Chirality arising from evanescently coupled rotated arrays of square patches

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Abstract

Two subwavelength metallic arrays of square patches are placed in close proximity, and one is rotated with respect to the other. Despite each patch array being non-chiral, information is conveyed via the evanescent fields, and polarization conversion results - the system has become electromagnetically chiral.

1. Introduction

Chirality is determined by the symmetry of a structure. The most obvious example of chirality is the symmetry of our hands. The left and right may be identical to their mirror image, however one cannot be translated to become the other. Electromagnetic (EM) chirality - the ability of a structure to induce rotation of the plane of EM polarisation on transmission or reflection may arise in a variety of ways. Sugar solution, for example, gives rise to rather weak rotations of polarisation due to the intrinsic chirality of the sugar molecules [1]. Anisotropic (uniaxial) liquid crystals, when arranged with their director twisted slowly (twist angle rotating by less than 2π in a few wavelengths of the radiation) may cause very strong polarisation rotation and as such this effect is used in displays [2]. Recently, the concept of chirality in metamaterials has become of great interest to the EM research community [3-12].

Metamaterials are materials that have been artificially structured with subwavelength elements, may be designed to possess EM properties not found in nature, such as negative refractive index, and artificial magnetism. In planar chiral metamaterials the chiral elements are confined to a plane or surface and the rotation imposed on the incident radiation is perpendicular to the plane. Recent developments in chiral metamaterials have included twisted split ring resonators, both circular [3] [4] and "U" shaped split rings [5] [6], double layer rosettes [7], gammadions [8] [9], as well as cut wire pairs [10], and rotated crosses [11] [12]. In this study two layers, each comprised of a square arrays of subwavelength metallic patches, are spaced apart such that they are within each other's evanescent field, with one rotated relative to the other. The key observation is that while the constituent element of each array in themselves are definitely not chiral, the evanescently coupled combination gives a strong chiral response. This is a new type of evanescent chiral metamaterial.

Metamaterials in the form of metal patch arrays have been optimized for use as low pass filters, frequency selective surfaces and antenna arrays. Importantly the transmittance through the subwavelength structure is independent of the direction of linear polarization of the source. EM radiation is simply decomposed into the two unit vectors associated with the patch array, due to the 90 degree rotation symmetry of the array, both components experience the same geometry and therefore have the

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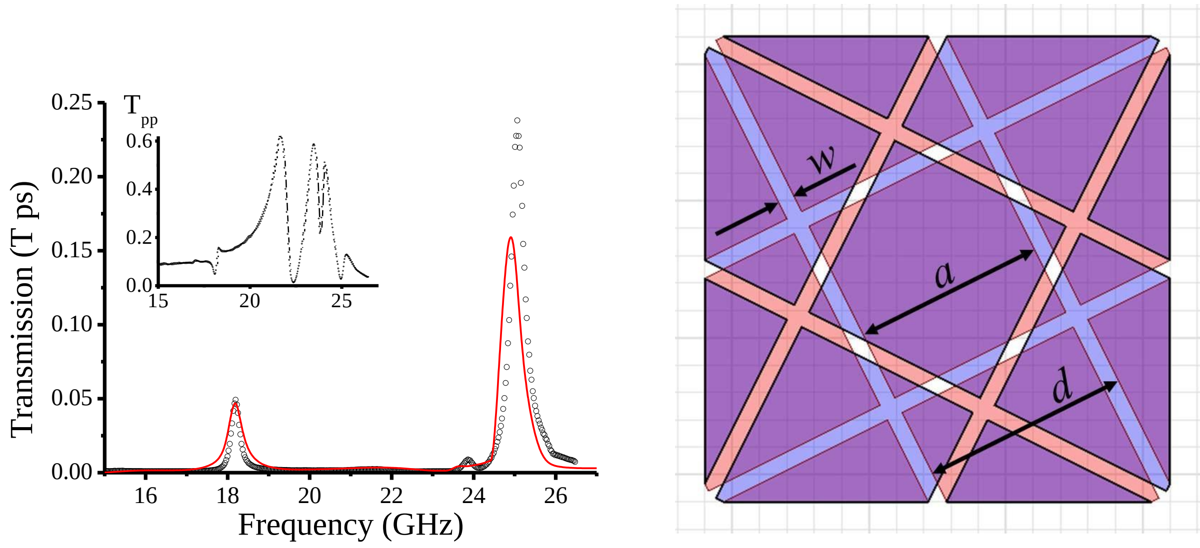
same transmission and reflection response. As a result the response in the subwavelength limit is not a function of polarization angle [13].

When the layer spacing between the two patch arrays is small (< 1 mm), the evanescent fields associated with the subwavelength pitch of the patch arrays may interact and therefore by misaligning the structure both transmission and reflection responses are perturbed (not shown). When the separation between patch arrays is large (not shown), they can be considered as planar isotropic effective media evidenced by the fact that the *x*,*y* position and alignment of layers does not alter the transmission or reflection response. In this study we rotate one patch array relative to the other, to produce "evanescent handedness". As this chiral behaviour depends upon the evanescent EM fields coupling between the patch arrays, only small separations will be considered.

2. Sample

The experimental sample consists of two arrays of metal patches 17.5 µm thick separated by 0.508 mm of dielectric (Rogers RO 4003 C). The patch arrays are rotated by ± 26.5 degrees, a (2,1) rotation, as shown in Fig. 1 (b). The EM response of this structure was modelled as a 2D infinite array using a finite element method. In order to obtain a model of manageable size, a small commensurate unit cell is required. The (2,1) rotation gives a unit cell $\sqrt{5}$ larger than the unit cell of a single un-rotated patch array ($\sqrt{m^2 + n^2} = \sqrt{2^2 + 1^2} = \sqrt{5}$). This is the smallest commensurate unit cell which may be modelled.

3. Results and Discussion



(a) (b)

Fig.1 (a) Experimentally observed (circles) and numerically modelled (line) cross-polarised transmission. Inset: Experimentally observed (circles) co-polarised transmission. (b) modelled unit cell for the rotated patch array structure shown in the *xy* plane, where *w* = 0.3 mm, *a* = 3.5 mm, and *d* = 3.8 mm.

Experimentally observed and numerically modelled cross-polarised transmission results are shown in Fig. 1(a). Three modes are evident as transmission peaks occurring at 18.22 GHz, 23.88 GHz, and 25.09 GHz. The mechanism responsible for the excitation of these three peaks, relies on the evanescent coupling of the resonant modes between the layers. In the absence of interaction between the layers, each patch array would simply decompose the EM wave into components along the unit vectors of the array and no polarisation conversion would occur. When the patch arrays are placed within the

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decay length of the evanescent fields associated with the subwavelength patch arrays, these diffractively coupled array modes are supported. Asymmetric and symmetric eigenmode field solutions are associated with each diffracted order of the commensurate unit cell. Here we observe a pair of modes at 23.88 GHz and 25.09 GHz, below the onset of first order diffraction in air. The lowest frequency mode observed at 18.22 GHz, is the symmetric solution for the commensurate unit cell for the diffraction edge in the dielectric. Here the asymmetric solution is very weakly coupled. These modes mediate the polarisation conversion via evanescent interaction of the arrays.

4. Conclusion

We propose a novel structure composed of two closely-spaced subwavelength square metallic patch arrays (not chiral arrays or elements), which when rotated with respect to one another, form an evanescently chiral metamaterial. Polarisation converting modes can be excited by an arbitrary linear polarised electromagnetic wave, which facilitate cross coupling between the layers through the overlapping evanescent fields, leading to polarisation conversion.

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