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Diode Switchable Chiral Metamaterial Structure for Polarization Manipulation

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Abstract—This communication presents a novel diode switchable chiral metamaterial structure that manipulates the polarization in different ways depending on the active bias lines. Three different bias states that provide three totally different behaviors have been considered: polarization rotator, circular polarization converter and linear to circular converter.

Keywords—Chiral metamaterial; diode; switchable

I. INTRODUCTION

Planar metamaterials are artificial structures constituted by metallic inclusions periodically distributed on a substrate. The electromagnetic properties of this kind of media come from the pattern and the geometric distribution of the inclusions rather than their components properties.

Tunable metamaterials are structures capable of changing its electromagnetic properties through the aid of external stimuli. These stimulations can be used to modify the conductivity of semiconducting substrates [1], alter geometric parameters in microelectromechanical systems [2], or bias semiconductor based diodes embedded into the metamaterial unit cells [3].

Focusing our attention on diode tunable metamaterials, in the literature it can be found several works focused on taking advance of the reflection features of these media: absorbers with metallic inclusions periodically distributed on a substrate. The electromagnetic properties of this kind of media come from the pattern and the geometric distribution of the inclusions rather than their components properties.

In this communication, a switchable chiral metamaterial (CMM) structure constituted by a bilayered CMM [9] with embedded diodes joining in series each unit cell with its neighbors, Fig. 1, is presented. Modifying the bias voltage, the diodes state and thus the connections with neighboring cells are changed. Consequently, different geometrical patterns can be obtained depending on the applied bias voltage. Along this work, three bias states of the schematic of Fig. 1 are analyzed. In each state, the bias lines are switched on or off in order to modify the polarization of an incident wave in these ways: as a polarization rotator, as a circular polarization converter and as a linear to circular polarization converter.

II. DIODE SWITCHABLE CHIRAL METAMATERIAL

Fig. 1 shows the pattern of each side of the proposed structure formed by the CMM and the PIN diodes. On each face, all the rows (columns) of diodes share the same bias line. As stated in [4], the diodes of the rows (columns) are turned on when the applied bias voltage is greater than the sum of their threshold voltages. In this forward biased state, the diode is modelled as a short circuit. Therefore, the unit cells of the rows (columns) are electrically connected. If no bias voltage is applied, the diode acts as an open circuit.

The switchable CMM has been implemented in Rogers RO4003C, with dielectric constant \( \varepsilon_r = 3.55 \), tan \( \delta = 0.0027 \), thickness \( d = 1.52 \text{ mm} \) and a copper cladding of 35 \( \mu \text{m} \). The geometrical parameters of the structure are displayed in the figure caption. For its numerical characterization, the transmission matrix for linearly polarized incident waves (1) have been obtained through numerical simulations using the Finite Differences Time Domain engine of the Keysight EMPro 3D EM software®.

\[
\begin{pmatrix}
E_{tx}^\text{in} \\
E_{ty}^\text{in}
\end{pmatrix} = T_{LP} \begin{pmatrix}
E_{x}^\text{inc} \\
E_{y}^\text{inc}
\end{pmatrix} = \begin{pmatrix}
t_{xx} & t_{xy} \\
t_{yx} & t_{yy}
\end{pmatrix} \begin{pmatrix}
E_{x}^\text{inc} \\
E_{y}^\text{inc}
\end{pmatrix}
\]

(1)

Fig. 1. Layout of each proposed structure side. Inset: Unit cell of the CMM structure. Dimensions (in mm): \( l_1 = 3.7, l_2 = 0.95, w = 0.7, a_1 = a_2 = 10 \).
From this transmission matrix, \( T_{LP} \), other related transmission matrices, linear to circular transmission matrix, \( T_{CL} \), and circular transmission matrix, \( T_c \), can be obtained [10]:

\[
T_{CL} = \begin{pmatrix} t_x & t_y \\ t_x & t_y \end{pmatrix} = \frac{1}{\sqrt{2}} \begin{pmatrix} t_{xx} + j t_{xy} & t_{xy} + j t_{yy} \\ t_{xx} - j t_{xy} & t_{xy} - j t_{yy} \end{pmatrix}
\]

(2)

\[
T_c = \begin{pmatrix} t_x & t_y \\ t_x & t_y \end{pmatrix} = \frac{1}{2} \begin{pmatrix} t_{xx} + t_{yy} + j(t_{xy} - t_{yx}) & t_{xy} - t_{yx} - j(t_{xy} + t_{yx}) \\ t_{xx} - t_{yy} - j(t_{xy} + t_{yx}) & t_{xy} + t_{yx} + j(t_{xy} - t_{yx}) \end{pmatrix}
\]

(3)

Here, \( t_{ab} \) represents the transmission coefficient of a wave with polarization \( a \) when the impinging wave displays polarization \( b \), wherein \( a \) and \( b \) may refer to \( x \) or \( y \) linear polarization or right-handed (RHCP, +) or left-handed (LHCP, -) circular polarization.

A. Polarization plane rotator

The first analyzed case occurs when the bias lines are off. Under this condition the unit cells are not electrically connected, resulting the well-known conjugated gammadion CMM [11], Fig. 2. This structure acts as polarization plane rotator providing pure rotation of 30°, Fig. 3.

![Fig. 2. Schematic of the pattern of each side of the Conjugated gammadion. Inset: Unit cell of the CMM structure.](image)

**Fig. 2.** Schematic of the pattern of each side of the Conjugated gammadion. Inset: Unit cell of the CMM structure.

**Fig. 3.** Polarization plane rotation of the conjugated gammadion.

B. Circular Polarization Converter

Next, the bias voltage is applied to the columns bias line of each side of the metamaterial. Thus, the diodes embedded in the vertical wires (parallel to the \( y \) axis) behaves as short circuits and the diodes of the horizontal wires act as open circuits. With this feed, the cells are interconnected by columns, resulting the structure of Fig. 4.

![Fig. 4. Schematic of the pattern of each side of the Circular Polarization Converter. Inset: Unit cell of the CMM structure.](image)

**Fig. 4.** Schematic of the pattern of each side of the Circular Polarization Converter. Inset: Unit cell of the CMM structure.

![Fig. 5. Linear transmission coeffs. of the Circular polarization converter.](image)

**Fig. 5.** Linear transmission coeffs. of the Circular polarization converter.

![Fig. 6. Circular transmission coeffs. of the circular polarization converter.](image)

**Fig. 6.** Circular transmission coeffs. of the circular polarization converter.

The polarization conversion ratio \( PCR = |t_{xz}|^2/(|t_{xz}|^2 + |t_{yz}|^2) \), i.e., the converter efficiency, is around 10.55 GHz greater than 90% (Fig. 7). It is worth of mention that, at this frequency, the efficiency is greater when the handedness conversion is from RH to LH because \( |t_-| > |t_+| \).

C. Linear to Circular Polarization Converter

Finally, the diodes of the vertical wires are biased on one side of the substrate, whereas on the other face the biased diodes are the horizontal ones. This schematic, shown in Fig. 8, behaves as a linear to circular polarization converter.
Fig. 7. Polarization conversion ratio of the circular polarization converter.

Fig. 8. Both sides of the Linear to circular polarization converter. Inset Unit cell of the CMM structure.

Fig. 9. Linear to Circular transmission coefficients of the linear to circular polarization converter

Fig. 10. Polarization conversion ratio of the linear to circular polarization converter.

REFERENCES


Fig. 11. Illustration of two different operating bands.