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Tightly arranged orthogonal mode antenna for 5G MIMO mobile terminal

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Abstract

This letter presents an orthogonal mode 4-antenna system operating in the 3.5-GHz band (3.3–3.6 GHz) for the fifth-generation (5G) multiple-input multiple-output (MIMO) mobile device. The 4-antenna system is composed of 2 identical tightly arranged antenna pairs, and each pair is formed with an arrow-shaped monopole and a bended dipole with gap-coupled feeding. The tightly-arranged antenna pair is face-to-face arranged on the front and back side of the substrate and the distance between the center of the 2 elements is only 1 mm; however, they have good isolation (better than 10 dB) and diversity performance (envelope correlation coefficient better than 0.11) with the help of orthogonal mode. This configuration provides promising solution for compactness of the MIMO antenna in mobile phone. The prototype was fabricated and measured, and the measured results show good agreements with the simulated ones.

KEYWORDS

fifth-generation (5G), mobile antenna, multiple-input multiple-output (MIMO), orthogonal mode, tightly arranged

1 | INTRODUCTION

With the rapid development of mobile communication, the demand for the capacity of wireless communication is strong. To satisfy the demand, multiple-input multiple-output (MIMO) technology, as a key technology of fifth-generation (5G) communication, provides a promising solution for enhancing the communication channel capacity. And there are an increasing number of commercial mobile phones used MIMO technology to improve the performance of mobile communication. Although MIMO technology can provide a pleasing performance for mobile communication, how to integrate a lot of antennas in a limited region with good isolation is a challenging task. It has been noted that the frequency spectrum 3.5 GHz has become one of the 5G bands in the World Radio-communication Conference 2015.[1] And very recently, the frequency spectrum 3.3–3.6 GHz has been identified preliminarily for 5G mobile communication by China ministry of industry and information technology.[2]

Recently, a number of publications presented the mobile phone antenna for 5G MIMO application.[3-9] The first 8 × 8 MIMO mobile phone antenna operating at 3.5 GHz is proposed in[3] with 8 capacitive coupling elements; however, the mutual coupling across the required band of the MIMO antenna is not presented in this paper. In reference,[4] a 3.5 GHz 10 × 10 MIMO mobile phone antenna with the open slot structure has been investigated, and the 10 dB isolation is obtained with the help of large distance (center to center distance 23 mm) between antenna elements. A 8 × 8 and 16 × 16 MIMO antenna with the same element structure has been presented in[5] using the neutralizing line to enhance isolation of the antenna element. The center-to-center distance of 2 antenna elements is 11 mm with the help of neutralizing line, which makes an intensively improvement compared with.[4] Two asymmetrically mirrored gap-coupled loop antennas are used to form 8 × 8 MIMO mobile phone antenna,[6,7] and the 2 asymmetrically mirrored antenna elements are mounted along one edge of the system ground plane, so that the edge-to-edge distance of 2 elements is 0.8 mm and the center to center distance is 3.9 mm. With such a tiny region occupied, a current cancellation method, which is similar to the principle of neutralizing line was investigated to achieve the isolation better than 10 dB across the 3.4–3.6 GHz. Furthermore, an orthogonal polarization method to decrease the mutual coupling of the 5G MIMO elements is described in[8]; however, the distance between the orthogonal polarization antenna pair is still large. In reference,[9] a dual polarization loop structure with good isolation performance and no ground clearance is described, which means 2 MIMO elements only occupy 1 antenna structure's region. Polarization diversity technology is a promising way to reduce the mutual coupling of the MIMO antenna

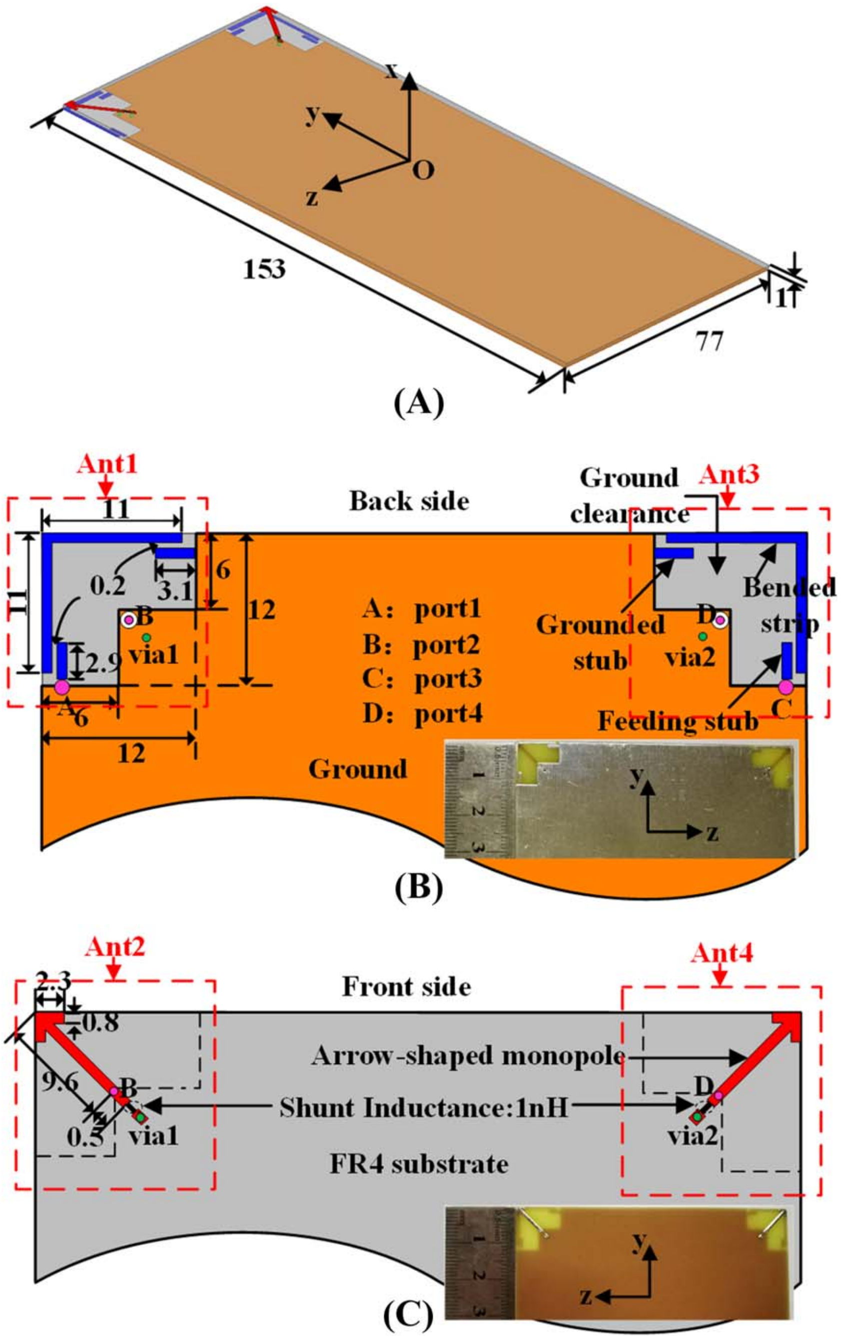

FIGURE 1 Geometry of the proposed antenna, unit all in mm. A, 3D structure; B, back side; C, front side [Color figure can be viewed at wileyonlinelibrary.com]

elements, even though the antenna elements are close to each other. There are a large number of publications achieving desirable isolation due to orthogonal polarization;[10–12] however, the orthogonal polarization technology is rarely applied in 5G MIMO mobile phone antenna.[8] Thus, we can achieve a desirable isolation by 2 orthogonal mode elements with tiny element distance.

In this letter, an orthogonal mode 4-antenna system operating in the 3.5-GHz band (3.3–3.6 GHz) for 5G MIMO mobile device has been investigated. The 4-antenna system includes 2 identical face-to-face tightly arranged antenna pairs, and each pair is composed of an arrow-shaped monopole antenna and a bended dipole with gap-coupled feeding. Due to the orthogonal mode of the tightly-arranged antenna pair, the isolation of the 4 × 4 MIMO system is better than 10 dB across the 3.3–3.6 GHz band although the spatial distance of the monopole and dipole of each antenna pair is tiny. Besides the promising impendence matching and isolation, the measured maximum antenna efficiency is 73.2% and 64.2% when fed through ports 1 and 2. Furthermore, the calculated envelope correlation coefficient (ECC) between all elements from simulated and measured complex electric

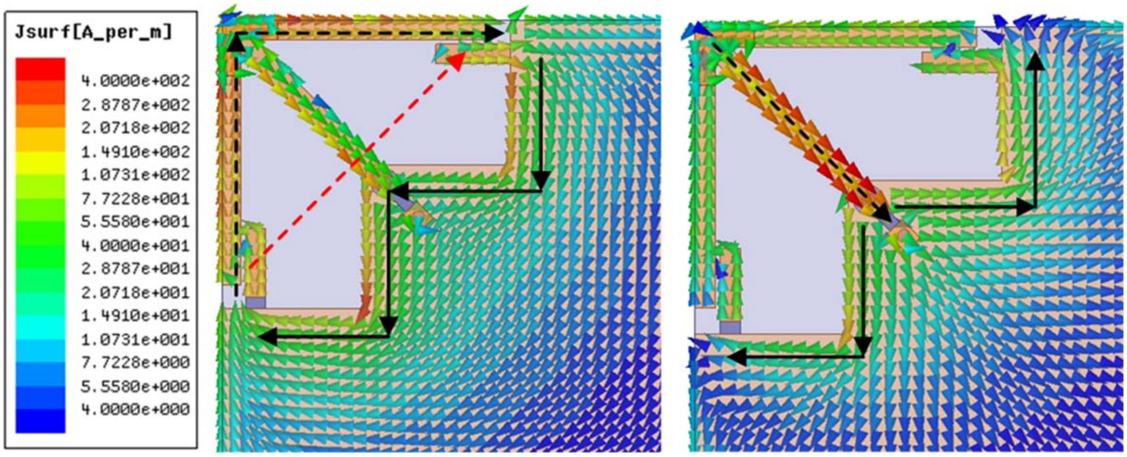

FIGURE 2 Vector current distribution of the tightly arranged antenna pair at 3.45 GHz fed through (A) port 1 and (B) port 2 [Color figure can be viewed at wileyonlinelibrary.com]

far field is reported, and both the simulated and measured ECC is <0.11, which shows a good spatial diversity performance of the 4 × 4 MIMO system. To the best of author's knowledge, the face-to-face tightly arranged antenna elements using orthogonal mode technology in the 5G MIMO mobile phone antenna has not been presented yet in the open literature.

2 | ANTENNA DESIGN

2.1 | Antenna configuration

Figure 1 illustrates the structure and dimensions of the proposed antenna. As can been seen in Figure 1A, the 4 elements are printed on a FR-4 substrate ($\varepsilon_r = 4.4$, $\tan\delta = 0.02$) and the size of the printed circuit board (PCB) is 153 × 77 × 1 mm^3. The structure on the upper right corner of the PCB is identical with the upper left corner. A metal ground with 2 L-shaped clearances is mounted on the back side of the PCB. It should be pointed out that the orange part

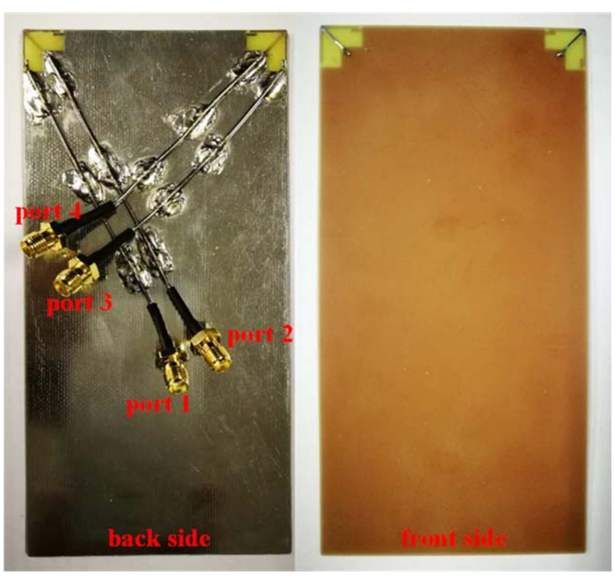

FIGURE 3 Photograph of the proposed antenna [Color figure can be viewed at wileyonlinelibrary.com]

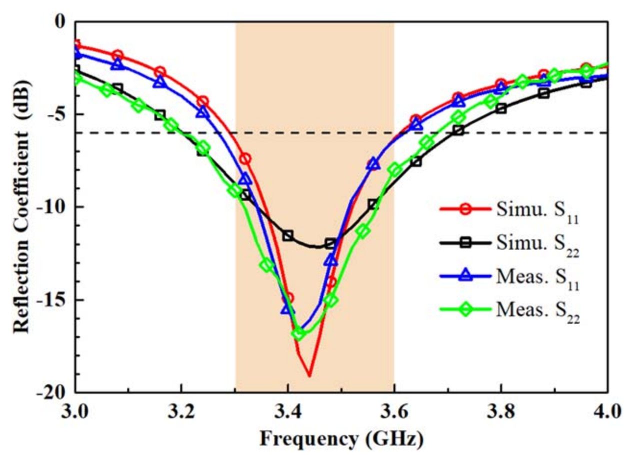

FIGURE 4 Simulated and measured reflection coefficient of the Ant1 and Ant2 [Color figure can be viewed at wileyonlinelibrary.com]

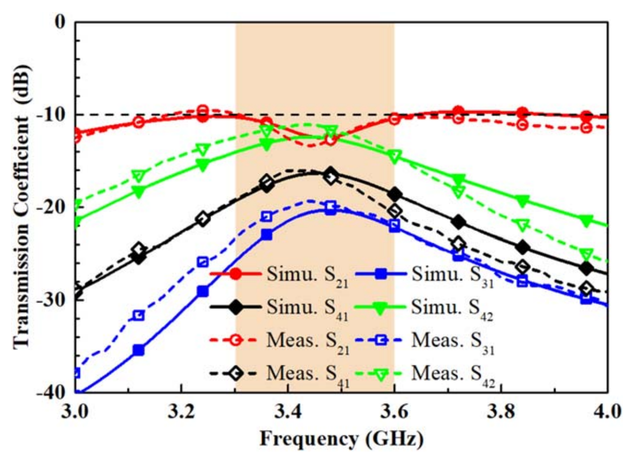

FIGURE 5 Simulated and measured transmission coefficient of the proposed antenna [Color figure can be viewed at wileyonlinelibrary.com]

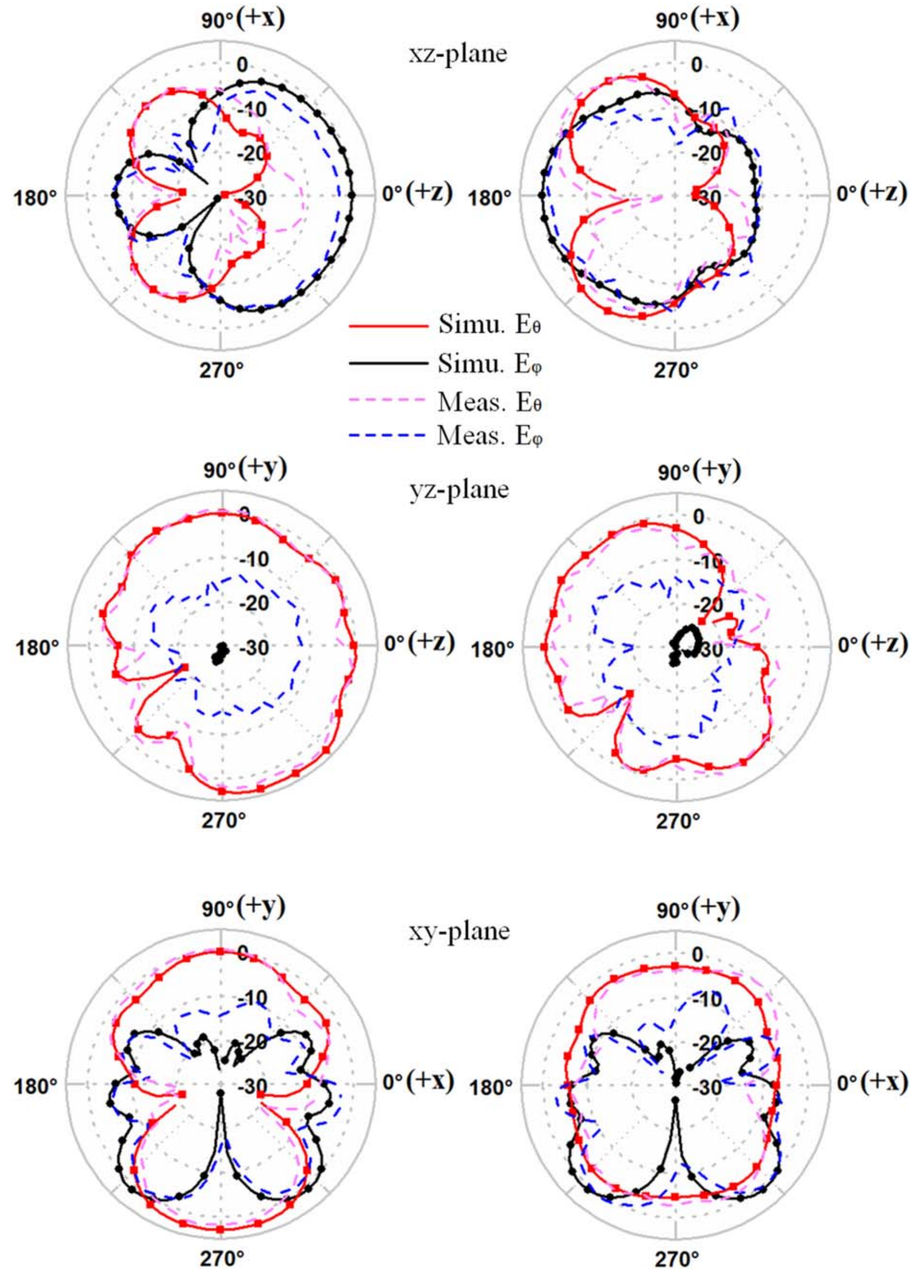

FIGURE 6 Simulated and Measured radiation patterns at 3.45 GHz of the proposed antenna. (A) port 1 and (B) port 2 [Color figure can be viewed at wileyonlinelibrary.com]

represents the metal while the gray part represents the FR4 substrate. Figure 1B shows the geometry of the back side of the antenna, 2 identical bended dipoles with gap-coupled feeding are deposited at the upper-left and upper-right corner of the PCB. When feeding through port 1 or 3 by semi-rigid cable, the feeding stub can appropriately excite the bended strip to achieving a $\lambda_g/2$ dipole mode, and a grounded stub is applied to keep the structure symmetric. The orthogonal mode will be deteriorated without the grounded stub. The front side of the antenna is shown in Figure 1C, a $\lambda_g/4$ arrow-shaped monopole is fed through port 2 using semi-rigid cable and a 1nH shunt inductance is embedded to improve the impendence match of the monopole. The parameter of the structure is optimized by high-frequency structure simulator (HFSS) 15.0 software.

2.2 | Isolation analysis

To illustrate the operating mechanism of the proposed antenna, the vector current distribution of the tightly arranged antenna pair at 3.45 GHz fed through ports 1 and 2 is reported. When fed through port 1, as shown in Figure 2A, a dipole mode is excited with the most of current distributed

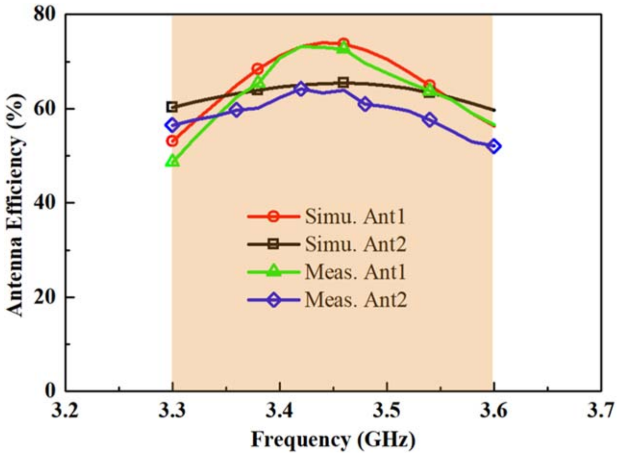

FIGURE 7 Simulated and measured antenna efficiency of the proposed antenna [Color figure can be viewed at wileyonlinelibrary.com]

on the bended strip and the superimposed current direction of the dipole is +45° which is illustrated by the red dash line. Furthermore, the black solid line in the Figure 2A shows the ground current distribution, and the direction of the ground current is same. However, when fed through port 2, as shown in Figure 2B, a monopole mode is excited and the current direction is −45° which is illustrated by the black dash line. Furthermore, the ground current distribution in Figure 2(b) shows an orthogonal ground current mode, which denotes the direction of the ground current is inverse. In brief, the good isolation performance of the 2 tightly arranged antenna elements is achieved due to 2 orthogonal modes: (1) the orthogonal current mode of the 2 antenna elements, so the spatial coupling will be eliminated; (2) the orthogonal ground current mode of the 2 antenna elements, so the coupling through the ground current can also be canceled out. Therefore, a good isolation is achieved with the help of the orthogonal mode, which is different from[6] theoretically. And the center to center distance is only 1 mm, which is more tightly arranged than.[6]

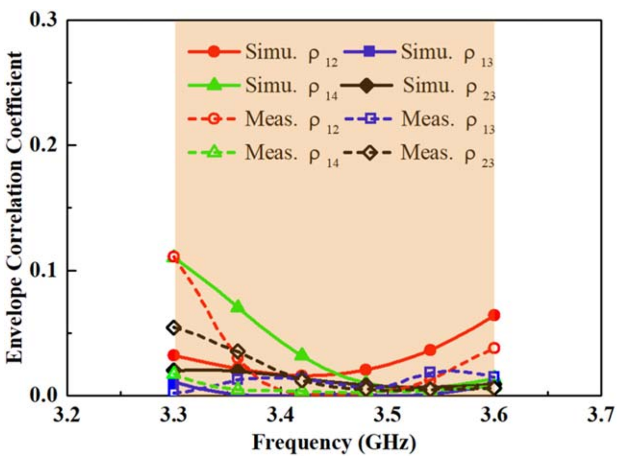

FIGURE 8 Simulated and measured ECC of the proposed antenna [Color figure can be viewed at wileyonlinelibrary.com]

3 | ANTENNA FABRICATION AND MEASUREMENT RESULTS

In order to validate the performance of the MIMO antenna system, a prototype of 4 × 4 MIMO mobile phone antenna was fabricated and measured. The photograph of the proposed MIMO antenna system is shown in Figure 3. The proposed MIMO antenna system has 4 ports, and four 50 Ω semi-rigid cables were used to feed 4 ports on the back side of the proposed antenna. It should be pointed out that the semi-rigid cables are placed away from the maximum current region of the ground in order not to affect the antenna's performance because the ground is part of the radiator.[13]

3.1 | S-parameter

The simulated and measured reflection coefficient of the MIMO antenna fed through ports 1 and 2 is illustrated in Figure 4. As seen in Figure 4, the reflection coefficient of the antenna is better than −6 dB across the desired band in 3.3–3.6 GHz for both elements. As for the Ant3 and Ant4, the performance is same as the Ant1 and Ant2 due to symmetrically disposed at the 2 sides of the PCB. So the results of Ant3 and Ant4 are not shown for brevity. Figure 5 shows the isolation between the 4 ports, which is <–10 dB across the desired band. Once again, the high port isolation is achieved in a tightly arranged antenna pair due to orthogonal mode.

3.2 | Radiation performance

The radiation patterns of the proposed antenna at 3.45 GHz when fed through ports 1 and 2 are shown in Figure 6. And the simulated and measured efficiency is reported in Figure 7. The difference between the simulated and measured efficiency is due to the fabrication error and the loss of the lumped inductance. The measured efficiency is 48.6%–73.2% and 52.1%–64.2% when fed through ports 1 and 2, which shows a good performance in mobile phone antenna.

3.3 | Diversity performance

The ECC is a significant parameter of the MIMO antenna system, which can quantitatively evaluate the performance of the MIMO system. The ECC of 2 antennas in a MIMO system can been calculated by the complex radiation far field, and the formulation is given in Equations 1 and 2.[13]

$$\rho_e \approx |\rho_c|^2 = \left| \frac{\oiint A_{12}(\theta,\varphi)\sin\theta d\theta d\varphi}{\oiint A_{11}(\theta,\varphi)\sin\theta d\theta d\varphi \cdot \oiint A_{22}(\theta,\varphi)\sin\theta d\theta d\varphi} \right|^2 \tag{1}$$

where

$$A_{ij}=E_{\theta,i}(\theta,\varphi)\cdot E^{*}_{\theta,j}(\theta,\varphi)+E_{\varphi,i}(\theta,\varphi)\cdot E^{*}_{\varphi,j}(\theta,\varphi) \quad (2)$$

The simulated and measured complex radiation far field of the antenna can be obtained by HFSS 15.0 and 3D measurement in anechoic chamber. By using Equations 1 and 2, the simulated and measured ECC can be deduced, as shown in Figure 8. The ECC of all antenna pairs are <0.11 across the desired band, satisfies the standard of low ECC in mobile phone (ECC < 0.5).[14] All in all, good diversity performance is achieved within the 3.3–3.6 GHz band.

4 | CONCLUSION

In this letter, an orthogonal mode tightly arranged antenna system operating in the 3.5-GHz band (3.3–3.6 GHz) for 5G MIMO mobile device has been studied. The 4-antenna system is composed of 2 face-to-face tightly arranged pairs, each pair includes an arrow-shaped monopole and a bended dipole. Small mutual coupling is obtained due to the orthogonal current mode of each pair. As a result, good isolation and diversity performance can be achieved with the $S_{21} < -10$ dB and ECC < 0.11 across the desired frequency band, and the maximum efficiency of the Ant1 and Ant2 is 73.2% and 64.2%, which shows a good performance in the mobile antenna.

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Compact size of the hybrid branch-line coupler using π-type transmission-line

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