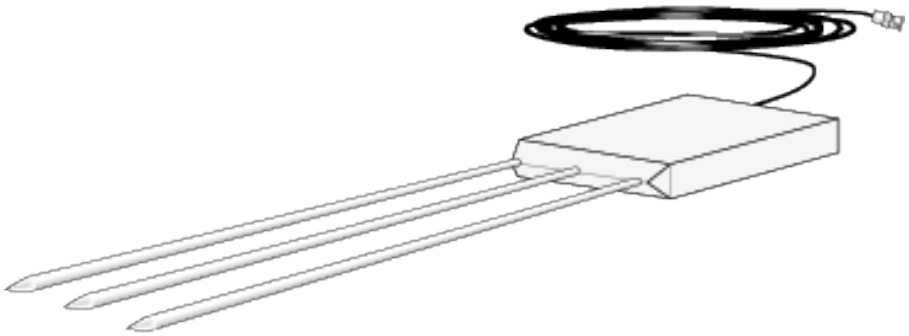
INSTRUCTION MANUAL

TDR Probes CS605, CS610, CS630, CS635, CS640, CS645

Revision: 5/17



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Use tripods, towers, and attachments to tripods and towers only for purposes for which they are designed. Do not exceed design limits. Be familiar and comply with all instructions provided in product manuals. Manuals are available at www.campbellsci.com or by telephoning (435) 227-9000 (USA). You are responsible for conformance with governing codes and regulations, including safety regulations, and the integrity and location of structures or land to which towers, tripods, and any attachments are attached. Installation sites should be evaluated and approved by a qualified engineer. If questions or concerns arise regarding installation, use, or maintenance of tripods, towers, attachments, or electrical connections, consult with a licensed and qualified engineer or electrician.

General

- Prior to performing site or installation work, obtain required approvals and permits. Comply with all governing structure-height regulations, such as those of the FAA in the USA.
- Use only qualified personnel for installation, use, and maintenance of tripods and towers, and any attachments to tripods and towers. The use of licensed and qualified contractors is highly recommended.
- Read all applicable instructions carefully and understand procedures thoroughly before beginning work.
- Wear a **hardhat** and **eye protection**, and take **other appropriate safety precautions** while working on or around tripods and towers.
- **Do not climb** tripods or towers at any time, and prohibit climbing by other persons. Take reasonable precautions to secure tripod and tower sites from trespassers.
- Use only manufacturer recommended parts, materials, and tools.

Utility and Electrical

- **You can be killed** or sustain serious bodily injury if the tripod, tower, or attachments you are installing, constructing, using, or maintaining, or a tool, stake, or anchor, come in **contact with overhead or underground utility lines**.
- Maintain a distance of at least one-and-one-half times structure height, 20 feet, or the distance required by applicable law, **whichever is greater**, between overhead utility lines and the structure (tripod, tower, attachments, or tools).
- Prior to performing site or installation work, inform all utility companies and have all underground utilities marked.
- Comply with all electrical codes. Electrical equipment and related grounding devices should be installed by a licensed and qualified electrician.

Elevated Work and Weather

- Exercise extreme caution when performing elevated work.
- Use appropriate equipment and safety practices.
- During installation and maintenance, keep tower and tripod sites clear of un-trained or non-essential personnel. Take precautions to prevent elevated tools and objects from dropping.
- Do not perform any work in inclement weather, including wind, rain, snow, lightning, etc.

Maintenance

- Periodically (at least yearly) check for wear and damage, including corrosion, stress cracks, frayed cables, loose cable clamps, cable tightness, etc. and take necessary corrective actions.
- Periodically (at least yearly) check electrical ground connections.

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TDR Probes CS605, CS610, CS630, CS635, CS640, CS645

1. Introduction

This document presents descriptions and instructions for Campbell Scientific Time Domain Reflectometry (TDR) probes and includes some TDR principles. Consult the TDR200 or TDR100 operating manual for comprehensive TDR instructions.

A single TDR probe can be connected to a TDR200 or TDR100 reflectometer. Multiple probes can be connected to the SDM8X50 or SDMX50 coaxial multiplexer.

2. Precautions

- READ AND UNDERSTAND the *Safety* section at the front of this manual.
- Care should be taken when opening the shipping package to not damage or cut the cable jacket. If damage to the cable is suspected, contact Campbell Scientific.
- The CS605 and CS610 are shipped with rubber caps covering the sharp ends of the rods. Remove the three caps before use.

3. Initial Inspection

- Upon receipt of a TDR probe, inspect the packaging and contents for damage. File damage claims with the shipping company.
- The model number and cable length are printed on a label at the connection end of the cable. Check this information against the shipping documents to ensure the correct product and cable length are received.

4. Overview

TDR probes are the sensors of the TDR measurement system and are inserted or buried in the medium to be measured. The probes are a wave guide extension on the end of coaxial cable. Reflections of the applied signal along the waveguide will occur where there are impedance changes. The impedance value is related to the geometrical configuration of the probe (size and spacing of rods) and also is inversely related to the dielectric constant of the surrounding material. A change in volumetric water content of the medium surrounding the probe causes a change in the dielectric constant. This is seen as a change in probe impedance which affects the shape of the reflection. The shape of the reflection contains information used to determine water content and soil bulk electrical conductivity.

PCTDR version 3 software supports sensor setup and includes a CRBasic program generator for TDR200 and TDR100 programs.

5. Specifications

5.1 Physical Description

TABLE 5-1. TDR Probe Physical Properties

Probe Model	Rods	Probe Head	Cable Type	Maximum Soil Bulk Electrical Conductivity	Maximum Cable Length (measured from the tips of the probe's rods to the reflectometer)
CS605	length 30.0 cm diameter 0.475 cm	length 10.8 cm width 7.0 cm thickness 1.9 cm	RG58	1.4 dS/m	15 m
CS610	length 30.0 cm diameter 0.475 cm	length 10.8 cm width 7.0 cm thickness 1.9 cm	RG8 low loss	1.4 dS/m	25 m
CS630	length 15.0 cm diameter 0.318 cm	length 5.75 cm width 4.0 cm thickness 1.25 cm	RG58	3.5 dS/m	15 m
CS635	length 15.0 cm diameter 0.318 cm	length 5.75 cm width 4.0 cm thickness 1.25 cm	LMR-200 low loss	3.5 dS/m	25 m
CS640	length 7.5 cm diameter 0.159 cm	length 4.5 cm width 2.2 cm thickness 1.0 cm	RG58	5.0 dS/m	15 m
CS645	length 7.5 cm diameter 0.159 cm	length 4.5 cm width 2.2 cm thickness 1.0 cm	LMR-200 low loss	5.0 dS/m	25 m

5.2 Measurement Parameters

TABLE 5-2. TDR Probe Measurement Properties

Probe Model	Probe Offset (meters)	Probe Constant for Electrical Conductivity (EC) Measurement, Kp (using this constant will provide EC in siemens/meter)
CS605 and CS610	0.090	1.74
CS630 and CS635	0.052	3.36
CS640 and CS645	0.035	6.40

5.3 Electromagnetic Compatibility

All TDR probes are CE compliant with performance criteria available upon request. RF emissions are below EN55022 limit.

6. Installation

TDR probes can be installed in any orientation: horizontally, vertically, or at an angle to the surface. The measured water content is the integral or average of the water content over the length of the probe rods. The probe rods should be completely surrounded by the soil or other media being measured. If portions of the probe rods are exposed to air, the algorithm for analyzing the waveform reflection may not be able to correctly locate the beginning and end of the probe rods.

Care must be exercised when inserting probe rods into the soil to minimize soil compaction around the rods. Compaction can leave air voids along the length of the rods. The region adjacent to the rod is the most sensitive so voids near the rods can be a significant source of error.

After the soil is disturbed for probe installation, most soils will experience rejuvenation of the soil structure with wetting/drying cycle and freeze/thaw cycles.

TDR probes can be buried or inserted into the soil. The CS605G Installation Guide should be used when inserting the CS605 and CS610 into the material being measured. A guide is generally not needed for the smaller diameter probes.

7. Operation

7.1 Probe Offset for Water Content Measurement

A portion of the TDR probe rods is surrounded by the probe head material and is not exposed to the material being measured. Probe offset is used to correct for this. TABLE 5-2 lists offset values for probes manufactured by Campbell Scientific. These values are entered in the datalogger instruction or in the PC-TDR software.

The values listed in TABLE 5-2 were determined using TDR probes with short cables. The shape of the waveform reflection is affected as cable length increases, and this can introduce error into the water content measurement. PC-TDR 3.0 or higher provides a wizard for calculating probe offset. Using probe offsets determined by the PC-TDR wizard will compensate for the cable losses. Probe offset values obtained this way will be greater than those listed in TABLE 5-2.

7.2 Probe Constant for Electrical Conductivity Measurement

The electrical conductivity measurement requires a probe constant to account for probe geometry. The probe constant is commonly referred as K_p. The probe constant is entered as a multiplier in the datalogger instruction for TDR200 or TDR100 EC measurement. The calibration wizard can calculate K_p. Using the K_p values in TABLE 5-2 will give electrical conductivity in the units siemens/meter. For the more common units of decisiemens/meter, multiply the TABLE 5-2 K_p values by 10.

7.2.1 Electrical Conductivity Error from Attenuation

Attenuation of the applied and reflected signal in the cable and multiplexers will affect the accuracy of the electrical conductivity measurement. For accurate electrical conductivity measurements, this attenuation must be accounted for.

The PC-TDR calibration wizard uses the Castiglione and Shouse (2003) method to account for EC attenuation error. The method requires electrical conductivity measurement with the probes in air and with the rods shorted with all system components in place (cable and multiplexers).

7.3 Water Content Measurement Error from Cable

The determination of water content using the TDR system relies on the evaluation of a pulse reflection from the TDR probe. The pulse generated by the TDR200 or TDR100 reflectometer and its reflections are subject to distortion during travel between the reflectometer and the TDR probe. The cable connecting the probe to the reflectometer has a characteristic impedance resulting in both resistive and reactive losses. Distortion of the waveform caused by cable impedance can introduce error into the water content determination.

FIGURE 7-1 presents waveforms collected from a 3-rod probe (CS610) for various cable lengths. As cable length increases, the rise time and the amplitude of the reflection are affected. The slopes and extrema used by the datalogger algorithm to analyze the waveform are shifted by the cable losses resulting in error. For the data shown in FIGURE 7-1, the water content measurement using the 66-meter cable was in error by about 1.5% volumetric water content when electrical conductivity is low. However, in saline soils, the error can be several percent. See Bilskie (1997) for complete results of the study.

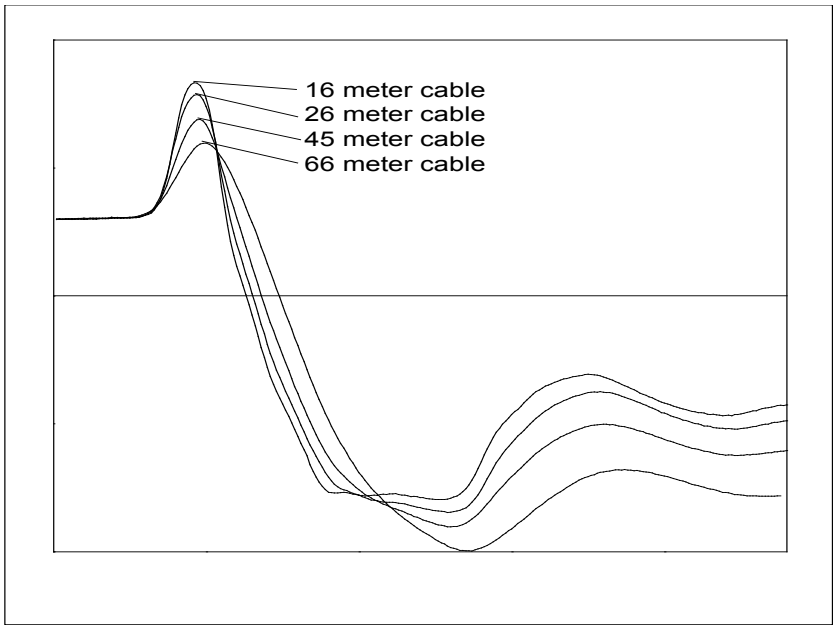

FIGURE 7-1. Waveforms collected in a sandy loam using CS610 probe with RG8 connecting cable. Volumetric water content is 24% and bulk electrical conductivity is 0.3 dS m^{-1}.

In general, water content is overestimated with increasing cable length. A calibration of volumetric water content with apparent dielectric constant for a given cable length can improve accuracy. Measurement precision at longer cable lengths will be maintained as long as soil electrical conductivity does not prevent a reflection from the end of the probe rods. This is discussed later in this section.

Minimizing cable lengths should always be considered in the design of a measurement system using TDR. If long cable lengths are necessary, the adverse effects can be minimized by using low attenuation cable such as RG8 or LMR-200. Careful probe design ensures correct probe impedance giving robust reflections.

7.4 Water Content Measurement Error from Soil Electrical Conductivity

The signal at the probe will be attenuated when ionic conduction occurs in the soil solution. This inherent attenuation is used in TDR measurements to determine soil electrical conductivity as described by the following equation:

$$\sigma = \frac{K_p}{Z_c}\frac{1-\rho}{1+\rho}$$

The presence of ions in the soil solution provides a path for electrical conduction between TDR probe rods. The attenuation of the signal can affect the accuracy and resolution of water content measurements. FIGURE 7-2 presents a series of waveforms when a solution with an electrical conductivity of 1.0 dS m^{-1} is added to a soil which has essentially no salt present. FIGURE 7-3 shows data for solution with high electrical conductivity.

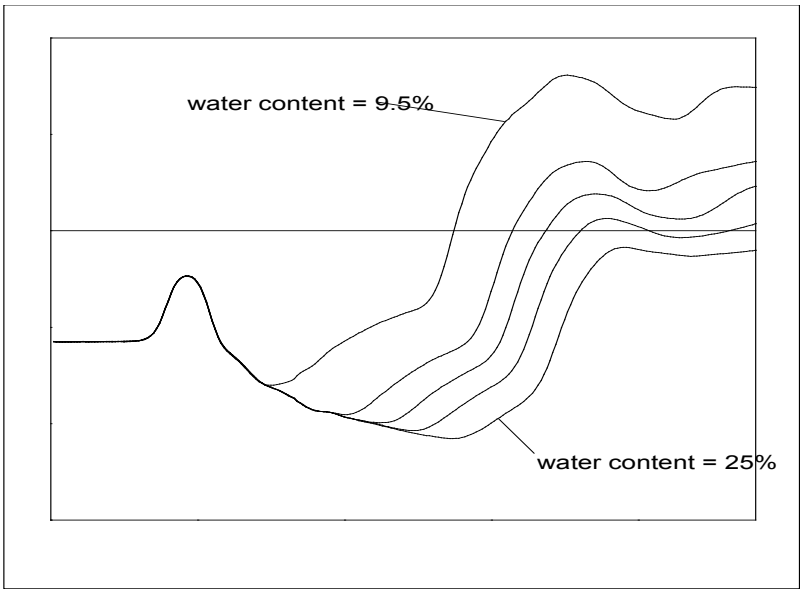

FIGURE 7-2. Waveforms collected in a sandy loam using CS610 probe with RG8 connecting cable. Volumetric water content values are 10, 16,18, 21 and 25%. Solution electrical conductivity is 1.0 dS m^{-1}.

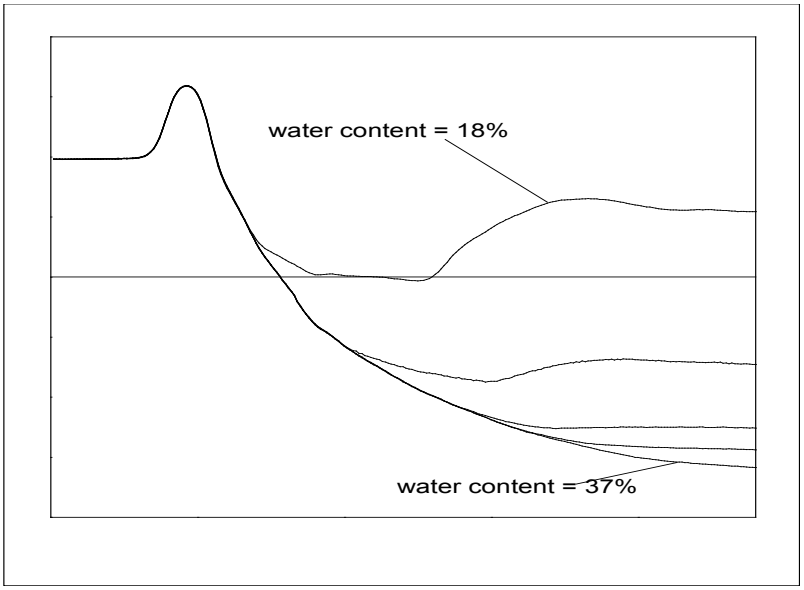

FIGURE 7-3. Waveforms collected in a sandy loam using CS610 probe with RG8 connecting cable. Volumetric water content values are 10, 18, 26, 30 and 37%. Solution electrical conductivity is 10.2 dS m^{-1}.

The combined effect of long cable runs and high soil electrical conductivity must be considered when TDR measurements are taken.

8. References

Bilskie, Jim. 1997. “Reducing Measurement Errors of Selected Soil Water Sensors.” Proceedings of the International Workshop on Characterization and measurement of the hydraulic properties of unsaturated porous media. 387-396.

Castiglione, P. and P.J. Shouse. 2003. The effect of ohmic cable losses on time-domain reflectometry measurements of electrical conductivity. Soil Sci Soc Am J 2003 67: 414-424.

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