# TDR/MUX/mpts

TDR/MUX/mpts stands for Volumetric Moisture Content, Temperature, Electrical Conductivity (Salinity) and Capillary Pressure in Porous Materials


# USER MANUAL

# ETDR101 User Application

December 2020, Rev. 1.4

## LIMITED WARRANTY AND LIMITATION OF LIABILITY

This E-Test product will be free from defects in material and workmanship for one year from the date of purchase. This warranty does not cover damage from ESD discharge or accident, neglect, misuse, alteration, contamination, or abnormal conditions of operation or handling. Resellers are not authorized to extend any other warranty on E-Test behalf.
To obtain service during the warranty period, contact your reseller or producer to obtain return authorization information, then send it with a description of the problem.
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To contact E-Test, call the telephone number: +48 508499494
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## SAFETY INFORMATION

The Product complies with:

- ANSI/ISA-82.02.01
- CAN/CSA-C22.2 No. 61010-1-12: 3rd Edition
- UL 61010-1: 3rd Edition
- IEC/EN 61010-1:2010

# 1. PREFACE

The purpose of this Manual is to present the features of the TDR/MUX/mpts meter as well as the related probes developed in the Institute of Agrophysics Polish Academy of Sciences, Lublin, Poland and manufactured in E-Test, Sp. z o.o., Motycz, Poland.

The TDR/MUX/mpts is a measurement device for soil moisture (on the base of Time Domain Reflectometry technique), electrical conductivity (salinity), soil temperature and soil capillary pressure.

Soil water content and electrical conductivity are measured by FP/mts field probes (see page 15) and LP/ms laboratory probes (see page 16).
LP/t laboratory probes measure soil temperature (see page 17).
LP/p laboratory probes measure soil capillary pressure (see page 18).

The manual first describes the device's physical interfaces, labels and serial number details.

Following chapters provide instructions on how to operate the device with PC version of the program **ETDR101.exe** that can control the device from a PC compatible computer connected by USB link.

Next chapters enlists the features of TDR/MUX/mpts device in detail and describe the available compatible probe types.

Last chapter enlists references that further explain the idea of TDR soil moisture measurements and hardware solutions. Most valuable and recommended sources are (Malicki and Skierucha 1989) and (Skierucha et al. 2012).

## 2. DEVICE IDENTIFICATION AND SERIAL NUMBERS

Each measurement device manufactured in E-Test Sp. z o.o. is provided by a unique 8 characters serial number (Fig. 1).

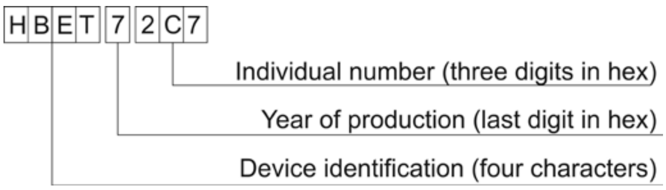


Fig. 1. Serial numbers of the measurement devices from E-Test Sp. z o.o..

When contacting with the producer the user is asked to provide the serial number for identification of the individual device.

## 3. TDR/MUX/MPTS EXTERNAL CONNECTIONS AND SIGNS

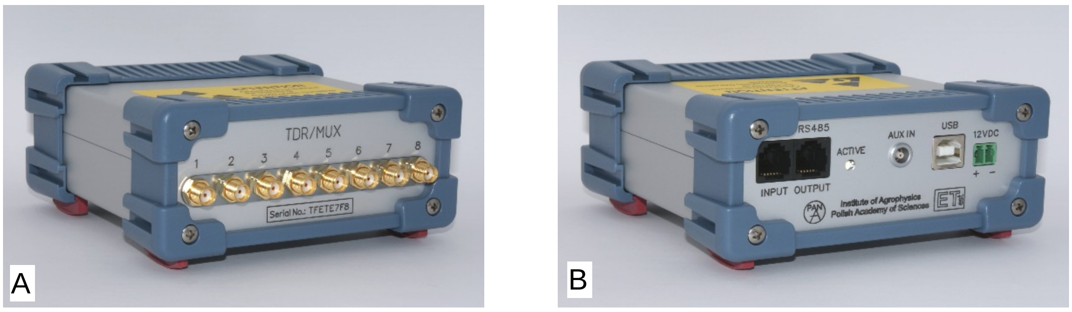


Fig. 2. A - front and B - rear views of the TDR/MUX/mpts device.

### 3.1. FRONT PANEL DESCRIPTION

The front panel of TDR/MUX/mts (Fig. 2A) contains the following:

- Eight coax input ports labelled 1, 2, …, 8 of SMA or MCX type depending on the kind of connectors attached to the TDR probes. The laboratory probes LP/ms (see page 16) are usually terminated by SMA or MCX plugs and FP/mts (see page 15) probes by SMA plugs, although it may depend by the user choice while ordering.
- AUX port for auxiliary soil temperature (LP/t – see page 17) or soil capillary pressure (LP/p - see page 18) probes connected in parallel and individually selected by unique serial numbers.

### 3.2. REAR PANEL DESCRIPTION

**The rear panel** of TDR/MUX/mts (Fig. 2B) contains the following:

- Power supply socket labeled 12VDC. The supply voltage may be in the range 10-14 VDC, chosen for the possible supply from lead acid 12 VDC accumulator or from a filtered voltage source. The example connections of the measurement system consisting of several TDR/MUX/mpts devices connected in a chain are presented in Fig. 3).

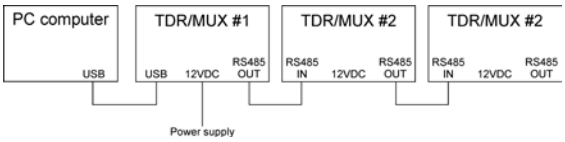


Fig. 3. Example connections of the measurement system consisting of a PC computer and three TDR/MUX devices connected in a chain.

- USB connector to PC compatible computer for testing the device or controlling its operation during the measurements by supplied software.
- POWER LED indicating the device connection to the system supply.
- RJ12 socket for serial RS485 INPUT and OUTPUT to connect up to 16 TDR/MUX/mpts devices in a chain (Fig. 4).

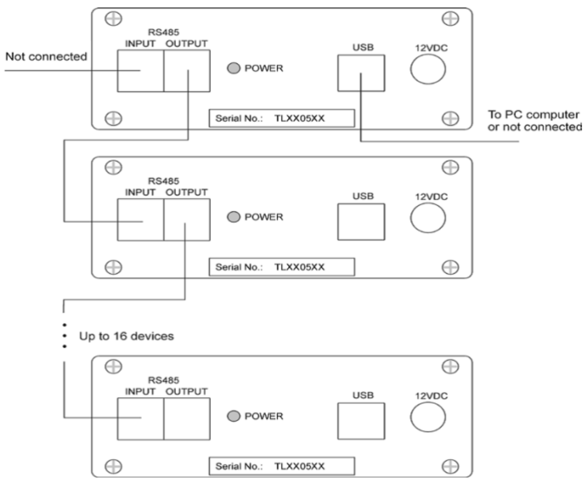


Fig. 4. Connection of multiple TDR/MUX/mpts devices in a chain to control the measurement experiment with up to 128 TDR probes (LP/ms and/or FP/mts).


ATTENTION Warning label for being aware of electrostatic discharge. The user should ground the middle pole of the SMA plug from a TDR probe before connecting to the meter. Also, it is recommended not to touch the rods of the TDR probe when it is connected to the TDR/MUX/mpts meter.

## 4. OPERATION WITH PC COMPUTER

The TDR/MUX/mpts measurement device can be operated with PC compatible computer by dedicated program **ETDR101.exe** when connected by a USB cable.
All versions of the **ETDR101.exe** PC software can be downloaded from https://www.e-test.eu/downloads.html website of the E-Test Sp. z o.o.

## 4.1. ETDR101 Program for Operation with PC Computer

The program **ETDR101.exe** allows to:

− perform single measurement on selected probe,
− individually calibrate each TDR probe (i.e. fix the electrical length and the "dead time" of a probe as well as account for individual characteristics of the channel) and send this data to the device,
− read the data stored in the internal memory of the device to PC computer

The operation of the **ETDR101** application software is presented below by describing the individual message and operation windows generated by this program. Using this program it is possible to perform measurements with both FP/mts and LP/ms probes. The USB cable should connect a PC compatible computer working Windows system and a TDR/MUX/mpts device. Running the without the USB cable will result in displaying the error message window (Fig. 5).

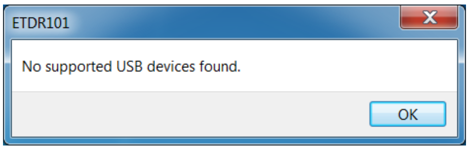


Fig. 5. The error message when a USB cable is not connected to the TDR/MUX/mpts meter.

No special drivers are necessary for proper communication between the TDR/MUX/mpts and a PC computer. After connecting the device to PC compatible computer by USB cable and starting, the program displays the main **ETDR** system control window (Fig. 6) with:
− The device unique serial no.: **TFETE6F0**.
− Menu tabs for switching to other menu tab windows: **Basic** (default), **Advanced** and **Calibration.**
− Selection of a virtual channel. Up to 8 channels can be calibrated for various cable lengths and geometry of a TDR probe (FP/mts or LP/ms probes) – menu tab **Advanced.**
− **Cable length calibration** button for performing **Standard calibration** or **Non-standard calibration** of TDR probes (described later) – menu tab **Calibration.**
− **Amplitude vs. time** (in nanoseconds) graph window for displaying the TDR waveform reflected from the sensor inserted into the tested material.

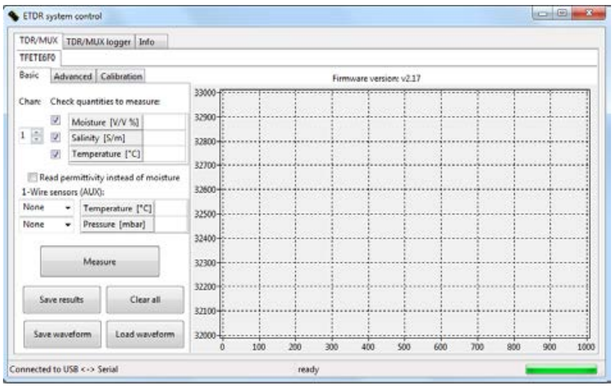


Fig. 6. **ETDR101** system control window with **Basic** menu tab selected.

## 4.2. FP/mts and LP/ms probes calibration (menu tab Calibration)

Before measurement each TDR probe should be calibrated. There are three types of calibrations: cable length calibration, standard calibration and non-standard calibration.

### 4.2.1. Cable length calibration

Having selected the **Calibration** tab, channel number (1 - 8) and pressing the **Cable length calibration** button, the program locates the measurement time window at the parallel rods of the TDR, i.e. calculates the length of cable between the coax connector at the device and an artificial time marker in the FP/mts or LP/ms probes (Fig. 7A).

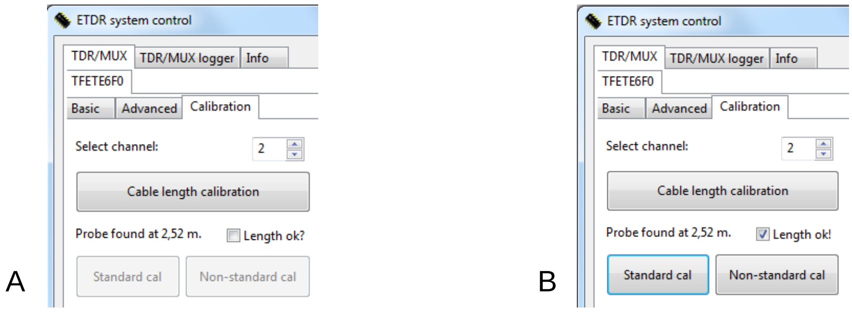


Fig. 7. Cable length calibration: A - confirmation of the cable length; B - continuation of a TDR probe calibration after fixing the cable length. In case of the coax cable break or shortage, the calculation of the cable length will not be reliable and the TDR probe is probably not usable.

When the displayed cable length (Fig. 7A) is approximately equal to the calculated one, the user should proceed with selecting the **Length ok?**. Then the user can perform standard calibration or non-standard calibration of the probe selected in the virtual channel (Fig. 7B).

### 4.2.2. Probe standard calibration

This type of calibration uses two reference dielectric standards: air and water.

#### 4.2.2.1. LP/ms probe standard calibration

After performing the **Cable length calibration** and having pressed the **Standard cal** button a part of the **ETDR101** system window is further expanded with two additional push buttons: **Cal in ert** (Ertacetal™) and **Cal in water** (Fig. 8).

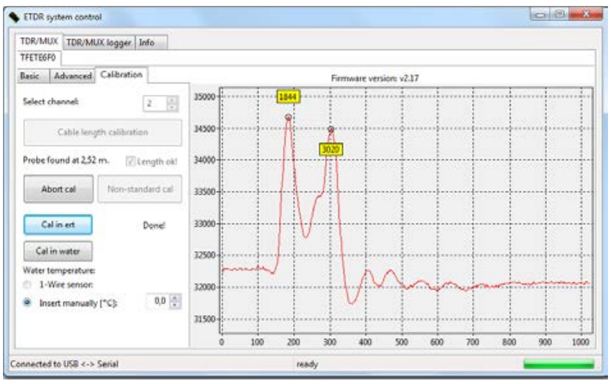


Fig. 8. **ETDR101** system control window after performing a part of the standard calibration using Ertacetal™ calibrator.

The LP/ms probe should be calibrated using the dedicated Ertacetal$^{TM}$ calibrator. Having performed standard **Cal in ert** the user should insert the probe into water. The temperature of water could be written by user or automatically download after pressing **1-Wire sensor** buttom. Selecting the right LP/t sensor for temperature measurement is possible in menu **Basic/1-Wire sensors** (Fig. 9).

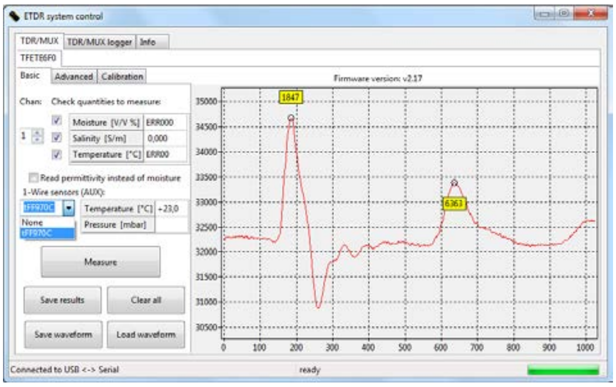

Fig. 9. **ETDR101** system control window after performing a part of the standard calibration using Ertacel$^{TM}$ calibrator.

Beware of providing a distance of at least 5 cm from the rods to the borders of the container with water. After a few seconds a new waveform appears with reflections of the pulse from the parallel rods inserted in water.

The standard calibration terminates successfully after pressing the **Apply calibration** push button. The geometrical parameters of the probe in the chosen virtual channel 1 are written to the internal memory of the TDR/MUX/mpts. Thus the user can perform measurements with up to 8 various probes provided that he switches the virtual channels to the corresponding probes calibrated in the exact channels. More information about the calculations during a TDR probe calibration you can find in (Skierucha, Wilczek, and Alokhina, 2008).

### 4.2.2.2. FP/mts probes standard calibration

Before pressing the **Cal in air** push button (Fig. 10), the user should keep the probe in air having a distance of not less than 5 cm from any object close to the probe rods.

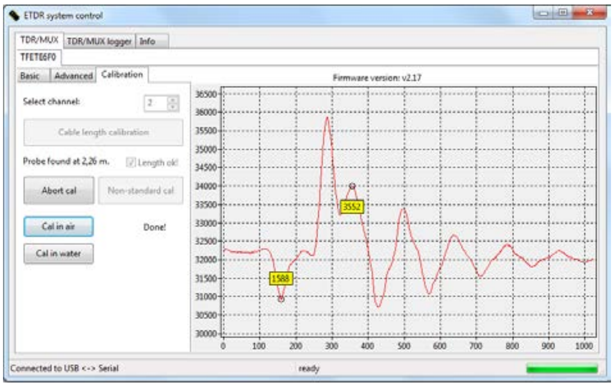

Fig. 10. **ETDR101** system control window after performing a part of the standard calibration with air.

Having performed standard calibration with air the user should insert the probe into water (preferably clean deionised or clean tap water of about 20$^{o}$C) and press the **Cal in water** push button (Fig. 11). Beware of providing a distance of at least 5 cm from the rods to the borders of the container with water. After a few seconds a new waveform appears with reflections of the pulse from the parallel rods inserted in water.

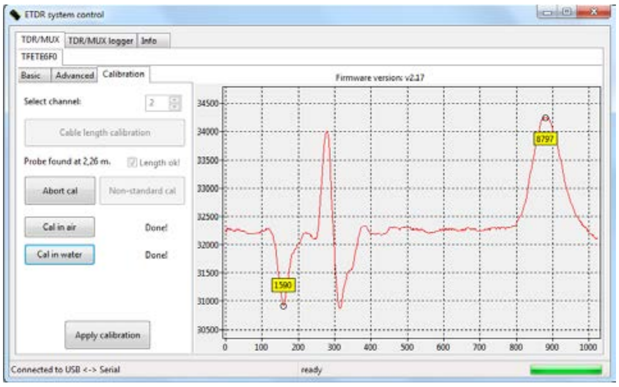


Fig. 11. **ETDR101** system control window after performing a part of the standard calibration with water.

Pressing the **Apply calibration** push button allows the data stored in the internal memory of the device.

### 4.2.3. Probe non-standard calibration

The introduction of non-standard probe results from the user demands for different length of the probe parallel waveguide. In case of short probes the calibration medium of low dielectric constant value should not be air because of troubles in distinction the pulse reflected from the rods end (the reflections from the rods beginning and end overlap). Even in case of a standard laboratory probe LP/ms the calibration medium of low dielectric constant is Ertacetal$^{TM}$ ($\varepsilon$ = 3.8) to ensure distinct reflections. The calibration media for standard TDR probes are presented in Table 1.

Table 1. Calibration media for standard field (FP/mts) and laboratory (LP/ms) probes

| Type of probe | Recommended media of low value of dielectric constant | Recommended media of high value of dielectric constant |
|---|---|---|
| FP/mts | Air ($\varepsilon$ = 1) | Water ($\varepsilon$ = 81, water temperature = 18°C) |
| LP/ms | Ertacetal$^{TM}$ (3.8) | Water ($\varepsilon$ = 81, water temperature = 18°C) |

For non-standard probes the user can chose the calibration media by himself using data from Table 2. He should be aware that the measured values of dielectric constant should be between the low and high values of calibration media dielectric constants (to minimise the measurement error).

Table 2. Calibration media for non-standard field (FP/mts) and laboratory (LP/ms) probes. Dielectric constant values and the temperature dependencies are taken from Handbook of Chemistry and Physics, CRC, 2002

| **Medium** | **Dielectric constant, $\varepsilon$** | **Temperature dependence** |
|---|---|---|
| Water | 80.1 (T=293.2 K) | $\varepsilon$ = 0.24921E3-0.79069*T+0.72997E-3*T^2 (273 < T (K)< 373) |
| Benzene | 2.28 (T = 293.2 K) | $\varepsilon$ = 0.26706E1-0.91648E-3*T-0.14257E-5*T^2 (293 < T (K)< 513) |
| Acetone | 21.01 (T=293.2 K) | $\varepsilon$ = 0.88157E2-0.343*T+0.38925E-3*T^2 (273 < T (K)< 323) |
| Metanol | 33 (T=293.2K) | $\varepsilon$ = 0.19341E3-0.92211*T+0.12839E-2*T^2 (177 < T (K)< 293) |
| Ethanol | 25.3 (T=293.2K) | $\varepsilon$ = 0.15145E3-0.87020E1*T+0.19570E-2*T^2 (177 < T (K)<293) |
| Teflon | 2.5 | - |
| Ertacetal | 3.8 | - |

Non-standard calibration procedure is described in the figures below.

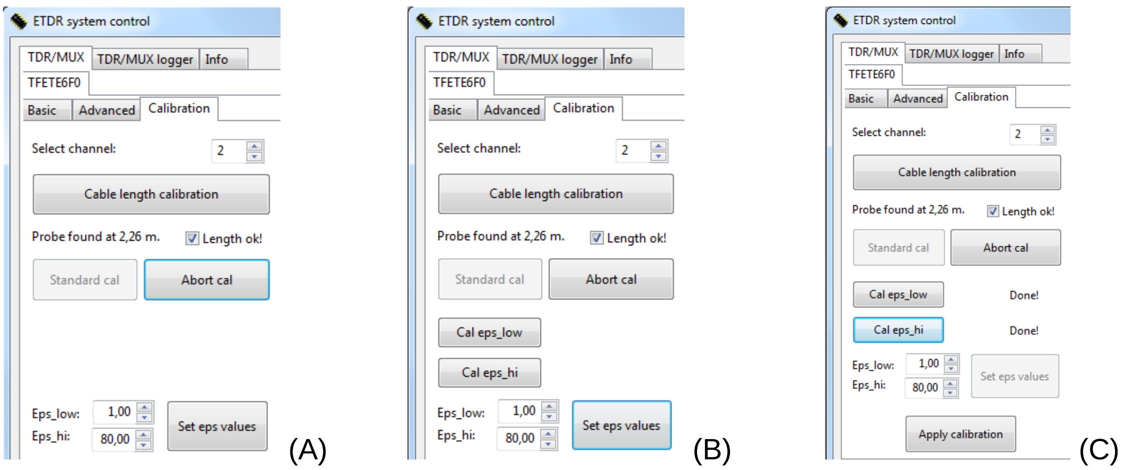


Fig. 12. Non-standard calibration procedure

- (Fig. 12A) Expansion of the control window after pressing the **Non-standard cal** press button. The user can adjust the reference values of dielectric constant of the two calibration media. The pushbutton **Set eps values** confirms the choice.
- (Fig. 12B) Consecutive pressing of **Cal eps_low** and **Cal eps_hi** starts the calibrations in the respective media and the graph window shows the waveforms.
- (Fig. 12C) After completing the non-standard calibration the user should press the **Apply calibration** push button to write the respective calibration data for the chosen virtual channel to the internal memory of the TDR/MUX/mpts.

## 4.3. Measurement (tab menu *Basic*)

The window under the tab menu **Basic** is for performing measurements of soil moisture (in vol. % or bulk dielectric constant), temperature (ºC), salinity (represented by electrical conductivity in $mS^{-1}m$) and matrix pressure (mbar).
Each measurement can be done on the chosen virtual channel that should be earlier calibrated with the corresponding FP/mts or LP/ms probe. Also, the user can switch between vol. % or relative dielectric permittivity (bulk dielectric constant $\varepsilon_a$) for presentation of soil moisture content. Having the value of bulk dielectric constant $\varepsilon_a$ from the measurement the user can apply any conversion formula to receive moisture content $\theta_v$. The most popular formula of Topp (Topp, Davis, and Annan 1980):

$$\theta_v = -5.3 \times 10^{-2} + 2.92 \times 10^{-2}\varepsilon_a - 5.5 \times 10^{-4}\varepsilon_a^2 + 4.3 \times 10^{-6}\varepsilon_a^3 \quad (1)$$

The relation $\theta_v = f(\varepsilon_a)$ used as default in FOM2/mts meter is:

$$\begin{array}{ll} \text{for } \sqrt{\varepsilon_a} < 6, & \theta_v = 0.1064\sqrt{\varepsilon_a} - 0.1582 \\ \text{else} & \theta_v = -0.5596\sqrt{\varepsilon_a} + 0.1733 \end{array} \quad (2)$$

To have the volume % of moisture content, $\theta_v$ should be multiplied by 100.

After inserting a TDR probe into the measured medium and pressing the **Measure** push button, the measurement proceeds. A single time of measurement for three variables is about 6 seconds (approximately: moisture content 1 sec., salinity 1 sec, temperature 4 sec.). The measurement results are displayed in the left part of the window. If the user does not want to measure a physical parameter, he can unmark it.
The measurement results and 1024 points of data covering the sampling time window of 10 ns time width can be saved in text files with extensions *.txt and *.grf, respectively. The default storage directory is the same as the location of the **ETDR101** program.
The user can load the stored waveform for comparison with the other one (Fig. 13).

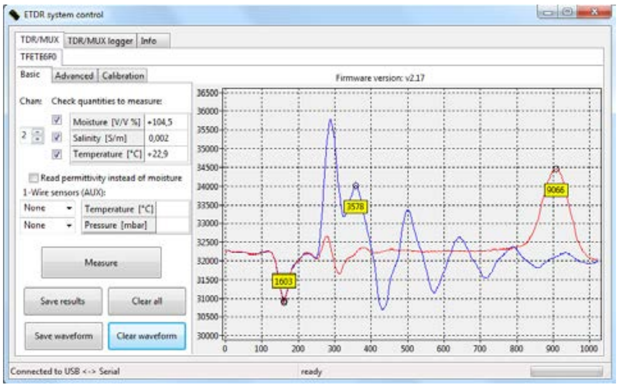


Fig. 13. Comparison of currently measured waveform (air) and a loaded one (water) using FP/mts.

## 4.4. Advanced (tab menu Advanced)

Using **Advanced** tab menu the user can check or assign FP/mts and LP/ms probes to individual virtual channels of the TDR/MUX/mpts meter (Fig. 14). After assigning, the user should calibrate the chosen probes in these channels. The channel configuration is written to the internal non-volatile memory of the meter.

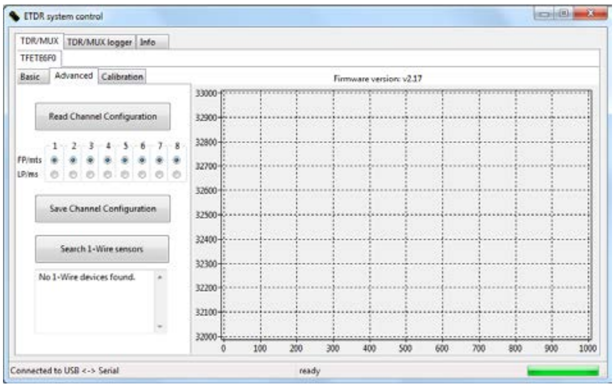


Fig. 14. Assignment of FP/mts or LP/ms probes to individual virtual channels of the TDR/MUX/mpts. **Advanced** menu tab selected.

When another type of probe than the one assigned to the virtual channel is connected to the TDR/MUX/mpts meter, the device generates an error message **ERR001** after measurement (Fig. 15).

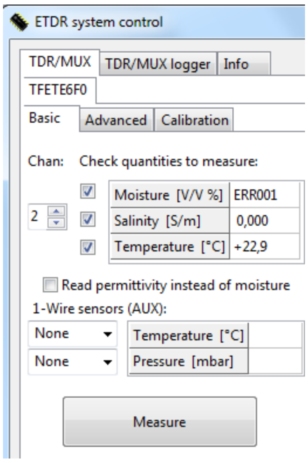


Fig. 15. The effect of incorrect assignment of the probe type to the individual virtual channel. The measurement is done but the **Moisture [V/V%]** is marked with the error code **ERR001**.

## 5. UTILITY FEATURES OF TDR/MUX/MPTS

- TDR/MUX/mpts is controlled from a PC compatible computer by USB interface using a dedicated application software (http://www.e-test.eu/downloads.html **)**.
- Measurement ports:
    - Eight virtual channels for soil moisture (TDR method), electrical conductivity (salinity) and temperature using an integrated FP/mts probe and/or LP/ms miniprobes (without temperature),
    - AUX port for soil temperature using LP/t and/or soil matrix pressure using LP/p probes: up to 16 probes connected in parallel,
- operates with probes with different cable lengths (from 1.5 as a standard to 6 m for FP/mts and 1.5 as a standard to 4 m for LP/ms, the user is asked the state the cable length before ordering a probe),
- pulse: $\sin^2$-like needle pulse having 200 ps rise-time,
- time of test of a single FP/mts probe: moisture – 2 s, temperature – 5 s, electrical conductivity – 2 s,
- time of test of a single LP/ms probe: moisture – 2 s, electrical conductivity – 2 s, temperature - …., matrix pressure - ….
- time of test of a single LP/t or LP/p connected to AUX channel: 1 s (future use),
- FP/mts, LP/ms and LP/t probes can work in the -20°C ÷ +50°C temperature range,

# 6. SPECIFICATIONS

**Range of readings**
volumetric moisture ..: 0÷100 %, temperature ..: -20÷+50°C, electrical conductivity ..: 0.000÷1S/m matrix pressure ..:200÷1000 mBar

**Accuracy**
moisture absolute error...................... : displayed water content ±2 % or less if the measured soil is individually calibrated,
temperature absolute error.................. : ±0.5°C or less if read from individually calibrated probe,
electrical conductivity relative error…. : ±10 % for 0 ÷ 1 S/m or less if read from individually calibrated probe,
matrix pressure error………… : ±5 hPa

**Resolution of readings**
volumetric moisture ................. : 0.1 %, temperature .................. : 0.1°C, electrical conductivity ………… : 1 mS/m
matrix pressure …………. :

**Temperature**
Operating ............................................ : 5 °C to +50 °C Storage ..................................................... : -10 °C to +50 °C

**Relative Humidity** ............................ : 0 % to 90 % (5 °C to 35 °C), 0 % to 75 % (35 °C to 40 °C), 0 % to 45 % (40 °C to 50 °C)

**Altitude**
Operating ............................................ : <2000 m Storage ..................................................... 12 000 m

**Wireless Frequency** ................................. 2.4 GHz ISM Band 20 meter range
**Size (LxWxH)** ............................................ 11.2 cm x 11.5 cm x 4.2 cm (4.41 in x 4.53 in x 1.65 in)
**Weight** ....................................................... 350 g (12.34 oz)

## Maintenance

- *The meter is not user serviceable.*
- *No special maintenance means are required.*
- *If the apparatus is to be stored, recharge the battery each three - four months*

## Notice for Battery Replacement

- *Device has an internal battery. For your safety, do not remove the battery incorporated in the product. If you need to replace the battery, contact to selected service point or dealer for assistance.*
- *Li-Ion Battery is a hazardous component which can cause injury.*
- *Battery replacement by non-qualified professional can cause damage to your device.*

## Electromagnetic Compatibility (EMC)

International IEC 61326-1: Portable Electromagnetic Environment, IEC 61326-2-2 CISPR 11: Group 1, Class A
***Group 1:*** *Equipment has intentionally generated and/or uses conductively-coupled radio frequency energy that is necessary for the internal function of the equipment itself.*
***Class A:*** *Equipment is suitable for use in all establishments other than domestic and those directly connected to a low-voltage power supply network that supplies buildings used for domestic purposes. There may be potential difficulties in ensuring electromagnetic compatibility in other environments due to conducted and radiated disturbances.*
***Caution:*** *This equipment is not intended for use in residential environments and may not provide adequate protection to radio reception in such environments. Emissions that exceed the levels required by CISPR 11 can occur when the equipment is connected to a test object.*

## Accessories

FP/mts - FIELD PROBE FOR MOISTURE, TEMPERATURE AND SALINITY OF SOIL
LP/ms - LABORATORY MINIPROBE FOR SOIL MOISTURE AND SALINITY
USB cable
Battery charger

# 7. TDR/MUX/MPTS COMPATIBLE PROBES

## 7.1. FP/mts - FIELD PROBE FOR MOISTURE, TEMPERATURE AND SALINITY OF SOIL

FP/mts (Fig. 16) is a Time-Domain Reflectometry (TDR) probe for momentary or semi-permanent installation. Thin-wall PVC body of the probe provides ultimate low heat conductivity, thus allowing to avoid the parasite "thermal bridge" effects on distribution of soil moisture in the probe's sensor vicinity. Through a pre-drilled pilot hole it can reach any depth without destroying either the soil structure or disturbing the heat and mass transport in the soil. For semi-permanent installation the probe can be inserted horizontally through a sidewall of a soil pit or slantwise, from the soil surface. The probe installed once may be left intact in the soil for as long as necessary, then drawn out at the end of the experiment.
FP/mts is a probe for in situ field simultaneous measurement of the soil moisture, temperature and salinity (electrical conductivity) of the soil from the same sampling volume.

Fig. 16. FP/mts - field probe for moisture, temperature and salinity of soil.

The probe is suitable for periodic measurements at random and/or fixed locations, where instantaneous profiles of water content, temperature and salinity are to be determined by readings taken at various levels of the soil profile (Fig. 17). It may also be applied as a mobile probe for momentary measurements in surface layer of the soil, by walking over the field and inserting the probe in the soil surface layer at chosen sites.

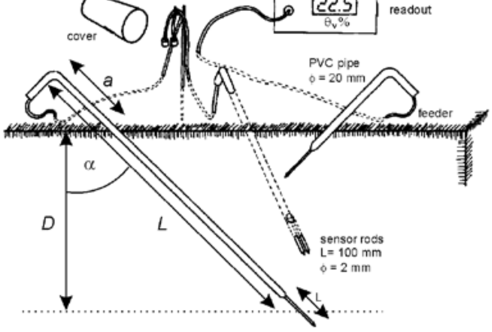


Fig. 17. The principle of installation of the FP-type probes. In order to minimize disturbances in the soil structure the probes are inserted into the soil via pilot holes, circularly distributed over the soil surface. The holes run

slantwise and converge along a chosen vertical line. The cables are buried below the soil surface to protect them against the UV sun radiation as well as against rodents.

Features of FP/mts probes:

- sensor: a section of a transmission line made of two, 100 mm long parallel stainless steel rods having 2 mm diameter and separated by 16 mm,
- sensor support: a section of a PVC tube having 2 cm outer diameter and optional length (15 cm - 150 cm or longer) dependent on the intended depth of the sensor installation,
- cable length: from 1.5 to 6 m from the sensor to the terminating connector,
- region of influence (Fig. 18): a cylinder having approximated diameter of 5 cm and height of 11 cm, circumferenced around the sensor rods.

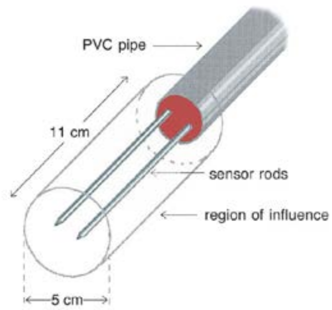


Fig. 18. A draft illustrating the approximate region of influence of the FP probe, defined as a solid beyond of that changes in water content do not markedly affect readings of moisture

## 7.2. LP/ms - Laboratory miniProbe for soil moisture and salinity

LP/ms - a laboratory miniprobe (Fig. 19) designed for monitoring changes in water and salt distribution in soil columns or in soil cores sampled with standard sampling equipment.

Fig. 19. LP/ms - Laboratory miniProbe for soil moisture and salinity

Several LP/ms can be inserted through the sidewall of a soil column or a steel sampling cylinder (Fig. 20), thus allowing for vertical scanning of the instantaneous moisture and electrical conductivity profiles.

Features of LP/ms probes:

- installation hole: metric thread diameter of 8 mm, height of 3.3 mm,
- sensor:
    - a section of a transmission line made of two,

    - 53 mm long parallel stainless steel rods diameter of 0.8 mm,
    - separated by 5 mm,
- cable length: from 1.5 to 4 m from the sensor to the terminating connector (or multiplexer),
- sphere of influence: a cylinder having diameter of about 5 mm and height of about 60 mm, circumferenced around the sensor rods.

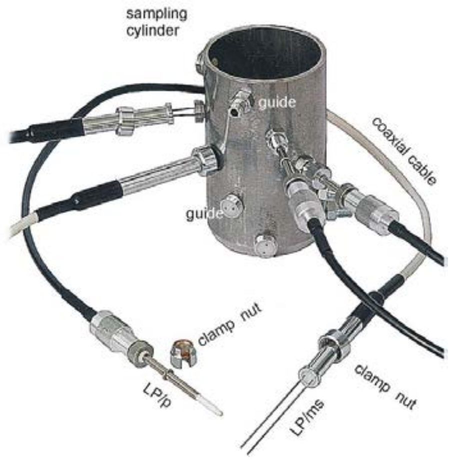


Fig. 20. A set of LP/ms and LP/p miniprobes inserted through a 2.75 mm thick wall of a sampling steel cylinder, having height of 100 mm and 55 mm inner diameter. The wall of the cylinder is provided with tapped holes equally distributed along the cylinder height in order to monitor independent layers of the soil. The holes are aligned spirally to minimize mutual shadowing in the vertical direction.

### 7.3. LP/t - LABORATORY PROBE FOR SOIL TEMPERATURE

LP/t is a laboratory probe (Fig. 21) for monitoring instantaneous profiles of soil temperature in soil columns or in undisturbed soil cores. Thin-wall half-rigid polyethylene body of the probe provides ultimate low heat conductivity, thus allowing avoiding the parasite “thermal bridge” effects. Several LP/t probes can be inserted through the wall of the soil column or the sampling cylinder, thus allowing for vertical recording of the instantaneous profiles of temperature. Such an array, when combined with miniprobes for soil moisture/salinity and also probes for matrix pressure (see LP/ms and LP/p flyers), makes it possible to collect a set of corresponding temperature data from non-isothermal transition of drying or wetting front, from which readings of bulk electric conductivity as well as matrix pressure can be temperature corrected. Also heat transport coefficients (thermal conductivity, thermal diffusivity, specific heat) can be determined if a heat flux meter (not provided by E-Test) is installed in the column under investigation.

The wall of the cylinder containing a soil core is provided with tapped holes (8 mm diameter). A guide is screwed into the hole prior to the probe installation. This guide helps to avoid air gap around the probe, which otherwise might result while installing. LP/t is pushed into the soil core and fixed with a screwed gland.

Features of LP/t probes:

- sensor: a temperature dependent current source,
- range: temperature between -20°C and +60°C,
- resolution: 0.01°C,
- absolute error: not more than ±1°C or ±0.1°C if individually calibrated,
- cable length: 2 m or other length when requested,

- installation hole: 8 mm diameter tapped with 8/1.5 mm thread.

Fig. 21. LP/t - laboratory probe for soil temperature

## 7.4. LP/p - LABORATORY MINIPROBE FOR SOIL WATER CAPILLARY PRESSURE

**ATTENTION:** LP/p laboratory probes use gauge pressure sensors and their pressure measurement is relative to the local atmospheric pressure. Therefore it is forbidden to insert a metal head of the probe into water.

LP/p (Fig. 22) is a laboratory miniprobe designed for monitoring instantaneous profiles of soil water capillary pressure (matrix pressure, suction force) in soil columns or in undisturbed soil cores sampled with standard sampling equipment.

Fig. 22. LP/p - laboratory miniprobe for soil water capillary pressure

The wall of a cylinder containing the soil core is provided with tapped holes (8 mm diameter). A guide is screwed into the hole prior to the probe installation. This guide helps to avoid air gaps between the ceramic suction cup and the soil, which otherwise might result while inserting the probe into the soil.
LP/p is pushed into the soil core and fixed with a clamp nut. Several LP/p can be inserted through the wall of a soil column or a steel sampling cylinder, thus allowing for vertical scanning of the instantaneous water pressure profiles (see below). Such an array, when combined with similarly installed miniprobes for soil moisture (see the LP/ms flyer), makes it possible to collect

a set of corresponding water content and matrix pressure data from drying or wetting front transition (Fig. 23).

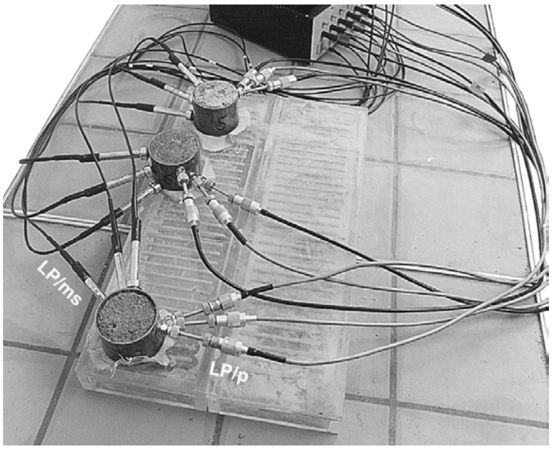


Fig. 23. Reading instantaneous profiles of soil water capillary pressure, moisture and salinity from arrays of the LP/p and LP/ms miniprobes

From the collected data set, after further processing, one can obtain a complete set of the unsaturated water flow characteristics of the soil, that is: water retention (pF-curve), unsaturated water conductivity (k-function), differential water capacity and unsaturated water diffusivity.

Features of LP/p probes:

- sensor:
  - pressure diaphragm: a 15 mm long ceramic cup, 3 mm in diameter,
  - pressure transducer: an integrated, fully active Wheatstone bridge with four piezoresistive strain gauge resistors diffused into a silicon diaphragm,
  - air entry pressure: about 900 mbar,
- offset drift: ± 20 mbar/month,
- relative error: ± 15 %,
- resolution: 1 mbar,
- delay: 0 to 800 mbar in about 120 s, 800 to 0 mbar in about 3 s,
- cable length: 2 m,
- installation hole: 8 mm diameter,
- tapped with 8x1 mm thread.

## 8. REFERENCES

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