Tri-band 2×2 5G MIMO Antenna Array

Son Chu*, Md Nazmul Hasan†, Jiaruo Yan*, and Can C. Chu‡,
* *Department of Engineering Science, University of Oxford, Oxford, United Kingdom*
{son.chu, jiaruo.yan}@eng.ox.ac.uk
† *School of Electrical and Computer Engineering, Sungkyunkwan University, Suwon, South Korea*
mnazmulh@ieee.org
‡ *School of Electrical and Electronics Engineering, University of Transport and Communications, Hanoi, Vietnam*
chucongcan@utc.edu.vn

***Abstract*—A tri-band 2×2 MIMO antenna array for 5G applications is presented. It consists of two orthogonally-placed compact tri-band 28/38/60 GHz antennas with the realized gain varying between 3.5 and 8.5 dBi over the operating frequencies. Each individual antenna maintains a monopole-like radiation pattern across these bands. In addition, the MIMO characterization of the proposed array is discussed. The simulation results show that the envelope correlation coefficient of the array is excellent with a maximum value of less than 0.0015 whereas the diversity gain almost attains 10 dB over the entire operating frequency. The simple planar structure of the MIMO array also offers an ease of fabrication and practical integration with other electronic components**

***Index Terms*—Ultra wideband antenna, multi-band antenna, MIMO antenna, 5G antenna.**

I. Introduction

The absolute global standard of fifth generation (5G) mobile communication has yet to be fixed but intensive researches in industry and academia led by USA, European Union, South Korea, China and Japan are going on at present. Although the worldwide commercial launch of the fifth generation (5G) mobile communication is expected by 2020, South Korea has launched 5G for the first time in the world in a major international event - PyeongChang 2018 Olympic Winter Games in February 2018 [1]. However, the transition from 4G to 5G is not a simple scaling issue as 5G will necessitate a set of newly developed frameworks. As a consequence, 5G users will be offered unprecedented data rate of $1 - 10$ Gbps, almost ten times larger than what current long term evolution (LTE) network can offer [2].

Two potential spectra are regarded as the potential candidate for 5G communication, namely sub-6 GHz band and mm-wave bands such as 28 GHz, 38 GHz, 60 GHz, and 73 GHz [3]. Moreover, current mobile communication standards including 3G, 4G, and LTE-Advanced are implemented using lower microwave regions below 6 GHz. As the spectrum lying in lower microwave region is getting congested, the use of millimeter wave (mm-wave) in 5G communication is fundamental in materializing the phenomenal data rate [3]. Although it is well known in the wireless engineering community that the rain and atmosphere degrade the mm-wave signals heavily, when one considers the fact that today's cell sizes in urban environments are on the order of 200 m, it becomes clear that mm-wave cellular can overcome this issue [4]. In fact, an extensive discussion was presented in support of the use of mm-wave for 5G in [4], and confirmed in other works [3], [5], [6]. Also, 5G will require multiple-input multiple-output (MIMO) antenna array to ensure higher data rate.

Recently, 28 GHz switched five-beam antenna system based on a rectangular waveguide and a reconfigurable semiconductor circuit (RSC) with slots is reported [7]. Another compact printed quasi Yagi antenna having an impedance bandwidth of $56.3 - 65.2$ GHz with a peak gain of 8.9 dBi was reported [8]. A recent work on flexible microstrip antenna fabricated on Polyethylene terephthalate (PET) substrate using silver nano-particles as the conductive ink of inkjet printer was reported to work in X-band region, a candidate band for 5G [9]. Several other studies have showcased 5G MIMO antenna array configurations [10], [11]. However, to the best of authors' knowledge, millimetre wave tri-band 5G antennas have not been reported much in literature. Multiple-band input impedance matching allows a single 5G antenna to work at separated frequency bands of interest, making the entire device more economic and less chunky.

In this work, we present a compact omnidirectional tri-band 5G antenna operating over $28 - 60$ GHz, with a size of $20 \times 20 \times 0.787$ mm^3. Furthermore, a 2×2 MIMO antenna array has been designed and its characterisation is discussed. The proposed antenna can find applications in mm-wave 5G wireless communication operating in 28, 38, and 60 GHz. The design of the proposed antenna is then presented in section II, followed by section III providing the simulation results. After that, section IV discusses MIMO antenna array design and results, followed by the concluding remarks in section V.

II. Single Antenna Design

Fig. 1 illustrates the comprehensive design of the proposed tri-band $28/38/60$ GHz antenna with the optimized dimensions being listed in Table I. The area of the antenna is 20 mm×20 mm. The substrate is ROGER RT/duroid 5880 with the thickness of 0.787 mm, relative permittivity of 2.2, and loss tangent of 0.0009 measured at 10 GHz. Fig. 2 depicts the reflection coefficient and the realized gain of the antenna versus frequency. To achieve the return loss larger than 10 dB at these 5G bands, a planar circular monopole antenna has been improved by introducing a notching partial ground plane and a modified annular ring patch. A good impedance matching at

TABLE I: Dimensions of the proposed antenna

Parameters	S_x	S_y	S_z	G_y	SL_x	SL_y	d_x	d_y	l	R_1	R_2	R_3	R_4	R_5	g	MS_x	MS_y
Value (mm)	20	20	0.787	9.88	1.5	1	2.5	4	4.2	5	2.2	1.6	1	1.86	0.56	1.4	10

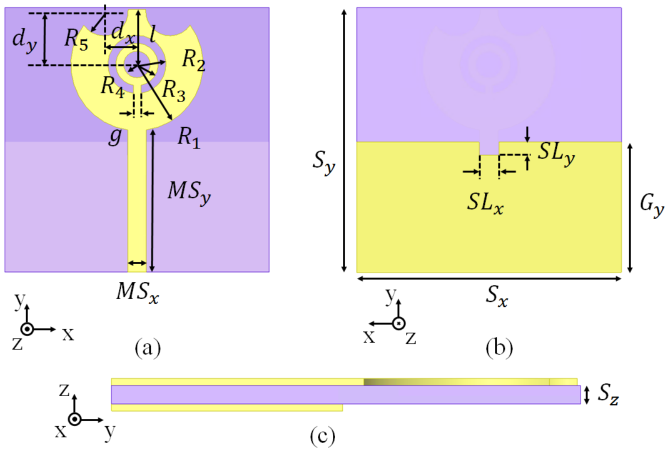

Fig. 1: Physical structure and dimensional parameters of the tri-band antenna, (a) top view, (b) bottom view and (c) side view.

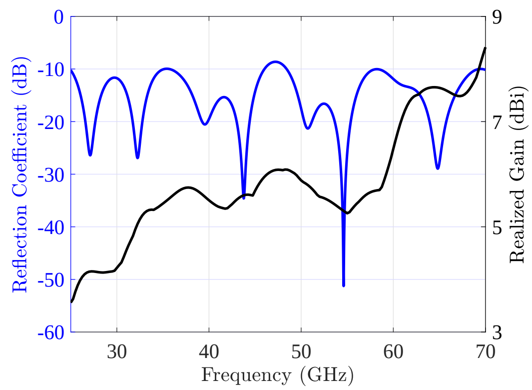

Fig. 2: Simulated reflection coefficient (S_{11}) of the antenna.

28, 38 and 60 GHz, therefore, has been achieved. Besides, the simulated radiation patterns of the antenna in the E-plane (yz-plane) and H-plane (xz-plane) at these three frequencies are shown in Fig. 3. Expectedly, a typical monopole-type radiation is observed, mostly omnidirectional and bidirectional in E-plane and H-plane respectively. Distortions at high frequency in the radiation patterns occur due to the nature of surface current density.

To gain an insight into the antenna design, the simulated surface current distributions at 28, 53, and 60 GHz are illustrated in Fig. 4. It can be observed that at 28 GHz, the surface current flows along the edges of the outer ring and the truncated path. The inner rings contributes in radiation owing to the surface current flowing along its periphery at higher frequencies (38 and 60 GHz). Two symmetric sectoral truncation are inserted near the top of the patch in order to

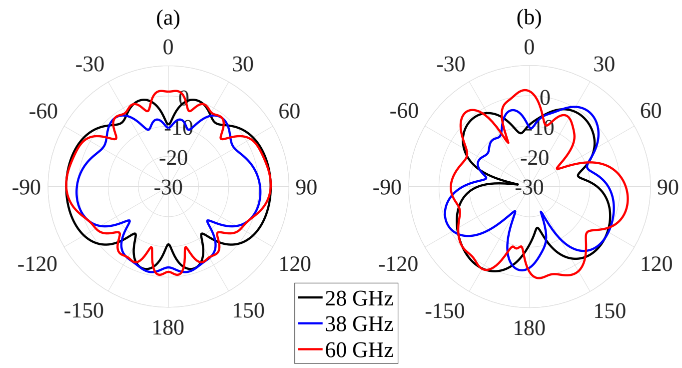

Fig. 3: Simulated radiation patterns of the antenna in (a) E-plane and (b) H-plane at 28 GHz, 38 GHz, and 60 GHz.

divert surface current, forcing the currents from both sides of the patch to concentrate at the truncation.

III. MIMO Array Design

The physical layout of the 2×2 MIMO antenna array is presented in Fig. 5. Basically, one antenna is placed perpendicular next to the other. This configuration ensures that the polarisations of two antennas are different because of their spatial orientation. Hence, the mutual coupling between two components can be minimized. For MIMO antenna characterisation, the envelope correlation coefficient (ECC) (ρ_e) and diversity gain (G_d) are important parameters to quantify signal interference between channels [12], [13]. In principle, ECC is a measure of crosstalk among MIMO channels, approximately expressed in terms of the S-parameters of the MIMO antenna system [12]:

$$\rho_e = \frac{|S_{11}^* S_{12} + S_{21}^* S_{22}^*|^2}{(1 - (|S_{11}|^2 + |S_{21}|^2))\,(1 - (|S_{22}|^2 + |S_{12}|^2))} \qquad (1)$$

where S_{11}, S_{12}, S_{21}, and S_{22} is the S-parameters of the 2×2 MIMO array. Besides, the diversity gain G_d of MIMO antennas can be calculated from the ECC ρ_e as [13]:

$$G_d = 10\sqrt{1 - |\rho_e|} \qquad (2)$$

In practical MIMO applications, ρ_e should be less than 0.3 and G_d tends to 10 dB. Fig. 6 showcases the envelope correlation coefficient and diversity gain over the entire operating bands. It is noteworthy that the ECC of the proposed MIMO array is exceptionally small, less than 0.0015 over the entire operating frequency range, yielding a superior diversity gain of nearly 10 dB.

IV. Conclusion

An tri-band MIMO array comprising two tri-band antennas is proposed and investigated. The tri-band 28/38/60 GHz

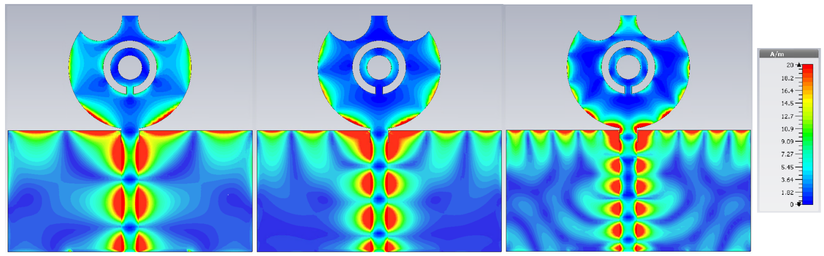

Fig. 4: Simulated surface current density at (a) 28 GHz, (b) 38 GHz, and (c) 60 GHz.

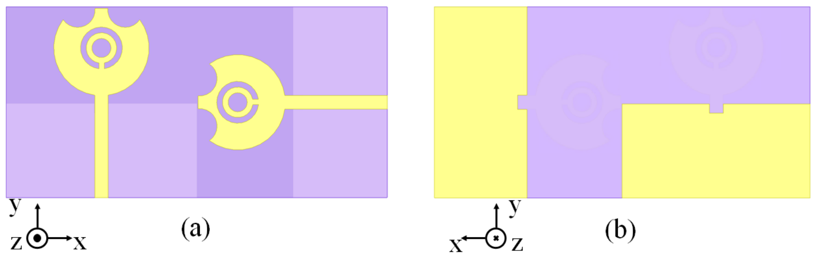

Fig. 5: Physical structure of the proposed 2×2 MIMO antenna array, (a) top view, and (b) bottom view.

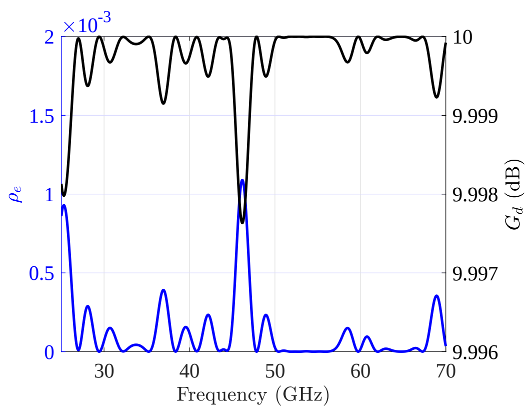

Fig. 6: Simulated envelope correlation coefficient and diversity gain of the proposed 2×2 MIMO antenna array.

antenna is notably compact with a total size of 20 mm×20 mm×0.787 mm. The 2×2 MIMO antenna array is constructed by simply placing one antenna orthogonally next to the other. The simulation results demonstrate that with an extremely low envelope correlation coefficient and an excellent diversity gain, the proposed antenna array is suitable and can be utilized in 5G MIMO applications.

Acknowledgment

The authors wish to thank fellow members of the Oxford Metamaterials Network (OxiMETA) for fruitful discussions.

References

[1] J. Ko, S. Hur, S. Lee, Y. Kim, Y.-S. Noh, Y.-J. Cho, S. Kim, S. Bong, S. Kim, J. Park, D.-J. Park, and D.-H. Cho, "28 GHz channel measurements and modeling in a ski resort town in pyeongchang for 5G cellular network systems," in *Proc. European Conference on Antennas and Propagation (EuCAP)*, 2016, pp. 1–5.

[2] M. Agiwal, A. Roy, and N. Saxena, "Next generation 5G wireless networks: A comprehensive survey," *IEEE Commun. Surv. Tutor.*, vol. 18, no. 3, pp. 1617–1655, 2016.

[3] W. Hong, "Solving the 5G mobile antenna puzzle: Assessing future directions for the 5G mobile antenna paradigm shift," *IEEE Microw. Mag.*, vol. 18, no. 7, pp. 86–102, 2017.

[4] T. S. Rappaport, S. Sun, R. Mayzus, H. Zhao, Y. Azar, K. Wang, G. N. Wong, J. K. Schulz, M. Samimi, and F. Gutierrez, "Millimeter wave mobile communications for 5G cellular: It will work!" *IEEE Access*, vol. 1, pp. 335–349, 2013.

[5] Z. Qingling and J. Li, "Rain attenuation in millimeter wave ranges," in *Proc. International Symposium on Antennas, Propagation and EM Theory*, 2006, pp. 1–4.

[6] S. Joshi, S. Sancheti, and A. Goyal, "Rain attenuation measurements for short-range millimetre-wave radio link," *Electron. Lett.*, vol. 42, no. 2, pp. 72–74, 2006.

[7] Y. Yashchyshyn, K. Derzakowski, G. Bogdan, K. Godziszewski, D. Nyzovets, C. H. Kim, and B. Park, "28 GHz switched-beam antenna based on S-PIN diodes for 5G mobile communications," *IEEE Antennas Wirel. Propag. Lett.*, vol. 17, no. 2, pp. 225–228, 2018.

[8] C.-Y. Hsu, L.-T. Hwang, C.-Y. Feng, F.-S. Chang, S.-M. Wang, and K.-Y. Cho, "Design of a printed 60 GHz quasi-yagi antenna for millimeter wave wireless communication applications," in *Proc. Asia-Pacific Microwave Conference (APMC)*, vol. 2, 2015, pp. 1–3.

[9] M. Tighezza, S. Rahim, and M. Islam, "Flexible wideband antenna for 5G applications," *Microw. Opt. Technol. Lett*, vol. 60, no. 1, pp. 38–44, 2018.

[10] A. T. Alreshaid, R. Hussain, S. K. Podilchak, and M. S. Sharawi, "A dual-element MIMO antenna system with a mm-wave antenna array," in *Proc. European Conference on Antennas and Propagation (EuCAP)*, 2016, pp. 1–4.

[11] M. S. Sharawi, M. Ikram, and A. Shamim, "A two concentric slot loop based connected array MIMO antenna system for 4G/5G terminals," *IEEE Trans. Antennas Propag*, vol. 65, no. 12, pp. 6679–6686, 2017.

[12] S. Blanch, J. Romeu, and I. Corbella, "Exact representation of antenna system diversity performance from input parameter description," *Electron. Lett.*, vol. 39, no. 9, pp. 705–707, 2003.

[13] K. N. Poudel and W. Robertson, "Metamaterial inspired antenna design for massive MIMO, 5G communications system," in *Proc. USNC-URSI Radio Science Meeting (Joint with AP-S Symposium)*, 2017, pp. 103–104.