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# A Compact High Isolation Four Elements MIMO Antenna System for 5G Mobile Devices

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## HIGHLIGHTS

- An effective design of a compact high isolation four elements antenna system operating on 3.5 GHz is presented for 5G MIMO mobile phone devices.
- The self-isolated method is a very good technique for antenna array isolation enhancement.
- Desirable antenna miniaturization and the simple structure of the proposed antenna element are achieved.
- Good antenna and MIMO performances are attained from the proposed antenna system.

## ARTICLE INFO

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## ABSTRACT

A Compact high, isolation Multi Input Multi Output Antenna system working on 3.5 GHz (3400 - 3600) MHz is presented for the 5G mobile terminals. Four antenna elements are employed to construct the proposed MIMO antenna system. These antennas are located over two slim side-edged frames of a mobile device to meet the present trend requirements of slim and full-screen smartphone devices. A modified Hilbert fractal monopole antenna and an I-shaped feeding line construct the antenna element's front part. At the same time, an L-shaped short to the system's ground plane is used for the antenna element's back part. The overall monopole antenna element's size printed on the mobile frame's side edge is (9.72 mm × 5.99 mm). Hence, the desirable antenna miniaturization is achieved. Based on the spatial diversity and self-isolated techniques, the proposed four-element MIMO antenna system achieves high isolation (better than 16.3 dB). The scattering parameters, antenna gains, antenna efficiencies, and radiation pattern characteristics have been evaluated to assess the proposed antenna element's performance. Besides, the MEGs and ECCs are investigated to appreciate the proposed system's MIMO performance. Desired antenna and MIMO performances are achieved by the proposed four-element MIMO antenna system, so it can be a good candidate for the future 5G mobile handsets.

## 1. Introduction

Recently, with the increasing growth of wireless communication technologies, the demand for high transmission rates and smart services has been very requested. Because of their advantages of high transmission rate, high access rate, short latency, and high spectral efficiency, the 5G wireless communication systems have attracted increasing attention in both academic and industrial fields [1]. To improve the channel capacity and spectrum efficiency without needing more bandwidth and/or transmitting power, the MIMO antenna approach has been adopted in 5G mobile handsets [2]. The MIMO antenna systems can be utilized in two scenarios. The first one is called a spatial diversity technique since the same data stream is sent over the various antennas to propagate across uncorrelated propagation (spatial) paths. This technique improves the system's reliability and makes it immune to a multipath fading environment. The second scenario is a so-called spatial multiplexing technique. The data stream is divided into parts. Each piece of data is placed on an antenna to send across different propagation paths. This is an interesting technique used in modern communication systems to increase the transmitted data rate without more bandwidth and/or transmitting power [3]. It is noteworthy that using one of these two techniques is governed by the status of the wireless fading environments. Since the MIMO system with spatial multiplexing technique is powerfully used in a rich multipath wireless channel (high SNR) and in a poor multipath wireless channel (low SNR), the spatial diversity technique is the solution [4]. However, because of the limited space of the mobile terminal device, the isolation problem will be appeared by increasing the number of antennas. Hence, this problem impact will strictly affect the antenna system performance [5]. So the achievement of a better MIMO antenna system performance in terms of low Envelope correlation coefficients (ECCs) and high isolation with a



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compact antenna size is still a challenge. Many efforts have been made to improve the isolation and achieve the desired performance of MIMO antenna systems. A two-element MIMO antenna system employing the decoupling network isolation technique was reported in [6-9].

In contrast, the hybrid electric and magnetic coupling technique was adopted in a two elements MIMO antenna system [10]. In [11], a four antenna elements MIMO system based on self-decoupled antenna pairs has been presented. Furthermore, the spatial diversity technique was used for the four elements MIMO antenna system [12]. In addition, other techniques have also been adopted, such as the polarization diversity technique [13], hybrid decoupling (ground slot and neutralization line) [14], neutralization line [15], and self-isolated technique [16, 17].

This paper presents a compact high, isolation four elements antenna system operating on 3.5 GHz (3400-3600) MHz for 5G MIMO mobile phone devices. High isolation (better than 16.3 dB) and very low Envelope correlation coefficients (ECCs) are obtained based on the spatial diversity and self-isolated techniques. Furthermore, desirable antenna miniaturization and simple structure of the proposed antennae are achieved where the overall antenna size printed on the side-edge mobile frame is (9.72 mm × 5.99 mm). Besides, the proposed antenna system has a good antenna and MIMO performances. The CST Microwave studio software (version 2019) is employed for modeling and simulating the proposed four antennas MIMO system.

## 2. Proposed Four Elements MIMO Antenna System

The geometry and the detailed dimensions of the proposed four-element compact MIMO antenna system for the 5G mobile phone devices are presented in Figure 1. The proposed MIMO system's four antennas are located at the top four corners of the mobile device, and they have the same structures and dimensions. Each antenna element is printed on the inner and outer surfaces of the two long side edges mobile frame substrate, which meets the present trend requirement of a full-screen mobile phone device. The main system board size (150 × 75) mm$^2$ is chosen as a typical size 5.5-inch mobile phone device. To meet a slim smartphone device requirement, the mobile's frame side edges located vertically on the main system board are selected to be 7 mm in height. A double-sided FR4 substrate of 0.8 mm height, which has 4.3 relative permittivities and 0.02 loss tangent, is used for designing the main mobile circuit board and its frame. Figure 2 shows the structure and dimensions of a single antenna element, divided into front and back parts. As shown in Figure 2-a, the front part consists of a modified Hilbert fractal monopole antenna and an I-shaped feeding line. The adorable Hilbert space-filling property is utilized for attaining very good antenna compactness. Since the overall planer antenna dimension printed on the long side frame is (9.72 mm × 5.99 mm) working on the (3.4-3.6) GHz interested band. Figure 2-b depicts the antenna back part, an L-shaped connected by a 0.5 mm short stub directly under the L-shape's vertical stub to the main system ground. The coupling capacitance generated by the antenna back part is behind the proposed antenna's desirable impedance matching. To feed the antenna elements, a 50 Ω SMA connector is employed and connected to the antenna feeding lines via holes from the backside of the main system's ground.

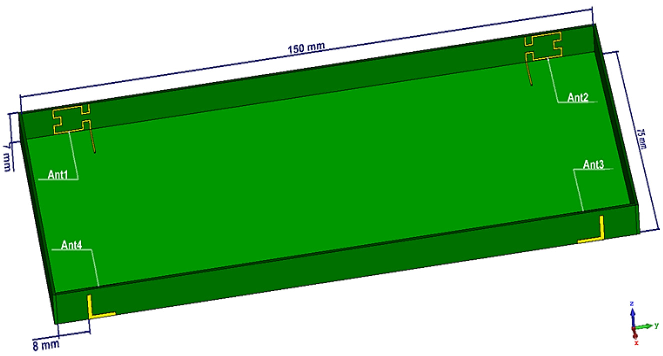
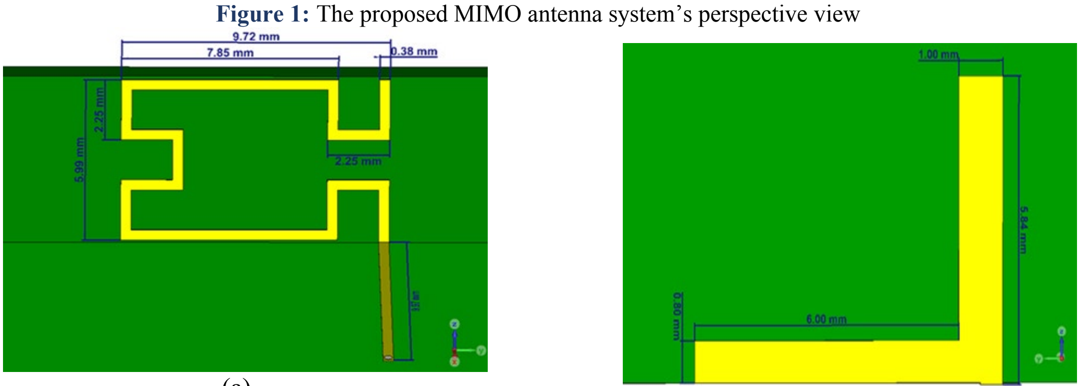



**Figure 1:** The proposed MIMO antenna system's perspective view




(a) (b)

**Figure 2:** Single antenna element (a) the front side (b) the backside

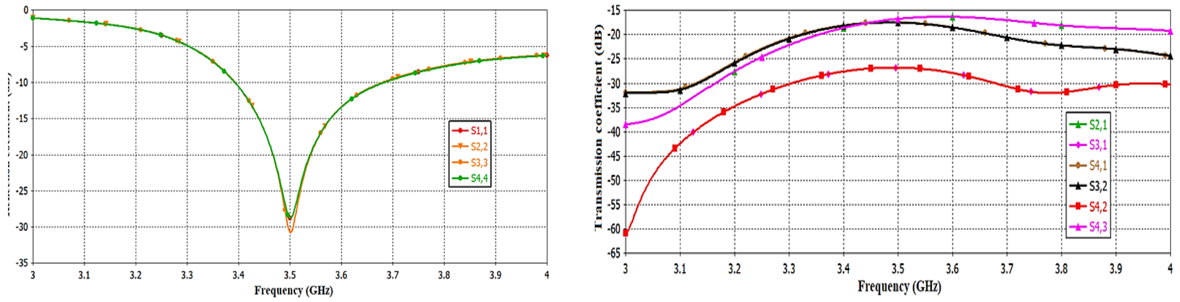



**Figure 3:** S-parameters (a) reflection coefficients (b) transmission coefficients

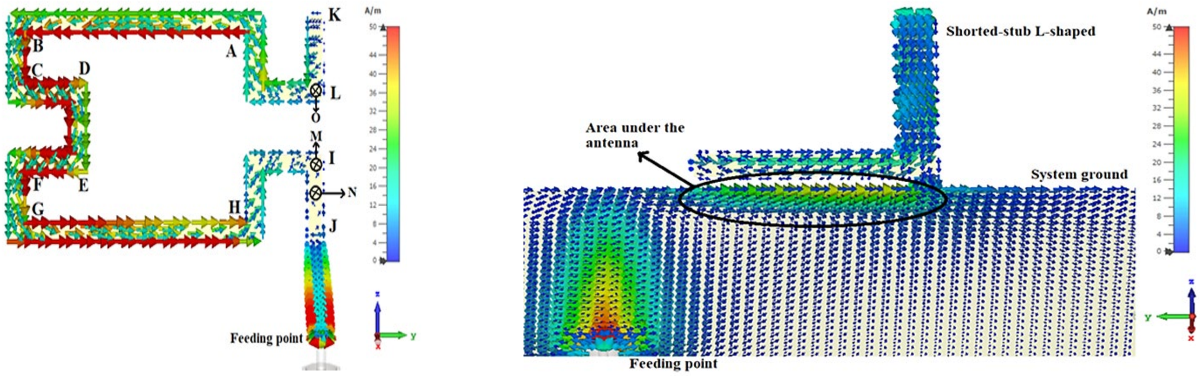



**Figure 4:** Surface current distributions at the resonance frequency of 3.5 GHz (a) front side (b)backside

# 3. Results and Discussion

## 3.1 Antenna performance

Figure 3 depicts the simulated S parameters results of the proposed four antenna elements MIMO system. As observed in Figure 3-a, a desirable impedance matching is achieved overall the band of interest (3400-3600) MHz. The reflection coefficients of all four antennas verify less than -10 dB (2:1 VSWR). Because of the similarity and abbreviation, only the necessary transmission coefficients of the proposed antenna system are shown in Figure 3-b. As a result, high isolation between antennas is obtained. The transmission coefficients $S_{2,1}$ and $S_{4,3}$ are better than 16.3 dB, $S_{3,1}$ and $S_{4,2}$ are better than 27.5 dB (diagonal distance between the specified antennas), and the coefficients $S_{4,1}$ and $S_{3,2}$ are better than 18.2 dB along with the working band. The self-isolated and spatial diversity techniques are behind the desirable isolation of the proposed four-element MIMO antenna system. The optimal orientation and location of the antenna elements at the top four corners of the mobile device have been chosen to adopt the spatial diversity technique and utilize the mobile's space as much as possible. The miniaturization of the proposed antenna plays a vital role in isolation enhancement which can provide more space between antennas. In addition, the compact antenna elements have the self-isolated property where the current flowing through the excited antenna element and the main system's ground plane is bounded under the antenna region.

To further explain the proposed antenna element working principle, the surface current distributions at 3.5 GHz resonance frequency are presented in Figure 4. The antenna front side's surface current distributions are depicted in Figure 4-a. The main current concentration is along the current flowing path (ABCDEFGH) and surely on the feeding line. The current path's length is about 23 mm, representing 0.268 $\lambda_0$ ($\lambda_0$ acts as the 3.5 GHz free space wavelength). Thus, the 0.25 $\lambda_0$ monopole-like mode working on 3.5 GHz is represented by this path. In addition, the intensity current of the KL and IJ sections is very weak, and the points O, M, and N are treated as the null points of the current. The surface current distributions of the antenna element's backside (shorted-stub L-shaped) and the related part of the proposed system's ground plane are illustrated in Figure 4-b. One can observe from the figure that the current concentration is focused on the area under the antenna, which is the reason behind the antenna's self-isolated property.

The total and radiation antenna efficiencies of the proposed MIMO systems' four antennas are exhibited in Figure 5. Desirable antenna efficiencies are achieved along with the operating band, which are between (64%-74%) for total efficiencies and (72%-81%) for radiation efficiencies. The four antennas' gain over the working band is depicted in Figure 6. As it is seen, the gains are almost stable along with the operating band, and high gains of all antennas are obtained where the maximum gains are about 5.1 dB. Figure 7-a and 7-b show all antennas' three-dimensional and two-dimensional radiation patterns at 3.5 GHz resonance frequency. Each antenna element has a maximum gain direction different from other antennas' maximum gain directions, indicating a very good pattern diversity feature of the proposed 4-element MIMO antenna system. Moreover, all sides of the mobile device board are completely covered by these four antennas' radiation patterns. So a desirable radiation coverage performance is obtained by the proposed MIMO antenna system.

### 3.2 MIMO performance

Important metrics, which are the ECCs and Mean effective gains (MEGs), are used to evaluate the MIMO performance of the proposed antenna array. The ECC is defined as measuring the antennas' radiation patterns independency [18]. Depending on the far-field radiation patterns, the ECC is determined using Eq. (1) [19].

$$\rho_e = \frac{\left|\iint_{4\pi}[\vec{F}_1(\theta,\varphi) * \vec{F}_2(\theta,\varphi)]\, d\Omega\right|^2}{\iint_{4\pi}\left|\vec{F}_1(\theta,\varphi)\right|^2 d\Omega \iint_{4\pi}\left|\vec{F}_2(\theta,\varphi)\right|^2 d\Omega} \quad (1)$$

Where the $\overrightarrow{F_i}(\Theta,\varphi)$ is the three-dimensional far-field radiation, the solid angle is defined by ($\Omega$), and the Hermitian product operator is denoted by (*). Figure 8 demonstrates the ECCs between antennas of the proposed 4-element MIMO antenna system, calculated based on Eq. (1) under the hypothesis of uniform channel propagation (due to the similarity, only the necessary ECCs are plotted). All ECCs of the proposed system are less than 0.017 overall for the interested band. As it is known, the accepted ECC value is less than 0.5. So the proposed four elements MIMO antenna system has a very small ECCs value compared with the acceptance criteria. Thus, the proposed MIMO antenna system realizes a high diversity performance.

The other important parameter is the MEG which can be demonstrated as the ratio of the antenna's mean received powers to the total mean incident power when the antenna is moved over a random mobile environment route. Equation (2) can obtain the MEG value [20].

$$MEG = \int_0^{2\pi}\int_0^{\pi}\left(\frac{XPR}{1+XPR}\, G_\theta(\theta,\varphi)P_\theta(\theta,\varphi) + \frac{1}{1+XPR} G_\varphi(\theta,\varphi)P_\varphi(\theta,\varphi)\right)(\sin\theta)\, d\theta\, d\varphi \quad (2)$$

The XPR denotes the cross-polarization power ratio, and the theta and phi components of the incoming plane waves are indicated as $P_\Theta$ and $P_\varphi$ respectively, and the antenna gain components are described by $G_\Theta$ and $G_\varphi$ Respectively. To obtain a desirable MIMO antenna system performance, the criteria of Eq. (3) should satisfy the MIMO antennas' MEGs [21].

$$\frac{MEG_i}{MEG_j} \cong 1 \quad (3)$$

Where the MEGs of the $i$ and $j$ antennas are indicated by $MEG_i$ and $MEG_j$, respectively. The MEGs of all the four MIMO systems' antennas are presented in Figure 9. Equation (2) is used to evaluate the antennas' MEGs under the propagation channel assumption of the Gaussian distribution for the elevation direction and uniform distribution for the azimuth direction. One can see that the criteria mentioned in Eq. (3) are confirmed by the proposed MIMO antenna system. In addition to that, the MEGs of all four antennas are stable over the working band of interest.

A summary performance comparison of the proposed four elements MIMO antenna system with some other recent MIMO antenna systems reported for the 5G mobile terminals is presented in Table 1. Compared with other MIMO antenna systems, the proposed one has a smaller size and lower ECC. Furthermore, good system isolation and eight antenna total efficiencies are obtained by adopting the self-isolation property and spatial diversity technique. There is no additional antenna efficiency loss by adding parasitic decoupling elements. So it can be seen from Table 1 that the proposed four elements MIMO antenna system can provide a MIMO system with a very comparable antenna and MIMO performance.

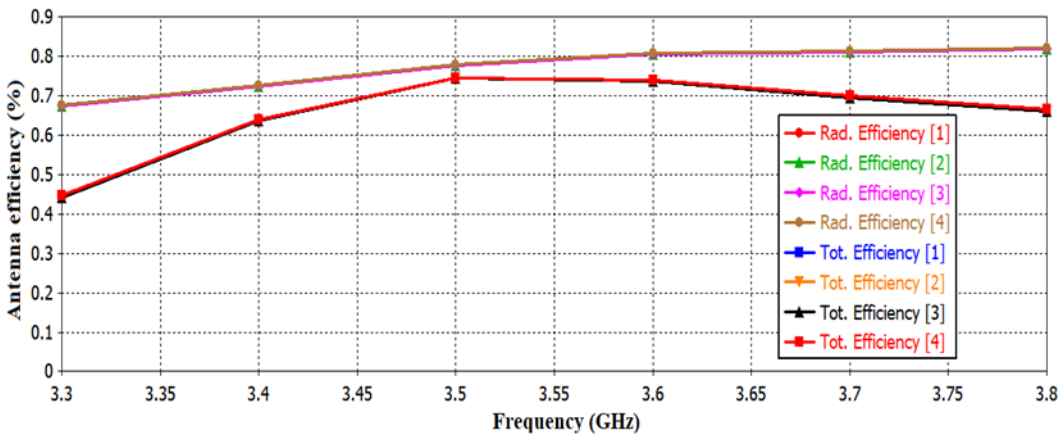



**Figure 5:** Antenna efficiency

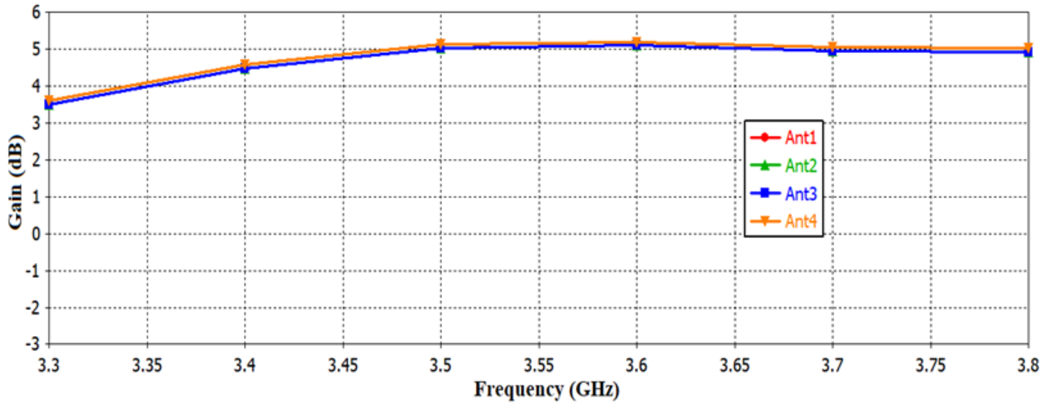
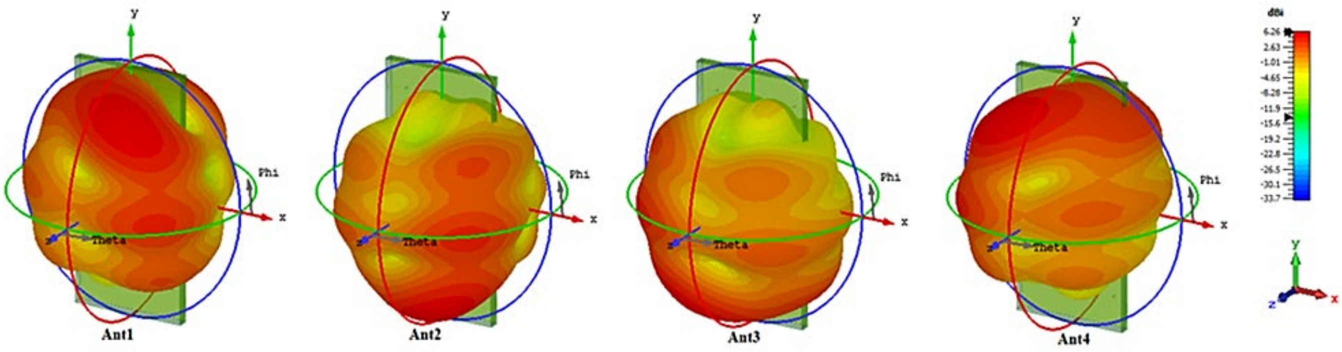
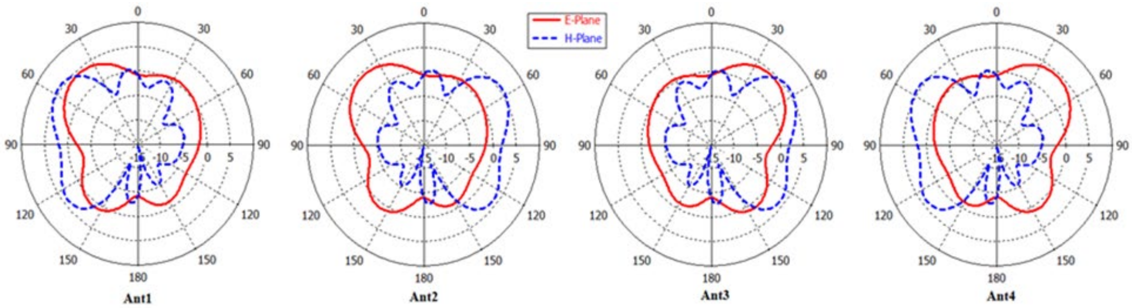



**Figure 6:** Antenna gain




(a)




(b)

**Figure 7:** Antennas' radiation patterns at 3.5 GHz resonance frequency (a) 3-D radiation patterns (b) 2-D radiation patterns

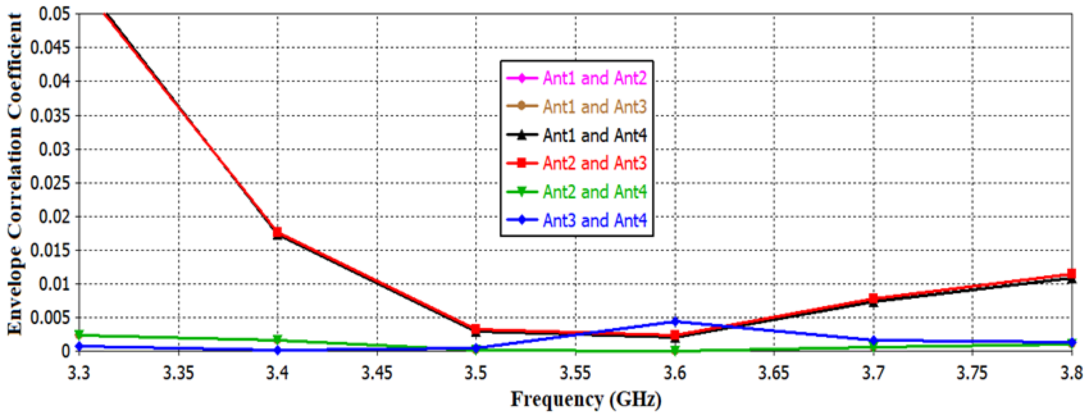



**Figure 8:** ECCs of the proposed MIMO antenna system

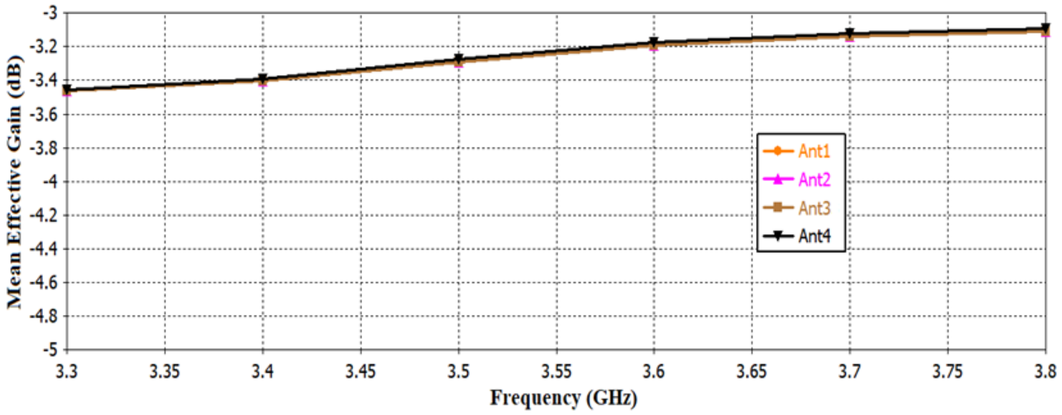



**Figure 9:** MEGs of the four MIMO antennas

**Table 1:** Performance comparison

| Ref. | Bandwidth (GHz) | Total Efficiency (%) | Isolation (dB) | ECC | Antenna Element Size (mm × mm) | MIMO Order | Isolation Technique |
|---|---|---|---|---|---|---|---|
| 11 | (3.4-3.6) (4.8-5.0) | >50 | >17.5 | <0.14 | (22 × 7) | 4 × 4 | Self-isolated |
| 22 | (3.3-4.2) | >40 | >10 | <0.06 | (42 × 42) | 4 × 4 | Self-isolated |
| 23 | (3.3-4.2) | >61 | >17.9 | <0.05 | (26 ×6.2) | 4 × 4 | Self-isolated |
| 14 | (3.3-3.6) | (45-60) | >15 | <0.15 | (12.5 × 4.9) | 8 × 8 | Ground slot etching and Neutralization line |
| 13 | (2.55-2.65) | (48-58) | > 13 | < 0.2 | (18.6 ×18.6) | 8 × 8 | Polarization diversity |
| This work | (3.4-3.6) | (64-74) | >16.3 | <0.017 | (9.72 × 5.99) | 4 × 4 | Self-isolated and spatial diversity |

## 4. Conclusion

A four-element MIMO antenna system is proposed for the 5G mobile phone devices. The adorable space-filling feature of the Hilbert fractal geometry is utilized to attain very good antenna compactness. Furthermore, by adopting the spatial and self-isolated techniques, desirable isolation (better than 16.3 dB) is obtained by the proposed four antennas MIMO system. Again, very low ECCs are achieved (lower than 0.017), making the proposed antenna system work on high diversity performance. In addition to that, good MEGs are attained, and the optimal MIMO performance criteria of the MEGs MIMO antennas are confirmed. As a result, desirable antenna performance is obtained, including scattering parameters, antenna gains, antenna efficiencies, and antenna radiation characteristics. Due to the good antenna and MIMO performance results, the proposed four antenna elements MIMO system can be considered a good candidate for the future 5G mobile phone terminals.

### Author contribution

All authors contributed equally to this work.

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### Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

### Conflicts of interest

The authors declare that there is no conflict of interest.

## References

**[1]** C. Z. Han, L. Xiao, Z. Chen ,T. Yuan, Co-Located Self-Neutralized Handset Antenna Pairs with Complementary Radiation Patterns for 5G MIMO Applications, IEEE Access, 8 (2020) 73151–73163. https://doi.org/10.1109/ACCESS.2020.2988072

**[2]** A. Zhao, Z. Ren, Size Reduction of Self-Isolated MIMO Antenna System for 5G Mobile Phone Applications, IEEE Antennas Wirel. Propag. Lett., 18 (2019) 152–156. https://doi.org/10.1109/LAWP.2018.2883428

**[3]** J. Sui and K. L. Wu, Self-Curing Decoupling Technique for Two Inverted-F Antennas with Capacitive Loads, IEEE Trans. Antennas Propag., 66 (2018) 1093–1101. https://doi.org/10.1109/TAP.2018.2790041

**[4]** Y. Wu, C. Xiao, Z. Ding, X. Gao , S. Jin, A Survey on MIMO Transmission with Finite Input Signals: Technical Challenges, Proc IEEE Inst. Electr. Electron. Eng., 106 (2018) 1779–1833. https://doi.org/10.1109/JPROC.2018.2848363

**[5]** Y. Li, C. Sim, Y. Luo , G. Yang, High-Isolation 3.5 GHz Eight- Antenna MIMO Array Using Balanced Open-Slot Antenna Element for 5G Smartphones, IEEE Trans. Antennas Propag., 67 (2019) 3820–3830. https://doi.org/10.1109/TAP.2019.2902751

**[6]** C. Wu, C. Chiu , T. Ma, Very Compact Fully Lumped Decoupling Network for a Coupled Two-Element Arra , IEEE Antennas. Wirel. Propag. Lett., 15 ( 2015) 158–161. https://doi.org/10.1109/LAWP.2015.2435793

**[7]** L. Zhao, L. K. Yeung, K. Wu, A Coupled Resonator Decoupling Network for Two-Element Compact Antenna Arrays in Mobile Terminals, IEEE Trans. Antennas Propag., 62 (2014) 2767–2776. https://doi.org/10.1109/TAP.2014.2308547

**[8]** L. Zhao , K. Wu, A Dual-Band Coupled Resonator Decoupling Network for Two Coupled Antennas, IEEE Trans. Antennas Propag., 63 (2015) 2843–2850. https://doi.org/10.1109/TAP.2015.2421973

**[9]** K. Qian, L. Zhao , K. Wu, An LTCC Coupled Resonator Decoupling Network for Two Antennas, IEEE Trans. Microw .Theory. Tech., 63 (2015) 3199–3207. https://doi.org/10.1109/TMTT.2015.2464816

**[10]** C. Xue, X. Y. Zhang, Y. F. Cao, Z. Hou, MIMO Antenna Using Hybrid Electric and Magnetic Coupling for Isolation Enhancement, IEEE Trans. Antennas. Propag., 65 (2017) 5162–5170. https://doi.org/10.1109/TAP.2017.2738033

**[11]** Z. Ren and A. Zhao, Dual-Band MIMO Antenna With Compact Self-Decoupled Antenna Pairs for 5G Mobile Applications, IEEE Access, 7 (2019) 82288–82296. https://doi.org/10.1109/ACCESS.2019.2923666

**[12]** A. J. Salim, R. S. Fyath , J. K. Ali, A New Miniaturized Folded Fractal Based PIFA Antenna Design for MIMO Wireless ApplicationsInt. Conf. Electr. Eng. Inform. Commun. Technol., (2019) 36–40. https://doi.org/10.1145/3321289.3321298

**[13]** M. Y. Li, Z. Q. Xu, Y. L. Ban, C. Y. D. Sim , Z. F. Yu, Eight-Port Orthogonally Dual-Polarised MIMO Antennas Using Loop Structures for 5G Smartphone, IET Microw. Antennas. Propag.,11 (2017) 1810–1816.

**[14]** W. Jiang, B. Liu, Y. Cui , W. Hu, High-Isolation Eight-Element MIMO Array for 5G Smartphone Applications, IEEE Access, 7 (2019) 34104–34112. https://doi.org/10.1109/ACCESS.2019.2904647

**[15]** J. Guo, L. Cui, C. Li , B. Sun, Side-Edge Frame Printed Eight-Port Dual-Band Antenna Array for 5G Smartphone Applications, IEEE Trans. Antennas. Propag., 66 (2018) 7412–7417. https://doi.org/10.1109/TAP.2018.2872130

**[16]** A. Zhao , Z. Ren, Multiple-Input and Multiple-Output Antenna System with Self-Isolated Antenna Element for Fifth-Generation Mobile Terminals, Opt. Technol. Lett. , 61(2019) 20–27.

**[17]** M. Y. Muhsin, A. J. Salim, J. K. Ali, An Eight-Element MIMO Antenna system for 5G Mobile Handsets, Int. Symp. Comput. Commun., (2021) 1– 4. https://doi.org/10.1109/ISNCC52172.2021.9615663

**[18]** J. Li et al, Dual-Band Eight-Antenna Array Design for MIMO Applications in 5G Mobile Terminals, IEEE Access., 7 (2019) 71636–71644. https://doi.org/10.1109/ACCESS.2019.2908969

**[19]** H. Zou et al., Dual-Functional MIMO Antenna Array With High Isolation for 5G/WLAN Applications in Smartphones, IEEE Access, 7 (2019) 167470–167480. https://doi.org/10.1109/ACCESS.2019.2953311

**[20]** Z. Qin, W. Geyi, M. Zhang , J. Wang, Printed Eight-Element MIMO System for Compact and Thin 5G Mobile Handest, Electron. Lett., 52 (2016) 416–418.

**[21]** K. L. Wong, C. Y. Tsai , 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 Trans. Antennas. Propag., 65 (2017) 1765–1778. https://doi.org/10.1109/TAP.2017.2670534

**[22]** I. R. R. Barani, K. Wong, Y. Zhang , W. Li, Low-Profile Wideband Conjoined Open-Slot Antennas Fed by Grounded Coplanar Waveguides for 4 × 4 5G MIMO Operation, IEEE Trans. Antennas. Propag., 68 (2020) 2646–2657. https://doi.org/10.1109/TAP.2019.2957967

**[23]** A. Zhao , Z. Ren, 5G MIMO Antenna System for Mobile Terminals, IEEE Int. Symp. antennas propag . Radio Sci.Meet., (2019) 427–428. https://doi.org/10.1109/APUSNCURSINRSM.2019.8888835