Sensors Converge

Accurate Soil Moisture Sensing

Accurate soil sensing using changing magnetic properties with moisture

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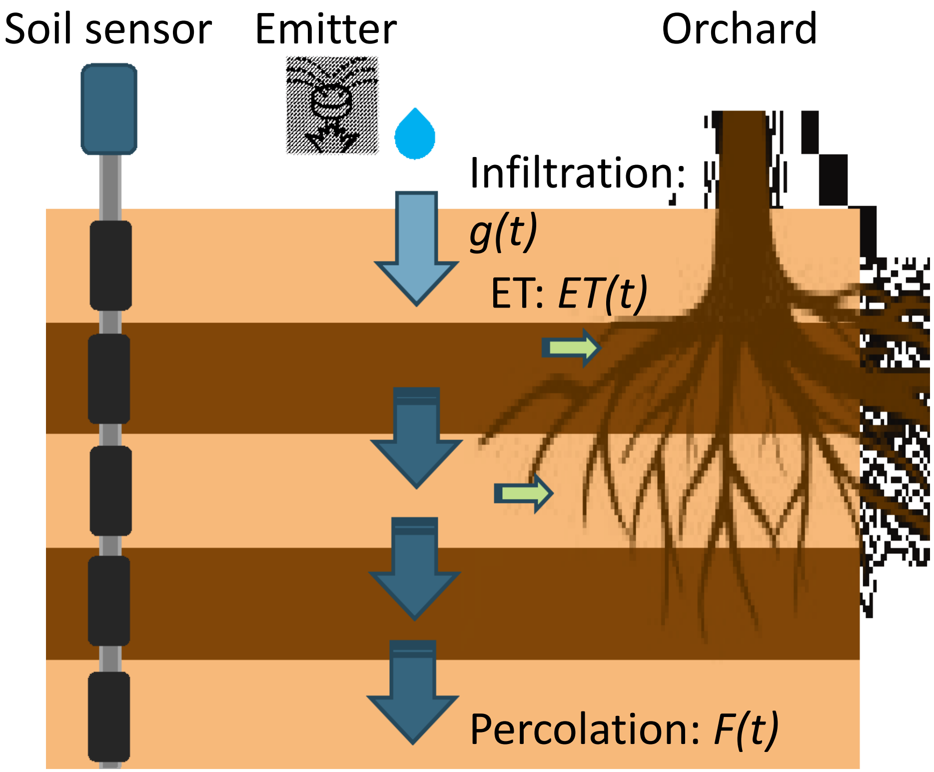
Soil Moisture Sensing for Precision AgTech

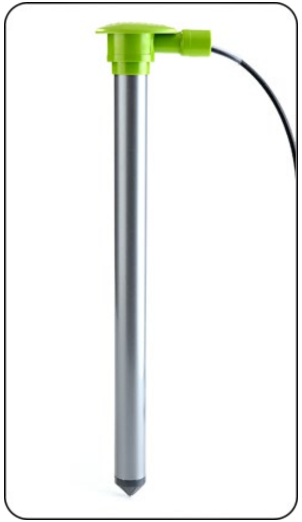
Example use case:

Soil moisture sensing on a commercial farm to determine needed irrigation in an orchard

Determining percolation rate and water usage using soil moisture sensing



Soil Moisture Sensor Evolution



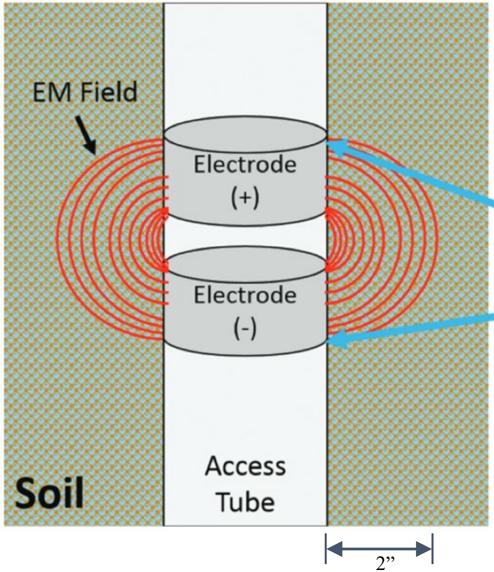
Fork Sensing
Single-level
Capacitive Sensing
Circa 2000

Drill and Drop
Multi-level
Capacitive Sensing
Circa 2010

Drill and Drop
Multi-level
Magnetic Sensing
Circa 2020

Range of Capacitive vs. Magnetic Comparison

Capacitive



Most of the water measured is sensed within 1” of tube. Heavily influenced by water running down tube outside wall.

Magnetic Sensing

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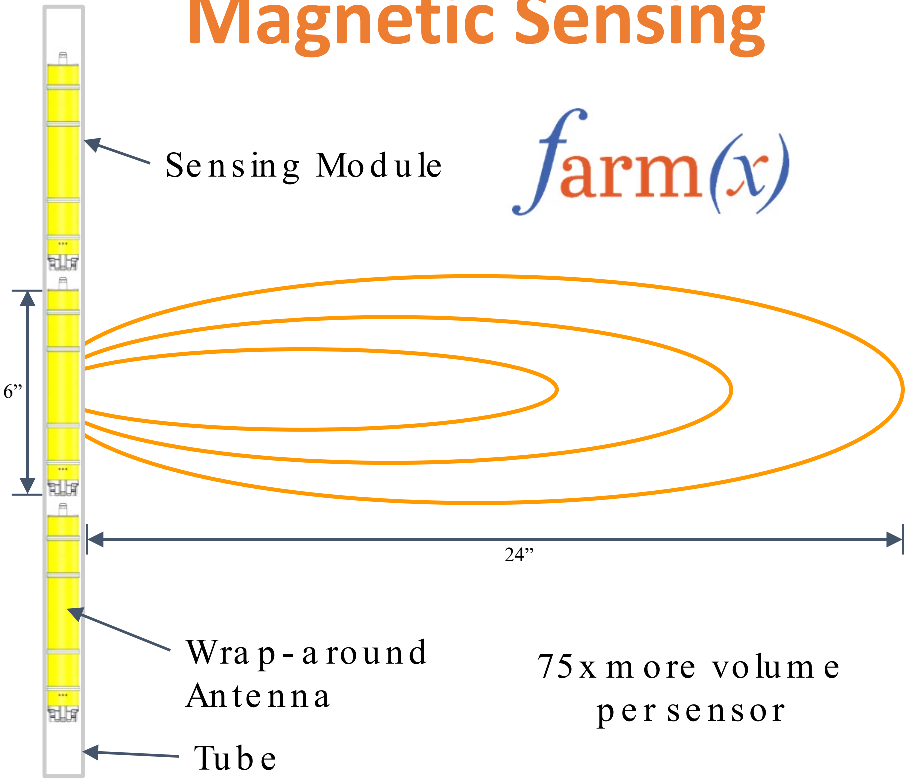

75x more volume per sensor

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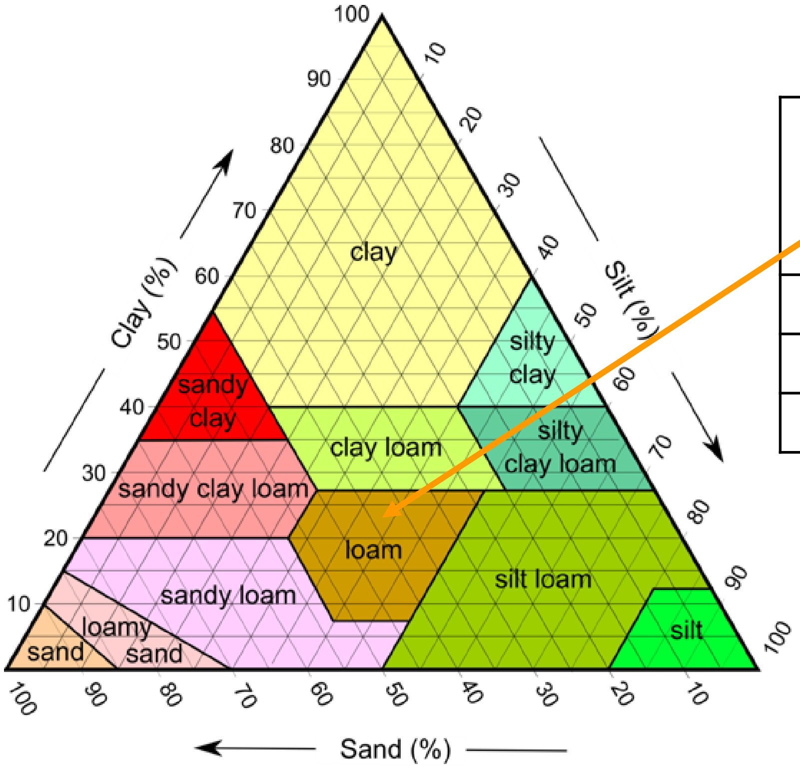
Magnetic Permeability changes with moisture



Loam Soil Moisture (VWC)	μ_r@120 MHz
2.5%	0.94
8.2%	0.95
25.6%	0.97

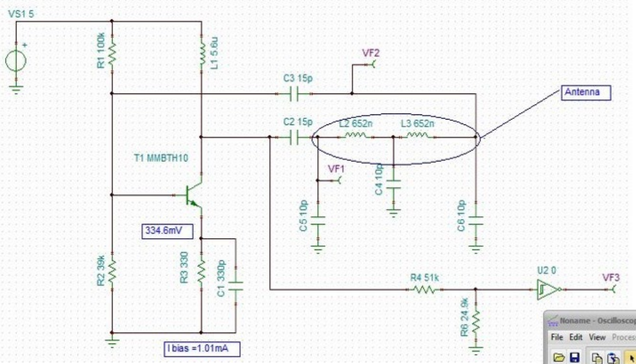
Values of Relative Permeability (μ_r) taken from soil measurements made under supervision of Sandia National Laboratories, see:
https://inis.iaea.org/collection/NCLCollectionStore/_Public/27/040/27040410.pdf

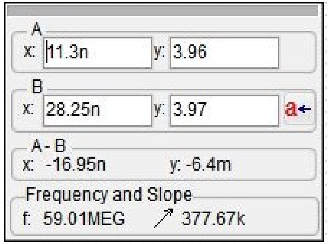
Detecting shift in magnetism in the sensor

Inductance shifts with moisture by detecting change in magnetic permeability

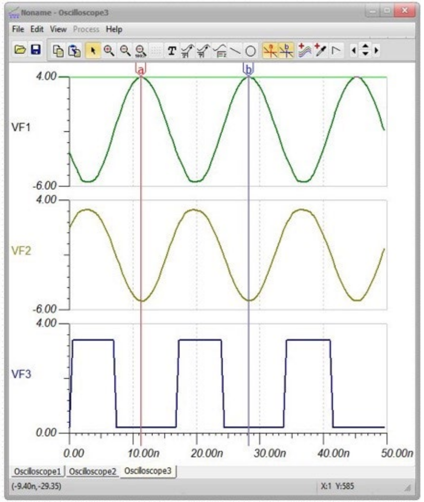
- The sensor’s antenna acts as a “variable core inductor” when coupled to soil
- The magnetic permeability of the ”variable core inductor” changes as the soil varies from dry to wet. This shifts the inductance in an oscillator tank circuit, which we measure.
- Inductance of the variable core inductor is proportional to the magnetic permeability
- Example inductances as moisture changes:
  - Dry Conditions has an inductance of 1304 nH
  - 50% Wet Conditions has an inductance of 1324 nH
  - 100% Wet Conditions has an inductance of 1344 nH
- Not a perfect model as there are small losses in the enclosure and packaging

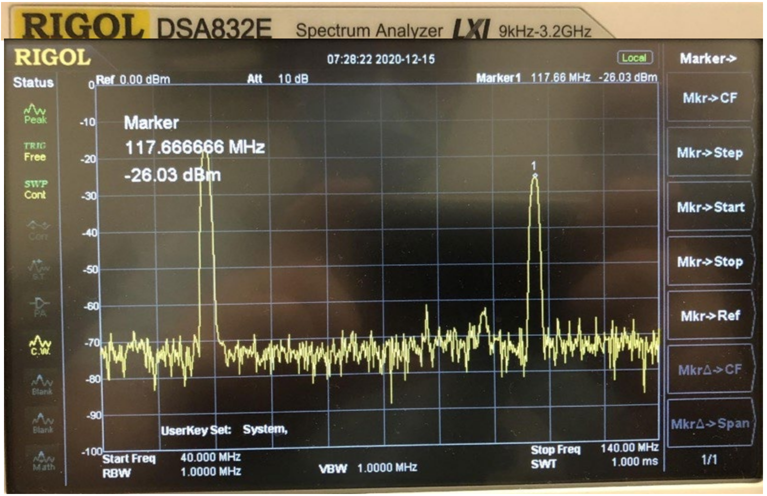
Example sensing element electronics





In simulations, the VF2 sine wave is "flatter" than the VF1 sine wave. This is achieved by the transistor bias. This flattening of the spectrum for VF2 induces both a 1st and 2nd harmonic, as shown by a Spectrum Analyzer measurement in Air. Need nominally 120 MHz for sampling soil moisture (2nd harmonic), which is seen with this trace:

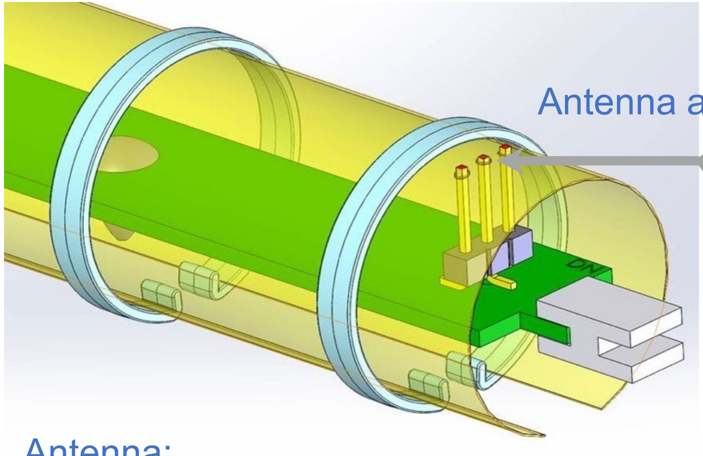




<u>Simulation of Full Dry</u>

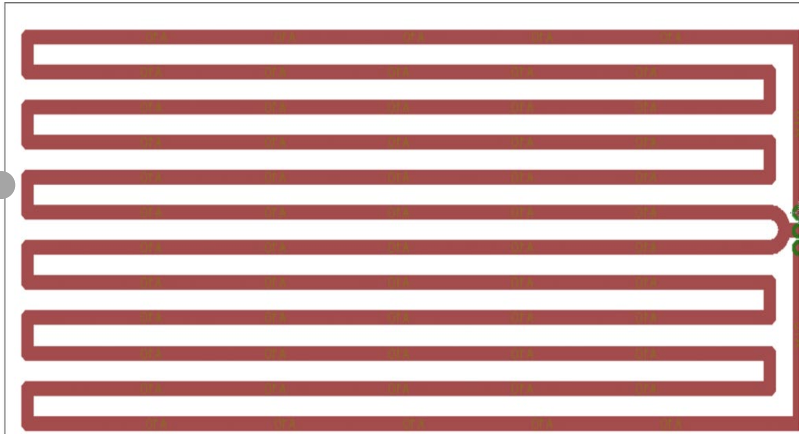
Antenna Inductance is 1304 nH
Primary Frequency: 59.01 MHz
2^{nd} Harmonic: 118.02 MHz

Sensing element with it's antenna



Antenna attached to PCBA

Top view of a Single Sided Flex Circuit
80 mil traces
Center tap antenna
2.6 inches by 5.5 inches



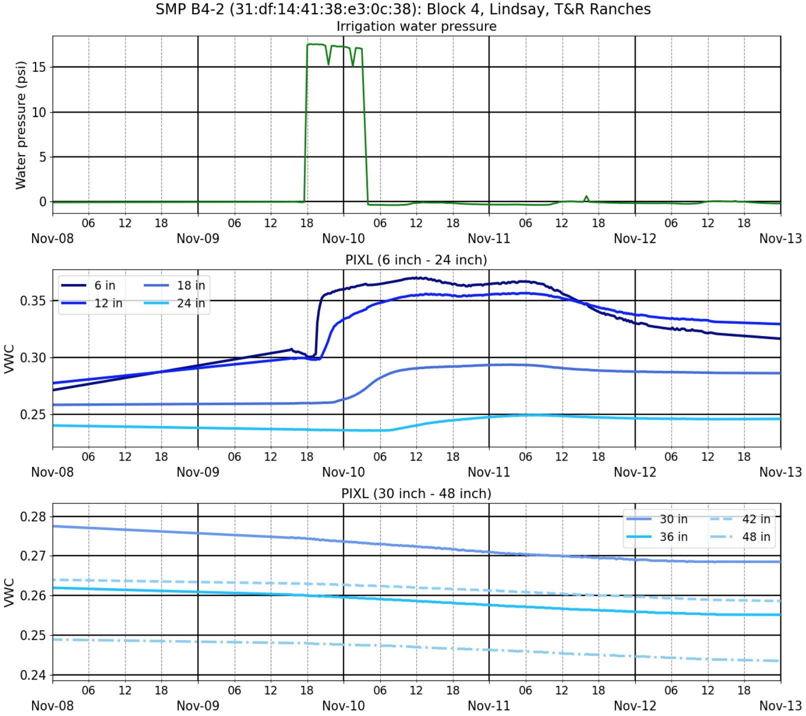
Antenna:

- Wraps on outside of a clamshell
- Secured in place with clips
- Soldered to a header on the PCB assembly that has the oscillator circuit on it

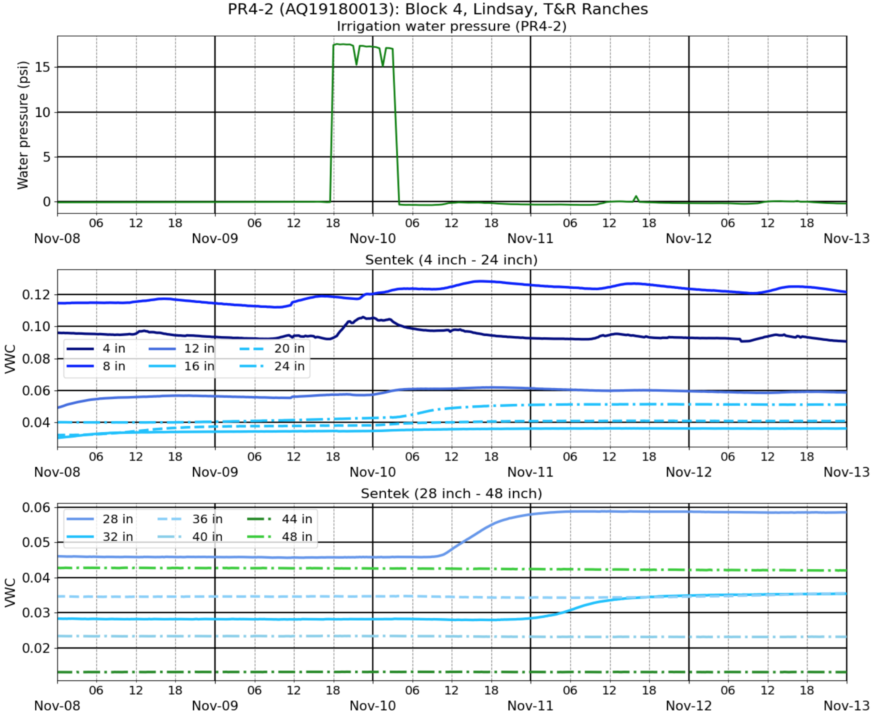
PCBA with antenna is enclosed in a waterproof outer pipe during final assembly

Field Results: Magnetic vs. Capacitive Sensing

Magnetic Sensing



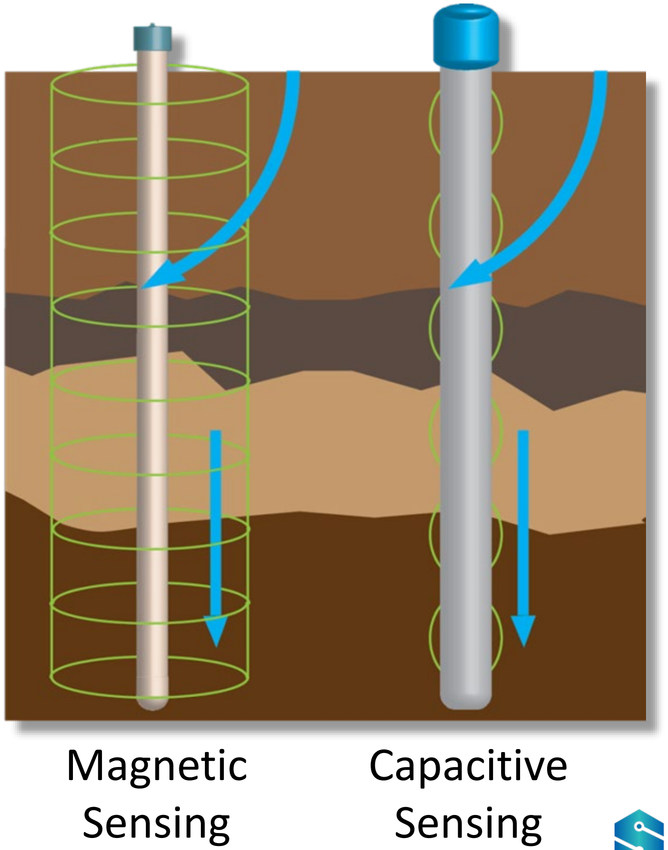
Capacitive Sensing



Benefits of larger sensing volume of soil moisture

Benefits of larger sensing volume:

- Hydrostatic -- moisture. Hydrodynamics - speed of water
- We measure moisture flow over time
- Continuous sensing volume not slices at sensed depths enables soil water flow through root zone monitoring by sensing directional flow, both up and down
- Larger sampling volume reduces anomalous readings from rocks and cracks



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Conclusion

- Soil moisture sensing is critical for improving cost effectiveness of irrigation for commercial farming
- A new generation of soil sensing is possible by measuring the shift in the magnetic properties of soil when it changes its moisture content
- The implementation of a sensor is cost effective and low power, which enables commercialization of this technology
- Growing food effectively is possible with better utilization of resources, enabled by sensing farm conditions, including it’s soil moisture content during irrigation