Measurement of Soil Capacitance Using Pulse Width Technique

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Abstract. Soil water content is an important parameter in many engineering, agricultural and environmental applications. Capacitance measurement methods are used to measure the soil moisture or water content. Many capacitance soil moisture sensors employ a probe consisting of two electrodes. The capacitance between the probes varies as a function of water content in the soil. The capacitance measurement setup has been developed indigenously to measure capacitance of solid samples at low frequencies using integrated circuit of Monostable Multivibrator. The change in pulse width measured by using Tektronix TDS 2024 four channel digital storage oscilloscope. In this paper capacitance of soil samples from different locations of Pune district of Maharashtra State was measured at room temperature. The details of its interface to measure capacitance of soil samples and evaluated results are explained in this paper.

1. Introduction

Soils directly and indirectly affect agricultural productivity, water quality and the global climate through its function as a medium for plant growth and as regulator of water flow and nutrient cycling. Soil water content can be directly measured using the oven drying method which is accurate and inexpensive; however, it is time-consuming and labour-intensive. In addition, there are indirect techniques which utilize other soil parameters as a proxy to estimate soil water content. Soil water content sensing relying on changes in capacitance due to soil water content is commonplace. Many use the capacitance to vary the frequency of oscillation of a multivibrator or some other form of oscillator [1-2]. Others such as Time or Frequency Domain Reflectometry measure the effect on a RF pulse due to sample impedance [3-7]. Several studies have explored relationship between capacitance of soil and soil water content [8-11].

The objective of this manuscript is to measure capacitance of soil samples from different locations of Pune district of Maharashtra State using pulse width measurement technique [12]. It employs an inexpensive and widely used IC’s viz. IC-555 and IC-74121.
2. Experimental
The experimental setup for capacitance measurement consists regulated power supply, square wave oscillator (astable multivibrator), monostable multivibrator, 200 MHz digital oscilloscope and measurement cell (Cylindrical capacitor) [12]. The block diagram of experimental setup are represented in Figure 1.

2.1. Power Supply:
There are many types of power supply. Most are designed to convert high voltage AC mains electricity to a suitable low voltage supply for electronic circuits and other devices. A power supply can by break down into a series of blocks, each of which performs a particular function as shown in figure 3. Each of the blocks is shortly described below: Transformer steps down high voltage AC mains to low voltage AC. Rectifier converts AC to DC, but the DC output is varying. Smoothing smooth the DC from varying greatly to a small ripple. Regulator eliminates ripple by setting DC output to a fixed voltage.

![Figure 1. Block diagram of experimental setup of pulse width technique.](image-url)

1. Regulated power supply
2. Square wave oscillator (Astable multivibrator),
3. Monostable multivibrator,
4. 200 MHz Digital oscilloscope,
5. Measurement cell (Cylindrical capacitor).

Figure 1. Block diagram of experimental setup of pulse width technique.
2.2. **Square wave oscillator (Astable multivibrator)**

2.2.1. *The 555 Oscillator*

The **555 Timer IC** can be connected either in its monostable mode thereby producing a precision timer of a fixed time duration, or in its bistable mode to produce a flip-flop type switching action. But we can also connect the 555 timer IC in its Astable mode to produce a very stable **555 Oscillator** circuit for generating highly accurate free running waveforms whose output frequency can be adjusted by means of an externally connected RC tank circuit consisting of just two resistors and a capacitor.

The **555 Oscillator** is another type of relaxation oscillator for generating stabilized square wave output waveforms of either a fixed frequency of up to 500 kHz or of varying duty cycles from 50 to 100%. In order to get the 555 Oscillator to operate as an Astable Multivibrator, it is necessary to continuously re-trigger the 555 IC after each and every timing cycle. This is basically achieved by connecting the Trigger input (pin 2) and the Threshold input (pin 6) together, thereby allowing the device to act as an astable oscillator. Then the 555 Oscillator has no stable states as it continuously switches from one state to the other. Also, two separate resistors, R1 and R2 with their junction connected to the discharge input (pin 7) as shown figure 4 below.

2.2.2. **Astable 555 Oscillator**
In the 555 Oscillator, pin 2 and pin 6 are connected together allowing the circuit to re-trigger itself on each and every cycle allowing it to operate as a free running oscillator. During each cycle capacitor, C charges up through both timing resistors, R1 and R2 but discharges itself only through resistor, R2 as the other side of R2 is connected to the Discharge terminal, pin 7. Then the capacitor charges up to $2/3Vcc$ (the upper comparator limit) which is determined by the $0.693(R1+R2)C$ combination and discharges itself down to $1/3Vcc$ (the lower comparator limit) determined by the $0.693(R2C)$ combination as shown in figure 5. This results in an output waveform whose voltage level is approximately equal to $Vcc - 1.5V$ and whose output "ON" and "OFF" time periods are determined by the capacitor and resistors combinations.

2.3. Monostable Multivibrator

The DM74121 is a monostable multivibrator featuring both positive and negative edge triggering with complementary outputs. An internal $2k\Omega$ timing resistor is provided for design convenience minimizing component count and layout problems. This device can be used with a single external capacitor. Inputs (A) are active-LOW trigger transition inputs and input (B) is an active-HIGH transition Schmitt trigger input that allows jitter-free triggering from inputs with transition rates as
slow as 1 volt/second. A high immunity to \( V_{CC} \) noise of typically 1.5V is also provided by internal circuitry at the input stage.

2.3.1. Features
   - Triggered from active-HIGH transition or active-LOW transition inputs.
   - Variable pulse width from 30 ns to 28 seconds.
   - Jitter free Schmitt-trigger input.
   - Excellent noise immunity typically 1.2V.
   - Stable pulse width up to 90% duty cycle.
   - TTL, DTL compatible.
   - Compensated for \( V_{CC} \) and temperature variations.
   - Input clamp diodes.

2.3.2. Functional Description
The basic output pulse width is determined by selection of an internal resistor \( R_{INT} \) or an external resistor \( R_{EXT} \) and capacitor \( C_{EXT} \). Once triggered the output pulse width is independent of further transitions of the inputs and is function of the timing components. Pulse width can vary from a few nano-seconds to 28 seconds by choosing appropriate \( R_{EXT} \) and \( C_{EXT} \) combinations. There are three trigger inputs from the device, two negative edge-triggering (A) inputs, one positive edge Schmitt-triggering (B) input.

DC regulated power supply has been developed using IC-7805. IC-555 and IC-74121 are used for astable and monostable multivibrator respectively. Sample cell, which is locally available which is of suitable dimension cylindrical cell, serve as a cylindrical capacitor and it is used as an experimental capacitor in monostable multivibrator circuit. Digital storage (Tektronix TDS 2024 four channel digital storage oscilloscopes) oscilloscope is used for the measurement of out pulse of Monostable multivibrator.

DC regulated power supply gives constant dc biasing voltage to astable and monostable for its proper operation. Astable multivibrator serves as a trigger source to monostable multivibrator and monostable multivibrator generates pulse, the time of the pulse is determined by an external resistor and capacitor connected. The length of the pulse (pulse width) is determined by the formula:

\[
T_W = 0.69 \times R_{ext} \times C_{ext}
\]  

(1)

Where, \( R_{ext} \) and \( C_{ext} \) are the external resistance and capacitor respectively. The change in pulse width is depending on value of external capacitor used in the timing circuit of monostable multivibrator, which is depending on the material which in the sample cell (Cylindrical capacitor). Finally, these observations are recorded with the help of digital storage oscilloscope. Thus, pulse widths without sample and with sample are recorded, difference between these pulses will directly give value of capacitance of sample.

Pulse width depends on values of external resistance and capacitor used in the timing circuit of monostable multivibrator. As external resistance is constant so the pulse width depends on external material which is placed in the sample cell (cylindrical cell) or capacitance.

From equation (1) it is clear that positive pulse width is directly proportional to the capacitance of the capacitor:

\[
T_m - T_0 = 0.69 \times R_{ext} \times (C_m - C_0)
\]  

(2)
Where $T_m$ and $T_0$ are the pulse widths with and without medium

$$\Delta T = 0.69 \times R_{ext} \times \Delta C \quad (3)$$

3. Results and Discussion

The observed waveforms for with and without sample are shown in Figure 6. Change in pulse width for soil samples collected from different regions are reported in Figure 7.

Figure 6. Waveforms for without sample and with sample
From figure 7, it is observed that pulse width changes with change in sample. The measured pulse width, pulse difference between without and with sample for ten soil samples collected from different regions of Pune district, Maharashtra, India are reported in Table 1. From Table 1, it is observed that $\Delta T$ is higher for the sample 1 (43.43ns) from the location (Latitude:18.0534; Longitude: 74.2825) whereas it is found lower for sample 10 (25.47ns) from the location (Latitude: 18.0957; Longitude: 74.2898). The pulse width increases with increase dielectric constant or capacitance of the medium used in the sample holder [12]. Measurement of soil permittivity through capacitance methods was first introduced by Dean, et al. [13].

Table 1. The measured pulse width, pulse difference between without and with sample for ten soil sample.

| Sr. No. | Location of sample | Pulse Width ($T_m$) ns | $\Delta T = (T_m - T_o)$ ns* |
|---------|--------------------|-----------------------|-----------------------------|
|         | Latitude | Longitude | Trial-1 | Trial-2 | Trial-3 | Average |                  |
| 1       | 18.0534  | 74.2825   | 342.50  | 344.50  | 344.10  | 343.70  | 43.43           |
| 2       | 18.0939  | 74.4234   | 339.00  | 339.30  | 338.30  | 338.87  | 38.60           |
| 3       | 18.1183  | 74.2678   | 337.00  | 337.50  | 339.30  | 337.93  | 37.67           |
| 4       | 18.1438  | 74.2971   | 334.20  | 333.00  | 332.00  | 333.07  | 32.80           |
| 5       | 18.1279  | 74.2443   | 332.50  | 332.30  | 331.40  | 332.07  | 31.80           |
| 6       | 18.2062  | 74.2150   | 330.30  | 332.00  | 333.00  | 331.77  | 31.50           |
| 7       | 18.1034  | 74.2348   | 326.80  | 326.00  | 327.00  | 326.60  | 26.33           |
| 8       | 18.0957  | 74.2898   | 324.50  | 325.70  | 327.50  | 325.90  | 25.63           |
When the amount of water changes in the soil, capacitance changes due to the change in dielectric permittivity that can be directly correlated with a change in soil water content [8]. It is shown that greater percentage of soil water content cause greater value of capacitance [8].

An increase in the soil volumetric water content causes an increase in the dielectric constant of the soil, due to the larger number of water dipoles. An increase in the capacitance is also expected because the relationship between capacitance and the dielectric constant which is directly proportional [9]. From Table 1 and Figure 6, it is observed that the pulse width is different for different soil samples. We compare estimated pulse width of soil samples with capacitance by utilizing the relationship between the volumetric soil water content and the capacitance (Equation (3) and the relationship between the capacitance and the dielectric constant [9].

4. Conclusions
The soil capacitance can be used as an efficient tool to establish a reliable soil water content profile. The capacitance of soil sample from different locations is measured using pulse width measurement technique. Pulse width is found to be different for different soil samples which directly related to the capacitance of the soil. Capacitance of soil is directly related to the dielectric constant and both related to water content in soil. This study would help to conduct further research of getting information of soil water content through pulse width measurement.

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