# Compact-Size Fractal Antenna with Stable Radiation Properties for Wi-Fi and WiMAX Communications

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## *Abstract*

In this study, a novel fractal ring antenna with a compact size of 24×9×0.8 $mm^3$ was configured using three iterations. Low profile, circular polarization, and measured operating bands (4.5–6.5 GHz) meet specifications of the upper band used in Wi-Fi and WiMAX applications. The antenna featured, stable radiation properties, especially gain and efficiency, in the notched band (92%). In deep, the antenna impedance, reflection coefficients, surface current distribution and circular polarization for the three iterations had been studied to improve the process of antenna design and its radiation characteristics

***Keywords:*** Fractal ring, compact size, Wi-Fi and WiMAX

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## 1. Introduction

By the invention of radio, a revolution of communication began, which elevated to a new level by the introduction of modern technologies such as satellite, cell phone ,GPS,W-Fi and WiMAX. With these modern technologies, voice, data and multimedia transceived between users at anytime and anywhere with very high speed and capacity. The increasing use of the number of wireless communication equipment, especially the portable types, has provided competitive opportunities in the market to meet the needs. One of the most important parts of these communication devices is the antenna, so many types of antennas had been designed to fulfill the stringent requirement of the modern communication systems. Given the increasing use of wireless local area network (WLAN) and Worldwide Interoperability for Microwave Access (WiMAX) in recent years [1,2], different antennas for WLAN/wireless fidelity (Wi-Fi) standards of 2.4–2.484/5.15–5.825 GHz and WiMAX standards of 2.5–2.6/3.4–3.6/5.25–5.85 GHz has been designed to support these types of wireless communication.

When the length of the antenna is less than quarter of the wavelength of the operating frequency, it is difficult to have good radiation properties. But through using a fractal geometry antenna, where the shape is repeated in a limited size, in a way that increases the total length of the antenna to match, for example, half of the wavelength of the corresponding desired frequency, the size limitations can be overcome in this case. There many fractal geometries such as the tree, Koch, Minkowski and Hilbert fractals that are used in designing this type of antenna [3].

Universal serial bus (USB) dongles are used in many portable communication devices, such as laptops and PADs, to transmit and receive data with high bit rate. Although USB dongles used with portable devices, the desired antenna must solve serious challenges, such as size, multi band, and stability of radiation characteristics (gain and efficiency) in notched bands.

## 2. Related Work

Recently, researchers attempted to apply certain monopole antennas of different shapes such as: loop spiral [4], planar monopole [5], ground slotted [6], monopole fed by CPW [7], strip-monopole [8], as USB dongles. A compact UWB antenna was presented in [9], a loading loop resonator was used in this design to achieve notched bands of 5.2-5.7 GHz. Interferences of 3.5 GHz are rejected by folding the arms of the fork-shaped radiator. The physical size of the antenna is 30 mm × 21 mm × 0.8 mm, a gear-shaped tooth structure fed by a small CPW was used in the design of the antenna in [10], the notched band is 2.39-24.53 GHz with LP. The compact size of the antenna is 30 mm × 30 mm × 1.6 mm. Three conductive layers in the structure of the mushroom metamaterial used in the substrate-integrated waveguide cavity-backed slot antenna in [11] has a complex structure and covers only the upper band used for Wi-Fi and WiMAX applications. The frequency range (1.5-4)GHz with LP radiation by using Koch snowflake fractal shaped antenna reported in [12], the geometry of the fractal antenna is, the overall size of the antenna is 80x40x1.58 mm. [13] designed a Minkowski model fractal loop monopole antenna fabricated on an FR4 substrate with an overall size of 10 mm × 45 mm × 0.8 mm. The antenna was configured by three iterations to cover frequency bands of 2.3-3.9 and 4.9-5.4 GHz. [14] investigated an H-fractal antenna that

was configured by seven iterations. The antenna was fabricated on an FR4 dielectric substrate with dimensions of 120 mm × 120 mm × 1.6 mm to achieve dual operating bands 2.4-2.49 and 5.1-5.8 GHz. [15] Used Wunderlich-shaped fractal split ring resonator (WSRR) to create CP radiation in designing the proposed antenna to achieve ARBW 1.86% of the operating band 3.4-3.6 GHz. [16] reported fractal antenna used logarithmic spiral antenna(LFA) and Fibonacci spiral antenna (PFA) structures to generate CP with narrow ARBW which is about 1.3% of the operating band around the resonant frequency 6GHz. Other researchers reported [17–23] slot or fractal antennas with operating bands cover the requirements of Wi-Fi and WiMX applications.

**Table 1** illustrates the comparison between the proposed antenna and related antennas investigated in [4,5,6,9,10,11,12,13,14,15 and 16] about some important charectrerstics such : impedance bandwidth, gain, size, efficiency, ARBW and weakness points. According to **Table 1**, most of the previous related antennas are linearly polarized radiation . So, it is needed to design antenna has compact size, circularly polarized , stable radiation properties , high efficiency , and acceptable gain values that can be used for Wi-Fi and WiMAX applications.

The aim of this study is to propose a monopole meandered ring antenna that covers the frequency range of 4.5–6.5 GHz to meet specifications of the upper operating band of 5–5.9 GHz for Wi-Fi and WiMAX applications with circularly polarized radiation , high efficiency in a compact size.

**Table 1.** Comparison between the proposed antenna and related antennas in [3,4,5,8,9,10,11,12,13,14,15, and 16 ].

| Ant. | BW (GHz) | Gain (dB) | Size (mm) | Efficiency % | ARBW (GHz) | Weak points |
|---|---|---|---|---|---|---|
| [4] | (2.3-2.7) (4.5-6) | 1.9-3.9 | 50x10x1 | 55 | LP | Low efficiency LP. |
| [5] | 5.1-6.5 | 1.9 | 48x10x1.57 | 86 | LP | Doesn't cover all bands, LP |
| [6] | (2.4-2.6)(5-6) | 1.5-4 | 60x15x1.6 | 80 | LP | Low gain at low band, LP |
| [9] | (5.2-5.7) | -7~ 4 | 30x21x0.8 | - | LP | Rogers 4003 substrate, LP, covers only two bands. |
| [10] | (2.39–2.453) | - | 30x30x1.6 | - | LP | Covers only upper band , LP, no efficiency values |

| Ant. | BW (GHz) | Gain (dB) | Size (mm) | Efficiency % | ARBW (GHz) | Weak points |
|---|---|---|---|---|---|---|
| [11] | (4.5-5.6) | 2-6 | 55 × 47 × 4.8 | 70-85 | LP | 3 conductive layers, LP and doesn't cover all required frequencies. |
| [12] | (1.5-4) | 2.2~2.4 | 80x40x1.58 | 60-79 | LP | LP, the thickness is not slandered, doesn't cover the (5-6) GHz band, complex geometry |
| [13] | (2.4-3.9) (4.9-5.4) | -0.5 ~2.5 | 45x10x0.8 | - | LP | LP, doesn't cover all frequency requirements, no efficiency values |
| [14] | (2.4-2.49) (5.1-5.8) | 1.9~7 | 120x120x1.6 | - | LP | Large size, doesn't cover all requirement band, LP |
| [15] | (3.4-3.6) | 6 | 45x40x2.5 | 85 | 0.1 | Cover only 3.5GHz band, thickness too much, |
| [16] | (2.7-10.3) | - | 54x36x1.5 | 85-95 | 1.1 | No values of gain , dos not cover 2.5GHz band. |
| **Prop.** | 4.5-6.5 | 2.2-2.4 | 24x9x0.8 | 92 | 0.08 | Covers only upper band |

## 3. Antenna Study

### 3.1 Antenna Design

In this study, the proposed antenna with a compact size of 24×9×0.8 $mm^3$ was configured by a three-step process. The radiator of reference antenna (**Fig. 1(a)**) is a square patch with dimensions (X=Y=9 mm) and is separated from the ground by a gap g of 0.3 mm. According to the empirical equation (1), the dimension of the square patch can be calculated for the resonant frequency ($f_r$= 5GHz ) and substrate FR-4 with $\epsilon_r = 4.3$ .

$$W = \frac{c}{f_r\sqrt{\frac{\epsilon_r+1}{2}}} = 36mm \quad (1)$$

To miniaturize the dimension of the antenna , let $X = Y = \frac{W}{4} = 9mm$

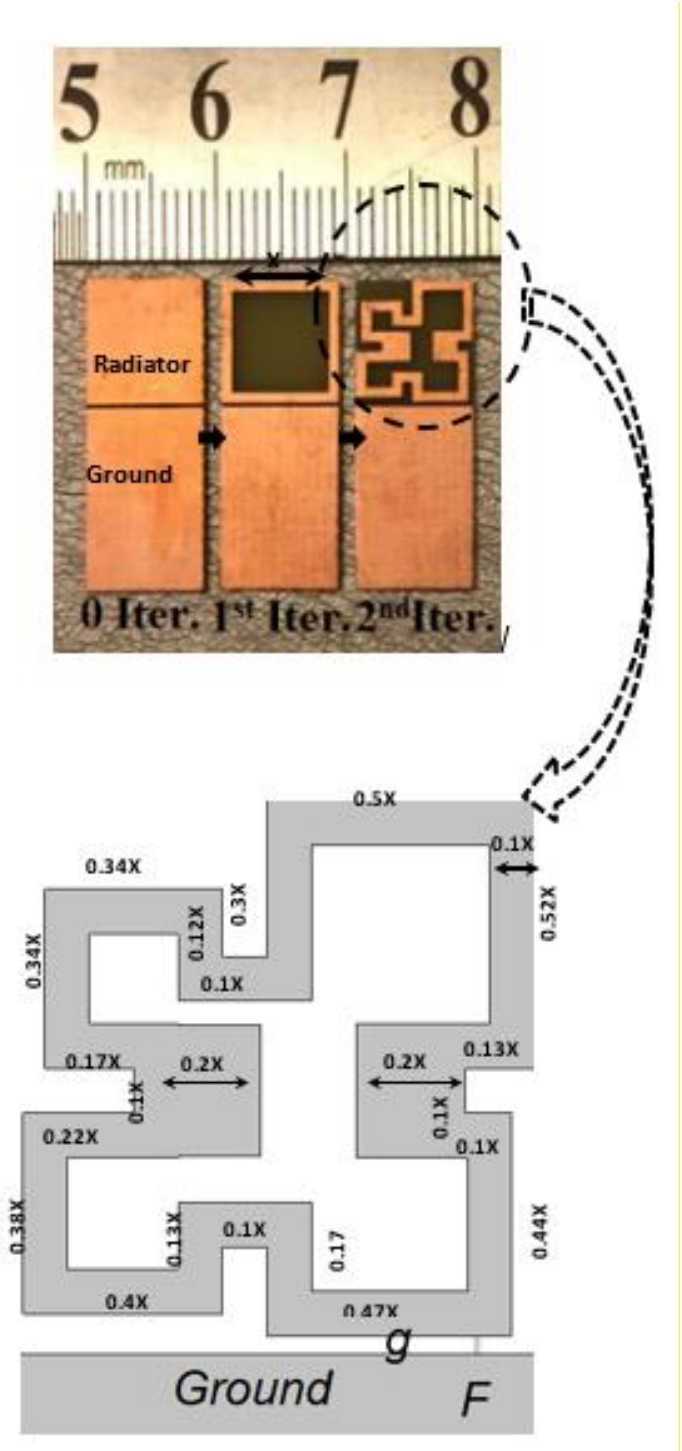



**Fig. 1.** The process of configuring the meandered ring antenna.

The ground plate features a rectangular shape with dimensions of 9.7×9 $mm^2$. The radiator and ground are printed on the same side of the commercial substrate (FR-4) with $\varepsilon_r$= 4.3, tan δ =0.027, and thickness= 0.8 mm.

**Fig. 1** (the upper part) shows the first iteration in the design of antenna with square slot cuts in the radiator plate to configure the square ring with arm width equal to *0.1X*. In the second iteration, the square ring is modified as a meandered ring to increase its electrical length to generate more resonant frequencies, which are collected to obtain a notched operating band of 4.4–6.7 GHz, as shown in **Fig. 2**. All dimensions of the meandered ring are denoted as a function of *X*, which corresponds to the dimension of the square ring in the first iteration, as indicated in **Fig. 1** (the lower part).

All dimensions of the meandered ring are denoted as a function of x, which corresponds to the dimension of the square ring in the first iteration, as indicated in Fig.1 (the lower part). The length of the square ring in the first iteration equals (4x).

Length of the upper arm= 0.5X+0.3x+0.1X+0.12X+0.34X= 1.36X (2)

Length of left arm =0.34X+0.17X+0.1X+0.22X+0.38X=1.21X (3)

Length of bottom arm = 0.4X+0.13X+0.1X+0.17X+0.47X= 1.27X (4)

Length of right arm = 0.44X+0.1X++0.1X+0.13X+0.52X= 1.29X (5)

Thus, the total length of meandered ring equals (5.13X). Length of meandered ring increases by a factor of 1.28 compared with the length of the square ring of the same size in the first iteration. Of course, the increase in length of the four arms leads to increase in the length of the surface current paths and thus generate new resonant frequencies which collected together to give a wide impedance bandwidth and this is clear in **Fig. 2** (the solid curve) where the operating band increased when the ring becomes meandered at the 2nd iteration. In **Fig. 2**, the operating band expanded during the process of meandered ring configuration.

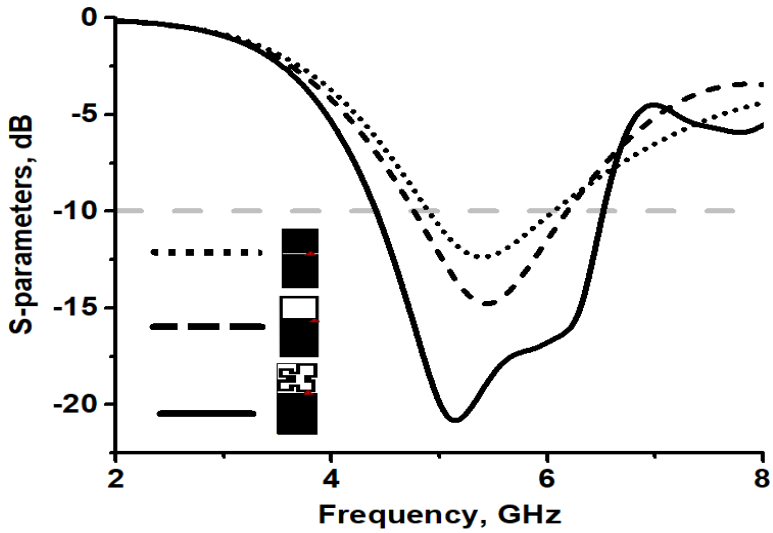



**Fig. 2.** The simulated reflection coefficient for the $0^{th}$ iteration, 1st iteration and the 2nd iteration.

**Fig. 3** depicts the real (black curves) and the imaginary (blue curves) parts of the impedance values for the three antennas. Values of real-part impedance for all antennas are almost equal at frequencies less than4.7 GHz. Thereafter, the values of real-part impedance for the second iteration are closer to the input impedance of excitation port (50 Ohms-red line), especially at the frequency range of 5.1–6.4 GHz. **Fig. 3** shows that negative imaginary values (capacitance) are observed in curves of imaginary part impedance for all antennas at frequencies less than 4.4 GHz. At the frequency band of 4.4–6 GHz, values of imaginary part are closer to zero (red line), that is, only real-part impedances for the three antennas are almost resistant. This property gives stable matching factor which leads to stable gain and efficiency during the operating band.

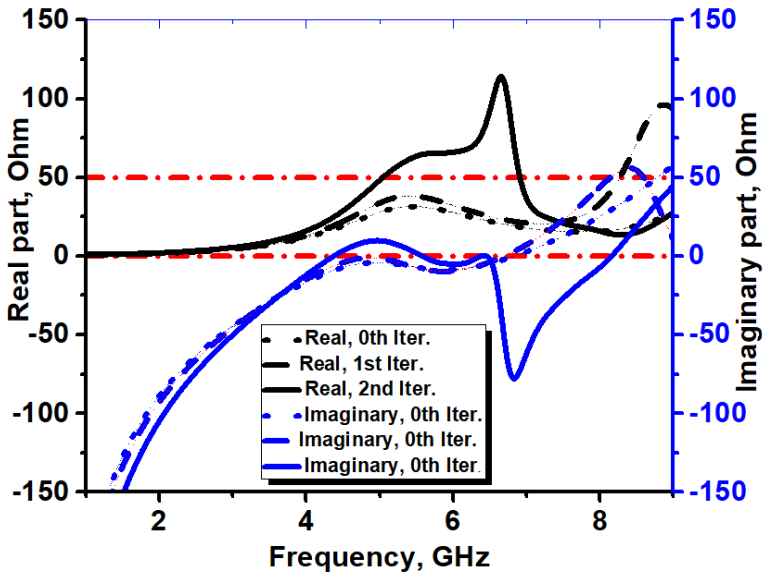



**Fig. 3.**The impedance values of the three iterations

**Table 2** illustrates some important radiation properties for each iteration, such as, impedance bandwidth, efficiency, gain and ARBW. It's clear that most of the required specifications of antennas used for Wi-Fi and WiMAX can be achieved at the 2nd iteration due to improving the values of radiation properties during the progress of antenna configuration, especially the impedance bandwidth, efficiency, gain and an ARBW as shown in **Table 2**.

**Table 2.** The radiation properties for all iterations of the meandered ring fractal antenna.

| Iteration | BW (5-6) (GHz) | Efficiency % | ARBW <3dB (GHz) | Gain (dB) | Lower S1,1 (dB) | State |
|---|---|---|---|---|---|---|
| ***0th*** | (5.2-6) | 50-65 | - | -12~0 | -10 | Low efficiency, low gain and LP. |
| ***1st*** | (4.7-6) | 60-75 | - | 1~3 | -14 | Doesn't have stable value of gain and LP |
| ***2nd*** | (4.4-6.7) | 85-90 | 0.083 | 2.2~2.4 | -20 | Optimum |

### 3.2 Surface Current Distribution

The maximum distribution current at 5GHz for the 0iteration are mainly concentrated close to the feeding point on the patch and ground plates, as it is shown in **Fig. 4** while in the 1st iteration, the currents are distributed in the additional area, especially on the square ring which leads to generate new resonant frequency than, the operating band is expanded compared with that at 0th iteration. The distribution of surface current on ground plate is the same at all iterations because there is no changed in surface current path at the ground plate during the progress of antenna configuration compared with radiator plane.

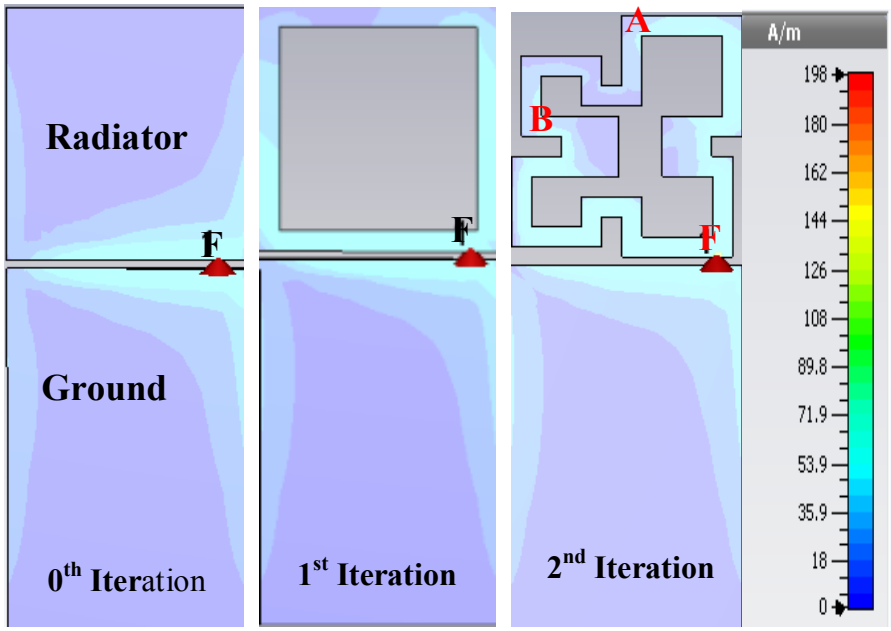



**Fig. 4.** The surface current at 5GHz for all iterations.

It is observed in **Fig. 4** (2nd iteration) that the surface current has two paths, the first path starts from feeding point *F* , then passes through the right arm to the point *A*, it has a total length equals to(1.79X=16mm) which is about ¼ of the wavelength for the resonant frequency 5GHz. The other path which is almost perpendicular to the first and starts from the feeding point *F* then passes through the bottom arm to the point *B*, the total length of second path is equal to (1.87X= 17mm) which is about ¼ of the wavelength for the resonant frequency 5GHz. So, there are two equal components of surface current normal to each other provide orthogonal components of electric fields in turn that generate circularly polarized radiation at 5GHz.

### 3.3 Circular Polarization

The length of the 1st surface current path from feeding point *F* to the point *A* is 16mm almost equals to the length of 2nd surface current path from feeding point to point *B*, these normal components are about ¼ of the wavelength for 5GHz created CP as its

clear in **Fig. 5** which represents the surface current distribution for phases 0°, 90°, 180°, and 270° at 5 GHz resonant frequency. Surface current circulates clockwise along the upper and lower right quarters and counter-clockwise along the lower left quarter for the phases 0° and 180°

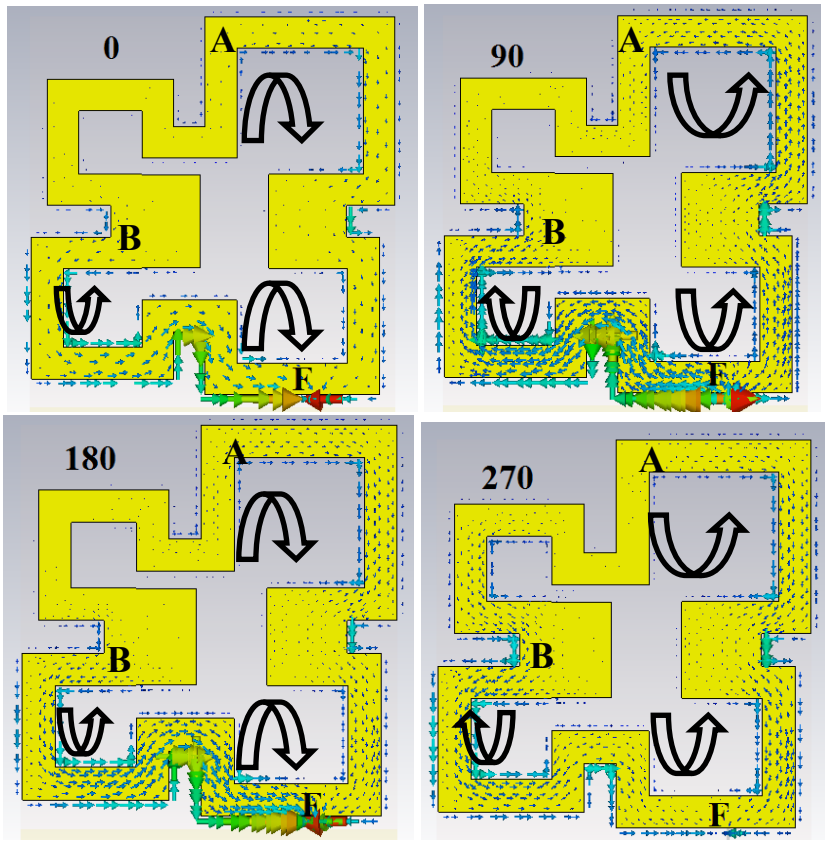



**Fig. 5.** Surface current for sequential phases (0°, 90°, 180°, and 270°) at 5 GHz.

**Fig. 5** shows the direction of circulation the surface current when the phase becomes 90° and 270°. **Fig. 6** depicts the left and right polarizing radiation in E-plane at 5 GHz and 5.8 GHz, it's clear that the phase difference between the radiation patterns at 5 GHz is about 86 degrees while at 5.8 GHz is 180 degrees, that means, there is CP radiation at 5GHz only. This study matches the surface current distribution which indicates that there is a circular polarization radiation at 5GHz generated by dual orthogonal components of electrical field which created by surface currents that flow along the perpendicular arms of the meandered ring at the feed point as shown in **Fig. 4**.

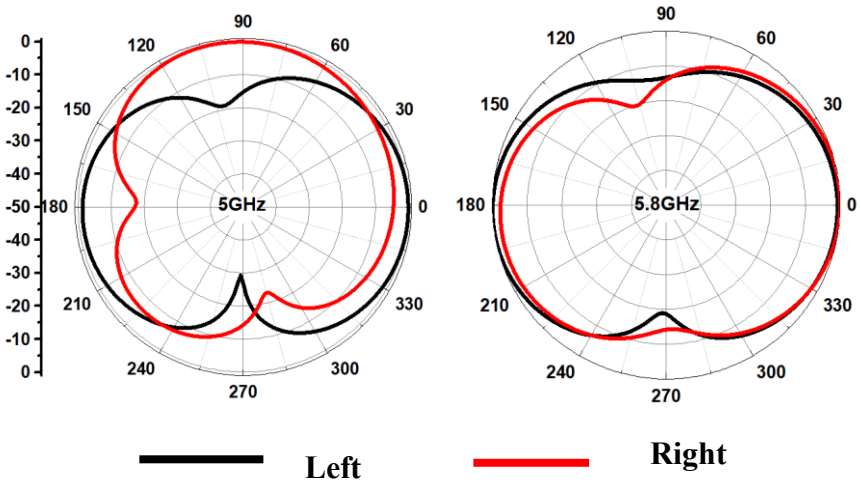



**Fig. 6.** Simulated left and right polarization in E-plane at 5GHz and 5.8GHz.

## 4. Measurements and Results

**Fig. 7** represents the photographs of the all iterations prototypes, it's clear that the size of the proposed antenna is compact that can be used for portable communication devices.

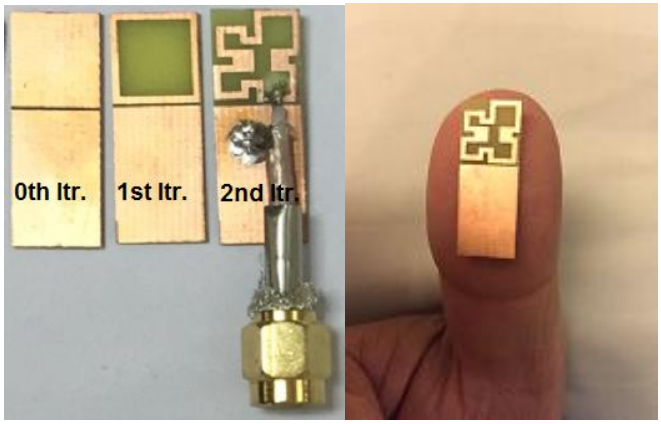



**Fig. 7.** The prototypes of all fractal antenna iterations.

Measured impedance bandwidth for the proposed antenna compresses to the frequency band of 4.8–6.7 GHz compared with the simulated impedance bandwidth of 4.4–6.7 GHz and the resonant frequency shifted to 5GHz compared with 5.8GHz for the simulated value as it is shown in **Fig. 8**. That takes place due to impurities of some of the materials that are used in prototypes and due to the soldering.

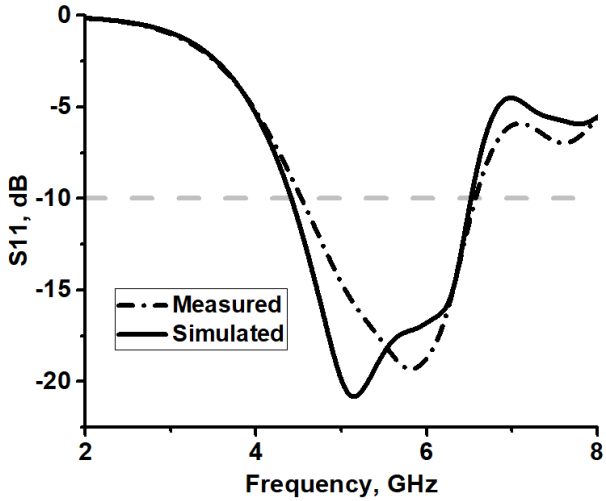
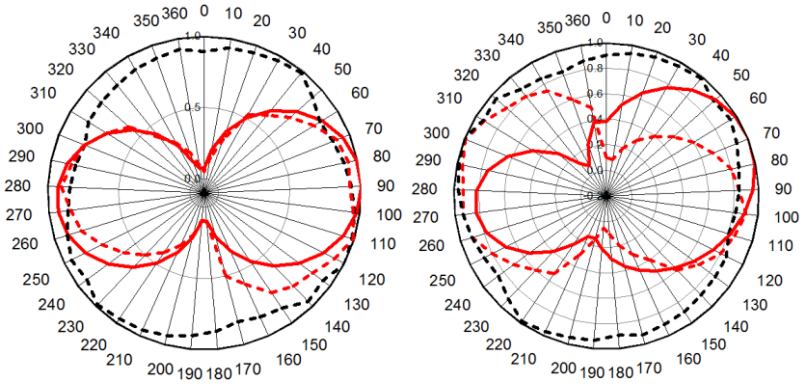



**Fig. 8.** The measured (dashed) and simulated(solid)$S_{1,1}$ for the proposed antenna.

**Fig. 9** shows a distinguishing agreement between simulated (solid) and measured (dashed) patterns. Radiation patterns in the H-plane (black curves) for the proposed antenna are almost omnidirectional at 5 and 5.8 GHz. Figure 5.21b shows that the radiation pattern at 5.8 GHz is similar to that at 5 GHz, but the former is more directional.

At E-plane (when phi=0), the radiation patterns looked like number 8 where two major lobes observed shifts by an angle of 180 degrees as its shown in **Fig. 9(a)** (the red curves) while at 5.8GHz, the radiation pattern in E-plane had dual asymmetrical major lobes.



a b

**Fig. 9.** Simulated(solid) and measured(dashed) radiation pattern.

a. At 5GHz.
b. At 5.8GHz.

**Fig. 10** depicts the measured (dashed curves) and the simulated (solid curves) values of the gain, efficiency and an axial ratio. At frequency bands of 5–6 GHz, measured gain values (black dashed curve) are almost constant 2.3–2.4 dB, and measured efficiency (blue gashed curve) reaches −0.45dB (92%), whereas measuring axial ratio bandwidth compress to the frequency range 4.95-5.2GHz (approximately 8.3% of operating band) around a resonant frequency of 5 GHz.

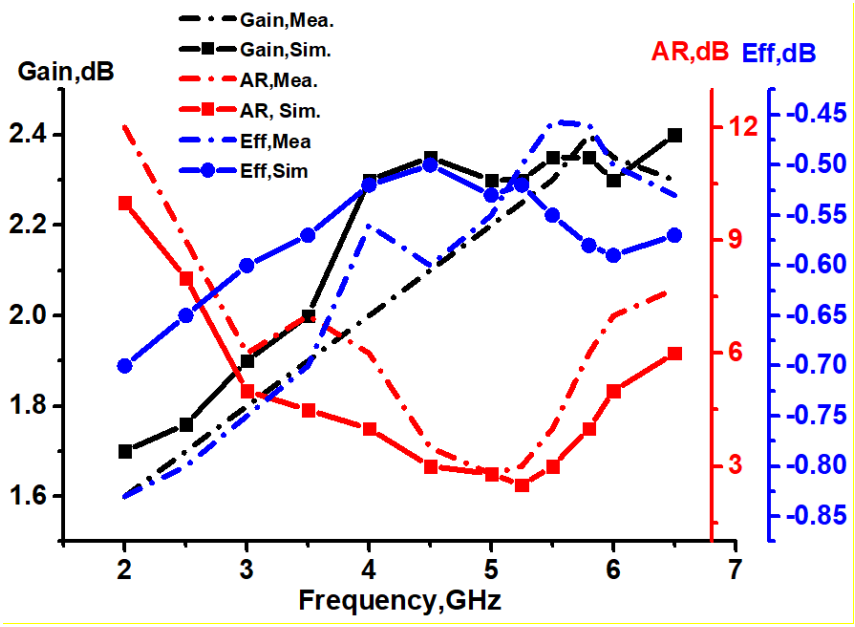



**Fig. 10.** Measured(dashed) and simulated (solid) gain, AR and efficiency for the antenna.

## 5. Conclusion

In this research, a novel fractal ring antenna presented. The proposed antenna had stable radiation properties, especially the gain and efficiency during the operating band. This feature is distinguished by the proposed antenna from the other previous antennas in addition to the compact size. Referring to **Table 1**, the proposed antenna covers only the upper bandwidth of (5GHz-5.9GHz) that is used for Wi-Fi and WiMAX applications. The proposed antenna in this study is the smallest size, low profile, higher efficiency (92%), stable gain, and a matching factor. Also, the proposed fractal ring antenna is circularly polarized with an ARBW of 83 MHz, which is about 8.3% of the operating band. Thus, the meandered ring monopole antenna compared with 11 previously related antennas is the best to be used in portable communication devices.

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