Planar Metasurface as Generator of Bessel Beam Carrying Orbital Angular Momentum

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***Abstract* – In this paper, a planar metasurface operating in microwave region to generate Bessel beam carrying orbital angular momentum (OAM) is proposed. The beam generator is realized by utilizing the abrupt phase changes at the interface of the metasurface, instead of the gradual phase differences in the optical lenses. The proposed planar metasurfaces are designed and simulated respectively, and the results show that the desired beams can be generated efficiently by using a compact planar 2-D structure.**

***Index Terms* – Metasurface, Bessel beam, Orbital Angular Momentum.**

1. Introduction

Recently, great interests have been attracted in vortex beam because of its substantially enhanced information storage ability. Recently, non-diffracting Bessel beams carrying OAM have been demonstrated the ability to retain over an extended propagation distance in a propagation-invariant manner and to transport information encoded in the vortex beams[1], which makes it useful in high-speed optical and quantum communications systems. Conventionally, Bessel beams are produced by axicons or computer generated holograms[2], which are difficult to be fabricated and integrated with other elements. Metasurface provides a powerful solution to this situation[3-5]. In this paper, a planar metasurface which can generate Bessel beam carrying OAM and realize the efficient bunching transmission of the electromagnetic wave is proposed and simulated.

2. Unit cell structure.

In this paper, a novel strip unit cell structure has been designed and simulated. The unit cell is composed of a square patch placed in the center and two strips buckled around the square. The thickness of the substrate is 2mm and the permittivity is 2.2. Fig. 1(b) and Fig. 1(c) show the simulation results of the unit cells with different rotation angles. Under circularly polarized incidence, the transmission coefficients of the cross-polarized component can achieve 0.5 at the resonant frequency, which has been demonstrated to be the limit for infinitesimally-thin metasurface[6]. The desired abrupt phase change, which is twice of the rotation angle, can be easily achieved as shown in Fig. 1(c).

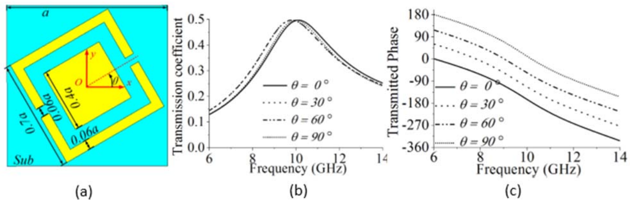

Fig. 1 Unit cell structure and the simulated results. (a)The structure of the proposed unit cell. (b)The transmission coefficients and (c) the phase changes of the cross-polarized component.

3. Planar metasurface as vortex beam generator.

The vortex beams carrying OAM have the phase distribution of $\exp(il\Phi)$ at the transverse plane, where l is the topological charge, Φ is the angular coordinate. To achieve the desired OAM beam with a factor of l, the introduced abrupt phase change by the unit cell at the position of (x, y) requires to be:

$$\varphi_1(x,y) = l \bullet \arctan\left(y/x \right)$$

Which means the unit cell needs to be rotated by $0.5 \cdot \varphi_1(x,y)$. Two different metasurfaces are designed with $l=1$ and $l=3$, respectively. The simulated amplitude and phase distribution results of the vortex beams are shown in Fig 2. It shows that the phase changes at the transverse plane equals $l \cdot 2\pi$, which agrees very well with the theoretical value.

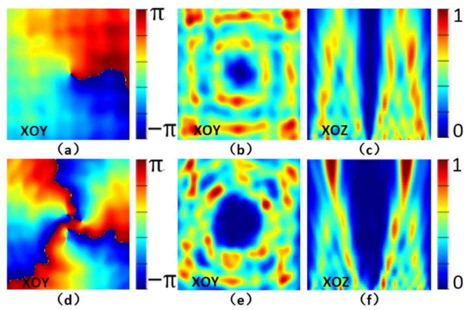

Fig. 2 Simulated results of the proposed vortex beams of $l=1$ and 3. (a), (d) Simulated results of the phase distribution in xoy plane for $l=1$ and 3. (b), (e) Simulated results of the electric field distribution in xoy plane for l=1 and 3. (c), (f) Simulated results of the electric field distribution in xoz plane for $l=1$ and 3.

4. Bessel beams carrying OAM

It is well known that the power intensity of cylindrical vector beams with a Bessel profile is much higher than other beams. Better still, high-intensity focus on a considerable distance can realize non-diffracting ability[7]. This property has been extensively used in many regions, such as sub-wavelength light routing, color filtering and so on. The planar metasurface, which is designed to produce Bessel beam carrying OAM, is composed of an array of proposed unit cells rotated in intrinsic angles. In order to obtain the desired Bessel beam for the unit cell at the position of (*x, y*), the phase distribution on the metasurface needs to be:

$$\varphi_2(x,y)=\sqrt{x^2+y^2}\sin\beta$$

where β is the angle between the transmitted wave and *z* axis. Combining two phase distribution $\varphi_1(x,y)$ and $\varphi_2(x,y)$ together, the desired Bessel beams carrying OAM can be realized. Note that, it means the Bessel beam carries no OAM when *l* equals to 0, i.e. the transmitted cross-polarized wave can be simplified to a pure Bessel beam. Utilizing the full-wave simulations based on the finite-difference time-domain technique (FDTD), the field distributions of the Bessel beam ($l=0$, $\beta=10°$) at the *xoz* and *yoz* plane are simulated as shown in Fig. 3. The beam shows the property of bunching transmission along *z* axis.

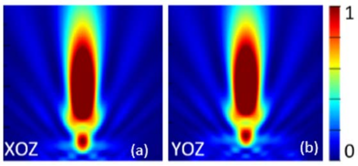

Fig. 3 Simulation results of the Bessel beam. (a) The transmitted cross-polarized field distribution at *xoz* plane. (b) The transmitted cross-polarized field distribution at *yoz* plane

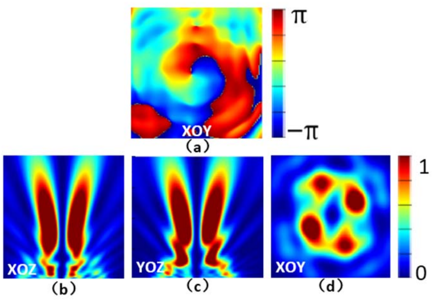

Fig. 4 Simulated results of the Bessel beam carrying OAM. (a) Phase distribution of cross-polarized component at the transverse plane. (b), (c) and (d) The electrical field distribution at *xoz*, *yoz* and *xoy* plane.

Fig. 4 shows the electrical field and phase distributions of the Bessel beam carrying OAM. From Fig. 4(a) we can find that the phase change at the transverse plane is 2π which corresponds to $l=1$. Compared with Fig. 2(c) and (f), Fig. 4 (c) and (d) illustrate that the cross-polarized wave shows bunching transmission property because of the phase distribution of $\varphi_2(x,y)$ of the proposed metasurface.

As is discussed, the cross-polarization conversion efficiency of the proposed unit cell can reach the demonstrated limit[4]. The efficiency of the proposed beam generators, which is defined as the ratio of the energy carrying by the desired beam to the energy of the incident wave, is also simulated and shown in Fig. 5. The maximum efficiency realized can be beyond 20% at the resonant frequency, which is much higher than the published designs[3-5].

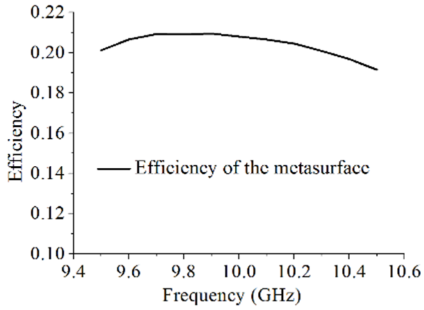

Fig. 5 The cross-polarization conversion efficiency of the proposed beam generator.

5. Conclusion

In summary, planar microwave metasurfaces to generate vortex beam, Bessel beam and Bessel beam carrying OAM are designed and simulated in this paper. By combining two kinds of phase distributions together, the generated beam shows that the properties of gradual phase changes at the transverse plane and the bunching transmission simultaneously. The simulation results show that the efficiency of the proposed beam generator can reach 21% at the resonant frequency, which makes a great progress of the single-layer transmission-type metasurface. Utilizing metasurface with phase discontinuities at the interface, the desired beam can be realized efficiently, and the beam generator can be easily fabricated and integrated with other systems.

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