# Design and Analysis of Koch Fractal Slots for Ultra-Wideband Applications

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**Abstract** In this paper, a design of a dual-band Koch fractal antenna is proposed. Patch antenna has dimensions of 30 mm × 18 mm × 0.76 mm which operates in ultra-wideband (UWB) with a notch band from 5 to 6 GHz. Further, the design is modified using different Koch fractal geometries to observe the multi-band resonant behavior of the antenna. The modified antenna has dimensions of 18 mm × 18 mm × 0.8 mm. By modifying the shape of radiating patch and ground with fractal shapes and by introducing slots, impedance bandwidth and radiation characteristics were improved. The proposed antenna works well for WiMAX and WLAN applications with approximately 95% radiation efficiency. The parametric analysis is carried out for various parameters in order to obtain better return loss characteristics. The design is simulated using HFSS software, and the performance is measured by obtaining the antenna parameters.

**Keywords** Koch fractal · WiMAX · WLAN · UWB · HFSS

## 1 Introduction

The growing demand for wireless communications in recent years requires antennas which can provide large impedance bandwidths, high data rate, and higher gain. Ultra-wideband (UWB) is one such technology that provides very large bandwidth and higher data rates [1]. But the main disadvantage of using UWB technology is electromagnetic interference (EMI). To eliminate the interference problems, UWB

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antennas are designed to achieve band notch characteristics [2–6]. Designing an antenna for wireless applications requires compactness and cost-effectiveness. Using the microstrip antennas for these applications is the right choice because of the numerous advantages provided by microstrip antennas [7–10]. Several designs have been proposed to achieve UWB response using microstrip antennas [11–15]. Single-, double-, and triple-band rejections are achieved by rearranging the radiating element or by cutting slots on patch, ground plane [16] or by introducing additional stubs on any of the radiating patch or ground plane [17]. Achieving wide bandwidth offers a low gain in the resonant band. The compromise between bandwidth and gain should be made before designing the antenna. Several techniques have been proposed to improve the gain while maintaining the required bandwidth [18].

The antenna miniaturization is getting much attention in the recent years since the fractal geometries are introduced into antenna design [19]. Fractal structures are used widely to reduce the size of the antenna and to achieve multi-band resonant behavior. Several fractal designs have been proposed to get multiple band resonances and at the same time more compact and high-impedance bandwidth structures [20–23]. The idea of fractals can also be used to achieve UWB range. By using the different fractal geometries, UWB with band rejection can also be designed [24].

In this paper, a rectangular printed patch antenna is designed to achieve the ultra-wideband behavior. By introducing additional stub on ground plane, band notch characteristics are achieved. Frequency band from 5 to 6 GHz is rejected from the ultra-wideband to eliminate the interference with WLAN. Implementing Koch fractal in antenna design provided the multiple band resonances. Different Koch fractal geometries were designed and compared.

## 2 Design Methodology

The designed antenna was fabricated using a low-cost FR4 substrate with 0.8 mm thickness and 4.4 relative permittivity. The dimensions of patch, ground plane, and slots were given in Table 1. Making use of defected ground structures and slots suppresses the surface waves, which in turn improves the bandwidth significantly.

Figure 1a shows the slotted ultra-wideband patch antenna. Frequency notch band characteristics are obtained with the addition of radiating stub as shown in Fig. 1b.

### *2.1 Design of Fractal Antenna*

By using the fractal geometries in antenna design, multi-band response can be achieved. To achieve multi-band characteristics, this design Koch fractal geometry as shown in Fig. 2a–c is considered, and the results were compared for different fractal designs. The dimensions of slots were presented in Table 2.

**Table 1** Dimensions of UWB antenna

| Description | Symbol | Dimension in mm |
|---|---|---|
| Patch length | $L$ | 18 |
| Patch width | $W$ | 14.4 |
| Ground plane length | $l_1$ | 14.4 |
| Substrate thickness | $H$ | 0.76 |
| Dielectric constant | €r | 4.4 |
| Slot length | $h_1$ | 3 |
| Slot width | $w_1$ | 3.5 |
| Stub length | $A$ | 5.3 |
| Stub width | $B$ | 7 |
| Feed line width | $w_f$ | 1.4 |
| Feed line length | $l_f$ | 15.6 |

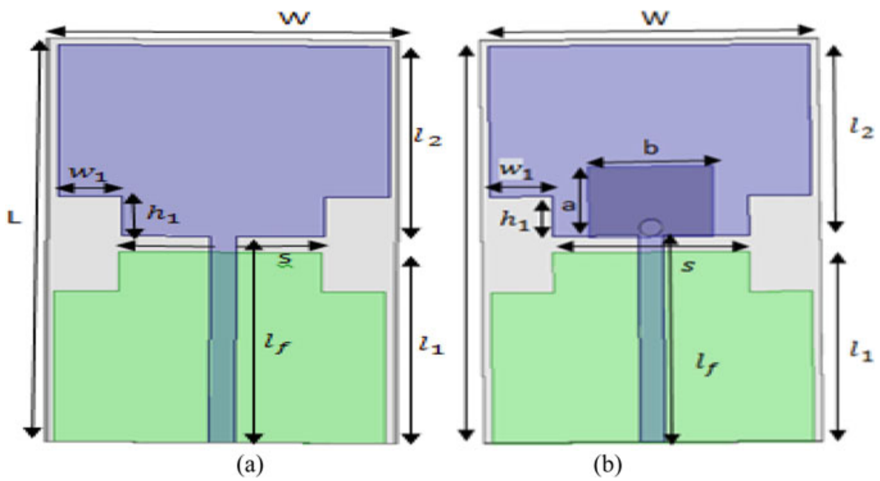



**Fig. 1** **a** UWB antenna without notch element. **b** UWB antenna with notch element

# 3 Results and Discussions

## *3.1 Parametric Study*

Ultra-wideband response for the microstrip antenna is obtained by introducing bevel slots on both radiating patch and ground as shown in Fig. 1a. The return loss plot for design 1 (UWB antenna without notch element) is given in Fig. 3a.

Notch band characteristics for the rectangular microstrip printed patch antenna are obtained by optimizing the width and length of the stub placed on ground plane. The parametric analysis results for UWB antenna with additional stub in ground

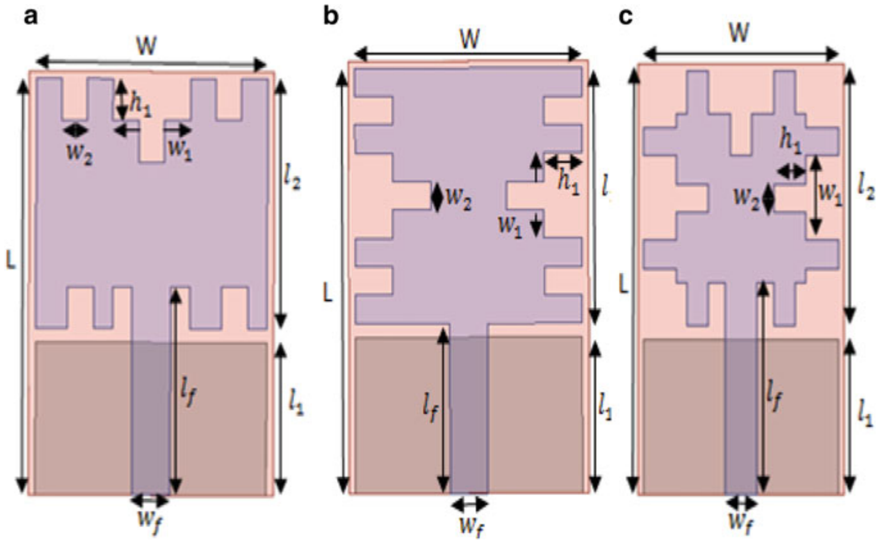



**Fig. 2** **a** Koch fractal antenna with upper and bottom slots. **b** Koch fractal antenna with right and left slots. **c** Koch fractal antenna with slots in all sides

**Table 2** Dimensions of fractal antenna

| Description | Symbol | Dimension in mm |
|---|---|---|
| Substrate length | $L_s$ | 30.5 |
| Substrate width | $W_s$ | 19 |
| Patch length | $L$ | 18 |
| Patch width | $W$ | 18 |
| Ground plane length | $l_1$ | 14.4 |
| Patch length | $l_2$ | 18 |
| Substrate thickness | $H$ | 0.76 |
| Dielectric constant | €r | 4.4 |
| Slot length | $h_1$ | 3 |
| First slot width | $w_1$ | 6 |
| Second slot width | $w_2$ | 2 |

plane were presented in Fig. 3b, c. The optimized values for stub length and width are given in Table 1. For stub length and width A and B, designed antenna operates in UWB range, rejecting the band from 5 to 5.9 GHz. The optimized return loss plot was given in Fig. 3d.

To achieve multi-band resonance, a Koch fractal is designed by two iterations. The return loss characteristics were given in Fig. 3e.

Fractal geometries act as combination of inductors and capacitors. By properly designing the fractal structure, required multi-band resonance can be obtained. By

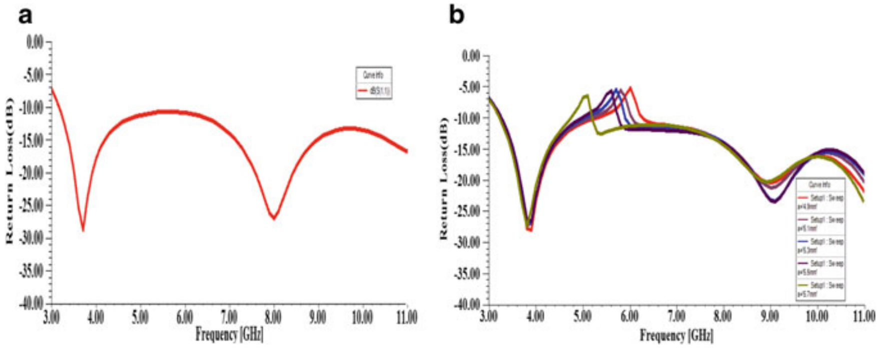



**Fig. 3** **a** Return loss of UWB antenna without stub. **b** Effect of stub length on return loss

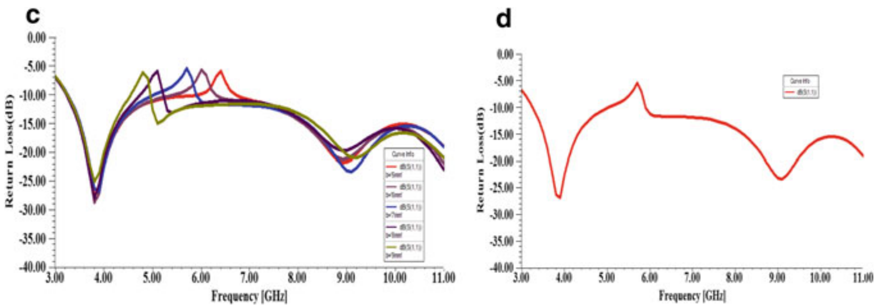



**Fig. 3** **c** Effect of stub width on return loss. **d** Optimized return loss plot with single notch

using Koch fractal with all side slots, dual-band resonance at frequencies 3.3 and 5.5 GHz is obtained. The fabricated antenna and return loss plot for Koch fractal antenna are shown in Fig. 3f, g. Table 3 gives the comparison between three Koch fractal designs and notch band antenna design.

## *3.2 Return Loss*

Return loss plots for simulated and fabricated antenna are shown in Fig. 3g. Results were same except for few deviations. From Fig. 3g, it should be noted that designed antenna works for both WiMAX (3.3 GHz) and WLAN (5.5 GHz) bands.

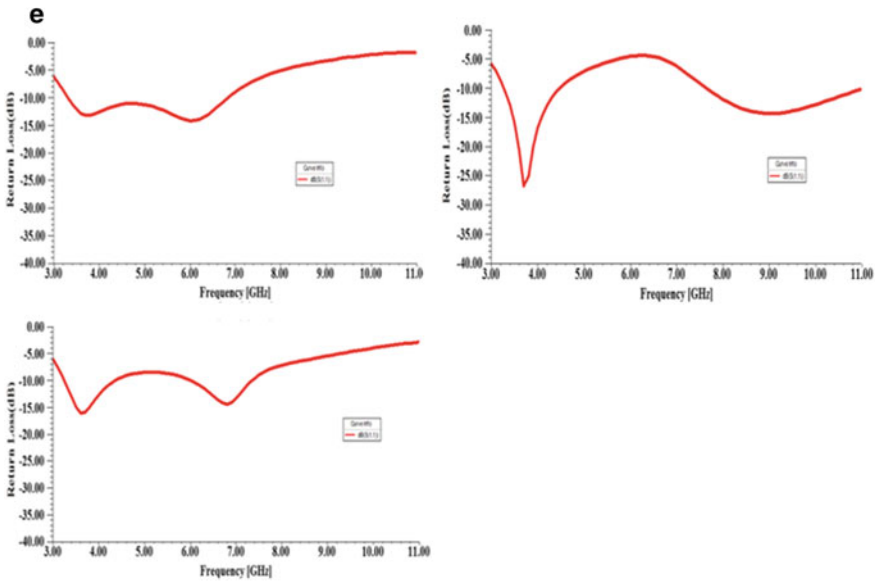
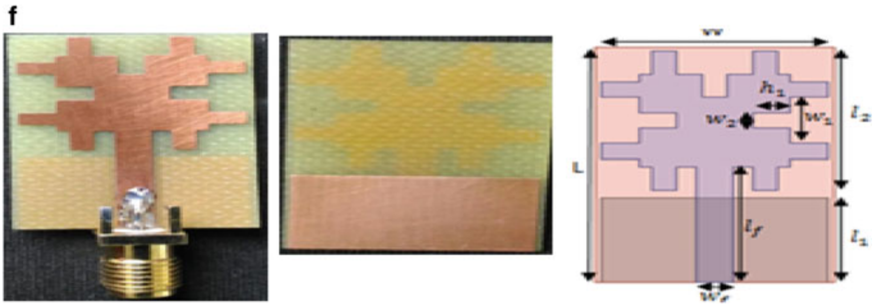



**Fig. 3** **e** Koch fractal antenna return loss for designs 1, 2, and 3, respectively



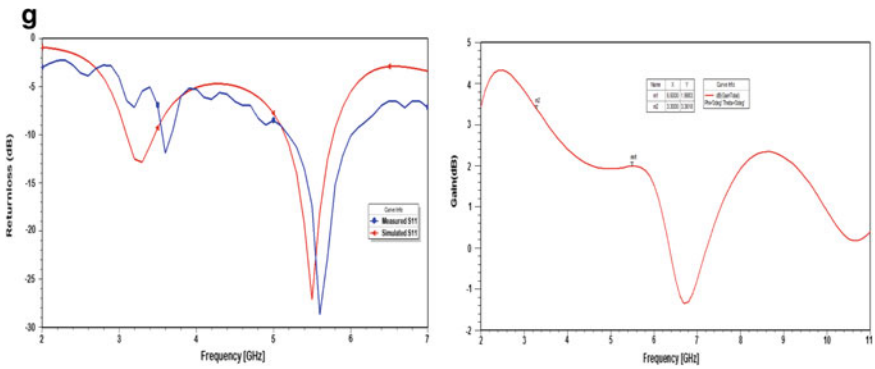




**Fig. 3** **f** Fabricated and simulated antenna. **g** Return loss plot for Koch fractal antenna with all side slots (*red curve*-simulated, *blue curve*-measured) and gain versus frequency plot

**Table 3** Comparison of resonant frequencies

| Description | Resonant band (GHz) | Gain (dB) |
|---|---|---|
| UWB antenna without stub | 3.2–11 | 2.064 |
| UWB antenna with stub | 3.2–11 with notch at 5–5.9 | 2.39 |
| Koch fractal with bottom and upper slots | 3.4–6.8 | 2.25 |
| Koch fractal with right and left slots | 3.7, 8.8 | 2.05 |
| Koch fractal with all side slots | 3.3, 5.5 | 3.3, 1.9 |

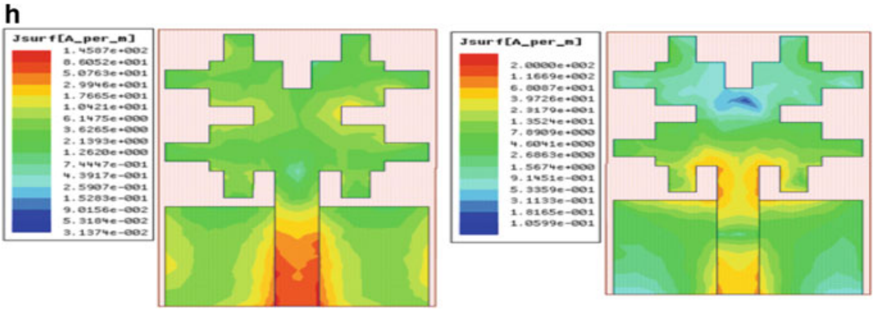



**Fig. 3** **h** Electric field distributions at frequencies 3.3 and 5.5 GHz

## *3.3 Gain Versus Frequency*

As shown in Fig. 3h, gain values obtained at frequencies 3.3 GHz and 5.5 GHz are 3 dB and 2 dB, respectively.

## *3.4 Electric Field Distribution*

Field distribution at two resonant frequencies is shown in Fig. 3h. Maximum current is distributed at the edges of the patch which is responsible for maximum radiation at the edges.

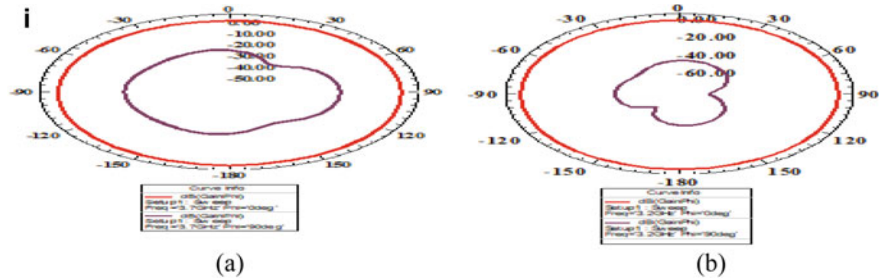



**Fig. 3** **i** 2-D radiation pattern for UWB antenna. **a** Without stub and **b** with stub

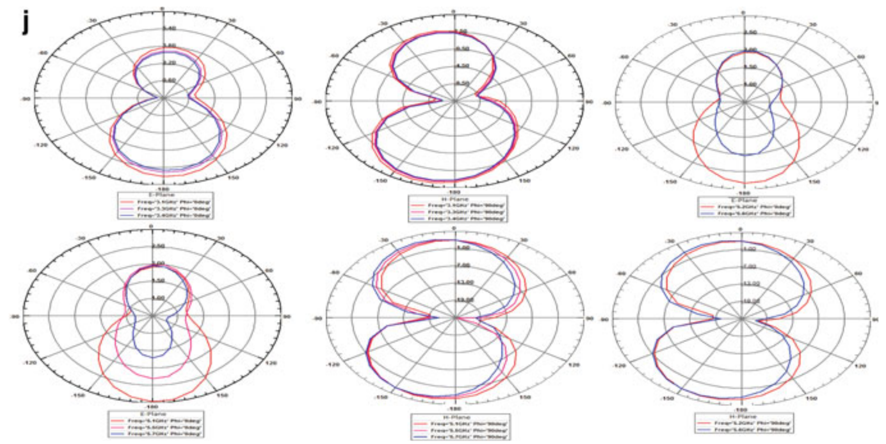



**Fig. 3** **j** Radiation patterns in both E-plane and H-plane for frequencies 3.14, 3.3, 3.4, 5.16, 5.5, and 5.76 GHz

### *3.5 Radiation Pattern*

The two-dimensional far-field pattern for UWB antenna without and with stub is presented in Fig. 3i, j. Figure 3k shows the radiation patterns for resonant frequencies and lower and higher cutoff frequencies. It shows that in both cases, the antenna radiates in nearly omni-directional manner.

The radiation plots for Koch fractal antennas were given in Fig. 3a–c.

## 4 Conclusion

The performance of the proposed antenna is evaluated for different fractal configurations. The antenna is simple and compact. The results show that the antenna can

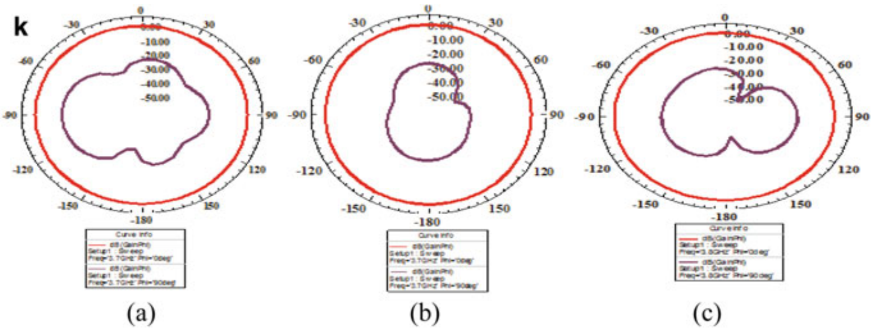



**Fig. 3** **k** 2-D radiation pattern for Koch fractal antenna. **a** Upper and bottom slots, **b** right and left slots, and **c** all side slots

be used for multiple bands. As a future work, printed fractal antenna can be further extended to achieve the ultra-wideband characteristics.

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