Broadband Cross Polarization Converter Formed by Twisted F-shaped Chiral Metamaterial

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Abstract— A broadband cross polarization converter (CPC), formed from a Twisted-F Shaped Chiral Metamaterial (TFSCM), having high optical activity is reported in this work. The proposed structure supports high polarization conversion efficiency which is demonstrated numerically. The enhanced optical activity is observed which exhibits the presence of cross coupling phenomena between magnetic fields and is explained on the basis of surface current distribution.

1. INTRODUCTION

Metamaterials are tailored composite man-made materials made up of sub-wavelength size building blocks. It possessed different properties from their constituent materials. Those properties are produced mainly due to geometry of unit cell structure. By properly designing these structure one can achieve unique properties such as negative refractive index, extreme permittivity or permeability values, and negative magnetic permeability which are beyond from natural available materials. This unique property leads to new solutions and possibilities in various applications from information processing and telecommunication to sensing, imaging and security [1]. Specially the property of negative refractive index have possibility to produce the light of high resolution without any diffraction limits that will leads to new possibilities in data storage devices, imaging and lithography [1]. As well as the property of backward wave propagation (phase and group velocity are anti-parallel) can be used in variety of telecommunication devices such as transmission lines, waveguides, antenna, filters etc. [1].

A very interesting category of metamaterial is Chiral metamaterial. Now days it attracted much attention in controlling light polarization. It exhibits high value of optical activity (polarization rotation of linear polarized wave) and circular dichroism (left- and right-handed circularly polarized light absorption difference) that will highly exceeds these phenomena [2–4]. Another unique capability of Chiral metamaterial is in achieving, negative refraction through alternative Chiral route. It provides negative refractive index for circular polarized light.

In this work we present, Twisted-F Shaped Chiral Metamaterial (TFSCM) structure which supports high cross-polarization efficiency due to presence of large optical activity.

2. TFSCM DESIGN AND OPTICAL ACTIVITY

In Fig. 1(a), geometry of unit cell of TFSCM is shown. It consists of Chiral metallic pattern printed on both side of dielectric spacer. FR-4 substrate of 1 mm thick used as dielectric spacer having dielectric constant and loss-tangent respectively is 4.3 and 0.025. On front and back side of dielectric spacer, metallic pattern of F-shaped is printed and rotated opposite by 25° along the direction of electromagnetic wave propagation.

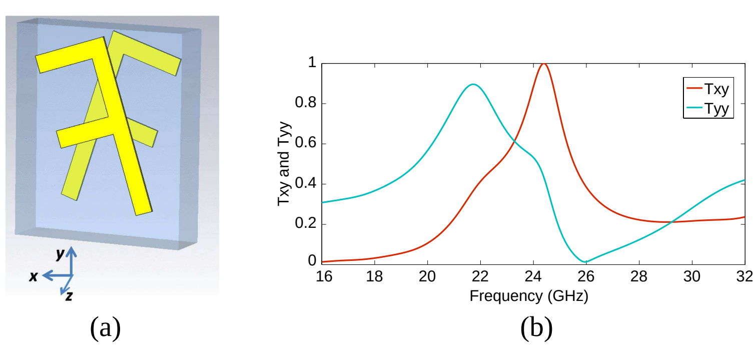

Figure 1. (a) Unit cell of TFSCM structure. F-shaped metallic inclusions are printed on both side of FR-4 dielectric substrate. (b) Cross (T_{xy}) and co-polarization (T_{yy}) transmission coefficients of the TFSCM.

To understand the optical behavior of TFSCM, we perform numerical simulations of the structure. For that purpose we used, Finite Integration Technique/Method based CST Microwave Studio (Computer Simulation Technology GmbH, Darmstadt, Germany) software. In simulation, periodic boundary is applied in x and y directions and absorbing boundary is applied in z direction. At one side of the structure, linearly polarized EM wave is incidents having electric field in y-direction. On other side of the structure, transmitted electric field is measured in x and y directions. Further the value of electric field is used in order to calculate, cross (T_{xy}) and co-polarization (T_{yy}) transmission coefficients as per Equations (1) and (2) [2].

$$T_{xy} = E_x^t / E_y^i \tag{1}$$
$$T_{yy} = E_y^t / E_y^i \tag{2}$$

Here E_y^i is incident electric field in y direction, E_y^t is transmitted electric field in y direction and E_x^t is transmitted electric field in x direction. In Fig. 1(b), the numerical simulation results of T_{xy} and T_{yy} are presented. It is observed that regime of cross-polarization is found in frequency range 23.26 to 29.25 GHz. Other distinct features of TFSCM seen in Fig. 1 are (i) The regime of maximum cross-polarization also have non-zero value of co-polarization (e.g., co-polarization transmission level at 24.4 GHz is $T_{yy} = 0.43$). (ii) Regime of cross polarization also consists frequency points where transmission amplitude of co-polarization is almost zero (e.g., cross and co-polarization amplitude level respectively at 25.95 GHz are $T_{xy} = 0.013$ and $T_{xy} = 0.39$).

The proposed design supports high transmission level of cross polarization conversion (T_{xy}) which is a sign of large optical activity. To derive the full picture of optical activity of the proposed structure one need to analyse transmission level of circular polarized wave. This information is

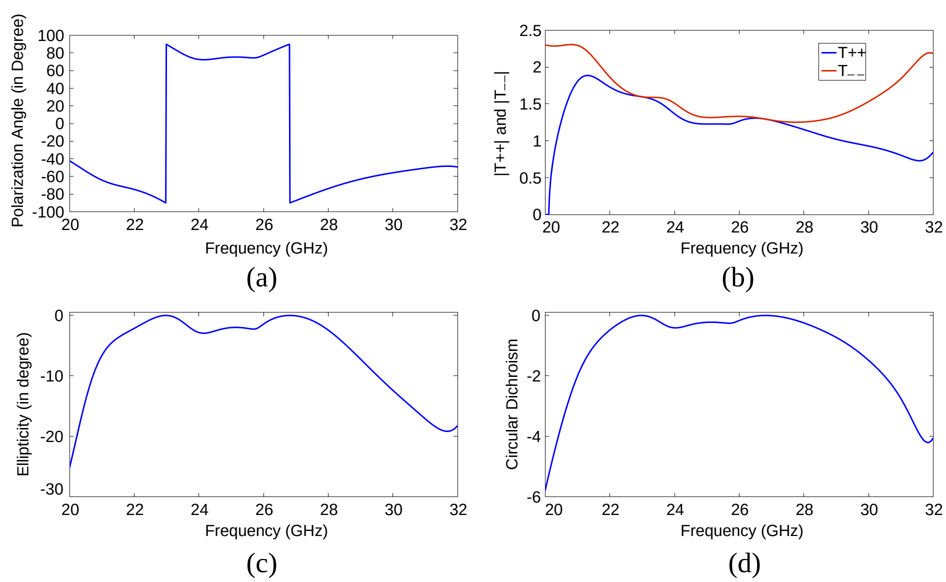

Figure 2. (a) Polarization rotation angle. (b) Right handed and left handed circular polarization coefficients. (c) Ellipticity. (d) Circular dichroism.

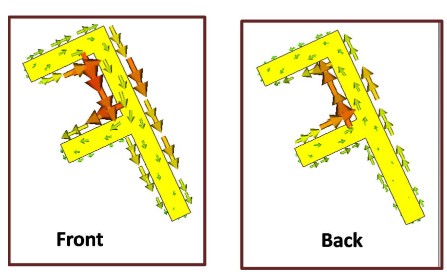

Figure 3.

directly obtained from transmission data of linearly polarized wave by Equations (3) and (4) [1].

$$T_{++} = 1/2((T_{xx} + T_{yy}) + i(T_{xy} + T_{yx}) \tag{3}$$
$$T_{--} = 1/2((T_{xx} + T_{yy}) - i(T_{xy} + T_{yx}) \tag{4}$$

Here T_{--} and T_{++} respectively are left and right handed circular polarization coefficients. Ellipticity (η), Polarization rotation angle (θ) and Circular Dichroism (CD) are also used in order to characterize optical activity of the structure. The value of those parameters are calculated from the transmission levels of LCP (T_{--}) and RCP (T_{++}) by Equations (5), (6) and (7).

$$\theta = 1/2[\arg(T_{++}) - \arg(T_{--})] \tag{5}$$
$$\eta = 1/2\tan^{-1}[(|T_{++}| - |T_{--}|)/(|T_{++}| - |T_{--}|)] \tag{6}$$
$$CD = |T_{++}|^2 - |T_{--}|^2 \tag{7}$$

The polarization rotation angle is plotted in Fig. 2(a). It is observed that the value of polarization rotation angle is sustain around 90° for spectrum 23 to 26.8 GHz. In this spectrum y-polarized beam is converted to x-polarized beam. In identifying, pure optical activity the Ellipticity is a prime indicator. The Chiral metamaterial should possess pure optical activity for CPC design. For that the value of Ellipticity should be minimum. The Elliptcity is a measure of degree of circular/elliptical polarized wave and its low level describes the maintaining linearly polarized state at output. It is observed from Fig. 2(c) that the structure supports pure optical activity for a wide frequency spectrum 23.12 to 29.15 GHz. From Figs. 2(b) and (d) this can be confirmed, where Fig. 2(b) dictates that for corresponding spectrum (22.98 and 26.82 GHz) transmission levels of LCP and RCP are almost same and Fig. 2(d) shows that at frequency of 22.98 and 26.82 GHz Ellipticity become almost zero which is a desirable feature of an ideal CPC design.

In order to describe the mechanism of cross polarization and strong optical activity of TFSCM. We analyse the surface current distribution on twisted F-shaped structure. In Fig. 3, simulation results of surface current distribution is shown at 23.12 GHz. It is observed that magnetic dipoles are excited on top and bottom layer by incident EM wave and arrange anti-symmetrically due to anti-parallel flow of current in top and bottom metal plates. The coupling in between pair of magnetic dipoles leads to cross polarization transmission and strong optical activity.

3. CONCLUSION

In this paper, we have presented a new geometry of Chiral metamaterial and explore its optical activity numerically. Simulation results show that TFSCM supports cross-polarization characteristics over a wide frequency spectrum.

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