A Compact Fractal Based Printed Monopole Antenna for WiBro, WiMax and UWB Applications

Mahmood T. Yassen, Jawad K. Ali, Ali J. Salim, Seevan F. Abdulkareem, Ali I. Hammoodi and Mohammed R. Hussan

Abstract*— In this paper a compact Koch fractal based printed monopole antenna has been introduced as a candidate for use in applications in which the WiBro, WiMax, ISM and UWB services are integrated. The monopole radiating element has a rectangular shape with two slots cut from each corner. In addition, the sides of the radiator, except that of the feed line direction, have been modified to be in the form of Koch fractal curve of third iteration. A small rectangular slot has been made in the ground plane beneath the feed line. The antenna has been fed with an offset 50 Ohm microstrip transmission line. Both the antenna and the feed line have been printed on an FR-4 substrate with a thickness of 1.59 mm and relative permittivity of 4.4. Modeling and performance evaluation of the proposed antenna have been carried out using a method of finite integration technique (FIT) based EM simulator, CST Microwave Studio. Simulation results show that the proposed antenna offers an impedance bandwidth, for return loss ≤ –10 dB in the range of 2.3 – 11.5 GHz. Furthermore, the proposed antenna radiating element has a compact size of 20 × 20 mm^2.

Keywords:- Compact fractal antenna, Microstrip transmission line, Printed monopole antenna, Wireless applications .

I. INTRODUCTION

Recently, the ability to incorporate more than one communication standard into a single system has become an increasing demand for a modern portable wireless communication device. Due to the limited space, it often requires an antenna to serve several applications such as Bluetooth, and UWB applications [1]. Ultra-wide band (UWB) technology is emerging as a solution for IEEE 802.15.3a (TG3a) standard [2]. The purpose of this is to provide a specification for a low cost, low complexity, low power, and high data-rate wireless connectivity among devices within personal operating space. UWB technology has received an impetus and attracted academia and industrial attention in the wireless world ever since Federal communication commission released a −10 dB bandwidth of 7.5 GHz (3.1-10.6) GHz with an effective isotropic radiated power (EIRP) spectral density of –41.3 dBm/MHz for communication applications [3].

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On the other hand, fractal antenna engineering is swiftly evolving field that aims at developing a new class of antennas that are multiband and wideband [4-6]. A fractal is a self-repetitive geometry which is generated using an iterative process and whose parts have the same shape as the whole geometry but at different scales. Another property of fractal geometries, which makes them attractive candidates for use in the design of fractal antennas, is their space-filling property. This feature can be exploited to miniaturize antenna elements. Koch curve shown in Figure 1 is a good example of self-similar space-filling fractals which have been used to develop miniaturized antennas [7].

Various planar monopole antennas, with different shapes of the radiating elements, have been reported in [8-18] for UWB applications. More research work has been devoted to design compact antennas covering additional services, such as Bluetooth, WiBro, WiMax and others, besides the UWB have been reported [19-23].

In this paper, the design of a compact printed monopole antenna based on Koch fractal geometry is presented. The antenna radiating element has been fed with an offset microstrip line. The radiator of this antenna is built using a square patch with two rectangular slots made at each corner. The sides of the square, except for that in the direction of the feed line, have been made to take the form of Koch fractal curve of third iteration. The ground plane also is provided with a rectangular slot beneath the feed line.

With this design a multiple resonant frequencies are excited and merged to form a simulated operating bandwidth of 2.3-11.5 GHz with return loss ≤ − 10 dB. This bandwidth is suitable for Wireless Broadband (WiBro) 2.3-2.4 GHz, Industrial Scientific Medical (ISM 2.4-2.484) GHz, Worldwide Interoperability for Microwave Access (WiMax) 2.5-2.7 GHz and Ultra-Wideband (UWB) 3.1-10.6 GHz applications.

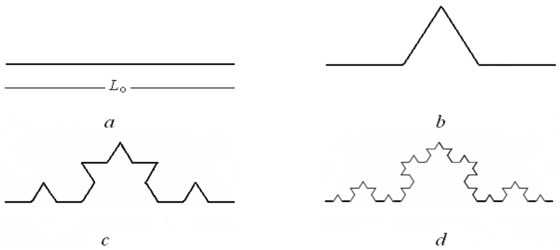


Figure: 1 The generation process of the Koch pre-fractal structure; (a) the generator, (b) the 1st iteration, (c) the 2nd iteration, and (d) the 3rd iteration.

II. THE PROPOSED STRUCTURE

Figure 2 shows the layout of the proposed fractal based printed monopole antenna structure which contains the radiator and the offset microstrip feed line. The total size of the antenna including the ground plane is 40×38 mm^2, which has been supposed to be printed on an FR4 substrate of thickness 1.59 mm, and relative permittivity of 4.4.

The radiator having dimension W × L is excited using an offset 50 ohm microstrip feed line. The dimension of offset feed line is Wf × Lf whereas the center of the feed line is offset by d1 mm from the center of radiator.

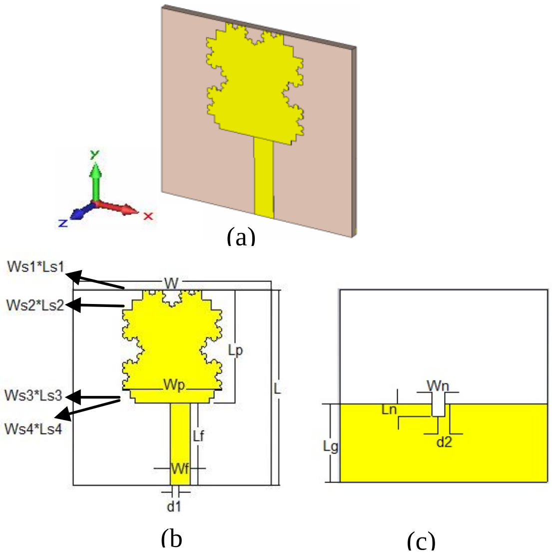


Figure: 2 (a) perspective view of the entire antenna structure (b) front view (c) bottom view.

Two slots have been cut from each corner of radiator in stepped manner with the dimensions Ws1 × Ls1, Ws2 × Ls2, Ws3 × Ls3, and Ws4 × Ls4. The left length, right length, and the upper width of the radiator have been modified in the form of Koch fractal curve of third iteration. Figure.2 (c) shows the bottom view of the structure which contains the reduced ground plane. The ground plane has the same width of substrate and the length Lg. A rectangular slot with dimensions of Wn × Ln has been introduced at upper side of the ground plane and beneath the microstrip feed line. The center of this slot is offset from the center of ground plane by d2 mm.

Table 1 summarizes the detailed dimensions of the proposed antenna parameters as labeled in Figure 2. The resulting fractal structure has the characteristic that the length increases, while maintaining the space occupied. This increase in length decreases the required volume occupied for the fractal antenna at resonance. It is found that:

$$L_n = (\frac{4}{3})L_{n-1} \qquad (1)$$

where, L_n is the length of the nth iteration fractal structure.

Table 1Detailed dimensions of the proposed antenna

Structure geometry	Parameters (mm)
radiator	*Wp = 20, Lp = 22*
feed line	*Wf = 4, Lf = 16, d1 = 1.75*
upper slots	*Ws1 = 2, Ls1 = 2, Ws2 = 2, Ls2 = 2*
lower slots	*Ws3 = 1.5, Ls3 = 1.5, Ws4 = 1, Ls4 = 1*
ground plane	*Lg = 15.45*
ground plane slot	*Wn = 2.5, Ln = 2.45, d2 = 1*
substrate	*W = 40, L = 38*

III. THE ANTENNA DESIGN

The proposed antenna has been designed to resonate with the lower frequency at 2.3 GHz. Observing the influence of the various parameters on the antenna performance and from the surface current at lower resonant frequency, it has been found that the dominant factors in this antenna are the middle perimeter for two length of the radiator which have been modified in the form of Koch fractal curve of third iteration, and the lower width Wp without the two slots, as an effective length, in terms of the guided wavelength λg.

$$\lambda_g = \frac{\lambda_\circ}{\sqrt{\varepsilon_{re}}} \qquad (2)$$

where ε_{eff} is the effective dielectric constant. The value of ε_{eff}, for a microstrip line width to the substrate height ratio Wf/h ≥ 1, can be determined by Equation 3:

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(\frac{1}{\sqrt{1 + 12h / L_0}}\right) \qquad (3)$$

The effective length Le can be formulated by:

$$Le = 0.72Lp + (Wp - (Ws_3 \times Ls_3 + Ws_4 \times Ls_4)) \qquad (4)$$

Then the lower resonant frequency, f_{01}, relative to twice effective length is formulated by:

$$f_{01} \approx \frac{c_\circ}{2Le\sqrt{\varepsilon_{eff}}} \qquad (5)$$

where c_o is the speed of light in free space.

IV. SIMULATION RESULTS AND DISCUSSION

As shown in Figure 3, the proposed antenna covers an operating bandwidth of 2.3 - 11.5 GHz for return loss ≤ −10 dB. The resulting bandwidth is suitable for many wireless applications such as WiBro (2.3-2.4) GHz, ISM (2.4-2.484) GHz, WiMax (2.5-2.7) GHz and UWB (3.1-10.6) GHz applications. As observed from Figure3, the first resonance frequency (2.66 GHz), at which the value of return loss S11 is -34.19 dB. The second and third resonance frequencies are (6.25 GHz) and (8.75 GHz), at which the values of return loss S11 are -16.48 dB and -30.36 dB respectively. Due to these resonance frequencies the antenna exhibits an UWB response and the values of return loss are well below −10 dB throughout the UWB frequency band.

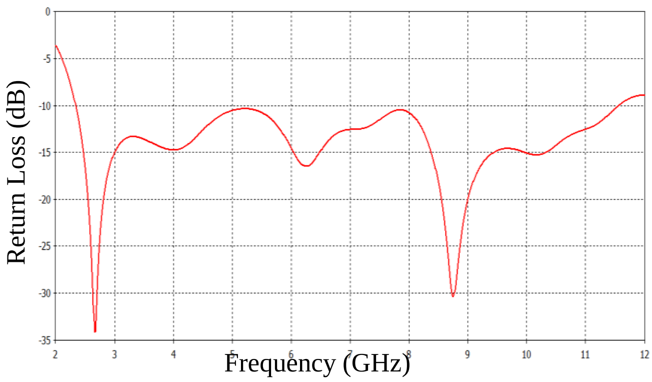
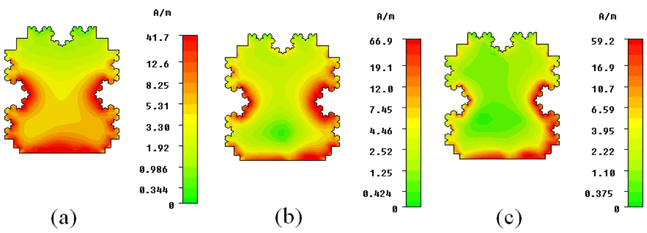


Figure: 3 Simulated return loss response of the modeled antenna.

The dimension of the slot in the ground plane beneath the microstrip feed line is the most crucial parameter for getting the broad bandwidth as well as proper impedance matching to maximize the antenna's radiation efficiency. The optimized value of length of this slot is found to be 2.45 mm and that of the width is 2.5 mm.

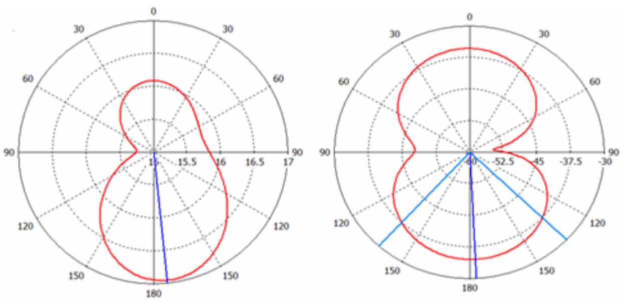
To get more insight about the radiation characteristics of the radiating elements parts, the current distribution on the surface of the antenna radiator has been investigated at some selected frequencies. Figure 4 shows the surface current distribution of the proposed antenna at the three selected resonant frequencies of 2.66, 6.25 and 8.75 GHz respectively. Figure 4 (a) illustrates the surface current at 2.66 GHz. As it is implied that the major contribution for the generation of this resonant frequency are the lower width of the patch, the middle edge of both side lengths of the patch which have been modified in the form of third iteration Koch fractal curve.

On other hand, the surface current at the second resonant frequency 6.25 GHz depicted in Figure 4 (b) which illustrates that the current is mainly concentrated at the lower right steps of the patch, and the middle edge of both lengths of the patch. Consequently, it is clear that the radiating path at this frequency is shorter than that of the previous frequency leading to a higher resonance. It is expected then that, for the third frequency, the current density is concentrated on shorter radiating path to result in higher resonance as compared with the two previous cases.



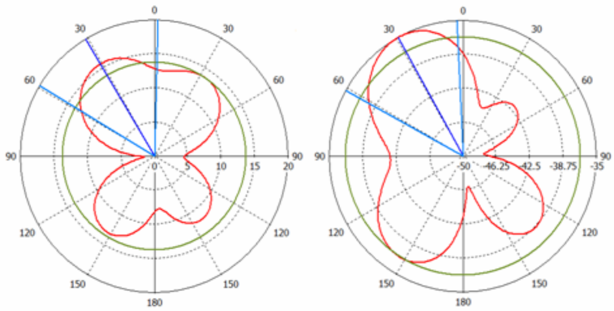
(a) (b) (c)

Figure: 4 Simulated current distributions on the surface of the proposed antenna at (a) 2.66 GHz, (b) 6.25 GHz, and (c) 8.75 GHz.



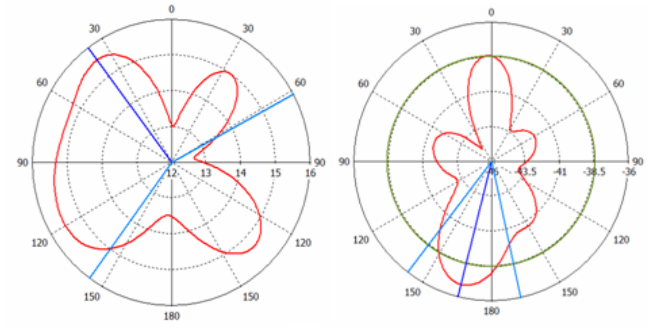
E-plane (XZ-plane) H-plane (YZ-plane)

(a)



E-plane (XZ-plane) H-plane (YZ-plane)

(b)

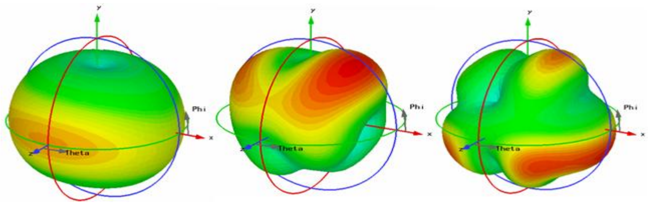


E-plane (XZ-plane) H-plane (YZ-plane)

(c)

Figure: 5 Simulated far–field radiation patterns for the total electric field at (a) 2.66 GHz, (b) 6.25 GHz, and (c) 8.75 GHz.

Figure 4 (c) shows that the radiator parts that are attributed to the generation of third resonant frequency 8.75 GHz are the right perimeter of the patch, the lower width of the patch.



(a) (b) (c)

Figure: 6 Simulated 3D total electric field patterns of the proposed antenna at (a) 2.66 GHz, (b) 6.25 GHz, and (c) 8.75 GHz.

The simulated radiation patterns of the proposed antenna for E-plane and H-plane at the three resonant frequencies are shown in Figure 5. Based on the results of radiation patterns at XZ-plane for E-plane and YZ-plane for H-plane at the three resonant frequencies 2.66 GHz, 6.25 GHz, and 8.75 GHz respectively, it can be seen that the proposed antenna has relatively stable radiation patterns at the three frequency points and also has nearly omnidirectional radiation pattern, which indicate that the proposed antenna is a suitable and candidate for WiBro, ISM, WiMax and UWB integrated applications. The 3D radiation patterns corresponding to the three resonant frequencies are also shown in Figure 6.

V. PARAMETRIC STUDY

This section presents the effects of the location of the feed line and the introduced slot in the ground plane. The distance between the structure center and the feed line center, d1 has been varied from 0 to 1.75 mm.

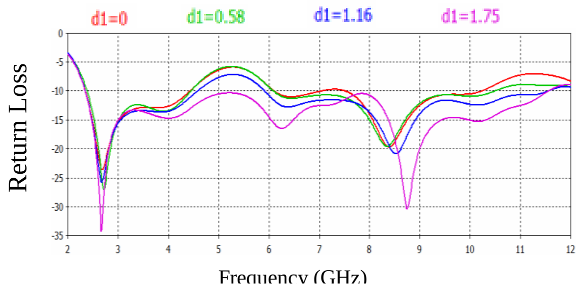


Figure: 7 Simulated return loss responses of the proposed antenna with the feed line position as a parameter.

The observed return loss responses are shown in Figure 7. As d1 increases from 0 to 1.75 mm, it can be clearly seen that the upper resonant frequency increases from 10.2 GHz to 11.5 GHz. For the three resonant frequencies, as the distance between the center of the feed line and the center of the structure varied that also varies the values of reflection coefficient. Also for values of d1 from 0 to 1.16 mm there is a band rejection from 4.4 GHz to 6 GHz in the return loss response.

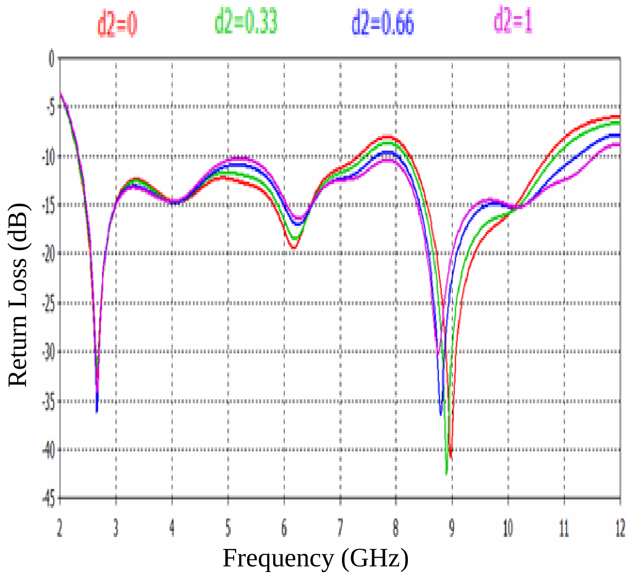


Figure:8 Simulated return loss responses of the proposed antenna with the ground plane slot position as a parameter.

The effect of the ground plane slot position is shown in Figure 8. The distance between the center of the feed line and the center of the structure of the proposed antenna, d2 has been varied from 0 to 1 mm. It can be clearly seen that the upper resonant frequency increases from 10.7 GHz to 11.5 GHz and there is a band rejection for d2 values from 0 to 0.66 mm but at undesired range of frequencies for ultra wide band application. The values of return loss are also varied for the three resonant frequencies corresponding to the variation of the distance d2. The parametric study shows that by a proper choice of the distances d1 and d2, the desired range of frequency for the additional services besides the UWB applications to be covered.

VI. CONCLUSION

A microstrip line fed compact Koch fractal based radiator printed monopole antenna is presented in this paper as an UWB with enhanced bandwidth to integrate more communication services. The proposed antenna has been analyzed using a method of finite integration technique EM simulator, CST Microwave Studio. Simulation results show that the proposed antenna has been found to offer an enhanced operating bandwidth extending from (2.3 – 11.5) GHz for return loss ≤ -10 dB. This means that the proposed antenna is suitable to cover additional communication services such as WiBro (2.3-2.4) GHz, ISM (2.4-2.484) GHz, WiMax (2.5-2.7) GHz besides the UWB (3.1-10.6) GHz applications. The compact size and the simple structure of the proposed antenna make it suitable for mobile UWB systems with integrated WiBro, ISM, and WiMax services.

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