The Design of Fractal Antennas for UWB using MoM

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***Abstract*—In this paper the fractal method is used to realize two novel antennas useful for Ultra Wideband Radio. Fractals have self-similarity, which lends them to simple replication and desirable space filling for current path maximisation in a given footprint. Candidate fractal antennas considered here are a modified Minkowski fractal and a Koch-Square loop fractal. Both antennas are optimized to operate within the FCC UWB mask with a -10 dB of reflection loss. Reasonable gain and broadside directivity are also achieved. The antennas were synthesised with the Method of Moments package 4NEC2X.**

***Keywords*— Fractal antennas, UWB, MoM, Impulse radio.**

I. INTRODUCTION

Ultra-Wideband radio (UWB), which first received attention as long ago as 1963 [1], has recently become topical as a low power short-range technology suitable for wireless body area networks. In essence this type of radio spreads its power spectral density over a bandwidth that is not typical for narrowband communication systems.

Whilst initially time hopping impulse response pulse position modulated systems were discussed, current candidates under IEEE 802.15.3a (short fat pipe), consider only multiband OFDM or direct sequence CDMA. The FCC recommended spectral mask allows for a bandwidth between 3.1 and 10.6GHz with special power limits outdoors to allow harmonisation of UWB with legacy technologies such as GSM and UMTS [2, 3].

Because of the relatively large bandwidth available to the licensed version of UWB (7.5 GHz) when compared to cellular, which spans several bands and is often combined with WLAN (≈1.6GHz), UWB antennas are required to operate over a spectral range more than four times as big within the same footprint on the communications device. Fractals are a method for achieving the enhanced bandwidth within restricted space [4, 5].

Although there are studies as early as the 17th century the term fractal was first defined by Benoit Mandelbrot in 1975 [6]. In general we see that a fractal is any geometric shape that can be split into smaller parts, each of which is rough copy of the first. In essence a shape is fractured into smaller versions of itself. The most useful fractals for antennas have been found to be those based on an equation. Iterations of the equation create a new shape by either by splitting into smaller similar elements or growing by adding into new elements on a larger scale. When metallised to make a radiating structure, all parts offer a current path which can be rigorously defined and is can be long in relation to the space occupied by the geometry. Such fractal shapes have been used so far to achieve multi band antennas, with wide bandwidth and economy of scale [7, 8].

In this paper, we show how two different structures for fractal antennas may be used for UWB applications. The main characteristics for the structures are synthesised employing the Method of Moments thin wire code (4NEC2X). The achieved results show that the proposed structures may be used for applications operating within UWB range of frequencies.

The rest of the paper is organized as follows: in Section II, we describe the antenna structures for fractal geometry technology. Next a system model with the performance evaluation and simulation results are presented and discussed for the proposed structures. Finally conclusions are given in section III.

II. SYSTEM MODEL

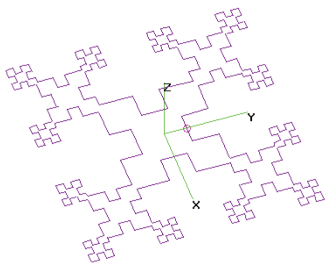
Several numerical techniques exist to predict the performance of free-space and fractal antennas. All numerical techniques involve solving discrete forms of Maxwell's equations for time-varying fields. A popular technique in use is Method-of-Moments (MoM). Example use of this method is given in [9, 10]. Since the MoM method is numerically efficient, Mom electromagnetic engines run with optimisation algorithms such as Genetic Algorithms can be very powerful as a tool.

The design methodology for configurations of the proposed antennas are illustrated in the following subsections. The structures are shown in two views: in the *x-y* plane and in 3-D, and the used angles: θ measured from y-axis in x-y plane and $\varnothing$ measured from the z-axis.

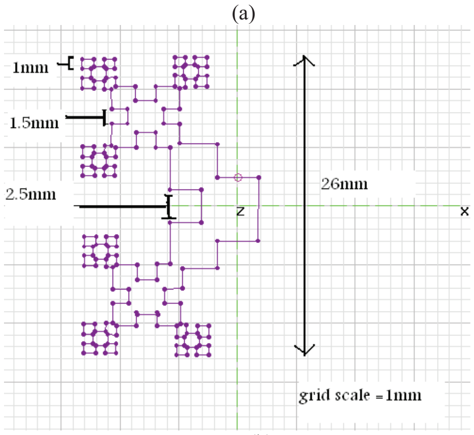
A- Modified Minkowski fractals

The structure of the Minkowski is presented here with simulated results for antenna characteristics and dimensions for build. In Fig. 1 is shown the geometry of the antenna, in space, as depicted in Fig. 1-a with $\theta = 37^o$ and $\varnothing = 341^o$ and the projection which shown in Fig. 1-b for stage of 3 of the fractal. The total length is 26 mm with fractal elements 2.5 mm, 1.5 mm, and 1 mm.

Fig. 2 illustrates the simulation results for the VSWR (voltage standing wave ratio) (at top of the figure) and the reflective coefficient (at the bottom) with frequency. The multi-frequency behavior can be seen. The resonant frequencies located at: 1.21, 2.42, 3.38, 4.46, 5.31, 6.27, and 6.7 GHz. The VSWR is considered between the antenna and the excitation source, which have a characteristic impedance of 50 Ω. These frequencies give reflection coefficients: -5, -14, -14, -2, -8, -8, and -16.2, respectively. The wire conductivity is assumed to be 5.7×10^7 and the voltage source is 1v. The total number of wires used was 172 and the total number of segments is 172.



(a)



(b)

Fig. 1 The layout of a Minkowski fractals (a) in 3-D with $\theta = 37^O$ and $\varnothing = 341^O$ and (b) in x-y plane.

Figure 3 (top) shows the variation of the real and imaginary parts of the input impedance with the frequency. Because of the fractal design it is worth looking in detail at the input impedance. At the resonant frequencies the input resistance has peak values of 5 kΩ, 4 kΩ, 4 kΩ, 3.5 kΩ, 0.4 kΩ, and 0.05 kΩ.

The same figure illustrates, at its bottom side, variation of the input impedance and the phase with the frequency. The impedance values are: 6 kΩ,, 3.5 kΩ, 3.6 kΩ, 3.1 kΩ,, 3 kΩ,and 0.35 kΩ, which corresponding changes in the phase values of 160°, 140°, 120°, 90°, 110°, 70° and 120°, respectively. The radiation pattern is analyzed in Fig. 4 for the two dimentional for cases $\varnothing = 0^o$ (a), $\varnothing = 90^o$ (b), and $\varnothing = 180^o$ (c). The the 3D pattern is illustrated in Fig. 5.

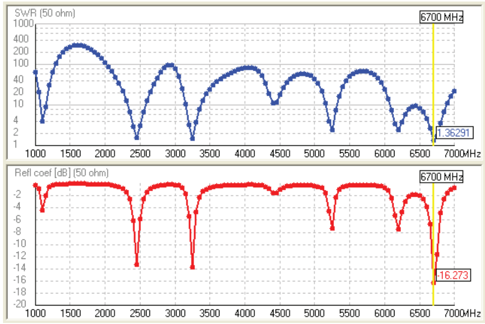


Fig. 2 Simulation results for the Modified Minkowski fractals: standing wave ratio (top) and the reflective coefficient (bottom) as functions of frequency.

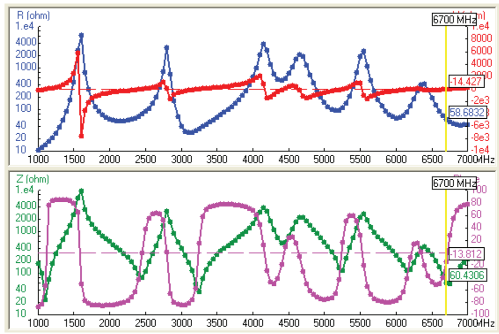
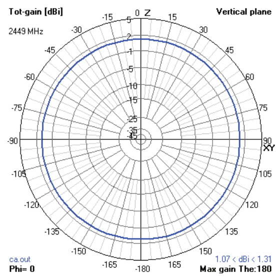


Fig. 3 Input resistance (top) and input impedance (b) for the modified Minkowski fractals.



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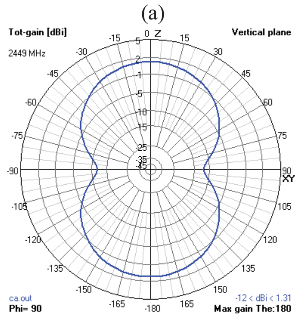

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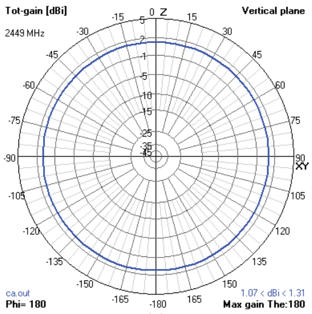


(c)

Fig. 4 2D radiation patterns: (a) Ø = 0°, (b) Ø = 90° and, (c) Ø = 180°.

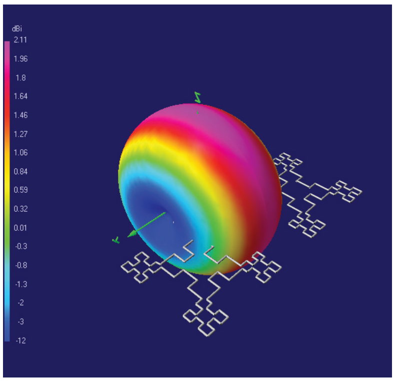


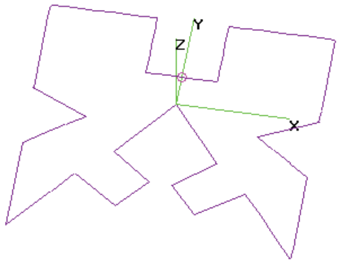
Fig. 5 Radiation pattern in 3D for Modified Minkowski antenna.

B- Fractal of Koch-Square Loop

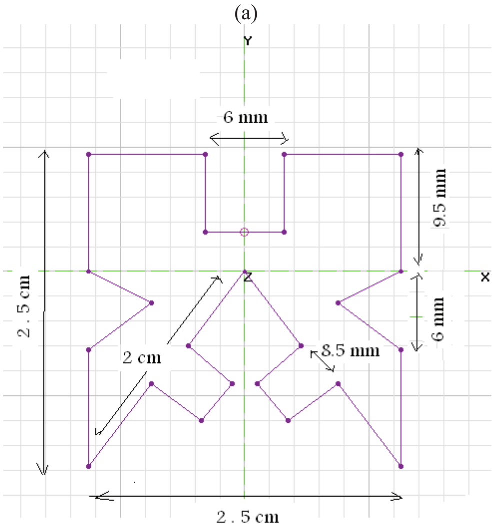
This design is illustrated in Fig. 6 and comprises three squares with Koch curves. The size of the elementary square is the same as for the dipole design, 6 x 6 mm and Koch curves, which are adjusted to the resonant frequency. The geometry of the antenna in 3D is given in Fig. 6-a with θ = 37° and $\varnothing$ = 279°. The projection in the x-y plane is plotted in Fig. 6-b. The initial length is 2.5 cm and the fractal elements are 8.5 cm, and 6 cm for the square part, while for the triangular part are 2.5 cm and 6 mm. The total number of wires was 23 and total number of segments was 83.

Simulated standing wave ratio is shown in Fig. 7 (top). The resonance frequencies at 2.4 GHz,4.4 GHz, 6.2 GHz, 8.3 GHz, and 10.1 GHz and are related to the number of iterations of the loop structure. These values correspond to -15 dB, -16 dB, -8 dB, -4 dB and -2 dB, respectively, for the reflection coefficient shown in Fig. 7 (bottom). Resistance and reactance of the input impedance with frequency are simulated and the achieved results shown in Fig. 8 (top). It is clear that the changes in input reactance is marginal, while variation in resistances are 2.5 kΩ, 2.4 kΩ, 2.6, 0.4 kΩ kΩ and 0.35 kΩ at the resonance frequencies. The amount of variation in the phase is almost 120° at the first three corresponding frequency, and around 90° for the last two others.

The radiation patterns at the resonant frequencies for the third iterated fractal antenna at its resonant frequencies are shown in figure 9. The antenna is in the x-y plane, as in Fig. 9-a and the patterns are provided for three different planes that correspond to the $\varnothing$ = 90° and 180° and orthogonal planes. These show that, for the first two resonances, the shape of the radiation pattern remains the same. This is unlike a normal dipole antenna, given in the literature, where additional nulls appear with each subsequent resonance. This difference is due to the overall size of this radiator remaining less than that of an equivalent linear dipole at these frequencies.



(a)



(b)

Fig. 6 The layout of Koch-Square loop fractals (a) in 3-D with θ = 37° and $\varnothing$ = 279° and (b) in x-y plane.

The Figure 9 illustrates the radiation pattern for the antenna when in the three different planes: $\varnothing$ = 0° (a), $\varnothing$ = 90° (b), and $\varnothing$ = 180° (c). The achieved results show the symmetry in the pattern when the difference between the planes is 180°. The 3-D pattern is shown in Fig. 10. The radiation is perpendicular to the plane of the antenna.

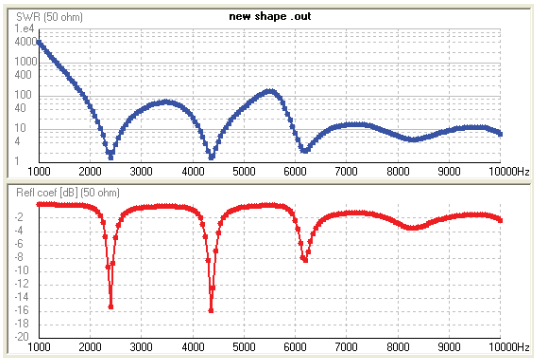


Fig. 7 Standing wave ratio (top) and reflection coefficint (bottom) as a function of the frequency.

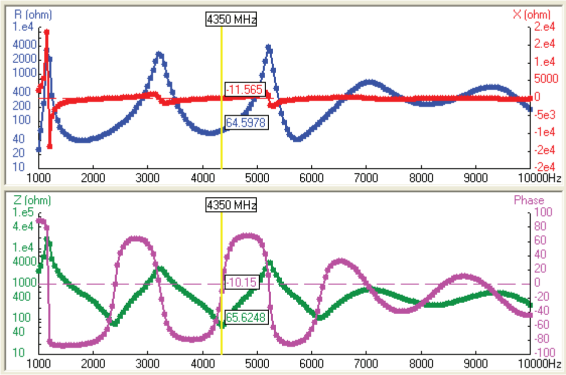
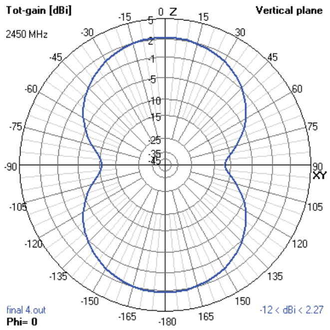
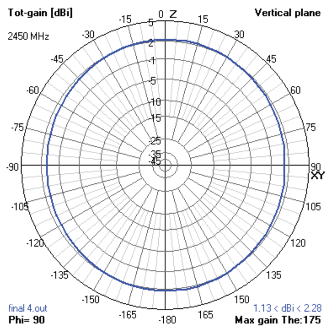


Fig.8 Input impedance: resistance (top) and total impedance (bottom) as a function to the frequency.



(a)



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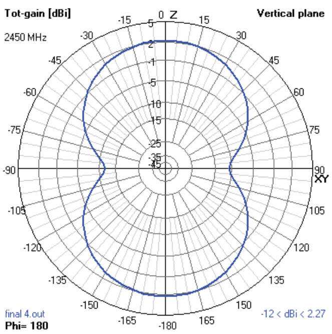

(c)

Fig. 9 2D radiation patterns: (a) Ø = 0°, (b) Ø = 90°, (c) Ø = 180°.

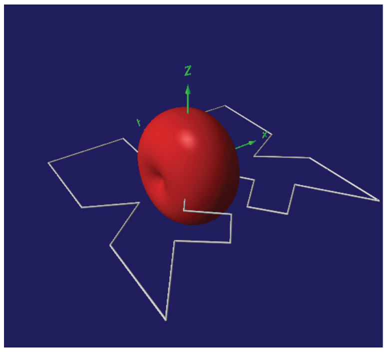

Fig. 10 Radiation pattern in 3D for Koch-Square Loop antenna.

III. Conclusions

This paper has presented designs for two structures of fractal antennas namely a Modified Minkowski and a Koch-Square Element. Both can be used for UWB applications within the FCC specification. The proposed antennas were simulated with using the 4NEC2X simulator. Results have shown that the gain is relatively high in the direction perpendicular to the plane in which the antennas lay. For these antennas, since the input impedance is close 50Ω, the necessity for additional matching components is lessened.

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