Effect of the measurement target output resistance and voltmeter input resistance on measured values

I. Effects of Output Resistance and Input Resistance

To accurately measure voltage, it is necessary to exercise caution with regard to the measurement target's (voltage source's) output resistance and the voltmeter's input resistance. Although the ideal voltage source output resistance is 0 Ω, in fact there is always an output resistance present (Fig. 1). For large batteries, this resistance may reach several milliohms, and for small batteries, several hundred ohms. When measuring bridge output from a strain gauge or other instrument (Fig. 2) or the output voltage from Resistance Temperature Detector (RTD) or thermistor, it is necessary to assume an output resistance that ranges from several hundred ohms to several hundred kilohms. Even for measurement targets with a small output resistance, it is necessary to assume a contact resistance on the order of several kilohms due to degradation of the test probes (when using test probes).

When the measurement target has a large output resistance, the measured value is attenuated due to division with the voltmeter's input resistance (Fig. 4). As an example, measuring a coin cell with an open circuit voltage of 3 V and an output resistance of 1 kΩ with a voltmeter that has an input resistance of 10 MΩ will result in error of approximately 0.01%:

$$\frac{10\text{M}\Omega}{10\text{M}\Omega + 1\text{k}\Omega} \times 3\text{V} = 2.9997\text{V}$$

To perform measurement without the effects of the output resistance, it is necessary to use a voltmeter that has a large input resistance. Typical digital multimeters allow the input resistance to be selected, approximately 10 MΩ for the 100 V and 1000 V ranges, and 10 MΩ or 10 GΩ or greater for ranges of 10 V and less (Table 1). When measuring a voltage of 10 V or less, the effects of the measurement target's output resistance can be significantly lessened by setting the input resistance to 10 GΩ or greater.

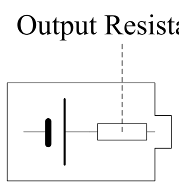

Fig. 1 Output resistance

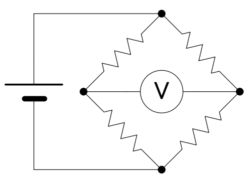

Fig. 2 Measurement of a strain gauge

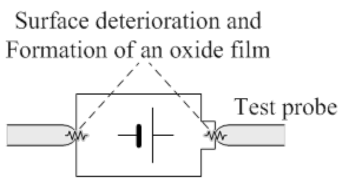

Fig. 3 Test probe contact

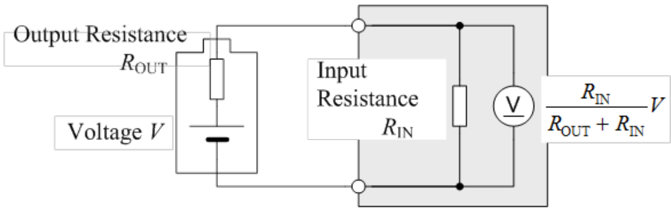

Fig. 4 Voltage source output resistance and measured values

Table 1 Digital multimeter input resistance

Measurement range	Input resistance R_{IN}
100mV	10MΩ or >10GΩ
1000mV	
10V	
100V	10MΩ
1000V	

II. Measurement precautions

Voltmeter input circuitry typically incorporates a capacitor in order to reject high-frequency component signals. When the measurement target is connected to the instrument, this capacitor is charged (Fig. 5). If the voltmeter has a low input resistance (10 MΩ, etc.), the capacitor will be discharged by the input resistance. On the other hand, if the voltmeter has a high input resistance (greater than 10 GΩ, etc.), the capacitor will discharge very little, even if the measurement target is disconnected. Consequently, the voltmeter will continue to display a value close to the previously measured voltage for a short period of time, even after the measurement target has been disconnected (Fig. 6).

The above phenomenon does not pose a problem when measurement work can be carried out while checking measured values, but caution is necessary when measuring multiple targets while automatically switching among them by means of a relay (a technique known as scanning measurement). Fig. 7 and Fig. 8 illustrate a measurement setup in which a relay is used to switch between two batteries. Assume that the 3.7 V battery is connected normally to Ch. 1, and the 3.6 V battery is not connected normally to Ch. 2 due to an issue such as test probe wear. Measurement of Ch. 1 will yield the normal measured value of 3.7 V since the test probes are in contact with the battery (Fig. 7). By contrast, measurement of Ch. 2 will display a value close to 3.7 V (the voltage with which the capacitor was charged during the measurement of Ch. 1) since the test probes are not in contact with the battery (Fig. 8). Although this phenomenon can be avoided by lowering the voltmeter's input resistance (to 10 MΩ, etc.), the resulting error will increase in magnitude if the test probes' contact resistance increases.

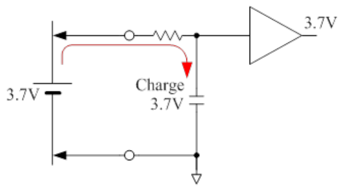

Fig. 5 Contact with measurement target

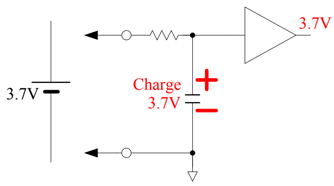

Fig. 6 Residual charge of capacitor

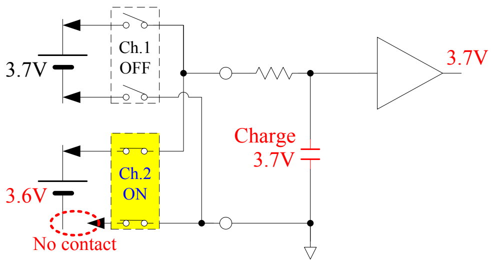

Fig. 7 During measurement of Ch. 1 (normal)

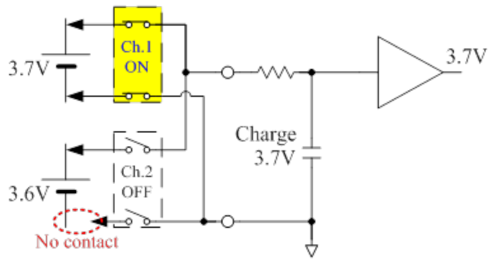

Fig. 8 During measurement of Ch. 2 (no test probe contact)

III. Actual Measured Values

The authors prepared three 18650-size lithium-ion batteries and performed scanning measurement from Ch. 1 through Ch. 3 with the measurement circuit illustrated in Fig. 9. Fig. 10 illustrates the measurement results when all channels were connected normally. Ch. 2 yielded a stable reading of the expected value of 3.845 V. Fig. 11 illustrates the measurement results when Ch. 2 was left open. In that instance, Ch. 2 yielded a voltage of around 4 V, close to the measured value for Ch. 1.

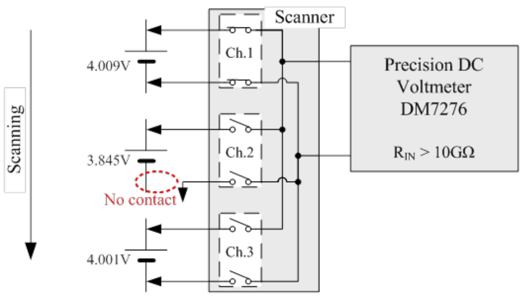

Fig. 9 Scan measurement connection diagram

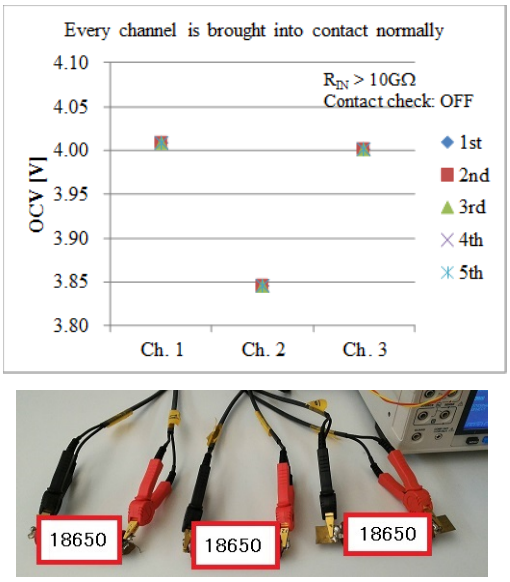

Fig. 10 Normal measurement of all channels

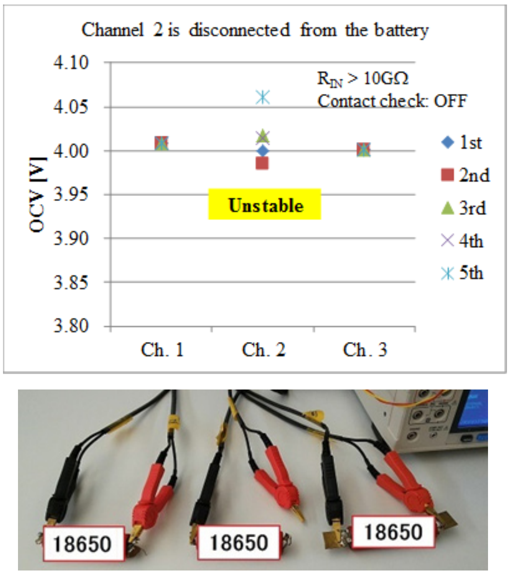

Fig. 11 Measurement with Ch. 2 left open

IV. Dealing with connection issues

Using a voltmeter like the DM7276 that provides contact check functionality is an effective way to address connection issues. Fig. 12 illustrates the measurement results obtained using the same connection method shown in Fig. 11 but with the Precision DC Voltmeter DM7276's contact check function enabled. Measurement of Ch. 2 triggered a contact error before the measured value could be displayed, preempting the judgment process. By utilizing the contact check function, it is possible to prevent erroneous measurement and thereby implement highly reliable testing.

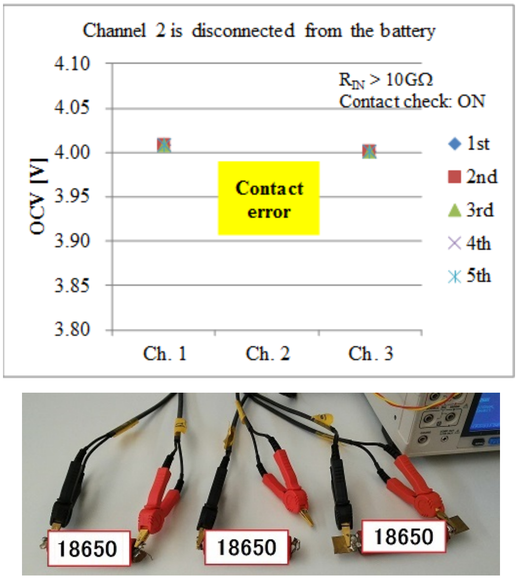

Fig. 12 Measurement with Ch. 2 left open and the DC voltmeter's contact check function enabled

V. Summary

-1. In voltage measurement, it is necessary to use a voltmeter with a large input resistance when measuring a target with a large output resistance or when contact between the test probes and the measurement target is poor.

-2. Voltmeters with a large input resistance tend to continue to display the last measured value when the test probes are left open, instead of displaying a measured value of 0 V.

-3. Using a voltmeter with a contact check function (such as the Hioki DM7276) is an effective way to prevent erroneous judgment caused by a connection issue.