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A fractal-based printed slot antenna for multi-band wireless applications

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A Fractal-based Printed Slot Antenna for Multi-band Wireless Applications

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Abstract— Fractal geometries have shown to be attractive for antenna designers because of the unique features they offer. In this paper, a printed fractal based slot antenna has been introduced to be used in multi-band wireless applications. The slot structure of the proposed antenna is of an octagonal shape with a Koch fractal curve of the second iteration is applied on each of its sides. The slot structure has been etched on the ground plane of a substrate with relative permittivity of 4.4 and 1.6 mm thickness. On the reverse side of the substrate, a 50 ohm microstrip line feed has been etched. To enhance the coupling with the slot, the feed line has been loaded with a circular stub with embedded complementary circular split ring resonator. Based on the lowest resonant frequency, it has been found that the largest dimension of the proposed antenna slot structure is less than half the guided wavelength. Parametric study shows that the resulting antenna offers a multi-band behavior with enhanced gain and fractional bandwidths, besides the reasonable radiation characteristics throughout the resonating bands. With appropriate dimension scaling, the proposed antenna could be a suitable candidate for use in a wide variety of multi functions wireless applications.

1. INTRODUCTION

Various fractal geometries have become attractive for antenna designers to produce compact and multi-band antennas benefiting from their unique properties; space filling and self similarity respectively. Conventional fractal geometries such as Koch, Cantor, Hilbert, Sierpinski and other fractal curves have been successfully used to produce dual-band and multi-band printed slot antennas for various wireless applications.

In this context, the use of fractal geometries in the design of printed slot antennas can be classified into two categories. In the first category, direct application of fractal geometries has been adopted [1–5]. In this case, the fractal geometries constitute the whole antenna slot structures. However, dual-band and multi-band printed slot antennas with fractal slot structures based on circular shapes are reported in the literature [6–8]. In the second category, where indirect application of fractal geometries is suggested, the antenna slot structure is composed of a combination of Euclidian structures, such as triangle, square, rectangle and other polygons, and fractal geometries superimposed on these structures, where each line segment is replaced by fractal curve with certain iteration level [9–14].

It is worth to note that in the majority of the research work regarding the antenna design according to the second category, the feed lines are loaded with some type of stubs to enhance the coupling of the different resonant bands. Furthermore, antennas with stub loaded feed lines are characterized by relatively high gain as compared with those without stubs. Stubs have been found with different sizes and shapes. It has been reported with a square ring shape [12], a widened rectangular shape [13], a rectangular shape with embedded slot [14], etc..

In this paper, a microstrip line fed printed fractal slot antenna has been presented as a candidate for use in multi-band wireless applications. The slot structure of the proposed antenna is composed of an octagonal shape with each of its line segments being replaced by a 2nd iteration Koch fractal geometry. The antenna has been fed with a $50\,\Omega$ microstrip line etched on the reverse side of the substrate. To enhance the coupling of the various resonant bands, the feed line has been loaded with a circular stub. For additional coupling of the resonant bands, a complementary circular split ring resonator, CCSR, has been embedded in the circular stub. However, this CCSR offers a simple tuning means of the antenna resonant bands without changing the antenna dimensions.

2. THE ANTENNA STRUCTURE AND DESIGN

The slot structure of the proposed antenna is essentially based on the conventional octagonal shape. Each side of the octagon has been modified to be in the form of a 2nd iteration Koch fractal geometry. The slot structure has been etched on the top side of the substrate with feed line has been printed on the reverse side, Figure 2. Modelling and performance evaluation of the proposed antenna has been carried out using commercially available EM simulator HFSS from Ansoft Corporation [15]. An initial design, has been carried out with a slot radius of 22.5 mm being etched on a ground plane dimensions of $75 \times 75\,\text{mm}^2$ and with 3.05 mm width microstrip feed line printed on the reverse side of an FR-4 substrate with relative permittivity of 4.4 and 1.6 mm thickness. With these parameters and feed line length, L_f, of 33 mm, the antenna offes a return loss response with a lowest resonant frequency, f_1, of about 2.43 GHz. However, there is another resonance occur at 1.3 GHz but it is not highly coupled.

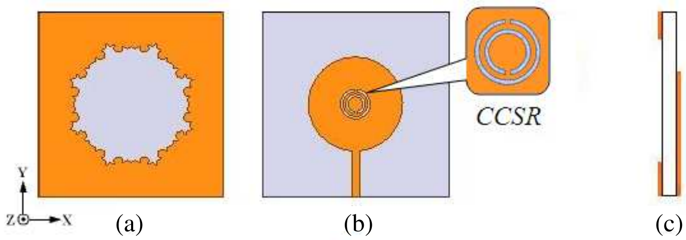


Figure 1: The structure of the proposed antenna with respect to the coordinate system. (a) The front view. (b) The bottom view with an enlarged section showing the CCSR, and (c) the side view.

To enhance the coupling of the resonant bands, the feed line has been loaded with a circular stub cocentred with and beneath the slot structure as shown in Figure 1(b). Starting with a stub radius, R_S, of 18 mm, the antenna offers a return loss response with four resonant bands centered at about 1.41, 2.35, 3.76, and 5.05 GHz respectively. As a means of further coupling and tuning of the resulting resonances, a complementary circular split ring resonator, CCSR, with a width and inter-ring spacing of 1 mm each, has been embeded at the center of the stub. With a stub radius, R_S, of 18 mm and a CCSR with inner radius, R_{CCSR}, of 6 mm, the antenna offers a return loss response with four resonant bands centered at about 1.10, 2.45, 3.96, and 5.25 GHz respectively. In this case, the lowest resonant frequency can be expressed in terms of the antenna slot perimeter, P_{SLOT}, and the substrate effective permittivity, $\varepsilon_{\mathit{eff}}$, as:

$$f_1 = \frac{2c}{P_{\text{SLOT}}\sqrt{\varepsilon_{\mathit{eff}}}} \tag{1}$$

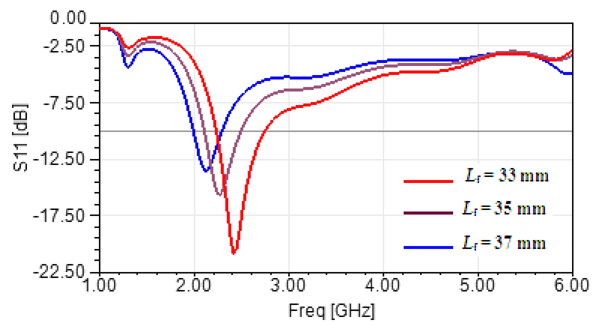
where c is the speed of light in the free space. To save space, the derivation of Equation (1) will not be mentioned here. The combination of the feed line stub and the CCSR makes the proposed antenna possesses a wide variety of resonating bands covering almost all the recently available wirelss services within the adopted frequency range.

3. PERFORMANCE EVALUATION

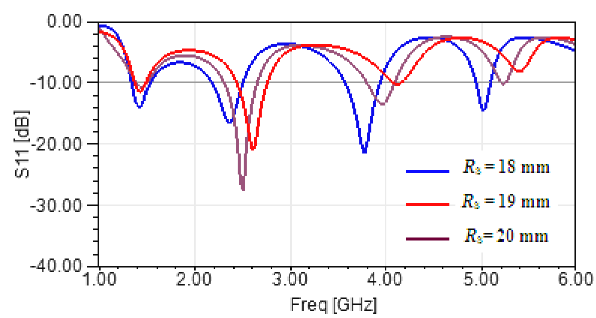
A parametric study has been conducted to demonstrate the effects of many antenna parameters on its performance. Figure 2(a) demonstrates the effect of the feed line length variation on the return loss response of the antenna without loaded stub. Simulated return loss responses depicted in Figure 2(a) reveal that the antenna possesses a single resonant band within the swept frequency range 1–6 GHz. However, there is another resonant band out of this range positioned at about 8 GHz which is out of our attention. The effect of the variation of the feed line length is to change the position of the resonant band. The feed line length, L_f, has been increased from 33 to 37 mm in steps of 2 mm. As L_f increaes, the the resonant frequency has shifted higher to the right with correspondingly enhanced coupling.

The second parameter that has been adopted in the parametric study is the feed line loading stub size. Figure 2(b) demonstrates the antenna return loss responses corresponding to circular stub radii ranging from 18 to 20 mm in steps of 1 mm. It is implied that, the appearance of four resonant bands within the same swept frequency range is attributed to the feed line loading with the circular stub. In addition, the variation of the stub radius, R_S, has almost no effect on the lowest frequency band. However, different degrees of coupling have been achieved with the various values of R_S. Smaller stubs tend to lower the other resonant bands but with more enhanced coupling. On the other hand, with the use of stubs radii greater than 20 mm, the coupling becomes weaker and the higher resonant bands start to disappear.

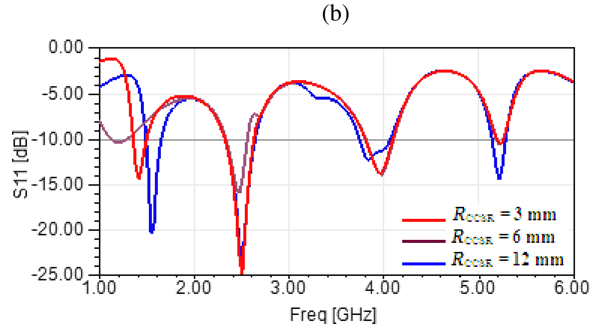
The last step of the parametric study is to evaluate the effects of the embedded CCSR in the feed line stub on the resulting antenna performance. Observing the antenna return loss responses depicted in Figure 2(c), it is clear that the variation of the CCSR inner radius predominantly affects the first and the fourth resonant bands. The effect on the first resonant band is to shift its position permitting a considerable range of tunability, while the effect on the fourth band is to support the coupling leading to enhanced bandwidth. The far field radiation patterns for the E and H planes, at the centers of the four frequency bands, are shown in Figure 3. The results show a monopole like radiation characteristics with almost omnidirectional radiation. Furthermore, the corresponding gain at the four frequencies are of about 6.0, 2.3, 4.0, and 4.0 dB respctively. Figure 4 displays the surface current distribution on the modelled antenna with a circular stub of 17 mm radius and embedded CCSR with inner radius of 5 mm, at the four resonant bands. The effect of the CCSR on the antenna performance is clearly shown at f_1 and f_4. This confirms the results depicted in Figure 3(c), where the introduction of the CCSR predominantly affects the first and the fourth resonant bands. Observing the return loss responses depicted in Figures 1(b) and (c), it is clear that the proposed antenna could be presented as a candidate to cover different wireless applications such as Bluetooth, WLAN, SDAR-S, ISM, GPS, RFID, WiMAX.



(a)



(b)



(c)

Figure 2: The simulated antenna return loss responses for (a) the antenna without loaded stub and the feed line as a parameter, (b) the antenna with loaded stub with stub radius as a parameter, and (c) the antenna with loaded stub and CCSR with CCSR radius as a parameter.

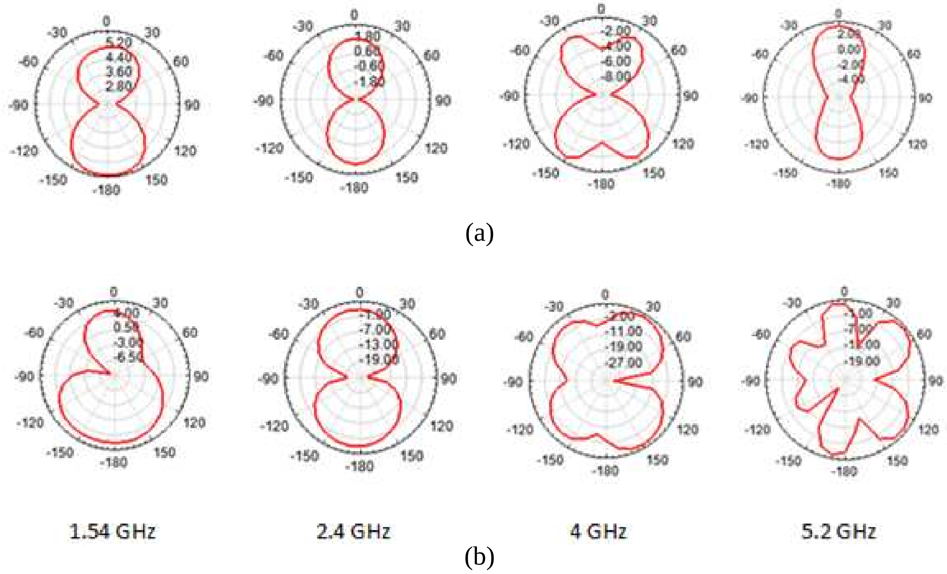
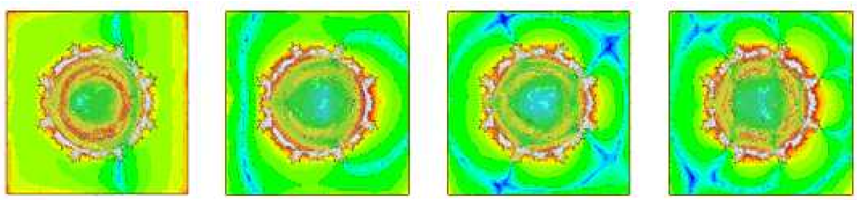


Figure 3: The simulated far field radiation patterns of the modelled antenna with circular stub of 17 mm radius and embedded CCSR with inner radius of 5 mm at the four resonant bands. (a) The E-plane, and (b) the H-plane.



(a) (b) (c) (d)

Figure 4: The simulated surface current distribution on the modelled antenna with circular stub of 17 mm radius and embedded CCSR with inner radius of 5 mm at: (a) f_1=1.54 GHz, (b) f_2=2.40 GHz, (c) f_3=4.00 GHz, and (d) f_4=5.20 GHz.

4. CONCLUSIONS

In this paper, a fractal based slot printed antenna with stub loaded microstrip feed line has been presented. The proposed antenna has shown to possess a multi-band behavior covering most of the commercial wireless services. It has been shown that the existence of the feed line stub enhances the coupling of the resonating bands. On the other hand, the introduction of the embedded CCSR in the circular stub structure provides an additional means of slight tuning of the resonant bands with further coupling. Furthermore, the proposed antenna offers good radiation characteristics and considerable gains throughout the resonant bands. This makes the proposed antenna a suitable candidate for use in a wide variety of multi function wireless applications. It is hopeful that the proposed antenna be attractive for antenna designers for the high degree of freedom it provides.

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