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Compact CPW-Fed Broadband Circularly Polarized Monopole Antenna with Inverted L-shaped Strip and Asymmetric Ground Plane

***Abstract**. The design of a coplanar waveguide-fed (CPW-fed) broadband circularly polarized printed monopole antenna is proposed. The antenna consists of a simple rectangular radiator monopole, an inverted L-shaped strip, a horizontal stub, and a modified asymmetric ground plane. Simulation results indicate that the impedance bandwidth (IBW) is 121% (1.575–6.4 GHz), and the axial ratio bandwidth (ARBW) is 64.3% (2.85–5.55 GHz). A parametric study is performed for verification. Results indicate that the proposed antenna is suitable for different wireless communications systems.*

Streszczenie.** Zaprezentowano projekt szerokopasmowej cyrkularnej jednobiegunowej anteny. Antena składa się z z prostokątnego radiatora, paska o odwróconym kształcie L I asymetrycznej płaszczyzny uziemionej. Symulacje wykazały dobrą pracę w paśmie 2.85 – 5.55 GHz. Wyniki symmulacji porównano z wynikami badania modelu.* ***Projekt szerokopasmowej cyrkularnej anteny o kształcie odwróconej litery L z zasilaniem typu CPW

Keywords: *broadband antenna, monopole antenna, circularly polarized (CP), Axial Ratio (AR)*
Słowa kluczowe: antena szerokopasmowa, antena cyrkularna

Introduction

The current demand for circularly polarized (CP) broadband antennas is increasing with the development of wireless communications. CP antennas are preferred over linearly polarized (LP) antennas because of several advantages, such as resistance to inclement weather, reduction of multipath losses, and suppression of equipment's orientation sensitivity[1–3]. Recently, printed CP monopole antennas with a simple structure, a low profile, a broad bandwidth, and low cost have been widely used in modern wireless communication systems[4–8]. However, traditional printed CP monopole antennas are LP due to their weakness in horizontal current [8–11]. Therefore, the design of printed CP monopole antennas with a compact size is an important research topic for antenna designers.

Several printed CP monopole antennas made through various techniques have been proposed [12–23], such as a straight monopole with an asymmetric ground plane [12] and an inverted C-shaped with an open rectangular loop [13]. A compact design using simple techniques has also been used to produce CP antennas. Moreover, many printed CP monopole antennas with broad impedance bandwidth (IBW) and axial ratio bandwidth (ARBW) have been presented by using a moon-shaped radiator and a ground plane [14], a rectangular monopole with an asymmetric ground plane and an open rectangular parasitic loop [15], and a straight monopole with a couple of parasitic strips [16]. Other techniques are cutting the angles of a rectangular monopole and employing an asymmetric ground plane [17], using an asymmetric triangular stub and introducing a slit in the C-shaped radiator [18], coin-shaped radiator with an asymmetric ground plane [19], and a straight monopole with a couple of parasitic strips [20]. Previous designs with broad IBW and ARBW require great effort, and bandwidth broadness is achieved at the expense of antenna dimensions.

To overcome this limitation, several wideband printed CP monopole antennas with a relatively compact size have recently been proposed, such as a coupling G-shaped parasitic strip in an inverted C-shaped monopole [21], a cross-shape monopole with a modified ground plane [22], and an inverted L-shape monopole using a hook-shape strip to the partial ground plane [23], a wide IBW and ARBW have been achieved with compact antenna size, but the IBW and ARBW must be widened to cover most wireless communications, thereby designing a broadband printed CP monopole antenna with a compact size remains an important challenge for antenna designers.

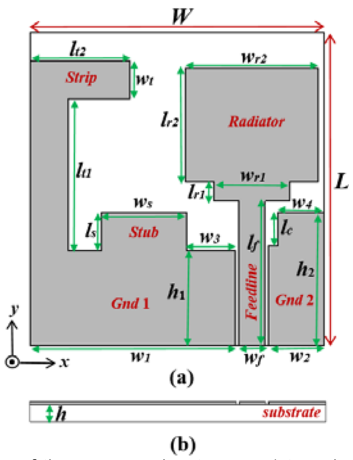

Fig. 1. Geometry of the proposed antenna: a) top view and b) side view.

Table 1. The optimized dimensions of proposed antenna

parameter	value	parameter	value	parameter	value
W	31	w_t	4	l_c	3.5
L	33	w_{r1}	8	l_s	4
w_f	2.7	w_{r2}	14	l_{t1}	16
w_1	21.6	w_s	9	l_{t2}	10.5
w_2	5.9	l_f	15.25	h	0.8
w_3	5.13	l_{r1}	2	h_1	10
w_4	4.9	l_{r2}	12	h_2	14

In this research, a simple and compact coplanar waveguide feeding (CPW-Fed) broadband CP monopole antenna is proposed. The proposed antenna is designed to obtain an IBW and an ARBW that are broader than 100% and 60%, respectively. A compact size is maintained, and neither complex structures nor passive components are used. By using a rectangular radiator and placing an inverted L-shaped strip and a rectangular stub on the left ground plane, the presented antenna has an IBW of 121% (1.575 – 6.4 GHz) and an ARBW of 64.3% (2.85–5.55 GHz). The design and development stages and the parametric study are presented in the following sections.

Antenna Design and Analysis

1. Antenna Design

The configuration of the designed antenna is illustrated in Fig. 1. The antenna is printed on an FR4 dielectric substrate (εr = 4.4, $tan\delta$ = 0.02) with dimensions of 31 × 33 × 1.6. The antenna is fed by a CPW feedline with an impedance of 50 Ω. The simulation is performed in CST Microwave Studio. The proposed antenna is based on a simple rectangular radiator, an asymmetric ground plane, and inverted L-shaped and rectangular stubs nested on the left CPW ground plane.

2. Antenna Development Stages

To describe the antenna development in detail, Fig. 2 depicts the design stages of the proposed antenna. The performance of S_{11} and AR is shown in Figs. 3 (a) and (b), respectively. By connecting the CPW feedline with the rectangular patch on the top of the substrate, the conventional CPW-Fed monopole antenna is achieved in Ant. 1. The first response is near the center frequency (3.65 GHz) with a wideband IBW of 34% (3.4 – 4.8 GHz), as observed in Fig. 3(a). Ant. 1 is purely LP. Hence, the AR values exceed 12 dB (AR > 12 dB), as shown in Fig. 3(b).

In Ant. 2, an asymmetric ground plane is applied (Fig. 2) to decrease the AR values, as shown Fig. 3(b). Ant. 2 still radiates LP waves because AR > 5 dB. However, a slight IBW extension with a high frequency is achieved, as displayed in Fig. 3(a). In Ant. 3, the feedline and the radiator are translated to the right to change the mode antenna currents. A first narrow CP band is generated at 4.5 GHz, as shown in Fig. 3(b). Furthermore, the IBW is slightly shifted to the left, as observed in Fig. 3(a).

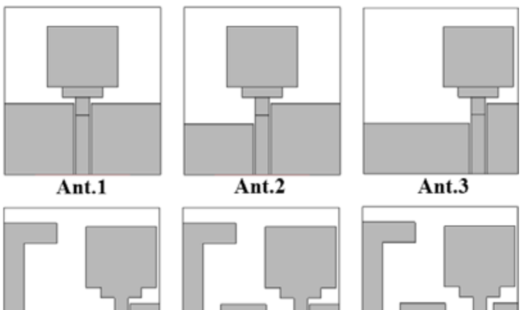

Fig. 2. Six improved prototypes of the proposed antenna

By placing the inverted L-shaped on the left corner of the left ground plane in Ant. 4, a great IBW extension toward the low frequency is achieved with an IBW of 101% (1.55–4.75 GHz). Most AR values decrease because the left strip plays an important role in balancing the vertical and horizontal components while maintaining a 90° phase deference. Thus, two new CP bands are respectively generated at 4.2 and 5 GHz, as revealed in Fig. 3(b). A horizontal stub is placed at the left ground plane of Ant. 5 to extend the IBW toward the high frequency side. The maxima limit of the IBW is shifted from 4.75 GHz to 6.75 GHz. Hence, a broadband IBW is obtained with an IBW of 123% (1.6–6.75 GHz), as depicted in Fig. 3(a). Moreover, a broad CP bandwidth is achieved with an ARBW of 52% (3.1–5.25 GHz), as shown in Fig. 3(b) where the improvement of the AR values is attributed to the horizontal stub, which contributes in supporting the horizontal currents.

Finally, in Ant. 6, a vertical slit is introduced at the right CPW ground to reduce the mutual coupling between the antenna feedline and the CPW ground. Thus, a noticeable improvement in impedance matching over a wide range of IBW is achieved, especially at middle frequencies. Fig. 3(a) reveals that the final simulated IBW is 121% (1.575–6.4 GHz), and the ARBW is extended to achieve 64.3% (2.85 – 5.55 GHz). Moreover, 56% overlap with the IBW, as shown in Fig. 3(b).

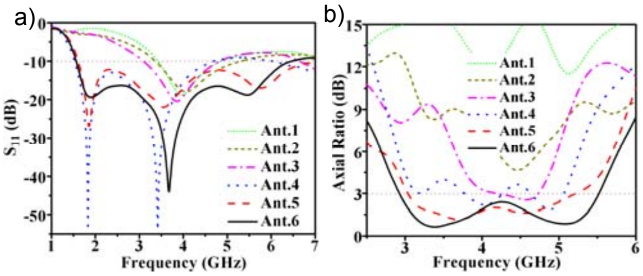

Fig. 3. Simulated results from Ant. 1 to Ant. 6: a) S11 and b) AR

3. Parametric Study

The effects of various parameters on the performances of S_{11} and AR are analyzed below. Through a parametric study, we can achieve a compact antenna size and validate the proposed CP antenna. In this section, three parameters are studied (i.e., w_1, g_1, and ls_1) by using the CST Microwave Studio. The other parameters are fixed at optimized value.

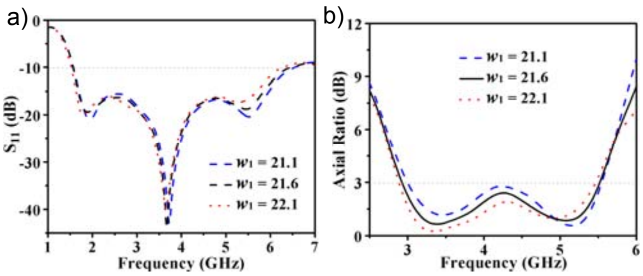

Fig. 4. Effect of w1 on the proposed antenna performance: a) S11 and b) AR

3.1 Effect of the Left CPW Ground Plane Width (w_1)

The effect of w_1 is investigated in Fig. 4. Fig. 4(a) shows that the variations of w_1 have no noticeable effect on most IBW, except that high frequencies tend to shift up as w_1 decreases. Nevertheless, these frequencies have a great effect on the CP band where all the AR values are sensitive to the changing value of w_1, as depicted in Fig. 4(b). The reason is that the width of the ground plane plays an important role in balancing the current distributions on the CPW ground planes and the parameter w_1 responsible for the location of the feedline and the rectangular radiator patch. Thus, when w_1 decreases, the AR values at middle frequencies worsen; when w_1 increases, the entire ARBW tends to shift down. Finally, to obtain the broadest IBW with good impedance matching and the widest ARBW, the optimal w_1 value is 21.6 mm.

3.2 Effects of Horizontal Stub Length (ls)

The effects of stub length (ls) on IBW and ARBW are shown in Fig. 5. Fig. 5(a) illustrates that the S_{11} at middle and high frequencies is strongly affected by the varying ls, but that at low frequency slightly changes. When ls decreases, IBW broadens toward the high frequency. However, the S_{11} values at the middle band (4–5.5) deteriorate, whereas those at this band improve as ls increases. Moreover, the maxima of IBW tends to shift to low frequency. ARBW is affected by the varying ls value because the length of the horizontal stub has an important role in supporting the horizontal current. Therefore, when *l*s decreases, the AR values deteriorate at all ARBW frequencies. Fig. 5 (b) shows that a value of 4 mm provides improved S_{11} and AR results.

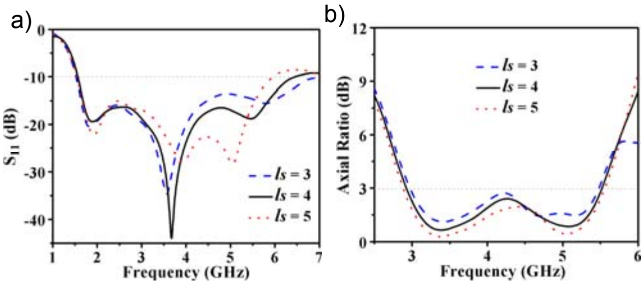

Fig. 5. Effect of *l*s on proposed antenna performances: a) S_{11} and b) AR

3.3 Effects of Vertically Slit Length (*l*c)

Finally, the effect of slit length (*l*c) on antenna performance is depicted in Fig. 6. When *l*c = 3 mm, the AR values at middle frequency improve, but ARBW reduces. In addition, S_{11} deteriorates at middle and high frequencies, except for a slight S_{11} enhancement at low frequency. When lc = 4 mm, ARBW becomes broader than that at optimal value, whereas the AR values at middle frequency are very near 3 dB. S_{11} also improves at the upper frequency range, as shown in Fig. 6(b). The value of *l*c is set to 3.5 mm to obtain the best impedance matching and a wide ARBW.

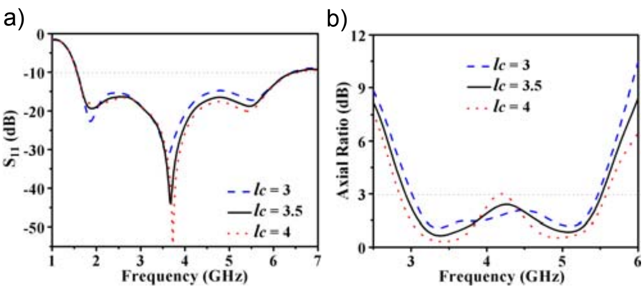

Fig. 6. Effect of *l*c on proposed antenna performances: a) S_{11} and b) AR

Results and Discussions

The optimized antenna is analyzed through the explanation of the antenna evolution steps and the parametric study. The simulation results of the designed antenna performances (S11, AR, and gain) are plotted. The simulated IBW is 121% (1.575–6.4 GHz) and centered around 4 GHz, as observed from Fig. 7(a). Meanwhile, Fig. 7(b) illustrates the simulated AR and antenna gain. The ARBW is 64.3% (2.85–5.55 GHz), which successfully covers the LTE, WiMAX, and WLAN bands. The simulated gains are 2.1, 2.4, and 3.85 dBi at 2.4, 3.5, and 5.2, respectively, where the simulated peak gain average for the CP band is between 2 and 4 dBi.

Fig. 8 shows the simulated normalized radiation patterns in the *xoz* and *yoz* planes at 3.5, 4.5, and 5.2 GHz. The proposed antenna can provide a bidirectional wave, a right-hand circular polarization in the +z direction, and a Left-hand circular polarization in the −z direction.

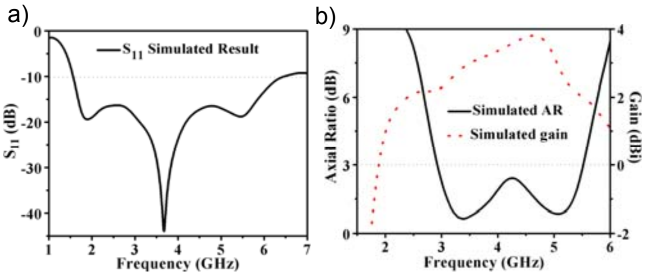

Fig. 7. Simulated results of the designed antenna: (a) S11, (b) AR, and gain

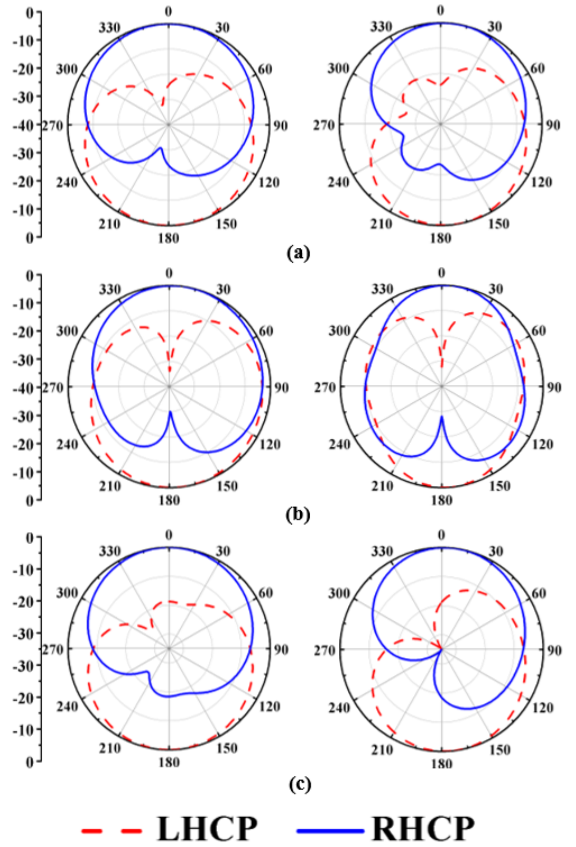

Fig. 8. Simulated radiation patterns at (a) 3.5, (b) 4.5, and (c) 5.2 GHz

For benchmarking, the proposed CP antenna is compared with the recent referred antennas in Table 2 in terms of fc, IBW, ARBW, and size. Two new columns are added in the last table in terms of ARBW/size and overlapping ratio for further investigation of the realized antenna. Table 2 indicates that in most cases, the proposed antenna offers a better antenna performance than the others in recent works.

Conclusion

A simple compact broadband CP monopole antenna is designed. A broad IBW can be achieved by translating a rectangular monopole. Moreover, a broad ARBW can be generated by placing an inverted L-shape strip and a horizontal stub. The simulated IBW and ARBW are 121% (1.575–6.4 GHz) and 64.3% (2.85–5.55 GHz), respectively. The realized CP antenna is simple, compact, low cost, and has broadband (IBW and ARBW) properties, making the antenna suitable for different wireless communications systems, especially those for indoor use.

Table 2 Comparison of proposed antenna with recent CP monopole antennas

Ref	*fc* (GHz)	IBW (%)	ARBW (%)	Size(mm^2) λ_o^2	IBW/ size	AR/ size
[12]	6.8	58.8	47.8	25 × 24 0.3	1.96	1.55
[13]	7.6	87.7	65.2	25 × 25 0.4	2.19	1.63
[14]	2.9	50	49.3	46 × 70 0.31	1.62	1.59
[15]	2.86	96.5	63	50 × 55 0.25	3.84	2.5
[16]	3.4	88	64.7	55 × 50 0.35	2.5	1.8
[17]	4.1	94	76	50 × 48 0.44	1.2	2.1
[18]	4.3	106	104	49 × 55 0.55	1.9	1.9
[19]	5.8	89.2	71	50 × 50 0.93	0.95	0.76
[20]	4.6	87.2	83.9	55 × 55 0.72	1.2	1.16
[21]	5.8	62.9	53.9	32 × 30 0.36	1.75	1.5
[22]	6	55.5	42.6	16 × 22 0.14	3.9	3
[23]	3.48	56	63.6	44 × 44 0.26	2.15	2.4
This work	4	121	64.3	31× 33 0.18	6.7	3.57

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