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RESEARCH PAPER

Design of compact dual-frequency antenna with bandwidth enhancement

LIPING HAN, LONGFEI HAO, LIYUN YAN, RUNBO MA AND WENMEI ZHANG

A compact dual-frequency antenna with enhanced bandwidth is proposed in this paper. Dual-frequency operation is realized by cutting a slot in the elliptical patch, and bandwidth enhancement is achieved by using a partial ground plane. Compared with the conventional half-wave antenna, the antenna has a compact size of 24 × 20 mm², which equals to 0.38 λ_1 × 0.31 λ_1 (λ_1, the guided wavelength at the first resonant frequency). The dual-frequency antenna with a partial rectangle ground and a partial arc-shaped ground is investigated for impedance matching. Simulated results indicate that the antenna with a partial arc-shaped ground can obtain a larger bandwidth for two bands than that with a partial rectangle ground. Experimental results show that the antenna with a partial arc-shaped ground can operate in 2.4 and 5 GHz bands, which covers the 2.4, 5.2 and 5.8 GHz for wireless local area network. The impedance bandwidths of two bands are 9.5 and 13.6%, respectively. Also, good radiation performances have been achieved at two bands.

Keywords: Compact, Dual-frequency, Partial ground, Bandwidth improvement

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I. INTRODUCTION

The rapid development of wireless communication technology has led to an increasing demand for dual-frequency antennas. Also, microstrip antennas have found extensive applications due to their light weight and small size. In recent years, numerous microstrip antennas with dual-frequency characteristics have been successfully designed for wireless applications [1]. Usually, the dual-frequency operation is realized by the use of two resonators [2], two resonant modes of one patch [3–5], shorting pins [6], and reactive loading technique [7]. However, the impedance bandwidth of the first band is usually narrow. Bandwidth enhancement can be obtained by using thick air or foam substrate [8], parasitic patch [9–11], reactive loading technique [12, 13], photonic band-gap or electromagnetic band-gap structure [14, 15], matching network [16], suitable slots in the radiating patch or the ground plane [17], and a reflecting board [18].

In this paper, a compact dual-frequency antenna is proposed. The dual-frequency operation is achieved by embedding an open-ring slot in the radiating patch. Moreover, a method for enhancing the bandwidth of dual-frequency antenna is studied by using a partial ground. Simulated results show that the antenna with a partial arc-shaped ground can obtain a larger bandwidth for two bands than that with a partial rectangle ground. Experimental results show that the antenna with a partial ground can operate in 2.4 and 5 GHz bands, with good agreement between the simulated and measured results.

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II. ANTENNA DESIGN

The geometry of the compact dual-frequency antenna is shown in Fig. 1. It consists of three layers, the top layer is the elliptical patch, the middle layer is the substrate, and the bottom layer is the ground plane. An open-ring slot is etched in the radiating patch to realize dual-frequency operation. The antenna is designed to operate at 2.4 and 5.2 GHz bands, and is simulated using Ansoft High Frequency Structure Simulator. The substrate is FR4 with a thickness of 1.6 mm, relative permittivity of 4.4 and loss tangent of 0.02. The optimized parameters are, $a = 9.1$, $b = 7$, $l_s = 37.6$, $w_s = 0.3$, and $d = 1.2$ mm, respectively. When the center of the ground plane is chosen as the origin of coordinates, the feeding point is at (−2.5 mm, 0). The proposed antenna has a compact size of 24 × 20 mm² (0.38 λ_1 × 0.31 λ_1).

Figure 2 shows the simulated $|S_{11}|$ with and without the open-ring slot in the patch. It can be seen that when a slot is etched in the patch, a new frequency (f_1) is excited. As a result, a dual-frequency antenna can be obtained. The numerical analysis of slot size is performed. Figure 3 shows the $|S_{11}|$ for different slot sizes. It is obvious that as l_s increases, f_1 decreases significantly while f_2 decreases slightly. Also, f_1 and f_2 are not sensitive to w_s. In the case of $l_s = 37.6$ mm and $w_s = 0.3$ mm, the resonant frequencies of the antenna are 2.38 and 5.18 GHz, respectively. Further research indicates, f_1 is controlled by the dimensions of the patch and the length of the slot, and f_2 is determined by the dimensions of

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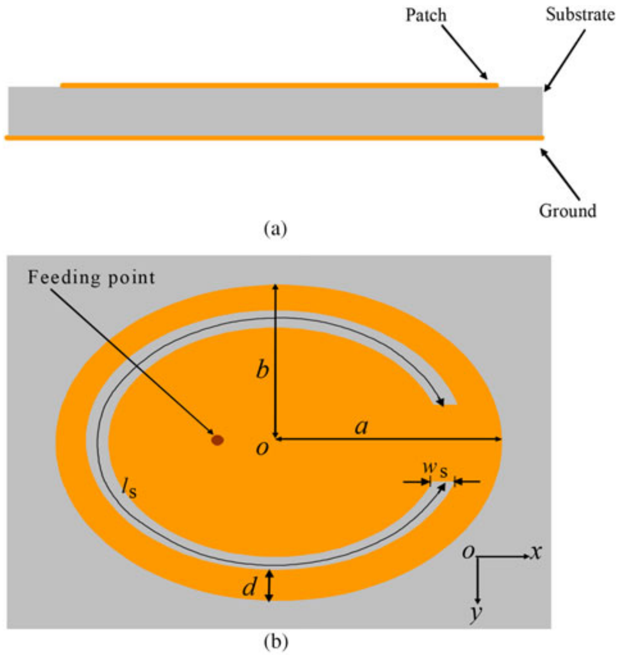

Fig. 1. Geometry of antenna, (a) side view; (b) top view.

the patch, that is,

$$\lambda_1 = \pi\left[1.5(a+b) - \sqrt{ab}\right] + 2d + l_s, \quad (1)$$

$$\lambda_2 = \pi\left[1.5(a+b) - \sqrt{ab}\right], \quad (2)$$

where λ_i is the guided wavelength at f_i. From Figs 2 and 3, we can see that the bandwidth at f_1 is narrow, and it cannot meet the requirements for wireless communications.

III. BANDWIDTH ENHANCEMENT

To enhance the bandwidth at f_1, the method of using a partial ground is adopted. We study the dual-frequency antenna with

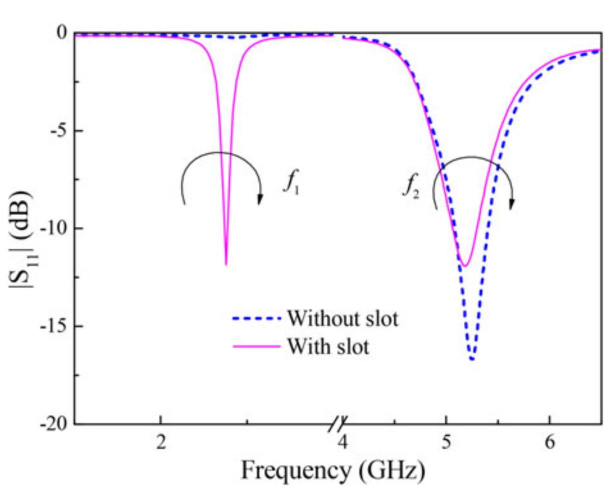

Fig. 2. $|S_{11}|$ with and without slot in the patch.

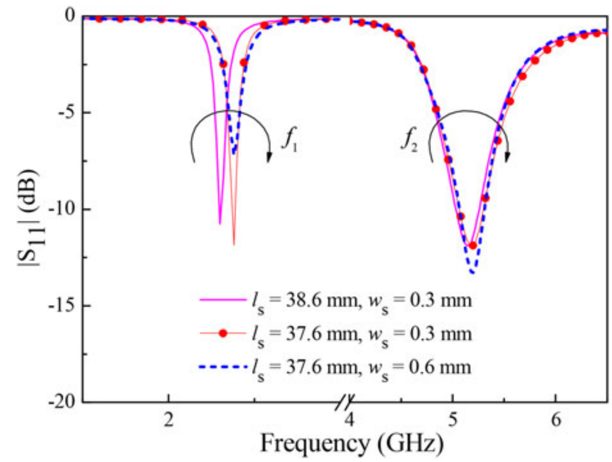

Fig. 3. $|S_{11}|$ for different slot sizes.

a partial rectangle ground and a partial arc-shaped ground. Figure 4 shows the bottom view of antenna.

For the antenna with a partial rectangle ground, the effect of the partial ground dimensions on the antenna performance is investigated. Figure 5 shows the $|S_{11}|$ for different l_g. It indicates that the slot in the ground can change the input impedance of antenna, and introduce two new resonant frequencies (f_1' and f_2'). By properly adjusting the value of l_g, two new frequencies close to f_1 and f_2 can be obtained, and that the impedance bandwidth of two bands can be improved. Also, it is clear that as l_g increases, the impedance matching in the first band becomes better, while that in the second band becomes worse. In the case of $l_g = 14.3$ mm, the antenna can obtain a better bandwidth of 10.8% (2.27–2.53 GHz) and 11.2% (5.08–5.68 GHz) in two bands, respectively.

In the case of the partial arc-shaped ground, let x_g denote the x-coordinate of the center of arc in the ground. The numerical analysis for different x_g in case of $r = 11$ mm is performed, and the result is shown in Figure 6. It is clear that the new frequencies decrease with the decreasing of x_g. In the case of $x_g = -11.9$ mm (62% patch overlaps with the ground plane), the maximum bandwidth of 10% (2.29–2.53 GHz) and 13.8% (5.13–5.89 GHz) in two bands is obtained, respectively. It can cover the 2.4, 5.2, and 5.8 GHz bands for wireless local area network (WLAN). Therefore, the partial arc-shaped ground is adopted in this paper. Additionally, the radiation efficiency of the antenna is 65% at f_1 and 89% at f_2. Compared with that of antenna with whole ground, it is increased by 24 and 21%, respectively.

In order to illustrate the mechanism of bandwidth improvement using partial ground, the simulated surface current distribution at the second band is shown in Fig. 7. It can be seen that, at f_2, strong current appears on the patch for both antennas with whole ground and partial ground. At f_2', the current on the patch is weak for the antenna with whole ground, but it is strong for the antenna with partial ground. Also, it is obvious that the current path length of the antenna with whole ground is greater than that with partial ground, as shown in Fig. 7(b) and 7(d). That is to say, when a partial ground is employed, a higher resonance (f_2') is excited and the bandwidth of the antenna is improved.

Furthermore, the effects of arc slot dimension, feeding point position and nearby metal object on the performance of antenna are investigated. We found that the bandwidth of

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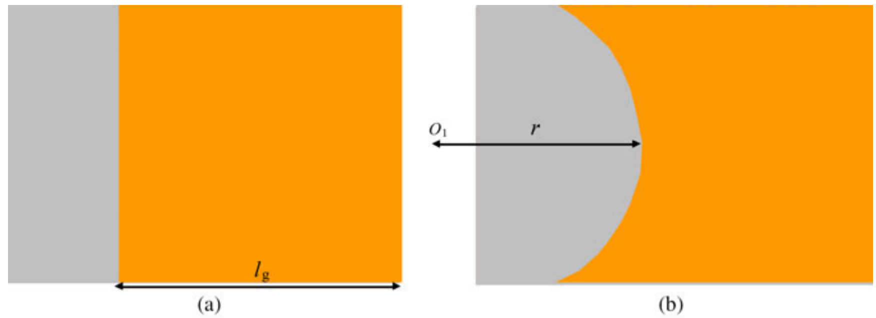

Fig. 4. Bottom view of antenna with partial ground, (a) rectangle ground; (b) arc-shaped ground.

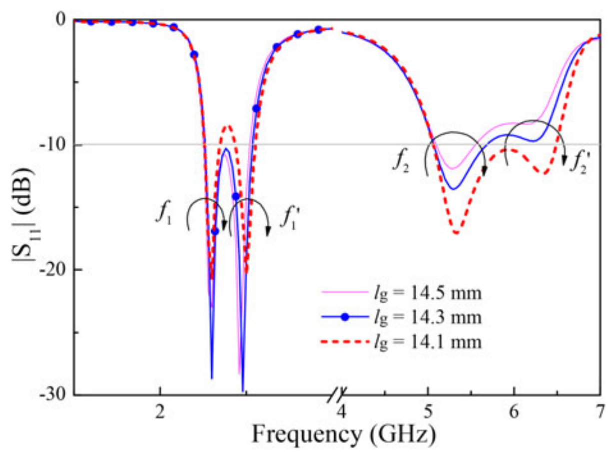

Fig. 5. $|S_{11}|$ for different l_g.

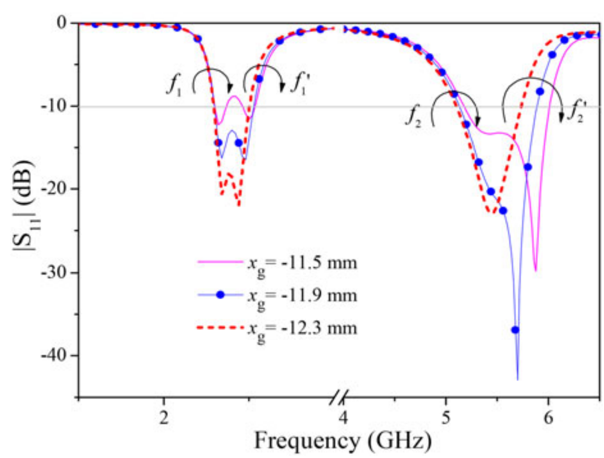

Fig. 6. $|S_{11}|$ for different x_g.

two bands increases as the dimension of arc slot in the ground increases. In order to cover the 2.4, 5.2, and 5.8 GHz bands for WLAN, the dimension of arc slot should be properly adjusted. Figure 8 shows the $|S_{11}|$ for different x_f, which denotes the x-coordinate of the feeding point. It is observed that, when x_f increases, the impedance matching becomes poor. Also, when metal object is placed below the antenna, both the impedance matching and the radiation performance become poor.

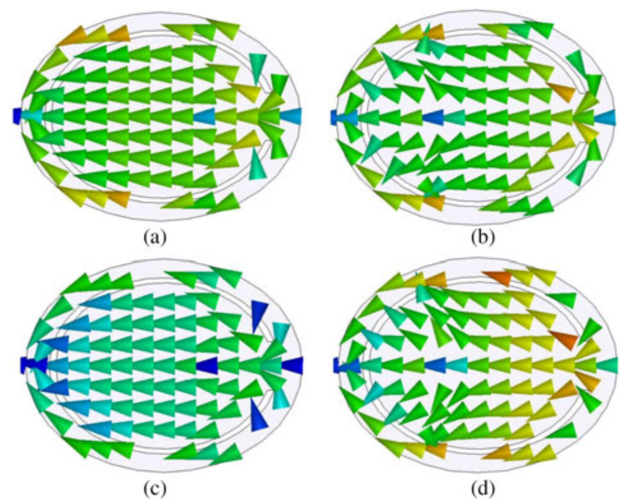

Fig. 7. Surface current distribution at the second band, (a) at f_2 with whole ground; (b) at f_2 with partial ground; (c) at f_2' with whole ground; (d) at f_2' with partial ground.

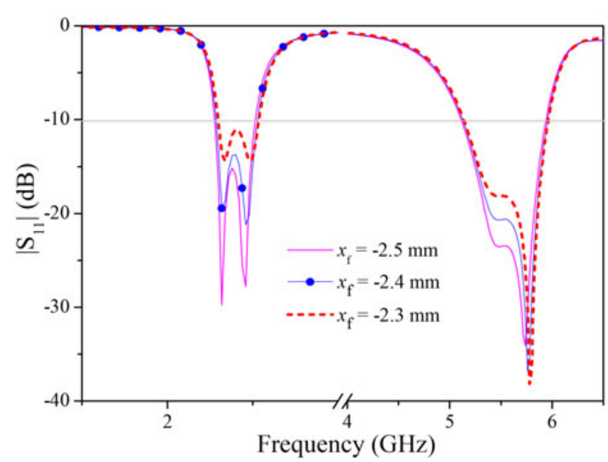

Fig. 8. $|S_{11}|$ for different x_f.

IV. EXPERIMENTAL RESULTS

The proposed antenna is fabricated on inexpensive FR4 substrate with the relative permittivity of 4.4 and thickness of 1.6 mm. Figure 9 shows the photograph of antenna. It is fed

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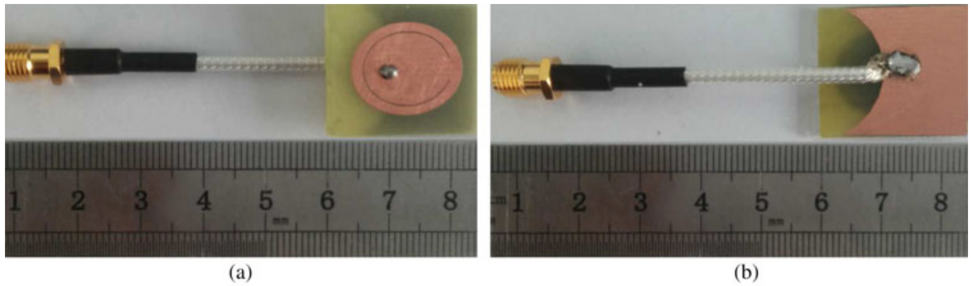

Fig. 9. Photograph of antenna, (a) top view; (b) bottom view.

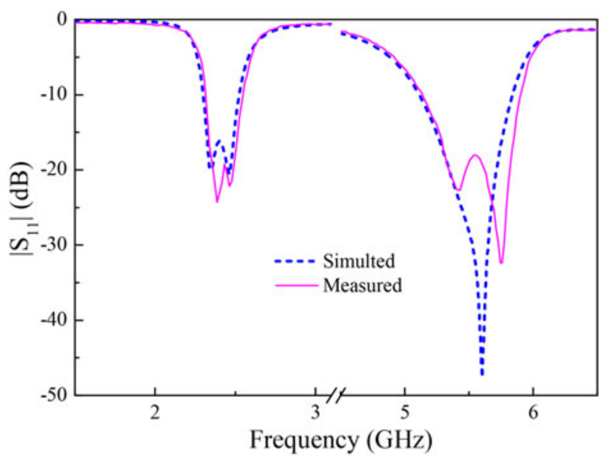

Fig. 10. Simulated and measured $|S_{11}|$.

by a coaxial probe through a SubMiniature version A (SMA) connector. The external conductor of SMA is soldered together with the ground plane. The dimensions of the antenna are, $a = 9.1$, $b = 7$, $l_s = 37.6$, $w_s = 0.3$, $d = 1.2$, $x_g = -11.9$, and $r = 11$ mm, respectively. The N5230A vector network analyzer and the 8092 antenna measurement system are used to measure the antenna.

The simulated and measured $|S_{11}|$ of the antenna is shown in Fig. 10. Good agreement between the simulated and measured results is obtained. It can be seen that the antenna can operate in 2.4, 5.2, and 5.8 GHz bands. The measured bandwidths of two bands are 9.5% (2.31–2.54 GHz) and 13.6% (5.14–5.89 GHz), respectively. The difference between the simulated and measured results is mainly caused by the SMA connector and the fabrication tolerances.

Figure 11 shows the normalized measured radiation patterns at two bands. Here, the *E*- and *H*-plane are in the *xz*- and *yz*-plane, respectively. We can find that broadside radiation patterns in *E*- and *H*-planes are obtained. Also, the direction of maximum radiation at f_1 has about 10° of deviation from the normal direction due to the asymmetry of the ground. Figure 12 shows the measured gains in two bands. The peak gain in two bands is 0.43 and 4.15 dBi, respectively.

V. CONCLUSION

A compact dual-frequency antenna is proposed. Compared with the conventional half-wave antenna, the antenna has a compact size of 24×20 mm², which equals to $0.38\ \lambda_1 \times 0.31\ \lambda_1$. Also, a bandwidth enhancement method of using a partial ground for dual-frequency antenna is studied. A dual-frequency antenna with a partial rectangle ground and a partial arc-shaped ground is investigated using electromagnetic simulations. Simulated results show the antenna with a partial arc-shaped ground provides a larger bandwidth for two bands than that with a partial rectangle ground.

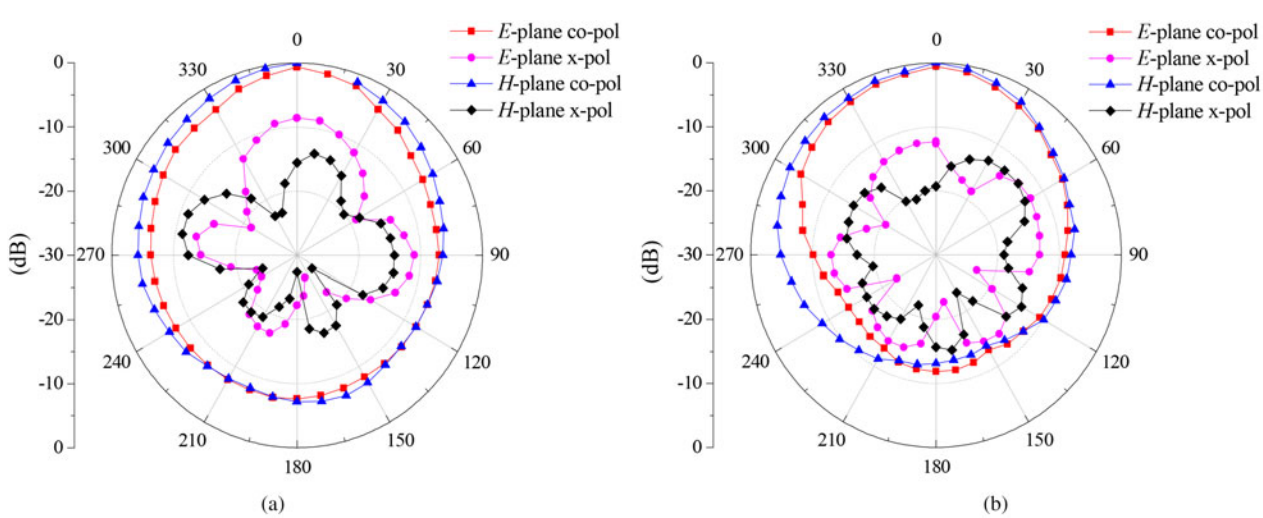

Fig. 11. Measured radiation patterns, (a) at f_1; (b) at f_2.

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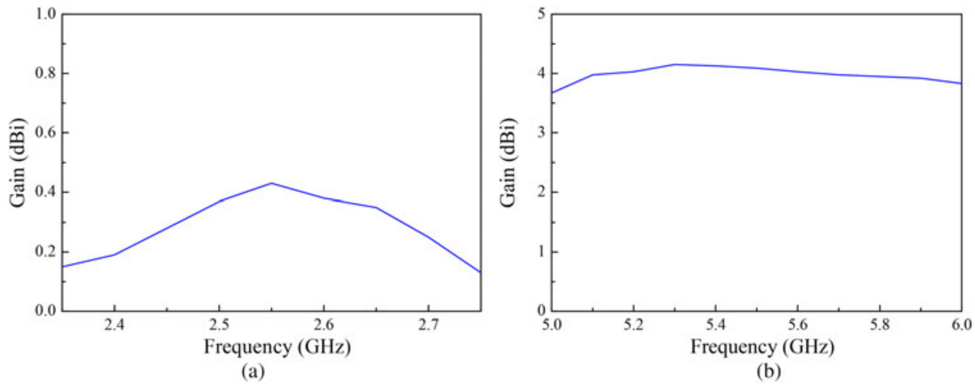

Fig. 12. Measured gains, (a) in f_1 band; (b) in f_2 band.

Experimental results indicate that the antenna with a partial arc-shaped ground can operate at 2.4 and 5 GHz bands for WLAN. The bandwidths of two bands are 9.5 and 13.6%, respectively. Also, good radiation performances have been achieved at both bands. The antenna is of low cost and suitable for wireless communication application.

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