Design of a Miniature Fractal Microstrip Antenna for RFID Tag

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Abstract. This paper presents the miniaturization of a microstrip antenna at 915 MHz in the ISM "Industrial Scientific and Medical" band. This microstrip antenna is designed for RFID tag system, using the fractal technique, on FR4 substrate. The simulation is performed using CST Microwave Studio. The total area of the final circuit is 66.84 x 68.015 mm^2. The validated antenna has a good matching input impedance range from 910 MHz to 920 MHz with a stable radiation pattern, a loss return of -40.67 dB, a directivity of 2.35 dB, and a gain of 1.62 dBi.

Keywords: Microstrip Antenna, RFID tag, Miniature Antenna, Fractal Koch, 915 MHz, UCODE HSL IC.

1 Introduction

The RFID (Radio Frequency Identification) system is generally composed from a reader, and one or more transponders or tags. The communication between the reader and the tag is achieved by using the electromagnetic field. RFID is practiced in a variety of applications as access control, transport, bank, health, and logistic. Most RFID systems operate in either the low frequency region (30–300 kHz), the high frequency band (3–30 MHz), the ultra-high-frequency band (300 MHz–1 GHz), or in the microwave band (1GHz–40 GHz) [1-7].

The microstrip antennas consist of three parts which are radiating element, substrate and ground, and can be designed on many structure shapes such as rectangular, elliptic, circular and triangular, etc. They are famous to be low-profile, low weight, ease of fabrication, conformable to planar and non-planar surfaces and mechanically robust. Rectangular patch is the basic and the most used microstrip antenna in wireless communication [8-10].

One major consideration for handheld and portable RFID applications is the compact size. Therefore, the design of miniature antennas tag is important. Many techniques are used to miniaturize the antenna size, as the slot technique, the fractal structure, the Defected Ground Structure (DGS), or the use of Metamaterial structure. One of the techniques used to design easily a miniature antenna is the use of the fractal structures. The fractal technique is based on the repeat of an initial radiating structure in arbitrary or regular scales, in order to obtain the operational characteristics of the antenna [11-12].

The space filling by scaled replicas of the generator, leads to antenna configurations with electrically large lengths although they have small size thus. There are many popular fractal geometries, referred in the literature, as the Koch fractal, the Sierpinski fractal, the Hilbert fractal, the Minkowski and the Square Curve fractals. The Koch fractal microstrip patches are

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commonly used in virtue of their attractive properties: they have small size, a single feeding port is enough, multi-frequency performance, satisfactory polarization properties and gain [13-21].

In this paper, a novel design of a miniature low cost microstrip antenna for RFID Tag is proposed at frequency of 915 MHz, this antenna is designed by using the fractal structure and the nested slot fed. This circuit is validated by optimization methods integrated in CST-MW Studio.

2 Tag antenna design

The proposed antenna is composed of a rectangular radiating patch with a FR4 substrate that is characterized by:

- ✓ Dielectric constant $\varepsilon r = 4.4$
- ✓ Loss tangent $\tan\delta = 0.025$
- ✓ Thickness H = 1.58 mm
- ✓ Metal thickness t= 0.035 mm

A chip named UCODE HSL IC, SL3ICS3001 (UCODE High Frequency Smart Label) from NXP Semiconductor was chosen because it can be used in small passive smart tags. The chip can operate at 867 MHz, 915 MHz, and 2450 MHz. At the 915 MHz frequency, the chip impedance is 34.5 – j 815 Ohms.

The antenna impedance must be equal to the conjugate of the chip impedance in order to have the maximum power transfer to the tag. The nested slot method is used to conjugate the impedance matching with the tag chip, the matching chart in [21], give some idea about the nested slot dimension.

The size reduction of this microstrip antenna is based on the space filling property of fractal geometries, by designing the non radiating edges of patch with the Koch curve.

As shown in the **Figure** 1, the geometry of the first iteration is made by seven copies of the basic geometry (iteration 0), so n is equal to 7. Also, the lengths of the segments making up the geometry of the first iteration, are reduced by a factor of 4, so h = 4. The reduction reached with 2 iterations of width patch is equal to $(n/h)^2 = (7/4)^2 = 3.06$.

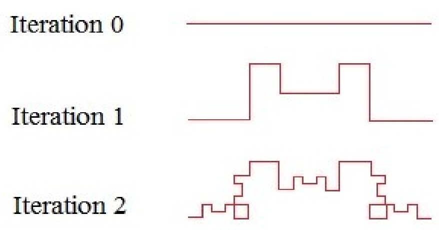

Fig. 1. The 3 iterations of the KOCH Curve.

The size reduction increases with the iteration number and the fundamental resonant frequency decreases when the number of iterations increases.

The patch antenna with the fractal side has the length L and width W. It is connected to nested slot fed. The length L and width W are related to the resonant frequency, to the permittivity and to the thickness of substrate; this length and width can be calculated, theoretically for a conventional patch antenna, by the transmission line method [5].

There is no conducting ground plane placed on the other side of the substrate. **Figure** 2 illustrates the face of the antenna:

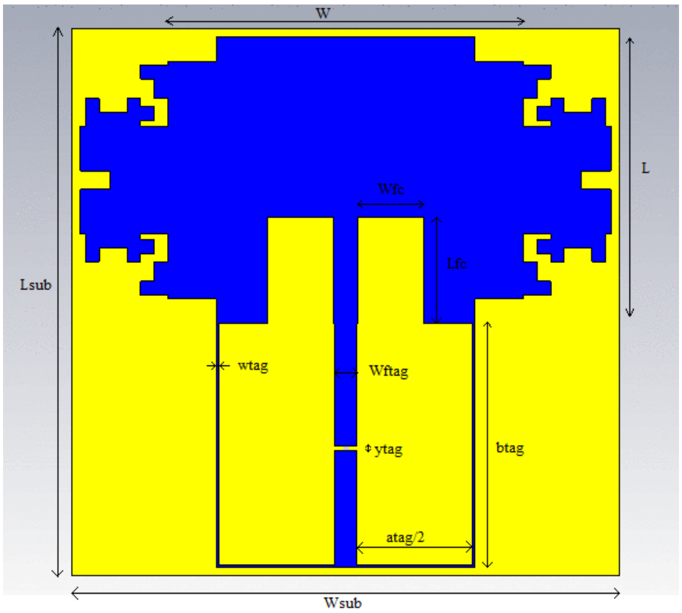

Fig. 2. Geometry of the proposed antenna: Top face.

The following Table 1 indicates the dimensions of the proposed antenna:

Table 1. Antenna Dimensions

Antenna Dimensions	Optimized Value (mm)
L	35
W	44.14
Lsub	66.84
Wsub	68.015
Lfc	13
Wfc	8.2
atag	32.14
btag	29.83
wtag	0.26
Wftag	2.76
ytag	0.5

3 Results and discussion

Using the fractal structure to minimize the patch size, a new antenna structure with fractal side and nested slot fed is proposed. The width and length value of patch antenna are optimized on CST EM solver.

The following **Figures** 3 and 4 show the real and imaginary part of antenna impedance according to the frequency. The simulated antenna impedance at 915 MHz is Zin = 38.4 + j 815 Ohms, and therefore having excellent impedance match with the chip impedance which is 34.5 – j 815. Good impedance matching could ensure a longer antenna reading distance, which is an important condition for RFID application.

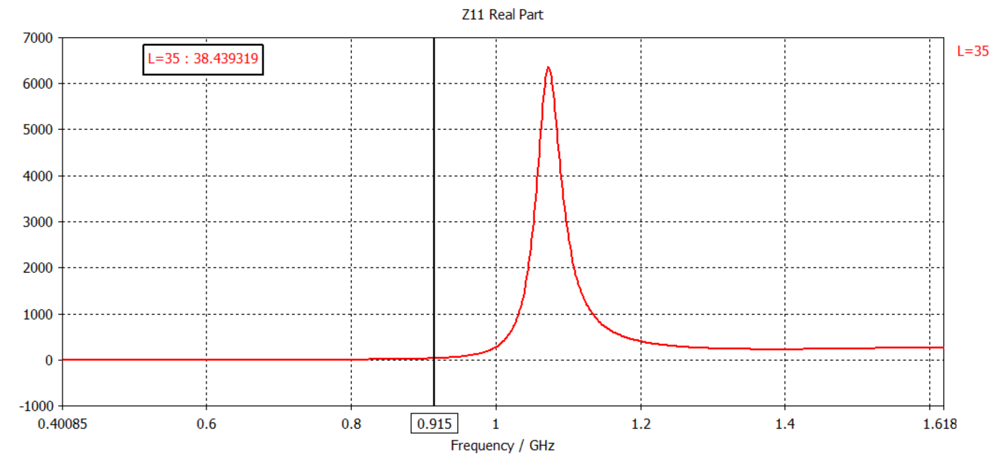

Fig. 3. Real part of simulated antenna impedance.

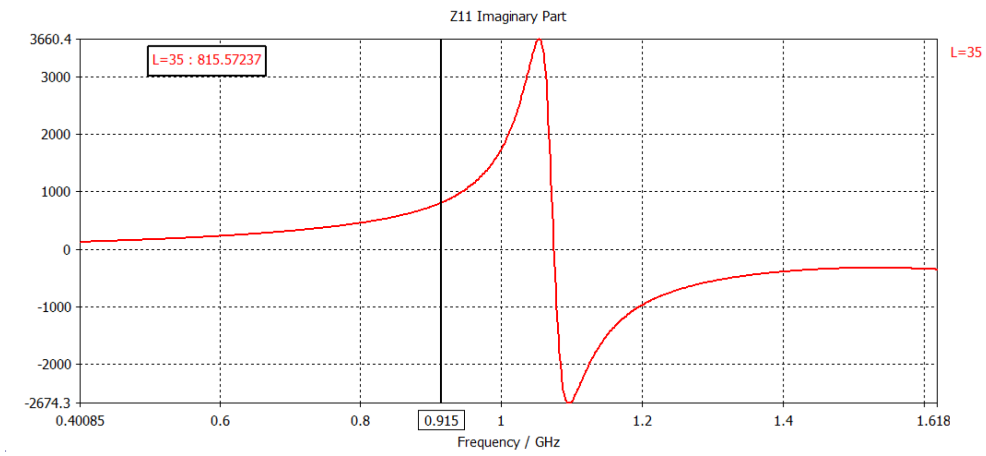

Fig. 4. Imaginary part of simulated antenna impedance.

Figure 5 shows the return loss S11 result for the antenna, it has good matching input impedance in the ISM band.

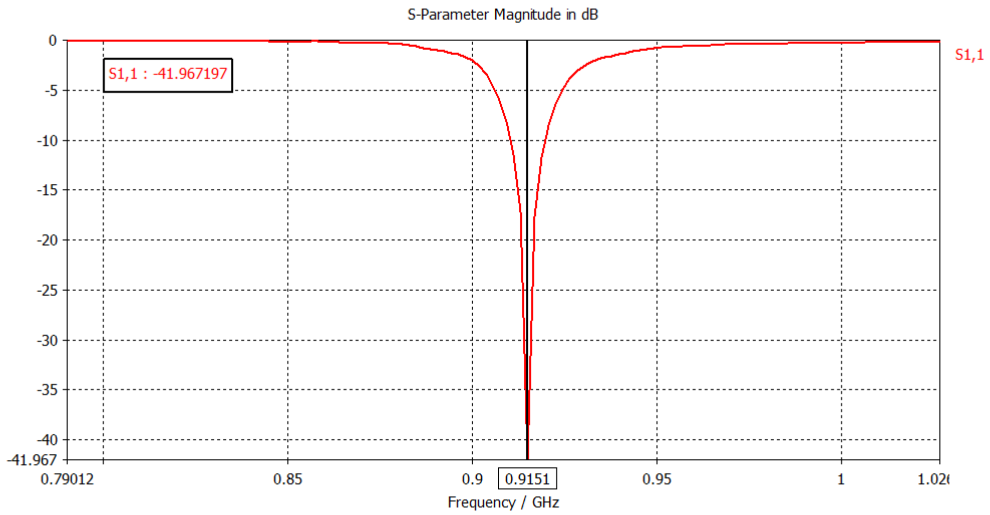

Fig. 5. Return loss (S11) value of the proposed antenna.

The return loss (S11) obyained is equal to –40.67 dB with this patch antenna at frequency 915 MHz. The bandwidth value is equal approximately to 10 MHz.

Figures 6 and 7 illustrate the 2D radiation patterns at E-plane and H-plane respectively. The proposed antenna has an omni-directional radiation pattern for both H-plane and E-plane, that means this tag antenna can be easily detected by reader antenna in any direction. The angular width is 87.4 degree at 915 MHz.

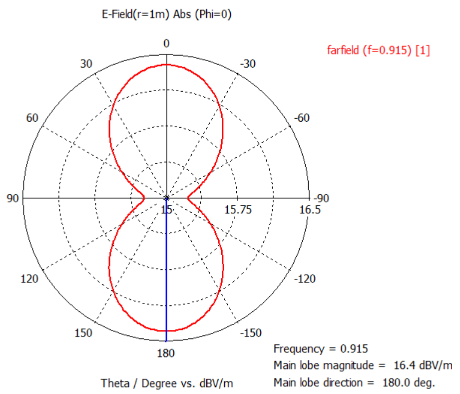

Fig. 6. 2D radiation patterns at E plane of the proposed antenna.

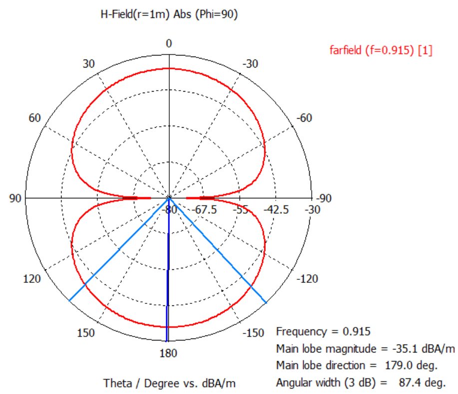

Fig. 7. 2D radiation patterns at H plane of the proposed antenna.

Figure 8 illustrates the surface current distribution of the proposed antenna at 915 MHz. A maximum current is observed around the low side, and around the feed line.

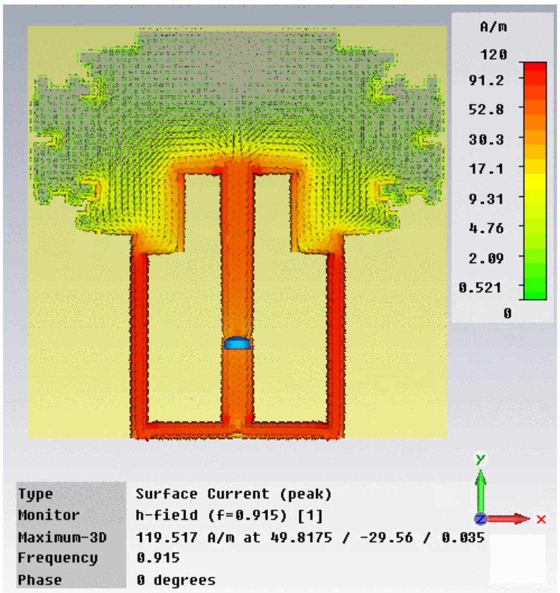

Fig. 8. Surface current distributions of the proposed antenna.

Figures 9 and 10 illustrate the directivity and the gain at the 3D radiation pattern at 915 MHz. The gain and directivity are equal respectively to 1.62 dBi and 2.35 dB, this gain is correct for RFID application in near field. The radiation pattern is omni-directional as presented in these figures.

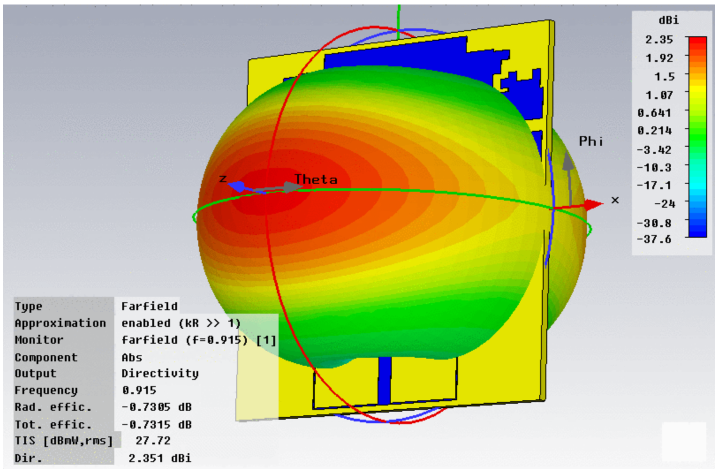

Fig. 9. 3D radiation pattern of the proposed antenna (Directivity).

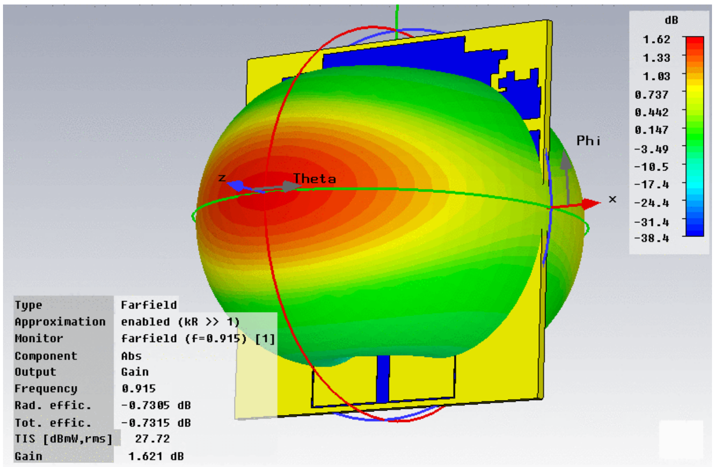

Fig. 10. 3D radiation pattern of the proposed antenna (Gain).

As shown in **Figure** 11, the size characteristics of the proposed antenna structure, Wsub x Lsub= 66.84 x 68.015 mm^2, is very small compared to the conventional rectangular radiating patch antenna at the operating frequency, Wsub x Lsub= 101 x 97.2 mm^2.

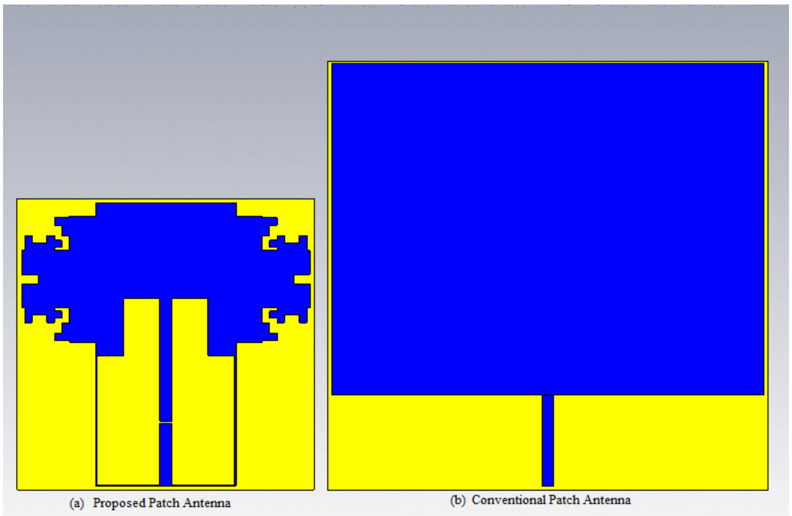

Fig. 11. (a) Proposed patch antenna, (b) Conventional patch antenna.

The results obtained of the proposed antenna, resumed in Table 2 and 3, show that a good miniaturization of the antenna dimensions is obtained with a good return loss S11, and an acceptable bandwidth for RFID applications.

As shown in Table 2, the total size reduction is for example equal to 53.7% compared to the conventional rectangular patch antenna. It is smaller than the True 3D Antenna (38%)

[22], and has approximately the same size reduction as the novel broadband UHF RFID tag antenna (56.8%) [23].

Table 2. Total Size Result Comparison between Proposed Antenna and Others Antennas

Patch Antenna 915 MHz	Wsub (mm)	Lsub (mm)	Total size reduction (Wsub x Lsub)
Conventional antenna	101	97.2	
True 3D Antenna for UHF RFID Application [22]	78	78	38 %
A Novel Broadband UHF RFID Tag Antenna [23]	106	40	56.8 %
Proposed Antenna	**66.84**	**68.015**	**53.7 %**

Table 3. Result Comparison between Proposed Antenna and Others Tag Antenna

Patch Antenna 915 MHz	S11 (dB)	Bandwidth (MHz)	Directivity (dB)
True 3D Antenna for UHF RFID Application [22]	- 28.93	244	-
A Novel Broadband UHF RFID Tag Antenna [23]	- 17.3	17	3.6
Proposed Antenna	**- 40.67**	**10**	**2.35**

4 Conclusion

This paper has presented a design of a new patch antenna with fractal structure for RFID Tag. A size reduction of antenna dimension (WsubxLsub) equal to 53.7% has been obtained compared with conventional rectangular patch. It provides appropriate characteristics, with a return loss equal to -40.67 dB, a bandwidth of 10 MHz, the directivity equal to 2.35 dB, and a gain equal to 1.62 dBi. This tag antenna has an omni-directional radiation pattern which makes RFID tags placed in any direction can be recognized by RFID readers. The antenna has been designed on a standard FR4 substrate and will be realized with conventional Printed Circuit Board (PCB) techniques in order to validate its results. This antenna can be used in inventory control or asset tracking.

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