Design of Compact Passive Tag Antenna for Practical RFID Applications

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Abstract— The communication quality between an RFID tag and a reader in a RFID network, especially the parameters of the passive tag antenna such as reading range, directivity and return loss, is affected by several factors from the environment. For practical RFID application, since the environment is complex and volatile, these factors include metallic surface of products, absorptions and impacts from neighbor tag antennas like scattering and mutual coupling. In this paper, it consists of the analysis of impacts caused by these factors and the design of passive tag antennas with resonant frequency 915 MHz able to be used in practical RFID applications against those impacts. Comparing with former ones, the proposed antenna reduces the size of the tag antenna to approximately commercial standard (18 mm × 48 mm × 3 mm) by using certain structures applied in the unit cell of metamaterial or HIS, while the properties including directivity, return loss and input impedance are still appropriate for RFID applications. Simulation results from HFSS indicates that at 915 MHz, the return loss can be about −21 dB, as most of the power can be radiated into the space towards the receiver. Meanwhile, the input impedance $Z_0 = 9.4738 + j143.9189\,\Omega$, perfectly matching the impedance of the RFID chip placed on the top surface of the antenna. The above improved parameters play an important role in prolonging the reading range.

1. INTRODUCTION

Radio frequency identification (RFID) is a flourishing technology used for automatic object identification method for the efficient tracking, attracting more and more attention recently. In the last decade, with the development of the Internet of thellongs, a considerable number of studies have been conducted on the design of RFID tag antenna for practical applications. When operated at higher frequency such as UHF band, RFID antenna has longer reading range, faster reading speed and lower collision [1]. However, as RFID tag is always directly attached to objects like metal containers or engineering plastics (ABS) boxes, parameters of tag antenna can be seriously deteriorate such as input impedance, radiation pattern, bandwidth, and return loss. These changes lead to bad performance as a result, especially for dipole antenna widely used in RFID applications [2].

Several solutions have been proposed to design UHF antennas operating at the surface of certain object. Since metallic objects are very common in transportation, and metallic surface has the most severe impact on UHF antenna, designing an anti-metallic UHF RFID tag antenna is the most crucial work to antenna engineers. Methods like planar inverted F antennas (PIFA) using a shorting plate [3] and printed inductor [4] have been proposed to improve the antenna performance against metallic boundary effect, while using the structure of HIS cell to design RFID antenna has been proved to be quite useful and efficient [5].

In this letter, a compact RFID passive tag antenna is proposed for metabolic object application. And the impacts from the size of metallic object and the material of metalloid object are also analyzed. The antenna configuration will be explained in Section 2 while Sections 3, 4 demonstrate simulations and solutions to surface effect by metalloid material.

2. UHF ANTI-METALLIC PASSIVE RFID ANTENNA DESIGN

The proposed metallic RFID tag is comprised of two patches and several structures used for impedance match. Figure 1 shows the configuration of the antenna. The material used in substrate is FR4, whose relative permittivity is 4.4. And the RFIC chip is Impinj Monza 4, whose input impedance is $(11 - j143)\,\Omega$ at 915 MHz (the operating frequency in North America).

The mechanism of the antenna can be approximately represented by an equivalent transmission line circuit. The simplified equivalent circuit model of assembled RFID tag antenna is shown in

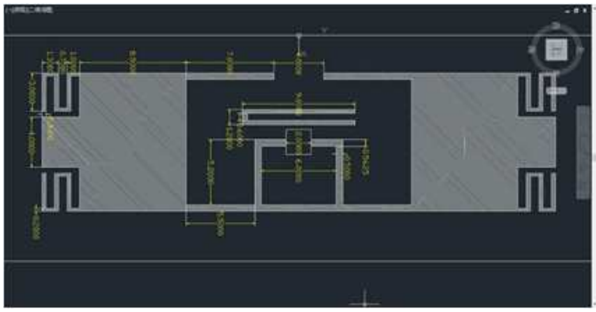


Figure 1: Configuration of the proposed RFID tag antenna.

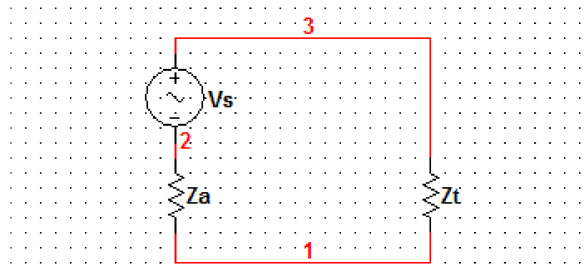


Figure 2: Simplified equivalent circuit model of tag antenna.

Figure 2. The V_s is the equivalent power source, $Z_a = R_a + jX_a$ is the impedance of the antenna, and $Z_c = R_c + jX_c$ is the impedance of the RFIC chip (here is Monza 4). From the transmission theory [6], for the maximum power transfer, the impedance of antenna and chip must meet condition of conjugating match

$$\begin{cases} R_a = R_c \\ X_a = -X_c \end{cases} \tag{1}$$

So the maximum power the chip can obtain from the antenna is

$$P_{\max} = \frac{|V_s|^2}{4R_a} \tag{2}$$

From the equivalent circuit, another important parameter is S_{11} which is defined as

$$\Gamma = \frac{Z_c - Z_a}{Z_c + Z_a} = 1 - \frac{4 \times R_C \times R_a}{(R_C + R_a)^2 + (X_C + X_a)^2} \tag{3}$$

Thus the return loss (RL) is defined as

$$\mathrm{RL} = -S_{11} = 20 \log |\Gamma| = 20 \log \left| \frac{Z_c - Z_a}{Z_c + Z_a} \right| \tag{4}$$

Return loss represents how much power has been scattered back to the antenna instead of being absorbed by the chip.

When the radiated power delivered to the RFIC chip is larger than its threshold energy P_{th}, it will be activated, and the maximum reading range for a RFID tag antenna will be

$$r_{\max} = \frac{\lambda}{4\pi} \sqrt{\frac{P_t G_t G_r \tau}{P_{th}}} \tag{5}$$

where P_t is the power delivered from the RFID reader, G_t and G_r are the gain of reader and antenna. And τ is the power transmission coefficient, defined as $1 - \Gamma$, plays the most crucial role in prolonging the reading range.

To obtain a workable reading range, the most important work is impedance match. The impedance of the antenna can be influenced by the size and shape of the structures on the substrate. And some certain structures like T-match network are designed to adjust the impedance of the antenna, especially for reactance conjugating match.

3. RESULTS FROM MODELING AND SIMULATION

The antenna design is modeled and simulated using Ansoft high-frequency simulation software (HFSS). The metal sheet under the substrate is $0.5\lambda \times 0.5\lambda$ [5], as the surface of the metal to which tag antenna attaches. Figure 3 shows the impedance of the proposed antenna by HFSS simulation.

The impedance of the antenna operated at 915 MHz is $(9.4738+j143.9189)\,\Omega$, and the impedance of the chip is $(11-j143)\,\Omega$, respectively. From formula (4), the Return loss (in dB) can be calculated, and Figure 4 shows the curve of return loss with frequency 860–960 MHz.

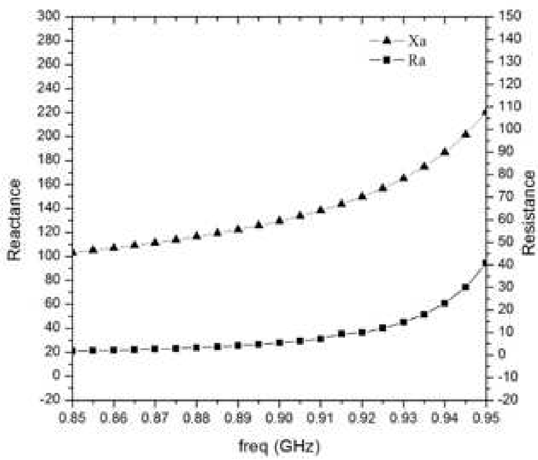


Figure 3: Impedance curve of the tag antenna.

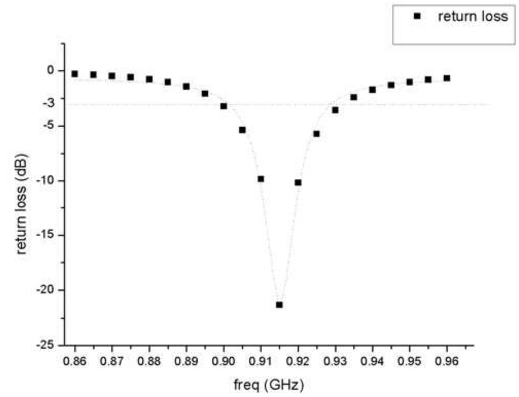


Figure 4: Return loss of the tag antenna.

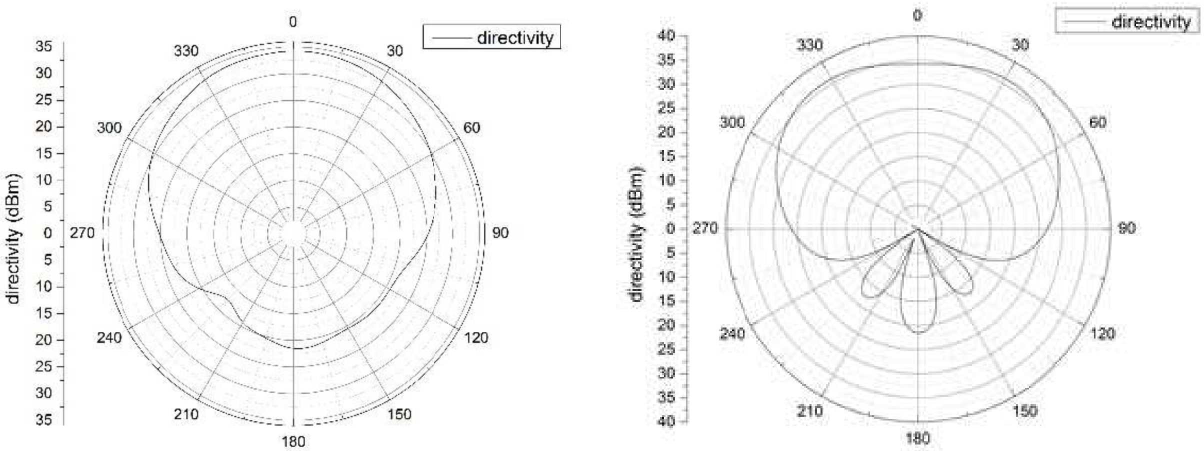


Figure 5: Radiation pattern of XOZ plane and YOZ plane.

The simulated resonant frequency is $f = 915\,\text{MHz}$, at which the return loss is $-21.2\,\text{dB}$, and the $-3\,\text{dB}$ bandwidth is about 900–928 MHz (3.11%).

Furthermore, the radiation pattern of the proposed antenna are shown in Figure 5. The directivity of XOZ and YOZ plane is larger than 30 dBm, while the return loss at 915 MHz is $-21.2\,\text{dB}$, there is enough energy to activate the chip.

4. IMPACT FROM THE GROUND PLANE ON TAG ANTENNA

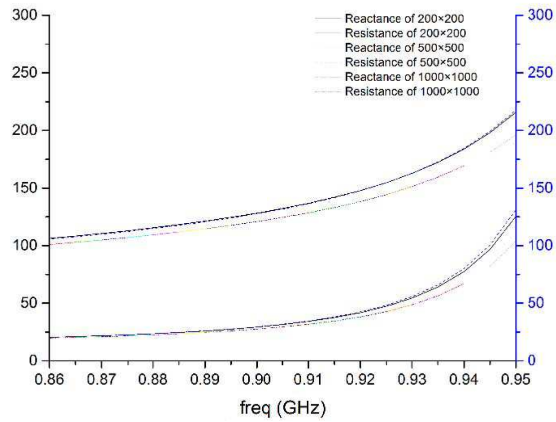
For better use in practical RFID application, more researches about the performance of the proposed antenna in different conditions are conducted.

Firstly, the antenna is attached to metal objects of different surface size. Table 1 shows the sizes of the metallic objects and parameters such as impedance and return loss of the antenna at 915 MHz. And Figure 6 shows the impedance, return loss and radiation pattern of the antenna. When the size of the object be-comes larger from 0.5λ to 2λ, the impedance and return loss change slightly. However, when the size is too much large ($1000\,\text{mm} \times 1000\,\text{mm}$), the resonant frequency shifts to 925 MHz, at which the return loss is almost equal to previous cases. This is from the fringing effect. So, for the best optimize, the size of the object surface should not be larger than $3\lambda \times 3\lambda$.

To verify the impact from attached object of different materials, the proposed antenna is put on the surfaces of objects made of ABS, Acrylic Slab, Cardboard and Pine Plywood. Table 2 indicates the properties of these materials. Figure 7 shows the impedance, return loss and radiation pattern by simulation.

Table 1: Impedance and return loss of the antenna in each cases at 915 MHz.

Size of the metallic object	Impedance/Ω	Return loss/dB
$200\,\text{mm} \times 200\,\text{mm} \times 15\,\text{mm}$	$9.16 + j142.10$	-19.87
$500\,\text{mm} \times 500\,\text{mm} \times 15\,\text{mm}$	$9.33 + j141.69$	-19.68
$1000\,\text{mm} \times 1000\,\text{mm} \times 15\,\text{mm}$	$8.11 + j133.11$	-6.36



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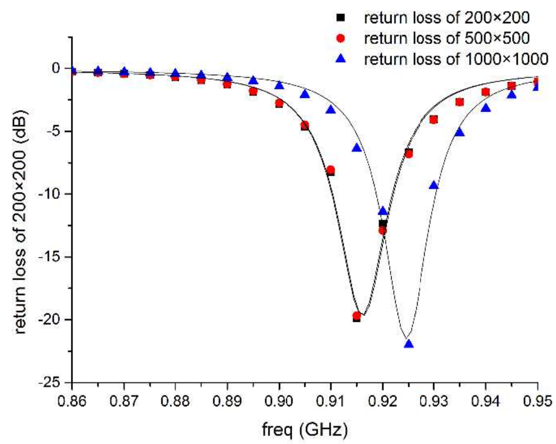

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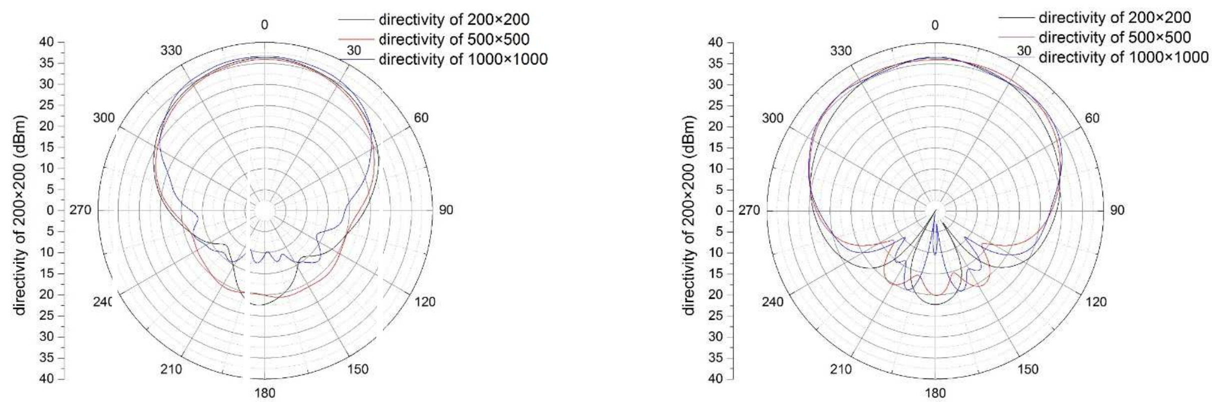


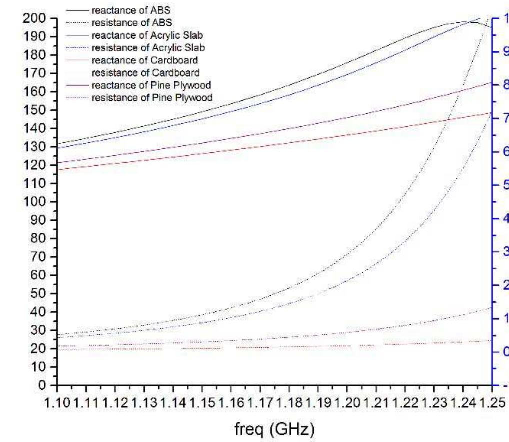
(c)

Figure 6: (a) Impedance of the antenna in three cases. (b) Return loss of the antenna in 3 cases. (c) Radiation pattern of XOZ plane and YOZ plane.

Table 2: Properties of the materials.

material	**Relative Permittivity**	**Dielectric Loss Tangent**	**Size of the object/mm^3**
ABS	2.8	0.01	$150 \times 150 \times 15$
Acrylic Slab	2.6	0.0061	$150 \times 150 \times 15$
Cardboard	1		$150 \times 150 \times 15$
Pine Plywood	1.7	0.036	$150 \times 150 \times 15$

The simulation results show that metalloid material has a negative impact on the proposed antenna, as the resonant frequency shifts to higher than 1.15 GHz. It is because as there is no metallic layer on the bottom of antenna, the effect capacity C became much smaller, which resulted in higher resonant frequency. It is not so difficult to optimize the frequency shift. One possible solution is adhering the proposed antenna to an optimized metal sheet, then put the sheet on the surface of these metalloid materials. Figure 8 shows the simulation result of the solution (taking ABS for example). At 915 MHz, the impedance is $(9.630 + j144543)\,\Omega$, and return loss is -20.0 dB, accordingly.



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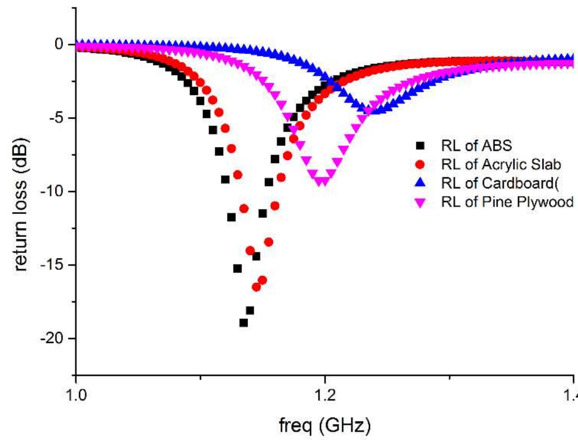

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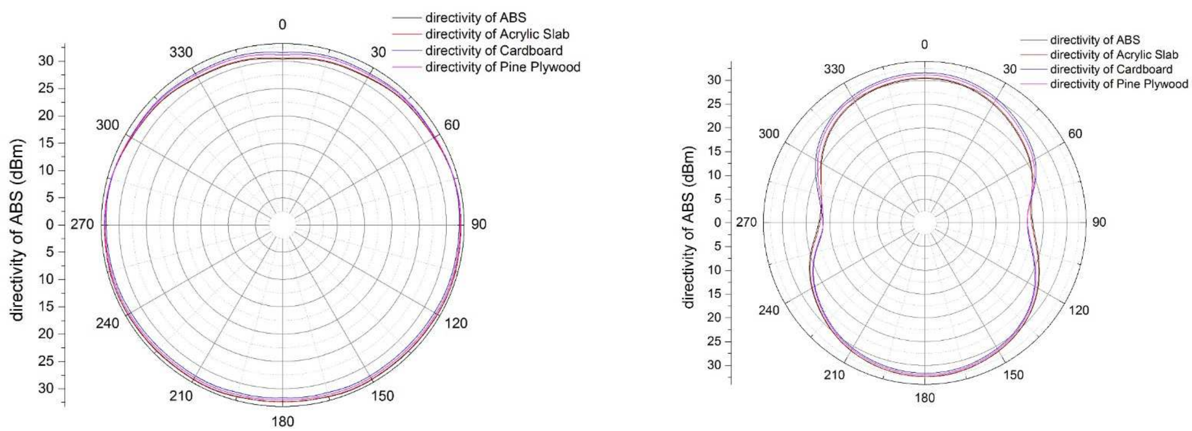

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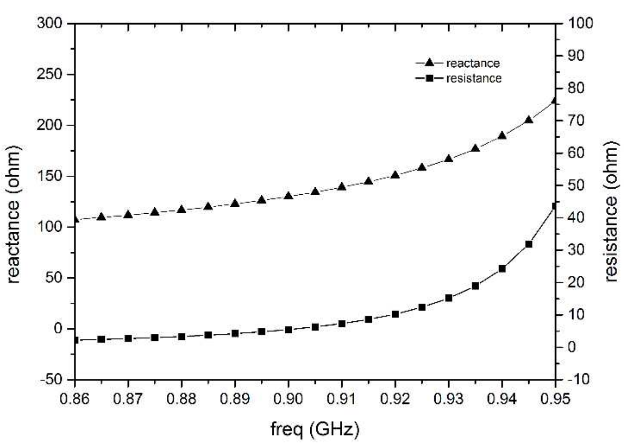
Figure 7: (a) Impedance of the antenna in these cases. (b) Return loss of the antenna in these cases. (c) Radiation pattern of XOZ plane and YOZ plane.



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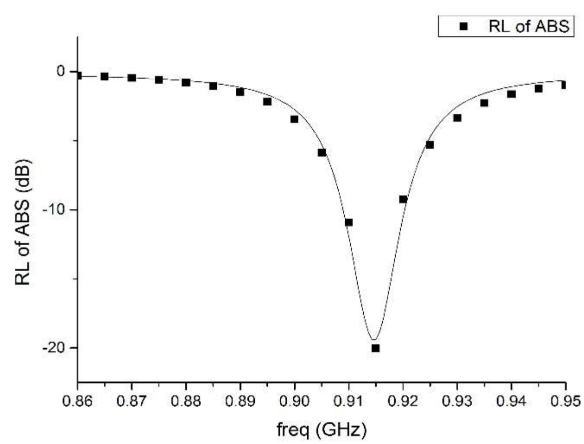

(b)

Figure 8: (a) Impedance of the antenna with metallic sheet. (b) Return loss of the antenna with metallic sheet.

5. CONCLUSION

In this letter, a compact and slim passive anti-metallic RFID tag antenna operated at 915 MHz is presented and implemented, and the impact caused by attached object has been investigated by simulation. Although the size of metal sheet and metalloid material will shift the resonant frequency to a higher one, it can be solved by adding a metallic sheet with optimized size at the bottom of the antenna. All in all the proposed antenna can be used in practical RFID application.

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