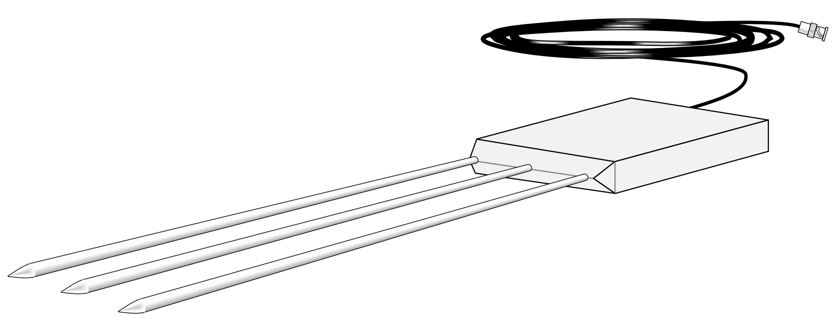
INSTRUCTION MANUAL

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

Revision: 9/13



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PLEASE READ FIRST

About this manual

Please note that this manual was originally produced by Campbell Scientific Inc. (CSI) primarily for the US market. Some spellings, weights and measures may reflect this origin.

Some useful conversion factors:

Area:	1 in^2 (square inch) = 645 mm^2
Length:	1 in. (inch) = 25.4 mm
	1 ft (foot) = 304.8 mm
	1 yard = 0.914 m
	1 mile = 1.609 km
Mass:	1 oz. (ounce) = 28.35 g
	1 lb (pound weight) = 0.454 kg
Pressure:	1 psi (lb/in2) = 68.95 mb
Volume:	1 US gallon = 3.785 litres

In addition, part ordering numbers may vary. For example, the CABLE5CBL is a CSI part number and known as a FIN5COND at Campbell Scientific Canada (CSC). CSC Technical Support will be pleased to assist with any questions.

About sensor wiring

Please note that certain sensor configurations may require a user supplied jumper wire. It is recommended to review the sensor configuration requirements for your application and supply the jumper wire is necessary.

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1. Introduction

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

A single TDR probe can be connected directly to the TDR100 or multiple probes connected via the SDMX50-series Coaxial Multiplexers.

Before using the TDR probes, please study:

- Section 2, *Cautionary Statements*
- Section 3, *Initial Inspection*

2. Cautionary Statements

- Care should be taken when opening the shipping package to not damage or cut the cable jacket. If damage to the cable is suspected, consult with a Campbell Scientific application engineer.

- The CS605 and CS610 are shipped with rubber caps covering the sharp ends of the rods. Remove the three caps before use.

- The TDR100 is sensitive to electrostatic discharge damage. Avoid touching the center conductor of the panel BNC connector or the center rod of TDR probes connected to the TDR100.

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.

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 TDR100 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.

7.1.1 Calculating Probe Offset

Probe offset can be calculated using information from PC-TDR. The probe rods are immersed in water of known temperature, algorithm values are collected in the terminal emulator mode of PC-TDR, and simple calculations provide custom offset values. See Appendix A, *Discussion of TDR Probe Offset and a Simple Laboratory Method for Calculation*, for calculation method.

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. Using probe offsets determined by the method described in Appendix A, *Discussion of TDR Probe Offset and a Simple Laboratory Method for*

Calculation, with all cabling from TDR100 to probe in place 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 TDR100 EC measurement. K_p is set in PC-TDR using *Settings/Calibration Functions/Bulk Electrical Conductivity*. 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.

Probe constant can be calculated using PC-TDR. Selecting *Settings/Calibration Functions/Bulk Electrical Conductivity* will present a button to Measure Cell Constant. The method requires submersion of the TDR probe rods in de-ionized water of known temperature. See PC-TDR HELP for simple instructions. It is recommended to make several K_p determinations and use the average value.

Probe constant can also be calculated using the method presented in Appendix B, *Correcting Electrical Conductivity Measurements*. This method accounts for signal losses in system cabling and multiplexers.

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.

A paper published by Castiglione and Shouse (2003) describes the error and a method to account for the 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).

Appendix B, *Correcting Electrical Conductivity Measurements*, presents a summary of the Castiglione and Shouse (2003) method and an adaptation of the method for the TDR100 system.

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 TDR100 and its reflections are subject to distortion during travel between the TDR100 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.

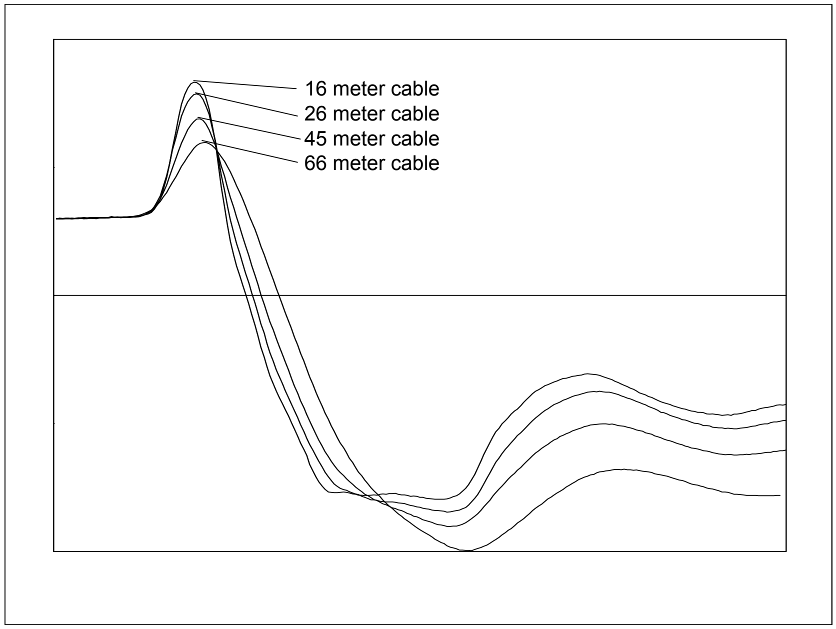

FIGURE 7-1. Waveforms collected in a sandy loam using CS610 probe with RG8 connecting cable. Volumetric water content is 24% and bulk electrical conductivity is 0.3 dS m^{-1}.

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 equation [5] in the TDR100 manual. 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.

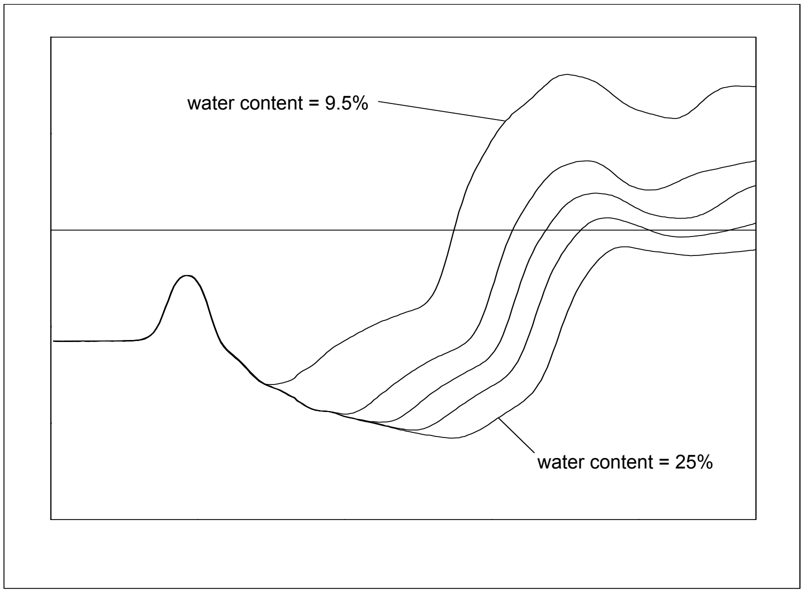

FIGURE 7-2. Waveforms collected in a sandy loam using CS610 probe with RG8 connecting cable. Volumetric water content values are 10, 16,18, 21 and 25%. Solution electrical conductivity is 1.0 dS m^{-1}.

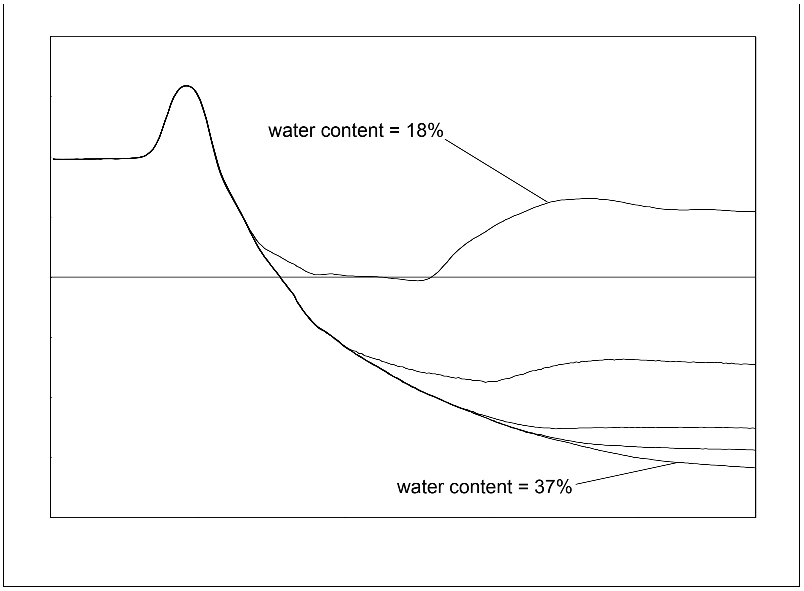

FIGURE 7-3. Waveforms collected in a sandy loam using CS610 probe with RG8 connecting cable. Volumetric water content values are 10, 18, 26, 30 and 37%. Solution electrical conductivity is 10.2 dS m^{-1}.

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.

Appendix A. Discussion of TDR Probe Offset and a Simple Laboratory Method for Calculation

A.1 Discussion of Probe Offset

Probe offset accounts for the segment of the TDR probe rods that is part of the probe head and is not exposed to the media surrounding the probe rods. The location of the beginning of the probe that is calculated in the TDR100 operating system is the point along the cable where the transition from the 50 ohm cable to the TDR probe impedance occurs. The distance from this transition to the point where the rods come out of the probe head is constant and can be accounted for.

The TDR100 operating system uses the following equation to calculate the ratio of apparent rod length to actual rod length, La/L. This ratio is equal to the square root of dielectric permittivity, $\sqrt{\varepsilon}$.

$$\frac{La}{L} = \frac{\frac{end - start}{V_p} - ProbeOff}{L} \qquad [A1]$$

La	apparent length (m)
L	actual rod length (m)
V_p	relative propagation velocity (1.0)
ProbeOff	probe offset (m)
start	distance into window for beginning of rods (m)
end	distance into window for end of rods (m)

To examine the sensitivity of La/L to probe offset, multiply equation [A1] by L and take the 1st derivative of La with respect to probe offset.

$$\frac{d}{d(ProbeOff)}\left(\frac{end - start}{V_p} - ProbeOff\right) = -1 \qquad [A2]$$

The sensitivity of the apparent length measurement, La, is directly related to probe offset. A probe offset difference of 0.005 changes La by –0.005. The water content error for saturated soil is 0.16% volumetric water content. In very dry soil the error is 0.20%. There is a slight dependence of probe offset on water content but the amount is within the resolution of the water content measurement.

A.2 The Compounding Effect of Signal Attenuation in Connecting Cables

The probe offset values provided in the operating manual were calculated from measurements in the Campbell Scientific soils laboratory. The method is described below. The length of cable for the laboratory calculations was 3 meters or less. As cable length increases, signal loss occurs in both amplitude and bandwidth. As a result of bandwidth loss, the slope of the waveform at the beginning of the probe decreases with increasing cable length. The probe start is determined from the intersection of a line tangent to the waveform at the steepest point and of a line that is essentially horizontal. See FIGURE A-1. The probe offset correction identifies the location where the rods exit the probe head.

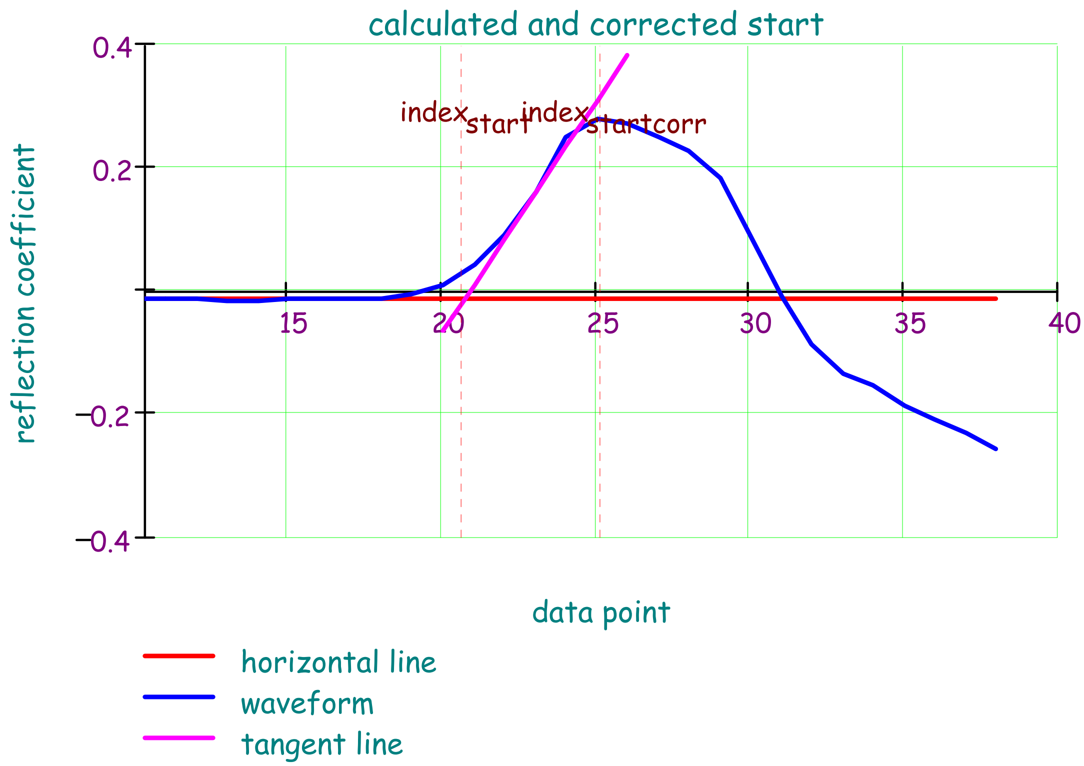

FIGURE A-1. Example of start of TDR probe determination

The slope of the tangent line decreases as cable length increases, and the intersection of the two lines will shift in the direction of greater apparent probe rod length.

Calculating the probe offset using the method described below and with all cables and multiplexers in place will optimize the accuracy of water content measurements.

A.3 Method for Calculating Probe Offset Using Information from the Terminal Mode of PC-TDR

Letting $V_p = 1$ and solving [1] for ProbeOffset gives:

$$\text{ProbeOff} = \text{end} - \text{start} - \text{La} \qquad [A3]$$

The start and end distance values are determined by an algorithm in the TDR100 operating system. The apparent length, La, excluding the offset, is related to actual rod length and permittivity by:

$$\text{La} := \text{L} \cdot \sqrt{\varepsilon(\text{T})} \qquad [A4]$$

The rod length, L, is the physical length of the rods (m). For 3-rod TDR probes with longer outer rods, the length of the outer rods is used.

The dielectric permittivity of water can be calculated from water temperature using:

$$\varepsilon(\text{T}) := 78.54 \cdot \left[1 - 4.5791 \cdot 10^{-3} \cdot (\text{T} - 25) + 1.19 \cdot 10^{-5} \cdot (\text{T} - 25)^2 - 2.8 \cdot 10^{-8} \cdot (\text{T} - 25)^3\right] \qquad [A5]$$

TABLE A-1 contains dielectric permittivities for a typical range of temperatures and may be used in lieu of equation [A5]. Substituting the calculation of La using equations [A4] and [A5] into equation [A3] leaves the end and start distances as the only unknowns. These values can be acquired directly from the TDR100 algorithm by using the terminal emulator mode of PC-TDR.

A.3.1 Procedure for Calculating Probe Offset

Connect all cabling and multiplexers to be used for field or laboratory measurements.

Immerse the TDR probe rods in DI or tap water. The container must be large enough to ensure rods are at least 5 cm from container walls.

Use PC-TDR as follows:

1. Enter values for **Waveform** parameters. Suggested values are: Average = 4, Points = 251. Relative propagation velocity, Vp, must be 1. Choice of start point and waveform length depends on the length of the cable and the actual probe rod length. There should be about 0.5 meters before the probe, enough distance for probe apparent length in water (approximately 9 times rod length), and enough distance for the waveform past the end of the probe. The distance for the end can be approximated as 3 times rod length.

2. Enter the value for **Probe Rod Length** in meters and set **Probe Offset** to 0 m.

3. Click the **Water Content** button to send the values to the TDR100 and to have it calculate La/L and provide start and end values.

4. Enter **Terminal Mode** using *Options/Terminal Emulator*.

5. Press Enter until > appears (the line commands are not case sensitive)

6. Type GVAR then Enter.

7. It is recommended that step 6 be repeated several times and that the average values of Start and End be used for following calculations.

   GVAR returns the uncorrected *Start* and *End.* These values must be converted to distance from index values. This is done as follows:

$$start_{distance} := \frac{start}{datapoints - 1} \bullet WaveformLength \qquad end_{distance} := \frac{end}{datapoints - 1} \bullet WaveformLength$$

Equations [A3] and [A4] are then used to calculate probe offset.

A.3.2 An Example Using CS605

- Measured TDR probe rod length: $L := 0.3$ m.

- Measure temperature of water in column $T := 24.4°C$.

- Determine actual dielectric permittivity of water using following equation or values in TABLE A-1.

  $$\varepsilon(T) := 78.54 \bullet \left[1 - 4.5791 \bullet 10^{-3} \bullet (T-25) + 1.19 \bullet 10^{-5} \bullet (T-25)^2 - 2.8 \bullet 10^{-8} \bullet (T-25)^3\right]$$

  $$\varepsilon(T) = 78.76$$

  $$La := L \bullet \sqrt{\varepsilon(T)}$$

  $$La = 2.66\,m$$

- Waveform parameters for PC-TDR

  $WindowLength := 5\,m \qquad datapoints := 251 \qquad Vp := 1.0$

  $Probe\ length = 0.3\,m \qquad Probe\ offset = 0\,m$

- Start and end index values from terminal emulator mode of PC-TDR as described above

  $start_{index} := 32.44 \qquad end_{index} := 169.87$

- converting waveform index to apparent distance

  $$start_{distance} := \frac{start_{index}}{datapoints - 1} \bullet WindowLength$$

$$end_{distance} := \frac{end_{index}}{datapoints - 1} \cdot WindowLength$$

$$start_{distance} = 0.65 \qquad end_{distance} = 3.4$$

$$ProbeOffset := \frac{-\left(La \cdot V_p - end_{distance} + start_{distance}\right)}{V_p}$$

$$ProbeOffset = 0.086$$

TABLE A-1. Dielectric permittivity values for range of temperatures. From equation [A5].

Temperature (°C)	Dielectric Permittivity
15	82.23
15.5	82.04
16	81.85
16.5	81.67
17	81.48
17.5	81.29
18	81.1
18.5	80.92
19	80.73
19.5	80.55
20	80.36
20.5	80.18
21	79.99
21.5	79.81
22	79.63
22.5	79.44
23	79.26
23.5	79.08
24	78.9
24.5	78.72
25	78.54
25.5	78.36
26	78.18
26.5	78

TABLE A-1. Dielectric permittivity values for range of temperatures. From equation [A5].	
Temperature (°C)	**Dielectric Permittivity**
27	77.82
27.5	77.65
28	77.47
28.5	77.29
29	77.12
29.5	76.94
30	76.76

Appendix B. Correcting Electrical Conductivity Measurements for System Losses

TDR system cabling and multiplexers introduce losses of the applied and reflected signals which can lead to error in measurement of electrical conductivity. The following information is based on a method presented in paper published by Castiglione and Shouse (2003). The method has been tested by Campbell Scientific and found to provide excellent results. Refinement of the method is provided to allow implementation using Campbell Scientific dataloggers and TDR100 system.

B.1 Description of Method

The method is essentially a calibration and involves collecting system characterization measurements with all system components in place; TDR100, multiplexers, all cabling, and probes. The steps in the process are:

1. measure reflection coefficient with probe rods open and with probe rods shorted

2. determine probe constant, K_p, using one solution of known electrical conductivity

3. use values collected in above steps to generate simple function to correct EC measurements

4. incorporate calibration function in datalogger program.

The method defines corrected reflection coefficient, $\rho_{corrected}$, using the equation

$$\rho_{corrected} = 2\left(\frac{\rho_{uncorrected} - \rho_{open}}{\rho_{open} - \rho_{shorted}}\right) + 1 \qquad \text{[B1]}$$

$\rho_{corrected}$ is then used to determine the conductance, G, with a TDR probe rods immersed in a solution of known electrical conductivity. $\rho_{uncorrected}$ is the refection coefficient at distance 200 m (example given below). The equation for conductance is:

$$G = \left(\frac{1}{Z_u}\right)\left(\frac{1-\rho_{corrected}}{1+\rho_{corrected}}\right) \qquad \text{[B2]}$$

with Z_u the system impedance, 50 ohms.

K_p is the slope of a graph of electrical conductivity versus electrical conductance, $\sigma = K_p G$. Since this function passes through the origin, only one measurement of G is needed with a probe immersed in a solution of known electrical conductivity. K_p is calculated as the ratio of electrical conductivity to electrical conductance and presented in equation [B3].

$$K_p = \frac{\sigma}{G} \quad \text{[B3]}$$

With K_p determined, a calibration equation can be derived that corrects EC measurements for system losses.

B.2 Detailed Method Description

B.2.1 Collecting Reflection Coefficient with Probes Open and Shorted

The EC measurement is independent of frequency and uses reflection coefficient values from locations well after probe reflections have stabilized. A distance of 200 meters is chosen for the measurement.

The ρ_{open} value is collected with the probe suspended in air. The $\rho_{shorted}$ value is collected with the end of the probe rods shorted while suspended in air. ρ_{open} and $\rho_{shorted}$ values are easily determined using PC-TDR. Set waveform parameters to:

Average = 4 Points = 20 Start = 200 Length = 1.

Click *Get Waveform* and adjust graph scale using the *Adjust Axes Range* button to allow determination of reflection coefficient to nearest 0.005.

ρ_{open} and $\rho_{shorted}$ values can also be collected using a datalogger. See Section B.2.4 , *CR1000 Program for Collecting ρ_{open} and $\rho_{shorted}$ Values*, for CR1000 datalogger program that can be used to collect ρ_{open} and $\rho_{shorted}$ values.

B.2.2 Determining K_p

K_p is the slope of electrical conductivity, σ, as a function of conductance, G. Completely immerse the probe rods in a solution of known or measured electrical conductivity. TABLE B-1 provides KCl amounts for a range of solution electrical conductivities. Since σ is zero when G is zero, K_p is simply the ratio of the known or measured electrical conductivity to the conductance, G, measured using equations [B3] and [B1].

TABLE B-1. Standard KCl Solutions

Electrical Conductivity @ 25°C (decisiemens/meter)	Grams of KCl/liter of solution
111.34	74.2460
12.86	7.4365
1.409	0.7440
0.147	0.0744

The temperature effect is described by:

$$EC_T = EC_{25} \bullet (1 + 0.02 \bullet (T - 25)) \qquad [B4]$$

where EC_{25} is the electrical conductivity at 25°C and EC_T is the electrical conductivity at other temperatures.

B.2.3 Deriving Calibration Function

Using the K_p, ρ_{open} and $\rho_{shorted}$ values for each probe, the uncorrected electrical conductivity as measured by the TDR100 can be corrected to give accurate EC values that account for system losses. To do this, a range of EC values is chosen for $\sigma_{uncorrected}$ in equation [B5] and $\sigma_{corrected}$ values calculated for the chosen range of $\sigma_{uncorrected}$.

$$\sigma_{corrected} = -K_p \bullet \frac{\sigma_{uncorrected} \bullet Z_u - K_p + \rho_{air} \bullet \sigma_{uncorrected} \bullet Z_u + \rho_{air} \bullet K_p}{Z_u \left(\rho_{shorted} \bullet \sigma_{uncorrected} \bullet Z_u + \rho_{shorted} \bullet K_p + \sigma_{uncorrected} \bullet Z_u - K_p\right)} \qquad [B5]$$

This equation has a quadratic form. The correction is easier to use if a curve is fit to the $\sigma_{corrected}$ values for the chosen range of $\sigma_{uncorrected}$. This quadratic is implemented in the datalogger program to given the final result that is corrected electrical conductivity. This must be done for each probe.

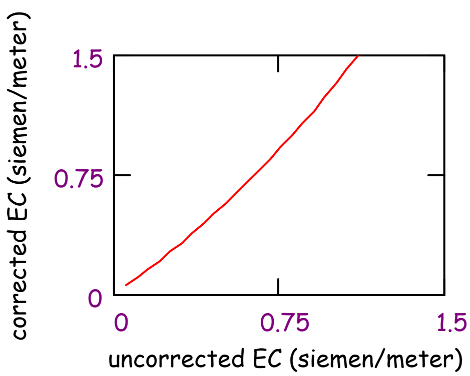

FIGURE B-1. Example of corrected and uncorrected electrical conductivity values.

The fitted equation for this probe is

$$\sigma_{corrected} = 0.01 + 0.95 \bullet \sigma_{uncorrected} + 0.35 \bullet \sigma_{uncorrected}{}^2$$

B.2.4 CR1000 Program for Collecting ρ_{open} and $\rho_{shorted}$ Values

```
'This example program is written for 4 TDR probes connected to
'a single multiplexer.  It will be necessary to add instructions in
'subroutine TDR if more probes are used.

'CR1000 Series Datalogger
'Declare Public & Dim Variables
Public wave(30), vector(20)
Public rho(2)
Public channel as long
Public Open as boolean
Public Shorted as boolean
Public SDMports as boolean
Public WriteToOutput as boolean
Dim I
'Declare Constants
'Flag logic constants
const high = true
const low = false

'Define Data Tables
DataTable (rhoTable,1,-1)
  Sample(1,channel,Long)
  Sample (2,rho(),IEEE4)
EndTable

‘
sub TDR                          'set multiplexer address code for specific system
  Select Case channel
  Case 1
    TDR100 (wave(),0,1,1001,4,1.0,20,200,1.0,0.075,0.0,1,0)
  Case 2
    TDR100 (wave(),0,1,2001,4,1.0,20,200,1.0,0.075,0.0,1,0)
  Case 3
    TDR100 (wave(),0,1,3001,4,1.0,20,200,1.0,0.075,0.0,1,0)
  Case 4
    TDR100 (wave(),0,1,4001,4,1.0,20,200,1.0,0.075,0.0,1,0)
  EndSelect
endsub

'Main Program
BeginProg
  Scan (5,sec,0,0)
    if Open=high then
      TDR
      For I=1 To 20
        vector(I)=wave(I+9)
      Next
      AvgSpa (rho(1),20,vector(1))
      Open=low
    endif

    if Shorted=high then
      TDR
      For I=1 To 20
        vector(I)=wave(I+9)
      Next
      AvgSpa (rho(2),20,vector(1))
      Shorted=low
    endif
'write results to output storage
    If WriteToOutput=high Then
      CallTable rhoTable
      WriteToOutput=low
    EndIf
```

```
'setting SDMports high will configure control ports 1 thru 3 to allow connection
'of TDR100 to PC using PC-TDR
    If SDMports=high Then
      PortsConfig (&B00000111,&B00000000)
      SDMports=low
    EndIf
  NextScan
EndProg
```

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