# Chiral Media Based on Periodic Distribution of Cranks. The Four Cranks Resonator

**G.J. Molina-Cuberos[1], A.J. García-Collado[2], I. Barba[3], A.C.L. Cabeceira[3], J. Represa[3] and J. Margineda[1]**

[1]Grupo Electromagnetismo, Universidad de Murcia
Campus Espinardo, E-30100, Murcia, Spain
[2]Departamento Ciencias Politécnicas, Universidad Católica San Antonio
E-30107, Guadalupe, Murcia, Spain
[3] Departamento de Electricidad y Electrónica, Universidad de Valladolid
E-47071, Valladolid, Spain

**Abstract**

A new structure consisting of four cranks, as the unit cell, to produce electromagnetic activity at microwave frequencies is proposed. A chiral medium is build by means of a 2D periodical distribution of the unit cell in printed circuit boards. By using a free-wave experimental setup, we have found that the medium presents electromagnetic rotatory dispersion and circular dichroism at the X-band frequency range. The maximum on the rotation angle is observed at the end of the band with a magnitude of around 170 deg. Numerical studies confirm the experimental results and allow to study the phenomena in the Ku band, where another small resonance is found.

## 1. Introduction

Traditionally isotropic chiral materials at microwave frequencies are obtained by means of random distribution of elements with chiral symmetry in a host substrate [1]. During the last years, alternative fabrication methods, based on periodic distributions of planar or quasi-planar particles have been proposed. Among the new methods, conventional printed-circuit board (PCB) is an outstanding technique widely used in metamaterial design. The unit cell is implemented by using conductive vias and holes and is repeated forming a 2D periodical lattice. 3D structures are also possible by accumulation of several PCBs. This is a low-cost technique, which enables high flexibility in the design of the elementary cell and reduces the homogeneity problems associated with the random distribution of particles [2].

PCB technology has been used by Barba et al. [3], to design a unit cell formed by eight symmetric cranks with different orientations which is able to produce electromagnetic activity (the condensed symmetric node, CSN). They found that the rotation angle is basically proportional to the number of layers of the material. García-Collado et al. [4] also obtained electromagnetic active media by locating four metallic cranks, with the same handedness, in a cross shape structure. Both designs show the typical characteristics of chiral media based in random distribution of elements, such us circular dichroism and reciprocity.

In this paper we present the first results of a structure, the four cranks resonator (4CR), composed by four cranks in a packed configuration forming a parallelepiped. The unit cell has the advantage compared with the two previously described, to present a higher density of cranks in a given volume.

ISBN 978-952-67611-0-7

## 2. Results

Fig. 1 (left) shows the distribution of cranks forming the 4CR, where $l_1 = l_2 = 3.5$ mm and $l_3 = 2.4$ mm are the segment size, $d_1 = d_2 = 4.5$ mm the separation distance between cranks in the node, and $d_1\prime = d_2\prime = 9.0$ mm the separation between unit cells. A similar configuration of cranks, produced by bending copper wires, was used by Cloete et al. [5] to conclude that chirality is not a fundamental requirement for enhance microwave absorption. A sample composed by 14 x 14 unit cells was manufactured using standard FR4 substrate and placed in a free-wave experimental setup for characterization. The interested reader is refereed to [4] and references therein for a detailed description of the experimental setup and measurement method, here we briefly described its main characteristics.

The incident beam, a linearly polarized wave, is focused by an ellipsoidal concave mirror so that diffraction problems are minimized, even with relatively small samples. The transmitting antenna is placed at one of the mirror foci and the sample at the other one. The rotation angle of the transmitted polarization ellipse is defined as the difference between the polarization direction of the incident wave and the direction of the major axis of the transmitted elliptically polarized wave. In order to characterize the transmitted wave, the receiving antenna can rotate around the longitudinal axis, which allows the measurement of the transmission coefficient for any polarization. The co- and cross-polarization. $S21_{CO}$ and $S21_{CR}$ are related with the tilt angle of the ellipse $\tau$, by:

$$\tau = \frac{\pi}{2} - \frac{1}{2} tan^{-1} \left( \frac{2 S21_{CO} S21_{CR}}{S21_{CO}^2 - S21_{CR}^2} cos\left(\phi\right) \right) \tag{1}$$

where $\phi$ is the phase difference between $S21_{CO}$ and $S21_{CR}$. In principle $\tau$ is not completely determined by equation (1), because there is uncertainty of $2n\pi$, where $n$ is an integer. In order to measure the angle uniquely, we make use that at low frequencies, below the expected resonant frequency, the rotation angle should be zero.

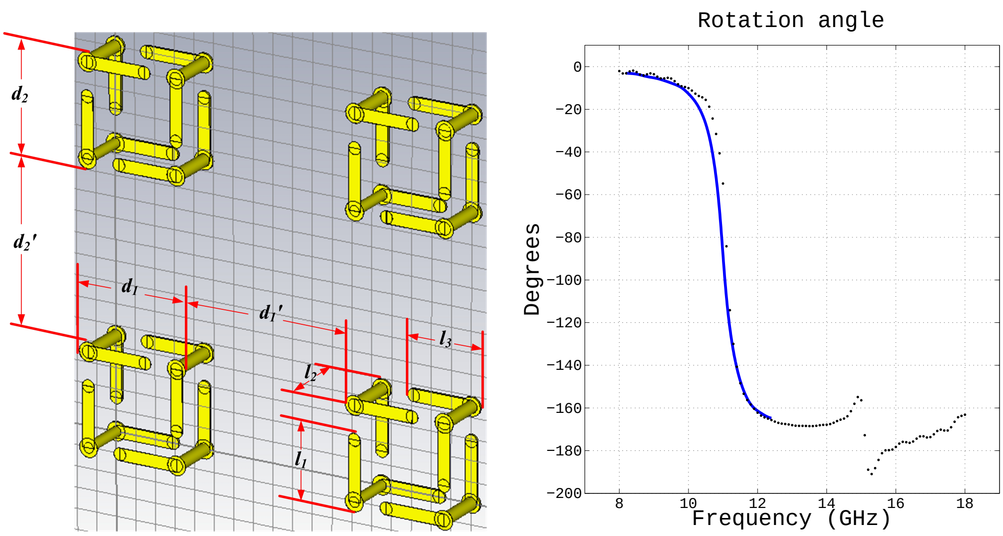


Fig. 1: Left: CST$^{TM}$ 2009 model of four unit cell. Each crank is composed by two arms 3.5 mm long, one in each side of the board (2.4 mm of thickness), plus a vie connecting both. Right: Rotation angle, for a linearly polarized incident wave: measurements (blue line) and simulation (black dots).

Fig. 1(right) shows the angle of rotation of a linearly polarized wave obtained experimentally (blue line). We observe that the angle increases (in magnitude) with the frequency in all our experimental frequency range, from 8.2 to 12.4 GHz, and it seams to be near to the local maximum at the end of the range. In order to know the behavior of the sample beyond 12.4 GHz, the propagation of a plane wave through the structure was modeled by making use of CST Studio Suite2009$^{TM}$, which is a commercial software based in the finite difference method. The numerical results are also shown in Fig. 1 (black dots). It can be observed that the rotation angle reaches a maximum (in magnitude) of around 170 degrees. This is not a sharp extreme, but a plateau with around 2 GHz width, followed by a resonance at around 15 GHz. The secondary resonance seems to depend on the frequency following a Condon model, which has been also found in chiral media based on random inclusions of helices or cranks [1], [6].

The circular dichroism, due to the different absorption coefficient of a right- and left-handed circularly polarized wave in the material, can be determined once the major and minor axes of the transmitted elliptically polarized wave are know. To do that we make use of:

$$OA = \left[\frac{1}{2}\left(S21_{CO}^2 + S21_{CR}^2 + \sqrt{(S21_{CO}^4 + S21_{CR}^4 + 2S21_{CO}^2 S21_{CR}^2 cos(2\phi)}\right)\right]^{1/2} \quad (2)$$

$$OB = \left[\frac{1}{2}\left(S21_{CO}^2 - S21_{CR}^2 + \sqrt{(S21_{CO}^4 + S21_{CR}^4 + 2S21_{CO}^2 S21_{CR}^2 cos(2\phi)}\right)\right]^{1/2} \quad (3)$$

where, $OA$ and $OB$, are the major and minor axes, respectively. We have found that sample presents circular dichroism between 10.5 and 11.5 GHz, which is the frequency range where the rotation angle change more quickly with the frequency.

## Conclusions

Here we present a new structure able to produce electromagnetic activity at microwave frequencies. The unit cell is composed by four symmetric cranks and is build by using PCB technology. We demonstrate that a material formed by a two dimensional lattice of such structures, periodically repeated in space, presents electromagnetic rotatory dispersion and circular dichroism in the X-band frequency range, with a maximum on the rotation angle of around 170 deg.

### Acknowledgments

This work was supported by the Spanish Ministerio de Ciencia e Innovación (project TEC 2010-21496-C03-02).

## References

[1] C.R. Brewitt-Taylor, P.G. Lederer, F.C. Smith and S. Haq. Measurements and prediction of helix-loaded chiral composites, *IEEE Transactions on Antennas and Propagation*, vol. 47, no. 4, pp. 692-700, 1999.

[2] I. Barba, A.C.L. Cabeceira, A.J. García-Collado, G.J. Molina-Cuberos, J. Margineda and J. Represa, Quasi-planar Chiral materials for microwave frequencies in *Electromagnetic Waves / Book 2*, InTech - Open Access Publisher, 2011.

[3] I. Barba, A. Cabeceira, A. Gómez and J. Represa, Chiral Media Based on Printed Circuit Board Technology: Numerical Time-Domain Approach, *IEEE Transactions on Magnetics*, vol. 45, no. 3, pp. 1170-1173, 2009.

[4] A.J. García-Collado, G.J. Molina-Cuberos, J. Margineda, M.J. Núñez and E. Martín, Isotropic and homogeneous behavior of chiral media based on periodical inclusions of cranks, *IEEE Microwaves and Wireless Components Letters*, vol. 20, no 3, pp. 176-177, 2010.

[5] J.H. Cloete, M. Binglea and D. B. Davidson, The Role of Chirality and Resonance in Synthetic Microwave Absorbers, *AEU - Int. J. of Electronics and Communications*, vol. 55, no 4, pp 233-239, 2001.

[6] G.J. Molina-Cuberos, A.J. García-Collado, J. Margineda, M.J. Núñez and E. Martín, Electromagnetic Activity of Chiral Media Based on Crank Inclusions, *IEEE Microwave and Wireless Components Letters*. vol. 19, no. 5 , pp. 278-280, 2009.

 