Polarization plane rotation produced by 3D chiral metamaterial structures in W-band

Oscar Fernández Fernández, Álvaro Gómez Gómez, Angel Vegas García

Universidad de Cantabria, Plaza de la Ciencia s/n, 39005 Santander, España
oscar.fernandez@unican.es

Abstract

Metamaterials are artificial composite materials that exhibit further properties neither available in the nature nor observed in its constituents, or enhancing the composite features relative to the individual properties of its constituents. Among them, we can highlight the Chiral Metamaterials (CMM), which present, besides negative refractive indices, high rotation angles of the polarization plane rotation [1].

Regarding to CMMs manufacturing, several techniques can be found: (i) the traditional one, wherein helical inclusions are dispersed in a dielectric host medium [2] and (ii) the newer based on the Printed Circuit Board Technology [3]. Besides its lower cost of manufacturing, the latest technique is featured by its designability and easiness of characterization using commercial software. In this communication a comparative parametric study focused on the variation of the polarization plane rotation angle (θ) versus different geometric parameters of several plane CMMs is performed.

A. Structures under analysis

Along this work two sets of planar structures implemented in PCB and exhibiting 3D chirality are analyzed in W-band (75-110 GHz). The first one, called mutual twist structure, is composed of chiral [3] (Fig. 1a) or achiral [4] (Fig. 1b) designs printed on both sides of the PCB with a relative rotation angle (ϕ) between each face. The second set, named *specular structures*, presents a 2D chiral geometry on one side of the PCB and its enantiomer, with or without rotation, on the other face (Fig. 2) [5]-[7].

B. Structures characterization

Applying the parameter retrieval algorithm published in [8] the aforementioned structures are characterized by obtaining the transmission (t_{++} and t_{--}) and reflection ($r_{++} = r_{--} = r$) coefficients of both right- (+, RHCP) and left- (–, LHCP) handed circularly polarized waves. In t_{++} notation, the first subscript corresponds to the circular polarization type of the transmitted wave, and the second one refers to the circular polarization type of the incident wave. The optical activity introduced by the chiral medium generates a rotation of the polarization plane (θ), which can be calculated from:

$$\theta = \frac{1}{2}\left[\arg\left(t_{++}\right) - \arg\left(t_{--}\right)\right]$$

C. Parametric study

As it was previously mentioned, one of the main features of the CMM is the high values of the polarization plane rotation that they produce. Thus, in our parametric study, we focus our attention on analyzing the CMM structure geometric characteristics dependence on the rotation of the polarization plane. As example, the rosette-type structure will be tested (see Fig. 1).

Fig. 3 shows the variation of θ vs frequency for different values of the most significant parameters of the structure: relative twist between the rosettes (ϕ), line width (w) and unit cell side length (g). At this point, it is important to note that its 3D chirality is due to the relative twist (ϕ) existing between the stamps of each face. From Fig. 3a, it can be seen that, since for $\phi = 0$ the polarization plane of the transmitted wave does not rotate ($\theta = 0$), the structure is achiral. In contrast, when ϕ is increased the CMM sample shows chirality. Additionally, Fig. 3b shows that an increasing of w produces an enlarging of the rosette electrical length and, consequently, a reduction of the structure operating frequency. Finally, in Fig. 3c the effects of the unit cell side length are depicted. It can be seen that when the unit cell size length is increased, the distance between neighboring cells enlarges and, consequently, θ is reduced.

In order to go further, the behaviors of same type of structures are compared. Thus, Fig. 4 presents the variation of θ versus frequency for each group of assemblies. In all cases the Rogers RO3003 dielectric with $\varepsilon_r = 3$, tg $\delta = 0.0013$ and 5 mils (127 µm) thickness is used. From Fig. 4a, it can be seen that, for the same ϕ and dielectric thickness, the crosses provide greater rotation angles than the rosettes do. Meanwhile, the rosettes present the advantage of being a more compact geometry than the crosses. Thus, for a given operating frequency, the rosettes unit cell will be smaller than the crosses one. The reduction of the unit cell geometry allows placing a greater number of rosettes per unit of area. Finally, for the specular structures (see Fig. 4b), a very different behavior is observed between the responses of the squared, L-shaped and wheeled rosettes.

Acknowledgements

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Figures

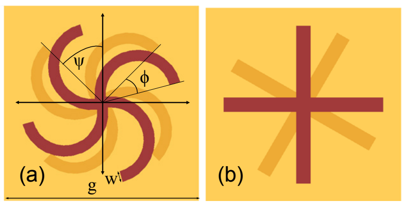

Fig. 1. Schematic of mutual twist type structures: (a) rosettes [1] and (b) crosses [3].

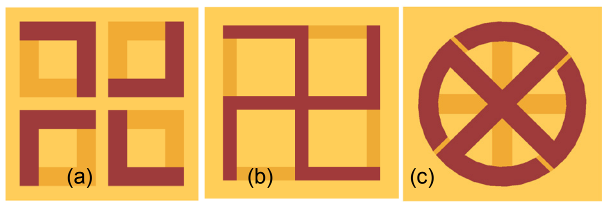

Fig. 2. Schematic of specular structures: (a) "L-shaped" , (b) conjugated gammadion and (c) wheel.

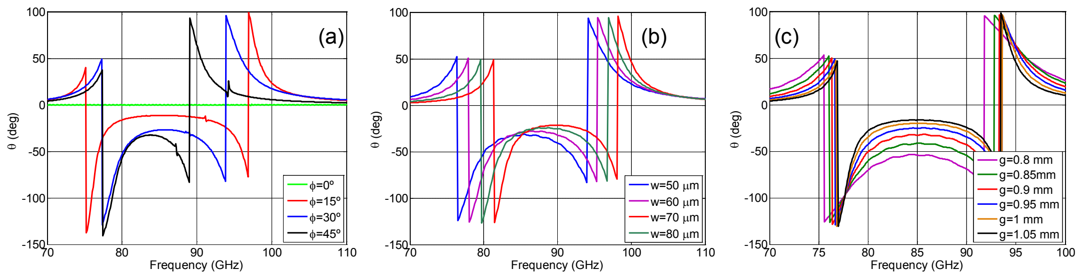

Fig. 3. Variation of the polarization plane rotation angle versus frequency for the structure of Fig. 1a for several values of (a) relative twist angle, (b) line width and (c) unit cell side length.

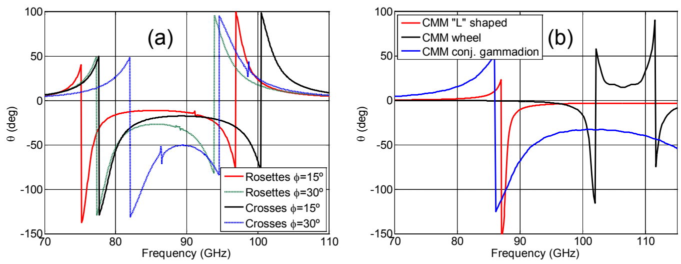

Fig. 4. Variation of the polarization plane rotation angle versus frequency for several (a) rosette- and (b) specular- type structures.