

## A CPW-FED WIDEBAND KOCH SNOWFLAKE FRACTAL MONOPOLE FOR WLAN/WiMAX APPLICATIONS

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**Abstract**—A dual wideband CPW-fed slotted Koch snowflake fractal monopole, which is suitable for WLAN/WiMAX applications, is presented. The proposed antenna has been analyzed and designed with Ansoft HFSS<sup>TM</sup> v.11. Then an experimental prototype is fabricated and measured. It is compact with a total size of  $41.5 \text{ mm} \times 27 \text{ mm} \times 1 \text{ mm}$  ( $L \times W \times T$ ). Results of simulation and measurement indicate that the proposed fractal monopole with a U-shaped slot has dual impedance bandwidths 2.35–4.25 GHz and 4.8–5.95 GHz, which covers WLAN bands (2.4/5.2/5.8 GHz) and the WiMAX bands (2.5/3.5/5.5 GHz) respectively. In addition, good radiation performances such as omnidirectional and doughnut-shaped directivity and goodish gain over the operating bands have been obtained.

### 1. INTRODUCTION

In recent years, with widespread deployment of short distance wireless communications, such as Wireless Local Area Networks (WLANs), the demand for compact, low cost, multiband and broadband antenna has increased rapidly. The two commonly used protocols of WLANs are WiFi and WiMAX. WiFi, which relays data and promises higher data rates and increased reliability based on access point, is designed to operate in 2.4 GHz (2.40–2.48 GHz) band and 5 GHz bands (5.15–5.35 GHz, 5.725–5.825 GHz in the United States and 5.15–5.35 GHz, 5.47–5.725 GHz in Europe). And also, there is another low cost, easily deployable, broadband wireless access commonly named WiMAX

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(Worldwide Interoperability for Microwave Access), which is allocated the 2.5–2.69/3.4–3.69/5.25–5.85 GHz bands. On the requirements of miniaturization and integration of modern communication system, it is necessary for an antenna to cover all these bands.

Printed planar monopole antennas are attractive for WLAN because they have low profile, they can be etched on a single substrate and can provide the feature of wide broadband or multiband operation. A coplanar waveguide (CPW) feed makes them more suitable for compact wireless communication system because of its features like uniplanar structure, easy fabrication and circuit integration. Another important advantage of CPW-fed is wider bandwidth than CPS and microstrip line. Fractal shaped antennas exhibit some interesting characteristics, which correlate with their geometrical properties. Fractals mean broken or irregular fragments, which describe a complex set of geometries ranging from self-similar or self-affine to other irregular. Fractal structures are generally composed of multiple copies of themselves at different scales and the size of a fractal is determined by the initiator and iteration number. The fractal, which is applied to antenna design, is usually a pre-fractal or a quasi-fractal but not a mathematically fractal geometry with infinite scale. So, a quasi-fractal with several iterations can be utilized for a specific multiband antenna. Each frequency band is corresponding to a specific scale of the fractal. Fractal antenna engineering is an emerging field that employs fractal concepts for developing new types of antennas with notable characteristics. The self-similarity of fractal structures results in a multiband behavior of antennas [1–4] and frequency-selective surfaces (FSS) [5]. Fractal antennas and arrays also exhibit lower side-lobe levels [6]. In the past, a lot of work has been done in the area of fractal antenna engineering [7–9]. Fractal techniques have been applied to monopoles [10, 11], patch [12], loops [13], dipoles [14], and slot antennas [15–17]. It was shown that the electrical performance of Koch fractal monopoles is superior to that of conventional straight-wire monopoles, especially when operated in the small-antenna frequency regime. In [10], the behavior of a Koch curve fractal monopole antenna is discussed and the results show that as the number of iterations on the small fractal Koch monopole are increased, the quality factor of the antenna approaches the fundamental limit for small antennas.

Although a wide-band antenna operating from 2.3 to 6 GHz is sufficient, Wideband antenna is usually difficult possesses the most desirable properties for different bands and susceptible to interference and noise or vice versa, so a good filter is needed. A dual band antenna design would significantly relax the requirements imposed upon the filtering electronics within the wireless device and would

be cost-effective. Etching a particular feature in the interior of the radiating element of a planar monopole is a simple means for creating a frequency notch while maintaining the wide-band operation [11, 14]. In this paper, the properties of a Koch snowflake fractal monopole antenna will be presented and discussed. The properties the Koch iteration technique has been applied to a simple antenna to obtain first iteration and second iteration fractal versions of the monopoles antenna and a half wavelength U-shaped slot is integrated with the wide-band Koch monopoles antenna for the filter action. This way the antenna achieves dual wide-band operation satisfying the WLAN and WiMAX bands simultaneously along with a compact profile by virtue of the Koch fractal based boundary geometry.

## 2. ANTENNA DESIGN

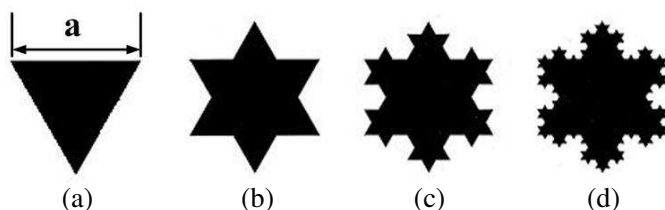
### 2.1. Koch Fractal Technique

Koch fractal geometry was originally introduced by Helge von Koch in 1904. The Koch geometry can be generated using an iterative function system (IFS) represented by a set of affine transformations [7, 8]. The basic geometry that is analyzed throughout this paper is the monopole antenna with Koch fractal boundary. This geometry is obtained by replacing the sides of an equilateral triangle by a Koch curve. In Figure 1, the Koch island fractal at different iteration stages is shown.

At each new iteration  $n$ , the area of the island increases. Let  $S_n$  be the area at iteration  $n$ , then the area of the next iteration can be computed as

$$S_{n+1} = S_n + \frac{\sqrt{3}}{12} \left(\frac{4}{9}\right)^{n-1} * a^2 \tag{1}$$

where  $a$  is the side of the initial triangle that has an area  $S_0 = (\sqrt{3}/4)a^2$



**Figure 1.** Koch snowflake geometry in its different iteration stages. (a) Initiator. (b) First iteration. (c) Second iteration. (d) Third iteration.

in Figure 1(a). The geometric series given by (1) converges to

$$S = \frac{2\sqrt{3}}{5}a^2 \quad (2)$$

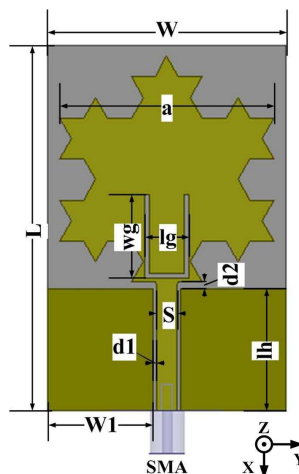
All the iterations are circumscribed inside a circumference of radius  $r = \sqrt{3}a/3$ . However, the perimeter increases at each new iteration. Let  $l_n$  be the perimeter at iteration  $n$ , then the overall perimeter for iteration  $n$  is given by

$$l_n = 3a \left(\frac{4}{3}\right)^n \quad (3)$$

For the fractal, an infinite perimeter bounding a finite area is obtained. Despite of the increasing irregularity of the boundary, the manufacturing process does not become more complex at each new iteration. The patch can be manufactured by standard photoetching technique. The fundamental limitation in building the antenna is given by the resolution of the photo etching process. When the number of iterations is increased, the new added details in the structure cannot be resolved, and they are not reproduced in the manufactured element. So the physical construction of the fractal is not possible. Only objects with a limited number of iterations can be built.

## 2.2. Koch Fractal Monopole Antenna Design

The configuration of the proposed Koch snowflake U-shaped slotted fractal monopole for dual band operation is illustrated in Figure 2.



**Figure 2.** Geometry of the proposed antenna.

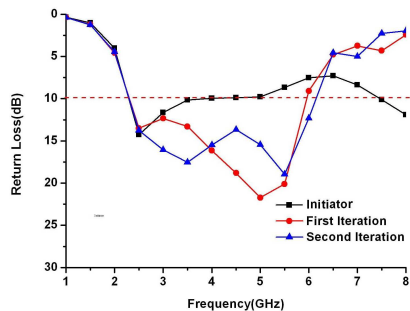
As shown in Figure 2, the designed antenna which is printed on FR-4 substrate with thickness of  $T = 1$  mm, and  $\epsilon_r = 4.4$ , has a compact dimension of  $41.5 \text{ mm} \times 27 \text{ mm}$  ( $L \times W$ ). Note that both the radiation patch and the central trace are etched on the same surface of the substrate, and so are the two rectangular grounds which are on the both sides of the central trace. The width of the central trace is denoted as  $S$  is fixed at  $2.2 \text{ mm}$  to implement  $50 \text{ Ohm}$  characteristic impedance, and a standard SMA connector is connected to facilitate its connection with other communication devices. The initiator of the patch is an equilateral triangle of side, in of which two Koch iterations are carried out on sides, as shown in Figures 1(a)–(d).

This antenna structure is easy to design and to achieve a stable dual band with a U-shaped slot. To investigate the performance of the proposed antenna in terms of achieving dual band operations, the commercially available simulation software Ansoft HFSS™ V.11 was used for numerical analysis and to obtain the proper geometrical parameters, as listed in Table 1.

To design the dual band antenna, we have applied three techniques to the proposed antenna: the use of (i) patch with Koch fractal boundary, which can lead to a small size, (ii) a partial ground plane, which can lead to a good impedance matching, and (iii) a U-shaped slot etching in the interior of the radiating patch, which can result in a dual

**Table 1.** The optimized antenna parameters. (Unit: mm).

$L$	$W$	$a$	$W_1$	$l_h$	$S$	$d_1$	$d_2$	$w_g$	$l_g$	$T$
41.5	27	24.3	12	13.8	2.2	0.4	0.7	9.5	4	1

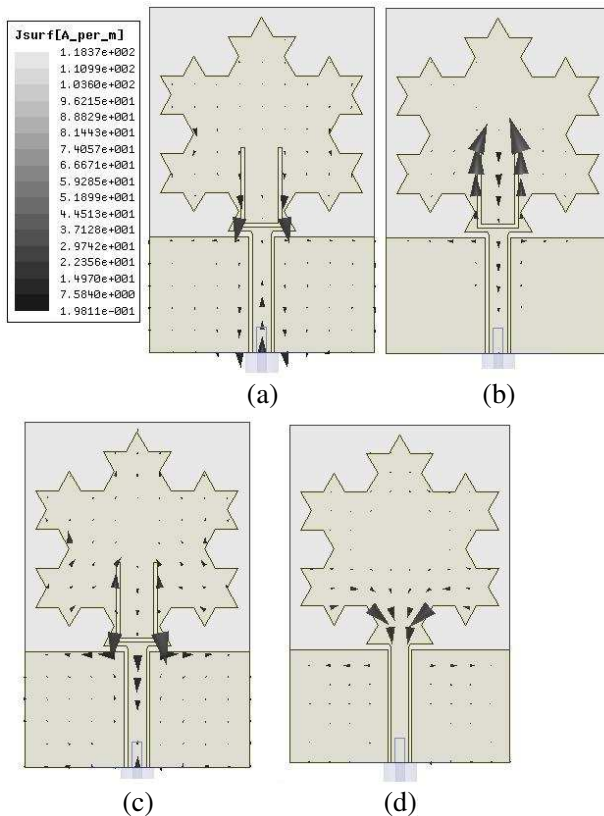


**Figure 3.** Simulated return loss of the CPW-fed Koch monopole antenna (without the slot) for different iterations of the patch ( $\epsilon_r = 4.4$ ,  $h = 1 \text{ mm}$ ,  $L = 41.5 \text{ mm}$ ,  $W = 27 \text{ mm}$ ,  $a = 24.3 \text{ mm}$ ,  $w_1 = 12 \text{ mm}$ ,  $l_h = 13.8 \text{ mm}$ ,  $S = 2.2 \text{ mm}$ ,  $d_1 = 0.4 \text{ mm}$ ).

band. By selecting these parameters listed in Table 1, the proposed antenna can be tuned to operate in the 2.35–4.25 GHz and 4.8–5.9 GHz frequency ranges satisfying the WLAN and WiMAX bands.

### 3. RESULTS AND DISCUSSION

The geometry of the simple Koch snowflake fractal, the first iteration Koch, the second iteration Koch and the third iteration Koch are shown in Figures 1(a), (b), (c), and (d), respectively, Figure 3 plots the simulated return loss of the antenna (without the U-shaped slot) for the different iteration stages of the Koch geometry starting from the equilateral triangle.



**Figure 4.** Simulated current distribution on the radiation patch and the slot at (a) 2.5 GHz, (b) 4.5 GHz and (c) 5.3 GHz and (d) 4.5 GHz without slot.

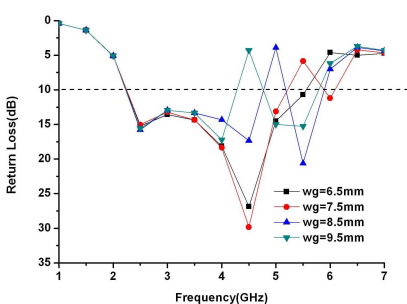
With the fixed CPW parameters, and the length  $a$  of the side of the initial triangle is fix at 24.3 mm, the simulated result shows that the resonant frequency of the monopole antenna increases with the increase in the number of iterations. Even though the perimeter of the patch boundary increases by a factor of 33% with each iteration, the change in resonant frequency does not follow the same order. Also, it is observed that the Koch snowflake fractal geometry enhancing the impedance bandwidth of the monopole antenna. The operating band of the antenna shifts from 2.3–3.65 GHz to 2.3–6.15 GHz as the number of iterations increase to 2. Further increase in the iteration order causes only a minor increase in the operating frequency. The second iteration monopole is operating at the bandwidth of 2.3–6.15 GHz, which completely covering the WLAN/WiMAX bands.

The surface current distribution on the conducting layer and the U-shaped slot are simulated using Ansoft HFSS™ V.11 and plotted in Figure 4.

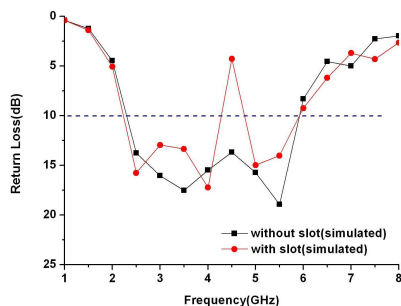
A half wavelength U-shaped slot etched out on the wide-band antenna notches out the corresponding frequency ( $f_{slot}$ ) leading to a dual wide-band operation. Figure 5 plots the simulated return loss of the antenna for different slot lengths. As the slot length increases from 17 mm ( $w_g = 6.5$  mm) to 23 mm ( $w_g = 9.5$  mm), the notched frequency shifts from 6.0 GHz to 4.5 GHz, following (4) as

$$L_{slot} \approx \frac{c}{2f_{slot}} \left( \sqrt{\frac{\epsilon_r + 1}{2}} \right)^{-1} \tag{4}$$

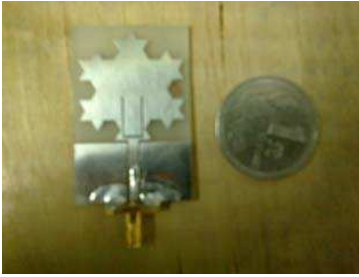
where  $L_{slot}$  is the length of the U-shaped slot, which equals to  $2 * w_g + l_g$ .



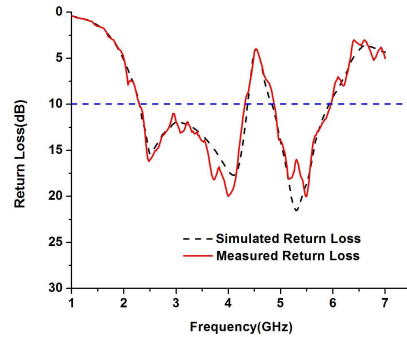
**Figure 5.** Return loss of the antenna for different slot lengths. ( $l_g$  is fixed at 4 mm,  $w_g$  shifts from 6.5 mm to 9.5 mm).



**Figure 6.** Simulated return loss of the antenna with and without slot. ( $w_g = 9.5$  mm,  $l_g = 4$  mm).



**Figure 7.** The photograph of the proposed antenna.



**Figure 8.** Measured and simulated return loss of the antenna with the U-shaped slot.

Figure 6 shows the simulated return loss of the Koch snowflake fractal monopole antenna with and without slot. When  $L_{\text{slot}} = 23$  mm ( $w_g = 9.5$  mm,  $l_g = 4$  mm), the notched frequency is 5.3 GHz. The antenna with the U-shaped slot expressed the characteristic of wide dual band.

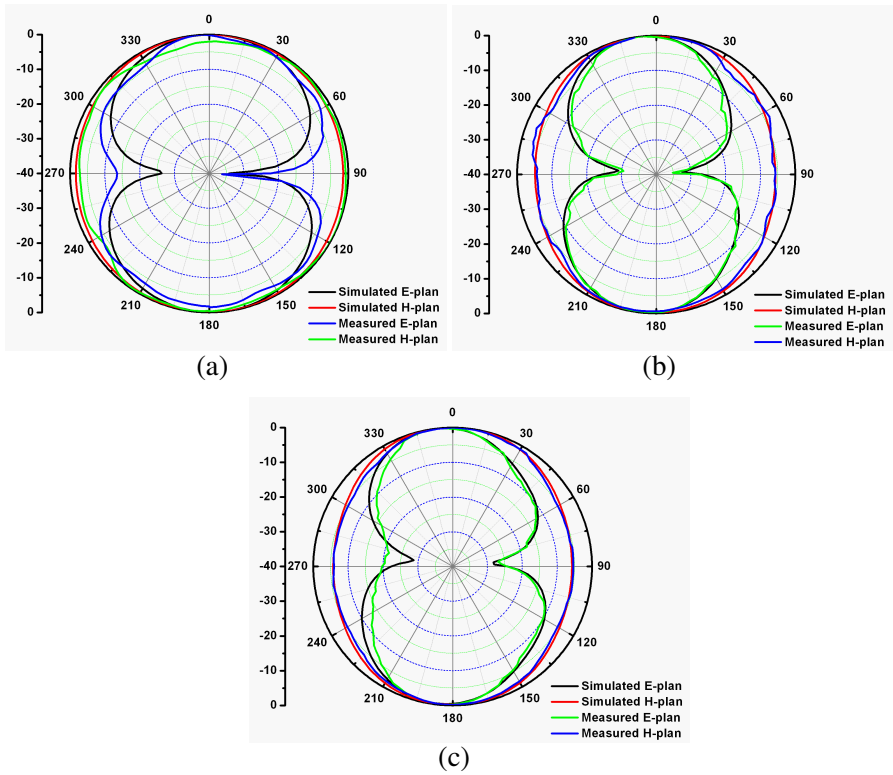
The surface currents on the patch at 4.5 GHz are shown in Figures 4(b) and (d), with and without the slot. It shows how the excited surface currents on the antenna interfere destructively due to the presence of a U-shaped slot ( $w_g = 9.5$  mm), hence causing the antenna to be non-radiating at that frequency.

The prototype of proposed antenna (Figure 7), with dimensions as in Table 1, is fabricated and its impedance was measured using a WILTRON-37269A Vector Network Analyzer.

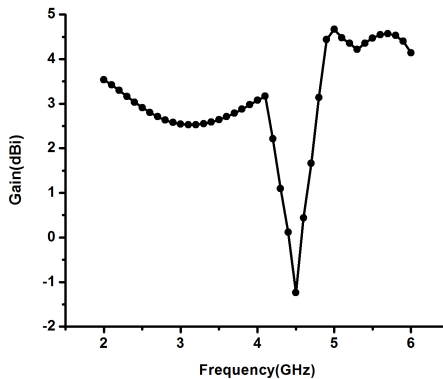
The simulated and measured return loss of the antenna plotted in Figure 8, show good agreement. The 10 dB bandwidth of the wide-band antenna (without the slot) is 3.6 GHz (2.35–5.95 GHz). With the U-shaped slot, the antenna gives dual wide-band performance with a 10 dB bandwidth of 1.9 GHz (2.3–4.25 GHz) and 1 GHz (4.95–5.95 GHz) in the lower and upper bands respectively. Thus, it covers the 2.4–2.484 GHz, 5.15–5.35 GHz, and 5.725–5.825 GHz WLAN bands, and the 2.5–2.69 GHz, 3.4–3.69 GHz, and 5.25–5.85 GHz WiMAX bands.

The far-field radiation characteristics of the proposed dual band antenna have also been studied. The normalized radiation patterns of  $E_\theta$  and  $H_\phi$  simulated and measured at 2.5, 5.3 and 5.8 GHz are plotted in Figure 9, respectively. As depicted, the radiation patterns are stable and in the considered bands this antenna exhibits nearly





**Figure 9.** Simulated and measured radiation pattern  $E$ -plane polarization pattern  $E_{\theta}$  and  $H$ -plane polarization pattern  $H_{\phi}$  of proposed antenna at (a) 2.4 GHz, (b) 5.3 GHz, (c) 5.8 GHz.



**Figure 10.** Gains of the proposed dual band antenna.

omni-directional radiation patterns in the  $H$ -plane ( $y$ - $z$  plane) and dipole-like directional patterns in the  $E$ -plane ( $x$ - $z$  plane).

Additionally, the simulated on-axis gains of the proposed antenna in the operating bands are plotted in Figure 10, and the direction is the  $Z$ -axis in Figure 2. It is seen that the gain remains above 2.0 dBi in the WLAN and WiMAX bands. Simulation studies indicate that the antenna radiation efficiency is greater than 80% throughout the operating band.

#### 4. CONCLUSION

A compact CPW-fed dual wideband fractal monopole antenna has been proposed for WLAN 2.4/5.2/5.8 GHz and WiMAX 2.5/3.5/5.5 GHz applications. The simulated and measured results show that the introduction of the Koch snowflake fractal patch geometry increases the frequency broadband of the monopole antenna. The antenna size inclusive of the ground plane is  $41.5 \text{ mm} \times 27 \text{ mm} \times 1 \text{ mm}$  ( $L \times W \times T$ ) and a simple U-shaped slot ensures dual wideband operation covering WLAN bands and WiMAX bands. The radiation patterns at 2.5, 5.3 and 5.8 GHz and the antenna gain in 2–6 GHz frequency range is also presented. The results show a large impedance bandwidth with relatively stable and omnidirectional radiation patterns which makes the monopole suitable for broadband wireless communication applications. Additionally, the planar and simple structure makes it ease of design and fabrication.

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