A New UHF Anti-Metal RFID Tag Antenna Design With Open-Circuited Stub Feed

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***Abstract*—A new UHF RFID tag antenna used on the surface of a metallic object is proposed in this paper. In practical RFID applications, metals appear in many occasions. However, the UHF band is very sensitive to metal. When the tag antenna is near a metal, its impedance matching, radiation efficiency and directivity change and the reading distance is reduced so quickly that it cannot work. Therefore, it's necessary to employ some special handling or use a special tag so that it can be applied on the metal surface. After several rounds of design optimization and experimental validation, the designed tag antenna can work in the 920 MHz frequency band and is able to maintain a good performance on the metal surface. What's more, it has some advantages such as planar structure, small size and low cost. The proposed tag antenna provides an effective solution for metal identification applications in the UHF frequency band, which is validated by simulation results and practical test.**

I. INTRODUCTION

RFID is a kind of contactless automatic identification technology based on radio frequency principle. Utilizing radio frequency (RF) signals and their spatial coupling and transmission characteristics, RFID technology drives RFID tag circuit to launch its storage displacement encoder, automatically identify stationary or moving targets, and efficiently get targeting information and data. Compared with the bar code, it has many advantages such as a long read distance, non-visible identification, rapid reading and writing and so on. The combination of RFID technology with the Internet and wireless communications network can achieve the tracking of goods and sharing of information worldwide. Therefore, it has broad applications in many areas such as the logistics supply chain, production automation, public information services, traffic management and military.

RFID tag antenna is particularly sensitive to the environment [1], and the environment of a good location can bring a huge impact on the tag's antenna. In many occasions, we have to identify metal objects, such as motor vehicle, cylinders, containers, weapons and equipment and so on. When ordinary UHF tags are placed on the metal surface, the tag antenna impedance matching, radiation efficiency, and directivity change accordingly [2]. Therefore, the reading range will rapidly reduce, or even the tag cannot be read. Such metal-sensitivity greatly limits its application in the logistics industry. So we need to design anti-metal RFID tags to make it perform well on the metal surface.

The existing design methods of anti-metal tag are as follows: (1) adjusting the distance between the tag antenna and the metal surface; (2) inventing electromagnetic wave absorbing film [3]; (3) employing electromagnetic band gap (EBG) structure [4]; (4) using special anti-metal tag antenna design methods. Adjusting the distance will increase the size of the antenna. It is not convenient because there is no uniform method of adjustment. Most of the high frequency electromagnetic wave absorbing film costs a lot. So it's not an economical way to be widely used in the UHF band. EBG structure can inhibit a particular band of electromagnetic wave propagation to reduce the sidelobe level and increase the gain, but the structure of production is too complicated. So it is not conducive to production.

In this paper, we present an anti-metal tag antenna structure which employs a microstrip antenna model, where the embedded feed is used to adjust the real and imaginary parts of the antenna impendance by changing the depth of embedding and the length of an open-circuited stub. Thus the antenna impedance with an imaginary part is realized to maximize the transmission efficiency. In addition, two rectangular gaps in a radiation patch are done to adjust the operating frequency. The remainder of this paper is organized as follows. In Section II, we describe the tag antenna model. In Section III, a new tag antenna structure is presented. Simulation results are shown in Section IV. Comparison between practical test results and simulation results is in Section V. Finally, we conclude in Section VI.

II. TAG ANTENNA MODEL

Currently, there are two kinds of popular anti-metal tag antenna using special anti-metal tag antenna design methods: the short-circuited stub structure [5], [6]and the open-circuited stub structure [7], [8]. The anti-metal tag antenna with the short-circuited stub structure, in which the radiation pins of the chip is connected to the radiation pins of the antenna, uses the short-circuited stub structure where the ground pin of the tag chip is connected to ground of the antenna through the stub. Compared to the anti-metal tag antenna with the short-circuited stub structure, the anti-metal tag antenna with the open-circuited stub structure can realize a big reactance value (i.e. the imaginary part of impendance) which can be matched to RFID IC chip.

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We choose the microstrip antenna as the antenna model and propose a new anti-metal tag antenna with the open-circuited stub structure. On one side of the dielectric substrate whose thickness is much smaller than a wavelength, we cover the metal radiation sheet whose length is shorter than a half wavelength in the dielectric substrate. On the other side of the dielectric substrate, we cover the thin metal layer as a ground plane to form a microstrip antenna. The microstrip antenna is small, has a light weight and is easy to be made. Since we take the metal ground plane into consideration, when we put the antenna on metal surface, its performance will improve significantly.

According to transmission line theory, we know when the impedance of the antenna is conjugately matched with that of RFID IC chip, RF performance is the best, and reading range of tag antenna is the largest. Therefore, in order to be able to easily adjust the impedance of the antenna to a better impedance matching, we select the embedded microstrip feed.

A radiation patch, a substrate and a grounded conductor form a cavity resonator. The length of the radiation patch is the resonant length, which is approximately given by

$$L = 0.49 \times \frac{\lambda}{\sqrt{\varepsilon_r}} = 0.49 \times \frac{c_0}{f_0\sqrt{\varepsilon_r}} \quad (1)$$

where λ is the wavelength at the resonant frequency of f in free space and c_0 is speed of light and ε_r is the relative permittivity of the substrate. If f_0= 920 MHz and $\varepsilon_r = 4.6$, then $L = 74.5$ mm.

When the substrate medium of the tag antenna is selected, the resonant frequency which is decided by length of the radiation patch of the tag antenna is unchangeable, and the range of the adjustment of input impedance is limited.

III. Tag antenna structure

Two-dimensional geometry of the tag antenna is shown in Fig. 1. Top view and bottom view of the proposed tag antenna are shown in Fig.1(a) and Fig.1(b), respectively. The existing tag antenna is shown in Fig.1(c) [7]. Fig.1(d) shows the detailed size of L_2. Three-dimensional structure of the proposed tag antenna, which consists of an antenna radiating surface, a stub and a metallic ground plane, is shown in Fig. 2. We choose an FR4 substrate whose relative permittivity is $\varepsilon_r = 4.6$. The size of the substrate is $L_0 \times W_0 \times H_0 = 140\text{mm} \times 40\text{mm} \times 2\text{mm}$, where L_0, W_0 and H_0 denote the length, the width and the thickness of the tag antenna, respectively.

The antenna's radiating surface located on the top of the substrate is smaller than the substrate. The length of the antenna's radiating surface is $L_1 = 73$ mm in our tag antenna. The width W_1 on the top view of the tag antenna is 26 mm. The back of the substrate is a reference ground which is all covered by copper. The initial embedded width is $W_3 = 10$ mm and the embedded depth is L_3. The width of the open-circuited stub is $W_2 = 3$ mm and its length is denoted by L_{stub}. L_2=L_{stub}+L_{slot}+L_{raised}. L_{slot} and L_{raised} denote the length of the slot and the length of the raised, respectively. By

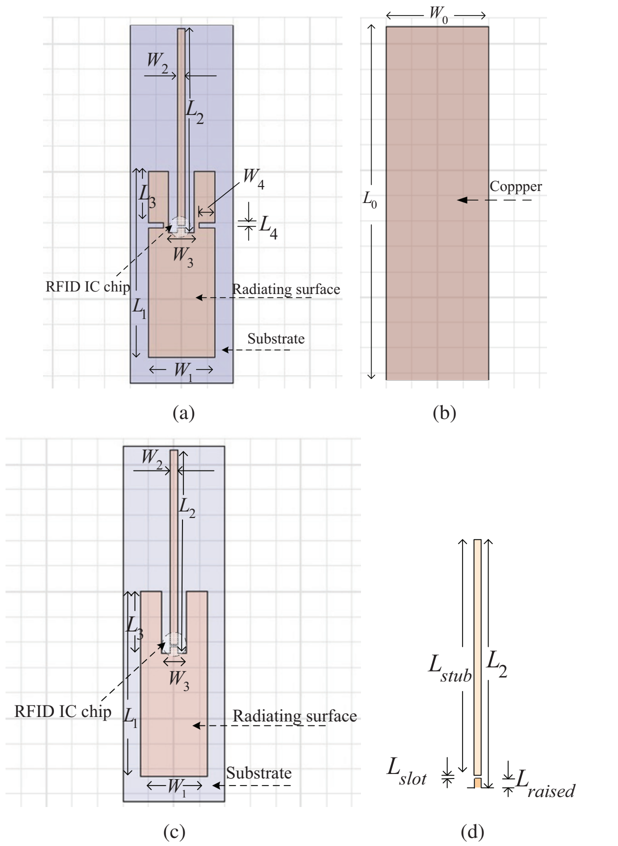


Fig. 1. Two-dimentional geometry of tag antenna. (a) Top view of the proposed tag antenna with two rectangular gaps of $L_4 \times W_4$. (b) Bottom view of the the proposed tag antenna. (c) Top view of the existing tag antenna without two rectangular gaps of $L_4 \times W_4$. (d) The detailed size of L_2.

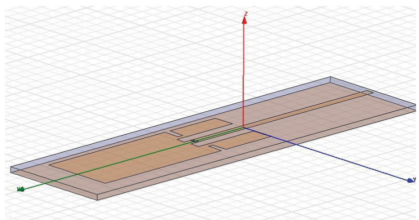


Fig. 2. Three-dimensional geometry of the proposed tag antenna.

changing the embedded depth L_3 and the length L_{stub} of the open-circuited stub, we get the impedance matching. Before adjusting the impedance matching, L_{slot}=1 mm, L_{raised}=2.46 mm. That is to say, L_2 only varies with L_{stub}.

In our proposed tag antenna, two identical rectangular gaps of $L_4 \times W_4$ are used, where $L_4 = 2$ mm, $W_4 = 6$ mm (W_4 and L_4 denote length and width of the gap, respectively.) We use this method to get an operating frequency (920 MHz) in the condition of impendance maching.

Before the antenna is designed, it is necessary for us to analyse the antenna theory model and the equivalent circuit of the antenna. In the following, we study the parameters guiding role and the influence of various parameters of the antenna. The transmission line model of the embedded-fed microstrip patch antennas is shown in Fig. 3. Antenna radiating surface and the open-circuited stub can be considered as two microstrip transmission lines. A feed port is located between them. We can see that the input impedance of the antenna is composed of the impedance of microstrip line and the impedance of radiating microstrip line in series form. Therefore, the input impedance of the antenna can be written as:

$$Z_{in} = Z_{in}^1(l_1) + Z_{in}^2(l_2) \tag{2}$$

where $Z_{in}^1(l_1)$ is the impedance of the antenna radiating microstrip line, and $Z_{in}^2(l_2)$ is the impedance of the open-circuited stub.

The equivalent transmission line length of antenna radiating surface is $l_1 \approx L_1$. Wavenumber is β and the characteristic impedance is Z_0^1. R_r denotes the radiating resistance of the radiating surface. Therefore, the input impedance of the radiating microstrip line is calculated as [9]:

$$Z_{in}^1(l_1) = Z_0^1 \frac{R_r + jZ_0^1 tan(\beta l_1)}{Z_0^1 + jR_r tan(\beta l_1)} \tag{3}$$

The length of the equivalent transmission line of the open-circuited stub is $l_2 \approx L_{stub}$. Its characteristic impedance is Z_0^2. The other end is also an open-circuited load Z_L. The impedance of the stub can be expressed as [9]:

$$Z_{in}^2(l_2) = -jZ_0^2 \frac{1}{tan(\beta l_2)} \tag{4}$$

Therefore, the input impedance of the tag antenna port is:

$$Z_{in} = Z_0^1 \frac{R_r + jZ_0^1 tan(\beta l_1)}{Z_0^1 + jR_r tan(\beta l_1)} - jZ_0^2 \frac{1}{tan(\beta l_2)} \tag{5}$$

It means that the input impedance of the antenna can be changed by adjusting the length of microstrip lines.

IV. Simulation Results

We use the electromagnetic simulation software HFSS12 as simulation tool. Simulation parameters are defined as follows: L_3 and L_{stub} are variables, 920 MHz is the center frequency, 620 MHz∼1220 MHz is the scanned region, 5 MHz is the sweep step, a metal plane attached on the surface of tag antenna is of size $200 \times 200 mm^2$. The chip we select is Alien's Higgs-3 [10].

As shown in Fig. 4, the parallel resistance of the Higgs-3 is 1500 Ω, and the parallel capacitance of the chip is 0.85 pF. The

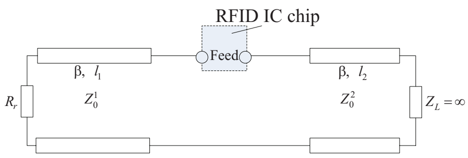


Fig. 3. Transmission line model of tag antenna.

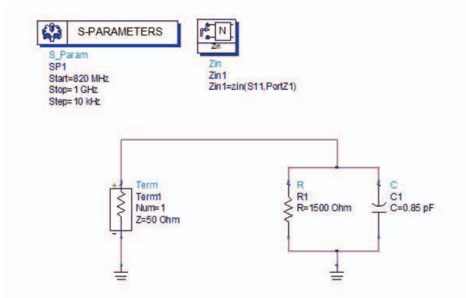


Fig. 4. The equivalent circuit diagram of RFID IC chip.

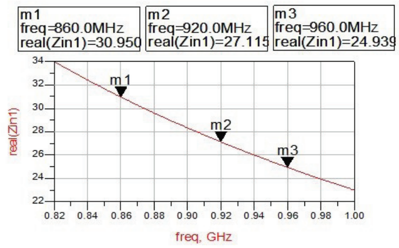


Fig. 5. The real part of Higgs-3's impedance (resistance) at different frequency.

equivalent circuit diagram of the RFID IC chip is shown in Fig. 4. We use the ADS software to draw the equivalent circuit and test it. When the operating frequencies are 860 MHz, 920 MHz, 960 MHz, the impedance of Higgs-3 is shown in Fig. 5 and Fig. 6. So we can conclude that the chip impedance at 920 MHz is about $Z = 27 - j200(\Omega)$.

In order to achieve impedance matching, the design goal of the UHF anti-metal tag antenna at 920 MHz should be $Z = 27 + j200(\Omega)$. In the following simulation, we focus on the effects by changing L_3 and L_{stub}. Referencing these changing trends, we optimize the parameters and get the best matching target.

First, setting L_{stub} as contant and changing L_3, we do the simulation. We can see the impact on input resistance of the tag antenna by L_3 in Fig. 7. When L_3 increases, the resistance of the antenna will reduce.

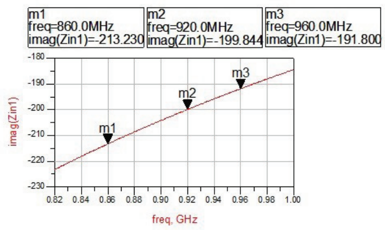


Fig. 6. The imaginary part of Higgs-3's impedance (reactance) at different frequency.

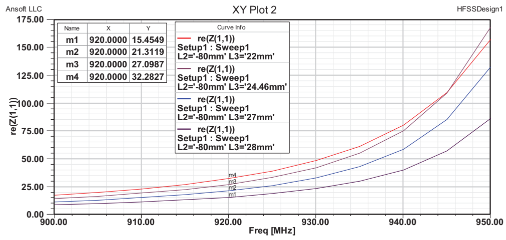


Fig. 7. The variation of antenna impedance (resistance) with different L_3 at $L_2 = 80$ mm.

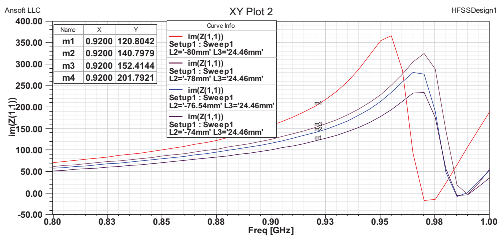


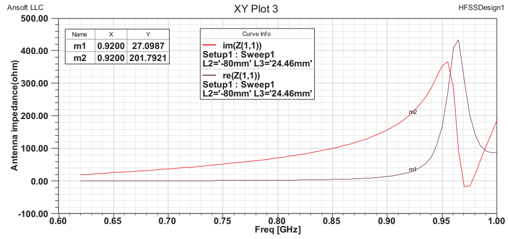
Fig. 8. The variation of antenna impedance (reactance) with different L_2 at $L_3 = 24.46$ mm

Then, we apply the same method to the simulation. We can get the input reactance of the tag antenna as shown in Fig. 8. When L_{stub} increases, the reactance increases accordingly. Therefore, we can draw the conclusion that increasing the length of the open-circuited stub can increase the reactance of the tag antenna. That is to say, its length can adjust the imaginary part value of impedance. By simulation, we change the size of L_3 and L_{stub} until we achieve the impedance matching. The final optimized results are $L_3 = 24.46$ mm and L_{stub} =76.54 mm (i.e.L_2=80 mm). With these sizes, the simulation curves of the antenna impedance are plotted in Fig. 9(a). The input impedance of the tag antenna at 920 MHz is about $Z = 27 + j201(\Omega)$, which is matched to that of Alien's Higgs-3 Chip. By simulating the model of Fig. 1(c), we also get Fig. 9(b). From Fig. 9(b), we can see the input impedance of the tag antenna at 920 MHz is $14.382+j166.419(\Omega)$, which is not matched to that of Alien's Higgs-3 Chip.

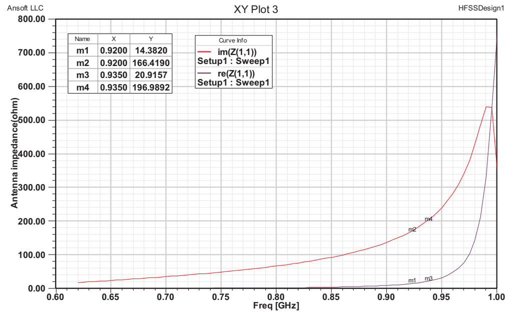
The curve of return loss of the proposed tag antenna is shown in Fig. 10(a). At 920 MHz, the minimum value of S_{11} is -47 dB. Obviously, we get a tag antenna with excellent performance because S_{11} is smaller than -15 dB. By simulating the model of Fig. 1(c), we also get the curve of return loss as shown in Fig. 10(b). From Fig. 10(b), we can see the operation frequency of the tag antenna is 935 MHz. As shown in Fig. 9(b), the input impedance of the tag antenna at 935 MHz is $20.9157 + j196.9892(\Omega)$, which is also not matched to that of Alien's Higgs-3 Chip.

With the optimal size, the proposed tag antenna radiation pattern at 920 MHz is shown in Fig. 11. We can see that the XOZ plane is equivalent to the plane of $\phi = 0°$ and the YOZ plane is equivalent to the plane of $\phi = 90°$.

We also find the antenna has good directivity features in

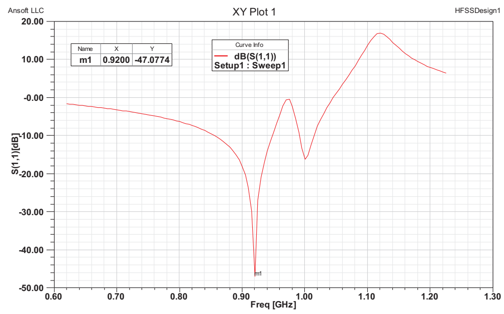


(a)

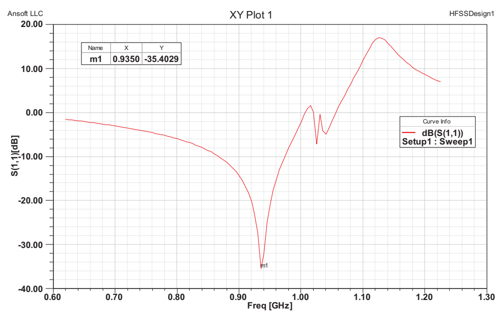


(b)

Fig. 9. Antenna impedance curves. (a) The proposed tag antenna with two rectangular gaps of $L_4 \times W_4$. (b) The tag antenna without two rectangular gaps of $L_4 \times W_4$.



(a)



(b)

Fig. 10. S_{11} of the tag antenna. (a) The proposed tag antenna with two rectangular gaps of $L_4 \times W_4$. (b) The tag antenna without two rectangular gaps of $L_4 \times W_4$.

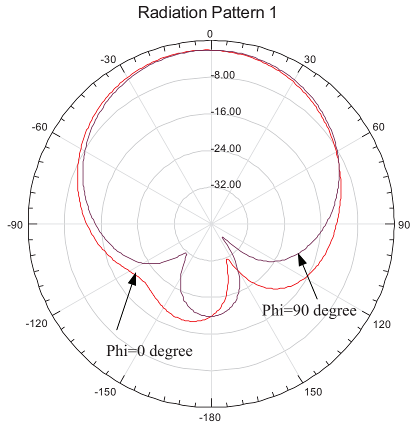


Fig. 11. Antenna radiation pattern of EH plane

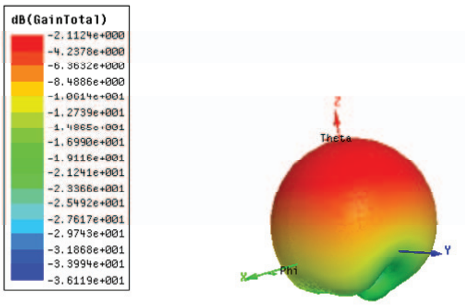


Fig. 12. Three-dimensional antenna pattern

the semicircle of E plane and H plane. The three-dimensional antenna pattern is shown in Fig. 12.

V. Comparison between Practical Test Results and Simulation Results

We made the practical tag antenna and used the Agilent E5071c network analyzer to test antenna VSWR, as shown in Fig. 13. The measured S_{11} values are shown in Fig. 14. It is close to its simulation data.

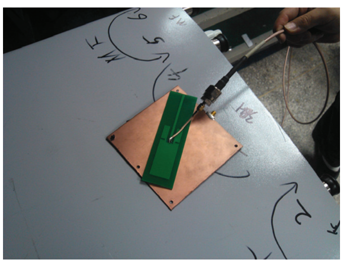


Fig. 13. Practical test

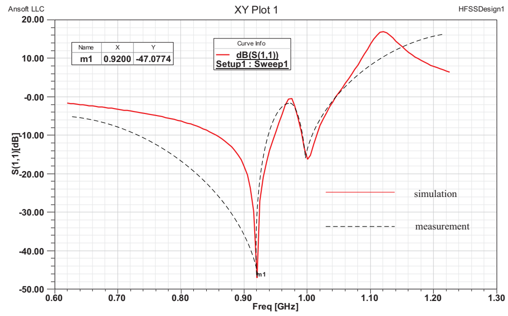


Fig. 14. S_{11} value

VI. Conclusion

In this paper we proposed a new anti-metal tag antenna with open-circuited stub embedded feed. Its reflection loss S_{11} is less than -15 dB at 920 MHz. It has a planar structure, including thin and low cost. Its maximum reading distance is more than 2.5 m. The proposed tag antenna can be used in the metal object management.

Acknowledgement

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