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A New Fractal Based PIFA Antenna Design for MIMO Dual Band WLAN Applications

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Abstract— This paper introduces the design of a dual-band internal F-PIFA (Fractal Planar Inverted F-antenna) as a candidate for use in the dual band WLAN (wireless local area network) MIMO (multi-input multi-output) applications. At first, the 4th iteration Koch's fractal geometry has been applied to the edges of the conventional rectangular patch structure to design a single compact antenna with a dual band resonant behavior. The radiating fractal based patch has been printed on a substrate with relative permittivity of 4.1 and thickness of 0.9 mm, and the antenna has been fed with 50 Ω probe. This antenna is located at the corner of a copper ground plane of 0.05 mm thickness and dimensions of $110 \times 70\,\mathrm{mm}^2$. It has been found that the resulting F-PIFA has the dimensions of about 21 mm × 15 mm × 6.2 mm, making it suitable for mobile terminal applications. Furthermore, the proposed antenna offers a dual band resonance with a frequency ratio of about 2.41; resulting in bandwidths, for return loss ≤ -10 dB, covering the two WLAN band standards. Modeling and performance evaluation of the proposed antenna have been carried out using the CST Microwave Studio. The modeled antenna has been applied to a 4 by 4 MIMO system suggested for use in dual band WLAN applications. Simulation results show that the suggested system offers ≤ -10 dB impedance bandwidths of about 300 MHz with an isolation of about 12 dB, for the lower band, and 570 MHz with an isolation of higher than 22 dB, for the upper band. This makes the proposed system suitable for use in MIMO dual band WLAN applications.

1. INTRODUCTION

When a multiple-element antenna array embeds into the small mobile terminal, it should be small as much as possible. Some additional requirements should be met, e.g., good isolation (low mutual coupling) and diversity performance for multiple antennas besides the usual requirements of a conventional single antenna such as compact structure, light weight, low profile and robustness. The antennas are required to be small and yet their performances have to be maintained [1]. Therefore, in designing the antenna for the mobile terminal, it is important to balance the trade-off between size and performance [2]. In MIMO (multi-input multi-output) systems, multiple antenna elements are required at both transmitter and receiver. The multiple antennas at the both ends of the systems provide independent paths in the multipath fading environment [3]. As a result, the design of two or more antennas on a small mobile terminal for the MIMO systems is more challenging compared to the design of a single conventional antenna in the mobile terminal [4].

Inserting developments in the field of antenna miniaturization have been introduced in the form of fractal antennas. A fractal is a self-similarity structure, which means that a small part of the structure is a scaled-down copy of the original structure. The term fractal means broken or irregular fragments to describe complex shapes that possess an inherent self-similarity or self-affinity in their geometrical structures [5]. There are a few researches on the combination of fractal and PIFA (Planar Inverted-F Antenna) topology. A miniaturized PIFA has been proposed for dual-band mobile phone application by employing Hilbert geometry [6]. A Fractal PIFA antenna based on the Sierpinski carpet has been presented in [7] to obtain a multiband antenna. The proposed antenna achieved -6 dB return loss at the required GSM (Global System for Mobile Communications), UMTS (Universal Mobile Telecommunications Systems) and HiperLAN frequencies. A combination of microstrip patch antenna with a Koch pre-fractal edge and a U-shaped slot has been proposed for multi-standard use in GSM1800, UMTS, and HiperLAN2 [8]. Making use of a PIFA structure, the multi-band behavior has been obtained with broadened the lower resonant band covering GSM 1800 and UMTS. The HiperLAN2 band has been covered by insertion of a U-slot structure. An antenna arrangement of two Koch fractal patch PIFA elements has been studied.

2. ANTENNA STRUCTURE

In this paper, Koch fractal geometry is applied on the edges of the radiating plate. This concept has a considerable effect on the resonant length of the antenna structure. The design of this antenna is mainly based on the PIFA antenna. The performance of the modified PIFA depends on number of structure parameters, such as antenna height, H, radiating plate length, L and radiating plate width, W as illustrated in Figure 1. The dimensions of the ground plane (L_G and W_G) for this antenna are similar to those of most mobile terminal like personal digital assistant (PDA) or handset. The optimized dimensions of the proposed PIFA model are shown in Table 1. The radiating fractal based plate is printed on a substrate with relative permittivity of 4.2 and thickness of 0.9 mm, and the antenna is fed with a 50 Ω probe.

Applying fractal geometry on PIFA antenna configuration yields fractal (FPIFA) antenna. Fractal PIFA antenna can be miniaturized by adding indentations along all the edges of the radiating plate. These edges represent the resonant length of the plate used to miniaturize the size as shown in Figure 1(a). The fractal radiating plate, shown in Figure 2(b), is generated with four iterations. This is the result of adding the indentations along the resonant length of the radiating plate in the first iteration and repeating the process at similar scale. The FPIFA antenna on a ground plane is illustrated in Figure 3.

The simulation results indicate that the proposed antenna can achieve a bandwidth, for ($S_{11} < -10$ dB), of about 300 MHz (2.2174–2.521 GHz) at 2.4 GHz and 570 MHz (5.5317–6.1052 GHz) at 5.8 GHz as shown in Figure 4. The radiation patterns of the proposed antenna at the two resonance frequencies; 2.4 GHz and 5.8 GHz are illustrated in Figure 5. These patterns are presented for two elevation planes; XZ ($\varphi = 0°$) and YZ ($\varphi = 90°$), and for the azimuth XY plane ($\theta = 90°$). In the higher band one can note that the electric field approximately has an equal value at all points in XY plane more than those in the lower band. Maximum values of the field stretching

Table 1: Dimensions of the reference PIFA antenna.

Parameter	L	W	H	L_G	W_G
Value (mm)	21	15	6.2	110	70

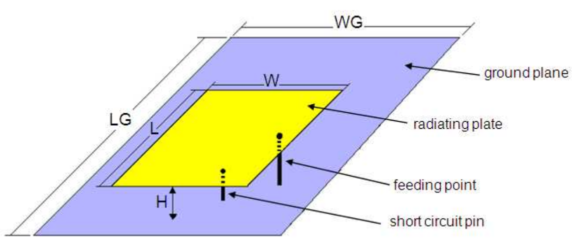
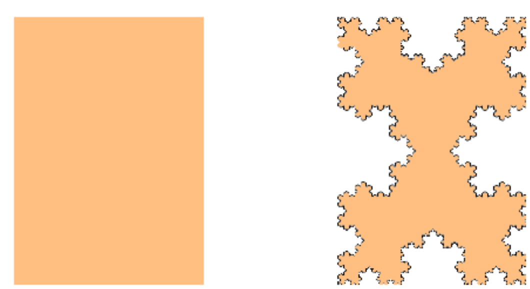


Figure 1: Schematic diagram of the PIFA antenna.



(a) (b)

Figure 2: (a) The rectangular radiating plate, and (b) the Koch fractal based radiating plate.

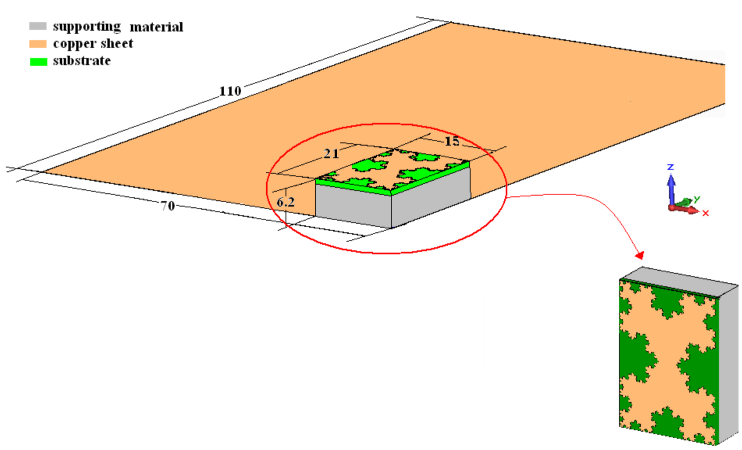


Figure 3: Schematic diagram of the FPIFA antenna; (all dimensions in mm).

from the direction 30° of the 60° in the upper half of the lower band in the YZ plane, while the highest values in the upper band are confined in the direction of 60° to 90°. Good omnidirectional radiation patterns at the two frequencies are obtained. The whole shapes of the radiation patterns are suitable for modern terminals. This antenna almost provides the same radiation pattern at the two resonant frequencies.

3. FOUR-ELEMENT DIVERSITY FPIFA DESIGN

In this section, a four-element diversity antenna based on the proposed FPIFA is designed on the same ground plane. The proposed design involves four elements of FPIFA antennas being located in each corner of the ground plane. The diversity antenna array has to be carefully designed to achieve low correlation as much as possible between the antennas. Since the proposed FPIFA antenna has the property of dual polarization, therefore mutual coupling between the antennas can be reduced by arranging the antennas. The optimized design of the diversity antenna array is shown in Figure 6.

The distance between antennas 1 and 2 (3 and 4) is approximately 40 mm which corresponds to

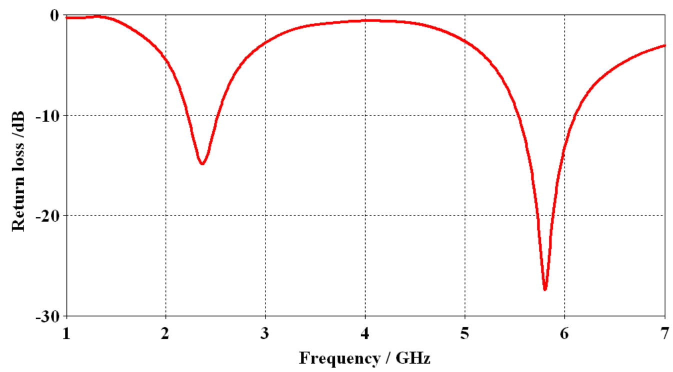


Figure 4: Simulated return loss of the FPIFA antenna.

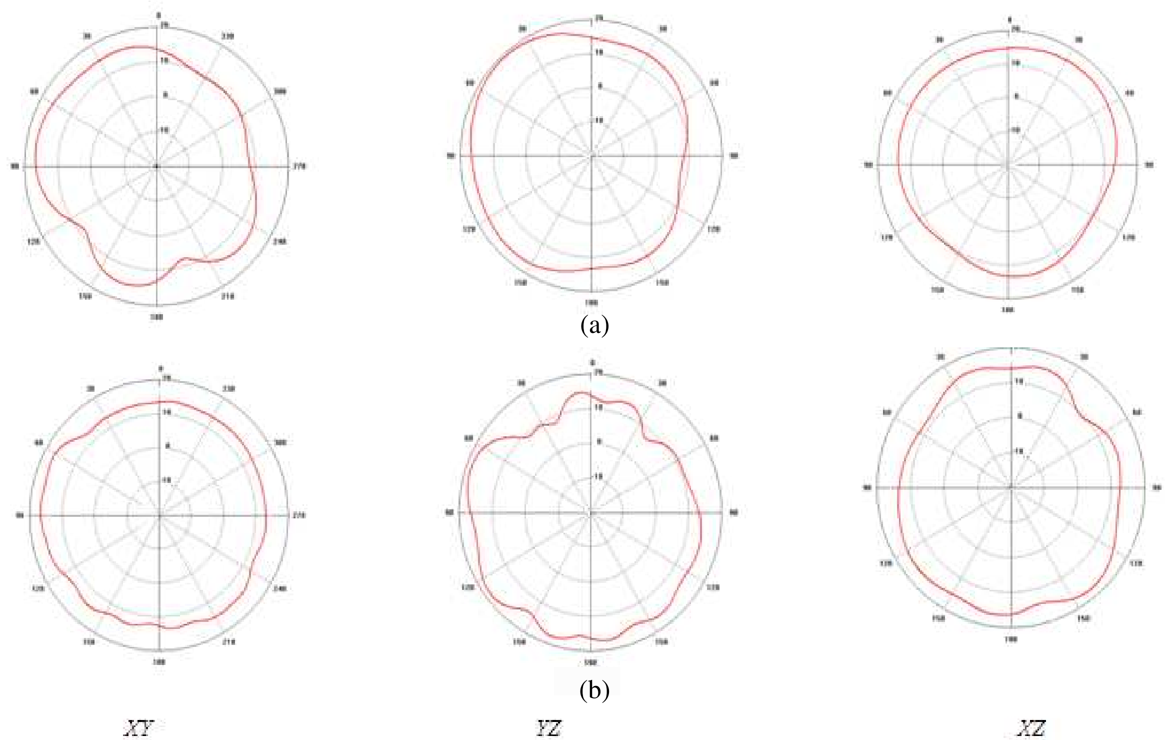


Figure 5: Simulated radiation patterns in the XY, YZ and XZ planes at (a) 2.4 GHz, and (b) 5.8 GHz for the single FPIFA.

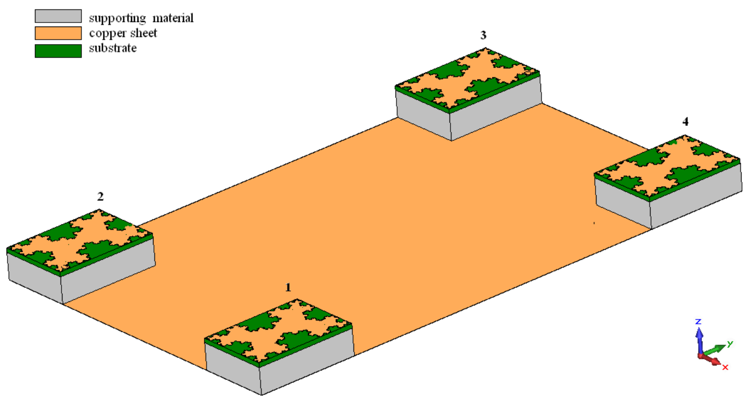


Figure 6: Schematic diagram of four-element diversity FPIFA antenna array placed on the same ground plane.

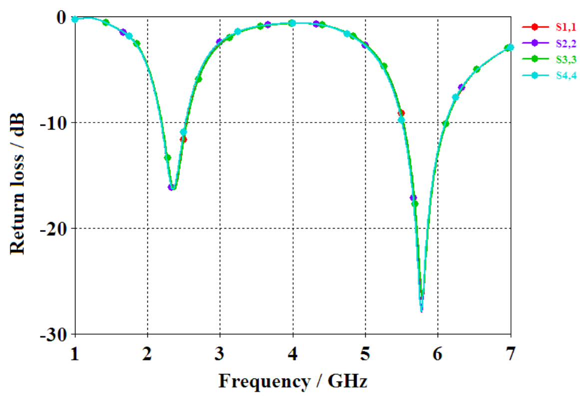


Figure 7: Return loss characteristics from the simulated results of the FPIFA antenns1, 2, 3, and 4.

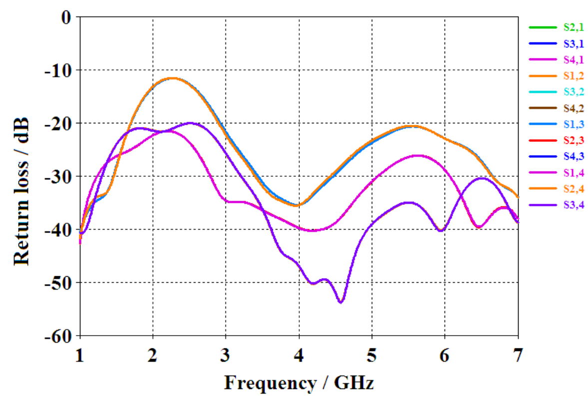


Figure 8: Isolation between each pair of antennas on the diversity FPIFA antenna array.

0.32 λ at 2.4 GHz, while the distance between antenna 1 and 4 (2 and 3) is 68 mm which corresponds to 0.54λ at 2.4 GHz. Although the spacing between antennas does not exceed half wavelength, the obtained results show good isolation between antennas. The simulated return loss performance of each antenna of the four-element diversity antenna array is plotted in Figure 7. The simulated S_{11}, S_{22}, S_{33} and S_{44} are exactly identical due to the optimization process used for choosing the positions of the feed and the shorting pin for each antenna. It is clear that the bandwidths of the antennas are the same.

Despite the fact that the antennas share the same ground plane; there is no any individual ground plane for each antenna, the simulation results show that the isolation between elements is low which means an acceptable value for good diversity performance. This is attributed to the spread surface current on the ground plane which leads to an increase in the mutual coupling between elements. Figure 8 shows the isolation between each pair of antennas obtained from the simulations. Isolation of more than 12 dB for each pair of antennas (1, 3) and (2, 4) is achieved in the lower band and more than 20 dB in the higher band. Isolation for other pairs is higher than 22 dB in the two bands. In other words, mutual coupling is relative very low between the antennas. Therefore, a low correlation between the antennas could be realized and would lead to well diversity performance.

4. CONCLUSIONS

A fractal based PIFA configuration has been investigated, in this work, to design MIMO antennas for 2.4 GHz and 5.8 GHz bands. Reduction of antenna size has been performed by means of applying Koch fractal geometry. This reduced the size of the radiating patch of antenna by a 33% as compared with conventional patch. Furthermore, the space diversity has been adopted and applied to the proposed antenna. According to simulation results the suggested system offers ≤ -10 dB impedance bandwidths of about 300 MHz with an isolation of about 12 dB, for the lower band, and

570 MHz with an isolation of higher than 22 dB, for the upper band.

REFERENCES

1. Costa, J. R., E. B. Lima, C. R. Medeiros, and C. A. Fernandes, "Evaluation of a new wideband slot array for MIMO performance enhancement in indoor WLANs," *IEEE Trans. Antennas Propag.*, Vol. 59, No. 4, 1200–1206, 2011.
2. Fujimoto, K., *Mobile Antenna Systems Handbook*, 3rd Edition, Artech House, Inc. 2008.
3. Zhang, S., P. Zetterberg, and S. He, "Printed MIMO antenna system of four closely-spaced elements with large bandwidth and high isolation," *Electron. Lett.*, Vol. 46, No. 15, 1052–1053, 2010.
4. Jensen, M. A. and J. W. Wallace, "A review of antennas and propagation for mimo wireless communications," *IEEE Trans. Antennas Propag.*, Vol. 52, No. 11, 2810–2824, 2004.
5. Habib, L., "Fractal monopole antenna," U.S. Patent, No. 7, 248, 223, B2, July 24, 2007.
6. Azad, M. Z. and M. Ali, "A miniaturized hilbert PIFA for dual-band mobile wireless applications," *IEEE Antennas Wireless Propag. Lett.*, Vol. 4, 59–62, 2005.
7. Saidatul, N. A., A. H. Azremi, R. B. Ahmad, P. J. Soh, and F. Malek, "Multiband fractal planar inverted F antenna for mobile phone application," *Progress In Electromagnetics Research B*, Vol. 14, 127–148, 2009.
8. Guterman, J., A. A. Moreira, and C. Peixeiro, "Microstrip fractal antennas for multistandard terminals," *IEEE Antennas Wireless Propag. Lett.*, Vol. 3, 351–254, 2004.