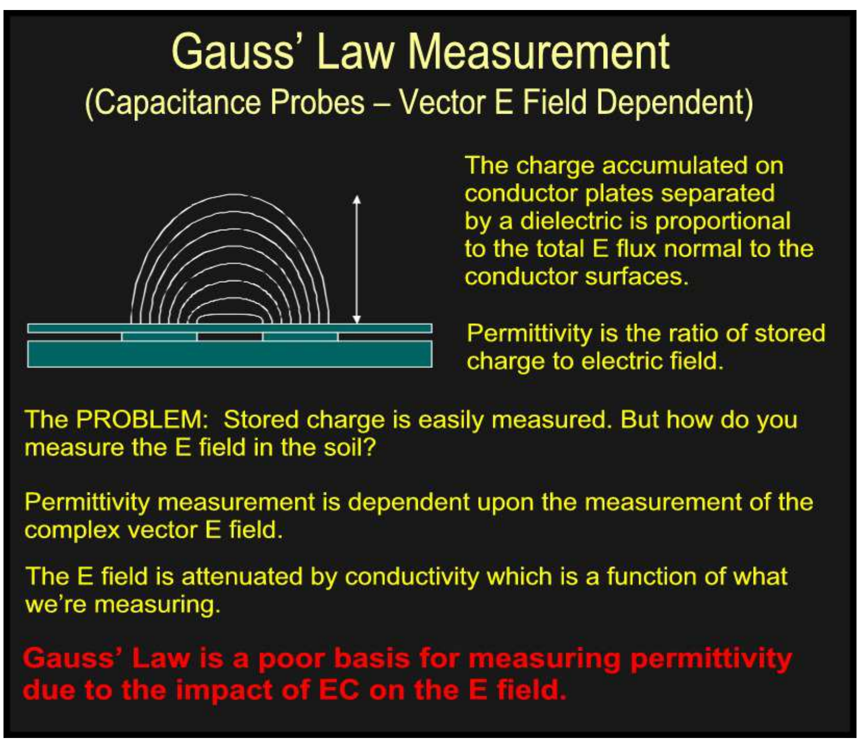
The Accurate Way to Soil Moisture Sensing

A Technical White Paper

In this white paper we will explain in scientific detail why Acclima soil moisture sensor technology is superior to other technologies in terms of technique and cost.

Permittivity is a property of matter – and is well characterized especially for all materials that are electrically non-conductive. Water in its pure form is non-conductive. Permittivity quantifies the electron charge holding capacity for insulating materials. It is the ratio of stored electronic charge to applied electric field (Gauss' Law). If two conductive plates are separated by air and are connected to a battery an electron charge will build up on the positive plate (and an electron deficiency on the other plate). The two plates then form a storage mechanism for electrons. The amount of electronic charge per unit voltage applied is governed by the permittivity of the medium between the plates. If the plates are then immersed in water the number of stored electrons will increase 80 times. Thus by monitoring the current flow into and out of the plates resulting from an applied voltage change, it is possible to know something about the water content of the medium between the plates. Probes designed around this concept are frequently referred to as 'capacitive probes'. But a more precise definition would be Gaussian Probes since they are based in Gauss' Law. Some permittivity probes do not appear to be 'capacitive' probes by their architecture yet are nevertheless based in Gauss' Law.

Even though Gaussian sensors are more credible than their predecessor counterparts they suffer from a serious flaw – that being errors associated with soil electrical conductivity (EC). If we are monitoring soil moisture in soils that do not conduct electricity, then Gaussian Probes will work well. But when the soil receives a little fertilizer or saline irrigation water the electron flow described by Ohm's Law interferes with the ability to measure the 'capacitive' current and soil electric field – regardless of the particular circuit approach used in the sensor design. When the soil is conductive electrical currents flow through soil in the presence of the applied electric fields. This occurs on a transient basis even when the plates are insulated from the soil. The currents create reverse fields in the soil (opposite to the applied field) that attenuate the local field in the soil. An increase in transient current flow also occurs. The ratio of E-field to charge then increases causing a serious overestimation of permittivity and water content. Some Gaussian sensor manufacturers have attempted to compensate their probes for electrical conductivity, but soil electrical conductivity is very



strongly dependent on water content. The two variables are not orthogonal and attempting to compensate water content with water-content-dependent conductivity measurements is futile. Because of the prevalence of Gaussian sensors in the marketplace it is very important to include 'measurement stability vs. soil electrical conductivity' in the evaluation of a soil moisture sensor. The EC stability of a sensor is the most important parameter – much more important than absolute accuracy. The accuracy of a sensor can be calibrated in the field but its susceptibility to erroneous readings due to changing conductivity cannot be compensated for. Increases in conductivity will be reported as increases in water content and the user has no reference for understanding what the 'real' water content is. If the user is controlling irrigation based on unstable readings he can easily lose his crop.

Fortunately there is another basic law of physics that can be used to measure permittivity that is immune to electrical conductivity. This is the Ampere/Faraday Law (actually two laws) that describe electromagnetic wave propagation. The speed at which light travels is governed by two properties of matter – electrical permittivity and magnetic permeability. Nearly all soils are non-magnetic and so the speed of light in soil is governed only by permittivity. Electrical conductivity has no effect on the speed of light but it does attenuate the wave. If we can measure the speed of light in the soil we can find the permittivity without interference from soil conductivity. But we must be able to make accurate time measurements on events that occur in billionths of a second with accuracies and resolutions in the trillionths of a second. And we must be able to detect the timing of the first arrival of energy – even though the wave may have diminished severely due to soil conductivity. A popular instrument that does this is called the Time Domain Reflectometer. The TDR contains a step function generator that launches an instantaneous or fast-rising voltage on a transmission line. The voltage propagates down the transmission line similar to the ripple that propagates down a rope tied to a tree. When the wave comes to the end of the transmission line it reflects back to the origin – just like the example of the rope tied to a tree. If we accurately measure the time taken for the round trip we can determine quite precisely what the permittivity of the medium is – independent of all other parameters. From the permittivity we can derive the water content.

Typical TDR Setup

Expensive | User Unfriendly | Limited Applicability

TDR instruments have been used since the 1980s for measuring soil water content. Clark Topp and others developed the procedure and experimentally derived a basic relationship between permittivity and water content called the Topp equation. TDR instruments had been used for finding breaks and shorts in underground cables. Applying them to measuring soil water content was a major breakthrough to accurate and stable soil water content measurements – but an expensive breakthrough. Today the TDR is used along with the neutron probe as reference instruments for establishing accurate soil water content readings. Neither instrument is suited for long-term deployment in the field due to cost, bulk and power considerations.

Over the past decade Acclima developed and patented a means of transmitting and receiving very fast rising signals and measuring their propagation time through soil with trillionths of a second resolution and accuracy. This facilitated the development of a TDR soil moisture sensor where the waveform generator, the digitizing receiver and the precision timing circuitry were small enough to be incorporated directly into the probe in a small, low cost package. The first embodiment of the technology was a Time Domain Transmissometer wherein the step function voltage is applied to one end of a transmission line that folds back to the housing where it is received. By folding the waveguide back to the circuit board we avoid the need to separate a reflected wave from the incident wave as is required in a Time Domain Reflectometer. We also avoid the attenuation of the waveform that occurs when it is reflected at the end of the waveguide. The TDT technology is more easily implemented than TDR technology and the TDT device can operate in much more conductive soils than a TDR device can. Otherwise they are equivalent and both offer immunity to errors caused by soil conductivity. With Acclima's introduction of TDT technology the cost of TDR-type technology was reduced from tens of thousands of dollars to hundreds of dollars. This makes it practical to install the sensor permanently thus offering stable soil moisture readings with TDR credibility at a small fraction of conventional TDR costs.

The importance of the digitizing process cannot be overemphasized. Soil conductivity and problems with the frequency response of clay soils distort the waveform and cause the received step function edge to smear out and diminish in amplitude. It is necessary to explore the weaker first appearance of energy in order to get an accurate propagation time measurement. Without finding this point the sensors would be sensitive to the electrical conductivity the soil. Special algorithms that Acclima has developed are used to find this first energy arrival and distinguish it from noise and artifacts of the incident wave. It should be noted that other sensors are on the market that purport to be propagation time based. All of these are analog sensors that do not digitize the waveform and are 'blind' with regard to the first energy arrival. They are not capable of the immunity to electrical conductivity that the Acclima sensors offer.