A new TDR multiplexing system for reliable electrical conductivity and soil water content measurements

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Time domain reflectometry (TDR) is a standard method to estimate soil water content and bulk soil electrical conductivity. In many applications, several TDR probes are installed in soil columns or field setups, and TDR measurements are acquired using a multiplexing system. Commercially available multiplexers share a common ground, which might lead to inaccurate TDR measurements when probes are installed close together or at sites with high electromagnetic noise. Therefore, a new eight-channel differential multiplexer (50C81-SDM) was developed that allows communication with standard TDR equipment. In a first step, the new multiplexer was tested to analyse channel noise and channel to channel variability for open reflection coefficients and travel times. The results indicate that there is no significant difference between the channels for both the open reflection coefficient and travel times. Second, the 50C81-SDM multiplexer was tested using TDR probes installed in electrolyte solutions and a sand tank. In contrast to multiplexers with a common ground, they showed no interference of closely spaced TDR probes (spacing ranging from 5 to 95 cm). On the other hand, the SDMX50 multiplexer showed absolute differences in bulk electrical conductivities of >0.001 Sm^{-1} for high volumetric water contents and high bulk electrical conductivities. Measurements at a test site with high electromagnetic noise showed the applicability of the 50C81-SDM multiplexer in such environments, but only if the entire TDR setup was disconnected from the permanent power supply.

50C81-SDM Multiplexer

- **50 Ω differential eight channel coaxial multiplexer**
- **supporting Campbell SDM communications protocol**

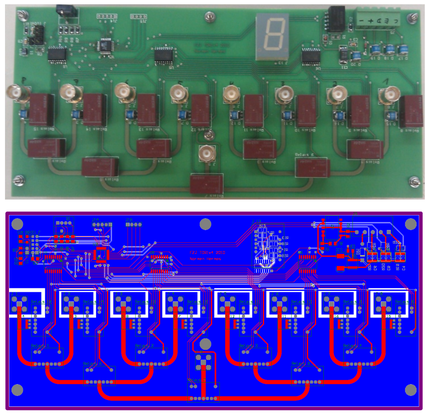


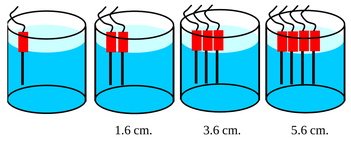
Photo (top) and printed circuit board (PCB) (bottom) of the 50C81-SDM 50 Ω eight channel differential coaxial multiplexer.

Experimental Setup

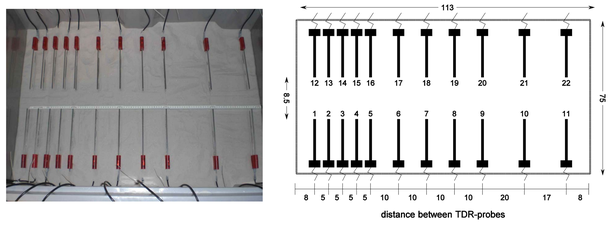
- **Measurement of electrical conductivity in different electrolyte solutions using different TDR spacing**
- **EC ranges from 0.007 S m^{-1} to 1.553 S m^{-1}**
- **TDR-probes either connected to SDMX50 or 50C81-SDM**
- **Calculation of EC**

$$\sigma_{soil} = \frac{K_p}{R_L - (DR_c + R_0)}$$

K_p = probe constant (m^{-1})
R_L = load resistance (W)
D is the cable length (m)
R_c = is the cable resistance (W m^{-1})
R_0 = additional series resistance (W)

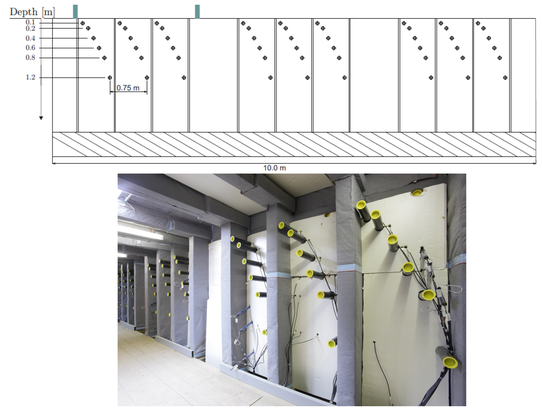


- **Measurement of electrical conductivity in a sand box with varying TDR spacings (5-95 cm)**
- **Varying the water content in sandbox**
- **TDR-probes either connected to SDMX50 or 50C81-SDM**
- **Calculation of EC**



Sandbox experiment with horizontally installed TDR sensors at different spacings.

- **Acquiring of TDR waveforms typically used for water content and electrical conductivity estimation**



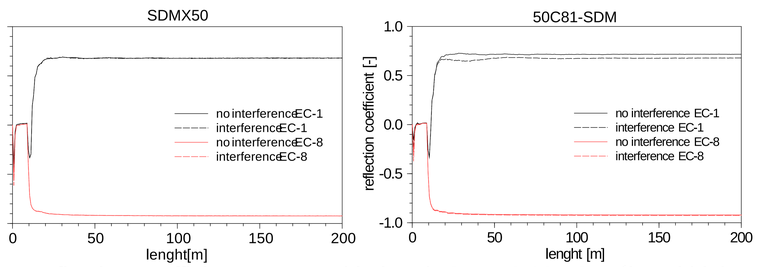
Schematic sketch (top) and photo (bottom) of the TDR trench used for field experiments.
Field shows high electromagnetic noise due to ground currents.

Results

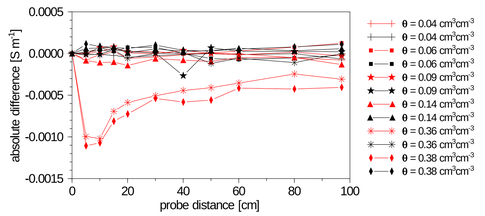
Analyzing the channel reproducibility using open reflection coefficient as a criteria.

test	*source*	*sum of squares*	*df*	*mean square*	*F-value*
travel time	channel to channel variability	0.0361	7	0.0052	2.12
	noise	0.1363	56	0.0024	
	total	0.1724	63		
open reflection coefficient	channel to channel variability	1.12E-5	7	1.61E-6	1.39
	noise	6.45E-5	56	1.15E-6	
	total	7.58E-5	63		

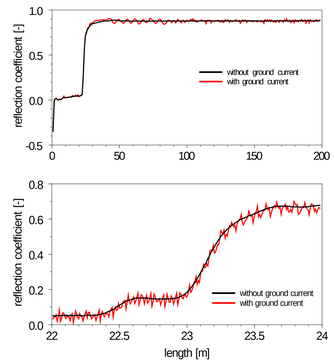
Results of the ANOVA for the eight replicated measurements for each multiplexer channel performed on all eight channels (n = 64) showed that the noise (inner channel variability) is larger as the channel to channel variability for the open reflection coefficient.



Reflection coefficient measured in low (EC-1 = 0.007 S m^{-1}) and high (EC-8 = 1.553 S m^{-1}) conductive solution. No-interference refers to only one TDR probe connected to multiplexer channel 1 and interference refers to two TDR probes connected to channel 1 and 2, respectively.



Absolute difference in measured electrical conductivity [S m^{-1}] of the sand for five water contents measured by probe 1 for the SDMX50 (red curves), and probe 12 for the 50C81-SDM multiplexer (black curves) both connected to channel 1, whereby all other (passive) TDR probes were connected to channel 2.



Acquired TDR waveforms at different window length with and without 50 Hz interference from ground-current at the test site Selhausen. Note that all waveform were acquired with the same TDR probe and the 50C81-SDM multiplexer either connected or disconnected from the permanent power supply.

Overall, the 50C81-SDM multiplexing system resolved all shortcomings and provided accurate soil water content and electrical conductivity data even in challenging environments with significant electromagnetic noise.

References: Castiglione, P., Shouse, P.J., and Wraith, J.M. 2006. Multiplexer-induced interference on TDR measurements of electrical conductivity. Soil Science Society America Journal. 70: 1453-1458.