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Design of hexagonal shape reconfigurable antenna for wireless communications

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ABSTRACT

Circularly polarized reconfigurable antenna plays an important role in applications which requires frequency reuse and to mitigate the effect of multipath interference. In this paper, circularly polarized reconfigurable patch antenna operating at 2.3 GHz band is presented. The antenna consists of a radiating patch incorporated with a square-shaped slot at its center. Ultra-miniature switches are placed in the gap region of the slot in the radiating element for reconfiguring antenna geometry and thereby achieving polarization reconfiguration. The antenna achieves either left-hand polarization or right-hand polarization depending upon switching of the corresponding pair of MEMS switches. The performance of the antenna is validated using high-frequency structure simulator tool and the results are compared with other conventional antennas. The antenna gives a good impedance bandwidth of 70MHz between 2.295GHz – 2.365GHz in the operating band with a peak gain of 5dBi. It also achieves wider 3dB axial ratio beamwidth od 140^0 along with good cross-polarization isolation of -12 dB for RHCP and -13 dB for LHCP configurations at its operating frequency and hence better suitable for application in areas of modern wireless communication.

1. INTRODUCTION

Polarization reconfigurable circularly polarized (CP) antenna plays a vital role in satellite communication, radars etc. These antennas have exceptional characteristics such as insensitivity of the antenna orientation, minimizes the effect of multipath interference, frequency reuse and hence designing of such antennas are highly desirable for modern wireless communications. In general polarization reconfiguration is achieved by either modifying the geometry of the antenna structure or by modifying the feeding network. These antennas can be either dual polarized antenna (Horizontal and vertical polarized) or circularly polarized antenna (Left-hand polarization or right-hand polarization). With the increase in demand for wireless technologies, the circularly polarized antenna has gain popularity due to its robustness against multipath loss, antenna alignment etc. There are several traditional techniques to develop CP antennas. One of the most popular techniques is by incorporating appropriate slots in the radiating element and thereby perturbs the surface currents to achieve CP radiation. However, these circularly polarized antenna suffers from poor 3dB axial ratio beam width.

In [1], a novel dual polarization antenna is demonstrated. The antenna is fed by coplanar feed techniques. It utilizes two complementary spiral slots in its ground plane to achieve dual polarization. Compared to conventional dual polarized antennas which have dual ports, the antenna uses a single port for excitation. A circularly polarized patch with the U-shaped slot is presented in [2] to improve the axial ratio bandwidth of the antenna. A Reconfigurable rhombus-shaped patch antenna with Y-shaped feed for polarization diversity is shown in [3]. Here PIN diodes are inserted between the Y-shaped Feed and the radiating Patch. This antenna configuration consumes additional space for feed geometry. A single fed reconfigurable patch antenna is discussed in [4]. It includes a square patch with truncated corners along with a ring slot at its center. In [5], a circularly polarized complementary antenna is presented. It comprises a dipole and a quarter wave patch. The polarization nature can be reconfigured by manipulating the DC biasing voltages of the diodes. A circular patch with four slits along with RF switches for polarization reconfiguration is presented in [6]. In [7], a pair of folded dipoles with square contours is presented. CP radiation is achieved by adjusting the distance between the dipoles which has a minimal effect on the impedance match. However, the design suffers from greater front to back ratio. Helical antenna of various configurations is used in [8] to achieve CP radiation and Patch antenna with suspended substrates [9] is used to enhance the beamwidth. However, it increases the thickness of the substrate. In most of the conventional antenna discussed utilizes either PIN diodes for reconfiguration which requires additional biasing network for excitation or reconfigurable feed network which requires additional space for feed network and increases antenna profile.

In this paper, a polarization reconfigurable patch antenna is proposed. A square shaped slot is etched out from the radiating patch. Eight ultra-miniature switches (TL3780) are used for switching the nature of polarization. The use of a tactile switch in place of pin diodes eliminates the need for additional biasing network and hence reduces antenna profile. The antenna operates at 2.3 GHz band with a center frequency of 2.33 GHz. The antenna achieves good axial ratio beamwidth and less cross polarization in operating frequency and hence finds application in modern wireless communications.

2. GEOMETRY OF PROPOSED MODEL

2.1 Antenna geometry

Figure 1 shows antenna geometry with square shaped slot incorporated in the radiating element. The antenna is modelled on FR_4 substrate having a relative permittivity of $\varepsilon_r = 4.4$ and dielectric loss tangent of $\zeta = 0.02$. The antenna profile is made symmetrical in order to eliminate unnecessary frequency shift between polarization reconfiguration and also to achieve uniform radiation pattern.

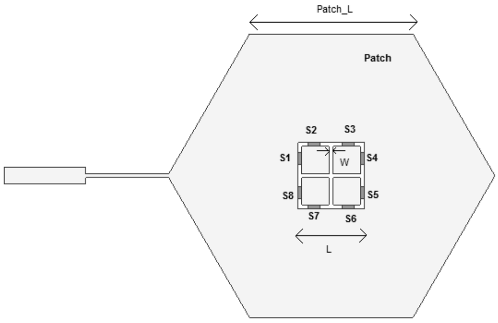
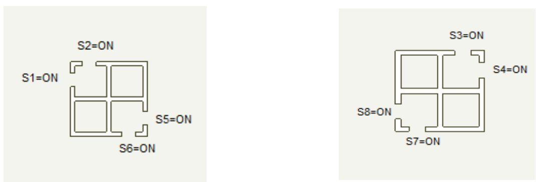


Figure 1. Antenna geometry

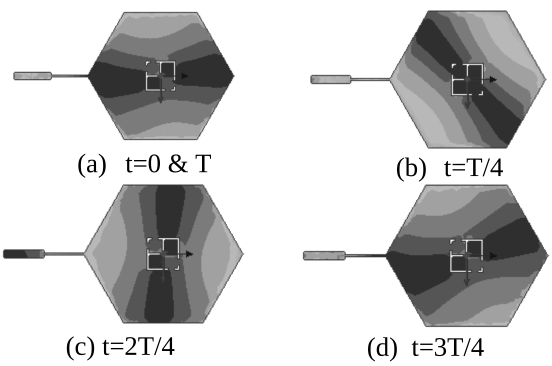


(a)LHCP (b)RHCP

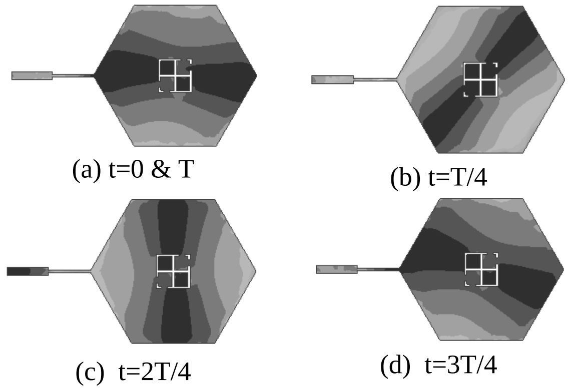
Figure 2. Antenna configurations

In order to have a low profile thickness, the substrate is chosen to have a thickness of 1.6 mm and overall length and width of 70 mm x 70mm. A quarter wave transformer is used for impedance matching. It connects 50Ω feed line with the radiating patch element. Eight ultra-miniature switches are used in the slots for polarization reconfiguration. These switches are symmetrically placed in slot region and bridge the gap between the inner patch with the outer patch. By switching corresponding switches the nature of polarization can be reconfigured according to the needs as shown in Figure 2.

2.2 Electric field distribution



(a) LHCP



(b) RHCP

Figure 3. Electric field distribution

Figure 3 shows the current distribution over the surface of the radiating patch element. In the antenna geometry shown in Figure 2(a), the electrical length of the left half side of the radiating element is larger when compared to right half of the radiating element. This introduces a phase difference between electric field components E_x and E_y. The length of the slot is adjusted to have a phase difference of 90 degree between electric field components. This perturbs the surface current towards anti-clockwise direction and hence achieves left-hand circular polarization. Similarly, in Figure 2(b), the electrical length of the right half side of the radiating element is larger when compared to left half of the radiating element and hence perturbs the surface current towards anti-clockwise direction achieving right-hand circular polarization

2.3 Principle of operation

In order to achieve circular polarization, the antenna has to radiate two orthogonal modes TM_{01} and TM_{10} mode simultaneously with equal amplitude and 90-degree phase difference. This can be accomplished by reconfiguring the structure of the radiating element and thereby perturbing surface current on the radiating patch. Eight ultra-miniature tactile switches are used to reconfigure the polarization characteristics of the antenna. The switches are placed in the gap between the slot regions and establish a contact between the slot regions by applying force (100 gram-force) on the switch which indicates ON state. The polarization reconfiguration is achieved by switching the appropriate pair of switches and thereby reconfiguring antenna geometry. Compare 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.

3. PARAMETRIC ANALYSIS

The dimension of the slot predominantly affects the performance characteristics including operating frequency and purity of polarization at that operating frequency. Hence the slot dimension is taken as a vital parameter for tuning desired performance characteristics. The width (W) of the slot is taken as 1/20th of patch side length which is small compared to the length of the antenna, parametric analysis on the effect of slot width is neglected and hence slot length alone is taken into consideration.

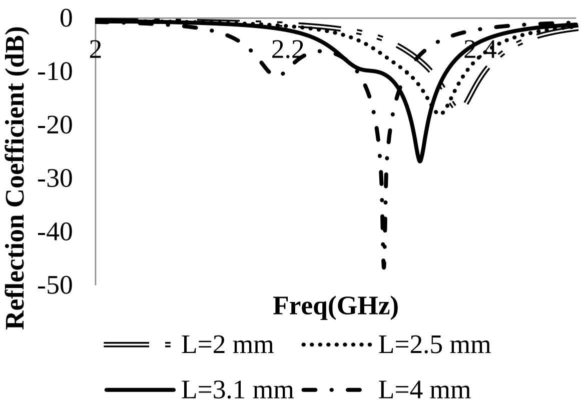


Figure 4. Variation of reflection coefficient vs. slot length

The proposed model is designed and simulated using Ansoft high-frequency structure simulator. Switches used in the proposed antenna are TL3780 tact series and is modeled as per manufacturing specification by replacing with equivalent lumped elements. According to the datasheet [10], On state of the switch provides 500mΩ contact resistance and OFF state of the switch provides 50MΩ insulation resistance. With the increase in slot length (L), the dimension of the outer patch increases and hence the antenna resonates at lower frequencies as shown in Figure 4. The model is designed to operate at 2.3 GHz band and hence slot length of 3 mm is taken as optimum length for its design.

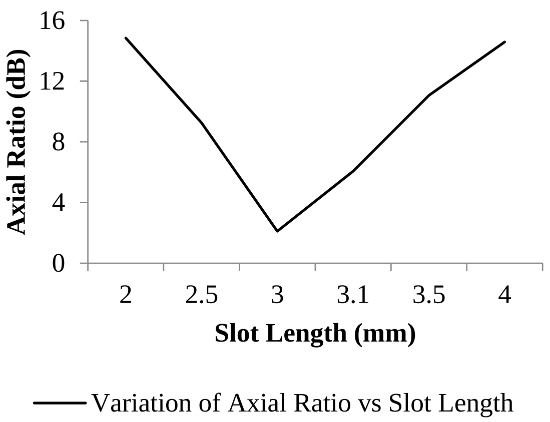


Figure 5. Variation of axial ratio vs. slot length

Figure 5 shows a variation of axial ratio with a change in slot length. Based on the parametric analysis, the optimum dimensions of slot length (L) is calculated as 3mm.

Table 1. Antenna specifications

Parameter	Specification
Patch_L	18.65 mm
L	3.00 mm
W	0.92 mm

4. RESULTS AND DISCUSSION

The performance of the antenna is analyzed using Ansoft HFSS and the results are discussed below. Figure 6 shows the reflection coefficient for both left hand and right-hand circular polarization. As seen from Figure 6 the antenna achieves an -10dB impedance bandwidth of 70 MHz (2.295 - 2.365 GHz) for both LHCP and RHCP configuration in the operating 2.3GHz band and has a center frequency of 2.33GHz.

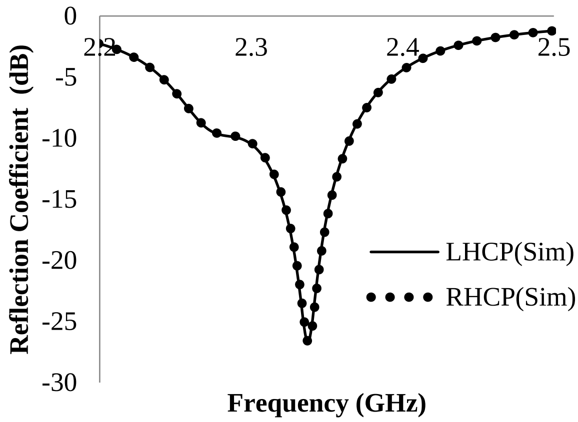


Figure 6. Impedance curve

From the impedance curve, it is observed that there is no frequency shift between left-hand polarization and right-hand polarization. This may be due to symmetrical geometry configuration between left-hand polarization and right-hand polarization. The radiation pattern of the proposed model at an operating frequency of 2.33 GHz is shown in Figure 7.

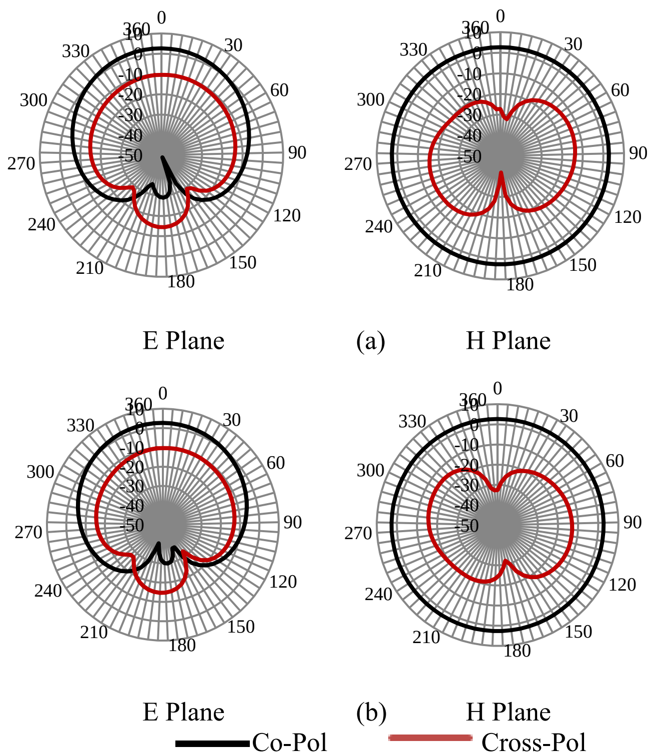


Figure 7. Radiation pattern of (a) LHCP (b) RHCP

When the switch pair (S1, S2) and (S5, S6) is ON, the antenna radiates left-hand circular polarization and when the switch pair (S3, S4) and (S7, S8) is ON, the antenna radiates right-hand circular polarization. A symmetrical radiation pattern around the zenith is seen. A good cross-polarization isolation of -13 dB for left-hand circular polarization and -12 dB for right-hand circular polarization is achieved at the

2.33GHz operating frequency.

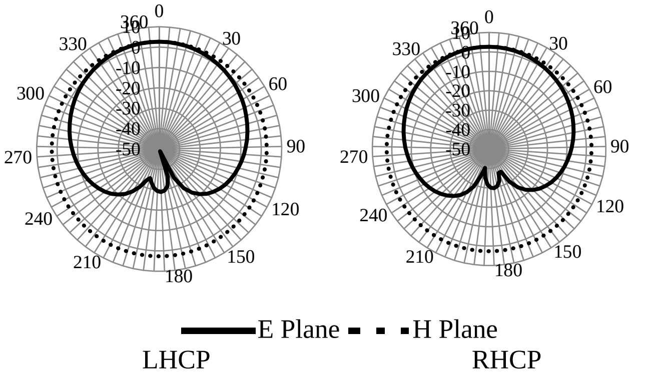


Figure 8. Radiation pattern measured at the minimum axial ratio

Figure 8 shows E plane and H plane radiation characteristics for left-hand and right-hand circular polarization. It is seen that the antenna gives a good axial ratio over a wide beam angle of 140^0 ($-70^0 \leq AR \leq 70^0$) for both LHCP and RHCP configuration. The antenna gives a simulated gain of around 5.09 dBi for LHCP and 5.05 dBi for RHCP configuration.

Table 2. Performance comparison of the proposed model with traditional antenna model

Parameter	Proposed Model	Ref. [11]	Ref. [12]
Reflection Coefficient (dB)	-27.06 dB	-15 dB	-17 dB
Maximum Gain (dB)	5 dBi	6.3 dB	1.5 dB
3dB Axial Ratio beam width (dB)	140^0	$85^0 \pm 2^0$	100^0

Table 2 gives the performance comparison of the proposed model with traditional antenna designs. It is observed that the antenna achieves a wider axial ratio beamwidth with better reflection coefficient characteristics when compared to other models. This ensures a wide field coverage in wireless communication systems.

5. CONCLUSIONS

A low profile circularly polarized reconfigurable antenna is presented. The antenna comprises a square shaped slot etched at its center. The nature of polarization is reconfigured by means of switches placed symmetrically in the slot regions. The antenna gives a measured -10 dB impedance bandwidth from 2.295 GHz to 2.365 GHz in the operating band. The antenna also achieves a good peak gain of 5.09dBi and 5.05 dBi for LHCP and RHCP at operating frequency. Radiation pattern results show the antenna has a good cross-polarization isolation of -12 dB and -13 dB for RHCP and LHCP configurations with wider axial ratio beamwidth of 140^0 and hence finds suitable for modern wireless communications.

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