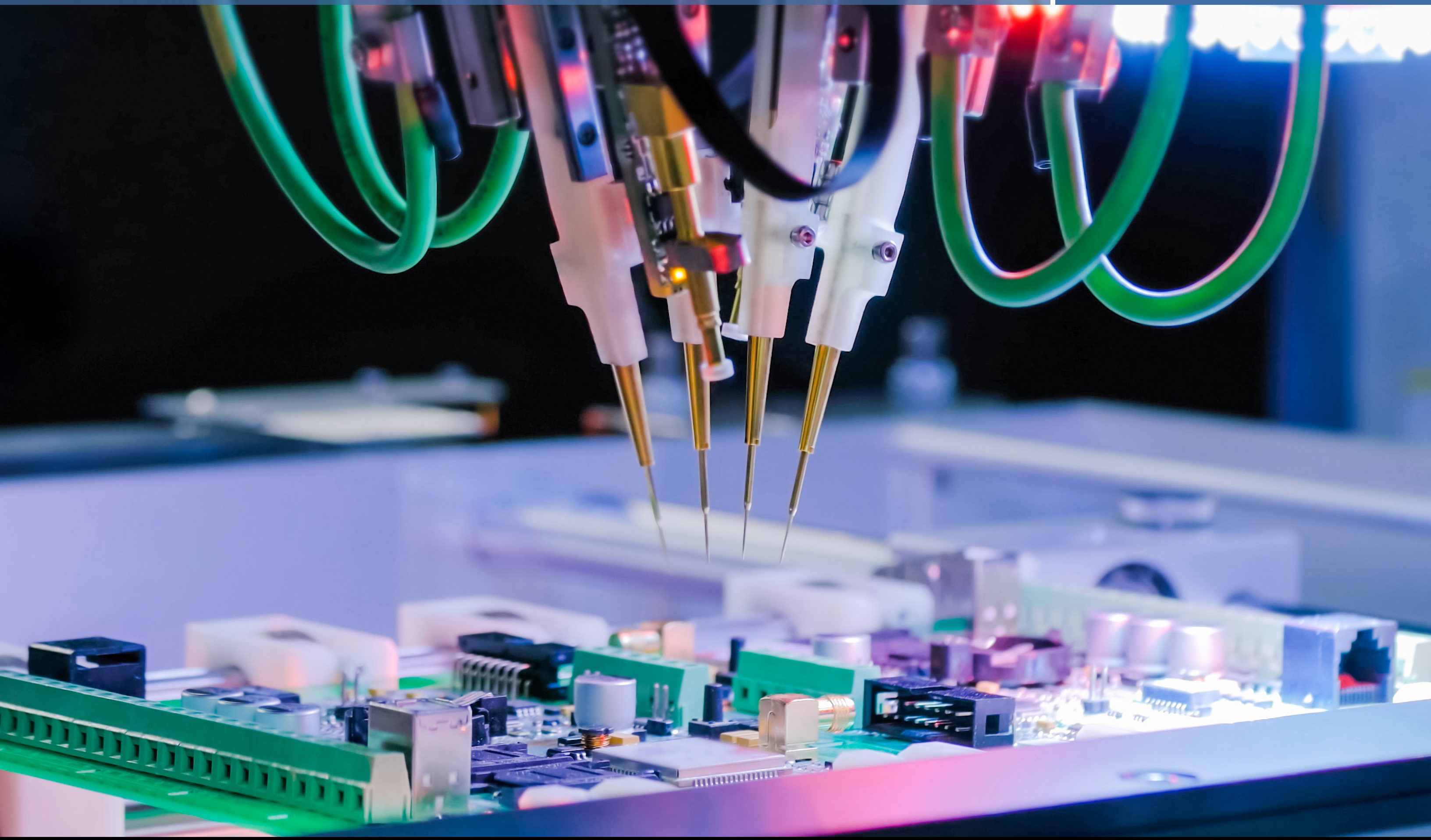
SOLUTION BRIEF



Solving for Common Low Resistance Measurement Accuracy Issues

KEYSIGHT

Introduction

A resistance measurement requires cable leads to connect to both ends of the resistive component from your test instrument. However, no wire or cable is a perfect conductor. The cables connecting your test instrument to the resistive component or device under test (DUT) will add some resistance to the overall measurement.

Think about every cable as a resistor even though the resistance of the cable is usually very small, in the range of about a hundredth of an ohm (0.01 Ω) if it is about a foot long. But this adds up quickly if the cable is longer and has connection resistance. If you are trying to measure a DUT with a resistance that is many orders of magnitude greater than 0.1 Ω, then you can safely ignore the cable resistance effects. But if you are trying to measure a DUT with only a few ohms of resistance, the error the cable resistance introduces can significantly skew your measurement results.

This solution brief will compare the differences between making a 2-wire and a 4-wire resistance measurement. The 4-wire resistance measurement method offers a more accurate way to measure small resistance than the 2-wire method. However, there are trade-offs. The brief will also explore several applications that need to use a 4-wire measurement method. You can typically use a digital multimeter (DMM), a micro-ohm meter, or a source-measure meter to conduct a 2-wire and 4-wire resistance measurements. By the end of the brief, you will be able to make the right decision and investment for your test setup.

Comparisons Between 2-Wire and 4-Wire Measurement Methods

A typical benchtop DMM offers two resistance measurements: 2-wire and 4-wire ohms.

The 2-wire resistance measurement is the simplest and most common method. A two-wire measurement is an acceptable option in applications where the unknown resistance is relatively high or where accuracy requirements are low.

Figure 1 shows a 2-wire resistance measurement setup where the shaded portion of the diagram is the internal circuitry of a DMM or a micro-ohm meter. The unshaded portion of the diagram shows the differential inputs high (HI) and low (LO), where each of the cable leads connects to R, which is the DUT. The lead cables have innate resistances; use R_{lead} as the symbol to represent them. The measuring instrument will source out a known current, I_{test}, and measure the voltage, V_m, across HI and LO inputs. When you apply Ohm's law to the measurement, you have:

$$R + R_{lead} + R_{lead} = \frac{V_m}{I_{test}}$$

If R is many orders of magnitude greater than 0.1 Ω, then,

$$R = \frac{V_m}{I_{test}}, \text{ where } R_{lead} \text{ is negligible.}$$

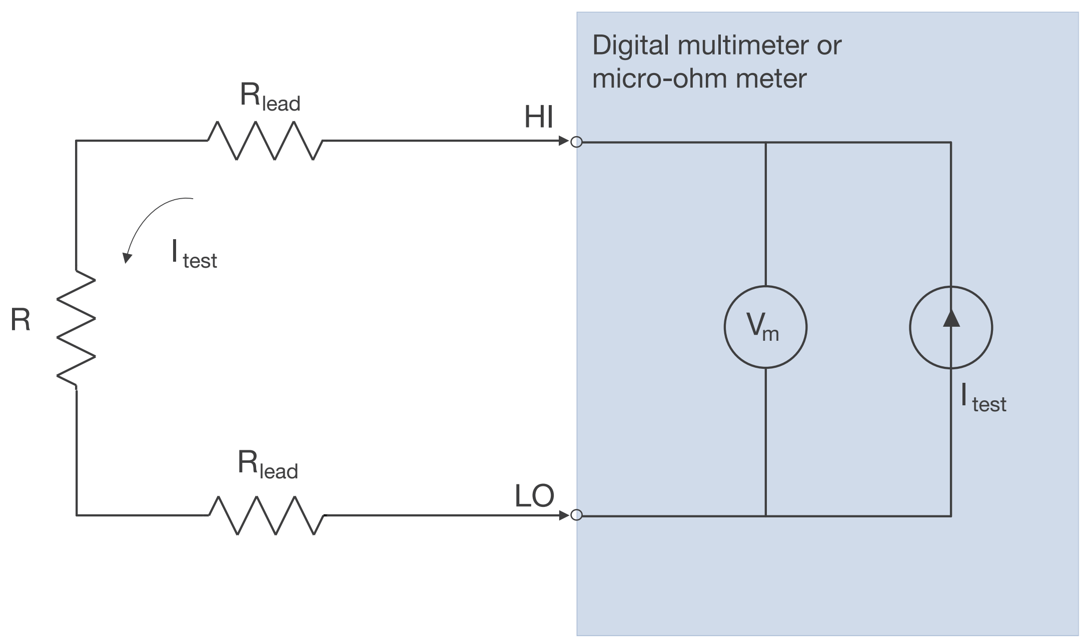


Figure 1. A 2-wire resistance measurement setup where R is the device under test

When you want to measure low resistances in a few ohms, milliohms, or less, it is very important to remove the effects of the cable resistance. To accomplish this, you will need to eliminate the resistive voltage drop caused by the current flow through the cable and measure only the resistive effects associated with the test structure or DUT. Using a 4-wire measurement enables this process.

The 4-wire measurement, or the Kelvin measurement measures very low resistances using four-terminal sensing. The four-terminal sensing technique requires two separate lines for each terminal on the structure that you want to measure. One pair of lines forces current to the DUT, and the other pair of lines senses the voltage measurement. The measurement separates the lines that supply current to the DUT from the lines that measure the voltage drop across the device. Since the sense lines making the voltage measurement do not conduct any current, there is no voltage drop due to cable resistance. Therefore, you eliminate cable resistance effects.

The 4-wire measurement method is available in most benchtop DMMs. However, it is uncommon to see handheld DMMs use this method since it adds cost and requires space for its implementation. The connections for four-wire resistance measurements appear in Figure 2.

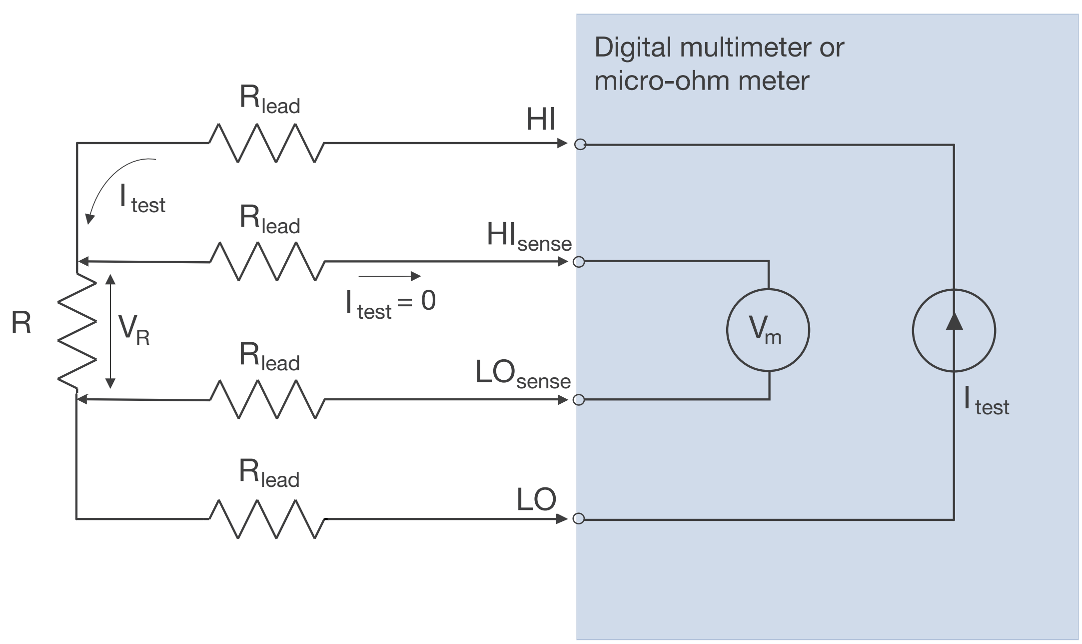


Figure 2. A 4-wire resistance measurement setup where R is the device under test

Figure 2 shows 4-wire leads coming out of the test instrument. The 4-wire leads consist of a pair of current source wires and a pair of voltage sensing wires in parallel; they connect to R or the DUT. Similar to the 2-wire measurement method, the current source wires generate a voltage drop across R along the HI and LO lead wires. However, the second pair of leads separate from the current source leads to form a direct voltage loop that measures the voltage drop across R. The second pair of voltage sense leads is H_{Isense} and LO_{sense}. Since the resistance of the voltmeter is very high (on the order of 10M ohms), the lead wire resistance has little effect on the measurement. Since the R_{lead} is negligible and independent of the current source, I_{test}, you have:

$$V_R \approx V_m$$

where V_R is the voltage across the resistor R or DUT and the meter measures the voltage as V_m:

$$R = \frac{V_m}{I_{test}}$$

Table 1 below shows a table that summarizes the advantages and disadvantages of the 2-wire and 4-wire setups.

Table 1. Comparison of 2-wire and 4-wire resistance measurement setups

	Advantages	**Disadvantages**
2-wire resistance measurement setup	• Easiest and most common setup for typical resistance measurements • Suitable for large resistance measurements	• Measurement includes test-lead resistances and contact resistances
4-wire resistance measurement setup	• Accurately measures small resistances • Method reduces test lead resistances and contact resistances automatically	• Costly setup due to twice the number of cables • Need better interconnects like gold plating to reduce interconnect resistances

Applications That Need a 4-Wire Measurement Method

The majority of resistance measurements you make do not require a 4-wire resistance measurement setup. However, there are some applications that do require the 4-wire method. Here below are five examples of applications that require the 4-wire method.

Measuring low resistances for high precision components

It is hard to provide specific threshold guidance, such as if less than 100 ohms range of measurements, then use the 4-wire Kelvin method. The reason is that it depends on your requirements for the accuracy, measurement speed performance and the electrical noise level of your environment. However, in the less than 100 ohms range, assume that you need to take a closer look at your resistance measurement setup.

Many high precision components generally require 4-wire resistance measurements, such as testing high precision instrument amplifiers, differential amplifiers, gyro navigation controls, pressure sensors, and integrated circuit wafer probing. Figure 3 shows the intricacies involved in making accurate and repeatable measurements using Kelvin probes on a wafer test station.

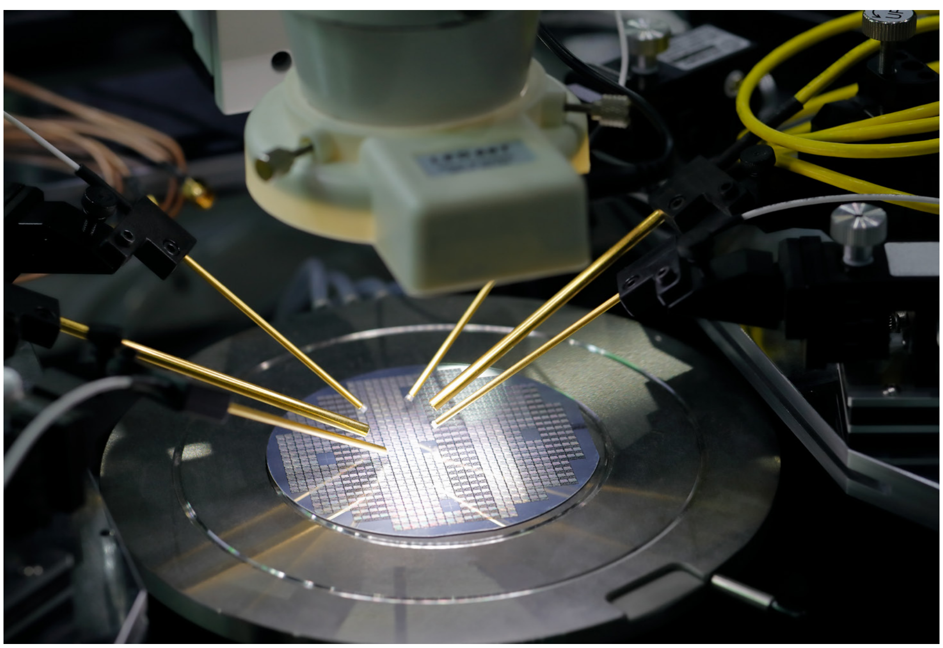


Figure 3. Integrated circuit wafer probing test station

Measuring resistances over long cables / leads in your test setup or connections through switch contacts

Sometimes in automated manufacturing tests, you require test fixtures for your DUTs. You may also need to test multiple DUTs in your test fixtures. Cables from your test instrument need to be long due to limited space, while switches are used to test multiple DUTs. However, extra-long cables and extra connections will add resistance from your test instrument to the DUTs. Hence, the need for a 4-wire measurement method to reduce the unwanted resistance from test cables.

Measuring temperature using resistance temperature sensors such as resistance temperature detectors or thermistors

There are various types of temperature sensors to meet your test requirements, such as broad temperature range, cost, size, fast response, and accuracy. For greater accuracy, resistance temperature detectors or thermistor sensors are the better choices. The advantage of using resistance temperature detectors or thermistor sensors is that they are resistive elements. Because they are resistive elements, you can eliminate unwanted measurement errors due to cable and connection resistance by using the 4-wire resistance measurement method. Figure 4 shows medical laboratory equipment which requires precise temperature control.

Measuring current sense shunt resistors with precision

Many applications require monitoring of precise dynamic current, especially medical devices, battery chargers, programmable power supplies, or any circuitries that need over-current protection. One solution is to place current sense resistors at strategic locations on the circuit application. Measure voltage across the current sense resistor, and obtain the current in real-time through the Ohm’s law equation. If the current sense resistors require long leads to measure their voltages and precision results, then a 4-wire measurement is ideal for the application.

Power sources using remote sensing to source voltage close to the load accurately

Many power sources use the 4-wire remote sensing method to provide accurate output control. For example, a direct current (DC) power supply typically adjusts to ensure accurate programmed DC voltage sources to the load if constant voltage (CV) is set. However, if the output leads to the load are very long, the voltage you source to the load will be lower than the programmed DC voltage due to the lead resistance of the cables. This situation is where the 4-wire method becomes extremely useful to compensate the voltage drop across the cables.

Summary

A 4-wire measurement method is the most accurate method to measure small resistances, especially in ranges below 100 ohms. The 4-wire method eliminates measurement errors that long leads and switches introduce in your test setups. The method is also very useful when you need to monitor for accurate and precise temperature changes.

Many Keysight test and measurement instruments integrate the 2-wire and 4-wire measurement methods as a standard feature.

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