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Time Domain Scattering of Waves from Perfectly Conducting Half-Plane in Dispersive Space: Field-State Approach

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Abstract

The time domain scattering of electromagnetic waves is studied by using the concept and solution techniques related to state equations in system theory. The concepts and solution techniques related to state equations in system theory are supported with suitable extensions and modifications for the case of inclusion of dispersive materials. The state space model of system theory is extended and applied to the scattering of transient waves from half-planes where the filling dielectric is considered as Debye material. The perfectly conducting half-plane embedded in an infinitely large and homogeneous Debye material. The transient waves are studied.

1. Introduction

A method suitable for time domain and/or full wave and field investigations of complex electromagnetic environs is designed with extensions and modifications to state space formalism and state equation solution. The Author call the method *field-state approach* (F-SA). Both the state space approach (SSA) and field-state approach are discussed with their solutions those are provided with integral equations in time domain. The plane wave incidence is considered. The amplitude of incident plane wave is chosen as Gaussian pulse. Author calls alterations of the state space approach *Modified State Equations Formalism* (MSEF). The space-time matrix state equation solution is derived by converting it in a Wiener-Hopf Problem modification process (WHPmp) [1]-[8].

2. The Details of Problem

Author considers the pec half-plane defined with y=0 and 0<x<∞. The boundary conditions are provided below:

$$\boldsymbol{E}_x(x,0,t)=0, \qquad for\ x>0 \qquad (1).$$

$$\boldsymbol{H}_z(x,0,t)=J_{Sx}, \qquad for\ x>0 \qquad (2).$$

$$\boldsymbol{E}_x^+(x,0+0,t)=\boldsymbol{E}_x^-(x,0-0,t), \quad for\ -\infty<x<\infty \qquad (3).$$

$$\boldsymbol{H}_z^+(x,0+0,t)=\boldsymbol{H}_z^-(x,0-0,t), \quad for\ -\infty<x<0 \qquad (4).$$

The permittivity and permeability are given below:

$$\varepsilon=\varepsilon_{\mathbf{0}}\left[\delta(t)+\frac{\varepsilon_s-\varepsilon_\infty}{t_0}e^{-\frac{t}{t_0}}u(t)\right] \qquad (5).$$

$$\mu=\mu_0\left[\delta(t)+\frac{\mu_s-\mu_\infty}{t_0'}e^{-\frac{t}{t_0'}}u(t)\right] \qquad (6).$$

The u(t) is the unit step function, $\delta(t)$ is Dirac's distribution, ε_s is the static permittivity, μ_s is the static permeability, ε_∞ is the infinite frequency permittivity, and μ_∞ is the infinite frequency permeability and t_0 and t_0' are relaxation times.

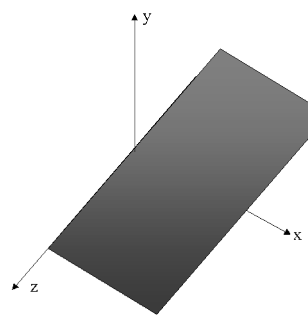

Figure 1. The problem configuration. The pec half plane scatterer and dispersive environ.

3. Suitable Presentation

Modified State Equations Formalism is derived from the field equations written in Laplace transform domain. The fundamental form is below, where $(\dot{\cdot})=\partial/\partial t$, $(^{++})$ illustrates the region $x>0$ and $y>0$, and the symbols, ϕ, I, V, and U are usual nomenclatures of electric and/or magnetic fluxes, currents, and/or potentials:

$$
\begin{aligned}
&u(t)\dot{\Phi}^{++}(P_0,t) \\
&= u(t)T_0\Phi^{++}(P_0,t) \\
&- \lambda^{-1}m_0\delta(t)\dot{\Phi}^{++}(P_0,t) \\
&- \delta(t)\Phi^{++}(P_0,t) \\
&- \lambda^{-1}m_0\dot{\delta}(t)\Phi^{++}(P_0,t)
\end{aligned} \quad (7).
$$

$$
+\begin{bmatrix} K & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -1 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 \end{bmatrix} \times \begin{bmatrix} \Phi_0^{++}(P_0,t)\delta(t) \\ C^{++}(P_0,t)\delta(t) \\ G^{++}(P_0,t)\delta(t) \end{bmatrix}
$$

$$
K = -2\varepsilon_0\left(1 + \frac{\varepsilon_s - \varepsilon_\infty}{t_0}u_0\right) \quad (8).
$$

$$
\Phi(P_0,t) = \begin{bmatrix} \phi^e(x_0\, y,z,t) \\ \phi^e(x,y_0,z,t) \\ \phi^h(x,y,z_0,t) \end{bmatrix} \quad (9).
$$

$$
\mathrm{C}(P_0,t) = \begin{bmatrix} I^e(x_0\, y,z,t) \\ I^e(x,y_0,z,t) \\ I^h(x,y,z_0,t) \end{bmatrix} \quad (10).
$$

$$
\mathrm{G}(P_0,t) = \begin{bmatrix} V^e(x_0\, y,z,t) \\ U^m(x,y_0,z,t) \\ U^m(x,y,z_0,t) \end{bmatrix} \quad (11).
$$

$$
T_0 = \begin{bmatrix} \frac{1}{t_0} & 0 & 0 \\ 0 & \frac{1}{t_0} & 0 \\ 0 & 0 & \frac{1}{t_0'} \end{bmatrix} \quad (12).
$$

$$
m_0 = \begin{bmatrix} \mathcal{E}_0 & 0 & 0 \\ 0 & \mathcal{E}_0 & 0 \\ 0 & 0 & \mu_0 \end{bmatrix} \quad (13).
$$

$$
\lambda = \begin{bmatrix} \varepsilon_0\frac{\varepsilon_s - \varepsilon_\infty 1}{t_0} & 0 & 0 \\ 0 & \varepsilon_0\frac{\varepsilon_s - \varepsilon_\infty}{t_0} & 0 \\ 0 & 0 & \mu_0\frac{\mu_s - \mu_\infty}{t_0'} \end{bmatrix} \times \begin{bmatrix} e^{-\frac{t}{t_0}} & 0 & 0 \\ 0 & e^{-\frac{t}{t_0}} & 0 \\ 0 & 0 & e^{-\frac{t}{t_0'}} \end{bmatrix} \quad (14).
$$

The Gaussian pulse plane wave incidence below is used in the formulation:

$$
H_z^i = e^{-a(\tau - bt)^2}cos(kxcos\phi_0 + kysin\phi_0 + \omega t) \quad (15).
$$

4. Conclusions

The scattering of electromagnetic waves are studied with the concepts and solution techniques related to the state equations in system theory with supporting of suitable extensions and modifications those convert the Wiener-Hopf Problem to a solvable field-state approach. The inclusion of dispersive materials is considered. The state model of system theory is extended and applied to the scattering of transient waves from half-planes by using field-state approach with modified state equations formalism. The approach produces the exact total solution in time domain. The method opens the way to solve the electromagnetic problems involving pulses in complex materials and environs.

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