USER'S MANUAL

Protek 9216A Digital LCR Meter

PROTEK 9216A
Digital LCR Meter

User's Manual

Volume 1: Basic Operation Rev. 3.0

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Revision History

Date	Version	Changes
Original		
3/2009	Version3.0	Manual Revision due to Deletion of GPIB Function

Introduction

Important Background Information

The PROTEK 9216A DIGITAL LCR Meter is a high quality instrument that gives you many years of good service. Please read the information in this chapter before using or applying power to the meter. Information on operating and using the meter is given in the following chapters.

Warranty

PROTEK warrants that this product will be free from defects in materials and workmanship for a period of one year from the date of purchase. If any such product proves defective during this warranty period, PROTEK, at its option, either will repair the defective product without charge for parts and labor, or will provide a replacement in exchange for the defective product.

In order to obtain service under this warranty, the customer must notify PROTEK of the defect before the expiration of the warranty period and make suitable arrangements for the performance of service. The customer shall be responsible for packaging and shipping the defective product to the service center designated by PROTEK, with shipping charges prepaid. PROTEK shall pay for the return of the product to customer if the shipment is to a location within the country in which the PROTEK service center is located. The customer shall be responsible or paying all shipping charges, duties, taxes, and any other charges for products returned to any other locations.

This warranty shall not apply to any defect, failure or damage caused by improper use or improper or inadequate maintenance and care. PROTEK shall not be obligated to furnish service under this warranty:

- To repair damage resulting from attempts by personnel other than PROTEK representatives to install, repair or service the product;

- To repair damage resulting from improper use or connection to incompatible equipment; or

- To service a product that has been modified or integrated with other products when the effect of such modification or integration increases the time or difficulty of servicing the product.

This warranty is given by PROTEK with respect to this product in lieu of any other warranties, expressed or implied. PROTEK and its vendors disclaim any implied warranties of merchantability or fitness for a particular purpose.

PROTEK's responsibility to repair or replace defective products is the sole and exclusive remedy provided to the customer for breach of this warranty. PROTEK and its vendors will not be liable for any indirect, special, incidental, or consequential damages irrespective of whether PROTEK or the vendor has advance notice of the possibility of such damages.

General Safety Summary

Review the following safety precautions to avoid injury and prevent damage to this product or any products connected to it.

NOTE: Only qualified personnel should perform service procedures.

Preventing Injury

Use Proper Power Cord. To avoid fire hazard, use only the power cord specified for this product.

Avoid Electrical Overload. To avoid electric shock or fire hazard, do not apply a voltage to a terminal this is outside the range specified for that terminal.

Ground the Product. This product is grounded through the grounding conductor of the power cord. To avoid electric shock, the grounding conductor must be connected to earth ground. Before making connections to the input or output terminal of the product, ensure that the product is properly grounded.

Do Not Operate Without Cover. To avoid electric shock or fire hazard, do not operate this product with covers or panels removed.

Use Proper Fuse. To avoid fire hazard, use only the fuse type and rating specified for this product.

Do Not Operate in Wet/Damp Conditions. To avoid electric shock, do not operate this product in damp or wet conditions.

Do Not Operate in an explosive atmosphere. To avoid injury or fire hazard, do not operate this product in an explosive atmosphere.

Keep Probe Surface clean. To avoid electric shock and erroneous readings, keep the probe surface clean.

Preventing Instrument Damage

Maintenance, Repair, and Storage

This equipment is composed of many high-precision components and components which require high internal pressure. Care is required when handling or storing this equipment.

Occasionally, if the surface of the panel is dirty, rub the affected area lightly with a soft cloth soaked in a light neutral detergent or alcohol. Never use highly volatile material such as benzene or paint thinner.

The ideal ambient temperature range for storing this equipment is $-10°C$ to $+60°C$ (14°F to 140°F).

To avoid personal injury, do not remove the product covers. Do not operate the product without the covers properly installed.

Two spare fuses are shipped with this equipment.

In order to maintain this equipment in a stable and efficient operating condition, calibrate the equipment after every 1,000 hours operating time or every 6 months, whichever is shorter.

Product Damage Prevention

Use Proper Power Source. Do not operate this product from a power source that applies more than the voltage specified.

Provide Proper Ventilation. To prevent product overheating, provide proper ventilation.

Do Not Operate With Suspected Failures. If you suspect there is damage to this product, have it *Suspected Failures*   inspected by qualified service personnel.

Do not immerse in Liquids Clean the probe using only a damp cloth. Refer to the cleaning instructions.

Line Voltage Requirements

Refer to the following table for the correct operating voltage ranges for this LCR meter. Check the line voltage prior to connecting to the power source, and verify that it is within a voltage range listed below.

Rating	Operating Voltage Range
AC 115 V	AC 98 V–132 V
AC 230 V	AC 196–253 V

If the LCR meter is to be used at a voltage other than 230V AC, the operating voltage may be changed by the following procedure ·

- Remove the power cable from AC input.
- Insert a flat-bladed screwdriver into the slot located on right side of the fuse holder cap; remove the cap by pressing and then pulling up the screwdriver.
- Rotate the cap on the fuse holder to set the voltage to the desired level.
- Connect power cable to the AC input.

If a voltage below AC 115 V is required, the power cable and fuse may need to be changed. In such case, contract your nearest dealer for appropriate service.

After use, disconnect the equipment from the AC outlet.

Fuse Requirements

In order to prevent circuit damage resulting from over current, use the correct fuse value. The fuse ratings are as follows.

Circuit No.	Shape (diameter × length) mm	Rating	Remarks
F1101	5.2 × 20	250 V T500 mA	For AC I15V
		250 V T250 mA	For AC 230 V
F601	5.2 × 20	250 V F250 mA	

The internal fuse rating is as follows:

Circuit No.	Shape (diameter × length) mm	Rating	Remarks
F602	5.2 × 20	250 V F250 mA	

Note: Refer to the section on troubleshooting in the Reference Manual for instructions on replacement of the internal fuse.

Conventions Used in This Manual

- In this manual, you will find various procedures, which contain steps of instructions for you to perform. To keep these instructions clear and consistent, this manual uses the following conventions:

- Operating procedures and names of front panel controls are in uppercase and **boldface** print.

- The case of each name used in the manual is the same (Initial Capitals or UPPERCASE) as that used on the instrument itself.

- Instruction steps are numbered (1, 2, 3,), unless there is only one step.

- When steps require that you make a sequence of selections using front panel controls and keys, an arrow ($\rightarrow$) is used in the text to indicate an LED result when a front panel entry is made. Also, whether a name is a key or LED display reading is clearly indicated:

    Example: Press DISP $\rightarrow$ (Entry) $\rightarrow$ ENTER

Safety Terms

The following terms are also used in this manual:

- **WARNING**   identifies conditions or practices that could result in injury.

- **CAUTION**   identifies conditions or practices that could result in damage to this product or other property.

- **NOTICE**   identifies conditions or practices that could result in incorrect test data.

Product Familiarization

Description of the LCR Meter and Its Features

In this chapter, the controls and connections of the LCR Meter are described, and its basic operation is summarized in terms of the meter's specifications, features and options, and operating modes.

Front Panel Components

The front panel and its displays, controls, and connections are shown in the following illustration:
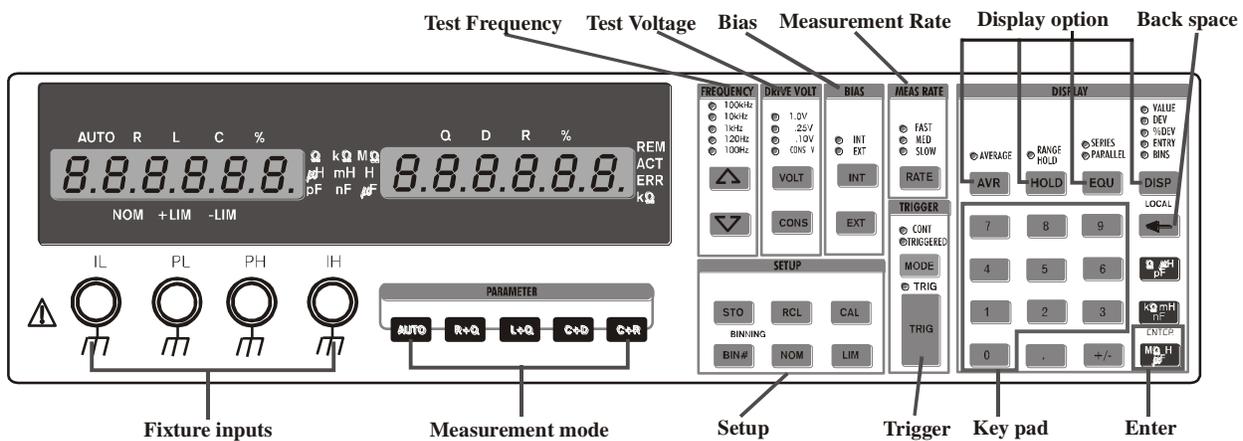
First, the displays, controls, and connections on the left side of the front panel are explained, and then the many buttons and keys on the right side are described.

Fixture Inputs

The input terminals labeled IL, PL, PH, and IH connect the test fixture or adapter to the instrument, as discussed in the section in Chapter 3 on "Connecting a Component." Two of the terminals provide a current source to the component under test, and the other two terminals provide a high impedance connection to measure the voltage across the device. This four-wire or "Kelvin" type of measurement setup is designed to increase accuracy by reducing the amount of current in the voltage-sensing wires. **Warning:** Do not connect any active voltage source to these terminals, especially high voltages.

Measurement Modes and the Mode Selection Keys

These keys select the measurement to make on the component under test. One of five measurement modes may be selected: Auto, R+Q, L+Q, C+D or C+R. The selected

mode is indicated by LEDs above the alphanumeric displays. The operation of each mode can be explained as follows:

- **AUTO**　　　　In this mode, the meter automatically selects the most appropriate measurement on the device. The selection is made according to the following criteria:

    - If $|Q| < 0.125$, the meter selects the R+Q measurement mode.

    - If $Q > +0.125$, the meter selects the L+Q measurement mode.

    - If $Q < -0.125$ and the meter is in the series equivalent circuit mode, the C+R measurement mode is selected.

    - If $Q < -0.125$ and the meter is in the parallel equivalent circuit mode, the C+D measurement mode is selected.

- **R+Q**　　　　In this mode, resistance is displayed on the main parameter display and the Q (quality factor) is displayed on the secondary parameter display. The R-value is either the series or parallel equivalent resistance of the component under test. The unit for R is Ω, kΩ, or MΩ. The Q value is the dimensionless ratio of the imaginary part of the component's impedance to its real part. If Q has a positive (+) value, the reactive component of the device under test is inductive. If Q has a negative (−) value, it is capacitive.

- **L+Q**　　　　In this mode, the series or parallel equivalent inductance value of a component under test is displayed on the main parameter display units in units of µH, mH, or H, and its dimensionless Q value is displayed on the secondary parameter display.

- **C+D**　　　　In this mode, the series or parallel equivalent capacitance value of a component under test is displayed on the main parameter display in units of pF, nF, or µF. On the secondary parameter display, the dimensionless ratio $D = 1/Q$ is given. D is normally a small value for a good capacitor.

- **C+R**　　　　In this mode, the capacitance is displayed on the main parameter display and the equivalent resistance is displayed on the secondary parameter display. The unit for resistance is Ω unless the kΩ indicator LED is lit.

Alphanumeric Displays and Parameter Indicators

The two 5-digit (plus sign) LED[1]-segmented alphanumeric displays provide measurement results, entered parameter values, and status messages. The left display gives the value of the main parameter of the component under test (L, R, C) and the right display gives the value of its secondary parameter (Q,D, R, %). Above and next to these two alphanumeric displays are various LEDs that, when lit, indicate something about the measurement:

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[1] LED = light-emitting diode

- **AUTO, R L, C, %**   LEDs that indicate the measurement type for the main parameter

- Q, D, R, %   LEDs that indicate the measurement type for the secondary parameter

- Ω, kΩ, MΩ LEDs indicating the units of the value being displayed on the left
  μH, mH, H
  pF, nF, μF

- kΩ The right-side display is dimensionless or has units of ohms unless this LED is on.

- REM, ACT, ERR   These LEDs give information on the status of the remote control (computer) interface operations.

  - REM: Indicates that the display is being controlled remotely via the interface connector on the rear panel.

  - ACT: Indicates that the remote control interface is active.

  - ERR: Indicates that a remote command contained an error.

- NOM, +LIM, −LIM   Indicates which Binning[2] parameter is being entered

Programming and Operator Interface Keys

On the right side of the front panel of the LCR meter, there are many buttons and keys for programming test conditions and for general operator interface. These keys are grouped according to function, and some groups have LED indicators associated with them show which option has been selected.

- **Frequency**   The 9216A has five selectable fixed frequencies with an accuracy to 100ppm (0.01%). 100Hz, 120Hz, 1kHz, 10kHz or 100 kHz may be selected by pressing the up/down keys on the front panel keypad until its corresponding LED is illuminated.

- **Drive Voltage**

  - **VOLT** Pressing the VOLT key, the output voltage will cycle through three fixed output drive voltages (0.1V, 0.25V, 1.0V). An LED indicates the selected drive voltage. If NO LED is lit, then the output drive voltage is in the vernier mode.

  - **CONS** This key sets the meter to the constant voltage mode.

- **BIAS**   The bias mode is used only for capacitance measurements. Pressing these keys for any other measurement will generate the "bias for c" error message.

  - **INT**   Selects a 2.0 VDC internal bias.

  - **EXT**   Selects a voltage from an external source to be applied to the capacitor under test.

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[2] Binning is explained later.

- **MEAS RATE** Selects the measuring rate. At frequencies of 1 kHz or greater, slow (2 measurements per second), medium (10 measurements per second, and fast measurements (20 measurements per seconds) may be selected.

- **DISPLAY**

  - **Average** The average of 2 to 20 measurement readings will be displayed. The number of measurements in the average is selected from the keypad.

  - **HOLD** This key holds the meter in its current measurement range. Pressing the hold key a second time returns the meter to the Auto-Range mode. A specific range may also be entered from the numeric keys on the keypad.

  - **EQU** This key toggles the equivalent circuit for the component under test between a series or parallel circuit.

  - **DISP** The DISP key cycles through the display parameters that may be selected. The display parameters that may be selected are:

    - **VALUE** The measured value of the device under test is displayed.

    - **DEV** The deviation from a value previously entered is displayed.

    - **% DEV** The percent deviation from a previously entered value is displayed.

    - **ENTRY** Used for entering parameter values.

   - **BINS** Selects the bin number when Binning is enabled.

Note: Certain displays are not available unless data has been entered. For example, DEV and % DEV are not available unless a nominal value has already been entered. Also, BINS is not available unless binning data has previously been entered.

  - **←** Backspace key used for correcting mistakes when entering numeric data. This key also serves as the "Local" function.

  - **[0]...[9]** These keys are used to enter parameters and are only active when the meter is in the ENTRY mode.

  - **ENTER** [Ω, μH, pF], [kΩ, mH, n F], [MΩ, H, μF]. These three keys are used for entering numeric parameters in the entry mode (e.g. R, L, C values). The bottom-most key (MΩ, H, μF) may be used as a general entry key for entering parameters not listed on the keypad, such as percent %.

- **SETUP**

  - **STO**, **RCL** The 9216A can store up to nine setups in the memory. To store the present configuration in memory location #*n*, press **STO** [n] $\rightarrow$ **ENTER**. To recall a setup, press **RCL** $\rightarrow$ [n] $\rightarrow$ **CAL ENTER**.

  - **CAL** Enables a series of internal calibration routines, including open/short and settling time calibration, output amplitude drive, and internal self-tests.

  - **BIN#**, **NOM**, **LIM** These keys are used to enter Binning parameters. The **BINNING** LED is on when Binning is enabled and the optional handler is active.

- **TRIGGER**

- **MODE** This key toggles between continuous (**CONT**) or **TRIGGERED** measurements .

- **TRIG** When **TRIGGER** mode is selected, measurements are initiated when this key is pressed or by the handler or computer interfaces. The **TRIG** LED will flash when this mode is enabled.

Rear Panel Components

The rear panel and its controls and connections are shown in the following illustration:
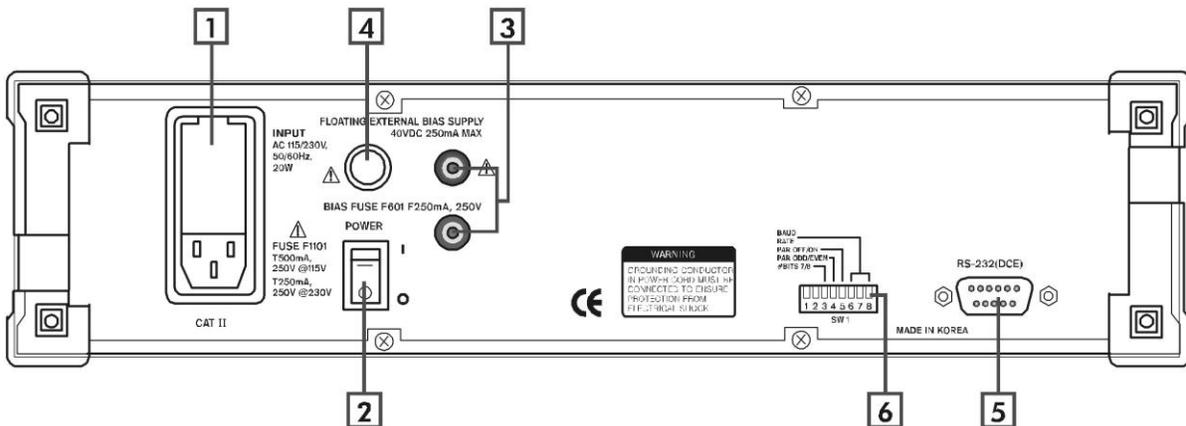
[1] AC POWER CONNECTOR The AC power cord is inserted into this connector. The fuse and line voltage selector are located in the connector housing.

[2] POWER SWITCH Turns the meter on and off.

[3] EXTERNAL BIAS INPUT Two banana plugs are used to input an external bias voltage. The bias supply voltage must be floating and well filtered. Neither input connector can be referenced to ground.

[4] EXTERNAL BIAS FUSE Protects external bias circuit from currents greater than 250 mA.

[5] RS232 DB25 This connector allows the meter to communicate as a DCE (data communications equipment, e. g. a modem) to a DTE (data terminal equipment, e.g., a computer) using the RS-232C protocol. For further information, refer to the material on remote programming in the Reference Manual.

[6] SW1 The switches set the RS232C protocol parameters. The Baud rate, word length and parity may be set.

Specifications

Display

- Measurement Modes: Auto, R+Q, L+Q, C+D, C+R

- Equivalent Circuit: Series or Parallel

- Parameters Displayed: Value, Deviation, % Deviation or Bin Number. Deviation and % deviation are calculated from a stored relative value

- Averaging: 2–10 Measurements

- Measurement Range: R+Q: R: 0.0001Ω–2000 MΩ
                                                   Q: 0.00001–50
                               L+Q: L: 0.0001 µH–99999 H
                                                   Q: 0.00001–50
                               C+D: C: 0.0001 pF–99999 µF
                                                   D: 0.00001–10
                               C+R: C: 0.0001 pF–99999 µF
                                                   R: 0.00001Ω–99999 kΩ

Test Conditions

- Test Frequency: 100 Hz, 120 Hz, 1 kHz, 10 kHz, 100 kHz
  Frequency accuracy: ±100ppm.

- Drive Voltage: Preset Levels: 0.10, 0.25, and 1.0 Vrms.
  Vernier: 0.1 to 1.0 Vrms with 50 mV resolution.

- Drive level accuracy: ±2%.

- Measurement Rates: (a) Slow (2 meas./sec.), Medium (10 meas./sec.), or Fast (20 meas./sec.) for test frequencies of 1 kHz and above.

  (b) Approx. 0.6, 2.4, or 6 measurements per second at 100 Hz and 120 Hz.

- Ranging   Auto or Manual

- Triggering   Continuous, Manual, or Remote over RS232 or Handler Interface

- Bias Voltage   Internal: 2.0 VDC ±2%
  External: 0 to +40 VDC (fused @ 0.25 A)

Accuracy

- Conditions: Allow 30 minutes of warmup before measurements; all accuracies are at 23° C (73°F) ±5°C

- Basic accuracy 0.05%. Refer to the accuracy section in the Reference Manual for detailed specifications.

- The following summarizes typical accuracy specifications:

Accuracy	Value
better than 1% for	$R > 0.125\ \Omega$ and $R < 16\ M\Omega$
	$L > 2.5\ \mu H$ and $L < 25\ kH$
	$C > 1.25\ pF$ and $C < 12.8\ mF$
better than 5 % for	$R > 21\ m\Omega$ and $R < 96\ M\Omega$
	$L > 420\ nH$ and $L < l50\ kH$
	$C > 0.21\ pF$ and $C < 77\ mF$
at the following conditions:	
	1.0V, 0.5V, or 0.25V output voltage
	Slow or medium measurement speed
	Q and D < 0.1 for R and C
	Q > 10 for L
	100Hz, 120Hz or 1 KHz test frequency for R
	100 Hz test frequency for L_{max} and C_{max}
	10 KHz test frequency for L_{min} and C_{min}

Features and Options

General Features

Feature	Specification
Fixture	4-wire Kelvin fixture for parts with radial and axial leads
Protection	Protected up to 1 Joule of stored energy, 200 V DC for charged capacitors; fused at 0.25 A output current for biased measurement
Zeroing	Open and short circuit compensation. Compensation Limits: short circuit: $R<20\Omega$, $Z<50\Omega$, open circuit: $Z>10k\Omega$
Binning	Up to 8 Pass Bins, QDR and General Fail Bins, all defined by the front panel or computer interface. Binning setups may be stored in nonvolatile memory
Self Test	Tests the ROM, CPU, nonvolatile RAM, clock generator, A/D converter, internal bias, multiplier, output drive circuitry, gain circuitry, and source resistances.
Store and Recall memory	Stores and recalls nine complete instrument setups. Recall 0 recalls the default setup.
RS232 Interface	All instrument functions can be controlled or read over the interface.
Operating Conditions	0 to 50℃ at a relative humidity of 0 to 80%
Power	20 Watts, 110/220 VA, 50/60 Hz
Dimensions	4 ¼ " H × 14 ¼ " W × 15" D
Weight:	12 ¾ lbs
Warranty	Two year parts and labor on materials and workmanship

Options

Feature	Specification
IEE-488 interface	Instrument functions can be controlled and read over this interface
Handler/sorter interface	DB male connector provides the signal lines for binning, instrument status and input trigger. **Note: option consists of both interfaces**
Kelvin clips	Provides connection to devices that are not easily accommodated by the test fixture. Polarity is indicated for biased measurements.
SMD Tweezers	Provides connection to surface mount components
BNC fixture adapter	Connects remote fixtures or devices to the 9216A

Basic Operations

How the 9216A Operates and What It Can Do

The 9216A LCR meter is very versatile in that the user can customize the measurement and operating modes to obtain the best results in a particular situation. In this chapter, the basics of the meter's operation are summarized.

Operation of the LCR Meter For the First Time

Before using 9216A LCR Meter, ensure that it is properly installed, and powered on.

To get the maximum accuracy for your most critical measurements you should know how to select the various options and to set up the test conditions and the proper use of the test fixture you have chosen to use with your meter.

Unpacking and Inspection

After unpacking the 9216A LCR Meter, verify that all parts are included and have not been damaged during transportation. Retain the packing materials.

Packing Contents:

- 9216A LCR Meter
- Radial Fixture
- Power Cord
- User Manuals

Installation

To properly install and power on the meter, perform the following steps:

- Be sure you have the appropriate operating environment.
- Leave a space of at least 5.1 cm (2 in) on each side of the meter for proper ventilation.
- Check the fuse for proper type and rating.
- Check for proper electrical connections.
- Connect the proper power cord to the power connector on the rear panel.

When turned on, the meter will first enter the self-test mode and perform the following procedure: first, it will display the program version "0X" and the model number "HC9216" for about three seconds. Next, the meter will display "test" and "….." while it performs the self-test. If all tests are successful, "test pass" will be displayed as a result. In order for the self-test to operate correctly, it is important to follow certain startup procedures.

Before Applying Power

Prior to turning the unit on, be sure there are no components in the input fixture. Components in the fixture will cause the self-test to fail and display an error code.

Before Using the Test Fixture

When the self-test is completed, "over range" will be displayed, and the user can proceed to set up the test conditions and to make measurements. For maximum accuracy, however, a "null calibration" of the test fixtures needs to be performed before taking any measurements.

Fixture Options

On the front panel of the instrument there are four BNC connectors designated IL, PL, PH, IH. In what is known as a "4-wire Kelvin connection," two of these terminals provide current to and from the device under test, and two of the terminals sense the potential (voltage) across the device. Separate wires are used for sensing the voltage so to minimize the effect of the current in the sensing wires inside the meter and to minimize stray impedance that can cause measurement errors.

There are several fixtures available for special measurements: Radial fixture (standard), Kelvin clips, SMD tweezers, and BNC adapter. The optional fixtures may be purchased through our distributors.

The standard 9216A test fixture attaches to the four input terminals on the front
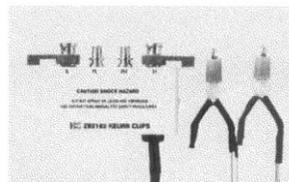
Kelvin Clips   SMD Tweezers

panel of the meter and provides two polarized, spring-loaded connection slots to secure radial-leaded components under test while they are being measured. The fixture also accommodates axial-leaded components whose leads are bent to enable insertion into the fixture. Most components will plug into this test fixture, thereby eliminating the need for special fixtures.

Null Calibration Procedure

Whenever the test configuration is changed, including a change of the fixture, open and short circuit "null" calibrations should be made prior to taking measurements to compensate for stray impedances, such as component lead impedance, and fixture, cable and other stray capacitance. Null calibration should be performed after any change in fixture configuration or for changes in the drive amplitude. This calibration corrects for all frequencies and all ranges-it is not necessary to re-calibrate for changes in frequency. For critical measurements, null calibration should be performed frequently at some interval during the course of measurements.

The LCR meter store open and short circuit calibration data in nonvolatile memory. These data values are stored with the **STO** key and recalled using the **RCL** key, allowing null calibration data to be saved for different fixtures.

The null calibration procedure is on the menu that is invoked by pressing the **CAL** (Calibrate) key in the **SETUP** group of keys on the front panel of the meter. To perform a null calibration, press the **CAL** key until the message "nuLL cAL" appears on the alphanumeric display. Pressing the **ENTER** key while this message is being displayed causes the message to change to "Short cAL."

The short-circuit null calibration is done by placing a wire in the fixture (thereby shorting the fixture's terminals) that is between 26 to 16 AWG (0.02" to 0.05" or 0.51 to 1.30 mm dia.). The calibration proceeds automatically after the user presses the **ENTER** key and moves hands and any miscellaneous objects away from the fixture. When the short circuit calibration is finished, the meter prompts the user for the next operation by displaying the message "oPEn cAL."

To perform the open-circuit null calibration, remove the shorting wire, press **ENTER** and again move hands away from the fixture. When the unit has finished, it displays the message "cAL donE." To dismiss this message and return to a normal display mode, press the **DISP** (Display) key.

Changing Test Setup Parameter Settings

When powered on, the 9216A LCR Meter initially uses the default test setup parameters, which include selection of the automatic (**AUTO**) measurement mode, and the result of the measurement is displayed on the alphanumeric readout. For most measurements, the test conditions in the automatic mode are sufficient. However, by pressing the parameter keys on the front panel, the user may enter customized test setup parameter selections, and by pressing the keypad keys, enter the desired values of test parameters. Test parameters that are not associated with dedicated keys on the front panel or keypad, such as the number of measurements being averaged, deviation measurements, etc., may be entered by pressing the **DISP** key to enter the **ENTRY** mode. Table 3-1 below shows appropriate settings for typical component values.

Table 3-1 Test Setup Parameter Settings for Typical Component Values.

Component	Value	Meas. Mode	Equiv. Circuit	Frequency
Unknown	Any	AUTO	Series	1 kHz
Resistor	< 1 kΩ > 1 kΩ	R+Q	Series	1 kHz 100 or 120 Hz
Inductor	< 10 μH 10 μH–1 mH 1 mH–1H > 1H	L+Q	Series	100 kHz 10 kHz 1 kHz 100 or 120 Hz
Capacitor	< 10 pF 10 pF–400 pF 400 pF–1 μF > 1 μF	C+D C+D C+D C+R or C+D	Parallel Series or parallel Series Series	10 kHz 10 kHz 1 kHz 100 or 120 Hz

Default Setup

Holding down the backspace key (←) key while turning on the power to the meter causes the meter to have the default setup values as listed in the table below. **Note:** All user calibration settings and values will be lost.

To prevent the user calibration settings from being destroyed, after turning on the meter without pressing the backspace key, press **RCL** → [0] → **ENTER**. This key sequence will reset the meter to the default settings listed in the table below without affecting user-entered calibration values. See the sections that follow for more details on the settings listed in the table below.

Table 1-1: 9216A default settings

Setting	Value
Parameter	AUTO
Frequency	1KHz
Drive Voltage	1.0Vrms.
Bias	OFF
Measurement Rate	SLOW
Averaging	OFF
Range Hold	OFF
Equivalent Circuit	SERIES
Display	VALUE
Trigger Mode	CONT
Binning	OFF

Measurement Mode

The measurement mode is selected by pressing one of the four keys in the **PARAMETER** group of keys on the front panel.

AUTO   In this mode, the meter automatically selects the most appropriate measurement on the device. The selection is made according to the following criteria:

> If |Q| < 0.125, the meter selects the R+Q measurement mode.

> If Q > +0.125, the meter selects the L+Q measurement mode.

> If Q < −0.125 and the meter is in the series equivalent circuit mode, the C+R measurement mode is selected.

> If Q < −0.125 and the meter is in the parallel equivalent circuit mode, the C+D measurement mode is selected.

R+Q In this mode, resistance is displayed on the main parameter display and the Q (quality factor) is displayed on the secondary parameter display. The R-value is either the series or parallel equivalent resistance of the component under test. The unit for R is Ω, kΩ, or MΩ. The Q value is the dimensionless ratio of the imaginary part of the component's impedance to its real part. If Q has a positive (+) value, the reactive component of the device under test is inductive. If Q has a negative (−) value, it is capacitive.

L+Q   In this mode, the series or parallel equivalent inductance value of a component under test is displayed on the main parameter display units in units of µH, mH, or H, and its dimensionless Q value is displayed on the secondary parameter display.

C+D   In this mode, the series or parallel equivalent capacitance value of a component under test is displayed on the main parameter display in units of pF, nF, or µF. On the secondary parameter display, the dimensionless ratio D = 1/Q is given. D is normally a small value for a good capacitor.

C+R   In this mode, the capacitance is displayed on the main parameter display and the equivalent resistance is displayed on the secondary parameter display. The unit for resistance is Ω unless the kΩ indicator LED is lit.

Frequency

The output frequency is accurate to 100ppm (0.01%). Frequencies are set by pressing the up/down keys ($\Delta\nabla$) on the front panel keypad until the LED corresponding to the desired frequency is illuminated. If the meter is on range hold on Range 0, the 100 kHz frequency selection is disabled. If 100 kHz is selected while in Range 0, the meter will beep and "r-f error" (range frequency error) will be appear on the alphanumeric display. For more details, see the section on Range.

Drive Voltage

The 9216A meter has three fixed output rms voltages, 0.1 V, 0.25 V and 1.0 V. These voltages are selectable from the front panel. A variable rms voltage is also available, which is adjustable from 0.1 V to 1.0 V with 50 mV resolution. The accuracy of the voltage levels is 2% or greater. To select a fixed voltage, press and release the **VOLT** key located in the **DRIVE VOLT** section on front panel keypad until the LED indicates the desired voltage.

To set the variable output voltage:

1. Press the **CAL** keypad button. The DISP LED will indicate the ENTRY mode. On the alphanumeric display, "vtest" and the current voltage will be shown.

2. Enter the desired output voltage from the numeric keypad (0.1 to 0.9 may be entered) and press **ENTER** (MΩ H μF key).

3. The output voltage may be set in 50mV steps. NOTE: If the drive voltage is a value other than one of the three fixed voltages the CONS LED will light .

The output voltage is applied to the device under test through a source impedance. Thus, the voltage across the device is always less than or equal to the output drive voltage. The available source impedances for the four auto ranging selections made by the meter are 25 Ω (Range 3), 400 Ω (Range2), 6.4 kΩ (Range 1) and 100 kΩ (Range 0), all of which are accurate to 2%. The source impedance is automatically selected as a function of the measurement range, unless the unit is in the constant voltage mode. In the constant voltage mode, the source impedance is always 25 Ω. See the section on Range for determining which measurement range the meter is using.

Figure 3-1 shows the voltage across the Device Under Test (DUT) vs. the DUT impedance for the different measurement ranges. The values are normalized to a 1.0-V output drive setting for different applied voltages; that is, the Figure plots the normalized voltage across the DUT, given by

$$(V_{DUT}/V_{source}) = R_{DUT}/(R_{source} + R_{DUT})$$

Note that the voltage applied to the DUT is nearly equal to the output voltage at the upper end of each range and decreases due to lower impedance toward the lower end of the range. This is because of the impedance of the voltage source. If the meter is in the constant voltage (CV) mode, the source impedance is always set to 25 Ω. For any DUT with impedance significantly larger than 25Ω, the voltage across the part is essentially equal to the output drive voltage.

For most devices, including resistors and capacitors, and for many inductors, the 1.0 Vrms setting is the most appropriate setting. For some inductors and for semiconductor or active devices, such as diodes and transistors, the 0.25 or 0.1 Vrms setting should be used. Certain devices require a specific test voltage, such as Z5U ceramic disk capacitors (test voltage = 0.5 Vrms). In these cases, use a variable voltage setting to obtain the exact voltage required. In general, use the largest voltage possible for the best signal-to-noise ratio and accuracy.
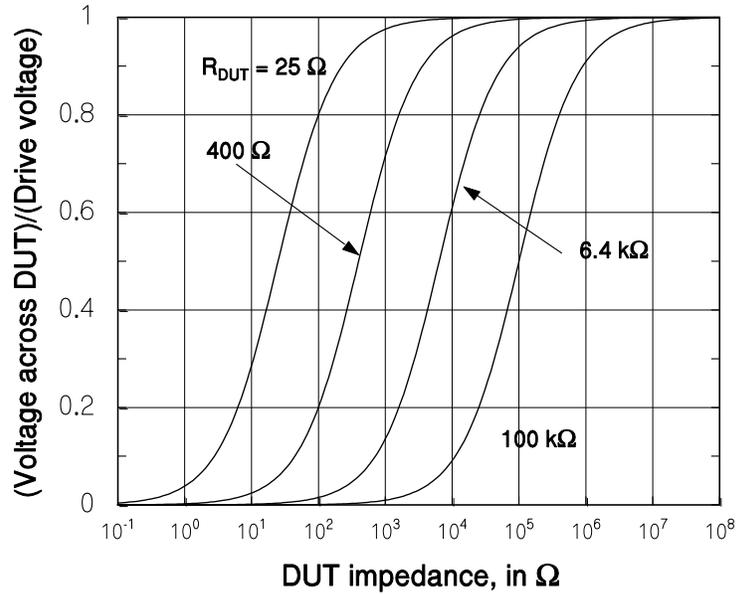
Figure 3-1. Normalized Voltage Across DUT vs. DUT Impedance

Bias

Internal or external DC bias voltages can be applied to capacitors. Electrolytic and tantalum capacitors need a positive bias for accurate measurements, although the meter bipolar test voltage will not typically be enough to damage them. The 2 VDC internal or up to 40 VDC external bias voltage allows measurements to be made while approximating actual operating conditions. The external bias capability also allows C-V measurements to be made on semiconductor devices.

Notice: Always be certain that the capacitor being tested is inserted with the correct polarity. The bias voltage is always positive to the right and is marked on the meter. Failing to observe the correct polarity can result in the destruction of the component under test and possibility injury. Beware that capacitors can hold their charge for a long time if removed from the fixture without discharging the DC bias voltage.

Warning: Care must be taken to discharge the capacitor after making measurements, especially when using a high external bias voltage. Failing to discharge the device can result in damage to the device, damage to the meter, or possible injury. The meter is protected internally against discharging capacitors with up to 1 joule of stored energy (C*V/2).

The internal and external bias circuitry will work only if the unit is in the C+D or C+R mode. Bias voltage cannot be applied if the meter is in the R+Q, L+Q or AUTO mode.

The error message "bias for c" will appear if the bias button is pressed in an inappropriate mode. Whenever the bias circuitry is active, the meter is in the constant voltage mode, so that the voltage across the capacitor under test will

stabilize in a reasonable amount of time. See the section on the constant voltage mode for effects on ranges and accuracy.

It will take a short while for the internal circuitry and the DUT to stabilize after applying the bias voltage. The time is primarily determined by the RC time constant of the source resistance and the capacitor under test, plus the internal AC coupling capacitor of 0.47 µF. During this time, the reading on the meter may change if it is continuously triggered. In this case, the initial readings should be disregarded. If this is a problem, use the triggered mode (simply wait a short time before triggering) or increase the settling time. See the section on measurement rate for information on how to set the settling time. In addition, the capacitance of some capacitors will slowly drift after a change in DC voltage.

Internal Bias

To apply the 2.0V DC internal bias voltage to the capacitor under test, first verify that the capacitor is connected to the test fixture with correct polarity (positive to the right). Press the **INT** key to apply the bias voltage. After a second or two, the reading should be stable. Before removing it from the fixture, press the **INT** key a second time to switch off the bias in order to discharge the capacitor.

External Bias

The meter has rear panel connectors to allow an external bias voltage of up to +40 VDC to be applied across the capacitor under test. This supply must be floating (neither side connected to ground) and must be current limited to less than 250mA. A linear supply is recommended (instead of a switching supply). The supply should be well filtered, to remove ripple from the bias voltage. Connections to the bias supply are made on the rear panel with two banana jacks. The red jack is the positive side of the supply and the black, the negative. There is an internal diode within the unit to prevent a negative voltage from being applied. The bias supply lines are fused with a 250mA fuse on the rear panel, next to the banana jacks. If the meter does not yield stable readings when the external bias switched is on, check this fuse. If the bias supply is connected backwards, there is a good chance that the bias supply fuse will blow. Provisions are needed to discharge the bias voltage from the capacitor under test before removing it from the fixture. In general, external switches or discharging resistors should be provided along with the bias supply to ensure safe operation.

To apply an external bias voltage, ensure that the bias supply is connected correctly. Verify that the capacitor is installed with the correct polarity in the test fixture (positive to the right). Next press **EXT** button to apply the bias voltage. After a second or two, the reading should be stable. After the measurement is complete, discharge the capacitor under test before removing it from the fixture.

For occasional nonproduction use with small capacitors (<500 µF) and low bias voltages (<20 VDC), the meter can discharge the capacitor internally. Press the **EXT** button to switch off the bias. The capacitor will then discharge through the meter in the same manner as the internal bias.

Another solution for somewhat larger bias voltages and/or capacitors is to connect a resistor across the terminals of the bias supply. Switch off the bias supply and allow the capacitor to discharge through the resistor before removing it from the fixture. Make certain the discharge resistor is rated to handle the steady state current that the bias voltage will generate through it and that the supply can provide this additional current. For larger capacitors or higher supply voltages it will be necessary to provide external switches to remove the bias voltage and discharge the capacitor.

Measurement Rate

The 9216A has three measurement rates, which are selected by pressing the Rate button. Slow, medium or fast rate may be selected. Table 3-2 lists the maximum measurement rates attainable when the meter is not in the auto-range mode, binning is disabled, and the RS232 interface is active. The measurement affects the accuracy with slow and medium being the most accurate and fast being the least accurate.

The actual measurement time can be calculated from the following equation:

$$T_{meas} = T_s + (N_i/f + T_{di} + T_{rs} + T_d)\, N_m + T_{calc}$$

where T_s = settling time, N_i = number of test frequency cycles used in the measurement, f = test frequency, T_{di} = deintegration time, T_{rs} = resync time, T_d = delay time, N_m = number of submeasurements per measurement, and T_{calc} = calculation time. T_{di}, T_d and T_{calc} are constants, while T_{rs} and f are set by the measurement frequency. N_i and N_m are determined by the measurement rate and T_s can be set by the user. See Table 3-3 for the appropriate values.

In addition to these factors, the measurement time is increased when using auto ranging, binning RS232 interface. Binning adds about 2.5 ms to the total measurement time. Autoranging adds $n*(T_{meas} - 1\text{ ms})$ where n = number of range changes required and T_{meas} is calculated according the equation given above.

It is difficult to determine the exact amount of time added when using RS-232 interfaces, since it is dependent on baud rate, the speed of the computer, and the software. It takes about 5 ms for the meter to respond to send back over the interface.   In   general,   simple   commands   and   responses   like

Table 3-2 Measurement Rates (Number of Measurements/Sec)

Frequency	Slow	Medium	Fast
100KHz	2.8	14	28
10KHz	2.8	14	27
1KHz	0.7	13	24
120Hz	0.7	2.8	7
100Hz	0.6	2.4	6

Table 3-3: Table for appropriate values

Variables	Appropriate Values for Variables				
N_m	Slow	8			
	Medium	8			
	Fast	5			
N_i		100/120Hz	1KHz	10KHz	100KHz
	Slow	20	40	400	4000
	Medium	4	4	40	400
	Fast	2	2	20	200
T_{xx}	T_{rs}	T_{di}	T_d	T_{calc}	T_s
	1/f	2 ms	2 ms	3 ms	2–99 ms

setting the frequency or checking what range the meter is on, can be returned in about l0 ms. Longer responses, like XALL?, can take as long as 2 seconds over the RS-232. If communications speed is critical, the binary data format, which reduces the number of bytes transferred, can be used.

Settling Time

Occasionally it is advantageous to delay making a measurement after the meter is triggered. This allows bias voltages on capacitors to stabilize or contacts on a handler to debounce. The settling time is set in 1ms intervals from 2 to 99 ms.

To set the settling time,

1. Press the **CAL** key until the "settle" message appears in the left alphanumeric display and the present settling time, in the right display.

2. Enter the new settling time value, from 2 to 99.

3. Press the **ENTER** key.

If an illegal value is entered, the meter will beep and display "range error."

Triggering

The 9216A can make measurements continuously or in response to a trigger. To change the trigger mode:

1. Press the **MODE** key in the **TRIGGER** group of front panel keys until the desired mode LED is on; either CONT or TRIGGERED may be selected.

2. In the continuous mode, the meter will trigger itself at its maximum measurement rate. In the trigger mode, the trigger can be from the TRIG button or from the RS232 or Handler interface.

The TRIG LED will flash whenever the **TRIG** key is depressed and the meter will make a single measurement.

Note: When making a measurement, the meter will ignore any triggers it receives until the current measurement is complete.

Store and Recall

The STO and RCL buttons allow nine complete instrument setups to be saved in nonvolatile memory. All the test conditions, including binning, configuration and open short circuit compensation, are saved.

To store a setup,

 1. Press the **STO** button, which will display the "store" message.

 2. Press the number where the setting is to be stored ([1]–[9]), then press the **ENTER** button.

To recall a stored setting,

 1. Press the **RCL** button, which will display "rcl".

 2. Press the number where the setting is stored ([1]–[9]), and then press the **ENTER** button

Notes: 1. **STO**$\rightarrow$ 0$\rightarrow$ **ENTER** will give an error since the factory default setting is stored in location 0.

 2. **RCL**$\rightarrow$ 0$\rightarrow$ **ENTER** returns the default setup, including null calibration values.

 3. If a "cal error 4" appears during the self-test, or a "rcl error" message appears when recalling a setup, the stored setup was lost and must be re-entered.

Range

The meter has four measurement ranges, designated by the numbers 0 to 3. The range may be selected manually or the meter cans auto range. Table 3-4 specifies the impedance ranges for each of the measurement ranges. Each of the four ranges has a source impedance of approximately the mid-scale impedance. Note that the measurement ranges determine an impedance range (not a parameter value range), so the ranges of inductance and capacitance depend upon the test frequency. The parameter f is the test frequency. In addition, the impedance of a capacitor is inversely proportional to its capacitance, so larger capacitors are measured in the lower impedance ranges.

Table 3-4: Measurement Range and Impedance Range

Range	Source R	Resistance	Inductance	Capacitance
3	25.0 Ω	10 μΩ–100.0 Ω	0.0001 μH–(15.9/f) H	99999 μF–(1.59/f) mF
2	400 Ω	100.0 Ω–1.6 kΩ	(15.9/f) H–(255/f) H	(1.59/f) mF–(99.5/f) μF
1	6.4 Ω	1.6 kΩ–25.6 kΩ	(255/f) H–(4074/f) H	(99.5/f) μF–(6.22/f) μF
0	100 kΩ	25.6 kΩ–2000 MΩ	(4074/f) H–99999H	(6.22/f) μF–0.0001pF

* f is test frequency

Autoranging Mode

During normal operations, the meter automatically changes to the most accurate range for the device under test. When the meter measures an impedance that is out of its current range, it goes up or down one range, and makes another measurement. If this measurement is within the current range, it displays it. If not, it changes ranges (if available), and repeats this process.   There is built-in hysteresis to avoid repeated range changes when a component is on a range boundary.   Up-range changes occur when the impedance measured exceeds 450% of the mid-scale impedance (i.e, the source impedance), or 12.5% over the nominal range limit. Down-range changes occur when the measured impedance drops below 22% of the mid-scale impedance, or 12.5% below the nominal range. See Table 3-5 for the actual values where the range changes occur.

Table 3-5 Range Change Points When Autoranging

Ranging To Lower Impedances		*Ranging To Higher Impedances*	
Range Change	Impedance	Range Change	Impedance
2 to 3	$Z < 88\ \Omega$	3 to 2	$Z > 115\ \Omega$
1 to 2	$Z < 1.4\ k\Omega$	2 to 1	$Z > 1.8\ k\Omega$
0 to 1	$Z < 22.4\ k\Omega$	1 to 0	$Z > 29.9\ k\Omega$

RANGE HOLD Mode

It is sometimes desirable to disable auto ranging since it takes nearly a complete measurement cycle each time a range changes occurs. This can be annoying if there are no parts in the fixture and the meter is continuously triggering, since an empty fixture appears as a very large (nearly infinite) impedance. The meter will auto range to range 0 (range 1 for 100 kHz) and then auto range back to the appropriate range when a part is inserted in the fixture. Range holding is helpful if measurement speed is a concern or if a number of parts with similar values are being measured.

There are two ways to implement a RANGE HOLD mode:

1. The present measurement range can be held simply by pressing the **HOLD** key. The LED above the **HOLD** key indicates that the meter is in the RANGE HOLD mode.

2. A measurement range can also be directly entered from the ENTRY display. Select the ENTRY display using the **DISP** key, then press **HOLD**. The message "range" will appear in the left display, and the present range, 0–3, will appear in the right display.   Enter the desired range and press the **ENTER** button.

Use the **DISP** key to return to the desired display. The RANGE HOLD LED will be on. If an invalid range is entered, the meter will beep and display the message "range error" and not accept the range entry. Range 0 cannot be entered when the frequency is set to 100kHz. If this is attempted, the meter will beep and display an "r-f error" (range-frequency error). To return the meter to the auto ranging mode, simply press the **HOLD** button.

Constant Voltage (CONS) Mode

Occasionally, a test will require using a specific drive voltage that is not possible using the normal source resistance for that measurement range. In these cases, press the **CONS** key and thereby set the source impedance to a fixed 25 Ω. The voltage across the component under test will be almost constant for all devices with impedance substantially larger than 25Ω. When the meter is in constant voltage mode, the measurement range changes to avoid overloading the meter. However, it also reduces the accuracy of the measurement by a factor of 2. See the accuracy section in the Reference Manual for more detail. Tables 3-6 and 3-7 list the impedance ranges when using the constant voltage mode.

Under certain conditions, the "over load" message will be displayed. This normally occurs when the unit is in the constant voltage mode with the range hold on. To correct this, simply change to a higher impedance range, or use auto ranging.

Table 3-6 Measurement and Impedance Ranges for Constant Voltage Mode

Range	Source R	Resistance	Inductance	Capacitance
3	25.0 Ω	10 μΩ–360 Ω	.0001 μH–(57/f) H	99999 μF–(442/f) mF
2	25.0 Ω	360 Ω–5.76 kΩ	(57/f) H–(917/f) H	(442f) mF–(27.7/f) μF
1	25.0 Ω	5.76 kΩ–90.0 2kΩ	(917f) H–(1432/f) H	(27.7/f) μF–(1.77/f) μF
0	25.0 Ω	90.0 kΩ–2000 MΩ	(1432/f) H–99999 H	(1.77/f) μF–0.0001 pF

Table 3-7: Range change Points when Auto-Ranging in Constant Voltage Mode

Ranging to a Lower Impedance		Ranging to a Higher Impedance	
Range to Change	Impedance	Range to Change	Impedance
2 to 3	Z< 315Ω	3 to 2	Z< 400Ω
1 to 2	Z< 5.04KΩ	2 to 1	Z< 6.4KΩ
0 to 1	Z<78,.8KΩ	1 to 0	Z<100KΩ

Series and Parallel Equivalent Circuits

Generally, as illustrated in Figure 3-2, any non-ideal component has a different value for a series or parallel equivalent circuit due to the characteristics of the component. The "quality" of an inductor is expressed by Q, the ratio of the reactive (inductive) part of its impedance to its resistive part. The quality of a capacitor is similarly defined, as summarized in Table 3-8. Often it is more useful to calculate a capacitor's "dissipative factor," which is the inverse of its Q[1]. As Q for inductors decreases towards 10 and Q for resistors or D for capacitors increase towards 0. 1, the series and parallel circuit values begin to diverge. Most
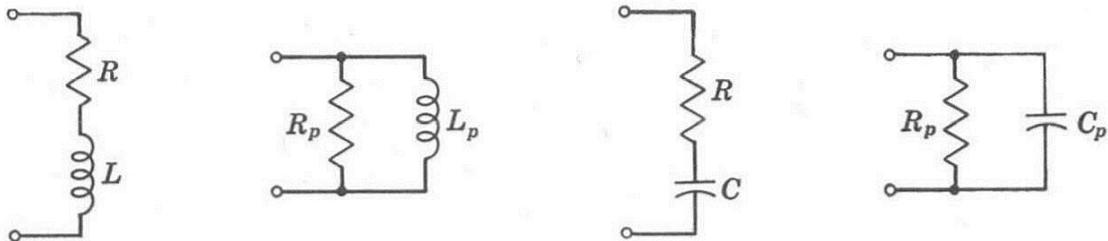
components have an approximate value for the series equivalent circuit. Manufacturers often specify which representation should be used when testing their devices.

Figure 3-2 Series and Parallel Equivalent Circuits.

Table 3-8 Quality Factors for Equivalent Circuits.

Component	Equivalent Circuit	Q
Inductor	Series	$\omega L/R$
	Parallel	$R_p/\omega L_p$
Capacitor	Series	$1/\omega CR$
	Parallel	$\omega C_p R_p$

Display Types

The **DISP** key can select one of five different types of displays. A display is selected by repeatedly pressing the **DISP** key until till the LED indicates the desired display option. These options are described as follows:

VALUE: This is the default display mode when the meter is turned on.

DEV: In the Deviation display mode, the difference between the currently measured component value and a previously entered value is displayed. The Deviation display is selected by repeatedly pressing the **DISP** key until the DEV

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[1] W. L. Everett and G. E. Anner, *Communication Engineering* (3rd edition), McGraw-Hill, 1956.

LED is lit. The Deviation display is not available in the AUTO mode and if no nominal value has been previously entered.

To Enter a Nominal Value,

1. Press and release the **DISP** key until the ENTRY LED is lit.

2. Select the measurement mode by pressing one of the keys in the PARAMETER group of keys on the front panel.

3. The left alphanumeric display shows the currently stored nominal value.

4. Enter a new nominal value using the numeric keypad.

5. Press the appropriate enter key (Q, µH, pF, Ω), (kΩ, mH, nF) or (MΩ, H, µF).

% DEV In this mode, the meter displays the difference between the currently measured component value and a previously entered value as a percentage. It is also not available in the AUTO mode or if no nominal value has been previously been entered.

ENTRY In the ENTRY display mode, the user is permitted to enter nominal values, measurement conditions and calibration data. If an out of range or incorrect value is entered, the meter will beep and display a "range error" message.

PROTEK 9216A
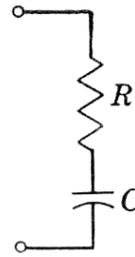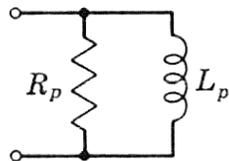# Digital LCR Meter
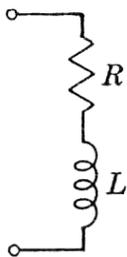
User's Manual
Volume 2: Reference
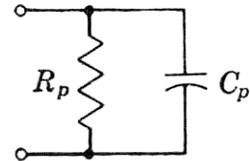
Table of Contents

Background on Components and Measurements

Properties of Resistors, Inductors, and Capacitors

The measurements made by the 9216A Digital LCR Meter are based on the definitions of impedance and the properties of discrete components designed to provide impedances in electronic circuits.

Definitions of Resistive and Reactive Parameters

Let the sinusoidal voltage and current in an electronic circuit at a particular frequency f be represented in the complex or phasor notation, given respectively by

$$V(t) = |V| \cos(\omega t + \theta_v) \tag{1a}$$

$$= |V| e^{j(\omega t + \theta_v)} = (|V| e^{j\theta_v}) e^{j\omega t} \tag{1b}$$

$$I(t) = |I| \cos(\omega t + \theta_i) \tag{2a}$$

$$= |I| e^{j(\omega t + \theta_i)} = (|I| e^{j\theta_i}) e^{j\omega t} \tag{2b}$$

where $j = \sqrt{-1}$, $\omega = 2\pi f$, and θ_v and θ_i are symbols for phases of the voltage and current relative to the frequency f. The impedance of a circuit component is defined as the complex number Z, in ohms, that gives the ratio of the voltage across the component to the current in the component:

$$Z = Z(\omega) = \frac{V(t)}{I(t)} = \frac{|V| e^{j(\omega t + \theta_v)}}{|I| e^{j(\omega t + \theta_i)}} = \frac{|V|}{|I|} e^{j(\theta_v - \theta_i)} \tag{3}$$

Component Categories

From equation (3), we observe that if the phases of the voltage across the component and the current in it are equal, then the impedance is a real number:

$$Z = \frac{|V|}{|I|} e^{j(0)} = \frac{|V|}{|I|} \tag{4}$$

In this situation, the impedance is purely *resistive*, as an ideal resistor would be.

If the phase of the voltage is 90 degrees ($\pi/2$ radians) ahead of the phase of the current, then the impedance is a positive imaginary number:

$$Z = \frac{|V|}{|I|} e^{j(\pi/2)} = j \frac{|V|}{|I|} \tag{5}$$

In this situation of positive, imaginary impedance, the impedance is purely *inductive*, as an ideal inductor would be. The impedance of an ideal inductor with inductance L is a linear function of frequency, given by $Z_L = j\omega L$.

If the phase of the voltage is 90 degrees ($\pi/2$ radians) behind the phase of the current, then the impedance is a negative imaginary number:

$$Z = \frac{|V|}{|I|} e^{j(-\pi/2)} = -j \frac{|V|}{|I|} \qquad (6)$$

In this situation of negative, imaginary impedance, the impedance is purely *capacitive*, as an ideal capacitor would be. The impedance of an ideal capacitor with capacitance C is the inverse of a linear function of frequency, given by $Z_C = 1/j\omega C = -j/.\omega C$.

Actual circuit components are not purely resistive, inductive, or capacitive. Actual capacitors and inductors have impedances with resistive parts, and their impedances may not be linear functions of frequency or independent of the voltage. The general expression for impedance, therefore, considers that it has a real, resistive part R and an imaginary, *reactive* part: X:

$$Z = R + j X, \qquad (7)$$

Where $X = \omega L$ for an inductor and $X = -1/\omega C$ for a capacitor. Since the quantity X is traceable to the ratio of a voltage to a current, it is expressed in ohms. Often, it is desirable to express the impedance in ohms as a scalar (real) quantity; in that case, its magnitude $|Z| = \sqrt{R^2 + X^2}$ is used.

Units

The unit of resistance is the ohm, with the symbol Ω (omega). A 1-Ω resistor produces a one-volt voltage across it when the current is one ampere.

The unit of inductance is the Henry, with the symbol H. For a one-amp AC current, a 1-H inductor would produce an AC voltage across it whose magnitude is numerically equal to 2π times the frequency in Hertz.

The unit of capacitance is the Farad, with the symbol F. For a one-amp AC current, a 1-F capacitor would produce an AC voltage across it whose magnitude is numerically equal to the inverse of 2π times the frequency in Hertz.

Series and Parallel Equivalent Circuits

The impedances of Actual resistors, inductors and capacitors are combinations of resistance, inductance, and capacitance. The simplest models for actual inductors and capacitors are the series and parallel equivalent circuits shown in Figure 1-1.

For example, the complex impedance of an inductor is

$$Z = R + jX = R + j\omega L \qquad \text{(series equivalent circuit)} \qquad (8a)$$

$$= \frac{R_p \cdot j\omega L_p}{R_p + j\omega L_p} = \frac{R_p + jR_p\left(R_p/\omega L_p\right)}{1 + \left(R_p/\omega L_p\right)^2} \qquad \text{(parallel equivalent)} \qquad (8b)$$
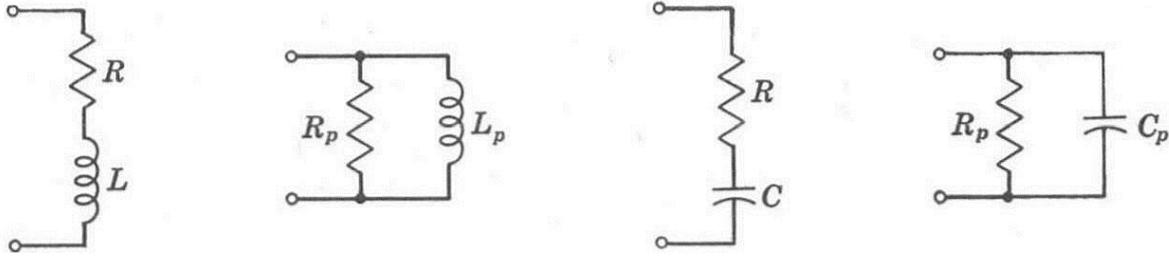
Figure 1-1 Equivalent circuits for inductors and capacitors.

The complex impedance of a capacitor is

$$Z = R + jX = R - j/\omega C \qquad \text{(series equivalent circuit)} \qquad (9a)$$

$$= \frac{R_p \cdot 1/j\omega C_p}{R_p + 1/j\omega C_p} = \frac{R_p}{1 + j\omega C_p R_p} = \frac{R_p(1 - j\omega C_p R_p)}{1 + (\omega C_p R_p)^2} \quad \text{(parallel equivalent)} \quad (9b)$$

Quality Factors

Originally, the quality factor Q was defined for an inductor as a measure of the efficiency of energy storage in the inductor when an AC current is passed through it. Mathematically, the definition is[1]

$$Q = 2\pi \text{ (max. energy stored)} \div \text{(energy dissipated per Hz)} \qquad (10a)$$

$$= 2\pi f \text{ (max. energy stored)} \div \text{(average power dissipated)} \qquad (10b)$$

Since the average power dissipated in the inductor with series resistance R is $|I|^2 R$ and the maximum energy stored in the inductor is $L|I|^2$, the quality factor for an inductor is given by

$$Q = \omega L / R. \qquad (11a)$$

By equating (8a) and (8b), the series equivalent circuit parameters R and L can be expressed in terms of the parallel parameters R_p and L_p. When that is done and substituted in equation (10a), we find that the quality factor also is written

$$Q = R_p / \omega L_p. \qquad (11b)$$

While the concept of the quality factor was originally applied to inductors, it may be extended so that the efficiency of energy storage in a capacitor may be expressed in terms of the circuit components and frequency. Thus, if the series resistance and capacitance of a capacitor are, respectively, R and C as in Figure 1-1, then (10b) is evaluated to be

$$Q = 1 / \omega CR. \qquad (12a)$$

By equating (9a) and (9b), the series equivalent circuit parameters R and C can be expressed in terms of the parallel parameters R_p and C_p. When that is done and substituted in equation (12a), we find that the quality factor for a capacitor also is written

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[1] W. L. Everett and G. E. Anner, *Communication Engineering*, McGraw-Hill, New York, 1956.

$$Q = \omega C_p R_p. \tag{12b}$$

Using the quality factor, the impedance of an inductor is seen to be

$$Z = R + j\omega L = R(1 + jQ) = \omega L(j + 1/Q) \tag{13a}$$

and the inductor's series equivalent circuit components can be expressed in terms of its parallel equivalent circuit components as

$$R = \frac{R_p}{1 + Q^2}, \qquad L = \frac{Q^2 L_p}{1 + Q^2} \tag{13b}$$

The impedance of a capacitor in terms of the quality factor is

$$Z = R + 1/j\omega C = R(1 - jQ) = \frac{1}{\omega C}(D - j) \tag{14a}$$

and the capacitor's series equivalent circuit components can be expressed in terms of its parallel equivalent circuit components as

$$R = \frac{R_p}{1 + Q^2}, \qquad C = (1 + D^2)C_p \tag{14b}$$

Accuracy and Calibration

How to Assess and Control the Accuracy

The accuracy achieved by the 9216A Digital LCR Meter depends on several factors. In this chapter, equations are given for estimating the accuracy of a specific measurement, and procedures are given for calibrating the meter.

Accuracy Specifications

Note: The accuracy of the 9216A that is stated in this chapter is valid for the following conditions: (a) a warm-up time of at least 30 minutes, (b) a temperature of $23°C \pm 5°C$, (c) the use of the built-in fixture, and (d) the completion of the open and short circuit calibrations. In addition, the component being measured must have the following characteristic: D < 0.1 for a capacitor, Q < 0.1 for a resistor, or Q > 10 for an inductor.

General Accuracy Equation

The accuracy of a measurement is a function of the "basic impedance accuracy" at the specific frequency, measurement rate, signal amplitude, and the impedance of the device under test (DUT) relative to the measurement range. The basic instrument accuracy can be determined from graphs given below. Additional factors affecting the accuracy are related to the measurement conditions and the impedance of the DUT. From these, the accuracy of a particular measurement in its optimal range is calculated. See below for the effects on measurements made out of an optimal range.

The basic equation for impedance accuracy equation is given by

$$\text{Accuracy in } \% = \pm [A \times K_i \times K_v + 100 \times (K_h + K_l)], \text{ where} \qquad (1)$$

A = the basic impedance accuracy from Figure 2-1, which should be multiplied by two if the unit is in constant voltage mode. Figure 2-1 is based on the fact that the best accuracy occurs when the impedance to be measured is greater than ¼ the source resistance and less than 4 times that resistance, and when the test frequency is 1 kHz or less.

K_i = integration time factor, as given in Table 2-1.

K_v = drive voltage error factor, as given in Table 2-2. Note from Table 2-2 that K_v is defined as equal to 1.0 for the primary drive voltages (1.0, 0.5, and 0.25 Vrms).

K_h, K_l = extreme range error terms, as given in Table 2-3. Note from Table 2-3 that K_l is negligible for impedances above 100 Ω and K_h is negligible for impedances below 1 kΩ, both at all frequencies.
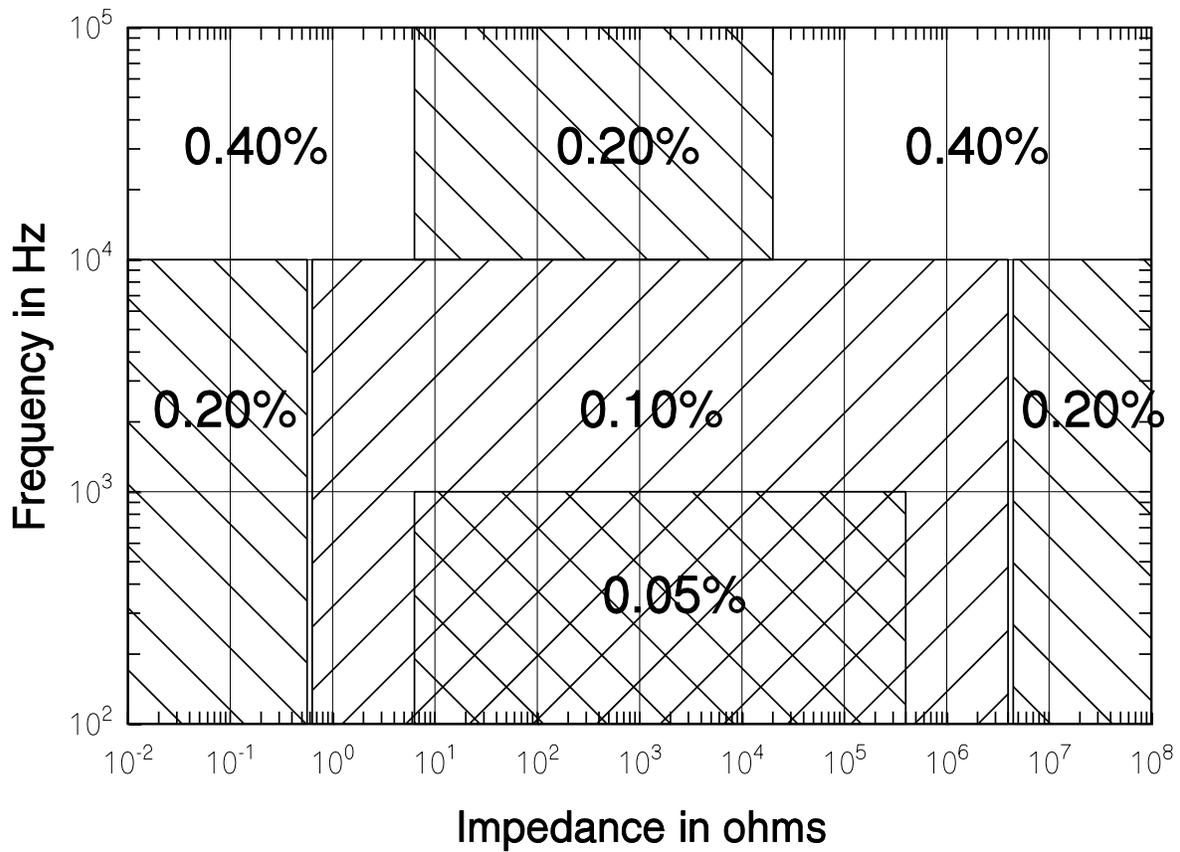
Figure 2-1 Basic Impedance Accuracy

Table 2-1 Integration Time Accuracy Factor, K_i

Meas. Rate	Frequency	Z_m	K_i
Slow, Medium	All	All	1
Fast	100 Hz to 1 kHz	$6.25\,\Omega < Z_m < 400\,k\Omega$	3
	All other		2

Table 2-2 Drive Voltage Error Factor, K_v

Vout (Vrms)	K_v
0.55 to 1.0	1/Vout
0.3 to 0.5	0.5/Vout
0.15 to 0.25	0.25/Vout
0.10	0.11/Vout

Table 2-3 Extreme Range Error Terms, K_h and K_l

Frequency	K_l	K_h
100 Hz, 120 Hz, 1 kHz	$(1\ m\Omega/Z_m)$	$(Z_m/2\ G\Omega)$
10 kHz	$(1\ m\Omega/Z_m)$	$(Z_m/1.5\ G\Omega)$
100 kHz	$(4\ m\Omega/Z_m)$	$(Z_m/50\ M\Omega)$

Accuracy Equations for Specific Measurement Modes

R + Q Accuracy

In the R + Q measurement mode, the basic impedance accuracy A in the equation for impedance accuracy may be read from Figure 2-1 directly while interpreting the "impedance" as "resistance." The resistance accuracy is calculated from equation (1) above, with the additional stipulation that if the measured Q has an absolute value greater than 0.1, then the basic resistance accuracy factor should be multiplied by the factor $(1 + |Q|)$. Let the basic resistance accuracy factor be denoted A_r. Then the accuracy of the measurement of Q is given by

$$\text{Accuracy of Q} = \pm\,[(A_r/100) \times (1+Q^2)] \qquad\qquad (2)$$

Note that the accuracy of Q is specified as a magnitude, *not* as a percentage.

L+Q Accuracy

The basic impedance accuracy depicted in Figure 2-1 applies to inductance measurements when the impedance is interpreted to be $2\pi f\,L$, where f is the test frequency in Hz and L is the inductance in Henrys. For convenience, Figure 2-1 is redrawn in Figure 2-2 with lines of constant inductance superimposed. Also, Table 2-3 is recreated for inductive impedances as Table 2-4. Note from Table 2-4 that the range error factor K_l is negligible for inductances above $15.9/f$ H and K_h is negligible for inductances below $159/f$ H.

The accuracy of the inductance measurement is calculated from equation (1) above, with the additional stipulation that if the measured Q has an absolute value less than 10, then the basic inductance accuracy factor should be multiplied by the factor $(1 + |1/Q|)$. Let the basic inductance accuracy factor be denoted A_l. Then the accuracy of the Q calculation is given by equation (2) with A_l substituted for A_r.

C+D Accuracy

The basic impedance accuracy depicted in Figure 2-1 applies to capacitance measurements when the impedance is interpreted to be $1/2\pi f\,C$, where f is the test frequency in Hz and C is the capacitance in Farads. For convenience, Figure 2-1 is redrawn in Figure 2-3 with lines of constant capacitance superimposed. Also, Table 2-3 is recreated for capacitive impedances as Table 2-5. Note from Table 2-5 that the range error factor K_l is negligible for capacitances below $1590/f$ μF and K_h is negligible for capacitances above $159/f$ μF.
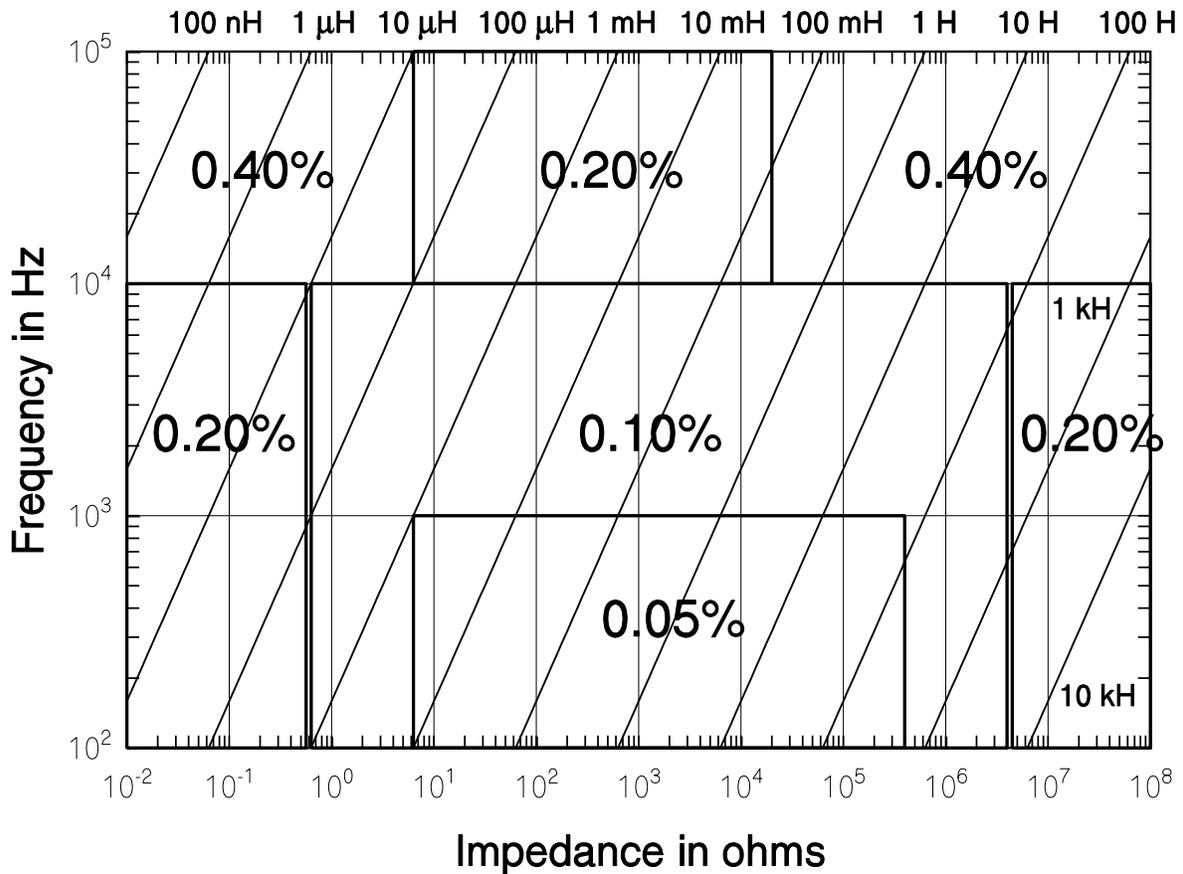
Figure 2-2 Basic Impedance Accuracy for Inductances

Table 2-4 Extreme Range Error Terms for Inductances, K_h and K_l

Frequency	K_l	K_h
100 Hz, 120 Hz	$(1\ \mu H/L_m)$	$(L_m/2.6\ MH)$
1 kHz	$(0.1\ \mu H/L_m)$	$(L_m/260\ kH)$
10 kHz	$(0.02\ \mu H/L_m)$	$(L_m/10\ kH)$
100 kHz	$(0.02\ \mu H/L_m)$	$(L_m/100\ H)$

The accuracy of the capacitance measurement is calculated from equation (1) above, with the additional stipulation that if the measured D has a value less than 0.1, then the basic capacitance accuracy factor should be multiplied by the factor (1 + D). Let the basic capacitance accuracy factor be denoted A_c. Then the accuracy of the D calculation is given by

$$\text{Accuracy of D} = \pm\,[A_c/100] \qquad\qquad (3)$$

Note that the accuracy of D is specified as a magnitude, *not* as a percentage.
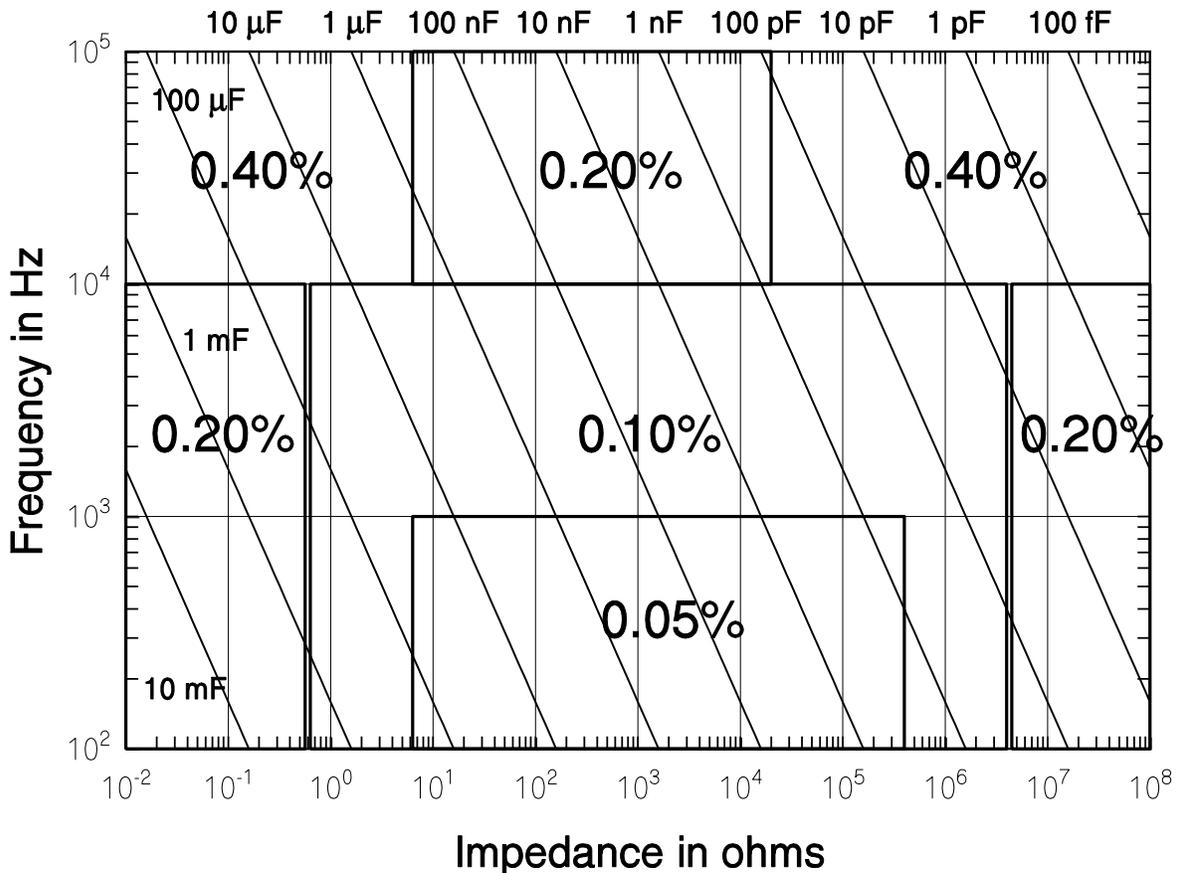
Figure 2-3 Basic Impedance Accuracy for Capacitances

Table 2-5 Extreme Range Error Terms for Capacitances, K_h and K_l

Frequency	K_l	K_h
100 Hz, 120 Hz	(2 pF/C_m)	(C_m/1600 mF)
1 kHz	(0.1 pF/C_m)	(C_m/160 mF)
10 kHz	(0.01 pF/C_m)	(C_m/16 mF)
100 kHz	(0.02 pF/C_m)	(C_m/200 μF)

C+R Accuracy

The basic impedance accuracy depicted in Figure 2-1 applies to capacitance measurements when the impedance is interpreted to be $1/2\pi f\,C$, where f is the test frequency in Hz and C is the capacitance in Farads. For convenience, Figure 2-1 is redrawn in Figure 2-3 above with lines of constant capacitance superimposed. Also, Table 2-3 is recreated for capacitive impedances in the C + R measurement mode as Table 2-6. Note from Table 2-6 that the range error factor K_l is negligible for capacitances below 1590/f μF

For small values of D (D < 0.1), the accuracy of the capacitance measurement in the C + R mode is calculated from equation (1) above, and the accuracy of the resistance

Table 2-6 Extreme Range Error Terms for Capacitances (C + R mode), K_h and K_l

Frequency	K_l	K_h
100 Hz, 120 Hz	$(2\ pF/C_m)$	$(C_m/2000\ mF)$
1 kHz	$(0.1\ pF/C_m)$	$(C_m/200\ mF)$
10 kHz	$(0.01\ pF/C_m)$	$(C_m/10\ mF)$
100 kHz	$(0.01\ pF/C_m)$	$(C_m/100\ \mu F)$

measurement is given by

$$\text{Accuracy of R in }\% = \pm\,[A_c \times (1 + 1/D)] \tag{4}$$

where A_c is the accuracy of the capacitance measurement (above) and

$$D = R/2\pi f C. \tag{5}$$

For D > 0.1, the impedance accuracy must first be calculated. To do this, first calculate the impedance of the DUT by adding the resistive and capacitive elements, either in series or parallel, as appropriate. Use the impedance accuracy graph to obtain impedance accuracy, and let it be denoted A_z. The accuracies of C and R are calculated from the impedance accuracy as follows:

$$\text{Accuracy of C in }\% = \pm\,[A_z \times (1 + |D|)] \tag{6}$$

$$\text{Accuracy of R in }\% = \pm\,[A_z \times (1 + 1/|D|)] \tag{7}$$

Accuracy When Holding a Nonoptimal Range

When a component is measured outside of its nominal range (in range hold), the accuracy of the measurement is reduced. The nominal ranges are defined as approximately four times above and below the nominal impedance value:

Range	Nominal Impedance Range
R3	6.25 Ω to 100 Ω
R2	100 Ω to 1.6 kΩ
R1	1.6 kΩ to 25.6 kΩ
R0 (100 Hz to 10 kHz)	25.6 kΩ to 400 kΩ

(R0 is not defined for 100 kHz.) Components that are measured while autoranging have only one set of extreme range terms (K_h, K_l) per frequency.

For components measured in the range hold mode, the values of K_h and K_l are different for each range. These values are calculated from parameters tabulated below in Tables 2-7 to 2-9 for resistive, inductive, and capacitive measurements, respectively.

Table 2-7 Parameters for Calculating K_l and K_h for Resistive Measurements

	$R_l = K_l \times Z_m$				$R_h = K_h \times Z_m$			
Frequency	R3	R2	R1	R0	R3	R2	R1	R0
100, 120, 1 kHz	1 mΩ	0.02 Ω	0.2 Ω	4 Ω	400 kΩ	6.5 MΩ	100 MΩ	2 GΩ
10 kHz	1 mΩ	0.02 Ω	0.2 Ω	4 Ω	400 kΩ	6.5 MΩ	100 MΩ	1.5 GΩ
100 kHz	4 mΩ	0.03 Ω	0.4 Ω	---	200 kΩ	3 MΩ	50 MΩ	---

Table 2-8 Parameters for Calculating K_l and K_h for Inductive Measurements

	$L_l = K_l \times L_m$				$L_h = K_h \times L_m$			
Frequency	R3	R2	R1	R0	R3	R2	R1	R0
100, 120 Hz	1 μH	20 μH	300 μH	5 mH	630 H	10 kH	160 kH	2.6 MH
1 kHz	1 μH	20 μH	300 μH	5 mH	630 H	10 kH	160 kH	2.6 MH
10 kHz	1 μH	20 μH	300 μH	5 mH	630 H	10 kH	160 kH	2.6 MH
100 kHz	1 μH	20 μH	300 μH	5 mH	630 H	10 kH	160 kH	2.6 MH

Table 2-9 Parameters for Calculating K_l and K_h for Capacitive Measurements

	$C_l = K_l \times C_m$				$C_h = K_h \times C_m$			
Frequency	R3	R2	R1	R0	R3	R2	R1	R0
100, 120 Hz	4 nF	240 pF	16 pF	2 pF	1600 mF	80 mF	6.7 mF	400 μF
1 kHz	400 pF	24 pF	1.6 pF	0.1 pF	160 mF	8 mF	670 μF	40 μF
10 kHz	40 pF	2.4 pF	0.16 pF	0.01 pF	16 mF	800 μF	40 μF	2.6 μF
100 kHz	8 pF	2.4 pF	0.02 pF	---	200 μF	80 μF	4 μF	---

Verification of Meter Performance

The performance verification procedures in this section test and verify the performance of 9216A and compare it to the specifications listed in Volume 1 of this manual. The first set of tests verifies the basic functionality of the unit. The second set of tests verifies the critical specifications of the 9216A. The results of each section can be recorded on the test sheet located at the end of this manual.

Functional Tests

These simple tests verify the basic functionality of the 9216A. They are not intended to verify the accuracy of the unit.

Item	Critical Specifications	Recommended Model
Analog Oscilloscope with × 10, 10MHz probes	100MHz Bandwidth	Tektronix 2445
24.9 Ω Resistor	0.1%	Dale CMF55 or equivalent
402 Ω Resistor	0.1%	Dale CMF55 or equivalent
6.34 kΩ Resistor	0.1%	Dale CMF55 or equivalent
100.0 Ω Resistor	0.1%	Dale CMF55 or equivalent
22 nF Capacitor	1% NPO	Murata Erie RPE series or equivalent

Front Panel Test

This test verifies the front panel display digits, LEDs, and keypad.

1. Turn on the unit while holding down the **DISP** key. A single segment in the third digit of the left display should be on.

2. Press the down arrow key ↓ to light each segment (seven total) and the decimal for the third and fourth digits of the left display, for a total of 16 segments. Only one segment or decimal point should be on at a time. (Pressing the up arrow key ↑ will step backward through the pattern.)

3. Press the down arrow key ↓ again (17th time) to light all the segments of all 12 digits. The AUTO LED will also be on.

4. Press the down arrow key ↓ repeatedly to light the 25 LEDs in the display and the 26 LEDs on the keypad. The LEDs turn on one at a time, from top to bottom and left to right, first for the display, and then for the keypad. Only one LED should be on at a time.

5. After all of the LEDs have been tested, further pressing of the front panel keys will display the key code associated with each key. Each key has a different key code, starting with 01 at the upper left, and increasing from top to bottom then left to right.

6. The unit must be switched off to leave this mode.

Self Tests

The internal self tests verify the functionality of the 9216A. Turn on the unit. The ROM program and model name will be displayed for about three seconds. Next the message "tESt...." will be displayed while the unit performs its self tests. After the tests are completed the unit should display 'tESt PASS' to indicate that the tests were successful. If not, an error message will appear. See the TROUBLESHOOTING section for a description of the error messages.

Output Voltage

This test checks the 9216A output voltage for the correct frequency and amplitude.

1. Set the 9216A to 1 kHz, 1 V and constant voltage. Set the scope to 1 V/div vertical and 0.5 ms/div horizontal. Connect a ×10 probe to the scope.

2. Place the tip of the probe into the "+" side of the fixture and connect the ground clip to the center guard.

3. The scope should display a sine wave that occupies two divisions horizontally and about 5.5 divisions peak to peak vertically (1.0 Vrms - 2.83 V peak to peak). There should be no irregularities in the waveform.

4. Change the amplitude setting of the 9216A to 0.25 and 0.10 V in succession and verify that the output is within 2% of nominal.

5. Set the amplitude back to 1.0 V. Change the 9216A and scope settings to verify that the output at 100 Hz, 120 Hz, 10 kHz and 100 kHz is within 2% of nominal.

Resistance Measurement

This test verifies that the 9216A operates and is able to measure a component in each of its ranges. The readings obtained should be within ±(tolerance of the component + tolerance of the 9216A).

1. Press the key sequence **RCL 0 ENTER** to put the unit in its default setup.

2. Perform open and short circuit calibrations for the fixture configuration to be used. See Volume 1 for details on these null calibrations.

3. Set the unit to the R+Q measurement mode, series equivalent circuit, and 1 kHz test frequency. Install the 24.9 Ω resistor.

4. Verify that the meter reads the resistance correctly to within ±0.15%. Verify that Q is a small value, about +0.0001 or smaller. Install the 402 Ω resistor. Verify that the meter reads the resistance correctly to within ±0.15%. Verify that Q is a small value, about +0.0001 or smaller.

5. Change the equivalent circuit to parallel. Install the 6.34 kΩ resistor. Verify that the meter reads the resistance correctly to within ±0.15%. Verify that Q is a small value, about −0.0001 or smaller.

6. Install the 100 kΩ resistor. Verify that the meter reads the resistance correctly to within ±0.15%. Verify that Q is a small value, about −0.0002 or smaller.

Capacitance Measurement

This test verifies that the 9216A is able to measure components at different frequencies. The limits of the readings are the same as before: ± (component tolerance + meter tolerance).

1. If the fixture configuration has changed, perform open and short circuit calibration.

2. Set the 9216A to the C+D measurement mode, parallel equivalent circuit, and 1 kHz test frequency.

3. Install the 22 nF capacitor. Verify that the unit reads the capacitance correctly to within 1.10%. Verify that D is below 0.0001.

4. Set the unit to 100 Hz. Verify that the capacitance reading is close to the value measured above and within the tolerance stated above. Repeat for 120 Hz. D values should be below 0.0001.

5. Repeat for 10 kHz. At 10kHz, the tolerance is 1.15%. For 100 kHz the tolerance is 1.25%. D values should be below 0.001 for 10 kHz and 0.01 for 100 kHz.

Performance Tests

These tests are intended to measure the 9216A's conformance with its published specifications. These test results, along with the results of the functional tests, can be recorded on the test sheet at the end of this manual.

Necessary Equipment

Instrument	Critical Specifications
Time Interval Counter	Time Interval Accuracy: 1 ns max
DC/AC Voltmeter	5 ½ digit DC accuracy, true RMS AC to 100 kHz
Resistance decade box	Accuracy 0.02%: 1 Ω to 1 MΩ
Capacitance decade box	Accuracy 0.05%: 1000 pF to 10 μF

Test conditions: at least 30 minutes of warm-up time, and a temperature in the range of 23°C $\pm$ 5 °C.

Frequency Accuracy

This test measures the accuracy of the different output frequencies. They should be within 0.01% (100 ppm) of the nominal value.

1. Set the Z-9216 to its default conditions by pressing the key sequence **RCL 0 ENTER**. Set the unit to constant voltage mode, 1 kHz test frequency, and remove any part from the fixture.

2. Install the BNC adapter on the fixture. Connect the IH lead to the frequency counter.

3. Verify that the frequency counter reads 1 kHz $\pm$ 0.1 Hz (+0.01%). Record the result.

4. Repeat step 3 at 100 Hz, 120 Hz, 10k Hz and 100 kHz. The frequencies should all be within 0.01% of the nominal frequency. Record the results.

Amplitude Accuracy

This test measures the amplitude accuracy of the drive output. It should be within 2.0% of the nominal value for all of the amplitude settings.

1. Connect the AC/DC voltmeter across the two sides of the fixture. A small piece of wire inserted in each side of the fixture is a convenient way to connect the DVM. Do not connect either end to ground. Set the DVM to AC volts, auto ranging.

2. Set the 9216A to its default conditions by pressing the key sequence **RCL 0 EN-TER**. Set the unit to constant voltage mode. The output voltage should be 1.0 Vrms at 1 kHz. Verify that the voltage reading is between 0.98 and 1.02 Vrms. Record the result.

3. Repeat step 2 for 100 Hz, 120 Hz, and 100 kHz. All voltage readings should be between 0.98 and 1.02 Vrms. Record the results.

4. Set the frequency to 1 kHz. Set the voltage sequentially to 0.25V and 0.10V. The DVM should read within 2.0% of the nominal values (between 0.245 and 0.255 and between 0.098 and 0.102, respectively). Record the results.

5. Set the DVM to DC volts. Set the 9216A to the C+D measurement mode, 100 kHz test frequency, 0.10 V drive voltage with internal Bias on. Verify that the DC voltage is 2.0 VDC $\pm$ 2%.

Impedance Accuracy

These tests confirm that the 9216A meets its impedance measurement accuracy specification. Precision impedance standards are required. The minimum and maximum acceptable values are determined by adding the tolerance of the 9216A and that of the standard. For example, at 1.000 kΩ the tolerance is $\pm$0.05%, the tolerance of the resistance standard is $\pm$0.02%, and thus the total tolerance is $\pm$0.07% or $\pm$0.7 Ω. So the range of acceptable values is 999.3 Ω to 1000.7 Ω. If standards with different tolerances are used, the acceptable limits will have to be adjusted.

Resistance Accuracy

1. Connect the Fixture Adapter to the 9216A. Install a BNC to stacking banana plug adapter on the end of each BNC cable. Tape over (or cut off) the ground leads of the plugs connected to the orange (PH) and purple (PL) cables. Connect the ground leads of the red (IH) and blue (IL) cables to the case ground of the decade box. Plug the orange and purple signal leads to the "+" and "−" terminals on the decade box. Plug the red signal lead into the orange signal lead and plug the blue signal lead into the purple signal lead. Set the 9216A to its default conditions by pressing **RCL 0 ENTER**, then press the **R+Q** key and set the test frequency to 1 kHz.

2. Unplug the red/orange lead pair from the "+" terminal of the decade box and plug them into the blue/purple lead pair. Perform short circuit calibration. Remove the red/orange lead pair form blue/purple lead pair and locate them at the same separation from the blue/purple pair as they will be during operation. Perform open circuit calibration.

3. Connect the red/orange lead pair to the "+" terminal of the decade box. Set the dials to all zeros. Note the resistance value that the 9216A measures. This is the resistance of the switch contacts and connectors. Enter this as a relative value in the entry display. Set the 9216A to the DEV display mode.

4. Set the decade resistor and the 9216A according to the values in the Resistance Accuracy Table below. Verify that the readings fall within the acceptable values. Record the results.

Resistance Accuracy Table

resistance	range	conditions	Tolerance + R tol.
10.0	3	1 kHz series	9.9930 - 10.007
25.0	3	1 kHz series	24.983 - 25.018
25.0	3	10 kHz series	24.970 - 25.030
25.0	3	100 kHz series	24.945 - 25.055
100.0	3	1 kHz series	99.930 - 100.07
100.0	2	1 kHz series	99.930 - 100.07
400.0	2	1 kHz series	399.72 - 400.28
400.0	2	10 kHz series	399.52 - 400.48
400.0	2	100 kHz series	399.12 - 400.88
1.600 k	2	1 kHz parallel	1.5989 k - 1.6011 k
1.6000 k	1	1 kHz parallel	1.5989 k - 1.601 k
6.4000 k	1	1 kHz parallel	6.3955 k - 6.4045 k
6.4000 k	1	10 kHz parallel	6.3923 k - 6.4077 k
6.4000 k	1	100 kHz parallel	6.3859 k - 6.4141 k
25.0000 k	1	1 kHz parallel	24.983 k - 25.018 k
25.0000 k	0	1 kHz parallel	24.983 k - 25.018 k
100.0000 k	0	1 kHz parallel	99.930 k -100.07 k
100.0000 k	0	10 kHz parallel	99.880 k -100.12 k
400.0000 k	0	1 kHz parallel	399.72 k - 400.28 k

* if the Q value is greater than 0.1, the allowed tolerance must be multiplied by (1+Q)

Capacitance Accuracy

1. Connect the adapter ground leads of IH and IL to ground terminal of the decade capacitor. Connect the IH and PH leads to the "+" terminal of the decade capacitor. Connect the IL and PL leads to the "–" terminal of the decade capacitor box. Set the 9216A to its default conditions by pressing the key sequence **RCL 0 ENTER**, then select the R+Q measurement mode and the 1 kHz test frequency.

2. Unplug the IH, PH leads from "+" terminal of the decade capacitor box and plug them into the "–" terminal of the decade capacitor box. Perform short circuit calibration. Unplug the IH, PH leads from "–" terminal of the decade capacitor box, then perform open circuit calibration.

3. Connect the IH, PH leads to the "+" terminal of the decade capacitor box. Set the capacitance to zero.

4. Note the capacitance value the 9216A measures. This is the capacitance of the switch contacts and connectors. Enter this as a relative value in the entry display. Set the 9216A to the DEV display mode.

5. Set the decade capacitor and the 9216A according to the values in the Capacitance Accuracy Table below. Verify that the readings fall within the acceptable values. Record the results.

Capacitance Accuracy Table

Capacitance	Frequency	Range	9216A tol. + C tol.
1.0 nF	1 kHz	0	.99930 nF - 1.0007 nF
1.0 nF	10 kHz	1	.99880 nF - 1.0012 nF
1.0 nF	100 kHz	2	.99780 nF - 1.0022 nF
10.0n	100 Hz	0	9.9930 nF - 10.007 nF
10.0 nF	1 kHz	1	9.9930 nF - 10.007 nF
10.0 nF	10 kHz	2	9.9880 nF - 10.012 nF
10.0 nF	100 kHz	2	9.9780 nF - 10.022 nF
100 nF	100 Hz	1	99.930 nF - 100.07 nF
100 nF	1 kHz	2	99.930 nF - 100.07 nF
100 nF	10 kHz	2	99.880 nF - 100.12 nF
100 nF	100 kHz	3	99.780 nF - 100.22 nF
1.000 μF	100 Hz	2	.99930 μF - 1.0007 μF
1.000 μF	1 kHz	2	.99930 μF - 1.0007 μF
1.000 μF	10 kHz	3	.99880 μF - 1.0012 μF
10.000 μF	100 Hz	2	9.9930 μF - 10.007 μF
10.000 μF	1 kHz	3	9.9930 μF - 10.007 μF

Calibration Procedures

Introduction

Calibration of the 9216A is composed of several parts: open and short circuit calibrations, standard resistor calibration, and amplitude calibration.

The open and short circuit calibrations (described in Volume 1 of this manual) are off-set corrections to correct for any stray impedances of the test fixture. These Calibrations may be performed at any time and should be done whenever the fixture is changed.

The standard resistor calibration sets the accuracy of the 9216A, since it allows the LCR meter to determine the values of its internal standard resistors. Standard resistor Calibration need only be performed periodically to account for component aging and drift.

Amplitude calibration sets the amplitude of the AC test signal, and only needs to be done periodically. The amplitude calibration does not affect the 9216A's accuracy.

Calibration Enable

The 9216A is shipped with amplitude calibration disabled. When calibration is disabled only the open and short circuit calibrations are allowed. The internal calibration enable jumper must be set to enable amplitude and resistor calibration. To set the jumper, re-move the 9216A top cover by removing its four retaining screws (this will break the calibration seal). In the rear center of the circuit board is a three pin jumper labeled JP1001. Use the jumpers to connect the center pin and the "cal" pin to enable calibration. Connecting the center pin and the "normal" pin will disable calibration.

Calbytes

The 9216A calibration is controlled by calibration constants ("calbytes") that the firmware uses to adjust the impedance calculations. These calbytes are stored in the 9216A RAM. Recalibration of the 9216A involves determining new values of the calbytes and storing them in the RAM. The calbyte values that are determined at the time of the 9216A manufacture are also stored in ROM and may be recalled at any time. The standard resistor calbytes are automatically determined by the standard resistor calibration subroutines. The amplitude calbytes must be manually determined.

The 95 amplitude calbytes, which are one-byte integers in the range of 0 to 255, are directly adjustable from the front panel and are organized as shown in Table 2-10. The 120 floating point frequency correction, reference resistor values, and open and short circuit calbyte values, whose organization is given in Table 2-11, are automatically determined by the 9216A's calibration subroutine. These calbytes cannot be directly changed from the front panel, but they may be changed via the computer interfaces.

Table 2-10 Organization of Amplitude Calbytes to Amplitude and Frequency

	Frequency				
Amplitude	**100 Hz**	**120 Hz**	**1 kHz**	**10 kHz**	**100 kHz**
0.10 V	0	1	2	3	4
0.15 V	5	6	7	8	9
0.20 V	10	11	12	13	14
0.25 V	15	16	17	18	19
0.30 V	20	21	22	23	24
0.35 V	25	26	27	28	29
0.40 V	30	31	32	33	34
0.45 V	35	36	37	38	39
0.50 V	40	41	42	43	44
0.55 V	45	46	47	48	49
0.60 V	50	51	52	53	54
0.65 V	55	56	57	58	59
0.70 V	60	61	62	63	64
0.75 V	65	66	67	68	69
0.80 V	70	71	72	73	74
0.85 V	75	76	77	78	79
0.90 V	80	81	82	83	84
0.95 V	85	86	87	88	89
1.00V	90	91	92	93	94

Table 2-11 Organization of Floating Point Calbytes

Calbyte Number	Name	Meaning
0	Frequency Correction	Deviation from nominal, in ppm
1–40	Reference Resistor Values	Impedance values organized in real and imaginary pairs
41–80	Open Circuit Values	Admittance values organized as real and imaginary pairs
81–120	Short Circuit Values	Impedance values organized in real and imaginary pairs

Necessary Equipment and Conditions

To perform the amplitude, frequency, or standard resistor calibration, the following equipment is needed:

- A time interval counter, with an accuracy of 1 ns or better.

- An AC/DC voltmeter, with 5 ½ -digit DC accuracy and true RMS AC measurements to 100 kHz.

- Standard resistors, with resistance known to 0.01% and Q accuracy known to 25 ppm. The resistor values needed are 95.300 kΩ (R0), 5.970 kΩ (R1), 374.0 Ω (R2), and 25.10 Ω (R4).

- A fixture-to-BNC adapter.

The conditions for calibration include a warm-up time of at least 30 minutes and an ambient temperature of 23°C $\pm$ 2°C.

Amplitude Calibration

This procedure calibrates the output amplitude at the different frequencies and output voltages. To adjust the calbytes, press the **CAL** key until the message "cl I" appears in the display, where I is an integer. The present value of that calbyte will appear in the right display. The ↑ and ↓ frequency keys step through the different amplitude calbytes. New values are entered using the numeric entry keys.

1. Connect the AC/DC voltmeter across the two sides of the fixture. A small piece of wire inserted in each side of the fixture is a convenient way to connect the DVM. Do not connect either end to ground. Set the meter to AC volts, auto ranging. Set the 9216A to its default conditions by pressing the keys, **RCL 0 ENTER**. Set the unit to constant voltage mode.

2. Measure the amplitude and frequency for amplitude calbyte 0 (0.10 V and 100 Hz). If the value is not within 2% of the nominal value, enter the new calbyte using the formula:

$$NewCalbyte = \frac{Vnom}{Vmeas} \times CurrentCalbyte$$, rounded to the nearest integer

3. Verify that the amplitude is within 2% of the nominal value. See Table 2-12 below for the acceptable limits for each amplitude.

4. Repeat steps 2 and 3 for 120 Hz, 1 kHz, 10 kHz, and 100 kHz (Calbytes 1, 2, 3 and 4) at this amplitude (0.10 V). Note that, for each amplitude, the calbyte numbers are in order of ascending frequency.

5. Repeat steps 2 to 4 for each amplitude in the table. At each amplitude, repeat the measurement for each frequency, starting with 100 Hz and increasing to 100 Hz.

Table 2-12 Amplitude Limits

Calbyte	Nominal Voltage	Limits
0-4	0.100	0.098-0.102
5-9	0.150	0.147-0.153
10-14	0.200	0.196-0.204
15-19	0.250	0.245-0.255
20-24	0.300	0.294-0.306
25-29	0.350	0.343-0.357
30-34	0.400	0.392-0.408
35-39	0.450	0.441-0.459
40-44	0.500	0.490-0.510
45-49	0.550	0.539-0.561
50-54	0.600	0.588-0.612
55-59	0.650	0.637-0.663
60-64	0.700	0.686-0.714
65-69	0.750	0.735-0.765
70-74	0.800	0.784-0.816
75-79	0.850	0.833-0.867
80-84	0.900	0.882-0.918
85-89	0.950	0.931-0.969
90-94	1.000	0.980-1.020

Frequency Calibration

This procedure measures the accuracy of the 9216A clock. The exact clock frequency is used in calculating capacitance and inductance values. The clock correction factor is stored in parts per million (ppm).

1. Set the 9216A to its default conditions by pressing the keys **RCL 0 ENTER**. Set the unit to constant voltage mode at 1 kHz, and remove any part from the fixture.

2. Install the BNC adapter to the fixture. Connect the IH lead to the frequency counter.

3. Determine the new calbyte by the formula, Calibyte = (frequency − 1000.000) × 1000.

4. To adjust the clock calbyte, press the **CAL** key until "Std cAL" appears on the display. Press **ENTER** once to get into this menu structure, and then press **CAL**

until the message "df" appears on the left alphanumeric display and the current value on the right display. Enter the new value, in ppm using the entry keys. To exit the standard cal menu, press **CAL** until the "quit CAL" message appears, and then press **ENTER**.

Standard Resistor Calibration

This procedure determines the value of the internal standards for the different frequencies and ranges. The 9216A does this by measuring a precisely known resistor and recomputing the values it uses when calculating the impedance of a part. These values are the primary accuracy standard of the instrument, so the exact value of the calibration resistor, both real and imaginary parts, must be known. In addition, the 9216A and the calibration resistors must be placed in a temperature controlled room and allowed to stabilize at least 30 minutes before attempting calibrate.

The standard cal menu is entered as follows: Press the **CAL** key until "Std cAL" appears on the alphanumeric display. Press **ENTER** once to get into this menu structure. Next press **CAL** until the "rAngE" message appears on the left display. From here the desired range can be entered (using the **0** to **3** numeric keys and **ENTER**) and will appear on the right display.

After the range has been entered, pressing **CAL** will cycle through a series of menus. Pressing **ENTER** in any of these will either load that value or begin the action listed. Two different parameters must be set, "r Std" (standard resistor resistance value) and "q Std" (Q of the standard resistor). Resistance values are entered using the Ω, **k**Ω, and **M**Ω keys and Q is entered in ppm. Negative Q's denote capacitive resistors and positive Q's denote inductive ones. The different actions are "StArt cAl" (start cal), "Fctry cAL" (factory cal) and "quit cAL" (quit cal). These activities will, in order, begin calibration of the current range, recall the factory default values, or exit the cal menu.

1. Inspect the fixture contacts for dirt or waxy build up. If the fixture appears dirty, clean it. Remove any adapters or components from the fixture.

2. Perform open and short circuit calibration.

3. Plug the R0 calibration resistor into the fixture. Enter the cal menu as described above and enter range 0.

   - Press **CAL** until "r Std" (resistance standard) is displayed. Enter the resistance of R0.

   - Press **CAL** to display "q Std: (Q standard) and enter the Q of the standard in ppm.

   - Press **CAL** to display "StArt cAL" (start cal). Begin the calibration by pressing **ENTER**, making sure to keep hands and any other objects away from the fixture.

4. Repeat step 3 for the other three ranges (1, 2 and 3). When finished, exit the cal menu by pressing **CAL** until "quit cAL" is displayed and then press **ENTER**.

5. After calibration, verify that the calibration is accurate. Perform open and short circuit calibration. Insert the standards in the fixture and measure them at 1 kHz, series equivalent circuit. The R and Q readings should agree to within one least significant digit of the standard values.

6. Check the standards at different frequencies. Use the series equivalent for the two smaller resistors and the parallel equivalent for the two larger ones. R should remain relatively constant and Q should scale with frequency (i.e. Q at 10kHz is $10 \times$ Q at 1 kHz). If any of the values are too far from the nominal values, recalibrate that range.

7. Before making measurements, run open and short circuit calibration with the fixture configuration to be used.

Remote Control of the LCR Meter

Remote Programming Reference

The 9216A LCR meter may be controlled and programmed remotely using either an RS232 Any computer supporting either of these interfaces may be used with the 9216A. Both interfaces are simultaneously active and are accessed via the connectors on the rear panel. The 9216A responds to commands from either interface and returns answers to the interface from which the command came. All front and rear panel features (except power) may be controlled.

Using the Interfaces

RS232 Interface

The RS232 interface specifies how to transfer data between a data terminal equipment (DTE), such as a computer, and a data communications equipment (DCE), such as a modem. The interface includes two signal lines that can be used for half-duplex (one-way) or full duplex (simultaneous two-way) operation. Additional lines are used for controlling the flow of the data in the sense that data cannot be transferred unless the appropriate flow control line is first asserted (changed from 0 to 1).

The RS232 Interface Standard

The RS232 interface specifies a 9-pin connector as the interface in data communications networks—a 9-pin D-SUB male connector at the DTE (data terminal equipment) and a 9-pin D-SUB female connector at the DCE (data communications equipment)—with the pins designated as shown in Table 3-1.

The most common RS232 signals are the following:

- Request to Send (RTS) and Clear to Send (CTS): The RTS signal line is asserted by the computer to inform the modem that it wants to transmit data. If the modem decides that it is read to receive data, it will assert the CTS line. Typically, once the computer asserts RTS, it will wait for the modem to assert CTS before transmitting data.

- Data Terminal Ready (DTR) and Data Set Ready (DSR): This line is asserted by the computer to inform the modem that it is ready to receive data. In response, the modem will assert DSR to indicate that it is turned on.

- Data Carrier Detect (DCD): This control line is asserted by the modem, informing the computer that it has established a physical connection to another modem and is ready to transfer data.

Table 3-1 RS-232 Signals and Pin Assignments
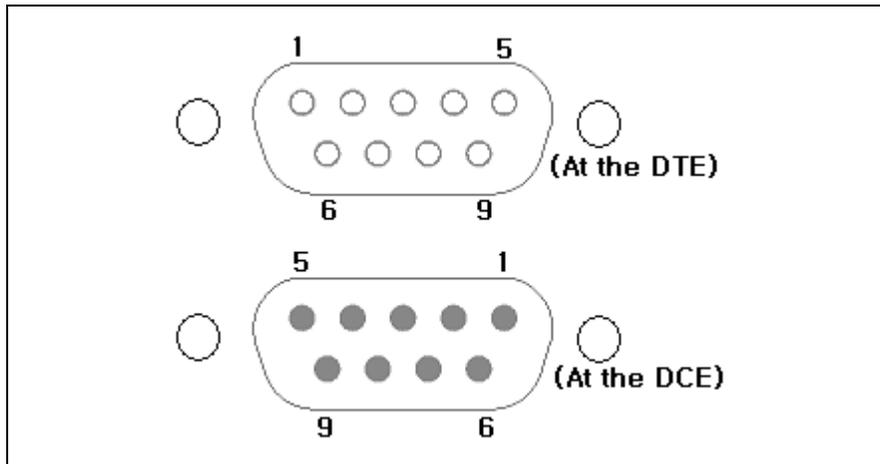
Pin	Signal	Direction	Description
1	DCD	←	Data carrier detect
2	RX	←	Receive Data
3	TX	→	Transmit data
4	DTR	→	Data terminal ready
5	GND	—	Signal ground
6	DSR	←	Data Set Ready
7	RTS	→	Request to send
8	CTS	←	Clear to Send
9	RI	←	Ring indicator

In the application of the RS232 interface to the remote control of the LCR Meter, the meter plays the role of a modem, and the flow of data is primarily measurements transmitted from the meter to the computer.

Setting Up to Use the RS-232 Interface

The 9216A is configured as a DCE (transmit on pin 3, receive on pin 2) and supports the CTS/DTR hardware handshaking discussed above. The CTS signal (pin 8) is an output of the meter indicating that the 9216A is ready, while the DTR signal (pin 4) is an input to the meter that is used to control the 9216A transmissions. If desired, the handshake pins may be ignored and a simple three-wire interface (pins 2, 3 and 5) may be used.

Before communicating with the 9216A, the RS232 characteristics must be set. As shown in Table 3-2, the RS232 interface is configured using the rear panel switches SW1-1 to SW1-7. The last three switches set the baud rate to 300, 600, 1200, 2400, 4800, or 9600 baud. Parity may be enabled or disabled, and set to even or odd, and, the number of bits in a data byte may be set to 7 or 8.

Note: the 9216A must be set to eight data bits if binary data output formats are used.

Communications with the 9216A use ASCII characters. Commands may be in either UPPER or lower case and may contain any number of embedded space characters. A command to the 9216A consists of a four-character command mnemonic, arguments if necessary, and a command termination. The terminator may be either a carriage return <CR> or line feed <LF> on RS232, or a line feed <LF> or EOI. No command processing occurs until the meter receives a command termination. Commands may require one or more parameters. Multiple parameters are separated by commas ",".

Multiple commands may be sent on one command line by separating them by semi-colons ";". The difference between sending several commands on the same line and sending several independent commands is that when a command line is parsed and executed the entire line is executed before any other device action proceeds.

There is no need to wait between commands. The 9216A has a 256-character input buffer and processes commands in the order received. If the buffer fills up, the 9216A will to hold off handshaking on RS232. If the buffer overflows the buffer will be cleared and an error reported. The output buffer may be cleared by using the Device Clear universal command.

The present value of a particular parameter may be determined by querying the 9216A for its value. A query is formed by appending a question mark "?" to the command mnemonic and omitting the desired parameter from the command. If multiple queries are sent on one command line (separated by semicolons, of course) the answers will be returned in a single response line with the individual responses separated by semicolons. The default response delimiter that the 9216A sends with any answer to a query is carriage return-line feed <CR> <LF> on RS232 and line feed plus EOI, except for binary answers, which are delimited by a line feed signal <LF> on both interfaces. All commands return integer results except as noted in individual command descriptions. Example command formats are given in Table 3-5.

Table 3-5 Examples of Command Formats

FREQ 2 <LF>	Sets the drive frequency to 100 Hz (one-parameter command)
FREQ ? <LF>	Queries the drive frequency (query of one-parameter command
BLIM 0, 3, 100 <LF>	Sets the upper limit of bin 3 to 1000 Ω (three-parameter command
BLIM ? 0, 3 <LF>	Queries the upper limit of bin 3 (query of a three-parameter command)
*IDN ? <LF>	Queries the device identification (query with no parameters)
*TRG <LF>	Triggers a measurement (command with no parameters)
FREQ 1; FREQ ? <LF>	Sets frequency to 120 Hz, then queries the frequency.

List of Commands

VARIABLES	i, j Integers x Real Number
MEASUREMENT SETUP	
$STL(?) {i}$ AVGM(?) {i} BIAS(?) {i} CIRC(?) {i} CONV(?) {i} FREQ(?) {i} MMOD(?) {i} NAVG(?) {i} PMOD(?) {i} RATE(?) {i} RNGE(?) {i} RNGH(?) {i} VOLT(?) {x}	Set (query) settling time to between $i = 2$ and $i = 99$ milliseconds. Set (query) averaging on ($i = 1$) or off ($i = 0$) Set (query) DC bias to internal ($i = 1$), external ($i = 2$), or off ($i = 0$) Set (query) equivalent circuit to series ($i = 0$) or parallel ($i = 1$) Set (query) constant voltage mode on ($i = 1$) or off ($i = 0$) Set (query) drive frequency to 100 Hz(0), 120 Hz(1), 1 kHz(2) or 100 kHz(4) Set (query) measurement mode to continuous ($i = 0$) or triggered ($i = 1$) Set (query) number of measurements to be averaged from $i = 2$ to $i = 10$ Set (query) parameter mode to Auto(0), R+Q(1), L+Q(2), C+D(3), or C+R(4) Set (query) measurement rate to Fast(0), Medium(1) or Slow(2) Set (query) meas. range to 100 kΩ(0), 6.4 kΩ (1), 400 Ω, (2) or 25 Ω (3) Set (query) range hold to enabled ($i = 1$) or disabled ($i = 0$) Set (query) drive voltage to 0.1 V $\leq x <$ 1.00 V with 0.05 V resolution.
MEASUREMENT CONTROL	
PREL(?) {x} STRT STOP *TRG	Set (query) nominal parameter value for deviation and %deviation to x (Ω,F,H) Starts a measurement. Stops the current measurement. Same as STRT.
MEASUREMENT OUTCOME	
OUTF(?) {i} XALL? XBIN? XDLT? XMAJ? XM1N? XPCT?	Set (query) the output format to verbose (0) or concise (1) ASCII, or verbose (2) or concise (3) binary. Returns major and minor parameters plus bin number. Returns bin number of current measurement. Returns deviation between major parameter and nominal value. Returns value of the major parameter. Returns value of the minor parameter. Returns percent deviation between major parameter and nominal value.

BINNING	
BCL	Clears nominal values and limits for all bins. All bins are closed.
BING(?) $\{i\}$	Set (query) binning to enabled ($i = 1$) or disabled ($i = 0$).
BLIM(?) $i\ j\ \{x\}$	Set (query) upper ($i = 0$) or lower ($i = 1$) limit of bin j (0-7) to x%.
BNOM(?) $i\ \{x\}$	Set nominal value of bin i to x
SETUP CONTROL	
*IDN?	Returns the 9216A identification string.
*OPC(?)	Set bit in Standard Event Status byte when measurement is complete.
*RCL $\{i\}$	Recall setting i.
*RST	Reset unit to default configuration.
*SAV$\{i\}$	Save current setup as setting i.
*WAI	Wait until all measurements are completed before proceeding.
STATUS	
*CLS	Clear all status registers.
*ESE(?) $\{i\}$	Set (query) the Standard Event Status Byte Enable register to value i (0-255).
*ESR? $\{i\}$	Query Standard Status byte. If i is included, only bit i is queried.
*PSC(?) $\{i\}$	Set (query) power-on status clear bit to clear ($i = 1$) or maintain ($i = 0$) status values.
*SRE(?) $\{i\}$	Set (query) the Serial Poll Enable register to value i (0-255).
*STB? $\{i\}$	Query Serial Poll status byte. If i is included, only bit i is queried.
SENA(?) $\{i\}$	Set (query) LCR Status Enable register to value i (0-255).
STAT? $\{i\}$	Query LCR Status byte. If i is included, only bit i is queried.

Status Displays and Error Messages

Adjacent to the right alphanumeric displays, the 9216A has three front panel status LEDs that provide positive indication of commands and communications to help verify operations during the development of control programs. The ACT LED flashes whenever a character is received or sent over either interface. The ERR LED flashes when an error has been detected, such as an illegal command, or parameter out of range. The REM LED is lit whenever the 9216A is in a remote state (front panel locked out).

The 9216A reports two types of errors that may occur during command execution: command errors and execution errors. Command errors are errors in the command syntax. For example, unrecognized commands, illegal queries, lack of terminators, and non-numeric arguments are examples of command errors. Execution errors are errors that occur during the execution of syntactically correct commands. For example, out of range parameters and commands that are illegal for a particular mode of operation are classified as execution errors.

The NO COMMAND bit is a bit in the serial poll register that indicates that there no commands waiting to be executed in the input queue. This bit is reset when a complete command is received in the input queue and is set when all of the commands in the queue have been executed. This bit is useful in determining when all of the commands sent to the 9216A have been executed. This is convenient because some commands,

such as taking a measurement, or auto calibration, take a long time to execute and there is no other way of determining when they are done. The NO COMMAND bit may be read while commands are being executed by doing a serial poll. There is no way to read this bit over RS232. Note that using the *STB? query to read this bit will always return the value 0 because it will always return an answer while a command is executing - the *STB? command itself.

Definitions of Status Bytes

Serial Polling

bit	name	usage
0	Ready	The 9216A is ready to perform a measurement
1	Not used	
2	Not used	
3	LCR	An unmasked bit in the LCR status register has been set.
4	ESB	An unmasked bit in the standard status byte has been set.
5	RQS / MSS	SRQ (Service Request) bit.
6	No command	There are no unexecuted commands in the input queue.

Standard Event

bit	name	usage
0	OPC	Set by the OPC command when all measurements are complete
1	Not used	
2	Query Error	Set on output queue overflow (too many responses waiting to be transmitted.)
3	Not used	
4	Execution err	Set by an out of range parameter, or non-completion of some command due a condition such as an incorrect operating mode.
5	Command err	Set by a command syntax error, or unrecognized command
6	URQ	Set by any key press
7	PON	Set by power on

Measurement

bit	name	usage
0	Math Error	Set on a floating point error.
1	A/D Error	Set when an A/D conversion fails.
2	Overload	Set when the gain stage is overloaded.
3	Under range	Set when a measurement is below the nominal range of values for the present range
4	Over range	Set when a measurement is below the nominal range of values for the present range
5	Out of Range	Set when the unit is unable to make a valid measurement on the current range.
6	Not used	
7	mem err	The stored settings were invalid on power up.

Binning

Using the LCR Meter to Sort Components

The 9216A has built in features to aid in component sorting, which is useful for production testing, incoming inspection, device matching, or tests in which multiple components of similar value must be measured. The binning feature simplifies parts sorting by eliminating the need to read the major and minor parameters and then deciding what to do with the part. The STO and RCL keys allow up to nine binning configurations to be entered and recalled. The configuration can also be programmed over one of the computer interfaces. The 9216A can sort components into as many as ten separate bins-eight pass bins, a minor parameter failure bin, and a general failure bin. Binning operations can either be performed using the keys in the BINS group of keys, over the standard RS232 computer interface

Binning Options

Three different types of binning schemes are supported by the 9216A: Pass/Fail, Overlapping, and Sequential. Pass/Fail has only two bins; good parts and all others. Overlapping (nested) bins have one nominal value and are sorted in progressively larger bins (for example, ±1%, ±2%, ±3%, etc.). Sequential bins can have different nominal values, each separated by a percentage (for example, 0.9*nom, 0.95*nom, 1.0*nom, 1.05*nom, with 5% limits). Alternatively, sequential bins can be set up with a single nominal value and asymmetrical limits (for example, −3% to −1%, −1% to 1%, to 3%). Bin limits are pairs and can be symmetrical (for example, ±2%) or asymmetrical (for example, −5% to −1%).

Binning Examples

Nested Bins

Suppose that batch of 100 Ω resistors are to be sorted according to tolerance. The bins can be set up for this purpose as follows:

Bin 0:	99 Ω < R < 101 Ω	(±1%)
Bin 1:	98 Ω < R < 99 Ω, 101 Ω < R < 102 Ω	(±2%)
Bin 2:	97 Ω < R < 98 Ω, 102 Ω < R < 103 Ω	(±3%)
Bin 3:	96 Ω < R < 97 Ω, 103 Ω < R < 104 Ω	(±4%)
Bin 8:	QDR (quality deficiency report) failure (if Q is too high)	
Bin 9:	General failure bin (parts not falling into any other bin)	

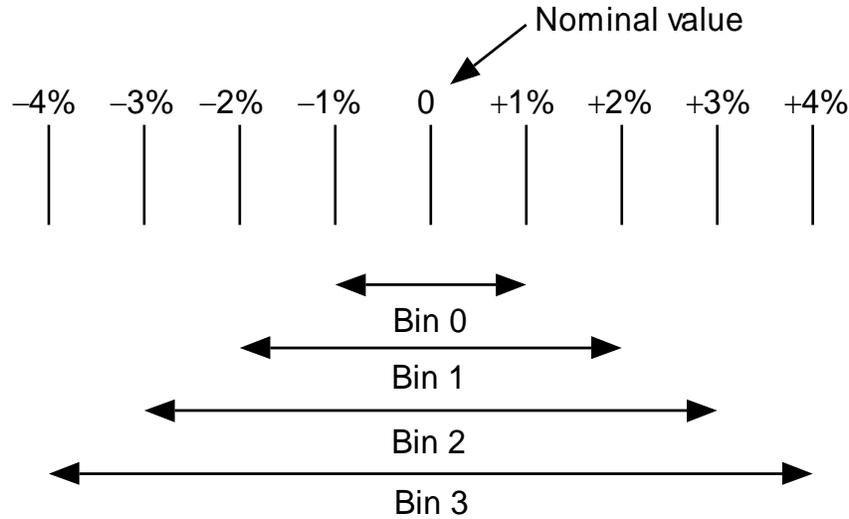Figure 4-1 illustrates\ this example of nested bins.

Figure 4-1 Example of Nested Bins

Sequential Bins With Different Nominal Values

Suppose that the batch of nominally 100 Ω resistors is to be sorted according to actual value instead of according to tolerance, as in the previous example. Then the bins can be set up to have different nominal values, with each bin width expressed as a percentage of the nominal value:

Bin 0:   98 Ω ±1%
Bin 1:   100 Ω ±1%
Bin 2:   102 Ω ±1%
Bin 3:   104 Ω ±1%
Bin 4:   106 Ω ±1%
Bin 8:   QDR failure (if Q is too high)
Bin 9:   General failure bin (parts not falling into any other bin)

Figure 4-2 illustrates this example of sequential bins with different nominal values.

Sequential Bins With a Single Nominal Value

Suppose that the batch of nominally 100 Ω resistors is to be sorted according to tolerance, as in the first example, but with the ability to distinguish between the low and high values. Then the bins can be set up to have the same nominal values, with each bin having asymmetric limits that are expressed as a percentage of the nominal value:

Bin 0:   95 Ω < R < 97 Ω   (−5%, −3%)
Bin 1:   97 Ω < R < 99 Ω   (−3%, −1%)
Bin 2:   99 Ω < R < 101 Ω   (−1%, +1%)
Bin 3:   101 Ω < R < 103 Ω   (+1%, +3%)
Bin 4:   103 Ω < R < 105 Ω   (+3%, +5%)
Bin 8:   QDR failure (if Q is too high)
Bin 9:   General failure bin (parts not falling into any other bin)

Figure 4-3 illustrates this example of sequential bins with different nominal values.
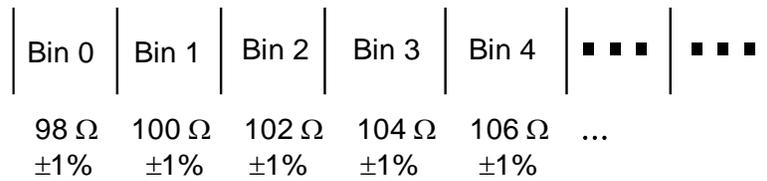
```
| Bin 0 | Bin 1 | Bin 2 | Bin 3 | Bin 4 | ■ ■ ■ | ■ ■ ■ |
```

98 Ω   100 Ω   102 Ω   104 Ω   106 Ω   ...
±1%   ±1%   ±1%   ±1%   ±1%

Figure 4-2 Example of Sequential Bins With Different Nominal Values

Nominal value

```
| Bin 0 | Bin 1 | Bin 2 | Bin 3 | Bin 4 | ■ ■ ■ | ■ ■ ■ |
```

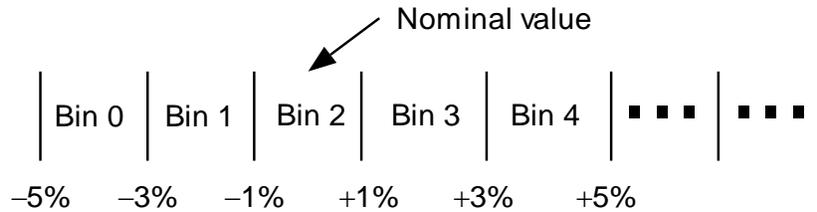−5%   −3%   −1%   +1%   +3%   +5%

Figure 4-3 Example of Sequential Bins With a Single Nominal Value

General Procedures

Binning data can be entered manually using the **BIN#**, **NOM**, and **LIM** keys, or over the RS232

A bin is defined by a bin number, with a nominal value and upper and lower limits (in per cent). If a nominal value is not entered for a bin, it will take the nominal value of the next lower bin. Bin 0 is the exception; if bin 0 does not have a nominal value and limits, all parts will fail. Parts that fall into more than one bin are assigned to the lower numbered bin. Thus, the tightest tolerance should be assigned to the lowest bin number. Any parts that fall into gaps between bins are assigned to the general failure bin (Bin 9). If only one limit of a pair is entered, the limits will be assumed to be a symmetric pair ($\pm$ X%, where "X" is the entered limit value). Unused bins should be closed (assigned 0% limits). After bin clear or **RCL 0**, all bins are closed.

Parts that would fall into both the general failure bin (Bin 9) and the QDR failure bin (Bin 8) are assigned to the QDR fail bin only. The QDR limits are maximums depending on which parameter is being measured. if a Q value is negative, (for a resistor) the absolute value should be entered, and the meter performs a comparison between the absolute value of the QDR reading and the QDR limit. There are no limits for the QDR bin, only a nominal value. To disable the QDR comparison, set the nominal value to its extreme value, as listed in Table 4-1.

Table 4-1 QDR Limits and Extreme Values

Measurement Mode	QDR Limit	Extreme Value
R + Q	Q maximum	9999.9
L + Q	Q minimum	0
C + D	D maximum	9999.9
C + R series	R maximum	99999
C + R parallel	R minimum	0

Procedures

Initial Setup

To enter binning information the unit cannot be in the AUTO parameter mode. Make certain that the unit is set to the correct measurement mode (R+Q, L+Q, C+D or C+R). Press the **BIN#** key, which will bring up the bin entry display and put the unit in the entry mode. If any previous binning information needs to be cleared, press the **BIN#** key until the "bin CLEAR" message appears.

Press the **ENTER** key to clear all bin data and display "CLEAR donE".

To enter new bin data or to edit old bin data (if it was not previously cleared), press the **BIN#** key until displays "bin *x*". Enter the desired bin number (press a numeric key, **0** through **8**, then **ENTER**). The bin number will appear on the right alphanumeric display. This is the bin for which subsequent nominal and limit values will be entered.

Nominal Values for Pass Bins 0 to 7

To enter the nominal value, press the **NOM** key. The NOM LED below the alphanumeric display will turn on. The display will show the present nominal value, or "----" if the bin was previously shown closed in the left display. If a nominal value is needed for this bin, enter the desired nominal value with the numeric keys and the unit entry keys. The new nominal value, including units, will be displayed. Note that a nominal value does not have to be entered for each bin. If a bin does not have a nominal value, it will use the one from the bin below it.

Limits for Pass Bins 0 to 7

To enter the limits, press the **LIM** key. The display will show the present upper limit value, or "----" if no limit was given previously. The +LIM LED below the display will turn on. Enter the limit value in percent using the numeric keys and the **ENTER** key. If it is necessary to enter a non-symmetrical limit pair, press the **LIM** key a second time to display the present lower limit value. The -LIM LED will turn on. Enter the lower limit in the same fashion as the upper one. For symmetric limits, enter only the upper value; the lower limit will be the negative of the upper limit. If no limits are entered for a bin, that bin will remain closed, even if it has a nominal value.

Values for Fail Bins 8 and 9

To set the QDR limit value, select Bin 8 (using the keys **BIN# 8 ENTER**) and press the **NOM** key. This action will generate a display of the present QDR limit, or "----", in the right alphanumeric display and turn on the NOM LED. Input the value with the numeric keys and press the **ENTER** key. Resistors for the C+R mode are entered in Ω (the allowable range of resistance values is only 0 to 9999 Ω, so no kΩ or MΩ key is needed). There are no limits for the QDR bin.

Bin 9, the general failure bin, cannot be set. Parts that do not fall into any other bin are assigned to this bin.

Enable Binning

To enable or disable binning, press the **BIN#** key until the "Sort Off" or "Sort On" message appears. Pressing the **ENTER** key from this display toggles binning (sorting) on and off. When binning is enabled, the BINNING LED is on, the BINS display is active, and the handler interface (if installed) is active. The handler interface is active whenever binning is enabled, whether or not the BINS display is on. See the Handler section for more information on the Handler interface.

Using a Worksheet and Reusing Setups

Before entering binning information, it is usually better to write down the desired binning setup since it is a fairly complicated procedure. See the binning worksheet below in Table 4-2.

Also, be sure to save setups that are used often. Certain setups can be edited, for example, one percent resistors using the same nominal value—a different value of resistance can be sorted by simply changing the nominal value, if the only nominal value entered was for Bin 0. For this reason, it is often better to enter sequential binning data with a single nominal value and different percentage limits, instead of with different nominal values.   It is advisable to check the nominal values and limits before making measurements, to be certain that they have not been modified. The binning setup can be viewed in the same manner as it was entered; just do not press the **ENTER** key unless a value needs to be changed.

Table 4-2 Binning Worksheet

Date:			
Nominal Value of Component:			
Tolerance to be sorted to:			
Entered by:			
Type of binning:	Pass/Fail Nested Sequential		
Bin #	Nom	+lim	-lim
0			
1			
2			
3			
4			
5			
6			
7			
8		-----	------
9	-----	-----	-----

Summary of Binning Setups

Pass/Fail Setup

Enter the nominal value and limits for Bin 0. Enter the QDR fail value for Bin 8. Make sure no other bins are open (set their limits to zero). Parts that pass fall into Bin 0; and all other parts fall into Bin 8 or Bin 9.

Nested or Overlapping Bins

Enter the nominal value and limits for Bin 0. For subsequent bins, enter only the limits, making sure the tighter tolerance parts use the lower bins. If the limits are symmetrical, only enter the upper limit. Enter the QDR limit for Bin 8. Make sure all other bins are closed. Parts that pass fall into one of the pass bins. Parts that fail the QDR test fall in Bin 8 and parts that fall into no other bin fall into Bin 9.

Sequential Bins

For sequential bins with a single nominal value, follow the same procedure as for nested bins mentioned above.

For sequential bins with multiple nominal values, enter the nominal value and limits for each open bin. If the limits are symmetrical, only enter the upper limit. Enter the QDR fail value for Bin 8. Make sure that unused bins are closed (limits set to zero) and there are no unwanted gaps between bins.

Parts that pass fall into one of the pass bins. Parts that fail the QDR test fall in Bin 8 and parts that fall into no other bin fall into Bin 9.

Troubleshooting

Hints for Solving Problems

In this chapter, suggestions are given for solving common troubleshooting problems

General Problems

Nothing Happens at Turn-on

Make sure that the power entry module on the rear panel is set for the AC line voltage for your region, that the correct fuse is installed, and that the line cord is inserted all the way into the power entry module. The selected line voltage may be seen through the clear window, just below the fuse.

When the unit is plugged in and turned "ON", the unit's program version number and model name will be briefly displayed. Then the self-tests should execute.

Reset Procedure

If the unit displays no sensible message, the "cold boot" procedure may fix the problem. To reset the instrument, turn the unit off. Then, while holding the backspace key ([←]), turn the unit "ON". This procedure initializes the RAM and recalls the factory calibration and default values. The default parameter values and instrument settings are listed in Volume 1 of this manual.

Internal Fuse Check

If the unit powers on correctly but makes unstable or wildly inaccurate readings, the internal fuse may be blown. This can also cause the unit to fail the self-test (Out Err3). To change this fuse, the top of the unit must be removed. To do this, first turn off and unplug the unit. Next remove the four screws located on the bottom at the comers of the unit. Place the unit right side up on its feet and gently slide the plastic top off the metal base.

It is necessary to slide the top gradually off the fixture and the back panel, since it fits tightly over these. When the top is removed, stand it on its left side near the unit to avoid damaging the front panel cables. The internal fuse is located near the fixture, on the right hand side of the unit. Remove the old fuse and inspect it for damage. If it is damaged, replace it with a 250V, F250mA fuse. Replace the top, taking care to align it over the fixture and rear panel. Finally, replace the four screws and verify that this fixed the unit.

External Bias Fuse Check

If the unit makes unstable or wildly inaccurate reading when an external bias is applied, the external bias fuse may be blown. To change it, power off and unplug the unit. Use a

screwdriver to remove the fuse holder and the fuse from the rear panel. It isn't always possible to see the damage to a fuse, so it can be helpful to measure it with an ohmmeter. If it is damaged, replace it with a 250V, F250mA fuse. Replace the fuse holder and fuse and verify that the unit operates correctly.

Error Messages

The following lists explain all of the error messages that the 9216A can generate. The messages are divided into operational errors (errors in using the instrument), self-test errors, and calibration errors. The messages are listed alphabetically.

Operational Errors

These error messages may appear during normal front-panel operation and generally are warnings for incorrect operation.

Message	Meaning
Bias For C	The 9216A DC bias function may only be used for capacitance measurements. Set the parameter mode to either C+D or C+R to use DC bias.
Cony Error	An A/D conversion that is either too short or too long can produce this error. Continued errors may indicate a hardware problem.
Float Error	An error in a floating point math routine occurred.
F-R Error	Frequency-Range incompatibility. The 100kΩ range may not be used with the 100 kHz drive frequency.
Over Load	The 9216A input is overloaded. This can happen transiently as parts are changed or if a part with too small an impedance is measured on the constant drive voltage setting.
Over Range	The impedance is beyond the 9216A measurement ability on the current range. If range hold is active, change to a higher range.
Range Error	Parameter in command is out of allowed range for that command.
Rcl Error	Non-volatile RAM has been corrupted. User calibrations and settings may be lost. If this error occurs frequently, check the battery.
Syn Error	The command syntax is invalid. See the programming section for correct command syntax.

Self-test Errors

These errors may occur during the 9216A self-test. In general, these messages indicate 9216A hardware problems. If the errors occur repeatedly, the unit may have an electrical problem. The messages are listed alphabetically. Also listed is the status value returned by the *TST? command.

Message	Status	Meaning
AD Error	6	The A/D converter failed its test. The test measures 0 V and ±2 VDC.

Bias Error	7	The 9216A internal DC bias source failed its test.
Cal Error	4	The RAM calibration data has become corrupt. The factory values will be reloaded from ROM. This message is not a problem unless it occurs frequently, which could indicate a problem with the battery backup circuits.
Code Err XX	2	The 9216A ROM has a checksum error. XX is the checksum value.
CPU Error	1	The 9216A has detected a problem in its CPU.
Data Error	3	CPU RAM failed a read/write test.
Det Error	6	The square wave multiplier failed its DC rejection test.
Drv Error i	7	The output drive circuitry failed its test. i is an error code indicating the failure point.

i	error
0	100 Hz amplitude failure
1	120 Hz amplitude failure
2	1 kHz amplitude failure
3	10 kHz amplitude failure
4	100 kHz amplitude failure
5	0.25 V amplitude attenuator failure
6	0.1 V attenuator failure

Freq Error i	5	The frequency clock generator failed its test. i is an error code indicating the failure point.

i	error
0	100 Hz failure
1	120 Hz failure
2	1 kHz failure
3	10 kHz failure
4	100 kHz failure

Gain Error	8	The instrumentation amplifier failed its gain test. i is an error code indicating the failure point.

i	error
0	the $\times 2$ gain failed
1	the $\times 4$ gain failed
2	the $\times 8$ gain failed
3	the $\times 20$ gain failed

Out Error	9	The source impedance selection circuitry failed its test. This error can occur if a part is in the fixture during the test. i is an error code indicating the failure point.

i	error

0	the 100 kΩ range failed	
1	the 6.4 kΩ range failed	
2	the 400 Ω range failed	
3	the 25 Ω range failed	

Calibration Errors

These error messages can be generated by the open, short, and standard calibration procedures. If the 9216A fails calibration, try running the procedure again. Repeated failure can indicate a hardware problem. The parameter limits are fixed and are set so that all units should easily calibrate within those limits. The messages are listed alphabetically, also listed is the status value returned by the *CAL? command.

Message	Status	Meaning
Cal Error	1	The measurement is bad due to overload, A/D error, or math error. This error can occur during short circuit, open circuit, and standard resistor calibration.
Cal Error	2	The impedance measured in the short circuit calibration was too large. The 9216A expects the impedance to be < 50 Ω, and the resistance to be less than 10 Ω. Make sure that the fixture has a good low impedance short in it during short circuit calibration.
Cal Error	3	The impedance measured in the open circuit calibration is too small. The 9216A expects the impedance to be > 10 kΩ at all frequencies and ranges. Make sure that there are no parts in the fixture during open circuit calibration. Also, keep hands and other objects away from the fixture during calibration.
Cal Error	4	Standard resistor calibration error. The 9216A expects that standard resistor calibration will not change the value of the internal resistors by more than $\pm$ 3%. Check to be sure that the correct calibration resistor for the range being calibrated is in the fixture.

RS-232 Problems

Make sure that the RS-232 baud rate, parity, and word size are set to match that expected by the controlling computer. The default settings are 1200 baud, no parity, 8 bit data. The 9216A always sends two stop bits, and will correctly receive data sent with either one or two stop bits.

When connecting to a PC, use a standard PC serial cable, not a "null-modem" cable. The 9216A is a DCE (Data Communications Equipment) device, and so should be connected with a "staight" cable to a DTE device (Data Terminal Equipment). The "minimum" cable will pass pins 2, 3 and 7. For hardware handshaking, pins 5 and 20 (CTS and DTR) should be passed. Occasionally, pin 6 and 8 (DSR and CD) will be needed; these lines are always asserted by the 9216A.

9216A TEST PERFORMANCE RECORD

Serial #:	Date:
Tested by:	
Equipment used:	

FUNCTIONAL TESTS

		Pass	Fail
Front Panel Test			
Self Test			
Drive Voltage			
Resistance Test	24.9 Ω		
	400 Ω		
	6.4 kΩ		
	100 kΩ		
Capacitance Test			

FREQUENCY ACCURACY

Test Frequency	Minimum	Actual	Maximum
100 Hz	99.99 Hz		100.01 Hz
120 Hz	119.99 Hz		120.01 Hz
1 kHz	999.90 Hz		1000.1 Hz
10 kHz	9999.0 Hz		10001.0 Hz
100 kHz	99990.0 Hz		100010.0 Hz

AMPLITUDE ACCURACY

Amplitude	Frequency	Minimum	Actual	Maximum
1.0 Vrms	1 kHz	0.98 Vrms		1.02 Vrms
1.0 Vrms	100 Hz	0.98 Vrms		1.02 Vrms
1.0 Vrms	120 Hz	0.98 Vrms		1.02 Vrms
1.0 Vrms	10 kHz	0.98 Vrms		1.02 Vrms
1.0 Vrms	100 kHz	0.98 Vrms		1.02 Vrms
0.25 Vrms	1 kHz	0.245 Vrms		0.255 Vrms
0.1 Vrms	1 kHz	0.098 Vrms		0.102 Vrms
Internal Bias		1.96 VDC		2.04 VDC

RESISTANCE ACCURACY					
Resistance	Range	Conditions	Value	Pass	Fail
10.0	3	1 kHz, series			
25.0	3	1 kHz, series			
25.0	3	10 kHz, series			
25.0	3	100 kHz, series			
100.0	3	1 kHz, series			
100.0	2	1 kHz, series			
400.0	2	1 kHz, series			
400.0	2	10 kHz, series			
400.0	2	100 kHz, series			
1.6000 k	2	1 kHz, parallel			
1.6000 k	1	1 kHz, parallel			
6.4000 k	1	1 kHz, parallel			
6.4000 k	1	10 kHz, parallel			
6.4000 k	1	100 kHz, parallel			
25.0000 k	1	1 kHz, parallel			
25.0000 k	0	1 kHz, parallel			
100.0000 k	0	1 kHz, parallel			
100.0000 k	0	10 kHz, parallel*			
400.0000 k	0	1 kHz, parallel			
* If the Q value is greater than 0.1, the allowed tolerance must be multiplied by $(1 + Q)$.					

CAPACITANCE ACCURACY					
Capacitance	Frequency	Range	Value	Pass	Fail
1.0 nF	1 kHz	0			
1.0 nF	10 kHz	1			
1.0 nF	100 kHz	2			
10.0 nF	100 Hz	0			
10.0 nF	1 kHz	1			
10.0 nF	10 kHz	2			
10.0 nF	100 kHz	2			
100 nF	100 Hz	1			
100 nF	1 kHz	2			
100 nF	10 kHz	2			
100 nF	100 kHz	3			
1.000 μF	100 Hz	2			
1.000 μF	1 kHz	2			
1.000 μF	10 kHz	3			
10.000 μF	100 Hz	2			
10.000 μF	1 kHz	3			