The Full Wave Analysis of Fractal Antennas

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Abstract: The Full Wave Method(FDTD) was used to analysis some fractal antennas. The computational results are in good agreement with the experiments in the documents for the Hilbert curve . The results shown that fractal geometries can be implemented to miniaturize the antenna size compared to the normal antenna, too. Also the self-similar nature in the Sierpinski fractal geometry can be utilized for operating a fractal antenna at various frequencies, Furthermore, the far field patterns of the fractal antennas remain almost the same at their resonant frequencies.

Key words: fractal, antenna, FDTD

1. Introduction: Challenges in Telecommunication services require a major integration of actual and future systems (GSM, CDMA, DECT, GPS, 3G systems...) and a full mobility (terminal size and weight reduction, low consume, wide coverage). These trends need the improvement of antenna multiband behavior and size reduction. Since they were first described by the French mathematician Benoit Mandelbrot in the mid-1970s, repeating geometric figures known as fractals[1]have fascinated many scientists. Fractal antennas[2][3] and fractal arrays are also notable recently. A fractal element antenna, or FEA, is one that has been shaped in a fractal fashion, either through bending or shaping a volume, or introducing holes. The fractal antenna have mutiple-frequency bands. The individual band corresponding to resonant frequencies are generally narrow, other important feature of this fractal antenna include low profile. Hilbert curve fractal antenna with several important characteristics was recently proposed[6].The Method of Moment has been used for Hilbert fractal antenna analysis, and the difference between the experiment and the calculation is evident[6]. In this paper, The FDTD method[7] was used for the analysis of the Hilbert fractal antenna , the Input impedance and patterns were calculated . Further, The application of Hilbert fractal and the Sierpinski fractal antenna on the multiband and low profile antenna were also analyzed.

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2.The Fractal structure of Hilbert curves antenna

Various iteration stages of fractal Hilbert curves and H curves are shown in Figure 1 and Figure 2 separately. In Figure 1 It may be observed that geometry at a stage can be obtained by putting together four copies of the previous iteration, connected to additional line segments.

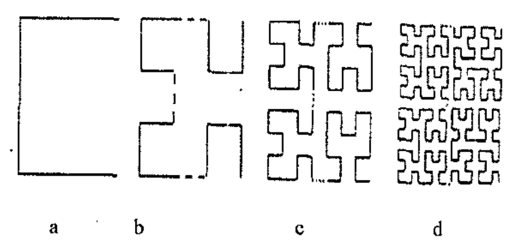


Fig1 Generation of four iteration of Hilbert curve (a.order=1,b.order=2,c.order=3,d.order=4)

It would be interesting to identify the fractal properties of these geometries. The plane-filling nature is evident by comparing the first few iterations of the geometries. With the increasing of the orders, The Hilbert curves are almost filling a plane. This could lead to a significant advantage in antennas since the resonant frequency can be reduced considerably for a given area by increasing the fractal iteration order. Thus, These approach strive to overcome the fundamental limitations of small antennas.

3 FDTD analysis of the antennas:

The FDTD full wave method is very suitable for modeling fine structure, the dielectric present can be taken into account easily if necessary, and all the frequency characteristics can be obtained by just one calculation in time domain, so the FDTD method is very available for the multiband and wideband analysis.

The Voltage in time domain at the feed point can be obtained by,

$$\oint_l \vec{E} \cdot dl = V(t, z_1) \quad , \qquad (3)$$

The current in time domain surrounding the metal strip,

$$\oint_l \vec{H} \cdot dl = I(t, z_1) \quad . \qquad (4)$$

The voltage and current can be obtained after the Fourier transformation:

$$V(\omega, z_1) = \int_{-\infty}^{+\infty} V(t, z_1) e^{-j\omega t} dt \quad , \qquad (5)$$

$$I(\omega, z_1) = \int_{-\infty}^{+\infty} I(t, z_1) e^{-j\omega t} dt \quad . \qquad (6)$$

The input impedance at the feed point can be obtained by,

$$z_0(\omega) = V(\omega, z_1) \Big/ I(\omega, z_1) \quad . \qquad (7)$$

The far field pattern of the antenna can be deduced from the near field value after the transformation in time domain,

$$\begin{aligned} \vec{e}_\theta &= -\mu w_\theta - u_\varphi \\ \vec{e}_\varphi &= -\eta w_\varphi + u_\theta \end{aligned} \qquad (8)$$

all the parameters' notation can be found in[7]

4. Numerical simulation

4.1 Hibert fractal antenna input impedance:

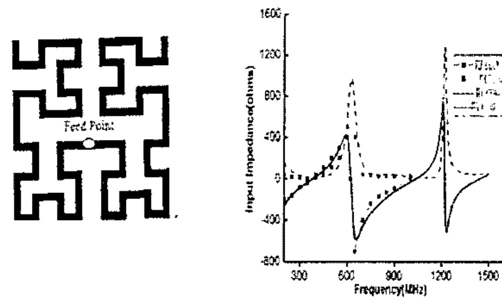


Fig2 Hilbert Fractal antenna(order=3) and its input impedance

The feed source point is located at the point of symmetry for these structure. A fractal geometry of third iteration in Fig3 (nominal outer dimension=7cmx7cm) with a wire of 1.3mm diameter is analyzed for comparison with the experiment[6].

The Gaussian pulse source was used,

$$E_z = e^{-(t-t_0)^2 / T_0^2} \quad , \qquad (9)$$

$$T_0 = 16.7 \times 10^{-12} s, t_0 = 3 T_0$$

The real and imaginary parts of the input impedance of the Hilbert curve fractal antenna with three iterations are shown in Fig 4, it can be seen the simulation results are in good agreement with the experiment. At the same time, the resonant frequencies are 380MHz,1050MHz and 1500MHz respectively (the imaginary part is equal to zero), this shows the multiple resonant characteristics of the antenna, as well as the self-similarity of its characteristics. For Comparison,the lowest resonant frequency of the dipole antenna with length 7cm is 2.14GHz, so the resonant frequency (with the same size)is reduced greatly.

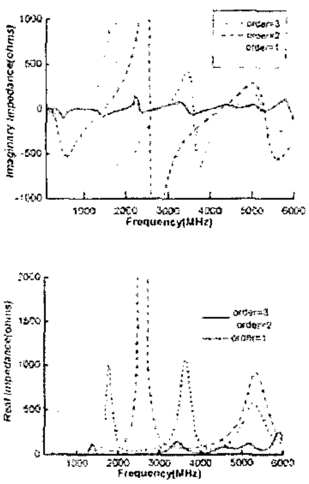


Fig3.The input impedances of Hilbert antenna

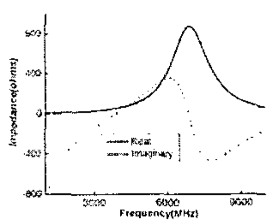


Fig 4 The Input impedance of the dipole antenna

To explore the plane-filling characteristics of the antenna geometry, these iterations are also made within the same area of 3cmx3cm(with a wire of .1mm diameter)and the 1, 2 and 3 order Hilbert fractal input impedance character are shown in Fig3. It shows the self-similarity of the antenna characteristics. Another important one to be noticed is the lowest resonant frequency in each case. The resonant frequencies for the first iteration is 1300MHz, for the second iteration 1000MHz, and for the third iteration 700MHz. This shows a reduction in resonant frequency with an increase in the fractal iteration order, despite the outer dimensions of the antenna remains the same. The lowest resonant frequency for the dipole with length 3cm is about 5 GHz(shown in Fig 4), which is much higher than those of the first iteration of fractal antenna

4.2 The far field of the fractal antenna patterns

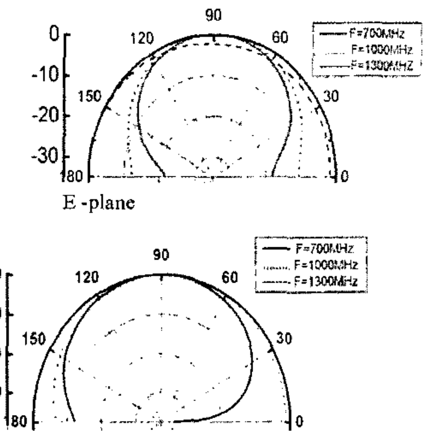
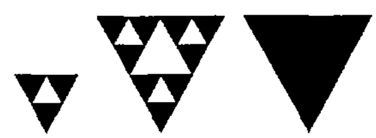


Fig 5 The third iteration of Hilbert curve fractal antenna

The far field pattern of the fractal antenna can be deduced from (8). The result shows that at least for the first two resonances, the shape of the radiation pattern remain the same. This is in contrast to a normal dipole antenna additional nulls appear with each subsequent resonances.

4.3. The Sierpinski[4] [5]and Bowtie antennas



a b c d (a Sierpinski (1 order), b (Sierpinski 2 order),c Big Bowtie,d Small Bowtie)

Fig 6 the profile of the Sierpinski and Bowtie antennas

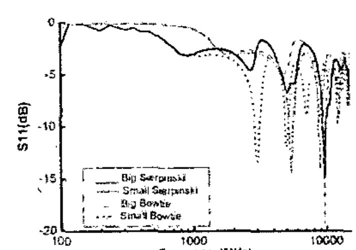


Fig7 The s11 value of the Sierpinski and bowtie

It can be seen from Fig 6 that the bigger Bowtie has the same outline area as that of the Bigger Sierpinski, so for the smaller bowtie and smaller Sierpinski.

Plotted in Fig7 is the input match versus frequency on a logarithmic scale. The bigger Bowtie have the same reflection wave at the same frequency as the those of the bigger Sierpinski, these two antennas occupy the same area, thus their lowest resonances are the same, too. The highest frequency resonances for the bigger Sierpinski is also the fourth resonances of the bigger bowtie antenna. The even logarithmic spacing between the resonances can be seen in this plot.Each resonance is approximately twice that of the one before. This is what would be intuitively expected knowing that the self-similar features of the geometry are scaled be a factor of two for each generating iteration.

5.Conclusions

The effect of self-similarity and plane-filling properties of fractal Hilbert are studied using the FDTD method. The input impedance of the Hilbert fractal antenna is in good agreement with the experiment. The results establish the link between the self-similarity of the antenna geometries and frequency response, such as multiband characteristics for both the Hilbert fractall antennas and Sierpinski antennas. Another important advantage of using Hilbert is its plane-filling characteristics to realize resonant antenna with a smaller overall physical size. Further , the far field patterns remain almost the same at the first two resonant frequencies.

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