

A NOVEL SMALL-SIZE SINGLE PATCH MICROSTRIP ANTENNA BASED ON KOCH AND SIERPINSKI FRACTAL-SHAPES

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Abstract—A novel fractal structure using Koch and Sierpinski fractal-shapes is proposed. By inserting the Sierpinski carpets into the single patch and etching the inner and outer patch edges according to Koch curves, the resonant frequency of the patch antenna can be lowered significantly. And the higher of the iteration order of the fractal shapes, the lower the resonant frequency becomes. In this paper, a novel small-size single patch microstrip antenna based on the proposed fractal-shapes is designed, fabricated and measured. It is experimentally found that the size reduction can reach 80.3%. Compared to the conventional square single patch antenna, the proposed antenna maintains comparable radiation patterns. Therefore, the small-size single patch microstrip antenna considered here can be applied to portable wireless communication systems requiring small devices.

1. INTRODUCTION

Antenna miniaturization design is an important issue in integrated wireless communication systems. Significant research activities and interests have been aroused in academic field to reduce the microstrip patch antenna size [1–11]. Numerous literatures on design of the single patch microstrip antenna miniaturization have been presented, which can be categorized into three major styles of antenna structures. The simplest design is to adopt high dielectric constant substrate. However, this method can not only raise product costs, but also obtain rather limited maximum size reduction. The most adopted method is to change radiation patch shapes or ground plane structures, which is the

hot spot to reduce the microstrip patch antenna size, such as inserting slots into the patch to increase the electric length of the antenna [1], loading the edges of the patch with inductive elements [2], etching periodical slow wave structures in the ground plane [3, 4], loading shorting post technique [5]. Meanwhile, combination of these methods is also applied to achieve size reduction [6]. Though this technology utilized in [6] can achieve maximum 75% size reduction, the radiation patterns have changed greatly as a result of the asymmetrical structure. Furthermore, the introduction of shorting posts raises the fabrication difficulties and product cost.

Recently, fractal technique has been widely applied to antenna design to reduce the antenna size [7–11]. Small-size antennas by etching fractal shapes into the patch edges have been introduced in [8]. The maximum size reduction can only achieve 45%. In [7], the proposed edge-fed Sierpinski carpet microstrip patch antenna achieves a maximum 33.9% size reduction. By combining fractal shapes such as Koch and Sierpinski fractal shapes, antenna size can be reduced significantly [9, 10]. In [9], the antenna combining bowtie and Sierpinski fractal-shapes can obtain 67% maximum size reduction, but the radiation characteristics has changed greatly. The antenna considered in [10] which adopts Koch and Sierpinski shapes gains 77.1% size reduction.

In this paper, a novel small-size single patch microstrip antenna based on Koch and Sierpinski fractal-shapes is proposed. By inserting the Sierpinski carpets into the single patch and etching the inner and outer patch edges according to Koch curves, the novel small-size antenna is designed and fabricated. The measurement results have demonstrated that the antenna can achieve 80.3% size reduction and maintains comparable radiation patterns compared to the normal square patch.

2. DESIGN OF THE FRACTAL SHAPE

As is shown in Figure 1, the fractal structure is designed based on Koch islands and Sierpinski carpets. The fractal pattern can be formed by inserting the Sierpinski carpets whose iteration factor is set to $1/3$ and etching the inner and outer edges according to the Koch curves whose iteration factor is $1/4$. Figure 1 demonstrates the generation process of the proposed fractal structure. The iteration orders from Figures 1(a) to (d) are zeroth, first, second and third, respectively. In order to study size reduction of the proposed fractal structure utilized in microstrip patch antenna, four antennas with the configurations in Figure 1 are computed on the substrate with relative

permittivity of 2.65 and the thickness of 0.5 mm. All of the antennas have the same dimension, which are with the length of 60 mm and the width of 60 mm. The reflection coefficients of four antennas are plotted in Figure 2. As can be seen in the Figure 2, the antennas in Figures 1(a)–(d) are resonated in 1.535 GHz, 0.794 GHz, 0.673 GHz and 0.663 GHz, respectively. In this paper, the resonant frequency of the antenna is taken as the minimum magnitude of S_{11} . In [12], Hofer has shown that inserting a slit in a transmission line generates an inductive loading effect. Meanwhile, by inserting slots into a patch antenna, it will yield capacitive coupling along the edges and coupling within each slot [1]. Therefore, the Sierpinski carpets can be equivalent to inductive loading, and the Koch shapes on the patch edges can be seen as capacitive loading. The multiple effects are accumulated to reduce the resonant frequency. As the iteration order number increases, the average electrical length of the antennas increases, then the resonant frequency of the patch antenna decreases gradually. The resonant frequency lowering effect is insignificant when the iteration order becomes higher [7, 8].

It is also observed from Figure 2, compared with the conventional square antenna (with zeroth), the resonant frequency of the patch antenna with the third iteration order can be reduced to 43%. That is to say that the frequency reduction rate η is equivalent to 0.43. Because the configurations of the fractal shape are all centrosymmetrical, the antenna radiation patterns are expected to be maintained. Therefore, the proposed fractal geometry with the third iteration order can be successfully utilized in the design of the small-size microstrip antenna.

3. DESIGN OF THE PROPOSED FRACTAL SMALL-SIZE ANTENNA

The fractal microstrip patch antenna using the fractal structure shown in Figure 1(d) is designed following the procedure below. The

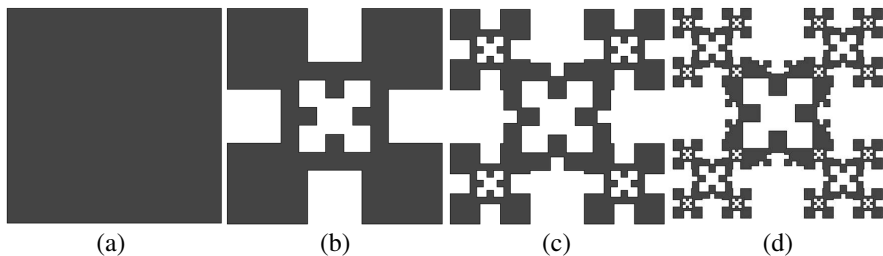


Figure 1. Generation process of the proposed fractal geometry.

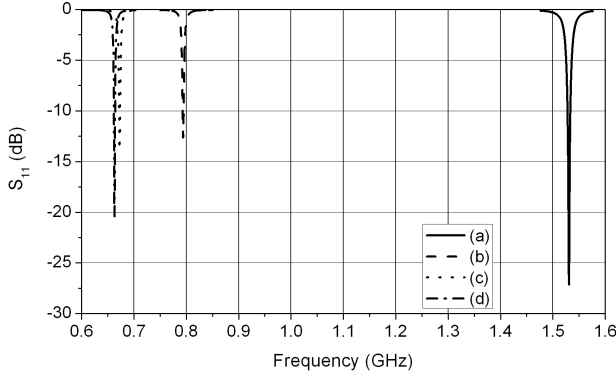


Figure 2. Reflection coefficients of the four antennas.

Sierpinski iteration factor is $1/3$, the Koch iteration factor of the inner and the outer edges are set to $1/4$ and $1/4$, respectively. The antenna is fabricated on the substrate with the dielectric constant of 2.65 and the thickness of 0.5 mm. The design procedure of the antenna which utilizes the proposed fractal pattern can be summarized as follows:

- 1) Specify the operated frequency f_0 , and then obtain the transformation frequency f_t through the formula listed below;

$$f_t = f_0/\eta \quad (1)$$

- 2) Decide the initial dimensions of the patch antenna according to the transformation frequency f_t . The following approximate equations are suggested;

$$W = \frac{c}{2f_t\sqrt{\varepsilon_e}} - 2\Delta\omega \quad (2)$$

$$L = \frac{c}{2f_t} \left(\frac{\varepsilon_r + 1}{2} \right)^{-1/2} \quad (3)$$

where

$$\varepsilon_e = \frac{\varepsilon_r + 1}{2} + \left(\frac{\varepsilon_r - 1}{2} \right) \left(1 + \frac{10h}{W} \right)^{-1/2} \quad (4)$$

$$\Delta\omega = 0.412h \frac{(\varepsilon_e + 0.300) \left(\frac{L}{h} + 0.264 \right)}{(\varepsilon_e - 0.258) \left(\frac{L}{h} + 0.8 \right)} \quad (5)$$

In this design, the proposed antenna is a square antenna. Therefore, the width and the length of the patch antenna are equal in size.

- 3) Match the patch by one quarter wavelength impedance transformer, and implement the optimization function of the Ansoft Designer software. Then, properly adjust the dimensions of the patch and impedance transformer to make it resonate at the frequency point f_t .
- 4) Design the fractal-shaped microstrip antenna according to the fractal structure proposed here. Insert the Sierpinski carpets into the patch devised in step 3) whose iteration factor is set to 1/3 and etch the inner and outer edges according to the Koch curves whose iteration factor is 1/4.
- 5) Optimize the fractal-shaped antenna matched by one quarter wavelength impedance transformer using Ansoft Designer software. Then fractal-shaped antenna with optimal dimensions which operates at the specified frequency point f_0 can be obtained.

4. RESULTS AND DISCUSSIONS

The configuration of the proposed small-size antenna is shown in Figure 3. In this design, the proposed fractal-shaped small size antenna is specified to operate at 900 MHz (GSM Band). According to the design procedure in Section 3, the structure dimensions of the proposed antenna are listed as followed: $L_{sub} = 120$ mm, $W_{sub} = 100$ mm, $L_p = 44.9$ mm, $W_p = 44.9$ mm, $L_{trans} = 48.2$ mm, $W_{trans} = 0.3$ mm,

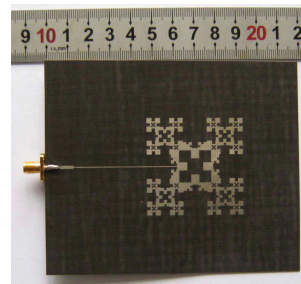
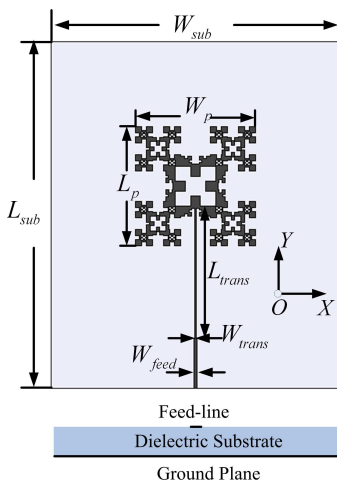


Figure 3. Schematics diagram of the proposed small-size antenna.

Figure 4. Photograph of the proposed antenna.

$W_{feed} = 1.3$ mm. The proposed antenna is fabricated for experiment use and its photograph is shown in Figure 4.

The impedance characteristics of the fabricated small-size fractal patch antenna are measured through a Vector Network Analyzer. Figure 5 shows the simulated and measured reflection coefficients of the proposed antenna. There is some difference between the specified results and measurement results. The measured resonant frequency point is at 918 MHz, while the simulated resonant frequency point is at 900 MHz. This may be caused by the fabrication inaccuracy and discontinuity between the feed-line and the SMA junction. However, this has also demonstrated that the validity of the design method in Section 3. In order to study the sensitivity of dimensional changes of the proposed antenna, the relationship between the dimension and the resonant frequency is analyzed, as is shown in Figure 6. When changing the same value in size, the resonant frequency of the proposed antenna changes greater than the one of the conventional patch antenna. Therefore, the proposed antenna requires high fabrication accuracy.

The far-field radiation characteristics are measured in by a far field measurement system in an anechoic chamber. The radiation patterns are shown in Figure 7. As can be seen in Figure 7, whether the E -plane radiation pattern or the H -plane, the radiation patterns resemble the conventional single patch microstrip antenna. The proposed antenna exhibits good radiation patterns and low cross polarized levels. Compared with the conventional patch antenna with same dimensions without fractal shapes, the 3-dB beamwidth has been broadened which is because that the electrical length between the radiation edge and the ground plane is shortened as the resonance

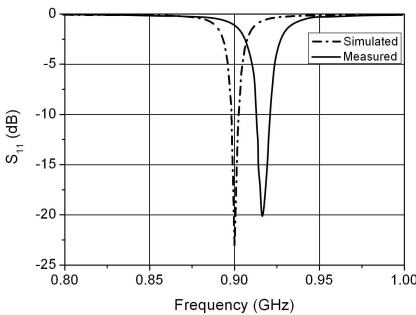


Figure 5. Simulated and measured reflection coefficient of the proposed antenna.

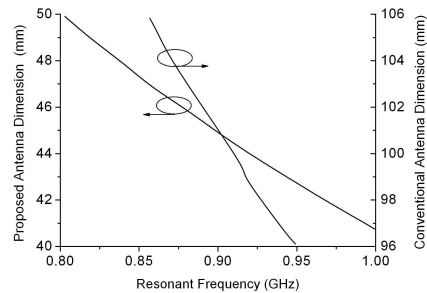


Figure 6. Simulated resonant frequency with different values for the proposed antenna and the conventional square antenna.

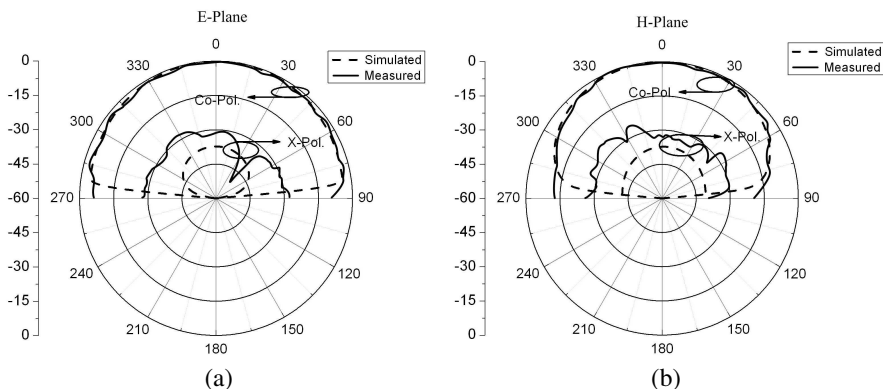


Figure 7. Radiation patterns of the proposed antenna at the resonant frequency. (a) *E*-plane, (b) *H*-plane.

decreases [10]. The measured gain of the proposed antenna is -1.0 dBi. It is obvious that the maximum gain is really low. This low gain may be attributed to several reasons. The proposed antenna has realized 80.3% size reduction, thus the antenna effective radiation area is reduced significantly with the size reduction. In addition, the proposed antenna is fabricated on the substrate with thickness of 0.5 mm. The thinner of the substrate on which the antenna is built, the low efficiency the antenna becomes. Meanwhile, the accuracy of the dielectric loss of the material used and the limited accuracy of the available tools are also important aspects that affect antenna gain.

While the proposed antenna operates at the 918 MHz, the radiation patch dimensions of are $44.9\text{ mm} \times 44.9\text{ mm}$. Compared with the conventional microstrip patch antenna with the dimensions of $101.2\text{ mm} \times 101.2\text{ mm}$, the size reduction of the proposed antenna can reach to 80.3%. Based on the measured results comparison of small-size patch antennas between this paper and other literatures is shown in Table 1. It can be seen that the size reduction of the proposed small-size antenna is smaller than that of other microstrip patch antennas introduced by other literatures. To my best knowledge, the size reduction of the proposed antenna has reached the maximum in the design of microstrip patch small-size antennas so far. In addition, the proposed small-size exhibits good radiation patterns and realizes low product cost. Therefore, the small-size microstrip fractal-shape antenna considered here can be widely utilized in portable wireless communication systems.

Table 1. Comparison of different small-size antennas.

Antennas	Size reduction	Radiation patterns	Gain (dBi)	Practical application
[7]	33.9%	broaden	--	Low product cost
[1]	35%	change little	-0.4	Low size reduction
[4]	65%	change little	--	Low integrated level
[11]	75%	asymmetry	4.4	High product cost
[6]	75%	asymmetry	1.5	High product cost
[10]	77.1%	broaden	-1.1	Low product cost
Proposed	80.3%	broaden	-1.0	Low product cost

--, gain not shown in the paper

5. CONCLUSION

In this paper, a novel fractal structure using Koch curves and Sierpinski carpets is introduced. A small-size microstrip antenna based on the proposed fractal structure is proposed. Compared with the conventional microstrip patch antennas without fractal shapes, the proposed antenna achieves 80.3% size reduction and maintains comparable radiation patterns. The proposed small-size antenna can be applied to portable wireless communication systems successfully.

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