Design of Robust UHF RFID Tag Antenna for Free-space and Metal Surface

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Abstract— Here, we present a robust RFID tag antenna with an appropriate structure that would operate adequately as a dipole in free space and as a relatively efficient microstrip antenna when placed on a metal surface. Good impedance matching is achieved by the use of a T-matching network in the both cases. For low-cost fabrication and simple structure, the antenna is printed on a single-layer substrate without a ground plane or shorting. The measured results show that the half-power bandwidth is 1 GHz (730 MHz–1.7 GHz) and 110 MHz (845 MHz–955 MHz) when in free space and on the metal surface, and the both reading distances are about 8 m measured by using a commercial measurement system.

1. INTRODUCTION

Radio frequency identification (RFID) is a rapidly developing technology which uses RF signals for automatic identification of objects. And the UHF RFID system operates at the bands of North and South America (902–928 MHz, FCC band), China (840–845 MHz and 920–925 MHz) and Europe (866–869 MHz). A typical RFID system consists of transponders and transceivers such as tag and reader. In a passive back-scattered RFID system, the reader transmits a modulated signal to the tag and the tag backscatters a signal with identification data to reader at the same time. A passive UHF RFID tag usually includes an antenna and a RF chip which has a memory to store identification data [1].

UHF RFID system has been widely used in many areas such as supply chains, airport luggage management and animal tracking. However, most normal tags are very sensitive to the working environment [2], especially the metal objects, reflecting and loss make the reading distance decreased [3]. When the tag placed on the metal surface, the electromagnetic boundary condition that there is no tangential electric field component on a metal surface brings some obstacles to detect metallic items by RFID tags, as most tag antenna's excitation significantly depends on a tangential electric field. Of course, some solutions for metallic item identification have been presented in the previous papers. Among existing solutions, the earliest is to insert a one quarter wavelength (about 82 mm around 915 MHz) spacing between an antenna and a metallic object making the whole structure suffer from being bulky and easily damaged. And some metal-friendly tags including an inserted ground plane have also been proposed. These antennas adequately operate on various dielectrics as well as metallic objects, because the inserted ground plane can properly eliminate influence from underlying objects. However, its bulky, complicated geometry and hemisphere radiation pattern not only limit their application in some cases but also increases both cost and difficulty in mass production.

A new type of antenna as a dipole or microstrip with the classical features is proposed in [4], while its size is very large. Here, we will have a further research on this type tag antenna with a novel structure in this paper. The presented antenna works as a dipole in the free space or placed on some dielectric objects such as paper, glass and foam, and when attached on the metal surface, has a good performance as a microstrip using the metallic object surface as its ground plane.

2. ANTENNA DESIGN

The structure of the proposed robust RFID tag antenna for free space and metal surface is illustrated as Figure 1. For low-cost fabrication and simple structure, the antenna is printed on a single-layer substrate without a ground plane or shorting. Here we use a FR4 substrate with thickness 0.3 mm, relative permittivity 4.4, and loss tangent 0.02. When the tag antenna placed on the metal surface as a microstrip antenna, there is a layer of foam between the tag and the metal surface. The proposed tag antenna can't be placed on the metal surface directly because of the poor performance. There is an air-layer between the tag and the metal objects in the simulation.

Here, we choose the Impinj Monza$^{\mathrm{TM}}$ 4 QT as the tag chip, which exhibits an impedance of $11 - j143\,\Omega$ at 915 MHz. In order to deliver the maximum power between the antenna and chip,

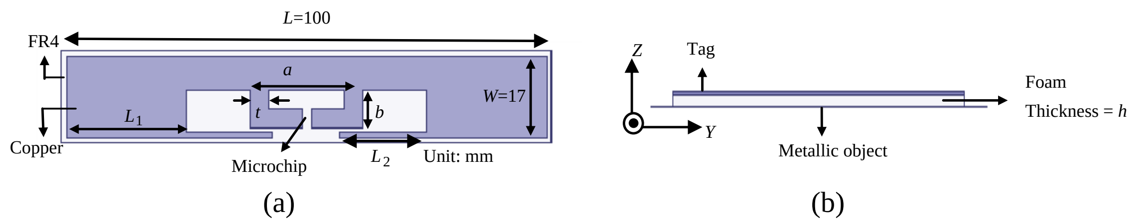

Figure 1: Detailed geometry of the proposed tag antenna. (a) Top view. (b) Side view when placed on the metal surface.

the input impedance of the antenna needs to be $11 + j143\,\Omega$. The T-matching network is normally used to decrease the resistance and to increase the reactance to provide conjugate impedance to the IC impedance [5, 6]. We have known that, it is able to use a T-match to effectively modify the impedance of dipole antenna and simultaneously to feed and provide an impedance match for a microstrip antenna. So the proposed antenna can use a T-matching network to achieve impedance matching.

For the antenna's structure, we choose the W and L according to the classical formula so that the antenna, as a microstrip, has a resonant frequency of approximately 920 MHz. But the calculated theoretical values are too large for many practical applications. So the folded element can be beneficial to realize the antenna miniaturization [6]. The parameters ($a = 23.7$, $b = 8$, $t = 4$) are modified until a suitable tradeoff between the dipole's and microstrip's impedance is achieved. And we choose the $L_1 = 25$ and $L_2 = 18$, when the both resonant frequency close to 920 MHz and the structure is small.

3. SIMULATED AND MEASURED RESULTS

The simulated results of the antenna are carried out from HFSS, which is a full wavelength numeric electromagnetic simulation tool. To validate the performance of the designed antenna, a prototype, shown in Figure 2, was fabricated to do some experiments in a partially anechoic environment.

We have already mentioned that there will be a layer of foam between the tag and metallic object, Figure 3 shows that the s_{11} features with changing foam's thickness h, we can see that there is a small frequency deviation and so we can believe that the antenna can have a good performance

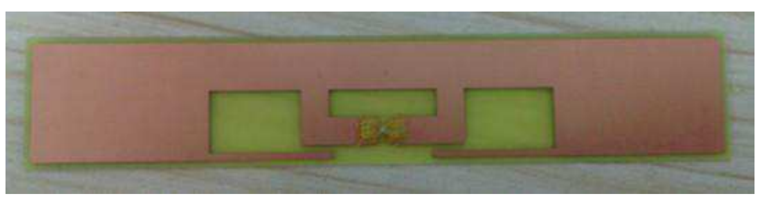

Figure 2: Picture of the fabricated robust tag antenna.

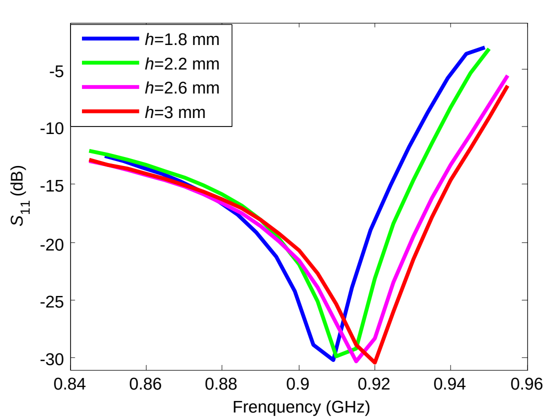

Figure 3: The S_{11} characteristic when placed on the metal with the varying thickness h.

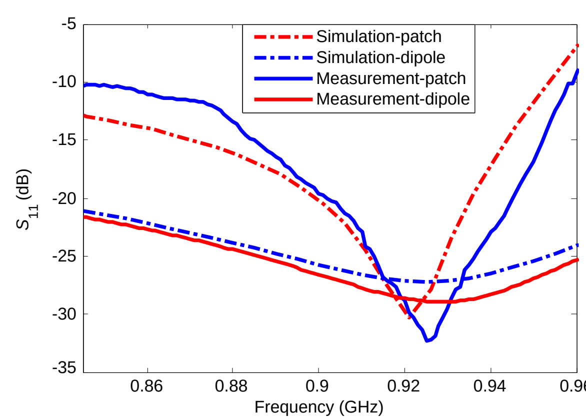

Figure 4: The comparison of simulated and measured S_{11} of the proposed antenna.

with the thickness changing from 2 mm to 3 mm, clearly, when the thickness is 3 mm or greater, the performance will be better. This about 3 mm foam is used in the actual measurement.

Figure 4 shows the simulated and measured s_{11} in both cases. From the figure we can see that both the measured results agree with the simulated ones with a slight deviation. The -10 dB bandwidth of the antenna, as a dipole, is very wide from 730 MHz to 1.7 GHz, not fully shown in this figure, and ranges from 845 MHz to 955 MHz when as a microstrip, the band both can cover the Chinese RFID UHF band (920–925 MHz).

Figure 5 shows the simulated resistance R and reactance X of the antenna when in free space behaving as a dipole, and when on the metal behaving as a microstrip. In free space, there is no much change in impedance over the band, however, as a microstrip, the reactance has a significant increase following the frequency and the resistance is little bit small, but can be accepted. Obviously, there is not a very perfect impedance matching when the antenna works as a microstrip, while the power transfer coefficient is effective.

Since it is difficult that the tag antenna matches to a coaxial line, the measurement of testing radiation patterns is hard to implement, here we just give the simulated data. Figure 6 shows the radiation patterns in YOZ plane. We can see that both have a good gain. A 2 dB enhancement in gain could be achieved when the proposed tag antenna placed on a $150 \times 150\,\text{mm}^2$ metal plate.

In addition, we measured the tag sensitivity and reading distance of the fabricated tags in an anechoic chamber in the both cases, using a commercial measurement system, Tagformance Lite of Voyantic Corporation. Figure 7 presents the reading characteristic when the tags are mounted in free space (on the foam) and on the metal surface. As shown in Figure 7, although the measured results show the operating frequency offset, especially in free space, according with the measured return loss, such small deviation is not enough for affecting practical application. We have got that, there is a higher gain when the tag placed on the metallic surface at 920 MHz, which is why the red curve in Figure 7 shows a farther reading distance in the band 920 MHz–925 MHz, however, the

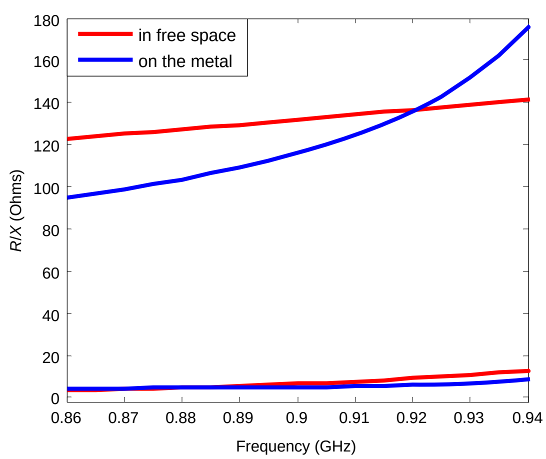

Figure 5: The simulated impedance of the proposed antenna at 920 MHz.

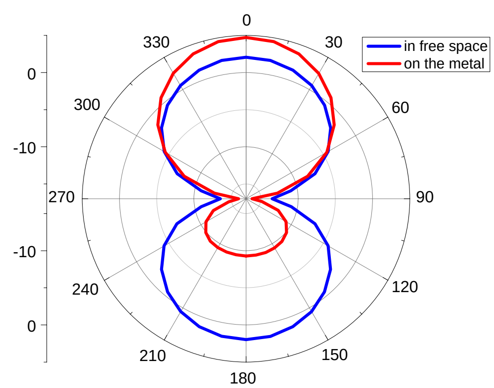

Figure 6: The simulated radiation pattern of the proposed antenna at 920 MHz in YOZ.

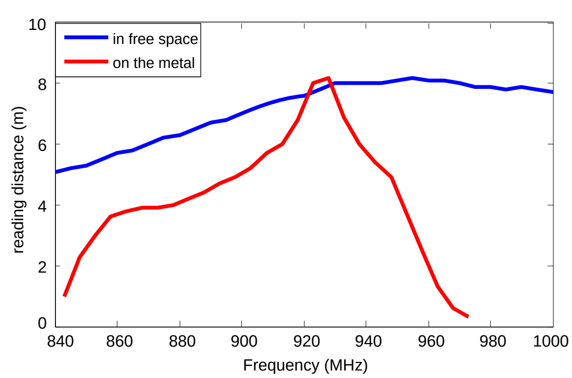

Figure 7: The reading distance of the proposed tag measured by Tagformance Lite.

not very perfect impedance matching when as a microstrip explains why the distance on the metal only a bit bigger than that in free space.

4. CONCLUSION

A robust tag antenna is proposed in the UHF band which can be applied as a dipole in free space, and as a microstrip on the metal surface. Good impedance matching is achieved by geometrically adjusting the size of the T-matching network, which is a classical impedance matching to a dipole, and when attached to metal surface, operates as a microstrip antenna with balanced edge feeds. The tag antenna has half-power bandwidth of 1 GHz and 110 MHz, in free space and on the metal, respectively. We got that the expected reading distance on both cases is about 8 m by a Tagformance Lite. The proposed tag antenna would be suitable for practical applications dealing with free-space and metallic objects.

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