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TRANSIENT ELECTROMAGNETIC WAVE SCATTERING FROM DISPERSIVE ANISOTROPIC LAYERED MEDIUM

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Transient electromagnetic (EM) wave scattering from a stratified anisotropic medium with temporal and spatial dispersion is considered. The dispersive anisotropic medium is modeled by constitutive relations that involve four second rank tensor susceptibilities, containing time convolution integrals. Scalarization approach to the solution of transient EM scattering problems in layered anisotropic medium is outlined. As a practical application the physical model of the effective absorber was proposed and numerically investigated.

1. Introduction

Performance of virtually all modern wide-band communication systems, e.g. mobile services and multimedia wireless networks can be enhanced with the use of novel composite materials with specially designed EM properties. Among such materials photonic crystals [1], chiral and omega media [2] and left-handed materials [3] have been thoroughly investigated recently. These media can be manufactured by embedding conductive or magnetodielectric resonance inclusions in the host medium. As a rule complex microstructure of composite materials leads to their macroscopic anisotropy. The main reasons for such anisotropy are the complicated shape of inclusions, ordered spatial arrangement of the particles, electromagnetic anisotropy of the host medium and in some cases electromagnetic interaction between particles.

2. Statement of the Problem and Solution Scheme

We consider impulse plane wave $\vec{E}_{in} = \vec{e}_{in} F(t) \exp(i\vec{k}_{in} \cdot \vec{R})$ obliquely incident in the direction of the vector $\vec{k}_{in}$ on a homogeneous anisotropic layer that occupies the domain of space $-\infty < x,y < \infty$, $0 < z < d$. EM properties of the medium are modeled by the constitutive equations [4]:

$$\begin{aligned} \vec{D} &= \vec{E} + 4\pi\Big(\hat{\chi}_{ee} * \vec{E} + \hat{\chi}_{em} * \vec{H}\Big), \\ \vec{B} &= \vec{H} + 4\pi\Big(\hat{\chi}_{me} * \vec{E} + \hat{\chi}_{mm} * \vec{H}\Big), \end{aligned} \tag{1}$$

where the asterisk stands for the time convolution integral

$$\hat{\chi}_{\nu\tau} * \vec{E}(\vec{R},t) = \int_{-\infty}^{t} \hat{\chi}_{\nu\tau}\left(\vec{R}, t - t'\right) \cdot \vec{E}(\vec{R},t')\,dt' ,$$

involving second rank tensor susceptibilities $\hat{\chi}_{\nu\tau}$ $(\nu,\tau = e,m)$. The cross-susceptibilities $\hat{\chi}_{em,me}$ arise due to spatial dispersion of the medium. The boundary value problem includes the Maxwell equations along with standard boundary conditions. Besides, the susceptibilities kernels $\hat{\chi}_{\nu\tau}$ are assumed to be identically zero for $t < 0$ due to causality.

EM scattering problems in stratified anisotropic medium can be efficiently solved by reducing the vector boundary problem to the equivalent scalar one for the so called potentials [5]. This procedure is based on the EM field decomposition on the transversal and longitudinal, with respect to the stratification axis, components

$$\vec{E} = \vec{E}_\perp + \vec{z}_0 E_z , \quad \vec{H} = \vec{H}_\perp + \vec{z}_0 H_z ,$$

projecting the Maxwell equations on the special spatial basis $\vec{z}_0, \vec{z}_0 \times \nabla_\perp, \nabla_\perp$ with subsequent elimination of the longitudinal components. As a result we have the coupled system of two integral-differential equations for the scalar functions E, H

$$\mathrm{E}[\mathrm{H}](\vec{r},z,t) = \int_{-\infty}^{t} \vec{z}_0 \cdot \left(\nabla_\perp \times \vec{E}_\perp[\vec{H}_\perp]\right) dt'. \tag{2}$$

The basic advantages of such approach are reduction of the number of unknown quantities, coordinate invariance and the possibility of various numerical methods to be applied. The vector EM field can be reconstructed straightforwardly from potentials E, H, but some physical quantities, e.g. reflection and transmission coefficients, are represented directly in terms of potentials (2).

3. The Physical Model for Composite Wideband EM Absorber

The concept of perfectly matched layer (PML), reflectionless for any angle of monochromatic plane wave incidence has been discussed lately. In [6] the model of PML for the wideband signals was proposed using the concept of time-derivative Lorentz medium (TDLM). In such medium field time derivatives contribute to the polarization provided that the medium possesses both electric and magnetic properties. Physically time derivative behaviors allow one to broaden the frequency region in which a well-known matching condition $\varepsilon = \mu$ is satisfied [6].

The main problem with PML however is that it is principally unrealizable with only passive components. Idea proposed in [6] can be realized with the use of spatially dispersive anisotropic medium with tensor susceptibilities of the special kind

$$\hat{\chi}_{\nu\nu} = \chi_{\nu\nu\perp}\hat{I}_{\perp} + \chi_{\nu\nu||}\vec{z}_0\vec{z}_0, \; \hat{\chi}_{\nu\tau} = \chi_{\nu\tau}\vec{z}_0 \times \hat{I}_{\perp}, \quad (3)$$

where $\hat{I}_{\perp} = \vec{x}_0\vec{x}_0 + \vec{y}_0\vec{y}_0$. These materials can be engineered using single- or multi-resonance non-closed conductive elements with complex shape. As a particular example of physically realizable alternative of PML we consider below the material formed by the cubic lattice of "omega" [2] particles with ferrite cores.

In Fig. 1 the reflection coefficient for the case of normal incidence of quasimonochromatic [6], Gaussian

$$F(t) = -\sqrt{7}\,(7/6)(2x-1)\left[1-(2x-1)^2\right]^3,$$

and Laguerre

$$F(t) = -0.7\left[L_2(x) - L_0(x)\right],$$

$$L_m(x) = \frac{\exp\left(x/2\right)}{m!}\frac{d^m}{dx^m}\left[\exp(-x)x^m\right], \; x = t/T$$

E-polarized pulses on anisotropic composite slab backed with the perfect conductor is shown as a function of parameter χ_β. Parameter χ_β measures the contribution of time derivative terms in the electric and magnetic transversal susceptibility kernels

$$\chi_{\nu\nu,\perp}(t) = \frac{1}{2}e^{\left(-\frac{\Gamma}{2}t\right)}\left[\begin{array}{l}\omega_0\chi_\beta\cos at - \\ -\dfrac{\omega_0^2}{a}\left(\chi_\alpha - \dfrac{\Gamma\chi_\beta}{2\omega_0}\right)\sin at\end{array}\right],$$

where $a^2 = \omega_0^2 - \Gamma^2/4$, ω_0 is the resonance frequency, Γ is the damping coefficient, χ_α is the usual Lorenz susceptibility term [6]. For the numerical computations we choose these parameters to fit the results presented in [6], particularly period $T = 100$ fs. In Fig. 1 curves 1 and 2 correspond to the Gaussian and quasi monochromatic pulse scattering from PML TDLM [6], curve 3 corresponds to the case of Laguerre pulse scattering from composite layer with material parameters(3). Fig. 1 demonstrates that non-reflecting properties of anisotropic composite material (3) can be made very efficient, in principle the same order as the PML TDLM ones.

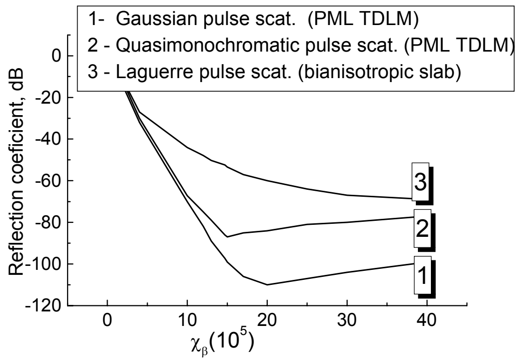

Fig. 1. *EMP reflection coefficient for anisotropic composite layer backed with PEC*

4. Conclusion

In this report the general scheme for handling transient EM problems in layered dispersive anisotropic medium is outlined. The model of wideband absorber is proposed and numerically investigated.

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НЕСТАЦИОНАРНОЕ РАССЕЯНИЕ ЭЛЕКТРОМАГНИТНЫХ ВОЛН В АНИЗОТРОПНОЙ ДИСПЕРГИРУЮЩЕЙ СЛОИСТОЙ СРЕДЕ

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В работе исследуется нестационарное рассеяние электромагнитных волн в анизотропной слоистой среде с пространственной и временной дисперсией. Анизотропная среда описывается материальными уравнениями типа временной свертки с ядрами восприимчивости, представляющими собой тензоры второго ранга. Предложена и численно исследована модель широкополосного поглощающего покрытия.

НЕСТАЦІОНАРНЕ РОЗСІЯННЯ ЕЛЕКТРОМАГНІТНИХ ХВИЛЬ В АНІЗОТРОПНОМУ ДИСПЕРГУЮЧОМУ ШАРУВАТОМУ СЕРЕДОВИЩІ

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У роботі досліджується нестаціонарне розсіяння електромагнітних хвиль в анізотропному шаруватому середовищі з просторовою і часовою дисперсією. Анізотропне середовище описується матеріальними рівняннями типу часової згортки з ядрами сприйнятливості, що являють собою тензори другого рангу. Запропонована і чисельно досліджена модель широкосмугового поглинаючого покриття.