Design of Pin Loaded Reconfigurable Patch Antenna for Wireless Communications

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Abstract **─** The design and performance analysis of a single fed reconfigurable patch antenna for circular polarization is presented. The patch has a square shaped slot etched on it. Four ultra-miniature diode switches are placed at appropriate positions to bridge the gap in the slot regions and are used to switch the nature of polarization between left-hand circular polarization (LHCP) and right-hand circular polarization (RHCP). The antenna achieves an impedance bandwidth (S11 ≤ -10dB) between 2.34 GHz to 2.4 GHz (2.53%) with a center operating frequency of 2.37 GHz. The surface current distributions on the radiating patch along with its corresponding radiation patterns measured at the operating frequency are plotted. The antenna achieves an axial ratio beam width (AR ≤ 3dB) of -25° to 50° for left-hand circular polarization and -40° to 45° for right-hand circular polarization. Measured radiation pattern results show the antenna has a good cross-polarization isolation of -16.2 dB for RHCP configuration and -16.54 dB for LHCP configurations and hence the antenna is suitable for modern wireless applications.

Index Terms **─** Antenna feeds, antenna radiation patterns, circular polarization, microstrip antennas, slot antennas.

I. INTRODUCTION

Antennas capable of receiving at diverse polarizations are widely used in satellite communication, radars [1-2]. The requirement for multifunctional antennas has increased recently in wireless communication and hence reconfigurable antennas are gaining much attention due to their ability to configure their state of polarization without a change in physical dimension of the antenna [3]. To achieve polarization reconfiguration, RF PIN diodes, MEMS switches, reed switches, variable capacitors and also photoconductive switches are used. The selection of switches depends on circuit complexity including biasing network and power consumption. In general, reconfigurable antenna are designed by means of reconfigurable feed network or by reconfiguring radiating structure. Lin and Wong [4] presented reconfigurable antenna by biasing the pin diodes sequentially. Dual-Polarized Antenna Based on Metal Ring is presented by Lizhong Song and Sai Li [5]. Lin, Wei, and Hang Wong [6] demonstrated a reconfigurable antenna by exciting radiating element by means of cross aperture having controlled RF switches.

Most of the conventional reconfigurable antennas utilizes a slot etched on the radiating element and reconfiguring it by means of pin diodes [7], RF switches or varactor diodes. Bharathi, Lakshminarayana, and Somasekhar [8] presented a reconfigurable antenna which comprises of a square slot etched on radiating element embedded with pin diodes for reconfiguring the structure of the radiating element. A reconfigurable monopole antenna integrated with mushroom-like meta-surface to improve antenna performance is presented by Cao, Cheung, and Yuk [9]. Another common method of realizing circular polarization is by truncating the corners of square patch antenna. Bharathi, Lakshminarayana, and Somasekhar [10] uses four PIN diodes on reconfigurable truncated corners which are used to connect the truncated patch with its radiating element for polarization reconfiguration. Row and Shih [11] found the use of variable capacitors for tuning resonant frequencies and also utilizes several diodes along with DC bias network for changing polarization states which increases the complexity of the feed system. Polarization reconfiguration can also be achieved by reconfiguring feed network by means of pin diodes Lin, Wong, and Ziolkowski [12]. An annular slot microstrip antenna with reduced number of switching elements is analysed in Saravanan and Rangachar [13] where polarization reconfiguration is achieved by switching the diodes in the feed network. The effect of quadrature hybrid

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network is used for achieving reconfigurable circular polarization Elhefnawy, Ismail, and Mandeep [14]. Varactor diodes are used recently to reconfigure the characteristics of the antenna Liang, Sanz-Izquierdo, Parker, and Batchelor [15]. By varying the bias voltage, the capacitance of the varactor diode is changed and thereby tuning the performance of the antenna. The polarization reconfiguration antenna by means of varactor diodes as presented in Babakhani and Sharma [16]. The model utilizes four varactor diodes to bridge the inner circular patch with outer concentric ring patch. The antenna is excited by means of two ports having 900 phase difference with each other which requires a separate feed network for feeding. Beno and Emmanuel [17] designed reconfigurable antenna by mechanical tuning of slot width along with rotation of strips on radiating patch. Lu, et al., [18] achieved polarization diversity by generating ±90 deg phase difference to signal going to patch element. Hucheng Sun and Sheng Sun [19] demonstrated reconfigurable antenna by inducing phase delay in the output ports by means of reconfigurable feed network. In recent times, fluid dielectrics are used for polarization reconfiguration due to its ability of linear control over polarization [20-21]. However, integration of these antenna model with other RF devices is difficult due to its requirement of separate fluid tank space.

The proposed antenna is a rectangular patch with a square shaped slot etched at its center operating at 2.37 GHz band. The antenna uses four ultra-miniature pin diodes for polarization diversity. Two bias lines are used to excite diodes for changing the shape of the radiating element and thereby achieving polarization diversity. A parametric analysis is carried out to study the effect of slot dimension over performance sensitivity of the antenna. The antenna is fabricated and its impedance and radiation characteristics are measured using antenna test systems and the obtained results are compared with simulation results. The simulation results agree with measured results and hence it is suited for modern wireless applications.

II. ANTENNA DESIGN

A. Antenna geometry

The antenna is designed on roger substrate (RO4350) having a size of 47 mm x 47 mm x 1.52 mm and having a relative permittivity ε_r of 3.66 and a loss tangent δ of 0.004. Figure 1 shows a rectangular patch having a dimension of 31.3 mm x 31.3 mm printed on roger substrate (RO4350) and a square shape slot is etched at its centre. The length and the width of the slot are obtained through parametric analysis of antenna performances over its dimensions. A 50Ω SMA coaxial connector is used to feed the antenna model whose characteristic impedance Z_0 is given below:

$$Z_0 = \frac{\eta_0}{2\pi\sqrt{\varepsilon_r}} ln\left(\frac{D}{d}\right)\Omega. \quad (1)$$

For an antenna to radiate effectively the antenna must be purely reactive and the reactive component in the impedance must be equal to zero at operating frequency. This is achieved by properly matching Z_0 and Z_{in}. A quarter wave transformer is used to match the impedance between radiating patch and the coaxial fed.

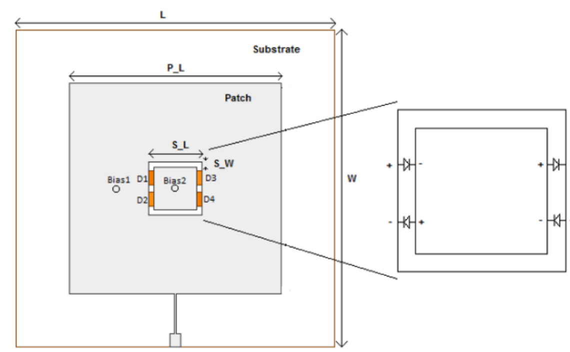

Fig. 1. Antenna geometry.

NXP BAP50-03, 50mA, 50V 2-pin diodes are used for polarization reconfiguration. The diodes operate at 0 to 12 GHz operating band with a minimum biasing voltage of 0.7V and hence best suited for reconfiguration. Four such ultra-miniature pin diodes are used for polarization diversity. The equivalent pin diode model is shown in Fig. 2. The diode has a minimum series resistance of 5Ω and inductance of 9nH under forward bias condition and maximum resistance of 50MΩ and capacitance of 0.35pf under reverse bias condition [22].

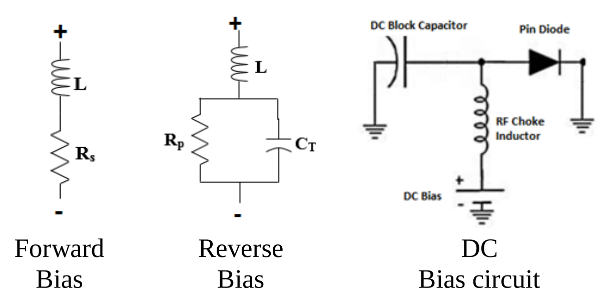

Fig. 2. Equivalent pin diode model and DC bias circuit.

The DC bias circuit comprises of RF choke inductor (TDK MLG0603Q Series Inductor, 22nH) to provide a DC bias path to the pin diode and also block the RF signal and a blocking Capacitor (AVX 0402 Series Ceramic Capacitors, 10pf) to avoid DC bias from reaching RF output.

B. Principle of operation

The antenna model comprises of square slot etched on the radiating patch. Four pin diodes are appropriately placed to bridge the gap in the slot region. The antenna generates either left hand polarization (LHCP) or right-hand polarization (RHCP) based on biasing potential given to excite the pin diodes. Table 1 gives the different operating states of the proposed antenna.

Table 1: Operating states

Bias 1	Bias 2	ON State	OFF State	Operating State
+3V	0 V	D1 and D4	D2 and D3	LHCP
0 V	+3V	D2 and D3	D1 and D4	RHCP

When a bias 1 terminal is excited with positive potential (+3 V), diodes D1 and D4 are forward biased (ON state) and diode D2 and D3 are reverse biased (OFF state). This reshapes the antenna structure as shown in Fig. 3 (a) and generates left hand circular polarization (LHCP). When a bias 2 terminal is excited with positive potential (+3 V), diodes D2 and D3 are forward biased (ON state) and diode D1 and D4 are reverse biased (OFF state). This reshapes the antenna structure as shown in Fig. 3 (b) and generates right hand circular polarization (RHCP).

(a) LHCP Configuration (b) RHCP Configuration

Fig. 3. Equivalent antenna structure.

III. PARAMETRIC ANALYSIS

Parametric analysis is carried to find the optimum dimension of the proposed antenna model. Ansoft high frequency structure simulator is used to tune the antenna dimensions and pin diode used in the antenna design is modelled based on the manufacture specification.

The performance of the antenna is greatly affected by slot dimension and hence it is taken as vital parameter to tune the antenna performance. The width of the slot is taken equivalent to the diode length given in manufacture data sheet. The length of the slot is tuned with respect to antenna operating frequency and axial ratio performances. From Fig. 4 it is observed that the resonating frequency of the proposed antenna model shifts from lower band to higher band with an increase in slot length due to increase in electrical length of the antenna and thereby making the antenna to resonate at the higher band with an increase in slot length.

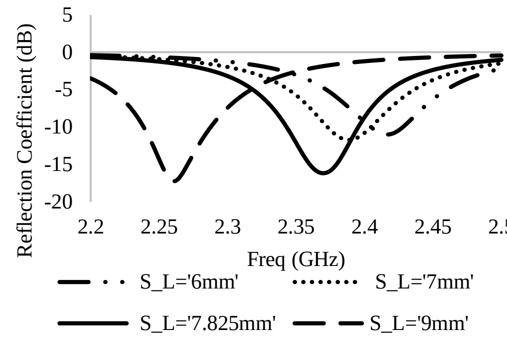

Fig. 4. Parametric analysis of Slot Length S_L on reflection coefficient.

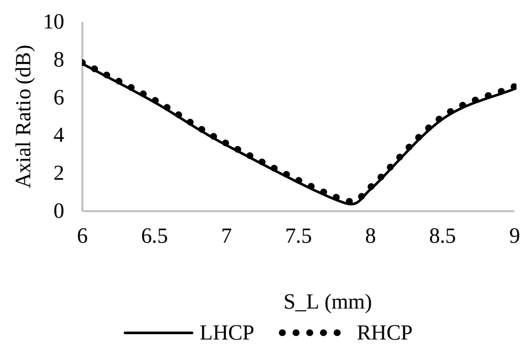

Fig. 5. Parametric analysis (Simulated) of slot ength S_L on axial ratio.

Figure 5 shows the slot length effect on the purity of circular polarization. As shown in Fig. 5 the axial ratio is greatly affected by slot length. An optimum value of slot length is chosen to have a minimum axial ratio and to have good AR characteristics. Since the LHCP and RHCP configuration are symmetrical with each other, the effect of slot length on the axial ratio of both LHCP and RHCP configuration is similar and antenna exhibits a similar pattern as shown in Fig. 5. Based on the parametric analysis, the optimum dimension of the and slot width (S_W) is taken as 1.5 mm and slot length (S_L) is taken 7.825 mm and the corresponding surface current distribution at different instants of time is shown in Fig. 5.

The current distribution plot corresponding to LHCP and RHCP configuration is given in Fig. 6. It is observed that electric field vector traces clock wise direction for LHCP mode and anti-clock wise direction for RHCP mode. Figure 7 shows a front view and back view of the fabricated antenna model. The model is fabricated on roger substrate (RO4350) having a thickness of 1.52 mm and having a length and width of 47 mm x 47 mm.

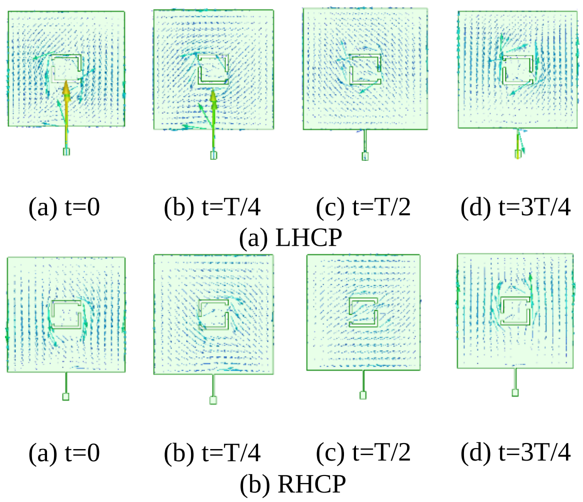

Fig. 6. Current distribution in LHCP and RHCP.

(a) Front view (b) Back view

Fig. 7. Fabricated antenna model.

IV. RESULTS AND DISCUSSIONS

The performance of the antenna is validated by measuring its impedance and radiation characteristics using field fox network analyzer (N9925A) and antenna test systems. The impedance characteristics for the proposed model at LHCP and RHCP mode is shown in Fig. 8. LHCP mode is excited by biasing diode pair D1 and D4 and RHCP mode is excited by biasing diode pair D2 and D3 by means of DC bias line. The antenna gives -10 dB measured impedance bandwidth of 60 MHz in the range 2.34 GHz- 2.40 GHz for both modes with a center frequency of 2.365 GHz in WiMAX band. The axial ratio is calculated from horizontally and vertical polarized components (E_1 and E_2) based on equation given below,

$$A = \sqrt{\frac{1}{2}\left(E_1^2 + E_2^2 + \sqrt{E_1^4 + E_2^4 + 2E_1^2E_2^2\cos(2\delta)}\right)}, \quad (2)$$

$$B = \sqrt{\frac{1}{2}\left(E_1^2 + E_2^2 - \sqrt{E_1^4 + E_2^4 + 2E_1^2E_2^2\cos(2\delta)}\right)}, \quad (3)$$

$$\tau = \frac{1}{2} arctan \frac{2E_1E_2 cos\ \delta}{E_1^2 - E_2^2}, \quad (4)$$

where δ is the phase difference between E_1 and E_2 and τ is the inclination of the polarization ellipse. The axial ratio (AR) is given by:

$$AR = \frac{2A}{2B} = \sqrt{\frac{E_1^2 cos^2\tau + E_1E_2 sin2\tau cos\ \delta + E_2^2 sin^2\tau}{E_1^2 sin^2\tau - E_1E_2 sin2\tau cos\ \delta + E_2^2 cos^2\tau}}. \quad (5)$$

The radiation characteristics of the antenna is measured using antenna test system and are shown in Fig. 9. It is observed that the antenna gives symmetrical radiation pattern and with better cross polarization isolation of ≥ 15 dB in the operating frequency.

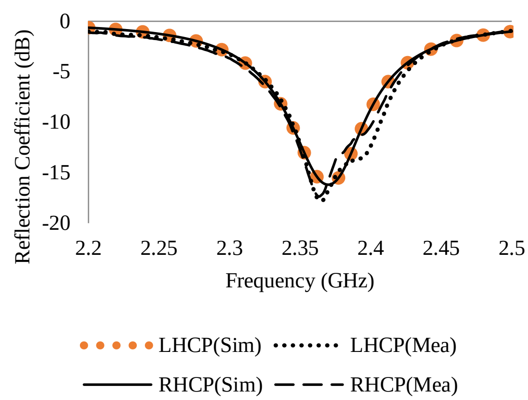

Fig. 8. Reflection coefficient (dB).

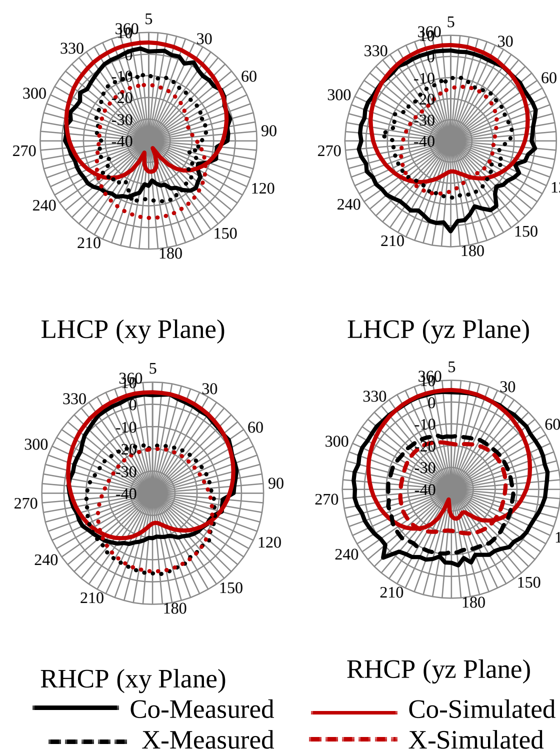

Fig. 9. Simulated and measured radiation pattern of LHCP/RHCP (dB).

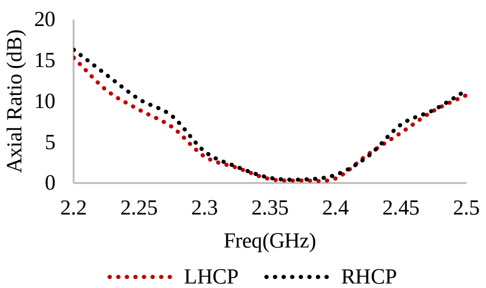

Fig. 10. Variation of the axial ratio (dB) against operating band (GHz).

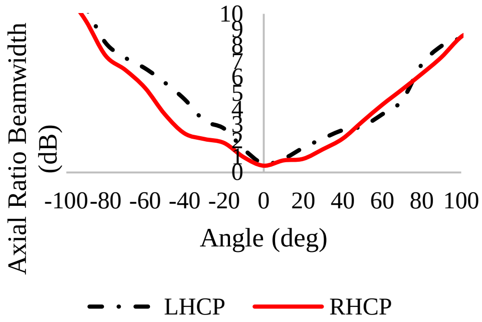

Fig. 11. Measured 3dB axial ratio beamwidth (dB).

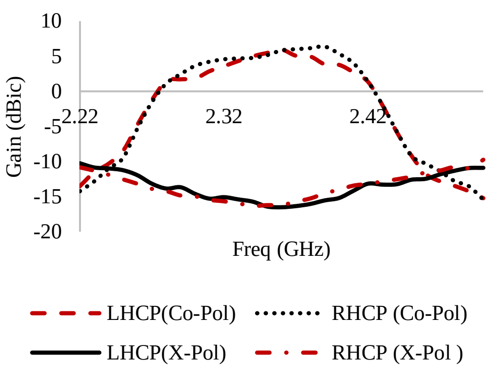

Fig. 12. Measured gain across the operating band for both modes.

Figure 10 shows that the antenna achieves a 3dB axial ratio bandwidth of 60 MHz (2.34 GHz - 2.4 GHz) for LHCP and RHCP configuration. The 3dB axial ratio beamwidth (ARBW) corresponding to both LHCP and RHCP mode is shown in Fig. 11. The antenna achieves a measured 3dB axial ratio beamwidth of -25°to 50°for LHCP and -40°to 45°for RHCP.

In order to validate the operating range of the proposed antenna, the gain characteristics of the proposed model with respect to operating band is measured using antenna test system and are shown in Fig. 12. The antenna archives a peak gain of 5.11 dBic in the LHCP mode and 5.52 dBic in the RHCP mode. The antenna gives stable gain response in the operating range as shown in Fig. 12.

Table 2 gives a performance comparison of the proposed antenna with some of the conventional antenna.

Table 2: Performance comparison of proposed antenna

Para.	Size (λ)	Switch	3dB AR Beam Width	3dB AR Band Width	X Pol Isolation
[6]	2.8λ x 2.8λ x 0.027λ	4 pin diodes	NA	NA	≥14 dB (±45° LP)
[8]	0.55λ x 0.55λ x 0.042λ	8 pin diodes	60° (LHCP, RHCP)	0.78% (5.09-5.12) GHz and 0.70% (5.68-5.72) GHz	17 dB (LHCP, RHCP)
[9]	0.46λ x 0.36λ x 0.107λ	9 DPDT	64° (LHCP) 46° (RHCP)	27.9% (1.42-1.88) GHz	13 dB (LHCP, RHCP)
[10]	1.15λ x 1.15λ x 0.12λ	12 pin diodes	60° (LHCP, RHCP)	0.05% (5.17-5.22) GHz and 0.12% (5.76-5.88) GHz	≥15 dB
[18]	2.98λ x 2.98λ x 0.37λ	4 pin diodes	58° (LHCP, RHCP)	10.5% from 2.35 to 2.61 GHz	≥20 dB
[19]	0.57λ x 0.57λ x 0.095λ	8 pin diodes	Not Reported	1.6% (923-943) MHz	≥20 dB
Proposed	0.37λ x 0.37λ x 0.012λ	4 pin diodes	75° (LHCP) 85° (RHCP)	2.54% (2.34-2.4 GHz)	16.2 dB (LHCP) 16.54 dB (RHCP)

Compared to other traditional antenna models, the proposed model achieves greater miniaturization along with the use of a reduced number of switching element for polarization reconfiguration. It is also observed that the proposed antenna achieves good AR beam width characteristics and also achieves better cross-polarization isolation in the operating band. Hence, the proposed model best suits for modern wireless communication systems.

V. CONCLUSION

A polarization reconfigurable rectangular patch antenna is presented. Four pin diodes are used for switching polarization states. The antenna achieves -10dB measured impedance bandwidth of 60 MHz in the range 2.34 GHz- 2.40 GHz for both LHCP and RHCP mode with a centre frequency of 2.365 GHz. The antenna gives two different polarization states (LHCP/RHCP) based on excitation of appropriate pair of diodes with a peak gain of 5.11 dBic gain in the LHCP mode and 5.52 dBic in the RHCP mode and also it gives good cross polarization isolation of ≥15 dB and a wider 3-dB axial ratio beam width of 75° (-25° ≤AR ≤50°) for LHCP and 85° (-40° ≤AR ≤45°) for RHCP configurations.

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