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A Compact MIMO Antenna System Design with Low Correlation from 1710 MHz to 2690 MHz

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Abstract—A compact and low-correlation multiple input multiple output antenna system covering 1710–2690 MHz band for wireless communication standards is proposed. It comprises two identical elements with coupled feeding plate and radiating strip, and each element has a volume of $24.5 \times 15 \times 1.2\,\mathrm{mm}^3$. Simulated and measured results show that it has good potentials for high-band-only mobile phone. 45% bandwidth (based on $S_{11} < -6\,\mathrm{dB}$), $-12\,\mathrm{dB}$ isolation, over 49% efficiency and less than 0.15 correlation coefficient are achieved in the frequency ranging from 1710 MHz to 2690 MHz. Several key parameters are also discussed in this study to better understand the antenna principles.

1. INTRODUCTION

Depending on different countries, the exact frequency range of each band for mobile communications might varies slightly: Digital Cellular System DCS1800 (1710–1880 MHz); Personal Communications Service PCS1900 (1850–1990 MHz); Universal Mobile Telecommunications System UMTS2100 (1920–2179 MHz); Long term evolution LTE2300 (2305–2400 MHz) and LTE2500 (2500–2690 MHz). More comprehensive information can be found on their respective websites and books [1, 2].

The long term evolution system has been introduced to provide better mobile broadband and multimedia services. As the key technology for multiplying the transmission rates in the LTE system [3], the multiple input multiple output (MIMO) technique has been widely studied. MIMO technology provides a good quality of service (QOS) in the multipath environment without additional power [4–6]. Nowadays, mobile handset terminals focus on the miniaturization design of the antennas. However, mutual coupling between the antenna ports affects the correlation in MIMO systems, and thus low correlation will be more and more difficult due to the compact volume in the mobile handsets.

A large number of designs were proposed to lower the correlation in the MIMO systems. The low correlation between antenna elements can be achieved by adding a decoupling network with the lumped elements, which makes the antenna design very complex [7, 8]. The decoupling designs are studied by adding hybrid coupler between antenna ports [9, 10]. The suspended line is added between the antenna elements to reduce the mutual coupling [11]. Meanwhile, it is not easy to be used in the wideband decoupling because the isolation is sensitive to the length and location of the suspended line. Since most MIMO antenna elements of recent mobile handsets are collocated on the same printed circuit board (PCB), the surface current distribution on the PCB induces mutual coupling between antenna elements and common ground plane. It is shown that a slit or stub on the ground plane can reduce the mutual coupling effectively [12–16].

In this paper, firstly, a single antenna is proposed to cover a wide operating frequency from 1710 MHz to 2690 MHz by using the coupled-feed. Then, based on the above single antenna, a MIMO system with antenna elements placed symmetrically at the edge of the substrate is proposed. The MIMO system achieves better than $-12\,\mathrm{dB}$ isolation and less than 0.15 correlation between the ports. The simulated results are obtained by the software High Frequency Structure Simulator (HFSS).

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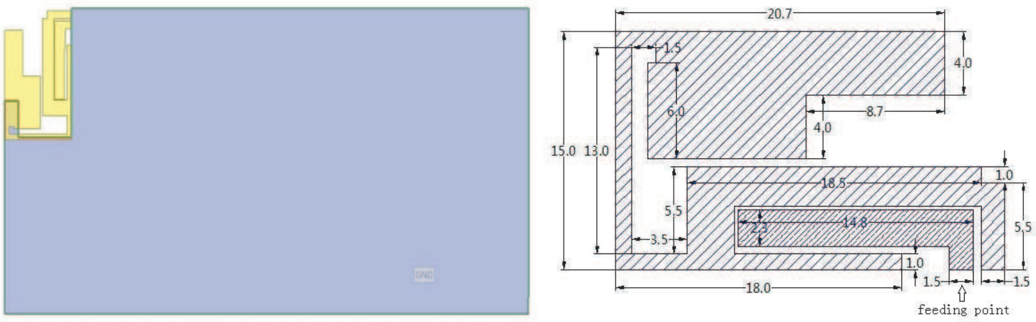
2. PROPOSED ANTENNA AND MIMO

The geometry of the proposed single antenna occupies areas of $24.5 \times 15\,\mathrm{mm}^2$. It is printed on the corner of the system circuit board. A 1.2 mm thick FR-4 substrate with relative permittivity of 4.4 and loss tangent of 0.02 is used as the system circuit board. It has a simple structure and mainly comprises a radiating strip and a coupling feed. Fig. 1(a) shows the geometry of the proposed single antenna, and Fig. 1(b) shows the dimensions of this antenna element.



(a) (b)

Figure 1. (a) The dimensions of the system circuit and the location of the antenna element. (b) The detailed dimensions of the antenna element. (unit: mm).

Based on the optimized dimensions, the simulated return loss of the proposed single antenna is shown in Fig. 2. It can be seen that the antenna has -6 dB impedance bandwidths of 1017 MHz (1674–2691 MHz), which covers the DCS/PCS/UMTS/LTE2300/LTE2500.

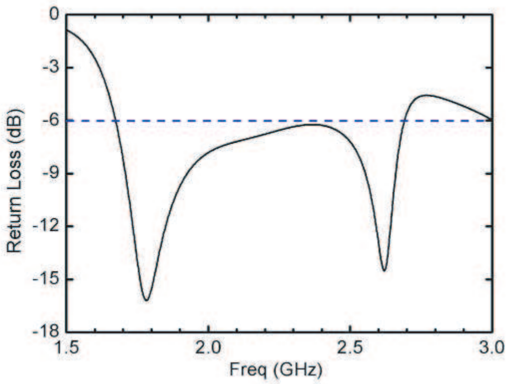


Figure 2. Simulated return loss of the proposed antenna.

Figure 3 shows surface current distributions of the proposed antenna. From the results, it is clearly seen that the vertical and top parts are more excited at 1.8 GHz and lower part is more excited at 2.6 GHz.

The radiation pattern of the proposed single antenna at 1.8 and 2.6 GHz are shown in Fig. 4, it is not ideal omni-directional pattern due to the un-symmetric location to PCB but quite typical and common for mobile handset device.

The MIMO system comprises two of the above antenna elements, which are identical and placed symmetrically at the two edges of the FR4 substrate with volume of $118 \times 58 \times 1.2\,\mathrm{mm}^3$. The configuration of this MIMO is shown in Fig. 5.

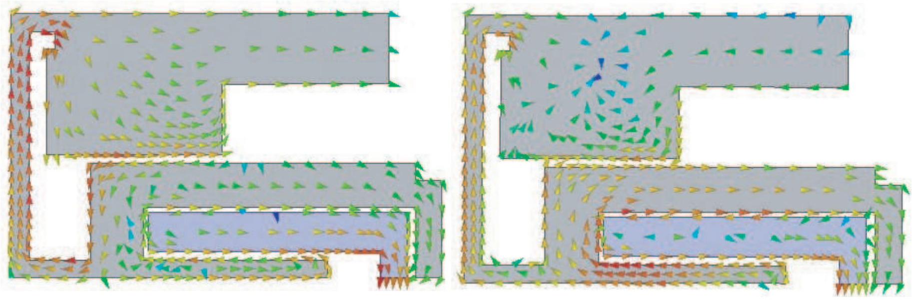
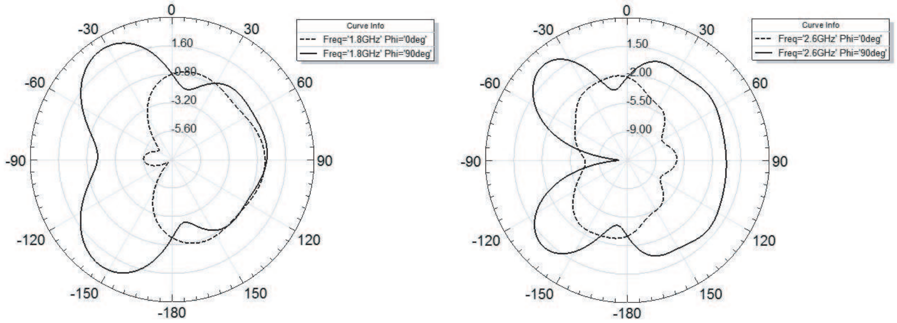

(a) (b)

Figure 3. (a) Simulated surface-current distributions at 1.8 GHz. (b) Simulated surface-current distributions at 2.6 GHz.



(a) (b)

Figure 4. Simulated radiation pattern. (a) At 1.8 GHz. (b) At 2.6 GHz.

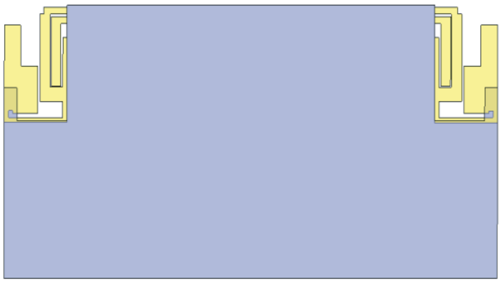


Figure 5. Configuration of the proposed MIMO antenna system.

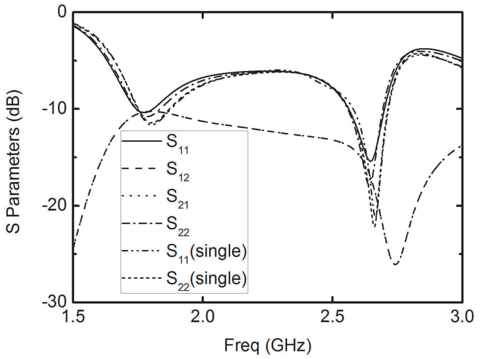


Figure 6. Simulated S parameters of the MIMO.

3. RESULTS AND DISCUSSIONS

The simulations for the S parameters of this MIMO are presented in Fig. 6. We can see that it has -6 dB impedance bandwidth of 1082 MHz (1661–2743 MHz) which covers the DCS1800/PCS1900/UMTS2100/LTE2300/LTE2500. The S_{11} (single) in Fig. 6 is obtained when antenna 1 is excited and simulated, antenna 2 is terminated to a 50-Ω load, and vice verse for antenna 2. From the results, we can see S_{11} and S_{22} matched well with S_{11} (single) and S_{22} (single). The simulated isolation between two ports is better than -10 dB over this band. To further evaluate the MIMO performance, basing on the simulated S parameters, we calculate the envelope of cross correlation through the following formula [17] and give the results in Fig. 7.

$$\rho_e = \frac{|S_{11}^* S_{12}^* + S_{21}^* S_{22}^*|^2}{\left[1 - \left(|S_{11}|^2 + |S_{21}|^2\right)\right]\left[1 - \left(|S_{22}|^2 + |S_{12}|^2\right)\right]}$$

The obtained correlation coefficient ρ_e is less than 0.15 over the designed bands between ports in the proposed design, which is acceptable for the MIMO applications [18]. Moreover, it is suitable for the mobile phone applications (require less than 0.5).

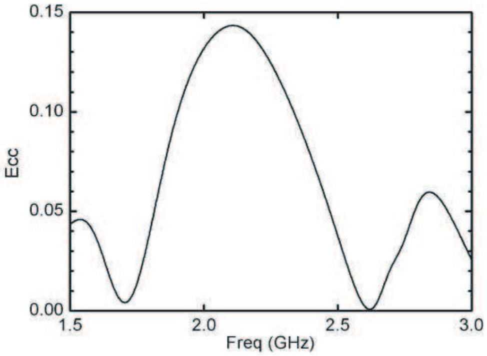


Figure 7. Envelope correlation coefficient obtained from the simulated S-parameters of the proposed antenna.

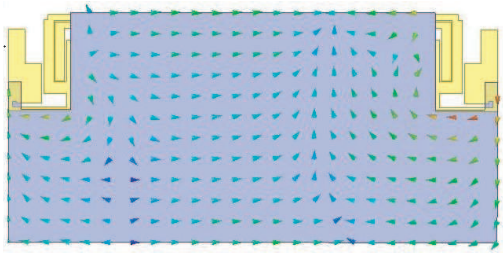
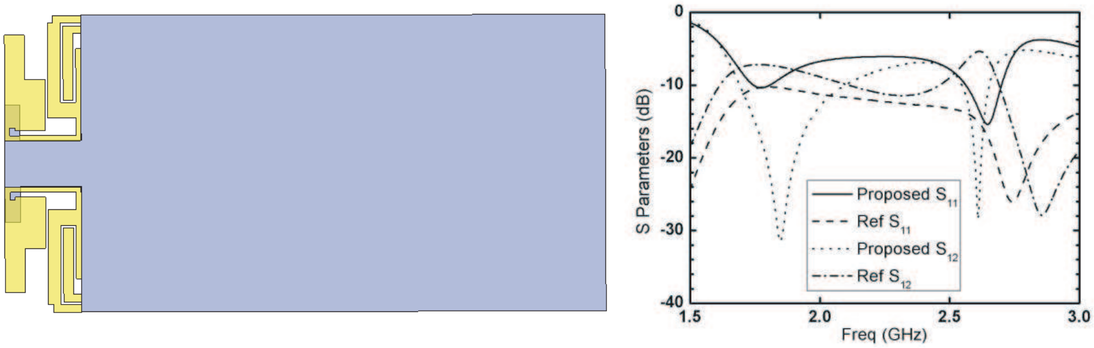


Figure 8. The ground current at 2.6 GHz.



(a) (b)

Figure 9. (a) Reference MIMO (side by side at bottom) in simulation. (b) S-parameter comparison with proposed MIMO antenna in simulation.

Figure 8 shows the current distribution on ground plane at 2.6 GHz. The ground current flows reversely at 30 mm about $\lambda/4$ for 2.6 GHz far away from the excitation port, which can better improve the isolation and correlation.

In mobile phone application, the MIMO antenna system can also be possibly positioned side by side at the bottom of the device as shown in Fig. 9(a). Simulation showed that the antenna bandwidth (Fig. 9(b)) and correlation coefficient (Fig. 10) are in good shape. However, the isolation between two antennas S_{21} is only about -10 dB. For this application scenario, better RF circuits are required to achieve system level performance.

To verify simulated S_{11} and isolation between two MIMO antennas, the proposed MIMO antenna was fabricated as shown in Fig. 11 and tested using E5071C vector network analyzer made by Agilent.

Figure 12 shows the measured S-parameters for the feeding ports. It can be seen that the measured return loss is less than -6 dB and the measured isolation is better than -12 dB in the range between 1710 MHz and 2690 MHz. The measurements agree with the simulated results well.

Other characters of the MIMO antenna, such as efficiency, gain and far-field radiation pattern, are also tested by an anechoic chamber. When port 1 is excited and measured, port 2 is terminated to a 50-Ω load, and vice verse for port 2.

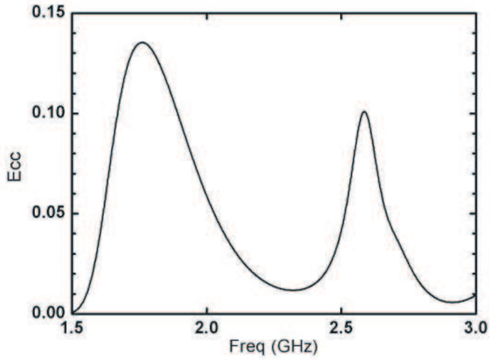


Figure 10. Envelope correlation coefficient from reference MIMO antenna.

Figure 11. Photo of the fabricated MIMO antenna.

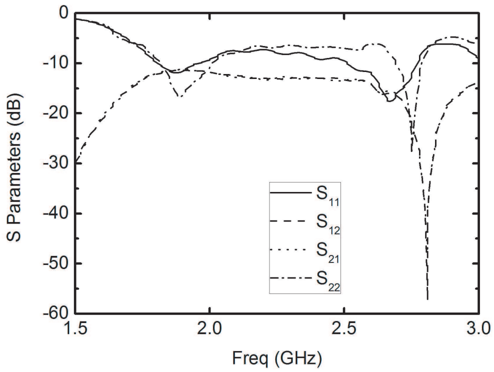


Figure 12. The measured S parameters.

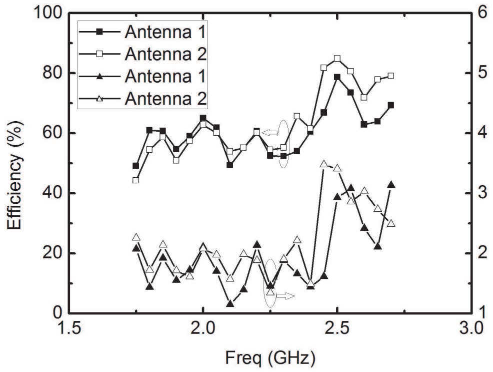
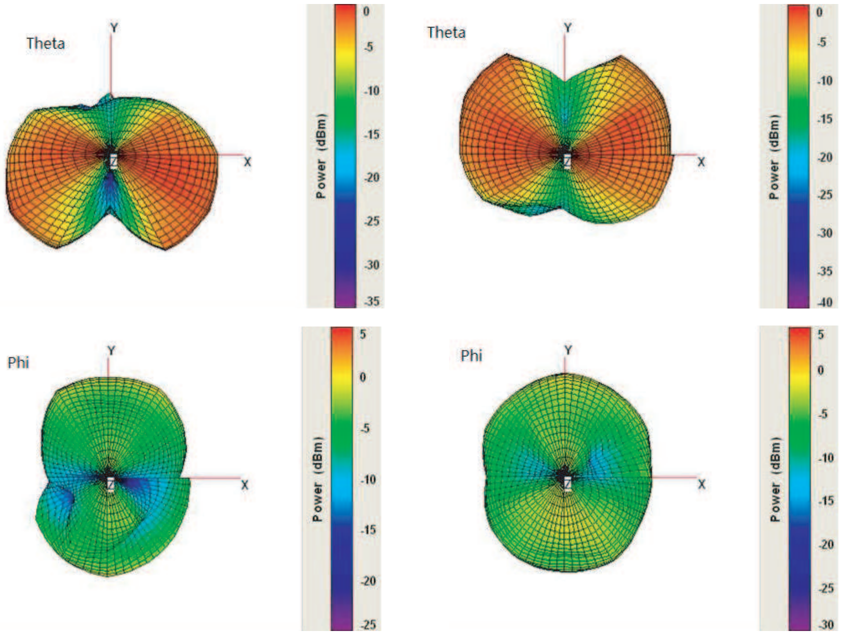
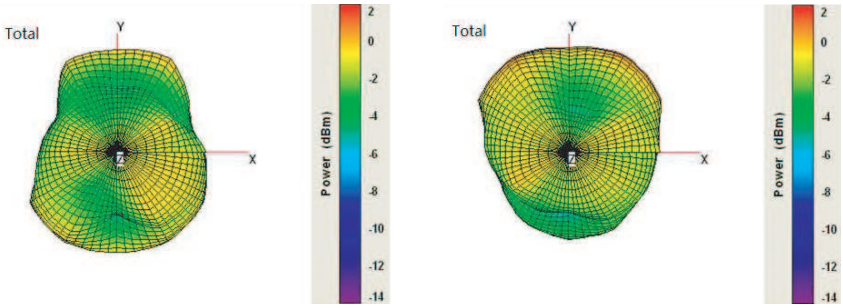


Figure 13. Measured antennas efficiencies and gains.





(a) (b)

Figure 14. Measured radiation patterns for the proposed MIMO antenna. (a) Antenna 1. (b) Antenna 2.

Figure 13 shows the measured efficiency and gain of feeding port 1, almost the same as feeding port 2. The efficiencies of antenna 1 and 2 are from 49% to 85% over the desired bandwidth. The gains of antenna 1 and 2 are from 1.15 dBi to 3.48 dBi.

Figure 14 shows that the measured radiation patterns for the designed antenna at 2300 MHz. Since the two antenna structures are symmetrical, the measured radiation patterns of two elements are similar.

4. CONCLUSION

The proposed MIMO antenna system comprises two identical elements with coupled feeding plate and radiating strip, and each element has a volume of $24.5 \times 15 \times 1.2\,\text{mm}^3$. It achieves -6 dB-impedance bandwidth, -12 dB isolation, over 49% efficiency and less than 0.15 correlation coefficient in the frequencies from 1710 MHz to 2690 MHz, and thus has good potentials for the Wide Area Network (WAN) MIMO applications in the high-band-only mobile phone.

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