App. Note Code: 2S-H

APPLICATION NOTE

Reducing TDR probe rod length to improve water content measurements in soils with high electrical conductivity

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Reducing TDR probe rod length to improve water content measurements in soils with high electrical conductivity

For soils with high electrical conductivity, shortening the rods on the TDR probes may improve the measurements. This application note:

- *discusses the effect of electrical conductivity on soil water content measurements,*
- *demonstrates how to calculate the maximum rod length that can be used for a given electrical conductivity or the maximum electrical conductivity for a given rod length,*
- *and presents a method using PCTDR measurements to estimate the effect of rod length changes.*

Effects of electrical conductivity on soil water content measurements

A pulse from the TDR100 travels toward probe rod ends and is reflected. The waveform used in algorithms for soil water content and bulk electrical conductivity is a superposition of the applied and reflected signals. When the probe rods are surrounded with an electrically conductive medium, the signal is attenuated along the rod length, and the reflection of the rod end is diminished. Eventually the reflection from the end becomes a straight, horizontal line, and the apparent rod length cannot be calculated. Without the apparent rod length, water content cannot be calculated. Figure 1 shows the trend of reflection attenuation with changing bulk electrical conductivity.

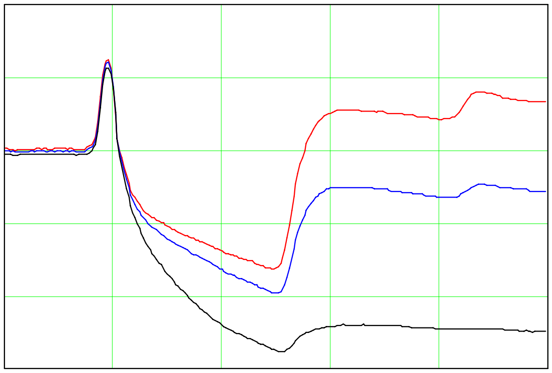

Figure 1. Waveforms from CS605 (30 cm, 3-rod TDR probe) in glass beads saturated with three different KCl solutions.

The reflection of the rod ends is at mid graph. The top trace is the lowest bulk electrical conductivity. There is enough rod end reflection in the bottom trace for accurate measurement of rod end location. The bulk electrical conductivity of the soil shown with the bottom trace is about 1.1 dS m^{-1}. The reflection was lost when bulk electrical conductivity increased to 1.47 dS m^{-1}.

Because the signal is attenuated as it travels down the waveguide, shortening the rods results in less attenuation. Decreasing rod length will increase the reflection from the end of the probe. Shortening the rods may be a solution to TDR attenuation problems when electrical conductivity is up to 50% above the limit with present rod length.

Reducing TDR probe rod length also reduces water content measurement resolution. However, the resolution probably won't become a limitation since the resolution of TDR water content measurements is very good. See Figure 3 and related article "Discussion of TDR probe rod length affect on water content resolution."

Estimating the effect of shortening TDR probe rods

The ratio of applied signal strength, V_a, to reflected signal strength, V_r, is dependent on the rod length, L, the dielectric permittivity, ε, and the bulk electrical conductivity, σ_b.

$$\ln\left(\frac{V_a}{V_r}\right) = 120 \cdot \frac{L}{\sqrt{\varepsilon}} \cdot \pi \cdot \sigma_b \qquad [1]$$

The maximum probe rod length that will provide a reliable reflection can be calculated by solving [1] for L and using typical values.

$$L = \frac{\ln\left(\frac{V_a}{V_r}\right)\cdot\sqrt{\varepsilon}}{120\cdot\pi\cdot\sigma_b} \qquad [2]$$

Both ε and σ_b can be measured with a TDR100. V_a and V_r can also be measured, or $\ln(V_a/V_r)$ can be calculated using TDR measured values for σ_b and ε. For a CS605, L = 0.3 m, in glass beads saturated with KCl solution, $\varepsilon = 30.25$, $\sigma_b = 0.147$ Siemens m^{-1}, $\ln(V_a/V_r)$ is calculated as:

$$120\cdot\frac{L}{\sqrt{\varepsilon}}\cdot\pi\cdot\sigma_b = 3.023 \qquad [3]$$

Consider that exp(3.023) or V_a/V_r is approximately 20. This indicates at least 5% of the applied signal must be reflected to reliably measure volumetric water content.

For the CS605, the maximum σ_b for a reliable volumetric water content measurement can be estimated by plotting $\sigma_b(L)$ or solving for a value of L.

$$\sigma_b(L) := \frac{1}{120}\cdot\frac{3.023}{L}\cdot\frac{\sqrt{30.25}}{\pi} \qquad [4]$$

Plotting the results

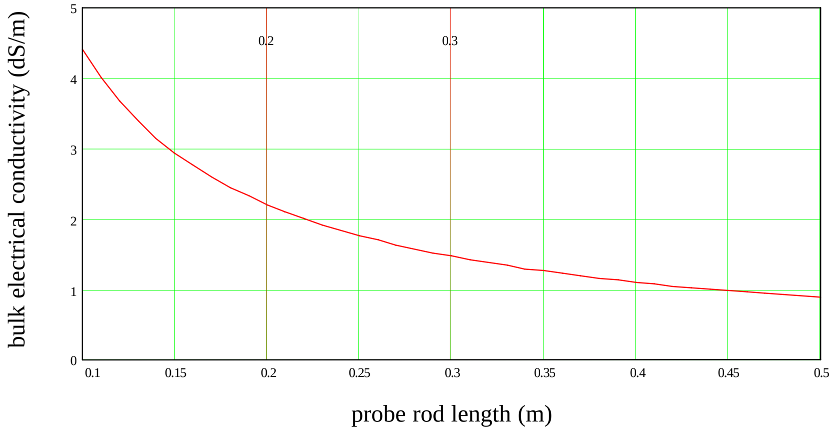

Figure 2. Maximum bulk electrical conductivity to obtain reliable reflection from CS605 rod ends for range of rod lengths.

If CS605 rods are cut from 0.3 m to 0.2 m, water content can be reliably measured when σ_b is less than 2.2 dS m^{-1}.

The effect of reducing rod length on water content measurement resolution

Reducing TDR rod length reduces water content measurement resolution. Figure 3 below shows the smallest change in volumetric water content that can be reliably measured using CS605 and TDR100 for a range of rod lengths. The resolution for the standard 0.3 m rods is approximately 0.16% volumetric water content. Shortening the rods to 0.2 m gives a resolution of 0.23% volumetric water content.

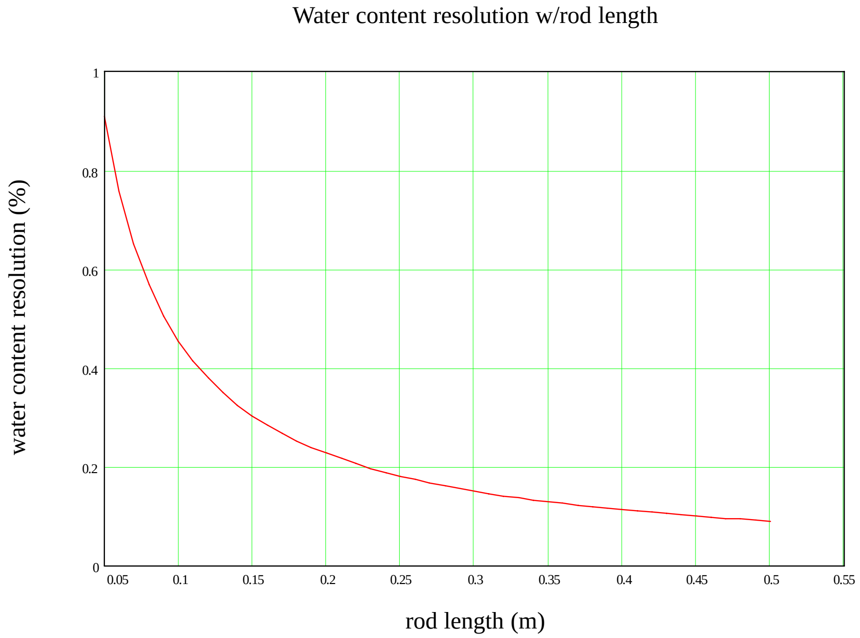

Figure 3. The estimated water content resolution for range of rod lengths for a given probe rod spacing and diameter.

Laboratory method to estimate the effect of shortening rods

This method can be applied to any probe design by suspending the probe in a column of water and adding salt (e.g., KCl or NaCl) to the water while monitoring the waveform and water content calculation in PCTDR.

NOTE

Electrical conductivity of solutions can change significantly with temperature.

- In PCTDR, select *Settings/Calibration Functions/Volumetric Water Content*. In the linear functions box, select User Defined and set the multiplier to 1.0 and the offset to 0. This will display La/L or $\sqrt{\varepsilon}$ after the Water Content button of PCTDR has been clicked.

- Immerse all of the probe's rods in the salt solution by suspending the probe. No part of the container should be within 4 cm of the rods.

- Increase the solution electrical conductivity by adding salt.

- When the rod end reflection approaches that of the bottom trace of Figure 1, add the salt slowly while carefully monitoring measured La/L to determine the maximum electrical conductivity the end of the probe can reliably detect. As the limit of the measurement is approached, the variability of the La/L increases. When the limit is reached, the measurement becomes nonsensical.

- If too much salt has been added, simply dilute with deionized water to lower electrical conductivity.

- After the maximum electrical conductivity has been reached, record the La/L from the Calculate Water Content box in PCTDR. La/L is equal to $\sqrt{\varepsilon}$. Also record the bulk electrical conductivity, σ_b.

- Solve for $\ln(V_a/V_r)$ using Equation [3]. Units are meters for L and Siemens m^{-1} for σ_b.

- Use Equation [2] to solve for the maximum rod length for a chosen bulk electrical conductivity or use Equation [4] to find the maximum bulk electrical conductivity for a chosen rod length.

Comments on cutting TDR probe rods

CAUTION

Once you shorten the rods of a TDR probe, the probe cannot be returned to Campbell Scientific and the warranty may be affected. The HydroSense rods can be shortened by using the 12 cm rod option instead of the 20 cm rod option.

- Determine the desired probe rod length as described in the preceding section.

- Note that the total length of the rod outside the epoxy including any tapered length is the value used for L.

- Cut each rod the same amount. Stainless steel rods can be cut with a hacksaw although the hardness makes this a slow process. The center rod of the CS605/610 is slightly shorter than the outside rods. Maintain this difference when shortening the rods.

- Taper the end of each rod to ease insertion into the soil. The rod end can have a radius or a point. The easiest way to taper the rod end is to use a file.