On the Frequency-Band Selection for Ground-Penetrating Radars Operating Over Lossy and Heterogeneous Grounds

Uğur Oğuz* and Levent Gürel
Department of Electrical and Electronics Engineering
Bilkent University
Bilkent, Ankara, Turkey
(uoguz@cem.bilkent.edu.tr, lgurel@ee.bilkent.edu.tr)

1 Introduction

The finite-difference time-domain (FDTD) method is one of the most versatile modeling and simulation techniques used for the investigation of subsurface-scattering mechanisms involving arbitrarily complicated inhomogeneities. The adaptability of the perfectly-matched layer (PML) absorbing boundary conditions (ABCs) to lossy and layered media improves the suitability of the FDTD to simulate subsurface-scattering problems, such as ground-penetrating-radar (GPR) scenarios [1].

A typical GPR scenario, displayed in Fig. 1, consists of air, ground, the buried target, and the radar unit. In this paper, the air is modeled by vacuum, ground is modeled by a heterogeneous and lossy dielectric half-space, and the buried target is modeled by a conducting disk. The GPR unit contains a transmitter and a receiver taht are isolated by conducting shields in order to degrade the large direct coupling (D) to the receiver with respect to the signal scattered from an embedded body (S). Practical GPR shields include high-performance absorbers on the inner walls of shield walls in order to prevent the resonance effects. In this paper, the absorbers mounted on the inner walls of the shield walls are simulated using the PML ABCs. This GPR model including conducting shield walls and PML absorbers is designed especially for computational studies [2]. The transmitting antenna is an x-polarized dipole, modeled by a single Yee cube of constant current density. The receiver is also modeled as a small dipole that samples the x component of the electric field in time. The time variation of the current source on the transmitter is given in [2].

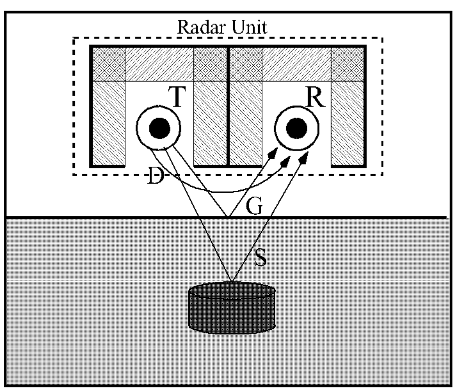

Figure 1: The typical GPR problem and the GPR configuration with a transmitter and a receiver.

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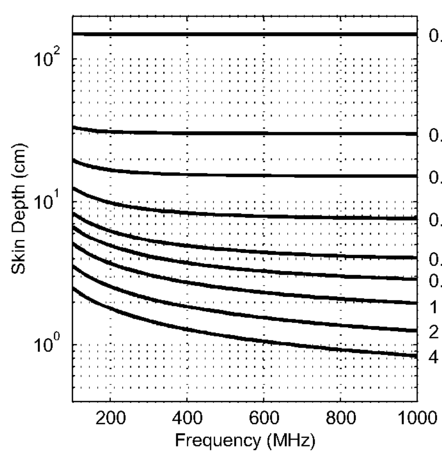
2 Properties of Lossy Media

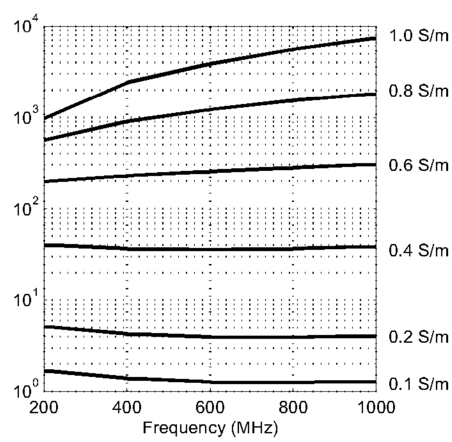
Although the electrical parameters, ϵ and σ, of real-life soils are almost constant for practical GPR frequencies [3], lossy grounds still yield different reflection and transmission coefficients for different frequency components. A useful parameter for the investigation of the relation between conductivity and frequency is the skin depth, δ, the distance through which the amplitude of a traveling wave decreases by a factor of $1/e$. Figure 2(a) displays the skin-depth values in the frequency band of 100 MHz 1 GHz for various conductivity values of a medium with $8\epsilon_0$ permittivity and μ_0 permeability. Figure 2(a) demonstrates that the skin depth of the medium has a small percentage of change in this frequency band for the conductivity values smaller than 0.2 S/m. However, after 0.2 S/m, the skin-depth values start to show more variation as the frequency is increased from 100 MHz to 1 GHz.

3 Simulation Results for Homogeneous Grounds

In this section, the results of simulations performed at a stationary point above the ground, i.e., A-scan results, will be presented. In these simulations, perfectly conducting disks, with 2.5 cm radius and 4 cm height, are buried 2.5 cm and 10 cm under the ground with $8\epsilon_0$ permittivity. The scattered-signal energies of the 2.5-cm-deep and 10-cm-deep targets are computed to reveal the amount of decay encountered by the incident wave as it propagates in the ground. The ground conductivity varies between 0.1 S/m 1.0 S/m and the center frequency is varied between 200 MHz–1000 MHz. For all configurations, the energy of the signal received from the 2.5-cm-deep target is divided by the energy of the signal received from the 10-cm-deep target. The resulting ratios are plotted in Fig. 2(b), which demonstrates that for conductivities below 0.5 S/m, changing the center frequency does not influence the energy scattered from the deeper target. However, after 0.6 S/m, decreasing the center frequency of the source signal from 1000 MHz to 200 MHz increases the relative energy of the target buried at 10 cm.



(a)



(b)

Figure 2: (a) The skin-depth values of the grounds with conductivities between 0.01 S/m 2.0 S/m. (b) The ratios of the energies of the S signals, scattered from targets buried 2.5 cm and 10 cm under the ground.

4 Simulation Results of Heterogeneous Grounds

In order to further demonstrate the effects of the frequency selection on the scattered signals, the B-scan simulation results of the shielded GPR model obtained above a highly-conductive heterogeneous medium will be given. The referred ground model, displayed in Fig. 3, is densely heterogeneous, containing 80 holes in the ground-air interface, 100 highly conducting and 200 less conducting small scatterers embedded in the ground. The target is a conducting disk with 2.5 cm radius and 4 cm height, buried 5 cm under the ground. Figures 4–6 present the scattered-field images of the conducting disk obtained with 200 MHz and 1000 MHz and 0.05 S/m, 0.2 S/m and 0.6 S/m ground conductivities, respectively. The scattered-field signals are obtained by subtracting an average D+G signal, which is extracted from extra simulations involving a target-free ground.

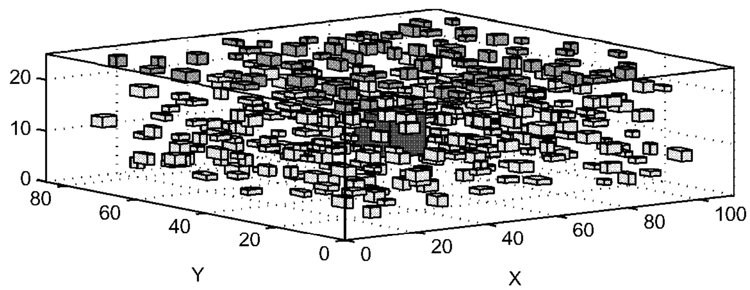


Figure 3: The heterogeneous ground model.

Figure 4 demonstrates that for the 0.05 S/m value of the ground conductivity, it is possible to visually detect the buried disk with both 200 MHz and 1000 MHz center frequencies. On the contrary, when the conductivity is increased to 0.6 S/m, it is not possible to observe the signals scattered from the disk for either center frequencies. However, for the 0.2 S/m conductivity value of the ground, the GPR with 200 MHz center frequency can detect the target, while the GPR with 1000 MHz center frequency cannot.

5 Concluding Remarks

The FDTD method and the PML ABC is applied to demonstrate the conductivity-frequency relations in a three-dimensional GPR problem involving lossy and heterogeneous ground. The selection of the center frequency of the source signal can influence the GPR measurements if these measurements are performed above a highly-conducting soil. However, since the skin depth of a typical ground model, with a conductivity value around 0.1 S/m, does not change rapidly, the enhancement of the target detection is not certain with the alteration of the center frequency.

References

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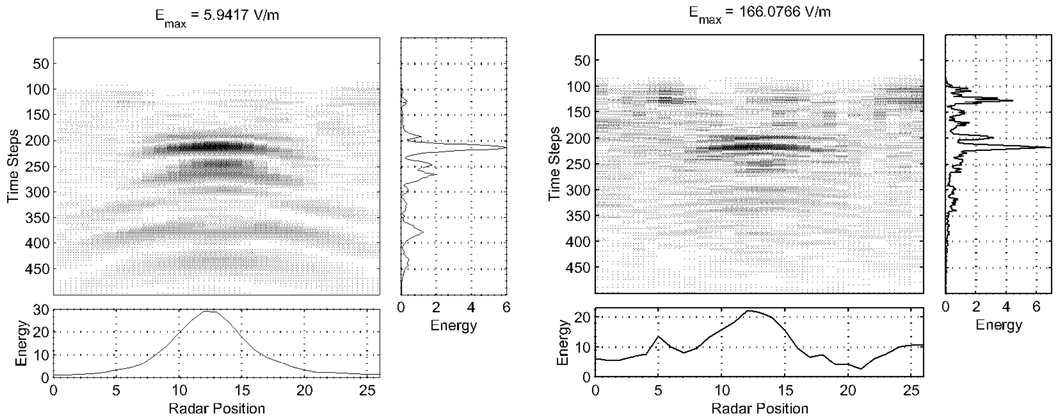
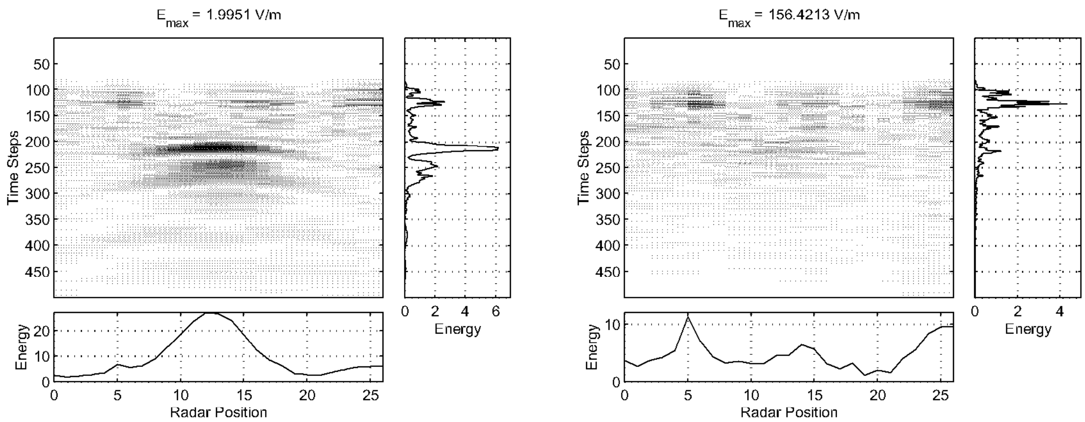
[2] U. Oğuz and L. Gürel, "Modeling of ground-penetrating-radar antennas with shields and simulated absorbers," *IEEE Trans. Antennas Propagat.*, accepted.

[3] D. J. Daniels, *Surface-Penetrating Radar*. London: IEE, 1996, Ch. III, pp. 33 60.



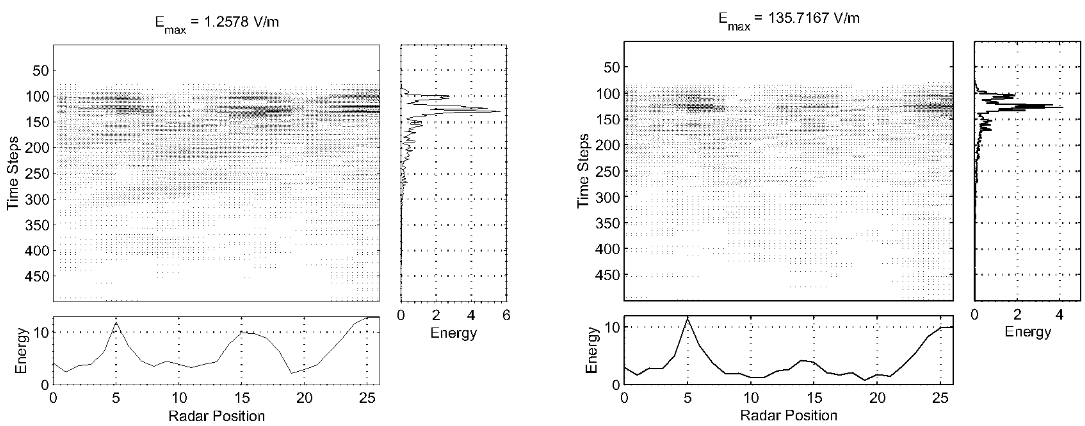
(a) (b)

Figure 4: Simulation results of a conducting disk, buried under a ground with conductivity 0.05 S/m, obtained at (a) 200 MHz and (b) 1000 MHz center frequency.



(a) (b)

Figure 5: Simulation results of a conducting disk, buried under a ground with conductivity 0.2 S/m, obtained at (a) 200 MHz and (b) 1000 MHz center frequency.



(a) (b)

Figure 6: Simulation results of a conducting disk, buried under a ground with conductivity 0.6 S/m, obtained at (a) 200 MHz and (b) 1000 MHz center frequency.