CPW-Fed Wideband Circularly Polarized Printed Monopole Antenna With Open Loop and Asymmetric Ground Plane

Kang Ding, Yong-Xin Guo, *Senior Member, IEEE*, and Cheng Gao, *Member, IEEE*

***Abstract*—A wideband circularly polarized (CP) printed monopole antenna with coplanar waveguide feeding is proposed. The antenna is composed of a rectangular monopole, an asymmetric ground plane, and a square-ring with an open gap at the bottom. By utilizing the asymmetric ground plane, CP radiation could be achieved at the upper band first. Then, a rectangular open loop is introduced to obtain wide-impedance bandwidth and broadband CP characteristic. The measured results demonstrate that the 10-dB impedance bandwidth reaches 96.5% (2.76 GHz, 1.48–4.24 GHz) and the 3-dB axial-ratio bandwidth is 63.3% (1.9 GHz, 2.05–3.95 GHz). In addition, parameter studies are performed, and surface current analysis is also given to show the operating mechanism of CP operation.**

***Index Terms*—Axial ratio (AR), circularly polarized, coplanar waveguide (CPW), monopole antenna.**

I. Introduction

Recently, circularly polarized (CP) antennas have received much attention in numerous communication systems such as GPS, RFID, WLAN, and WiMAX. In contrast with linearly polarized (LP), CP antennas produce distinct advantages such as insensitivity toward the equipment's orientation, resistance to inclement weather, and mitigated multipath losses. In the past few years, printed monopole antennas, due to the advantages of low profile, low cost, broadband operating bandwidths, and simple structure, have been studied in [1]–[3]. However, the monopole antennas mentioned above are all in LP operation. In general, the CP operation could be achieved by generating degenerate modes that are 90° out of phase. Many kinds of techniques have been presented for CP monopole antenna designs [4]–[10]. By utilizing the trapezoidal structure, a multiband coplanar monopole antenna with LP and CP operations was proposed in [4]. In [5], a simple printed monopole antenna having two arms with different length was also reported to introduce CP operation. In addition, simply adjusting the width of the coplanar waveguide (CPW) ground plane, CP operation at 1.57 GHz was excited by the asymmetrical ground plane in [6], but the common problem among them is the narrow CP bandwidth. Several wideband CP monopole antennas were presented in the literature [7]–[10]. By adopting a slot-monopole antenna, 30% axial-ratio (AR) bandwidth was obtained in [7]. However, the employment of a power division network led to a complex geometry and large size. Another method to produce CP operation is cutting a horizontal slit and embedding a vertical stub on the ground plane, achieving a CP bandwidth of 44.9% [8]. Meanwhile, chifre-shaped [9] or moon-shaped [10] monopole antennas have also been proposed for broadband CP radiation.

However, most of the broadband CP monopole antennas in [7]–[10] mainly utilize complex radiator structures or ground planes with slots and stubs embedded. In this letter, a simple rectangular monopole antenna with an asymmetric ground plane and an open loop is designed to achieve a broad impedance match and wideband CP operation bandwidth. Due to the use of the asymmetric ground plane, CP operation is introduced at the upper band first. In order to widen impedance and AR bandwidth, a square-ring with a gap at the bottom is placed at the left side of the monopole. The presented antenna shows a 3-dB AR bandwidth of 63.3% (1.9 GHz, 2.05–3.95 GHz), which covers WLAN (at 2.4 GHz) and WiMAX (at 3.5 GHz) frequency bands.

II. Antenna Design

A. Antenna Configuration

Fig. 1(a) illustrates the configuration of the proposed CPW-fed monopole antenna, and the fabricated photograph is also depicted in Fig. 1(b). The antenna is fabricated on top of an FR4 substrate with dimension of $W \times L \times h$, dielectric constant of 4.4, and loss tangent of 0.02. There is no metal printed on the back side of the substrate. A 50-Ω CPW feeding line with a width of w_f and two identical gaps of width g is produced to feed the rectangular monopole, which has a size of $w_s \times l_s$. Based on the slot structure in [11], an asymmetric ground plane with different height is introduced to excite upper-band CP operation and obtain a good impedance match. The CP mechanism will be explained by surface current distributions. On the basis of the monopole radiator and asymmetric ground plane, a square-ring with a gap at the bottom is employed to obtain an additional CP

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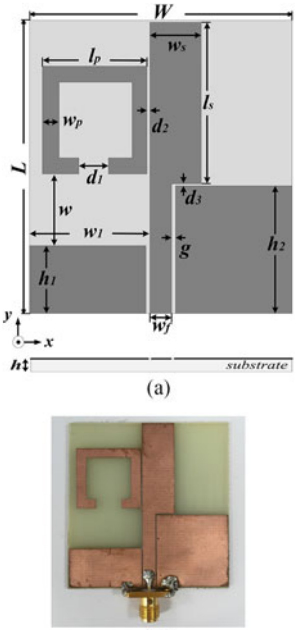

Fig. 1. Configurations and photograph of the proposed antenna. (a) Geometry of the designed antenna and (b) antenna prototype.

TABLE I
DIMENSION OF THE PROPOSED ANTENNA (UNIT: mm)

parameter	value	parameter	value
d_1	8	w_s	10
d_2	0.5	w_p	3
d_3	0.5	w_f	4
H	1	l_s	30.5
h_1	13	l_p	20
h_2	24	g	0.35
w	13.5	w_1	23
L	55	W	50

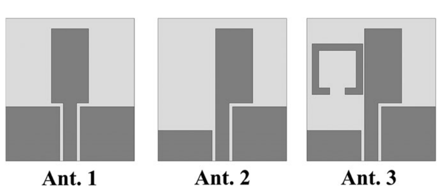

Fig. 2. Three prototypes of the monopole antenna.

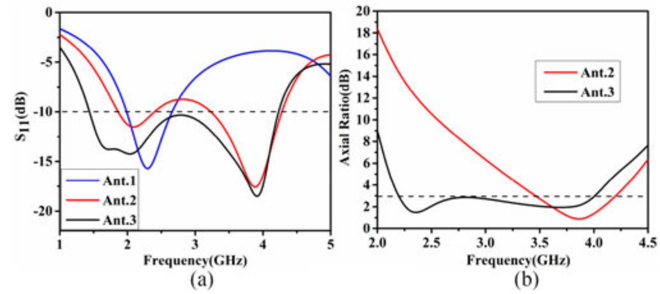

Fig. 3. Comparison of different monopole antennas: (a) S_{11}, (b) AR.

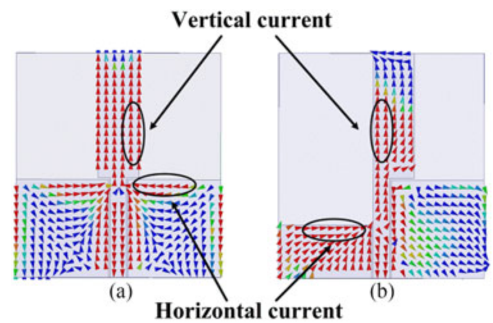

Fig. 4. Simulated surface current distributions. (a) Ant. 1 at 2.4 GHz, (b) Ant. 2 at 3.8 GHz.

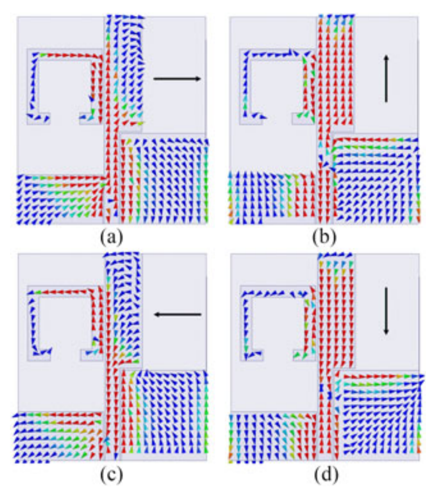

Fig. 5. Distributions of surface current on the proposed antenna at 3.0 GHz. (a) 0°, (b) 90°, (c) 180°, (d) 270°.

mode and widen impedance bandwidth. By tuning the gap size and the height of the asymmetric ground plane, two adjacent CP modes could be combined together to obtain broadband CP radiation. According to the simulation studies from ANSYS HFSS version 15, the optimized parameters are listed in Table I.

B. Operating Principle

To understand the operating principle of the designed antenna, three prototypes (Ant. 1–Ant. 3) are depicted in Fig. 2. The $|S_{11}|$ and AR performances of Ant. 1–3 are also compared in Fig. 3. First, a conventional CPW-fed monopole Ant. 1 is proposed to generate the fundamental resonant mode at 2.4 GHz, which is controlled by the quarter-wavelength of the monopole. As we know, it is difficult to generate CP radiation for a traditional monopole antenna because of the weak radiation in horizontal direction. This can be explained by the surface current distributions in Fig. 4. From Fig. 4(a), we can see that the current distributions of the two ground planes in horizontal direction are in the opposite direction. Therefore, the horizontal current is counteracted, and vertically polarized radiation could be produced due to the small horizontal components. Hence, it is LP and the value of AR in the whole band is too large, which is not shown in Fig. 3(b). The CP operation could be achieved by the excitation of two orthogonally modes with a 90° phase difference. In order to generate a horizontal component, an asymmetric ground plane and an asymmetric feeding of the monopole

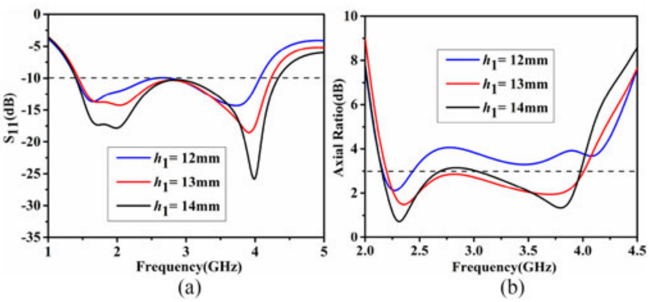

Fig. 6. Simulated results with different h_1: (a) S_{11}; (b) AR.

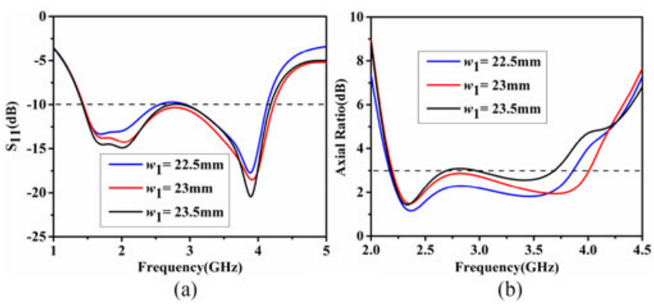

Fig. 7. Simulated results with different w_1: (a) S_{11}; (b) AR.

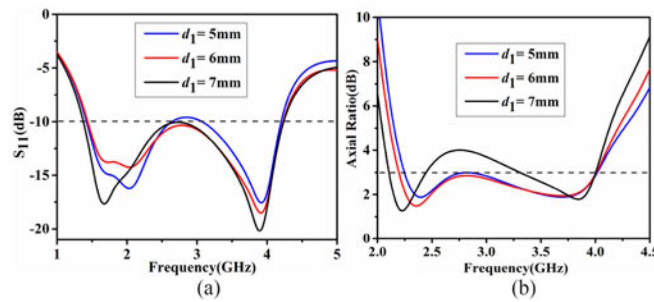

Fig. 8. Simulated results with different d_1: (a) S_{11}; (b) AR.

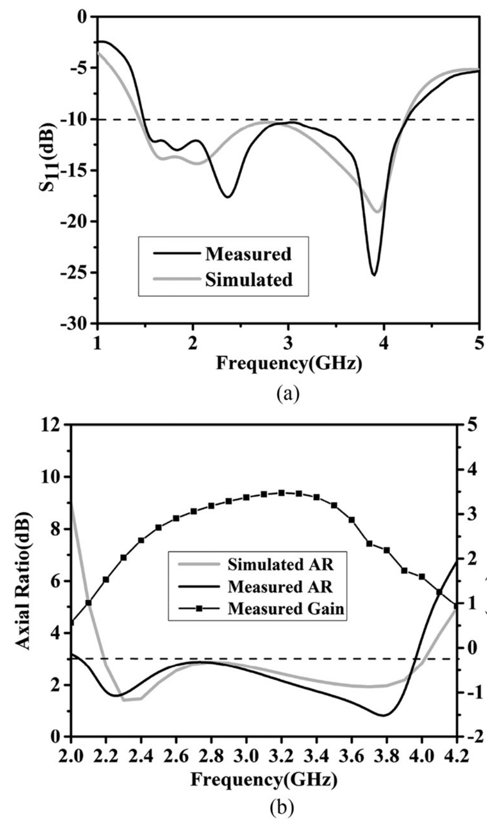

Fig. 9. Measured and simulated results for the designed monopole antenna: (a) S_{11}, (b) AR and Gain.

are adopted. Fig. 4(b) shows that horizontal currents are yielded at the left ground plane and the bottom of the monopole in Ant. 2. With the employment of the asymmetric ground plane and asymmetric feeding method, an additional resonant mode at 3.8 GHz and a narrow CP bandwidth between 3.4–4.4 GHz could be achieved simultaneously. Although CP radiation in the upper band is observed, the antenna could not possess broadband CP property. At the same time, the impedance bandwidth from 2.5–3.2 GHz is mismatched. In order to cover the WLAN band (2.4 GHz) and entire WiMAX band (3.3–3.8 GHz), a square-ring with a gap at the bottom is placed at the left part of the rectangular monopole. By employing the coupled effect between the square open-loop and the monopole, CP radiation can be generated at 2.4 GHz. The square-ring is capacitively coupled by the monopole radiator, which transmits energy on the square ring streaming like a traveling-wave mode, and therefore the CP operation in lower band is introduced. As it is revealed from Fig. 3, the lower CP band yielded by the square-ring could be merged with the upper CP mode to obtain a broad CP performance. In addition, the impedance matching in lower band is also improved to cover the whole 3-dB AR bandwidth. From the comparison results between the three antennas, Ant. 3 has both good impedance matching and wide CP bandwidth.

For the purpose of illustrating the CP principle, distributions of surface current at 3.0 GHz are analyzed in Fig. 5. Due to the current directions rotating anticlockwise, right-hand circular polarization (RHCP) wave could be achieved in the $+z$-direction.

C. Parameter Study

To get the optimized dimensions of the monopole antenna, different parameters study is analyzed. The height of the asymmetric ground plane and the gap size of the square-ring are mainly studied to show the effect on antenna performance.

The influences of the asymmetric ground plane's height are observed to have a great effect on the antenna's $|S_{11}|$ and AR in Fig. 6. With the change of h_1, both of the $|S_{11}|$ at the lower and upper bands are affected. Meanwhile, the value of AR in upper band is deteriorated when h_1 is reduced. Though wider impedance bandwidth is achieved for $h_1 = 14$ mm, the AR value becomes a little larger than 3 dB between 2.7–3.0 GHz. By considering the balance between the impedance and AR bandwidth, the optimal length is $h_1 = 13$ mm. Meanwhile, the width of the left ground plane is also investigated to study the effect of the antenna's performance. In Fig. 7(a), it is noted that the impedance bandwidth is slightly affected with the change of

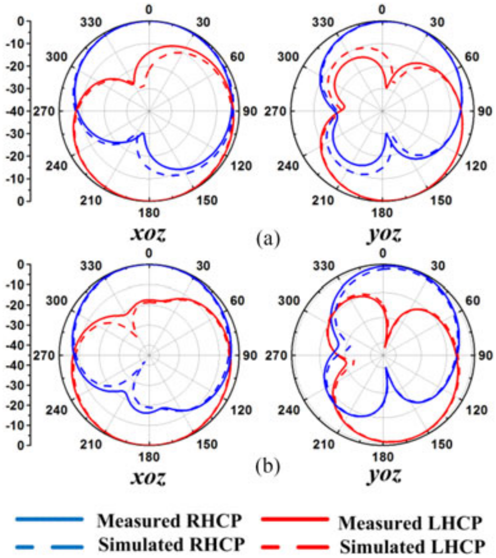

Fig. 10. Simulated and measured normalized radiation patterns in different planes: (a) 2.4 GHz, (b) 3.5 GHz.

w_1. From the simulated performances of AR, we could find that the width affects a lot on the upper CP mode while the AR in lower band remains unchanged. Thus, we can adjust the width of the left ground plane to obtain good CP behavior in upper band.

Fig. 8 illustrates the $|S_{11}|$ and AR curves by varying the value of d_1. As expected, the $|S_{11}|$ at lower band has some shifts, but the gap size has almost no influence on impedance bandwidth in the upper band. Meanwhile, the first CP mode shifts to lower band as d_1 increases. This is reasonable because the gap can control the current distributions on the loop, which leads to the generation of lower resonant CP mode. Finally, the optimal value is $d_1 = 6$ mm.

III. Experimental Verification

A prototype with the optimized dimension in Table I was measured to verify the simulated results of the designed antenna. The measured $|S_{11}|$ and simulated results are displayed in Fig. 9(a). From the figure, we can see that the measured and simulated 10-dB impedance bandwidths are 96.5% (1.48–4.24 GHz) and 98.2% (1.44–4.22 GHz), respectively. An excellent agreement is observed between them except for a little shift in lower band that is attributed to fabrication tolerance. The performances of measured and simulated AR at the broadside direction are illustrated in Fig. 9(b). It is shown that the measured 3-dB AR bandwidth ranges from 2.05–3.95 GHz with a CP bandwidth of 63.3% at the center frequency of 3 GHz. The CP bands of the presented antenna could completely cover the WLAN (2400–2484 MHz) and WiMAX (2500–2690 MHz, 3200–3800 MHz) bands. The measured gain in the broadside direction as a function of frequency is also shown in Fig. 9(b). The maximum antenna gain was 3.5 dBi at 3.2 GHz, and a peak gain between 0.5–3.5 dBi is achieved over the entire CP band. Fig. 10 shows the simulated and measured normalized radiation patterns in *xoz*-plane and *yoz*-plane of the monopole antenna at two different frequency bands of 2.4 and 3.5 GHz. Due to the bidirectional radiator, opposite circular polarization at both sides of the antenna is obtained. We can conclude that RHCP wave could be realized in the $+z$-direction within the whole band.

IV. Conclusion

A structurally simple low-profile broadband CP-printed monopole antenna is proposed and fabricated. By combining asymmetric ground plane and open loop, two adjacent CP modes could be coupled together to produce a broad 3-dB AR bandwidth. The measured 10-dB impedance bandwidth is 96.5% (2.76 GHz, 1.48–4.24 GHz), and the measured 3-dB AR bandwidth is 63.3% (1.9 GHz, 2.05–3.95 GHz). The antenna will be an attractive candidate for WLAN, WiMAX, and other broadband communications systems due to its simple structure, low profile, and wide bandwidth.

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