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A Miniaturized UWB Dipole Antenna Design by using Fractal Geometry

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Abstract **– In this article an ultra wideband hexagonal shaped double printed circular inscribed dipole antenna is presented with size miniaturization. For miniaturization fractal geometry is introduced. For simulation frequency spectrum from 2.99 to 10.45 GHZ(111%) is covered by the proposed antenna and in measurement it is in between 3.04 to 10.49 GHZ(110%) by using linearly tapered micro strip feedline instead of stepped feedline. As a result the volume and area of the antenna is miniaturized up to 35.89% and 16.67% severally as compared to other ceremonious UWB dipole antenna. The gain observed for simulation is 3.31 dBi and 2.06 dBi for measurement. Impedance bandwidth achieved, is 110%(3.04-10.149)GHZ. Remarkable agreement is found between measured and simulated results.**

Key Terms— Slotted hexagonal dipole antenna, Fractal geometry, Miniaturization, Ultra wide band(UWB) and wireless communication.

I. INTRODUCTION

In today's growing world high data rates with less power dissipation is an essential requirement for wireless communication systems. It can only be done by taking the UWB frequency spectrum from 3.1–10.6 GHz provided by FCC (Federal Communication Commission) which is license free [1].UWB technology is the most advantageous due to high data rate, low power dissipation, low cost etc. Impedance matching at UWB is a major challenge faced by ceremonious antenna. Many different designs like dipole, fractal, and monopole are discovered for UWB application. Among all these dipole structure has high impedance which results into perfect impedance matching and stable radiation pattern.UWB system is discovered with distinct shapes of dipole antenna structures like diamond, Planar teardrop, Elliptical, Shorted C shape arm, Slot loaded elliptical, Trapezoidal patch dipole, Rounded bow tie, Rectangular patch dipole, Sierpinskized Koch-like, sided multifractal dipole antenna. [2–11]. Miniaturization of antenna structure is another major challenge for wideband operating range. It can only be done by introducing fractal geometry to dipole antenna. The fractal geometry uses self-similar design to maximize the length as to increase the perimeter. They are also referred as multilevel and space filling curves. As reported several fractal structures such as Koch fractal monopole, Sierpinski carpet fractal monopole, and circular patch antenna with pentagonal cut, inner tapered tree shaped fractal antenna and so forth have been introduced. [12–16].

Antenna volume and active patch area are miniaturized by the third iterative process of hexagonal dipole antenna. The dimensions of the proposed antenna is 0.299 λ × 0.4385 λ × 0.0159 λ (30mm × 44mm × 1.6mm) at lower frequency of 2.99 GHz, where λ is wavelength. The resonance occurs at two different frequency bands: 3.01–10.47 GHz (110.7%) for conventional and 2.99–10.45 GHz (111%) for miniaturized antenna under simulation process.

The reflection coefficient S11 is found below -10db for the desired frequency spectrum. The high average radiation efficiency of 82.9% is observed during measurement in the operating band. The proposed UWB fractal dipole antenna is simulated by CST Microwave Studio (CST MWS) software [17] and Vector Network Analyzer is used for the measurement purpose. Table1 indicates the optimized parameters of proposed antenna.

TABLE 1 Proposed miniaturized fractal dipole UWB Antenna Parameters

Parameters	Optimized Value (in mm)
Length of substrate (L_S)	30
Width of substrate (W_S)	44
Branch length of hexagonal (a)	10
Width of feed line at connector end (W_1)	3.16
Width of feed line at patch end (W_2)	1.8
Width between feed line and hexagonal patch (W_3)	0.78
Width between side branch of patch and side edge of substrate (W_4)	3.42
Length of feed line from line to patch (L_1)	0.8
Length of feed line (L_2)	16
Height of ground (L_g)	3
Radius of 1st circular slot (r_1)	2.5
Radius of 1st circular slot (r_2)	4.5
Radius of 1st circular slot (r_3)	7

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The design is fabricated by using PCB prototype machine Caddo-71 which allows to fabricate just in minutes instead of weeks. The complete design analysis and comparison between the parameters like reflection coefficients, peak gain, radiation patterns and radiation efficiency of simulated and measured is depicted in further segment.

II. ANTENNA DESIGN AND ITERATIONS OF FRACTAL DIPOLE

The evolution of projected UWB fractal dipole antenna is presented in figure1. The proposed antenna is traced on a FR4 substrate (30 × 44 × 1.6 mm^3) having relative permittivity of 4.3, loss tangent of 0.02, and thickness 1.6 mm. The hexagonal shape with 3rd iterative fractal geometry is working as the radiator of the antenna structure. Due to its wide operating bandwidth with good radiation characteristics hexagonal fractal geometry is traced on both the sides of FR4 substrate which improves overall performance of the design with special references to its applicability. Fractalization approach is introduced to miniaturize the active patch area and volume that provides the reduction in overall antenna dimensions (L_S & W_S) and also reduces the active patch area by inserting the 3rd iterated fractal geometry with 50 ohm linearly tapered microstrip feed line, as shown in Figure 1 'b'.

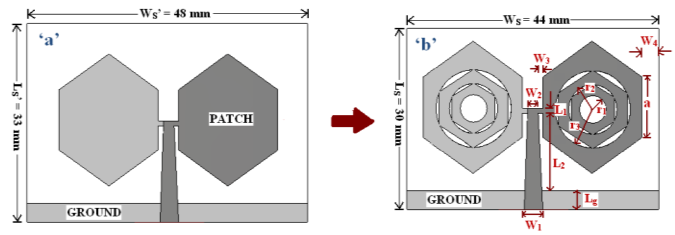

Figure 1 Evolution of the proposed fractal UWB dipole antenna with linearly tapered feed.

Table 2 gives the idea about the reduction of active patch and antenna volume.

Table-2 Analysis of fractal UWB dipole antenna miniaturization carried out as per design evolution.

Parameter	Conventional UWB Dipole Antenna ('a')	Proposed Fractal UWB Dipole Antenna ('b')	% Reduction (with respect to conventional UWB Dipole antenna)
Active Patch Area (in mm^2)	259.81	166.56	35.89
Volume of antenna (in mm^3)	2534.4	2112	16.67

The bottom side of the design is made of a rectangular shape ground plane (3 × 44 × 0.01 mm^3), below the micro strip feed line. There are many ways to feed antenna but for smooth transitions between the dipole element and the feed line linearly tapered micro strip is used.

All the iterations of the proposed antenna are well described in figure2 section. There are mainly four states of iteration process of which zeroth iteration is simply a UWB hexagonal dipole antenna, which is here working as radiating element. By making circular slot at the centre of zeroth iterative UWB dipole we get the first iteration of the projected antenna. Now the antenna performance will not be affected by this circular slot as current is distributed at the edges of the dipole. Remaining two states of iterations can be formed by scaling down the geometry by the same iteration factor.

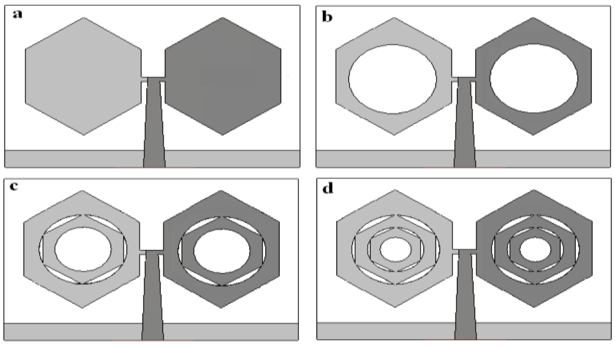

Figure 2 Iteration states of the proposed antenna.

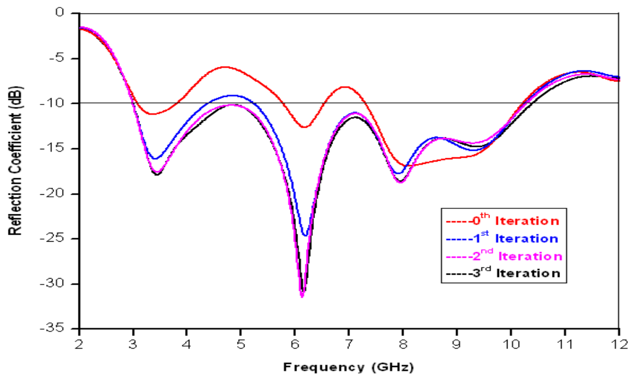

Figure 3 Comparison of iteration wise fractal dipole antenna.

Figure3 represents the comparison of reflection coefficient of all the iterations with its simulated ones and also procession of 0th – 3rd iterations, where impedance matching is amended by a great amount and bandwidth is also enhanced from its upper edge to greater frequency. This enhancement of bandwidth is done by the higher resonances which are due to iterations.

Figure 4 indicates the top and bottom view of the fabricated UWB hexagonal dipole antenna and optimization of dimensions can also be seen by the same. The fabrication and simulation is done by PCB prototype machine Caddo-71 and CST Microwave Studio (CST MWS) software [17] respectively. The analysis of reflection coefficient (S11) is done by VECTOR NETWORK ANALYZER.

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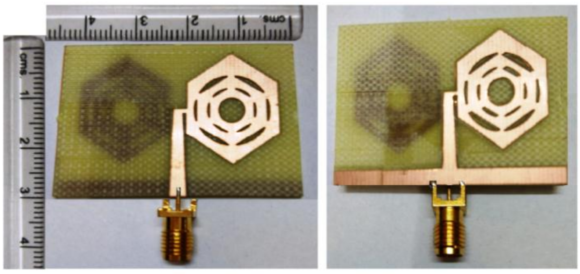

Figure 4 (a) Top view (b) Bottom view of fabricated prototype.

The comparison between the reflection coefficient of simulated and measured results is presented in figure 5, where the input reflection coefficient S_{11} is found below -10 dB for configuration of conventional and designed fractal (3^{rd} iterative) UWB dipole antenna. Impedance bandwidth of the proposed antenna is 110.7% (3.01–10.47 GHz) and 111% (2.99–10.45 GHz) respectively under simulation and 110% (3.04–10.49 GHz) in measurement. The experimented and simulated results are in good correspondence.

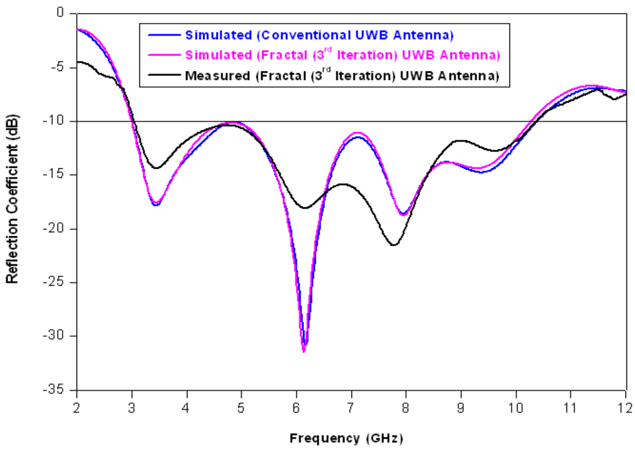

Figure 5 Simulated and measured reflection coefficient S_{11} of the UWB antenna for configuration a & b in Figure 1.

From Figure 5, it is comprehended that the same impedance bandwidth is achieved for zeroth and third iteration of the antenna but configuration 'b' exhibit smaller size as compared to 'a'. The reduction in active patch area and volume of antenna is about 35.89% and 16.67% respectively that can be seen by table 2. This reduction depicts that the miniaturization of UWB antenna is successfully carried out according to the design evolution in Figure 1.

Table-2 Analysis of fractal UWB dipole antenna miniaturization carried out as per design evolution.

Parameter	Conventional UWB Dipole Antenna ('a')	Proposed Fractal UWB Dipole Antenna ('b')	% Reduction (with respect to conventional UWB Dipole antenna)
Active Patch Area (in mm^2)	259.81	166.56	35.89
Volume of antenna (in mm^3)	2534.4	2112	16.67

Figure 6 points the gain versus frequency characteristics which is known as the best method to determine the gain of the antenna in which horn is used as the source antenna. From figure it is very clear that gain is reduced at lower frequencies but it is appreciably enhanced at greater frequencies. The high average antenna gain of 3.91 dBi and 3.16 dBi is obtained under simulation and measurement severally.

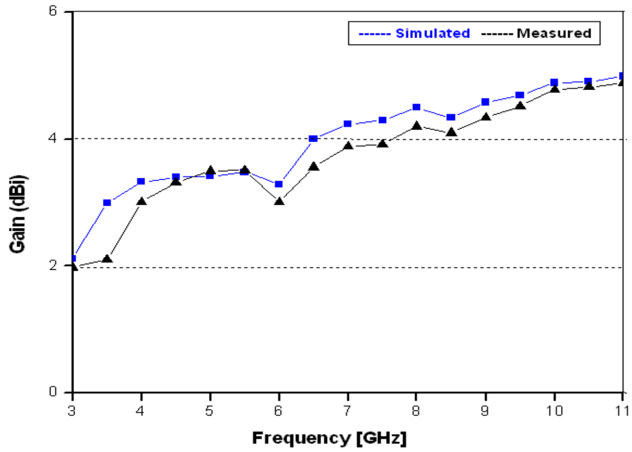

Figure 6 Simulated and measured gain of the proposed antenna.

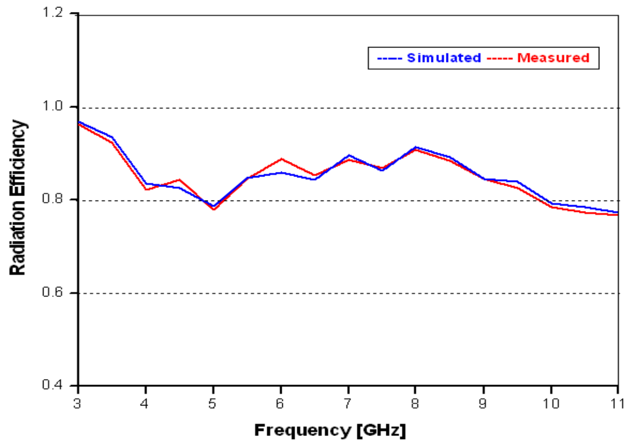

Figure 7 Simulated and measured radiation efficiency of the proposed antenna.

The complete analysis of the radiation efficiency of the design is shown in Figure 7 where peak realized radiation efficiency is 82.9% and it persists above 70% in all the desired UWB operating bands. This graph points the changes in radiation efficiency from 91.56% to 78.19% under simulation and 89.78% to 76.34% under measurements which indicates the radiation efficiency varies from 91.56% to 78.19% and 89.78% to 76.34% in simulation and measurement, respectively.

The comparison is made between E-plane and H-plan radiation pattern where good compatibility between simulated and measured observations is found with small changes, which are due to design misalignment. Radiation patterns are obtained at resonant frequencies 2.4 GHz, 5.4 GHz, 7.5 GHz and 10 GHz for two principal planes E-Plane and H-Plane. Quasi-omnidirectional and dumbbell radiation pattern are found in E-Plane and H-Plane respectively shown in Figure 8.

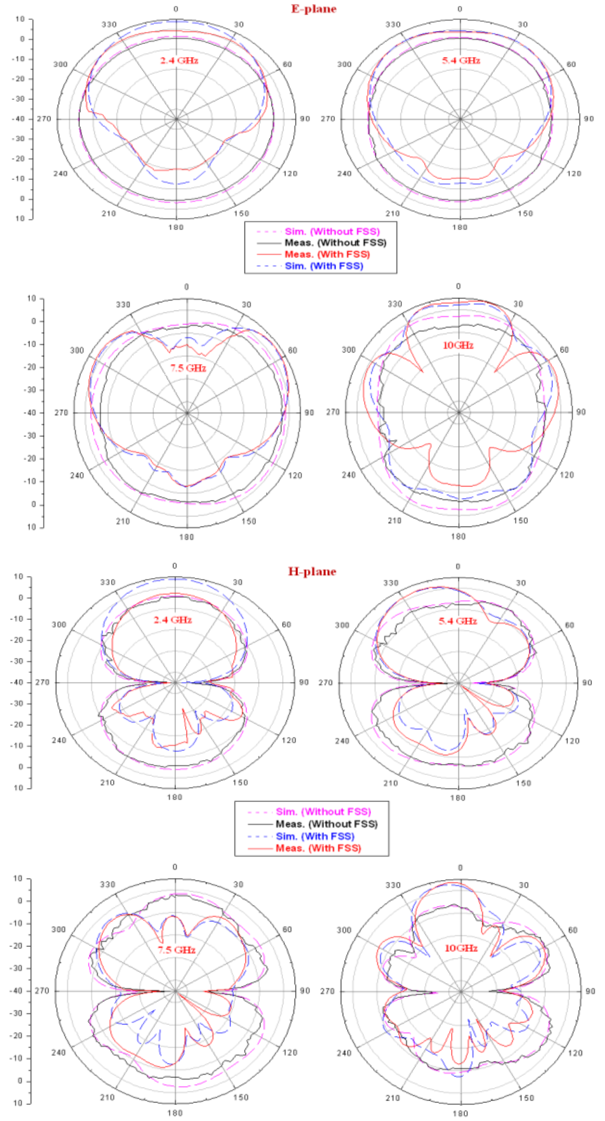

Figure 8 Measured and simulated radiation patterns at different resonant frequencies.

III. CONCLUSION

A perfect combination of dipole and fractal antenna is implemented and a compact hexagonal shaped fractal for UWB application is designed to achieve miniaturization as well as good impedance matching. Gain and peak average radiation efficiency are in good agreement with expected results. Squinting of radiation patterns is reduced by using a linearly tapered micro strip feed line and an omnidirectional radiation pattern are obtained in H plane. A prototype antenna is simulated by CST Microwave Studio and fabricated on FR4-lossy dielectric material which is the best suitable for wireless communication impedance matching.

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