A.A. 2021-2022

Corso di Laurea Magistrale in GEOSCIENZE

Metodi Elettromagnetici in Geofisica (6 CFU)
- MEMAG -

UD-5: Time Domain Reflectometry
- TDR -

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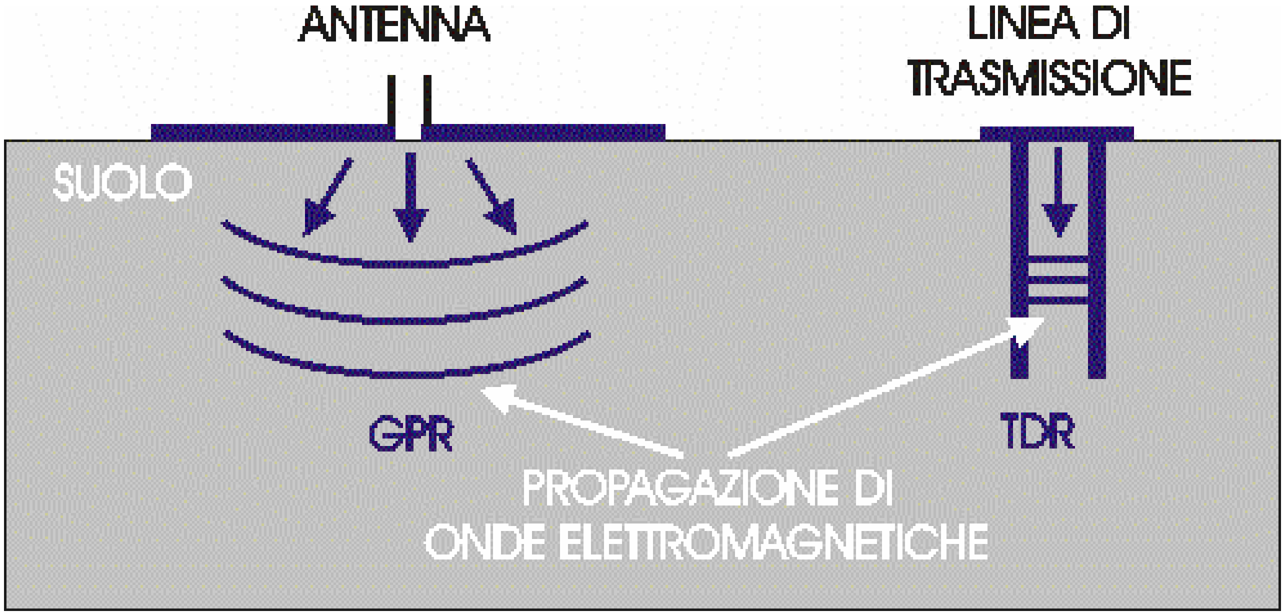
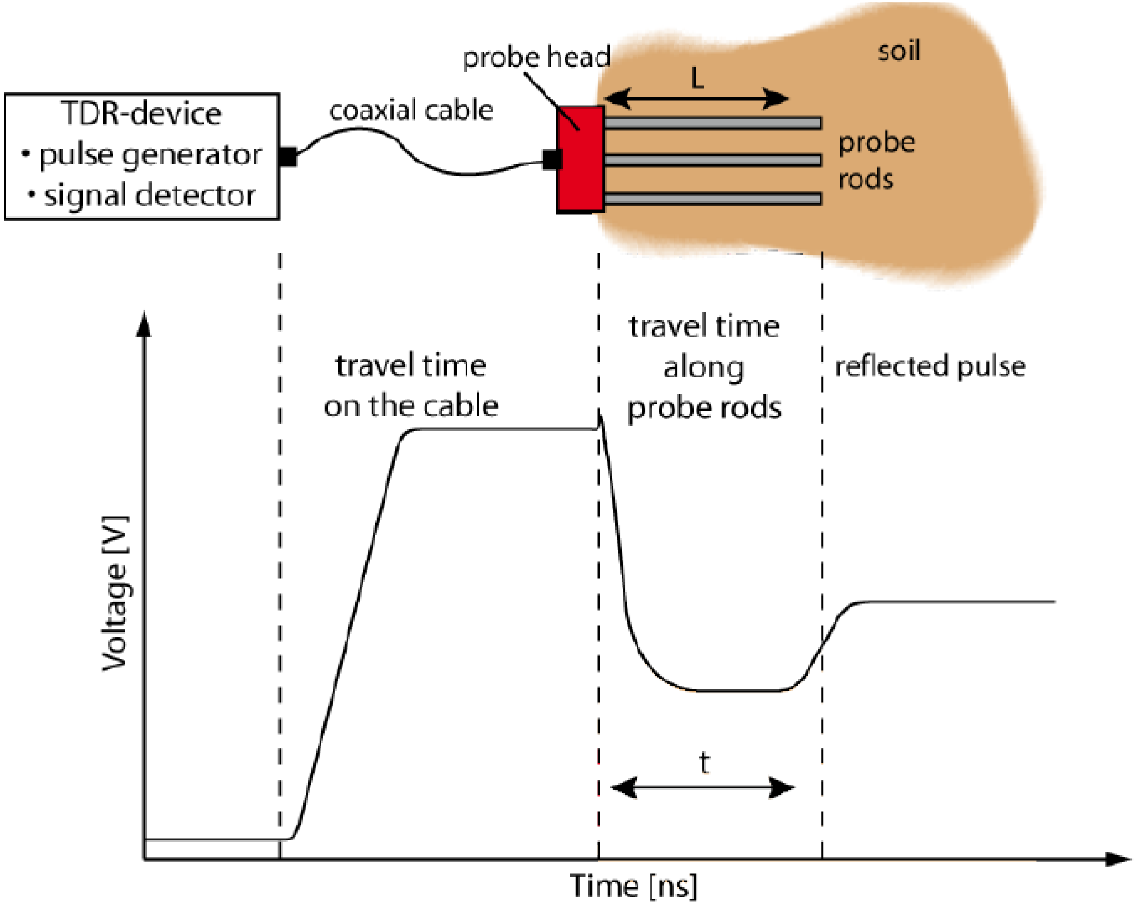
Time Domain Reflectometry - TDR

Time Domain Reflectometry (TDR) is a state-of-the-art method to measure volumetric water content and electrical conductivity of soils. The measurement principle is based on the analysis of the propagation velocity of guided electromagnetic waves along a TDR probe through the ground. It allows to determine the dielectric properties of the medium which are closely related to water content and electrical conductivity.

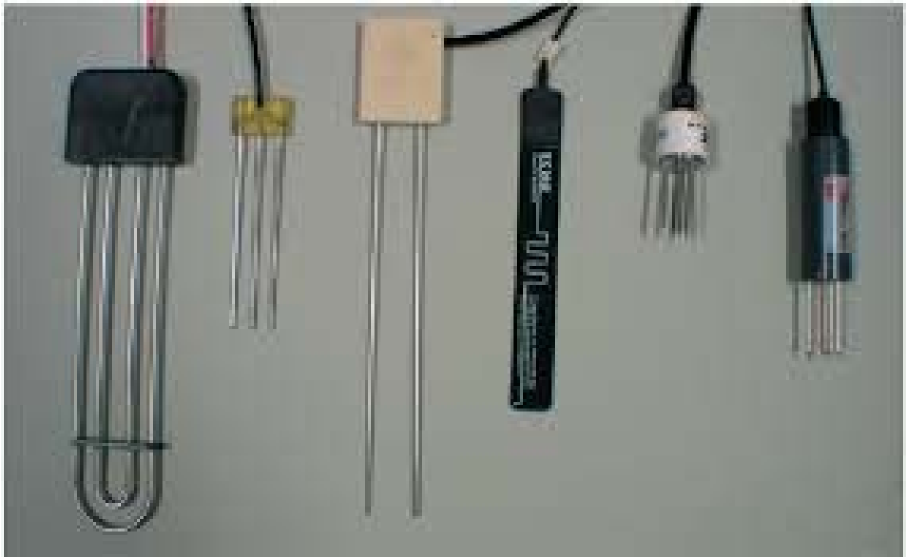


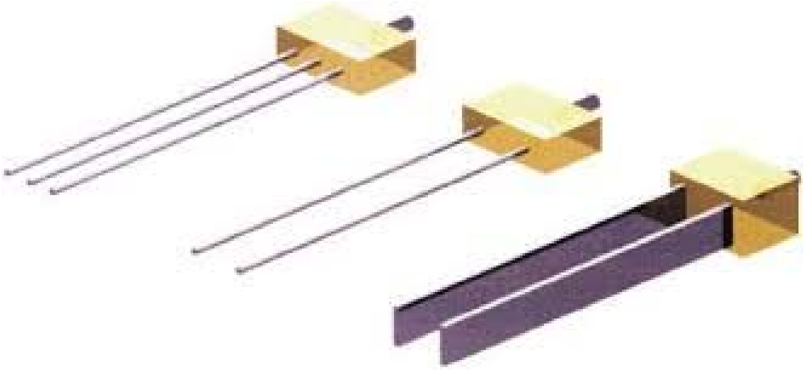
Time Domain Reflectometry - TDR

The measurement principle is based on the measurement of the propagation velocity of a step voltage pulse along a TDR probe through the ground. The probe is installed such, that the metal rods are completely surrounded by the soil material.



Time Domain Reflectometry - TDR





Time Domain Reflectometry - TDR

TDR was initially developed for detecting failures along transmission line cables - TDR devices are also known as “cable testers". The application in soil science is a modification of this technique.

In principle, the probe rods can be regarded as elongation of the coaxial cable where the middle rod is the inner conductor and the outer rods represent the outer conductor of the cable. The TDR device generates short electromagnetic pulses (frequency range: 20 kHz to 1.5 GHz) which propagate along the coaxial cable and further along the rods of the TDR probe. At positions where erratic changes in relative permittivity occur, part of the electromagnetic energy is reflected.

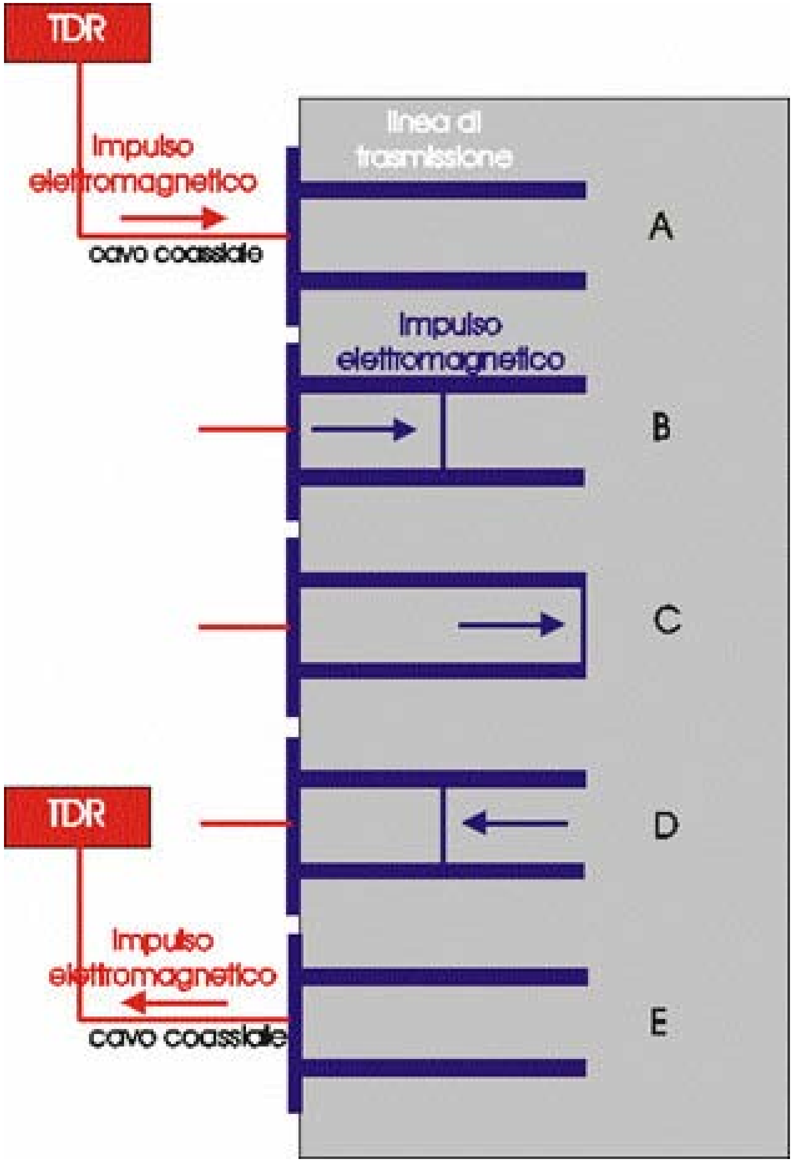
There are different types of TDR instruments with just two on more rods, but the basic principles is always similar.

At the head of the TDR probe, part of the electromagnetic energy is reflected due to the impedance jump between the cable and probe head material.

The remaining fraction of the signal propagates through the soil along the metal rods which serve as a wave guide. At positions where the dielectric properties of the soil change erratically, the signal is again partially reflected. In soils with low electrical conductivity the remaining part of the electromagnetic energy is finally reflected at the end of the probe rods.

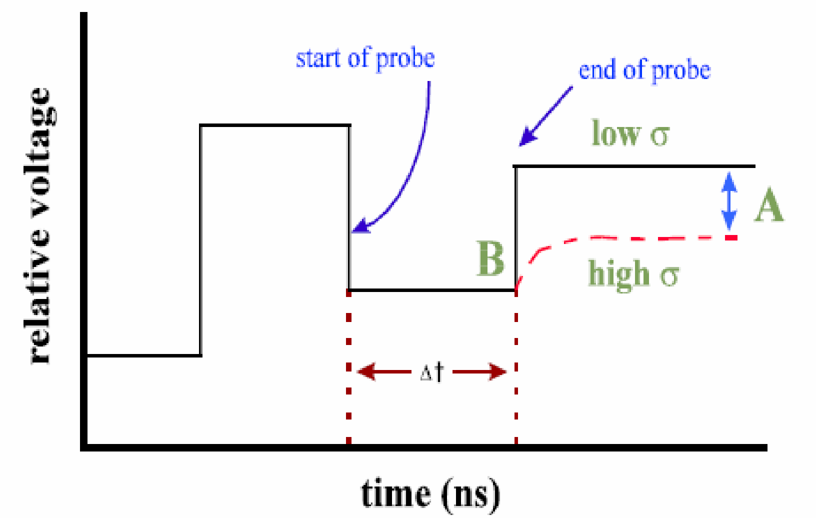
The temporal development of the voltage of the reflected TDR signal is recorded by the signal detector of the TDR device. From the signal response we can deduce the electrical properties of the material through which the electromagnetic pulse propagates.

Time Domain Reflectometry - TDR



Different steps of the EW pulse propagating intro the probing material. The TDR measurements are performed at single points, but several close tests can be done and possibly averaged to be more statistically sound.

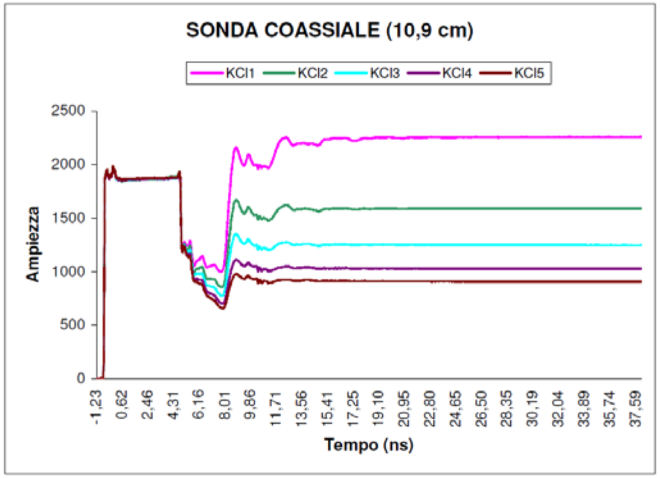
Time Domain Reflectometry - TDR

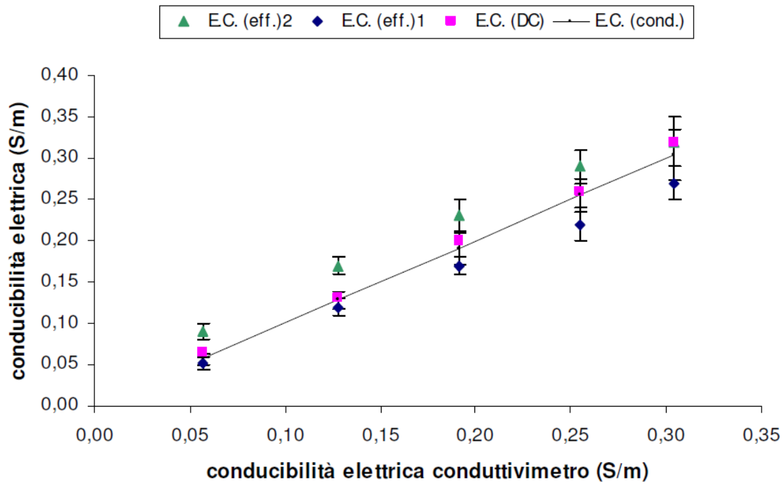


The TDR response must be calibrated on materials with known EM properties.
Such calibrations are related to both:

- **EM velocity ➔** distilled water or air
- **EM attenuation ➔** electrolytic solutions

Example solutions of KCl with molarities between 0.005M (KCL1) and 0.02M (KCL5)
With a coaxial probe of 10cm (From Pettinelli et al., 2008).





The accuracy is always higher for EM velocity (i.e. ε) than for σ.

TDR: Determination of the Relative Dielectric Permittivity

For the determination of the travel time of the electromagnetic signal along the TDR rods through the soil we use the two significant reflections which occur in the head and at the end of the rods of the TDR probe. From these two characteristic points we can deduce the two-way travel time t_{rod} of the electromagnetic signal through the soil: forth to the end of the probe and back to the probe head. With that one obtains the composite relative permittivity of the material which surrounds the probe rods.

$$\varepsilon'_c = \left(\frac{c t_{rod}}{2L}\right)^2$$

where L is the length of the TDR probe rods. The volumetric soil water content is determined from the measured relative permittivity using the CRIM formula (see UD-2b).

$$\theta = \frac{\sqrt{\varepsilon'_c} - \sqrt{\varepsilon'_{\text{matrix}}} - \phi\left(\sqrt{\varepsilon'_{\text{air}}} - \sqrt{\varepsilon'_{\text{matrix}}}\right)}{\sqrt{\varepsilon'_{\text{water}}} - \sqrt{\varepsilon'_{\text{air}}}}$$

Time Domain Reflectometry - TDR

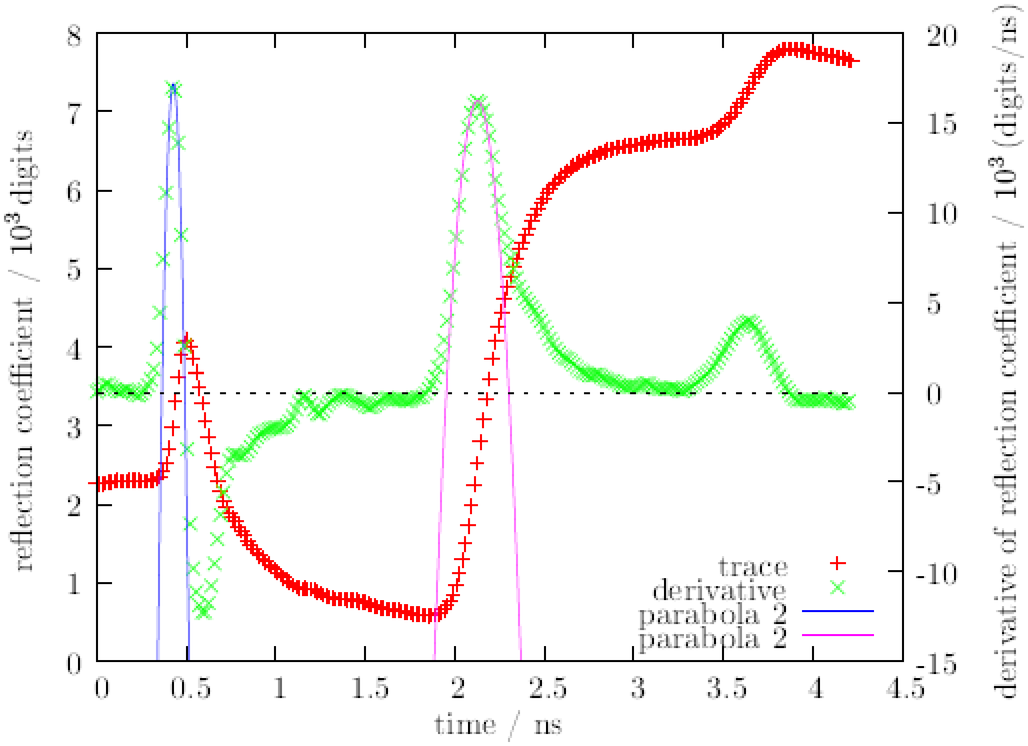
The reflection from the probe head is independent of the material between the probe rods an hence occurs always at the same travel time and serves as a reference in the travel time calculation. The travel time of the reflection from the rod ends depends on the propagation velocity of the electromagnetic wave through the soil. The difference of these two reflection points determines the travel time of the electromagnetic signal forth and back through the soil.

The travel time composes of the travel time through the probe head and along the probe rods

$$t_{probe} = t_{head} + t_{rods}$$

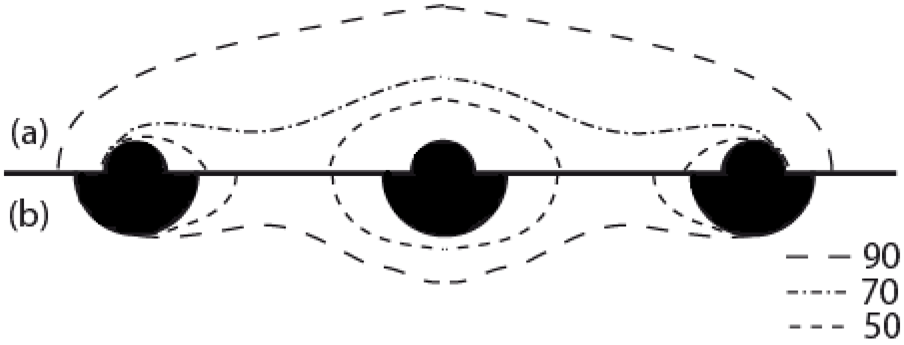
TDR measurements

In practice, the determination of the travel time of the electromagnetic signal is done by using the derivative of the TDR signal and taking the largest values of the derivative occurring at the EM impedance jump in the probe head and at the end of the rod, both taken as reference points.



TDR: measurement volume

The measurement volume of a TDR probe is the volume of soil which has an influence on the measured TDR signal.
The sensitivity of the TDR probe decreases exponentially perpendicular to the rod axes.
The volume fractions shown in Figure 3.3 are determined by the probe geometry and are independent of the permittivity of the surrounding material.
The measurement volume is primarily determined by the diameter and the distance between the probe rods: an increase in rod diameter leads to a smaller measurement volume; a larger rod distance causes a stronger attenuation of the high-frequency components of the TDR signal and hence a smaller measurement volume.



(a) rod distance:rod diameter = 10
(b) rod distance:rod diameter = 5

TDR: electrical conductivity

The DC conductivity (σ_{dc}) of the soil can be determined from the amplitude of the reflected TDR signal

$$\sigma_{\mathrm{dc}} = \frac{K}{Z}\frac{1-R_\infty}{1+R_\infty}$$

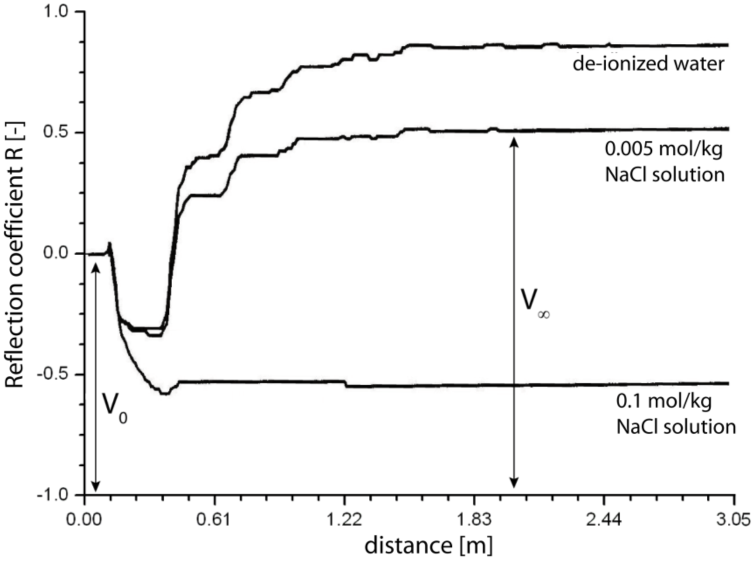
where K is a constant which is determined by the probe geometry, Z is the impedance of the cable and R∞ is the reflection coefficient at very long travel times where virtually no further reflections of the signal occur. At this point the reflection coefficient can be determined by:

$$R_\infty = \frac{V_\infty - V_0}{V_0}$$

where V∞ and V_0 are the signal amplitudes.

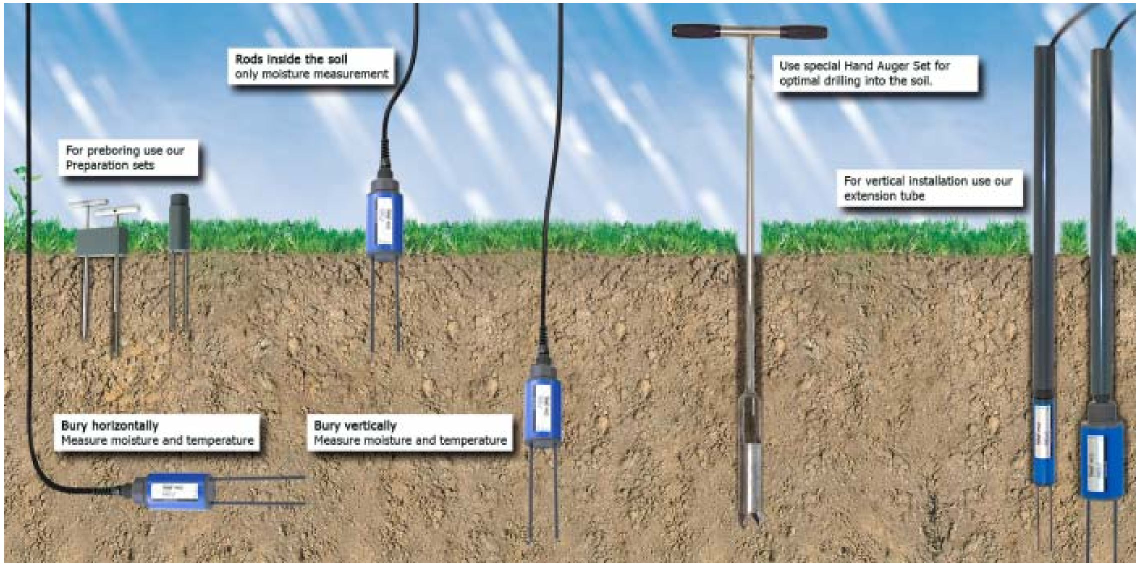
The probe geometry constant (K) can be determined by measuring signals in solutions with known electrical conductivity or by the Relation in which Z_0 is the probe capacity:

$$K = \left(\frac{\varepsilon_0 \varepsilon'}{L}\right) Z_0$$



TDR: measurements

The measurements can be performed both vertically or horizontally and both at or below the surface.



Rods inside the soil
only moisture measurement

For preboring use our
Preparation sets

Use special Hand Auger Set for
optimal drilling into the soil.

For vertical installation use our
extension tube

Bury horizontally
Measure moisture and temperature

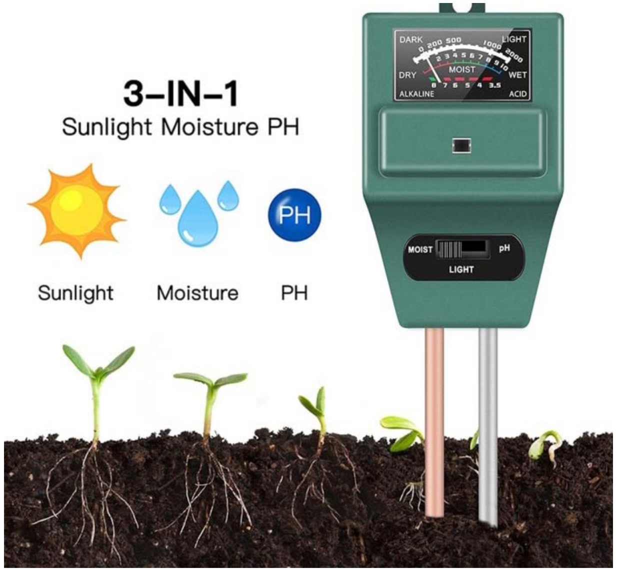
Bury vertically
Measure moisture and temperature

Depending by the length of the probes, their diameter and their geometry, different applications are possible. Often TDR are combined with other sensors to obtain integrated measurements

The **TRIME-PICO64** soil moisture sensor with an integrated soil temperature measurement system.
- Large measuring volume
- The best solution for heterogeneous and stony soils

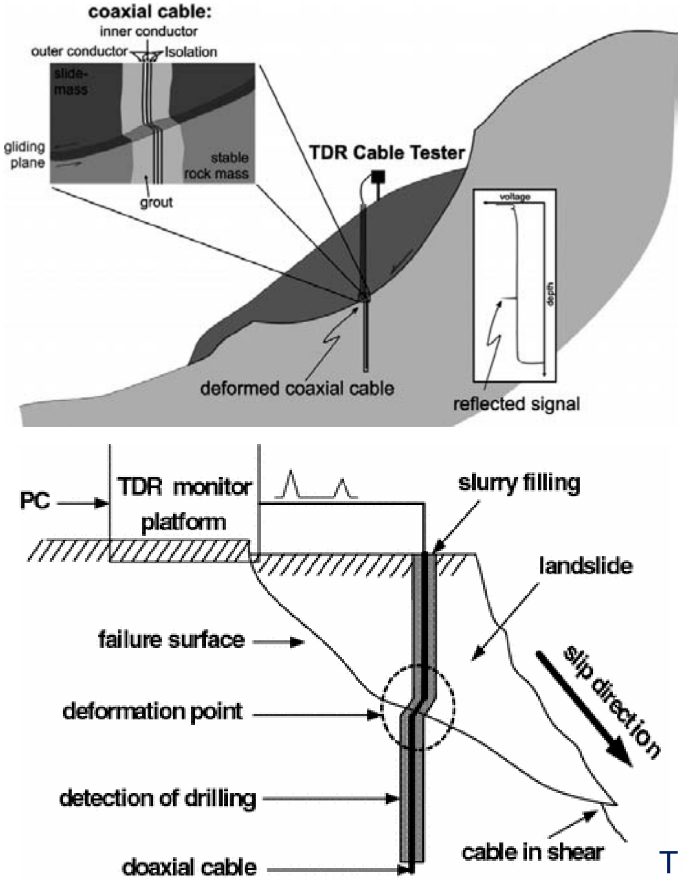
The **TRIME-PICO32** soil moisture sensor with an integrated soil-temperature measurement system.
- Ideal for irrigation control systems and soil moisture monitoring
- Perfect for sandy and loamy soils

The **TRIME-PICO IPH** tube access probe permits rapid, reliable, and non-destructive recording of water content profiles.
- Large measuring volume
- Ideal for soils with high conductivity

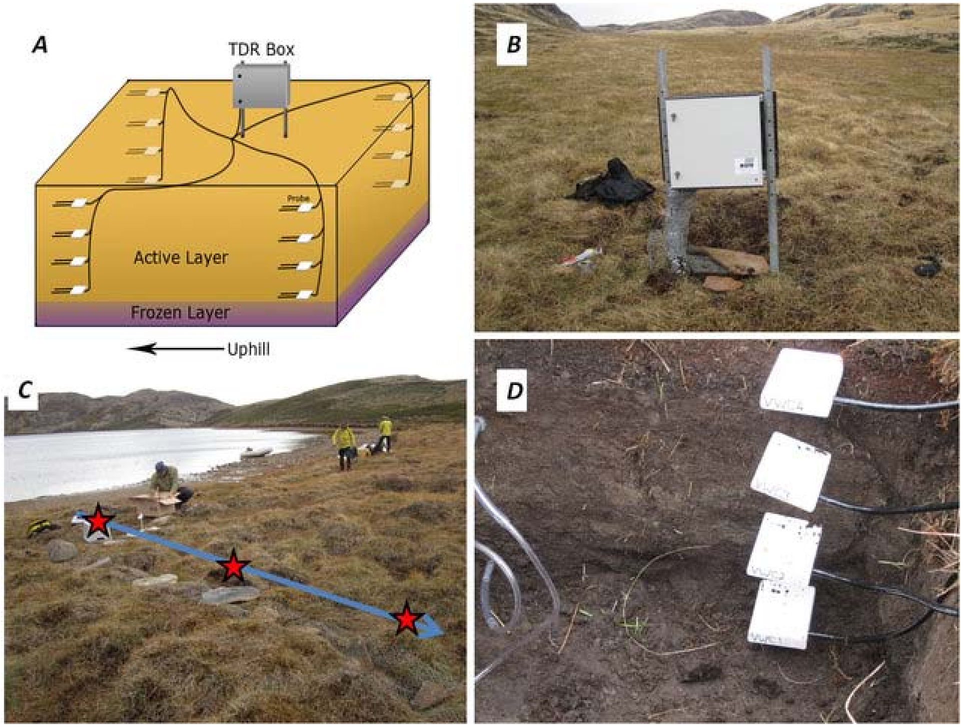


TDR: applications

Recent applications of long permanent coaxial cables have been proposed for landslide monitoring, location of unfrozen and frozen soils and to estimating concentrations of pollutant. In geotechnical and geological engineering, TDR is used for the same purposes, and also to measure frost depths, water levels, and displacements in soil and rock.



Thuro et al., 2012



Lindborg et al., 2014

TDR: concluding remarks

TDR probes can be installed vertically and horizontally in the soil. This way, one can investigate the complete profile down to a depth of a few meters.

Since the effective measurement volume of a TDR probe is relatively small, water contents determined from this method only represent local point measurements. For a spatial analysis of soil water content at the field scale a huge number of measurements is therefore required.

Furthermore, one has to apply adequate interpolation techniques in order to obtain meaningful spatial information about water content distribution.

In order to obtain a good TDR measurement it is necessary to establish a good contact between the soil and the probe rods and to avoid air gaps during installation.

Problems arise when gravels and rocky soils are present, while promising environmental and glaciological applications have been proposed.

Integration and mutual validation of TDR with GPR techniques are increasingly used and exploited.

Questions?