Defense Technical Information Center
Compilation Part Notice

ADP011657

TITLE: Inhomogeneous Bianisotropic Materials for Antenna and Circuit Applications in Microwave and Millimetre Wave Ranges

DISTRIBUTION: Approved for public release, distribution unlimited

This paper is part of the following report:

TITLE: International Conference on Electromagnetics of Complex Media [8th], Held in Lisbon, Portugal on 27-29 September 2000. Bianisotropics 2000

To order the complete compilation report, use: ADA398724

The component part is provided here to allow users access to individually authored sections of proceedings, annals, symposia, etc. However, the component should be considered within the context of the overall compilation report and not as a stand-alone technical report.

The following component part numbers comprise the compilation report:
ADP011588 thru ADP011680

Inhomogeneous Bianisotropic Materials for Antenna and Circuit Applications in Microwave and Millimetre Wave Ranges

A. Toscano, L. Vegni, and F. Bilotti

Department of Electronic Engineering, University of "Roma Tre"
Via della Vasca Navale 84, 00146 Rome, Italy
Tel. +39.06.55177003, Fax +39.06.5579078
E-mail: toscano@ieee.org, vegni@uniroma3.it, bilotti@uniroma3.it

Abstract

In this contribution we propose the use of general bianisotropic inhomogeneous materials for both radiating (i.e. microstrip antennas) and transmissive (i.e waveguides, transmission lines, filters, etc.) components in the microwave and millimetre wave frequency ranges. The analysis of such components is essentially developed via a rigorous full-wave approach in the spectral or in the spatial domain depending on the complexity of the boundary value problem to be solved and on the numerical technique to be used. For the transmissive components a fundamental mode approximate analysis is also employed in order to obtain very fast design formulas.

1. Introduction

Nowadays, materials with a continuous spatial variation of the refraction index can be easily synthesized in the optical field for graded index optical fibers and planar waveguides. Also in the solide – state applications we can control the carrier concentrations on the atomic scale, allowing, thus, the synthesis of components with an essentially continuous conductivity profile. Since in the microwave and millimetre wave frequency ranges the technological processes used in the optical and solid – state applications cannot be effective, the synthesis of such materials could be realized only by means of artificial dielectrics.

Artificial dielectrics with electromagnetic properties varying with the spatial coordinates can be synthesized via non-uniform metallic inclusions in a host material. In addition, by using, for instance, omega metallisations, we can think to introduce an anisotropic behaviour together with a magneto–electric effect. In such a way, thus, we can obtain a general inhomogeneous bianisotropic material.

The use of the inhomogeneous materials has been recently considered in some works [1-9] and, as shown, leads to some improvements both in circuit and in antennas applications. The dielectric inhomogeneity, for instance, can be used to control the filtering and matching properties of a transmission line [1-4] or the radiation properties of microstrip antennas (directivity, efficiency and bandwidth) [5-9].

The analysis of such components has been developed by means of the rigorous full-wave approach both in the spectral domain associated to the Method of Moments (MoM) and in the spatial domain associated to a variational formulation and a Finite Element Boundary Integral (FE-BI) numerical procedure. Moreover, in certain cases, especially when the propagation characteristics of a component are investigated an approximate approach based on the TEM or quasi-TEM propagation can be used together with the non-uniform transmission line theory.

The aim of this contribution is to extend the previous works [1-9] to the case of inhomogeneous bianisotropic materials leading to a closed form representation of the Green's dyads in the spectral domain and to a new variational formulation in the spatial domain.

2. Theory

The constitutive relations for an inhomogeneous bianisotropic material are:

$$\begin{cases} \mathbf{D} = \underline{\varepsilon}(\mathbf{r}) \bullet \mathbf{E} + \underline{\xi}(\mathbf{r}) \bullet \mathbf{H} \\ \mathbf{B} = \underline{\zeta}(\mathbf{r}) \bullet \mathbf{E} + \underline{\mu}(\mathbf{r}) \bullet \mathbf{H} \end{cases} \tag{1}$$

Assuming a harmonic time dependence exp[jωt] the Maxwell equations in a source free region can be written as:

$$\begin{cases} \nabla \times \mathbf{E} = -j\omega\underline{\zeta}(\mathbf{r}) \bullet \mathbf{E} - j\omega\underline{\mu}(\mathbf{r}) \bullet \mathbf{H} \\ \nabla \times \mathbf{H} = j\omega\underline{\varepsilon}(\mathbf{r}) \bullet \mathbf{E} + j\omega\underline{\xi}(\mathbf{r}) \bullet \mathbf{H} \\ \nabla \bullet \left[\underline{\varepsilon}(\mathbf{r}) \bullet \mathbf{E} + \underline{\xi}(\mathbf{r}) \bullet \mathbf{H} \right] = 0 \\ \nabla \bullet \left[\underline{\zeta}(\mathbf{r}) \bullet \mathbf{E} + \underline{\mu}(\mathbf{r}) \bullet \mathbf{H} \right] = 0 \end{cases} \tag{2}$$

Since the analysis of radiating and transmissive components is developed in different ways we will present it in two separate sub-sessions.

2.1 Radiating components

Here we consider planar integrated antennas of the kind depicted in Fig.1.
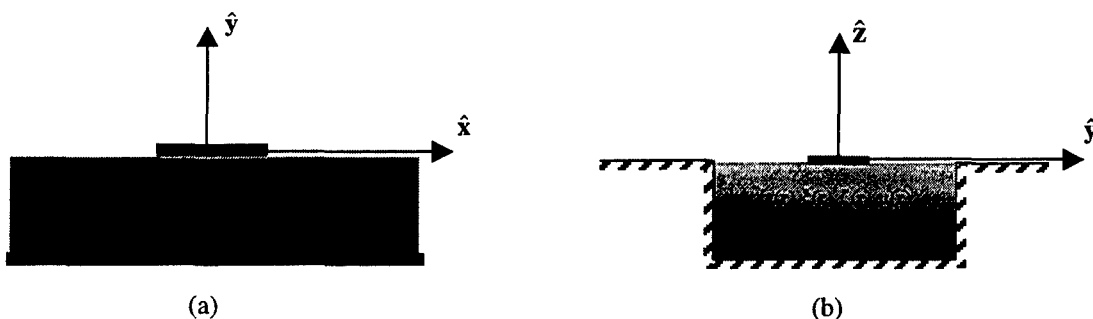

Fig. 1 Microstrip patch antenna configuration: Open planar integrated patch antenna (a); Cavity backed patch antenna (b).

The electromagnetic formulation of the antenna in Fig.1a is based on the full-wave analysis in the spectral domain and the numerical solution of the associated boundary-value problem is obtained via the method of moments (MoM). The fundamental step in this approach is the derivation of the spectral Green's dyad for the planar structure. In this case we consider the variation of the electromagnetic parameters only along the stratification direction and, starting from the curl Maxwell equations, we obtain, after a change of the reference system [6], the following relations in the spectral domain:

$$\begin{cases} \dfrac{dV(y)}{dy} = \underline{C}_{VV}(y) \bullet V(y) + \underline{C}_{VI}(y) \bullet I(y) \\ \dfrac{dI(y)}{dy} = \underline{C}_{IV}(y) \bullet V(y) + \underline{C}_{II}(y) \bullet I(y) \end{cases}$$

(3)

where $V = \left[\tilde{E}_v, \tilde{E}_u \right]^T$, $I = \left[\tilde{H}_u, \tilde{H}_v \right]^T$ and the elements of the matrices $\underline{C}_{VV}(y), \underline{C}_{VI}(y), \underline{C}_{IV}(y), \underline{C}_{II}(y)$ are complicate ratios involving the electromagnetic parameters. In order to decouple system (3) we impose $\underline{C}_{VV}(y) = 0$ and $\underline{C}_{II}(y) = 0$ obtaining, thus, after three derivative operations, the following fourth order decoupled differential equations:

$$\begin{cases} \dfrac{d^4 \tilde{E}_v}{dy^4} + A_{v3}(y)\dfrac{d^3 \tilde{E}_v}{dy^3} + A_{v2}(y)\dfrac{d^2 \tilde{E}_v}{dy^2} + A_{v1}(y)\dfrac{d\tilde{E}_v}{dy} + A_{v0}(y)\tilde{E}_v = 0 \\ \dfrac{d^4 \tilde{E}_u}{dy^4} + A_{u3}(y)\dfrac{d^3 \tilde{E}_u}{dy^3} + A_{u2}(y)\dfrac{d^2 \tilde{E}_u}{dy^2} + A_{u1}(y)\dfrac{d\tilde{E}_u}{dy} + A_{u0}(y)\tilde{E}_u = 0 \end{cases}$$

where the non constant coefficient $A_u(y)$ and $A_v(y)$ depend on the elements of the matrices $\underline{C}_{ij}(y)$. Once the solutions of such equations are found, the overall spectral electromagnetic field is also known in the grounded inhomogeneous slab and the Green's dyad can be easily determined.

The application of the MoM in order to calculate the unknown current density on the patch, is now a straightforward matter [7-8].

On the other hand the electromagnetic formulation for the antenna in Fig.1b is based on a variational approach together with the implementation of the Finite Element Boundary Integral (FE-BI) numerical method. The functional F(E) that has to be stationary for arbitrary variations of the E field is given by:

$$F(E) = <\underline{\mu}(r)^{a^{-1}} \bullet \left(\nabla \times E^a + j\omega\underline{\xi}(r) \bullet E^a \right), \nabla \times E + j\omega\underline{\zeta}(r) \bullet E > + \omega^2 < E^a, \underline{\varepsilon}(r) \bullet E > -$$

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

(3)

For the meaning of the apex a, of the vector J, of the surface S_{ap}, please, refer to [5].

After discretizing the cavity into finite elements of proper shapes (in this case bricks are used), and after expanding the electric field by using the edge-based vector basis functions as in [5] we obtain an algebraic system to be solved of the form $\underline{A} \bullet X = B$. The solution of such a linear system returns the electromagnetic field in the cavity and on the aperture surface and, thus, the derivation of the antenna characteristics is, now, a straightforward matter.

2.2 Transmissive components

Here we consider both planar and not planar waveguides as shown in Fig.2. These waveguides have been studied by means of different approaches. When the variation of the electromagnetic parameters is only along the stratification axis striplines and microstriplines have been analyzed in the spectral domain by using the same approach previously shown simply introducing the z dependence $\exp[-jk_z z]$ in the Maxwell equations. The integral equation written on the strip can be solved again via the MoM leading to an eigenvalue algebraic system whose solution returns the propagation characteristics of the waveguides. Striplines, microstriplines and rectangular waveguides with arbitrary variations of the parameters only on the cross sections have been analyzed by means of the full-wave approach in the spatial domain together with the Method of Lines (MoL) numerical procedure [10]. Finally, when the

parameter variation is only along the power flow direction, for the striplines and microstriplines the approximation of a TEM or quasi-TEM propagation has been used and the solution has been obtained by means of the non uniform transmission line theory as in [1-4].
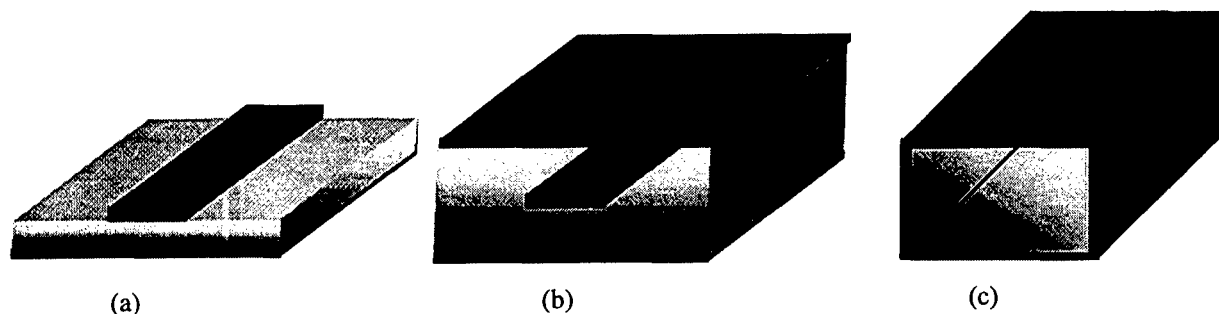

(a)   (b)   (c)

Fig. 2 Three different kinds of waveguides here considered: Microstripline (a); Stripline (b); Rectangular Waveguide (c).

3. Conclusion

In this contribution we have proposed the use of general bianisotropic inhomogeneous materials for both radiating and transmissive components in the microwave and millimetre wave frequency ranges. The analysis of such components has been essentially developed via a rigorous full-wave approach in the spectral or in the spatial domain together with different numerical techniques (MoM, FE-BI, MoL, etc.). Particularly, a new variational formulation for cavity backed microstrip patch antennas loaded with general inhomogeneous bianisotropic dielectrics and new analytical expressions of the spectral dyadic Green's functions for grounded slab loaded with the same materials have been derived as extensions of works previously published.

References

[1] F. Bilotti, A. Toscano, and L. Vegni, "Very fast design formulas for microwave non-homogeneous media filters," *Microwave Opt. Tech. Lett.*, pp. 218-221, Vol. 22, No. 3, Aug. 1999.

[2] L. Vegni, A. Toscano, and F. Bilotti, "Tapered stripline embedded in inhomogeneous media as microwave matching line," to appear on *IEEE Trans. Microwave Theory Tech.*

[3] F. Bilotti, L. Vegni, and A. Toscano, "A new stripline microwave high pass filter layout," *J. Electromag. Waves Applicat.*, pp. 423-439, Vol. 14, 2000.

[4] A. Toscano, L. Vegni, and F. Bilotti, "Generalized reflection coefficient for nonuniform transmission lines," *J. Electromag. Waves Applicat.*, pp. 945-959, Vol. 14, 2000.

[5] A. Toscano, L. Vegni, and F. Bilotti, "Scattering properties of antennas residing in cavities filled by inhomogeneous materials via a variational formulation," *J. Modern Opt.*, Vol. 46, No. 14, pp. 1995-2005, Nov. 1999.

[6] A. Toscano and L. Vegni, "Very general full-wave analysis of planar stratified media with inhomogeneous layers", *IEEE Trans. Antennas Propagat.*, Vol. 48, No. 4 pp. 631-632, Apr. 2000.

[7] L. Vegni, F. Bilotti, and A. Toscano, "Scattering properties of patch antennas loaded with inhomogeneous substrates via a combined spectral domain-moment method," to appear on *J. Modern Opt.*

[8] L. Vegni, F. Bilotti, and A. Toscano, "Microstrip disk antennas with inhomogeneous artificial dielectrics," *J. Electromag. Waves Applicat.*, pp. 1203-1227, Vol. 14, 2000.

[9] L. Vegni, A. Toscano, and F. Bilotti, "Mutual coupling between two circular patch antennas integrated in an inhomogeneous grounded slab," *Microwave Opt. Tech. Lett.*, pp. 294-297, Vol. 25, No. 5, Jun. 5, 2000.

[10] R. Pregla and W. Pascher, "The method of lines," in *Numerical Techniques for Microwave and Millimeter – Wave Passive Structures*, T. Itoh (Ed.). New York: Wiley, pp. 381-446, 1991.