A low-profile and wideband crossed dipole antenna based on AMC reflector for circularly polarized applications

Hongyin Zhang\textsuperscript{a)}, Fushun Zhang, and Fukun Sun\textsuperscript{b)}

National Key Laboratory of Antennas and Microwave Technology, Xidian University, Xi’an 710071, P.R. China
\textsuperscript{a)} honyin0701@163.com
\textsuperscript{b)} fksun12345@163.com

Abstract: Based on the AMC (Artificial Magnetic Conductor) reflector, a low-profile and wideband crossed dipole antenna for circularly polarized (CP) applications is presented in this paper. The antenna consists of a double-sided printed crossed dipole radiator, four parasitic loops and an AMC reflector. The crossed-dipole radiator is fed by a pair of vacant-quarter printed rings, generating circularly polarized radiation. By using the parasitic loops, an additional CP mode is produced, which combines with the original CP resonance to provide wideband CP operation. Also, an AMC reflector is used here to obtain unidirectional radiation pattern and the low-profile property. To verify the feasibility of the proposed design, a prototype has been fabricated and measured. The results show good performance of 10-dB impedance bandwidth is approximately 50.0% (1.29–2.15 GHz), and 3-dB axial ratio bandwidth of 27.7% (1.4–1.85 GHz). Moreover, the prototype has a low profile of 0.11\(\lambda_0\) (in terms of the center frequency of passband) and an average gain of approximately 8.9 dBiC within passband.

Keywords: low-profile antenna, wideband, circularly polarized antenna, AMC, crossed-dipole antenna

Classification: Microwave and millimeter-wave devices, circuits, and modules

References

[1] M. Matsunaga, \textit{et al.}: “A cross shaped spiral antenna radiating omnidirectional circularly and linearly polarized waves,” IEICE Electron. Express 9 (2012) 256 (DOI: 10.1587/elex.9.256).

[2] D.-H. Lee, \textit{et al.}: “Reconfigurable dual-slit perturbed patch antenna for circular polarization diversity,” IEICE Electron. Express 11 (2014) 20140384 (DOI: 10.1587/elex.11.20140384).

[3] Q. Liu, \textit{et al.}: “Dual-band circularly-polarized unidirectional patch antenna for RFID reader applications,” IEEE Trans. Antennas Propag. 62 (2014) 6428 (DOI: 10.1109/TAP.2014.2360704).
1 Introduction

Circularly polarized (CP) antennas have been increasingly popular in various wireless communication systems, including satellite, radar, wireless local area networks, and radio frequency identification systems due to their outstanding advantages of mitigating polarization mismatch and suppressing multipath interference [1, 2, 3]. With the recent trend in high-speed data transmission in wireless technology, the demand for CP antennas with wideband operation is also high.

The CP radiation is traditionally generated from two orthogonal dipole antennas, which should be excited by equal magnitudes and a 90° phase difference [4, 5, 6, 7]. However, these designs suffer from bidirectional radiation with a low broadside gain. Then, a perfect conductor (PEC) reflector is introduced below to obtain unidirectional radiation and improve the gain. Unfortunately, this geometry can increase the profile as high as approximately 0.25λ₀. For example, parasitic loops or parasitic strips are introduced in antennas [8, 9, 10] to further enhance wideband operation in terms of the impedance bandwidth and axial ratio (AR) bandwidth. And the CP unidirectional radiation is traditionally achieved by using metallic plates or metallic cavities below. It should be noted that the antenna in [11] has a low profile of 0.13λ₀ by introducing a parasitic dielectric slab above the ground plane. Meanwhile, the wideband CP operation is provided by its four-stepped rectangular patches.

In this paper, a CP crossed dipole antenna featuring both low profile and wideband is investigated. Here, to reduce the height, artificial magnetic conductor (AMC) is introduced as a reflector. The added parasitic loops can enhance the
impedance and AR bandwidth further. And Section 2 demonstrates these features in detail. Finally, a prototype operating at L-band is designed and fabricated. The prototype has a 10-dB impedance bandwidth of 50.0%, a 3-dB AR bandwidth of 27.7%, and a maximum gain of 9.3 dBi.

2 Antenna design and analysis

2.1 Antenna structure

Fig. 1 shows the configuration of the proposed low-profile and wideband CP antenna. The antenna can be divided into three parts, namely a double-sided printed crossed dipole, four parasitic loops and an AMC reflector. The crossed dipole as the primary radiator is double-sided printed on a square substrate of $80 \times 80 \times 0.5$ (mm$^3$) with a dielectric constant of 4.4 and a loss tangent of 0.02. Here, the dipoles are connected with two vacant-quarter 90° phase delay rings to generate CP radiation. The parasitic loops are placed between the dipoles on the top side of the substrate, which could produce another CP mode to enhance the bandwidth further. In addition, the AMC reflector is introduced here to obtain unidirectional radiation, meanwhile reducing the profile of the antenna. In this design, the AMC reflector is composed of two substrates and the dielectric constants and heights are both 4.4 and 0.5 mm. Between two substrates, an air gap with height of 14 mm is introduced. The whole antenna is centrally fed by a coaxial cable, whose inner conductor is soldered to the top dipole arm, whereas the outer conductor is connected to the bottom arm and the ground plane. It should be noted that three substrates of the antenna is processed separately and assembled as a whole finally. The detailed geometry and dimensions of the proposed antenna are given in Fig. 1 and Table I after optimization using ANSYS HFSS.

Fig. 1. Configuration of the proposed antenna. (a) 3D view, (b) Details of the double-sided crossed dipole, and (c) Side view.
2.2 Low-profile property

To reduce the height, AMC is introduced to the crossed-dipole antenna as a reflector here. The whole AMC structure consists of 7 × 7 periodically arranged square patches printed on an FR4 substrate, an air layer with height of 14 mm, and a metallic ground plane (154 mm × 154 mm). For installation conveniently, nylon material is used for the plastic post between them.

Fig. 2(a) plots the structure of the proposed AMC cell. And Fig. 2(b) demonstrates the reflection characteristics of the proposed AMC reflector. The resonance frequency of AMC surface corresponds to the 0° of the reflection coefficient phase. If the effective AMC reflection phase bandwidth is defined by a phase range of −90° to 90°, the AMC in-phase band is from 1.28 to 2.05 GHz. It should be noted

![Fig. 2. Analysis of the AMC reflector. (a) Unit cell; (b) The characteristic of reflection phase.](image)

![Fig. 3. Analysis of two antennas. (a) Reference antenna A; (b) The proposed antenna; (c) The properties of two antennas.](image)
that the phase bandwidth can be tuned by the thickness of the air layer, namely parameter $H_g$.

To better understand the low-profile performance of the proposed antenna, a reference antenna $A$ with PEC (perfect conductor) reflector is introduced. Under the constraints of similar impedance and AR bandwidth, the heights of two antennas from the reflectors (PEC or AMC) are compared here.

Fig. 3 shows the structures and properties of the reference antenna $A$ and the proposed antenna, respectively. It can be seen from the Fig. 3(c) that the reference antenna $A$ has an impedance bandwidth of 51.4% (1.3–2.2 GHz) and an AR bandwidth of 31.9% (1.45–2.0 GHz). The proposed antenna can achieve an impedance bandwidth of 50.9% (1.29–2.17 GHz) and an AR bandwidth of 26.9% (1.45–1.9 GHz). On the basis of the similar properties, two heights from the reflectors (PEC and AMC) are $HP = 32$ mm and $HA = 20$ mm, corresponding to $0.18\lambda_0$ and $0.11\lambda_0$ ($\lambda_0$ is free space wavelength at 1.7 GHz), respectively. Hence, it can be concluded that the proposed antenna achieves the low-profile performance compared to a conventional antenna with $\lambda/4$ reflector.

### 2.3 Wideband property

For the initial design with only crossed dipole, the antenna produces two resonances in the $|S_{11}|$ and one minimum AR point in the AR. To improve the operation bandwidth further, four parasitic loops are introduced here. The presence of the parasitic loops produces additional resonances and another minimum AR

![Fig. 4](image1)

**Fig. 4.** Performance comparison for the antenna with/without parasitic loops (a) $|S_{11}|$; (b) AR.

![Fig. 5](image2)

**Fig. 5.** Far-field performance for the antenna with/without parasitic loops (a) Phase difference; (b) Amplitude ratio.
point in the $|S_{11}|$ and AR profiles, respectively. By combining these resonances and minimum AR points generated by the crossed dipole and the loops, the wide impedance bandwidth and 3-dB AR bandwidth are obtained. This can be observed in Fig. 4(a) and Fig. 4(b). The proposed antenna can provide a 10-dB impedance bandwidth of 50.9% (1.29–2.17 GHz), and a 3-dB axial ratio bandwidth of 26.9% (1.45–1.9 GHz).

For better understanding the role of parasitic loops, the amplitude ratio and phase difference between two orthogonal modes in far field are investigated and shown in Fig. 5. Theoretically, CP radiation can be generated when the amplitude ratio of two orthogonal modes is in the range $-3$ to $+3$ dB and phase difference between these modes is around 90°. Fig. 5 demonstrates that the parasitic loops have small influence on phase difference and strong effect on amplitude ratio in the low-frequency band. With proper sizes of the parasitic loops, a wide CP bandwidth can be obtained.

### 3 Experiment results and discussion

To verify the design, a prototype of the proposed antenna has been fabricated and measured. And the photographs for the proposed antenna are shown in Fig. 6. Measurements on the impedance bandwidth are accomplished by the Wiltron 37269A Network Analyzer, and the gains and radiation patterns are measured by the time-gating method.

The simulated and measured $|S_{11}|$ and AR are depicted in Fig. 7, and good agreement between them is obtained. With reference to the figure, it is clearly

![Fig. 6. Photographs of the fabricated antenna prototype.](image)

![Fig. 7. Simulated and measured $|S_{11}|$ and AR of the proposed antenna (a) $|S_{11}|$; (b) AR.](image)
observed that the simulated and measured 10-dB impedance bandwidths ($|S_{11}| < -10$ dB) are 50.9% (1.29–2.17 GHz) and 50.0% (1.29–2.15 GHz). And the simulated and measured 3-dB AR bandwidths are 26.9% (1.45–1.9 GHz) and 27.7% (1.4–1.85 GHz), respectively.

In addition, Fig. 8 shows the simulated and measured normalized radiation patterns in the XOZ ($\varphi = 0^\circ$) and YOZ ($\varphi = 90^\circ$) planes at 1.5 GHz and 1.8 GHz. It can be seen the proposed antenna radiates directional fields. The measured 3-dB beamwidths at 1.5 GHz in the XOZ and YOZ planes are 66° and 69°, respectively. And the beamwidths at 1.8 GHz are 54° and 56°, respectively. And within the 3-dB beamwidths, the cross-polarization levels for two principal planes at two frequencies are lower than $-16$ dB.

Finally, the simulated and measured gains and radiation efficiencies across the operating band are shown in Fig. 9. In Fig. 9, the measured gains of 8.3 to 9.3 dBiC at $\theta = 0^\circ$ and efficiencies of 88%–89.5% are obtained within the CP bandwidth, respectively. The difference between simulated and measured efficiencies may be attributed to manufacturing error.

Fig. 8. Simulated and measured radiation patterns.

Fig. 9. Measured gains and radiation efficiencies of the proposed antenna.
In addition, a comparison of the proposed antenna with published referenced works is made in Table II. The selected reference antennas in this comparison are all the CP crossed dipole antennas. It could be seen from Table II that the proposed antenna provides the lowest profile and relatively higher gain over the operating bandwidth. Notably, the antenna in [10] has a higher average gain but a bigger cross section of $\frac{1.33\lambda_0}{0.86\lambda_0} \times \frac{0.11\lambda_0}{0.86\lambda_0}$.

It could be concluded that the proposed antenna with a reduced size has the good impedance and radiation properties.

### 4 Conclusions

A low-profile and wideband crossed dipole antenna for CP applications has been investigated and fabricated in this paper. Based on the AMC reflector, the proposed antenna can achieve a low profile of $0.11\lambda_0$. In addition, by introducing the parasitic loops, the CP bandwidth can be enhanced further. And the measured results show that the antenna demonstrates good impedance and radiation properties, which agree well with the simulated results. Due to its advantages of low-profile, high-gain and high radiation efficiency, the proposed antenna is suitable for wireless communication applications.