Numerical Study of the Scattering of a Short-Pulse Plane Wave by a Buried Sphere in a Lossy Medium

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ABSTRACT

The scattering by a buried sphere in the frequency domain with the use of the Finite Element Method (FEM) implemented by COMSOL Multiphysics, is analyzed. A short-pulse is used as an excitation with the spectrum spanning from 50 MHz to 1 GHz. In order to validate our results, a comparison with data available in the literature is presented, in the simple case of a perfectly-conducting (PEC) sphere. Afterwards, to gain insight on the role of the sphere radius and the distance of the buried sphere from the interface, other simulations are performed. The case of a dielectric sphere, instead of the perfectly-conducting one, is studied too.

INTRODUCTION

Exploiting the scattered electromagnetic waves from underneath the soil, the Ground Penetrating Radar (GPR) is a device that can detect the presence of objects buried in the earth [1]. For the study of GPR systems a great variety of numerical methods, from analytical approaches to time and frequency domain algorithms, have been employed [2].

Believing that COMSOL Multiphysics' RF module may be used to study the field solution for the impinging radiation on buried objects, the canonical problem of the scattering of a plane wave by a buried sphere in a lossy medium, which has been extensively studied in the past, has been modeled and validated: the comparison of the solution obtained by COMSOL with the data available in literature [3] offers a means to assess the accuracy of the simulations results.

STATEMENT OF THE PROBLEM

A sphere with radius *a* is buried in a half-space filled by a dispersive lossy medium at a distance *h* from the interface. We choose the origin of the referring frame to coincide with the center of the sphere as shown in Fig. 1.

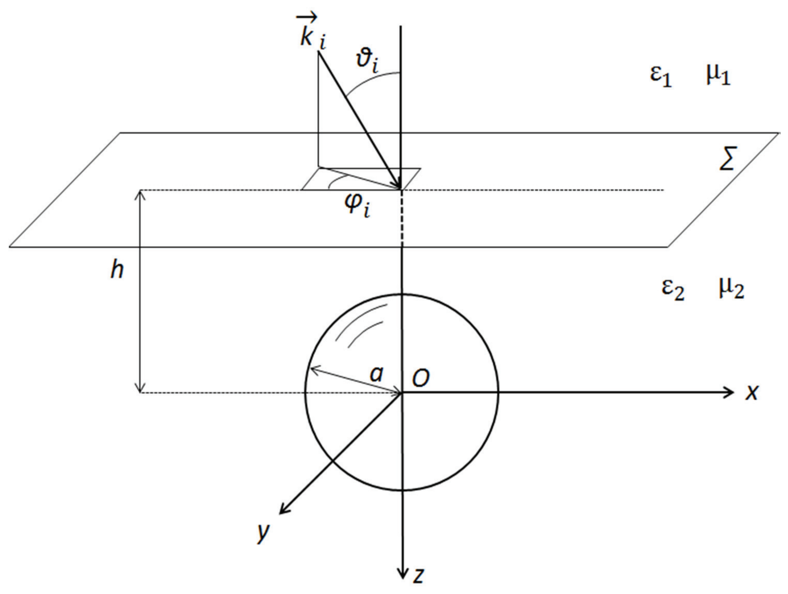


Fig. 1. Geometry of the problem.

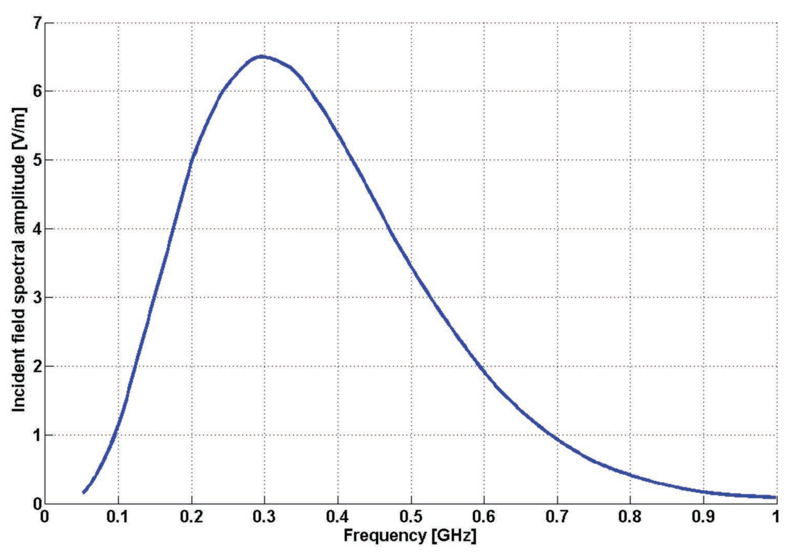


Fig. 2. Spectrum of the incident short-pulse field.

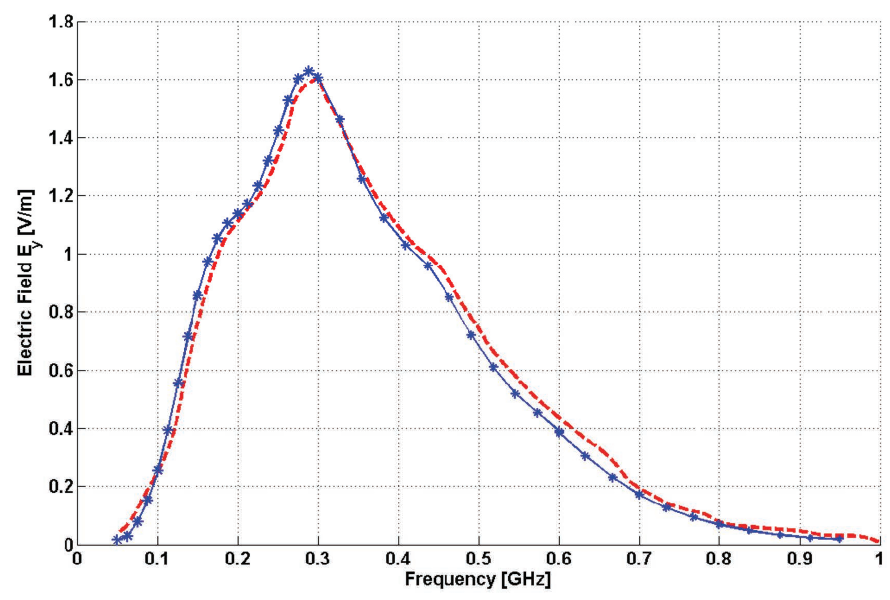
The excitation considered is a short-pulse with a spectrum spanning from 50 MHz to 1 GHz (Fig. 2), formed by a linearly s-polarized plane wave impinging normally to the interface, i.e., $\vartheta i=\varphi i=0$. The dispersion of the soil, supposed to be slightly wet clay, is implemented in COMSOL by interpolation of experimental data. This excitation is taken into account to be consistent with [3].

The RF module's scattered field formulation is used. The background field is analytically specified as follows:

$$\underline{E}_b(\underline{r}) = \begin{cases} \underline{E}_0 e^{i\underline{k}_i\cdot\underline{r}} + R\underline{E}_0 e^{i\underline{k}_r\cdot\underline{r}} e^{i\varphi_r} & z < -h \\ T\underline{E}_0 e^{i\underline{k}_t\cdot\underline{r}} e^{i\varphi_t} & z > -h \end{cases}$$

where R and T are the Fresnel reflection and transmission coefficients, respectively.

MODEL VALIDATION



As can be observed in Fig. 3, an excellent agreement between the COMSOL results and the reference data exists in the entire frequency range of interest.

Fig. 3 Comparison of the results obtained by COMSOL (continuous blue line) and those of Vitebskiy et al. [3] (dashed red line), for *a=15* cm and *h=30* cm.

SIMULATION RESULTS

Having established the validity of our model, in order to point out the effects of the variation of the geometrical parameters on the scattered field, we study the dependence of the scattered field with respect to the radius and depth of a PEC sphere (Fig. 4, 5) and that of an air sphere embedded in glass (Fig. 6-8).

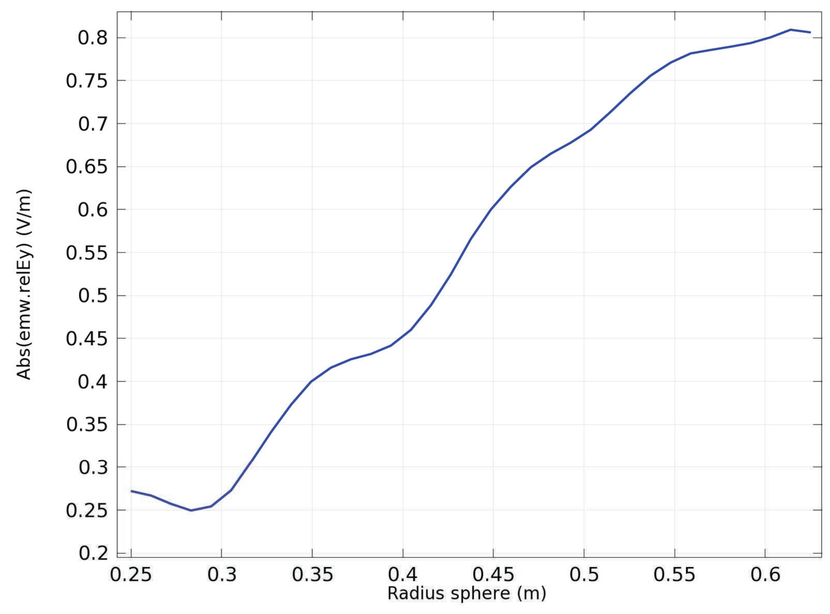


Fig. 4 Absolute value of the scattered electric field by a PEC sphere for *h=30* cm and radius varying from a_{min} =25 cm to a_{max} =2.5a_{min}).

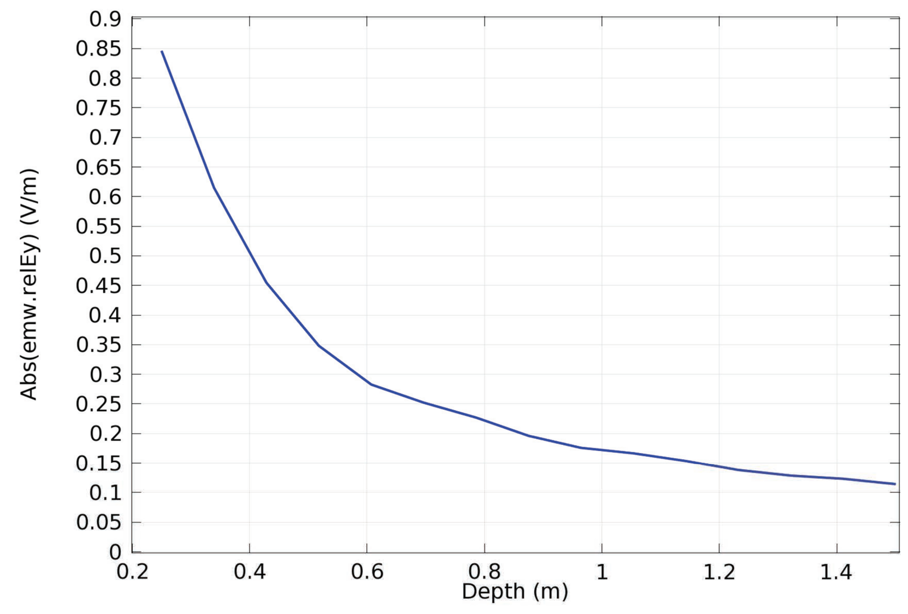


Fig. 5 Absolute value of the scattered electric field by a PEC sphere for *a=25 cm* and the depth varying from h_{min}=a to h_{max}=6a).

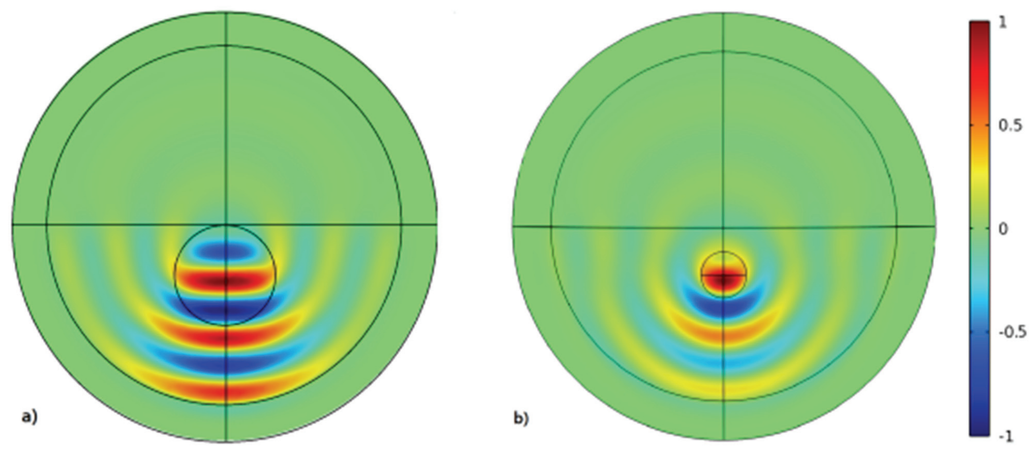


Fig. 6 Normalized scattered electric field by an air sphere on the plane *y=0* for a) $a = a_{max}$ =62.5 cm; b) $a = a_{min}$=25 cm.

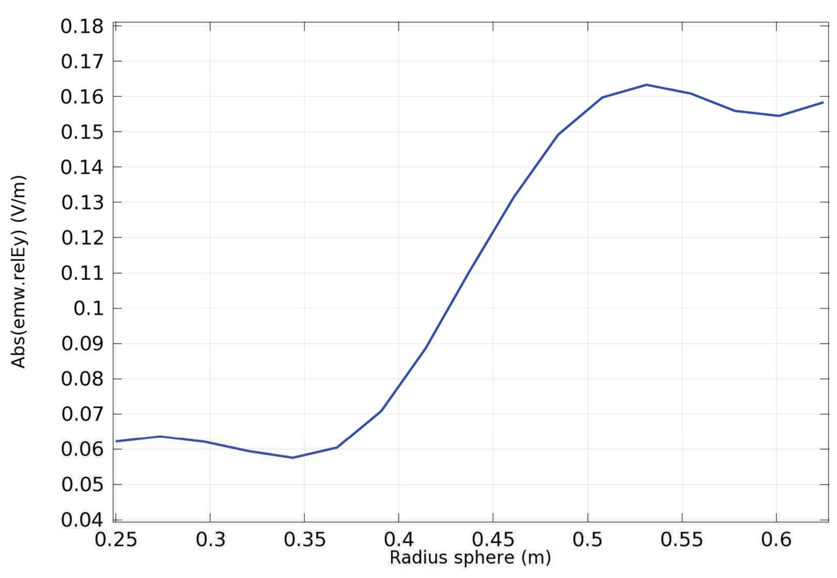


Fig. 7 Absolute value of the scattered electric field by an air sphere for *h=30* cm and radius varying from a_{min} =5 cm to a_{max} =62.5 cm.

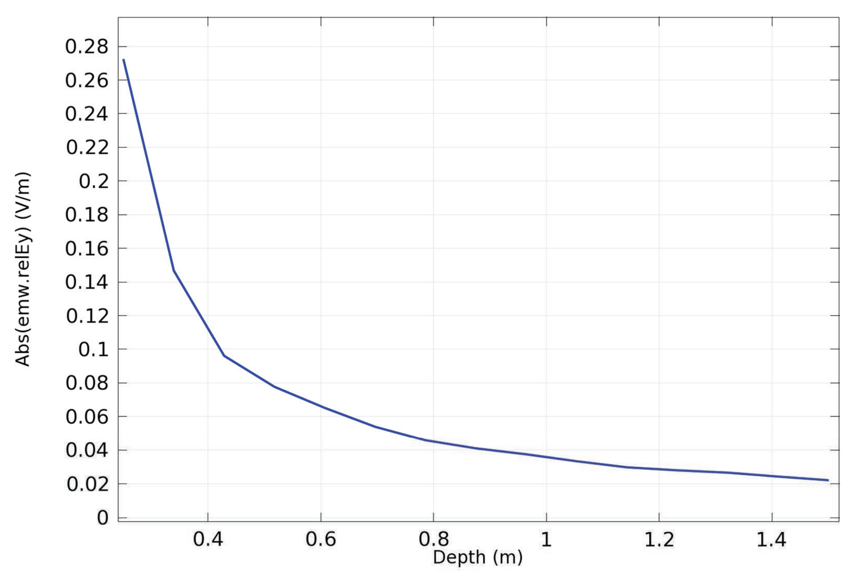


Fig. 8 Absolute value of the scattered electric field by an air sphere for *a=25 cm* and the depth varying from h_{min}=a to h_{max}=6a).

CONCLUSIONS

The simulation results provided by the COMSOL model used to calculate the field scattered by a buried PEC sphere are in very good agreement with previously published data. The RF module has been found to be a versatile and efficient tool for the study of the canonical problem of a buried sphere in a lossy medium in different configuration schemes. In future works, we plan to use the Transient Electromagnetic Waves Interface for the study of these canonical problems to compare the results obtained by employing other methods, both analytical and numerical..

REFERENCES

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