RFID Systems Composed of Multiband Antenna with Fractal Geometry

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Abstract. Two tri-band RFID tag and reader antennas are proposed in this paper. The primary aim of the proposed work isto achieve multi-band antennas by implementing fractal designs as radiating elements. The RFID reader antenna is createdby using modified fractal tree structure; the operating frequencies are 3.6 GHz, 5.8 GHz, and 8.2 GHz. The recursive rectangular is implemented in RFID tag antenna operates at 3.9 GHz, 5.9 GHz, and 8.2 GHz for the RFID applications of goods management, traffic toll fee collection, telemetry respectively. The proposed reader antenna achieved a highest read range of 87.5 cm and tag antenna accomplished 85.6cm.

Keywords: Multiband, Fractals, Radio Frequency Identification (RFID), Co-planar Wave Guide (CPW), Antenna.

1 Introduction

The Radio Frequency Identification (RFID) is an essential technology in a real world scenario. RFID is availed in Inventory Tracking, Attendee tracking and recording, Materials management, i.e., keeping tracking of goods, logistics transportation, and traffic toll fee collection [1]. The design of antenna is usually the bottleneck of a RFID reader and tag systems. It is operated at a variety of radio frequencies. Each and every country follows distinct frequencies for various applications. Different stages of antenna design, requires attention to issues like miniaturization of size, reduction in cost and performance improvisation. Therefore, design and implementation of a compact single antenna operating at multiple frequencies is a great challenge.

The aim of this antenna design is to managing the RFID reader applications. Next antenna is especially made for RFID tag application. The construction of reader and tag antennas are deployed from binary fractal tree structure and recursive rectangles respectively. The paper describes the design of fractal iteration in forthcoming modules. The RFID reader antenna design is fundamentally a dipole antenna, with few modifications. The proposed fractal antennas operate in SHF (Super High Frequency) range i.e., 3 GHz to 30 GHz, predominately used for high speed detection. As per theory, when frequency increases, the travel time for the signal decreases proportionally. From the literature survey, it is observed that the SHF RFID object moves at a maximum up to 145Km/h speed [2]. Therefore, essentially it is required in RFID goods management, RFID traffic toll fee collection and RFID telemetry purpose, where

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the collection of data is required while object are in move and also the size of antenna is small and sufficient to affix on logistics goods as well as attachable onto employee ID cards. The proposed antenna for the tag operation is also of unique construction with fractal design.

Fractal structures used in RFID systems are proposed for implementation based on space filling and self-similarity properties. Self-similarity property is to increase the electrical length of material that can transmit or receive the electromagnetic emission within a stipulated volume. By designing multiple numbers of dipole arms at a single surface, certain classes of fractal antennas can be used to operate effectively at different frequency bands (multiband). In fractal structures, the space-filling property is implemented for reducing the antenna size, while increasing the perimeter of the antenna within the given area.

This paper provides antenna design details and explores the RFID antenna simulation results in transient solver using EM design software. The attained results are compared with frequency domain solver and fabricated after obtaining adequate results. The fabricated prototype performance is measured with Vector Network Analyzer subsequently; the measured results are analyzed with simulated results.

2. Proposed Fractal Structure

Fractals are obtained by surface transformation such that it can be used as radiating elements. The fractal design is acquired from the elemental transformation of structures [3]. These may be a line, or surface or a volume of material and fractal structure can be derived.

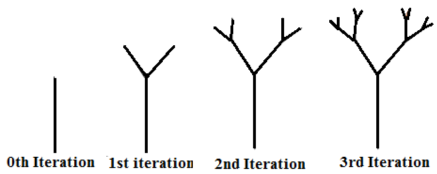


Figure. 1. Proposed antenna design stages of RFID Reader
(a) 0^{th} Iteration (b) 1^{st}Iteration(c) 2^{nd}Iteration(d) 3^{rd}Iteration

The various design stages of a binary fractal tree as depicted by Figure 1, are commonly made such that the angle encompassed between the twigs of all the stem is a constant. A modified binary fractal tree structure is proposed (Figure 1(a)), with the angle between the bifurcating twigs reduced by half in every iteration, resulting in miniaturization of fractal geometries that contain increased electrical lengths in a definite physical area. Further conformal, multi-band and low profile with broadband antennas are achieved for RFID system [4,5].Recursive rectangular configuration is proposed for the second antenna applicable in RFID tag operation. Figure 2 indicates proposed design iterations of the RFID tag antenna.

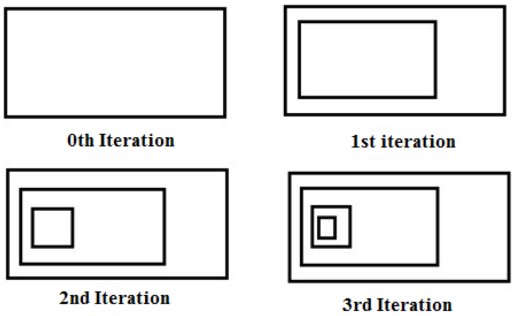


Figure. 2. Proposed Antenna Design for RFID Tag
(a) 0^{th}Iteration (b) 1^{st}Iteration(c) 3^{rd}Iteration(d) 4^{th}Iteration

3 Design of RFID Antennas

a) RFID Reader antenna

The literature survey details the integrations of multi-band in to a single plane using Co-Planar Waveguide Structure (CPW)[6 &7]. The outcome of introducing a secondary strip or slot, produces an additional band and good electrical properties are obtained by fractal design. The diagrammatic representation of the proposed RFID reader antenna is demonstrated in Figure 3.

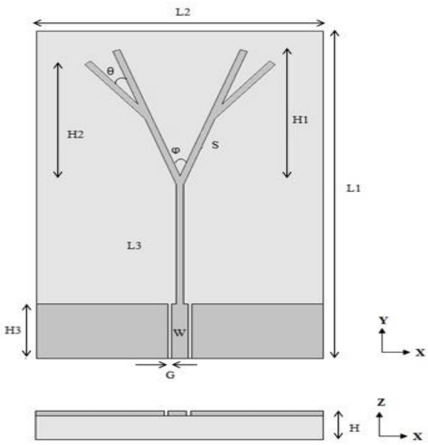


Figure. 3. Proposed RFID reader antenna using modified fractal tree structure, with CPW feed.

The reader antenna is designed on a substrate (FR4 lossy) with a 1.6mm thickness (loss tangent = 0.025and relative dielectric constant = 4.3) and is fed by 50 Ω coaxial connector. The complete substrate dimension is 40 mm x 60 mm. The designed resonating three frequencies of the antenna are f_1 = 3.6 GHz, f_2 = 5.7 GHz, and f_3 = 8.2 GHz. The dimensions of the antenna are H=1.6mm, H_1=23mm, H_2=21mm, H_3=10mm, L_1=60mm, L_2=40mm, L_3=22mm, S=1mm, W=2.2mm, G=0.5mm $\theta = 20^0$, $\varphi = 40^0$

b) RFID Tag Antenna

The proposed RFID tag antenna geometry is illustrated in Figure 4. A 50 Ω coaxial connector is fed on a designed FR4 substrate with 1.6mm thickness. The dimension of the antenna substrate is measured as 90 mm x 30 mm. In the RFID tag the feeding structure is the critical design part. The CPW feeding method [8] provides the freedom to use either the SMA connector orchip based and further tested via a VNA. The designed operating frequencies of the tag antenna are f_1=3.9GHz, f_2 = 5.9 GHz and f_3=8.2GHz respectively. The antenna dimensions are S_1=1.6 mm, S = 1 mm, W=2.4 mm, L_1=90 mm, L_2 = 30 mm, L_3=10 mm, G = 1mm. Figure 4 demonstrates the parameters corresponding to the measurements of the designed antenna.

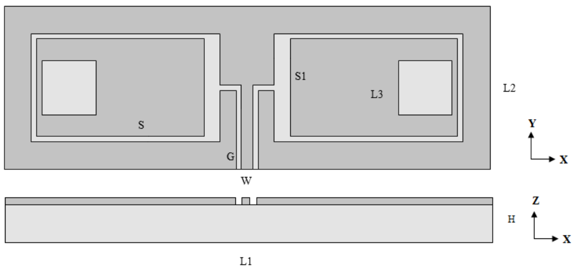


Figure. 4. Proposed RFID Tag antenna using recursive rectangular structure, with CPW feed

4 Results and Discussions

a) Reader antenna

The simulated results of S_{11}characteristics in time and frequency domain solvers of reader antenna are compared in Figure 5. The experimental results of the antenna operate at three different frequencies f_1, f_2, and f_3. The first frequency f_1 operates at 3.6 GHz, whose return loss value (S_{11}) is -19.41dB and the corresponding bandwidth is (-10dB) obtained at 248MHz and thepercentage bandwidth is 6.89. The subsequent occurrence is 5.7GHz and detectedS_{11} value of -20.38dB, the bandwidth (-10dB) obtained at 398MHz with a7.1 percentage bandwidth. The final frequency is falls in 8.2GHz, an S_{11}parameter of -20.63dB with a bandwidth (-10dB) at 405MHz and the corresponding bandwidth percentage is 4.96.

The obtained VSWR (measured @ VSWR=2) is given as 336 MHz for f_1, 423 MHz for $f_2$and 433MHz at $f_3$and the corresponding E and H plane field pattern of the reader antenna is exhibited in Figure 6.

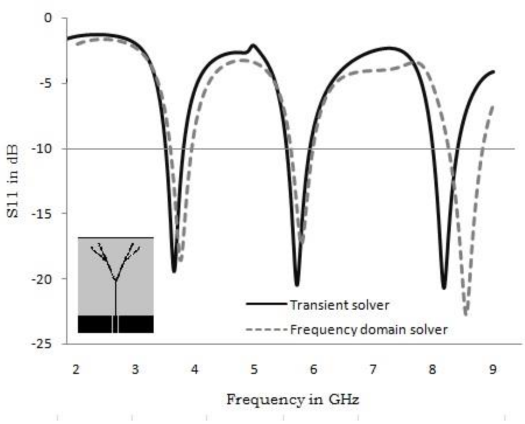
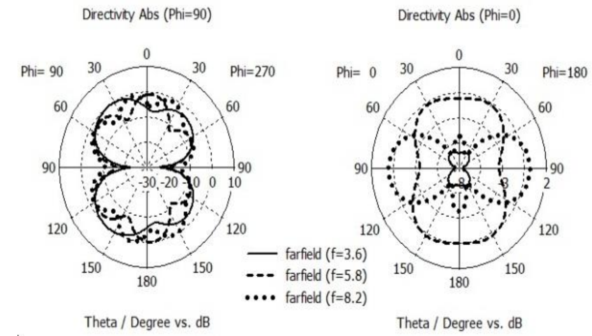


Figure. 5. Simulated S_{11} vs. Frequency graph of reader antenna based on transient and frequency domain solver



(a) (b)

Figure 6. Radiation results of RFID Reader.

(a) H field (b) E field b) Tag antenna

The simulated result of S_{11} vs. frequency chart of tag antenna is presented in Figure 7. First frequency is f_1 3.9 GHz, whose S_{11}occurs at -17.12 dB and obtained bandwidth (-10dB) at 238MHz and bandwidth percentage of 6.1.The next frequency is 5.9 GHz, S_{11}falls with -19.69 dB and the corresponding bandwidth is 181 MHz with bandwidth percentageof 3. The last frequency is giving S_{11} value of -20.31 dB with a bandwidth (-10 dB) of 310 MHz and 3.7 bandwidth percentage. The Figure 7 shows the simulated results of transient domain solver and frequency domain solvers encompassing high association with each other results.

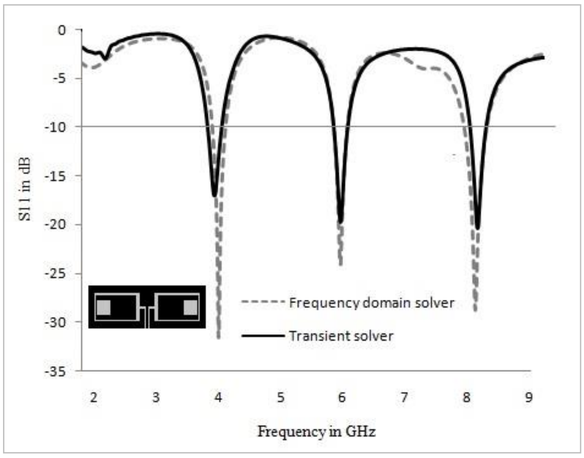
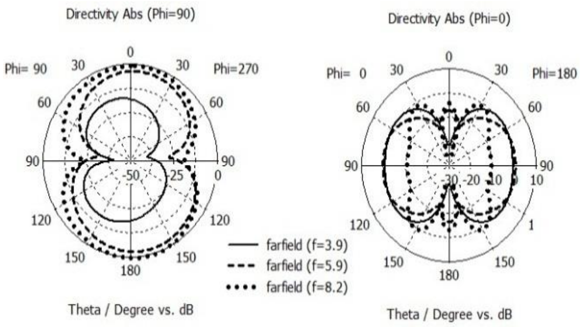


Figure. 7. Simulated S_{11} vs. Frequency graph of tag antenna based on transient and frequency domain solver

The tag antenna VSWR bandwidth (measured at VSWR=2) is given as 255MHz atf_1, 230 MHz f_2 and 285 MHz at f_3 and the corresponding E and H plane pattern is presented in Figure 8.



(a) (b)

Figure 8. Radiation results of RFID Tag antenna.
(a) H field (b) E field

5. Fabrication and Measurement of prototype

Prototype of Reader and Tag antenna

The RFID Reader and Tag antenna was fabricated post simulation and analysis, with FR-4 material as substrate. The authors preferred a chip-less design and testing. The simulation was carried out in transient solver and frequency domain solvers based on waveguide port. Practically, the SMA connectors were connected to the edge of the antennas and excitation was provided. The measurement of S_{11} characteristics was executed by Agilent E8363B VNA. The prototype of both reader and tag antenna are shown in the Figures 9. Figure 10& 11, indicating the comparison result of measurement and simulated S_{11} characteristics of reader antenna.

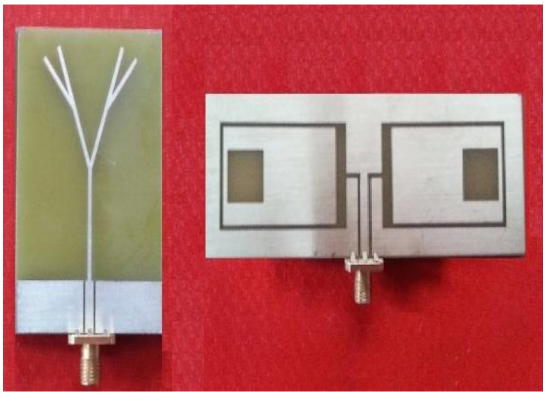


Figure 9. Fabricated prototypes of RFID Reader and Tag

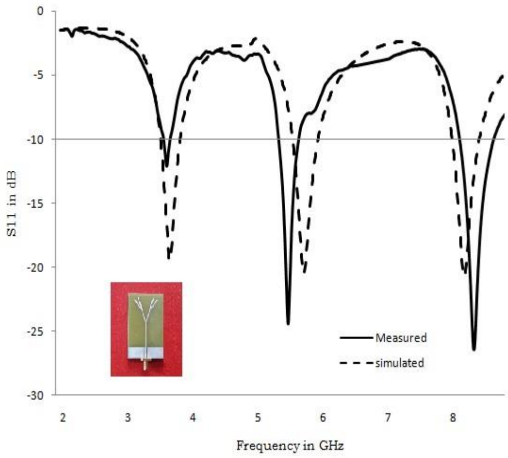


Figure. 10. Measured result and Simulated results of S_{11} vs. Frequency graph of reader

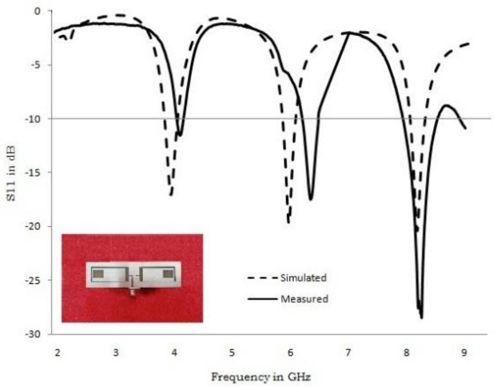


Figure. 11. Measured result and Simulated results of S_{11} vs. Frequency graph of tag

Measured results and simulated S_{11} characteristics arecompared andindicatedin Figures 10 and 11. The advantage of the CPW structure is that, at the same plane both ground and conductors are fabricated. It is used as a feeder element for antennas.

Calculation of Read range

The Friis Transmission Equation is used to evaluate the antenna parameters encompassing the gain of reader and tag antenna, received and transmitted powerP_R and P_T, operating frequency f_c,wavelength λ,read range R, velocity of light c, the gain of receiver and transmitter antenna $G_r$and G_t.

Power Density can be calculated from

$$p = \frac{P_T}{4\pi R^2} \quad (1)$$

Considering the transmit antenna gain G_t, then the power density becomes

$$p = \frac{P_T}{4\pi R^2} G_t \quad (2)$$

Assume the Effective Aperture of the antenna then the received power becomes

$$P_R = \frac{P_T G_t G_r \lambda^2}{(4\pi R)^2} \quad (3)$$

The read range can be calculated by above Friis Transmission equation

The reader and tag antenna read range is calculated by keeping3dBi gain as a reference, 4W as the transmitting powerand1mW as detectable least power. The calculated read range of both reader and tag antenna for various operating frequency is indicated in Table 1.

Table 1. Read Range Chart

Operating Frequency (GHz)	Type of Antenna	Antenna gain (dBi)	Calculated Read range (cm)
3.6	Reader	3.4	87.5
3.9	Tag	3.9	85.6
5.8	Reader	2.7	50.1
5.9	Tag	3.0	51.02
8.2	Reader	2.6	35.06
8.2	Tag	2.2	33.48

6. Conclusion

Fractal antennas are designed to conserve low profile, attain multiband and be miniature in size. In this publication RFID Reader and Tag antennas are introduced using fractal geometry. At -10 dB bandwidth, the obtained results of RFID tag antenna of 238 MHz @ 3.9GHz, 181MHz @ 5.9GHz, 310 MHz @ 8.2 GHz. Similarly, the results of the reader antenna of 248 MHz @ 3.6GHz, 398 MHz @ 5.8GHz, 405 MHz @ 8.2 GHzat -10 dB bandwidth. The highest RFID reader antenna read range is 87.5 cm and similarly, obtained maximum read range is 85.6cm by the tag antenna

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Author Bibliography

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