The Measurement of Soil Water Content Using the Dielectric Method*

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Abstract

The accurate and fast real-time measurement of the soil water content plays an important significance in water policy and precision irrigation. The measurement method based on soil dielectric properties has been the most potential measurement method. However, many soil water sensors based on the dielectric properties are not accurate because of the influence soil texture or structure. How the electromagnetic frequency affected the soil dielectric properties was studied by selecting the different frequency in the different soil texture or structure. The results of experiment show that the soil texture or structure have great influence on the soil dielectric properties in the low-frequency or the medium frequency, however, it has almost unaffected on the soil dielectric properties in the high-frequency or the very high frequency. Therefore, according to the soil texture and selecting the optimal frequency, the accuracy of the soil water sensor is greatly improved.

1. Introduction

The accurate and fast real-time measurement of the soil water content is critical to water conservancy, agriculture and automation of irrigation and drainage, and plays an important significance in water policy and precision irrigation [1]. At the beginning of the last century, the issue of the measurement of the soil water content was studied at home and abroad, and many measurement methods of the soil water content had been put forward. The drying method, the thermal properties, the neutron method, the impedance method, the capacitance method[2], the time domain reflectometry(TDR), the microwave, the frequency-domain reflectometry(FDR), the standing-wave method (SWR), near-infrared and the sensing method using large-scale remote have been more researched. However, some of the measurement methods of the soil water content are not widely used because of its defects and the complexity of soil texture. But, the measurement method based on soil dielectric properties has been widely used. Therefore, how the electromagnetic frequency affected the soil dielectric properties was studied by selecting the different frequency in the different soil texture or structure in this paper. The results of experiment show that the soil texture or structure have great influence on the soil dielectric properties in the low-frequency or the medium frequency, however, it has almost unaffected on the soil dielectric properties in the high-frequency or the very high frequency.

2. Theoretical foundation

The dielectric reflects the role and influence of the electric field by the way of the induction rather than the conduction mode [3]. The bound charges play a major role in the dielectric, and they moves by the gravity separation of the positive and the negative charge or the orientation of the electrode under the role of the

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electric field. The Debby model [4, 5] can more effectively analyze the dielectric properties of the dielectric, The relationship of the dielectric properties and the electromagnetic frequency is as follows:

$$\varepsilon(f)=\varepsilon_{\infty}+\frac{\varepsilon_0-\varepsilon_{\infty}}{1+j(f/f_m)} \qquad (1)$$

Where $\varepsilon(f)$ is the material dielectric constant, ε_0 is the static dielectric constant in the low frequency, ε_{∞} is the steady-state dielectric constant in the high frequency, f is the frequency of the electromagnetic wave, f_m is the dielectric loss peak frequency.

Equation (1) can be re-written as equation (2) and equation (3), the real part and the imaginary part of the material dielectric constant are as follow:

$$\varepsilon'(f)=\varepsilon_{\infty}+(\varepsilon_0-\varepsilon_{\infty})\frac{1}{1+(f/f_m)^2} \qquad (2)$$

$$\varepsilon''(f)=(\varepsilon_0-\varepsilon_{\infty})\frac{f/f_m}{1+(f/f_m)^2} \qquad (3)$$

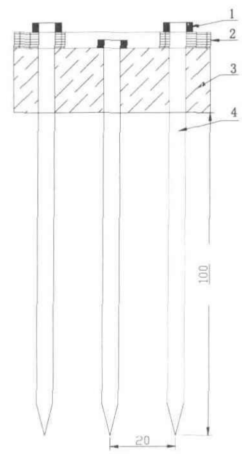
The formula (2) and formula (3)show that, if the electromagnetic frequency is far less than the material dielectric loss peak frequency, the real part of the material dielectric constant is zero, that is $f << f_m$, $\varepsilon' = \varepsilon_0$, $\varepsilon'' = 0$. If the electromagnetic frequency is far larger than the material dielectric loss peak frequency, the imaginary part of the material dielectric constant is zero, that is $f >> f_m$, $\varepsilon' = \varepsilon_{\infty}, \varepsilon'' = 0$. If $f = f_m$, the ε'' is a maximum value. Because of the influence of the dielectric loss, when the electromagnetic frequency is close to the material dielectric loss peak frequency, the ε' and the ε'' will change dramatically and affect strongly the dielectric constant.

From the above analysis, we can see that the soil dielectric loss frequency of the different soil texture has great influence on the soil dielectric. Therefore, it is necessary to ensure that the frequency of the soil dielectric is less than the smallest value of the soil dielectric loss peak frequency. The dielectric loss frequency of the different soil texture varies greatly; therefore, it is difficult to determine a suitable dielectric measurement frequency for all kinds of the soil. The effective approach taken is to make sure that the ratio of the soil water dielectric measurement frequency and dielectric loss frequency is less than a fixed value.

3. Experimental design and analysis

3.1Probe design

The soil sampling probe is critical to measure the water moisture content. Therefore, on the basis of the previous research[6-7], the soil water sensor probe of the cylindrical probe structure was produced as shown in Figure1, the soil water sensor probe mainly is consist of three fixed crew, two copper ring, a fixed probe insulating material (PVC rod), and three stainless steel needles. The dimension of the stainless steel needle is 5mm in diameter, 100mm in length, and 20mm in the distance of two stainless steel needles. The purpose of the design is apt to insert the soil and the sensor probe is not easily deformed.



1. Fixed crew 2. Copper ring
3. Insulating material (PVC) 4. Stainless steel needle

Figure 1. The structure of moisture probe

3.2 Test Circuit Design

The designed test circuit was half-wave rectifier filter circuit as shown in figure2. When the sinusoidal signal transported along the soil water probe, part of the sinusoidal signal was reflected because of the difference of the impedance of the probe and the soil. The sinusoidal signal would superpose with the reflected sinusoidal signal. The superimposed sinusoidal signal would charge the capacitor in the positive half-cycle by using the switching characteristics of the high frequency detector diode, and it would not charge the capacitor in the negative half-cycle. By passing three filter circuits, the sinusoidal signal become DC voltage with very small fluctuations. The voltage output changed with the range changes of the superimposed sinusoidal signal.

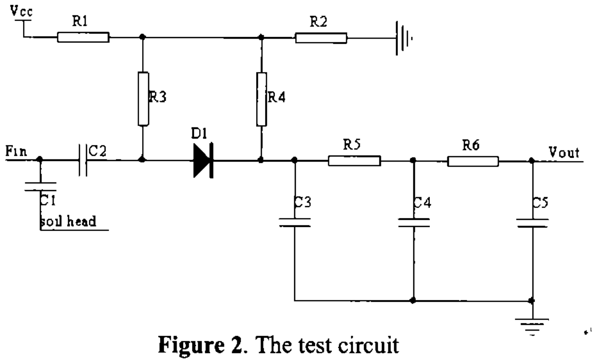


Figure 2. The test circuit

3.3 Selecting signal

In order to prevent the polarization of the probe, the sinusoidal signal was used in the experiment. The sinusoidal signals were generated by a function generator, and the amplitude of the sinusoidal signals was maintained constant at 3V and the frequency are 50 KHz, 3 MHz, 30 MHz and 150 MHz.

3.4 Soil Sample Preparation

The more common soil types, such as, clay, loam and sandy soil, are used to soil samples, and the soil physical properties are as shown in table1.

Table1: Soil physical properties

Soil type	Physical grains	Units weight (g/cm^3)
clay	75	1.27
loam	38	1.35
Sandy soil	23	1.48

The soil samples with different soil types were prepared in special covered containers, which are 8cm in diameter and 15cm in height. Before adding water, the soil samples were put into the oven-dried at 105°C for 24 hours and then ground to pass through a 2-mm sieve. Known weights of water were added to the soil samples to achieve desired the soil water contents. Measurements of the soil water content were initiated at least 24 hours after the water was added to allow the sample to reach equilibrium. The prepared soil water volume content is 12.56%, 18.73%, 25.34%, 32.16% and 40.08%.

Table2: The output voltage value in the different VWC(volume water content)and the different frequency

VWC (%)	Clay Freq(HZ)				Loam Freq(HZ)				Sandy soil Freq(HZ)			
	50K	3M	30M	150M	50K	3M	30M	150M	50K	3M	30M	150M
12.56	1.46	1.57	1.62	1.68	1.42	1.54	1.61	1.68	1.38	1.49	1.59	1.68
18.73	1.38	1.46	1.53	1.59	1.31	1.42	1.49	1.57	1.27	1.41	1.48	1.55
25.34	1.27	1.41	1.42	1.47	1.23	1.35	1.41	1.48	1.20	1.33	1.42	1.47
32.16	1.23	1.36	1.37	1.44	1.19	1.29	1.36	1.42	1.17	1.25	1.33	1.42
40.08	1.19	1.29	1.34	1.35	1.16	1.25	1.31	1.36	1.14	1.19	1.28	1.37

3.5 Analysis and discussion

3.5.1 Experimental analysis

The experimental data for the different volume water content of the clay, the loam and the sandy soil in the different frequencies of electromagnetic wave are attained as shown in the table 2 .

The curve of the voltage output and the frequency of the electromagnetic wave in the soil volume water content of the 12.56% is shown as figure3. we can see that, (1) the voltage output increases with the increase of the frequency of the electromagnetic wave for any types of the soil;(2) the voltage output of the sandy soil is larger than the loam, and the voltage output of the clay is the smallest in the same frequency when the frequency of the electromagnetic wave is less than 30MHz; (3) the differences of the voltage output for the sandy soil, the loam and the clay gradually decrease with the increase of the frequency of the electromagnetic wave;(4) the voltage output of the sandy soil, the loam and the clay is almost equal when the frequency of the electromagnetic wave is larger than 100MHz.

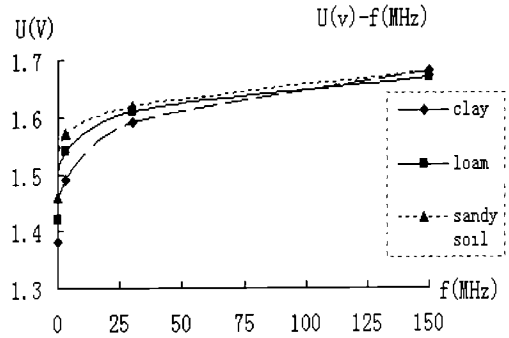


Figure 3. The U-f curve for VWC of 12.56%

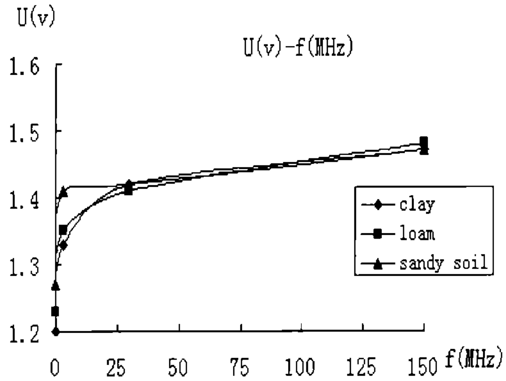


Figure 4. The U-f curve for VWC of 25.34%

The curve of the voltage output and the frequency of the electromagnetic wave in the soil volume water content of the 25.34% is shown as figure4, and The curve of the voltage output and the frequency of the electromagnetic wave in the soil volume water content of the 40.08% is shown as figure5.

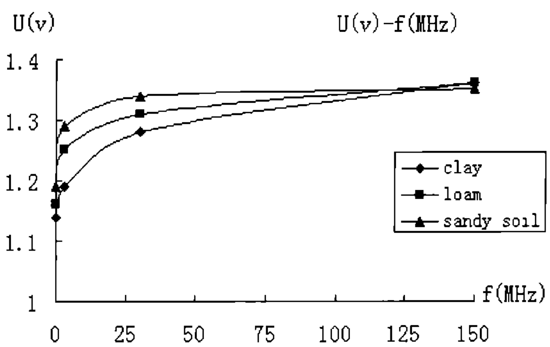


Figure 5. The U-f curve for VWC of 40.08%

From the figure4 and the figure5, we can know that the change law of the curve of the voltage output and the frequency of the electromagnetic wave is the same with the figure1; the difference is the difference of the voltage output in the same frequency of the electromagnetic wave.

The curve of the voltage output and the frequency of the electromagnetic wave in the different soil volume water content is shown as the figure6. we can see that (1)the voltage output become small in the same frequency of the electromagnetic wave when the value of the soil volume content is large, and vice versa;(2)the frequency of the electromagnetic has almost unaffected on the voltage output when the frequency of the electromagnetic is relative high.

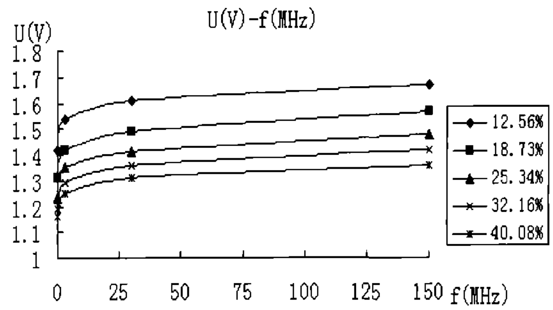


Figure 6. The U-f curve in different VWC

3.5.2 Discussion

Thought the above analysis, selecting the suitable frequency of the electromagnetic wave is critical to make the high-precision soil water sensor. The following aspects should be considered: (1) the sensor for measuring a particular type of soil water content can use the low or high frequency of the electromagnetic wave, but this kind of the soil water sensor can not use to measure the other type of the soil, otherwise, the measuring error will be large; (2) the sensor for measuring all types of the soil must use the high frequency of the electromagnetic wave, otherwise, the measuring precision will be low;(3) it is difficult to obtain the high frequency than the low frequency, so the cost of the sensor using the high frequency is higher than the sensor using the low frequency.

4. Conclusion:

(1) The experimental results show that the dielectric method is an effective method to measure the soil water content, and the voltage output become small in the same frequency of the electromagnetic wave when the value of the soil volume content is large, and vice versa.

(2) The voltage output of the sampling probe is not only by the effect of the soil water content, but also by the effect of the soil texture in the low frequency of the electromagnetic wave. However, the voltage output of

the sampling probe is only related with the soil water content.

(3)The high-precision soil water sensor can be produced by selecting the suitable frequency of the electromagnetic wave. For example, the sensor for measuring a particular type of soil water content can use the low or high frequency of the electromagnetic wave, however, the sensor for measuring all types of the soil must use the high frequency of the electromagnetic wave.

5.References

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