Defence Science Journal, Vol. 69, No. 1, January 2019, pp. 87-92, DOI : 10.14429/dsj.69.13049

Substrate Integrated Waveguide-fed Wideband Circularly Polarised Antenna with Parasitic Patches

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ABSTRACT

In this study, a wideband circularly polarised (CP) antenna is developed and demonstrated. The antenna comprises of two-layered substrates, the top layer holds a driven patch and eight surrounding parasitic patches of similar dimensions, and substrate integrated waveguide (SIW) based feeding topology is designed at the bottom layer. The driven patch is excited through coupling mechanism using a cross-slot carved on the upper clad of the SIW. The corners of the driven patch are curtailed and arms of the coupling slot made unequal, which constructively generates the CP wave. Moreover, the proposed antenna is prototyped, and experimentally verified. The antenna shows measured impedance and axial-ratio (AR) bandwidths of 1.29 GHz (21 per cent) and 460 MHz (7.35 per cent), respectively, while maintaining the high gain of ~8 dBic over the operating CP region. This design aids the favorable characteristics such as light weight, wide impedance and (AR) bandwidths, high-gain as well as lenience of production, and integration.

Keywords: Circularly polarised antennas; Parasitic patch; Substrate integrated waveguide; Wideband

1. INTRODUCTION

Circularly polarised (CP) antennas have been extensively employed in modern wireless communications due to their immunity to Faraday rotation, reducing the multipath propagation effects and flexibility in polarisation matching between transceiver antennas. The microstrip antennas are at all times a common choice for CP antennas owing to their light-weight, low fabrication cost and ease of manufacturing. Usually, these antenna structures suffer from inherently narrow impedance bandwidth, and unwanted bottom radiation[1,3]. Recently, state-of-the-art substrate integrated waveguide (SIW) arose as an alternative transmission medium that facilitates the pluses of low-loss transmission and low-cost manufacturing with maintaining the planar integrability[4,5]. The SIW provides a fresh way to design planar cavity-backed antennas and arrays with incorporated feeding networks for microwave and millimeter wave applications[6,7]. The SIW based feeding offers extra guarding against spurious radiation and moderates back radiations. Thus, this enhances the overall efficiency of an antenna assembly.

Numerous SIW based CP polarised antennas have been explored in the available works[7-12]. In spite of the good electrical performance, most of them suffer from narrow axial-ratio (AR) bandwidth, typically 2-3 per cent. To improve AR bandwidth, a sequentially rotated SIW fed antenna array was recommended[13]. However, such method would increase antenna size as well as complexity. Another widespread technique for accomplishing a wide AR bandwidth was suggested[14,15] using stacked configuration, but conventional lossy feeding techniques affect the radiation performance. Later on, many advances in designing of circularly polarised antennas are reported[16-19].

A wideband CP antenna is demonstrated using a two-layered stacked structure in this paper. Top substrate layer contains radiating elements, and an aperture coupled SIW based feeding network is designed on the bottom layer. The center part of the antenna is a corner truncated square patch which is excited by electromagnetic coupling mechanism using a crossed slot is carved on the upper metal clad of the SIW feedline and yields the CP wave. Furthermore, to improve AR bandwidth and impedance matching, the center patch is capacitively coupled with eight parasitic patches. Moreover, the SIW based feeding network reduces the surface wave and improves the gain in broadside direction. The proposed design profits the advantages of the enhanced bandwidth and cost-efficient fabrication as compared to conventional metallic cavity antennas.

($w_p = l_p = 12$, $w_{siw} = 20.5$, $w_t = 10.7$, $lsiw = 30.3$, $w_{ms} = 4.8$, $t = 0.8$, $l_t = 4$, $g_1 = 0.6$, $g_2 = 1.1$, $d = 1$, $p = 1.5$, $h = 1.57$, $l = 12.9$, $s = 10.8$, $s' = 13.4$, $t' = 3.9$, $t_p = 1$, $L = 44$, $L' = 62$, $W' = 50$). All dimensions are in mm.

2. ANTENNA DESIGN AND CONFIGURATION

2.1 Configuration

Three-dimensional perspective vision of the design is offered in Fig. 1(a). It is realised by using a two-layered Rogers 5880 substrate. The top layer contains a driven center patch with truncated corners and eight parasitic patches as exposed

Received : 03 May 2018, Revised : 26 November 2018
Accepted : 20 December 2018, Online published : 10 January 2019

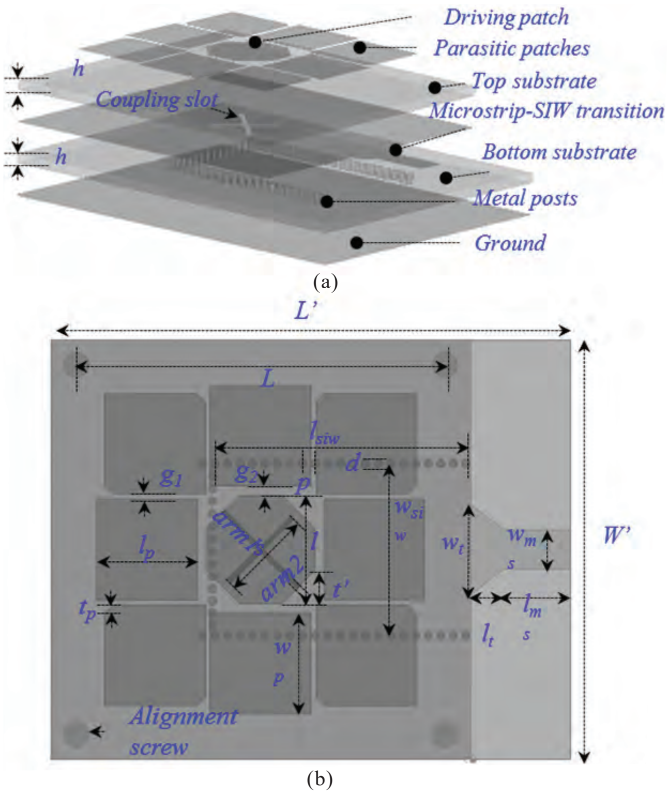


Figure 1. Antenna structure: (a) 3D view, (b) Top view.

in Fig. 1(b). The feeding network is premeditated on the bottom substrate which comprising of an SIW with a crossed slot on the upper clad of its broad wall and a microstrip-SIW tapered transition for measurement purpose. An SIW is shaped by implanting consecutive posts (metal) in the dielectric substrate that acts as the sidewalls. So, to confirm the least loss of electromagnetic waves from the gaps between two successive vias, diameter (*d*) and pitch space (*p*) of the via is chosen 1 and 1.5 mm, respectively[5]. The essential parameters of the SIW and microstrip-SIW transition are estimated by following the guideline given in[12]. Moreover, such feeding topology provides an extra protection from spurious radiation and helps to reduce the back-lobe radiation.

2.2 Design Process

The design progression of the antenna is exposed in Fig. 2.

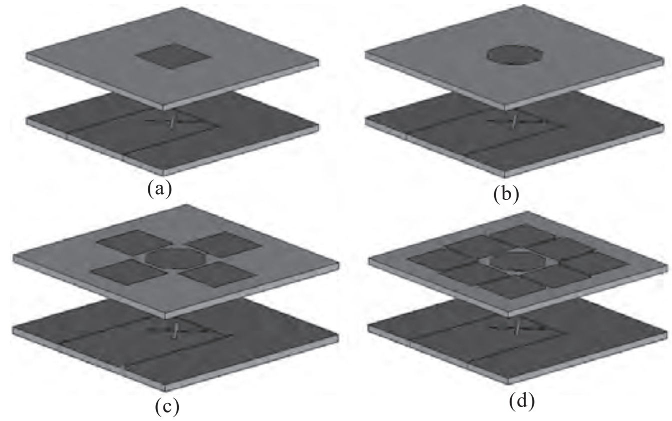


Figure 2. Design evolution: (a) ANT. I, (b) ANT. II, (c) ANT. III, and (d) ANT. IV.

The center frequency is chosen around 6 GHz in C-band (4-8 GHz). Initially, a square patch (ANT. I) is excited by an electromagnetic coupling mechanism with the help of cross slot imprinted on the upper clad of the SIW. The arms of the slot are kept unequal such that the CP performance can be realised using a single feed[7]. The unequal length of the cross slot excite the two nearby orthogonal modes of the directly coupled patch which yields CP. To increase matching with the coupling slot, the bends of the square patch are truncated (ANT. II). Further, to augment the impedance bandwidth, four square patches are arranged adjacent to the sides of the driven patch (ANT. III). The dimensions of these patches are chosen relatively smaller than the center patch. To achieve wide AR bandwidth, four corners-truncated square patches of identical dimensions are introduced at the four corners of the driving patch. The dimension of the all eight parasitic patches kept same. The corresponding simulated results of the proposed antenna including impedance bandwidth, AR and realised gain is shown in Fig. 3. Finally, this design shows an AR and -10 dB bandwidths of 628 MHz and 1.56 GHz with realised gain better than 9 dBic, respectively. To highlight the wideband mechanism of the design, a summary of the evolution stages is tabularised in Table 1. Moreover, this was simulated and optimised with the help of computer simulation technology (CST) tool. The optimum values of antenna parameters are as given in Fig. 1.

To understand the sense of the polarisation, the magnetic

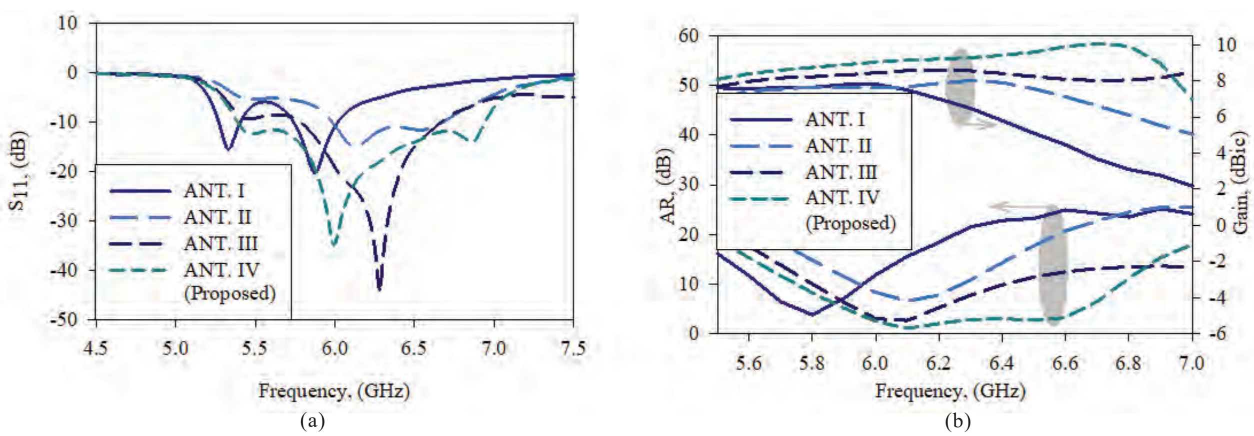


Figure 3. Corresponding antenna parameters: (a) Reflection coefficients (S_{11}) and (b) AR and gain.

field distribution at different time phases at on the upper layer is as shown in Fig. 4(a) and 4(b) at the frequency around 6.0 GHz and 6.6 GHz, respectively. It can be clearly witnessed that the sense of rotation is counterclockwise. Thus, the antenna demonstrates the right-handed-circular-polarisation (RHCP). The left-handed-circularly-polarised (LHCP) wave can be achieved by simply replacing *arm1* by *arm2* of the coupling crossed slot. Furthermore, the effect of two critical parameters (g_2-gap of coupled parasitic patches and t'-dimension of truncated corner) on performance of the proposed antenna is as shown in Fig. 5. It can be clearly perceived that both parameters affect the bandwidth (impedance and axial-ratio) matching conditions. Thus, these parameters are optimised in such a way it results maximum impedance and axial ratio bandwidths.

3. FABRICATION AND EXPERIMENTAL VALIDATIONS

The antenna is fabricated with the help of standard printed-circuit-board (PCB) procedure on a two-layered dielectric substrate. The two layers are aligned properly with

Table 1. Performance of different antennas

Case \ Result	-10 dB operating frequency range	Impedance bandwidth	3 dB ARBW
ANT. I	5.26-5.42 GHz, 5.75-6.01 GHz	158, 264 MHz	--, (Min. peak 3.7 dB at 5.8 GHz)
ANT. II	5.9-6.68 GHz	703 MHz	--, (Min. peak 6 dB at 6.1 GHz)
ANT. III	5.77-6.88 GHz	880 MHz	5.99-6.12 GHz (131 MHz)
ANT. IV (Proposed Ant.)	5.37-6.95 GHz	1.56 GHz	5.97-6.60 GHz (628 GHz)

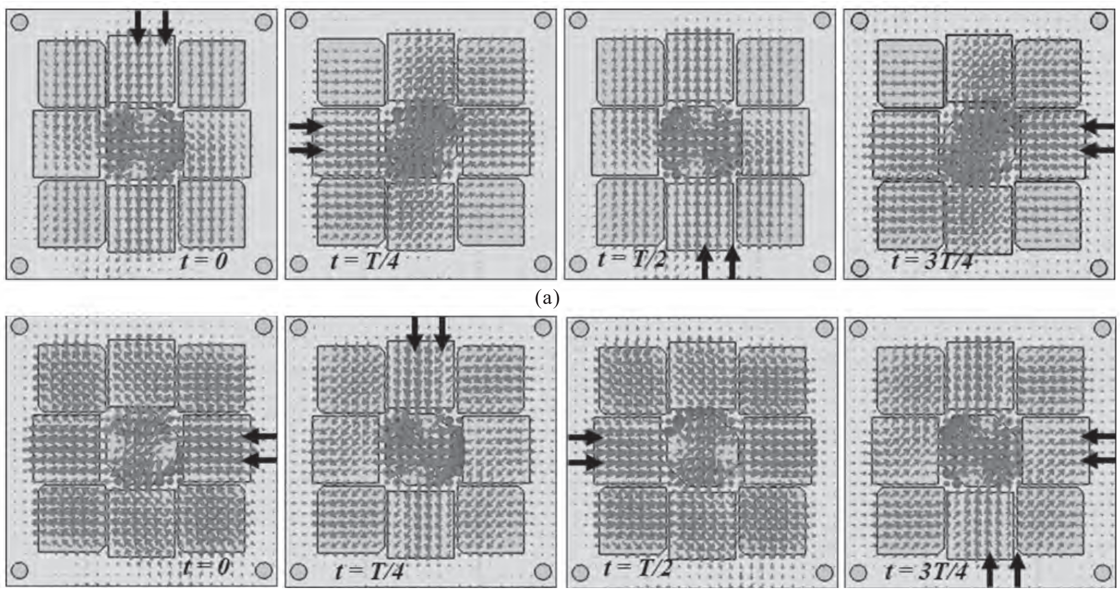


Figure 4. Magnetic field distribution at different time phases: (a) at 6.0 GHz, (b) at 6.6 GHz.

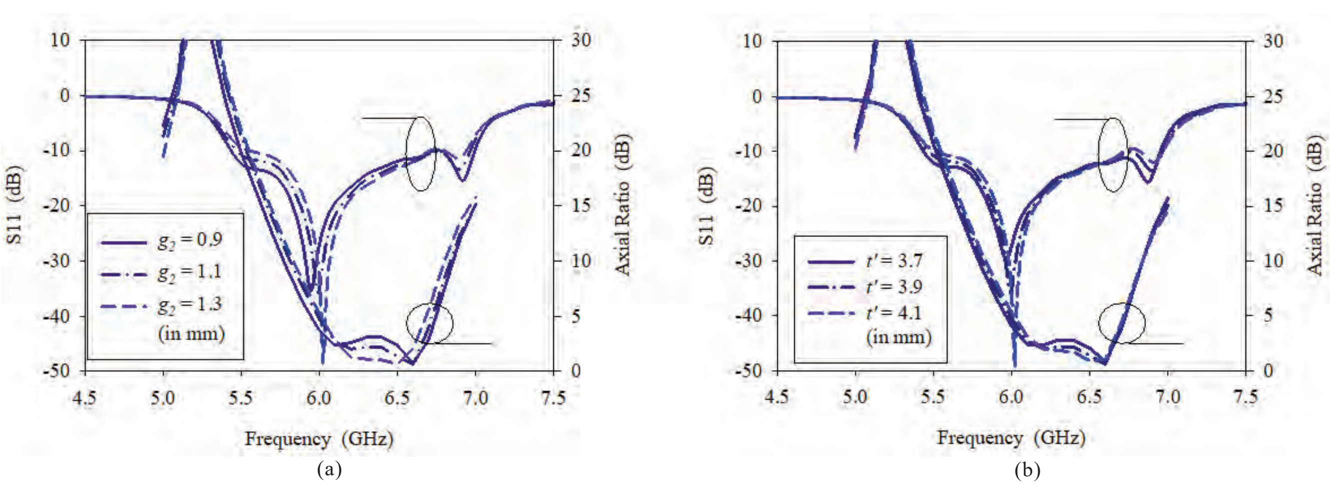
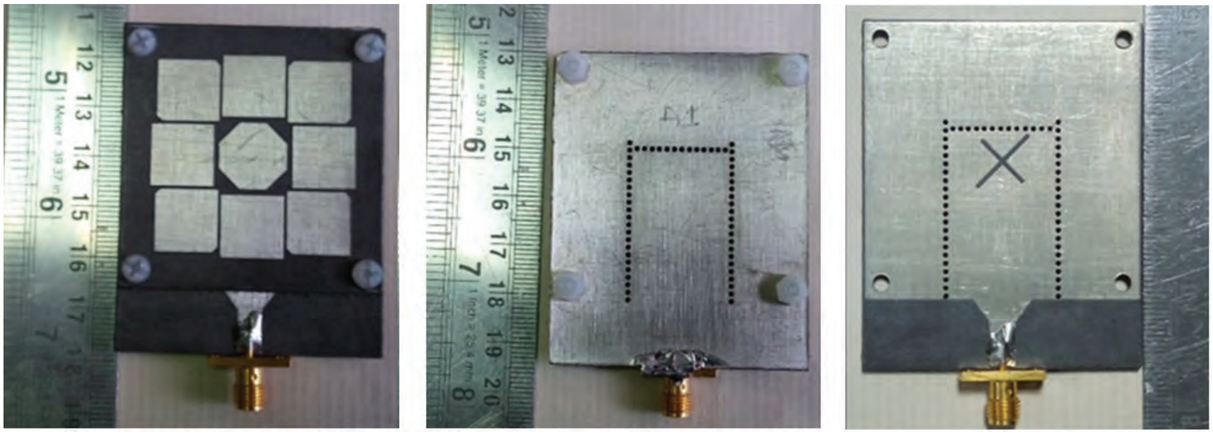


Figure 5. Variation in S-parameter (S_{11}) and axial ratio with change in (a) g_2 and (b) t'.

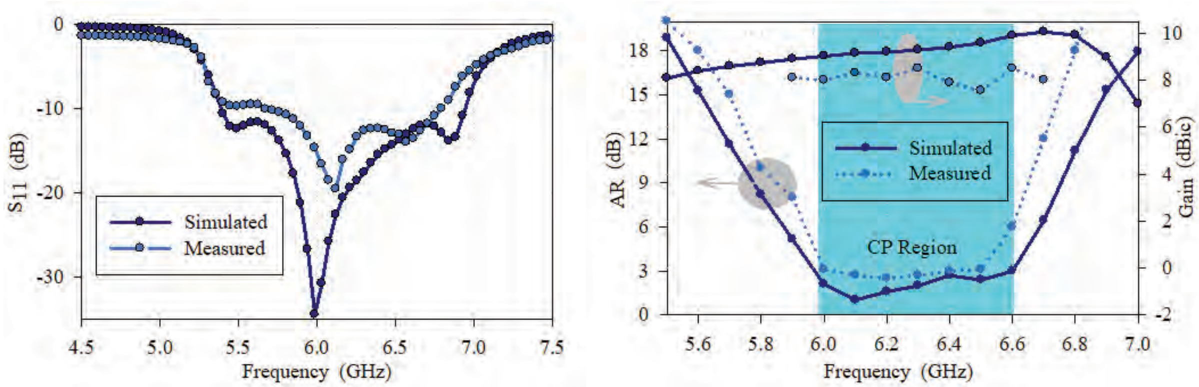


(a) (b) (c)

Figure 6. Fabricated prototype: (a) Top, (b) Bottom, and (c) SIW-based feed.

the help of four nylon screws. Figure 6 shows the prototyped antenna structure. The central truncated patch is excited by electromagnetic coupling by using SIW-based feedline. Further, the SIW feed is extended by 50 Ω microstripline to link with SubMiniature version A (SMA) for measurement purpose. The total size engaged by the antenna including the feeding network is 60 mm × 44 mm × 3.21 mm. To certify the concept, the experimental results are compared with their simulated counterparts. The comparison of the simulated and experimented reflection coefficients (S_{11}) is as shown in Fig. 7(a). The antenna shows measured and simulated impedance bandwidth of 1.29 GHz (5.5-6.79 GHz, 21 per cent) and 1.56 GHz (5.38-6.94 GHz, 25.53 per cent), respectively. The measured and simulated AR and gain performances are as shown in Fig. 7(b) which is 460 MHz (6.03-6.49 GHz, 7.35 per cent) and 625 MHz (5.97-6.60 GHz, 9.94 per cent), respectively. A little variation between the simulated and measured results that may be due to misalignment of the substrate layers and imperfect manufacturing. Also, the simulated radiation and total antenna efficiencies are provided in Fig. 8, which is better than 85 per cent in operating frequency band and almost 90 per cent in the CP region.

The normalised simulated and measured radiation profiles at the resonant frequencies for two principle cut-planes are displayed in Fig. 9. A good and stable RHCP radiation could be observed. This antenna radiates maximum in the broadside direction with reduced back-lobed radiation due to proposed shielded feeding topology. In each case antenna shows front-to-back-ratio (FTBR) of superior than 21.1 dB, which confirms unidirectional radiations over the wide operating frequency range. Also, cross-polar level (LHCP) is as shown in Fig. 9 that is nearly below 10 dB from the main lobe in all cases. Moreover, the proposed antenna displays topographies of good impedance matching, wide AR bandwidth, high gain, stable radiation patterns as well as ease of fabrication, and integration. A comparison of measured results of the previously reported work and this work is as shown in



(a) (b)

Figure 7. Comparison of measured and simulated results: (a) S_{11}, (b) AR and gain.

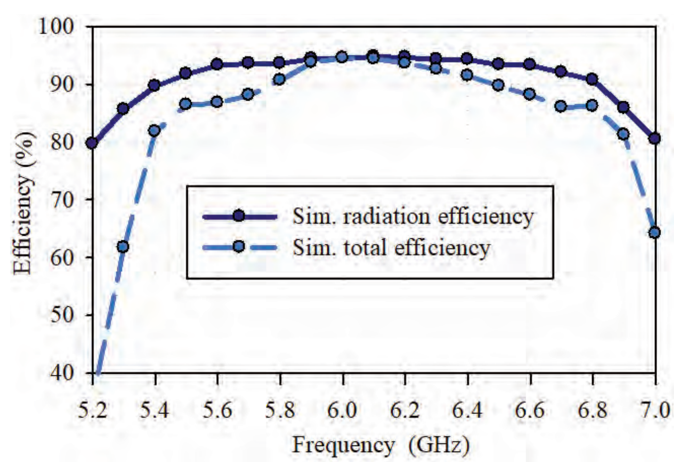


Figure 8. Simulated radiation and total antenna efficiencies.

Table 2. The performance comparison of the this work with previously reported

Properties	Proposed work	Han[10], *et al.*	Kim[11], *et al.*	Kim[12], *et al.*	Kumar[17], *et al.*	Razavi & Neshati	Jung[19], *et al.*
BW (%)	21.0	18.74	23.3	23.9	16.64	6.04	10.0
AR BW (%)	7.35	2.30	2.34	2.70	7.01	0.7	1.0
Gain (dBic)	8.0	5.57	7.79	6.6	5.1	4.2	6.8
Substrate thickness ($\varepsilon_r = 2.2$) (mm)	Two layered (1.57 mm each)	1.57	1.57	1.57	1.57	0.78	1.57
Area (in terms of electrical length) (λ_o^2)	1.0× 1.2	0.83 × 1.4	1.55 × 1.16	0.9× 1.5	1.3 ×1	0.13 ×0.5	0.6 ×0.8
Feeding techniques	SIW based aperture coupled feed	SIW plus microstrip line	SIW plus microstrip line	SIW plus microstrip line	SIW plus microstrip line	Microstrip	Microstrip

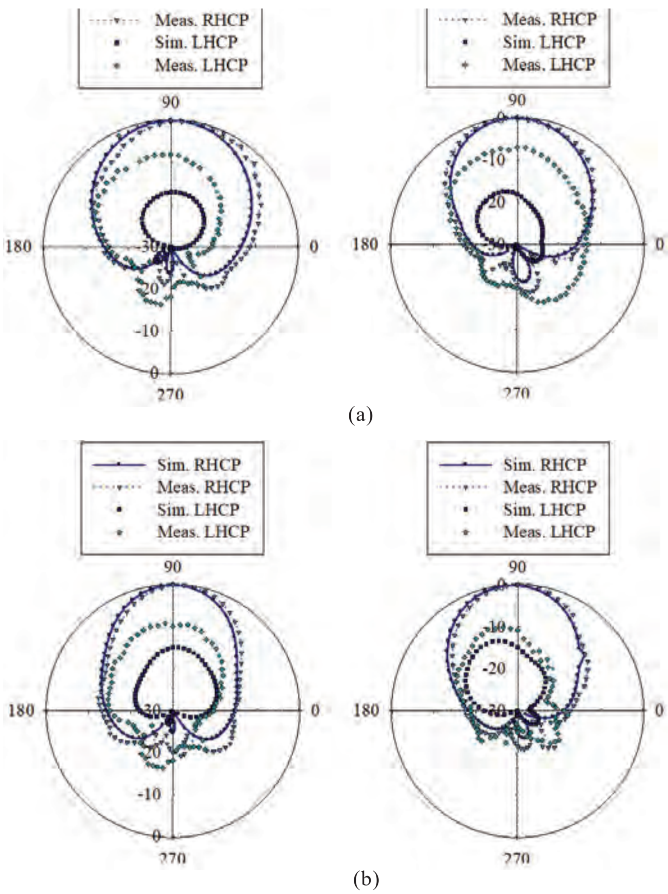


Figure 9. Radiation patterns in (i) $\phi = 0^o$, (ii) $\phi = 90^o$: (a) 6.0 GHz, and (b) 6.6 GHz.

Table 2. This can be understood easily that the performance of this work is relatively improved in terms of impedance and axial-ratio bandwidths, while other electrical parameters are comparable. Moreover, the electric performance of the proposed antenna is alike to convention metallic cavity backed antenna.

4. CONCLUSIONS

This study proposes a circularly polarised antenna with parasitic patches using a stacked structure for wideband applications. The antenna is fed by a coupling mechanism using a cross-slot, etched on the SIW based feedline. Eight parasitic patches are introduced around the driven patch which significantly enhances the -10 dB impedance and axial-ratio (AR) bandwidths. The measured data reveals that the antenna exhibits impedance and AR bandwidths of 21 per cent (1.29 GHz) and 7.35 per cent (460 MHz), respectively, with preserving high-gain of around 8 dBic. Besides, the feeding topology used for the proposed antenna reduces back-lobe radiation, hence improves radiation efficiency with unidirectional radiation characteristics.

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Her contribution in proposed is to helped in the fabrication and measurement of the current work.

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His contribution in the present work is to arrange measurement facility and overall guidance required to accomplish the task.