Wearable Sierpinski Dragon Fractal Patch Antenna for RFID Applications

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Abstract

The Radio Frequency Identification (RFID) system is one of ID technologies that are widely used for tracking objects easily and effectively. A standard RFID system is consisted of Tag and Reader. The tags include an antenna and a microchip with internal read/write memory. The tag antenna plays an important role in the overall RFID system performance factors,such as the read range. Integrating RFID tags intocloth makes it possible to monitor people with more security. In this paper, a new wearable textile antenna is presented for RFID applications. The proposed antenna structure is based on the 3rd iterationsSierpinski 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 cloths.In addition, the proposed antenna shape can be hidden in the cloth for security purposes. The designed antenna is printed using a substrate with εr = 1.8and 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 behaviorat 2.47GHz and 4.7 GHz with acceptable radiation characteristics with peak gains of about 3.393 dBi and read range equal to 5.730 m.

Key words: Sierpinski Dragon,RFID antenna, Wearable antenna, Fractal antenna

1. Introduction

RFID technology is just one of several technologies known as auto-identification (Auto-ID)technology which includes barcode, biometric, OCR, smart card,voicerecognition, and RFID[1]. RFID uses radio frequency waves to transfer data betweena reader (transceiver) and a moveable or stationary object (transponder or tag) to identify, categorize, and track the objects as they move through a controlled environment.The new generation of textile has the capability to conduct electricity and at the same time is wearable. There are much more applications involved if an antenna is made totally wearable

[2].Commonly, wearable antenna requirements for allmodern application require light weight, low cost, almostmaintenance-free and no installation. There are number ofspecialized occupation segments that apply body centriccommunication systems, such as paramedics, fire fighters,and military. Besides, wearable antennas also can be appliedfor youngsters, the aged, and athletes for the purpose ofmonitoring [3].

There are many researches implemented for the purpose of wearable applications the first published research work on wearable antennas presented in [4] which designed 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 an important 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 (ε_r= 1.1 to 1.2); therefore, the thickness generally determines the bandwidth.Nowadays, the new specific identification field of wearable textile labelsis 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 communication applications [9-10]. In this respect, a compact size triple-band fractal Koch textile antenna using 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 which 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.An investigation of effectof different types of ground planes using electro textiles ona patch-type UHF RFID tag antenna performancehas been presented in [12]. Various conductive fabrics and embroidery structures areused; the results show that depending on the ground planestructure 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 theconventional textile antenna presented in[13] shown in the Figure (1). The next step is to apply fractal geometry to this antenna structure aiming to obtain of an attractive shapewhich well easily included in the cloths design together with the possibility of being hidden for security purposes for RFID applications.For comparative purposes, it is designated as the reference antenna.

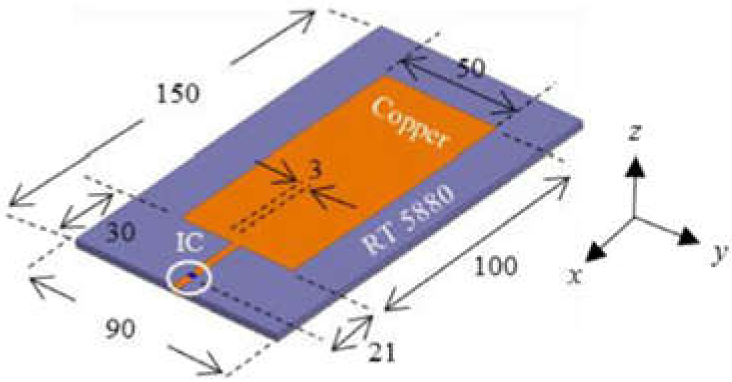

Figure (1).The layout of the wearabletextile antenna reported in [13]

The general concept of fractal can be applied to develop various antenna elements. Applying fractals 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. Furthermore 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].

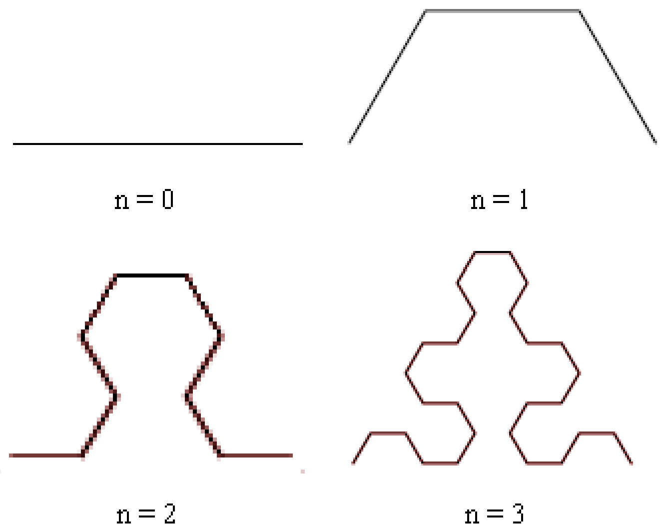

Figure (2): Steps of generation of the Sierpinski Dragonup to 3rd iteration level [15].

The total lengthof the Sierpinski dragon fractal curve, L_{n-1}at each iteration, *n*, canbe calculated by:

$$L_n = \frac{L_{n-1}}{2} * (3)^n$$

where *n* is the iteration level.

3. The Antenna Design

In this section,the design ofthe reference tag antennaoperating in the UHF RFID frequency is to be carried out. The geometry of this antenna is shown in Figure3(a)whiletheantenna dimensions aresummarized 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.

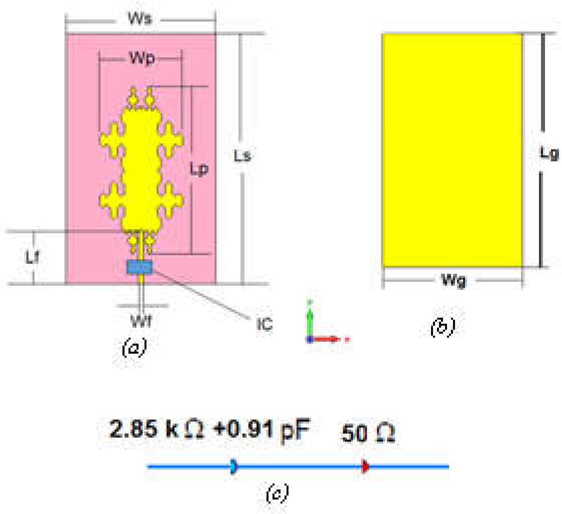

Figure (3): The layout of the modeled 3rd iteration reference antenna with coordinate system (a) Top view (b) Bottom view (c) IC chip

Table (1) Summary of the dimensions of reference antenna

Ls (mm)	Ws (mm)	l (mm)	w (mm)	Lg (mm)	Wg (mm)	Lf (mm)
150	90	100	50	150	90	30

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 doesn't satisfy the frequency ranges required for RFID application. To make the antenna resonates at a lower band corresponding to the 2.4 GHz ISM band, the whole antenna structure has to be scaled down. Table (2) summarizes the dimensions of the modeled antenna after being scaled down to produce the resonant response specified for RFID requirements.

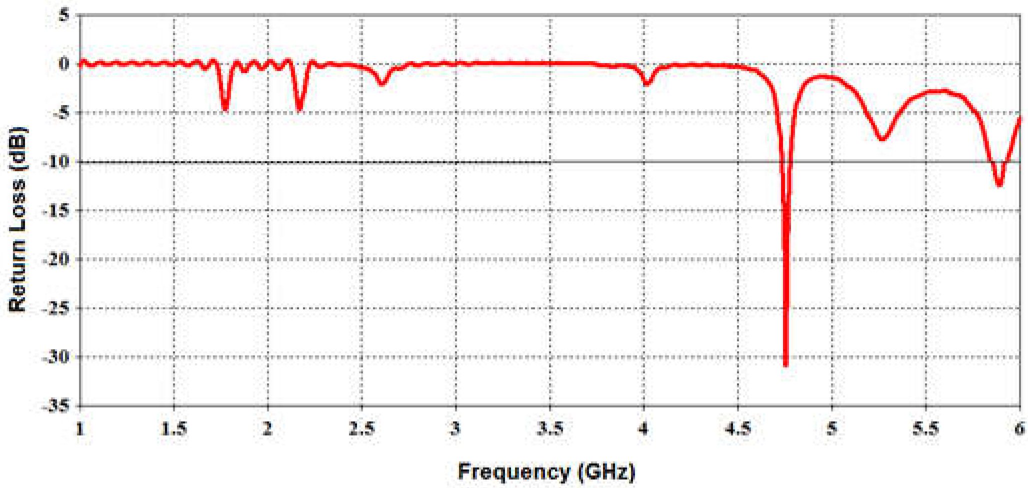

Figure (4): Simulated return loss response of the resulting 3rd iteration Sierpinski dragon antenna depicted in Figure (3) with the dimensions summarized in Table (2).

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

Ls	Ws	lp	wp	Lg	Wg	Lf	Wf
150	90	100	50	33.5	90	30	3

4. Performance Evaluation and Parametric Study

To get more insight of 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 Lg 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 2MHz 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.

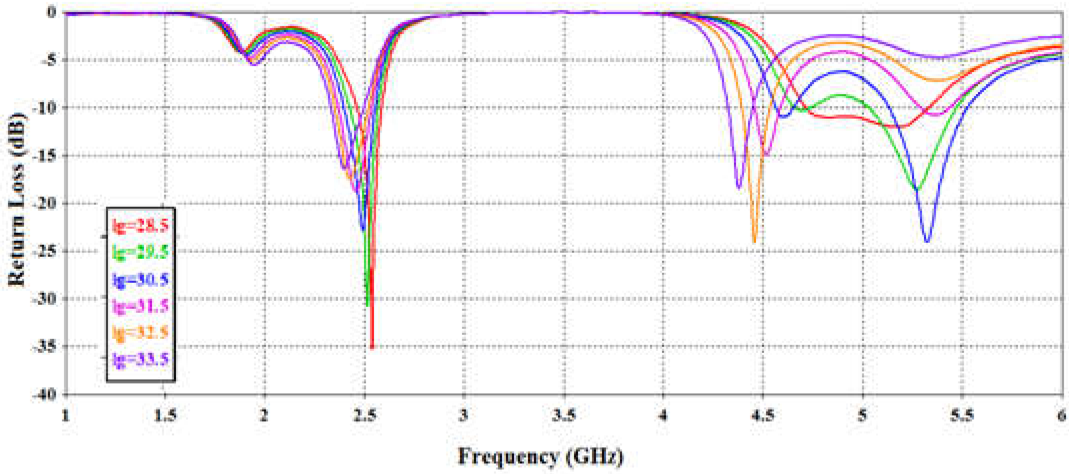

Figure (5): Simulated return loss responses of the resulting 3rd iteration Sierpinski dragon antenna with the effect of ground plane length.

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 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.

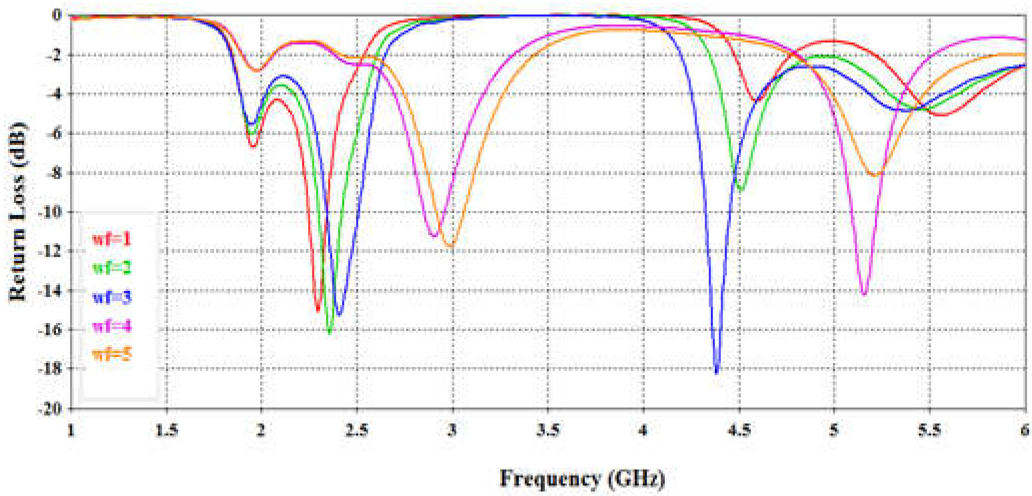

Figure (6): Simulated return loss responses of the resulting 3rd iteration Sierpinski dragon antenna with the effect of feed line width.

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 materialsfor 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.

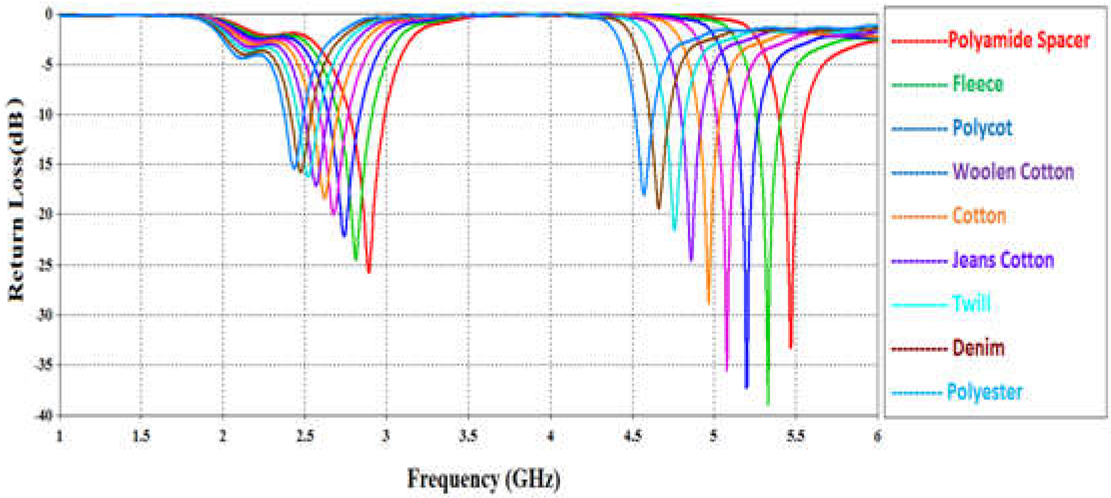

Figure (7): Simulated return loss response of the modeled antenna for different textile materials.

Table (3): Different textile materials used as antenna substrate

Material	ε_r	f_r (GHz)
Polyamide Spacer	1.1	2.892
Fleece	1.2	2.814
Polycot	1.3	2.676
Woolen Cotton	1.45	2.662
Cotton	1.54	2.568
Jeans Cotton	1.6	2.52
Cotton Twill	1.707	2.5
Denim	1.8	2.478
Polyester	1.9	2.436

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, when Figure 11 (a) show the far- field radiation pattern for lower band while the upper band was shown in Figure 11 (b).

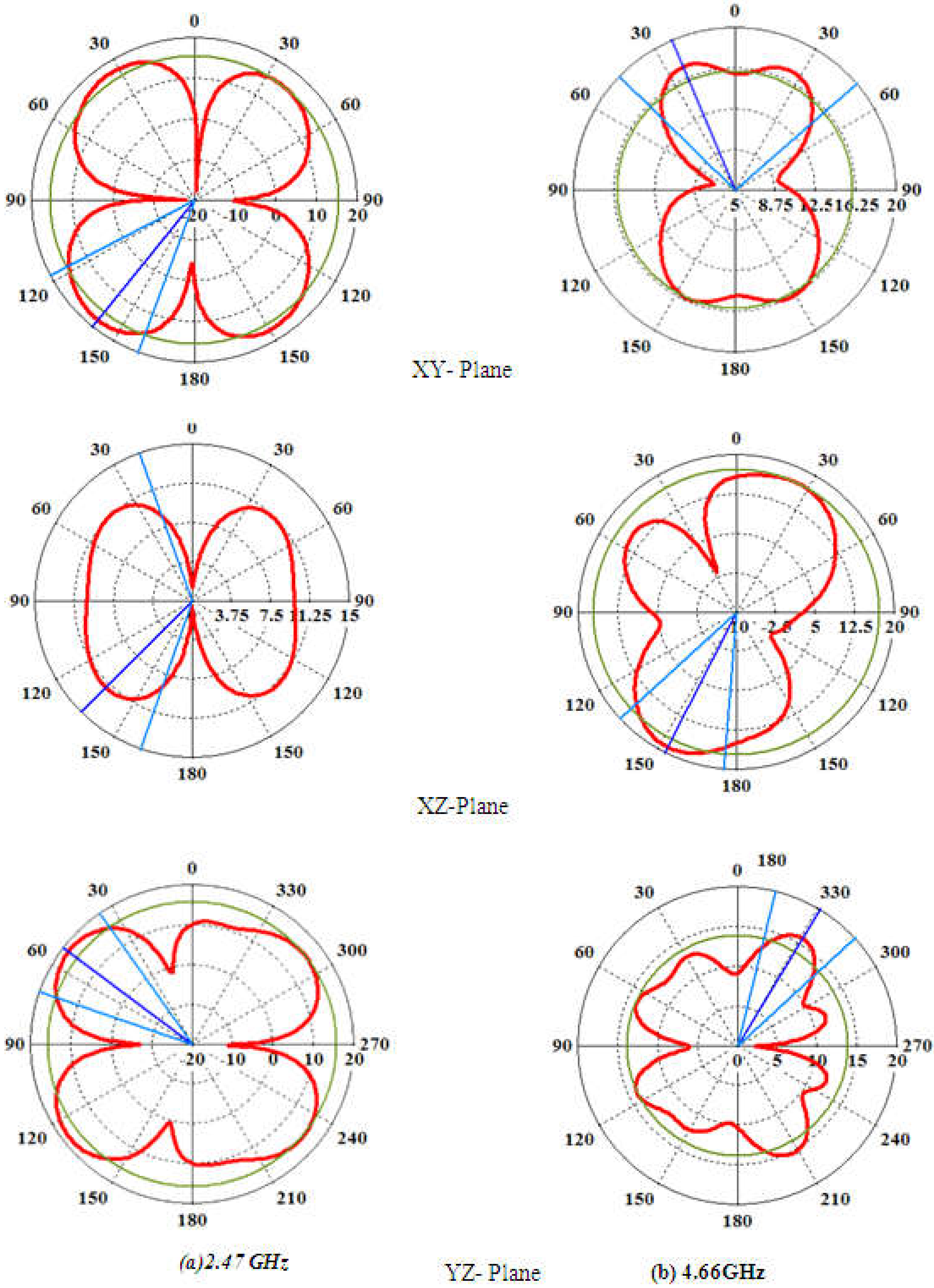

Figure (8): Simulated far- field radiation patterns for the total electric field of antenna at (a) 2.47 GHz (b) 4.66 GHz.

As far as the radiation properties are concerned, Figure (12) shows the simulated three-dimensional directivity radiation patterns ofthe resulting antennas. The directivity at 2.47GHz the center frequency of lower band is of about 3.880dBi as shown in Figure (12 (a)), whereas the directivity at 4.66GHz the center frequency of upper band is of about 4.343dBi for antenna printed on a textile substrate as shown in Figure (12 (b)).

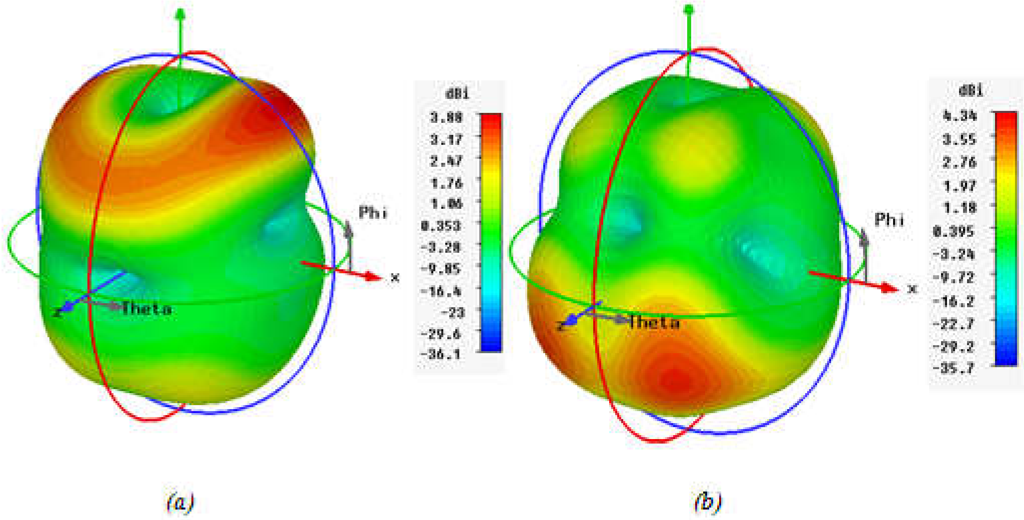

Figure (9): Simulated 3D directivity of the resulting rectangular patch antenna at

(a) 2.47 GHz and (b) 4.66 GHz

4.4Antenna Read Range

The most important tag performance characteristic is read range which 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. 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]:

.... (1)

Where λ is the wavelength, $Pt$is the power transmitted by thereader, Gt is the gain of the transmitting antenna, the product is the EIRP,Gr is thegain of the receiving tag antenna, Pth is the minimum threshold power necessary to provide enough power to the RFID tag chip, and τ is the power transmission coefficient given by [17,18].

$$\tau = \frac{4R_cR_a}{|Z_c+Z_a|^2} \qquad (2)$$

According to Equation (2), read range is proportional to the transmitted power from the reader antenna. But reader’s transmitted power cannot be increased limitlessly.The maximum possible read range rmax if the tag is perfectly matched to the chip (τ=1) is given by [17,18]:

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The maximum theoretical read range of the proposed RFID tag antenna $rmax$is calculated using Friis free-space formula (Equation 3).The calculated read ranges of the modeled antenna has 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 τ=1.

5. Conclusion

A new wearable RFID textile tag antennas has been presented in this paper. The proposed antenna structure is based on 3rd iteration Sierpinski Dragon fractal geometry as being applied to an originally rectangular patch shape. Besides the attractive shape required for security purposed, the presented antenna offered dual-band resonant behavior making it as an alternative candidate for use in many other communication 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.

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