Calculation of Scattered TM$_z$ Waves From a Cylindrical Dielectric Scatterer Buried Inside a Lossy Ground

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Abstract

A new numerical solution method is summarized for the problem of electromagnetic scattering from a cylindrical object of arbitrary cross-section buried in a lossy dielectric half-space that is considered to be flat. The surface equivalence principle and a decomposition method are employed to form a set of electric field integral equations (EFIEs) for the currents on the object and the portion of the surface most strongly interacting with the object. The Method of Moment (MoM) is used to solve the EFIEs in the frequency domain to obtain the scattered electric field.

1 Introduction

Solution of the electromagnetic scattering by a cylinder buried in a medium having a flat surface has been studied by many researches [1-2]. Therefore, several techniques have been employed to calculate the scattered fields. Then, these results are used to obtain information for buried objects [3].

The purpose of this work is to compute the scattered electric field from a cylindrical object of arbitrary cross-section buried in a lossy half-space by a new numerical solution method. The basis of the new solution method is that if an object is close to the surface, the electromagnetic fields will be nearly identical to that without the object, except within the region of finite extent near the object [4]. Thus, the equivalent current on the surface will be affected only in a finite portion of the surface near the object. By using this assumption, the EFIEs are obtained for the current on the object and the perturbation current (the difference current with object present and with object absent) on the surface. Then, MoM is used to solve the EFIEs in frequency domain.

2 Theory

Consider a TM$_z$ (horizontally) plane wave assumed to be incident on a cylindrical object of arbitrary cross-section buried in a two-dimensional infinite flat surface as shown in Figure 1.

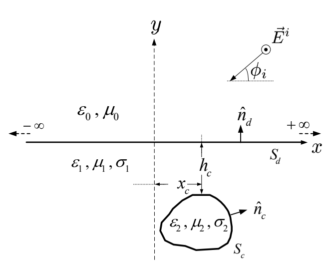

Figure 1: Geometry of cylindrical object buried inside a lossy ground.

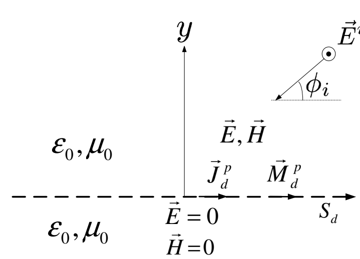

Figure 2: The external equivalence principle applied to the problem in Fig. 1.

The unknown currents are the equivalent perturbation currents on the surface and the equivalent currents on the object. These currents are obtained by using the surface equivalence principle [5]. The external

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equivalence principle is applied in Figure 2. Because the total field is zero just inside the flat surface;

$$\vec{E}^{P}_{ext}\left(\vec{J}^{p}_{d},\,\vec{M}^{p}_{d}\right)=0\Rightarrow S^{-}_{d} \tag{1}$$

where $\vec{E}^{P}_{ext}$ is the perturbational field produced by the difference, or perturbation currents $\vec{J}^{p}_{d}$ and $\vec{M}^{p}_{d}$. Then, the internal equivalence principle is applied in Figure 3 to the problem shown in Figure 1.

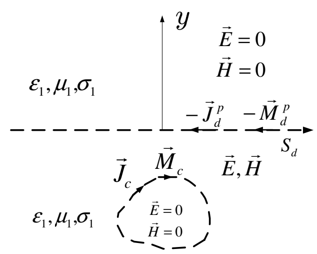


Figure 3: The internal equivalence principle applied to the problem in Figure 1.

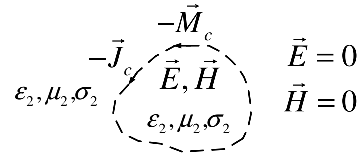


Figure 4: The external equivalence principle for the cylinder applied to the problem in Figure 1.

The total electric field is zero outside S_d and inside S_c:

$$\vec{E}^{P}_{int}\left(-\vec{J}^{p}_{d},-\vec{M}^{p}_{d}\right)+\vec{E}^{T}\left(\vec{J}_{c},\,\vec{M}_{c}\right)=-\vec{E}^{I}_{int}=0\Rightarrow S^{+}_{d} \tag{2}$$

$$\vec{E}^{P}_{int}\left(-\vec{J}^{p}_{d},-\vec{M}^{p}_{d}\right)+\vec{E}^{T}\left(\vec{J}_{c},\,\vec{M}_{c}\right)=-\vec{E}^{I}_{int}\Rightarrow S^{-}_{c} \tag{3}$$

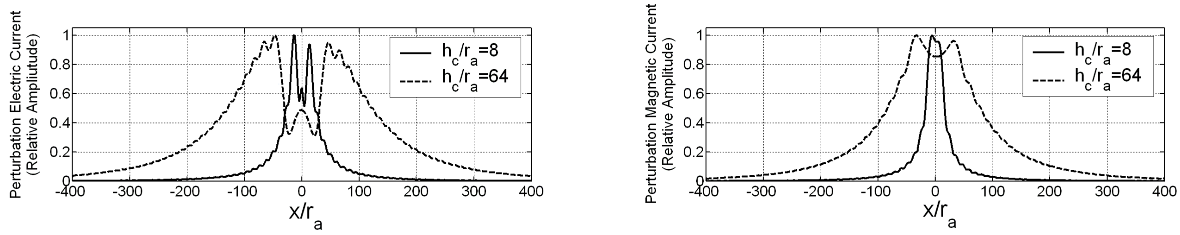
$\vec{E}^{I}_{int}$ on S^{-}_{c} obtained analytically in a closed form is the electric field value on the object points when the object is absent. $\vec{J}_c$ and $\vec{M}_c$ are the equivalent currents on the object. Figure 4 shows the external equivalence principle for the cylinder applied to the problem in Figure 1. The total field is zero on S^{+}_{c}.

$$\vec{E}^{T}\left(-\vec{J}_{c},\,-\vec{M}_{c}\right)=0\Rightarrow S^{+}_{c} \tag{4}$$

The equations (1-4) are solved numerically using MoM for four unknown surface currents ($\vec{J}^{p}_{d},\vec{M}^{p}_{d},\vec{J}_{c}$, and $\vec{M}_{c}$). The currents on the surfaces of S_d and S_c are approximated by linear segments. Then, pulse weighting functions are used to transform these EFIEs to linear equations. These linear equations are solved to obtain the unknown currents, and the far scattered field can be computed using only $\vec{J}^{p}_{d}$ and $\vec{M}^{p}_{d}$.

3 Numerical Results

If it is not indicated otherwise; for all MoM solutions, the value of 20 points per free-space wavelength (λ_0) is used to represent the currents on the object and the surface. The object is chosen to be a dielectric cylinder with circular cross-section of radius r_a, and the perturbation currents' behaviours are investigated in Figure 5 to validate the assumption that the equivalent current on the surface will be affected only in a finite portion of the surface near the object. As expected, when the object is buried deeper, the perturbation currents spread along the surface. So, it is important to select the truncation width (wl) carefully.



(a) (b)

Figure 5: Perturbation (a) electric and (b) magnetic currents on the flat surface for $\phi_i = \phi_s = 20°$, $r_a = 0.01$ m, $x_c/r_a = 0.0$, $\epsilon_1 = 15\,\epsilon_0$ F/m, $\epsilon_2 = 4\,\epsilon_0$ F/m, $\mu_1 = \mu_2 = \mu_0$ H/m, $\sigma_1 = 0.01$ Sm^{-1}, and $\sigma_2 = 0.0$ Sm^{-1}

After establishing the validity of our assumption, it is also necessary to determine the accuracy of the method. This can be done by choosing the space parameters under the flat surface as (ε_0, μ_0). Thus, the scattered field is expected to behave like a dielectric cylinder. The scattered E-field is first solved by decomposition method, and then by analytical method. Then, these two results are compared in Figure 6. It is seen that if the truncation width is chosen to be sufficiently long, the decomposition method gives very accurate results.

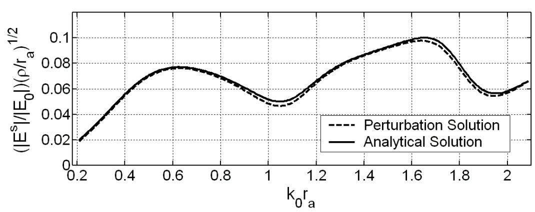


Figure 6: Scattered field (normalized amplitude) for $r_a = 0.01$ m, $\phi_i = \phi_s = 90°$, $x_c/r_a = 0.0$, $wl/r_a = 400$, $\epsilon_1 = \epsilon_0$ F/m, $\epsilon_2 = 4\,\epsilon_0$ F/m, $\mu_1 = \mu_2 = \mu_0$ H/m, and $\sigma_1 = \sigma_2 = 0.0$ Sm^{-1}

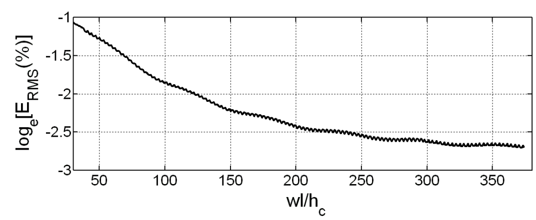


Figure 7: The approximation difference for $r_a = 0.01$ m, $\phi_i = \phi_s = 90°$, $x_c/r_a = 0.0$, $wl/r_a = 400$, $\epsilon_1 = \epsilon_0$ F/m, $\epsilon_2 = 4\,\epsilon_0$ F/m, $\mu_1 = \mu_2 = \mu_0$ H/m, and $\sigma_1 = \sigma_2 = 0.0$ Sm^{-1}

The root-mean square error (E_{RMS}) between the decomposition method and the analytical solution is calculated by using;

$$E_{RMS}(\%) = \sqrt{\frac{|E^A - E^P|^2}{|E^A|^2}} \tag{5}$$

where E^A and E^P show analytical and decomposition solutions; respectively. Then, the RMS error is calculated and shown in Figure 7. It is seen that the solution becomes more accurate for increasing truncation width.

After determining the method's accuracy, the object is chosen as a cylinder having different dielectric constant in Figure 8. There is a reduction of the magnitude of the scattered field as the incident angle deviates from 90°. Also, the scattered energy is concentrated around a scattering angle of 90° even for very small incident angle. It is also observed that the difference between the dielectric constant (ϵ_{r2} is the relative dielectric constant of the object) of the cylinder and the medium is effective on the scattered field amplitude.

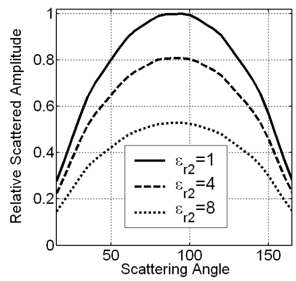


Figure 8: Scattered amplitude from a cylindrical scatterer with circular cross-section for $\phi_i = 30°$, $r_a = 0.01$ m, $h_c = 0.01$ m, $x_c/r_a = 0.0$, $\epsilon_1 = 15\,\epsilon_0$ F/m, $\mu_1 = \mu_2 = \mu_0$ H/m, $\sigma_1 = 0.01$ Sm^{-1}, and $\sigma_2 = 0.0$ Sm^{-1}

4 Conclusion

The scattered electric field from a cylinder buried in a lossy medium having an infinite flat surface excited by a TM$_z$ polarized electromagnetic wave has been solved by a new numerical solution method. The validity of perturbation assumption is shown by calculating the perturbation currents on the flat surface. Also, to investigate the accuracy of the method, the medium parameters are taken to be space parameters. It is seen that the method is very accurate. A detailed study of short-pulse scattering from objects buried in a lossy half-space will be undertaken in the future.

5 Acknowledgements

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6 References

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