Dual-ultrawideband Linear-to-circular Converter with Double Rotation Direction in Terahertz Frequency

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***Abstract*-In this paper, we propose a linear-to-circular (LTC) converter with a simple construction in Terahertz regime. There are many superior conversion properties of the proposed converter. Firstly, this converter operates in dual-band such as 0.44-0.76 THz and 1.10-1.72 THz. Secondly, the ultrawideband conversion is achieved, e.g. the relative bandwidths are ~53.3% and ~44%, respectively. Third, the right-hand polarization conversion (RHPC) and left-hand polarization conversion (LHPC) are respectively realized in the operating bands. Moreover, the high-efficiency LTC conversion is obtained, i.e. the efficiencies for RHPC and LHPC are greater than 99% and 90%, respectively.**

Keywords—linear-to-circular polarization converter, dual-ultrawideband, double rotation direction, terahertz frequency

Ⅰ. INTRODUCTION

Polarization is an important characteristic of electromagnetic waves and the polarization manipulations can be implemented in many applications. Conventional polarization manipulations are mainly realized using the wave-plate, which is made of birefringent materials such as crystalline solids and liquid crystals. However, the large thickness and the narrow bandwidth prevent them from being integrated into the micro-optical systems. Currently, polarization manipulation can be achieved by the anisotropic or chiral materials, yet still with thickness limitations and bulky configurations. Recently, metasurfaces, as a new way of polarization manipulation, have attracted increasing attentions.[1]. Attributing to the high efficiency, low profile and proficient processing, many investigations on metasurfaces manipulating polarization have been put forward. However, there are some limitations such as narrow band, single wideband and low efficiency[2-5].

In this paper, we propose a dual-ultrawideband linear-to-circular (LTC) converter with double rotation direction and the high conversion efficiency in terahertz frequency. It is composed of the infinite gold ribbons, dielectric material and gold ground. It has many predominant performances such as the right-hand polarization wave in 0.44-0.76 THz and left-hand polarization wave in 1.10-1.72 THz, the relative bandwidth of ~53.3% and ~44%, and the conversion efficiency greater than 90%.

Ⅱ. DESIGN OF THE CONVERTER

Figure 1 shows the period unit cell of the proposed converter with a simple structure. It consists of infinite gold ribbons, dielectric material and gold ground. The thickness of the gold ribbon is 200nm. The dielectric material is polyimide with the dielectric constant of 3, the loss tangent of 0.001 and the thickness h of 44.6μm. In addition, the other parameters of the converter are as follow: d=18.6μm, w=15μm, p=119.7μm, and b=18.9μm.

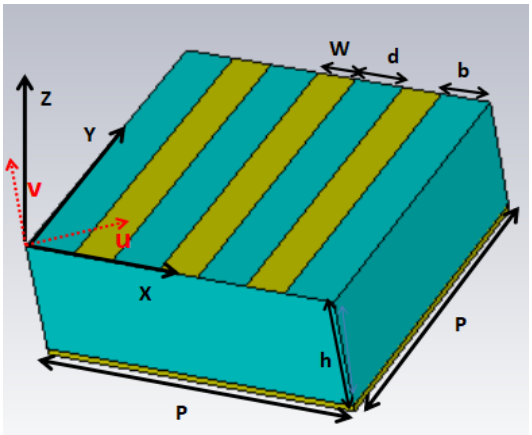

Fig.1 Unit cell diagram of the proposed LTC converter

Ⅲ. RESULTS AND ANALYSIS

We investigate the performance of the circular polarization converter by commercial software CST Microwave Studio. In the simulation, the unit boundary conditions were set in the x and y directions to simulate an infinite periodic array. Assuming the incident wave with u-polarization (45° relative +x-axis) propagates along -z-axis, the reflected wave can be expressed as: $\boldsymbol{Er} = E_{ur}\boldsymbol{e}_u + E_{vr}\boldsymbol{e}_v = r_{uu}exp(j\Phi_{uu})E_{ui}\boldsymbol{e}_u + r_{vu}exp(j\Phi_{vu})E_{ui}\boldsymbol{e}_v$. Where $r_{uu} = |E_{ur}/E_{ui}|$ and $r_{vu} = |E_{vr}/E_{ui}|$ denote the reflection coefficients of u-to-u and u-to-v polarization conversion, respectively. Due to the anisotropic characteristics of the metasurface, the two parts r_{uu} and r_{vu} have different magnitudes and phases[5]. In order to realize LTC, the magnitudes of r_{uu} and r_{vu} should be approximately equal and the condition of phases difference ($\Delta\Phi=\Phi_{vu}-\Phi_{uu}=\pm\pi/2+2n\pi$) should be satisfied.

The simulated results are illustrated in Fig. 2, from which we can clearly see that the magnitudes of the two reflection coefficients are almost equal and the phases difference are very close to 90^{o} in 0.44-0.76 THz and -90^{o} or 270^{o} in 1.10-1.72 THz. It implies that the circularly-polarized wave was obtained in these two ultra-wideband frequency ranges.

Further, in order to describe the polarization state of the reflective waves , stokes parameters are introduced below:

$$I = |r_{uu}|^2 + |r_{vu}|^2, Q = |r_{uu}|^2 - |r_{vu}|^2.$$
$$U = 2|r_{uu}||r_{vu}|\cos\Delta\Phi, V = 2|r_{uu}||r_{vu}|\sin\Delta\Phi.$$

Then we define V/I as normalized ellipticity to discuss the direction of polarization . When V/I=1, the reflected wave is left-hand circular polarization (LHCP) wave. When V/I=-1, the reflected wave is right-hand circular polarization (RHCP) wave[6]. Based on stokes parameters and calculation, we can get the normalized ellipticity of the converter, as shown in Fig. 3. It can be clearly seen that the range of 0.44-0.76 THz is very close to -1, implying the right-hand circular polarization (RHCP) is obtained in this ultra-wideband. And the range of 1.10-1.72 THz is very close to 1, implying that the left-hand circular polarization (LHCP) is obtained in this regime.

Next, We define $\sin 2\beta = V/I$ and introduce $AR=10\log_{10}(\tan\beta)$ to further describe the performance of LTC converter, where β is ellipticity angle. Fig. 4 shows the axial ratio of the converter, from which we can see the regimes of 0.44-0.76 THz and 1.10-1.72 THz are below 3dB. In other words, the RHCP reach the relative bandwidth up to 53.3% and LHCP reach the relative bandwidth up to 44%. The LTC converter realizes the good performance of dual circular polarization and dual-ultra-bandwidth.

What's more, the superior energy conversion efficiency is an excellent point for the converter. We define $\eta=(|E_{ur}|^2+|E_{vr}|^2)/|E_{ui}|^2 = |r_{vu}|^2+|r_{uu}|^2$ to measure the energy conversion efficiency. From Fig. 4, we can learn that the efficiency of RHCP is greater than 99% and the efficiency of LHCP is greater than 90%.

Interestingly, the proposed LTC converter can also keep a good stable performance under a large incident angle. As shown in Fig. 5, it can be found that the converter can maintain the characteristic of double ultra-wideband under the incident angles from 0° to 55° . The converter has an excellent performance for appliance.

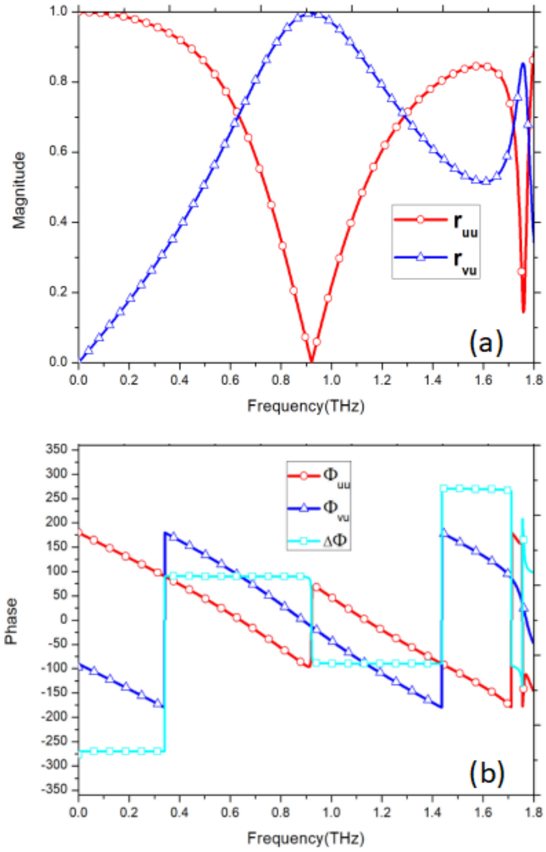

Fig.2 (a) Magnitudes and (b) phases of two reflection coefficients.

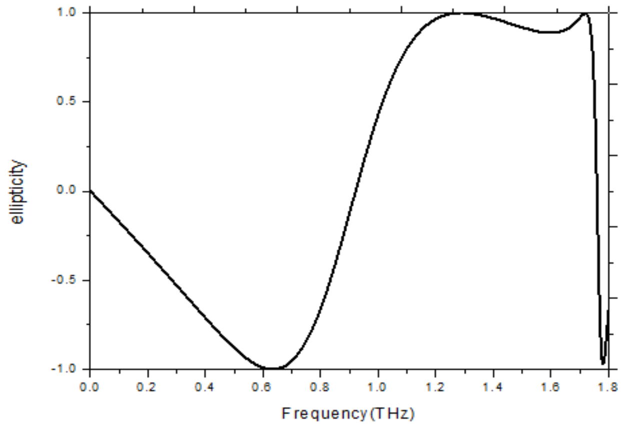

Fig.3 The ellipticity of the converter.

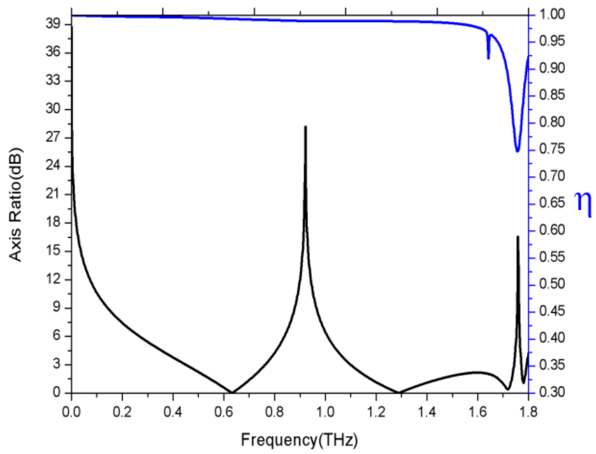

Fig.4 The AR (the black part) and efficiency (the blue part) of the proposed converter.

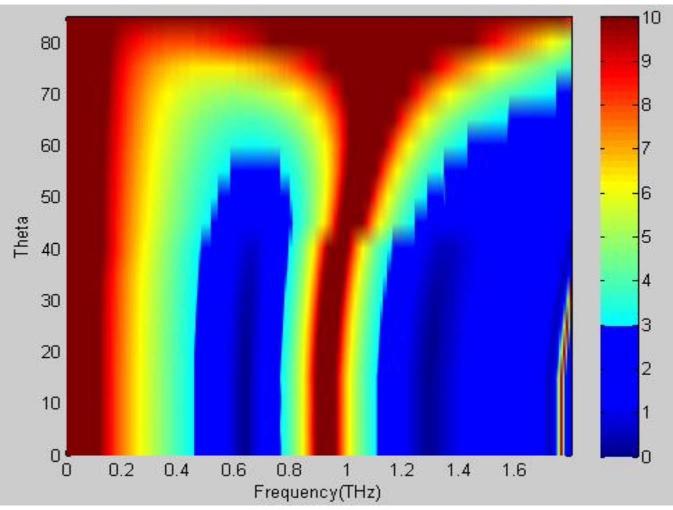

Fig.5 The AR under different incident angles. (The blue part indicates that is less than 3dB.)

Ⅳ. CONCLUSION

In terahertz regime, we propose a reflective dual-ultrawideband LTC converter. In the frequency range of 0.44-0.76 THz, the proposed converter can convert linear polarization wave into right-hand circular polarization wave, the relative bandwidth is 53.3% and the energy conversion efficiency is greater than 99%. In contrast, this converter realizes the left-hand circular polarization wave in the frequency range of 1.10-1.72 THz with the relative bandwidth of 44% and the conversion efficiency of 90%. The device has an excellent performance in many applications such as radar, medical treatment, and antenna.

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