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Research and Design of Soil Water Content Sensor Based on High-frequency Capacitive

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Abstract: Power supply and long distance cable are difficult in a field. Hence, a low power high-frequency capacitive soil water content sensor was developed. It consisted of an adjustable signal generating circuit, a signal attenuator, a true RMS detection circuit, a RC charge and discharge circuit, and two probe electrodes. The probe electrode was made up of PCB (Printed Circuit Board). In order to reduce entire energy consumption, the optimization design of sensor circuit was conducted. The results showed that the output voltage of the sensor had a positive linear correlation with soil volumetric moisture content, and the coefficient of determination R2 was 0.989. The stability and consistency of the soil moisture sensor met the needs of the long-term monitoring soil moisture content. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Soil moisture content, High frequency electromagnetic wave, Power consumption, Calibration

1. Introduction

Soil moisture is an important component of the soil, and is one of the important influencing factors affecting crop growth and yield [1]. Soil moisture monitor is the basis of the implementation of water-saving irrigation in precision agriculture [2], which is a key link in the process to realize the automation of agricultural irrigation. Real-time monitoring of soil moisture can timely understanding of the soil moisture content, and also has important significance for research on crop water requirement rule [3, 4]. The wireless sensor network can effectively solve to set up wiring problem of traditional monitoring methods, and it was used to farmland soil moisture monitoring because of a large area , a lot of points to be tested and an observation time. The wireless sensor network nodes generally use batteries, so sensor was required for a low work voltage and small energy consumption. However, the power supply voltage of most of the sensors on the market is higher, and the current of the sensor is around 25 mA, it's hard to meet the needs of agricultural development of the Internet of things. Therefore, based on the study of the principle of dielectric measurement mechanism of soil moisture, the soil moisture sensor of low power consumption, small volume and easy to bury was designed by using the low power consumption high frequency signal source and the detector circuit. It was used to real-time monitoring soil moisture at automatic irrigation systems, soil moisture monitoring system and internet of things of agriculture system.

2. Sensor Design

2.1. Sensor Structure

Sensor is mainly composed of adjustable signal generating circuit, signal attenuator, the RC charge and discharge circuit, true RMS detection circuit and comparing amplifier circuit, as shown in Fig. 1. The adjustable signal generating circuit was used to produce a high frequency oscillation signal as a sensor of excitation signal; Signal attenuator was used to reduce sine excitation signal amplitude within the measuring scope of the RMS detection circuit, and then added to the PCB probe. True RMS detector is used to convert the probe signal into the true effective value. The wave signal was converted into the equivalent dc voltage signal. The comparing amplifier circuit converted non standard voltage signal into the ideal standard voltage signal.

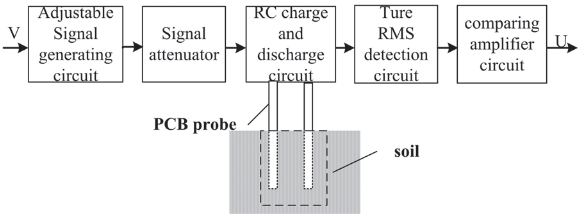

Fig. 1. Functional block diagram of soil moisture sensor.

Sensor consisted of electronic circuit PCB and PCB probe electrodes. Probe electrodes were two parallel structures, and it consisted of two rectangular Printed Circuit boards, and equipped with electronic Circuit PCB for electrical connections. The integrated molding structure of the sensor was shown in Fig. 2.

The dimensions of Probe electrode are 5 cm in length, 0.5 cm in width, 2 mm in thickness, and the inner side of the electrode distance is 0.5 cm. The triangle end of the probe was designed to easily insert into the soil. The probe PCB in apply copper layer on the surface of electrode coated with insulation layer, bare PCB probe electrode copper form the electric contact area to measure soil moisture content.

Fig. 2. Structure profile of soil moisture sensor.

2.2. Measuring Principle

When the sensor was placed in the soil, 100 MHz incentive signal was applied a first-order RC circuit, it consisted of the equivalent capacitance of the resistance R2 and probe, cycles of charge and discharge, and probe appeared the corresponding periodic waveform signals at the same time, and then the true RMS detector for true RMS was used to conversed this waveform signal into the equivalent dc voltage. When soil water content was changed, its dielectric constant changed, so as to the probe equivalent capacitance changed, resulted in changes of probe on the equivalent capacitance charge-discharge curves, namely the probe on the periodic waveform changed, the final caused changes in the sensor output dc voltage. Under the stimulus of sine signal, the charging voltage on the equivalent capacitance C was as follows:

$$U_c = V + (V_i - V)e^{-\frac{t}{RC}} \tag{1}$$

where U_c is the probe equivalent capacitance C on both ends of the voltage, V is the signal of high voltage, V_i is the signal of low voltage, t is the charging time, its size is decided by the frequency excitation signal, C is equivalent capacitance of the probe; R is the parasitic resistance of the circuit.

Capacity of equivalent capacitance C was associated with the surrounding medium of the probe and the parasitic capacitance of the probe itself [5, 6]. It was a function of the medium of dielectric constant epsilon and geometric factor, and the geometric factor was associated with the configuration of the probe electrode and the shape of the electromagnetic field in the medium.

$$C = \xi\varepsilon \tag{2}$$

where C is the equivalent capacitance of the probe, ξ is the geometric factors of the probe, ε is the dielectric constant of the medium.

Equation (3) could be obtained by equation (2) and equation (3).

$$\varepsilon = -\frac{t}{R\xi} * \frac{1}{\ln\frac{V_i - V}{U_c - V}} \tag{3}$$

By the characteristics of excitation signal, we could know that V_i was zero, so Equation (4) could be obtained by equation (3).

$$\varepsilon = \frac{t}{R\xi} * \frac{1}{\ln\frac{V - U_c}{V}}, \tag{4}$$

where U_c is the probe equivalent capacitance C on both ends of the voltage, V is the signal of high voltage, t is the charging time, R is the parasitic resistance of the circuit, ξ is the geometric factors of the probe, ε is the dielectric constant of the medium.

Because R, ξ, t, and V are constants, Equation (4) shows that the soil dielectric constant (ε) positive correlation and the voltage (Uc) of the probe are positive correlation.

2.3. Circuit Design

The experimental analysis results of different electromagnetic wave frequency measuring soil moisture showed that using electromagnetic wave measuring soil water content, the higher the frequency of electromagnetic waves, the less the soil moisture was affected by soil type. when the electromagnetic wave frequency was greater than 100 MHz soil moisture content was hardly affected by soil type [8-10]. The study of the power consumption of active crystal vibration showed that, in the case of a power supply voltage was constant, the lower the frequency, the smaller the power consumption, and in the case of a wave frequency was constant, the lower the power, the smaller the power consumption [11-13]. Thinking about the relationships of the power consumption, adaptability and accuracy of the sensor, in under the premise of guarantee sensor measurement accuracy satisfied the requirement of measurement, the power consumption of the sensor was reduced by lowering the working voltage of sensor, reducing the sensor frequency of excitation signal, and using integrated chips with low power consumption, etc.

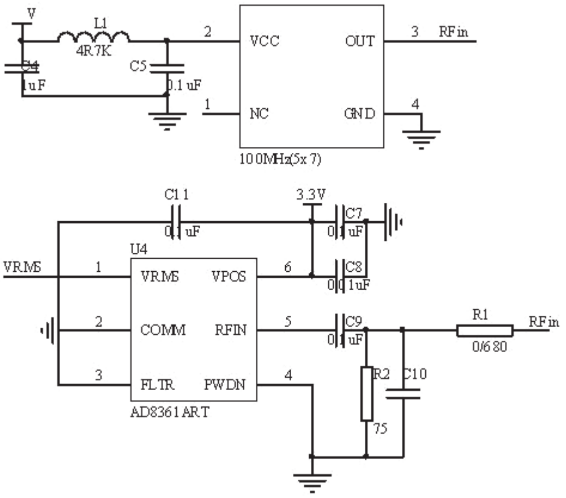

Fig. 3. Schematic circuit diagram of soil moisture sensor.

The schematic circuit diagram of soil moisture sensor was as shown in Fig. 3, the adjustable signal generating circuit was composed of the inductance L1, capacitance C4 and C5 and adjustable active crystal vibration circuit. Filter circuit on the circuit layout was close to the power input end of the active crystals, and it used to minimize Rf loop current and void adjustable active crystal vibration causing radiation associated with resonance frequency of current loop. The signal attenuator was used to adjust the value scope of adjustable active crystal vibration output sine signal to meet the demand of the input signal amplitude, so the true effective value detection circuit could easily detect the sine signal. Probe placed in the soil signal perception was quite a capacitor with soil as the medium. Its capacity was correlation with the probe surrounding medium and the parasitic capacitance of the probe itself. A first order RC circuit, which was composed of resistance R2 and the equivalent capacitance of the probe, charged and discharged according to the excitation signal cycles; True RMS detector converted the periodic signal of probe to the true effective value, and output the equivalent DC.

Active crystals model for SiT8003AL - 42-100.00000-25 was choose as adjustable crystal oscillator, because its advantages were lower power consumption of 3.6 mA, typical, standby current 5 uA and working at 1.8 V, 2.5 V and 3.3 V. Signal attenuator controlled the active crystal output signal amplitude of vibration within 390 mV, and the value of the R could not be too big, so as not to consume too much power consumption. The AD8361 was a mean-responding power detector for use in high frequency receiver and transmitter signal chains, up to 2.5 GHz. It was very easy to apply. It required a single supply only between 2.7 V and 5.5 V, a power supply decoupling capacitor, and an input coupling capacitor in most applications. The output was a linear-responding dc voltage with a conversion gain of 7.5 V/V rms. Capacitor C7 and capacitor C8 were decoupling capacitors for further filter out noise and ripple, it provided a clean working voltage for AD8361.Capacitor C11 was used to reduce the noise of AD8361 output signal. A high-pass filter circuit, which was constituted of R2, C9 and the input impedance of the AD8361, was allowed AD8361 signal input terminal for above a certain frequency signals.

3 Experiments and Analysis

3.1. Sensor Calibration Experiment

The calibration experiment was a necessary link in sensor design process [14]. This study used calibration for typical loam soil sample, the compositions of soil were: Sand: 11 %, powder: 11 %, clay: 18 %. Firstly, Farmland soil samples were passed through a 2-mm sieve, and were put into the oven-dried at 105 °C for 24 hours. 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 48 hours after the water was added to allow the sample to reach equilibrium. Calibration for moisture content of the soil sample was measured 3 times, and took the arithmetic mean, finally, and attained the measurement data of quadratic curve of least squares fitting. The calibration curve was as shown in Fig. 4, and the correlation coefficient R2 was 0.99.

We can know that from the Fig. 4, when the soil volumetric moisture content was lower than 50 %, the output voltage of the soil moisture sensor increased with the increase of soil water content. At the same time, in the process of sensor calibration, we found that when the value of soil volumetric water content was more than 50 %, the soil had reached saturation, the soil and water were separated, and the homogeneous soil samples was not possible to obtained. In the actual application process, when the field soil was saturated, the measurement for the soil moisture content had not actual meaning, therefore, in order to improve the measurement precision of sensors, the experiments of soil water content greater than 50 % were not calibrated.

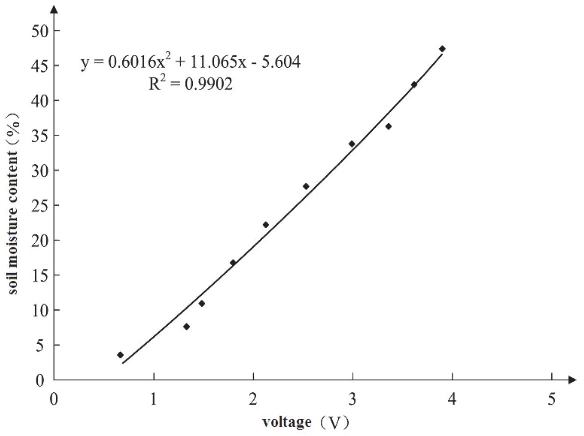

Fig. 4. The calibration curve of the soil moisture sensor.

3.2. Stability and Consistency Experiments

In order to validate the precision and the compatibility of the soil moisture sensor, stability and consistency experiment of the soil moisture sensor were designed.

The prepared samples of the soil water volume content were 10 %, 15 %, 20 %, 25 % and 30 %. The same soil moisture sensor was inserted into the standard measurement samples, each sample were measured 10 times, and recorded the measurement data.

From the Fig. 5, we can know that, when the soil standard samples were measured, there are certain gap between the value of the measurement and the value of standard sample, but the value of the measurement change around near the standard values, and maximum errors are within $\pm 2.5\%$. The measurement errors may come from disturbance the soil, the errors of the standard sample and human error, etc. Therefore, under the requiring precision of the soil sensor is not high, the stability of the sensor meets the requirement of the measurement.

Consistency test is to verify the interchangeability of soil moisture sensor, the prepared samples of the soil water volume content are 5 %,10 %, 15 %, 20 %, 25 % ,30 %, 35 %, and 40 %. The same soil moisture sensor was inserted into the standard measurement samples, each sample were measured 3 times, and recorded the measurement data, and the result is shown as Fig. 6.

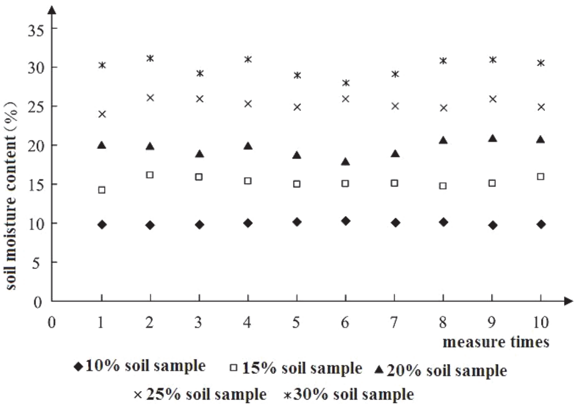

Fig. 5. The same soil moisture sensors measurement results in different soil samples.

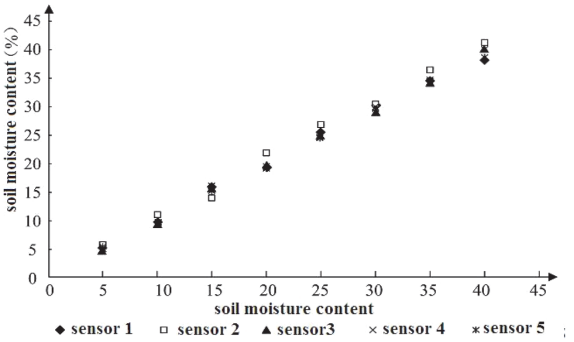

Fig. 6. The different soil moisture sensors measurement results in different soil samples.

From the Fig. 6, we can know that, when the soil standard samples were measured, there are certain gap between the value of the measurement and the value of standard sample, but the value of the measurement change around near the standard values, and maximum errors are within $\pm 3\%$. The measurement errors may come from disturbance the soil, the errors of the standard sample and human error, etc. Therefore, under the requiring precision of the soil sensor is not high, the consistency of the sensor meets the requirement of the measurement.

3.3. The Applications of Soil Moisture Sensor

To test the stability and low power consumption of the soil moisture sensor, the four months of uninterrupted continuous field test of the soil sensor was used in Doudian of Fangshan, Beijing from March to June of the 2012. Each wireless sensor node connects three soil moisture sensors, which are buried in depth of 20 cm, 40 cm, 60 cm; the measurement results were as shown in the Fig. 7.

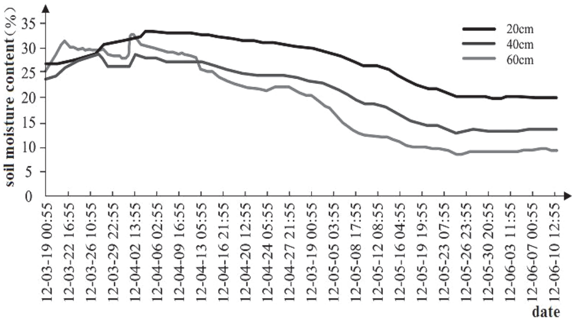

Fig. 7. The measurement results in Doudian.

As can be seen from the experimental data, the change trend of the three layers soil moisture content is the basically same, but the measurement results of the soil sensor of the 20 cm depth dramatic changed, the measurement results of the soil sensor of the 20 cm depth change slowly. The results show that the sensor can objectively reflect the change rule of soil water movement. Power consumption of the sensor meet the requirements of wireless nodes, the soil sensor is very suitable for farmland soil moisture monitoring.

4. Conclusion

1) A low power high frequency probe capacitance soil water sensor was designed to conveniently measure soil moisture content, because of using integrated molding design and PCB structure.

2) The power consumption of the soil sensor is reduced by selecting low-power chips and optimizing the circuit of the sensor on the base of analyzing the each part power consumption of the sensor circuit.

3) The sensor's output voltage is related with soil volumetric water content, and the correlation coefficient is 0.989, shows that using high frequency capacitance measuring soil water content is entirely feasible.

4) Calibration experiments and field application show that the stability of the soil moisture sensor can meet the requirements of generally measuring soil water content. Because soil sensor has a high laymen, similar sensor was used interchangeably, without affecting the accuracy of measurement.

Acknowledgments

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