Low-profile circularly polarized metasurface antenna with tailored reflection phase

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A low-profile metasurface antenna with circularly polarized radiation and tailored anisotropic reflection is proposed in this letter. The metasurface antenna composed of excitation structure (microstrip line with coupling slot) and a metasurface layer. The metasurface functions for two goals, generating circularly polarized wave for radiation and tailoring reflection phase for scattering, respectively. The overall structure of the metasurface antenna is compact with a dimension of \(0.67\lambda \times 0.67\lambda \times 0.05\lambda\) at 5 GHz. Numerical and measured results confirm that the metasurface antenna exhibits 11.1% – 10 dB S11 bandwidth from 4.68 to 5.23 GHz, 10.8% 3 dB axial ratio bandwidth from 4.782 to 5.37 GHz and a maximum gain of 6.83 dBic. Besides, the metasurface antenna achieves anti-phase reflection under orthogonal polarized incident waves at around 5 GHz. To demonstrate a potential application, 16 identical metasurface antennas are put in a \(4 \times 4\) array. The metasurface antenna array achieves directive circularly polarized radiation with a maximum gain of 15 dBic. On the other hand, when under normal illumination, the scattering field of metasurface antenna array is redistributed due to phase cancelation, so that the backward radar cross section of the array is significantly reduced, which is applicable for military platform.

Introduction: Metasurfaces are artificial material which contains subwavelength particles in planar structure. It has attracted tremendous interest owing to its advantage of tailoring electromagnetic waves [1]. One of the interesting applications of metasurfaces is to develop novel antenna with modified performance, which is called metasurface antenna (MSA). By loading metasurfaces as cover or substrate, different kinds of MSAs with extraordinary performance have been proposed, such as low-profile, wideband, high-gain, circular polarized (CP) radiation and so on [2–5]. On the other hand, along with the raise of demand in military platform, scattering performance of antenna has also become more and more important. It is a hot topic on reducing radar cross section (RCS) of antenna while keeping its radiation performance. Generally, the strategy of reducing backward RCS of antenna can be summarized as absorption, polarization conversion and reflection cancelation, which have been realized by MSAs loading with absorptive metasurface [6], polarization conversion metasurface [7] and coding metasurface [8]. However, these methods usually need large room to load the metasurfaces, which are not very reasonable and practical.

Here, a compact MSA with inherent CP radiation and tailored anisotropic reflection phase is present. The metasurface plays a dual role as polarization converter for radiation and artificial magnetic conductor for scattering. As a potential application, a MSA array is present to achieve high gain CP radiation and backward RCS reduction, which is applicable for military demand.

Design of proposed MSA: Figure 1 depicts the 2D view of the proposed MSA. The MSA is composed of two layers. The upper layer is a metasurface which contains \(4 \times 4\) rectangular metallic patches. These patches are printed on a 1.5 mm-thick FR4 substrate \((\epsilon_r = 4.3, \tan \delta = 0.02)\). The bottom layer is an excitation structure which is also made on a 1.5 mm-thick FR4 substrate. It contains a microstrip line on one side and a metallic ground with etched slot on the other side. The microstrip line has an inclined angle with respect to the \(z\)-axis while the slot is orthogonal to it. The two layers tightly adhere to each other without air gap between them. Table 1 shows the detailed dimensions of the proposed MSA. The overall size is only \(0.67\lambda \times 0.67\lambda \times 0.05\lambda\), where \(\lambda\) is the wavelength at 5 GHz. Figure 2 shows the fabricated MSA prototype. One can see that the whole structure is very compact and low profile.

When the MSA radiates, the metasurface layer is excited by the excitation structure and functions as polarization converter, which transforms linearly polarized waves to CP waves. This phenomenon can be attributed to the asymmetrical structure of slant microstrip line and slot as well as the polarization-dependent metasurface, which make different equivalent impedences for the two orthogonal components of E-field emitted from the slot. Detailed explanation can be found in [5]. In order to obtain good CP radiation, the value of \(\phi\) has been optimized to 56.5°. Figure 3 depicts the simulated and measured results of MSA. As depicted in Figure 3a, the measured –10 dB \(S_{11}\) bandwidth is 0.55 GHz (4.68–5.23 GHz) with a percentage of 11.1%. The measured 3 dB axial ratio bandwidth is 0.55 GHz (4.82–5.37 GHz) with a percentage of 10.8%, as shown in Figure 3b. The gain remains above 5.73 dBic in the band, and the maximum gain of 6.83 dBic is obtained at 5 GHz. Figure 4 depicts the radiation patterns. Good LHCP patterns are observed with no obvious side lobes. Meanwhile, the simulated cross-polarization level in normal direction is relatively low.

When plane waves impinging the MSA, the metasurface functions as a polarization-dependent artificial magnetic conductor, which produces diverse reflection phases under orthogonal polarized incident waves. The reflection phase is relevant to the dimension of the patches. In order to

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**Table 1. Dimensions of propose MSA, mm**

| Parameter  | Value  |
|-----------|--------|
| \(m\)     | 40     |
| \(h\)     | 3      |
| \(px\)    | 9.4    |
| \(py\)    | 7.8    |
| \(sl\)    | 16     |
| \(sw\)    | 0.2    |
| \(fl\)    | 13     |
| \(fw\)    | 1.3    |

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**Fig. 1 Configuration of proposed MSA**

**Fig. 2 Fabricated prototype of proposed MSA**

**Fig. 3 Measured and simulated results of proposed MSA. (a) S parameter. (b) Axial ratio and gain**

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obtain anti-phase reflection, $p_x$ and $p_y$ have been carefully optimized. Figure 5 demonstrates the reflection characteristics of the metasurface. It is shown that the reflection phases under x- and y-polarized incidence are of obvious difference in the band 4–6 GHz. The phase difference achieves 175° at 5 GHz. Besides, the reflection amplitude is upon 0.85 for both x- and y-polarized incident waves, implying nearly total reflection in this band.

Owing to the compact size and purposely designed radiation and reflection performance, as a potential application, the proposed MSA can be put into array to obtain both directive high gain CP radiation and scattering field control. To verify this idea, a $4 \times 4$ MSA array is designed and fabricated, as shown in Figure 6. The MSAs in adjacent rows are orthogonally arranged which are distinguished by white and grey colours in Figure 6a. Accordingly, the adjacent rows show different reflection phases for given polarized incident waves. On the other hand, the MSAs are fed with configured input phases by feeding network.

For radiation case, the radiation patterns at 5 GHz are depicted in Figure 7. Good LHCP patterns are obtained at normal direction in both xoz and yoz planes. The gain at boresight achieves 15 dBi and the half power beam width (HPBW) in xoz plane and yoz plane are 16° and 17.8°, respectively. In contrast, the gain of cross-polarization is less than −5 dBi at boresight. Simulated and measured results are in good agreement.

For scattering case, assuming y-polarized incident waves normally impinge on the MSA array, the simulated 3D RCS pattern is demonstrated in Figure 8a. It can be observed that the most of energy is reflected to the directions of ±42° in xoz plane, so that the backward reflection is significantly suppressed. In order to verify this result, the MSA array has been measured in an anechoic chamber. Two identical wideband horn antennas are normally placed in front of the sample to measure the reflection at normal direction. A same-size metal board has also been measured for reference. As shown in Figure 8b, RCS reduction can be observed in 4–6 GHz. More than 6 dB reduction is obtained in the band 4.28–5.23 GHz with a percentage bandwidth of 19.9%. The measured results are in good agreement with the simulation.

**Conclusions:** A novel low-profile MSA is presented in this letter. Owing to the metasurface reacts both for radiation and scattering, the MSA achieves CP radiation and tailored reflection phase. A potential application of proposed MSA has also been demonstrated in this work. A $4 \times 4$ MSA array has been designed and fabricated for high gain and wideband RCS reduction, which is applicable for military use.

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