Model 8009 Resistivity Test Fixture

Instruction Manual

8009-901-01 Rev. D / May 2019

8009-901-01D

KEITHLEY
A Tektronix Company

Model 8009

Resistivity Test Fixture

Instruction Manual

Document number: 8009-901-01 Rev. D / May 2019

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Safety precautions

The following safety precautions should be observed before using this product and any associated instrumentation. Although some instruments and accessories would normally be used with nonhazardous voltages, there are situations where hazardous conditions may be present.

This product is intended for use by personnel who recognize shock hazards and are familiar with the safety precautions required to avoid possible injury. Read and follow all installation, operation, and maintenance information carefully before using the product. Refer to the user documentation for complete product specifications.

If the product is used in a manner not specified, the protection provided by the product warranty may be impaired.

The types of product users are:

Responsible body is the individual or group responsible for the use and maintenance of equipment, for ensuring that the equipment is operated within its specifications and operating limits, and for ensuring that operators are adequately trained.

Operators use the product for its intended function. They must be trained in electrical safety procedures and proper use of the instrument. They must be protected from electric shock and contact with hazardous live circuits.

Maintenance personnel perform routine procedures on the product to keep it operating properly, for example, setting the line voltage or replacing consumable materials. Maintenance procedures are described in the user documentation. The procedures explicitly state if the operator may perform them. Otherwise, they should be performed only by service personnel.

Service personnel are trained to work on live circuits, perform safe installations, and repair products. Only properly trained service personnel may perform installation and service procedures.

Keithley products are designed for use with electrical signals that are measurement, control, and data I/O connections, with low transient overvoltages, and must not be directly connected to mains voltage or to voltage sources with high transient overvoltages. Measurement Category II (as referenced in IEC 60664) connections require protection for high transient overvoltages often associated with local AC mains connections. Certain Keithley measuring instruments may be connected to mains. These instruments will be marked as category II or higher.

Unless explicitly allowed in the specifications, operating manual, and instrument labels, do not connect any instrument to mains.

Exercise extreme caution when a shock hazard is present. Lethal voltage may be present on cable connector jacks or test fixtures. The American National Standards Institute (ANSI) states that a shock hazard exists when voltage levels greater than 30 V RMS, 42.4 V peak, or 60 VDC are present. A good safety practice is to expect that hazardous voltage is present in any unknown circuit before measuring.

Operators of this product must be protected from electric shock at all times. The responsible body must ensure that operators are prevented access and/or insulated from every connection point. In some cases, connections must be exposed to potential human contact. Product operators in these circumstances must be trained to protect themselves from the risk of electric shock. If the circuit is capable of operating at or above 1000 V, no conductive part of the circuit may be exposed.

Do not connect switching cards directly to unlimited power circuits. They are intended to be used with impedance-limited sources. NEVER connect switching cards directly to AC mains. When connecting sources to switching cards, install protective devices to limit fault current and voltage to the card.

Before operating an instrument, ensure that the line cord is connected to a properly-grounded power receptacle. Inspect the connecting cables, test leads, and jumpers for possible wear, cracks, or breaks before each use.

When installing equipment where access to the main power cord is restricted, such as rack mounting, a separate main input power disconnect device must be provided in close proximity to the equipment and within easy reach of the operator.

For maximum safety, do not touch the product, test cables, or any other instruments while power is applied to the circuit under test. ALWAYS remove power from the entire test system and discharge any capacitors before: connecting or disconnecting cables or jumpers, installing or removing switching cards, or making internal changes, such as installing or removing jumpers.

Do not touch any object that could provide a current path to the common side of the circuit under test or power line (earth) ground. Always make measurements with dry hands while standing on a dry, insulated surface capable of withstanding the voltage being measured.

For safety, instruments and accessories must be used in accordance with the operating instructions. If the instruments or accessories are used in a manner not specified in the operating instructions, the protection provided by the equipment may be impaired.

Do not exceed the maximum signal levels of the instruments and accessories. Maximum signal levels are defined in the specifications and operating information and shown on the instrument panels, test fixture panels, and switching cards.

When fuses are used in a product, replace with the same type and rating for continued protection against fire hazard.

Chassis connections must only be used as shield connections for measuring circuits, NOT as protective earth (safety ground) connections.

If you are using a test fixture, keep the lid closed while power is applied to the device under test. Safe operation requires the use of a lid interlock.

If a screw is present, connect it to protective earth (safety ground) using the wire recommended in the user documentation.

The symbol on an instrument means caution, risk of hazard. The user must refer to the operating instructions located in the user documentation in all cases where the symbol is marked on the instrument.

The symbol on an instrument means warning, risk of electric shock. Use standard safety precautions to avoid personal contact with these voltages.

The symbol on an instrument shows that the surface may be hot. Avoid personal contact to prevent burns.

The symbol indicates a connection terminal to the equipment frame.

If this symbol is on a product, it indicates that mercury is present in the display lamp. Please note that the lamp must be properly disposed of according to federal, state, and local laws.

The **WARNING** heading in the user documentation explains hazards that might result in personal injury or death. Always read the associated information very carefully before performing the indicated procedure.

The **CAUTION** heading in the user documentation explains hazards that could damage the instrument. Such damage may invalidate the warranty.

The **CAUTION** heading with the symbol in the user documentation explains hazards that could result in moderate or minor injury or damage the instrument. Always read the associated information very carefully before performing the indicated procedure. Damage to the instrument may invalidate the warranty.

Instrumentation and accessories shall not be connected to humans.

Before performing any maintenance, disconnect the line cord and all test cables.

To maintain protection from electric shock and fire, replacement components in mains circuits — including the power transformer, test leads, and input jacks — must be purchased from Keithley. Standard fuses with applicable national safety approvals may be used if the rating and type are the same. The detachable mains power cord provided with the instrument may only be replaced with a similarly rated power cord. Other components that are not safety-related may be purchased from other suppliers as long as they are equivalent to the original component (note that selected parts should be purchased only through Keithley to maintain accuracy and functionality of the product). If you are unsure about the applicability of a replacement component, call a Keithley office for information.

Unless otherwise noted in product-specific literature, Keithley instruments are designed to operate indoors only, in the following environment: Altitude at or below 2,000 m (6,562 ft); temperature 0 °C to 50 °C (32 °F to 122 °F); and pollution degree 1 or 2.

To clean an instrument, use a cloth dampened with deionized water or mild, water-based cleaner. Clean the exterior of the instrument only. Do not apply cleaner directly to the instrument or allow liquids to enter or spill on the instrument. Products that consist of a circuit board with no case or chassis (e.g., a data acquisition board for installation into a computer) should never require cleaning if handled according to instructions. If the board becomes contaminated and operation is affected, the board should be returned to the factory for proper cleaning/servicing.

Safety precaution revision as of June 2017.

Section 1

Getting started

In this section:

Introduction

The Model 8009 Resistivity Test Fixture allows volume resistivity measurements up to 10^{18} Ω-cm or surface resistivity measurements up to 10^{17} Ω. The test fixture is designed using a three-lug triaxial connector that allows simple connection to a Keithley Instruments Model 6517, 6517A, or 6517B Electrometer.

NOTE

All references in this manual to the 6517 are also valid for the 6517A.

Features

The 8009 test fixture features:

- Electrodes made from stainless steel for corrosion prevention.
- Switchable volume and surface resistivity modes.
- 6517 and 6517B Electrometer and High Resistance Meters operation.
- Safety interlock system and dual safety banana jacks for connection to 1 kV source in a 6517 or 6517B.

Accessories

The following is a list of accessories that are supplied with your 8009.

8009 supplied accessories

Model 6517-ILC-3	1- meter, 4-pin interlock cable
Model 6517B-ILC-3	3- meter, 4-pin interlock cable
Model 7078-TRX-3	A 3 ft. (0.9 m) low-noise triaxial cable that is terminated at both ends with 3-slot triaxial connectors. This is used to connect the 8009 test fixture to the 6517 Electrometer
8007-GND-3	Safety ground wire with ground lug

Cleaning

The 8009 electrodes should be periodically cleaned with methanol or other suitable solvent. The connectors should also be kept clean to prevent leakage when measuring low-level current.

When not in use, keep the supplied protective spacer installed between the electrodes. This will help prevent the surfaces of the electrodes from getting nicked and scratched.

Section 2

Operation

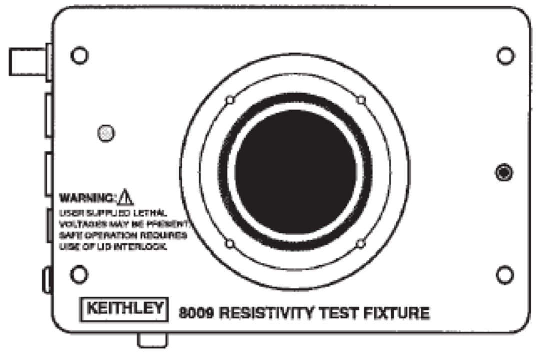
In this section:

Operation overview

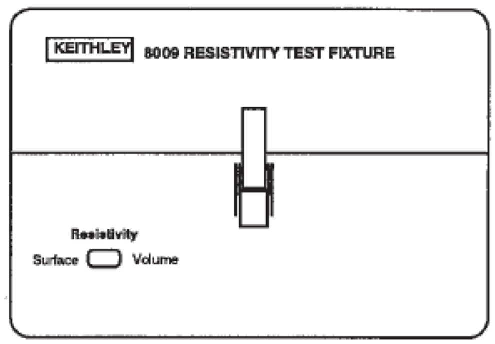
The basic method used to determine resistivity of a specimen is a two-step process. A test voltage is applied to the specimen, and the following current is measured. Then the test voltage value and measured current value are applied to the appropriate equation and resistivity is calculated.

The 8009 is shown in following figure. The top view shows the interior of the test fixture where the specimen is mounted. The front view shows the pushbutton switch that is used to select the desired resistivity test. The side view shows the test fixture connectors.

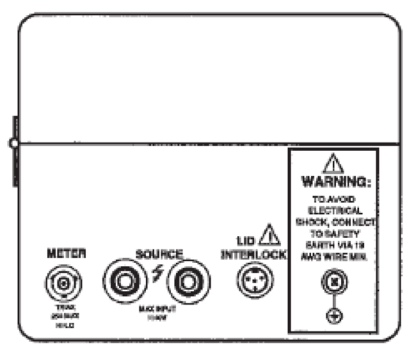
Figure 1: 8009 text fixture



A. Top view (sample mounting)



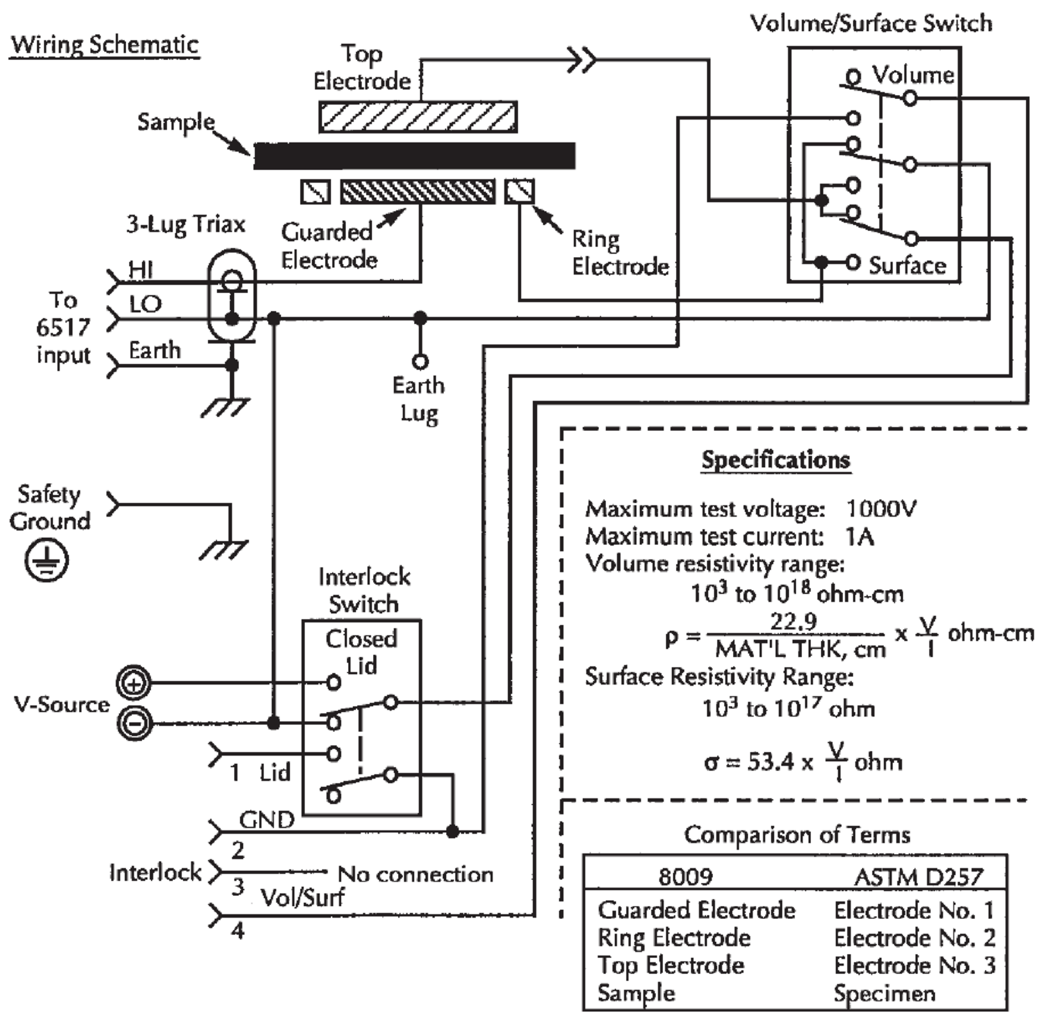
B. Front view (resistivity switch)



C. Side view (connectors)

The following figure shows a schematic diagram of the 8009. Note that the test fixture is externally connected to the electrode using a three-lug female triaxial connector. This connector will mate directly to the 6517 using the 6517-ILC-3 cable or to a 6517B using the 6517B-ILC-3 cable.

Figure 2: 8009 schematic diagram



NOTE

The included protective spacer should only be used when the 8009 is in the closed position and should never be used in a measurement.

ASTM standard

Methods, recommendations, and calculations used in this manual to make resistivity measurements are based on the following ASTM standard:

American Society for Testing and Materials, Standard Methods of Test for Electrical Resistance of Insulation Materials, ASTM Designation D257

Specimen mounting

The minimum and maximum sample sizes are listed in the specifications.

NOTE

Do not handle the specimen with bare fingers. Body oil will provide a conductive path and may corrupt the measurement. Acetate rayon gloves are recommended to prevent the spread of body oil. For best results, clean the specimen surfaces with an alcohol and ether mixture or other suitable solvent.

To mount the specimen in the 8009:

1. Remove the protective spacer.

NOTE

The top electrode in the 8009 is permanently attached to the top cover. A protective spacer is provided with the 8009 to protect the electrodes (this spacer can be used for a functional check of the 8009).

2. Center the specimen between the top and bottom electrodes of the 8009. Make sure there are no conductive paths between the electrodes other than those through the specimen.
3. Close the lid of the test fixture and secure the latch.
4. When your testing is complete, reinstall the protective spacer to protect the electrode surfaces from nicks and scratches in storage.

Connections

The following sections show connections for using your 8009 with a 6517 or a 6517B.

WARNING

The earth ground screw terminal of the 8009 Resistivity Test Fixture must be connected to a known safety earth ground using the supplied 8007-GND-3 ground wire or the #18 AWG or a larger wire.

The use of hazardous voltage requires that the interlock be used. The interlock circuit is activated when the 6517-ILC-3 or the 6517B-ILC-3 interlock cable (both supplied with 8009) is connected as shown in the following figures Whenever the lid of the 8009 is open, the 6517 or 6517B goes into standby, thus removing power from the test fixture.

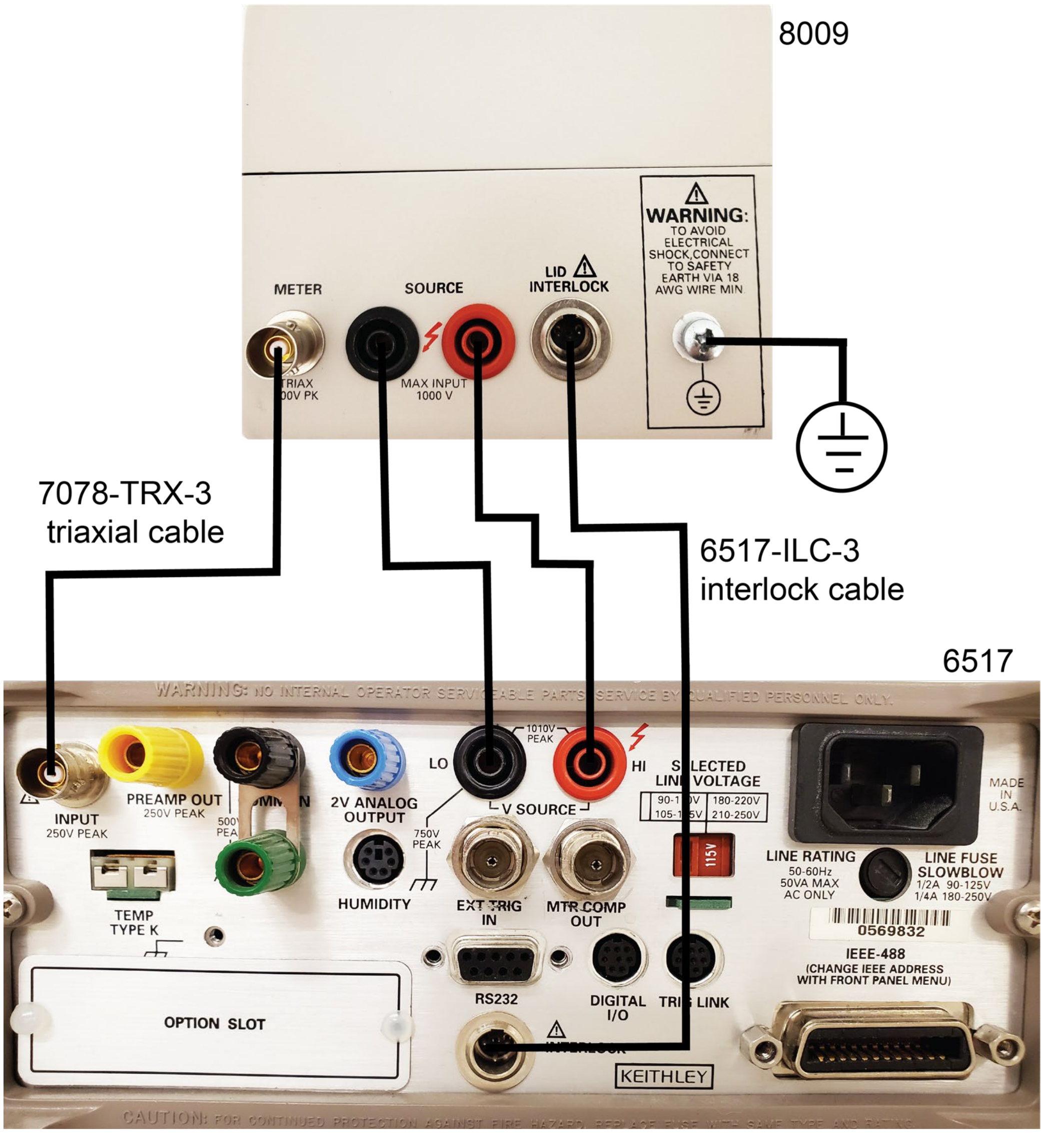
To prevent electrical shock that could cause injury or death:

Put the 6517 or 6517B voltage source in STANDBY before opening the lid of the Model 8009.

6517 connections

To connect the 6517 to the 8009 test fixture, refer to the following figure. The 7078-TRX-3 triaxial cable and the 6517-ILC-3 interlock cable are supplied with the 8009. Note that the ground link on the 6517 must be removed. Proper grounding will be performed by the 8009.

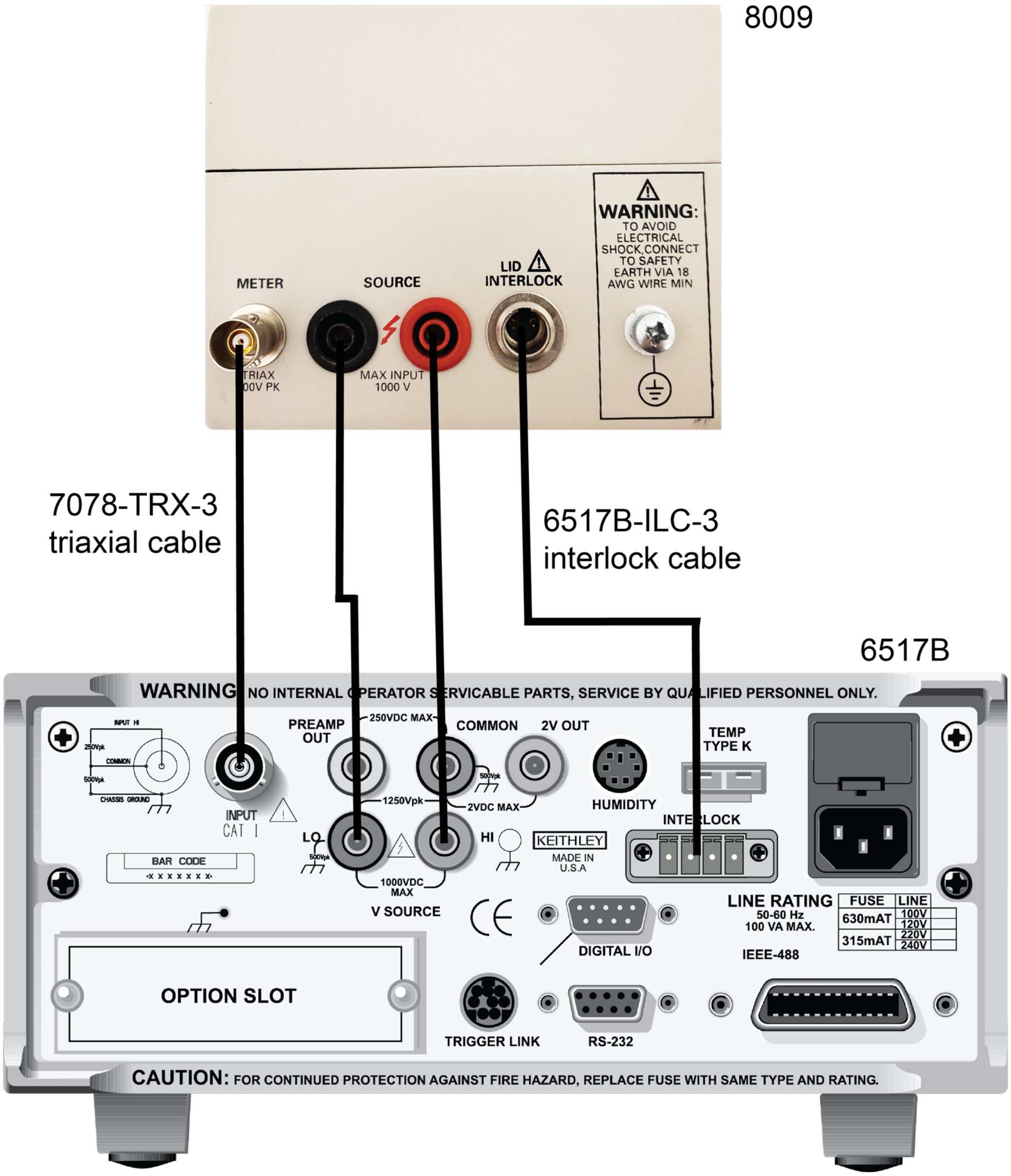
Figure 3: Connecting a 6517 to the 8009



6517B connections

Refer to the following figure to connect the 6517B to the 8009 test fixture. The triaxial cable and the 6517B-ILC-3 interlock cable are supplied with the 8009. Note that the ground link on the 6517B must be removed. Proper grounding will be performed by the Model 8009.

Figure 4: Connecting a 6517B to the 8009



Test voltage

Typically, specified test voltages to be applied to the specimen are 100 V, 250 V, 500 V, and 1000 V. The maximum test voltage that can be applied to the 8009 is 1000 V. The most frequently used test voltages are 100 V and 500 V. The 6517 can provide test voltages up to 1000 V.

Current measurement range and compliance limit

To make the most accurate resistivity measurement, the 6517 must be on the most sensitive (optimum) current measurement range. Place the 6517 in autorange to do this.

A current compliance limit protects the device under test (DUT). For almost all resistivity tests, protecting the specimen from excessive current is not a concern.

If manual ranging must be used, you may have to experiment to determine the best measurement range and subsequent compliance limit. For detailed information on compliance and measurement range selection, refer to the 6517 or 6517B reference manuals.

Electrification time

Electrification time is the total time that the specified voltage is applied to the specimen when the current measurement is made. For example, for an electrification time of 60 seconds, the current measurement is made after the specimen was subjected to the applied voltage for 60 seconds. Keep in mind that experimentation may dictate a different electrification time. Unless otherwise specified, an electrification of 60 seconds is recommended.

Resistivity measurement procedure

The previously detailed operating information is integrated into the following procedure to make resistivity measurements.

⚠ WARNING

The following procedure uses hazardous voltage that could cause severe injury or death. Exercise extreme caution when the voltage source is in operate.

NOTE

To calculate volume resistivity, the average thickness of the specimen must be known. If thickness is not known, use calipers to measure it.

To make resistivity measurements:

1. Mount the specimen in the 8009 test fixture. See Specimen mounting (on page 2-4) for detailed information.
2. Close the lid of the test fixture, secure the latch, and set the RESISTIVITY switch for the SURFACE or VOLUME test.
3. With power off, connect the test fixture the 6517 or 6517B. See Model 6517 connections (on page 2-5) or Model 6517B connections (on page 2-6) for more information.

WARNING

The use of hazardous voltage requires that the interlock be used. The interlock circuit is activated when the 6517-ILC-3 or the 6517B-ILC-3 interlock cable (both supplied with 8009) is connected as shown in the following figures Whenever the lid of the 8009 is open, the 6517 or 6517B goes into standby, thus removing power from the test fixture.

4. While in standby mode, set the voltage source to the appropriate test voltage. Typically, 500 V is used as the test voltage for specimens.
5. While in standby mode, set the 6517 or 6517B to an appropriate measurement range and current compliance limit. Autorange and a high-compliance limit satisfies the needs for most tests.
6. Put the voltage source in OPERATE mode, and after an appropriate electrification period, record the current reading from the display. Typically, an electrification period of 60 seconds is used.
7. Put the voltage source in standby mode.

Section 3

Derivation of resistivity equations

In this section:

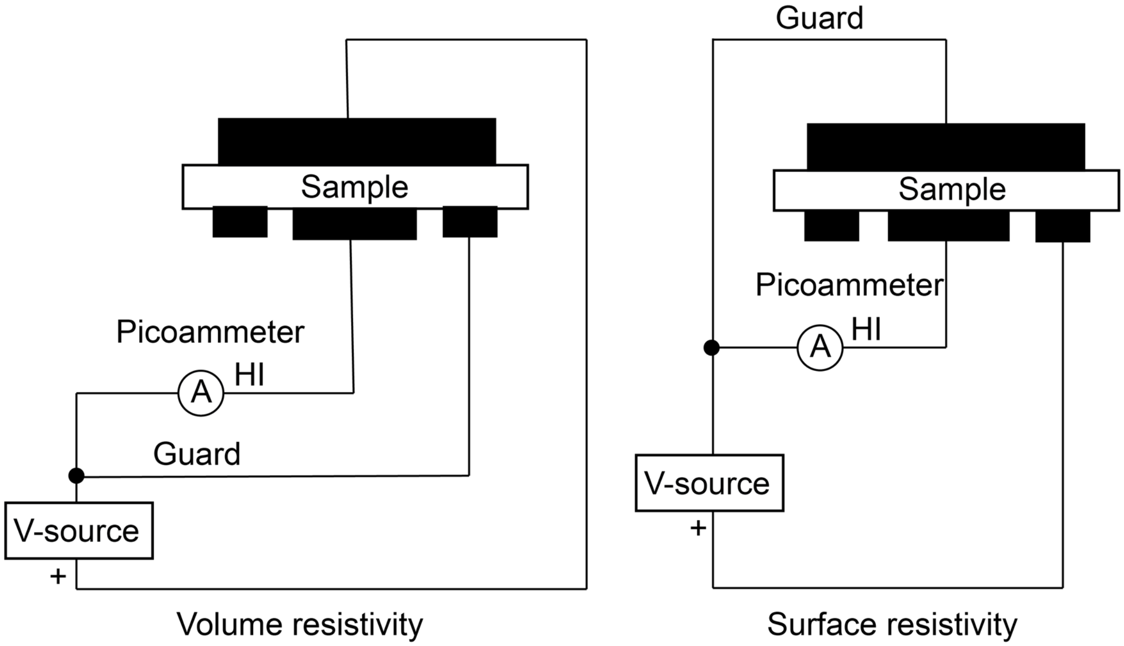
Resistivity calculations

For instruments that do not directly measure resistivity, this section provides the equations needed to calculate volume and surface resistivity using the applied test voltage and the measured current. If accuracy is not needed, nomographs can be used to approximate resistivity. This section also shows how to derive the equations used to calculate resistivity.

Calculating resistivity

The following equations are used to calculate volume and surface resistivity. They are based on the physical dimensions of the electrodes of the 8009. For more information on how these equations are derived, see Derivation of resistivity equations (on page 3-1).

Figure 5: Basic measurement techniques



Volume resistivity

Volume resistivity is the electrical resistance through a 1 cm cube of insulating material and is expressed in ohm-centimeters. Likewise, the electrical resistance through a 1 inch cube of insulating material is expressed as ohm-inches.

Volume resistivity (ρ) is measured by applying a voltage potential across opposite sides of the specimen, measuring the resultant current through the specimen, and then performing one of the following calculations.

$$\rho = \frac{22.9\ V}{t_c I}\ \Omega - cm$$

or

$$\rho = \frac{3.55\ V}{t_i I}\ \Omega - in.$$

Where:

ρ is the volume resistivity of the specimen

V is the applied voltage for the electrometer

t_c is the average thickness of the specimen in centimeters

t_i is the average thickness of the specimen in inches

I is the current reading from the electrometer

Surface resistivity

Surface resistivity is the electrical resistance of the surface of specimen material. It is measured from electrode to electrode along the surface of the specimen. Since surface length is fixed, the measurement is independent of the physical dimensions of the specimen.

Surface resistivity (ρ) is measured by applying a voltage potential across the surface of the specimen, measuring the resultant current, and then performing the following calculation:

$$\sigma = \frac{53.4\ V}{I}\ \Omega$$

Where:

σ is the surface resistivity of the specimen

V is the applied voltage from the electrometer

I is the current reading from the electrometer

Resistivity nomographs

With test voltage, measured current, and specimen thickness for volume resistivity known, resistivity can be approximated by using the appropriate nomograph. The following volume and surface resistivity figures show the nomograph for surface resistivity and the nomograph for volume resistivity.

Volume resistivity

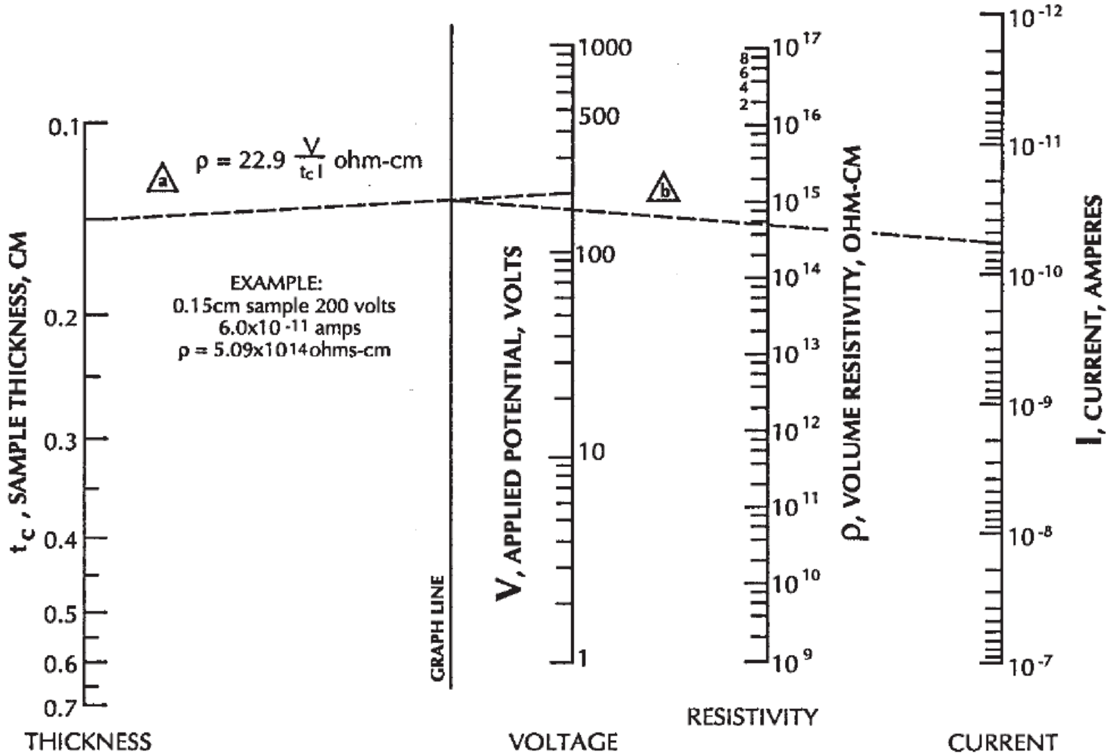
The volume resistivity nomograph, shown in the following figure, consists of four scales and a graph line. The four scales include thickness (in cm) and current.

To determine volume resistivity:

1. Plot the average specimen thickness (in cm) on the thickness scale.
2. Plot the test voltage value on the voltage scale.
3. Draw a straight line connecting the plotted thickness and voltage values. Note that this line will intersect the graph line.
4. Plot the measured current value on the current scale.
5. Draw a straight line from where the first line intersects the graph line to the plotted current value.
6. Read the volume resistivity value (in Ω-cm) from where the second line intersects the resistivity scale.

An example is shown on the following graph. The first dashed line (a) connects a specimen thickness of 0.15 cm to a test voltage of 200 V. The second dashed line (b) connects the graph line intersection point to a measured current of 6×10^{-11} amps (60 pA). The second dashed line (b) intersects the resistivity scale at approximately 5×10^{13} Ω-cm (5.09×10^{14} Ω-cm by calculation).

Figure 6: Volume resistivity nomograph



Surface resistivity

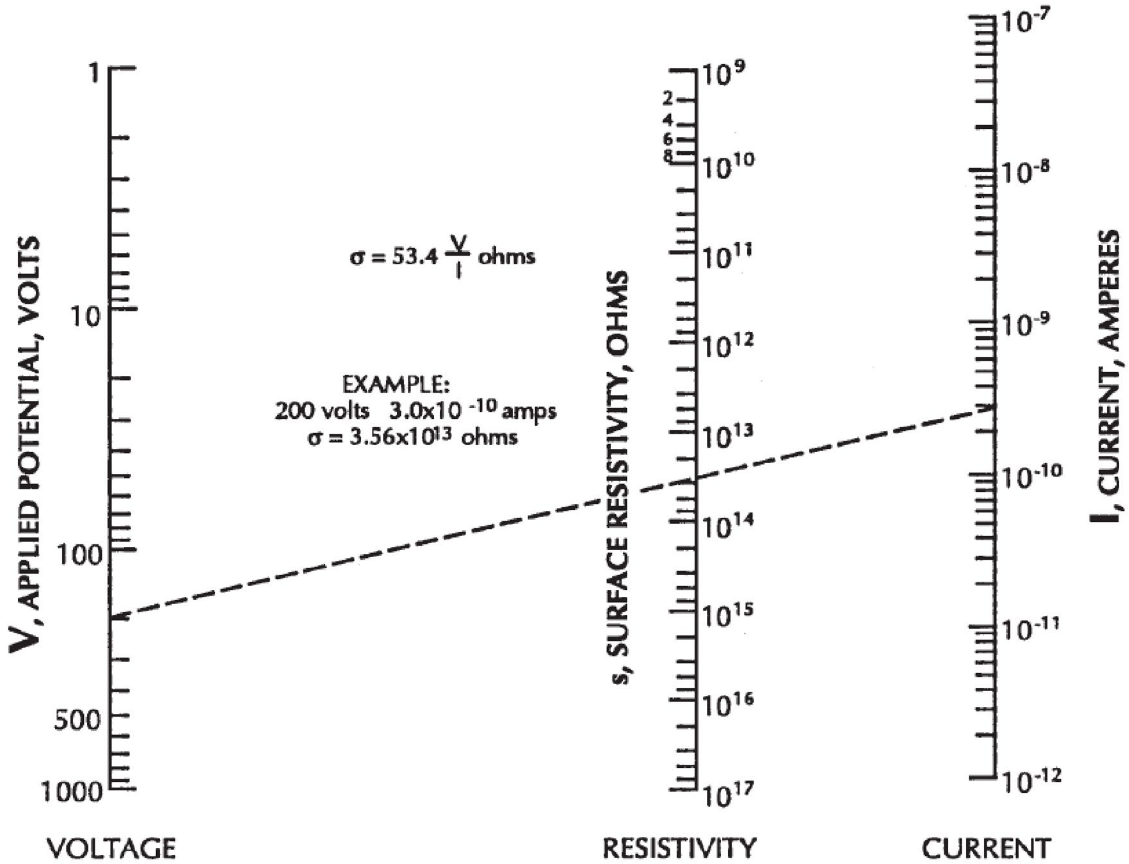
The surface resistivity nomograph is made up of three scales: voltage, resistivity, and current.

To determine resistivity:

1. Plot the test voltage value on the voltage scale.
2. Plot the measure current value on the current scale.
3. Draw a straight line connecting the plotted voltage and current values.
4. Read the surface resistivity value (in ohms) from where the drawn line intersects the resistivity scale.

An example is shown in the graph. The dashed line connects a test voltage of 200 V to a measured current of 3×10^{-10} amps (0.3 nA). The dashed line intersects the resistivity scale at just under 4×10^{13} Ω (3.56×10^{13} Ω by calculation).

Figure 7: Surface resistivity nomograph



Resistivity equations

The ASTM standard states that volume resistivity (ρ) shall be calculated as follows:

$$\rho = \frac{A}{t} R$$

Where:

A is the effective area of the guarded electrode for the electrode arrangement

R is the volume resistance in ohms

t is the average thickness of the specimen

For the 8009, which uses circular electrode, A is calculated as follows:

$$A = \frac{D_0^2}{t} \pi$$

Where D_0, which is the effective diameter of the guarded electrode, is 5.40 cm (2.123 in.), as calculated by the following equation:

$$A = \frac{(5.40)^2}{4} \pi = 22.9 \text{ sq cm}$$

or

$$A = \frac{(2.125)^2}{4} \pi = 3.55 \text{ sq in.}$$

By using the calculated values for A, the volume resistivity equation looks like this:

$$\rho = \frac{22.9}{t_c} R$$

or

$$\rho = \frac{3.55}{t_i} R$$

Where:

t_c is the average thickness of the specimen in centimeters

t_i is the average thickness of the specimen in inches

Volume resistance (R) is calculated by dividing the applied test voltage (V) by the subsequent measured current (I). By substituting R with V/I, the following equations that are used to calculate volume resistivity are realized:

$$\rho = \frac{22.9\ V}{t_c I}\ \Omega - cm$$

or

$$\rho = \frac{3.55\ V}{t_i I}\ \Omega - in.$$

The ASTM standard states that surface resistivity (σ) shall be calculated as follows:

$$\sigma = \frac{P}{g}\ R$$

Where:

R is the surface resistance in ohms

g is 0.125 inches. This is the distance between the guarded electrode and the ring electrode.

P is the effective perimeter of the guarded electrode for the particular electrode arrangement employed

For the 8009, which uses circular electrodes, P is calculated as follows:

$$P = D_0\pi$$

Where:

D_0, which is the effective diameter of the guarded electrode, is 2.125 inches, see the figure below. Then use this equation:

$$P = 2.125\pi$$

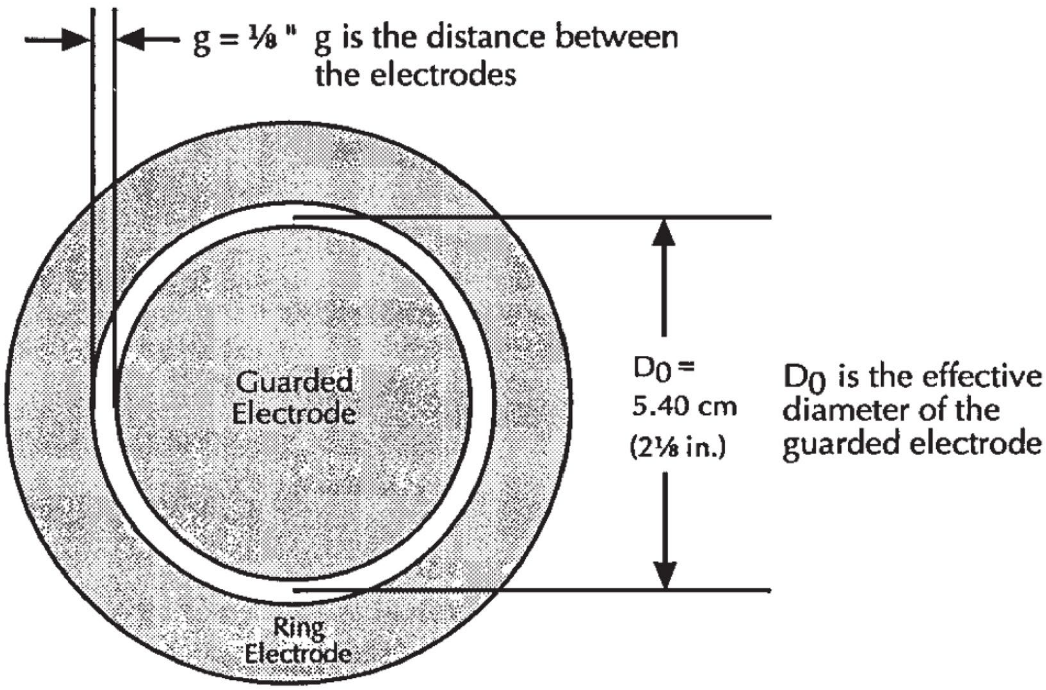
By substituting the values for g and P, the equation looks like this:

$$\sigma = \frac{2.125\ \pi}{0.125}\ R = 53.4R$$

Surface resistance (R) is calculated by dividing the applied test voltage (V) by the subsequent measured content (I). By substituting R with V/I, the following equation is used to calculate surface resistivity is known.

$$\sigma = \frac{53.4\ V}{I}\ \Omega$$

Figure 8: Electrode dimensions



NOTE

The figure above measures the diameter of the guarded electrode from the air gap rather than the edge of the electrode.

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