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Research Article

Dual Zeroth-Order Resonant USB Dongle Antennas for 4G MIMO Wireless Communications

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A multiband multiple-input multiple-output (MIMO) antenna system consisting of two antenna elements has been proposed for 4G USB dongle application. The designed MIMO antenna system with a compact volume of 25 mm × 30 mm × 3.5 mm operates in two zeroth-order resonance (ZOR) modes to cover the LTE band 13 (746–787 MHz), GSM850/900 (824–960 MHz), and LTE band 7 (2500–2690 MHz) simultaneously. A pair of L-shaped parasitic strips and an etching slot on the ground are employed to achieve good isolation between two elements. Measurement results show that proposed MIMO antenna system has total efficiency over 40% across the operation band and isolation less than −8 dB at the lower band and −16 dB at the upper band, respectively.

1. Introduction

To fulfill the requirement of 4G wireless communication, long-term evolution (LTE) has been proposed as a new standard to provide more flexible choice of frequency band and faster data transfer rate. Several LTE frequency bands have been introduced for better communication. Considering some new LTE frequency bands lower than ordinary 2G range, such as the LTE band 12 (698–746 MHz) and the LTE band 13 (747–787 MHz), the design of compact antenna for 4G USB dongle faces many huge challenges including larger electrical size of the antenna and stronger mutual coupling between different antennas.

Antenna based on composite right- and left-hand transmission line (CRLH-TL) theory has been developed as a promising technique due to its small size and better performance. Distinguished from the conventional structures, the zeroth-order resonance (ZOR) occurs in the CRLH-TL structure so that no phase variation exists along the structure at one particular frequency [1]. Therefore, antenna with this characteristic, namely, ZOR antenna, can achieve good performance without requiring the half-wavelength size. Moreover, antenna with the ZOR structure can obtain wider operation band [2].

As a core technology of LTE system, the MIMO technology has been of increasing interest because of its high utilization of frequency spectrum and high channel capacity, to name a few. However, a major difficulty in implementing MIMO technology is to reduce strong mutual coupling between compactly packed antennas and achieve good performance at the same time. To simultaneously overcome the locating and isolation problems within a small space inside the USB dongle, various techniques have been proposed. Built-in decoupling and matching networks [3, 4] are one of common methods to reduce mutual coupling between antennas. Another technique is to employ a parasitic unit to generate additional mutual coupling to counteract the original one [5–8]. What is more, an etching slot on the ground is an effective method to reduce the surface wave coupling [9, 10]. Up to now, there have been lots of studies on designing miniaturized MIMO antennas on USB dongle platform [11–13]. In the MIMO antenna system of [12], two chip antennas for dual-band wireless LAN use are closely spaced. In [13], MIMO antenna system consisting of two symmetrical meander radiators has been developed to operate from 704 MHz to 746 MHz.

In this paper, a multiband MIMO antenna with a compact size of 25 mm × 12 mm × 3.5 mm for 4G USB dongle has been proposed. The MIMO antenna system consists of two symmetrically antenna elements located at the top edge of the substrate to cover the LTE band 13 (746–787 MHz),

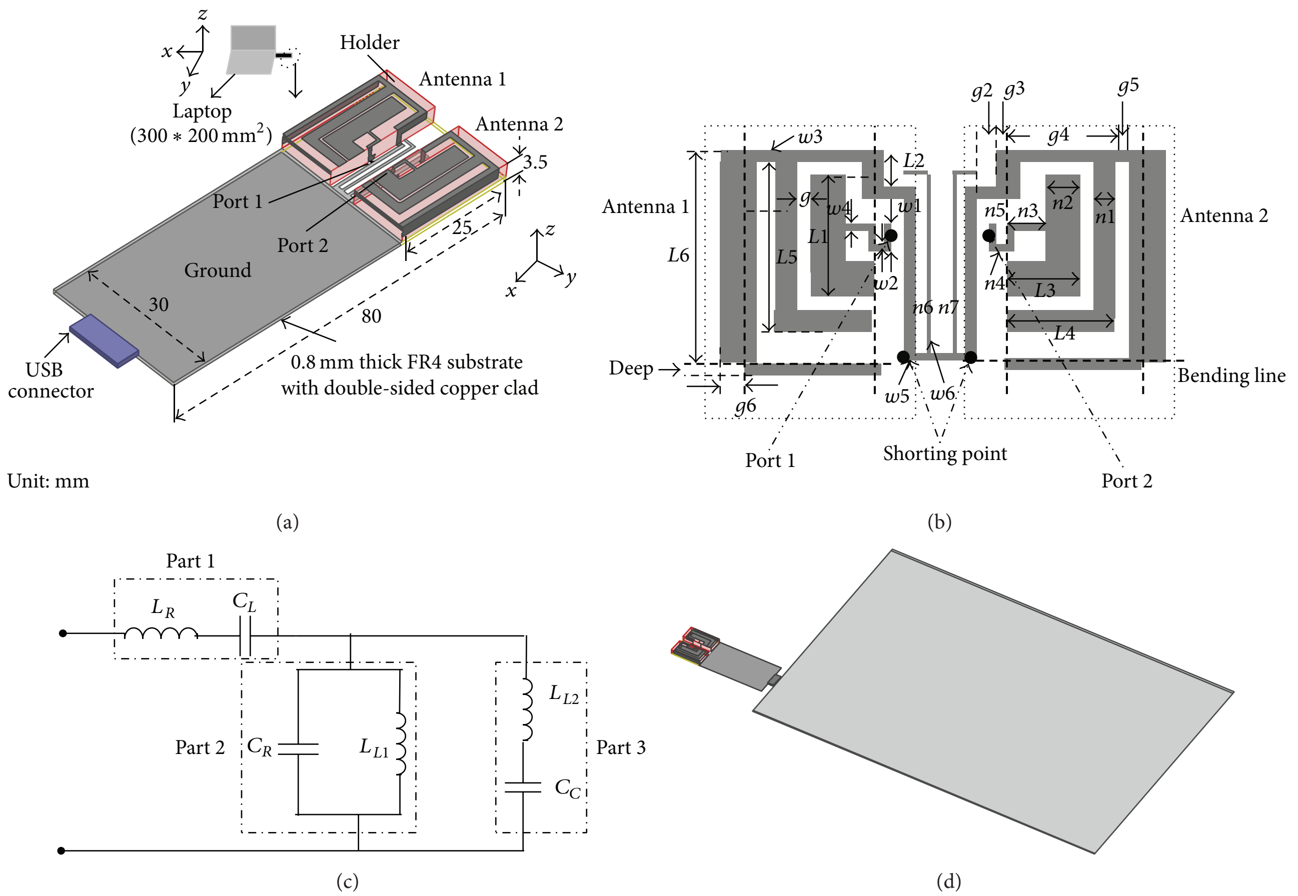

Figure 1: Geometry of the proposed multiband MIMO antenna system: (a) 3D view of the proposed MIMO antenna, (b) MIMO antenna and decoupling structure, (c) equivalent circuit of the unit antenna of the MIMO system, and (d) simulation model for the MIMO antenna system connected by the laptop.

GSM850/900 (824–960 MHz), and LTE 7 (2500–2600 MHz), simultaneously. A dual ZOR-based antenna is designed as the antenna element of the proposed MIMO system and thus a very wide operating frequency bandwidth is obtained. In addition, a pair of L-shaped parasitic strips and an etching slot on the ground are utilized to achieve good isolation. The measured results show that the isolation between two antennas is less than −8 dB over the lower band and −16 dB across the upper band, respectively. Total efficiency of antenna over 40% and omnidirectional radiation patterns are obtained across the operation bands.

2. Antenna Design

The MIMO system with a compact size of 25 mm × 30 mm × 3.5 mm is located at the top edge of the substrate. The FR4 substrate with $\varepsilon_r = 4.4$ is installed on the double-sided copper with a size of 30 mm × 55 mm. The system consists of two identical, symmetrical antenna elements which operate in the dual ZOR modes. The antenna is printed on a hollow plastic holder with a relative permittivity of $\varepsilon_r = 3.5$ and a wall thickness of 1.4 mm. A pair of L-shaped strips between two antenna elements and an etching slot on the ground

Table 1: Geometric parameters for the proposed MIMO antenna (unit: millimeters).

g	Deep	$w4$	$w1$	$w2$	$w3$	$w5$	$w6$	$n1$
0.1	1	0.5	1.5	0.5	1	0.3	0.5	3
$n2$	$n3$	$n4$	$n5$	$n6$	$n7$	$L1$	$L2$	$L3$
3.7	3	2.5	1	1.2	1	16.7	6	6.7
$L4$	$L5$	$L6$	$g2$	$g3$	$g4$	$g5$	$g6$	
9.8	17.8	23	2	1.5	11	1	2.5	

are introduced to obtain good isolation. Figures 1(a) and 1(b) show the geometry of the proposed MIMO antenna system, Figure 1(c) illustrates the equivalent circuit of the corresponding antenna element, and Figure 1(d) shows the simulation model for the MIMO antenna system connected by the laptop with the dimension of 300 mm ∗ 210 mm. Detailed dimensions of the MIMO system are given in Table 1.

It can be seen from Figure 1 that the antenna element in the MIMO system can be divided into three parts: Part 1 comprises a monopole fed by a wound fine strip, a coupling strip, and the fine seam between them. This part can be equivalent

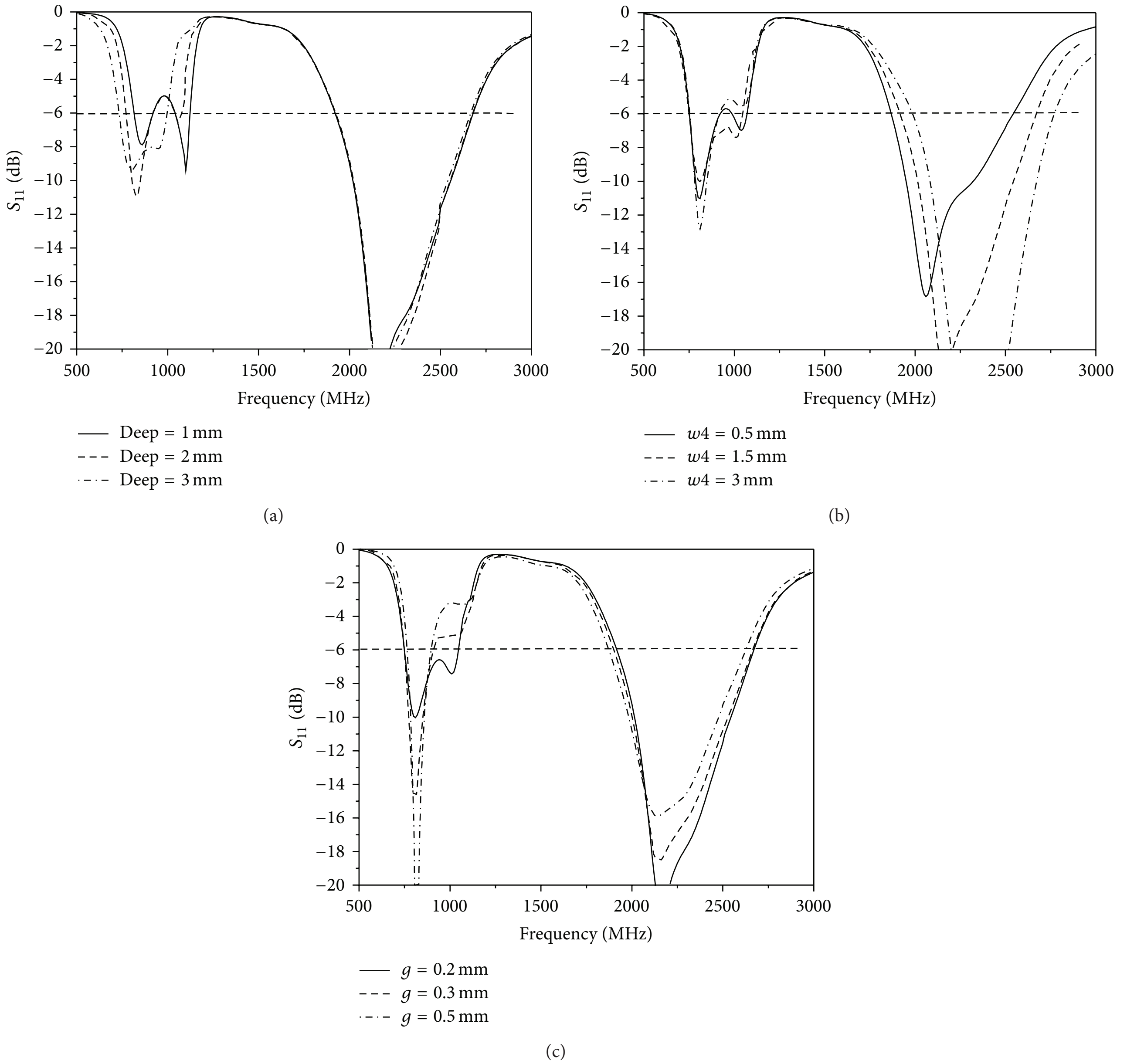

Figure 2: Variation of the return loss of the unit element of the proposed MIMO antenna with the increase of geometry parameters: (a) deep, (b) $w4$, and (c) g.

to the series left-hand capacitance (C_L) mainly produced by the coupling seam and right-hand inductance (L_R) generated by the rest. Part 2 corresponding to the grounded strip can be equivalent to the shunt left-hand inductance (L_{L1}) coming from the strip itself and right-hand capacitance (C_R) mainly coming from the interaction between the strip and other portions. Furthermore, Part 3 refers to the open circuit strip which is in parallel with Part 2 and can be equivalent to series left-hand inductance (L_{L2}) and the ground capacitance (C_C). According to the CRLH-TL theory [1], the first ZOR mode is produced by Part 1 and Part 3, which operates efficiently at lower frequency band. Simultaneously, Part 1 and Part 2 generate the other ZOR mode to cover the higher frequency band. The two ZOR modes interact with each other to obtain a wider operation band (746–960 MHz and 2500–2690 MHz). As shown in Figure 1(a), the USB dongle is inserted into a laptop for practical applications. Figure 2 shows the effect of three geometry parameters on the simulated return loss of the antenna element. It can be seen that parameters deep and $w4$ have a main effect on the lower band and the upper band, respectively, while parameter g influences the performance of the antenna across the whole operating frequency band. Figure 3 gives reflection coefficient and input impedance of the unit element of the proposed MIMO antenna. It can be seen from Figure 3(a) that the proposed unit element can operate at LTE band 13,

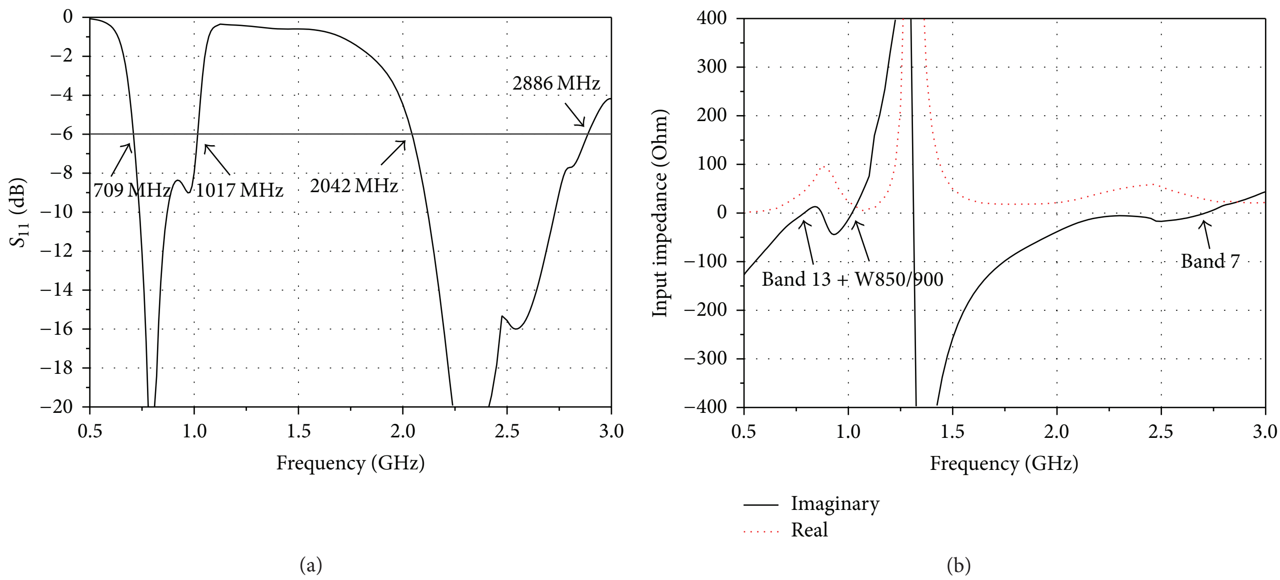

FIGURE 3: Performance of the unit element of the proposed MIMO antenna: (a) S parameter; (b) input impedance.

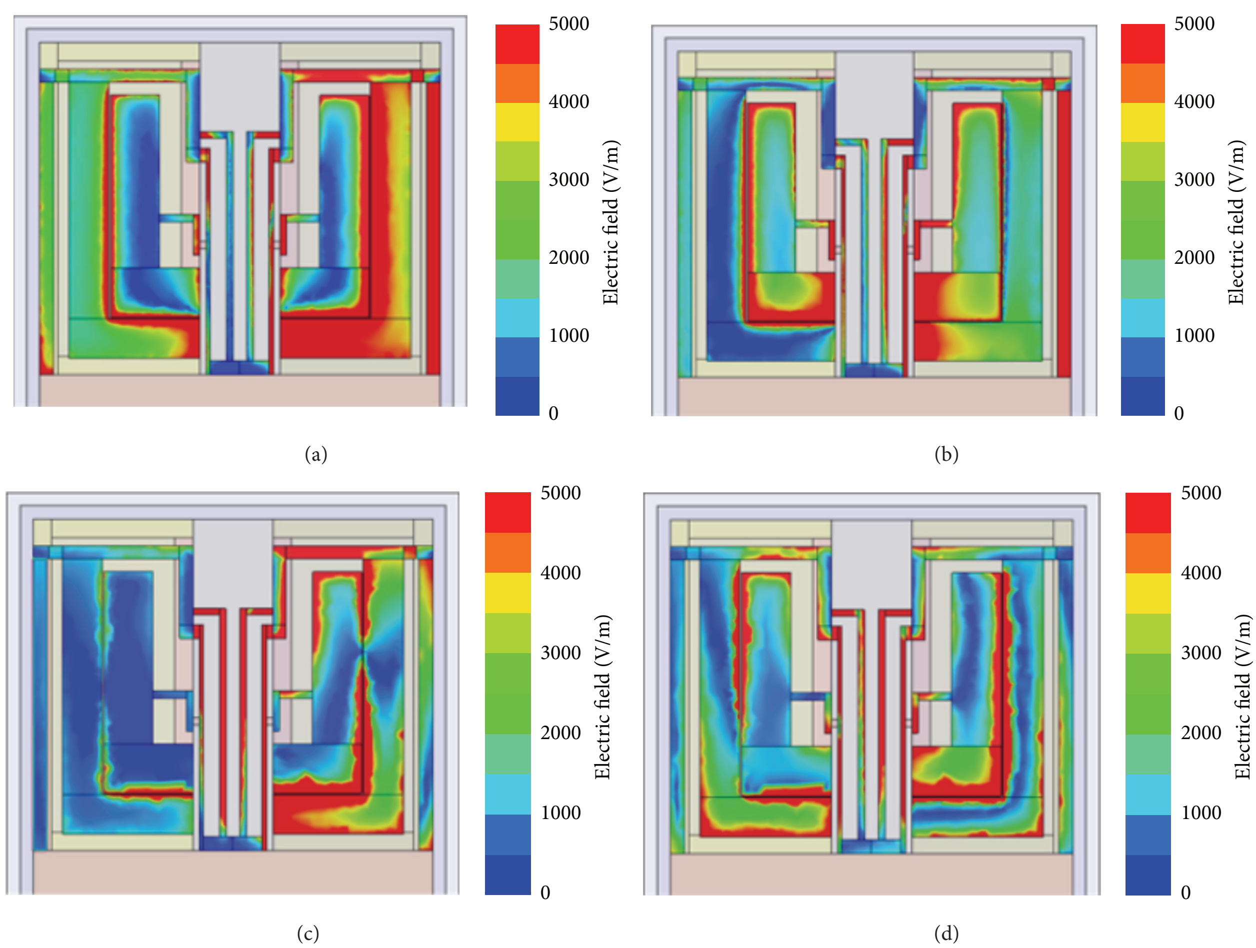

FIGURE 4: Simulated surface electric field distributions of proposed antenna: (a) 790 MHz, (b) 960 MHz, (c) 2500 MHz, and (d) 2690 MHz.

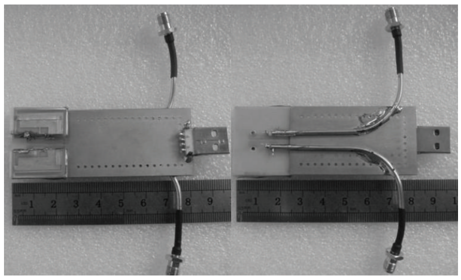

Figure 5: Photograph of the fabricated multiband MIMO antenna.

GSM850/900, and LTE band 7, simultaneously. According to Figure 3(b), we can see that there are two left-hand modes peaks occurring at low frequency band and high frequency band, respectively [1]. The left-hand mode at low frequency corresponds to the unbalanced CRLH transmission line, while the left-hand mode at high frequency corresponds to the balanced case [14].

The method of an etching slot is implemented in the MIMO antenna system, as shown in Figure 1(b). The ground between two antenna elements is etched to produce two thin strips which connect the feeding ports and the main ground. The structure is inherently a band-stop filter, which exhibits stop band over its low frequency band. Specifically, two shorting strips can be equivalent to two paralleled inductances and the seam between them can be referred to a capacitance [15]. Furthermore, a pair of L-shaped strips is located between two antenna elements to generate an additional coupling in the LTE band 7 to counteract the original one. The isolation of MIMO system across operating frequency band can be largely improved by using these two methods.

Figure 4 shows the simulated surface electric field distributions at four representative frequency points of 790 MHz, 960 MHz, 2500 MHz, and 2690 MHz, respectively, when antenna 2 is excited with antenna 1 terminated to 50 Ω. It can be seen from Figure 3 that Part 1 and Part 3 are excited as the first ZOR mode at lower band, while Part 1 and Part 2 are excited as the second ZOR mode at higher band. The dual ZOR modes verify the above discussions. In addition, a pair of L-shaped strips located between the two paralleled shorting lines generates an additional mutual coupling at the LTE band 7, according to Figure 4(c).

3. Results and Discussions

The proposed multiband MIMO antenna system is fabricated and studied. Photographs of a manufactured prototype are shown in Figure 5. Figure 6 shows the measured S parameters of the MIMO antenna system when the USB dongle is attached to a laptop computer. Due to the dual ZOR modes, the operating bandwidth can simultaneously cover band 13 (746–787 MHz), GSM850/900 (824–960 MHz), and LTE band 7 (2500–2690 MHz), a very wide operation bandwidth. Moreover, according to S_{12} result in Figure 6, the measured isolation between two antenna elements is less than −8 dB over the lower band and −16 dB across the upper band, respectively.

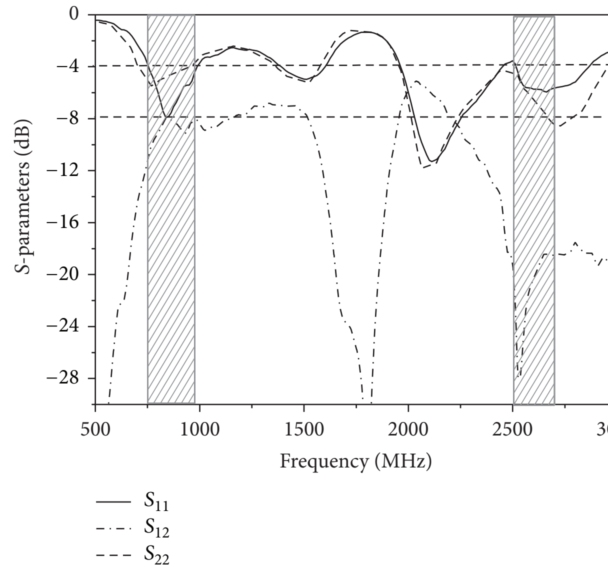

Figure 6: Measured S-parameters of the fabricated MIMO antenna.

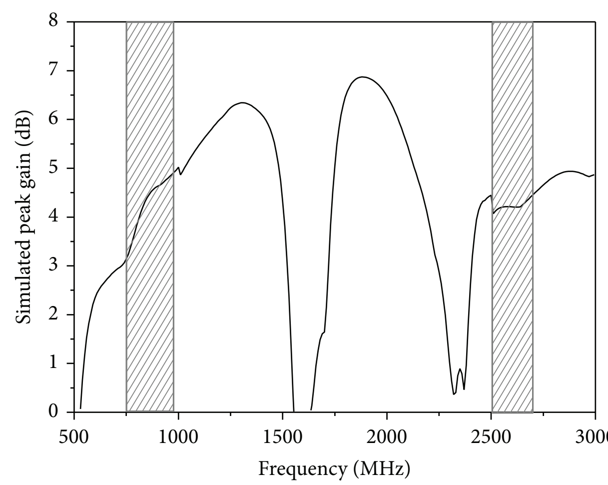

Figure 7: Simulated peak gain of the fabricated MIMO antenna.

Table 2: Measured total efficiency of antenna 1 and antenna 2.

Frequency (MHz)	768	843	920	2500	2700
Efficiency of antenna 1 (%)	33	41	44	38	52
Efficiency of antenna 2 (%)	21	40	43	41	63

Table 2 shows the measured total efficiency of two antenna elements with unmeasured port terminated in 50 Ω load. The total efficiency of antenna 1 is approximately over 40% across the service band while antenna 2 is a little low at the LTE band 13 (746–787 MHz). This is because of the disturbance of the feed cables and the plastic carriers. Figure 7 shows the simulated peak gain of the fabricated MIMO

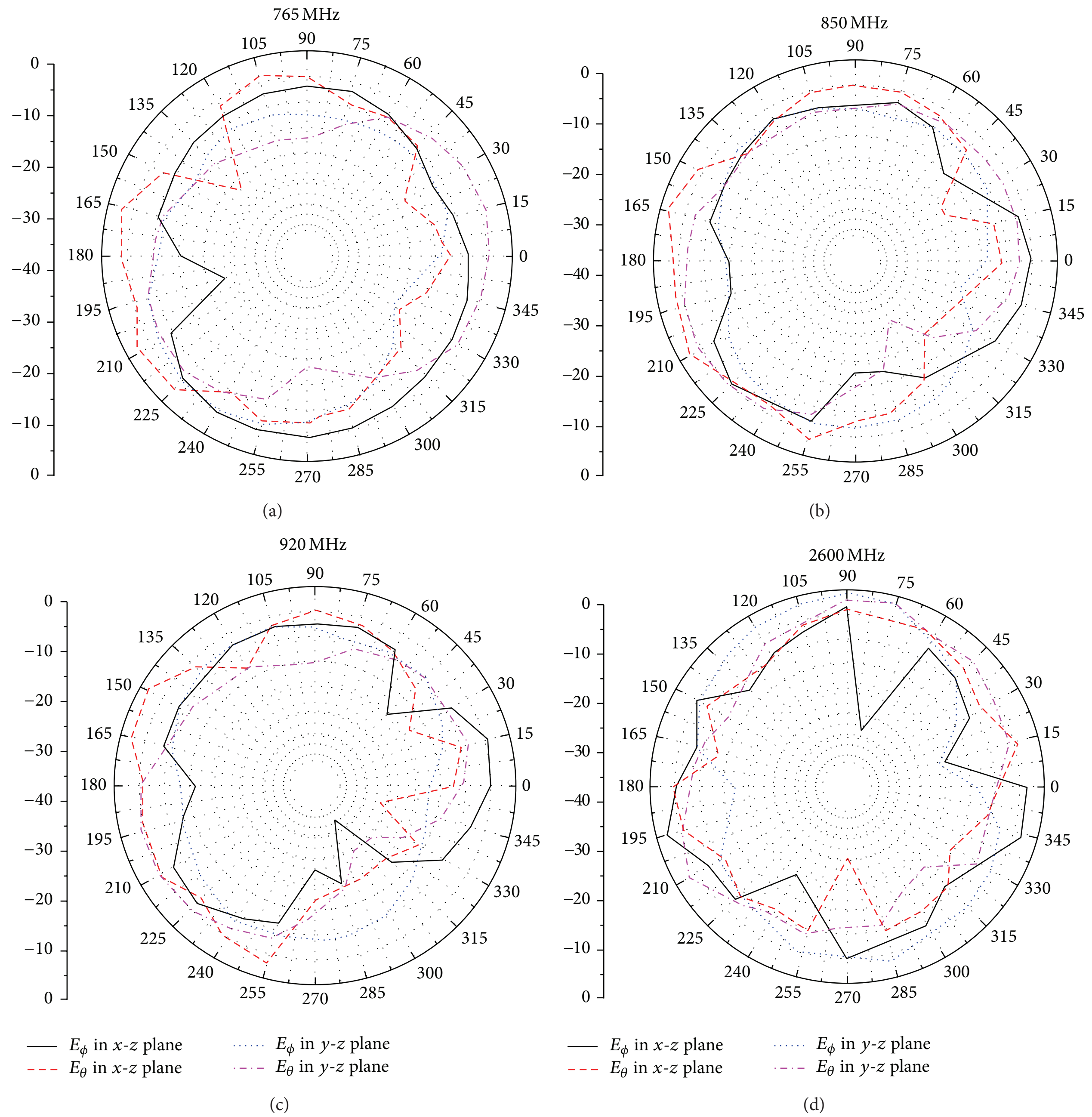

FIGURE 8: Measured two-dimensional radiation patterns of antenna 1 in the MIMO system.

antenna. The peak gain is approximately over 4 dB across the high frequency band and over 3 dB at the low frequency band. Measured two-dimensional radiation patterns of antenna 1 at 765 MHz, 850 MHz, 920 MHz, and 2600 MHz are plotted in Figure 8, respectively. In addition, Figure 9 shows the three-dimensional radiation patterns of two antennas at 890 MHz and 2600 MHz. The measured radiation patterns were not exactly omnidirectional but sufficient for USB dongle services in the service bands.

4. Conclusion

MIMO antenna system with a compact size of 25 mm × 30 mm × 3.5 mm covering the LTE band 13 (746–787 MHz), GSM850/900 (824–960 MHz), and LTE 7 (2500–2690 MHz) has been proposed for 4G USB dongle. The proposed antenna element in the MIMO system operates in dual ZOR modes, and thus a wide bandwidth can be obtained. A pair of L-shaped parasitic strips and an etching slot on the ground

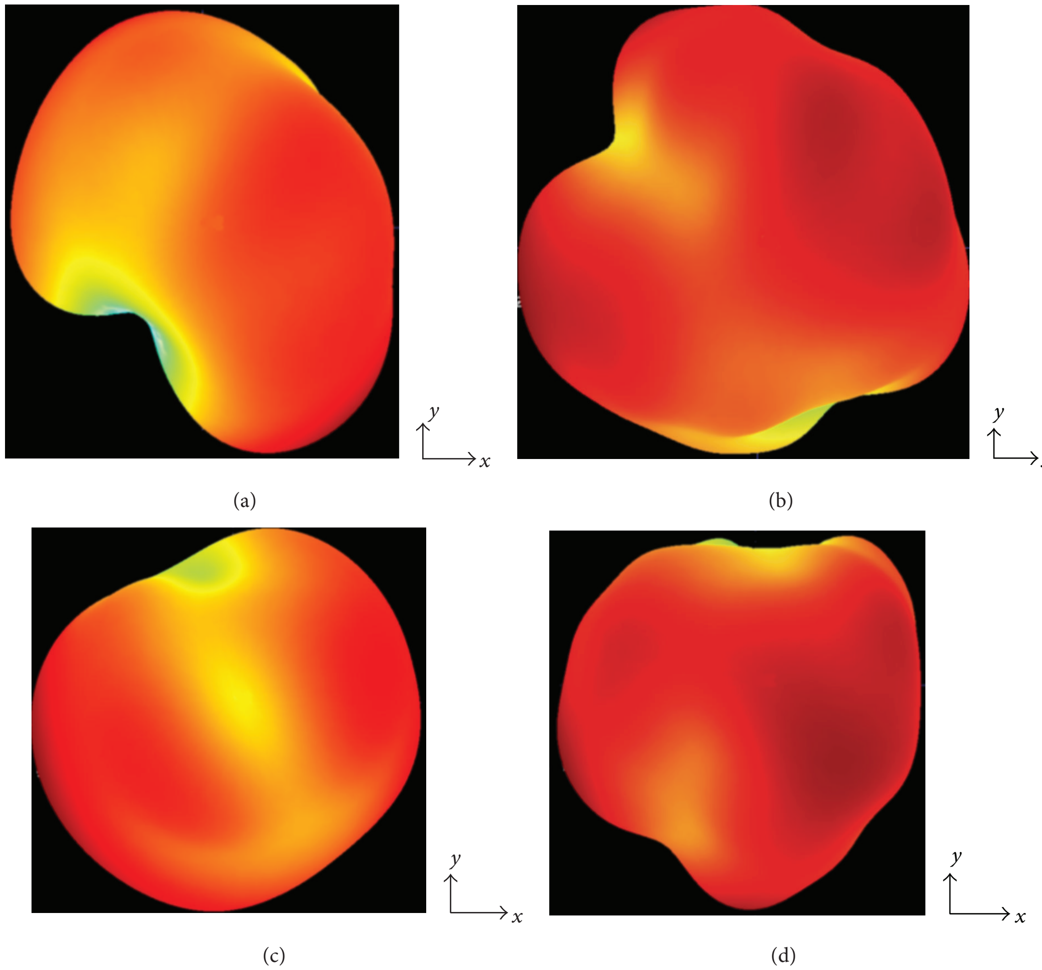

Figure 9: Measured three-dimensional radiation patterns of two antennas in the MIMO system: (a) antenna 1 at 890 MHz, (b) antenna 1 at 2600 MHz, (c) antenna 2 at 890 MHz, and (d) antenna 2 at 2600 MHz.

are introduced so that the isolation between two antennas is less than −8 dB over the lower band and −16 dB across the upper band, respectively. Therefore, the proposed antenna is applicable to 4G USB dongle applications due to its small size and good performance for each band.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

Acknowledgments

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