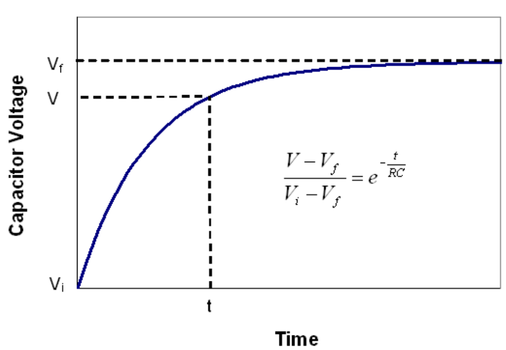
ECH$_2$O Dielectric Probes vs. Time Domain Reflectometers (TDR)

Capacitance and TDR techniques are often grouped together because they both measure the dielectric permittivity of the surrounding medium. In fact, it is not uncommon for individuals to confuse the two, suggesting that a given probe measures water content based on TDR when it is actually uses capacitance. With that in mind, we will try to clarify the difference between the two techniques. The capacitance technique determines the dielectric permittivity of a medium by measuring the charge time of a capacitor, which uses that medium as a dielectric. We first define a relationship between the time, t, it takes to charge a capacitor from a starting voltage, V_i, to a voltage V, with an applied voltage, V_f.

$$\frac{V - V_f}{V_i - V_f} = e^{-\frac{t}{RC}} \tag{1}$$

where *R* is the series resistance and C the is capacitance. The charging of the capacitor is illustrated in the following figure:



If the resistance and voltage ratio are held constant, then the charge time of the capacitor, t, is related to the capacitance according to:

$$t = -RC\ln\left[\frac{V - V_f}{V_i - V_f}\right] \tag{2}$$

For a parallel plate capacitor, the capacitance is a function of the dielectric permittivity (κ) of the medium between the capacitor plates and can be calculated by:

$$C = \frac{\kappa A}{S} \tag{3}$$

where A is the area of the plates and S is the separation between the plates. Because A and S are also fixed values, the charge time on the capacitor is a simple linear function (ideally) of the dielectric permittivity of the surrounding medium.

$$\frac{1}{\kappa} = \frac{1}{t}\left[\frac{RA}{S}\ln\left(\frac{V - V_f}{V_i - V_f}\right)\right] \tag{4}$$

Soil probes are not parallel plate capacitors, but the relationship shown in Eq. [3] is valid whatever the plate geometry. Time domain reflectometry (TDR) determines the dielectric permittivity of a medium by measuring the time it takes for an electromagnetic wave to propagate along a transmission line that is surrounded by the medium. The transit time (t) for an electromagnetic pulse to travel the length of a transmission line and return is related to the dielectric permittivity of the medium, κ, by the following equation:

$$t = \frac{2L\sqrt{\kappa}}{c} \quad (5)$$

where L is the length of the transmission line and c is the speed of light (3 x 108 m s in a vacuum). Thus, the dielectric permittivity is calculated

$$\kappa = \left(\frac{tc}{2L}\right)^2 \quad (6)$$

Therefore, the propagation time of the electromagnetic wave along the TDR probe is only a function of the square of the transit time and a fixed value (c/2L). Because c and L are a constant and a fixed length, respectively, TDR measurements are theoretically less susceptible to soil and environmental condition compared to capacitance sensors. However, the interpretation of TDR output can be a considerable source of error when high salinity diminishes the reflectance waveform or temperature changes the endpoint.

We cannot finish our comparison without discussing frequency. An oscillating voltage must be applied to a TDR or capacitance sensor to measure the reflection or charge time in the medium. The frequency of the oscillation is important because it is widely accepted that low frequencies (<10 MHz) are highly susceptible to changes in salinity and temperature. Because there is no limit on the possible input frequencies for either technique, it is important to verify the frequency of the soil moisture device you will use. In summary, although the theory behind the measurements is somewhat different, TDR and capacitance both measure dielectric permittivity to obtain volumetric water content. From a historic perspective, both TDR and capacitance have gained widespread acceptance, although some may perceive greater value in TDR compared to capacitance because of the extreme price difference. In general, reasonable measurements of volumetric water content can be obtained using either technique, and errors in measurements are often due more to poor installation methods than limitations in the techniques themselves.

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