Electromagnetic Scattering Interference Between Two Shallow Objects Buried Under 2-D Random Rough Surfaces

Magda El-Shenawee and Carey Rappaport

***Abstract*—A rigorous electromagnetic model has been used to analyze the scattering from two dielectric shallow objects buried under the two-dimensional (2-D) random rough ground (3-D scattering problem) as a means of predicting false alarms. The Method of Moments (MoM) accelerated by the Steepest Descent Fast Multipole Method (SDFMM) is used to compute the equivalent electric and magnetic surface currents on all scatterers (i.e., the rough ground and the two buried objects). The roughness parameters influence the scattering interference mechanism of the two objects, however, a large separation distance (e.g., several correlation lengths) showed stronger effect for small ground roughness.**

***Index Terms*—Multiple buried objects, rough surface scattering, Steepest Descent Fast Multipole Method (SDFMM).**

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 target 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], [2]. Using the $O(N)$ fast algorithm, the Steepest Descent Fast Multipole Method (SDFMM) [1], [5] tremendously accelerates the computations of the N unknown surface currents [1]–[5]. 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], [2]. The dependency of the observed scattering interference on the ground roughness parameters is investigated in this work.

It is necessary to mention that the SDFMM was validated with the MoM published in [6], with the Sparse Matrix Canonical Gradient (SMCG) method published in [7] and with the experimental measurements published in [8].

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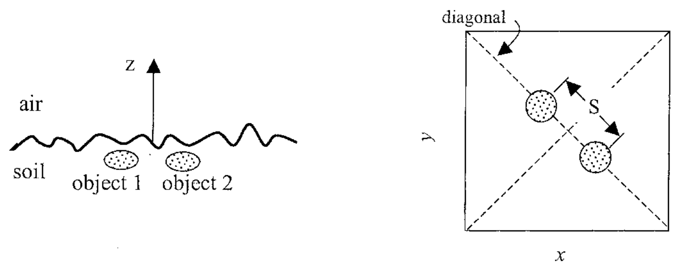

(a) (b)

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

II. Formulation

The rigorous electromagnetic model derived in [1], [2] is employed in this work where six integral equations are used to obtain the equivalent surface currents on the dielectric scatterers shown in Fig. 1 (3-D scattering problem). Four different regions are involved in this scattering problem; air, soil, first object 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 (Rao, Wilton, Glisson) vector basis functions [9]. 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 $2(N_1+N_2+N_3)\times 2(N_1+N_2+N_3)$ [1], [2]. 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]–[5].

III. Numerical Results

In this Section, we investigate the scattering interference between the two buried objects as a function of their separation distances and ground roughness parameters. 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 [10]. The 3-D objects are oblate spheroids with dimensions $a = c = 0.3\lambda_0$, $b = 0.15\lambda_0$

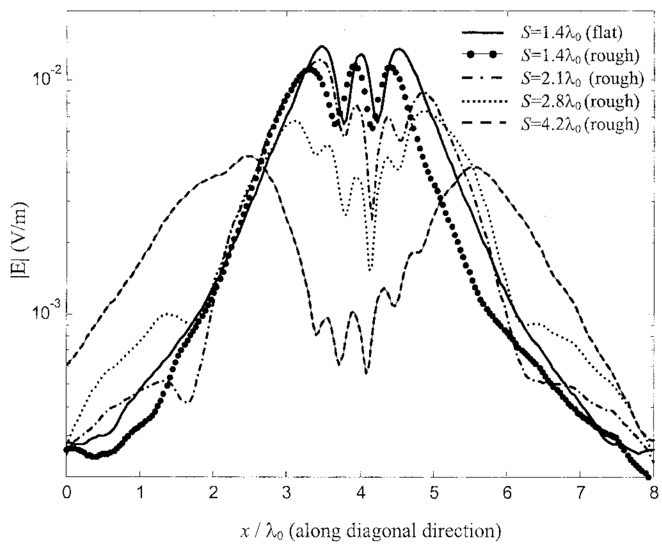

Fig. 2. Scattered electric near-field of just the two objects at $z = 0.5\lambda_o$ when $S/\lambda_0 = 1.4$–4.2 and ground roughness parameters are $\sigma/\lambda_0 = 0.1$ and $l_c/\lambda_0 = 0.5$. The separation distance S is shown in Fig. 1(b).

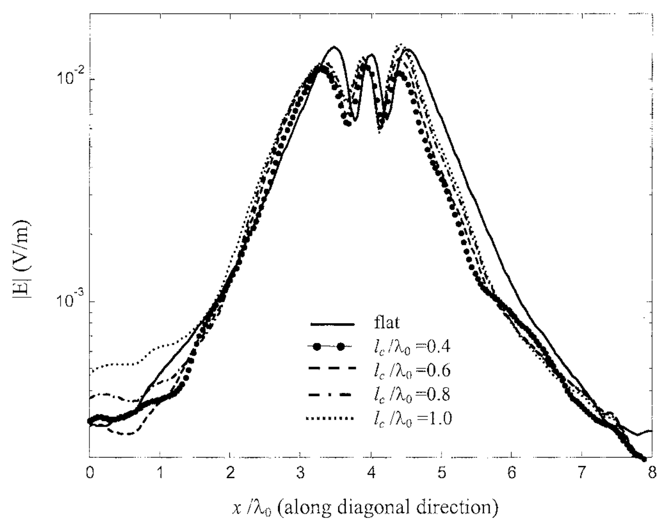

Fig. 3. Scattered electric near-field of just the two objects at $z = 0.5\lambda_o$ when $S/\lambda_0 = 1.4$ and ground roughness parameters are $\sigma/\lambda_0 = 0.1$ and $l_c/\lambda_0 = 0.4$–1.0.

and buried at depth $z = -0.4\lambda_0$ 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 $8\lambda_0 \times 8\lambda_0$ ground surface is discretized into 60 000 electric and magnetic surface current unknowns. Each object is discretized 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 [1], [2], [5].

In Fig. 2, the object signatures are plotted across the diagonal as shown in Fig. 1. When the two objects are separated by $S = 1.4\lambda_0$, 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

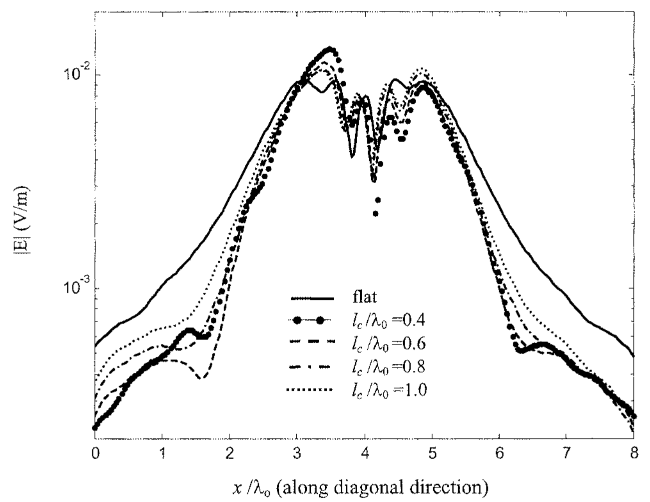

Fig. 4. Scattered electric near-field of just the two objects at $z = 0.5\lambda_o$ when $S/\lambda_0 = 2.1$ and ground roughness parameters are $\sigma/\lambda_0 = 0.1$ and $l_c/\lambda_0 = 0.4$–1.0.

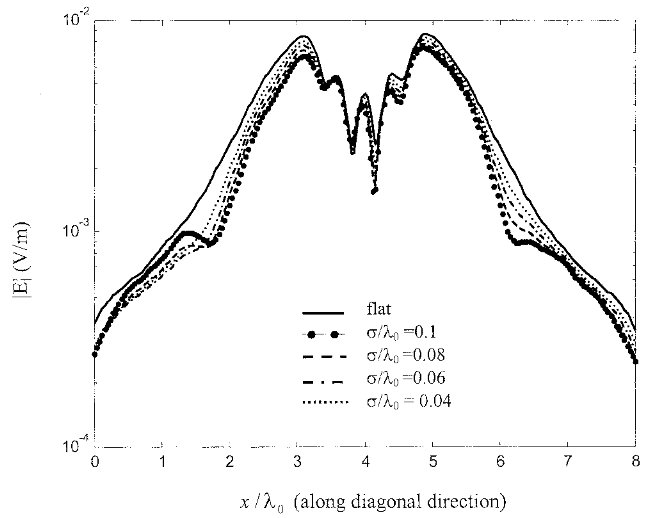

Fig. 5. Scattered electric near-field of just the two objects at $z = 0.5\lambda_o$ when $S/\lambda_0 = 2.8$ and ground roughness parameters are $l_c/\lambda_0 = 0.5$ and $\sigma/\lambda_0 = 0.04$–0.1.

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 $S = 2.1\lambda_0$ and $2.8\lambda_0$. These secondary peaks become insignificant when S is increased to $4.2\lambda_0$. As noticed in this figure, the asymmetry around the mid-point ($x = 4.0\lambda_0$) 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 (the ground center in this work). In Fig. 3, the separation distance is kept constant at $S = 1.4\lambda_0$, the rms height is kept constant at $\sigma = 0.1\lambda_0$ and the range for the correlation length l_c is from $0.4\lambda_0$ to $1.0\lambda_0$. The results clearly show the influence of the roughness parameters compared with the flat ground case. However, the strong interference (mid-point peak) is still observed in this case. Similar results were obtained upon varying σ from $0.04\lambda_0$ to $0.1\lambda_0$ and keeping the correlation distance constant at $l_c = 0.5\lambda_0$ (not presented here). This study is repeated

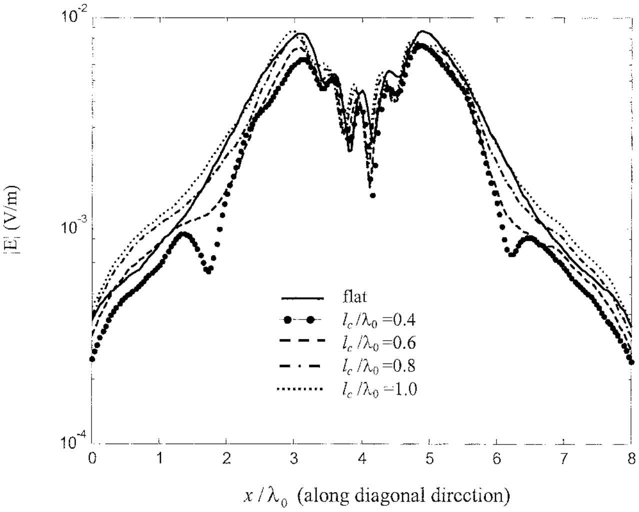

Fig. 6. Scattered electric near-field of just the two objects at $z = 0.5\lambda_o$ when $S/\lambda_0 = 2.8$ and ground roughness parameters are $\sigma/\lambda_0 = 0.1$ and $l_c/\lambda_0 = 0.4$–1.0.

for $S = 2.1\lambda_0$ as shown in Fig. 4 and for $S = 2.8\lambda_0$ as shown in Figs. 5 and 6. It is interesting to notice that when the separation distance becomes several correlation lengths, the number of secondary peaks increases as shown in Figs. 4–6. These results show that the effect of the separation distance between the two objects is dominating the scattering interference mechanism especially for the small ground roughness considered in this work.

IV. Conclusions

False alarms could easily occur because of the interference mechanism between the target and a clutter object, both are buried under the rough ground. The results show that the roughness parameters influence the scattered interference of the two objects, especially when their separation distance is several correlation lengths.

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