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Plane Wave Scattering from a Monoclinic Slab

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Modern manufacturing capabilities have made the rapid prototyping of ever-exotic materials possible. This capability allows one to easily infuse symmetry, or symmetry breaking, into material design to achieve electromagnetic material tensor properties beyond simple isotropic media, namely, anisotropic and bianisotropic materials. The motivation for the investigation of these advanced materials is that they provide enhanced control over an electromagnetic wave, such as co and cross-polarization control. The goal of this research is to investigate the interaction of an electromagnetic plane wave with a material slab in which monoclinic symmetry has been infused (this can be accomplished, for example, via monoclinic occlusions in a 3D printed nylon polymer).

To more clearly identify the salient features of scattering from a monoclinic slab immersed in free-space, it is assumed that the plane wave is normally incident along the z-direction (i.e., $\vec{k} = \hat{z}k_z$), and that the slab is non-magnetic. Thus, the slab permittivity is given by $\bar{\bar{\varepsilon}} = \hat{x}\hat{x}\varepsilon_{xx} + \hat{y}\hat{y}\varepsilon_{yy} + \hat{z}\hat{z}\varepsilon_{zz} + \hat{x}\hat{y}\varepsilon_{xy} + \hat{y}\hat{x}\varepsilon_{xy}$, and the slab permeability is μ_0. It is noted that the permittivity tensor is assumed symmetric, namely $\varepsilon_{yx} = \varepsilon_{xy}$, and that a preferential alignment of the crystallographic axes is chosen (as is evident by the form of the permittivity tensor). The wave equation for the electric field, namely $\bar{\bar{W}} \cdot \vec{E} = 0$, results from Maxwell's equations under the plane wave assumption, with $\bar{\bar{W}} = \bar{\bar{k}} \cdot \bar{\bar{k}} + \omega^2 \bar{\bar{\varepsilon}} \mu_0$ and $\bar{\bar{k}} = -\hat{x}\hat{y}k_z + \hat{y}\hat{x}k_z$. Setting the determinant of $\bar{\bar{W}}$ equal to zero identifies the eigenvalues (the allowed k_z propagation values) and subsequent insertion into the wave equation produces the eigenvectors, that is, the fundamental polarization states or basis vectors. Boundary condition enforcement at the monoclinic slab interfaces leads to the desired scattering parameters (i.e., the reflection and transmission coefficients). These scattering parameters reveal that both co-polarization, and importantly, cross-polarization occurs independent of the incident excitation polarization state. This is a crucial difference when compared to orthorhombic (or other sub-class non-isotropic) materials which cause cross-polarization only under special circumstances.

The details of the eigen analysis and subsequent derivation of the scattering parameters will be presented in detail, as well as other important findings, such as mode orthogonality. A significant future research effort remains, including extending the results to dielectric and magnetic monoclinic media, and the accommodation of an obliquely-incident electromagnetic plane wave. Future work also includes the experimental fabrication and electromagnetic material characterization of monoclinic media using a focused-beam measurement system.