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Fractal Based Miniaturized Microstrip Patch Antenna for Data Communication

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Abstract—**In this paper, simple Microstrip Patch antenna is presented. Further by introducing fractal concept to the Microstrip Patch antenna, bandwidth enhancement, self similarity, space filling properties are obtained. The space-filling property of fractal geometry is explored for size reduction by Sierpinski carpet iterations. The iteration is performed up to third order. The parameters of all the four antennas are optimized to a resonant frequency of 2.45 GHz. These antennas have many applications in short-range data communications such as wireless sensors, RFID and PAN. A comparison of fractal antenna with conventional Microstrip patch antenna is made regarding the bandwidth, radiation pattern, return loss, VSWR, and gain. Ansoft HFSS 11 is used to simulate the fractal antenna and Microstrip patch antenna.**

*Key Words—**Microstrip patch antenna, E-shaped Fractal, Sierpinski carpet, self-similar structures.***

I. Introduction

The increasing range of wireless telecommunication services and related applications is driving the attention to the design of small antennas. The telecom operators and equipment manufacturers can produce variety of communications systems, like cellular communications, global positioning, satellite communications, and others, each one of this systems operates at several frequency bands. To give service to the users, each system needs to have an antenna that has to work in the frequency band employed for the specific system. The tendency during last year's had been to use one antenna for each system, but this solution is inefficient in terms of space usage, and it is very expensive. The variety of communication systems suggests that there is a need for low cost, low profile, and miniaturized antennas.

Microstrip patch antennas with several advantages such as conformal nature, light weight, and easy integration with printed circuitry have made them perfect antennas meeting these requirements. Several methods have been suggested to reduce the size of Microstrip patch antenna. The conventional patch antennas are modified in various ways to reduce the size of antennas. The use of fractal geometry to conventional antenna structures is a new solution to the design of miniaturized antennas.

Fractal geometries have found an intricate place in science as a representation of some of the unique geometrical features occurring in nature. Fractal was first defined by Benoit Mandelbrot [5] in 1975 as a way of classifying structures whose dimensions were not whole numbers. These geometries have been used previously to characterized unique occurrences in nature that were difficult to define with Euclidean geometries, including the length of coastlines, the density of clouds, and branching of trees [5]. Fractals can be divided into many types; various types of fractal geometries are shown in Figure 1. The purpose of this article is to introduce the concept of the fractal, review the progress in fractal antenna study and implementation of fractal antenna and compare with Microstrip patch antenna.

Fractal is a geometrical shape that has two common properties of self-similarity and space filling, which are absent in Euclidean geometries. Self-similarity means, each part of the shape is a smaller version of the parent shape or original shape. It provides additional flexibility in antenna design by allowing reduction of antenna by same factor or different factor horizontally and vertically. This property can be applied to the design of multiband fractal antennas such as the Sierpinski Gasket Antenna [3] [4]. Space filling property can lead to the miniaturization of antenna.

The proposed antenna presents the application of fractal geometry to conventional antenna for optimization of its shape in order to reduce their overall size. This is due to the space filling property of fractal geometry.

This paper is organized as follows. The design of generator and Sierpinski Carpet Microstrip Patch Antenna (SCMPA)'s iterations along with feeding technique is discussed in Section II. Section III presents the simulation performed and the obtained results. The paper is concluded on Section IV.

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II. Antenna design

A. Generator

The rectangular Microstrip patch antenna is taken as the generator of Sierpinski Carpet Microstrip Patch Antenna as shown in Fig. 1(a). There are three essential parameters for design of patch antenna: resonant frequency (fc), dielectric material of the substrate (ε_r), and the thickness of substrate.

2.45 GHz has been chosen as the design frequency because of its low-cost components, location in ISM (industrial, scientific, and medical) band, and extremely low attenuation through the atmosphere. This frequency is used in WLAN (Wireless local Area Network), Bluetooth, RFID (Radio Frequency Identification) based wireless sensor nodes and other wireless applications. The dielectric material of the substrate selected for this design is FR-4 which has a dielectric constant (εr) of 4.7 and loss tangent equal to 0.019 with thickness of 1.6 mm.

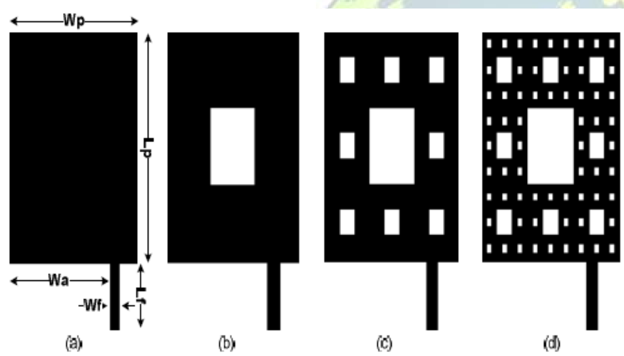

Figure.1 Schematics of designed antenna (a) Generator (b) Iteration 1 (c) Iteration 2 (d) Iteration 3

The design procedure of patch antenna is based on the transmission line model where patch dimensions are calculated by following the given simplified formulation [10].

The width of the antenna can be determined by

$$W = \frac{c}{2.f_c.\sqrt{\frac{\varepsilon_r + 1}{2}}} \quad (1)$$

The effective dielectric constant can be obtained by

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12.\frac{h}{W}\right]^{-\frac{1}{2}} \quad (2)$$

The dimension of the patch (length) is given by,

$$L_{eff} = \frac{c}{2.f_c.\sqrt{\varepsilon_{reff}}} \quad (3)$$

And its length is extended on each end by a distance ΔL due to fringing effect, which is given by,

$$\Delta L = 0.412\,h\,\frac{(\varepsilon_{reff} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{reff} - 0.258)\left(\frac{W}{h} + 0.8\right)} \quad (4)$$

The actual length L of the patch is given by,

$$L = L_{eff} - 2.\Delta L \quad (5)$$

W, L, h , f c, Ɛr, Ɛeff are width of patch, length of patch, eight of substrate, resonant frequency, dielectric constant of substrate, and effective dielectric constant of substrate in equation (1),(2),(3), (4) and (5) respectively.

B. SCMPA's Iterations

Miniaturization techniques on fractal structure involve the process of removing some part of the basic structure. In this paper, compact size antenna is obtained by etching the rectangular Microstrip patch as Sierpinski carpet of different iteration orders. In Sierpinski Carpet design, initially the rectangular patch is divided into nine smaller congruent rectangles and the central rectangle is removed. In further iteration, the remaining eight rectangles are divided into nine more congruent rectangles, removing central rectangle from each rectangle, and the similar procedure is followed for the other iteration. The schematic design of Sierpinski carpet of iteration 1, 2, and 3 is shown in Fig. 1(b), Fig.1(c), and Fig.1 (d) respectively.

The iterative process is based on the following rules:

$$N_n = 8^n \quad (6)$$

$$L_n = \left(\frac{1}{3}\right)^n \quad (7)$$

$$A_n = \left(\frac{8}{9}\right)^n \quad (8)$$

Where Nn is the number of rectangles covering the radiating material, Ln is the length ratio, and An is the ratio for the fractional area.

C. Feeding Techniques

There are many configurations that are used to feed Microstrip antennas. Among them, Microstrip line, coaxial probe, aperture coupling, and proximity coupling are the

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popular one. Sierpinski Carpet can be feed by coaxial or co-planer waveguide [11] but Microstrip line feeding is chosen in proposed antenna because of its simplicity to feed the generator and SCMPA's iterations as shown in Fig. 1(a), Fig. 1(b) , Fig. 1(c), and Fig. 1(d) respectively. The optimum feed point is necessary for better performance of an antenna. The antenna performs best when the transmission line is placed at a point where the current does not face any obstruction, and can be easily distributed over the entire patch [12]. In the proposed design, the feed position is adjusted for better performance and impedance matching by moving it slightly away from the center of the patch.

III. PARAMETRIC STUDY AND SIMULATION RESULTS

The antenna was simulated in Ansoft HFSS10 which is a high performance full-wave electromagnetic (EM) field simulator for arbitrary 3D volumetric passive device, having Microsoft windows graphical user interface. HFSS pioneered the use of the Finite Element Method (FEM) for EM simulation by developing/implementing technologies such as tangential vector finite elements, adaptive meshing, and Adaptive Lanczos-Pade Sweep (ALPS). Initially, edge-fed patch antenna was designed with the procedures mentioned in Section IIA. Then Sierpinski Carpet iteration was performed up to 3rd Iteration. The dimension of four antennas is shown in Table I.

Table I. Dimensions of SCMPAs and Size Reduction

Antenna	Wp (mm)	Lp (mm)	Wa (mm)	Area (mm^2)	Area Reduction
Generator	27	34.41	21.3	929.07	
Iteration 1	23.58	34.41	18	811.38	12.67%
Iteration 2	23.66	32.4	18	766.58	17.49%
Iteration 3	23.66	32.4	18	766.58	17.49%

All dimensions are in millimeter. The parameters mentioned in Table I such as Wp, Lp, Wa, and Lf are width of the patch, length of the patch, distance of the feed from edge of the patch, and length of feed respectively. These parameters are shown in Fig. 1(a). Since the dimensions of 2nd and 3rd iteration were similar, the further iteration was not designed as it will not have much effect on the antenna performance.

The optimum dimensions to resonate at 2.45 GHZ with impedance matching for these antennas were obtained through parametric analysis of HFSS for each iteration order. To perform the parametric analysis, initially length and width of patch antenna was modified to make the dip o f return loss at 2.45 GHz. The optimization process is followed by variation of feed position to obtain better impedance matching. The parameter 'Wa' and 'Wf' shown in Fig. 1(a) are adjusted to get good impedance matching. It is perceived that size of antenna is decreased with the increment of iteration order. The size reduction of 13% and 18% is observed after 1st iteration and 2nd iteration respectively. The area reduction with respect to generator is also shown in Table I.

The antenna parameters that were analyzed to evaluate their performances are Return loss, Radiation pattern, VSWR, and Gain. The simulated return loss of generator, iteration 1, iteration 2, and iteration 3 are shown in Fig. 2(a), Fig. 2(b), Fig. 2(c), and Fig. 2(d) respectively.

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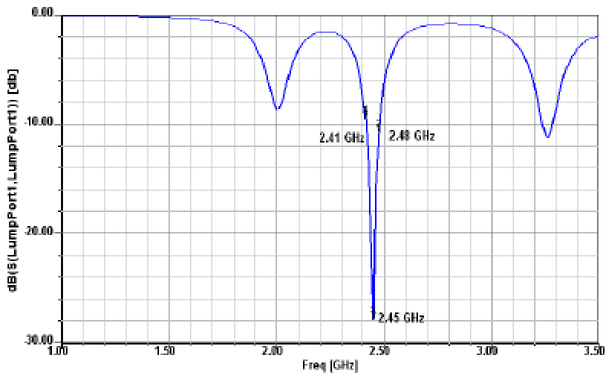
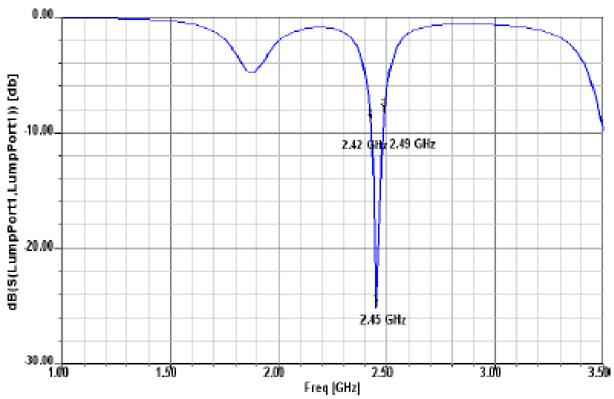
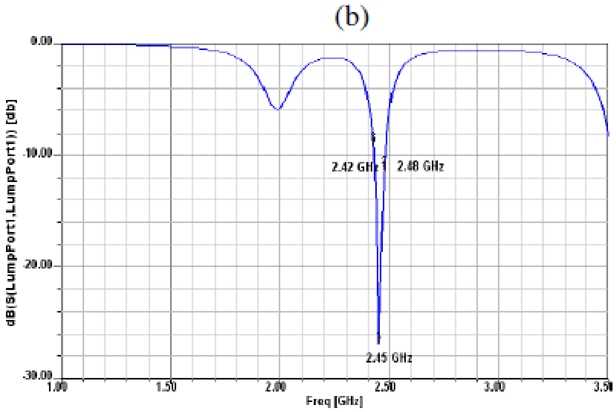


(a)



(b)



(c)

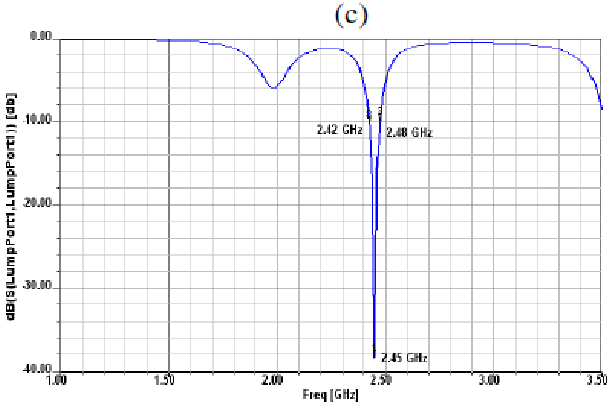


Figure.2 Simulated Return Loss of (a) Generator (b) Iteration 1 (c) Iteration 2 (d) Iteration 3

The obtained return loss and impedance bandwidth are shown in Table II. It is seen that all four antennas have better return loss and are less than -20 dB. The far field radiation pattern for the generator and the SCMPA's iterations is shown in Fig. 3(a), Fig. 3(b), Fig. 3(c), and Fig. 3(d) respectively.

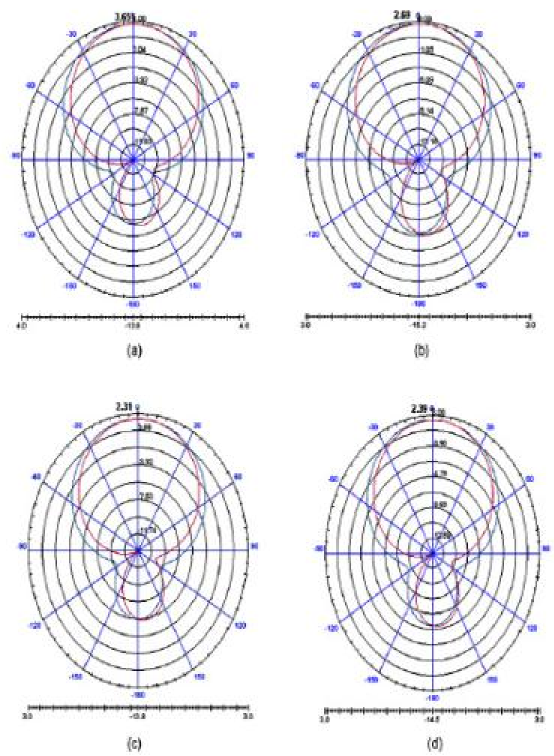


Figure.3 Radiation Pattern of (a) Generator (b) Iteration 1 (c) Iteration 2 (d) Iteration 3

The two radiation curves with phi =90degree (red) and phi=0degree (blue) at 2.45GHz is displayed for theta varying from -180° to 180°. The maximum gain of each antenna is depicted in their radiation pattern which is also tabulated in Table II. The similar nature of radiation pattern of the antennas verifies that process of iteration on the generator has not affected antenna radiation pattern.

Table II. Outputs of SCMPA

Antenna	Return Loss (dB)	Impedance BW (MHz)	VSWR	Gain (dB)
Generator	27.87	70	1.08	3.65

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Iteration 1	25.14	70	1.12	2.69
Iteration 2	26.90	60	1.09	2.31
Iteration 3	38.25	60	1.02	2.39

The VSWR characteristics of the designed antennas fall in between 1 to 2 which is illustrated in Fig. 4 and Table II. The gain of generator, iteration 1, iteration 2, and iteration 3 are also mentioned in Table II. The results demonstrates that generator (iteration 0), iteration 1, iteration 2, iteration 3, and iteration 4 are resonated at 2.45 GHz with good return loss, and similar radiation pattern. However, Iteration 3 has same dimension as that of iteration 2 but its return loss, gain, and VSWR are seen slightly different as shown in Table II.

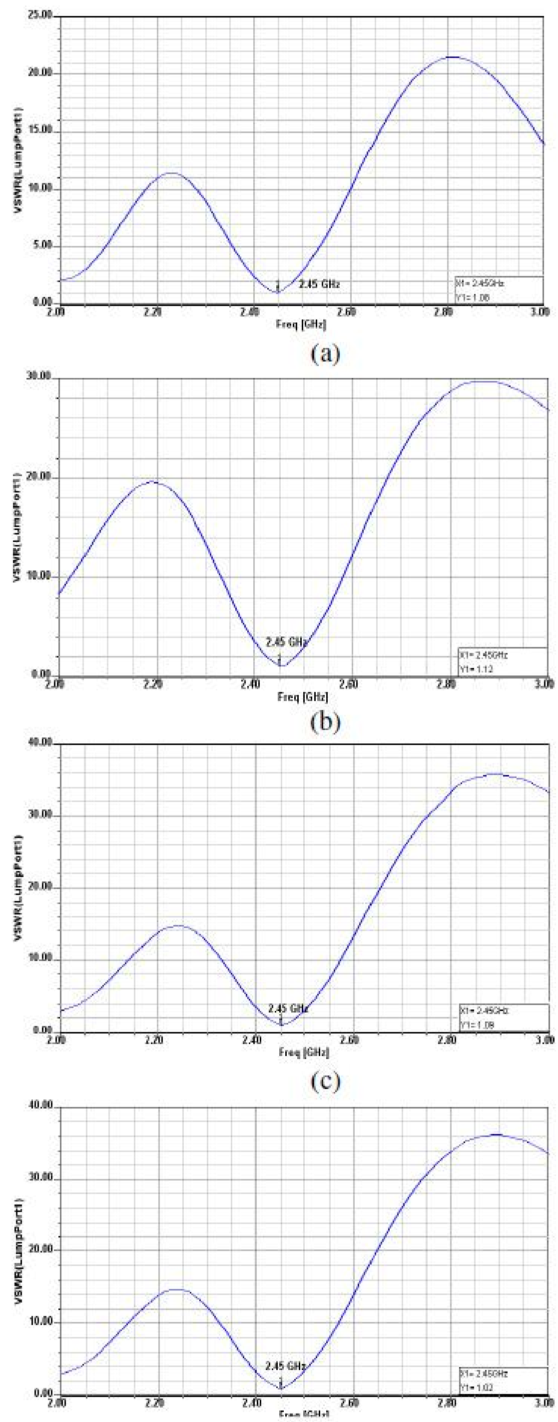

Figure.4 VSWR of (a) Generator (b) Iteration 1 (c) Iteration 2 (d) Iteration 3

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IV. Conclusion

The design of Sierpinski fractal based patch antenna, resonating at 2.45 GHz is presented in the paper. The size reduction is achieved through fractal iterations without affecting antenna performances such as return loss, radiation pattern, and VSWR. It is perceived that the increment of iteration order of fractal antenna leads to a higher degree of miniaturization. Since 2nd and 3rd iteration were similar, it can be surmised that truncating the fine structure of the fractal that is not discernable at the wavelengths of interest does not affect the performance of the antenna. Therefore miniaturized patch antenna integrating fractals can be designed using only a few generating iterations. Also, it can be deduced that a high degree of complexity in the structure of the antenna is not required for miniaturization of patch antennas using fractal geometry.

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