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A Novel Planar Dual Circularly Polarized Endfire Antenna

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ABSTRACT In this paper, a novel planar dual circularly polarized (CP) endfire antenna composed of a magnetic dipole Yagi element (MDYE) and electric dipole Yagi element (EDYE) is presented for 5.8-GHz WLAN application. Two orthogonal components E_x and E_y are provided by the EDYE and MDYE. By adjusting the amplitude of each component, the CP radiation is formed. Besides, a hybrid network composed of microstrip lines and parallel strip lines is used to excite MDYE. Dual circular polarization can be achieved by a simple and feasible 90ř directional coupler to control the radiation mode with no need of complex feeding structure. Moreover, the parameters of the proposed antenna are studied and the antenna is fabricated and measured. The theoretical design method has been numerically verified and experimentally validated. The simulation and measurement results show that the impedance bandwidth ($|S_{11}| < -10$dB) is 170 MHz (5710–5880 MHz) and 175 MHz (5715–5890MHz) at two feed ports. Besides, good radiation characteristics with the peak gains of 5.3 and 5.2 dBic can be obtained with an 18-dB front-to-back ratio (FTBR) at its resonance frequency. The simulated and measured results show that the standard PCB process is a reliable method for antenna fabrication.

INDEX TERMS Dual-CP antenna, axial ratio (AR), low profile, endfire radiation, WLAN.

I. INTRODUCTION

With the development of radar, satellite communication, electronic warfare and other technologies, the application of circularly polarized (CP) antennas are used more and more widely [1]–[3]. CP antenna has many advantages over linearly polarized (LP) antenna, such as ensuring a good match between the receiver and the transmitter and eliminating multipath reflections caused by many other objects. Planar CP antennas are attractive because they can be integrated with a conformable carrier surface [4]–[6]. In the past decades, various designs of dual-CP antennas have been reported.

A dual-band CP antenna fed by a dual-band substrate integrated coaxial line coupler is proposed in [7]. A microstrip patch array with dual circular polarization, using sequential rotating feeding network, is introduced in [8]. A broadband single layer dual-CP reflectarrays with LP feed is introduced in [9]. The unique structure of a compact dual-CP dielectric resonator antenna (DRA) is proposed in [10], of which the CP pattern is generated by multiple orthogonal modes and the polarization is determined by the phase of the feeding signal. A low profile dual-CP cavity-backed ring-slot antenna is introduced in [11]. However, all these antennas focus on producing broadside radiation pattern or omni-directional radiation pattern. In the published articles, there are few introductions of the dual-CP endfire antenna.

The Yagi array antenna [12] proposed in 1928 is a typical endfire antenna. The microstrip patch Yagi array antenna was firstly used for satellite communication in 1989 [13], [14]. After that, many planar Yagi array antennas were proposed in [15]–[21]. However, all antennas above are designed to realize linear polarization. The antenna is generated vertically polarized in [15]–[18] and horizontal polarized in [19]–[21]. Recently, planar endfire CP antennas combined with an aperture and a printed dipole is proposed in [22]–[24]. As studied in [22]–[24], a planar CP antenna with an endfire beam in parallel with the antenna's plane can be realized. But it could not achieve dual circular polarization.

In this paper, the proposed dual-CP endfire antenna is composed of a MDYE, a EDYE and a 90-degree directional coupler. The antenna has a simple structure with low profile, and could realize dual-CP and endfire radiation. The CP radiation pattern is achieved by the MDYE and EDYE, which create two orthogonal modes with a 90-degree phase shift.

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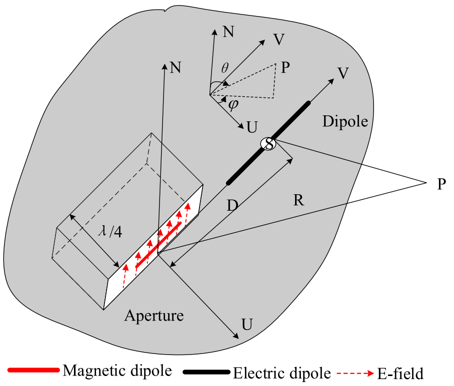

FIGURE 1. Planar endfire complementary CP antenna equivalent source model.

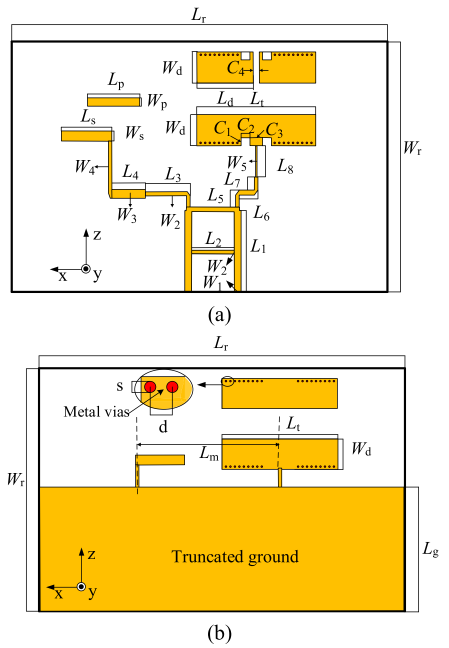

FIGURE 2. The geometry of the proposed antenna. (a) Top view. (b) Bottom view.

LHCP or RHCP radiation is achieved by selecting different feeding ports. Furthermore, there is an isolation of than 14 dB between two ports. Based on this configuration, the antenna can be easily realized and is very practical.

The paper is organized as follows. Details of the operating principle and the antenna design procedure are presented in Section II. Some main parameters of the designed antenna are studied in Section III. The simulation and measurement results of the proposed antenna are summarized and discussed in Section IV. Finally, the conclusion is in the Section V.

II. ANTENNA OPERATING PRINCIPLE AND DESIGN

Conceptual configuration consisting of electric dipole and magnetic dipole is shown in Fig. 1. Configurations of the proposed dual-CP endfire antenna is shown in Fig. 2. The antenna can be divided into three parts, a MDYE, an EDYE and a 90-degree directional coupler. A series of strips and patches are printed on the two sides of the substrate. The relative dielectric constant of the substrate is 2.65 with the thickness of $h = 1$ mm (0.02λ, λ is the free-space wavelength of the center frequency), and the dielectric loss tangent of 0.002. The size of the antenna is 99 mm × 60 mm × 1 mm.

TABLE 1. Parameters for the proposed antenna.

Parameter	Value (mm)	Parameter	Value (mm)	Parameter	Value (mm)
L_r	99	L_s	13.3	L_5	5.25
W_r	60	W_s	2.2	L_6	8.6
L_d	14.92	L_g	33	L_7	1.3
W_d	8.26	L_1	19	L_8	9
L_t	31	L_2	8	W_1	1.5
L_p	16	L_3	8.82	W_2	0.71
W_p	2	L_4	8.82	W_3	1.5
L_m	34.5	W_4	0.6	W_5	0.4
C_1	2	s	0.6	d	1.5
C_2	1	C_3	2.5	C_4	1.1

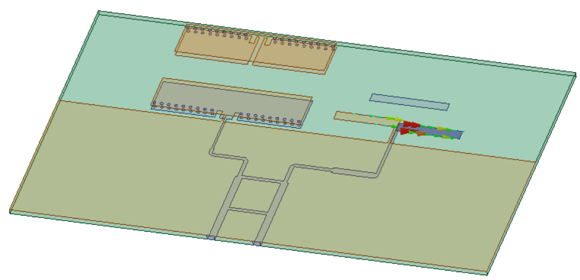

FIGURE 3. Electric field distribution for the main radiator of EDYE.

In order to achieve a good dual-CP property, the 90-degree directional coupler is designed to realize the desired amplitude and phase distribution of the MDYE and the EDYE. The antenna is placed horizontally in practical use. The proposed antenna is optimized by HFSS (High Frequency Structure Simulator) and final dimensions are listed in Table 1.

For the horizontally polarized Yagi element, the microstrip half-wave dipole is used as the main radiator of the EDYE. The horizontal strip added in front of the main radiator is used as the director, and the truncated ground is used as the reflector. From the electric field distribution in Fig.3, it can be illustrated that the EDYE can generate horizontally polarized components E_x.

For the vertically polarized Yagi element, the one-edge-shorted rectangular patch is used as the main radiator of MDYE. A similar one-edge-shorted rectangular patch with a gap in the middle serves as the director, while the truncated ground serves as the reflector. Because of the magnetic current distribution of the rectangular patch aperture, the one-edge-shorted rectangular patch could generate vertically polarized wave [25]. Fig. 4 shows the electric field distribution of the MDYE. From the electric field distribution, the MDYE will produce vertically polarized component E_y.

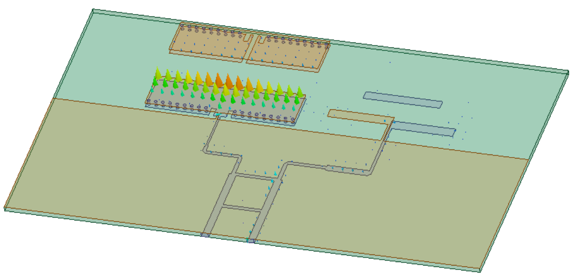

FIGURE 4. Electric field distribution for the main radiator of MDYE.

It can be seen from the analysis above that the EDYE and MDYE can generate two orthogonal electric field components E_x and E_y. Both elements can generate linearly polarized endfire radiation pattern. We regard the two elements as electric dipole and magnetic dipole. Conceptual configuration consisting of electric dipole and magnetic dipole is shown in Fig. 1. As studied in [26], the far field pattern generated by the electric dipole is expressed as

$$\vec{E}_e = j\frac{\omega\mu_0 I_0 l}{4\pi\eta r}(\widehat{\theta}\cos\theta\sin\varphi + \widehat{\varphi}\cos\varphi)e^{-jk_0 r}, \quad (1)$$

and the far field pattern generated by the magnetic dipole is expressed as

$$\vec{E}_m = j\frac{\omega\mu_0 I_0 l}{4\pi\eta r}(\widehat{\theta}\cos\varphi + \widehat{\varphi}\cos\theta\sin\varphi)e^{-jk_0 r}, \quad (2)$$

where I_0 is the amplitude, l is the length of dipole, η is the intrinsic impedance of vacuum, μ_0 is the permeability in free space.

When the phase difference between the two sources is δ ($\delta = \delta_0 + \zeta$, where δ_0 is the output phase difference of the feed network, ζ indicates the phase that is caused by the current flowing from the output of the feed network to the aperture, and ζ is equal to $k\lambda/4 = \pi/2$), the following components of the total fields can be obtained:

$$\begin{aligned}\vec{E}_t &= \vec{E}_m + e^{-j(k_0 d\sin\theta\sin\varphi+\delta)}\vec{E}_e \\ &= j\frac{\omega\mu_0 I_0 l}{4\pi\eta r}\begin{bmatrix}\widehat{\theta}\,(\cos\varphi + \cos\theta\sin\varphi f\,(\theta,\varphi)) \\ +\widehat{\varphi}\,(\cos\theta\sin\varphi + \cos\varphi f\,(\theta,\varphi))\end{bmatrix}e^{-jk_0 r},\end{aligned} \quad (3)$$

where

$$\begin{aligned}f\,(\theta,\varphi) &= e^{-j(k_0 d\sin\theta\sin\varphi+\delta)} \\ &= \cos(k_0 d\sin\theta\sin\varphi+\delta) - j\sin(k_0 d\sin\theta\sin\varphi+\delta)\end{aligned} \quad (4)$$

When $\theta = 90°, \varphi = 0, \delta_0 = 0° or 180°$, the total fields along the endfire direction (the u-axis) is

$$\vec{E}_t\,|_{+u} = j\frac{\omega\mu_0 I_0 l}{4\pi\eta r}(\widehat{\theta} \mp \widehat{\varphi}j)e^{-jk_0 r} \quad (5)$$

According to theoretical analysis, the phase difference between the wave radiated by MDYE and EDYE is 90-degree in the far field, when the feeding phase is same or has 180-degree difference. In order to obtain a dual-CP endfire radiation pattern, we need to make the feeding phase of MDYE and EDYE equal or opposite. Hence, we introduce a 90-degree directional coupler with a 90-degree phase delay strip line into the proposed antenna.

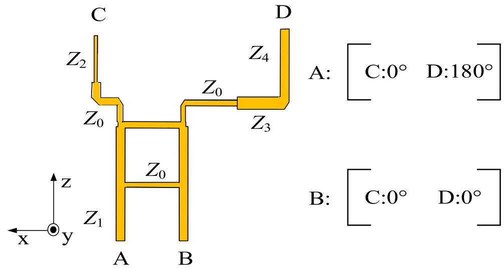

FIGURE 5. Configuration of the network.

TABLE 2. The detailed resistance values of the power divider.

	Z_0	Z_1	Z_2	Z_3	Z_4
Resistance(Ω)	100	70.71	120	70.71	110

Fig. 5. shows the 90-degree directional coupler with 90-degree phase delay strip line. The detailed resistance values of the feeding network are described in Table 2. The length of the microstrip lines marked as Z_1, Z_2 and Z_3 in Fig.5 is a quarter of λ. The detailed value of the parameters are listed in Table 1.

It can be found that the far-field polarization of the EDYE and the MDYE is orthogonal. Moreover, both the EDYE and the MDYE are endfire radiation modes. By adjusting the amplitude and the phase of the EDYE and the MDYE, the desired dual-CP endfire antenna can be achieved.

III. PARAMETRIC STUDY AND DESIGN OF PROPOSED ANTENNA

To verify the performance of the final designed antenna, we investigate the influence of some important parameters on S parameters, AR and front-to-back ratio. HFSS software is used to implement the simulation analysis.

A. MDYE PARAMETER OPTIMIZATION

The MDYE provides E_y component for the circular polarization of the proposed antenna in this paper. Actually,for the vertically polarized electric field, the low-profiled reflector can hardly influence its radiation. Usually, an extra reflector need to be added to improve the front-to-back ratio. In this paper, the top metal of the director element in the front of MDYE is split to enhance the mutual coupling of the driven element and director element, which is effective for improving the front-to-back ratio. The operation principle of the proposed MDYE is similar to that in [18]. Besides, a groove ($C_1 \times C_2$) is introduced on the driven element and the director element to improve impedance matching. Fig. 6 (a) is the geometry of a conventional MDYE, and (b) is the geometry of an improved MDYE of which director element is split.

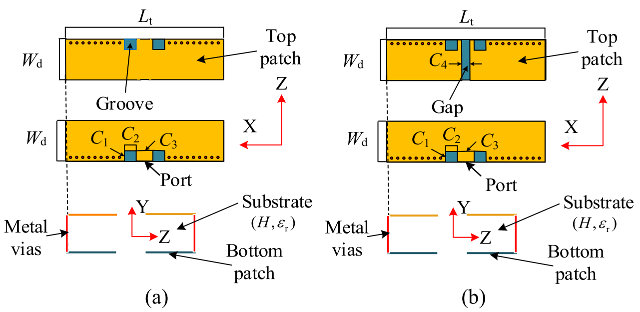

FIGURE 6. Evolution process of the proposed MDYE with front-to-back ratio enhancement. (a) Conventional MDYE. (b) Improved MDYE.

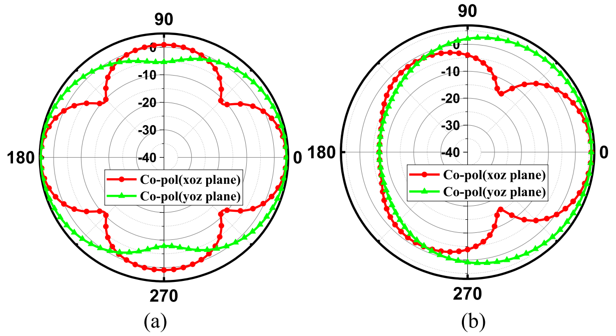

FIGURE 7. The influence of the front-to-back ratio of MDYE under two different configurations in Fig. 6 at 5.8 GHz. (a) Conventional MDYE. (b) Improved MDYE.

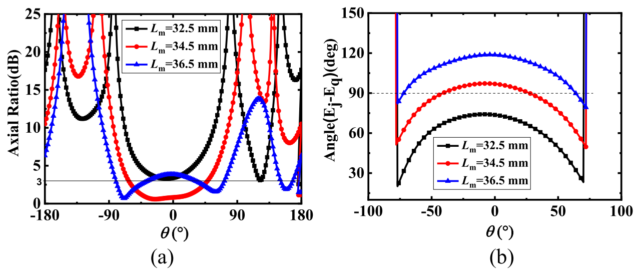

FIGURE 8. Parameter study of the AR (a) and Phase difference (b) with varied L_m at 5.8 GHz.

As shown in Fig. 7, the front-to-back ratio of the traditional MDYE is small, and the improved MDYE has a front-to-back ratio of up to 18dB. This method can solve the problem that the low-profiled reflector can hardly affect the vertical polarization of the electric field. In order to get desired front-to-back ratio, the length of C_4 is the key parameter. It is observed that the lowest front-to-back ratio is achieved when $C_4 = 1.1$ mm.

B. PHASE DELAY LINE

As shows in Fig. 8, the length between port C and port D (L_m) has great impact on AR because the phase difference between EDYE and MDYE can be controlled by L_m. Fig. 8 (a) shows that the AR at the endfire direction varies with the change of L_m. Fig. 8 (b) shows that the phase difference decreases as the length L_m increases within a certain range. The proposed antenna can guarantee a nearly 90-degree difference between two orthogonal components in far field with $L_m = 34.5$ mm. Moreover, the maximum amplitude of the EDYE and MDYE in far field is along the endfire direction (the z-axis). By adjusting the amplitude of the EDYE and the MDYE with 90-degree phase difference, the dual-CP endfire antenna can be achieved.

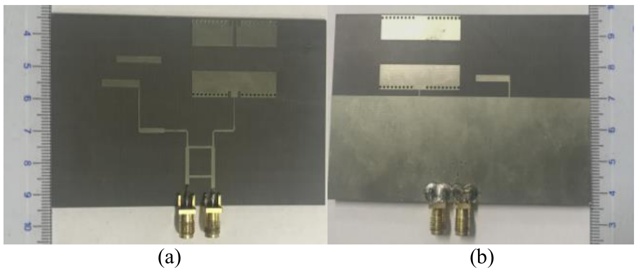

FIGURE 9. Photograph of the fabricated antenna. (a) Top view. (b) Bottom view.

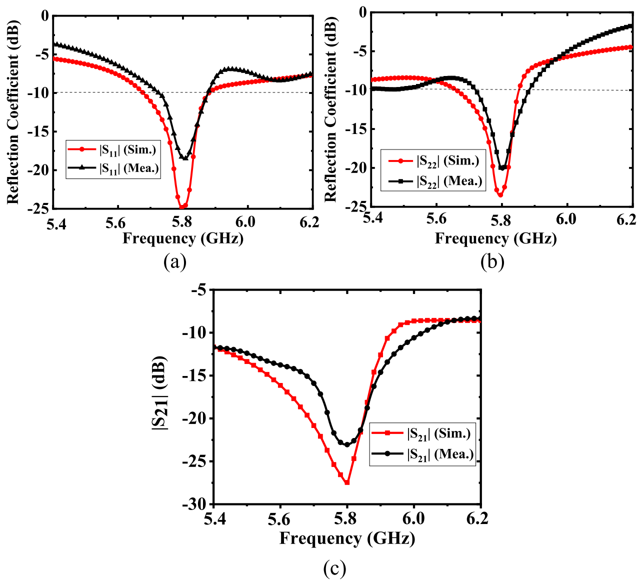

FIGURE 10. Measured and simulated S parameters of the proposed antenna. (a) Reflection coefficient of port A. (b) Reflection coefficient of port B. (c) Transmission coefficient.

IV. EXPERIMENTAL VERIFICATION

The prototype of the antenna has been fabricated to verify the proposed design. Photograph of the fabricated antenna is shown in Fig. 9. Then the antenna was also measured in the anechoic chamber to confirm the dual-CP endfire property.

The S parameters are measured using Agilent's N5230A. Measured and simulated reflection and transmission coefficients are shown in Fig. 10. Good agreements can be observed. It is worth mentioning that the isolation of two ports in the operating band is higher than 14 dB.

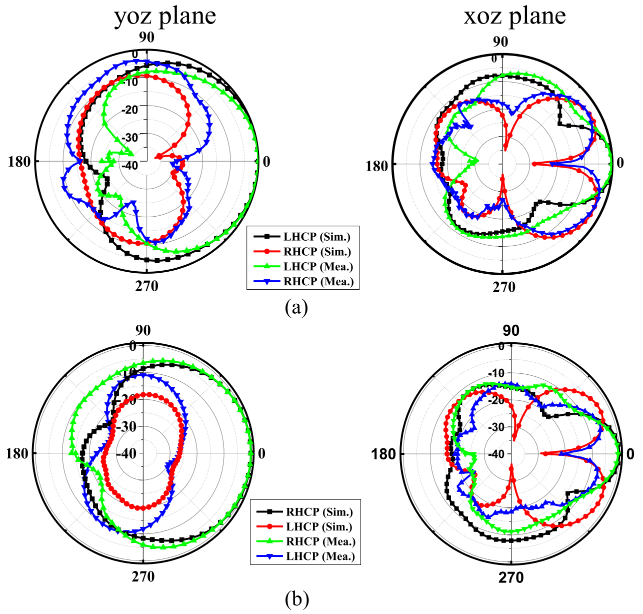

FIGURE 11. **The normalized radiation patterns on yoz and xoz plane for the proposed antenna at 5.8 GHz. (a) Port A is excited. (b) Port B is excited.**

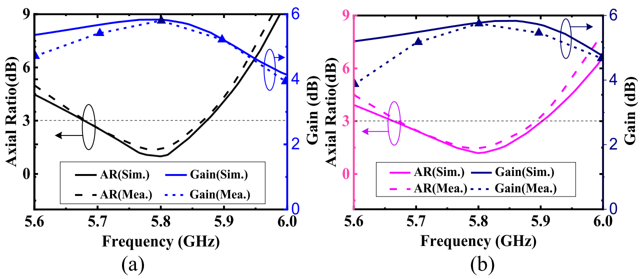

FIGURE 12. **Simulated and measured AR and endfire realized gains for the proposed antenna. (a) Port A is excited. (b) Port B is excited.**

The radiation characteristics of the antenna are also measured in anechoic chamber. The designed antenna has two ports, named port A and port B. In antenna measurements, the RF cable is linked to one port and the other port is connected with the 50-ohm matching load. Both measured and simulated normalized radiation patterns of the proposed antenna are presented in Fig. 11.

As can be seen from Fig. 11, when port A is excited, the co-polarization of the antenna is LHCP, and the cross-polarization is RHCP. The simulation and measurement results show that the LHCP is 28 and 22 dB higher than RHCP in the endfire direction. Similarly, when port B is excited, the RHCP is 29 and 22 dB higher than LHCP in the endfire direction.

The measured and simulated AR and endfire realized gains for the proposed antenna are shown in Fig. 12. As can be seen from Fig. 12, the measured results show that the 3-dB AR bandwidth are 200 MHz (5660-5865 MHz) and 220 MHz (5670-5890 MHz) with the peak gains of 5.3 and 5.2 dBic for Port A and B, respectively.

TABLE 3. **Comparison between reported works and the proposed antenna.**

Ref	Beam Direction	Dimensions (λ_0^3)	Polarization	Band-width (%)	Gain (dBi)	FTBR (dB)
[5]	Endfire	0.74×0.58×0.04	Single CP	2.5	2.6	8
[7]	Endfire	0.95×0.72×0.04	Single CP	1.9	2.3	10
[12]	Broadside	0.5×0.5×0.06	Dual CP	4	6	30
[22]	Endfire	1.7×3.1×0.07	Single LP	5	10.1	18
[23]	Endfire	1.11×1.11×0.05	Single CP	13	8	11
[27]	Endfire	N.A.	Dual CP	22.5	12.8	N.A.
This work	Endfire	1.90×1.16×0.02	Dual CP	3	5.3	18

V. CONCLUSION

A novel low profile, single layer, dual-CP endfire radiation antenna is designed. The proposed dual-CP endfire antenna is composed of a MDYE, a EDYE and a 90-degree directional coupler. The CP radiation pattern is achieved by the MDYE and EDYE, which create two orthogonal modes. Then, in order to realize the dual circular polarization modes, we introduce a 90-degree directional coupler into the proposed antenna. A comprehensive comparison with other typical CP endfire antennas is also listed in Table 3, including beam direction, dimensions, polarization, bandwidth, gain and FTBR. From Table 3, it is clear that the newly proposed antenna has a low profile planar structure (0.02λ), and can realize the dual-CP radiation mode. It produces strong endfire radiation, including a 5.2 dBic peak gain along the z-axis and a 18 dB front-to-back ratio. Therefore, the designed antenna is suitable for WLAN applications, and also provides a new option for designing an endfire array antenna.

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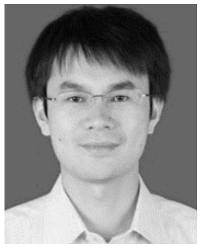
He was with the Institute, from 1983 to 2003. Since 2003, he has been with Xidian University, where he is currently a Professor with the National Key Laboratory of Antennas and Microwave Technology. His research interests include antenna theory and engineering design.



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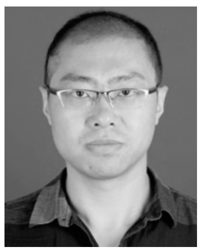

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