Circularly Polarized Reconfigurable Circular Microstrip Patch Antenna with Peripheral Cuts at 5.9 GHz

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Abstract - Circular microstrip antenna (CMSA) has gained much attention in recent past due to ease of design and analysis. In this paper a polarization reconfigurable circular microstrip patch antenna has been proposed for communication at 5.9GHz ISM band defined in IEEE 802.11p. Proposed design exhibits both the forms of circular polarization i.e. Left Hand Circular Polarization (LHCP) and Right Hand Circular Polarization (RHCP). Four PIN diodes mounted on the circular patch antenna serve the purpose of reconfigurability. PIN diodes are used in such a way to activate/deactivate some portion of the patch so as to perturb the surface current distribution resulting in two orthogonal electromagnetic modes generated which ultimately leads to circular polarization in the output radiation pattern. Simulations and optimizations have been performed on High Frequency Structure Simulator (HFSS) software[5]. Return losses at fundamental frequency of 5.9GHz are 19dB (LHCP) and 18dB (RHCP). -10dB return losses bandwidths achieved are 694MHz (LHCP) and 672MHz (RHCP) around center frequency of 5.9GHz is obtained. 3dB axial ratios of less than 1dBs are achieved with bandwidth value of around 155MHz in both the modes of configuration. Similarly polarization ratios of greater than 35dBs are obtained for LHCP and RHCP both.

Keywords: RHCP and LHCP Polarization, Reconfigurable Antenna and miniaturization of Antenna, Polarization Bandwidth.

I. INTRODUCTION

Circularly polarized circular microstrip antenna has many applications. And if polarization reconfigurability is also achieved than it makes the antenna more useful. Circular microstrip antennas are compact in size that suits the requirements of device miniaturization [1-3]. The proposed patch antenna design uses coaxial feeding mechanism. Coaxial feeding enables compact structure [3] and also facilitates in generating circular polarization [4]; as coaxial feeding mechanism does not disturb the symmetry of the structure. Symmetrical structure of CMSA makes it suitable choice for creating an antenna with circular polarization capability. Introducing small asymmetry as a result of mathematical/simulation driven dimensional changes in the form of slots, cuts, shorting pins, feeding point locations etc. in the otherwise symmetrical structure circular polarization can be generated. Unlike linear polarization antennas circular polarization antennas do not need orientation settings. While designing a circular polarization antenna modifying ordinary circular patch antenna gain and circular polarization bandwidth (axial ratio bandwidth) are two main design parameters to be optimized. As the modification generally means cutting slots from the patch; which certainly degrades gain performance. Slots should therefore be cut in the circular patch for optimum performance in terms of gain as well as circular polarization. Simulation software makes the task easy of optimizing the patch for the best possible circular polarization characteristics for the given parameters. Various proposed designs [6-15] of circular patch antennas with circular polarization have been discussed in the next section.

II. REVIEW OF LITERATURE

In Fan Yang et al. (2002) proposed a design of a rectangular patch antenna with switchable slots to achieve circular polarization diversity. Two orthogonal slots are incorporated into the patch and two pin diodes are utilized to switch the slots on and off. Matthias K. Fries et al. (2003) proposed a microstrip line fed reconfigurable (linear and circular both) circular slot antenna architecture for polarization switching. The antenna shape consisted of a slot-ring with perturbations which are switched on and off using PIN- diodes. Y. J. Sung at el. (2004) proposed a reconfigurable (linear and circular) square microstrip antenna with switchable polarization sense. The proposed antenna consisted of a corner-truncated square radiating patch, four small triangular conductors, and a microstrip line feed. Y. B. Chen at el. (2006) presented the analysis and design of a circular microstrip antenna using cavity model and fields within the cylindrical cavity, radiation pattern and resonant frequency had been calculated. S. Nikolaou at el. (2006) presented the use of pin diodes to reconfigure the impedance match and modify the radiation pattern of an annular slot antenna. The planar antenna was fabricated on one side of a Duroid substrate and the microstrip feeding line with the matching network is fabricated on the opposite side of the board. W. B. Wei at el. (2007) proposed a reconfigurable microstrip patch antenna allowing switching between two circular polarizations. It consisted of a square radiating patch and a 3dB hybrid coupler. Using only a single-polar-double-throw (SPDT) switch, the polarization switching was achieved. Rui-Hung Chen at el. (2008) proposed a single-fed reconfigurable microstrip antenna that could provide various polarization diversities. The antenna was excited by a microstrip feed line through aperture coupling. When two PIN diodes were used to respectively reconfigure the coupling slot and the open stub of the feed line, the polarization of the microstrip antenna could be switched between vertical and horizontal polarizations. Pei-Yuan Qin et al. (2010) proposed a U-slot microstrip patch antenna with reconfigurable polarization for wireless local area network (WLAN) applications. PIN diodes were appropriately positioned to change the length of the U-slot arms, which altered the antenna's polarization state. M. S. Nishamol et al. (2011) proposed a reconfigurable microstrip antenna with circular and linear polarization switching. By controlling the bias voltage of two PIN diodes, the polarization of the antenna could be switched between three states; two states for linear polarization (horizontal and vertical) and one state for circular polarization (RHCP). S. Pyo et al. (2012) proposed a switchable circularly polarized patch antenna with a compact size that used only a single PIN diode. The proposed antenna consisted of a corner-truncated square radiating patch with a cross-shaped slot on the ground, a triangular conductor, and one PIN diode. D. H. Lee et al. (2014) proposed a reconfigurable microstrip antenna with circular polarization-agile capability for wireless access in vehicular environments (WAVE). The proposed antenna consisted of a circular microstrip radiator on a back-sided circular slot with an added tab and a trimmed slot with two PIN diodes. Lokesh K. Sadrani et al. (2015) proposed a modified circular microstrip patch antenna with embedded circular slots to attain harmonic suppression and peripheral cuts for generating circular polarization (CP).

Circular patch antennas found in literature [6-15] made the foundation of the proposed work presented in this paper. This paper presents the results of optimization and analysis of circular microstrip antenna four circular peripheral cuts to generated circular polarization of both kinds i.e. RHCP and LHCP. This reconfigurability in circular polarization is achieved by switching ON/OFF alternatively the two pairs of PIN diodes mounted on the patch antenna itself. Optimizations have been performed to get maximum gain and axial ratio bandwidth for both the configurations. The design frequency of 5.9GHz has been chosen to be used in all the designs. Simulation software High Frequency Structure Simulator (HFSS) [5] is used to design, simulate and optimize the proposed antennas

III. PROPOSED METHODOLOGY

While designing a circular microstrip antenna taking into account the fringing [1-4] the expression for the radius of the circular patch becomes

$$a = \frac{F}{\left\{1+\frac{2h}{\pi \varepsilon_r F}\left[\ln\left(\frac{\pi F}{2h}\right)+1.7726\right]\right\}^{1/2}} \ldots\ldots\ldots\ldots\ldots (1)$$

Where,

$$F = \frac{8.791\times10^{9}}{f_r\sqrt{\varepsilon_r}} \ldots\ldots\ldots\ldots\ldots (2)$$

h=height of the substrate,

ε_r=dielectric constant of substrate.

Initial calculations based on the above design formulae (1) and (2) for the radius of the basic circular microstrip antenna and optimized value of substrate thickness and feeding point position are given in Table 1. Feeding point is obtained from HFSS optimization for 50Ω terminal impedance to avoid use of any impedance matching network between patch and coaxial cable. Feed point is optimized so that it must exhibit terminal impedance equal to the characteristic impedance of a coaxial cable (50Ω).

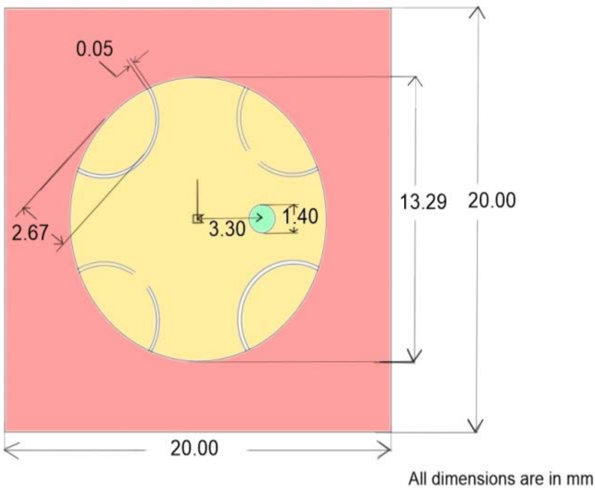


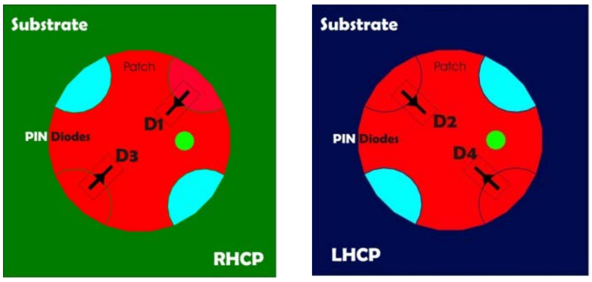
Fig. 3.1: Dimensions of the proposed circular microstrip antenna with reconfigurable circular polarization at 5.9GHz.

Table 1. Optimized radius and feeding point location of circular patch antenna.

Substrate Material	ε_r	Radius of patch R (in mm)	Height of substrate h(in mm)	Feeding point location (0, yf) in mm
FR-4	4.3	6.645	1.6	3.3

IV. SIMULATION/EXPERIMENTAL RESULTS

The proposed antenna is shown in Fig. 3.1. Two pairs of peripheral circular cuts are introduced in the patch at a line ±45° to vertical central line of the patch. This excites two orthogonal field components which are equal in magnitude and opposite in phase; resulting in circularly polarized radiation. This placement of peripheral cuts at +45° generates Right Hand Circular Polarization (RHCP) for -45° LHCP is obtained.



RHCP Antenna LHCP Antenna

Fig. 3.2: RHCP and LHCP Configurations

Fig.3.2 shows that when the PIN diodes D1 and D3 are ON they short the patch with two circular sectors at +45° from vertical while peripheral circular cuts at -45° from vertical are present.

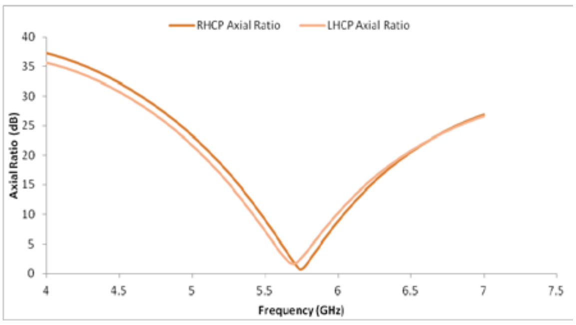


Fig. 3.3: Axial Ratio curves for the two configurations.

That results in right hand circular polarization RHCP as can be seen from the axial ratio curves of Fig.3.3. Fig.3.2 shows that when the PIN diodes D2 and D4 are ON they short the patch with two circular sectors at -45°from vertical while peripheral circular cuts at +45° from vertical are present.

That results in left hand circular polarization LHCP as can be seen from the axial ratio curves of Fig.3.3.

Fig.3.4 shows the return loss curves for the two configurations. Optimizations have been performed on return loss at initial level taking broad antenna dimensions viz. radius of the patch, feeding point position, height of the substrate etc. while axial ratio and return loss both have been performed on the four peripheral cut dimensions.

Antenna design obtained after parametric and optimization analysis through HFSS simulations exhibits left hand and right hand circular polarization properties. As compared to conventional circular patch the proposed antenna is compact in size. Because of change in path length of current on the patch; resonant frequency of the proposed antenna changes to lower values as seen in return loss curves of Fig.3.4.

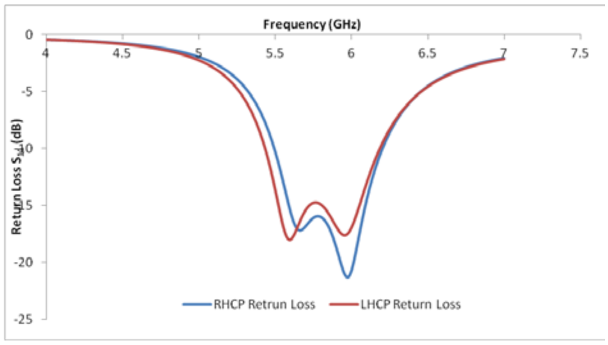


Fig. 3.4: Return loss S11 curves for the two configurations.

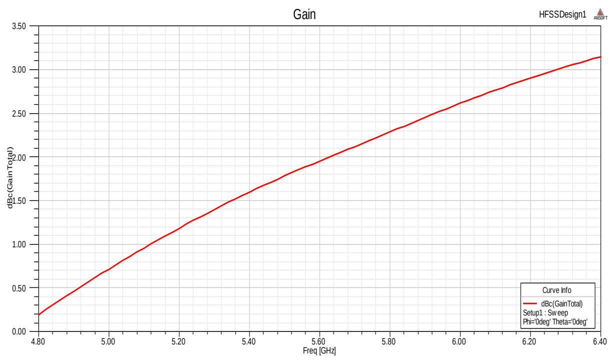


Fig. 3.5: Gain of RHCP and LHCP antenna.

Axial ratio plot of Fig.3.3 clearly indicates the presence of circular polarization as the axial ratio curves pass through the 3dB level near the design frequency of 5.9GHz. Table 2 shows the results of the two configurations.

Table 2: various results of the two antenna configurations.

S. No.	Parameters/Diode State	D1 and D3 On State	D2 and D4 On State
1	Polarization	RHCP	LHCP
2	Min RL @5.9GHz(dB)	19	18
3	Resonant Freq.(GHz)	5.88	5.88
4	-10dB BW(MHz)	672.3	694.2
5	Min AR (dB @ Freq.)	0.9	1.2
6	3 d-AR BW(%/MHz)	155	156.1
7	CP gain(dBi)	2.25	2.24

Table 2 shows that the new resonant frequency for both the configurations became 5.88GHz after optimization. -10dB return loss bandwidths obtained are 672MHz (RHCP) and 694MHz (LHCP). Minimum axial ratios in both the configurations are well below the suggested 3dB level required for antenna to exhibit circular polarization. 3dB axial ratio bandwidths are 155MHz (RHCP) and 156MHz (LHCP). Gain values are 2.25dBi (RHCP) and 2.24dBi (LHCP).

V. CONCLUSION

Two configurations obtained with the help of four PIN diodes exhibit good gain characteristics while maintaining good circular polarization (3dB axial ratio bandwidth) values follows at design frequency of 5.9 GHz. The proposed design is the result of optimizing the dimensions for good axial ratio (AR) bandwidths so as to get good CP characteristics.

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