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RESEARCH PAPER

Reconfigurable circularly polarized capacitive coupled microstrip antenna

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The design and measurement of reconfigurable circularly polarized capacitive fed microstrip antenna are presented. Small isosceles right angle triangular sections are removed from diagonally opposite corners for the generation of circular polarization (CP) of axial ratio bandwidth of 11.1%. Horizontal slits of different lengths are inserted at the edges of the truncated patch to provide the dual-band CP and by switching PIN diodes across the slits ON and OFF, reconfigurable circularly polarized antenna is realized. The antenna shows dual-band behavior with reconfigurable CP. In order to enhance the operation bandwidth of the antenna, an inclined slot was embedded on the patch along with PIN diodes across the horizontal slits. This proposed antenna gave an impedance bandwidth of 66.61% (ON state) ranging from 4.42 to 8.80 GHz and 68.42% (OFF state) ranging from 4.12 to 8.91 GHz and exhibits dual-frequency CP with PIN diode in OFF state and single-frequency CP with PIN diode in ON state with good axial ratio bandwidth. The axial ratio bandwidth of 4.42, 2.35, and 2.72% is obtained from the antenna. The antenna has a similar radiation pattern in all the three different CP bands and almost constant gain within the bands of CP operation.

Keywords: Antennas and propagation for wireless systems, Antenna design, Modeling and measurements

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I. INTRODUCTION

Microstrip antennas are frequently used in many wireless communication systems because of their attractive features such as planer profile, low cost, light weight, and easy to fabricate [1]. However, the types of applications of microstrip antenna are restricted by narrow bandwidth. Accordingly, increasing the bandwidth of microstrip antenna has been a primary goal of research in the field. In fact, many broadband microstrip antenna configurations have been reported in last few decades, such as increasing substrate thickness and decreasing its dielectric constant [2], using appropriate feeding technique and impedance matching method [3]. One of the popular methods to improve the bandwidth of a microstrip antenna is to create various resonant structures into one antenna by cutting slots of different shapes, such as U-shaped slot [4], V-shape slot [5], and by adding more patches [6]. These broadband methods cause some resonance frequencies to appear near the main patch and lead to the bandwidth broadening of the antenna. The capacitive coupled probe-fed microstrip antenna with wideband characteristics has been reported in [7].

In the current wireless communication system, circular polarization (CP) is used as one of the most common polarization types, as it is independent of transmitter and receiver orientation [8]. The CP waves can be generated, when two orthogonal field components with equal amplitude but in phase quadrature are radiated. The CP antennas can be classified as single feed type or dual feed type depending on number of feed points [1]. The dual feed approach requires the use of a 90° hybrid to provide necessary phase shift. However, this dual feed method has more complex geometry, larger size, and higher loss [1]. Thus, preference is given to single feed circularly polarized microstrip antenna. A single feed circularly polarized operation of the square patch by truncating a pair of patch corners is widely used in the single patch [9]. Kin-Lu Wong and Jian-Yi Wu [10] have presented a design that involves cutting slits in the square patch to achieve CP. The CP of the square microstrip antenna with four slits and a pair of truncated corner is presented in [11]. The CP can also be achieved with a circular microstrip antenna by adding a tuning stub [12]. It has been shown in [13] that CP can be generated by embedding a crossed shaped slot at the center of the circular patch. In [14], dual-band circularly polarized aperture-coupled stacked microstrip antenna is presented, but the design of the aperture-coupled stacked microstrip antenna is complicated because of its multilayer structure and feeding network. The CP in two distinct bands is realized by using two perpendicular ports and two power dividers to 90° phase shift for each band [15].

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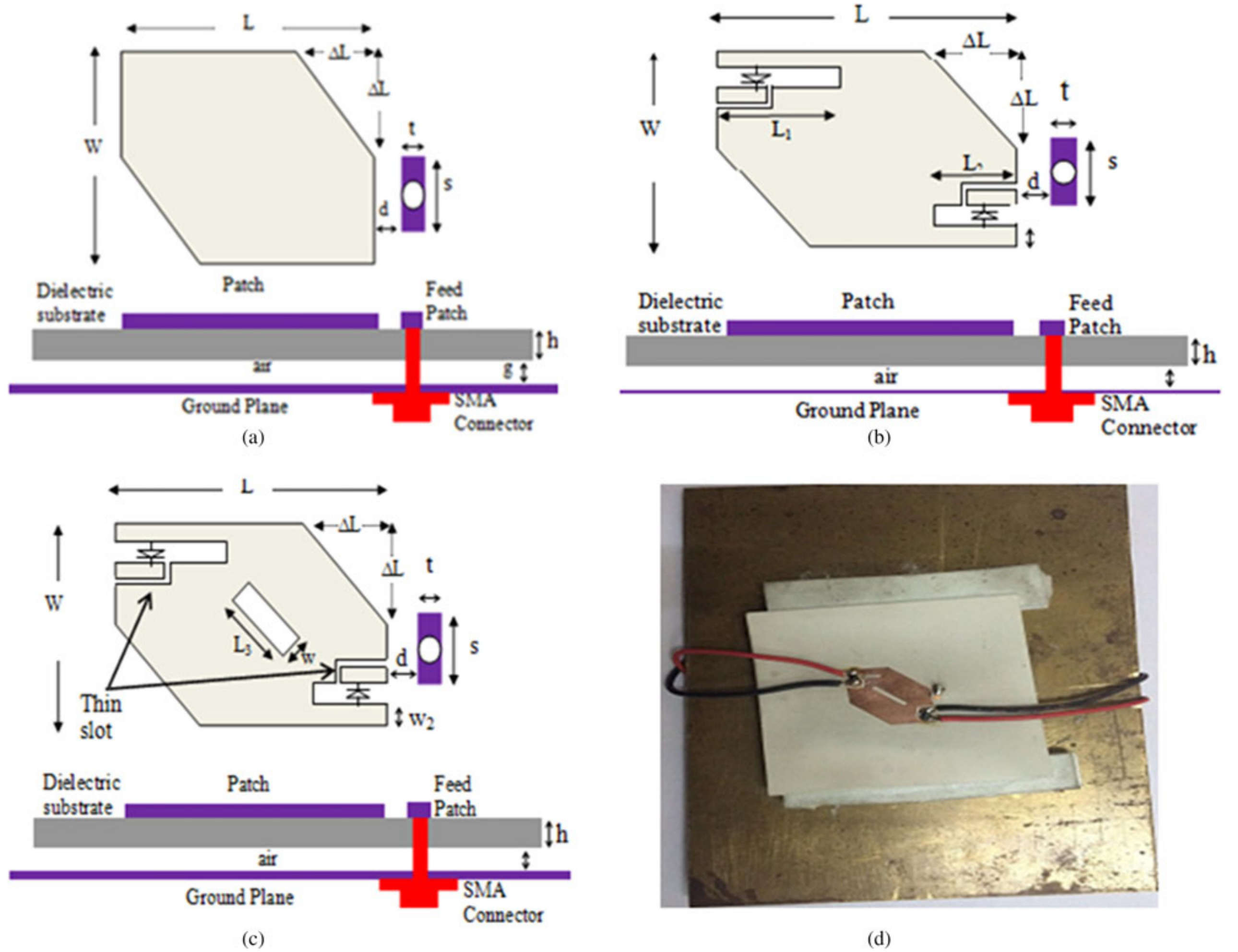

Fig. 1. Geometry of capacitive coupled probe-fed microstrip antenna (a) with truncated corner, (b) with PIN diode and horizontal slits on truncated patch, (c) with PIN diode, horizontal slits, and inclined slot on truncated patch, (d) fabricated structure of the proposed antenna.

However, this structure cannot operate in both frequency bands simultaneously. The antenna presented in [16] operates at dual frequencies with CP characteristics. The dual-band CP radiation is achieved by inserting slits and T-shaped elements at the patch. In [17], a single feed slotted patch structure is presented for generating CP in two frequency bands. This antenna has a problem that the axial ratio bandwidth is very narrow in both the frequency bands. Microstrip patch antenna with switchable polarization is presented in [18, 19] with the single feed. PIN diodes are used to obtain the polarization diversity characteristics of the antenna. Many studies have been reported in the literature that describes different methods for achieving the triple band CP operations [20–23]. The stacked Microstrip patch antenna is used to achieve triple band CP radiation [20, 21]. However, dual orthogonal feed makes the antenna complex. In [22], three layers stacked single feed microstrip antenna was designed to achieve triple band CP operation. A triple-band stacked design was introduced in [23], but all these designs have a narrow axial ratio bandwidth in the three frequency bands.

In this communication, a capacitive fed microstrip antenna with reconfigurable CP is reported. The design of the antenna is carried out in three stages. In the first one, small isosceles right angle triangular sections are removed from diagonally opposite corners for the generation of CP. In the second stage, truncated patch was loaded with horizontal slits of unequal lengths to create dual CP bands and PIN diodes are inserted across the both slits to generate three circularly polarized bands. CP in three distinct bands is achieved by switching PIN diodes ON and OFF on the gap of horizontal slits. Finally, a wideband antenna with reconfigurable CP is designed. This employs an inclined slot embedded on the patch with PIN diode across the horizontal slits to achieve the broadband performance. The impedance bandwidth of proposed antenna is 66.61% (ON state) ranging from 4.42 to 8.80 GHz and 68.42% (OFF state) in the frequency range 4.12 to 8.91 GHz with axial ratio bandwidths of 4.42, 2.35, and 2.72%. The bandwidth of the presented antenna is increased from 51 to 66.61% (ON state) and 68.42% (OFF state) as compared to capacitive coupled probe fed microstrip antenna [7] and also generates three distinct CP bands.

II. ANTENNA DESIGN

The geometry of reconfigurable circularly polarized capacitive coupled probe fed truncated corner microstrip antenna is shown in Fig. 1(a). A pair of opposite corner is truncated with equal side length of ΔL to excite two orthogonal modes with 90° phase shift that makes the antenna circularly polarized. A pair of horizontal slits of lengths L_1, L_2, and equal width w_1 with PIN diode is embedded on truncated patch to

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Table 1. Dimensions of antenna design.

Parameter	L	W	s	t	d	g	h
Values (mm)	15.5	16.4	3.7	1.2	0.5	6	1.56
Parameter	ΔL	L_1	L_2	L_3	w_1	w_2	
Values (mm)	7	6.75	3.70	8.0	1.0	1.0	

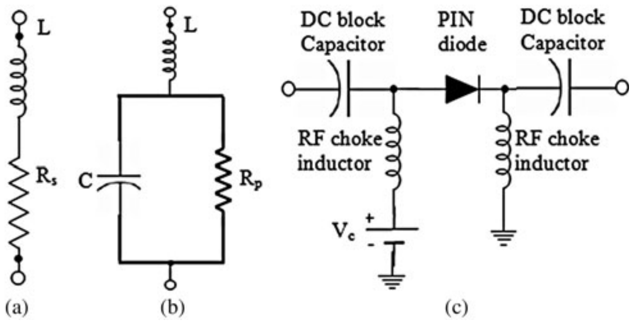

Fig. 2. Equivalent circuit and configuration of PIN diode bias circuit. (a) Forward bias, (b) reverse bias, and (c) bias circuit.

achieve three circularly polarized bands as shown in Fig. 1(b). In the simulation, ON condition of PIN diode is implemented with a through line of length 1 and width 0.5 mm. Figure 1(c) shows proposed antenna with reconfigurable CP. The slot is inclined at 135° with dimensions of $8 \times 1\ \text{mm}^2$.

The radiating patch and feed strip are placed on an RO3003 substrate with thickness $h = 1.56$ mm, dielectric constant $\varepsilon_r = 3.0$ and loss tangent $= 0.0013$ which rose in the air by g (6 mm). The SMA connector is used to connect the feed strip that capacitively couples the energy to the radiating patch. The separation between radiating patch and feed strip is d, feed strip length is t and width is s. The structure of the antenna is based on suspended capacitive fed microstrip antenna. The total height of the antenna ($g + h$) and effective dielectric constant are the key design parameters for the patch. The dimension of the radiating patch is calculated from the standard design expression after making necessary corrections in the key design parameter discussed above for the suspended dielectric [1, 24]. The impedance bandwidth may be maximized by using the design expression [7] given as

$$g \cong 0.16\lambda_o - h\sqrt{\varepsilon_r}, \tag{1}$$

where g is the air gap, ε_r and h are the dielectric constant and thickness of the substrate, respectively. Equation (1) is used to predict the initial value, while the final value would be within ±10% and may be obtained with simulation tools [7]. The feed strip can be considered as a rectangular microstrip capacitor as strip dimensions are much smaller as compared to the wavelength of operation and can be represented by terminal capacitances. The dimensions (t and s) of the terminal capacitances control the reactive part of the input impedance of the antenna [7]. The optimum dimensions of antenna obtained via iterative process that give broad impedance bandwidth and circularly polarized bands are listed in Table 1.

The proposed antenna was fabricated in microwave research laboratory of Ambedakar Institute of Advanced Communication and Technologies Research (AIACTR), Delhi, India. The vector network analyzer of series Agilent N5230 was used for the measurement. The substrate of

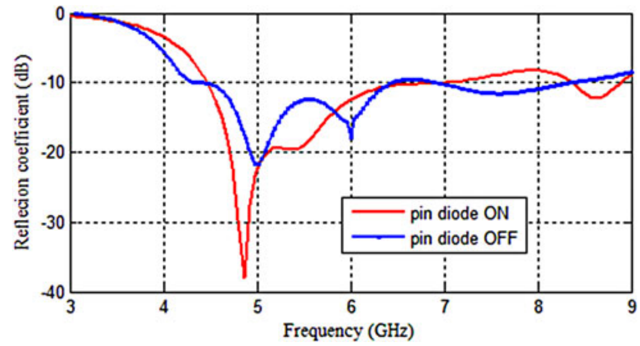

Fig. 3. Reflection coefficient of horizontal slit embedded truncated patch with PIN diode ON and OFF.

dimension $5 \times 5\ \text{cm}^2$ was taken for the fabrication and white paper board is used as support to provide an air gap.

III. RESULTS AND DISCUSSIONS

For the antenna design and simulation, IE3D simulation software is used which is based on MoM. The experimental verification is carried out to authenticate the antenna results. The final antenna is fabricated and is shown in Fig. 1(d) in ON and OFF states of the PIN diodes, respectively. The polarization of the antenna can be changed from linear to circular by truncating the opposite corners of the rectangular patch, which produces two orthogonal electric field components with equal amplitude and 90° phase difference. The single CP band with 3-dB axial ratio bandwidth of 11.1%, corresponding to the frequency range from 5.69 to 6.36 GHz is obtained with the truncation of dimension $7 \times 7\ \text{mm}^2$ at two opposite corners of the patch. Due to the truncation, the length of electrical patch decreases, which is responsible for gain reduction with respect to a reference antenna given in [7]. PIN diode is used as a switch in several microstrip antennas. GaAs PIN diode with forward voltage 0.73 V and forward current 12 mA is used for switching the antenna. The inclusion of copper strip indicates the PIN diode in ON state, while the absence indicates the OFF state of the diode [19]. The equivalent circuit of the PIN diode for the ON state (forward bias), OFF state (reverse bias), and bias circuit to control the states of diodes are shown in Figs 2(a)–2(c), respectively [18]. A thin slit in Fig. 1(c) is used for dc isolation and are connected to each other in an ac manner by capacitors. The aim here is to obtain the multiband CP operation. In order to achieve this aim, Fig. 1(a) is loaded with slits and PIN diodes. As a result, an antenna with triple CP bands is developed and the structure is shown in Fig. 1(b). Embedding slits with unequal length at the boundary of the truncated rectangular radiating patch and making the PIN diode ON and OFF is responsible for the multiband CP operation. Figure 3 shows the simulated reflection coefficient of the PIN-loaded antenna in OFF and ON condition of the diode. When the Diode is OFF, the antenna exhibits dual-band behavior in the frequency range from 4.39 to 6.42 GHz and from 6.98 to 8.27 GHz. The corresponding impedance bandwidth with OFF state of PIN diode is 37.55 and 16.97%. When the Diode is ON, the operating frequency is in the frequency range of 4.50 to 7.02 GHz and 8.4 to 8.87 GHz. The

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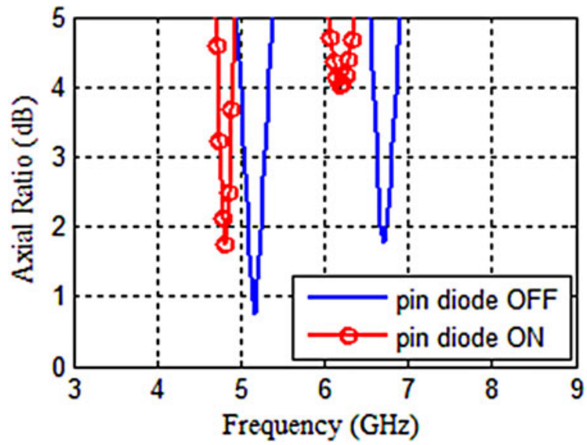

Fig. 4. Axial ratio of horizontal slit embedded truncated patch with PIN diode ON and OFF.

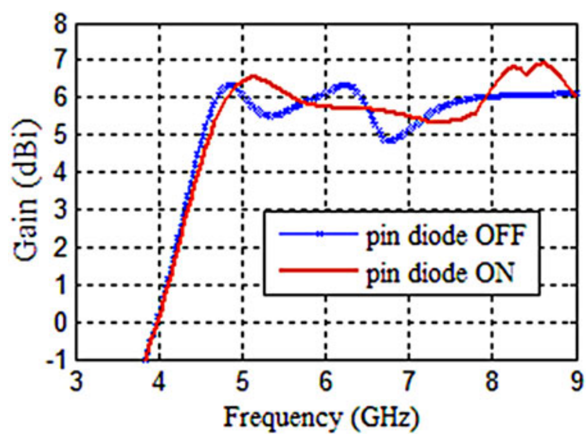

Fig. 5. Gain of PIN diode loaded truncated corner antenna with horizontal slits.

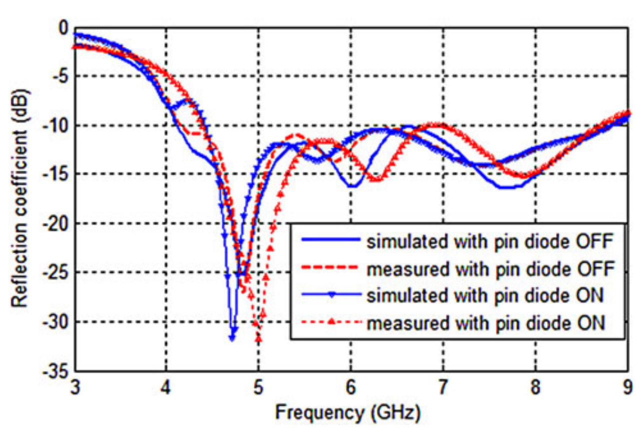

Fig. 6. Measured and simulated reflection coefficient for the proposed antenna with pin diode ON and OFF.

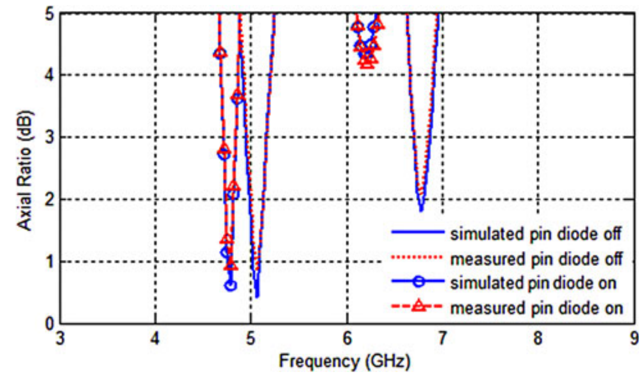

Fig. 7. Measured and simulated axial ratio for proposed antenna with PIN diode ON and OFF.

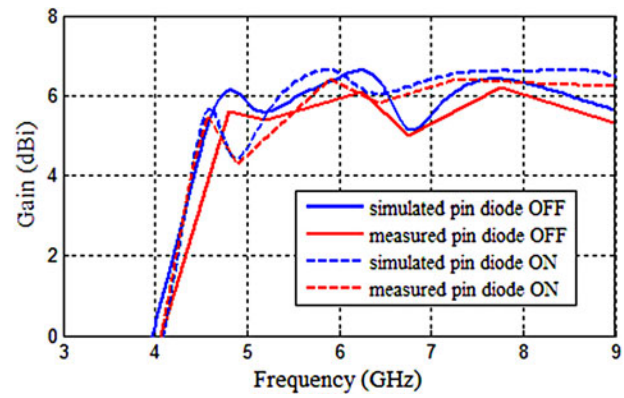

Fig. 8. Measured and simulated gain for proposed antenna.

corresponding impedance bandwidth with ON state of PIN diode is 43.75 and 5.54%.

The variation of axial ratio with frequency is shown in Fig. 4 and it is observed that for three frequency intervals the axial ratio is below 3-dB, which indicates that the antenna can generate CP in three distinct bands. When the PIN diodes are OFF, it is like a simple notch in the antenna and splits the single-band CP into double CP band – one above and one below the original CP band. The two CP bands were obtained in the frequency range of 5.03–5.28 GHz and 6.61–6.80 GHz. The 3-dB AR bandwidth is 4.81 and 2.83%. It is seen that center frequency of CP operation is changed to 5.16 and 6.7 GHz from 6.025 GHz as in the antenna with truncated corners. The ON state of PIN diode is like an ohmic resistance and makes gap connected and electric currents flow through the path. This effect of changed electric length of the surface current changes the resonant frequency of the two near degenerate orthogonal modes and antenna gives CP at different frequencies. Figure 4 also shows the axial ratio of PIN diode loaded antenna with horizontal slits in the ON states of the diode. The 3-dB axial ratio bandwidth is 2.49% in the frequency range 4.75–4.87 GHz. It is seen from the figure that the antenna provides reconfigurable CP bands by tuning the PIN diodes.

Figure 5 shows the simulated gain of antenna under both conditions of the diodes. It is seen that gain drop in some frequency interval. The reduction of gain occurs in the frequency ranges, where radiation is not in-phase and the phase difference decides the gain. The reduced gain in the last CP band indicates higher order orthogonal modes combining to produce CP.

To increase the operational impedance bandwidth, an inclined slot was introduced in Fig 1(b) and proposed antenna is shown in Fig 1(c). The PIN diodes are intact at the gap between two edges of the horizontal slits. When an inclined slot is cut inside the patch, there is a further increase in the length of the surface current path along the patch. The inclined slot and PIN diode create two different resonances for

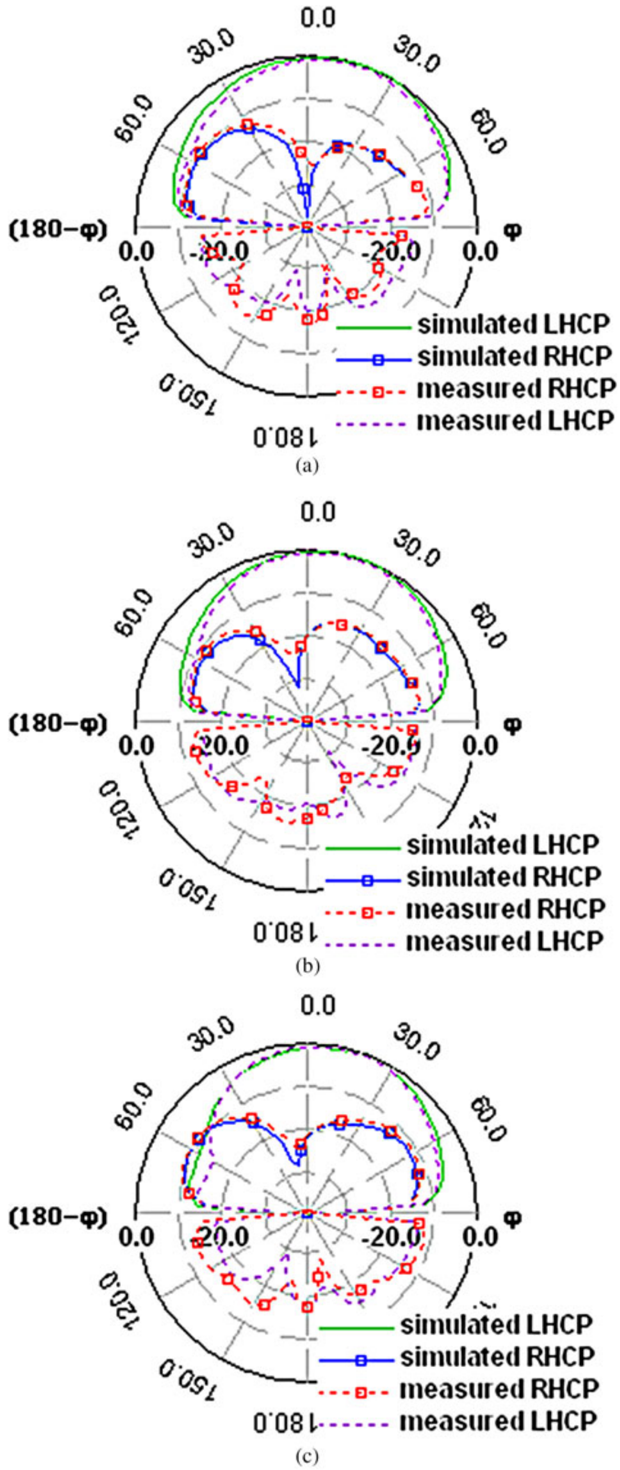

Fig. 9. Simulated and measured LHCP and RHCP patterns at (a) 4.97 GHz, (b) 4.77 GHz, and (c) 6.78 GHz.

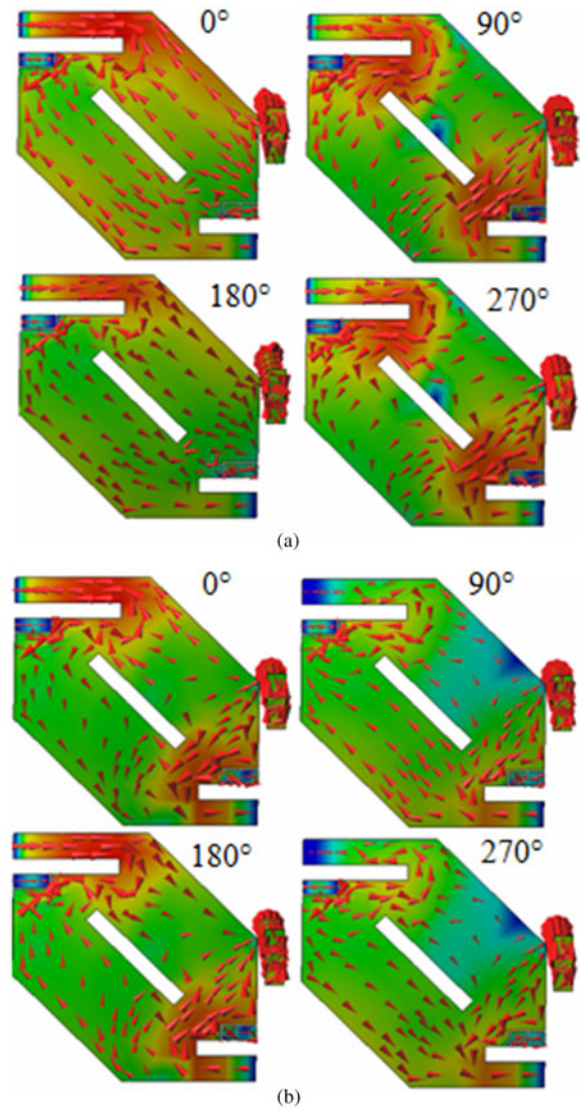

Fig. 10. Surface current distribution for proposed antenna with PIN diode OFF at: (a) 4.97 GHz and (b) 6.78 GHz.

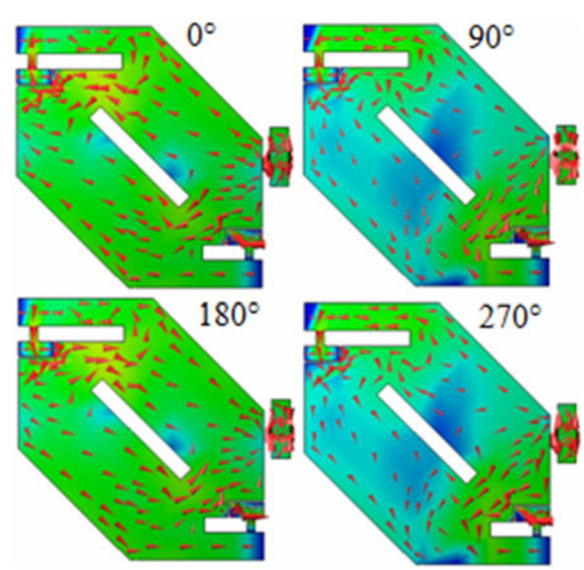

Fig. 11. Surface current distribution for proposed antenna with PIN diode ON at 4.77 GHz.

the patch. The closeness among the resonances makes the broadband characteristic in the antenna. The broader bandwidth of the proposed antenna is due to the better control of current distributions towards the higher frequencies of the bandwidth that is achieved due to the inclined slot. Figure 6 shows the simulated and measured reflection coefficient of the proposed antenna with ON and OFF states of the PIN diode. The antenna shows an impedance bandwidth of 66.61%, ranging from 4.42 to 8.80 GHz with ON state of the

Table 2. Comparison with earlier works.

References	**[6]**	**[7]**	**[11]**	**[14]**	**[22]**	**This work**
Feed type	**Complex**	**Single**	**Single**	**Complex**	**Single**	**Single**
Operational bandwidth	50%	50.4%	4.08%	50%	2.0% 1.5% 1.7%	66.61% (OFF) 68.42% (ON)
No. of patch	2	1	1	2	3	1
No. of CP bands	NIL	NIL	1	2	3	2 (OFF) 1 (ON)
Bandwidth of CP bands	NIL	NIL	NIL	3.00% 3.00%	3.40% 0.81% 0.85%	4.42% (OFF) 2.35%(OFF) 2.72%(ON)

PIN diode, while with OFF state of the PIN diode, the antenna operates in the frequency range of 4.12–8.91 GHz with an impedance bandwidth of 68.42%. In both states of the diode, the proposed structure provides better impedance bandwidth than previous work [7]. The measured result shown for comparison is in good agreement with the simulated result. The mismatch between the measured and simulated results existed, which may be mainly caused by fabrication imperfection. Figure 7 shows the measured and simulated axial ratio of PIN diode loaded proposed antenna in the two states of the diode. It is clear from the figure that the antenna provides reconfigurable circularly polarized bands by tuning the PIN diodes. The antenna exhibits CP in two bands with the frequency range from 4.94 to 5.16 GHz and from 6.70 to 6.86 GHz, when PIN diode is OFF, i.e. axial ratio bandwidth is 4.42 and 2.35%, respectively. With ON state of the diode the antenna has another CP band from 4.71 to 4.84 GHz with axial ratio bandwidth of 2.72%. The 3-dB axial ratio frequency range for all the three CP bands falls within the impedance bandwidth. Figure 8 depicts measured and simulated gain with frequency for inclined slot loaded microstrip antenna with PIN diode ON and OFF. It is clear from the graph that the gain is almost constant over the CP bands. The gain of the antenna was measured in an anechoic chamber using the substitution method. Two calibrated horn antennas of known gain were used as transmit antenna to measure the gain of antenna under test (AUT). AUT was used as receive antenna and placed on the positioner with required elevation and azimuth coverage. The horn antenna with calibrated gain was used as source antenna. The similar measurement process was repeated by replacing AUT with another horn antenna of known gain. The difference between two measured powers reflects the gain difference and absolute gain of the AUT is calculated. By changing the distance between transmit and receive antenna, the process was repeated and the average gain was considered as the final gain.

For the reception of the signal, it is important to find the direction of field rotation in terms of left hand circularly polarized (LHCP) wave and right hand polarized (RHCP) wave. The simulated and measured LHCP and RHCP far-field distribution in the E-plane at the center frequencies of individual CP bands 4.97, 4.77, and 6.78 GHz are shown in Figs 9(a)–9(c), respectively. From these figures, it is clear that the antenna is LHCP with considerable axial ratio beamwidth. A good amount of cross polar attenuation is obtained at all center frequencies.

Figures 10(a) and 10(b) show the current distribution on the radiating patch for different time frames: $t = 0(0^\circ)$, $t = T/4(90^\circ)$, $t = 2\,T/4(180^\circ)$, and $t = 3\,T/4(270^\circ)$ at the center frequencies of CP bands with PIN diode OFF, while Fig. 11 shows the same at the center frequencies of the CP band with PIN diode ON. The surface current distribution of the radiating patch at the time frames clearly indicates the circularly polarized field radiation. The field rotates in the clockwise direction, which results in exciting a LHCP radiation.

In addition, comparison with previously reported antennas is presented in Table 2. It is clear that proposed structure is simple and also generates more number of CP bands.

IV. CONCLUSION

A reconfigurable circularly polarized capacitive fed microstrip antenna has been designed and fabricated. The opposite corner truncated patch provides single band CP. Reconfigurable CP has been achieved by loading two horizontal slits of unequal lengths with PIN diodes on truncated patch. Reconfigurable CP has been realized by switching PIN diodes across the slits ON and OFF. Broadband performance of the proposed antenna is realized by embedding an inclined slot on the patch with PIN diodes across the horizontal slits. The impedance bandwidth of the proposed antenna has increased from 51 to 66.61% (ON state) and 68.42% (OFF state) as compared with capacitive coupled probe-fed microstrip antenna reported earlier and also generated three distinct LHCP bands. An axial ratio bandwidth for the proposed antenna of 4.42, 2.35, and 2.72% has been realized. Good LHCP performance has been achieved in the three bands with respect to cross-polar attenuation and axial ratio beamwidth. The results of proposed antenna show that it is very suitable for various wireless communication system applications. The proposed antenna is useful for 5 GHz WLAN and public safety WLAN (IEEE802.11y) at 4.9 GHz. The IEEE 802.11ac Wi-Fi at 5 GHz has the expected WLAN throughput of at least 1 Gigabyte/s and standard is recently approved in Jan 2014. The antenna also covers the transmit and receive frequency of the Indian National Satellite system in the C-band.

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