Design of Polarization Reconfigurable Patch Antenna for Wireless Communications

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Abstract **─** A single fed circularly polarized reconfigurable patch antenna is proposed. The antenna consists of a radiating patch incorporated with an H-shaped slot at its center. Four ultra-miniature switches are used for polarization reconfiguration. The antenna is designed to operate at the center frequency of 2.357 GHz. The antenna achieves either left-hand polarization or right-hand polarization depending upon switching of corresponding switches. The antenna parameters are simulated using Ansoft high-frequency structure simulator and are validated using an Agilent network analyzer (N9925A) and antenna test systems. The antenna achieves a good impedance match of 120MHz between 2.26GHz – 2.38GHz band and achieves low cross-polarization isolation of -22.82 dB for RHCP and -21.77 dB for LHCP configurations at its operating frequency. The antenna finds application in areas of modern wireless communication.

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

I. INTRODUCTION

Polarization reconfigurable antenna plays a major role in modern wireless communication system due to antenna orientation restriction and to enhance channel capacity and suppression of multipath interference. Therefore designing such antennas are highly desirable for wireless communications. In general, polarization reconfiguration is achieved by reconfiguring radiating element by means of pin diodes, RF switches or by reconfiguring feed network. Lin and Wong [1] demonstrated polarization reconfigurable antenna by reconfiguring feeding network through sequential excitation by means of pin diodes in the feed network. In [2], an aperture coupled polarization reconfigurable antenna is proposed which consists of controllable RF switches on a cross aperture to excite radiating element. A most common method of achieving polarization reconfiguration is by etching a slot on radiating element and reconfiguring it by means of pin diodes [3]-[4] to bridge the gap between the slots. A reconfigurable monopole antenna integrated with mushroom like meta-surface to improve antenna performance is presented in [5]. Panahi et al. [6] demonstrated a simple reconfigurable antenna using two pin diodes. Though the antenna achieves polarization diversity with minimum number of diodes, the axial ratio bandwidth of the antenna is far moved from resonant frequency of the antenna. Further the use of pin diodes in polarization reconfiguration requires additional biasing circuit and has to be carefully designed in such a way that it should not affect antenna performance characteristics.

Another approach for changing polarization states is achieved by modifying the feed network by means of PIN diodes, RF switches or by using varactor diodes. H.Sun and S.Sun [7] proposed reconfigurable antenna by reconfiguring feed network to induce phase difference in the output ports. In [8], polarization diversity is achieved by modifying feed network which gives outputs of different phases by means of v shaped coupling strip loaded in the feed network. This technique of reconfiguring feed network to achieve polarization diversity requires additional space for feeding network and also it is highly dependent on performance characteristics and affects its performance drastically when it is not properly designed. Recently liquid dielectric materials are widely studied for polarization reconfiguration [9]-[12]. Though these methods give linear control over polarization, it is difficult to integrate with most of the miniature devices due to its complexity in their control mechanism and requires additional space for the fluid tank. Varactor diode is used recently to reconfigure the characteristics of the antenna [13]. By varying the bias voltage, the capacitance of the varactor

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diode is changed and thereby tuning the performance of the antenna. Polarization reconfigurability is achieved using ultra miniature diodes as in [14] and [15] where two diodes are placed in the symmetrical slots of the patch antenna to get reconfigurability in polarization.

In this paper, a compact polarization reconfigurable patch antenna operating at 2.3 GHz band with a center frequency of 2.357 GHz is proposed. An H-shaped slot is etched in the radiating patch. Four miniature tactile switches (2mm x 3mm x 0.6mm) are used for switching the nature of polarization. The use of tactile switch eliminates the need of biasing circuit and hence reduces the antenna complexity and fabrication cost. The antenna achieves good 3-dB axial ratio beamwidth and better cross polarization isolation in operating band. The antenna is modeled using ansys electromagnetic tool and is fabricated over FR_4 substrate. The antenna performance is validated using network analyzer and antenna radiation pattern test system. The measured results are in good agreement with the simulated results and are compared with other traditional techniques.

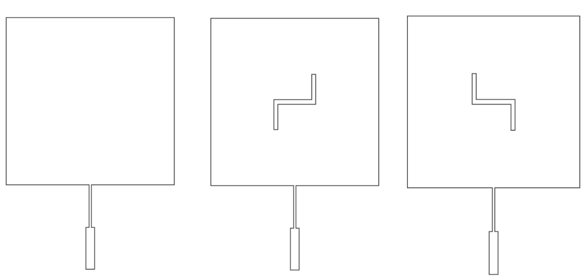
II. ANTENNA DESIGN CONSIDERATIONS

Initially a rectangular Microstrip antenna as shown in Fig. 1 (a) is modelled and its dimensions are calculated from equation (1)-(2):

$$W = \frac{c}{2f_0\sqrt{\frac{(\varepsilon_r+1)}{2}}}, \quad (1)$$

$$L_{eff} = \frac{c}{2f_0\sqrt{\varepsilon_{eff}}}. \quad (2)$$

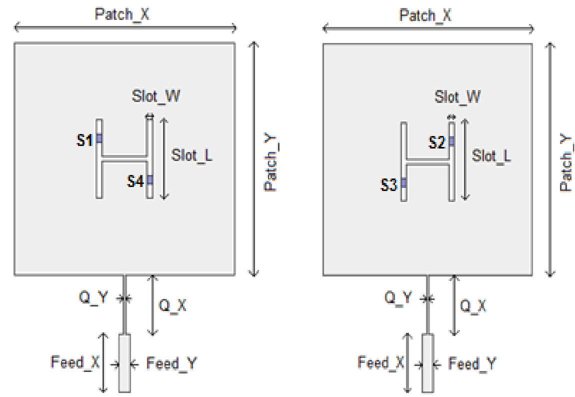
A slot of appropriate dimension is made along diagonal axis as shown in Figs. 1 (b) and 1 (c) to induce 90 degree phase difference between two orthogonal field components E_x and E_y and generates hand circular polarization. Parametric analysis of slot dimensions are carried to optimize antenna axial ratio performance to achieve better circular polarization purity at its operating band. Switches are used at appropriate places to switch between two geometries (Figs. 1 (b) and 1 (c)).



(a) LP (b) LHCP (c) RHCP

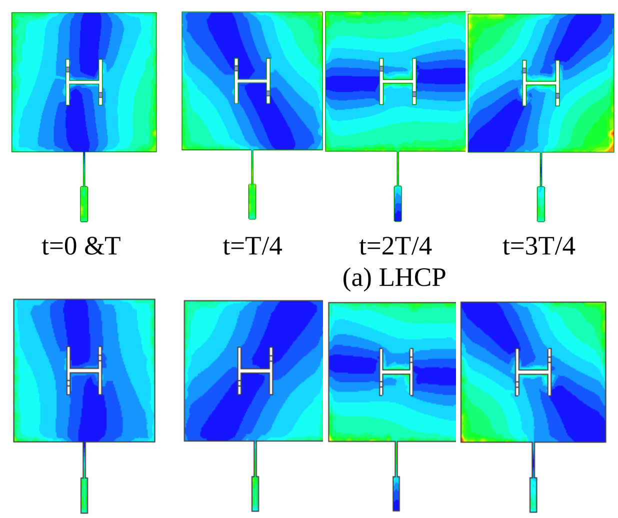
Fig. 1. Design geometries.

Figure 2 shows antenna model with H-shaped slot incorporated in the radiating element. The antenna is fabricated on fire retardant dielectric substrate (FR4) having a relative permittivity of $\varepsilon_r = 4.4$. In order to have low profile thickness, the substrate is chosen to have a thickness of 1.6 mm and overall length and width of the substrate is 57 mm x 57mm.



(a) RHCP (b) LHCP

Fig. 2. Geometry of proposed antenna.



t=0 &T t=T/4 t=2T/4 t=3T/4
(a) LHCP

t=0 &T t=T/4 t=2T/4 t=3T/4
(b) RHCP

Fig. 3. Simulated surface current distribution.

Four ultra-miniature tactile switches (TL3780) are used to reconfigure the polarization characteristics of the antenna. The switches are placed in the H-slot and establish a contact between the slot regions by pressing (100 gram-force) the switch which indicates ON state. According to the datasheet given by the manufacturer, the switch gives 500 mΩ initial contact resistance when in contact (ON state) and 50 MΩ when it is open (OFF state).The polarization reconfiguration is achieved by switching the appropriate pair of switches and thereby reconfiguring antenna geometry. Compared to traditional techniques to reconfigure polarization, the proposed method doesn't require any additional biasing circuit (as in pin diodes) or additional space for feeding network to achieve polarization diversity, and hence it is easy to integrate with other high frequency circuit components. Figure 3 shows the current distribution over the surface of the radiating patch element. The polarization reconfiguration is achieved by suitably switching ON the ultra-miniature tactile switch pair which produces two orthogonal modes which are spatially orthogonal, have equal magnitude and are in phase quadrature. Switch S2 and S3 is switched ON to get Left Hand Circular Polarization (LHCP) as shown in Fig. 3 (a) and Switch S1 and S4 is Switched ON to get Right Hand Circular Polarization (RHCP) as shown in Fig. 3 (b).

III. PARAMETRIC ANALYSIS

Parametric analysis is carried on the slot dimension of the antenna and its performance is discussed. The length of the slot is given as primary importance since it greatly affects the operating frequency and also the purity of polarization. Figure 4 shows a variation of slot length and its effect on the performance of reflection coefficient (dB). It is observed that the reflection coefficient curve moves towards to the lower band with an increase in slot length. This is due to the fact that, an increase in the length of slot increases the electrical length of the antenna and hence the antenna resonates at lower bands. The increase in the length of the slot also affects the purity of polarization. The length of the slot is chosen in such a way that, the electric field component E_x has 90 degree phase delay with respect to E_y field component.

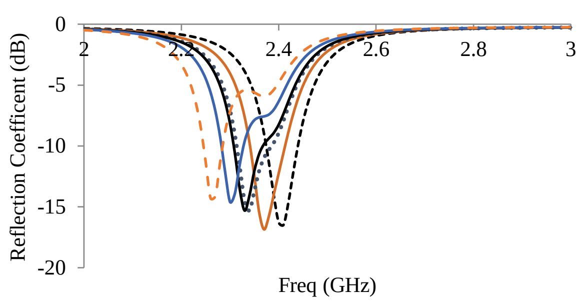


Fig. 4. Variation of reflection coefficient with respect to slot length.

IV. RESULTS AND DISCUSSIONS

Based on the parametric analysis discussed above, the optimum slot length, the dimension of antenna model is obtained and is given in Table 1.

Table 1: Antenna specification

Parameters	Specifications
Operating Frequency	2.34 GHz
Sub_X*Sub_Y*Sub_Z	57mm*57mm*1.6mm
Patch_X*Patch_Y	28.3mm * 28.3mm
Slot_L*Slot_W	7.075mm*0.705mm
Q_X*Q_Y	7.075mm*0.353mm
Feed_X*Feed_Y	7.075mm*1.415mm

The proposed model is fabricated on FR4 substrate as shown in Fig. 5. The model is integrated with switches at appropriate gap regions and are connected with 50 ohm SMA connector.

Fig. 5. Fabricated antenna.

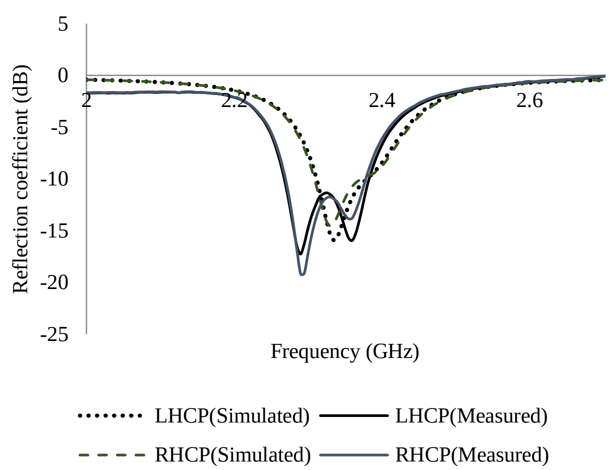


Fig. 6. Reflection coefficient (dB).

The reflection coefficient curve measured for both LHCP and RHCP polarization is compared with corresponding simulation results and are shown in Fig. 6 and shows that the antenna achieves a -10dB impedance bandwidth of 120 MHz (2.26GHz-2.38GHz) for both LHCP configuration and RHCP configuration and is much suitable for WLAN/WiMAX applications. The simulated and measured radiation pattern for the proposed antenna model operating at 2.34 GHz is shown in Fig. 7. The LHCP radiation pattern is taken by turning on switches S2 and S3 and RHCP radiation pattern is taken by turning on switches S1 and S4. The simulation results agree with measured results for both LHCP and RHCP configurations. The antenna gives symmetrical radiation performance around the zenith. The small difference in pattern between simulated and measured results is due to additional resistance created by the switches during on state and also due to fabrication loss and antenna alignment losses.

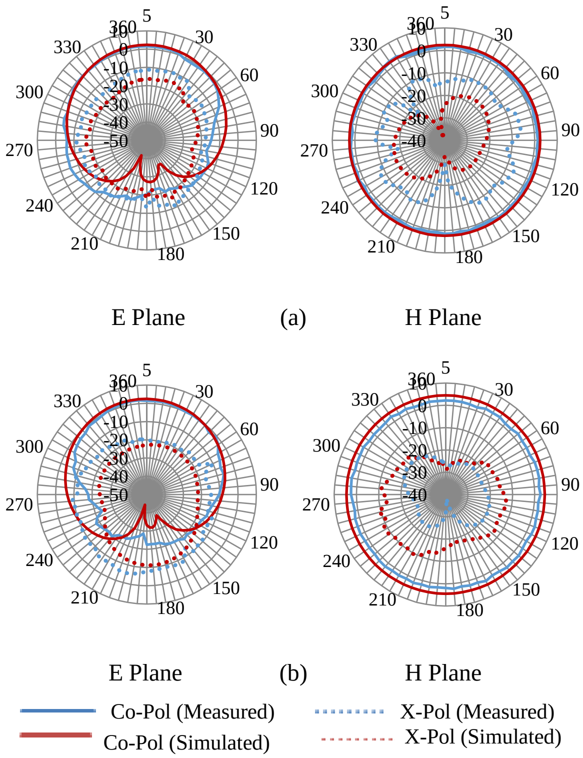


Fig. 7. Simulated and measured radiation pattern of (a) LHCP and (b) RHCP.

Figure 8 shows a variation of axial ratio against frequencies for both LHCP and RHCP configurations. The antenna gives minimum axial ratio at operating frequency for both the configurations and achieves a 3-dB axial ratio bandwidth of 60MHz (2.32GHz – 2.38GHz) for LHCP and 50MHz (2.32GHz – 2.37 GHz) for RHCP configuration.

Figure 9 shows axial ratio beamwidth characteristics of both LHCP and RHCP configurations. It is observed that the antenna achieves a good axial ratio over a wide beam angle of -50^0 to 40^0 for LHCP and -50^0 to 45^0 for RHCP.

The antenna gives a simulated gain of around 6.92dBic for LHCP and 6.84dBic for RHCP.

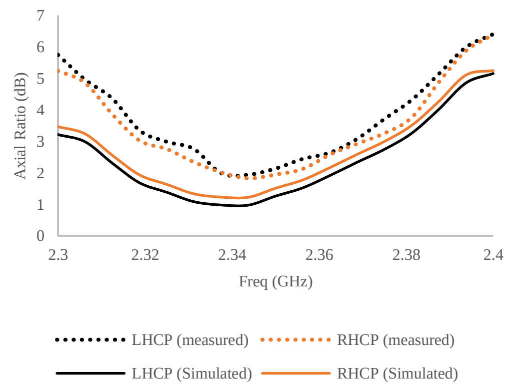


Fig. 8. Variation of axial ratio (dB) against operating band (GHz).

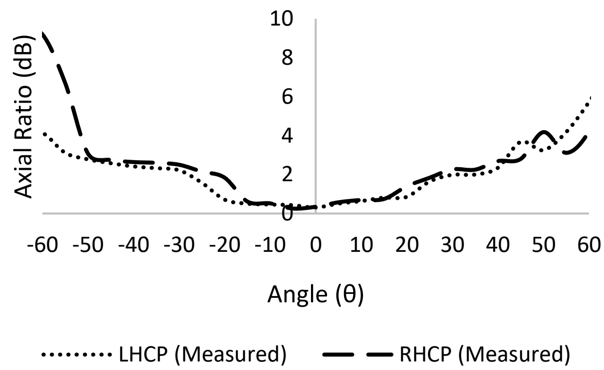


Fig. 9. Variation of axial ratio (dB) against beam angle (θ).

Figure 10 shows the setup used to measure antenna radiation pattern for the proposed model. The antenna is placed inside anechoic chamber and mounted over rotating turn table controlled by precision stepper motor whose control angles are given form antenna measurement software. The measured gain is calculated using two antenna method. A standard pyramidal horn antenna having a gain of 9dB is used as a reference antenna. The distance between two antennas (R) is measured and the gain is calculated using Friis transmission equation given below:

$$\frac{P_r}{P_t} = \left(\frac{\lambda}{4\pi R}\right)^2 G_t G_r. \quad (3)$$

Figure 11 presents the measured gain across the operating bandwidth for both modes. The antenna achieves a peak gain of 5.19 dBic for LHCP mode with efficiency of 50.1% and 5.17 dBic for RHCP mode with efficiency of 47.3%. The antenna also achieves cross polarization isolation of -22.82 dB for RHCP and -21.77 dB for LHCP configurations at its operating frequency.

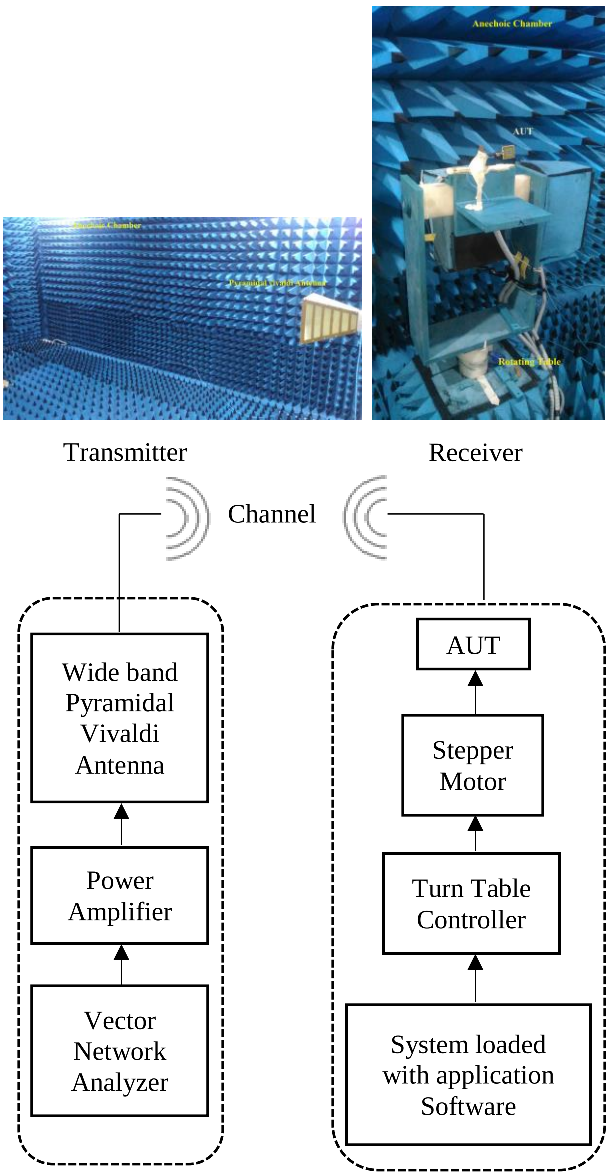


Fig. 10. Antenna measurement setup.

Table 2 gives performance comparison of proposed antenna with some of the conventional antenna. It is observed that the proposed antenna is compact and achieves good beam width characteristics with minimum number of switching elements and also achieves better cross polarization isolation in the operating band. However the proposed model operates at narrow band width and reduced radiation efficiency which can further improved by utilizing low loss dielectric substrate in place of FR_4 substrate.

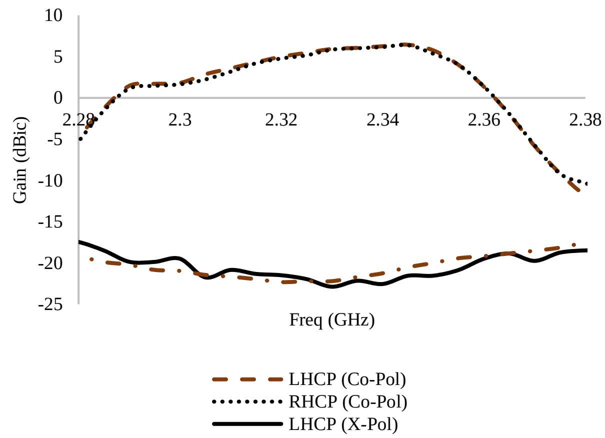


Fig. 11. Measured gain across the operating band for both modes.

Table 2: Performance comparison of proposed antenna

Parameters	[1]	[2]	[3]	[5]	Proposed Model
Size	0.80 λ x 0.80 λ x 0.26 λ	0.70 λ x 0.55 λ x 0.16 λ	7.28 λ x 2.08 λ x 0.06 λ	0.19λ x 0.19λ x 0.14λ	0.43 λ x 0.43 λ x 0.01 λ
Switching Element	8 Pin diodes	9 DPDT	2 Pin diodes	8 pin diodes	4 tactical Switches
3dB AR Band width (GHz)	(1.5 – 1.9) GHz	(1.42-1.88) GHz	(2.25-2.47) GHz	(5.68-5.9) GHz	(2.26 – 2.36) GHz
3dB AR Beam width	90^0 (LHCP, RHCP)	64^0 (LHCP) 46^0 (RHCP)	53^0 ($+45^0$ LP), 50^0 (-45^0 LP),	60^0 (LHCP, RHCP)	90^0 (LHCP) 95^0 (RHCP)
Cross Polarization Isolation	-20 dB (LHCP, RHCP)	-13 dB (LHCP, RHCP)	-10 dB (LHCP, RHCP)	-15 dB (LHCP, RHCP)	-21.77 dB (LHCP) -22.82 dB (RHCP)

V. CONCLUSION

In this paper, a compact H shaped slot circularly polarized reconfigurable antenna has been developed. The antenna is designed to operate at 2.3 GHz band. The proposed antenna achieves polarization diversity by means of miniature tactile switches which eliminates the need of additional biasing circuit or feed network for switching polarization state. The antenna achieves better cross polarization isolation of -22.82 dB for RHCP and -21.77 dB for LHCP configurations and also a wide 3-dB axial ratio beam width of 90^0 ($-50^0 \leq AR \leq 40^0$) for LHCP and 95^0($-50^0 \leq AR \leq 45^0$) for RHCP configurations, and hence it better suitable for modern wireless application which prefer CP antenna characteristics.

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