APPLICATION NOTE

Measuring Resistivity of Insulating Materials

Keysight B2985B/B2987B Electrometer / High Resistance Meter

KEYSIGHT

Introduction

The Keysight B2985B and B2987B Electrometer/High Resistance Meters streamline the characterization of surface and volume resistivity in insulating materials by providing accurate resistance or current versus time information in real-time through their front panels.

You can measure a material's surface or volume resistivity in film or sheet formats using the Keysight N1424 Resistivity Cell fixture and custom resistivity measurement fixtures for other sample forms or shapes.

Additionally, they provide an unmatched current measurement resolution of 10 aA (0.01 fA) and a built-in 1000 V voltage source that allows you to measure resistances of up to 10 PΩ (10^{16} Ω).

Insulation and surface resistance are typically measured 60 seconds after applying a test voltage (electrification) as per the ASTM D257 standard (unless otherwise specified), so it is important to be able to measure these parameters over time.

Important words used in the document:

Prefix in the metric system used in very low current:

- peta (P)= 10^{15}
- tera (T)= 10^{12}
- giga (G)= 10^{9}
- pico (p)= 10^{-12}
- femto (f)= 10^{-15}
- atto (a)= 10^{-18}

The B2985B and B2987B possess timer-based triggering and math functions that calculate the measurement data at specified times to provide resistivity data at various points. In addition, a trend graph of the resistivity versus test time can be plotted on the display to view resistivity changes until the point at which the final resistivity value is recorded.

This application note shows how you can effortlessly and accurately measure resistivity with the B2985B/B2987B and the N1424.

Note: The B2987B has an internal rechargeable battery that allows it to operate without being connected to AC power.

Figure 1. Keysight N1424 resistivity cell (Left) and B2987B (Right)

Resistivity Measurement

Measurement basics

There are two basic types of measurements used to determine resistivity: volume and surface. Each technique is explained in the following sections.

Volume resistivity measurements

Volume resistivity measurements typically employ the test fixture electrode configuration shown in Figure 2. The voltage source Vs is applied to the upper electrode, and the bulk current that flows through the test sample is measured as Im. The volume resistance Rv is then calculated using the equation Rv = Vs/Im. The bulk current flowing through the test sample to the guard electrode and the surface current flowing from the upper electrode to the guard are leakage currents; however, these currents flow into the low side of Vs, and they do not affect the magnitude of the ammeter current (Im) used to calculate Rv.

The volume resistivity ρv is obtained by ρv = EAR / STH x Rv / 10, where:
EAR = Effective area
STH = Sample thickness

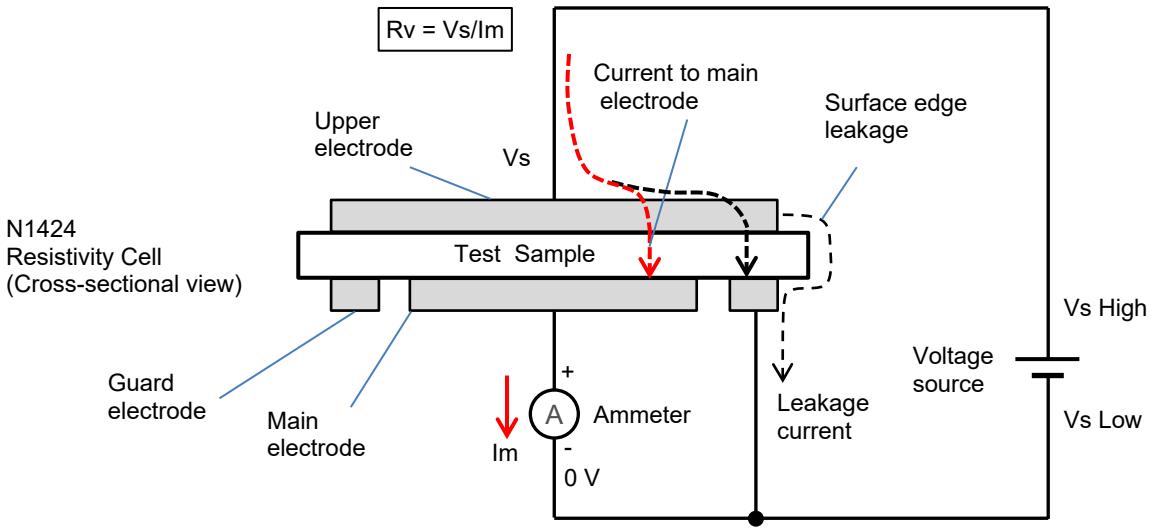


Figure 2. Volume resistivity measurements

Surface resistivity measurements

Surface resistivity measurements typically use the electrode configuration shown in Figure 3. The voltage source Vs is applied to the guard ring electrode, and the surface current flowing on the test sample's surface from the guard electrode to the main electrode is measured as Im. The surface resistance Rs is calculated using the equation Rs = Vs/Im. The current flowing from the guard ring to the upper electrode is leakage current; however, since it flows into the low of the Vs, it does not affect the ammeter current (Im) value used to calculate Rs.

The surface resistivity ρs is obtained by ρs = EPER/GLEN x Rs, where:
EPER = Effective perimeter
GLEN = Gap length

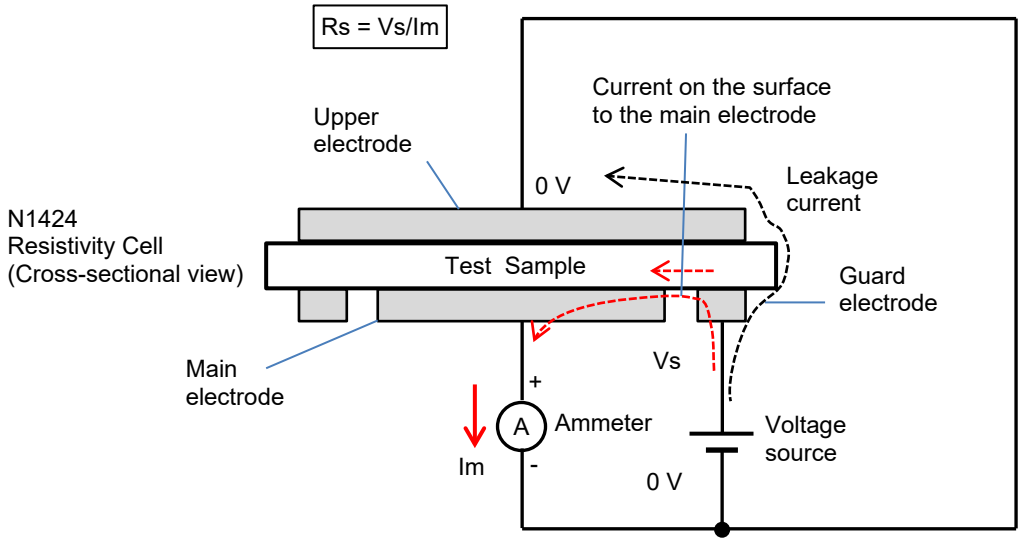


Figure 3. Surface resistivity measurements

The B2985B and B2987B can calculate and display these parameters using the built-in MATH function.

Measurement support capabilities

The B2985B and B2987B have many features to help with resistivity measurement.

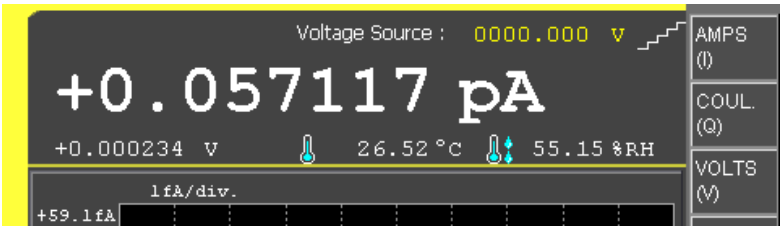
Measurement time setting

Resistivity measurements are typically made at a specified time after applying a stimulus. This is because the resistivity of insulating materials typically does not converge to a stable value quickly, which mandates that any resistivity specification has to state when the resistivity measurement should take place. Unless otherwise specified, 60 seconds after applying stimulus (electrification) is commonly used as the time to make a resistivity measurement (as specified in the ASTM D257 standard).

The B2985B and B2987B allow you to specify exactly when to measure after applying stimulus (electrification).

Humidity and temperature measurement

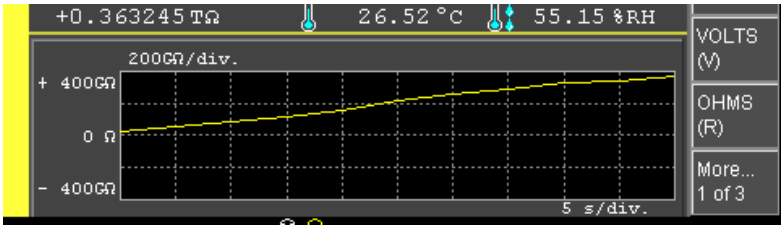
Since resistivity measurements are affected by ambient temperature and humidity, it is important to record this information when comparing resistivity measurements made on different materials.



The B2985B and B2987B allow you to measure and record the ambient temperature and humidity along with resistance measurement data.

Trend graph display

Since resistivity measurements typically vary after applying a voltage stimulus, it is convenient to be able to display resistivity changes from the start of the stimulus to the final measurement time.



The B2985B and B2987B allow you to monitor resistivity changes over time graphically.

Resistivity Measurement Examples using the N1424 Resistivity Cell

This section explains how to make resistivity measurements using the B2985B/B2987B and the N1424 Resistivity Cell test fixture.

Figure 4 shows a rear view of the B2987B and N1424 configured to measure resistivity.

Ensure you connect the interlock cables and set the N1413A's control switch to PULL position, "Floating DUT" mode.

You can switch between volume resistivity and surface resistivity measurements using the knob on the N1424 Volume/ Surface selector box, as shown in Figure 5.

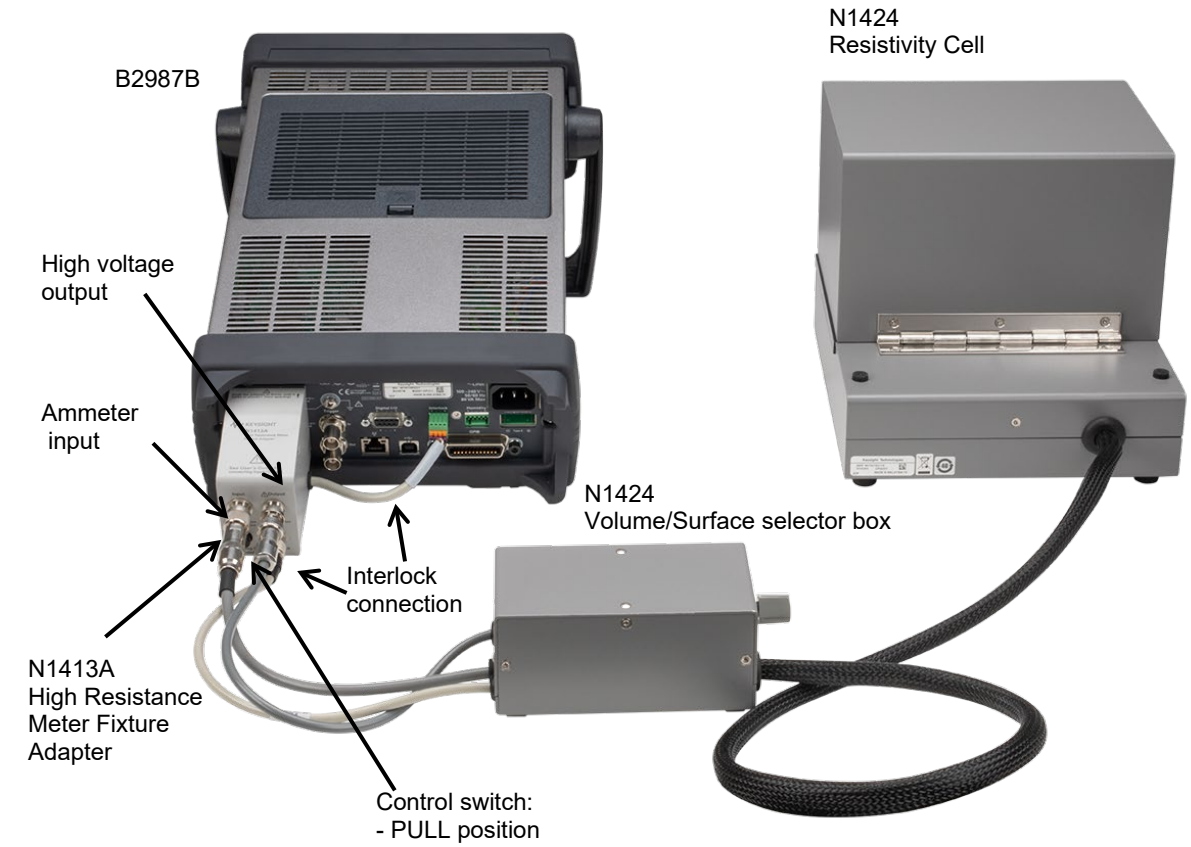


Figure 4. Configuring the B2987B and 16008B to make resistivity measurements

Figure 5. Selector switch of the N1424 Volume/Surface selector box

In the example shown, the fixture's test electrode is the standard one for the N1424 Resistivity Cell. Its dimensions are: Main: 50 mm diameter, Guard: 70 mm diameter (inside).

For the volume resistivity example, the test sample is a plastic film made from the same material used for static shielding bags to contain electrostatic sensitive devices.

For the surface resistivity measurement example, the test sample is a rubber sheet.

Details of the resistivity cell calculation are shown in Figure 6.

Note: Refer to the N1424 manual for more information about this test fixture.

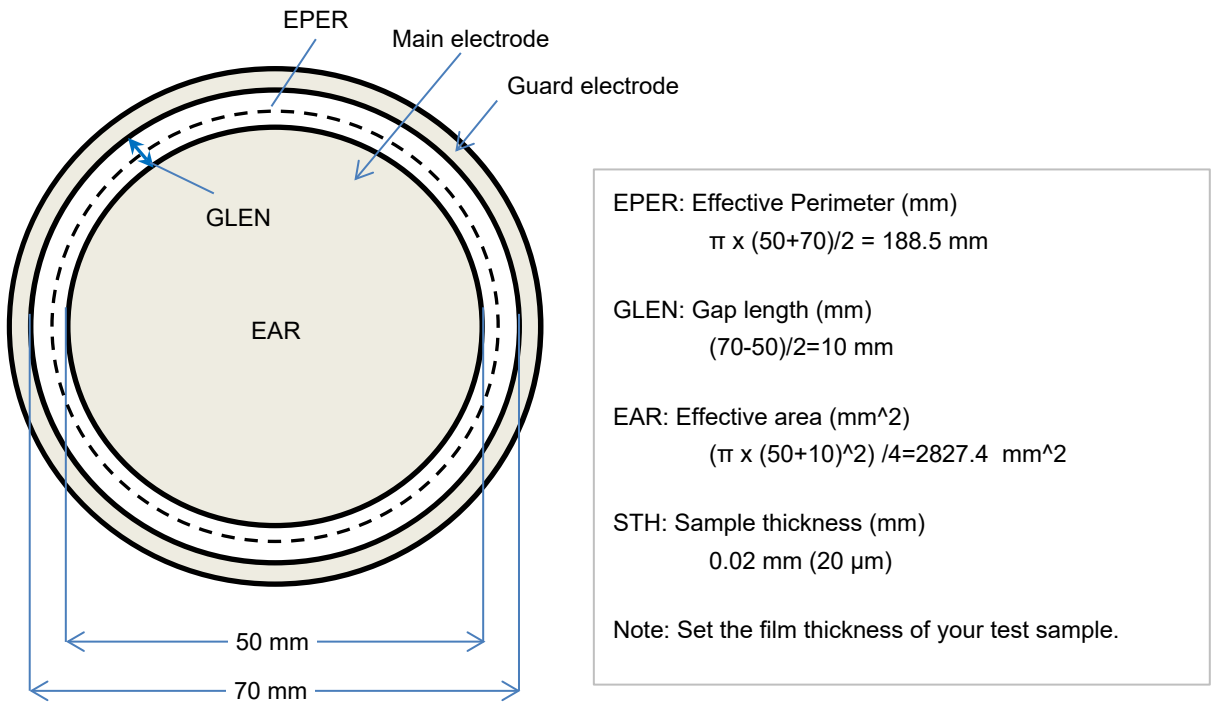


Figure 6. Test electrode dimensions and the resistivity calculation parameters

The sizes of each electrode and the measurable material sizes are listed in the table below.

Main electorode	Guard electode (Inner Diameter)	Guard electode (Outer Diameter)	Material size
ϕ 26 mm	ϕ 38 mm	ϕ 48 mm	50mm to 125 mm
ϕ 50 mm	ϕ 70 mm	ϕ 80 mm	82 mm to 125 mm
ϕ 76 mm	ϕ 88 mm	ϕ 98 mm	100 mm to 125mm

Example 1. Volume resistivity measurement

The following steps explain how to set up and measure volume resistivity.

Measurement steps of B2985B front panel operation

1. Place your test sample in the N1424 Resistivity Cell.

   Note: This example uses plastic film from a static shielding bag.

   Set the N1424 Volume/Surface Selector box selector switch to the “Volume” position.

2. Set the low terminal state of the voltage source.

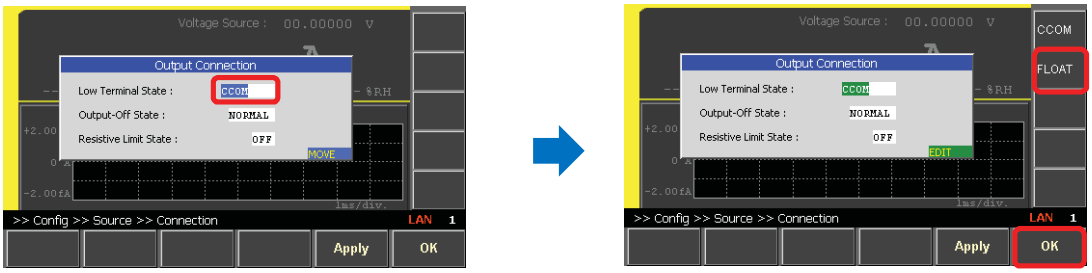
   1) Press the [View] key to show the [System Menu] function key.

   2) Press the [System Menu] key, and then press the [Config] key.

   3) Press [Source] key.

   4) Press the [Connection] key.

   5) Press the [knob] and select [FLOAT]. After that, press [OK].

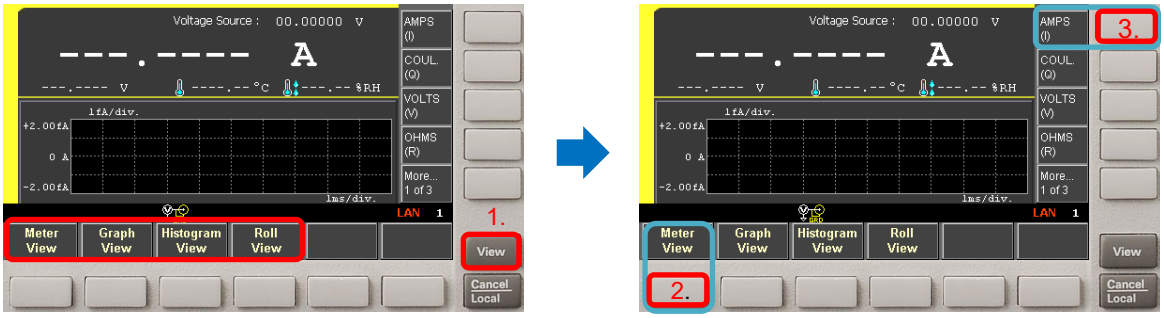


3. Set up to display the current on Meter View.

    1) Press the [View] key to show the View function key.

    2) Press the [Meter View] function key.

    3) Press the [AMPS (I)] assist key.



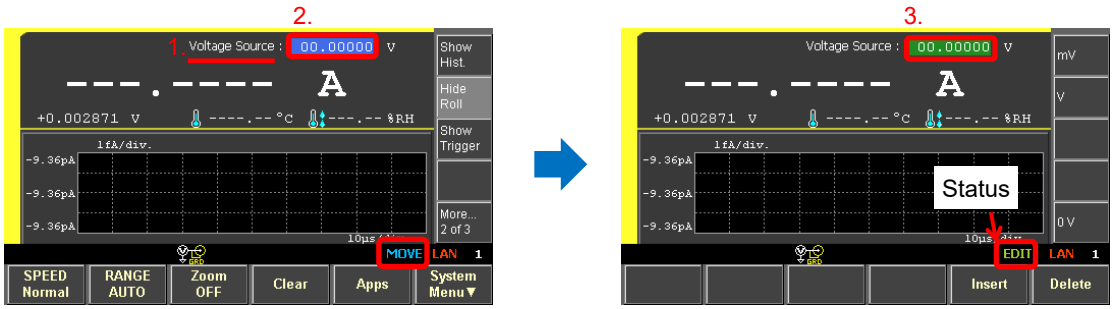
4. Set up for 0 V source.

    1) Check if the Voltage Source field is set to 0 V.

    2) If not, move the field pointer onto the Voltage Source value, and press the [knob] to edit the voltage.

    3) The field pointer changes to green (EDIT mode), and the status information will change to EDIT.

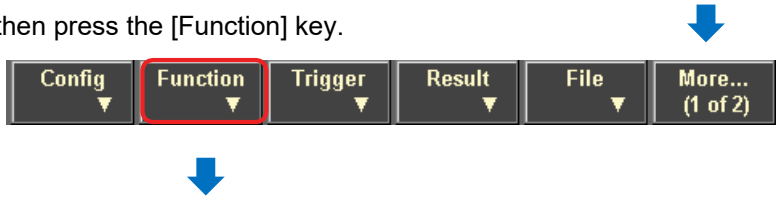
    4) Set the voltage to zero volts by rotating the [knob], and press [knob] to fix the value.



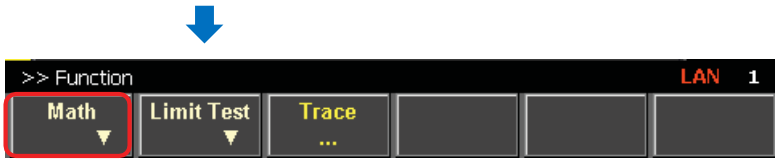
5. Set the MATH parameters for volume and surface resistivity computation.

    1) Press the [View] key to show the [System Menu] function key.

    2) Press the [System Menu] key, then press the [Function] key.



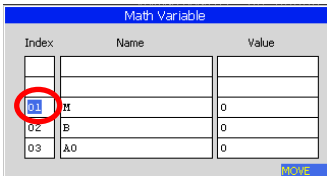
3) Press [Math] key.



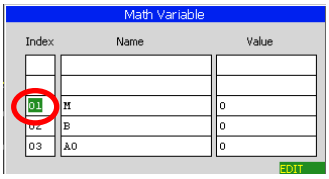
4) Press [Variable] key.

5) Set the values for Math Variables.

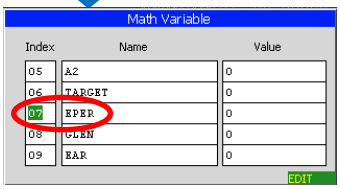
a.



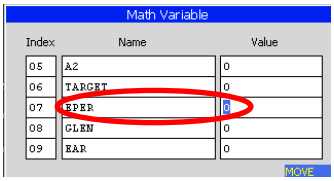
b. Click to EDIT mode



c. Rotate to move to index "07, EPER" (Effective Perimeter) field.



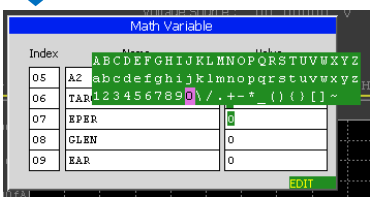
d. Click to MOVE mode



e. Rotate to move to "Value" field.

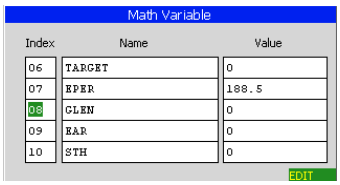
f. Click to enter the EPER value. Enter the value by using [knob] and the arrow keys.

g.



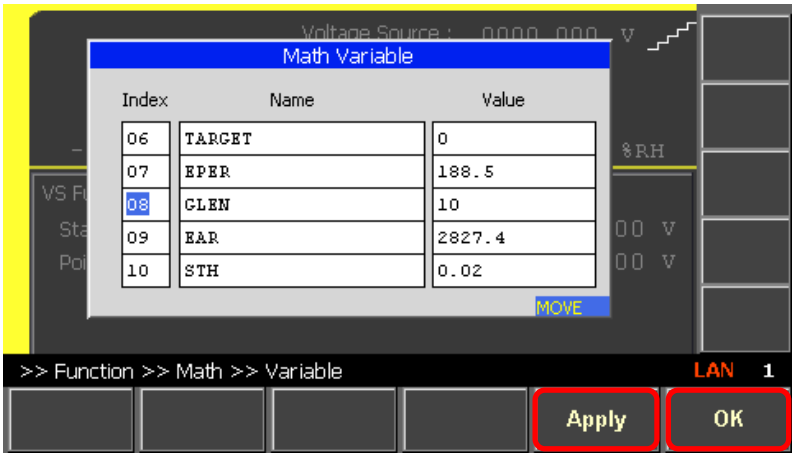
h. The "EPER" parameter is set to 188.5 (mm).

i. Then repeat the same steps for "08" to "10" index value.



6) After performing the abovementioned steps for the variables from index 08 to 10, all parameters should be set, as shown in the following figure.

Press the [Apply] and then [OK] keys to save the values and close the Math Variable input panel.

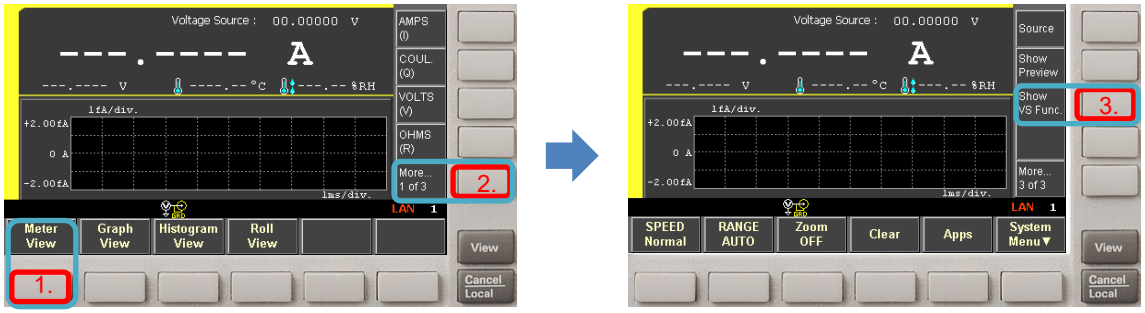


6. Show the VS Function menu.

1) Press the [Meter View] function key.

2) Press the [More ... 1 of 3] assist key twice so that the [More ... 3 of 3] softkey appears.

3) Press the [Show VS Func.] assist key to show the VS function menu.

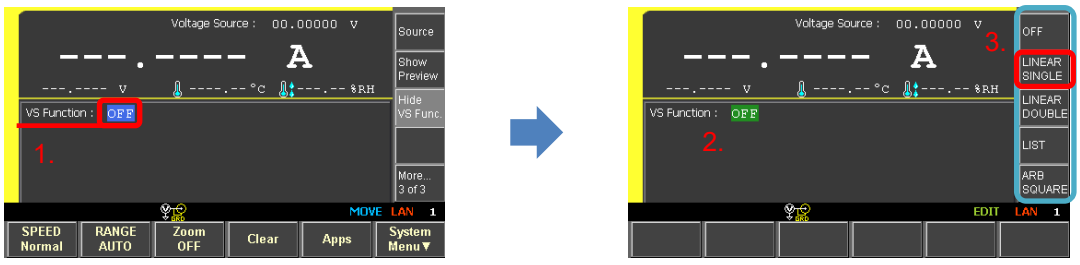


7. Set the VS Function to Linear Single sweep.

1) Move the cursor on the VS Function by rotating the [knob].

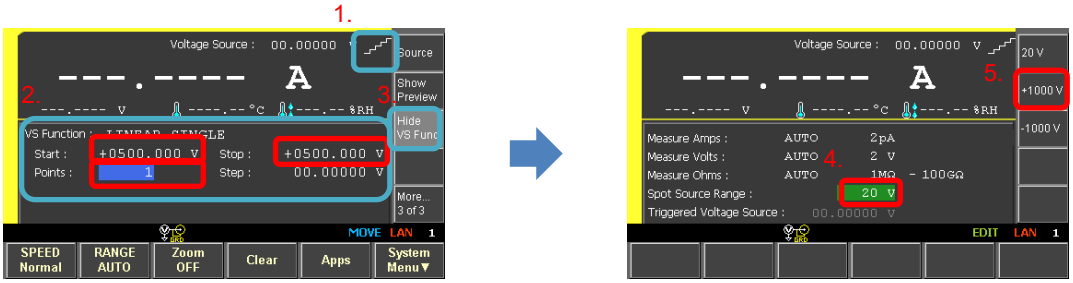
2) Click on the VS Function by pressing the [knob], and this changes the assist key menu.

3) Press the [LINEAR SINGLE] assist key.



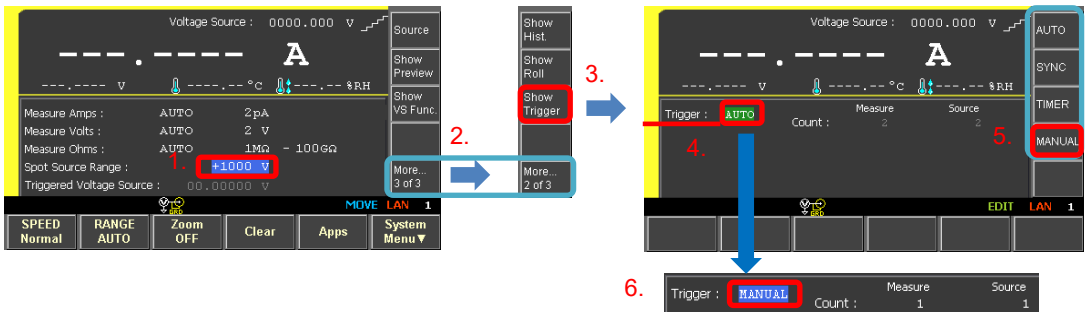
8. Set the sweep parameters.

   1) The Source shape indicator should have changed to indicate a linear single sweep.
   2) Edit the sweep parameters as follows. Start: 500 V, Stop: 500 V, Points: 1
   3) Press [Hide VS Func.] assist key. The VS range setting mode opens.
   4) Move the field pointer to “Spot Source Range”, and press the knob] to change the field to EDIT mode.
   5) Press the [+1000 V] assist key to set the VS source range to 1000 V.



9. Set the trigger mode to Manual.

   1) The VS source range indicates that it is set to the 1000 V range.
   2) Press the [More ... 3 of 3] assist key twice until it states [More ... 2 of 3].
   3) Press the [Show Trigger] assist key.
   4) Click on the Trigger mode and change to the EDIT mode. The assist keys change to the Trigger selection menu.
   5) Press the [MANUAL] assist key.
   6) The Trigger mode changes to MANUAL mode.



10. Set the trigger parameters.

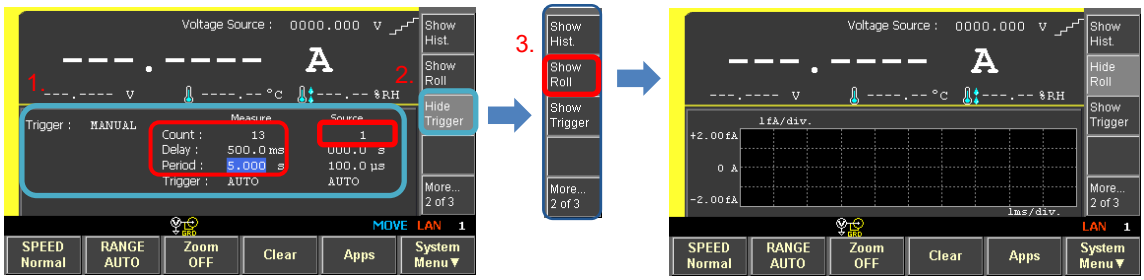
The trigger is set to 5-second intervals in the example, and the final sampling is at 60 seconds.

1) Change the Manual trigger parameters as follows;
   - Measure-Count: 13
   - Measure-Delay: 500 ms (set 500 ms delay after the bias voltage output.)
   - Measure-Period: 5 sec (Sampling is made in every 5 seconds.)
   - Source-Count: 1 (Start-Stop)
   - Measure & Source Trigger: AUTO

2) Press the [Hide Trigger] assist key.

3) Press the [Show Roll] assist key to prepare for the measurements.

4) The Meter View with the Roll View screen in the lower half of the display appears.



11. Optional setup

If you are using a humidity sensor and/or a thermocouple, connect these to the rear inputs of the B2985B and B2987B to measure both the humidity and the temperature of the test environment.

Note: Since humidity significantly impacts resistivity measurements, you should monitor it if you are measuring resistivity in an uncontrolled environment.

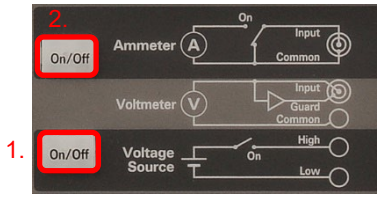
12. Turn on the output.

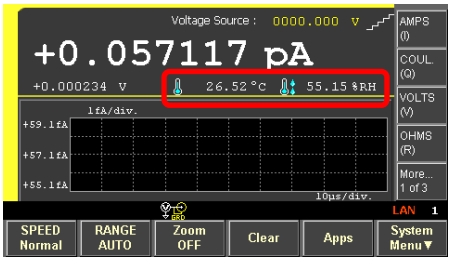
1) Press the Voltage Source [On/Off] key to output 0 V.

2) Press the Ammeter [On/Off] key to connect the ammeter.

A single current measurement is made automatically.

Note: This data is also displayed if humidity and temperature sensors are connected.





13. Set the MATH function to calculate volume resistivity.

    1) Press the [More ... 3 of 3] assist key twice until it states [More ... 1 of 3].

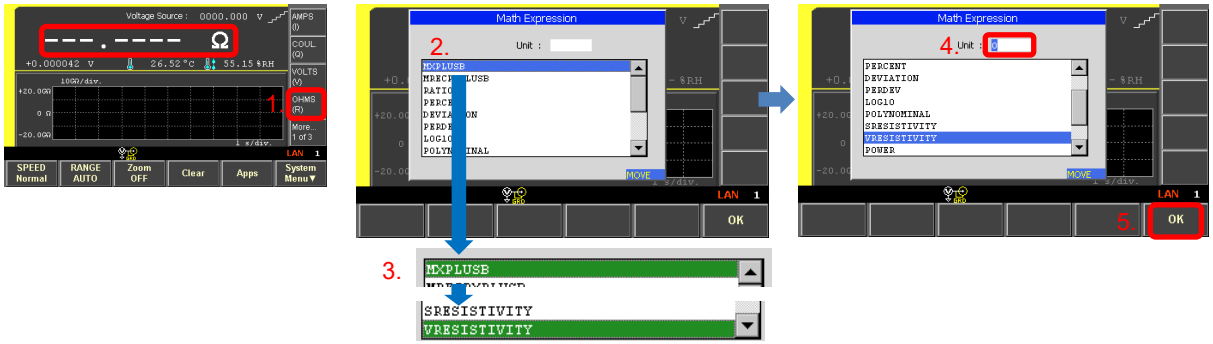
    2) Press the [OHMS(R)] assist key to change the measured parameter to resistance.

    3) Click on the [Math] key on the front panel. The Math Expression panel appears on the display.

    4) Click on the [knob], and change to EDIT mode, and scroll to the "VRESISTIVITY" MATH function, and click on the [knob].

    5) Rotate the knob, and move the focus to the Unit input field. Then, click on the knob, and enter the unit to "O" which indicates Ohm.

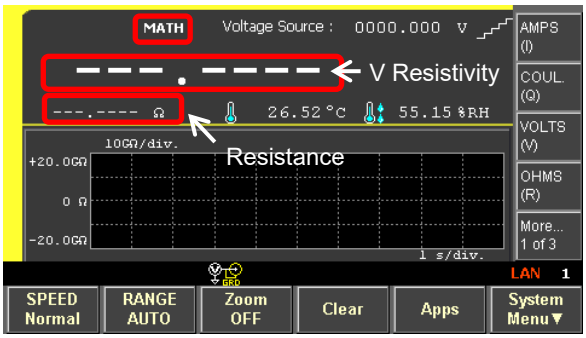
    6) Press the [OK] key to set the VRESISTIVITY MATH function.



The “MATH” indicator shows that the VRESISTIVITY function is set.

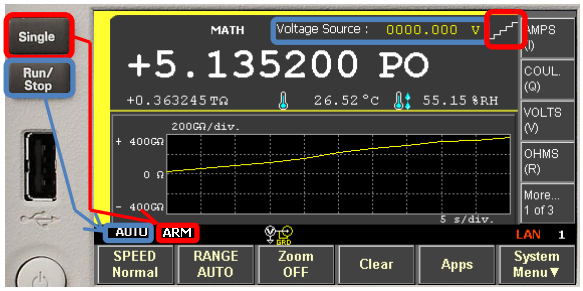
The data calculated by the Math function is shown in the main measurement data display field.

Resistance data is shown in the secondary measurement data display field.



14. Start the volume resistivity measurement.

    Press the [Single] measurement button. The [ARM] indicator lights and the sweep measurements start. The volume resistivity measurements are made in 5 seconds to 60 seconds. The Roll View plots the trend of the resistance data.

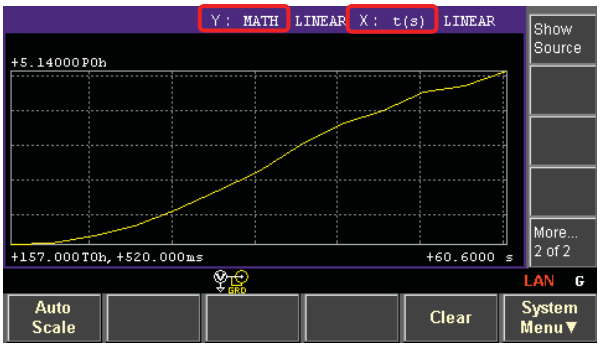


Note:

- The resistivity unit “PO” indicates Peta-Ω cm.
- The dimension of the volume resistivity is shown in Ω cm.
- The Roll View shows OHMS in the example. The Math data cannot be displayed in the Roll View.
- If the [Run/Stop] key is clicked, the [AUTO] indicator lights up, and a spot measurement by the Voltage Source value is repeated.

15. Plot volume resistivity vs the electrification time.

    1) Press the [View] key to show the View function key.
    2) Press the [Graph View] key to show the Graph View.
    3) Set the axis as follows by using the knob; Y: MATH, X: t (s)



Note: The Math data cannot be plotted in real-time during measurement. The Math data is plotted automatically versus time after the sweep measurement.

Example 2. Surface resistivity measurements

Surface resistivity measurements are identical to volume resistivity measurements with the following exceptions. Refer to the steps described in Example 1 while noting the following differences.

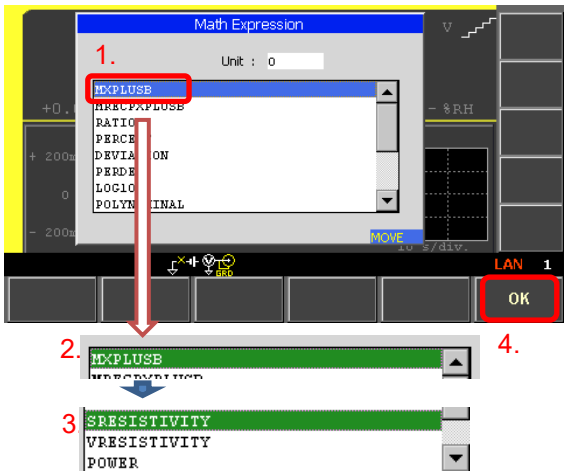
1. Place the test sample in the N1424 Resistivity Cell.

   Note: This example uses a rubber sheet as the test material.

   Set the N1424 Volume/Surface Selector box selector switch to the “Surface” position.

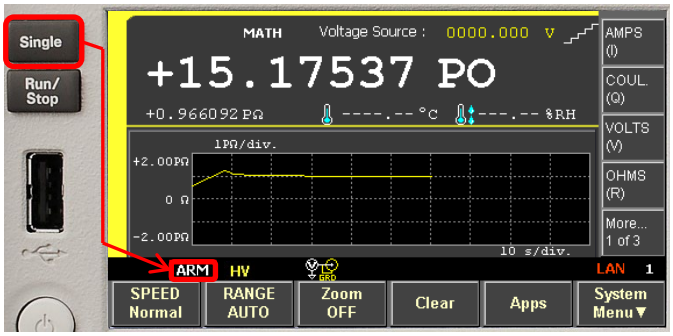
2. Set the MATH function to calculate surface resistivity measurements.

   1) Click on the [Math] key on the front panel. The Math Expression panel appears on the display.
   2) Click on the [knob], and change to the edit mode.
   3) Scroll to the "SRESISTIVITY" MATH function.
   4) Press the [OK] key to set the SRESISTIVITY MATH function.



3. Start the surface resistivity measurements.

   Press the [Single] measurement button. The [ARM] indicator lights and the sweep measurements start. The surface resistivity measurements are made in 5 seconds to 60 seconds.

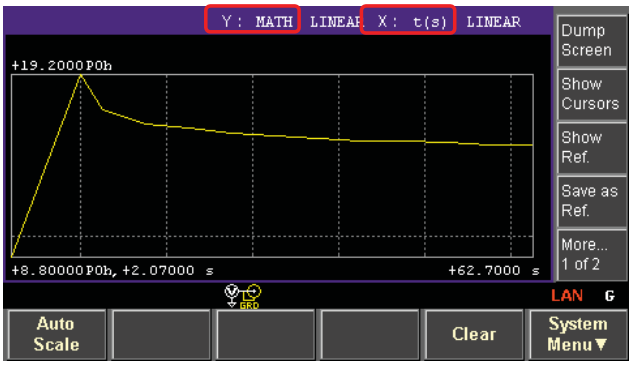


   Note:

   - The resistivity unit “PO” indicates Peta-Ohm.
   - The Roll View shows OHMS in the example. The Math data cannot be displayed in Roll View.

4. Plot surface resistivity vs the electrification time

   1) Press the [View] key to show the View function key.
   2) Press the [Graph View] key to show the Graph View
   3) Set the axis as follows by using the [knob]; Y: MATH, X: t (s)



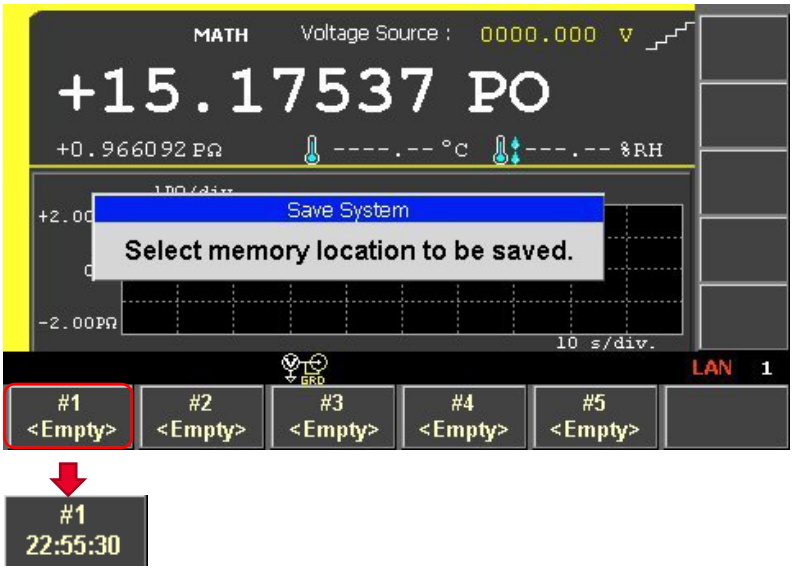
Example 3. Saving test setups

You can save test configurations and setups to either internal memory or an external USB device, allowing you to reuse test setups without reentering everything.

The following example shows how to save a setup to internal memory.

1. Press the [Save] key. A popup window with the message “Select memory location to be saved.” appears.
2. Press one of the function key locations displayed at the bottom of the instrument to select an internal memory location to save the current setup.

   You can recall the setup by pressing the [Recall] key and selecting the setup.



Conclusion

The Keysight B2985B and B2987B Electrometer/High Resistance Meters, along with the N1424 Resistivity Cell fixture, enhance the characterization of surface and volume resistivity materials. With a user-friendly interface and high accuracy, they can measure resistances up to 10 PΩ and source test voltages up to 1000 V. These meters allow specifying measurement delay times and include built-in math functions to calculate and display volume and surface resistivity based on test fixtures and sample dimensions. Featuring timer-based triggering and trend graph capabilities, they provide flexibility for characterizing advanced materials and devices. Learn more at www.keysight.com/find/B2980.