An Ultra-Wideband Reflective Linear-to-Circular Polarization Converter Based on Anisotropic Metasurface

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ABSTRACT In this work, an ultra-wideband and high-efficiency reflective linear-to-circular polarization converter based on an anisotropic metasurface is proposed, which is an orthotropic structure with a pair of mutually perpendicular symmetric axes $u$ and $v$ along $\pm 45^\circ$ directions with respect to the vertical $y$ axis. The simulated and experimental results show that the polarization converter can realize ultra-wideband linear-to-circular polarization conversion at both $x$- and $y$-polarized incidences, its 3dB-axial-ratio-band is between 5.8 and 20.4 GHz, which is corresponding to a relative bandwidth of 112%; moreover, the polarization conversion efficiency (PCE) can be kept larger than 99.6% in the frequency range of 6.1-19.8GHz. In addition, to get an insight into the root cause of the LTC polarization conversion, a detailed theoretical analysis is presented, in which the conclusion is reached that in the case of neglecting the little dielectric loss, the axial ratio (AR) of the reflected wave can be completely determined by the phase difference between the two reflection coefficients at $u$- and $v$-polarized incidences, and any anisotropic metasurface can be used as an effective LTC polarization converter when the phase difference is close to $\pm 90^\circ$.

INDEX TERMS Metasurface, polarization converter, circular polarization.

I. INTRODUCTION

Polarization is one of the fundamental properties of EM wave, which must be taken into consideration in most practical applications, so it is of great significance to control the polarization state of EM wave in real time. The traditional polarization control method is usually realized by utilizing the birefringence effect and optical activity of natural materials, which usually requires a long propagation distance to obtain phase accumulation, and will be limited by bulky volume in practical applications [1], [2]. Over the past decade, it has been found that metasurfaces can provide a convenient method for the polarization control of EM wave, which has aroused great concern. In recent years, many different polarization converters have been proposed based on various metasurfaces, which can perform different types of polarization conversion, such as reflective cross polarization conversion at linear-polarized (LP) [2]–[14], [30] or circular-polarized (CP) [13]–[19] incidence, transmissive cross polarization conversion at LP [5], [20]–[23] or CP [24]–[26] incidence, and reflective [27]–[32] and transmissive [33]–[45] linear-to-circular (LTC) polarization conversion at LP incidence. Compared with the polarization converters designed in conventional method, these polarization converters always have several better performances, such as thinner, wider band and higher efficiency. However, the existing References indicate that, though a large number of ultra-wideband cross polarization converters have been proposed successfully [3]–[13], most of these proposed LTC polarization converters were still difficult to realize ultra-wideband operation [27]–[29], [33]–[45]. In Reference [30], [41], an ultra-wideband reflective and transmissive LTC polarization converter has been proposed, however, their relative bandwidths are still only 80% and 74%, respectively.

In this work, one ultra-wideband and high-efficiency reflective polarization converter is proposed, which can realize ultra-wideband LTC polarization conversion at both
x- and y-polarized incidences, the relative bandwidth is up to 112%. It can convert a y-polarized wave into a right-handed CP (RHCP) one, but a x-polarized wave will be converted into a left-handed CP (LHCP) one. We carry out simulation and experiment to verify the polarization converter, and present a detailed theoretical analysis of the ultra-wideband LTC polarization conversion.

II. DESIGN AND SIMULATION

The proposed polarization converter is based on an anisotropic metasurface, which consists of one layer of patterned metal film printed on a grounded dielectric substrate and covered by a dielectric layer, it is a two-dimensional square lattice structure. One unit cell structure is illustrated in Fig. 1, it is indicated that the polarization converter is an orthotropic structure with a pair of mutually perpendicular symmetric axes \( u \) and \( v \) along \( \pm 45^\circ \) directions with respect to the vertical y axis. In addition, the geometrical parameters of the unit cell structure are all shown in Fig. 1. In our design, these geometrical parameters are selected as: \( P = 8.00 \) mm, \( r = 3.85 \) mm, \( w = 0.65 \) mm, \( h_1 = 3.00 \) mm and \( h_2 = 4.30 \) mm; moreover, the two metallic layers are both chosen as a same PTFE with a relative permittivity of 2.0 and a loss tangent of 0.0018, and the grounded plane, together with the patterned metal film, is modeled as a copper film with a thickness of 0.017 mm and an electrical conductivity of \( \sigma = 5.8 \times 10^7 \) S/m.

To numerically investigate the LTC polarization conversion performance of the design, we have carried out a series of numerical simulations by using Ansoft HFSS. When the input is set as a normal y-polarized wave, the obtained simulation results, the magnitudes of the co- and cross-polarization reflection coefficients \( r_{xy} \) and \( r_{yy} \), together with the phase difference \( \Delta \varphi_{yx} = \arg (r_{xy}) - \arg (r_{yy}) \), are shown in Fig. 2. Fig. 2(a) indicates that the magnitudes of \( r_{xy} \) and \( r_{yy} \) are basically equal to each other in the frequency range from 6.0 to 20.0 GHz; in addition, in Fig. 2(b), it is indicated that the phase differences \( \Delta \varphi_{yx} \) is basically always equal to \(-90^\circ\) in the band 5.0-21.5 GHz. According to the above simulation results, we can know that the reflected wave at the y-polarized incidence is much close to a RHCP one in the frequency range from 6.0 to 20.0 GHz.

In general, when the axial ratio (AR) of an EM wave is less than 3.0 dB, the EM wave can be regarded as a CP one. To specifically determine the effective bandwidth of the proposed polarization converter, based on these simulation results shown in Fig. 2, we have calculated the AR of the reflected wave using the following equation:

\[
\text{AR} = \left( \frac{|r_{yy}|^2 + |r_{xy}|^2 + \sqrt{a}}{|r_{yy}|^2 + |r_{xy}|^2 - \sqrt{a}} \right)^{1/2}.
\]

wherein \( a = |r_{xy}|^4 + |r_{xy}|^4 + 2|r_{yy}|^2 |r_{xy}|^2 \cos(2\Delta \varphi_{yx}) \). The obtained AR is shown in Fig. 3, it is indicated that the AR is much lower than 3.0 dB in the ultra-wide frequency range from 5.8 to 20.4 GHz, and the anticipated LTC polarization conversion is realized in this ultra-wide band, which is corresponding to a 112% relative bandwidth; moreover, the AR is kept lower than 1.15 dB in the frequency range of 6.1-19.8 GHz, which implies that the polarization conversion efficiency (PCE) of the polarization converter is much higher.

Furthermore, to demonstrate the higher PCE of the polarization converter concretely, based on the above simulation
results, we have calculated its LTC polarization conversion reflection coefficients using the following Eq. (2), and further obtained its PCE using Eq. (3).

\[
\begin{align*}
    r_{RHCP-\gamma} &= \sqrt{2} \left( r_{xy} + i r_{yx} \right) / 2, \\
    r_{LHCP-\gamma} &= \sqrt{2} \left( r_{xy} - i r_{yx} \right) / 2. \\
    \text{PCE} &= \frac{|r_{RHCP-\gamma}|^2}{|r_{RHCP-\gamma}|^2 + |r_{LHCP-\gamma}|^2}.
\end{align*}
\]

The magnitudes of the calculated \( r_{RHCP-\gamma} \) and \( r_{LHCP-\gamma} \) are shown in Fig. 4(a), it is indicated that the magnitude of \( r_{RHCP-\gamma} \) is much close to 0 dB in the 3dB-axial-ratio-band, which implies that the reflected wave at the \( \gamma \)-polarized incidence has basically all been transformed into a RHCP wave. Furthermore, the obtained PCE, shown in Fig. 4(b), indicates that the PCE can be kept larger than 99.6% in the frequency range of 6.1-19.8 GHz, which occupies 93.9% of the 3dB-axial-ratio-band (5.8-20.4GHz), it is indicated that the proposed polarization converter has much higher efficiency. In conclusion, it can be seen that the proposed polarization converter can convert the \( \gamma \)-polarized incident wave to a CP one with both ultra-wide bandwidth and high efficiency.

**III. THEORY ANALYSIS**

Why can the proposed polarization converter perform such an ultra-wideband and high-efficiency LTC polarization conversion? To get a physical insight into the root cause, we will carry out a detailed analysis below. The proposed polarization converter is based on an anisotropic metasurface, which is a symmetric structure with a pair of mutually perpendicular symmetric axes \( u \) and \( v \), so there will be no cross-polarized reflection components at \( u \)- and \( v \)-polarized incidences, and the reflection matrix \( R_{lin} \) at LP incidence in the U-V coordinate system can be expressed as:

\[
R_{lin} = \begin{pmatrix} r_{uu} & 0 \\ 0 & r_{vv} \end{pmatrix},
\]

wherein the co-polarization reflection coefficients \( r_{uu} \) and \( r_{vv} \) will be independent of each other due to the anisotropy of the metasurface structure, but the magnitudes of \( r_{uu} \) and \( r_{vv} \) will both be very close to 1.0 because of the little dielectric loss. Therefore, in the case of neglecting the little dielectric loss, the following equation can be established:

\[
r_{vv} = r_{uu} e^{-i \Delta \psi_{uv}}.
\]

wherein \( \Delta \psi_{uv} \) represents the phase difference between \( r_{uu} \) and \( r_{vv} \), which can be limited between \(-180^\circ \) and \(+180^\circ \).

For the symmetric axes \( u \) and \( v \) are along \( \pm 45^\circ \) directions with respect to the \( y \)-axis, the \( y \)- and \( x \)-polarized unit wave can be expressed as \( \hat{e}_y = \frac{\sqrt{2}}{2}(\hat{e}_u + \hat{e}_v) \) and \( \hat{e}_x = \frac{\sqrt{2}}{2}(r_{uu} - r_{vv}) \), respectively, the reflection matrix \( R_{lin} \) in the X-Y coordinate system can be deduced from the \( R_{lin} \) in the U-V coordinate system in Eq. (4). When the incident wave is supposed as a \( \gamma \)-polarized one \( E' = E_0 \hat{e}_\gamma = \frac{\sqrt{2}}{2}(\hat{e}_u + \hat{e}_v) \), by using the reflection matrix \( R_{lin} \) in Eq. (4), the total reflected wave can be expressed as:

\[
\begin{align*}
    E' &= E'_u \hat{e}_u + E'_v \hat{e}_v \\
    &= \frac{\sqrt{2}}{2} E_0 \left( r_{uu} \hat{e}_u + r_{vv} \hat{e}_v \right) \\
    &= \frac{\sqrt{2}}{4} E_0 \left[ (r_{uu} + r_{vv}) (\hat{e}_u + \hat{e}_v) + (r_{uu} - r_{vv}) (\hat{e}_u - \hat{e}_v) \right] \\
    &= E_0 \left( \frac{1}{2} (r_{uu} + r_{vv}) \hat{e}_y + E_0 \frac{1}{2} (r_{uu} - r_{vv}) \hat{e}_x \right).
\end{align*}
\]
it is implied that the co- and cross-polarization reflection coefficients at y-polarized incidence can be expressed as:

\[
\begin{align*}
    r_{yy} &= \frac{1}{2} (r_{uu} + r_{vv}) = \frac{1}{2} r_{uu} \left( 1 + e^{-j\Delta \varphi_{uv}} \right) \\
    r_{xx} &= \frac{1}{2} (r_{uu} - r_{vv}) = \frac{1}{2} r_{uu} \left( 1 - e^{-j\Delta \varphi_{uv}} \right).
\end{align*}
\] (7)

After a similar derivation at x-polarized incidence, the total reflection matrix \( R_{\text{lin}} \) in the X-Y coordinate system is obtained as follows:

\[
R_{\text{lin}} = \begin{pmatrix}
    r_{xx} & r_{xy} \\
    r_{yx} & r_{yy}
\end{pmatrix} = \frac{1}{2} \begin{pmatrix}
    r_{uu} & r_{uv} \\
    r_{vU} & r_{vv}
\end{pmatrix} = \frac{1}{2} r_{uu} \left( \begin{array}{c}
    1 + e^{-j\Delta \varphi_{uv}} \\
    1 - e^{-j\Delta \varphi_{uv}}
\end{array} \right).
\] (8)

According to Eq. (8), the following equation can be established:

\[
\frac{r_{xx}}{r_{xy}} = \frac{r_{yy}}{r_{yx}} = \frac{1 + e^{-j\Delta \varphi_{uv}}}{1 - e^{-j\Delta \varphi_{uv}}} = \frac{1 + \cos(\Delta \varphi_{uv}) - j \sin(\Delta \varphi_{uv})}{1 - \cos(\Delta \varphi_{uv}) + j \sin(\Delta \varphi_{uv})} = \frac{j \sin(\Delta \varphi_{uv})}{1 - \cos(\Delta \varphi_{uv})}
\] (9)

Eq. (9) indicates that the ratios between the co- and cross-polarization reflection coefficients at x- and y-polarized incidences are both a pure imaginary number, it is implied that the phase difference between them will always be equal to \( \pm 90^\circ \), which can be used to explain why the phase difference \( \Delta \varphi_{xy} \) shown in Fig. 2(b) is basically always equal to \(-90^\circ \) in the band 5.0-21.5 GHz. In addition, when \( \Delta \varphi_{uv} \neq 0^\circ \) or \( \pm 180^\circ \), the co- and cross-polarization reflection coefficients will not be zero, the reflected wave will be an elliptically polarized one; for the phase difference between the co- and cross-polarization reflection coefficients will always be equal to \( \pm 90^\circ \), the magnitude of the ratio between them can be regarded as the AR of the reflected wave, such the AR can be expressed as:

\[
\text{AR} = \begin{cases} 
    \frac{\sin(\Delta \varphi_{uv})}{1 - \cos(\Delta \varphi_{uv})} & \text{if } |\sin(\Delta \varphi_{uv})| \geq 1 - \cos(\Delta \varphi_{uv}) \\
    \frac{1 - \cos(\Delta \varphi_{uv})}{\sin(\Delta \varphi_{uv})} & \text{if } |\sin(\Delta \varphi_{uv})| < 1 - \cos(\Delta \varphi_{uv}).
\end{cases}
\] (10)

Furthermore, the equation \( r_{xy} / r_{yx} = r_{xx} / r_{yy} \) has appeared in Eq. (9), it is indicated that the ratio of y- to x-polarized reflected components at y-polarized incidence is always equal to the ratio of x- to y-polarized reflected components at x-polarized incidence, which implies that when an anisotropic metasurface can work as a LTC polarization converter at y-polarized incidence and convert a \( \gamma \)-polarized incident wave into a RHCP/LHCP reflected one, it can realize LTC polarization conversion at x-polarized incidence at the same time, however, the x-polarized incident wave will be converted into a LHCP/RHCP reflected wave.

In addition, based on Eq. (9), the magnitudes of \( r_{xx}, r_{yy} \) and \( r_{yx}, r_{xy} \) can be expressed as:

\[
\begin{align*}
|r_{yy}| &= |r_{xx}| = \frac{1}{2} |r_{uu}| \left| 1 + e^{-j\Delta \varphi_{uv}} \right| = \frac{1}{2} \left| 1 + \cos(\Delta \varphi_{uv}) - j \sin(\Delta \varphi_{uv}) \right| = \sqrt{(1 + \cos \Delta \varphi_{uv})/2} \\
|r_{xy}| &= |r_{yx}| = \frac{1}{2} |r_{uu}| \left| 1 - e^{-j\Delta \varphi_{uv}} \right| = \frac{1}{2} \left| 1 - \cos(\Delta \varphi_{uv}) + j \sin(\Delta \varphi_{uv}) \right| = \sqrt{(1 - \cos \Delta \varphi_{uv})/2}.
\end{align*}
\] (11)

Eq. (11) indicates when \( \Delta \varphi_{uv} = 0^\circ \), the magnitudes of \( r_{xy} \) and \( r_{yx} \) are both equal to zero, the polarization state of the reflected wave will remain the same as that of the incident wave; however, when \( \Delta \varphi_{uv} = \pm 180^\circ \), \( |r_{xx}| = |r_{yy}| = 0 \), so that a perfect cross polarization conversion will be realized; in addition, when \( \Delta \varphi_{uv} \neq 0^\circ \) or \( \pm 180^\circ \), the reflected wave will be elliptically-polarized, based on Eq. (11), the AR of the reflected wave can be expressed as:

\[
\text{AR} = \sqrt{(1 \pm \cos \Delta \varphi_{uv})/(1 \mp \cos \Delta \varphi_{uv})},
\] (12)

wherein the choice of addition and subtraction shall ensure that the AR is not less than 1.0 at all times.

The Eq. (10) and (12) both indicate when \( \Delta \varphi_{uv} = \pm 90^\circ \), the AR of the reflected wave is just equal to 1.0, and a perfect LTC polarization conversion will be realized. Why a perfect LTC polarization conversion can be realized when \( \Delta \varphi_{uv} = \pm 90^\circ \)? In fact, at x- and y-polarized incidences, the incident and reflected waves can both be regarded as a composite wave composed of u- and v-polarized components with equal amplitude in the case of neglecting the little dielectric loss, the two orthogonal components in the incident wave are in phase with each other, however, in the reflected wave, the phase difference between the two orthogonal components will be changed. When \( \Delta \varphi_{uv} = \pm 90^\circ \), the phase difference will be changed to \( \pm 90^\circ \), so the perfect LTC polarization conversion will be realized.

According to the above analysis, to make clear the root cause of the LTC polarization conversion for the proposed polarization converter, we have successively simulated it at u- and v-polarized normal incidences. The obtained simulation results, shown in Fig. 5(a), indicate that the phase difference \( \Delta \varphi_{uv} \) between \( r_{uu} \) and \( r_{vv} \) always stays close to \(+90^\circ \) in the frequency range between 6.0 and 20.0 GHz, which implies that the anticipated LTC polarization conversion will be realized in the ultra-wide frequency band. Why is the obtained \( \Delta \varphi_{uv} \) so good? To find out the cause, the other simulation results, the magnitudes of \( r_{uu} \) and \( r_{vv} \), together with their phase variations, are shown in Fig. 5(b) and (c). Their phase variations were calculated by the formula \( \varphi_{uv} = \Arg(R_{uv}) + 2k0S \), wherein \( S \) denotes the distance between Floquet Port and the polarization converter surface in the simulation structure. Fig. 5(b) shows that the magnitudes of \( r_{uu} \) and \( r_{vv} \) are both close to 1.0 at all frequencies, however, the data curves of \( r_{uu} \) and \( r_{vv} \) still have a certain amount of fluctuation,
they have two and three minimum values located at 7.22, 16.63 and 5.98, 14.29, 22.50 GHz, respectively, it is implied that there are two and three resonant modes excited by \( u \)- and \( v \)-polarized incidences respectively, which cause these local maximum dielectric losses. In addition, the curvatures of the data curves of \( r_{uu} \) and \( r_{vv} \) at different resonant frequencies are quite different, which implies that the Q values of these resonant modes are different. Furthermore, in Fig. 5(c), it is shown that the phase variations of \( r_{uu} \) or \( r_{vv} \) at each resonant frequency is different, it is just because these resonant modes have different Q values. According to the phase variations shown in Fig. 5(c), we can know the phase difference \( \Delta \phi_{uv} \) can stay close to +90° between 6.0 and 20.0 GHz, it is mainly because of the following two reasons: Firstly, compared with the first resonant mode (7.22GHz) at \( u \)-polarized incidence, the first resonant mode (5.98GHz) at \( v \)-polarized incidence has not only lower resonant frequency but also higher Q value, which makes the phase of \( r_{vv} \) decrease earlier and quicker, such the phase difference \( \Delta \phi_{uv} \) can be kept close to +90° in the band 6.0-9.0 GHz. Secondly, the Q values of the two second resonant modes (16.63, 14.29 GHz) at \( u \)- and \( v \)-polarized incidences are both very small, moreover, they are basically the same, which results in the same change trends of the phases of \( r_{uu} \) and \( r_{vv} \) along with the increasing of the frequency in the band 9.0-20.0 GHz, such the phase difference \( \Delta \phi_{uv} \) can still be kept close to +90° in the wide subsequent band. Finally, according to the phase difference \( \Delta \phi_{uv} \) in Fig. 5(a), we have calculated the AR of the reflected wave using Eq. (12), the calculated results, shown in Fig. 5(d), indicate that the calculated AR is essentially in agreement with the results shown in Fig. 3.

After the above analysis, it has been well understood why the polarization converter can perform such a high-efficiency and ultra-wideband LTC polarization conversion. Apart from the two first resonant modes at \( u \)- and \( v \)-polarized incidences, it can be attributed mainly to the two second resonant modes. The appropriate difference between the two first resonant modes causes the phase difference \( \Delta \phi_{uv} \) to be close to +90° in the band 6.0-9.0 GHz, but the similarity, together with the small Q values, of the two second resonant modes leads to \( \Delta \phi_{uv} \) to stay close to +90° in the wide subsequent band 9.0-20.0 GHz. Such the anticipated LTC polarization conversion is realized in the ultra-wide frequency band 6.0-20.0 GHz.

Now we have known that the proposed polarization converter can perform ultra-wideband and high-efficiency LTC polarization conversion, however, it is not based on a common metasurface, it has been covered by a dielectric layer with a thickness of 4.30 mm, the unit cell structure is thicker. In fact, to design an ideal polarization converter, we hope that it has not only a wider working frequency band, but also a better unit cell structure. Can we remove or thin the top dielectric layer? In order to optimize the unit cell structure, we have simulated it repeatedly when the thickness \( h_2 \) of the top dielectric layer was taken as different values. Several obtained simulation results, shown in Fig. 6, indicate that neither of the two second resonant modes at \( u \)- and \( v \)-polarized incidences will be excited when no top dielectric layer exists or the thickness \( h_2 \) is only 2.0 mm, which implies \n
\begin{figure}
\centering
\includegraphics[width=0.8\textwidth]{figure5}
\caption{Simulation results of the proposed polarization converter at \( u \)- and \( v \)-polarized normal incidences: (a) the phase difference \( \Delta \phi_{uv} \) between \( r_{uu} \) and \( r_{vv} \); (b) the magnitudes and (c) phase variations of \( r_{uu} \) and \( r_{vv} \); (c) the axial ratio (AR) of the reflected wave.}
\end{figure}
that the ultra-wideband LTC polarization conversion can’t be realized when the metasurface has not been covered by a dielectric layer with a certain thickness. To see why, after several simulations, the electric field distributions of the five resonant modes in the UZ or VZ longitudinal section of the proposed polarization converter unit cell structure are obtained and shown in Fig. 7, it is shown that the resonant electric fields of the two first resonant modes at \( u \)- and \( v \)-polarized incidences, together with that of the third resonant mode at \( v \)-polarized incidence, are mainly distributed between the adjacent conductor patches in different unit cells; however, the two second resonant modes are both much like a radiation mode, the resonant fields are completely distributed around the conductor patch in each unit cell, the resonance regions are very small. If the conductor patch in the unit cell structure is not covered by a dielectric layer with a certain thickness, this kind of resonance modes with very small resonance region will not be generated, which is understandable.

IV. EXPERIMENTAL RESULTS

Finally, in order to carry out an experimental validation for our design, we fabricated an experimental sample using standard print circuit board (PCB) technique, which consists of 40 \( \times \) 40 unit cells with an area of 320mm \( \times \) 320mm, its photograph is shown in Fig. 8(a). Firstly, we have measured its co- and cross-polarization reflection coefficients at vertical-polarized incidence, the schematic illustration of the measurement setup is shown in Fig. 8(b), in which the sample is irradiated by a vertical-polarized horn antenna as the transmitter at first, but the reflected wave is received by CP horn antenna as the receiver. Because the transmitter and receiver have been connected to the two ports of an Agilent E8363B Agilent network analyzer, the two reflection coefficients \( r_{RHCP-Ver} \) and \( r_{LHCP-Ver} \) were measured directly when the receiver was chosen as a RHCP and LHCP antennas respectively. In addition, for the bandwidth of CP antenna was limited, in order to validate the LTP polarization conversion performance of the experimental sample in the whole working bandwidth(5.8-20.4GHz), three pairs of RHCP and LHCP horn antennas with continuous working band (4-8GHz, 8-18GHz, 18-40GHz) have been used successively. After that, based on the measured \( r_{RHCP-Ver} \) and \( r_{LHCP-Ver} \), the AR of the reflected wave was obtained using the Equation \( AR = \frac{(|r_{RHCP-Ver}| + |r_{LHCP-Ver}|) / (||r_{RHCP-Ver}|| - |r_{LHCP-Ver}||)}{2} \).

Finally, when the transmitter was changed as horizontally polarized, the reflection coefficients \( r_{RHCP-Hor} \) and \( r_{LHCP-Hor} \), together with the AR of the reflected wave at horizontally polarized incidence, were measured through the same experimental steps. In this experiment, all the measured results are shown in Fig. 8(c) and (d), it is indicated that at vertically and horizontally polarized incidences, the measured...
V. CONCLUSION

In summary, a novel LTC polarization converter based on an anisotropic metasurface is proposed in this work, which can realize high-efficiency and ultra-wideband LTC polarization conversion in the frequency band from 5.8 to 20.4 GHz with a relative bandwidth of 112% at x- and y-polarized incidences, the effective LTC polarization conversion performance has been verified by both simulations and experiment. In addition, to get an insight into the root cause of the LTC polarization conversion, a detailed theoretical analysis was presented, it was indicated that, for any anisotropic metasurface with dual diagonal symmetry, if it is placed in the two coordinate systems in the same way, the phase difference between the co- and cross-polarization reflection coefficients at both x- and y-polarized incidences will always be ±90°, and the AR of the reflected wave can be expressed as:

\[ \text{AR} = \sqrt{(1 \pm \cos \Delta \phi_{uv})/(1 \mp \cos \Delta \phi_{uv})} \]

It is indicated that if the phase difference \( \Delta \phi_{uv} \) between \( r_{uu} \) and \( r_{vv} \) is close to ±90°, any anisotropic metasurface can be used as a LTC polarization converter.

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FIGURE 8. Photographs of the fabricated experimental sample (a), the schematic of the measurement setup (b) and the measured results: the reflection coefficients \( r_{RHCP→LP} \) and \( r_{LHCP→LP} \) (c) and the axial ratios (ARs) of the reflected waves at vertically and horizontally polarized incidences (d).
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