Octagonal Fractal Antenna for 5 GHz Band: Modelling and Evaluations

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Abstract—*A microstrip octagonal patch antenna with large bandwidth is proposed for broadband application. The antenna is designed with patch on upper surface and ground on lower surface. By using octagonal patch antenna, large efficiency performance can be achieved. The large bandwidth can be obtain with control on the antenna size. Designing and study of proposed antenna for 0.1 – 5GHz is discussed. For large operational frequency experimental results provides the value of VSWR less than 2. Based on the results, the proposed antenna can be used for broadband wireless communication.*

Keywords—Patch antenna, Octagonal fractal antenna, Broadband, VSWR, Bandwidth, Return loss, Radiation pattern.
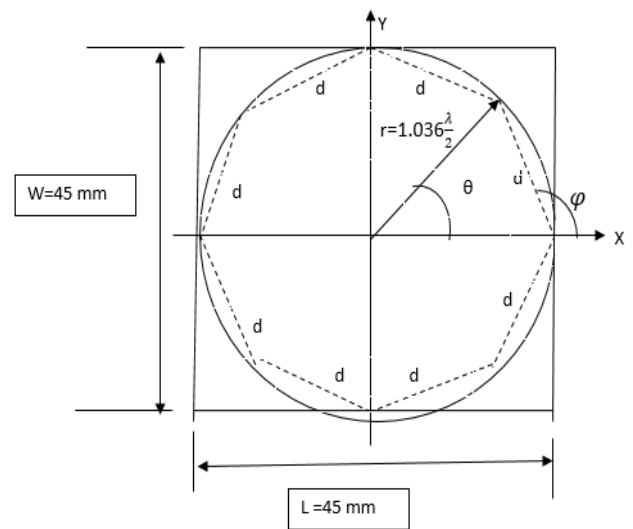
1. INTRODUCTION

Recently, mobile devices are developed rapidly for transferring data, voice, image and video due to user demands of high quality communication [1]. In order to meet the demands, wireless technology for communication must be upgraded. Large bandwidth operations are required for carrying high quality data. However, current available electromagnetic spectrum in microwave bands is limited and almost reserved for many applications. Study on electromagnetic spectrum usage in microwave bands was done where available spectrum is about 15-85% [2]. Therefore, effective electromagnetic spectrum usage are studied and developed.

In this paper, we propose a broadband antenna using an octagonal patch with a microstrip structure. The proposed antenna consist of an octagonal patch. The operational bandwidth can be adjusted by considering the size of octagonal patch [4-5]. Large operational bandwidth of almost 90% can be obtained by using the proposed antenna. Analysis and measurement results of the proposed antenna for broadband operation of 0.1-5 GHz are discussed and reported in detail.

2. DESIGN CONSIDERATIONS

The conventional octagonal arrays were obtained by arranging the elements in a surrounding way by concentric eight elements, in an equilateral triangle. The conventional octagonal arrays can also be observed as having single element at the centre of the circle. For the analysis of this array design with the help of recursive application, we assume a circular sub array of eight elements with element separation d = λ/2, as shown in figure 1 [6-8].

Fig 1: Geometry of Octagonal circular sub array generator

From the properties of octagonal we know that, the interior and the exterior angles are of 135^0 & 45^0 respectively [9]. So we conclude that

$$\cos\left(\frac{135^0}{2}\right) = \frac{\frac{d}{2}}{r} \rightarrow r = 1.306\left(d \; or \; \frac{\lambda}{2}\right) \quad (1)$$

The array factor in terms of mathematical equation can be written as

$$\hat{A}F_p(\theta,\varphi) =$$
$$\frac{1}{8^p}\prod_{p=1}^{p}\sum_{n=1}^{8} e^{j\delta^{p-1}[1.306\pi sin\theta \; \cos(\varphi-\varphi_n)+\alpha_n]} \quad (2)$$

Here $\varphi_{n} = (n-1)\frac{\pi}{2}$

$$\alpha_n = -1.306\pi sin\theta_0 \cos(\varphi_0 - \varphi_n)$$

In an array δ represents the scale factor. The scale factor δ controls the size of array with all recursive application. P represents the number of concentric octagons [10].

The total number of elements with P octagons can be represented as
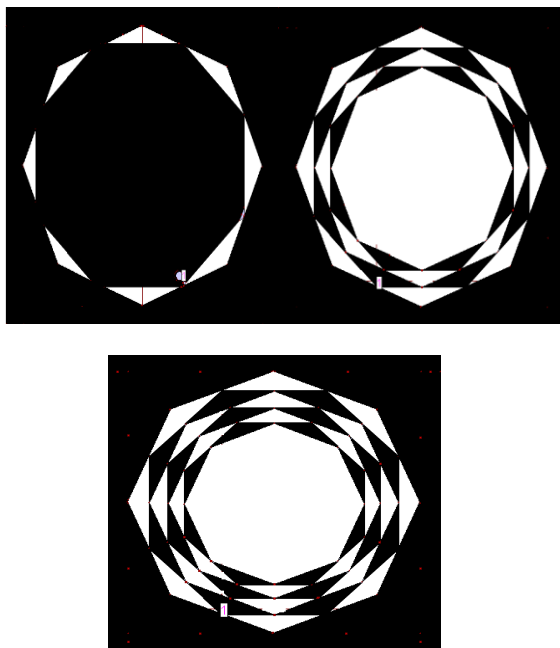
$$N_p = P(P+1) + 1 \qquad (3)$$

Fig 2: 1st, 2nd and 3rd iteration of proposed fractal antenna

The equation for calculating the array factor can be rewritten as [12]

$$\hat{A}F_p(\theta, \varphi) = \frac{1}{8^p} \prod_{p=1}^{p} \sum_{n=1}^{8} e^{j\delta^{p-1}} \psi_n(\theta, \varphi) \qquad (4)$$

Where

$$\psi_n(\theta, \varphi) = 1.306\pi[\sin\theta \cos(\varphi - \varphi_n) - \sin\theta_0 \cos(\varphi_0 - \varphi_n)] \qquad (5)$$

Let us assume $\delta = 1$, then the equation can be written as

$$\hat{A}F_p(\theta, \varphi) = \left[\frac{1}{8}\sum_{n=1}^{8} e^{j\psi_n(\theta,\varphi)}\right]^p \qquad (6)$$

To obtain the geometry of proposed Octagonal fractal shape, firstly we construct an octagon which is named as the base shape as shown in figure 1. For obtaining the first iteration of octagon we add one octagon inside the base octagon, as shown in figure 2 (1st Iteration) .The same process is repeated again to generate the second iterated shape as is also shown in figure 2 (2nd iteration) and similarly for third iteration.
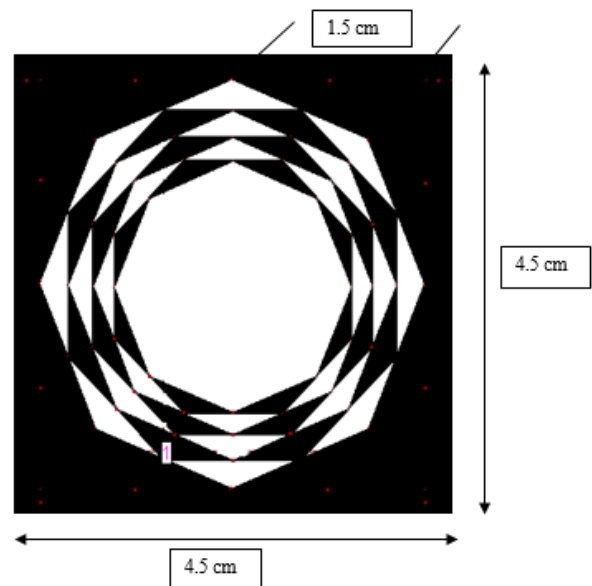
3. DESIGN DIMENSIONS FOR PROPOSED FRACTAL ANTENNAS

Fig 3: Basic design for 3rd iteration of slotted octagonal fractal antenna

To design the third iteration of Slotted Octagonal fractal antenna we take 1.5 cm side length. The ground patch is taken of 20.25 cm² (4.5 x 4.5 cm²) and outer dimension also taken of 20.25 cm² (4.5 x 4.5 cm²) on a piece of Glass Epoxy material with a dielectric constant of 0.5. The slab height of this piece is 1.6 mm.

To access the reliability and effectiveness of the design, the results validation of proposed Octagonal fractal antenna design must be verified by both software as well as hardware. This will show the performance overview of the design. The software simulation is done with the help of Zeland (IE3D). This will provide output in terms of 3D graphs. The hardware design of the same antenna is analyzed with Vector Network analyzer. So the analysis provides both type of results.

4. SIMULATION

Figure below represents the planner view at front end. IE3D software (Polygon Editor) is used to design the geometry of proposed octagonal antenna with calculated dimensions. From figure 4 it can be observed that, a probe feed is applied at the corner of the proposed design. Figure 5 shows the 3D design for slotted octagonal fractal antenna using IE3D software. Figure 6 represents the current distribution pattern for better understanding of the designed antenna.
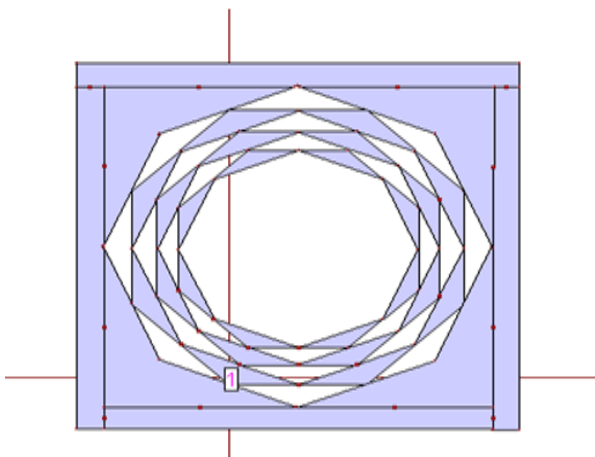
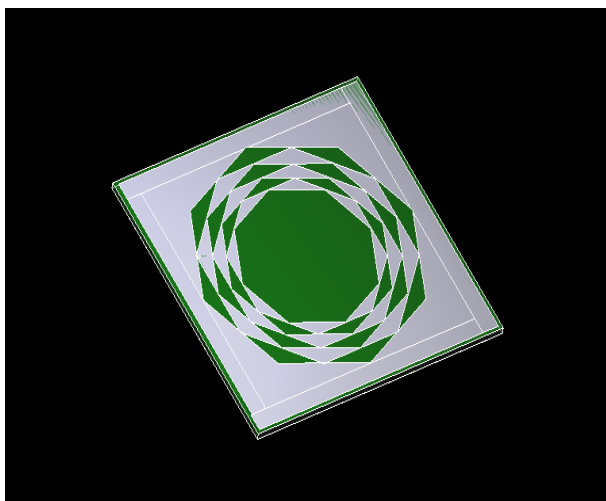**Fig 4:** 3rd iteration for Slotted Octagonal fractal antenna

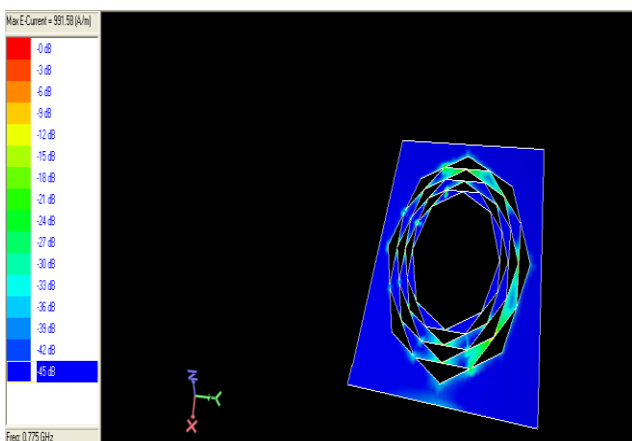**Fig 5:** 3 D geometry of 3rd iteration for slotted Octagonal fractal antenna

Fig 6: Current Distribution of 3rd iteration for Slotted Octagonal fractal antenna

4.1 Return loss [13]

The response of the return loss is represented in Figure 7. It can be noticed that the designed octagonal fractal antenna shows a return loss of 13.68dB, 14.82 dB and 25.378 dB at resonant frequencies of 1.67GHz, 3.85GHz and 5.347 GHz.
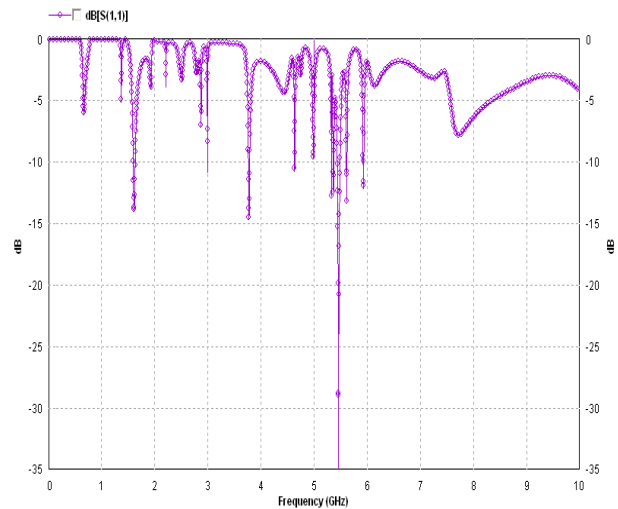

Fig 7: Return Loss characteristics for 3rd iteration of designed antenna

4.2 VSWR[13]:

VSWR is a quantity that imply how well the impedance of antenna has matched, which describes the power reflected from the antenna. It is seen in (Fig 8) that VSWR for the two operational frequencies is a real and positive number and nearly to 1, where VSWR = 1 implies a matched load.
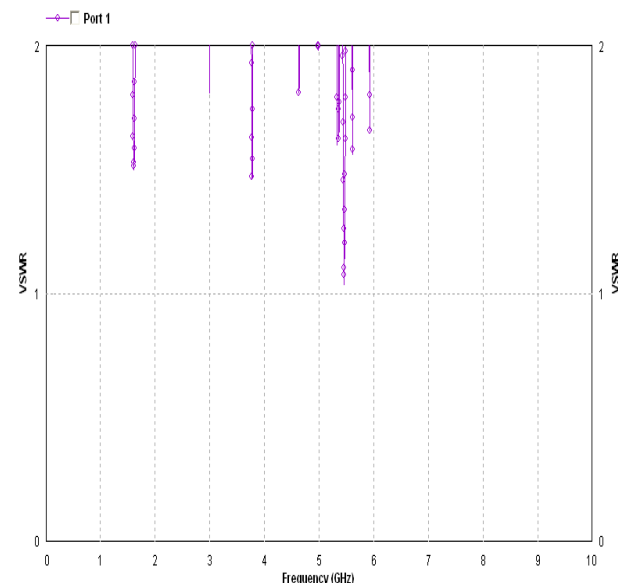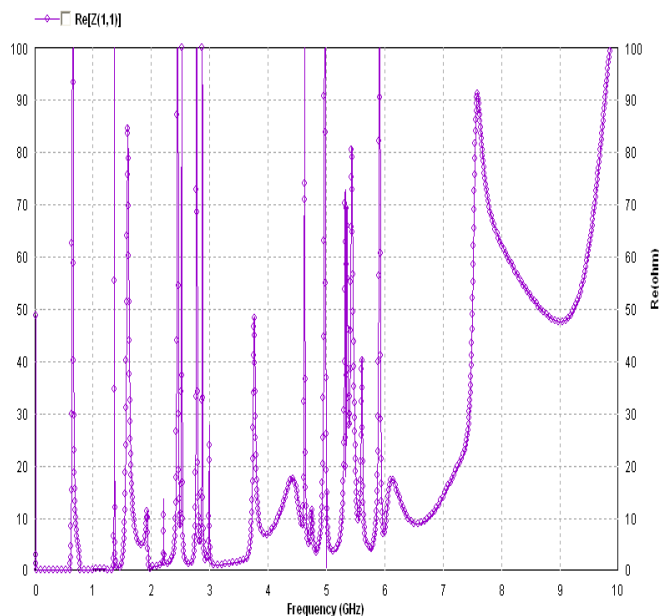

Fig 8: VSWR curve for 3rd iteration of designed antenna

We simulate the designed geometry using IE3D and obtain the various antenna parameters as user graphics format of
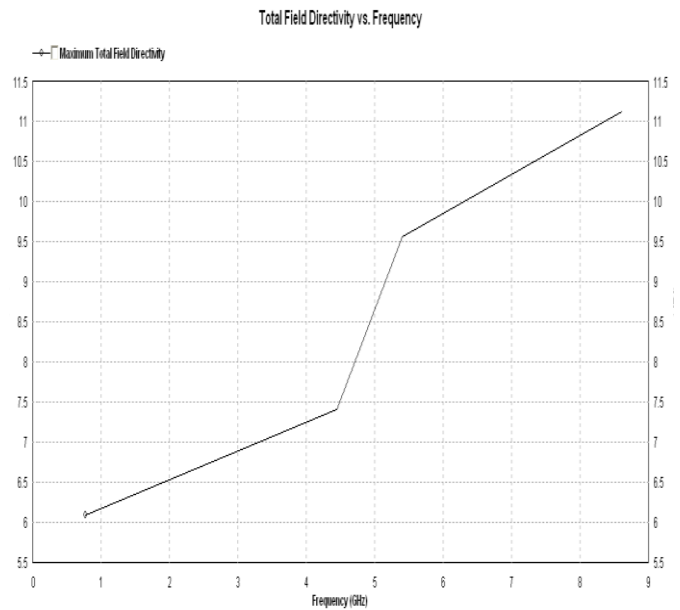
IE3D is accessible for analysis. The figure 7 represents the simulation characteristics for Return Loss (in dB) and as far as frequency to be resonant frequency. It must obtain a value such that S11 ≤ -10 dB. If it attains such a value then our designed antenna geometry will exhibit multiple frequency sample point. Similarly we can analyze by VSWR curve as shown in figure 8 (VSWR ≤ 2).

4.3 Input Impudence[13]:

The input impedance of this antenna design is found extremely sensitive to the width of the microstrip feed line (Figure 9) and thus the matching requirements at these frequencies are also fulfilled as indicated by the simulated results of return loss .
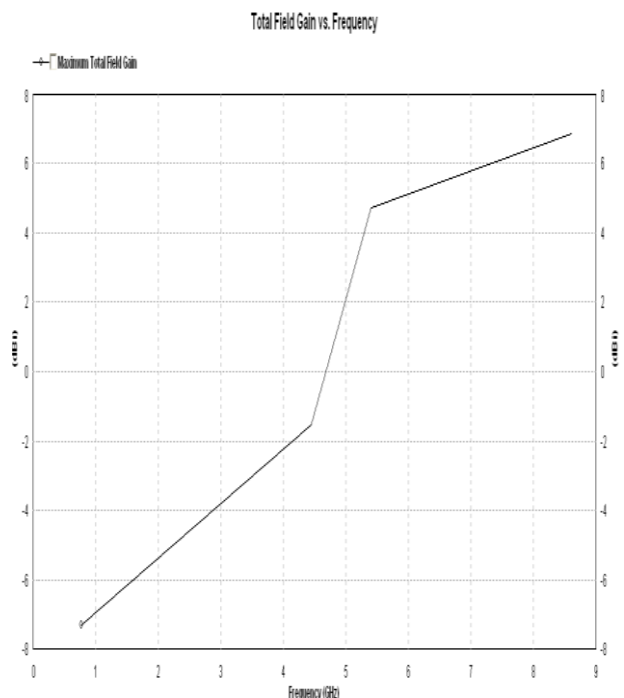

Fig 9: Impedance curve for 3rd iteration of designed antenna

Fig 10: Directivity characteristics for 3rd iteration of designed antenna

The figure 9 provides closer look on antenna impedance (plot consist curves for real impedance) and as the magnitude of impedance found to be 50Ω at all the resonant frequency points.

Fig 11: Total field Gain characteristics for 3rd iteration of designed antenna

Some other parameter of concern for the designed slotted octagonal antenna are also scrutinize for improvement in antenna outputs. Figure 10 shows the Directivity plot for the

design. After analysis of this curve we can conclude that the designed slotted octagonal antenna peruse significant Directivity in a range of from 6 dBi to 11.25 dBi for a large band of frequency. Total Gain plot is shown in figure 11. From this we can observe that total gain attains a maximum value of 7.5 dB.

4.4 Radiation Pattern[13]:

The radiation pattern is determined in the far field region and it is shown in (Figure 12), for both frequencies width two angles Ø= 0 and Ø = 90, the radiation patter is quite similar to a monopole antenna, it is omnidirectional for the first resonant frequency, in the second resonant frequency, two small beams appear and radiation pattern is quasi Omni directional.

Some other parameters of consideration are antenna efficiency & its impedance. Figure 12 illustrate radiation efficiency curve for the designed antenna.
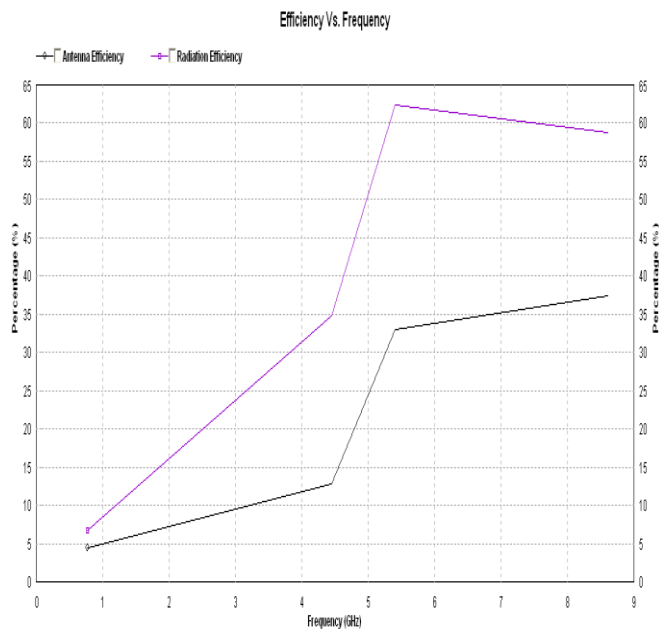

Fig 12: Antenna Radiation Efficiency characteristics for 3rd iteration of designed antenna
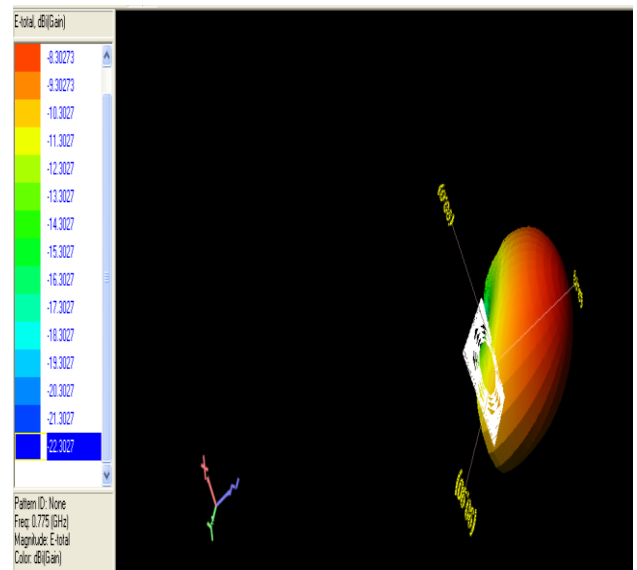

Fig 13: Radiation Pattern for 3rd iteration of designed antenna at 0.775 GHz

The designed antenna also represents significant improvement in radiation pattern. Figures 13 and figure 14 represents the 3D radiation pattern at 0.775 GHz and 5.08 GHz respectively.
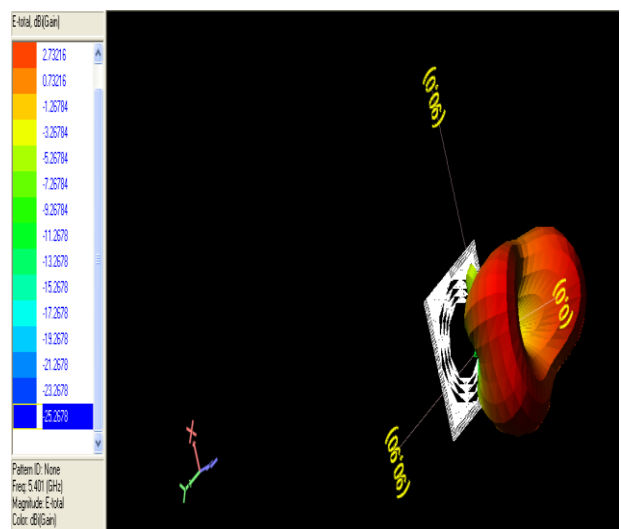

Fig 14: Radiation Pattern for 3rd iteration of designed antenna at 5.01 GHz

The figure 15 shows the fabricated antenna proposed by us. It is tested in the lab and analyzed with Network analyzer (VNA) for finding antenna parameters like Return Loss (S11) parameter in dB.

Fig 15: Return Loss characteristics of designed antenna at VNA screen.

5. RESULT

We propose, construct and test an Octagon shaped fractal antenna. This fractal antenna consist of simple iterative geometry. As per our expectation the designed geometry represents computability in wide range of frequencies (0.5 GHz up to 5 GHz). It also exhibits excellent operational parameters like radiation efficiency = 75% & maximum gain of 7.5 dBi with a maximum directivity of 10.5 dBi.

More we have drawn is a comparison curve of all the three iteration of Octagon fractal antenna as shown in figure 16. From this curve it is clearly observed that the resonance frequency is decrementing in logarithmic ratio when we move from first iteration to third iteration. The same is represented in the form of a table (Table .1). These observations verified the fractal behaviour of this antenna.
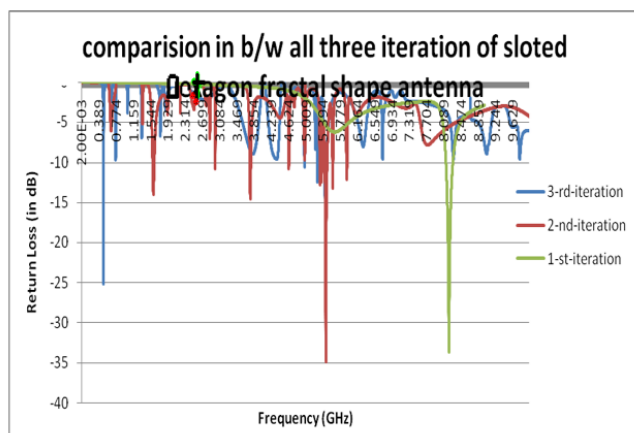

Fig 16: Simulated comparison characteristics of S11 (dB) for 1st ,2nd and 3rd iteration of designed antenna

Table .1 Comparison curve of Return loss for 1st ,2nd and 3rd iteration of designed Slotted Octagonal antenna

FREQUENCY	S_{11} 3RD ITERATION	FREQUENCY	S_{11} 2ND ITERATION	FREQUENCY	S_{11} 1ST ITERATION
1.67	-13.68	0.5	-26	8.2	-33
3.85	-14.82	5.2	-12		
5.347	-25.37				

6. CONCLUSION

Here a fractal antenna is designed which is capable to work at different frequencies. The simulation of antenna is done using IE3D software. The hardware testing is performed with the help of network analyzer. Various antenna characteristics has been taken into consideration during the designing like VSWR, input impedance, return loss, radiation pattern etc. With this work we can conclude that the effective length, space filling characteristics & scale factor are the important factors that effects the behavior of antenna while studying different iterations. The feed location and size of patch are also some parameters of concern.

We use IE3D for simulation, which is sufficient to simulate on higher frequencies. The designed geometry have efficient characteristics like high gain, efficiency & input impedance etc.

7. FUTURE SCOPE

Here in this paper, I have done compelling analysis of octagonal fractal geometry for wireless communication at different frequencies. Further area of development is antenna element minimization without degradation in efficiency. It will be a challenge for researchers to reduce the size with similar or improved results.

The absorption of electromagnetic energy can also be minimized at user's head. As surrounding of users by a strong electromagnetic energy for a long time may create health issues. The effect of the ground plane dimensions can be minimized to improve the antenna characteristics.

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