A distributed high-density resistivity meter working on a two-wire cable

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Abstract. High-density resistivity meter is a common instrument used in shallow geophysical exploration. At present, the structure of the centralized high-density resistivity meter is bulky, while the distributed instrument needs more than 7 core cables, and the long measuring line needs to relay power supply to the intelligent electrode to provide enough voltage, so it is not convenient to use in the field. Aiming at the above problems, a new type of distributed high-density meter is developed, which can realize the power supply, communication, and measurement functions of distributed high-density meter and carry out multi-channel measurement through the time-division multiplexing of a two-wire cable and the short-time power supply of supercapacitor. Finally, the performance of the instrument was verified by experiments.

1. Introduction

High-density resistivity meter is a geophysical exploration instrument that uses resistivity differences of underground medium to explore the shallow underground structure. It has the advantages of simple principle and low cost and is widely used to search for groundwater [1], mineral exploration [2], geological exploration [3], engineering detection [4], and so on. Since its development in the 1980s, the high-density resistivity meter has been highly automated and intelligent. Compared with the traditional DC resistivity meter, the high-density resistivity meter saves a lot of manpower and material resources and improves the working efficiency [5,6,7]. However, due to the large number and weight of cables required by the centralized high-density resistivity instrument, it is not suitable for long section measurement. Although the distributed high-density resistivity meter reduces the number of cables, it still needs more than 7 cores of multi-core cables, and it is easy to be damaged by dragging and twisting during use.

Liang B. H et al. [8] developed an electrode multi-channel remote control, which uses the wireless remote control to replace the running pole. Later, his team improved the cable lending remote control and used the necessary $A$, $B$, $M$, and $N$ wires to transmit the wired carrier signals to control the electrode switching and power supply. This method still required 4 core cables.
In this paper, a two-wire high-density resistivity meter is developed, which adopts a distributed structure. The two-wire structure reduces the overall weight of the instrument, making it more convenient and flexible to use.

2. Theory
The measuring principle of the traditional DC resistivity method is shown in figure 1. The current is injected into the ground through electrodes \( A \) and \( B \), and the potential difference between electrodes \( M \) and \( N \) is collected at the same time. Then according to the electrode device, the apparent resistivity \( \rho_s \) can be calculated as

\[
\rho_s = K \frac{\Delta U_{MN}}{I_{AB}}
\]

(1)

where \( K \) is the electrode device coefficient, and

\[
K = \frac{2\pi}{\frac{1}{AM} + \frac{1}{AN} - \frac{1}{BM} - \frac{1}{BN}}.
\]

Figure 1. Principle of DC resistivity method.

The high-density resistivity method is to arrange dozens of electrodes at one time and make the resistivity measuring device move along the measuring line automatically through the control of the electrical measuring instrument, to complete the measurement of the apparent resistivity of the whole section.

3. Design
3.1. Instrument Structure
The application environment of the high-density resistivity meter is complex, so the instrument needs to develop in the direction of easy to use, high flexibility, and easy expansibility. Combining the \( A, B, M, N, \) power line, and communication line of the distributed resistivity instrument can greatly reduce the volume and weight of the cable.

Figure 2. Instrument structure diagram.

The overall structure of the instrument is shown in figure 2, mainly including the master controller, intelligent electrodes, a twisted pair cable, and other parts. The structure block diagram of the master controller is shown in figure 3. It is mainly used to control each intelligent electrode, transmit and measure the current, and supply power for the intelligent electrode. The structure block diagram of the intelligent electrode is shown in figure 4, which is used to form an excitation loop and measurement
loop and measure voltage. Through time division multiplexing, twisted pair becomes communication line, power supply line and measurement signal line.

![Figure 3. Structural block diagram of the master controller.](image)

![Figure 4. Structure block diagram of the intelligent electrode.](image)

### 3.2. The topological structure of electrode devices

In order to realize the two-wire high-density resistivity meter, we designed a relay switch matrix, which can make the electrode become one of $A$, $B$, $M$ and $N$ by switching the state of relay switch, and it can also be both $N$ electrode and $M$ electrode.

The instrument can form three basic electrode arrays commonly used in the high-density resistivity method, namely, the wenner device ($\alpha$, $AMNB$), the dipole-dipole device ($\beta$, $ABMN$), and the differential device ($\gamma$, $AMBN$). The topology of the $AMNB$ electrode arrangement is shown in figure 5. Multi-channel measurement can be realized through $NM$ state, and $n$ electrode systems have at most $n-3$ channels. The current emission loop and the potential difference measurement loop of the two-wire instrument are composed of two-wire cables, so the electrode between the main controller and the $A$ electrode cannot measure the potential difference.

![Figure 5. Multi-channel $AMNB$ electrode topology.](image)

### 3.3. Short time power supply

When the instrument is measuring, the intelligent electrode behind electrode $A$ cannot take electricity from the two cables. The intelligent electrode uses a supercapacitor as a short-time power source during measurement. Compared with lithium batteries, supercapacitors charge faster and have a longer service life. When a supercapacitor discharges, the voltage decreases over time. A drop in voltage to a certain value will prevent the system from working properly. The capacity of the required ultracapacitor can be estimated by formula (2).

$$C = \frac{2 \times P \times t}{U_0^2 - U_{min}^2}$$

where $P$ is the output power that the supercapacitor needs to maintain, $t$ is the duration, $U_0$ is the initial voltage value of the supercapacitor, and $U_{min}$ is the minimum operating voltage. The charging circuit of the supercapacitors in the smart electrode is shown in figure 6.

![Figure 6. Supercapacitor charging circuit.](image)

The step-down module with wide-range DC input converts the $75 \sim 300$ V voltage output by the master controller into 12 V, and charges the super capacitor in a constant voltage manner. According
to the capacity of the ultracapacitor and the load capacity of the step-down module, appropriate current-limiting resistance is selected to ensure the normal operation of the power module.

3.4. Communication circuit and software design
Setting the default state of the smart electrode can either charge the ultracapacitor or communicate with the master controller. The master controller communicates with the intelligent electrode by encoding and decoding. The transmission circuit structure of the main controller is shown in figure 7. The level conversion and load capacity are improved by using the structure of complementary MOSFET, which is suitable for the situation where the communication distance of the two-wire distributed high-density resistivity instrument is long and there are many nodes. In the intelligent electrode, the 12 V pulse signal is successively reduced to the 5 V pulse signal after shaping by the Schmidt trigger after the resistor voltage divider and the regulator diode limiter. The transmission circuit of the intelligent electrode is the NMOS switching circuit, in which the NMOS is at the intelligent electrode, the current-limiting resistor, and the power supply are in the main controller.

![Diagram](https://example.com/diagram.png)

**Figure 7.** Block diagram of master controller sending and intelligent electrode receiving circuit.

MCU generates two kinds of pulse signals, the narrow pulse with a duty cycle of 0.25 and the wide pulse of 0.75, and codes them into binary "0" and "1" for communication. As shown in figure 8, an instruction consists of a synchronization code, an address code, and a data code. The synchronization code is used to give the reference time of the narrow pulse and the wide pulse, and the communication rate can be adjusted by changing the pulse width of the synchronization code. The communication circuit is validated on a 100m cable at a rate of 2000bps.

![Diagram](https://example.com/diagram.png)

**Figure 8.** The encoding format of instruction.

3.5. Data acquisition and compensation
Both the intelligent electrode and the master controller contain a data acquisition circuit to collect the potential difference and the current respectively. Choose 24-bit Σ - Δ ADC to get higher resolution. LDO and reference voltage chip respectively provide power supply and reference voltage to ADC, and they are both low-noise and low-drift chips. And add power and signal isolation to reduce the influence of digital circuits on the data acquisition circuit. Current sampling circuit of the differential signal transmission circuit by string access current 1 Ω sampling resistance. The differential signal of the potential difference acquisition circuit is obtained by the partial pressure resistance. Partial pressure resistance to extend the range to +/- 10 V, and make the input impedance of the data acquisition circuit greater than 2 MΩ. The voltage divider resistor will bring a larger gain error, which can be reduced by software calibration.

Resistance methods usually require spontaneous potential compensation. Electrode A and the electrode between it and the master controller do not disconnect the ultracapacitor charging circuit during measurement, so the actual measured current minus its operating current is the current injected into the ground. Figure 9 shows the relative timing of the measurements of the main controller and each electrode. Potential compensation and current compensation are achieved by measuring twice...
and taking the difference value. \( V_1 \) is spontaneous potential, the final potential difference is \( V_2 - V_1 \), \( I_2 \) is the working current, the final current is \( I_1 - I_2 \).

![Figure 9. The timing sequence of measurement.](image)

4. Test
To verify the performance of the instrument, pure resistance was used to test the instrument. The physical diagram of the instrument is shown in figure 10. Ten electrodes were used for measurement with a multi-channel \( AMNB \) device. Connect 7 resistors with a resistance of 10 \( \Omega \) and a current-limiting resistor in series, and measure the resistance of the 10 \( \Omega \) resistor. The measurement results of the instrument are consistent with those of the multimeter, as shown in figure 11. The maximum relative error is less than 1%.

![Figure 10. Physical diagram and test diagram of the instrument.](image)

![Figure 11. Pure resistance test results.](image)

5. Conclusion
The two-wire distributed high-density resistivity meter greatly reduces the weight and volume of the multi-core cable required by the instrument, and the number of motors can be set arbitrarily. Meanwhile, the intelligent electrode is small in size and easy to use. The instrument can use any quadrupole device for multi-channel acquisition, but the electrode between the \( A \) electrode and the main controller cannot be measured, which is determined by the structure of the two-wire instrument.
The function of communication and power supply has been verified by a pure resistance experiment, and the results obtained are basically the same as the actual values.

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