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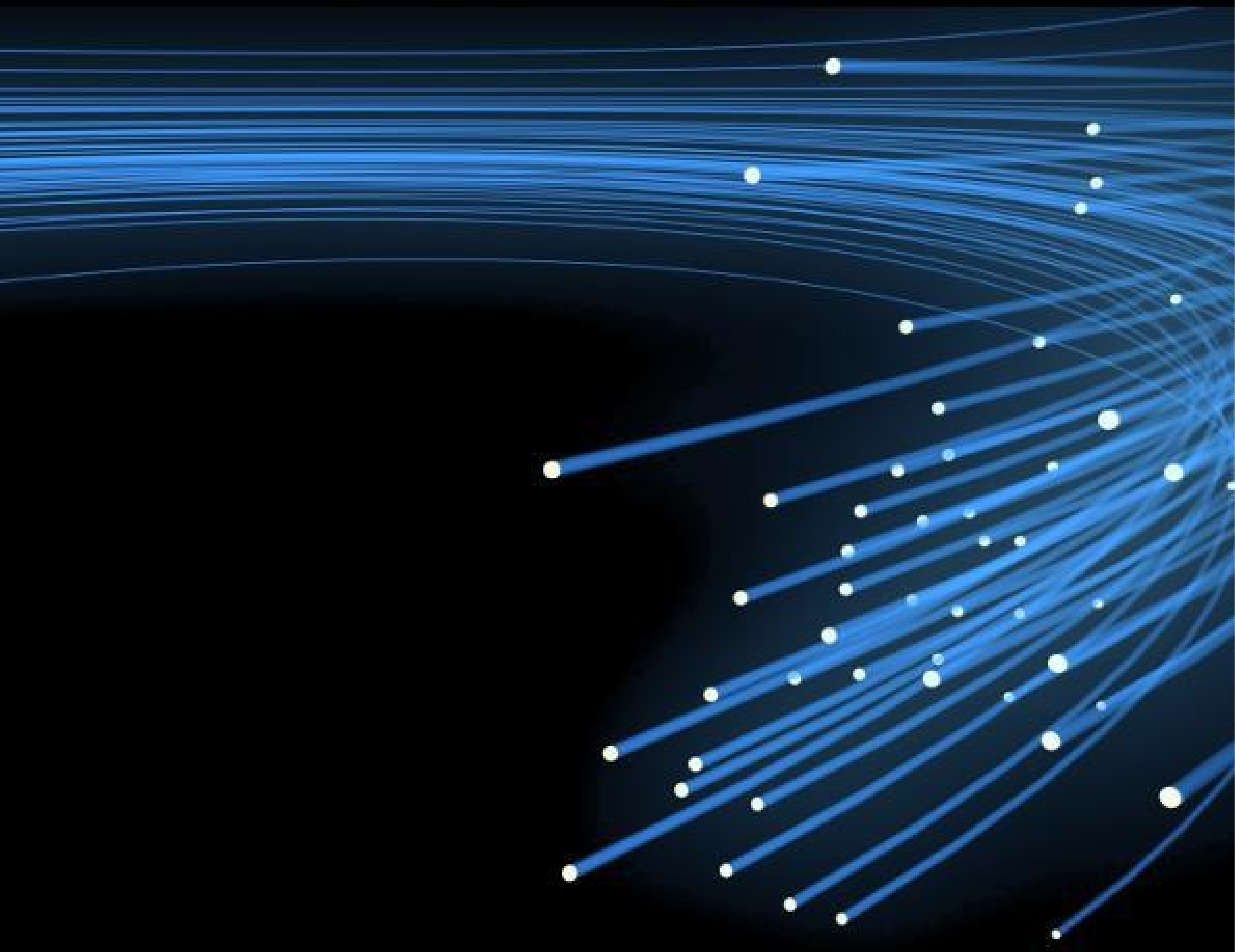

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A Complementary Chiral Metamaterial with Giant Electromagnetic Activity and Low Losses

Ismael Barba[1*], Ana Grande[1], Ana C. López-Cabeceira[1], José Represa[1], Gregorio J. Molina-Cuberos[2], Óscar Fernández[3] & A. Gómez[3]

[1]Universidad de Valladolid, Spain
[2]Universidad de Murcia, Spain
[3]Universidad de Cantabria, Spain
[*]corresponding author: ibarba@ee.uva.es

Abstract

A planar complementary metamaterial, as well as its corresponding inverse structure, has been designed and characterized. Numerical results (using commercial software) are presented here. The structure shows a giant gyrotropy (chirality) as well as very low losses.

1. Introduction

The use of "complementary" structures in PCB to perform metamaterial response has been established during the last years [1, 2]. In [1] it is shown that their transmission characteristics should be complementary too, i.e., if the "original" shape shows a resonant decrease in transmission characteristics at the frequencies of interest, in the "complementary" shape the transmission is resonantly enhanced at the same frequencies instead.

In a previous conference [3], we designed and characterized numerically a partially complementary chiral metamaterial, which presented negative refraction index in a resonant band. In this paper we present an enhanced version of the structure, in order to reduce material losses, and we compare it with its "full complementary" shape.

Fig. 1 and 2 show the designed structures: the "original" (i.e., the one composed by a distribution of metallic segments on a dielectric substrate) and the "complementary" (the one composed by a distribution of slots on a metal plate): the dielectric substrate has been made transparent in order to highlight the two metal layers. Another structure, very similar to the first one, has been studied in [4]. We have studied different dielectric substrates, from the traditional FR4 as in [3] to low-losses materials, like TACONIC TLC-30 and Rogers RO4003C, in order to enhance the transmission.

Looking at the figures, it is straightforward that both structures are geometrically chiral: i.e., they lack any mirror symmetry. From an electromagnetic point of view, chirality can lead to a cross-coupling between the electric and magnetic fields [5], so the refractive index has different values for right circularly polarized (RCP) and left circularly polarized (LCP) waves, following the equation

$$n_{\pm} = n \pm \kappa \,, \qquad (1)$$

where n_+ is the refractive index for a RCP wave, while n_- is the index for a LCP wave. n is the usual refraction index ($\sqrt{\varepsilon_{eff}\mu_{eff}}$) and κ is the cross-coupling parameter, also known as Pasteur or chirality index [5,6].

Looking at that equation, we can see that one of both indexes, n_+ or n_- would be negative if κ is high enough ($|\kappa| > n$, assuming n is positive) [6].

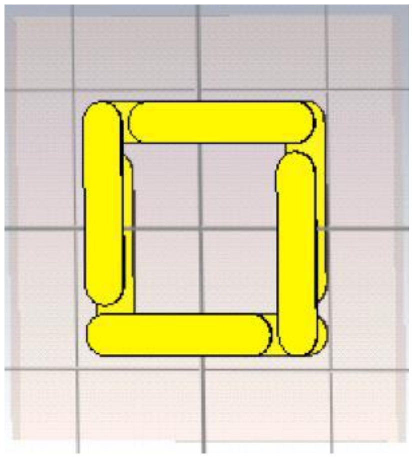

Figure 1: Geometry of the "original" planar metamaterial unit cell. It is composed by a dielectric substrate (removed) in the image, and metal (copper) traces on both its faces. The metal layer on the back face is the specular image of the front layer; so the geometry shows specular (chiral) asymmetry.

2. Design and characterization

In order to design a sample with a chiral electromagnetic response at microwave frequencies, we have used a basis cell of 16x16 mm, each segment/slot in Figs. 1 and 2 is 9.9x2 mm, and the minimum separation between them is 0.3 mm. That means the four segments/slots are enclosed inside a square of 12.2x12.2 mm. As mentioned, we have probed different dielectric plates between the two metal layers: TACONIC TLC-30 and Rogers RO4003C; both have similar properties (dielectric constant 3 and 3.38 respectively, and loss tangent 0.003 and 0.0027, respectively, so the results are similar. We also have probed different widths of the dielectric slab (0.03 and 0.06 inches). The lateral boundaries are modeled by means of periodic conditions, in order to simulate a periodic arrangement of cells.

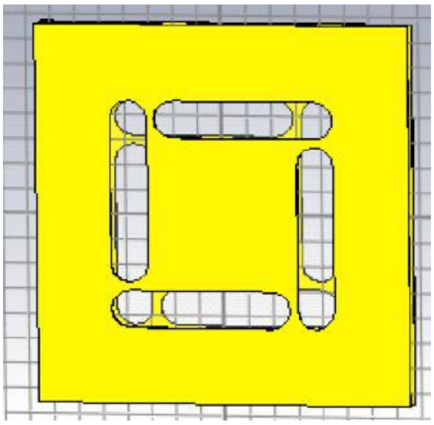

Figure 2: Geometry of the “complementary” planar metamaterial unit cell.

3. Results

We have modelled the response of our structure if a linear polarized plane wave incides normally on the slab. Due to the chirality of the structure, a rotation of the polarization plane is expected, and, therefore, we have measured the transmission coefficient in copolarization T_{CO} (i.e. the transmitted signal in the same polarization plane of the incident wave) and crosspolarization T_{CR} (polarization plane normal to the one of the incident wave), as well as the reflection coefficient R (the structure being reciprocal, no rotation was expected in the reflected wave and, indeed, it has not been found) [4]. Afterwards, we have used those results to calculate the effective Pasteur parameter of the structure.

3.1. Scattering Coefficients

In this paper, the results using two different dielectric slabs are presented. Figs 3 (“original” shape) and 4 (“complementary”) show the scattering parameters when the dielectric slab is 0.03 inches width and it is made of Taconic TLC 30. The simulation has been performed using time-domain CST Studio software. In Fig. 3 there is a first resonance (minimum of R and T_{CO} and maximum of T_{CR}), at 10.6 GHz, plus a second one (minimum of T_{CO}) at 12.4 GHz.. Fig. 4, instead, shows a first resonance (minimum of R and maximum of T_{CR} and T_{CO}) at 10.7 GHz, and a second one (again, minimum of R and maximum of T_{CR} and T_{CO}) around 12.1-12.2 GHz.

This results are in agreement with what is proposed in [1]: both shapes resonate in the same frequencies approximately but, while in the original shape, there is a minimum of the transmission for the (copolarization) transmission coefficient; in the complementary one there is a maximum of this coefficient.

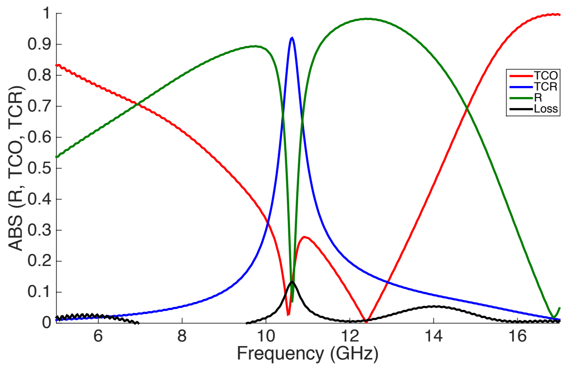

Figure 3: Reflection (R), Copolarization (TCO), and Crosspolarization (TCR) transmission coefficients, as well as relative losses for a plane wave normally incident over a periodic structure composed by cells as shown in Fig. 1. The dielectric slab is 0.03 inches width and it is made of Taconic TLC 30.

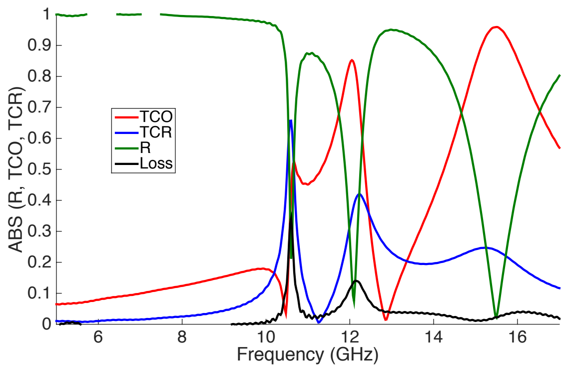

Figure 4: Reflection (R), Copolarization (TCO), and Crosspolarization (TCR) transmission coefficients, as well as relative losses for a plane wave normally incident over a periodic structure composed by cells as shown in Fig. 2. The dielectric slab is 0.03 inches width and it is made of Taconic TLC 30.

Figs. 5 and 6 show the scattering parameters when the dielectric slab is 0.06 inches width and it is made of Rogers RO4003C. In this case, the simulation has been performed using EMPRO software.

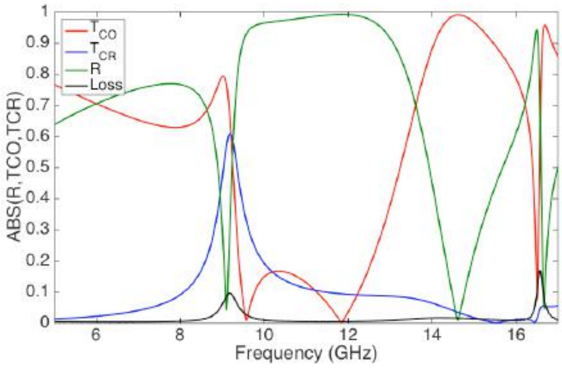

Figure 5: Reflection (R), Copolarization (TCO), and Crosspolarization (TCR) transmission coefficients, as well as relative losses for a plane wave normally incident over a periodic structure composed by cells as shown in Fig. 1. The dielectric slab is 0.06 inches width and it is made of Rogers RO4003C.

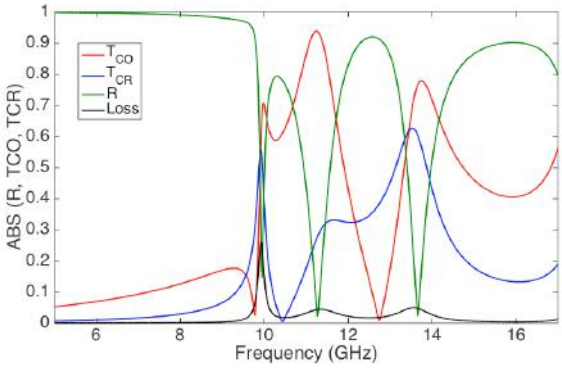

Figure 6: Reflection (R), Copolarization (TCO), and Crosspolarization (TCR) transmission coefficients, as well as relative losses for a plane wave normally incident over a periodic structure composed by cells as shown in Fig. 2. The dielectric slab is 0.06 inches width and it is made of Rogers RO4003C.

Looking at Figs. 5 and 6, the results are very similar to what was found in the first case: the resonances are placed now at slightly lower frequencies (9.1 GHz and 11.8 GHz in Fig. 5; 9.9 GHz and 10.4 GHz). The difference may be explained because of the higher dielectric constant of the slab.

In all the four figures, every resonance is associated with a strong rotation of the polarization plane (maximum value of T_{CR}). There are frequencies, coinciding with the resonances (Figs. 3 and 5) or close to them (Figs. 4 and 6) where the copolarization transmission coefficient is close to 0. That means the structures behave as a 90º polarization rotator, almost without dichroism (losses) at those frequencies.

At the same time, it is worth of noticing the high value of the total transmission coefficients in the resonant frequencies. To make them more evident, we have added in both figures the value of the energy losses ($1-R^2-T_{CO}^2-T_{CR}^2$). It is worth of being mentioned that those losses are almost negligible in most of frequencies, and stay in a low value even in the resonance frequencies.

3.2. Pasteur Parameter

The presence of a giant gyrotropy is, indeed, due to the chirality of both structures. We have calculated, too, the Pasteur parameter (κ) in every case; since the results are very similar, only the parameters for the first example (Taconic dielectric) are shown in Figs. 7 and 8.

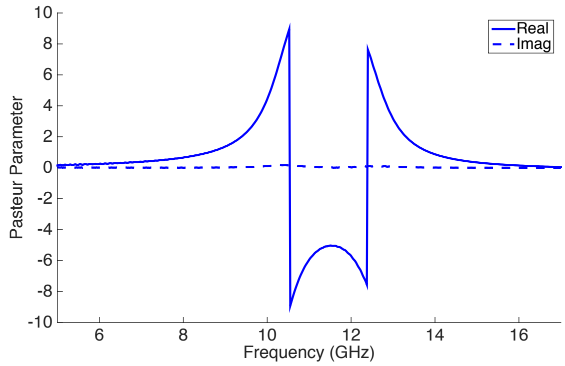

Figure 7: Effective Pasteur parameter (κ) of a periodic structure composed by cells like shown in Fig. 1. The dielectric slab is 0.03 inches width and it is made of Taconic TLC 30.

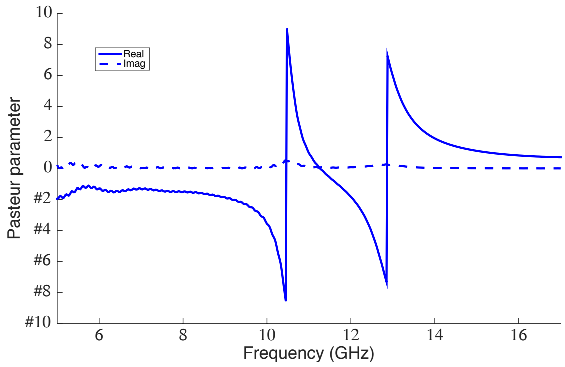

Figure 8: Effective Pasteur parameter (κ) of a periodic structure composed by cells like shown in Fig. 2. The dielectric slab is 0.03 inches width and it is made of Taconic TLC 30.

The chirality parameters show both resonant behaviors as predicted by the Condon model [5]. The resonances are placed too in similar frequencies: 10.5 GHz and 12.4 GHz for the "original" structure; 10.5 GHz and 12.8 GHz for the "complementary" one. They are also placed, approximately, at the same frequencies of the resonances in the scattering parameters (minimums of T_{CO} in Figs. 3 and 4). It is worth of noticing the change in the sign of the second resonance between the original and the complementary shapes.

In both cases the imaginary part (i.e., losses) is almost insignificant, even in resonance, while there is a huge real part (gyrotropy). Especially the "original" shape shows a significant real part (-5) during a wide band (11-12 GHz) virtually without losses.

Conclusions

A planar complementary metamaterial has been designed and characterized. Its scattering parameters have been numerically calculated, and compared with the corresponding values for its complementary structure. The comparison between both cases is in good agreement with the theoretical predictions. Both structures show a giant gyrotropy as well as an almost negligible dichroism, so their Pasteur parameter has also been calculated. They indeed present a strong chirality, with a low imaginary part.

Acknowledgements

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References

[1] H.-T. Chen, J.F. O'Hara, A.J. Taylor, R.D. Averitt, C. Highstrete, M. Lee, W.J. Padilla, Complementary Planar Terahertz Metamaterials, *Optics Express* 34, 10: 1084–1095, 2007.

[2] Z. Li, K.B. Alici, E. Colak, E. Ozbay, Complementary Chiral metamaterials with giant optical activity and negative refractive index, *Appl. Phys. Lett.* 98, 161907, 2011.

[3] I. Barba, A. Grande, A.C. López-Cabeceira, G.J. Molina-Cuberos, J. Represa, A partially complementary chiral metamaterial based on a four-cranks resonator, *9th European Conference on Antennas and Propagation, EuCAP'2015*, Lisbon, Portugal, 2015.

[4] Y. Yee, S. He, 90º polarization rotator using a bilayered chiral metamaterial with giant optic activity, *Applied Physics Letters*, 96: 20351, 2010.

[5] A.H. Sihvola, A.J. Viitanen, I.V. Lindell, S.A. Tretyakov, Electromagnetic *Waves in Chiral and Bi-Isotropic Materials*. Artech House, 1994.

[6] J.B. Pendry, A chiral route to negative refraction, *Science* 306, 5700: 1353-1355, 2004.