Notched Triangular Patch Antenna for Polarization Reconfigurability

Uma Shankar Modani
Gov. Engg. College, Ajmer, Rajasthan, India

Gajanand Jagrawal
Gov. Engg. College, Ajmer, Rajasthan, India

Anubhav Kanwaria
Gov. Engg. College, Ajmer, Rajasthan, India

ABSTRACT
This paper proposes a reconfigurable microstrip patch antenna with polarization states being switched between left-hand (LH) and right-hand (RH) circular polarizations (CP). The CP mode has been excited by perturbation element which is two parallel notches at the base of triangular patch. Two PIN diodes are placed on each notch to alter the current direction, which determines the polarization state. As notch rightwards (leftwards) to base center of triangular patch is shorted between the inside of the notch and the triangular patch, the proposed antenna yields left (right) handed circular polarization. This reconfigurable patch antenna with agile polarization has good performance and concise structure, which can be used for 5.77 GHz wireless communication systems.

Keywords
Microstrip antenna, circular polarization, reconfigurable antenna, U shaped slot.

1. INTRODUCTION
RECONFIGURABLE antennas play an important role in modern wireless communication systems, such as personal communications service (PCS) and wireless local area network (WLAN). Reconfigurable antennas with polarization diversity can realize frequency reuse, which expands the capability of communication systems, and are useful when the operating frequency band is limited [1, 2]. In addition, since a polarization diversity antennas can also alleviate the harmful influence caused by multipath effects [3], therefore a polarization control is required from a right-handed CP (RHCP) to a left-handed CP (LHCP) or vice versa. Therefore, electrically controllable antennas have been researched with switchable circularly polarization such as switching slots [4 - 7], switching feeding point [8 - 11], and a switching corner truncations [12 - 14].

In this paper, a reconfigurable microstrip patch antenna with two parallel notches is proposed. To verify the proposed scheme, a thin wire is utilized to have a short of notches. Because of the short of notches the current flow on the microstrip patch around the notches can be easily changed. Furthermore, the proposed antenna has a simple configuration on a planar substrate.

2. ANTENNA DESIGN
The Fig. 1 shows the configuration of the proposed single-fed circular microstrip patch antenna with two parallel notches. The antenna consists of two small rectangular strips in the notches and four PIN diodes are installed between rectangular strip and triangular patch at position *P* of 6.2 mm on a Roger 5880 substrate with the thickness of 3.2 mm and a relative dielectric constant of 2.2.

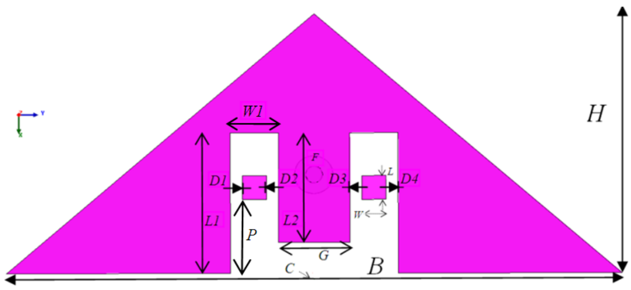


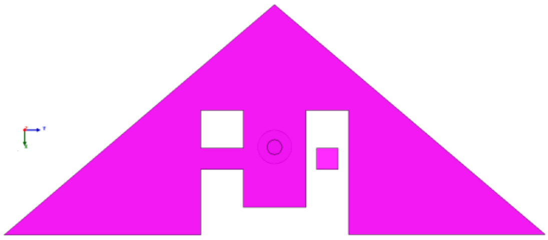
Fig 1: Geometry of the proposed antenna

Table 1. Dimensions of the radiating patch geometry

Parameters	Dimensions (mm)
C(Base point)	0,0,1.6
H	21.8
B	50.9
L1	11.8
L2	9.2
W1	4.0
G	5.9
P	6.2
*L * W(rectangular strip)*	2 * 2
Ground size	50 by 70

Triangular patch is connected to rectangular strips by PIN diodes which are symmetrically positioned in the two parallel notches with opposite polarities. The Triangular patch with base center coordinates *C* has the height *H* of 21.8 mm and Base *B* of 50.9 mm. Two parallel notches are cut with length *L1* & L2, width *W*, and gap between notches *G*. The feeding point of the antenna *F* is located at 8.3 mm apart from the base center of triangular patch to the negative *x*-axis. Fig. 2 shows the configurations of the prototype antenna. For the simulation purpose, the triangular patch and rectangular strip are connected by a copper wire with a length of 1 mm.

(a)

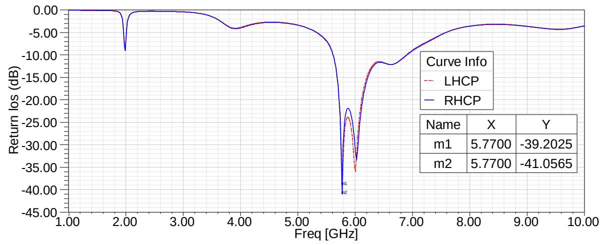


(b)

Fig 2: Geometry of simulated prototype antenna: (a) LHCP mode. (b) RHCP mode.

The antenna polarization is controlled by switching the bias voltage between the triangular patch and rectangular strips. As the Diode *D1*, *D2* is ON and the Diode *D3, D4* is OFF, the antenna has RHCP mode. During the Diode *D1*, *D2* is OFF and the Diode *D3, D4* is ON, the antenna presents LHCP mode. The proposed antenna is simulated with aid of the Ansoft HFSS.

Return loss have sharp down peaks or increased matching at two points as return loss varies from 1GHz to 10GHz with observed minimum return loss of less than -39dB is observed at the frequency 5.77GHz while other down peak is observed at slightly rightwards to 6.0GHz with return loss less than -30dB as shown in Fig.3(a). The two matching points together gives -20dB bandwidth of more than 400 MHz, although the proposed antenna has -10dB bandwidth greater than 1.2GHz.



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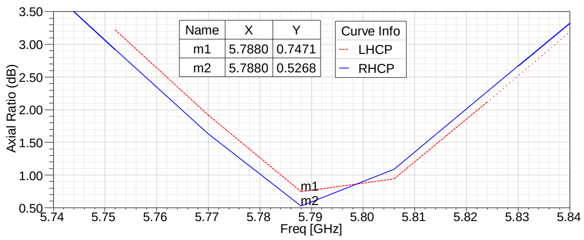


(b)

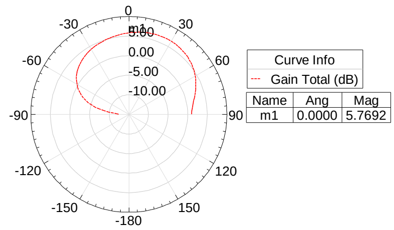
Fig 3: Rectangular plot for LHCP mode and RHCP mode (a) Return loss plot (b) Axial ratio plot

The observations of return loss versus frequency curve of antenna operating in two modes shown in Table 2 are similar which states the matching is stable when diode states are switched. Similar to return loss curve, axial ratio curve plot shown in Fig. 3(b) has shown that in the two operating modes CP performance is stable when the diode state is switched having almost same minimum axial ratio value at same minimum axial ratio point.

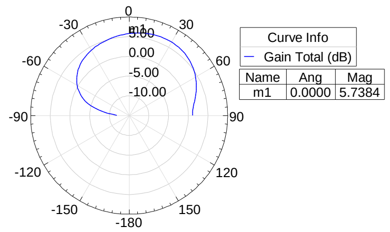
Table 2. Result of design antenna in two modes

Parameters ↓	**LHCP mode** at 5.77GHz	**RHCP mode** at 5.77GHz
Return loss (dB)	-39.20	-41.05
Impedance BW (MHz/%)	1295/22.4	1281/22.2
F_L(GHz)	5.617	5.613
F_U(GHz)	6.912	6.894

The design exhibits circular polarization reconfigurability around 5.77 GHz resonant bands for near to 85MHz CP bandwidth. Minimum axial ratio for LHCP mode is 0.74dB at 5.788GHz with total gain of 5.76dB while for RHCP mode minimum axial ratio is 0.52dB at 5.788GHz with total gain 5.73dB as shown in Fig. 3 and Fig. 4. It has also been shown in Fig. 4 that the total gain radiation patterns are having almost same shape for both the modes. Radiation pattern have variable gain as Theta varies from -90 degree to 90 degree with observed maximum gain of more than 5.75dB is observed for Theta 0 degree. Although considering antenna is operating for Theta - 60 degree to 60 degree, the gain curve is always greater than zero. The observations of Gain versus Theta curve is similar for antenna operating in both modes which states the radiation pattern is stable when diode states are switched.



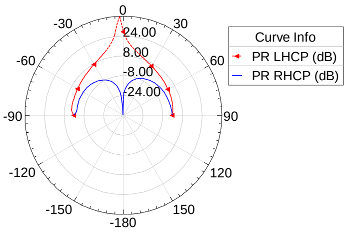
(a)



(b)

Fig 4: Total gain radiation pattern (dB) at Minimum axial ratio point, 5.788GHz, for E plane (a) LHCP mode (b) RHCP mode.

Around polarization band and at minimum axial ratio point, the polarization ratio radiation pattern plot has been shown for both the modes in Fig. 5, which indicates that the proposed antenna is left hand circularly polarized (LHCP) in every part of the curve for LHCP mode and right hand circularly polarized in every part of the curve for RHCP mode. Polarization ratio pattern have variable gain as Theta varies from -90 degree to 90 degree with observed maximum gain of more than 36dB is observed for Theta offset slightly leftwards to the 0 degree for Co polar curve (red coloured) while at the same plane for same theta observed gain is less than -36 dB for Cross polar curve (blue coloured) in the LHCP mode as shown in Fig. 5(a), which indicate high isolation and improved CP performance. The observations of PR radiation patterns shows Co polar curve is isolated from Cross polar curve in both the modes with one exceeding other in most part of curve which is a necessary thing for achieving good CP antenna. Since Co polar (desired mode) and Cross polar (undesired mode) component of LHCP mode is similar to RHCP mode therefore CP performance of both the modes is same and not affected by diode state.



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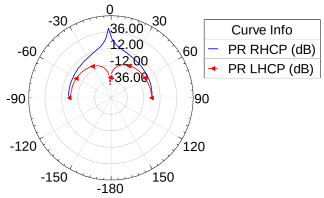


(b)

Fig 5: Polarization ratio radiation pattern for E plane at 5.788GHz (a) LHCP mode (b) RHCP mode.

The proposed antenna possesses positive gain at all planes in both the modes when theta is 0 degree for desired polarization reconfigurable band extending from 5.770GHz to 5.882GHz as shown in Fig. 6. Total gain curve indicates that the design has similar gain for both the mode for Theta 0 degree covering bandwidth 5.72GHz to 5.86GHz and the minimum gain points are observed at 5.86GHz and while maximum gain is observed at 5.72GHz. At minimum axial ratio points of 5.788GHz, gain obtained is 5.69dB and 5.73dB for LHCP and RHCP mode respectively. Gain radiation pattern and total gain rectangular plot shows that the proposed design has positive gain for Theta between -60 to 60 degree covering bandwidth 5.72 GHz to 5.86GHz.

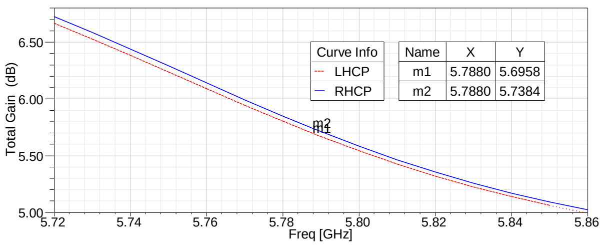


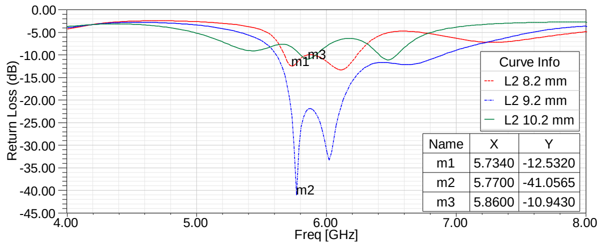
Fig. 6 Total gain rectangular plot for polarization band

3. STUDY OF VARIOUS PARAMETERS OF PROPOSED ANTENNA DESIGN

In this section, the antenna design parameters are varied and the effects of these variations on the return loss and axial ratio of the antenna have been observed. For this study, the antenna design shown in Fig. 2(b), RHCP mode has been used. Return loss mainly consists of two bands resonating at 5.77GHZ and 6.00GHz, which together covers bandwidth ≥1.28GHz in both the modes. The design has many parameters which need to be optimized to get desired results. The following section discusses the effect of variation of *L2*, *P*, and *G* parameters on return loss, minimum axial ratio value, and minimum axial ratio bandwidth.

3.1 Variation in the length of notches (*L2*)

The length of *L2* has been varied keeping all other parameters same as shown in Table 1 and the result of return loss plots and axial plots for three values have been shown in Fig. 7. It has been observed length of notch have significant effect on matching while minimum axial ratio value shows slight improvement with rightwards movement of minimum axial ratio point as notch length increases. Notch length *L2* of 9.2mm provide best matching for 5.72GHz to 5.85GHz band, while matching disturbs drastically as length of notch decreases or increases.



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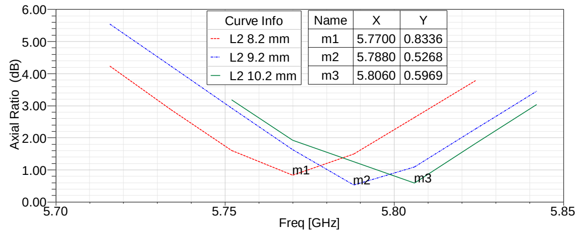
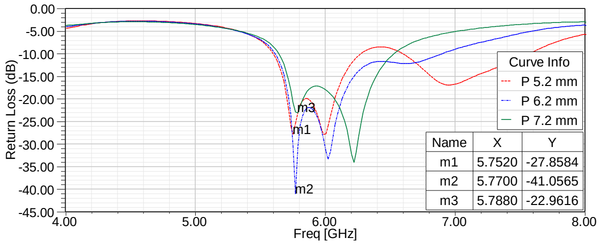


(b)

Fig 7: Rectangular plot for variation in length of notch (*L2*) (a) Axial ratio plot (b) Return loss plot.

3.2 Variation in the position of diode (*P*)

This part involves the variation of position of diode *P* keeping all other parameters same as shown in Table 1. The result of return loss plots for three values have been shown in Fig. 8. It has been observed that best matching with good minimum axial ratio value is obtained for *P* of 6.2mm near to 5.77GHz resonant band. Also at *P* of 6.2mm best matched resonant frequency (Fr) and minimum axial ratio (MAR) point are nearly same at 5.770GHz and 5.788GHz respectively. Diode position is an effective parameter for fine tuning and perfect alignment of resonant frequency (Fr) and minimum axial ratio (MAR) point. As *P* increases from 5.2mm to 7.2mm, the gap between Fr and MAR point decreases to 8MHz from 54MHz but observed matching at two positions for first band, which is resonating near 5.77GHz, is less than 30dB. The two resonating bands of return loss curve reaches closer as *P* decreases with rightward movement of MAR point and would combine to give single resonant frequency but with huge difference between Fr and MAR point ≥ 54MHz.



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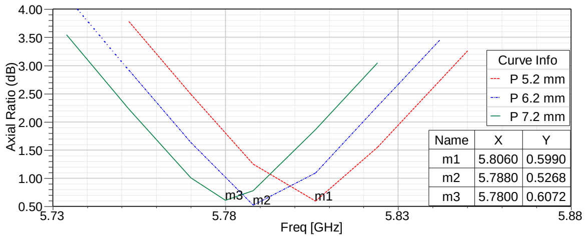
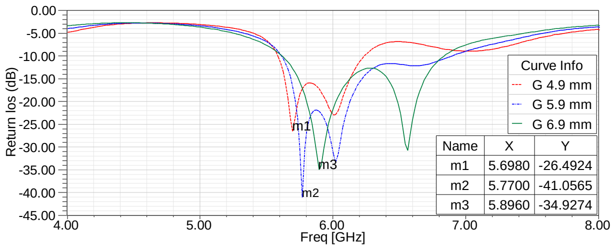


(b)

Fig 8: Rectangular plot for variation in position of diode (*P*) (a) Axial ratio plot (b) Return loss plot

3.3 Variation in the gap between notches (*L2*)

This part involves the variation of gap between notches *G* keeping all other parameters same as shown in Table 1. The result of return loss plots for three values have been shown in Fig. 9. It has been observed that the design is best matched with least MAR value for *G* of 5.9mm near to 5.77GHz resonant band. Also at *G* of 5.9mm best matched resonant frequency (Fr) and minimum axial ratio (MAR) point are nearly same at 5.770GHz and 5.788GHz respectively with difference of 18MHz only. Any value of *G* offset to 5.9mm will increase the gap between resonant frequency (Fr) and minimum axial ratio (MAR) point, which is about 36MHz (or 54MHz) for *G* 5.2mm (or 7.2mm). Fig. 9 also shows that the gap affects operating frequency substantially. The return loss curves and axial ratio curves both moves rightwards by more than 70MHz and 50MHz respectively as *G* is incremented in steps of 1mm, which indicates that after patch size, gap *G* is another important parameter deciding operating frequency. The obtained operating point can further be fine tuned by adjusting diode position as explained in next section.



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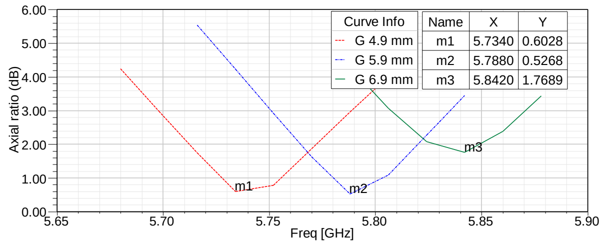

(b)

Fig 9: Rectangular plot for variation in gap between the notches (*G*) (a) Axial ratio plot (b) Return loss plot.

The design has nearly same peak directivity and peak gain value at operating frequency in both the modes which indicates radiation efficiency is almost near to 1 as shown in Table 3. Fig. 10 shows the design has good isolation for every part of plot with maximum isolation is observed for Theta 0 degree, where Co polar is one which is desired and Cross polar is one which is orthogonal to desired one.

Table 3 Simulated results of antenna parameter

Parameters →		Peak Directivity	Peak Gain	Radiation Efficiency (%)
RHCP	5.788GHz	5.074	5.066	99.98
LHCP	5.788GHz	5.103	5.091	99.77

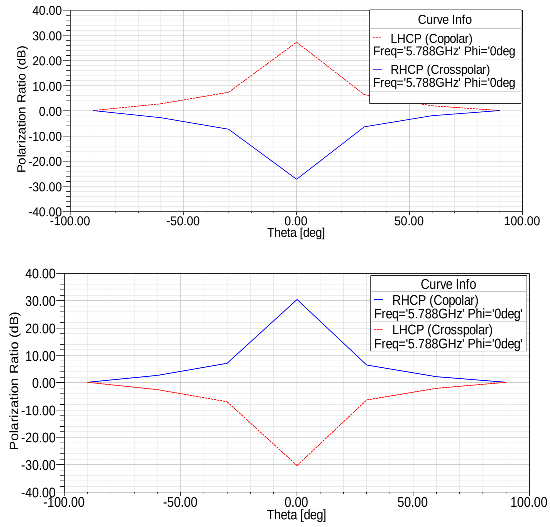

Fig 10: Polarization Ratio rectangular plot a) LHCP mode b) RHCP mode

4. CONCLUSIONS

A single probe-fed reconfigurable CP microstrip antenna with a notched triangular patch is presented for circular polarization diversities. It is shown that the polarization of the proposed antenna can be controlled between RHCP and LHCP by tuning the four PIN-diodes located in the notches ON and OFF over 5.77GHz ISM band. Therefore, the proposed simple switchable CP planar antenna can be applicable for mobile communication terminals with polarization diversities. The design exhibiting circular polarization Reconfigurability over ISM band 5.2GHz can be obtained just by altering the parameters.

5. REFRENCES

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