TDR TECHNOLOGY APPLIED TO SOILS

WATER CONTENT AND SOIL BULK ELECTRICAL CONDUCTIVITY MEASUREMENTS

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CONTENTS

ABSTRACT

Key words : Time Domain Reflectometry, TDR equipment, soil moisture measurement, soil apparent electrical conductivity.

Time Domain Reflectometry becomes a frequently used technique for soil moisture measurements but it can also be used for measuring the apparent electrical conductivity of soils.

This report introduce with a quick look on the basis theory of TDR measurement method and some of the different models used to estimate the dielectric properties of wet soil to establish relationships to water content. Two different approaches for signal processing are explain. Different designs, installation methods and sensitivity are exposed. The TDR use for soil bulk electrical conductivity is also explained.

A review of the TRD equipment proposed by five of the main manufacturers is finally done.

INTRODUCTION

The measurement of water content in soils is necessary to estimate the plants uptake, the recharge of the ground water, solute transport through the unsaturated zone with salt or pollutants transport, and surface wetness witch is known to be an important factor in surface runoff evaluation.

The main methods used for soil water measurements are classical gravimetric technique, neutron probe, and dielectric methods.

The oldest is the gravimetric method witch remains the reference. It don't needs technology but human time, repetitive measurements are impossible on short time periods, neither on the same location.

The neutron probe method is easy to use and fast for repetitive measurements but actually radioactive elements use is under sever controls. It is one of the reasons why electric methods, already known, have been developed.

Capacitive probes have been developed (Tran Ngoc lan, 1970; Wobschall, 1978 et Fumanal et al., 1989 Gaudu et al., 1993). They allow measurements in small volumes of soil but need to include temperature correction and an electronic circuit to compensate the electrical conductivity of the soil solution influence on permitivity.

Time Domain methods measure the time a fast pulse edge takes to travel along a section of transmission line. Two methods can be used,

For Time Domain Transmissometry (TDT), the pulse is observed at the other end of the transmission line from the transmitter, and the time measured is a one-way propagation time.

For Time Domain Reflectometry (TDR), the transmitted signal is reflected from some impedance discontinuity in the transmission line and superimposed on the same end of the transmission line as the transmitter. The time measured is a two-way time.

Fellner-Feldegg (1969) used TDR for measuring the dielectric constant in liquids. The Time Domain Reflectometry has been developed in the late 1970's by Davis and Chudobiak (1975) and Schmugge et al., (1980). Topp et al. (1980) Introduced this technique for soil moisture measurements. Signal processing from the same probe allows also to have simultaneously a measurement of the apparent electrical conductivity of soil. TDR is a relatively new technique now proposed by several manufacturers it can be useful to have a look on the principle of this technique and on the different items proposed by the main manufacturers.

TDR allows all equipment to be at one end of the transmission. TDT, on the other hand, requires an electrical connection at both ends of the transmission line, but the signal received is simpler to analyze, allowing for less expensive equipment. Most of the proposed equipments are based on TDR technology, but ESI's Gro·Point™ is based on TDT technology.

1 - THEORY OF THE TIME DOMAIN REFLECTOMETRY

Originally the Time Domain Reflectometry was only used to detect defaults in transmission lines and cables. A voltage pulse is injected into the cables. The pulse propagates along the cables as an electromagnetic signal in the frequency range of 1 MHz to 1Ghz. In coaxial lines the electromagnetic field is inside the cable. In parallel lines, the field is both between and around the cables. The pulse shape and the transit time depend on the cable properties, length and the termination of the cable where the signal is reflected. A TDR equipment typically consists of a 2 or 3 rods transmission line, a coaxial connecting cable and a TDR instrument to generate fast-rise-time pulses and to measure times. A probe is considered to consist of the transmission line and any structure or component between the transmission line and the connecting cable.

The TDR technique is based on the measure of the velocity v of an electromagnetic wave in the soil. This velocity depends on the dielectric constant of the soil and the dielectric constant mainly depends on the water content of this soil.

Velocity in soil

Velocity in vacuum

$$v = \frac{c_0}{\sqrt{\varepsilon_r \cdot \mu_r}} \qquad [1]$$

Dielectric constant of soil

Magnetic permeability = 1 for non magnetic materials

The large difference between the dielectric constant of water, about 80, and air (about 1) or dry soil (between 2 to 5) is the reason why the dielectric constant of a moist soil is highly dependent on his water content.

V must be measured in order to determine the dielectric constant.
Velocity measurement is transformed to a transit time measurement, t : the wave travels along the 2 or 3 rods of the probe with the length ***l***, is reflected at the end, and comes back.

So the velocity **v** is known by the measurement of the transit time ***t***

velocity

$$v = \frac{2l}{t} \qquad [2]$$

transit time

Rearranging Eq. 1 and 2 gives

$$\sqrt{K_a} = \frac{c_0 t}{2l} \qquad [3]$$

With $K_a = M_r . :_r$

$K_a = M_r$ is also called apparent dielectric constant of the medium or permitivity, as μ_r equals 1 in non magnetic materials as soils.

This transit time t is determined from the TDR waveform (Fig. 1).

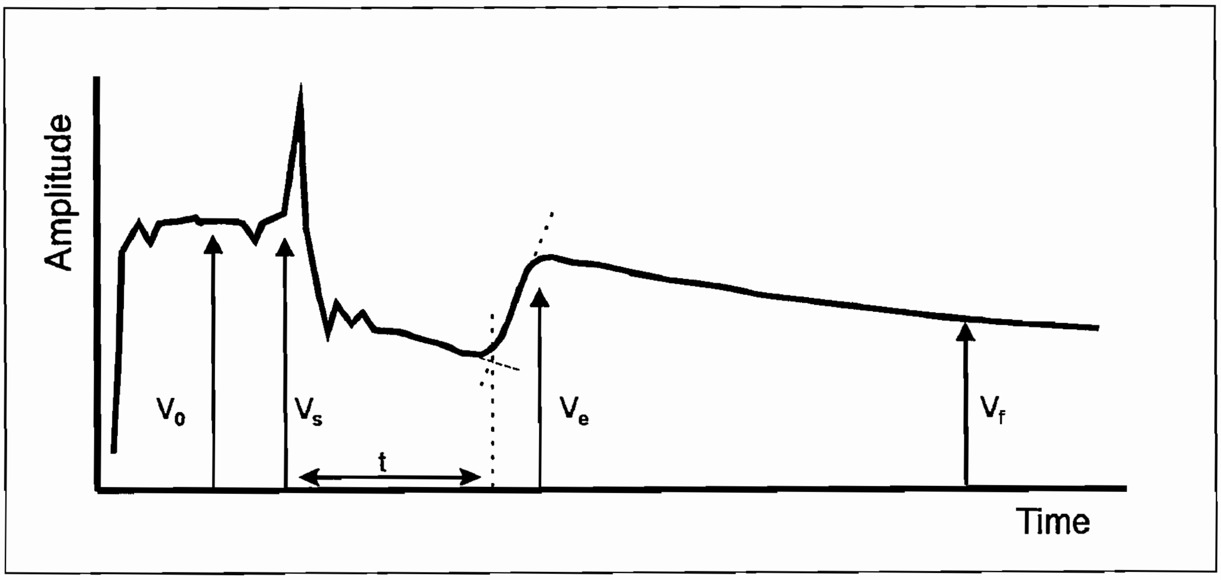


Fig. 1 : schematic TDR waveform

For a 15 cm long TDR probe the difference between the transit time in air (t_a) and in water (t_w) is only 8 ns.

$$t = \frac{2l}{c_o} \cdot \sqrt{\varepsilon_r} \qquad [4]$$

With

$$tw = \frac{0.3m}{3.10^8 ms^{-1}} \cdot \sqrt{81} = 9 \quad ns \qquad ta = \frac{0.3m}{3.10^8 ms^{-1}} \cdot \sqrt{1} = 1 \quad ns$$

So short transit times to be measured introduces two major constrains: the use of a specific high frequency electronic device and a minimum length of 15 to 20 cm for the probe rods.

Four significant voltage values can be determined from the TDR Trace (fig. 1):
V_0 : the amplitude of the TDR pulse
V_s : the amplitude after reflection from the beginning of the probe
V_e : the amplitude after reflection from the end of the probe
V_f : the reflected signal after a very long time

Transit time is used to determine water content, and many researchers have also derived relationships between the attenuation of the signal and bulk electrical conductivity (Dalton et al., 1984; Topp et al., 1988; Yanuka et al., 1988; Nadler et al., 1991; Heimovaara et al., 1995, Persson M., 1997 etc...).

2 - DIELECTRIC MODELS FOR SOIL WATER CONTENT MEASUREMENT

Several models have been developed to estimate the dielectric properties of wet soil for establishing relationships to water content.

- Polynomial equation

In 1969 Fellner-Feldegg used TDR for measuring the dielectric constant of liquids. In 1980, Topp, Davis and Annan based their method on the work of Fellner-Feldegg and introduced TDR for the measurement of soil moisture (Topp et al., 1980) ; They measured the apparent dielectric constant ε_r of a large number of soils and related it to volumetric water content Θ_v using an empirical third-order polynomial equation.

$$\varepsilon_r = 3.03 + 9.3\theta_v + 146\theta_v^2 - 76.7\theta_v^3$$

Or

$$\Theta_v = -5.3\ 10^{-2} + 2.92\ 10^{-2}\,\varepsilon_r - 5.5\ 10^{-4}\,\varepsilon_r^{\,2} + 4.3\ 10^{-6}\,\varepsilon_r^{\,3} \qquad [5]$$

Most of the researchers found it appropriate for their soils, but it is also possible to fit a relationship by a specific calibration. Two ways are used :

Some researchers use this “universal” equation but expressed it with their own constants, others calculate calibration curve for mineral and organic soils (Roth et al., 1992) and i.e. Jacobsen and Schjønning (1993) includes organic matter, clay content and dry bulk density to improve the calibration.

In 1995, Jacobsen and Schjønning made a review of various empirical equations and mixing models and suggested that the calibration of Topp et al. (1980) might be the first choice if the accuracy of ± 0.02 – 0.03 $m^3.m^{-3}$ was acceptable.

Malicki et al. (1996), proposed a general calibration including soil bulk density $>_s$

$$\theta = \frac{(K^{-0.5} - 0.819 - 0.168\rho_s - 0.159\rho_s^2)}{(7.17 + 1.18\rho_s)} \qquad [6]$$

they tested it in a wide range of bulk densities (0.13 to 2.67) and organic carbon content (0-487 g/kg).This calibration reduces the variance to one firth of the I estimates with a standard calibration. Jacobsen and Schjønning (1993) reported that for their own equation, influence of bulk density was demonstrated in laboratory but not in the field.

- Dielectric mixing models

Dielectric mixing models are also used by some researchers. A review can be find in Jacobsen and Schjonning (1995) and Persson M. (1997). They consider that the wet soil is a two or three phases system with soil matrix, water and air and calculate the bulk dielectric constant from the dielectric properties and volume of each fraction.

Birchak et al. (1974) produce a semi-empirical α model where Θ_i and K_i are the volume fraction and dielectric permittivity of phase i and α is a soil geometry parameter.

$$K^{\alpha} = \sum_{i} \theta_{i} K_{i}^{\alpha} \qquad [6]$$

for a three phases system (air, water and soil matrix) α is about 0.5 and then it results a linear relationship between $K^{0.5}$ and soil water content (Ledieu et al., 1986).

Roth et al. (1990) produce a two phases model where K_0 is dry soil permittivity, K_a wet soil permittivity and K_e water permittivity.

$$\Theta = (K_a^k - K_0^k) / (K_e^k - K_0^k) \qquad [7]$$

with $K_0 = 2.3$ $K_e = 80$ and $k = 0.637$

Ferré et al. (1996) Establish an other relationship

$$\Theta = e \sqrt{K_a} + f \qquad [8]$$

with $e = 1 / (K_e^k - K_0^k) = 0.118$ and $f = - K_0^k / (K_e^k - K_0^k) = - 0.814$ if $k = 0.5$

Ruelle et al. (2000) compared Topp third-order equation, with Ferré and Roth mixing models and show that these three relationships are not significantly different for the range of water moisture in agricultural soils (fig. 2).

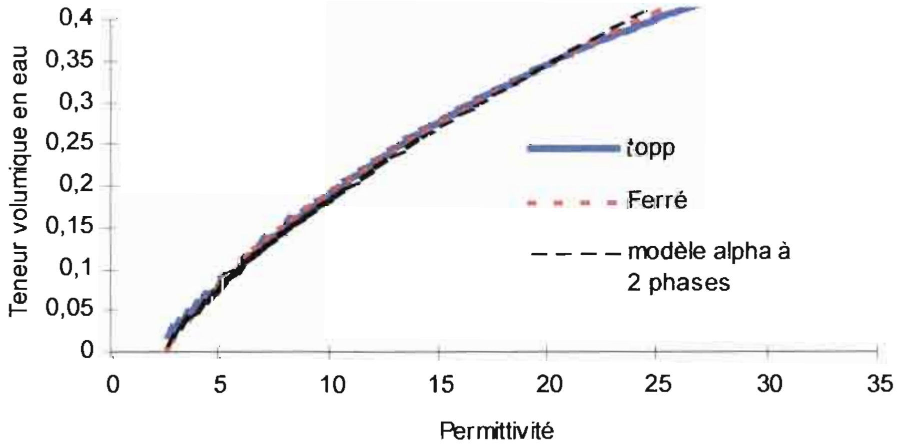


Fig. 2 : Topp third-order equation compared to Ferré and Roth mixing models (in Ruelle et al., 2000).

TDR probes with 2 or 3 rods are now also used to measure soil solution electrical conductivity for transient conditions with varying water content. This application allows also non destructive measurements of solute transport in the unsaturated zone (Persson M., 1997; Persson M. and Berndtsson R., 1998b).

- Medium characteristics influences on soil water measurements

Topp et al (1980) tested their calibration equation under different conditions of soil texture (sandy loam to clay), bulk density (1.14 to 1.44), temperature (10 – 36 °C), and salinity (non saline water, 2.10^3ppm NaCl, 10^{-2} N $CaSO_4$). They found that, under these conditions, K was not very sensitive to theses parameters.
Numerous authors have confirmed the calibration equation by Topp and Davis (1980), in various textural soil including Fe-rich volcanic soils (Grantz et al, 1990) and even under salinity conditions (Nadler et al., 1991).

But when the temperature increases from 1 to 40 °C, K increases from 10% (Davis, Chudobiak, 1975). Persson et al. (1998) studied temperature dependency in Time Domain Reflectometry and concluded that for water content measurements, it depends of soil texture and electrical conductivity. For sandy soils they suggest a temperature correction of – 0.00269 $6°C^{-1}$: 6 decreases when T°C increases. In clay and organic soils the temperature dependence is smaller and can, depending of soil bulk electrical conductivity, be negative or positive. But errors due to temperature changes are small compared with differences in soil properties for different probe locations. If high accuracy is needed, specially when measuring the relatives changes, e.g. between day and night for top soil layer, the temperature effect must be accounted for.

For organic matter, I is underestimated using the Topp and Davis equation (Herkelrath et al., 1991, Pepin et al., 1992) but Malicki et al. (1996) reported that it was overcome by accounting for bulk density or porosity.

For salinity, it is also said that I is overestimated by the Topp and Davis equation in soils moistened by saline water (Dalton et al.,1986, Noborio et al.,1994).

For layered soil, it was investigated by Topp et al. (1982a,b). For layers perpendicular to the TDR probe they propose a weight average of water content where z_i is the thickness of layer, I_i the volumetric water content of layer i and n the number of layers.

$$\theta = \frac{\sum_{i=1}^{n} zi\theta i}{\sum_{i=1}^{n} zi} \qquad [9]$$

But when a very wet layer is under a very dry one, it seems difficult to interprete the waveforms (Nadler et al., 1991).

3 - THE MEASUREMENT OF APPARENT ELECTRICAL CONDUCTIVITY OF SOIL

- Principle of the measurement

It has been seen (fig.1) that four significant voltage values can be determinate from a TDR trace:

V_0 : the amplitude of the TDR pulse
V_s : the amplitude after reflection from the start of the probe
V_e : the amplitude after reflection from the end of the probe
V_f : the reflected signal after a very long time

The attenuation of the signal can be used to determine soil bulk electrical conductivity. Numerous methods have been proposed by researchers and the most suitable (Nadler et al, 1991) seems to be the procedure of Dalton et al (1984).

$$\sigma_{\mathrm{dalton}} = \left(K_a^{1/2} / 120\pi L\right) \ln\left(V_t / (V_e - V_t)\right) \qquad [\,10\,]$$

But as concentration of the solution increases, the amplitude of the reflected signal decreases and can become indistinguishable because of waveform distortions due to loss of high frequencies.
The Giese and Tiemann (1975) method is an alternative procedure to determine electrical conductivity, not using the reflected voltage V_r.

$$\sigma_{G-T} = \left(\frac{K_P}{Z_L}\right)\left(\frac{1-\rho_f}{1+\rho_f}\right) \qquad [\,11\,]$$

K_p is the geometric constant of the probe (m^{-1}), Z_L is the characteristic impedance load of the transmission line (*) and $>_f = (V_f - V_0)/V_0$ (fig. 1).
K_p is experimentally determined by immersing the probe in solutions of known electrical conductivity N_t at T°C

$$K_p = \sigma_{\mathrm{ref}}(25°C) Z_L f_T \qquad [\,12\,]$$

f_T is a temperature correction coefficient

$$f_T = 1 + K_T(T - 25) \qquad [\,13\,]$$

K_T depends of the used solution: $K_T = 0.0191$ for a 0.01 M KCl solution

- Medium characteristics influences on bulk electrical measurements

Persson et al. (1998) have investigated the temperature dependence of the bulk electrical conductivity using a wide range of soil types and bulk electrical conductivities (sand, loamy sand, montmorillonite clay soil and even peat soil and Bulk electrical conductivities of wet soil from 0 to 1.2 dSm^{-1}). They found that it was very close to the temperature dependence of the soil extract. The temperature effect is independent of soil texture and then can be corrected for all soils using Eq. [13] with $K_T = 0.0191$.

4 - SIGNAL PROCESSING

- Classical methods

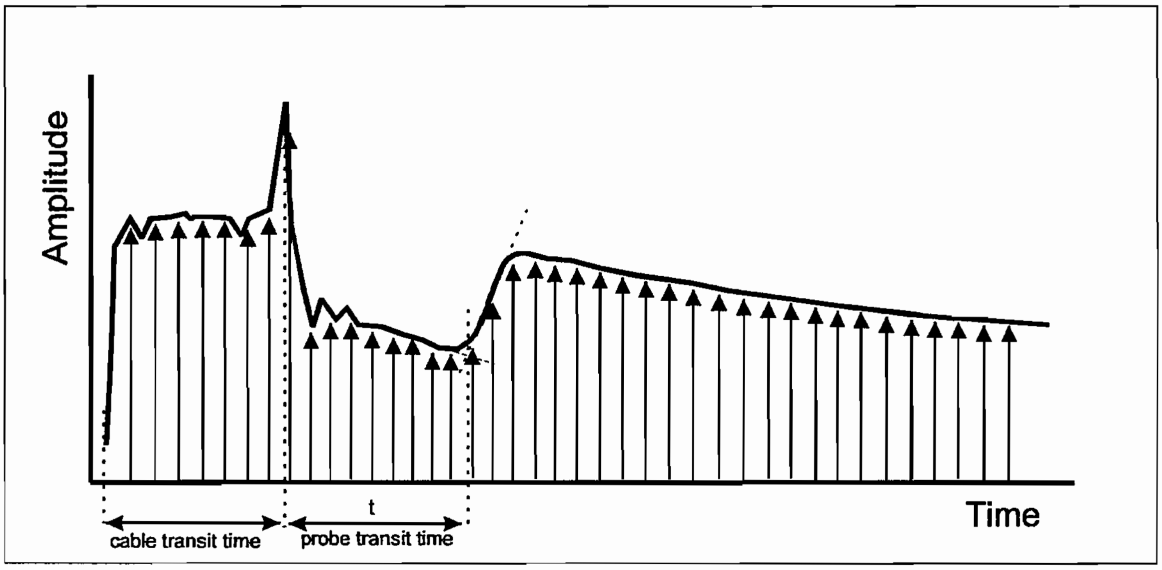


Fig. 3 : Classical TDR-pulse signal measurement (sampling technique)

The reflected TDR pulse is scanned by the sampling method. Each point of the pulse signal is measured as a voltage value at a distinct time. The transit time is graphically derived from the voltage signal (fig. 3).
That needs very expensive high frequency electronic components: a high frequency pulse generator and a high frequency oscilloscope.
The cable testers (e.g.Tektronix1502C) where the first devices based on this method but they are not really designed for measurements in rough environments. Here the y axis is defined as the ratio r of the amplitude of the reflected signal from a cable to the amplitude of the applied signal. If there is an open circuit in the cable, r = +1. If there is a short circuit, the signal is reflected through the soil with an opposite polarity and r = -1. So for measurements with TDR probes connected to a cable tester r is usually between –1 and +1. Different ways are used to find the reflection points of the signal. The initial reflection point is usually found by immersing the probe in water or in air (Heimovaara, 1993). Baker and Allmaras (1990) explain with details the way to find these points using a computer.
The TRASE system (Soil Moisture Eq. Corp., Santa Barbara, California) is based on a cable tester equipment but especially designed for soil moisture measurements.

The evaluation of the probe transit-time part of the curve is difficult for low water contents or short TDR-probes rods.
But this method allows to visualise full TDR waveforms which can be very useful to search physical interpretation of problematic results.

Fundinger et al. (1995) applied for IMKO GmbH a specially design TDR-technique to measure material moisture, the Time Domain Reflectometry with Intelligent Micromodule Elements (TRIME-Method).

- IMKO Gmbh TRIME method for moisture measurement

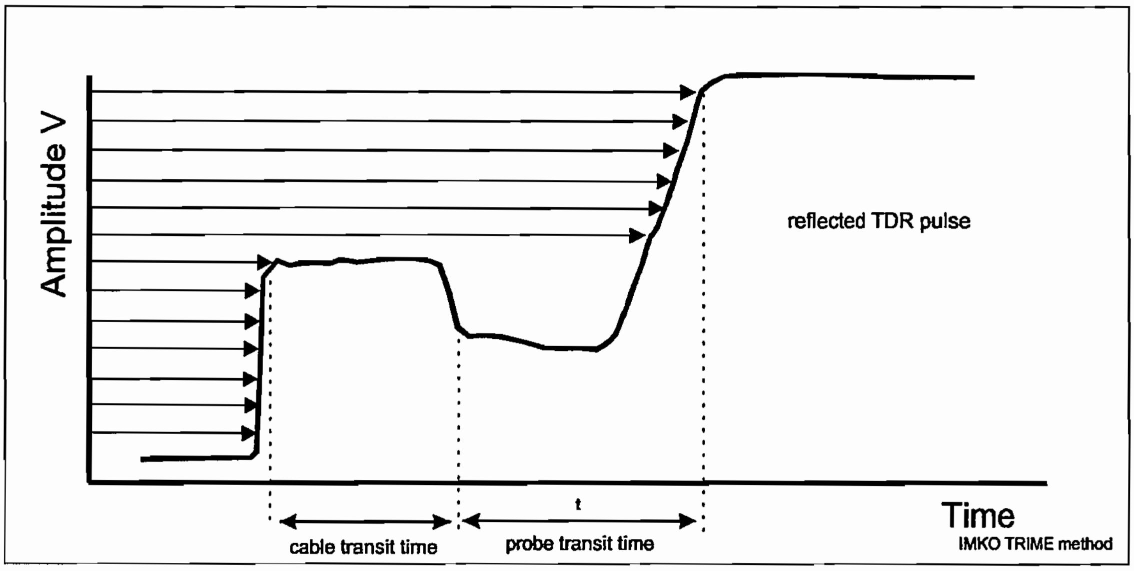


Fig. 4 : TDR pulse measurement with the TRIME Method (IMKO GmbH)

With this method, the points of the TDR pulse are determined by direct time measurements at distinct voltage levels.
This requires another pulse shape with a high amplitude of the reflected pulse and a reduction of the attenuation (fig. 4).
This shape is allowed by a suitable impedance matching between pulse generation output, the connecting cable and the probe. The coating of the rods with PVC is the second important measure to get this kind of signal:

- low frequencies are blocked
- only high frequencies (>> 300MHz) travel through the soil and can be attenuated.

Thus the total attenuation is reduced and the amplitude of the reflected pulse is higher.

The start of the generator switches on a counter and the counter is stopped when the voltage comparator detects the first reflection at the end of the probe.
A special algorithm derives the amplitude of the reflected pulse from measurements of particular points of the curve. When the amplitude, which depends of the electrical conductivity of the soil, has been determined, the transit time t_p is measured at the corresponding voltage. This gives short measurement times and low power consumption.

Because of averaging of many measurements, transit time can be known with a resolution of 3 ps. This allows also to work with short rods and with low water contents.
But with this system it is not possible to visualise the TDR wave. Particular calibrations are possible but in some cases (high clay soils) it is out of range of the inside standard curve and an error message is displayed.

- IMKO Gmbh TRIME method for electrical conductivity measurements

Because of his particular algorithm, the transmitted voltage of the TRIME voltage pulse cannot be determinated, making a determination of the bulk soil conductivity impossible with Eq. 10. As there is an offset in the amplitude range between the different TRIME probes and an offset between sandy and clay soils, a material-specific calibration is needed. It is possible to calibrate a relationship between the TRIME amplitude display and the bulk electrical conductivity of the medium using a conductometer for aqueous solutions and the four-electrodes technique measurements for solid materials. The calibration curve for the medium is then established using an exponential regression function.

5 – PROBES DESIGN

Most of the probes are two or three rods type. Some others are design for surface measurements, others to be introduced in access tubes. Noborio (2001) made a good review about design and installation of TDR probes. Laurent et al. (2001) studied the use of TDR Trime –tube system.
Davis introduced the two wire probe with an impedance matching transformer (in Noborio, 2001), but Spaans and Baker (1993) considered that an ordinal matching transformer is not suitable for electrical conductivity measurements (because the amplitude of the reflected signal decrease due to low frequencies attenuation). Yet an ordinal matching transformer with a 200 Ω TV antenna cable did not affect electrical conductivity measurements (Kachanovski et al., 1992, Ferré et al., 1998).
Three-wire type probes doesn't need an impedance-matching transformer and give simpler waveforms with a more distinct reflection wave and a better determination of travel time witch is suitable for measurements in saline conditions, but the reflection signal from the beginning of the probe differs in very dry and very wet soils.
Rectangular and flat probes have also been developed for surface measurements (Selker et al., 1993). Multipurpose TDR probes have also been developed, to measure simultaneously water content, heat capacity and thermal conductivity of soils (Noborio et al., 1996 , Ren et al. 1999).
Probes are generally stainless steel made, and the minimum probe length is between 0.1 to 0.2 m for a 20 – 25 m cable length. The use of 200 Ω TV antenna needs impedance-matching transformer cable but not for 50 or 75 Ω coaxial cable Yet for EC measurements it is important to have the same impedance between the cable tester output and the cable of the probe if using Eq. 11 (Giese – Tiemann 1975).
To minimise the skin effect around the rods Knight (1992) suggested that for two or three rods probes, d/s = 0.1 (with d diameter and s spacing) and Petersen et al. decreased to d/s = 0.02.
Effect of air gap: air gap around the rods can introduce errors of K measurements (Annan, 1977, Ferré et al., 1996), but EC is insensitive to quality of contacts between the rods and the soil (Nadler et al., 1991). Air gap surrounding less than 1/12 of rods circumference has no significant effect on the dielectric constant measurement, but three rods probes seems to be more sensitive to air gap than two rods ones (Knight et al., 1997). But Whalley (1993) found no difference about air gap.
Effect of pilot holes: there is a packing of the soil around the directly pushed probe (5 to 25% of increasing bulk density) witch contributes to lower water content readings compared to probe installed with pilot holes (Rothe et al., 1997).

Effect of cracks: Studied by Hokett et- al., (1992), in dry soil, air-filled cracks have only a small effect, but in wet soil measured water content can be reduced to 46%. On the over end, water-filled cracks effect is small in dry or wet soil.

Spatial sensitivity: sensitivity ends abruptly at the end of the electrodes. Water content near the soil surface is measurable with well fitted spacing designed TDR probes. Petersen et al.(1995) used a 2 cm spacing rods probe to measure θ as close as 1.5 cm from the surface and Nielsen et al. (1995) at 2.5 cm from the surface with a two-rods probe, with 5 cm between the rods. For a tube access probe with 44 mm diameter, the penetration depth is about 100 mm and 50 mm with a 44 mm probe (IMKO GmbH, 2000).

Pictures from Web sites

6 – DEVICES FOR FIELD MEASUREMENTS

IMKO MICROMODULTECHNIK GMBH **IMKO GmbH, Ettlingen**

TRIME FM 2 or 3

Picture from:www.imko.de

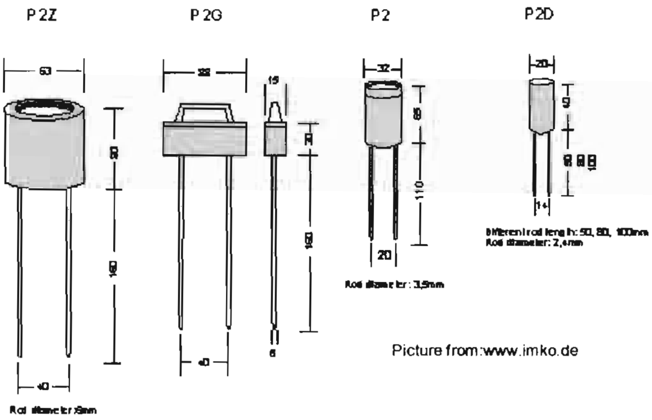
The TRIME-FM is a truly portable field-measuring Device for % volumetric moisture measurement

TRIME-FM2 version is for 2-rod probes

TRIME-FM3 version for all other TRIME probe types

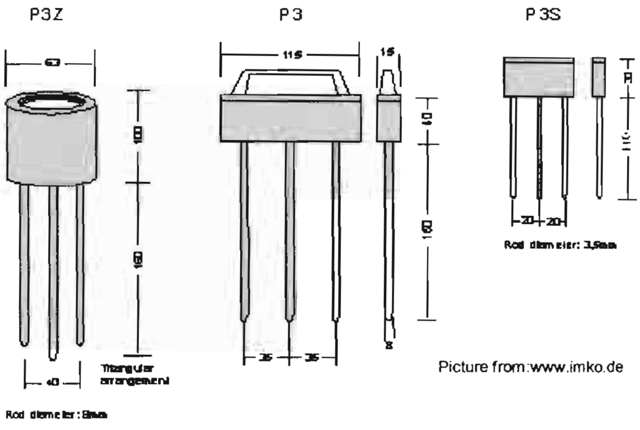
Display fonctions :
- **moisture %**
- **TDR level signal**
- **error messages**
- **battery level**

P2 rods family



Picture from:www.imko.de

P3 rods family



Picture from:www.imko.de

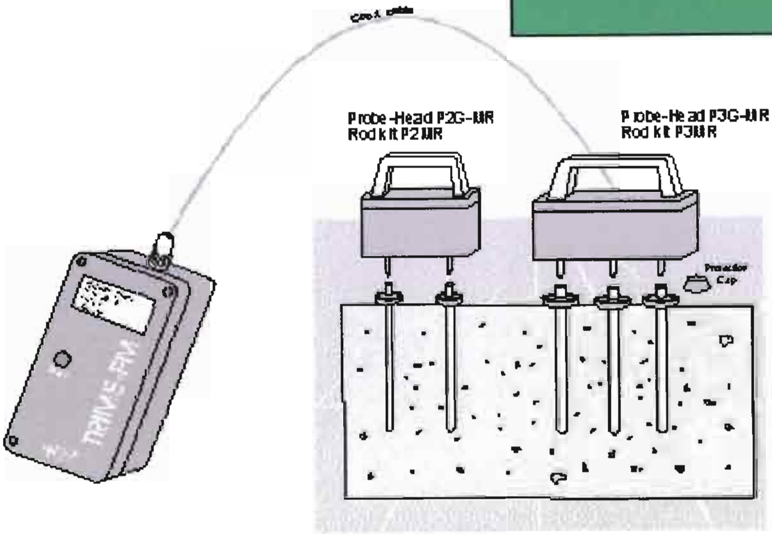
All rods are PVC coated to achieve the best measuring results

Bulk soil electrical conductivity up to 2 dS/m

For salinities up to 10 dS/m, special probes (C-versions) are available.

Multi-Rod-Probe-Head

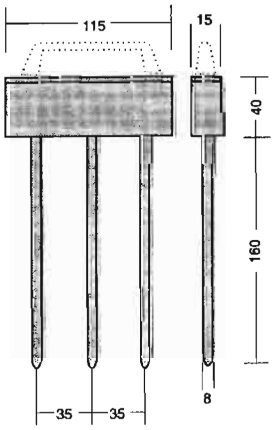
**To monitor moisture
in exactly the same location
at multiple sites**



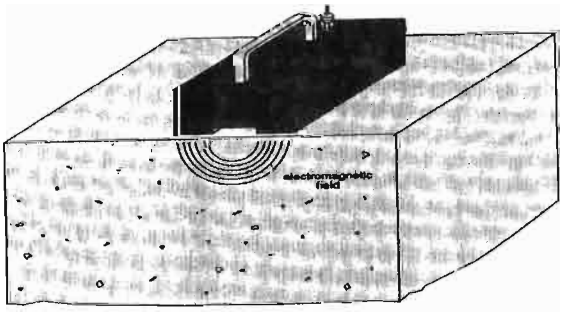
Dimensions of probe head and rods equivalent to P2G an P3G

Surface probes measurements

3-Rod
Probe
P3



For layer and surface



Pictures from:www.imko.de

TRIME T3

Picture from:www.imko.de

A TRIME TDR Device for vertical

Probe is designed to measure from the inside of the special TECANAT plastic access tubes

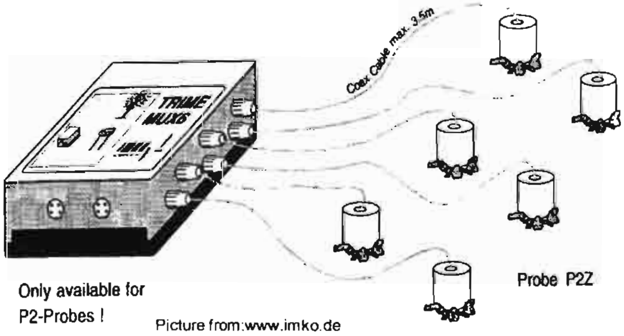
Measuring volume:
- vertical height, 15 cm
- soil penetration, 15 cm

Accuracy:
- +:- 2% vol.
- bulk soil electrical conductivity up to

DATA LOGGER

1 - HP Laptop-PC including PCMCIA Sram card
and a software for:
- the management of the measuring circuit
- the storage of the data

TRIME MUX 6 for multiplexing



Only available for
P2-Probes !

Picture from:www.imko.de

2 - New TRIME-Logger
- 70 000 measurements and external power supply
- programming and collecting out data via a RS 232 serial port
- with a laptop PC and the logger software under MS-Windows

CAMPBELL
SCIENTIFIC, INC.

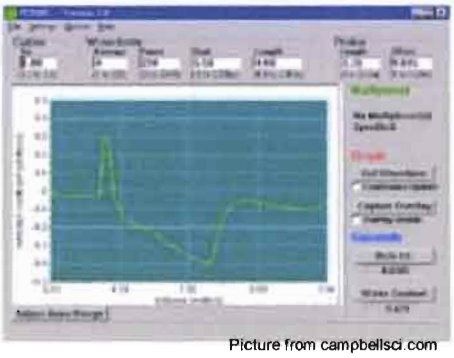
TDR System

Picture from campbellsci.com

Principal components of a TDR system:

- CSI datalogger,
- TDR100 Reflectometer,
- SDMX50-series coaxial multiplexers,
- interconnecting cabling,
- and TDR probes

PCTDR Windows Software



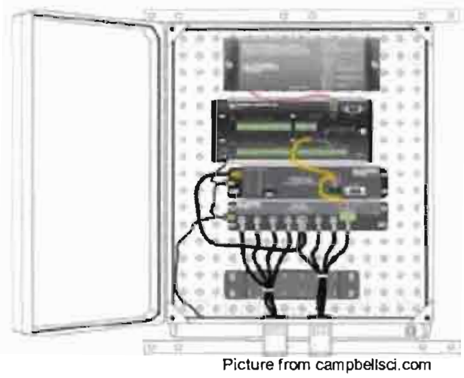
Picture from campbellsci.com

TDR100 Time Domain Reflectometer

Picture from campbellsci.com

- Determines volumetric water content and electrical conductivity in soil and other porous media
- Communicates with SDMX50-series coaxial multiplexers using SDM protocol CR10X and CR23X dataloggers
- Can be used in rock-mass deformation applications

SDMX50-Series Multiplexers



Picture from campbellsci.com

- Eight-channel coaxial switching devices
- Three levels of switching allows up to 512 soil water content or rock mass deformation cables to be connected to one TDR100

TDR Probes for external acquisition


CS

3-rod design
- 30 cm long, 0.48 cm diameter,
and 4.5 cm spacing between outer rods
- RG58 cable with maximum of 15 m length


CS 610

3-rod design
- 30 cm long, 0.48 cm diameter,
and 4.5 cm spacing between outer rods
- RG8 cable with maximum cable length of 25m.

TDR Probes with internal software


CS 615

CS615 L
- a self-contained water content sensor that uses
high-speed electronics in the body of the sensor
- measurement of the square wave by a datalogger's single-ended channel

Hydrosens

HydroSense consists of a probe and output display
- for portable volumetric water content measurements
- provides immediate soil water content readings.
- powered only by 2 AA batteries.

Pictures from campbellsci.com

SOILMOISTURE EQUIPMENT CORP.

TRASE system

System I:

- **a self-contained, portable unit for field use**
- **commands are entered via a key pad**
- **data are output on a display screen**
- **rechargeable battery pack**

Trase BE:

- **for use in stationary location**
- **electrical power from AC source or external battery**

Wave guides (from 15 to 65 cm long):

- **standard wave guide connector, for interchange of wave guide rods**
- **Slammer, a portable wave guide connector for heavy duty field use**
- **buriable wave guide, to be installed permanently**

Multiplexers:

- **16 channels TDR switching board**

TRASE System 1

Picture from Eijkelkamp brochure guide

Tektronix
Enabling Innovation


Picture from WWW.tektronix.com

1502c Metallic cable

Generally used to detect defaults in cables

- It is a TDR generator and analyser device
- it transmits electrical pulses down the cable under test
- the pulse energy is reflected back to the MTDR
- the reflections are displayed on a LCD screen
- waveform storage allows comparisons

Soil Science application

- laboratory experiments
- own hand made probes testing

But his rugged and portable design,

...... allows also field use

here connected to a Campbell probe and a Toshiba computer

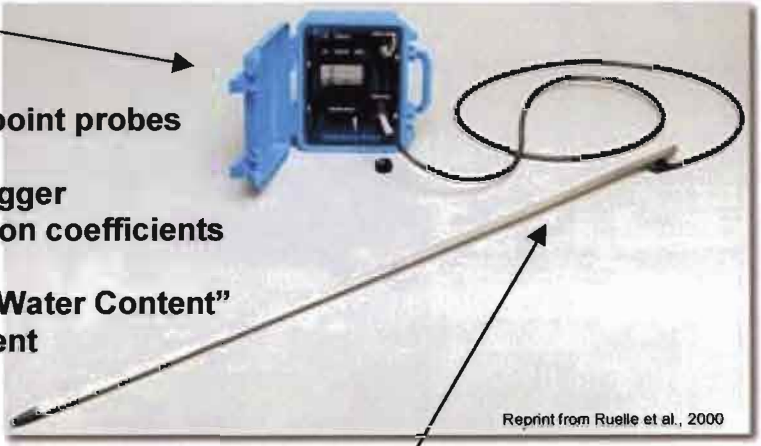

El Gouazine Watershed

Photo : P. Zante

esi ENVIRONMENTAL SENSORS INC.

MOISTURE·POINT® a TDR Technology

THE MP-917 Instrument for viewing and logging


Reprint from Ruelle et al., 2000

- Design to interrogate moisture point probes
- Display data retrieved
- Export data received to a datalogger
- Pre-loaded with factory calibration coefficients

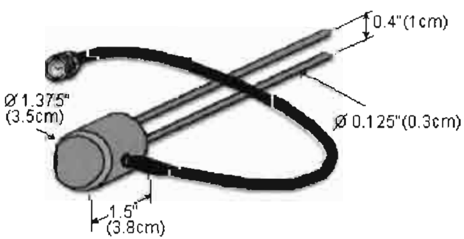
Displays an average "volumetric Water Content" along each probe or probe segment

View-point software for changing instruments parameters

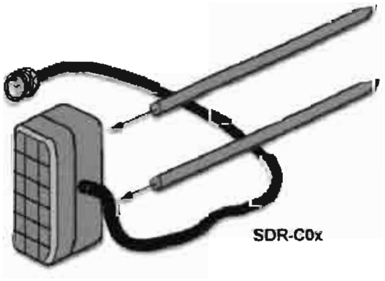
SYSTEM PROBES

- **Profiling probes**
  - **for continuous vertical profiles,**

- **Single Diode Probe**
  - **for 20 or 30 cm** depth measurements



Picture from WWW.esica.com



Picture from WWW.esica.com

GRO • POINT ™ a TDT Technology

Gro-Point use Time Domain Transmissometry
- the pulse is observed at the other end of the transmissior
- it is a one way propagation time measurement
- signal is simpler to analyse
- it is a less expensive equipment
- accuracy: +/- 1% volumetric soil moisture

But,
- it needs an electrical connection at both ends of the line
- it is a superior layer soil moisture measurement tool
- it is mainly used to assist growers, and the sensors are installed in the root zone

Various probes designs

Multi channel Datalogger

- up to 32520 measurements,
- one year life lithium battery
- optional temperature channel

Field data shuttle

- downloads the data
- checks the battery voltage
- can initiate a new measurement

4 Pictures from WWW.esica.com

7 - CONCLUSION

TDR is now an accurate instrument for measurements of solute concentrations in soil (Persson, 1997)
With a single TDR probe it is possible to measure simultaneously,

- Volumetric water content 6, generally calculated with the universal Topp et al. relationship [5]
- Apparent electrical conductivity of soil N_a, calculated with the Dalton or Giese and Tiemann relationship [10] or [11].

The best conditions for an optimum accuracy is found in low clay and organic matter soils with low electrical conductivity. Temperature dependant errors exist, they are small relative to other measurements errors, but they can be take in account.
A large choice of TDR systems is now available and selection depends on the aim of the use. For research purpose, systems with access to waveforms and a good interpreting software is a best choice.
TDR probes must be located not too far from the TRD measurement system, and it needs one probe for each depth measurement point. For surface or subsurface measurements (0 to 15-20 cm) it's quite impossible to drive down a portable probe when the soil becomes too dry. Compared to neutron probe access tubes, it is a great disadvantage especially for agricultural field studies. In these conditions it becomes an expensive solution to follow water and salt variations in a large scale area such as a watershed. TDR system with access tube will be a convenient solution, but it remains the actual air gap problem along the access tube to be avoided. Yet a great advantage for TDR system is to be a non-invasive technique to measure with the same probe simultaneously soil water content and electrical conductivity.

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http://www.campbellsci.com/centers/soil-a.html
http://www.campbellsci.com/tdr.html#probes

- ESI environmental sensors inc.

http://www.esica.com/products/index.html

- IMKO GmbH

http://www.imko.de/mitte.htm

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http://www.soilmoisture.com/prodinfo.htm

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