L-7

Time-Domain Simulation of Electromagnetic Scattering from Arbitrary Conducting Targets

*Yuya Kitaoka[1], Hiroshi Iwamatsu[2] , Shinichiro Ohnuki[3]

Abstract: We propose a novel computational technique for transient electromagnetic scattering problems. Electromagnetic waves in the complex frequency domain are obtained by the method of moments and they are numerically transformed into the time domain by the fast inversion of Laplace transform. We investigate transient electromagnetic scattering responses from arbitrary conducting targets and verify computational accuracy of our proposed method.

1. Introduction

Analysis of time-domain electromagnetic scattering problems is important for identification of various targets. Recently, time-domain analyses are performed by using popular algorithms, such as the finite-difference time-domain (FDTD) method or the cubic interpolated pseudo-particle method. In this paper, we apply a novel computational technique for time-domain electromagnetic scattering problems. Our technique is based on the method of moments (MoM) and the fast inversion of Laplace transform (FILT) [1][2][3]. The proposed technique can fully control our computational accuracy and is suitable for a parallel computing. Compared with results obtained by the FDTD method, we clarify that our method can perform reliable simulations.

2. Formulation

The scatterer shown in Figure 1 is uniform along the *z*-axis and the cross section is an arbitrary shape. In the rectangular coordinate system, the incident *H*-wave in the complex frequency domain can be defined by

$$\hat{H}_z^{(i)} = \hat{H}_0 \exp\left[S\left(X\cos\phi_{in} + Y\sin\phi_{in}\right)\right], \tag{1}$$

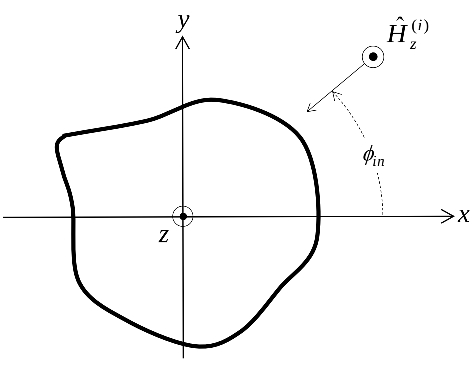


Figure 1. Geometry of a scatterer.

where $S = s\sqrt{\varepsilon_0\mu_0}a$, $X = x/a$, $Y = y/a$, and s is the complex frequency of Laplace transform, a is the radius of a circle which encloses the cylinder, ϕ_{in} is the angle of incidence, and $\hat{H}_0$ is the image function of the incident wave at $x = y = 0$.

In MoM, The scattered wave $\hat{H}_z^{(S)}$ can be expressed as

$$\hat{H}_z^{(S)} = -\frac{1}{2\pi}\sum_{i=1}^{N} J_t(X_i, Y_i)\left\{\hat{\mathbf{n}}(X_i, Y_i)\cdot\hat{\mathbf{R}}_i\right\} S\Delta C_i K_1(SR_i), \tag{2}$$

$\hat{\mathbf{R}}_i = \mathbf{R}_i / R_i$, R_i is the distance between the source point and the observation point, J_t is the surface current density, $\hat{\mathbf{n}}(X_i, Y_i)$ is the unit normal component of the source point, and $K_1(\bullet)$ is the first order of the modified Bessel function.

FILT is based on the approximation of the exponential function $\exp(S)$ in the Bromwich integral. The approximation $E_{es}(S,\alpha)$ can be represented by [3]

$$\begin{aligned} E_{es}(S,\alpha) &:= \frac{e^{\alpha}}{2\cosh(\alpha - S)} \\ &= \frac{e^{\alpha}}{2}\sum_{k=-\infty}^{\infty}\frac{j(-1)^k}{S - [\alpha + j(k-0.5)\pi]} \\ &= e^{S} - e^{-2\alpha}e^{3S} + e^{-4\alpha}e^{5S} - \cdots, \end{aligned} \tag{3}$$

where α is the approximate parameter. Substituting $E_{es}(S,\alpha)$ into the original Bromwich integral, the inverse Laplace transform can be expressed by

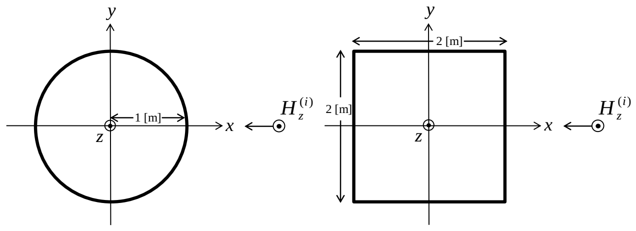
$$F(T) := \frac{1}{2\pi j}\int_{\gamma - j\infty}^{\gamma + j\infty} F(S) E_{es}(ST,\alpha)\, dS \cong \frac{e^{\alpha}}{T}\sum_{k=1}^{K} F_k, \tag{4}$$

$$F_k := (-1)^k \operatorname{Im}\left[H_z^{(S)}(S_k)\right],\quad S_k = \frac{\alpha + j(k-0.5)\pi}{T}, \tag{5}$$

$$T = \frac{ct}{a}, c = \frac{1}{\sqrt{\varepsilon_0\mu_0}}, \tag{6}$$

and K is the truncation number of FILT.

1 : Graduate Course of Electrical Engineering, Graduate School of Science and Technology, Nihon University.
2 : Research Institute of Science and Technology, Nihon University.
3 : Department of Electrical Engineering, College of Science and Technology, Nihon University.



(a) Circular cylinder.　　(b) Rectangular cylinder.

Figure 2. Geometries of cylindrical targets.

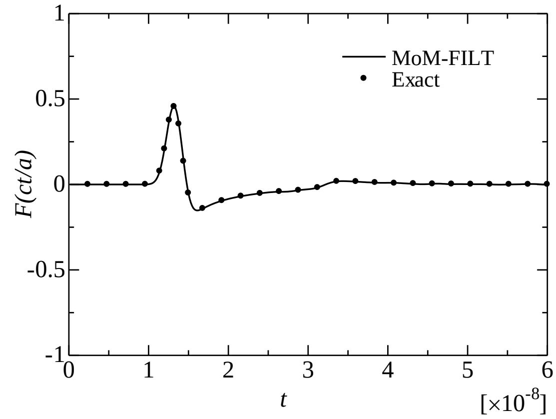


Figure 4. Time-domain responses from the circular cylinder.

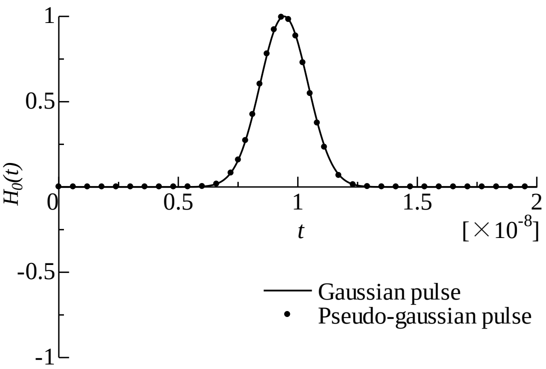


Figure 3. Incident waveform.

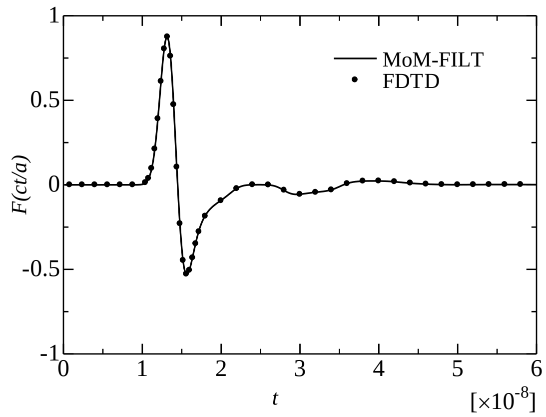


Figure 5. Time-domain responses from the rectangular cylinder.

3. Computational Results

Figure 2 represents (a) the circular cylinder and (b) the rectangular cylinder. We investigate time-domain scattering responses for the pseudo-gaussian pulse incidence whose function is defined as [4]

$$H_0(t) = 2^{-M} \sum_{k=0}^{M} (-1)^{k-\frac{M}{2}} C(M,k) \cdot \cos\left\{ \frac{(2k-M)}{\Delta M} t \right\} \left[u(t) - u(t-T_w) \right], \qquad (7)$$

where $T_w = \Delta\pi\sqrt{M}$, $\Delta = 1\times10^{-9}$, $C(M,k)$ is the binominal coefficient, and $u(t)$ is the unit step function. The pseudo-gaussian pulse is an excellent agreement with the gaussian pulse when $M = 36$ in Figure 3.

Figure 4 is a plot of the time-domain response from a conducting circular cylinder for the pseudo-gaussian pulse incidence when the radius a is 1 m. The solid line indicates the result of the MoM with FILT (MoM-FILT) and dots indicate that of the exact solution with FILT. Two methods give indistinguishable results.

Figure 5 shows the time-domain response from a conducting rectangular cylinder for the pseudo-gaussian pulse incidence when the cross section is 2 m × 2 m. The amplitude of the scattered wave is larger than that in Figure 4 due to the specular refection from the flat plate. Our result is almost equivalent to that by the FDTD method.

4. Conclusions

We have proposed a novel computational technique to analyze time-domain electromagnetic scattering problems. The responses obtained by our combinational method are in an excellent agreement with those by the analytical solution and FDTD methods.

5. Reference

[1]S. Ohnuki, and Y. Kitaoka, "Analysis of Transient Electromagnetic Scattering from Two-Dimensional Open-Ended Structures by Numerical Inversion of Laplace Transform," IEICE Trans. Electron., 2010, (in press).

[2]Y. Kitaoka, and S. Ohnuki, "Analysis of Electromagnetic Scattering Responses in Time Domain for Conducting Cylinders with Apertures," Proceeding of The 2009 International Symposium on Antennas and Propagation, TF2, pp. 699-702, October 2009.

[3]T. Hosono, "Numerical Inversion of Laplace Transform and Some Applications to Wave Optics," Radio Science, vol.16, pp.1015-1019, 1981.

[4]H. Hosono and T. Hosono, "Highly Anomalous Propagation of Pseudo-Gaussian Pulse", IEICE Trans. Electron., vol.E90-C, No.2, pp.224-230, Feb. 2007.