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A RFID TAG METAL ANTENNA ON A COMPACT HIS SUBSTRATE

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Abstract—Utilizing the special physical characteristic of a high impedance surface, a radio frequency identification tag antenna working at 920 MHz for metallic ground is proposed. The antenna not only overcomes the problem of impedance mismatching when placing on a metallic object, but also exhibits a low-profile antenna structure.

1. INTRODUCTION

UHF (Ultra High Frequency) RFID (Radio Frequency Identification) is a booming technology which can be used in many fields such as supply chain and security management. Dipole-type antenna is the main type of RFID tag antenna operated at the UHF band. But one critical issue is that such an antenna cannot be placed on metal objects, which can significantly change its input impedance, radiation pattern, and resonant frequency of the antenna [1, 2]. To solve this problem, several approaches have been employed including the use of a planar

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inverted-F antenna or an artificial magnetic conductor as the ground plane [3–5].

The high impedance surface (HIS) operated as a kind of artificial electromagnetic material functions as a perfect magnetic conductor with in-phase reflection and high impedance state within a specific frequency range. When a HIS is used as the ground plane of antenna, the problem caused by metallic objects can be mitigated; the gain of the antenna can also be increased; and a low-profile antenna can be realized. In this paper, a new type of HIS structure is proposed for a RFID tag dipole antenna. By etching slots around each metal patch, the high impedance frequency band can be shifted downward, while the size of a unit cell is maintained the same. Compared with the HIS which has via [6], this structure reduces the complexity of the antenna. And by bending the arms of a dipole in a meandering shape, the antenna is miniaturized without unacceptable degradation in radiation efficiency.

2. THEORY OF THE DESIGN

Electromagnetic wave reflects from a metallic surface with 180 degree phase reversal in the tangential electric field component. When a dipole-type RFID tag antenna is located close to a metal object, the reflected electric field significantly counteracts the electric field radiated by the tag. Consequently, the radiation pattern, input impedance and resonant frequency of the antenna are changed, and the radiation efficiency is degraded. The resistance of a tag chip is usually between a few ohms to tens of ohms, while the real part of the dipole antenna is close to zero when attached to a metallic surface. Therefore, the problem of impedance mismatch has to be solved.

According to the principle of duality, the electric field component of the incident and reflected waves are in phase on a perfect magnetic conductor surface. Therefore, the distance between the antenna and the repeating surface can be much less than a quarter of a wavelength. Through the use of a HIS, the reflected and incident electric fields due to the antenna have no phase difference, when the tag is located close to the HIS. So the antenna can be matched well with the tag. Hence, we can not only realize a low profile antenna, but also solve the problem occurred when the tag is placed on a metal. The perfect magnetic conductor does not exist in nature, while the artificial electromagnetic material — high impedance surface — exhibits the physical characteristic of the perfect magnetic conductor within a specific frequency band.

3. ANTENNA DESIGN AND RESULTS

A RFID tag antenna based on dipole technology is illustrated in Fig. 1. To reduce the size of a half-wave dipole, a meandering structure may be employed [7]. As shown in Fig. 1(a), a meandering antenna is designed and located on the top of the whole structure. The dielectric board employed is 2 mm in thickness with relative permittivity $\varepsilon_r = 2.65$. The antenna is designed for RFIC chip with an input impedance of about 20−j121 Ω, thus, the impedance of whole antenna should be 20+j121 Ω

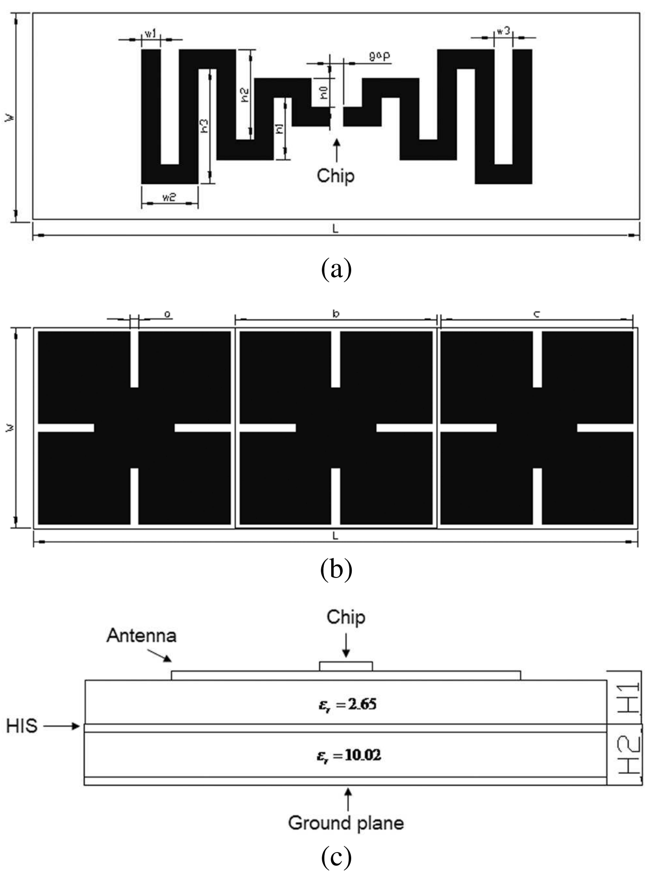

Figure 1. The structure of RFID tag antenna. (a) Dipole-type antenna structure, Gap = 3 mm, h_0 = 6 mm, h_1 = 13 mm, h_2 = 19 mm, h_3 = 24 mm, w_1 = 4 mm, w_2 = 12 mm, w_3 = 4 mm. (b) HIS structure, a = 2 mm, b = 41 mm, c = 43 mm. (c) Sectional view of RFID tag antenna, H_1 = 2 mm, H_2 = 1.52 mm.

to achieve impedance matching. The length of antenna is 129 mm ($0.396\lambda_0$, λ_0 represents the wave length of operating frequency), and the width is 43 mm ($0.132\lambda_0$) with the HIS. The total thickness is 3.52 mm ($0.011\lambda_0$). Hence, this RFID tag antenna has very small size and is in low profile, attracting for various applications.

The high impedance surface can be classed into two kinds. One has a hole in the dielectric board for short circuiting each metal patch to the ground, and the other is via-less. The structure with perpendicular vias increases the difficulty of fabrication, and it is expensive. The structure of periodic square PEC patches without vias is simple, but the size of such a structure is bigger than the one with vias at the same resonant frequency. In this paper, the proposed HIS has no via holes and is slotted around each square metal patch. Fig. 1(b) presents the dimensions of the HIS. The HIS consists of periodic metallic pattern etched on dielectric substrate, and the back of the substrate is metal ground plane. The dielectric board employed is 1.52 mm in thickness with relative permittivity $\varepsilon_r = 10.02$. This structure is easy to manufacture, and compared with the structure of periodic square PEC patches without vias, it has a smaller cell size at the same resonant frequency.

The cell of HIS without slots around metal patch which is illustrated in Fig. 2(a) can be viewed as parallel LC circuit in Fig. 2(b). And following expressions are effective inductance and capacitance [8].

$$L_{\mathit{eff}} = \mu_0 h \tag{1}$$

$$C_{\mathit{eff}} = \varepsilon_0 (\varepsilon_r + 1) \frac{M}{\pi} \ln\left(\frac{1}{\sin(\frac{\pi * a}{2 * M})}\right) \tag{2}$$

So the resonant frequency is given by

$$f = \frac{1}{2\pi\sqrt{L_{\mathit{eff}} C_{\mathit{eff}}}} \tag{3}$$

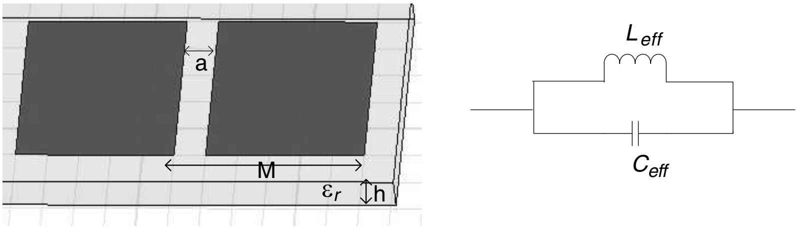

Figure 2. The cell of HIS without slot and equivalent circuit of HIS. (a) The cell of HIS without slot. (b) Equivalent circuit of HIS.

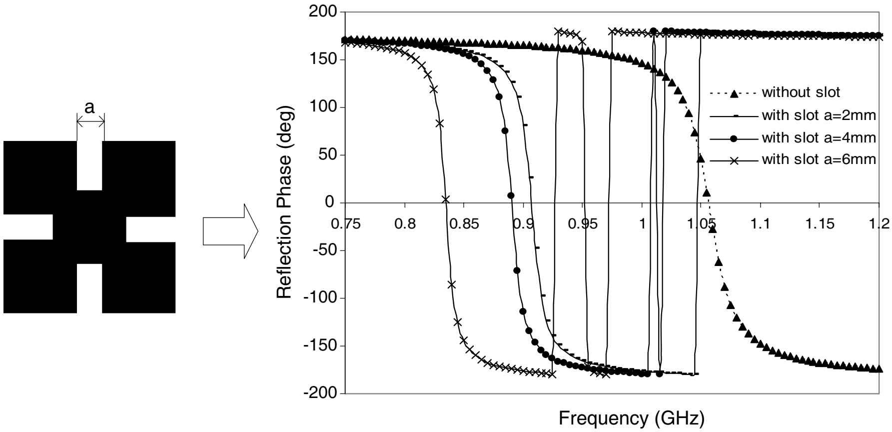

Figure 3. Proposed cell of HIS and simulated reflection phase with different size slot. (a) Proposed cell of HIS. (b) Simulated reflection phase with different size slot.

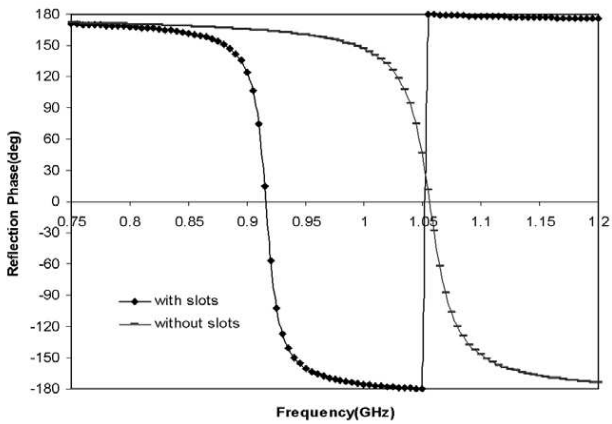

Figure 4. Simulated reflection phase of slotted patch and non-slotted patch.

The capacitive component is increased with slot around metal patch, and according to the expression (3), the resonant frequency is reduced. For reducing the size of HIS cell, the metal patch is slotted around as shown in Fig. 3(a). Fig. 3(b) shows the reflection phase when the value of 'a' is changed. The high impedance property can be achieved by adjusting the size of slot which is around the metal patch.

Figure 4 shows the reflection phases of the slotted patch and the non-slotted patch with the same unit cell area at a location which is 2 mm away from the HIS. It can be obtained that the reflection phase curve of non-slotted patch crosses the zero point at 1.09 GHz. Etching slots around the patch has an effect to reduce the zero crossing frequency point to 0.92 GHz. From 0.91 GHz to 0.93 GHz, the reflection phase varies from $+90°$ to $-90°$, which exhibits the characteristic of a high impedance surface.

Figure 5 shows the input impedance of whole antenna with a finite HIS (3-cells). The dimensions of each cell of HIS are 43 mm × 43 mm. We can see that the impedance curves of the real and imaginary parts

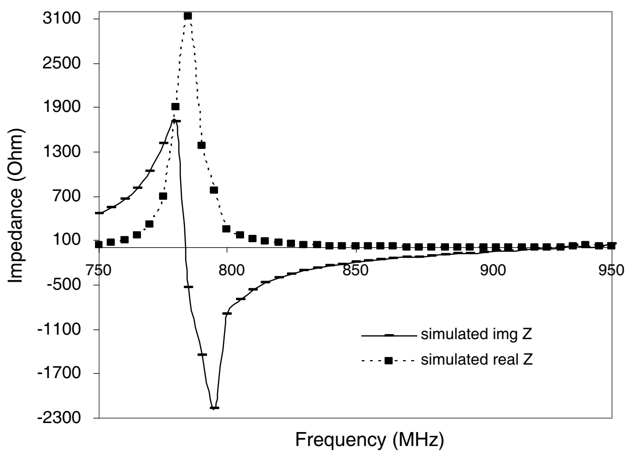

Figure 5. Simulated impedance of antenna with a finite HIS (3-cells).

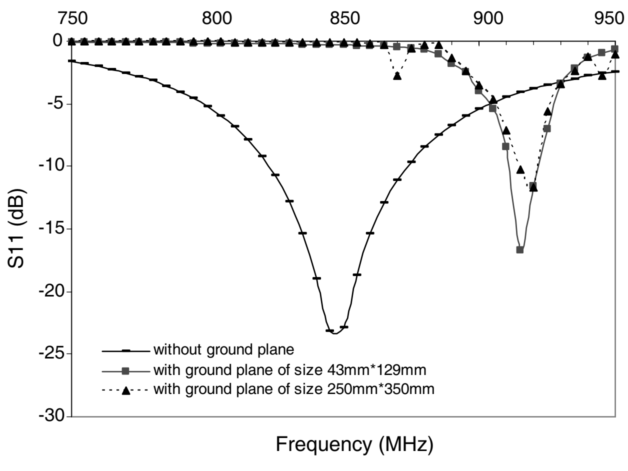

Figure 6. Simulated return losses of RFID tag antenna with HIS and without HIS on ground planes of different sizes.

become smooth from 900 MHz. Fig. 6 shows the simulated return loss curves of the antenna with a finite HIS (3-cells) and without HIS on different size ground planes. For the case with a small ground plane which has the same size of the 3-cell HIS substrate, the best impedance matching occurs at about 920 MHz, and the S_{11} is about -17 dB as shown in Fig. 6. The impedance bandwidth is about 1.1%. Compared with the single dipole antenna which is without HIS and ground plane, the resonant frequency shifts to the right. For the case with a large ground plane of size 250 mm*350 mm which may be assumed to infinite, the resonant frequency shifts to a higher value of about 925 MHz.

Figure 7 depicts the simulated radiation patterns of the antenna with the HIS which has metal ground plane size of 43 mm $*$ 129 mm and without the HIS at 920 MHz. It can be observed that the directivity and front-to-back ratio increase when the antenna is attached to the HIS. The gain of antenna with the HIS and a small ground plane is higher than that of the dipole antenna without the HIS and ground plane as shown in Fig. 8. When the metal ground plane goes to infinity, the gain of antenna with the HIS becomes lower. Fig. 9 shows the photograph of the fabricated RFID tag antenna.

The reading distance is examined when this tag antenna is placed on the metal ground plane with different sizes. The experiment is performed in air under the transmitted equivalent isotropic radiated power (EIRP) of 30 dBm from commercial reader. The reading distances for various cases are summarized in Table 1. The maximum reading distance achieves 3.1 m when the metal object has the same size of the HIS substrate.

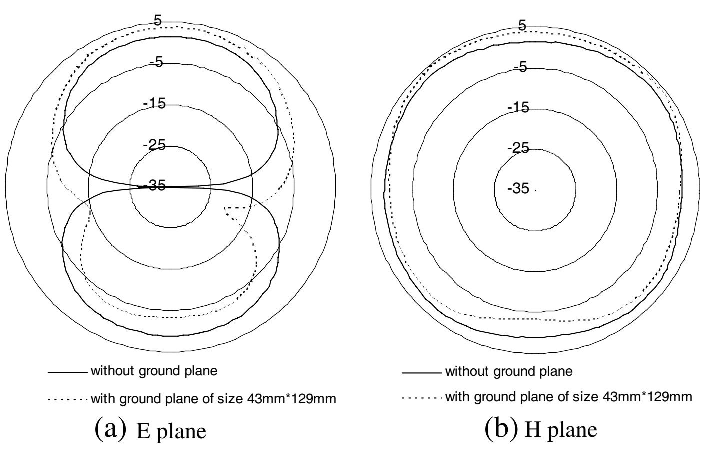

Figure 7. Radiation pattern at 920 MHz.

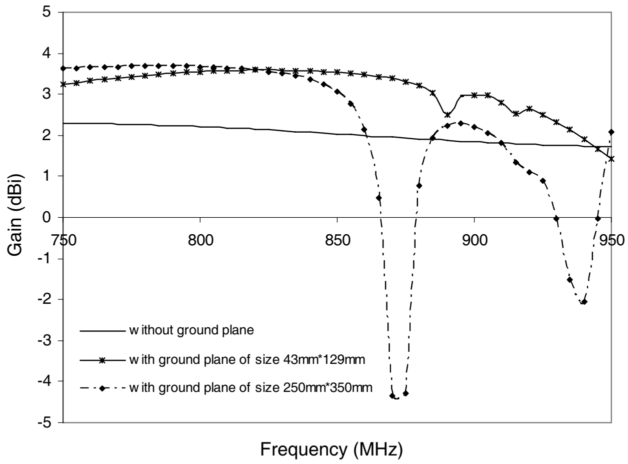

Figure 8. Simulated gain of the antenna with HIS and without HIS on ground planes of different sizes.

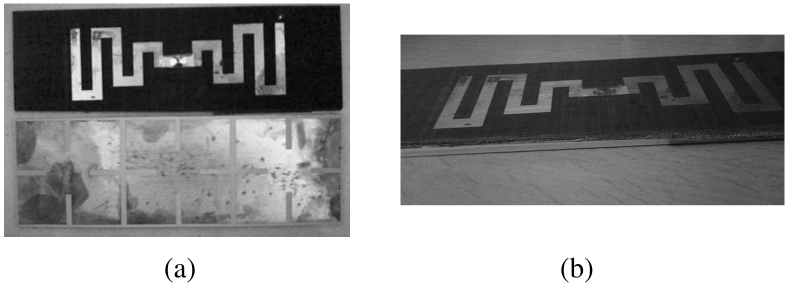

Figure 9. Photograph of RFID tag antenna. (a) The photograph of dipole-type antenna and HIS. (b) The whole antenna with an RFID chip.

Table 1. Maximum reading distance with and without metallic object.

	Without metallic object	Metallic object of size 43 mm × 129 mm	Metallic object of size 250 mm × 350 mm
With HIS	3.1 m	3.1 m	1.2 m
Without HIS	2.9 m	0	0

4. CONCLUSION

A new type HIS structure which is easy to fabricate is proposed to make RFID tag antenna design. The folded dipole effectively reduces the size of RFID tag antenna. The HIS not only solves problems which are caught by a metallic mounting structure, but also increases the gain of antenna. The measured maximum reading distance is 3.1 m, when the RFID tag antenna is attached to a finite metal plane of size 43 mm × 129 mm.

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