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Analysis of dipole-like ultra high frequency RFID tags close to metallic surfaces*

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Abstract: It is a challenge for passive RFID tags to be mounted on the surface of metal because the parameters of tag antennas, such as the impedance matching, the radiation efficiency and the radiation pattern, are seriously affected by the metallic surface. This paper presents the characteristics of the dipole-like antennas of ultra high frequency (UHF) radio frequency identification (RFID) tags that are placed close to metallic surfaces. The finite element method (FEM) and method of moment (MoM) were used to simulate the changes of the antenna parameters near the metallic surface. Two typical dipole-like antennas close to the metallic surface, a closed loop antenna and a loaded meander antenna, were modeled, and the performance was evaluated. Experiment was carried out and the results were in good agreement with the simulation, showing that a distance of 0.05λ~0.1λ (λ is the free space wavelength) from the metallic surface could make the dipole-like UHF RFID tag performance be acceptable.

Key words: Radio frequency identification (RFID), Tag, Metallic surface, Finite element method (FEM), Method of moment (MoM)
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INTRODUCTION

Radio frequency identification (RFID) is a technology used for identifying objects via radio waves, which attracts great interest in modern supply chain control. Compared to bar code, RFID tags can be read and written over a long distance with a very high data rate, no matter whether the tag is soiled or dirty. A typical passive RFID tag is composed of a chip and an antenna, with no internal battery. All the energy it needs is obtained from the electromagnetic (EM) wave transmitted by an RFID reader (Finken0 zeller, 2003). There are several frequency bands used in RFID applications, such as low frequency (LF), high frequency (HF) and ultra high frequency (UHF). Recently, the UHF RFID tag is gaining more and more popularity because of its long read range.

In many applications, the RFID tag needs to be placed on a metal surface. However, it is difficult for RFID tags, especially UHF label-type tags with dipole-like antennas to work on the metal surface because of the boundary conditions (Penttila *et al*., 2006). Several patch antennas and planar inverted F antennas (PIFAs) using the metallic surface as the ground plane have been proposed for metallic objects (Hirvonen *et al*., 2004; Kwon and Lee, 2005; Son *et al*., 2006). However, these antennas are not to be incorporated into designs or fabrications. An alternative way in practical application is to place the label-type tags at a distance from the metallic surface. In order to better understand the effects of the metallic surface on RFID antennas, some research has been carried out (Raumonen *et al*., 2003; Dobkin and Weigand, 2005; Prothro *et al*., 2006). However, these works did not give a comprehensive and clear explanation about the relationship between the performance (read range) of the dipole-like UHF RFID tag and the distance from the metallic surface, which is

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instructive and necessary in engineering application. Mo and Zhang (2007) introduced that a 0.25λ, rather than 0.5λ, distance from the metallic surface makes the dipole-like RFID tag antenna obtain more energy to power up the chip due to the boundary conditions. However, in UHF RFID applications, usually the distances below 0.25λ are the most interesting because of the space limitation.

This paper aims to study the performance of UHF RFID tags with dipole-like antennas close to the metallic surface with distances less than 0.25λ and to explain technically the relationship between the performance and the distance in detail. Two EM simulation methods were used, and all the parameters (such as the power transmission coefficient, the radiation efficiency and the directivity) that affect the performance of tags with the change of the distance between the tag and the metallic surface were simulated and measured.

THEORETICAL ANALYSIS

For a detailed analysis, the performance of the RFID tag is evaluated by calculating the parameters of the tag antenna. The most important criterion of RFID tag performance is its read range, which is determined by two limitations—the maximum distance at which the tag can receive enough power to activate the chip and the maximum distance at which the reader can detect the scattered signal. Because the sensitivity of the reader is much higher than that of the tag, the read range is mainly determined by the first limitation (Rao *et al*., 2005a). According to the Friis equation, the maximum read range of the tag can be written as

$$r = \frac{\lambda}{4\pi}\sqrt{\frac{P_t G_t G_r \tau}{P_{th}}}, \quad (1)$$

where λ is the free space wavelength, P_t is the power transmitted by the reader, G_t is the gain of the reader antenna, G_r is the gain of the tag antenna, τ is the power transmission coefficient between the tag antenna and the chip, and P_{th} is the threshold power of the chip. We have

$$G_r = D_r e_r, \quad (2)$$

where D_r is the directivity of the tag antenna and e_r is the radiation efficiency of the antenna. If the chip impedance is $Z_c=R_c+jX_c$ and the antenna impedance is $Z_a=R_a+jX_a$, then the power transmission coefficient can be written as (Rao *et al*., 2005b)

$$\tau = \frac{4R_c R_a}{|Z_c + Z_a|^2}, \quad 0\le\tau\le 1. \quad (3)$$

Because P_t, G_t and P_{th} cannot be changed by the metallic surface close to the tag, the read range of the tag is determined by the power transmission coefficient τ, the radiation efficiency e_r and the directivity of the tag antenna D_r.

When the RFID tag is attached to the metallic surface, the major factor that reduces RFID tag performance is the boundary conditions, which make the EM wave reflect from the metal surface with a phase reversal (Cheng, 1992; Reitz *et al*., 1992). This phase reversed reflection wave cancels the incident wave and reduces the energy the tag antenna obtains to make the chip active. The electric field near the metallic surface is of a standing-wave pattern, as given in Fig.1 (Fawwaz, 2001).

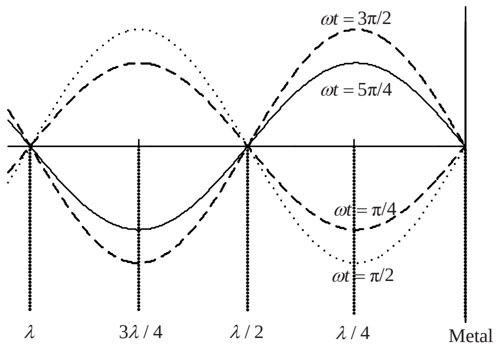


Fig.1 Standing-wave pattern of the electric field near the metallic surface

Therefore, when the tag antenna is placed close to the metallic surface, its radiation efficiency is seriously decreased because of the boundary conditions. At the same time, the metallic surface near the antenna changes its impedance matching and decreases its power transmission coefficient. Compared to the radiation efficiency and the power transmission coefficient, the directivity of the antenna keeps high when the distance from the metallic surface is very small. According to the basic antenna theory, for a dipole antenna, the metal plate acts as a flat sheet reflector and the antenna gain or directivity is enhanced when the distance is less than 0.25λ (Kraus and Marhefka, 2003).

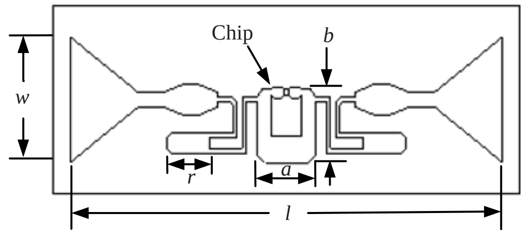
However, all above are theoretical analyses but no quantitative data on the distance of real RFID tags from the metallic surface with acceptable performance are available. Moreover, the quantitative changes of the tag antenna parameters with different distances close to the metallic surface are very important for understanding the performance of the tags. So, two EM simulation methods were used to analyze these changes quantitatively by calculating the changes of the antenna parameters mentioned above.

EM SIMULATIONS

Simulations were made with the finite element method (FEM) and the method of moment (MOM). Two typical RFID tags, a closed loop antenna and a loaded meander antenna, were modeled near the metal plate. The closed loop antenna is a reference design of Texas Instruments for its Gen2 RFID chip, whose impedance is about 13.5−j60 Ω at 915 MHz (Texas Instruments, 2006). The loaded meander antenna was specified by Rao *et al*.(2005b), matching to the chip of Philips' EPC 1.19 G2 RFID ASIC with an impedance of 17.5−j350 Ω at 868 MHz. Both of these two types of dipole-like antennas are the most commonly used antennas for RFID tags. Their dimensions are illustrated in Figs.2a and 2b, respectively. The substrate used for the closed loop antenna is polythylene terephthalate (PET) with a dielectric permittivity of 3.9 and the substrate used for the loaded meander antenna is polyester with a dielectric permittivity of 3.5. The closed loop antenna is designed for North America (902~928 MHz) while the loaded meander antenna is designed for Europe (866~869 MHz).

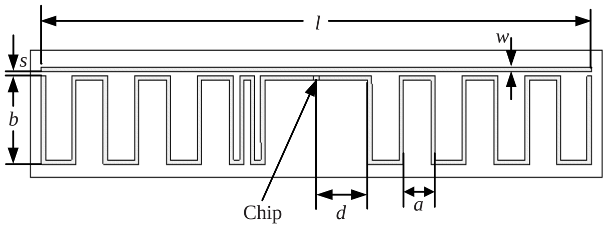
The size of the metal plate was 200 mm×200 mm. The tags were modeled with a close distance to the metal plate ranging from 0 to 5 mm with a step of 1 mm, from 5 to 40 mm (0.125λ) with a step of 5 mm and from 40 to 80 mm (0.25λ) with a step of 10 mm. The simulation setup is illustrated in Fig.3.

Through FEM and MoM, the parameters of the two tag antennas close to the metallic surface were calculated. Simulation results for the power transmission coefficient, the radiation efficiency and the directivity are shown in Figs.4a~4c. The power transmission coefficient and the radiation efficiency increased rapidly when the distance increased from 0 to 0.1λ. With further increase of the distance, the power transmission coefficient and the radiation efficiency changed slowly to the values in free space. In contrast to the power transmission coefficient and the radiation efficiency, the directivity of the antennas at φ=0 and θ=0 (φ is the angle rotated away from the x axis, and θ is the angle rotated away from the z axis) sharply increased from a certain value, not zero, to the



Parameter	l	w	r	a	b	t_s	t_a
Value (mm)	88.9	25.4	8.8	11.8	15	0.05	0.01

(a)



Parameter	l	w	s	d	a	b	t_s	t_a
Value (mm)	96	0.7	0.7	8.9	5.4	14	0.051	0.018

(b)

Fig.2 The schematic and dimension parameters for the two typical RFID tags. (a) Closed loop antenna; (b) Loaded meander antenna
t_s: substrate thickness, t_a: antenna trace thickness

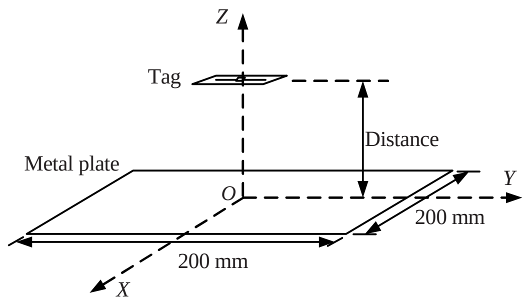


Fig.3 The setup for simulation

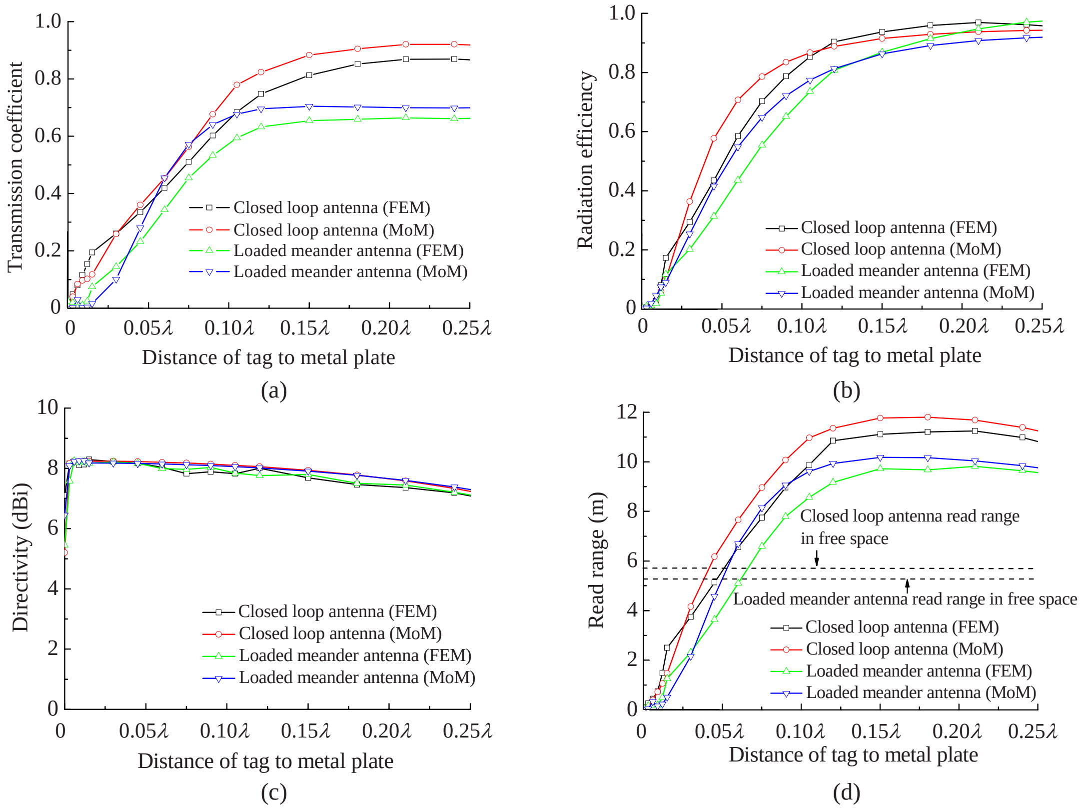


Fig.4 Simulated results for the two typical dipole-like RFID tags near the metallic surface by using the finite element method (FEM) and the method of moment (MOM). (a) Power transmission coefficient; (b) Radiation efficiency; (c) Directivity (φ=0, θ=0); (d) Read range

maximum value with the distance increasing from 0 to several millimeters. Then, the directivity decreased slowly. When the distance was between 0 and 0.25λ, the directivity of the antenna was higher than that in free space because of the reflection effect of the metallic surface.

The read ranges of the tags, with a minimum chip turn-on power of −10 dBm and a reader power of 4 W EIRP (effective isotropically radiated power), were evaluated in Fig.4d, showing that the performance of the tags close to the metallic surface increased rapidly when the distance increased from 0 to 0.1λ and reached the value in free space at the distance around 0.05λ. When the distance was between 0.1λ and 0.25λ, the read ranges kept steady and were much better than those in free space.

EXPERIMENTS

Two dipole-like UHF RFID tags, a closed loop dipole-like antenna and a meander loaded dipole-like antenna, were used in the experiment. The reader was a handheld RFID Reader MC9090-G of Symbol Technology®. The working frequency of the reader was between 902 and 928 MHz and the output power was 4 W EIRP. The tags were placed on the surface of metal plates with different distances and the read ranges of the tags were tested. Fig.5 shows the experiment setup.

Three steel plates with different sizes, 300 mm×300 mm, 200 mm×200 mm, and 100 mm×100 mm, were used for the experiment. The tags were placed with close distances to the steel plates ranging from 0 to 40 mm with a step of 5 mm and from 40 to 80 mm with a step of 10 mm. The read ranges of the two tags placed close to the metal plates of different sizes are plotted in Fig.6. It is easy to see that when the tags were attached directly to the surface of the metal plate, their read ranges were zero. However, with a small increase of the distance, the read ranges of the tags increased rapidly. When the distance between the tags and the metal plates was about 0.05λ, the performance was almost the same as that with no metal plate. When

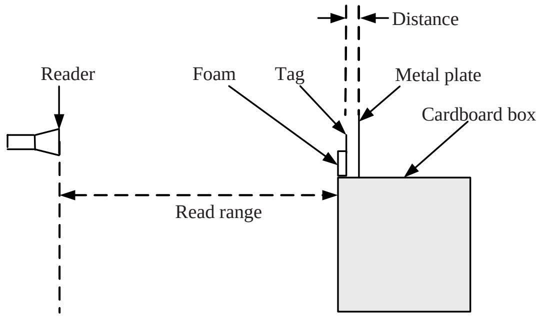


Fig.5 The setup for measurement

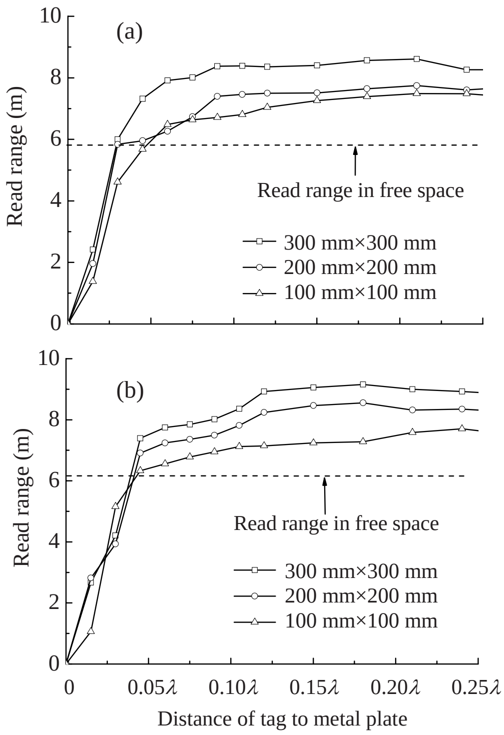


Fig.6 The measurement results of the performance of the RFID tags on metal plates of different sizes when the distance is less than 0.25λ. (a) Closed loop antenna; (b) Loaded meander antenna

the distance was between 0.1λ and 0.25λ, the performance was better than that with no metal plate. This result was consistent with the simulation result.

Compared with the simulation result, the performance of the tags in the measurement is acceptable with a smaller distance from the metallic surface. This is because the bandwidth of the reader was 902~928 MHz, while the simulation was only at the frequency of 915 or 868 MHz. This wider bandwidth somewhat overcomes the effect of impedance matching detuning.

CONCLUSION

The performance of UHF RFID tags with dipole-like antennas close to the metallic surface has been analyzed. By EM simulations of FEM and MoM, two typical dipole-like antennas for UHF RFID tag have been modeled near the metallic surface, and the variations in the parameters of the antennas with the change of the distance from the metallic surface have been studied. The experimental results were in good agreement with the simulation. Three findings can be concluded as follows:

(1) With a very short distance from the metallic surface, about 0.05λ~0.1λ, the performance of the tag increases to be in an acceptable level because the power transmission coefficient and the radiation efficiency increase rapidly and the directivity remains high. Therefore, if the dipole-like RFID tag has to be placed on metallic objects, a distance between 0.05λ and 0.1λ could be used according to the read range demands.

(2) Because of the slow increase of the power transmission coefficient and the radiation efficiency, the performance of the tag is stable when the distance between the tag and the metallic surface changes from 0.1λ to 0.25λ. Moreover, the maximum value is located in this range.

(3) If the impedance matching could be designed to be less affected by the metallic surface or be designed specifically for the metallic surface, a very close distance (less than 0.05λ) from the metallic surface could be achieved with acceptable performance.

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