# Triple band Compact Fractal Antenna with Defected Ground Plane for Bluetooth, WiMAX, and WLAN Applications

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## Abstract

This paper presents a novel compact coplanar waveguide (CPW) monopole fractal-shaped antenna using fractal patch composed of hexagons with defected ground plane. Inclusion of a pair of S-shaped slots on the ground plane is used to extend the antenna impedance bandwidth and to provide multiband operation. The antenna has a size of 35×35×1.27 mm$^3$ which makes it compact. The antenna is designed, fabricated and measured. Good performances in terms of return loss, gain and radiation pattern are obtained in the operating bands, which makes the proposed antenna a good candidate for multiband wireless systems. The obtained results show that the antenna operates at Bluetooth, Worldwide Interoperability for Microwave Access (WiMAX), and Wireless Local Area Network (WLAN).

## 1. Introduction

Nowadays, advanced antenna technology employs various types and models of antennas according to the area of the desired application. With the rapid development of wireless communication systems, it is attractive to design small size, low profile and multi-band antennas to cover simultaneously several standards, such as LTE, Bluetooth, WiMAX and WLAN bands into a single wireless system [1, 2]. For this reason, multiband wireless systems are required to avoid using several antennas for various operating frequencies [3]. To achieve this goal, a few techniques have recently been proposed to design multiband antennas.

For instance, different planar monopole antennas have been proposed such as compact dual-band annular-ring slot antenna (ARSA) [4], an inverted-U-shaped antenna with additional I- and L-shaped strips [5], hexagonal slot antenna with slits [6], convex pentagon shaped microstrip antenna [7]. In addition, a triple-stacked microstrip patch antenna has been proposed for dual and triple-band operation [8, 9], a coupled-fed PIFA printed antenna on a small-size FR4 substrate promising for 2.4/5.2/5.8 GHz WLAN operation in the laptop computer has been proposed in [10], and a quad-band printed IFA has also been suggested in [11] for operating at 0.9 GHz, 1.57 GHz, 1.8 GHz and 2.45 GHz. In addition, a new modified antenna using a semi-fractal technique has been developed for multiband RFID reader applications [12].

The slotted ground plane has also been used to obtain multiband responses [13]. By the introduction of two saw tooth shaped defected ground structures, the hexagonal microstrip antenna has been proposed in [14], operated for triband application. However, the proposed antenna occupies the smallest area and has simpler geometry to realize the required operating bands compared to other designs in [5, 8].

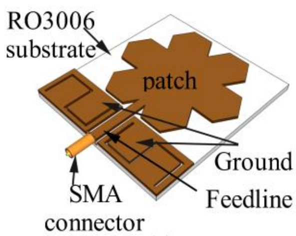
In this paper, we present a novel fractal shaped antenna with defected ground plane and fed by a coplanar waveguide (CPW) for the Bluetooth/WiMAX/WLAN systems.

The configuration of the proposed antenna arrives from the combination of small hexagon elements added to the corners of a simple hexagonal-shaped antenna to achieve a multi-resonance operation in a small area. The design of the proposed multiband antenna and the effect of their different parameters are discussed and presented in Section II. In Section III, experimental results are presented and compared to the simulated ones. Finally, the last section presents the conclusion.

## 2. Antenna design and analysis

Figure 1 shows the configuration of the proposed multiband fractal-shaped antenna. The 3-D view and photograph of the proposed antenna are shown in Figure 1(a) and (b), respectively.

The antenna is printed on a commercial dielectric substrate RO3006 with a thickness of 1.27 mm and relative permittivity of 6.15. The substrate dimensions are W×L, and the feed line has a width $W_f$=1.8 mm, which



(a)

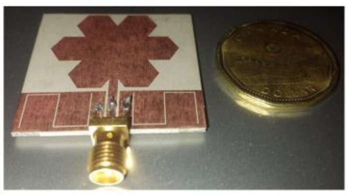

(b)

Figure 1: Configuration of the proposed antenna: (a) 3-D view, (b) photograph.

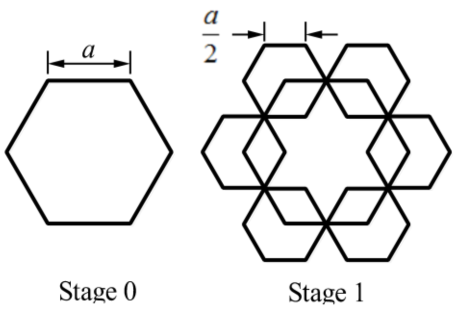



Figure 2: Iterations of the proposed Fractal antenna.

corresponds to a characteristic impedance of 50 Ω, and gap g=0.4 mm. The design of the antenna starts with a hexagon-shaped microstrip patch antenna, as shown in Figure 2.

In order to make the antenna operate in multiband, the concept of fractal is applied to the basic hexagon structure. The geometry of the proposed multiband antenna with dimensions is shown in Figure 3.

The proposed antenna consists of a conjunction of CPW microstrip feed line, slotted rectangular ground plane and fractal patch that is composed of six hexagons whose width is 4.6 mm. This modification on the ground plane enhances the matching between the patch and the feed line, which results in multiband operation. By increasing the number of the iterations in this design, the number of the resonance frequencies can be increased. The proposed antenna provides three resonance frequencies, which could be suitable for different wireless applications. All antenna parameters are simulated using CST Microwave studio 16 and measured using Agilent 8722ES network analyzer. The geometrical parameters of the antenna are listed in Table 1.

To study the effects of different parameters on the frequency response of the proposed antenna, numerical simulations were carried out in three scenarios:

i) The hexagon patch without slots on the ground plane (Ant.1);

ii) The fractal patch without slots on the ground plane (Ant.2);

iii) The proposed fractal patch with slots on the ground plane (Ant.3).

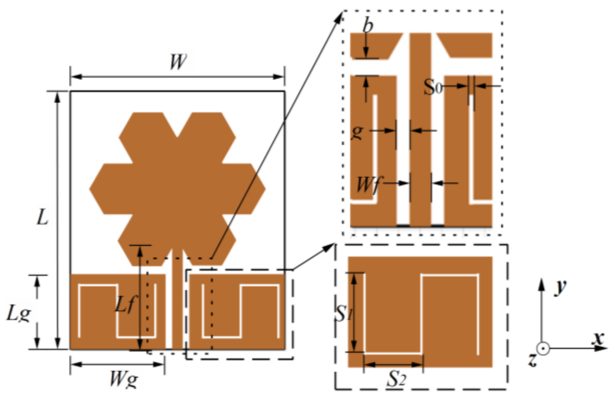



Figure 3: Geometry of the proposed structure.

Table 1: Parameters of the proposed antenna.

| Parameters | $L$ | $W$ | $L_g$ | $W_g$ | $L_f$ | $W_f$ |
|---|---|---|---|---|---|---|
| Value (mm) | 35 | 35 | 9.5 | 16.2 | 12 | 1.8 |
| Parameters | $g$ | $a$ | $b$ | $S_0$ | $S_1$ | $S_2$ |
| Value (mm) | 0.4 | 9.2 | 1.1 | 0.16 | 8 | 6 |

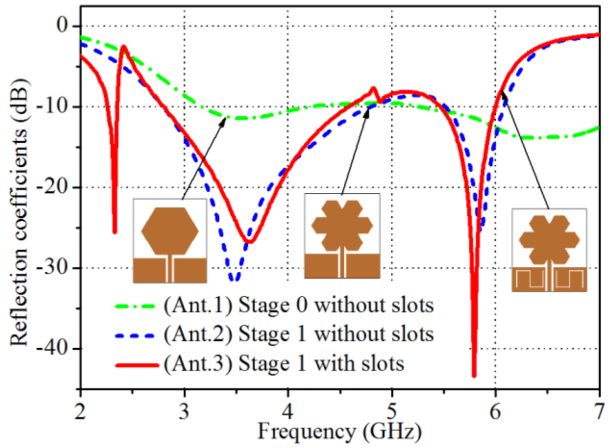



Figure 4: Simulated reflection coefficients of the different proposed stages.

The obtained results with captioned conditions are shown in Figure 4. It can be seen that, in scenario 1 when only the hexagon patch (Ant.1) is used, the antenna generates one frequency band at 3.5 GHz (WiMAX). In the second case (Ant.2), when hexagons are added at the corners of the first hexagon, this latter resonates at two bands: 3.5 and 5.7 GHz (WLAN). Finally, in the third case (Ant.3), when all the elements are used, the proposed antenna (Ant.3) generates three frequency bands: 2.4 GHz, 3.6 GHz and, 5.8 GHz, corresponding to Bluetooth, WiMAX and WLAN, respectively.

Simulations were carried out to investigate the effect of different parameters of the antenna on its performance. The length of the hexagonal patch $a$ and the distance between the patch and the ground $b$ affect the impedance matching.

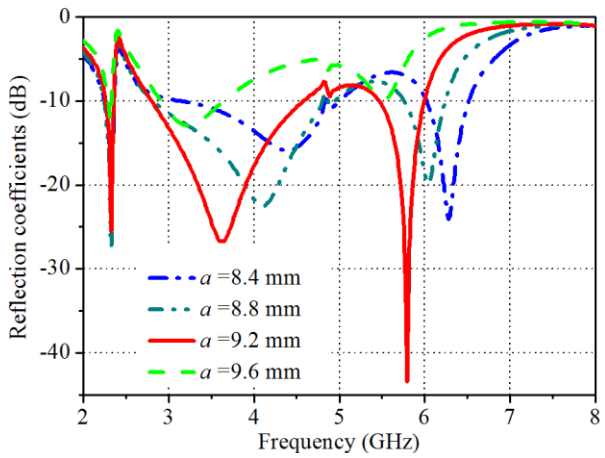



Figure 5: Effect of the design parameter $a$ on the reflection coefficients.

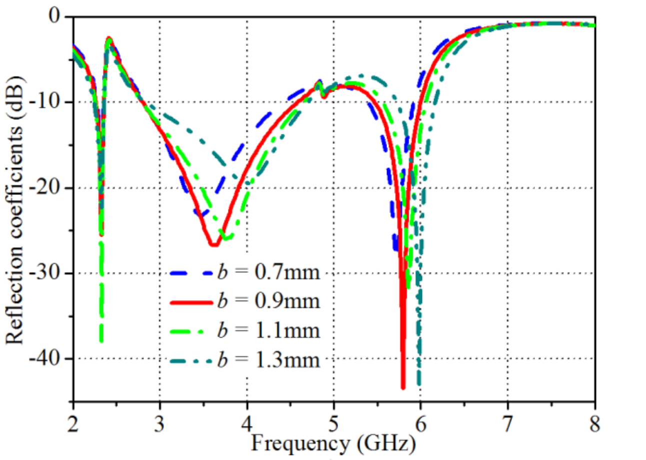


Figure 6: Effect of the design parameter *b* on the reflection coefficients.

Figure 5 and Figure 6 show that good input impedance matching for the WiMAX and WLAN bands can be achieved by tuning the values of the tow parameters *a* and *b*.

Figure 7 shows the effect of the slot width $S_0$ on the ground plane. It shows that the band position at 2.4 GHz can be tuned by the slot widths $S_0$ on the ground plane. Keeping the other parameters fixed, the lower resonance frequency corresponding to the Bluetooth band decreases slightly with decrease of the slot width $S_0$ on the ground plane. As a result, the bands of WLAN and WiMAX can be controlled simultaneously by tuning the length of the hexagonal patch *a* and the distance between the patch and the ground plane *b* with slight change in the Bluetooth band. Based on this parametric study, the optimal antenna parameters are chosen and listed in Table 1.

Figure 8 presents the surface electric current density on the proposed antenna radiator and ground planes at frequencies 2.4 GHz, 3.6 GHz and, 5.8 GHz. It is observed in Figure 8(a) that the electric current distribution at 2.4 GHz is located on the lower edge of the ground plane antenna. This means the antenna lower edge affects impedance

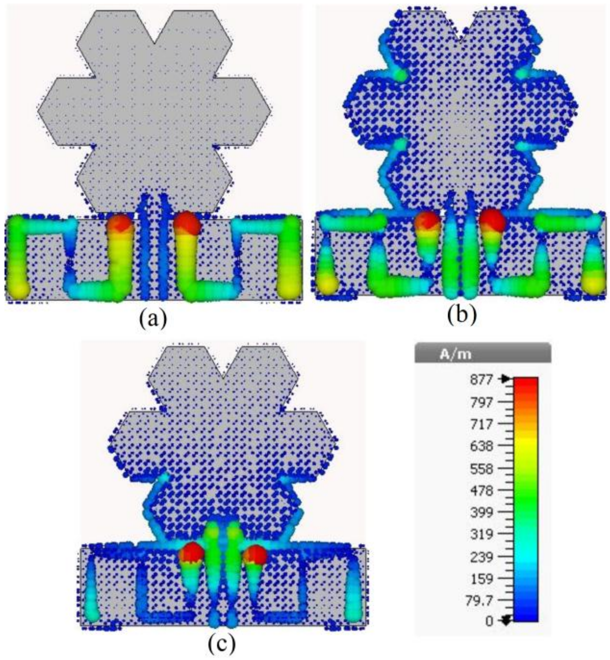


Figure 8: Simulated surface current distribution observed from the ground planeside: (a) 2.4, (b) 3.6 and (c) 5.8GHz.

characteristic at low frequencies. Figure 8(b) shows the electric current distribution at 3.6 GHz. Current distribution is mainly concentrated on the lower fractal elements and side edges. It is seen that the current distribution is more complicated than the first resonance frequency current distribution. The currents excited by the lower fractal elements have strongly affected and improved in the middle frequencies. The electric current distribution in the third resonant frequency, 5.8 GHz, is shown in Figure 8(c). It is observed that electric current has been excited by all the fractal elements. The current distribution confirms that the elements are parts of the radiating structure and have created the resonance at 3.6 and 5.8 GHz.

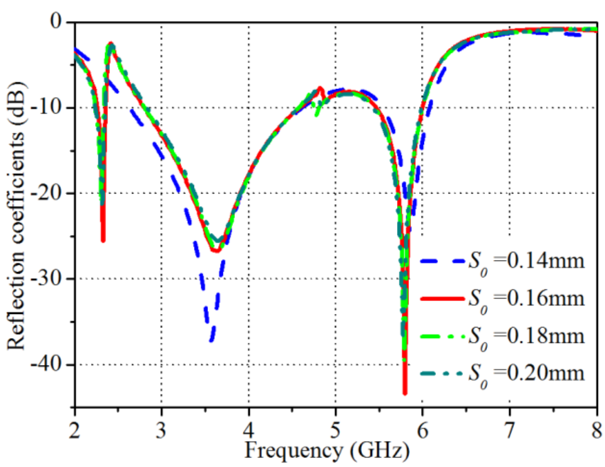


Figure 7: Effect of the design parameter $S_0$ on the reflection coefficients.

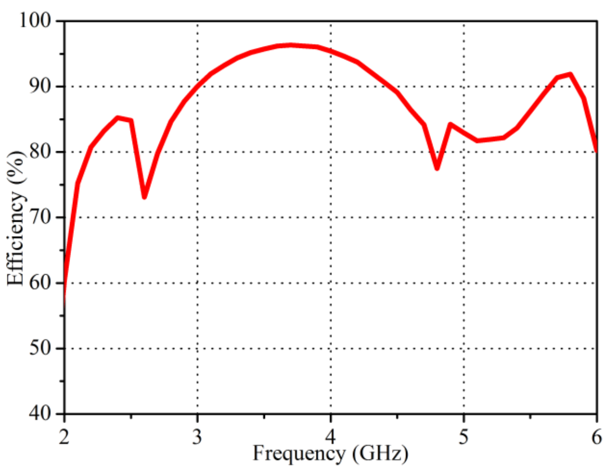


Figure 9: Radiation efficiency of the proposed antenna.

Figure 9 reports the radiation efficiency of the proposed antenna. It can be seen that the patch antenna has an average efficiency of 85%, at 2.4GHz, more than 95%, at its second operated frequency 3.6 GHz and 90% at the third frequency 5.8 GHz.

## 3. Measured and simulated results

To validate the proposed concept, an experimental antenna prototype was fabricated, tested and measured. The fabricated antenna is shown in Figure 1(b).The measurements were performed out using Agilent 8722ES Network Analyzer (Figure 10(a)) and inside an anechoic chamber (Figure 10(b)) for S-parameter, radiation pattern and gain measurements .

Figure 11 presents the simulated and measured reflection coefficients of the proposed antenna. 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 the antenna to the measurement system. The proposed antenna provides three resonance frequencies, which can be used for certain potential wireless applications.

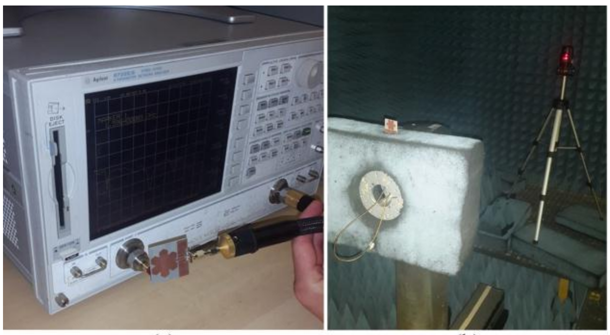



Figure 10: Measurement of (a) reflection coefficients by Network Analyzer, (b) radiation pattern inside an anechoic chamber.

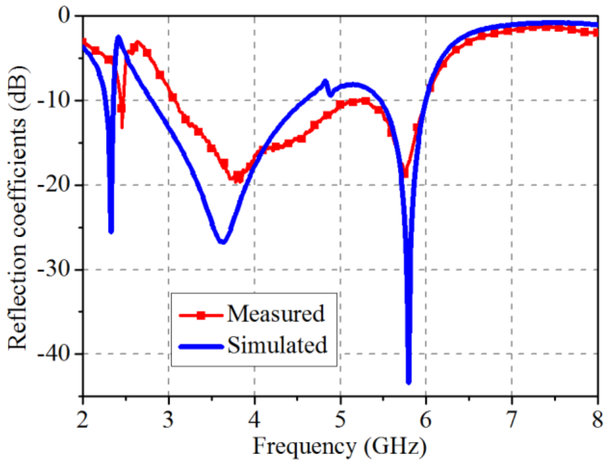



Figure 11: Measured and simulated reflection coefficients of the proposed antenna.

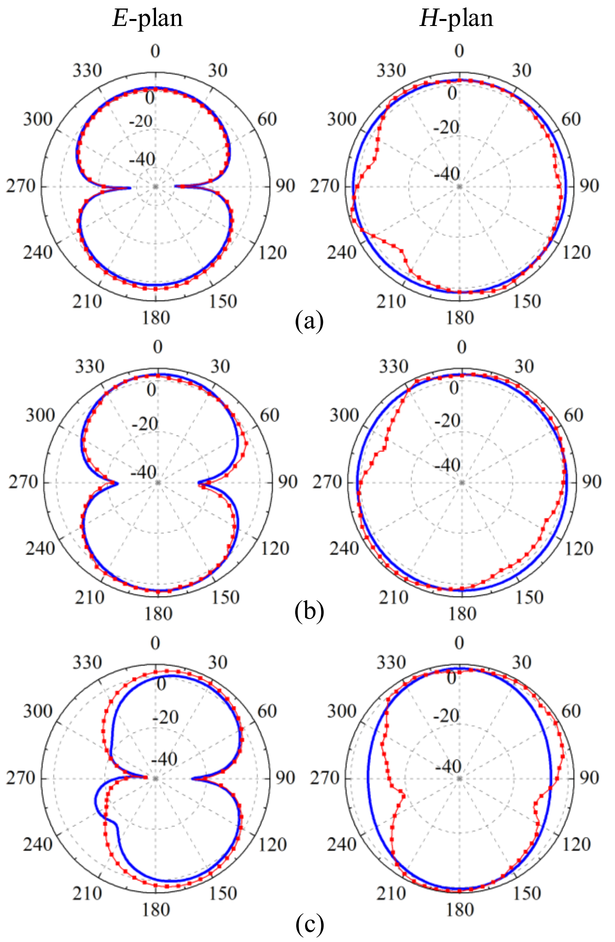



Figure 12: Measured (dashed line) and simulated (solid line) radiation patterns of the proposed antenna in H-plane and E-plane at (a) 2.4 GHz, (b) 3.6 GHz, and (c) 5.8 GHz.

The radiation patterns were simulated and measured at the resonant frequencies: 2.4 GHz, 3.6 GHz and 5.8 GHz in the two principal planes (*E*- and *H*-planes). At each frequency, the radiation patterns in the *E*- and *H*- planes are normalized. As seen in Figure 12, a good agreement between simulated and measured results is reached. Moreover, the radiation patterns in the *H*-plane (*yz*) are omnidirectional at all frequencies, although the *E*-plane (*xy*) radiation is bidirectional.

Table 2: Performance comparison of the proposed antenna with other reported antennas.

| Ref. | Size [mm$^2$] | Operating frequencies (GHz) |
|---|---|---|
| [5] | 52×55 | 2.4 ; 3.5 ; 5.3; and5.8 |
| [6] | 60 ×60 | 3.53 ; 4.15 and 5.08 |
| [7] | 102×83 | 1.82 ; 2.45 |
| [8] | 150×150 | 0.855 ; 1.715 |
| Proposed | 35×35 | 2.4 ; 3.6 and 5.8 |

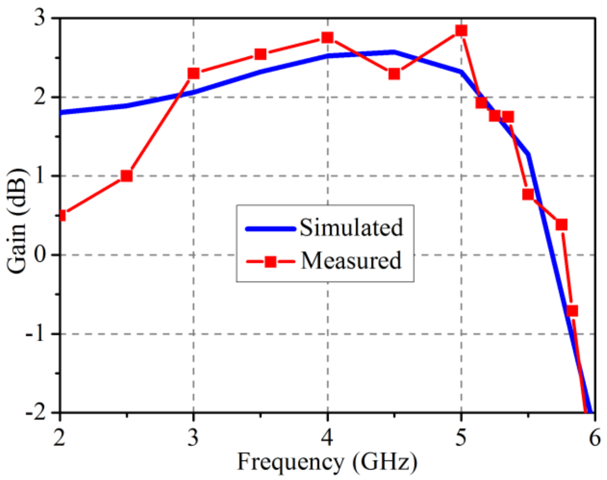


Figure 13: Measured and simulated gain of the proposed multiband antenna.

Figure 13 shows the simulated and measured gains of the proposed antenna over the operating frequency band. It is observed that the antenna has a stable performance over the proposed bands.

## 4. Conclusions

A novel compact coplanar waveguide (CPW) monopole fractal–shaped antenna with a slotted ground plane has been studied. This structure operates at three different bands: Bluetooth, WiMAX and WLAN. This multiband antenna has been designed by adding six small fractal hexagons to the hexagon-shape radiator monopole antenna with slotted ground plane. The performance enhancements in terms of compactness, gain stability, return loss, bandwidth and radiation pattern have been obtained and verified experimentally. The antenna exhibits an omnidirectional radiation pattern in the *H*-plane and bidirectional in the *E*-plane. However, the proposed antenna occupies the smallest area and has simpler geometry to realize the required operating bands compared to other designs as shown in Table 2. The position and the bandwidth of the bands can be controlled easily, which makes the proposed antenna suitable for multiband wireless communication systems.

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