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Inverted-L Antenna (ILA) Design Using Fractal for WLAN USB Dongle

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Abstract: This work presents an Inverted-L antenna design using the fractal geometry for dual band WLAN (2.4/5.2GHz) USB dongle application. The proposed antenna has the advantages of compact size, wide operation bandwidth and easy fabrication. The experimental results show that it has a S11<-10 dB bandwidth from 2.25 to 2.60 GHz and 5.06 to 5.62 GHz. The radiation performances of the proposed antenna in free space and when connected to a laptop computer were also studied in this work. The proposed antenna was designed and optimized by using Ansoft HFSS V13.

1 INTRODUCTION

There are several existing reported works concerning about the design of WLAN antennas for USB dongle applications. In [1], two internal multiband PIFA antennas were proposed for UMTS and WLAN applications for a USB dongle. Although both of them have compact size and can operate at multiple frequency bands, they are rather complicated to fabricate and the use of a short pin means that the size of the ground plane will play a significant role in determining the resonant frequencies. In [2], one printed monopole antenna was designed for WLAN USB dongle. This antenna employed the meander-line to reduce the occupied volume of the radiation element. However, this antenna can only operate at 2.4 GHz band, which is not enough for nowadays dual band WLAN applications. In [3], one two armed printed monopole for WLAN has been proposed. The use of multiple arms can provide an alternative solution in designing a multiband printed monopole. Yet, its size seems inappropriate for a USB dongle.

In the previous study [4], we have utilized the fractal to design a compact printed monopole antenna for dual-band WLAN USB dongle. In that design, the antenna has a planar structure and the feeding port is located at the end of the substrate. The radiation element with the feeding line and the ground plane are respectively printed at the top and bottom side of the substrate, which constitutes a typical approach for a printed monopole antenna design. This might be not convenient for most of the industry designs as other components, such as RF module, also need to be mounted on the same ground plane.

The aim of this work is to use the same fractal-based structure reported previously to design an Inverted-L Antenna (ILA), which has been widely used in the design of antennas for portable devices, allowing for the antenna element and ground plane to be printed on the same side of the substrate. This facilitates the integration of the antenna into industrial products. However, one inherent drawback for ILA is that it always has low input impedance [5]. The typical method that can be employed to solve this problem for an ILA is to short the antenna element to the ground, which can increase the input impedance of the antenna. Then the antenna becomes an Inverted-F antenna (IFA), whose input impedance is easier to be matched.

As will be presented later, the proposed fractal ILA can be easily matched without shorting the antenna to the ground plane and the experimental results show that this antenna exhibits broad operational bandwidth (S11<-10 dB) from 2.25 to 2.60 GHz and 5.06 to 5.62 GHz. Moreover, the radiation performances of the proposed antenna when connected to a laptop computer were also investigated by doing numerical simulations in HFSS.

2 Antenna Structure

Since the objective of this study is to design a printed fractal monopole antenna for WLAN USB dongle applications, based on the industrial requirement, the overall size of this antenna including the ground plane is chosen to be 20 mm × 60 mm and the available space for antenna design is limited to 20 mm × 10 mm. Fig. 1 shows the proposed ILA using the fractal geometry. This antenna is designed on Roger 4003 with thickness of 0.8 mm. In this design, as can be seen in the Fig. 1, the antenna element and the ground plane are printed on the same side of the substrate. The bottom of the substrate has no copper. Additionally, the feeding point lies on the left edge of the ground plane and this leaves enough space to mount other hardware components on the system ground plane.

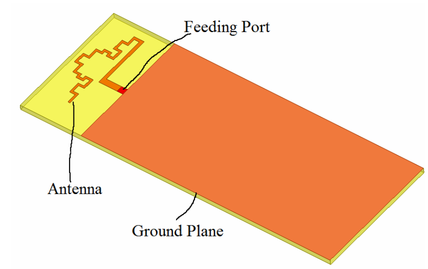


Figure 1: Proposed ILA based on the fractal geometry

A variation of the Koch fractal was used to the design of the proposed multiband printed monopole antenna. Fig.2 shows the first three iterations of the Koch fractal geometry. In this work, the second iteration of the fractal is employed in the designing of the antenna because for higher iterations, in order to describe it properly the microstrip line needs to be very narrow, which can in turn decrease the radiation efficiency of the antenna due to the conductor losses. The depth ***d*** shown in Fig.2 is a parameter that is used to construct the Koch fractal. This value can be varied as required, and in this work the value of ***d*** is set to be 1/5 of the line length at each iteration.

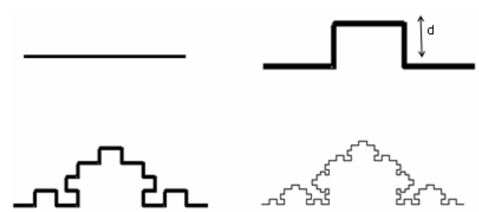
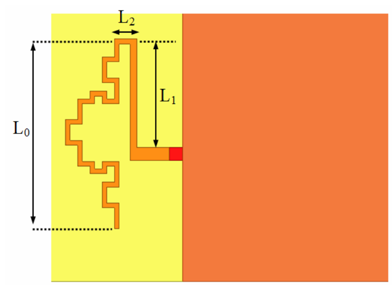


Figure 2: The first three iterations of Koch Fractal

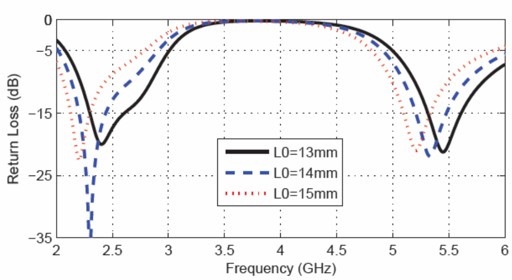
3 Simulation and Experimental Results

3.1 Parametrical Studies

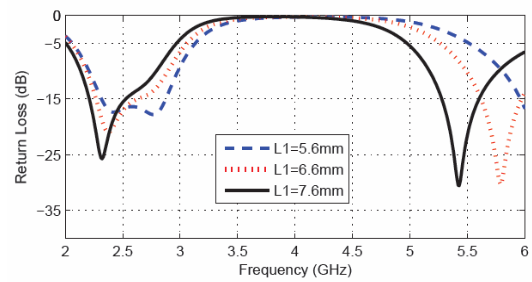
The antenna component needs to be taken as an integrated part of the entire layout of the transceiver. It is predictable that after assembling the overall product and connecting the USB dongle to a device, for instance a laptop computer, the radiation performance of the antenna will be affected. Therefore, parametrical studies of the proposed antenna are necessary, which can aid the tuning of the resonant frequency of the antenna in the final stage of product design. Two key parameters, L_0 which is related to the overall length of the fractal and L_1, which is length of the horizontal meander line, are chosen as the variables. These two parameters are labeled in Fig. 3 (a). Fig. 3 (b) and Fig.3 (c) present the simulated return loss of the proposed fractal ILA with different values of L_0 and L_1, respectively. It is found that the overall length of the fractal determines the resonant frequencies at both bands while the length of L_1 has major influences on the higher band. By utilizing these findings, the resonant frequencies of the antenna can be tuned to the desired resonant frequency according to the requirements. In the final prototype, the values of these parameters were chosen to be L_0=14mm, L_1=8.1mm and L_2=1.6mm.



(a)



(b)



(c)

Figure 3: Parametrical studies for the proposed antenna: (a) the layout of the antenna element; (b) simulated return loss of the antenna with different value of L0; (c) simulated return loss of the antenna with different value of L1

3.2 Measurement results

The proposed antenna was fabricated and Fig. 4 shows a photo of this prototype under return loss measurement. Fig. 5 shows the comparison of the return loss between simulation and measurement results. There is a good agreement between the simulated and measured return loss, both of which confirm that this antenna has a S11<-10 dB bandwidth from 2.25 to 2.60 GHz and 5.06 to 5.62 GHz.

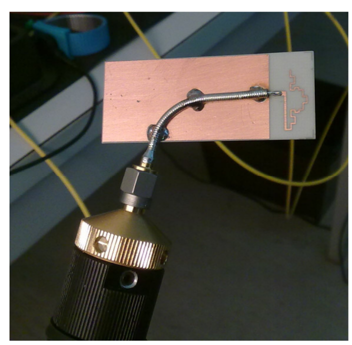


Figure 4: Photo of the fabricated prototype during return loss measurement

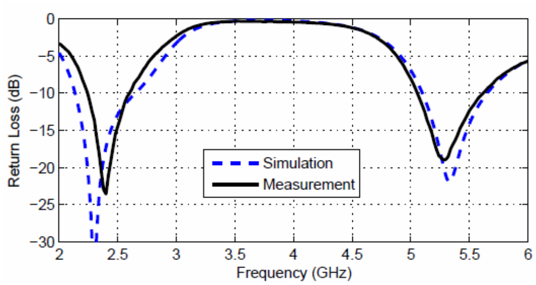
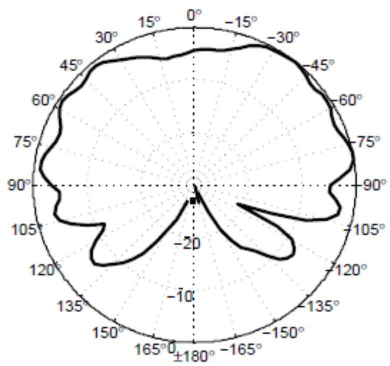
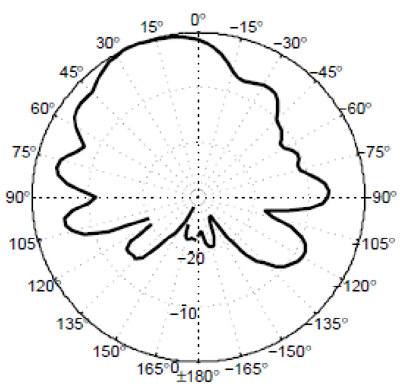


Figure 5: Comparison of the simulated and measured return loss of the fractal ILA

Fig. 6 shows the measured radiation patterns of this Fractal ILA at 2.4GHz at both E-and H-plane.



E Plane



H Plane

Figure 6: Measured radiation patterns of the printed multiband ILA antenna at 2.4GHz

3.3 Frequency Reduction of the Proposed Antenna

In order to show the effectiveness of antenna size reduction by using the fractal geometry, one more Inverted-F Antenna (IFA) was designed. This antenna uses the same substrate and the radiation element was also confined within the required area of size 20 mm × 10 mm, as shown in Fig.7.

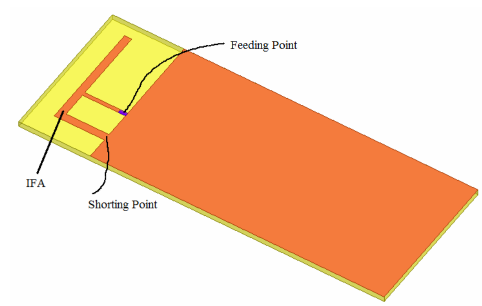


Figure 7: The structure of a typical Inverted-F antenna

Fig.8 compares the simulated return loss of this IFA with the proposed fractal ILA. As can be observed from Fig.7, the simple IFA can only operate at 3.85 GHz. Compared to the IFA, besides exhibiting a dual band operation, the proposed ILA antenna can resonate at 2.3 GHz, which represents a frequency decrease of 40%.

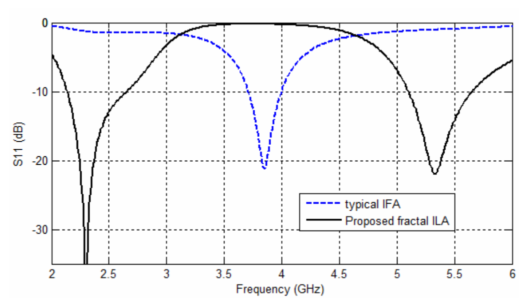
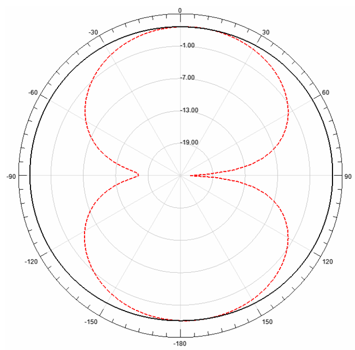


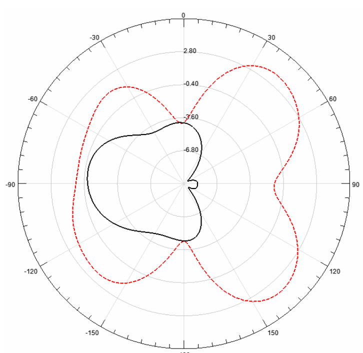
Figure 8: Comparison of the simulated return loss between the proposed fractal ILA and a typical Inverted-F antenna

3.4 Simulated Radiation Patterns

Fig. 9 presents the simulated 3D radiation pattern of the proposed antenna in Ansoft HFSS. It can be seen that at both bands, the H plane (Phi=0 degree) is almost omnidirectional while the E plane (Phi=90 degree) exhibits broad side radiation patterns.



f=2.3GHz



f=5.3GHz

Figure 9: The simulated radiation patterns of the proposed antenna in free space (Phi=0 degree: dashed line; Phi=90 degree: solid line)

The simulation results shows that the proposed antenna has maximum gain of 1.9 dBi at the lower band and 3.3 dBi at higher band with radiation efficiency higher than 95% at both bands.

4 Antenna Performance with the Existence of Laptop computer

The influence of the laptop on the radiation performance of the antenna was studied by simulating the USB dongle attached to a Laptop computer that is modeled as finite conductive material for simple consideration. When the USB dongle is connected to the laptop, it is equivalent to extend the size of the ground plan of the antenna to a much larger one. As the simulation software package used in this study, Ansoft HFSS, is a based on the Finite Element Method (FEM), in which the calculation is proportional to the size of the overall domain, therefore, to save simulation time and computation memory, the size of the laptop is truncated to half of the size of the real laptop computer. The simulation model is presented in Fig.10. The laptop is modeled by using two copper plates vertically joined together to mimic the case when the laptop is opened. Each of the copper plate is 20 cm long and 10 cm wide, which is approximately half of the size of a netbook PC.

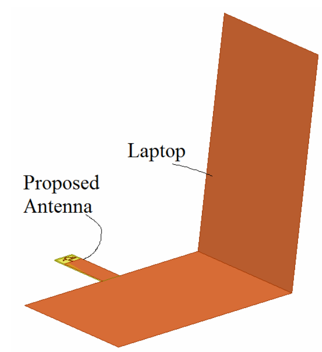


Figure 10: Simulation model of the USB dongle connecting to the laptop computer in HFSS

4.1 Return Loss

Fig.8 shows the comparison of the simulated return loss of the proposed antenna with and without connection to the laptop computer. As expected, when connecting to the laptop, the proposed antenna has some frequency shift at both bands. At the lower band, the amplitude of the return loss has degraded by more than 10 dB. After resizing the fractal, both resonant frequencies are tuned to the desired frequency bands, as shown in Fig.11 by black solid line. After tuning, the simulation results show that the proposed antenna (connected with the laptop) exhibits a VSWR 3:1 bandwidth, which is the standard accepted by most portable devices manufactures, over 2.36 to 2.54 GHz and 4.96 to 5.84 GHz. This covers the entire frequency bands for IEEE 802.11 a/b/g applications.

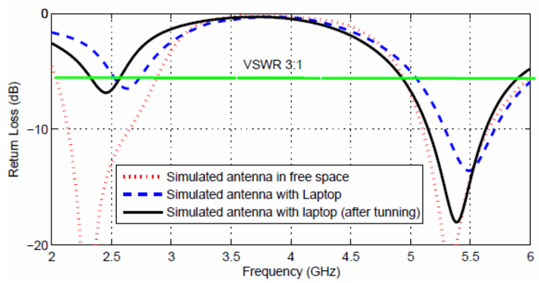


Figure 11: Simulated return loss of the proposed antenna with and without the laptop

Fig.12 presents the comparison of the simulated return loss of the proposed antenna with the laptop computer of different sizes. As can be seen from this figure, the size of the laptop computer affects in some degree the resonant frequencies of the antenna. However, above 15 cm the resonant frequencies of the antenna are no longer influenced by the length particularly at the lower band. This proves the validity of the simple simulation model of the laptop computer.

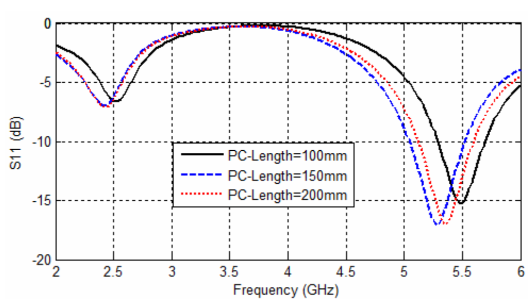
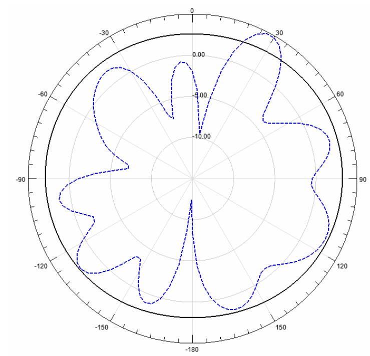


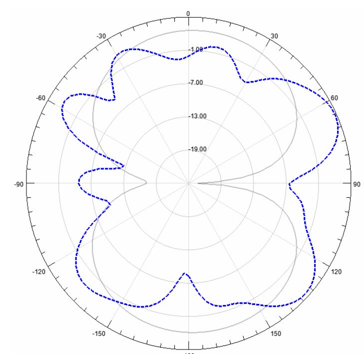
Figure 12: Simulated return loss of the proposed antenna with laptop computer of different length

4.2 Radiation Pattern

Fig.13 and Fig.14 presents the comparison between the simulated radiation patterns of the proposed fractal ILA in free space and connected with the laptop at 2 and 5 GHz band, respectively. It can be observed that there is a large influence from the laptop to the radiation patterns of the antenna. With the existence of the laptop computer, the radiation patterns of the antenna become more directive in certain angle. However, according to the simulation results, the radiation efficiency of the antenna at the lower band decreased to 60% while at the higher band, the radiation efficiency reduced to 50%. Compared to the case that it is radiating in the free space, the radiation efficiency at both bands has dropped by more than 40%.

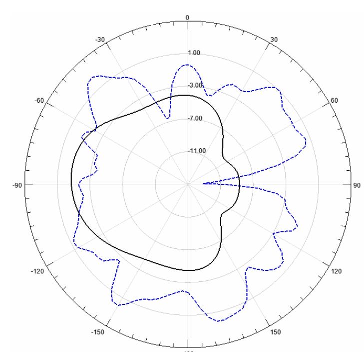


Phi=0degree

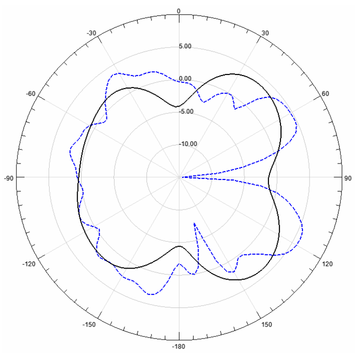


Phi=90 degree

Figure 13: Comparison of the simulated radiation patterns of the proposed antenna with (blue dashed line) and without (black solid line) connecting to the laptop computer at 2 GHz band



Phi=0 degree



Phi=90 degree

Figure 14: Comparison of the simulated radiation patterns of the proposed antenna with (blue dashed line) and without (black solid line) connecting to the laptop computer at 5 GHz band

5 Conclusion and Discussion

In summary, in this study a fractal ILA using the 2nd iteration of the Koch fractal geometry combined with the meander line has been proposed. This antenna exhibits wide operation bandwidth, moderate gain and high radiation efficiency. The radiation performance of the proposed antenna connecting to a laptop computer is also studied. It is found that connecting the USB dongle to the laptop computer can affect the resonant frequencies of the antenna and greatly change its radiation patterns. The frequency shifting of the proposed antenna caused by the laptop can be tuned by resizing the fractal, which has been justified by the simulation results.

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