Theory and Practice of Dielectric Soil Moisture Measurement

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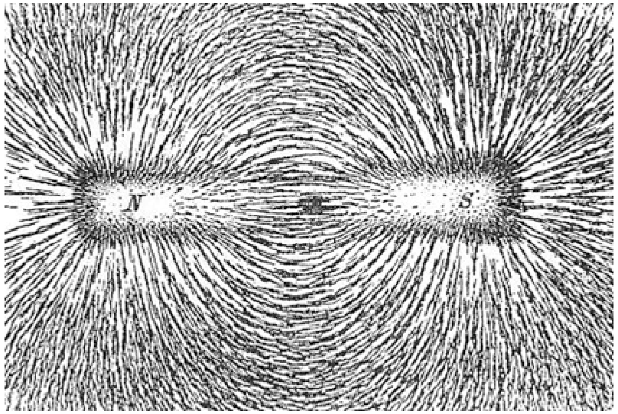
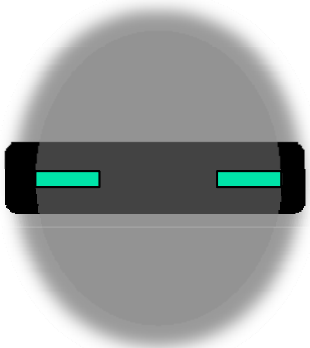
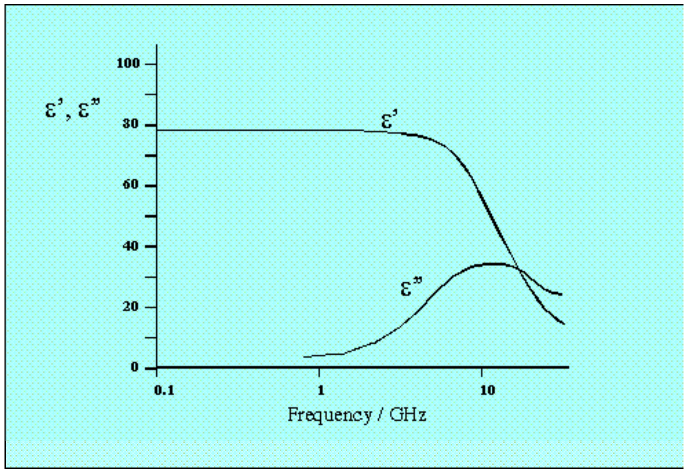
Introduction

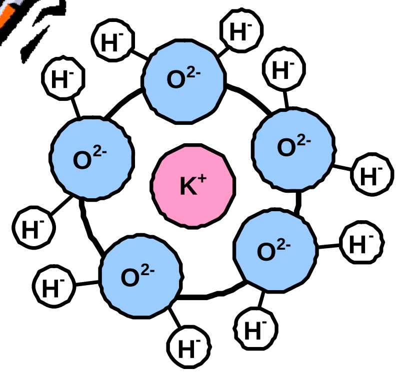
- Decagon Devices
  - Started in 1983 supplying instrumentation for measuring water potential
  - Goal
    - Develop robust instrumentation to take accurate data AND fit within a budget
  - Vision
    - In the future, measuring and modeling the natural environment will require more high quality, innovative, and inexpensive solutions

Outline









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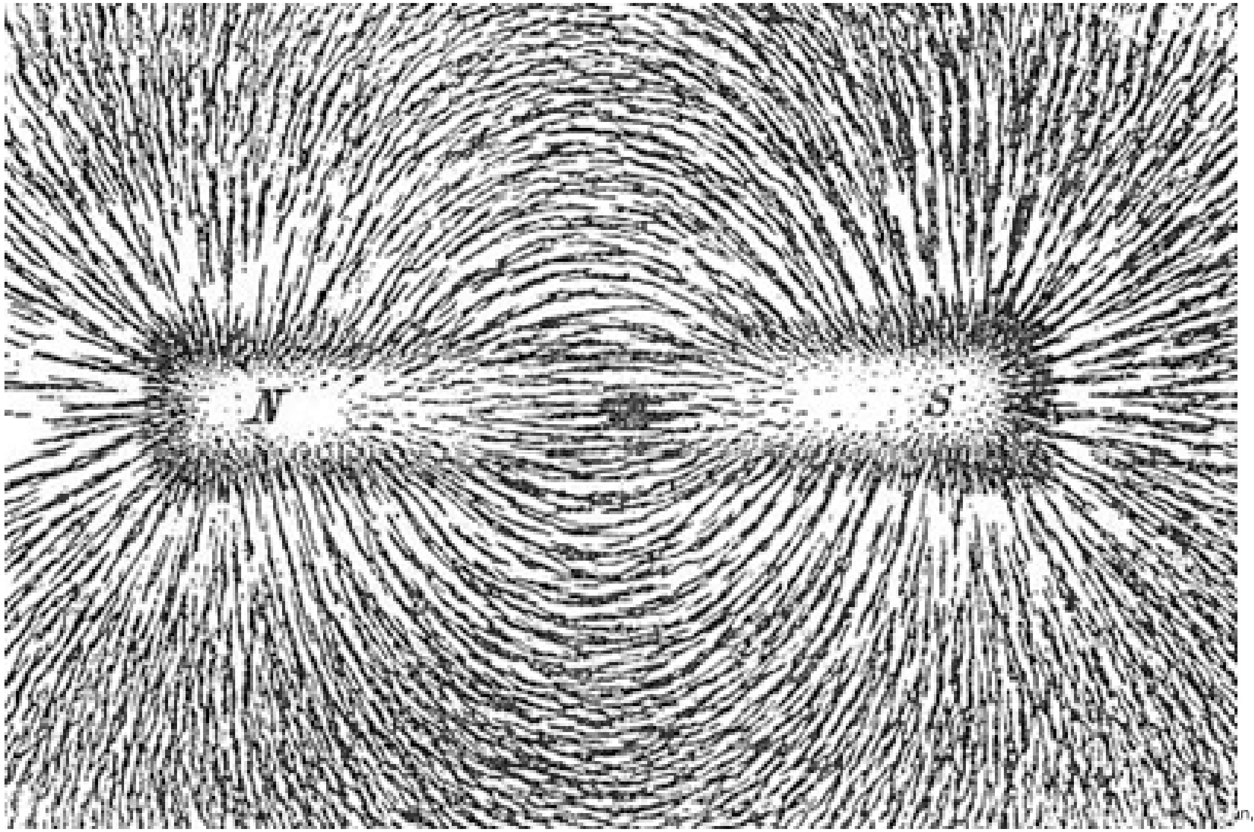
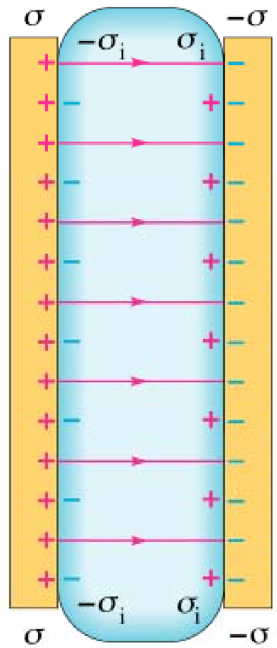
Electromagnetic fields

- Magnet and iron filings

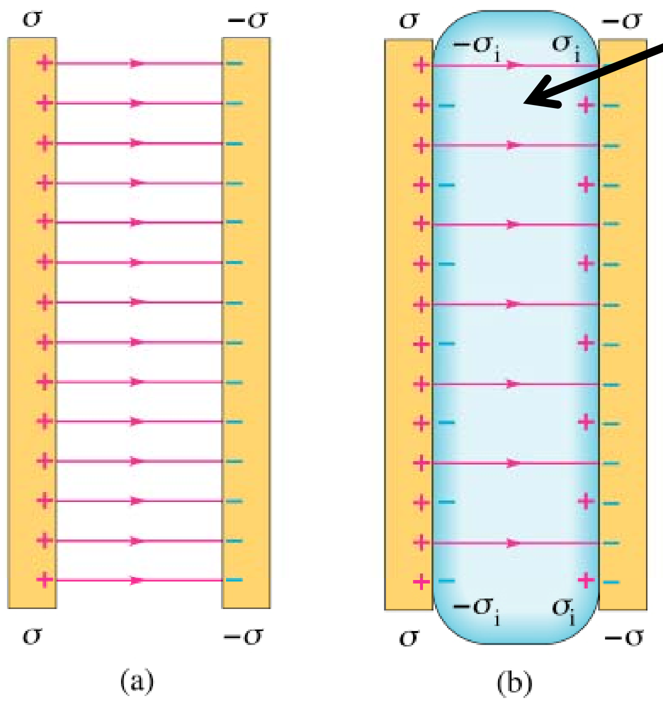




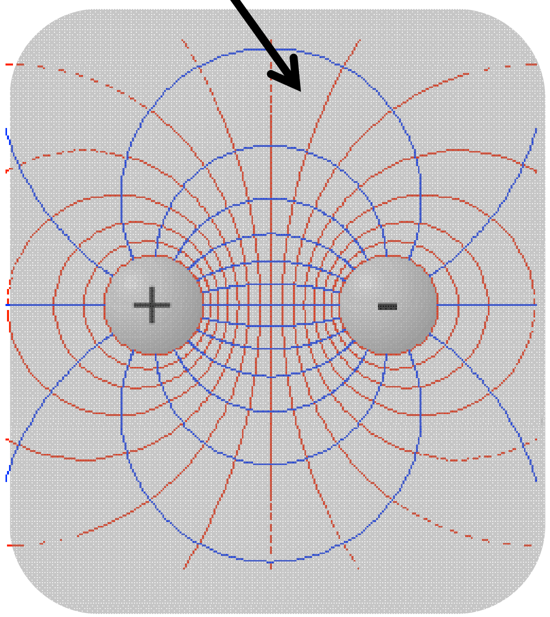
(b)

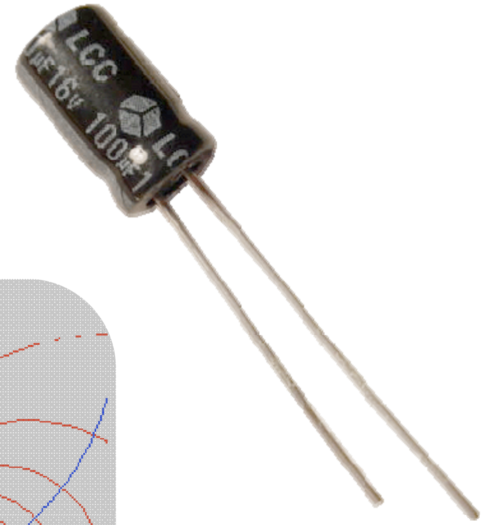
Electromagnetic fields

- EM fields using electricity



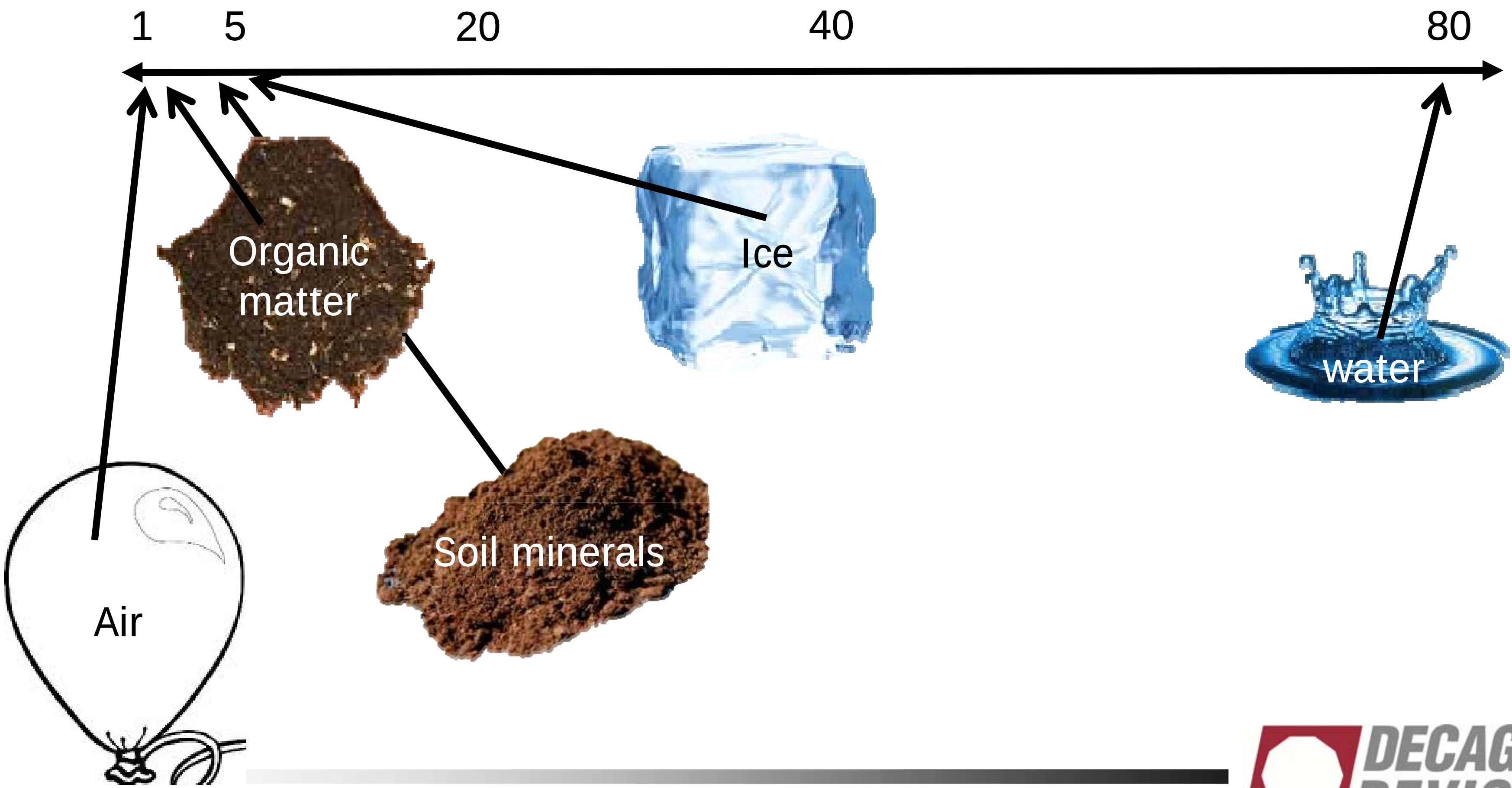
Dielectric material:
constant





Properties of dielectric materials

Dielectric constant: Ability to store charge



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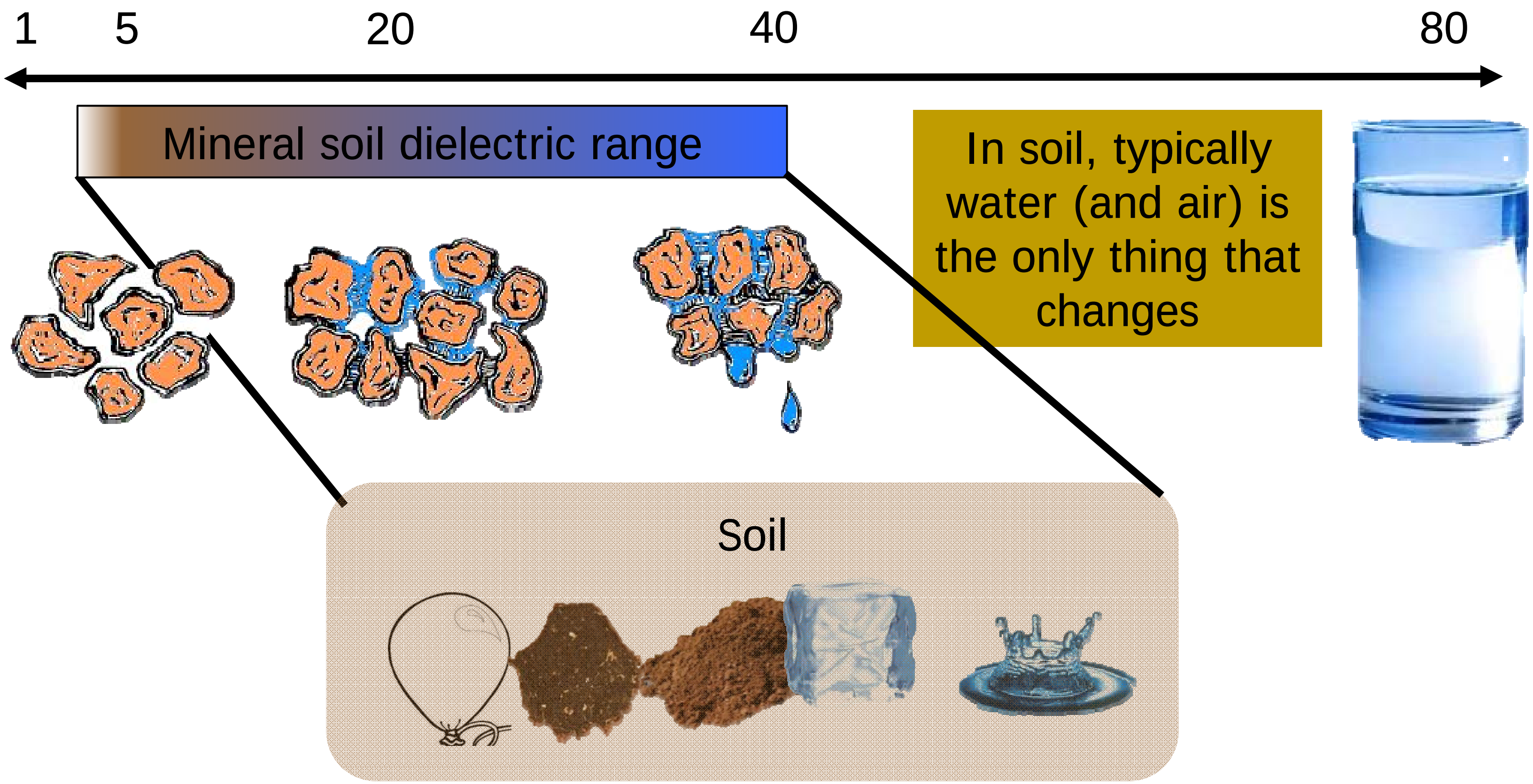
Properties of dielectric materials

Dielectric constant: Ability to store charge



Dielectric Mixing Model: FYI

- The total dielectric of soil is made up of the dielectric of each individual constituent
  - The volume fractions, V_x, are weighting factors that add to unity

$$\varepsilon_t^b = \varepsilon_m^b V_m + \varepsilon_a^b V_a + \varepsilon_w^b \theta + \varepsilon_{om}^b V_{om} + \varepsilon_i^b V_i$$

  - Where ε is dielectric permittivity, b is a constant around 0.5, and subscripts t, m, a, om, i, and w represent total, mineral soil, air, organic matter, ice, and water.

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Volumetric Water Content and Dielectric Permittivity

- Rearranging the equation shows water content, θ, is directly related to the total dielectric by

$$\theta = \frac{1}{\varepsilon_w^{0.5}}\varepsilon_t^{0.5} - \frac{(\varepsilon_m^{0.5}V_m + \varepsilon_a^{0.5}V_a + \varepsilon_{om}^{0.5}V_{om} + \varepsilon_i^{0.5}V_i)}{\varepsilon_w^{0.5}}$$

- Take home points
  - Ideally, water content is a simple first-order function of dielectric permittivity
    - Generally, relationship is second-order in the real world
  - Therefore, instruments that measure dielectric permittivity of media can be calibrated to read water content

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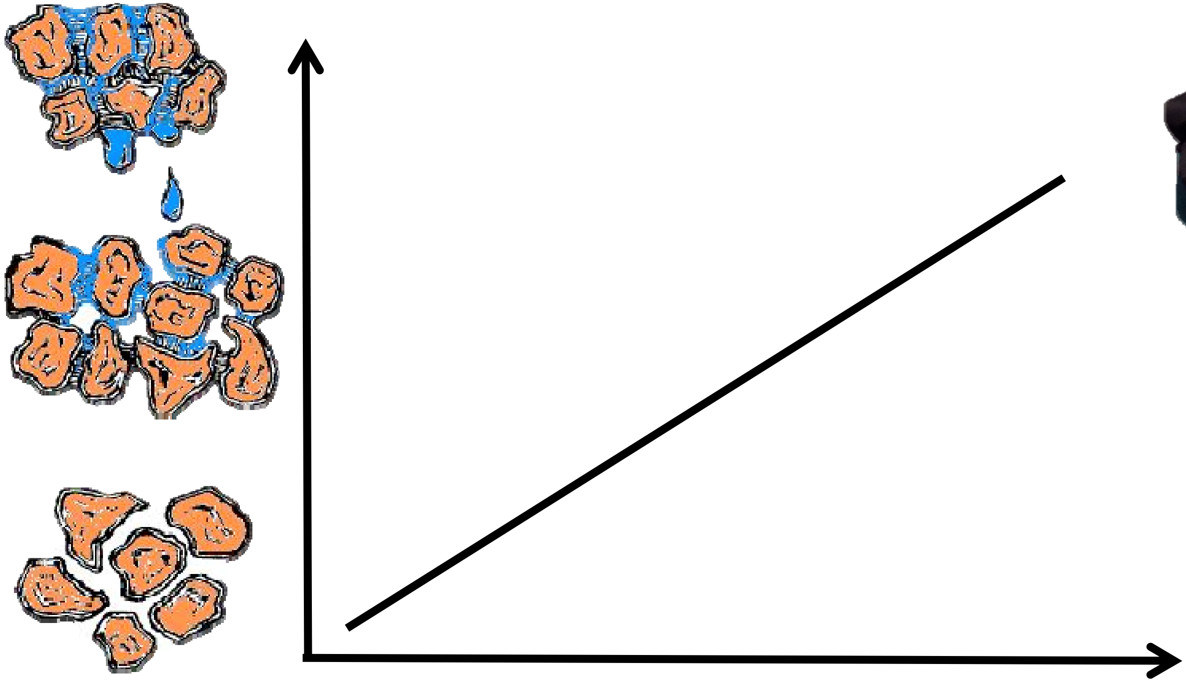
Calibrating dielectric to water content



$$\sqrt{\varepsilon_t}$$

$$\theta = a\sqrt{\varepsilon_t} - b$$

Reasonably consistent calibration with soil type
Problems: High EC, clay activity, temperature, bulk density

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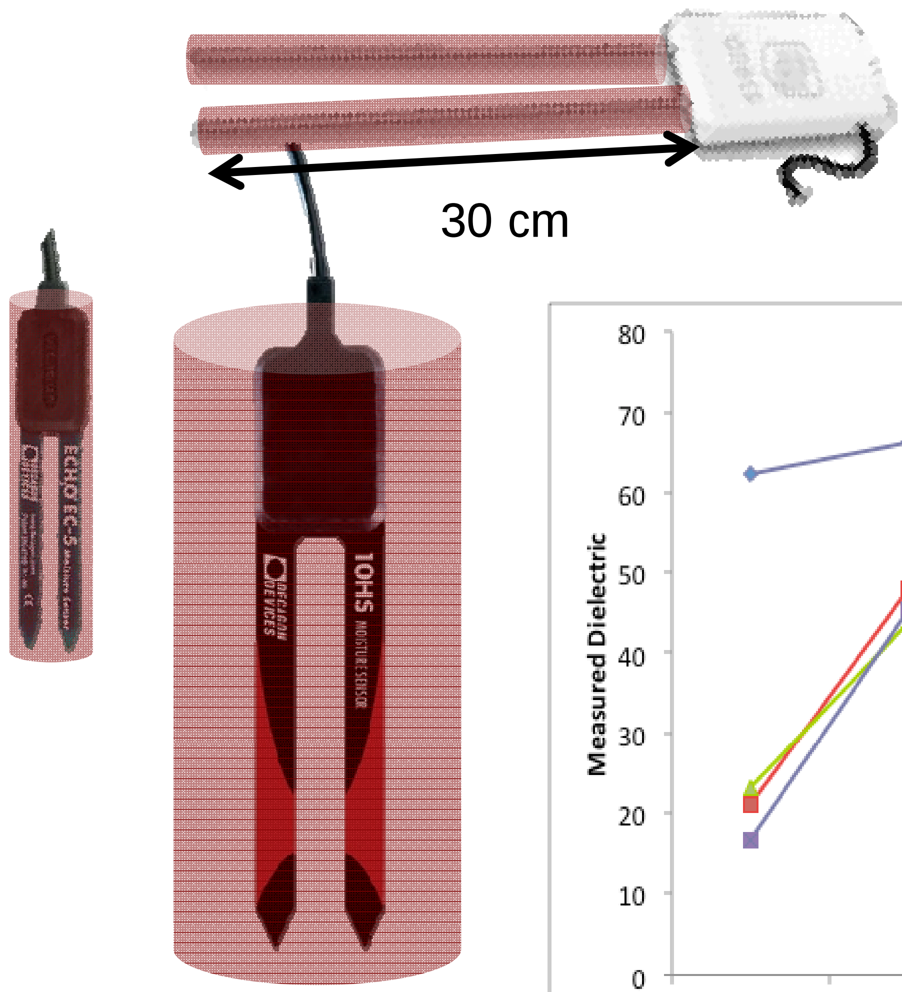
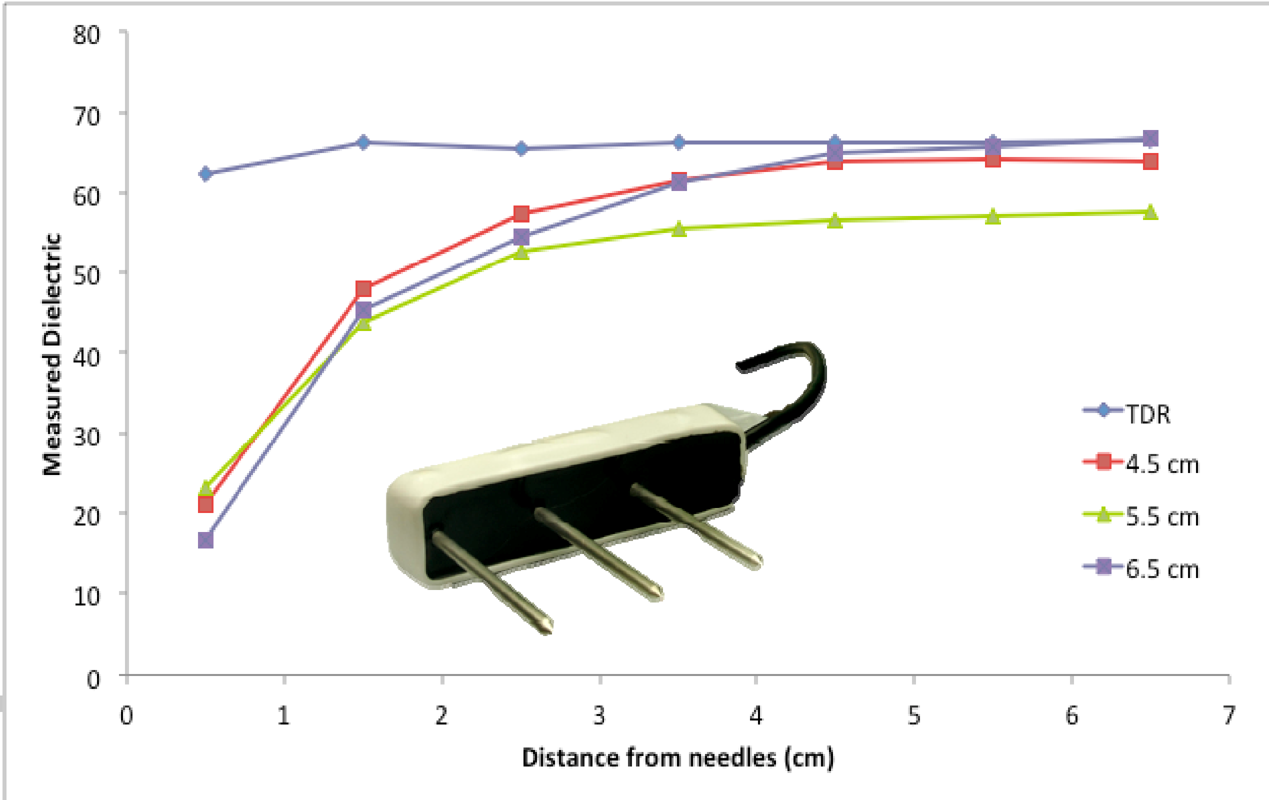
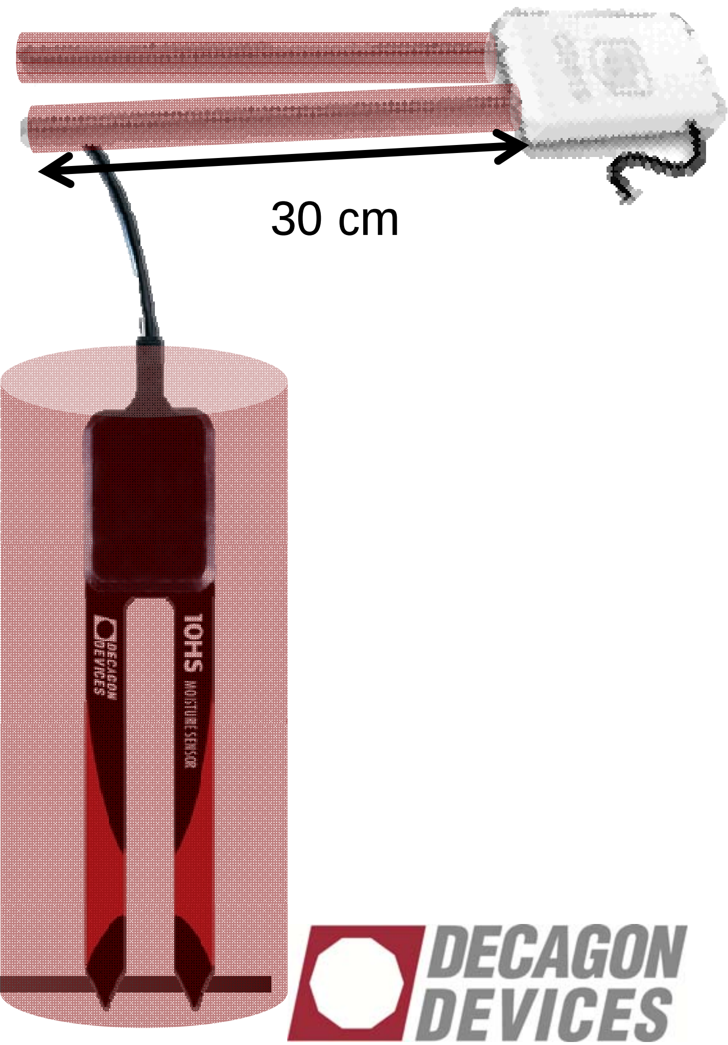
Volume of sensitivity





Volume of sensitivity

- Basic principles
  - Highest sensitivity closest to surface
  - Design of sensor rods can change volume of influence
  - Wider needle spacing only increases volume of influence to a point



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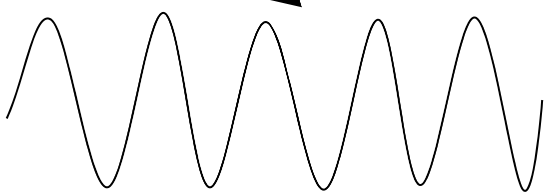
Measuring dielectric to get water content

Measuring Dielectric
2 choices

Time Domain

Frequency Domain



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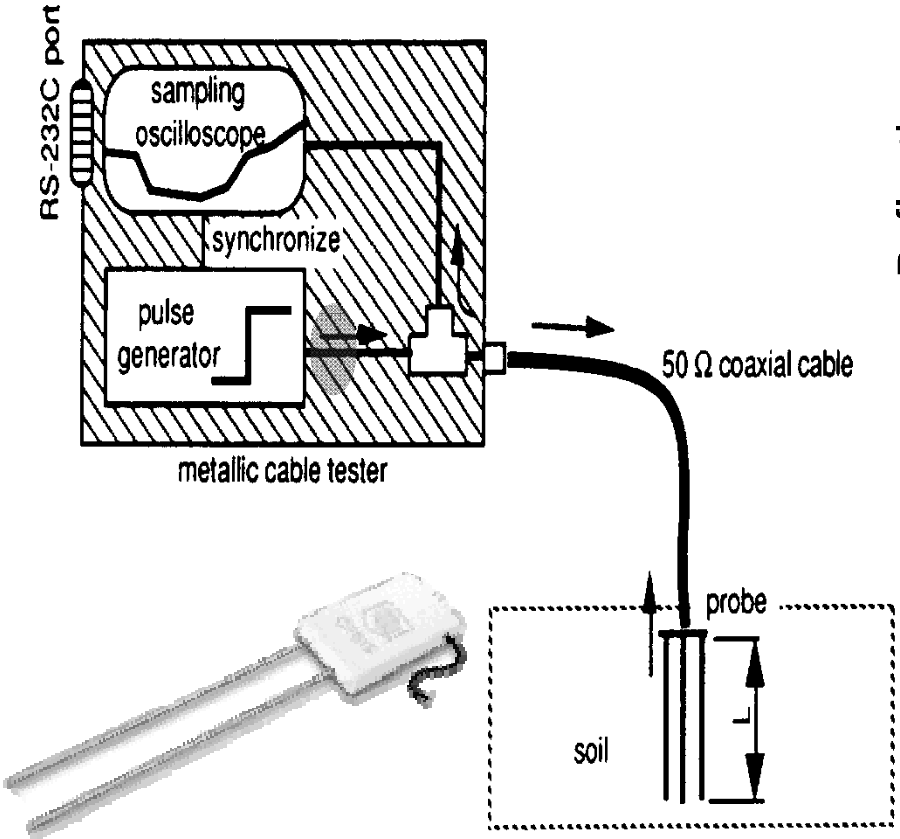
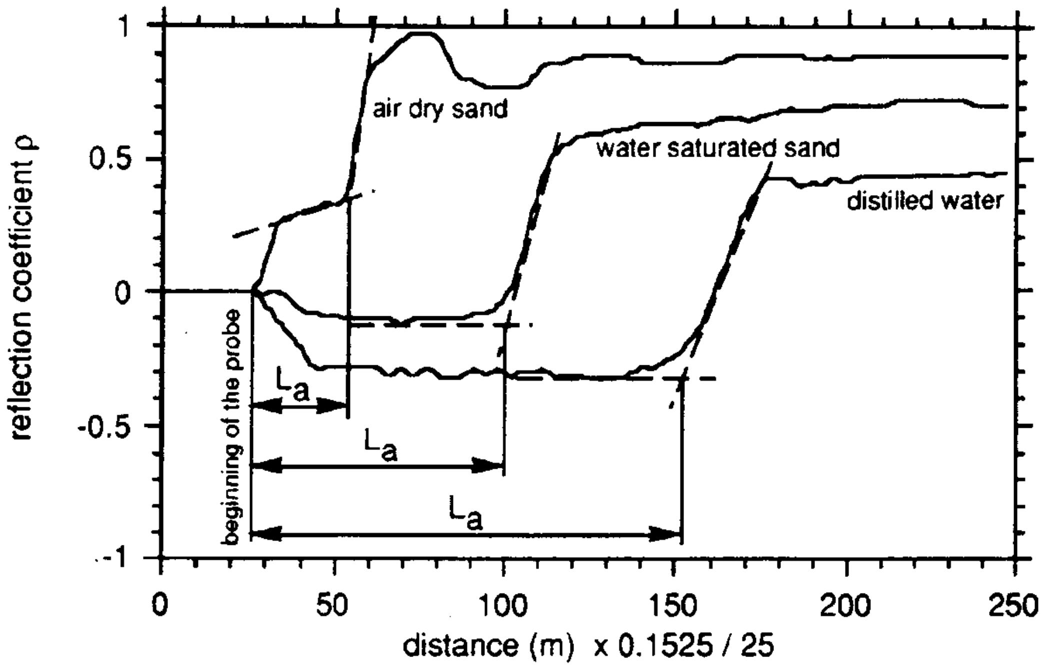
Dielectric Instruments: Time Domain Reflectometry



Kosuke Noborio, 1993

Dielectric Instruments: Time Domain Reflectometry

- Measures apparent length (L_a) of probe from an EM wave propagated along metallic rods
- L_a is related to ε and therefore θ



Kosuke Noborio, 1993

Problems with TDR?

- TDR is a good way to measure water content, why not use it?
- Cost
  - Expensive to purchase extensive installation
- Complexity
  - System requires expertise to set up
- Power consumption
  - Require significant battery capacity/solar panel

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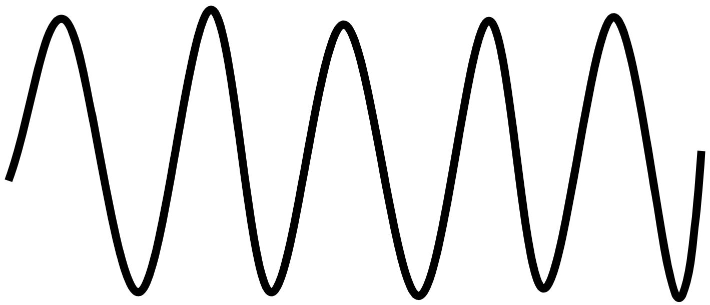
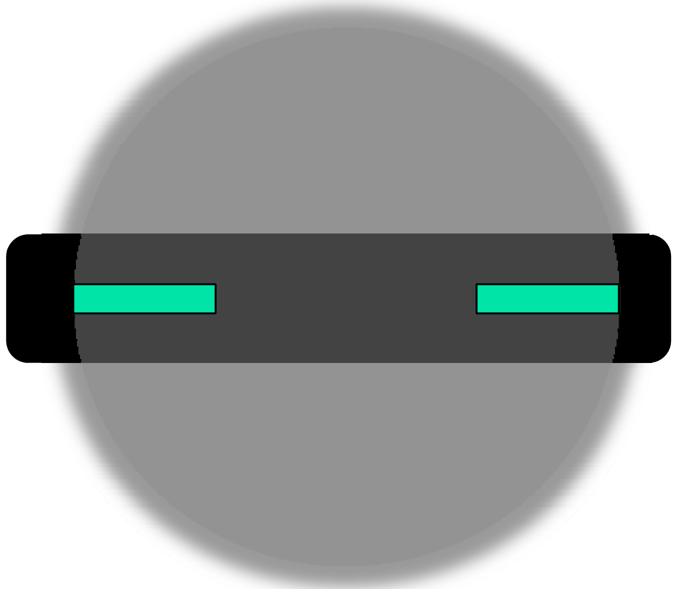
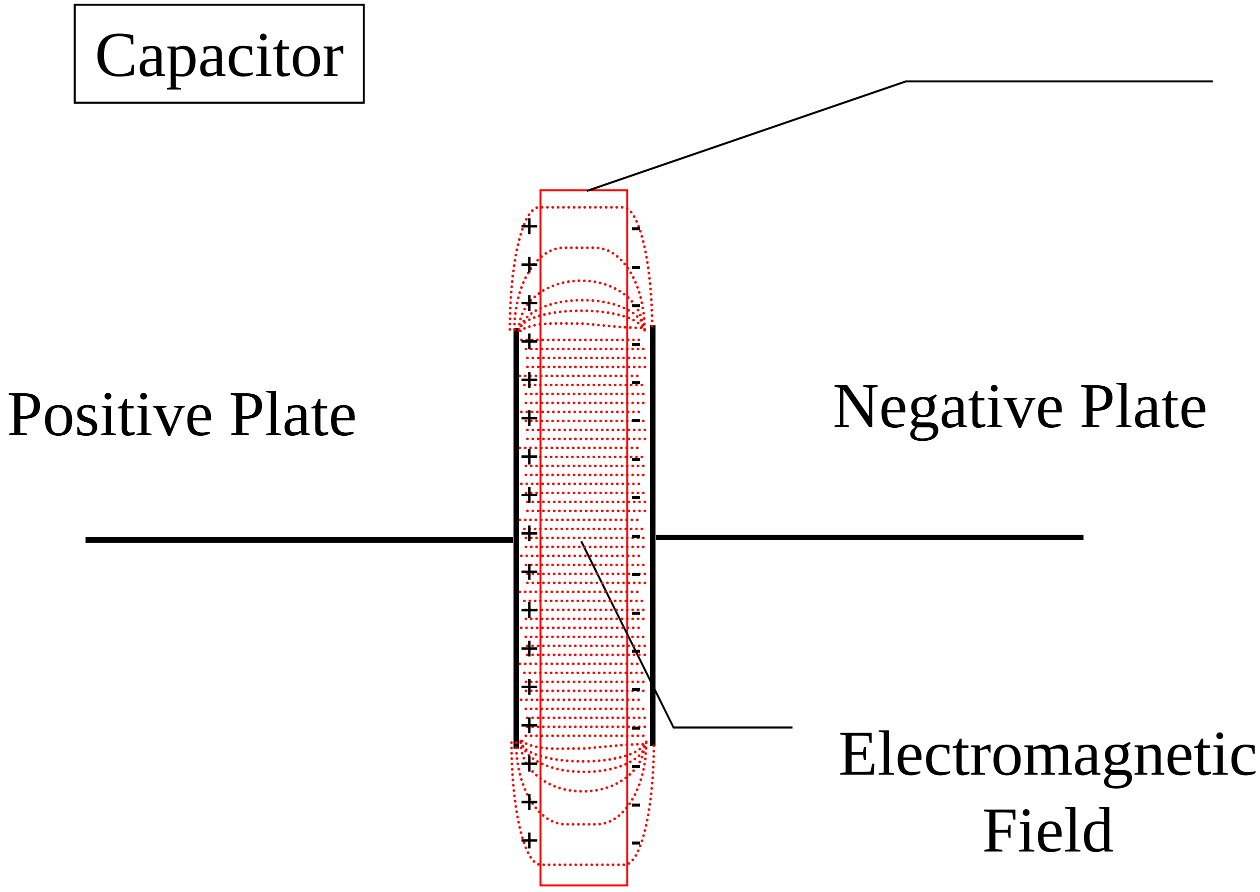
Frequency Domain (FDR or Capacitor)dielectric sensor basics

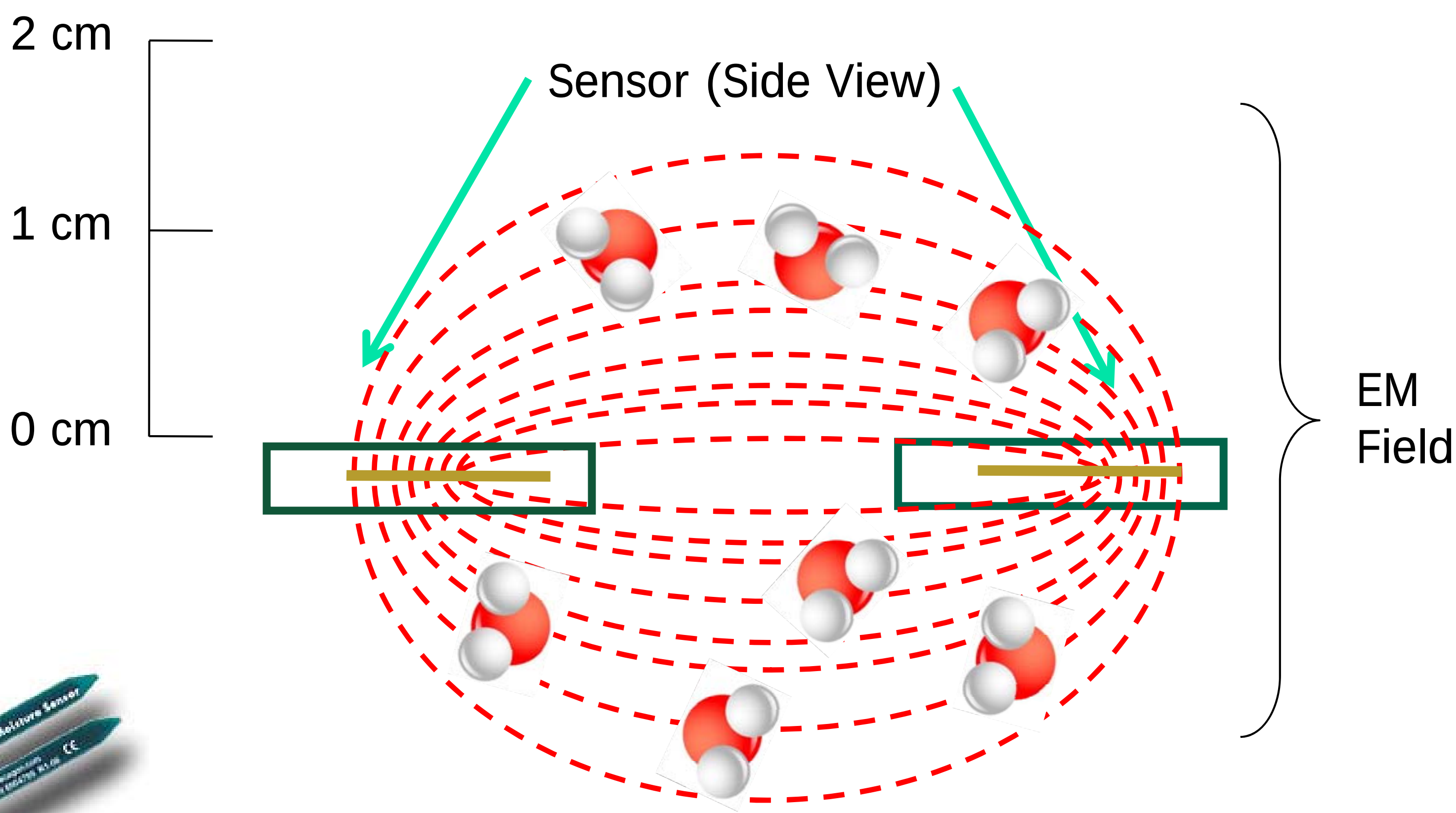




Typical Capacitor



Example: How Capacitance Sensors Function



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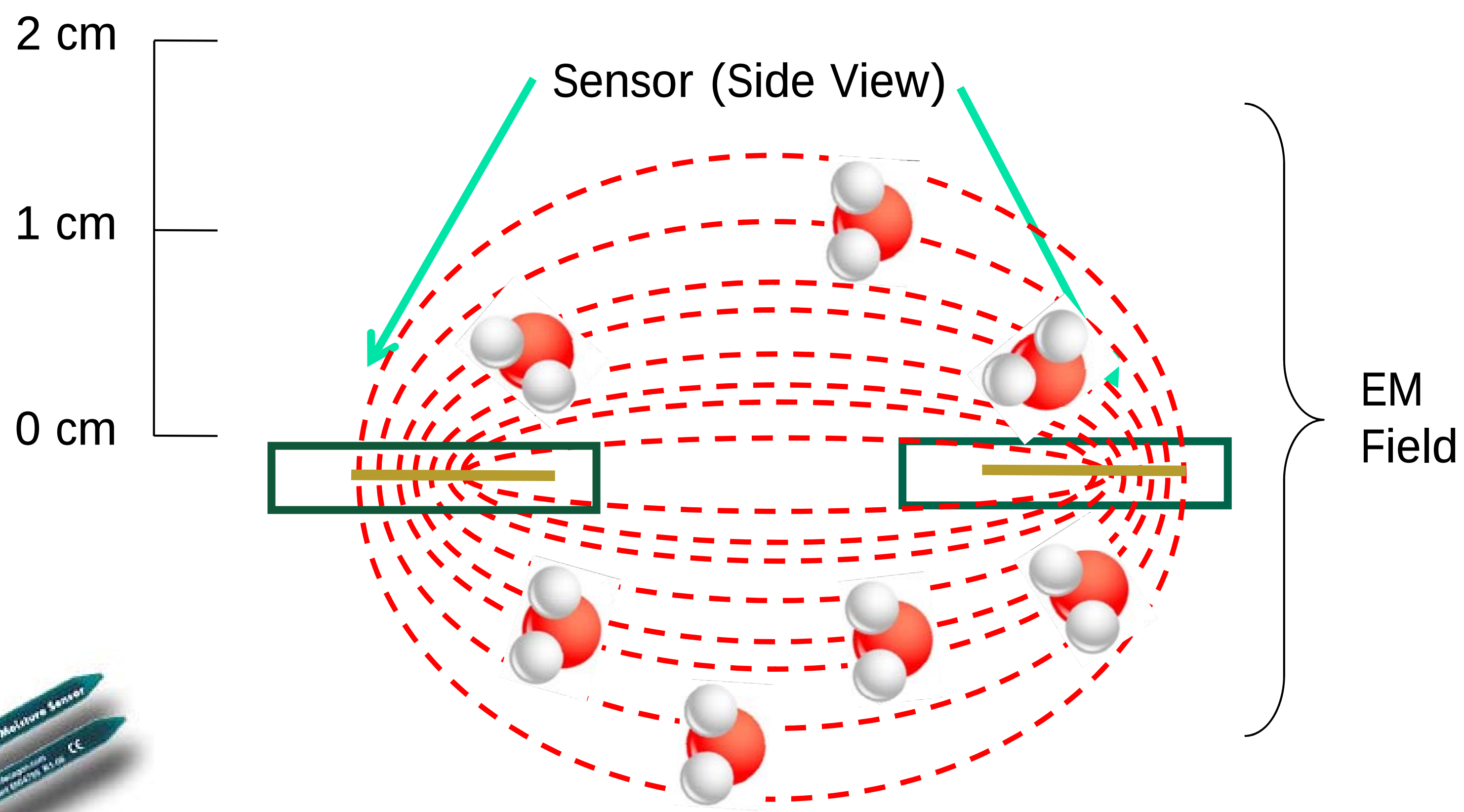

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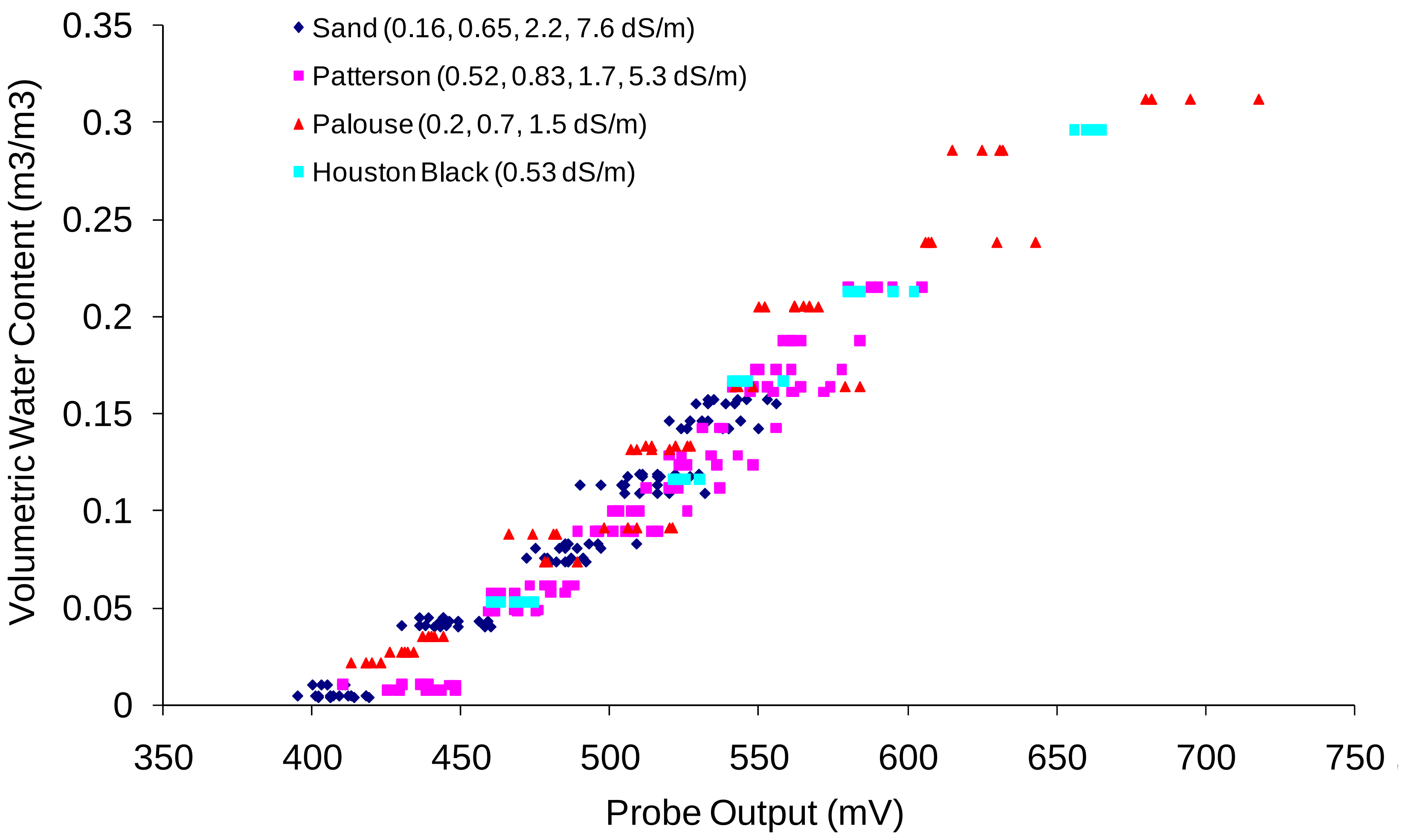
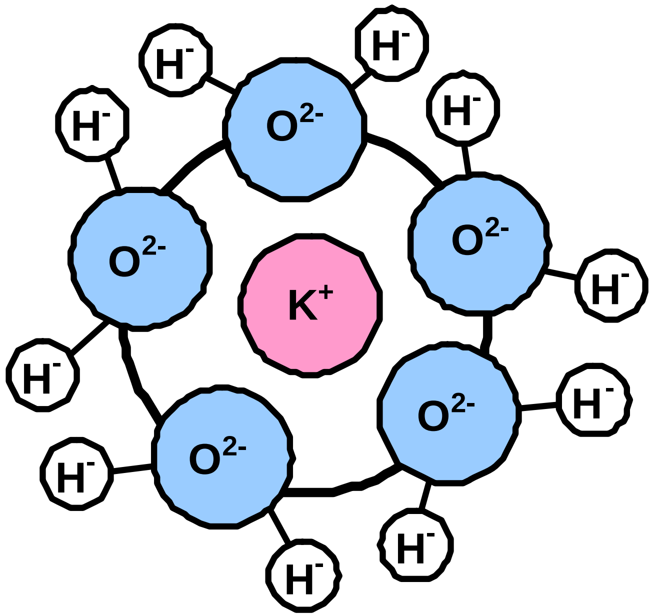
Calibration example: EC-5 Sensor



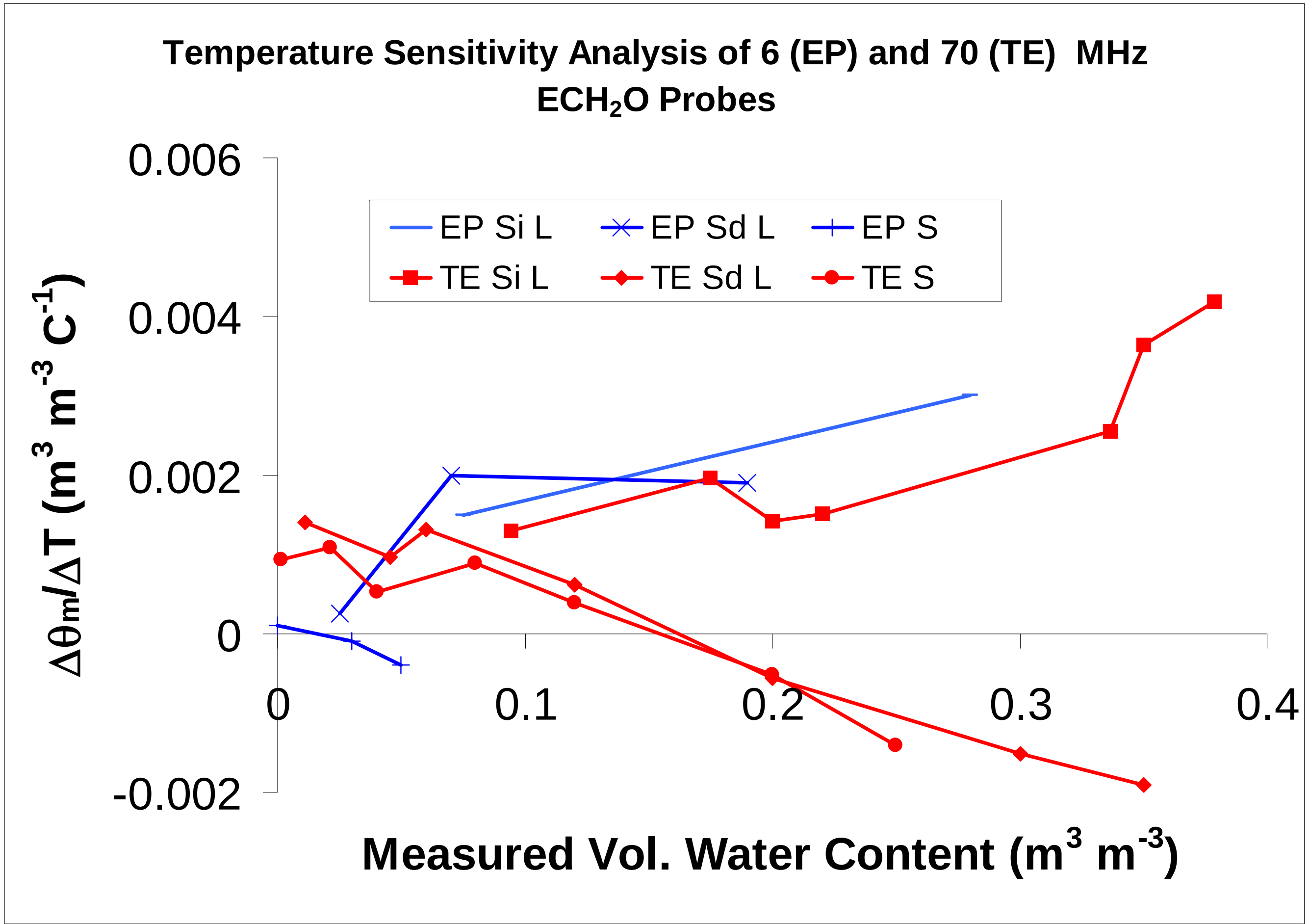
Limits to dielectric measurement accuracy

- Two important factors
  - Temperature
  - Electrical conductivity



Buehler, 2011

Temperature sensitivity



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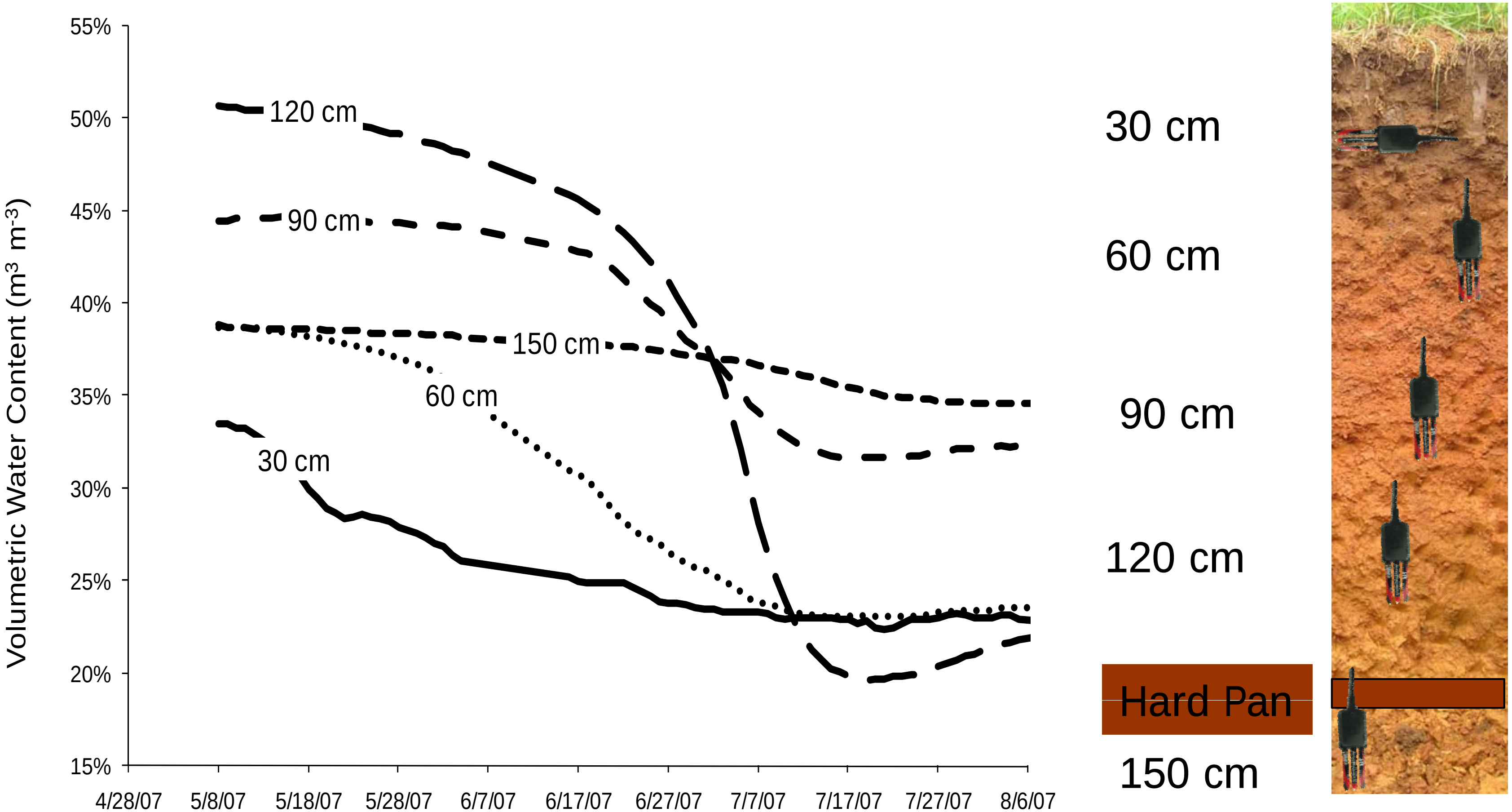
No temperature dependence in field study



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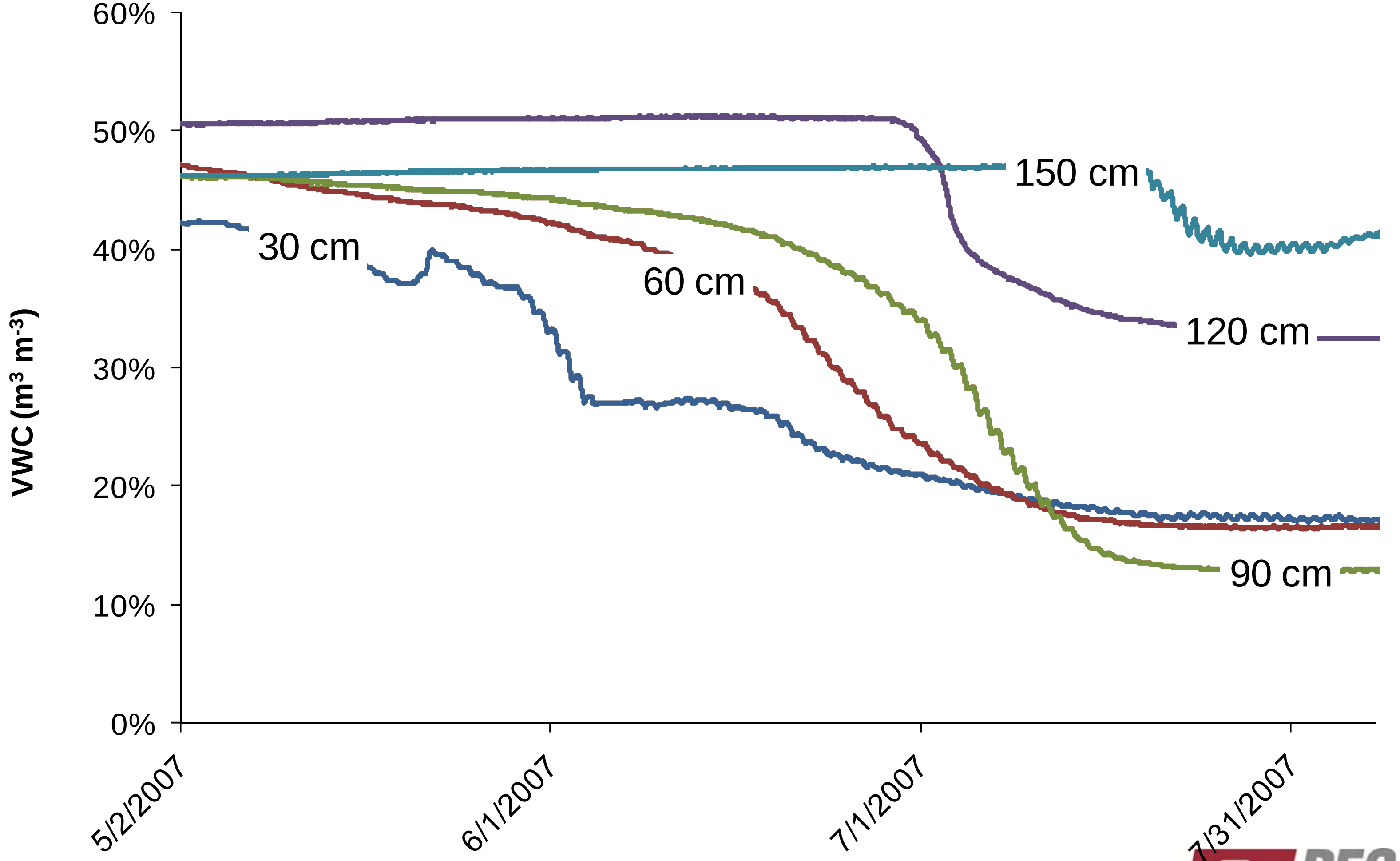
Diurnal fluctuations: Real or caused by temperature? (toe slope site)



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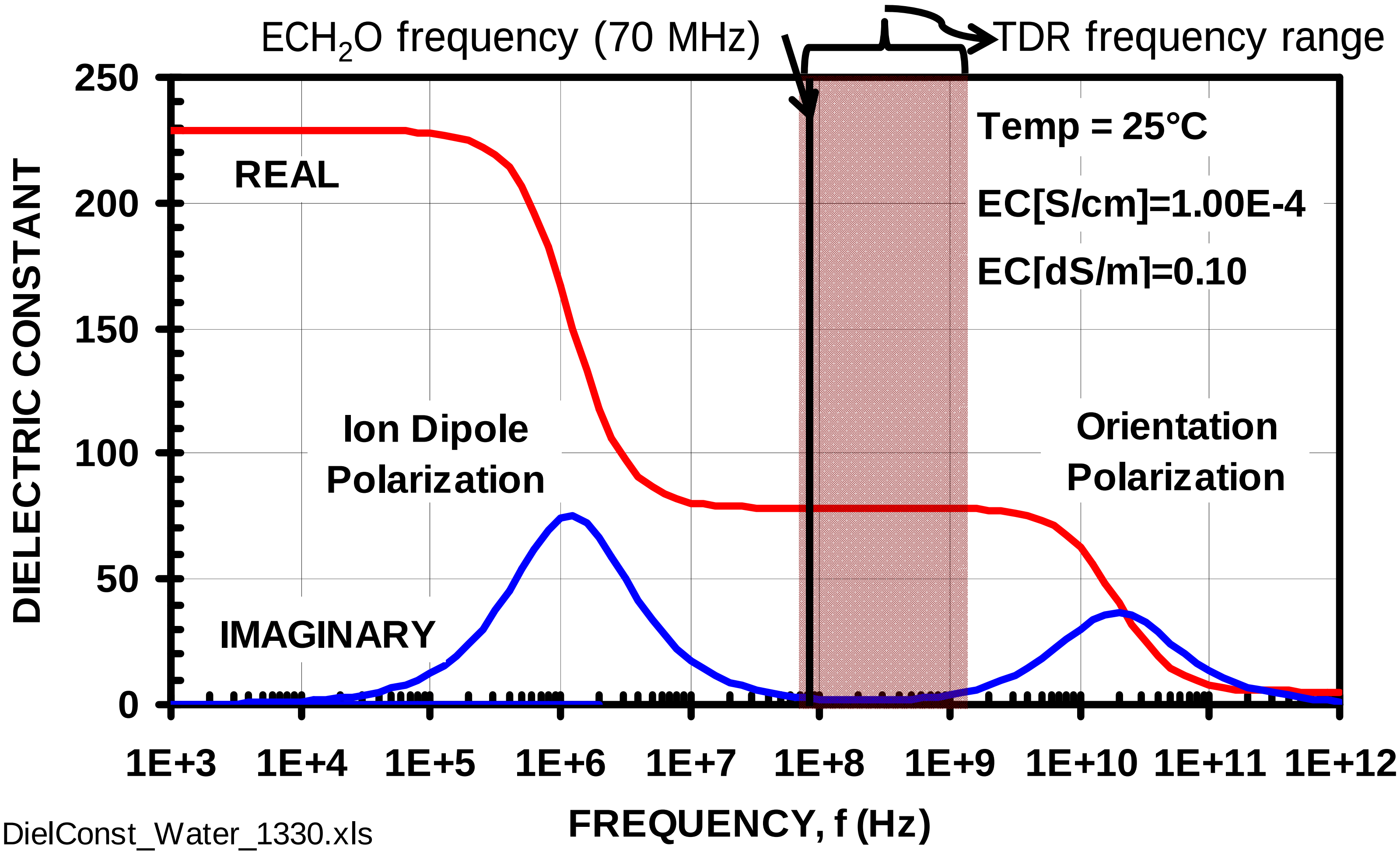
Dielectric Constant – EC Dependence



Buehler, 2011, ISEMA

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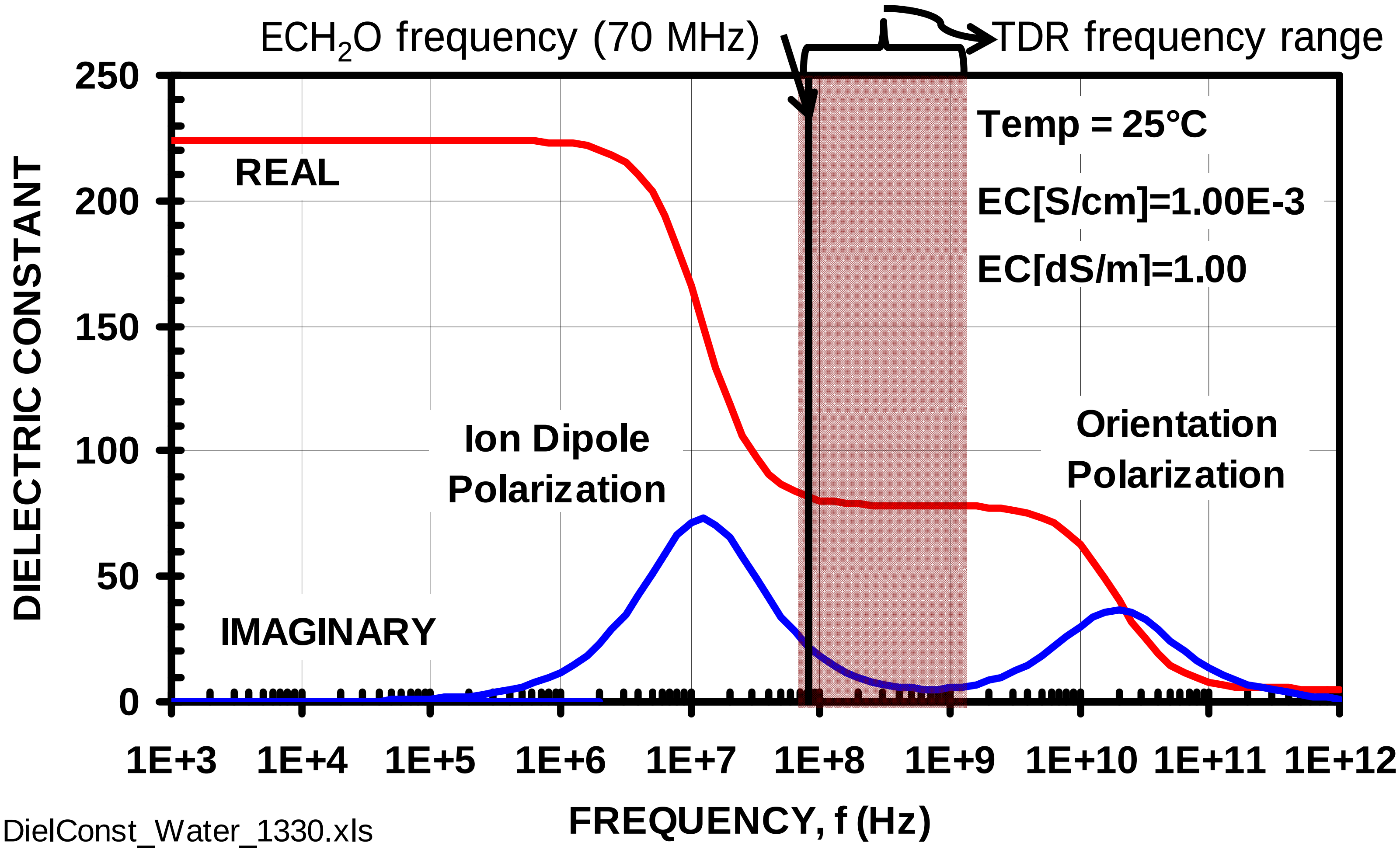

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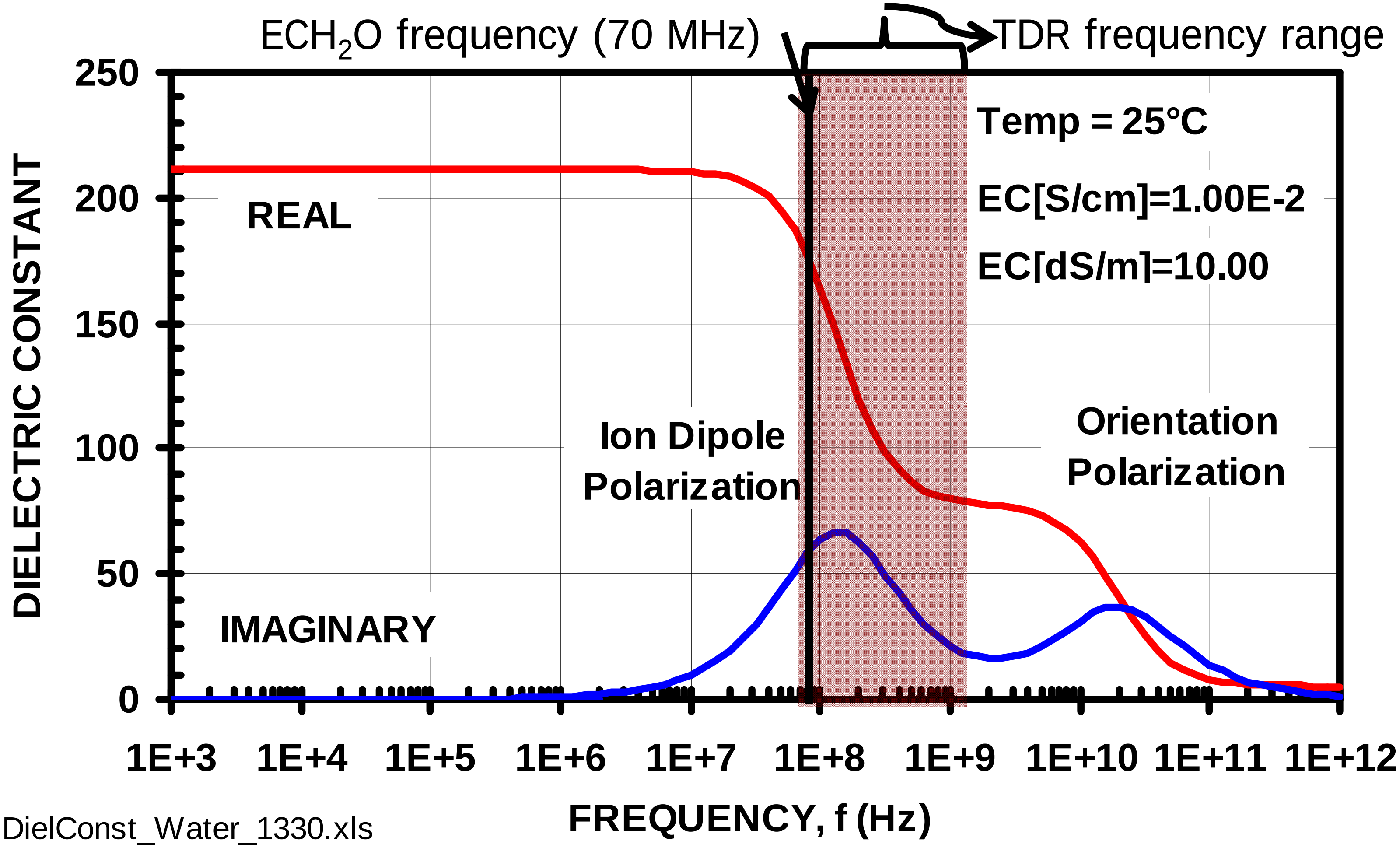

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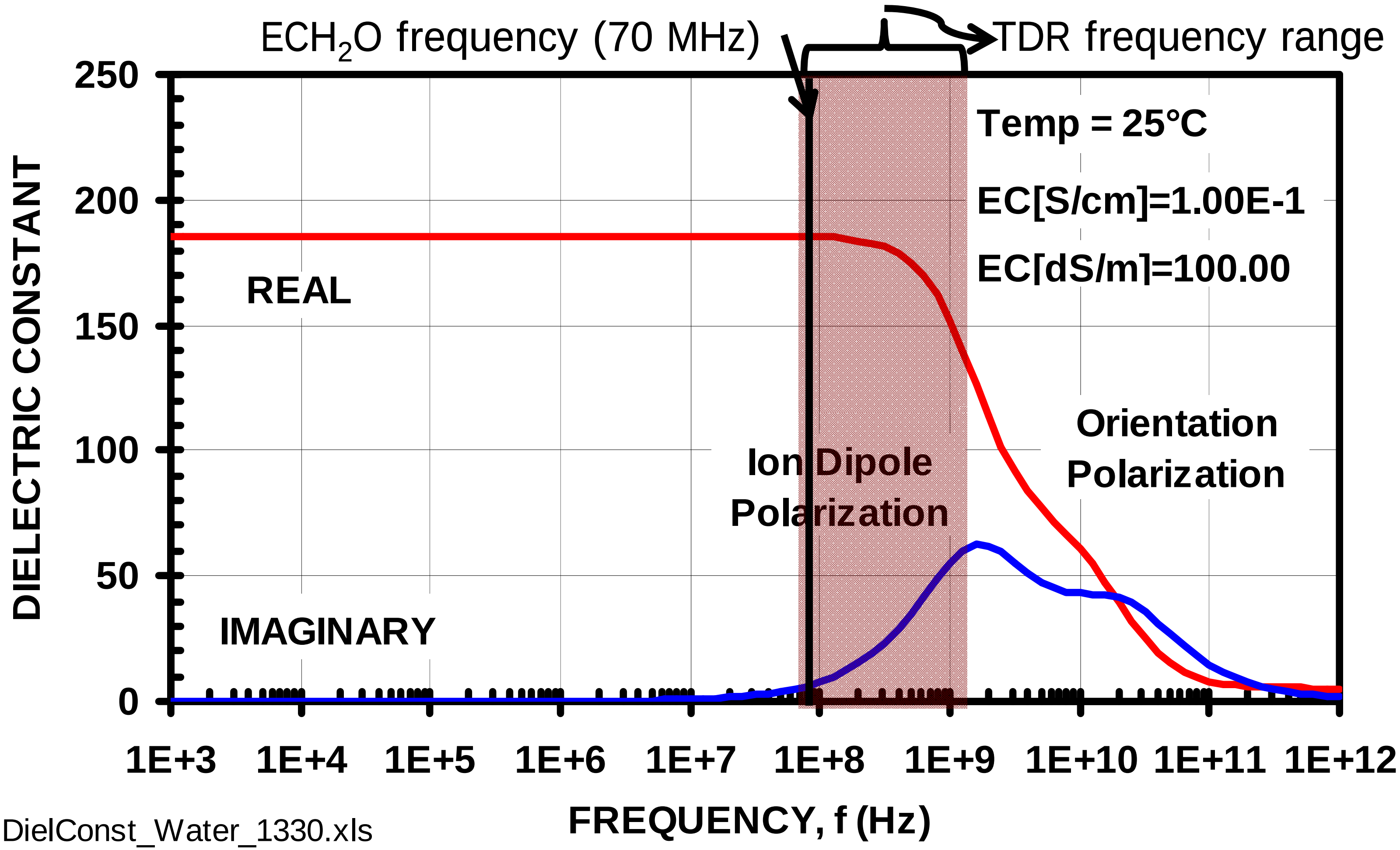
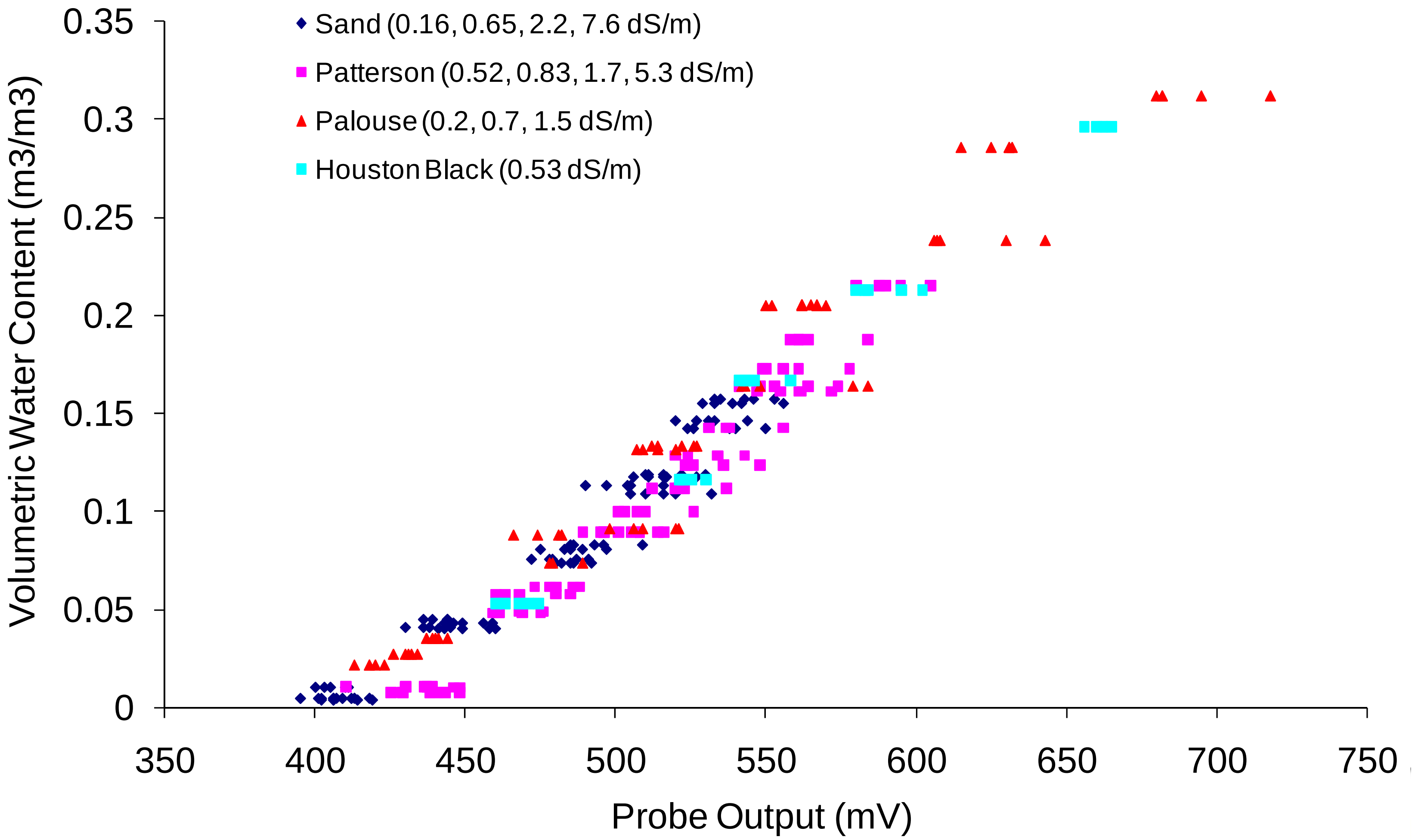


Buehler, 2011, ISEMA

EC-5 Sensor shows no significant EC effect in mineral soil



Conclusions

- Measuring charge storing capacity of soil (dielectric) gives approximation of water content
- TDR is a good measurement but has some drawbacks
- FDR (capacitance) can also measure dielectric effectively
- Other factors like temperature and EC can change sensor calibration, but not in typical situations

References

- Noborio, K. 1993. Time Domain Reflectometry (TDR): Measurements of water content and electrical conductivity of soil. Dept. of Soil and Crop Sci., Texas A&M University.