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Miniaturized Dual-Band Fractal Antenna with Omnidirectional Pattern for WLAN/WiMAX Applications

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Abstract—This paper presents a novel miniaturized dual-band fractal antenna for WLAN/WiMAX applications. The miniaturization of the proposed antenna is achieved by inserting, in the center ground of the antenna, square slots to excite two resonant modes simultaneously, leading to dual-band operation. The novelty of the proposed antenna is miniaturized size and ability to support multiband operations, which can be integrated in many electronic applications and wireless communication. This antenna has a compact size of only $25 \times 25\,\mathrm{mm}^2$ and fed by a $50\,\Omega$-microstrip feed line. To validate the design approach, an experimental prototype is fabricated and measured. The simulation and measurement results show that the antenna provides dual-band operation at 2.4 and 3.75 GHz with omnidirectional radiation pattern.

1. INTRODUCTION

Recently, great interest has been paid to multiband antennas to support various standard wireless communication systems [1]. For instance, broadband CPW-fed antennas are designed for wireless communication systems to simultaneously cover two different operation bands (1.5 and 3.5 GHz) applications [2]. However, for mobile wireless communication systems, it is challenging to miniaturize antenna size while keeping better performances, such as low profile, multiple operation bands, wide bandwidth, design simplicity and high efficiency. In this perspective, several antenna designs with various configurations have been proposed to provide dual and multiband operations [3–8] and [13]. In [3], a multiband slot antenna has been proposed for GPS, WiMAX and WLAN systems. Another work in [4] has suggested a multiband monopole antenna with small size $22 \times 50\,\mathrm{mm}^2$ operating with circular polarization for GNSS applications. In addition, multiband monopole antennas loaded by mushroom and CSRR metamaterial structures have been proposed in [5] for vehicular applications. Other approaches have been reported in [6] and [7], where the authors have exploited the use of ground plane slots for multiband operation. Moreover, in [8], a miniaturized antenna has been obtained by cutting the curved slots along the orthogonal directions of the patch radiator. The antenna in [9] utilizes shorting vias with etched Slots to achieve omnidirectional dual-band application. Fractal-shaped antennas is another common technique to introduce multiple bands and reduce the size of the antenna. In [10], a new modified antenna by semi-fractal technique has been used for multiband RFID reader applications at 3.8, 5.8, 8.2, and 9.7 GHz frequencies. A star-shaped fractal antenna has also been used to cover commercial and military applications [11]. A multiband Fractal Koch dipole textile antenna has been proposed in [12] for wearable applications (0.9 GHz, 2.45 GHz and 5.8 GHz). A Minkowski fractal formation with four Jerusalem cross (JC) loads has been suggested in [14] to achieve dual-band application with compact size. However, the proposed antenna occupies the smallest area and has simpler geometry to realize the required operating bands compared to other designs in [9] and [13, 14].

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In this paper, a new compact dual-band fractal antenna is proposed for WLAN and WiMAX applications. The proposed multiband antenna is studied and designed using the electromagnetic (EM) simulation tool CST. The methodology used to design the antenna is also described, and the effects of different parts of the antenna are discussed. Finally, to validate the proposed concept, an experimental prototype is fabricated and measured, and the obtained results are presented and discussed

2. ANTENNA DESIGN

The proposed antenna is shown in Fig. 1. This antenna uses a fractal geometry approach and composed of a microstrip feed line, a substrate, and a ground plane with slots. The most important parameter in our designing process is the simplicity of the antenna and its feeding structure so that the antenna can be fabricated easily in practice. Therefore, slot loaded ground plane with a feed line is considered as a radiating element and a microstrip line at the same time.

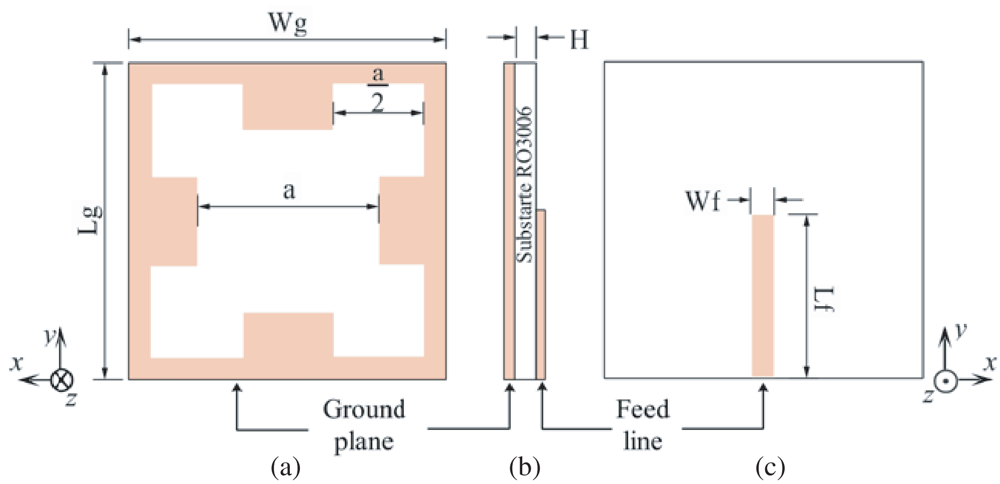


Figure 1. Configuration of the proposed antenna. (a) Bottom. (b) Side. (c) Top.

The design process antenna can be generated from using this algorithm:

Stage 0:

(i) Start with a square, with side length a, as illustrated in Fig. 2.

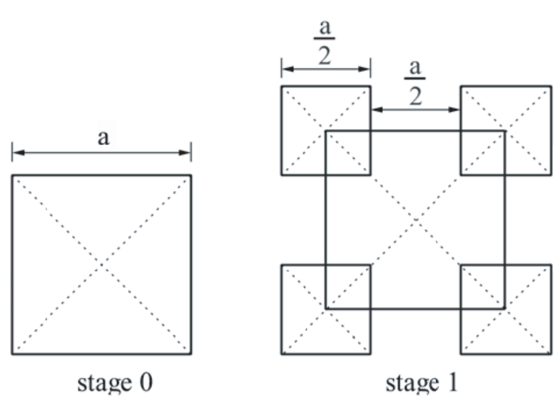


Figure 2. Iterations of the proposed fractal antenna.

Stage 1:

(i) At each convex corner of the previous square, place another square, centered at that corner, with half ($a/2$) the side length of the square from the previous stage.

(ii) Take the union of the previous stage with the collection of smaller squares placed in this way, as illustrated in Fig. 2.

In order to make the antenna operate in multiband, the concept of fractal is applied to the basic square slot structure in the ground plane. The fractal antenna is fed by a 50 Ω feed line with a strip width of 1.8 mm. A good impedance matching at the operating bands for the WLAN and WiMAX applications is achieved by fixing the optimum dimensions of the proposed antenna, as illustrated in Table 1. The antenna is designed using an RO3006 substrate of thickness $H = 1.27$ mm and relative permittivity $\varepsilon_r = 6.15$. The antenna parameters are simulated using CST Microwave studio 16. By increasing the number of the iterations in the proposed design, the number of resonance frequencies is increased. The proposed antenna provides two resonance frequencies, which leads to dual-band operation.

Table 1. Optimized parameter values of the proposed antenna.

Parameters	L_g	W_g	L_f	W_f	a	H
Values (mm)	25	25	12.5	1.8	15.1	1.27

Figure 3 shows the comparison between the simulated return loss S_{11} of the conventional square slot in the ground and that of the proposed fractal antenna. On Stage 0, when only the square slot is used, it is clear that the antenna generates one frequency band at 4.5 GHz. However, in Stage 1, when more than one fractal square slot is used, the proposed antenna provides two frequency bands (with $S_{11} < -10$) at 2.4 GHz and 3.75 GHz, which cover WLAN and WiMAX bands, respectively.

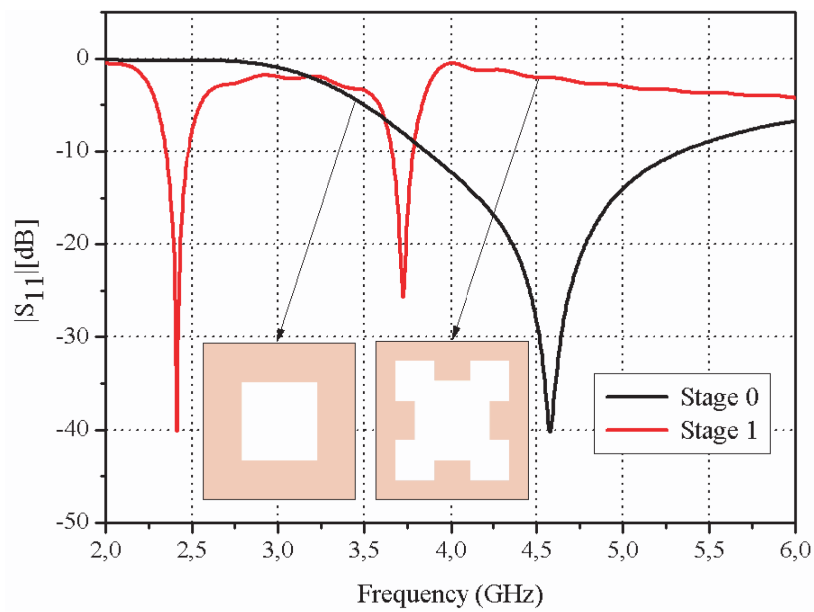


Figure 3. Simulated reflection coefficients for the two proposed stages.

It is seen that the lower frequency of the proposed antenna is slightly less than the corresponding frequency of the square slot antenna due to the larger surface of the fractal shaped antenna.

Simulations were carried out to investigate the effect of different parameters of the antenna on its performance. Figs. 4 and 5 show that good input impedance matching for the WiMAX and WLAN bands can be obtained by tuning the values of the parameters a and L_f. As a result, it is observed that the bands of WLAN and WiMAX can be controlled simultaneously by tuning the slot length in the ground "a" and the feed line length "L_f".

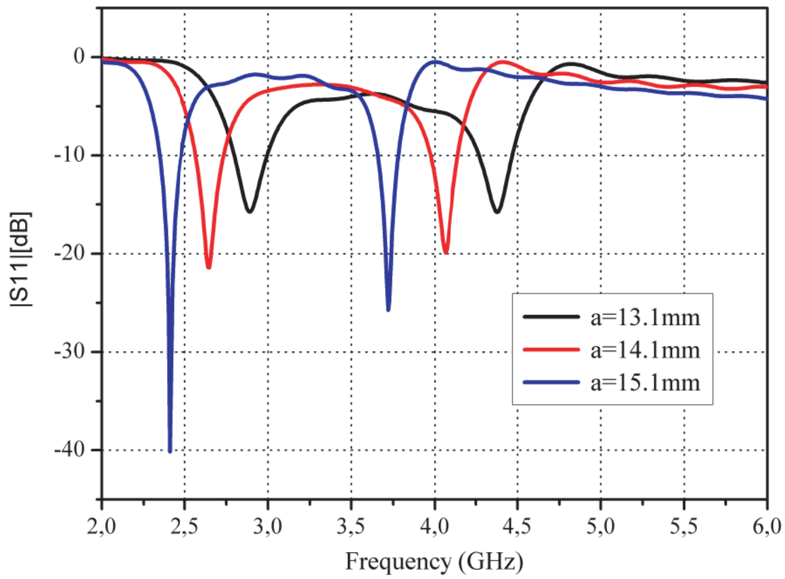


Figure 4. Effect of the grounded slot length a on the reflection coefficient.

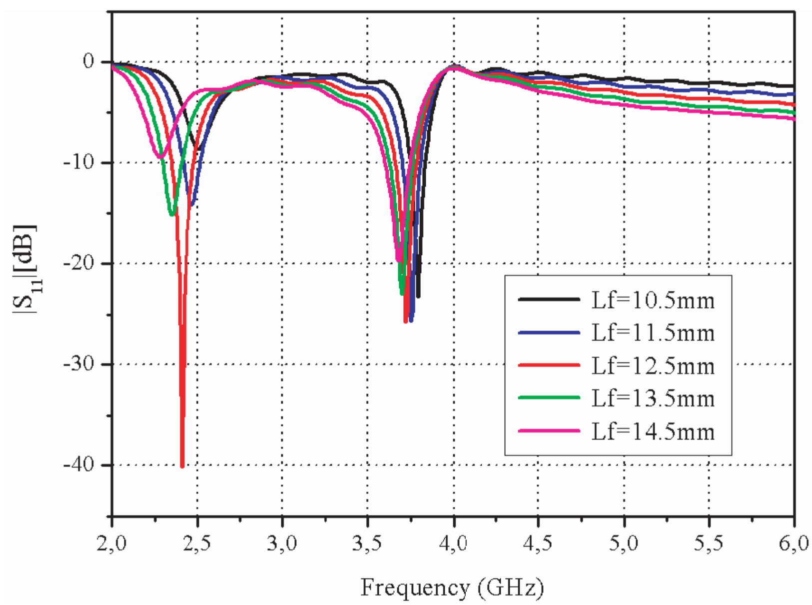
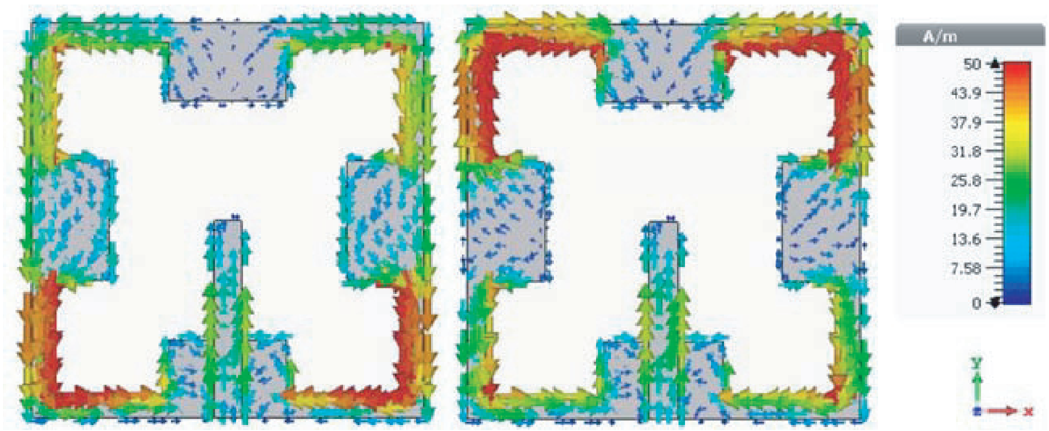


Figure 5. Effect of the feed line length L_f on the reflection coefficient.

The simulated surface current distributions seen from the design antenna at the resonant frequencies 2.4 and 3.75 GHz are shown in Fig. 6. From Fig. 6(a), it can be seen that the current distribution, at frequency 2.4 GHz, is mainly located on the low edges of the slot on the ground plane while Fig. 6(b) shows that the current is mainly located on the high edges of the slot on the ground plane for the resonant frequency 3.75 GHz.

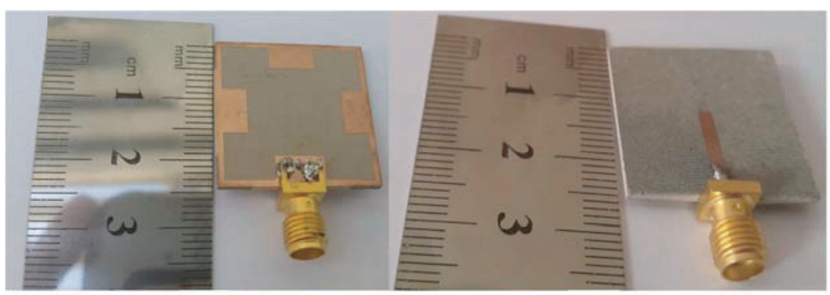
3. RESULTS AND DISCUSSION

To validate the proposed antenna design, an experimental prototype was fabricated, tested and measured using Agilent 8722ES Network Analyzer. Fig. 7 shows the photograph of the fabricated prototype.



(a) (b)

Figure 6. Simulated surface current distribution observed from the ground planeside: (a) 2.4 and (b) 3.75 GHz.



(a) (b)

Figure 7. Photograph of the fabricated antenna. (a) Bottom. (b) Top.

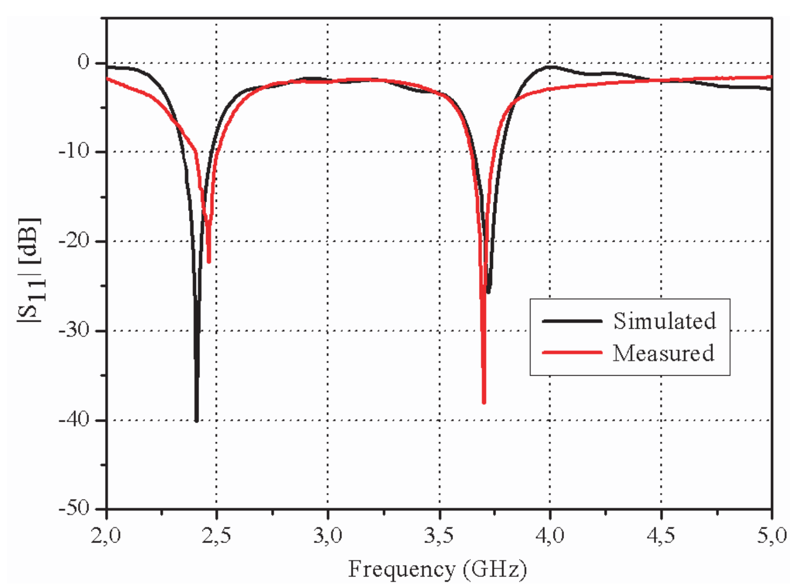


Figure 8. Measured and simulated reflection coefficients of the proposed antenna.

The comparison between the simulated and measured return-loss coefficients is shown in Fig. 8, where a good agreement between the simulated and measured results is achieved. The small difference is mainly due to the feeding cable used in measurement, which can be described as follows. In computer simulation, no feeding cable is used. However, in measurements, a feeding cable is needed to connect

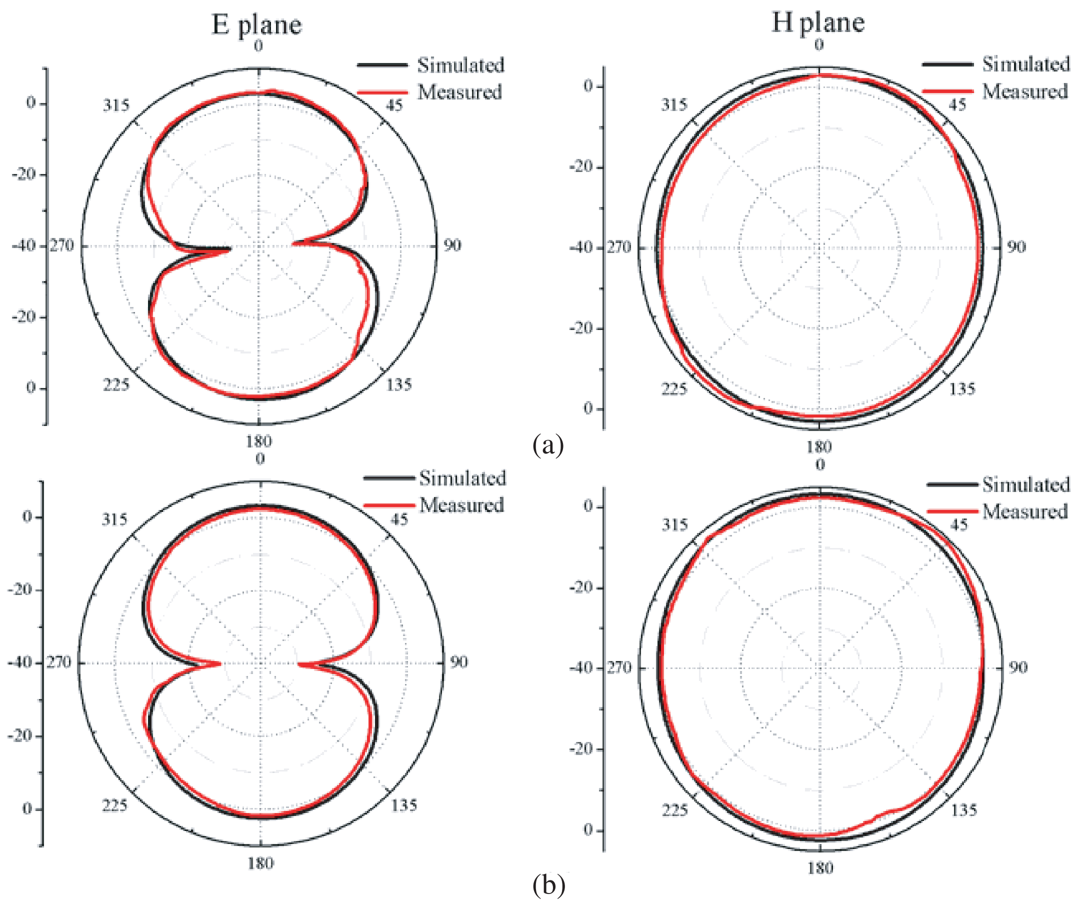


Figure 9. Measured and simulated radiation patterns of the proposed antenna in the H- and E-planes at (a) 2.4 GHz, (b) 3.75 GHz.

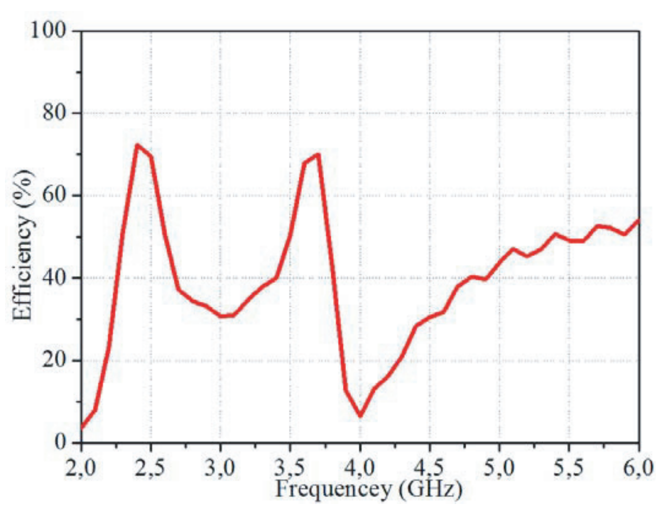


Figure 10. Radiation efficiency of the proposed antenna.

the antenna to the measurement system. At low frequencies, the ground plane of the antenna becomes electrically small and some currents will flow back from the antenna to the outer surface of the feeding cable. From these curves, it can be seen that the antenna provides two frequency bands, which can cover easily WLAN and WiMAX applications.

Figure 9 shows the far-field radiation patterns of the fabricated prototype at 2.4 and 3.75 GHz, respectively. Nearly omnidirectional radiation patterns in the H-plane (yz) and bidirectional radiation in the E-plane (xy) are achieved. At each frequency, the radiation patterns in the E- and H-planes are normalized. As seen in Fig. 8, it can be seen that a good agreement between simulated and measured results is reached.

Figure 10 reports the radiation efficiency of the proposed antenna. It can be seen that the patch antenna has an average efficiency of 70%, at 2.4 GHz and, more than 72%, at its second operated frequency 3.75 GHz.

4. CONCLUSION

In this paper, the design and analysis of a dual-band fractal antenna with square slotted in a ground plane has been presented. The design and fabrication process for the proposed antenna have been described. The originality of this work is that the feed line acts as a radiating element and excites the structure at the same time through the square slots etched in the ground plane. The antenna provides multi-band operation by etching slots on the ground plane, which is much easier to fabricate. The obtained results have shown that the proposed prototype covers two bands simultaneously at 2.4 GHz and 3.75 GHz for WILAN and WiMAX applications, respectively.

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