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Parametric study of TDR waveforms for Debye-type Dielectrics

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Time Domain Reflectometry (TDR) is widely used to determine the dielectric properties of soils and other materials. This measurement technique is capable of detecting permittivity information on large frequency bandwidth and it is very effective, being cheap, fast and suitable for outdoor applications.

Over the last 20 years, a great amount of work has been carried out in the area of TDR. Many contributions on the modeling of the measurement system, the design of probes, the measurement procedures as well as on the advanced methods for the estimation of permittivity spectra have been reported .

In this work, the behavior of the TDR responses of a Debye type dielectric is studied as a function of the probe and dielectric parameters. This parametric study has a wide range of applications. It can be useful for the analysis of the sensitivity of the measurement method to the permittivity spectrum and the optimization of the measurement setup, for the assessment of the condition of the estimation problem, as well as for the direct estimation of Debye parameters from characteristic points of the measured waveforms.

The analysis carried out is based on a simplified model of the measurement setup and on the decomposition of the TDR responses into a sequence of echoes. These echoes are analyzed separately and the influence of the parameters of the Debye model ($\varepsilon_s,\quad \varepsilon_\infty$, f_{rel}) on the shape of each echo is derived.

The main result of the study is that the qualitative behavior of the TDR response is controlled by the value of the normalized parameter τ= τ_{al} $(\varepsilon_\infty)^{1/2} 2\pi$ f$_{rel}$, where τ_{al} is the travel time in the empty probe. For small τ values, the rising edges of the TDR waveform are asymmetric and their time position is mainly controlled by ε_∞, whereas, for large τ values, the edges are symmetric and their time position is mainly controlled by ε_s.The threshold value of τ that separates the two possible behaviors depends on the value of the ratio $\varepsilon_s/\varepsilon_\infty$, and is about one for $\varepsilon_s/\varepsilon_\infty$=5, but the specific type of a measured waveform can be recognized by the shape of its rising edges. When the small τ condition holds, the measured waveforms are sensitive to all Debye parameters, whereas there is a reduced sensitivity to ε_∞ and f$_{rel}$for large τ values. This sensitivity reduction is a consequence of the bandlimiting effect of the dispersive wave propagation in the probe. The small τ condition holds for τ_{al} $(\varepsilon_\infty)^{1/2}$ $<$1/2π f$_{rel}$, i.e. for phase delay of the filled probe smaller than the dielectric relaxation time, and it can be hardly obtained for dielectrics with large relaxation frequencies, like water.

The behavior of the TDR responses is thoroughly discussed in the presentation of this work. Examples of the applications of these properties, direct estimation of some Debye parameters from the measured waveforms and the assessment of the condition of the Debye parameter estimation are given. Experimental validation of the analysis by means of measurement carried out by a Tektronic 1502C cable tester and a reference coaxial line probe are also presented.