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Dual-band dipole antenna for 2.45 GHz and 5.8 GHz RFID tag application

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Abstract: In this paper, a dual-band dipole antenna for passive radio frequency identification (RFID) tag application at 2.45 GHz and 5.8 GHz is designed and optimized using HFSS 13. The proposed antenna is composed of a bent microstrip patch and a coupled rectangular microstrip patch. The optimal results of this antenna are obtained by sweeping antenna parameters. Its return losses reach to −18.7732 dB and −18.2514 dB at 2.45 GHz and 5.8 GHz, respectively. The bandwidths (Return loss <=−10 dB) are 2.42~2.50 GHz and 5.77~5.82 GHz. And the relative bandwidths are 3.3% and 0.9%. It shows good impedance, gain, and radiation characteristics for both bands of interest. Besides, the input impedance of the proposed antenna may be tuned flexibly to conjugate-match to that of the IC chip.

Keywords: RFID, Dipole Antenna, Dual Frequency, Tag

1. Introduction

In the last few years, the wireless identification and communications technology has been developing rapidly [1]. Radio frequency identification (RFID) is obtaining a growing interest to wirelessly track and identify objects due to its cheapness and reliability [2-4]. Now RFID finds many applications in lots of areas like pallet tracking, electronic toll collection, parking lot access, information industry, medical and defense [5-7]. Generally speaking, in RFID system different frequency spectrums are allocated to different countries or regions. For instance, 840.5~844.5 MHz and 920.5~924.5 MHz in China, 865~867 MHz in India, 902~928 MHz in Argentina and America, 866~869 MHz and 920~925 MHz in Singapore, and 952~955 MHz in Japan, and so on [6, 7]. With the fast development of global economy, the exchanges of products made from different countries have become more and more frequent. In order to make the tag attached to the products effective, the RFID system should operate in dual-band or multi-band regime [8-12]. An RFID system consists of a transponder (tag), which stores an identification code, and of a detector (reader) that is capable to retrieve the identity of the tags through a wireless wave. The passive RFID tag usually is composed of a tag antenna and an IC chip [1, 2]. Tag antenna is a key part of RFID systems. Therefore, a design of dual-frequency or multi-frequency tag antenna is of great importance for RFID application in different countries. In the current paper, a novel dual-frequency tag antenna, i.e., 2.45 GHz and 5.8 GHz, is presented. It is composed of a bent microstrip patch and a rectangular microstrip patch. The rest of the present paper is organized as follows. Antenna design is described in Section 2. Section 3 presents the analysis and optimization results of the designed antenna. We give a brief conclusion in the last Section 4.

2. Antenna Configuration

The configuration of the proposed dual-band dipole antenna is illustrated in Fig. 1. This antenna works at 2.45 GHz and 5.8 GHz for RFID tag application. The basic structure of the designed antenna is composed of a bent and a rectangular microstrip patch. The common material FR4_epoxy, with relative dielectric constant $\varepsilon_r = 4.4$, loss tangent $\tan\delta = 0.017$ and thickness h =0.5 mm, is considered as substrate. The IC chip is connected to the bent microstrip patch, and the power exchanges between the bent and rectangular patch by coupling through the gap with length of a and width of e. The initial sizes of the proposed antenna are given as follows: the length and width of the rectangular microstrip is a =33 mm and g =2 mm; the length and width of the bent microstrip patch is b =8 mm and c =1 mm, respectively; the space of d =4 mm, and the gap width of e =1 mm.

The proposed antenna is analyzed and optimized by using Ansoft simulation software High Frequency Structure Simulator (HFSS) [13]. This work is given in Section 3.

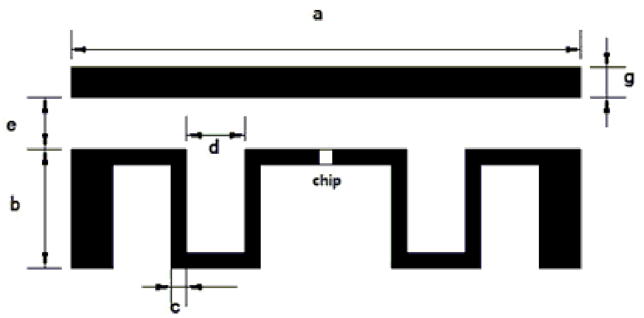

Fig. 1. *Configuration of dual-band tag antenna.*

3. Analysis and Optimization

HFSS is an interactive software package for calculating the electromagnetic behavior of a structure. It is a famous electromagnetic simulation tool used for antenna design, and the design of complex RF electronic circuit elements including filters, transmission lines, and packaging. In the present paper, the HFSS is thus employed to analyze and optimize the proposed antenna. Fig. 2 shows the return loss S11 of the initial antenna as a function of frequency. It can be seen clearly from Fig. 2 that the initial antenna has two resonating frequency points within 1~7 GHz, the first one at 2.39 GHz (S11=-10.6107 dB) and the second at 5.86 GHz (S11=-33.6484 dB). Neither of them is located at the expectation frequency points of 2.45 GHz and 5.8 GHz. The relative bandwidths (S11<=-10dB) of the first and second resonating frequencies are (2.40-2.39)/2.39=0.42% and (5.88-5.84)/5.86=0.68%, respectively. Obviously, they do not satisfy the requirements of RFID applications.

Proper impedance matching must be considered in antenna design. Common antenna is usually connected to coaxial cable with impedance of 50 Ω or 75 Ω. Consequently the value of input impedance of common antenna is adjusted to 50 Ω or 75 Ω. However in RFID system the tag antenna is linked to the IC chip whose input impedance may be an arbitrary value [14] and is thus no longer 50 Ω or 75 Ω. In order to achieve the purpose of maximum power transmission and improvement tag performance, proper impedance matching between the tag antenna and the IC chip is of considerable importance in RFID applications. Because the design and manufacturing of new IC chip is a big and costly venture, the input impedance of tag antenna is tuned to conjugate match to a specific IC chip available in the market [6]. The IC chip is usually a capacitive element and its input impedance is a complex value. We suppose that the input impedance of IC chip is Z_{chip}=(25-j136) Ω in our work. The value of tag antenna impedance is a function of frequency, as depicted in Fig. 3. One can observe that the values of input impedances are Z_1=(15.4+j160.7) Ω at 2.45 GHz and Z_2=(20.8+j103.3) Ω at 5.8 GHz. The purpose of conjugate matching between tag antenna and the IC chip do not achieve obviously. Accordingly, it can be found from Figs. 2 and 3 that both resonating frequency points and input impedances do not meet the design requirements yet. Therefore, the initial sizes of tag antenna must be optimized. Next, the effects of antenna sizes on their performances are analyzed.

In order to optimize the performances of initial antenna, the relevant parameters, like rectangular microstrip patch length a and width g , bent microstrip patch length b and space d , and the gap width e , are examined. Firstly, to investigate the influence of rectangular microstrip patch length a on antenna performances, one can assume that others parameters of initial antenna remain unchanged and parameter a varies from 30 mm to 36 mm only. Fig. 4 displays the return loss S11 as a function of frequency. It can be observed that within 1~7 GHz the larger the length a is, the lower are two harmonic frequencies. The effect of length a on antenna input impedance is depicted in Fig. 5. It can be found that at 2.45 GHz, the value of resistance increases from 13 Ω to 26 Ω and the reactance adds from 64 Ω to 237 Ω; and at 5.8 GHz, the resistance varies from 16 Ω to 20 Ω and the reactance changes from 16 Ω to 154 Ω, when length a varies from 30 mm to 60 mm. Therefore, a conclusion can be drawn that the values of resistance and reactance rise with the increase of length a and grow faster and faster.

Secondly, the effect of width g on antenna performances is investigated, as illustrated in Figs. 6 and 7. One may find that the return loss S11 within 1~7 GHz and input impedance remain unchanged nearly when the value of width g varies from 1 mm to 3 mm.

Now, let us examine the effect of bent microstrip patch length b on resonant frequency and input impedance, as shown in Figs. 8 and 9, respectively. One can observe from Fig. 8 that the harmonic frequency decreases with length b increasing. We can also find from Fig. 9 that not only at 2.45 GHz but also at 5.8 GHz the values of resistance and reactance increase as the length b increases.

Figs. 10 and 11 show the influence of bent microstrip patch space d on return loss and input impedance. Within 1~7 GHz the resonant frequency decreases with the increase of space d . Moreover, the change quantity of the second resonant frequency is larger than that of the first one. At 2.45 GHz, the real and imaginary parts of input impedance increase slowly as space d raise from 2 mm to 3 mm; but they also decrease slowly when the value of space d increases from 3mm to 4mm. Similarly, at 5.8 GHz the real component of input impedance is almost unvaried, and the imaginary component increases from -31 Ω to 86 Ω when space d varies from 2 mm to 4 mm.

Lastly, the influence of gap width e is analyzed as depicted in Figs. 12 and 13. Within 1~7 GHz the first harmonic frequency rises but the second does not change almost while the gap width e increases from 0.5 mm to 1.5 mm. At 2.45 GHz, the imaginary part of input impedance reduces from 250 Ω to 122 Ω but the real part remains unchanged when increasing the space d from 0.5 mm to 1.5 mm. And the change of input impedance at 5.8 GHz is very small.

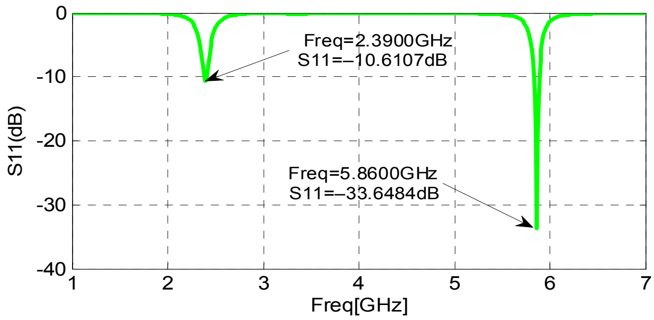

Fig. 2. *Return loss S11 of initial antenna.*

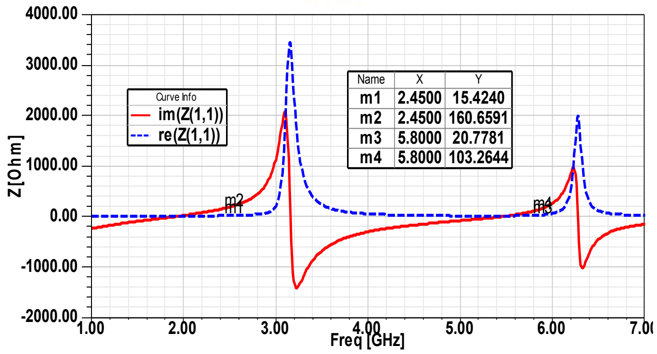

Fig. 3. *Input impedance of initial antenna.*

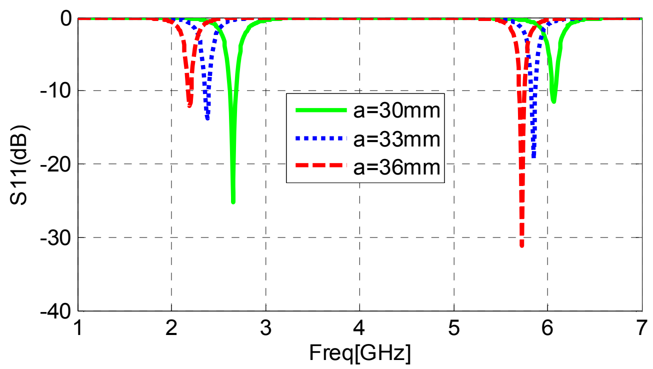

Fig. 4. *Influence of length a on resonating frequency.*

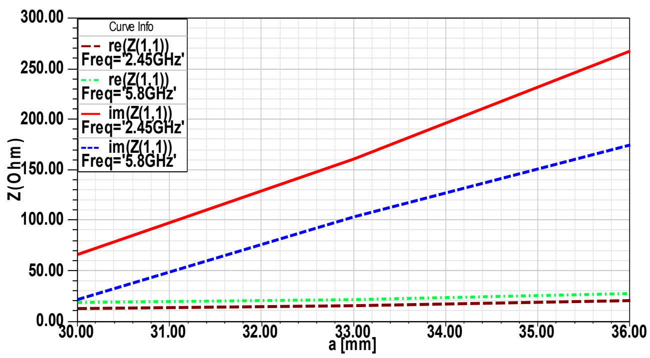

Fig. 5. *Effect of length a on input impedance.*

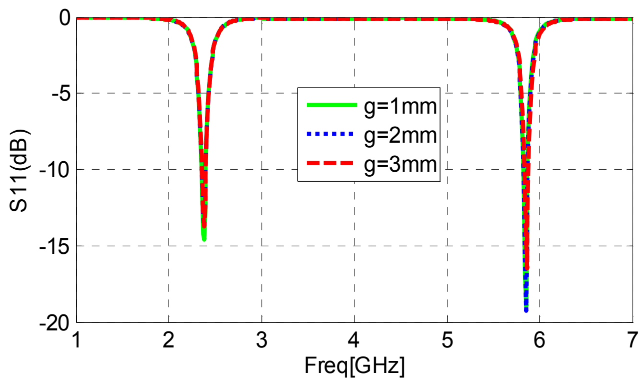

Fig. 6. *Return loss S11 with different width g.*

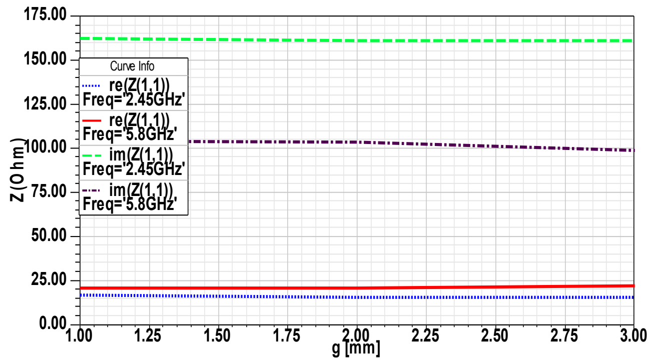

Fig. 7. *Input impedance with different width g.*

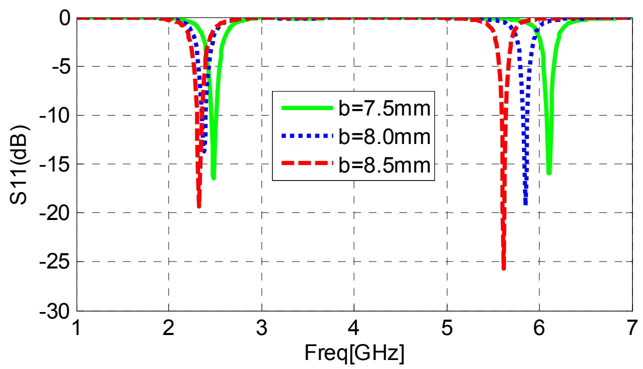

Fig. 8. *Influence of length b on resonating frequency.*

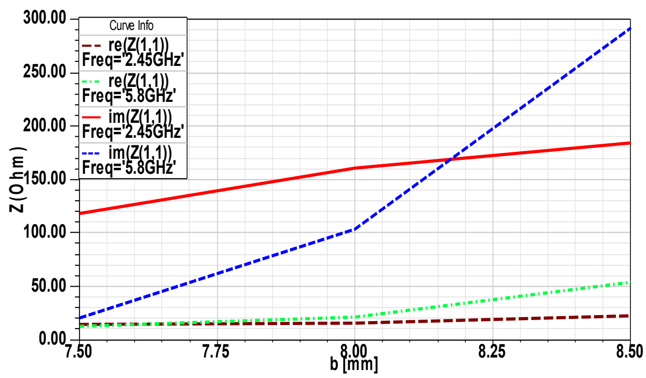

Fig. 9. *Effect of length b on input impedance.*

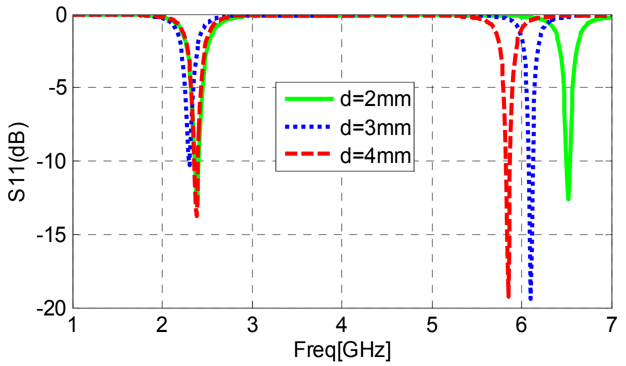

Fig. 10. *Influence of space* d *on resonating frequency.*

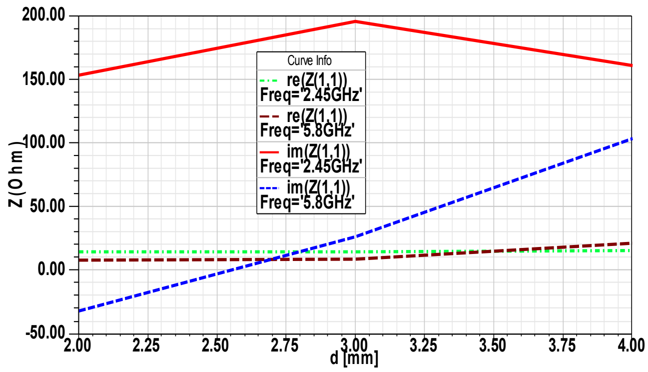

Fig. 11. *Effect of space* d *on input impedance.*

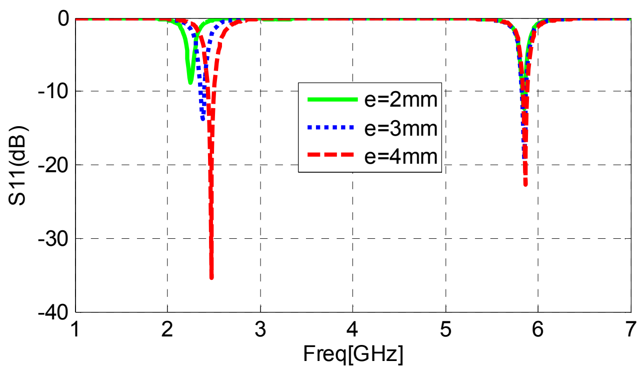

Fig. 12. *Influence of gap width* e *on resonating frequency.*

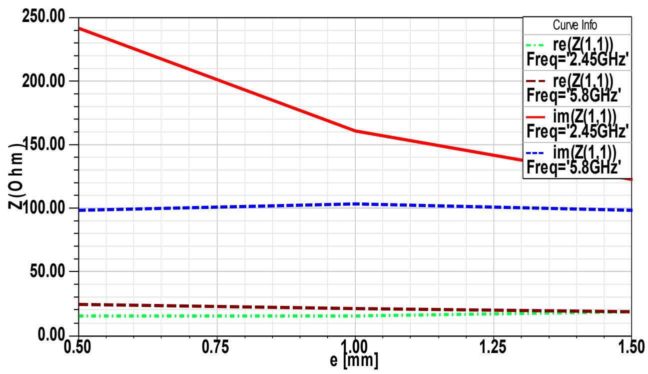

Fig. 13. *Effect of gap width* e *on input impedance.*

On the basis of analysis above, we find that the gap width e only affects on the first resonating frequency. We thus can drop the second resonating frequency point to 5.8 GHz by increasing the rectangular microstrip length a. Then the first resonating frequency can be tuned to 2.45 GHz by changing the value of gap width e. In a word, by optimizing the sizes of initial antenna repeatedly, the optimal dimensions of the proposed tag antenna are obtained at last. They are as follows: $a = 34.7mm$, $b = 8mm$, $c = 1mm$, $d = 4mm$, $e = 3.5mm$, $g = 2mm$, $h = 0.5mm$.

The return loss S11 as a function of frequency for the optimized tag antenna is illustrated in Fig. 14. It can be seen clearly that at the range of 1~7 GHz the antenna has two resonating frequency points, one at 2.45 GHz (S11=-18.7732 dB) and the other at 5.8 GHz (S11=-18.2514 dB). For the first resonating frequency of 2.45 GHz, the absolute bandwidth (S11<=-10dB) reaches to 80 MHz (2.42~2.50 GHz) and the fractional bandwidth is (2.50-2.42)/2.45=3.3%. For 5.8 GHz, the absolute and fractional bandwidths are 50 MHz and 0.9% respectively.

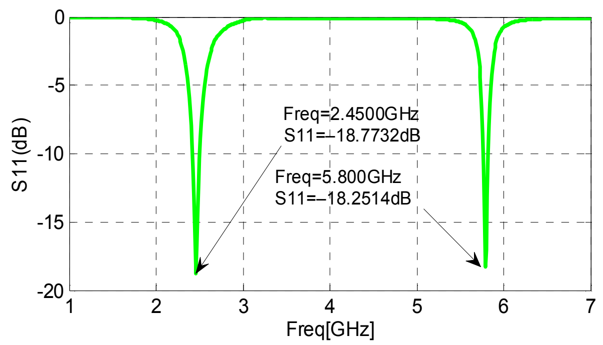

Fig. 14. *Return loss of optimized tag antenna.*

Fig. 15 presents the input impedance of the optimized tag antenna. It can be observed from Fig. 15 that the values of input impedance are Z1=(30.8+j132.1) Ω at 2.45 GHz and Z2=(20.2+j140.2) Ω at 5.8 GHz. Both are close to the conjugate value of Zchip=(25-j136) Ω, which is an assumed value of input impedance of the IC chip. This mean it has a good conjugate match between the IC chip and tag antenna. Generally, the resistance of most of RFID IC chips varies from 10 Ω to 30 Ω, and the reactance limits in the range of (100~300) Ω. Therefore, the purpose of conjugate matching can be achieved only by tuning the parameter a or b . This may meet the impedance matching requirement of most of RFID IC chips.

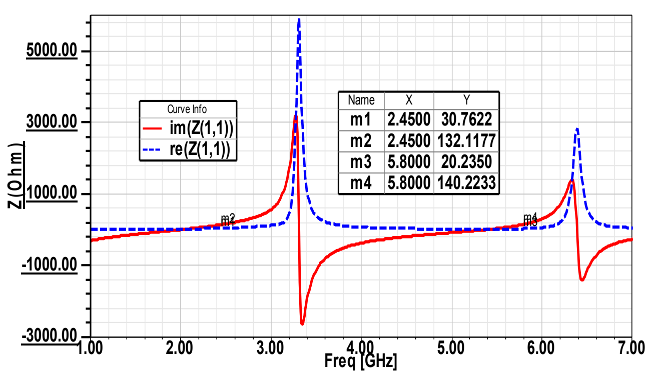

Fig. 15. *Input impedance of optimized tag antenna.*

Antenna gain is an important index to measure antenna electric performance. The larger the total gain is, the farther the read range of RFID system become. The 3D gain patterns of the optimized tag antenna at 2.45 GHz and 5.8 GHz are displayed in Figs. 16 and 17, respectively. The values of maximum gain are 2.68 dBi at 2.45 GHz and 3.27 dBi at 5.8 GHz. These performance indexes meet the requirements of RFID applications. In order to observe the pattern more clearly, Fig. 18 illustrates the 2D radiation patterns in xz-plane ($\text{phi} = 0^{\circ}$) and yz-plane ($\text{phi} = 90^{\circ}$) at 2.45GHz. The radiation in xz-plane is maximum and omnidirectional, and yet in yz-plane is a poor directionality. The similar chart for 5.8 GHz is shown in Fig. 19. It can be seen from Fig. 19 that in xz-plane the radiation exhibits an approximation to omnidirectional pattern, but in yz-plane the sidelobe appears at $\theta = 0^{\circ}$ or $\theta = 180^{\circ}$.

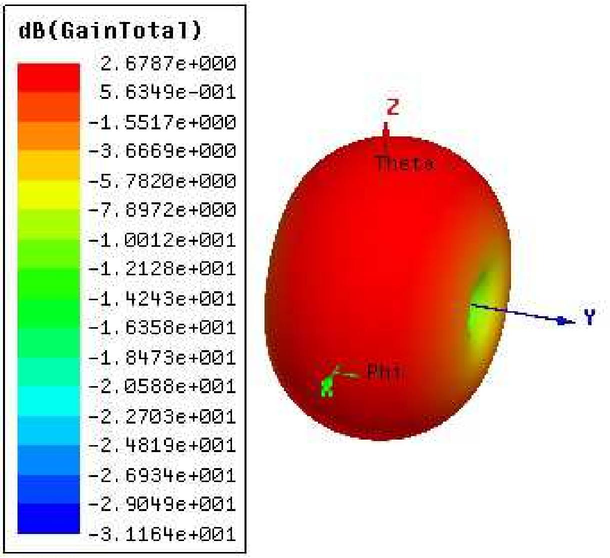

Fig. 16. *3D gain pattern at 2.45 GHz.*

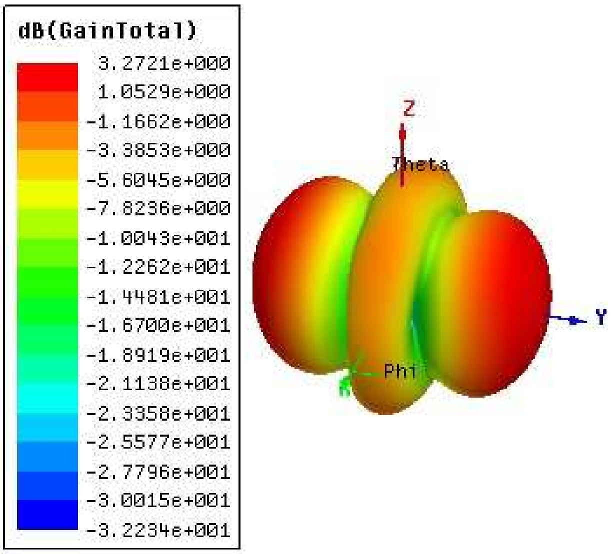

Fig. 17. *3D gain pattern at 5.8 GHz.*

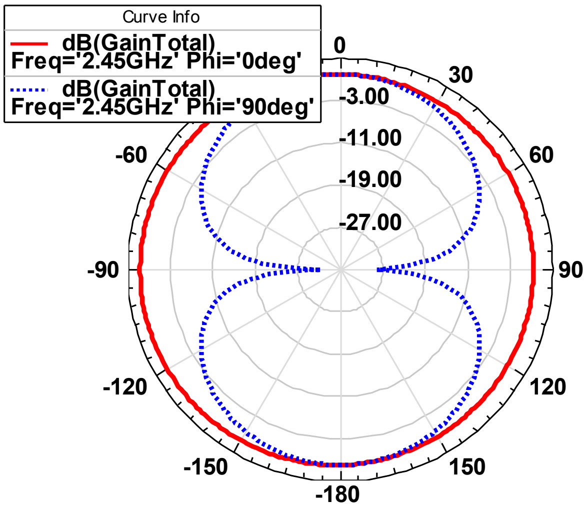

Fig. 18. *2D radiation patterns at 2.45 GHz.*

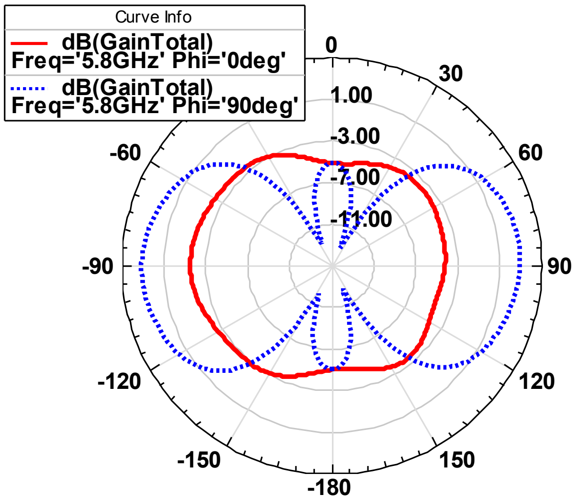

Fig. 19. *2D radiation patterns at 5.8 GHz.*

4. Conclusions

With the rapid development of RFID technology and applications, the operating frequency of tag antenna has been developing to microwave wavebands (2.45GHz, 5.8GHz). The design of tag antenna at these wavebands has become more and more important. In the present paper, the tag antenna with dual-band work frequency, i.e. 2.45GHz and 5.8 GHz, is proposed. Its performances are analyzed and optimized by using the HFSS. The simulation results demonstrate the designed tag antenna satisfy the application requirements of RFID system. It can find applications in traffic or logistics management.

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