Chiral SRR metasurfaces for circular polarisation conversion

Mariam Aznabet[a], Otman El Mrabet[a], Miguel Beruete[b,c], Miguel Navarro-Cía[d], Mohammed Essaidi[a]

(a) Information And Telecommunication Systems Lab, Faculty Of Science, Abdelmalek Essaadi University of Tetouan, Morocco
(b) Antennas Group-TERALAB, Universidad Pública de Navarra, Campus Arrosadía, 31006 Pamplona, Spain
(c) Institute of Smart Cities, Public University of Navarra, 31006 Pamplona, Spain
(d) School of Physics and Astronomy, University of Birmingham, Birmingham, Edgbaston B15 2TT, UK

mariamaznabet@gmail.com

***Abstract*— A circular polarization dual band metamaterial polarization rotator composed of two double split ring resonators rotated 90° with respect to each other is presented. Asymmetric transmission between T_{xx} and T_{yy} and symmetric transmission between T_{xy} and T_{yx} has been achieved. The circular polarization is caused by the symmetric transmission between T_{xy} and T_{yx}. The design has been demonstrated numerically at microwaves frequency. The structure holds promise for ultra-compact polarizing devices for any frequency range given the scalability of the approach.**

Keywords— ***Split Ring Resonators; Metasurfaces; Circular polrization; Chiral metamaterial;***

I. INTRODUCTION

Chiral materials (CM) have attracted more attention because of their ability to rotate the light in the optic range. The asymmetric properties of substances in solid form such as quartz, or in liquid such as turpentine and sugar solutions, exhibit very small optical activity or chirality [1]. Besides to these features, their reduced symmetry makes them of great use in the enhancement of nonlinear process [2]. To make easier the introduction of those features into real applications, other schemes have appeared more recently that exploit the engineer dispersion of periodic structures based on photonic crystals [3] and metamaterials [4-6]. The latter one seems to be more interesting because, apart from some unconventional properties such as perfect lens issue [7], properties shown by photonic crystals can be achieved in principle in more compact structures as a result of the subwavelength dimension of their unit cell.

Up to now, chiral metamaterials (CMM) have been demonstrated in the microwave, terahertz and near-infrared frequency ranges [8, 9]. It has been shown that CMM can have high efficient polarization conversion even for thin structures [10, 11-13], circular polarizer based on double and triple split ring resonator [14-17]. An effective method to design a simple circular polarization based on CMM is based on constructing the mirror of the unit cell on the backside of the supporting substrate.

In this work, a circular polarization dual band metamaterial polarization rotator composed of two double split ring resonators shaped with the same dimensions is proposed. In order to have the mirror image of the front side into the back side we rotate the front side by 45° clockwise direction and the back side with 45° counterclockwise direction which make the two double split ring resonators twisted 90° to each other as shown in fig. 2. We also discuss the nature of the resonances and the influence of the particle bi-anisotropy, demonstrating that the polarization rotation is due to the longitudinal magnetic dipole coupling between stacked SRRs. Thus, one can say that our metamaterial structure enables the propagation of the magnetoinductive waves (MIWs) [5].

This paper is organized as follow: in part II, details the proposed structure Section III present results and discussion of simulation and some demonstration of circular polarization. Finally, some conclusions are drawn in Section IV, which also summarizes the main contributions of this work.

I. CHIRAL METAMATERIAL DESIGN

The proposed structure is composed of a matrix of conventional EC-SRRs [4, 6] printed on both sides of a dielectric substrate. To break the symmetry of the structure the EC-SRRs in each layer are rotated with an angle of 90° with respect to each other, see Fig. 1(a). Such structure permits asymmetric transmission for linearly polarized EM waves only [13].

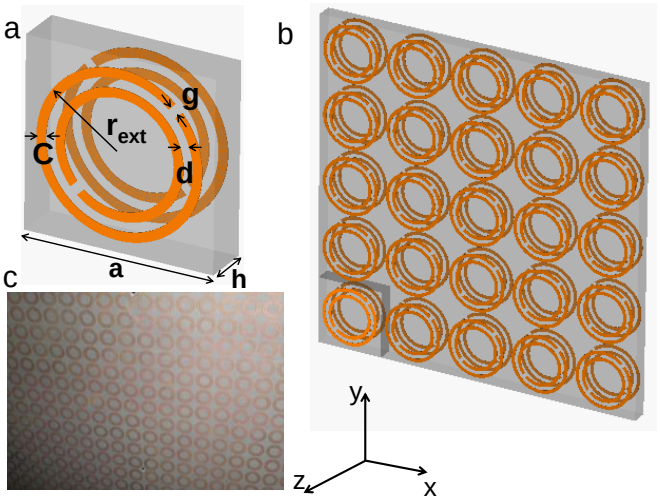


Fig. 1 Unit cell schematic (a) of the proposed metasurface (b). (c) Photograph of the fabricated structure.

In the design the loss-free dielectric substrate chosen is ARLON CuClad 250 with a relative permittivity of ε_r = 2.43 and a thickness of h = 1.48 mm, while the metallic elements are made of copper with thickness of 35 µm. Fig. 1(a) shows the schematic diagram of the unit cell with a dimension of 8×8 mm^2, which is approximately $\lambda_0/8$ at the SRR fundamental resonance. The dimensions of the SRRs are the same as in Refs. 18-20: outer radius r_{ext} = 3.5 mm, widths of metal strips distance between inner and outer rings and width of ring splits $c = d = g$ = 0.4 mm. These parameters give a theoretical quasi-static resonance frequency of about 5 GHz, in accordance with the theory developed in Ref. 21.

II. RESULTS AND DISCUSSION

The frequency domain solver of the commercial software CST Microwave Studio™ has been used to investigate numerically the asymmetric transmission of the proposed structure. Periodic boundary conditions in the transverse direction are set up together with Floquet ports. This type of ports allows setting the number of Floquet modes that will be considered for the simulation. Two fundamental Floquet modes TE(0,0) and TM(0,0) have been selected as excitation, which have the electric field along the *y*- and *x*-axis, respectively, and act as normally-incident linearly polarized plane waves. A tetrahedral mesh was used to map accurately the circular shape of the EC-SRRs. The scattering parameters for linearly polarized incident wave propagation along the +z direction can be described by Jones Matrix [22,23] is

$$T_{lin} = \begin{pmatrix} T_{xx} & T_{yx} \\ T_{xy} & t_{yy} \end{pmatrix}$$

To study the electromagnetic chiral response of the proposed CMM structure, we transform the linear matrix to the circular polarization and the transmitted waves can be expressed as

$$T_{cir} = \frac{1}{2}\begin{pmatrix} T_{xx} + t_{yy} + i(t_{xy} - t_{yx}) & T_{xx} - t_{yy} - i(t_{xy} + t_{yx}) \\ T_{xx} - ty_y + i(t_{xy} + ty_x) & T_{xx} + t_{yy} - i(t_{xy} - t_{yx}) \end{pmatrix}$$

Supposing linearity of the structure, linear transmission coefficients T_{xx} and T_{yx} are obtained from simulations when the incident wave is *x*-polarized (E_x). Similarly, for a *y*-polarized (E_y) incident wave, linear transmission coefficients T_{yy} and T_{xy} are obtained. The parameters T_{yx} and T_{xy} represent cross-polarization, whereas T_{xx} and T_{yy} denote co-polarization. The numerical simulation Fig. 2 shows that the level of T_{xx} and T_{yy} is roughly -25dB at the first dip around 4.14 GHz for the *x*-polarized and -25dB at the second dip around 5.1 GHz for the *y*-polarized. Fig. 2 also shows that the first peak appears around 4.14 GHz and has a peak value of -22.7 dB for T_{xy} and for T_{yx}. The second one is around 5.1 GHz and reaches -19 dB for T_{xy} and for T_{yx}. The chiral response of the proposed CMM is evaluated by the Δ parameter, which is defined as the difference between the two-incident electromagnetic wave directions.

$$\Delta^{x}_{lin} = |t_{yx}|^2 - |t_{xy})|^2 = - \Delta^{y}_{lin} \quad (1)$$

$$\Delta^{+}_{cir} = |t_{xx}-t_{yy}+i(t_{xy}+t_{yx})|^2 - |t_{xx}-t_{yy}+i(t_{xy}+t_{yx})|^2 = -\Delta^{-}_{cir} \quad (2)$$

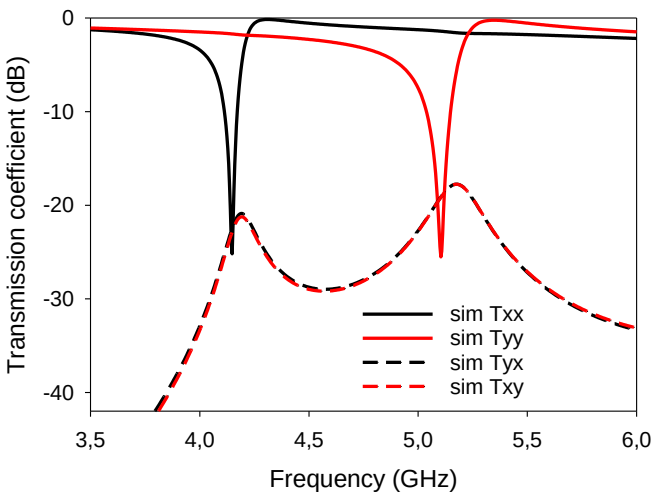


Fig. 2. Simulated transmission coefficient.

When the *x*-polarized and *y*-polarized wave normally incidents into the structure along the + z direction, the wave is well coupled to the structure through the gap in SRR and converted normally to *y* polarization and *x* polarization due to the cross coupling between two metallic layers when passing through the slab, the same mechanism occurred along the opposite direction. The asymmetric transmission parameter Δ was calculated through equations (1) and (2) for both linear polarizations and circular polarizations, and is illustrated in Fig. 3. Note that cross-polarization components T_{xy} and T_{yx} are equal, which essentially has no zero asymmetric transmission of circular polarization according to equation (2), when increasing the frequency, the value of parameter for circular

linear polarizations experiences a rapid increase and extents the maximum of 0.06 and 0.13 at frequency of 4.14 GHz and 5.18 GHz respectively. However, due to the obvious asymmetry in the structure, there is no asymmetric transmission for linear polarized waves as indicated in Fig. 3.

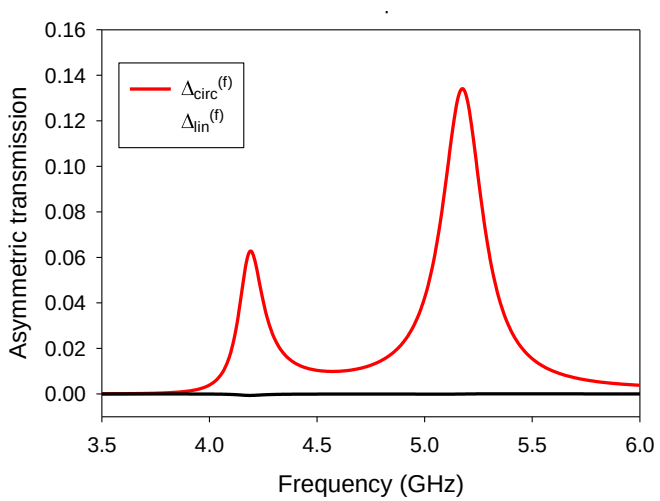


Fig. 3. The asymmetric transmission for linear and circular polarization.

III. Conclusion

A CP Double Split ring resonators based on CMM has been proposed and demonstrated in microwave frequency. Simulation results show the ability to transform a linear polarized wave to a circular polarized wave due to the specific asymmetry of the structure. The circular polarization has been achieved at the both resonance frequency band. The resuls indicate no asymmetric transmission for linear polarised wave. The proposed structure could be scaled in the other frequency band.

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