

Measuring Insulating Material Resistivity Using the B2985A/87A

Keysight B2985A/B2987A Electrometer/High Resistance Meter



Introduction

The Keysight B2985A and B2987A Electrometer/High Resistance Meters simplify the surface and volume resistivity characterization of insulating materials by providing accurate resistance or current versus time information in real time on 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, as well as by using custom resistivity measurement fixtures for other sample forms or shapes.

The Keysight B2985A and B2987A Electrometer/High Resistance Meters provide unmatched current measurement resolution of 10 aA (0.01 fA). They also have a built-in 1000 V voltage source that allows you to measure resistances of up to 10PΩ ($10^{16}\Omega$).

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.

The B2985A and B2987A possess timer-based triggering and math functions that can perform calculations on 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 B2985A/B2987A's display to view resistivity changes up until the point at which the final resistivity value is recorded.

This application note shows how easily you can make accurate resistivity measurements with the B2985A/87A and the N1424.

Note: The B2987A has an internal rechargeable battery that allows it to operate without being connected to AC power.

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}

Resistivity Measurement

1. 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 1. The voltage source V_s is applied to the upper electrode and the bulk current that flows through the test sample is measured as I_m . The volume resistance R_v is then calculated using the equation $R_v = V_s/I_m$. 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 V_s and they do not affect the magnitude of the ammeter current (I_m) used to calculate R_v .

The volume resistivity ρ_v is obtained by $\rho_v = EAR/STH \times R_v$, where:

EAR = Effective area

STH = Sample thickness

Surface resistivity measurements

Surface resistivity measurements typically use the electrode configuration shown in Figure 2. The voltage source V_s 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 I_m . The surface resistance R_s is calculated using the equation $R_s = V_s/I_m$. The current flowing from the guard ring to the upper electrode is leakage current; however, since it flows into the low of the V_s it does not affect the value of the ammeter current (I_m) used to calculate R_s .

The surface resistivity ρ_s is obtained by $\rho_s = EPER/GLEN \times R_s$, where:

EPER = Effective perimeter

GLEN = Gap length

The B2985/87A can calculate and display these parameters using the built-in MATH function.

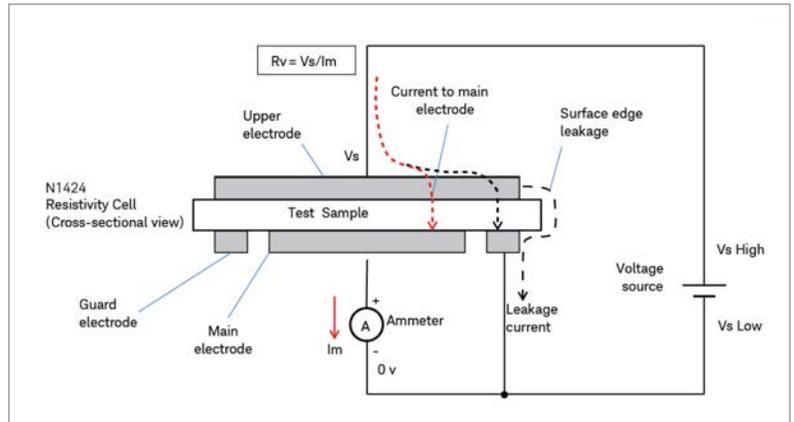


Figure 1. Volume resistivity measurements

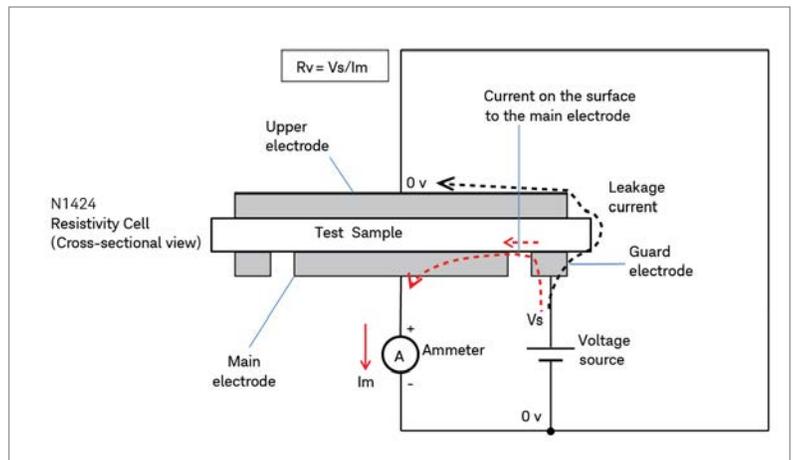


Figure 2. Surface resistivity measurements.

Resistivity Measurement (continued)

2. Measurement Support Capabilities

The B2985A and B2987A have many features to help with resistivity measurement.

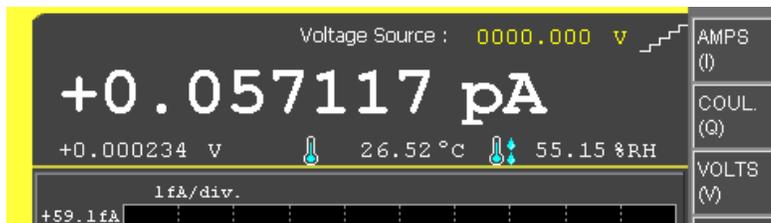
Measurement time setting:

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 at what time the resistivity measurement should take place. Unless otherwise specified, 60 seconds after applying stimulus (electrification) is commonly used as the time at which to make a resistivity measurement (as is specified in the ASTM D257 standard).

The B2985A and B2987A allow you to specify exactly what time to make a measurement after applying stimulus (electrification).

Humidity and temperature measurement:

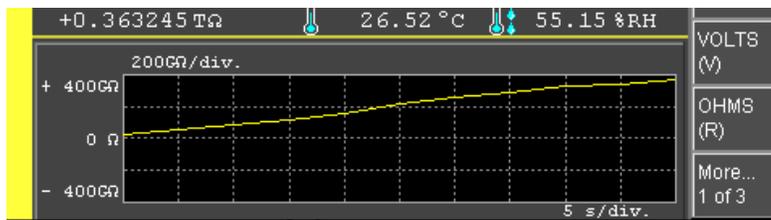
Since resistivity measurements are affected by ambient temperature and humidity, it is important to record this information when comparing resistivity measurements made on different materials.



The B2985A and B2987A allow you to measure and record both the ambient temperature and the humidity along with resistance measurement data.

Trend graph display:

Since resistivity measurements typically vary after the application of 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 B2985A and B2987A allow you to monitor the resistivity changes graphically over time.

Resistivity Measurement Examples using the N1424 Resistivity Cell

This section explains how to make resistivity measurements using the B2985A/87A and the N1424 Resistivity Cell test fixture.

Figure 3 shows a rear view of the B2987A and N1424 configured to make resistivity measurements.

Make sure that 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 4.

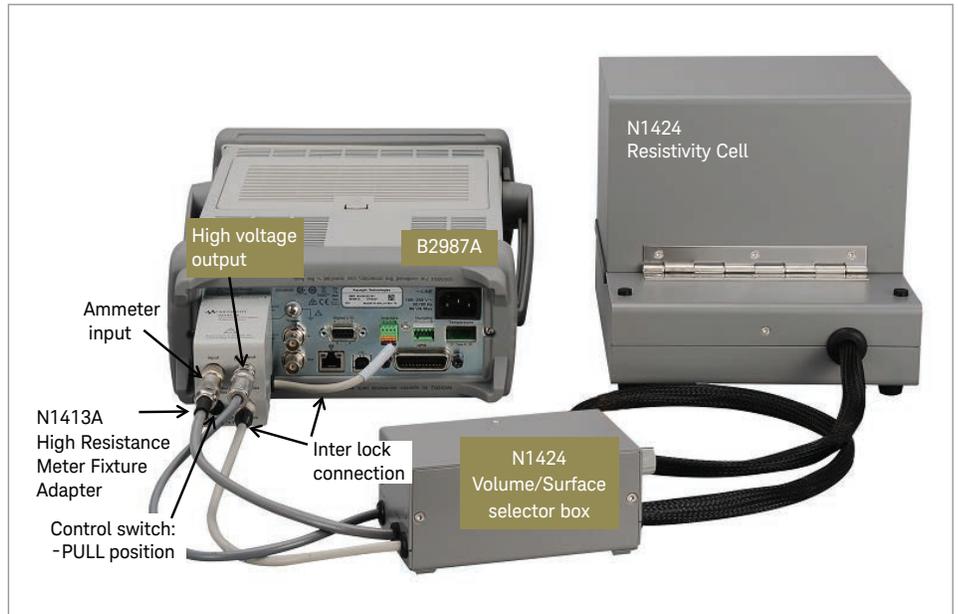


Figure 3. B2987A and N1424 configured to make resistivity measurements.



Figure 4. 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 as that 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 5.

Note: The following link to the N1424 manual can provide you with more information on this test fixture:

<http://literature.cdn.keysight.com/litweb/pdf/N1424-90000.pdf>

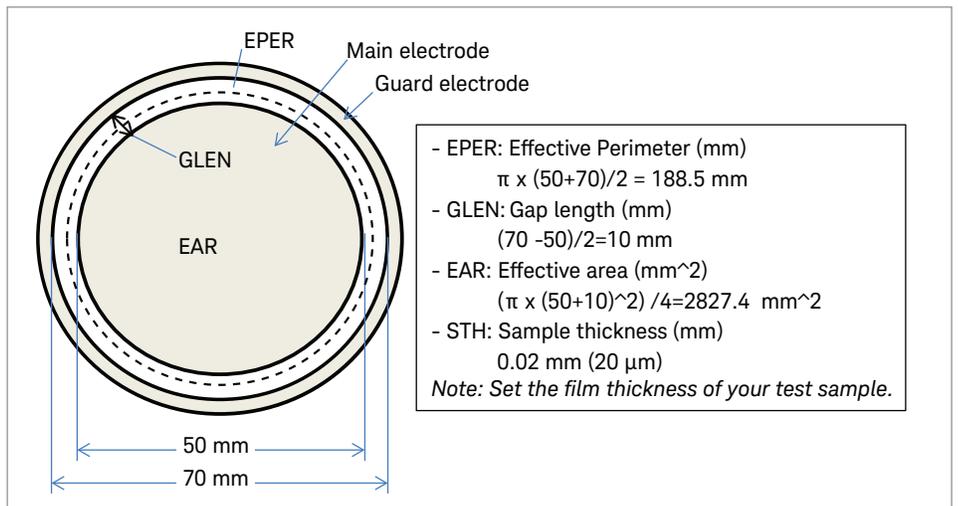


Figure 5. Test electrode dimensions and the resistivity calculation parameters.

Resistivity Measurement Examples using the N1424 Resistivity Cell (continued)

The following examples describe how to setup and measure both volume and the surface resistivity.

The setups used in these examples can be downloaded from the following link: www.keysight.com/find/SensitiveMeasurement

Example 1. Volume resistivity measurement

The following steps explain how to setup and measure volume resistivity.

Measurement steps of B2985A 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. Setting up the low terminal state of the voltage source.

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



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



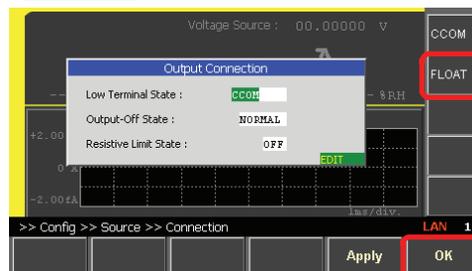
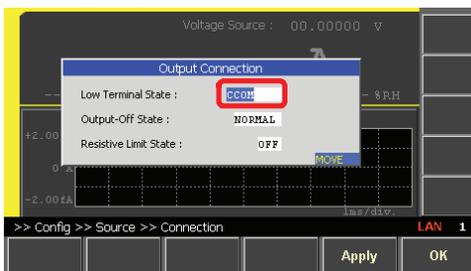
Step 3. Press [Source] key.



Step 4. Press [Connection] key.



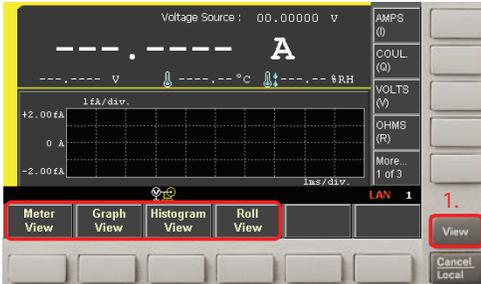
Step 5. Press  and select **FLOAT**. And then press **OK**



Example 1. Volume resistivity measurement (continued)

3. Press the [View] key to show the function key View menus. Next, press the [Meter View] function key, and then press the [AMPS (I)] assist key.

(1) Press **View** key to show the View function key.



(2) Press **Meter View** key, then

(3) press **AMPS (I)** key.



4. (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 [knob] to edit the voltage.

(3) The field pointer changes to green (EDIT).

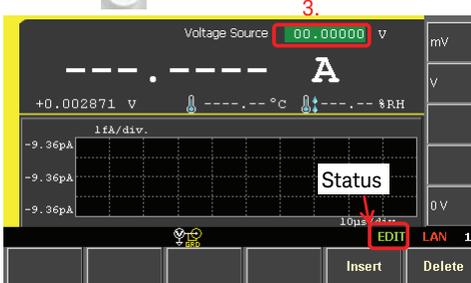
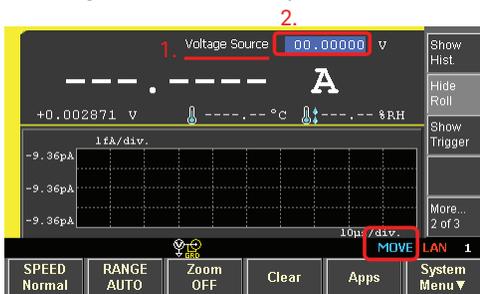
(4) Set the voltage to zero volts. Use the arrow keys to select which digits to edit.

(1) If the Voltage Source value is not 0 V, perform the following steps.

(2) Rotate **Knob** and to move the field pointer onto the Voltage Source value, and press to edit the voltage.

(3) The field pointer changed 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. Setting up the MATH parameters for volume and surface resistivity computation:

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



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



Step 3. Press [Math] key.



Step 4. Press [Variable] key.



Example 1. Volume resistivity measurement (continued)

6. The math variable input panel opens.

The Index is set to the "01" position (as shown in step "a" of the following figure).

Perform steps "b" to "i" in the following figure, and set the index 7 variable to 188.5 (mm) as shown in step h.

a. Index 01 is selected.

Index	Name	Value
01	M	0
02	B	0
03	A0	0

b. Click to EDIT mode

Index	Name	Value
01	M	0
02	B	0
03	A0	0

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

Index	Name	Value
05	AZ	0
06	TARGET	0
07	EPER	0
08	CLEN	0
09	EAR	0

d. Click to MOVE mode

Index	Name	Value
05	AZ	0
06	TARGET	0
07	EPER	0
08	CLEN	0
09	EAR	0

e. Rotate to move to "Value" field.

Index	Name	Value
05	AZ	0
06	TARGET	0
07	EPER	0
08	CLEN	0
09	EAR	0

f. Click to enter the EPER value.

g. Enter the value by using [knob] and the arrow keys.

Index	Name	Value
05	AZ	0
06	TARGET	0
07	EPER	188.5
08	CLEN	0
09	EAR	0

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

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

Index	Name	Value
06	TARGET	0
07	EPER	188.5
08	CLEN	0
09	EAR	0
10	STH	0

7. After performing the steps shown above for the variables from index 08 to 10, all of the parameters should be set as shown in the following figure.

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

All the resistivity Math parameters are set.

Press [Apply] then [OK] key to set and close the input panel of the Math Variable.

Index	Name	Value
06	TARGET	0
07	EPER	188.5
08	CLEN	10
09	EAR	2827.4
10	STH	0.02

>> Function >> Math >> Variable

Apply OK

Example 1. Volume resistivity measurement (continued)

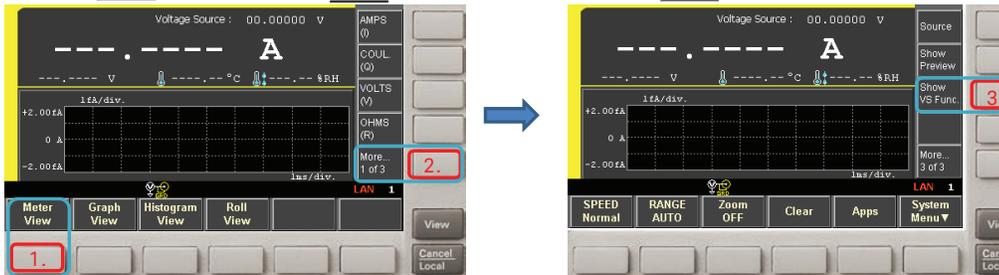
8. Set the measurement test voltage.

- (1) Press the [Meter View] function key.
- (2) Then 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.

(1) Press **Meter View** key, then

(2) press **More... 1 of 3** key two times until **More... 3 of 3** key appears.

(3) press **Show VS Func.** key.

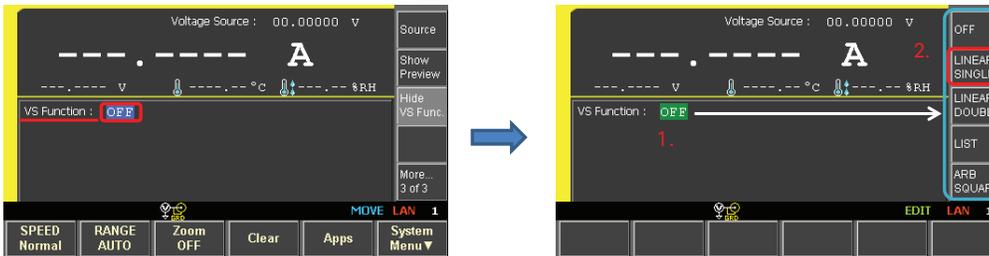


9. Change the VS Function to EDIT mode, and select the [LINEAR SINGLE] assist key.

(1) Click on the VS Function by , and this changes the assist key menu.

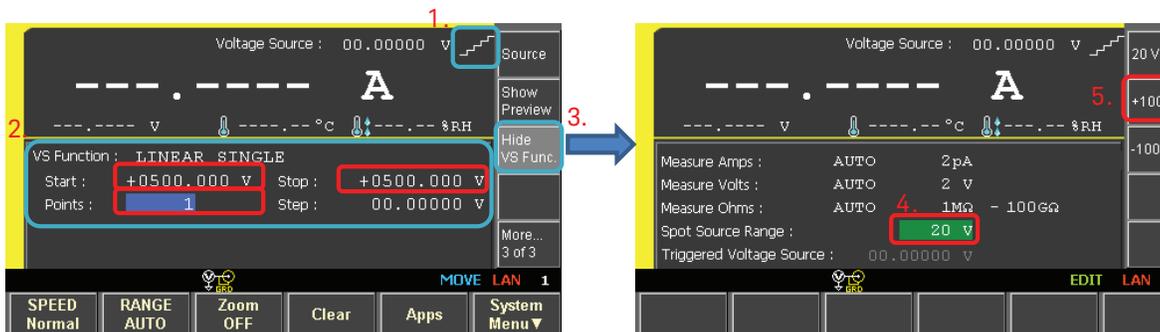
(2) Press **LINEAR SINGLE** assist key.

Move the cursor on the VS Function by rotating .



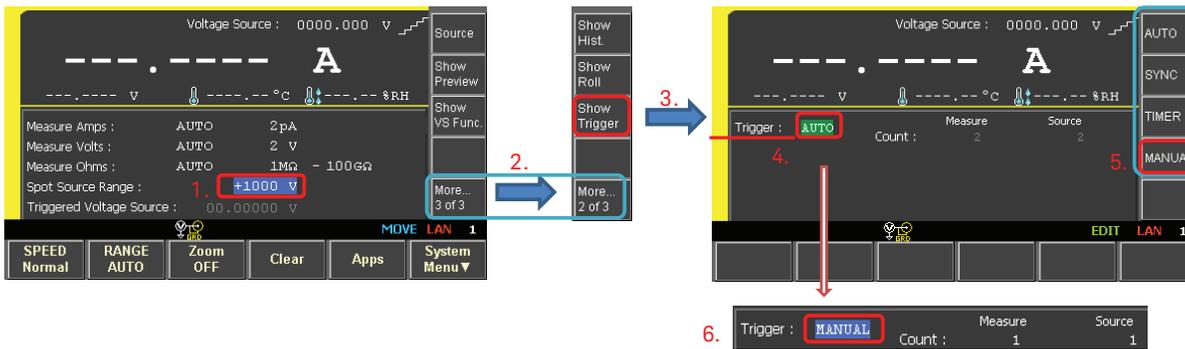
10. Set the sweep parameters by performing the steps shown in the following figure.

- (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.



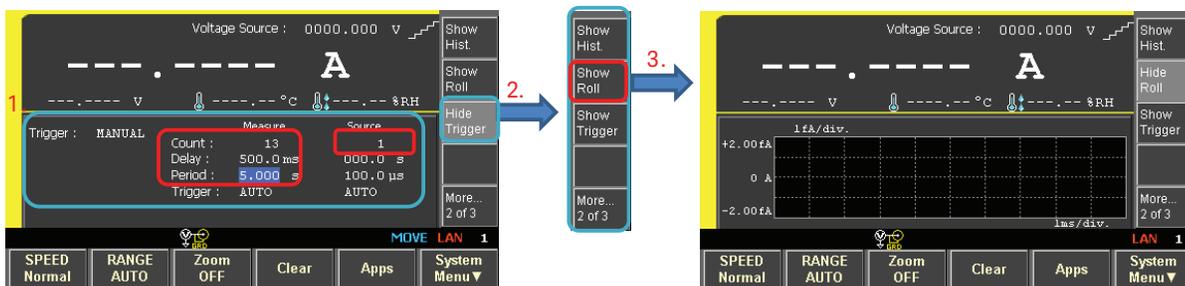
Example 1. Volume resistivity measurement (continued)

11. (1) The VS source range indicates that it is set to the 1000 V range.
- (2) Press the [More ... 3 of 3] assist key two times 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.



12. The Manual Trigger parameter input field opens.
In the example, the trigger is set to 5 seconds interval 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 output of the bias voltage.)
 - Measure-Period: 5 sec (Sampling is made in every 5 seconds.)
 - Source-Count: 1 (Start-Stop)
 - Measure & Source Trigger: AUTO
- (2) Press [Hide Trigger] assist key.
- (3) Press [Show Roll] assist key to prepare for the measurements.
The Meter View with the Roll View screen in lower half of the display appears.



13. Optional setup

If you are using a humidity sensor and/or a thermocouple, connect these to the rear inputs on the B2985A/87A so that you can measure both the humidity and the temperature of the test environment.

Note: Since humidity has a large impact on resistivity measurements r , if you are measuring resistivity in an uncontrolled environment you should monitor it.

Example 1. Volume resistivity measurement (continued)

14. Output ON.

- (1) Press the Voltage Source [On/Off] key to output 0 V.
- (2) Then, press the Ammeter [On/Off] key to connect the ammeter.
- (3) A single current measurement is made automatically.

Note: If humidity and temperature sensors are connected then this data is also displayed.

(1) Voltage Source On

(2) Ammeter On

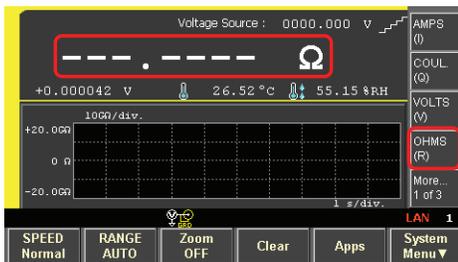
(3) A measurement is made automatically.

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

- a. The Meter View unit changes to “Ω”.
 - b. The following steps set the MATH function to calculate volume resistivity.
- Follow the steps from 1 to 3 shown in b. section of the next figure.

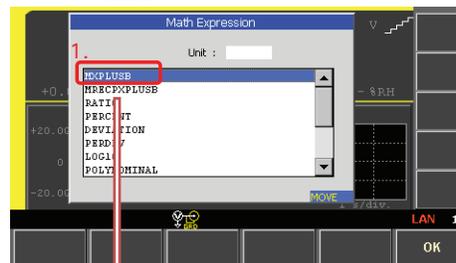
a. OHMS measurement setting:

Press [OHMS(R)] assist key. The measurement mode changes to OHMS mode.



b. Volume resistivity MATH setting:

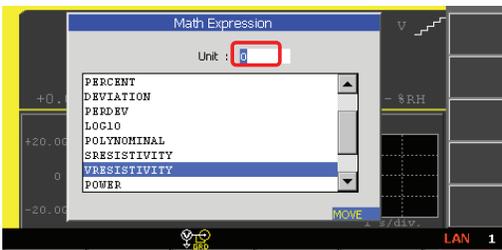
- (1) Click on the **Math** key on the front panel. The Math Expression panel appears on the display.
- (2) Click on the **EDIT** knob, and change to EDIT mode.
- (3) Scroll to the "VRESISTIVITY" MATH function, and click on the **EDIT** knob.



c. Next set the "Unit" character of the measurement data display for the resistivity MATH function.

Follow steps 1 to 3 as shown in the next figure:

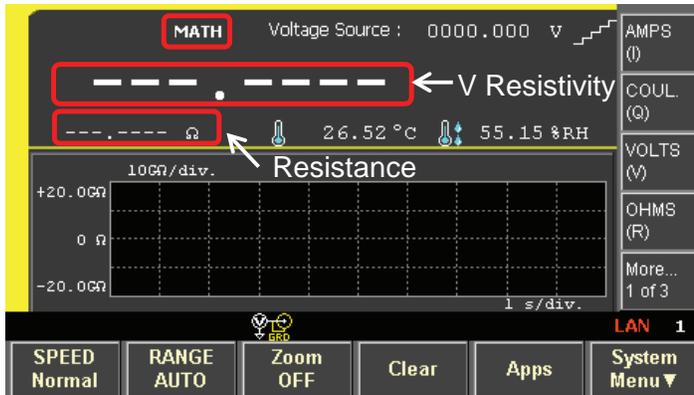
- (1) Rotate the **EDIT** knob, and move the focus to the Unit input field.
- (2) Click on the **EDIT** knob, and enter the unit to "O" which indicates Ohm.
- (3) Press [OK] key to set the VRESISTIVITY MATH function.



- 2.
- 3.

Example 1. Volume resistivity measurement (continued)

16. 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.

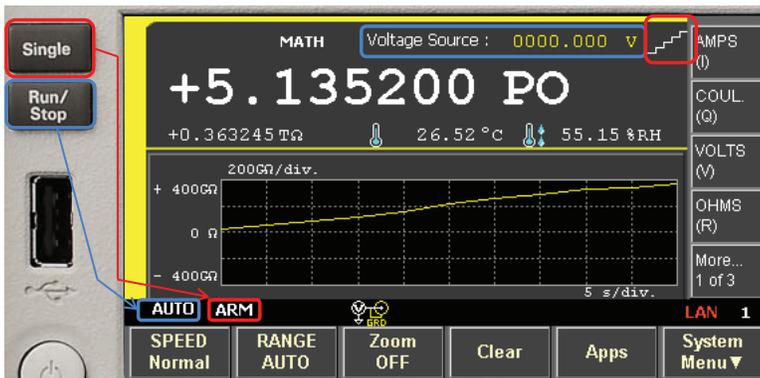


17. The following operations execute the volume resistivity measurement.
Press the [Single] measurement button.
The volume resistivity measurements are made in 5 seconds to 60 seconds.
The resistivity unit “PO” indicates Peta-Ohm/cm.
Note: The dimension of the volume resistivity is shown in Ωcm .

Click the [Single] key. The [ARM] indicator lights and the sweep measurements start.

Note:

1. The Roll View shows OHMS in the example. The Math data cannot be displayed in the Roll View.
2. If click the [Run/Stop] key, [AUTO] indicator lights and a spot measurement by the Voltage Source value is repeated.



The Roll View plots the trend of the resistance data.

Note: Roll View cannot plot Math data, but it is still useful to check measurement data trends.

Example 1. Volume resistivity measurement (continued)

18. The Math data can be plotted in the Graph View.

Perform the following steps to plot volume resistivity v the electrification time.

(1) Press  key to show the View function key.

(2) Press  key to show the Graph View.

(3) Set axis as follows by using the  knob.

Y : MATH

X : t (s)

The next graph will be obtained.



Note: The Math data cannot be plotted in real time during measurement.

The Math data is plotted automatically versus time after the sweep measurement is complete.

Example 2. Surface resistivity measurements

Surface resistivity measurements are essentially identical to volume resistivity measurements with the following exceptions.

Refer to the same 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.

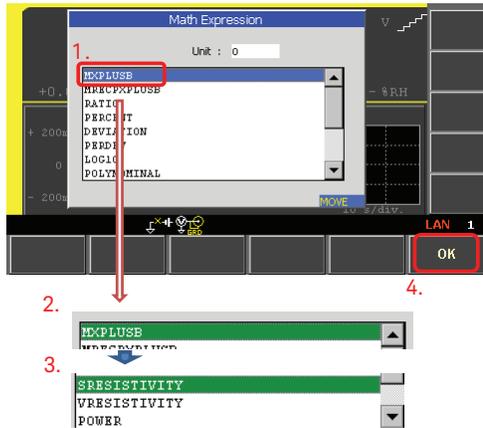
Set the N1424 Volume/Surface Selector box selector switch to the "Surface" position.



2. The following steps setup the MATH function to calculate surface resistivity measurements. Perform steps (1) to (4) as shown in the following figure.

b. Surface resistivity MATH setting:

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

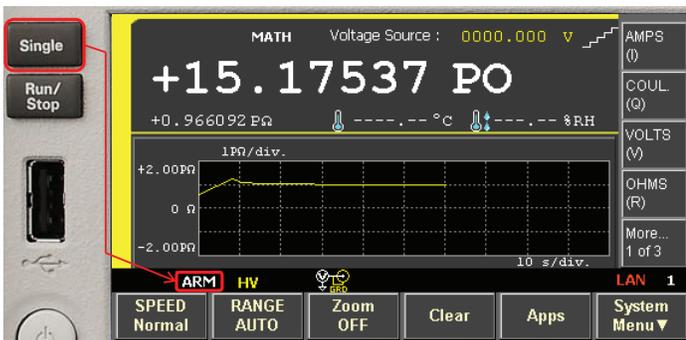


3. Start the surface resistivity measurements.
Press [Single] measurement button.
The surface resistivity measurements are made in 5 seconds to 60 seconds.
The resistivity unit "PO" indicates Peta-Ohm

Click the [Single] key. The [ARM] indicator lights and the sweep measurements start.

Note:

1. Roll View shows OHMS in the example. The Math data cannot be displayed in Roll View.



Example 2. Surface resistivity measurements (continued)

4. The Graph View results are shown.

- (1) Press **View** key to show the View function key.
- (2) Press **Graph View** key to show the Graph View
- (3) Set axis as follows by using the **Y** key.
Y : MATH
X : t (s)
The next graph will be obtained.



Example 3. Saving test setups

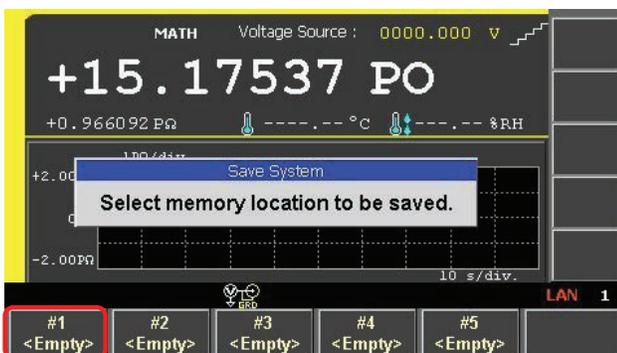
You can save test configurations and test setups to either internal memory or to an external USB device, allowing you to reuse test setups without having to reenter everything.

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 at which to save the current setup.

Later, you can recall the setup by pressing the [Recall] key and selecting the setup.

Press **Save** key, and select one of the memory key to save the setup.



#1
22:55:30 → The saved setup can be recalled by Pressing **Recall** key.

Conclusion

The Keysight B2985A and B2987A Electrometer/High Resistance Meters combine with the N1424 Resistivity Cell fixture to provide improved surface and volume resistivity materials characterization. In addition, they offer a user-friendly graphical user interface and superior measurement accuracy.

The Keysight B2985A/B2987A Electrometer/High Resistance Meter can measure resistances of up to 10 PΩ ($10^{16}\Omega$) and it can source test voltages of up to 1000 V.

You can specify any measurement delay time after application of the test voltage, including the typical 60 seconds as specified in the ASTM D257 standard.

The B2985A/B2987A has built-in math function capabilities that can perform calculations on the measurement data and (using the dimensions of your test fixture and test sample) can display both the volume and the surface resistivity.

The timer based triggering and trend graph features provide the flexibility necessary to characterize exotic new state-of-the-art materials and devices.

Learn more at: www.keysight.com

For more information on Keysight Technologies' products, applications or services, please contact your local Keysight office. The complete list is available at: www.keysight.com/find/contactus

