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ELECTROMAGNETIC SCATTERING FROM A PERFECTLY CONDUCTING STRIP EMBEDDED IN A DIELECTRIC CYLINDER

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Summary

Scattering from a perfectly conducting strip arbitrarily embedded inside a dielectric cylinder of circular or elliptical cross-section is investigated. The geometry of a strip of width 2s embedded in an elliptic cylinder is illustrated in Fig. 1. The circular dielectric coating of the strip is also considered as a special case of the elliptic cylinder when the semi major and semi minor axes a and b, respectively, are set equal. The dielectric material is assumed to be homogeneous, isotropic, lossless and nonmagnetic. The problem is two dimensional and hence all field components are uniform along the z direction. An incident plane wave with \( e^{j\omega t} \) time dependence is normally incident at an angle \( \phi_0 \) with respect to the x-axis. For a TM to z polarized wave the incident electric field component is then represented in terms of the elliptical coordinate system \((u, v, z)\) as

\[
E_z^i = E_0 \frac{1}{\sqrt{2\pi}} \left[ \sum_{m=0}^{\infty} \frac{1}{N_m} R_m^{1} (c_0, \xi_d) S_m (c_0, \eta_d) S_m (c_0, \cos \phi_0) \right.
\]
\[
+ \sum_{m=1}^{\infty} \frac{1}{N_m} R_m^{0} (c_0, \xi_d) S_m (c_0, \eta_d) S_m (c_0, \cos \phi_0) \right] \tag{1}
\]

where \( k_0 \) is the free space wave number, \( \xi_d = d \cosh u \cos v, \eta_d = d \sinh u \sin v, c_0 = k_0 d, \xi_d = \cosh u, \eta_d = \cos v, S_m \) and \( S_0 \) are even and odd angular Mathieu functions while \( R_m \) and \( N_m \) are even and odd radial Mathieu functions and the normalization factors \( N_m \) and \( N_0 \) are defined in [1]. Two regions surrounding the conducting strip are defined; namely region I is the free space outside the dielectric cylinder, while region II is the dielectric material. In region II the wave number \( k_1 = k_0 \sqrt{\varepsilon_r} \), where \( \varepsilon_r \) is the relative permittivity of the dielectric material. The scattered field in any region can be obtained by solving the wave equation in the elliptical coordinate system. The resulting z component of the scattered field in region I can be expressed as
\[ E_z^I = E_0 \sqrt{\delta t} \sum_{m=0}^{\infty} A_m R_m^4 (c_0, \xi_d) S_m (c_0, \eta_d) \]
\[ + \sum_{m=0}^{\infty} B_m R_m^4 (c_0, \xi_d) S_m (c_0, \eta_d) \]

While in region II the z-component of the electric field is given by
\[ E_z^{II} = E_0 \sqrt{\delta t} \sum_{m=0}^{\infty} \left[ C_m R_m^1 (c_d, \xi_d) + D_m R_m^2 (c_d, \xi_d) \right] S_m (c_d, \eta_d) \]
\[ + \sum_{m=1}^{\infty} \left[ F_m R_m^1 (c_d, \xi_d) + G_m R_m^2 (c_d, \xi_d) \right] S_m (c_d, \eta_d) \]

where \( c_d = k_1 \), and \( A_m, B_m, C_m, D_m, F_m \) and \( G_m \) are unknown scattering coefficients. These unknown coefficients are determined by enforcing the continuity of the tangential components of the electric and magnetic fields on the dielectric free space interface and by forcing the tangential component of the electric field to be zero on the surface of the conducting strip. However, in order to apply the boundary condition on the surface of the conducting strip, the field expressions in region II must be transformed to the local coordinates of the conducting strip \((u_s, v_s, z)\) by using the additional theorem of Mathieu functions \([2, 3]\), i.e.
\[ R_m (c_d, \xi_d) S_m (c_0, \eta_d) = \sum_{n=0}^{\infty} K_{\xi n, s} R_m (c_s, \xi_s) S_m (c_s, \eta_s) \]
\[ + \sum_{n=1}^{\infty} W_{\xi n, s} R_m (c_s, \xi_s) S_m (c_s, \eta_s) \]

where \( c_s = k_1 \),
\[ K_{\xi n, s} = \frac{\pi (j)^{n-1}}{N_{\xi n} (c_s)} \sum_{s=0}^{\infty} \sum_{m=0}^{\infty} (-j)^{s+m} D_{\xi s}^n (c_d) D_m (c_s) B_{\xi s, m} \]
\[ W_{\xi n, s} = \frac{\pi (j)^{n-1}}{N_{\xi n} (c_s)} \sum_{s=0}^{\infty} \sum_{m=0}^{\infty} (-j)^{s+m} D_{\xi s}^n (c_d) D_m (c_s) Q_{\xi s, m} \]
\[ B_{\xi s, m} = J_{m-s} (k_1, c) \begin{bmatrix} \cos (s \psi - m \psi_1) \\ \sin (s \psi - m \psi_1) \end{bmatrix} \]
\[ + (-1)^s J_{m+s} (k_1, c) \begin{bmatrix} \cos (s \psi + m \psi_1) \\ \sin (s \psi + m \psi_1) \end{bmatrix} \]
\[ Q_{\xi s, m} = J_{m-s} (k_1, c) \begin{bmatrix} \sin (s \psi - m \psi_1) \\ \cos (s \psi - m \psi_1) \end{bmatrix} \]
\[ - (-1)^s J_{m+s} (k_1, c) \begin{bmatrix} \sin (s \psi + m \psi_1) \\ \cos (s \psi + m \psi_1) \end{bmatrix} \]
where \( \psi_1 = \pi + \psi - \beta \), the superscript \( i \) is equal to 1, 2, 3 or 4, and the summation over \( s \) is to be extended over even values of \( s \) if \( \ell \) is even and over odd values of \( s \) if \( \ell \) is odd, the summation over \( m \) is related to \( n \) similarly. The constants \( D_{m}^{n} \) and \( D_{m}^{n} \) are the coefficients of the infinite series of the angular Mathieu functions in terms of trigonometric functions [4]. The application of the boundary conditions and the orthogonality of the Mathieu functions leads to an infinite set of equations which can be written in a matrix form as follows;

\[ [2] \{ A \} = [V] \]

where the elements of the column matrix \( [A] \) are the unknown coefficients \( A_{m} \) and

\[ [2] = [Z^{e}] - [Z^{o}] [Z^{o}]^{-1} [Z^{o}] \]

\[ [V] = [V^{e}] - [Z^{o}] [Z^{o}]^{-1} [V^{o}] \]

where the elements of the above matrices are given by

\[ Z^{e}_{n,m} = \sum_{\ell = 0}^{\infty} \frac{K_{n,\ell} \cdot H_{e}^{m}, \ell}{N_{e}(c_{d}) \cdot RED_{\ell}} \cdot [REC^{2}_{\ell,m} R_{e}^{n}(c_{s,1}) - REC^{1}_{\ell,m} R_{e}^{n}(c_{s,1})] \]

\[ Z^{o}_{n,m} = \sum_{\ell = 0}^{\infty} \frac{W_{n,\ell} \cdot H_{o}^{m}, \ell}{N_{o}(c_{d}) \cdot RED_{\ell}} \cdot [REC^{2}_{\ell,m} R_{o}^{n}(c_{s,1}) - REC^{1}_{\ell,m} R_{o}^{n}(c_{s,1})] \]

\[ Z^{e}_{n,m} = \sum_{\ell = 1}^{\infty} \frac{K_{n,\ell} \cdot H_{o}^{m}, \ell}{N_{o}(c_{d}) \cdot ROD_{\ell}} \cdot [ROC^{2}_{\ell,m} R_{e}^{n}(c_{s,1}) - ROC^{1}_{\ell,m} R_{e}^{n}(c_{s,1})] \]

\[ Z^{o}_{n,m} = \sum_{\ell = 1}^{\infty} \frac{W_{n,\ell} \cdot H_{o}^{m}, \ell}{N_{o}(c_{d}) \cdot ROD_{\ell}} \cdot [ROC^{2}_{\ell,m} R_{o}^{n}(c_{s,1}) - ROC^{1}_{\ell,m} R_{o}^{n}(c_{s,1})] \]

\[ V^{e}_{n} = \sum_{\ell = 0}^{\infty} \sum_{m = 0}^{\infty} \frac{1}{N_{e}(c_{d}) \cdot N_{o}(c_{o}) \cdot RED_{\ell}} \cdot S_{e}(c_{o}, \cos \phi_{o}) \]

\[ + \sum_{\ell = 1}^{\infty} \sum_{m = 1}^{\infty} \frac{1}{N_{o}(c_{d}) \cdot N_{o}(c_{o}) \cdot ROD_{\ell}} \cdot S_{o}(c_{o}, \cos \phi_{o}) \]

\[ V^{o}_{n} = \sum_{\ell = 0}^{\infty} \sum_{m = 0}^{\infty} \frac{1}{N_{e}(c_{d}) \cdot N_{o}(c_{o}) \cdot RED_{\ell}} \cdot S_{e}(c_{o}, \cos \phi_{o}) \]

\[ + \sum_{\ell = 1}^{\infty} \sum_{m = 1}^{\infty} \frac{1}{N_{o}(c_{d}) \cdot N_{o}(c_{o}) \cdot ROD_{\ell}} \cdot S_{o}(c_{o}, \cos \phi_{o}) \]

where the expressions \( REC^{i}_{\ell,m} \), \( ROC^{i}_{\ell,m} \), \( RED^{i}_{\ell,m} \), \( ROD^{i}_{\ell,m} \) and \( M_{\ell,m} \) are
functions of even and odd radial Mathieu functions and the geometrical and electrical parameters of the scatterer. The coefficients $A_m$ are then determined after truncating the matrices in equation (9) to a finite number of elements. Subsequently, the coefficients $B_m$ can be evaluated from equation (2). The far scattered electric field is then calculated using the asymptotic expansions of $R_m^4$ and $R_m^4$. The accuracy of the numerical results are investigated for a variety of physical and electrical parameters by comparing the scattered field pattern with the numerical results based on other techniques [5,6]. It is found that the numerical computations based on this analysis is rapidly convergent and few terms are needed to obtain a reasonably accurate results.

Figure 1. Geometry of the problem.

References