Miniaturized Concentric Hexagonal Fractal Rings Based Monopole Antenna for WLAN/WiMAX Application

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Abstract. *In this paper a new antenna design technique is introduced in order to achieve tri-band operation as well as antenna miniaturization. The technique consists of using two concentric first-iterative hexagonal rings connected to each other as a radiating patch fed with a Y-shaped micro-strip line. The proposed antenna operates at three frequency bands to cover 2.4/5.8 GHz WLAN bands and 3.5/5.5 GHz WiMAX bands applications. The numerical analysis and simulation are carried out with CST MWS. The measured return losses of the proposed antenna show good performance and good agreement with the simulated ones. Consequently the proposed antenna with compact size of 9.7 mm x 17 mm x 1.63 mm is well suited for wireless applications.*

Keywords

Fractal antenna, tri-band, miniaturization, WLAN, WiMAX

1. Introduction

With the rapid development in the communication systems, there is an increasing demand for compact size antennas. Besides, more requirements in terms of multi-band and broad operation are needed. Consequently, several studies have been conducted to design miniaturized multiband antennas which can support multiple communication applications [1–3]. Thus, numerous antenna size reduction techniques have been reported elsewhere; for example, introduction of defected microstrip structure (DMS) [4], using a defected ground structure (DGS) [5–7] and loading the patch with shorting posts [8].

The introduction of fractal geometries in the antenna design is very interesting solution to achieve compact, low profile with multi-band and broadband characteristics. This is the result of the attractive properties of fractal geometries which are self-similarity and space filling [8–15]. Multiband and broadband [8–13] behavior is the result of the self-similarity property and the size reduction is achieved with space filling property [14–17].

In this paper, a new technique of miniaturization is proposed and investigated. The technique consists of using two concentric fractal shaped rings as radiating patch. The two rings are connected with a microstrip line to achieve triple band operation as well as size reduction. Based on this technique a compact tri-band mictrostrip patch antenna is designed and proposed. The radiating patch based on first-order hexagonal rings is fed with a Y-shaped transmission line as can be seen in Fig. 1. Thus, the antenna resonant frequencies can be tuned by changing the dimensions of the two fractal rings as well as the dimensions of the Y-shaped feed line. In order to validate the proposed technique, the antenna is simulated, fabricated and measured. The proposed tri-band antenna with compact size of $9.3 \times 17 \times 1.63\ \text{mm}^3$ operates at three different bands coverings the 2.4/5.6/5.8 GHz WLAN and 3.5 GHz WiMAX applications. The simulated and measured return losses of the proposed antenna are presented and discussed.

2. Antenna Structure

Figure 1 shows the geometry of the proposed two concentric fractal rings dual-band antenna along with its dimensions, fabricated on a 1.63 mm thick FR4 substrate with permittivity and loss tangent of 4.3 and 0.02, respectively. The proposed antenna with a planar size of only $9.3 \times 17\ \text{mm}^2$ is composed of two connected concentric fractal shaped rings acting as a radiating element and a Y-shaped feed structure printed on the top side of the substrate and a partial ground plane embedded in the other side of the substrate.

The proposed fractal ring shape is selected for antenna miniaturization issue and its procedure of generation is illustrated in Fig. 1(c). The second fractal ring, which has the same center as the first one, connected to the outer ring is used to generate multiple resonances and to achieve compactness. Hence the resulted antenna resonates at three different frequencies covering the 2.4/5.6/5.8 GHz WLAN and 3.5 GHz WiMAX bands. Furthermore, the slot etched in the ground plane is used to improve the impedance matching of the antenna. After an extensive simulation study, the geometrical parameters of the antenna have been optimized and are listed in Tab. 1. The antenna design and study is done with help of a powerful full wave electromagnetic simulator CST suite 2017.

3. Simulation Results and Parametric Studies

In order to understand why the second fractal ring is used and how it affects the antenna resonances, different antennas involved in the design evolution are simulated and studied. The three antennas involved in the design evolution are illustrated in Fig. 2 and their simulated return losses are plotted in Fig. 3. Initially, a single band antenna is designed as illustrated in configuration Ant. 1 of Fig. 2. This antenna is composed of a first-order hexagonal fractal ring radiating patch fed by a Y-shaped transmission line. The introduction of the fractal shaped radiating ring increases the total current path length as a result of which Ant. 1 resonant at 3.5 GHz as illustrated in Fig. 3. If the parameter S1 is further increased to 2.7 mm (maximum length before overlapping), the resonant frequency decreases and reaches down to 3.26 GHz (not able to reach the desired frequency of 2.45 GHz). Thus, the tuning of S_1 for Ant. 1 has a limitation and cannot shift the resonance as low as 2.45 GHz. This is why the second fractal ring is introduced in this work in order to create a resonance at 2.45 GHz without increasing the antenna dimensions. The use of a parasitic element, when correctly coupled to the driven monopole, is a useful mechanism to create a broadband and a dual-band antenna [18], [19]. By loading Ant. 1 by the second fractal ring to design Ant. 2, the electromagnetic coupling (EM) between the two rings has led to dual band operation as well as the first resonance shift to 3.44 GHz as can be seen in Fig. 3. To achieve compact size and triple band operation the two fractal rings are connected to each other by means of a strip line (Ant. 3) as can be seen in Fig. 2. It can be noted from the figure that the simulated 10-dB impedance bandwidths of the three operating bands were 2.43% (2.43–2.49 GHz), 23.1% (3.25–4.10 GHz) and 25.3% (5.43–7.0 GHz).

The simulated return losses of the proposed antenna for different positions of the connecting strip are shown in Fig. 4. It is clearly seen from the figure that the connection position affects significantly the antenna operating bands. When the connection is set at position P1 as illustrated in Fig. 4(a), the antenna operates at two frequency bands centered at 2.43 GHz and 3.92 GHz. When the connection is established at position P2 (Proposed antenna), three operating bands are obtained. However, if the connection is placed at P3 only two bands are exited whereas if the connection is placed at P4 only one mode is exited. Consequently, optimum results are obtained for connection strip placed at P2.

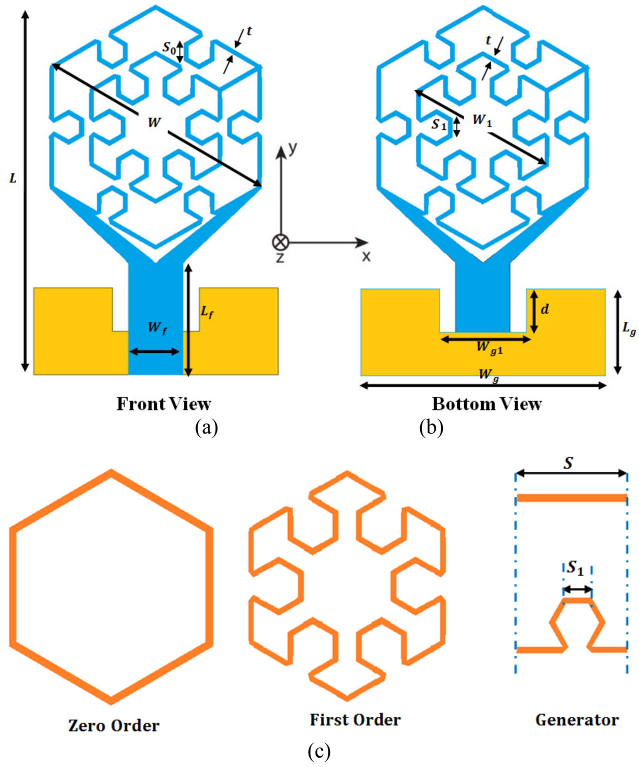


Fig. 1. Geometry of the proposed antenna:, (a) top view, (b) bottom view and, (c) the recursive-generation procedure for a hexagonal fractal curve.

Parameter	Value (mm)	Parameter	Value (mm)
L	17	W	10.7
L_f	5.42	L_g	4
W_f	2.5	W_g	4.5
t	0.2	d	2.0
S_1	0.8	t	0.2
W_1	6.45	W_{g1}	2.5

Tab 1. Geometrical dimensions of the proposed antenna.

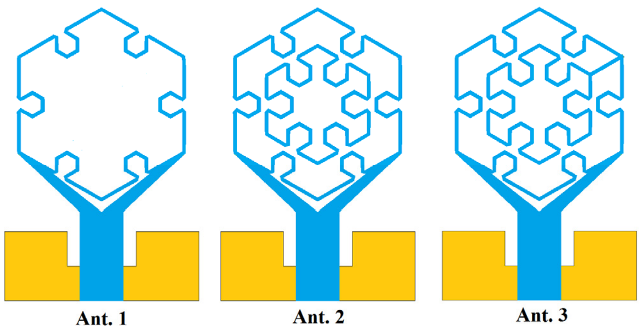


Fig. 2. Geometry of various antennas involved in the design evolution.

The simulated return losses of the proposed antenna when the side length of the small hexagonal open ring S_0, for the first iteration, of the external fractal ring is changed are presented in Fig. 5. It is clearly seen from the results that by increasing S_0 from 0.6 to 0.9 mm with a step of 0.1 mm, the three operating bands are significantly affected. For the first resonance, by increasing the value of S_0, the resonant frequency shifts to lower frequencies. As for the second band, the lower cut-off frequency is slightly shifted to lower frequencies whereas the upper cut-off frequency sifts significantly to higher frequency resulting in bandwidth widening. For the third band, significant shift of the lower cut-off frequency is observed when S_0 is decreased. Consequently, it can be concluded that optimum results are obtained for $S_0 = 0.8$ mm.

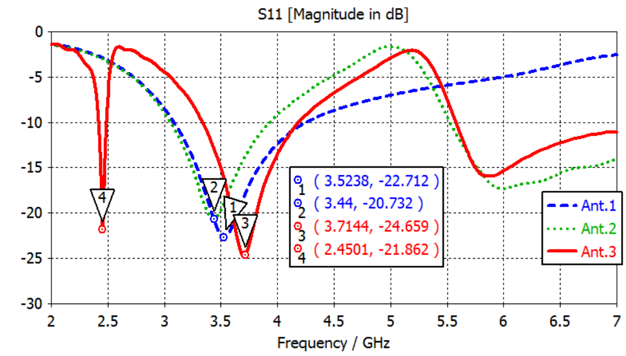
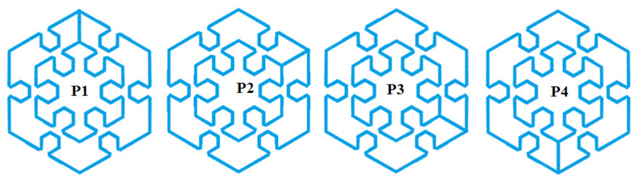
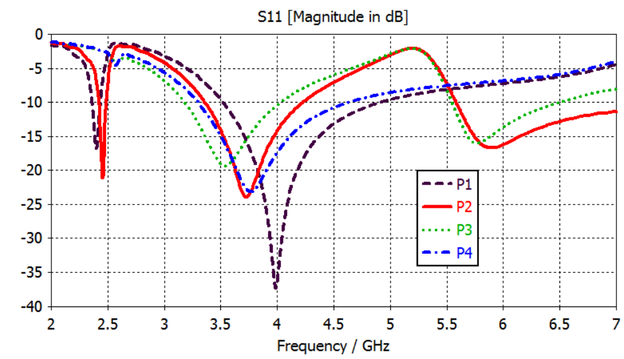


Fig. 3. Reflection coefficient vs frequency of various antenna structures.



(a)



(b)

Fig. 4. (a) Position of the connection strip and (b) effect of the position of the connecting strip on the reflection coefficient.

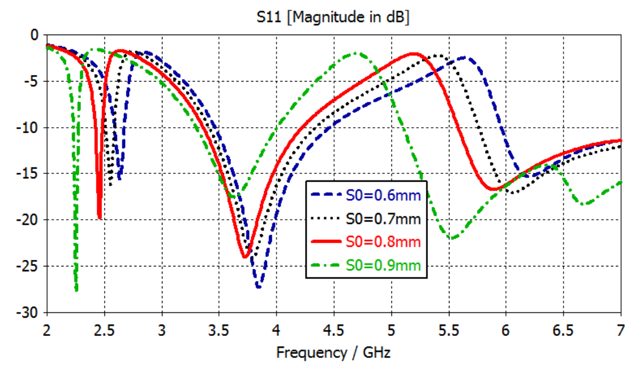


Fig. 5. Effect of S_0 on the reflection coefficient.

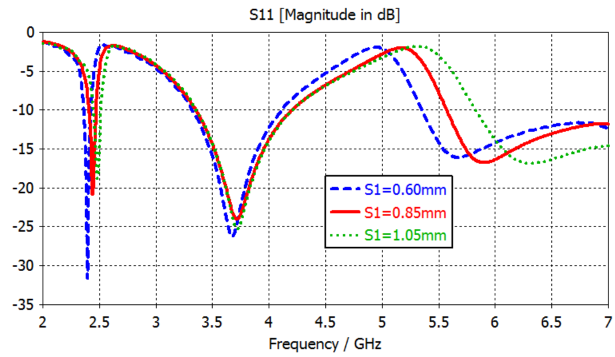


Fig. 6. Effect of variation of S_1 on the reflection coefficient.

The effect of changing the parameter S_1 on the antenna return losses characteristics is depicted in Fig. 6. It can be concluded from the figure that by increasing the value of S_1 the lower cut-off frequency of the third band is shifted toward higher frequency, the first resonance is also slightly increased while the higher cut-off frequency of the second band increases. It can be clearly concluded that optimum results are obtained for $S_1 = 0.85$ mm.

To further understand the operating mechanism of the proposed antenna, the current distribution at the three resonant frequencies are simulated and presented in Fig. 7. At the first resonant frequency, the current is mostly concentrated on the two fractal rings. Thus this resonance can be finely tuned by changing the parameters of the radiating rings. Large concentration of current is seen on the outer fractal ring at the second resonance. Accordingly, this resonance can be controlled by changing the outer ring dimensions. At the last operating frequency of 5.8 GHz, high concentration of current occurs on the feed line and on the two fractal rings.

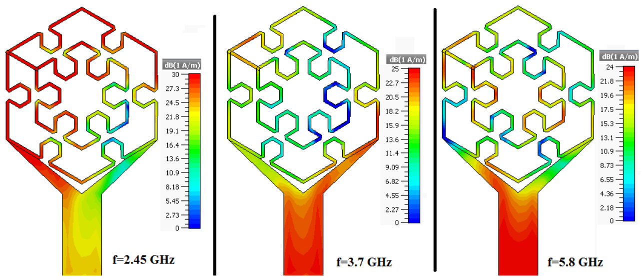


Fig. 7. Simulated current distribution at resonant frequencies.

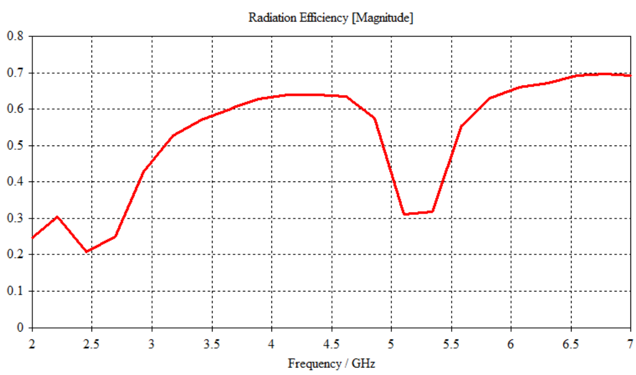


Fig. 8. Simulated radiation efficiency versus frequency.

This band can be controlled by changing the fractal rings configuration and dimension.

The antenna radiation efficiency is simulated and is plotted in Fig. 8. A peak gain of about –6.4, –1.5, and –2 dB are observed at 2.45, 3.7, and 5.8 GHz, respectively. Also, the maximum radiation efficiency of about 30%, 60%, and 62% is observed at 2.45, 3.7, and 5.8 GHz, respectively.

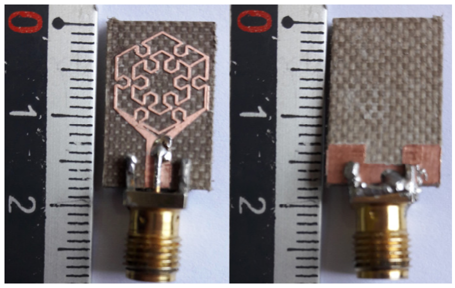


Fig. 9. Fabricated prototype of the proposed antenna.

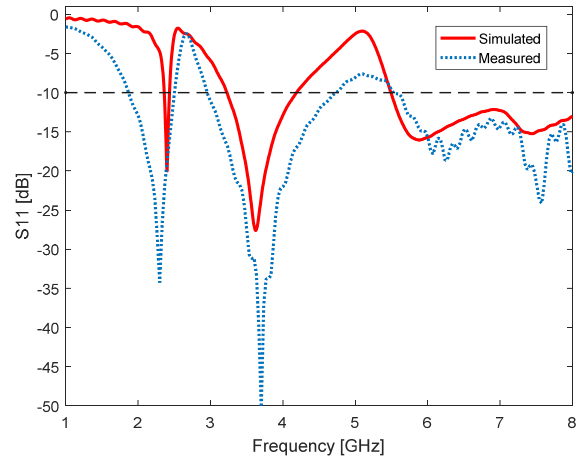


Fig. 10. Simulated and measured reflection coefficient of the proposed antenna.

4. Simulation and Measurement Results

Figure 9 shows the proposed antenna fabricated on a low cost widely available FR4 substrate of thickness 1.6 mm, relative permittivity 4.3, and loss tangent of 0.02. The simulated and measured return losses results of the antenna are illustrated in Fig. 10. It can be observed that the simulated and measured results are in good agreement, showing a tri-band operation with measured 10-dB impedance bandwidths of 686 MHz (1814–2500 MHz, 31.8%), 1770 MHz (2967–4737 MHz, 45.9%) and 1461 MHz (5539–7000 MHz, 23.3 %). The slight difference seen between the simulated and the measured results is basically due to the manufacturing tolerances and the uncertainty of the thickness and dielectric relative constant of the substrate added to the quality of the SMA connector which contributes in the discrepancy recorded between the simulated and measured results. Furthermore, due to the small size of the antenna the electrical size of the ground plane became small as compared to the wavelength. In this situation, the SMA connector and a part of the VNA connecting cable act as an additional ground plane [26]. Consequently, the current will flow back from the antenna to the connecting cable. However, the obtained bandwidth covers widely the WLAN (2.4, 5.6 and 5.8 GHz) and WiMAX (3.5 GHz) applications.

The antenna radiation pattern has been measured in an anechoic chamber. The simulated and measured radiation patterns of the proposed antenna in the E and H planes at different frequencies (2.45, 3.7 GHz, and 5.8 GHz) are plotted in Fig. 11. For all frequencies, the antenna has a monopole-like radiation pattern in the E-plane and an omnidiretional radiation pattern in the H-plane which makes it well-suited for the intended applications. The slight difference between measured and simulated radiation patterns are attributed to perturbation in the radiation pattern introduced by the positioner during the measurement process and the inaccuracies introduced by the measurement setup.

A comparison between the proposed antenna and other antennas reported in the literature is presented in Tab. 2. By comparing the reported antennas footprints, it is clearly seen that the proposed antenna has the smallest one. Consequently, it can be concluded that the proposed antenna achieves significant size reduction. Moreover, in terms of impedance matching performance, the proposed antenna outperforms almost all the reported antennas.

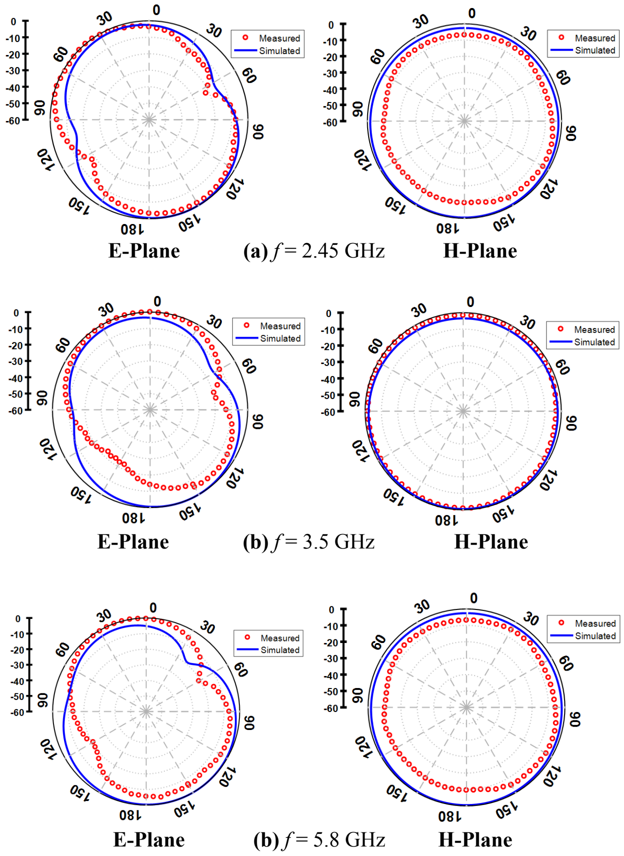


Fig. 11. Simulated and measured radiation pattern of the proposed antenna at different frequencies.

Ref.	Frequency (GHz)	Antenna Footprint	Bandwidth (%)
[20]	2.5 3.47 5.75	0.022 λ_0^2	6.45% 3.03% 5.9 %
[21]	1.9 2.5	0.062 λ_0^2	5.8% 4.0%
[22]	2.4 3.5	0.026 λ_0^2	5.7% 6.3%
[23]	2.4 5.2	0.102 λ_0^2	10.3% 19%
[24]	2.4 3.5	0.024 λ_0^2	123.5% 24%
[25]	2.45 3.50 5.35	0.113 λ_0^2	2.0% 2.0% 5.7%
This work	2.4 3.5 5.8	0.016 λ_0^2	31.8% 45.9% 23.3%

Tab. 2. Comparison between the proposed antenna size and application bands with other compact antennas.

5. Conclusion

A novel miniaturized tri-band antenna for wireless communication has been designed, fabricated and tested. The proposed antenna consists of a two concentric fractal radiating rings fed with a Y-shaped microstrip line. By connecting the two fractal rings tri-band operation along with size reduction have been achieved. The proposed antenna has exhibited omnidirectional radiation patterns in the three operating bands. Furthermore, the measured results of the proposed antenna with compact size of $9.3 \times 17\ \mathrm{mm}^2$ have shown good agreement with the simulated ones.

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