Compact Dual-band Antenna Based on CRLH-TL for WWAN/LTE Terminal Applications

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Abstract: In this paper, a compact dual-band antenna based on composite right/left-handed transmission line (CRLH-TL) is proposed for WWAN/LTE wireless terminal applications. By employing two symmetrical CRLH structures, the proposed antenna can easily produce two wide separate operating frequency bands with a compact size of 25×25×6mm^3. Additionally, a pair of matching strips is introduced on both sides of the feeding line to further improve the impedance characteristics of the terminal antenna. To demonstrate the design concept, the CRLH-based antenna has been simulated, fabricated and measured. The experimental results demonstrate the proposed antenna is capable of working over the frequency ranges of 0.66-1.06GHz and 1.68-2.88GHz with $|S_{11}|$<-6dB, which can cover the bands of LTE700, GSM850, GSM900, GSM1800, GSM1900, UMTS, LTE2300 and LTE2500 for wireless terminals. Moreover, the MIMO operating performance of the proposed antenna element is also studied, and an enhanced isolation between the antenna elements is obtained by utilizing the defected ground structures and grounded branches. Besides, the measured total efficiency and calculated envelope correlation coefficient (ECC) are also presented and discussed.

Key words: CRLH-TL; MIMO; terminal antenna; WWAN/LTE

I. INTRODUCTION

As modern mobile communication technologies evolve, wireless terminal devices are expected to meet more diverse communication standards, which inevitably requires that the terminal antennas can cover more than one working bands in a single system. Meanwhile, the available space for antenna design in mobile devices is limited due to the increase of terminal functions. Therefore, designing a compact multiband terminal antenna with satisfactory performance is not only a fundamental requirement but also a significant technological challenge.[1] To address this problem, various antenna design methods have been reported in recent years.[2-14] The proposed antennas with coupling feed in Refs. 2-4 can excite several resonant modes to obtain multiband operation. In Refs. 4-6, lumped capacitors and inductors are utilized to realize a compact design for the terminal antenna. To realize the wideband operation, a LC matching circuit is employed in Refs. 6-11. Besides, in Refs. 12-14, the frequency-reconfigurable technology is introduced to reduce the occupied space of antennas and still ensure their wide operating band.

As an artificial electromagnetic material, the metamaterials (MTMs) have been proliferated rapidly in recent years with extraordinary electromagnetic properties, such as the characteristics of zero-order resonance, simultaneous negative permittivity and permeability, etc.[15] The metamaterials have been widely introduced in the antenna design to improve antenna performance.[16-19] In Refs. 17-19, the antennas obtain wide operating bands and good radiation characteristics by employing the composite right/left-handed transmission line (CRLH-TL) structures in the designs of terminal antennas. The antenna in Ref. 18 for mobile handsets is proposed with the size of 35×52×2.4mm^3, which can cover the common mobile communication bands for LTE/GSM/UMTS/WLAN/WiMAX applications. In Ref. 19, dual CRLH unit cells are employed to realize dual zero-order resonance characteristics, which make the antenna obtain wide impedance bandwidth and high efficiency.

In this paper, a compact antenna based on CRLH-TL for WWAN/LTE mobile handset application is proposed. By utilizing dual CRLH structures, the proposed antenna obtains wide operating bandwidths of 0.66-1.06GHz and 1.68-2.88GHz to cover 2G, 3G and 4G frequency bands with a compact size of 25×25×6mm^3. Both the simulated and measured results are in good agreement. Besides, to prove the feasibility of the proposed antenna element for MIMO operation, a two-element MIMO antenna array composed of two proposed CRLH-based antennas is also presented and discussed. The simulated and measured results indicate that the antenna array can obtain good isolation in the operating bands by employing the defected ground structures and grounded branches.

II. ANTENNA CONFIGURATION AND DESIGN

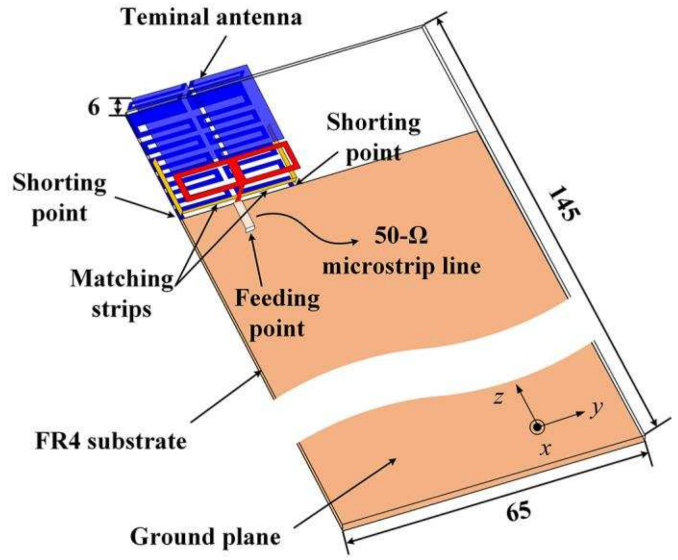

FIGURE 1 Configuration of the proposed antenna with the mobile terminal platform.

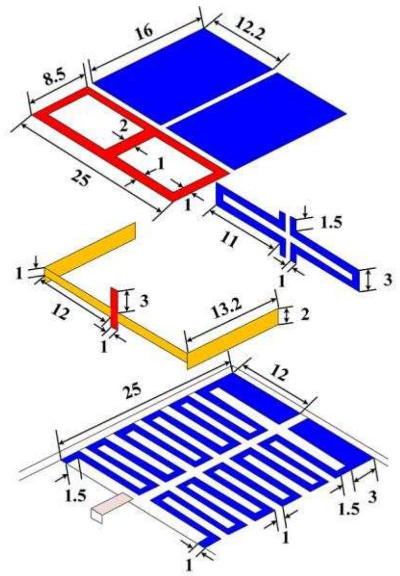

FIGURE 2 Detailed configuration of the proposed antenna.

The proposed compact antenna with the mobile terminal platform is shown in Figure 1. This terminal antenna based on CRLH-TL is designed on a single-sided FR4 PCB with a total dimension of 145×65×1mm^3. The relative permittivity and the loss tangent of the FR4 substrate are 4.4 and 0.02, respectively. The proposed antenna is placed at the corner of the substrate with a size of 25×25×6mm^3, and supported by a foam with the thickness of 5mm. The antenna is excited by a 50-Ω microstrip line. The detailed dimensions of the antenna are illustrated in Figure 2, and the unit of the proposed antenna is millimeter.

As is shown in Figure 3(a), the proposed antenna is composed of a dual-loop structure (indicated in red color), two symmetrical radiation units (Part1 and Part2, indicated in blue color) and a pair of matching strips (indicated in yellow color). Based on the theory of the CRLH-TL, the equivalent circuit of the proposed antenna is shown in Figure 3(b). The gaps between the dual-loop structure and the top rectangular patches are equivalent as two left-handed series capacitances C_{L1}, C_{L2}. Meanwhile, the shorted meander lines connected with top patches are equivalent as two left-handed shunt inductances L_{L1}, L_{L2}. On the other hand, the equivalent series right-handed inductances L_{R1}, L_{R2} are realized by the dual-loop structure, and the shunt right-handed capacitances C_{R1}, C_{R2} are generated from the gaps between top blue patches and ground plane. To simplify the circuit, radiation resistances are not shown in equivalent circuit. Furthermore, a pair of matching strips on both sides of the feeding line are employed to improve the impedance matching in the lower and higher bands.

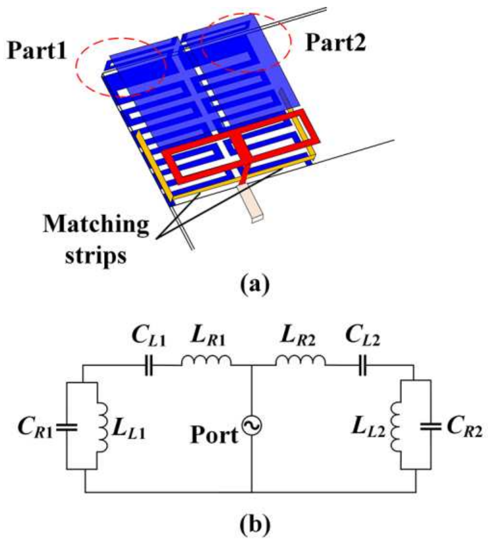

FIGURE 3 (a) Configuration and (b) equivalent circuits of the proposed antenna.

To better illustrate the design process and operating mechanism of the proposed antenna, three different antennas involved in the antenna design evolution process are shown in Figure 4. The simulated $|S_{11}|$ results of the various antennas involved are shown in Figure 5. Ant 1 in Figure 4 is the case with Part 1 and a loop structure. It can be seen from Figure 5 that Ant 1 generates two high-frequency resonant mode at around 2200MHz and 2880MHz respectively to cover a wide higher band. And a low-frequency resonance around 690MHz is also obtained owing to the left-handed mode of the CRLH unit structure. To extend the lower operating bandwidth, another CRLH unit cell is employed in Ant 2 by introducing the Part 2 and dual-loop structure. So, Ant 2 can obtain a wider lower frequency band while the impedance matching is not good enough in the lower and higher bands. To improve its operating performance, a pair of matching strips is introduced in Ant 3, the proposed antenna. As is shown in Figure 5, the proposed antenna can achieve wider operating bands for WWAN/LTE mobile handset application, and the impedance bandwidth for $|S_{11}|$<-6dB is 690-980MHz and 1690-2710MHz.

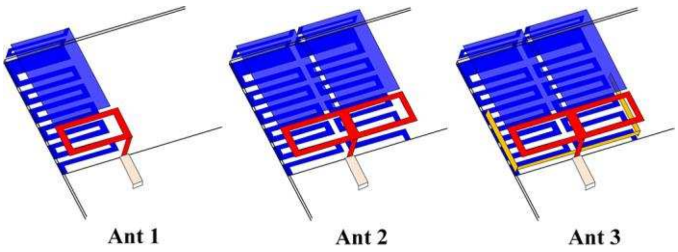

FIGURE 4 Configurations of various antennas involved in the design evolution process.

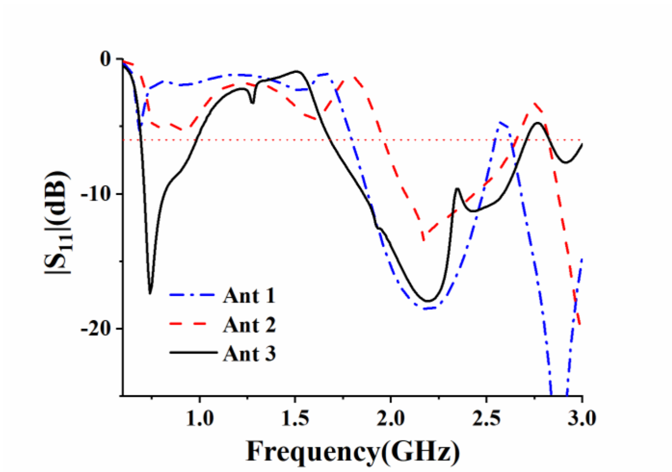

FIGURE 5 Simulated $|S_{11}|$ of various antennas involved.

To further demonstrate the working characteristics of the proposed antenna clearly, the simulated surface current distributions of the whole antenna at 800MHz and 2000MHz are shown in Figure 6. Figure 6(a) displays that the main current is concentrated along the rectangular dual loop structure and meandered shorted lines, which are mainly contributors to the lower left-handed resonant modes covering 690-980MHz. Meanwhile, at 2000MHz, the top patches obviously feature a stronger current than that at 800MHz, which indicates that the right-handed resonant modes are excited to cover the higher operating frequency band. The above analyzed results are quite in accordance with the design principle of the proposed antenna.

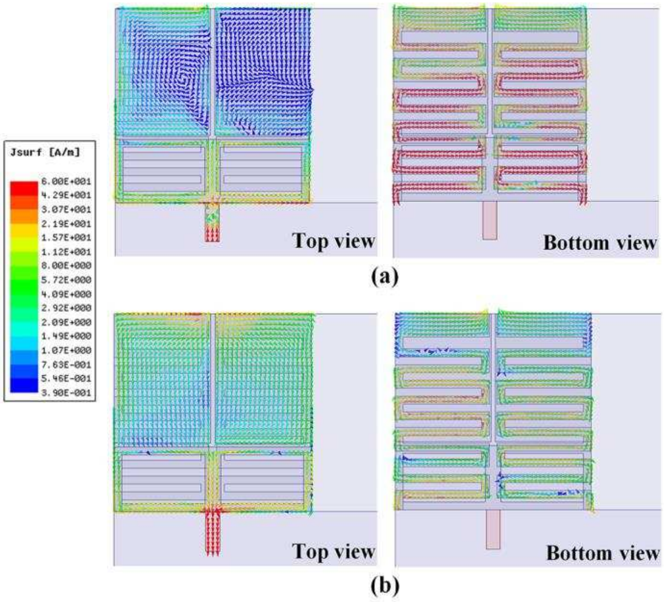

FIGURE 6 Simulated top and bottom surface current distributions of the proposed antenna at (a) 800MHz and (b) 2000MHz.

III. EXPERIMENTAL RESULTS AND DISCUSSION

Based on the detail dimension given in Figures. 1 and 2, the proposed antenna was fabricated and measured. The experimental results are obtained by Rohde Schwartz R&S E5071C Vector Network Analyzer. The simulated and measured $|S_{11}|$ are shown in Figure 7, and the results agree well with each other. The slight difference is mainly caused by the manufacture errors and substrate property. As is shown in Figure 7, the proposed antenna can operate at two wider frequency bands, 0.66-1.06GHz and 1.68-2.88GHz with $|S_{11}|$<-6dB, which can cover the LTE700, GSM850, GSM900, GSM1800, GSM1900, UMTS, LTE2300, and LTE2500 bands for wireless terminals.

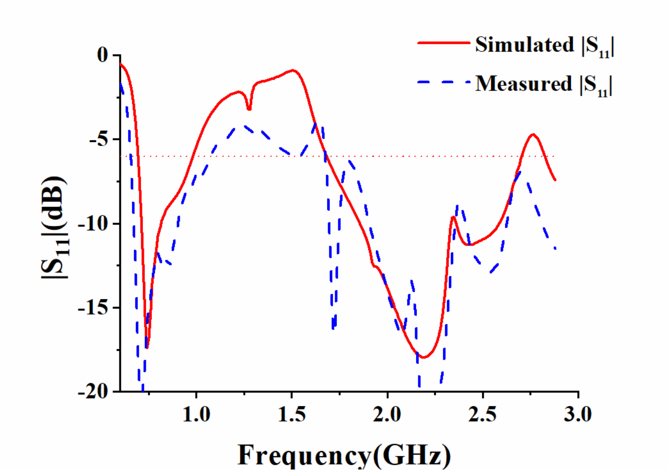

FIGURE 7 Simulated and measured $|S_{11}|$ of the proposed antenna.

As is shown in Figure 8, the simulated and measured 2-D normalized radiation patterns at 825MHz and 2250MHz are presented. At the lower frequency (825MHz), dipole-like radiation patterns can be observed in the xz and yz planes, and in the xy plane, an omnidirectional radiation pattern can be seen. At the higher frequency (2250MHz), more fluctuations in the radiation patterns are observed. All of the measured radiation patterns in accordance with the simulated results.

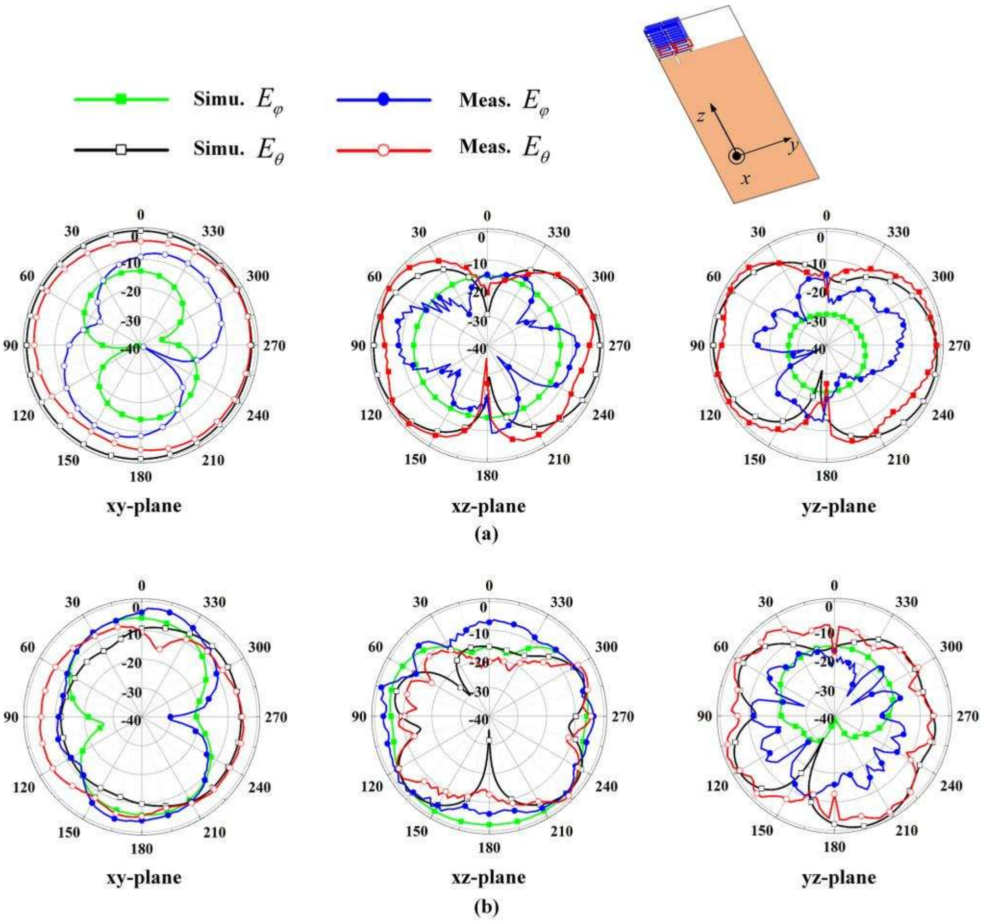

FIGURE 8 Simulated and measured 2-D normalized radiation patterns of the proposed antenna at (a) 825 and (b) 2250MHz.

Figure 9 exhibits the measured efficiency and gain for the proposed antenna in the operating bands. In the lower band, the measured efficiency varies from 47% to 65%. And in the higher bands, the measured radiation efficiency varies from 38% to 85%. The efficiency is acceptable and meets the requirement for the practical mobile terminal antenna applications. The measured gains for the lower band ranges from -0.2 to 3 dBi, while in the higher band the measured gain is from -0.2 to 3.5 dBi.

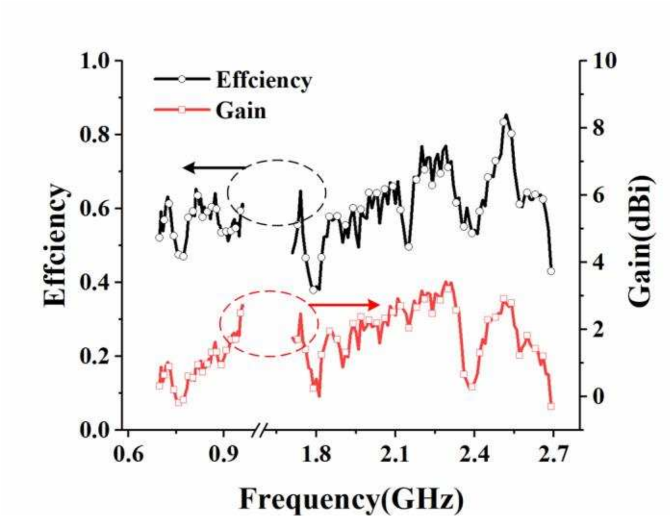

FIGURE 9 Measured efficiency and gain of the proposed antenna in the lower and higher bands.

IV. MIMO IMPLEMENTATION

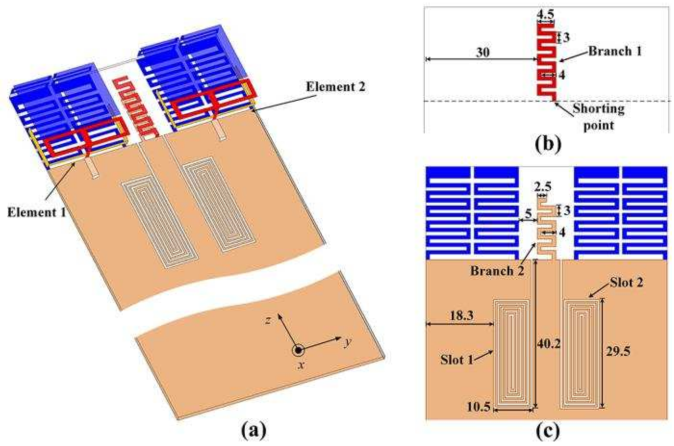

FIGURE 10 (a) Configuration of the proposed two-element MIMO antenna with decoupling structures and detailed dimensions of the decoupling structures: (b) front and (c) back of the substrate.

From the last decade, large channel capacity and high spectral efficiency become more significant for handheld devices. Recently, MIMO technology has been widely utilized to enlarge the channel capacity and hence exploit multipath propagation.[20] However, the antennas must be placed closely in the modern terminal handset, which results in strong mutual coupling between the antenna elements. To solve this problem, various decoupling techniques have been reported, such as decoupling network[21], neutralization line technique[22], defected grounded structure[23] and grounded branch[24].

In this section, a two-element MIMO antenna shown in Figure 10(a) is proposed for terminal applications. The proposed MIMO antenna is composed of two identical antenna units studied in section 2, which are placed symmetrically in the same side of the ground plane. The defected ground structures and grounded branches, including a pair of spiral slots and two meandered branches, are employed to improve the isolation between the antennas in the lower and higher bands, respectively. Detailed dimensions of the decoupling structures are shown in Figure 10(b) and (c). To illustrate the effect of the decoupling structures on the antenna performance, the simulated S-parameters results of the proposed two-element MIMO antenna with and without decoupling structures are shown in Figure 11. The curves of $|S_{22}|$ are similar to the results of $|S_{11}|$ due to the symmetrical structure, so the results of $|S_{22}|$ is not shown in Figure 11. It can be seen obviously that the -6dB impedance bandwidth of two coupled antenna elements becomes narrower because of the strong mutual coupling in the lower band, and the isolation is also difficult to satisfy the operating requirement in the higher band. By introducing the decoupling structures, the -6dB impedance bandwidth is extended to cover 660-970MHz and 1590-2690MHz, and the mutual coupling is also improved. From the simulated results, the isolation is better than -13.5dB in the lower band, and better than -15dB in the higher band.

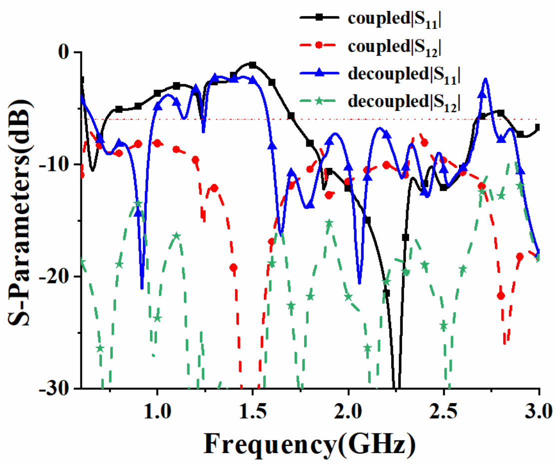

FIGURE 11 Simulated S-parameters results of the proposed two-element MIMO antenna with and without decoupling structures.

To investigate the decoupling mechanism of the proposed MIMO antenna, simulated magnetic field distributions of the proposed MIMO antenna at 825MHz and 2250MHz are shown in Figure 12. It can be seen the magnetic energy is mostly trapped by the spiral slot 1 in the lower band, when port 1 is excited and port 2 is terminated with matched load. Meanwhile, as shown in Figure 12, the main magnetic energy is concentrated on the meandered branches 1 and 2 in the higher band. By employing the proposed decoupling structures properly, it is effective to reduce the magnetic coupling between the two antenna elements in the lower and higher operating bands.

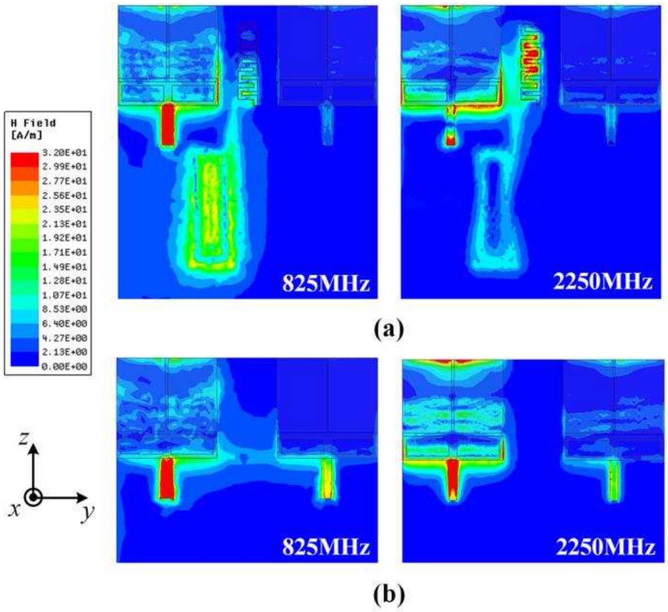

FIGURE 12 Simulated magnetic field distributions of the proposed MIMO antenna (a) with and (b) without the decoupling structures at 825MHz and 2250MHz, when port 1 is excited and port 2 is terminated with matched load.

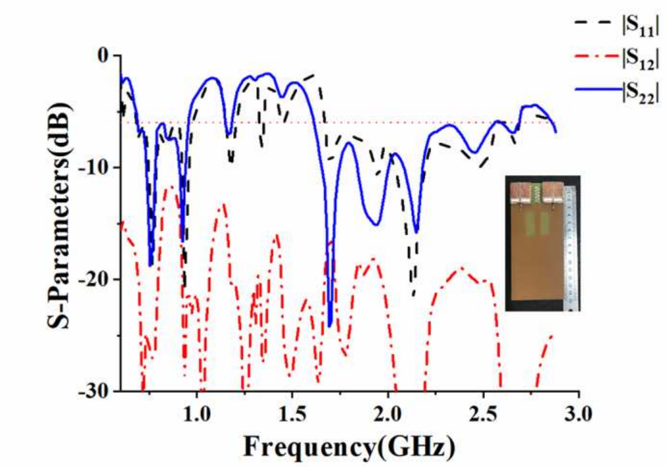

FIGURE 13 Measured S-parameters results of the proposed two-element MIMO antenna with decoupling structures.

Based on the optimized dimensions, the proposed MIMO antenna is fabricated and measured. The measured S-parameters results of the proposed two-element MIMO antenna is shown in Figure 13, and the prototype of the MIMO antenna is inset in Figure 13. It can be seen the proposed MIMO antenna works in two wide frequency bands, which covers 690-960MHz and 1670-2690MHz with return loss better than 6dB. Meanwhile, the isolation of the two-element MIMO antenna is better than 12dB and 15dB in the lower and higher bands, respectively. The measured return loss and isolation all satisfy the requirements for 2G, 3G and 4G wireless terminal applications.

The simulated and measured 2-D normalized radiation patterns of Element 1 of the proposed two-element MIMO antenna at 825 and 2250MHz are shown in Figure 14. Due to the identical antenna unit and symmetrical placement, the radiation patterns of Element 2 are not shown in this section for brevity. In Figure 14, a dipole-like radiation pattern is observed at 825MHz, and more variations and nulls are shown in the patterns at the 2250MHz. The measured patterns are in good agreement with the simulated results. The measured total efficiency and calculated ECC of the proposed two-element MIMO antenna are shown in Figure 15. The calculated ECC is obtained by the measured 3-D far-field vector radiation patterns. For the lower band, the measured total efficiency varies in the range is of 31%-55%, and the calculated ECC is lower than 0.15. For the higher band, the measured total efficiency is about 30%-70%, and the calculated ECC is lower than 0.07.

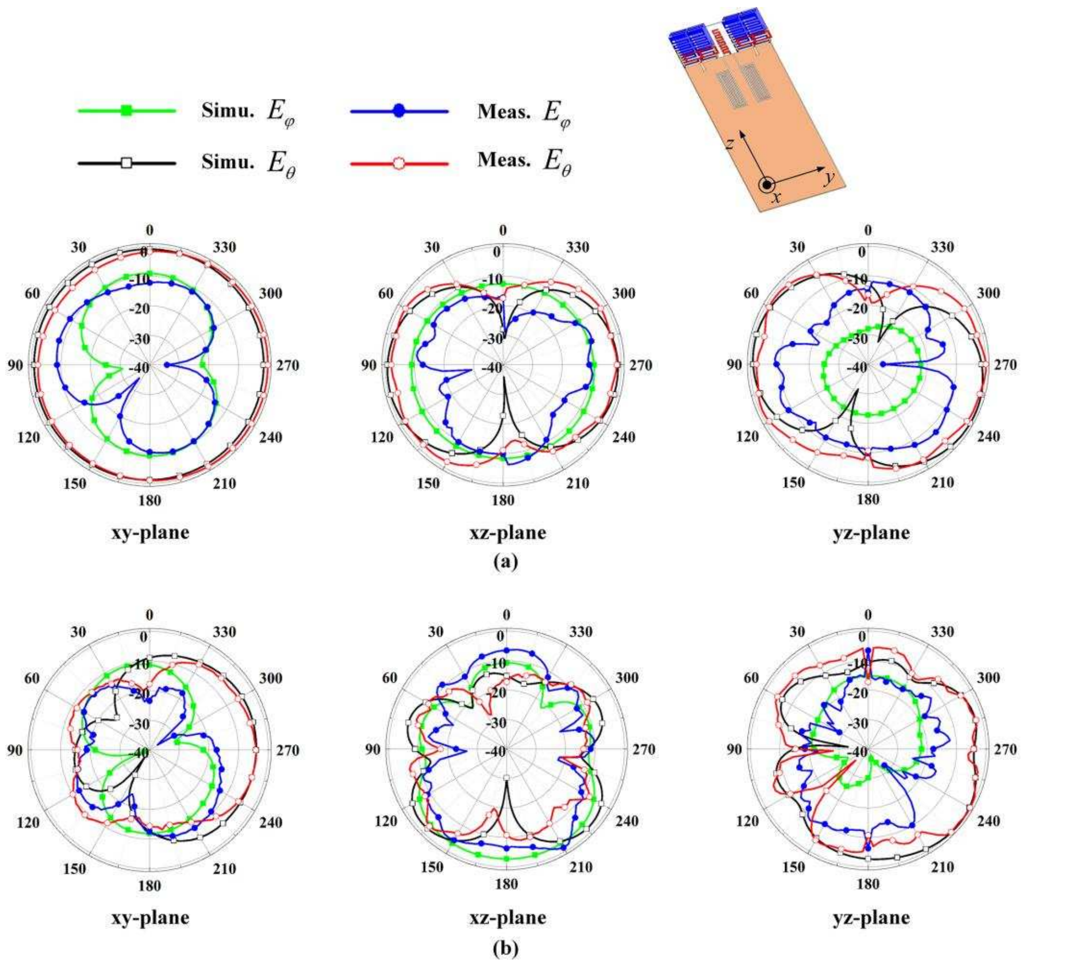

FIGURE 14 Simulated and measured 2-D normalized radiation patterns of Element 1 for the proposed two-element MIMO antenna at (a) 825 and (b) 2250MHz.

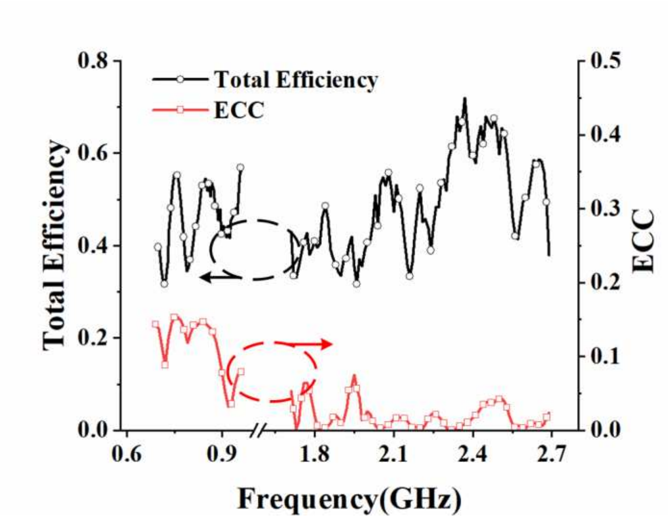

FIGURE 15 Measured total efficiency and calculated ECC of the proposed two-element MIMO antenna in the lower and higher bands.

V. CONCLUSION

A compact dual-band antenna based on CRLH-TL has been proposed for WWAN/LTE mobile handset application. The proposed antenna is placed at the corner of the substrate with a compact size of 25×25×6mm^3. In order to operate at two wide operating frequency bands, dual symmetrical CRLH structures are applied in the antenna design. The matching strips are employed to further improve the -6dB impedance bandwidth of the proposed antenna element. To demonstrate the design concept, the CRLH-based antenna has been simulated, fabricated and measured. The measured results are quite in accordance with the simulated results. It proves that the proposed antenna can operate at two wide frequency bands, 0.66-1.06GHz and 1.68-2.88GHz with $|S_{11}|$<-6dB, which can cover the LTE700, GSM850, GSM900, GSM1800, GSM1900, UMTS, LTE2300 and LTE2500 bands for wireless terminals. Moreover, gain and efficiency are also obtained according to the measured result. Finally, a two-element MIMO antenna composed of two proposed CRLH-based antenna elements is also proposed and validated. By employing the defected ground structures and grounded branches, an enhanced isolation between two antenna elements is obtained. Both the measured and simulated results prove that the two antenna elements can operate at 2G,3G and 4G frequency bands for MIMO applications.

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Yingzeng Yin received the B.S. degree and the M.S. degree and Ph.D. degree in electromagnetic wave and microwave technology from Xidian University, Xi'an, China, in 1987, 1990 and 2002, respectively. He is currently a Professor with the National Laboratory of Science and Technology on Antennas and Microwaves, Xidian University, Xi'an, China.

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