High Directivity Broadband Hexagonal Fractal Ring Antenna with Modified Ground

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ABSTRACT

A highly directive fractal antenna with a novel shape is proposed in this paper. Finite Element Method based simulations were carried out on the first three iterations of a hexagonal fractal ring and the performance was measured in terms of the resonant behavior, directivity, radiation efficiency, current distribution, and radiation pattern. The second iteration fractal antenna radiates well along the broadside direction at the fundamental mode of operation. The ground plane was modified to improve the performance further. The antenna, etched on an FR4 substrate, has a directivity of 11.8 dB along the broadside direction with multi-frequency broadband performance over the frequency range of 3.12–7.46 GHz. Therefore, the proposed fractal antenna can be used for Wireless LAN applications. The antenna was fabricated and measured in order to validate the results.

Keywords: Directional Antennas, Wireless LAN, Finite Element Analysis

1. INTRODUCTION

Antenna size and performance have become decisive factors in the field of wireless communication systems due to the exponential demand for small multifunctional antennas. Antenna designers have taken immense efforts to achieve desirable characteristics in antennas while keeping a compact profile by using different performance improvement techniques. Hence, the design of fractal antennas is a blooming field of interest in antenna engineering. Fractal antennas are based on geometric shapes that repeat themselves over a variety of scaled sizes keeping the shape looking the same viewed at different scales. B. Mandelbrot first theorized fractal geometry to characterize geometries that are not defined by the standard Euclidean geometry [1].

Fractal antennas could perform better than the standard microstrip antennas with Euclidean shapes (like square, rectangular, circular etc.) due to their multi-frequency operability, high gain/directivity, improved bandwidth and smaller physical dimensions [2]. Examples of small fractal antennas with high directivity based on the Sierpinski bowtie [3], Sierpinski Gasket [4], Sierpinski bow-tie [5], Sierpinski carpet [6], Koch Island [7], Koch Snowflake [8], fork [9] and Mandelbrot [10] etc. can be found in literature. High-directivity antennas based on different techniques such as superstrates [11], zero-index metamaterial [12], electromagnetic band gap resonator [13–14], modified Peano space-filling curve [15], photonic band-gap materials [16] and Fabry-Perot resonators [17] are also reported in the literature. However, the antennas based on the aforementioned techniques have a high profile and could be bulky. In contrast, fractal antennas are compact as the fractal shape is etched on one side of a thin substrate while the ground plane is etched on the other side. Even though single element high directivity microstrip antennas designed by using optimization techniques are compact, limited work has been reported due to the complex design methodology [18–19]. In this sense, fractal antennas are good candidates for designing high directivity antennas on a small substrate.

This paper proposes a compact hexagonal fractal geometry which generates a highly directive radiation pattern over a broadband. Bandwidth enhancement of fractals with high gain has been achieved by techniques consisting of a superstrate [20] or higher iteration fractal shapes [21–24]. Only a limited number of planar antennas achieved both the aforementioned objectives [22–24]. Obtaining a directivity of 12.7 dB with 12% impedance bandwidth at the central frequency of the operating band, 3.52 GHz by using a Koch fractal boundary is presented in [22]. A fern-leaf inspired fractal planar antipodal Vivaldi antenna exhibits a fractional bandwidth of 175% with a high directive gain of 10 dBi [24]. In this sense, design of a broadband high directivity antenna with a planar compact configuration is challenging.

After studying different approaches, a novel fractal

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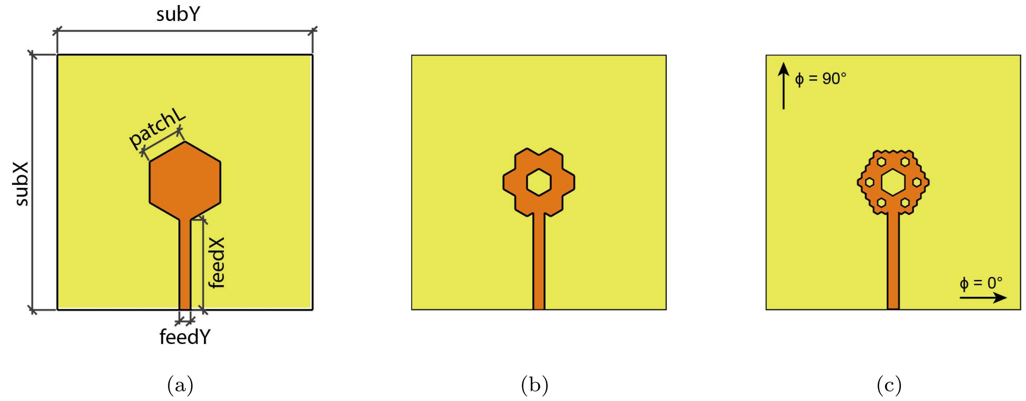


Fig.1: *Antenna geometry; (a) generator patch, (b) first iteration, and (c) second iteration.*

Table 1: *Dimensions of the hexagonal fractal ring antenna.*

Parameter	subY	subX	notchY	gndX	slotY	slotX	patchL	feedX	feedY
Dimension (mm)	50	50	6.25	42.67	4.2	8	8	19	2.2

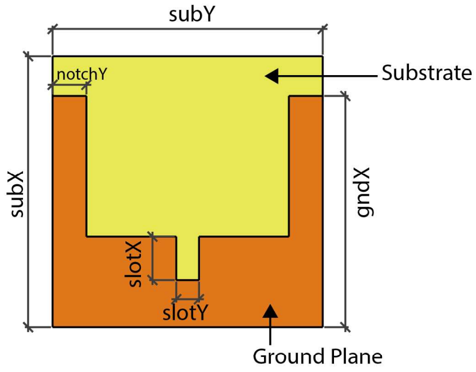


Fig.2: *Modification of the Ground Plane.*

shape with a ring of hexagonal slots on a hexagonal patch etched on a thin substrate is proposed in this paper. The ground plane was modified to improve antenna performance further. Section 2 presents the antenna specifications and the design methodology. In Section 3, results are discussed, and a comparison is made between different antenna configurations with the same patch area.

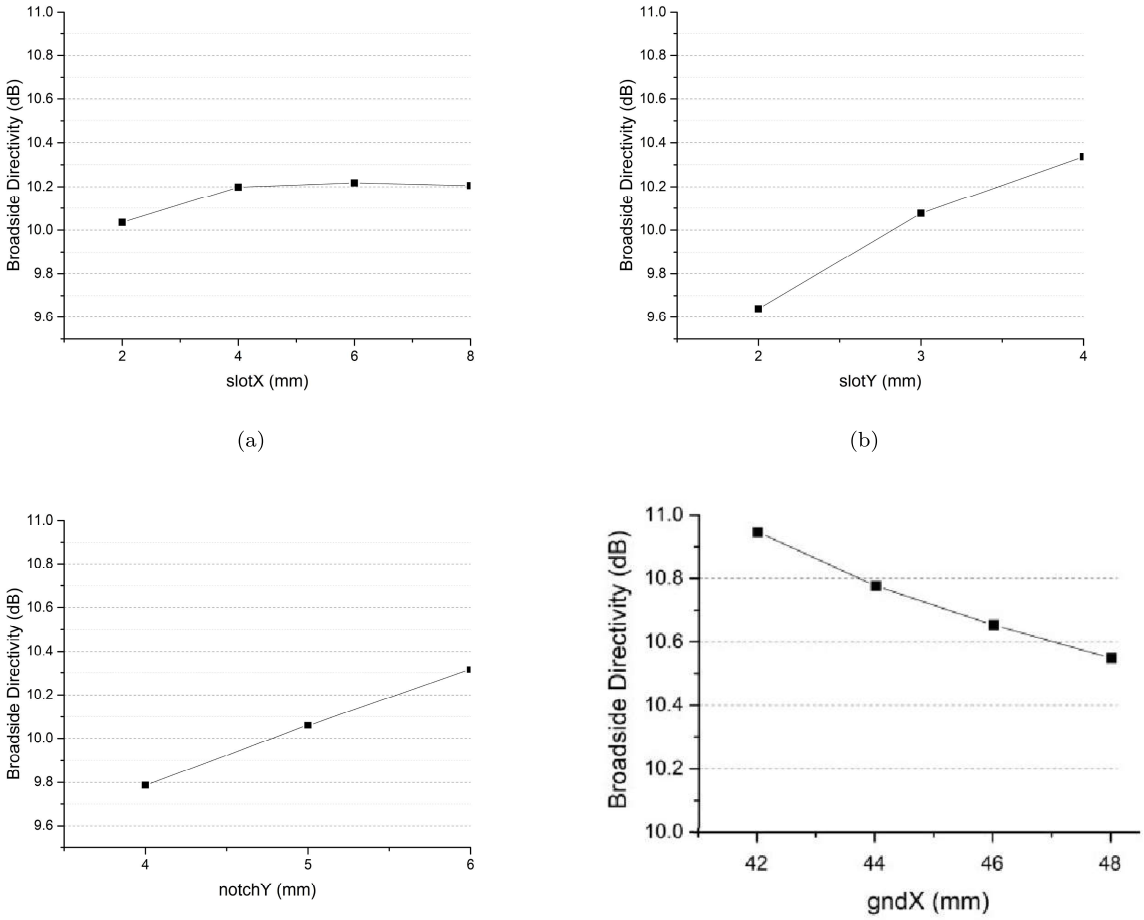
2. DESIGN METHODOLOGY

The research objective is to design a compact antenna with an enhanced bandwidth and a maximized broadside radiation. A regular hexagonal shape was taken as the initial generator and the first two fractal iterations were designed on FR4 substrate having a thickness of 1.6 mm, a relative permittivity (ε_r) of 4.4 and a dielectric loss tangent (δ) of 0.02. The substrate size was set to 50 mm × 50 mm.

The antennas were modeled using Finite Element Method (FEM) based Ansoft High Frequency Structure Simulator (HFSS) 13.0 simulation tool. The patch was fed by a 50 Ω microstrip line and the driven terminal solution type was used along with a lumped port at the edge of the feed line for excitation. Length of the feed line from the radiating patch to the edge of the substrate (feedX) is 19 mm and width of the feed line (feedY) is 2.2 mm.

The fractal geometries of the three candidate fractal structures are illustrated in Fig. 1. Side-length of the generator hexagon was set to 8 mm after several trials. In order to obtain the 1st iterated design, a smaller hexagon with 1/3 of the size of the generator was removed from the centre. Further, six more similar hexagonal-shaped slots were removed from the generator such that the centre of each hexagon lies at the corners of the generator hexagon. The smaller hexagons, each of a side length 1/9th of that of the generator were removed from the 1st iterated structure to obtain the 2nd iterated design.

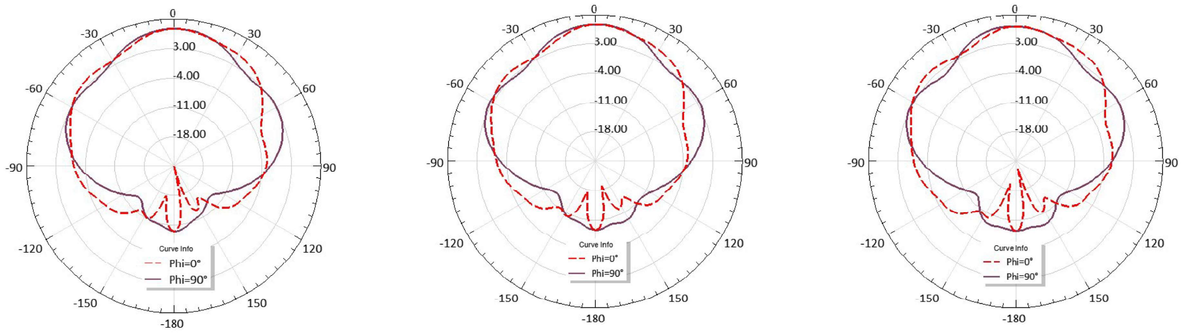
First the antennas were designed and simulated on a full ground plane with the size of 50 mm × 50 mm. Some slots were added to the ground plane in order to improve the performance (Fig. 2). Derivative analysis method was used to optimize the slots on the ground plane. Firstly, a small slot was proposed on the ground plane. The length of the slot (slotX) was changed in the range of 2 mm–8 mm and the best directivity could be obtained at 8 mm (Fig. 3(a)). Then its width (slotY) was changed in the range of 2 mm–4 mm, while keeping slotX = 8 mm (Fig. 3(b)). The dimension slotY was refined further around 4 mm and the best performance could be obtained at 4.2 mm. Secondly, a big slot was also proposed keeping two narrow arms at the edge of the substrate parallel to the feed line. The best value for notchY was searched in the range of 4 mm–6 mm (Fig. 3(c)) and it was fur-



(a) (b)

(c) (d)

Fig.3: *Parameter study of ground plane dimensions; (a) slotX, (b) slotY, (c) notchY, and (d) gndX.*



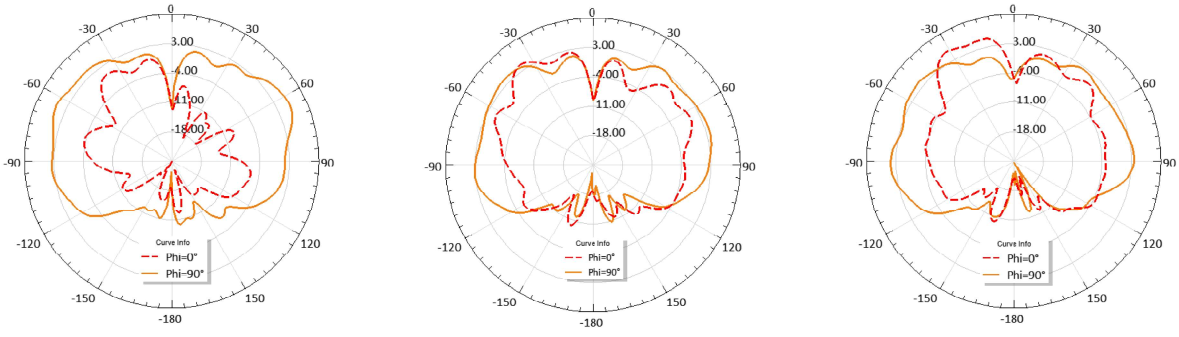
(a) (b) (c)

Fig.4: *Radiation patterns of antennas with full ground plane at 5.8 GHz at Phi = 0° and Phi = 90° planes; (a) generator patch, (b) iteration 1, and (c) iteration 2.*

ther refined around 6 mm. Length of the narrow arms (gndX) was also optimized in the range of 42–48 mm (Fig. 3(d)). The best directivity could be achieved when gndX = 42 mm and it was further refined to improve the directivity. The dimensions of the hexagonal fractal ring antenna are given in Table 1.

3. RESULTS AND DISCUSSION

The hexagonal fractal ring antennas with a full ground resonate around 5.8 GHz and 9.6 GHz at the fundamental mode and the second order mode respectively (Fig. 4). The broadside directivity of the generator patch, iteration 1 fractal and iteration 2 fractal at 5.8 GHz are 7.7 dB, 7.61 dB and 7.17 dB respec-



(a) (b) (c)

Fig.5: *Radiation patterns of antennas with full ground plane at 9.6 GHz at Phi = 0° and Phi = 90° planes; (a) generator patch, (b) iteration 1, and (c) iteration 2.*

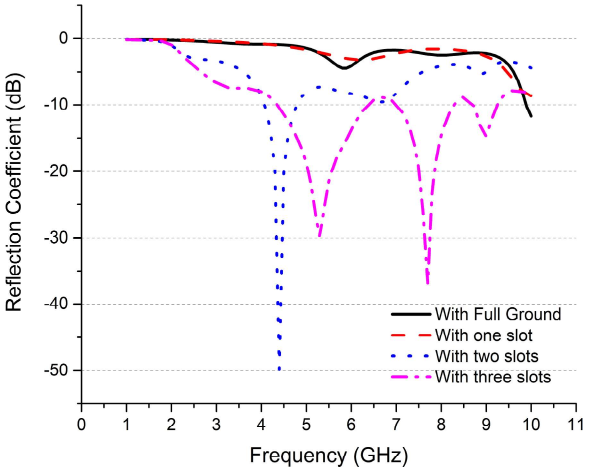


Fig.6: *S_{11} plot.*

tively. As per the simulation results, the antennas radiate along the broadside direction with a moderate gain at the fundamental mode of operation (Fig. 5), but the bandwidth is inadequate for wireless communication applications. In contrast, they demonstrate a better resonance at the second order mode around 9.6 GHz, but the gain is low (Fig. 5). Therefore, only the fundamental mode of operation was considered to modify the ground plane.

Resonant behaviour of the iteration 2 antennas were analysed to understand how the addition of slots on the ground plane improve the bandwidth gradually. With no or one slots, the iteration 2 antenna does not show any $S_{11} < -10$ dB bandwidth. When two slots were etched, the antenna exhibits a narrow bandwidth around 4.5 GHz and 6.5 GHz. With one more slot, the bandwidth could be enhanced (Fig. 6).

Hence, the 2nd iteration fractal ring resonates with $S_{11} < -10$ dB in the frequency range of 3.6–5.5 GHz and 6.2–7.4 GHz with a broadside directivity of 11.3 dB at 5.2 GHz after modifying the ground plane (Fig. 7). The peak directivity of the proposed antenna (with modified ground) is 4.1 dB higher than the traditional antenna (without modified ground).

The hexagonal fractal ring with modified ground plane has been fabricated by using a PCB prototyping machine (Fig. 8). Its resonant behavior and the radiation cuts were measured by using an Agilent N5242a vector network analyzer and an anechoic chamber respectively (Fig. 9). The measured frequency response exhibits a slight shift compared to the simulated results. That may have occurred due to the tolerances in the dielectric permittivity, loss tangent and thickness of the FR4 sheet.

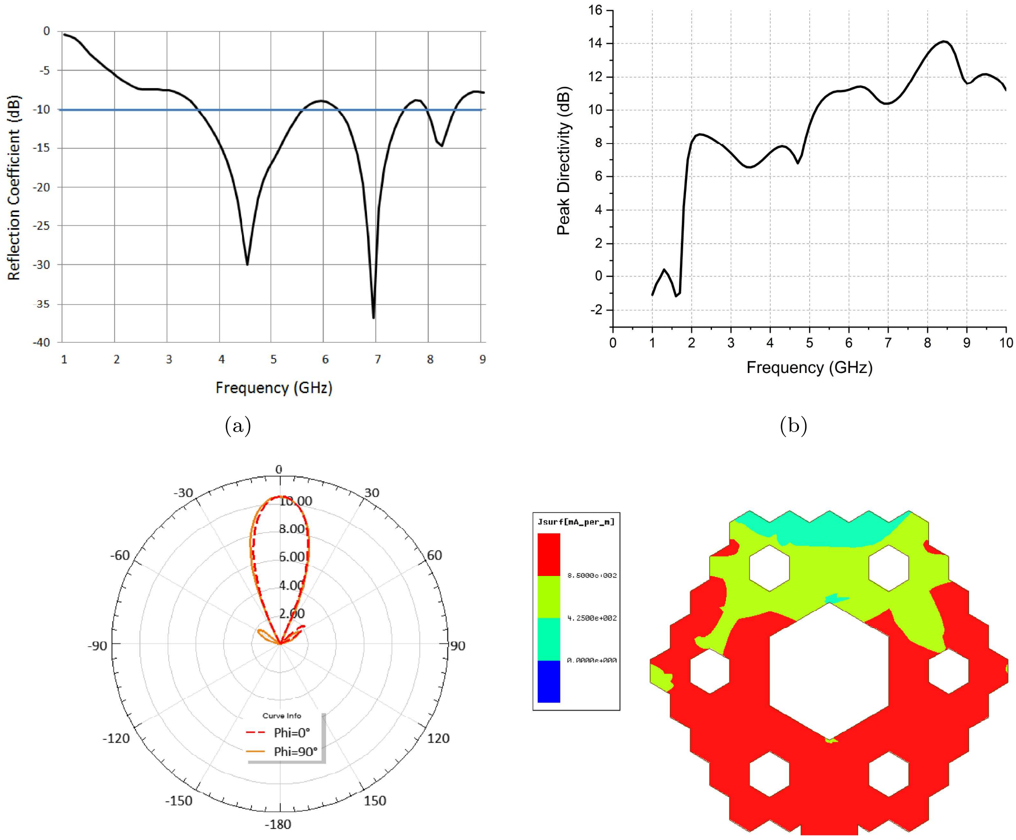
The fabricated antenna is broadband demonstrating a good impedance matching in the entire band from 3.12–7.46 GHz. Therefore, it is suitable for the LTE higher band in the range of 3.4–3.8 GHz, U-NII low (5.15–5.35 GHz) for WLAN operation, U-NII mid (5.47–5.725 GHz) for WiFi operation and U-NII high (5.725–5.875 GHz) for WLAN operations. The measured normalized radiation patterns at $\phi = 0°$ and $\phi = 90°$ are shown in Fig. 9(b). The peak measured directivity is 11.8 dB.

Further, the performance of the hexagonal fractal ring has been compared with a rectangular MPA that utilizes the same patch area etched on the same substrate. The antenna resonates at 7.1 GHz with a moderate directivity of 6.7 dB along the broadside direction. The results prove the miniature performance of the fractal antennas. In order to make this antenna resonate around 5.2 GHz, a larger patch area of 17.56 mm × 13.2 mm is required. Even with a larger rectangular patch, high directivity performance can't be obtained.

Table 2 summarizes the performance of the simulated and fabricated designs. According to the results, fractal geometry miniaturizes the antenna, while maximizing the directivity and enhancing the bandwidth.

4. CONCLUSION

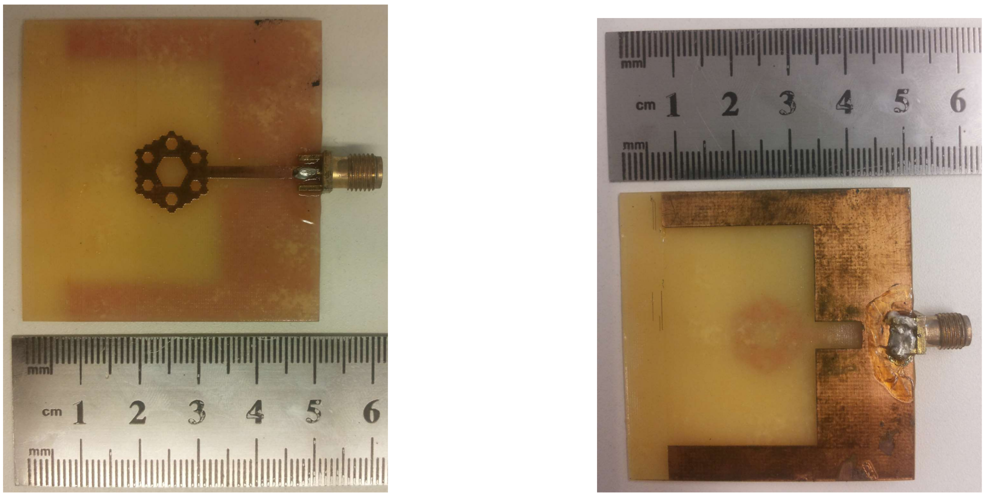
A multi-frequency broadband miniature antenna with high directivity has been developed by using a novel fractal geometry. The maximum directivity of the fabricated antenna is 11.8 dB along the broadside



(a) (b)

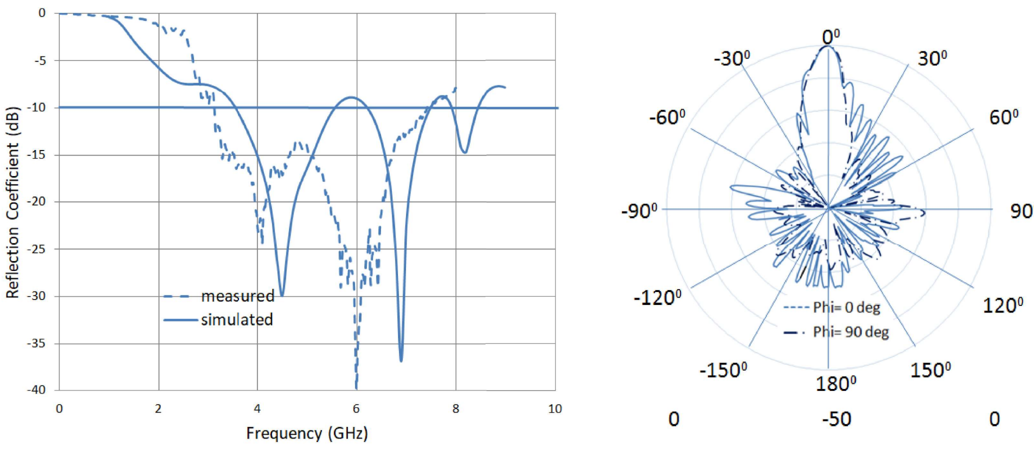
(c) (d)

Fig.7: *Performance of the hexagonal fractal ring antenna with modified ground plane; (a) S_{11} plot, (b) variation of broadside directivity, (c) radiation pattern on Phi = 0° and Phi = 90° planes at 5.2 GHz, and (d) current distribution at 5.2 GHz.*



(a) (b)

Fig.8: *Fabricated antenna; (a) fractal patch and (b) ground plane.*



(a)

(b)

Fig. 9: *Performance of the fabricated antenna; (a) S_{11} plot, (b) radiation pattern on Phi = 0° and Phi = 90° planes at 5.2 GHz.*

Table 2: *Summary of results.*

Design	Resonant frequency (GHz)	Bandwidth (GHz)	Directivity (dB)
Simulated rectangular patch with the same footprint of the fractal	7.1	0.1	6.78
Simulated iteration 2 fractal with full ground	5.8 9.6	0 0.5	7.17 5.35
Simulated iteration 2 fractal with modified ground	5.2	3.1	11.32
Fabricated antenna	5.2	5.5	11.81

direction, with a fractional bandwidth of 116%. The proposed planar antenna with the modified ground plane is a promising replacement to horn or parabolic antenna if it is used in an array.

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