A Study on Effects of Conductive Layer Thickness on Performance of UHF RFID Tags

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1. Introduction

Nowadays, the Radio Frequency Identification (RFID) is applied on many applications such as transportation, inventory and traceability. When comparing with the bar code, the RFID tags are more desirable on properties such as non-line-of-sight communication and high data storage [1]. When comparing the operating frequency of RFID tags between HF and UHF, the later one is likely to benefit from a long-range reading. However, the price of UHF RFID tags is still too high for commercial use. To reduce the price, the appropriate method of producing the RFID tags should be realized. In general, there are two main methods to produce the RFID tags. The first one is the subtractive method which the conductor covered on the substrate such as FR4 is etched by the photolithographic process following the shape of designed antenna [2]. This method results in the much loss of conductor and the chemical solvent for etching process. The other is the additive method which the conductive ink is directly printed on the substrate. The advantage is that conductive ink is not wasted. However, most of the conductive ink has low conductivity comparing with copper or silver. This can cause the decrease in the RFID tag performance. To increase the performance, the conductive layer thickness needs to be increased. This means the more quantity of the conductive ink and the higher costing. It is known that the amount of current flow in each area of the antenna is different, where the feeding point tends to be the area with the highest current flow. When the conductive layer thickness in high current flow area is increased, the performance of the RFID tags would be increased too [3].

In this paper, we study the effects of the conductive layer thickness on the performance of the UHF RFID tags. To achieve the highest performance RFID tags, various structures and thickness ratios of conductive layer are varied while the quantity of the conductor is controlled. In the second section, the evaluation procedure and antenna configurations are described. In the evaluation, the conventional dipole antenna and the dipole antenna with the inductive matching network are used. The third section is the results and discussions. The fourth section is the comparison of the effects of conductive layer thickness on the RFID tag read range. The last section is the conclusions.

2. Evaluation Procedure

In the performance evaluation, the radiation efficiency is used to compare the performance of the RFID tag antennas which the structures and the thickness ratios of conductive layer are different. The radiation efficiency is the ratio of the gain (G) and the directivity (D) of tag antenna, *Radiation efficiency =G/D.*

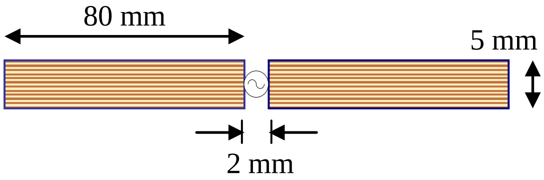


Figure 1: Configuration of conventional dipole antenna

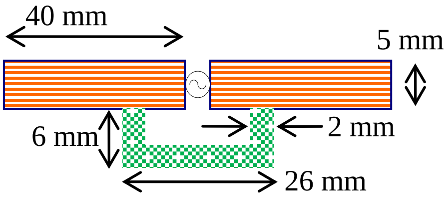
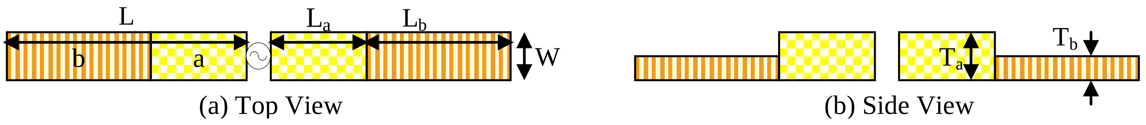


Figure 2: Configuration of dipole antenna with inductive matching

We use the simulation software, Advance Design System (ADS), to simulate the antennas and obtain both of gain and directivity values. The simulated tag antennas are a conventional dipole and a dipole with inductive matching network, illustrated by Fig. 1 and Fig. 2, respectively. In the simulation, the frequency of 920 MHz is chosen following the requirements of UHF RFID in Thailand. The antenna substrate is configured as polyester (PET) where the dielectric constant and loss tangent are 3.5 and 0.002, respectively. The thickness of substrate is 0.051 μm and the conductivity of the conductive layer, silver ink, is 1.6×10^6 S/m [4].

2.1 Evaluation of the Conventional Dipole Antenna

The shape of the conventional dipole antenna is as shown as Fig.1. Each part of dipole is divided into area *‘a’* and area *‘b’* with the length of L_a and L_b, respectively, as shown in Fig. 3 (a)., The feeding point is in area ‘a’, and the total length of each part of dipole L ($L = L_a + L_b$) is 80 mm while the width of dipole is 5 mm. In the evaluation, the length L_a is varied in range of 0.1L – 0.4L and the thickness ratio (R_{ab}), referred as the ratio between the thickness of area *‘a’* (T_a) and that of area *‘b’* (T_b) ($R_{ab} = T_a/T_b$), is also varied. To compare the radiation efficiency of these antennas, the conductor quantity of them is controlled for equivalent of 4 mm^3.



(a) Top View

(b) Side View

Figure 3: The structure of conductive layer on dipole antenna

2.2 Evaluation of the Dipole Antenna with Inductive Matching

In the second evaluation, the inductive matching network is added to the conventional dipole antenna to match the impedance of the antenna with the conjugate impedance of the IC chip (NXP UCODE G2XL: C=0.9 pF, Q=9). The shape of this tag antenna is shown in Fig.2 while the structure and the thickness ratios of the conductive layer are varied in the same manner as the conventional dipole antenna shown in Fig.3. To study the effect of thickness of the inductive matching part on the performance, the evaluations are divided into 3 cases as listed in Table 1.

Table 1: The evaluation case for dipole antenna with inductive matching

Case	Thickness of matching network	$R_{ab}(T_a / T_b)$	L_a /L
I	T_a	1, 2, 3, 4, 5, …	0.1, 0.3, 0.5
II	T_b	1, 2, 3, 4, 5, …	0.1, 0.3, 0.5
III	Fixed	1, 2, 3, 4, 5, …	0.3

3. Results and Discussions

Figure 4 shows the radiation efficiency of the conventional dipole antenna. The conventional dipole with L_a=0.1L has the highest radiation efficiency at every values of the thickness ratios, while the radiation efficiency of conventional dipole with increased L_a (0.2L – 0.4L) are decreased in descending order. These results show that nearer to the feeding point the conductive layer thickness is increased, the higher radiation efficiency the conventional dipole have. Considering the radiation efficiency at the different thickness ratio, we can see that when the thickness ratio is increased, the radiation efficiency is increased at the earliest interval before it is decreased afterward. These mean that properly increasing the conductive layer thickness around the feeding point (area *‘a’*) can improve the radiation efficiency. However, if the difference of the thickness of both areas *‘a’* and *‘b’* is too much, the radiation efficiency would be decreased. The simulation results show that the thickness ratio should not be higher than 3-5 otherwise the radiation efficiency would be decreased.

Figure 5 shows the radiation efficiency of the dipole antenna with inductive matching network. For the case I of this antenna which the thickness of inductive matching is increased and equal to T_a, the radiation efficiency when L_a=0.1L changes similarly to the previous evaluation of the conventional dipole antenna. That is properly increasing the conductive layer thickness around the feeding point can improve the radiation efficiency, where the proper thickness ratio is about 3-4 for this case. When L_a=0.3L, the length L_a is equal to the distance between the feeding point and the connection point of the matching part and high radiation efficiency at every values of the thickness ratio can be achieve. These results conflict with the previous evaluation of the conventional dipole antenna where the highest radiation efficiency can be achieve when the length L_a=0.1L. However, this result implies that the area from feeding point to connection point of inductive matching part is very important. To gain high radiation efficiency, we should also increase the conductive layer thickness from the feeding point to connection point. For the last evaluation of case I when L_a=0.5L where its length passes to the connection point, the radiation efficiency results like the previous case with L_a=0.3L but they are in lower values. This result also agrees with the previous evaluation on the conventional dipole antenna where the antenna with shorter length L_a gives higher radiation efficiency.

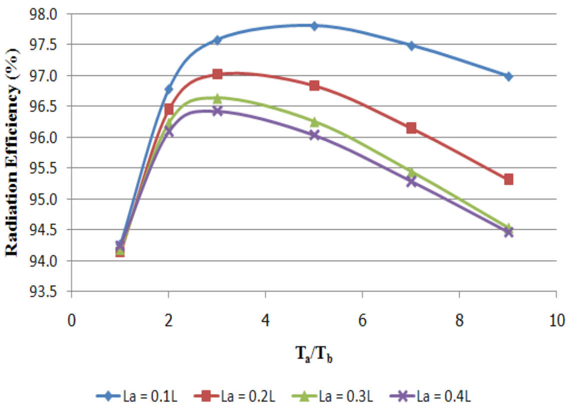


Figure 4: The radiation efficiency of conventional dipole antenna (without inductive matching)

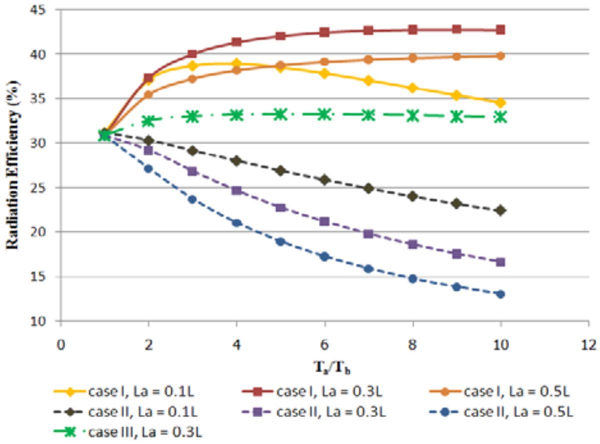


Figure 5: The radiation efficiency of dipole antenna with inductive matching

For the dipole antenna with inductive matching in case II, the thickness of the inductive matching part is decreased and equals to T_b For L_a=0.1L, the radiation efficiency is decreased when the thickness ratio is increased. It shows that increasing only the conductive layer thickness around the feeding point of dipole antenna with inductive matching is not enough to achieve higher radiation efficiency. Moreover, the radiation efficiency is more decreased as well. The radiation efficiency when L_a = 0.3L and L_a = 0.5L also decreases when the thickness ratio is increased, which agree with the previous evaluation on the conventional dipole antenna where the antenna with shorter L_a gives higher radiation efficiency. When comparing the results in case I and case II, we can see that the increase of the conductive layer thickness on the inductive matching area is very influential to the radiation efficiency.

In order to verify the important of increasing the thickness on the matching area, the antenna is simulated in case III in which the thickness of inductive matching part is constant and L_a = 0.3L. The result shows that increasing the conductive layer thickness around feeding point can increase the radiation efficiency. But the increase of radiation efficiency in this case is lower than that in case I. This again emphasizes that increasing the conductor thickness in inductive matching area highly effect to the radiation efficiency.

As the results of all above evaluations, it can be seen that in order to achieve high radiation efficiency, we should increase the conductive layer thickness of the area from the feeding point to connection point of the antenna and the inductive matching part including all area of the inductive matching part.

4. Read Range

When comparing the results of radiation efficiency in Fig.4 and Fig.5, it can be seen that the radiation efficiency of dipole antenna with inductive matching is comparatively lower than that of the conventional dipole antenna. However, the dipole antenna with inductive matching can take the advantage of matching with the conjugate impedance of the IC chip or the power transmission coefficient (τ). The read range of the UHF RFID tag which is the maximum distance that the reader can communicate with the tag can be calculated as in (2) [1]. G_{ant} and G_{tag} are the gain of transmitting reader antenna and tag antenna, respectively. P_{tx} is the power delivered to the transmitting reader antenna. $P_{min,tag}$ is the minimum threshold power required to power up RFID chip [1]. When $P_{min,tag}$ and $P_{tx}G_{ant}$ equal to -15dBm and 4W EIRP respectively, the read range of the conventional dipole tag with L_a=0.1L and the dipole antenna with conductive matching tag in case I with L_a=0.3L are shown in Fig.6.

$$\text{Read range} = \left(\frac{\lambda}{4\pi}\right)\sqrt{\frac{\tau P_{TX} G_{ant} G_{tag}}{P_{\min,tag}}} \qquad (2)$$

The results in Fig.6 show that the read range of the dipole with inductive matching is higher than that of the dipole without inductive matching. This implies that to make a long read range tag, we should adjust the shape of antenna to match with the conjugate impedance of the IC chip for increasing the power transmission coefficient. After that we can adjust the thickness of the conductive layer for increasing the radiation efficiency.

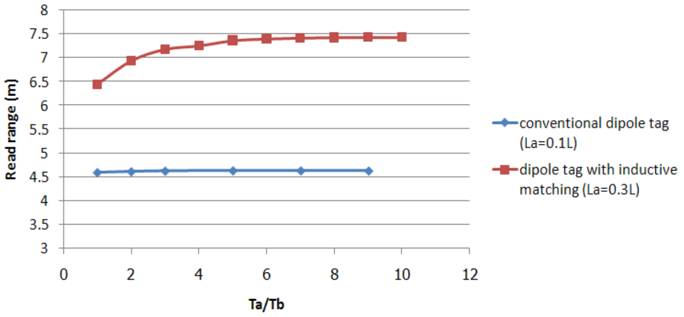


Figure 6: The read range of conventional dipole tag (L_a=0.1L)
and dipole tag with inductive matching (L_a=0.3L)

5. Conclusion

In this paper, we studied the effect of conductive layer thickness on performance of UHF RFID tags. When the conductive layer thickness in high current flow area is increased and that in low current flow area is decreased, the performance of tags can be increased. The conductive layer thickness of the tag based on dipole shape including inductive matching network are varied in various forms to compare the radiation efficiency.

The results show that properly increasing the conductive layer thickness around the feeding point can increase the radiation efficiency. However, the difference of thickness should not be higher than 3-5 otherwise the radiation efficiency would be decreased. In addition, the increase of the conductive layer thickness on the inductive matching area and the area from feeding point to connection point of the matching part and the dipole part is also very influential to the radiation efficiency. The efficiency of the antenna can be maximized if the conductive layer thickness of these areas is increased. Finally, we found that even though the inductive matching network makes the radiation efficiency decrease, the increase of power transmission coefficient can increase the read range of the RFID tag.

References

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