Design of UHF Tag Antenna Based on Internet of Things

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Abstract. This paper presents a detailed study of UHF RFID system on tag antenna design and performance measure methods based on antenna design knowledge and electromagnetic theory. The paper analyzes the characteristics of UHF tag antenna. The paper provides the compact UHF antenna that covers 840MHz~965MHz. The impedance of the antenna is easy to adjust. The tag antenna has a good performance which satisfies the design requirements. The paper studies the effect of the metallic ground on the tag antenna performance and designs a low-profile anti-metal UHF tag antenna. An antenna with a pair of F-slots is proposed. The antenna can achieve the good complex impedance matching between the antenna and chip. The simulation results show the anti-metal antenna has good working bandwidth from 840MHz to 965MHz and return loss $S_{11}<-10$dB.

1. Introduction
Internet of things (IOT) is a new technology revolution in the world. Internet of things can connect everything using information equipment of the RFID system, and life will be more intelligent. Recently, the Internet of things technology has been used in logistics transportation, environment protects, assets management, unmanned supermarket and so on. With the development of the internet of things, a lot of research has been done. These achievements are mainly focused on the low power design of RFID chip[1,2]. RFID tag theory research is proposed in[3,4], the research on distance and small size in the design of the RFID tag antenna design is presented[5,6]. Future research on UHF RFID tag antennas is mainly in the following aspects: UHF/UWB combined indoor certification and positioning system research[7,8]. Miniaturized, high-efficiency UHF RFID tag antenna is conformal to wearable devices and flexible, such as transparent wearable RFID tags are proposed in[9,10]. Research on RFID tag antenna combined with wireless sensors is proposed in[11,12]. Radio frequency identification technology has been used to identify objects and people for many years. Although its function is similar to bar code, it has many advantages in its application, such as reading far, anti-pollution, and carrying information. Low-frequency RFID has a good effect on penetrating water and metal. However, because the low-frequency propagation mode is in the form of inductive coupling, the low-frequency RFID read/write distance is similar to that of the reading antenna, so in most environments, the reading distance is no more than 1 m, usually several tens of centimeters. Working in the UHF band or the microwave band, because the mode of propagation is electromagnetic wave propagation, it has a farther reading distance. Labels are often attached to many objects as markers. When the tag antenna is in close contact with the metal, the conventional tag can hardly be read, and the metal has a great influence on the tag antenna.

As RFID applications continue to expand, the environment for label applications is more complex, such as many irons. Box-packaged articles, metal products, laboratory asset management, weapons and equipment, containers, etc. require tag antennas to have better adaptability to various
environments. Metals have the greatest impact on the performance of tag antennas in various environments. The paper analyzes the effects of metal backplanes on tag antennas and designs a metal-resistant UHF RFID tag antenna.

2. Theory of UHF RFID tag antenna
The UHF RFID system uses the radiation of electromagnetic waves for energy exchange and data communication. The reader sends a modulated command signal to the tag through the reader antenna, and the signal will be captured by the tag antenna. The signal will be re-modulated by the tag chip and sent to the reader antenna through the tag antenna. The reader extracts the corresponding tag information according to the received signal. It can be seen that the antenna plays a vital role in the entire communication process. It should be said that the antenna of the UHF RFID system determines the performance of the entire system. The content of the paper mainly explains the tag antenna design method.

The application field of UHF RFID system can be divided into two types: the first is to replace the barcode for the identification of a single small item. The tag antenna is required to be as small as possible and the cost is low. Most of tag antennas use folded dipole antennas. Second, it is applied to large and medium-sized systems such as assembly line systems, bulk product inspection, vehicle management, and security fields. The requirements of tag antenna performance, reading speed, and reading distance are relatively high. The working environment of the tag antenna is relatively complicated. These problems result in a large variety of tag antennas and poor versatility. The UHF RFID tag antenna is studied in the paper. The paper solves the problems of tag antenna complexity and poor environmental adaptability, and the tag antenna can effectively and stably work on the surface of metal and non-metallic items. It is a primary factor to ensure the performance of the tag antennas. The choice of the tag antenna type is also based on this requirement. The common types of the tag antenna includes folded dipole antennas, microstrip antennas, and inverted-F antennas. Folded dipole antennas are not suitable for the metal environment, because of their low performance and large influence on the metal surface. Microstrip antennas and inverted-F antennas are often used in the design of anti-metal tag antennas because they can make full use of metal surfaces as the ground plane of the antenna. The two antennas have their own characteristics such as the bandwidth, gain and impedance characteristics are a good consistency. The inverted-F antenna is developed from a microstrip antenna. Its structural feature is that the radiation surface of the antenna needs to be connected to the ground plane through a short-circuit surface or a through-hole. The radiation surface of the antenna can be on a plane or a different plane from the ground plane. Because it is connected to the ground, the resonance length of the antenna is shortened to $\lambda/4$, which reduces the overall size. The design of the inverted-F tag antenna also focuses on the position, size, number, radiation surface, and feeding method of the short-circuit surface and the through-holes. Microstrip antennas are slightly larger than inverted F antennas and generally smaller than $\lambda/2$. The radiation surface of the antenna and the ground plane are on different planes, and the microstrip antenna does not need any short-circuit surface or through-hole to connect the two planes, which reduces the engineering complexity and costs. The design of the tag antenna focuses on the structure of the radiating surface, the base dielectric, the ground plane structure.

Microstrip antennas are the best choice for tag antennas due to their relatively small size, low cost, simple structure, and ability to work on non-metallic and metallic surfaces. In the design process of a microstrip antenna, the design concept of an inverted-F antenna is added under the premise of ensuring the simple structure of the antenna to achieve better gain, bandwidth, and impedance characteristics.

The design of tag antenna is realized through the electromagnetic field simulation of the antenna. Antenna simulation can not only improve the accuracy of antenna design, save design time and cost, but also have an intuitive understanding of the overall performance of the antenna, which is convenient to improve the antenna. For UHF RFID tag antennas, it is difficult to accurately measure the antenna impedance and gain parameters. At this time, the electromagnetic field simulation method is particularly important.
Electromagnetic field simulation, also known as computational electromagnetics, is a method of numerically computing electromagnetic problems through computers. It can be divided into numerical methods and high-frequency methods. The numerical method is suitable for the structure size of the antenna and the wavelength of the radiated electromagnetic waves, which are usually within a dozen wavelengths. The high-frequency method is more suitable for structures with larger sizes. Numerical methods are divided into two categories: differential equation method and integral equation method. Each type has a method based on the frequency domain and a method based on the time domain. High-frequency methods are divided into two types based on field calculations and current-based calculations, as shown in Fig. 1. For UHF RFID tag antennas, the size of the antenna is small and generally smaller than the radiation wavelength, so the relevant calculation methods is the numerical calculation method that is emphasized here. The numerical simulation methods with more practical applications are the finite element method, the moment method, and the finite integration method in the time domain. The finite difference time method (FDTD) is relatively complicated and is rarely used in small antenna designs. The three main methods are described:

(1) The finite elements method (FEM) is a numerical technique that approximates mathematical boundary value problems. It first discretizes basic units in a finite area and then calculates the value of each elementary unit node by the difference function and boundary conditions. Finally, the required field parameters are obtained. The finite element method is more suitable for the simulation of three-dimensional models, and it has higher accuracy and shorter calculation time when calculating physical models of small size. It can be seen that the finite element method has innate advantages. The HFSS (High Frequency Structure Simulator) simulation software commonly used nowadays is HFSS (High Frequency Structure Simulator), which is recognized by the industry for its simple interface and rich functions.

(2) Moment method (MoM) obtains the radiation pattern and impedance of the antenna by approximating the current integral equation. Its principle is relatively simple, and the calculation speed is extremely fast, which is suitable for the simulation of planar antennas. Common commercial moment method electromagnetic simulation software includes IE3D from Zeland, Ansoft Designer from Ansoft, and ADS from Agilent.

(3) The Finite integrate time domain (FITD) method calculates the model in the time domain and then inverts it to the frequency domain and obtain the final result. It has good calculation accuracy and calculation speed for large bandwidth models, and it is also a commonly used simulation method.

Figure 1. Classification of electromagnetic field simulation methods
most widely used commercial time-domain finite integral method electromagnetic field simulation software is CST's Microwave Studio.

The UHF RFID tag antenna is a channel for energy acquisition and signal transmission of the tag. Its performance directly affects the overall performance of the UHF RFID system. The purpose of tag antenna design is to get an antenna with excellent performance parameters. The performance parameters of the tag antenna include impedance matching with the tag chip, power transmission coefficient, and reflection coefficient, and the maximum reading distance of the tag. These are standard parameters for measuring whether the tag antenna meets the design requirements. Antenna radiation pattern and bandwidth are also important for tag antennas. The radiation pattern determines the range in which the tag can be identified. Bandwidth determines the area in which the tag can be used. It should be said that these two parameters are required according to the actual use environment of the label. For tag antennas, the actually required bandwidth is generally small and the identification range is generally limited to a certain range, so it is easier to meet the requirements. The tag antenna is directly connected to the tag chip. There is no impedance conversion part in the middle, and the tag chip is a balanced feed and its impedance is complex impedance. It is not suitable for the traditional 50 Ω (or 75Ω) coaxial to connect a network analyzer. At the same time, the most important and intuitive indicator is the maximum reading distance of the tag. It requires the tag antenna and the tag chip to be connected together through a certain process and then measured by a reader. The measurement of the tag antenna emphasizes the tag system rather than the antenna itself. Other performance indicators of the antenna can be reflected in the reading distance. The maximum reading distance of the tag is the most important performance parameter of the UHF RFID tag antenna. It is also the most valuable system performance parameter of the tag antenna. There are two methods to accurately measure the maximum reading distance of a tag: the microwave dark room method and the transverse electromagnetic wave transmission room method.

3. Design of anti-metal UHF RFID tag antenna

According to the theory of reflection and refraction of electromagnetic waves, when the medium is discontinuous, electromagnetic waves are reflected and refracted at the interface of the medium. The field in free space becomes the field of the composite wave of the incident wave and the reflected wave. Due to the phase difference between the incident wave and the reflected wave, the field strength of the synthesized wave is reduced or enhanced. The result will directly affect the read rate of the tag antenna.

As can be seen from the skin effect, when the electromagnetic wave enters the metal interior from the metal surface, its energy will decrease with the depth. In other words, when encountering metal, most of the energy of electromagnetic waves will be outside the metal. Accordingly, metal still has a shielding effect on the electromagnetic field. Electromagnetic wave can reach the depth inside the metal, which can be expressed by skin depth:

\[
δ = -\frac{1}{\sqrt{\pi f \mu \sigma}}
\]  

(1)

As the formula (1) to know, The higher frequency of the electromagnetic wave, the harder it is to get inside the metal. In general, high-frequency electromagnetic waves can only exist on the surface of a good conductor and can hardly pass through the metal, so the metal plays a shielding role.

3.1 Design of UHF tag antenna

The paper proposed the UHF tag antenna, as shown in Fig.2. The tag antenna consists of radiating surface, a short-circuited end line, and a dielectric substrate. The structure parameters of the provide tag antenna are shown in table1. The dielectric substrate is FR4 copper clad laminate, the relative dielectric constant is 4.4, the loss tangent is 0.02, and the thickness is1.6 mm. The presented antenna uses the structure of a common microstrip patch with the slot.
Figure 2. The presented antenna structure: (a) top view (b) side view

Table 1. Parameters of the presented antenna.

| Parameters | Length |
|------------|--------|
| L          | 76 mm  |
| W          | 41.5 mm|
| L1         | 70 mm  |
| Ws         | 3 mm   |
| W1         | 5 mm   |
| Win        | 10 mm  |
| L1n        | 41 mm  |
| Ls         | 37 mm  |

The structure of the tag antenna is based on the rectangular microstrip antenna. The original size (length L, width W) of the radiating patch is calculated by the transmission line model. A pair of F-shaped slots are opened, the embedded structure is used for feeding, and the tag antenna pins are respectively connected to the radiating surface of the antenna and the short-circuited stub, the end of the short-circuited stub is connected to the metal ground through the slot. The embedded F-shaped groove changes the current path on the surface of the original radiating patch and excites a plurality of resonant modes. By adjusting the size and position of the F-shaped groove, the resonant mode can be well coupled, thereby expanding the antenna bandwidth; The short-circuit stub feeding can effectively reduce the input impedance of the antenna, achieve conjugate matching with the tag chip, and also reduce the size of the antenna.
3.2 Effect of Short stub Length on tag Antenna Input Impedance

The ANSYS Electronics Desktop2015 was used to simulate and optimize the provided tag antenna, and the center frequency was set at 915MHz. In order to characteristics of the tag antenna on the metal object, the tag antenna is placed on the metal plane of 70×100mm².

As shown in Fig.3, the input impedance of the tag antenna decreases with the increase of the length of the short stub, and the change of the length of the short stub has a significant adjustment effect on the imaginary part of the input impedance of the tag antenna. When \( L_s \) is 36mm, the real part of the impedance of the tag antenna at 915MHz is 204.4Ω, which is very close to the imaginary part of the impedance of the target chip.

![Figure 3. Influence of different stub length on the imaginary part of the tag antenna](image)

3.3 Effect of metal backplane size on resonant frequency

The performance of the tag antenna meets the design requirements when the tag antenna is attached to a metal of 70×100mm² as shown in Fig.4. In order to further study the influence of the metal backplane on the tag antenna, when the tag antennas are respectively placed on the metal backplane of 200×200mm² and 400×400mm², the simulation results are shown in Fig.5. It can be seen that the resonant frequency of the antenna occurs. A slight offset, but still in the UHF band (840MHz ~ 965MHz), the return loss is also less than -10dB, it can be seen that the metal backplane has less influence on the resonant frequency of the antenna.

![Figure 4. the provided tag antenna attached to a metal back plate](image)
To verify the proposed antenna design, a prototype of the antenna is fabricated, as shown in Fig. 6. The return loss result is measured by a vector network analyzer (VNA), as shown in Fig. 7. All the simulations are computed by ANSYS Electronics Desktop 2015 based on the finite-element method (FEM).

Figure 5. Influence of the size of the metal back plate

Figure 6. Influence of the size of the metal back plate

Figure 7. Return loss of the proposed antenna
As can be seen from the plot, the antenna operates from 860MHz to 960MHz. The simulated results closely resemble the measured result at the lower and upper resonant frequency points validating the design of the proposed antenna array.

4. Conclusion
The paper proposed an anti-metal tag antenna based on the common rectangular microstrip tag antenna. By forming a pair of axially symmetric F-shaped grooves on the rectangular microstrip patch, two resonant modes are formed, and the position and size of the F-shaped groove are adjusted to couple the two resonant modes, widen the bandwidth. Using the short stub, the input impedance of the antenna and the impedance matching of the tag chip can be effectively realized without increasing the size of the antenna. The effects of different sizes of metal backplanes on the performance of tag antennas were investigated. The results show that the performance parameters of the designed antenna are less affected by the metal backplate. There is no obvious change in the resonant frequency and input impedance of the antenna. The paper presented the tag antenna covering operating bandwidth from 840MHz to 965MHz, and satisfy most of the Application requirements for tag antennas.

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