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A Minkowski Fractal Circularly Polarized Antenna for RFID Reader

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Abstract: A design of fractal-like antenna with circular polarization for radio frequency identification (RFID) reader applications is presented in this article. The modified Minkowski fractal structure is adopted as radiating patch for size reduction and broadband operation. A corner-truncated technology and a slot-opened method are employed to realize circular polarization and improve the gain of the proposed antenna, respectively. The proposed antenna is analyzed and optimized by HFSS. Return loss and maximum gain of the optimized antenna achieve to -22.2 dB and 1.12 dB at 920 MHz, respectively. The optimized design has an axial ratio (AR) of 1.2 dB at central frequency of 920 MHz and impedance bandwidth (S11<=-10 dB) of 40 MHz (4.3 %). Its input impedance is (57.9-j2.6) Ω that is close to input impedance of coaxial line (50 Ω). Numerical results demonstrate that the optimized antenna exhibits acceptable performances and may satisfy requirements of RFID reader applications. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Radio frequency identification (RFID), Reader antenna, Minkowski fractal, Circularly polarized (CP).

1. Introduction

Radio frequency identification (RFID), which was originated from World War II, is a wireless non-contact technology that uses radio frequency electromagnetic fields to exchange information, for the purposes of automatically identifying and tracking tags attached to objects [1-2]. It mainly comprises a tag for transmitting product information and a reader for receiving data. In recent years, RFID technology has attracted much attention and has been rapidly developed, since it is a key technology of Internet of Things (IoT). Nowadays so many practical and significant applications in various fields can be found easily, for example distribution logistics, electronic toll collection, goods tracking, and intelligent transportation systems [2-5]. Usually, according to its operating frequency, RFID system can be classified as low-frequency (LF-RFID), high-frequency (HF-RFID), ultra-high frequency (UHF-RFID), and microwave frequency bands RFID, respectively [1-2], in which the UHF-RFID system is the most popular owing to its low cost and high performances. Therefore the antenna presented in this paper is operated in UHF bands. In fact, each country or region possesses its own spectrum resources for UHF RFID applications, e.g., 840.5–844.5 and 920.5–924.5 MHz in China, 866–869 MHz in Europe, 865–867 MHz in India, 902–928 MHz in North and South of America, 866–869 and 920–925 MHz in Singapore, and 952–955 MHz in Japan, and so on [1-2, 6].

In whole RFID domain the reader antenna with the property of circular polarization is required to guarantee the reliability of communicating between reader and tag, because the tag attached to the product is usually arbitrarily oriented and its antenna is almost linearly polarized [7-8]. Consequently, circular polarization plays a very important performance in the design of reader antenna. According to polarized theory, to let antenna emit CP wave, the key is to stimulate two linearly polarized waves with orthogonal polarization, and their amplitudes are equal and their phase differences are 90 degree. In order to design CP reader antennas, several suggestions have been proposed, such as corner-truncated patch antennas [1], dual-fed or hybrid-fed exciting antennas [9], slot-opened patch antennas [10], and CPW slotted patch antennas [2, 11].

In this paper, we design a fractal-like CP antenna for RFID reader applications. For the purpose of compacting dimensions and extending bandwidth, the modified Minkowski fractal concept is adopted. To achieve circular polarization, a corner-truncated patch is utilized owing to its simplicity and easy fabrication. And a ground plane with opening slot is employed to improve the gain of the designed antenna. The simulated results show that the optimized antenna exhibits acceptable performances in terms of return loss, total gain, AR, and impedance matching. The remainder of the present paper is organized as follows. The configuration of the proposed antenna is given in Section II. The analyses and optimization are described in details in Section III. A brief summary is given in the last Section IV.

2. Antenna Configuration

A fractal, which was firstly put forward in 1975 by Mandelbrot [12], is a natural phenomenon or a mathematical set and exhibits an inherent self-similarity in their geometrical structure [13]. The fractal concept has been applied to design antennas for size compactness and multiband operation [13-14], e.g., Koch fractal antenna [15], Sierpinski triangle fractal [16], Hilbert fractal antenna [17], and so on. In this letter, the modified Minkowski fractal is employed to design a CP reader antenna for RFID applications. Fig. 1 illustrates the generation procedure for the Minkowski fractal, which is reconstructed by replacing the central zone with indentation length by indentation width. Here indentation factor (IF) can be defined as the ratio of indentation width to indentation length [18]. It determines the internal structure of Minkowski fractal obviously. It was found that the Minkowski fractal patch antenna exhibits good characteristics of size reduction and resonating frequency decline. Moreover the resonant frequency drops gradually as the increase of iteration order. However, if the order of iteration increases past two, the resonant frequency reduces very slowly, and both the complexity of fractal structure and the difficulty of manufacturing ascend sharply. Thus generally the iteration order of Minkowski fractal is no more than two. In our design the iteration order equals to one. The configuration of the proposed antenna is depicted in Fig. 2.

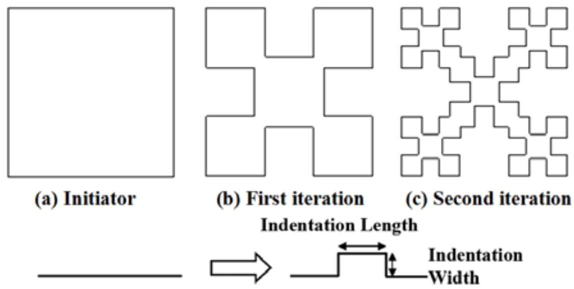


Fig. 1. Geometries of Minkowski fractal (0~2 order).

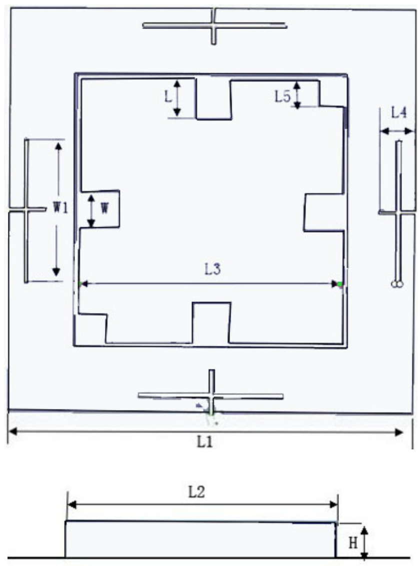


Fig. 2. Configuration of the proposed antenna.

This antenna consists of three layers. The top layer is a radiating square patch of side length L3, which is a modified Minkowski fractal (IF=L/W) with two square truncations of side length L5 at diagonal corners for implementing CP performance. The FR4_epoxy with relative dielectric constant of $\varepsilon_r = 3.6$, loss tangent of $\tan\delta = 0.017$, square side length L2 and thickness H, is selected as substrate and is placed at the middle layer. The square ground plane of side length L1 is placed at the bottom layer. For improving the gain of the designed antenna, the cross-shaped grooves with length L4 and width W1 (see Fig. 2) is opened on the square ground plane. There are usual two feeding methods for CP antenna, i.e., single feed and hybrid feed. The hybrid feed is more complex and expensive than the single feed. Therefore the single feed is considered in our design. The coaxial cable (50 Ω) is split into two wires (screen and core) and they are connected to the top patch and the ground plane separately. The advantages of the designed antenna are simpler structure, lower cost and easier fabrication when compared with other reader antennas [19-20]. The initial sizes for the designed antenna are listed in Table 1, in which L6 denotes the spacing between feeding point and the origin of antenna model, and L7 represents the width of the slot on the ground plane.

Table 1. Initial sizes of the proposed antenna.

Parameter	**L**	**L1**	**L2**	**L3**	**L4**	**L5**
Value (mm)	10	112	75	73	10	7
Parameter	**L6**	**L7**	**W**	**W1**	**H**	
Value (mm)	17	1	10	40	4.5	

3. Analyses and Optimization

HFSS (high frequency structural simulator), which is based on the finite element method, is an interactive software package for calculating the electromagnetic behavior of a structure. It is one of several commercial tools used for antenna design. With the help of HFSS 13, the proposed antenna is analyzed and then optimized. The simulation model for the designed antenna is illustrated in Fig. 3.

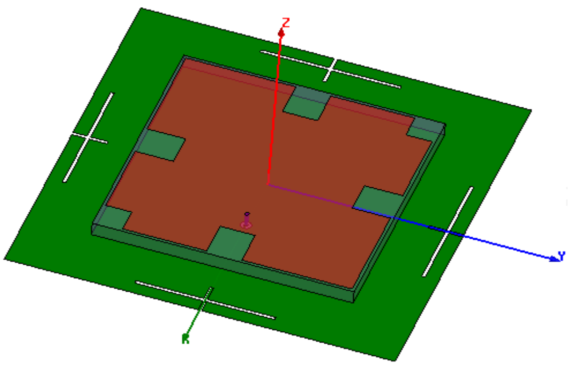


Fig. 3. Simulation model for the designed antenna in HFSS.

The simulated return loss of proposed structure is depicted in Fig. 4. It is evident that the simulated result exhibits an impedance bandwidth (S11<=−10 dB) of 34 MHz (3.6 %) that satisfies the requirements of broadband basically. However, the central frequency point is located at 928 MHz (S11=−24.3 dB) that is out of range of 920~925 MHz. Fig. 5 shows the input impedance as a function of frequency. The input impedance at desired frequency point of 920 MHz is Z_{reader}=(66.6+j7.1) Ω, which does not proper mach to 50 Ω. From Fig. 4 and Fig. 5, it can be seen that the simulated results do not achieve the requirements of RFID reader applications. Thus the given structure must be optimized. Now let us analyze the effect of parameters on performances of proposed antenna. The parameters demanded to be individually analyzed are as follows: indentation width L, patch length L3, length of square truncation L5, spacing between feeding point and the origin of antenna model L6, and substrate thickness H.

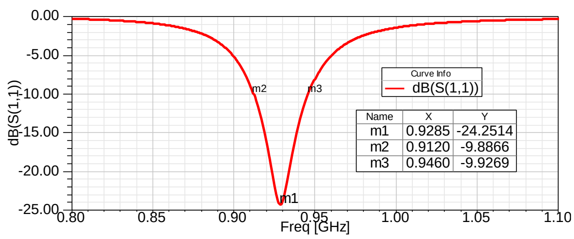


Fig. 4. Retrun Loss versus frequency characteristic of initial antenna.

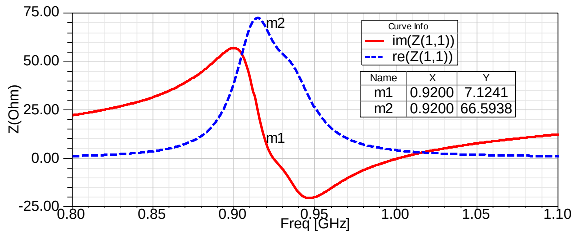
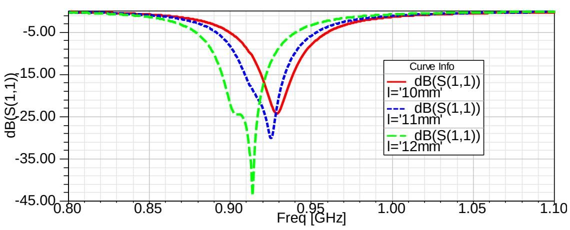
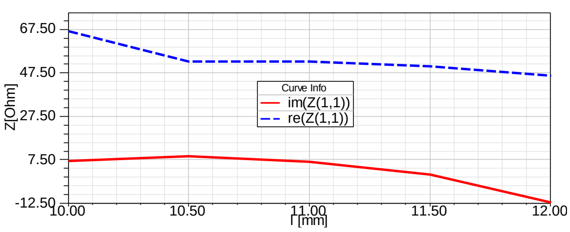


Fig. 5. Input impedance versus frequency characteristic of initial antenna.

In order to study the effect of indentation width L on return loss and input impedance, we suppose that only parameter L changes from 10 mm to 12 mm and other parameters remain unvaried. Fig. 6 shows the influence of indentation width L on return loss and input impedance, respectively.



(a) Return loss

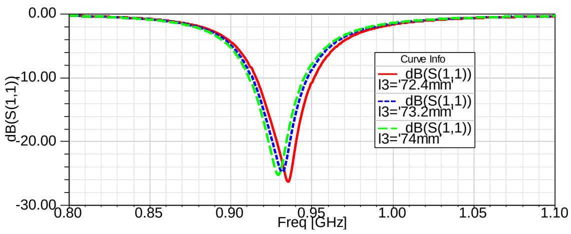


(b) Input impedance

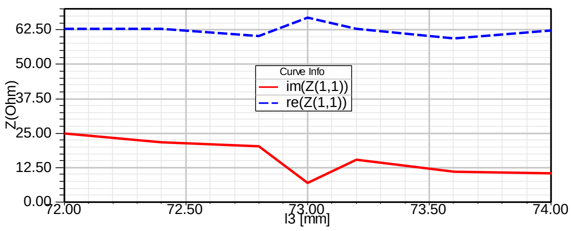
Fig. 6. Influence of parameter L on the antenna performances.

It is found that within 0.8~1.1 GHz the resonating frequency drops gradually with the increase of indentation width L. The real part of input impedance reduces slowly from 66.6 Ω to 45.9 Ω as L increases from 10 mm to 12 mm. Nevertheless, the imaginary part waves from 7.1 Ω (inductive) to - 11.8 Ω (capacitive).

Next the effect of patch length L3 on antenna performances is investigated, as depicted in Fig. 7. It can be seen that the return loss S11 and relative bandwidth within 0.8~1.1 GHz is slightly affected by L3 of 72 mm to 74 mm. The resistance remains unchanged nearly and the reactance exhibits a tendency of lessen and exists a minimum between 72.75 mm and 73.25 mm.



(a) Return loss

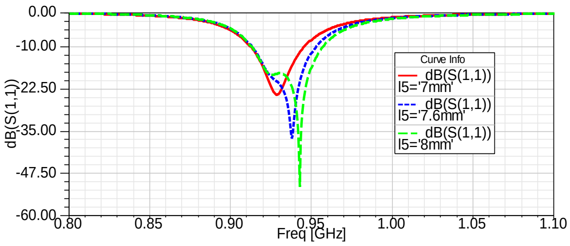


(b) Input impedance

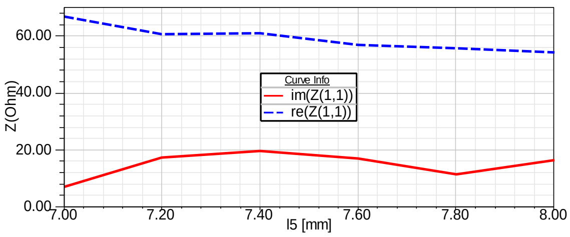
Fig. 7. Effect of patch length L3 on antenna performances.

The investigation of length of square truncation L5 on return loss and input impedance is given in Fig. 8. One can find that the value of resonating frequency rises and return loss descends as the parameter L5 ranges from 7 mm to 8 mm, but the relative bandwidth almost remains constant. It can be seen from Fig. 8(b) that the real part of input impedance has a little decrease but the imaginary part shows a little increase and waves between 7.1 Ω and 19.7 Ω.

The examination of the spacing between feeding point and the origin of antenna model L6 is conducted, as illustrated in Fig. 9. We can see that within 0.8~1.1 GHz the resonating frequency is scarcely influenced by parameter L6, but the value of return loss decreases while increasing the spacing L6 from 15 mm to 20 mm. It can be observed obviously from Fig. 9(b) that two curves exhibit the opposite tends. The real part of input impedance shows an up trend from 52.1 Ω to 76.8 Ω, but the imaginary part has a undulate trend from 16.8 Ω to 20.3 Ω. Thereupon, the impedance matching can be easily achieved by tuning the parameter L6.

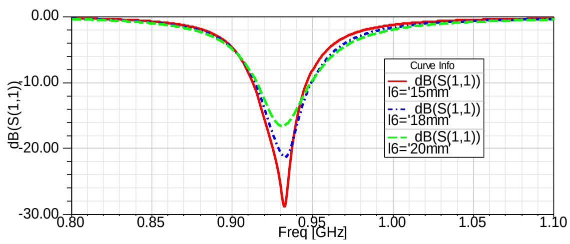


(a) Return loss

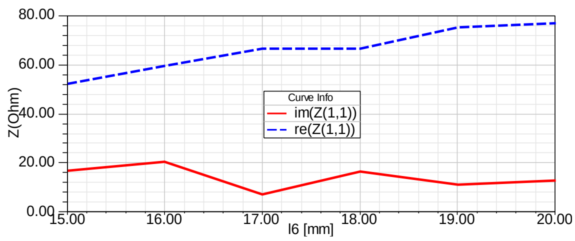


(b) Input impedance

Fig. 8. Influence of parameter L5 on antenna performances.



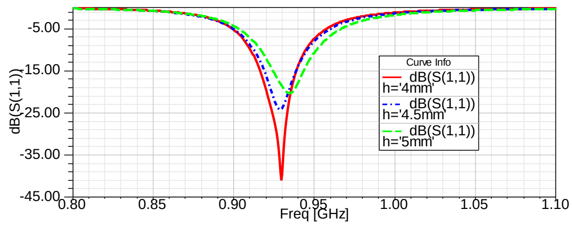
(a) Return loss



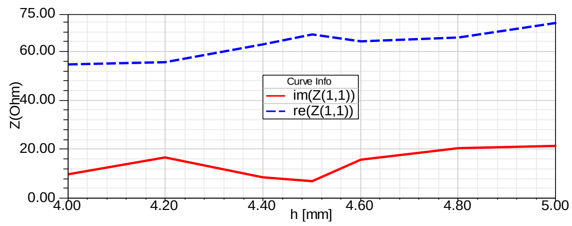
(b) Input impedance

Fig. 9. Effect of spacing L6 on antenna performances.

Lastly, we study the influence of substrate thickness H on antenna performances, as described in Fig. 10. The resonance frequency varies slightly but return loss S11 corresponding to the resonating frequency increases when parameter H grows from 4 mm to 5 mm. The resistance increases from 54.5 Ω to 71.5 Ω, but the reactance slightly waves from 9.9 Ω to 21.5 Ω. One can also tune the substrate thickness H to achieve the purpose of impedance matching of 50 Ω.



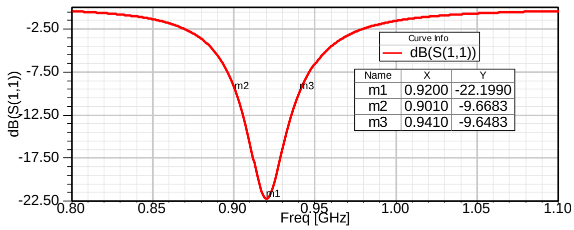
(a) Return loss



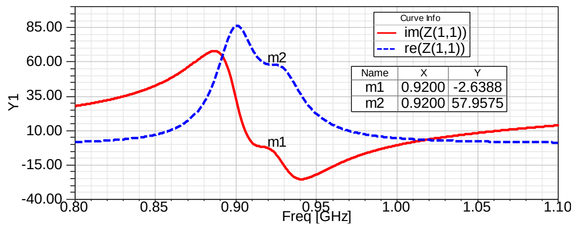
(b) Input impedance

Fig. 10. Effect of substrate thickness H on antenna performances.

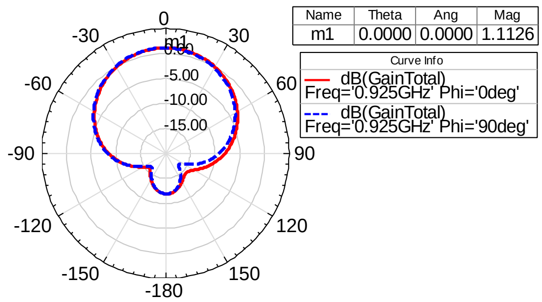
Based on analysis above, we can know that parameters L and L5 have a great effect on the resonating frequency, and the return loss is affected heavily by the parameters L3, L6 and H, and the input impedance is determined chiefly by the parameters L, L5, L6, and H. Consequently through the repeated optimization, the optimal dimensions for the proposed antenna are obtained. They are L=11 mm, L3=73.2 mm, L5=7.5 mm, L6=18 mm, H=4.9 mm, and other sizes remain unchanged. The optimal results for the proposed antenna are given in Fig. 11. The requirement of return loss S11<=−10 dB must be satisfied in RFID applications. It may be observed clearly from Fig. 11(a) that the optimized antenna exhibits a bandwidth (S11<=−10 dB) of 901~941 MHz (4.3 %) with central frequency of 920 MHz. In general, the coaxial cable with input impedance of 50 Ω is used as the feed line of reader antenna. It is thus employed to back feed the designed antenna. From Fig. 11(b) one can get the input impedance at resonating frequency of 920 MHz is Z_{read}=(57.9-j2.6) Ω, which is close to the impedance value of 50 Ω. This indicates that there exist a proper impedance matching between the optimized antenna and coaxial cable. Gain is a very important index in measuring antenna performances. At 920 MHz, Fig. 11(c) displays the 2D radiation patterns in the x-z and y-z planes, and the 3D gain pattern is shown in Fig. 11(d). It can be discerned that the patterns in x-z plane and y-z plane overlap nearly and the maximum gain of G=1.12 dB locates at the direction of $\theta = 0^\circ$, $\varphi=0^\circ$. On the upper half plane the optimized antenna exhibits a spherical radiation and has an excellent symmetry. Additionally, AR is a key index that represents a CP degree and not less than 0 dB, i.e., AR>=0 dB. When AR=0 dB, it means the antenna works at pure CP state. In practical applications, the range of 0<=AR<=3 dB is acceptable for the CP antenna. The AR versus frequency of the optimized antenna is depicted in Fig. 11(e). It is seen that the AR equals to 1.16 dB at the central frequency of 920 MHz. In short, the performances of the optimized antenna can meet the requirements of RFID system.



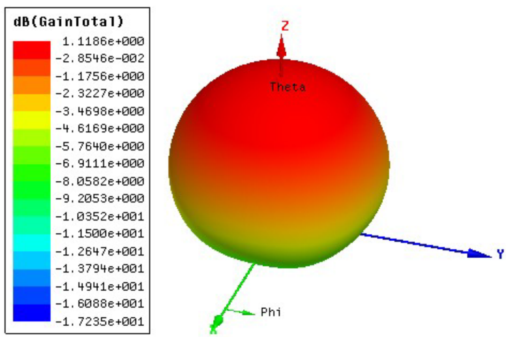
(a) Return loss S11 versus frequency



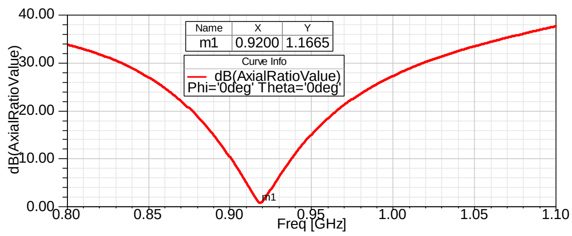
(b) Input impedance versus frequency



(c) 2D radiation patterns in X-Y and Y-Z planes



(d) Simulated 3D gain pattern



(e) AR versus frequency

Fig. 11. Simulated results of the optimized antenna.

4. Summary

In this article we have successfully designed a CP antenna for UHF RFID reader applications. Three measures are adopted to achieve the requirements of design. First way is to use a modified Minkowski fractal as radiating element for compacting dimension and broadening bandwidth. The second is to utilize the square truncation to obtain the circular polarization. In order to promote the gain of the proposed antenna, the slot-opened technology is employed lastly. This antenna has the advantages of simplicity, easy manufacture, and miniaturization. The analysis of the proposed structure is carried out by HFSS. The numerical results demonstrate that performances of the optimized antenna are acceptable for practical RFID applications.

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