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Proceeding Paper

Dual-Band Shared-Aperture Multimode OAM-Multiplexing Antenna Based on Reflective Metasurface †

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Abstract: In this paper, a novel single-layer dual-band orbital angular momentum (OAM) multiplexed reflective metasurface array antenna is proposed, which can independently generate OAM beams with different modes in the C-band and Ku-band, and complete flexible beam control in each operating band, achieving the generation of an OAM beam with mode l = −1 under oblique incidence at 7G with 94.4% mode purity, and having a wider usable operating bandwidth at 12G with a wide operating bandwidth, and an OAM beam with mode l = +2 is generated under oblique incidence, achieving 82.5% mode purity, which verifies the performance of the unit, makes preparations for the next research, and provides new possibilities for communication in more transmission bands and larger channel capacity.

Keywords: metasurface antenna; dual band; orbital angular momentum (OAM); reflection array antenna; dual mode

1. Introduction

Metamaterials are artificial composite structures at sub-wavelength scales that break the physical laws exhibited by conventional materials, giving them extraordinary special properties. Metasurface (MS), as a novel two-dimensional metamaterial structure, can break through the limitations of traditional natural materials. In the field of RF microwave, the frequency, amplitude, phase, polarization, and radiation direction of the beam can be artificially regulated according to the needs, so it is used to realize beam deflection, convergence, polarization conversion, and vortex wave generation. The digital information coding metasurface has added a bridge between physical and information sciences since it was proposed in 2014 [1]; with the development of coding metasurface, there is a greater desire to enhance the information capacity of digital coding, and OAM provides a brand new degree of freedom independently of the time, frequency, and polarization domains due to the infinity of modes and the orthogonality among different modes, which has great potential in channel capacity expansion and spectral efficiency enhancement.

At present, there have been many advances in the work of combining metasurfaces and OAM [2–5], accompanied by the discovery of applications; metasurfaces with miniaturization and easy integration characteristics have shown great advantages in practical applications [6], especially for OAM transmitters, and metasurfaces can independently generate multiplexed OAM beams, which effectively reduces the complexity of the system [7]. The current OAM-related metasurface research focuses on the generation of multiplexed OAM beams [8–12], and is beginning to try to combine with other multiplexing techniques and further communication experiments in the microwave frequency band [13]. However, the current communication experiments are very rare, and most of the frequency bands are in high-frequency bands such as W. Therefore, it is a good research direction to try to carry out OAM-multiplexing communication experiments in the C-band and Ku-band, which

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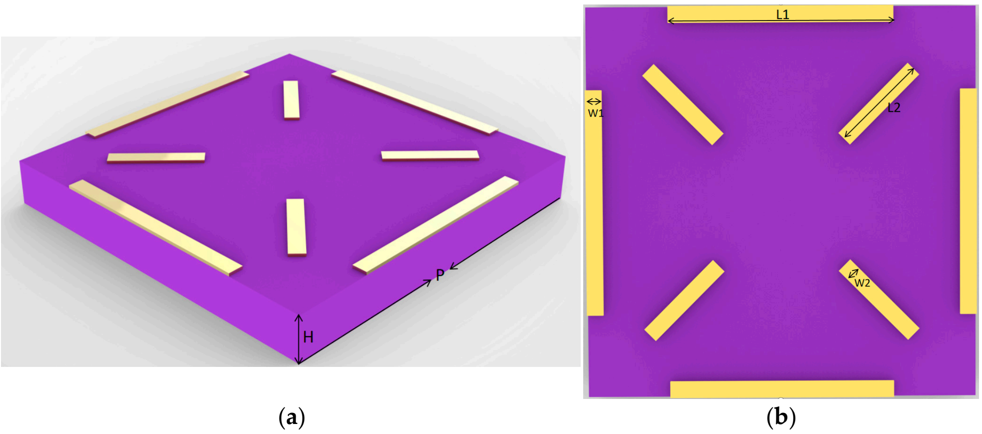
are commonly used in terrestrial and satellite communications. In this paper, we propose a reflective metasurface unit that can be used in C/Ku bands and carry out a series of pre-verification works using it. We design a dual-band multi-frequency OAM-multiplexing antenna based on a reflective metasurface, which can independently manipulate the electromagnetic waves in the C-band (7 GHz) and the Ku-band (12 GHz), and realize the generation of −1 and +2 OAMs in 7 GHz and 12 GHz bands, respectively, under the oblique incidence case. The OAM beams of l = −1 and l = +2 are generated in the 7 GHz and 12 GHz frequency bands, respectively, under oblique incidence, which verifies the excellent electromagnetic manipulation capability of the unit and makes preliminary work for the design of the metasurface antenna communication experiments under the excitation of dual-feeders, and it has the potential to be used for the application of transmitting more information in the communication transmission.

2. Design of the Metasurface Unit

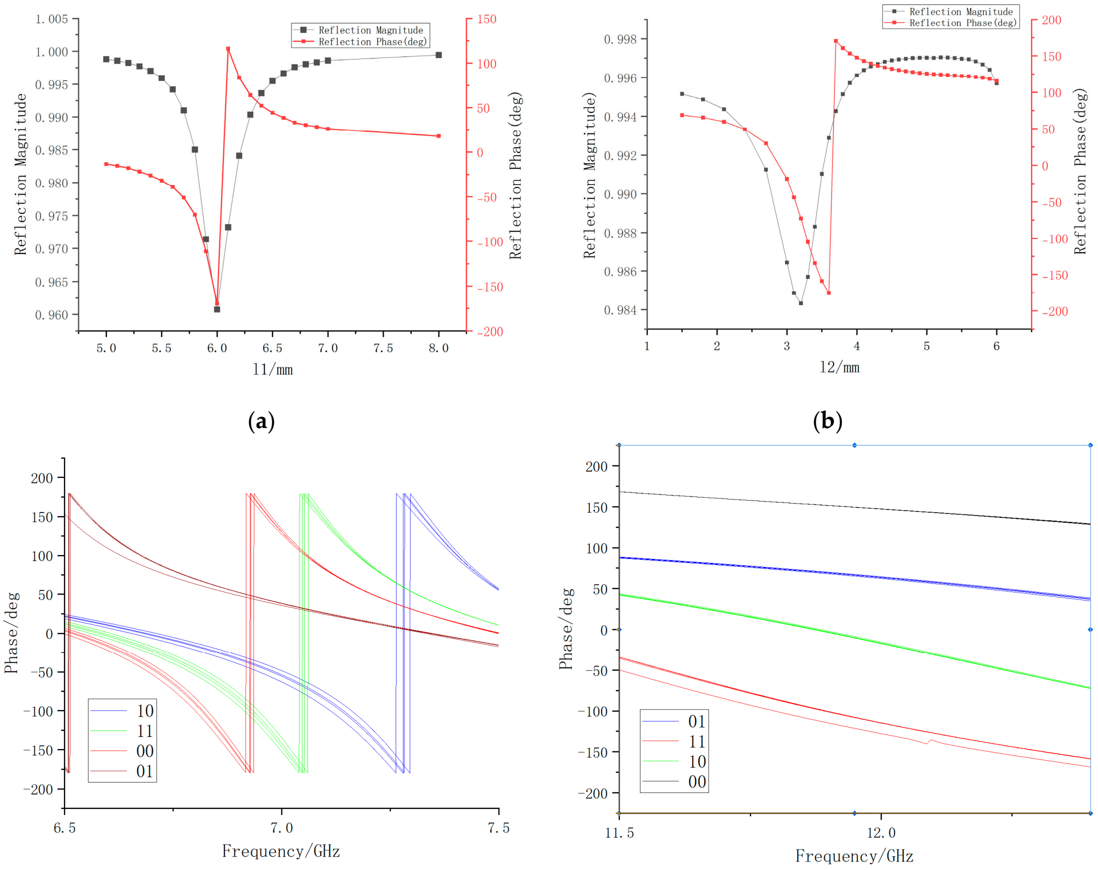
Figure 1a,b show the basic shape of the metasurface cell. The 2-bit cell consists of a metal patch, a dielectric substrate, and a metal ground, and the uppermost metal patch consists of four diagonal dipoles of the same length and four metal strips symmetrically placed against the edge of the dielectric, and after careful optimization and adjustment of the geometrical parameters, the following parameters are obtained: the dielectric height H = 1.5 mm, the edge length P = 12 mm, and the dielectric material used is a composite substrate TF-2 (dielectric constant of 14 and loss angle tangent of 0.001).



(**a**) (**b**)

Figure 1. Unit structure and dimensions: P = 12 mm, L1 = 6 mm, L2 = 4 mm, H = 1.5 mm, W1 = 0.5 mm, and W3 = 0.5 mm. (**a**) the oblique view, (**b**) the top view.

This structure is characterized by the fact that each frequency band depends on only one geometric parameter independently, e.g., by controlling the length of L1 between 5 and 7 mm while keeping W1 = 0.5 mm, the 360° phase coverage of the reflected electromagnetic wave at 7 GHz can be achieved, as shown in Figure 2a, and by controlling L2, the same can be achieved for the 360° phase coverage of the reflected electromagnetic wave at 12 GHz, as shown in Figure 2b. Then, we obtain the 2-bit phase arrangement with a 90° difference, and by choosing the appropriate geometrical parameters of L1 and L2, as shown in Table 1, and verified by the simulation results that the unit can realize the independent control of electromagnetic wave without mutual interference by adjusting the two geometrical parameters in two frequency bands, as shown in Figure 2c,d, it can be observed that at 7 and 12 GHz, the phase response curves are clearly divided into four groups with a 90° difference, and each group includes four curves, which illustrates that the change in the L2 parameter has a minimal effect on the phase with the reflection at 7 GHz, and the situation is similar at 12 GHz. Moreover, the reflection amplitude attenuation is less than −0.1 dB in all the cases, which shows excellent reflection performance in this metasurface work.



(**a**) (**b**)

(**c**) (**d**)

Figure 2. Reflective magnitude and phases (**a**) at 7 GHz and (**b**) at 12 GHz; (**c**,**d**) curves of 16 reflection phase simulation results at 7 and 12 GHz for the 2-bit cell.

Table 1. Coding states with geometric parameters at each operating band.

Frequencies [GHz]	Parameters	Coding States with Geometric Parameters			
		00	**01**	**10**	**11**
7	L1 (mm)	6.12	6.6	5.72	5.98
12	L2 (mm)	4	1.9	3	3.32

3. The Design of the Metasurface Antenna Array and Simulation

With the above-mentioned metasurface unit, we have designed a multimode OAM beam-reflecting hyperplane array antenna that can independently control bilinearly polarized electromagnetic waves at 7 and 12 GHz. The device can simultaneously reflect electromagnetic waves of different bands and polarizations and generate OAM vortex beams of −1 and mode l = +2s, i.e., when the incident wave is obliquely injected into the antenna at an inclination angle of 25°, the x-polarized incoming wave at 7 GHz will be reflected as an x-polarized −1-mode OAM beam and the y-polarized incoming wave at 12 GHz will be reflected as a +2-mode OAM reflector beam. Therefore, we have to take into account the phase compensation in the case that the incident wave is incident at a 25° slope when assembling the array.

It is also necessary to add the helical phase difference that constructs the vortex beams.

$$\Phi(x, y) = l\varphi = l\arctan(y/x) \tag{1}$$

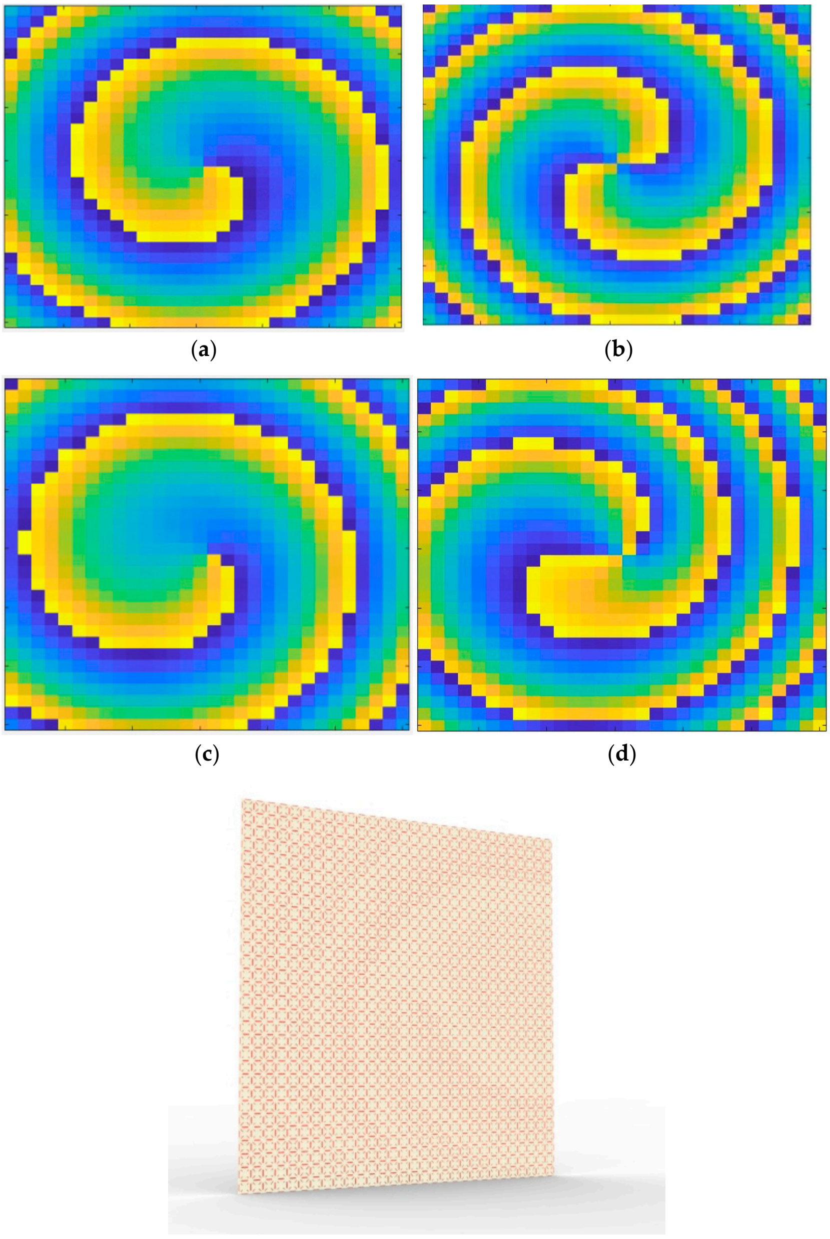
in which l is the topological charge, and φ is the azimuth angle. The topological charge l is an integer, indicating the number of twists of the wavefront.

The outward compensation of the incident wave and the spiral phase difference are superimposed on each other to form the final phase-compensated distribution of the two polarizations.

$$\Phi_{mn} = \frac{2\pi}{\lambda} d_{mn} + l\arctan(y/x) \tag{2}$$

λ is the wavelengths of the incident wave, and d_{mn} is the distance from the center position of the array to the equivalent phase center of the feed source.

We form the array by finding the coding unit with the closest phase at each phase point based on the calculated phase distribution. Finally, we obtain a 30 × 30 metasurface array, reflecting the x-polarized incident wave at 7 GHz to obtain the −1 mode OAM beam, and the reflection phase distribution of each cell in the array is shown in Figure 3a, and reflecting the y-polarized incident wave at 12 GHz to obtain the mode l = +2 OAM beam, and the phase distribution is shown in Figure 3b.



(**a**) (**b**)

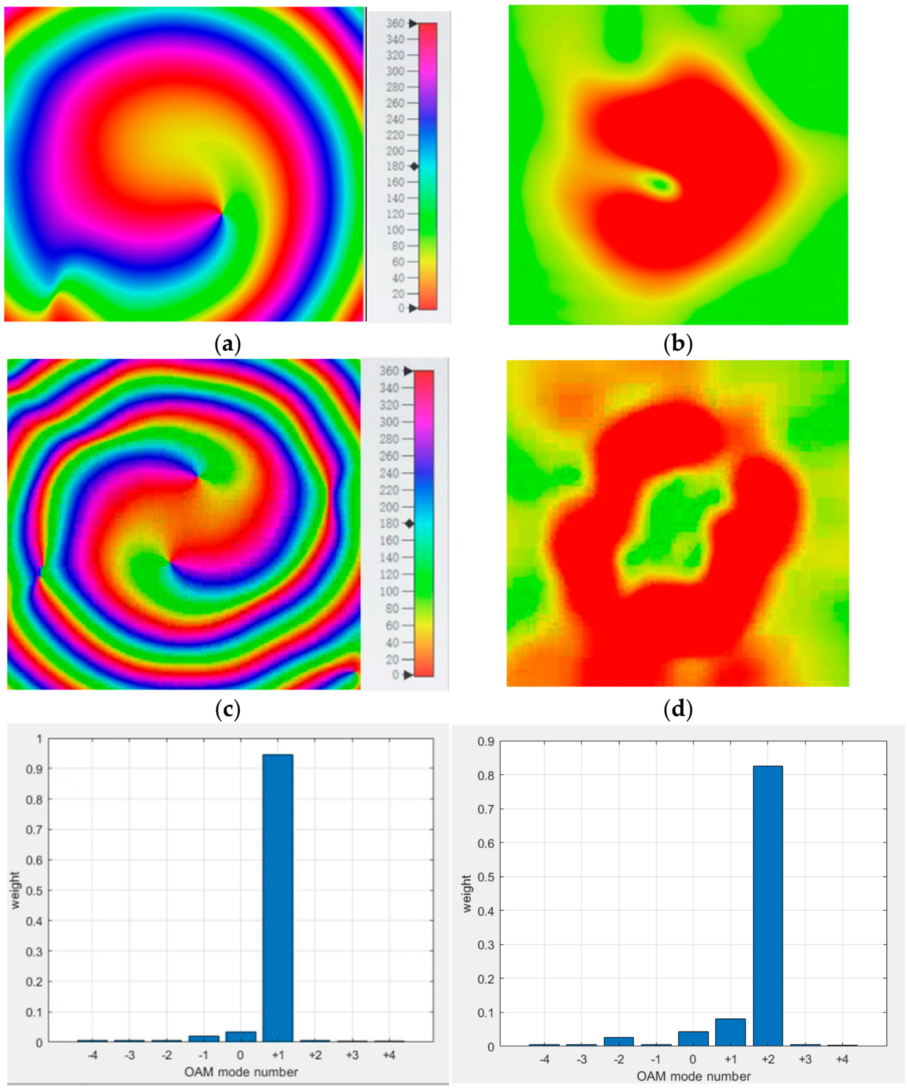
(**c**) (**d**)

(**e**)

Figure 3. (**a**,**b**) are the phase distributions of the array antenna in two modes, l = −1 and l = +2, for positive incidence of the horn, and (**c**,**d**) are the phase distributions of the horn at 25° oblique incidence; (**e**) is the model of the array.

In the actual simulation, to facilitate the actual test in the subsequent study, we chose to use oblique incidence, and the angle between the incident wave and the normal to the center of the array antenna is 25°, and the adjusted phase distribution of the cells is shown in Figure 3c,d. The array model and schematic are shown in Figure 3e.

Figure 4a shows the phase distribution of the reflected wave obtained after the 7 GHz x-polarized incident wave is reflected by the metasurface antenna, and it can be seen that the phase is distributed according to a spiral shape, which fits the phase distribution that the vortex beam of the −1 mode should have, and as can be seen in Figure 4b, the amplitude distribution of the main beam in the simulation result is circular, and the amplitude in the middle portion is lower than that of the surroundings, which proves that the reflected wave is the −1 mode of the OAM beam. As shown in Figure 4e, the designed metasurface antenna produces a vortex wave purity of 94.4% at 7 GHz.



(**a**) (**b**)

(**c**) (**d**)

(**e**) (**f**)

Figure 4. (**a**,**b**) are the l = mode l = +2 OAM beam phase distribution and amplitude for x-polarization, and (**c**,**d**) are the l = −1 mode OAM beam phase distribution and amplitude for y-polarization. (**e**) Histograms of an OAM spectrum weight l = −1; (**f**) histograms of an OAM spectrum weight l = +2.

Figure 4c shows the phase distribution of the reflected wave after the 12 GHz y-polarized incident wave is reflected by the supersurface antenna, and it can be seen that the phase is distributed according to the spiral shape, which fits the phase distribution of the vortex beam in the mode l = +2, and it can be seen in Figure 4d that the amplitude distribution of the main beam in the simulation results is ring-shaped, and the amplitude in the middle is lower than that in the surroundings, which proves that the reflected wave is the OAM beam with mode l = +2. As shown in Figure 4f, the designed metasurface antenna produces a vortex wave purity of 82.5% at 12 GHz.

Therefore, the two results show that the metasurface antenna has the function of OAM multiplexing in the dual frequency bands of 7 and 12 GHz, and at the same time, the beams with different polarizations of the two modes are reflected, which verifies the unit's potential for information carrying.

4. Conclusions

In this paper, we design a reflective 2-bit metasurface antenna that can independently perform beam modulation in the 7 and 12 GHz dual bands, and by adjusting the reflection phase of each unit, it can reflect incident waves with dual-linear polarizations and generate multimode OAM beams with different polarizations. The simulation results show that this OAM-multiplexed reflectarray antenna based on programmed metasurfaces has the excellent performance of independently controlling the reflected electromagnetic waves without affecting each other in the C and Ku bands, and can achieve multimode OAM multiplexing under oblique incidence, which is conducive to the design of a metasurface antenna that can reflect the +25° and −25° incidence waves in the same frequency band by calculating the phase distributions and filling the coded metasurfaces in a further study. By calculating the phase distribution and filling in the coded metasurface, we try to design a metasurface antenna that can reflect +25° and −25° incident waves in the same frequency band so that the metasurface antenna can reflect OAM beams with different modes and polarizations in the same frequency band by adjusting the angles and polarizations of the incident waves, and then we try to carry out the communication experiments, which demonstrates that combining the metasurface and the OAM has the great potential of bringing more channel capacity and more information transmission, and the design of the dual-band enlarges the range of the unit's application.

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