A Study of Mutual Coupling Reduction with Two Closely-spaced Dual-band Fork-Shape Monopoles

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Abstract

A simple approach to reduce the mutual coupling between two closely-spaced dual-band antennas is proposed in this paper. The dual-band antenna has a fork shape, which inherently shows good isolation at the upper band (5.2 GHz). By utilizing the neutralization technique, the isolation at the lower band (2.45 GHz) is significantly improved, making the pair of antennas suitable for dual-band MIMO system in WLAN applications.

Keywords : Dual-band Mutual coupling Closely-spaced Diversity MIMO

1. Introduction

Recently, the demand for high quality of service (QoS) in wireless communications has grown up rapidly. Multi-input multi-output (MIMO) technique with antenna diversity has become a well-developed solution to provide improved channel capacity with high data transmission rate. Nevertheless, due to the limited available space in modern portable devices, the mutual coupling between the closely-spaced antenna elements in a small volume rises significantly and tends to deteriorate the performance in a multi-antenna system. To tackle this issue, the common approaches include etching slots on the ground plane [1], adding additional coupling paths to cancel out the mutual coupling [2], inserting the electromagnetic band gap (EBG) structures to suppress the surface wave coupling [3], and etc.

To keep the overall size compact, in this paper, we adopt two methods to reduce the mutual coupling between the two closely-spaced dual-band antennas. Firstly, the antenna geometry is designed carefully with a fork shape to achieve inherently good isolation at the upper band; the neutralization approach [4] is then applied, by connecting the two closely-spaced antennas with a suspended line, to reduce the mutual coupling at the lower band.

2. Design of the Dual-band Antenna Element

The geometry of the dual-band antenna is illustrated in Fig. 1 along with the design parameters. The monopole antenna, featuring a fork shape, is composed of two branches, whose lengths are about one quarter guided wavelength at the center frequencies of the lower and upper bands, 2.45 and 5.2 GHz, respectively. The Y-junction between the radiating strips helps improve the impedance matching. The antenna is printed on the top side of a 1.6-mm FR4 substrate ($\varepsilon_r = 4.2$ and $\tan\delta = 0.02$), occupying an area of 10.1×14.65 mm^2. A ground plane, with a size of 28×30 mm^2, is etched on the bottom side.

The simulated and measured reflection coefficients of the proposed dual-band antenna are described in Fig. 2. The antenna was simulated and measured by Ansoft HFSS and Agilent PNA E8363B, respectively. A good agreement can be observed except for a slight frequency deviation in the upper band. The discrepancy is mainly caused by the fabrication tolerance and the parasitic coupling of the SMA adaptor. Referring to the figure, the antenna, with $|S_{11}| < -10$ dB, covers the whole WLAN bands from 2.33-2.93 GHz and 4.59-5.52 GHz. The simulated and measured *xz*- and *xy*-plane radiation patterns at 2.45 and 5.2 GHz are plotted in Fig. 3(a) and (b), respectively. The antenna radiation patterns were measured in an anechoic chamber using the NSI 700S-90 scanner. The fork-shape antenna shows donut-like radiation patterns, and has peak gains of 2.75 and 3.59

dBi, respectively, at 2.45 and 5.2 GHz. The measured radiation efficiencies are 78.4% and 79% in the two bands.

3. Decoupling of Two Closely-spaced Dual-band Fork-shape Monopoles

For the purpose of achieving small usage space in handheld devices, the pair of antennas, for MIMO applications, should be closely integrated. The antennas in close proximity would interact with each other and hence devastatingly deteriorate the system performance. Taking into consideration the potential mutual coupling between the fork-shape antennas, as shown in Fig. 4(a), in the proposed scheme, the short resonating branches are placed apart from each other. This spatial arrangement significantly reduces the coupling in the upper band, and, in turn, simplifies the decoupling network. Referring to the figure, the two antennas are separated, with an edge-to-edge distance, by merely 2.1 mm (0.017 λ_0 at 2.45 GHz); it is equivalent to a center-to-center separation of 12.2 mm (0.1 λ_0). The ground plane is 30 × 40 mm^2. The simulated two-port *S*-parameters of the antenna system without employing any decoupling technique is shown in Fig. 5. Clearly from the figure, while the mutual coupling in the upper band is below -15 dB due to the large spacing between the short resonating branches, the coupling in the lower band is significant and reaches up to -5 dB; additional manipulation is therefore required to achieve dual-mode antenna decoupling.

To suppress the unwanted coupling between the resonating paths in the lower band, a neutralized line, with a length of 9.1 mm and a width of 0.9 mm, is introduced; the layout is shown in Fig. 4(b). A pair of short-circuited stubs is used for impedance matching. The neutralized line, also referred to as the suspended line, is inductive. Together with the capacitive coupling between two antennas, the neutralized line actually functions as a parallel LC resonator in-between the radiators. As the LC tank resonates, the input impedance is open-circuited; it therefore blocks away the coupling between the radiators. For comparison purpose, the simulated two-port *S*-parameters of the antenna pair with the neutralized line inserted are plotted in Fig. 5, as well. As can be observed, in both the lower and upper bands, the impedance matching and port isolation are simultaneously achieved.

The decoupled antenna network shown in Fig. 6 was fabricated and experimentally verified. The simulated and measured *S*-parameters are compared in Fig. 7. At 2.45 GHz, the measured $|S_{11}|$ and $|S_{21}|$ are -13.3 and -15.6 dB, respectively, while they are -14.6 and -18.1 dB at 5.2 GHz. The usable bandwidths, defined by $|S_{11}|$ and $|S_{21}|$ < -10 dB, are 2.34-2.5 GHz and 4.53-5.46 GHz, which cover the 2.4-/5-GHz WLAN bands. The simulated and measured *xz*- and *xy*-plane radiation patterns are illustrated in Fig. 8. In the measurement, the port 1 is excited while the port 2 is terminated with a 50-Ω load. The measured peak gains are 1.43 and 3.84 dBi at 2.45 and 5.2 GHz, respectively, accompanying with radiation efficiencies of 52.4% and 57.3%. The performance can be further examined by the envelope correlation coefficient (ECC), which is defined by [5]

$$\rho_e = \frac{\left|S_{11}{}^{*}S_{12} + S_{21}{}^{*}S_{22}\right|^2}{\left(1-\left(\left|S_{11}\right|^2+\left|S_{21}\right|^2\right)\right)\left(1-\left(\left|S_{22}\right|^2+\left|S_{12}\right|^2\right)\right)\eta_1\eta_2} \tag{1}$$

Where η_n is the radiation efficiency of the antenna decoupling system whereas port 1 or port 2 is either excited. The inherent envelope correlation coefficients (ρ_e) of the dual-band antenna system are calculated of 0.585 and 0.0055, respectively, at 2.45 and 5.2 GHz. With the neutralized line and impedance matching network, the envelope correlation coefficients can be improved to 0.0175 and 0.0047 at the center frequencies of the operation bands.

4. Conclusion

In this paper, a new scheme for realizing dual-band antenna decoupling network for MIMO applications has been introduced and discussed. A dual-band fork-shape monopole is proposed and used in the MIMO antenna system. Due to the layout arrangement along with inserting a neutralized line in-between the radiators, the isolations of the two closely-spaced dual-band monopoles are improved obviously. The proposed dual-band MIMO antenna system features a very compact size, and will find a variety of applications in personal handheld/portable devices.

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Acknowledgments

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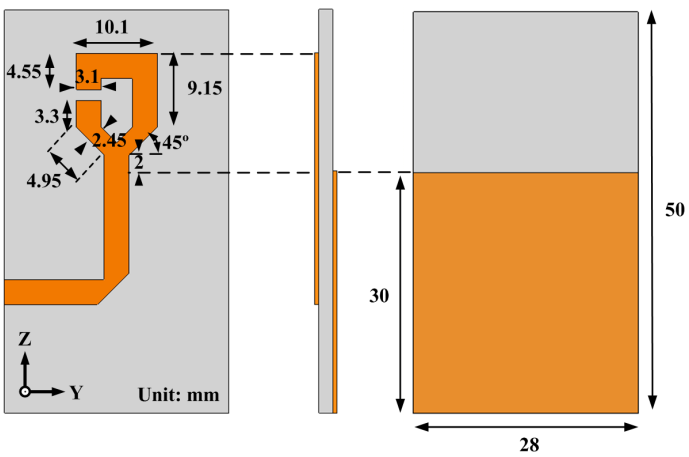


Figure 1: Layout of the Proposed Fork-shape Dual-band Monopole Antenna.

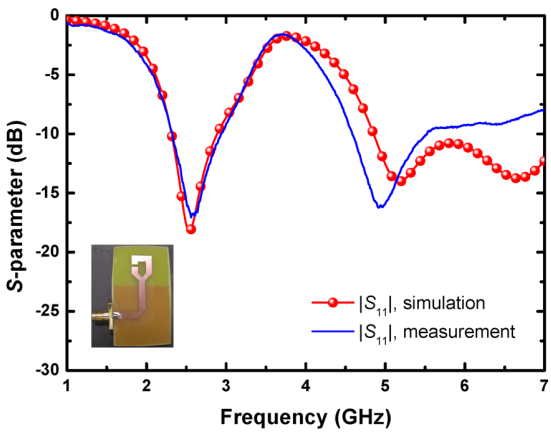


Figure 2: Simulated and Measured Reflection Coefficients of the Fork-shape Antenna.

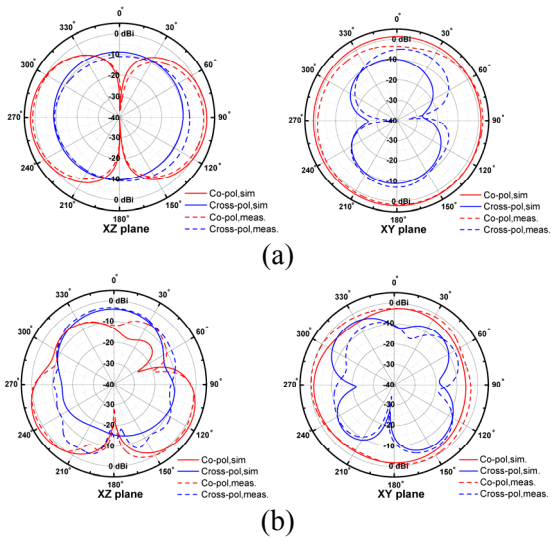
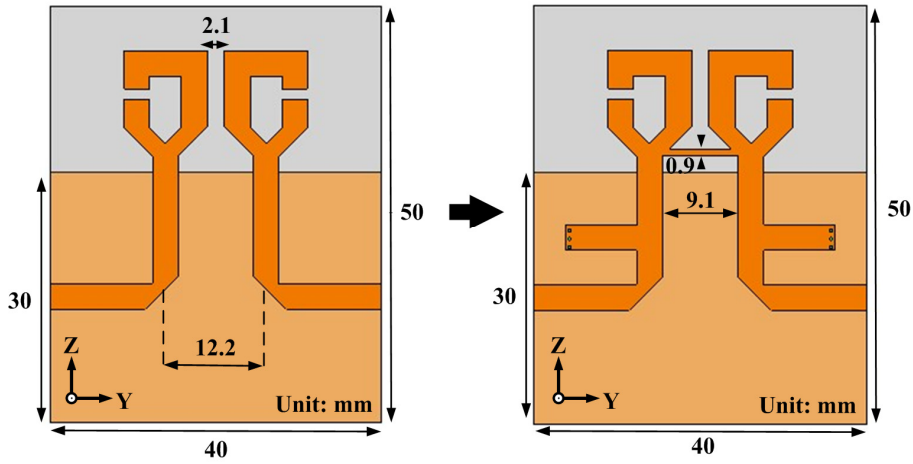


Figure 3: Simulated and Measured Radiation Patterns of the Fork-shape Antenna at (a) 2.45 GHz. (b) 5.2 GHz.



(a) (b)

Figure 4: Two Closely-spaced Dual-band Fork-shape Monopoles with (a) Mutual Coupling and (b) Decoupled Neutralized Line and Matching Stubs.

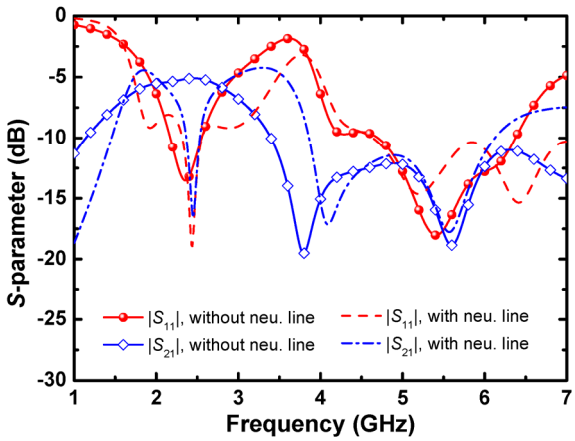


Figure 5: Simulated Two-port *S*-parameters of the Closely-spaced Antenna System with and without the Neutralized Line for Decoupling.

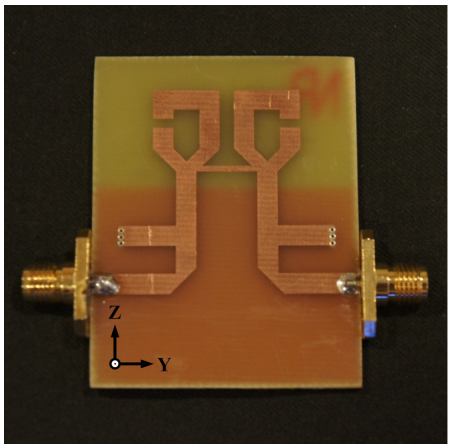


Figure 6: A Fabricated Sample of the Dual-band MIMO Antenna System with Decoupled Neutralized Line and Matching Stubs.

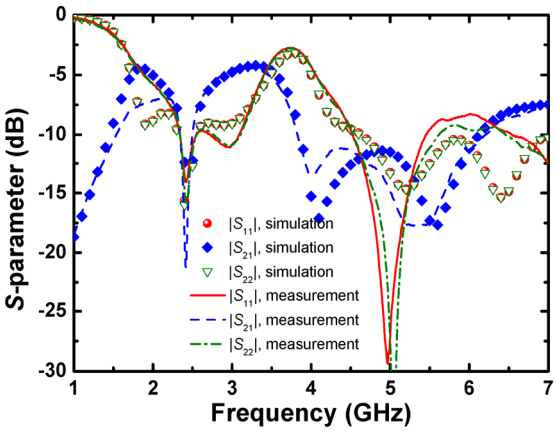
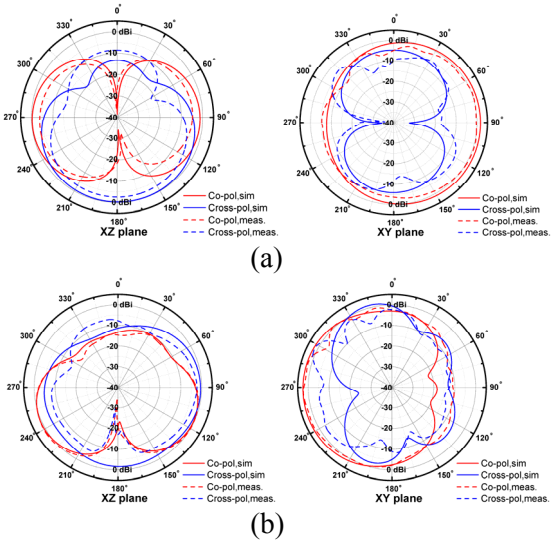


Figure 7: Simulated and Measured Two-port *S*-parameters of the Closely-spaced MIMO Antenna System with the Neutralized Line.



(a)

(b)

Figure 8: Simulated and Measured Radiation Patterns of the Closely-spaced MIMO Antenna System at (a) 2.45 GHz. (b) 5.2 GHz.