TDR WiFi

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1. Theoretical TDR background

Estimation of θ by TDR is based on previous calculus of the bulk dielectric constant, ε_a, which is estimated according to (Topp e tal., 1980)

$$\varepsilon_a = \left(\frac{ct_L}{2L}\right)^2 \tag{1}$$

where L (m) is the length of the TDR probe embedded in a media, c (3 x 10^8 m/s) is the velocity of light and t_L (s) is the travel time for the pulse to traverse the length L of the TDR guide. t_L is calculated as the difference between the time at which the signal enters the TDR rods (first peak) and the time when the trace arrives at the end of the TDR probe, or second reflection point. This last point is commonly calculated with the *tangent method* (Heimovaara, 1993). The relationship between ε_a and θ can be expressed as (Topp et al., 1980)

$$\theta = -0.053 + 0.0292\varepsilon_a - 0.00055\varepsilon_a^2 + 0.0000043\varepsilon_a^3 \tag{2}$$

The bulk electrical conductivity, σ, is commonly calculated with the long-time TDR waveform Giese and Tiemann (1975) analysis, according to

$$\sigma = \frac{K_p}{Z_r}\left(\frac{1-\rho_{\infty,scale}}{1+\rho_{\infty,scale}}\right) \tag{3}$$

where Z_r is the output impedance of the TDR cable tester (50 Ω), K_p (m^{-1}) is the probe-geometry-dependent cell constant value, $\rho_{\infty,scale}$ is the scaled steady-state reflection coefficient, which is calculated according to (Lin et al., 2008)

$$\rho_{\infty,Scale} = 2\frac{(\rho_{air}-\rho_{SC})(\rho-\rho_{air})}{(1+\rho_{SC})(\rho-\rho_{air})+(\rho_{air}-\rho_{SC})(1+\rho_{air})}+1 \tag{4}$$

where ρ, ρ_{air} and ρ_{SC} are the long-time reflection coefficient measured in the studied medium, in air and in a short-circuited probe, respectively.

2. Hardware description

The TDR wireless system for θ and σ measurements presents the following components (Fig. 1)

- A TDR-100 cable tester
- A null modem serial cable DB9 male - DB9 male
- A M5Stack processing unit that integrates a WiFi connectivity
- A battery module for M5Stack (700mAh) stackable board
- A RS232 to TTL serial port converter module DB9 connector
- A M5stack base26 proto industrial board module
- Device with WiFi connection

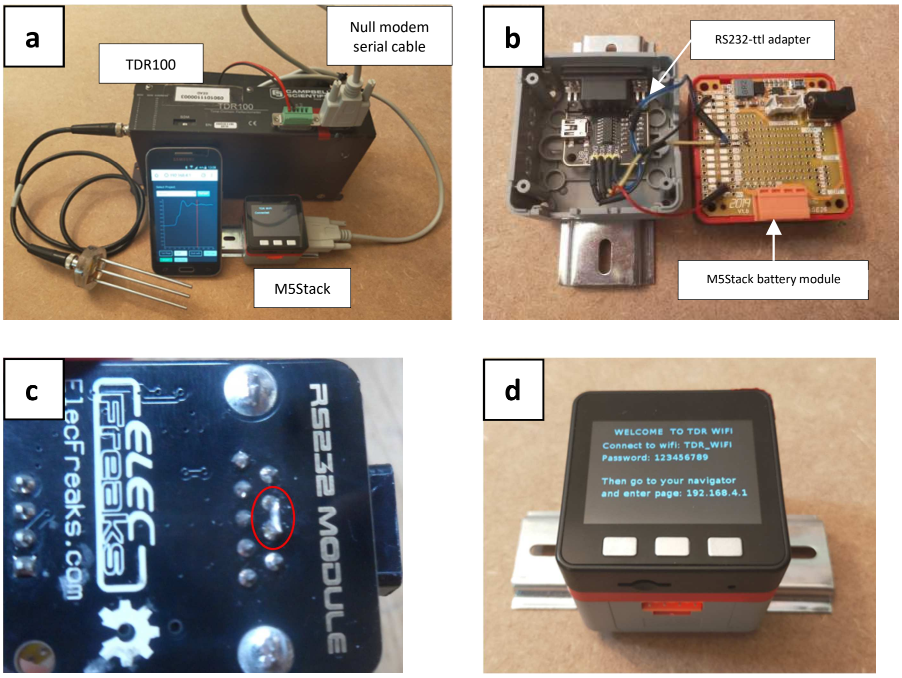

Figure 1. (a) TDR-WiFi components, (b) pins configuration between the M5Stack UART port and the RS232-TTL adapter, (c) detail of the RS232-TTL adapter modification, and (d) M5Stack module

The M5Stack was assembled to a 700mah battery, which confers several hours autonomy to the processing unit. The M5Stack UART port was connected to a RS232-TTL adapter (Fig. 1b). Connections between battery module board and output pins of the RS232-TTL adapter are shown in Figure (1b). The connections between the TTL output pins and the inputs of the M5Stack motherboard are as follow: GNB => 35; VCC => 5V ; RXD => 16; TXD => 17 (Fig. 1b). To connect the RS232-TTL adapter with the TDR cable tester, a small modification to configure the RS232 as null modem was performed (Fig. 1c). Finally, the RS232-TTL adapter together the M5Stack and battery module were assembled into a module, which allowed packing all components in a 5 cm^3 box (Fig. 1d). If necessary, the M5Stack can be connected to an auxiliary battery through a UART port. The TDR cable tester is connected to the processing unit through to null modem serial cable DB9 male-DB9 male. All hardware needed to make the Wifi-TDR system is summarised in the http://swi.csic.es/?page_id=283 web address. In the following sections we describe the software that controls and makes all the components to work together, in order to record and analyse TDR waveforms from a smartphone connected via WiFi to the M5Stack.

3. Processing unit software

The processing unity was programmed in *M5 UI Flow*, a development for M5Stack in Blockly and MicroPython programming languages, in our case using MicroPython. The first goal of the software is to allow that the M5Stack acted as a server between the user and the TDR device through a web page read with a smart-phone. The software was compatible with Campbell TDR-100 device. To connect the TDR device with the smart-phone, the M5stack and the smart-phone WiFi should be previously connected. Once the phone recognizes the M5stack WiFi, a phone web browser should be opened and the 192.168.4.1 address selected. We recommend using Chrome or Firefox browsers. The 123456789 password should be then introduced. Once selected the WiFi-TDR address, it opens a user friendly user interface, which is divided in three sections (Fig. 2a): (i) a drop down window for project management, (ii) a table that store the TDR waveforms and (iii) an exporting data function to transfer/download the data from the M5Stack to the phone.

Wifi-TDR works at 9600 bauds, so, TDR100 device should be configured to this velocity. WiFi-TDR data are organized in projects where the TDR waveforms and estimated θ and σ are saved. All projects are created, selected or executing through the project manager drop down located at the top of the main webpage (Fig. 2a). By clicking the configuration button, a new window to define the project characteristics opens (Fig. 2b). A new name should be defined every time a new project is created or the configuration of a former project is modified. The configuration includes the TDR window position (Cursor) and amplitude (Dis/Div), geometry of the TDR probe (Prove length, Constant K) and characteristics to measure σ. Once defined the project configuration, a TDR waveform should be recorded by pressing the *Refresh* button (Fig. 2b). This allows the user checking if the TDR waveform is correctly located. TDR waveforms are expressed as the reflection coefficient as a function of time. The first peak of the TDR waveform should be defined before saving the project. This first peak can be fixed by pressing on the TDR waveform screen or by introducing the corresponding time. Once the project saved, the configuration data cannot be changed again.

The required project can be selected by pressing on the drop down window (Fig. 2a). Once selected the project, TDR waveform can be acquihired by clicking on the *Refresh* button. This button opens a new window that shows the current TDR waveform (blue line in Fig. 2c) and the first peak previously defined in configuration (Fig. 2c). The TDR signal can be saved by clicking on the *Save* button located at the bottom of the window (Fig. 2c). θ is automatically estimated with the tangent method by clicking on the $\theta\,(m^3\ m^{-3})$ button (yellow lines in Fig. 2c). A manual definition of the second reflection point can be also designated by pressing the *Manual 2nd reflection* option. In this case, the second reflection point can be redefined on the TDR waveform screen or by introducing its time. Once the second reflection point fixed, the $\theta\,(m^3\ m^{-3})$ button should be clicked again. The soil bulk electrical conductivity can be also estimated by pressing the *EC* button. This is calculated from a long time TDR waveform (green line in Fig. 2c) recorded by the cable tester. Some comments can be also included within each TDR waveform window. All data are automatically saved by pressing the *Save* button.

All saved TDR waveforms and θ or σ are centralized in a data base displayed in a table form located under the project management drop down (Fig. 2a). The table is organized in four columns. Second and third columns define the project name and the date and time of the recorded TDR waveforms, respectively. The fourth column includes the *Results* icons that allow opening the windows containing the stored TDR signal and the measured θ or σ (Fig. 2c). θ could be recalculated by modifying the first peak and second reflection point.

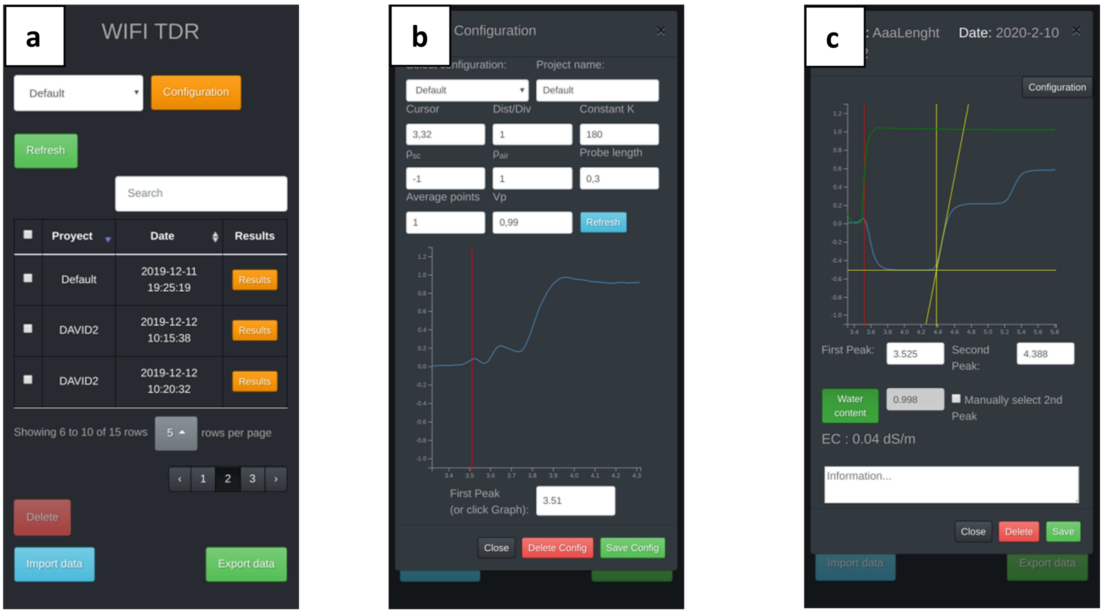

Figure 2. (a) Main page of the WiFi-TDR webpage, (b) configuration webpage, and (c) refresh TDR waveform webpage.

The stored TDR waveforms can be exported by clicking the *Export data* button located at the bottom of the main page (Fig. 2a). The TDR waveform to be exported can be selected by pressing the squares contained in the first column of the results table. The data is exported in *.json* format file, and the exported files are stored in the download folder defined by default by the browser. The name of the files can be redefined previous its exportation. The exported data contains the name, settings, the TDR waveforms for θ and σ measurements, and the calculated the water content, dielectric constant and bulk electrical conductivity, if estimated.

4. Webpage for TDR waveform analysis

Since the objective of the portable system is to ease and makes θ and σ samplings faster, a complementary free access web page (http://swi.csic.es/tdrwifi/) for subsequent and more accurate estimates of θ and σ was also developed. This webpage is designed to import the *.json* files generated by the smart-phone application (Fig. 3). The imported data is sorted in a four-column table, in a similar way that described in the smart-phone application. The TDR waveform can be individually analysed by opening the icons located in the fourth column, or analysed in groups after selecting the desired data to be analysed and clicking the *Calculate Selected* button. In a similar way, the recorded TDR data can be opened individually on in group. This allows checking that the analyses have been correctly done. Similarly to that described for the smart-phone application, if necessary, the TDR waveform can be manually reanalysed. Once all θ and σ calculated, the results can be exported in a *.csv* file format, which output file includes the name of the project, the date and time of the measurement, configuration data, TDR waveforms, ε_a, θ and/or σ estimates (Fig. 3).

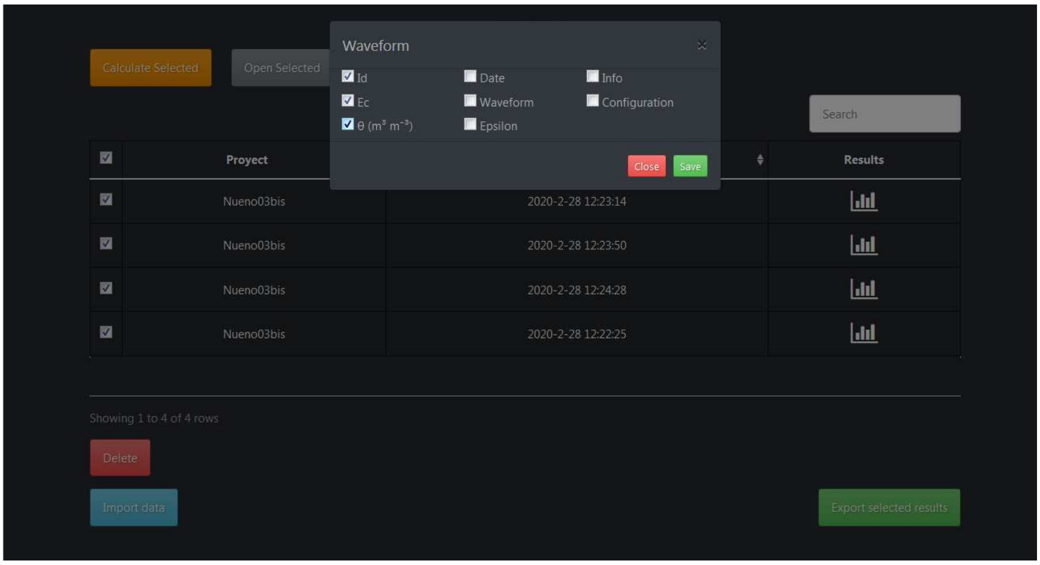

Figure 3. Webpage for analysis of the measured TDR waveform

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