Highly Isolated Compact Tri-Band MIMO Antenna with Trapezoidal Defected Ground Plane for 5G Communication Devices

Muhammad Usman[#1], Kioumars Pedram[*2], Yuanwei Zhu[†3], Chao Yu[†4], Anding Zhu[#5]

[#]RF & Microwave research Group, University College Dublin, Dublin, Ireland
[*]Electrical Engineering Department, Urmia University, Urmia, Iran
[†]State Key Laboratory of Millimeter Waves, School of Information Science and Engineering, Southeast University, China
{[1]muhammad.usman, [5]anding.zhu}@ucd.ie, [2]pedram.qmars@gmail.com, {[4]chao.yu, [5]ywzhu}@seu.edu.cn

Abstract— **In this paper a compact tri-band MIMO antenna has been proposed for 5G wireless communication devices. The isolation of -20 dB has been obtained between the two input ports using meander line structures and five vias incorporating at different places of the structure. Two rectangular slots have been etched on the radiating patch to further improve antenna performance. The designed antenna provides multiband characteristic in S, C and X frequency bands. Different characteristic parameters such as Envelope Correlation Coefficient, diversity gain, electric field distribution and radiation pattern are also presented and discussed . The overall antenna volumetric size is 42×34×1mm³ .**

Keywords— **5G , Antenna, Meander-line, Multiple Input Multiple Output**

I. INTRODUCTION

With the increasing demand for higher data rate and reliable communication in 5G wireless systems, multiple-input multiple-output (MIMO), antennas have been introduced as they increase data rate and channel capacity in the communication systems as well as communication reliability[1]. Since in the MIMO antennas more than one antenna is used in transmitter and/or receiver, some of the radiated power from each antenna can be absorbed by the other one, so mutual coupling is one of the challenging area of research in MIMO antenna systems for 5G wireless systems. On the other hand, different signals are transmitted through various paths which can cause multipath fading which is one of the important problems in these systems. Therefore, system performance can be degraded[2][3].

To overcome these obstacles, the traditional solution is to put the antennas far from each other (usually half the wavelength) or orthogonal to each other, but this requires a large physical space which is not the case in modern handheld wireless communication devices. Since the mutual coupling between elements is a challenging issue, various techniques to decrease the coupling between elements have been introduced in literature during the past years. In [4] a defected ground structure has been employed to suitably reduce the coupling between two antennas. Electromagnetic band gap structures have been widely used in MIMO antennas to overcome the problem of the mutual coupling in array antennas and consequently improve the isolation. Metamaterial structures are also of great importance for this purpose and various studies have been conducted and published in the literature [5][6].

Due to their low cost and simple structure, microstrip antennas are of great importance in MIMO antennas. Although these antennas suffer from a low bandwidth which is a major obstacle for them to be used in wireless communication systems, a lot of solutions have been introduced to overcome this problem. Using different shapes of slots on the radiator and/or ground plane, employing parasitic elements near the radiating patch , are among different methods used in microstrip antennas to improve the bandwidth. Moreover, vias have been extensively utilized in antennas to further enhance antenna performances. A metamaterial inspired fractal antenna has been introduced in which employs vias to improve the performance[7].

In this paper a compact tri-band MIMO antenna has been proposed for 5G wireless communication systems. The proposed microstrip antenna is with two trapezoidal shaped defected grounds , employing six meander line structures, two rectangular slots and five vias to provide multiband capability. The design has been optimized in order to get impedance matching and at the same time low mutual in all the frequency bands.

II. ANTENNA DESIGN

A. Microstrip Antenna

The proposed antenna has been designed on a FR4 substrate with thickness of 1mm, relative permittivity of 4.4 ,and loss tangent of 0.025. The proposed antenna configuration along with step by step evolution has been illustrated in Fig. 1. Moreover, dimensions of the structure have been provided in table. 1.

Table 1. Dimension of the proposed structure (all are in mm)

parameter	L	W	S	W_f	W_s	L_s
Size(mm)	42	34	18	3.8	0.5	12
parameter	L_g	L_v	W_g	d	M	n
Size(mm)	3.75	3.375	14	1	0.25	-2

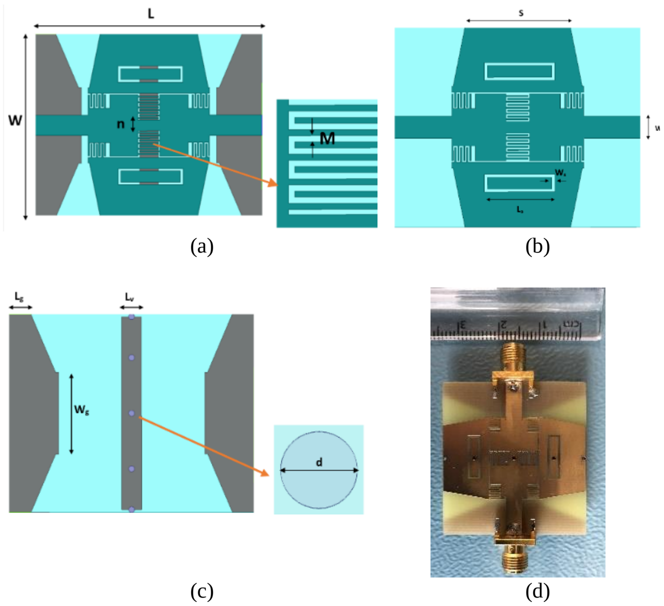


Fig. 1. (a) Geometry of the proposed antenna, (b) top view, (c) bottom view, (d) Fabricated antenna

B. *MIMO Antenna*

Initially a microstrip patch MIMO antenna has been designed as the basic antenna. Defected ground planes have been used to improve the impedance bandwidth. The full wave software has been utilized to simulate the structure. Results related to this step have been shown in Fig. 2(a). As can be seen, a single resonance with bandwidth between 8-10GHz has been obtained with an acceptable isolation of better than -13dB. Since the purpose of the design is an antenna with multiband property, in the next step, four meander line structures have been employed on the four corners of the radiating patch. The simulated results are depicted in Fig. 2(b). clearly, two frequency bands in 3.5 and 5GHz have been generated due to the meander lines; since they increase the surface current paths and accordingly improve the impedance bandwidth. Clearly seen, two other resonances have been created in 3.5 and 5GHz. Yet, the mutual coupling in the middle and higher frequency bands are suitable but in the lower band needs to be improved. In the third step, to further enhance the impedance bandwidth and isolation, two other meander line structures have been created at the center of the radiating patch and the results show another resonance in 3GHz. The mutual coupling in the higher band has been improved slightly while in the lower band it should be enhanced. Fig. 2(c) shows the s-parameters in the third step.

C. *Vias*

Three vias have been added to the structure with 0.5mm radius which effects can be found in Fig. 3(a). Obviously, the mutual coupling has been improved in 4GHz. Then, two rectangular slots have been etched on the patch and two other vias have been employed on the centre of these slots. As expected, in 2.8GHz a good impedance matching of -20dB and isolation of -24dB have been obtained as shown in Fig. 3(b).

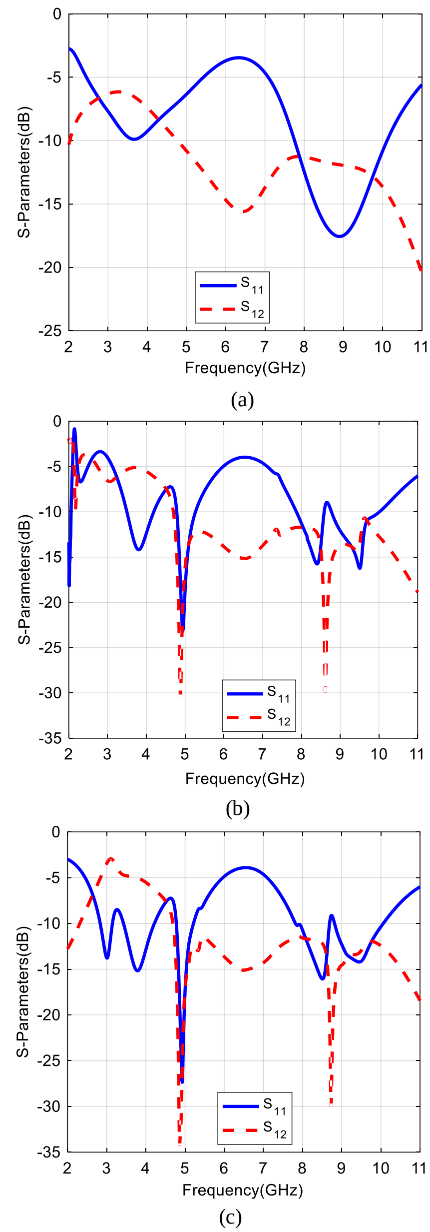


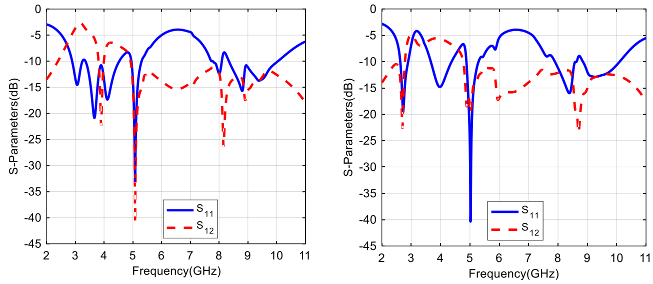
Fig. 2. Simulated S-parameters for (a) Trapezoidal radiating patches, (b) the structure with four meander lines at the corners, (c) the structure with four meander lines at the corners and two meander lines at the center.

D. *Defected Ground Plane*

Two rectangular ground planes have been changed to the trapezoidal shape, which improved both the impedance matching and isolation between elements; this can be seen in Fig. 4, 2.8, 5-5.2 and 8-10GHz frequency bands good impedance matching and isolation of less than -20dB has been obtained.

E. *Parametric Study*

In order to reach the best result, parametric study has been performed for the space between two centered meander lines, named as n. Fig.5 (a) and (b) show the simulated S_{11} and S_{12} for this parametric study, respectively. Considering both the impedance bandwidth and mutual coupling n=-2 has been chosen as a suitable value for this structure.



(a) (b)

Fig. 3. (a) The structure with three vias, (b) the structure with rectangular slots and two vias at the center of the slots.

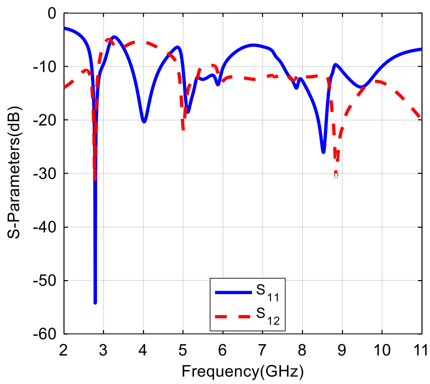


Fig. 4. The structure with trapezoidal defected ground planes

III. Results and Discussion

A. E-field Magnitude

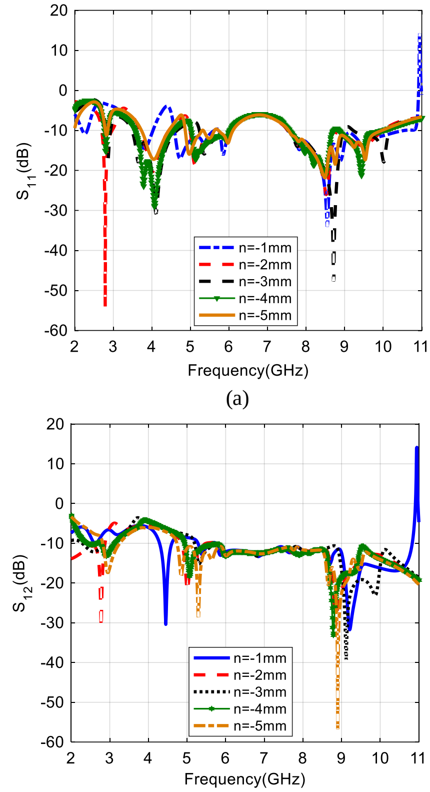
For further investigation, electric field distribution on the radiating elements in three desired resonance frequencies are illustrated in fig 6, it can be seen that, the two rectangular slots and two vias at their centres are responsible for 2.8GHz resonance while in the 5.2 and 9.5GHz mostly four meander lines at the corners and two meander lines at the centre create resonances and almost no surface wave is concentrated around the slots. Therefore, according to the electric field magnitude when one port is excited, the other one is completely isolated; it means that the mutual coupling between two elements is low which is one of the important challenges in MIMO antennas. Furthermore, with the determined antenna length and width, the dominant mode can be seen and other lower modes can be achieved by using vias and meander lines.

B. Envelope Correlation Coefficient

Generally, the ECC less than 0.5 is considered suitable for a MIMO system. It is usually in a relation with diversity gain such that by increasing the isolation between elements, ECC is also increases and vice versa. The ECC is calculated according to S-parameters as follow:

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

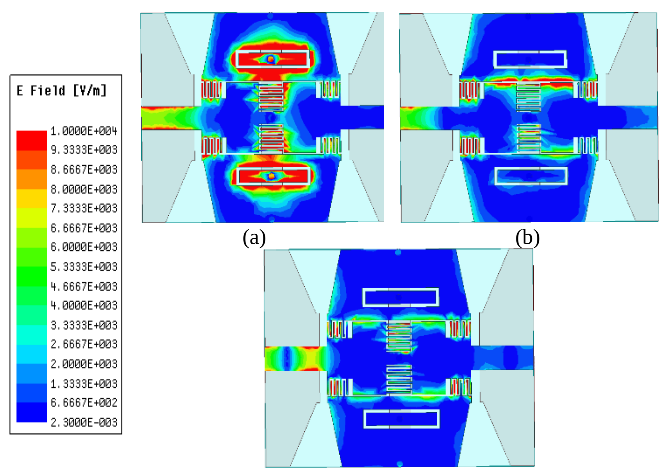
Fig.7 shows the ECC for the proposed structure which satisfies the required criteria in the whole operating bands.



(a)

(b)

Fig. 5. Parametric study for different values of n (a) S_{11} (b)S_{12}



(a) (b)

(c)

Fig. 6. Electric field distribution in (a) 2.8, (b) 5.2, (c) 9.5GHz

C. Radiation Pattern

The radiation patterns in 2.8GHz and 5.1GHz have been illustrated in Fig.9 when one port is excited while the other one is matched to 50Ω load. As expected, omnidirectional and bi-directional radiation patterns have been obtained in the specified frequencies, which makes the proposed structure suitable for wireless communication systems.

D. Diversity Gain

The next important parameter in MIMO antennas is diversity gain which is calculated according to the following formula as in [8]:

$$G_{app} = 10\sqrt{1-|\rho|}\,,\ |\rho| = \rho_e \qquad (2)$$

in which ρ_e is the calculated ECC. The diversity gain of the proposed structure has been shown in Fig.8 . it can be seen that the DG in the entire band is better than 9.6 which fulfills the requirements in MIMO antennas.

IV. Conclusion

A highly isolated tri-band MIMO antenna has been proposed in paper. The desired bandwidth and high isolation have been obtained through five meander line structures, vias, rectangular slots and defected ground planes. The compact antenna has a size of 34×42×1mm^3 which can be a good candidate for 5G wireless communication systems.

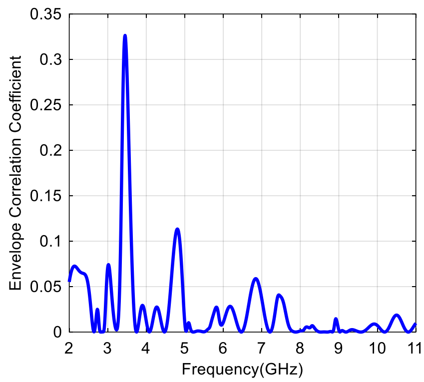


Fig. 7. Calculated Envelope Correlation Coefficient

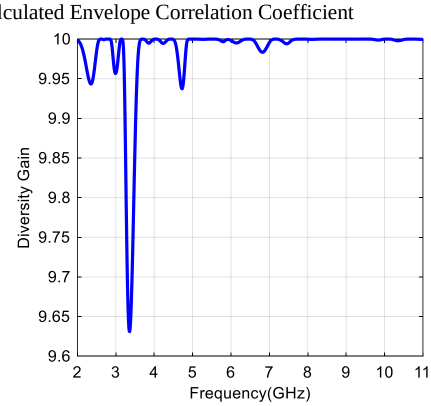


Fig. 8. Diversity Gain for the designed MIMO Antenna System

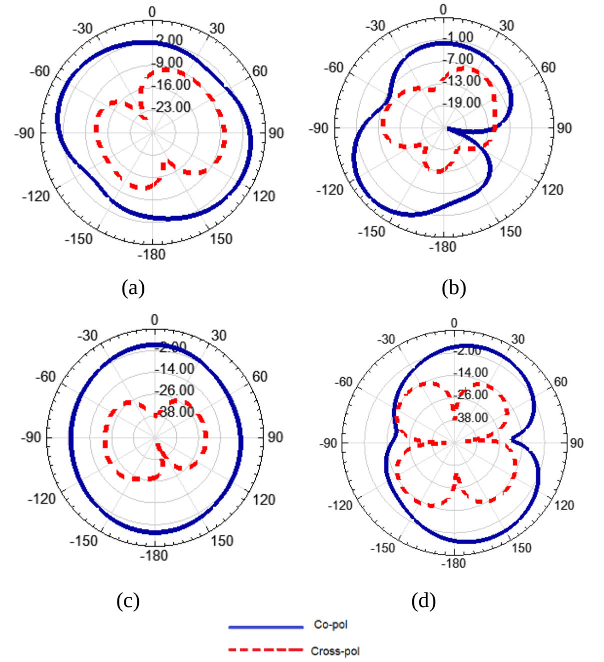


Fig.9 . Radiation patterns of the proposed antenna in 2.8 and 5.1 (a), (c) E-plane, (b), (d) H-plane

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References

[1] A. Ghosh, A. Maeder, M. Baker and D. Chandramouli, "5G Evolution: A View on 5G Cellular Technology Beyond 3GPP Release 15," in IEEE Access, vol. 7, pp. 127639-127651, 2019.

[2] S. Lu, H. T. Hui and M. Bialkowski, "Optimizing MIMO Channel Capacities Under the Influence of Antenna Mutual Coupling," in IEEE Antennas and Wireless Propagation Letters, vol. 7, pp. 287-290, 2008.

[3] M. Usman, R. A. Abd-Alhameed, and P. S. Excell, "Design considerations of MIMO antennas for mobile phones," in Proceedings of the Progress in Electromagnetics Research Symposium 2008, PIERS 2008 Hangzhou, pp. 718–722, china, March 2008.

[4] S. Luo, Y. Li, T. Jiang and B. Li, "FSS and Meta-material Based Low Mutual Coupling MIMO Antenna Array," 2019 IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting, Atlanta, GA, USA, 2019, pp. 725-726.

[5] S. Luo and Y. Li, "A Dual-Band Antenna Array with Mutual Coupling Reduction Using 3D Metamaterial Structures," 2018 International Symposium on Antennas and Propagation (ISAP), Busan, Korea (South), 2018, pp. 1-2.

[6] I. Syrytsin, S. Zhang, G. F. Pedersen and A. S. Morris, "Compact Quad-Mode Planar Phased Array With Wideband for 5G Mobile Terminals," in IEEE Transactions on Antennas and Propagation, vol. 66, no. 9, pp. 4648-4657, Sept. 2018.

[7] I. Syrytsin, S. Zhang, G. F. Pedersen and A. S. Morris, "Compact Quad-Mode Planar Phased Array With Wideband for 5G Mobile Terminals," IEEE Transactions on Antennas and Propagation, vol. 66, no. 9, pp. 4648-4657, Sept. 2018

[8] H. Alsaif, M. Usman, M. T. Chughtai, and J. Nasir, "Cross Polarized 2×2 UWB-MIMO Antenna System for 5G Wireless Applications," Progress in Electromagnetics Research M, Vol. 76, 157-166, 2018.