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Design and Analysis of a Novel Miniaturized Microstrip Fractal Antenna for WLAN/WiMAX Applications

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Abstract: This paper is a new comparative study via numerical calculations and experimental measurements of various designs of fractal antennas. The geometry of the antennas dual ‑ broadband (2.5/5.77 GHz and 2.4/6.18 GHz) for WLAN/ WiMAX applications is inspired by the Sierpinski carpet and the Minkowski. The simulated and measured results show a good agreement over the bandwidth. We also performed a comparison with current comparable antenna designs, demonstrating the superiority of the proposed antenna regarding applicability in telecommunication technology.

Keywords: Fractal antennas, Miniaturization, Dual-band.

1 Introduction

An antenna is a conducting element that transforms electric power into the energy of electromagnetic and opposite radiation. The same antenna can be used to receive or emit if it is fed while running. In their third and fourth generation, the systems of telecommunications require in a deterministic way, the exploitation of intelligent antennas and multiband.

According to B Mandelbrot the objects fractals (1975) are abstract objects which cannot be physically implemented. It is an object of a geometric figure or a natural object which presents the same irregularity at all the scales and in all its parts [1]. One of the significant advantages of the antenna fractal is that we obtain more than one group of resonance. The concept fractal can be used to reduce the size of the antenna, such as the dipole of Koch, the monopoly of Koch, the Koch loop, and the Minkowski loop [2 – 14]. That can be used to reach several bandwidths or to increase the bandwidth of each band because of the auto-similarity in the geometry, like the dipole of Sierpinski and dipole of tree fractal [2 – 14].

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Our work consists of being studied and the realization of novel fractal antennas; we highlighted the advantage of the use of fractals in the field of telecommunications. The results obtained are very encouraging and show the interest of these types of antennas in the various multiband fields.

A full-wave simulation was performed by the CST Microwave Studio software according to a second iteration, the three designs of fractal antennas considered from antenna plates conducting square, indicated like a basic antenna. This is a design of multiband antennas, based on a fractal geometry, which has high radiation efficiency and high gain. We have built a prototype and performed simulations, obtaining good coincidence with measurements, regarding impedance, gain, return loss, the far-field radiation pattern, and polarization characteristics.

2 The Antenna Designs

Initially, the portion of experimental realized antenna is shown in Fig. 1. The antenna is designed by a square (copper with thickness of 0.03 mm) named patch iteration 0, with length of 27 mm, established on a square substrate FR4 with thickness of 1.53 mm and length of 60 mm, posed on a metallic layer (copper also thickness of 0.03mm) named ground plane with a length of 60 mm.

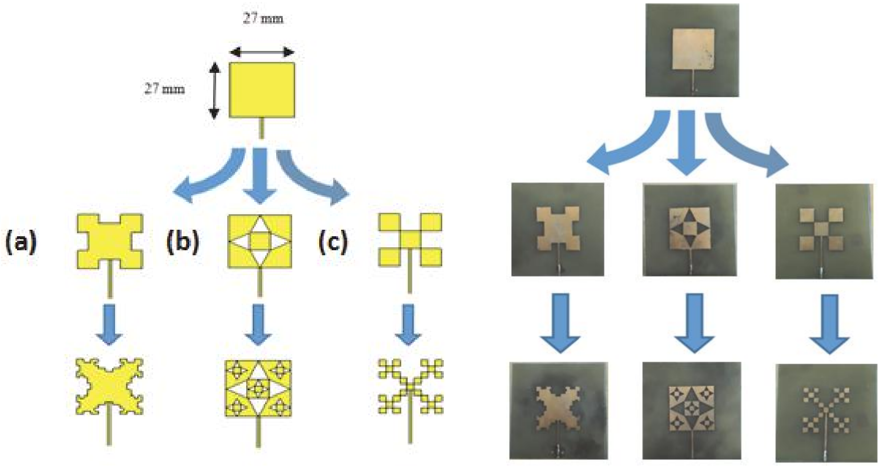
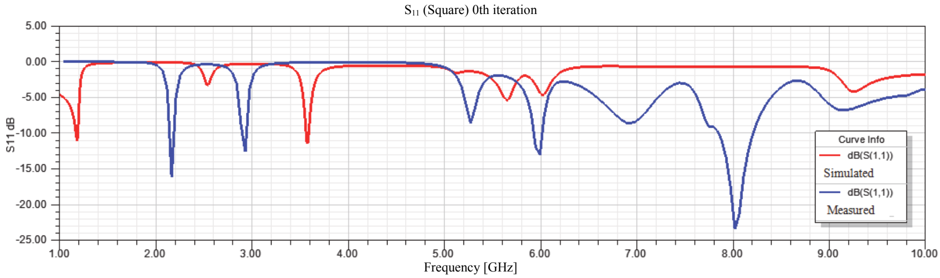


Fig. 1 – *Schematic of the different fractal antennas:* (a) *Rectangular Minkowski;* (b) *Triangular Sierpinski carpet;* (c) *Square Minkowski.*

3 Results and Discussion

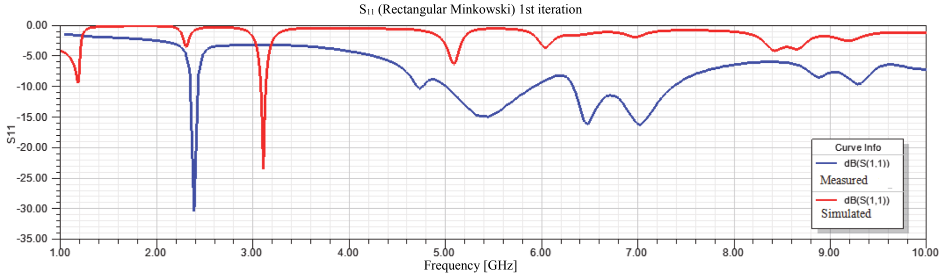
The fabricated fractal antennas are shown in Fig. 1. The comparison of the numerical calculations and experimental measurements are given in Figs. 2 – 9.

Fig. 2 – *Photo of fabricated antenna on the test setup.*



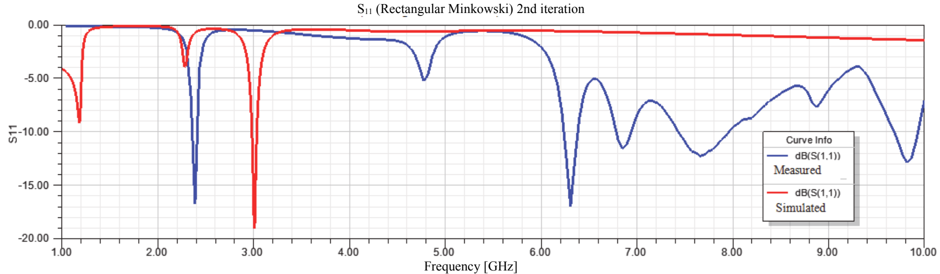
S_{11} (Square) 0th iteration

Fig. 3 – *Comparison of* S11 (*Square* 0th *iteration*)
for simulation and measurement results.



S_{11} (Rectangular Minkowski) 1st iteration

Fig. 4 – *Comparison of Return Loss* (*Rectangular Minkowski* 1st *iteration*)
for simulation and measurement results.



S_{11} (Rectangular Minkowski) 2nd iteration

Fig. 5 – *Comparison of Return Loss* (*Rectangular Minkowski* 2nd *iteration*)
for simulation and measurement results.

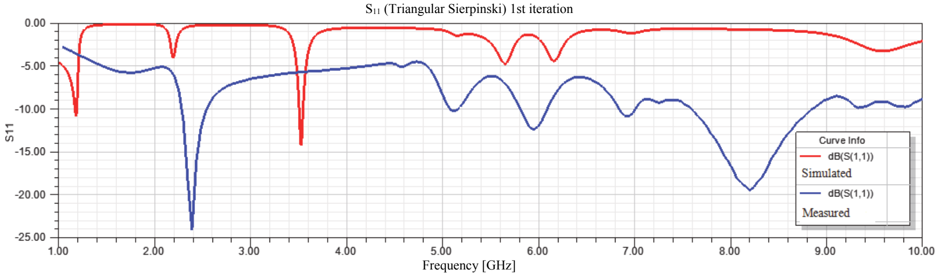


Fig. 6 – *Comparison of Return Loss* (*Triangular Sierpinski* 1st *iteration) for simulation and measurement results.*

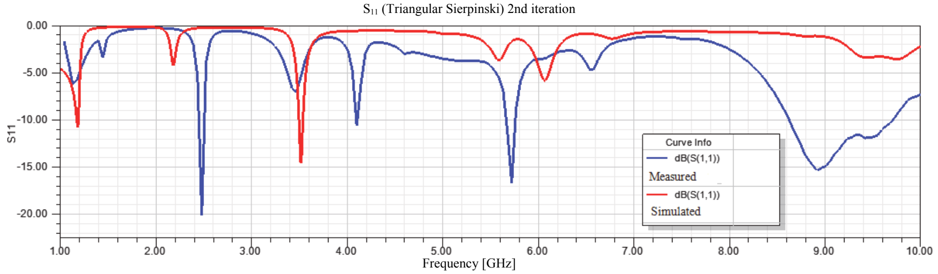


Fig. 7 – *Comparison of Return Loss* (*Triangular Sierpinski* 2nd *iteration*) *for simulation and measurement results.*

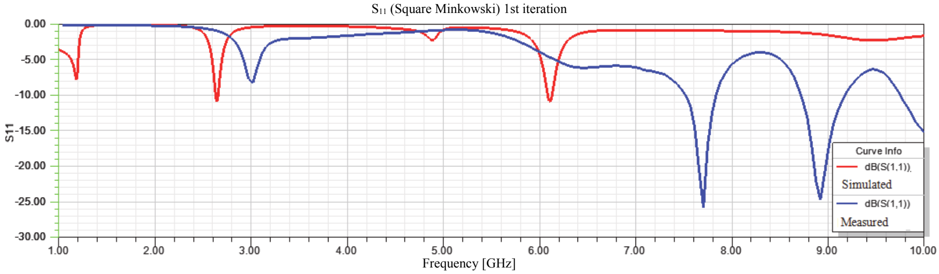


Fig. 8 – *Comparison of Return Loss* (*Square Minkowski* 1st *iteration*) *for simulation and measurement results.*

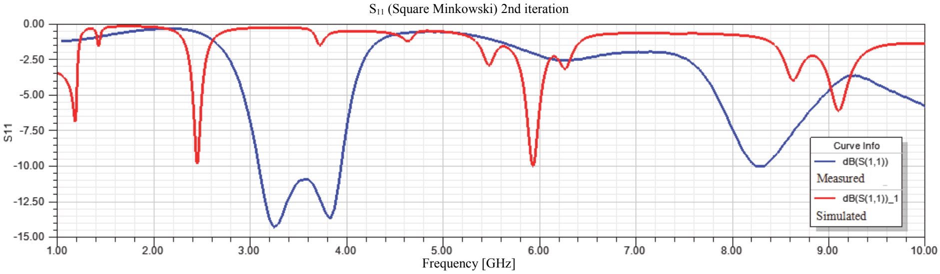


Fig. 9 – *Comparison of Return Loss* (*Square Minkowski* 2nd *iteration*) *for simulation and measurement results.*

As shown in Fig. 4, the Rectangular Minkowski antenna (1st iteration) displays that return loss is below –10 dB at 2.4 GHz. Fig. 5 shows, the Rectangular Minkowski antenna (2nd iteration) displays that return loss is below –10 dB at 2.4 GHz/6.18 GHz.

Fig. 6 shows that, the Triangular Sierpinski antenna (1st iteration) displays that return loss is below –10 dB at 2.4 GHz. In Fig. 7, the Triangular Sierpinski antenna (2nd iteration) displays that return loss is below –10 dB at 2.5 GHz/ 5.77 GHz.

From the Fig. 8, the Square Minkowski antenna (1st iteration) displays that return loss is below –10 dB at 7.77 GHz/8.9 GHz. Fig. 9 shows, the Square Minkowski antenna (2nd iteration) displays that return loss is below –10 dB at 3.2 GHz.

The following figures correspond to the comparisons between the various shapes of antennas in the two iterations.

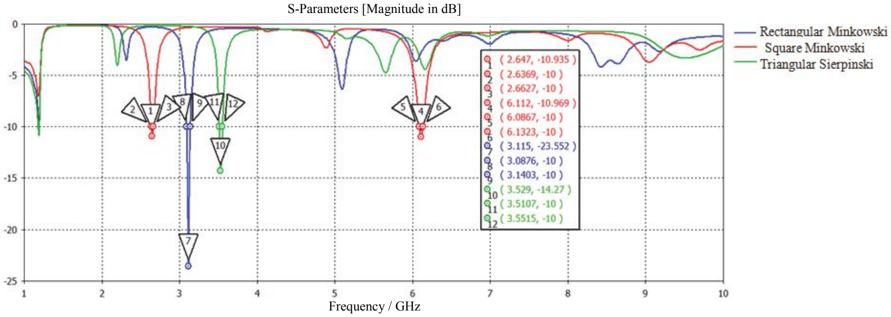


Fig. 10 – *Comparison of* S_{11} (1st *iteration) for: Rectangular Minkowski, Triangular Sierpinski carpet, and Square Minkowski.*

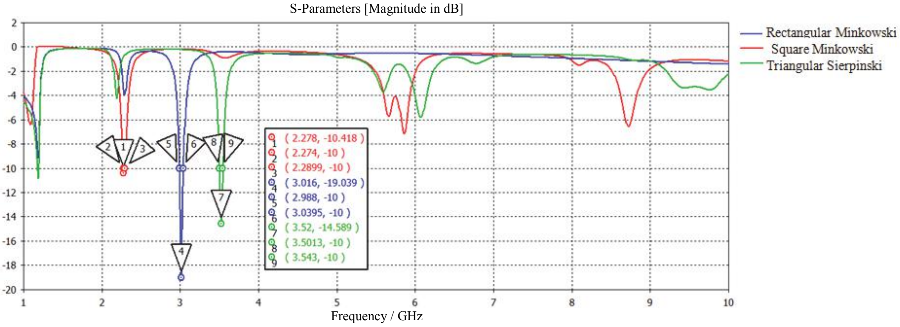


Fig. 11 – *Comparison of* S_{11} (2nd *iteration) for: Rectangular Minkowski, Triangular Sierpinski carpet, and Square Minkowski.*

Table 1

The resonance frequency and quality factor for 1st iteration.

Antennas	Rectangular Minkowski	Triangular Sierpinski	Square Minkowski
Frequency measured	2.4 [GHz]	2.4 [GHz]	7.77 [GHz] / 8.9 [GHz]
Frequency simulated	3.12 [GHz]	3.53[GHz]	2.27 [GHz] /2.64 [GHz]
Quality factor Q	59.52	86.50	103.09/134.05

Table 2

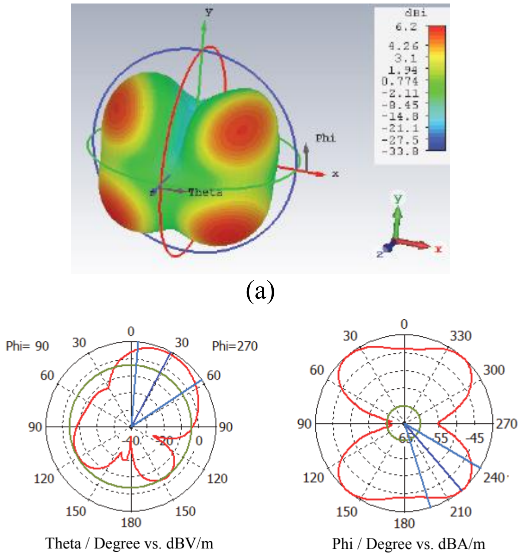
The resonance frequency and quality factor for 2nd iteration.

Antennas	Rectangular Minkowski	Triangular Sierpinski	Square Minkowski
Frequency measured	2.4 / 6.18 [GHz]	2.5 / 5.77 [GHz]	3.2[GHz]
Frequency simulated	3.02 [GHz]	3.52 [GHz]	2.27 [GHz]
Quality factor Q	58.82	84.46	144.93

According to **Table 2** and **Table 1**: for the Square Minkowski antenna, we notice that the quality factor augments according to the increase in the iteration 1st and 2nd. Consequently, we can use this antenna in selective applications such as the fields biomedical, and space field (aeronautics); where the precision is required. In the case of the Triangular Sierpinski and Rectangular Minkowski antennas, the quality factor according to each iteration undergoes a reduction. It thus results from it that this antenna is not convenient for selective application.

For the second-order of the novel antenna (Triangular Sierpinski), the corresponding 3D radiation patterns with E and H plane patterns are set in Figs. 12b, 13b and 14b, we can find that the antennas radiate mainly in the Z direction with very good radiation patterns. From the E-plane (Y-Z plane) with $\Phi = 90°$ for the second order antenna, we find that the antenna is radiating exactly in the Z direction with an angular width of 49.3°, 78.6°, at 2.5 GHz, and 5.77 GHz respectively.

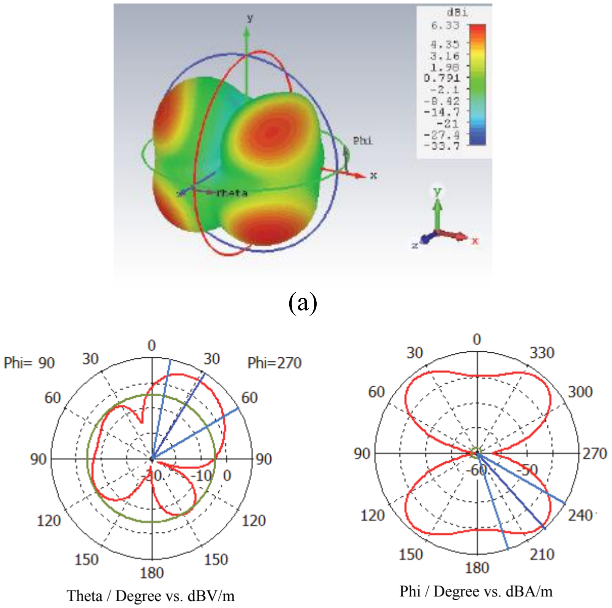
From the 3D pattern and the H-plane (X-Y plane) with $\theta = 90°$ for, we can see that the Horizontal radiation is mainly. Fig. 15 shows the corresponding VSWR for the antennas, it can be easily seen that the antennas have a very good impedance matching with minimal reflection loss.



(a)

(b)

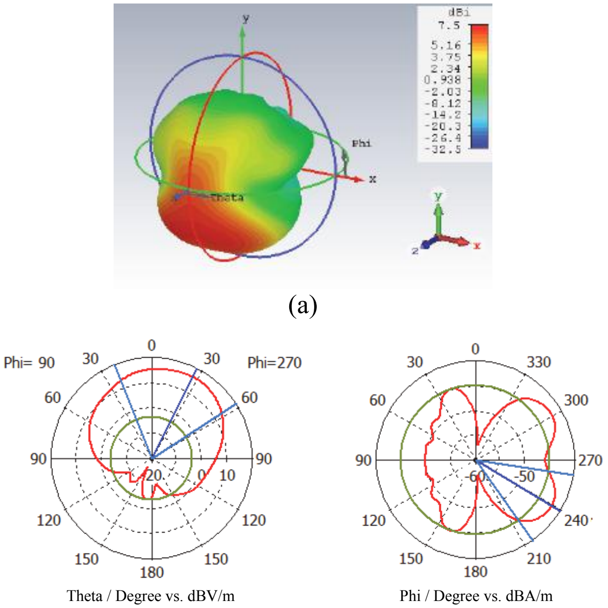
Fig. 12 – (a) *3D Radiation Pattern at* 2.5 THz; (b) *E Plane* (Φ = 90°) *and H Plane* (θ = 90°) *pattern at* 2.5 THz (*First order*).



(a)

(b)

Fig. 13 – (a) *3D Radiation Pattern at* 2.5 THz; (b) *E Plane* (Φ = 90°) *and H Plane* (θ = 90°) *pattern at* 2.5 THz (*Second order*).



(a)

(b)

Fig. 14 – (a) *3D Radiation Pattern at* 5.77 THz; (b) *E Plane* (*Φ = 90°*) *and H Plane* (θ = 90°) *pattern at* 5.77 THz (*Second order).*

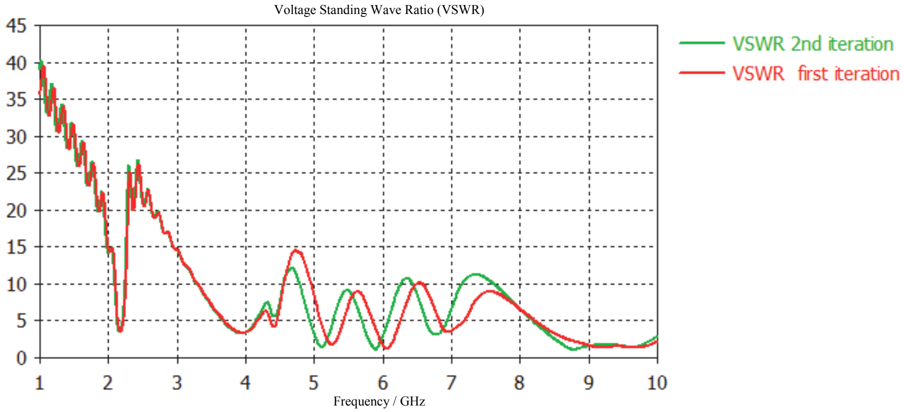


Fig. 15 – *VSWR for substrate thickness of* 1.53 mm.

The diagram of radiation evolves with the frequency. The more the frequency increases and the more the opening of the principal lobe small. Comparing the performance of our antennas with another antenna, reported in [10, 11] in terms of antenna size is set in **Table 3**.

Table 3
Comparison between the antennas

Ref	Antenna size [mm^2]	Total area [mm^2]	Frequency bands [GHz]	Targeted application	Number of Frequency bands
[10]	75×75	5625	2.4/5.2	WLAN/ WiMAX	Dual-band
[11]	48×38	2000	2.6 /5.0/ 6.2 / 7.1/ 8.5	WLAN/ WiMAX	Five-band
Novel Triangular Sierpinski	27×27	729	2.5 / 5.77	WLAN/ WiMAX	Dual-band
Novel Rectangular Minkowski	27×27	729	2.4/6.18	WLAN/ WiMAX	Dual-band

4 Conclusion

In conclusion, we have studied both theoretically and experimentally of novel Microstrip patch fractal antennas (Novel Rectangular Minkowski, and novel Triangular Sierpinski). The dimensions of proposed geometry are 27mm×27mm×1.6mm which is small and multiband in behavior. These antennas have great advantages over the other antennas, where the dimension is the smallest of the antennas in [10, 11]. Through the results, these antennas work well at S, C, and X bands.

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