A Low-Profile Dual-Polarized Crossed Dipole Antenna on AMC Surface

Rui He, Ze-Hong Yan, and Yan-Bo Meng

National Key Laboratory of Antennas and Microwave Technology
Xidian University, Xi'an, China
576770279@qq.com, zhyan@mail.xidian.edu.cn

Abstract **─** A low-profile dual-polarized crossed dipole antenna on artificial magnetic conductor (AMC) surface is presented in this paper. The antenna consists of two orthogonal dipoles, a periodic arrangement of artificial magnetic conductors and a ground floor. The antenna has a section height of only 13mm ($0.13\lambda_0$, λ_0 is the wavelength in free space at 3 GHz). With utilizing the 6×6 unit cell of square patch based AMC, the antenna can achieve a wide band. To verify this design, a prototype of this antenna is designed, fabricated and measured. Measured results exhibit that bandwidth from 2.9 GHz to 3.32 GHz (S11< -10dB) for one port and from 2.995 GHz to 3.47 GHz (S22< -10dB) for another port are obtained, respectively. Meanwhile, the isolation between two ports is less than -30 dB, and stable radiation patterns are realized in operating frequency band.

Index Terms **─** AMC (artificial magnetic conductor), crossed dipole antenna, low-profile.

I. INTRODUCTION

In recent years, artificial magnetic conductors (AMC) have become an important research tendency in the field of metamaterials. Metamaterials have extremely valuable electromagnetic properties that do not exist in nature, breaking the physical limits of traditional materials or structures, opening up a new research space for the development of classical electromagnetic theory. Currently widely studied metamaterials include LHM (Left-handed materials), EBG (Electromagnetic band gap) and AMC (Artificial magnetic conductor). Among them, AMC structures feature in-phase reflection in designed frequency band.

The artificial magnetic conductor (AMC) structure was proposed by an American scholar Sievenpiper when studying the mushroom-type EBG structure [1]. It can exhibit the in-phase reflection characteristics of a perfect magnetic conductor (PMC) to a plane wave in a specific frequency range. Thus it has wide application in high performance antenna, radar target stealth, microwave transmission and many other aspects. The structural characteristics of AMC are similar to the reflection characteristics of an ideal magnetic conductor. For the incident plane wave which is perpendicular to the surface, the AMC has the effect of same phase reflection. That is to say, reflected wave and incident wave have no phase change. It is well known that a perfect electric conductor (PEC) has a reflection phase of 180^o for a normally incident plane wave, while a perfect magnetic conductor (PMC), which does not exist in nature, has a reflection phase of 0^o [2]. This is the opposite scenario if an AMC is placed instead of PEC due to its reflection of electromagnetic wave with zero phase shift [3]. Therefore, the AMC structure is used as the reflection surface of the antenna, and the distance between the antenna and the reflection surface is effectively reduced to realize the low-profile characteristics [4].

Traditionally, the dual-polarized crossed dipole antenna equipped with a metal reflector has a high profile. In order to miniaturize the antenna, the reduction of the profile has become a research trend [5].

In this paper, a low-profile dual-polarized crossed dipole with an AMC surface is studied. The dual-polarized antenna can simultaneously transmit and receive two orthogonally polarized electromagnetic waves. The presented antenna can operate in a band ranging from 2.9 GHz to 3.32 GHz (S11< -10dB), 2.995 GHz to 3.47 GHz (S22< -10dB) with a height of $0.13\lambda_0$ (λ_0 represents the wavelength in free space at 3 GHz). A 6×6 unit cell of square patch based AMC is loaded to the antenna to make it compact. Also, the better radiation performance is realized. Through simulation and measured results, the designed antenna can basically meet the industry standard of mobile communication base station antenna and can be applied to dual-polarized base station antenna.

II. ANTENNA DESIGN

The proposed dual-polarized crossed dipole antenna with an AMC reflector is shown in Fig. 1. The 3-D configuration includes two perpendicularly crossed-dipoles, an AMC surface, and a ground plane.

A. Dual-polarized crossed dipole

The two dipoles utilized in this paper have the same structure. For a single printed dipole antenna, it is printed on one side of the FR4 substrate with a relative dielectric

Submitted On: November 30, 2018
Accepted On: April 9, 2019

permittivity of 4.4, a loss tangent of 0.02, and a thickness of 0.5mm. While, the feeding line and the balanced balun are printed on the other side of the substrate. The detailed structure of a single dipole antenna is demonstrated in the Fig. 2. Figure 2 (a) shows the side view of the proposed antenna, and Fig. 2 (b) shows the feeding structure.

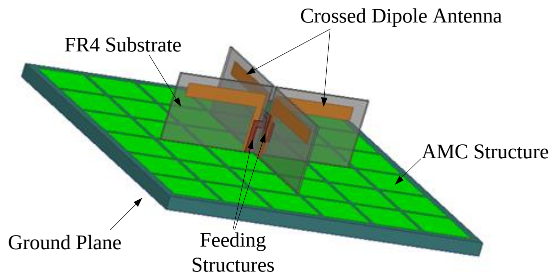


Fig. 1. 3D-view of the proposed antenna.

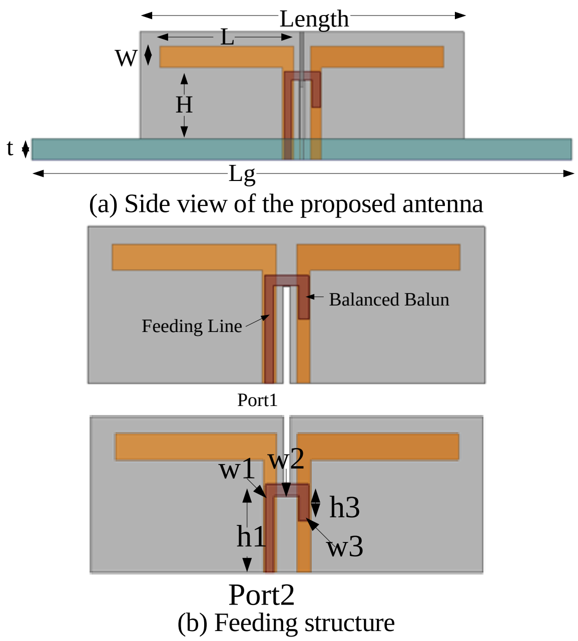


Fig. 2. Configuration of the proposed antenna.

B. AMC principle

As a periodic artificial electromagnetic material, AMC has the in-phase reflection characteristics of plane waves. The basic structure of the AMC unit consists of a substrate with dielectric loss, a metal patch over the substrate, and a metal floor. When the electromagnetic wave incident perpendicularly, its impedance can be regarded as the capacitive patch array, the loss medium and the perceptual metal floor three parallel, as shown in Fig. 3. L1 and C are the inductance and capacitance between the AMC units, R includes the dielectric loss of the substrate and the ohmic loss of the metal, and L2 is the inductance between the metal patch and the floor. The admittance and reactance expressions of the circuit are as follows:

$$Y = \frac{1}{j\omega L_1 + 1/j\omega C} + \frac{1}{R} + \frac{1}{j\omega L_2}, \quad (1)$$

$$Z = \frac{1}{Y} = \frac{j\omega R L_2(1-\omega^2 L_1 C)}{R(1-\omega^2 L_1 C - \omega^2 L_2 C) + j\omega L_2(1-\omega^2 L_1 C)}. \quad (2)$$

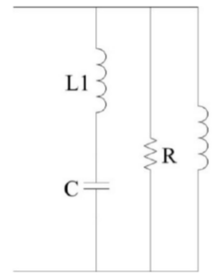


Fig. 3. AMC equivalent circuit.

C. Proposed AMC design

The geometry of proposed planar AMC unit cell is depicted in Fig. 4. It consists of a square patch on the same FR4 substrate which mentioned before, but with the thickness of 3mm. The unit cell is 11mm×11mm and the gap between two patches is 1mm, shown in Fig. 5 (a). Because the dipoles are placed vertically, the cell spacing should be considered when designing the cell structure to ensure that the antenna can be placed.

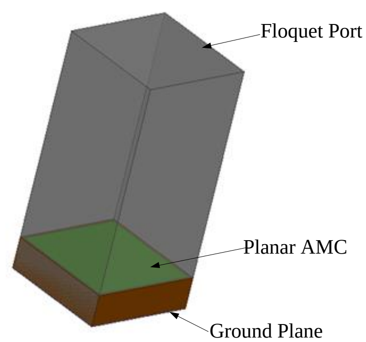
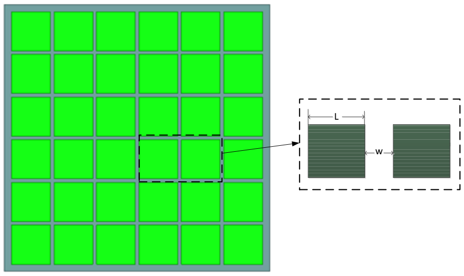


Fig. 4. Geometry of the AMC.

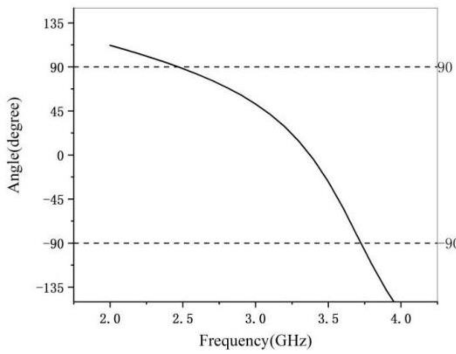
III. SIMULATION AND RESULTS

A. Analysis of the AMC unit cell

The AMC surface can be constructed by periodic unit cells, which is composed of metallic ground and dielectric substrate. It is known to be useful for improving antenna radiation performance and achieving low-profile design. AMC reflector is designed by means of reflection phase characterization [6].The resonance frequency of AMC surface corresponds to the 0° of the reflection coefficient phase, and the operating bandwidth is defined by the phase between +90° and -90° [7]. Figure 5 shows the AMC unit cell configuration and the corresponding reflection phase.



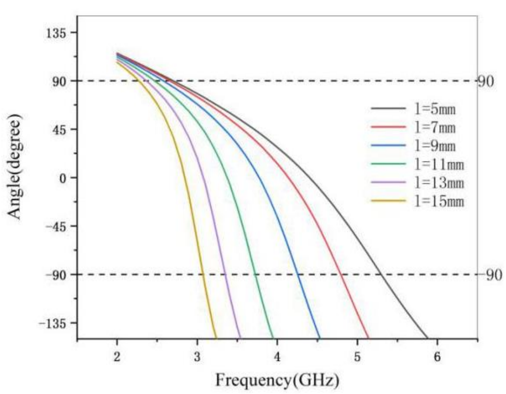
(a) AMC unit cell (L=11mm, w=1mm, height of FR4 is 3mm)



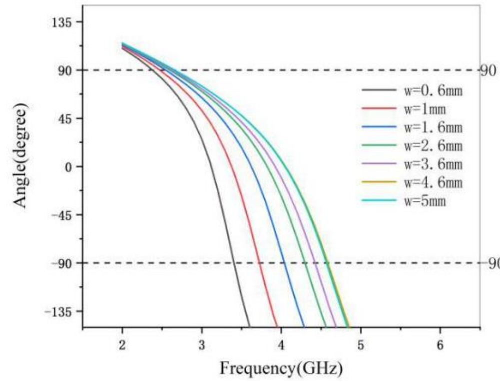
(b) Reflection phase

Fig. 5. AMC unit cell and reflection phase.

Figure 6 shows the simulated reflection phases of different size of square patches. Figure 6 (a) shows the reflection phases when the edge length of AMC unit L varies from 5mm to 15mm with all other dimensions fixed as in Fig. 5. As L increases, the reflection phase bandwidth increases and the frequency increases. Figure 6 (b) shows the reflection phases when the size of the gap between two patches w varies from 0.6mm to 5mm while other parameters remain unchanged. As w increases, the reflection phase bandwidth also increases and the frequency increases. In short, the operating band of present AMC unit cell can be basically independently controlled by the main physical parameters. So we choose the size of L is 11mm, and w is 1mm. The zero phase reflection band of the AMC ground plane is from 2.48 GHz to 3.72 GHz, shown in Fig. 5 (b).



(a)



(b)

Fig. 6. Reflection phases of different size of square patches.

B. Results and discussions of the proposed antenna

For comparison, the antennas without AMC surface and with perfect electric conductor (PEC) reflector are also simulated. The PEC reflector has a size of 80×80mm^2 under the dual-polarized crossed dipole with a distance of about 25mm (one quarter of wavelength). The AMC is arranged in 6×6 units, the height of the substrate is 3mm, the size of the FR4 substrate is also 80×80mm^2 and the height of the antenna is 10mm from the substrate, shown in Fig. 7. We obtained the measurement results by processing the physical objects and testing. Figure 8 shows the performance of different antennas.

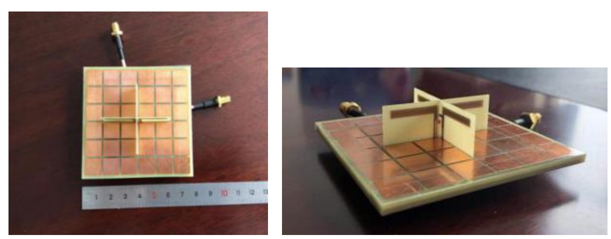
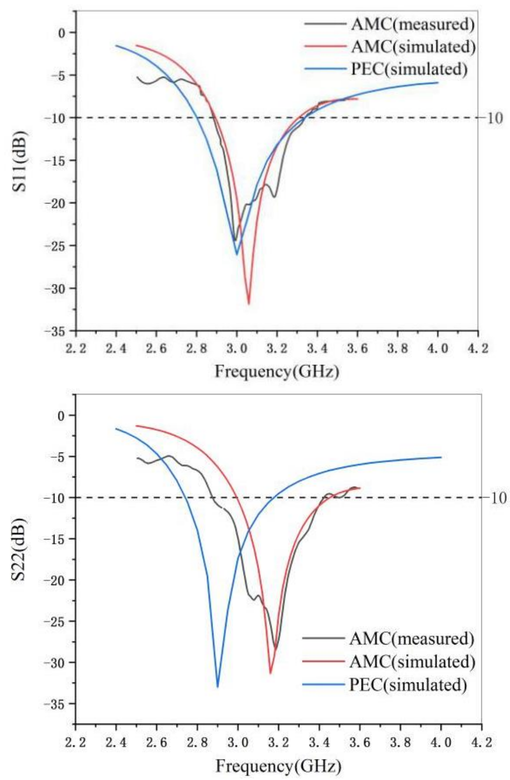
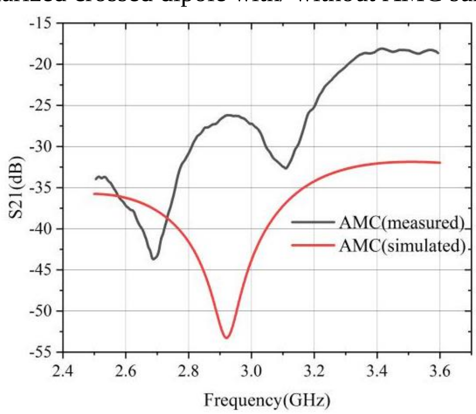


Fig. 7. Prototypes of the proposed antenna.

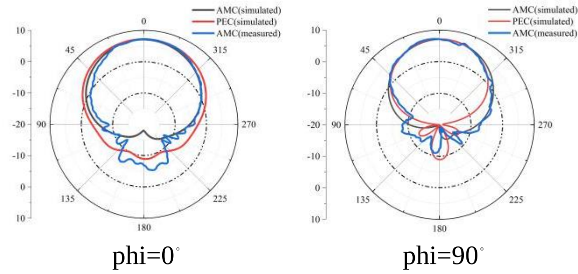
The ANSYS HFSS which is based on the finite element method (FEM) [8] is employed to simulate the antenna system. Simulated reflection coefficients of dual-polarized crossed dipole with and without AMC surface are shown in Fig. 8 (a). The bandwidth for S_{11}< -10 dB is from 2.85 GHz to 3.22 GHz, and for S_{22}< -10 dB is from 2.92 GHz to 3.35 GHz. The antenna's bandwidth is slightly narrowed due to the AMC's influence on impedance matching. The physical measured results of the processed antenna are also roughly the same as the simulation results, but the frequency offset is due to the error in the antenna processing accuracy. The height of the dual-polarized antenna with PEC as the reflecting surface is 25mm, and the height of the dual-polarized antenna with loaded AMC to the grounding plate is only 13mm. As the antenna height decreases, the size of the feeding lines and baluns needs to be adjusted, and their low height may also affect the performance of the antenna. As shown in the Fig. 8 (b), the isolation between two ports of dual-polarized crossed dipole with AMC surface simulated by HFSS can all reduce to -30 dB, which can meet the needs of the application. But in the measurement, the isolation increases because the measured environment is not completely ideal and processing error. When using electromagnetic simulation software, the antenna model feed port we set is ideal. In the actual processing, the coaxial cable is used to feed, and the distance between the two ports is very small, so we use insulating tape to isolate the two ports.



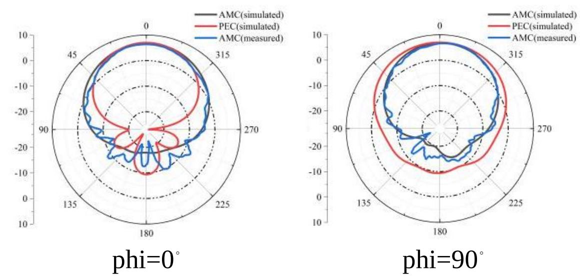
(a) Simulated/measured reflection coefficients of dual-polarized crossed dipole with/ without AMC surface



(b) Isolation between two ports of dual-polarized crossed dipole with AMC surface



(c) Radiation patterns of dual-polarized crossed dipole with/without AMC surface (port1 excitation) and measurement at 3.1GHz



(d) Radiation patterns of dual-polarized crossed dipole with/without AMC surface (port2 excitation) and measurement at 3.2 GHz

Fig. 8. Comparisons between the antenna with and without AMC surface (simulated/measured).

The Fig. 8 (c) shows the proposed antenna loading of AMC/PEC, and the measured results of the proposed antenna for port 1 at 3.1 GHz. The Fig. 8 (d) is the radiation pattern of antenna with and without AMC and the measurement for port2 at frequency 3.2GHz. A HB antenna rapid measurement system is used to measure the radiation patterns and gain. It can be noticed that the back radiation strength is reduced enormously with the AMC ground plane in the simulated results. In the working frequency band, the designed antenna has a stable radiation pattern with a front-to-back ratio of 24 dB, while the antenna of PEC reflector is 15dB. However, in the measurement, the back-lobe gain of the antenna is increased due to the incomplete idealization of the measured environment. Finally, the proposed antenna is reduced in profile, and AMC has a certain inhibitory effect on surface waves.

IV. CONCLUSION

In this paper, a dual-polarized crossed dipole antenna loaded with artificial magnetic conductors is designed. The in-phase reflection characteristics of AMC are used instead of metal plates to achieve directional radiation and reduce the profile height of the antenna. Through simulation analysis, the bandwidth for S_{11}< -10 dB is from 2.9 GHz to 3.32 GHz, and for S_{22}< -10 dB is from 2.995 GHz to 3.47GHz. Besides, the isolation between ports is less than -30 dB, and the radiation pattern is stable, which has wide application value in the design of modern communication base stations.

REFERENCES

[1] D. Sievenpiper, L. J. Zhang, R. F. J. Broas, et al., “High-impedance electromagnetic surfaces with a forbidden frequency band,” *IEEE Transactions on Microwave Theory and Techniques*, vol. 47, no. 11, pp. 2059-2074, 1999.

[2] H. R. Khaleeel, H. M. Al Rizzo, D. G. Rucker, and Y. Al-Naiemy, “Flexible printed monopole antennas for WLAN applications,” *IEEE APSURSI International Symposium on Antennas and Propagation*, Spokane, WA, July 2011.

[3] H. R. Khaleel, H. M. Al-Rizzo, and D. G. Rucker, “An AMC based antenna for telemedicine applications,” *ACES Journal*, vol. 27, no. 1, Jan. 2012.

[4] F. Yang and Y. Rahmat-Samii, “Reflection phase characteristics of the EBG ground plane for low profile wire antennas,” *IEEE Trans. Antennas Propag*., vol. 51, pt. 1, pp. 2691-2703, Oct. 2003.

[5] Y. He, Z. Pan, X. Cheng, Y. He, J. Qiao, and M. M. Tentzeris, “A novel dual-band, dual-polarized, miniaturized and low-profile base station antenna,” *IEEE Trans. Antennas Propag*., vol. 63, no. 12, pp. 5399-5408.

[6] A. Alemaryeen and S. Noghanian, “AMC integrated textile monopole antenna for wearable applications,” *ACES Journal*, vol. 31, no. 6, June 2016.

[7] G. Li, H. Zhai, L. Li, C. Liang, R. Yu, and S. Liu, “AMC-loaded wideband base station antenna for indoor access point in MIMO system,” *IEEE Trans. Antennas Propag*., vol. 63, no. 2, pp. 525-533, Feb. 2015.

Ansoft’s HFSS, www.ansoft.com