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Hydrology and Earth System Sciences Discussions

Interactive comment on "Efficient reconstruction of dispersive dielectric profiles using time domain reflectometry (TDR)" *by* P. Leidenberger et al.

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The paper shows a new approach for the determination of spatial distributed electrical parameters for two- and three-wire probes from TDR traces. The reconstructed parameters are based on the Debye model description. The dispersive dielectric soil and probe parameters ϵ, σ and μ_0 are linked approximately to the transmission line parameters C', G' and L'. The optimization procedure yields to a frequency dependent permittivity $\epsilon_r(\omega)$ and a conductivity σ. Both parameters may vary with space. These dispersive dielectric profiles can be used to describe the water content of the surrounding material. The paper is well presented and gives a good overview to recent studies.

The following comments may help to improve the clarification and eliminate minor errors:

1. In addition to the detailed literature studies in chapter 1.1 it should be noted that spatial determinations of transmission line parameters have been carried out earlier to determine water content profiles (i.e. Lundstedt or Schlaeger). A short hint to frequency-domain methods could help the reader to classify time-domain methods to a more global state (i.e. Norgren).

   Lundstedt, J.: Inverse problems on nonuniform transmission lines - A time-domain wave-splitting approach to signal restoration, internal source and parameter reconstruction, Ph.D. thesis, Royal Institute of Technology, Stockholm, 1995.

   Schlaeger, S.: A fast TDR-inversion technique . . . , 2005. (already cited)

   Schlaeger, S. Inversion von TDR-Messungen zur Rekonstruktion räumlich verteilter bodenphysikalischer Parameter, Ph.D. thesis, Institut für Bodenmechanik und Felsmechanik der Universität Karlsruhe, 2002.

   Norgren, M., and He, S.: An optimization approach to the frequency-domain inverse problem for a nonlinear LCRG transmission line, IEEE Transactions on Microwave Theory and Techniques, 44(8), 1503-1507, 1996.

2. In Chapter 2.1.1 equation 14 a wrong algebraic sign is used (and also in table 1, parallel resistive capacitive termination). The term $\frac{R_K^{'} C_T}{\Delta t}$ should be positive. The authors should also check their numerical algorithms for this term.

3. As mentioned by Prof. Hübner the plausibility of equations 16 and 18 (with respect of the values from table 4) and equations 19 and 21 (with respect of the values from table 3) has to be checked. The velocity $v = \frac{1}{\sqrt{L' C'}}$ of a propagating wave in a material with $\epsilon = 1$ should be the same as the speed of light. For the two-wire probe it differs more than 50%, for the three wire probe more than 10%. The deviation between the approximately derived parameters C', G', and L'

(equations 19-21) for the two-wire probes and the exact parameters is quite large. To extrapolate this error to the three-wire case is questionable and should be proved. In particular, field-capable probes must be build robust to be inserted into the soil so κ is mostly lower than 5 (see also this effect in figure 2), especially for longer probes.

4. The approximation of the transmission line parameters (equations 16-18 or 19-21) in chapter 2.1.2 are only valid for uncoated probes with circular conductors. If the shape of the two- or three-conductor probes differs from this specification the approach may fail.
   Due to the relevant frequency-domain of a standard TDR device the minimal spatial resolution of the reconstructed parameters is in the range of centimetres. To motivate the effort of a reconstruction the probe length should be larger than 50 cm. Also many applications in engineering or agriculture are interested in a much larger observation area than the presented probe for field measured data so probe lengths between 2 and 10 meters may be required. To ensure a wave propagation without too much electrical losses probes are often coated with some dielectric material. The authors may investigate if their approach can be used for these coated waveguides.

5. The optimization procedure in chapter 2.3 uses the sum of absolute values of the difference between calculated and measured TDR traces (equation 31) instead of squared differences. It is not clear why this may not lead to local minima during the optimization process (minimization of squared differences is a well used approach in optimization). On the other hand in figures 13 to 19 the “squared error” of the individuals is printed. Is this error correlated to equation 31?

6. The usage of the letters I (upper case i - for the conducting current) and l (lower case L - for the probe length) in appendix 6 may confuse the reader (especially when using this font). Perhaps the authors should think of a different notation.

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7. The notation in figure 1 for the longitudinal coordinate of the probe (z) does not fit with the notation of the finite-difference discretization (Δx).

8. To enhance the comparability of different setting for calculated TDR traces the authors may think about a connection of several figures. Figures 5-7, 8-9, and 10-11 could be printed in three (not seven) individual figures.

9. In figures 13-15 the reconstruction procedure has been applied to synthetic data. It would be helpful to add these given parameter distributions to the presented conductivity and permittivity profiles so the reader can imagine the quality of the reconstruction.
   When looking at figure 14 one can see that there is a change in permittivity in the area of θ_2 but zero-conductivity in the same area whereas the conductivity does not vanish in the area of θ_1 and θ_3. An explanation of this effect will be helpful to the reader.

10. The reconstructed profiles of field measured data in chapter 3.3.2 look very promising. They should be completed and validated with independent reference measurements. Perhaps the reconstruction algorithm should be tested on a more challenging water content profile. A water content (or dispersive dielectric) profile on longer transmission lines where multiple reflections occur may be an adequate task.

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