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# Gyro-Chirality Effect of Bianisotropic Substrate On the operational of Rectangular Microstrip Patch Antenna

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**Abstract**: In this paper, the gyrotropic bi-anisotropy of the chiral medium in substrate constitutive parameters ($\xi_c$ and $\eta_c$) of a rectangular microstrip patch antenna is introduced in order to observe its effects on the complex resonant frequency, half-power bandwidth and input impedance. Numerical calculations and analysis based on the dominant mode are carried out to show that the latter is directly related to the former. This paper is based on the Moment Method as full-wave spectral domain approach using sinusoidal basis functions. Two new results, namely the appearance of the difference ($\xi_c-\eta_c$) and sum ($\xi_c+\eta_c$) of the two magneto-electric elements are obtained in the electric transverse components and Green tensor expressions, respectively. These new results can be considered as a generalisation form of the previously published work.

Keywords: Microstrip antenna; Chiral; Gyrotropy; Bi-anisotropy; Moment Method.

## 1. Introduction

The antennas resonators first appeared in the 1950s and researchers starting work on this technology on the 1970s [1]-[2]. Recently, a big interest was dedicated to complex materials (example magnetized ferrites, anisotropic dielectrics, meta-materials, chiral, .. etc.), and their effects on the possible realization of devises based on MIC (Microwave Integrated Circuits) and antenna based on APC (Antenna Printed Circuits) [1]-[5].

The chiral materials was first introduced in 1988 by Engheta [6], it is then used as substrates in the design of printed antennas, the term 'chirostrip' was invented later on. Chiroptical guides were developed in 1989, and named by Engheta and Pelet in [7]. These invented meterials have opened new field of theoretical studies on the properties of these patch antennas and chiral-based resonators: examples, new polarizations [8], coupling TE/TM wave generation [9], crossing polarizations, 'slow' resonant frequency [10], bandwidth and

surface wave [11]. The resolution of Maxwell's equations, in such structures, had not been completely finished before 2001 [12], [13]. And since then , the interaction of electromagnetic fields with chiral materials has been studied, in which the chiral medium is used in many applications relating antenna arrays [6], radome antennas, microstrip substrates [6] [8] and waveguides [7] [14].

Using chiral materials as substrate and superstrate for the propose of MIC (Microwave Integrated Circuits) and APC (Antenna Printed Circuits), was reported in [15]-[21]. In addition to, Toscano et al. [18] and Zebiri et al. [19]-[21] have lately proved that the chiral substrates can advantageously be used to adjust the antenna resonant frequency and to increase or decrease the bandwidth, and to improve the input impedance [21], this will be reflected in a better adaptation.

The effect of the chiral medium on the waveguides propagation was the subject of many researchers such as the electromagnetic propagation in waveguides filled with bi-isotropic/chiral materials were reported in the literature [22]-[28]; these media were also used in microstrip antennas not only to improve the resonant frequency and bandwidth but also reduce losses due to the surface waves radiation from microstrip antenna printed on a chiral substrate [17] [19] [20] [27]-[31]. The propagation characteristics of the anisotropic transmission lines have also prompted some interesting works as in [32]-[36].

A chiral medium could be either reciprocal [37] or nonreciprocal in accordance with this magneto-electric parameter [25] [38]-[41]. The general linear medium is described by bi-anisotropic constitutive relations given in [38] [42]. The effect of this medium with these constitutive parameters can be considered as symmetrically or asymmetrically structures in electronic components parameters [43] [44].

The research work presented in [45] focused on chiral medium, for which those reciprocal bi-isotropic medium whose existence was out of controversy-nonreciprocal bi-isotropic medium that have neither been found nor manufactured; and the possibility of their existence is currently under discussion in the open literature [46], [47]; in addition to the nonreciprocal behavior of particular classes of such materials has also been studied in [48]-[50]. In this work, a gyrotropic bi-anisotropy of chirality for a rectangular patch antenna is detailed and discussed in terms of complex resonant frequency, half-power bandwidth and input impedance. New results were achieved for example: a direct link between the antenna parameter and property of chirality were established; and the effects of non-reciprocity combined with reciprocity anisotropy of such a medium have been predicted.

## 2. Theory

### 2.1 Chiral medium

The geometry under consideration is shown in Fig. 1, the rectangular patch with dimensions (a, b) along the two axes (x, y) respectively is printed on a grounded bianisotropic dielectric slab of thickness $d_1$. This bianisotropic medium is characterized by four independent constitutive tensors.

For bianisotropic medium, **D** and **B** are respectively related to both **E** and **H**. The expression of the field components will be restricted by consideration of the macroscopic constitutive relations in the following form [31] [33] [51] [52]:

$$B = \overline{\overline{\mu}} H + \overline{\overline{\xi}} E \qquad (1)$$

$$D = \overline{\overline{\varepsilon}} E + \overline{\overline{\eta}} H \qquad (2)$$

Where the permeability, permittivity and magneto-electric elements are given respectively by [31] [33] [51]-[53]:

$$\overline{\overline{\mu}} = \begin{bmatrix} \mu_t & 0 & 0 \\ 0 & \mu_t & 0 \\ 0 & 0 & \mu_z \end{bmatrix}, \; \overline{\overline{\varepsilon}} = \begin{bmatrix} \varepsilon_t & 0 & 0 \\ 0 & \varepsilon_t & 0 \\ 0 & 0 & \varepsilon_z \end{bmatrix}, \; \overline{\overline{\xi}} = j \begin{bmatrix} 0 & \xi_c & 0 \\ -\xi_c & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} \text{ and } \overline{\overline{\eta}} = j \begin{bmatrix} 0 & \eta_c & 0 \\ -\eta_c & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} (3)$$
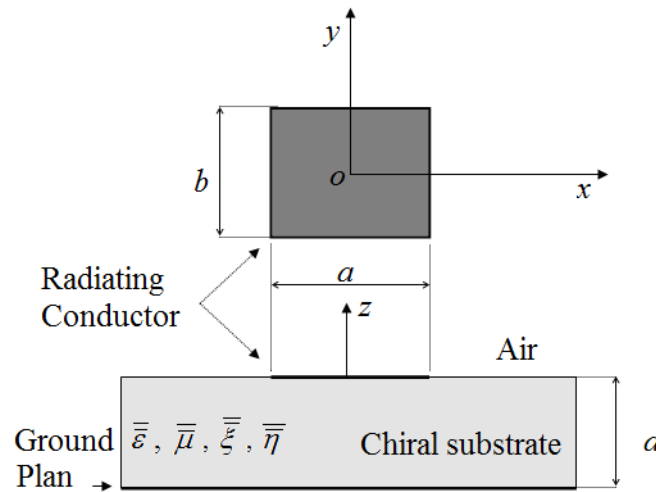


**Fig. 1:** Rectangular microstrip patch antenna with chiral substrate

In [19] [20] a special case of the above magneto-electric elements is treated. As a definition the bianisotropic medium is a generalization of the anisotropic and chiral medium [15], where there are different types of anisotropic medium: uniaxial, biaxial, gyrotropic, etc. An important step in the distinction between anisotropic medium comes through splitting the constitutive parameter dyadic x (x=$\overline{\overline{\mu}}$, $\overline{\overline{\varepsilon}}$, $\overline{\overline{\xi}}$ and $\overline{\overline{\eta}}$) into two parts, symmetric and antisymmetric [50] [54]:

$$\overline{\overline{x}} = \begin{bmatrix} x_x & x_{xy} & x_{xz} \\ x_{yx} & x_y & x_{yz} \\ x_{zx} & x_{zy} & x_z \end{bmatrix} = \begin{bmatrix} x_x & 0 & 0 \\ 0 & x_y & 0 \\ 0 & 0 & x_z \end{bmatrix} + \begin{bmatrix} 0 & x_{xy} & x_{xz} \\ x_{yx} & 0 & x_{yz} \\ x_{zx} & x_{zy} & 0 \end{bmatrix} \qquad (4a)$$

$$\underbrace{\phantom{\begin{bmatrix} x_x & 0 & 0 \\ 0 & x_y & 0 \\ 0 & 0 & x_z \end{bmatrix}}}_{\text{symmetric} \rightarrow \text{uniaxial,biaxialanisotropy}} \quad \underbrace{\phantom{\begin{bmatrix} 0 & x_{xy} & x_{xz} \\ x_{yx} & 0 & x_{yz} \\ x_{zx} & x_{zy} & 0 \end{bmatrix}}}_{\text{antisymmetric} \rightarrow \text{gyrotropicanisotopy}}$$

This simplified to:

$$\bar{\bar{x}} = \underbrace{x_x \bar{u}_x \bar{u}_x + x_y \bar{u}_y \bar{u}_y + x_z \bar{u}_z \bar{u}_z}_{\text{symmetric}} + \underbrace{x_g \bar{u}_z \times \bar{I}}_{\text{antisymmetric}} \tag{4b}$$

Where

$$x_g = \begin{bmatrix} 0 & x_{xy} & x_{xz} \\ x_{yx} & 0 & x_{yz} \\ x_{zx} & x_{zy} & 0 \end{bmatrix} \tag{4c}$$

And $\bar{I}$ is the unit dyadic.

The symmetric part of the x dyadic has principal axis along the x, y, z directions, and these elements determine the axial, uniaxial and biaxial anisotropy. Concerning the other elements $x_g$ (antisymmetric part) they present the gyrotropic anisotropy of medium. Furthermore, when all the constituent parameters are scalar, in this case the medium becomes bi-isotropic. Regarding the gyrotropic bi-anisotropy constitutive parameters $\bar{\bar{\xi}}$ and $\bar{\bar{\eta}}$ given by equation (3), it is possible to use several medium types, depending on the constitutive tensors of equation (3), the linear complex medium are given as follows [53] [55] [56]:

$$\bar{\bar{\xi}} = \bar{\bar{\eta}} = 0 \tag{5}$$
[55] [56]
$$\bar{\bar{\xi}} = \bar{\bar{\eta}} \neq 0 \tag{6}$$
[53] [55] [56]
$$\bar{\bar{\xi}} = -\bar{\bar{\eta}} \tag{7}$$
[55] [56]
$$\bar{\bar{\xi}} \neq \bar{\bar{\eta}} \tag{8}$$
[55]

## 2.2 Green's Tensor Evaluation

Assuming an $e^{i\omega t}$ time variation and starting from Maxwell's equations in the Fourier transform domain, one can show that the transverse magnetic (TM or E) and transverse electric (TE or H) counterparts of the tangential electric and magnetic fields in the Fourier domain for an anisotropic bounded region having anisotropy tensor type given by (3), can be expressed in compact matrix form as follows:

$$\tilde{E}_S(\kappa_s, z) = \begin{bmatrix} \tilde{E}^e(\kappa_s, z) \\ \tilde{E}^h(\kappa_s, z) \end{bmatrix} = e^{-\kappa_0 \frac{1}{2}(\xi_c - \eta_c)z} \left( e^{j\bar{\kappa}_z z} \bar{A}(\kappa_s) + e^{-j\bar{\kappa}_z z} \bar{B}(\kappa_s) \right) \tag{9}$$

$$\widetilde{H}_S(\kappa_s,z)=\begin{bmatrix}\widetilde{H}^e(\kappa_s,z)\\\widetilde{H}^h(\kappa_s,z)\end{bmatrix}=e^{-\kappa_0\frac{1}{2}(\xi_c-\eta_c)z}\left(\overline{g}(\kappa_s)\overline{A}(\kappa_s)e^{j\overline{\kappa}_z z}+\overline{h}(\kappa_s)\overline{B}(\kappa_s)e^{-j\overline{\kappa}_z z}\right) \tag{10}$$

Where $\overline{\overline{E}}_S$ and $\overline{\overline{H}}_S$ are the transverse electric and the magnetic components according to the TE and TM modes.

$$\kappa_0=\omega\sqrt{\mu_o\varepsilon_o} \tag{11}$$

$$\overline{\kappa}_z=\begin{bmatrix}\kappa_z^e & 0\\0 & \kappa_z^h\end{bmatrix}=\begin{bmatrix}\left(\kappa_0^2\left(\varepsilon_t\mu_t-\left(\frac{\xi_c+\eta_c}{2}\right)^2\right)-\frac{\varepsilon_t}{\varepsilon_z}\kappa_s^2\right)^{\frac{1}{2}} & 0\\0 & \left(\kappa_0^2\left(\varepsilon_t\mu_t-\left(\frac{\xi_c+\eta_c}{2}\right)^2\right)-\frac{\mu_t}{\mu_z}\kappa_s^2\right)^{\frac{1}{2}}\end{bmatrix} \tag{12}$$

$$\kappa_s^2=\kappa_x^2+\kappa_y^2 \tag{13}$$

$$\overline{A}(\kappa_s)=\begin{bmatrix}j\frac{1}{\kappa_s^2}\frac{\varepsilon_z}{\varepsilon_t}\left(-\kappa_0\frac{1}{2}(\xi_c+\eta_c)+j\kappa_z^e\right)A^e\\\frac{1}{\kappa_s^2}\omega\mu_0\mu_z A^h\end{bmatrix} \tag{14}$$

$$\overline{B}(\kappa_s)=\begin{bmatrix}j\frac{1}{\kappa_s^2}\frac{\varepsilon_z}{\varepsilon_t}\left(-\kappa_0\frac{1}{2}(\xi_c+\eta_c)-j\kappa_z^e\right)B^e\\\frac{1}{\kappa_s^2}\omega\mu_0\mu_z B^h\end{bmatrix} \tag{15}$$

$$\overline{g}(\kappa_s)=\begin{bmatrix}\dfrac{\omega\varepsilon_0\varepsilon_t}{j\left(-\kappa_0\frac{1}{2}(\xi_c+\eta_c)+j\kappa_z^e\right)} & 0\\0 & \dfrac{j\left(\kappa_0\frac{1}{2}(\xi_c+\eta_c)+j\kappa_z^h\right)}{\omega\mu_0\mu_t}\end{bmatrix} \tag{16}$$

$$\overline{h}(\kappa_s)=\begin{bmatrix}\dfrac{\omega\varepsilon_0\varepsilon_t}{j\left(-\kappa_0\frac{1}{2}(\xi_c+\eta_c)-j\kappa_z^e\right)} & 0\\0 & \dfrac{j\left(\kappa_0\frac{1}{2}(\xi_c+\eta_c)-j\kappa_z^h\right)}{\omega\mu_0\mu_t}\end{bmatrix} \tag{17}$$

Using Maxwell equations it is possible to express the longitudinal components of the electric and magnetic field in the chiral medium according to the following expressions

$$\widetilde{E}_z(\kappa_s,z)=A^e e^{j\kappa_z^e z}+B^e e^{-j\kappa_z^e z} \tag{18}$$

$$\widetilde{H}_z(\kappa_s,z)=A^h e^{j\kappa_z^h z}+B^h e^{-j\kappa_z^h z} \tag{19}$$

Where the spectral coefficients $A^e$, $A^h$, $B^e$ and $B^h$ are functions of the variables $\kappa_s$, $\kappa_z^e$ and $\kappa_z^h$, these are respectively the free space propagation for TE and TM modes.

The proposed structure is studied and the boundary conditions have been applied after then the dyadic Green's function is obtained, this is expressed as in the following tensor:

$$\overline{\mathbf{G}}(\kappa_s) = \frac{1}{j\omega\varepsilon_0}\mathrm{diag}\left[\frac{N^e}{D^e}\kappa_z\kappa_z^e, \frac{1}{D^h}\kappa_0^2\mu_t\right]\cdot\sin\left(\overline{\kappa}_z d_1\right) \tag{20}$$

Where:

$$N^e = \frac{1}{\kappa_z^{e2}}\left(\kappa_0^2\varepsilon_t\,\mu_t - \frac{\varepsilon_t}{\varepsilon_z}\kappa_s^2\right) \tag{21}$$

$$D^e = \frac{1}{\kappa_z^e}\left(\kappa_z^e\kappa_z\varepsilon_t\,\cos\left(\kappa_z^h d_1\right) + j\left(\kappa_z^{e2} + \tfrac{1}{2}\kappa_0\left(\xi_c + \eta_c\right)\right)\left(\kappa_0\tfrac{1}{2}\left(\xi_c + \eta_c\right) - j\kappa_z\varepsilon_t\right)\right)\sin\left(\kappa_z^e d_1\right)\right) \tag{22}$$

$$D^h = \kappa_z^h\cos\left(\kappa_z^h d_1\right) + j\left(\kappa_z\mu_t - j\tfrac{1}{2}\kappa_0\left(\xi_c + \eta_c\right)\right)\sin\left(\kappa_z^h d_1\right) \tag{23}$$

$$\kappa_z^2 = \kappa_0^2 - \kappa_s^2 \tag{24}$$

For an electric and non-magnetic medium having biaxial anisotropy with regard to the permittivity, the previous expressions are well detailed in [57], and for the case $\xi_c = \eta_c$ we obtain exactly the same detailed expression in [19].

## 2.3 Integral Equation Solution

The integral equation describing the electric field on the patch is expressed with the application of the boundary conditions [19]-[21][58]-[59] as:

$$\int\!\!\int_{-\infty}^{\infty} d\kappa_s \overline{F}\left(\overline{\kappa}_s, \overline{r}_s\right)\cdot\overline{\mathbf{G}}(\kappa_s)\cdot\widetilde{\mathbf{J}}(\kappa_s) = 0 \tag{25}$$

Galerkin's procedure of the moment method in the Fourier domain can be used, which enables the integral equation in (25) to be discretized into matrix equation. Where the surface currents **J** on the patch are expanded into a finite series of basis functions $J_{xn}$ and $J_{ym}$. We substitute the vector Fourier transform of the basis function into (25) [19]-[21]. Thus, the integral equation (25) is brought into the following matrix equation:

$$\begin{bmatrix}\left(\overline{\mathbf{B}}_1\right)_{N\times N} & \left(\overline{\mathbf{B}}_2\right)_{N\times M} \\ \left(\overline{\mathbf{B}}_3\right)_{M\times N} & \left(\overline{\mathbf{B}}_4\right)_{M\times M}\end{bmatrix}\cdot\begin{bmatrix}\left(\mathbf{a}\right)_{N\times 1} \\ \left(\mathbf{b}\right)_{M\times 1}\end{bmatrix} = \mathbf{0} \tag{26}$$

Where: $(\overline{B}_1)_{N \times N}$, $(\overline{B}_2)_{N \times M}$, $(\overline{B}_3)_{M \times N}$ and $(\overline{B}_4)_{M \times M}$ are the elements of the digitalized matrix equation.

Equation (26) has a non-trivial solution only in the case where the condition below is verified.

$$\det(\overline{\mathbf{B}}(\omega)) = 0 \tag{27}$$

Because the resonator is designed to operate near its resonant frequency, and all its characteristics are estimated around this frequency, equation (27) is called characteristic equation for the complex resonant frequency $f = f_r + i f_i$, where $f_r$ : is the resonant frequency and $f_i$: expresses the losses by radiation in the case of radiating antenna, the half power bandwidth is defined in [19]-[21][57]-[59] as:

$$BW = \frac{2f_i}{f_r} \tag{28}$$

## 2.4 Input impedance formulation

The input impedance of an antenna can be calculated as a combination of electric field dispersed with the current on the probe, according to the following expression:

$$Z_{in} = -\left( \sum_{m=1}^{M} I_{xm} V_{xm} + \sum_{n=1}^{N} I_{yn} V_{yn} \right) \tag{29}$$

With: $I_{xm}$ and $I_{yn}$ are the coefficients to be determined, and m and n define the number of basic functions along the directions x and y, respectively and:

$$V_{xm} = \frac{1}{4\pi^2} \int\int_{-\infty}^{+\infty} J_{xm} e^{-i(\kappa_x x_f + \kappa_y y_f)} \int_0^d G_{zx} dz d\kappa_x d\kappa_y \tag{30}$$

$$V_{yn} = \frac{1}{4\pi^2} \int\int_{-\infty}^{+\infty} J_{yn} e^{-i(\kappa_x x_f + \kappa_y y_f)} \int_0^d G_{zy} dz d\kappa_x d\kappa_y \tag{31}$$

$G_{zx} = G_{zx}(\kappa_x, \kappa_y, z)$ and $G_{zy} = G_{zy}(\kappa_x, \kappa_y, z)$ are the spectral Green functions for the chiral substrate case, where $\tilde{J}_{xm} = \tilde{J}_{xm}(\kappa_x, \kappa_y, z)$ and $\tilde{J}_{yn} = \tilde{J}_{yn}(\kappa_x, \kappa_y, z)$ are the Fourier transforms of the basis functions in the spectral domain.

Attempt some algebraic calculations, the final forms can be stated as follows:

$$V_m^p = \frac{1}{4\pi^2 \omega \varepsilon_0} \frac{\varepsilon_t}{\varepsilon_z} \iint \frac{\kappa_z \sin(\kappa_z^e d) \kappa_y \tilde{J}_y}{\kappa_z^e T} d\kappa_x d\kappa_y \tag{32}$$

$$V_n^p = \frac{1}{4\pi^2 \omega \varepsilon_0} \frac{\varepsilon_t}{\varepsilon_z} \iint \frac{\kappa_z \sin(\kappa_z^e d) \kappa_x \widetilde{J}_x}{\kappa_z^e T} d\kappa_x d\kappa_y \tag{33}$$

$$T = \varepsilon_t \kappa_z \cos(\kappa_z^e d) + j\varepsilon_z \kappa_z^e \sin(\kappa_z^e d) \left(1 - \frac{1}{2} \frac{\kappa_0}{\kappa_z^e}(\xi_c + \eta_c)\tan(\kappa_z^e d)\right) \tag{34}$$

Where the surface currents **J** on the patch are expanded into a finite series of basis function $J_{xn}$ and $J_{ym}$.

For a digital convergence of equations (32)-(34), we have followed the steps discussed in [21][60]-[62]. For the case $\xi_c = \eta_c$ it is found that they are the same as in [21].

## 3. Numerical Analysis

The effect of bianisotropic substrate provided with gyro-chirality upon the complex resonant frequency, the half-power bandwidth and the input impedance has been studied. It is assumed the relative permittivity of the medium is $\varepsilon_{1x} = \varepsilon_{1z} = 2.32$, and the dimensions of the rectangular patch are 1 cm×1.5 cm as shown in Fig. 1. The normalized real part of the resonant frequency with respect to the fundamental mode frequency $f_o$, is given in Fig. 2.a, 3.a and 4.b respectively. The half-power bandwidth with respect to the substrate thickness and for different values of the magneto-electric element is presented in Fig. 2.b-4.b.

According to the results shown in Fig. 2, 3 and 4 of the resonant frequency and the bandwidth; in addition to Fig. 5 and 6 of the input impedance, the following summarized remarks could be illustrated:

- The effect of the chirality is remarkable only for thick layers, whereas for those infinitely small this effect is unperceived.
- In the case of a positive chirality, for all of the four cases (($\xi_c$=0, $\eta_c$=+2), ($\xi_c$=+2, $\eta_c$=0) in Fig. 2, ($\xi_c$=+1,25, $\eta_c$=+0,75) in Fig. 3; the real resonant frequency increases, but the band-width part decreases; and actually the effect of the two parameters in this case is added and they were in good agreement with those found in literature [19]. However for the negative chirality case characterized by ($\xi_c$=0, $\eta_c$=-2), ($\xi_c$=-2, $\eta_c$=0)), leads to opposite variations compared to the preceding ones, and also compared with the case ($\xi_c$=$\eta_c$=-1) that it gives the same effect as in [19].
- In the latter case ($\xi_c$=-$\eta_c$), it is noted that no effect of chirality was absolutely observed on the resonance frequency and bandwidth, though it is apparently remarkable in the formula of equation 3.
- Figs. 5 and 6, show that the input impedance is directly related with the chirality, which leads to consider this effect for achieving a better impedance matching. The parameters amplitudes vary depending on the chirality, as reported in [1], whereas the case of chiral bi-isotropic medium was considered, these parameters are constant in amplitude, that proposed good advantageous for the circuit design; on the other hand, the two cases (($\xi_c$=0, $\eta_c$=+2), ($\xi_c$=+2, $\eta_c$=0) in Fig.5, have the same effect on the input impedance for ($\xi_c$=+1 , $\eta_c$=+1); however, the negative chirality case characterized by ($\xi_c$=0, $\eta_c$=-2),

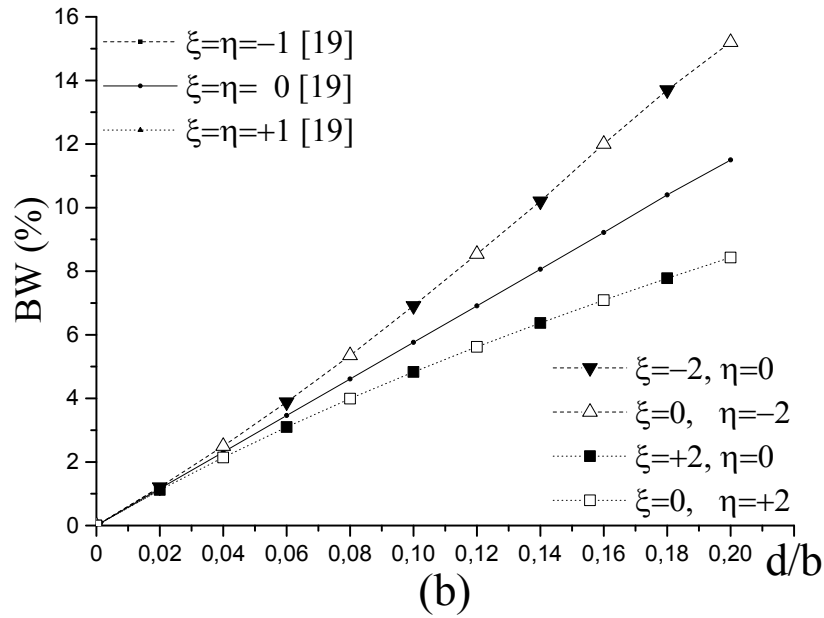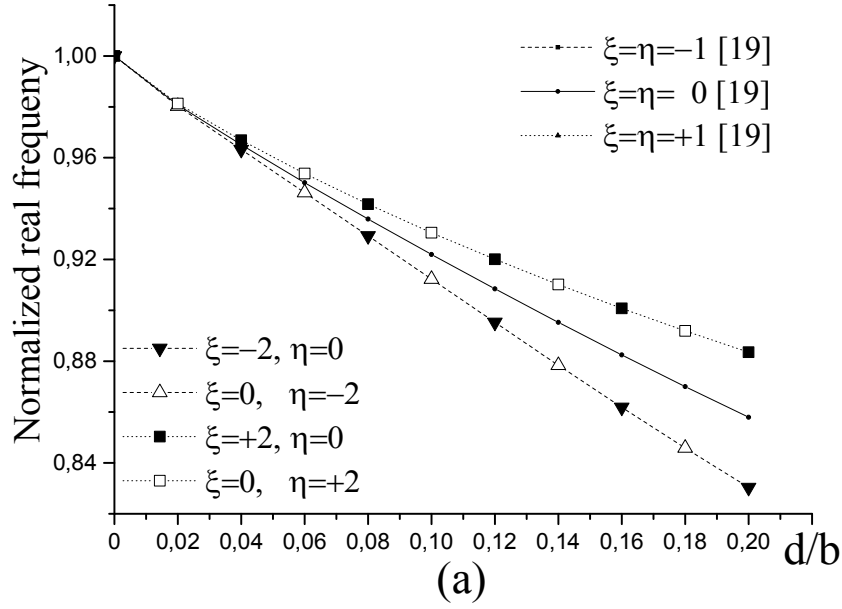($\xi_c$=-2, $\eta_c$=0)) illustrated in Fig. 6 shows that the chiral medium becomes an isotropic dielectric.



(a)



(b)

**Fig. 2:** Chirality effect on the (a) real part of resonant frequency, (b) half-power bandwidth; for ($\bar{\bar{\xi}} \neq \bar{\bar{\eta}}$, ($\bar{\bar{\xi}} \neq 0$, $\bar{\bar{\eta}} =0$) and ($\bar{\bar{\xi}} =0$, $\bar{\bar{\eta}} \neq 0$)), a=1.5cm, b=1cm, $\varepsilon_r$=2.35.
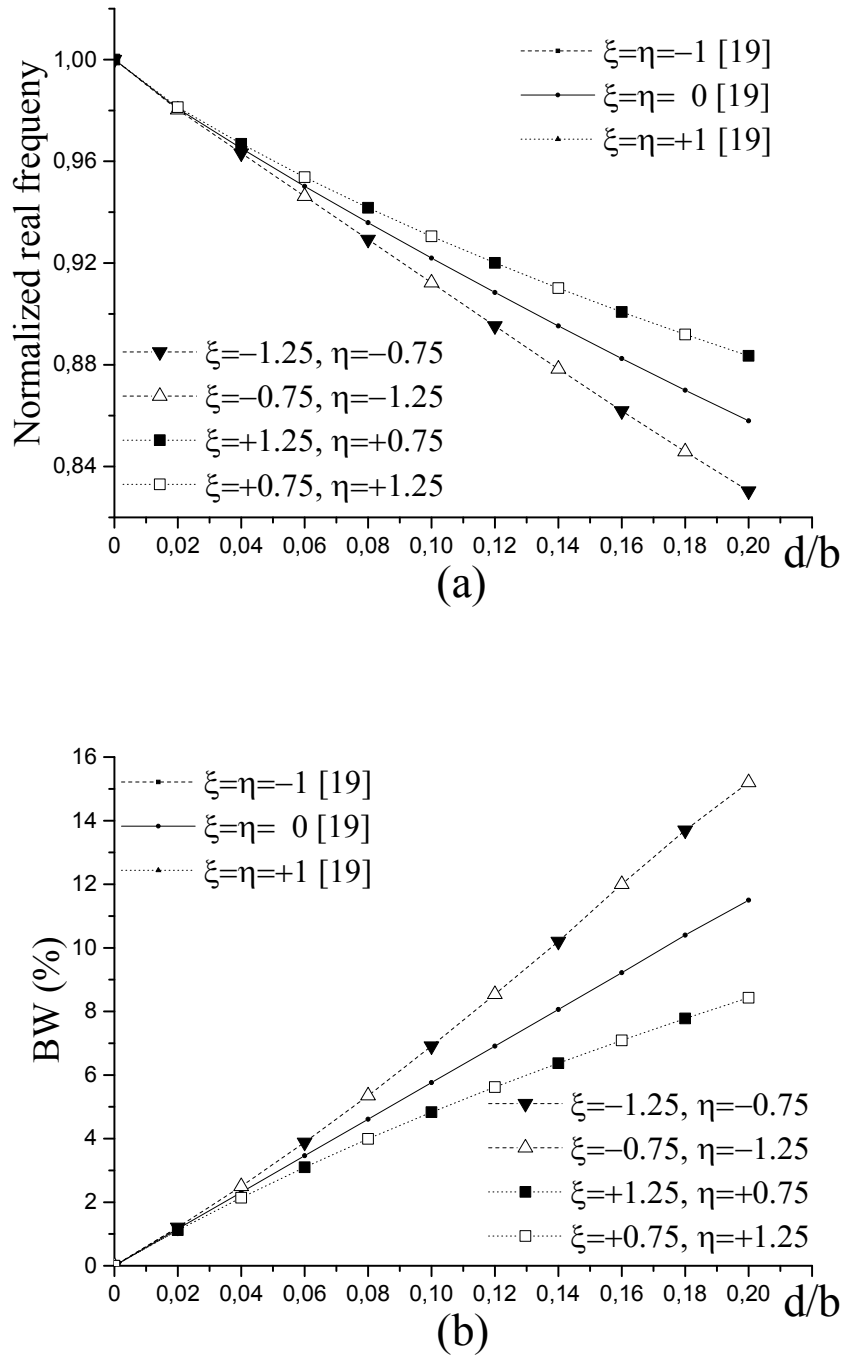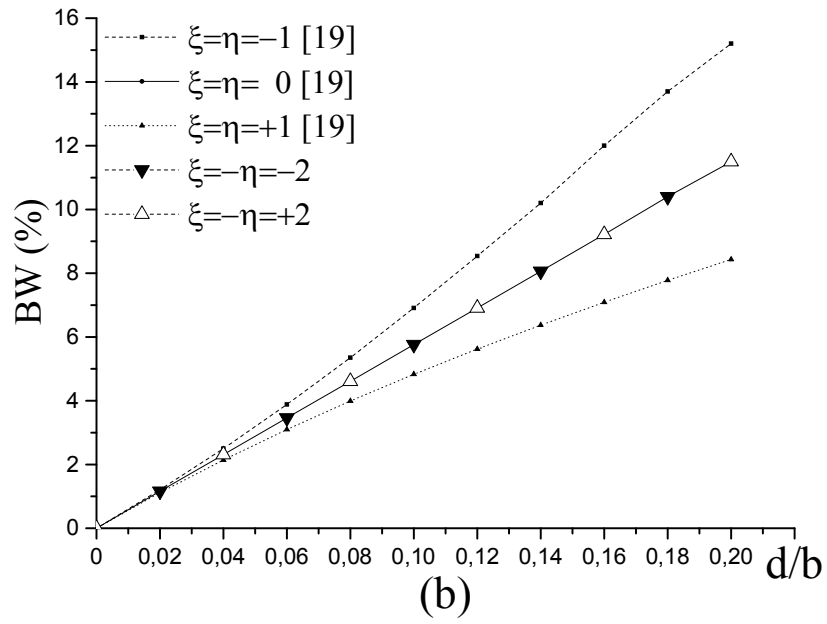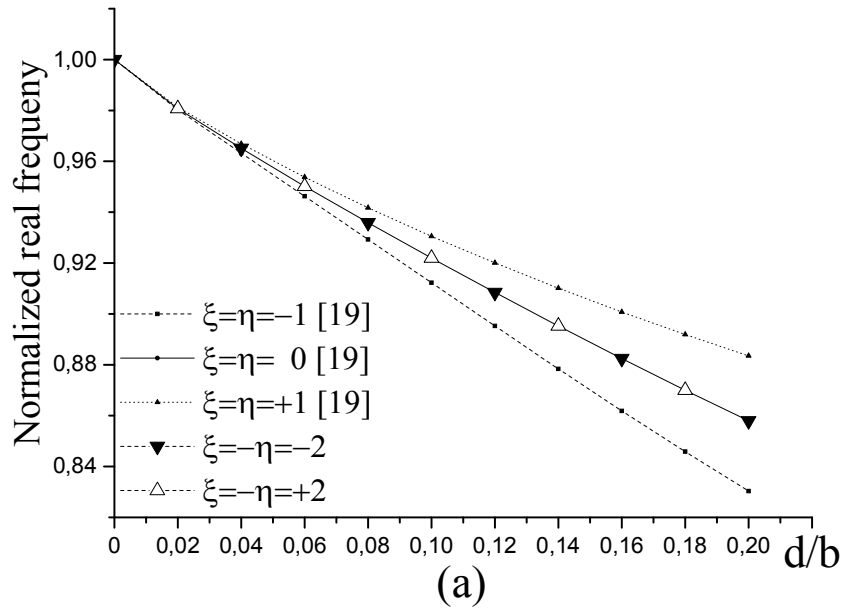
(a)



(b)

**Fig. 3:** Chirality effect on the (a) real part of resonant frequency, (b) half-power bandwidth; for ($\bar{\bar{\xi}} \neq \bar{\bar{\eta}}$, $\bar{\bar{\xi}} \neq 0$ and $\bar{\bar{\eta}} \neq 0$), a=1.5cm, b=1cm, $\varepsilon_r$=2.35.

**Fig. 4:** Chirality effect on the (a) real part of resonant frequency, (b) half-power bandwidth; for ($\overline{\overline{\xi}} = -\overline{\overline{\eta}}$), a=1.5cm, b=1cm, $\varepsilon_r$=2.35.

(a)



(a)

**Fig. 5:** Chirality effect on the (a) real part of the input impedance, (b) imaginary part of the input impedance; for (a=7.62cm, b=11.43cm, x0=1.52cm, y0=0.385 cm, εx=εz=2.64), ($\overline{\overline{\xi}} \neq \overline{\overline{\eta}}$, and ($\overline{\overline{\xi}} \neq 0$, $\overline{\overline{\eta}} = 0$), ($\overline{\overline{\xi}} = 0$, $\overline{\overline{\eta}} \neq 0$)).

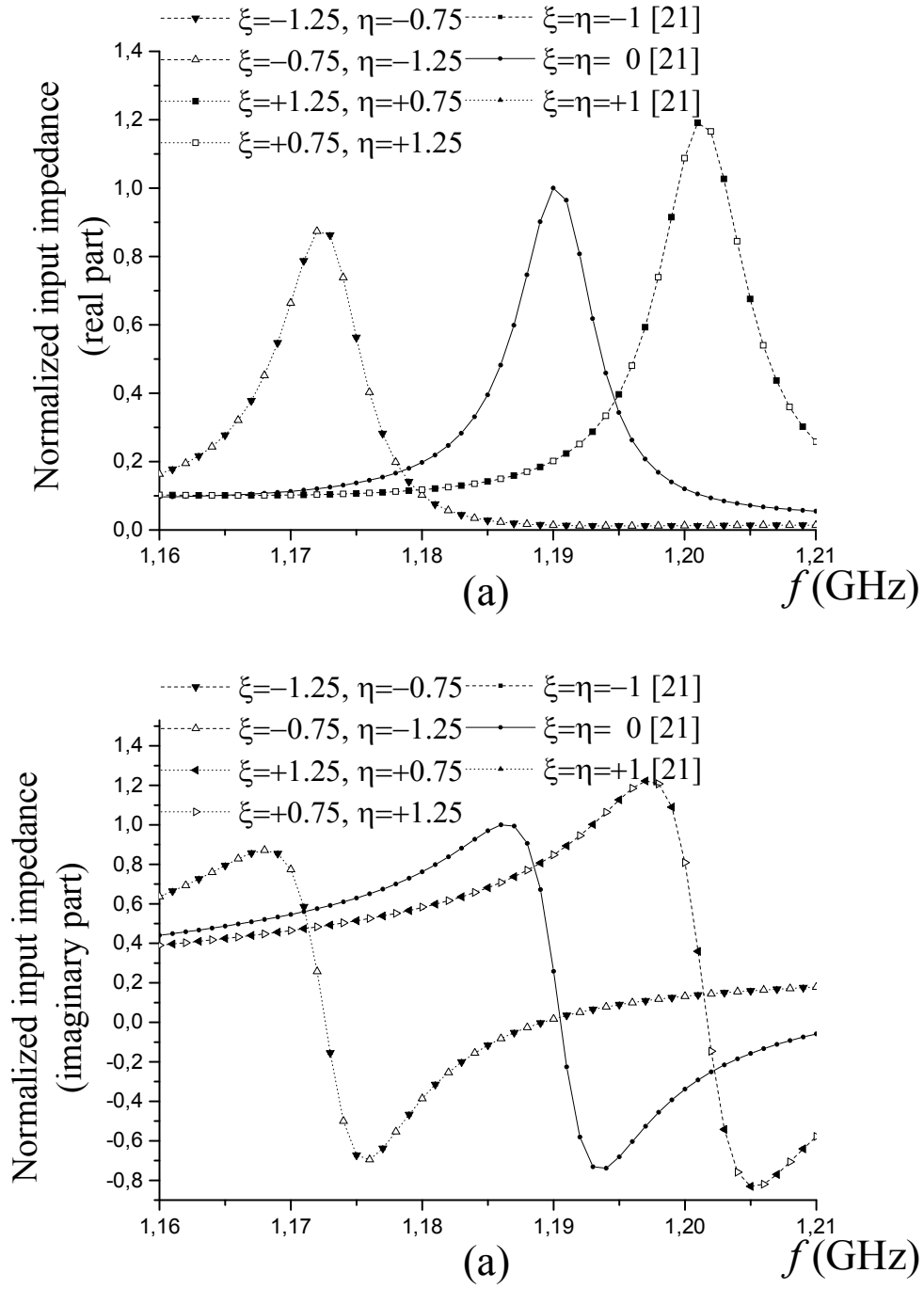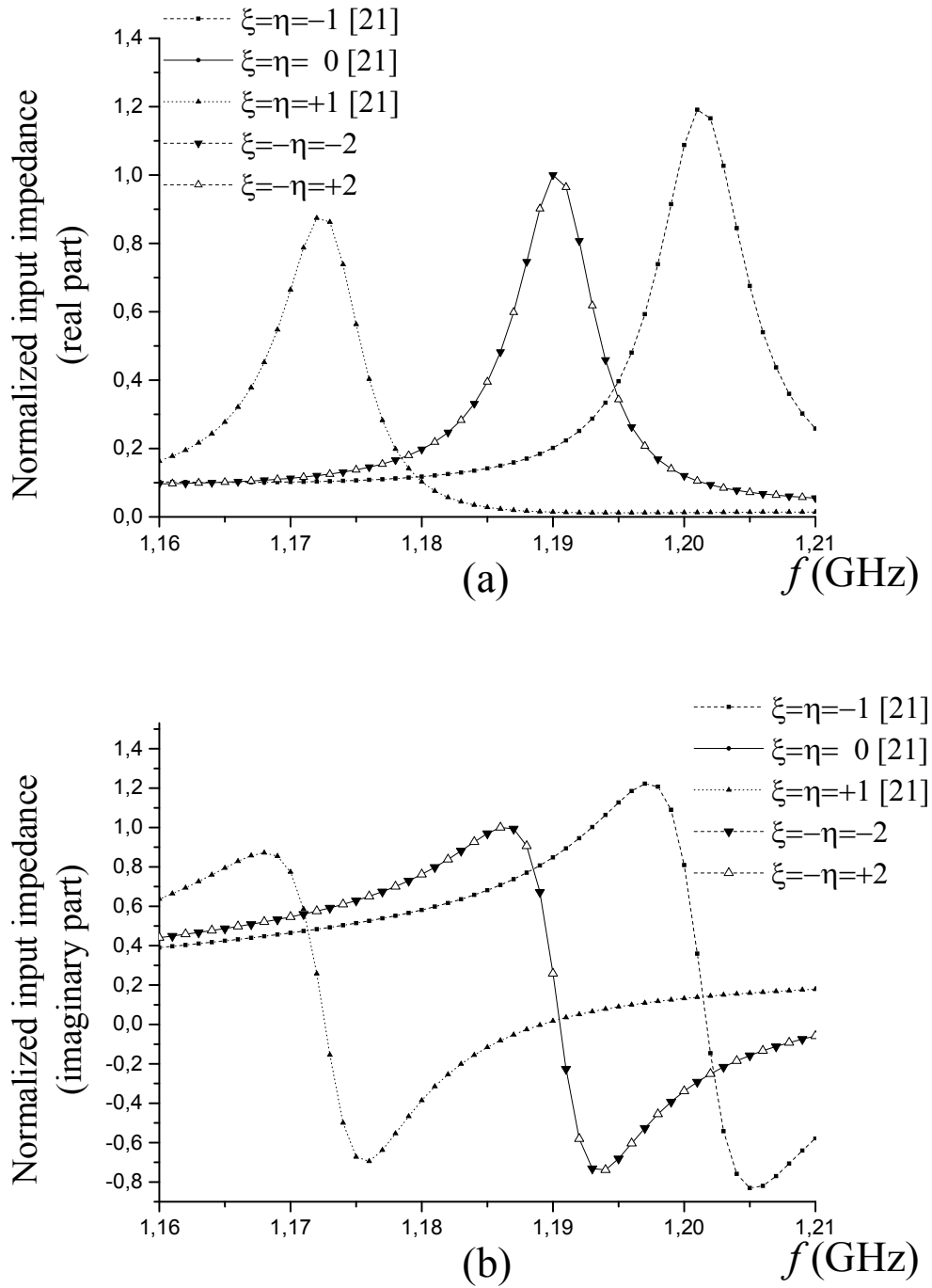**Fig. 6:** Chirality effect on the (a) real part of the input impedance (b) imaginary part of the input impedance; for (a=7.62cm, b=11.43cm, x0=1.52cm, y0=0.385 cm, εx=εz=2.64), and ($\bar{\bar{\xi}}$ =-$\bar{\bar{\eta}}$ ).

## 4. Conclusions

The effect of bianisotropic substrate provided with gyro-chirality on microstrip patch antenna has been presented. The results in terms of the complex resonant frequency, half-power bandwidth and input impedance have been calculated and compared with earlier work. Two new results were concluded; the first was that the effective magneto-electric element

$\frac{1}{2}\left(\xi_c + \eta_c\right)$ is the addition of the two elements $\xi_c$ and $\eta_c$ on the input impedance. The second effect with the gyro-chiral parameter on the transverse components was appearing in equations (3) and (4)), by the introducing the coefficient $e^{-\kappa_0 \frac{1}{2}\left(\xi_c - \eta_c\right)z}$, that expresses loss or gain, subject to the choice of the two constitutive parameters $\xi_c$ and $\eta_c$. It can also be noted that it represents the asymmetric and the non-reciprocity effect that can be added to these parameters in the transverse components.

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