CIRCULARLY POLARIZED C-SHAPED SLOT PATCH ANTENNA WITH RECONFIGURABLE POLARIZATION

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Abstract: - *A polarization reconfigurable, compact-sized, low-profile circularly polarized, omnidirectional antenna has been designed. The circular polarization has been obtained by the combination of vertical polarization by micro-strip patch along with C-Shaped slot and horizontal polarization by bended slots etched on the ground plane. Reconfigurability of the polarization has been achieved by electronically controlling the states of the pin diodes. This changes the effective orientation of the annular slots on ground plane and Polarization can be altered between Left-Hand Circular Polarization (LHCP) and Right-Hand Circular Polarization (RHCP). The proposed design has a compact size and operates at TM_{01} mode. Experimental results have shown good agreement with the simulation results. This antenna has axial ratio below 3dB, gain of 5.91 dBi and return loss of -32 dB at 2.4 GHz. It is suitable for ISM band application (IEEE 802.11 b/g/n- wifi).*

Key Words: Compact size, Patch antenna, polarization reconfigurable , PIN diodes .

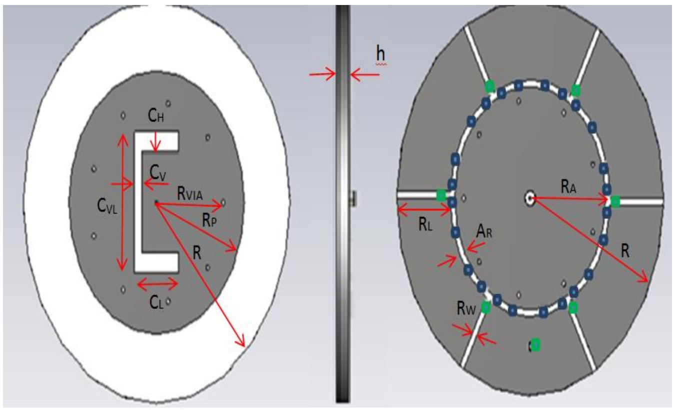
1. INTRODUCTION

Reconfigurable antenna is an emerging area of research as it helps in increasing the system capacity and realizing multiple functions. Within the extensive ambit of wireless communications, circularly polarized antennas can offer many edge over linearly polarized antennas. Circularly polarized antenna is used in wireless communication as it does not require strict alignment between the transmitting and the receiving antennas. Omni directional antenna realized by Dielectric Resonator Antenna (DRA) with alford loop [1] and monopolar patch antenna with curved branches [2] lead to high return loss but have very less gain. Patch antenna with slots and shorting vias [3] and microstrip array antennas [4] also suffer the same limitation and they have large thickness which is not suitable for the application in mobile terminals. Zeroth-order resonance patch antenna [5] has negative gain which is not desirable. Both Ring and U-shaped slot antenna [6,7] and E-shaped patch antenna [8] have less directivity. By tuning the curvatures of the vortex slots, the polarizations can be made equal in amplitude and a good CP (Circular Polarization) property is obtained [9]. Short dipole and a small loop excited by the same current are orthogonal to each other and 90 different in phase and the Omni directional CP radiation is achieved [10,11]. Antenna consists of loop elements [12], monopole elements [13] or dielectric elements [14] to provide omni directional circular polarization. A top-loaded monopole mode is excited by a disk-loaded coaxial probe [15] to obtain conical radiation pattern.

In this research paper, the antenna design section gives the details of the measurement of the antenna and then the operation of antenna as to how it achieves reconfigurable polarization. To maximize polarization efficiency in both line-of-sight (LOS) and non-LOS cases through C-Shaped patch and circular polarization reconfigurable antennas which can switch between RHCP and LHCP. Parametric analysis has been done to achieve the desired results. Comparative study has been done which clearly shows that the proposed system has higher gain and return loss.

2. Antenna Design:

The proposed antenna consists of a circular patch of radius Rp. The antenna has the same radius R for the substrate and the ground. The substrate used is FR-4 with relative permittivity ε_r of 4.4, loss tangent of 0.02 and thickness of h. Figure 1 shows the design of the proposed antenna and its specifications are given in Table 1.The vias are etched from patch up to the ground. There are 9 vias of diameter d and the distance between the centre of the antenna and the via is R_{VIA}. The patch consists of a C-shaped slot. The ground plane consists of a slot with inductors placed in it. A small annular slot is etched and the inductor is placed in order to choke the high-frequency current and dc line is connected to the inner metal.



a) b) c)

Fig 1.a) Top view b) Side view and c) bottom view of the proposed antenna

TABLE 1 Parameters of the proposed antenna

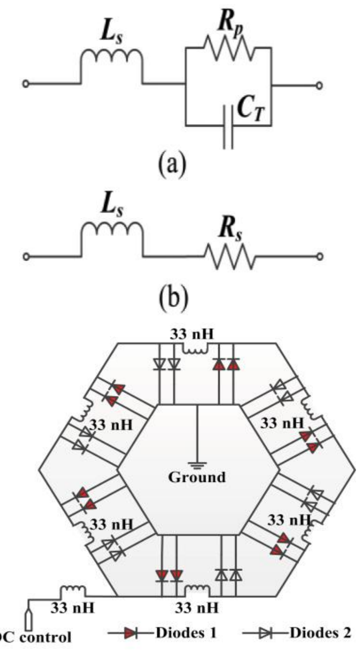
C_V	C_H	C_L	C_{VL}	R_{VIA}	R_P
3.2mm	6mm	20mm	42mm	30mm	39.5mm
R	R_L	R_W	A_R	**RA**	**H**
60mm	26mm	2mm	2mm	34mm	3.175mm

3. Principle of operation of proposed antenna:

The proposed antenna can be realized by combining the two types of low profile wide band radiator to generate omni directional vertically and horizontally polarized waves. Circular polarization is obtained by combining two orthogonal polarized waves which have the same magnitude but a phase difference of 90 degrees. Vertical polarization is obtained by the circular patch along with the C-shaped slot. The horizontal radiation is obtained by the annular and radial slots. Six radial slots are arranged at an interval of 60 degrees. The annular slot helps in coupling as it is perpendicular to the patch which forces the current to flow around the slot. Hence electromagnetic coupling is introduced to excite the radial slots which produce horizontal radiation. The energy coupling between the patch and the slots is stable within wide frequency range which leads to the stable antenna performance within wide-frequency band. By varying the position and the number of shorting pins, fundamental modes TM_{01} can be tuned to form a wide band response. The circular polarization can be changed by changing the orientation of the sequential bended slots. This can be done using diodes.

Diodes are placed across the slots so as to reconfigure the orientation of the slots. Totally 4 diodes are placed between two radial slots; out of them a pair of diodes is placed in the opposite direction. A resistance of 1.5Ω, inductance of 0.7 nH, a cut-off capacitance of 0.15 pF, and a serial resistance of 5 kΩ are the characteristics of the diode. PIN diodes, SKYWORKSSMP1345-079LF, are used in this design as they have low capacitance and low resistance. When the diodes are on, it acts as a metal strip and allows the flow of current from the outer ground plane to the inner ground plane. When the diodes are off, it acts as a slot and there is no current flow from the outer to the inner ground plane. Thus orientation of slots is changed.

To attain LHCP the diodes 1 are ON and the diodes 2 are OFF and vice versa for RHCP. Inductors are placed at radial slots of 33-nH for dc control. At microwave frequency inductor's impedance is very high; as a result high frequency current is blocked. The equivalent circuit of dc biasing is shown in figure 2 where their values are L_S = 0.7 nH, C_T = 0.15 pF, R_P= 5kΩ, R_S = 1.5Ω. A small annular slot is etched in the ground plane in order to achieve ac/dc isolation. The diodes are energised by a dc voltage of 5V and the antenna by coaxial cable.



c)

Fig.2. RF equivalent circuit models for PIN diodes (a) OFF-state (b) ON-state (c) equivalent circuit of dc biasing.

4. Parametric analysis:

Each parameter in this design has its own significance. Changing a single parameter would lead to discrepancy in the result. A clear analysis of each parameter has been done. The number of radial slots plays a major role as it determines the magnitude of the horizontal polarized waves. They are directly proportional.

To achieve good circular polarization 6 radial slots are etched. The length of the radial slot R_L determines the resonant frequency. By adjusting the width of the arc slot A_R we can produce 90 degree phase shift between two orthogonal linear polarizations as it not only acts as a coupler but also as a section of transmission line. The width and the length of the C-slot are changed in order to achieve the desired return loss.

In this section some important parameters of the proposed antenna are discussed. The following parameters are studied when the antenna works as an RHCP antenna. Chart 1 shows frequency band versus $|S_{11}|$ for different horizontal slot widths.

From the graph, it is observed that there is a variation in return loss, bandwidth, and centre frequency shift for width. When C_H increases from 4.2mm to 9mm, the centre frequency of the $|S_{11}|$ band ($|S_{11}| \leq$ -10 dB) also increases from 2.38 GHz to 2.42 GHz. However, with C_H increasing, $|S_{11}|$ increases and the $|S_{11}|$ band becomes wider. The optimum result is obtained at C_H = 6mm.

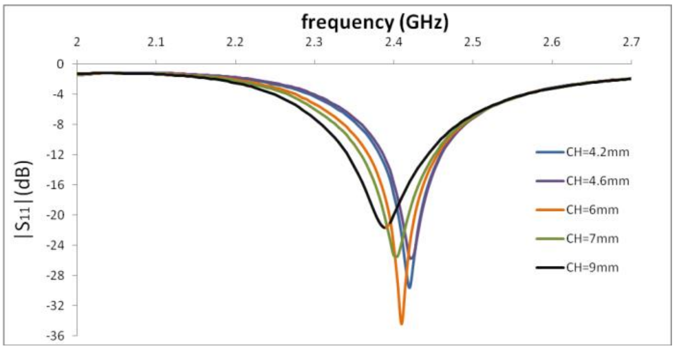


Chart -1: Frequency band versus $|S_{11}|$for different horizontal slot width

Chart 2 shows frequency band versus $|S_{11}|$ for different vertical slot widths. From the graph, it is observed that there is variation in return loss when the width of the vertical slot is changed. When C_V varies from 2.8mm to 3.4mm, the centre frequency of the $|S_{11}|$ band ($|S_{11}| \leq -10$ dB) varies from 2.41GHz to 2.43 GHz. However, with C_V varying, the left side of the $|S_{11}|$ curve slightly changes and the right side of the $|S_{11}|$ curve almost remains the same. Optimum result is obtained for C_v= 3.2mm.

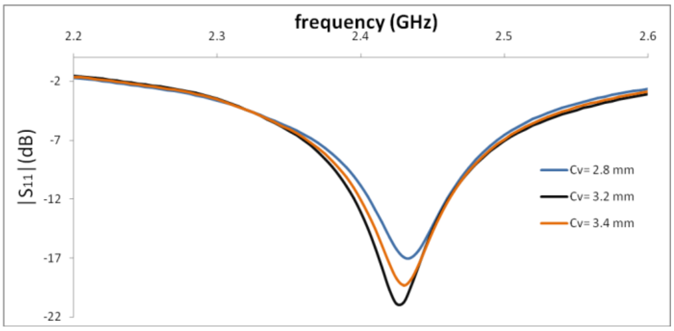


Chart-2: Frequency band versus $|S_{11}|$for different vertical slot widths

5. Results and Discussion:

All the simulations have been carried out using CST Microwave Studio 2015, and the measurements have been made using E5071C ENA series vector network analyzer. To validate the design concept, the prototype has been fabricated and tested. ±5V dc voltages have been applied on the dc biasing line with 33Ω series resistor connected to it in order to attain LHCP/RHCP configuration. Simulated and measured results of gain and axial ratio have been used to construct a graph. Chart 3 shows the simulated and measured gains of the RHCP antenna and the LHCP antenna for the various frequency ranges. At centre frequency the simulated gain is 6.02dBi and the measured gains of the LHCP and RHCP antenna are 5.91 dBi and 5.85 dBi respectively. It has a desirable measured directivity of 6.086 dBi at 2.41 GHz. Gain is improved by putting slots in the ground plane as the resonant frequency is shifted towards the lower side by maintaining slot's length and width. The antenna has stable gains across the entire band at both states. For any antenna directivity should be higher than the gain and the same has been achieved due to the annular split ring at the bottom surface.

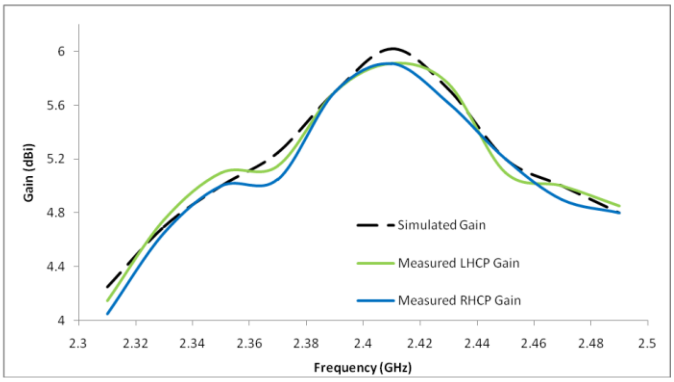


Chart-3: Simulated and Measured gains of the proposed antenna

The axial ratio of the proposed antenna is below -3 dB which indicates the circular polarization as shown in chart 4 In the simulation axial ratio bandwidth (AR ≤ 3 dB) is from 2.41 to 2.425 GHz. The measured axial ratio bandwidth (AR ≤ 3 dB) of the LHCP antenna is 17MHz, from 2.408 to 2.425 GHz, while that of the RHCP antenna is 28MHz, from 2.404 to 2.432 GHz. Therefore, the overlapped axial ratio bandwidth of the antenna is from 2.408 to 2.425 GHz (17MHz). It can be seen that the measured axial ratio bandwidth shifts to a higher frequency for both the LHCP antenna and the RHCP antenna. The simulated axial ratio is 2.9, whereas the measured axial ratios are 2.19 and 1.99 for LHCP and RHCP respectively. The axial ratio is maintained in this range with help of coaxial feed-line. The measured VSWR of the antenna is 1.038.

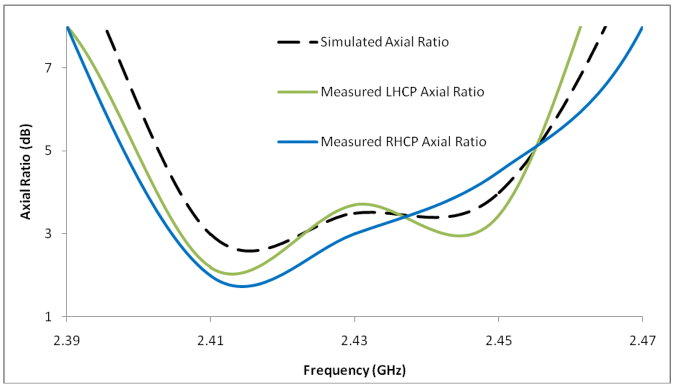


Chart-4: Simulated and Measured Axial ratios of proposed antenna

The chart 5 shows the simulated left and right hand polarization for theta = 90 and phi = 243 at frequency 2.41 GHz. The main lobe magnitude is 2.8 dBi and 2.9 dBi for left and right polarization respectively. There exits minor lobe of -2.9 dB. Generally the side lobe magnitude of-20 dB is not desirable. This has been achieved significantly where the power usage is not wasted and efficiency of directivity 6.09

dBi is achieved. The figure 3 shows the directivity of the proposed antenna.

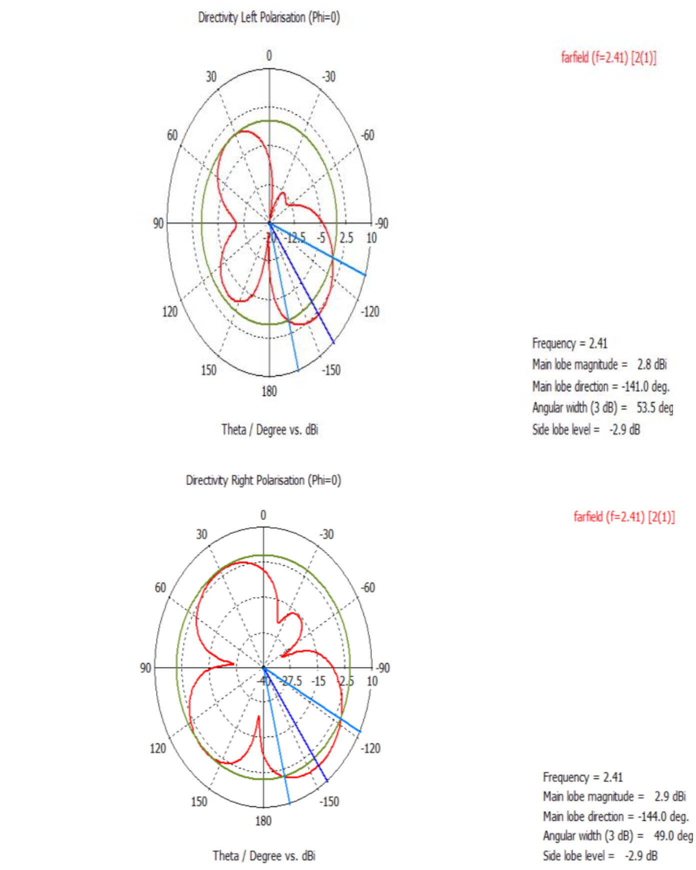


Chart-5: Left polarization of proposed antenna and Right polarization of proposed antenna

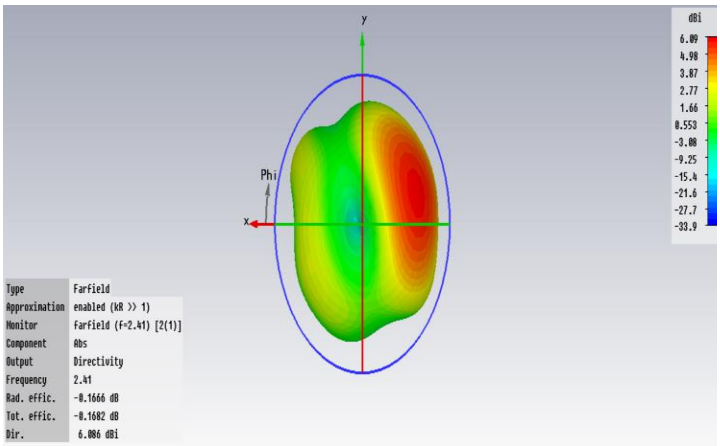


Fig-3: Directivity of the proposed antenna

Chart 6 shows the simulated and the measured return losses of the proposed antenna. The simulated $|S_{11}|$ band ($|S_{11}| \leq -10$ dB) is from 2.32 to 2.49 GHz which is similar to the measured result from 2.315 to 2.5 GHz. This shows the maximum return loss of -34.457dB at 2.41 GHz and this helps in reducing the SWR at reception. This is achieved by increasing the width of the C-shaped slot (C_V and C_H). The simulated bandwidth is 0.170 GHz, whereas the measured bandwidth is 0.185 GHz.

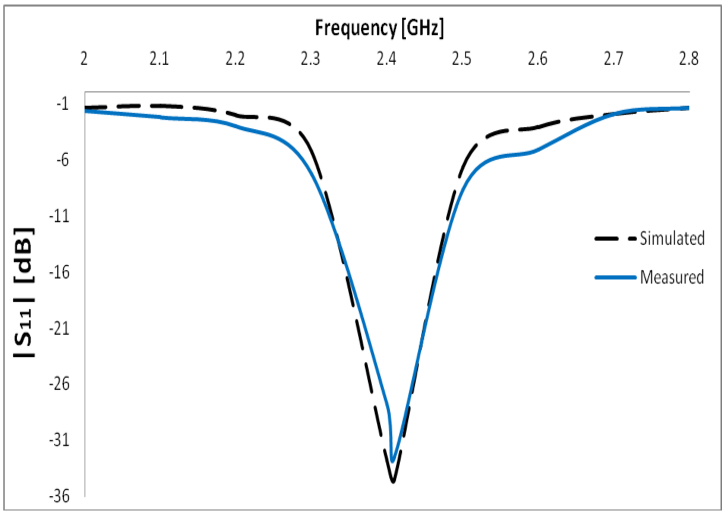
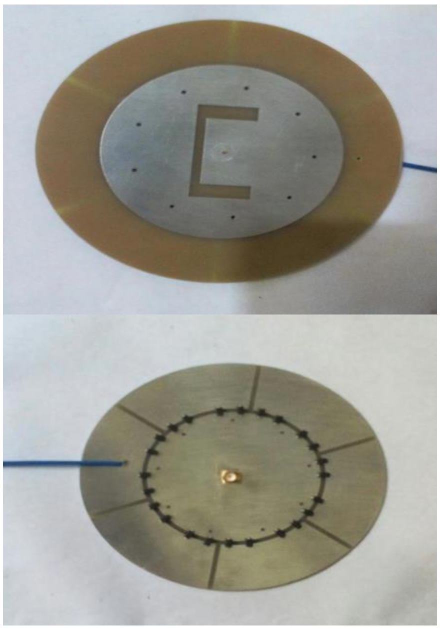


Chart-6: Frequency band versus $|S_{11}|$ for measured and simulated return loss of proposed antenna.

The simulated results agree well with the measurements. The small discrepancies could be attributed to the inherent numerical error of the electromagnetic simulator, fabrication and measurement tolerance. Figure 4 shows the fabricated antenna.



a) b)

Fig-4: Prototype of the fabricated antenna (a) Front view (b) Back view

6. Comparisons of antenna design:

The performance of the proposed antenna and the various other antenna designs are listed in Table 2.This table compares the proposed work with the existing states of art and comparison is made on d same .

TABLE -2 : Comparison with the existing state of art

Ref. No.	Type of antenna	Centre frequency (GHz)	Gain (dB)	Return loss (dB)	Bandwidth (%)	Polarization Reconfigurable
[1]	DRA with Alford loop	2.42	1.8	-32.24	7	No
[2]	Patch antenna with slots and shorting vias	2.89	1	-22.15	51.7	No
[3]	Zeroth-order resonance patch antenna	1.49	-0.4	-15.05	0.5	No
[4]	Monopolar patch with curved branches	2.49	4.7	-32	19.3	No
[6]	Microstrip array antennas	2.48 2.89	3.2 2.4	-27.12	1.6 2	Yes
[10]	Six-edge irregular polygon shaped slot antenna	2.45	3.5	-8.53	4.5	Yes
Proposed antenna	C-Shaped slot antenna	2.4	5.8	-32.8	7.05	Yes

The performance of the proposed antenna and the various other antenna designs are listed in Table 2. This table compares the proposed work with the existing states of art and comparison is made on d same . From the comparison it can be inferred that the listed antennas have less return loss and gain than the proposed antenna. Even though the return loss of [1,4] is similar to that of proposed antenna, the gain of these antenna is extremely less whereas the proposed antenna has gain of 5.8. Higher gain antennas transmit more power to the receiver and thus increases the strength of the signal it receives. Similarly, when return loss is greater than 20 db there would be only 1% reflection and 99% power into the antenna. The proposed antenna has a return loss of -32.8, so there would be nearly 100% power into the antenna. Out of these antennas only [6,10] and the proposed antenna are reconfigurable. Within these antennas , only proposed antenna has higher bandwidth and lowest profile.

From this comparison table the conclusion that the proposed antenna has low profile, higher gain and return loss than the other antenna designs, can be arrived at.

7. Conclusion:

A C-Shaped slot patch antenna was designed with circular polarization. The polarization was reconfigured between Left-Hand Circular Polarization (LHCP) and Right-Hand Circular Polarization (RHCP) using diodes by controlling their on/off states by dc biasing circuit to change the effective orientation of the annular slot on the ground plane. Good LHCP/RHCP radiation was generated when positive or negative voltage was applied as the case may be. Return loss was increased for 100% power into the antenna and in order to reduce VSWR by introducing C-Shaped slot. Moreover because of higher gain antenna transmits more power to the receiver. Experimental results showed good agreement with the simulation results. The proposed antenna features simple structure, stable radiation patterns, acceptable gain, directivity and axial ratio which in turn make it suitable for ISM band application.

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