AN IMPROVED NUMERICAL SIMULATION OF ELECTROMAGNETIC SCATTERING FROM PERFECTLY CONDUCTING RANDOM SURFACES

Yisok Oh* and Kamal Sarabandi

Radiation Laboratory
Department of Electrical Engineering and Computer Science
The University of Michigan, Ann Arbor, MI 48109-2122

1. Introduction

Numerical simulation of electromagnetic scattering from a one-dimensional perfectly conducting random surface is of interest, primarily for its application as a benchmark for evaluation of approximate theoretical models. Since rough surfaces are targets of infinite extent, approximations to the geometry or the formulation of the problem must be considered to make the numerical solution tractable. The standard method to suppress the edge effects of a finite surface sample is the tapered illumination approximation [1]. This approximation is numerically inefficient because the effective illuminated width of the sample surface is much smaller than the physical surface width.

In this paper, the effect of the edges of the surface samples is minimized by controlling the conductivity of the surface near each edge by adding an appropriate tapered resistive sheet. It is shown that the scattering simulation based on the new technique is more efficient than the standard method. Also the backscattering coefficient predicted by the new technique is accurate for incidence angles as high as 80° while the angular validity range of the standard method is limited to 60°.

2. Formulation

The backscattering coefficient of a one-dimensional conducting surface is obtained by a Monte Carlo simulation. The scattered fields from N randomly generated sample surfaces are computed numerically, and the backscattering coefficient of the random surface is obtained from the statistics of the scattered fields. The surface current density $\mathbf{J}_s$ on each random surface excited by an incident plane wave can be determined numerically by the method of moment (MoM). For hh-polarization the electric field integral equation (EFIE) is used for evaluation of the surface current density

$$\mathbf{E}^i(\bar{\rho}) = \frac{k_0 Z_0}{4} \int_l \mathbf{J}_s(\bar{\rho}')\, H_0^{(1)}(k_0|\bar{\rho} - \bar{\rho}'|)dl', \tag{1}$$

and for vv-polarization the magnetic field integral equation (HFIE) is used

$$-\hat{n} \times \mathbf{H}^i(\bar{\rho}) = -\frac{1}{2}\mathbf{J}_s(\bar{\rho}) + \frac{i}{4}\int_l \hat{n} \times \left\{\mathbf{J}_s(\bar{\rho}') \times \nabla' H_0^{(1)}(k_0|\bar{\rho} - \bar{\rho}'|)\right\} dl', \tag{2}$$

After a sample surface is discretized into M ($= D/\Delta x$) cells, (1) and (2) are cast into matrix equations using pulse basis function and point matching technique.

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Table 1: Roughness parameters used for the random surface generation

Surface Name	ks	kl	λ	s	l	Δx	D	N	Applicable Models
				meters					
S-1	0.21	2.2	0.24	0.0079	0.082	0.01	2.4	60	SPM
S-2	0.62	4.6	0.24	0.0237	0.175	0.02	4.8	60	
S-3	1.04	7.4	0.24	0.0396	0.281	0.02	4.8	60	PO

The surface current induced by a horizontally polarized incidence wave exhibits the familiar singularity near the edges of the surface which has a significant effect on the backscattered field away from normal incidence. However, this is not the case for the vertically polarized incidence wave. To suppress the singular behavior of the current a tapered resistive sheet is added to each end of the surface sample. Using the following boundary conditions for resistive sheets,

$$[\hat{n} \times \mathbf{E}]^{+}_{-} = 0, \quad \hat{n} \times (\hat{n} \times \mathbf{E}) = -R\mathbf{J}, \tag{3}$$

the integral equation for the induced current becomes

$$\mathbf{E}^{i}(\bar{\rho}) = R(\bar{\rho})\mathbf{J}_{e}(\bar{\rho}) + \frac{k_0 Z_0}{4} \int_{l} \mathbf{J}_{e}(\bar{\rho}')\, H_0^{(1)}(k_0|\bar{\rho} - \bar{\rho}'|)dl', \tag{4}$$

where R is the resistivity of the resistive sheet.

The resistivity profile, $R(x)$, plays an important role in suppression of the edge current. Using trial and error the following tapered function was chosen:

$$R(x) = \begin{cases} 0, & |x| \le D/2 \\ 0.005 Z_0 \left(\frac{D/2 - |x|}{D_R}\right)^4, & D/2 \le |x| \le D/2 + D_R \end{cases} \tag{5}$$

where D is the width of the sample surface and D_R is the width of the resistive section. For evaluation of the backscattering coefficient the induced current on the resistive sheet and narrow portions of the conducting surface near the edges (D_E) is discarded.

3. Numerical Results

To demonstrate the validity of the numerical simulation, an algorithm that generates the sample surfaces with desired statistics is developed using a standard approach [2]. Table 1 shows the roughness parameters of three different surfaces with Gaussian autocorrelation function. In this table k is wavenumber, λ is the wave length, s is the rms height, l is the correlation length, Δx is the sampling interval, D is the width of a sample surface, and N is the number of sample surface. The roughness parameters of S-1 and S-3 surfaces are in the validity regions of the small perturbation method (SPM) and the physical optics (PO) model, respectively. Each sample surface has the width of D with an extended region of D_E and a resistive sheet of the length D_R at each end as shown in Fig. 1. Both D_E and D_R are chosen to be 1λ considering the trade-off between computation time and edge effect reduction. Even though currents on the whole regions are computed by the method

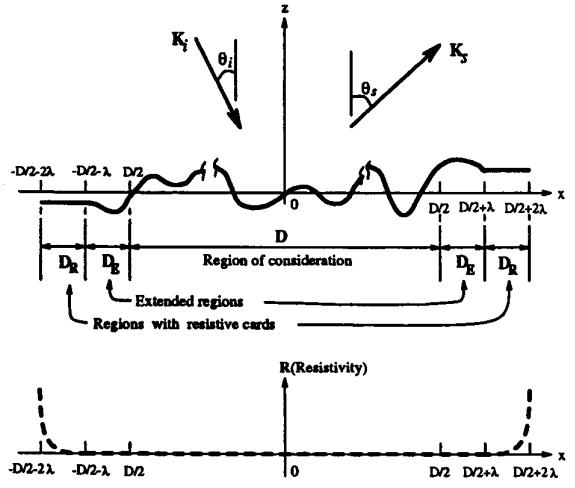

Figure 1: The extension of the random surface with resistive cards.

of moments, the currents only on the region of consideration (D) are used for computation of the scattered field to avoid inclusion of disturbance caused by the resistive sheet.

The backscattering coefficients of S-1 and S-3 are compared with the solutions of the small perturbation method (SPM) and the physical optics (PO) model, respectively. The backscattering coefficients of S-1 computed by this technique for vv- and hh-polarizations show an excellent agreement with the solution of the SPM as shown in Fig. 2(a). The numerical solution for S-3 also shows an excellent agreement with the PO prediction for incidence angles below 80° as shown in Fig. 2(b). The PO solution is obtained through exact evaluation of involved integrals [3]. It is shown that the numerical simulations agree very well with the theoretical models at two extreme roughness conditions, which provides assurance on its accuracy for surfaces with intermediate roughness conditions for which there exists no theoretical model.

It is well known that the phase-difference statistics provides valuable information about the scattering mechanisms. This numerical technique is used to compute the co-polarized phase-difference statistics of the random surface S-2 (Table 1). The distribution of the co-polarized phase-difference ($\phi_c = \phi_{hh} - \phi_{vv}$) statistics at 50° is shown in Fig. 3(a). Figure 3(b) shows that the standard deviation of the ϕ_c increases as the incidence angle increases.

References

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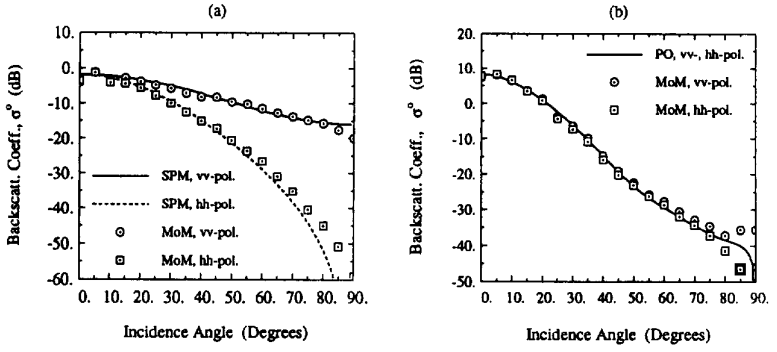

Figure 2: The solution by the method of moments compared with (a) the small perturbation method for the random surface S-1 and (b) the physical optics solution for the random surface S-3 (Table 1).

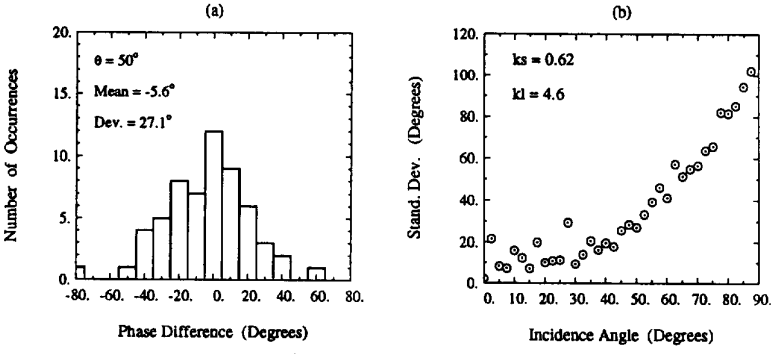

Figure 3: The distribution of the phase difference between σ°_{hh} and σ°_{vv} of the surface S-2 (a) at 50° and (b) standard deviation of the distribution.