MAIN EFFECTS OF CHIRAL LOADING MATERIALS IN MICROSTRIP ANTENNAS

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Abstract. *The paper describes the main effects of chiral materials employed as substrates for microstrip patch antennas. An extended variational formulation and a hybrid finite element-boundary integral numerical method have been jointly applied to simulate cavity backed patch antennas with chiral loading media. Strong reduction of the antenna dimensions compared to the isotropic case and good wide-band performances have been found to be the main effects of chiral substrates. Finally, the effects of chiral superstrates on conventional patches have been also pointed out through several numerical results.*

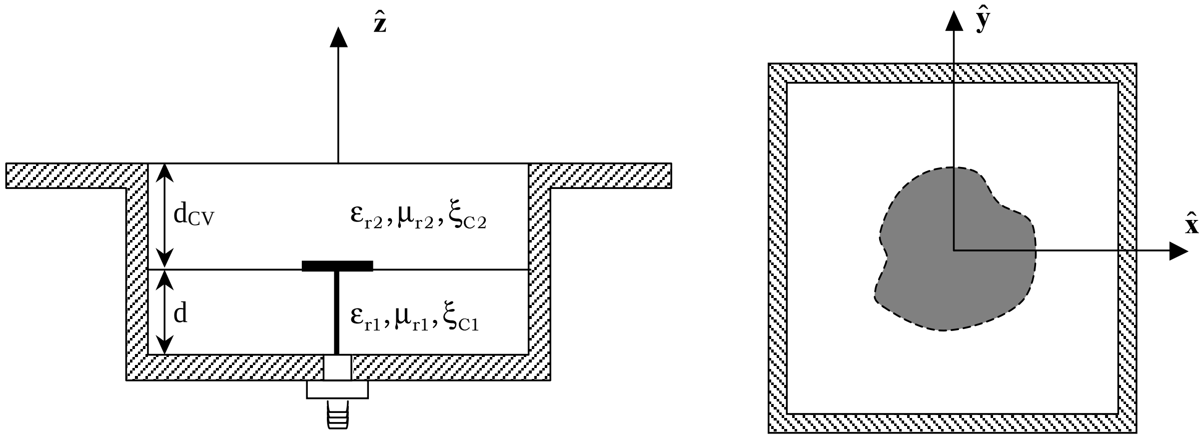
1. Introduction. Chiral materials are very well known in optical and microwave communities, due to their interesting properties. At first, chiral behavior has been discovered at optical frequencies as demonstrated in a long list of works (e.g. [1]). The first interesting feature investigated was the separation of a plane wave propagating in an infinite chiral medium into two circularly polarized waves. Such waves propagate inside the medium with different phase velocities and, therefore, chiral materials have been considered very useful to build optical components changing the polarization of an electromagnetic field.

Later, to export this kind of features also in the microwave frequency range, big efforts have been devoted to build up experimental layouts involving chiral media. At the microwave frequencies these materials can be obtained as artificial dielectrics with inclusions of chiral particles in a host body. The history of chiral media shows that the first kind of inclusions employed were metallic helices with left or right handness (e.g. [2]). After that, other kinds of chiral inclusions have been considered to obtain materials with different characteristics.

Particularly, among the first applications of chiral media in the microwave frequency range, waveguide propagation of electromagnetic fields has been investigated (e.g.[3]). Nevertheless, the actual employment of chiral media as substrates for integrated circuits and antennas was not allowed, due the quite large dimensions of chiral inclusions (in order to resonate, in fact, the length of helices and of other chiral inclusions must be about half wavelength). So, the study of patch antennas with chiral loading materials, e.g. [4], was only a theoretical investigation. Nowadays, technological efforts in material science at microwave frequencies give chiral composites suitable for integrated circuits and antennas. Particularly, the employment of magnetostatic resonators (Yttrium Iron Garnet thin films grown on a Gadolinium Gallium Garnet substrate) with a loading metallic strip on the top, allows to realize very compact substrates exhibiting the magneto-electric effect [5]. Due to these technological advances, it is now very interesting to investigate the main features of chiral materials when used as substrates for integrated circuits, especially for antenna applications.

In this contribution, the main features of chiral media as substrates for microstrip antennas will be investigated. More in detail, a study of the resonant frequency shift and of the cross-polarization levels when increasing the material chirality will be performed. Eventually, the effects (resonant frequency shift, radiation resistance, gain, cross-polarization variations, etc.) of chiral superstrates on patch antennas will be shown as well.

2. Formulation of the electromagnetic problem. The antenna layout here considered is depicted in Fig.1.



a) side view b) top view

Fig.1 Geometry of the electromagnetic problem considered. The patch is fed in the depicted case by a coaxial probe, but the formulation is given for a general kind of electric excitation (including also microstrip-line, plane wave, etc.).

In order to study this radiating component, a variational formulation is here considered. Following [6] the functional completely equivalent to the boundary value problem under analysis is given, in each layer of Fig.1, by:

$$F(\mathbf{E},\mathbf{E}^a) = \frac{1}{\mu_0} < \nabla\times\mathbf{E}^a + \omega\mu_0\xi_C\mathbf{E}^a, \nabla\times\mathbf{E} - \omega\mu_0\xi_C\mathbf{E} > + \omega^2\left(\varepsilon_0\varepsilon_r + \mu_0\xi_C^2\right) < \mathbf{E}^a, \mathbf{E} > -$$

$$- < \mathbf{E}^a, j\omega\mathbf{J} > - < j\omega\mathbf{J}^a, \mathbf{E} > + 2\omega\frac{k_0}{\eta_0}\int_{S_{ap}}\left(\hat{\mathbf{n}}\times\mathbf{E}^a\right)^* \bullet \int_{S'_{ap}} \underline{\mathbf{G}}(\mathbf{r},\mathbf{r}') \bullet \left[\hat{\mathbf{z}}\times\mathbf{E}(\mathbf{r}')\right] dS' dS$$

where all the symbols have been already explained in [6]. Each layer material is supposed to be in the general case a chiral medium described, in the time harmonic monochromatic time dependence regime, by the following constitutive relations:

$$\begin{cases} \mathbf{D} = \left(\varepsilon_0\varepsilon_r + \mu_0\xi_C^2\right)\mathbf{E} - j\mu_0\xi_C\mathbf{H} \\ \mathbf{B} = j\mu_0\xi_C\mathbf{E} + \mu_0\mathbf{H} \end{cases}$$

where ξ_C is the so called *chirality admittance* of the medium.

Imposing the stationary condition for the variational functional $F(\mathbf{E},\mathbf{E}^a)$, the solution of the resulting equation is obtained numerically employing a combined finite element-boundary integral code as presented in [7]. Once the electromagnetic field in the structure of Fig.1 is completely solved, it is possible to calculate the main radiating features of the antenna. Moreover, from Fig.1, when d_{CV}=0 is imposed, the developed formulation allows to study also an antenna with only a chiral substrate (no superstrate effect is considered).

3. Numerical results. At first, the main features of chiral loading materials will be presented without superstrate presence. In Fig.2 the reduction of the resonant frequency and the slight increase of the cross-polarization level when increasing the chirality admittance are reported.

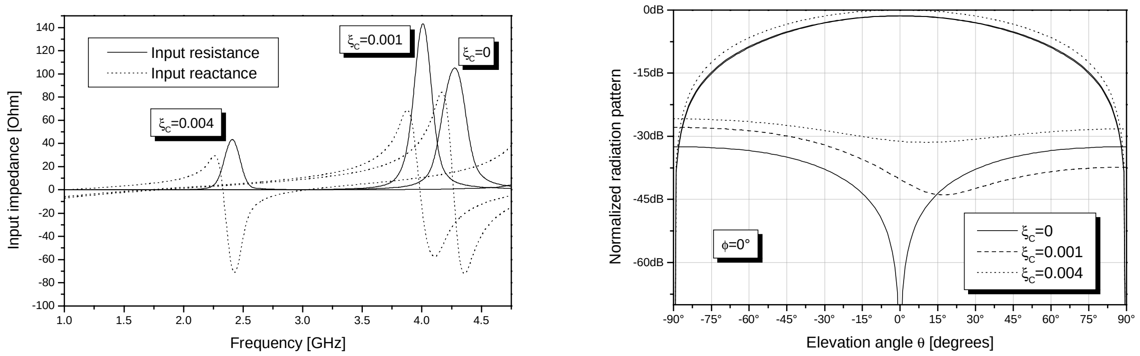


Fig.2 Input impedance and radiation pattern on the ϕ=0° plane (at the resonant frequencies) of an edge-fed square patch (2cm×2cm) residing on top of a square cavity (10cm×10cm×0.1cm) for different chiral substrates. The feed is parallel to the y axis. The isotropic case (ξ_C=0) has ε_r=2, μ_r=1.

It is worth noticing that chirality allows to build very compact antennas for a fixed working frequency compared to the isotropic case, without decreasing to much the polarization purity.
On the other hand, in Fig.3 the effect of the chirality on the impedance bandwidth of an U-slot patch is considered.

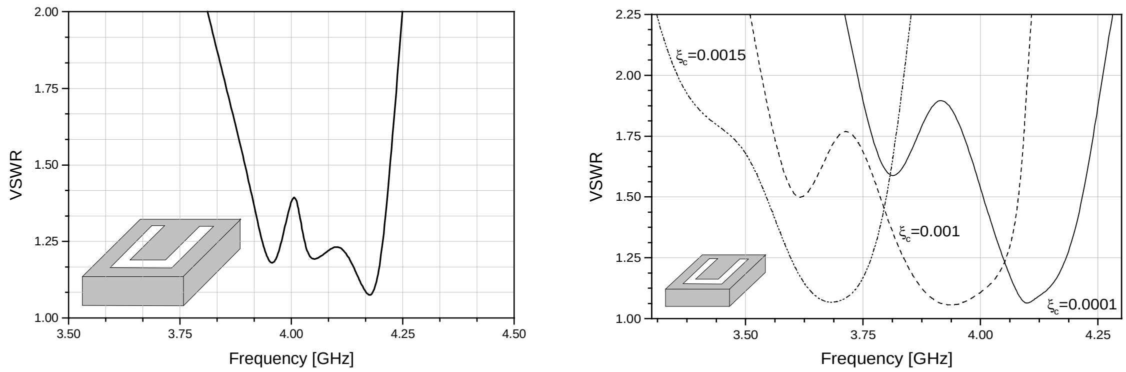


Fig.3 VSWR at the input port of an U-slot patch antenna as a function of frequency for an isotropic substrate with ε_r=2.33 (left) and for different chiral materials (right) with the same permittivity ε_r=2.33.

For fixed dimensions, the matched frequency band shifts towards lower values and the bandwidth increase from 11% (in the isotropic case) to 14% when ξ_C=0.001.
Finally, in Fig.4 some interesting effects of chiral covers on patch antennas mounted on a conventional dielectric are presented.

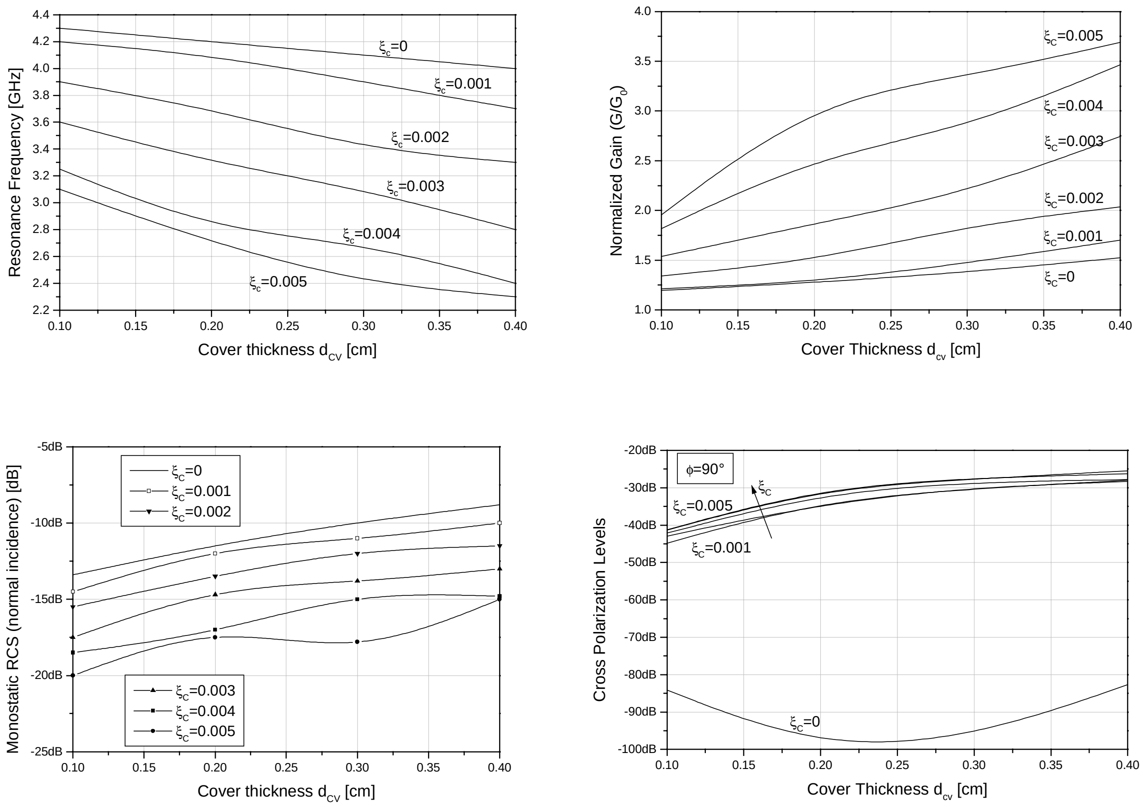


Fig.4 Resonant frequency, normalized (with respect to the case without cover) gain, RCS and cross-polarization level variations as a function of the cover thickness for different chiral media in the case of a square patch (2cm×2cm) mounted on an isotropic substrate (ε_r=2.2) and covered with a chiral layer.

4. Conclusion. The main effects of chiral media employed as substrates and/or superstrates for patch antennas have been presented in this contribution. Resonant frequency reduction (and, thus, dimension reduction at a given frequency), increase of cross-polarization levels, reduction of the RCS, increase of the gain for fixed antenna dimensions are the main observed properties.

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