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Analysis of a read range of passive RFID tags attached to metallic plates and a simplified analysis model

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1. Introduction

Today RFID (Radio Frequency Identification) which consists of an IC chip and antenna has attracted many attentions. This is the automatic recognition technologies which carry on the recognition management to human and things by use of the simple contact-less wireless IC tag. However, it is said that RFID is likely to be influenced in the vicinity of metallic plate and various characteristics change suddenly.

It has already presented that 5mm spacing between the μ-chip and the metallic plate can achieve the same maximum read range as in 2.45GHz band free space [1]. However, it is not reported why the same amount of maximum read range can be achieved with this spacing and the reason is remained unclear.

In this paper, we will analyze the changes of the maximum read range of passive RFID tags in the vicinity of the metallic plates by experiment and computer simulation and show its mechanism theoretically.

Furthermore, we will propose a simplified analysis model in order to reduce a computational complexity. In this proposal, it will be shown that μ-chip antenna is identical with a dipole antenna with respect to receiving power at a load, if their antenna length is the same. The experimental results of μ-chipRW are compared with the read range obtained from the dipole antenna model, and the validity of the simplified analysis model will be shown.

2. The Definition of Ratio of Maximum Read Range

2.1 Ratio of Maximum Read Range from Friis Formula

The ratio of maximum read range is calculated from Friis formula in RFID.

(a) Without metallic pleat (Free space) (b) With metallic pleat

Fig. 1 Friis formula.

First, the system configuration without the metallic plate is shown in Fig. 1(a). R_0 is the maximum read range by Friis formula. In this case, Z_L is a matched load for the antenna input impedance.

$$R_0 = \frac{\lambda}{4\pi}\sqrt{\frac{P_t G_t G_{r0}}{P_{th}}} \qquad (1)$$

In contrast, the system configuration with the metallic plate is shown in Fig. 1(b). R_M is the maximum read range.

$$R_M = \frac{\lambda}{4\pi}\sqrt{\frac{P_t G_t G_{rM}\tau}{P_{th}}} \qquad (2)$$

Where P_t is the receiving power, P_{th} is the minimum threshold power necessary to provide enough power to the RFID tag chip, G_t is the gain of the R/W antenna, G_{r0} and G_{rM} are gains of the RFID tag

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antenna without metallic pleat and with metallic pleats respectively. τ is the power transmission coefficient given by (3) [2].

$$\tau = 1 - |\Gamma|^2 = 1 - \left| \frac{Z_L - Z_a^*}{Z_L + Z_a} \right|^2 = \frac{4R_L R_a}{|Z_L + Z_a|^2} \qquad (3)$$

Where $Z_L = R_L + jX_L$ is chip input impedance and $Z_a = R_a + jX_a$ is antenna input impedance. The power transmission coefficient τ expresses the change of the Z_a and mismatch by the metallic plate. Ratio of maximum read range a is given by (4).

$$a = \frac{R_M}{R_0} = \sqrt{\frac{G_{rM}\tau}{G_{r0}}} \qquad (4)$$

The ratio of maximum read range is determined by these three parameters: Tag antenna gain without metallic plate G_{r0}, tag antenna gain with metallic plate G_{rM} and power transmission coefficient τ.

3. Simulation Result of Maximum Read Range

To calculate the ratio of maximum read range between tag and R/W by tag gain G_{rM} with metallic pleat, tag gain G_{r0} and power transmission coefficient τ, the μ-chip antenna model is employed. Electromagnetic field simulator EEM-MOM which is based on the moment method is used [3].

Fig. 2 shows the structure of simulated antenna [4]. Length of the μ-chip antenna is 53mm. This antenna is composed of the slit of L-shape and this is used to adjust the input impedance. The feeding point is the corner of L-shape slit. The y axis is divided into seven, and z axis is divided into 265.

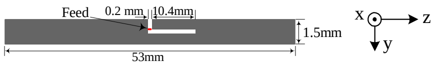


Fig. 2 μ-chip antenna model.

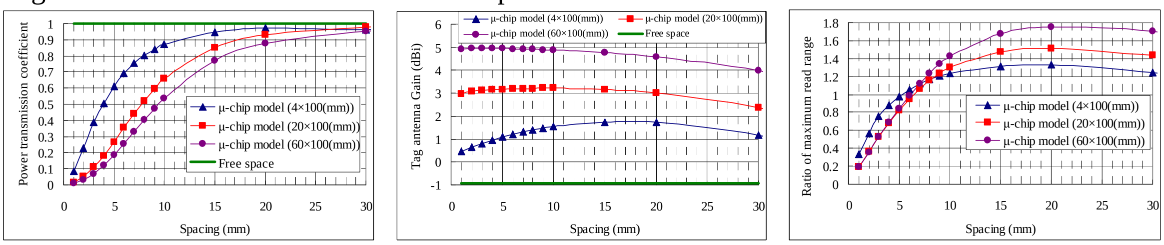
Circularly polarized gain G_{rM} and antenna input impedance Z_a are calculated for metallic plate of 4×100mm, 20×100mm and 60×100mm by the simulation. The coefficient τ was calculated by using (3). Because the antenna input impedance is 9.314+ j55.223Ω, the load impedance of 9.314-j55.223Ω is employed as the matched load in free space. Moreover, gain without a metallic plate G_{r0} is also calculated. The resulting three parameters are shown in Fig. 3(a) and (b).

The ratio of maximum read range calculated from Friis formula is shown in Fig. 3(c).

It was theoretically shown that the same read range as in free space can be achieved by the several mm spacing for the metallic plate. This is considerably smaller spacing for the wave length and noteworthy fact in the practical situation. The reason of this phenomenon explained as follows.

When a metallic plate exists in the vicinity of tags, the power transmission coefficient τ becomes to be small with decreasing the spacing because the input impedance of the antenna is altered. However, on the other hand, since the antenna gain is increased by the existence of metallic plate in contrast with the power transmission coefficient, the same power as in free space is introduced to the load and the same maximum read range can be achieved.

For example, in the case of metallic plate (60×100mm), the power transmission coefficient of μ-chip model is as one forth times as in the case of without metallic plate when the spacing between the tag and metallic plate is 6mm. On the other hand, the tag antenna gain of μ-chip becomes 4 times. Therefore the same power as in free space is supplied to the load and the communication range because the same as that in the free space.

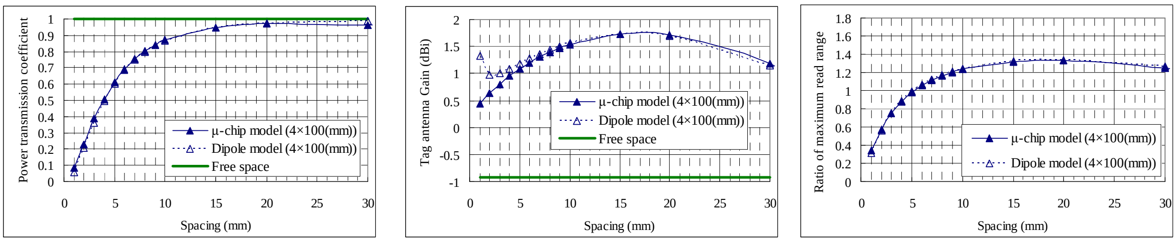


(a) Power transmission coefficient (b) Tag antenna gain (c) Ratio of maximum read range

Fig. 3 Simulation of μ-chip antenna model.

4. Simplification of μ-chip model

As for an internal structure of the μ-chip tag antenna, it takes large amount of analysis time and this is inherent in the complex structure. The problem is solved by using the dipole antenna model instead of μ-chip model. The comparison of the three parameters of the dipole antenna model and the μ-chip antenna model are shown in Fig. 4(a) and (b) respectively.



(a) Power transmission coefficient (b) Tag antenna gain (c) Ratio of maximum read range

Fig. 4 Comparison of simulation result of μ-chip antenna model and dipole antenna model.

Here, we can see that the ratio of maximum read range of the μ-chip antenna model and the dipole antenna model is corresponding to each other from Fig. 4(c).

The reason to which the ratio of maximum read range is corresponding is probably thought as follows. The μ-chip antenna model would be composed of the dipole antenna, the matching circuit which transforms the matched load of the dipole antenna Z_L' to the chip impedance Z_L, and IC chip as shown in Fig. 5. In contrast, the dipole antenna model is composed of the antenna and the matched load. Because matching circuit is no loss circuit, it does not influence the receiving power in the IC chip. Therefore, the ratio of maximum read range becomes the same between them.

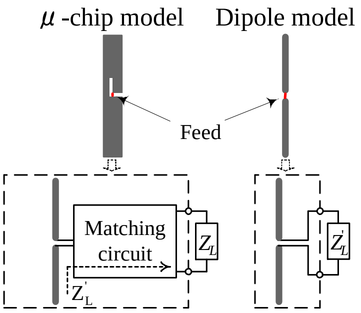


Fig. 5 Comparison of analysis model.

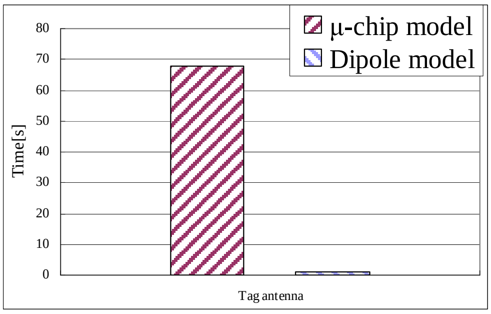


Fig. 6 Comparison of computation time.

Generally, the structure of the feeding point is uncertain in the RFID tag antenna. Therefore, the input impedance of the antenna is also unknown. In addition, the input impedance of the chip is usually unknown, too. The analysis technique shown here is very effective for such kind of the special circumstances of the RFID tag antenna.

We can see that analysis time of the dipole antenna model is greatly shortened than that of the μ-chip model as shown in Fig. 6. Where, CPU is Intel Core Duo 2.8GHz and 3Gbytes memory is installed.

5. Experimental Results

The experiments to confirm the validity of the analysis are conducted. The RFID tag used in experiment is μ-chipRW [5]. The antenna length is 56mm.

Furthermore, the experimental results are compared with the simulation results of the dipole model. Because the input impedance of the dipole antenna at 56mm length is 60- j40Ω, the load impedance of 60+ j40Ω is installed as a matched load. The ratio of maximum read range was calculated by (4).

Next, the experimental environment is shown in Fig. 7. The metallic plate (W×L×H = 150×200×0.5mm) exists behind the RFID tag. The spacing between the tag and metallic plate is D. The maximum read range was examined by the experiment in anechoic chamber. Five maximum read range measurement at different time are carried out and averaged for each spacing. The resulting range is regarded as maximum read range value. Then, the maximum read range is normalized by that in the free space.

Comparison of the experimental result of the μ-chipRW and dipole antenna simulation results with metallic plate are shown in Fig. 8.

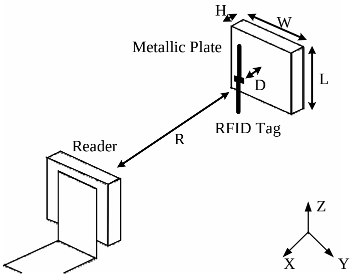


Fig. 7 Experimental setup.

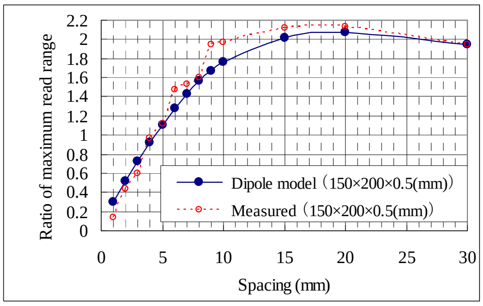


Fig. 8 Comparison between experimental results and simulation results.

We can confirm the good agreement between the experimental results of μ-chipRW and the simulation results of the dipole antenna model.

Furthermore, it is confirmed that the same maximum read range as in the free space can be achieved by separating around 5mm (0.04λ) spacing between the RFID tag and the metallic plate.

6. Conclusion

In this paper, the theoretical analysis and the experimental results on the ratio of maximum read range of RFID with metallic plate have been shown. The results enable to confirm the following items.

The ratio of maximum read range in case of exiting metallic pleat behind the RFID tags is analyzed by the method of moment and Friis formula. It has been shown that the same read range as in free space can be obtained by separating several mm spacing. This spacing is considerably short for the wave length and noteworthy fact in practical situation.

This reason is as follows. The input impedance of the antenna is changed by the existence of the metallic pleat and the power transmission coefficient becomes small by impedance mismatch. However, on the other hand, since the gain is increased by metallic pleat, the same read range as in free-space can be obtained by around several millimetres spacing.

Next, we have theoretically shown that the dipole antenna model provides the same maximum read range as that of the μ-chip antenna model and this agreement has been evaluated experimentally. This theory is effective to analyze the receiving power of the RFID tags with uncertain feed point structure. In addition, it has shown that the calculation time by the method of moment is considerably reduced by introducing the dipole model.

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