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

P. Leidenberger et al.

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The authors acknowledge the paper's detailed study by referee S. Schläger and thank him for his constructive suggestions. The paper will be revised on the basis of these comments. We answer the comments of schlaeger2005b as follows:

1. ***referee:*** *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). (...)*
   authors: In the revised version of the paper we will cite lundstedtetal1996 and norgrenetal1996. The respective Ph. D. theses will not be cited because they are difficult to obtain and are therefore of limited use if cited as references.

2. ***referee:*** *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.*

   authors: We appreciate the referee pointing out this error. It will be corrected as suggested in the revised version. There is no relevant change in the results visible, but for a revised version we will recalculate all graphs.

3. ***referee:*** *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.*

   authors: We thank the referee for emphasizing this issue; we first underestimated its importance, but now did a more detailed analysis. First, we want to point out that Eq. (19) is incorrect. The correct form is

$$C'_{2,approx.} = \frac{\pi\epsilon}{\ln(2\kappa - 1)}. \quad (1)$$

   Calculating the speed of light with the correct formula and the values from Tab. 3 leads to an error of 6%. In a revised version of the paper we will compare the approximation of the three rod probe to finite element simulations.

4. ***referee:*** *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*

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conductors. If the shape of the two- or three-conductor probes differs from this specification the approach may fail.

authors: We agree, but leave this issue open for further studies. The results presented here already cover a wide range of applications, for instance all classical TDR probes.

referee: *Due to the relevant frequency-domain of a standard TDR device the minimal spatial resolution of the reconstructed parameters is in the range of centimeters. 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.*

authors: The referee raises an important issue: spatial resolution and maximal extend of measurement. For many applications, a spatial resolution of a few centimeters is quite sufficient. However, there is some technical latitude to improve this by increasing the frequency. As to the length of the probe, we agree that there are applications that benefit from larger measuring volumes. There is no fundamental limit to apply our solutions to such probes. The practical problems that arises, however, is the signal attenuation. This then is the motivation for using isolated probes, which brings us back to the previous comment. The application we have in mind is water contend measurement in soils, vertical profiles down to at most 2 m. Here, traditional TDR probes are well suited and the additional information gained with the reconstruction are most valuable.

5. ***referee:*** *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*

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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?

authors: We use the sum of absolute values of the difference, because it is a robust estimator, typically used for non-Gaussian, randomly distributed errors. In contrast the sum of squared differences, the L_2-norm, is only applicable to Gaussian noise. The label "squared error" in Fig. (13) to (19) is wrong. We plot in this figures the error, as described above.

6. ***referee:*** *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.*

   authors: Will be done.

7. ***referee:*** *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).*

   authors: This will be dealt with in a revised version, as suggested by the referee.

8. ***referee:*** *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.*

   authors: Will be done.

9. ***referee:*** *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.*

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authors: We will supply appropriate information on permittivity in a revised version. Ohmic conductivity in this experimental setup can be neglected.

referee: *When looking at figure 14 one can see that there is a change in permittivity in the area of 2 but zero-conductivity in the same area whereas the conductivity does not vanish in the area of 1 and 3. An explanation of this effect will be helpful to the reader.*

authors: The conductivity reconstructed in Fig. 13 and 14 can be neglected from the practical point of view. The conductivity in the order of $5 \cdot 10^{-6} \frac{S}{m}$ can be neglected in soil physics.

10. ***referee:*** *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.*

    authors: The main challenge of this work has been to reconstruct measured traces with relatively low reflection but including the reconstruction of parameters describing the Debye model of dispersive behavior. However, we will include a a reconstruction of larger variations of permittivity and conductivity along the probe in the revised paper.

References

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