KEITHLEY

Model 3321 LCZ Meter
Operator's Manual

WARRANTY

Keithley Instruments, Inc. warrants this product to be free from defects in material and workmanship for a period of 1 year from date of shipment.

Keithley Instruments, Inc. warrants the following items for 90 days from the date of shipment: probes, cables, rechargeable batteries, diskettes, and documentation.

During the warranty period, we will, at our option, either repair or replace any product that proves to be defective.

To exercise this warranty, write or call your local Keithley representative, or contact Keithley headquarters in Cleveland, Ohio. You will be given prompt assistance and return instructions. Send the product, transportation prepaid, to the indicated service facility. Repairs will be made and the product returned, transportation prepaid. Repaired or replaced products are warranted for the balance of the original warranty period, or at least 90 days.

LIMITATION OF WARRANTY

This warranty does not apply to defects resulting from product modification without Keithley's express written consent, or misuse of any product or part. This warranty also does not apply to fuses, software, non-rechargeable batteries, damage from battery leakage, or problems arising from normal wear or failure to follow instructions.

THIS WARRANTY IS IN LIEU OF ALL OTHER WARRANTIES, EXPRESSED OR IMPLIED, INCLUDING ANY IMPLIED WARRANTY OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR USE. THE REMEDIES PROVIDED HEREIN ARE BUYER'S SOLE AND EXCLUSIVE REMEDIES.

NEITHER KEITHLEY INSTRUMENTS, INC. NOR ANY OF ITS EMPLOYEES SHALL BE LIABLE FOR ANY DIRECT, INDIRECT, SPECIAL, INCIDENTAL OR CONSEQUENTIAL DAMAGES ARISING OUT OF THE USE OF ITS INSTRUMENTS AND SOFTWARE EVEN IF KEITHLEY INSTRUMENTS, INC., HAS BEEN ADVISED IN ADVANCE OF THE POSSIBILITY OF SUCH DAMAGES. SUCH EXCLUDED DAMAGES SHALL INCLUDE, BUT ARE NOT LIMITED TO: COSTS OF REMOVAL AND INSTALLATION, LOSSES SUSTAINED AS THE RESULT OF INJURY TO ANY PERSON, OR DAMAGE TO PROPERTY.

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Manual Print History

The print history shown below lists the printing dates of all Revisions and Addenda created for this manual. The Revision Level letter increases alphabetically as the manual undergoes subsequent updates. Addenda, which are released between Revisions, contain important change information that the user should incorporate immediately into the manual. Addenda are numbered sequentially. When a new Revision is created, all Addenda associated with the previous Revision of the manual are incorporated into the new Revision of the manual. Each new Revision includes a revised copy of this print history page.

Revision A (Document Number 3321-900-01) .... March 1991
Addendum A (Document Number 3321-900-02).. May 1993
Addendum A (Document Number 3321-900-03)....................................... December 1995
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KEITHLEY Safety Precautions

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

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

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

The types of product users are:

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

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

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

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

Keithley products are designed for use with electrical signals that are rated Installation Category I and Installation Category II, as described in the International Electrotechnical Commission (IEC) Standard IEC 60664. Most measurement, control, and data I/O signals are Installation Category I and must not be directly connected to mains voltage or to voltage sources with high transient over-voltages. Installation Category II connections require protection for high transient over-voltages often associated with local AC mains connections. Assume all measurement, control, and data I/O connections are for connection to Category I sources unless otherwise marked or described in the Manual.

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

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

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

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

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

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

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

The instrument and accessories must be used in accordance with its specifications and operating instructions or the safety of the equipment may be impaired.

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

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

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

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

2/02

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

The ⚠ symbol on an instrument indicates that the user should refer to the operating instructions located in the manual.

The ⚡ symbol on an instrument shows that it can source or measure 1000 volts or more, including the combined effect of normal and common mode voltages. Use standard safety precautions to avoid personal contact with these voltages.

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

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

Instrumentation and accessories shall not be connected to humans.

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

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

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

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Safety Precautions

The following safety precautions should be observed before using the Model 3321 LCZ Meter and any associated instruments.

This instrument is intended for use by qualified personnel who recognize shock hazards and are familiar with the safety precautions required to avoid possible injury. Read over this manual carefully before using the instrument.

Exercise extreme caution when a shock hazard is present at the test circuit. The American National Standards Institute (ANSI) states that a shock hazard exists when voltage levels greater than 30V rms or 42.4V peak are present. **A good safety practice is to expect that hazardous voltage is present in any unknown circuit before measuring.**

Inspect the connecting cables and test leads for possible wear, cracks, or breaks before each use.

For maximum safety, do not touch the test cables or any instruments while power is applied to the circuit under test. Turn off the power and discharge any capacitors before connecting or disconnecting cables from the instrument.

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

Instrumentation and accessories should not be connected to humans.

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Table of Contents

4   GPIB Interface

List of Illustrations

List of Tables

3   Operation

4   GPIB Interface

SECTION 1
General Information

1.1 INTRODUCTION

This section contains general information about the Model 3321.

1.2 PRODUCT DESCRIPTION

The Model 3321 LCZ Meter is a high accuracy (0.1% basic accuracy), full function LCZ meter. It includes an IEEE-488 interface to control operation from a computer.

The Model 3321 drives a device under test (DUT) with a known voltage sine wave signal. Impedance is derived by precisely measuring the resultant current that flows through the DUT.

1.2.1 Condensed Specifications

The following condensed specifications help summarize the capabilities of the Model 3321. Complete, detailed instrument specifications are located in Appendix A.

Measurement Functions: L, C, |Z|, Q, D, ESR, G, θ. These functions can be automatically selected.

Basic Accuracy: 0.1% (at 1kHz)

Measurement Ranges (Display):

|Z|	$0.1m\Omega$ to $19.999M\Omega$
C	0.001pF to 199.99mF
L	0.1nH to 19.999kH
Q, D	0.0001 to 19999
θ	-180.00° to +179.99°

Measurement Frequency: 120Hz, 1kHz, 10kHz or 100kHz.

Measurement Signal Level: 1V rms, 50mV rms

Equivalent Circuit: Series, parallel and automatic

DC Bias:

DC Bias: Internal: 2V
External: 0 to ±35V

Zero Correction: Automatic (OPEN, SHORT).

Measuring Time: FAST (64ms), MED (150ms), SLOW (480ms).

1.2.2 Features

- High Accuracy — Basic accuracy of 0.1% with display resolution of 0.0001 at 4-1/2 digits.
- Wide Frequency Range — Four frequency selections in the range from 120Hz to 100kHz.
- Two Measurement Signal Levels — Selectable sine wave signals of 50mV rms or 1V rms can be applied

to the DUT. Also, the signal can be biased by selecting the 2V internal DC bias or by externally applying a DC bias up to ±35V.

- Variety of Measurement Functions — In addition to the conventional functions including L, C, D and Q, you can also display the equivalent series resistance (ESR), parallel conductance (G), and polar coordinates expression ($|Z| - \theta$).
- Automatic Function and Range Selection — In addition to the conventional autorange feature, function and the equivalent circuits can also be automatically selected.
- Built-in DC Bias Power Supply — The built-in 2V DC bias power supply is used to measure the capacitance of polarized devices such as electrolytic capacitors and semiconductors.
- IEEE-488 Interface — Allows the instrument to be controlled by a computer.

1.3 WARRANTY INFORMATION

Warranty information is located on the inside front cover of this instruction manual. Should your Model 3321 require warranty service, contact the Keithley representative or authorized repair facility in your area for further information. When returning the instrument for repair, be sure to fill out and include the service form at the back of this manual in order to provide the repair facility with the necessary information.

1.4 MANUAL ADDENDA

Any improvements or changes concerning the instrument or manual will be explained in an addendum included with the manual. Be sure to note these changes and incorporate them into the manual.

1.5 SAFETY SYMBOLS and TERMS

The following symbols and terms may be found on an instrument or used in this manual.

The symbol ⚠ on an instrument indicates that the user should refer to the operating instructions located in the instruction manual.

The **WARNING** heading used in this manual explains dangers that might result in personal injury or death. Always read the associated information very carefully before performing the indicated procedure.

The **CAUTION** heading used in this manual explains hazards that could damage the scanner card. Such damage may invalidate the warranty.

1.6 INSPECTION

The Model 3321 was carefully inspected, both electrically and mechanically, before shipment. After unpacking all items from the shipping carton, check for any obvious signs of physical damage that may have occurred during transit.

Report any damage to the shipping agent immediately. Save the original packing carton for possible future reshipment. The following items are included with every Model 3321 order:

- Model 3321 LCZ Meter
- Model 3321 Instruction Manual
- Additional Accessories as ordered.

If an additional instruction manual is required, order the manual package, Keithley part number 3321-901-00. The manual package includes an instruction manual and any pertinent addenda.

1.7 OPTIONAL ACCESSORIES

The following accessories are available from Keithley for use with the Model 3321:

1. Model 3323 Direct Test Fixture. Allows leaded parts to be directly inserted into this test fixture.
2. Model 3324 4-Terminal Alligator Clip Test Lead. Designed for four-terminal components, in which the current-supplying terminals and voltage-measurement terminals are separated.
3. Model 3325 Kelvin Clip Test Lead. Uses two clips for four-terminal connections. Used to measure large or irregularly-shaped components which cannot be inserted into the Model 3323 test fixture.
4. Model 3326 Chip Component Test Leads. This tweezer-type test lead set permits easy connection to surface mounted chip components.

The cables for all the above test leads are shielded to minimize stray capacitance.

1.8 SPECIFICATIONS

Model 3321 specifications may be found in Appendix A of this manual.

SECTION 2
Getting Started

2.1 INTRODUCTION

This brief section will guide the user through front panel operation. This section is intended to acquaint the user with basic operation. Detailed operation is covered in Section 3.

> **NOTE**
> Front and rear panel views of the instrument (which may be helpful in locating controls, annunciators or connectors) are provided by Figures 3-1 and 3-2. These drawings are located in Section 3.

2.2 POWER-UP

The instrument is designed to operate from 90-132V or 198-250V line voltage ranges at 48 to 62Hz. Perform the following steps to connect the instrument to line power:

1. Check the rear panel LINE SUPPLY selector switch and make sure the setting agrees with the line voltage available in your area. If the switch setting needs to be changed, perform the procedures in paragraph 3.3. Keep in mind that changing the line voltage setting requires a fuse change.

> **CAUTION**
> To prevent damage to the instrument that may not be covered by the warranty, make sure the rear panel LINE SUPPLY switch is set to the correct line voltage setting.

2. The power cord is supplied with the instrument. Connect the female end of the power cord to AC receptacle on the rear panel, and connect the other end to a grounded AC outlet.

> **WARNING**
> The instrument is equipped with a 3-wire power cord that contains a separate ground wire and is designed to be used with grounded outlets. When proper connections are made, instrument chassis is connected to the power line ground. If the AC outlet is not grounded, the rear panel safety earth ground terminal must be connected to a known safety earth ground using #18 AWG (or larger) wire.

3. Turn on the instrument by depressing the POWER switch in to the ON position. The instrument will perform its power up sequence (see paragraph 3.3.4). After successfully completing the power up tests, the instrument will assume default conditions

that configure the instrument for immediate measurements.

NOTE
The instrument is ready for immediate use. However, to achieve rated accuracy, the instrument must be allowed to warm up for at least 1/2 hour.

2.3 BASIC MEASUREMENTS

A measurement is performed by applying a known rms signal level at a specific frequency to the DUT and then calculating and displaying the results.

NOTE
The following procedure assumes that the instrument is configured to its power-up default conditions. If you are not sure about the setup configuration, simply turn the power off and then on again.

NOTE
The following procedure uses the Model 3323 Test Fixture to connect DUT to the instrument (see Figure 2-1). If using test cables, make sure 4-terminal connections are used as explained in paragraph 3.4.

Perform the following steps to make basic L, C or Z measurements:

1. Connect the Model 3323 Test fixture to the instrument. This test fixture allows easy DUT connection to the instrument, and provides accurate measurements by eliminating the stray capacitance of test cables.
2. Note that automatic function is selected as denoted by the AUTO annunciator to the left of the yellow AUTO key. In AUTO function, the instrument will automatically select the appropriate function (L, C or Z) for the device connected to it.

3. Install the DUT (device under test) into the test fixture. The appropriate function for the DUT will be selected and the measurements will be displayed as follows:

NOTE
The exponent symbol annunciators (p, n, u, m, k and M) for the readings are located to the right of each display.

A. For inductors (L), the [A] DISPLAY provides the reading in henries (H), and the [B] DISPLAY provides the quality factor (Q).
B. For capacitors (C), the [A] DISPLAY provides the reading in farads (F), and the [B] DISPLAY provides the dissipation factor (D).
C. For resistors, the [A] DISPLAY provides the Z reading in ohms (Ω), and the [B] DISPLAY provides the phase shift (θ) of approximately 0°.

The above procedure requires no instrument settings by the operator. The test is completely automated by simply using the power-up default setup configuration to test DUTs. Of course this setup configuration is not desirable for all measurements and thus, requires the operator to modify appropriate operating parameters, such as the test signal level and frequency.

The test signal level and frequency can be modified as follows:

Signal Level — On power up, the test signal level is set to 1V rms as denoted by the front panel 1V LEVEL annunciator. To select the alternate signal leveL (50mV rms), simply press the 50mV LEVEL key on the front panel.

Signal Frequency — On power up, the test frequency is set to 1kHz as denoted by a FREQ annunciator. To select one of the other frequencies (10kHz, 100kHz or 120Hz), press and release the appropriate FREQ key.
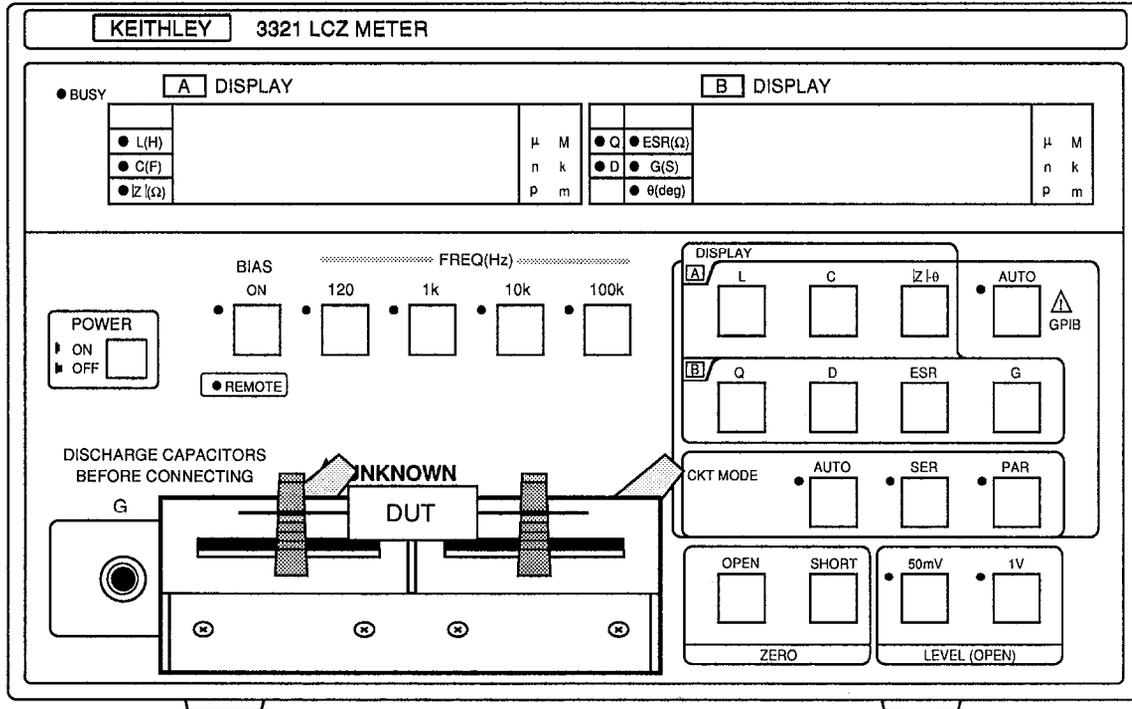
Figure 2-1.   Model 3321 Test Fixture Connection

SECTION 3
Operation

3.1 INTRODUCTION

This section covers front panel operation. For operation over the GPIB bus, see Section 4.

3.2 FRONT AND REAR PANEL FAMILIARIZATION

The following information describes the controls, annun-ciators and connectors on the front and rear panels of the instrument.

The front and rear panels of the instrument are shown in Figure 3-1 and Figure 3-2.

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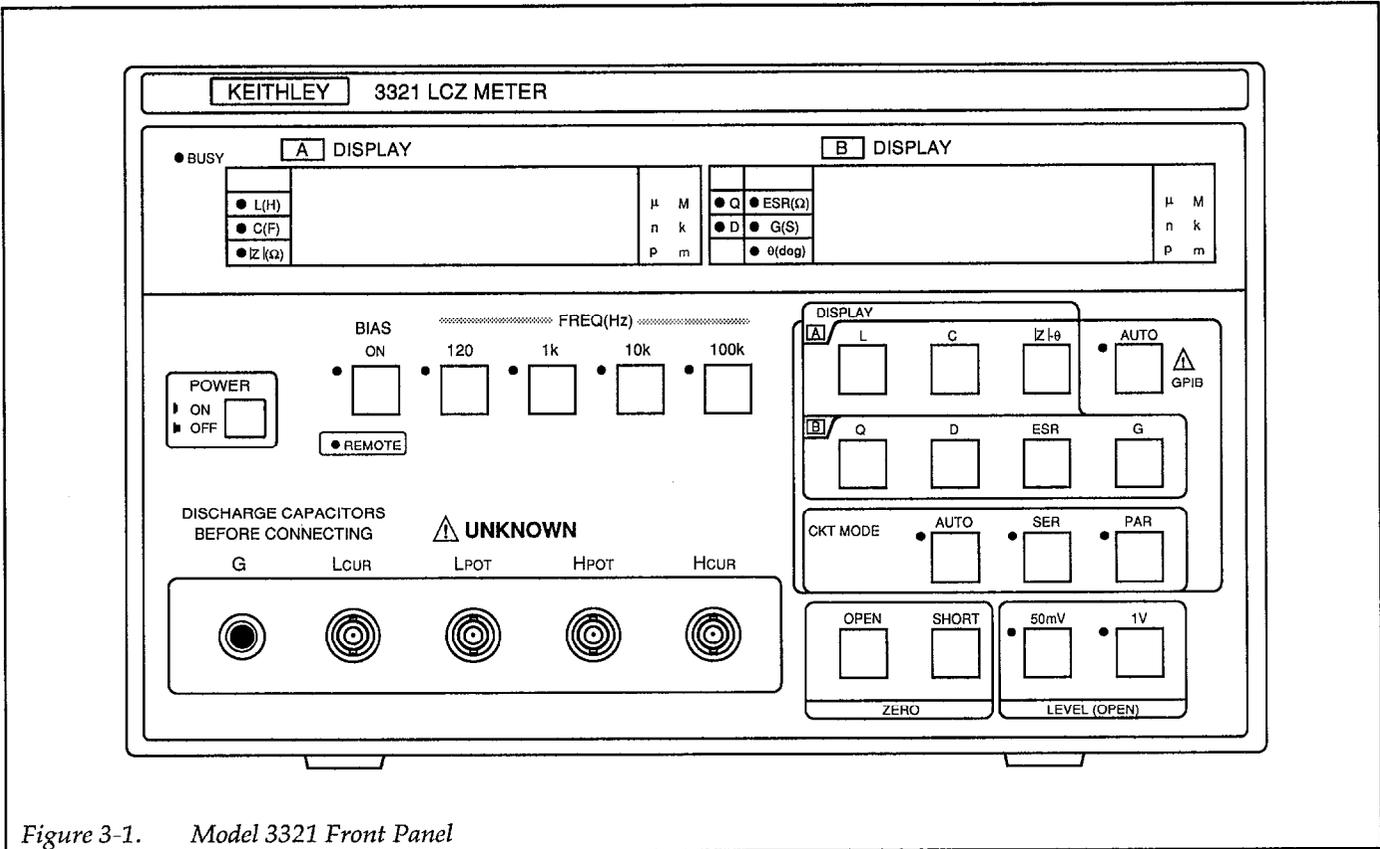
Figure 3-1.   Model 3321 Front Panel

3.2.1   Front Panel

A **DISPLAY/** **B** **DISPLAY** 4-1/2 Digit Displays —
Primarily used to display the measurement for the se-
lected function and function parameter. The selected
function and function parameter are indicated by annun-
ciators to the left of the two displays. The annunciators to
the right of the displays indicate the magnitude of the
reading using exponent symbols (i.e. k, u, M, etc.).

A DISPLAY Function Indicators — These annuncia-
tors denote the selected function:

L   Self inductance (H)
C   Electrostatic capacity (F)
|Z| Resistance or impedance (Ω)

Note: The values of L, C and Z change according to
whether the equivalent circuit is in series or parallel
mode.

B DISPLAY Function Parameter Indicators — These
annunciators denote the selected function parameter:

Q   Quality factor
D   Dissipation factor (D = 1/Q)
ESR   Equivalent series resistance
G   Parallel conductance
θ Phase angle of impedance

Exponent annunciators (both displays) — The following
exponent annunciators are used to denote the magnitude
of the reading:

M =   mega = 10^6
k =   kilo = 10^3
m =   milli = 10^{-3}
n =   nano = 10^{-9}
μ =   micro = 10^{-6}
p =   pico = 10^{-12}

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Front Panel Indicators:

BUSY — This indicator lights when a measurement is being made. This indicator is off while in OPEN or SHORT.

REMOTE — This indicator is on when the GPIB interface is in the remote state. While in remote, the front panel controls are disabled.

FREQ (Hz) — Denotes the frequency (120Hz, 1kHz, 10kHz or 100kHz) that was selected using the FREQ keys.

CKT MODE — Denotes the equivalent circuit that was selected using the CKT MODE keys.

AUTO   Automatic selection mode; SER or PAR automatically selected.
SER   Series equivalent circuit.
PAR   Parallel equivalent circuit.

Note: CKT selections only affect readings on [A] DISPLAY.

LEVEL (OPEN) — Denotes the level of the measurement signal that was selected using the LEVEL keys.

50m   50mV rms signal level. Basic accuracy is lowered using this level.
1   Standard 1V rms signal level.

The indicated signal level is the voltage applied to the output while under a "no load" condition. The output impedance of the signal source is approximately 100Ω. When connecting the signal to a device that has an impedance of less than 1kΩ, loading will cause the signal level to drop below the indicated voltage level.

Front Panel Controls:

POWER ON-OFF

The "in" position turns power on and the "out" position turns power off. After turning power off, wait at least three seconds before turning it back on.

BIAS ON Key

Pressing this key enables the internal 2V bias power supply. Pressing the key a second time disables the bias supply. With the rear panel BIAS INT/EXT switch set to the EXT position, the BIAS ON key will instead control the externally applied bias supply.

NOTE
The bias supply can only be enabled with the C (capacitance) function selected and AUTO function disabled.

FREQ (Hz) Keys:

These keys are used to select the frequency of the measurement signal. The enabled annunciator denotes which frequency is selected.

120 — Pressing this key sets the measurement frequency to 120Hz.

1k — Pressing this key sets the measurement frequency to 1kHz.

10k — Pressing this key sets the measurement frequency to 10kHz.

100k — Pressing this key sets the measurement frequency to 100kHz.

[A] DISPLAY Keys:

The following keys are used to select the measurement function. The reading for the selected function is shown on the [A] DISPLAY. The default function parameter (Q, D or θ) for the selected function is automatically selected and shown on the [B] DISPLAY.

L — Pressing this key selects the inductance (L) function and displays the reading in henries (H). The selected default function parameter is Q.

C — Pressing this key selects the capacitance (C) function and displays the reading in farads (F). The selected default function parameter is D.

|Z|– θ — Pressing this key selects the impedance (Z) function and displays the reading in ohms (Ω). Note that this function is used to measure resistance. The phase angle (θ) for the impedance measurement is shown on the [B] DISPLAY.

[B] DISPLAY Keys:

The following keys are used to select an alternate function parameter (Q, D, ESR or G) for the L or C function. The reading for the function parameter is shown on the [B] DISPLAY.

The function parameter keys are not operational with the AUTO function feature enabled. Pressing one of these keys with AUTO enabled results in "Err 13".

Q — Pressing this key displays the quality factor (Q) for the L or C measurement.

D — Pressing this key displays the dissipation factor (D) for the L or C measurement.

ESR — Pressing this key displays the equivalent series resistance (ESR) for the L or C measurement.

G — Pressing this key displays the conductance (G) for the L or C measurement.

AUTO/GPIB Key:

This dual function key is used to select the AUTO function feature, or to check and/or change the GPIB address/delimiter.

AUTO — Pressing and immediately releasing this key enables the AUTO function feature. With AUTO function enabled, the instrument determines the type of device connected to its input and automatically selects the appropriate measurement function. AUTO function is disabled by pressing one of the function selection keys (L, C or $|Z|-\theta$).

GPIB — By pressing and holding in this key for approximately three seconds, the current GPIB address and delimiter will be displayed on the [B] DISPLAY.

The address and delimiter values are separated by the decimal point. Valid address values are 0 to 30. Delimiter values can be 0 (for <CR><LF>) or 1 (for <CR> only). Use the $|Z|-\theta$ key and ESR key to change the address value, and use the G key to toggle the delimiter.

The displayed address and delimiter values can be entered by again pressing the GPIB key. The instrument will return to the normal measurement display state.

CKT MODE Keys:

The following keys are used to select the equivalent circuit:

AUTO — With AUTO CKT MODE enabled, the equivalent circuit (SER or PAR) will automatically be selected (enabled).

The AUTO CKT MODE is automatically enabled if the AUTO function feature is enabled. With AUTO function enabled, AUTO CKT MODE cannot be disabled. With AUTO function disabled, AUTO CKT MODE can be disabled by pressing the SER or PAR key.

SER — This key is only operational if AUTO function is disabled. When operational, pressing this key will disable AUTO CKT MODE (if enabled), and select (enable) the series (SER) circuit mode.

PAR — This key is only operational if AUTO function is disabled. When operational, pressing this key will disable AUTO CKT MODE (if enabled), and select (enable) the parallel (PAR) circuit mode.

ZERO Keys:

Zero correction measures the residual impedance and stray admittance, and then automatically corrects the displayed reading caused by these errors. The following keys are used to perform zero correction:

OPEN — To perform zero correction, open the input and press the OPEN key.

SHORT — To perform zero correction, short the input and press the SHORT key.

LEVEL (OPEN) Keys:

These keys are used to select the rms voltage level of the measurement signal.

50mV — Press this key to set the level of the measurement signal to 50mV rms.

1V — Press this key to set the level of the measurement signal to 1V rms.

Measurement Terminals:

UNKNOWN — The following front panel connectors are used to connect the DUT to the instrument:

G — Ground terminal that is connected to the chassis of the instrument. Used for shielding.

L CUR — Current detection terminal
L POT — Voltage detection terminal (Low)
H POT — Voltage detection terminal (High)
H CUR — Drive signal output terminal.

The bias voltage and the drive signal can be monitored on these terminals.
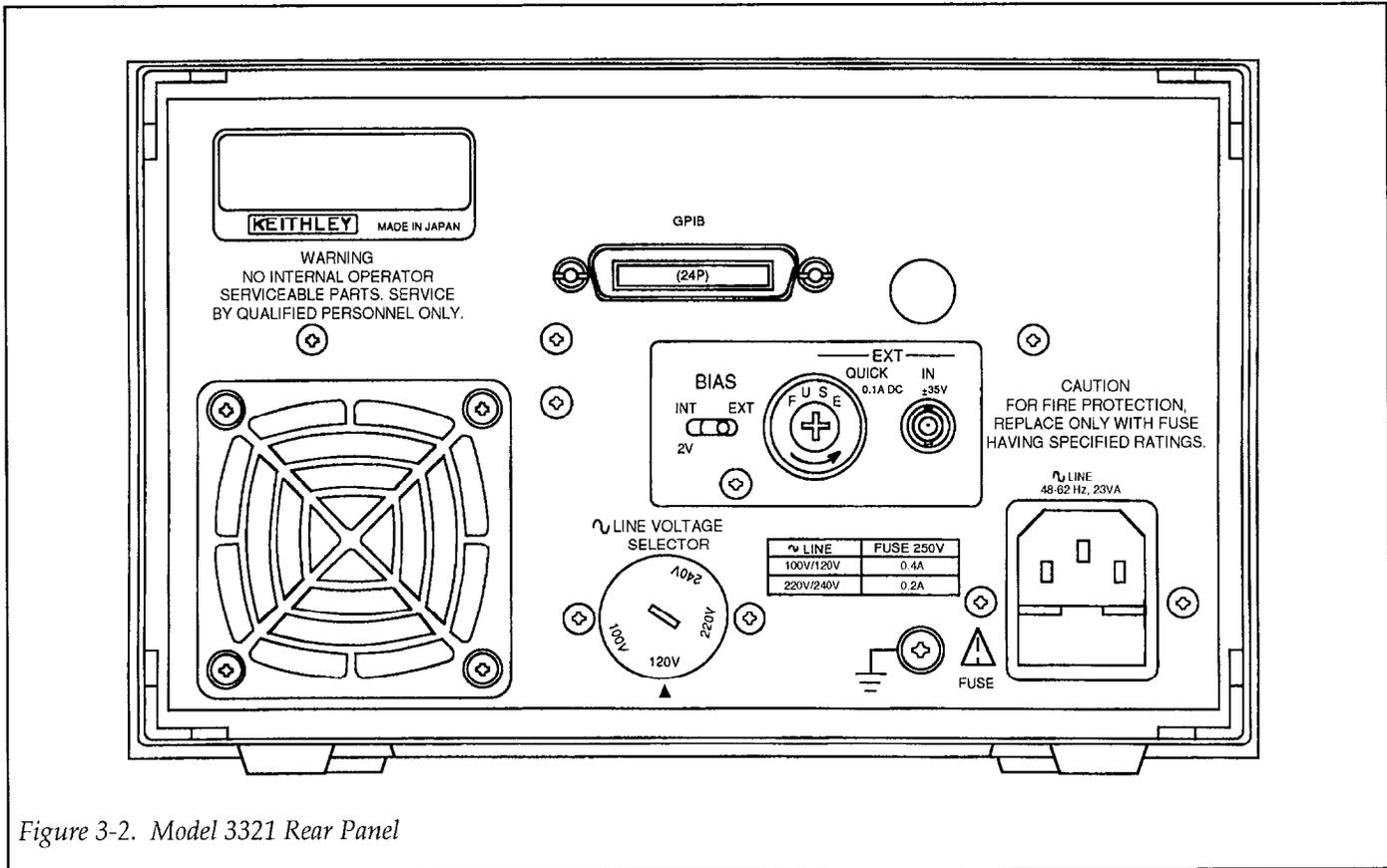
Figure 3-2. Model 3321 Rear Panel

3.2.2   Rear Panel

GPIB — This connector is used to connect the GPIB interface of the instrument to GPIB interface of a computer. See Section 4 for details.

BIAS — The following switch, fuse and input connector pertain to using an external bias supply:

INT/EXT Switch — This toggle switch is used to switch between the built-in (INT) bias power supply (2V) and the externally (EXT) applied bias supply (up to 35V).

Fuse — Maintenance fuse for the external power supply (0.lA quick acting type).

IN Connector — BNC connector used to connect the external bias supply to the instrument power input connector. Use a 0 to ±35V supply with low ripple and noise.

CAUTION
0 to ±35V is the maximum voltage that can be applied to the BIAS IN connector. Voltages outside this range may blow the fuse and cause damage to the instrument.

Ventilation Fan — The fan is used to keep the inside of the instrument free from damaging heat build-up. The fan pulls cool air into the instrument and expels warm air out of the vents in the top cover. For proper ventilation:

1. Maintain at least 10cm between the rear panel and a wall.

2. Do not block the air vents in the top cover.

3. Clean the air filter periodically to prevent clogging. Figure 3-3 shows how to remove the filter for cleaning.

WARNING
Be sure to turn off the power and remove the power cord before removing or installing the filter.

Figure 3-3.   Cleaning Air Filter
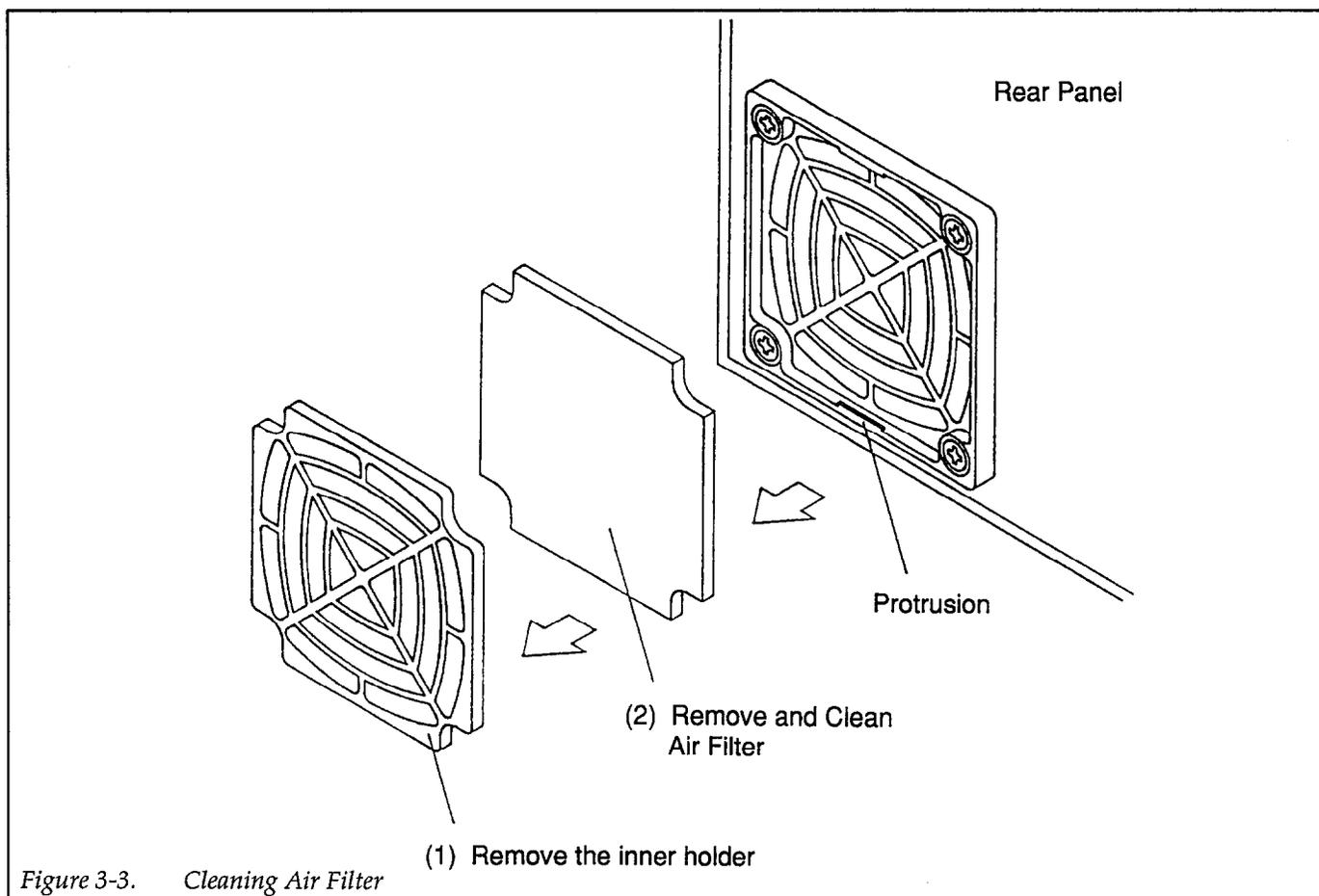
LINE SUPPLY — Set this switch to the available line voltage. Changing the line voltage setting will require a fuse change. See paragraph 3.3.1 for details.

CAUTION
To prevent damage to the instrument that may not be covered by the warranty, be sure to turn off power and disconnect the line cord before changing the line voltage setting. Do not use a fuse other than the one specified for the line voltage setting.

Safety Ground Terminal — If the instrument is not connected to a safety earth ground through the supplied 3-prong line cord, connect this terminal to a known safety earth ground using #18 AWG (or larger) wire.

LINE 48-62Hz — Power Receptacle and Fuse. Use the supplied line cord to connect the instrument to the line power. Fuse replacement is covered in paragraph 3.3.2.

3.3   POWER-UP PROCEDURE

3.3.1   Line Voltage Setting

The instrument is designed to operate from 90-132V or 198-250V line power ranges at 48 to 62Hz. Perform the following procedure to set the line voltage:

WARNING
Make sure the instrument is disconnected from the power line and all other equipment before proceeding.

1. Check the line voltage setting of the LINE SUPPLY switch on the rear panel. To change the setting, use a flat-blade screw driver to set the rotary switch to the setting that best matches the available line power.

2. If the switch setting was changed, install a fuse consistent with the operating voltage as described in the next paragraph.

3.3.2   Fuse Replacement

A rear panel fuse located inside the AC LINE receptacle is used to protect the power line input of the instrument. If the fuse needs to be replaced (line voltage switch setting changed or blown fuse), perform the following steps:

WARNING
Make sure the instrument is disconnected from the power line and other equipment before replacing the fuse.

1. Using a flat-blade screw driver, pry open the fuse drawer as shown in Figure 3-4.
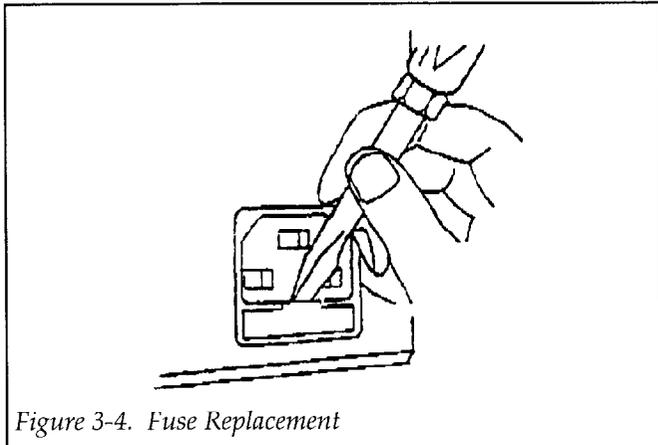
Figure 3-4. Fuse Replacement

2. Remove the fuse from the fuse clip. Notice that there is a spare fuse in front of it.

3. Replace the fuse with the following type:

Line Voltage	Fuse Rating	Keithley Part No.	Littelfuse Part No.
100V/120V	0.4A	FU-80	239.400
	0.5A	FU-71	239.500
220V/240V	0.2A	FU-96-3	239.200
	0.25A	FU-96-4	239.250

CAUTION
Do not use a fuse with a higher current rating than specified, or instrument damage may occur.

4. Push the fuse drawer back into the receptacle.

3.3.3   Power Cord

Connect the female end of the power cord to the AC receptacle on the rear panel of the instrument. Connect the male end of the cord to a grounded AC outlet.

WARNING
The instrument is equipped with a 3-wire power cord that contains a separate ground wire and is designed to be used with grounded outlets. When proper connections are made, instrument chassis is connected to the power line ground. If the AC outlet is not grounded, the rear panel safety earth ground terminal must be connected to a known safety earth ground using #18 AWG (or larger) wire.

CAUTION
Be sure that the power line voltage agrees with the indicated voltage of the LINE SUPPLY switch. Failure to observe this precaution may result in instrument damage not covered by the warranty.

3.3.4   Power Up Sequence

To turn on the instrument, depress the POWER button. During the power up cycle, the unit will perform the following:

1. All annunciators and display segments will turn on for a few seconds. This allows you to check for defective indicators or display digits.

2. The revision level of the firmware is displayed briefly on the ⟦ A ⟧ DISPLAY. For example:

     -1.10-

3. The self-check on memory elements and self-calibration of internal circuits are performed. During this period, the "CAL" message will be displayed on the ⟦ A ⟧ DISPLAY and a countdown from 7 to 0 will take place on the ⟦ B ⟧ DISPLAY. Any errors that occur are denoted by error messages on the display. Table 3-6 explains the error messages.

4. The unit will begin normal operation in accordance with the power-up configuration discussed in the next paragraph.

3.3.5 Default Conditions

Default conditions are the setup conditions that the instrument will return to when the instrument is powered up (or when a DCL or SDC command is sent over the GPIB bus). The default conditions for the instrument are summarized by Table 3-1.

Table 3-1. Power-up Defaults

Parameter	Setting	Remark
[A] DISPLAY	AUTO	
[B] DISPLAY	(AUTO)	
CKT MODE	AUTO	
FREQ	1kHz	
DELAY	Zero	
LEVEL	1Vrms	
Zero correction	No correction	1
BIAS	Off	1
Header output	Inhibit (GPIB "HD 0")	1
SRQ output	Inhibit (GPIB "RQ 0")	1
Address	2	1, 2, 3
Delimiter	<CR> <LF>	1, 2

Remarks:
1. The setting for this parameter cannot be saved in one of the ten battery back-up memories. The setting for all other parameters can be returned to the power-down condition by recalling Memory 0.
2. The setting for this parameter is stored in battery backed-up memory and automatically returns to the last programmed value on power-up.
3. Address 2 is factory default, but can be changed by the user.

3.4 TEST CONNECTIONS

In general, 4-wire measurements are made on the device under test using the front panel BNC type terminals. A test fixture, such as the Model 3323 which connects directly to the front panel, or test cables can be used to make connections to the DUT.

The UNKNOWN terminals are described as follows:

G — Ground terminal for guard that can be used to shield the DUT.

L CUR — Current detection terminal

L POT — Voltage detection terminal (Low)

H POT — Voltage detection terminal (High)

H CUR — Drive signal output terminal. Delivers the DC bias and the sine wave signal.

When using individual cables, refer to Figure 3-5 and use the following rules to connect them:

1. Connect the voltage detection terminals (H POT and L POT) to the inner position on the DUT leads as shown in the illustration.
2. Keep cables as short as possible.
3. If using long cables, twist the two voltage cables together, then twist the two current cables together. Finally, twist the two separate cable pairs together to form one twisted cable assembly.
4. At the DUT, connect the shields of the BNC cables together.

Arrangement of
cables for twisting
(See Figure 3-10A)
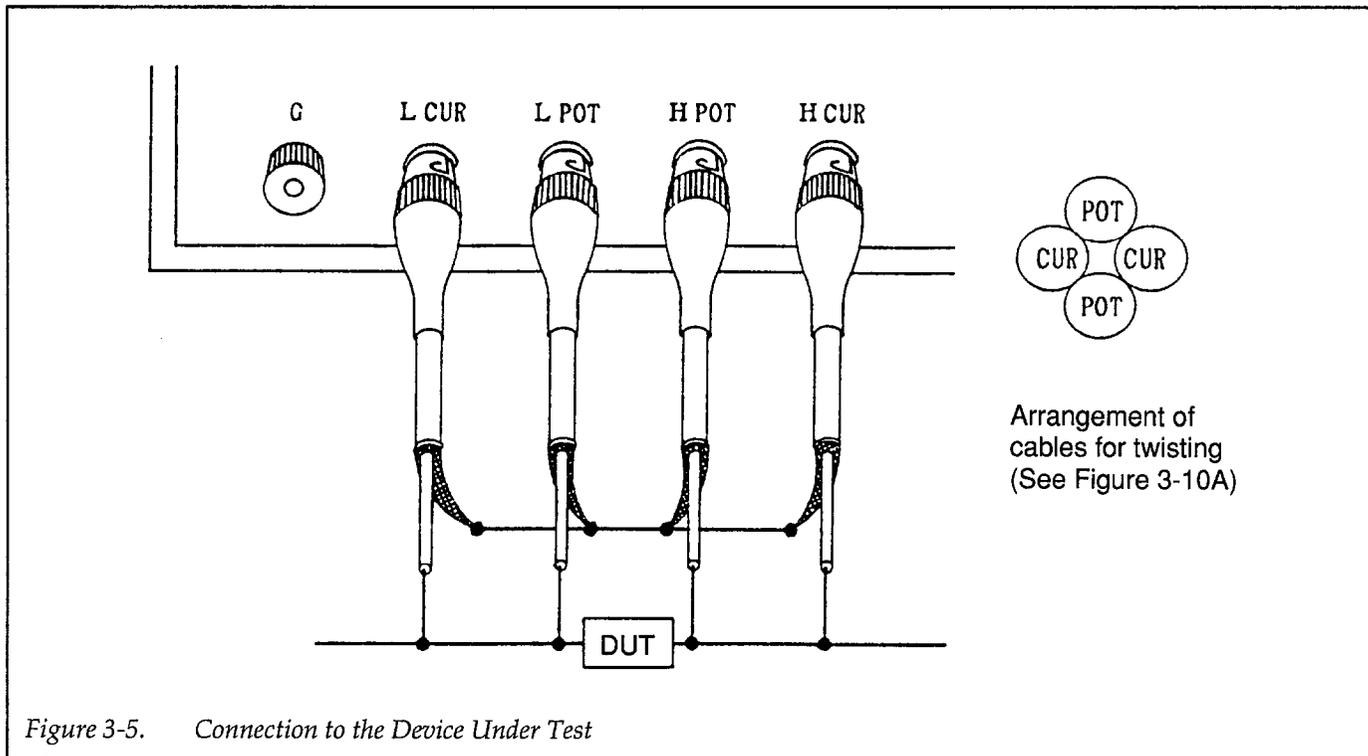
Figure 3-5.   *Connection to the Device Under Test*

3.5 BASIC MEASUREMENTS

To achieve rated accuracy, zero correction must first be performed as explained in paragraph 3.9. In general, zero correction is performed by first opening the measurement terminals and pressing the OPEN key. After completion of the OPEN correction, the terminals are then shorted and the SHORT key is pressed.

3.5.1 Measurement Function Selection

The basic measurement functions are selected using the [A] DISPLAY keys or the yellow AUTO key. The selected function is denoted by the annunciators located to the left of the [A] DISPLAY. The measurement of the selected function is provided on the [A] DISPLAY. The exponent annunciators for the measured reading are located to the right of the [A] DISPLAY. Available functions include:

AUTO — Automatic function selection. With AUTO function selected, the instrument will determine the type of device connected to the input and automatically select the appropriate measurement function.

L (H) — Self-inductance (self-induction factor)

C (F) — Electrostatic capacity

$|Z|$ – θ (Ω) — Resistance or impedance

To manually select the desired function, simply press and release the appropriate [A] DISPLAY key.

Automatic Function Selection — When AUTO is enabled, the instrument selects the function, function parameter and equivalent circuit automatically. It does this by measuring the phase angle (θ) of the DUT connected at the input. Table 3-2 defines the selected function and function parameter that is based on the internally measured phase angle (θ):

Table 3-2. AUTO Function Selections

Internally Measured Phase Angle (θ)	Function	Function Parameter
+90° ±45°	L	Q
–90° ±45°	C	D
Other than the above	$|Z|$	θ

While in AUTO function:

1. Function parameters are automatically selected. Pressing any [B] DISPLAY key will result in "Err 13".
2. The equivalent circuit (CKT) is automatically (AUTO) selected (SER or PAR).

3.5.2 Measurement Function Parameter Selection

The measurement parameter for the selected function is selected using the [B] DISPLAY keys. Note however, that if AUTO function is enabled, these keys are inoperative (Err 13). In AUTO function, the measurement parameter is automatically selected.

The selected function parameter is denoted by the annunciator located to the left of the [B] DISPLAY. The [B] DISPLAY provides the reading of the selected parameter, while the exponent part of the reading is located to the right of the display. The available function parameters include:

Q — Quality factor

D — Dissipation factor (D = 1/Q)

ESR (Ω) — Equivalent series resistance

G (S) — Parallel conductance

θ (deg) — Phase angle of impedance

Note that there is not a separate key to select θ (Deg). θ (Deg) is automatically selected when $|Z|-\theta$ function is selected.

To select the desired function parameter (AUTO off), simply press and release the appropriate [B] DISPLAY key.

When ESR or G is selected, the equivalent series resistance, or parallel conductance is displayed, respectively.

The readings for Q, D and θ are not related to the equivalent circuit.

3.5.3 Equivalent Circuit Selection

The equivalent circuit (see Figure 3-6) is selected using the CKT MODE keys. Note that if AUTO function is enabled, the CKT MODE keys are inoperative (Err 15) and the equivalent circuit is placed in the AUTO mode.

Figure 3-6. *Equivalent Circuits of Device Under Test*
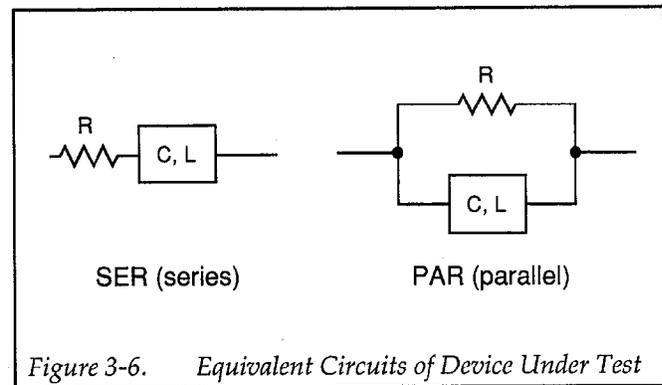
The CKT annunciators on the front panel denote the selected equivalent circuit. The equivalent circuit selections include:

AUTO — Automatic equivalent circuit selection
SER — Series Circuit
PAR — Parallel Circuit

To manually select the equivalent circuit (assuming AUTO function is disabled), simply press and release the appropriate CKT MODE key.

With AUTO CKT MODE enabled, the instrument selects an equivalent circuit automatically. The selected circuit is determined according to the combination of selected function, function parameter, and phase angle. Table 3-3 summarizes the combinations that determine the equivalent circuit while AUTO CKT is enabled.

Table 3-3. AUTO Equivalent Circuit Selections

Conditions for selection of series mode (SER)		Conditions for selection of parallel mode (PAR)	
Function	Function Parameter	Function	Function Parameter
L, C L, C, ($|Z| \leq 1k\Omega$) $|Z|$	ESR Q, D θ	L, C L, C, ($|Z| > 1k\Omega$)	G Q, D

3.5.4 Measurement Range Selection

Measurement range selection for the selected function is performed automatically. Reading range for the function parameter ([B] DISPLAY) is also selected automatically.

The instrument will go to the optimum (most accurate) range to make the measurement.

Table 3-4 lists the impedance ranges for the instrument. Notice that the valid measurement range is frequency and level dependent. The reading limits for each range are defined by the Lower Limit Extension and the Upper Limit Extension. The instrument will not measure levels that fall outside of these limits.

The optimum measurement is performed and displayed on the range that is bounded by the Lower Limit and Upper Limit (see Table 3-4). For example, for a 10kΩ measurement, the displayed reading will occur on Range 3.

Hysteresis — A hysteresis of approximately 10% is used to keep the instrument from changing ranges for a reading that varies along the borderline of two ranges. When a reading is increasing, the instrument will up range immediately after 19,999 counts. For example, on Range 2, assume a reading of 1.9999kΩ. If the reading increases by one count, the instrument up ranges and reads 2.000 kΩ on Range 3. When the reading is decreasing, the instrument will down range after 1800 counts. Continuing with the same example, a decreasing reading will read 1.800 kΩ on Range 3. When the reading decreases one more count, the instrument will down range to Range 2 and read 1.7999 kΩ. Thus, a window of 200 counts is provided for reading variances.

Measurement Capabilities

The measurement capability of each function and function parameter is summarized as follows:

$|Z|$, ESR

Type:	Exponent representation
Resolution:	4 1/2 digits (19999 digits max); Minimum reading = 0.1mΩ
Range:	0.0mΩ, ±(0.1mΩ to 19.999MΩ)

C

Type:	Exponent representation
Resolution:	4 1/2 digits (19999 max)
Range:	0.000pF, ±(0.001pF to 199.99mF)

The range of $|C|$ changes according to frequency:

120Hz	:	0.000nF to 199.99mF
1kHz	:	0.0pF to 19.999mF
10kHz	:	0.00pF to 1.999mF
100kHz	:	0.000pF to 199.99µF

L

Type:	Exponent representation
Resolution:	4 1/2 digits (19999 max)
Range:	0.0nH, ±(0.1nH to 19.999kH)

The range of $|L|$ changes according to frequency:

120Hz	:	0.0µH to 19.999kH
1kHz	:	0.00µH to 1.9999kH
10kHz	:	0.000µH to 199.99H
100kH	:	0.0nH to 19.999H

G

Type:	Floating-point representation
Resolution:	4 1/2 digits (19999 max)
Range:	0.000µS, ±(0.001µS to 199.99S); Equivalent to 1GΩ to 5mΩ

Q, D

Type:	Floating-point representation
Resolution:	4 1/2 digits (19999 max)
Range:	.0000, ±(.0001 to 19999)

θ

Type:	Fixed-point representation
Resolution:	0.01°
Range:	−180.00° to +179.99°

Deviation Range information for deviation is covered in paragraph 3.6.3.

Calculating Admittance and Susceptance

Admittance Y ($|Y|$ and θy) and susceptance B are not displayed by the instrument, but can be calculated as follows:

$$|Y| = 1/|Z|$$
$$\theta y = -\theta$$
$$B = |Y| \bullet \sin \theta y = -X/(R_s^2 + X^2)$$

where; Rs is the value of R (=ESR) for the series equivalent circuit (SER).

Table 3-4. Impedance Ranges

Level	Frequency	Range	Reference Resistance (Ω)	Applied Impedance Range (Ω)			
				Lower Limit Extension	Lower Limit **	Upper Limit ***	Upper Limit Extension
1V	120Hz	*1	100	—	0	5	11
	1kHz	2	100	0.9	5	2 k	11 k
	10kHz	3	1 k	980	2 k	20 k	110 k
		4	10 k	9.8 k	20 k	200 k	1.1 M
		5	50 k	49 k	200 k	2 M	5.5 M
		*6	50 k	450 k	2 M	20 M	∞
	100kHz	*1	100	—	0	5	11
		2	100	0.9	5	2 k	11 k
		3	1 k	980	2 k	20 k	110 k
		4	10 k	9.8 k	20 k	200 k	1.1 M
		*5	10 k	90 k	200 k	2 M	∞
		*6	10 k	90 k	200 k	2 M	∞
50mV	120Hz	*1	100	—	0	5	11
	1kHz	2	100	0.9	5	2 k	11 k
	10kHz	3	1 k	900	2 k	20 k	110 k
		4	10 k	9 k	20 k	200 k	1.1 M
		5	50 k	45 k	200 k	2 M	5.5 M
		*6	50 k	450 k	2 M	20 M	∞
	100kHz	*1	100	—	0	5	11
		2	100	0.9	5	2 k	11 k
		3	1 k	900	2 k	20 k	110 k
		4	10 k	9 k	20 k	200 k	1.1 M
		*5	10 k	90 k	200 k	2 M	∞
		*6	10 k	90 k	200 k	2 M	∞

*Extension range
**Lower limit values are inclusive.
***Upper limit values are not inclusive.

3.6 FREQUENCY SELECTION

The impedance of a device under test changes with frequency. Therefore, it is advisable to measure the device at its operating frequency.

Use the following guidelines to select a measurement frequency:

120Hz: Use to measure large values of C

1kHz: Use to measure intermediate values of R, L and C

10kHz and 100kHz: Use to measure small values of L and C

To select one of the four measurement frequencies labeled on the front panel (120Hz, 1kHz, 10kHz, 100kHz), press and release the appropriate FREQ key. The selected frequency is denoted by the enabled annunciator.

3.7 SIGNAL LEVEL SELECTION

The instrument measures devices by applying an rms signal (at the selected frequency) and then measuring the subsequent current. The signal levels that can be selected are 50mV rms and 1V rms.

The 1V signal level can be used for most measurements. For semiconductors that have non-linear characteristics that are affected by signal magnitude, use the 50mV level.

The front panel LEVEL annunciator denotes the current signal level. To select the alternate level, simple press the 50mV or 1V key.

The specified signal levels are maintained for devices that have an impedance of 1kΩ or more. At lower impedances, loading lowers the level of selected signal.

Note: After a signal level is selected, the displays will blank until the next measurement is completed.

3.8 DC BIAS

When measuring capacitance (C), a DC bias can be applied. This bias allows capacitance changes in semiconductor junctions due to applied voltage to be measured.

The instrument has a built in 2V bias that can be used, or an external bias voltage from 0 to ±35V can be applied via a BNC connector on the rear panel. The bias voltage (and drive signal) can be monitored on the H CUR terminal.

DC bias cannot be used to measure L, R or Z. Pressing the BIAS key while in one of these functions will result in "Err 14".

Bias Stabilization Time — When bias is abruptly changed by turning BIAS on to its peak value, some time is required to allow the bias voltage to stabilize before an accurate capacitance measurement can be made. Use the following equation to determine the time required to achieve stability:

Stabilization time (in seconds) $= 4 + 0.015C$
where; C is the capacitance in μF

Perform the following steps use DC bias:

1. If using an external supply, connect it to the BIAS EXT IN BNC connector on the rear panel. Make sure the supply is in standby and is set for 0V.

CAUTION
To prevent damage to the instrument, do not apply voltage that is not within the 0V to ±35V range. Also, adhere to the precautions and considerations explained after this procedure.

2. Set the rear panel BIAS switch. If using the internal supply, set the toggle switch to the INT 2V position. If using an external bias supply, set the toggle switch to the EXT position.
3. Using the [A] DISPLAY keys, select the C function. Note that AUTO function must be disabled. DC bias cannot be enabled in AUTO function.
4. Connect the device to be measured.

CAUTION
When checking a polarized device, make sure to observe polarity. Also, make sure to discharge capacitors before connecting them to the input.

5. Enable DC bias by pressing the BIAS key. When BIAS is enabled, its annunciator will turn on. Note that if a different function is selected, BIAS will disable.

6. If using an external bias source, increase the bias source gradually from zero to the desired level.

7. The capacitance reading using a DC bias will be displayed.

8. If using an external bias source, gradually decrease the level to 0V.

9. Disconnect the device.

External Bias Supply Precautions and Considerations:

1. Ripple and Noise — The power supply must have low ripple and noise (<1mV rms). It is recommended that a switching type power supply not be used. If ripple and noise are large, measurement accuracy is lowered.

2. Measuring Large Capacitors with High Voltage — When measuring more than $100\mu F$ using a bias of more than 10V, connect the capacitor to the input with the bias supply set to 0V, and then increase the voltage gradually. After completing the measurement, decrease the voltage gradually to 0V and then disconnect the device.

3. Voltage Regulation — For a bias voltage of 10V or more, the voltage level must be changed at a slow rate of speed (<10V/sec). Otherwise, the EXT 0.1A protection fuse (accessed from the rear panel) will blow.

3.9 ZERO CORRECTION

Zero correction is performed to cancel the effects of residual impedance and stray admittance caused by test fixtures and test cables.

3.9.1 Zero Correction Procedures

OPEN — Stray Admittance Measurement:

Perform the following steps to perform the OPEN correction procedure:

1. Open the measurement terminals as shown in Figure 3-7.

2. Press the OPEN key. The instrument measures the stray admittances for all frequencies and stores the values in memory. On the [A] DISPLAY, the message "OP 9" will be displayed. During the execution of the correction, the display will count down to "OP 0", which signals the end of the correction procedure. The instrument will then return to the normal measurement state using the corrected values to calculate readings. Note that during the execution of the correction procedure, stray capacitance readings will be displayed on the [B] DISPLAY.

NOTE
For the OPEN correction, make sure L CUR is connected to L POT, and H POT is connected to H CUR as shown in Figure 3-7.
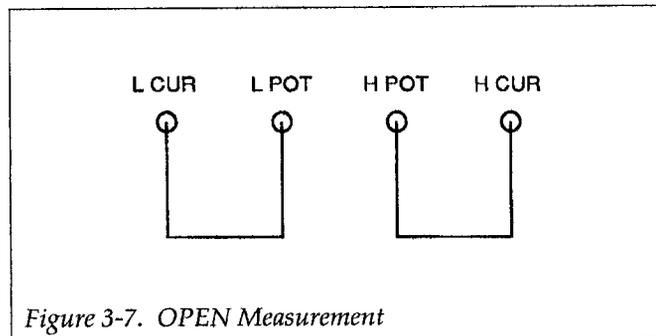
Figure 3-7. OPEN Measurement

SHORT — Residual Impedance Measurement:

Perform the following steps to perform the SHORT correction procedure:

1. Short the measurement terminals as shown in Figure 3-8.

2. Press the SHORT key. The instrument measures the residual impedance for all frequencies and stores the values in memory. On the [A] DISPLAY, the message "SH 9" will be displayed. During the execution of the correction, the display will count down to "SH 0", which signals the end of the correction procedure. The instrument will then return to the normal measurement state using the corrected values to calculate readings. Note that during the execution of the correction procedure, residual impedance readings will be displayed on the [B] DISPLAY.

NOTE
For the SHORT correction, make sure L CUR, L POT, H POT and H CUR are all connected together as shown in Figure 3-8.

L CUR   L POT   H POT   H CUR
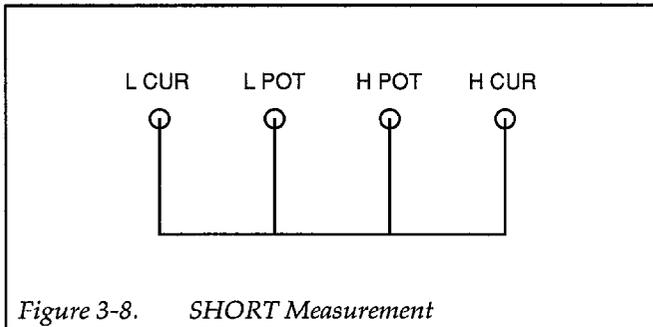
Figure 3-8.   *SHORT Measurement*

3.9.2   Equivalent Circuits of Measurement System

If the correction values obtained and stored in memory are represented by measurement circuits shown Figure 3-9 use the following equation to calculate the true impedance:

$$Zx = 1/(Ym - Ypp) - Zss$$

3.9.3   Correctable Range

$| Zss |$ < approx. 3Ω (Rss < approx. 3Ω, Lss < approx. $5\mu H$ at 100kHz)

$| Ypp |$ < approx. $10\mu s$ (Rpp = $1/Gpp$ > approx. $100k\Omega$, Cpp < approx. 16pF at 100kHz)

If a value exceeds the correctable range, an error results, an the correction factor (value of zero) does not change. The instrument measures the overall impedance including residual impedance and stray admittance, and then corrects the residual impedance and the stray admittance by calculation. Therefore, if the magnitude of the residual impedance or stray admittance comes close to the magni-

tude of the measured impedance, or if the two magnitudes are reversed, the measuring accuracy is lowered. In this case, calibrate the instrument using an external standard.

3.10   MEASUREMENT CABLES

3.10.1   Cable Requirements

When using the cables, maintain the four-terminal configuration all way to the device under test. Use the coaxial cables, and twist them as illustrated in Figure 3-10(a). Make sure the cables are arranged as shown in the cross-sectional view to minimize errors when performing low impedance measurements. If it is impossible to bundle the four cables, twist the two current cables together, and then twist the two voltage cables separately. The shorter the cables, the less the error.

Perform the OPEN and SHORT zero correction under conditions that are similar to the actual measurement condition. In other words, leave the cables connected to the instrument, and perform the open and short at the DUT end of the cables.

Low Impedance Measurements:

Model 3324 4-Terminal Alligator Clip Test Leads — If possible, twist the two current leads and the two voltage leads separately as shown in Figure 3-10(b).

Model 3325 Kelvin Clip Test Leads — If possible twist the two leads together as shown in Figure 3-10(c).

High Impedance Measurements:

When measuring high impedances (i.e. low capacitance at high frequency) use cables that are shielded all the way to the test clips. This will minimize stray capacitance between high and low. The Models 3324 and 3325 test leads are properly shielded for this application.

Y m : Virtual admittance

Z x : Measured impedance

Z ss : Residual impedance (series)

R ss : Residual resistance

L ss : Residual inductance

Y pp : Stray admittance (parallel)

G pp : Stray conductance

C pp : Stray capacity

(a) Normal measurement mode

(b) OPEN measurement mode

(c) SHORT measurement mode

Figure 3-9.   Equivalent Circuits of Measurement System

(a) How to bundle cables

Cross-sectional view

(b) Model 3324

(c) Model 3325

Figure 3-10.   *Test Cables*

3.10.2 Additional Error

The accuracy specifications are based on making measurements at the input connectors of the instrument. When using cables to connect to a DUT, additional error is introduced due to stray capacitance and voltage drop.

Additional Error in High Impedance Region:

The additional error in the high impedance region that is caused by test cables is summarized in Table 3-5.

Additional Error in Low Impedance Region:

Test cables add the following error to | Z | measurements of <2Ω:

- 120Hz, 1kHz: 0.2m Ω
- 10kHz: 0.3mΩ
- 100kHz: 1.5mΩ

Table 3-5. Additional Error of | Z | Caused by Test Cables (Reference Data)

Reference Resistance (Ω)	Frequency	
	10kHz	100kHz
1kΩ	—	0.2%
10kΩ	0.02%	2%
50kΩ	0.1%	—

3.11 ERROR MESSAGES

Errors may result from the following:

1. Self-check (power-up test or zero measurement during OPEN or SHORT correction).
2. Invalid front panel setting.
3. Programming error over the GPIB bus.

On power-up, the instrument performs self-tests on its memory elements and denotes a failure with one of the following messages that cannot be cleared:

Self-test Failure Messages:

Message		Description
EEEEE	nnnnn	Memory Failure
where:	n = 2	Invalid cal constants
	n = 4-7	RAM error
	n = 9	ROM error

The error messages caused by improper operation that are displayed by the instrument are listed and explained in Table 3-6.

It is possible to get the following messages on the [A] and [B] DISPLAYS if the instrument is exposed to excessive noise fields:

[A] DISPLAY: FFFFF   [B] DISPLAY: 66666

To clear this error, turn off power and turn power back on after three seconds. If this error occurs frequently, the instrument may be defective. Contact your sales representative or the factory.

Clearing Error Messages

Once an error message is displayed, it will remain displayed until it is cleared by the operator. The instrument is effectively inoperable while the error message is displayed.

Clear from front panel — An error message can be cleared by pressing any front panel key. In this case, the operation inherent to the key does function.

Clear over the GPIB bus – An error can be reset by sending the device clear command (DCL, SDC) over the bus.

Note: If "EEEEE" or "FFFFF" is displayed on the [A] DISPLAY section or when an error number exceeds 50, the instrument is not functioning properly. Turn off power, and then turn power on again after three seconds. If the error message does not clear, the instrument is defective. Contact your sales representative or the factory.

Table 3-6. Error Messages

Error	Message
Err 12	Entered value exceeds measurement range.
Err 13	Attempted to select a function parameter (Q, D, ESR or G) while AUTO function is enabled.
Err 14	Attempted to enable BIAS, while AUTO, L or Z function selected. Bias can only be used for capacitance (C) measurements.
Err 15	With the Z-θ function selected, you attempted to select the Q, D, θ, ESR or G parameter. With the L or C function selected, you attempted to select the θ(deg) parameter.
Err 16	With the ESR parameter selected, you attempted to select the parallel equivalent circuit (PAR). With the G parameter selected, you attempted to select the series equivalent circuit (SER).
Err 21	Occurs during power-up when battery back-up memory fails. GPIB address defaults to 2, and delimiter defaults to <CR> <LF>.
Err 22	Zero correction value exceeds the tolerance.
Err 31	Attempted to send a command string that is too long. All commands in string are ignored.
Err 32	Illegal header; received a header that was not defined.
Err 33	Illegal header; inquiry performed when programmed to perform an operation, or operation performed when programmed to perform an inquiry.
Err 34	Illegal parameter; parameter expected but not sent.

3.12 GPIB Address and Delimiter

At the factory, the GPIB address is set to 2 and the delimiter is set for carriage return, line feed <CR><LF>.

The yellow GPIB key is used to check and/or change the current address and delimiter for the GPIB. When enabled, the values that define the address and delimiter are shown on the ⬛B DISPLAY.

The address and delimiter values are displayed in the following form:

aa.d

Where:

aa is the address in the range from 0 to 30.
Decimal point (.) separates the address value and delimiter value.
d is one of the following values used to define the delimiter:
0 = <CR><LF>
1 = <CR> only

Perform the following steps to check and/or change the GPIB address and/or delimiter:

1. Press and hold in the yellow GPIB key for a few seconds until the address and delimiter values are shown on the ⬛B DISPLAY. For example if the factory default settings are currently being used, the following values will be displayed:

   2.0

   If it is desired to retain the displayed values, again press the GPIB key to exit from this mode.
2. To change address and/or delimiter, perform one or both of the following steps.
   A. Address Change — Use the | Z | - θ key to increment the address, and use the ESR key to decrement the address.
   B. Delimiter Change — Use the G key to toggle the value between 0 and 1.
3. With the desired values displayed, press the GPIB key to exit from this mode.

Note: the GPIB address and delimiter are stored in battery backed-up memory and are not lost when power is cycled.

SECTION 4
GPIB Interface

4.1 INTRODUCTION

The GPIB Interface is a general-purpose interface bus system recognized by the IEEE (Institute of Electrical and Electronics Engineers) in 1975 in the U.S and is a method of standardizing the data input/output transfer between measuring instruments and peripherals including remote control functions.

By designing each controller and peripheral device into an interface conforming to this standard, it is possible to establish complete hardware compatibility between each device.

Up to 15 devices may be connected to a single interface bus with data transfer performed by three handshake lines. These handshake lines ensure reliable data transfer between data senders and receivers even though they may have different transfer rates.

Various names have been applied to the GPIB, including IEEE–488 bus. The official name, however, is the "IEEE-

Std 488-1978: IEEE Standard Digital Interface for Programmable Instrumentation."

It has virtually the same specifications as the IEC bus, although the connector differs, making it usable with this bus by means of connector adapters.

4.1.1 Major GPIB Specifications

- Overall cable length: 20m max.
- Cable lengths between device: 4m max.
- Number of devices on bus (including controller): 15 max.
- Transfer method: 3 Handshake Lines
- Transfer rate: 1M bytes/s (max.)
- Data transfer: 8 Bits parallel
- Signal lines:
    Data bus: 8 Lines
    Control bus: 8 Lines
    Handshake lines: DAV, NRFD and NDAC
    Control lines: ATN, REN, IFC, SRQ and EOI
    Signal/system grounds: 8 Lines
- Signal logic: Negative
    True (low-level): 0.8V max.
    False (high-level): 2.0V min.
- Interface Connector: See Figure 4-1

Figure 4-1. Interface Connector
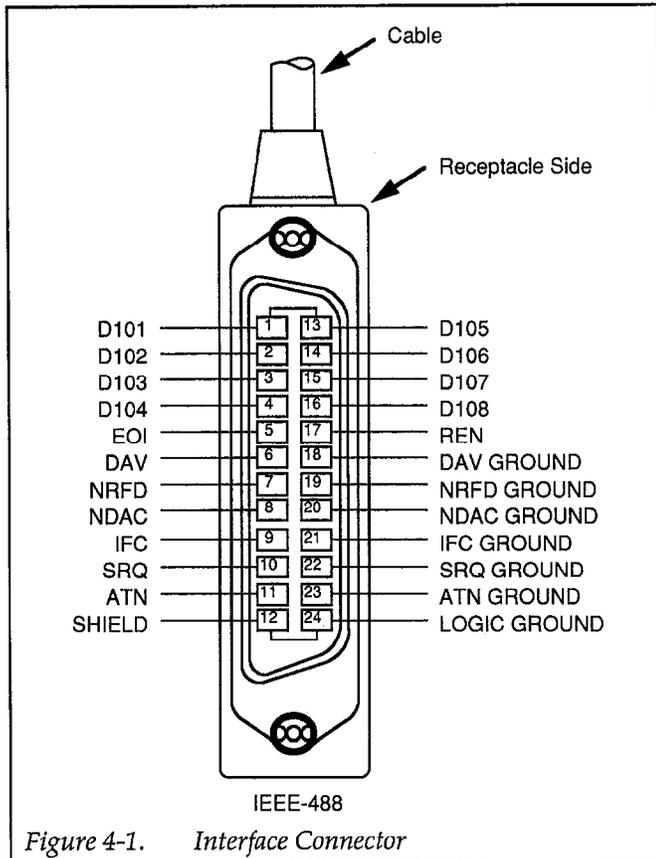
4.1.2 Bus Line Signals and Operations

The GPIB bus line consists of 24 lines, including 8 data lines, 8 control lines and 8 signal/system ground lines.

Data Bus (DIO1 to DIO8) — These are the data input/output lines which are also used to input and output both address and command information. The type of data present on these lines are identified by means of the ATN line. DIO1 is the least significant bit (LSB).

Handshake Bus (DAV, NRFD, NDAC) — These three lines are handshake lines used to ensure reliable data transfer.

- DAV (DAta Valid) — This line indicates that the data on the DIO lines sent from a talker or the controller is valid.
- NRFD (Not Ready For Data) — This line indicates the condition of readiness of listeners to accept data on the DIO lines.
- NDAC (Not Data ACcepted) — This line indicates the condition of acceptance of data by listeners.

Control Bus (ATN, REN, IFC, SRQ, EOI):

- ATN (ATteNtion) — This line is an output line from the controller which indicates whether the signals on the DIO bus are data signals or commands.
- REN (Remote ENable) — This output line from the controller switches devices between remote control and local control.
- IFC (InterFace Clear) — The output line from the controller clears the interface of devices.
- SRQ (Service ReQuest) — This control line is used to call the controller from a talker or a listener. The controller detects this signal and executes a serial or parallel poll operation.
- EOI (End Or Identify) — This is used to indicate the end of a multiple byte transfer sequence or, in conjunction with ATN, to execute a parallel poll.

4.1.3 GPIB Handshaking

GPIB handshaking is performed by checking the status of all the listeners and inhibiting the next data transfer until all listeners have received the data. Handshaking allows the slowest device on the bus to perform data transfer reliably. The handshaking operations are executed by the following status signals:

NRFD = High level. All listeners are ready for accepting data.

DAV = Low level. A talker is outputting valid data to the data bus.

NDAC = High level. All listeners have completed data reception.

The handshaking timing diagram is shown in Figure 4-2.
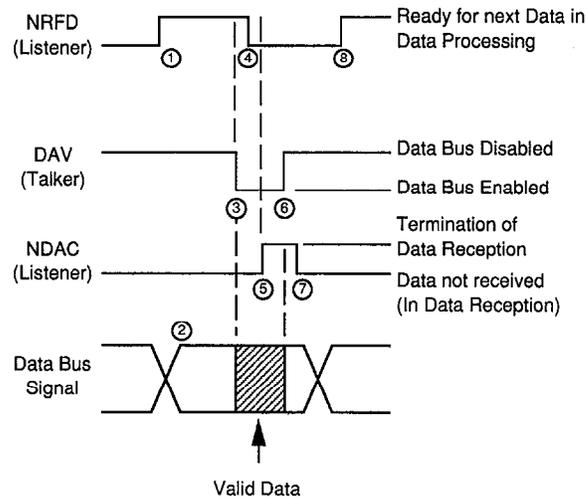
① Indicates that all listeners are waiting for data.
② The talker outputs data to be sent to the data lines.
③ The talker checks NRFD and if high, DAV is set low to indicate to the listener that data is valid.
④ When the DAV goes low, the listener reads data and NRFD is set low,
indicating to the talker that data processing is in progress. Each listener sets
NDAC high at the completion of data input. The NDAC of the bus is the OR
function of the NDACs from each listener.
⑤ When all listeners have completed receiving data, NDAC goes high (result of
the OR output) indicating to the talker that data reception has been completed.
⑥ The talker sets DAV high indicating to the listener that the data on bus is not valid.
⑦ The listener checks whether DAV is high and sets NDAC low, completing the handshake.
⑧ Indicates that all listeners have completed data processing and is waiting for next data.

Figure 4-2.   Handshake Timing Diagram

4.1.4   Data Transfer Example

Figure 4-3 provides a data transfer example using the three-line handshake process. In this example, the data "ABC" is sent, followed by the delimiter "CR/LF".

4.1.5   Basic Talker Functions

- Only one talker may exist on the GPIB at any time.
- When the controller ATN signal is high, data is sent to the listeners.
- Source handshaking is performed automatically.
- A service request (SRQ) is sent to the controller.
- The talker function is enabled for both the local and remote modes.
- The talker function is canceled by any of the following:

Whenever the talker address of another device is received.
Whenever the device is specified as a listener.
Whenever untalk (UNT) is received.
Whenever IFC is received.

4.1.6   Basic Listener Functions

- Two or more listeners may exist on the GPIB at any time.
- When the controller ATN signal is high, data is received from a talker.
- Acceptor handshake is performed.
- The listener function is canceled by any of the following:
Whenever the device is specified as a talker.
Whenever unlisten (UNL) is received.
Whenever IFC is received.
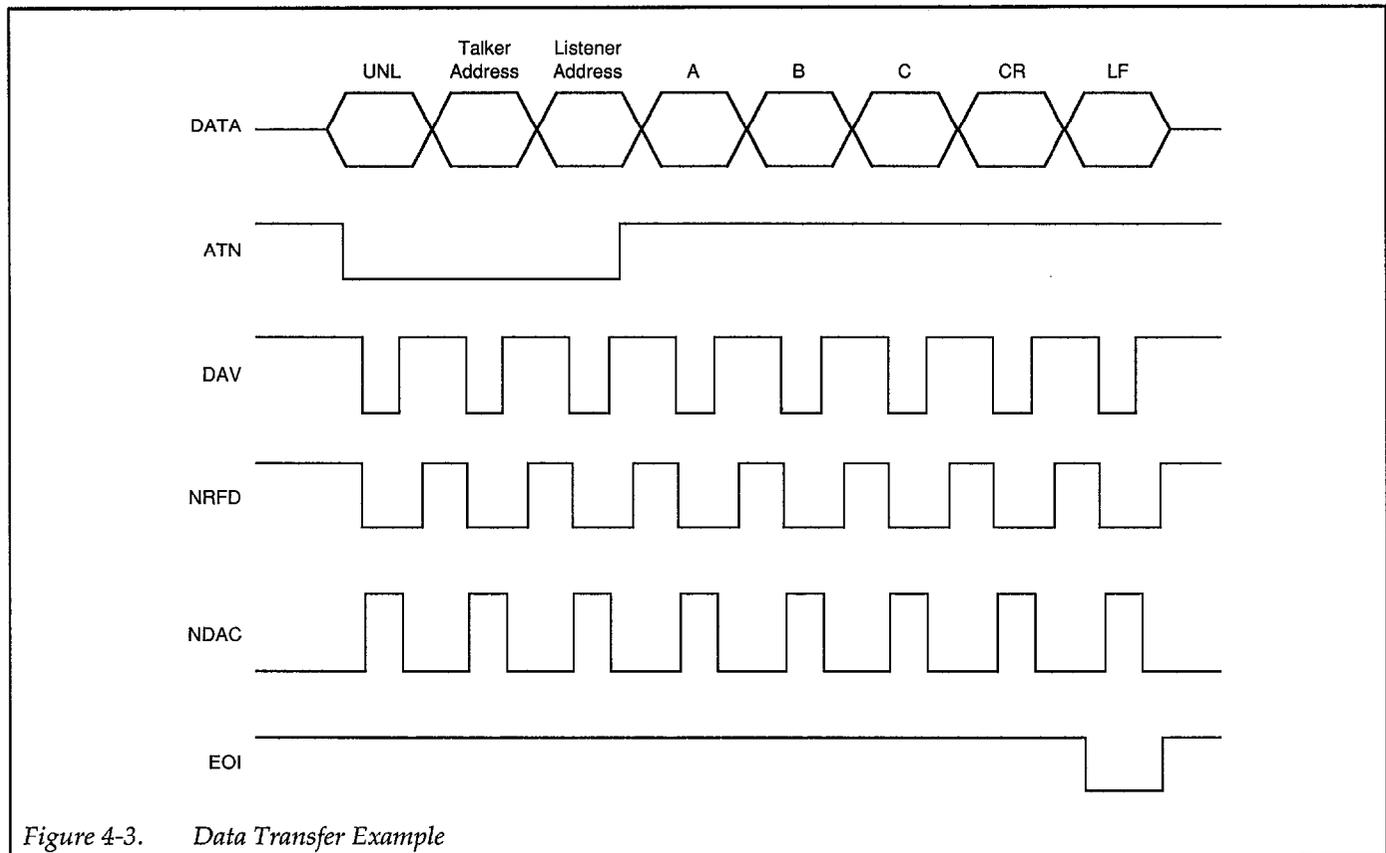
Figure 4-3.   Data Transfer Example

4.1.7   Major Specifications of Controller Functions

- Only one controller can be active on GPIB.
- Sets the ATN signal low to control the listener and talker, and transmission of commands such as device clear.

- Outputs IFC and REN signals.

4.1.8   Multi-line Interface Message

The multi-line interface message is the data output from the controller when the ATN signal is low. This is shown in Table 4-1.

Table 4-1. Multi-Line Interface Message

COLUMN / ROW	b1	b2	b3	b4	Col 0 (000)	MSG (ACG)	Col 1 (001)	MSG (UCG)	Col 2 (010)	Col 3 (011)	MSG (LAG)	Col 4 (100)	Col 5 (101)	MSG (TAG)	Col 6 (110)	MSG	Col 7 (111)	MSG
0	0	0	0	0	NUL		DLE		SP	0		@	P		`		p	
1	1	0	0	0	SOH	GTL	DC1	LLO	!	1		A	Q		a		q	
2	0	1	0	0	STX		DC2		"	2		B	R		b		r	
3	1	1	0	0	ETX		DC3		#	3		C	S		c		s	
4	0	0	1	0	EOT	SDC	DC4	DCL	$	4		D	T		d		t	
5	1	0	1	0	ENQ	PPC³	NAK	PPU	%	5		E	U		e		u	
6	0	1	1	0	ACK		SYN		&	6		F	V		f		v	
7	1	1	1	0	BEL		ETB		'	7		G	W		g		w	
8	0	0	0	1	BS	GET	CAN	SPE	(	8		H	X		h		x	
9	1	0	0	1	HT	TCT	EM	SPD	)	9		I	Y		i		y	
10	0	1	0	1	LF		SUB		*	:		J	Z		j		z	
11	1	1	0	1	VT		ESC		+	;		K	[		k		{	
12	0	0	1	1	FF		FS		,	<		L	\		l		|	
13	1	0	1	1	CR		GS		-	=		M	]		m		}	
14	0	1	1	1	SO		RS		.	>		N	^		n		~	
15	1	1	1	1	SI		US		/	?	UNL	O	_	UNT	o		DEL	

Column group definitions:

- Col 0 MSG: ADDRESSED COMMAND GROUP (ACG)
- Col 1 MSG: UNIVERSAL COMMAND GROUP (UCG)
- Col 2 MSG: LISTENER ADDRESSES ASSIGNED TO DEVICES (LISTEN ADDRESS GROUP — LAG)
- Col 3 MSG: LISTENER ADDRESSES ASSIGNED TO DEVICES (UNL) — LISTEN ADDRESS GROUP (LAG)
- Col 4 MSG: TALKER ADDRESSES ASSIGNED TO DEVICES (TALK ADDRESS GROUP — TAG)
- Col 5 MSG: TALKER ADDRESSES ASSIGNED TO DEVICES (UNT) — TALK ADDRESS GROUP (TAG)
- Col 6 MSG: MEANING DEFINED BY PCG — SECONDARY COMMAND GROUP (SCG)
- Col 7 MSG: MEANING DEFINED BY PCG — SECONDARY COMMAND GROUP (SCG)

Columns 0–5: PRIMARY COMMAND GROUP (PCG)

NOTES

1. MSG IS THE INTERFACE MESSAGE
2. b1 = DIO8 ... b2 = DIO7
   DIO8 IS NOT USED
3. HAS SECONDARY COMMAND

4.2 GPIB Programming Example

Most of the functions of the instrument can be controlled by the GPIB, allowing automated test systems to be configured.

When using the GPIB, set the address and delimiters for the GPIB from the panel (see paragraph 3.8.5). Before making any measurements over the GPIB, perform zero correction as explained in paragraph 3.15.

After performing the above operations, the instrument can be programmed to make measurements and read data over the GPIB, as illustrated in the following example program. The following program is written in BASIC 2.0 for the HP 9000 Series 200 computer:

```
100  DIM A$ [64]
110  ABORT 7
120  CLEAR 702
130  OUTPUT 702; "FR 1E3;LV 1;DA 2;DB 1;CK 1;TG"
140  ENTER 702;A$
150  PRINT " C(F) D"
160  PRINT A$
170  END
```

Sample Data:

```
C(F) D
0.0E–12, –0.1201
```

Program Analysis:
100	Assign the length of the character string
110 to 120	Initialize the GPIB
130	Set the measurement conditions and the display, and then allow the instrument to start measurements.
	FR 1E3: Frequency = 1kHz
	LV1: Level = 1V
	DA2: DISP – A = C
	DB1: DISP – B = D
	CK1: Series equivalent circuit
	TG: Apply trigger
140	Reads data.
150	Prints header.
160	Prints data.

4.3 GPIB SPECIFICATIONS

4.3.1 Interface Functions

The interface functions of the instrument are listed in Table 4-2.

Table 4-2. Interface Functions

SH1	All functions of transmit handshake
AH1	All functions of receive handshake
T6	Has basic talker function, serial poll, talker canceled by MLA function, no talk only function
L4	Has basic listener function, listener canceled by MTA function, no listen only function
SR1	All functions of service request
RL2	Has remote/local switching function, no lock-out function
PP0	No parallel poll function
DC1	All functions of device clear
DT1	All functions of device trigger
C0	No controller function

4.3.2 Bus Drivers

The specifications of the bus drivers of the instrument are listed in Table 4-3.

Table 4-3. Bus Drivers

Data Bus	DIO1 to DIO8	Open Collector
Handshake Bus	NRFD, NDAC DAV	Open collector Tri-state
Control Bus	SRQ EOI	Open collector Tri-state

4.3.3 Address

The address of the instrument can be set within the following range:

0 to 30 (Decimal)

4.3.4   Receive and Transmit Codes

Receive Codes in Listener Mode

ISO 7-bit codes (JIS/ASCII) are used. The MSB (parity bit) of 8-bit data is ignored. Uppercase letters and lowercase letters are treated the same.

<Effective letters>

! " # $ % & ' ( ) * + , − . /

0 1 2 3 4 5 6 7 8 9 : < = > ? @

A B C D E F G H I J K L M N O P Q R S T U V W X Y Z

[¥] ^ _ '

a b c d e f g h i j k l m n o p q r s t u v w x y z

{ | } ~

* is only for the JIS code. For the ASCII code, a backslash is assigned.

The characters other than the above (control code including space, semicolon, and tab) are ignored and do not enter the receive buffer. <CR> (carriage return) and <LF> (line feed) are effective only for the delimiters indicating the end of the program code.

Transmit Codes in Talker Mode

ISO 7-bit codes (JIS/ASCII) are used without parity code (MSB of 8-bit data = 0). Alphabet is transmitted in uppercase letters.

4.3.5   Delimiters

In Listener Mode (when the instrument receives)

Any <CR>, <LF> or END message (EOI line in data transfer mode = LOW: True), or all of their combinations can be accepted.

In Talker Mode (when the instrument transmits)

<CR> or <CR> <LF> — The END message is output with the last letter (of a delimiter) of the transmit data.

4.3.6   Program Codes

The instruction used to control the instrument over the GPIB or to read the setting or measured data is called a program code. The program code is classified as follows.

- Setting message: Performs setting or operation command.
- Inquiry message: Reads setting or measured data.

Execution

A program code is stored in the receive buffer, interpreted when its delimiter is received, and then executed. When the execution terminates, the receive buffer is cleared and ready for the next receive.

Receive Buffer

Capacity of buffer: 256 letters. A space, semicolon, <CR> and <LF> do not enter the receive buffer.

When the instrument receives a long program code in excess of the capacity of receive buffer and the buffer overflow, an error results. In this case, all the codes are ignored, and the receive buffer is cleared.

Basic Syntax

The basic syntax of the program code is shown Figure 4-4.

SP	: Space code
;	: Semicolon code

Header	: Programs a major category such as functions, operation objects.
Parameter	: Values to be set expressing selection
Delimiter	: Indicates the end of a program code.
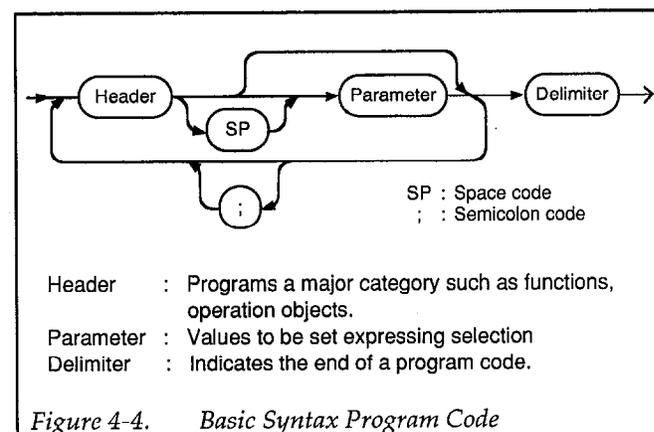
Figure 4-4.   Basic Syntax Program Code

Program codes can be sent successively within the capacity of receive buffer. When sending program codes suc-

cessively, spaces or semicolons can be inserted for easy reading.

Parameter

There are three numeric formats for parameters. Any format can be used if the value is within an acceptable range. However, the standard format is determined for each parameter and if a different format is used, it is converted to the standard format. When the number of significant digits is too large, it is rounded to the specified resolution.

<Standard format>

- NR1 (Integer representation format)
  (Example)   99   056   −1234   +24

- NR2 (Floating-point representation format)
  (Example)   1.2   .001   −160.5   +003.82

- NR3 (Exponent representation format)
  (Example)   12E3   9.8E+02   +04.5E−6   −.007E+09

Program Codes

The program codes for the instrument are provided in Table 4-4.

The standard form is in parenthesis under the header of each setting message. The form for the parameter to be sent is in the parenthesis under the header of output format.

Table 4-4. List of Program Codes

Name or Function of Parameter	Setting Message		Inquiry Message	Output Format	
	Header	Parameter	Header	Header	Parameter
[A] DISPLAY	DA (NR1)	0 to 3 (to 6) (0 : AUTO)	?DA	DA (NR1)	1 to 6 (4 : AUTO L)
[B] DISPLAY	DB (NR1)	0 to 4 (0 : Q)	?DB	DB (NR1)	0 to 4 (3 : X)
CIRCUIT	CK (NR1)	0 : AUTO, 1: SER, 2 : PAR	?CK	CK (NR1)	1, 2 (MAN) 3, 4 (AUTO)
MEASURED DATA	—	—	?DT	DT	n1,n2 (DISPLAY–A, B)
FREQUENCY	FR (NR3)	120, 1E+3, 10E+3, 100E+3	?FR	FR (NR3)	120, 1E+3, 10E+3, 100E+3
LEVEL	LV (NR1)	0 : 50mV 1 : 1V	?LV	LV (NR1)	0, 1
BIAS ON/OFF	BO (NR1	0 : OFF, 1 : ON	?BO	BO (NR1)	0 to 1
MAN TRIG	TG	—	—	—	—
ZERO OPEN	OP	—	—	—	—
ZERO SHORT	SH	—	—	—	—
HEADER	HD (NR1)	0 : DISABLE 1 : ENABLE	?HD	HD (NR1)	0 to 1
SERVICE REQUEST	RQ (NR1)	0 : DISABLE 1 : ENABLE	?RQ	RQ (NR1)	0 to 1
STATUS	—	—	?ST	ST (NR1)	0 to 127

Table 4-5. Response to Interface Messages

IFC (Interface Clear)	Initializes the GPIB Interface. (Cancels Listener or Talker)
DCL (Device Clear) or SDC (Selective Device Clear)	Resets an error. Clears the transmit and receive buffers of the GPIB. Holds the issue of SRQ. (Status byte is reset.) Inhibits the issue of SRQ. (Equivalent to "RQ 0") Inhibits the header output. (Equivalent "HD 0") Resets the wait state for end of measurement in manual trigger mode.
GTL (Go To Local)	Establishes the local mode.
GET (Group Execute Trig)	Starts measurement (Same as trigger by program code) Once trigger is applied by the GET command, the next GET command is ignored until the end of measurement.

4.3.7   Response to Interface Messages

The response to the interface messages of the instrument are provided by Table 4-5.

Notes:

1. Display parameter and frequency do not change by the IFC command. The IDC command is valid for all the devices connected to the bus.
2. Though the GET command is invalid in the local mode, the DCL and SDC commands are valid in the local mode.
3. The SDC, GTL and GET commands are in the address command group (see Table 4-1). Thus, they are valid only when the instrument is programmed as a listener. On the other hand, the DCL command is in the universal command group, and is always valid for all devices provided with the device clear function.

4.3.8   Remote/Local Operation

Remote

When the instrument is assigned as a listener when the REN message is true (REN line = Low: 1), the remote mode is established, and the REMOTE light on the front panel turns on. In the remote mode, operation over the GPIB is possible, and the key entry from the front panel (except for error reset) is invalid. Although a measurement is not interrupted when the transition from local to remote is made, the auxiliary setting mode (SET UP) is reset (EXIT).

Local

When the REN message becomes false (REN line = High: 0) or when the instrument receives the GTL command, the local mode is established, and the REMOTE light turns off. In the local mode, the settings from the front panel are enabled, and the GPIB program codes are ignored. The GET command is also invalid. Measurement cannot be interrupted when the remote mode is changed to the local mode.

4.3.9 Service Request (SRQ)

Issue SRQ:

When an SRQ is issued, SRQ is sent in the following cases:

- When one measurement is completed in the manual trigger mode
- When the zero correction of OPEN or SHORT is completed

Reset SRQ:

- After reading status by performing a serial poll
- After receiving the inquiry message for reading status ("?ST")
- When the device clear command is received. (DCL or SDC command)

4.3.10 Status Byte

The status byte sent in response to serial polling and inquiry messages is defined by Table 4-6 as follows.

Table 4-6. Status Byte

Bit	Content	Condition to be set (1)	Condition to be reset (1)
7 MSB	Always zero		
6	RQS	When issuing the SRQ command	When receiving the device clear command* After reading the status byte.**
5	ERR	Zero correction error (Correction value is too large.)	When receiving the device clear command After reading the status byte When the zero correction is normally performed.
4	BUSY	Under measurement (Zero correction included)	Under non-measurement
3	Zero	End of zero correction of OPEN or SHORT (Abnormal end included)	When receiving the device clear command After reading the status byte When starting zero correction
2	Always zero		
1	Always zero		
0 LSB	Always zero		

*Device clear: DCL or SDC command
**Status byte read: Reading of the status byte by the inquiry message "?ST" or serial poll performed when issuing the SRQ command. (Reset is not performed by the serial poll when the SRQ command is not issued.)

4.3.11 Process Time

The data transfer rate is dependent on the speed of the controller, and the process time of the instrument is slower when making measurements. Table 4-7 provides the process time for standard program codes during non-measurement phases of operation. The process time is slightly different from parameter to parameter.

Table 4-7. Process Time of Program Codes (Reference Data)

Setting Message		Inquiry Message	
Header	Processing Time (Approx.)	Header	Processing Time (Approx.)
DA	6ms	?DA	4ms
DB	5ms	?DB	4ms
CK	5ms	?CK	4ms
—		?DT	12ms
FR	7ms	?FR	5ms
LV	5ms	?LV	4ms
BO	5ms	?BO	4ms
TG	3ms	—	
OP	3ms	—	
SH	3ms	—	
HD	4ms	?HD	4ms
RQ	4ms	?RQ	4ms
—		?ST	5ms

The process times shown in Table 4-7 includes the following data transfer time:

> Receive (to the instrument): approx. 250µs/byte
> Transmit (from the instrument): approx. 120µs/byte

The process time for inquiry messages is the time from the start of program code reception to the completion of response message transmission. When sending a header for an inquiry, add the following value to the process time:

> 0.5ms approx.

4.4 SETTING GPIB ADDRESS AND DELIMITER

The GPIB address and delimiter can be checked and/or changed from the front panel and summarized as follows. For the detailed procedure, refer to paragraph 3.12 in Section 3.

GPIB Key — By pressing and holding in this key for approximately three seconds, the current GPIB address and delimiter will be displayed on the [B] DISPLAY.

The address and delimiter values are separated by the decimal point. Valid address values are 0 to 30. Delimiter values can be 0 (for <CR><LF>) or 1 (for <CR> only). Use the |Z| – θ key and ESR key to change the address value, and use the G key to toggle the delimiter.

The displayed address and delimiter values can be entered by again pressing the GPIB key. The instrument will return to the normal measurement display state.

The entered address and delimiter are retained when power is turned off. However, when they are lost due to a memory error when power is turned on, they become default values (address = 2, delimiter = 0; <CR><LF>).

4.5 GPIB PROGRAMMING

Program codes which are used to control the instrument or read the setting or measured data over GPIB are stored in the 256-byte receive buffer, and interpreted and executed when the end of the program code is displayed. The syntax of a program code is as follows.

<Header> < Parameter> < Delimiter>

- Header: Assigns a classification, including functions and operation objectives.
- Parameter : Indicates setting values and selection values. There are three types; NR1 (integer representation), NR2 (floating-point representation) and NR3 (exponent representation)
- Delimiter : <CR>, <LF>, etc. which indicates the end of a program code.

For details on syntax, see paragraph 4.3.6.

When the instrument is placed in the remote mode during measurement, and a setting or inquiry is performed, the measurement is interrupted.

4.5.1 Setting Messages

An instruction used to perform an instrument setting or operation is called a setting message. The setting messages for the instrument are provided by Table 4-8.

Examples of setting messages:

"FR 10E3" — Sets frequency to 10kHz.
"DA 0" — [A] DISPLAY, [B] DISPLAY and CKT are placed in the automatic selection mode.

CAUTION
Note that the zero correction operation of OPEN and SHORT and the measurement in the manual trigger mode are held up when the next program code is received during their execution.

4.5.2 Inquiry Messages

An instruction to read an instrument setting or the measured data is called an inquiry message. Each message consists of the inquiry header that is preceded with "?". Inquiry messages are listed in Table 4-9. The response to the message is in the format of "header" + "parameter" + "delimiter".

Headers

The output of a header is optional. The header output is inhibited when power is turned on or when the device clear command is received.

Parameters

The following formats are available for parameters. The type of output and the number of digits (number of letters) are determined according to the inquiry messages.

- NR1: Integer
  "0", "1", etc.
- NR2: Floating-point representation (no exponent part)
  "12.345", etc. When this format is used, the position of the decimal point may be fixed or variable.
- NR3: Exponent representation (with exponent part)
  "15.75E+03", etc.
  When this format is used, the exponent becomes a multiple of 3 in the range of E–12 (10^{-12}) to E+06 (10^6)

which is consistent with the how the front panel display handles exponents.

Generally, a zero in NR3 is expressed by making both the mantissa and exponent zeros ("0.0000E+00"). However, for a measured value, only the mantissa becomes zero.

Notes:

1. Leading zeros are omitted (except for one zero before a decimal point), and data is right-justified.
2. The plus sign (+) for positive numbers is omitted. However, the plus sign (+) for the exponent is included. The exponent always has two digits.

Delimiters

The following two delimiters can be selected from the front panel:

- <CR> <LF> (carriage return and line feed)
- <CR> (carriage return only)

The END message is output with the last letter (the last letter after a delimiter) of the response of the instrument to an inquiry (EOI line = Low).

Notes

1. When the instrument is programmed as a talker without sending an inquiry message, a single blank and a delimiter are output except immediately after a measurement is performed in the manual trigger mode.
2. When more than one inquiry is performed, only the last inquiry is valid. Other inquiries are ignored.
3. The response to an inquiry is canceled when the following operation is performed without receiving the response after sending an inquiry command.

   - Program code "TG"
   - GET command

Example of response to inquiry:

"?FR" (Frequency) – "1E+03" or "FR 1E+03"
"?DT" (Measured value) – "123.45E–03, 0.0012" or "DT 123.45E–03, 0.0012"

The example responses are shown with and without the header.

Table 4-8. Setting Messages

Parameter Name or Function	Program Code		Operation and Setting Range	Inquiry
	Header	Parameter		
[A] DISPLAY	DA	NR1 Integer	<Function> Range: 0 = AUTO 1 = L 2 = C 3 = |Z| 4 to 6 = AUTO	Yes
[B] DISPLAY	DB	NR1 Integer	<Function Parameter> Range: 0 = Q 1 = D 2 = ESR 3 = G 4 = θ	Yes
CIRCUIT	CK	NR1 Integer	<Equivalent circuit> Range: 0 = AUTO 1 = SER 2 = PAR 3 to 4 = AUTO	Yes
FREQUENCY	FR	NR3 Exponent Type	<Frequency> Range: 120 = 120Hz 1E3 = 1kHz 10E3 = 10kHz 100E3 = 100kHz	Yes
LEVEL	LV	NR1 Integer	<Measuring signal level> Range: 0 = 50mVrms 1 = 1Vrms (Open)	Yes
BIAS ON/OFF	BO	NR1 Integer	<Bias> Range: 0 = Off 1 = On	Yes
MAN TRIG	TG	—	<Manual Trigger> Establishes manual trigger mode and applies trigger. (Measurement is started.)	No
ZERO OPEN	OP	—	<Stray admittance correction> Starts OPEN correction.	No
ZERO SHORT	SH	—	<Residual impedance correction. Starts SHORT correction.	No
HEADER	HD	NR1 Integer	<Header Output> Range: 0 = Inhibit (Not output) 1 = Admit (Output)	Yes
SERVICE REQUEST	RQ	NR1 Integer	<Service Request> Assigns whether or not to output SRQ. Range: 0 = Inhibit (Not output) 1 = Admit (Output)	Yes

Table 4-9.   Inquiry Messages

Parameter Name or Function	Inquiry Message Header	Output Format and Content of Inquiry		Setting
		Header	Parameter	

[A] DISPLAY	?DA	DA	<Function>
			Type: NR1 (Integer)
			Range: 1 = L
			           2 = C
			           3 = |Z|
			           4 = AUTO L
			           5 = AUTO C
			           6 = AUTO |Z|
			No. of letters: 2 (4)
				Yes

[B] DISPLAY	?DB	DB	<Function Parameter>
			Type: NR1 (Integer)
			Range: 0 = Q
			           1 = D
			           2 = ESR
			           3 = G
			           4 = θ
			No. of letters: 2 (4)
				Yes

CIRCUIT	?CK	CK	<Equivalent circuit>
			Type: NR1 (Integer)
			Range: 1 = SER
			           2 = PAR
			           3 = AUTO SER
			           4 = AUTO PAR
			No. of letters: 2 (4)
				Yes

MEASURED DATA	?DT	DT	<Measured data> Format: [A] DISPLAY and [B] DISPLAY Type and Range: Different from parameter to parameter No. of letters: 23 (25) max.	No

+

Inquiry Messages (Cont.)

Parameter Name or Function	Inquiry Message Header	Output Format and Content of Inquiry		Setting
		Header	Parameter	

FREQUENCY	?FR	FR	<Frequency>
			Type: NR3 (Exponent type)
			Range: 120E+00: 120Hz
			           1E+03: 1kHz
			          10E+03: 10kHz
			        100E+03: 100kHz
			No. of letters: 8 (10)
				Yes

LEVEL	?LV	LV	<Measuring signal level> Type: NR1 (Integer) Range: 0 = 50mVrms 1 = 1Vrms No. of letters: 2 (4)	Yes
BIAS ON/OFF	?BO	BO	<Bias> Type: NR1 (Integer) Range: 0 = Off 1 = On No. of letters: 2 (4)	Yes
HEADER	?HD	HD	<Header output> Type: NR1 (Integer) Range: 0 = Inhibit (Not output) 1 = Admit (Ouptut) No. of letters: 2 (4)	Yes
SERVICE REQUEST	?RQ	RQ	<Service request output> Type: NR1 (Integer) Range: 0 = Inhibit (Not output) 1 = Admit (Output) No. of letters: 2 (4)	No

STATUS BYTE	?ST	ST	<Status byte>
			Type: NR1 (Integer)
			Range: 0 to 127
			          Converter to decimal notation and
			            output
			No. of letters: 4 (6)
				No

+

4.5.3 Reading Measured Data

Request for Measured Data

Measured data can be read by the following two methods:

- Request data by the inquiry message "?DT"
- Allow the instrument to measure data by the setting message "TG" or the GET command.

1. "?DT"
   This command places the last measured reading in the transmit buffer, and is sent when the instrument is programmed to talk.
2. "GT" or GET Command
   When a trigger is applied by the "GT" or GET command, the instrument stops the ongoing measurement and starts a new measurement. When the new measurement finishes, the data is staged in the transmit buffer. If the instrument is assigned as a talker immediately after a trigger is applied, the data will not be sent until the completion of the measurement (the listener will wait until the measurement finishes). When a remote trigger is applied, the instrument remains in a single trigger mode as long as the remote state is maintained. In other words, when one measurement finishes, the next measurement does not occur until an external trigger is applied.

   When the next trigger is applied without reading data, the transmit buffer is cleared, but SRQ is not reset. Note that the data output by the "TG" is canceled if another program is sent after the "TG".

Data Format

Data that correspond to the [A] DISPLAY and the [B] DISPLAY readings are separated (delimited) by a comma (,).

   "[HEADER] Data of [A] DISPLAY, Data of [B] DISPLAY Delimiter"

The header output is enabled and disabled by the setting messages "HD 0" and "HD 1" respectively. A delimiter <CR> <LF> or <CR> is selected from the front panel using SET UP GPIB. The END message (EOI line = Low) is output with the last command of the delimiter.

Each measured value is output in the same format as it is displayed on the front panel, and is summarized as follows:

L, C, R, |Z|, ESR, G, X

Type:	NR3 (exponent representation) Exponent part is a multiple of 3.
Resolution:	4-1/2 digits (19999 max. typically 2000 to 19999)
Range:	0.0000E–12, (0.0001E–12 to 19999.E+06) The display range is restricted by the types of parameters, ranges and phase angles. The exponent and a decimal point are output without fail.
"OF":	"99999.E+06"
"UF":	"–99999.E+06"
"OU":	"88888.E+06" (L, C, R, |Z|); 0.0000E+00")ESR, G, X)
Blank:	"77777.E+06"
No. of letters:	11

Q, D

Type:	NR2 (Floating-point representation)
Resolution:	4-1/2 digits (19999 max.)
Range:	0.0000, (0.0001 to 19999.)
"OF":	"99999."
"UF":	"–99999."
"OU":	"0.0000"
Blank:	"77777."
No. of letters:	7

θ

Type:	NR2 (Floating-point representation)
Resolution:	0.01
Range:	–180.00 to +179.99
"OU"	"0.00"
Blank:	"777.77"
No. of letters:	7

Notes:

1. The plus sign (+) is omitted and is implied by its absence. However, it is included for the exponent.
2. The major differences between the data displayed at the front panel and the GPIB output are as follows:

Front Panel Display	GPIB Output
K,μ, etc.	E+03, E–06, etc.
.1234	0.1234
OF, UF, OU	Numbers like "99999.E+06"
Blank; measured value not displayed	Numeric like "77777."

4.6 MEASUREMENTS OVER GPIB

Measurement over the GPIB is basically the same as making measurements from the front panel. Before using the GPIB, make sure front panel operation (Section 3) is understood.

4.6.1   Preparation

1. Input/output Connections — Connect a test fixture or test leads to the instrument, and perform zero correction.
2. Initial GPIB Settings:

   - Interface clear (IFC) — Initialize the GPIB system by sending the interface clear command from the controller.
   - Remote enable (REN) — Send the REN message from the controller to enable the instrument to respond to GPIB commands. The REN command must be true (REN line = Low). To control the instrument over the GPIB, REN must be maintained true unless some front panel operation is needed.
   - Device clear (DCL, SDC) — Initialize the GPIB system of the instrument by sending a device clear command from the controller. The transmit and receive buffers will be cleared, and any previous error will reset. SRQ will disable, and the header for an inquiry message will disable.

4.6.2   Measurement and Reading of Data

This paragraphs describes how to make a measurement and send the reading (data) over the GPIB bus to the controller.

Set Measurement Conditions

Example:	"FR 1E3;LV 1"
FR 1E3:	Frequency = 1kHz
LV 1:	Measuring signal level = 1Vrms (output open)

Set Display

Example:	"DA 2; DB 1;CK 1"
DA 2:	C is displayed on $\boxed{A}$ DISPLAY (electrostatic capacity)
DB 1:	D is displayed on $\boxed{B}$ DISPLAY (Dissipation)
CK1:	Equivalent circuit (CKT) is series (SER).

Perform Measurement
Send the following command string to select the manual trigger mode, and make a single measurement:

   "TG"

TG:	Applies a trigger and performs one measurement. The GET command can be used instead.

Read Data
Once the measurement has been made, the reading (data) is sent to the computer by programming the instrument to talk.

SRQ can be used to ensure that the measurement is completed before sending the reading by programming the instrument to talk. To enable SRQ, send the following command before making the measurement:

   "RQ 1"

When an SRQ occurs, serial poll the instrument to confirm that the RQS bit is set, and then program it to talk.

Another way to verify the completion of a measurement is to read the status byte using the "?ST" inquiry message and wait until the BUSY bit (Bit 4) is reset.

4.7 GPIB OPERATING CONSIDERATIONS

Before connecting or disconnecting GPIB cables, be sure to turn off the instrument. When other equipment is connected to the bus, turn off that equipment also.

- When using the GPIB, make sure all equipment connected to the bus is turned on.
- Exercise care for delimiters. If the same delimiters are not used, the bus could hang up.
- Up to 15 units (including the controller) can be connected to the GPIB bus at one time.
- Cable length restriction:

Total transmission path length = 2m × (no. of units) or 20m (whichever is shorter). Maximum length of one cable = 4m.
- The GPIB is intended to be used in an environment that is not subjected to excessive electrical noise.

4.8 GPIB ERRORS

When an error occurs during GPIB bus operation, an error message (see Table 4-10) is displayed and the command string is ignored. After analyzing a displayed GPIB error, it can be cleared by pressing any front panel key or by sending a device clear command over the bus.

Table 4-10. GPIB Error Messages

Err12	The entered parameter value exceeds the rated range
Err13	Display assignment error While **[A]** DISPLAY in AUTO, an item of **[B]** DISPLAY is assigned, CKT is assigned, or deviation display is assigned.
Err14	Illegal request for DC bias While **[A]** DISPLAY in AUTO, L, R or $|Z|$, you attempted to turn on DC bias.
Err15	Function parameter assignment error. With the Z function selected, you attempted to select the Q, D, ESR or G parameter. With the L or C function selected, you attempted to select the θ (deg) parameter.
Err16	Equivalent circuit assignment error. With the ESR parameter selected, you attempted to select the parallel equivalent circuit (PAR). With the G parameter selected, you attempted to select the series equivalent circuit (SER).
Err22	Zero correction abnormal Zero correction value exceeds the tolerable range.
Err31	Receive buffer over-flow A program code is too long for the receive buffer. Command string is ignored.
Err32	Illegal header Receives a header that is not assigned.
Err33	Illegal header Though only a setting can be made, an inquiry is made, or though only an inquiry can be made, a setting is made.
Err34	Illegal parameter Required parameter missing.

4.9 EXAMPLE PROGRAMS

This section provides some example programs used to control the instrument over the GPIB. The personal computer used for those examples is listed as follows:

HP 9000 Series 200 Computers

Series 200 computers, HP9816, 9826, 9836, etc.
BASIC 2.0 software

All the programs assume that the GPIB address of the instrument is set to 2 and the delimiter is set to <CR> <LF>.

4.9.1 GPIB Initialization

The following program will initialize the GPIB:

Sample program to initialize the GPIB:

```
100  ABORT 7
110  CLEAR 702
```

Program Analysis:

Line No.	Operation
100	Send the IFC (Interface Clear) command.
110	Send the SDC (Selective Device Clear) command.

Normally REN is enabled, unless otherwise programmed, and the delimiter is <CR> <LF> unless otherwise programmed by the OUTPUT statement.

4.9.2 Display Setting

The following example program will set the display of the instrument. When this program is executed, C and D will be measured repeatedly at 1kHz. Make sure the GPIB was previously initialized (see paragraph 4.9.1) before using this program.

Sample program to set the display:

```
100  OUTPUT 702; "FR 1E3;DA 2;DB 1;CK 1"
```

4.9.3 Inquiry

The following sample program will inquire and display the currently selected frequency and signal level settings. Make sure the GPIB was previously initialized (see paragraph 4.9.1) before using this program.

```
100  OUTPUT 702;"HD 0"
200  OUTPUT 702;"?FR"
210  ENTER 702;Fr
220  PRINT "FREQ = ";Fr;" Hz"
230  PRINT
300  OUTPUT 702; "?LV"
310  ENTER 702;Lv
320  L$="1V"
330  IF Lv=0 THEN L$="50mV"
340  PRINT "LEVEL = "L$
```

Program Analysis:

Line No.	Comment
100	Inhibits a header output.
200 to 220	Inquires and displays the frequency.
300	Inquires the signal level.
310 to 340	Receives and displays the data.

+

4.9.4   SRQ and Serial Poll

The following sample program will acquire measured data using SRQ. Measurements are performed at a frequency of 1kHz and are displayed on the computer CRT. Make sure the GPIB was previously initialized (see paragraph 4.9.1) before using this program.

Sample program to SRQ and serial poll:

```
100  DIM A$[64]
110  OUTPUT 702;"FR 1E3;DA 2;DB 1;CK 2"
120  ON INTR 7 GOSUB 200
130  OUTPUT 702; "RQ 1"
140  OUTPUT 702; "TG"
150  ENABLE INTR 7;2
160  GOTO 160
170  !
180  !
200  S=SPOLL (702)
210  IF BINAND(S,64)=0 THEN 260
220  OUTPUT 702; "?DT"
230  ENTER 702;A$            !ENTER 702;C,D
240  PRINT A$               !PRINT
                            "C=";C;"F,
                            D=";D

250  TRIGGER 702
260  ENABLE INTR 7
270  RETURN
```

Program Analysis:

Line No.	Comment
100	Assigns the length of the character string.
110	Sets measurement conditions. Frequency = 1kHz, [A]DISPLAY = C, [B]DISPLAY = D, parallel equivalent circuit.
120	When SRQ is received, branch to the subroutines starting from line 200.
130	Enable SRQ of the instrument.
140	Applies the remote trigger to make measurement.
150	Admits the SRQ interruption.
200	Performs the serial poll.
210	Confirms that the RQS bit of a status byte is set, waits for the completion of zero correction.

220 to 240	Receives and displays measured values.
250	Applies a trigger by the GET command and allows the instrument to start the next measurement.
260	Admits the next SRQ interruption.

4.9.5   Measurements

The following sample program measures an electrolytic capacitor:

Sample program to measure electrolytic capacitor:

```
100  DIM A$[64]
110  ABORT 7
120  CLEAR 702
130  OUTPUT 702; "LV 1;DA 2;DB 2"
140  OUTPUT 702;"BO 1"
150  Wtm=15                    !wait time (s)
160  T=TIMEDATE+Wtm
170  WHILE TIMEDATE<T
180  END WHILE
200  RESTORE Flist
210  PRINT "FREQ(Hz)   C(F)   ESR(ohm)"
220  READ F$
230  WHILE F$<>"*"
240  OUTPUT 702; "FR"&F$
250  Wtm=2
260  T=TIMEDATE+Wtm
270  WHILE TIMEDATE<T
280  END WHILE
290  OUTPUT 702;"TG"
300  PRINT " "&F$&" ";
310  ENTER 702;A$
320  PRINT A$
330  READ F$
340  END WHILE
350  OUTPUT 702; "BO 0"
360  PRINT
370  PRINT "End of job"
380  STOP
390  !
400  Flist: !
410  ! Frequency list
420  DATA "120", "1E3", "10E3", "100E3", "*"
430  END
```

Program Analysis:

Line No.	Comment
100	Assigns the length of the character string.
110 to 125	Initializes the GPIB.
130	Sets measuring conditions. Measuring signal level =1V,measurement range = automatic, speed = MED. [A]DISPLAY = C, [B]DISPLAY = ESR, no deviation and no bin display, series equivalent circuit, manual trigger mode, trigger delay time 1s.
140 to 180	Turns on the DC bias and allow capacitor time to charge.
200	Assigns a frequency table.
210	Displays a header.
220 to 340	Read and display the frequency
220, 330	Deletes a frequency from a frequency table.
230	"*" is displayed at the end of the table.
240 to 280	Set a frequency and allow to settle.
290	Apply trigger to make a single measurement.
300	Displays a measured frequency.
310 to 320	Read and display the measured value.
350 to 380	Turn off the bias and finish measurement.
400 to 420	Frequency table

A.1 MEASUREMENT PARAMETERS

Kinds of Parameters

• Main Parameters

AUTO: Selects the main parameters, sub-parameters and equivalent circuits automatically.

L: Self-inductance (unit: H, henry)

C: Capacitance (unit: F, farad)

|Z|: Magnitude of impedance (unit: Ω)

There are series and parallel measuring modes for each of L, C and R.

• Sub-parameters

Q: Quality factor (quality of circuit)

D: Dissipation factor (= tan δ = 1/Q)

ESR: Equivalent series resistance (unit: Ω)

G: Parallel conductance (unit: S, siemens; 1/Ω; Mho)

θ: Phase angle of impedance (unit: degree)

• Equivalent Circuits

AUTO: Automatic selection

SER: Series

PAR: Parallel

• Automatic Parameter Selection

Parameters can be automatically selected by the phase angle of impedance.

$\theta = +90° \pm 45° \rightarrow$ L - Q

$\theta = -90° \pm 45° \rightarrow$ C - D

$\theta =$ Other than the above $\rightarrow$ |Z| - θ

• Automatic Selection of Equivalent Circuits

Equivalent circuits can be automatically selected by the value and phase angle of impedance, and the combination of parameters.

Conditions for Selection of Series Mode		Conditions for Selection of Parallel Mode	
L, C	- ESR	L, C	- G
L, C (|Z| ≤1kΩ)	- Q, D	L, C (|Z| > 1kΩ)	- Q, D
|Z|	- θ		

Displayed Resolution

4-1/2 digits (19999 max)

D and Q Resolution: 0.0001 min

θ Resolution: 0.01°

Measuring (display) Range

|Z|, ESR: 0.1mΩ to 19.999MΩ

C: 0.001pF to 199.99mF

L: 0.1nH to 19.999kH

Q, D: 0.0001 to 19999

G: 0.001µS to 199.99S

θ: −180.00° to +179.99°

These ranges are dependent on the frequency, measuring range, and phase angle of impedance.

Accuracy

Accuracy Guarantee Conditions

• Warm-up time: 30 minutes.

• Ambient temperature and humidity: 23° ±5°C, ≤90% RH.

• Zero correction: Performed under the above conditions.

• Calibration period: 12 months.

Accuracy of |Z| and θ

For 0.2Ω ≤ |Z| ≤ 20MΩ, see Table A-1.

For |Z| < 0.2Ω, see Table A-2.

For |Z| >20MΩ, see Table A-3.

Notes:

1. When a measurement is made at twice line frequency, the measured value may deviate beyond the accuracy range due to interaction with line frequency.

2. When the operating temperature is 5°-40°C, add the value shown in Table A-4 to that in Table A-1. Double the values shown in Table A-2 and A-3.

3. Tables A-1 through A-3 show the worst case value in each impedance range. Obtain the correct accuracy in the following ranges by linear interpolation:

• |Z| = 1M to 20MΩ

In this range, as impedance increases, accuracy decreases.

acc1: Accuracy shown in one range below the range including a Z in Table A-1.

acc2: Accuracy (worst case value) shown in the range including a Z in Table A-1.

• |Z| = 0.2 to 2Ω

In this range, as impedance decreases, accuracy decreases.

acc1: Accuracy (worst case value) shown in the range including a Z in Table A-1.

Specifications subject to change without notice.

Notes Cont.:

acc2: Accuracy shown in one range above the range including a Z in Table A-1.

$$acc = [acc1 \, (Z2 - Z) + acc2 \, (Z - Z1)] \, / \, (Z2 - Z1)$$

Z: Magnitude of measured impedance (measured value)

Z1: Lower limit value of each impedance range in Table A-1.

Z2: Upper limit value of each impedance range in Table A-1.

acc: Measuring accuracy of impedance Z ($|Z|$ is displayed by %, and θ by degree.)

acc1: Measuring accuracy of impedance Z1

acc2: Measuring accuracy of impedance of Z2

When obtaining the accuracy in the ambient temperature ranging from 5°-40°C, add each corresponding value in Table A-4 to acc1 and acc2 in advance.

• When level = 50mV rms, accuracy is not guaranteed in the following ranges.

$|Z| \geq 20M\Omega$

$|Z| \geq 2M\Omega$ and frequency = 100kHz

$|Z| < 0.2\Omega$

Accuracy of ESR and G

In the case of Q < 0.1 (D > 10), use the accuracy of $|Z|$:

$|ESR| = |Z|$

$|G| = 1 / |Z|$

Accuracy of L and C

In the case of Q > 10 (D < 0.1), use the accuracy of $|Z|$:

$$L = \frac{|Z|}{2\pi f}$$

$$C = \frac{1}{2\pi f \, |Z|}$$

where f is the test frequency in Hz.

Refer to Figure A-1, Conversion from LC to $|Z|$.

Accuracy of D and Q

In case D<<1 (Q>>1), use the following equations:

Accuracy of D = $\pm(0.0175 \times \theta$ accuracy (deg))

Accuracy of Q = $\pm(0.0175 \times \theta$ accuracy (deg) $\times Q^2)$

In any parameter, add the $\pm1/2$ count, i.e., half of the resolution to the displayed value as actual accuracy.

Table A-1. Accuracy of |Z| and θ for 0.2Ω ≤ |Z| <20MΩ

|Z| (Ω)	LEVEL =1V rms Frequency, (Hz)				LEVEL = 50mVrms Frequency, (Hz)			
	120	1k	10k	100k	120	1k	10k	100k
10M≤ |Z| <20M	3.0% 1.5°	1.0% 0.8°	3.5% 2.0°	20.0% 12.0°	7.0% 4.0°	3.5% 2.0°	8.5% 5.0°	– –
5M≤ |Z| <10M	1.5% 0.9°	0.5% 0.4°	1.8% 1.1°	10.0% 6.0°	3.5% 2.0°	1.7% 1.0°	3.5% 2.0°	– –
2M≤ |Z| <5M	0.75% 0.45°	0.3% 0.2°	0.9% 0.6°	5.0% 3.0°	2.0% 1.2°	0.9% 0.6°	1.6% 1.0°	– –
1M≤ |Z| <2M	0.36% 0.22°	0.2% 0.1°	0.4% 0.2°	3.0% 2.0°	1.0% 0.6°	0.4% 0.25°	0.8% 0.5°	14.0% 8.0°
200k≤ |Z| <1M	0.25% 0.15°	0.15% 0.09°	0.27% 0.16°	2.0% 1.2°	0.5% 0.3°	0.3% 0.18°	0.4% 0.25°	7.0% 4.0°
20k≤ |Z| <200k	0.15% 0.10°	0.1% 0.04°	0.25% 0.15°	1.2% 0.8°	0.3% 0.18°	0.16% 0.08°	0.32% 0.18°	3.0% 1.5°
2k≤ |Z| <20k	0.14% 0.09°	0.1% 0.03°	0.15% 0.08°	0.8% 0.6°	0.25% 0.15°	0.16% 0.06°	0.24% 0.14°	2.0% 1.2°
10≤ |Z| <2k	0.13% 0.08°	0.1% 0.03°	0.13% 0.1°	0.7% 0.5°	0.20% 0.12°	0.15% 0.06°	0.23% 0.13°	1.6% 1.0°
2≤ |Z| <10	0.25% 0.15°	0.15% 0.07°	0.32% 0.2°	1.5% 0.8°	0.5% 0.3°	0.25% 0.14°	0.5% 0.3°	4.0% 2.3°
1≤ |Z| <2	0.35% 0.22°	0.2% 0.12°	0.5% 0.3°	2.0% 1.2°	1.0% 0.6°	0.5% 0.3°	0.8% 0.5°	8.0% 5.0°
0.5≤ |Z| <1	0.7% 0.45°	0.4% 0.25°	0.8% 0.5°	3.3% 2.0°	1.8% 1.1°	1.0% 0.6°	1.5% 0.9°	14.0% 8.5°
0.2≤ |Z| <0.5	1.4%	0.8%	1.25%	5.5%	3.7%	2.0%	2.9%	28.0%

|Z| Accuracy: ±% reading shown on upper line.

θ Accuracy: ± degrees shown on lower line.

Table A-2. Accuracy of |Z| and θ for |Z| <0.2Ω

|Z| (Ω)	LEVEL =1V rms Frequency, (Hz)			
	120	1k	10k	100k
0≤ |Z| <0.2	1.7% +0.2m	1.0% +0.2m	1.4% +0.3m	6.0% +3m

|Z| Accuracy: ±(% reading + R) shown.

θ Accuracy: (θ Accuracy for 0.2≤ |Z| <0.5 in Table A-1) × (0.2Ω/ |Z|)

Table A-3. Accuracy of |Z| and θ for |Z|≥20MΩ

| |Y| (S)	LEVEL =1V rms Frequency, (Hz)			
	120	1k	10k	100k
0≤|Y|≤50nS	1.8nS	0.6nS	2.1nS	12nS

|Z| Accuracy: Specified by the ± deviation (S) of admittance |Y| shown.

θ Accuracy: (θ Accuracy for 10M≤|Z|<20M in Table A-1 × (|Z|/20MΩ).

Table A-4. Additional Error for 5°-40°C

|Z| Ω	LEVEL =1Vrms Frequency, (Hz)		LEVEL = 50mVrms Frequency, (Hz)	
	120 to 10k	100k	120 to 10k	100k
10M≤|Z|<20M	0.2% 0.12°	2.0% 1.2°	0.3% 0.2°	— —
5M≤|Z|<10M	0.12% 0.07°	1.0% 0.6°	0.2% 0.12°	— —
2M≤|Z|<5M	0.07% 0.04°	0.5% 0.3°	0.14% 0.09°	— —
200k≤|Z|<2M	0.04% 0.024°	0.20% 0.12°	0.1% 0.06°	0.6% 0.4°
20k≤|Z|<200k	0.04% 0.024°	0.20% 0.12°	0.06% 0.035°	0.3% 0.2°
2k≤|Z|<20k	0.04% 0.024°	0.08% 0.05°	0.06% 0.035°	0.15% 0.1°
10≤|Z|<2k	0.04% 0.024°	0.08% 0.05°	0.06% 0.035°	0.15% 0.1°
2≤|Z|<10	0.04% 0.024°	0.10% 0.06°	0.2% 0.12°	1.0% 0.6°
1≤|Z|<2	0.07% 0.04°	0.18% 0.1°	0.4% 0.24°	2.0% 1.2°
0.5≤|Z|<1	0.12% 0.07°	0.33% 0.2°	0.8% 0.5°	4.0% 3.5°
0.2≤|Z|<0.5	0.2% 0.12°	0.6% 0.4°	2.0% 1.2°	10.0% 6.0°

(a) Conversion diagram

(b) C → |Z|

(c) L → |Z|
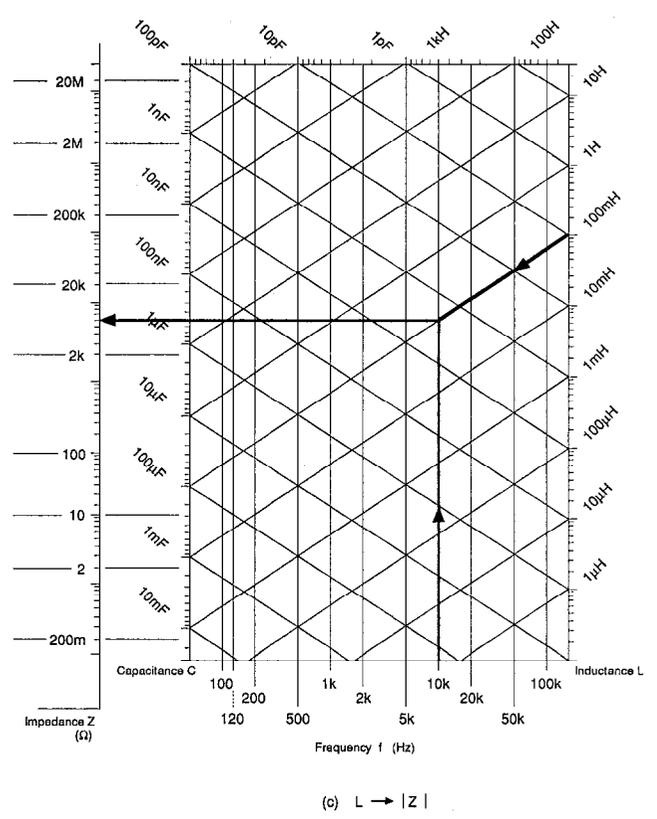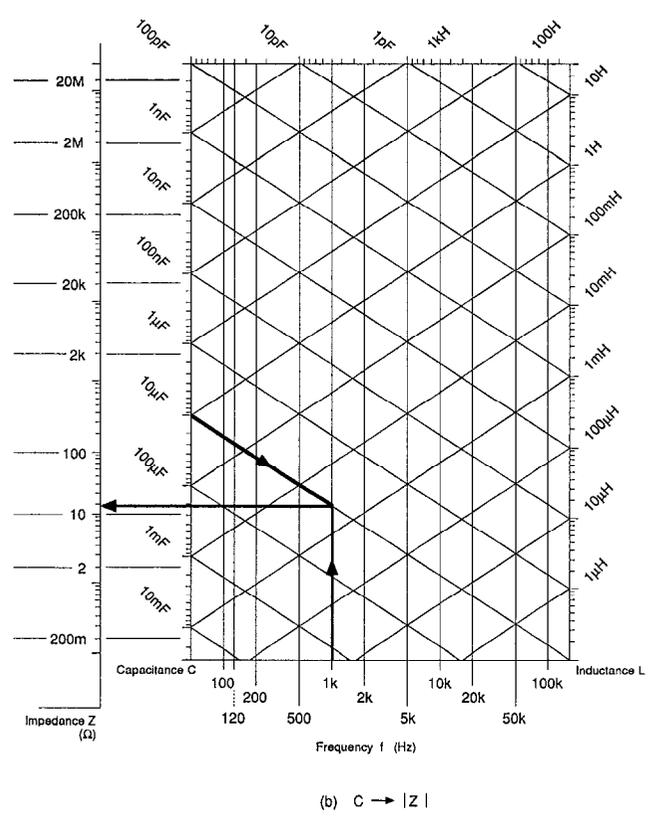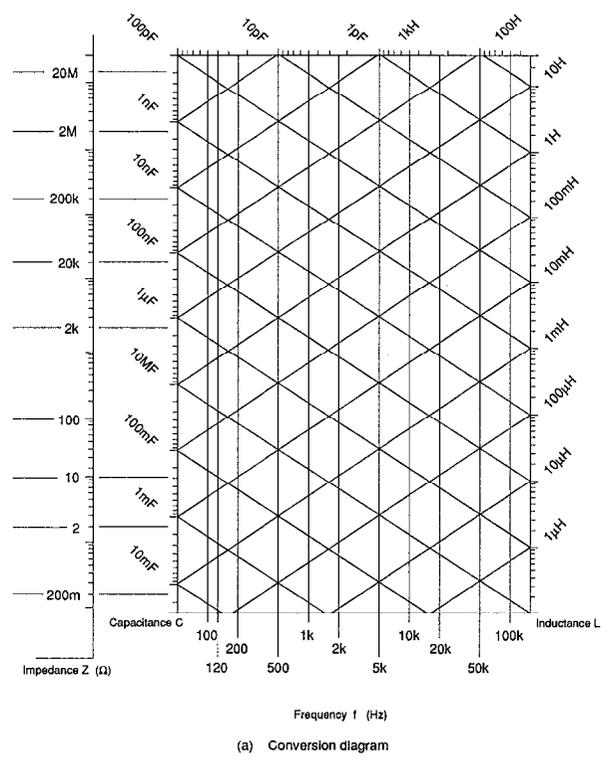
Figure A-1. Conversion Diagram from L or C to |Z|

Examples of Determining Accuracy

Ex. 1: Find the accuracy when R=33kΩ, f=l0kHz, 1V, while Q<0.1.

1. Find the accuracy from Table A-1, using the following parameters: 1V, 10kHz and 20k to 200kΩ.
2. When operating within a temperature range from 5 to 40°C, add the value in Table A-4.
3. When accuracy is needed for ≥1MΩ or ≤2Ω, interpolate the value according to Note 3.
4. Add ±1/2 count of display value. When the display shows a measured value of 33.14kΩ, the 1/2 count becomes 0.005kΩ.

Ex. 2: Find the accuracy when C = 10μF, f=lkHz, 50mV, while D < 0.1.

1. Find |Z| from Figure A-1 Conversion Diagram.
   - Find the line descending from C = 10μF. Find the vertical line from frequency = lkHz. Mark their intersection.
   - Extend a horizontal line from the intersection, to the left side. Read the value of |Z| (≈16Ω). Also, you can calculate the accuracy using the following equation.

$$|Z| = |1/2\pi fC|$$

2. Find the accuracy from Table A-1, using the following parameters: 50mV, lkHz and 10 to 2kΩ.
3. When operating within a temperature range from 5 to 40°C, add the value in Table A-4.
4. When accuracy is needed for ≥1MΩ or ≤2Ω, interpolate the value according to Note 3.
5. Add ±1/2 count of display value.

Ex. 3: Find the accuracy when L = 680μH, f=l00kHz, while Q > 10.

1. Find |Z| from Figure A-1 Conversion Diagram.
   - Draw a straight line from L = 680μH, in parallel with the ascending lines. Find the intersection with the vertical line at frequency = 100kHz.
   - Read |Z| as shown in Ex. 2. Also, you can calculate the accuracy using the following equation:

$$|Z| = |2\pi fL|$$

2. Find the accuracy from Table A-1, using the following parameters: f=l00kHz and 10 to 2kΩ. Repeat procedures 3 to 5 in Ex. 2.

Ex. 4: Find the accuracy of |Z| at any θ and for parameters other than θ.

1. Measure |Z| and θ, or calculate the accuracy, using the other parameters.

$Q = 1/D$	$|\theta| = |\arctan Q|$
$= 2\pi fLs/ESR$	$|Z| = |2\pi fLs/\sin\theta|$
$= 1/(2\pi fCs\ ESR)$	$= |1/(2\pi fCs\ \sin\theta|$
$= 2\pi fCp/G$	$= |1/(2\pi fCp\ \sin\theta|$
$= 1/(2\pi fLp\ G)$	$= |2\pi fLp/\sin\theta|$

   f: Frequency (Hz)
   Suffix s: Series equivalent circuit
   p: Parallel equivalent circuit

2. Find the accuracies of |Z| and θ. Refer to Ex. 1.
3. Find the maximums and minimums of |Z| and θ from the measured values and accuracies of |Z| and θ.

   Z max, min = Measured value |Z| × [1 ± Accuracy of |Z| (%)/100]
   θ max, min = Measured value θ ± Accuracy θ (degree)

4. Find the maximums and minimums of the parameters for the four sets of combinations of maximums and minimums of |Z| and θ,

using the calculating equation of each parameter. B is a susceptance, i.e., an imaginary component of admittance.

ESR	$= |Z| \cos\theta$	G	$= (1/|Z|)\cos\theta$
X	$= |Z| \sin\theta$	B	$= -(1/|Z|)\sin\theta$
Ls	$= X/2\pi f$	Lp	$= -1/2\pi fB$
Cs	$= -1/2\pi fX$	Cp	$= B/2\pi f$
Q	$= |\sin\theta|/\cos\theta$	D	$= \cos\theta/|\sin\theta|$

5. The accuracy is the value that the error of 1/2 count of display is added to |maximum value-measured value| or |minimum value-measured value|, whichever is greater.

A.2 MEASURING SIGNAL

Frequency
   Range: 120, 1k, 10k, 100k (Hz)
   Accuracy: ±0.005% (±50ppm)

Signal level (HCUR open voltage with terminal)

1Vrms:	±3% at 1kHz
	±4% at 120Hz to 10kHz
	±5% at 100kHz
50mVrms:	±5% at 1kHz
	±6% at 120Hz to 10kHz
	±7% at 100kHz

DC bias
   Internal: 2V, ±5%
   External: 0 to ±35V

A.3 MEASURING RANGE

Number of ranges: 6 (Reference resistance: 100Ω, 1kΩ, 10kΩ, 50kΩ, upper and lower extension ranges 2)

Selection: Automatic

A.4 MEASURING SPEED (reference value)

Measuring time (fixed range and auto trigger mode)
   When the range is not switched, the following values become effective:
   150ms (typ) 1kHz, 1kΩ
   600ms (max) all ranges, all frequencies

Automatic range switching time (per range)
   The automatic range switching time is nearly equal to the measuring time. When the frequency is ≤120Hz and the impedance is ≥1MΩ, it will take time for the measured value to stabilize. When measuring a device whose impedance changes according to the magnitude of the measuring signal, time will extend until the value of the device becomes stable.

Level switching stabilization time: 200ms to 4s
   The level switching stabilization time will change according to the kinds of devices under test. Time increases when measuring nonlinear elements, such as diodes, or when switching from 1V to 50mV. This is the time required for the stabilization of measured values. The time needed to change the device under test is excluded.

Bias stabilization time: (4 + 0.015C)s
   Where C=capacitance of device under test (μF).

Frequency switching stabilization time: 150ms to 4s
   The frequency switching stabilization time increases when a high frequency is changed to a low frequency (e.g.: 100kHz to 120Hz)
   Also, time changes according to the device under test. This is the time required for the stabilization of the measured value. The time taken to change the device under test is excluded.

A.5 TRIGGER

Trigger mode: Automatic only.
Trigger delay time: 0 to 199.99s

A.6 MEASUREMENT TERMINALS

4 terminals (BNC) + guard terminal

A.7 SETUP MEMORY

Memory Content: All settable data (except bias on-off).
Battery Life: 3 years minimum when stored at 40°C max.

A.8 GPIB

Interface Functions: SH1, AH1, T6, L4, SR1, RL2, PP0, DC1, DT1, C0.

Setting: Of the items settable via the front panel, all the parameters except address and delimiter of GPIB can be set. Also, trigger, OPEN/SHORT compensation and memory operation can be performed.
Readout: All the settable parameters, measurement data and status.
Standards: Based on IEEE-488-1978 and IEEE-488A-1980.
Code: ISO 7 bit code (ASCII code).

A.9 GENERAL

Power requirements: AC line voltage: selectable to 100V, 120V, 220V, 240V ±10% (250V max.). 48 to 62Hz, approx. 21VA.
Operating Environment: 0° to 40°C, 10 to 90% RH (non-condensing).
Storage Environment: -10 to +50°C, 10 to 80% RH (non-condensing).
Dimensions, Weight: 216mm wide × 132.5mm high × 350mm deep (8-1/2 in. × 5-1/4 in. × 13-3/4 in.), excluding protrusions. Net weight 3.6kg (7.9lb.).

SIDE VIEW

350 mm (13 3/4 in.)

135.5mm
(5 11/32 in.)

132.5mm
(5 7/32 in.)

FRONT VIEW

KEITHLEY   3321 LCZ METER

216 mm (8 1/2 in.)
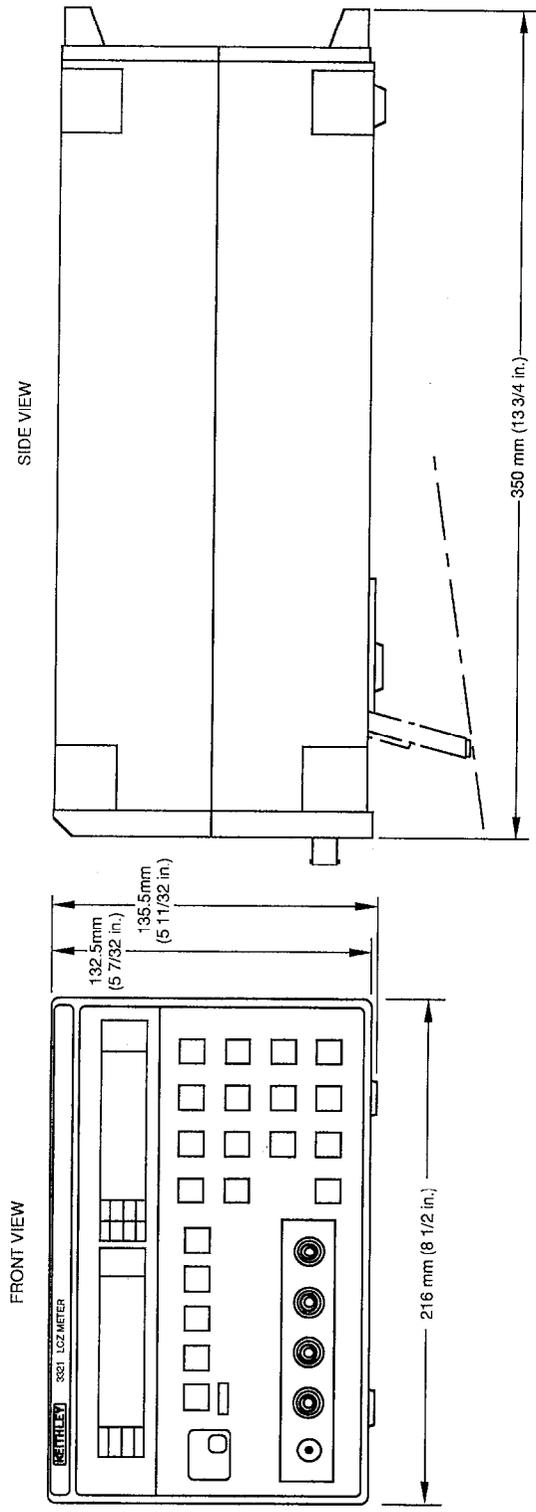
Figure A-2. Dimensions

KEITHLEY

Service Form

Model No. _____ Serial No. _____ Date _____

Name and Telephone No. _____

Company _____

List all control settings, describe problem and check boxes that apply to problem. _____

_____

❏ Intermittent   ❏ Analog output follows display   ❏ Particular range or function bad; specify

❏ IEEE failure   ❏ Obvious problem on power-up   ❏ Batteries and fuses are OK
❏ Front panel operational   ❏ All ranges or functions are bad   ❏ Checked all cables

Display or output (check one)

❏ Drifts   ❏ Unable to zero
❏ Unstable   ❏ Will not read applied input
❏ Overload

❏ Calibration only   ❏ Certificate of calibration required
❏ Data required
(attach any additional sheets as necessary)

Show a block diagram of your measurement system including all instruments connected (whether power is turned on or not).
Also, describe signal source.

Where is the measurement being performed? (factory, controlled laboratory, out-of-doors, etc.)

_____

What power line voltage is used? _____ Ambient temperature? _____ °F

Relative humidity? _____ Other?_____

Any additional information. (If special modifications have been made by the user, please describe.)

_____

Be sure to include your name and phone number on this service form.

Specifications are subject to change without notice.

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