 2019, 2019.

[15] J. Guo, L. Cui, C. Li, B. J. I. T. o. a. Sun, and propagation, "Side-edge frame printed eight-port dual-band antenna array for 5G smartphone applications," vol. 66, no. 12, pp. 7412-7417, 2018.

[16] B. Yang, Z. Yu, Y. Dong, J. Zhou, W. J. I. T. o. A. Hong, and Propagation, "Compact tapered slot antenna array for 5G millimeter-wave massive MIMO systems," vol. 65, no. 12, pp. 6721-6727, 2017.

[17] D. A. Sehrai et al., "A novel high gain wideband MIMO antenna for 5G millimeter wave applications," vol. 9, no. 6, p. 1031, 2020.

[18] N. Hussain, M.-J. Jeong, A. Abbas, and N. J. I. A. Kim, "Metasurface-based single-layer wideband circularly polarized MIMO antenna for 5G millimeter-wave systems," vol. 8, pp. 130293-130304, 2020.

[19] J. Khan et al., "Design and performance comparison of rotated Y-shaped antenna using different metamaterial surfaces for 5G mobile devices," vol. 2, pp. 409-420, 2019.

[20] J. Khan, D. A. Sehrai, U. J. J. o. E. E. Ali, and Technology, "Design of dual band 5G antenna array with SAR analysis for future mobile handsets," vol. 14, pp. 809-816, 2019.

[21] N. Shoaib, S. Shoaib, R. Y. Khattak, I. Shoaib, X. Chen, and A. J. I. a. Perwaiz, "MIMO antennas for smart 5G devices," vol. 6, pp. 77014-77021, 2018.

[22] S. Iffat Naqvi et al., "Integrated LTE and millimeter-wave 5G MIMO antenna system for 4G/5G wireless terminals," vol. 20, no. 14, p. 3926, 2020.

[23] S. F. Jilani and A. Alomainy, "Millimetre-wave T-shaped antenna with defected ground structures for 5G wireless networks," in 2016 Loughborough Antennas & Propagation Conference (LAPC), 2016, pp. 1-3: IEEE.

[24] E. Al Abbas, M. Ikram, A. T. Mobashsher, and A. J. I. A. Abbosh, "MIMO antenna system for multi-band millimeter-wave 5G and wideband 4G mobile communications," vol. 7, pp. 181916-181923, 2019.

[25] S. I. Naqvi et al., "An integrated antenna system for 4G and millimeter-wave 5G future handheld devices," vol. 7, pp. 116555-116566, 2019.

[26] U. Ullah, M. Al-Hasan, S. Koziel, I. B. J. I. T. o. A. Mabrouk, and Propagation, "Series-slot-fed circularly polarized multiple-input–multiple-output antenna array enabling circular polarization diversity for 5G 28 GHz indoor applications," vol. 69, no. 9, pp. 5607-5616, 2021.

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