Dual-Band Fractal Antenna with Bandwidth Improvement for Wireless Applications

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Summary
In this paper, a dual-band Koch Snowflake antenna is proposed for wireless communication systems. Fractal geometry, CPW-feed and stepped ground planes are used to improve the impedance bandwidth. By properly introducing a hexagonal split-ring slot to radiating element, a lower frequency band is generated. The proposed structure is fabricated and tested. Experiment results exhibit dual-band of 0.73-0.98 GHZ and 1.6-3.1 GHz which makes this antenna suitable candidate for GSM900, GSM1800, UTMS2100, Wi-Fi 2400 and LTE2600 bands. In addition, a good radiation pattern, a satisfactory peak gain and a radiation efficiency, which reaches 95%, are achieved.
Key words:
Fractal antenna; Dual-band; CPW-feed; Slot; Stepped ground planes.

1. Introduction

The evolution of wireless communication technology has increased the demand for wideband, multiband, miniaturized and high efficiency antennas. These kinds of antennas with such features are used due to their simple designs and the ease of integration. Many researchers are focused to design antennas that obey the different characteristics mentioned above. Therefore, several techniques are used to overcome the problem of large size and keeping the wideband or multiband behavior.

Fractal antennas have experienced a significant growth. Numerous works have applied fractal geometries to create innovative antennas which can operate in different applications. This approach has shown good results in terms of improving antenna performance. Fractal geometries are characterized by two essential properties that give them the opportunity to be preferred to other forms. The first property is self-similarity [1] of fractal structure which is composed by several shapes identical to the overall form but with different scales. This aspect leads to the generation of wideband or multiband antennas. The second property of fractal geometry is space filling [2]. This property has a direct relationship to the size of the antenna. Indeed, the electrical length of fractal antenna can be extended without widening the area and total volume of the antenna. Therefore, space filling is a key feature of antenna miniaturization. Fractal patterns are studied by researchers with the aim of applying their properties in the design of either single antenna or antenna array [3]. Thus, geometry of fractal structures plays a crucial role in determining resonance frequencies. The most known fractals are Koch curves, Sierpinski Carpet/Gasket and Minkowski geometry.

To meet the demands of broadband communication systems, several searches for fractal antennas have been reported in recent years [4-9]. The combination of fractal geometry and rectangular ground plane is presented in [4] to achieve a miniaturized wideband antenna for wireless applications. Fractal concept is proposed in [5] to improve the bandwidth and to decrease the size of a flexible antenna to be suitable for ultra-wideband applications. In [6], a hexagonal fractal geometry is investigated to design a broadband antenna with compact size and high directivity. In [7], the combination of Minkowski fractal geometry with the octagonal shape helps to increase the electrical length of antenna and to reduce its size in order to obtain a compact broadband antenna for wireless applications. A microstrip patch antenna that includes a square Sierpinski shaped slot with a total size of 34 x 34 mm^2 and an operating band of (2.7-5.7 GHz) is presented in [8]. A cantor fractal slots inserted on a compact hexagonal patch antenna covering a bandwidth from 3.22 to 6.5 GHz is presented in [9] to be suitable for vehicular communications. Also, many studies have been focused to design fractal antennas which satisfy multiband operation [10-15].

This article aims to design a compact fractal antenna using CPW feed for wireless applications. In order to increase the impedance bandwidth, Koch Snowflake geometry with two iterations and partial ground planes are proposed. To further improve the bandwidth stepped shape is applied to the ground plane. Finally, a hexagonal split-ring slot is introduced on the radiating element. Therefore, a dual-band behavior is achieved. Simulation results are

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performed using HFSS and then verified with experimental measurements.

Section 2 presents the antenna design. Section 3 describes different techniques, that includes number of iterations, modified ground plane and the insertion of slot, used for achieving the desired bands. Also, other features of antenna are discussed. The prototype of antenna with different experimental measurements such as reflection coefficient, radiation patterns, and radiation efficiency are presented in Section 4. The last section concludes this work.

2. Antenna Design

The final geometry of the proposed dual-band fractal antenna is depicted in Fig. 2. The designed antenna consists of Koch Snowflake radiator which includes a hexagonal split-ring slot, a CPW transmission line and stepped ground planes. Antenna design is totally printed on the top side of the substrate. The design process is divided into three steps as shown in Fig. 4. The first step is the generation of Koch Snowflake geometry with two iterations as can be seen in Fig. 4(a), using the recursive procedure presented in Fig. 1. The second step includes the modification of the partial ground planes to form stepped ground planes as depicted in Fig. 4(b). Finally, to achieve the desired dual band operation, a hexagonal split-ring slot is introduced in the Koch Snowflake radiator as shown in Fig. 4(c).

The proposed structure is printed on Plexiglas substrate of dimensions 60 mm x 70 mm x 4 mm with a dielectric constant and loss tangent of 2.6 and 0.0057, respectively. A CPW feed line is used with W_f and a equal to 5 and 0.338 mm, respectively. The optimized parameters of the designed antenna are illustrated in Table 1.

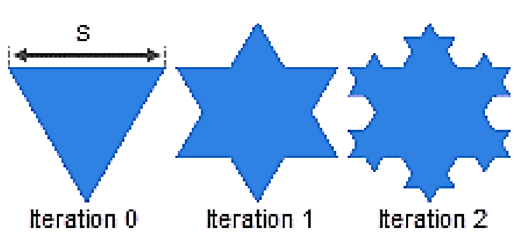


Fig. 1 Koch Snowflake iterations.

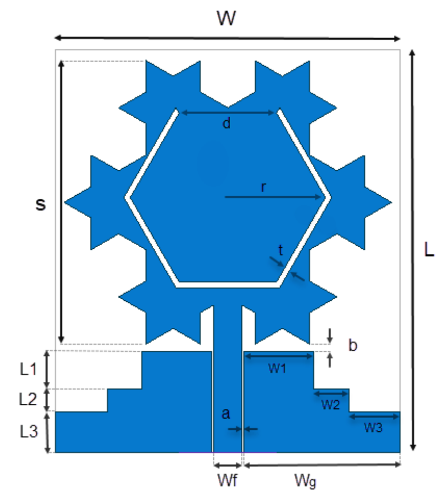


Fig. 2 Fractal antenna geometry.

Table1: The optimized antenna parameters

Parameters	*Value(mm)*	*Parameters*	*Value(mm)*
W	60	W_3	9
L	70	L_1	6.5
S	49.3	L_2	4
d	16.95	L_3	7
r	16.95	W_g	27.162
t	1	W_f	5
W_1	12.162	a	0.338
W_2	6	b	1.31

3. Results and Discussion

The S_{11} curves for different iterations of the proposed fractal antenna (without the stepped ground plane and the hexagonal split-ring slot) are illustrated in Figure 3. The developed antenna begins with an equilateral triangle which resonates at 1.23 GHz with a bandwidth of 0.99-1.65 GHz. the application of the first iteration of Koch geometry allowed the occurrence of two frequency bands, covering the 1-1.61 GHz band and 2.12-2.59 GHz band. The second iteration leads on the one hand, to the appearance of new frequency band from 3.41 to 3.54 GHz. On the other hand, to the merging of the two frequency bands of the first iteration to form a wideband from 0.89 to 2.54 GHz. These results can be explained by the electrical length of the proposed antenna which increases with the evolution of iterations and consequently increases the number of resonant frequencies and improves the impedance bandwidth.

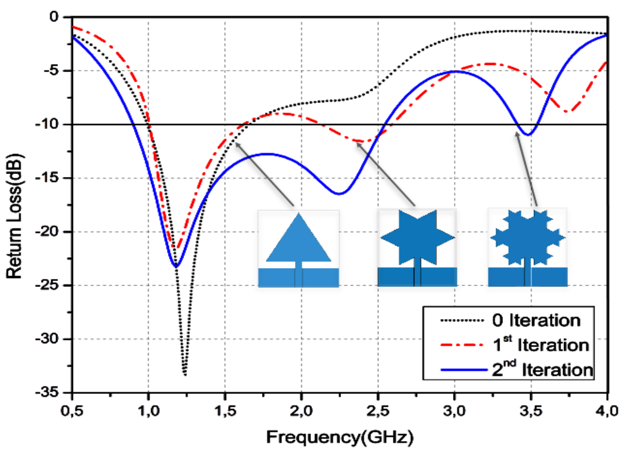
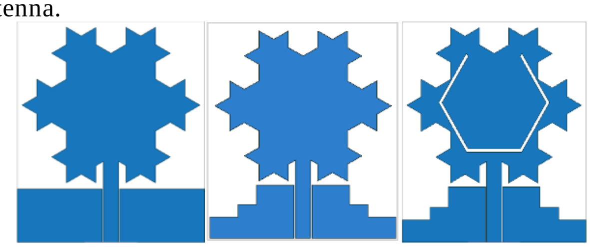


Fig. 3 S_{11} of different iterations of the proposed antenna.

The study is continued with the second iteration Koch antenna. As shown in Fig. 4, this antenna is modified to give an antenna with SGP (Stepped Ground Planes). Then, a slot is added to the radiating element to design the proposed antenna.



(a) (b) (c)

Fig. 4 Evolution steps of the proposed antenna: (a) 2^{nd} iteration, (b) 2^{nd} iteration + SGP, (c) 2^{nd} iteration+SGP+slot.

Fig. 5 shows a comparison between the reflection coefficient S_{11} of the second iteration Koch antenna previously studied (Fig. 4(a)) and the S_{11} of the modified antenna (Fig. 4(b) and Fig. 4(c)). As can be seen, the addition of stepped geometry on the partial ground planes expands significantly the bandwidth of the antenna. The bandwidth of antenna with SGP is 0.96-3.48 GHz. Then, a hexagonal split-ring slot is introduced in the radiator. This technique leads to the appearance of a lower resonant frequency of 0.85 GHz with a band of 0.7-1.3 GHz. The upper band become from 1.39-3.18 GHz. Thus, the Koch Snowflake geometry combined with the stepped ground planes and the incorporation of slot contribute to a bandwidth improvement and the achievement of dual band.

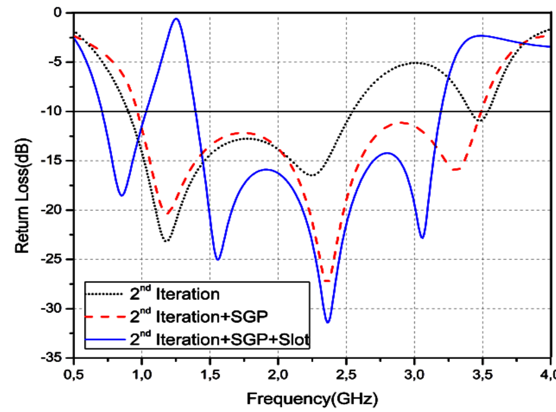
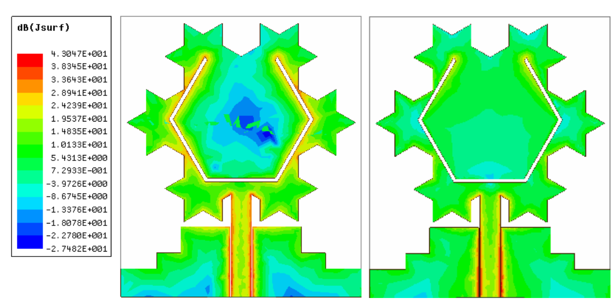
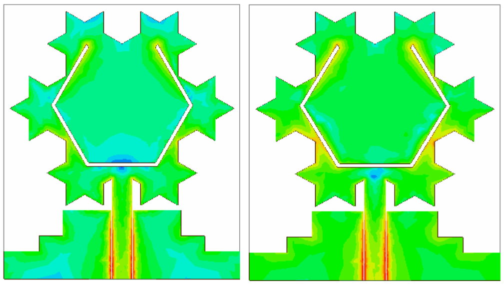


Fig. 5 S_{11} curves for different configurations of the antenna.

Fig. 6 presents the current distribution on the fractal radiator and ground planes at the four selected resonant frequencies of 0.9,2.1,2.4 and 2.6 GHz. It is noticed from Fig. 6(a) that the electric current distribution at 0.9 GHz is concentrated on the hexagonal split-ring slot, the upper edge of the ground planes, the junction of the Koch radiator and feed line and the gap between the feed line and ground planes. This result confirms that the fractal geometry, slot, feed and ground plane affect the impedance characteristics at lower frequencies. The current distribution at 2.1 GHz and 2.4 GHz as shown in Fig. 6(b) and (c) is dominant on the gap between the feed line and ground planes which confirms the impact of gap parameter on impedance matching at these frequencies. It is clear from Fig. 6(d) that the current at 2.6 GHz is mainly concentrated on the gap between the feed and ground plane. There is also current on the upper and lower edge of slot. Thus, the influence of gap parameter and hexagonal slot on impedance matching is important at higher frequencies. Consequently, the parameters that built the Koch Snowflake geometry, feed line, the slot and ground planes are optimized in order to achieve the operating bands and improve the impedance bandwidth.



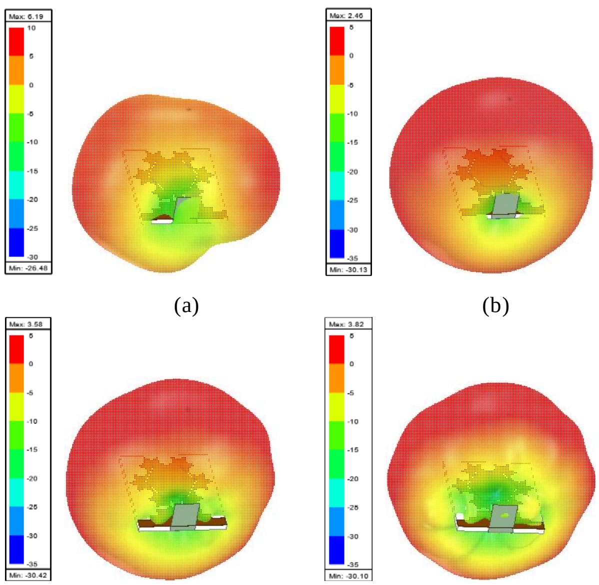
(a) (b)



(c) (d)

Fig. 6 Current distributions of the proposed fractal antenna at (a) 0.9, (b) 2.1, (c) 2.4 and (d) 2.6 GHz.

The simulated 3D gain of the proposed antenna at the selected frequencies are presented in Fig. 7. This antenna has 6.19, 2.46, 3.58 and 3.82 dB at 0.9, 2.1, 2.4 and 2.6 GHz respectively.



(a) (b)

(c) (d)

Fig. 7 3D radiation patterns at (a) 0.9, (b) 2.1, (c) 2.4 and (d) 2.6 GHz.

4. Fabrication and Measured Results

To validate the simulated results described in the previous part, the designed antenna is manufactured and tested. In this part, the measured results are presented and compared with the simulated results. the fabricated antenna is shown in Fig. 8.

The simulated and measured S_{11} curves are depicted in Fig. 9.A good concordance is shown between the two curves. A small deviation between them is due to experimental errors. Based on the measured reflection coefficient, the proposed antenna operates at dual bands. The first band resonates at 0.85 GHz having a bandwidth from 0.73 GHz to 0.98 GHz which cover GSM900 band. The second operating band extends from 1.6 GHz to 3.1 GHz. This wideband can meet GSM1800, UTMS2100, Wi-Fi 2400, LTE2600 frequency bands.

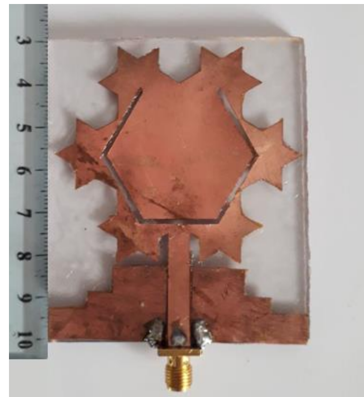


Fig. 8 Fabricated antenna.

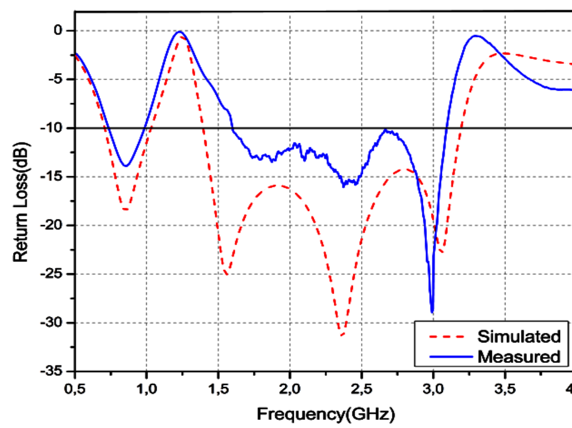
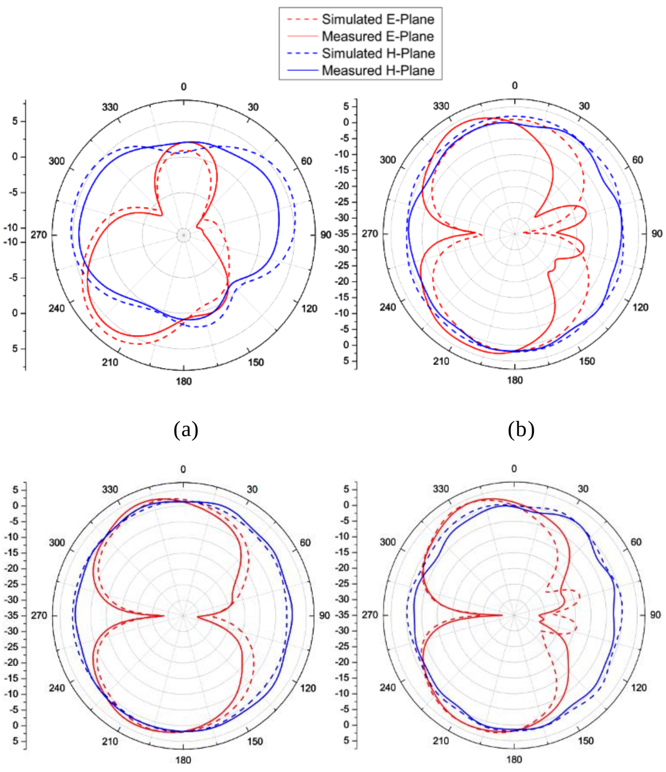


Fig. 9 Measured and simulated reflection coefficient of the proposed antenna.

The simulated and measured E-plane and H-plane radiation patterns of the proposed antenna at 0.9, 2.1, 2.4 and 2.6 GHz are illustrated in Fig. 10. From this figure, the measured radiation patterns at all selected frequencies are bidirectional in the E-plane while radiation patterns are omni-directional in the H-plane.

Fig. 11 presents the measured peak gain and radiation efficiency of the proposed antenna. Over the lower band 0.73-0.98 GHz, the peak gain varies from 3.39 to 3.98 dB. However, over the wide operating band 1.6-3.1 GHz, the peak gain varies from 2.74 to 5.09 dB with values of 4.19, 3.53 and 3.98 dB at 2.1, 2.4 and 2.6 GHz respectively. Radiation efficiency ranges from 65% to 70% for the lower band and ranges from 85% to 95% for the upper band.



(a) (b)

(c) (d)

Fig. 10 Measured and simulated radiation patterns at (a) 0.9, (b) 2.1, (c) 2.4 and (d) 2.6 GHz.

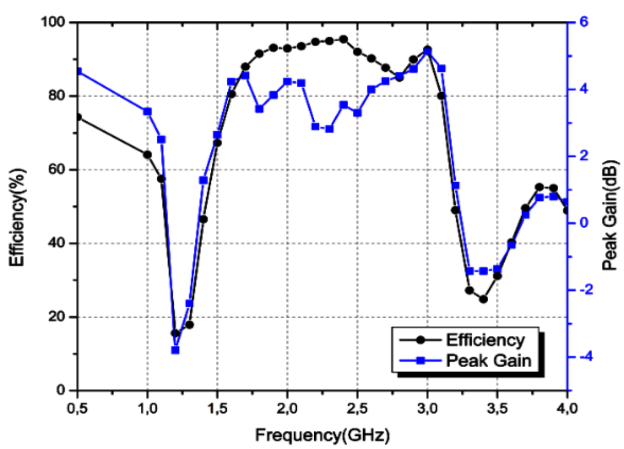


Fig. 11 Measured peak gain and radiation efficiency of the proposed antenna.

5. Conclusion

A Koch Snowflake CPW-fed antenna has been presented. By employing fractal geometry with stepped ground planes and introduction of a hexagonal split-ring slot on the radiating element dual band operation is achieved. The fabricated structure offers a bandwidth from 0.73 GHz to 0.98 GHz and a broad band from 1.6 GHz to 3.1 GHz which gives this antenna the opportunity to be an excellent candidate for various wireless applications in GSM900, GSM1800, UTMS2100, Wi-Fi 2400 and LTE2600 bands. The designed antenna exhibits a bi-directional radiation pattern and omni-directional radiation pattern in E-plane and H-plane, respectively. Satisfactory values of peak gain are reached throughout the two operating bands with a maximum radiation efficiency of 70% at the lower frequency band and 95% at the higher frequency band.

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