

Extra Compact Two Element Sub 6 GHz MIMO Antenna for Future 5G Wireless Applications

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Abstract—In this paper, a single band two element MIMO antenna for future 5G wireless applications at 5 GHz is presented. The antenna consists of T over T shaped meander microstrip lines printed on the front side and defected ground structure on the back side of an RT Rogers 5880 substrate, which are able to excite a resonance mode. The antenna operates at 4900 to 5060 MHz ($|S_{11}| < -10$ dB) covering the 5G NR band n79. The antennas are to be placed symmetrically along the edges at the corners of the Smartphone panel. The isolation in the case of two elements MIMO antenna is enhanced by an I-shaped ground slot. The mutual coupling reduction is facilitated by 10 mm neutralization line (NL) at both hands. The prototype is fabricated to validate the proposed model. The measured results show good accordance with simulated results. The main performance results wherever possible of the proposed design are calculated, compared, and analyzed with the measured results.

1. INTRODUCTION

The enhancement of the transmitting and receiving efficiencies of a wireless mobile communication network remains the biggest worry as the demand of intelligent services and high data rate increase day by day. In order to address the concern, various techniques have been introduced like implementation of multiple input multiple output (MIMO) antenna transmission technique. MIMO antenna effectively improves the spectral efficiency and channel capacity resulting in significant increase in LTE applications and will be one of the vital technologies in 5G communication [1]. The various constraints that need to be considered while designing an antenna like size, high isolation, ease of fabrication, ease of integration, and low profile must be overcome in order to qualify the design for MIMO antenna system for smartphones [2]. The 5G new radio (NR) frequency band is further divided into two sub frequency band, frequency range one (FR1) working in sub 6 GHz (or > 6 GHz band) and frequency range two (FR2) working in millimeter range (mm-Wave band) as per Technical Specification (TS) 38.101 of 3rd Generation Partnership project (3GPP) [3]. Various techniques and methods have been reported in recent times for 5G MIMO antenna arrays for smartphone handsets operating in sub-6 GHz band [4–9]. These MIMO antenna designs resonate at single frequency band at sub-6 GHz bands like 2.55–2.65 GHz, 3.3–3.6 GHz and are fit for mobile phones without metal frame, and some are suitable for mobile phone with metal frames [10–13].

The design of a MIMO system for 5G mobile terminals is a challenging task since the positioning of the antenna elements in a small space results in poor isolation, in turn altering the system performance characteristics. Various efficient methods have been proposed to reduce mutual coupling and enhance isolation such as defected ground structures (DGSs), lumped elements, neutralization line, and electromagnetic band gap structures. Reportedly, several studies and antenna element structures

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have been proposed in [14–20] consisting of slot antennas, loop antennas, ring antennas, planer antennas, etc.

In this paper, a two element MIMO antenna array structure is presented. The proposed antenna covers the frequency band of 4900 to 5060 Hz with little intricacy. The thin substrate used in designing the antenna is Rogers 5880 RT. The design of the proposed antenna is done in such a manner that the maximum isolation between the radiating elements achieved is -21.3 dB. The isolation is enhanced by the help of defected ground structure. In addition, the elements can be placed on the sides of the smart phone panel resulting in providing maximum space for the electronic components. The monopole antennas are placed orthogonally having dimensions of $14.37 \times 6.75 \text{ mm}^2$ each. The radiating elements are fed via a feed line directly connected to a 50Ω SMA connector placed on the edge of the structure, thus reducing required ground clearance. The design is symmetrical in shape consisting of T over T shaped meander microstrip lines with a 10 mm neutral line.

2. DESIGN, ANALYSIS AND PERFORMANCE OF SINGLE ANTENNA STRUCTURE

2.1. Antenna Configuration

The geometry and dimensions of the proposed antenna element for 5G metal frame smartphone is shown in Figure 1. The proposed antenna consists of a Rogers 5880 RT substrate with thickness (h_s) = 0.254 mm, relative permittivity (ϵ_r) = 2.2, and loss tangent ($\tan \delta$) = 0.0009. On the back side of the substrate a defected ground structure of length (L_s) and width (W_s) with truncated slot of length (L_4) is used. The dimensions (in mm) of the prototype are optimized as:

$L1$	4	$L2$	0.77	$L3$	0.5	$L4$	2	L_s	7	$W1$	10.4
$W2$	4	$W3$	7.2	$W4$	3.7	$W5$	11	W_s	11		

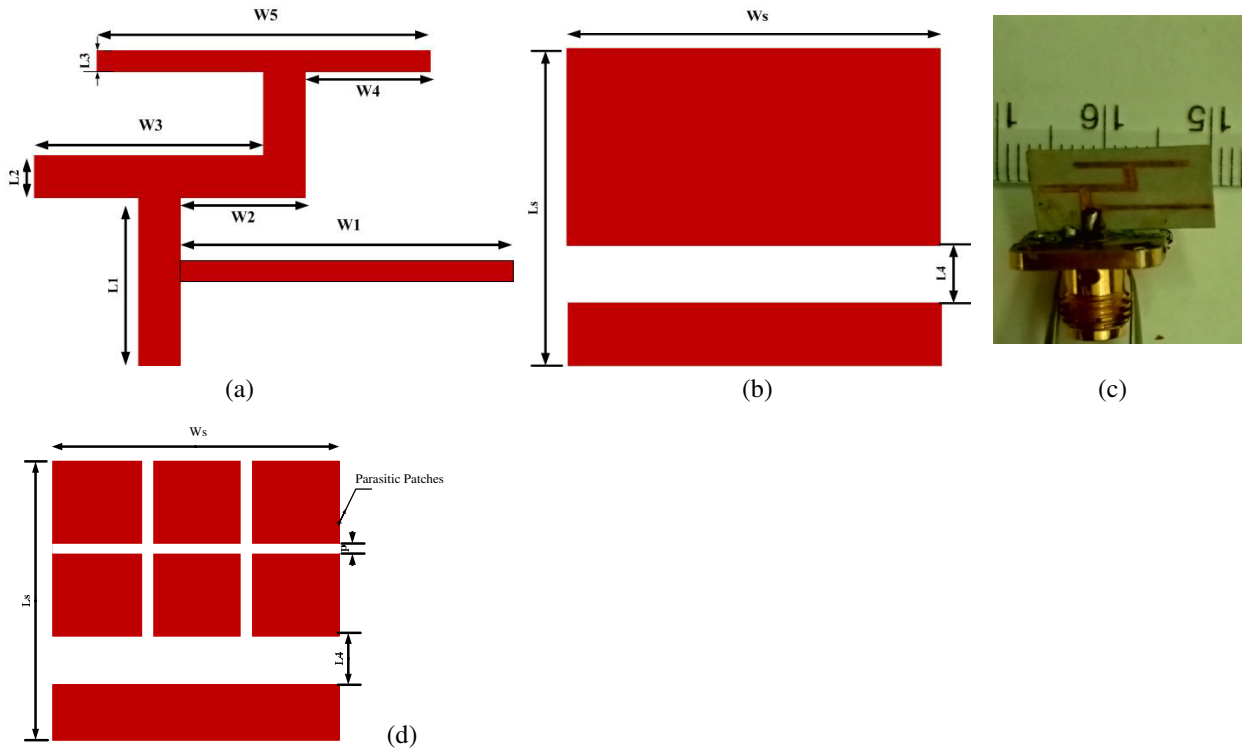


Figure 1. Layout of proposed antenna. (a) Front view. (b) Back view. (c) Prototype. (d) Back view with parasitic patches.

A rectangular microstrip line is used for feeding the antenna having characteristics impedance of $50\ \Omega$ with the width of 0.77 mm through an SMA (miniature-A) connector. The design of the proposed antenna consists of folded monopole arms to achieve quarter wavelength of operation. The resonance mechanism gets introduced because of the arms $W2$ and $W3$ as can be seen from surface current distribution, and in Figure 3(a) the current is mostly confined in these arms due to higher resonant frequency and minimum current flows in the neutral line resulting in greater isolation. The high surface current in the folded antenna arms depicts the quarter wavelength resonance of the design. A CST Microwave Studio Suite (MWS) is considered and employed for all inclusive simulations, analysis of parameters, and evaluation of the performance of the proposed antenna.

2.2. Performance of Single Element Antenna

This section describes the performance parameters in terms of reflection coefficient, gain, efficiency, surface current, and radiation pattern of the proposed antenna. CST commercial simulation tool is used to calculate these parameters.

2.2.1. Reflection Coefficient

Figure 2 shows the simulated and measured S -parameters (S_{ii}) of the proposed antenna. A single band resonant response is obtained at 5 GHz with -10 dB return loss bandwidth. On optimization there is good understanding between measured and simulated results. On optimization there is good agreement between measured and simulated results, some discrepancies are attributed to fabrication errors. The antenna was designed with the target of attaining resonance at 5 GHz so as to cover the 5G NR band n79. In this design, the bandwidth of 160 MHz is obtained which is higher than the minimum value (100 MHz) set for the sub 6 GHz design by ITU-R Report ITU-R M.2410-0 (11-2017), and for higher frequencies it is 1 GHz [21]. Furthermore, the bandwidth of the design can be increased by adding capacitive square parasitic patches on ground surface as shown in Figure 1(d). A 2×3 array of square patches is introduced with optimized gap given by p such that it encompasses the main radiating loop. In the case of meander microstrip line monopole elements, the bandwidth enhancement is limited due to impedance mismatch by the structure itself. If the reactance approaches zero, better impedance matching is obtained. Adding square parasitic patches behind the antenna element leads to better matching resulting in improved bandwidth as shown in Figure 2(b).

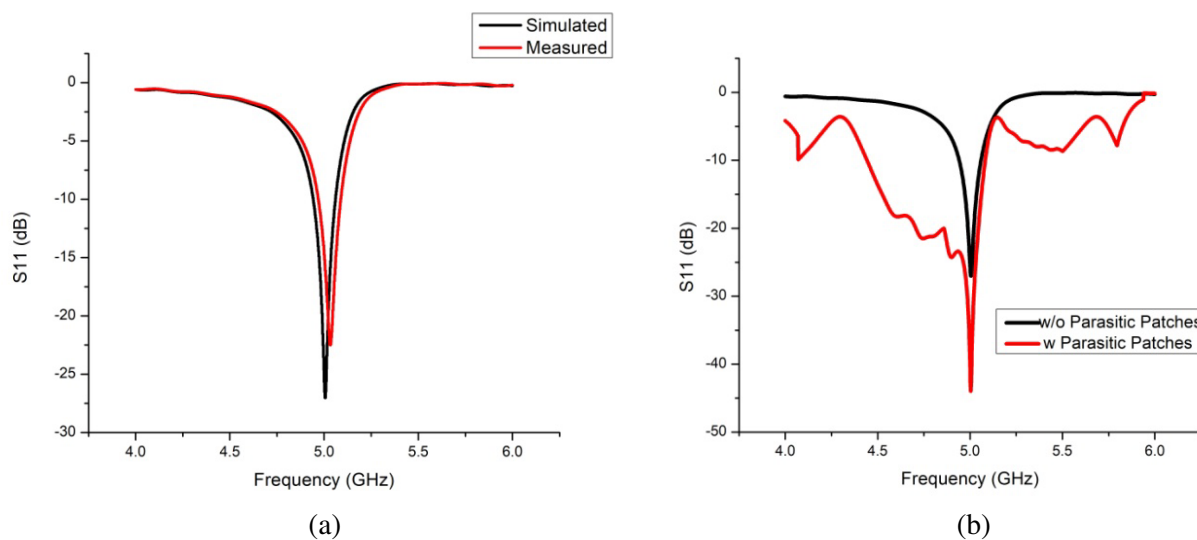


Figure 2. (a) Simulated and measured S_{11} of a single antenna. (b) Simulated S_{11} with parasitic patches and without parasitic patches.

2.2.2. Surface Current Distribution

As seen in Figure 2, the proposed antenna operates in single band with resonating frequencies of 5 GHz. The obtained operating frequency range agrees well with 5G NR n79 frequency band. It can be seen from Figure 3 that each conductive strip plays a key role in forming the performance of the antenna. The surface current distribution confirms the claim that all the meander lines in the antenna yield the resonance frequency in S_{11} curve. The relation between the resonance frequency and antenna parameters/physical characteristics is given as:

$$Fr = \frac{c}{2L} \sqrt{\frac{2}{\varepsilon_r + 1}} \quad (1)$$

where Fr is the resonant frequency, L the total electrical length of the antenna structure, c the velocity of light, and ε_r the permittivity. The fine tuning and appropriate placing of meander line conductive elements produce the desired resonating frequency.

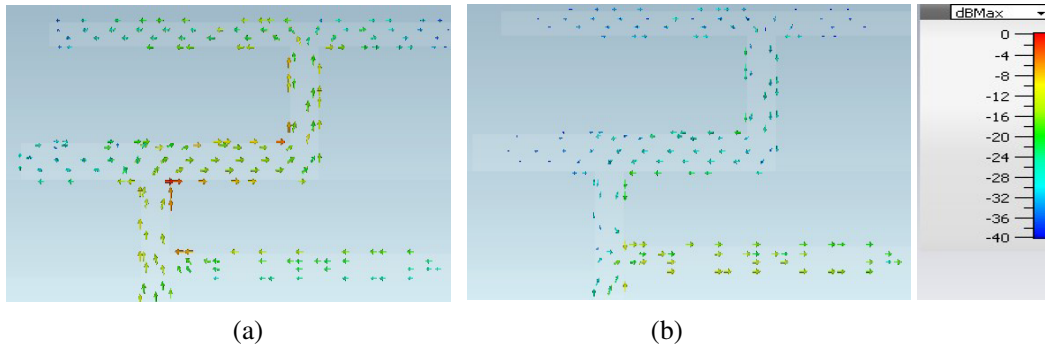


Figure 3. Simulated surface current distributions at (a) 5 GHz and (b) 5.1 GHz.

2.3. Realized Gain and Total Efficiency

The plots of realized gain and total efficiency are shown in Figures 4(a) and (b) at the frequency operating band NR n79 for the proposed prototype. As evident from the figure, the maximum gain of 1.95 dBi and total maximum efficiency of 79.50% are attained at 5 GHz i.e., at desired resonating frequency.

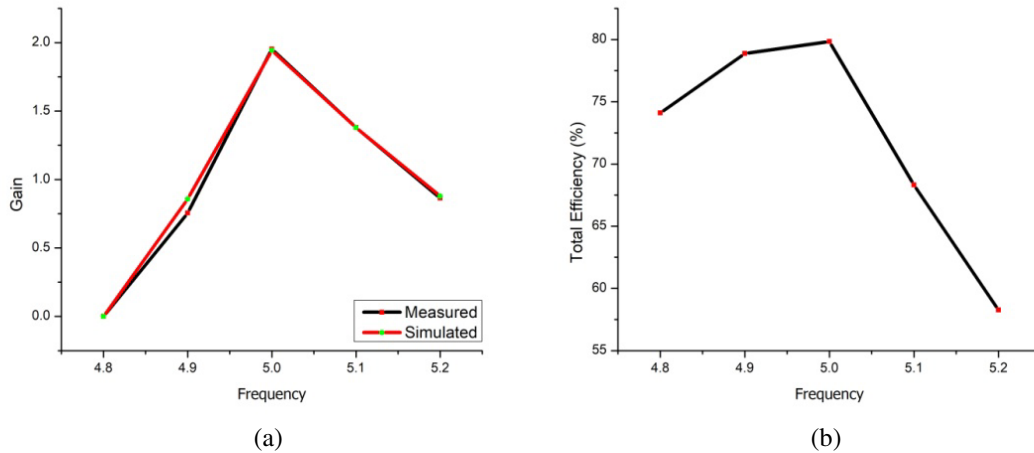


Figure 4. Gain and total efficiency plots of the proposed prototypes.

2.4. Radiation Patterns

This section presents the 2D radiation patterns at 4.9 GHz, 5.1 GHz, and at resonance frequency 5 GHz in the operation frequency band of 4.9 to 5.1 GHz of the proposed antenna. Figures 5(a) and (b) show the cross-polar and co-polar radiation patterns of the proposed antenna, respectively. It is seen from the figure that the proposed antenna has bidirectional radiation at resonance frequency in both E plane and H plane.

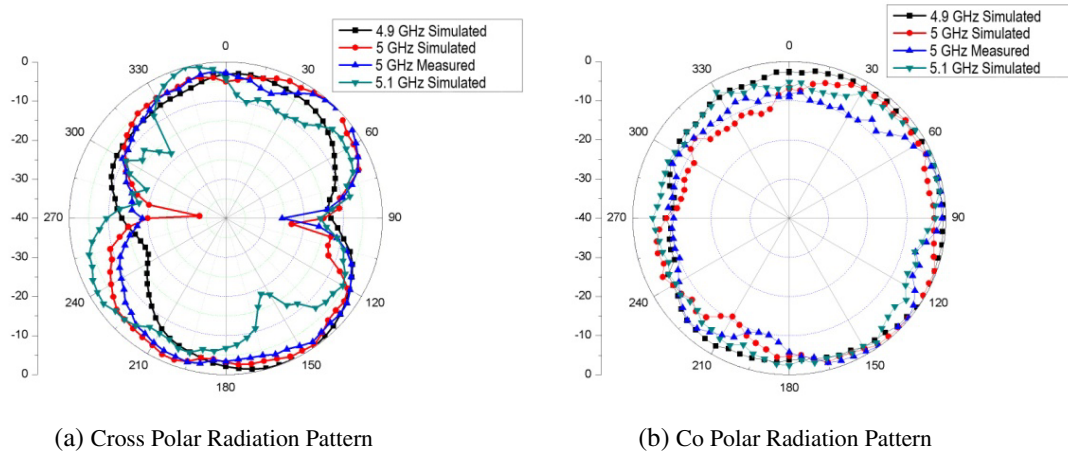


Figure 5. Radiation patterns of proposed antenna at 4.9 GHz, 5 GHz and 5.1 GHz. (a) Cross polar. (b) Co polar.

3. TWO ELEMENT MIMO CONFIGURATION AND PERFORMANCE

The geometry and detailed configuration of the proposed MIMO antenna are shown in Figures 6(a) and (b). The size of the MIMO structure is $30 \times 6.75 \times 0.32 \text{ mm}^3$ typically designed for mobile handsets. The substrate used is Rogers 5880 RT substrate with thickness of 0.254 mm, $\epsilon_r = 2.2$, and $\tan \delta = 0.0009$.

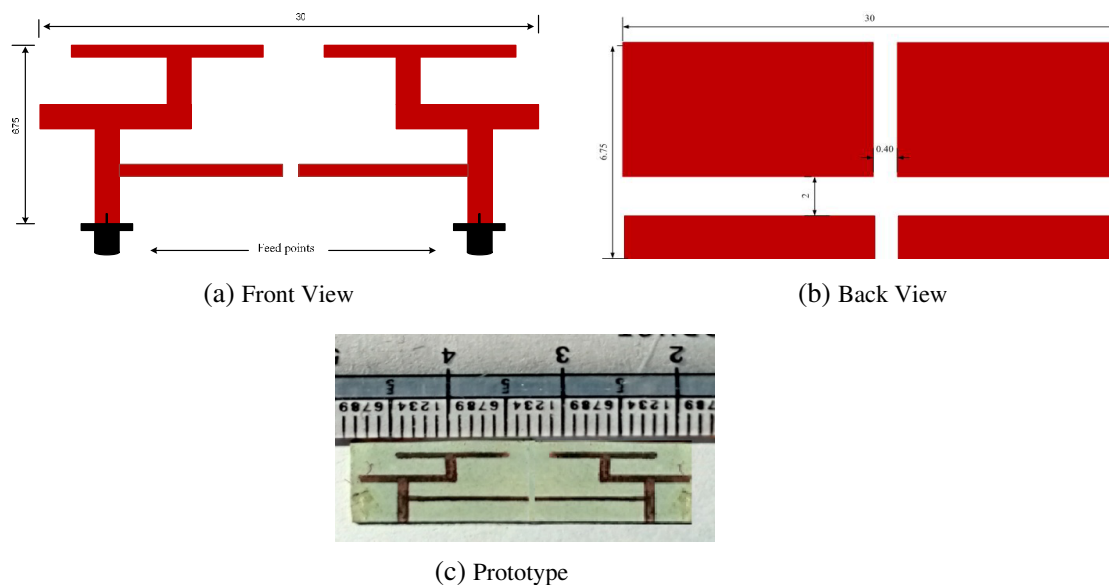


Figure 6. Geometry of two element MIMO antenna. (a) Front view. (b) Back view. (c) Fabricated prototype.

The monopole antenna is folded and is placed orthogonally with each other. The antenna elements are fed by a 50Ω feed line directly connected with an SMA connector. Since the SMA connector is connected on the edge of the prototype, no ground clearance is needed. The antenna design is symmetrical in shape and is placed on the edges at corners of the mobile handset.

The simulated reflection coefficient of the two element MIMO antenna is given in Figure 7. Optimized arms $W1$, $W3$, and $W5$ are responsible for resonating the antenna at 5 GHz. The reflection coefficients curve is below -10 dB at resonating frequency, and the maximum isolation obtained is less than -20 dB (-21.3 dB). Good isolation comes from the fact of reducing surface waves travelling in the antenna substrate. These surface waves cause mutual coupling resulting in degrading radiation efficiency and channel capacity of individual antenna element as well as MIMO configuration. To mitigate this threat, the substrate used in this design is very thin and cannot let surface waves to travel via substrate. Furthermore, when placing the antenna elements in the MIMO system spacing is made sufficient, i.e., $\lambda/2$ that also helps in reducing mutual coupling. Thus from the above results it can be revealed that the above 2×2 MIMO antenna design ensures good isolation between two orthogonal neighboring elements while achieving the desired single frequency band.

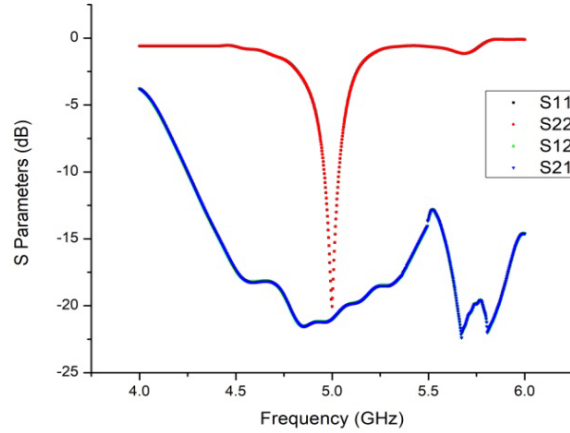


Figure 7. Simulated S parameters.

4. ENVELOPE CORRELATION COEFFICIENT AND DIVERSITY GAIN

Envelope Correlation Coefficient (ECC) is an important parameter used for expressing the strength of correlation between antenna elements of a MIMO antenna system. ECC is massively adopted by authors in order to estimate the diversity performance of the MIMO antenna systems. The antenna radiators must have weak ECC as the data streams need to be transmitted independently and simultaneously. The ECC is calculated using Equation (2) for an N -port MIMO antenna system.

$$\rho_e(i, j, N) = \frac{\left| \sum_{n=1}^N s_{i,n}^* s_{n,j} \right|^2}{\left| \prod_{k=i,j} \left(1 - \sum_{n=1}^N s_{k,n}^* s_{n,k} \right) \right|^{1/2}} \quad (2)$$

where ρ_e is the correlation between two antenna elements, and N is the number of antenna elements.

The diversity gain (DG) of a MIMO antenna system is an important parameter that discusses the increase in signal to interference ratio in a MIMO antenna while incorporating different diversity schemes and is dependent on correlation coefficient ρ_e . Diversity gain can be calculated by using Equation (3).

$$DG = 10 \times \sqrt{1 - |\rho_e|} \quad (3)$$

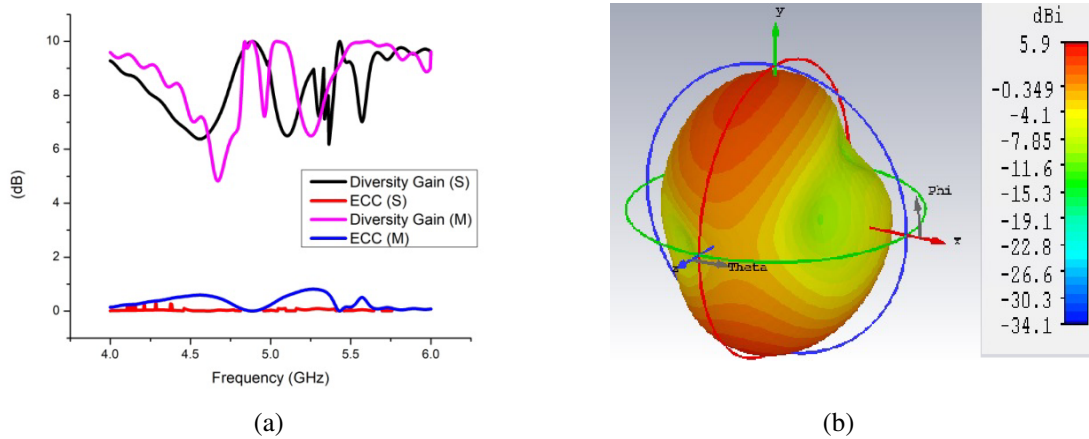


Figure 8. (a) ECC and diversity gain. (b) 3D radiation pattern for the proposed two element antenna design.

The ECC and DG of the two port MIMO antenna are shown in Figure 8. It is evident that the value of ECC is less than 0.05 dB meaning that the isolation is good between the antenna elements. The value of DG is touching 10 dB in the operating band. Therefore, the proposed MIMO antenna system has acceptable performance in diversity.

Moreover, the 3D radiation pattern of the antenna is shown in Figure 8(b) depicting the directional radiating nature away from human head at 5 GHz resonating frequency having directivity of 5.9 dBi. Using pattern diversity the omnidirectional radiation pattern can be obtained for the proposed antenna.

Table 1 discusses the performance of the proposed structure and its comparison with the previous state of art. As seen from the table the proposed antenna has minimum height as compared with the other works done by researchers. In addition, the isolation of the antenna is better than -20 dB making it a potential candidate for smartphone MIMO applications.

Table 1.

Ref.	Antenna Size (Single Element)	Bandwidth (GHz)	Efficiency (%)	Isolation (dB)	ECC (dB)
[7]	$19 \times 5 \times 0.8$	3.3–3.6 (-10 dB)	50–76	-11	< 0.15
[9]	$30 \times 30 \times 1$	3.3–3.9 (-6 dB)	60	-25	< 0.15
[12]	$1 \times 60 \times 0.8$	3.4–3.6 (-6 dB)	45–60	-16	< 0.10
[16]	$3 \times 8 \times 0.8$	3.4–3.8 (-10 dB)	50–60	-10	< 0.10
[17]	$16 \times 4 \times 1$	3.4–3.59 (-6 dB)	38.6–56.4	-16	< 0.40
Pro.	$14.37 \times 6.75 \times 0.32$	4.9–5.06 (-10 dB)	79.5	-21.3	< 0.05

5. CONCLUSION

This paper presents a compact two element sub-6 GHz MIMO antenna for future 5G wireless applications. The antenna element with miniaturized meander microstrip lines provides the flexibility to incorporate the structure on the edges of the smartphone reducing the add-on space. Compared with the other similar 5G antennas, the antenna has obvious low profile characteristics. In addition, a neutralization line is used to reduce mutual coupling in the structure. The proposed antenna was fabricated and measured finding the results in good agreement with the simulated ones. The isolation of better than -20 dB and envelope correlation of < 0.05 dB are achieved making it a suitable candidate for MIMO applications.

REFERENCES

1. Shafi, M., A. F. Molisch, P. J. Smith, T. Haustein, P. Zhu, P. De Silva, and G. Wunder, "5G: A tutorial overview of standards, trials, challenges, deployment, and practice," *IEEE Journal on Selected Areas in Communications*, Vol. 35, No. 6, 1201–1221, 2017.
2. Yang, H., *Massive MIMO Meets Small Cell*, Springer, 2017.
3. [online] <https://www.3gpp.org/DynaReport/38-series.htm>.
4. Li, Y., Y. Luo, and G. Yang, "High-isolation 3.5 GHz eight-antenna MIMO array using balanced open-slot antenna element for 5G smartphones," *IEEE Transactions on Antennas and Propagation*, Vol. 67, No. 6, 3820–3830, 2019.
5. Qin, Z., W. Geyi, M. Zhang, and J. Wang, "Printed eight-element MIMO system for compact and thin 5G mobile handset," *Electronics Letters*, Vol. 52, No. 6, 416–418, 2016.
6. Sun, L., H. Feng, Y. Li, and Z. Zhang, "Compact 5G MIMO mobile phone antennas with tightly arranged orthogonal-mode pairs," *IEEE Transactions on Antennas and Propagation*, Vol. 66, No. 11, 6364–6369, 2018.
7. Deng, J. Y., J. Yao, D. Q. Sun, and L. X. Guo, "Ten-element MIMO antenna for 5G terminals," *Microwave and Optical Technology Letters*, Vol. 60, No. 12, 3045–3049, 2018.
8. Wong, K. L., C. Y. Tsai, and J. Y. Lu, "Two asymmetrically mirrored gap-coupled loop antennas as a compact building block for eight-antenna MIMO array in the future smartphone," *IEEE Transactions on Antennas and Propagation*, Vol. 65, No. 4, 1765–1778, 2017.
9. Parchin, N. O., Y. I. A. Al-Yasir, A. H. Ali, I. Elfergani, J. M. Noras, J. Rodriguez, and R. A. Abd-Alhameed, "Eight-element dual-polarized MIMO slot antenna system for 5G smartphone applications," *IEEE Access*, Vol. 7, 15612–15622, 2019.
10. Ojaroudi Parchin, N., H. Jahanbakhsh Basherlou, Y. I. Al-Yasir, A. Ullah, R. A. Abd-Alhameed, and J. M. Noras, "Multi-band MIMO antenna design with user-impact investigation for 4G and 5G mobile terminals," *Sensors*, Vol. 19, No. 3, 456, 2019.
11. Ren, A. and Y. Liu, "A compact building block with two shared-aperture antennas for eight-antenna MIMO array in metal-rimmed smartphone," *IEEE Transactions on Antennas and Propagation*, Vol. 67, No. 10, 6430–6438, 2019.
12. Lu, J. Y., K. L. Wong, and W. Y. Li, "Compact eight-antenna array in the smartphone for the 3.5-GHz LTE 8×8 MIMO operation," *2016 IEEE 5th Asia-Pacific Conference on Antennas and Propagation (APCAP)*, 323–324, IEEE, July 2016.
13. Zhang, X., Y. Li, W. Wang, and W. Shen, "Ultra-wideband 8-port MIMO antenna array for 5G metal-frame smartphones," *IEEE Access*, Vol. 7, 72273–72282, 2019.
14. Li, M.-Y., Z.-Q. Xu, Y.-L. Ban, C.-Y.-D. Sim, and Z.-F. Yu, "Eight-port orthogonally dual-polarised MIMO antennas using loop structures for 5G smartphone," *IET Microw. Antennas Propag.*, Vol. 11, 1810–1816, 2017.
15. Jiang, W., B. Liu, Y. Cui, and W. Hu, "High-isolation eight-element MIMO array for 5G smartphone applications," *IEEE Access*, Vol. 7, 34104–34112, 2019.
16. Wong, K.-L. and J. Lu, "3.6-GHz 10-antenna array for mimo operation in the smartphone," *Microwave and Optical Technology Letters*, Vol. 57, 1699–1704, 2015.
17. Cai, Q., Y. Li, X. Zhang, and W. Shen, "Wideband MIMO antenna array covering 3.3–7.1 GHz for 5G metal-rimmed smartphone applications," *IEEE Access*, Vol. 7, 142070–142084, 2019.
18. Abdullah, M., S. H. Kiani, and A. Iqbal, "Eight element multiple-input multiple-output (MIMO) antenna for 5G mobile applications," *IEEE Access*, Vol. 7, 134488–134495, 2019.
19. Masoodi, I. S., I. Ishteyaq, K. Muzaffar, and M. I. Magray, "Low cost substrate based compact antennas for 4g/5g side-edge panel smartphone applications," *Progress In Electromagnetics Research Letters*, Vol. 91, 145–152, 2020.
20. Ishteyaq, I., I. S. Masoodi, and K. Muzaffar, "Eight-port double band printed MIMO antenna investigated for mutual-coupling and SAR effects for sub-6 GHz 5G mobile applications," *Progress In Electromagnetics Research C*, Vol. 113, 111–122, 2021.

21. “Minimum requirements related to technical performance for IMT-2020 radio interface(s),” Archived (PDF) from the original on January 8, 2019; Retrieved August 16, 2019.