Analysis of Electromagnetic Scattering by an Object Located on a Rough Surface Using Time-Domain Integral Equations

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Abstract: Some results of a numerical investigation on electromagnetic scattering by a 2-D target located on a time-evolving rough surface are presented in this paper. The time responses of the current distributions and far-zone field are computed using TDIE approach. Finally, the MoM-IDFT scheme is introduced to depict the accuracy of the presented technique for the transient scattering by a complex object integrated with the rough surface.

Key words: TDIE, MoM-IDFT, Transient Scattering.

1. Introduction

Time-domain integral equation (TDIE) techniques possess a number of advantages when used to analyze wideband or nonlinear or time-varying electromagnetic scattering and radiation phenomena [1-2]. During the past decade, many different TDIE approaches have been proposed to model transient scattering by conducting or dielectric bodies, but only few scheme is presented to solve problems of electromagnetic scattering by an object on a rough surface. On the other hand, most of previous studies on such a complicated scattering problem have considered the scattering from a target on a single rough surface realization as a function of the aspect angle in term with Monte Carlo methods, or have considered the scattering from target over a rough surface use a four path model based on the coherent reflection coefficient of the rough surface. It is hard, however, to handle the time-dependence of the scattering by an object on a realistic time-evolving rough surface (such as a sea surface) in those models

In this paper, the numerical model of transient scattering from one-dimensional (1-D) PEC rough surface and the surface with a two-dimensional (2-D) PEC object are deduced. A novel algorithm for the calculations of transient far-fields for TDIE in two dimensions is presented and the numerical results are also compared with Method of Moment associated with the inverse discrete Fourier transformation technology (MoM-IDFT), to prove the better effectiveness and accuracy of this technique for transient scattering from complex rough surfaces associated with the targets

2. Description of the Numerical Model

2.1. One-dimensional Gaussian rough surface

For 1-D Gaussian rough surface, the Gaussian spectrum is given by,

$$f\left(x_n\right)=\frac{1}{L}\sum_{m=-N/2}^{N/2} F\left(K_m\right) exp\left(-jK_m x_n\right) \qquad (1)$$

where L is the total length of the rough surface, and the $F(K_m)$ is defined as

$$F\left(K_m\right)=\sqrt{2\pi L W\left(K_m\right)}\begin{cases}\frac{1}{\sqrt{2}}\left[N\left(0,1\right)-jN\left(0,1\right)\right] & 1\le m\le N/2-1\\ N\left(0,1\right) & \mathrm{m}=0,N/2\end{cases} \qquad (2)$$

We can change the roughness spectrum amplitude density function $W\left(K_m\right)$ in order to establish the different surfaces. For Gaussian roughness spectrum, $W\left(K_m\right)$ is defined as

$$W\left(K_m\right)=\frac{h^2 l}{2\sqrt{\pi}}\exp\left(\frac{K_m^2 l}{4}\right) \qquad (3)$$

where $N\left(0,1\right)$ denotes a random number with Gaussian distribution, h stands for the rms height, l represents the correlation length, and $K_m=\frac{2\pi m}{L}$.

In this study, the surface is meshed by N points, the spatial step size is Δx, the total length of rough surface is $L=N\Delta x$, $x_n=n\Delta x\ (n=1,2,\cdots,N)$ and each segment is considered as an infinite conducting strip in three-dimensional space, in order to establish the electrical field integral equations by using the TDIE method.

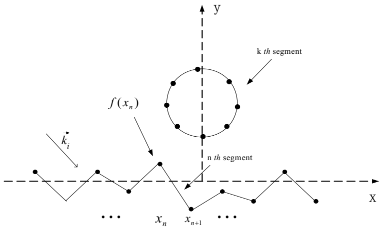

Fig. 1 The geometry of a target situated above a rough surface

2.2. TDIE approach

We assume that a 2-D PEC cylinder is located above 1-D rough surface shown in Fig. 1. The boundary condition of zero tangential electrical field is enforced on both target and rough surfaces, so that we have the time-domain electrical field integral equation as

$$\hat{n}\times[\vec{E}^{inc}(\vec{r},t)-\frac{\partial\vec{A}(\vec{r},t)}{\partial t}]=0 \qquad (4)$$

For the TDIE formulation of 2-D object, $\vec{A}(\vec{\rho},t)=\frac{\mu}{4\pi}\int_S\frac{1}{R}\vec{J}(\vec{\rho}',t-\frac{R}{c})ds'$, where $\vec{J}(\vec{\rho}',t)$ denotes the surface current density but the line current density, this is the major difference between the TDIE method with method of moments (MoM). We adopt the pulse basis function and the Galerkin's method of moments approach, Equation (4) could be written as a matrix equation given below

$$[Z][I(t_j)]=[U] \qquad (5)$$

where Z and U are decided by

$$\begin{aligned}A(\vec{\rho}_m,t_j)&=\frac{\mu}{4\pi}\sum_{n=1}^{NN}\sum_{k=-KK}^{KK}I_n(t_j)\left[1-\frac{R_{mnk}}{c\Delta t}\right]Q_{mnk}\\&+\frac{\mu}{4\pi}\sum_{n=1}^{NN}\sum_{k=-KK}^{KK}I_n(t_{j-1})\left[\frac{R_{mnk}}{c\Delta t}\right]Q_{mnk}+\tilde{A}(\vec{\rho}_m,t_j)\end{aligned} \qquad (6)$$

while Z is the first term of Eq. (6), and U denotes the second and third terms of Eq. (6).

Equation (6) is the implicit equation of marching-on-in-time (MOT) in reference [4], where $Q_{mnk}=\int_{\Delta Snk}\frac{1}{R_m}ds'$, $R_{mnk}=\sqrt{|\vec{\rho}_m-\vec{\rho}_n'|^2+(k\Delta\tau_n)^2}$, $\vec{\rho}_m$ and $\vec{\rho}_n'$ are the center of m *th* and n *th* segments, respectively. When R_{mnk} fits in with $t_j\geq t_j-\frac{R_{mnk}}{c}>t_{j-1}$, $I(t_R)$ could be handled by

$$I(t_R)=\left[\frac{R_{mnk}}{c\Delta t}\right]I_n(t_{j-1})+\left[1-\frac{R_{mnk}}{c\Delta t}\right]I_n(t_j). \qquad (7)$$

2.3 Incidence wave representation

In order to keep the continuity of surface current in calculation region, we adopt here the taper Gaussian impulse wave with a window function $\exp(-[\frac{g}{l}(\vec{\rho}\cdot\hat{x}-x_0)]^2)$, where g is the attenuation factor, to keep incident field be zero at the edge of the rough surface.

3. Numerical Results

In all our computations, the case of TM polarization is considered, where the parameters $E_0=377V/m$, $T=4LM$, $ct_0=6LM$, $L=12.8m$, $N=100$, $\Delta t=ct_0/10$ and $g=2.7$.

Fig. 2 shows the transient scattering characteristics of the model shown in Fig. 1 where Fig. 1(a) shows time response of the current at rough surface center point, while Figs. 1(b) and 1(c) dipect the responses from the far fields at forward direction and back direction, respectively. In calculation we choose that correlation length is $l=0.4m$, rms height is

$h = 0.05m$, the radium of the cylinder is $0.5m$, the distance between the cylinder with the rough surface is $D = 1m$, and the cylinder circle is divided by 60 segments. To test the validity of this approach, we compare the results obtained by using presented method with those using the MoM-IDFT method, and the comparison is also depicted in Fig. 2. The TDIE approach works as well as the MoM+IDFT. To further characterize the scattering effects of the target on rough surface, the time responses of far fields in Fig. 2(b) and Fig. 2(c) are compared in Fig. 3 with those from the rough surface in the absence of the cylinder. It is found that the back scattering has been obviously enhanced when the object is located over the rough surface.

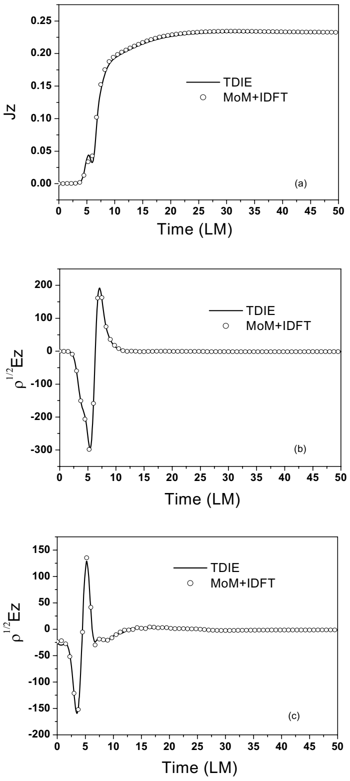

Fig. 2 Tansient scattering characteristics of a 2-D PEC cylinder is located above 1-D rough surface

4. Conclusion

The numerical investigation of electromagnetic scattering by a 2-D target located on a time-evolving rough surface is carried out in this paper. The time responses of the current distribution and far-zone field are computed using the TDIE approach. The MoM-IDFT scheme is introduced to depict the accuracy of the presented technique for the transient scattering by a complex object integrated with the rough surface.

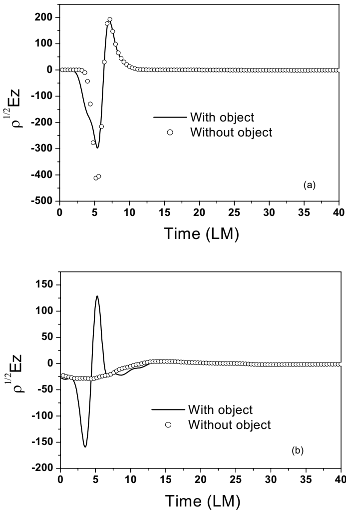

Fig. 3 Time response effect of the object in complex scattering

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