FOM2/mts

TDR Field Operating Meter for Volumetric Moisture Content,
Temperature and Electrical Conductivity (Salinity) of Porous Materials

USER MANUAL

May 2017, Rev. 1.2

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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.
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TO PREVENT POSSIBLE PERSONAL INJURY, READ ALL SAFETY INFORMATION BEFORE YOU USE THE PRODUCT.

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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 FOM2/mts 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 FOM2/mts and is a measurement device for soil moisture (on the base of Time Domain Reflectometry technique), and electrical conductivity (salinity). The FOM2/mts device is a functional upgrade of the discontinued FOM/mts, with the following main features:

- Electrical parameters, basic functionality, operation with FP/mts probes and measurement accuracy of the new the FOM2/mts are the same as for the old FOM/mts.
- FOM2/mts does not have a display and a keyboard. The user interface in an Android device (e.g. Android mobile). The application software is available at Google Play.
- The communication between the FOM2/mts and a mobile is by Bluetooth Low Energy (Android versions from 4.3 and above).
- Due to implemented modifications and manufacturing improvements the new FOM2/mts is more economical solution than the old FOM/mts, without losing measurement accuracy, with the increase of the device performance and the end user satisfaction.

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

Following chapters provide instructions on how to operate the device:

- with dedicated Android mobile software available at Google Play.
- 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 FOM2/mts 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).

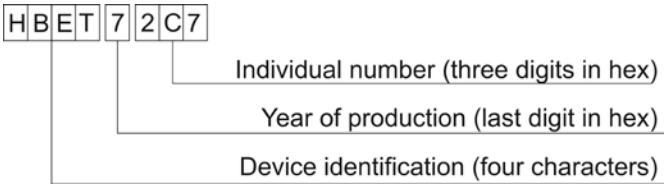


Fig. 1. Serial numbers of the measurement devices from E-Test Sp. z o.o..

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

3 FOM2 EXTERNAL CONNECTIONS AND SIGNS

Fig. 2. Rear panel of the FOM2/mts device

Fig. 3. Front panel of the FOM2/mts device

Power button. Push the button until the LED under the icon is blinking. Connecting a USB cable from a PC computer and the operation under control of **ETDT101** program do not require starting the device with the power button.	SMA type coaxial socket for connecting a FP/mts or LP/ms (works only with **ETDR101** PC compatible application software) TDR probes.
TDR The LED below shows that the device performs measurements.	MMCX-12 micro coaxial socket for future connections of LP/t and LP/p laboratory probes for the measurement of temperature and capillary water pressure of porous materials, respectively.
The micro USB socket below is for connecting a standard mobile battery charger or a USB cable to a PC computer. The LED below is on when charging the internal battery of when a micro USB cable connects the meter with a PC computer. The LED below is blinking when the meter is connected wirelessly to an Android device (ex. Android mobile).	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 FOM meter.

4 OPERATION WITH ANDROID MOBILE AND PC COMPUTER

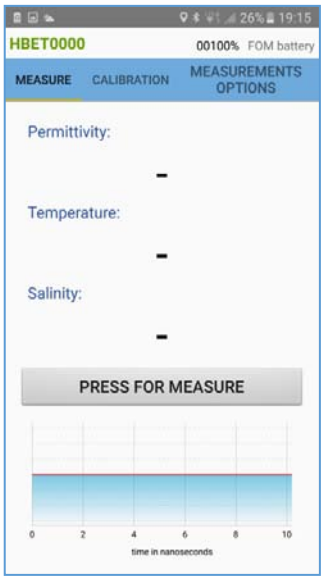
The FOM2/mts measurement device can be operated:

- with PC compatible computer by dedicated program **ETDR101.exe** when connected by a USB cable,
- with Android device (mobile phone or tablet) when connected by Bluetooth Low Energy (Android versions 4.3 and above).

The operations software for FOM2/mts is continuously improved to introduce new features and meet the objective of being user friendly.
The latest version of Android software is available at Google Play.
All versions of the **ETDR101.exe** PC software can be downloaded from www.e-test.eu website of the E-Test Sp. z o.o., from the **DOWNLOAD** section.

4.1 FOM2 application for operation with Android device (mobile or tablet)

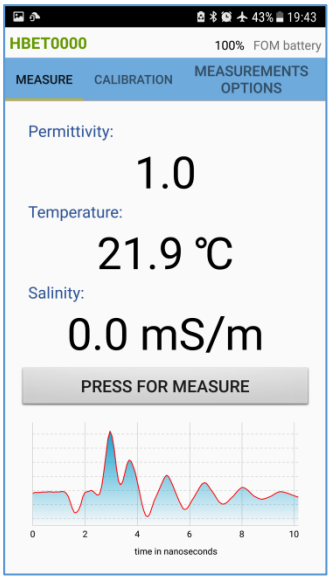
Installation of the FOM2/mts dedicated Android software should be done with the help of Google Play digital distribution service (search for FOM2).
Operation of the FOM2/mts meter working in manual mode with an Android device is presented on a set of screenshots below and described accordingly.



The default screen of the app after starting the FOM program.

At the top you can see the device's serial no. **HBET0000** and the energy state of the internal battery (in % of the full charge).

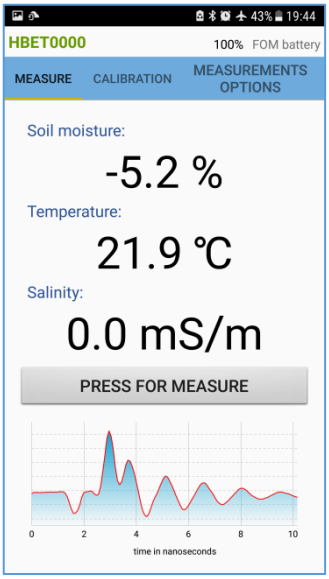
Pressing the **PRESS FOR MEASURE** push button starts the process of measurement. It takes about 6 sec.

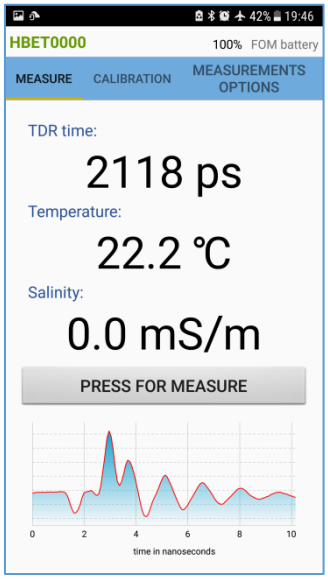


The measured medium is air and the meter outputs its dielectric permittivity, temperature and electrical conductivity (salinity).

The values of the earlier selected measured variables are displayed. Before the first measurement of a probe it should be calibrated (described later).

The bottom part of the screen shows the waveform reflected from the connected FP/mts probe.



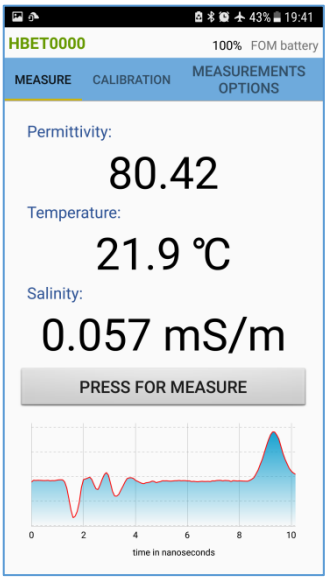


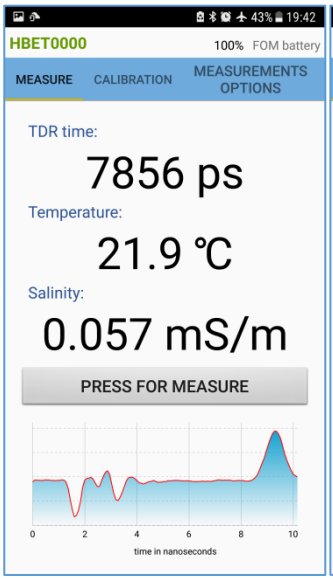
The measured medium is air and the meter outputs its temperature and electrical conductivity (salinity).

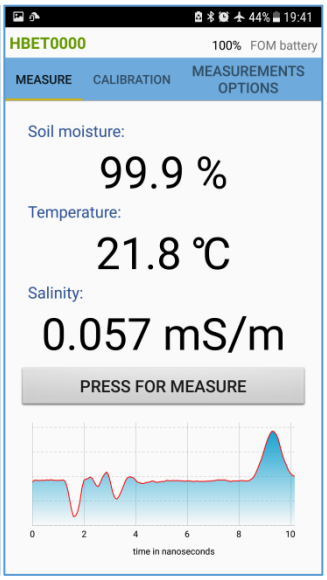
The results of the TDR measurements are represented by vol. % (left) or return travel time (right) of the electric pulse along the probe rods inserted into air as the measured medium.

The value of -5.2% of soil moisture comes from the applied calibration (see Eq. (2) on page 14).

The horizontal variable of the reflected waveform is time in nanosecond (10^{-9} s) as the unit.

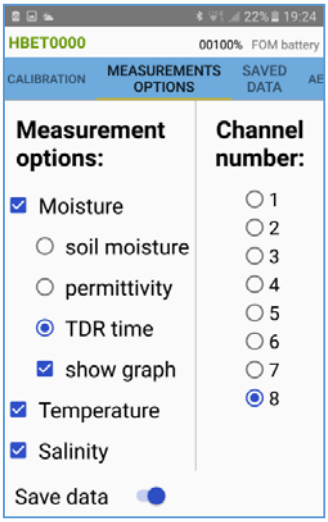






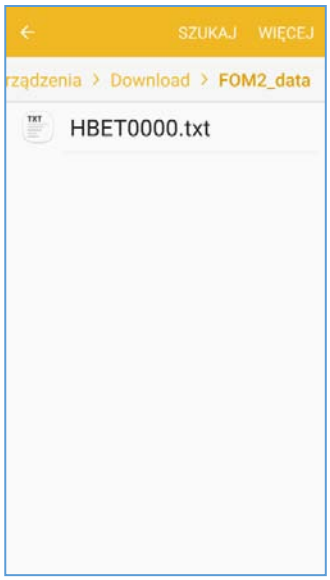
The measured medium is water.

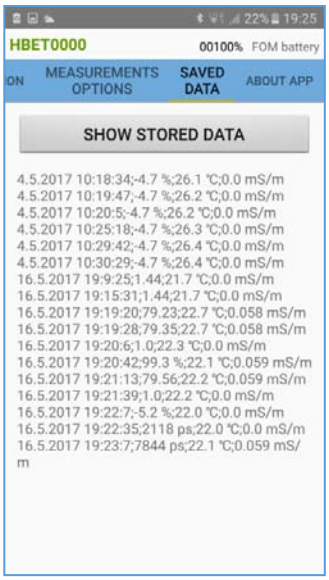
Various TDR readouts of the FOM2/mts meter: dielectric permittivity, travel time and vol. %, from left to right, respectively.



MEASUREMETS OPTIONS tab menu with the choices of the measured and registered variables and a virtual channel selection.

CALIBRATION tab menu for making calibration of a FP/mts probe assigned to the selected virtual channel. Proceed with the calibration by responding to the activation of successive push buttons. The calibration details are presented earlier in the in the description of the **ETDR** application software (see page 10).





Recorded data is stored in the internal memory of the Android mobile device, in Download and then FOM2_data directory path, in a text file named HBETXXXX.txt, where XXXX is a serial no. of the meter (see page 5)

4.2 ETDR101 Program for Operation with PC Computer

The FOM2/mts measurement device communicate with PC compatible computer by dedicated program **ETDR101.exe** free application software when connected by a USB cable. The program 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 FOM2/mts device. Running the without the USB cable will result in displaying the error message window (Fig. 4).

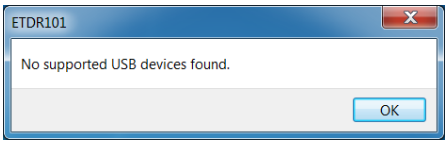


Fig. 4. The error message when a USB cable is not connected to the FOM2/mts meter.

No special drivers are necessary for proper communication between the FOM2/mts 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. 5) with:

- The device unique serial no.: **HBET0000**.
- 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.

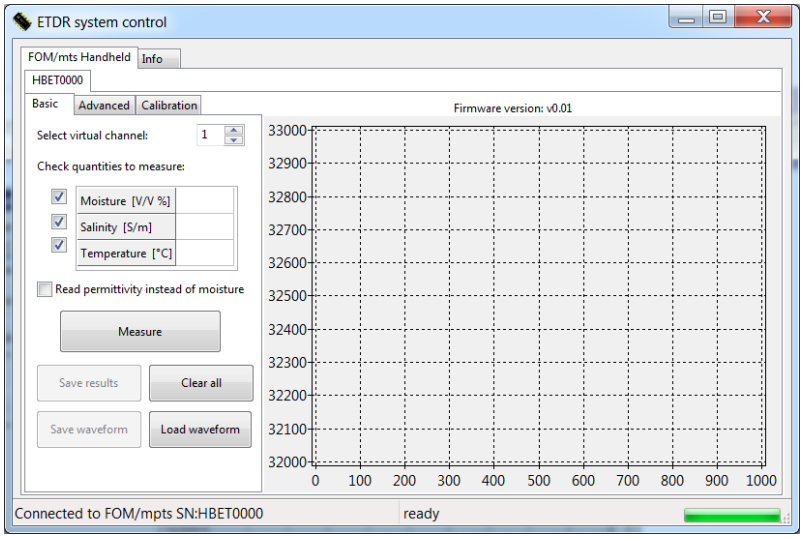


Fig. 5. The **ETDR** system control window with **Basic** menu tab selected.

4.2.1 FP/mts and LP/m 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.

4.2.1.1 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. 6).

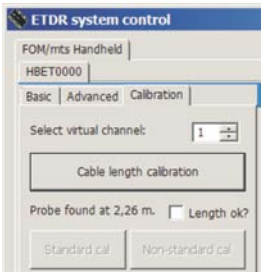


Fig. 6. Confirmation of the cable length

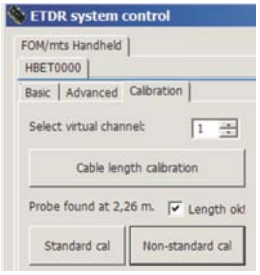


Fig. 7. Continuation of a TDR probe calibration after fixing the cable length. In case of the coax cable break or shortage, the calculation of the cable length will not be reliable and the TDR probe is probably not usable.

When the displayed cable length (Fig. 6) is approximately equal to the calculated one, the user should proceed with confirming the cable length and selecting the **Length ok?**. Then the window is expanded for the purpose of standard calibration or non-standard calibration of the probe selected in the virtual channel (Fig. 7).

4.2.1.2 Probe standard calibration

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

After performing the **Cable length calibration** and having pressed the **Standard cal** button a part of the **ETDR** system window is further expanded with two additional push buttons: **Cal in air** and **Cal in water** (Fig. 8).
Before pressing the **Cal in air** push button, the user should keep the probe in air having a distance of more than 5 cm from any object close to the probe rods.

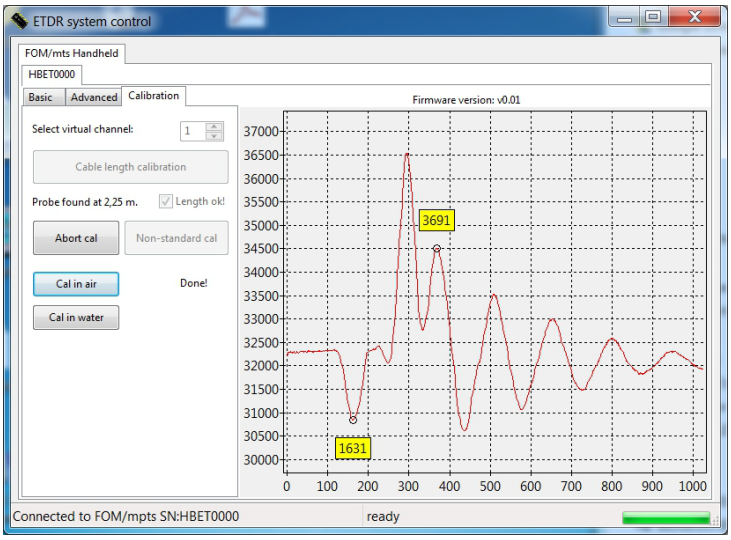


Fig. 8. ETDR system control window after performing a part of the standard calibration with air.

The graph in Fig. 8 and Fig. 9 presents a sampling time window of about 10 ns width showing the waveform reflected from the FP/mts probe rods in air and water, respectively. The marked extremes show reflections of the electric pulse from: the artificial time marker (1631 ps from the beginning of the time window) and the end of the probe rods (3691 ps for air and 9226 for water).

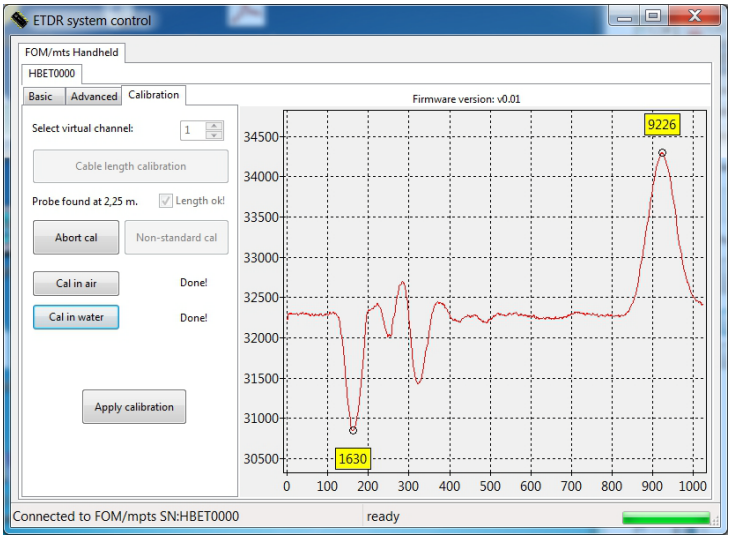


Fig. 9. **ETDR** system control window after performing a part of the standard calibration with water.

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. 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 FOM2/mts meter. 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).

4.2.1.3 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 (ε = 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 (ε = 1)	Water (ε = 81, water temperature = 18°C)
LP/ms	Ertacetal (3.8)	Water (ε = 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, ε**	**Temperature dependence**
Water	80.1 (T=293.2 K)	ε = 0.24921E3-0.79069*T+0.72997E-3*T^2 (273 < T (K)< 373)
Benzene	2.28 (T = 293.2 K)	ε = 0.26706E1-0.91648E-3*T-0.14257E-5*T^2 (293 < T (K)< 513)
Acetone	21.01 (T=293.2 K)	ε = 0.88157E2-0.343*T+0.38925E-3*T^2 (273 < T (K)< 323)
Metanol	33 (T=293.2K)	ε = 0.19341E3-0.92211*T+0.12839E-2*T^2 (177 < T (K)< 293)
Ethanol	25.3 (T=293.2K)	ε = 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.

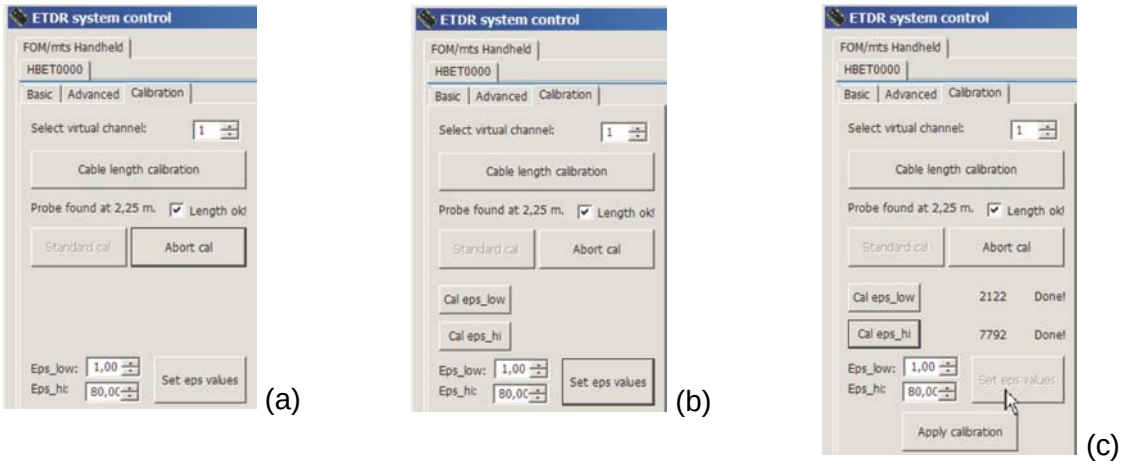


Fig. 10. Non-standard calibration procedure

- (Fig. 10a) 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. 10b) 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. 10c) 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 FOM2/mts.

4.2.2 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) and salinity (represented by electrical conductivity in mS/m).

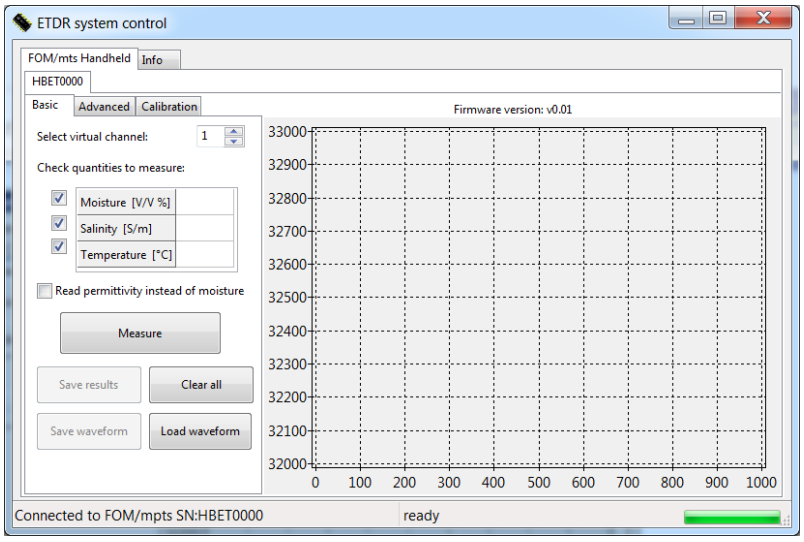


Fig. 11. **ETDR** system control window with tab menu **Basic** selected.

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 (apparent dielectric constant) for presentation of soil moisture content. Having the value of bulk dielectric constant ε_a from the measurement the user can apply any conversion formula to receive moisture content θ_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:

$$\begin{aligned} \text{for } \sqrt{\varepsilon_a} < 6, \;\; \theta_v &= 0.106397\sqrt{\varepsilon_a} - 0.158247 \\ \text{else} \;\; \theta_v &= -0.559595\sqrt{\varepsilon_a} + 0.173288 \end{aligned} \quad (2)$$

To have the volume % of moisture content, θ_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.). After the measurement the 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. 12).

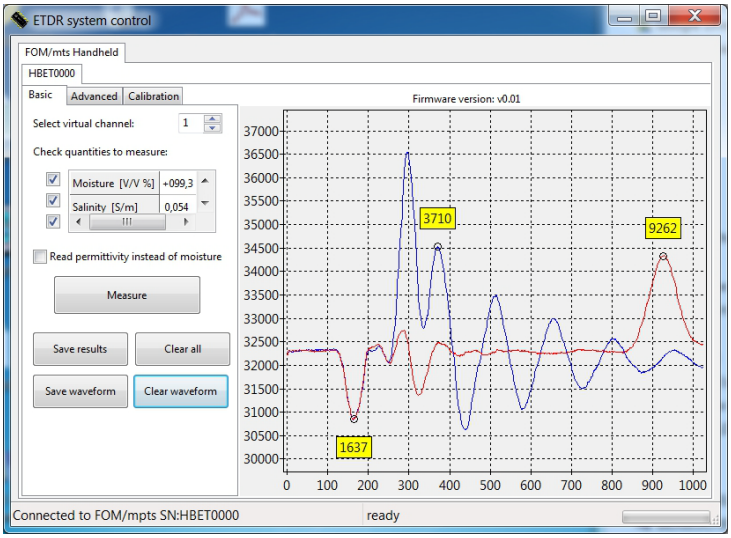


Fig. 12. Comparison of currently measured waveform (air) and a loaded one (water).

4.2.3 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 FOM2/mts meter (Fig. 13). 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 FOM2/mts meter.

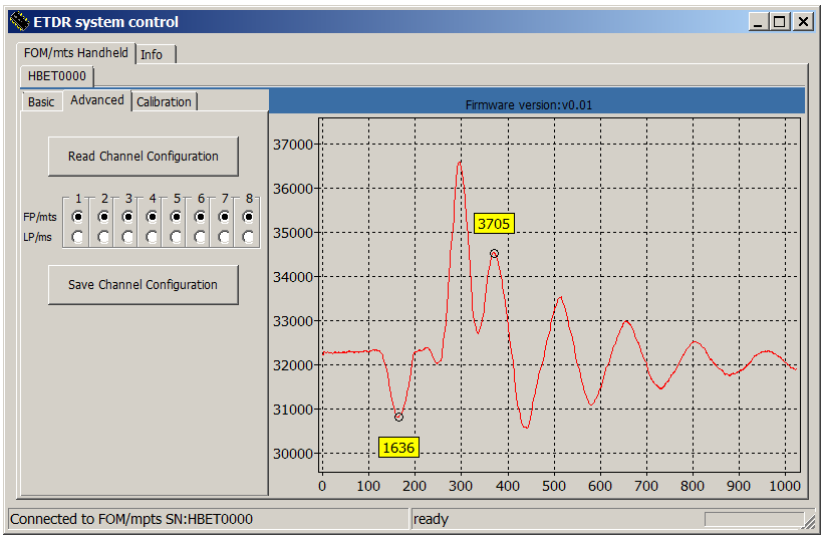


Fig. 13. Assignment of FP/mts or LP/ms probes to individual virtual channels of the FOM2/mts meter. **Advanced** menu tab selected.

When another type of probe than the one assigned to the virtual channel is connected to the FOM2/mts meter, the device generates an error message **ERR001** after measurement.

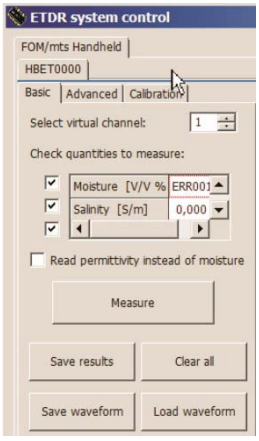


Fig. 14. The effect of incorrect assignment of the probe type to the individual virtual channel. The measurement is done but the **Moisture [V/V%]** is marked with the error code **ERR001**.

5 UTILITY FEATURES OF FOM2/MTS

- FOM2/mts is controlled from an Android device (mobile or tablet, Android versions from 4.3 and above) by means of wireless Bluetooth Low Energy 4.0 communication or 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 (future use),
- operates with probes with different cable lengths (from 2.5 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 – 4 s, electrical conductivity – 2 s,
- time of test of a single LP/ms probe: moisture – 2 s, electrical conductivity – 2 s,
- 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 ÷ 1 S/m
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,
Resolution of readings
volumetric moisture ..... : 0.1 %, temperature ..... : 0.1°C, electrical conductivity …… : 1 mS/m
Battery Type ..... : Li-Polymer, 2500 mAh, 3.7VDC (possible factory replacement)
Battery Life ..... : 3000 measurements or 182 days of stand-by
Charging ..... : >0.5A/5V micro USB plug charger or power bank
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 (HxWxL) ..... 1.9 cm x 7.0 cm x 12.5 cm (0.75 in x 2.76 in x 4.92 in)
Weight ..... 200.5 g (7.05 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 FOM2/MTS COMPATIBLE PROBES

7.1 FP/MTS - Field Probe for moisture, temperature and salinity of soil

FP/mts (Fig. 15) 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 avoiding the parasite "thermal bridge" effects on distribution of soil moisture in the probe's sensor vicinity. Through a preaugered pilot hole it can reach any depth without destroying either the soil structure or disturbing the heat and mass transport in the soil. For semipermanent 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. 15. 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. 16). 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.

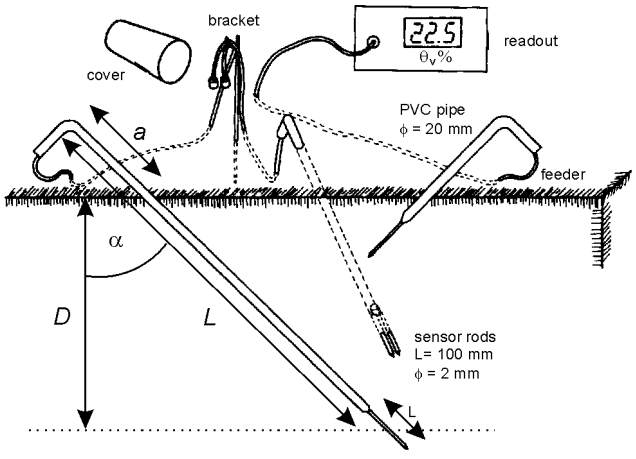


Fig. 16. The principle of installation of the FP-type probes. In order to minimize disturbances in the soil structure the probes are inserted into the soil via pilot holes, circularly distributed over the soil surface. The holes run slantwise and converge along a chosen vertical line. The cables are 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: from1.5 to 6 m from the sensor to the terminating connector,
- region of influence (Fig. 17): a cylinder having approximated diameter of 5 cm and height of 11 cm, circumferenced around the sensor rods.

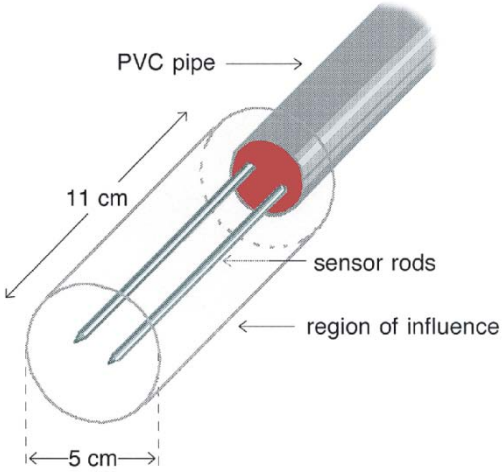


Fig. 17. A draft illustrating the approximate region of influence of the FP probe, defined as a solid beyond of that changes in water content do not markedly affect readings of moisture

7.2 LP/MS - Laboratory miniProbe for soil moisture and salinity

LP/ms - a laboratory miniprobe (Fig. 18) designed for monitoring changes in water and salt distribution in soil columns or in soil cores sampled with standard sampling equipment.

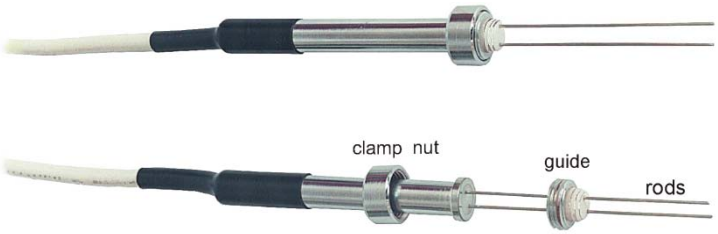


Fig. 18. LP/ms - Laboratory miniProbe for soil moisture and salinity

Several LP/ms can be inserted through the sidewall of a soil column or a steel sampling cylinder (Fig. 19), thus allowing for vertical scanning of the instantaneous moisture and electrical conductivity profiles. Such an array, when combined with similarly installed minitensiometers (LP/p), makes it possible to collect a set of corresponding water content and matrix pressure gradient data from drying or wetting front transition. From this one can obtain a complete set of the soil unsaturated water flow characteristics, i.e. water retention (PF-curve), water conductivity (k-function), and differential water capacity and unsaturated water diffusivity.

Features of LP/ms probes:

- installation hole: metric thread diameter of 8mm, 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, 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.

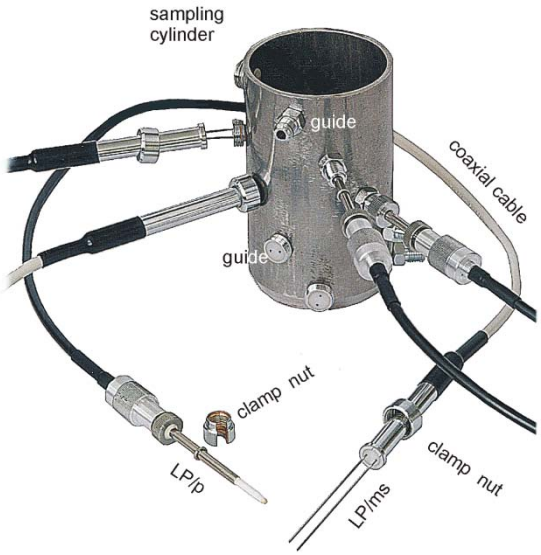


Fig. 19. A set of LP/ms and LP/p LOM miniprobes inserted through a 2.75 mm thick wall of a sampling steel cylinder, having height of 100 mm and 55 mm inner diameter. The wall of the cylinder is provided with tapped holes equally distributed along the cylinder height in order to monitor independent layers of the soil. The holes are aligned spirally to minimize mutual shadowing in the vertical direction.

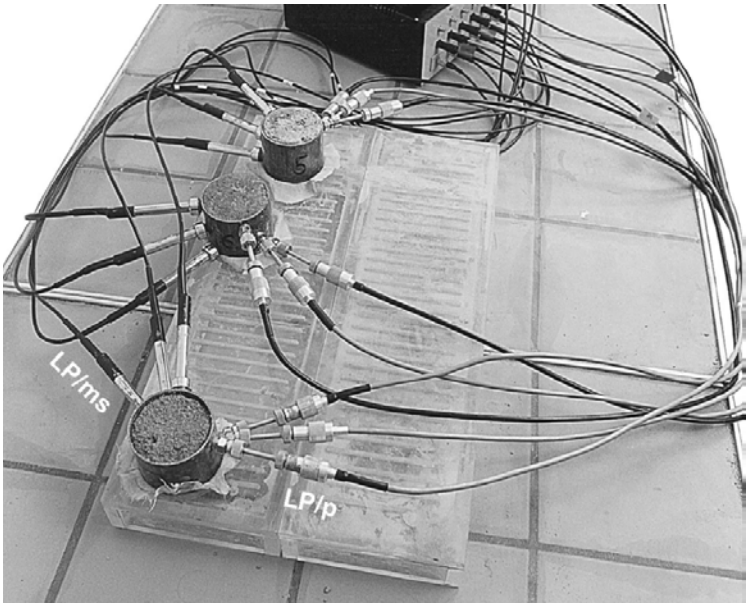


Fig. 20. Reading instantaneous profiles of soil water capillary pressure, moisture and salinity from arrays of the LP/p and LP/ms miniprobes

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.

8 REFERENCES

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