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Fractal Dielectric Resonator Antenna for Wideband Applications

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Abstract—*The Co-planar waveguide slot loop fed fractal dielectric resonator antenna is proposed for wideband wireless applications. The antenna uses Minkowski fractal shape for design and optimization. Self-similar property of fractal geometry is utilized to bring higher order modes close together to realize a wide impedance bandwidth. Furthermore, using dielectric resonator improves bandwidth and radiation characteristics. Antenna simulation and optimization is carried out using Ansoft HFSS. It is shown that proper adjustment of the indentation factor (iterations) results in merging of higher modes to give a wide impedance bandwidth.*

Keywords: *DRA, Minkowski Fractal, Co-planar waveguide, Wideband*

1. INTRODUCTION

Wireless communications have grown at a very rapid pace across the world over the last few years, which provide a great flexibility in the communication infrastructure of environments such as large office buildings, hospitals, factories. Wireless technology has undergone different phases of development ever since its inception. Over the years there have been different standards of this technology that evolved out of the demands. Presently, in strategic as well as public domain the wireless devices and systems need to cater to different frequencies, should be small in size, broadband and should be of low cost [1]. To achieve the necessary applications a high performance wide band antenna with excellent radiation characteristics are required. Over the past few years, the dielectric resonator antenna (DRA) has received extensive attention due to its several advantages such as light weight, shape flexibility, low profile, low dissipation loss, high dielectric strength and higher power handling capacity, different available feeding mechanism. DRA can be in a few geometries including cylindrical, rectangular, spherical, half-split cylindrical, disk, hemispherical and triangular shaped [2].

On the other hand, Fractal shaped antennas exhibit some interesting features that stem from their inherent geometrical properties. The self-similarity of certain fractal structures results in a multiband behaviour of self-similar fractal antennas and frequency-selective surfaces. From the other point of view, high convoluted shape and space-filling properties of certain fractals allow to reduce volume occupied by a resonant element. Although complex objects with similar properties of the fractals could be defined, the use of fractal geometries has the advantage that irregular complex objects can be described in a well-defined geometrical framework.

The main motivation of this project is now a days, mobile communication systems are becoming increasingly popular. Antennas for software-defined and / or reconfigurable radio systems need to have ultra-wide band or multi-band characteristics in order to be flexible enough to cover any possible future mobile communication frequency bands. One approach to provide such flexibility is to construct multi-band antenna that operates over specific narrowband frequencies. However, it would be extremely difficult to accurately achieve the frequency requirements of all future communication system. Alternatively, a small wideband antenna that covers a wide range of frequencies can be a good candidate not only for current multi-band applications but also for future communication systems operating on new frequency bands. Recently, it has been demonstrated that a wideband monopole antenna is promising to be used for mobile wireless devices such as notebook computers, mobile phones, and PDA (personal digital assistance) phones. With bandwidths as low as a few percent, wide band applications using conventional Microstrip patch designs and DRA designs are limited. Other drawbacks of patch antennas include low efficiency, limited power capacity, spurious feed radiation, poor polarization purity, narrow bandwidth, and manufacturing tolerance problems.

2. LITERATURE SURVEY

Fractal-shaped antennas show some interesting features that stalk from their inherent geometrical properties. The self-similarity of certain fractal geometries result in wideband behaviour of these types of fractal antennas. From another point of view, high convoluted shape and space-filling properties of certain fractals allow to reduce volume occupied by a resonant element. Although complex objects with similar properties of the fractals could be defined, the use of fractal geometries has the advantage that irregular complex objects can be described in a well-defined geometrical framework [5]

The recent years have witnessed a significant focus and interest paid towards the development of Dielectric Resonator Antennas (DRAs). The erstwhile era has been dominated by the growth and development of planar antennas like patch antennas. However, with escalation in frequency of operation of communication systems, the ohmic losses become non-linear and it increases drastically. These losses are completely absent in DRAs due to absence of any metal inclusion. A number of different geometries of DRAs have been well investigated over the years like rectangular, cylindrical, hemispherical, triangular, etc. Every individual shape offers its own advantages in terms of physical dimensions and radiation efficiency. However, the hemispherical geometry has always drawn attention due to simplicity of analysis. A major emphasis has been laid on design of Hemispherical Dielectric Resonator Antennas (HDRAs) for broadband applications. Some of the techniques include multilayer stacking of dielectrics with different permittivity air gap in HDRA modification and generation of new geometries like half HDRA, quarter HDRA A fractal is a mathematical set which means self similar patterns. By self similar pattern, it is meant that the fundamental unit of a structure is the same as the structure itself. This mathematical concept has been extensively used in the planar antennas for wideband applications. In the field of dielectric resonator antennas, a study on the novel frustum shaped DRA with Koch Island and inverted Koch Island has been carried out offering a wide bandwidth of operation. Similarly, novel fractal geometries have been investigated for rectangular and cylindrical DRAs for broadband applications as well [6].

3. SYSTEM DESIGN

3.1 Proposed Antenna Design

Description of Minkowski Fractal Antenna: The design for the proposed antenna has been undertaken in three parts

First, the dimensions of the Euclidean rectangular DRA resonating in the TEy111 mode are calculated using Marcatili's dielectric waveguide model as shown below

$$f_r = \frac{c}{\sqrt{\varepsilon_r}} k = \frac{c}{\sqrt{\varepsilon_r}} = \sqrt{k^2{}_x + k^2{}_y + k^2{}_z} \quad (1)$$

$$\text{Where,} k_x = \frac{\pi}{A_i k_2} = \frac{\pi}{2H}$$

$$k_y \tan\left(\frac{k_y B}{2}\right) = \sqrt{(\varepsilon_r - 1)(k^2{}_0 - k^2{}_y)} \quad (2)$$

$$\text{Also} k^2{}_x + k^2{}_y + k^2{}_z = k^2 = \varepsilon_r k^2{}_0 \quad (3)$$

Where f_r is the design frequency kx, ky, kz and are the wave numbers in the x,y,z directions, respectively. A, B and H are the length, width and height of the DRA, respectively, and ϵ is the permittivity of the DRA. DRA material of permittivity ϵ =10mm is chosen for this study.

The above equations yield dimensions of A= 21mm, B= 18 mm and H=5 mm corresponding to a resonant frequency of 5.5 Ghz. Following the design of RDRA, the CPW fed slot loop in conjunction with dielectric loading is designed as a feed. CPW is chosen as the feed owing to its relatively low loss, ease of fabrication, no drilling of role among other advantages. A thorough study of CPW feed to DRA was done by Ghosh their study reveals that a CPW loop feed occupies the least area. Taking this point into consideration, parametric studies are per- formed to obtain the best resonance characteristics. To design the loop, FR4 is chosen as the substrate with dimensions of 50 mm x 50 mm having relative permittivity of ϵ = 4.4 and height d=1.6 mm. Once the Euclidean DRA has been characterized fractal geometry is applied on its boundary as shown in Fig. 1

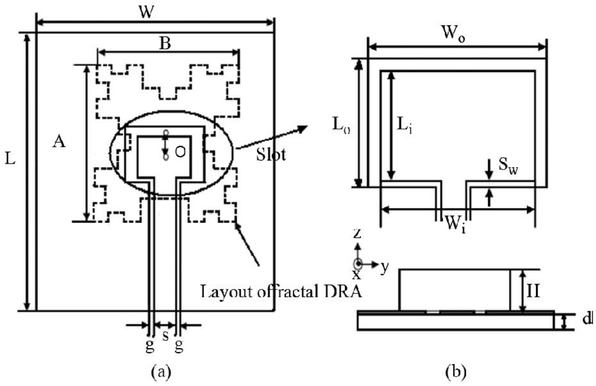

Fig. 1: Configuration of Antenna: (a) Top view with feed layout and (b) Side view.

The generation procedure for the fractal is depicted in Fig. 2. The fractal is formed by displacing the middle one-third of each straight segment (indentation length) by some fraction called the indentation width. Indentation factor: (i) is defined here as the ratio of indentation width to the indentation length. The resulting structure has five segments for every one of the previous iteration, but not all of the same scale. Changing the indentation factor causes a shift in the resonant frequencies, so proper tuning of the indentation factor is necessary to obtain wideband characteristics.

3.2 Parametric Study of Fractal DRA

In this section we will focus on utilizing self-similar properties of fractal geometry to increase the bandwidth. Since we started with rectangular geometry, Minkowskiisland is a good choice for the fractal geometry to be implemented. The finalized design parameters for the Euclidean geometry are chosen as the initial parameters for the parametric study of fractal DRA (FDRA). The parametric study was limited to the second iteration keeping in mind fabrication tolerances.

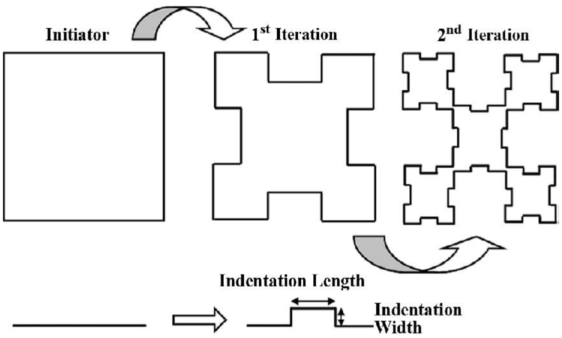

Fig. 2: Generation of a Minkowski Island Fractal Curve.

1) Rectangular DRA (Initiator): As described in the previous section a CPW slot loop fed rectangular DRA is designed as the initiator to the ensuing fractal designs. To improve coupling between the DRA and the feed section, a tuning stub is incorporated in the design. DRA fed by a CPW slot loop with and without a tuning stub.

2) Indentation Width (First Iteration): In the first stage of parametric study we investigate the effect of change in indentation width while keeping the indentation length fixed at one third of the linear segment. Fig.2 shows the reflection coefficient characteristics when the indentation width is varied. The variations in resonant frequency and bandwidth with change in the indentation factor are shown in fig. It is seen that with an increase in indentation factor the resonant frequency keeps increasing. This increase in frequency may be attributed to a reduction in the overall dielectric material. From (1) we notice that the resonant frequency of the DRA is dependent on its size or volume. Hence a decrease in the overall volume results in an increase in the resonant frequency. It is also noticed with an increase in the indentation factor higher order modes tend to converge resulting in a wideband response. Further increase in indentation factor results in an increase in the indentation width with a corresponding deterioration of impedance matching. This happens because the slot loop gets exposed with an increase in the indentation factor resulting in impedance mismatch.

3) Indentation Width (Second Iteration): In this stage of our study we analyze the effect of a second order iteration on the RDRA boundary. Here too it is evident that as the indentation factors increase the resonant frequencies increase. By carefully observing the electric field pattern of the fractal DRA it is seen that the first and second resonances for the fractal geometry may be attributed to the larger inner rectangle of the DRA, whereas; the third resonance may be accredited to the four outer rectangles of the DRA. The similarities in the first two resonances indicate that incorporation of fractal geometry results in self-similar behaviour of the antenna as predicted. It is convenient for the designer to have an approximate formula to calculate the resonant frequency.

3.3 Co-planar feed

The Co- planar feed is a very common technique used for coupling in dielectric resonator antennas. The coupling level can be adjusted by locating the DRA over the loop. The coupling behaviour of the co-planar loop is similar to coaxial probe, but the loop offers the advantage of being non-obtrusive. By moving the loop from the edge of the DRA to the canter, one can couple into either the HE11 mode or the TE011 mode of the cylindrical DRA.

4. CONCLUSION

An investigation on the use of fractal geometry in dielectric resonator antennas for bandwidth enhancement is performed in this work. A novel Minkowski boundary fractal geometry with a CPW fed loop slot is proposed and characterized. Parametric study is carried out to investigate the antenna design parameters.. The fractal DRA has also been compared to its more conventional fractal patch counterpart.

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