Effect of the Substrate, Metal-line and Surface Material on the Performance of RFID Tag Antenna

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I. Introduction

The radio frequency identification (RFID) is being used widely in various environments such as stores, factories, security systems and transportation cards, etc. A great deal of research has been reported on the development of tag antennas, but the effects of the substrates and metal-lines on the performance of a tag antenna have not been studied in detail. In addition, there have been few studies on the performance degradation of a tag depending on the target's surface material to which the tag antenna is attached.

In this paper, we examine how the characteristics of a tag antenna are altered by the substrate and metal-line materials. A simple tag antenna with the meander line radiator and T-matching network is optimized using Pareto genetic algorithm (PGA) to guarantee the maximum performance under variety of conditions. We then observe the effects of various targets' surface materials on the performance degradations such as the readable range, the radiation efficiency and the shift in the resonant frequency.

II. Antenna Characteristics

Generally, a tag antenna consists of the conducting metal-line and the dielectric substrate. In this paper, the performance changes of the tag antenna due to a variety of these materials are studied using a simple meander type tag structure as shown in Fig. 1. To construct the meander structure, the antenna's main radiator is bent with *c* and *d* as its parameters; *e* is the width of the bent line. The T-matching network is adopted for conjugate matching with a commercial tag chip and is located at the center of the antenna with dimensions of *a* and *b* [1]. To search for optimal tag antenna's performance for a given

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condition, we employ a PGA [2] in conjunction with an IE3D of Zealand EM simulator [3].

The resulting readable ranges for the given tag antenna size are shown in Fig. 2. Three different substrate materials of PET (ε_r: 3.9, tanδ: 0.003, thickness: 50μm), Duroid (ε_r: 2.2, tanδ: 0.0009, thickness: 127μm) and FR-4 (ε_r: 4.25, tanδ: 0.02, thickness: 1.6mm) are used to examine the effect of the substrate material and thickness on the performance. They are marked as the triangle, circle and rectangular in the figure, respectively. The readable range rapidly decreases as the antenna size is reduced since the radiation efficiency of the antenna is dropped. Usually, the high loss substrate such as FR-4 results in greater degradation of the antenna efficiency and therefore the tag antenna with such a substrate possesses shorter readable range. However, if we use thin substrate such as PET, the readable range of the tag can be greatly increased nearly to the value of the low-loss and high-cost substrate material such as Duroid despite the fact that the loss tangent of PET is about the same as that of FR-4. Figure 3 shows the radiation efficiency as a function of the substrate thickness for a given antenna size (kr=0.6). As expected, the efficiency decreases as the thickness of substrate increases. The thin substrate, which is less than 0.4 mm, shows little difference in the radiation efficiency over 80%.

Currently, the printing methods using conducting ink, instead of etching technology, are being employed for low-cost fabrication. The low-cost printing methods, however, result in decreased conductivity of the metal-line on the tag antenna [4]. The performance comparison between the silver ink printing and copper etching is shown in Fig. 5. The copper and silver ink are marked as triangles and rectangles, respectively. The performance degradation of silver ink becomes more significant with a small antenna size (kr < 0.55) since the low conductivity of the metal-line drastically increases the conducting loss which results in a drop in the radiation efficiency.

Next, we examine the performance change due to a variation of the meal-line thickness as shown in Fig. 6. The antennas are printed on PET substrate with copper metal-line whose thickness is varied between 0.1 μm and 5 μm. The resulting readable ranges are again rapidly decreased when the thickness of the copper-line is less than 0.7 μm. This is caused by the fact that when the thickness of metal-line is less than the skin depth (about 0.7 μm at 900 MHz for copper), the antenna efficiency is greatly reduced due to the significant conducting loss in the metal-line. From these results, we can see that the thickness of the metal-line should be larger than the skin depth for adequate readability.

Finally, the degradations in the antenna efficiency and the readable range are analyzed when the tag is attached on a target object with a number of different dielectric materials (all 2 mm-thick). The resulting degradation of the antenna efficiency is plotted for various target materials with different permittivities and losses in Fig. 5. Clearly, the efficiency decreases as we increase both the permittivity and losses of the target objects. The readable range shows a similar trend as the antenna efficiency, namely it decreases when the tag is attached to a high permittivity and high loss target objects. These results show that the electrical property of the target object should be taken into account when designing the tag antennas for a given application.

III. Conclusion

In this paper, we studied the effect of the substrate, metal-line and surface material on the performance of RFID tag antennas. To examine the performance changes of the tag antenna, we used PGA optimization with a simple meander type tag structure. The results showed that readability of the tag antenna with the thin high-loss substrate could be increased similar to the low-loss substrate material if the thickness was less than 0.4 mm. The readability of the tag antenna significantly degraded with silver ink especially when the size was less than $kr = 0.55$ and it also decreased when the thickness of the metal-line is less than the skin depth. Finally, the readability of the tag is drastically decreased when the tag is attached to a high permittivity and high loss target objects.

Reference

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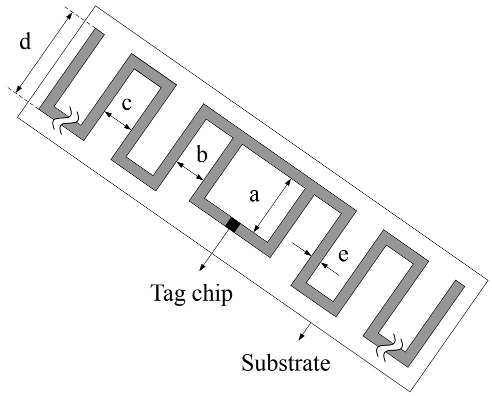

Fig. 1. Geometry of the meander tag antenna

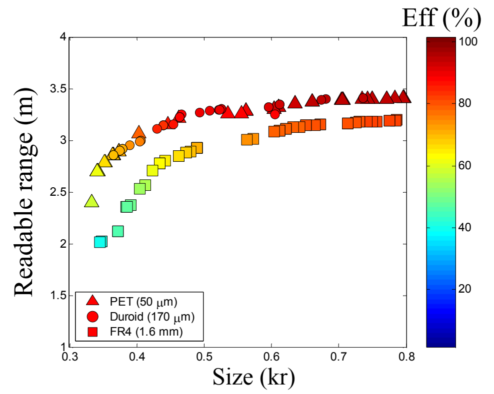

Fig. 2. The readable range vs. the antenna size and the substrate materials

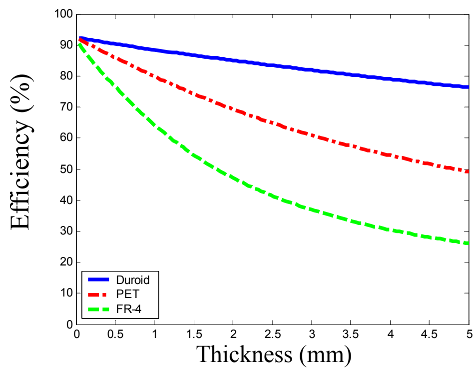

Fig. 3. The efficiency vs. the substrate thickness and substrate materials.

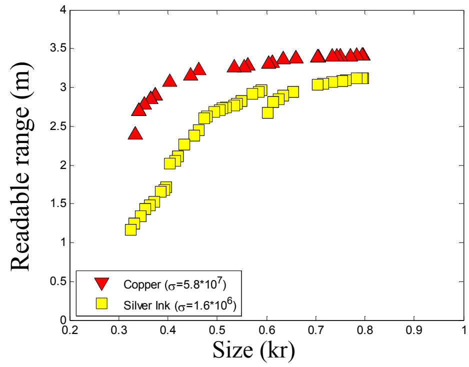

Fig. 4. The readable range vs. the antenna size and the metal line conductivity.

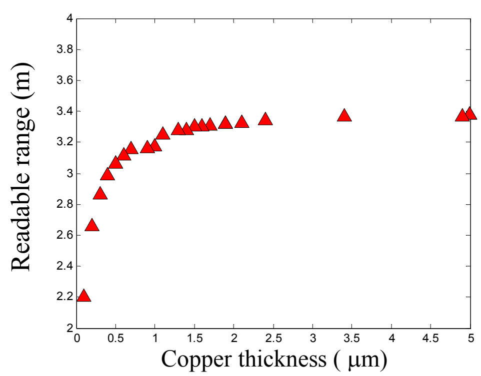

Fig. 5. The readable range vs. the metal line thickness

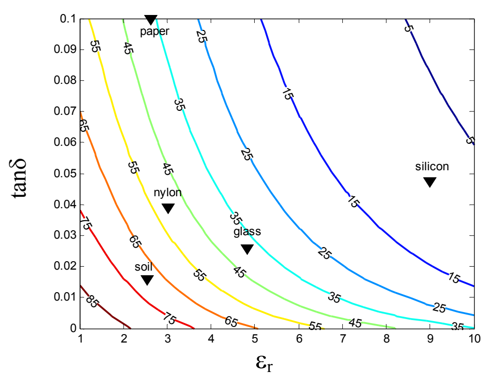

Fig. 6. The efficiency vs. the material property of the target objects