Miniaturized Tag Antennas with Artificial Magnetic Conductor for UHF RFID On-body Applications

Chien-Wen Chiu and Cheng-Yan Yang
Department of Electronic Engineering, National Ilan University, Ilan 260, Taiwan

Abstract— The paper presented a compact dipole tag antenna with a miniaturized artificial magnetic conductor for UHF RFID on-body applications. Two kinds of artificial magnetic conductor are designed and studied in order to insulate the influence from the human body. The miniaturized AMC structure is then placed on the button of a folded dipole tag antenna connected with a Monaz® 4 microchip. The tag with the AMC is designed and simulated by the simulator HFSS. The design structure is also constructed to verify the simulation results. The study finds that the tag with the AMC can increase antenna gain and reading range. When the tag is put close to a human body, the foldeddipole tag can achieve about 6 m reading distance.

1. INTRODUCTION

UHF RFID technique is popular in the logistics, inventory management or bioengineering. A UHF tag does not work well when it is put close to a human body or held in hand. The input impedance, radiation pattern, and realized gain of the tag antenna are influenced because of the body-proximity effects. The influences are caused by absorption, diffraction, and scattering of electromagnetic waves due to the lossy and conducting human body. The body-proximity effects must be considered when a tag is held or put on the body. Some literatures have studied the effect of the human body on the designed tags [1, 2].

Recently, a few scholars proposed artificial magnetic conductors (AMCs) to insulate the effect of the human body for wearable device or RFID applications [3, 4]. Ta et al. proposed a two-dimensional square metal patch as the unit cell of the artificial magnetic conductor (AMC) [5]. Then, four T-type slots are symmetrically inserted into each side of the metal patch to miniaturize the AMC size and lower the first resonant frequency. The bandwidth is limited although it is a low profile AMC structure. Recently, Hadarig et al. presented a kind of AMC using capacitive interdigital structure. The AMC structure exhibits proper bandwidth and higher angular stability under oblique incidence [6]. Using an artificial magnetic conductor (AMC) in the backplane of the tag actually helps to reduce the influence of a human body and increase reading range. However, the tag with an AMC is still large and bulky for on-body applications.

In this presentation, two kinds of AMC structure were studied for on-body applications, one is a square metal patch with T-type slots structure [5] and the other is four rectangular metal pads with interdigital capacitive structure [6]. Considering the minimum operating bandwidth and antenna sizes, we compared the performance between the two AMC structures after simulation and chose the minimum-size AMC structure. Then a miniaturized dipole tag antenna was designed and placed on the above of the AMC structure to insulate the influence from the human body. The designed tag on the AMC substrate is then placed close to a four-layer stratified elliptical cylinder human model to study the performance of the designed tags. In Section 2, we designed and compared two AMC structures. Section 3 is devoted to designing a folded-dipole tag antenna with an AMC. In Section 4, the tag with the miniaturized AMC is pasted on a human body. The gain and reading range of the folded-dipole with and without AMC are compared. Finally, Section 5 draws some conclusions.

2. AMC DESIGN

AMC structures have many kinds of physical type. An AMC is composed of a frequency selective surface (FSS) placed above a perfect ground plane and a dielectric material. A two-dimensional square metal patch was initially used as the unit cell of artificial magnetic conductor (AMC). To lower the resonance frequency, four T-type slots are symmetrically inserted into each side of the metal patch [5]. Each slot is designed with $L_p = 40$ mm and $W_p = 3$ mm so that the operating frequency is reduced to 915 MHz. The periodic square patch is built on a grounded FR4 substrate with height = 3.2 mm, $\varepsilon_r = 45$ and loss tangent = 0.02. The study finds that the AMC with 3×3 T-slot patch-typed unit cells is too large and narrow band to be applied on the human body.

To miniaturize the overall size in the low frequency, the unit cell of a new AMC which consists of four rectangular metal pads with interdigital capacitors connected by two striplines is studied [6] as Figure 1 shows. The four rectangular metal pads behave like capacitors but the two striplines provide the inductive behaviour. The gap between the adjacent unit cells forms an interdigital capacitance. It is a key design factor for designing smaller unit cells at the low operating frequency [6]. The AMC structure is expected to be employed to design a tag antenna for on-body applications. Figure 1 shows the geometric configuration of the unit cells of the AMC structure. The geometric sizes are $W = 40\,\mathrm{mm}$, $a = 13.7\,\mathrm{mm}$, $b = 12\,\mathrm{mm}$, $c = 12\,\mathrm{mm}$, $d = 1.6\,\mathrm{mm}$, $e = 15.4\,\mathrm{mm}$ and $f = 24.1\,\mathrm{mm}$. To reduce cost, we chose a FR4 substrate with $\varepsilon_r = 45$ and loss tangent $= 0.02$ as the AMC carrier. The unit cell size is $34.1 \times 34.1\,\mathrm{mm}^2$ and the substrate thickness is 3.2 mm. The gap width between each unit cell is 1 mm.

The AMC model is established in the ANSYS's HFSS simulator. The simulated model includes two PEC walls and two PMC walls to model an infinite periodic structure and then a wave port is setup as an exciting source. Figure 2 shows the simulated reflection phase of the FSS AMC. The simulated result indicates that the miniaturized AMC has a high impedance surface at 925 MHz. The AMC surface becomes PEC as the operating frequency near 800 MHz or 1 GHz. The best operating frequency of the PMC surface is located near about 925 MHz. The useful bandwidth which ranges from 919–934 MHz is about 1.6%. The proposed AMC structure is not easy to implement so that the EM simulated software, FEKO, is evoked to verify the accuracy of the simulation results by HFSS. The simulated results by HFSS show agreement with the simulated results of FEKO. It confirms the simulation by HFSS is acceptable.

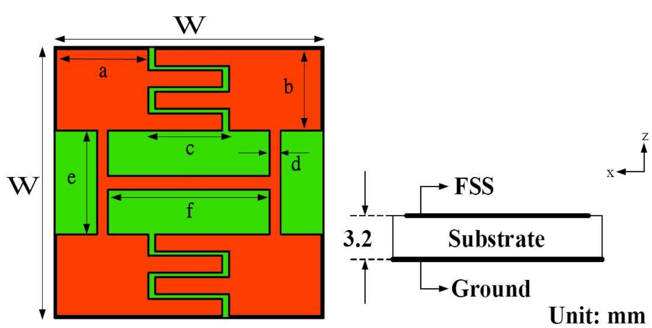

Figure 1: AMC structure, (a) top view and (b) side view and excitation method.

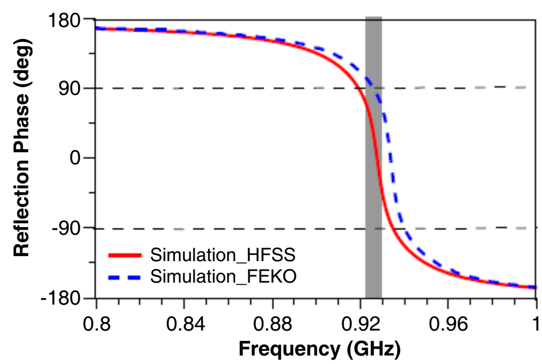

Figure 2: Simulated reflection phase on the AMC.

3. LINEARLY POLATIZED TAG DESIGN ON AMC

In this paper, a microchip of the Impinj Monaz® 4 is chosen to design the tag. The chip exhibits an impedance of 11-j143 at 915 MHz [7] when its configuration is singled-ended connection. A folded-dipole tag antenna printed on FR4 is proposed to miniaturize the antenna size. In order to achieve maximum power transfer, we added a T-matching structure which its coupling effect can micro tune the input impedance of the folded-dipole tag antenna. The geometric sizes of the dipole antenna with the T-matching transformer are shown in Figure 3. Figure 4 shows the input impedance for the dipole antenna with a symmetric T-matching transformer. Figure 5 shows the return loss. The tag is also fabricated to perform experiments by the Agilent EN5071B VNA. The comparison between simulation and measurement is also shown in the figures. The measured results show agreement with the simulation results. The impedance bandwidth is about 3% (902–928 MHz). The maximum realized gain is about 2.3 dBi in the free space, just like that of a half-wavelength dipole antenna.

In order to achieve minimum size, we used 3×2 miniaturized AMC unit cells. The folded-dipole is superposed on the miniaturized AMC surface with 1 mm gap. The AMC causes a little shift on the impedance so that the antenna with the AMC has less 0.8 dB gains than the original folded dipole in the free space. The advantage using the AMC is to let the tag antenna can be pasted near a lossy human body. Therefore, we optimize the folded-dipole with the miniaturized AMC and make it conjugate match the microchip with input impedance of 5-j70 Ω. Finally, geometric sizes of the optimized structure on the AMC are shown in Figure 6. The simple T-matching transformer is sufficient to achieve conjugate match with the microchip. Figure 7 shows the return

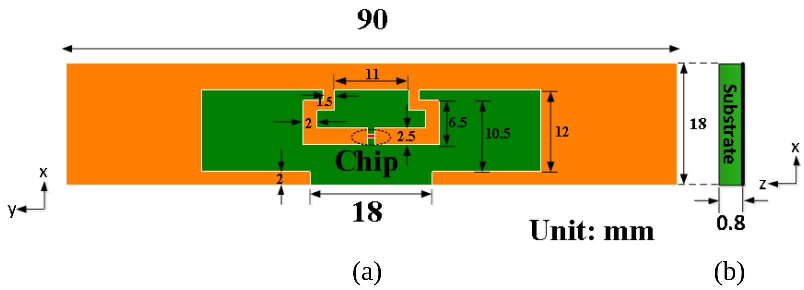

Figure 3: Folded-dipole tag antenna with a T-matching structure, (a) top view and (b) side view.

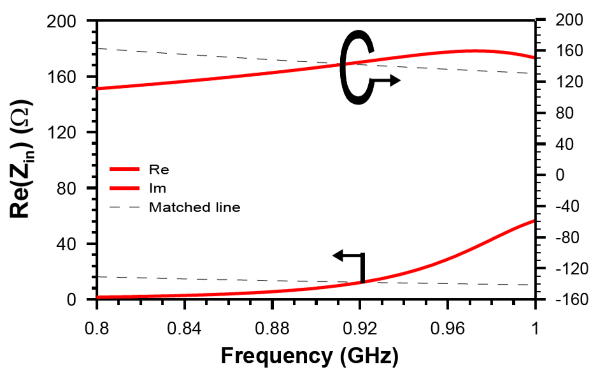

Figure 4: The input impedance of the folded-dipole with a T-matching structure.

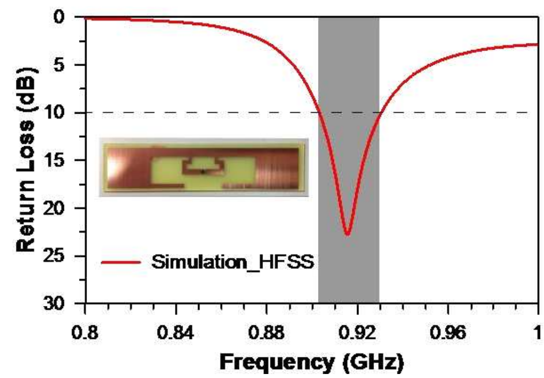

Figure 5: Simulated return loss.

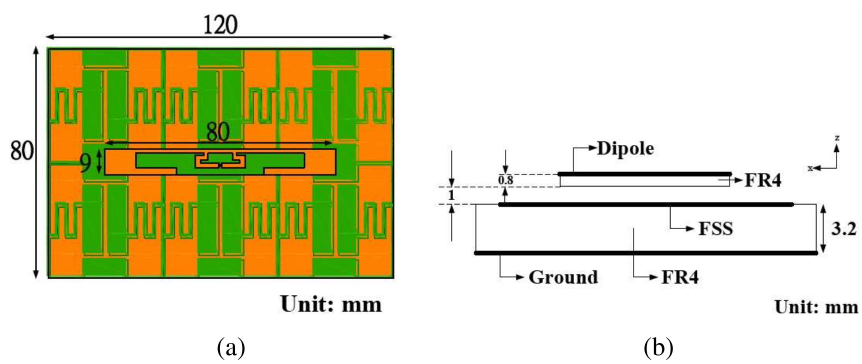

Figure 6: Geometric sizes of the optimized folded-dipole on the AMC, (a) top view and (b) side view.

loss of the optimized foldeddipole on the miniaturized AMC The impedance bandwidth is only 1.6% (917–929 MHz). The simulated results by HFSS show agreement with the simulated results by FEKO.

Figure 8 shows the realized gain of the optimized foldeddipole on the miniaturized AMC plane and the foldeddipole on a ground plane. The result indicates that the antenna gain of the folded dipole on the AMC plane is still conserved. We hope the AMC plane or PEC plane can preserve antenna gain to avoid injury from a lossy human body in the beginning. However, the study finds that the antenna with a PEC plane does not preserve the benefit. The reading range for the foldeddipole with the AMC is about 9.2 m when it is predicted by the Friis formula. The foldeddipole on the miniaturized AMC has immunity against the influence of the object. Although the simulated radiation patterns at 915 MHz is not shown here, the study finds the main beam is concentrated on the $+Z$ axis. The antenna gain of the antenna with the miniaturized AMC is better than that of the original foldeddipole without the PMC or on the PEC.

The tag with AMC was constructed to measure the reading range. The reading range from a reader to the tag was measured in the aisle near our lab. The measured reading range is about 8 m as the UHF RFID reader has 4 W EIRP output power. The measured reading range shows acceptable agreements with the predicted reading range which is about 9.2 m. Figure 9 shows the photograph of the manufactured folded-dipole tag on the AMC. The whole antenna system is only $80 \times 120\,\mathrm{mm}^2$, which is suitable for on-body applications if using a flexible printed circuit board.

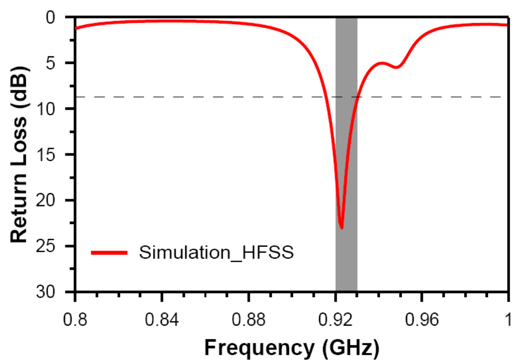

Figure 7: Return loss of the optimized T-matching folded-dipole on the designed AMC.

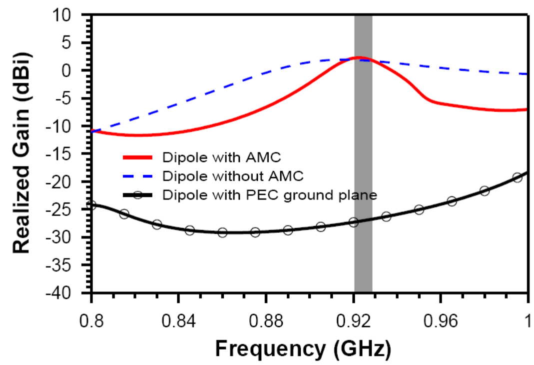

Figure 8: Realized gain of the optimized T-matching folded-dipole with and without AMC.

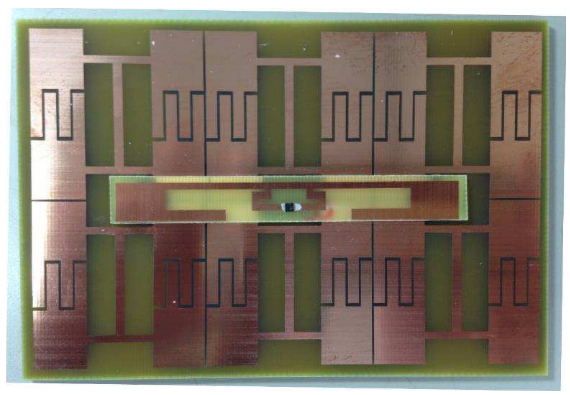

Figure 9: Photograph of the manufactured T-matching folded-dipole.

4. TAG APPLIED ON HUMAN BODY

Our original research motivation is devoted to improving reading range of the UHF RFID system for on-body applications. When the foldeddipole without AMC is put close to a human body, the realized gain of the tag antenna and reading range becomes very poor. The radiation efficiency of the folded-dipole on the human body reduces much lower than that of the folded-dipole in the free space. This section will study impacts on the tag due to the human body. Figure 10 shows a cylindrical human model. The human model consists of a stratified elliptical cylinder with four layers to model our torso. The physical and geometrical parameters can be found in the Table 1 of the reference [1]. The height of the model is 400 mm, which is similar to the length of our torso. The folded-dipole with or without the AMC in Section 3 has a good reading range in the free space. However, the AMC can help to insulate the effects of the human body on the tag. To compare fairly, the folded-dipole in the free space is 6.2 mm away from the human body but the folded-dipole with the AMC is 2 mm away from the human body. This is due to consider the thickness of the AMC.

Considering the body phantom model, we simulated the realized gain and radiation efficiency for the tags with and without AMC by HFSS. Figure 11 shows the realized gain of the folded-dipole with and without AMC when they are put close to the human model. The study finds that the influence due to the body effect is small for the tag with AMC. The maximum realized gain of the designed T-matching dipole without AMC is about 2.3 dBi in the free space. The realized gain for the designed dipole on the AMC is about 1.5 dBi since the AMC has 0 reflection phase and would not cause destructive interference between direct and reflected waves. When the tag with AMC is placed near the human model, the realized gain for the tag with AMC is about 1.0 dBi but the realized gain of the tag antenna without AMC is only -5.8 dBi. Figure 11 also shows the radiation efficiency of the folded-dipole with and without AMC when they are placed close to the

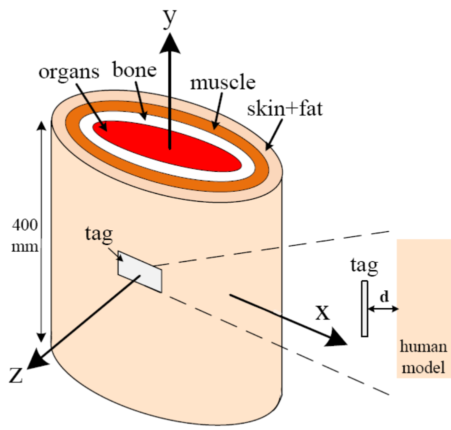

Figure 10: A cylindrical human model.

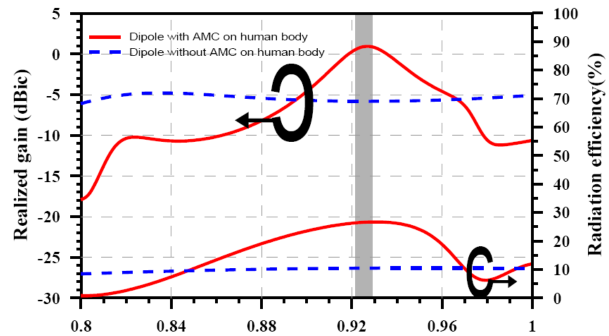

Figure 11: Radiation efficiency and realized gain of the T-matching folded-dipole tag put on the human body.

human model. The result indicates that the radiation efficiency of the folded-dipole without AMC is about 10%. The reason is because the majority EM wave is almost absorbed by the human body. However, the maximum radiation efficiency can be up to 30% for the tag with AMC.

The practical structure is constructed to measure the reading ranges when it was pasted on the chest of a practical human body. The comparisons are summarized as follows. The measured reading range is about 8.4 m for the tag with AMC in the free space and 7 m for the tag without AMC as the UHF RFID reader has 4 W EIRP output power. Considering the real body-proximity effects on the tag, the measured reading range can achieve 6 meters for the tag with AMC but only 2.8 m for the tag without AMC. Since the folded-dipole with AMC has maximum radiation efficiency of 30%, the realized gain is better than that of the dipole without AMC. Therefore, it can achieve longer reading range than that without AMC.

5. CONCLUSION

In this paper, we proposed a foldeddipole tag antenna with a symmetric T-matching transformer and a miniaturized AMC on the backplane. The artificial magnetic conductor is employed to avoid the influence of the human torso. The study finds that the miniaturized AMC is successfully applied on the tag to increase antenna gain and insulate the human body effect. The measured reading range is improved when the tag is passed on the human body. Although the antenna size is a little large for UHF RFID applications, the maximum predicted reading of the foldeddipole with FSS AMC can achieve 6 m.

REFERENCES

1. Tsai, M. C., C. W. Chiu, H. C. Wang, and T. F. Wu, "Inductively coupled loop antenna design for UHF RFID on-body applications," *Progress In Electromagnetics Research*, Vol. 143, 315–330, 2013.
2. Chiu, C. W., M. C. Tsai, H. C. Wang, and T. F. Wu, "Broadband T-matching loop tag antenna design for on-body UHF RFID applications," *Microwave and Optical Technology Letters*, Vol. 56, No. 5, 1194–1200, May 2014.
3. Raad, H. R., A. I. Abbosh, H. M. Al-rizzo, and D. G. Rucker, "Flexible and compact AMC based antenna for telemedicine applications," *IEEE Transactions on Antennas and Propagation*, Vol. 61, 524–531, Feb. 2013.
4. Hadarig, R. C., M. E. D. Cos, and F. Las-Heras, "UHF dipole-AMC combination for RFID applications," *Antennas and Wireless Propagation Letters*, Vol. 12, 1041–1044, 2013.
5. Ta, S. X. and I. Park, "Dual-band low-profile crossed asymmetric dipole antenna on dual-band AMC surface," *Antennas and Wireless Propagation Letters*, Vol. 12, 587–590, 2013.
6. Hadarig, R. C., M. E. D. Cos, and F. Las-Heras, "Novel miniaturized artificial magnetic conductor," *Antennas and Wireless Propagation Letters*, Vol. 12, 174–177, 2013.
7. Murata Manufacturing Co., [Online]. Available: http://www.murata.com.