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# Wideband Reconfigurable Antenna for Industrial, Scientific and Medical Applications

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## ABSTRACT

The capability of reconfigurable antenna to cater different requirements for various applications with a single antenna has attracted researchers and scientists to explore the field. This paper proposes a wideband reconfigurable antenna design suitable for industrial, scientific and medical (ISM) applications. The design makes use of two PIN diodes to switch between four modes. The defected ground structure with the help of two 'Via' improves the antenna gain appreciably. The orthogonal feed helps in producing circular polarization. The suitability of the antenna for medical applications is being supported with the help of SAR analysis performed. The antenna has been simulated on commercially available Ansoft High Frequency Structure Simulator (HFSS) version 13.0.

**Keywords:** *Reconfigurable antenna, PIN diode, ISM applications, Circular Polarization, Linear Polarization, Wideband.*

## 1. INTRODUCTION

The wireless industry has a new trend to acknowledge more than one requirement with a single antenna that has promoted the popularity of reconfigurable antennas with each passing day [1]. Various reconfigurable antennas have been reported so far that have used different techniques to achieve diversity in antenna characteristics viz. frequency, polarization, pattern, bandwidth and a combination of two or more of these [2],[3]. The antenna current is altered in order to achieve the diversity by varying the radiating edges parameters, changing the material characteristics (e.g. permittivity, permeability etc.) or by modifying the antenna dimensions [4],[5]. A meta surface based frequency reconfigurable antenna has been proposed and analyzed in [6] that was suitable for WLAN and ISM applications. A pattern reconfigurable antenna has been presented in [7], that resulted in orthogonal radiation patterns with the help of a single PIN diode. Authors of [8] have proposed a simple polarization reconfigurable antenna that exhibits both LHCP and RHCP polarizations with the help of four PIN diodes. A frequency reconfigurable antenna has been investigated in [9]. The antenna resonates at seven different frequencies as per the switching conditions of three PIN diodes. Paper [10] suggests a frequency reconfigurable antenna with an arc shaped slot in the antenna ground. The antenna operates in six different modes and uses five PIN switches that change the arc length accordingly. A radiation pattern and polarization reconfigurable antenna has been presented in that [11] results RHCP and LHCP polarized antenna with three directions of radiation pattern between -20º to +20º. A polarization reconfigurable antenna has been reported in [12] exhibiting four linear polarizations along with LHCP and RHCP. The antenna employed twelve PIN diodes for the purpose of achieving polarization diversity. A wideband antenna with frequency and pattern diversities is presented in [13] which operates in six modes exhibiting frequency and pattern diversity. A frequency reconfigurable antenna has been proposed in [14] that operates in 2 single band and two dual band modes. A wideband reconfigurable antenna with beam switching is designed in [15] with a fractional bandwidth of 26.75%. A reconfigurable antenna with pattern diversity for 2.45 GHz has been designed in [16] for Internet of thing (IoT) devices and mobile stations. In addition to industrial and scientific applications reconfigurable antennas are gaining popularity in medical applications and wearable devices [17]–[31].

## 2. ANTENNA DESIGN

The geometry of the proposed reconfigurable antenna is depicted in figure 1. The antenna has been designed on a 3.2 mm thick FR4 substrate. The dimensions of the antenna have been listed in Table 1. The proposed design comprises of a circular ring with a defected ground structure. The ground is connected to the radiating patch with the help of two circular 'via' of 1 mm diameter each. 'Via' have been used in the design to enhance the antenna gain. The patch is being fed with two orthogonal microstrip feeds. A PIN diode has been placed in one feed (P1). A cross has been placed in the circular ring and a PIN diode (P2) has been placed at the centre of the cross. The orthogonal feed results in circular polarization.

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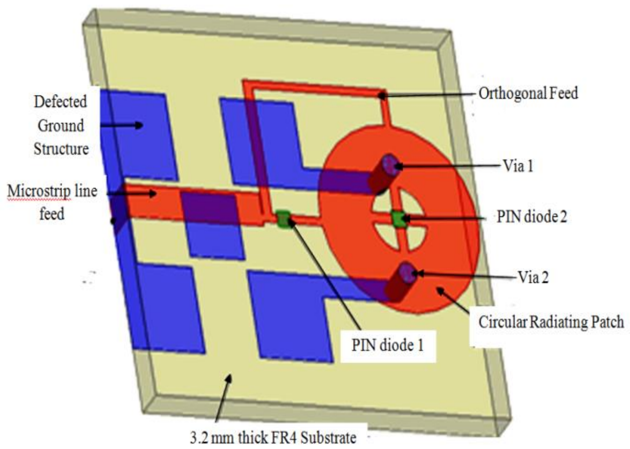


**Fig. 1 (a): Antenna Design**

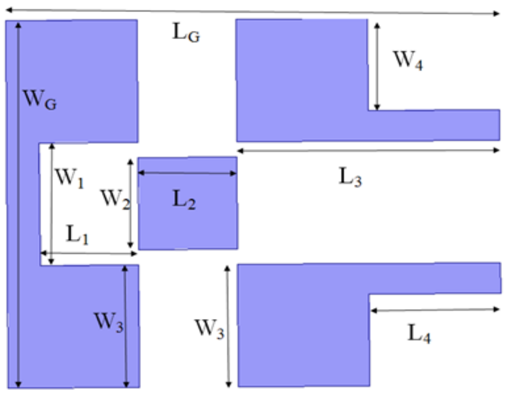


**Fig. 1 (b): Antenna Ground**

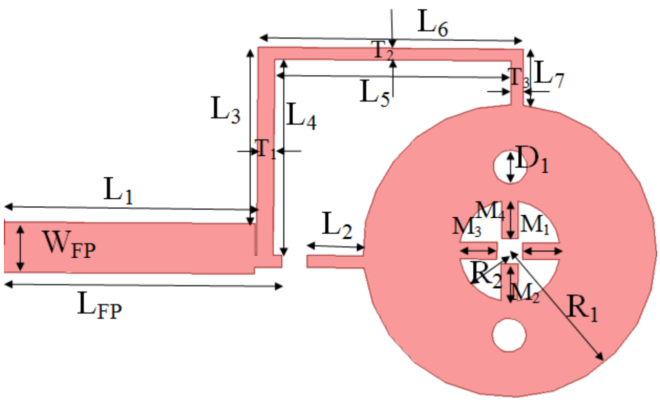


**Fig. 1 (c): Antenna Patch**

The switching conditions of the two diodes set the operating modes. The operational modes (states) of the antenna along with the two diodes switching condition and resonant frequencies have been enlisted in table 2.

**Table 1: Antenna Dimensional Details**

| Parameter | Dimension (mm) | Parameter | Dimension (mm) |
|---|---|---|---|
| $W_{FP}$ | 3 | $L_G$ | 30 |
| $L_{FP}$ | 16.5 | L1 | 6 |
| $L_1$ | 14.9 | L2 | 6 |
| $L_2$ | 3.9 | L3 | 16 |
| $L_3$ | 9 | L4 | 8 |
| $L_4$ | 13 | $W_G$ | 24 |
| $L_5$ | 13.28 | W1 | 8 |
| $L_6$ | 15 | W2 | 6 |
| $L_7$ | 3.5 | W3 | 8 |
| $T_1$ | 1 | W4 | 6 |
| $T_2$, $T_3$ | 0.72 | R1 | 8.7 |
| $D_1$ | 1 | R2 | 3 |
| $M_1$, $M_2$, $M_3$, $M_4$ | 2.25 | | |

**Table 2: Antenna Operational Modes**

| Mode / State | PIN Diode P1 | PIN Diode P2 | Operating frequencies (GHz) |
|---|---|---|---|
| 0 | OFF | OFF | 3.97, 5.95, 8.11 |
| 1 | OFF | ON | 3.88, 4.87, 5.905, 8.065 |
| 2 | ON | OFF | 3.835, 4.96, 6.085, 7.975 |
| 3 | ON | ON | 3.88, 4.96, 6.13, 8.02 |

For simulation the ON condition of the PIN diode is being represented by a series resistance $R_S$ (=3 Ohms) and the OFF condition is being simulated by a parallel combination of a resistance $R_P$ (=5 Kilo ohms) and a capacitance $C_P$ (=0.15 microfarads) [32].

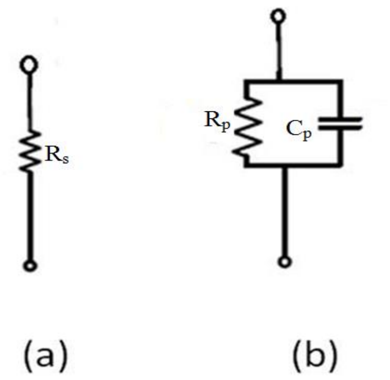


**Fig. 2: Equivalent Circuit of PIN Diode**

## 3. PIN Diode Switch

PIN diodes have been used in the proposed design for switching. For the purpose its biasing circuit has been designed as shown in fig. 3. The 0.1 µF capacitors have been used to block dc currents and to pass the ac signal. The diode is switched ON and OFF with the help of 3 volts voltage source and a switch. 1KΩ and 560 Ω resistors act as current

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limiting resistors. When the switch is OFF there is no biasing voltage for the PIN diode and thus it is OFF.

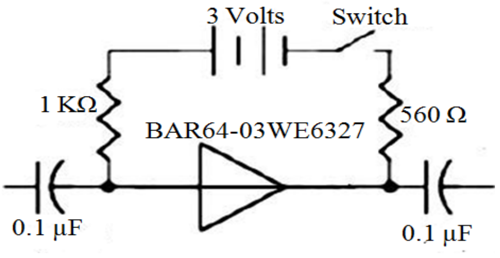


**Fig. 3: PIN diode Switch**

When the switch is ON the PIN diode is switched ON and provides a path to the ac current.

## 4. RESULTS AND DISCUSSION

The proposed design has been simulated on commercially available Ansoft HFSS version 13.0. The simulation results have been shown in figures 4-6. Figure 4 and shows reflection coefficient and peak gain of antenna with respect to frequency in modes 0, 1 and in modes 2, 3 respectively. The axial ratios of the antenna in all four modes have been plotted in figure 6 with respect to frequency.

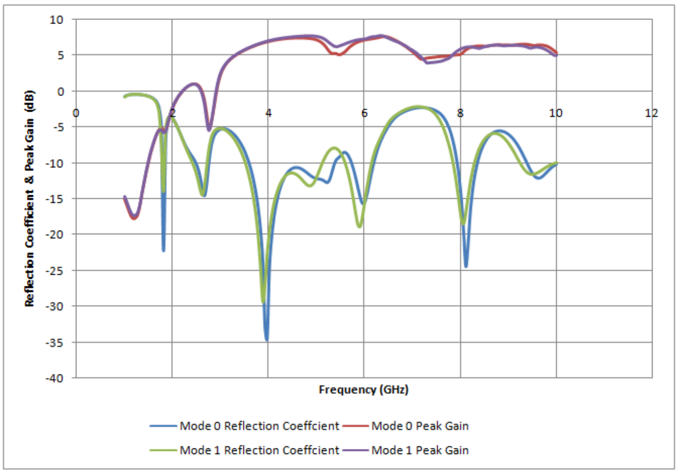


**Fig. 4: Reflection Coefficient and Peak Gain Vs Frequency for modes 0 &1**

The antenna resonates in four modes at thirteen different frequencies ranging from 3.835 GHz (in mode 2) to 8.11 (in mode 0) GHz. The reflection coefficient ranges from -13.1829 dB (in mode 1 at 4.87 GHz) to -34.5405 dB (in mode 0 at 3.97 GHz). Peak gain of the antenna varies from 5.70 dB (in mode 2 at 7.975 GHz) to 7.74 dB (in mode 1 at 4.87 GHz). The antenna exhibits a minimum value of axial ratio at 8.11 GHz in mode 0 (=0.89 dB) and a maximum value at 3.97 GHz in mode 0 (=37.09dB).

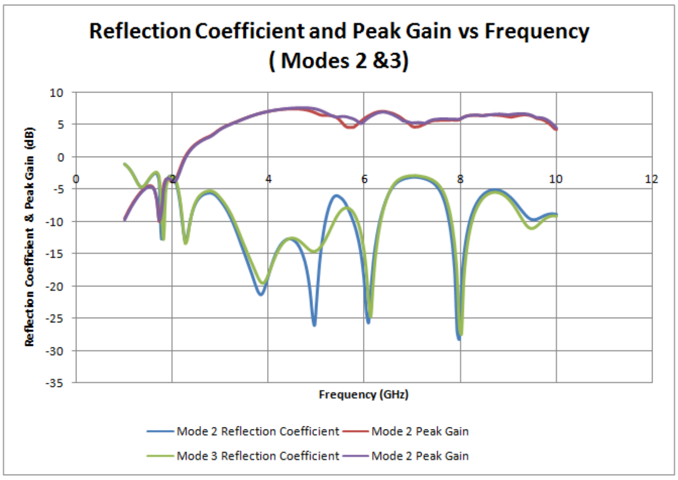


**Fig. 5: Reflection Coefficient and Peak Gain Vs Frequency for modes 2 &3**

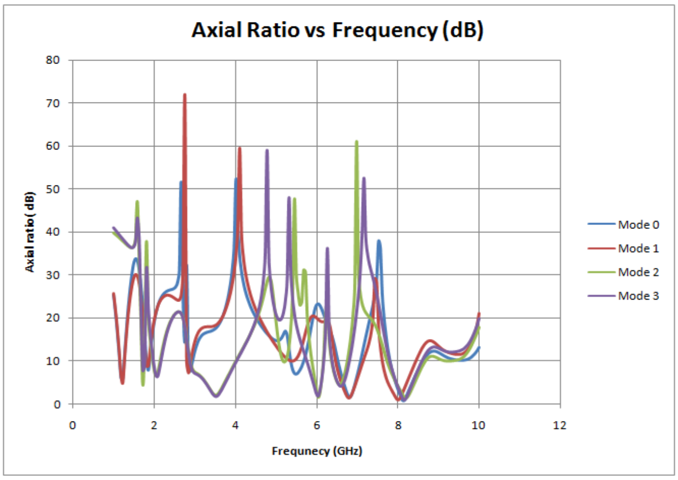


**Fig. 6: Axial Ratio Vs Frequency for modes 0, 1, 2 &3**

### A. FREQUENCY DIVERSITY

The proposed design offers reconfiguration in frequency as it resonates at a total 13 different frequencies in various modes as shown in tables 2 and 3. Table 3 tabulates the simulation results.

**Table 3: Simulation Results of proposed Antenna**

| MODE 0 | | | | |
|---|---|---|---|---|
| $F_R$ (GHz) | S11 (dB) | Peak Gain (dB) | Gain (dB) | Axial Ratio (dB) |

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| | | | | |
|---|---|---|---|---|
| 3.97 | -34.5405 | 6.974412 | 6.796731 | 37.0931 |
| 5.95 | -15.6055 | 7.148503 | 1.492562 | 21.8513 |
| 8.11 | -24.4384 | 5.840115 | -0.88721 | 0.885985 |

**MODE 1**

| FR (GHz) | S11 (dB) | Peak Gain (dB) | Gain (dB) | Axial Ratio (dB) |
|---|---|---|---|---|
| 3.88 | -29.2919 | 6.832909 | 6.706999 | 25.91033 |
| 4.87 | -13.1829 | 7.740082 | 7.304205 | 15.28767 |
| 5.905 | -18.8766 | 7.235036 | 1.404207 | 20.42425 |
| 8.065 | -18.4584 | 6.083076 | -0.62395 | 1.538951 |

**MODE 2**

| FR (GHz) | S11 (dB) | Peak Gain (dB) | Gain (dB) | Axial Ratio (dB) |
|---|---|---|---|---|
| 3.835 | -21.2828 | 6.711049 | 6.608453 | 6.778105 |
| 4.96 | -25.9495 | 6.794242 | 6.192723 | 22.52694 |
| 6.085 | -25.5519 | 6.311584 | -6.76419 | 2.78068 |
| 7.975 | -28.1069 | 5.698709 | 0.556719 | 4.543553 |

**MODE 3**

| FR (GHz) | S11 (dB) | Peak Gain (dB) | Gain (dB) | Axial Ratio (dB) |
|---|---|---|---|---|
| 3.88 | -19.5085 | 6.808445 | 6.701364 | 7.4262 |
| 4.96 | -14.5795 | 7.403899 | 6.986683 | 22.26223 |
| 6.13 | -24.6405 | 6.259391 | -5.44055 | 6.153542 |
| 8.02 | -27.3686 | 5.919155 | 0.097183 | 3.598314 |

## B. POLARIZATION RECONFIGURATION

The antenna design exhibits linear polarization at 3.97 GHz in mode 0. The axial ratio is 37.09 dB in this case. For linear polarization, the axial ratio, which is the ratio of minor to major axis of polarization ellipse, should be infinite, ideally. In practical values greater than 30 dB is considered. Linear polarization results when either of the below mentioned condition is satisfied:-

1. Either $E_x = 0$ or $E_y = 0$
2. Angle between $E_x$ and $E_y = 0°$ or 180°.

It is clear from table 4 that in mode 1 at 3.97 GHz the angle between $E_x$ and $E_y$ is 178.3464 (approx. 180°).

For Circular polarization axial ratio should be 1 (0dB) ideally. Practically axial ratio values less than 3 dB are considered as the cases of circular polarization.

**Table 4: E-field Details of Antenna**

| Mode | $F_r$ [GHz] | $E_X$ (V /m) | $E_Y$ (V /m) | Angle between $E_x$ and $E_y$ (°) |
|---|---|---|---|---|
| 0 | 3.97 | 13.38616 | 10.37651 | 178.3464 |
| 1 | 8.065 | 5.283167 | 4.828814 | 98.702 |
| 2 | 6.085 | 2.488446 | 2.532193 | 71.98975 |
| 3 | 8.02 | 5.186079 | 5.860878 | 67.944 |

Circular polarization results whenever $E_x = E_y$ and the angle between these two electric field components is not equal to 0° or 180°. From table it is clear that the above listed condition is being satisfied in modes 1, 2 and 3 at 8.065, 6.085 and 8.02 GHz respectively thereby offering left hand circular polarization in these cases. Figures 6-8 show the LHCP and RHCP gain in 1, 2 and 3 at 8.065, 6.085 and 8.02 GHz respectively.

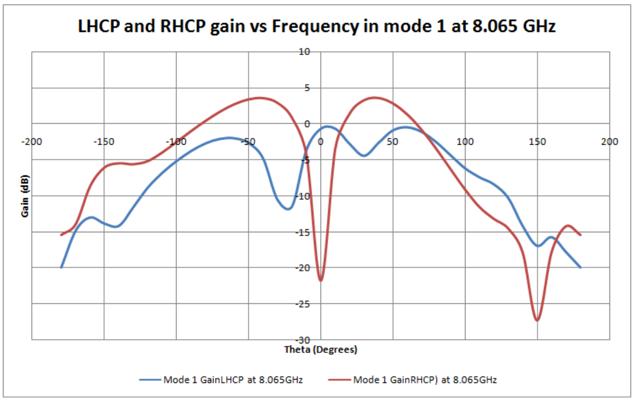


**Fig. 7: LHCP and RHCP Gain Vs Theta in mode 1 at 8.065 and phi = 0°**

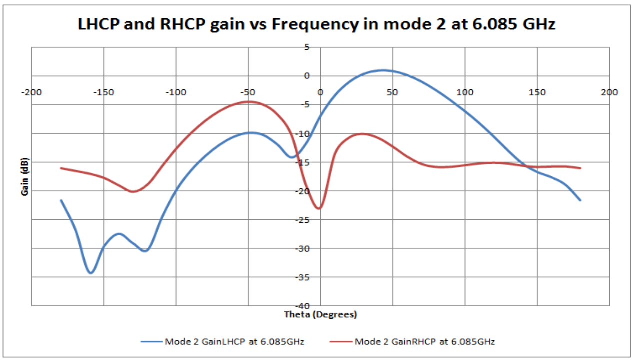


**Fig. 8: LHCP and RHCP Gain Vs Theta in mode 2 at 6.085 and phi = 0°**

It is clear from the figures that the LHCP gain in all the cases is at least 15 dB more than RHCP gain at theta = 0°, confirming left hand circular polarization in the mentioned cases.

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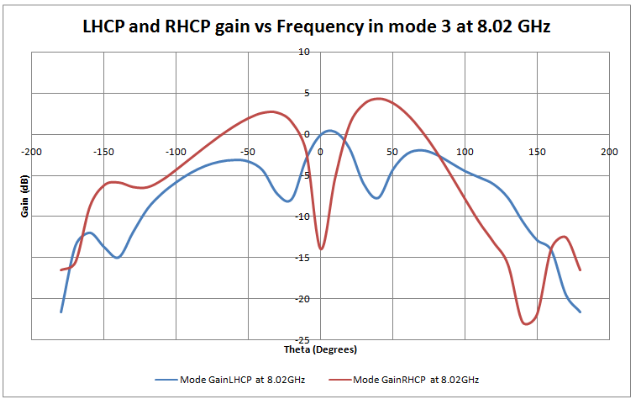


**Fig. 9: LHCP and RHCP Gain Vs Theta in mode 3 at 8.02 and phi = 0°**

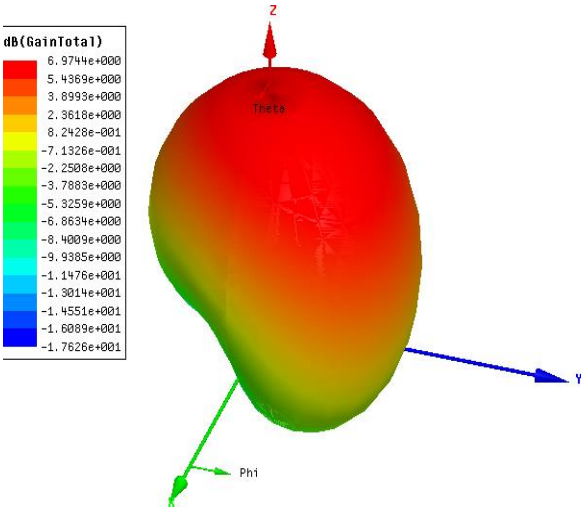


**Fig. 10: 3D polar plot in mode 0 at 3.94 GHz**

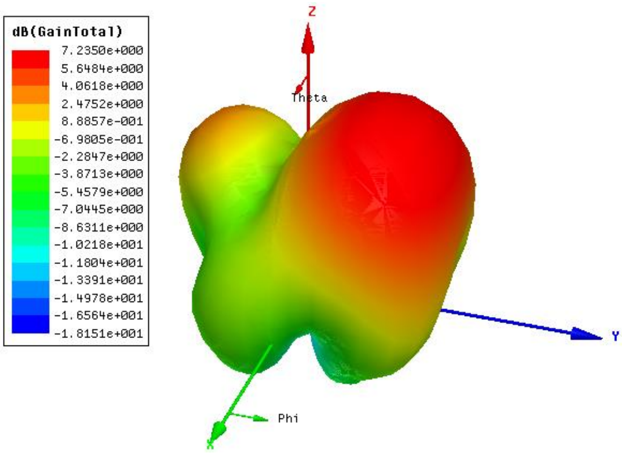


**Fig. 11: 3D polar plot in mode 1 at 5.905 GHz**

## C. PATTERN DIVERSITY

Proposed antenna offers diversity in radiation pattern which can be verified by the antenna gain 3D polar plots in figures 10-13.

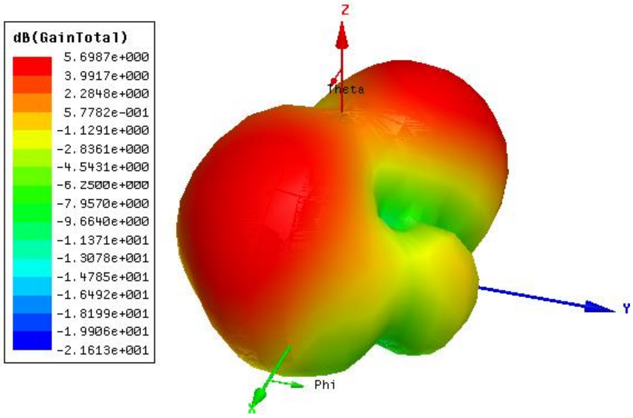


**Fig. 12: 3D polar plot in mode 2 at 7.975 GHz**

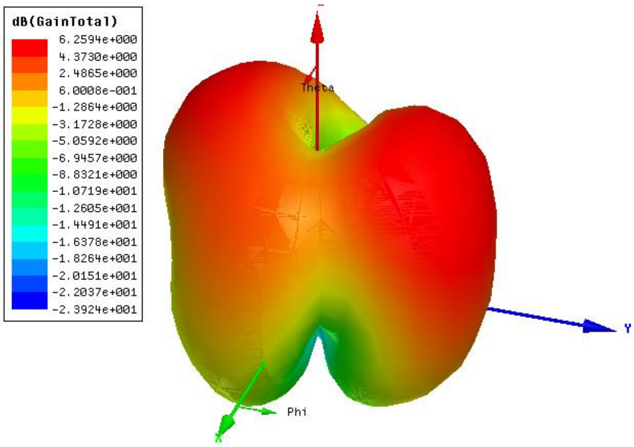


**Fig. 13: 3D polar plot in mode 3 at 6.13 GHz**

## D. WIDEBAND OPERATION

The proposed design exhibits wideband operation in all the four modes as shown table 5.

**Table 5: Fractional Bandwidth of Antenna**

| Mode | Operating Frequency (GHz) | -10 dB Fractional Bandwidth |
|---|---|---|
| 0 | 3.97 | 39% |
| 1 | 3.88 | 36.56% |
| | 4.87 | 36.56% |
| 2 | 3.835 | 47.2% |
| | 4.96 | 47.2% |
| 3 | 3.88 | 47.81% |
| | 4.96 | 47.81% |

# 5. CONCLUSION

The proposed design offers the advantages of reconfiguration capability in frequency, polarization as well as pattern in four modes with wideband characteristics and appreciably high gain. The antenna frequencies make it a good choice for industrial, scientific and medical (ISM) applications. The suitability of antenna for wearable devices has been supported with SAR analysis in mode 0 at 3.97 GHz on human arm six layer tissue models as shown in figure 14.

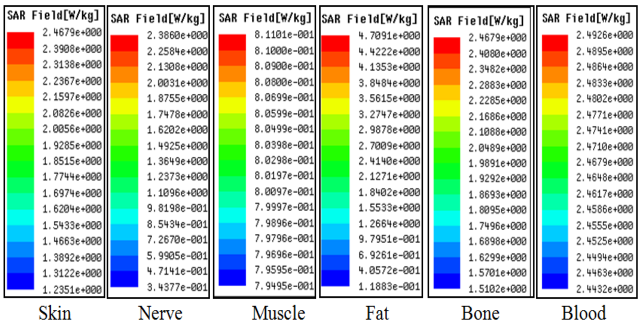


**Fig. 14: SAR analysis results of antenna in mode 0 at 3.97 GHz**

The proposed antenna has been compared with some reference antennas in table 6.

**Table 6: Comparison of proposed design with reference antennas**

| Ref. No. | $F_r$ (GHz) | Size (mm) | No. of Modes | Max. BW (%) | Max. Gain (dB) | Switching elements |
|---|---|---|---|---|---|---|
| 8 | 5.5-6.21 | 45X45 | 2 | 19.5 | 4.3 | 4 PIN diodes |
| 10 | 1.82-2.46 | 80X80 | 6 | 3.4 | 7.1 | 5 PIN diodes |
| 13 | 3.25-4.2 | 40X30 | 6 | 17.4 | 2.8 | 4 PIN diodes |
| 15 | 5.31-6.95 | 60X60 | 4 | 26.75 | 5.95 | 4 PIN diodes |
| 31 | 2.456-14.384 | 39X36 | 16 | 36.81 | 6.73 | 4 PIN diodes |
| This work | 3.835-8.11 | 30X24 | 4 | 47.81 | 7.30 | 2 PIN diodes |

### Conflict of interest

The authors declare that they have no known conflict of interest that may appear to influence the work reported in this paper.

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