9th European Conference on Antennas and Propagation, to be held in Lisbon, Portugal, on 12-17 APRIL 2015. http://www.eucap2015.org/

A partially complementary chiral metamaterial based on a four-cranks resonator

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***Abstract*— A partially complementary bilayer chiral metamaterial (CMM) is proposed and numerically studied. It exhibits a strong optical activity and a small circular dichroism. The retrieval results reveal that a negative refractive index is realized in a narrow band around the resonance of the chirality parameter.**

***Index Terms*—Metamaterials, chirality, numerical simulations.**

I. Introduction

Recently, metamaterial chirality has been proposed as an alternative route to achieve negative refraction, [1]. This has lead to the creation of "chiral metamaterials" (CMM): they show some other exotic properties, as giant optical activity and circular dichroism [2]. Different bi-layer chiral structures have been proposed to achieve this chirality [3]. More recently, Li et al. used the Babinet's principle as a new approach to design "complementary" CMM [4].

In this work, we have designed and investigated a chiral metamaterial, based on a structure, partially complementary of the "four cranks resonator" implemented on Printed Circuit Board in [5]. Our structure includes two metal layers, complementary of the ones studied in [5]; we have also removed the vias in the substrate (FR4) sheet present in the reference. The resulting geometry is shown in Fig. 1. The present structure is geometrically chiral: i.e., it lacks any mirror symmetry; that means, from the electromagnetic point of view, that there is a cross-coupling between the electric and magnetic fields. As a result, the refractive index has different values for right circularly polarized (RCP) and left circularly polarized (LCP) waves. The constitutive relationships, assuming a bi-isotropic behavior, can be described in the frequency domain by:

$$\begin{pmatrix} D_x \\ B_x \end{pmatrix} = \begin{pmatrix} \varepsilon & -j\kappa / c_0 \\ j\kappa / c_0 & \mu \end{pmatrix} \begin{pmatrix} E_x \\ H_x \end{pmatrix} \qquad (1)$$

and similar equations for y- and z components. ε and μ are, respectively, the equivalent permittivity and permeability of the medium, c_0 is light speed in vacuum, and κ is known as "Pasteur" or chirality parameter. Following these equations, the refractive indices are $n_{\pm} = n \pm \kappa$ where n_+ is the refractive index for a RCP wave, while n_- is the index for a LCP wave. In this way, we may obtain the refractive index n ($\sqrt{\varepsilon_r \mu_r}$) from the equivalent indices for RCP and LCP waves.

II. Procedure

In order to obtain the constitutive parameters, we have used a free space technique, in which we calculate them from the scattering parameters for a plane wave normally incident on the chiral structure [6]. The simulations have been performed using a commercially available simulator in time domain, CST Studio Suite. The procedure to obtain afterwards the constitutive parameters from the scattering ones is also described in [5,6]

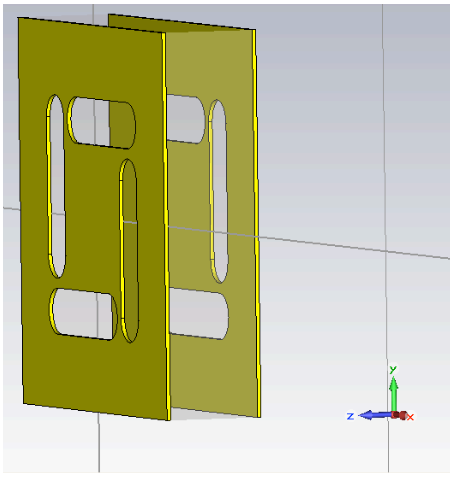

Fig. 1. Example of our structure: the substrate, FR4, placed between the two metal (copper) layers, has been removed to allow the view of the second metal layer

III. Results

We have simulated a structure like the one proposed in Fig. 1. The cell is 10x10mm, and the width of the FR4 sheet is 2.4 mm. Each slot is 4.95mm long and 2.4mm wide, and the minimum distance between adjacent slots is 0.15mm. Fig.2

shows the reflection and transmission coefficients for circularly polarized waves, as well as the rotation of the polarization angle of the transmitted wave, for a linearly polarized incident wave.

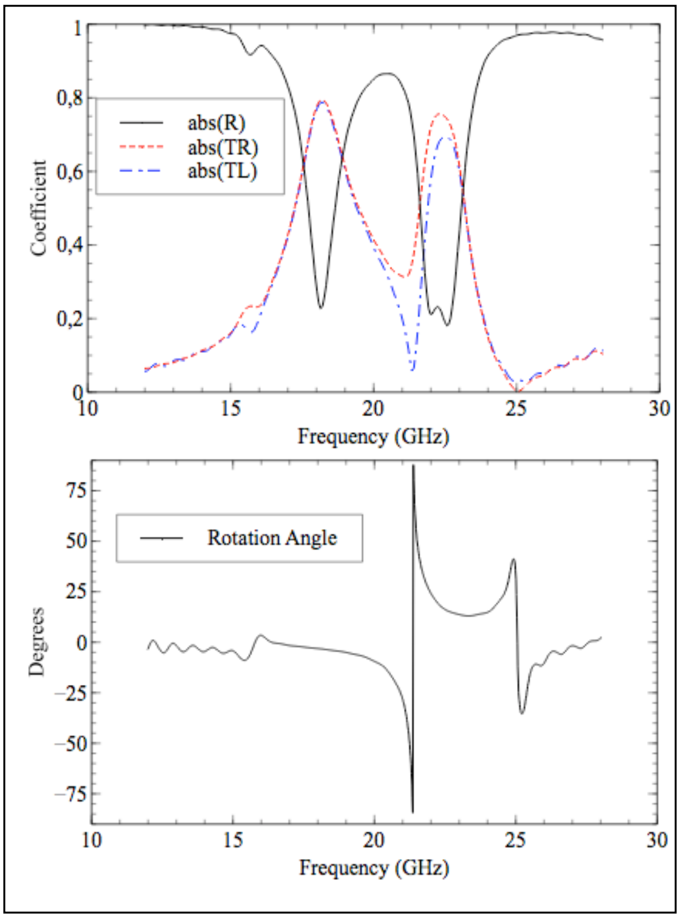

Fig. 2. Up: Scattering parameters for a normally incident wave, circularly polarized: R: reflection coefficient. TR: Transmission coefficient for a RCP wave. TL: Transmission coefficient for a LCP wave. Down: rotation of the polarization angle for a normally incident wave, linearly polarized.

In Fig. 2 it is shown that there is a transmission band between 16 GHz and 24 GHz, approximately, similar to a electromagnetic bandgap (EBG) behavior [7]. Outside of this band, most of the wave is reflected. Inside the band of interest, there is an area between 21 and 23 GHz with a strong circular dichroism (different transmission coefficient for RCP or LCP incident signals). The rotation of the polarization angle shows a resonance at 21.36 GHz. Using the results shown in Fig. 2, we may obtain the effective constitutive parameters of the medium, shown in Fig. 3.

In that figure, the Pasteur parameter shows a resonance at 21.18 GHz, very near of the maximum of the rotation of the polarization angle. It corresponds with the minimum of the transmission coefficient, for a RCP wave, at 21.09 GHz, and is very close to the minimum of the transmission coefficient for a LCP wave, at 21.34 GHz (Fig. 2). Moreover, there is a narrow band around this resonance frequency (21.17-21.39 GHz) where the real part of the refraction index is negative.

CONCLUSION

We have designed and studied a CMM structure. The numerical study shows that it is possible a giant optical activity (polarization rotation up to 87.8º). The structure shows also a strong optical dichroism, an EBG behavior, and a negative refractive index.

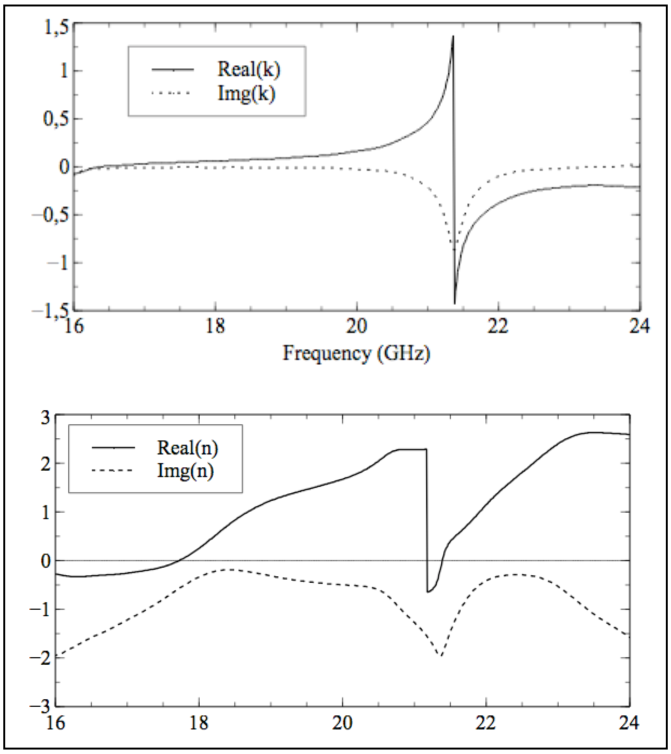

Fig. 3. Complex constitutive parameters: Pasteur parameter (κ) and refraction index (n)

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