UHF RFID Tag Antenna Design for Nearly Located Objects

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Abstract: A passive ultra high frequency (UHF) radio frequency identification (RFID) tag antenna designed for managing objects which are closely located is proposed in this study. In some particular applications, the RFID tag attached to the objects are extremely close to each other. Therefore, a planar dipole antenna with meander structure used as a RFID tag antenna is designed to reduce the performance decrease due to the influence of other tags nearby. In this study, the proposed planar meander dipole tag antenna is compared with a simple dipole tag antenna. It is numerically and experimentally demonstrated that the proposed antenna has good performance when the tags are attached to a dielectric and closely located.
Keyword: Radio frequency identification (RFID), Tag antenna, Ultra high frequency (UHF)

1. Introduction

In recent years, radio frequency identification (RFID) is one of the most promising technologies for wireless identification system and sensor network system [1][2]. It widely replaces the current barcode system because of longer reading range, high data capacity, and non-line-of-sight readability. Through the characteristic of the RFID system, it is applied in retail store, security, electronic wallet, and so on. One of the most common applications using RFID systems is goods management [3]. RFID system can provide a convenient way to track the inventory and assets [4].

A RFID system consists of RFID tags, a RFID reader antenna, a reader, and a computer. The RFID tags can be attached to objects which need to be managed or tracked. An RF signal sent from the reader can be radiated through the reader antenna. The signal is received by the tag and backscatter the signal to the reader.

However, the RFID tags are easily affected by the environment. A passive RFID tag consists of a tag antenna and an application specific integrated circuit (ASIC). When the tag antenna is attached to the object or the distance between each tag is extremely close, the impedance of the tag antenna is influenced due to the effects of the other objects nearby. It causes the mismatching between the tag antenna and the ASIC, and the performance of the tag may have a great chance to decrease. For example, when the RFID system is used in the office or the library to realize the document and book management, the objects are arranged tightly on the shelf. Hence, the distance between each tag is short, and the performance of tags is influenced.

The sensitivity degradation of tags in arrays due to the shadowing and mutual coupling has been studied in [5][6][7]. It has been shown that the tag detuning is the major problem causes the mismatching between the tag and ASIC, and the distance between each tag larger than 1 cm has less influence of the other tags [6]. However, the tags are always attached to the objects which could be made of paper, plastic, or high dielectric material such as glasses or ceramics and so on. Therefore, RFID tags which can be operated in close location and attached to objects with high permittivity are required.

In this study, an UHF RFID tag antenna which has good resistance to the influence of other objects nearby is proposed. It has better performance when the tag is near the other tag or attached to objects with high relative permittivity. Numerical simulation of the proposed tag antenna is performed using the method of moments, and the increase of power transmission ratio is demonstrated. Additionally, the prototype of the proposed tag antenna is fabricated, and the experimental study also shows that the proposed tag antenna has good performance when the tag attached to the high dielectric and closely located objects.

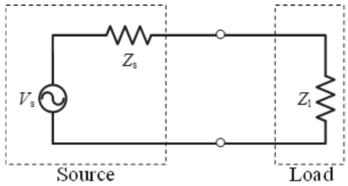

Figure 1: Generator-load network circuit.

2. Evaluation method

A RFID tag consists of an antenna and a chip. It can be considered as an one-port network circuit [8] and the equivalent network circuit is shown in Fig. 1. The circuit represents a generator-load circuit with a complex source and a load impedance, where Z_l is the load impedance, Z_s is the internal impedance of the voltage source, and $V_s$is the source voltage.

The power wave reflected from the load back to source can be defined as the power wave reflection ratio Γ

$$\Gamma = \frac{Z_l - Z_s^*}{Z_l + Z_s} \tag{1}$$

and the power reflection ratio $|\Gamma|^2$ shows the ratio of the maximum power available from the source is not delivered to the load.

$$|\Gamma|^2 = \left|\frac{Z_l - Z_s^*}{Z_l + Z_s}\right|^2, 0 \le |\Gamma|^2 \le 1 \tag{2}$$

The power transmission ratio t can be written as

$$t = 1 - |\Gamma|^2, 0 \le t \le 1 \tag{3}$$

It is demonstrated that the load impedance Z_l and the source impedance Z_s must be conjugate matched to achieve the maximum power transmit to the load. In this report, the power transmission ratio is used to evaluate the input power to the tag chip.

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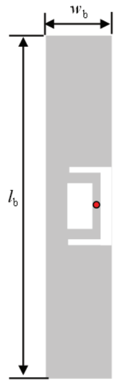


Figure 2: Geometry of planar dipole antenna.

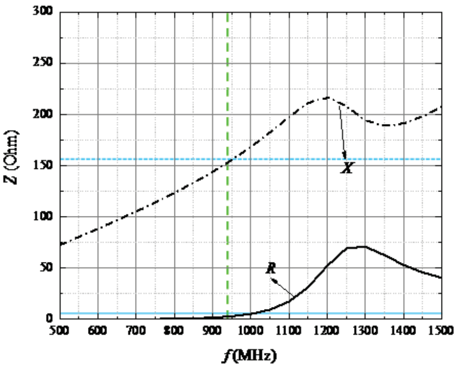


Figure 3: Input impedance of the planar dipole antenna.

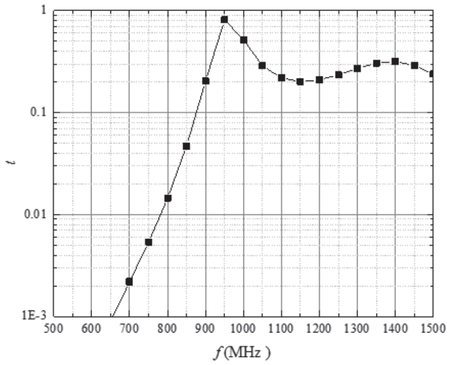


Figure 4: Power transmission ratio of dipole antenna between planar dipole antenna and chip.

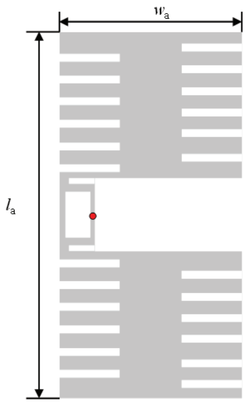


Figure 5: Geometry of proposed relatively large antenna.

3. Tag Antenna Design

In order to achieve the maximum power transmission ratio, the RFID tag antennas were designed that the antenna impedance is conjugated matched to the chip. Two sizes of the passive RFID tag antenna were designed to investigate the relation between the electrical size of the antenna and the reading performance.

3.1 Relatively small antenna

A relatively small planar diploe antenna was designed for UHF RFID system as shown in Fig. 2, where $l_a = 90$ mm and $w_a = 17$ mm. It is designed to conjugate match to the RFID chip [9].

The impedance of the chip at 920 MHz with -13 dBm incident power is $7.2 - j156.5\ \Omega$. The input impedance of the tag antenna and the power transmission ratio between the chip and the antenna are shown in Fig. 3 and 4, respectively. It is demonstrated that the input impedance of the planar dipole antenna and the chip impdeance are conjugated and the power transmission ratio is achieved to maximum value around 920 MHz.

3.2 Relatively large antenna

In order to obtain the lower resonance frequency, the size of tag antenna is enlarged. However, the size of the tag antenna should be reduced to fit into the detected objects, a meander dipole antenna which is using the same chip impedance as the pervious one as shown in Fig. 5 is proposed, where $l_a = 100$ mm and $w_a = 50$ mm. The input imnpedance of the proposed relatively large antenna is shown in Fig. 6. It is demonstrated that the input impedance of the proposed antenna is smaller than the conjugated impedance of the chip in both real part and imaginary part.

3.3 Numerical analyze

The proposed two sizes of antenna in both conditions of attched to a high dielectric object and located closely are analyzed by using method of moment and the simulation results are shown in Fig. 7 and Fig. 8, respectively. The black line and the red line show the input impedance of the relatively small antenna and the relatively large antenna, respectively. The contour line shows the power transmission ratio between the chip and the antenna with different input impedance at 920 MHz.

Figure 7 shows that the relatively small antenna has higher power transmission ratio to the chip when the tag is far from the other one, but the proposed relatively large antenna has better power transmission ratio when the tag is close to the other one. Figure 8 shows that the dipole antenna attached to the dielectric has larger variations in the impedance. On the other hand, the relatively large antenna has better resistance to the di-

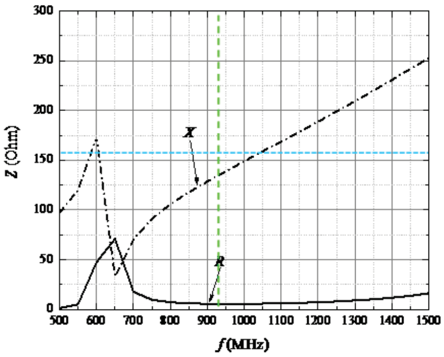


Figure 6: Input impedance of proposed relatively large antenna.

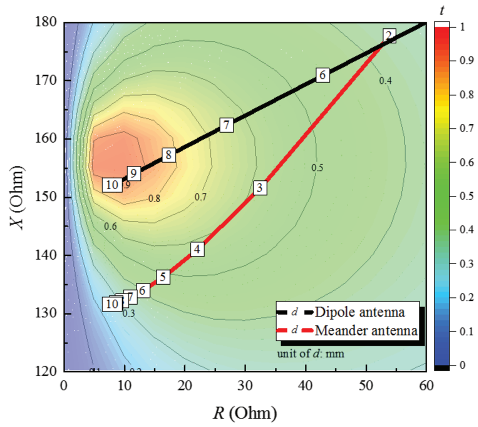


Figure 7: Power transmission ratio of two tags close to each other with different d.

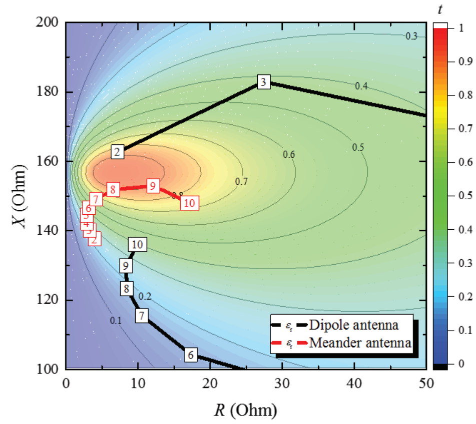


Figure 8: Power transmission ratio of one tag attached to dielectric with different ε_r.

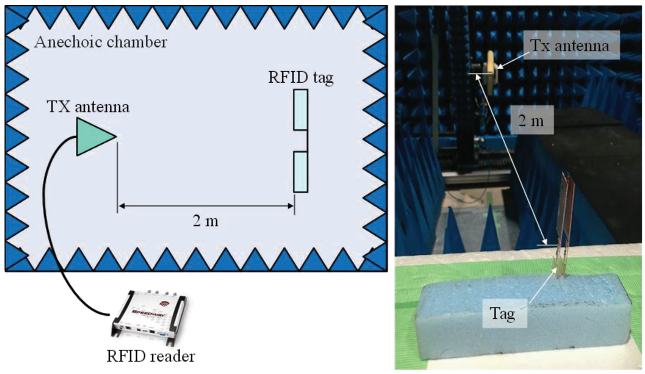


Figure 9: Diagram and photo of experiment environment

electric. It is demonstrated that the proposed relatively large antenna has higher power transmission ratio when the tag closes to the other one or the tag is attached to the dielectric.

4. Experiment

The designed antennas with two electrical sizes were fabricated, and the RIFD chips (Impinj Monza 4) were soldered on both antennas. Two experiments are presented in this section. First, the fabricated tags were put on the dielectric objects to examine the influence of the dielectric on the tags. Second, two tags were located nearly with a highly small gap between them to study the influence from another tag nearby.

In the experimental studies, the performance of the tag antenna was evaluated by using the Friis free space formula [10] as

$$\frac{P_r}{P_t} = G_r G_t t \left(\frac{\lambda}{4\pi R}\right)^2 \tag{4}$$

where shows the ratio of power available at the input of the receiving antenna P_r to output power from the transmitting antenna P_t. G_t and G_r are the gain of the reader antenna and tag antenna respectively. λ is the wavelength, R is the read range, and t is the power transmission ratio given by (3).

The experiment environment is shown in Fig. 9. The fabricated tags were tested in anechoic chamber, and the RFID reader was Impinj R420. The distance between transmitting antenna and tag antennas was 2 m. P_t increased until the tag antenna was activated, and the minimum active power was obtained. It is known that the same RFID tag chip should have the same minimum active power. Because every variable except P_t and t in (4) is a constant, the performance of an RFID tag can be evaluated by using P_t. The smaller the P_t is, the better power transmission ratio the tag has.

The first experiment: the tags are attached to an object with various permittivities and sizes as shown in Fig. 10. Figure 11 and Table 1 explain the photos and the parameters of the objects, respectively. The material with $\varepsilon_r = 2.34$ was made of High Density Polyethylene (HDPE), and the material with $\varepsilon_r = 3.7$ was made of Monomer-Cast Nylon (MC Nylon). These materials are similar to the objects made of polypropylene and paper. The material with $\varepsilon_r = 10$ which was made of high dielectric Polyphenylene Ether (PPE) were analogous to the objects made of glasses and so on.

Two tag antennas were fabricated for each size of antenna to ensure that both tags had similar performance. The minimum active power of each case is shown in Table 2. The designed tag antenna with larger electrical size (Antenna ♯2) had larger minimum active power than

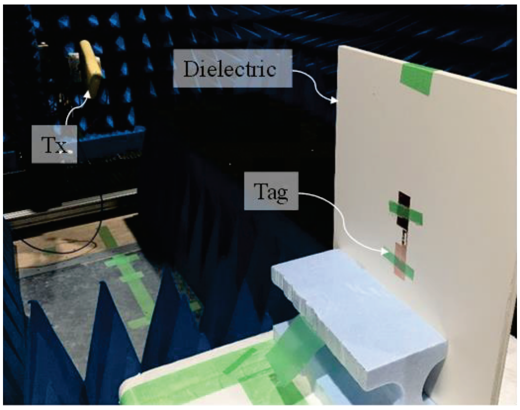
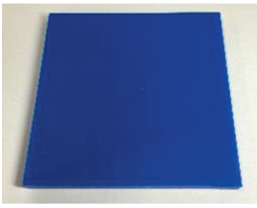
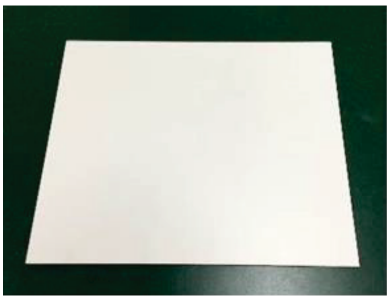


Figure 10: A RFID tag attached to dielectric object to be tested.

(a) no. 1



(b) no. 2



(c) no. 3

Figure 11: Three types of material for tag evaluation.

Table 1: Parameters of dielectric objects for tag evaluation

no.	size [mm]	ε_r	material
∗1	90×75×75	2.34	HDPE
∗2	150×150×10	3.7	mc nylo
∗3	150×150×20	3.7	mc nylo
∗4	330×255×9	10	high ε_r PPE

Table 2: Minimum active power of tags attached to dielectric objects

	Antenna ♯1		Antenna ♯2	
ε_r	no. 1	no. 2	no.1	no.2
free space	16.5	17.25	19.75	19
2.34*1	18.25	18.75	17.25	16.5
3.7×1*2	18.75	18.75	18.25	17.5
3.7×2*3	20.75	20.75	19	18.25
10*4	16	16.5	16	16.5

unit of minimum active power: dBm

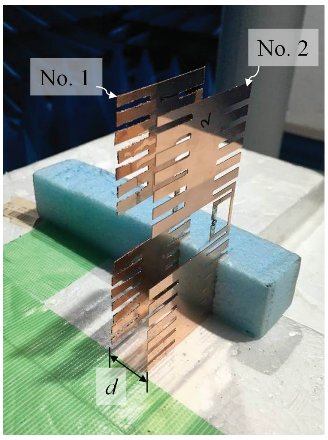


Figure 12: A RFID tag closely located to another tag.

the small antenna (Antenna ♯1) when the tags were put in free space. When attached to the objects, Antenna ♯2 had smaller minimum active power than Antenna ♯1. It demonstrates that the tag of antenna with larger electrical size has better performance when the tag is attached to dielectric objects.

The second experiment: two fabricated tags were located intensively as shown in Fig. 12. The distance between two tags d was varied from 2 mm to 100 mm to investigate the influence of the other tag nearby.

The minimum active power of the tags in each case are shown in Table 3. Antenna ♯2 has smaller minimum active power than Antenna ♯1 when the distance between two tags are 2 mm. It proves that the relatively large antenna has better performance when the tags are located closely.

Table 3: Minimum active power of the tag closed to another one

	Antenna ♯1		Antenna ♯2	
d_g [mm]	no. 1	no. 2	no.1	no. 2
2	18.25	18.75	17.25	16.5
5	18.75	18.75	18.25	17.5
10	20.75	20.75	19	18.25
20	20	20.5	19	19
50	19.25	19.75	19.25	19.25
100	18.25	18.5	19.5	19
One tag	16.5	17.25	19.75	19

unit of minimum active power: dBm

5. Conclusions

In some applications of the RFID system, tags are attached to the objects such as books or folders and the distance between each tag is extremely short. Therefore, the RFID tag is influenced by the attached objects and the other tags close to it. In this paper, a relatively large antenna which has good performance on high dielectric objects and closely located has been proposed. The simulation results show that deciding the input impedance of the tag antenna is important for tag design. The relatively large tag antenna has higher power transmission ratio than the small antenna when the tags are located closely or attached to a dielectric. The conjugate matching between tag antenna and chip has been realized so that the resistance of the tag to other objects has been enhanced. Finally, the experimental results showed that the tag antenna with larger electrical size has lower minimum active power than the small one when tags are attached to objects and intensively located objects. The result demonstrates that the designed electric large tag antenna have good performance when the other dielectric objects and other tags nearby.

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