A Novel Multi-Element Fractal PIFA with Wide Pattern Coverage for 915 MHz RFID Wireless Sensors

R. H. Bhuiyan*, R. Dougal, and M. Ali
Department of EE, University of South Carolina, Columbia, SC 29208, USA
E-mail: alimo@engr.sc.edu

Abstract

The performance of a single-element PIFA and a multi-element PIFA are studied and compared to determine their suitability in RFID sensor tags for placement on rotating platforms. Each antenna operates in the 915 MHz frequency band and occupies a maximum area of 90 by 90 sq. mm. It is demonstrated that using the multi-element PIFA in place of the single-element PIFA, 33.33% bandwidth enhancement and superior radiation pattern coverage can be obtained.

Introduction

Radio Frequency Identification Devices (RFID) are a class of popular wireless devices that are currently being used to track and identify various objects. The prospect of an RFID device as a communication module in wireless sensor networks is promising. Extensive research on RFID antennas has been going on all over the world. The objectives are to reduce the antenna size, increase the read range, enhance the radiation patterns, and decrease the sensitivity of antennas to nearby materials.

Hua and Ma [1] proposed a 90 mm by 90 mm microstrip-fed printed dipole antenna for 902-928 MHz RFID handheld readers with high front-to-back ratio. Their proposed design reduces the absorbed electromagnetic energy in users. Lu et al. [2] designed a 13.56 MHz implantable MEMS based inductively coupled RFID transponder. Marrocco [3] developed a small 860-960 MHz RFID transponder antenna which radiated low power compatible with the human body. Using genetic algorithm, Calabrese et al. [4] designed a dual band (870 MHz, 2.45 GHz) miniaturized meandered slot antenna for RFID sensors.

A major existing problem in RFID sensor networks is the uncertainty of the relative spatial positioning of the reader antenna and the tag antenna. Especially if the tag antenna is on a movable platform or on a rotating object like a motor, this problem becomes more challenging. Since the location of the reader unit in a sensor network may not be known in advance, so the tag antenna should ideally radiate in every possible direction. Therefore it is important to investigate the possibility of designing and developing an RFID tag antenna having very good radiation coverage with as little of a pattern null as possible. Besides this, the RFID antenna has to be insensitive to nearby metals. The antenna along with the accompanying circuitry should also fit within a specific surface area or volume [5].

To resolve these issues, we have studied two fractal PIFAs in this paper. First, we investigated a single-element fractal PIFA on a 90 mm by 90 mm ground plane. Second,

---

1 This work was supported in part by the US Office of Naval Research under grant N00014-02-1-0623.
we studied a multi-element PIFA consisting of one driven element and three parasitic elements each of which are terminated with a reactive impedance. This concept is more similar to diversity antennas [6] except unlike diversity antennas the passive elements are terminated with reactive impedances. We found that compared to the single-element PIFA, a better radiation coverage, wider bandwidth as well as improved return loss performance can be obtained using one active and three passive elements in the fractal PIFA configuration. Note that unlike the ESPAR scheme described in [7] the proposed scheme primarily focuses on wider pattern coverage instead of scanning the beam in a specified direction.

Fig. 1(a) shows the geometry of the proposed single-element fractal PIFA. The antenna is constructed on a 90 mm by 90 mm ground plane. The height of the antenna from the ground plane is 5 mm. The antenna is in air, but in practice a foam substrate can be used to support it. There are 25 fractal arms each with a length of \( m = 3.2 \) mm. The antenna has a length, \( x \) of 22 mm and width, \( y \) of 37.8 mm. The width of the copper trace that was used to form the antenna is 1 mm. Fig. 1(c) shows the location of the feed and the shorting pin. The shorting pin is always at the edge of the ground plane. The distance between the shorting pin and the feed is 1.5 mm. All antennas were modeled and analyzed using HFSS. The width of the feed and the shorting pin were 1 mm.

Fig. 1(b) shows the proposed multi-element fractal PIFA. It is constructed using four identical antenna elements. The construction and dimensions of each element is the same as those of the single-element PIFA. The four elements are placed at the corners of the ground plane in such a way that any two nearest elements have their axes perpendicular to each other. Of the four elements, only one element has an active feed

![Fig. 1. Top views of the (a) single-element PIFA and the (b) multi-element PIFA; (c) 3-D view of the single-element PIFA.](image-url)
whereas three other elements have passive capacitive terminations in their feeds. The feed capacitance is 10 pF for all three passive elements. Both the single element and the multi-element antennas are designed to operate at around 915 MHz. Each antenna size is such that it fits within a standard area of 152×102 sq. mm [5].

Results

Ansoft HFSS solver was used to analyze the antenna behavior. The return losses of the two antennas are shown in Fig. 2. The resonant frequency of the single-element PIFA is 911 MHz whereas that of the multi-element PIFA is 909 MHz. The bandwidths for S11 <= -10 dB are 12 MHz and 16 MHz for the single-element PIFA and the multi-element PIFA, respectively. So by using the multi-element PIFA a bandwidth increase of 4 MHz was obtained.

![Fig. 2. Comparison of return loss performances between single-element PIFA and multi-element PIFA.](image)

Results

Ansoft HFSS solver was used to analyze the antenna behavior. The return losses of the two antennas are shown in Fig. 2. The resonant frequency of the single-element PIFA is 911 MHz whereas that of the multi-element PIFA is 909 MHz. The bandwidths for S11 <= -10 dB are 12 MHz and 16 MHz for the single-element PIFA and the multi-element PIFA, respectively. So by using the multi-element PIFA a bandwidth increase of 4 MHz was obtained.

![Fig. 2. Comparison of return loss performances between single-element PIFA and multi-element PIFA.](image)

Fig. 3. Computed total radiation patterns of the single-element PIFA and the multi-element PIFA in the (a) Φ=0° plane and (b) Φ=90° plane.

Fig. 3 and Fig. 4 show the comparison of the total radiation patterns between the single-element PIFA and the multi-element PIFA in three different planes. Patterns were normalized with respect to the maximum gain in that particular plane. Fig. 3(a) illustrates the total radiation patterns in the Φ=0° plane. The multi-element antenna has higher gain from θ=0° to θ=−130° and θ=60° to θ=150°. In other angles, both antennas have almost the same gain coverage. The multi-element antenna has higher gain across 220°. In Fig. 3(b) we have shown comparison of radiation patterns in the Φ=90° plane. In this plane, the single-element PIFA performs better. It gives higher gain from θ=10° to θ=180°. The gain

![Fig. 3. Computed total radiation patterns of the single-element PIFA and the multi-element PIFA in the (a) Φ=0° plane and (b) Φ=90° plane.](image)

Fig. 3. Computed total radiation patterns of the single-element PIFA and the multi-element PIFA in the (a) Φ=0° plane and (b) Φ=90° plane.

Fig. 3 and Fig. 4 show the comparison of the total radiation patterns between the single-element PIFA and the multi-element PIFA in three different planes. Patterns were normalized with respect to the maximum gain in that particular plane. Fig. 3(a) illustrates the total radiation patterns in the Φ=0° plane. The multi-element antenna has higher gain from θ=0° to θ=−130° and θ=60° to θ=150°. In other angles, both antennas have almost the same gain coverage. The multi-element antenna has higher gain across 220°. In Fig. 3(b) we have shown comparison of radiation patterns in the Φ=90° plane. In this plane, the single-element PIFA performs better. It gives higher gain from θ=10° to θ=180°. The gain

![Fig. 3. Computed total radiation patterns of the single-element PIFA and the multi-element PIFA in the (a) Φ=0° plane and (b) Φ=90° plane.](image)
improvement along other angles is marginal. The multi-element PIFA has slightly better gain only from $\theta=0^\circ$ to $\theta=-90^\circ$. Fig. 4 gives the comparison in the $\theta=90^\circ$ plane. In this plane, the single-element PIFA has better gain coverage from $\Phi=50^\circ$ to $\Phi=130^\circ$. On the other hand, the multi-element PIFA outperforms the single-element PIFA from $\Phi=0^\circ$ to $\Phi=50^\circ$, $\Phi=-150^\circ$ to $\Phi=270^\circ$ and $\Phi=330^\circ$ to $\Phi=360^\circ$. Thus in the $\theta=90^\circ$ plane, the multi-element PIFA gives superior coverage across a wider pattern angle than the single-element PIFA. The performance enhancements obtained using the multi-element PIFA is summarized in Table 1.

Fig. 4. Computed total radiation patterns of the single-element PIFA and multi-element PIFA in the $\theta=90^\circ$ plane.

Table 1. Comparison between the single-element PIFA and the multi-element PIFA.

| Parameter                  | Single-element PIFA | Multi-element PIFA | Improvement 
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Bandwidth</td>
<td>12 MHz</td>
<td>16 MHz</td>
<td>4 MHz</td>
</tr>
<tr>
<td>Pattern in the $\Phi=0^\circ$ plane</td>
<td>None</td>
<td>$220^\circ$</td>
<td>$220^\circ$</td>
</tr>
<tr>
<td>Pattern in the $\Phi=90^\circ$ plane</td>
<td>$170^\circ$</td>
<td>$90^\circ$</td>
<td>$-80^\circ$</td>
</tr>
<tr>
<td>Pattern in the $\theta=90^\circ$ plane</td>
<td>$80^\circ$</td>
<td>$200^\circ$</td>
<td>$120^\circ$</td>
</tr>
</tbody>
</table>

References


