Polarization Reconfigurable Antenna for X-Band Satellite and Marine RADAR Applications

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Abstract: This paper describes the design of polarization reconfigurable single fed patch antenna with two perturbed rectangular ring slots and two PIN diodes at different positions on the ground plane. The topology of patch antenna is suitable for 9.3 GHz satellite and marine RADAR applications. The sense of polarization is controlled by switching of the PIN diodes can generate two circularly polarized (RHCP&LHCP) as well as linearly polarized waves. In this design, slots are placed in ground plane which avoids additional DC biasing and minimizes effect caused by PIN diode on radiation performance of patch antenna so that the patch is unperturbed, which leads concise structure. The simulated results for placements of slots at different positions on the ground plane results in three polarization states with acceptable return loss. This design achieves good impedance bandwidth, axial ratio, gain and radiation properties. Simulation study has been done by incorporating HFSS V-16.2 platform.

***Index Terms*– Polarization reconfigurability, perturbation, RHCP, LHCP.**

I. INTRODUCTION

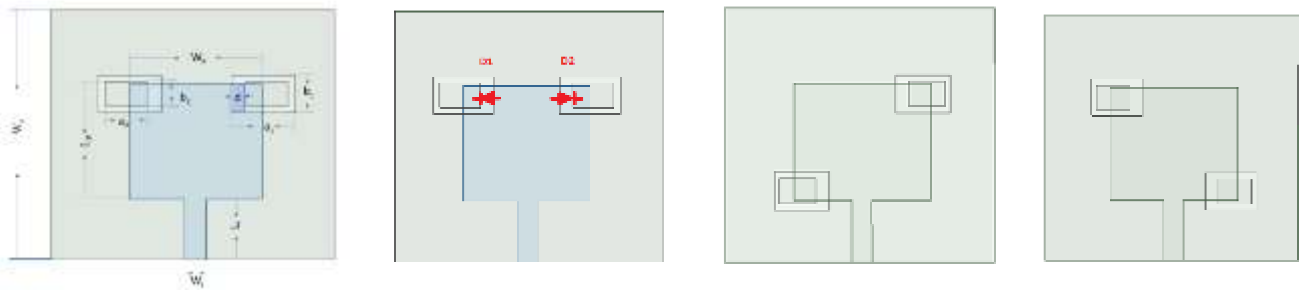
An antenna which has capability to change operating frequencies, polarization and radiation patterns without changing its fundamental characteristics is called reconfigurable antenna [1]. Reconfigurability is achieved through physical, electrical and mechanical changes in the antenna design [2]. Reconfigurable antennas development has become crucial for modern wireless systems like wireless local area network (WLAN), modern RADAR systems, etc. Reconfiguration of bandwidth can be done in cognitive-radio application, has an operating bandwidth of 2GHz-10GHz. In military applications, SATCOM antennas which are implemented by PARCA SDR technology so that satellite can easily track vehicle on the ground. In medical applications PIFA antennas are used for bio-implantation [3-5]. An antenna can change its polarization without changing its fundamental characteristics like gain, radiation pattern etc. is called polarization reconfigurable antenna. Polarization reconfigurability is achieved by altering the direction of surface currents and hence EM fields [6].The polarization reconfigurable antenna has a greater immunity to signal interference which is caused by changing environment [7]. An undesired influence caused by the multipath effects are attenuated by the antennas with polarization diversity and reduces polarization mismatch between transmitter and receiver. Antennas with circular polarization can transmit signal more intensively which can reduce clutter from hail or frozen rain drops [8]. The antenna having switching capability between linear and circular polarizations can make it more versatile [9]. The methods to generate CP wave are corner truncation, slots on the patch, with active devices and with different feed techniques etc. Perturbation of slots is one of the methods to achieve CP wave, the general procedure for perturbation is removing or adding a small part of patch. This small part of patch is connected through active devices like PIN diodes, varactor diodes and MEMS for achieving reconfigurability [10]-[11].

A polarization reconfigurable antenna using slots on the patch is designed and mainly concentrated on modifications of physical properties of patch, for this design operating bandwidth is low [12]. A cross slot reconfigurable circular patch is designed with four PIN diodes has low impedance bandwidth [13].Corner truncated square patch is designed with four PIN diodes with DC biasing circuit which makes the design complicated [14].A center perturbed square ring slot on the patch antenna is capable of switching among linear polarization and circular polarization [15]. By changing the U -slot length of the square patch antenna can excite CP wave, makes antenna design is complicated [16].An aperture coupled patch antenna with quadric-polarization diversity consists of eight PIN diodes is capable to generate linear and circularly polarized waves. Designing of feed network and bias circuits for diodes makes complicated design [17].

In this paper, merely a square patch antenna with two small rectangular loop slots, placed at different positions in the ground plane is designed. The separated ground plane parts are connected through two PIN diodes. Advantage this design is patch structure is not disturbed, the diodes are placed in ground plane, which avoids DC biasing circuits and minimizes effect caused by PIN diode on radiation performance of patch antenna that makes antenna design very concise and easy to fabricate. As the designed antenna has polarization agility suitable for modern RADAR systems and satellite communications.

II. ANTENNA DESIGN

In this paper the square shaped patch antenna is designed for X-Band applications with resonant frequency of 9.3 GHz. Basic rectangular microstrip line feeding is used. RT duroid 5880 is used as substrate with dielectric constant and loss tangent are 2.2 and 0.0009 respectively. The dimensions of designed antenna are shown in figure.1 and values are tabulated in Table.1. The rectangular loop slots with lengths a1 and a2, widths of b1 and b2 are designed in the ground plane. On one side of both loop slots width ‘d’ is taken for the placement of PIN diodes. BAR64 series PIN diodes are used for switching action. In the on-state the diode has 2.1Ω resistance and 0.17pf capacitance in the off-state according to the data sheet.



(a) (b) (c)

Figure 1 : (a) Top view and bottom view of Patch Antenna (Case I). (b) Diagonal configuration (Case II). (c) Diagonal configuration (Case III).

Table 1: Design parameters of antenna

S.No.	Design specifications	Dimensions (mm)
1	Length of patch (LP)	9.3
2	Width of patch (WP)	9.4
3	Substrate length (Ls)	20.2
4	Thickness of the substrate (h)	0.508
5	Length of the Feed (Lf)	4.9
6	Width of the Feed (Wf)	1.5
7	Length of the outer rectangle ($a1$)	4.5
8	Width of the outer rectangle ($b1$)	3
9	Length of the outer rectangle ($a2$)	3
10	Width of the outer rectangle ($b2$)	2
11	The gap for diode placement (d)	1

III. OPERATING PRINCIPLE

In this design the two loop slots are placed at upper corners in Case I, right diagonal corner and left diagonal corners of the patch in Case II and Case III respectively are presented in figure 1. On ground plane rectangular loop slots are separated two small parts and PIN diodes are connected between the main ground plane and two small planes. When either of the rectangular loop slots is excited by a PIN diode produces CP waves and produce linearly polarized waves when both diodes are excited.

In Case I as shown in figure 1(a), there are three conducting parts in ground plane. By the excitation ground plane can produce linearly polarized wave, if diode D1 is in on-state and D2 is in off-state, the right-hand side perturbed part is excited with a phase of 90^0, resultant field will be interaction between fields due to ground plane fields and perturbed part of the ground plane to produced CP waves. The direction of resultant field vectors is moved anti-clock wise which leads RHCP. Similarly, for the diode D1 is in off-state and D2 is on-state the resultant field vectors are moves clock wise so that patch can produce LHCP wave. For the both diodes D1 and D2 are in “on” and “off” states the effect caused by the perturbed slots are cancels which leads linear polarization.

(a) (b) (c)

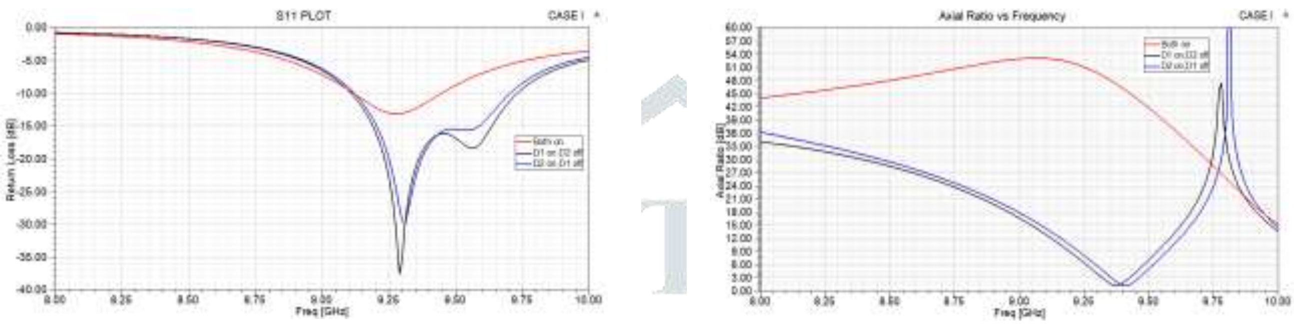
Figure2: Simulated Electric field distribution on patch for Case I (a) D1 “on”, D2 “off”(b) D1 “off”, D2“on” (c) Both “on”

In Case II, shown in figure 1(b) diodes D1 and D2 are connected in diagonal manner. If one of the diodes is in off-state, designed antenna produces LHCP wave. When both diodes are in on-state patch radiates linearly polarized wave.

In Case III, diodes D1 and D2 are connected in diagonal manner which is shown in figure1(c). If anyone of the diodes is in off-state, the antenna produces RHCP wave. When both diodes are in on-state patch radiates linearly polarized wave.

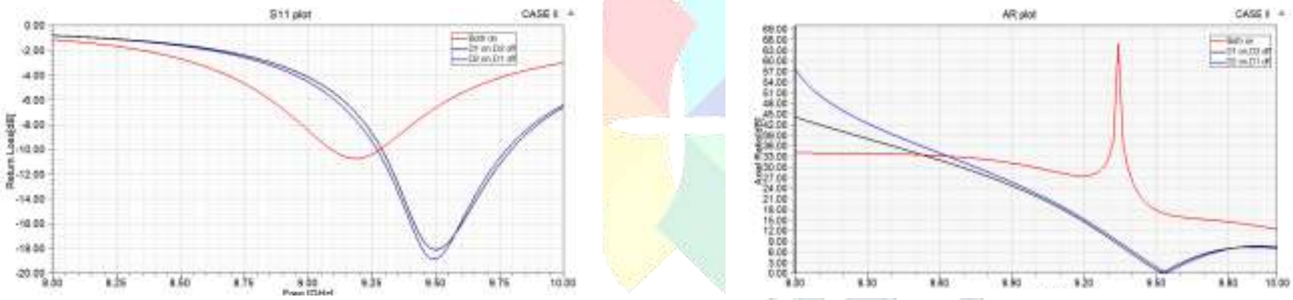
IV.SIMULATED RESULTS

The antenna is designed to resonate at 9.3GHz frequency. Three different cases are considered for the analysis purpose. Case I slots at top corners of the patch, Case II right diagonal arm and Case III left diagonal arm of the patch. The important antenna parameters such as return loss, axial ratio, impedance Bandwidth, gain, radiation patterns and electric field vectors are analyzed. The results were presented for different operating conditions of PIN diodes for all the above three cases. Fig 3 shows results for case I. Similarly Fig 4 and Fig 5 represents results for case II and case III respectively. Case I achieves linear, RHCP and LHCP polarizations with good axial ratio values. In Case II and III linear and either LHCP or RHCP is achieved depending on the slot positioning in right or left diagonal arm of the patch.



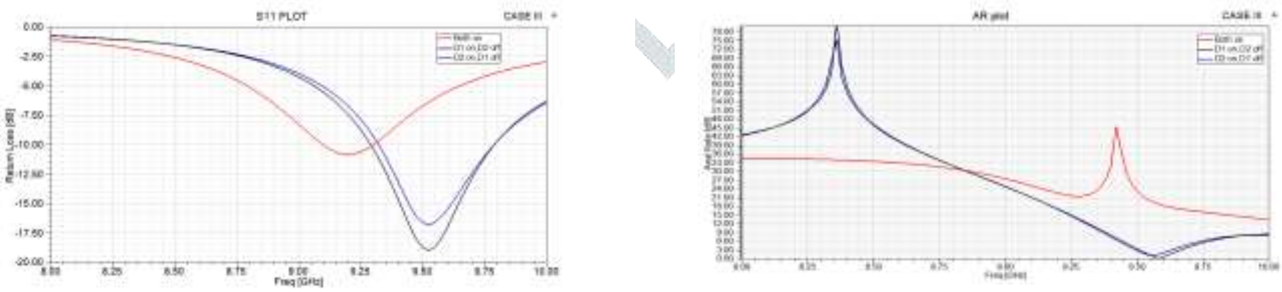
(a) (b)

Figure 3: Case-I (a) Plot of Return loss vs. Frequency (b) Plot of axial ratio vs. Frequency



(a) (b)

Figure4: Case II (a) Plot of Gain vs. Frequency (b) Plot of axial ratio vs. Frequency

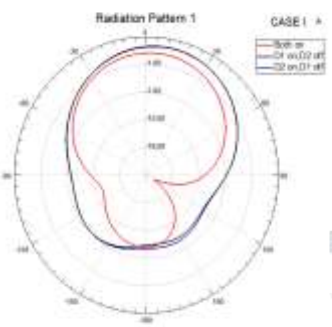
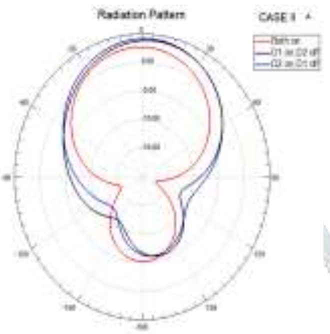
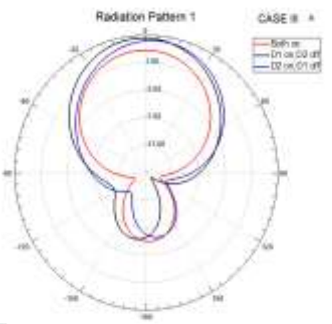
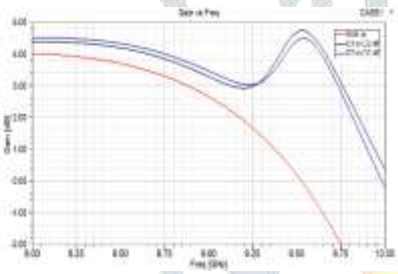
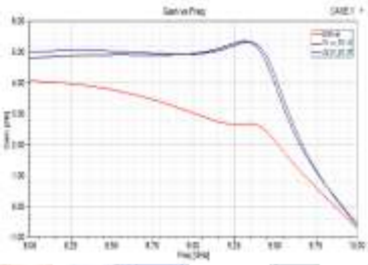
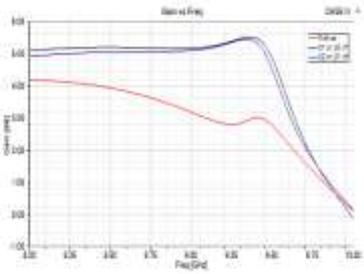


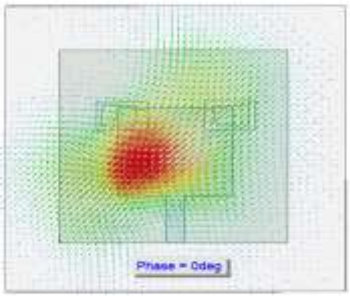
(a) (b)

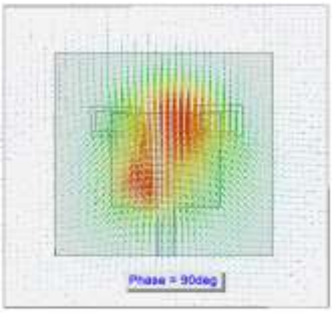
Figure 5: Case III (a) Plot of Gain vs. Frequency (b) Plot of axial ratio vs. Frequency

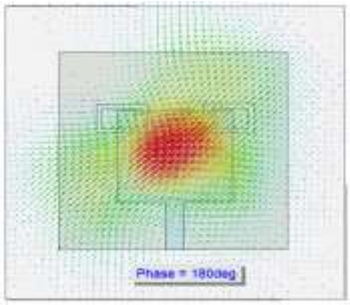
The electric field distribution at distance of λ/4 from the patch is observed at different instants for all three cases. Fig 6 (a-e) shows electric field vectors distribution for Case I when D1 “off” and D2“on”. It can be noticed from figure 6 that electric field vectors are rotating anti clock wise so it is called as LHCP. RHCP is observed for diode D1 in “on” state and D2 in “off” state. Similarly for the first case, if both diodes are in on-state electric field vectors are linear. For case II, both diodes are in “on” state the field vectors are linear to the patch and when one of the diodes is in “on” state the field vectors are moving clock wise which indicates LHCP. Similarly, for the third case, both diodes are in “on” state the field vectors are linear to the patch with either one of the diodes is in “on” state the field vectors are moving anti-clock wise which indicates RHCP. Simulated 2D radiation patterns and 3D polar plots are presented in table 2 and table 3 respectively. It is observed from radiation patterns that the peak gain obtained maximum for case III, and cross polar component is minimum compared with Case I and Case II.

Table 2: Simulated 2D Radiation Pattern

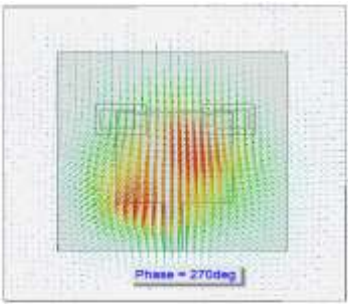
Parameters	CASE –I	CASE –II	CASE –III
2D-Radiation Pattern			
Gain vs. Frequency			

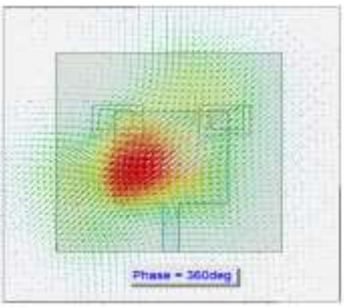






(a) **(b)** **(c)**





(d) **(e)**

Figure 6: Case I (a-e): Electric field vectors for LHCP at different phase angles when D1 “off”, D2“on”

Table 3: Simulated 3D Polar Plot

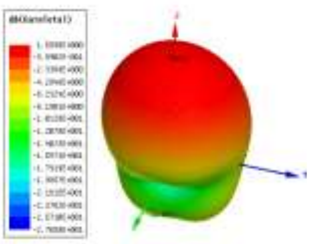
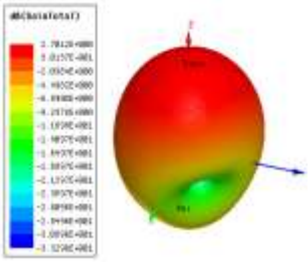
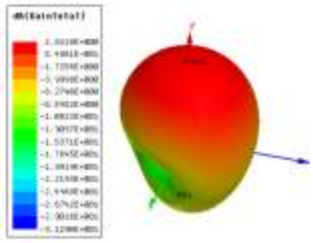
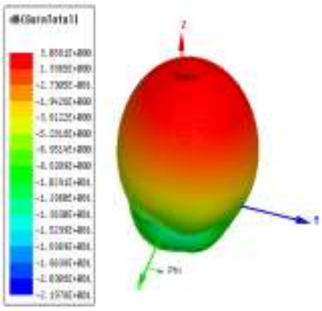
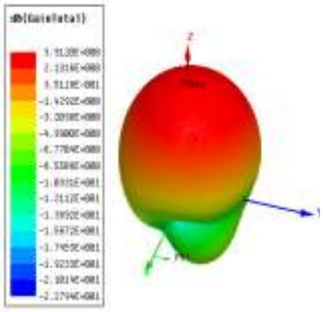
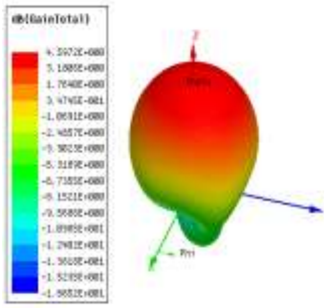
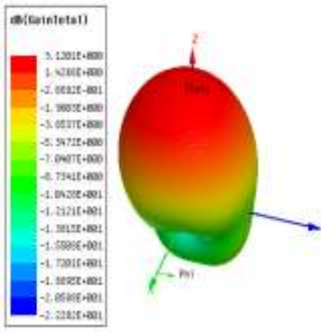
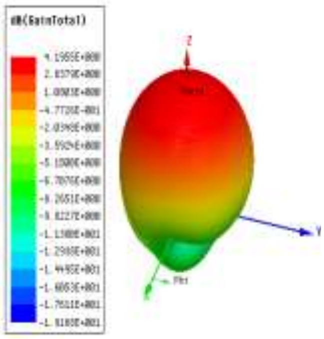
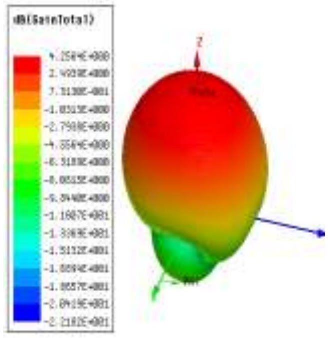
Parameters	CASE –I	CASE –II	CASE –III
3D Polar Plot (BOTH ON)			
3D Polar Plot (D1 ON&D2 OFF)			
3D Polar Plot (D1 OFF&D2 ON)			

Table 4: Simulated results for three cases

Parameters	CASE -I			CASE -II			CASE -III		
	BOTH ON	D1 ON	D2ON	BOTH ON	D1 ON	D2 ON	BOTH ON	D1 ON	D2 ON
Type of polarization	Linear	RHCP	LHCP	Linear	LHCP	LHCP	Linear	RHCP	RHCP
S_{11}(dB)	-13.13	-37.47	-29.68	-10.66	-18.05	-18.85	-10.88	-18.9	-16.7
BW(MHz)	330	620	580	200	510	515	200	500	470
Gain(dB)	1.55	3.06	3.12	2.70	3.91	4.19	2.80	4.59	4.25
Axial Ratio(dB)	50	1.29	1.21	27.79	0.21	0.29	22	1.44	0.05
VSWR	1.61	1.09	1.06	1.85	1.47	1.46	1.79	1.33	1.33
% BW	3.54	6.66	6.2	2.15	5.48	5.53	2.15	5.37	5
AR BW (MHz)	NA	110	100	NA	150	150	NA	130	150

IV. CONCLUSION

In this paper polarization reconfigurable microstrip patch antenna with rectangular loop slots in the ground plane, to resonate at 9.3GHz is designed for satellite communications in X-Band (8 to 12) GHz. PIN diodes are used to switch between different polarizations. As there are no DC biasing circuits on the patch side, the design of antenna is concise and can be easily fabricated. From simulation results shown in Table 4, it is evident that Case I has better operating conditions in terms of impedance bandwidth of 620MHz, return loss -37.47 dB and polarization conditions. Acceptable gain of more than 3dB achieved but a good amount of gain enhancement is achieved in case II and Case III. A good and acceptable value of axial ratio for all designs is observed.

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