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Broadband and Gain Enhanced Bowtie Antenna with AMC Ground

Xue-Yan Song*, Chuang Yang, Tian-Ling Zhang, Ze-Hong Yan, and Rui-Na Lian

Abstract—A low-profile wideband bowtie antenna backed by artificial magnetic conductor (AMC) ground is presented for gain enhancement. The proposed bowtie antenna, loaded with an open stub in the upper layer, has broadband property. By using an AMC reflector, consisting of 6×9 metallic patches, the bidirectional radiation of the bowtie antenna is changed to unidirectional radiation. The distance between the bowtie antenna and the AMC surface is only $\lambda/10$ at 3.75 GHz. Both the bowtie antenna and the AMC surface are fabricated and measured. The measured results demonstrate good and stable performances, including maximum gain of 8.27 dBi, and flat gain response with variation of 0.6 dB in the wide impedance matching ($S_{11} < -10$ dB) band from 3.05 GHz to 4.35 GHz (35.1%). Furthermore, the maximum cross-polarization level is -17 dB for both E and H planes, and the measured front-to-back ratios are more than 18 dB. Good agreement between the simulated and measured results validates the proposed design approach.

1. INTRODUCTION

Artificial magnetic conductors, formed by two- or three-dimensional periodic arrays of metallic elements printed on a grounded dielectric substrate, were proposed [1] and have since been widely utilized in many applications. Because of the in-phase reflection property, the artificial magnetic conductor structure is designed to replace the perfect electric conductor (PEC) for reducing back-radiation, increasing gain and broadening bandwidth of antenna elements [2–4]. One important application of AMCs is as the ground plane of bowtie antennas for low-profile design with increased forward directivity.

With the rapid development in electronics and wireless communication technology, higher requirements are put forward to antenna system. Wideband and compact antennas are required by global positioning system (GPS), satellite communications system, and personal communications system. In the past, studies in pursuit of increasing the bandwidth brought about the development of special class of patch antennas. Among these antennas, the printed bowtie antenna deserves consideration because of the advantages such as broad bandwidth, compact and simple structure, low profile, light weight, and easy fabrication [5, 6].

Mounting AMC surface under the bowtie antenna as ground to achieve low profile and high gain has been studied before [7–10]. Nevertheless, achieving broadband property with low profile becomes a real challenge. The impedance bandwidths of the combined antenna are less than 12% in [7–9] though the profiles are extremely low. With the total height of approximately $\lambda/24$, a conformal metamaterial-inspired Egyptian axe dipole antenna is introduced in [7], while the relative impedance bandwidth of the composite antenna is only 3.06%. In [8], a novel low-profile and high-gain bowtie antenna adopting an AMC ground plane as reflecting surface is proposed, which achieves a low profile about $\lambda/12$ in the free space at 2.58 GHz and a relative impedance bandwidth of only 11.63%. Moreover, in [9], a coplanar waveguide-fed bowtie-shaped meander slot antenna is designed upon an AMC ground, exhibiting a

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* Corresponding author: Xue-Yan Song (xysong@stu.xidian.edu.cn).
The authors are with the National Key Laboratory of Antennas and Microwave Technology, Xidian University, Xi'an, Shaanxi 710071, China.

relative impedance bandwidth of only 10.34%, maintaining a low profile. In addition, a wideband AMC is recently designed in [10] as the ground plane of a bowtie antenna for gain enhancement and low profile. The distance between the antenna and the AMC is $\lambda/8$ in free space at 1.7 GHz, while the relative bandwidth of the combined antenna is only 16.7% (1.64–1.94 GHz).

To achieve broad bandwidth property with a low profile, this paper presents a broadband bowtie antenna operating from 3.12 GHz to 4.43 GHz based on the previous research in [10]. And a novel AMC surface, employing a single-layer metallic patch as unit cell, is proposed and located under the bowtie antenna with a distance of only $\lambda/10$ in free space at 3.75 GHz for gain enhancement and low profile performances. To further enhance the gain of the proposed antenna, a 5-mm-height copper wall is designed around the AMC ground. Experimental results show that, the composite antenna achieves a wide impedance bandwidth ($S_{11} < -10$ dB) of 36.05%, a maximum gain of 8.35 dBi, and a front-to-back ratio of 25 dB. Moreover, the maximum cross-polarization level at the four frequencies of interest is -18 dB for both E and H planes.

2. GEOMETRY AND DESIGN OF THE PROPOSED ANTENNA

2.1. Bowtie Antenna Design

The bowtie antenna, as shown in Figure 1(a), is printed on both sides of a 2-mm-thick FR4 substrate ($\varepsilon_r = 4.4$, $\tan\delta = 0.02$), which achieves impedance matching by adopting a trapezoidal balun on the bottom side to connect with the SMA connector [10]. And on the top side, an open stub is added to broaden the bandwidth and achieve impedance matching characteristics. Figure 1(b) illustrates S_{11} of the bowtie antenna with and without the stub. It can be seen that S_{11} of the bowtie antenna without stub is greater than -9 dB. However, S_{11} decreases when the stub is added on the top side of the bowtie antenna. Obviously, the impedance characteristics of the bowtie antenna with the stub are better than that of the bowtie antenna without the stub.

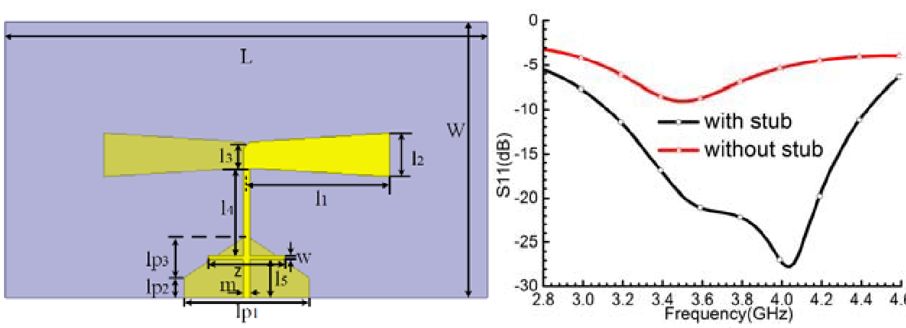

Figure 1. (a) Top view of bowtie antenna, and (b) S_{11} of the bowtie antenna with and without stub. The dimensions of the bowtie antenna are as follows: (unit: mm): $L = 60$, $W = 34.5$, $m = 0.8$, $l_1 = 17$, $l_2 = 5.5$, $l_3 = 3.3$, $l_4 = 10.95$, $l_5 = 4.5$, $z = 9.5$, $w = 0.5$, $lp_1 = 15.6$, $lp_2 = 2.5$, $lp_3 = 5$.

2.2. AMC Design

The AMC surface can reflect incident waves with small phase shift for enhanced front radiation and provide a low profile due to its in-phase reflection property. The frequency band, in which the reflection phase is within $-90°$ and $+90°$, is defined as the in-phase band of the AMC structure [2]. The design process of the proposed AMC unit cell is depicted in Figure 2(a). According to [11], the planar square AMC has the simplest structure but exhibits the largest in-phase bandwidth among all the planar passive AMC structures. As the unit cell of the AMC structure, the planar square is equivalent to the slot aperture shown in Figure 2(a). Therefore, the cross slot AMC has the merit of broad bandwidth. When four rectangular slots are loaded on the cross aperture, the inductance of the unit patch and the coupling capacitance between two neighbouring patches decrease, which can contribute to the increase in bandwidth of the AMC surface. As shown in Figure 2(a), as the unit cell of the periodical structure, the structure of cross aperture loaded with four orthogonally rectangular slots is equivalent to the metallic patch structure shown in Figure 2(b), which therefore is finally adopted as the unit cell of the proposed AMC surface. The AMC surface is composed of metallic ground, 3-mm-thick FR4 grounded dielectric substrate and periodical metallic patches, without any grounded via. To further enhance the gain, the 5-mm-hight copper wall is located around the AMC ground [12].

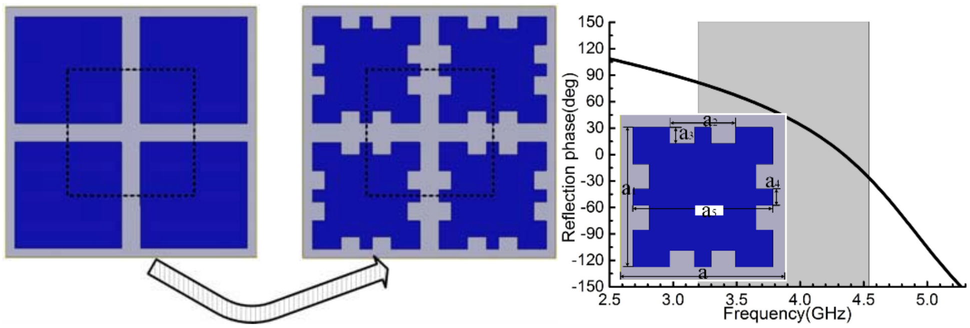

Figure 2. (a) The design process of the AMC unit cell. (b) Geometry and simulated reflection phase of the proposed AMC unit cell. The dimensions of the bowtie antenna and the AMC element are as follows: (unit: mm): $a_1 = 8.5$, $a_2 = 4$, $a_3 = 1$, $a_4 = 1$, $a_5 = a_1$, $a = 10$.

The simulated reflection phase of the proposed AMC structure in Figure 2(b) shows a wide in-phase bandwidth of 48.5%, ranging from 3.0 GHz to 4.92 GHz. The reflection phase response of the AMC unit cell is simulated by using HFSS Floquet-port model. The values of parameters a_1, a_2, a_3, a_4 and a_5 determine the in-phase frequency band, among which a_1 makes the largest contribution to the bandwidth. With the increase of a_1, the center frequency decreases, and the bandwidth becomes narrow.

3. DISCUSSION OF THE BOWTIE ANTENNA OVER AMC

Figure 3 depicts the geometry of the proposed bowtie antenna over the AMC, from which it can be noted that the 6×9 periodical AMC array is designed as the ground plane and is located underneath the bowtie antenna with a distance of H to achieve high gain and low profile.

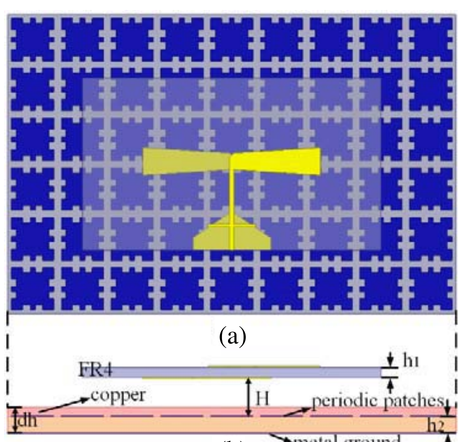

Figure 3. Geometry of the proposed bowtie antenna with AMC. (a) Top view and (b) side view of the proposed antenna. $h_1 = 2$ mm, $h_2 = 3$ mm, $H = 8$ mm, $dh = 5$ mm.

3.1. Comparison of Bowtie Antenna with and without AMC and Analysis of the Height *H*

Figure 4 illustrates the comparison on the simulated reflection coefficients of the bowtie antenna with and without AMC. It can be seen that parameter S_{11} of the bowtie antenna with AMC ground is slightly worse than that of the bowtie antenna only because of the existence of mutual coupling between the AMC reflector and the bowtie antenna.

It can also be observed from Figure 4 that the bandwidth and impedance matching characteristics are related with parameter H. That is because large distance decreases the mutual coupling between the bowtie antenna and the AMC ground plane, and the decrease in the mutual coupling can thus lead to good impedance matching characteristics and wide bandwidth. However, large distance will result in high profile. Therefore, $H = 8$ mm is finally selected for the low profile and good impedance matching purpose. And -10 dB impedance bandwidths of the bowtie antenna with and without AMC are 3.07–4.42 GHz and 3.12–4.43 GHz, respectively. It can be obviously seen that with AMC ground, there is a slight shifting of the frequency band while the bandwidth is almost unchanged.

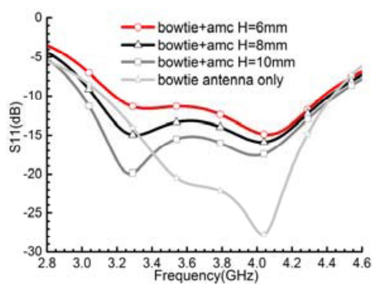

Figure 4. Simulated S_{11} of the bowtie antenna with and without AMC.

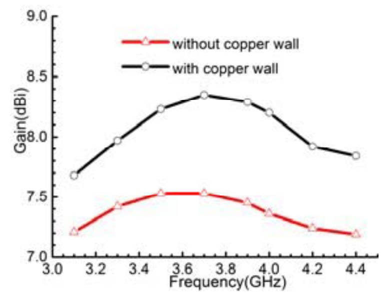

Figure 5. Simulated gain of the proposed antenna with and without copper wall.

3.2. The Influence of the Copper Wall on the Proposed Antenna

To further enhance the total gain of the proposed antenna, a 5-mm-hight copper wall is designed around the AMC ground. The simulated gains of the proposed antenna with and without a copper wall are illustrated in Figure 5, from which it can be observed that with the copper wall, the gain of the proposed antenna can be increased by 1 dB. This is because the existence of the copper wall decreases the distance between the bowtie antenna and the ground, which increases the total gain. On the other hand, the existence of the copper wall can also bring about the increase in mutual coupling between the AMC ground and the bowtie antenna. To obtain good matching and high gain simultaneously, a compromise is finally made to set the parameter dh as 5 mm.

4. SIMULATION AND MEASUREMENT RESULTS

In order to validate the simulated results, the proposed bowtie antenna on the AMC structure is fabricated and practically measured, as shown in Figure 6. Figure 7(a) depicts the measured and simulated reflection coefficients of the proposed antenna. It is demonstrated that the measured S_{11} of the bowtie antenna with AMC ground is worse than that of the bowtie antenna without AMC ground, which accords with the comparison conclusion on the simulated S_{11} in the same two conditions. It can also be noted from Figure 7(a) that the measured impedance bandwidth ($S_{11} < -10$ dB) of the composite antenna ranges from 3.05 GHz to 4.35 GHz, corresponding to a 35.1% relative bandwidth, while the simulated one is from 3.07 GHz to 4.42 GHz (36.05%). The discrepancies between the measured and simulated results are caused by the effect of the SMA connector and the fabrication and measurement errors. In this paper, the bandwidth is wider, and the profile is lower than the results in [10].

Moreover, the gain of the antenna was simulated and validated by measurement in the bore sight direction, as shown in Figure 7(b). The measured and simulated results are in good agreement and demonstrate a maximum gain around 8.27 dBi and 8.35 dBi, respectively. Moreover, a stable measured

Figure 6. Photograph of the proposed bowtie antenna and AMC. (a) The bowtie antenna, (b) the AMC surface, and (c) the structure of the composite antenna.

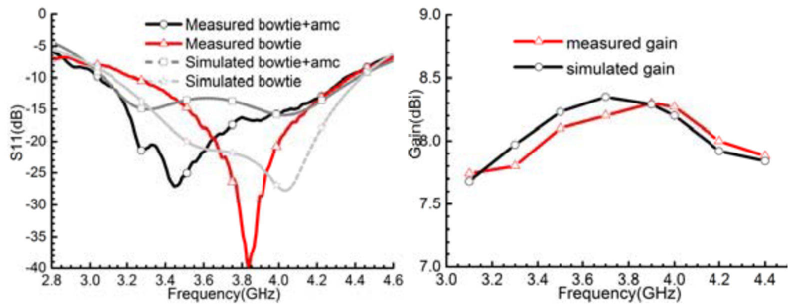

Figure 7. Measured and simulated (a) S_{11} and (b) gain of the proposed antenna.

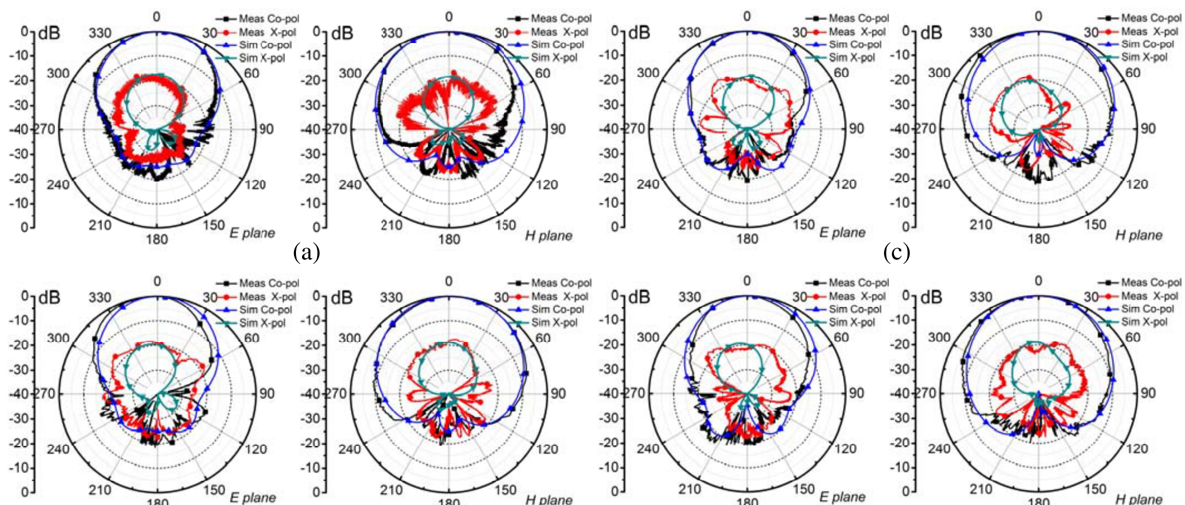

Figure 8. Measured and simulated radiation patterns of the proposed antenna. (a) 3.2 GHz, (b) 3.5 GHz, (c) 3.9 GHz and (d) 4.2 GHz.

gain response with a variation of 0.6 dB is yielded. It can also be noted that the measured gain is slightly different from the simulated one, which arises from the fabrication and measurement errors and instability of the dielectric substrates.

The radiation patterns of the proposed antenna were further measured in an anechoic chamber. Figure 8 plots the measured and simulated radiation patterns at 3.2, 3.5, 3.9 and 4.2 GHz for both E and H planes. It can be seen that the measured and simulated results at the four operating frequencies show good consistency with each other except for some fluctuations in the measured cross-polarization and the back lobes of the measured co-polarizations, probably caused by the noises in the anechoic chamber. According to the results in Figure 8, at the four frequencies, the measured and simulated maximum cross-polarization levels are -17 dB and -18 dB, respectively, and the measured and simulated front-to-back ratios are more than 18 dB and 25 dB, respectively, for both E and H planes. The slight inconsistencies between the measured and simulated results might be due to the fabrication and measurement errors.

5. CONCLUSION

A broadband bowtie antenna with AMC ground is proposed in this paper. The proposed bowtie antenna, loaded with an open stub in the upper layer, has the merit of broad bandwidth. An AMC surface composed of 6×9 metallic patches is designed and located under the bowtie antenna with a distance of only $\lambda/10$ in the free space at 3.75 GHz for high gain and low profile. Both the bowtie antenna and AMC surface are fabricated and measured. The measured and simulated results are in good agreement and demonstrate good and stable performances such as broad bandwidth, high gain, front-to-back ratio and low cross-polarization level.

ACKNOWLEDGMENT

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