JOURNAL OF THE KOREAN INSTITUTE OF ELECTROMAGNETIC ENGINEERING AND SCIENCE, VOL. 11, NO. 1, MAR. 2011 JKIEES 2011-11-1-01

DOI : 10.5515/JKIEES.2011.11.1.001

Design of a Flexible Planar RFID Tag Antenna with Low Performance Degradation from Nearby Target Objects

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Abstract

In this letter, we propose a novel tag antenna that has low performance degradation with nearby dielectric material. We obtained a stable reading performance and a broad matching bandwidth on nearby dielectric materials by employing a T-matching network with thick line width and capacitively slot-loaded arms. We then built the proposed antenna and measured the tag sensitivity to examine the reading characteristics with nearby dielectric materials. The measured results clearly demonstrate stable tag sensitivity with various nearby dielectric materials, such as foam, acrylic-plastic, glass, and ceramic plates. To more closely observe the antenna characteristics with nearby dielectric materials, we also examined the impedance variation and surface current distribution with respect to the dielectric constant of nearby target objects, which ranged from $1\times\varepsilon_0$ to $16\times\varepsilon_0$.

Key words : UHF RFID Tag, Stable Reading Performance, Tag Sensitivity.

Ⅰ. Introduction

Recently, the application of radio frequency identification (RFID) in the UHF band (860～960 MHz) has been extended to item-level tagging, where multiple numbers of tags attached to small target objects could be detected by a reader with a high level of reliability [1]. Especially, tags used in this application should have stable reading characteristics with low performance degradation by various nearby target objects. To date, several studies have reported reductions in this readability degradation [2, 3]. For example, a method for addition of a ground plate has been introduced, but this rigid multilayer structure usually results in higher manufacturing costs and limits application of this method to stiff targets only [2]. Some researchers have inserted an absorbing layer to remedy the field perturbation caused by nearby target objects, but this method reduces the radiation efficiency of the tag, resulting in a short reading distance [3].

In this letter, we propose a flexible planar tag antenna that can operate in the vicinity of various dielectric materials with relatively low performance degradation. We obtained a stable reading performance with nearby target objects by using a T-matching network with thick line width and capacitively slot-loaded arms. We then measured the tag sensitivity, which is the minimal power required to activate the tag [4]. The measurement of the proposed antenna showed stable tag sensitivity even when the tag was attached to targets made of foam, acrylic-plastic, glass, and ceramic plates. Finally, to explain the stable reading performance of the proposed antenna, we examined the impedance variation and current distribution with respect to the dielectric constant of nearby target objects, which ranged from $1\times\varepsilon_0$ to $16\times\varepsilon_0$.

Ⅱ. Antenna Geometry and Characteristics

The geometry of the proposed antenna is shown in Fig. 1, where the numbered vertexes correspond to the bent positions listed in Table 1. The size of the antenna is 95×3 mm, and the conducting body of the antenna is etched onto a substrate of polyethylene terephthalate (PET: ε_r=3.9, $\tan\delta$=0.003, thickness=50 μm) for flexibility and low-cost fabrication. A commercial microchip (Impinj Monza2) that has an input impedance (Z_{chip}) of $18-j192\ \Omega$ (including the effect of flip-chip bonding) is placed at the middle of the antenna body [5]. The microchip has a wave wake-up threshold power level of -11.5 dBm at 910 MHz. The body of the proposed antenna consists of capacitively slot-loaded arms and a T-matching loop with a wide stripline. The capacitive loading caused by the inserted slits in the radiating arm can reduce the antenna size and, at the same time, in-

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Manuscript received May 31, 2010 ; revised November 10, 2010. (ID No. 20100531-011J)

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Table 1. Geometric position for half of the proposed tag antenna.

Vertex No.	X (mm)	Y (mm)	Vertex No.	X (mm)	Y (mm)
1	2.125	2.5	14	40	0
2	8.0	2.2	15	47.5	0
3	10.5	1.9	16	47.5	3
4	11.25	1.3	17	19.7	3
5	11.5	0.5	18	21.5	1
6	0.25	0.5	19	27	1
7	0.25	0	20	34	2
8	38.5	0	21	34	1.5
9	38.5	0.5	22	26.5	0.5
10	39	1.0	23	20.5	0.5
11	45	2.0	24	19	2.1
12	45	1.2	25	17	3
13	40	0.4			

crease the matching bandwidth with various types of nearby target objects [1]. In addition, the wide stripline of the T-matching network spreads out the near electric field over a broad surface, and thus, the currents on the T-matching network are not easily perturbed by the nearby dielectric target objects [6]. The impedance of the antenna is then tuned by adjusting the design parameters, such as the length and width of the arm and the dimensions of the T-matching loop.

We assumed that the target objects have dielectric properties from ‘air-like’ to ‘ceramic-like’ as would be found in real situations of item-level tagging applications. To observe the antenna’s reading performance, we examine the tag sensitivity, which is defined as the minimal power required for activating the tag, as shown in eq. (1) [4].

$$P_{tag\,min.} = \frac{P_{chip\,min.}}{(1-\Gamma_{tag}^{2})Eff_{tag}D_{tag}} \tag{1}$$

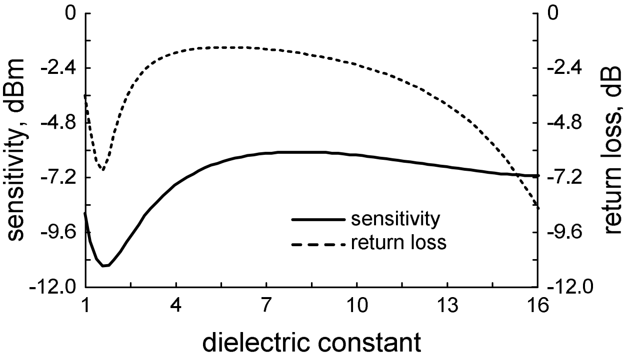


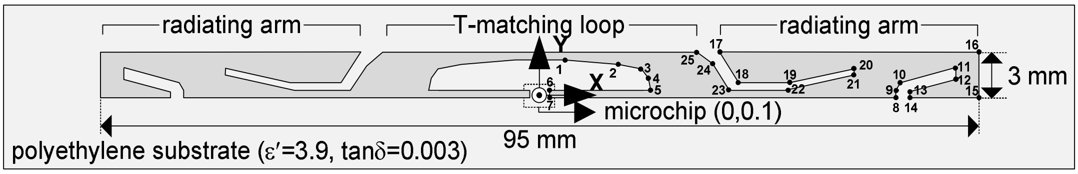
Fig. 2. Simulated tag sensitivity (——) and return loss (------) of the proposed tag.

where the threshold power $P_{chipmin.}$ of the microchip is −11.5 dBm. Γ_{tag}, Eff_{tag}, and D_{tag} are the reflection coefficient, the radiation efficiency, and the directivity of the tag at 910 MHz, respectively. These three values are obtained using a full-wave electromagnetic simulator of IE3D from Zeland [7]. The design goals for our antenna are then tag sensitivity of less than −6 dBm in the free-space condition and, at the same time, a variation under 6 dB when the tag is attached to various dielectric target objects ranging from $1\times\varepsilon_0$ to $16\times\varepsilon_0$ (infinitely long in the x-y direction and 5 mm thick). This means that the designed tag antenna should exhibit a reading distance of about 3~6 m when the tag is tested with a reader antenna with 36 dBm effective isotropically radiated power (EIRP).

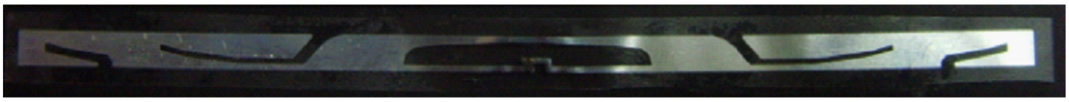
Fig. 2 shows the computed tag sensitivity and return loss at 910 MHz as a function of various dielectric constants of target objects. The tag sensitivity is lower than −6 dBm throughout the entire region (from $1\varepsilon_0$ to $16\varepsilon_0$). The reflection coefficient gradually increases to $4\varepsilon_0$ and then the value stabilizes or gradually decrease until $16\varepsilon_0$.

Ⅲ. Measurement and Operating Principle

We experimentally verified the performance of the



(a) Configuration of the proposed tag antenna



(b) Photo of the fabricated tag

Fig. 1. The proposed tag.

proposed tag by measuring tag sensitivities with various target objects made of foam ($1.5\varepsilon_0$), acrylic-plastic ($3\varepsilon_0$), glass ($4\varepsilon_0$), and ceramic ($10\varepsilon_0$). The measurement was carried out using the Voyantic measurement system, Tagformance Lite, in an anechoic chamber [8]. The measured results with four different dielectric target materials are illustrated in terms of frequency in Fig. 3. The suggested tag shows stable tag sensitivity between −10.1 dBm and −7.4 dBm at 910 MHz with all four target materials. As expected, a measured reading range from 3.9 m to 5.4 m was obtained with a reader having 36 dBm EIRP. These results clearly satisfy our design goals, which are a variation in tag sensitivity less than 6 dB and a reading distance of between 3 m and 6 m for various nearby target objects.

To more closely examine the stable reading performance, we investigated the antenna impedance, return loss and current distribution when the tag was placed on dielectric material ranging from $1\varepsilon_0$ to $16\varepsilon_0$. Fig. 4 shows the simulated impedance and return loss when the target objects have dielectric constants of $1\varepsilon_0$(——), $5\varepsilon_0$ (------), $10\varepsilon_0$ (-·-·-·-) and $16\varepsilon_0$ (-··-··-), respectively, where the dotted line in Fig. 4(a) implies the conjugate input impedance for the microchip. As shown in Fig. 4(a), the proposed tag exhibits a relatively low resistance variation of 4 Ω to 80 Ω and a low reactance variation of 91 Ω to 185 Ω. Consequently, as shown in Fig. 4(b), this low impedance variation results in a relatively good impedance matching (return loss <−1.5 dB) and a low reading distance variation of only 2.6 m in response to nearby dielectric materials. Fig. 5 shows the normalized surface current distribution of the proposed antenna. As the dielectric constant increases, current spreads on the wide T-matching stripline and the slot-loaded arms.

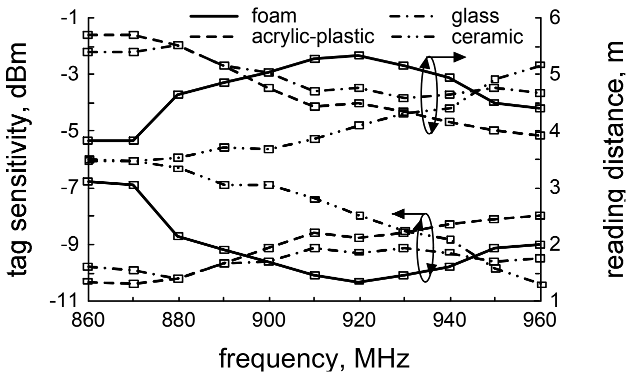
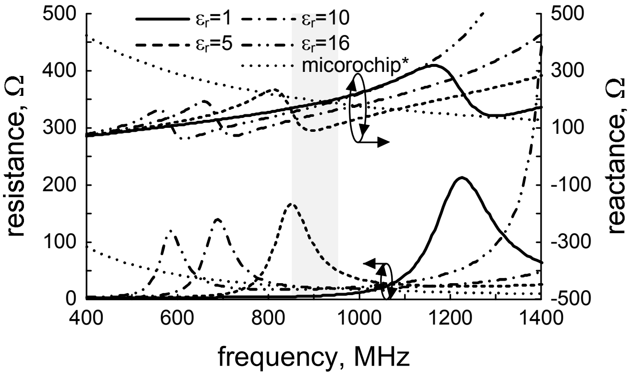
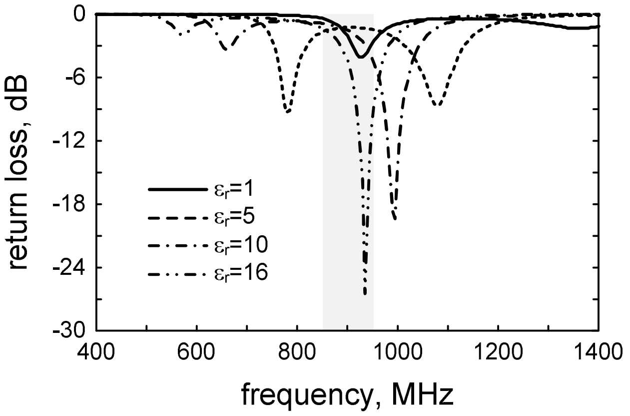


Fig. 3. Tag sensitivity and reading distance of the proposed tag attached on foam (——), acrylic-plastic (------), and glass (-·-·-·-) objects with dimensions of 200×200×5 mm^3 and on a ceramic (-··-··-) object with dimensions of 125×61.5×7 mm^3.



(a) Impedance characteristic



(b) Matching characteristic

Fig. 4. Characteristics of the proposed antenna when the dielectric constant of target objects is $1\varepsilon_0$ (——), $5\varepsilon_0$(------), $10\varepsilon_0$(-·-·-·-) and $16\varepsilon_0$(-··-··-).

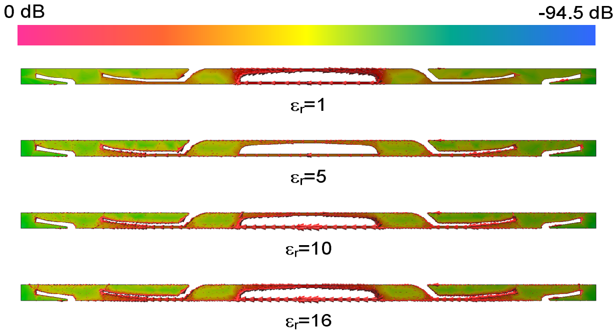


Fig. 5. Normalized current distribution of the proposed antenna when the dielectric constant of the target object is $1\varepsilon_0$, $5\varepsilon_0$, $10\varepsilon_0$ and $16\varepsilon_0$.

Ⅳ. Conclusion

In this paper, we suggested a novel slim tag antenna with a low performance variation due to nearby dielectric target objects. We reduced the performance degradation from nearby target objects by employing a T-matching network with thick line width and capacitively slot-loaded arms. We verified the stable reading performance by measuring the tag sensitivity and the reading distance when the tag antenna was attached to various target materials, such as foam, acrylic-plastic, glass, and ceramic objects. The impedance variation and current distribution on various nearby dielectric target objects ranging from $1\varepsilon_0$ to $16\varepsilon_0$ indicated that the proposed antenna has relatively a low variation in its impedance and it has efficient current flow on both special T-matching stripline and slot-loaded arms. Thus, this study clearly showed that the proposed antenna is appropriate for item-level tagging applications.

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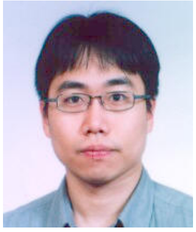

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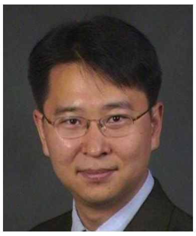

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