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# Development and performance test for a new type of portable soil EC detector

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**ABSTRACT:** The soil electrical conductivity (EC) refers to the capability for soil to conduct current. It is a comprehensive reflection of soil salinity and moisture. Therefore, acquiring soil EC rapidly and accurately can provide better guidance for farming production. Based on improving four-electrode method, a new portable soil EC detector with six electrodes was developed and its performance was tested. Inside two electrodes and outside two electrodes were used to measure soil EC near the surface and in deeper soil, respectively. And middle two electrodes were used to input a constant current to soil. The stability tests of the current source showed that the amplitude fluctuation was less than 3%.

**Keywords:** Soil EC detector; Four-electrode method; Precision agriculture

## 0 Introduction

China is the largest agricultural producer and consumer in the world. With the rapid development of agriculture, large amounts of chemical fertilizers and pesticides were used to increase the crop yield. It has resulted in soil erosion, agricultural pollution and groundwater pollution and decreased soil productivity consequently. Precision agriculture, as a new farming approach, aimed at avoiding waste and excessive fertilizer spraying caused by blind input in farmland<sup>[1,2]</sup>.

Precision agriculture technology is an information-based agricultural management system. Implementing spatial-temporal variable management could achieve true sense of the “intensive farming” based on information and

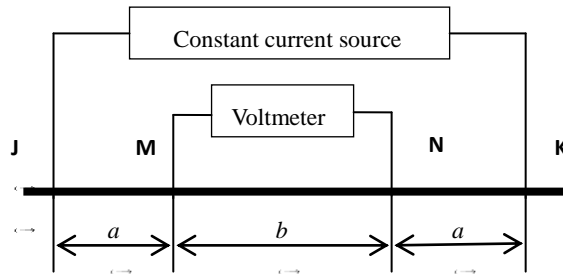
advanced technology<sup>[3]</sup>. Soil researches has shown that soil electrical conductivity (EC) contains a wealth of information for analyzing soil nutrients and physicochemical properties<sup>[4]</sup> and can reflect the soil salinity, moisture, organic matter content, soil texture, structure and porosity, etc. Acquiring soil EC effectively is of great significance to determine the spatial-temporal distribution of soil parameters<sup>[5]</sup>.

In this paper, we tried to improve the traditional current-voltage four-electrode method to better fit for in-situ measuring, and aimed at developing a in-situ soil EC detector with low price, easy operation, high measurement precision, integral control procedures and data processing procedures.

## 1 Materials and methods

### 1.1 Principle of soil EC detector development

Figure 1 is a typical structure of the current-voltage four-electrode approach, including two current electrodes (J and K) and two voltage electrodes (M and N). By loading constant amplitude current as excitation signal through two current electrodes, the soil EC can be calculated according to the voltage collected from two voltage electrodes.



**Figure 1** Principal diagram of current-voltage four-electrode method

The earth is complex object with uncertain cross-sectional area and length. Researches showed that the earth EC could be measured according to formula (1)<sup>[6]</sup>.

$$\sigma = \frac{\left( \frac{1}{d_{JM}} - \frac{1}{d_{JN}} \right) - \left( \frac{1}{d_{KM}} - \frac{1}{d_{KN}} \right)}{2\pi} \frac{I}{V_{MN}} = k(a, b)V_{MN}^{-1} \quad (1)$$

where,  $\sigma$  (with unit of S/m) is the value of EC ;  $I$  (with unit of A) is the current

provided by the constant current source.  $V_{MN}$  (with unit of V) is the voltage measured between the M and N electrode;  $k(a,b)$  (with unit of m) is the function with variables of  $d_{JM}$ ,  $d_{JN}$ ,  $d_{KM}$  and  $d_{KN}$ ; Besides,  $a=d_{JM}=d_{KN}$ ,  $b=d_{MN}$ .

To measure the EC in deep soil layer, two electrodes were added on the basic four electrode theory, which is shown in Figure 2. Moreover, accurate circuits were designed to ensure constant alternating current could be loaded between two current electrodes, and the voltage of inside and outside electrodes could be collected accurately.

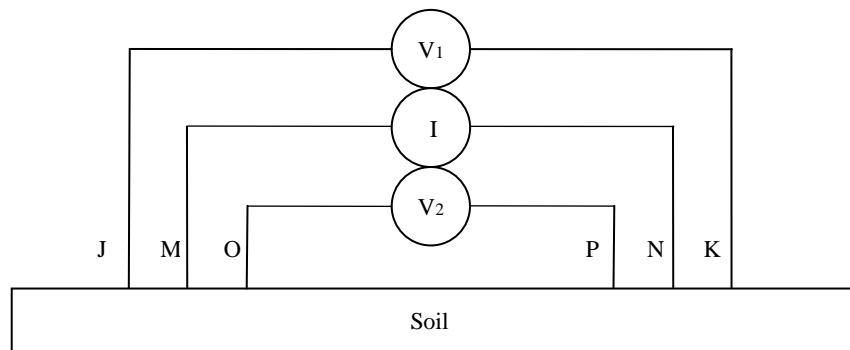


Figure 2 Schematic of improved current-voltage four-electrode method

## 2 Results and discussions

### 2.1 Soil EC in-situ detecting system design

In-situ measurement system of soil EC was designed as shown in Figure 3. It mainly includes signal generating circuit, output signal conditioning circuits and data acquisition circuit.

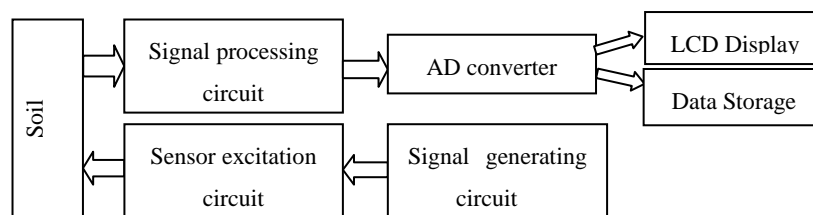


Figure 3 System diagram

## 2.2 Circuits development

### 2.2.1 Sinusoidal signal generating circuit

ICL8038 was used as waveform generator to output sinusoidal signals. After processed by LM324, the circuit produced stable alternating current source avoiding distortion caused by oversized signal.

Figure 4 is 300Hz sinusoidal signal generating circuit.  $C_{15}$  and  $R_2$  were used to implement low-pass filter, playing the role of cutting off direct current and conducting alternating current. Resistors of  $(R_{14}+R_x)$  ( $R_{15}+R_{13}-R_x$ ) were used to adjust the amplitude of current source of  $I_1$ ,  $I_2$  and duty cycle square wave. Tests indicated that in order to minimize the total harmonic distortion of signal (TDH), it was necessary to keep  $(R_{14}+R_x)$  and  $(R_{15}+R_{13}-R_x)$  equal.  $R_{16}$  was used to adjust the shape of the sinusoidal signal. Tests showed that when  $R_{16}=82\text{ k}\Omega$ , TDH kept the minimum.  $C_3$  and  $(R_{14}+R_x)$  were used to adjust the frequency of output sinusoidal signal calculated by formula (2).

$$f=0.3/[(R_{14}+R_x)]/C_3 \quad (2)$$

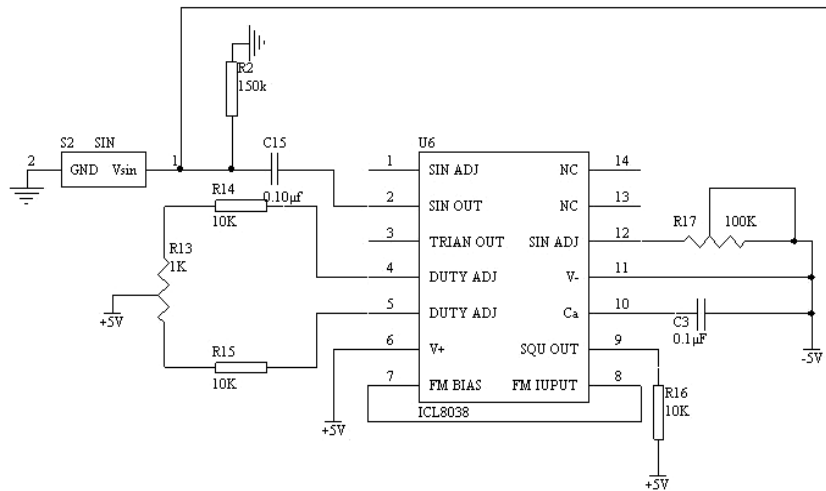


Figure 4 Sinusoidal signal generating circuit

### 2.2.2 Constant current source circuit

Experiments and literatures suggested that the soil EC measuring accuracy mainly depended on the constant amplitude alternating current source when using current-voltage four-electrode method<sup>[7,8]</sup>. Figure 5 is the circuit diagram of stable

alternating current source controlled by LM324. LM324 series are devices of the four op amp with differential input and have some advantages compared with standard op amp. With 3~32V supply, the quiescent current is only one fifth of the MC1741's. In digital systems, it can easily provide the necessary interface circuitry without extra supply. In Figure 5, the benchmark (pin 3 in LM324, the input signal) of the AC source is Sinusoidal signal, which is the output signal from the sinusoidal signal generator ICL8038.

This circuit was with high output impedance and the output current could be controlled by programming digital potentiometer. It could be automatically adjusted with different impedance conditions and designed to fit for the soil EC with low

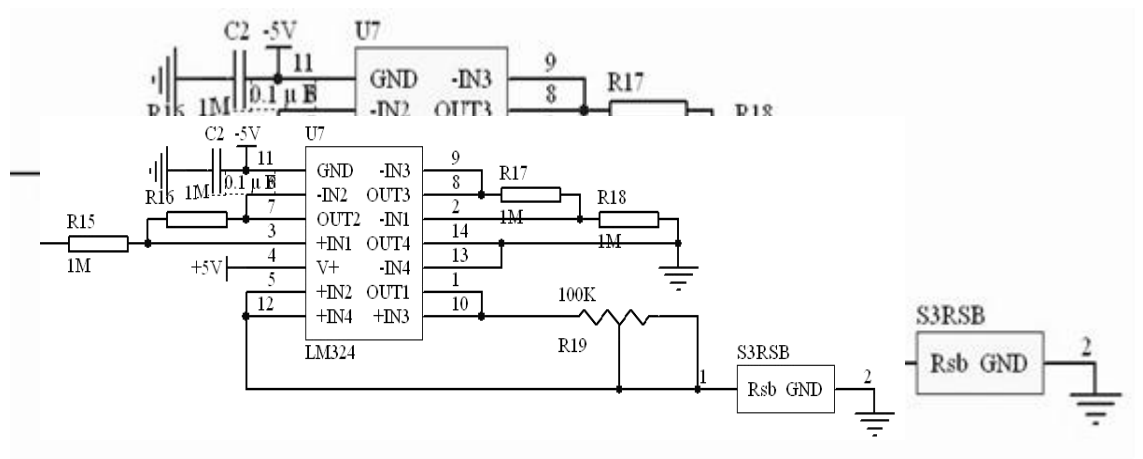


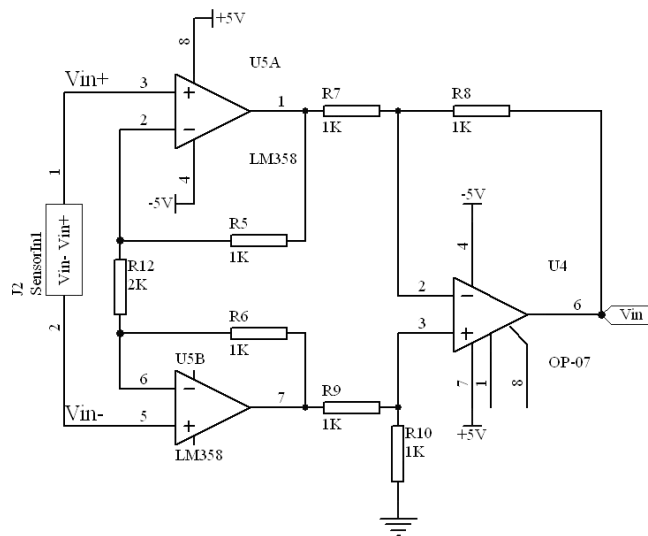
Figure 5 Constant current source circuit

### 2.2.3 Differential circuit

Unbalanced texture and structure of soil are likely to cause the instability of the signal. A subtraction circuit was designed to reduce signal instability, remove unreasonable signal, enhance useful signal and improve the accuracy. The differential circuit is shown as Figure 6. It was the combination amplifying circuit of inverting input and non-inverting input, and implemented the subtraction between  $V_{in+}$  and  $V_{in-}$ . In the ideal conditions, two input voltages of the op amp were equal. It meant that there were virtual short and common-mode voltages between both ports of the op amp. When  $R_5=R_6$  and  $R_7=R_8=R_9=R_{10}$ ,  $V_{in}$  can be calculated by formula (3).

$$V_{in} = 1 + 2R_{17}/R_{16}[(V_{in+}) - (V_{in-})] \quad (3)$$

Because of common-mode voltage, the op amp with higher common-mode rejection ratio should be chosen and the bias voltage of the op amp should be taken into consideration. In the case of the above two factors and cost reason, LM358 and OP07 were used in this paper. This circuit was with high input impedance and low output impedance, which is suitable for the signal conditioning circuit.



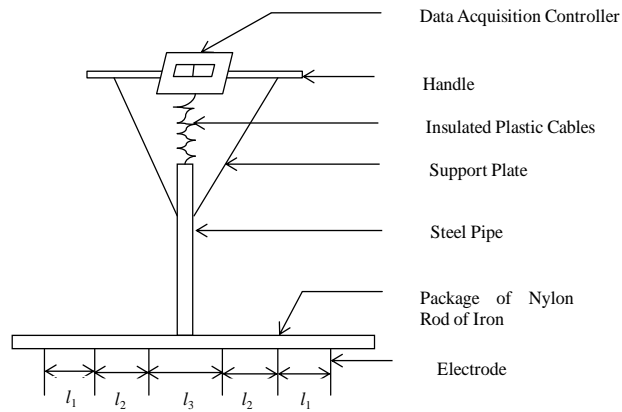
**Figure 6** Differential circuit

### 2.3 Design and development of in-situ soil EC detector

The electrode and structure and structure of the detector, signal generating circuit, signal conditioning circuit, LCD module and storage module were designed and developed. In addition, the system was set aside many peripherals used for future extensions.

#### 2.3.1 Hardware integration and development

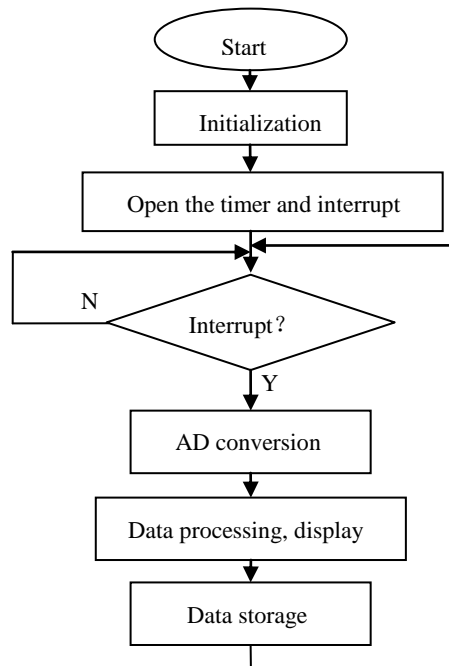
The structure of the in-situ soil EC detector is shown in Figure 7. The instrument consisted of handle, straight pipe, electrodes, data acquisition controller and other components. After measuring the voltage of the electrodes, the detector calculated EC, and then displayed and stored data.



**Figure 7** Schematic of the in-situ soil EC detector

### 2.3.2 Software design and development

The overall software flow chart is shown in Figure 8.



**Figure 8** Overall flow chart of the system software



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