Internal Report

ManTDR software for making manual TDR measurements
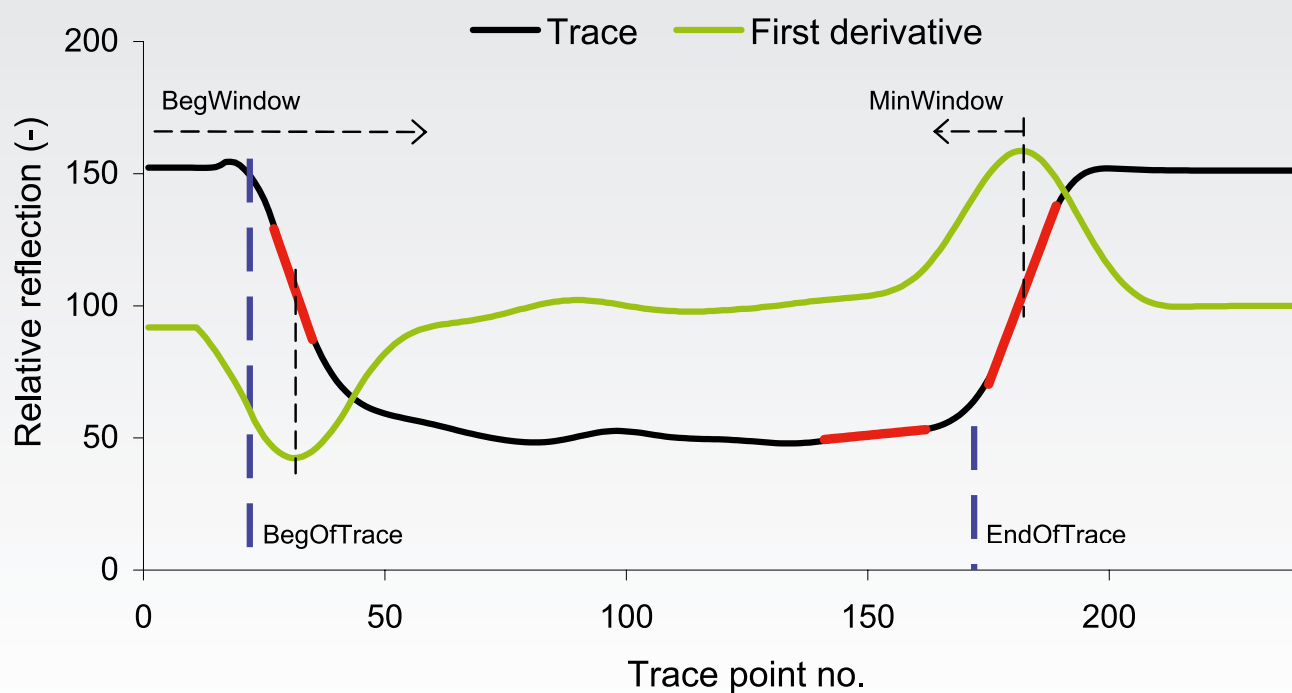
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ManTDR software for making manual TDR measurements

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Contents

1. Summary

The **ManTDR** software is developed for manual measurement of volumetric soil water content using the TDR100 TDR instrument (Campbell Scientific, Logan, UT, USA). The software is developed in Turbo Pascal (Borland International, Scotts Valley, CA, USA) for the DOS operating system. The current version will run on most PC compatible computers including the robust Allegro (DOS) field computer (Juniper Systems, Logan, UT, USA). An earlier version of the software, **AutoTDR**, (Thomsen, 1994) was developed for the Tektronix model 1502 cable tester (Tektronix, Beaverton, OR, USA) and the Husky field computer, both of which are no longer available. The **AutoTDR** software is still being maintained and will also run on the Allegro field computer. The software will work with most of the probe designs introduced in the literature although only popular balanced and unbalanced probe types are discussed here. A balanced probe system including typically $4-8$ probes, short 200 Ω twin-axial cables and a connecting post (hub) is introduced. The probe system is typically used where it is important to minimize the disturbance to vegetation and soil conditions or simply to make it easier to locate the probes. A test version of the software is available from the author upon request.

2. Introduction

The software introduced in this user's guide has been used for making routine TDR measurements for several years. The first user's guide (Thomsen, 1994) includes more details on the gradual development of the software. Petersen et al. (1995) published the first paper based on measurements made with the software. In general the user interface is highly graphical and the user is encouraged to experiment with the parameter setting and watch how the trace analysis is affected. During routine measurements a quick glance at the analysed trace is sufficient to tell the experienced user if a measurement is successful or has to be repeated.

A balanced probe system including typically $4-8$ probes and a central hub connected to the individual probes using short 200 Ω twin-axial cables is developed for use with the software. The probe system minimizes the disturbance to vegetation and soil conditions and makes it easier to locate probes. The probe system in introduced in Appendix 1.

In a parallel development, software for automated multiplexed measurements of soil water content and electrical conductivity (Thomsen et al., 2000) was also developed. The most recent version of this software, **AutoTc64,** uses both the TDR100 and the Tektronix cable tester as TDR instrument. Plauborg et al. (2005) used **AutoTc64** to make measurements in a potato trial. A short manual to the **AutoTc64** software is included as Appendix 2. It is assumed that the user of the **AutoTc64** manual has at least some familiarity with the **ManTDR** software. More information on the automated system can be obtained from the author.

The manual is organised as several brief chapters with headings that hopefully guide the user to the needed information.

Before reading further into the manual it is suggested to go directly to Chapter 10 providing a quick guide to making the first measurement.

3. User interface

The main menu of the of the user interface is displayed when the **ManTDR** software is initiated:

> **M**ake Measurement
> **S**tore Measurement
> **P**arameter setting
> **F**iles and Setup
> **V**iew Parameters
> **W**rite Trace to File
> **E**xit

Menu options are selected by typing the first character (highlighted) of the menu line. After selecting an option the next menu level is displayed.

- Making, displaying and storing measurements is discussed in Chapters 6 and 7.
- Parameter setting and viewing is discussed in Chapter 4
- File naming and file structure is discussed in Chapter 9
- Reanalysis of stored traces with alternative parameters is discussed in Chapter 11

4. Parameter setting

Current parameter values can be changed by selecting *Parameter Setting* (P). Before parameters are changed the user can specify if all parameters should first be reset to their default values. When the programme is initiated parameters are always set to their default values. The parameters are displayed and changed sequentially in the order listed below. If a parameter value is to be retained Enter is pressed. To view the parameters only select *View Parameters* (V)**.**

The parameter default values are optimised for the common two wire balanced probe (type 1) including an impedance matching and balancing transformer (balun). See Chapter 5 for further information on available probe types. Usually parameters can be left at their default values. Only if a different probe type is used or conditions are unusual is it necessary to change parameters.

Below the parameters and their values are introduced. In Figures 1 and 2 the parameters are introduced in graphical form.

LastPoint (between 100 and 251. Default = 251) specifies the last trace point to be included.
BegWindow (between 10 and 75. Default = 60) specifies the window in screen points where the algorithm searches for the beginning of probe
MinWindow (between 8 and 50. Default = 20 specifies the distance in screen points from the steepest (inflexion) point on the end-of-probe reflection where the algorithm searches for the end of probe. Increase this parameter if the TDR trace is highly attenuated due to longer probe cable or electrically more conductive soil than typical
RegresRange (between 5 and 30. Default = 8) specifies the length in screen points of the regression lines fitted to portions of the trace during analysis (location of beginning and end of probe)
SmootheWindow (between 5 and 30. Default = 8) specifies the width of the averaging (smoothing) filter in screen points. Traces are smoothed before analysis to reduce noise in input data
*ProbeType* (between 1 and 3. Default = 1) specifies the probe type used. Probe type 1 equals the common two-wire balanced probe, type 2 the unbalanced two or three wire probe and type 3 is like the type 1 probe only analysed differently. Other specialised probe types are available but not introduced here
TraceOffset (between 0 and 0.25. Default = 0) specifies the distance in m from the true probe starting point to the beginning identified by the software. Necessary for the type 2 probe but usually not needed for a type 1 probe
*TraceMax* (between 0.2 and 1.0. Default = 0.7) and *TraceMin* (between −1.0 and −0.2. Default = -0.7) are used for scaling the trace in the height direction. Experiment to test the function of these parameters

The parameters *SmootheWindow, RegresRange* and *MinWindow* are automatically scaled according to the length resolution of the acquired trace and the length of the TDR probe. The parameter scaling according to probe length is logarithmic based on experimentation whereas resolution scaling is proportional. The user can deactivate parameter scaling by first selecting *File and Setup* (F) from the main menu and then *Scale Parameters* (S) from the second menu level. Because of the parameter scaling it is usually not necessary to adjust parameters when measuring on probes of varying length. The effect of parameter scaling can be tested by making measurement on e.g. probes of varying length and viewing the current parameter values by selecting View Parameters (V). *It is highly recommended that the parameter scaling option be left on.* From the *File and Setup* (F) menu item it is also possible to deactivate the automatic numbering of measurement probes or measurements by selecting *Increment Probe No.* (I).
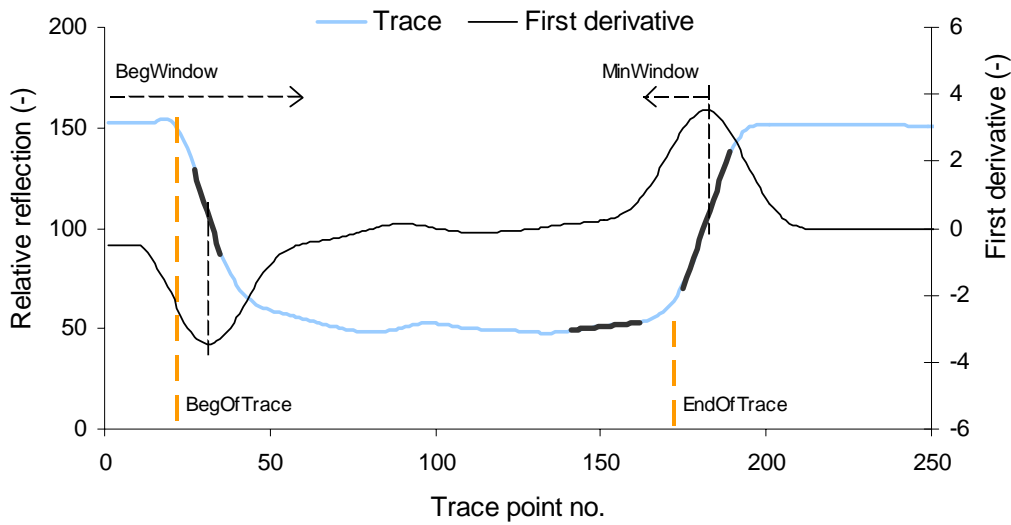
Figure 1. Graphical output from the analysis of a 0.2 m balanced (type 1) probe placed in moist sand. The length of the projection of the regression lines in screen points is controlled by the ***RegresRange*** parameter. ***RegresRange*** and the parameters indicated in the figure are discussed in Chapter 4. The beginning of probe, ***BegOfTrace***, is placed at the intersection of the first regression line and a horizontal line (not shown) through the highest trace value in front of it. The end of probe, ***EndOfTrace***, is placed at the intersection of the next two regression lines. The available probe types are introduced in Chapter 5. The results etc. of the analysis are listed in Table 1.
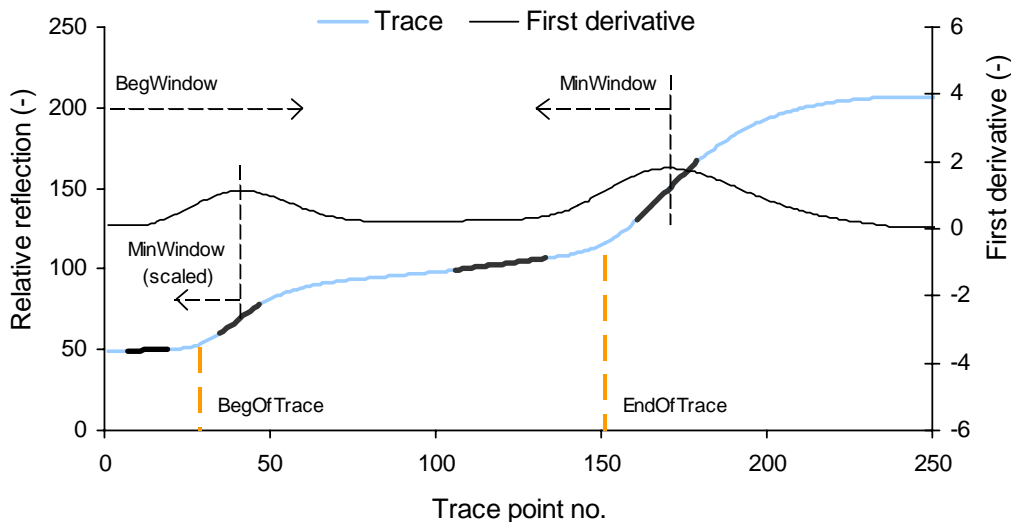
Figure 2. Graphical output from the analysis of a 0.2 m unbalanced (type 2) probe placed in moist sand. The length of the projection of the regression lines in screen points is controlled by the ***RegresRange*** parameter. ***RegresRange*** and the parameters indicated in the figure are discussed in Chapter 4. The beginning of probe, ***BegOfTrace***, and end of probe, ***EndOfTrace***, are located at the intersection of the two pairs of regression lines. The available probe types are introduced in Chapter 5.

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5. Probe types

Traces from a number of probe types can be analysed. Only the three most common types are discussed here. Information on more special probe types can be obtained from the author.

Type 1. The common balanced two-wire probe design including an impedance matching pulse transformer (balun). See Appendix 1 for details on the probe system usually used for manual measurements. Type 1 probes are almost exclusively used for making manual TDR measurements in the field because the robust detachable probe rods allow the insertion of probes as long as 1 m or more. Typically probe systems including several probes are used in the field in order to easily locate measurement positions and minimise disturbance to plant and soil conditions. A typical trace produced by a type 1 probe can be seen in Figure 1.

Type 2. Two or three wire unbalanced probe design without a balun transformer (Zeglin and White, 1989; Heimovaara and Bouten, 1990). Type 2 probes are rarely used for making manual TDR measurements in the field. The probe rods and 50 Ω coaxial cable are usually soldered directly together, and the probe is difficult to insert as a unit into typical field soils. This design has, however, been found useful-sometimes even preferable-because of the well defined trace produced for certain laboratory and other conditions where relatively short probes are used. Type 2 probes alone or in a mix with type 1 probes have been used in projects where automated multi-probe measurements have been made under field conditions (Schelde et al., 1998). A typical trace produced by a type 2 probe can be seen in Figure 2. For a type 2 probe the beginning of probe is located inside the probe head before the actual beginning (Figure 2). Because of this effect a trace offset value, ***TraceOffset,*** has to be specified. The trace offset value can be changed like the other parameters by selecting ***Parameter Setting*** (P) from the main menu. The value of ***TraceOffset*** can be estimated by making measurements on a type 2 probe immersed in water. By making both a probe type 2 and a probe type 1 measurement ***TraceOffset*** can be calculated as the difference between the resulting ***TdrLength*** values, where ***TdrLength*** is the apparent length of the measuring probe. *Note that it is important that only the probe rods and not the probe head is immersed in water.*

Type 3. Designed like the type 1 probe. If the topsoil is very dry the soil surface (or beginning of probe) can be difficult to identify using the standard procedure. Instead the software will search for a slight peak along the trace where the probe physically starts (see Figure 1). If a slight peak is not present this procedure will also give erroneous results. If a peak is present but not placed at the actual beginning of probe a trace offset value, ***TraceOffset***, that corrects for this can be specified. The trace offset value can be changed like the other parameters by selecting ***Parameter Setting*** (P) from the main menu. The value of ***TraceOffset*** can be estimated by making measurements on a type 1 probe immersed in water. By making both a probe type 1 and a probe type 3 measurement ***TraceOffset*** can be calculated as the difference between the resulting ***TdrLength*** values, where ***TdrLength*** is the apparent length of the

measuring probe. *Note that it is important that only the probe rods and not the probe head is immersed in water.*

6. Trace acquisition

Trace acquisition is initiated by selecting *Make Measurement* (M) from the main menu. After the initial selection the user is prompted for:

1. Length of measuring probe (***ProbeLength*** with values between 0.05 and 1.5 m. Default = 0)
2. If a trace window is to be selected (only necessary for the first measurement or when probe length or length of probe cable changes)
3. If acquisition of trace window selected, the approximate length of the probe cable (***CableLength*** with values between 0 and 50 m. Default = 0) has to be specified

The Campbell TDR100 has no instrument screen and manual controls and the procedure described above will display a low resolution trace on the computer screen. The low-resolution trace is placed at a variable distance, ***CableLength***, from the instrument along the probe cable. Next the keyboard cursor controls are used to mark the beginning and end of the active trace and the selected trace length is reacquired at higher resolution and analysed and displayed. This procedure can be repeated if necessary. After trace acquisition the trace is automatically analysed as discussed in Chapter 7.

7. Trace analysis

After selecting a trace window and acquiring a trace as discussed in Chapter 6 the trace is analysed using probe type specific algorithms. For an introduction to automated trace analysis see the papers by Baker and Allmaras (1990) and Heimovaara and Bouten (1990). **ManTDR** performs trace analysis in the following general steps:

1. The 251-point trace is smoothed using a moving average filter. The width of the filter in screen points is defined by the parameter ***SmootheWindow***
2. Using the smoothed trace as input the local slope (first derivative) of the trace is calculated
3. Minimum and maximum points on the slope curve are used for locating 'beginning' (***BegOfTrace***) and 'end' (***EndOfTrace***) of the measuring probe as shown graphically in Figure 1 and Figure 2 for the two main probe types. See Chapter 5 for a discussion of available probe types. Briefly the sought points on the input trace are located by fitting two first order regression lines to trace segments bordering the 'beginning' and 'end' of the measuring probe and calculating the intersection points. Heimovaara and Bouten (1990) discuss the procedure in more detail. The length of the regression lines in screen points is defined by the parameter ***RegresRange***. The settings of

SmooteWindow and *RegresRange* are usually left at default values but modifying (usually increasing) their values can sometimes improve trace analysis significantly. As a starting point assign approximately the same value to the two parameters

4. The empirical calibration function by Topp et al. (1980) is used for calculating water content. See Chapter 8 for a discussion of calculation of water content. Details on trace analysis, results etc. is displayed in alphanumerical form (Table 1). If selected graphical information analogous to the information shown in e.g. Figure 1 is then displayed. *It is highly recommended that the user inspects the graphical output before storing the results of the analysis*

5. If successful measurement results can be stored together with the user supplied probe identification number. The file structure is discussed in Chapter 9. The user can select to save the original trace together with the results by selecting *Write Trace to File* (W) or just the results by selecting *Store Measurement (S)*. If a trace is stored it can be reanalysed as discussed in Chapters 9 and 11

Table 1. Example of **ManTDR** alphanumerical output. Data from the trace analysis shown in Figure 1.

Hour	=	15	*Minute*	=	18
VpSetting	=	0.67	*LenPerPoint*	=	0.0022
Probelength	=	0.200	*TdrLength*	=	0.497
BegOfTrace	=	22.0	*EndOfTrace*	=	171.3
ProbeType	=	1	*TraceOffset*	=	0.000
ProbeNo	=	1	*WaterCont.*	=	10.74
KaCalc	=	6.18			

The parameters and variables shown in Table 1 are introduced in different chapters. Below a short introduction is provided. A more comprehensive discussion is given in the chapter numbers listed in parenthesis after the name:

- *Hour*, *Minute* give time of measurement
- *VpSetting* specifies the relative propagation velocity of the TDR pulse (fixed at 0.67)
- *LenPerPoint* is the length in m per trace point calculated using *VpSetting* = 0.67
- *ProbeLength* (6,8) specifies the length of the measuring probe in m
- *TdrLength* (5,8) is the apparent length (*VpSetting* = 1) of the measuring probe in m
- *BegOfTrace, EndOfTrace* (5,7) are the probe beginning and end points on the active trace
- *ProbeType* (4,5) specifies the probe type used
- *TraceOffset* 4,5) specifies the offset in m of the beginning of probe
- *ProbeNo* specifies the probe or measurement number assigned to a measurement
- *WaterContent* (8) is the water content calculated using the Topp equation
- *KaCalc* (8) is the calculated apparent dielectric constant of the moist soil

8. Calculation of water content

Water content is calculated using the empirical calibration function by Topp et al. (1980):

$WaterContent =$
$(-5.3\ 10^{-2} + 2.92\ 10^{-2}\ KaCalc - 5.5\ 10^{-4}\ KaCalc^{2} + 4.3\ 10^{-6}\ KaCalc^{3})\ 100,$

where **WaterContent** is the volumetric water content in percent and **KaCalc** is the apparent dielectric constant of the moist soil. **KaCalc** is calculated during trace analysis using:

$KaCalc = (TdrLength\ /\ ProbeLen)^{2},$

where **TdrLength** is the TDR measured apparent length of the measuring probe and **ProbeLen** is the physical length of the probe. **TdrLength** is calculated using a relative propagation velocity of 1, as for vacuum, and should always be greater than **ProbeLen**. See Chapter 7 for details on trace analysis.

TdrLength and **ProbeLen** are both output to the measurement file when a measurement is stored. This allows the user to use a calibration function other than the Topp equation (Topp et al., 1980). See Chapter 9 for details on file structure.

9. File naming and structure

ManTDR generates two text file formats. Annotation and measurements are stored in measurement files with the forced extension MES. Annotation, measurements and input traces are stored together in trace files with the forced extension TRA. File names are specified by first selecting *Files and Setup* (F) from the main menu and then either *Measurement File* (M) or *Trace File* (T). After file selection the file name is entered. See Chapters 6 and 7 for a discussion on making measurements and storing data.

The data content of the two file types is listed below. Both file types include the first 9 columns of information. The following 10 columns are specific for the trace file and provides the information needed for reanalysing trace data:

1. *Year*
2. *Month*
3. *Day*
4. *Hour*
5. *Minute*
6. *ProbeNo*
7. *ProbeLen*
8. *TdrLength*
9. *WaterContent*

10. *TraceLength*
11. *VpSetting*
12. *LenPerPoint*
13. *FirstPoint*
14. *LastPoint*
15. *BegWindow*
16. *MinWindow*
17. *RegresRange*
18. *ProbeType*
19. *TraceOffset*

Most of the parameters are either obvious as date and time or defined in Chapter 7. New parameters are:

- *10. TraceLength* specifies the number of data points in the trace (here always 251)
- *12. LenPerPoint* is the length per trace point in m

The 19 header values of the trace file is followed by the **TraceLength** (251) byte values of the TDR trace. Trace files can be reanalysed and displayed by first selecting *File Setup* (F) from the main menu and then Analyse *Trace* (A) from the next menu level. Reanalysing trace data will give the same result as the initial analysis. See Chapter 11 for a discussion on how traces can be reanalysed using alternative parameters.

10. Quick tour

After connecting the system including a PC compatible computer, the Campbell TDR100 TDR instrument and a TDR probe embedded in soil or placed in a bucket with tap water the **ManTDR** software is initiated. *Note that the first serial port (COM 1) of the computer should be used.* Below it is shown that only probe length and length of sensor cable have to be specified in order to make a measurement:

1. Select *Make Measurement* by typing M
2. Specify the length of the TDR probe by typing e.g. 0.5
3. Select selection of trace window by typing Enter
4. Specify approximate (do not overestimate) cable length by typing e.g. 2.5
5. Use cursor keys to place cursor vertical lines near the 'beginning' and 'end' of active trace
6. Type Enter twice to reacquire the selected trace segment
7. The active trace is now acquired and analysed and the tabular results displayed
8. Type Enter to display the analysed trace
9. Finally type Enter to return to the main menu

11. Reanalysis of stored traces

Reanalysis of stored traces is initiated by first selecting *File and Setup* (F) from the main menu and then *Analyse Trace* (A) from the second menu level. The name of the trace file to be included is prompted for. See Chapters 6 and 7 for a discussion of trace acquisition, analysis and storage and Chapter 9 for details on the file structure. Traces are reanalysed using the parameters stored in the trace file and the result is identical to the initial measurement. This option is included for documentation purposes. Alternatively traces can be analysed from outside the main program. This requires that the TDR100 is not connected or offline when ManTDR is initiated. In this mode the user can select to change one or more of the trace analysis parameters incl. probe type. When initiated with the TDR unit offline only analysis of stored traces is possible. By reanalysing the trace file and viewing especially the graphical output the effect of changing parameter values can be instantly evaluated.

12. References

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Petersen, L.W, Thomsen, A., Moldrup.,P., Jacobsen, O.H. & Rolston, D.E., 1995. High-resolution time domain reflectometry. Sensitivity dependency on probe design. Soil Science 159, 149-154

Plauborg, F., Iversen, B.V. & Lærke, P.E., 2005. In situ comparison of three dielectric soil moisture sensors in drip irrigated sandy soils. Vadose Zone Journal 4, 1037-1047

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Thomsen, A., Hansen, B. & Schelde, K., 2000. Application of TDR to water level measurement. Journal of Hydrology 236, 252-258

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13. Appendix 1

The ManTDR software is typically used with a probe system including several (4 – 8) individual measuring probes connected to a central hub with short (2 – 4 m) twin-axial cables.

Probe hub (Figure 1)
A 6-probe version of the hub is shown in Figure 1. The hub includes a base plate and the stacked probe terminals.

Cabling and connectors (Figure 2)
Figure 2 shows the probe terminal and the 200 Ω twin-axial signal cable connecting the terminal and the probe head. Figure 2 also shows how the probe head is connected to the 2 probe rods using locking screws. The probe rods can be of any length between 0.05 and 1.5 m. A typical length combination is 0.2, 0.5 and 1.0 m. If the probes are inserted from the soil surface the water content of the soil layers 0 – 20, 20 – 50 and 50 – 100 cm can be calculated by subtraction.

Hand balun (Figure 3)
A hand balun is used for connecting the TDR instrument to the individual probes. The balun transformer balances the TDR signal and matches the impedance of the TDR instrument (50 Ω) to the impedance of the probe system (200 Ω). The hand balun is shown in Figure 3.

Probe installation (Figure 4)
Probes are installed using the 5 steps illustrated in Figure 4:
1. Probe rods are driven into the soil using a hammer, 5 cm spacer and hammer block
2. Spacer is removed before hammer block touches it
3. Upper side of hammer block (without guide holes) used to drive rods fully into the soil
4. Holes in probe rods to receive connecting pins are aligned and locking screws put in
5. Probe head is attached and locking screws tightened

It is important that the probe rods are driven fully into the soil so there is no air gap between probe head and soil surface.

TDR system (Figure 5)
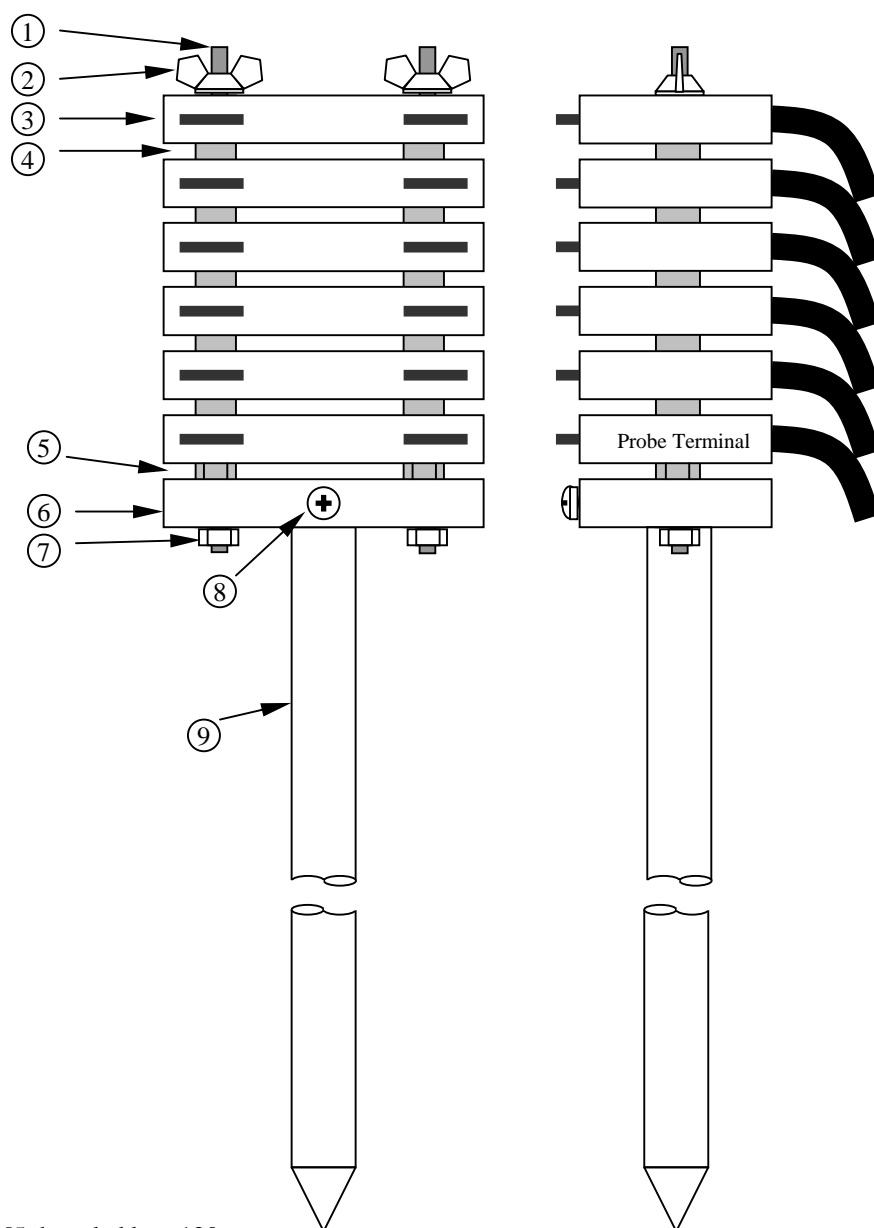Figure 5 shows the measurements system including:
- Allegro field PC
- TDR100 TDR instrument
- Hand balun
- Communication cable

The measurement system and rechargeable batteries are carried in a small backpack when making field measurements.

Figure 1

① 2 x M5 threaded bar, 120 mm
② 2 x M5 Wing Nuts
③ 6 x Probe terminal
④ 10 x Nylon separators
⑤ 2 x Nuts
⑥ 1 x Hub base
⑦ 2 x M5 self locking nuts
⑧ 1 x Plastic screw
⑨ 1 x Hub post

TDR Probe HUB 6	Appendix 1. Page 17	
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Probe Terminal

Figure 2
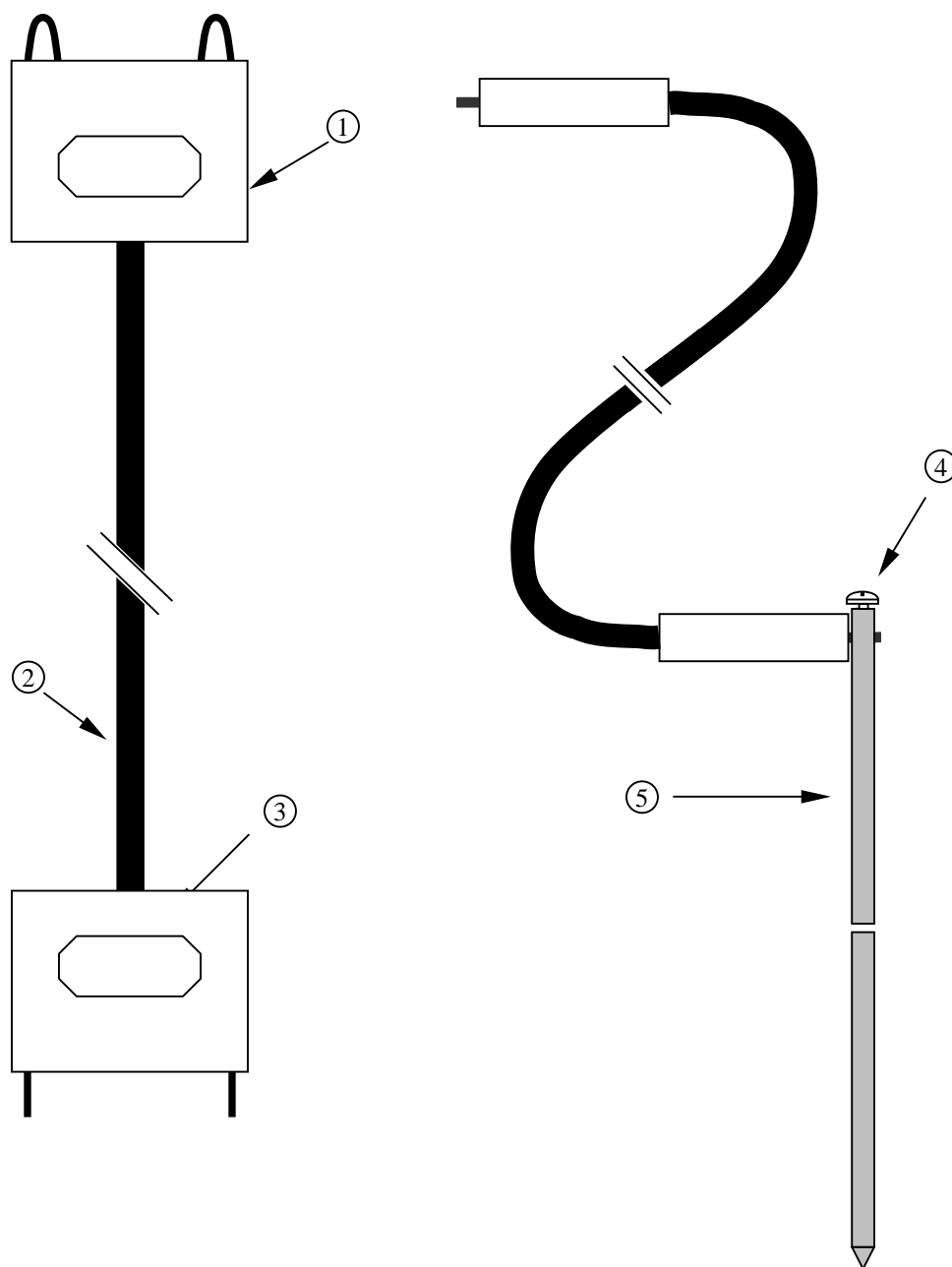
①   1 x Probe Terminal
②   1 x 3 m Custom Twin axial cable, 200 ohms
③   1 x Probe Head
④   2 x M4 Screw
⑤   2 x Probe rods (Various lengths)

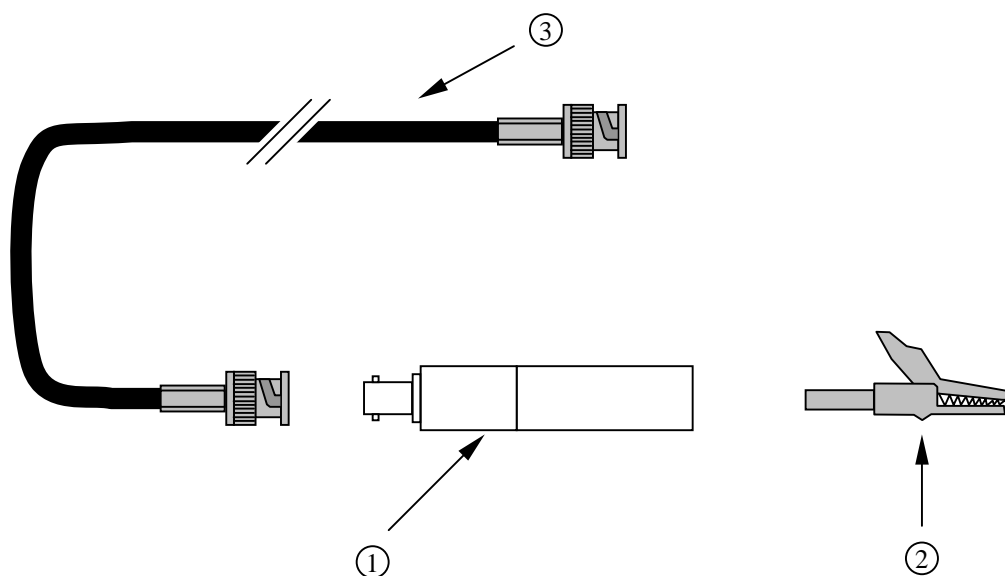| **TDR Probe Vertical**	**Appendix 1. Page 19**
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Figure 3

① 1 x Balun house (200:50)
② 2 x 2 Replaceable Croc Clips, 4 mm
③ 1 x 50 ohms coaxial cable, RG-58

TDR Hand balun	**Appendix 1. Page 21**	
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Figure 4

Nylon Hammer

① Hammer Block ③

④

⑤

Spacer

Hammer Block

Spacer

①

②

Hammer Block

③

②

⑥

⑦ Soil surface

Probe Head

④

⑤

OK!

Soil surface

Pro... H...

ERROR!
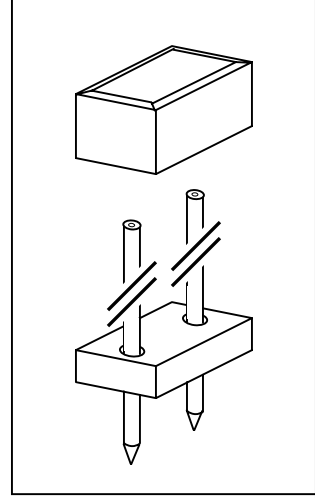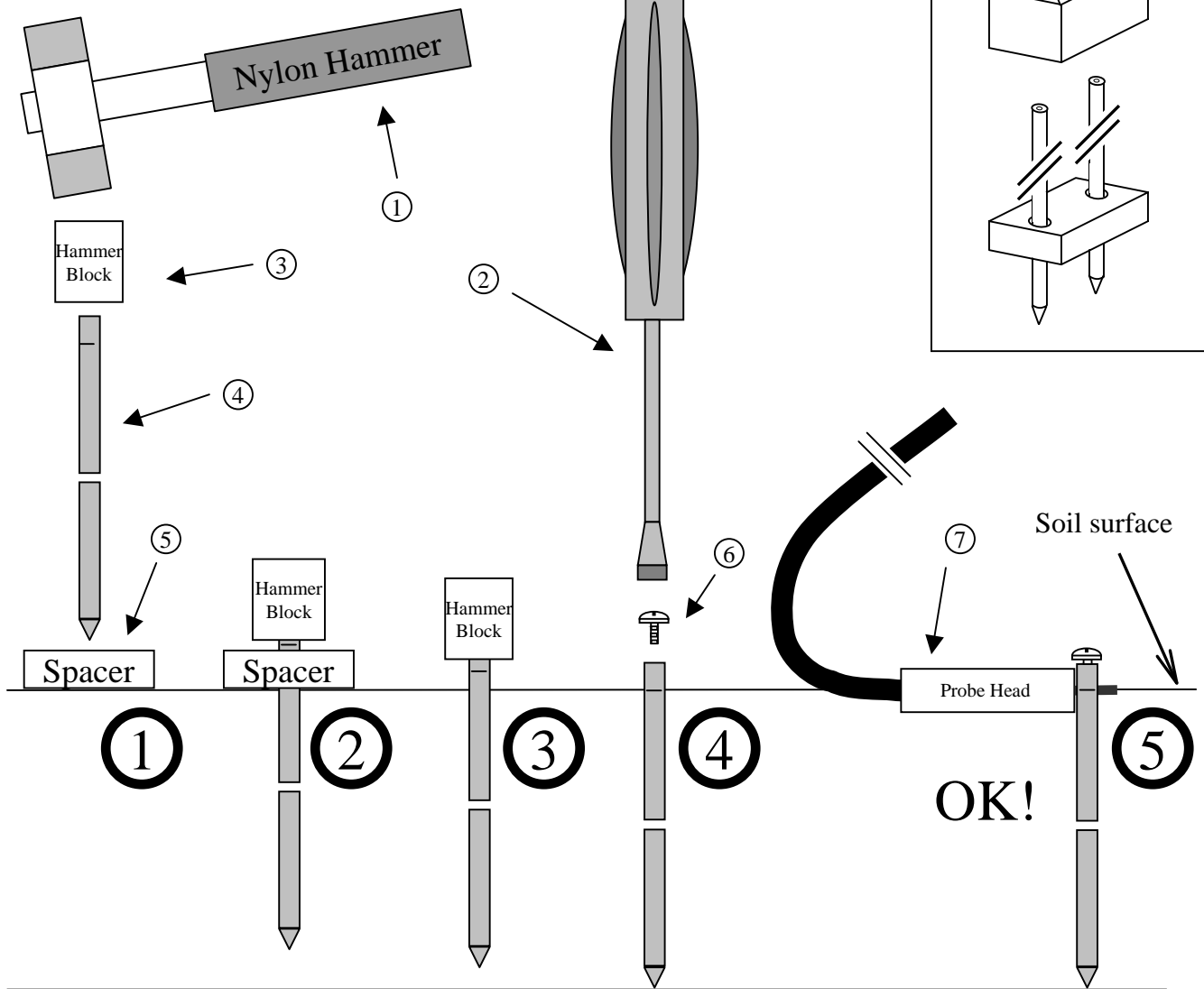
① Nylon Hammer
② Straight screw driver
③ Hammer block
④ 2 x probe rods
⑤ Probe spacer
⑥ 2 x Locking screws
⑦ Probe head

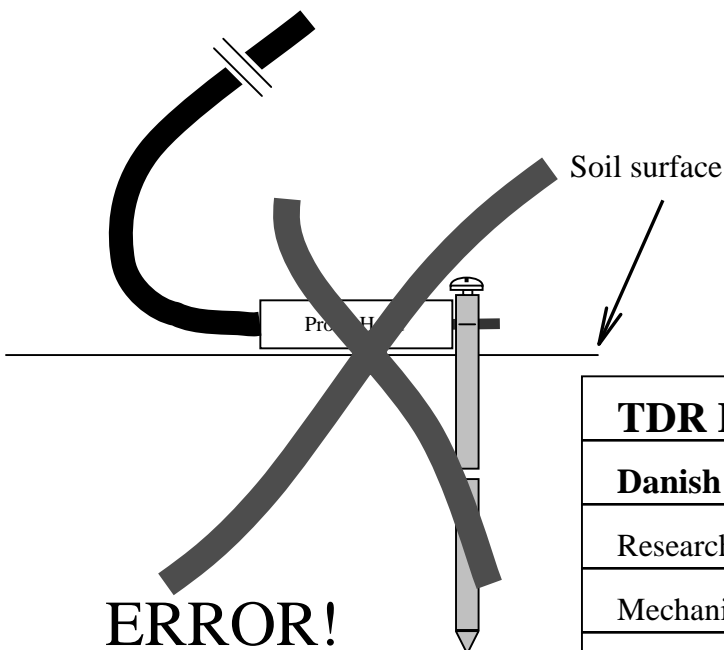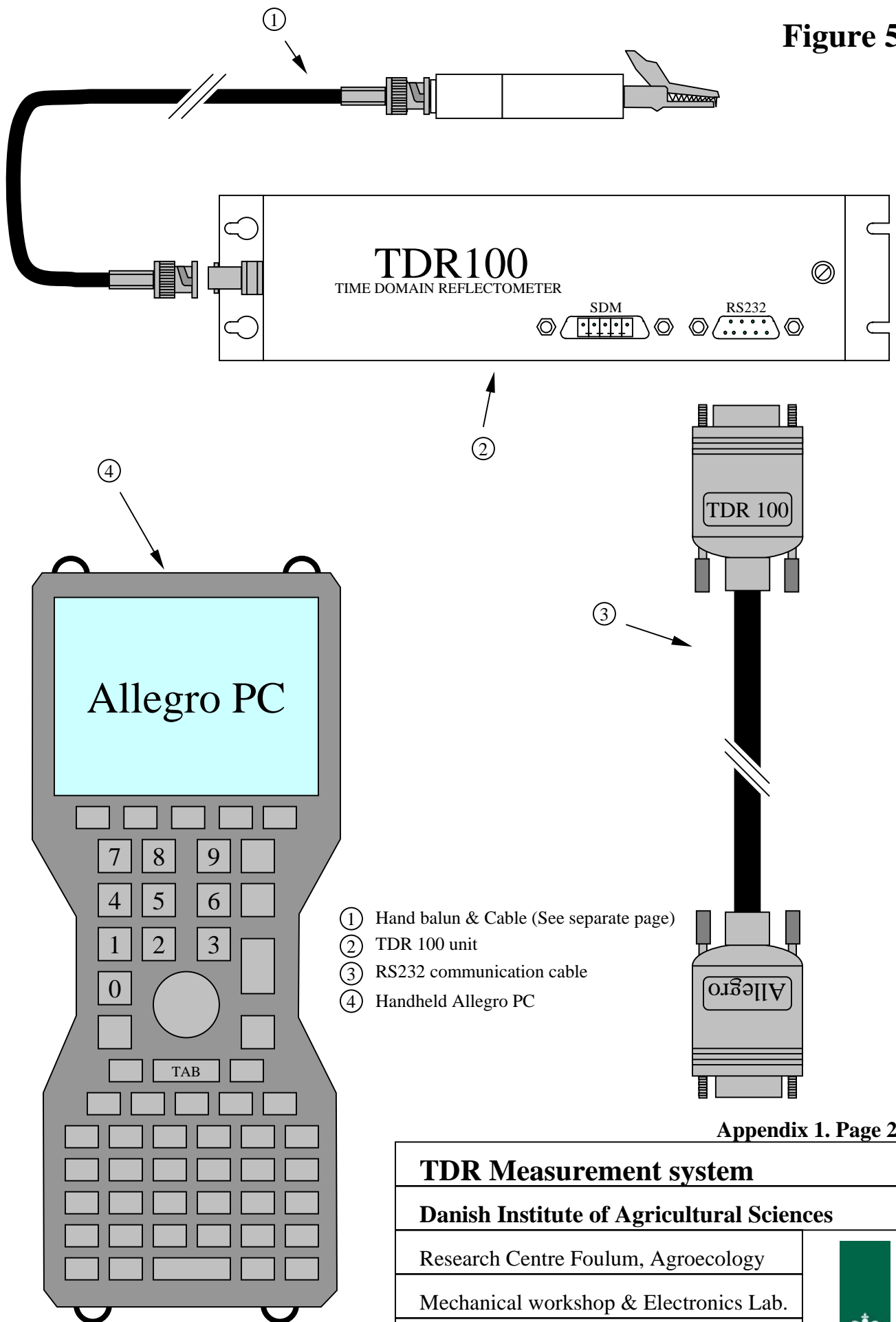| **TDR Probe Mounting**	**Appendix 1. Page 23**
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Figure 5

TDR100
TIME DOMAIN REFLECTOMETER

SDM RS232

TDR 100

Allegro PC

Allegro

① Hand balun & Cable (See separate page)
② TDR 100 unit
③ RS232 communication cable
④ Handheld Allegro PC

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TDR Measurement system	
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14. Appendix 2

AutoTc64 Short Manual

Contents

1. Introduction

The **AutoTc64** software is primarily developed for the **TC64** measurement system. **TC64** is a self-contained 64-channel TDR system including a PC compatible processor and up to eight 8-channel multiplexers. The software will use either the Tektronix 1502 cable tester (**AutTc64T**) or the Campbell TDR100 (**AutTc64C**) as TDR instrument. The **TC64** is described in the service manual included with the system.

The **AutoTc64** software will run in a standard configuration on most PC compatible computers.

The software is developed in Turbo Pascal for PC's running under DOS. The user is encouraged to experiment with parameter settings etc. to get familiar with the functioning of the software. Reanalysing stored trace data can instantly test the effect of changing e.g. trace analysis parameters. For most situations, however, the default parameters should perform adequately.

Before reading the introduction to the user interface (Chapter 2) it is suggested to go directly to the quick tour portion (Chapter 3) of the manual to experience how the software functions.

2. User interface

The main menu of the user interface is displayed when the software is initiated:

Files, Analysis, Sampling and System
Begin Automated Measurements
Generate Multiprobe Parameter File
Test Parameter File
Update Trace Analysis Parameters
View Current Parameters
Exit, Auto and Slave Operation

Menu options are selected by typing the first character (highlighted) of the menu line. After selecting an option the next menu level is displayed. Below the second level of the interface is introduced:

Files, Analysis, Sampling and System

Measurement File
Parameter File
Trace File
Analyse Trace File
Create/Update INI-file
Sampling Interval
GSM Modem
WatchDog

The three files types are assigned a default name if not assigned a name here. Files have forced extension names (MES, PAR and TRA) that cannot be changed by the user. The system will store measured TDR traces if specified (see ***Test Parameter File*** menu option). These files can be reanalysed (e.g. with alternative parameters) or simply used as documentation. Most users do not have to change the default TDR trace analysis parameters. If parameters are changed to optimise trace analysis the alternative parameters can be stored in the system INI-file (always called AutoTDR.INI). Selected options (GSM modem and watchdog timer support. See Chapter 4), sampling interval etc. are also stored in the INI-file. Selecting options etc. will automatically create an updated INI-file.

Begin Automated Measurements

Measurements can be initiated if a parameter file has been previously created (see **G**enerate Multiprobe Parameter File menu option). The user is asked to verify file names. File names can only be changed by first exiting to the main menu. After files have been assigned the user is asked for a sampling interval (cont, 2m, 15m, 1h, 2h, 4h or 6h). If continuous measurements is selected the number of repeated measurements (cont, 5, 10, 15, 20 or 25) has to be specified. A fixed number of repeated measurements are typically used for generating calibration data.

Generate Multiprobe Parameter File

The user is asked to verify the name of the parameter file. If an existing file is assigned the user has to approve that the file is overwritten. After file selection the user has to specify if measurement of probe impedance (inversely related to electrical conductivity) has to be included. Next the total number of probes (between 1 and 64), probe type (1 = balanced and 2 = unbalanced probe. Other more specialised probe types are available but not described here),

probe-length (between 0.05 and 1.5 m) and trace offset (between 0 and 0.1 m. Usually not used for a type 1 probe but necessary for a type 2 probe) is specified.

At this point users of the Tektronix cable tester have to use the instrument controls to place and scale the active part of the trace on the instrument screen. The Campbell TDR100 has no instrument screen and manual controls and the procedure includes selecting the active part of the trace from a low-resolution trace displayed on the computer screen. The low-resolution trace is placed at a variable distance from the instrument along the probe cable by specifying the approximate length of the cable (between 0 and 50 m). Next the keyboard cursor controls are used to mark the beginning and end of the active trace and the selected trace length is reacquired and displayed. This procedure can be repeated if desired.

Using both instruments all the information required to retrieve the traces as visually selected is stored in the parameter (PAR) file.

Test Parameter File

During testing the information stored in the parameter (PAR) file is used to activate the probes one by one. Probe information, measurement results and the acquired traces and their analysis is displayed on the screen. The acquired traces can be stored in a trace (TRA) file to serve as documentation and used in optimising trace analysis parameters. If the parameter file needs improvement a new parameter file has to be generated and the testing procedure repeated. *It is not possible to modify the parameter file on a single probe basis.*

Update Trace Analysis Parameters

The parameters used in the analysis and display of TDR traces can be updated on a probe type (rather than individual probe) basis. Only the probe types 1 (balanced probe including an impedance matching balancing transformer) and 2 (two or three rod probe without balancing transformer) are discussed in the following.

Initially the parameters can be set to the default values. This is usually also useful after experimenting with parameter values before the 'best' values are selected and stored in the INI-file. Below the parameters and their values are introduced:

FirstPoint (between 1 and 75. Default = 1) specifies the first point of the 251 point trace to be included in the analysis

LastPoint (between 125 and 251. Default = 251) specifies the last point to be included

SmootheWindow (between 5 and 20. Default = 10) specifies the length of the averaging (smoothing) filter in screen points. Traces are smoothed before analysis to reduce noise in input data

RegresRange (between 5 and 25. Default = 10) specifies the length in screen points of the regression lines fitted to portions of the trace during analysis (location of beginning and end of probe)

BegWindow (between 10 and 75. Default = 55) specifies the window in screen points where the algorithms searches for the beginning of probe. Increase this parameter if the trace is placed farther to the right on the screen than expected. This is often an alternative to generating a new parameter file

MinWindow (between 8 and 40. Default = 17) specifies the distance in screen points from the steepest (inflexion) point on the end-of-probe reflection where the algorithms searches for the end of probe. Increase this parameter if the TDR trace is highly attenuated due to longer probe cable or electrically more conductive soil than expected

TraceMax and ***TraceMin*** (Campbell TDR100) are used for scaling the trace in the height direction. Experiment to test the function of these parameters

View Current Parameters

Displays the currently active trace analysis parameters (and other parameters) for each probe type.

Exit, Auto and Slave Operation

Used for exiting the program or invoking 1) automated measurements where the system will make measurements and store results until interrupted or 2) slave measurements where measurements are requested and stored by a master station.

For automated (self initiated after reboot or power up) measurements an inline parameter (a or A) is added to the program name in the AUTOEXEC file (e.g. **AutTc64C** /a)

3. Quick tour

After connecting the system including at least a PC compatible computer, the TDR instrument (here the Campbell TDR100 is assumed) and a TDR probe embedded in soil or placed in a bucket with tap water the **AutTc64C** software is initiated. Below mostly default values simply selected by typing Enter are used to generate and test a one-probe parameter set. If run on a **TC64** system including multiplexing a larger parameter set can be generated and tested.

1. Select *Generate Parameter File* menu option by typing 'G'
2. Accept the default parameter file by typing 'Y'
3. Select not to measure probe impedance by typing 'N'
4. Select a single probe system by typing '1'
5. Select probe type by typing e.g. '1'
6. Specify the length of the TDR probe by typing e.g. '0.5'
7. Specify zero offset by typing '0.0'
8. Select selection of trace window by typing 'Y'
9. Specify approximate (do not overestimate) cable length by typing e.g. '2.5'
10. Use cursor keys to place cursor lines at 'beginning' and 'end' of active trace
11. Type Enter to reacquire selected trace segment
12. Type Enter to return to main menu
13. Select ***T****est Parameter File* menu option by typing 'T'

14. Accept the parameter file by typing 'Y'
15. Select not to store traces by typing 'N'
16. A trace is now acquired and the tabular results displayed
17. Type Enter to display the analysed trace
18. Finally type Enter to return to main menu

4. GSM and watchdog timer

For PC's with two serial ports or the **TC64** a GSM modem can be connected to COM 2 and activated for remote monitoring and data transfer. The **TC64** watchdog timer can be activated for automated reboot after system stop. At present the watchdog can only be disabled by manual reboot.

5. Measurement file

For each measurement the following information is written to the measurement (MES) file:

1. Year
2. Month
3. Day
4. Hour
5. Minute
6. Number of probes
7. Probe impedance (0 if not included)
8. Apparent dielectric constant
9. Water content
10. Impedance (if selected)

Measurements 8 – 10 are repeated for each probe.