A Low-Profile Planar Broadband
UHF RFID Tag Antenna for Metallic Objects

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Abstract—A low-profile planar broadband tag antenna mountable on metallic objects for UHF RFID systems is presented. The antenna has a planar structure without the need of shorting pins or plates, which lowers the cost in mass production. By embedding the odd symmetric slots to the proposed antenna, two adjacent resonant modes are excited to enhance the operating bandwidth. The simulated half-power impedance bandwidth of the proposed antenna is 132 MHz (838-970 MHz) that covers the worldwide UHF RFID frequency bands (840-960 MHz).

I. INTRODUCTION

Radio frequency identification (RFID) in the ultra-high frequency (UHF) has been widely used in access control, electronic ticketing, goods flow systems, and many other emerging applications [1]. The frequency allocation for RFID systems in the UHF band varies in different regions. In China, for example, the frequency range is 840-845 MHz and 920-925 MHz. In Europe, the frequency range 865-868 MHz is allocated to the UHF RFID system whereas it is 902-928 MHz in the US. So it is necessary to design a broadband RFID tag antenna that covers the entire UHF RFID frequency bands (840-960 MHz).

In many practical applications, tags need to be placed on metallic objects. However, some problems must be solved due to the electromagnetic wave scattering from the metallic objects. Some metal tag antennas mountable on metallic objects have been studied and presented [2-4]. These antenna structures, however, have some shortcomings, such as high cost or difficulty of fabrication, because they require shorting pins or plates. For mass production of the tag, the cost of the tag should be as low as possible. Therefore a planar antenna design with no shorting pins or plates is a good candidate for a low cost RFID tag. In [5-6], fully planar antennas have been proposed, but the bandwidth is not wide enough to cover the worldwide UHF RFID frequency bands. Therefore, a UHF RFID tag mountable on metallic objects with completely planar structure and broadband characteristic is desirable and worth developing.

In this paper, a completely planar broadband UHF RFID tag patch antenna with odd symmetric slots is proposed. Two resonant modes are generated by the odd symmetric slots to broaden the half-power bandwidth of the proposed antenna. Details of the antenna design and obtained simulated results are presented and discussed.

II. ANTENNA DESIGN

Fig. 1 shows the configuration of the proposed antenna. The tag antenna consists of a radiation U-shape patch with a horizontal slot and odd symmetric slots perpendicular to the horizontal one, which is coupled inductively to the feeding loop. The rectangular feeding loop with a gap is reserved for placing the chip at the center. The feeding loop provides the required input reactance for conjugate matching to highly capacitive chip input impedance. The gap between the loop and the U-shape patch is crucial for the tuning of the input resistance. By appropriately adjusting the dimension of loop size $l6$ and the gap width g, the conjugate matching between the antenna impedance and the chip impedance is achieved. By embedding the odd symmetric slots and horizontal slot on the U-shape patch, two adjacent resonant frequencies are excited in the operating bands. The resonant frequencies can be easily tuned by the length of the odd symmetric slots $l4$ and $l5$.
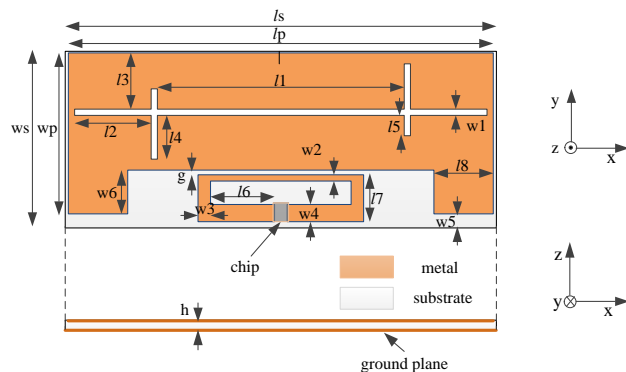
Figure 1. Configuration of the proposed antenna.

The antenna is etched on a thin 1.6 mm FR4 substrate ($\varepsilon_r = 4.4, \tan \delta = 0.02$), which is placed on a 73×30 mm^2 ground plane. The simulated results are obtained using Ansoft HFSS based on the finite element method. The antenna is designed for microchip Impinj Monza 3, which has an input impedance of $32-j216\ \Omega$ at 915 MHz and a minimum power sensitivity of -15 dBm. The optimized value of each parameter is given in Table 1. In order to study the effect of the parameters, only the chosen parameters are changed at one time, while the others are kept as in Table 1.

TABLE 1. Optimized dimension for the proposed antenna. (unit: mm)

Parameter	Value	Parameter	Value	Parameter	Value
ls	73	ws	30	lp	72
wp	29	l1	40	l2	14
l3	9.5	l4	7.7	l5	14
l6	11	l7	8	l8	10
w1	1	w2	1	w3	2
w4	3	w5	2	w6	7.4
g	1.3	h	1.6		

III. RESULTS AND DISCUSSIONS

Fig. 2 shows the simulated input impedance of the proposed antenna with odd symmetric slots and even symmetric slots. As can be seen in the figure, one resonant frequency is generated by the even symmetric slots while two resonant frequencies are generated by the odd symmetric slots due to the perturbation of current flows, making the bandwidth enhancement possible. Fig. 3 shows the simulated current distribution of the radiation patch at 882 MHz and 928 MHz. It is observed that the current paths are controlled by the slots on the patch and we can deduce that the resonant frequencies can be tuned by the length of the odd symmetric slots $l4$, $l5$. The resonant frequency of the antenna with different lengths of $l4$, $l5$ is given in Fig. 4. It can be illustrated by the figure that as the length of $l4$ and $l5$ are increased, the resonant frequencies are moved to the lower frequencies due to the longer current path.

Figure 2. The simulated impedance of the proposed antenna with odd symmetric slots and even symmetric slots.

(a)

(b)

Figure 3. Simulated current distribution of radiation patch: (a) at 882 MHz and (b) at 928 MHz.

Figure 4. The simulated impedance of the antenna with different lengths of $l4$ and $l5$.

(a)

(b)

Figure 5. Simulated impedance characteristics (l4 = 7 mm, l5 = 3 mm): (a) impedance of the antenna with different g and (b) impedance of the antenna with different l6.

The conjugate matching between the antenna and the chip can be easily achieved by adjusting the loop dimension ($l6$) and the gap width (g) between the loop and the radiation patch. Fig. 5 depicts the simulated impedance characteristics of the antenna with different $l6$ and g. Fig. 5(a) shows the simulated impedance versus frequencies with different g. As g increases, the resistance of the antenna is decreased. Fig. 5(b) shows the simulated impedance with different $l6$. As $l6$ increases, the impedance of the proposed antenna is increased. Also, we can see that coarse tuning of the impedance is achieved via $l3$ and fine tuning via g. Then, adjusting $l3$ and g, the proposed antenna can be easily designed for different microchips with different chip impedance.

The power reflection coefficient, $|s|^2$, which is used to determine the power transfers from the antenna to the chip, can be calculated as:

$$|s|^2 = \left|\frac{z_c - z_a^*}{z_c + z_a}\right|^2 \qquad (1)$$

where Z_c is the impedance of the chip, Z_a the impedance of the antenna. The simulated power reflection coefficients of the proposed antenna when placed on different sizes of ground plane are presented in Fig. 6. The simulated half-power impedance bandwidth of the designed antenna (ground size: 200×200 mm^2) is 132 MHz from 838 MHz to 970 MHz (fractional bandwidth is 14.6%), which covers the whole bandwidth requirements of UHF RFID.
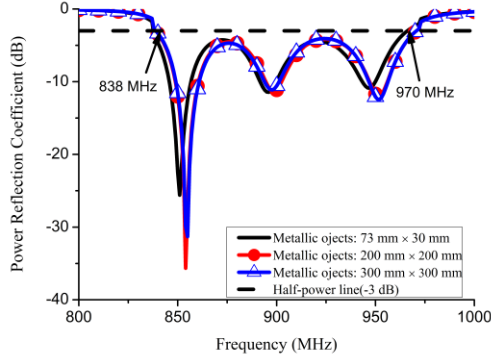
Figure 6. Simulated power reflection coefficient against frequency of the proposed antenna with different sizes of ground plane.

According to the free space Friis formula, the theoretical prediction read range, r, can be obtained by [7]:

$$r = \frac{\lambda}{4\pi} \times \sqrt{\frac{EIRP \times G_{\text{tag}} \times (1 - |s|^2)}{P_{\text{th}}}} \qquad (2)$$

where λ is the free-space wavelength, $EIRP$ the effective isotropic radiated power of the reader, G_{tag} the tag antenna gain, $|s|^2$ the power reflection coefficient, P_{th} the threshold power necessary to provide enough power to the tag chip.
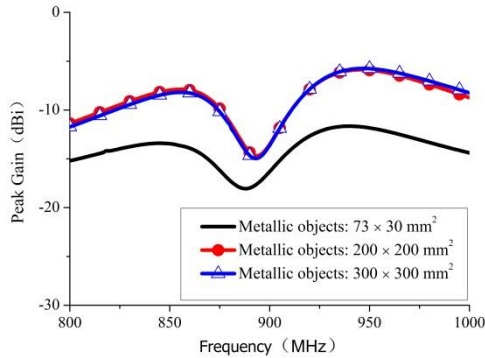

Figure 7. Simulated gains against frequency of the proposed antenna with different sizes of ground plane.

The peak gains of the proposed antenna when it is placed on different sizes of ground plane are shown in Fig. 7. The normalized radiation pattern of the tag when it is set on a 200×200 mm^2 metallic object is shown in Fig. 8. The maximum read distance ($EIRP$ is set to 3.2 W) when the tag is set on different sizes of metallic objects at some chosen frequencies are given in Table 2. As shown in Table 2, the maximum read range of the proposed antenna, which is placed on a 200×200 mm^2 metallic object, is up to 4.3 m.
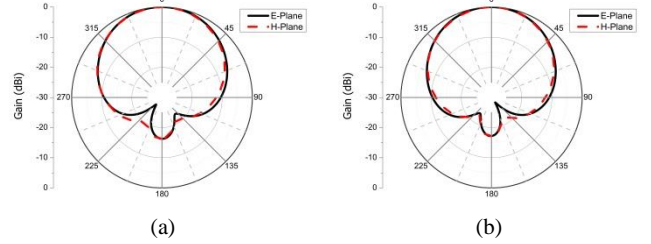

Figure 8. Simulated normalized radiation patterns of the proposed antenna: (a) 866 MHz and (b) 915 MHz

TABLE 2. Calculated maximum read range when antenna is placed on different sizes of metallic objects at some chosen frequencies.

Country	Band centre (MHz)	Read range (m)		
		Metallic object: 73×30 mm^2	Metallic object: 200×200 mm^2	Metallic object: 300×300 mm^2
China	843	1.8	2.8	2.6
Europe	866	1.4	3.0	2.8
USA	915	1.6	2.6	2.6
China	923	1.8	3.0	3.0
Japan	953	2.1	4.3	4.3

IV. CONCLUSIONS

A compact broadband UHF RFID tag antenna using odd symmetric slots is designed for metallic objects application. The proposed tag is easy for mass production as it does not need any shorting pins or plates. By embedding the odd symmetric slots in the patch antenna, two resonant modes are excited to achieve a broader bandwidth. The half-power impedance bandwidth of the proposed antenna is 132 MHz (838-970 MHz), i.e. fractional bandwidth 14.6%, covering the worldwide frequency band of UHF RFID (840-960 MHz). The maximum read range of the proposed antenna is about 4.3 m when it is placed on a 200×200 mm^2 metallic object.

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