

# Broadband Circularly Polarized CPW-Fed Asymmetrically-Shaped Slot Patch Antenna for X Band Applications

Boualem Mekimah<sup>1, \*</sup>, Tarek Djerafi<sup>2</sup>, Abderraouf Messai<sup>1</sup>, and Abdelkrim Belhedri<sup>1</sup>

**Abstract**—A broadband circularly polarized CPW-fed slot patch antenna is presented in this paper. The proposed geometry consists of two unequal L-shaped arms, feeding asymmetrically-shaped slots at two opposite corners to achieve wider circularly polarized bandwidth in stable radiation, without any external polariser. The antenna performance exhibits a wide 3-dB axial ratio bandwidth (3-dB ARBW) of 2.8 GHz, starting from 7.4 GHz until 10.2 GHz, within the 10-dB impedance bandwidth (10-dB IBW) of 3.2 GHz (7–10.2 GHz). Results show a stable radiation in the broadside direction, in which the antenna shows a maximum gain of 4 dBi in bidirectional broadside radiation. The proposed structure occupies a global size of  $24 \times 22 \times 0.25$  mm<sup>3</sup>. The outcomes are achieved making, therefore, the proposed antenna an excellent candidate for performed systems within X band range.

## 1. INTRODUCTION

In recent years, researchers have shown great interest in broadband circularly polarized antennas (CPA) due to their practical advantages, compared to broadband linearly polarized antennas (LPA). In contrast to LPA, CPA is an efficient solution in reducing polarization mismatch, multipath fading effect, and allows more flexibility in the orientation of transmitting and receiving antennas [1–4]. The circular polarization is achieved when two orthogonal modes are excited in equal amplitude and 90° out-of-phase. This may be realized in different ways including: singly fed patch and dual fed patch using offset line or hybrid junction [1–4].

A considerable number of works of CPA adopt coplanar waveguide feed (CPW-feed), as in [1, 3, 5, 6]. These different ways have shown wide CP bandwidth and simple feed. However, most of the literature pays particular attention only to extending axial ratio bandwidth (ARBW), without considering the simplicity of the design and the stability of the main lobe direction, which shows limited performance in the same design [2–4]. For example, in [2], the proposed slot antenna exhibits a matching bandwidth of 3.62 GHz (1.10–4.72 GHz), with 3.42 GHz of ARBW (1.26–4.68 GHz); however, the antenna shows significant instability in the main lobe direction. Similarly, in [3], the proposed geometry suffers from significant instability in its radiation, even it has an ultra-wideband of 10.33 GHz (2.67–13 GHz), with 2 GHz of ARBW (4.9–6.9 GHz). On the other hand, the design complexity and the large volume of CPA, as in [5–13], are major constraints against the recognised need for low-cost and miniaturised devices, as well as the design simplicity and repeatability at another frequency. Some other designs use more than three mechanisms to achieve the desired bandwidth like in [3] and [8]. The purpose of this work is to enhance the broadside radiation stability in wider CP bandwidth with high simplicity. The proposed configuration is composed of a CPW-fed line, exciting an asymmetrically shaped slot patch antenna via two unequal L-shaped arms, where the CP feature is obtained through the latter. The antenna

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\* Corresponding author: Boualem Mekimah (b\_mekimah@umc.edu.dz; boualem.mekimah@emt.inrs.ca).

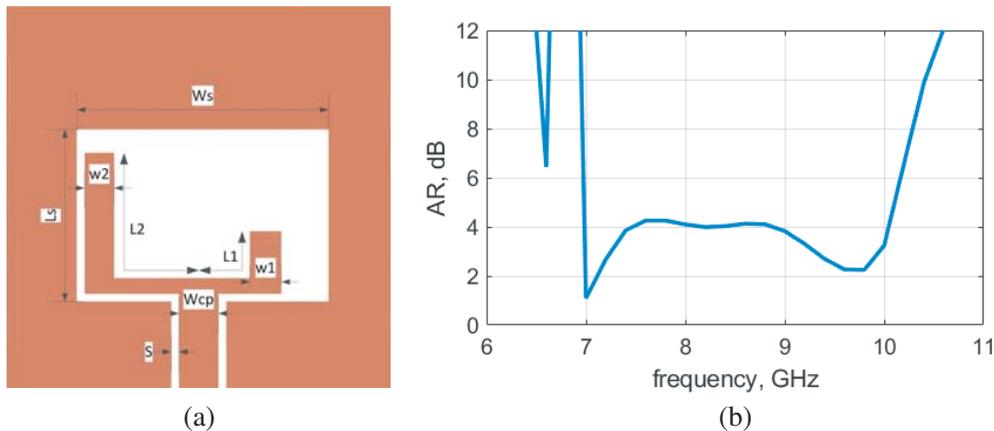
<sup>1</sup> Département d'électronique, Laboratoire d'électromagnétisme et des Télécommunications, Université Frères Mentouri Constantine1, 25000 Constantine, Algérie. <sup>2</sup> Institut national de la recherche scientifique (INRS), 800 rue de la Gauchetière Ouest, Place Bonaventure, Montréal, Canada.

performance shows a wide 3-dB ARBW that overlaps with a wide 10-dB impedance bandwidth (IBW). This antenna operates over the frequency range of 7 GHz to 10.2 GHz with a CP bandwidth of 7.4 GHz to 10.2 GHz. The proposed antenna radiates efficiently in the broadside direction with a maximum gain of 4 dBi. The antenna has the advantages of wide axial ratio bandwidth, very simple planar structure with low complexity in low profile; furthermore, it radiates bi-directionally in the broadside direction with high stability in terms of main beam direction. These features are among the numerous challenges in designing broadband CPA. The paper is structured as follows. In the second section, the proposed antenna design is presented. Simulated and measured results are presented and discussed in the third section. Concluding notes are given in the last section.

## 2. ANTENNA DESIGN

A rectangular slot antenna is the complementary of a rectangular patch antenna, in which they resonate at the same dominant frequency mode of  $\lambda/2$ , where the electric and magnetic fields are interchanged. The slot version of patch as the slot dipole achieves wider bandwidth. To feed the slot patch antenna, with increasing the bandwidth and conserving the fed simplicity in planar configuration, the CPW-fed will be used.

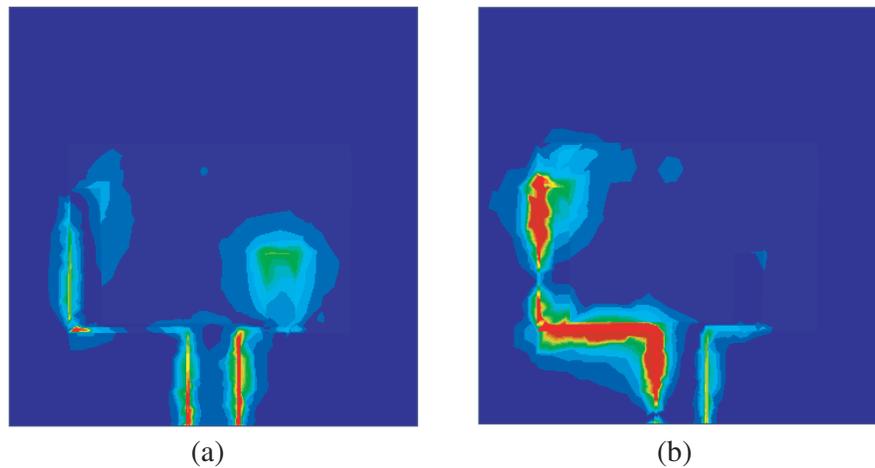
The circular polarisation can be produced either by exciting two orthogonal modes with equal amplitude and  $90^\circ$  of phase difference, or alternatively with four excitations ( $0^\circ$ ,  $90^\circ$ ,  $180^\circ$ , and  $270^\circ$ ). However, two diagonal  $180^\circ$  out-of-phase modes can also give circular polarisation in wider bandwidth. This is equivalent to having two single patches having CP mode, in which they are fed in diagonal, and to compensate the dual-feeding,  $180^\circ$  out-of-phase excitation should be ensured. The proposed structure is illustrated in Fig. 1(a). CPW-feed is used to feed two arms having lengths  $L_1$  and  $L_2$ , respectively. The phase difference between the two arms is equivalent to  $180^\circ$  ( $L_1 + L_2 = \lambda/2$ ).



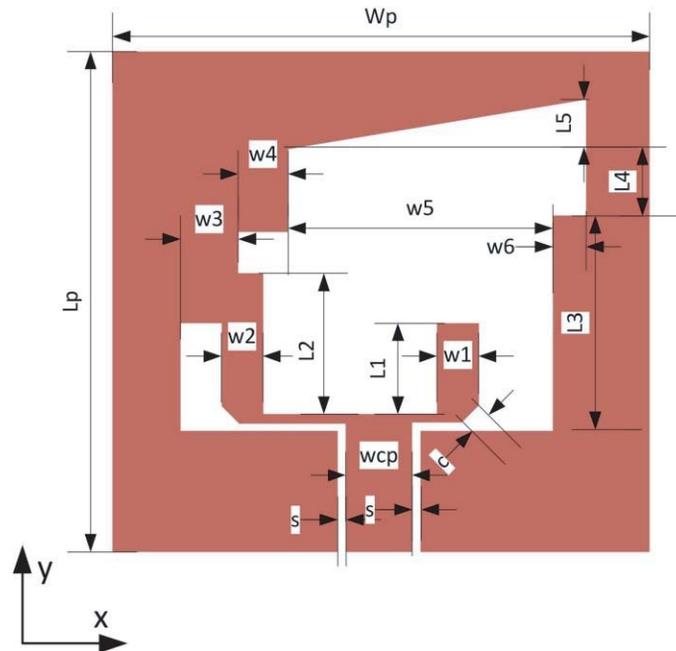
**Figure 1.** Initially proposed geometry with its AR against frequency. (a)  $L_s = 16$  mm,  $W_s = 19.6$  mm,  $L_1 = 12.6$  mm,  $L_2 = 21.9$  mm,  $w_{cp} = 4$  mm,  $s = 0.25$  mm,  $w_1 = 2.5$  mm,  $w_2 = 2.5$  mm. (b) AR in dB against frequency in GHz of the initial geometry.

The fact that the two orthogonal modes should be  $90^\circ$  out-of-phase to obtain CP radiation confirms that each strip generates its own CP mode. The result of the achieved axial ratio is obtained by full wave simulator, as shown in Fig. 1(b). The result shows excellent potential with wide bandwidth of 7 GHz to 10 GHz, at a level of AR around 4 dB at the middle of the band.

Figure 2 portrays the electrical field distribution at different time intervals of  $0^\circ$  (Fig. 2(a)) and  $90^\circ$  (Fig. 2(b)), in which the same distribution at respectively  $180^\circ$  and  $270^\circ$  is observed. This confirms the rotation of the field in the initial proposed geometry. The principle of this antenna is based on exciting a rectangular slot via two L-shaped strips at two opposite points. It is clear from the field distribution that the antenna generates a circularly polarized wave. To clean and enhance the antenna performance, asymmetrically shaped slots should be used to ensure the circular polarization with lower values of AR



**Figure 2.** Field distribution at 10 GHz of the initially proposed geometry. (a)  $\omega t = 0^\circ, 90^\circ$ . (b)  $\omega t = 90^\circ, 270^\circ$ .

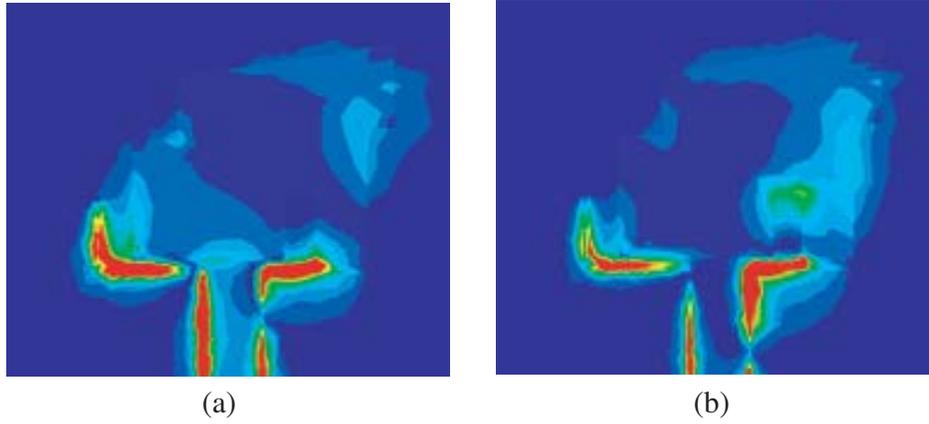


**Figure 3.** Geometry of the final antenna:  $L_1 = 8.4$  mm,  $L_2 = 17.1$  mm,  $L_3 = 10.6$  mm,  $L_4 = 4.4$  mm,  $L_5 = 2.5$  mm,  $w_1 = 2.15$  mm,  $w_2 = 2.15$  mm,  $w_3 = 2.9$  mm,  $w_4 = 3.1$  mm,  $w_5 = 13.6$  mm,  $w_6 = 2$  mm,  $w_{cp} = 4$  mm,  $s = 0.25$  mm,  $c = 1$  mm,  $L_p = 24$  mm,  $W_p = 22$  mm.

in wider bandwidth. The asymmetry is introduced in slot patch shape, as well as in the two arms to excite the slot at two opposite points as illustrated in Fig. 3. The resulting antenna geometry gives therefore an AR lower than 3-dB in wider bandwidth as it is sought.

Before explaining the performance enhancement, we shed light on electric field behaviour of the final antenna. The field intensity is displayed at different time instants in Figs. 4(a) and 4(b).

The electric field distribution is portrayed at two angular times of  $0^\circ$  and  $90^\circ$ , in which it gives the same distribution at respectively  $180^\circ$  and  $270^\circ$ . The figure demonstrates that the proposed CP antenna gives a left handed circular polarization (LHCP) radiation in the  $+z$  direction. Unlike the initial design, the field covers all the whole slot structure.

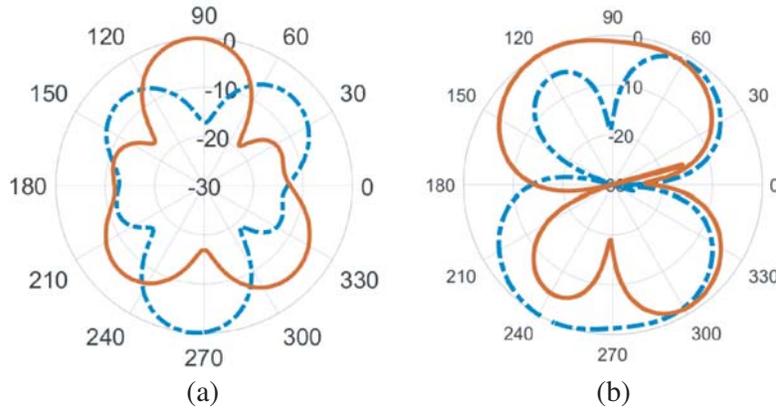


**Figure 4.** Electric field behaviour at different time instants at 10 GHz of the optimized antenna. (a)  $\omega t = 0^\circ, 90^\circ$ . (b)  $\omega t = 90^\circ, 270^\circ$ .

The designed antenna is composed of a dielectric substrate RT/duroid 6002 having a dielectric constant of 2.94, loss tangent of 0.0012, and height of 0.25 mm, with a cladding thickness of 0.0175 mm. The proposed antenna occupies an overall size of  $24 \times 22 \times 0.25 \text{ mm}^3$  ( $0.56\lambda_0 \times 0.51\lambda_0 \times 0.005\lambda_0$ ).

### 3. RESULTS AND DISCUSSION

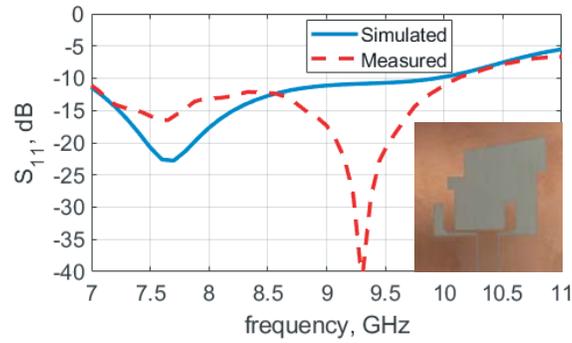
Computations using the finite elements method (FEM) commercial software (Ansoft HFSS version 2018) have been performed. As set out in Fig. 5, it is apparent that the simulated radiation patterns of both RHCP and LHCP are sufficiently separated at 9 GHz, in both of  $xoz$ -plane ( $\varphi = 0^\circ$ ) and  $yo z$ -plane ( $\varphi = 90^\circ$ ). This separation exceeds 17 dB in the broadside direction, where the RHCP radiation is in blue and the LHCP one in red.



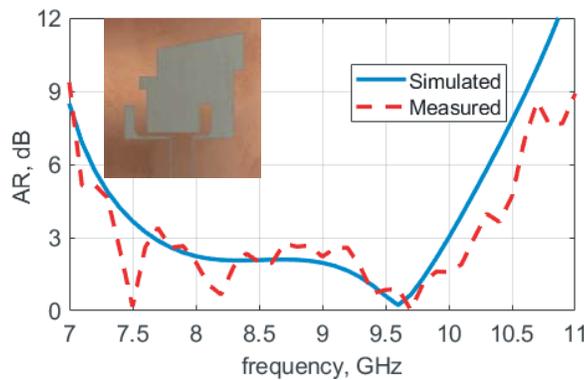
**Figure 5.** The simulated radiation patterns of the optimized antenna; LHCP radiation is the continued line in red and RHCP radiation is the dashed line in blue, at 9 GHz. (a)  $\varphi = 0^\circ$ . (b)  $\varphi = 90^\circ$ .

A 10-dB IBW of 3.2 GHz, starting from 7 GHz up to 10.2 GHz, is estimated from the result depicted in Fig. 6 (with prototype photograph in inset). The measured data in the reflection coefficient  $|s_{11}|$  are realized with the network analyzer Agilent 8722ES with standard SOLT calibration. The difference between the simulated and measured results in Fig. 6 is due to the SMA connector. In fact, the SOLT calibration defines the reference line at level of the VNA cable and does not avoid the SMA effect.

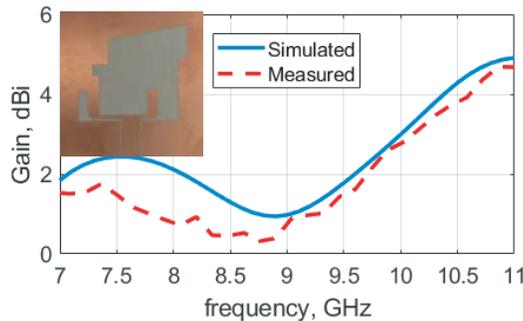
Simulated and measured bandwidths show good agreement. As can be seen in Fig. 7, the antenna performance exhibits a 3-dB ARBW of 2.8 GHz, with a lower value of 0.1 dB noticed at respectively



**Figure 6.** Magnitude of  $S_{11}$  in dB versus frequency in GHz of the optimized antenna; the prototype photograph is in the inset.



**Figure 7.** Axial ratio in dB against frequency in GHz of the final antenna.

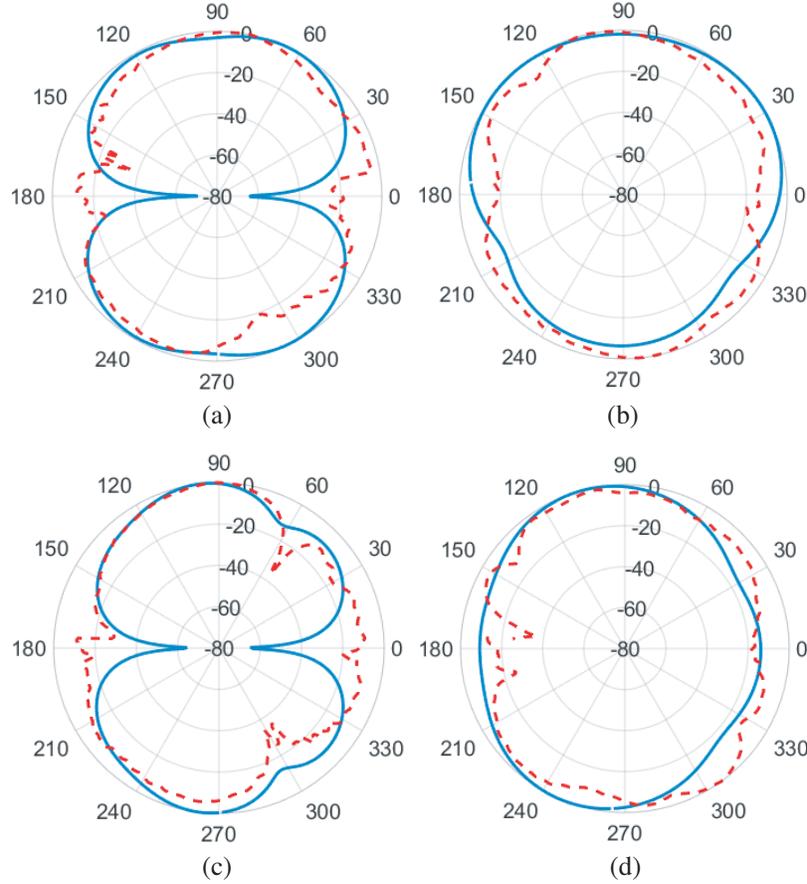


**Figure 8.** Realized gain in dBi as a function of frequency in GHz of the final antenna.

7.5 and 9.7 GHz. The measurement setup uses linear antenna measurement in two planes ( $E$ - and  $H$ -planes) to estimate the AR performance. The reached performance that stands out in this result is the broadband of frequency range, in which the antenna shows stable CP radiation in the bi-directionally broadside direction. The peak gain evolution against frequency is plotted in Fig. 8, in which the gain attains its maximum value of 4 dBi, in the broadside direction.

As shown in Figs. 9(a), 9(b), 9(c), and 9(d), the radiation patterns are bidirectional in the broadside direction at respectively 7 GHz and 9 GHz in both of the  $xoz$ -plane ( $\varphi = 0^\circ$ ) and  $yo z$ -plane ( $\varphi = 90^\circ$ ). For the radiation parameters, a Compact Range Antenna Test system, with linearly polarized antenna, is used.

With all these interesting outcomes, the antenna shows the ability to operate with stable CP radiation across the whole frequency range of 7 GHz to 10.2 GHz. Results show that the obtained



**Figure 9.** Radiation patterns of the proposed antenna; dashed line in red is the measured data and continued line in blue is the simulated ones. (a)  $\varphi = 0^\circ$  at 7 GHz. (b)  $\varphi = 90^\circ$  at 7 GHz. (c)  $\varphi = 0^\circ$  at 9 GHz. (d)  $\varphi = 90^\circ$  at 9 GHz.

antenna design ensures data transfer within wide CP bandwidth, in the broadside direction with stable CP performance.

Table 1 compares the performance of different proposed designs in the literature with the proposed one. The proposed design shows higher beam stability than the comparable designs in terms of complexity, as in [2–4]. The only ones showing high stability have high complexity. For instance

**Table 1.** Comparison of the proposed antenna with those published in the literature.

Ref.	ARBW (GHz)	Gain (dBi)	$\varepsilon_r$	size (mm <sup>3</sup> )	Beam stability	Complexity
[2]	1.26–4.68 (115.2%)	4.51	4.4	90 × 100 × 1	low	low
[3]	4.9–6.9 (32.2%)	4.32	4.4	60 × 60 × 0.8	low	low
[4]	3.22–5.9 (58.7%)	6.18	3.5	38 × 38 × 1.52	low	low
[7]	2–3.1 (42.7%)	8.4	N/A	150 × 150 × 32	high	high
[8]	3.5–4 (16%)	8.8	2.55	76 × 76 × 16.13	high	high
[11]	5.72–6.62 (15.5%)	11.5	2.2/1.2	100 × 100 × 23.25	high	high
[12]	7.72–8.04 (4.06%)	3.8	4.4	80 × 80 × 5	high	high
[13]	4.09–4.26 (4.1%)	11.02	N/A	110 × 110 × 5	high	high
Proposed	7.4–10.2 (31.82%)	4	2.94	24 × 22 × 0.25	high	low

in [7], the given antenna geometry is a non-planar structure with complex shapes and occupies a large size making the antenna very complex. Similarly, in [8, 11] both designs containing multilayers make the complexity high even their radiation stability is good. Works in [12, 13] show narrow ARBW with complex designs. The proposed design has one of the smallest sizes with adequate bandwidth. The majority of designs use thicker substrates in order to increase the bandwidth, in contrast to our design which occupies very thin height of  $0.25 \text{ mm}$  ( $0.005\lambda_0$ ). The simplicity of the proposed design facilitates the transition to another frequency.

#### 4. CONCLUSION

A new low-cost, broadband, simply CPW-fed, CP slot patch antenna has been proposed in this paper. The antenna is singly fed using a CPW-fed line to excite the asymmetrically-slot via two unequal L-shaped arms with  $180^\circ$  out-of-phase excitation. The resulting antenna achieves broad CP bandwidth with stable radiation in low profile. The operating frequency range of  $3.2 \text{ GHz}$  ( $7\text{--}10.2 \text{ GHz}$ ) is achieved overlapping the CP bandwidth of  $2.8 \text{ GHz}$  ( $7.4\text{--}10.2 \text{ GHz}$ ) with the maximum peak gain of  $4 \text{ dBi}$ . The proposed antenna radiates bi-directionally in the broadside direction with stable CP performance. These significant outcomes associated with simple frequency translation make the antenna suitable for a large number of wireless applications within the X band as well other bands. The proposed geometry also shows potential to operate in broader CP bandwidth with additional investigation.

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