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Low-Profile Omnidirectional Antenna with Dual Polarizations for 2.4 GHz WLAN Applications

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Abstract—A low-profile antenna is proposed in this letter for realizing dual polarizations with omnidirectional radiation patterns. Vertical polarization is obtained by a modified annular ring slot antenna, and horizontal polarization is obtained by a modified printed arc dipole array. By combining the ground plane of the ring slot antenna and the dipole array on the same layer, the profile of the antenna is reduced to minimum extent. The proposed prototype has a low profile of 0.024λ (λ is the free-space wavelength at 2.4 GHz). To verify the design, the proposed antenna is fabricated and measured. Measured reflection coefficients, isolation, and radiation patterns data agree well with the simulated results. The common band of vertical and horizontal polarizations makes the proposed antenna satisfy the WLAN diversity systems with omnidirectional characteristic.

1. INTRODUCTION

Adopting polarization diversity, dual-polarized antennas are commonly used in modern wireless communication systems [1]. Having the advantages of mitigating the polarization mismatch, enhancing spectrum, improving the channel capacity and diversity gain [2, 3], dual-polarized antennas are applicable to communication mobile terminals and base stations. Moreover, since it can substitute two space-isolated orthogonal polarization antennas, a dual-polarized antenna has the merits of reducing costs and saving space. Besides, for some special circumstances which needed 360° full coverage properties, it is required for dual-polarized antennas to provide omnidirectional radiation patterns.

During the last decades, numerous researches on omnidirectional dual-polarized antennas can be found in the literature [4–9]. In [4], a slender columnar cuboid with two orthogonal slots is introduced. To reduce its high profile, a modified structure is presented in [5]. By using a cavity-backed notch, it is only 60% of the volume in [5]. A horizontal dipole array is a common form to achieve horizontal polarization [6–9]. By combining printed dipoles and vertical polarized antennas such as biconical antenna [6], discone antenna [7, 9], and monopole [8], dual-polarized radiation patterns with omnidirectional characteristic can be achieved. However, due to having relatively high profiles, the above antennas are not adequate for space-constrained applications. Besides, high profile antennas may meet the risk of considerable wind resistance, resulting hardly conformal to the carriers.

In this letter, a low-profile omnidirectional antenna with dual polarizations is proposed for the 2.4 GHz WLAN system. The vertical and horizontal polarizations are obtained by combining an annular ring slot antenna with a modified printed arc dipole array. The proposed prototype has a low profile of $0.024\lambda_0$ (λ_0 is the free-space wavelength at 2.4 GHz). The common band for vertical and horizontal polarizations makes the proposed antenna satisfied with WLAN diversity systems with omnidirectional characteristic.

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2. ANTENNA DESIGN

Geometry of the proposed omnidirectional dual-polarized antenna is shown in Fig. 1. It comprises an annular ring slot antenna and a printed arc dipole array, both printing on a double-layer FR4 substrate with different thicknesses. The annular ring slot antenna consists of a circular patch and a concentric annular ring printed on the upper surface of the upper substrate. A circular ground is printed on the lower surface of the upper substrate (the middle layer). Around the ground, a set of conductive vias are added on the upper substrate. By adjusting the parameters of the annular ring slot antenna, it generates vertical polarization with an omnidirectional radiation pattern in the horizontal plane over a wide bandwidth. For horizontal polarization, six arc dipoles working as an arc dipole array are printed on the middle layer adjacent to the circular ground. In order to form a symmetrical structure, they are printed in a sequential, rotating arrangement with an equal inclination angle of 60°. Thus, the arc dipole array forms a circular loop for horizontal polarization omnidirectional radiation. Because of the conductive vias, the horizontal polarization mode and the vertical polarization mode can work independently without interference. Therefore, the proposed antenna can achieve both omnidirectional vertical and horizontal polarizations with low profile.

Two feeding networks of the vertical and horizontal polarizations are printed on the lower surface

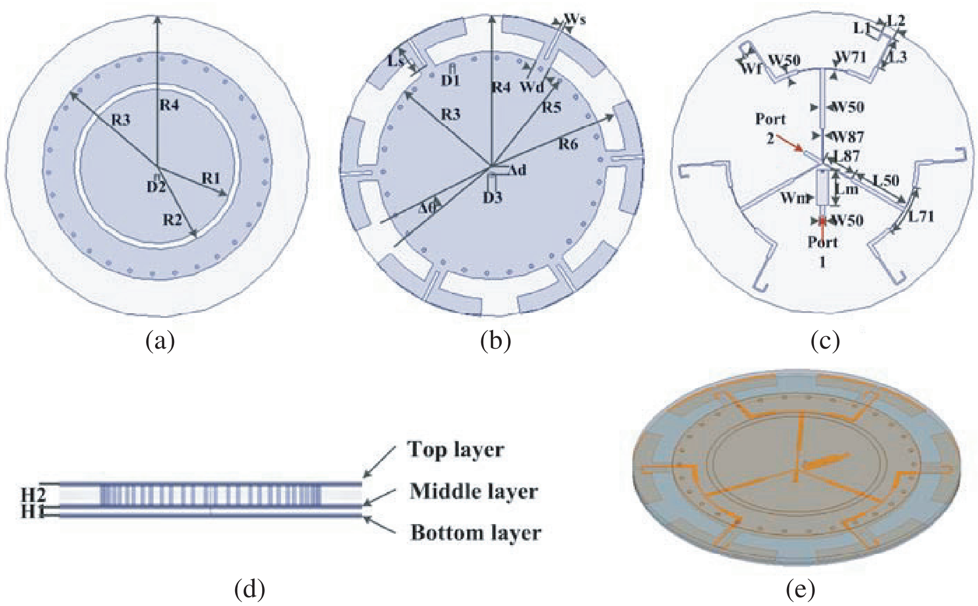


Figure 1. Geometry of proposed antenna. (a) Top layer. (b) Middle layer. (c) Bottom layer. (d) Side view. (e) 3D view.

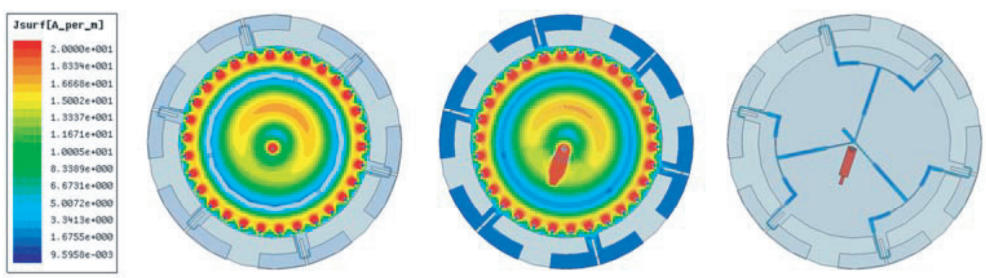
Table 1. Main parameters of proposed antenna.

Parameters	$R1$	$R2$	$R3$	$R4$	$R5$	$R6$	$D1$	$D2$	$D3$
Value (mm)	37.7	40.6	56	74	52.9	65.4	1.3	2	3
Parameters	Δd	$L1$	$L2$	$L3$	$L50$	Lm	$L87$	$L71$	$W71$
Value (mm)	4.3	3.9	4.7	15.6	29.3	17.6	16.4	24.3	0.44
Parameters	$W50$	Wf	$W87$	Wm	Wd	$H1$	$H2$		
Value (mm)	1.9	0.8	0.64	5.3	7.8	1	2		
Parameters	$\Delta\theta$								
Value (degree)	12								

of the lower substrate (bottom layer). The vertical polarization mode is excited by Port 1. A microstrip to coaxial transition is utilized to connect the antenna feeding port to the circular patch. The extended microstrip line works as impedance matching. Port 2 is working to excite the horizontal polarization mode. It is connected to the feeding network of the arc dipole array which is comprised of six broadband baluns and a six-way power divider. For solving the overlapping problem of the two ports, the transition is moved from the centre some distance without deteriorating the impedance matching and radiation patterns of both two modes. The final optimized main parameters of the antenna are listed in Table 1.

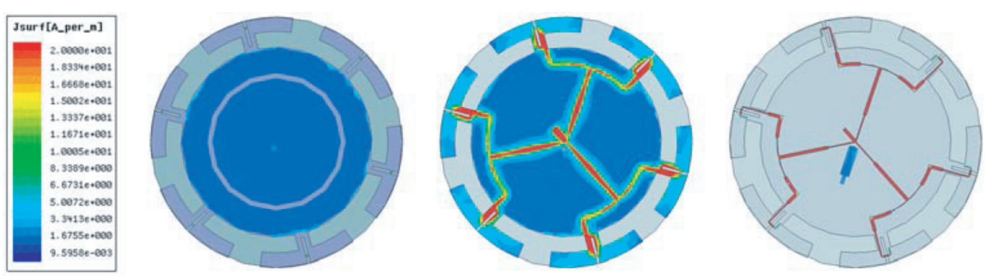
3. SURFACE CURRENTS DISTRIBUTION

To verify the polarization diversity characteristic, the surface currents distributions of the low-profile antenna with different feeding ports are studied. The surface currents distributions at 2.45 GHz are shown in Figs. 2 and 3. When Port 1 is excited, the surface currents are mainly concentrated on the annular ring slot antenna. Because the feeding port is not located symmetrically to the center, the currents distribution on the inner circle is asymmetric. Fortunately, the concentric annular ring and conductive vias modify the surface currents distribution around the circular patch, making the horizontal radiation pattern to keep omnidirectional. It is also worth noting that very little current flows in the dipole array because of the inserted conductive vias. Thus, the vertical polarization with omnidirectional radiation pattern in horizontal plane is obtained.



(a) (b) (c)

Figure 2. Simulated current distribution of the proposed antenna fed by Port 1. (a) Top layer. (b) Middle layer. (c) Bottom layer.



(a) (b) (c)

Figure 3. Simulated current distribution of the proposed antenna fed by Port 2. (a) Top layer. (b) Middle layer. (c) Bottom layer.

On the other hand, when Port 2 is excited, as shown in Fig. 3, the energy is transmitted through the lower substrate to the middle layer. The surface currents flow through the power divider and broadband baluns to the dipoles. The directions of the surface currents on the dipoles all go clockwise, which is not shown in the figure. Little current flows into the top layer. Therefore, the horizontal polarization with the omnidirectional radiation pattern in horizontal plane is achieved.

4. SIMULATED AND MEASURED RESULTS

The designed dual-polarized antenna has been simulated, fabricated and measured. The electromagnetic commercial software HFSS is used for simulation. The proposed antenna is made by the double-layer FR4 substrate with relative permittivity of 4.4 and substrate loss tangent of 0.02. The antenna is fed by two coax lines. The inner conductor of the coax lines are soldered on microstrip lines for Port 1 and Port 2 respectively. Near the feeding ports, additional conducting vias with a diameter of 1.5 mm are manufactured to connecting the middle layer and the bottom layer. Thus, the outer conductor of the coax lines can be connected to the ground through the conducting vias. Its photograph is shown in Fig. 4.

(a) (b) (c)

Figure 4. Photograph of the proposed antenna. (a) Top view. (b) Bottom view. (c) 3D view.

The measured and simulated reflection coefficients of Port 1 and Port 2 and isolation are illustrated in Fig. 5. Vertical polarization mode is fed by Port 1 and shows a measured 10-dB impedance bandwidth of 7.3% (2.36 GHz–2.54 GHz) whereas the horizontal polarization mode is excited by Port 2 with an 11.1% (2.3 GHz–2.57 GHz) impedance bandwidth. Area (shaded) illustrates the usable common band, which can cover the desired WLAN band (2.4 GHz–2.484 GHz). Over the whole operating band, the measured isolation between the two ports shows a desirable result better than −30 dB.

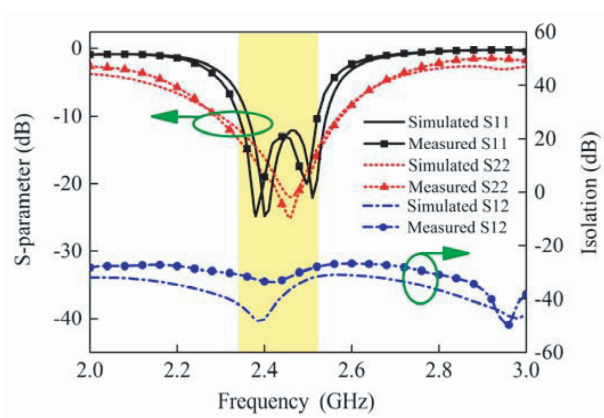


Figure 5. Measured and simulated S-parameters of proposed antenna.

Radiation patterns are simulated and measured in common bandwidth of the two ports. The radiation patterns at 2.45 GHz are shown as an illustrative example in the following. Fig. 6 shows the far-field radiation patterns for vertical polarization (Port 1). It can be seen that the gain variations in the XOY plane are less than 1.0 dBi whereas the cross-polarisation remains less than −14.9 dB. Vertically polarized electric-monopole-like radiation patterns are obtained as illustrated in the XOZ and YOZ planes. The patterns showed in the XOZ and YOZ planes have cross-polarizations within the main lobe keep less than −18 dB.

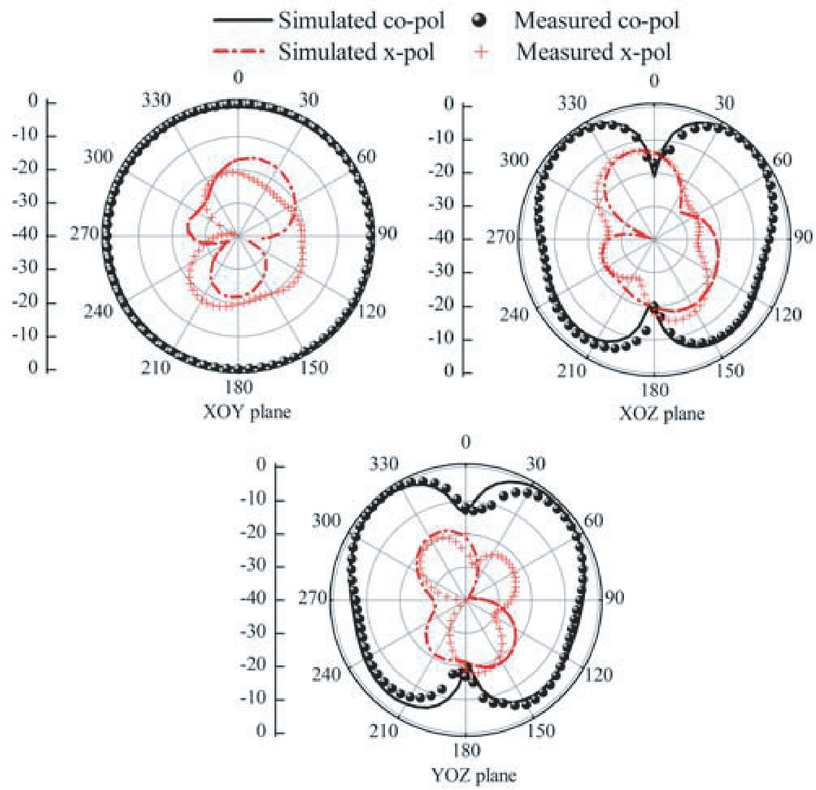


Figure 6. Measured and simulated far-field radiation patterns of the proposed antenna fed by Port 1.

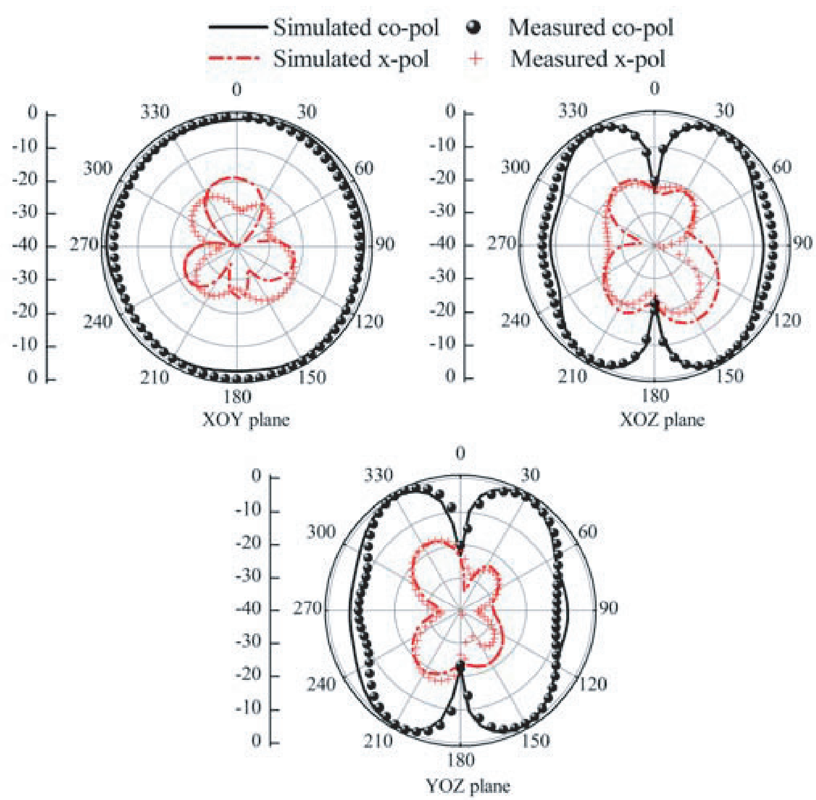


Figure 7. Measured and simulated far-field radiation patterns of the proposed antenna fed by Port 2.

The measured and simulated far-field radiation patterns for horizontal polarization (Port 2) are shown in Fig. 7. The results at XOY plane demonstrate good omnidirectional performance. The gain variation is less than 2.6 dBi whereas the cross-polarisation is less than -17.3 dB at XOY plane. Horizontally polarized radiation patterns are illustrated in the XOZ and YOZ planes with the cross-polarizations less than -17.6 dB. The directions of maximum radiation are moved away from the horizontal axis in the XOZ and YOZ planes due to the influence of the ground plane in the middle layer.

5. CONCLUSION

A low-profile antenna with omnidirectional dual-polarizations is proposed for WLAN applications. By combining a modified annular ring slot antenna with a modified printed arc dipole array, the proposed composite antenna achieves dual-polarised omnidirectional radiation patterns. The proposed prototype has a low height of $0.024\lambda_0$ (λ_0 is the free-space wavelength at 2.4 GHz). Measured results demonstrate that the presented antenna achieves a 10-dB impedance bandwidth of 7.3% (2.36 GHz–2.54 GHz) for vertical polarization and 11.1% (2.3 GHz–2.57 GHz) for horizontal polarization, respectively. Over the operating band, the isolation between the two polarizations is less than -30 dB. Good performance in low-profile, omnidirectional dual-polarizations and high isolation proves it a good candidate for WLAN applications.

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