Investigation on Current Comparator with Electrical Shielding to Improve the Measured Values

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***Abstract*- Generally, resistance measurements at high accuracy and precision using current comparator bridge system uses the comparison of resistors by measuring the current ratio corresponding to voltage drop equality. When adjusting the circuit until the bridge is balanced, the voltage between resistors is null and the voltage drop across resistors is equal with opposite polarity. This can be used to calculate the resistance value. This null voltage can be detected by Null detector. In Some case, measuring system must be connected terminally to Null detector, whose external connections may generate some electrical effects in the measuring circuit. This paper studies on the size of the electrical shielding box installed on the junction between Null detector and the other equipments. The differences between using a normal cable and a low thermoelectric EMF cable in measuring systems, which may affect the voltage accuracy, are also discussed. Finally, it has been found that the applications of the low thermoelectric cable and the shielding box can decrease voltage error. The size of the shielding box is related with the voltage error on the Null detector at balance condition of the bridge.**

***Index terms*- Electrical shielding, current comparators, resistance measurements**

I. INTRODUCTION

A current comparator bridge system is very effective for the resistance measurement [1], for example Direct Current Comparator (DCC) [2], Cryogenic Current Comparator (CCC) [3], etc. In application of bridge systems for resistance measurement, a Null detector must be used to detect the different voltage, which should be null. In this case, a DC nanovoltmeter is taken into action. When the bridge is in balance condition, in ideal case, the voltage between resistors must be zero and the DC nanovoltmeter must display zero. However, some errors may occur, which cause some voltage drop on the DC nanovoltmeter and the display is not on zero position. The electromagnetic interference (EMI), which exists in normal environment, can disturb the measuring systems and the connection terminal in circuit can generate voltage by the thermoelectric. These important phenomena cause the error on the measured values of DC nanovoltmeter and these affect the measured resistance values.

II. RESISTANCE BRIDGE BASED ON A CURRENT COMPARATOR

In general, a current comparator bridge circuit consists of two sides, primary and secondary side, which compare a known and an unknown resistor, as shown in Fig. 1. The null voltage must be detected between both resistors. Inside the primary and secondary circuit, there are the winding coils and two sources depending on bridge type. One or both of current sources can be adjusted until the voltage across resistors is equal [4]. For this balance condition, the primary and secondary circuits are assumed to be connected with the current sources as shown in Fig. 2.

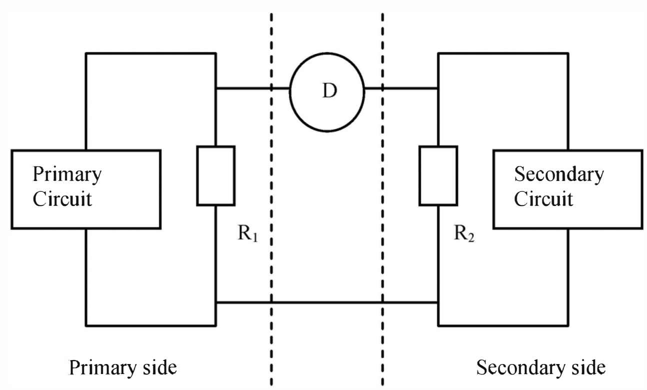

Fig.1 Resistance Bridge diagram

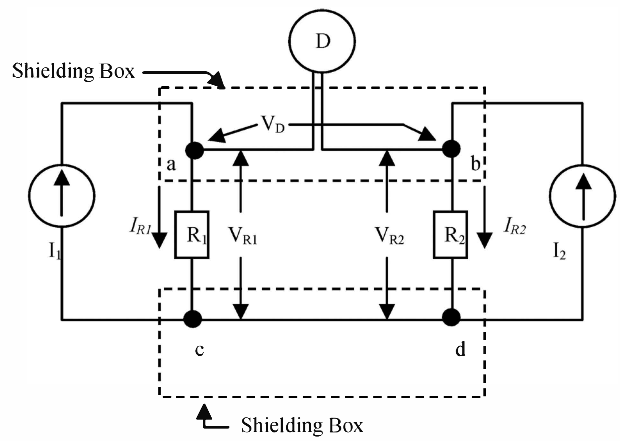

Fig.2 Equivalent circuit of current comparator bridge

According to Fig.2, when the bridge is in balance condition ($V_D = 0$),

$$V_{R1} = V_{R2} \tag{1}$$

$$I_{R1} \bullet R_1 = I_{R2} \bullet R_2 \tag{2}$$

Usually, the voltage across DC nanovoltmeter is small, therefore the effects due to thermoelectric voltage (thermoelectric EMF) can cause a big error for the measured values. The thermoelectric EMF is the most common source of interferences in low voltage measurements. These voltages are generated when different parts of circuit are at different temperatures and when the conductors made of different materials are joined together. However, the thermoelectric EMF can be cancelled by well performing two measurements of currents with opposite polarity [5].

III. MATHEMATICAL MODEL

At the bridge balance condition, the voltage across DC nanovoltmeter is given by

$$V_D = V_{R1} - V_{R2} \tag{3}$$

$$V_D = I_{R1} \bullet R_1 - I_{R2} \bullet R_2 \tag{4}$$

The abcd Loop in Fig. 2. can be redrawn as shown in Fig. 3.

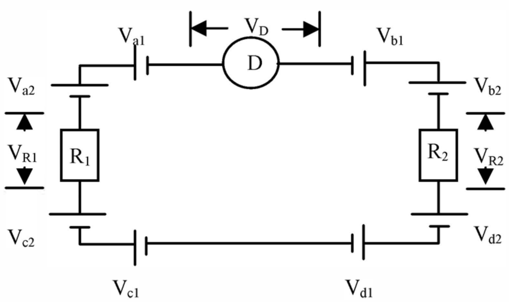

Fig. 3. Equivalent circuit for abcd loop

When the currents from both current sources are injected into the circuit,

$$\begin{aligned} V_{D1} = &(V_{R1} + \Delta V_{R1}) - (V_{R2} + \Delta V_{R2}) \\ &- V_{a1} + V_{a2} + V_{c2} + V_{c1} - V_{d1} - V_{d2} - V_{b2} + V_{b1} \end{aligned} \tag{5}$$

All conductors at point a, b, c and d are made of the same materials and the voltages across the all cable are assumed to be $V_{a1} = V_{b1} = V_{c1} = V_{d1}$. Then, Eq.5 can be shortened to be:

$$\begin{aligned} V_{D1} = &(V_{R1} + \Delta V_{R1}) \; - (V_{R2} + \Delta V_{R2}) \\ &+ V_{a2} + V_{c2} - V_{d2} - V_{b2}\,. \end{aligned} \tag{6}$$

By the current reversal method, the effects of thermoelectric EMF can be cancelled. When the currents are in opposite polarities,

$$\begin{aligned} V_{D2} = &(V_{R1} + \Delta V_{R1}) \; - (V_{R2} + \Delta V_{R2}) \\ &- V_{a2} - V_{c2} + V_{d2} + V_{b2} \end{aligned} \tag{7}$$

The combination between V_{D1} and V_{D2} can be used to cancel the thermoelectric EMF. In practice, V_D value contains some errors (ΔV_D), which is given by:

$$V_D + \Delta V_D = \begin{bmatrix} (V_{R1} + \Delta V_{R1}) \; - (V_{R2} + \Delta V_{R2}) + \\ (V_{R1} + \Delta V_{R1}) - (V_{R2} + \Delta V_{R2}) \end{bmatrix} / 2 \tag{8}$$

$$\Delta V_D = \left[(\Delta V_{R1}) - (\Delta V_{R2}) + (\Delta V_{R1}) - (\Delta V_{R2})\right] / 2 \tag{9}$$

And average voltage across DC nanovoltmeter is

$$\Delta V_{Dav} = \left[(\Delta V_{D1}) + (\Delta V_{D2})\right] / 2 \tag{10}$$

Usually ΔV_{Dav} should be very small near zero. If ΔV_{Dav} is not zero or small enough, these can affect the accuracy of measurement values.

IV. MEASUREMENT METHOD AND RESULTS

In measurement test, a current comparator method is used by detecting the voltage across a known and an unknown resistor and analyzing the voltage across a Null detector (V_D) displayed on the screen of the Null detector at bridge balance condition. The bridge circuit has been connected as shown in Fig.2. The currents are injected from the both sources and are adjusted to reach the bridge balance condition. The voltage across the Null detector (V_{D1}) is recorded. The polarity of the current is reversed and the voltage across the Null detector is re-measured (V_{D2}) at that condition. The average voltages across the Null detector with the connection at the terminals are measured and recorded as a reference. Then, more connection points between the null detector and both resistors are added and again the average voltages across the Null detector (ΔV_{Dav}) are measured at different conditions. In test procedures, the low thermoelectric and typical cables are used in three conditions: without shield, with shielding box No.1 and shielding box No.2. The size of aluminum shielding box can be seen in Table 1 and it has been tested at the current of 30 and 70 μA. The reference average voltages across the Null detector are measured without the connection at the terminals.

According to the equipments for measurement setup, a calibrator is used as the current source and two standard resistors of 100 ohms are applied. The DC nanovoltmeter is used as a Null detector and the shielding boxes made of aluminum and all the equipment can be seen in Fig. 4.

The measurement results are written in Table 1, which consists of the reference average voltage across the Null detector without connection points and the voltage across the Null detector at different conditions. Besides, the results are plotted as shown in Fig.5 with the deviation from the references.

Fig. 4. Equipments for measurement system

TABLE 1.
Results of measurement

Current test (µA)		ΔV_{Dav} (nV) ; Without connected terminally to DC nanovoltmeter		
30		-40		
70		20		
Current test (µA)		ΔV_{Dav} (nV) ; Using connected terminally to DC nanovoltmeter		
		Without shield box	Shield box No.1 (H : 54.9 mm., W : 88.9 mm., L : 114.3 mm.)	Shield box No.2 (H : 55.9 mm., W : 120.8 mm., L : 171.8 mm.)
30	Normal cable	-12	-17	-11
70		38	34	33
30	Low thermoelectric cable	-64	-48	-42
70		9	30	27

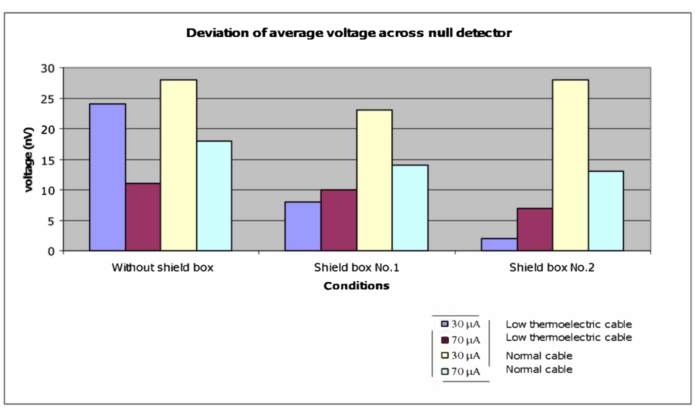

Fig. 5. Deviation of average voltage across null detector when used connected terminally and without connected terminally to DC nanovoltmeter

V. Conclusion

According to this measuring system, it has been found that the use of the general cable and low thermoelectric cable without shielding will deliver a quite high difference in the average voltage. When shielding is applied at the terminals, the difference in the average voltage can be reduced. In case that the junction is without electrical shielding box, the average null voltage ΔV_{DAV} are indicated in Table 1.

As the size of the shielding box and the source currents have been increased, it is found that the average voltage is reduced. The difference in the average voltage can be reduced lower than 10 nV. This means that the size of the shielding box and the test current affect the accuracy of the measured values. According to the experiments, the injection of higher current has affected the average voltage less than the injection of lower one.

In general, the uses of the low thermoelectric cable are more expensive than the uses of the typical cable. Therefore, the typical cable used in this work has to be shielded and be large enough at the high current condition. This can help to protect the external interferences and reduce in the deviation of the average voltage.

For future works, the shielding boxes with different sizes and different cable types should be investigated including the different tests should be performed. This can evaluate the deviation of average voltage accurately and precisely and help to test the system at different measurement points. The equipments will be used more properly and effectively. Also the cost of the equipment and cable usage can be reduced.

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