Parametric Investigation of Ground Roughness on the Interference Between the AP-Mine and a Clutter-Object Buried Under Two-Dimensional Random Rough Surfaces

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Abstract

In realistic landmine fields, the anti-personnel plastic mine is often buried nearby a clutter-object under the ground. The presence of a second object buried near the mine under a two-dimensional (2-D) rough ground can easily obscure the target and/or cause a false alarm. The separation distance between the AP mine and clutter-object plays a significant role on the probability of true or false alarm in this situation. A rigorous electromagnetic model has been developed to analyze the scattering mechanism between the target and the clutter-object, between the target and the rough ground, between the clutter-object and the rough ground and the multiple scattering between different spots on the rough ground itself. The new rigorous model is based on the classical electromagnetic equivalence theorem leading to producing six new integral equations. Using the Method of Moment (MoM), the new integral equations are transformed into a linear system of equations to be solved for the unknown electric and magnetic currents on the surface of three scatterers; (1) rough ground, (2) target and (3) clutter-object. The MoM impedance matrix completely represents every interaction between these three scatterers. The superior Steepest Descent Fast Multipole Method (SDFMM) is used to tremendously speed up the computations of the unknown MoM surface currents.

I. INTRODUCTION

In realistic minefields, buried anti-personnel (AP) nonmetallic mines are often closely accompanied by underground clutter-objects. The presence of this object considerably obscures the targets causing a false alarm during the detection process. The separation distance between the AP-mine and the clutter-object plays a primary role on the probability of false alarms. A rigorous electromagnetic model has been developed to analyze the scattering mechanism of two dielectric objects buried beneath a rough ground surface as reported in [1]. Using the $O(N)$ fast algorithm, the Steepest Descent Fast Multipole Method (SDFMM) [2-3] tremendously accelerates the computations of the N unknown surface currents [1,4]. When the two objects were located close to one another under flat ground, the strong scattering interference generates a false response appearing to be a third buried object [1]. The dependency of the observed scattering interference on the ground roughness parameters is investigated in this work.

II. FORMULATION

The rigorous electromagnetic model derived in [1] is employed in this work where six integral equations are used to obtain the equivalent surface currents on dielectric scatterers shown in Fig. 1 (3-D scattering problem). Four different regions are involved in this scattering problem; air, soil, first object

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and second object. The unknown electric and magnetic currents on the ground surface, on the target surface, and on the clutter object surface are approximated using the well-known RWG vector basis functions [5]. After some algebraic manipulations, the linear system of equations is obtained as: $\overline{\overline{Z}}\,\overline{I} = \overline{V}$, where the total impedance matrix $\overline{\overline{Z}}$ has order of $2(N_1 + N_2 + N_3) \times 2(N_1 + N_2 + N_3)$. The number of electric and magnetic current unknowns (edges) on the ground, on the target and on the second object are $2N_1$, $2N_2$ and $2N_3$, respectively. The tested tangential incident electric field $\overline{E}^{inc}$ and the tested normalized magnetic field $\eta_1 \overline{H}^{inc}$ on the exterior of the ground surface are expressed in $\overline{V}$. The SDFMM is implemented to significantly accelerate solving the linear system of equations for the unknown current coefficients [1-4].

III. NUMERICAL RESULTS

In this Section, we investigate the scattering interference between the two buried objects as a function of their separation distances and the ground roughness. Several values for the root mean square height σ and the correlation length l_c are considered with emphasis on small roughness parameters for the AP-mine detection application. The incident wave is assumed to be a Gaussian beam at normal incidence that is carefully tapered to minimize edge effects [6]. The two objects are oblate spheroids with dimensions $a = 0.3\lambda_0$, $b = 0.15\lambda_0$ and at depth $z = -0.4\lambda_o$ measured from the center. The relative dielectric constant of the ground soil is assumed to be $\varepsilon_r = 2.5 - j0.18$ and for both objects is assumed to be $\varepsilon_r = 2.9 - j0.072$. The $8\lambda_o \times 8\lambda_o$ ground surface is discretized into 60,000 electric and magnetic surface current unknowns. Each object is disretized into 600 electric and magnetic surface current unknowns. In order to analyze the object signatures, the electric fields scattered from each rough ground are removed by subtraction similar to our work in [4].

In Fig. 2, the object signatures are plotted across the diagonal as shown in Fig.1. When the two objects are separated by $S = 1.4\lambda_o$, the results show three peaks of almost equal magnitudes; the first peak is above the first object, the second peak is above the second object and the third peak is at mid-point between them. This third peak is due to the strong constructive interference between the two objects. This phenomenon could easily cause a false alarm during the detection process. However, when the separation distance increases, the mid-point peak is dissolved into several secondary peaks as observed when $S = 2.1\lambda_o$ and $2.8\lambda_o$. These secondary peaks become insignificant when S is increased to $4.2\lambda_o$. As noticed in this figure, the asymmetry around the mid-point ($x = 4.0\lambda_o$) is clearly caused by the random roughness of the ground. Moreover, the magnitudes of all peaks decrease with increasing separation distance because the objects are further from the beam footprint center (ground center in this work). In Figs. 3 and 4, the separation distance is $S = 1.4\lambda_o$, the range for σ is $0.04\lambda_o$-$0.1\lambda_o$ and the range for l_c is $0.4\lambda_o$-$1.0\lambda_o$. The results clearly show the influence of the roughness parameters, however, the observed strong interference (mid-point peak) is slightly affected by the ground roughness in this case. This study is repeated for $S = 2.1\lambda_o$ as shown in Figs. 5 and 6, and for $S = 2.8\lambda_o$ as shown in Figs. 7 and 8. It is interesting to notice that when the separation distance becomes several correlation lengths, as shown in Figs. 6 and 8, stronger scattered interference is observed. This is demonstrated by the increase in the number of secondary peaks from three in the flat ground case to four and five in the rough ground case as shown in Figs. 6 and 8, respectively. This mechanism could increase the possibility of false alarms.

IV. CONCLUSIONS

False alarms could easily occur because of the interference mechanism between the target and a second nearby object buried under the ground. The roughness parameters strongly influence the scattering interference mechanism between the two objects, which could increase the probability of false alarms.

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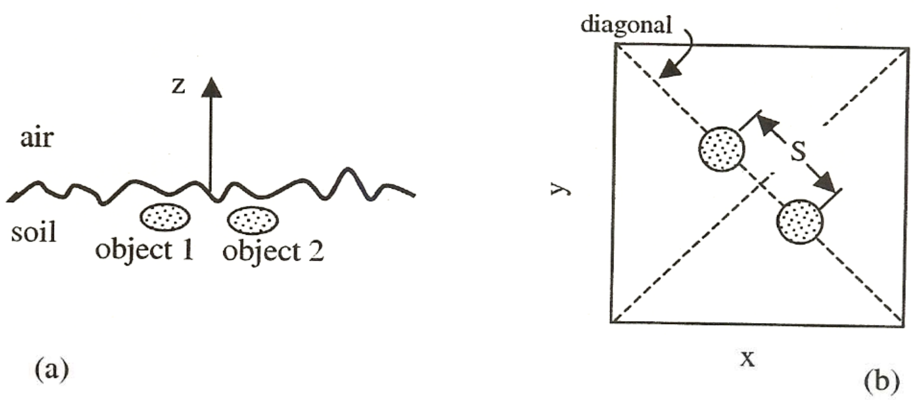

Fig. 1. (a) Cross section along the diagonal direction for two objects buried under rough ground, (b) Top view.

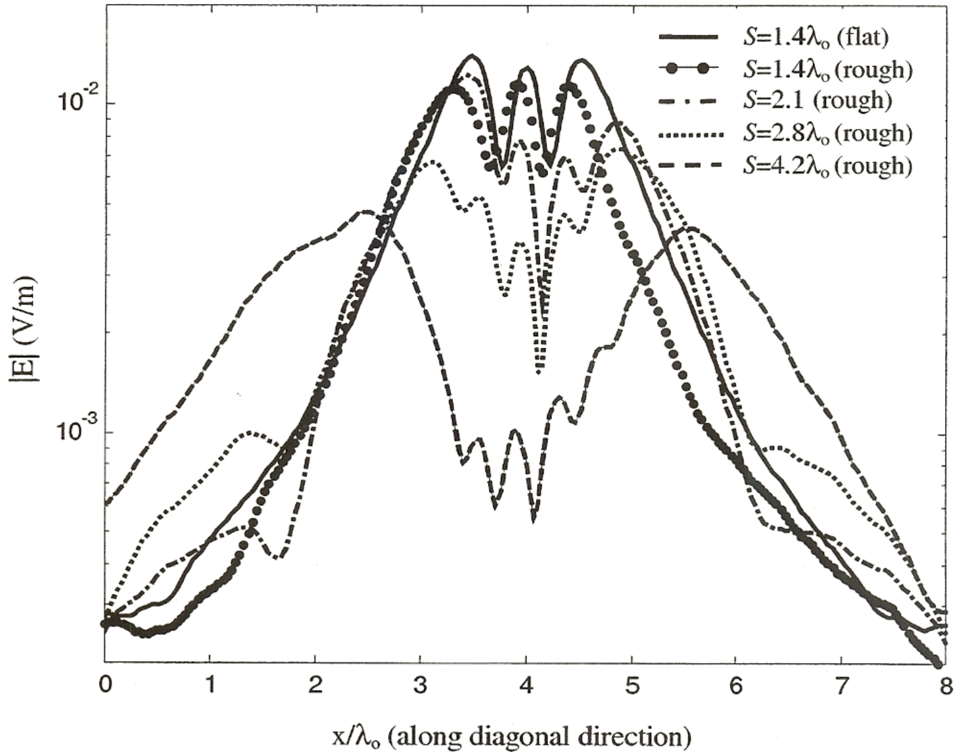

Fig. 2. Scattered near-electric field of just the two objects at normal incidence when S/λ_o =1.4-4.2 and ground roughness parameters are σ/λ_o=0.1 and l_c/λ_o=0.5. The separation distance S is shown in Fig. 1b.

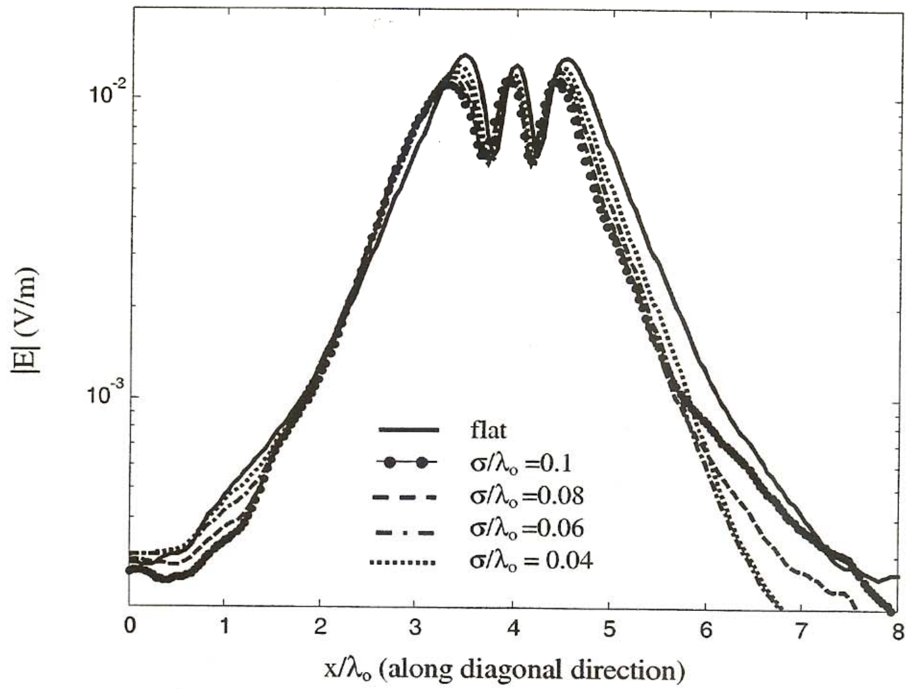

Fig. 3. Scattered near-electric field of just the two objects at normal incidence when $S/\lambda_o = 1.4$ and ground roughness parameters are $l_c/\lambda_o = 0.5$ and $\sigma/\lambda_o = 0.04$-0.1.

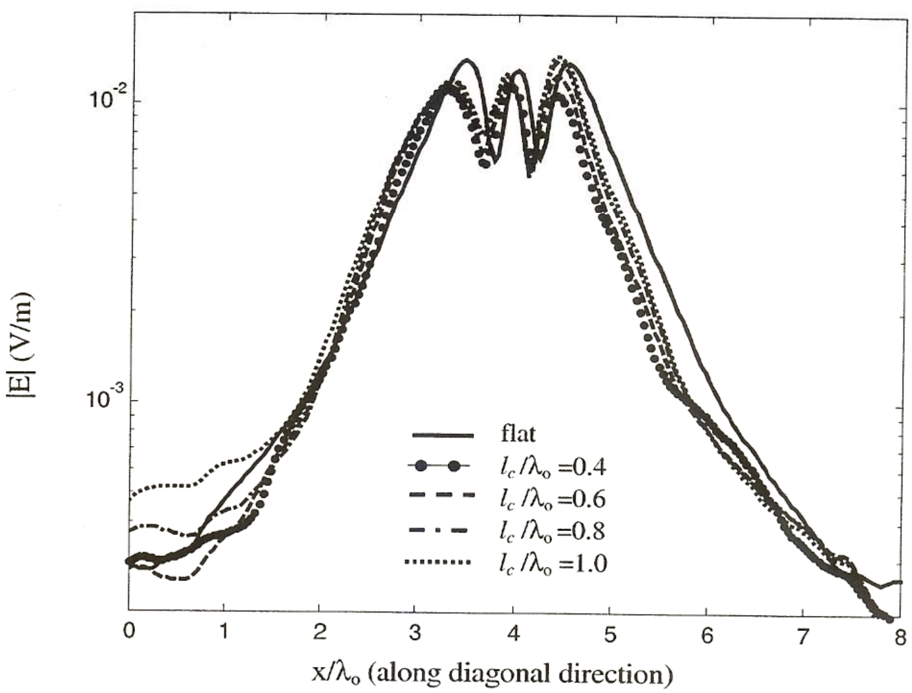

Fig. 4. Scattered near-electric field of just the two objects at normal incidence when $S/\lambda_o = 1.4$ and ground roughness parameters are $\sigma/\lambda_o = 0.1$ and $l_c/\lambda_o = 0.4$-1.0.

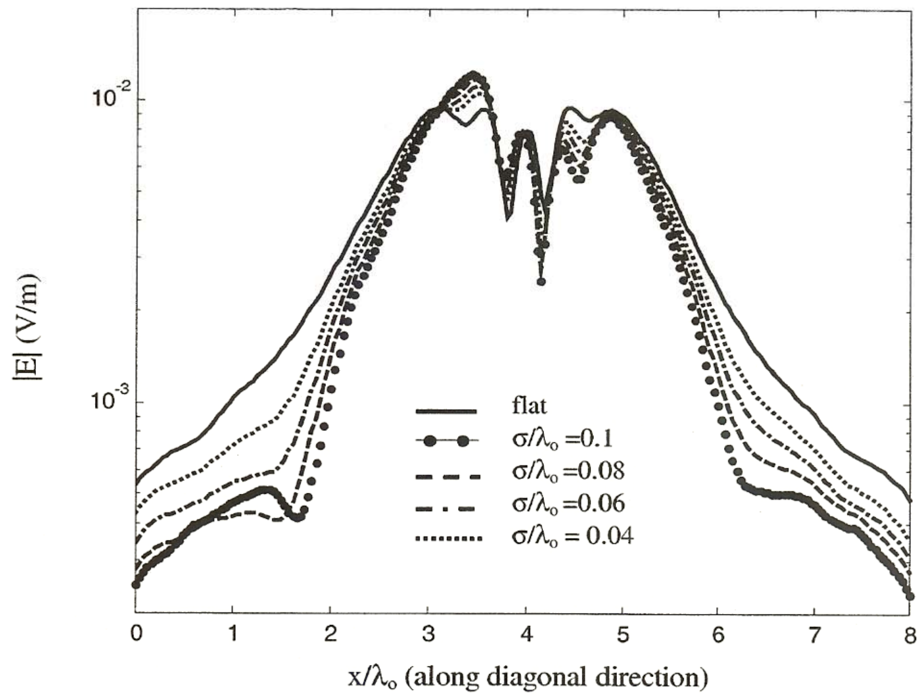

Fig. 5. Scattered near-electric field of just the two objects at normal incidence when S/λ_o=2.1 and ground roughness parameters are l_c/λ_o=0.5 and σ/λ_o=0.04-0.1

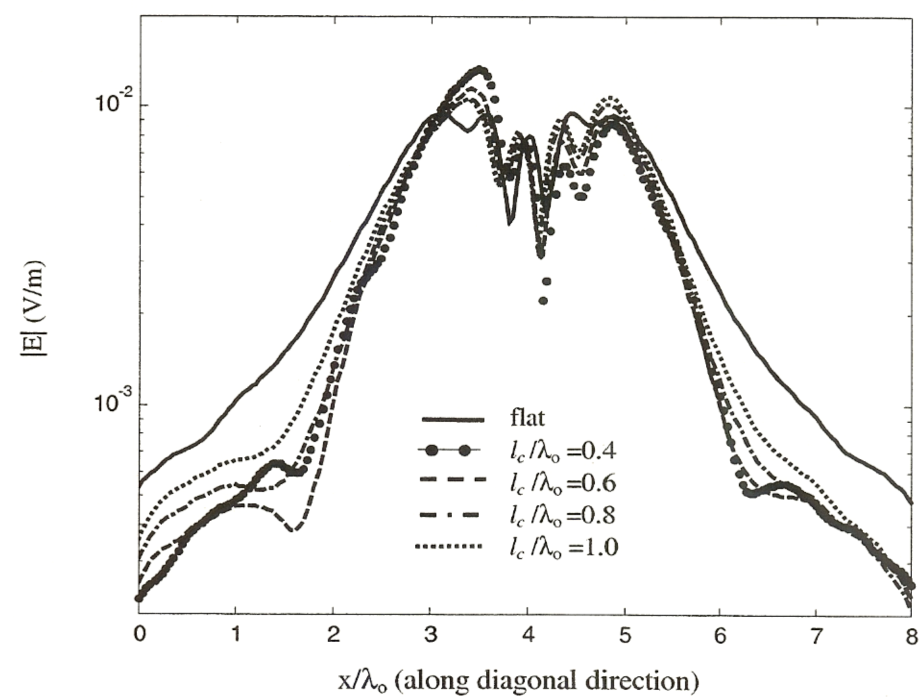

Fig. 6. Scattered near-electric field of just the two objects at normal incidence when S/λ_o=2.1 and ground roughness parameters are σ/λ_o =0.1 and l_c/λ_o =0.4-1.0.