Accurate Analysis of GPR First-Arrival Signals for the Evaluation of Soil Permittivity Parameters

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ABSTRACT

The possibility to obtain a quick estimation of the soil electromagnetic (EM) parameters by means of a simple fixed-offset GPR system is a topic of increasing scientific interest. In effect, a quite straightforward and attractive technique has recently been proposed [1],[2], which basically exploits the dependence of interfacial-antenna transmitted/received (Tx/Rx) signals on the EM parameters of the background medium. Various theoretical and experimental investigations have been presented and discussed in previous investigations [3],[4], with the aim of quantifying the physical parameters affecting the features of the received 'first-arrival wave' (also known as 'early-time signal', ETS). Type, location, and distance of the Tx/Rx antennas, as well as the transmitted waveforms, deeply affect the features of such GPR 'footprints'.

In order to assess the practical potentials of this approach for evaluating the soil permittivity parameters, in this contribution an extensive analysis is implemented by means of a numerical EM tool for evaluating the GPR ETS features. Experimental investigations with commercial GPR systems from appropriate laboratory scale measurements (see Fig. 1(a)), have also been performed and discussed in connection with what derived theoretically and numerically [2],[4].

Critical issues of such procedures are related both to the definition of what are the more revealing 'signal attributes' [1],[2] that enable for predictable correlation to the ground permittivity values, and to what kind of 'functional relations' can be derived among the involved physical parameters.

The proposed numerical analysis basically considers a ground-coupled GPR model (as sketched in Fig. 1(b)), which is capable to accurately represent the detected ETS in realistic operative scenarios. In Fig. 2(a), a comparison between simulated and measured time-domain traces has been reported, where direct and reflected wave contributions are emphasized in a specific environment. Such a result shows that our numerical setup is able to adequately represent the various signal contributions in typical ground-coupled antenna configurations.

This powerful instrument allows us to extensively analyze the ETS obtained, e.g., by changing the relative permittivity value ε_r of the background medium, as shown in Figs. 2(b) and 2(c), where the ETS trace and the relevant 'instantaneous envelope' are shown, respectively.

Different 'observable parameters' have been investigated in order to achieve a consistent and possibly predictable behavior of the ETS features with respect to the permittivity variations. As an example, in Fig. 2(d) the normalized value of the energy of the collected signals has been evaluated, which shows a good 'excursion' (i.e., 'resolution') between maximum and minimum values of permittivity (especially for value of ε_r up to 10). In this frame, also an innovative 'spectral approach' has been investigated, based on a suitable evaluation of the behavior of the carrier frequency amplitudes of the collected signals.

As a result of these analyses, novel promising outcomes have been grasped with the purpose of assessing the effective potential of this technique in operative conditions.

References

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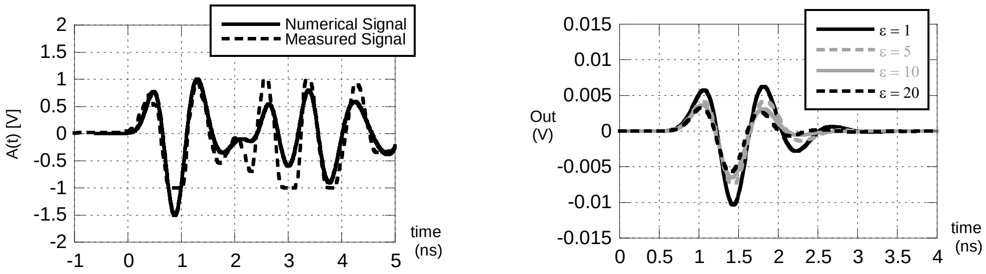
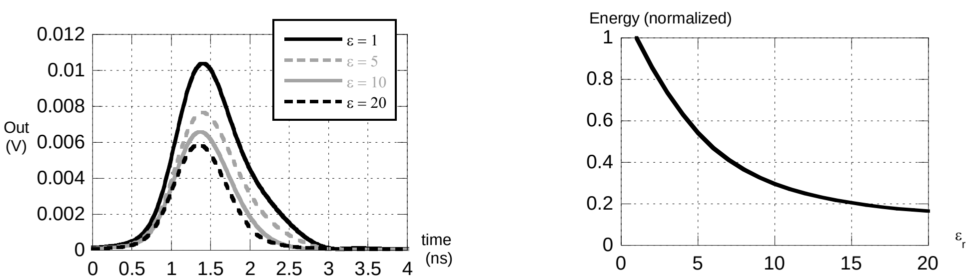
(a) (b)

Figure 1. Experimental (a) and numerical (b) setups for the analysis of ETS features. An air/dielectric (sand) environment is investigated by means of a GPR system with fixed interfacial antennas. The ground parameters can be changed in controllable ways.



(a) (b)



(c) (d)

Figure 2. (a) A typical measured signal voltage waveform *A* vs. time *t* (dashed line) gathered by a GPR, compared to a numerical trace(solid line) derived by the simulation setup. Direct and first reflected waves, due to the presence of a bottom metal sheet in the configuration of Fig. 1(a), are shown. (b) Simulated ETS traces vs. *t* collected for different value of the relative permittivity ε_r. Both the first and second peaks of the traces show a good sensitivity to the background medium variations. (c) ETS instantaneous envelope amplitude vs. *t*. (d) Example of signal energy vs. medium permittivity. A pretty regular behavior has been obtained, which can suitably be interpolated with a second-order polynomial.