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Simple broadband circularly polarized monopole antenna with two asymmetrically connected U-shaped parasitic strips and defective ground plane

Hussein Alsariera[1], Z. Zakaria[2], A. A. M. Isa[3], Sameer Alani[4], M. Y. Zeain[5], Othman S. Al-Heety[6], S. Ahmed[7], Mussa Mabrok[8], R. Alahnomi[9]
[1,2,3,4,5,6,8,9]Department of Electronic and Computer Engineering,
University Teknikal Malaysia Melaka (UTeM), Malaysia
[7]Faculty of Engineering and Technology, Multimedia Universty, Malaysia

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ABSTRACT

A simple compact broadband circularly polarized monopole antenna, which comprises a simple monopole, a modified ground plane with an implementing triangular stub and two asymmetrically connected U-shaped parasitic strips, is proposed. Simulation results show that the proposed compact antenna (0.62λo×0.68λo) achieves a 10-dB impedance bandwidth (IBW) of 111% (1.7 to 5.95 GHz) and a 3-dB axial ratio bandwidth (ARBW) of 61% (3.3–6.2 GHz) with a peak gain between 2.9–4 dBi for the entire ARBW. With its broad IBW and ARBW, compact size and simple structure, the proposed antenna is suitable for different wireless communications.

Corresponding Authors:

Hussein Alsariera,
Department of Electronic and Computer Engineering,
University Teknikal Malaysia Melaka (UTeM),
Jalan Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia.
Email: husseinalsareira@gmail.com

1. INTRODUCTION

Printed monopole antennas are widely used in modern wireless communications due to its attractive features, such as small size, low profile, easy fabrication, omnidirectional coverage and ability to provide wide or broad bandwidth [1–7]. Modern wireless communications require circular polarisation (CP) more than linear polarisation (LP), especially when the transmitter and receiver antennas are not in polarisation alignment, because a circularly polarised antenna can reduce the mismatch between the transmitter and receiver. This scenario can minimise the Faraday rotation effect to provide a stable communication link and mitigate the multipath interference [8–15].

In general, CP is generated by two orthogonal electric field components, namely, horizontal (E_{Hor}) and vertical (E_{Ver}) electric field components, which have equal amplitudes and a 90° phase difference. However, the radiation of a traditional monopole antenna is LP due to the weak radiation in the horizontal component. Therefore, several techniques have been proposed in [16–24] to generate CP operation. CP was achieved in [16] by coupling a rectangular open patch with an inverted C-shaped monopole in addition to placing a vertical rectangular stub on the ground plane. CP was achieved using a simple monopole and placing an inverted L-strip on the right coplanar waveguide (CPW) ground in [17]. A compact antenna size was offered by previous designs in [14, 15], but several printed CP broadband antennas were presented in [18–22] due to the narrow impedance bandwidth (IBW) and axial-ratio bandwidth (ARBW) amongst them [14, 15]. In [18], a C-shaped monopole was modified in the ground plane by placing two triangular stubs and a simple monopole antenna coupled with two spiral strips [19], an inverted strip with an open slot in the middle of the ground plane [20], a simple radiator with two parasitic open loops. The modification also involved improving the ground plane with horizontal and vertical slots [21], a rectangular monopole and an asymmetrical ground plane in [22]. However, the printed monopole antennas in [18–22] had broad IBW and ARBW, but the bandwidth extension was achieved by extending the antenna design dimensions.

To achieve broad IBW and ARBW with a compact antenna size, [23] presented several printed antenna designs. An inverted L-shaped feeding with a hook-shaped ground [23–26], a parasitic G-shaped strip coupled with an inverted C-shaped [24] and P-shaped monopole coupled with a single parasitic strip improved the ground plane with a rectangular horizontal stub [25]. A coin-shaped radiator with an asymmetric CPW-fed ground plane [26] was observed. Previous designs with IBW and ARBW were obtained in compact sizes. Nevertheless, IBW and ARBW must be improved to cover most of wireless communications.

In this study, a simple broadband CP monopole antenna is proposed. With a parasitic strip, a broad IBW is achieved beside the dropdown whole of AR values. The first CP band is obtained by placing a triangular stub on the right side of the ground plane for further IBW and ARBW enhancement. Then, a slot is introduced in the triangular stub. The presented antenna has an IBW of 111% (1.7–5.95 GHz) and an ARBW of 61% (3.3–6.2 GHz).

2. ANTENNA DESIGN AND ANALYSIS

2.1. Antenna design

Figure 1 shows the configuration of the designed printed CP antenna. The antenna is printed at the top of a 50×55 mm^2 FR4 substrate with a 1.6 mm thickness, a 4.4 dielectric constant and a 0.02 loss tangent. The antenna is fed with a 50 Ω microstrip transmission line with width wf_1 and length lf_1. Impedance transformation is applied with wf_2 and lf_2 dimensions to obtain good impedance matching. The proposed antenna is based on simple straight-line monopole radiator, a modified ground plane and two asymmetrically connected U-shaped parasitic strips (CUSPS). Table 1 lists all the optimised parameters according to CST microwave studio.

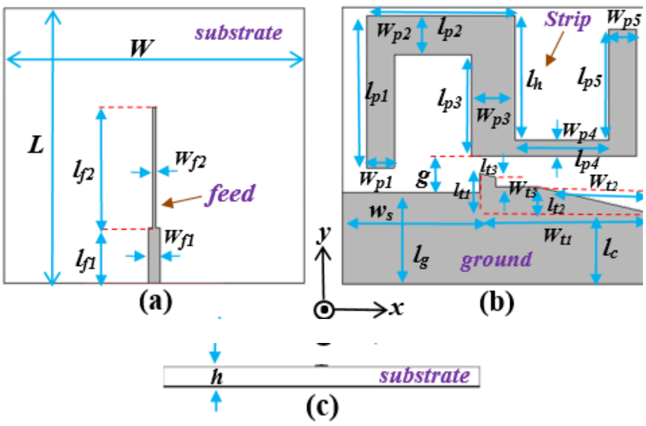

Figure 1. Prototype of proposed printed CP antenna;
(a) Parameterized front view (b) parameterized back view (c) cross-sectional view

Table 1. The optimized dimensions of proposed antenna

Parameter	Value	Parameter	value	parameter	value
W	55	wt_1	30	lp_2	27
L	50	wt_2	19	lp_3	18.5
wf_1	2.2	wt_3	7.7	lp_4	17
wf_2	0.65	w_s	25	lp_5	20
wp_1	5	g	5	lt_1	7
wp_2	7	lf_1	10	lt_2	4.2
wp_3	8	lf_2	22	lt_3	1.8
wp_4	3	l_g	16.5	lc	13
wp_5	5	lp_1	27.5	l_h	22.5

2.2. Antenna development steps

Four prototypes (Ants. 1 to Ant. 4) are illustrated in Figure 2 to explain the development steps of the proposed antenna,. S_{11} and AR simulated results are also depicted in Figure 3. Ant. 1, which is a straight-line monopole with dual width and approximately quarter wavelength length, is proposed to generate the fundamental resonance at centre frequency (3.8 GHz), as shown Figure 3 (a). The antenna radiates LP waves in this step in which the AR values are large (>15 dB). Figure 3 (b) is presented after the CUSPS in Ant. 2. Almost all IBW results are improved, especially at the low and mid frequencies, as observed in Figure 3 (a). Thus, an improvement for ARBW is achieved. However, the AR values remain large (> 7 dB); thus, the radiation of Ant. 2 is LP in the entire band.

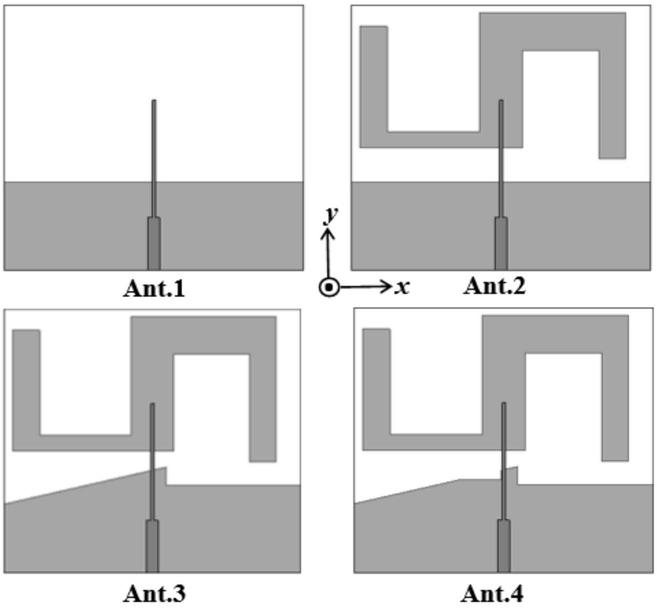

Figure 2. Four steps in the development of the proposed antenna

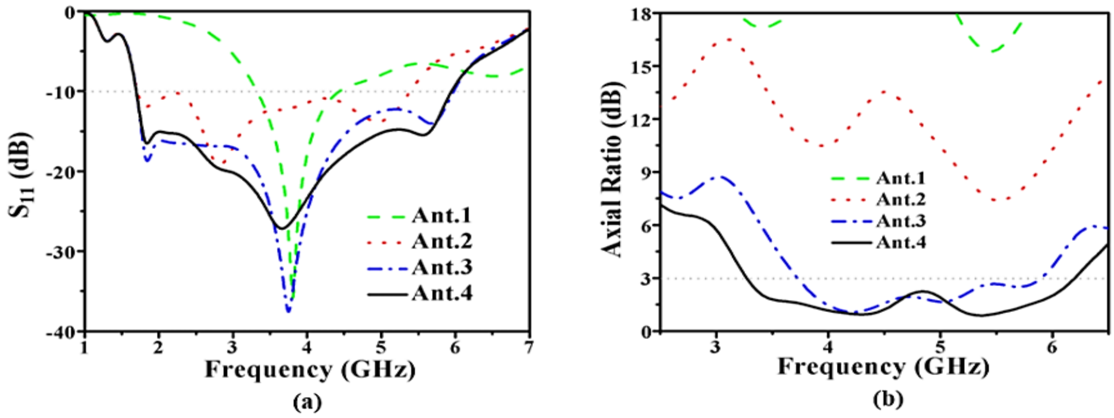

Figure 3. Simulated results of Ant.1 to Ant. 4: (a) S_{11}, (b) AR

A triangular stub with asymmetric lengths is introduced to the ground plane in Ant. 3 to generate the fundamental CP band with ARBW (3.7–5.9 GHz), as shown in Figure 3 (b). This enhancement is due to the increase in surface current paths in horizontal components and an improvement for impedance matching in the entire IBW. An opening rectangular slit in the triangular stub contributes to obtaining a balance between the amplitude of two orthogonal modes (E_{Hor} and E_{Ver}) with a maintaining correct phase deference (90°). In the improvement of the CP band at lower and upper frequencies, the ARBW is extended to become

(3.3–6.2GHz), as shown in Figure 3 (b). Figure 3 (a) shows that this slit facilitates the improvement in impedance matching at upper frequencies.

2.3. Parametric study

To assess the effects of several critical parameters on IBW and ARBW, this section presents the study on three parameters (lf_2, g, lt_1). The method of parametric study is based on [27–33].

2.3.1. Effects of upper part length of feed line lf_2

Figure 4 depicts the influences of the upper part length on antenna performance when lf_2 = 21 mm. The IBW at upper frequencies tend to become broader as length decreases. Moreover, an improvement is observed at the centre and lower frequencies; however, the S_{11} values at the 4–5.5 GHz range deteriorates when lf_2 = 23 mm. The antenna loses IBW in bandwidths ranging from 5.5 GHz to 6 GHz. In addition, the S_{11} values at lower frequencies deteriorate; whereas, the variation of lf_2 has minimal effects on AR values. The value of 22 mm is observed to provide the optimal result.

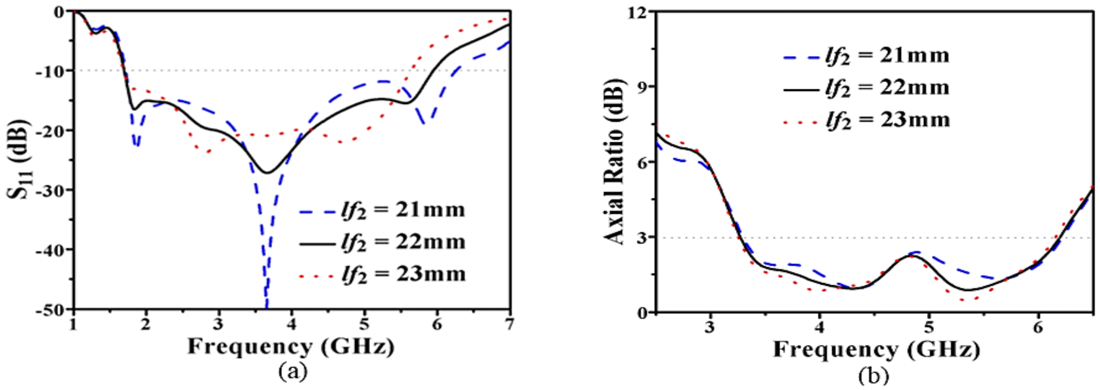

Figure 4. Variation of S_{11} and AR with respect to l_{f2}: (a) S_{11} and (b) AR

2.3.2. Effects of location of parasitic strip (CUSPS) (g)

The proposed antenna performance is investigated with changing gap (g) between the ground plane and parasitic strip. The variation of the g value plays an important role on both antenna performance (IBW and ARBW) when g = 4 mm. An improvement on IBW at the lower and middle frequencies can be achieved. The IBW is affected at the upper frequency band, as shown in Figure 5 (a). AR is strongly affected with the decreased g, as well as enlarged ARBW (from 3.2–6.2 GHz to 2.9–6.5 GHz), as shown in Figure 5 (b). When g = 6 mm, the S_{11} values deteriorate at lower and mid band, but the S_{11} values at upper band have improved, as observed in Figure 3 (a). Increasing g shrinks the ARBW and AR values at mid frequencies and become close to 3dB, as shown in Figure 5 (b). A value of 5 mm is maintained to obtain the broadest ARBW and optimal IBW result.

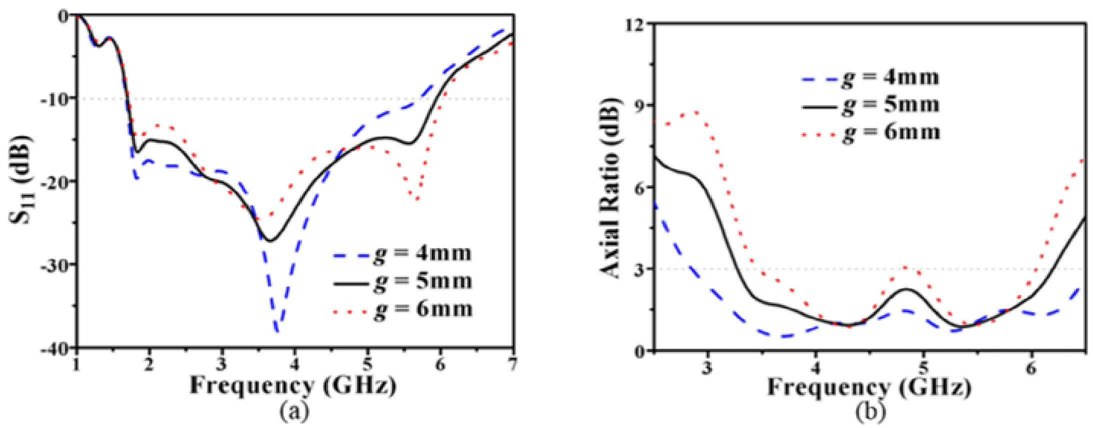

Figure 5. Variation of S_{11} and AR with respect to g: (a) S_{11} and (b) AR

2.3.3. Effects of triangular length lt_1

Figure 6 shows the effect of triangular length lt_1 on antenna performance (S_{11} and AR). Figure 6 (a) shows that as the triangular length decreases, the S_{11} values at the mid band improves. Figure 6 (b) shows that the S_{11} values at the lower and upper bands worsen, and the IBW slightly decreases. The AR values are also found to be sensitive with variations of the triangular length. Decreasing the lt_1 also decreases the ARBW. Therefore, when the triangular length lt_1 is tuned, IBW and ARBW can be controlled. The optimal value for triangular length lt_1 is 7 mm.

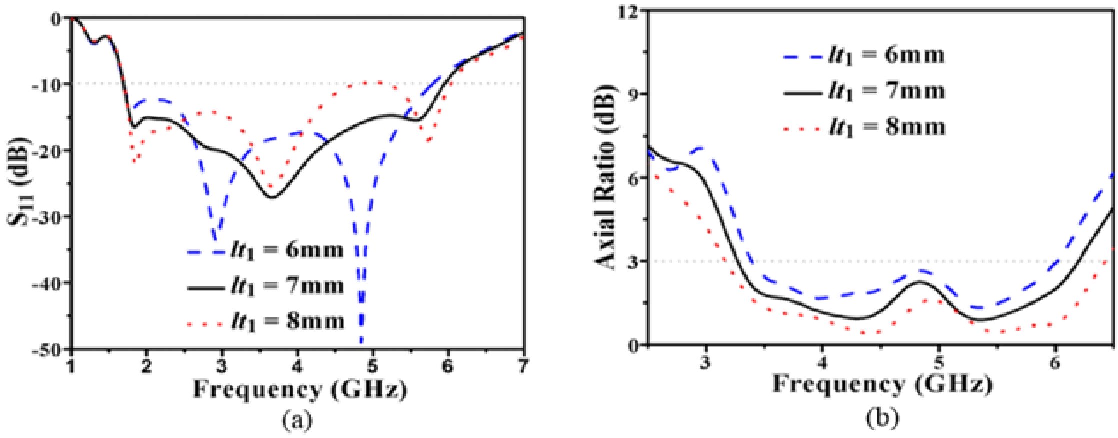

Figure 6. Variation of S_{11} and AR with respect to l_{t1}: (a) S_{11} and (b) AR

3. RESULTS AND DISCUSSIONS

The proposed antenna with optimised dimensions in Table 1 is investigated through the stages of antenna development as shown in Figure 2 and a parametric study (2.3). Figure 7 shows the final simulation results, that is, an IBW of 111% (1.7–5.95 GHz). Figure 8 shows the simulated AR and gain results in which the simulated AR is 61% (3.3–6.2 GHz). The simulated peak gain is between 2.9 and 4 dBi in the obtained CP band; hence, the maximum simulated gain is 4 dBi at 5.4 GHz.

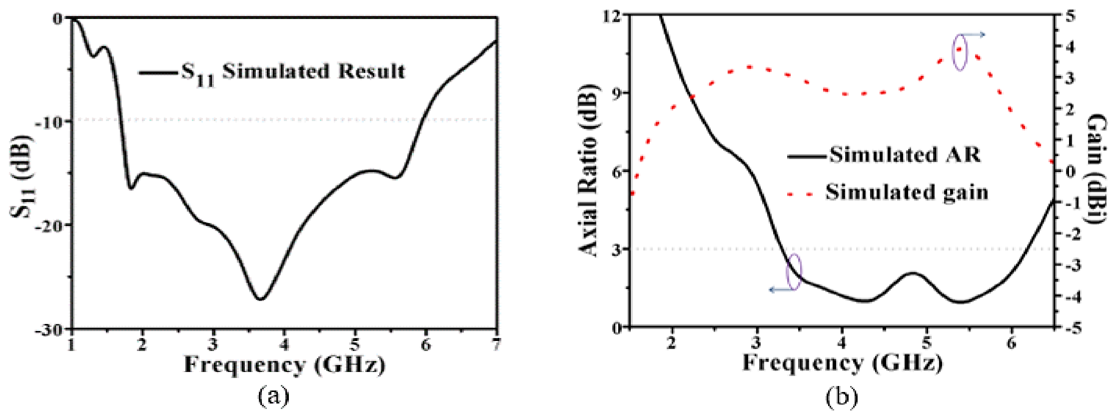

Figure 7. The simulated results of the designed antenna: (a) S_{11} and (b) AR and gain

Figure 8 depicts the simulated radiation patterns in the XZ (φ = 0°) plane and YZ (φ = 90°) of the proposed antenna at three different frequency bands of 2.4, 3.5 and 5.2 GHz. The proposed antenna can radiate CP waves via the bidirectional radiator. Two opposite sense radiations, namely, right hand circular polarisation (RHCP) and left hand circular polarisation (LHCP) at both sides are generated. The antenna radiates an RHCP wave towards the +z direction and an LHCP in the −z direction.

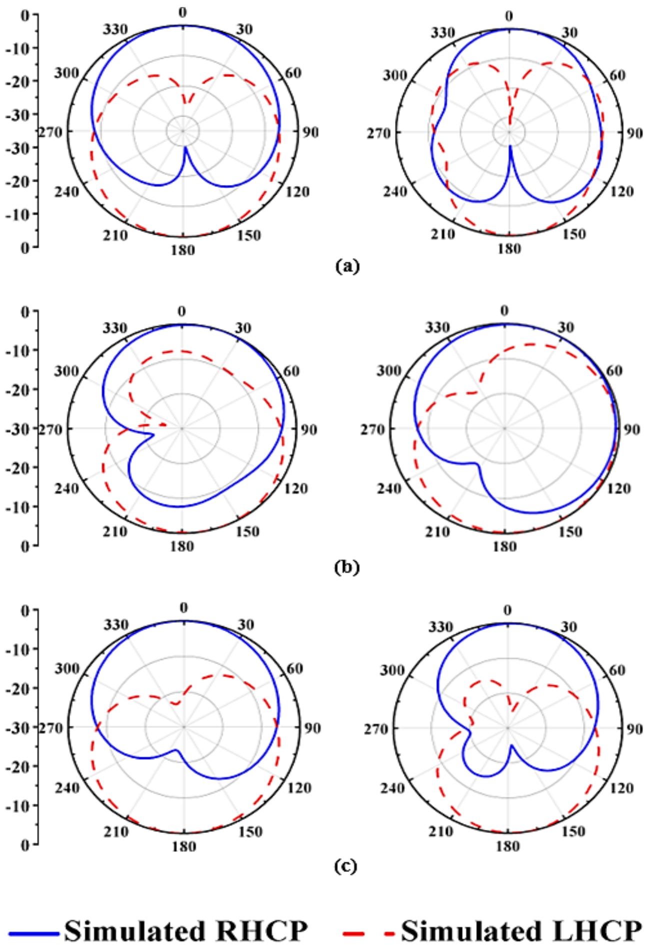

Figure 8. Simulated radiation patterns at (a) 3.5, (b) 4.8 and (c) 5.8 GHz

4. CONCLUSION

A broadband CP monopole antenna with wide IBW and ARBW, simple design and compact size is designed and investigated by coupling the parasitic strip with a modified ground plane and implementing a triangular stub. A wide CP band is achieved with total dimensions of $0.62\lambda_o \times 0.68\lambda_o$. The simulated IBW and ARBW are at 111% (1.7–5.95 GHz) and 61% (3.3–6.2 GHz) respectively. The proposed antenna can provide a bidirectional radiation with symmetry waves. Therefore, the proposed antenna is suitable for many wireless communications, especially indoor wireless ones such as WLAN, WiMAX and LTE, due to its compact size and ability to radiate CP waves from both antenna sides.

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