CPW-Fed Fractal Monopole Antenna for UWB Communication Applications

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Abstract **─** This paper presents the results of a novel fractal monopole antenna that exhibits Ultra-Wideband (UWB) performance. Higher order iteration of the fractal motif constituting the antenna was analyzed and its performance evaluated in order to optimize the antenna's characteristics. Compared to a typical circular monopole antenna, the proposed antenna generates reflection-coefficient resonances that significantly improve its impedance bandwidth by 160%. The antenna's measured performance conforms to the desired UWB specifications.

Index Terms **─** CPW-fed, fractal technology, small antenna, UWB.

I. INTRODUCTION

In recent years, many fractal geometries have been used to develop antennas by utilizing the attributes of fractal geometry to perturb the antenna's electromagnetic field [1,2]. Fractals are complex geometric designs that repeat themselves and can be described as 'self-similar' and independent of scale [3,4]. Ultra-wideband antenna designs are driven by two desires: i.e., to make an antenna for a given frequency band as small as possible and to make an antenna cover several bands [5-8]. Fractal antennas have performance parameters that repeat periodically with an arbitrary fineness dependent on the iteration depth. Although the finite iteration depth fractal antenna is not frequency independent, it however can cover frequency bands close together.

Fractal geometries are usually generated by applying an infinite number of times an iterative algorithm, such as the Multiple Reduction Copy Machine (MRCM) algorithm [9]. This iterative procedure involves using an initial structure called generator, which is replicated many times at different scales, positions and directions to construct the final fractal shape. The properties exhibited by fractals make them ideal to miniaturize wideband antennas with characteristics very similar to their larger counterparts [10-13]. In the case when the dimensions of an antenna are much smaller than the wavelength at its operating frequency, the efficiency of the antenna deteriorates drastically, since its radiation resistance decreases and the reactive energy stored in its near field increases [14]. However, fractal geometry provides an amazingly satisfying solution to this problem without undermining the antenna's characteristics. Hence, fractal geometries have become an inventive approach for designing miniaturized wideband and multiband antennas.

In this paper, we present a novel miniaturized CPW-fed fractal antenna that exhibits ultra-wideband performance. The proposed fractal monopole antenna is engendered in an iterative fashion, leading to self-similar structure. The antenna design operates across 2.10 to 19.04 GHz for VSWR≤2. Unlike other antennas reported in

Submitted On: May 29, 2013
Accepted On: July 25, 2014

the literature to date, the proposed antenna displays a good omni-directional radiation pattern, even at higher frequencies. The fractal monopole antenna was analyzed using Ansoft's High Frequency Simulator (HFSS™). Simulated and measured results are presented to validate the usefulness of the proposed antenna's structure for UWB applications.

II. FRACTAL ANTENA STRUCTURE

Production of the proposed fractal monopole antenna involved replication of a geometric motif with some scaling and translation. Figure 1 shows the three steps required to create the fractal monopole antenna for UWB applications. The fractal antenna shown in Fig. 1 (c), is generated with an initial circular microstrip patch in Fig. 1 (a) of radius R_1. An equilateral triangle is inscribed inside the circular patch, as shown in Fig. 1 (b). A second circle of diameter R_2 is inscribed inside this triangle so that it touches the sides of the equilateral triangle. The triangle is then subtracted from the outer and inner circular patches. This process is repeated and the third iteration uses a circle with diameter of R_3. The upper segments of the circular patches are then subtracted to realize the required fractal geometry representing the radiating patch. Finally, the upper section of the ground-plane is truncated in a tapered shape, as shown in Fig. 1 (c), with the aim of reducing area of radiating patch.

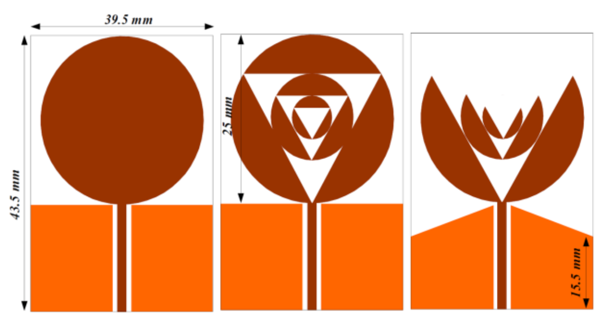


Fig. 1. Steps required to create the antenna structure.

The finalized microstrip monopole antenna design used a third order iteration fractal as an infinite iterative structure, it's not practically possible because of fabrication constraints. The proposed antenna was constructed from FR4 substrate with thickness of 1.6 mm, relative dielectric constant of 4.4, and loss tangent tanδ=0.02. The width of the microstrip feed-line is fixed at 1.36 mm. The antenna's dimensions are 28 mm × 35 mm.

III. ANTENNA PERFORMANCE

The proposed antenna's characteristics were investigated by changing one of its parameters at a time, while keeping fixed all others to make the effect of that parameter clear in the plots. The fractal antenna's performance was analyzed in order to determine its optimal parameters using HFSS™. The optimum magnitudes of the proposed antenna's physical parameters defined in Fig. 2, are given in Table 1.

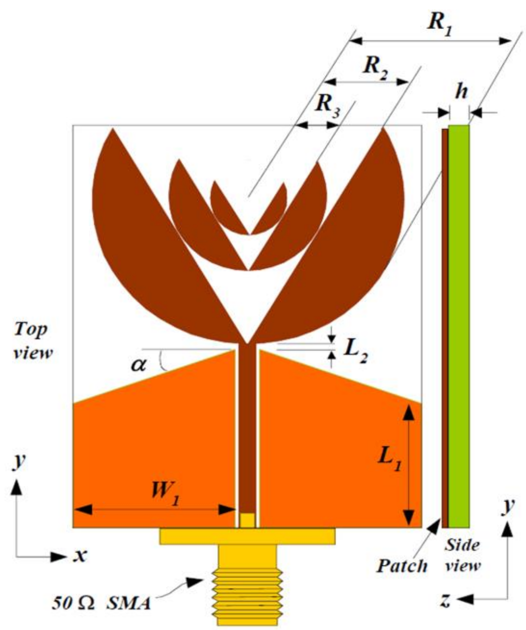


Fig. 2. The proposed antenna structure showing characterizing parameters.

Table 1: Dimensions (mm) of the proposed antenna

R_1	R_2	R_3	W_1	L_1	L_2	α
12.5	6.25	3.125	13.09	13.89	0.22	7º

The effect of the iteration order on the fractal geometry constituting the proposed monopole antenna was studied. Reflection-coefficient characteristic for the first, second and third order iteration is presented in Fig. 3. It is observed that the impedance bandwidth of the antenna effectively improves over the lower and upper frequency range as number of iterations increases. Although the overall effect on the reflection-coefficient is not significant, however, the order of iteration can affect the antenna's radiation efficiency as will be shown later.

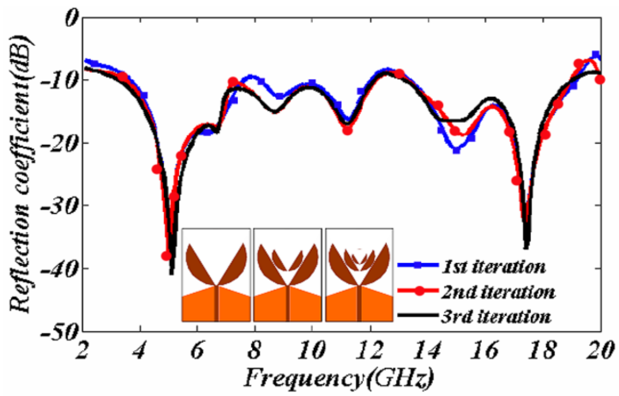


Fig. 3. Reflection-coefficient plot for the first three iterations of the antenna.

The effect of the ground-plane width (W_1) on the antenna's response is shown in Fig. 4, which shows very small changes in the parameter's dimensions and can significantly influence the antenna's reflection-coefficient. However, reflection-coefficient ≤ -10 dB is maintained over a very large bandwidth when it's optimized.

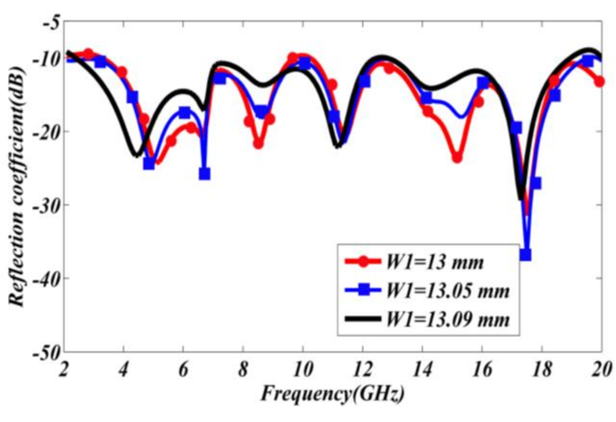


Fig. 4. Simulated reflection-coefficient plot for different values of W_1.

It was also observed, small changes in the ground-plane length L_1 can affect the antenna's reflection-coefficient response, as shown in Fig. 5. Although L_1 can improve the reflection-coefficient, this is to the detriment of the impedance bandwidth. Here, L_1 is optimized to realize a very large bandwidth extending between 2-20 GHz for reflection-coefficient ≤ -10 dB.

Figure 5 also shows the simulated reflection-coefficient characteristics for different values of L_2. It shows small change in L_2 has a significant effect on the reflection-coefficient response as well as on the antenna's impedance matching. The value of L_2 of 0.22 mm provided the optimum response.

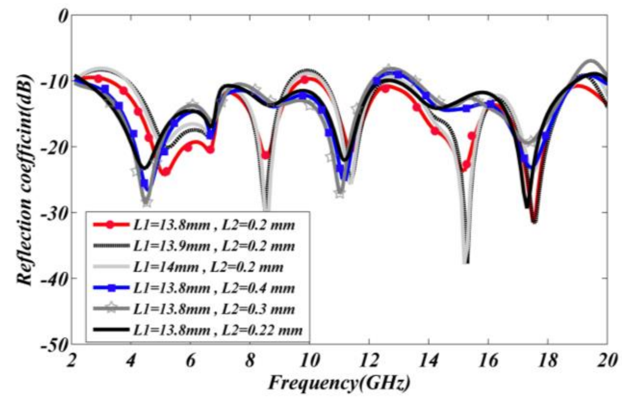


Fig. 5. Simulated reflection-coefficient plot for different values of L_1 and L_2.

Another parameter that has an influence on the bandwidth of the antenna is the ground-plane truncation angle α, depicted in Fig. 6. The simulation results show increase in α cause the reflection-coefficient to change significantly, especially over the lower frequencies. Also, an increase in α can enhance the antenna's reflection-coefficient. It was found α of 7° to provide an optimum impedance bandwidth.

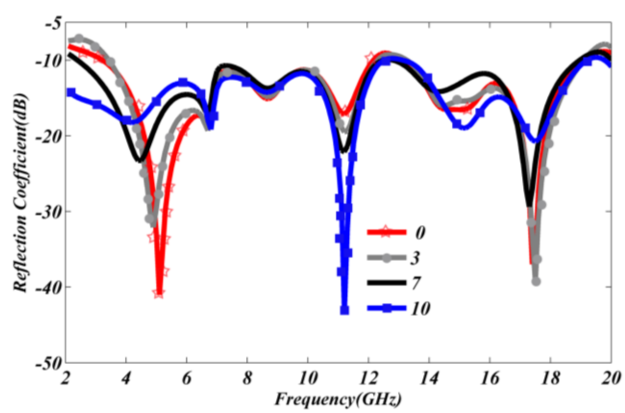


Fig. 6. Simulated reflection-coefficient plot for different values of α.

Comparison of reflection-coefficient characteristic for a typical circular monopole antenna and the proposed monopole fractal antenna is shown in Fig. 7. The circular monopole has the same diameter of 25 mm and feed-line dimensions as in Fig. 1 (a), and was constructed on the same dielectric substrate. The spectrum of the antenna shows numerous reflection-coefficient resonances corresponding to the various modes generated within the fractal structure. Shown in Fig. 7, is also the measured performance of the proposed antenna. The antenna's performance was measured in an anechoic chamber and its connector was enveloped in an RF absorbing material to provide a non-reflecting environment. The disparity between the simulated and measured responses of the proposed antenna is attributed to inaccurate simulation modeling and manufacturing tolerance and imperfect soldering effect of the SMA connector. The antenna's measured impedance bandwidth extends from 2.1 to 19.04 GHz, for which its reflection-coefficient characteristic is better than 10 dB. This performance exceeds the UWB as defined by FCC. The proposed antenna clearly exhibits a superior performance in terms of impedance bandwidth compared to the conventional circular monopole.

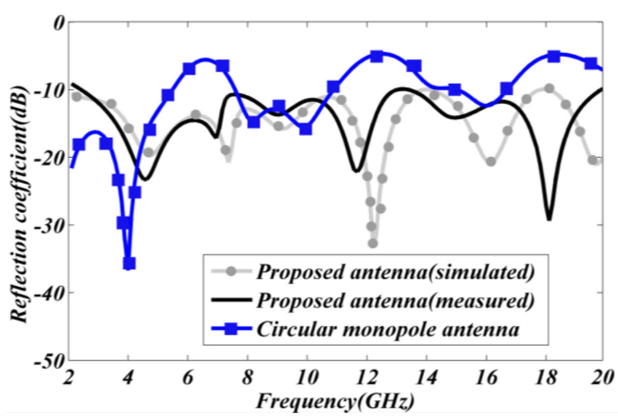


Fig. 7. Simulated and measured reflection-coefficient plot for a simple circular monopole and the proposed antenna.

Figure 8 shows the current distribution over the antenna at various spot frequencies. This indicates areas of the antenna that are critical at a given frequency. Knowledge of this can be used to modify the structure to optimize the characteristics of the antenna. At 3 GHz, the intensity of the current is strongest across the entire feed-line and the area of the ground-plane immediately next to the feed-line. The current is also excited at the intersection of the feed-line and 1st iteration patch segments, as well as at the lower and uppers ends of the 2nd and 3rd iteration segments. At 6 GHz, the current intensity is strongest at the middle and outer ends of the feed-line, intersection of the feed-line and 1st iteration patch segments, as well as middle and outer sections of the 1st iteration segments. Current is exited at the lower end of the 2nd iteration segments. At 8 GHz, the current distribution over the feed-line and fractals is similar to that at 6 GHz, but the intensity is moderately reduced. The current excited over the 2nd iteration segments has now moved to its upper end. At 10 GHz, current distribution over the fractal antenna is similar to that at 6 GHz; however, the distribution over the ground-plane close to the feed-line is much more intense and current is excited over the 1st iteration segments.

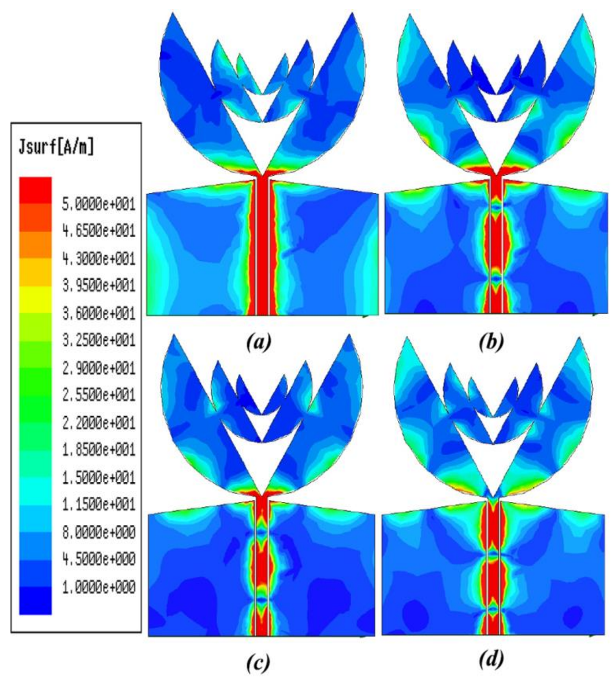
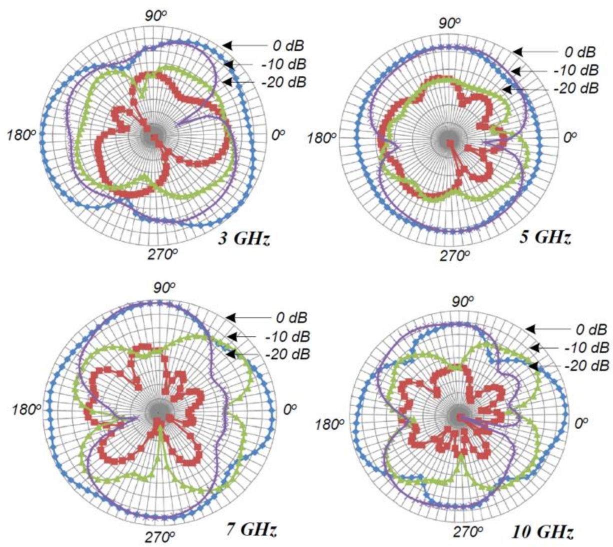


Fig. 8. Current distributions over the proposed antenna at: (a) 3 GHz, (b) 6 GHz, (c) 8 GHz, and (d) 10 GHz.

Figure 9 shows the measured radiation patterns of the fractal antenna, including the co-polarization and cross-polarization in the *H* and *E*-

planes. The radiation patterns were measured in an anechoic chamber. It can be seen that the radiation patterns plane are nearly omni-directional for the four frequencies; however, with varying field intensity.



E-plane (co, cross)
H-plane (co, cross)

Fig. 9. Measured *E*-plane (*x*-*z*) and *H*-plane (*y*-*z*) radiation patterns of the proposed fractal antenna at various spot frequencies.

Gain versus frequency response for the three iterations of the antenna, as well as the efficiency of the optimized third order iteration, are shown in Fig. 10. The gain for the three iterations are approximately the same between 3-5 GHz; however, the gain of the fractal with a higher iteration order generally provides a higher gain between 6-8 GHz. Maximum gain of 4.9 dBi is obtained at around 9 GHz. The efficiency of the proposed antenna for iteration-3 increases with frequency and varies between approximately 74-92%. Reflection coefficient, gain, efficiency and radiation pattern are important parameters of UWB antennas. Other important parameters include system transfer function and group delay. Ideally, group delay in UWB applications should be constant over the entire bandwidth as well. To assess these parameters, two identical fractal antennas proposed here were mounted 60 cm from each other, which corresponds to approximately six wavelengths at the lower frequency of the band of operation and in the antenna's far-field region. The group delay measurement is shown in Fig. 11. This varies between around ±1 ns, but drops down to -2.8 ns at round 6.8 GHz as a result of the fractal structure.

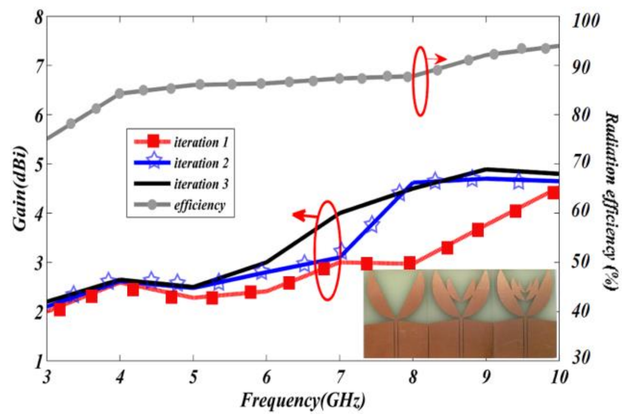


Fig. 10. Gain and efficiency plots for the three fractal iterations of the proposed antenna.

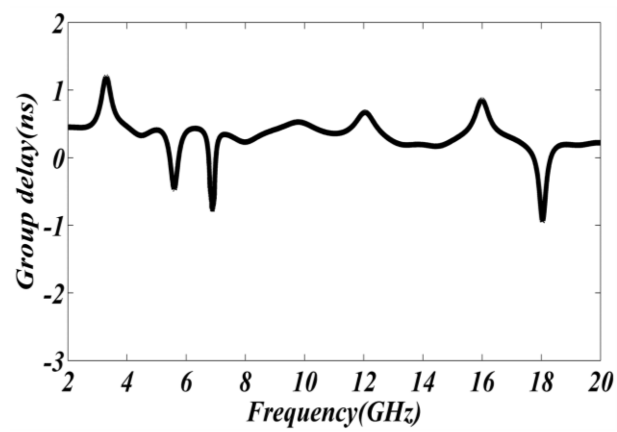


Fig. 11. Group delay plot of the antenna.

Various fractal configurations have been used for monopole antenna designs which include a combination of Giusepe Peano and Sierpinski Carpet [11], and Pythagorean Tree [12] fractals geometries. Table 2 presents a summary comparing the proposed fractal antenna with fractal antennas in references [11] and [12]. It is observed that the proposed antenna has more resonances, a wider impedance bandwidth, higher gain performance and is less complex than antennas in [11] and [12].

Table 2: Isalient characteristics of the proposed antenna compared with references [7,8]

	f_n (GHz)	S_{11} (dB)	f_c (GHz)	Peak Gain (dBi)	BW (for VSWR=2)	UWB Coverage	Structure Complexity	Size (mm^2)
Proposed antenna, 1st iteration (α=0º)	5, 9, 11, 17	-33, -12, -14, -33	11.60	4.7	4.2-19.0 GHz, 127%	No	Low	28×35
Proposed antenna 2nd iteration (α=0º)	5, 8, 11, 17	-35, -13, -15, -33	11.55	4.8	4.1-19.0 GHz, 129%	No	Low	28×35
Proposed antenna 3rd iteration (α=7º)	4, 6, 11, 17	-24, -15, -20, -30	10.57	4.9	2.1-19.0 GHz, 160%	Yes	Low	28×35
Combination of Giusepe Peano and Sierpinski Carpet Fractals [11]	2, 11	-16, -19	7.00	4.5	1-13 GHz, 171%	Yes	High	20×25
Pythagorean Tree Fractal [12]	4.1, 7.2, 8.3	-26, -22, -34	6.89	1.9	2.6-11.1 GHz, 123%	Yes	Very high	25×25

VI. CONCLUSION

A miniature CPW-fed monopole antenna was presented, that was developed using a novel fractal geometry that is shown to exhibit ultra-wideband performance. It is shown that the bandwidth and gain of the antenna improves with increase in iteration order of the fractal geometry. The measured results show that the impedance bandwidth of the proposed antenna can be enhanced by truncating the ground-plane that is adjacent to the radiating patch. The measured results also confirm the antenna provides good radiation patterns that satisfy the requirements for UWB communication applications.

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