THE REALIZATION OF RADIO FREQUENCY IDENTIFICATION HANDSET ANTENNA BASED ON INTERNET OF THINGS

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Abstract. Radio frequency identification (RFID) as an automatic identification technology is one of the core technologies of Internet of Things. RFID handset is known for its light and portable characteristics; therefore, reducing the volume of RFID antenna which is the forefront and important component of RFID system without influencing working distance is an important direction of its design. According to the rules of information exchange and communication based on Internet of Things, this study investigated the effects of antenna parameters on system performance using a passive RFID system. It was found that, when the read-write distance was fixed, the higher the frequency was, the larger the one-way space loss would be; for antennae with the same structure size, higher frequency could bring better gain effects; the polarization property of antennae was the same as the polarization property of electromagnetic waves; the matching of the polarization of receiving antenna and incoming wave could induce polarization loss. A kind of RFID near-field antenna which was suitable for near-distance reading was designed through analyzing the design principles of a kind of microstrip-fed monopole near-field antenna. Then the antenna was manufactured based on simulation using High Frequency Structure Simulator (HFSS). The actual test suggested that the front end of the antenna could read the tags which were 6 cm away and 3 to 4 tags at once, which was applicable to actual application environment.
Keywords: RFID, Internet of Things, tag, antenna.

1. Introduction

The Internet of Things is an extended network based on the Internet, with its user extending to between any two articles for information exchange and communication, which can be used to realize the identification, positioning, tracking, monitoring and management of target objects by taking advantage of relevant technologies [1]. RFID is one of the core technologies [2], with antenna

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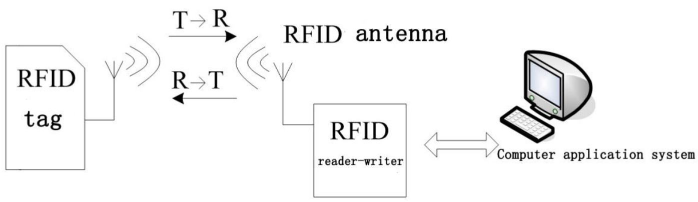

Figure 1: The main framework of RFID system

as a key component in information exchange, which is a main factor influencing the performance of RFID system.

RFID handset which is light, portable and cheap has been extensively applied in life. To adapt to the characteristic of convenience, small volume of antenna and large working distance are required for the antenna of handset. Therefore, how to design antenna with a small size without influencing precision is one of the hot spots for development. Currently, ultra high frequency band RFID antenna miniaturization develops fastest. Foreign experts have made many studies on RFID antenna miniaturization. To reduce the size of spiral curve antenna, Raumonen et al. [3] from Finland successfully applied electromagnetic band gap structure into reader-writer. N. Michishita [4] proposed a kind of evenly spaced meander-line dipole antenna and the design minimized the size of the antenna to $16mm \times 13mm$. Based on relevant technical data in China and abroad, this study investigated the design principles and miniaturization of handset antenna and successfully designed and manufactured a kind of handheld antenna which was suitable for near-distance reading. The antenna was found being able to satisfy application requirements after test.

2. RFID system

RFID, a kind of non-contact automatic identification technology, realizes the communication between host computer and information carrier using radio-frequency signals through space coupling (alternating magnetic field or electromagnetic field). A typical RFID system is composed of application system software, reader, middleware and electronic tag [5], as shown in figure 1.

The working process of RFID is as follows. Firstly, an antenna installed on a reader gives off radio-frequency signals within a specified frequency range. The electronic tag receives the radio-frequency signals released by the reader after entering into the magnetic field, obtains energy from induced current generated by space coupling, and sends product information stored in the chip. Or, the reader captures electromagnetic waves radiated by an active electronic tag, reads the information, decodes them, and sends them to the central application system for processing.

3. Effects of RFID antenna parameters on system performance

According to different functions and roles of antenna in RFID system, it can be typed into tag antenna and reader antenna [6]. Tags in passive RFID system keep working relying on electromagnetic waves launched by reader-writer. Thus, we will explain the effects of main antenna parameters on the performance of passive RFID system [7].

(1) Gain

Gain refers to the ratio of density of signal power generated by real antenna and ideal radiating element at the same point of a space under the condition of equal input power [8]. As to the effect of antenna gain on read-write distance, only when transmitting power and antenna gain increase by at least 12 dB can the read-write distance double. When transmitting power remains unchanged, the maximum identification distance of RFID system can be affected by antenna gain and working frequency band. Suppose the transmitting power of the reader-writer as $P^{reader}_{trasnmitted}$ and R as the power density of tag beyond read-write distance. Then the power density of the tag at R distance was:

$$S_1 = \frac{G_{reader} P^{reader}_{transmitted}}{4\pi R^2}. \tag{1}$$

(1) Power received by tag $p^{tag}_{recerved} = S_1 A_{tag}$ and $A_{tag} = \frac{G_{tag}\lambda^2}{4\pi}$. Therefore, we have:

$$P^{tag}_{recerved} = \left(\frac{l}{4\pi R}\right)^2 G_{reader} G_{tag} P^{reader}_{transmitted} \tag{2}$$

The echo power density of tags at the position of the reader-writer was:

$$S_2 = \frac{G_{tag} P^{tag}_{recerved}}{4\pi R^2}. \tag{3}$$

Similarly, we have:

$$P^{reader}_{back} = \left(\frac{l}{4\pi R}\right)^4 G^2_{reader} G^2_{tag} P^{reader}_{transmitted}. \tag{4}$$

Where G_{reader} stands for the gain of reader-writer antenna, A_{tag} stands for the effective area of tag antenna, G_{tag} stands for the gain of tag antenna, and A_{reader} stands for the effective area of reader-writer antenna.

If the sensitivity of the reader-writer was $P^{reader}_{sensitivity}$, then the read-writer distance was:

$$R = \frac{l}{4\pi} \sqrt[4]{\frac{P^{reader}_{transmitted} G^2_{reader} G^2_{tag}}{P^{reader}_{sensitivity}}}. \tag{5}$$

Generally, the working frequency of backscattered RFID system is 915 MHz, 2.45 GHz and 5.8 GHz; the corresponding wavelength is 0.328 m, 0.122 m and

0.051 m. It could be known from formula (5) that, the maximum reader-writer distance R was in a proportion relation with working wavelength λ, i.e., when the distance was equal, the higher the frequency was, the larger the one-way space loss was. Space loss was:

$$SL = \left(\frac{4\pi R}{l}\right)^2. \tag{6}$$

Generally, the size of antenna is in a direct proportion to its working wavelength, i.e., the lower the frequency, the longer the wavelength, the larger the size of antenna, and the larger the size of tag. Therefore, for antenna with the same structure size, high frequency can bring higher gain. The size of antenna is a major limiting factor in the miniaturization of tag and reader-writer. Thus in the selection of working frequency of RFID system, factors such as antenna gain, space loss and structure size should be considered as well.

(2) Polarization

The polarization property of antenna refers to the variation rules of electric field vector at the maximum radiation direction or the maximum receiving direction along with time variation [9]. At some point in a space, the figure drawn by the end of electric field vector includes linear polarization, circular polarization, etc. If the polarization of transmitting antenna and receiving antenna is different or incoming wave polarization does not match with antenna popularization, then signals received will be smaller, which is called polarization loss. Suppose the electronic field of incoming wave as $\overrightarrow{E}_l = \widehat{\rho}_w E_l$ and the electronic field polarization of receiving antenna as $\overrightarrow{E}_a = \widehat{\rho}_w$, among which, $\widehat{\rho}_w$ stands for the unitary vector of incoming wave, $\widehat{\rho}_a$ stands for the polarization direction of antenna, and $\widehat{\rho}_0$ stands for the polarization direction orthogonal to the polarization direction of antenna. Introducing polarization factor $PLF = |\widehat{\rho}_w g \widehat{\rho}_a|^2 = |\cos\varphi_p|$, we have $PLF(dB) = 10\log_{10} PLF$. Then the power received by antenna was $P_r = P_{\max} g PLF$ and $P_r(dB) = P_{\max}(dB) + PLF(dB)$ ($P_{\max}$: the maximum power received in polarization matching). If the electromagnetic wave was circular polarization, polarization unitary vector could be expressed as:

$$\widehat{\rho}_w = \frac{\sqrt{2}}{2}(\widehat{\rho}_a \pm j\widehat{\rho}_0),$$

then $PLF = 1/2$ and $PLF(dB) = -3dB$.

In conclusion, the weakening of receiving power of antenna induced by polarization matching could affect system performance. Thus the selection of antenna with specified polarization property is also an important step in the establishment of RFID system and antenna design.

4. Internet of things based RFID handset antenna

Internet of things realizes communication and information exchange by extending user side to objects and integrating computer interconnect network. Internet

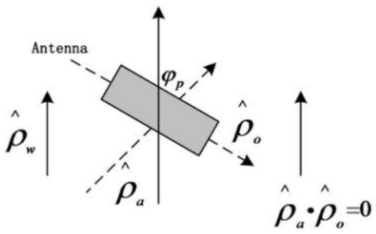

Figure 2: Antenna polarization and the polarization direction of incoming wave

of things is composed of perception layer, network layer and application layer. Perception layer is composed of various sensors, which is the source of information. RFID is the most important technology in sensing layer. In complex and various application environments, RFID system performance determines the quality of Internet of things to some extent [10].

In recent years, RFID handset has rapidly developed for its favorable characteristics such as portable shape and stable read. Reader-antenna, subsequent signal processing circuit and power supply unit are all inserted into a small handset. Therefore, antenna miniaturization is a key research subject currently. Microstrip antenna, yagi antenna and doublet antenna are commonly used in RFID system.

RFID system can be divided into remote system, short-range system and super short-range system. Super short-range distance systems such as access identification system and bus IC card charging system identify targets which are 0.1 cm to 10 cm away. Taking super short-range system as an example, this study explored the near-field antenna of RFID handset used in short-distance reading occasions.

4.1 Design principles of near-field antenna

Monopole antenna is a kind of common radiating antenna unit. Figure 3 shows the structure of ordinary monopole antenna which is composed of an above-ground conductor with a length of $\lambda/4$ and the infinite floor [11]. The effect of ground is simulated by the mirror image of antenna. In this way, monopole antenna can be equivalent to symmetrical dipole with $l/2$ long arm in free space. Certainly, such equivalence is only effective for half space above ground because there is no radiation field under floor.

Bending technology is adopted because the near-field antenna of handset put forward high requirement on the size of antenna [12]. The simplest and most classical example of bending technology is inverted-L antenna (Figure 3b) or folded monopole antenna which is obtained by bending the top of monopole antenna for 90 degrees. To realize impedance matching more conveniently, inverted-F antenna emerges (Figure 3c). Planar inverted f antenna which is

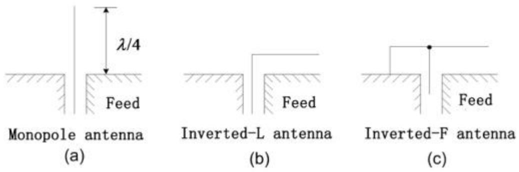

Figure 3: The basic structure of monopole antenna

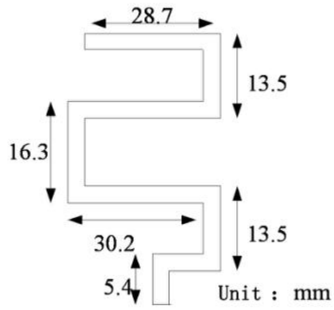

Figure 4: The basic structure of microstrip bending monopole antenna

famous later is obtained by transforming inverted-F antenna into a plane structure. Thus microstrip bending monopole was used to meet the requirement on antenna miniaturization.

To make the resonant frequency of antenna be ultra high, there are requirements on the overall length and bending mode of antenna radiating unit. Figure 4 demonstrated the basic structure of microstrip bending monopole antenna.

The radiation of traditional monopole shaped like a ring is strong on two sides and weak in the middle. As the near-field antenna designed in this study requires that radiation gain should not be too high, the middle part with weak radiation was taken as the transmitting terminal and the radiation of the right side and reverse side was limited using certain methods. In this way, the two sides would not misread other tag data on the premise that the front end could read tag.

4.2 Antenna processing and testing data

A series of variables were set as parameters for scanning according to the design methods of microstrip monopole antenna [13] and using HFSS software; then a structure figure with simulation data was obtained, as shown in figure 3. Based on that, a piece of RF4 dielectric-slab was used in the design of microstrip monopole antenna model with UHF. In the process of testing, due to the strong radiation performance of microstrip monopole, it was easy to read the next

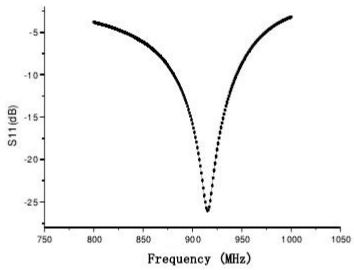

Figure 5: Return loss testing data of the near-field antenna of handset

target tag during the joint debugging of system, which did not conform to actual application environment. Thus, an earth terminal was designed for the antenna using plated-through hole. Moreover, 50Ω of impedance matching was added at end to directly guide a part of energy to the metal grounding structure to consume it compulsively, prevent it to radiate to spatial field, and avoid excessively large field intensity. Though this method could effectively reduce the reading distance of antenna, asymmetric antenna radiation was found in the process of testing. As the large impact of the metal grounding structure at the edge of the long side of the dielectric-slab on the radiation performance of antenna leads to the weakened radiation to antenna grounding structure, the radiation to antenna was asymmetric. Therefore, the end of the antenna with relatively strong radiation was attached with a piece of FR4 dielectric material to prevent the spatial field radiation of antenna artificially and make radiation relatively asymmetric.

The near-field antenna of handset ($60mm \times 40mm \times 4mm$) was processed based on the model and simulation data; coaxial SMA feed was adopted. After the matched resistance and feed interface were welded and the two layers of dielectric-slabs were fixed, a vector network analyzer was connected [14]. Return loss testing data obtained are shown in figure 5.

The above testing data of the near-field antenna of handset suggested that, the antenna satisfied the application requirement of UHF antenna. However, actual measurement has not been performed. Next, the actual reading effect of the antenna was tested by establishing the actual application environment of the near-field antenna. Firstly, to ensure the actual application effect of the product, the antenna should be used along with corresponding readers and tags. The picture of the handset is shown in figure 6.

A tag was pasted on the back of each target object, numbered as 01, 02, 03, 04 and 05. All the objects were placed vertically. The near-field antenna of the handset was connected with the reader. The antenna was ensured to put vertically. The end of the antenna with relatively weak radiation was used in near-field environment to avoid the tags to be misread by the end with relatively

Figure 6: The picture of the handset

Testing distance / Tag number	01	02	03	04	05
5cm	v	v	v	v	v
6cm	v	v	v	v	v
7cm	v	v	×	v	v
8cm	v	×	×	v	v

Figure 7: Testing results of joint debugging of antenna of the handset

strong radiation. The height of the antenna was equal to the height where the tags were pasted. The input power was set as 30 dBM, i.e., 1w. Whether near-field antenna can read tags which was 10 cm away was observed.

Joint debugging testing results of the system are shown in table 4. In the table, $\surd$ indicated that the tag could be read in that distance and $\times$ indicated it could not be read. The analysis of the testing data suggested that, the front end of the antenna could ensure it to read tag which was 6 cm away and read 3 $\sim$ 4 tags once, which conformed to practical application environment.

However, the field intensity of the two ends of the antenna was higher than that in the middle, which was consistent with the radiation property of the near-field antenna. Thus, the height of the antenna should be ensured. Tags will be misread if the right side or reverse side is close to tags, because the field intensity of plane radiation of monopole antenna is large. But in practical package, antenna is installed inside metal shell, which can restrain the strong radiation of the two ends of antenna.

5. Conclusions

RFID is one of the core technologies of Internet of Things, in which, antenna is a key component responsible for information exchange. This study demonstrated the key points and difficulties of antenna design through investigating the effects of antenna parameters on system performance. It was concluded that, when the read-write distance was fixed, the higher the frequency was, the larger the one-way space loss was; for antenna with the same structure size, higher frequency could bring higher gain; the polarization property of antenna was the polarization property of electromagnetic wave; the matching of the polarization of receiving antenna and incoming waves could generate polarization loss. Therefore, the gain, structure size and polarization matching of antenna should be considered together in the antenna design of RFID system.

In this study, a kind of RFID near-field antenna which is applicable to short-distance read was designed. The antenna was made based on the simulation model which was obtained using HFSS software and the size of the antenna was reduced using bending technology. Actual measurement suggested that, the antenna satisfied the application requirement of UHF antenna.

As the radiation near-field of antenna is difficult to be accurately described and complete design guidance theories are still lack of, the design scheme in this study which was determined through data testing is deficient inevitably and thus the adaptability of antenna in practical application environment remains to be discussed.

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