RADIATION AND SCATTERING FEATURES OF PLANAR PATCH ANTENNAS WITH COMPLEX SUBSTRATES

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ABSTRACT

The effect of chirality and bi-anisotropy on patch antenna features is pointed out in this contribution. A variational formulation and a finite element numerical technique are employed to analyze cavity antennas with stratified complex loading materials. Strong reduction of the antenna dimensions (more attractive when using overlay configurations) and good performances also in wide-band layouts make such radiating components suitable for applications in modern telecommunication systems.

INTRODUCTION

Modern mobile communication system receivers require good compactness, low profile, low weight and also low cost. Since antennas mounted on them must exhibit the same properties, microstrip antennas seem to be the best candidates for this kind of applications. Nevertheless, such antennas exhibit narrow bandwidth and low radiation efficiency. Since large bandwidth and good efficiency are two of the most important features of radiating elements for multimedia telecommunication systems, in order to overcome the inherent limits of microstrip antennas, a lot of new and more complicate configurations have been recently proposed in the open technical literature. More in detail, to improve the radiation efficiency patch antennas are housed in metallic cavities [1]-[3]. Perfect conducting walls, in fact, avoid the excitation of electromagnetic field configuration travelling in the antenna substrate (surface waves) and subtracting power from the radiation. Moreover, surface waves affect the shape of the radiation pattern introducing an undesired ripple on the main beam. Cavities, thus, allow also to improve the purity features of the radiation pattern. The solution of using metallic walls, however, is effective only in the low spectrum of microwave frequencies due to the presence of conductive losses on real conductor in practical layouts (losses in this case increase as the square root of the frequency and in the millimeter wave frequency range conductive losses can be higher than those ones due to the surface wave power trapping in the substrate). On the other hand, in order to improve the impedance bandwidth of microstrip antennas and make such components suitable for multimedia telecommunication system applications, new patch shapes with the presence of slots have been also presented [4]-[6]. The achieved bandwidth enhancement in these cases allows to successfully employ patch antennas in broad band applications, such as multimedia services given by the new generation of mobile telecommunication systems. On the other hand, complex media have been recently considered as very promising substrates for microstrip antennas for a lot of reasons. Reduction and control of the radar cross section, electronically controlled beam direction and shape, improvement of directivity, bandwidth and radiation pattern shape, are among the main properties up to now carried out. Moreover, it is found that chiral and some bi-anisotropic materials allow to change the resonant frequency of patch antennas. Particularly, when increasing the chirality or the bi-anisotropy, the resonant frequency reduces compared to the isotropic case and, thus, it is possible to build more compact radiating components for a fixed working frequency [7]. This feature is very attractive in the design of modern communication system receivers when equipment compactness is a mandatory requirement. In this contribution we propose the employment of complex media as substrates for broad-band antenna layouts housed in metallic cavities. Firstly, we propose again some layouts recently presented in the open technical literature, utilizing conventional isotropic substrates and showing good bandwidth features (U-slot patches, E-shape microstrip antennas, etc.). After that, we substitute the substrate with a complex one (chiral, bi-anisotropic, etc.) in order to show the main effects of non conventional dielectrics on the antenna features. Numerical results obtained show that bandwidth features are not affected by complex materials (i.e. the configuration is still effective for a broad-band behaviour) while we can achieve a strong reduction of the antenna dimensions. In addition, we propose the study of complex material covers on patch antennas loaded with isotropic conventional media. In this case the thickness of the cover and the chirality (or bi-anisotropy) are two different independent keys to control the resonant frequency of the antenna allowing a stronger reduction than in the previous case of no-cover layouts. Some numerical results showing the variation of the resonant frequency as a function of the chirality and of the cover thickness are also presented.

FORMULATION OF THE PROBLEM AND NUMERICAL RESULTS

The analytical approach here employed to study cavity antennas with complex loading materials is an extension of the rigorous variational formulation presented in [8]-[10]. The new correct expression for the variational functional is given by:

$$\begin{aligned} F(\mathbf{E},\mathbf{E}^a) = &< \underline{\boldsymbol{\mu}}^{a^{-1}} \bullet \left(\nabla\times\mathbf{E}^a + j\omega\underline{\xi}\bullet\mathbf{E}^a\right), \nabla\times\mathbf{E} + j\omega\underline{\zeta}\bullet\mathbf{E} > +\omega^2 < \mathbf{E}^a, \underline{\boldsymbol{\varepsilon}}\bullet\mathbf{E} > - \\ &- < \mathbf{E}^a, j\omega\mathbf{J} > - < j\omega\mathbf{J}^a, \mathbf{E} > +2\omega^2\varepsilon_0 \int_{S_{ap}} \left(\hat{\mathbf{n}}\times\mathbf{E}^a\right)^* \bullet \left[\int_{S_{ap}} \underline{\mathbf{G}}(\mathbf{r},\mathbf{r}')\bullet\left[\hat{\mathbf{z}}\times\mathbf{E}(\mathbf{r}')\right]dS'\right]dS \end{aligned} \qquad (1)$$

where $\underline{\boldsymbol{\varepsilon}}(\mathbf{r})$, $\underline{\boldsymbol{\mu}}(\mathbf{r})$ are the permittivity and permeability tensors, respectively; $\xi(\mathbf{r})$ and $\zeta(\mathbf{r})$ are the tensors describing the magneto-electric effect, and the other symbols are defined in [7]. Equations obtained imposing that the functional (1) is stationary are solved numerically by means of an efficient algorithm based on the Finite Element Method (FEM). A self made numerical code with a visual interface has been developed, so that final users can design and test their own layouts choosing in a very intuitive way both the physical dimensions of the antenna and the electromagnetic properties of the dielectric materials used. In Fig.1 the bandwidth performances of a chiral loaded U-slot patch antenna are presented. Chirality permits a reduction of the resonant frequency (and, thus, of the antenna dimensions for a fixed working frequency) without affecting the bandwidth (in some cases, instead, an improved bandwidth can be observed).

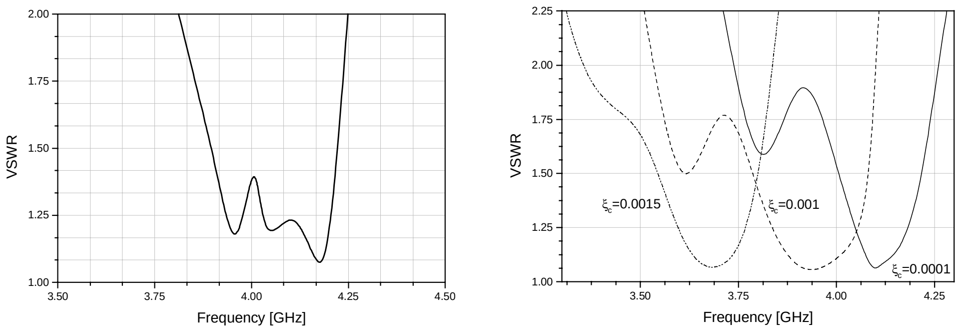

Fig.1 VSWR as a function of frequency for a U-slot patch antenna with an isotropic substrate (left) and with different chiral dielectrics (right). The antenna is housed in a cavity and has the following geometrical and electrical parameters: 1 cm (slot width); 7 cm (U long arm length); 5 cm (U horizontal arm length); $10\,\text{cm} \times 10\,\text{cm} \times 0.08\,\text{cm}$ (cavity); ε_r=2.33.

In Fig.2 the main effects of a chiral overlay on a microstrip antennas are presented.

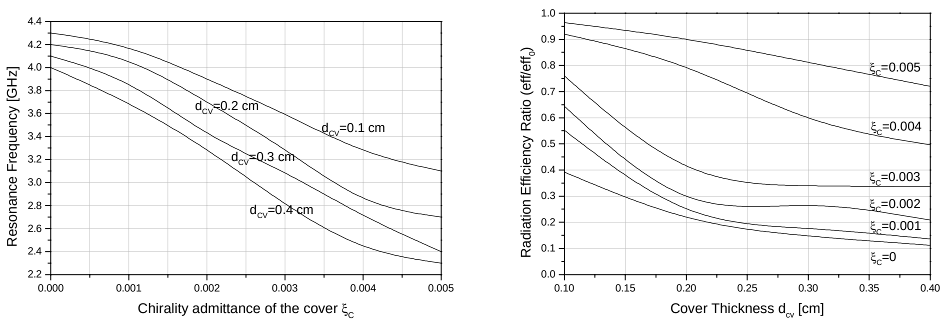

Fig.2 Resonant frequency (left) and normalized (to the value of uncovered antenna) radiation efficiency (right) as a function of the cover chirality and thickness. Dimensions: $10\,\text{cm} \times 10\,\text{cm}$ (cavity); 0.08 cm (isotropic substrate thickness) $2\,\text{cm} \times 2\,\text{cm}$ (patch); ε_r=2.2.

Also in this case a good reduction of the resonant frequency with respect to the isotropic case can be observed. Moreover, it is found that the greater is the chirality admittance of the cover, the higher is the radiation efficiency.

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