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Multiband Behaviour of Sierpinski Fractal Antenna

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ABSTRACT

With the advance of wireless communication systems and their increasing importance, wideband and low profile antennas are in great demand for both commercial and military applications. Multiband and wideband antennas are desirable in personal communication systems, small satellite communication terminals and other wireless applications. This study presents bow-tie printed antenna design and simulation based on dipole antenna concepts and its simulation using Method of Moments (MoM). The wideband response is obtained for this structure. Then MATLAB® is used to implement fractal shapes on the basic configuration. This antenna as a wideband solution is used in monolithic wireless communication applications that require multi-resonance frequencies. These features can be improved by fractalizing the antenna. While the bandwidth of the antenna can be changed by different flare angles, its fractalizing controls the multiband feature without any significant change on the radiation pattern. Numerical results of the antenna radiation characteristics, including input impedance, input reflection coefficient and radiation pattern, are presented and compared for mode-2 Sierpinski fractal shapes which is implemented on the basic bow-tie antenna.

Key words: Multiband antenna, Sierpinski fractal, bow-tie antenna, reflection coefficient, radiation pattern, antenna gain

INTRODUCTION

Multiband and wideband antennas are desirable in personal communication systems, small satellite communication terminals and other wireless applications. Some of these applications also require an antenna to be embedded into the airframe structure. Traditionally, a wideband antenna in the low frequency wireless bands can only be achieved with heavily loaded wire antennas, which usually means that different antennas are needed for different frequency bands. Recent progress in the study of fractal antennas suggests some attractive solutions for using a single small antenna operating in several frequency bands. The self-similar properties of certain fractals result in a multiband behavior of the antennas while, the highly convoluted shape of these fractals makes possible the reduction in size and consequently in mass and volume, of certain antennas as investigated by Puente *et al.* (1998). These reductions can make possible to combine multimedia, communication and tele-detection functionalities in a reduced space like a handy phone, a wristwatch or a credit card e.g., a fractal antenna can provide GPS (Global Positioning System) services within a conventional mobile cellular phone. Since Hertz times, the design of electrically small antennas has always been a topic of great interest, related first to the development of radiotelegraphy and radio broadcasting. In the last few years, the fast growing development of

mobile communication brought the need for devices that require their components to be ever smaller and lighter, capable of adjusting its frequency of operation and to operate in a multiband mode. Some recent results by Puente *et al.* (1998) and Baliarda *et al.* (2000) showed that fractal antennas have excellent multiband properties and low resonant frequencies. An overview of the early work on these antennas is summarized by Werner *et al.* (1999).

Radiation efficiency and impedance bandwidth decrease with the size of the antenna, making small antennas inefficient by nature, for these effects are accompanied by high currents in the conductors, high ohmic losses and large values of energy stored in the antenna near field. The inefficient performance of small antennas is summarized by the high values of its quality factor Q , as predicted by the fundamental limit and stated by Chu (1948) and McLean (1996).

This limit was set assuming that an infinitesimally small antenna radiates only a TE_{10} or TM_{01} spherical mode that depends on the electric size of the antenna given by ka , where k is the wave number at resonance and a the radius of the smallest sphere that encloses the antenna. Real antennas radiate more reactive modes, contributing to larger Q values. Lowering the Q factor of an electrically small antenna, defined as $Q < 1$, is only possible by a proper use of the volume that surrounds it with the objective of exciting only a TE_{10} or TM_{01} mode. Hence in order to meet the following attributes for antenna designs, i.e., the compact size, low profile, conformal and multiband or broadband, a number of approaches for designing multi-band antennas have been summarized by Maci and Gentili (1997).

FRactal ANTENNAS

As we see fractals have been studied for about a hundred years and antennas have been in use for as long. Fractal antennas are new on the scene. Nathan Cohen, a radio astronomer at Boston University, was a fractal antenna pioneer who experimented with wire fractal antennas (von Koch curves) and fractal planar arrays (Sierpinski triangles). He built the first known fractal antenna in 1988 when he set up a ham radio station at his Boston apartment.

Think of a fractal antenna for what it is: a tuned LC circuit. Remember, the distinction between wideband and multiband is “simply” a question of size of the gaps between frequencies of similar antenna performance compared to the fineness dictated by the application.

Fifty years ago V.H. Rumsey, a candidate for the title Father of the Frequency Independent Antenna, developed what has become our modern notion of broadband antennas. Rumsey’s principle is that the impedance and pattern properties of an antenna will be frequency independent if the shape is specified only in terms of angles (Kraus, 1998).

Rumsey’s work was, no doubt, inspired by the 1949 publishing of the work of Mushiake and Uda on the constant impedance of self-complementary antennas for all frequencies (half the intrinsic impedance of free space).

The search for the super wideband antenna is driven by two desires: (1) make an antenna for a given frequency band as small as possible and (2) make an antenna cover several (many) bands. The fractal antenna has performance parameters that repeat periodically with an arbitrary fineness dependent on the iteration depth.

Therefore, although the finite iteration depth fractal antenna is not frequency independent, it can cover frequency bands arbitrary close together! Also, remembering that radiation comes from accelerating charges, the typical fractal shape (with all those little bends and kinks) makes for good radiation (higher radiation resistance) because of all that acceleration going on as the charges are forced to negotiate all those sharp turns.

Some results by Puente *et al.* (1998) and Baliarda *et al.* (2000) showed that fractal antennas have excellent multiband properties and low resonant frequencies. An overview of the early work on these antennas is summarized by Werner *et al.* (1999).

There has been a considerable amount of recent interest with the possibility of developing new types of antennas that employ fractal rather than Euclidean geometric concepts in their design. Today the best tools for fractal antenna analysis are hybrid type antenna modelers based on traditional Method of Moment (MoM) analysis (Hodges and Rahmat-Samii, 1997).

SIERPINSKI FRACTAL ANTENNA

Using a bow-tie as a generator, a crescent number of triangles are removed in the half of height of anterior space to create a Sierpinski antenna. This defines the growth of fractal. To each growth realized, a new resonant frequency is obtained. The scale factor of a location of the new triangle (half of height) defines the rate of a new resonant frequency (approximately). Figure 1 shows some stages obtained in a bow-tie antenna.

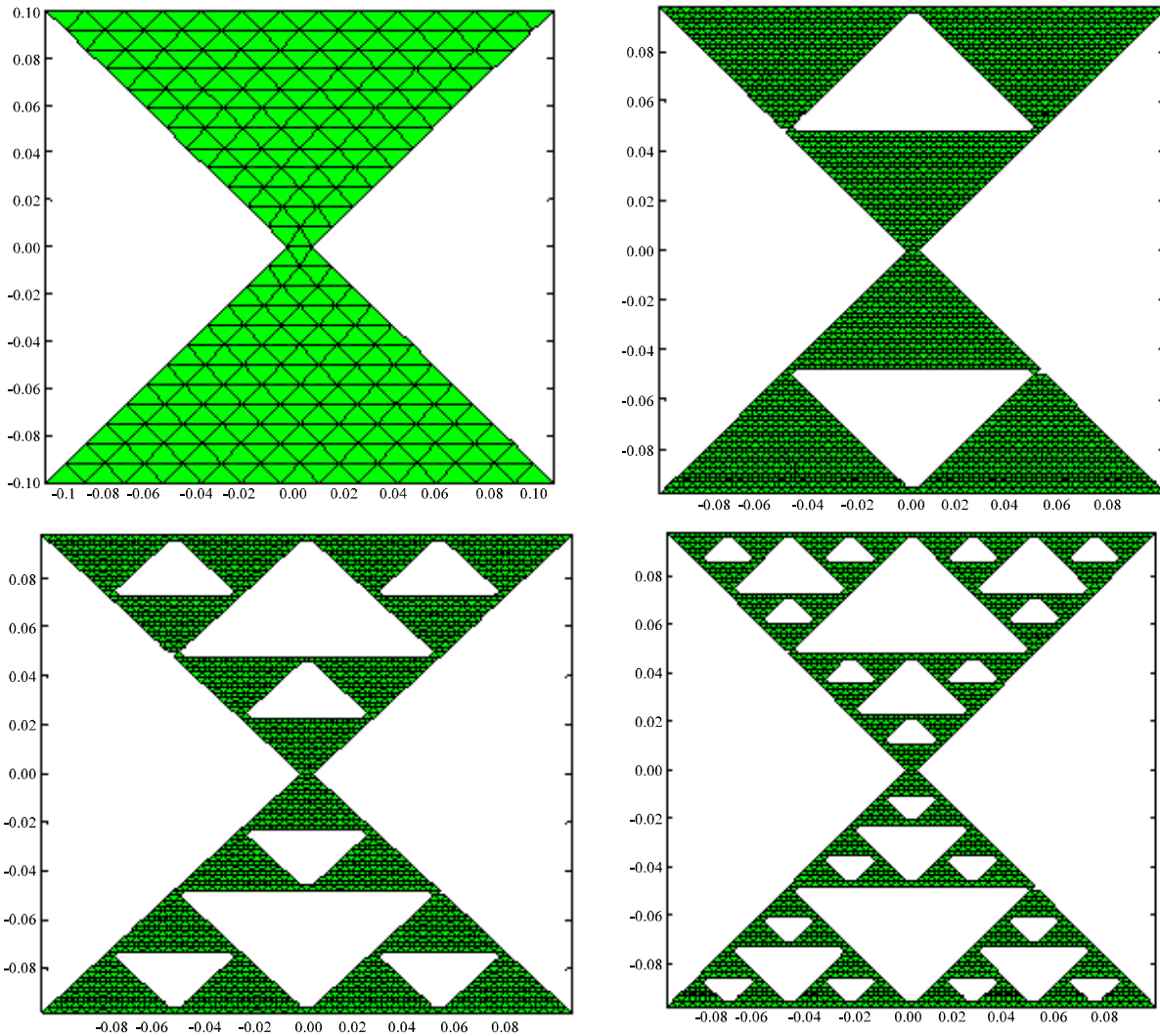


Fig. 1: Geometry of the bow-tie fractal antenna

To the first stage, one triangle is removed of the antenna. To the second stage, one triangle is removed in each triangle created in the anterior stage and so on.

DESIGN METHOD

The good way to design a fractal antenna involves, basically, the definition of six items:

- Size of the seed antenna
- No. of bands wanted
- Stage of growth of the fractal
- Stage of growth of the dipoles in the method of the moments
- Feeding point
- Angle of the antenna

The seed antenna will generate the next stages of fractal antenna. The dimensions of the seed antenna define the first frequency in the Sierpinski antenna. The number of bands wanted defines the growth of the fractal. The growth stage is the same of the number of frequencies minus one. Puente *et al.* (1998) observe in the Fig. 1 that when the number of stages begins to grow, the format of the generated triangles becomes round. Such effect provokes simulation mistakes with the method of the moments. Then, when the number of stages grows, it is necessary to increase the dipoles number in the method of the moments. Varying the angle of the antenna, the reason among the obtained frequencies varies. Like this, it is possible to accomplish a fine adjustment in the wanted frequencies.

RESULTS

The simulated bow-tie and Sierpinski Fractal antenna with stage of growth $S = 2$ and flare angle 90° is shown in Fig. 2. Figure 3 and 4 compare the input impedance of the fractal antenna with input impedance of bow-tie antenna. The impedance behaviour of the fractal antenna indicates a typical resonant structure. The input resistance has large peaks, whereas the input reactance has multiple nulls.

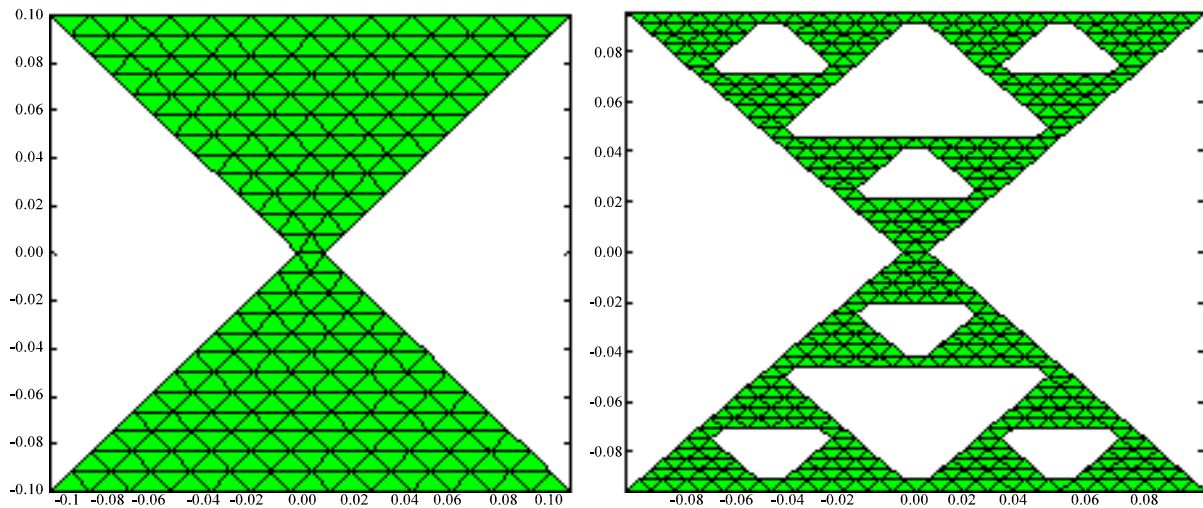


Fig. 2: Simulated Bow-tie and Sierpinski Fractal antenna with stage of growth $S = 2$ and flare angle 90°

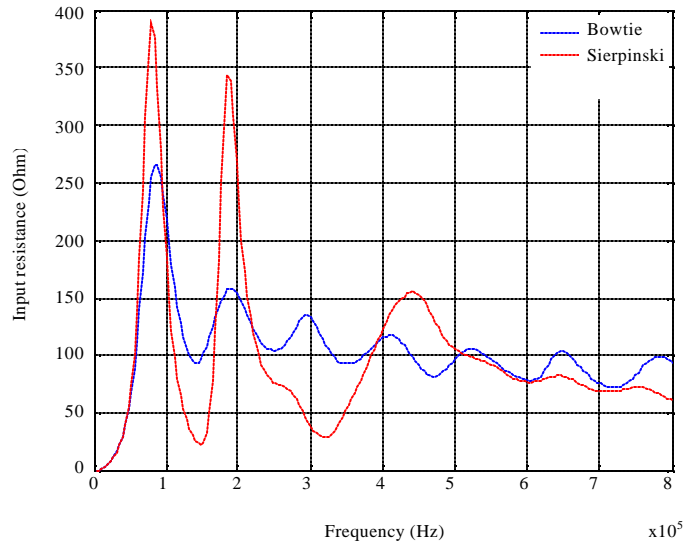


Fig. 3: Fractal antenna input resistance as a function of frequency (ratio of total length/wavelength). Resistance of equivalent bow-tie

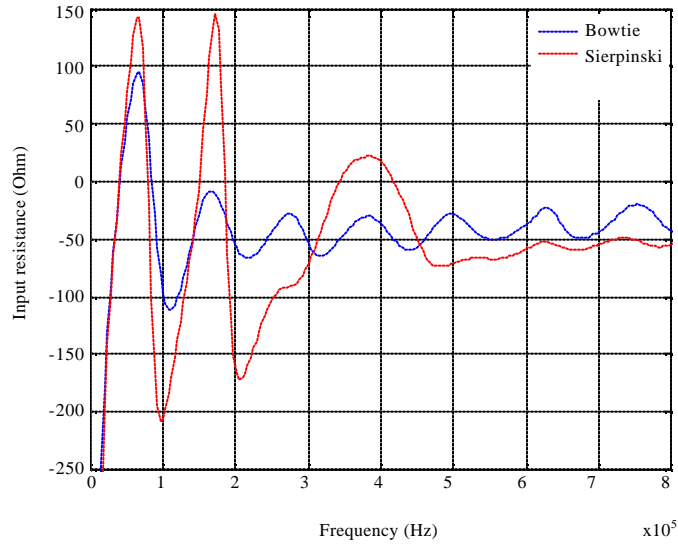


Fig. 4: Fractal antenna input reactance as a function of frequency (ratio of total length/wavelength). Reactance of equivalent bow-tie

In the analysis of impedances, the multi-band behaviour of the fractal is not yet specified. We are interested in the resonances that are characterized by the zero input reactance and maximum power radiated by the antenna. Furthermore if the input resistance at these resonances will be well matched to a 50Ω load, the multi-band behaviour will be established.

The radiated power of the fractal antenna and of equivalent bow-tie is shown in Fig. 5. At low frequencies (below 0.5 GHz) both power dependencies are nearly the same. It is observed that the fractal antenna has three resonances. The number of resonances is thus the number of fractal

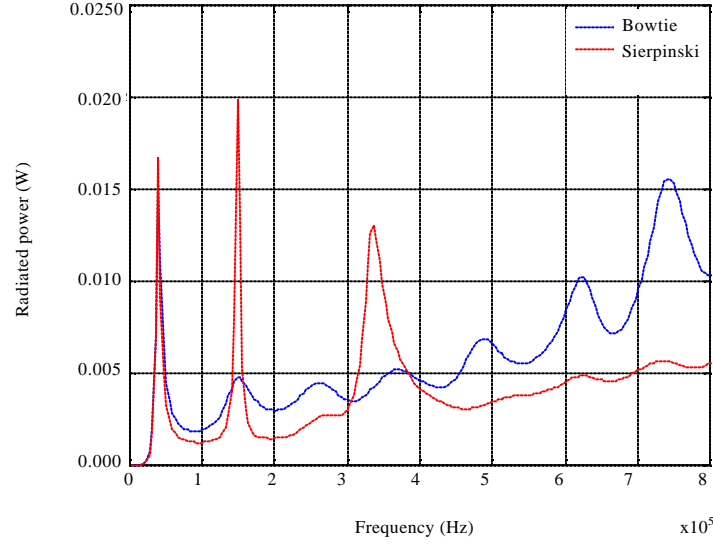


Fig. 5: Radiated power of the fractal and bow-tie antennas

stages ($S = 2$) plus one. The first resonance is that of the pure bow-tie and corresponds to $f_1 = 0.4$ GHz. This resonance occurs whether or not the fractal structure is present. The second resonance $f_2 = 1.48$ GHz corresponds to first fractal iteration and the third resonance at $f_3 = 3.367$ GHz corresponds to the second fractal iteration. The frequency ratios

$$\frac{f_2}{f_1} = 3.7 \frac{f_3}{f_2} = 2.27$$

Asymptotically tend to 2 when the number of fractal stages increases as predicted by theory Puente *et al.* (1999). The resonant bands are thus log-periodically spaced, by a factor of 2, which is exactly the scale factor that relates triangle size at each stage of growth.

To investigate the resonances more properly, the input reflection coefficient, Γ , of the transmitting antenna is checked, which is given by the equation

$$\Gamma = \frac{Z_A - 50\Omega}{Z_A + 50\Omega}$$

Figure 6 shows the magnitude of the reflection coefficient to logarithmic scale versus frequency. It is seen that the power resonances are directly associated with the minima of the reflection coefficient, which enables us to design a well-matched antenna at these frequencies.

The corresponding resonance bands are the multi-bands of the fractal antenna. The relative bandwidth at each band typically reaches 7 to 20% Puente *et al.* (1999). Figure 7 shows the surface current distribution on the fractal antenna surface at $f_2 = 1.4$ GHz (second resonance). The self-similarity of the current distribution can be observed. Figure 8 and 9 gives radiation

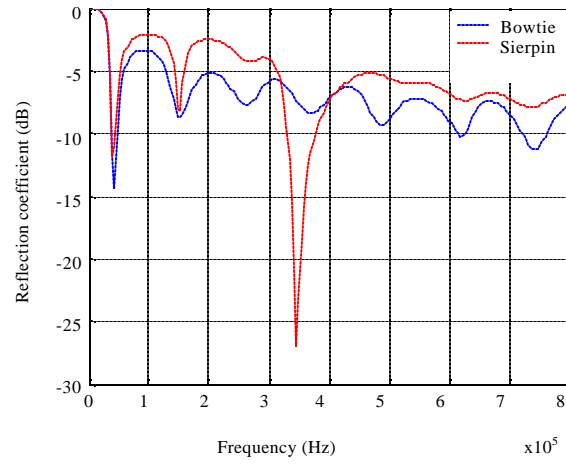


Fig. 6: Input reflection coefficient of the fractal and bow-tie antennas

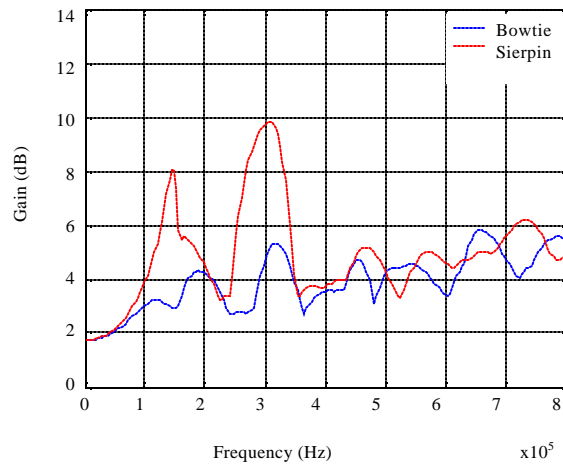


Fig. 7: Gain of the fractal and bow-tie antennas

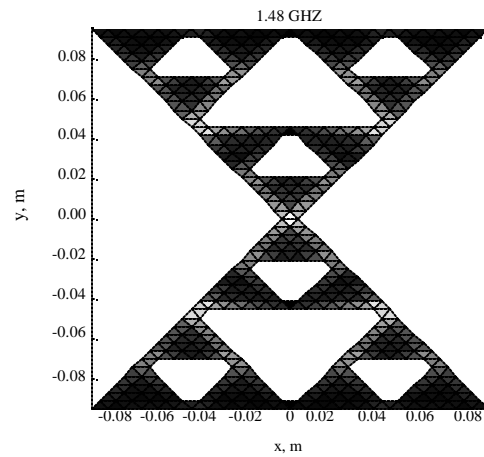


Fig. 8: Fractal antenna surface current distribution at second resonance

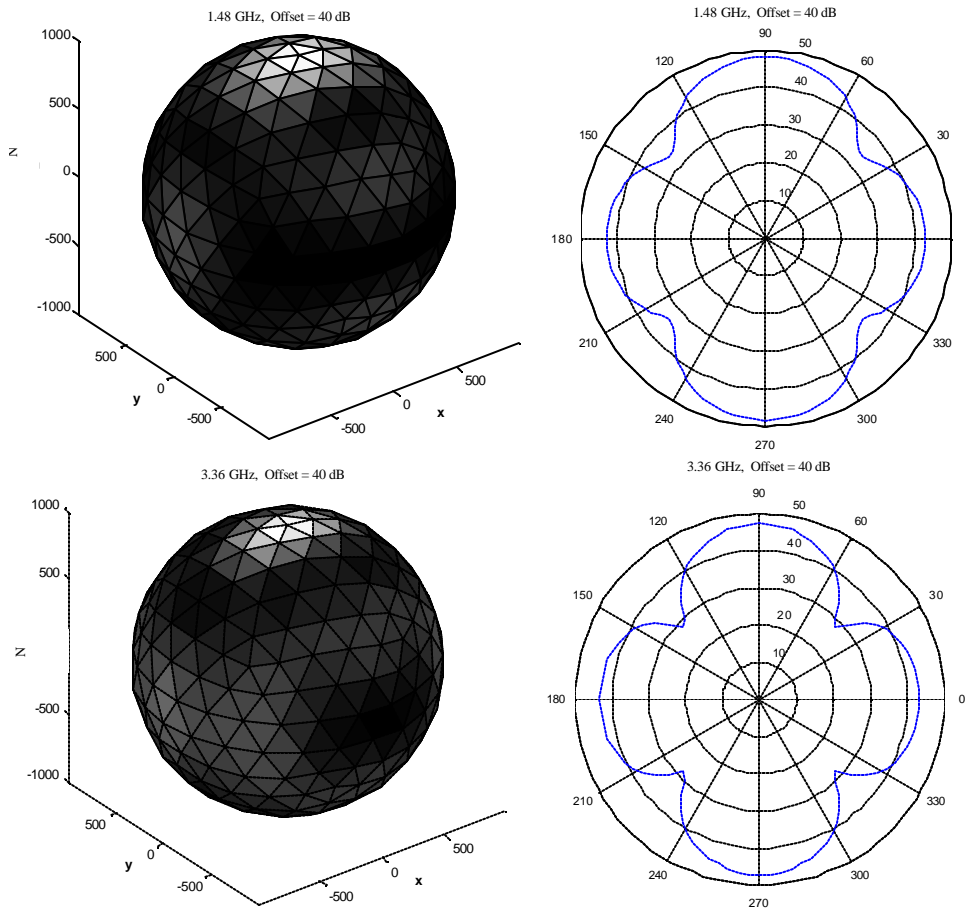


Fig. 9: Radiation pattern for second and resonance of the fractal antenna

patterns at second and third resonant frequencies, respectively. Compared to the bow-tie radiation patterns, the fractal antenna produces a directional beam of higher gain at the resonant frequencies.

CONCLUSION

Applying Sierpinski fractal shapes on a bow-tie antenna will cause the total frequency band of the antenna to be repeated in a log-period basis with a spacing factor, which is related to the mode of the fractalizing scheme. Mode-2 fractal shape is investigated in this study to show how these fractions affect the operating band of the main antenna.

Since, the primary structure of the antenna is a multiband one we can set the repeated resonances between those operating bands by using different fractal shapes, flare angles and proper dimensions of the main structure. In this way, fractal shapes give us an extra freedom in spacing the operating frequencies in desired bands and bandwidths; moreover, they provide multiband and wideband features simultaneously. These antennas can be used in any communication system that is supposed to operate in different frequency bands and requires a relatively high bandwidth and a constant radiation pattern in all operating frequencies.

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