



# Wireless Soil Moisture Sensor Based on Fringing Capacitance

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# Goals

- ◆ To develop a soil moisture sensor based on fringing capacitance
- ◆ Sensors should be able to remain implanted for long periods and be remote readable
- ◆ They should be suitable for use in sensor arrays which cover a wide area
- ◆ Utilize IEEE 1451 standard transducer protocol (including TEDS)

# Moisture Sensor Methods

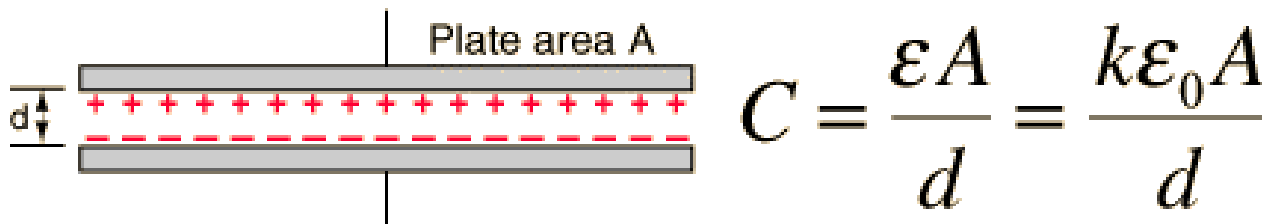
## -in solids and liquids-

- ◆ Embedded humidity sensor (based on partial pressure proportional to water concentration in solid/liquid which is in equilibrium with gas in closed chamber)
- ◆ Infra-red absorption ( $\text{H}_2\text{O}$  absorbs at 1400 nm)
- ◆ Electrical conductivity increases with water content (very material dependent, especially salt content)
- ◆ **Capacitance**, based on high dielectric constant of water (80) relative to soil particles (3-4) in the rest of the material
- ◆ RF loss/ microwave reflection – combination of capacitance and conductance effects at high frequency

# Capacitance Sensors

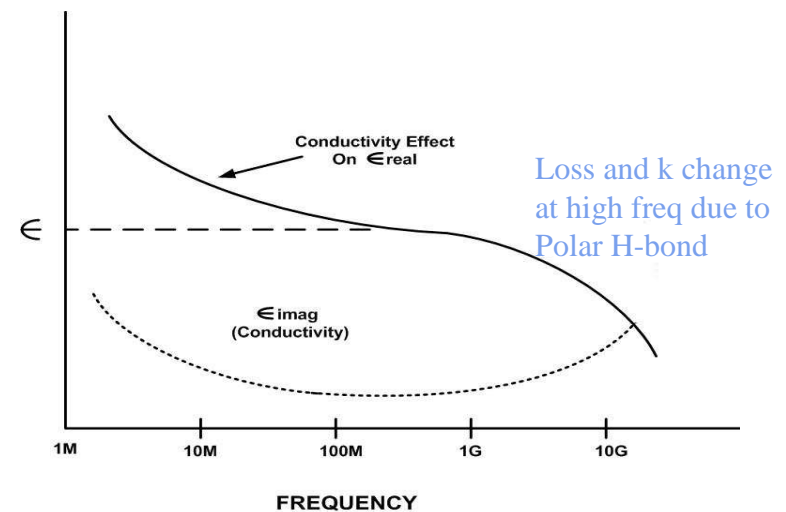
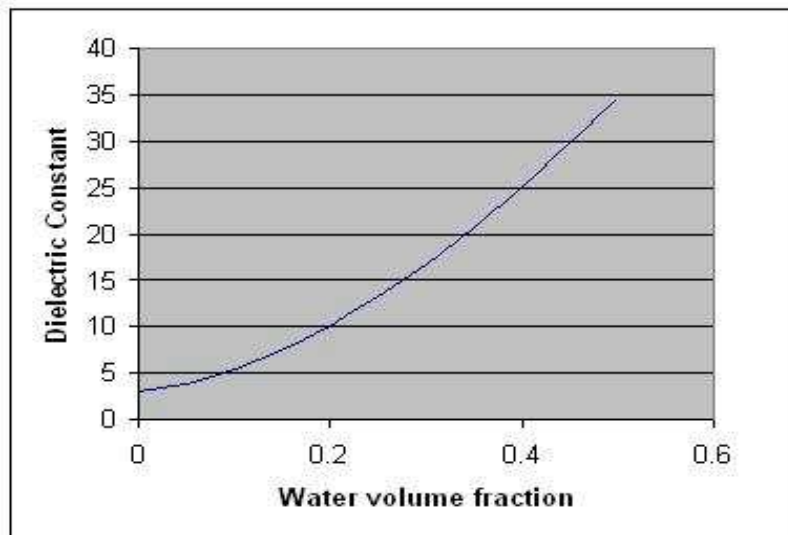
-with parallel plate configuration-

- ◆ Parallel plate is most familiar geometry
- ◆ Capacitance ( C ) is proportional to dielectric constant (k), as required for a capacitance sensor detecting water
- ◆ Typically C is in range of 10 – 100 pfd (easy to measure)


$$C = \frac{\epsilon A}{d} = \frac{k\epsilon_0 A}{d}$$

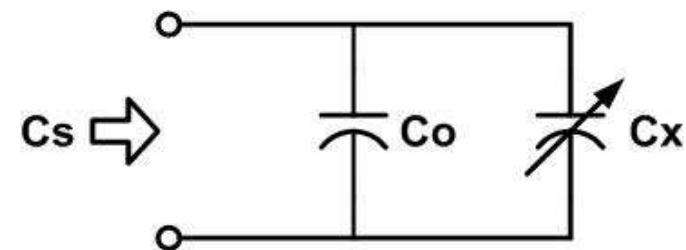
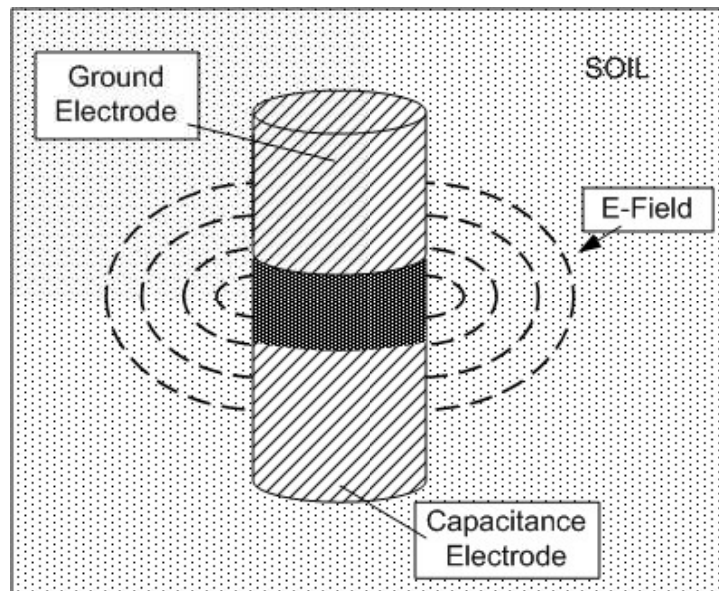
# Dielectric Dependence on Moisture Content and Frequency

- ◆ Theory based on mixtures of dielectric particles which are conducting (dielectric permittivity has imaginary & real components) – see references.
- ◆ Dielectric constant is dependence on moisture content by volume (not weight) and is non-linear (unexpected).
- ◆ Dielectric constant (both real and imaginary parts) increase as the frequency decreases – best to operate at higher frequencies



# Capacitance Sensor with Fringing Electric Field

- ◆ Fringing field allow penetration into soil outside sensor case
- ◆ Part of sensor capacitance ( $C_s$ ) is sensitive to moisture outside (e.g.  $C_x$ )
- ◆ Works with many materials in addition to soil

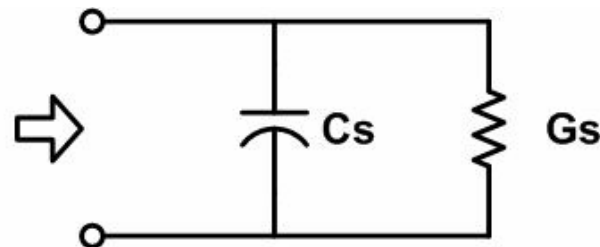


Equivalent Circuit

# Direct Effects of Conductivity on Circuits

- ◆ Soil is usually conducting due to salt content (frequency dependent).
- ◆ Equivalent circuit for sensor capacitance has shunt conductance.
- ◆ The shunt conductance effects simpler sensor readout circuits or signal conditioners (including the resonance frequency of LC circuits and the time constant of RC circuits).
- ◆ Bridge type readouts, which can independently measure the real and imaginary parts of the impedance, are not directly effected (but, as noted above, particle conductance also changes the real part of k).

$$1/Z_s = j\omega C_s + G_s$$



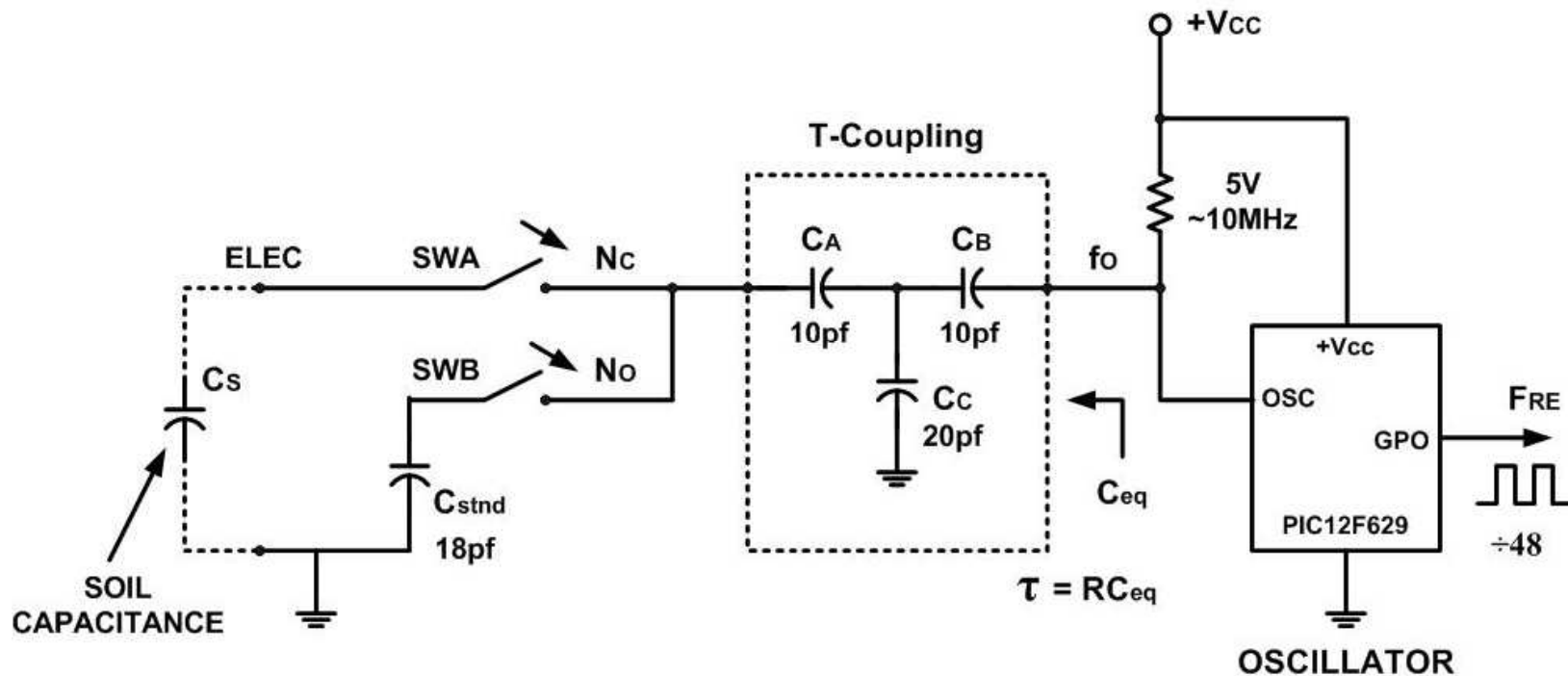
# Reducing Conductance Effects with Capacitance T-Network

- ◆ The output of a capacitance T network is (with proper component selection) nearly purely capacitive (little shunt conductance) even if the input is not
- ◆ Such a network is ideal for coupling capacitance sensors which have the undesirable conductance effects
- ◆ A disadvantage is that the capacitance change at the T network output is much less than the input, thus requiring high resolution measurements
- ◆ Oscillator or frequency shift capacitance sensor readouts typically have the required resolution, but drifts with time.
- ◆ Frequency shift, or difference relative to unconnected sensor, compensates for drift effectively



# Frequency Shift Oscillator Circuit with Capacitance T-coupling Network

- ◆ SWA connects sensor electrode ( $C_s$ ) to oscillator via T-coupling network
- ◆ SWB connects a calibration or standard capacitor ( $C_{\text{std}}$ ).
- ◆ Output (FRE) is freq ( $F_o$ ) divided by 48. Microcomputer oscillator used.

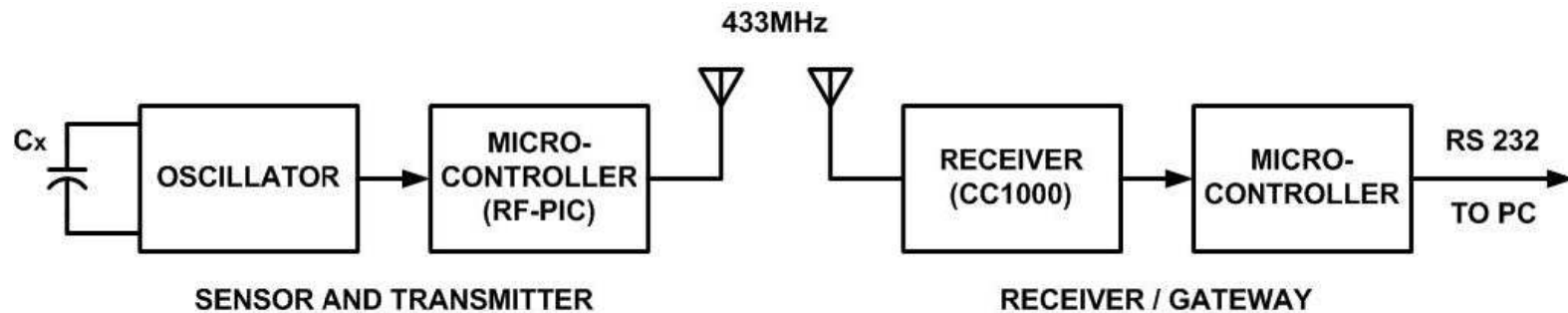


# Sensor Frequency Shift Normalization

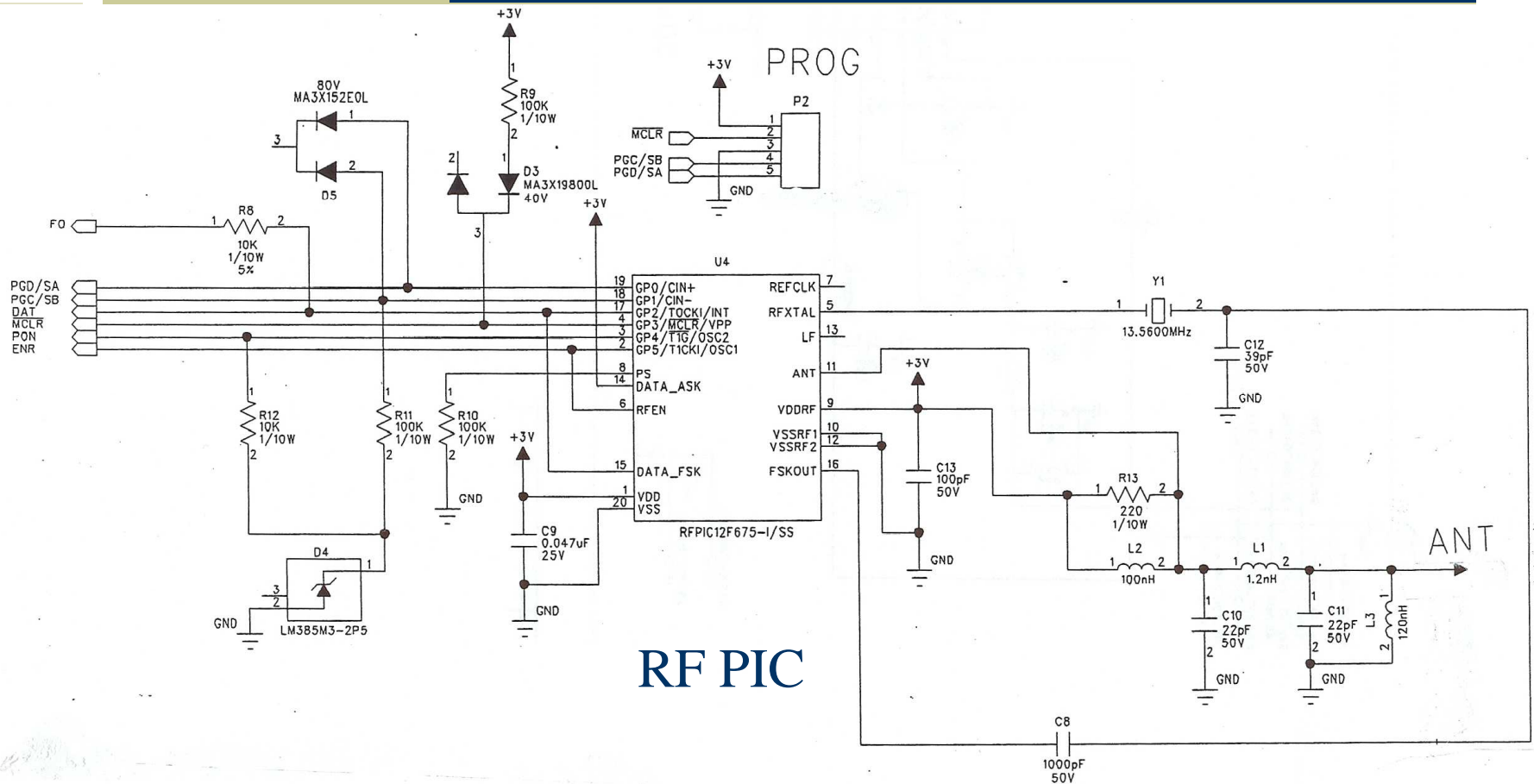
- ◆ Frequency shift is frequency difference with sensor in and out.
- ◆ The shift due to the standard capacitance is also determined.
- ◆ The normalized shift ( $Y$ ) is the sensor shift (due to sample with moisture) divided by the standard capacitance shift.
- ◆ The normalized shift with the sensor in air ( $Y_0$ ) is then subtracted.

$$Y = \frac{\Delta F_s}{\Delta F_c} = \frac{F_{ob} - F_{os}}{F_{ob} - F_{oc}} - Y_0$$

# Block Diagram of RF Transmitter and Receiver



# Circuit Diagram of Microcontroller and Transmitter

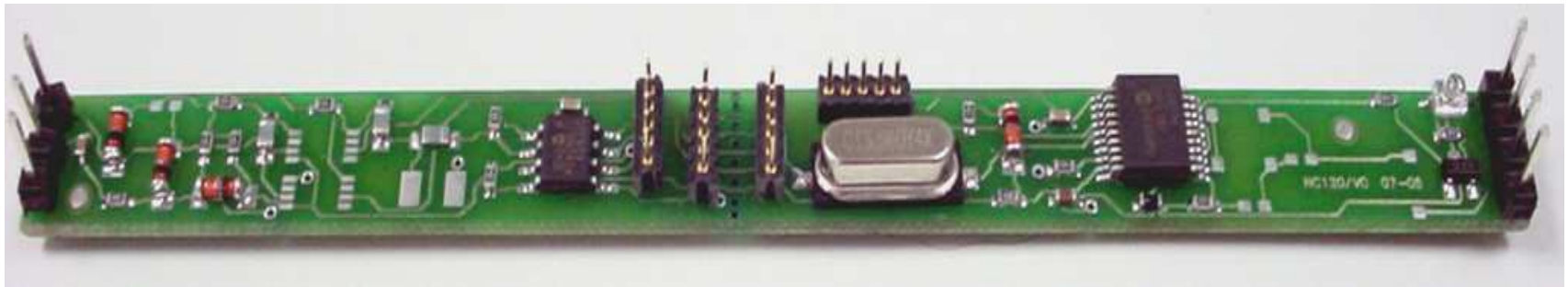


RF PIC

# Sensor Printed Circuit Board

Oscillator/T-network

Transmitter



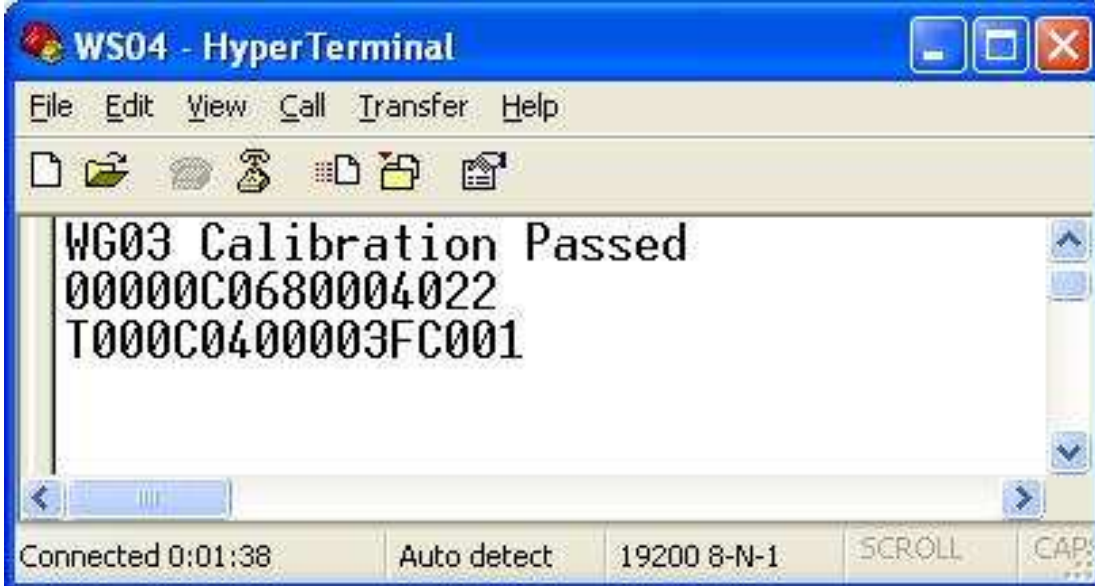
## Photo of Soil Moisture Sensor in Case

- ◆ Battery (2 AA cells) inside
- ◆ RF connector (SMA) at end
- ◆ Dimensions: 16 mm dia., 210 mm long



# Data Readout

- ◆ Data send in hourly (else sleep mode)
- ◆ IEEE 1451 TEDS (Dot 4 style) send daily



The image shows a screenshot of a HyperTerminal window titled "WS04 - HyperTerminal". The window has a menu bar with "File", "Edit", "View", "Call", "Transfer", and "Help". Below the menu bar is a toolbar with icons for file operations and communication. The main text area displays the following data:

```
WG03 Calibration Passed  
00000C0680004022  
T000C0400003FC001
```

At the bottom of the window, there is a status bar with the following information: "Connected 0:01:38", "Auto detect", "19200 8-N-1", "SCROLL", and "CAP".



# Receiver and Gateway Specifications

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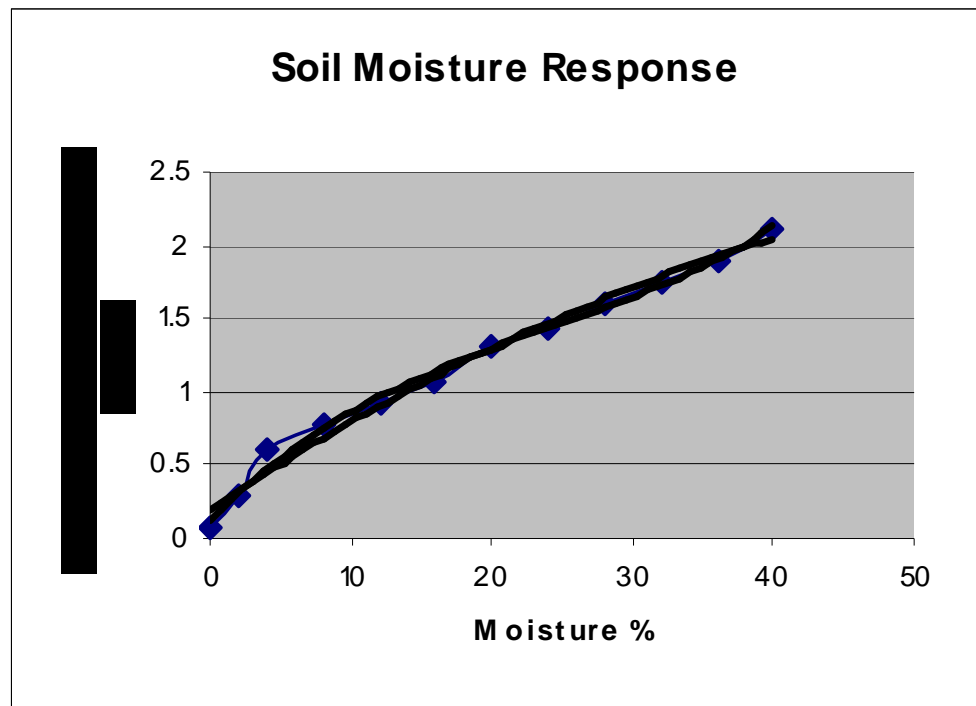
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- ◆ Data send in bursts (433 MHz)
- ◆ FM Manchester encoding
- ◆ All transmissions have address/ID information
- ◆ Sync and CRC characters are needed also
- ◆ Receiver connects PC via RS232 serial line
- ◆ Optional Internet (via Ethernet) gateway/NCAP available
- ◆ Further calibration and conversion to IEEE 1451.5 format is planned.



# Sensor Response to Soil Moisture

- ◆ Data is reproducible but curve differs from theory
- ◆ Calibration for specific soils needed.



# References

- ◆ D. Wobschall, "A Frequency Shift Dielectric Soil Moisture Sensor," IEEE Geosci. Electronics, Vol. GE16, 112-118 (1978).
- ◆ D. Wobschall, "A Theory of the Complex Dielectric Permittivity of Soil Containing Water: The Semi-Disperse Model," IEEE Geo. Trans. 15 49-58 1977
- ◆ T. J. Kelleners, et al, "Frequency Dependence of the Complex Permittivity and Its Impact on Dielectric Sensor Calibration in Soils," Soil Sci.. Soc Am. J. 69:67-76 (2005).
- ◆ IEEE-P1451 "A Smart Transducer Interface Standard for Sensors and Actuators" <<http://www.ic.ornl.gov/p1451/p1451.html>>
- ◆ D. Wobschall, "A Minimal Dot4 NCAP with a Compatible Sensor Bus," Sicon/05 (Houston, Jan 2005).

# Summary

- ◆ A wireless soil moisture sensor based on fringing capacitance was developed.
- ◆ The theory and operating principles of the sensor were discussed, including the frequency shift and normalization methods
- ◆ The wireless transmitter and data protocol were described.
- ◆ A typical sensor response (normalized frequency shift vs. % moisture by volume) was presented.
- ◆ The IEEE 1451 Dot 4 standard transducer protocol (including TEDS) was described, including provisions for conversion to the IEEE 1451.5 standard.

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