Biconical Patch Antenna with Inscribed Fractal Sierpinsky Gasket for Low Range Wireless Communication Systems

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Abstract: - In this paper, a biconical patch antenna with inscribed third iteration fractal Sierpinsky gasket is designed and optimized for operating at unlicensed ISM frequency bands. A circular split ring resonator (CSRR) is used as a defected ground-plane structure for improving antenna matching. The initial design step of the proposed antenna is based on the design methodology of multi-resonant Sierpinsky fractal patch antennas with inscribed triangular fractal geometry. Building on this, a simulation tool for high frequency electromagnetic structures is employed to optimize antenna performance. The experimental prototype is built and characterized using an antenna pattern measurement equipment and a network analyzer. Experimental results shown that the built antenna presents return losses of -23 dB, coupling bandwidth percentage of 10 %, antenna gain of 6.8 dBi, and VSWR of 1.14 at the 2.4 GHz resonant frequency. The corresponding values at the 5.9 GHz resonant frequency are -33 dB, 9 %, 8.7 dBi, and 1.043, respectively. These results show that the proposed antenna presents suitable characteristics for low range wireless communications such as WiFi (wireless LAN), Bluetooth, and ZigBee technologies.

Key-Words: - Patch Biconical Antenna, Sierpinsky Gasket, Fractal Geometry, Multiband Antennas.

1 Introduction

Due to the increasing demand of wireless communication applications requiring high data rates, five generations (5G) technologies will be introduced in the near future developed to achieve superior performance over nowadays wireless and mobile communication systems [1]. In these scenarios, the development of high performance antennas will be of paramount importance.

In this research direction, patch antennas have been developed to achieve requirements such as miniaturization, low profile, compatibility with electronic circuits, easy design methodologies, among others [1]-[2]. On the other hand, multi-band antennas are required in cognitive radio networks; also wideband antennas are required in ultra wideband systems. To solve this requirements, a diversity of fractal geometries (such as the Sierpinsky gasket, Hilbert curve, snowshape of Knoch, hexagonal, “E”, “T” and “U” shapes, among others) has been combined with the patch technologies to improve antenna performance in terms of multiband and wideband characteristics [3]-[13]. Also, several fractal patch antennas with multiband behavior have been proposed for wireless local area network (WLAN) applications. Among these antennas, we found the biconical (also known as bowtie) patch one. The multi-band behavior of the biconcal antenna has been improved by the use of the Sierpinsky gasket fractal geometry [9]-[11]. On the other hand the coupling efficiency of the bowtie antenna has been improved by the use of ground-plane defects [11]-[16]. In this paper, we propose the use of both patch and ground-plane defects in the structure of the biconical patch antenna to improve both multi-band behavior and return losses. In particular, patch defects are introduced by means of the Sierpinsky gasket geometry [6]-[8], while ground-plane defects are incorporated by means of the circular split ring resonator (CSRR) technique [14]-[16].

The rest of the paper is organized as follows. In Section 2, the methodology for the initial design of the proposed biconical patch antenna with inscribed fractal triangles and circular split ring resonator is presented. Section 3, presents the analysis of the simulation and experimental results of the proposed antenna. Finally, the conclusions are given in Section 4.

2 Problem Formulation

The conventional biconical patch antenna is modified using the Sierpinsky triangle fractal geometry to stress its dual band behavior. Thus, the design methodology used for conventional gasket fractal antennas is employed. In this sense, the resonant frequency of the n-th iteration of the gasket (denoted by f_n) can be computed as follows [7]:

$$f_n \approx k \frac{c}{h_1} \delta^n \quad (1)$$

where k is a constant whose value depends on the substrate type, c is the value of the speed of light in vacuum, h_1 represents the height of the largest triangle, δ is the (log periodic) scale factor ($\delta \approx 2$), and n is a natural (generally integer) number that corresponds to the n-th iteration. In this work, a FR4 substrate with a dielectric constant equals to 4.4 is considered, consequently, $k \approx 0.26$. Fig. 1 illustrates the proposed biconical patch antenna with inscribed fractal triangles of three iterations.

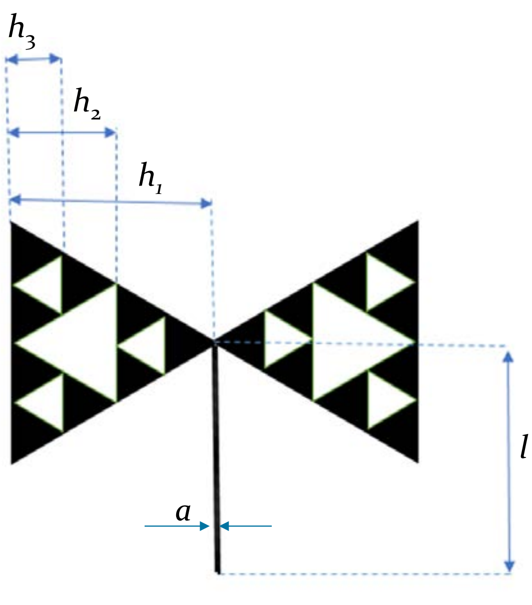

Fig. 1. Proposed Biconical patch antenna with inscribed fractal Sierpinsky gasket.

The fractal biconical patch antenna is obtained by joining two Sierpinsky gaskets as it is shown in Fig. 1. Fig. 1 also shows that a $\lambda/4$ feed transmission line that corresponds to the fundamental resonant frequency of the Sierpinsky fractal geometry (i.e., 2.4 GHz) is employed. Notice that three iterations gaskets are employed for the fractal biconical patch antenna.

Thus, the initial design of the fractal biconical patch antenna is as follows. Given the fundamental resonant frequency f_1=2.4 GHz, the second resonant frequency f_2=4.8 GHz, $\delta \approx 2$, and $k \approx 0.26$, from (1) it is obtained that the height of the largest triangle h_1=31.2 mm and $h_i = h_{i-1}/2$ (for i=2, 3,…) for the subsequent iterations. Notice that this is an approximated design methodology and the performance of the biconical patch antenna is optimized using the simulation tool for high frequency electromagnetic structures.

As it is well known, the Sierpinsky gasket presents poor impedance match at the fundamental resonant frequency. This is the reason why the development of Sierpinsky gasket based antennas employs the second resonant frequency as the operating one. However, this approach results in larger antenna systems (i.e., the low profile requirement for modern antennas is not reached). To overcome this drawback, a defected ground structure is employed. In particular, a circular split ring resonator (CSRR) technique is used here to achieve efficient coupling at the fundamental resonant frequency of the gasket fractal based biconical patch antenna.

A circular ring in the vacuum is matched to a frequency given by the following equation [16]:

$$f = \frac{1}{2\pi\sqrt{LC}} \quad (2)$$

where f is the resonant frequency of the circular ring, L is the approximated inductance of the closed ring and it is given by

$$L = \mu_0 R_m \left(\ln \frac{8R_m}{h+w} - 0.5 \right) \quad (3)$$

where μ_0 is the magnetic permeability of the vacuum, R_m is the average value of the inner and outer radius of the circular ring, h is the height of the ring, and w is the difference between the inner and outer radius of the ring. C is the sum of capacitances between the gap and the surface of the ring and it is given by

$$C = C_{gap} + C_{surf} \quad (4)$$

where

$$C_{gap} = \varepsilon_0 \left[\frac{wh}{g} + \frac{2\pi h}{\ln\frac{2.4h}{w}}\right] \quad (5)$$

$$C_{surf} = \frac{2\varepsilon_0 h}{\pi} \ln\frac{4R_m}{g} \quad (6)$$

ε_0 is the electric permittivity of the vacuum, and g is the value of the aperture of the ring.

As stated above, equations (2) to (6) corresponds to a circular ring resonator operating in the vacuum and are used for the initial design of the defected ground structure of our proposed antenna.

Thus, during the simulation process, the original dimensions of the gasket and the dimensions of the circular ring resonator are changed in order to adjust, as near as possible, the first two resonant frequencies at 2.4 GHz and 5.2 GHz, respectively, and, at the same time, obtain reasonable values for the return losses.

3 Problem Solution

In this section, simulation and experimental results of the proposed bowtie patch antenna with inscribed fractal triangles and circular split ring resonator are presented and compared.

3.1 Simulation Results

After the initial design of the proposed antenna was completed, the resulting electromagnetic structure was simulated using the High Frequency Structure Simulation (HFSS) software of ANSYS. This simulation tool was also used to adjust the different dimensions of the electromagnetic structure in order to obtain the desired resonant characteristics of the antenna. In this section, we present simulation results of the optimized electromagnetic structure of the proposed antenna. Fig. 2 shows the simulated electromagnetic structure.

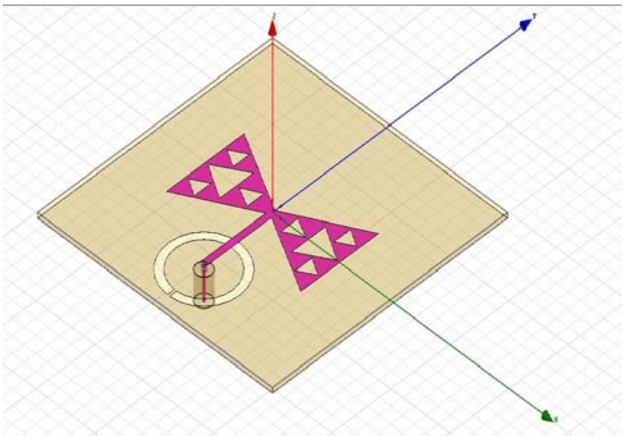

Fig. 2. Simulated electromagnetic structure.

In Figs. 3 and 4, return loss (RL) and standing wave ratio (VSWR) are plotted versus frequency, respectively. From these figures, it is observed that the proposed bowtie antenna presents excellent performance characteristics at the desired frequency bands (i.e., 2.4 GHz and 5.2 GHz). That is, the simulated electromagnetic structure presents return loss equals to -19.6 dB, coupling bandwidth percentage (CBP) of 6 %, and VWSR equals to 1.7 at the 2.4 GHz frequency band. The corresponding values at the 5.2 GHz frequency band are -28.6 dB, 3.8 %, and 1.3. Also, from Figs. 3 and 4, it is observed that the simulated antenna presents two additional resonant frequencies: 1.65 GHz and 6.26 GHz. Indeed, at the 6.26 resonant frequency, the antenna presents the best performance in terms of return loss and VWSR (RL= -39.99 dB, and VWSR=1.02), while at the resonant frequency of 1.65 GHz, it presents the best performance in terms of coupling bandwidth (CBP=13 %). The 1.656 GHz resonant frequency corresponds to the highest dimension of the antenna (i.e, 2h1), while the 6.26 GHz resonant frequency corresponds to the smallest dimension of the antenna (i.e., h3). Of course, as it was explained in Section 2, the 2.4 GHz and 5.2 GHz resonant frequencies correspond to the first and second iteration of the fractal gasket.

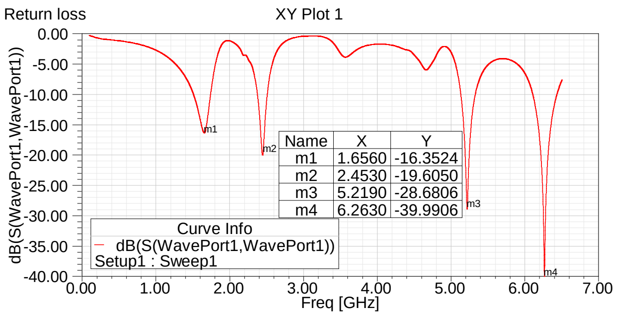

Fig. 3. Return loss for the simulated fractal bow-tie antenna.

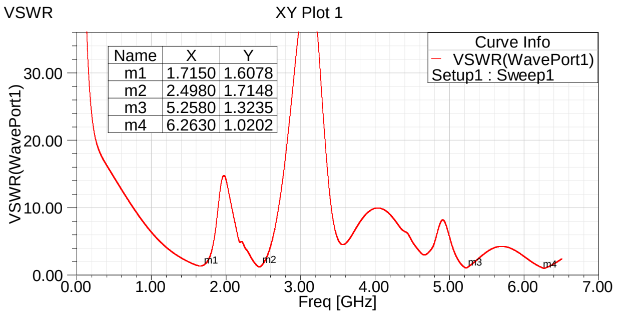

Fig. 4. Voltage Standing Wave Ratio for the simulated fractal bow-tie antenna.

On the other hand, Fig. 5 (Fig. 6) shows the complex impedance at the input port of the antenna around the 2.4 (5.2) GHz frequency band. In Fig. 5 (Fig. 6), frequency is swept form 2 (5) GHz to 3 (6.5) GHz. From Fig. 5 (Fig. 6) it is observed that the simulated electromagnetic structure presents good impedance match at the 2.4 (5.2) GHz frequency band. That is, in both frequency bands, the real part of the input impedance is near to 1.0, while the imaginary part is reasonably small (near to zero). This impedance matching was achieved by the joint use of the quarter wavelength microstrip transformer and the circular split ring resonator.

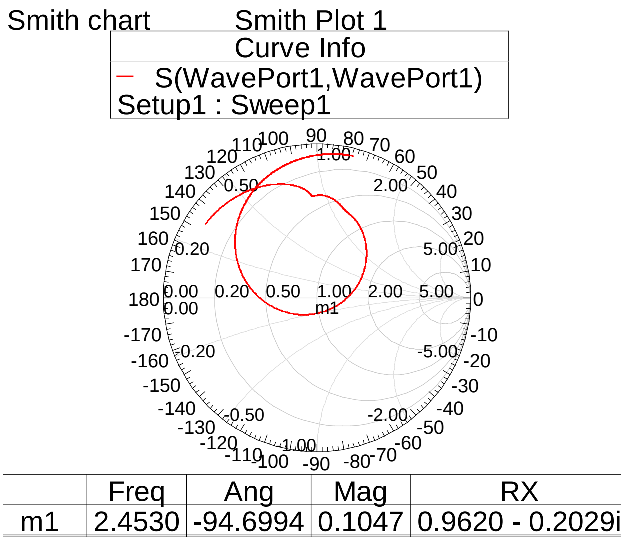

Fig. 5. Complex impedance versus frequency (the specific value at 2.45 GHz is remarked).

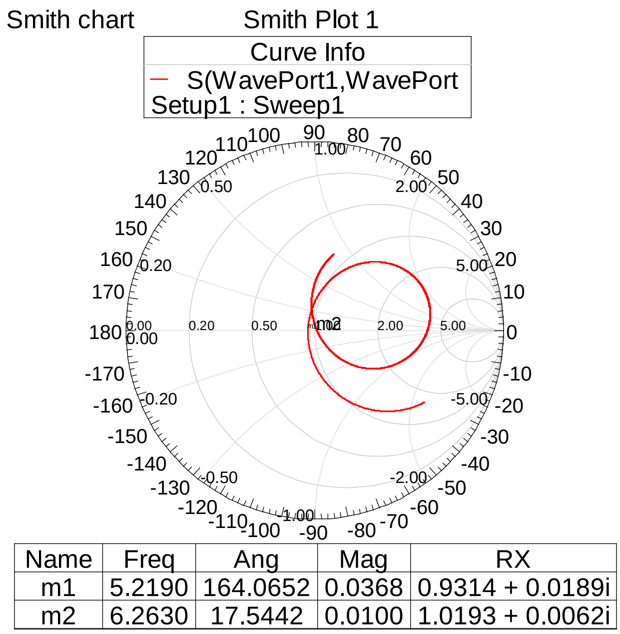

Fig. 6. Complex impedance versus frequency (specific values for the 5.2 GHz and 6.26 GHz are remarked).

On the other hand, Fig. 7 (Fig. 8) shows the antenna radiation pattern at the 2.4 GHz (5.2 GHz) frequency band. From Fig. 7 (Fig. 8), it is observed an antenna gain of -2.37 dBi (5.43 dBi) at the 2.4 GHz (5.2 GHz) frequency band. Notice that, due to the presence of the CSRR, a back lobe (i.e., along the opposite direction of the *z* axe) is presented in the radiation pattern. Even, for the 5.2 GHz case, the radiation pattern is clearly bidirectional. Thus, this antenna is more suitable to be used at the access point than at the portable unit.

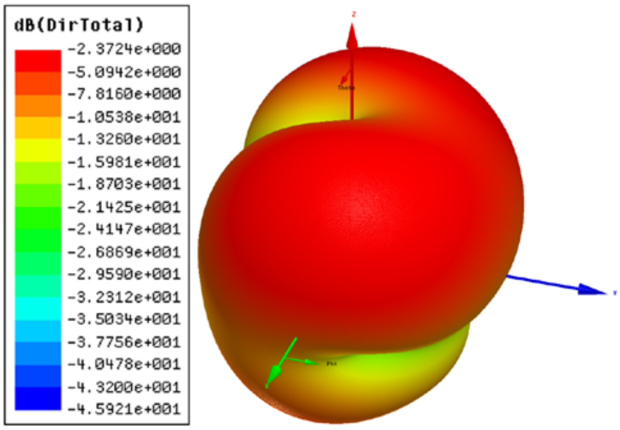

Fig. 7. Radiation pattern (directivity) at f = 2.4 GHz.

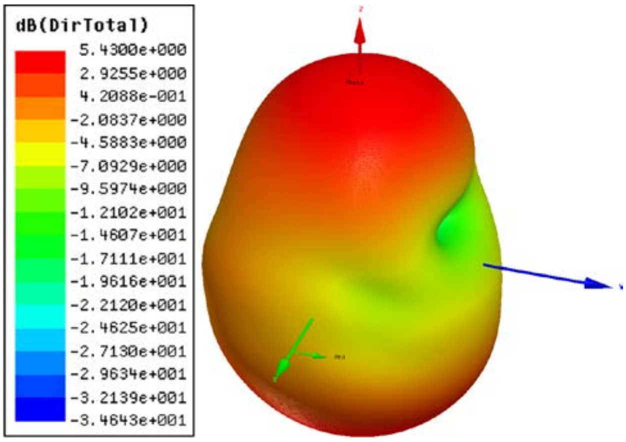

Fig. 8 Radiation pattern (directivity) to f = 5.2 GHz.

3.1 Experimental Results

Once simulation results were satisfactory, we proceed to build the experimental prototype of the proposed antenna. In this section, experimental measurements of the built antenna are presented. The proposed antenna was characterized by the jointly use of an antenna pattern measurement equipment, a network analyzer, and an antenna measurement software. These equipment and the developed antenna are shown in Fig. 9.

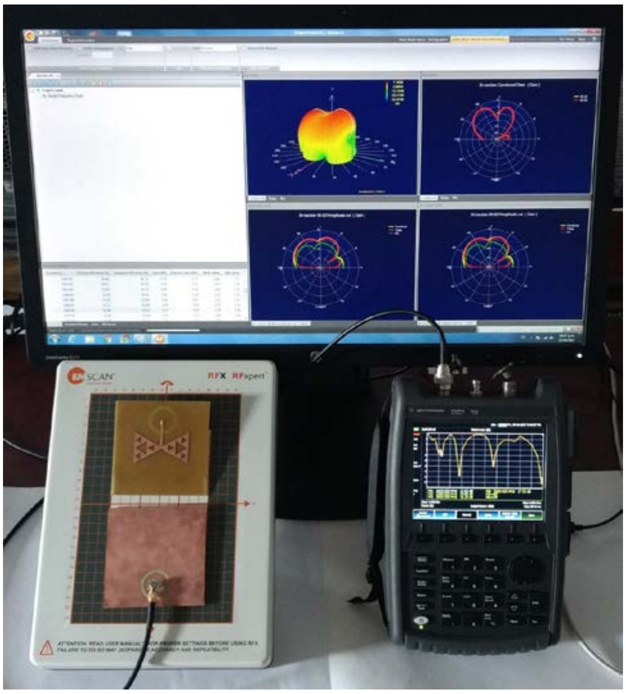
Fig. 9 Experimental measurement scenario.

In Figs. 10 and 11, experimental return loss (RL) and experimental voltage standing wave ratio (VSWR) are plotted versus frequency, respectively. From these figures, it is observed that the proposed bowtie antenna presents excellent performance characteristics at the 2.4 GHz and 5.9 GHz frequency bands. That is, the experimental antenna prototype presents return loss equals to -23.6 dB, coupling bandwidth percentage (CBP) of 10.7 %, and VSWR equals to 1.14 at the 2.37 GHz frequency band. The corresponding values at the 5.98 GHz frequency band are -33.6 dB, 9 %, and 1.04. Also, from Figs. 10 and 11, it is observed that the experimental antenna presents two additional resonant frequencies: 1.53 GHz and 3.87 GHz. Table 1 compares simulation and experimental results for the proposed antenna. Table 1 compares simulation and experimental results in terms of resonant frequencies, return losses, coupling bandwidth percentage and standing wave ratios. From Table 1, it is observed that, for the 2.4 GHz band, simulation and experimental results are in good agreement. On the other hand, the main difference between simulation and experimental results is regarding the objective for resonate about 5.2 GHz: the experimental prototype fail to reach this goal. In fact, if Figs. 3 and 10 are compared, good agreement between simulation and experimental results is observed regarding the first, second, and fourth resonant frequencies. On the other hand, results regarding the third resonant frequency differ considerably (5.2 GHz for the simulation results against 3.8 GHz for the experimental results). It is not clear the exact reason of this, nonetheless, this resonant frequency can be experimental adjusted by varying the size of the inscribed fractal triangles of second and third iterations. This is a topic of our current research.

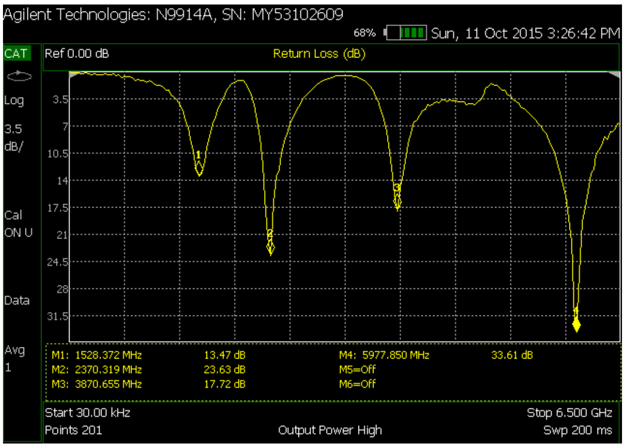

Fig. 10. Experimental return loss versus frequency.

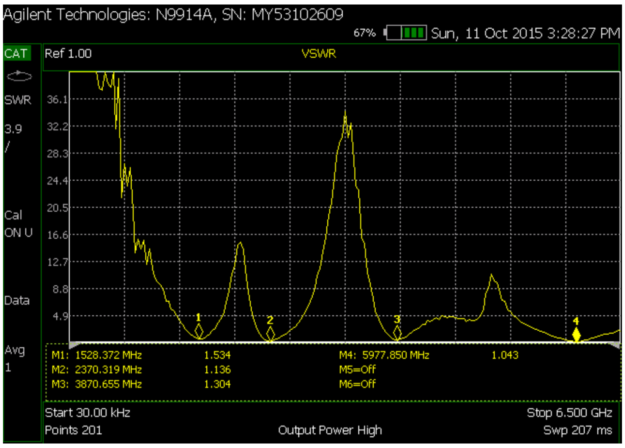

Fig. 11. Experimental VSWR versus frequency.

Table 1. Comparison between simulation and experimental results.

Parameter	Simulation		Experimental	
f_n (GHz)	2.45	5.22	2.37	5.98
RL (dB)	19.2	28.6	23.6	33.6
CBP (%)	6.0	3.8	10.7	9.0
VSWR	1.30	1.02	1.14	1.04

On the other hand, Fig. 12 (Fig. 13) shows the complex impedance at the input port of the experimental antenna around the 2.4 (5.9) GHz frequency band. In Fig. 12 (Fig. 13), frequency is swept form 2 (5) GHz to 3 (6.5) GHz. From Fig. 12 (Fig. 13) it is observed that the simulated electromagnetic structure presents good impedance match at the 2.4 (5.9) GHz frequency band. That is, in both frequency bands, the real part of the input impedance is near to 50 ohms, while the imaginary part is reasonably small (near to zero). As explained before, this impedance matching was achieved by the joint use of the quarter wavelength microstrip transformer and the circular split ring resonator.

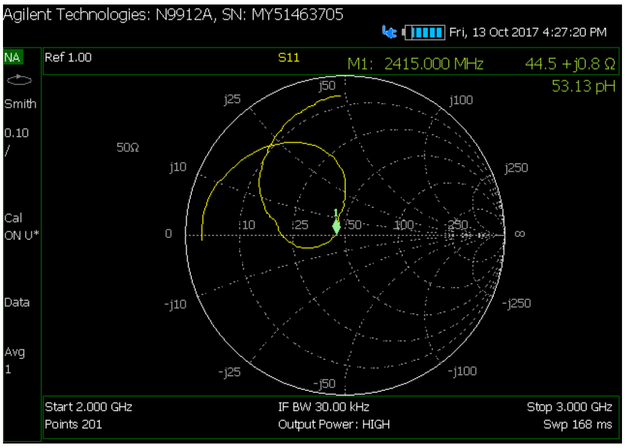

Fig. 12. Complex impedance versus frequency (the specific value at 2.415 GHz is remarked).

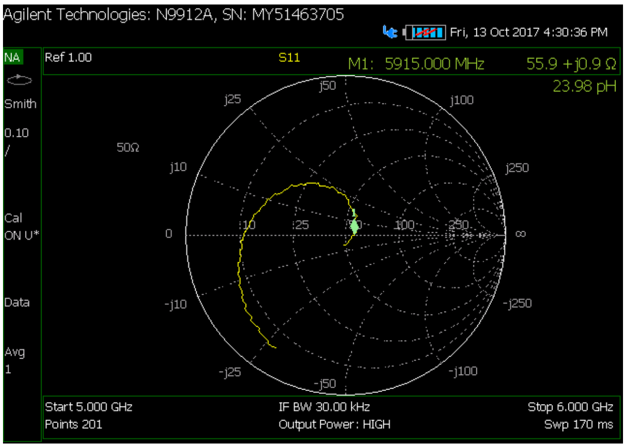

Fig. 13. Complex impedance versus frequency (the specific value at 5.915 GHz is remarked).

On the other hand, Fig. 14 (Fig. 15) shows the antenna radiation pattern at the 2.37 GHz (5.98 GHz) frequency band. From Fig. 14 (Fig. 15), it is observed an antenna gain of 7.16 dBi (9.54 dBi) at the 2.37 GHz (5.98 GHz) frequency band. These values are excellent for low range mobile applications such as wireless local and personal area networks.

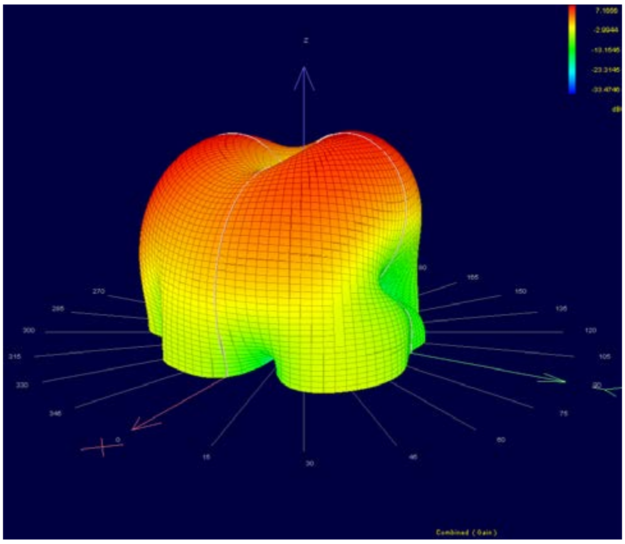

Fig. 14. Experimental radiation pattern (directivity) at *f* = 2.37 GHz.

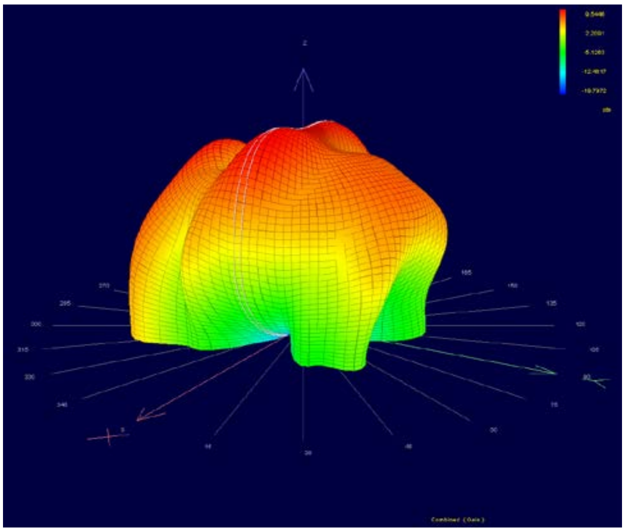

Fig. 15. Experimental radiation pattern (directivity) at *f* = 5.98 GHz.

4 Conclusion

In this paper, a fractal-based biconical patch antenna with defected ground structure for low range wireless communications applications is proposed and studied. To achieve a multi-band operation (i.e., 2.4 GHz and 5.2 GHz unlicensed bands), the initial design of the proposed antenna is based on the Sierpinsky gasket (triangular) fractal geometry. In the patch of the biconical antenna, a defect based on the Sierpinsky fractal geometry was introduced to achieve a multi-band behavior. Also, a ground plane defect based on the circular split ring resonator technique was introduced to improve return losses at the first two resonant frequencies; consequently a low profile antenna system was obtained. Experimental results showed that the designed antenna has two resonant frequencies in the ISM bands: 2.37 GHz and 5.98 GHz with return losses of -23.6 dB and -33.6 dB and coupling bandwidth percentages of 10.7 % and 9 %, respectively. Also, the experimental antenna prototype presents gains of 7.16 dBi and 9.54 dBi at 2.37 GHz and 5.98 GHz, respectively. Thus, the proposed antenna is an excellent choice for low range wireless applications.

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