Bistatic Scattering from a Buried Object in A Two-Layered Media with Two Rough Interfaces Using FDTD

S. H. Mirjahanmardi, A. Tavakoli
Electrical Engineering Department
Amirkabir University of Technology
Tehran, Iran
shmirjahanmardi@aut.ac.ir

P. Dehkhoda
Institute of Communications Technology and Applied Electromagnetics
Amirkabir University of Technology
Tehran, Iran

Abstract—Here, finite difference time domain method is implemented to evaluate the electromagnetic scattering from a three dimensional buried object beneath a two dimensional rough surface with two sub-layers. The whole structure is illuminated by an incident Gaussian plane wave. Firstly, the convergence of the technique is checked and then its accuracy is proved by comparing the results with a full wave commercial software. Finally, the radar cross sections (RCS) of different cases are studied and the difference between the structure with the buried object and without the object is shown.

Keywords—Finite Difference Time Domain; Rough Surface; Layered Media; Buried Object.

I. INTRODUCTION

Electromagnetic scattering from layered media with rough interfaces including buried object(s) has been evaluated vastly by various analytical, semi-analytical methods. Examples of analytical methods are: the small perturbation method [1,2] and the small slope approximation [3]. Mode-expansion method is a kind of semi-analytical approach that is reported in [4]. Most of these studies have been done for buried object detection which has lots of applications such as underground water and pipe detection.

Because of limitations of the analytic methods and their complexity, a lot of researchers tend to solve the electromagnetic problems numerically [5-9]. Although a lot of numerical researches have solved scattered fields from rough surfaces in the presence of objects, few reports exist for layered media with buried object [8, 10] or without buried objects [11, 12].

In this paper a two-layered media with two rough interfaces is considered. Fig.1 shows the structure with an object beneath the rough surfaces. An incident plane wave excites the structure. A code based on finite difference time domain (FDTD) technique is developed and applied to evaluate the scattered electromagnetic (EM) fields and the radar cross section (RCS).

The theory of FDTD is not described here, as it is vastly in [13, 14]. The manuscript is organized as follows. In Section II, convergence of the method is checked for a two layered rough surface structure with a buried conductor (PEC) sphere in the middle layer. Then, in section III, the accuracy of the technique is verified by CST Microwave studio for an oblique incident excitation illuminating the structure that includes a lossy sphere in the lowest layer. Finally, the developed FDTD code is applied to calculate the scattered field and the RCS difference can be observed between absent and presence the object in section IV.

II. CONVERGENCE CHECK

Convergence check is the first step in developing any numerical approach. The results should converge to a certain value by decreasing the dimension of the discretized cells. Here, the problem for which we check the convergence is a two layered structure with two rough interfaces (Fig. 1) that have been generated using the following Gaussian function.
Figure 2: Evaluated Ex for various sizes of discretization cells versus time (ns) at the middle point 0.1λ₀ below the upper rough surface using FDTD.

\[ W(K_x, K_y) = \frac{h^2 l_x l_y}{4\pi} \exp\left[-(K_x^2 l_x^2 + K_y^2 l_y^2)/4\right] \]  

(1)

where \( K_x = 2\pi x/L_x \) and \( K_y = 2\pi y/L_y \). \( L_x \) and \( L_y \) are size of the surface along \( x \) and \( y \) directions, respectively, \( h \) is the root mean square (rms) height of the surface and \( l_x \) and \( l_y \) are correlation lengths of the rough surfaces directed in \( x \) and \( y \) directions, respectively.

The relative dielectric constants of the layers in Fig. 1 are \( \varepsilon_2 = 4.5 - j0.6 \), \( \varepsilon_3 = 6.5 - j0.798 \) and for the above half space is \( \varepsilon_1 = 1 \). \( \lambda_0 = 1\)m is the considered wavelength and the correlation lengths are \( l_x = l_y = 0.1\lambda_0 \) while \( h = 0.3\lambda_0 \). Thickness of the middle layer with \( \varepsilon_2 \) is 0.4\( \lambda_0 \) and the lower layer is truncated at 1.3 \( \lambda_0 \) thickness. Please be noted that for all cases of this paper, the infinite ground surface is truncated and limited to a 7\( \lambda_0 \) \( \times \) 7\( \lambda_0 \) structure. To overcome the reflection effect of truncation, eight cells of the convolutional perfect match layer (CPML) [15] are considered at the truncated sides.

An electric conductor sphere (PEC) with 0.2\( \lambda_0 \) radius is placed in the center of the structure at 0.3\( \lambda_0 \) beneath the average of upper rough surface. A \( x \)-polarized incident Gaussian plane wave with center frequency of 300 MHz impinges normally into the structure. The whole structure is discretized and FDTD code is applied to calculate the total \( x \) component of the electric field (Ex) at 0.1\( \lambda_0 \) below the average location of the upper rough surface. To obtain converged results, the dimension of the cells is decreased from 0.1\( \lambda_0 \) to 0.025\( \lambda_0 \) and the relative rms error is compared with a pre-defined value; here the determined error is set to be 4%. Fig. 2 and Table 1 show the Ex for different cell sizes versus time and the relative rms error at each discretization level, respectively.

<table>
<thead>
<tr>
<th>Size of Cells (mm)</th>
<th>Relative RMS Error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>-</td>
</tr>
<tr>
<td>60</td>
<td>19.36</td>
</tr>
<tr>
<td>50</td>
<td>11.32</td>
</tr>
<tr>
<td>40</td>
<td>9.84</td>
</tr>
<tr>
<td>30</td>
<td>8.90</td>
</tr>
<tr>
<td>25</td>
<td>3.48</td>
</tr>
</tbody>
</table>

All of the results given in Fig. 2 are normalized to the maximum value of electric field in each step. As in Table 1, the minimum error is 3.48% for the last state.

III. VERIFICATION

To verify the accuracy of the developed FDTD code, CST Microwave Studio is considered as the reference. A two layered ground with two rough interfaces is considered again. The media contains a lossy sphere with the relative dielectric constant of \( \varepsilon_r = 2.9 - j0.0029 \) in the center of the structure at 0.3\( \lambda_0 \) beneath the average of upper rough surface. The structure is illuminated by a \( x \)-polarized obliquely incident plane wave at \( \theta_i = 30^\circ \). The rough interfaces are sinusoidal with \( h = 0.1\lambda_0 \) and ten oscillations in the truncated area.

Table 1. Error calculation for each step by decreasing the size of cells

Here, to avoid long text, only results of two points are compared between the FDTD code and CST software in Fig. 3. The size of the cells are considered to be the same as the last convergence level in the previous section.
The third Iranian Conference on Engineering Electromagnetic (ICEEM 2014), Dec. 3-4, 2014

IV. NUMERICAL RESULTS

In this section bistatic RCS of a two layered rough interface structure with a buried object is studied. The structure of the ground is the same as in section III except that the rough surfaces are generated randomly by (1). A $0.8\lambda_0 \times 0.8\lambda_0 \times 0.6\lambda_0$ PEC rectangular cube is placed at $0.2\lambda_0$ below the average of the upper rough surface. The normal incident wave is the same as in section II. Fig. 4 compares RCS as a function of scattering observation angle ($\theta$) for $\phi=0$ for two cases; the media without the buried object and the media with the buried object. Please note that the results are normalized to the truncated area ($7\lambda_0 \times 7\lambda_0$). As expected, it is observed that the co-polarized coefficients have much significant values rather than cross-polarized ones. The maximum RCS difference between two cases occurs around $\theta=22^\circ$ in both co-polarized coefficients.

By increasing the size of the object to $1.2\lambda_0 \times 1.2\lambda_0 \times 0.6\lambda_0$ in Fig. 5, it is observed that as we expected the difference between the RCS of two cases is increased in the co-polarized RCS. As it is seen, the difference between two RCSs (with and without object cases) is not sensible around the backscatter. In the other words it is necessary to calculate bistatic scattering in different observing angles in order to detecting the buried object.

V. CONCLUSIONS

In this paper FDTD method was implemented to calculate the bistatic scattering from a rough layered media in the presence of buried object. The developed code was checked for its convergence and also verified by the CST Microwave Studio. Then, the RCS co-polarized and cross polarized characteristics were demonstrated for two cases of the rough media with the buried object and without the buried object. It is observed that the co-polarized RCS difference in two cases is increased for the larger objects. To show the ability of the developed code objects with sharp corner (box) and curved surface (sphere) were examined.
Figure 4. RCS scattering coefficients versus scattering observation angle, a) vertical-vertical, b) horizontal-horizontal, c) vertical-horizontal, d) horizontal-vertical coefficients.

Figure 5. RCS co-polarized scattering coefficient for a 1.2λ0×1.2λ0×0.6λ0 rectangular cube

REFERENCES


