Wearable Sierpinski Dragon Fractal Patch Antenna for RFID Applications

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Abstract
Radio Frequency Identification (RFID) system is one of ID technologies that are widely used for tracking objects efficiently. A standard RFID system is consisted of Tag and Reader. The tag includes an antenna and a microchip with internal read/write memory. The tag antenna plays a significant role in the overall RFID system performance factors, such as the read range. Integrating RFID tags into cloth makes it possible to monitor people with more security. In this paper, a new wearable textile antenna is presented for RFID applications. The structure of the proposed antenna is based on the 3rd iterations Sierpinski dragon fractal curve. The main goal of using this type of fractal geometry is because it can provide suitable and attractive shape, which is well easily included in the clothes. In addition, the proposed antenna shape can be hidden in the cloth for security purposes. The designed antenna is printed using a substrate with $\varepsilon_r = 1.8$ and thickness of 1.37 mm. Modeling and performance evaluation of the proposed antenna have been carried out using the commercial Finite Integration Technique (FIT) based EM simulator, CST Microwave Studio (CST MWS). Results show that the antenna presents dual-band resonant behaviour with acceptable radiation characteristics with peak gains of about 3.393 dBi and read range equal to 5.730 m.

Keywords: Sierpinski Dragon, RFID Antenna, Wearable Antenna, Fractal Antenna
1. Introduction

RFID technology is just one of several techniques known as auto-identification (Auto-ID) technology that includes barcode, biometric, OCR, smart card, voice recognition, and RFID [1]. RFID uses radio frequency waves to identify, categorize, and track the objects as they move through a controlled environment. The new generations of textile have the capability to conduct electricity and at the same time are wearable. There are much more applications involved if an antenna is made totally wearable [2]. Commonly, wearable antenna requirements for all modern applications include light weight, low cost, maintenance-free, and no installation. There are a number of specialized occupation segments that apply body-centric communication systems, such as paramedics, firefighters, and military. Besides, wearable antennas also can be used to youngsters, the aged, and athletes for the purpose of monitoring [3].

Many researchers had implemented various antenna designs for the purpose of wearable applications. The first published research work on wearable antennas presented in [4] which developed a dual-band PIFA antenna operating at GSM frequency (900MHz) and Bluetooth frequency (2.4GHz). The effect of different conductive materials on the performance of WLAN antenna was studied in [5]; the results have shown that the conductive material plays a significant role in optimal textile antenna design. The same authors in [6] studied the effect of six dielectric textile materials on the performance of GPS antenna with circular polarization at 1.575 GHz, all have nearly the same permittivity ($\varepsilon_r= 1.1$ to 1.2); therefore, the thickness generally determines the bandwidth. Nowadays, the new specific identification field of wearable textile labels is quickly growing up. It is especially used for textiles traceability, positioning, broadcasting and also security [7]. Besides the lowest price, textile tag antenna has to resist the laundry cycles, which means humidity, temperature and pressure. A new design method of a RFID fiber tag antenna with electric-thread using sewing machine was proposed in [8], where the tag antenna can be embedded to any cloths instead of being attached to cloths.

On the other hand, fractal geometries have been widely adopted in the design various antennas for a wide variety of communications applications [9-10]. In this respect, a compact size triple-band fractal Koch textile antenna using the first iteration of Koch geometry of a dipole antenna structure for wearable applications has presented in [11]. The flare angle of the antenna design is varied to three different values that are 30, 45 and 60 degrees respectively. The relationship between stitch and thread density with respect to the conductivity of an embroidery antenna studied in [2] and [8] when stitch and thread density increased the conductivity is also increased. The investigation of the effect of different types of ground planes using electro textiles on a patch-type UHF RFID tag antenna performance has been presented.
in [12]. Various conductive fabrics and embroidery structures are used; the results show that depending on the ground plane structure and density, it is possible to influence the tag impedance behavior and radiation characteristics.

In this paper, a textile rectangular patch tag antenna for RFID applications based on third iterations \( n=3 \) Sierpinski dragon curve has been presented for RFID applications.

2. The Proposed Antenna Structure

The first step of the proposed antenna presented in this paper is the investigation of the conventional textile antenna presented in [13] shown in the Figure (1). The next step is to apply fractal geometry to this antenna structure to obtain an attractive shape. The resulting antennas will be easily included in the clothes design together with the possibility of being hidden for security purposes for RFID applications. For comparison, it is designated as the reference antenna.

![Figure (1). The layout of the wearable textile antenna reported in [13]](image)

Fractal geometries can be applied to develop various antenna elements. Applying fractal geometries to antenna elements allows for smaller, resonant antennas that are multiband frequency. The fractal technique can be used to reduce antenna size and develop low profile antennas. In addition, the dimension of geometries can be defined through Euclidean dimension, self-similarity dimension [14]. In this paper, a Sierpinski dragon fractal curve is applied to the antenna design. The steps of generation of the Sierpinski dragon fractal curve, up to the third iteration, are shown in Figure (2) [15].
The total length of the Sierpinski dragon fractal curve, $L_n$, at each iteration, $n$, can be calculated by:

$$L_n = \frac{L_{n-1} \times 3^n}{2}$$

where $n$ is the iteration level.

3. The Antenna Design

In this section, the design of the reference tag antenna operating in the UHF RFID frequency is to be carried out. The geometry of this antenna is shown in Figure 3(a) while the antenna dimensions are summarized as in Table (1). The antenna is implemented on 3.175-mm-thick RogerRT/Duroid 5880 substrate, the overall antenna dimensions are 150*90 mm$^2$. The length and width of the feed line have been adjusted to attain an inductive input impedance to conjugate-match the tag antenna to the capacitive tag NXP IC. This IC was specified to have an equivalent input parallel resistance and capacitance of 2.85 kΩ and 0.91 pF, respectively.
The antenna with the layout depicted in Figure 3 has been modeled, and its performance has been evaluated within the swept frequency range of (1–6) GHz using the prescribed substrate. Modeling and performance evaluation of the proposed antenna have been carried out using the commercial Finite Integration Technique (FIT) based EM simulator, CST Microwave Studio (CST MWS) [16]. Figure 4 depicts the simulated return loss response of the modeled antenna with the prescribed dimensions. The antenna offers dual-band at center frequencies of 4.75 GHz and 5.9 GHz within the sweep frequency with return loss $S_{11}$ of less than -10 dB. It is clear that the proposed antenna does not satisfy the frequency ranges required for RFID application. The whole antenna structure has to be scaled down to make it resonates at a lower band corresponding to the 2.4 GHz ISM band. Table (2) summarizes the dimensions of the modeled antenna after being scaled down to produce the resonant response specified for RFID requirements.
Figure (4): Simulated return loss response of the resulting third iteration Sierpinski dragon antenna depicted in Figure (3) with the dimensions summarized in Table (2).

Table (2): Summary of the modified antenna dimensions, in (mm), for RFID requirements.

<table>
<thead>
<tr>
<th>$L_s$</th>
<th>$W_s$</th>
<th>$l_p$</th>
<th>$w_p$</th>
<th>$L_g$</th>
<th>$W_g$</th>
<th>$L_f$</th>
<th>$W_f$</th>
</tr>
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<tbody>
<tr>
<td>150</td>
<td>90</td>
<td>100</td>
<td>50</td>
<td>33.5</td>
<td>90</td>
<td>30</td>
<td>3</td>
</tr>
</tbody>
</table>

4. Performance Evaluation and Parametric Study

To get more insight on the effects of some antenna parameters on its performance, the modeled antenna performance, in terms of the input return loss $S_{11}$, has been evaluated many times. For this purpose, antenna performance has been investigated subject to the effects of varying the ground plane dimensions, the feed line width, and the textile materials.

4.1 Effect of ground plane

In the terms of the antenna ground plane dimensions, it has been found that reasonable results can be obtained with $L_g$ varies in the range of (30-36) mm. The corresponding results are demonstrated in Figure (5). Figure (5) depicts the return loss responses of the proposed antenna with the ground plane length as a parameter within the sweep frequency of (1-6) GHz. For the different ground plane lengths, the antenna offers dual-band return loss resonant responses with interesting features. The center of the lower resonant band is varied in a range of about 2 MHz corresponding to a ground plane length variation of about (1) mm. On the other hand, the centers of the upper resonant bands are considerably changed. It is obvious that the upper resonant bandwidth offered by the antenna is wider than that of the lower one. The best results when ground plane length is 33.5 mm the antenna offers dual-band return loss...
resonant response matching with RFID frequency range at 2.40 GHz and 4.38 GHz which matched with the defense system applications.

![Graph](image1.png)

**Figure (5):** Simulated return loss responses of the resulting third iteration Sierpinski dragon antenna with the effect of the ground plane length.

### 4.2 Effect of feed line width

The proposed antenna depicted in Figure (3) with the dimensions demonstrated in Table (2) has been modeled with prescribed substrate but varying feed line width. Simulation results reveal that, for a certain extent, still offers a dual bands resonance as shown in Figure (6). For small variations of feed line length, the effect on the upper resonant band position is considerably larger than that of the lower band. However, for larger values of feed line width, the upper resonant band starts to diminish.

![Graph](image2.png)

**Figure (6):** Simulated return loss responses of the resulting third iteration Sierpinski dragon antenna with the effect of feed line width.
4.3 Effect of textile materials

The effect of different textile materials on the antenna performance is studied in terms of the antenna return loss response within the prescribed swept frequency range. The corresponding simulated return loss results are shown in Figure (7). The commonly used materials for RFID application include Jeans Cotton, Twill, Denim, and Polyester textile. Simulation results show that Jeans Cotton, Twill, Denim, and Polyester textile materials satisfy the RFID application, where the dielectric constant is in the range between (1.6-1.9). Table (3) shows the textile material with their dielectric constant. In summary, due to the varying dielectric constant, materials with higher dielectric constants will result in lower resonant band and vice versa.

![Figure (7): Simulated return loss response of the modeled antenna for different textile materials.](image)

<table>
<thead>
<tr>
<th>Material</th>
<th>$\varepsilon_r$</th>
<th>$f_r$ (GHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyamide Spacer</td>
<td>1.1</td>
<td>2.892</td>
</tr>
<tr>
<td>Fleece</td>
<td>1.2</td>
<td>2.814</td>
</tr>
<tr>
<td>Polycot</td>
<td>1.3</td>
<td>2.676</td>
</tr>
<tr>
<td>Woolen Cotton</td>
<td>1.45</td>
<td>2.662</td>
</tr>
<tr>
<td>Cotton</td>
<td>1.54</td>
<td>2.568</td>
</tr>
<tr>
<td>Jeans Cotton</td>
<td>1.6</td>
<td>2.52</td>
</tr>
<tr>
<td>Cotton Twill</td>
<td>1.707</td>
<td>2.5</td>
</tr>
<tr>
<td>Denim</td>
<td>1.8</td>
<td>2.478</td>
</tr>
<tr>
<td>Polyester</td>
<td>1.9</td>
<td>2.436</td>
</tr>
</tbody>
</table>
The simulated far-field radiation patterns for the total electric field in the x-y plane, the x-z plane, and the y-z plane at the center frequencies of the two resonant bands of this antenna have been shown in Figure 11. Figure 11 (a) show the far-field radiation pattern for lower band while the upper band was illustrated in Figure 11 (b).
Figure (8): Simulated far-field radiation patterns for the total electric field of the antenna at (a) 2.47 GHz (b) 4.66 GHz.
As far as the radiation properties are concerned, Figure (12) shows the simulated three-dimensional directivity radiation patterns of the resulting antennas. The directivity at 2.47 GHz, the center frequency of the lower band, is of about 3.880 dBi as shown in Figure (12 (a)). In addition, the directivity at 4.66 GHz the center frequency of the upper band is of about 4.343 dBi for antenna printed on a textile substrate as shown in Figure (12 (b)).

![Simulated 3D directivity](image)

**Figure (9): Simulated 3D directivity of the resulting rectangular patch antenna at**

(a) 2.47 GHz and (b) 4.66 GHz

4.4 Antenna read range

The most important tag performance characteristic is the read range that is the maximum distance at which RFID reader can detect the backscattered signal from the tag. Because reader sensitivity is typically high in comparison with tag, the read range is defined by the tag response threshold. The read range is also sensitive to the tag orientation, the material the tag is placed on, and to the propagation environment. The read range can be calculated using Friis free-space formula as [17,18]:

$$ r = \frac{\lambda}{4\pi} \sqrt{\frac{P_t G_t G_r \tau}{P_{th}}} \quad \cdots \cdots (1) $$

Where $\lambda$ is the wavelength, $P_t$ is the power transmitted by the reader, $G_t$ is the gain of the transmitting antenna, the product is the EIRP, $G_r$ is the gain of the receiving tag antenna, $P_{th}$ is the minimum
threshold power necessary to provide enough power to the RFID tag chip, and $\tau$ is the power transmission coefficient given by [17,18].

$$\tau = \frac{4R_cR_a}{|Z_c+Z_a|^2} \quad \text{……………….. (2)}$$

According to Equation (2), read range is proportional to the transmitted power from the reader antenna. However, reader’s transmitted power cannot be increased limitlessly. The maximum possible read range $r_{\text{max}}$ if the tag is perfectly matched to the chip ($\tau=1$) is given by [17,18]:

$$r_{\text{max}} = \frac{\lambda}{4\pi} \sqrt{\frac{P_t G_t G_r}{P_{th}}} \quad \text{……………….. (3)}$$

The maximum theoretical read range of the proposed RFID tag antenna $r_{\text{max}}$ is calculated using Friis free-space formula (Equation 3). The calculated read ranges of the modeled antenna have been found to be 5.730 m with a gain of 3.393 dBi at the center of the lower resonant band. The reader’s output power is set to 4.0 W EIRP, threshold power required to turn on the NXP chip (-17.5 dBm) and for perfect matching when $\tau=1$.

5. Conclusions

A new wearable RFID textile tag antenna has been presented in this paper. The proposed antenna structure has a shape based on the third iteration Sierpinski Dragon fractal geometry as being applied to an originally rectangular patch shape. Besides the attractive shape required for security purposes, the presented antenna offered dual-band resonant behavior making it as an alternative candidate for use in many other communications services. A parametric study has been conducted to demonstrate the effects of different antenna parameters on its performance. Using a substrate with dielectric constant of 1.8 and thickness of 1.37 mm to represent a textile material, the antenna has been found to offer a dual-band resonances centered at 2.47 GHz and 4.7 GHz. In addition, simulation results have shown that the proposed textile antenna presents acceptable radiation characteristics with peak gains of about 3.393 dBi and read range equal to 5.730 m for the lower band.
References


