Perturbed Rectangular Sierpinski Carpet Geometry Based Miniaturized Fractal Patch Antenna

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Abstract

During this decade, the design of small-size wireless communication devices was key topic in the field of communication engineering. The design of miniaturized antenna is an important parameter to reduce the overall size of the wireless communication devices. Many approaches have been proposed to design the miniaturized antennas. Recently, fractal antenna geometry has been employed to design the miniaturized antennas by a number of researchers. The self-similarity and space filling properties of fractal geometries result in fitting of more electrical length in small physical area. This result in larger current paths which lead to miniaturized antenna design. In this paper, new fractal geometry is proposed with 37.88 % of size reduction in the antenna size at 1.975 GHz. The designed fractal antenna, named as perturbed rectangular Sierpinski carpet (PRSC), is obtained by replacing the straight boundaries of the rectangular Sierpinski Carpet geometry by a hybrid fractal curve obtained by combining Koch and Minkowski fractal curves. The antenna performance has been analyzed by IE3D software based simulation followed by measured results of the fabricated antenna. The simulated and experimented results are compared that demonstrate a good agreement. The substrate having dielectric constant of 2.2 and thickness of 1.6 mm is used and the designed antenna has a gain of 5.83 dBi.
**INTRODUCTION**

The design of miniaturized microstrip antennas by employing fractal geometry has received considerable attentions in recent past. Numbers of literatures are available stating the critical facts and challenges to be addressed for such antennas. In [1] authors have proposed a small size fractal antenna based on Koch fractal geometry which exhibits circular polarization and is designed for 902–928 MHz radio frequency identification systems. Fractal slot geometry is deployed by [2] to design a compact antenna having circular polarization and broadband resonant behavior with a good gain. In [3], authors have utilized the Minkowski fractal geometry to design a miniaturized co-planar waveguide fed fractal slot antenna is loaded with a dielectric resonator to achieve the multiband performance as well as to enhance the impedance bandwidth and overall gain of the antenna. An octagonal-shaped fractal antenna with Sierpinski fractal geometry proposed by [4] has compact size and demonstrated ultra wideband (UWB) property. A quasi self-complementary microstrip antenna with Koch fractal boundary has been designed by [5] for UWB operation with 30% reduction in area of the antenna. In [6] authors have used a modified Sierpinski-carpet fractal geometry to design a multi-resonant antenna in 1–20 GHz range. The lowest bands of the antennas have UWB performance with good radiation characteristics. In [7] authors have realized a compact antenna using the edge-fed rectangular Sierpinski shape of the second iteration and have achieved a 20% size reduction. The above discussion shows that the design of miniaturized antennas using fractal antennas is an important area which requires to be explored further.

In this paper, a new perturbed rectangular Sierpinski carpet geometry is proposed as a solution to designing of the miniaturized antennas. The proposed antenna shows size reduction characteristics of the order of 37.88% compared to normal Sierpinski carpet. The paper is organized in five sections. The design of the antenna is explained in Sec. 2. The simulation results are discussed in Sec. 3 and the Sec. 4 presents the experimental verification followed by the conclusion in Sec. 5.

**DESIGN OF THE PROPOSED ANTENNA**

The starting shape for the proposed design is the rectangular Sierpinski carpet fractal geometry with 1/3rd of iteration factor as shown in Figure 1. The authors of [7] have proved that this shape has miniaturization characteristics.
Recently, many researches have been proposed that size reduction of antenna can be achieved by using fractal geometry as the boundary of the radiating patch [8-10]. Taking a clue from this, in this paper size reduction is achieved by using fractal curves in place of straight line boundaries of the various slots of the Sierpinski carpet depicted in Figure 1. The resulting geometry, named as the perturbed rectangular Sierpinski carpet (PRSC) antenna, shows size reduction characteristics as the fractal boundary slots result in relatively larger current paths.

The Koch and Minkowski curves are combined as shown in Figure 2 to form the new hybrid fractal curve and dimensions $L_1$ and $D_1$ of the curve are calculated from the overall length ‘$L$’ of the initiator.

\[ L_1 = \frac{L}{7} \]
\[ D_1 = \frac{L_1}{2} \]

The shapes of first and second iteration of the proposed PRSC antenna designed using the hybrid fractal curve as boundary is shown in Figure 3. The outer dimensions of the first and second iterations are $34.02 \text{ mm} \times 46.77 \text{ mm}$ and $33.89 \text{ mm} \times 43.58 \text{ mm}$ respectively and these are taken from the antenna shapes of [7], however, a co-axial feed is used instead of microstrip line. The antenna is implemented using a substrate
having dielectric constant, $\varepsilon_r = 2.2$ and thickness of 1.6 mm similar to that has been used by [7]. The feed points are (6.5, -22) and (11.675, 3.425) respectively for first and second iterations.

![Figure 3](image)

**Figure 3.** PRSC fractal antenna (a) first iteration geometry, (b) second iteration geometry.

RESULTS AND DISCUSSION

The antenna is simulated using moment method based IE3D software and the simulated results are discussed in this section. The $S_{11}$ results of the antenna are presented in Figure 4 which shows that the first iteration shape of the PRSC antenna resonates at 2.311 GHz and the resonant frequency of the second iteration shape is 1.975 GHz. It has been demonstrated by [7] that the standard rectangular Sierpinski carpet antennas having dimensions equal to the dimensions of proposed PRSC antenna radiates at 2.45 GHz. So, the use of proposed hybrid fractal curve geometry results in shift of resonant frequency towards lower side of frequency scale. Thus, the proposed PRSC antenna has better size reduction capability than the fractal antenna of [7].

![Figure 4](image)

**Figure 4.** $S_{11}$ plots of proposed PRSC antenna (a) first iteration results, (b) second iteration results.
The dimensions of standard rectangular microstrip antenna at resonating frequency are calculated using the expressions given in [11] which come out to be 39.6mm and 60.04 mm resulting in an area of 2377.58 mm$^2$. For same resonant frequency, second iteration of the proposed PRSC antenna has area of only 1476.92 mm$^2$ which is 62.12% of the area of standard rectangular microstrip antenna. So the proposed PRSC antenna results in a size reduction of 37.88% at 1.975 GHz. The hybrid fractal generated by combining the Koch and Minkowski curves is used as the boundary of slots of the antenna. This resulted in the hybrid fractal boundary for the slots of antenna results in changed current paths and modified capacitive loading which in turn lead to shift of the resonant frequency towards the lower end of frequency scale. The comparison of the size reduction capability of second iteration of the proposed PRSC antenna with rectangular Sierpinski carpet of [7] and with other published results is shown in Table 1 and it is evident that the proposed PRSC antenna has better size reduction characteristics than the earlier published results.

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Fractal Geometry</th>
<th>Ref. Paper</th>
<th>Size Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Planar Log-Periodic Koch-Dipole</td>
<td>[12]</td>
<td>11 %</td>
</tr>
<tr>
<td>2</td>
<td>Crown Square Microstrip Fractal</td>
<td>[13]</td>
<td>16.84 %</td>
</tr>
<tr>
<td>3</td>
<td>Rectangular Sierpinski Carpet</td>
<td>[7]</td>
<td>20 %</td>
</tr>
<tr>
<td>4</td>
<td>Rectangular Meander Log-Periodic</td>
<td>[14]</td>
<td>21.6 %</td>
</tr>
<tr>
<td>5</td>
<td>Quasi self complementary with Koch fractal boundary</td>
<td>[5]</td>
<td>30 %</td>
</tr>
<tr>
<td>6</td>
<td>Perturbed Rectangular Sierpinski Carpet</td>
<td>Proposed Design</td>
<td>37.88 %</td>
</tr>
</tbody>
</table>

The radiation plots of the proposed PRSC antenna are shown in Figure 5 (a) and (b) of the first iteration. The second iterations plots are depicted in Figure 6 (a) and (b) respectively. These plots depict that for both iterations, the proposed antenna has omni-directional patterns. The peak gain of the first iteration antenna is 6.83 dBi whereas the gain of the second iteration antenna is 5.83 dBi.

The relative lower value of the gain for second iteration is expected due to less metallic region in second iteration as compared to first iteration. The directivity values are also calculated and these come out to be 7.59 dBi and 7.28 dBi respectively for first and second iteration geometries.
The hybrid curve is developed in such a way that it does not affect the shape of the radiation patterns. This can be visible from the omnidirectional radiation patterns presented in the above figures. The important issues which are taken into account in this paper are mainly to increase the current length by newly proposed curved slots while ensuring that it does not results in detoriation of shape of the patterns.
EXPERIMENTAL RESULTS

The prototype of the second iteration geometry of the proposed PRSC antenna is fabricated and tested using the vector network analyzer R&S model ZVL. The prototype is shown in Figure 7 and the experimental results are shown in Figure 8. The measured resonant frequency value is 1.999 GHz with $S_{11}$ of $-26.42$ dB.

![Figure 7. Fabricated prototype of proposed PRSC antenna.](image)

![Figure 8. Experimental results of proposed PRSC antenna.](image)

The comparison of experimental and simulation results is given in Table. 2 that show the measured resonance frequency and simulated $S_{11}$ magnitude are in good agreement.
Table 2. Comparison of simulated and experimental results.

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Parameter</th>
<th>Simulated Value (IE3D)</th>
<th>Experimental Value</th>
<th>Percentage Deviation (Ref. experimental value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Resonant frequency (GHz)</td>
<td>1.975</td>
<td>1.999</td>
<td>1.2%</td>
</tr>
<tr>
<td>2</td>
<td>S11 (dB)</td>
<td>–24.28</td>
<td>–26.42</td>
<td>8.09%</td>
</tr>
</tbody>
</table>

CONCLUSIONS

A new fractal antenna geometry having size reduction characteristics is developed and tested in this paper. The proposed antenna geometry is designed by perturbing the rectangular Sierpinski carpet geometry hence is named as perturbed rectangular Sierpinski carpet. The straight boundaries of the slots of the Sierpinski carpet are replaced by a new hybrid fractal curve generated using the combination of Koch and Minkowski fractal curves. The antenna shows a gain of 5.83dBi for second iteration of the fractal geometry with a directivity of 7.28dBi. The simulation and experimental results of the proposed PRSC antenna are in good agreement. A size reduction of 37.88% is achieved as compared to standard rectangular microstrip antenna at resonant frequency of 1.975GHz and also found to have better size reduction characteristics than many previously proposed fractal antennas. The hybrid curve used in the slots of the fractal antenna led to larger current path thus pushing the resonant frequency to lower value for the same overall physical size. Further work to optimize the proposed geometry for desired resonant frequency is in progress. This proposed geometry seems to be a promising technique to develop miniaturized antenna for personal and wireless communication mainly in the L and S bands.

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REFERENCES


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