VOL. 3, NO. 4, SEPTEMBER 2008

Reconfigurable Patch Slot Antenna for Circular Polarization Diversity

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Abstract— **A novel design of a microstrip patch antenna incorporated by two orthogonal L-shaped switchable slots is proposed to achieve circular polarization. Two pin diodes are inserted in to these L-shaped slots and by making these two pin diodes ON and OFF the antenna will radiate with either right handed circular polarization or left handed circular polarization with wide bandwidth. This antenna can be used in Unlicensed & licensed WiMAX (IEEE802.16a), future planetary missions and satellite link. Further it has better return losses when compared to traditional "Reconfigurable patch antenna with switchable slots for polarization diversity".**

***Index Terms*- Polarization, reconfigurable, slot, pin diode.**

I. INTRODUCTION

In high-performance aircraft, spacecraft, satellite, and missile applications, where size, weight, cost, performance, ease of installation, and aerodynamic profile are constraints, low-profile antennas may be required. At the same time the applications which require circular polarization are also increased day by day. This reconfigurable antenna can be used in every application which requires polarization diversity. In this antenna two L-shaped slots are incorporated as shown in fig.1.This shape is specifically chosen since it gave better results. Two Pin diodes are kept in these slots. By making these two diodes ON and OFF separately the reconfigurable antenna is made to radiate both right handed circular polarization and left handed circular polarization. As LHCP and RHCP are time separated there would be no coupling between these two polarizations. The validity of this concept is demonstrated by simulation results of essential parameters like return loss, radiation patterns both in LHCP and RHCP.

II. STURCTURE OF ANTENNA

The structure of this antenna is simple and compact. The outer dimension of this antenna is just 18X18 mm. The lower left corner of the antenna is assumed to be as origin (0, 0). The two slots are incorporated as shown in fig.1. All dimensions are in mm.

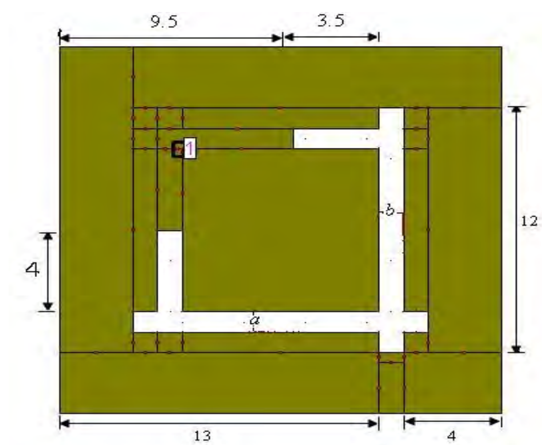

Fig 1: Antenna Structure

The Microstrip antenna is constructed on RT /duriod 5880 substrate. The parameters of the substrate are as follows

Name	: RT /duriod 5880
Dielectric Constant (ε_r)	: 2.22
Loss tangent (Tanδ)	: 0.0009
Thickness	: 3.175 mm
Permeability (μ_r)	: 1

Two L-shaped slots of width 1mm are incorporated in the antenna as shown in fig.1. The lengths of two slots within horizontal L-shaped slots are 12 mm and 4 mm respectively and widths in vertical L-shaped slot are 12 mm and 3.5 mm respectively. The width of these slots is exactly 1 mm. Here two PIN diodes (HPND 4005) 'a' and 'b' are placed in each slot as shown in figure at points (7.975, 4) and (13, 9.675). The diode 'a' is kept in such way that its positive terminal is faced to feed point (1). And the second diode 'b' is kept so that its negative terminal is faced towards the feed point (1) as in fig. This is to achieve ON and OFF states for both diodes for polarization diversity [5]. Very less voltage of 2 Volts is enough for these diodes to switch between ON and OFF states. It is also worthwhile to point out that MEMS switches can be utilized here for the same functionality with a lower insertion loss. But in IE3D simulation tool there is no facility to implement switches and diodes. So just ON diode is replaced by a short metal and OFF diode is assumed to be a open space.

The feed given here is coaxial feed with connecting radius equal to 0.5mm. The feed is given exactly at point (5, 13) which is marked as '(1)' in fig. 1. The antenna can be made to resonate at different points by changing the feed position on the diagonal axis. The feed point (1) comes exactly on the diagonal axis of the antenna.

III. ANTENNA OPERATIONAL MECHANISM

The Patch elements both rectangular and the circular, radiate primarily linear polarized waves if conventional feeds with no modifications are used. However, circular and elliptical polarizations can be obtained using various feed arrangements with slight modifications of the elements. Circular Polarization can be obtained if two orthogonal modes are excited with a 90^0 time-phase difference between them. This can be accomplished by adjusting the physical dimensions of the patch and using either single, double, or more feeds. One of the ways to excite ideally circular polarization is to feed the element at two adjacent edges to excite the two orthogonal modes; the TM^x_{010} with the feed at one edge and TM^x_{001} mode with the feed at the other edge. The quadrature phase difference is obtained by feeding the element with a 90^0 power divider or 90^0 hybrid. In this method it is necessary to connect two feeds and one extra circuit for 90^0 power divider.

But in "Reconfigurable Patch Antenna Using Switchable L-shaped Slots for circuit Polarization Diversity" there is no need of power divider and also multiple feeds. Polarization Diversity can be achieved with single feed itself. This is the main advantage of the present antenna. As the antenna is reconfigurable it has two slightly different structures. In one structure it radiates Left Handed Circular Polarization and in other form it radiates Right Handed Circular Polarization. Separate explanation is given for both RHCP and LHCP antennas clearly. Here polarization diversity is achieved by two pin diodes by making one diode ON and other OFF.
When input voltage is given, diodes have different dc voltages on their two sides. If a negative voltage (such as -2 V for a HPND) is supplied, diode 1 is turned ON and second diode 2 is turned OFF and it is reversed for +ve voltage input. By making diodes 'a' and 'b' ON and OFF respectively the antenna radiates right handed circular polarization and when 'a' is OFF and 'b' is ON the antenna radiates left handed circular polarization. For RHCP antenna, diode 'a' is replaced by a metal and diode 'b' is replaced by just an open space. For LHCP antenna diode 'b' is replaced by a metal and diode 'a' is replaced by just an open space. The length of this metal is 1mm and width is around 0.05mm. The RHCP and LHCP antennas are shown in fig. 2 and 3 respectively.

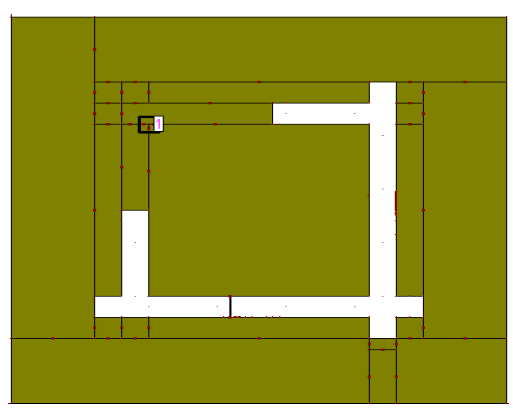

Fig 2: RHCP antenna

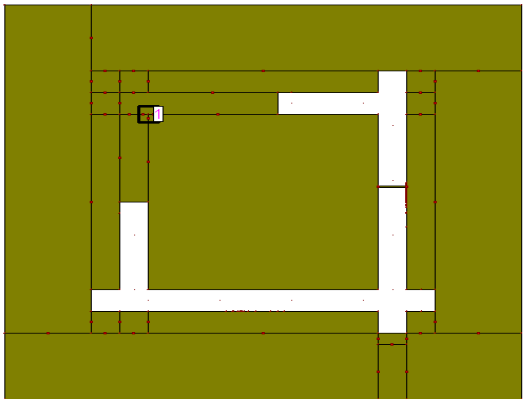

Fig 3: LHCP Antenna

The cavity model is used to explain the operations. For a normal square patch antenna, when the feed point is located on its diagonal line, both TM^x_{010} and TM^x_{001} mode waves are excited at the same frequency. After adding L-shaped slots, the resonant frequencies of both modes change. The basic working of antenna can be understood easily by the electromagnetic equations of TM^x_{010} and TM^x_{001} modes in patch. X-axis is assumed to be perpendicular to patch surface and corresponding electric and magnetic fields within the cavity are written as:

$$E_X = -j\frac{(k^2 - k_X^2)}{\omega\mu\in} A_{mnp} \text{ X}$$

$$\cos(k_X x')\cos(k_Y y')\cos(k_Z z') \qquad (1)$$

$$E_Y = -j\frac{k_X\ k_Y}{\omega\mu\in} A_{mnp} \text{ X}$$

$$\sin(k_X x')\sin(k_Y y')\ \cos(k_Z z') \qquad (2)$$

$$E_Z = -j\frac{k_X\ k_Z}{\omega\mu\in} A_{mnp} \text{ X}$$

$$\sin(k_X x')\cos(k_Y y')\sin(k_Z z') \qquad (3)$$

$$H_X = 0 \qquad (4)$$

$$H_Y = -j\frac{k_Z}{\mu} A_{mnp} \text{ X}$$

$$\cos(k_X x')\cos(k_Y y')\sin(k_Z z') \qquad (5)$$

$$H_Z = -j\frac{k_Y}{\mu} A_{mnp} \text{ X}$$

Examining these equations it is understood that x-component of magnetic field of both modes is zero (i.e. magnetic components in the direction (x-axis) of motion waves are zero) and hence these waves are called Transverse Magnetic Waves. In TM^x_{010} mode waves H_Z component is present and where as in TM^x_{001} mode H_Y component is present which is quite opposite to TM^x_{010} mode. Also based upon the equations from 1 to 6, the distribution of the tangential electric field along the side walls of the cavity for the TM^x_{010} and TM^x_{001} modes respectively is shown in fig. 4 and 5. In these figs. one can notice that in TM^x_{010} mode the field becomes zero along length L and in TM^x_{001} mode the field becomes zero in other side (i.e. along length W).

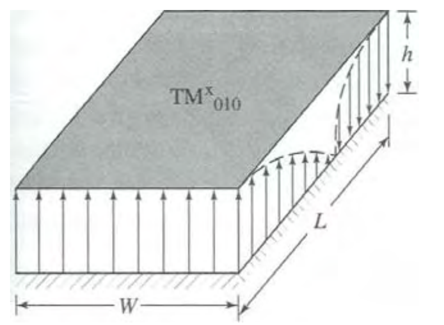

Fig 4: TM^x_{010} electric field

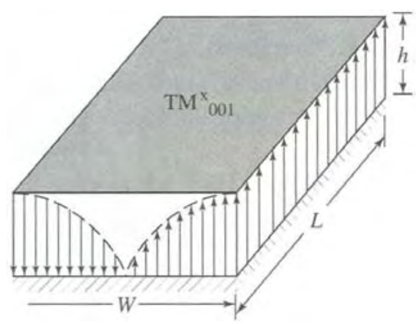

Fig 5: TM^x_{001} electric field

Examining all these facts it can be said that the diode ‘a’ in figure 1(also horizontal L-shaped slot) can only effect TM^x_{010} mode and diode ‘a’ (also vertical L-shaped slot) will only effect the TM^x_{001} mode. Therefore, the effect of the horizontal L-shaped slot on the TM^x_{010} mode and the effect of vertical L-shaped slot on TM^x_{001} are both highly trivial. In RHCP antenna diode 'a' is made ON and diode 'b' is made OFF. Due to TM^x_{010} mode electric current flow through the diode 'a' and at the same time TM^x_{001} mode current is not allowed to flow through diode 'b' as it is OFF. Further TM^x_{001} mode current is forced to travel around the vertical L-shaped slot. By this effect resonant frequency of TM^x_{001} mode greatly decreases. In LHCP antenna diode 'b' is made ON and diode 'a' is made OFF. Due to this TM^x_{001} mode electric current flow through the diode 'b' and at the same time TM^x_{010} mode current is not allowed to flow through diode 'a' as it is OFF. TM^x_{010} mode current is forced to travel around the horizontal L-shaped slot. By this effect resonant frequency of TM^x_{010} mode greatly decreases. Therefore due to the slots and diodes the resonant frequencies of the two modes become different. The frequency difference is controlled by the slot length, position and also switch position. If this frequency difference is properly designed, the radiation fields of the TM^x_{010} and TM^x_{001} mode have the same magnitude and are 90^0 out of phase at a midpoint frequency. As a result, a RHCP and LHCP patterns can be obtained depending open the ON and OFF states of two switches. The antenna is simulated using IE3D software and all the parameters are obtained. The simulation results of this antenna are also given .

IV. RESULTS

The above antenna is tested several times with IE3D software tool with the same dimensions as shown in fig.1. Excellent results are observed. Exactly same results are obtained in both RHCP and LHCP antenna. The gain and VSWR are 6.4 dB and 1.02 for both RHCP and LHCP antenna respectively.

More importantly return loss is just -40 dB in both RHCP and LHCP antenna. The return loss, frequency curve is shown in figs. 6 and 7 for RHCP and LHCP. The resonating frequencies for RHCP and LHCP antennas are 4.44 GHz and 4.49 GHz respectively. The bandwidth of both antennas is very wide. It is around 535 MHz for both antennas. Efficiency of both shapes is 75 %.

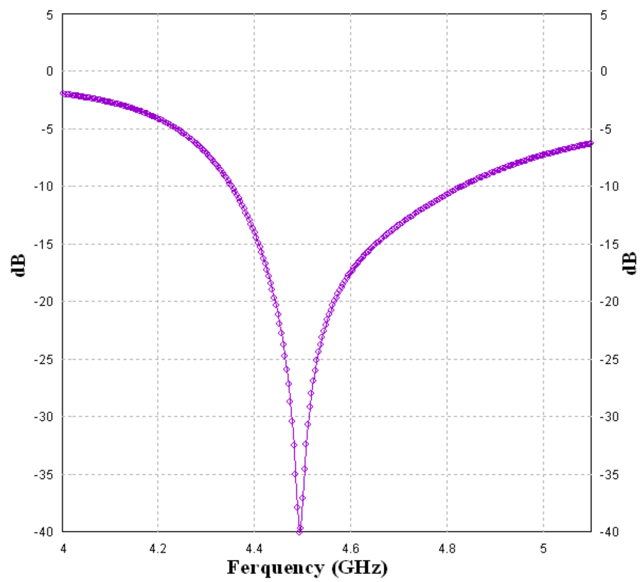

Fig 6: Return loss of RHCP antenna

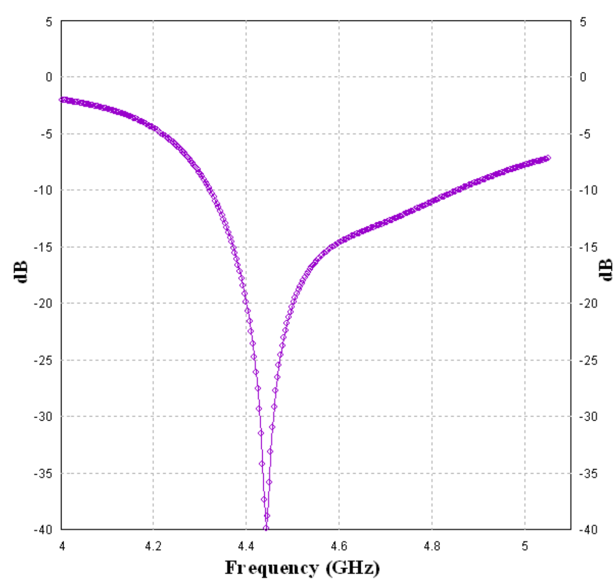

Fig. 7: Return loss of LHCP antenna

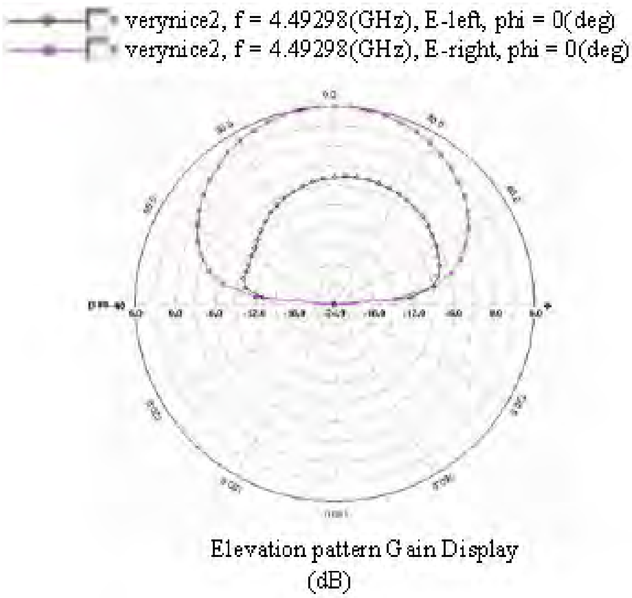

Fig8: E-right and E-left field patterns for RHCP

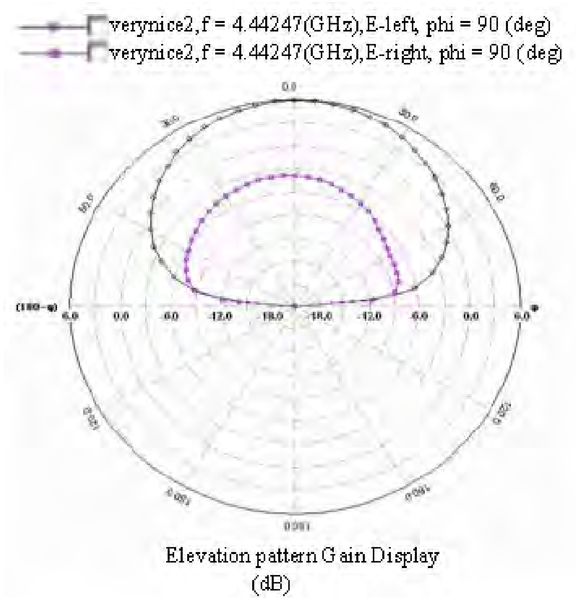

Fig.9: E-right and E-left field patterns for LHCP

The fig. 8 and 9 are radiation patterns of RHCP and LHCP antennas taken in polar co-ordinates for phi=0 (deg) and phi=90(deg). The figs. contain two curvatures. The red curve is E-right and black curve is E-left. These two figs. give very useful information about the antenna. It can be noticed that for RHCP antenna E-left (black curve) is inside the E-right (red curve) i.e. the gain for E-right curve is very large when compared to E-left curve. So this results in Right Handed Circular Polarization.

This condition is exactly reversed in the case of LHCP antenna. For LHCP antenna E-right (red) curve is inside the E-left (black) curve, which tells that the gain of E-left is greater than E-right and results in Left Handed Circular Polarization. There is a difference of around 9dBi gain between E-right and E-left components in both RHCP and LHCP. Fig. 10 and 11 show E-total curves in polar co-ordinates. Both E-total curves for RHCP and LHCP antennas are found exactly same.

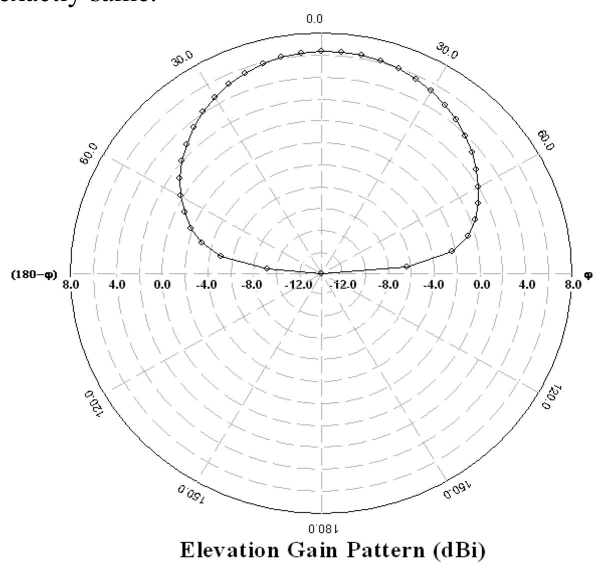

Fig 10: E-total for RHCP antenna

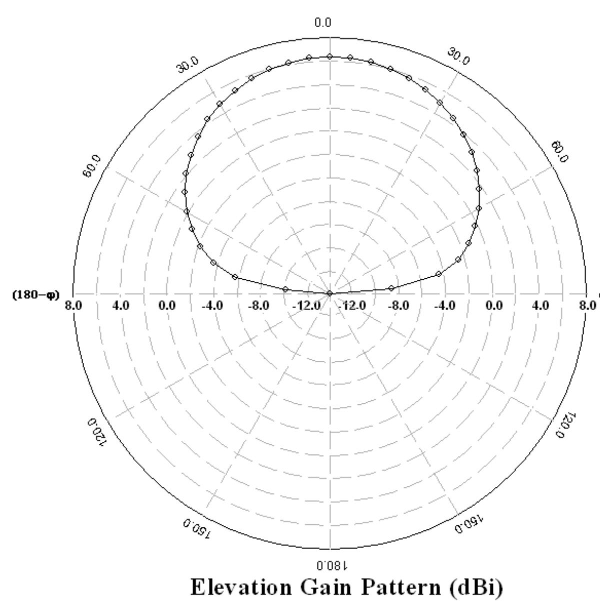

Fig 11: E-total for LHCP antenna

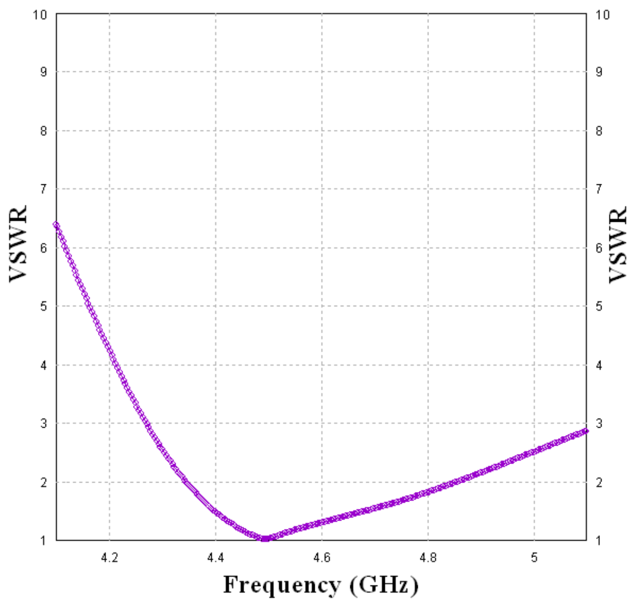

Fig 12: VSWR for RHCP

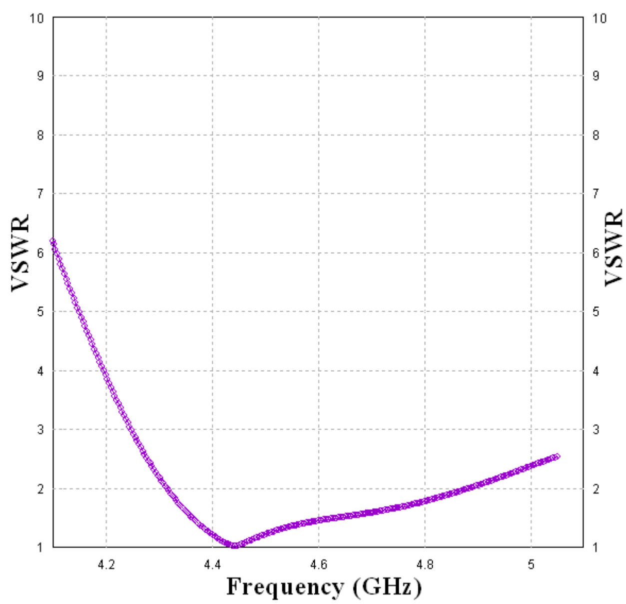

Fig 13: VSWR of LHCP

Fig. 12 and 13 shows VSWR for RHCP and LHCP. These graphs also exactly same and minimum VSWR is 1.02 for both RHCP and LHCP antennas. Even axial ratio's for both modes of the antenna also very nice nearly equal to 1.The antenna, having good return loss when compared to traditional antenna that is selected in IEEE paper which is titled as "Reconfigurable Antenna with Switchable Slots for Circular Polarization" Fig. 14 shows that the comparison of traditional patch and new antenna for RHCP and Fig. 15 shows that the comparison of traditional patch and new antenna for LHCP. So this antenna has more advantages when compared with conventional old antenna. The graphs are shown below. The actual antenna is having around -32 db return loss, but this new antenna is having -40 dB.

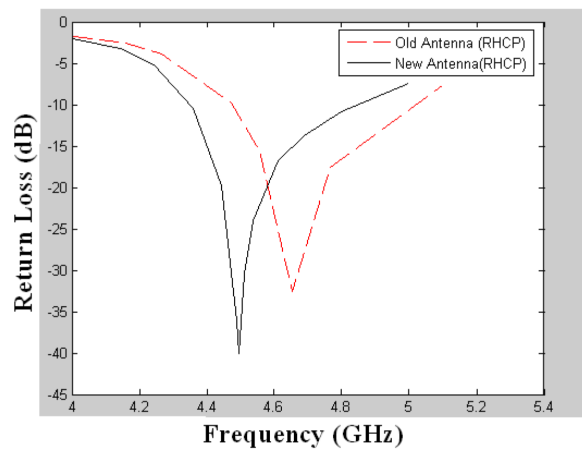

Fig 14: Return Loss comparison

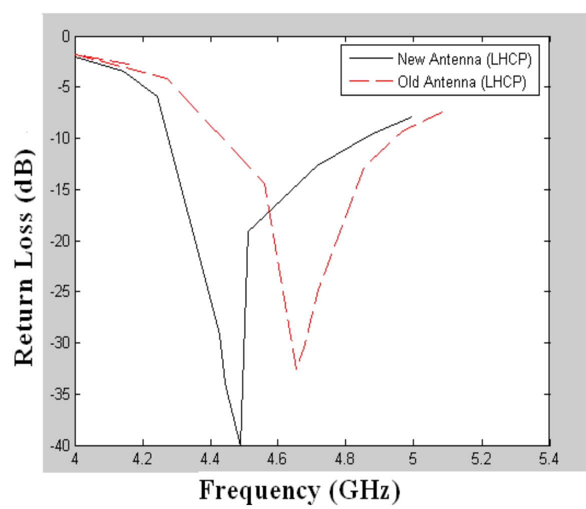

Fig15: Return Loss Comparison

V. CONCLUSION

A reconfigurable patch antenna for circular polarization using switchable L-shaped slots is presented in this paper. By making two diodes in slots ON and OFF antenna is media to radiate right handed circular polarization and left handed circular polarization radiated. With single feed polarization, diversity achieved in this antenna. This antenna can be used for Unlicensed and Licensed WiMAX (IEEE802.16), satellite communication, WLAN and space robots.

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