Design and Simulation of Reconfigurable Microstrip Patch Antenna with Frequency and Pattern Switching

Avinash Kumar Singh, Dheeraj Sharma, Vinita Agrawal
Department of Electronics and Communication Engineering
Swami Keshvanand Institute of Technology, Management & Gramothan, Jaipur
Email- er.avinash18@gmail.com[1], dheeru.sharma701@gmail.com[2], vinitaagrawalec@gmail.com[3]

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Abstract: **Wireless communication system are being used for a number of applications nowadays and for that, a number of antennas or a single antenna with multiple functional capabilities has become inevitable. This paper attempts to design a frequency as well as pattern reconfigurable with single rectangular spiral microstrip patch antenna using electrical reconfiguration method. Designed antenna has ability to switch its frequency band and accordingly its pattern is also switch in right side from the main beam direction near 50°, by using pin diode as a switch. Two cases are being taken into account. The first case; when switch is OFF, it gives results in an operation at 1.77 GHz with radiation pattern in elevation plane with θ = 0° and having gain is equal to 4.92 dB and the second case; when switch is ON, it offer operations at 2.47 GHz with radiation pattern in elevation plane with θ = 50° in right side from the main beam direction with gain 5 dB. This concept helps to reduce the antenna size, cost, and gives more flexibility for a equipment to be operated in different modes. It has advantages of ability to detect target signal, filter out interference signal, and power saving.**

Keywords: **Rectangular spiral microstrip patch, PIN diode switch, Frequency and Pattern reconfigurable.**

1. INTRODUCTION

Microstrip patch antennas play an increasingly significant role in the reconfigurable antenna field because of their considerable advantages, such as low profile, low cost, ease of fabrication, conformable to planar and non-planar surface, and easy to be integrated with other RF components [1]. It has various shapes like square rectangular, circular, triangular, annular ring etc., here we use rectangular spiral shape microstrip patch antenna. It has property of reduced size and easy to connect diode switches in between the arms. Spiral patch antenna operates in three modes. first one is travelling wave formed on spiral arms, allows for broadband performance second is leaky wave leaks the energy during propagation through spiral arms to produce radiation and third is fast wave, it is traveling wave on a leaky-wave antenna, with a phase velocity greater than the speed of light [2]. This type of wave radiates continuously along its length. Highly directive beams at an arbitrary specified angle can be achieved with this type of antenna, with a low side lobe level.

Reconfigurability, when used in the context of antenna, is the capacity to change an individual radiators fundamental operating characteristics through electrical, physical or by other means. Reconfigurable antennas have found their extensive applications at cellular radio systems, radar systems, satellite communication systems, smart weapon protection, etc. A large number of standards can be supported by reconfigurable antennas, in mobile and satellite communication. The most significant advantage of reconfigurable antennas is that, they can replace a number of single function oriented antennas.

Reconfigurable technique are of four types; frequency reconfigurable, pattern reconfigurable, polarization reconfigurable and multiple or compound reconfigurable. Here, we use multiple reconfigurable techniques. In this technique two or more parameter of the antenna can be reconfigurable like frequency and pattern, pattern and polarization, frequency and polarization or all these parameters are reconfigured together.

Most of the pattern reconfigurable antennas only have single operating frequency band. A pattern reconfigurable antenna that has multiband characteristic can improve the whole system performance. Frequency and pattern reconfigurable can be used in sensing spectrum. Sweeping from one mode to another, also can decide which direction each frequency is used. Matching stubs are used to match the antenna to different frequency and pattern, PIN diodes are used as switches to activate or deactivate the stubs creating a reconfigurable matching network. Frequency and pattern reconfigurable antennas are very useful because it can present variety of characteristics which lead to an improved signal to noise ratio (SNR) as well as higher quality of services (QOS) of the hole system [3-6]

2. ANTENNA STRUCTURE

The antenna is designed and simulated using Ansoft HFSS 11.0 software, an EM simulator based on the Finite Element Method (FEM). The geometry of right handed (anti-clockwise direction) microstrip spiral patch antenna is presented in Fig.1. The spiral is printed on a finite-size dielectric substrate backed by a finite-size conducting plane. Both the substrate and conducting planes are square with a side length L less than $0.6\lambda_o$ (λ_o: wavelength in free space) [7]. Spiral antenna radiates from a region called active region where the circumference of spiral equals wavelength [2].

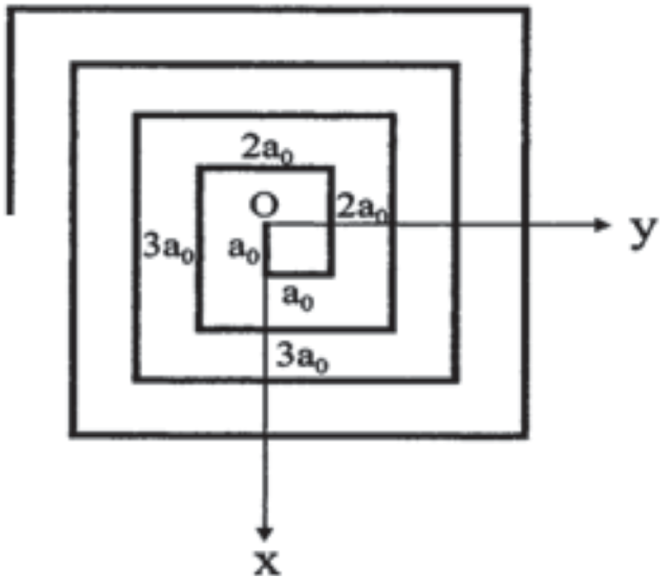

Fig. 1. Geometry of antenna

a_o is initial length of spiral structure.

o is origin of spiral patch.

The designed antenna which has to operate in two band of frequency with pattern reconfigurable ability incorporated into that patch for these two band of frequency by using PIN diode switch in outermost arm. To decide the switch position, a narrow study has to be made by placing at different positions and then its desired position is found and then optimization has to be made. Substrate used here is FR4 which has dielectric constant of 4.4 and coax feed is used to give excitation to the patch.

A. Antenna Dimensions

The parameters for Antenna Dimensions have to be taken from Reference paper [7] "Tilted- and Axial-Beam Formation by a Single-Arm Rectangular Spiral Antenna with Compact Dielectric Substrate and Conducting Plane".

Test frequency = 2.49 GHz

Thickness of substrate (h) $\approx$ 0.134 λ_o

Length/width of substrate and ground ˂ 0.6 λ_o

Width of patch w = 0.0134λ_o

Dielectric Constant ε = 4.4

First two arms length of patch a_o = 0.0503λ_o

Next two arms length of patch = 2a_o

And so on…..

Here, λ_o is free space wavelength = c/f

Where; c is speed of light = 3×10^8 m/s

f is test frequency = 2.49 GHz

Detail dimensions of designed antenna shown below in the table.

Table 1

	Length (mm)	Width (mm)
Patch	ao = 6.04	1.62
Substrate	70	70
Ground	70	70

Fig.2 shows the schematic diagram of the proposed antenna. A left handed (clock-wise direction) rectangular spiral microstrip patch antenna is designed. For this, first we make initial arm length from the center of the substrate, then move on next arm in clock-wise direction and so on, after that all the arms are unite together. The feeding network used here is a coaxial probe center feed, with connecting radius equal to 0.07mm. When excitation is giving through feeding network, current is move from center of patch to clock-wise direction and therefore fields are left hand circularly polarized. The dimension of this antenna is optimized to operate in the resonance frequency around 2.49 GHz with return loss less than 10 dB.

Spiral antennas have lowest and highest operating frequencies which can be calculated from the following relations [2] :

$$f_{high} = c/2\pi r_1 \quad (1)$$

$$f_{low} = c/2\pi r_2 \quad (2)$$

Where;

c corresponds to speed of light.

r_1 is inner radius, which is measured from center of the spiral to center of the first turn.

r_2 is outer radius, which is measured from center of the spiral to center of the outermost turn.

From above equation it is concluded that, if turn of spiral patch increases, the frequency characteristic of antenna is decreases. If turns of spiral patch decreases, the frequency characteristic of antenna is increases.

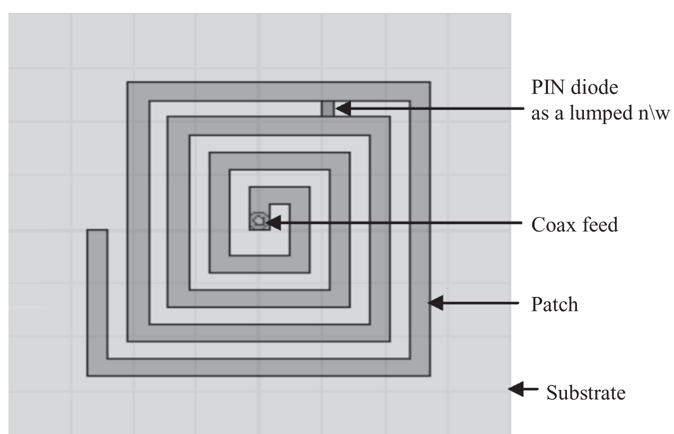

Fig.2. Designed Antenna by using HFSS (Top view)

A. Switching with PIN Diode

The frequency and pattern can be changed by coupling between turns of antenna through electronic, mechanical, or other means

[8-15]. Here, we choose switching by electrical PIN diode method due to its fast switching speed, pure resistance at RF frequency, high current handling capacity and excellent isolation. A Practical PIN diode switch is use here with size of 1.59 x 1 mm^2. In HFSS simulation, diode switch are modeled with a lumped element network. The PIN diode SMP1340 is forward-biased with 0.7 V and 10 mA. The PIN diode exhibits an ohmic resistance of 1.0 Ω and for the forward bias in which switch is in ON state, and an intrinsic capacitance of 0.35 pF for reverse bias in which switch is in OFF state. Fig. 3 shows the equivalent circuit for the PIN diode switch in the ON and OFF states.

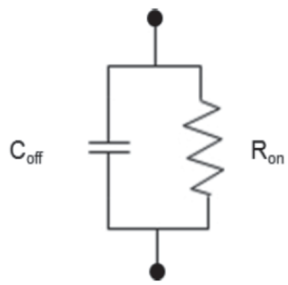

Fig. 3. Simplified PIN diode circuit

Fig. 4 shows the surface with its E & H field. When switch is in OFF state then its surface current and field are distributed over all the length of the patch and its radiation pattern is directed along the null point in YZ-plane. And when switch is in ON state then outer arm of patch is short circuited and then its electrical length of patch is cut by switch and all its surface current and field is transferred to inner arm of the patch and direction of radiation pattern shifted with some angle from the main beam direction along in YZ-plane.

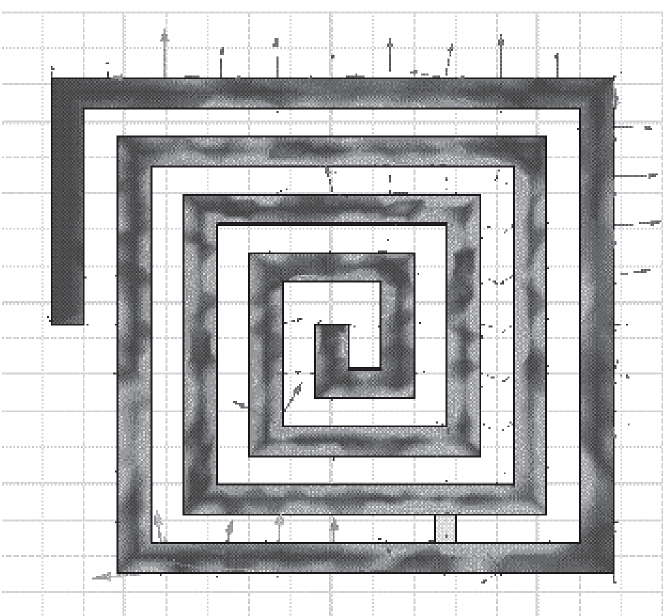

Fig. 4(a). Surface current when switch OFF

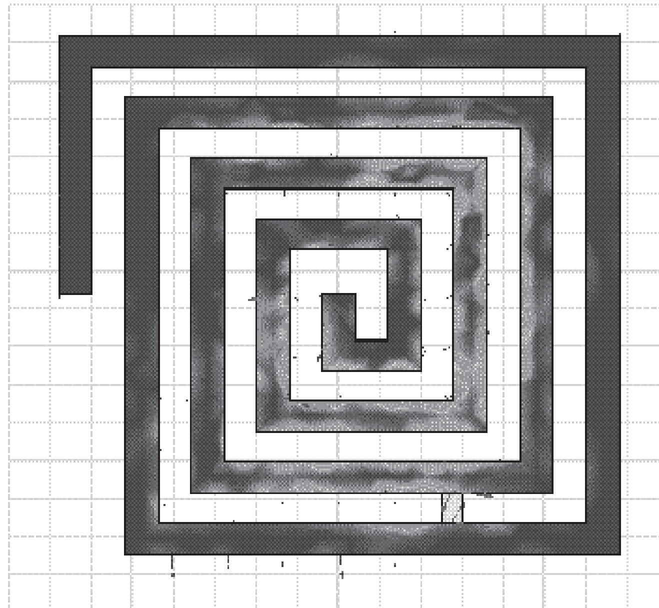

Fig. 4(b). Surface current when switch ON

Fig. 4. Surface current for both the state of switch

3. SIMULATED RESULT AND ANALYSIS

The work presented here introduces multiple reconfigurability with a single reconfigurable microstrip rectangular spiral patch antenna structure, capable to control the main beam direction using a PIN diode switch for two different frequency. The designed antenna alters the radiation pattern according to the state of switch On/Off, and accordingly resonant frequency also changes. The performance of proposed antenna in terms of return loss, vswr, smith chart, frequency Vs. gain plot, axial ratio, radiation pattern and 3-D polar plot for both the state of switch have been studied as follows.

A. Return Loss

Fig. shows the simulated result of return loss in terms of return loss (dB) vs. frequency (GHz) of designed antenna for both the state of switch. When switch is in OFF state then resonances frequency is 1.77 GHz with return loss -29.51 dB, and when switch is in ON state then resonance frequency is 2.47 GHz with return loss -25.88 dB.

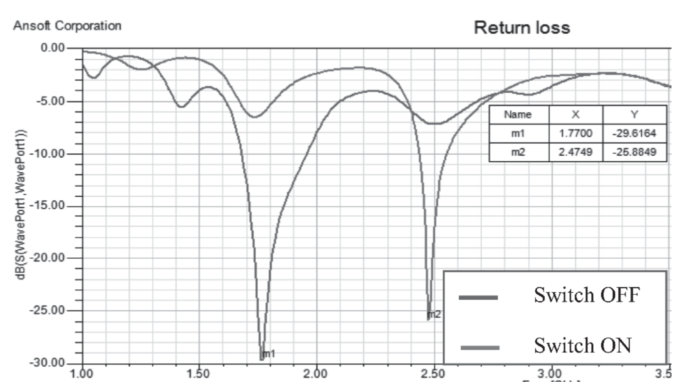

Fig. 5. Return loss Vs. Frequency plot

A. VSWR

Voltage standing wave ratio is defined in terms of reflection coefficient that is, it's a measure of mismatch between the characteristics impedance Z_0 and the actual impedance Z_L at the load. For efficient transmission and reception of signal VSWR should be less than 2. In this designed antenna, for 1.77 GHz VSWR is 1.06 and for 2.47 GHz VSWR is 1.1.

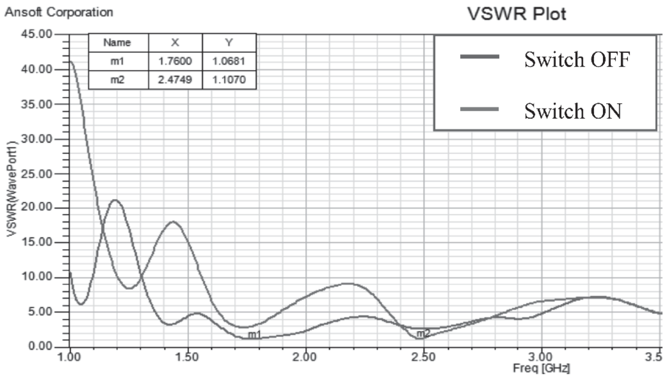

Fig. 6. VSWR vs. Frequency plot

A. Smith Chart

Smith chart is used to calculate reflection coefficient and VSWR for a known Z_L and Z_0, provided we have;

$Z_L/Z_0 = R + jX =$ Normalized load impedance

Therefore, VSWR and reflection coefficient are minimum if resistance and reactance value is minimum that is frequencies should be lies on center axis of smith chart.

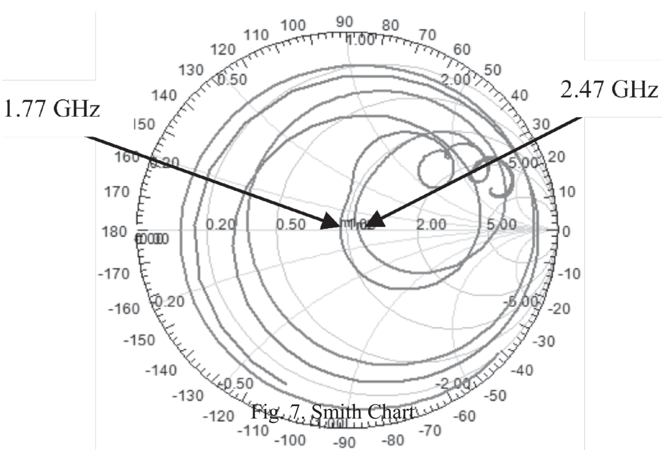

Fig. 7. Smith Chart

A. Gain Vs. Frequency

Gain Vs. frequency plot for designed antenna is shown below. Here gain for OFF state at 1.77 GHz is 4.71 dB and for ON state at 2.47 GHz is 5.22 dB.

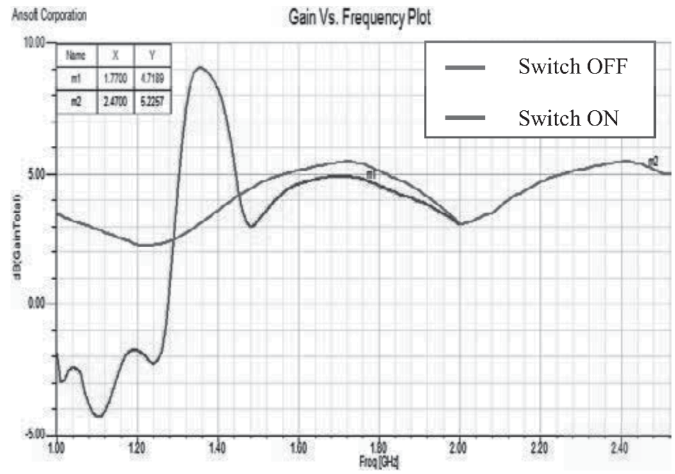

Fig. 8. Gain vs. Frequency plot

E Axial Ratio

Axial ratio indicates that the deviation from circular polarization is less than 3 dB over the specified angular range. Here, Axial ratio at 1.77 GHz is 3.01 dB and for 2.47 GHz is 2.93 dB.

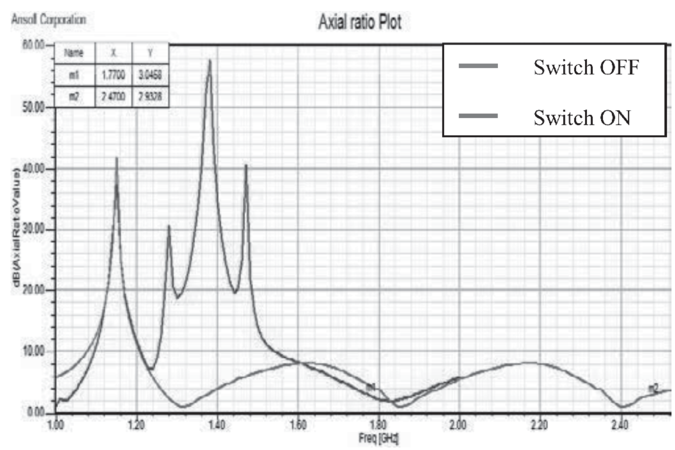

Fig. 9. Axial Ratio vs. Frequency plot

F. 2-D Radiation Pattern

Fig. show the simulated radiation patterns at resonance frequency 1.77 & 2.47 GHz in elevation plane for both the state of switch. When designed antenna operates in OFF state, the beam maximal direction in the elevation plane is 0°, with gain 4.92 dB. On other hand, when it operates in ON state, the beam maximal direction in elevation plane is near -50° that is right side from the main beam direction of 50°, with gain 5 dB.

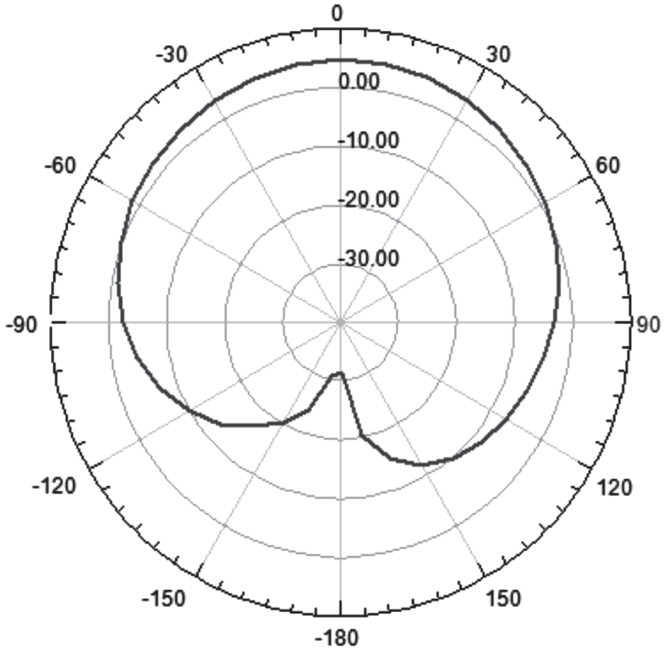

Fig. 10(a). Radiation pattern (LHCP) in elevation plane with maximal beam direction at 0° in OFF state

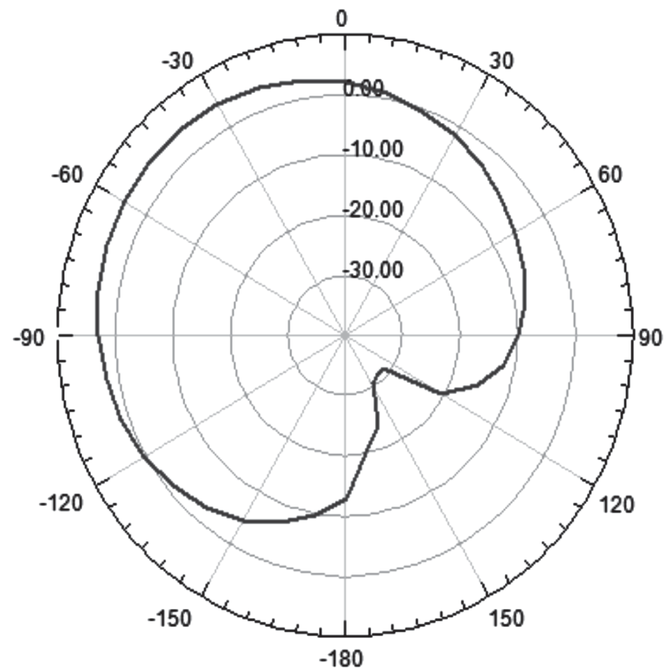

Fig. 10(b). Radiation pattern (LHCP) in elevation plane with maximal beam direction near at -50° in ON state

3-D Polar Plot

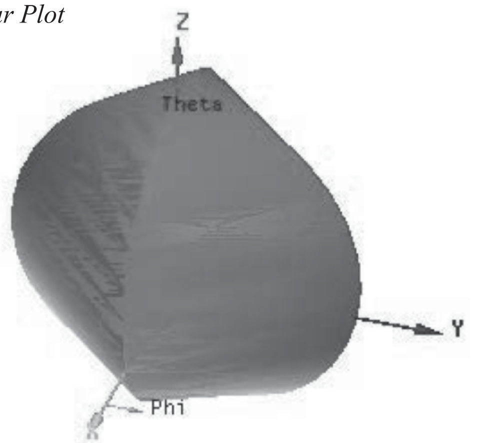

Fig. 11(a). 3-D polar plot (LHCP) in elevation plane with maximal beam direction at 0° in OFF state

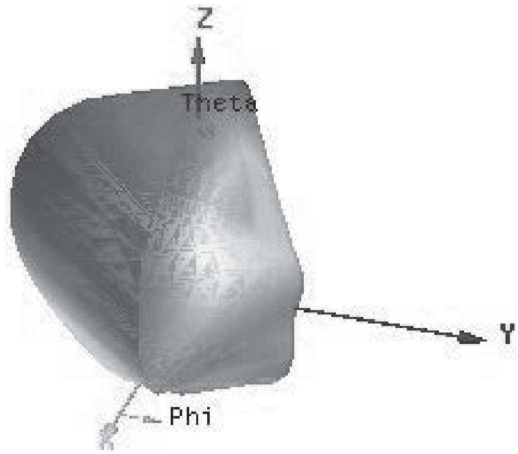

Fig. 11(b). 3-D polar plot (LHCP) in elevation plane with maximal beam direction at -50° in ON state

4. CONCLUSION

A design for frequency and pattern reconfigurable rectangular spiral microstrip patch antenna has been presented. The antenna can switch between two different frequencies and accordingly pattern also get switch by employing PIN diode as a switch. Frequency and pattern reconfigurable antennas are very useful because it replaces multiple antennas by a single antenna element and it has variety of characteristics which lead to an improved signal to noise ratio (SNR) as well as higher quality of services (QOS) of the whole systems. It can use in WLAN (wireless local area network) & IRNSS (Indian Regional Navigational Satellite System.

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