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Performance of GPR Influenced by Electrical Conductivity and Dielectric Constant

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Abstract

The geological radar or GPR (Ground Penetrating Radar) is an electromagnetic system used in non-destructive investigations of subsoil. It is based on the emission by an antenna coupled to the ground, of short electromagnetic pulses of harmonic waves sweeping a certain frequency band. We discuss in this work, the simulation of radar signals GPR, using Reflexw. Note, however, that the operation of this program is based on numerical methods including finite difference method time domain (FDTD) for this software. The simulations we have performed include the following items: an iron bar, a plastic tube and a plastic water bottle. Have led us to find that the electromagnetic waves are very sensitive to variations in the dielectric permittivity and electrical conductivity.

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Keywords: Ground Penetrating Radar; electrical conductivity; dielectric constant; influence.

1. Introduction

The purpose of this part is to make a theoretical study by simulating the propagation of electromagnetic waves from the ground radar in heterogeneous media (geological). The phenomenon of propagation will be considered through the reflected waves: principle on which the GPR work [1, 2].

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The software Reflexw, enabled us the simulation of the ground as a function of its electrical and magnetic parameters. A number of models have been designed to simulate the variety of geological conditions. A rectangular block was used an initial model for simulation. The first model is a simple profile to give an idea on the propagation of electromagnetic waves in different materials and the effects of electromagnetic parameters (σ, ε and μ) on the wave. The second model is used to study the propagation of electromagnetic waves (reflected waves) in geological backgrounds from radargrams.

Ground-penetrating radar (GPR) is a geophysical method that employs an electromagnetic technique. The method transmits and receives radio waves to probe the subsurface. And the method has been extensively used in many applications, such as archaeology, civil engineering, forensics, geology and utility detection [3].

Dielectric constant of the host material plays an important role in GPR technology [5]. Finding out the velocity and the depth of the target dielectric constant is important. In this study it is aimed to identify the behavior of GPR waves under different dielectric constant of the hosting material [6]. The electrical properties of the ground directly beneath a ground penetrating radar (GPR) antenna very close to the earth's surface (ground-coupled) must be known in order to predict the antenna response. In order to investigate changing antenna response with varying ground properties, a series of finite difference time domain (FDTD) simulations were made for a bi-static (fixed horizontal offset between transmitting and receiving antennas) antenna array over a homogeneous ground [10, 7]. The FDTD approach to the numerical solution of Maxwell's equations is to discretize both the space and time continua. Thus, the spatial and temporal discretization steps play a very significant role since the smaller they are the closer the FDTD model is to a real representation of the problem [8]. However, the values of the discretization steps always have to be finite, since computers have a limited amount of storage and finite processing speed. Hence, the FDTD model represents a discretized version of the real problem and of limited. Construction and Building Materials [9]. The building block of this discretized FDTD grid is the Yee cell named after Kane Yee who pioneered the FDTD method [4, 11]. The interactions of EM waves with physical media can be quite complex and the most exact models known for EM interactions use quantum mechanics [12].

2. Theoretical background

EM in subsurface material is dominate by Maxwell's equation and its behavior in subsurface material is strongly dependent on its electrical conductivity and dielectric constant (ε_r) and we can express the electric and magnetic fields as in equation 1

$$\begin{aligned} \Delta \times E &= -jw\mu H \\ \Delta \times H &= E\sigma + w\varepsilon E \end{aligned} \tag{1}$$

The radar wavelet propagates through the soil while the velocity of the wavelet depends on the dielectric properties of the ground as Eq 2:

$$v = c/\sqrt{\varepsilon_r} \tag{2}$$

GPR transmits a pulsed electromagnetic wave from a transmitter and signals are received by a receiving antenna. The transmitted signal propagates through the subsurface material and reflected by objects given through Eq 3 and refraction of electromagnetic waves is formulated by Snell's law Eq 4 [3]:

$$R = \left(\sqrt{\varepsilon_2} - \sqrt{\varepsilon_1}\right) / \left(\sqrt{\varepsilon_2} + \sqrt{\varepsilon_1}\right) \tag{3}$$

$$\sin\alpha_1 / v_1 = \sin\alpha_2 / v_2 \tag{4}$$

where α_1, α_2 are attenuation coefficient of materials.

3. Results and discussion

3.1. Simulation of GPR signals for a few objects

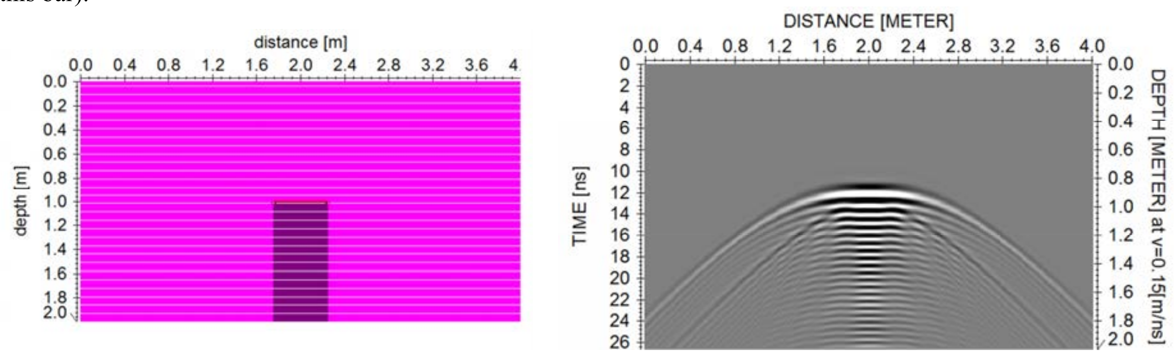
To simulate GPR signals requires a number of parameters, as the frequency of the antenna used, the geometry of the subsoil well as the dielectric permittivity, the magnetic permeability and electrical conductivity the interfering backgrounds in the simulation, physical properties of materials as shown in Table 1.

Table1: Physical properties of materials [3]

Material	Relative permittivity	Conductivity (S/m)
Plastic	3	0.00004
Iron	1.45	$9.99*10^{6}$
Freshwater	81	0.0005
Dry sand	3	0.00001

- **Buried iron bar**

To perform the simulation with Reflexw, the ground, in which the bar is buried, is simulated by concrete whose dielectric characteristics are presented in Table 1. The iron bar is buried at a depth of 1 m and is located, on the surface, between 1.75 m and 2.25 m of X-axis (Fig.1a). The simulation frequency is set at 800 MHz. Each emission and reflection of the simulated signal are recorded on a time window of 30 ns with a space increment of 7 cm. The results obtained are synthesized and displayed as radargram shown in Fig 1b. In this figure we notice the presence of two diffraction hyperbole that indicates the presence of iron bar (exactly the depth at which it was assumed buried this bar).



a b

Fig.1. Radargram of the buried iron bar in the concrete at a depth 1m. (a) Modeling (b) Simulation by Reflexw

- **Buried plastic tube without water**

The plastic object is considered very low conductivity as shown in Table 1. One makes the simulation, as in the previous case, in dry sand at a depth of 1 m (Fig .2b), the modeling as shown in Figure 2a.

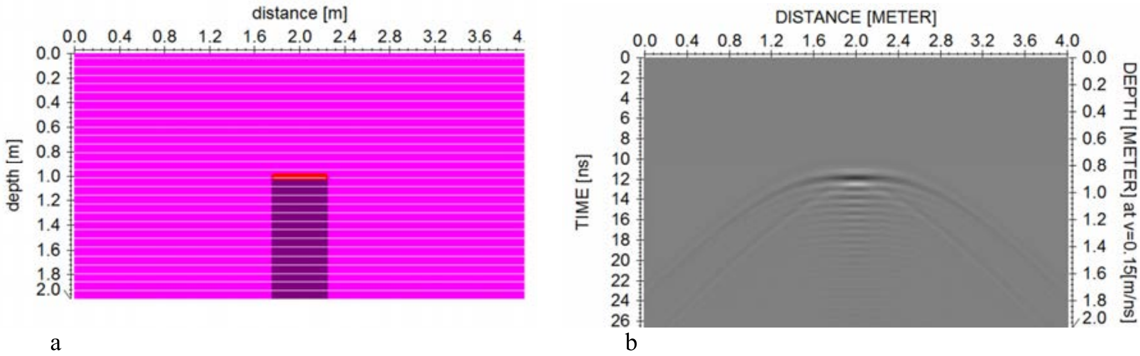


Fig.2. Radargram of a plastic tube buried in the dry sand at a 1 m; (a) Modelling; (b) Simulation by Reflexw

- **Buried plastic tube with water**

In Figure 3 the simulation proposed in this section concerns a plastic tube containing water which is a high electrical permittivity element as shown in Table 1. One makes the simulation, as in the previous case, in dry sand at a depth of 1 m. Figure 3a reveals the presence of several hyperbolas corresponding to several consecutive reflections but at different times for the frequency used (800 MHz). Indeed, the water contained in the plastic tube, considered a dielectric, has a high permittivity which reduces the propagation velocity of the electromagnetic waves. This accounts for the delay observed when receiving the signal. In this figure we can observe the subhorizontal and sub-parallel interface of the plastic tube.

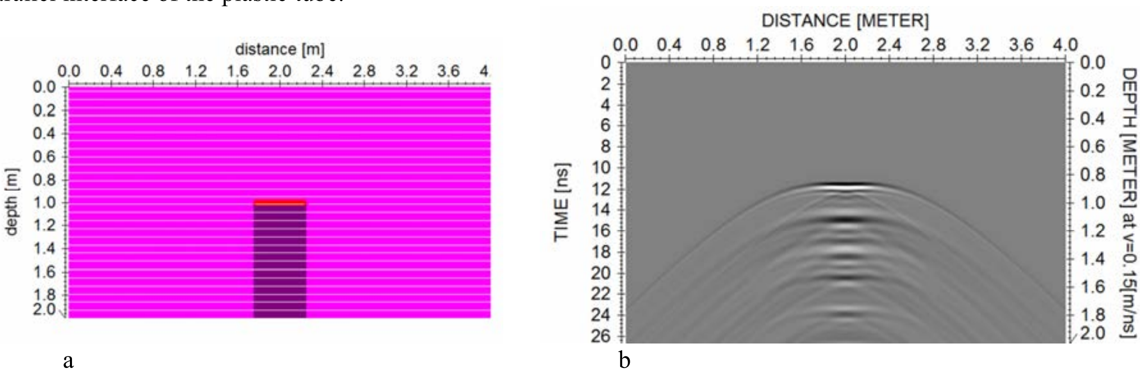


Fig.3. Radargram of a plastic tube filled with water buried in the dry sand. (a) Modeling (b) Simulation by Reflexw.

3.2. Cavity models

This model consists of a buried cavity in the concrete, depending on the material with which the cavity is filled and this model gives an idea about the form of several geological media, physical properties of materials as shown in Table 2.

Table 2: Physical properties of materials [3]

Material	Relative permittivity (F/m)	Conductivity (S/m)
Dry sand	3	0.00001
Air	1	0
Concrete	5	0.001
Clay	19	0.002

This model is a geologic medium of 4m wide and 1m deep. It is constituted by a circular cavity of 0.1 m in diameter within the concrete to a depth of 0.5m from the ground surface. The medium in which the cavity is buried is composed of air: the diagram of this structure is given in Fig 4a.

To study the effect of the geological medium constituting the cavity on the propagation of the electromagnetic wave, we made several simulations using the same materials which were used. This allows us to see the response of geological radar in the case of a cavity which is a very close case of reality (pipe, mine, air cavity and other defects in the soil) as shown in figures 4b, 4c, 4d.

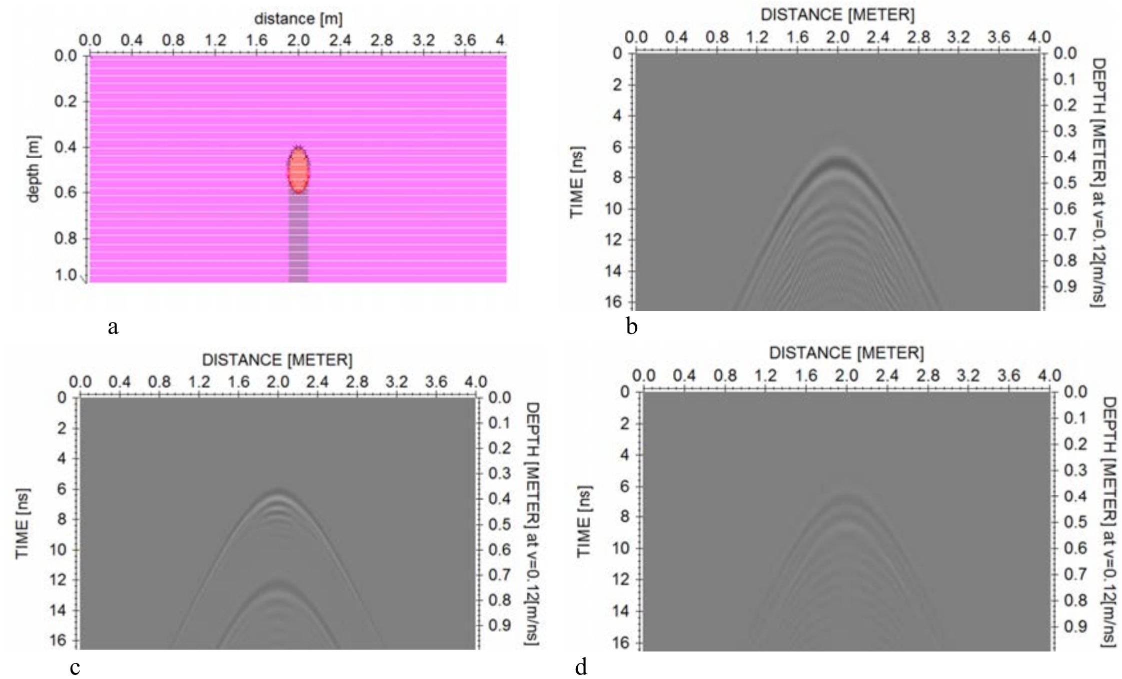


Fig .4. Radargram of the filled cavity model (a) Modeling (b) Air cavity; (c) Clay cavity; (d) Dry sand cavity

4. Conclusion

The obtained results from the simulations that were conducted on different buried objects (iron bar, tube and plastic bottle) have shown that detection of these objects by the GPR radar is possible. This needs signal processing of the obtained radargrams. A hyperbola that appears in a radargram indicates the existence of a buried object. Its depth can be determined by considering the hyperbola apex. The other part of this work was about simulation of different geological mediums to understand the phenomenon of the propagation of electromagnetic waves in the ground as it is affected by the medium heterogeneity and texture. The change of the permittivity causes the reflection of the electromagnetic waves, while the conductivity attenuates these waves. The higher is the permittivity of the dielectric medium, the higher is the amplitude of the reflected waves.

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