Frequency Reconfigurable Patch Antenna Using PIN Diode at X-Band

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***Abstract*-In this paper the design of an X-band frequency reconfigurable patch antenna has been demonstrated using PIN diode. A square slot has been introduced in order to realize PIN diode effect in antenna parameters. The tuning of frequency is realized by changing its effective electrical length, which is controlled by different mode of the PIN diode by applying different bias voltages across it along the slot of the antenna. An annular slot rectangular patch antenna is used and a gap of 2mm is used to attach PIN diode. When the PIN diode is forward biased i.e gap is closed by PIN diode and current will flow along the outer ring. ±60 MHz (1.34 %) tuning of frequency has been obtained by applying the bias voltage of 3 volt. The structure has been simulated in ADS software. Simulated and measured performances are presented. Results are used to demonstrate that there is good agreement between the simulated and measured results. The match between simulation and measured results suggests that proposed candidate can be used as a frequency reconfigurable antenna.**

Key-words: Electronic tuning; frequency reconfigurable antenna; concentric patch; PIN diode.

I. INTRODUCTION

Reconfigurable antennas, that are capable of resonating at multiple frequencies and have phase tuning capability using different structures, are desirable at different applications [1]. Present antenna requirement should be enabled with different capability like navigation and combat applications [1]. A frequency reconfigurable antenna provides the capability for the antenna to be operated only the desired frequency range while rejecting neighboring ones [2]. This reduces interference which will consequently increase S/N ratio, thus channel capacity or power efficiency [2]. For an antenna to be capable of covering most of the applications (frequency bands, phase tuning, pattern and polarization reconfiguration) and comprehensive wideband modes are desired and some such designs are now presented [2]. By applying different patch size wide range of phase change can be obtained in reflectarray antenna [3]. Use of concentric patch [4] is another option to get wide phase change. Use of PIN diodes between two patches has the ability to change phase as well as pattern reconfiguration in desired range [5]-[6].For getting more bandwidth and gain sometimes E-shaped or H-shaped patch with slot can be used to get desired results [7]-[8]. By varying slot length or by keeping copper strip in slot phase tunability can be obtained [8]. Here copper strips are acting as a switch to sweep pattern for different frequencies of operation. For phase shifting operation ferroelectric material may also be used. Basically ferroelectric material provides variable permittivity when the DC bias voltage across it is changed [9]-[10]. This property makes this type of material as an attractive candidate for Beam Steering operation. Here only frequency reconfigurable antenna prototype has been presented. Microstrip slot antenna has the potential to be a better candidate for frequency reconfiguration because it offers wide frequency range tuning and the conveniences of tuning the resonant frequency with switches of varactors across the slot [11]. A combination of PIN diode and varactor diode is used in [12] where a reconfigurable slot antenna is capable to reconfigure up to nine frequency bands. In this paper an annular slot rectangular patch antenna has been shown at X band by which frequency tunability can be obtained up to ±60 MHz for different bias voltages.

II. CHARACTERISTICS OF PIN DIODE

The most important property of the PIN diode is the fact that it can, under certain circumstances, behave as an almost pure resistance at RF frequencies, with a resistance value that can be varied over a range of approximately 1Ω to 10 kΩ through the use of a DC or low frequency control current. When the control current is varied continuously, the PIN diode is useful for leveling and amplitude modulating an RF signal. When the control current is switched “on” and “off” or in the discrete steps, the device is useful for switching, pulse modulating, attenuating and phase shifting of an RF signal [13].

When a forward bias is applied to the diode, carrier injection takes place into the intrinsic layer. Electrons are injected into the intrinsic ν or π layer from the n-layer and holes are injected from the p-layer. [14].

Simplified lumped element equivalent circuits of a PIN diode in reverse-bias and forward-bias conditions are shown in figure 1. L and C_T represent the series inductance and shunt capacitance of the PIN diode, R_s is the ohmic contact series resistance, and C_j is the junction capacitance of the diode. Under forward bias condition R_f is the total diode resistance consisting of intrinsic layer resistance and ohmic contact resistances. We have used the equivalent circuit model parameters of a package PIN diode are L≅0.09 nH, C_T≅0.15 pF, R_s≅2 Ω, C_f ≅0.02 pF, and R_p =1000Ω. The notation has been used as per figure 1. The forward bias current is about 100 mA and reverse breakdown voltage at 10 μA is about 5V.

In this paper we have used SMD type PIN diode and size of the PIN diode is in the order of 0.5 mm in length, which is very small in size. When PIN diode is connected in forward bias only resistance has significant effect. In reverse bias capacitance and resistance play significant effect in changing the resonance frequency. When PIN diode is ON condition the current directly go through the switch and current path will reduce and antenna resonates at higher frequency and

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reverse effect has been observed for OFF condition of the PIN diode.

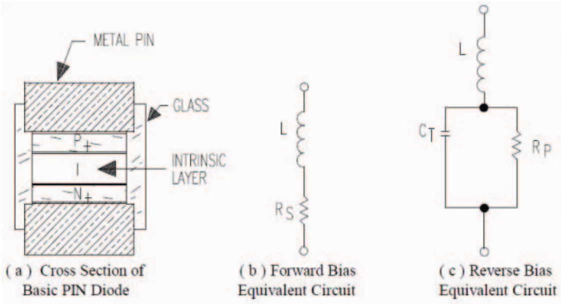

Figure 1: PIN Diode and the Corresponding equivalent Circuits [13]

III. THE ANTENNA DESIGN

The proposed antenna has been discussed in this section. The antenna design has two layers. In between upper layer and bottom layer foam has been introduced to get wide bandwidth. Figure 2 demonstrates the geometry of the design with a square slit cut in the patch to make the outer ring as a parasitic patch. Taconic (TLY) with permittivity of 2.2 and substrate thickness of 0.127 mm and 0.508 mm has been used for fabrication in the bottom layer and in top layer respectively. The stack up of the design is shown in figure 3.

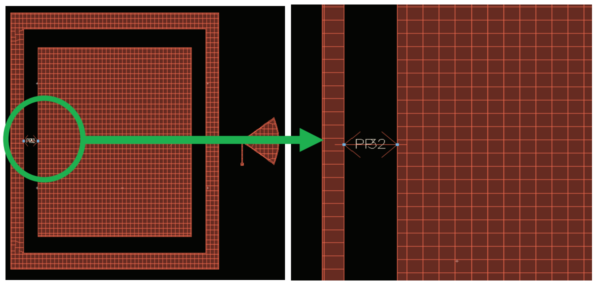

Figure 2: Proposed prototype of the antenna with equivalent pin diode circuit in ADS software.

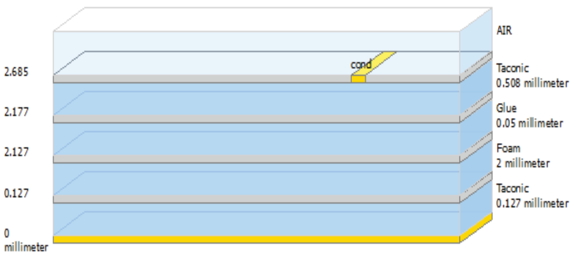

Figure 3: Design of stack up of the proposed antenna in ADS software.

Coaxial SMA connector has been used to excite the patch and rapid optimization has been done in the feeding positions for matching with 50 Ω impedance. Also foam of height 2 mm has been used to attach two layers of Taconic (TLY) dielectric material ($\varepsilon_r = 2.2$) with glue (3M adhesive material). The resonant frequency of the antenna is 8.7 GHz while the introduction of slit in between patch has reduced the frequency in lower side because slit cut will introduce inductance. Return loss for the resonant frequency is -18.7 dB and gain of 5.7 dBi has been obtained. For giving biasing connection a λ/4 radial stub (figure 4) has been designed and it is integrated with the total antenna. Further optimization has been done so that introduction of radial stub should not affect the original resonant frequency of the antenna. Radial stub is a radial transmission line which is used mainly in microwave circuits to ground the wide band RF signal. The equivalent circuit of radial stub is series connection of inductance and capacitance.

While designing the radial stub we have optimized the stub length to achieve short circuit at desired frequency which is confirmed from figure 5.

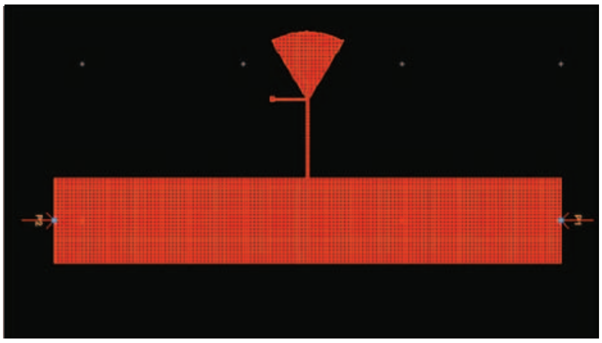

Figure 4: Signal flow diagram in Radial stub in ADS

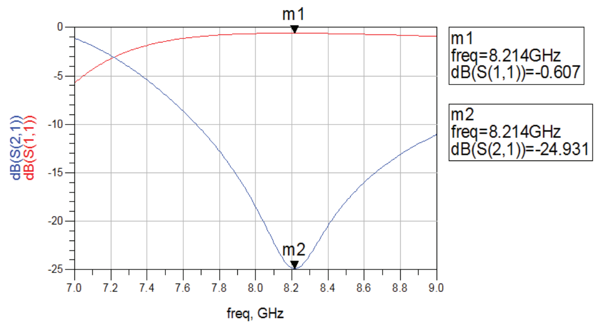

Figure 5: Simulated return loss and insertion loss of radial stub

IV. SIMULATED AND MEASURED RESULTS

The simulation of the proposed structure has been carried in commercial available software ADS to realize the effects of PIN diode and results have been discussed in the below figures. Simulation results shows with minima of S_{11} of -18.7 dB at 8.7 GHz which is in good agreement with measured result also in figure 6 and 16 respectively.

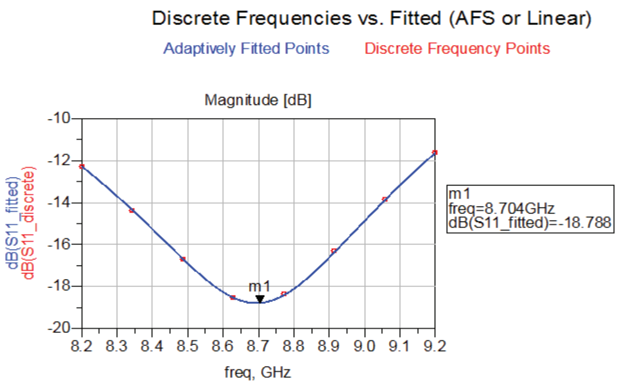

Figure 6: S_{11} of -18.7 dB of integrated antenna structure at 8.7 GHz.

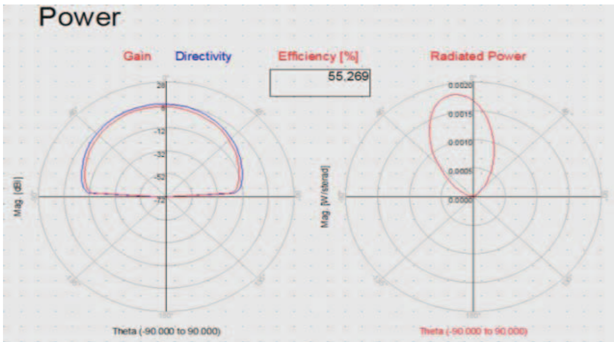

Figure 7: Radiation pattern at 8.7 GHz

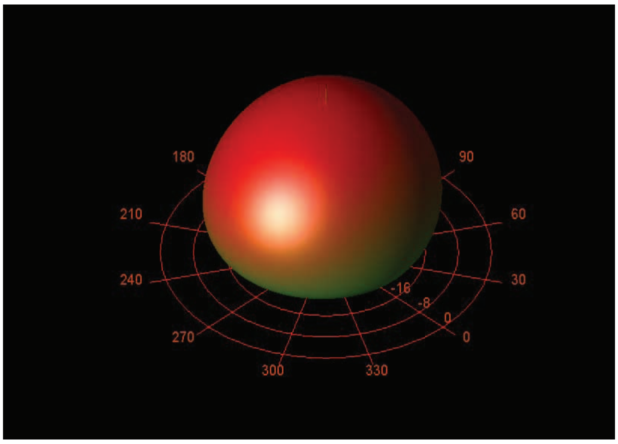

Figure 8: Radiation pattern for E-field (Co-polarization) at 8.7 GHz with equivalent impedance of PIN diode of 1000 ohm.

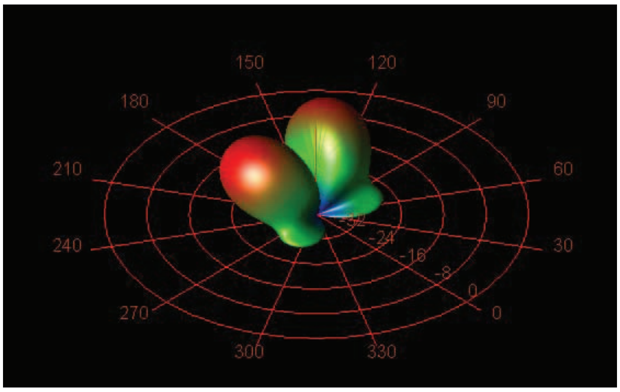

Figure 9: Radiation pattern for E-field (Cross-polarization) at 8.7 GHz with equivalent impedance of PIN diode of 1000 ohm.

In figures 7 to 9 are describing different power pattern and radiation pattern for patch using PIN diode of 1000 ohm. In figure 11 different antenna parameters has been cited.

Here for simulation the equivalent impedance of PIN diode has been used and practically SMD type PIN diode has been integrated to realize the changes in frequency. For reverse bias and forward bias condition impedance (1000-10i) Ω and 3.5 ohm has been calculated. In order to get good OFF condition of the PIN diode the shunt capacitor value should be low for obtaining very good isolation loss.

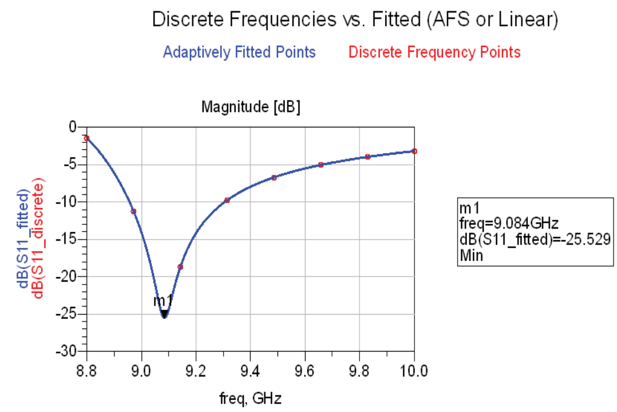

Figure 10: S_{11} of -25.5 dB at 9.08 GHz with PIN diode equivalent impedance of 3.5 ohm in ADS simulator.

TABLE I. ANTENNA PARAMETERS IN ADS SIMULATOR

Gain (dBi)	5.79
Directivity (dBi)	8.66
Power radiated (Watts)	0.00183
Maximum intensity Watts/Steradian)	0.00107
Axial ratio (dB)	50
Angle of intensity (deg)	Theta=6; Phi=180.

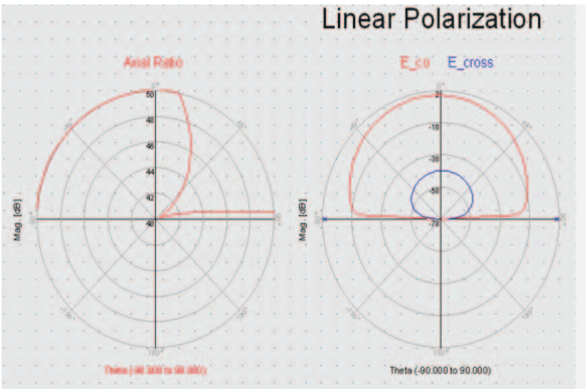

Figure 11: Simulated axial ratio and Radiation pattern (Co and Cross polarization) by using PIN diode in ADS simulator.

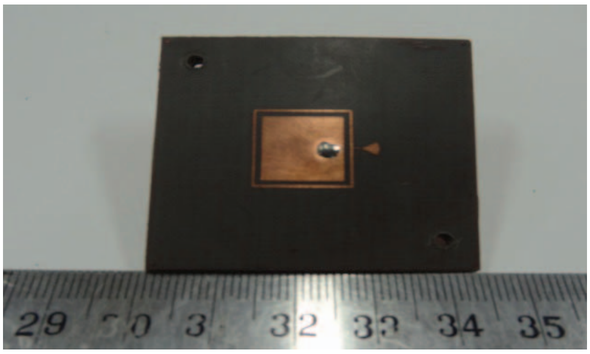

Figure 12: Fabricated patch antenna without p-i-n diode (scale in cm).

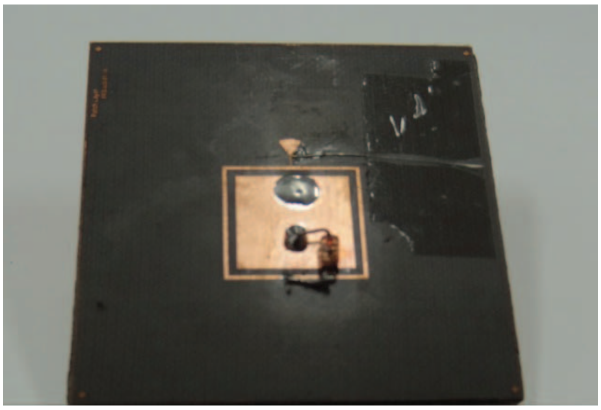

Figure 13: Fabricated patch antenna with p-i-n diode (scale in cm).

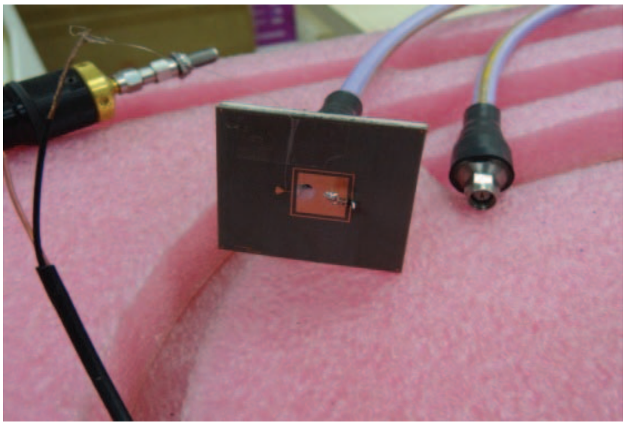

Figure 14: Return loss measurement of patch in PNA with bias voltage.

In the below figures from 15 to 17 Simulated and measured results have demonstrated. From figure 17 it is confirmed frequency can be tuned up to ±60 MHz in either side by applying different bias voltages and S_{11} of -21.2 dB at 9.4 GHz, -18.5 dB at 9.52 GHz and -20.2 dB at 9.46 GHz have been demonstrated by applying 0 volt, 1.5 volt and 3 volt respectively across PIN diode.

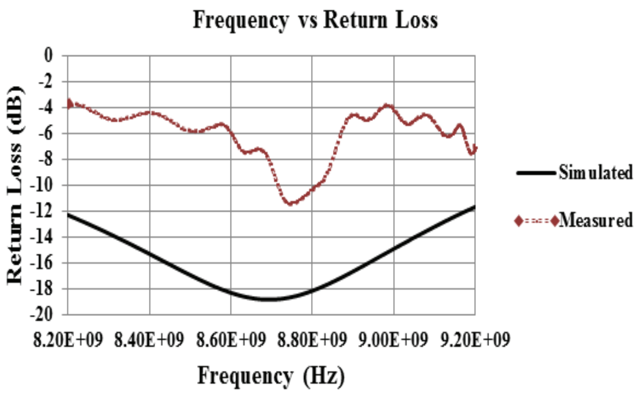

Figure 15: Simulated and measured return loss of patch with-out PIN diode.

In figure 15 variations in measured and simulated results can be attributed for diameter of hole in ground plane during fabrication.

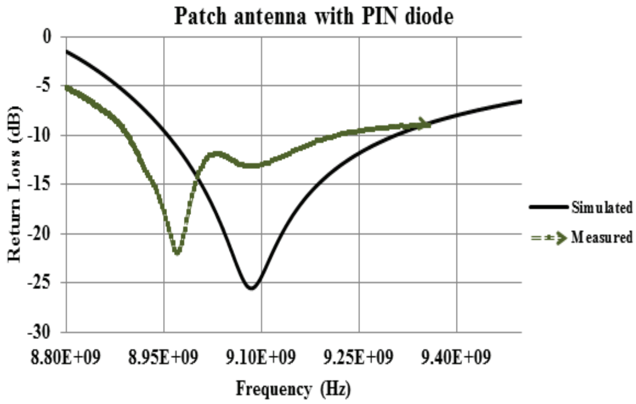

Figure 16: Simulated and measured return loss of patch with PIN diode.

The discrepancy between simulated and measured results can be attributed due to fabrication tolerance as slit dimension is very small.

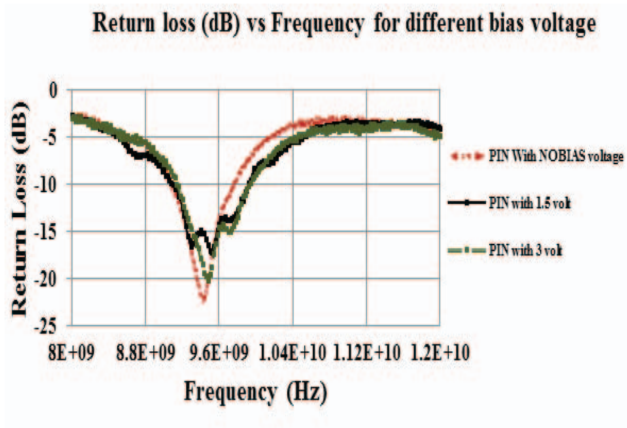

Figure 17: Measured return loss of patch with PIN diode for different bias voltage.

TABLE II. Measured return loss and gain for different bias voltage

Bias voltage (Volt)	Return Loss (dB)	Measured Gain (dBi)
0 volt	-21.2 dB at 9.4 GHz	4 dBi
1.5 volt	-18.5 dB at 9.52 GHz	5.9 dBi
3 volt	-20.2 dB at 9.46 GHz	6.1 dBi
No bias voltage and no PIN diode	-18.7 dB at 8.7 GHz	5.78 dBi

For different bias voltage radiation pattern and gain also have been measured in anechoic chamber. Measured gains have been listed in Table 2.

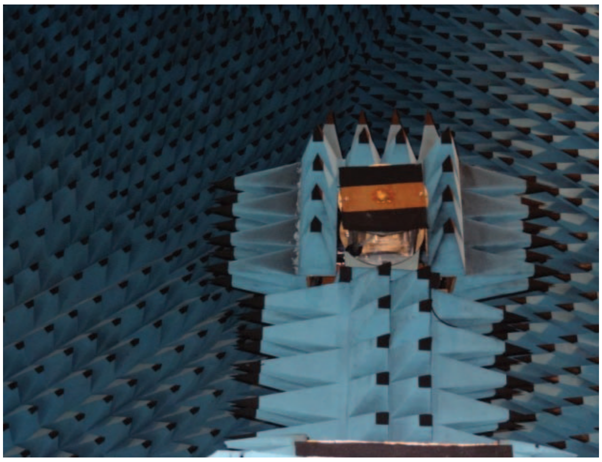

Figure 18: Patch with PIN diode for measurement in anechoic chamber.

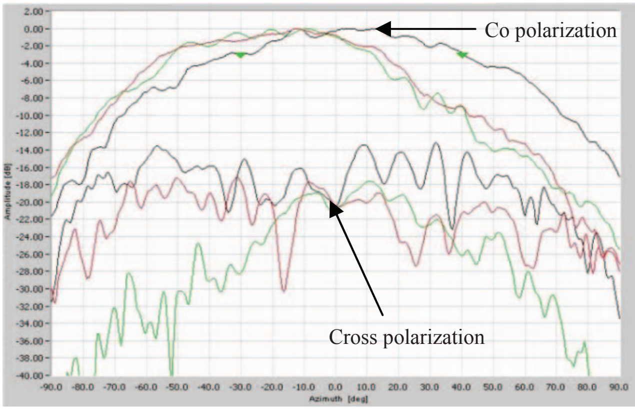

Figure 19: Patch with-out PIN diode for measurement in anechoic chamber for 8.7 GHz.

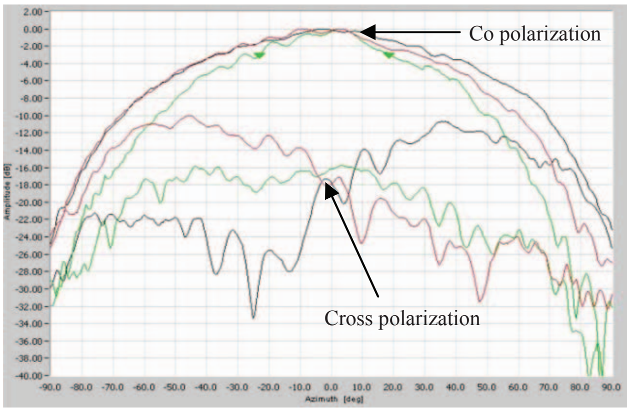

Figure 20: Patch with PIN diode for measurement in anechoic chamber for 9 GHz.

Figures 19 to 22 are measured results in anechoic chamber for different frequencies for different frequencies. From measured results and simulation results it is confirmed that there is good agreement between two results.

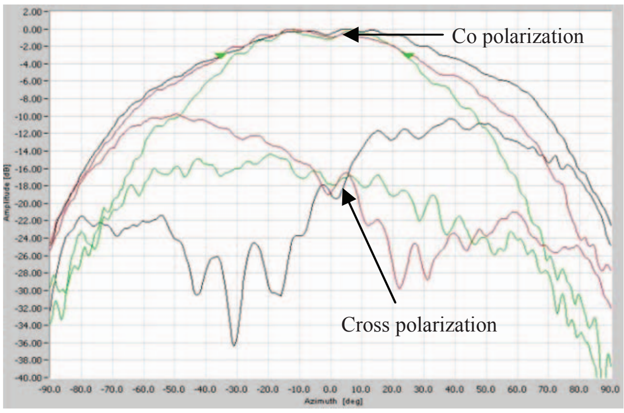

Figure 21: Patch with PIN diode for measurement in anechoic chamber for 9.2 GHz.

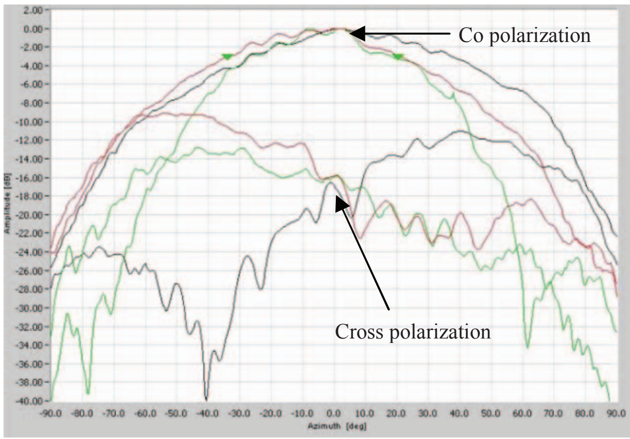

Figure 22: Patch with PIN diode for measurement in anechoic chamber for 9.4 GHz.

V. CONCLUSION

An X-band frequency reconfigurable affordable, compact, patch antennas is proposed in this paper. The physics behind the structure is based on changing the effective length of a resonant slot length by controlling connections of PIN diode for different bias voltages.

By comparing simulation and measured results it may be concluded that the shifting in frequency of the integrated antenna may be attributed for presence of glue between two dielectric materials. By using PIN diode ±60 MHz (1.34 %) frequency shift has been obtained. 5.9 dBi and 6.1 dBi gains has been measured at 9.46 GHz and at 9.52 GHz respectively. Axial ratio of 50 dB has confirmed that the polarization of the antenna is linear. Overall this paper encompasses the feasibility of PIN diode in antenna with better frequency reconfigurability.

ACKNOWLEDGEMENT

The authors wish sincere thanks to HRD Head, Engineers of MSAD & AMF in SAC, ISRO for supporting constantly throughout the work. Authors are also very thankful to University professors for arranging project work in SAC.

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