Near-Field Fractal RFID Reader Antenna for Item Level Tagging

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Abstract: This paper proposes a novel methodology for designing near-field fractal antenna operating at European Ultra-High Frequency (UHF) for Radio Frequency Identification (RFID) systems. The principle of Oppositely Directed Current (ODC) technique is implemented to generate homogeneous magnetic field above the surface area meant for near-field RFID application. The conceptual theoretical framework of the design based on the fractal structure can be applied. The fabricated RFID reader antenna operates at 867 MHz with reflection coefficient $S_{11}$ -30 dB, thus the reader antenna covering UHF RFID band range. The reading capabilities of the antenna are determined by the interrogation area of, 190mm x 243mm. It is adequate for object tracking and detection systems in pharmaceutical management and chemical industries.
Keywords: Near-field analysis, Radio Frequency Identification (RFID) reader antenna, Ultra-High Frequency (UHF), Item level tagging, Fractal antenna.

1. INTRODUCTION

In tracking and detection system, most researchers investigating that the effective functioning of near-field radio frequency identification antenna (RFID) requires optimum magnetic field strength to be provided within specific interrogation zone [1]. Achieving intense and constant magnetic field dissemination becomes more challenging, during operating frequencies upsurge to ultra-high frequencies (UHF) band [2].

RFIDs find important applications in today’s technology driven society and it is a promising method in contactless tracking and identification. The applications can be library book management, employee attendance management, factory inventory management, vehicle identification and traffic toll collection. As frequency is high, the signal can travel in short time, resulting in fast tracking however, this initiates signal distortion due to obstructions such as liquids and metals [3]. Here, the permanent tags are spotted more persistently on numerous target objects specifically bottles containing liquids like drugs, acids, oil, water, clothes and small items, causing communication barrier between reader and tag [4]. Especially, tracking the items in drug and pharma industries which has glitches due to impediments in near field.

Recent reports in UHF RFID system (usually 900 MHz) proves that near field communications have been broadly pertinent for item-level tagging. Ordinary RFID reader antennas for far-zone reading lags on performance efficiency in near-zone RFID applications [5 - 7]. The near field communication is an emerging communication technology, for which the application which demands fast data transfer in short distance with low power.

In near-field analysis, the RFID reader antenna has to produce uniform strong magnetic field. To improve the reading stability, the amount of magnetic field should be distributed uniformly in the reading zone [8]. Commonly, loop antennas having capacity to make strong magnetic field. Amid the several forms of loop antenna, single or multi-turn antennas and conventional solid line loop antennas are used extensively in near-field reader antennas. On the other hand, smaller circumference loops produce intense magnetic field at the loop core centre, but there is rapid decrease in
magnetic field strength with distance from the centre, thereby obtaining limited reading area [9&10]. A Modified Fractal Pinwheel tiling is proposed here, to improvise the electrical performance with compact structure.

2. ANTENNA DESIGN & OPERATION

2.1 Opposite Direction Current

Highly strong magnetic field can be generated by Opposite Directed Currents (ODCs) procedure. ODCs are generated over a board surface area by duel fed dipoles with current direction of 180° out of phase [11]. However, the duel feed structure improves the complexity in the RFID system. Hence, single feed ODC can be implemented in the reader antenna. It consists of triangular slot and gradual increase of the distance between ODC pair is achieved by triangular slot at the middle of the antenna; thereby producing high intensity magnetic field on surface of the antenna. The figure 1 shows the direction of surface current.

![Figure 1. Simulated Result of the Proposed Antenna Indicates Surface Current Direction](image)

Modified fractal Pinwheel tiling structure helps to increase the electrical length and application of ODC principle is implemented at the edges of the tapered slot opening. The tapered slots were used for high directivity and high frequency applications.

2.2 Antenna Geometry

In this, the reader antenna was designed on FR-4 substrate (dielectric constant $\varepsilon_r=4.3$, loss tangent $\delta = 0.02$ and thickness $H = 1.5$ mm). It has triangular shaped opening, and the slot line is fed by a very narrow
micro-strip line, carefully placed at antenna’s posterior side. The slot width is around 0.35m which is very small in comparable to its wavelength. Complete dimension of the antenna is 90 x 90 mm. Modified fractal pinwheel tiling is implemented as a space filling structure in this paper. Fractals are self-similar and space filling patterns. The antenna operates at 867MHz with $S_{11}$ of -39dB at second iteration.

![Figure 2. Different Iterations of Modified Fractal Pinwheel Tiling](image)

The fractal geometry is based on the Modified pinwheel tiling is shown in figure 2. Let $T$ be the right triangle. That $T$ can be divided in four copies of its image. The iterations can be obtained by suitable rescaling and translating/rotating of triangles by infinite increasing sequence, all made of isometric copies of $T$.

3 RESULT AND DISCUSSION

3.1 $S_{11}$ Characteristics

Figure 3 indicates the measured and simulated results of RFID reader antenna. The measured impedance bandwidth is 190MHz (780-970 MHz) after the optimization, simulated result is (at 10 dB level) 823-914 MHz, the
obtained bandwidth is 91 Megahertz. The results are found to be in good correlation with simulated results.

![Graph showing measured and simulated S11 vs Frequency]

**Figure 3.** Measured and Simulated $S_{11}$ vs Frequency Graph

### 3.2 VSWR Bandwidth

VSWR calculation was carried out by taking 2 as a reference line. The bandwidth of VSWR is 93 MHz i.e., from 824 to 917 MHz. Least VSWR of 1.06 is attained at 867 MHz, obviously at operating frequency.

### 3.3 Surface Current Distribution

In near-field analysis, surface current flow is very important. The direction and flow of the surface current distribution is depicted in figure 1 and observation of opposite direction currents is attained on this RFID reader antenna plane.

The minimum and optimum power detection by a viable RFID near-field tag is 20dBA/m. After the simulation, taking 20dBA/m as a reference, the obtained interrogation area is 190mm x 243mm. It is significant that there are no nulls transpiring at centre of the antenna. The interrogation area is more than two times greater than the proposed antenna size. Also found that the maximum field strength is -7.20dBA/m by a distance of 50 mm from reader antenna.
Figure 4. RFID Reader Antenna of magnetic field at 50 mm.

**Figure 4 a**: x-y cut plane in z axis

**Figure 4 b**: x-z cut plane in y axis.

**Figure 4 c**: x-z cut plane in y axis with Bakelite.

**Figure 4 d**: x-z cut plane in y axis with Glycerine in test tube

The Figure 4(a) shows the RFID Reader Antenna of magnetic field at distance 50mm in the x-y plane. Figure 4(b) presents x-z cut plane at a height 50mm from the antenna centre. The obtained magnetic field is roughly -23 dBA/m in the near field which gratifies the near field detection necessities. Thus, good read distance is comparatively achieved.

Figure 4(c) shows the simulation result which is obtained in real time application. Taking Bakelite as obstruction placed in front of the antenna with 45 mm distance. The dimension of the Bakelite is 40 x 50 x 10 mm length, height and thickness respectively. The simulation result gives slight degradation around -9.9 dBA/m.
Figure 4(d) depicts simulation results of different real time application. It is the x-z cut plane of magnetic field with glycerine contained in a Plexiglas test tube as obstruction. The dimensions of each test tube are approximately 1.4 cm diameter and 14 cm height. The antenna is positioned at 50mm distance from the test tube and kept at a spacing of 2 mm. The simulated result indicates a real time scenario similar to chemical tracking, and reduction of around -0.3 dBA/m is obtained after the obstruction, and it is tolerant.

4 FABRICATION AND MEASUREMENT

4.1 Fabricated Prototype

The antenna is developed on FR-4 (lossy) substrate and the substrate thickness is 1.5mm having sufficient mechanical stiffness. At the back side, the strip-line is deposited with PEC material with the thickness of 0.35 m. With the same thickness, front side also PEC panel deposited with V shape opening and fractal design is etched out carefully. The prototype of fractal RFID Reader antenna is shown in figure 5.

![Fabricated Prototype of Fractal RFID Reader Antenna](image)

Figure 5. Fabricated Prototype of Fractal RFID Reader Antenna

4.2 Measurement Setup

The RFID reader antenna is developed on FR-4 substrate and the fabrication cost is reduced due to the availability of FR-4 material. In this design of antenna, no active elements were used so that low profile and simplicity were maintained. The micro-strip feed was soldered to sub-miniature version-A (SMA) connector of 50Ω impedance on the prototype.
Measurements have been carried out using Agilent E8363B vector network analyser (VNA) to trace the magnetic field strength in the Z direction of the proposed antenna. The antenna was fed by a microwave source, with a power of 20 dBm. The measurement setup is shown in figure 6. A fixture was made using foam with dielectric constant 1 and the antenna was placed over it with a set of five test tubes with a distance of 2mm each, containing liquid as obstruction which will ensure the performance of the antenna. A field meter with field probe provision is used to measure the magnetic field. The position marks are made on the probe kept at the fixture to uphold precision and the procedure was repetitive for the field measurements at different points on the z axis.

![Measurement Setup](image)

**Figure 6.** Measurement Setup: Near-Field Measurement

Table 1 compares the interrogation area with other literatures and the proposed antenna, results in larger interrogation area which is good enough for RFID applications.

Proposed design has minimum input power 20dBm with good read range. The antenna prototype is small as well as simple compared to the existing antennas. Dealing with the RFID applications, this antenna will be useful in several applications mainly chemical and pharmaceutical item tracking, as a compact and cost efficient alternative.
Table 1. Comparison Result with Other Antennas

| Sl.No. | Reference No. | Interrogation Area (mm) | Antenna Size (mm) |
|--------|---------------|-------------------------|-------------------|
| 01     | 12            | 200 x 190               | 95 x 200          |
| 02     | 13            | 154 x 154               | 175 x 189         |
| 03     | Proposed Antenna | 190 x 243              | 90 x 90           |

The Table 2 shows the performance analysis of the novel RFID reader for pharmaceutical and chemical applications. This includes the results from the measured and simulated antenna.

Table 2 Performance Analysis of the Fractal RFID Reader Antenna

| Sl.No. | Parameter                              | Value                        |
|--------|----------------------------------------|------------------------------|
| 01     | Operating frequency                    | 867MHz                       |
| 02     | Impedance Bandwidth                    | 190 MHz (measured)           |
| 03     | $S_{11}$ at 867 MHz                    | -29dB                        |
| 04     | VSWR Band width                        | 93MHz (simulated)            |
| 05     | Interrogation area at 50 mm from plane in Z direction | 190 mm x 243 mm |
| 06     | Size of the Antenna                    | 90 mm x 90 mm                |
| 07     | Read distance                          | 9.47 cm                      |
| 08     | Read distance with Bakelite            | 8.7 cm                       |
| 09     | Read distance with Glycerine as Obstruction | 8.9 cm                     |
| 10     | Antenna input power                    | 20dBm                        |

5. CONCLUSION

It will be always challenging to design a simple and low profile antenna for UHF near field RFID applications. The proposed modified fractal pinwheel tiling antenna has substantiated the capability of producing a uniform intense magnetic field in and around the antenna. The complete size of the antenna is approximately 90 x 90 mm only. The
designed antenna operates at 867 MHz, and possesses appropriate bandwidth of 190 MHz which is sufficient to cover USA and Canadian UHF RFID bandwidth of 902 - 928 MHz and European UHF RFID bandwidth of 865 - 868 MHz. The prototype is fabricated and measured. Taking Bakelite and Glycerine as obstruction, small acceptable degradation in the simulated results was found for tracking it in chemical and pharmaceutical industries. The simulated results are validated using experimental measurements and results are in consistent association with simulated results. Thus proposed work is an acceptable cost efficient and compact alternative for item level tagging.

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Acknowledgments

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