

Recent software improvements in moisture (TDR method), matric pressure, electrical conductivity and temperature meters of porous media

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Abstract. The FOM/mts (Field Operated Meter of moisture, temperature and salinity of soils) and TDR/MUX/mpts (Time Domain Reflectometry meter with a multiplexer for measurement of moisture, matric pressure, temperature and salinity of soils) are measurement devices developed and manufactured in the Institute of Agrophysics Polish Academy of Sciences (IA PAS), Lublin, Poland. They are recently redesigned to increase the functionality, accuracy and to provide user friendly way of operation.

The main improvements are as follows:

- ability to connect the devices to PC compatible computer by a standard USB link using the universal program ‘ET USB Communicator’,
- identification of the devices by unique serial numbers,
- device firmware upgrade by means of running a provided program on the PC computer connected to the device,
- individual probe calibration,
- ability to connect a number of additional temperature (LP/t – Laboratory Probe for soil temperature measurement) and matric pressure (LP/p – Laboratory Probe for soil matric pressure measurement) using the auxiliary input (applies to TDR/MUX/mpts),
- probe type selection (choice between laboratory LP/ms or field FP/mts probes) in the TDR channel.

Also the description of universal MIDL (Multi Interface Data Logger) data logger that can control the TDR/MUX/mpts devices is presented.

Keywords: soil water content, time domain reflectometry, porous media, user interface

materials defined as a space-temporal recording of the water properties that stimulate the phenomena and processes observed in the soil-plant-atmosphere system. Water status of soil, as a porous material should be expressed by minimum five variables: amount of water in the soil *ie* soil water content, soil water potential, salinity, oxygenation and temperature (Malicki and Bieganowski, 1999). The most difficult are the electric measurement of soil water potential and soil water content, therefore they are the subject of permanent research. The reflectometric method for soil water content and electrical conductivity measurement has become popular since the publication of Topp *et al.* (1980) and common use of TDR meters. The Institute of Agrophysics PAS has its share in the development of methods and TDR technique (Malicki and Skierucha, 1989; Malicki and Walczak, 1999; Malicki *et al.*, 1994; Skierucha and Malicki, 2004; Skierucha *et al.*, 2005).

The description below presents selected features of newly introduced software and hardware upgrades in FOM/mts and TDR/MUX/mpts. The objective of these developments is: (1) to increase the accuracy of measurement of soil moisture, matric potential, electrical conductivity (salinity) and (2) to provide the user with friendly and reliable software. These devices together with MIDL data Logger meters are basic elements of monitoring systems of soil physical and chemical environment.

INTRODUCTION

Increasing demands on water resources result in the continuous development of tools to optimize water management. One of the most important, beside the simulation models of water balance (Walczak and Sławiński, 2000), is monitoring of water status in porous

USER SOFTWARE

Apart from the autonomous way of work when the devices are controlled by internal electronics, the meters can operate by means of the dedicated computer program ‘ET USB Communicator’ running PC computer in Microsoft

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Windows environment. This program operates with the both devices, FOM/mts and TDR/MUX/mpts (Manual FOM/mts..., 2006), and is continuously upgraded to follow hardware and software improvements of the measurement devices and to manage the operation of new meters that will be introduced in the IA PAS offer. The program allows the user to: perform single measurement on selected probe to test the device and the probe, individually calibrate each TDR probe (*ie* fix the electrical length and the 'dead time' of a probe as well as account for individual characteristics of the channel) and send the data to the device, load the data stored in the internal memory of the device to PC computer (applies to FOM/mts handheld meter), control the probes measurement sequence and time period between the measurement series (applies to TDR/MUX/mpts meter in the data logger mode of operation), generate a script file defining the devices and probes measurement sequence for later importing by the MIDL data logger (MIDL: Data logger ..., 2004). The connection between the device or devices (in case of multiple TDR/MUX/mpts meters) and PC computer is by a standard USB link after installation a virtual serial port (COM port) on the PC. After connection the device/devices to the PC computer and selection of the installed serial port, the connected device/devices are polled to read their serial numbers and then the next window, named operation window, opens.

Operation windows

The entry window to the 'ET USB Communicator' program is presented in Fig. 1A. The 'ET USB Communicator' can control only one FOM/mts handheld meter. The operation window for this meter is presented in

Fig. 1B and for TDR/MUX/mpts in Fig. 2. The command buttons are grouped in two frames: Calibration and Measurement. Some commands are also accessible from the menu at the upper part of the window.

The program enables to perform single or combined measurements of all three variables. The measurement of soil moisture, salinity (electrical conductivity) and temperature takes 1, 1.5 and 3 s, respectively. During the process the user is asked not to disconnect the USB cable from the handheld device. It is most advised not to move the probe in the measured sample in order to receive reliable results. After this time the result is received and displayed in the „Program Log” field. The reflectogram used to calculate the moisture value is also displayed in new window (Fig. 3). The marked points on the reflectogram represent the time distance, which is the base for the calculation of the soil water content by reflectometric method. The numerical data of the received reflectogram can also be exported in the form of text file.

Up to 16 devices can be controlled by the 'ET USB Communicator' and the user can choose the current device for testing, calibration and configuration. This can be done by selection a serial number from the 'Select device' text box (Fig. 2).

Currently the FOM/mts device operates with various probes (FP/mts or LP/ms) only in the program mode *ie* when controlled by 'ET USB Communicator'. This option will be soon available in the autonomic mode of operation.

The TDR/MUX/mpts device can measure the following probes:

- FP/mts - field probe for the measurement of soil moisture (by TDR technique), temperature and electrical conductivity (using 8-channel coaxial port),

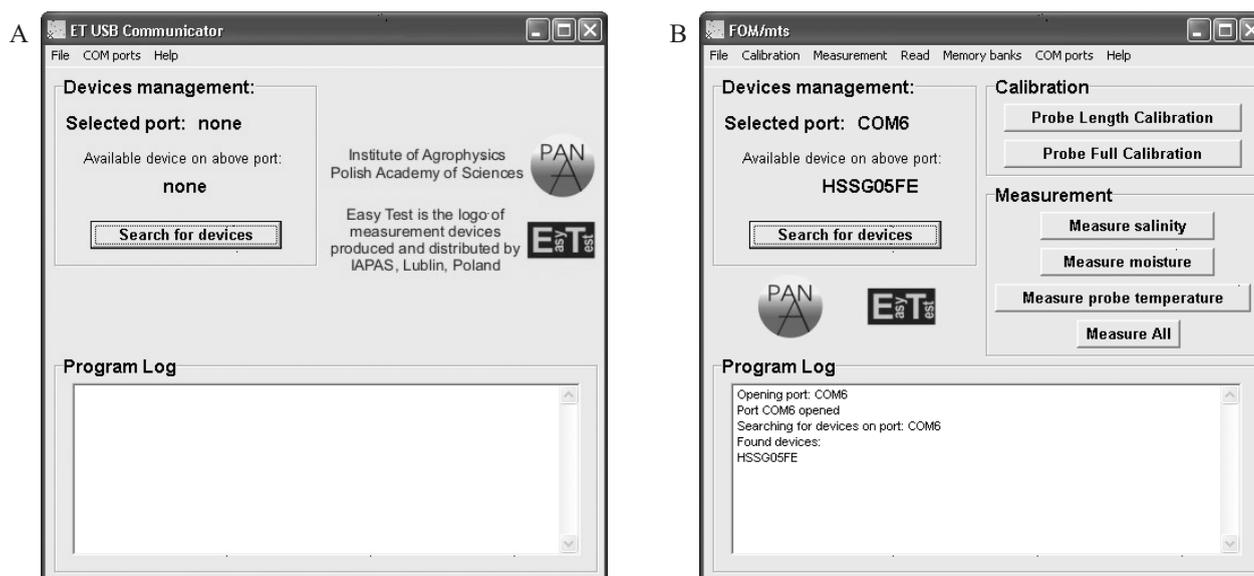


Fig. 1. The ET USB Communicator window: A – program entry window common for all devices, B – operation window for FOM/mts handheld meter.

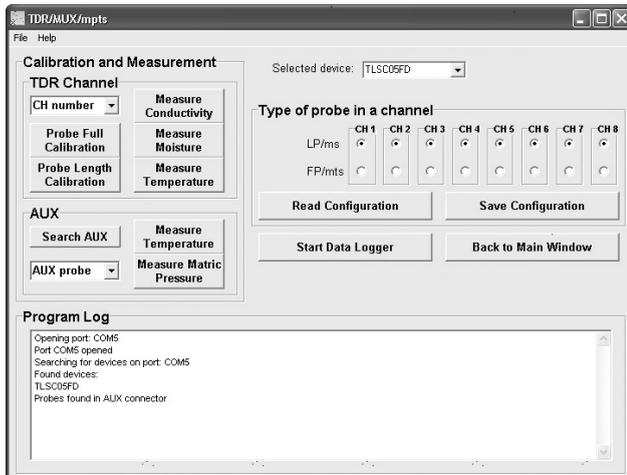


Fig. 2. Operation window for TDR/MUX/mpts meter.

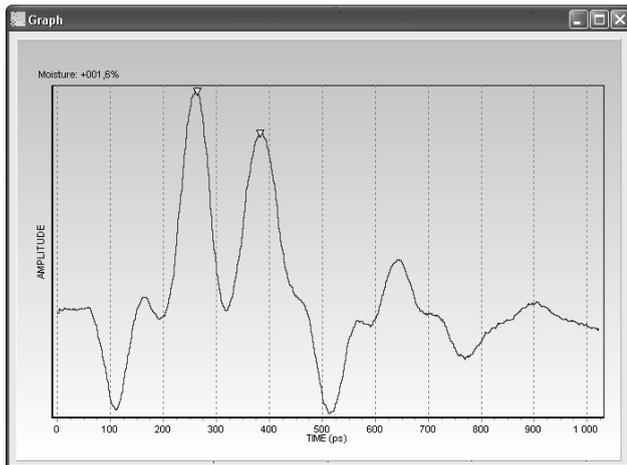


Fig. 3. TDR reflectogram from FP/mts probe connected to FOM/mts or TDR/MUX/mpts device controlled by 'ET USB Communicator'.

- LP/ms - laboratory probe for the measurement of soil moisture and electrical conductivity (using 8-channel coaxial port),
- LP/t – laboratory probe for the measurement of temperature (using auxiliary port),
- LP/p – laboratory probe for the measurement of soil matrix pressure (using auxiliary port).

The LP/t and LP/p probes are connected in parallel to the auxiliary port using the standard 1-Wire protocol (DS18B20: Programmable..., 2001). Each of these probes is identified by a unique serial number. If the AUX probes are connected to the TDR/MUX device when the operation window from Fig. 2 opens, the program automatically identifies all their serial numbers and they are accessible to the user.

When opening the TDR/MUX/mpts window the program reads from the device the type of TDR probe selected to individual channels (*ie* either LP/ms option for Laboratory Probes or FP/mts option for Field Probes). In case of other configuration of TDR probes the user should manually select the type of TDR probe by choosing appropriate toggle switch under the selected channel number (CH1, CH2, ... or CH8). Then, this configuration should be saved in the device for storing in the non-volatile memory by pushing the 'Save Configuration' command button. The "Read Configuration" command button is for back reading of the recently written data and verification of the chosen selection.

Probe calibration

Probe length calibration localizes the TDR sensor rods at the end of the coaxial cable and this feature allows using TDR probes of various cable lengths.

The probe full calibration determines characteristic parameters of the individual TDR probe in a channel and stores them in the device internal memory. These parameters are not accessible to the user but they are taken into account in calculation of soil apparent dielectric permittivity and moisture. The TDR probe parameters can change due to long term and temperature drifts as well as the different geometries of FP and LP probes. Calibration of FP probes is done with two media: air and water. Calibration of LP probes is done with a provided calibrator (a cylinder from ertacetal with two narrow holes for inserting the needles of the probe – for low dielectric constant values) and water. The calibration in water requires information about its temperature that is easily available for FP probes with inherent temperature sensor. For LP sensors the user must provide water temperature by:

- measuring it with a thermometer and filling in the appropriate text box when no auxiliary (AUX) temperature probe is selected, or
- measuring it with a selected 1-Wire temperature probes connected to the auxiliary port (the selected LP/t AUX probe should be inserted together with the calibrated probe into water).

During calibration procedure the user should follow the instructions given in the information windows. The more detailed calibration information implemented in the program 'ET USB Communicator' features is presented in the Manual FOM/mts... (2004).

Device identification

Each measurement device manufactured in the IA PAS is provided by a unique eight characters serial number (Fig. 4). The commands from the PC computer to the device are preceded by this number for selective addressing.

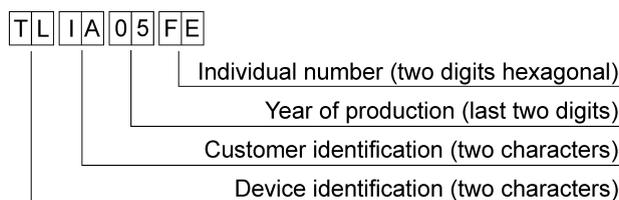


Fig. 4. Serial numbers of the measurement devices from the IA PAS, Lublin.

The first two characters of the serial number contain the information identifying the device. The identification codes of the implemented devices is shown in Table 1.

The type of the device *ie* FOM/mpts or TDR/MUX/ mpts, connected to PC compatible computer is automatically detected by the program ‘ET USB Communicator’ after starting it. Then, the next window appears, which is dedicated to the management of the specific device. The PC computer can control only one FOM/mpts device or up to sixteen TDR/MUX/mpts devices. The example connections of several TDR/MUX/mpts devices are presented in Figs 5 and 6.

TDR/MUX/mpts devices can be connected in series and they are supplied by means of the linking cable RS485. In the example from Fig. 5, the external supply of 12VDC is connected preferably to the first in series TDR/MUX/mpts device and the power inputs (marked 12VDC) of other devices are not connected. In the example from Fig. 6 the external power supply of 12VDC is connected to the MIDL Data Logger and the TDR/MUX/mpts devices are supplied by means of the cable connected in series.

Table 1. Device identification codes

Device identification	
First character	Second character
H – handheld soil moisture (TDR), temperature and salinity meter	S – standard version or Slave (MIDL)
T – TDR/MUX/mpts 8-channel soil moisture, matrix pressure, temperature and salinity meter	M – Master (MIDL)
M – Multi-Interface Data Logger (MIDL) voltage meter for potentiometric measurements	G – GPS option
I – 8-channel high input impedance voltage meter for potentiometric measurements	F – field version
B – battery	L – laboratory version
	1 – Li-Polymer 3.6V/1500 mAh

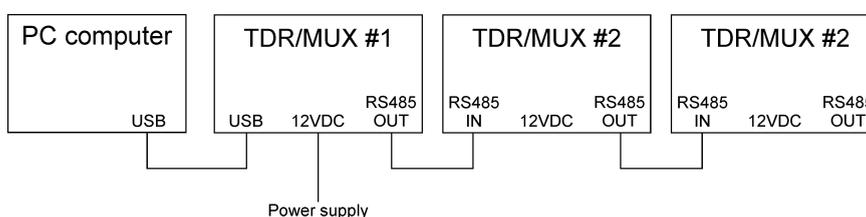


Fig. 5. Example connections of the measurement system consisting in a PC computer and three TDR/MUX devices connected in series.

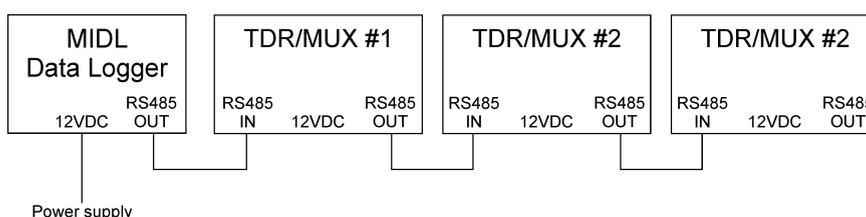


Fig. 6. Example connections of the measurement system consisting in a MIDL Data Logger and three TDR/MUX devices connected in series.

Firmware upgrade

The firmware (software embedded into the internal electronics of a device) of the FOM/mts and TDR/MUX devices is continuously improved to meet the objective of being user friendly. The latest version of firmware is available on request from the IA PAS, Lublin, Poland or can be downloaded from the WEB site www.easytest.lublin.pl. The process of firmware upgrade consists in the execution of appropriate files FOMXXXXX.exe or TDRXXXXX.exe, where XXXXX is the upgrade version. It is requested not to interrupt the execution of the above files.

Increased number of LP/t and LP/p probes in the auxiliary port

Currently two types of probes can be applied in TDR/MUX/mpts device auxiliary port: LP/t – laboratory probe for temperature measurement and LP/p – laboratory probe for soil matric pressure. The probes are connected in parallel and they are identified electronically by the individual serial number. Each probe has a label with its serial number containing six alphanumeric characters preceded by a letter t – for temperature probes and a letter p – for soil matric pressure transducer, ex. t45BE1D or pEAC016. The number of probes connected to the auxiliary port depends on the total length of cable probes, which introduce capacitance of the channel. The experience data show that the port operates correctly with 16 probes of 6 m length each.

Data logging features

The TDR/MUX/mpts device operated with the ‘ET USB Communicator’ program can work in laboratory or field conditions as data logger. The example sequence of measurements and time distance between the measurements series are presented in Fig. 7.

The width of a time window for each device differs because not all channels in the device may be measured. The TDR/MUX/mpts devices controlled by the program are identified by various serial numbers.

In data logger mode (Fig. 8) of operation the PC computer sends commands to the individual devices, receives the data and stores in individual for each device text files for further processing. The user determines the sequence of probes measurement in connected devices and time period between the beginnings of consecutive

measurement series. Opening the Data Logger window is associated with the execution the following operations by the program:

- reading the serial numbers of TDR/MUX/mpts devices connected in the measurement system and updating the ‘Select device’ box,
- importing the assignment of probe types (FP/mts or LP/ms) in the individual channels of each device and updating the ‘Probe type’ selection (it is inactive in this window),
- searching for 1-Wire probes connected to AUX port for further selection by the user.

After selecting the current device in the ‘Select device’ box, the user determines which values will be measured in the channels associated with LP/ms and FP/mts probes. The FP/mts probes measure soil moisture, θ (% vol.), electrical conductivity, σ ($S\ m^{-1}$), and temperature, T ($^{\circ}C$), and all of these variables may be selected. The LP/ms probes measure only θ and σ , and selection for temperature is inactive for this type of probe.

Each channel has two associated AUX probes for the measurement of probes connected to the device by 1-Wire link, *ie* LP/t temperature and LP/p soil matric pressure probes. When the user assigns the particular 1-Wire probe to the channel, it cannot be selected again for other channels.

The example selection from Fig. 8 shows that the device with the serial number TLDL05FE has all channels equipped with LP/ms probes with selected soil moisture and electrical conductivity measurement values active and one AUX probe in the 1st channel for temperature measurement.

Output data format

Pressing the ‘Start’ command button initiates the Data Logger operation of the TDR/MUX/mpts device. The ‘ET USB Serial Communicator’ will send commands to the device and receive data from the sensors for storage in the text files. Each device connected to the computer will have a separate data file named after its serial number *ie* for the device TLIA05F0 the output data file is named TLIA05F0.txt, etc. Pressing ‘Stop’ command button saves all output data files associated with the TDR/MUX/mpts devices in the system to the same folder where the ‘ET USB Serial Communicator’ program is located (default folder).

The format of output data file is presented in Fig. 9 and it allows importing into a spreadsheet program. The first line of the output data file contains headers. They represent:

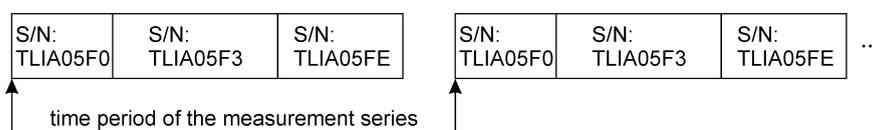


Fig. 7. Example of the sequence of measurements and time distance between the measurement series for three TDR/MUX/mts devices identified by various serial numbers.

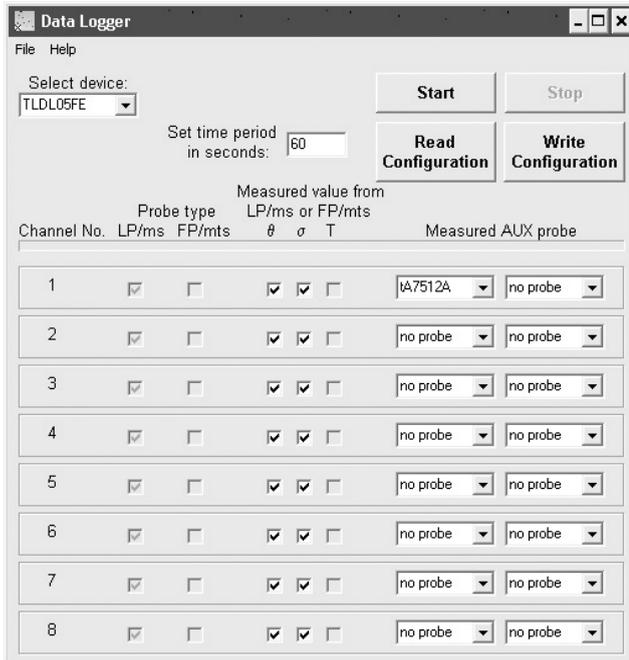


Fig. 8. Data Logger window TDR/MUX/mpts device.

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counter date/time M1 S1 X11 X12 M2 S2 T2 X21 X22 ... M8 S8 T8 X81 X82
0 2005-04-27/16:41:09 +008,2 0,000 +15,1 470 +009,8 0,000 +12,4 +17,7 +17,8 ... +014,3 0,000 +15,3 +17,5 510
1 18:39:31 +008,4 0,000 +14,9 472 +009,9 0,000 +12,8 +17,4 +17,9 ... +006,7 0,000 +15,2 +12,8 513
2 20:37:54 +008,4 0,000 +14,0 470 +010,1 0,000 +12,7 +17,5 +17,2 ... +006,7 0,000 +15,0 +12,6 516
3 22:36:16 +008,5 0,001 +12,9 475 +010,1 0,000 +12,3 +17,6 +17,0 ... +006,2 0,000 +15,7 +12,0 521
...

```

Fig. 9. Format of the output data file generated by Data Logger window of the 'ET USB Serial Communicator' for the configuration of probes from Fig. 8.

- counter: number of the measurement series executions (numeric value starting from zero),
- date/time: date and time for the start of the current measurement series execution (date is written only once a day and repeats at midnight), format: YYYY-MM-DD/HH:MM:SS
- M1...M8: value of moisture (%) in channels 1..8, format: +###,#,
- S1...S8: value of electrical conductivity (Sm^{-1}) in channels 1...8, format: #,###,
- T1...T8: value of temperature ($^{\circ}\text{C}$) in channels 1..8, format: +##,#,
- X11..X81 and X12...X82 for probes in AUX channels, format for temperature ($^{\circ}\text{C}$) probes is +##,#, format for matric pressure (mbar) probes is ###.

The following lines of the output file contain data arranged according to the headers.

Exporting Data Logger configuration to the script file to work with MIDL data logger

The Data Logger window facilitates exporting the script file that can be loaded to the MIDL data logger. It can work without PC computer in field installation of TDR/MUX/mpts devices. The MIDL data logger is characterized by low power consumption facilitating long time battery operation, short distance wireless communication, internet connections and high data storage capacity. The script file is a text file with commands interpreted and executed by the microcontroller in the MIDL device in a cyclic way. The commands include starting measurement of a chosen sensor, storing the measurement results, introducing the data logger into sleep mode for a chosen time period, etc.

Having configured channels by the 'ET USB Serial Communicator' in each TDR/MUX/mpts device in the measurement system the user selects Export Script in the File menu to choose the name and location in the PC computer. Loading the created script file to the MIDL data logger can be done using for example Internet FTP protocol.

CONCLUSIONS

1. The described measurement devices developed in the IA PAS represent modern trends in the development of measurement systems characterized by low power consumption, high capacity of storage memory and possibility to control the measurement process from any place in the world using Internet connection or application of wireless radio connection (in the case when the access to the monitored object is limited) and a user friendly interface.

2. The continuous hardware and software upgrade of the measured devices follows the general technological development. The plans for the future include the introduction of global wireless data transmission using GPRS modems and the commercial GSM network and the implementation of short distance transmission protocols for the data exchange among sensors and field installed master data loggers.

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