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DESIGN AND SIMULATION OF FREQUENCY RECONFIGURABLE MICROSTRIP PATCH ANTENNA USING VARACTOR DIODES

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ABSTRACT

This paper presents asingle band pentagon shaped microstrip patch antenna that works at 7.5GHz with a return loss of -43.48dB. The antenna has been designed on 1.59 mm FR-4 substrate with dielectric constant of 4.4 and loss tangent of 0.02. The patch has been further reconfigured into a dual band and a triple band antenna by applying fractal shape and frequency reconfiguring the antenna geometry using varactor diodes. It finds applications for defence and secure communication in C band (4 GHz to 8 GHz) and X band (8 GHz to 12 GHz) applications where antenna can be used for satellite communication and RADAR applications. Proposed antenna has been designed using IE3D and results are analysed in terms of gain, return loss, directivity and bandwidth.

Keywords- Dual band antenna, Fractals, Frequency reconfiguration, microstrip patch antenna, triple band antenna.

I. INTRODUCTION

The demands on communication systems have increased dramatically in recent years. Modern communication systems often incorporate numerous radio transceivers each operating at a different frequency. It is no longer practical to provide a dedicated antenna element for each individual radio. Fortunately a frequency reconfigurable antenna, based on using a single radiating element is able to cover a variety of different frequencies and beam-width [1].Multiband antennas are of interest for wireless communication systems because they could substitute for multiple individual antennas, which would reduce the implementation size, cost, and complexity [2]. Reconfigurable antenna is an antenna which is capable of reconfiguring its characteristics such as frequency, radiation pattern, bandwidth and polarization to adapt the environment. In recent days the reconfigurable antennas are attaining great attention especially in future wireless communication systems due to its ability to reduce front end system and allow pre-filtering at the receiver. The reconfigurable antennas also contain many other features besides its reconfigurable capability, the features like low cost, multipurpose functions, and size miniaturization. Microstrip antenna has been used as a platform to design reconfigurable antenna[3]. Many switching techniques are used to get any operating state of frequency reconfigurable antenna for example; any desired single band resonant frequency and corresponding tuning band or multiband resonant frequencies. Patch antenna uses diode for switching purpose which controls the surface current path length for different mode of switches [4].

This paper presents a frequency reconfigurable patch antenna which is capable of being switched between dual-band or triple-band operation. The antenna incorporates three varactor diodes which are located within the slots produced from fractal geometry. The performance of the patch is analysed using IE3D EM simulation software in terms of gain, bandwidth and directivity.

II. DESIGN PROCEDURE

In this section, the pentagon shaped patch will be designed followed by the implementation of fractal geometry and hence frequency reconfiguring the patch for multiband performance.

2.1 Pentagon patch design

The patch is designed using FR-4 substrate with dielectric constant ($\varepsilon r = 4.4$), substrate thickness (h = 1.59mm), resonant frequency (fr = 7.5GHz) and loss tangent =0.02. Length of the pentagon patch has been computed [5] by using the equations (1)-(4):

$$F = \frac{8.791 * 10^9}{fr\sqrt{\varepsilon_r}} \quad (1)$$

The radius of the patch is computed as follows:

$$a = \frac{F}{\sqrt{1 + \frac{2h}{\pi \varepsilon_r F}\left[\ln\left[\frac{\pi F}{2h}\right] + 1.7726\right]}} \quad (2)$$

The effective radius of the patch is given by:

$$a_e = a\left(1 + \frac{2h}{\pi \varepsilon_r a}\left(\ln\left(\frac{\pi a}{2h}\right) + 1.7726\right)\right)^{0.5} \quad (3)$$

The length of the patch is then found by using the following relation:

Length of the pentagon patch = 1.175 *a_e (4)

The initial calculated length of the patch is found to be l=6.575mm with an effective radius of 5.596mm. The pentagon patch is simulated in IE3D using the initial estimates as shown in Fig.1.

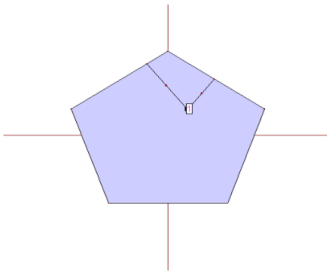

Fig. 1. Pentagon patch geometry

The patch is found to be resonating at 7.74GHz with a return loss of -44.66dB.The patch is then optimized by changing its length.For a patch length of 6.8mm the resonance is obtained at 7.5GHz with a return loss of -43.48dB as shown in Fig.2.

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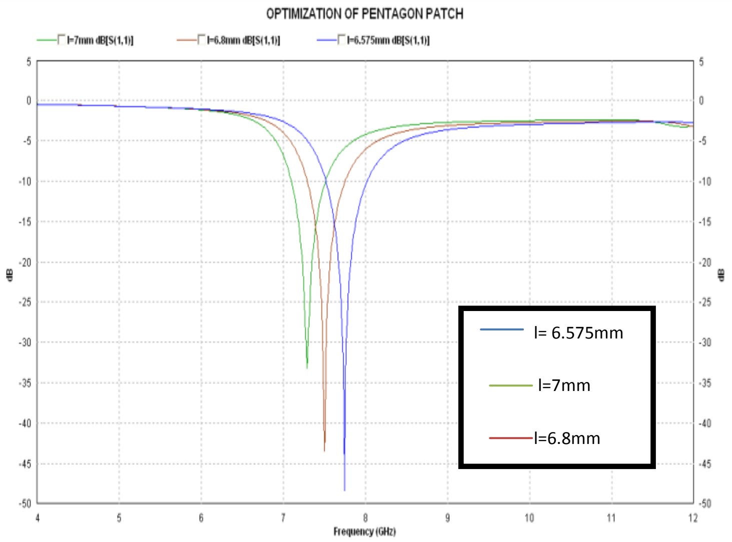

Fig.2.Optimization of pentagon patch

Hence a single band pentagon shaped microstrip patch antenna was designed and simulated to obtain resonance at 7.5GHz with return loss of -43.48dB having an impedance bandwidth of 6.12%.

2.2 Fractal geometry

For designing a multiband antenna, first, the fractal geometry has been implemented, and then, frequency reconfiguration has been carried out. By using basic geometry relations, the first iteration is derived as follows:

$$\frac{y}{a} = 2.618 \qquad (5)$$

Where y = length of the original pentagon patch

a = length of the inner pentagon patch

$$x = y - 2a \qquad (6)$$

Where x = base length of the isosceles triangle

$$z = \sqrt{a^2 -} \qquad (7)$$

Where z=height of the isosceles triangle

$x_1 = x/2$

This gives us x=1.606mm and z=2.469mm. The first iteration has been designed in IE3D as shown in Fig.3.

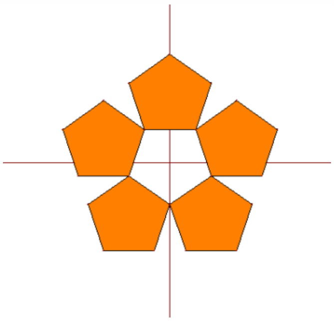

Fig.3. Fractal geometry

Now the reconfiguration of the patch is carried out by using a switching mechanism. 3 varactor diodes have been used appropriately in the fractal geometry to produce double band and triple band antenna.

2.3 Frequency Reconfiguration of the patch

Reconfiguration of the fractal pentagon patch antenna has been carried out by using 3 varactor diodes in various positions of the geometry.Here the Varactor diode is modelled as a MIM capacitor integrated into the slots. The positions of the diode are then varied thereby changing the electrical length hence obtaining better resonance.

2.3.1 Dual band antenna

In this section 2 varactor diodes will be used at appropriate locations in the proposed pentagon fractal patch to obtain dual band frequency response. The diodes will be placed at different locations in the slots to find the location at which the S11 parameters show the best performance.

2.3.1.1 Diodes D1 and D2

The diodes D1 and D2 are placed in the slots as shown in Fig 4 in the pentagon fractal geometry. Various locations for the diode were tried from which the one which showed the best performance is for diodelocation (-1.425,2) and(-2.3,-0.725) with probe feed at (-2.95,2.925).

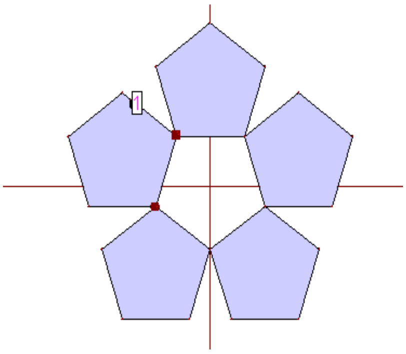

Fig.4. Diodes D1 and D2 embedded in the patch

2.3.1.2 Diodes D2 and D3

The diodes D2 and D3 are placed in the slots as shown in Fig 5 in the pentagon fractal geometry. Various locations for the diode were tried from which the one which showed the best performance is for diode location (-2.225, -0.725) and (0,-2.3) with probe feed at (-1.8,-1.4).

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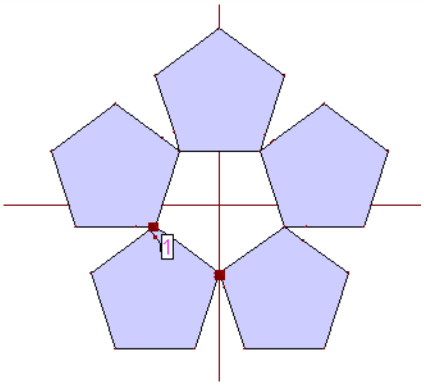

Fig.5. Diodes D2 and D3 embedded in the patch

2.3.1.3. Diodes D3 and D4

The diodes D3 and D4 are placed in the slots as shown in Fig 6 in the pentagon fractal geometry. Various locations for the diode were tried from which the one which showed the best performance is for diode location (0, -2.35) and (2.275, -0.725) with probe feed at (2.225, -1.325).

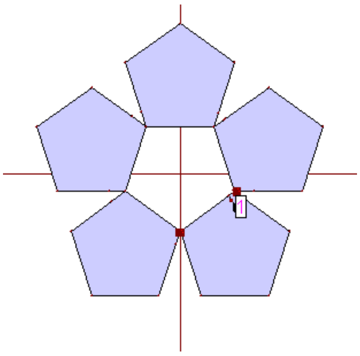

Fig.6. Diodes D3 and D4 embedded in the patch

2.3.1.4. Diodes D4 and D5

The diodes D4 and D5 are placed in the slots as shown in Fig 7 in the pentagon fractal geometry. Various locations for the diode were tried from which the one which showed the best performance is for diode location (1.425, 1.975) and (2.325, -0.75) with probe feed at (2.825, 2.725).

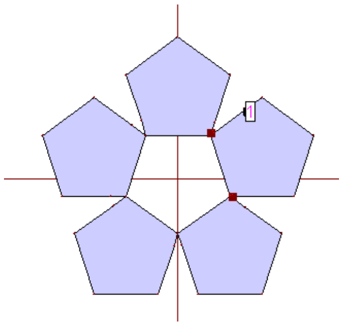

Fig.7. Diodes D4 and D5 embedded in the patch

2.3.1.5 Diodes D5 and D1

The diodes D5 and D1 are placed in the slots as shown in Fig 8 in the pentagon fractal geometry. Various locations for the diode were tried from which the one which showed the best performance is for diode location (1.75, 1.9) and (-1.375, 1.9) with probe feed at (0.9, 2.25).

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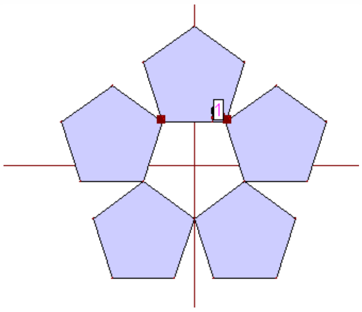

Fig.8. Diodes D5 and D1 embedded in the patch

2.3.2 Triple Band Antenna

In this section 3 varactor diodes will be used at appropriate locations in the proposed pentagon fractal patch to obtain triple band frequency response. The diodes will be placed at different locations in the slots to find the location at which the S11 parameters show the best performance.

2.3.2.1 Diodes D1, D2 and D3

The diodes D1, D2 and D3 are placed in the slots as shown in Fig 9 in the pentagon fractal geometry. Various locations for the diode were tried from which the one which showed the best performance is for diode location (-1.4,1.925), (-2.25, -0.75) and (0,-2.325) with probe feed at (-3.625,-1.875).

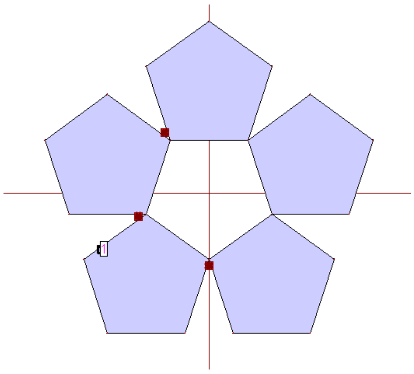

Fig.9. Diodes D1, D2 and D3 embedded in patch

2.3.2.2 Diodes D2, D3 and D4

The diodes D2, D3 and D4 are placed in the slots as shown in Fig 10 in the pentagon fractal geometry. Various locations for the diode were tried from which the one which showed the best performance is for diode location (-2.15,-0.7) , (0,-2.275) and (2.15, -0.7) with probe feed at (0.8, -2.225).

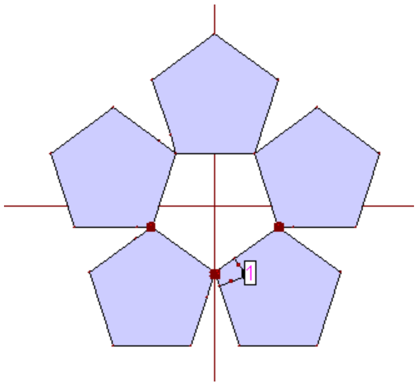

Fig.10. Diodes D2, D3 and D4 embedded in patch

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2.3.2.3 Diodes D3, D4 and D5

The diodes D3, D4 and D5 are placed in the slots as shown in Fig 11 in the pentagon fractal geometry. Various locations for the diode were tried from which the one which showed the best performance is for diode location (0, -2.45), (2.3, -0.75) and (1.425, 1.95) with probe feed at (1.925, -1.325).

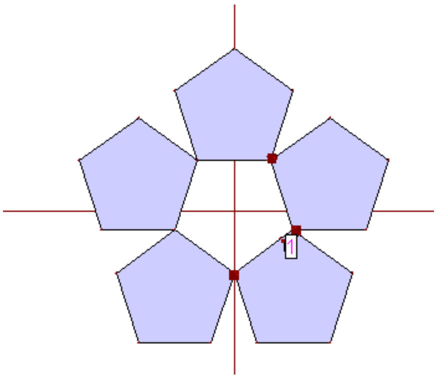

Fig.11. Diodes D3, D4 and D5 embedded in patch

2.3.2.4. Diodes D4, D5 and D1

The diodes D4, D5 and D1 are placed in the slots as shown in Fig 12 in the pentagon fractal geometry. Various locations for the diode were tried from which the one which showed the best performance is for diode location (-1.35, 1.875) , (1.375, 1.875) and (2.225, -0.725) with probe feed at (1.875, 1.525).

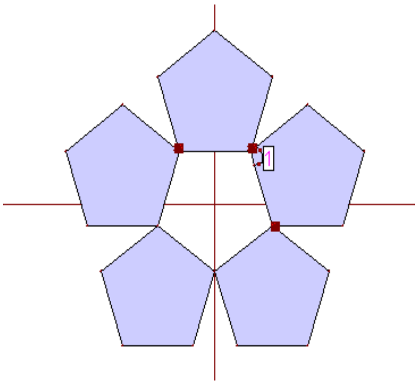

Fig.12. Diodes D4, D5 and D1 embedded in patch

2.3.2.5 Diodes D5, D1 and D2

The diodes D5, D1 and D2 are placed in the slots as shown in Fig 13 in the pentagon fractal geometry. Various locations for the diode were tried from which the one which showed the best performance is for diode location (1.45, 2.05) , (-1.45, 2) and (-2.325, -0.725) with probe feed at (-3.4, 3.275).

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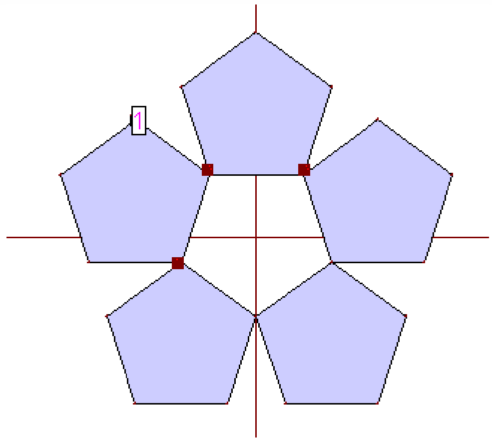

Fig.13. Diodes D5, D1 and D2 embedded in patch

III. RESULTS

This section shows the S11 curves for various iterations of diode locations for dual band antenna in Fig.14 and triple band antenna in Fig.15. The varactor diode modelled as MIM capacitor in ie3d was embedded in the designed fractal pentagon patch to attain reconfiguration. The different positions of the varactor diode for each case was simulated and analysed in terms of return loss. The case which showed the best performance i.e. minimum value of return loss (i.e. S11< =-10 dB) was considered to be the best and are listed below in Table I and II for single band ,dual band and triple band antenna.

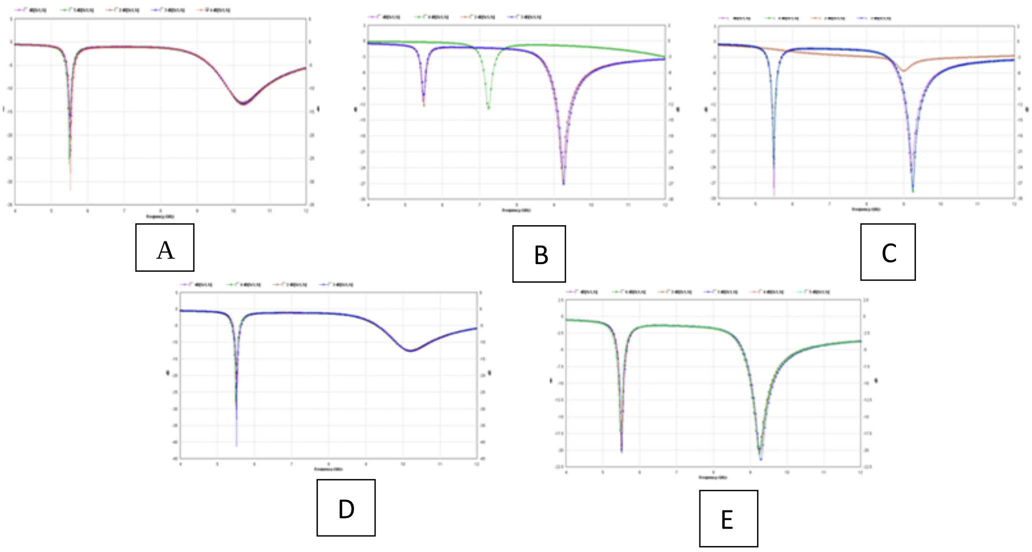

Fig.14: Simulated S11 curves for Dual band antenna (A) Diode D1 and D2 (B) Diode D2 and D3 (C) Diode D3 and D4 (D) Diode D4 and D5 (E) Diode D5 and D1

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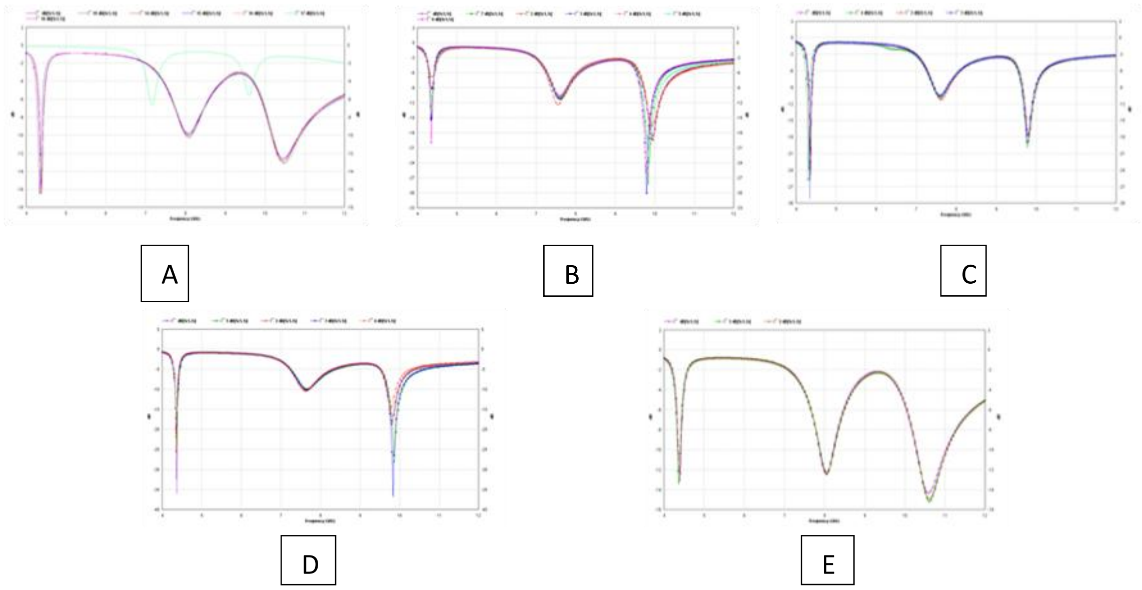

Fig.15: Simulated S11 curves for Tripe band antenna (A) Diode D1, D2 and D3 (B) Diode D2, D3 and D4 (C) Diode D3, D4 and D5 (D) Diode D4, D5 and D1 (E) Diode D5, D1 and D2

TABLE I: SUMMARY OF RESULTS FOR SINGLE BAND AND DUAL BAND ANTENNA

S_N0	Resonant Frequency (GHz)	Return Loss(dB)	Frequency Range (GHz)	Impedance Bandwidth
Patch	7.5	-43.48	7.295-7.75	6.12%
Diode D1 and D2	i) 5.53 ii)10.28	-30.257 -13.53	5.47-5.59 9.860-10.827	2.169% 9.406%
Diode D2 and D3	i)5.5 ii)9.24	-12.24 -27.08	5.47-5.54 9.016-9.565	1.272% 5.94%
Diode D3 and D4	i)5.516 ii)9.28	-20.168 -21.51	5.459-5.582 9.040-9.631	2.23% 6.368%
Diode D4 and D5	i)5.516 ii)10.20	-34.88 -12.65	5.459-5.582 9.811-10.737	2.23% 9.078%
Diode D5 and D1	i)5.5 ii)9.204	-29.48 -24.83	5.43-5.557 8.983-9.524	2.309% 5.877%

TABLE II: SUMMARY OF RESULTS FOR TRIPLE BAND ANTENNA

S_No	Resonant frequency (GHz)	Return loss(dB)	Frequency range(GHz)	Impedance Bandwidth
Diodes D1,D2 and D3	i)4.393 ii)8.082 iii)10.483	-16.176 -10.256 -13.127	4.352-4.426 8.016-8.164 10.1967-10.901	1.684% 1.83% 6.718%
Diodes D2,D3 and D4	i)4.36 ii)7.59 iii)9.79	-15.656 -11.044 -29.99	4.311-4.393 7.475-7.713 9.6475-9.9918	1.88% 3.135% 3.516%
Diodes D3,D4 and D5	i)4.35 ii)7.59 iii)9.786	-27.507 -10.456 -17.826	4.311-4.393 7.516-7.68 9.673-9.95	1.88% 2.16% 2.83%
Diodes D4,D5 and D1	i)4.36 ii)7.63 iii)9.811	-34.327 -10.36 -18.759	4.327-4.40 7.58-7.713 9.68-9.967	1.67% 1.74% 2.925%
Diodes D5,D1 and D2	i)4.368 ii)8.04 iii)10.606	-13.427 -12.28 -15.166	4.33-4.401 7.87-8.22 10.295-11.049	1.625% 4.35% 7.109%

IV. CONCLUSION

The single band pentagon shaped patch was designed for **7.5GHz** with an impedance bandwidth of 6.12%, gain of 3.498dBi, directivity of 6.827dBi and efficiency of 46.085%. The patch was then modified for multiband performance using fractal geometry and reconfigured to produce dual band and triple band antenna. For dual band antenna, **5.5GHz (5.5-5.516GHz**) band was obtained which can be used for Wi-Fi and cordless telephone applications. **(9.20-10.28GHz)** band was obtained which can be used for military requirement for land, airborne and naval radars. For triple band antenna, **(4.35-4.368GHz)** band was obtained which can be used for C band applications. **(7.59-8.04GHz)** band was obtained which can be used by military for satellite (uplink) and in earth exploration satellite (downlink).**(9.786-10.606GHz)** band was obtained which can be used for terrestrial broadband applications.

V. ACKNOWLEDGEMENT

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