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

*Benjamin Baker
Department of Electrical & Computer Engineering
University of South Carolina
Columbia, SC 29208

Thinh Q. Ho and James C. Logan
NCCOSC, RDT&E Division
San Diego, CA 92152-5000

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,

$$\begin{align*}
[\varepsilon] &= \varepsilon_0 \begin{bmatrix} 
\varepsilon_{xx} & \varepsilon_{xy} & 0 \\
\varepsilon_{yx} & \varepsilon_{yy} & 0 \\
0 & 0 & \varepsilon_{zz}
\end{bmatrix} \\
[\mu] &= \mu_0 \begin{bmatrix} 
\mu_{xx} & \mu_{xy} & 0 \\
\mu_{yx} & \mu_{yy} & 0 \\
0 & 0 & \mu_{zz}
\end{bmatrix}
\end{align*}$$

(1)

where $$\varepsilon_0$$ and $$\mu_0$$ are the free space permittivity and permeability.

![Geometry of the thin plate and cylindrical shell](image)

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

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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
\[
E_z(\vec{p}) = \frac{-k\eta}{4} \int I_s(\vec{p}') H_0^{(2)}(k|\vec{r}' - \vec{p}|) d\sigma' + \frac{k}{4j} \int M_s(\vec{p}')(\vec{n} \times \hat{\vec{k}}) H_0^{(2)}(kR) d\sigma'
\]  
(2)

by taking large argument expansions of the Hankel functions. In the above equation, \( \phi' \) is the angle
that unit normal makes with the x-axis, and \( \vec{p} \) corresponds to the direction of the far field. The RCS
is defined through the following relation:
\[
\sigma = \lim_{\rho \to \infty} \left( \frac{2\pi\rho}{|E_0|^2} \right)
\]
(3)

where \( E_0 \) 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]
\[
\vec{E}^t = -\frac{1}{2} \frac{k\eta}{4} I_s(\rho, \phi) H_0^{(2)}(k|\vec{p} - \vec{p}'|)
\]
(4)

and
\[
\vec{H}^t = -\frac{\nabla \times \vec{E}^t}{j \omega \mu}
\]
(5)

with \( I_s \) 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 \( \mu_{zz} \) 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° and 45° 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 (\( \phi_b = 180^\circ \)). 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 \( \phi = 45^\circ \). 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 \( \varepsilon_{xx} \) and \( \varepsilon_{yy} \) range from 5 - 0.1 to 5 - 0.125 and from 4.5
-0.09 to 4.5 -0.125, respectively, the shell is lossy with inner and outer radii 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 [\varepsilon] while keeping the others
constant. The real parts of \( \varepsilon_{xx} \) and \( \varepsilon_{yy} \) 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 $\varepsilon_{xx}$ and $\varepsilon_{yy}$ is small.

References


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) \( \sigma_{xx} \) (b) \( \sigma_{yy} \)

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