Physical Interaction of Electromagnetic Fields with Biological Systems: Applications to Detection and Identification of Threat Agents

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ABSTRACT

Biological materials usually possess some degree of chirality. Connonical solutions for electromagnetic fields in chiral media are the right and left circular polarized waves. To provide a full wave (rigorous) basis for the analysis of general scattering problems, Generalized Fourier Transforms for irregular chiral media are used. They provide the interrelationships between the incident, reflected, transmitted, surface and laterally scattered waves at the interface between free space and the chiral media. A set of Generalized Telegraphists Equations that account for diffuse scattering in non specular directions, as well as coupling between the different species of the circular polarized waves are derived on imposing exact boundary conditions at rough interfaces. Following procedures similar to those used in archival media Maxwells equations are converted into the following Generalized Telegraphist's Equations for chiral media,

$$\frac{-d}{dx}a_{ij}\left(x,u\right)-jqa_{ij}\left(x,u\right)=\sum_{mn}S_{ijmn}\left(u,u'\right)a_{mn}\left(x,u'\right)+K_{ij}\left(x,u\right)/4 \qquad -\infty<q<\infty$$

in which a_{ij} and b_{ij} are the forward and backward traveling wave amplitudes, S_{ijmn} are the scattering coefficients, K is the source term and $\left(q,u,o\right)$ are components of the wave vector. Reflection coefficients at a free space-chiral medium interface are expressed in matrix form, both in terms of circular (C) and linear (L) polarized waves:

$$E_r^C\equiv\begin{pmatrix}E_r^R\\E_r^L\end{pmatrix}=\begin{pmatrix}R^{RR} & R^{RL}\\R^{LR} & R^{LL}\end{pmatrix}\begin{pmatrix}E_i^R\\E_i^L\end{pmatrix}\equiv R^C E_i^C \qquad E_r^L\equiv\begin{pmatrix}E_r^V\\E_r^H\end{pmatrix}=\begin{pmatrix}R^{VV} & R^{VH}\\R^{HV} & R^{HH}\end{pmatrix}\begin{pmatrix}E_i^V\\E_i^H\end{pmatrix}\equiv R^L E_i^L$$

in which the subscripts *i* and *r* denote incident and reflected and the superscripts *C* and *L* denote circular and linear. The relationships between the circular and linear polarized fields are also expressed in matrix form as follows

$$E_i^C=\begin{pmatrix}E_i^R\\E_i^L\end{pmatrix}=AE_i^L\ ,\ A\equiv\begin{pmatrix}1 & -j\\1 & j\end{pmatrix} \qquad E_r^L=\begin{pmatrix}E_r^V\\E_r^H\end{pmatrix}=A^{-1}E_r^C$$

Thus the relationship between R^C and R^L is given by

$$R^L=A^{-1}R^C A$$

When the degree of chirality is small $\left|k_1\beta_1\right|^2<<1$, the linear cross polarized reflection coefficients are (to first order).

$$\frac{1}{2}jk_1\beta_1T_{10}^VT_{01}^H\tan^2\theta_1\begin{pmatrix}0 & 1\\-1 & 0\end{pmatrix}\equiv\begin{pmatrix}0 & R^{VH}\\R^{HV} & 0\end{pmatrix}$$

in which the transmission coefficients for the vertically and horizontally polarized waves are T_{ij}^V,T_{ij}^H. They are related to the circular like polarized scattering coefficients. Thus chirality impacts primarily upon the eight off diagonal terms of the Mueller Matrix (consistent with the experimental observations). Physical interpretation of the scattering mechanism at a free space – chiral media interface and the specific dependence of the Mueller Matarix elements (due to chirality) upon frequency and angle of incidence are presented. It is also necessary to determine whether the degree of cirality is sufficiently large to conduct species level discrimination in the presence of spurioes contributions to scattering due to surface roughness, etc. The results of the analysis are consistent with reciprocity, duality and energy conservation in electromagnetic theory.

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