INTERNATIONAL JOURNAL OF MICROWAVE AND OPTICAL TECHNOLOGY,
VOL.15, NO.2, MARCH 2020

New CPW-fed Broadband Circularly Polarized Planar Monopole Antenna Based on a Couple of Linked Symmetric Square Patches

Hussein Alsariera[1]*, Zahriladha Zakaria[1]*, A. A. M. Isa[1], Othman S. Al-Heety[1], M. Y. Zeain[1] , Mussa Mabrok[1], R. Alahnomi[1] , Sameer Alani[1], S. Ahmed[2]

[1] Department of Electronic and Computer Engineering, University Teknikal Malaysia Melaka (UTeM), Jalan Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia
[2] Faculty of Engineering and Technology, Multimedia University, Jalan Ayer Keroh Lama, Bukit Beruang, 75450, Melaka, Malaysia.
E-mail: zahriladha@utem.edu.my and husseinalsareira@gmail.com

***Abstract*-A new broadband circularly polarized planar monopole antenna with coplanar waveguide feeding (CPW-fed) is proposed. This antenna consists of a couple of linked symmetric square patches (CLSSP), an asymmetric ground plane and two strips connected to the left ground plane by the CLSSP radiator and a straight strip. A broad impedance bandwidth (IBW) is achieved. Moreover, a broad axial ratio bandwidth (ARBW) is obtained by using an asymmetric ground plane and an inverted L-shaped strip. Simulation results demonstrate that IBW reaches 119% (1.56–6.18 GHz) and ARBW is 88.9% (2–5.2 GHz). The latter is completely overlapped by the simulated IBW. In addition, antenna performance is investigated by studying different parameters.**

***Index Terms*- *monopole antenna, broadband antenna, circularly polarized (CP), axial ratio (AR)*.**

I. INTRODUCTION

Circularly polarized (CP) antennas, which exhibit the advantages of reducing multipath interference, polarization mismatch losses and Faraday rotation effects and providing a flexible and stable communication link between the transmitter and the receiver, have been widely used in various modern wireless communication systems [1–3]. Regarding antenna performance, a broad impedance bandwidth (IBW), a broad axial ratio (AR) bandwidth (ARBW) and compact size are considered when selecting an antenna type and prototype design. Printed monopole antennas have received considerable attention in modern wireless communication systems because they offer many advantages, such as a low profile, a simple structure and the ability to provide broadband IBW and ARBW [4–9].

Designing a single broadband monopole antenna with CP property is highly desirable to cover multiple communication frequencies because such antenna positively and significantly affects the system size, interference, cost and complexity [10–14]. Therefore, various antenna topologies and techniques have been proposed in the literature to achieve wide ARBW for planar CP monopole antennas. Examples include a simple monopole antenna with parasitic strips [15], a loaded spiral stub [16], a C-shaped radiator patch with two asymmetric triangular stubs connected to the ground plane [17], a coin-shaped radiator [18] and a simple straight monopole antenna with two loaded open loops [19]. However, CP antennas [15–19] have relatively broader IBW and ARBW compared with those of other antenna types, but such bandwidth extension is achieved at the expense of enlarging the physical dimensions of CP antennas.

Therefore, various broadband CP monopole antennas have been proposed in [20–23] to alleviate the challenge of achieving trade-off between antenna size and achieved bandwidth

IJMOT

INTERNATIONAL JOURNAL OF MICROWAVE AND OPTICAL TECHNOLOGY,
VOL.15, NO.2, MARCH 2020

(IBW and ARBW). These antennas have an inverted L-shaped strip with a thin horizontal open slot [20], a C-shaped radiator patch in addition to loading a G-shaped parasitic strip [21], a hook-shaped partially ground plane with an inverted L-shaped feed line [22] and a cross-shaped radiator with a modified ground plane [23]. Although the techniques proposed in [20–[24] are used to achieve a wide CP band with compact size, IBW and ARBW remain narrow. To cover most wireless communication systems with a relatively compact size, a compact CP monopole antenna with broader IBW and ARBW is desirable.

In the present letter, a simple and compact coplanar waveguide (CPW)-fed CP monopole antenna is proposed. This antenna is designed to achieve broad IBW and ARBW without the use of slots or passive components. It provides a good trade-off ratio between achieved bandwidth (IBW, ARBW) and antenna size due to its use of a couple of linked symmetric square patches (CLSSP) and straight and inverted L-shaped strips that are connected to the left CPW ground. The designed antenna obtains an IBW of 119% (1.56–6.18 GHz), which is considerably wider than those in recent studies. Meanwhile, ARBW reaches 88.9% (2–5.2 GHz).

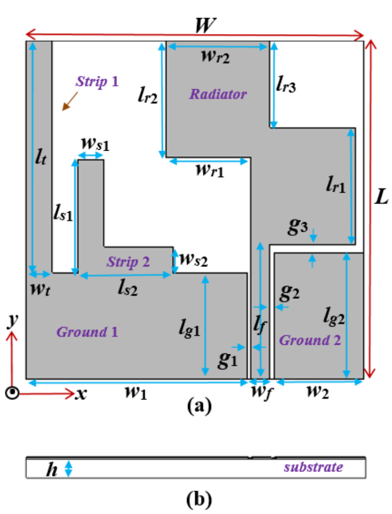


Fig. 1. Proposed printed CP antenna: (a) front and (b) side views

II. ANTENNA DESIGN AND ANALYSIS

A. *Antenna Design*

Figure 1 presents the configuration of the proposed antenna. The antenna is printed on top of a $W \times L$ mm^2 FR4 substrate with a dielectric constant of 4.4, a thickness of 0.8 mm^2 and a loss tangent of 0.02. The proposed antenna is fed by a 50 Ω microstrip line on the bottom side with *w* (width) and *l* (length). The gap between the feed line and the CPW ground is *g*. The dimensions of the antenna prototype are optimized using CST Microwave Studio and presented in Table 1.

Table 1: Dimensions of the proposed antenna (Unit: mm)

Parameter	Value	Parameter	Value	Parameter	value
W	39	l_{s1}	13	l_{g1}	12.25
L	39	l_{s2}	11	l_{g2}	14.5
w_f	2.2	l_{r1}	13.5	g_1	0.5
w_1	25.5	l_{r2}	13.5	g_2	0.5
w_2	10.3	l_{r3}	10	g_3	1
w_t	3	l_f	15.5	w_{r1}	9.9
w_{s1}	3	l_t	26.75	w_{r2}	12.1
w_{s2}	3	h	0.8	t	0.035

B. *Antenna Development Stages*

The structure topology of the coplanar waveguide (CPW-Fed) antenna is considered as one of most suitable ones for broadband CP printed monopole antennas due to its different advantages. These advantages include the ability to provide wideband, broadband, or ultra-wideband IBW with compact size and obtain broadband CP bandwidth; uniplanar geometry; omnidirectionality; and easy integration with broadband communication systems [25],[26].

The main drawback of the CP monopole antenna is the manner of obtaining a broad CP bandwidth with its compact size. To overcome this limitation, we propose a geometry with a left strip and modified ground plane so as to extend the IBW and CP band, respectively, without maximizing the antenna size.

INTERNATIONAL JOURNAL OF MICROWAVE AND OPTICAL TECHNOLOGY,
VOL.15, NO.2, MARCH 2020

Ant.1 is a normal planar monopole antenna that consists of the two rectangular monopoles, the length of the two radiator patch is approximately a quarter wavelength, and the initial value of patch length (l_o) is obtained by using this formula:

$$l_o = l_{r1} + l_{r2} \approx \frac{\lambda_o}{4} = \frac{\lambda_r}{4\sqrt{\varepsilon_{eff}}} = \frac{c}{4 f_r \sqrt{\varepsilon_{eff}}}$$

Where

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2}$$

Where, λ_r is the free-space wavelength of the monopole resonant frequency f_r, ε_{eff} is the approximated effective dielectric constant and c is the speed of light.

Then the development of the proposed antenna design is based on the parametric study. The dimensions of the stub and strips are also varied to obtain the broad IBW and ARBW.

To explain the proposed antenna design procedure, five prototypes are presented in Figure 2. The simulated S_{11} and AR results are plotted in Figures 3 (a) and 3 (b) respectively. A conventional CPW-fed monopole antenna is improved by using two ground planes with symmetric lengths. In additional to placing a microstrip line with a length of approximately a quarter wavelength and a radiator patch (i.e. CLSSP) above the substrate, as depicted in Figure 2 Ant.1. The feed line length, ground length and radiator dimensions are optimised to obtain the best impedance matching and the fundamental resonance at the centre frequency with an IBW of 1.25 GHz (3.5–4.75 GHz), as shown in Figure 3 (a). At this stage, the antenna is linearly polarised (LP) because the AR values are extremely large (AR > 13 dB), as observed in Figure 3 (b). To generate the second resonant frequency at lower frequencies and extend the IBW at the centre frequency to the upper frequency side, the width of the left CPW ground is tuned, as depicted in Figure 2 Ant. 2. A slight improvement in AR values is achieved for the full band except for the AR values at the band (4.8–5.75 GHz), as shown in Figure 3 (b). Nevertheless, the AR values remain large (AR > 10 dB). Thus, the radiation wave of the proposed antenna at this stage is still LP.

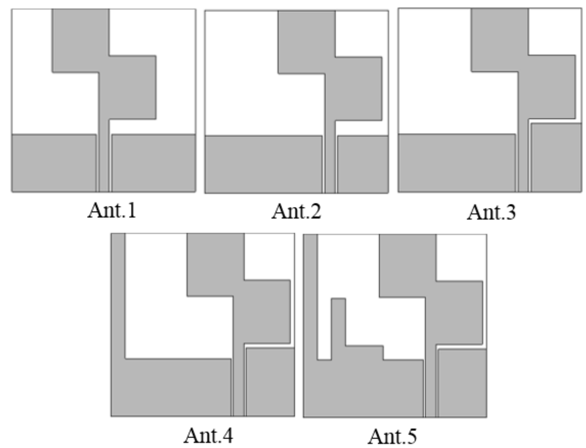


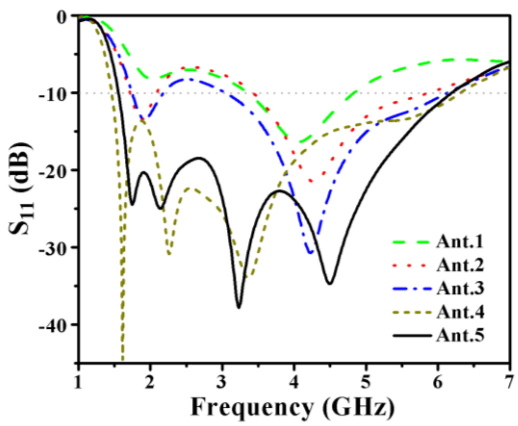
Fig. 2. Development of the proposed antenna.

To further improve IBW and ARBW, an asymmetric ground plane is applied by tuning the length of the right CPW ground plane (l_{g2}), as depicted in Figure 2 Antenna 3. The simulated results of Antenna 3 exhibit better antenna performance compared with that of Antenna 2, as shown in Figures 3 (a) and 3 (b). In Antenna 4, a simple straight strip is placed on the left edge of the left CPW ground plane to enlarge IBW at the lower and upper frequencies and further improve the S_{11} values in the entire IBW, particularly at the mid-frequency band, as observed in Figure 3 (a). Moreover, the straight strip plays an important role in AR enhancement, generating dual CP bands at 2.9 GHz and 4.6 GHz with 0.8 GHz (2.6–3.4 GHz) and 0.85 GHz (4.25–5.1 GHz), respectively, as shown in Figure 3 (b).

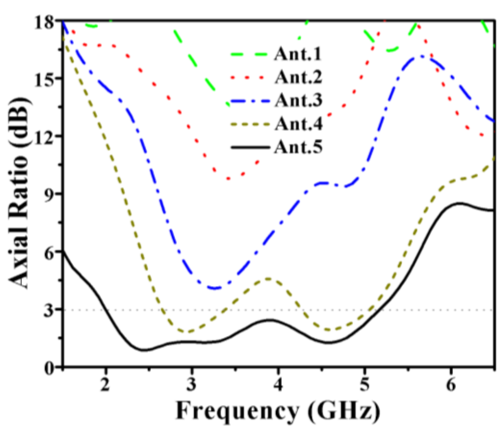
Lastly, in Antenna 5, an inverted L-shaped strip is introduced into the left side of the CPW ground plane to improve the S_{11} values, as shown in Figure 3 (a), and to merge the dual CP bands, shift the minimum of AR towards the lower frequencies from 2.6 GHz to 2 GHz and slightly

INTERNATIONAL JOURNAL OF MICROWAVE AND OPTICAL TECHNOLOGY,
VOL.15, NO.2, MARCH 2020

shift towards the upper frequencies, as shown in Figure 3 (b). The final simulation results of the proposed antenna (Antenna 5) are an IBW of 4.62 GHz (1.56–6.18 GHz) and an ARBW of 3.2 GHz (2–5.2 GHz), as shown in Figures 3 (a) and 3 (b).



(a)

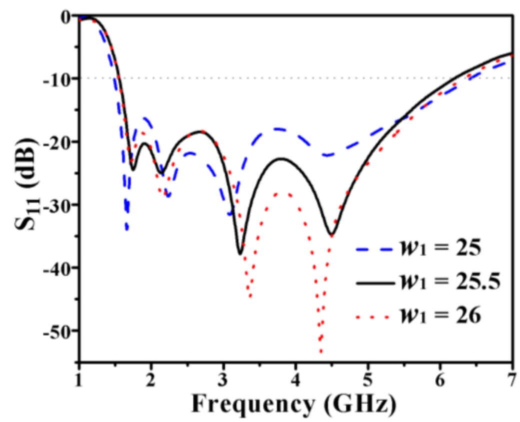


(b)

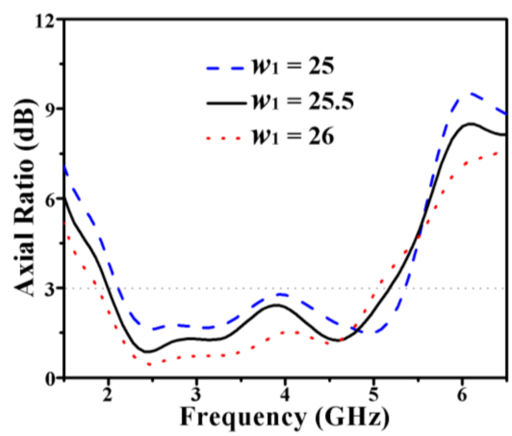
Fig. 3. Simulation results of Antennas 1 to 5: (a) S_{11} and (b) AR

Lastly, in Antenna 5, an inverted L-shaped strip is introduced into the left side of the CPW ground plane to improve the S_{11} values, as shown in Figure 3 (a). to merge the dual CP bands, shift the minimum of AR towards the lower frequencies from 2.6 GHz to 2 GHz and slightly shift towards the upper frequencies, as shown in Figure 3 (b). The final simulation results of the proposed antenna (Antenna 5) are an IBW of

4.62 GHz (1.56–6.18 GHz) and an ARBW of 3.2 GHz (2–5.2 GHz), as shown in Figures 3 (a) and 3 (b).



(a)



(b)

Fig. 4. Simulation results of the optimized antenna with different w_1 values: (a) S11 and (b) AR.

C. *Parametric Study*

To understand the contribution of different parameters to the IBW and ARBW simulation results, three parameters are analyzed, namely, the left ground plane width (*w*1), the gap between the left ground plan e and the feed line (*g*1) and the inverted L-shaped length (*ls*1) using CST Microwave Studio and applying the method in [27],[28], The other parameters remain constant at an optimal value, as shown in Table 1.

INTERNATIONAL JOURNAL OF MICROWAVE AND OPTICAL TECHNOLOGY,
VOL.15, NO.2, MARCH 2020

1. *Effects of w_1*

Figure 4 illustrates the effects of varying w_1 values on antenna performance (S_{11} and AR). IBW becomes broader as w_1 decreases, but a slight interruption occurs at mid-frequency, as shown in Figure 4 (a). In addition, the entire ARBW is sensitive with varying w_1 values. ARBW tends towards the lower or upper frequency bands when w_1 increases or decreases, as shown in Figure 4(b). Thus, varying w_1 can achieve broader IBW and the best AR values. Accordingly, w_1 = 25.5 mm is selected to obtain the broadest IBW with acceptable ARBW.

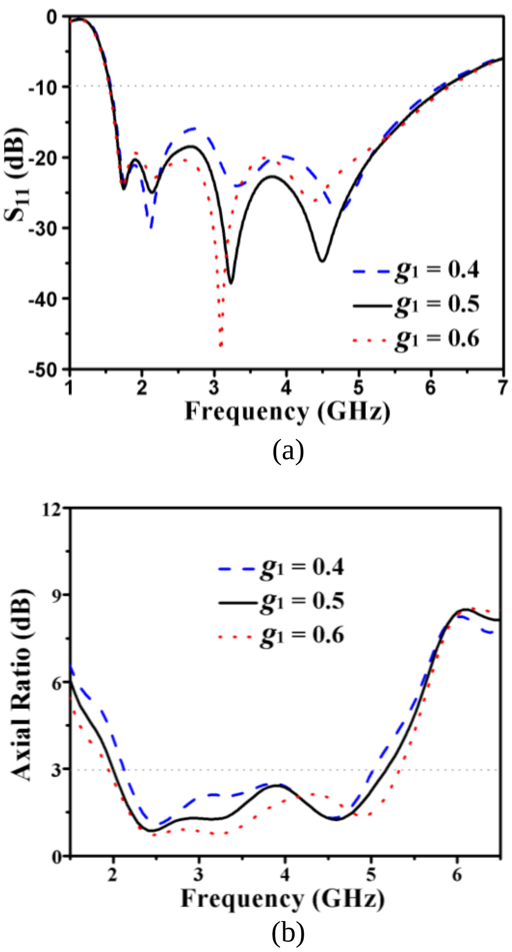


Fig.5. Simulation results of the optimized antenna with different g_1 values: (a) S11 and (b) AR.

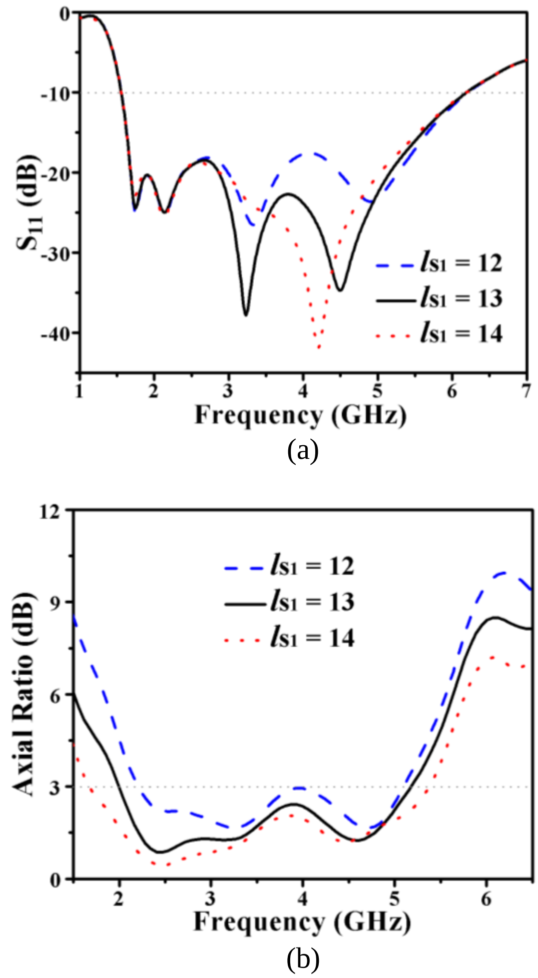


Fig. 6. Simulation results of the optimized antenna with different l_{s1} values: (a) S_{11} and (b) AR.

2. *Effects of g_1*

Figure 5 shows S_{11} and AR versus g_1. This figure indicates that g_1 exerts considerable impact on IBW at mid-frequency. The S_{11} values worsen with decreasing g_1 value. In addition, ARBW contracts with decreasing g_1 value. When g_1 = 0.6, the S_{11} values at 2–3.4 GHz improve but those at the upper frequencies deteriorate, as indicated in Figure 5 (a). Meanwhile, the AR values improve with increasing g_1 as observed in Figure 5 (a). Lastly, to obtain the broadest ARBW with good impedance matching, the optimal value for g_1 is set as 0.5 mm.

INTERNATIONAL JOURNAL OF MICROWAVE AND OPTICAL TECHNOLOGY,
VOL.15, NO.2, MARCH 2020

3. Effects of ls_1

The S_{11} and AR of the proposed antenna are investigated with varying lengths ls_1. As shown in Figure 6, the parameter ls_1 considerably influences the S_{11} values at the mid and upper frequency bands. By contrast, it does not have any noticeable impact on the S_{11} values at the lower frequency band, as depicted in Figure 6 (a). Meanwhile, changing the value of ls_1 has a remarkable effect on antenna AR values. When ls_1 decreases with respect to the optimal value, the minimum of ARBW tends to shift towards the high-frequency band from 2 GHz to 2.2 GHz. Meanwhile, ARBW is enlarged with an increase in ls_1, as shown in Figure 6 (b). The value ls_1 = 13 mm is selected to obtain the best impedance matching and optimised ARBW.

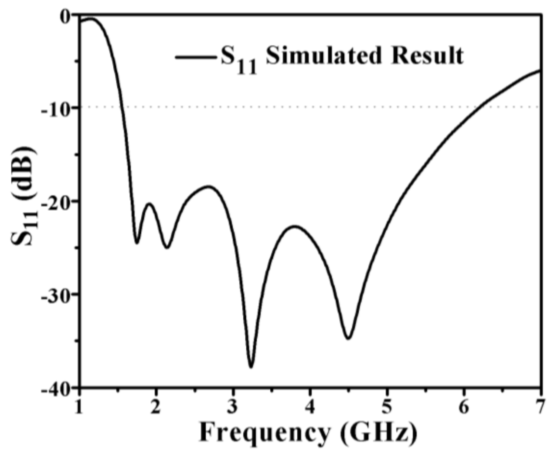
III. RESULTS AND DISCUSSIONS

As indicated in Table 1, all the dimensions of the proposed antenna have been optimized to obtain the best impedance matching with broad IBW and ARBW. The antenna was designed using CST Microwave Studio, as depicted in Figure 1.

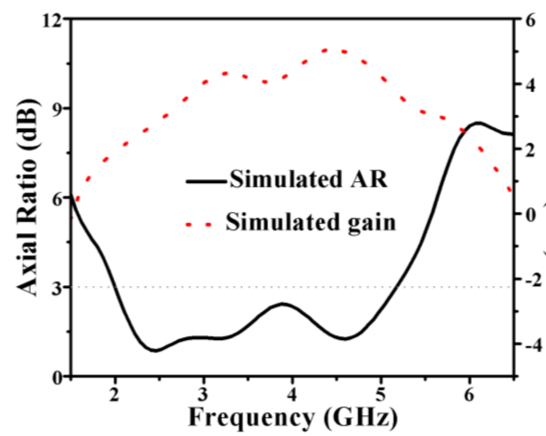
Figure 7 shows the simulation results for S_{11} and AR and the realized gain results of the proposed antenna. As indicated in Figure 7 (a), excellent impedance matching is achieved because all the S_{11} values are below -18 dB with a broad IBW of 119% (1.56–6.18 GHz). Figure 7 (b) illustrates that the proposed antenna exhibits high CP purity because all the AR values are below 2.5 dBi.

The obtained ARBW is 88.9% (2–5.2 GHz), with 70% overlapping with IBW. A stable realized gain is achieved, as shown in Figure 7 (b), where the maximum realised gain is 5 dBi at 4.45 GHz, with a peak gain between 2–5 dBi for the entire ARBW and an average realized gain of 2.3 dBi for the entire IBW.

Figure 8 depicts the radiation pattern of the proposed antenna at 2.4, 3.5 and 5.2 GHz in the xz (0°) and yz (90°) plane. The proposed antenna can offer a bidirectional radiation pattern with left hand circular polarisation in the +z direction and right-hand circular polarization in the −z direction. To enhance the antenna gain and achieve a unidirectional radiation pattern, a metallic reflector is employed at λ/2 distance below the original antenna, but this may affect the IBW and ARBW [29],[30].



(a)



(b)

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

To benchmark the proposed CP monopole antenna, the antenna is compared with recent broadband CP monopole antennas in terms of IBW, ARBW and size. In addition, two new comparison terms are added to Columns 6 and 7 for further investigation and to easily understand

INTERNATIONAL JOURNAL OF MICROWAVE AND OPTICAL TECHNOLOGY,
VOL.15, NO.2, MARCH 2020

the trade-off between the achieved IBW and ARBW and antenna size.

As indicated in Table 2, the proposed antenna exhibits the best trade-off between the achieved IBW, ARBW and antenna size with a factors of 4.6 and 3.33 respectively, in additional to the proposed antenna has the superiority in terms of IBW and ARBW broadness and size compactness in most cases, especially for that antennas with similar centre frequency of the proposed antenna.

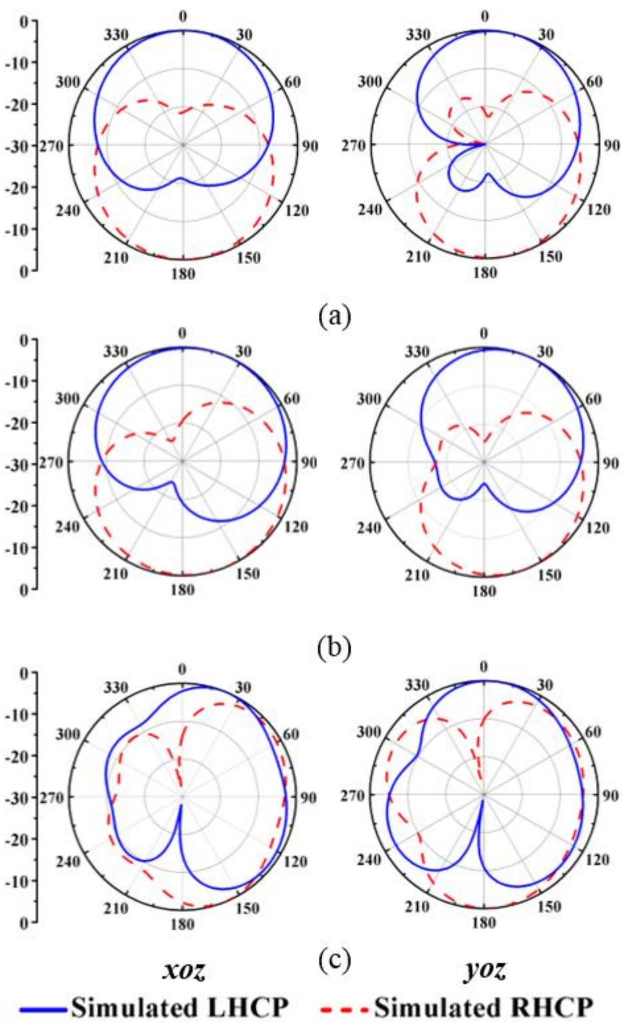


Fig. 8. Simulated radiation patterns at (a) 2.4, (b) 3.5 and (c) 5.2 GHz

Table 2: Comparison of the proposed antenna with recently developed CP monopole antennas

Ref	*fc* (GHz)	IBW (%)	ARBW (%)	Size(mm^2) λ_o^2	IBW/ size	AR/ size
[15]	3.4	88	64.7	55 × 50 0.35	2.5	1.8
[16]	4.1	94	76	50 × 48 0.44	1.2	2.1
[17]	4.3	106	104	49 × 55 0.55	1.9	1.9
[18]	5.8	89.2	71	50 × 50 0.93	0.95	0.76
[19]	4.6	87.2	83.9	55 × 55 0.72	1.2	1.16
[20]	6.8	58.8	47.8	25 × 24 0.3	1.96	1.55
[21]	5.8	62.9	53.9	32 × 30 0.36	1.75	1.5
[22]	3.48	56	63.6	44 × 44 0.26	2.15	2.4
[23]	6	55.5	42.6	16 × 22 0.14	3.9	3
This work	3.9	119	88.9	39 × 39 0.25	4.6	3.33

VI. CONCLUSION

A compact CP printed monopole antenna with asymmetric ground plane is presented and analysed in this work. A straight strip is placed on the left ground plane to broaden IBW and an inverted L-shaped strip is also introduced into the left ground plane to broaden and improve ARBW. The simulation results show that the antenna has broad IBW and ARBW of 119% (1.56–6.18 GHz) and 88.9% (2–5.2 GHz) respectively. Moreover, the proposed CP antenna has overlapping ARBW and IBW of 70%. The antenna is compact and has a simple structure, low cost, broad IBW and ARBW and the ability to provide bidirectional radiation waves, making it suitable for many wireless communication systems, particularly indoor wireless communication systems due to its CP property.

ACKNOWLEDGMENT

The authors are grateful to Universiti Teknikal Malaysia Melaka for GRA grant number (06-01-14-SF0142L00028).

INTERNATIONAL JOURNAL OF MICROWAVE AND OPTICAL TECHNOLOGY,
VOL.15, NO.2, MARCH 2020

REFERENCES

[1] U. Ullah and S. Koziel, "A Novel Coplanar-Strip-Based Excitation Technique for Design of Broadband Circularly Polarization Antennas with Wide 3 dB Axial Ratio Beamwidth," *IEEE Trans. Antennas Propag.*, vol. 67, pp. 4224–4229, Jan. 2019.

[2] H. Sariera, Z. Zakaria, A. A. M. Isa, and R. Alahnomi, "A Review on monopole and dipole antennas for in-building coverage applications," *Int. J. Commun. Antenna Propag*., vol. 7, pp. 386–396, May. 2017.

[3] H. Zhang, Y. Guo, and G. Wang, "A Wideband Circularly Polarized Crossed-Slot Antenna with Stable Phase Center," *IEEE Antennas Wirel. Propag. Lett.*, vol. 18, pp. 941–945, May. 2019.

[4] H. Zhai, D. Yang, L. Xi, and D. Feng, "A new CPW-fed broadband circularly polarized printed monopole antenna for UWB application," *Microw. Opt. Technol. Lett.*, vol. 60, pp. 364–369, Feb. 2018.

[5] M. S. Ibrahim, "Low-Cost, Circularly Polarized, and Wideband U-Slot Microstrip Patch Antenna with Parasitic Elements for WiGig and WPAN Applications," *Proc. of 13th European. Conf. on Antennas and Propagation*, Krakow, Poland, pp. 1453–1456,Sep. 2019.

[6] A. M. Ibrahim, I. M. Ibrahim, and N. A. Shair, "A Compact Quad Bands-Notched Monopole antenna for Ultra-Wideband Wireless Communicatione," *RELIGACION*, vol. 17, , pp. 815–24, Jul. 2019.

[7] A. M. Ibrahim, I. M. Ibrahim, and N. A. Shair, "A Compact Sextuple Multi-Band Printed Monopole Antenna," *Opcion*, vol. 86, pp. 1448–1467, Jun 2018.

[8] A. M. Ibrahim, I. M. Ibrahim, and N. A. Shairi, "Design a Compact Wide Bandwidth of a Printed Antenna using Defected Ground Structure," *J. Adv. Res. Dyn. Control Syst*, vol. 11, pp. 1065–1076, Oct. 2019.

[9] A. Alhegazi, Z. Zakaria, N. A. Shairi, R. A. Alahnomi, and H. Alsariera, "Reconfigurable Filtering-Antenna with triple Band Notches for UWB Applications," *Int. J. Eng. Res. Technol.*, vol. 12,pp. 3076–3081. Dec, 2019.

[10] K. Ding, Y. X. Guo, and C. Gao, "CPW-Fed Wideband Circularly Polarized Printed Monopole Antenna with Open Loop and Asymmetric Ground Plane," *IEEE Antennas Wirel. Propag. Lett.*, vol. 16, pp. 833–836, Sep. 2017.

[11] R. Xu, J. Y. Li, and J. Liu, "A Design of Broadband Circularly Polarized C-Shaped Slot Antenna with Sword-Shaped Radiator and Its Array for L/S-Band Applications," *IEEE Access*, vol. 6, pp. 5891–5896, Dec. 2017.

[12] H. S. M. Sariera, Z. Zakaria, and A. A. M. Isa, "Broadband CPW-Fed Monopole Antenna for Indoor Applications," *J. Telecommun. Electron. Comput. Eng*., vol. 10, pp. 31–34, Apr. 2018.

[13] M. Y. Zeain, M. Abu, Z. Zakaria, H. S. M. Sariera, and H. Lago, "Design of helical antenna for wideband frequency," *Int. J. Eng. Res. Technol.*, vol. 11, pp. 595–603, Apr. 2018.

[14] H. Sariera, Z. Zakaria, and A. A. M. Isa, "A Broadband P-Shaped Circularly Polarized Monopole Antenna with a Single Parasitic Strip," *IEEE Antennas Wirel. Propag. Lett.*, vol. 18, pp. 2194–2198, Sep. 2019.

[15] K. Ding, C. Gao, Y. Wu, D. Qu, and B. Zhang, "A Broadband Circularly Polarized Printed Monopole AntennaWith Parasitic Strips," *IEEE Antennas Wirel. Propag. Lett*., vol. 16, pp. 2509–2512, Jul. 2017.

[16] Q. Chen, B. Li, X. Min, H. Zhang, and L. Yang, "Wideband Inverted-L Microstrip-via-Fed Circularly Polarized Antenna with Asymmetrical Ground for WLAN/Wimax Applications," *Frequenz*, vol. 72, no. 7–8, pp. 333–341, 2017.

[17] H. Tang, K. Wang, R. Wu, C. Yu, J. Zhang, and X. Wang, "A Novel Broadband Circularly Polarized Monopole Antenna Based on C-Shaped Radiator," *IEEE Antennas Wirel. Propag. Lett.*, vol. 1225, pp. 5–8, Mar. 2016.

[18] T. Chen, J. Zhang, and W. Wang, "A Novel CPW-Fed Planar Monopole Antenna with Broadband Circularly Polarization," *Prog. Electromagn. Res. 84*, vol. 84, pp. 11–20, Aug. 2019.

[19] G. Feng, L. Chen, and X. Shi, "A broadband circularly polarized monopole antenna employing parasitic loops and defective ground plane," *Microw. Opt. Technol. Lett*, mop.31998, Jun. 2019.

[20] Q. Chen, H. Zhang, L. Yang, B. Xue, and X. Min, "Broadband CPW-Fed Circularly Polarized Planar Monopole Antenna with Inverted-L Strip and Asymmetric Ground Plane for WLAN Application," *Prog. Electromagn. Res*., pp. 91–100, Aug. 2017.

[21] M. Midya, S. Bhattacharjee, and M. Mitra, "Broadband Circularly Polarized Planar Monopole Antenna with G-Shaped Parasitic Strip," *IEEE Antennas Wirel. Propag. Lett.*, vol. PP, pp. 1–1, Apr. 2019.

[22] M. T. Islam and M. J. Singh, "A Compact Printed Monopole Antenna With Wideband Circular Polarization," *IEEE Access*, vol. 6, pp. 54713–54725, Sep. 2018.

[23] H. Z. Gyasi, Kwame Oteng, Guangjun Wen, Daniele Inserra, Yongjun Huang and Jian Li, Affum Emmanuel Ampoma, "A Compact Broadband Cross-Shaped Circularly Polarized Planar Monopole Antenna with a Ground Plane Extension," *IEEE Antennas Wirel. Propag. Lett*., vol. 17, pp. 335–338, Feb. 2018.

[24] H. Alsariera *et al.*, "Simple Broadband Circularly Polarized Monopole Antenna with Two

INTERNATIONAL JOURNAL OF MICROWAVE AND OPTICAL TECHNOLOGY,
VOL.15, NO.2, MARCH 2020

Asymmetrically Connected U-shaped Parasitic Strips and Defective Ground Plane ," *Telkomnika*, vol. 18, 2020.

[25] J. Y. Jan, C. Y. Pan, K. Y. Chiu, and H. M. Chen, "Broadband CPW-fed circularly-polarized slot antenna with an open slot," *IEEE Trans. Antennas Propag.*, vol. 10, march. 2013.

[26] H. Alsariera *et al.*, "A compact broadband coplanar waveguide fed circularly polarized printed monopole antenna with asymmetric modified ground plane," *Int. J. RF Microw. Comput. Eng.* pp. 1–12, jan. 2020.

[27] S. Alani, Z. Zakaria, and A. Ahmad, "Miniaturized UWB elliptical patch antenna for skin cancer diagnosis imaging," *Int. J. Electr. Comput. Eng.*, vol. 10, no. 2, pp. 1422–1429, Feb. 2019.

[28] H. Sariera, Z. Zakaria, and A. A. M. Isa, "New Broadband L-shaped CPW-fed Circularly Polarized Monopole Antenna with Asymmetric Modified Ground Plane and a Couple Series-aligning Inverted L-shaped Strip," *AEUE - Int. J. Electron. Commun.*, vol. 118, p. 153139, 2020.

[29] K. Oteng Gyasi, Wen. Guangjun and A.B, Muhammad "A Compact Broadband Circularly Polarized Slot Antenna with Two Linked Rectangular Slots and an Inverted-F Feed Line," *IEEE Trans. Antennas Propag.*, vol. 66, no. 12, pp. 7374–7377, Dec. 2018.

[30] T. Y. Han, Y. Y. Chu, L. Y. Tseng, and J. S. Row, "Unidirectional circularly-polarized slot antennas with broadband operation," *IEEE Trans. Antennas Propag.*, vol. 56, pp. 1777–1780, Jun. 2008.