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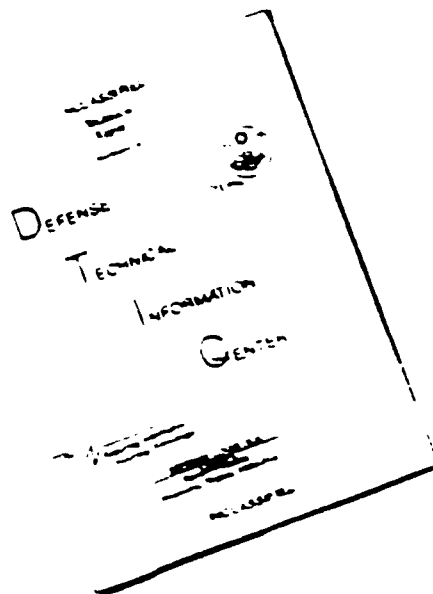Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503

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Many composite materials that are used in practice exhibit anisotropic properties. To account for these effects, several integral equation formulations for scattering and radiation by anisotropic objects have been proposed. The purpose of this paper is to present some numerical results on how the anisotropy affects the scattering behavior of a thin plate and radiation characteristics of a line source placed inside a cylindrical shell. Although in practice most situations are three-dimensional, a great deal of information on the EM nature of composite structures can still be obtained from studying two-dimensional geometries.

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ANISOTROPIC EFFECTS ON SCATTERING AND RADIATION PROPERTIES OF TWO-DIMENSIONAL OBJECTS

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Introduction

Many composite materials that are used in practice exhibit anisotropic properties. To account for these effects, several integral equation formulations for scattering and radiation by anisotropic objects have been proposed [1-3]. The purpose of this paper is to present some numerical results on how the anisotropy affects the scattering behavior of a thin plate and radiation characteristics of a line source placed inside a cylindrical shell. Although in practice most situations are three-dimensional, a great deal of information on the EM nature of composite structures can still be obtained from studying two-dimensional geometries.

Formulation

Fig. 1 shows the geometry of the thin flat plate and the cylindrical shell. The medium is anisotropic and is characterized by the following form of permittivity and permeability tensors,

$$[\varepsilon] = \varepsilon_0 \begin{bmatrix} \varepsilon_{xx} & \varepsilon_{xy} & 0 \\ \varepsilon_{yx} & \varepsilon_{yy} & 0 \\ 0 & 0 & \varepsilon_{zz} \end{bmatrix} \qquad [\mu] = \mu_0 \begin{bmatrix} \mu_{xx} & \mu_{xy} & 0 \\ \mu_{yx} & \mu_{yy} & 0 \\ 0 & 0 & \mu_{zz} \end{bmatrix} \qquad (1)$$

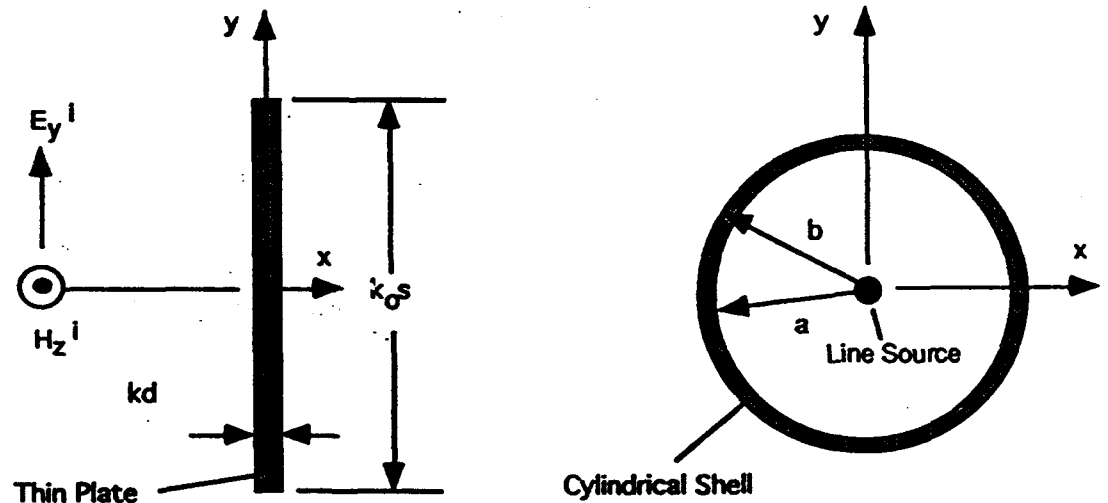where ε_0 and μ_0 are the free space permittivity and permeability.

Fig. 1. Geometry of the thin plate and cylindrical shell

The formulation of scattering and radiation problems has already been outlined in reference [3]. Since the duality concept can be applied to obtain the TE solution, once the TM solution is known, the formulation for both of these problems is restricted to the TM case. The radar cross

section (RCS) of the plate can be computed after the equivalent surface currents have been determined using surface integral equations. The z-component of the scattered electric field is obtained from

$$E_z^s(\bar{\rho}) = \frac{-k\eta}{4}\int_c J_z(\bar{\rho}')H_o^{(2)}(kR)ds' + \frac{k}{j4}\int_c M_s(\bar{\rho}')(\hat{n}' \bullet \hat{R})H_1^{(2)}(kR)ds' \tag{2}$$

by taking large argument expansions of the Hankel functions. In the above equation, ϕ' is the angle that unit normal makes with the x-axis, and $\bar{\rho}$ corresponds to the direction of the far field. The RCS is defined through the following relation:

$$\sigma = \lim_{\rho \to \infty}\left(2\pi\rho\left|\frac{E_z^s}{E_z^i}\right|^2\right) \tag{3}$$

where E_z^i is the incident plane wave field.

The anisotropic shell is illuminated by a source placed inside. For this particular case, the TM polarized line source has the E and H fields that are given by [4]

$$\bar{E}^i = -\hat{z}\frac{k\eta}{4}I_o f(\rho,\phi) H_o^{(2)}(k|\bar{\rho}-\bar{\rho}'|) \tag{4}$$

and

$$\bar{H}^i = \frac{-\nabla \times \bar{E}^i}{j\omega\mu} \tag{5}$$

with I_o and $f(\rho,\phi)$ being the line source current and taper pattern function, respectively. The integral equations are then solved for the surface equivalent currents on the shell, and the radiation pattern is computed from them.

Results

The scattering properties of a thin plate due to TE excitation are shown in Figs. 2 and 3. The anisotropic plate is lossless and is characterized by three sets of material parameters, namely ($\varepsilon_{xx} = 2$, $\varepsilon_{yy} = 4$), ($\varepsilon_{xx} = 4$, $\varepsilon_{yy} = 2$), ($\varepsilon_{xx} = 2$, $\varepsilon_{yy} = 4$, $\varepsilon_{xy} = -\varepsilon_{yx} = 2$) with zz-element of permeability equal to 2. The excitation to the scatterer is a polarized plane wave with frequency of 300 MHz. Both incidence angles of 0^0 and 45^0 are considered. For broadside incidence, the RCS patterns of plates with different diagonal permittivity tensors differ significantly. This is particularly evident in the backscattering direction ($\phi_s = 180^0$). At this angle, the RCS corresponding to case (b) is nearly 30 dB lower than the calculated RCS for case (a). The introduction of $\varepsilon_{xy} = -\varepsilon_{yx} = 2$ seems to raise the RCS level in both forward and backscattering directions. As the direction of incidence is skewed, the scattered field from the plate also changes. Fig. 3 shows the RCS of the plate when $\phi_i = 45^0$. Under such conditions the incident field, which now has both x- and y- components, senses every element of $[\varepsilon]$ tensor.

In the above cases, the anisotropic medium is assumed to be characterized by tensor elements whose numerical values are quite different from one another. For the following case dealing with radiation from a line source inside a circular shell, medium parameters corresponding to those of actual composites that were determined from the measurements are used. Particularly, for the E-glass composite, where tensor elements ε_{xx} and ε_{yy} range from $5 - j0.1$ to $5 - j0.125$ and from $4.5 -j0.09$ to $4.5 -j0.1125$, respectively, the shell is lossy with inner and outer radiii chosen to be 0.1 and 0.125 m. The polarized source at 400 MHz is located at the center and is assumed to be radiating uniformly in all directions. Fig. 4 shows the power loss as a function of the anisotropy and material conductivity. The two curves are calculated by varying one element of $[\sigma]$ while keeping the others constant. The real parts of ε_{xx} and ε_{yy} are 5 and 4.5, respectively. Notice that the power loss is not the same for increasing loss tangent values in x- and y-directions. The corresponding radiation pattern of the shell is shown in Fig. 5. Despite the highly symmetric geometry and uniformity of the

excitation, the radiation pattern is not uniform. This is a direct consequence of material anisotropy even though the actual difference between ε_{xx} and ε_{yy} is small.

References

[1]   R.D. Graglia and P.L.E. Uslenghi, "Electromagnetic Scattering from Anisotropic Materials, Part II: Computer Code and Numerical Results in Two-Dimensions," IEEE Trans. AP, Vol. 35, Feb. 1987, pp. 225-232.

[2]   J.C. Monzon, "On a Surface Integral Representation for Homogeneous Anisotropic REgions: Two-Dimensional Case," IEEE Trans. AP, Vol. 36, Oct. 1988, pp. 1401-1406.

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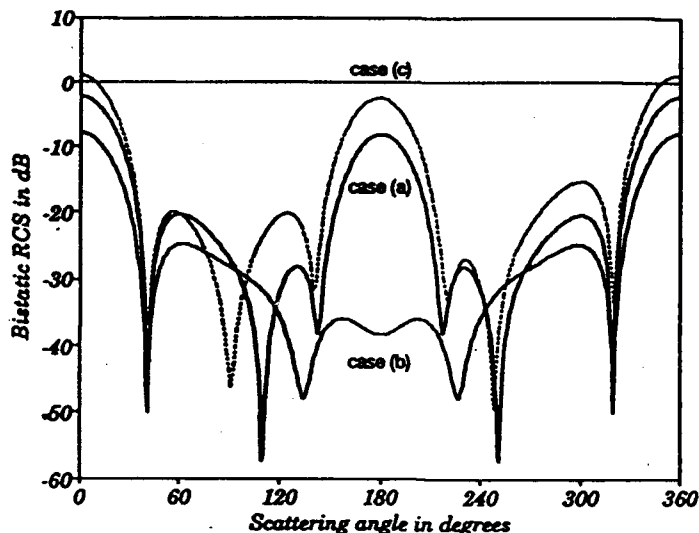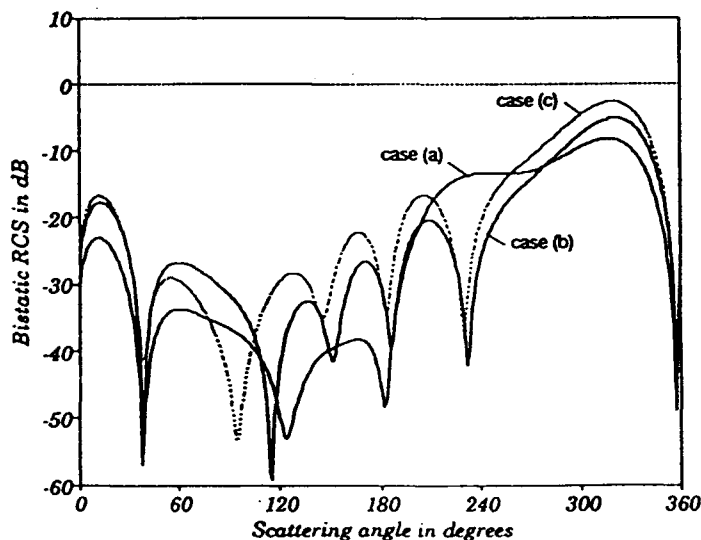[4]   C. A. Balanis, *Advanced Engineering Electromagnetics*, Wiley, New York, 1989, p. 573.

Fig. 2. Scattering cross section of a thin plate with 0° incidence (a) $\varepsilon_{xx} = 2$, $\varepsilon_{yy} = 4$ (b) $\varepsilon_{xx} = 4$, $\varepsilon_{yy} = 2$ (c) $\varepsilon_{xx} = 2$, $\varepsilon_{yy} = 4$, $\varepsilon_{xy} = -\varepsilon_{yx} = 2$

Fig. 3. Scattering cross section of a thin plate with 45° incidence (a) $\varepsilon_{xx} = 2$, $\varepsilon_{yy} = 4$ (b) $\varepsilon_{xx} = 4$, $\varepsilon_{yy} = 2$ (c) $\varepsilon_{xx} = 2$, $\varepsilon_{yy} = 4$, $\varepsilon_{xy} = -\varepsilon_{yx} = 2$
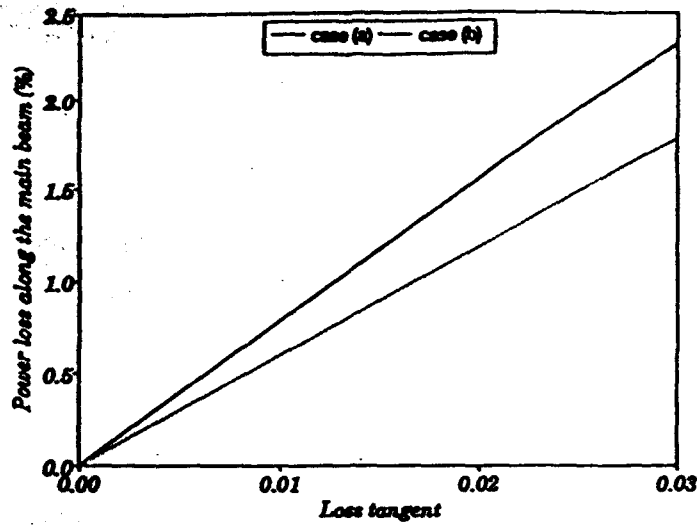
Fig. 4. Power loss in the main beam direction versus loss tangent (a) σ_{xx} (b) σ_{yy}
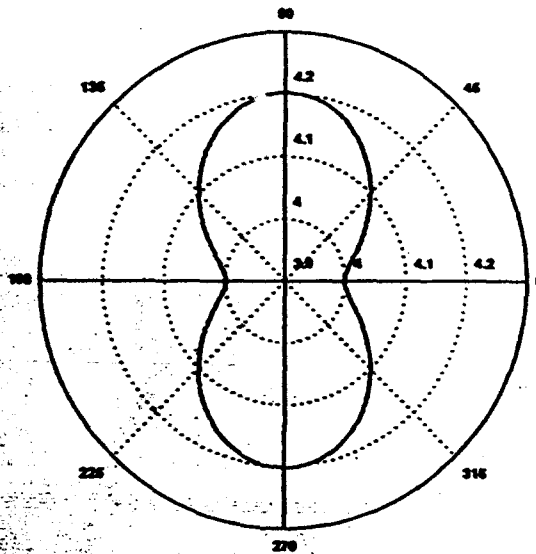

Fig. 5. Radiation pattern of a uniform line source located inside anisotropic shell