On the Design of Nano-arm Fractal Antenna for UWB Wireless Applications

Raj Kumar and [1]Sheetal Gaikwad
Microwave and Millimeter wave Lab., DIAT (DU), Girinagar, Pune-411025,India
[1]M. Tech. (Microwave Engg)
Pune Institute of Computer Tech., Pune, India
Email:dr.rajkumarkumar@yahoo.com

***Abstract* – This paper presents the design of a nano-arm fractal antenna suitable for ultra wide band applications. The CPW-feed and fractal concept have been used to achieve the ultra wide bandwidth. The shape of the fractal geometry, the number of iterations and the number of nano-arms are the deciding factors for achieving wider impedance bandwidth. The experimental result of the fractal antenna exhibits ultra wideband characteristics in the frequency range of 2.55 GHz to 11.84 GHz corresponding to an impedance bandwidth of 131.77%. The measured radiation patterns of the proposed antenna are nearly omni-directional in the H–plane and bidirectional in the E-plane. The antenna can be useful for modern wireless communication, medical imaging and ground penetrating radar.**

***Index Terms* –** Planar Monopole antenna, Multiband antenna, Fractal Geometry, CPW - Feed and UWB System

I. INTRODUCTION

The recent progress in UWB wireless communication applications has remarkably increased the demand for wideband antennas with smaller dimensions than conventionally possible [1]. The antenna size with respect to the wavelength is the parameter that will have an influence on the radiation characteristics, gain and efficiency. Conventional microstrip antenna has limitations of narrow bandwidth, low gain and size of $\lambda/2$ [1-2]. There are several techniques reported in the open literature to improve the bandwidth of the microstrip patch antenna such as insertion of air gap, stacking, ground coupling etc. The coupling effect is possible by changing the feed type and selecting proper values for its parameters. CPW feed offers better resonant characteristics and higher impedance bandwidth. [3-4].

The fractal geometry along with the CPW feed can be used for achieving ultra wide bandwidth [4]. The fractal geometry is supported by its two properties i.e. self similarity and space filling [5]. The self-similarity property is useful for multiband or ultra wideband (UWB) feature while space filling property is useful for antenna miniaturization. Using these properties, several UWB monopole antennas have been reported in the literature [6-11]. This paper presents an UWB antenna with andwidth beyond the required FCC band. Several modifications in the antenna structure like adding arms, increasing the number of iterations and introducing slots in the ground plane have been made to achieve the desired impedance bandwidth. A detailed parametric analysis has been presented and discussed. The simulated results of this antenna have been validated with experimental results.

The fractal antenna structure taken for investigation is shown in Figure.1. This fractal antenna is designed on a substrate of dielectric constant ε_r = 4.3, thickness 1.53 mm and with dimensions 63.5 mm x 65 mm. The fractal antenna is constructed from a solid circular disc of radius 12.5 mm as shown in Fig. 1.

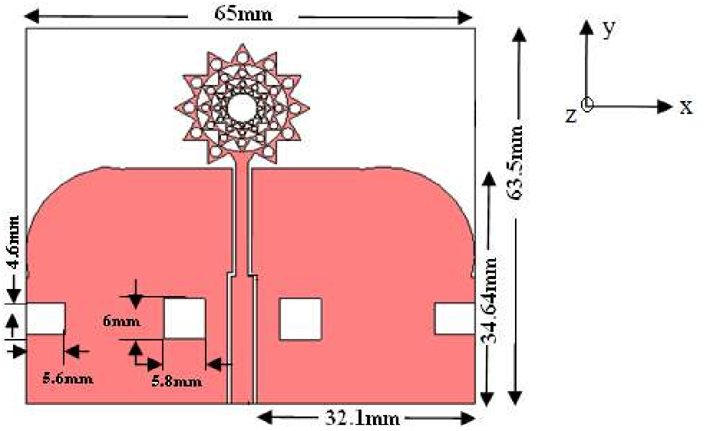

Fig. 1. Four iterative Concentric Nano-arm fractal antenna and its side view

This fractal antenna is constructed by using a set of scaled versions of the same shape which is similar to the concept of Sierpinski Gasket. In the first iteration, the perimeter of the circular patch is divided into twelve equal arcs, on the inner side of each arc; an isosceles triangle is drawn with an angle of 40 degrees from the perpendicular bisector of each node (edge of each arc). The resultant shape appears to be a chain of twelve inward looking triangles. This portion is etched off from the base. As a second step in the first iteration, eleven circular slots of 1 mm diameter have been drawn having their centres at a distance of 3.75 mm on the inner side of each node (except for the node near the feed) on the line connecting the node and the centre. These circular slots are then etched off the base. The resultant geometry from here onwards is referred to as the generator. This constitutes the first iteration.

The 2^{nd} iteration is a reduced copy of the design of the first iteration, repeated in an inner circle of 8.125 mm radius (which is 0.65 times of 12.5mm). Likewise the third and the fourth iterations are repetitions of their previous ones at a reduced ratio of 0.62, within the concentric circles. The infinite iterative structure which is ideally perceivable is not practically possible because of fabrication constraints. So for the present investigation, a fourth iterative Fractal Antenna is finalized and extensively studied with respect to its characteristics.

The CPW feed and its parameters such as the gap between the feed and the ground and the width of the feed are the critical factors which decide proper impedance matching. For the initial stage, they are fixed as 0.4 mm and 3.2 mm respectively. CPW feed offers excellent impedance bandwidth along with better radiation characteristics. Every dimension of the proposed antenna has been optimized to give the most appropriate results.

II. CURRENT DISTRIBUTION

The surface current density distribution is simulated at 2.3 GHz for the proposed fractal antenna corresponding to the first, second, third and fourth iterations and is illustrated in Fig. 2. Maximum current distribution is observed near the gap between the feed and the ground, on the edges of the radiating patch, on the ground near to the patch, and along the x-axis of the ground plane. That is why the size of the patch, the width and the length of the ground plane, the gap between the ground and the patch, the gap between the ground and the feed, all are crucial parameters for achieving the wide impedance bandwidth and need to be optimized.

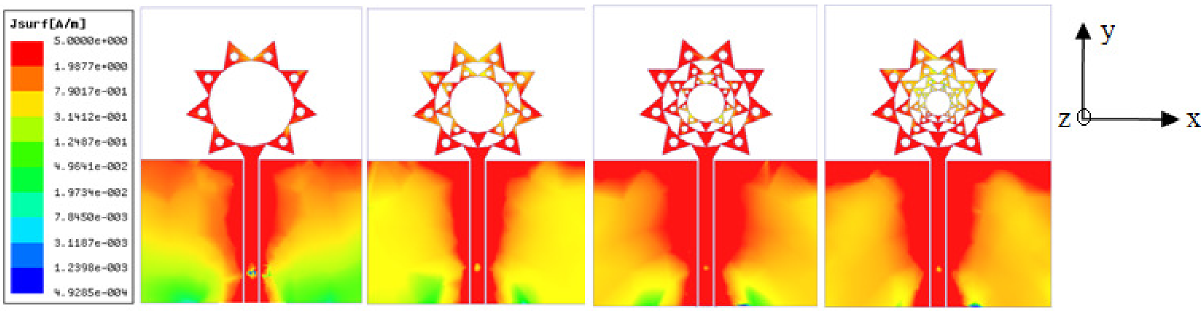

Fig. 2. Surface current density at 2.3 GHz for four iterations

III. SIMULATED RESULTS AND DISCUSSIONS

The proposed fractal antenna has been designed on the substrate of permittivity ε_r = 4.3 and thickness 1.53 mm. The substrate size of the antenna has been taken as 63.5 mm x 65 mm. The antenna was designed and fabricated with optimized dimension. A parametric study of the antenna was carried out using HFSS software based on the Finite Element Method.

Initially, the fractal monopole antenna is simulated with the simple circular patch of radius 12. 5mm with CPW feed. The ground plane length and width are taken to be 34.64 mm and 31.1 mm. But with this circular patch and rectangular ground plane, the required UWB impedance bandwidth is not achieved. The twelve nano - arm fractal antenna as shown in Fig. 2 is simulated with respect to the various parameters for achieving the UWB characteristics. The parametric study with respect to various parameters is discussed below.

A. Effect in the Number of Iterations

The parametric study with respect to the number of iterations has been performed. The iterative behaviour of the fractal antenna is carried out and shown in Fig. 3. The circular microstrip patch antenna of radius 12.5 mm resonates at a frequency of 2.45 GHz. After the application of fractal geometry, the resonant frequency is shifted to the lower frequency side at 2.2 GHz. This is due to the increase in the resonant length due to the application of fractal geometry. The application of fractal leads to the reduction in the size of the patch. There is a distinct shift in the fundamental resonant frequency dip as the number of iterations goes on increasing.

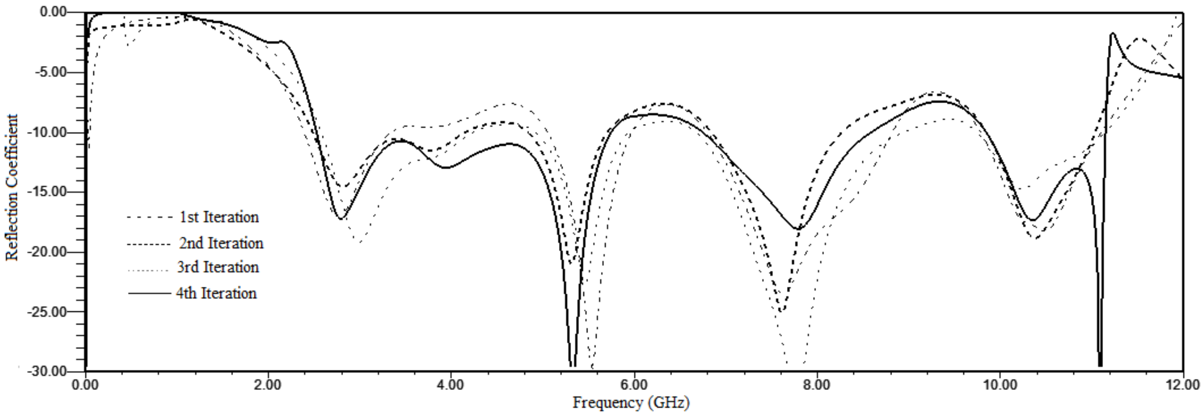

Fig. 3. Effect on the return loss characteristics due to increase in iterations

As the number of iterations increases, the first resonant frequency dip on the reflection coefficient curve shifts to the lower frequency side as illustrated in Fig. 3. It is also observed that the reflection coefficient improves as iteration increases through out the band. As seen in Fig. 3, the reflection coefficient is poor for the first iteration but improves substantially at the fourth iteration through out the operating band. This is one of the importance characteristic of fractal geometry that impedance matching improves with proper number of iterations. It means no extra circuitry is required for the impedance matching of a fractal antenna. This behaviour of the antenna is observed till the fourth iteration. So, a fouth iterative twelve nano-arm fractal antenna is considered for further investigation. This antenna is said to exhibit -10 dB reflection coefficient bandwidth in the frequency range of 2.6 GHz to 11.8 GHz.

B. Effect of Ground Plane Length (G_L)

The length of the ground plane plays a vital role in determining the UWB characteristics. The effect on the reflection coefficient characteristics of the variation in the ground length is shown in Fig. 4. The ground plane length is varied in steps of 2 mm from 28.64 mm to 34.64 mm. As the length of the ground plane increases, the reflection coefficient curve is shifted to the lower frequency side. This is clearly observable near the second, third and fourth dips of the reflection coefficient curve shown in Fig. 4. It is observed that better performance is achieved at 34.64 mm ground length throughout the band.

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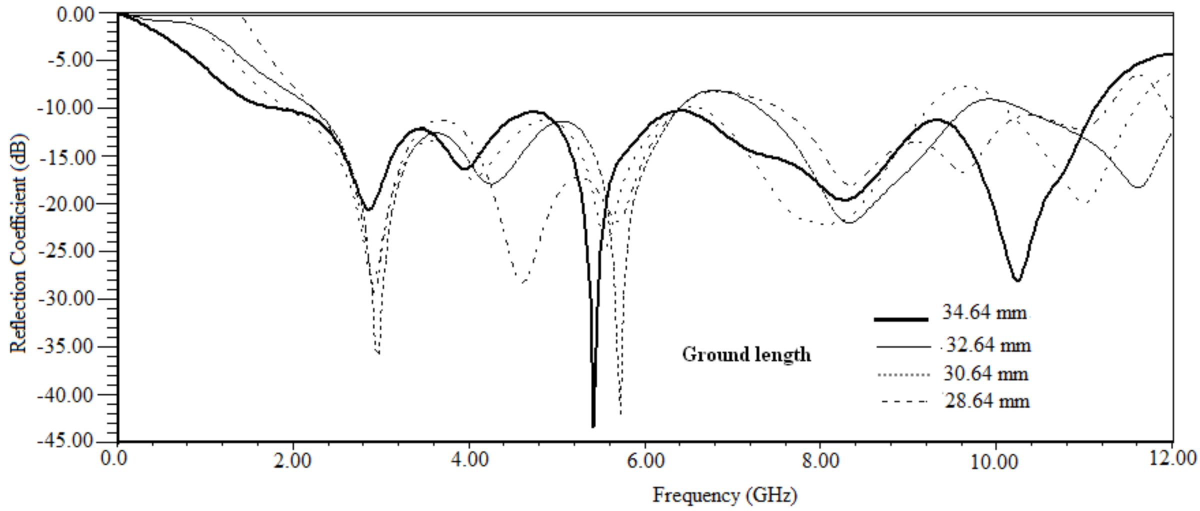

Fig. 4. Effect of variation in length of the ground plane

C. Effect of Ground Plane Width (G_w)

Here, the width of the ground plane of the proposed fractal monopole antenna is varied and its effect on the antenna bandwidth is observed. The proposed antenna has been simulated for various ground plane widths (G_W) from 27.2 mm to 31.2 mm. The simulated results with respect to various ground widths (G_W) are shown in Fig. 5. It is observed that as the ground width increases the first resonant frequency shifts to the lower frequency side. The optimum ground width obtained by fixing all other optimized parameters is 31.2 mm for optimum impedance matching throughout the band. For values smaller and larger than the optimized ground width, the optimum impedance bandwidth is disturbed. It means that there is one value of ground width for optimum impedance matching.

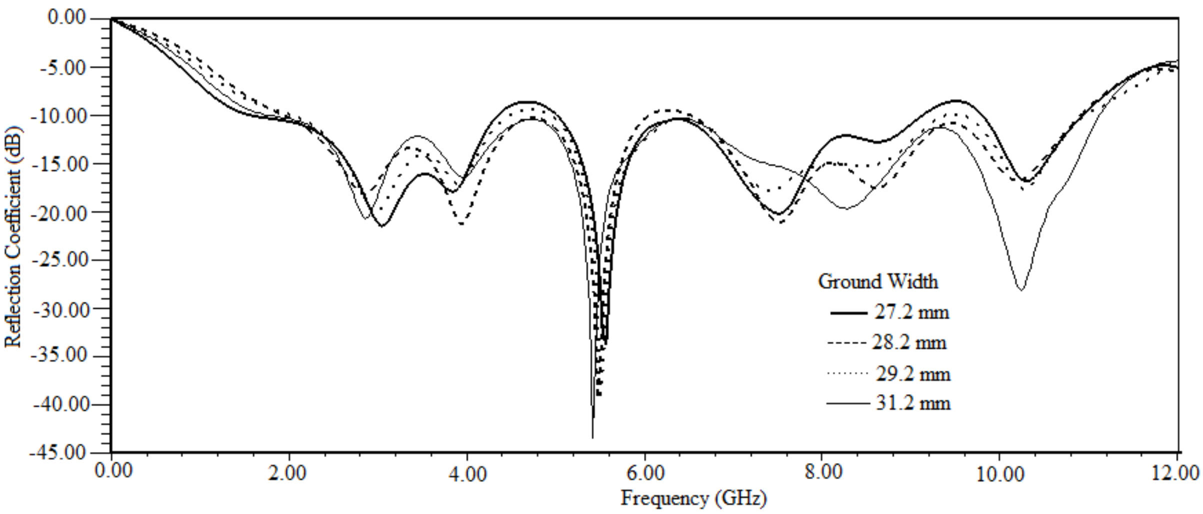

Fig. 5. Effect of variation in width of the ground plane

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D. Effect of Gap between Patch and Ground (G_{P-G})

The gap between the patch and the ground is also a critical factor in determining the impedance bandwidth of the antenna. Hence, a parametric analysis with respect to the gap between the patch and the ground is done with respect to the fourth iterative fractal antenna. The behaviour is observed by varying the gap (G_{P-G}) in steps of 0.1 mm. The gap between the patch and the ground is varied to 0.4 mm, 0.5 mm, 0.6 mm, and 0.7 mm and their corresponding reflection coefficient characteristics are shown in Fig. 6.

There is no one to one correspondence between the change in the reflection coefficient and the gap between the patch and the ground. As the ground plane is closer to the radiating patch, most of the fields will be radiated and less fringing fields reside in the substrate.

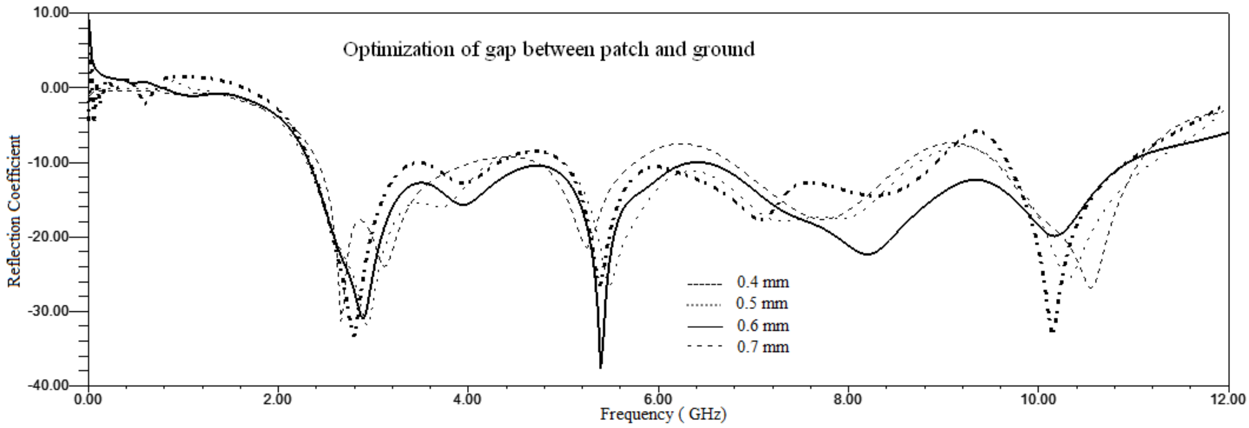

Fig. 6. Variation of gap between patch and the ground

No noticeable change in the bandwidth is observed here. An increase in the gap between the patch and the ground results in decreasing the reflections which in turn leads to an improvement in the return loss. It also results in the maximum coupling of signal between them. The optimum reflection coefficient in the frequency range of 2.2 GHz to 11.0 GHz is obtained for the gap of 0.6 mm according to Fig. 6.

E. Effect of the Gap between the Feed and the Ground

This twelve nano-arm fractal antenna is fed with CPW feed and it is well known that for better impedance matching, the gap between the feed and the ground, and the width of the feed are the deciding parameters. Here the width of the feed is kept constant at 3.2 mm. The gap between the feed and the ground is selected so as to provide best matching for the 50 ohm line. The separation between the feed and the ground was optimized over various values to yield wider bandwidth. The optimum gap between the ground and the feed is obtained as 0.5 mm. At this gap, the impedance is around 50 ohms.

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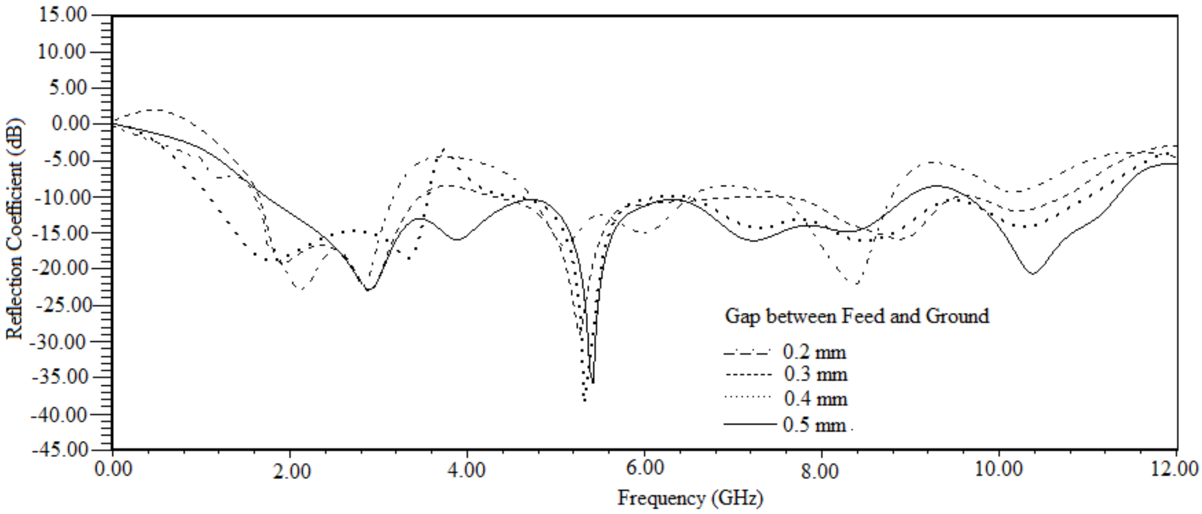

Fig. 7. Effect of the separation between feed and ground

The reflection coefficient characteristics for different values of the gap between the feed and the ground are shown in Fig. 7. For this particular configuration, the gap between the feed and the ground is kept as 0.5 mm. After parametric optimization, the gap between the patch and the ground is kept as 0.6 mm and the length of the ground as 34.64 mm. There is only minor variation in the impedance bandwidth with respect to the width of the ground. Hence the width of the ground plane is kept as 32.1 mm. The width and the height of the substrate is taken as 63.5 mm and 65 mm. The simulated VSWR plot in the frequency range of interest is shown in Fig. 8. It is observed that the VSWR is less than 2 in the range from 2.6 GHz to 11.8 GHz.

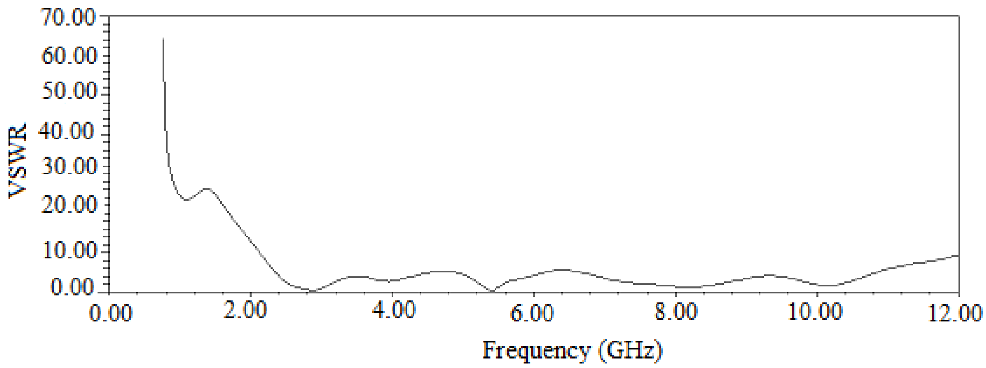

Fig. 8. VSWR of proposed twelve nano arm fractal antenna

F. Modified Ground Plane

It was difficult to get the reflection coefficient of the antenna below -10 dB. To improve the reflection coefficient, the ground plane is modified by rounding the corners and etching rectangular slots in the ground plane. The simulation results with the simple rectangular ground plane and with the modified ground plane are shown in Fig. 9.

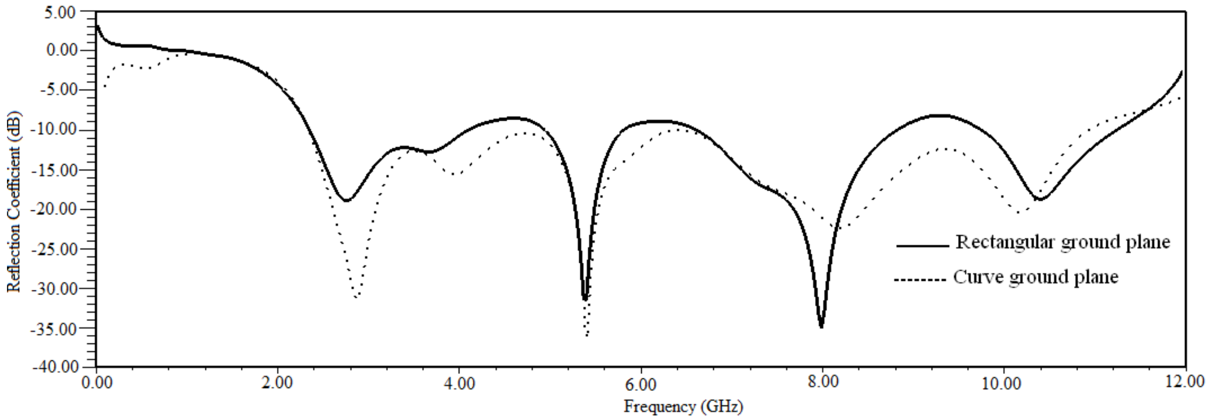

Fig. 9. Simulated reflection coefficient with and without modified ground

IV. EXPERIMENTAL, SIMULATED RESULTS AND DISCUSSION

The proposed fractal antenna with CPW - feed is shown in Fig. 1. The antenna was fabricated with optimized dimensions and tested. The experimental results were acquired using Vector Network Analyzer R & S ZVA40. The experimental result exhibits the impedance bandwidth from 2.55 GHz to 11.84 GHz corresponds to 131.77 %. The experimental result shows the resonance dips at frequencies 2.875 GHz, 5.45 GHz, 8.05 GHz and 10.35 GHz as shown in Fig. 10. The simulated resonance dips are evident as current maxima (red colour) on the feed line and the ground plane as shown in Fig. 11. These resonance dips merge with each other to give the overall impedance bandwidth from 2.55 GHz to 11.84 GHz. This antenna was simulated using HFSS and CST Microwave studio software. The measured results are compared with simulated results. The measured result are in close agreement with the simulated results obtained from HFSS and CST MWS software as shown in Fig. 10. There is a slight devation between the two simulated results. This is because both the software are based on different Numerical techniques. There is also slight deviation between experimental and simulated results. This deviation may be because of fabrication tolerances, uncertainty in substrate thickness and dielectric constant and lower quality of SMA connector used.

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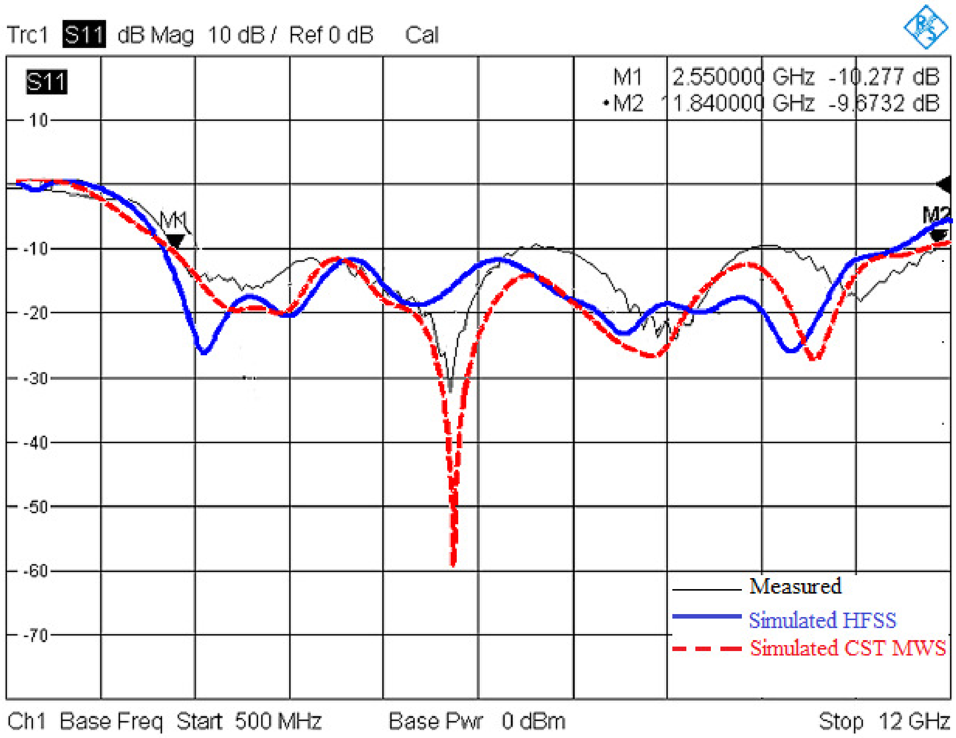
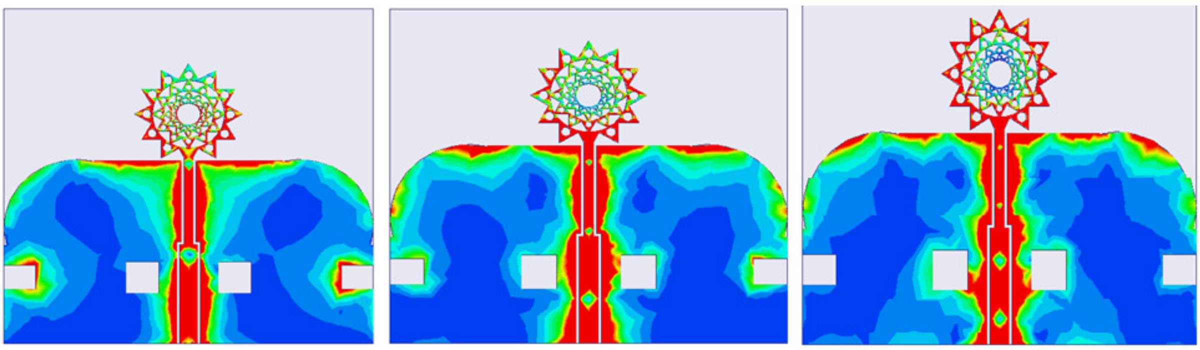


Fig. 10. Mesured and Simulated Reflection Coefficient of proposed twelve nano arm fractal antenna



5.4 GHz 8.0 GHz 10 GHz

Fig. 11. Simulated current of proposed fractal antenna for multiple resonance dips as current maxima (Red colour)

The radiation patterns in the two principal planes viz, the E-plane and the H-plane were measured in the inhouse anechoic chamber. The radiation patterns were measured at selective frequencies. The H – plane radiation patterns were measured at 3.0 GHz, 4.05 GHz, 4.95 GHz, 6.0 GHz, 7.05 GHz, 8.25 GHz, 10.35 GHz and 11.32 GHz. And are shown in Fig. 12. The simulated radiation patterns in the H- plane from HFSS and CST MWS software are calculated as shown in Fig. 13. The nature of the H – plane radiation patterns is nearly omnidirectional. The measured and simulated radiation patterns are in close agreement. Similary, E – plane radiation patterns were measured at 3.85 GHz, 4.8 GHz, 6.075 GHz, 7.05 GHz, 8.1 GHz, 9.45 GHz, 10.95 GHz and 11.55 GHz. The E – plane radiation patterns are shown in Fig. 14. The simulated radiation patterns in E- plane from HFSS and CST MWS software are calculated as shown in Fig. 15. The nature of radiation patterns is nearly figure of eight

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in the E –plane. The radiation patterns in both the planes slightly deteriorate as the frequency goes on increasing. This may be due to the higher magnitude of higher modes at higher frequencies and the fractal geometry of the antenna. At lower frequencies omni directional nature of radiation patterns in H - plane and bidirectional nature of radiation pattern in E - plane are evident.

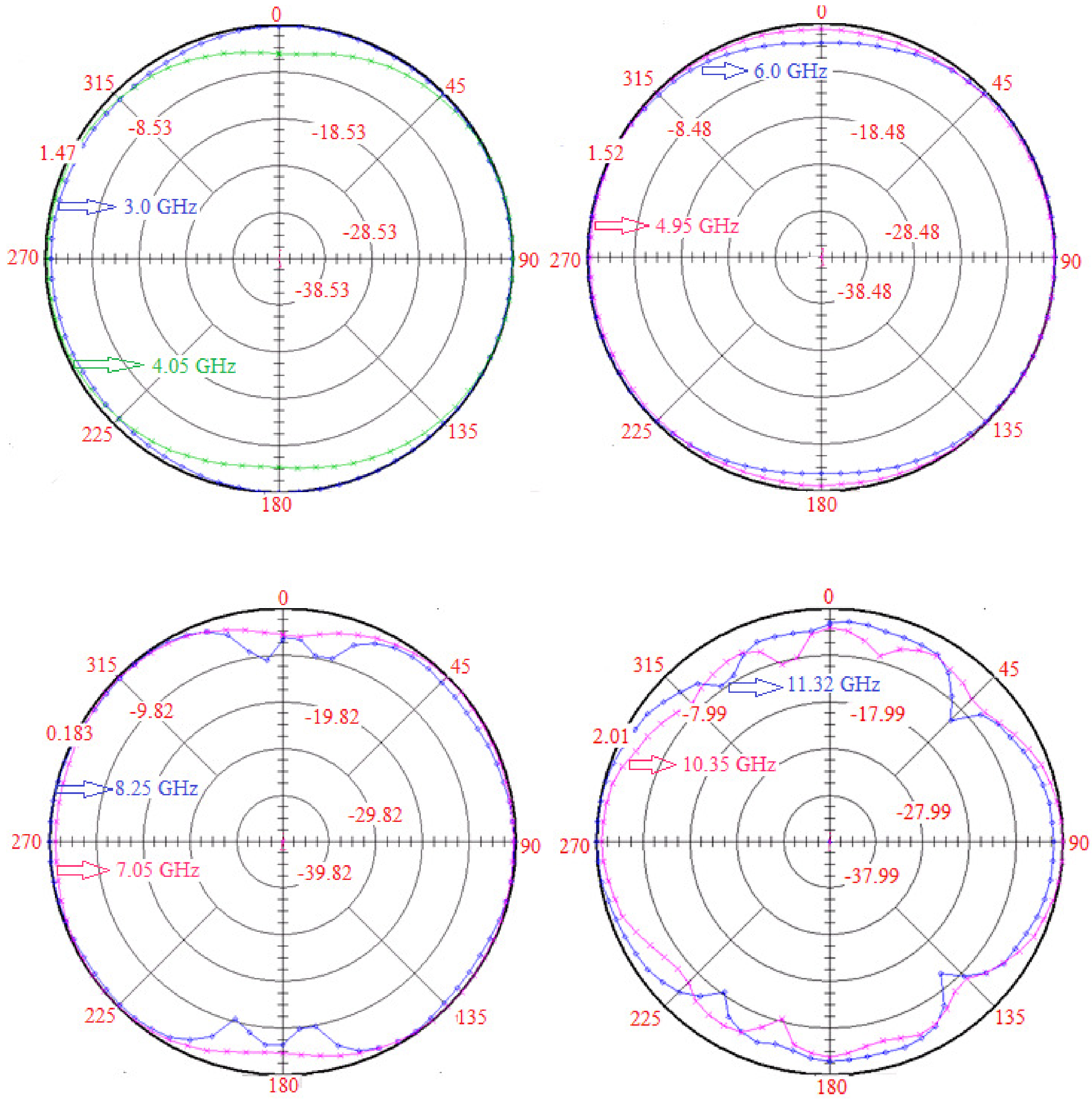

Fig. 12. Measured radiation patterns in H – plane at 3.0, 4.05, 4.96, 6.0, 7.05, 8.25,10.35 and 11.32 GHz

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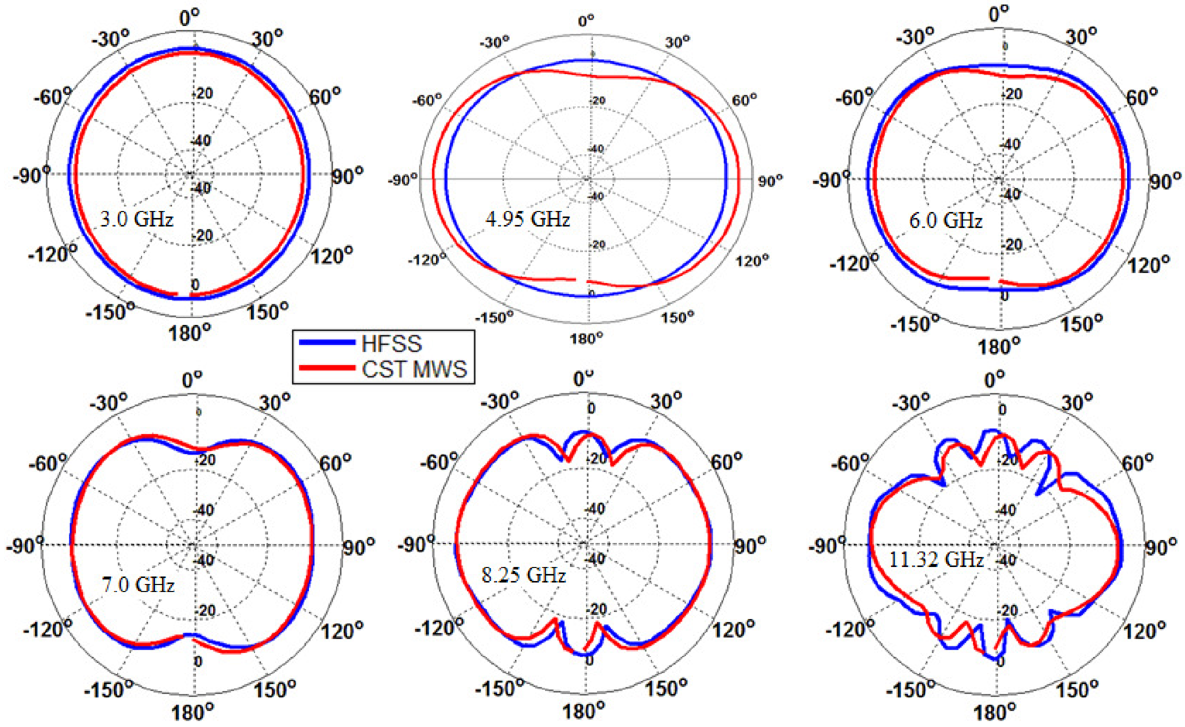
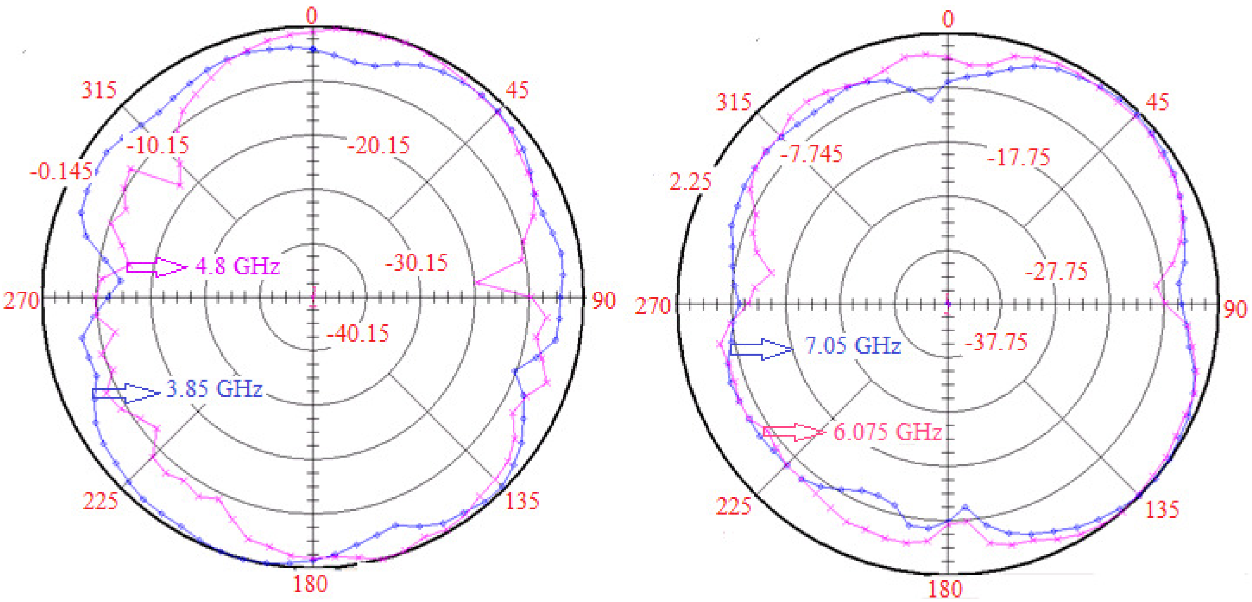


Fig. 13. Simulated radiation patterns in H – plane at 3.0, 4.95, 6.0, 7.05, 8.25 and 11.32 GHz



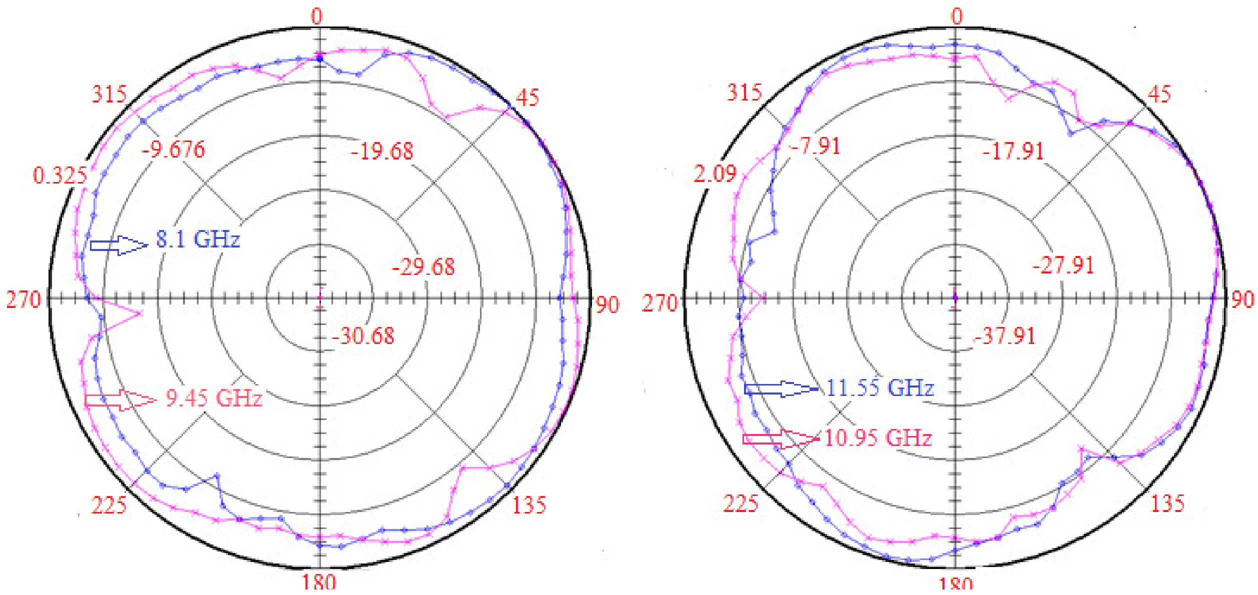


Fig. 14. Measured radiation patterns in E – plane at 3.85, 4.8, 6.075, 7.05, 8.1, 9.45,10.95 and 11.55 GHz

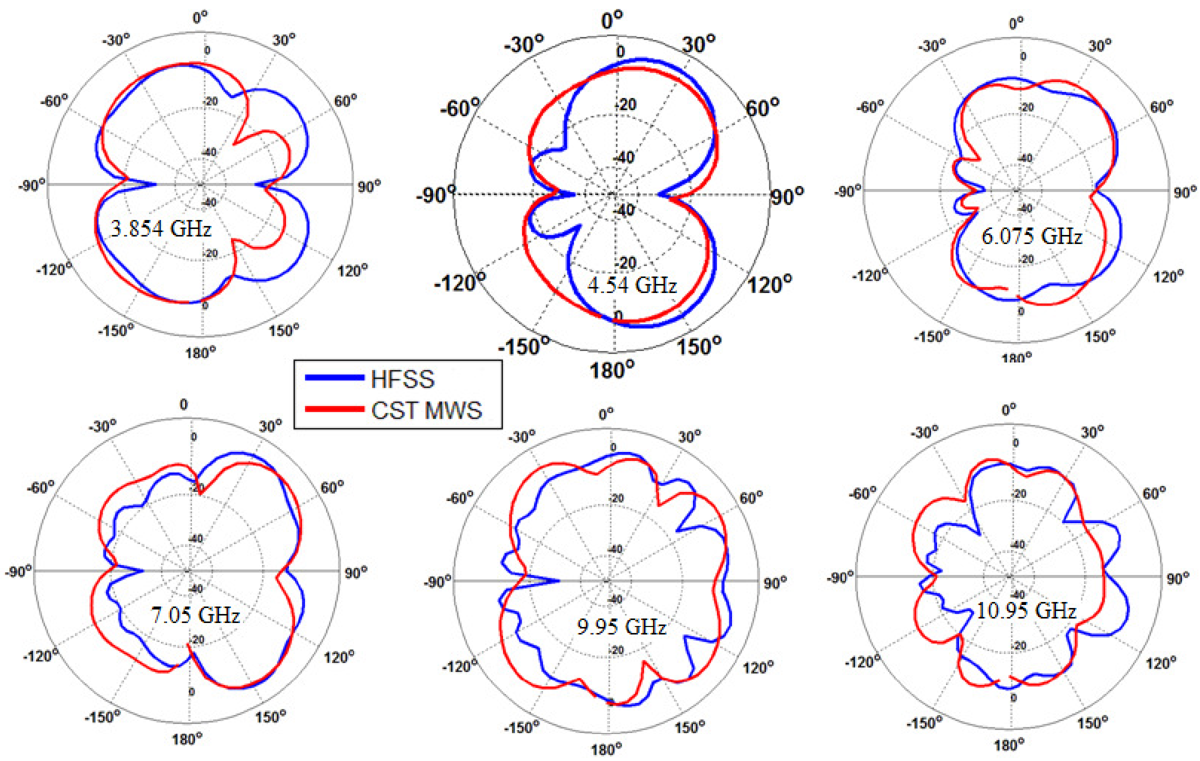


Fig. 15. Simulated radiation patterns in E – plane at 3.854, 4.54, 6.075, 7.05, 9.45 and 10.95 GHz

The peak gain and radiation efficiency of the antenna have been simulated using HFSS and CST microwave studio software. The simulated peak gain of the antenna is shown in Fig. 16. The simulated peak gain calulated from HFSS is very close to that calculated from CST microwave studio. The slight deivation in the peak gain is due to the fact that the software are based on different numerical techniques. The peak gain increases as the frequency increases. It is because at higher frequencies the wavelength becomes shorter in comparison to the radiation patch size. The peak gain beyond frequency 8 GHz is almost around 5 dBi. This is because, beyond this frequency cross polarization loss as well substrate loss increases. The simulated radiation efficiency is also in very good agreement from both the software (HFSS and CST Microwave studio) as shown in Fig. 17. The radiation efficiency decreases as the frequency increases. It reduces to 65 % at 12 GHz from 90 % at 3 GHz . This is because lossy dielectric FR4 substrate of dielectric constant $\varepsilon_r = 4.4$ and thickness h =1.6 mm was used.

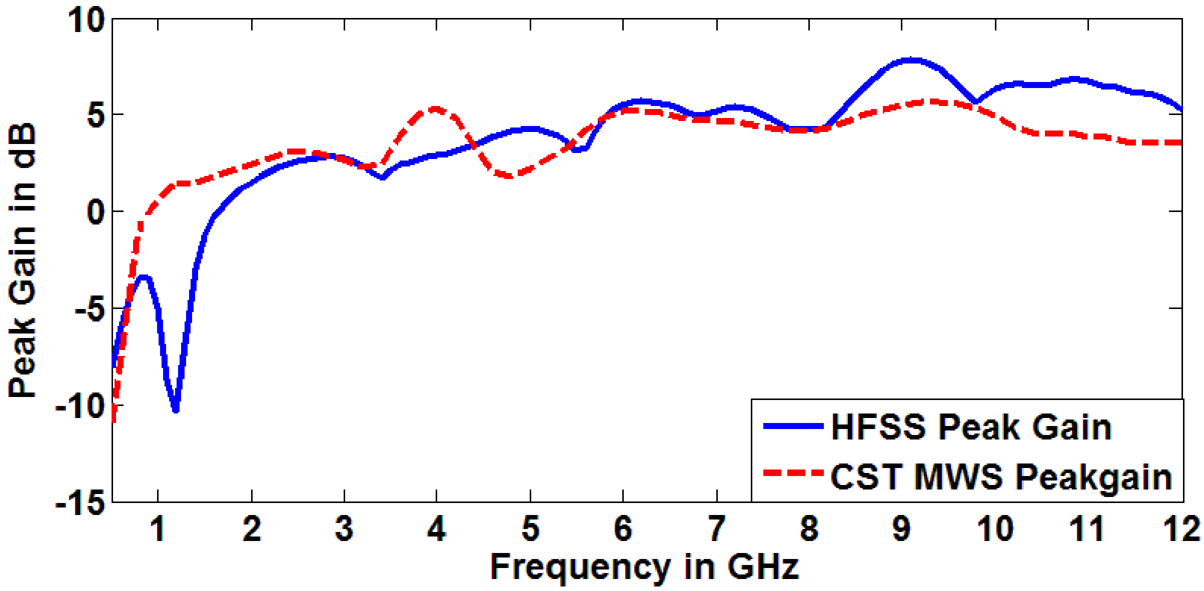


Fig. 16. Simulated peak gain of proposed antenna

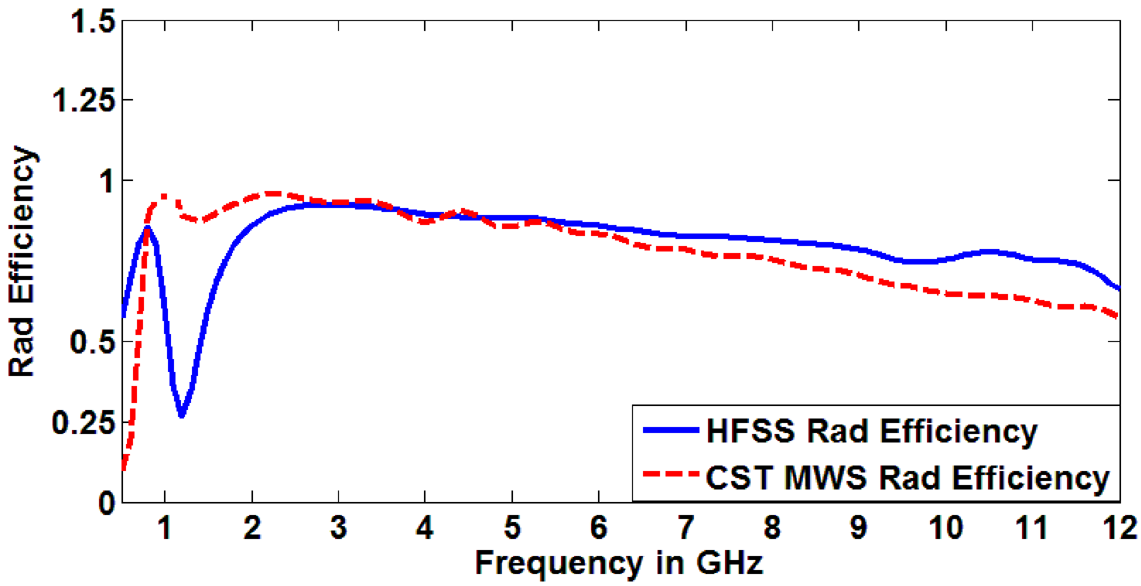


Fig. 17. Simulated radiation efficiency of proposed antenna

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V. CONCLUSIONS

A fractal antenna suitable for UWB applications is designed and experimentally validated. The parametric study of the antenna with respect to various design parameters has been performed to obtain ultra wide bandwidth. The proposed fractal antenna exhibits wide band characteristics in the frequency range from 2.55 GHz to 11.84 GHz corresponding to the impedance bandwidth of 4.64:1. The modification in the ground plane improves the -10 dB reflection coefficient bandwidth throughout the band. The radiation pattern of the antenna has been found to be nearly omni-directional in the H-plane and bidirectional in the E-plane. This property of the antenna makes it a suitable candidate for modern UWB applications. The antenna is compact, light weight, low cost, simple to fabricate and easy to integrate with MIC/MMIC devices. The antenna may be useful for applications like modern wireless communication, precision positioning systems, ground penetrating radar, vehicular radar and medical imaging.

VI. ACKNOWLEDGMENTS

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