Polarization Agile Reconfigurable Rectangular Patch Antenna for Biomedical Applications

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Abstract – A polarization agile patch antenna resonating at 2.4 GHz ISM band is presented. The antenna is based on a rectangular radiating element along with reconfigurable parasitic patches located at its periphery of the radiating element. Two switching diodes are used to reconfigure the geometry of the radiating element. Upon proper biasing of the switching diodes the antenna attains linear or circular (LHCP/RHCP) polarization states. The entire antenna is modelled using a high-frequency structure simulator and is validated using an Agilent network analyser (N9925A) and antenna test systems for measuring impedance and radiation characteristics. Over the entire operating band, the antenna shows better impedance matching and achieves -10 dB impedance bandwidth of 100 MHz (2.40-2.5 GHz) in linear state and 85 MHz (2.41-2.495 GHz) in the circularly polarization states along with peak gain of 5.61 dBi for LP state and 4.98 dBi for CP state in the operating range.

Index Terms – impedance matching, microstrip patch, polarization reconfiguration, radiation pattern.

I. INTRODUCTION

Patch antennas play a crucial role in biomedical communications with external devices for monitoring patients due to their miniaturization and low weight. These antennas come with various geometries and materials according to the requirement of monitoring patients. In order to have a better signal link, orientation between transmitter and receiver antenna must be maintained. However, it is always possible for both the antennas to maintain line of sight orientation. Hence the need for circular polarized antennas replacing traditional antennas becomes important [1–2]. These on-body wearable antennas for monitoring patients health issues must have low back radiation with reduced specific absorption rate (SAR) values and also must perform well on moving bodies [3]. A wideband circularly polarized patch antenna for bio telemetric application is presented in [4]. The antenna utilizes 2×2 multiple-input multiple-output (MIMO) radiating patches with defected ground structures which leads to back radiation towards patients tissue. Moreover, these MIMO antennas are densely packed which increases the mutual coupling between the antenna elements. The isolation can be improved by placing adjacent radiating elements perpendicular to each other [5]. In order to improve the antenna performances, different structures, including electromagnetic band-gap (EBG) and high impedance surfaces, are utilized. A compact monopole based on EBG structure for wearable applications [6] and a high impedance surface-based patch [7] are presented. However, these structures

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require complexity of the antenna design and also a number of substrate layers required for the antenna. In order to reduce cross talks between the antenna, a filtering antenna is incorporated along with traditional circularly polarized antennas [8], which requires additional design space for a filtering antenna and also increases the complexity of the design. A 3D printed ultrawideband antenna system with stable impedance matching has been proposed in [9]. Polarization reconfigurable antennas are widely used due to their ability to switch polarization in real time [10]. The reconfigurable antennas have better cross polarization isolation and mitigate the multipath reception of signals, which improves signal quality. This reconfiguration can also be achieved by means of MEMS switches [11] with better miniaturization.

Most of the literature utilizes fixed circularly polarized state patch antennas with increased number of switching elements for switching polarization states. This reduces efficiency of the antenna greatly. In this paper, a polarization agile patch with reduced number of switching elements modelled on single layer substrate is designed. The bottom side of the antenna is fully grounded to arrest the undesired back radiation. The antenna is operating at 2.4 GHz ISM band, and its impedance and radiation characteristics are validated through measured results.

II. GEOMETRY OF THE PROPOSED ANTENNA

The geometry of the proposed patch is shown in Fig. 1. The rectangular patch is taken for its simplicity and better control over its dimensions on design performances. Moreover, the geometry is symmetrical and hence avoids undesired frequency shifts between the frequencies between polarizations states, which makes it ideal for biomedical applications. The antenna is modelled on low-cost fire-retardant substrate with permittivity of 4.4 and loss tangent of 0.02. The overall antenna is modelled on single lay substrate having a dimension of 50×50 mm with thickness of 1.6 mm. Two parasitic patches are placed on either side of the antenna geometry in order to reconfigure the antenna structure, thereby modifying the surface current distribution over the antenna radiating element. A shorting via is made in the parasitic patch to complete the DC bias path. Two switching diodes are placed between the parasitic element and the radiating element. Upon proper biasing, the diodes bridge the parasitic element with radiating patch and thereby makes the path for the surface current to flow through parasitic elements, which leads to additional phases for achieving different polarization reconfiguration.

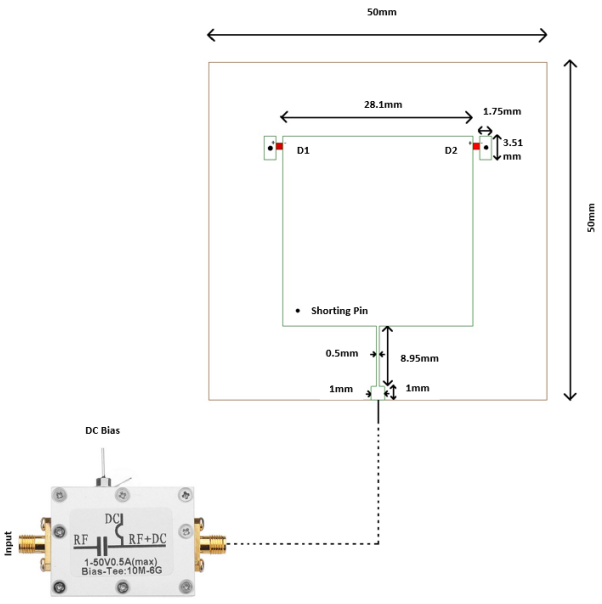


Fig. 1. Antenna geometry.

The feed position is chosen in such a way that it matches the impedance of the radiating element by means of using a quarter-wave transformer between the radiating elements and the feed point.

III. PRINCIPLE OF OPERATION

Polarization reconfiguration is achieved by properly biasing the pin diodes (NXP BAP50-03, 50 mA, 50 V). The resistance of the diodes during its operation plays a crucial role in the radiation efficiency of the antenna. The pin diodes are chosen in such a way that it must have a minimum forward resistance during ON condition. The pin diodes used in the model will have a series resistance and inductance of 5 Ω and 1.8 nH during ON state and shunt capacitance 0.35 pF with the reverse resistance of 500 kΩ during OFF state. The equivalent circuit model of the pin diode used is given in Fig. 2. Figures 2 (a), (b) show the diode equivalent circuit model during ON and OFF state. Figure 2 (c) shows the equivalent circuit corresponding to the biasing circuit. It comprises a DC block capacitor and RF choke inductor for isolating the bias network from the antenna elements and hence avoids direct coupling.

The diodes are placed in such a way that the cathode of the diode D1 points towards the radiating patch while the anode points towards the parasitic patch, which has shorting vias with the ground for the DC path. Similarly, the anode of the diode D2 points towards the radiating patch while the cathode points towards the parasitic patch, which has shorting vias with the ground for the DC path. A Tee- Bias network is used for properly biasing the pin diodes to achieve polarization

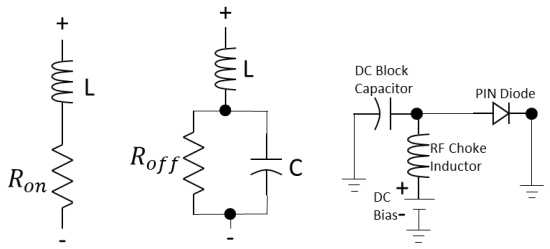


Fig. 2. Equivalent circuit model of the pin diode and biasing circuit.

reconfiguration. Table 1 shows the different operating modes of the proposed antenna model.

Table 1: Different operating modes

S. No.	DC Bias Voltage	Diode D1	Diode D2	Polarization State
1	0 V	OFF	OFF	LP
2	+2 V	OFF	ON	RHCP
3	-2 V	ON	OFF	LHCP

When no bias voltage (0 V) is given, both diodes are in OFF state, and the geometry resembles a simple rectangular patch antenna and gives a linear polarization state that resonates at center frequency. When DC bias voltage of +2 V is given, diode D2 turns into ON state as the anode of the diode D2 points towards the radiating patch while the cathode points towards the parasitic patch, which has shorting vias with the ground and hence closes the DC path. Thus, the length of the patch in the right symmetry increases slightly, which introduces additional phase shift between the electric currents (E_x and E_y) . This generates two orthogonal modes with same amplitude with -90^0 phase difference and hence attains right-hand circular polarization.

Similarly, when DC bias voltage of -2 V is given, diode D1 turns into ON state as the cathode of the diode D2 points towards the radiating patch while the cathode points towards the parasitic patch, which has shorting vias with the ground and hence closes the DC path. Thus, the length of the patch in the left symmetry increases slightly, which introduces additional phase shift between the electric currents (E_x and E_y) . This generates two orthogonal modes with the same amplitude with $+90^\circ$ phase difference and hence attains left-hand circular polarization. The surface current distribution corresponding to different polarization states are shown in Fig. 3.

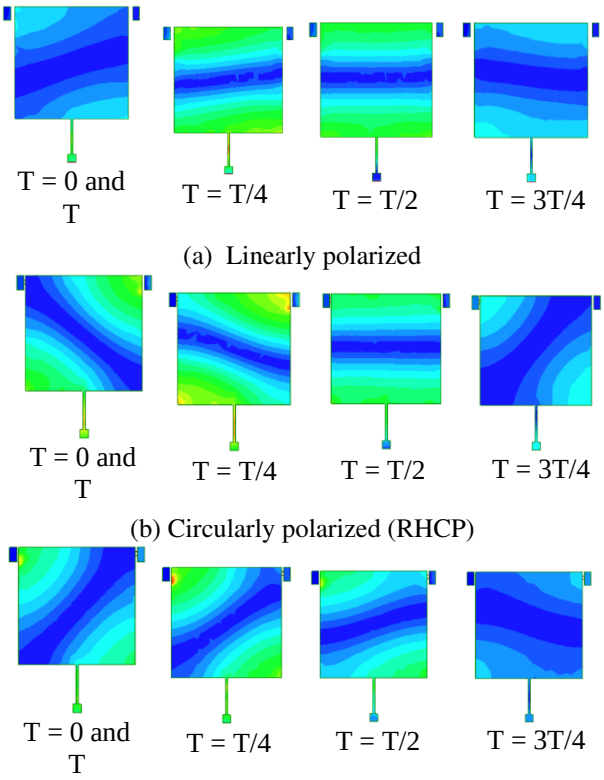


Fig. 3. Surface current distribution.

IV. RESULTS AND DISCUSSION

The performance of the proposed antenna is validated by measuring its impedance and its radiation characteristics. The antennas are fabricated on FR4 substrate and are connected with 50 ω SMA connector, as shown in Fig. 4. The diodes are placed to bridge the radiating patch with the outer parasitic elements. A standard T bias switch is coupled with SMA connector input for biasing the RF switch to switch its polarization characteristics. The shorting pin is punched at its radiating patch center for providing a DC path during biasing of the diodes.

The impedance characteristics are measured with Agilent network analyzer (N9925A) and are compared with simulated results, as shown in Fig. 5. From Fig. 5 it is inferred that the antenna attains a -10 dB impedance bandwidth of 100 MHz (2.40-2.5 GHz) in linear state and 85 MHz (2.41-2.495 GHz) in the circularly polarization states respectively.

The radiation measurement setup used to analyze the radiation characteristics of the antenna is shown in Fig. 6.

Figure 7 shows the radiation characteristics of the antenna, which are measured using an antenna test system that comprises a pyramidal horn antenna having a standard gain of 9 dB placed inside the anechoic

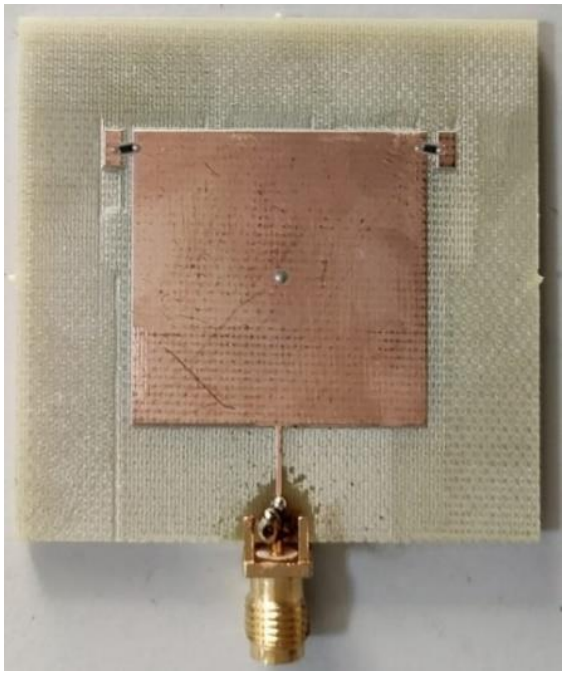


Fig. 4. Fabricated prototype.

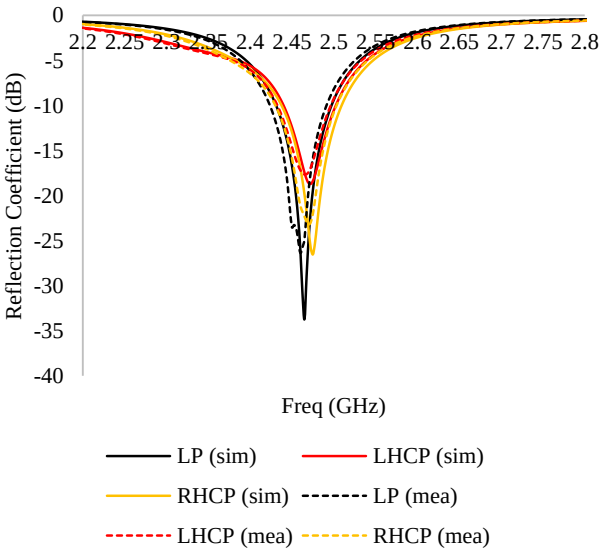


Fig. 5. Reflection Coefficient (dB).

chamber. The test antenna is placed at a far-field distance of $2D^2/\lambda$ from the transmitter antenna, and the gain of the test is calculated based on the Friis transmission equation:

$$P_r = P_t G_r G_t \left(\frac{\lambda}{4\pi R}\right)^2 . \quad (1)$$

The relative gain corresponding to the fabricated prototype is measured for both the planes. The antenna

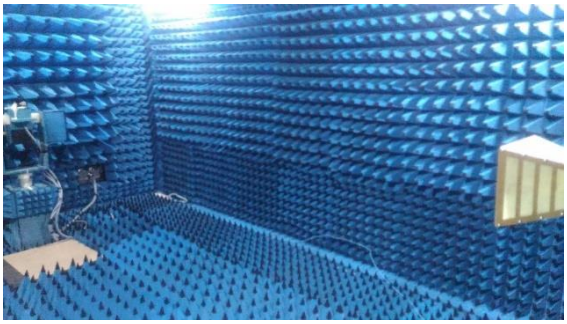
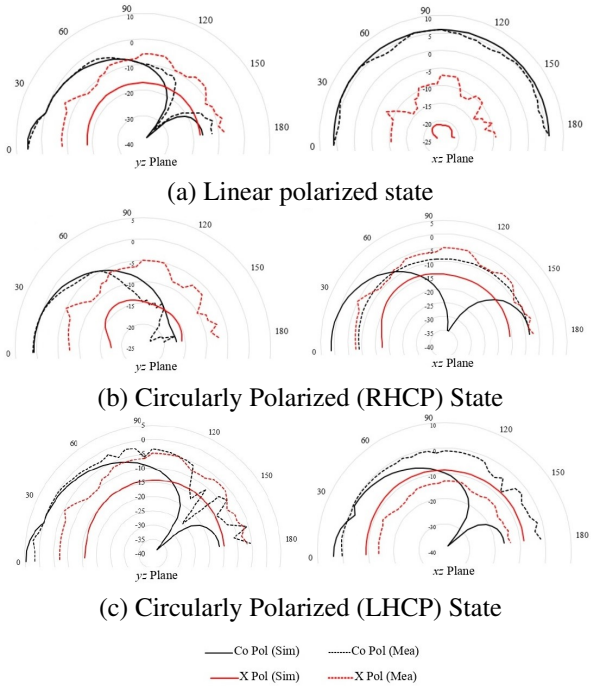


Fig. 6. Measurement setup environment for test antenna.



(a) Linear polarized state

(b) Circularly Polarized (RHCP) State

(c) Circularly Polarized (LHCP) State

Fig. 7. Radiation characteristics of the proposed antenna.

attains symmetrical radiation pattern in the direction of propagation. The antenna attains maximum gain of 5.61 dBi for the LP state and 4.98 dBi for the LHCP/RHCP state.

The axial ratio bandwidth corresponding to the proposed model for LHCP and RHCP modes is given Fig. 8. It is inferred that compared to impedance bandwidth, the axial ratio bandwidth is lesser, since the tangential components of the electric fields are attenuated closed to the ground surface. The model attains axial ratio bandwidth of 2.42-2.51 GHz in the operating band.

Specific absorption rate (SAR) is used to quantify the electromagnetic radiation over human tissues, and SAR is calculated by

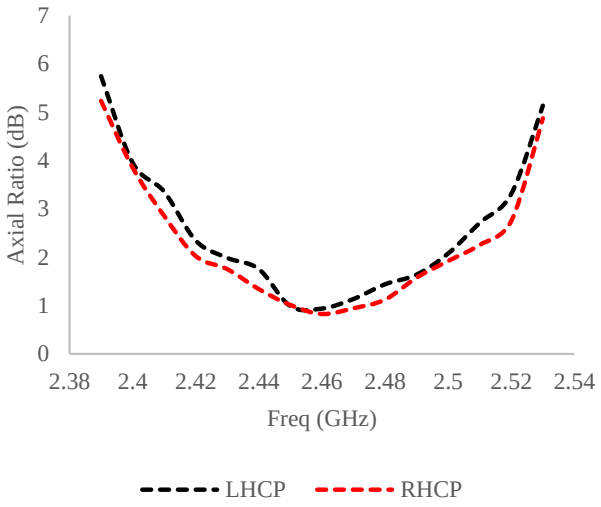


Fig. 8. Axial ratio bandwidth of the proposed antenna.

$$\mathrm{SAR} = \frac{\sigma \left| E^2 \right|}{\rho}, \tag{2}$$

where σ and ρ are thermal conductivity, $(\mathrm{S/m})$ mass density $(\mathrm{kg/m^3})$ of the tissue medium, and E is the electric field intensity $(\mathrm{V/m})$, which is calculated from the power input using the relation given here:

$$Power\left(\mathrm{W/m^2}\right) = \frac{\left(E\left(\mathrm{V/m}\right)\right)^2}{377}. \tag{3}$$

An agar based homogenous tissue model is prepared to mimic human tissue (palm) having a permittivity of 26.47 [12] to measure the SAR value of the proposed model. The model achieves a minimum SAR value of 0.385 W/kg at its operating bands.

Performance comparison of the proposed model with other conventional models is given in Table 2. Most of the traditional antennas utilize linear polarization or fixed circular polarization techniques, which limits their application. The proposed model utilizes reconfigurable polarization characteristics with a minimum number of electronically controlled switching diodes without sacrificing the impedance and radiation characteristics of the antenna in its operating band. In addition to that, the antenna attains minimum SAR value at the operating band, which makes it suitable for biomedical applications.

Table 2: Performance comparison of the proposed antenna

Ref	Size $(\mathrm{mm^3})$	Operating Freq.	Polarization	Axial Ratio Bandwidth	SAR (W/kg)
[13]	25 × 20 × 0.07	2.45 GHz	Linear	1.22%	1.0
[14]	14 × 14 × 05	2.45 GHz	Circular	6.93%	0.494
[15]	24 × 22 × 0.7	2.45 GHz	Linear	24.4%	0.719
[16]	21 × 13.5 × 0.254	2.45 GHz	Circular	53.8%	0.78
Proposed	50 × 50 × 1.6	2.45 GHz	Circular	44.8%	0.385

V. CONCLUSION

A polarization reconfigurable antenna based on switching pin diodes is presented. The antenna is designed at the 2.45 GHZ ISM band and attains three different polarization states upon proper biasing of the switching diodes. The model is validated by fabricating on single FR4 substrate, and the measured results are compared with simulated results. The antenna achieves -10 dB impedance bandwidth of 100 MHz (2.40-2.5 GHz) in linear state and 85 MHz (2.41-2.495 GHz) in the circularly polarization states along with a peak gain of 5.61 dBi for LP state and 4.98 dBi for CP state in the operating range. The antenna attains maximum axial ratio bandwidth of 44.8% in the operating band with a SAR value of 0.385 W/kg.

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