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Design of Compact Tri-Band Fractal Antenna for RFID Readers

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ABSTRACT

In this paper, a multiband and miniature rectangular microstrip antenna is designed and analyzed for Radio Frequency Identification (RFID) reader applications. The miniaturization is achieved using fractal technique and the physical parameters of the structure as well as its ground plane are optimized using CST Microwave Studio. The total area of the final structure is 71.6 x 94 mm^2. The results show that the proposed antenna has good matching input impedance with a stable radiation pattern at 915 MHz, 2.45 GHz, and 5.8 GHz.

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1. INTRODUCTION

Radio Frequency Identification (RFID) is the wireless use of electromagnetic field to identify tagged objects and is used in a variety of fields such as access control, transport, banks, health, and logistic. An RFID system is generally composed of a reader and tags. The communication between the reader and the tags is achieved by modulated backscattering of the reader's carrier wave signal. Most RFID systems operate in either the low frequency band (30–300 kHz), the high frequency band (3–30 MHz), the ultra-high-frequency band (300 MHz–3 GHz), or the microwave band (3GHz–40 GHz) [1-5].

One major consideration for handheld and portable RFID reader applications is the compact size. Therefore, the design of miniature reader antennas is important. In this circumstance, fractal antennas are very attractive choice because of their well-known advantages of low profile, lightweight, and easy production. There are many popular fractal geometries, such as the Koch fractal, the Sierpinski fractal, the Hilbert fractal, the Minkowski, and the Square Curve fractals. The Koch fractal microstrip patches are attractive because of their small size and multiband capabilities [6-23].

In this paper, a miniature low cost microstrip multiband antenna, based on the Koch fractal structure, is proposed. Using CST-MW Studio, the antenna is designed and optimized to operate at 915 MHz, 2.45 GHz, and 5.8 GHz frequencies.

2. RESEARCH METHOD

The proposed antenna is a rectangular radiating patch fed by a 50 ohms microstrip line and uses an FR4 substrate with dielectric constant $\varepsilon_r = 4.4$, loss tangent tanδ = 0.025, thickness H = 1.60 mm, and metal thickness t = 0.035 mm.

2.1. Conventional Patch Antenna

Rectangular patch antenna has two dimensions, the length L_{patch} and width W_{patch}, which are related to the resonant frequency, to the permittivity and to the thickness of substrate by the following conventional equations discussed in [24]:

$$W_{Patch} = \frac{c}{2f\sqrt{\frac{\varepsilon_r+1}{2}}} \quad (1)$$

$$L_{Patch} = L_{eff} - 2\times\Delta L \quad (2)$$

where c is the speed of light, f is the resonant frequency and ε_r is the substrate's dielectric constant L_{eff} is the effective length given by:

$$L_{eff} = \frac{c}{2f\sqrt{\varepsilon_{eff}}} \quad (3)$$

and ΔL is the length extension, given by:

$$\Delta L = 0.412h\frac{(\varepsilon_{eff}+0.3)\times\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{eff}-0.258)\times\left(\frac{W}{h}+0.8\right)} \quad (4)$$

where, h is the height of substrate and ε_{eff} is the effective dielectric constant which can be determined by:

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2}+\frac{\varepsilon_r-1}{2}\left(1+12\left(\frac{h}{W}\right)\right)^{-\frac{1}{2}} \quad (5)$$

In this case, the dimensions of the conventional patch antenna at frequency 915MHz are: L_{patch} = 76 mm, W_{patch} = 99 mm.

2.2. Fractal and Slots Techniques

Fractals antennas use the space-filling properties to miniaturize the classic antenna elements. The line that is used to represent the fractal can meander to fill the available space. This line is electrically long but compacted into a small physical space [24].

The size reduction of the proposed microstrip antenna is achieved by etching the patch edges according to Koch curve. Multiple iterations of the Koch fractal are shown in Figure 1. To form the first iteration, the original line segment is partitioned into n=9 equal line segments of 1/5 the original length. This corresponds to a reduction of 9/5 for the first iteration, $(9/5)^2$ for the second iteration, and so on.

Three slots are inserted into the patch antenna in order to adjust the other resonances generated by the fractal technique. By this insertion the current is forced to flow through a long path around the slots and change the additional resonance around 2.45 GHz and 5.8 GHz.

Figure 2 shows the proposed patch antenna with fractal side of length L and width W, a microstrip feed line of length L_f and width W_f, and three inserted slots. The conducting ground plane with length L_{gnd}, which is placed on the other side of the substrate, is optimized to have a good gain. The width W_f of the microstrip feed line is fixed at 2.7 mm.

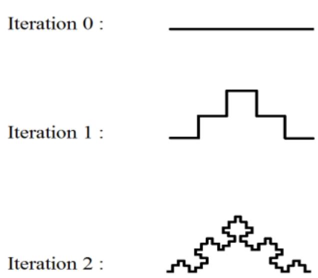
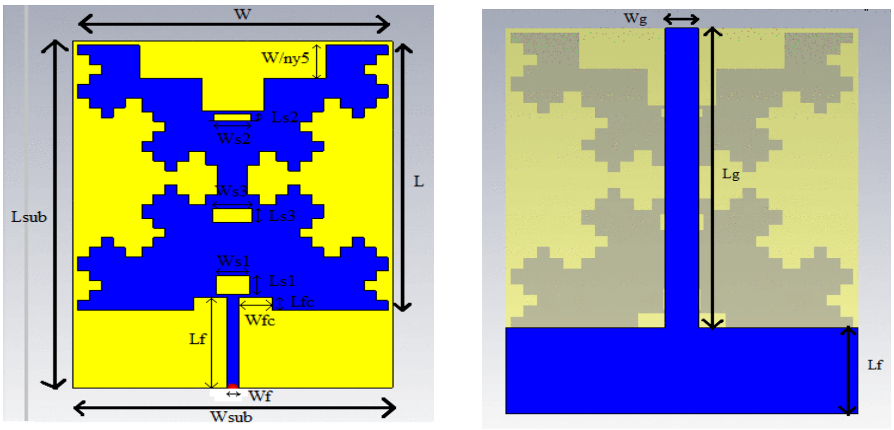


Figure 1. The three iterations of the Koch Curve



(a) (b)

Figure 2. Geometry of the proposed antenna: (a) Top Face and (b) Back Face

The dimensions of the proposed antenna are presented in Table 1.

TABLE I. Antenna Dimensions

Antenna Dimensions	Optimized Value (mm)
L	72
W	69.6
L_{sub}	94
W_{sub}	71.6
L_{s1}	5
W_{s1}	7.6
L_{s2}	2
W_{s2}	8.4
L_f	21
W_f	2.7
L_{fc}	3.6
W_{fc}	7.5
W_g	6.8
L_g	73

3. RESULTS AND ANALYSIS

3.1. Simulation Results

Using the fractal structure and the slots technique to minimize the patch size, we have proposed an antenna structure with fractal side and three slots. The influence of different parameters of the proposed antenna has been studied by using CST simulation software which is based on the Finite Integration Technique. Figure 3, shows the influence of different slots lengths values (L_{s1}, L_{s2}, L_{s3}) to adjust the resonance antenna at 915 MHz, 2.45 GHz and 5.8 GHz. Figure 4 shows the return loss S_{11} of the proposed antenna after many optimizations, which has good matching input impedance at the three resonant frequencies of 915 MHz, 2.45 GHz, and 5.8 GHz. It is also noted that a return loss of less than -10 dB was achieved for all three frequencies with a bandwidth varying from 68 MHz to 168 MHz.

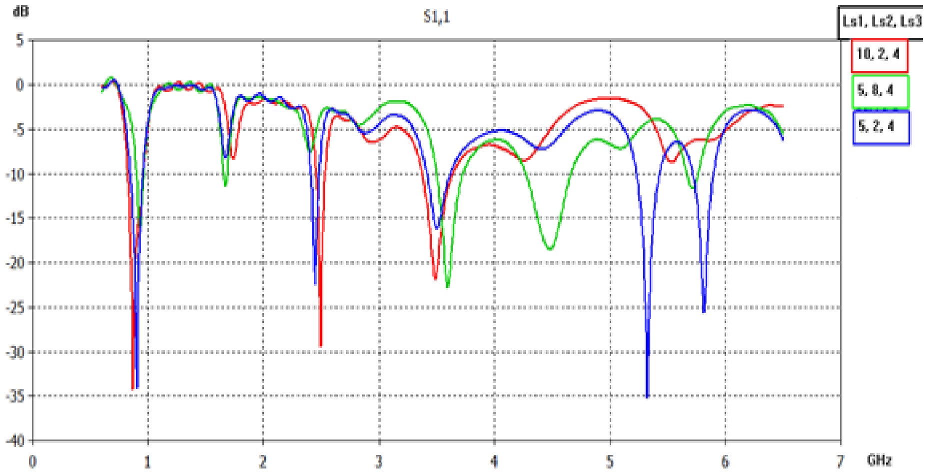


Figure 3. Return loss S_{11} of the proposed antenna with different slots length

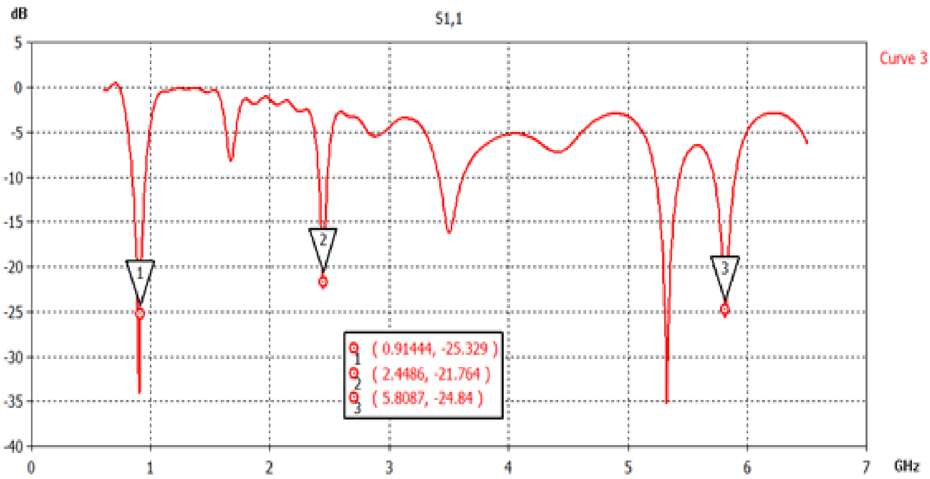
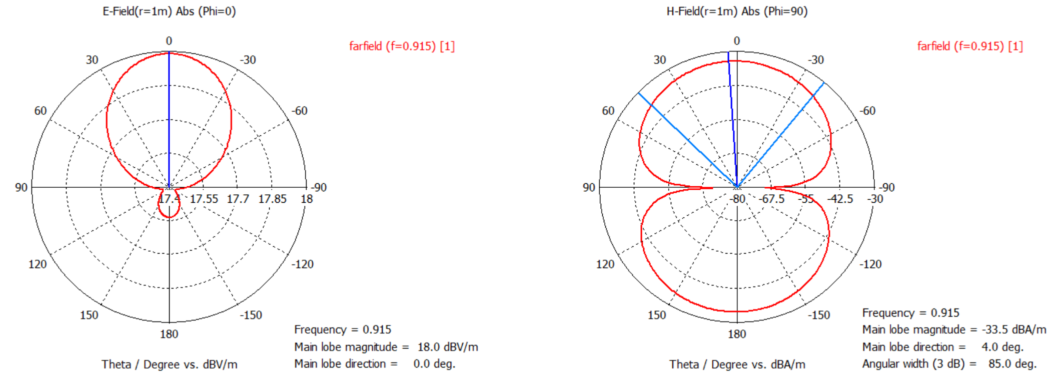


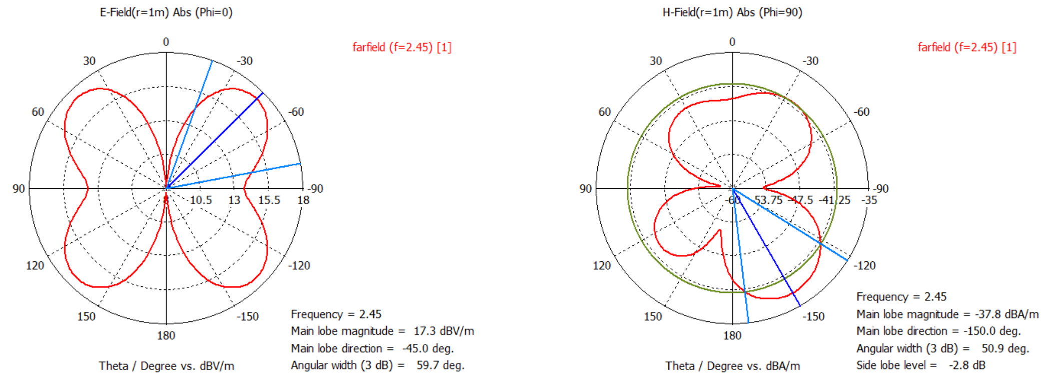
Figure 4. Return loss S_{11} of the proposed antenna

On the other hand, Figure 5 to Figure 7 show the 2D E-plane and H-plane radiation patterns at 915 MHz, 2.45 GHZ, and 5.8 GHz. The proposed antenna has an omni-directional radiation pattern for both H-plane and E-plane at 915 MHz. The angular width is 85 degrees at 915 MHz, 50.9 degrees at 2.45 GHz, and 27 degrees at 5.8 GHz. The achieved bandwidths and gain, which are summarized in Table 2, are very suitable for RFID applications.



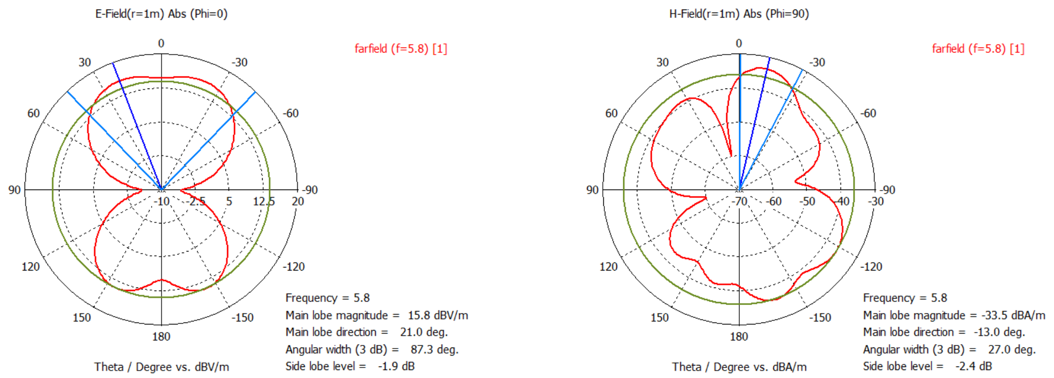
(a) (b)

Figure 5. 2D radiation pattern at 915 MHz in the: (a) E-plane, (b) H-plane



(a) (b)

Figure 6. 2D radiation pattern at 2.45 GHz in the: (a) E-plane, (b) H-plane



(a) (b)

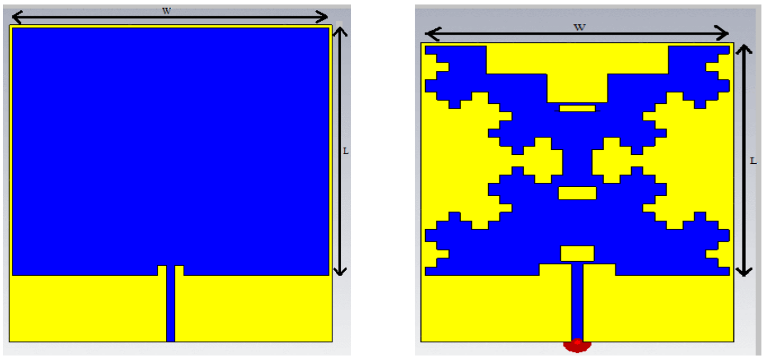
Figure 7. 2D radiation pattern at 5.8 GHz in the: (a) E-plane, (b) H-plane

Figure 8 and Table 3 compare the size of the proposed patch structure (69.6 x 72 mm^2) with the size of a traditional rectangular patch antenna (99 x 77.6 mm^2) at the same operating frequency of 915 MHz. This corresponds to 34.77% reduction in size. This antenna is also smaller than the fractal antenna proposed in

[25] which has a size of 72 x 96 mm^2 and has approximately the same FR4 substrate and operates at the same frequency bands (910 MHz, 2.4 GHz and 5.8 GHz).

Table 2. Performance of the Proposed Antenna

Frequency	S11 (dB)	Bandwidth (MHz)	Gain (dBi)	Directivity (dBi)
915 MHz	- 32.9	122	3.25	2.78
2.45 GHz	- 20.1	68	2.62	4.56
5.8 GHz	- 24.6	184	3.31	6.9



(a) (b)

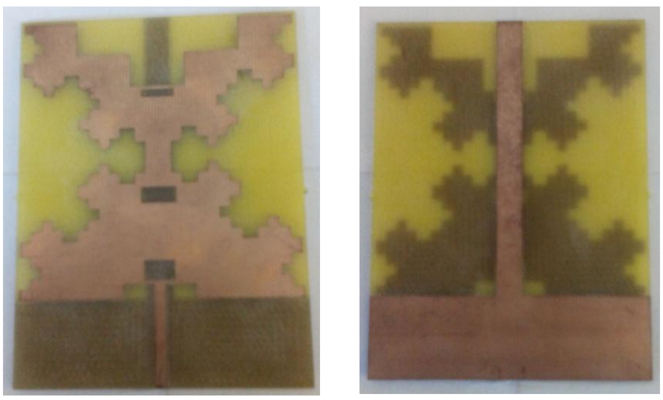
Figure 8. (a) Ordinary Patch Antenna, (b) Proposed Patch Antenna

Table 3. Patch Antennas Size Comparison

Patch Antenna 915 MHz	W (mm)	L (mm)	Patch size reduction (WxL)
Conventional Patch Antenna	99	77.6	
Proposed Patch Antenna	69.6	72	34.77 %

3.2. Experimental Results

A prototype of the antenna has been realized as shown in Figure 9.



(a) (b)

Figure 9. The antenna prototype achieved: (a) Top Face, (b) Back Face

Figure 10 compares the simulated and measured return loss of the antenna and the results, which are summarized in Table 4, show good agreement with a return loss of approximately -10 dB at the tri-band frequencies of 915 MH, 2.45 GHz, and 5.8 GHz.

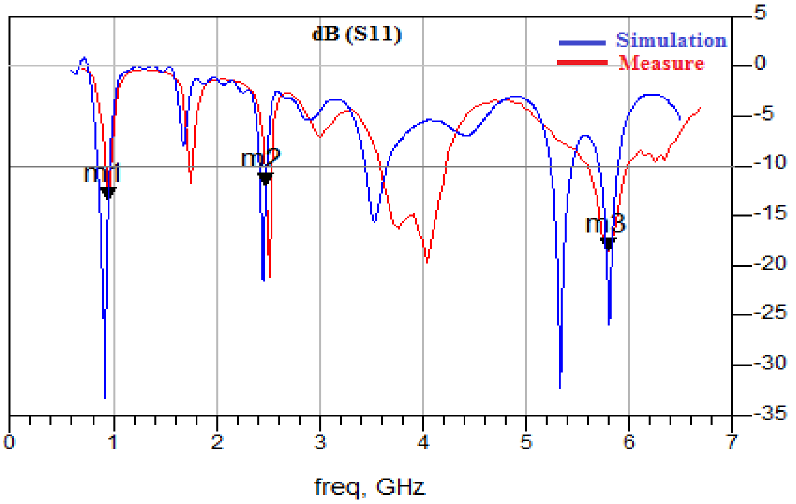


Figure 10. Measured and simulated return loss of the proposed antenna

Table 4. Resume of Simulated and Measured Results

Frequency	S11 (dB)	S11 (dB)	Bandwidth (MHz)	Bandwidth (MHz)
	Simulated	Measured	Simulated	Measured
915 MHz	- 32.9	- 11.0	122	52
2.45 GHz	- 20.1	- 10.0	68	80
5.8 GHz	- 24.6	- 18.6	184	370

4. CONCLUSION

This paper proposed a new tri-band patch antenna for RFID readers. The design was based on fractal structures and slot techniques to achieve a size reduction of 35% when compared with a conventional rectangular patch. The antenna was designed using a standard FR4 substrate and realized with conventional Printed Circuit Board (PCB) techniques. A return loss of less than -10 dB was achieved with a bandwidth varying from52 MHz to 370 MHz and a gain between 2.62 dBi and 3.31 dBi.

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Mohamed Latrach (Member of IEEE and URSI-France) received the Ph.D. degree in electronics from the University of Limoges, Limoges, France. He is currently Professor of microwave engineering in the Ecole Supérieure d'Electronique de l'Ouest (ESEO), Angers, France, where he is Head of the RF-EMC research group. His research interests include: design of hybrid & monolithic active and passive microwave circuits, metamaterials, LH materials, antennas, rectennas and their applications in wireless communications, wireless power transmission (WPT), sensors connected objects, etc. Mohamed LATRACH has supervised several PhD, postdoctoral and master/engineer students, with many publications in national and international conferences and journals. He has also holds 3 patents. He serves as a reviewer for various journals and congress. He has delivered numerous invited presentations and has participated in many projects.