**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.
Model 6220 DC Current Source
Model 6221 AC and DC Current Source
User’s Manual
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 622x-900-01) ................................................................. June 2004
Revision B (Document Number 622x-900-01) ................................................................. June 2005
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 Measurement Category I and Measurement Category II, as described in the International Electrotechnical Commission (IEC) Standard IEC 60664. Most measurement, control, and data I/O signals are Measurement Category I and must not be directly connected to mains voltage or to voltage sources with high transient over-voltages. Measurement 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 ca-**
bles 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.

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

The $\mathcal{A}$ symbol on an instrument indicates that the user should refer to the operating instructions located in the manual.

The $\mathcal{E}$ 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 $\mathcal{H}$ symbol indicates a connection terminal to the equipment frame.

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.
# Table of Contents

## 1 Getting Started

- Introduction ............................................................................................................. 1-2
- User’s Manual content and structure ............................................................... 1-2
- Capabilities and features .................................................................................. 1-2
- General information ............................................................................................... 1-3
  - Warranty information ..................................................................................... 1-3
  - Contact information ....................................................................................... 1-3
  - Safety symbols and terms .............................................................................. 1-3
  - Unpacking and inspection ............................................................................. 1-3
  - Options and accessories ............................................................................... 1-4
- Front and rear panel familiarization ................................................................. 1-4
  - Front panel summaries .................................................................................. 1-4
  - Rear panel summaries ................................................................................... 1-8
- Heat sink and cooling vents ................................................................................ 1-9
- Power-up ............................................................................................................... 1-11
  - Line power connection ................................................................................ 1-11
  - Source preset .................................................................................................. 1-12
  - Disabling the front panel ............................................................................. 1-12
- Menus .................................................................................................................... 1-13
  - CONFIG menus ............................................................................................ 1-13
  - Direct access menus ..................................................................................... 1-13
- Editing controls ..................................................................................................... 1-14
  - Source and compliance editing .................................................................... 1-14
  - Menu navigation ............................................................................................ 1-14
- Password ............................................................................................................... 1-16
- Remote interface .................................................................................................. 1-17
- Error and status messages ................................................................................... 1-17
- Default settings .................................................................................................... 1-18
  - Save and restore setups .............................................................................. 1-18
  - Select power-on setup ................................................................................ 1-19
- SCPI programming ............................................................................................... 1-19
  - Optional command words ............................................................................ 1-19
  - Query commands .......................................................................................... 1-19
2 Output Connections

Output connectors ................................................................. 2-2
  Triax connector ................................................................. 2-2
  Ground points ................................................................. 2-3
  LO and GUARD banana jacks ........................................... 2-3
  INTERLOCK ................................................................. 2-4

Output configurations ......................................................... 2-5
  Triax inner shield ............................................................ 2-6
  Triax output low .............................................................. 2-7

Guards .................................................................................. 2-8
  Triax Cable Guard ........................................................... 2-8

Floating the current source .................................................. 2-9

Connections to DUT ............................................................. 2-9
  Supplied triax cable .......................................................... 2-9
  Basic connections ............................................................ 2-10
  Shields and guarding ....................................................... 2-10

Using a test fixture .............................................................. 2-12

3 DC Current Source Operation

Current source output capabilities ........................................ 3-2
  Source ranges ................................................................. 3-2
  Compliance ................................................................. 3-3
  Output power (source or sink) ........................................... 3-3
  Output response ............................................................ 3-5

Setting source and compliance ........................................... 3-8
  Source and compliance editing ........................................ 3-8
  Autorange ................................................................. 3-11
  Source preset ............................................................... 3-12

Sourcing current ............................................................... 3-12
  Remote programming – source output commands .......... 3-15

Applications ................................................................. 3-16

4 Sweeps

Sweep overview ............................................................... 4-2
  Linear staircase sweep ................................................... 4-2
  Logarithmic staircase sweep .......................................... 4-2
  Custom sweep .............................................................. 4-2

Sweep characteristics ....................................................... 4-4
  Custom sweep editing .................................................... 4-4
  Using auto-copy with custom sweeps ......................... 4-4
  Source ranging ........................................................... 4-4
  Sweep delay ............................................................... 4-5
5 Delta, Pulse Delta, and Differential Conductance

Operation overview ........................................................................................................... 5-2
Test systems ..................................................................................................................... 5-4
  Keithley instrumentation requirements ................................................................. 5-4
  System configurations ............................................................................................ 5-4
  System connections .............................................................................................. 5-5
  DUT test connections .......................................................................................... 5-8
  Configuring communications .............................................................................. 5-9
  Triggering sequence ................................................................ ....................... 5-10
Readings .......................................................................................................................... 5-11
  Display readings ............................................................................................. 5-11
  Measurement units .......................................................................................... 5-11
  Read commands .............................................................................................. 5-13
Delta .................................................................................................................................. 5-13
  Model 622x measurement process ..................................................................... 5-13
  Configuration settings .................................................................................... 5-15
  Operation ....................................................................................................... 5-16
  Setup and arm commands .............................................................................. 5-19
Pulse Delta ....................................................................................................................... 5-21
  Model 6221 measurement process ..................................................................... 5-21
  Pulse Delta outputs ........................................................................................ 5-22
  Configuration settings .................................................................................... 5-26
  Operation ....................................................................................................... 5-29
  Setup commands ............................................................................................ 5-32
Differential Conductance ............................................................................................... 5-34
  Model 622x measurement process ..................................................................... 5-34
  Configuration settings .................................................................................... 5-37
  Operation ....................................................................................................... 5-38
  Setup and arm commands .............................................................................. 5-41
6 Averaging Filter, Math, and Buffer

Averaging filter ................................................................. 6-2
  Averaging filter characteristics ...................................... 6-2
  Filter setup and control .................................................. 6-4
  Remote programming – Averaging filter ....................... 6-4
Math ................................................................................. 6-5
  mX+b and m/X+b (reciprocal) ......................................... 6-5
  Configuring mX+b and m/X+b ........................................... 6-6
  Remote programming – Math ............................................ 6-6
Buffer ................................................................................ 6-7
  Buffer characteristics ..................................................... 6-7
  Storing readings ............................................................ 6-8
  Recall ............................................................................. 6-8

7 Wave Functions (6221 Only)

Wave function overview .................................................. 7-2
  Setting waveform parameters ....................................... 7-3
  Ranging ......................................................................... 7-3
  Frequency ....................................................................... 7-4
  Offset ........................................................................... 7-4
  Duty cycle ....................................................................... 7-5
  Phase marker ................................................................... 7-6
  Duration .......................................................................... 7-7
  Externally triggered waveforms ..................................... 7-7
Front panel wave function operation ................................. 7-8
  Using the wave function menu ....................................... 7-8
  Generating a sine wave ................................................. 7-10
  Generating an arbitrary waveform .............................. 7-11
Remote wave function operation ...................................... 7-12
  Programming sine waves ............................................. 7-13
  Programming arbitrary waveforms ............................ 7-14
  SCPI commands — wave functions ............................ 7-15

A Specifications

B SCPI Tables (Abridged)
## List of Illustrations

<table>
<thead>
<tr>
<th></th>
<th>Getting Started</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Figure 1-1 Models 6220 and 6621 front panels</td>
<td>1-5</td>
</tr>
<tr>
<td></td>
<td>Figure 1-2 Model 622x rear panel</td>
<td>1-8</td>
</tr>
<tr>
<td></td>
<td>Figure 1-3 Menu editing keys</td>
<td>1-14</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Output Connections</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Figure 2-1 Triax connector and grounds points</td>
<td>2-2</td>
</tr>
<tr>
<td></td>
<td>Figure 2-2 LO and GUARD banana jacks</td>
<td>2-3</td>
</tr>
<tr>
<td></td>
<td>Figure 2-3 INTERLOCK</td>
<td>2-4</td>
</tr>
<tr>
<td></td>
<td>Figure 2-4 Output configurations – triax inner shield connected to Output Low</td>
<td>2-5</td>
</tr>
<tr>
<td></td>
<td>Figure 2-5 Output configurations – triax inner shield connected to Cable Guard</td>
<td>2-6</td>
</tr>
<tr>
<td></td>
<td>Figure 2-6 Basic connections to DUT</td>
<td>2-10</td>
</tr>
<tr>
<td></td>
<td>Figure 2-7 Noise shield</td>
<td>2-10</td>
</tr>
<tr>
<td></td>
<td>Figure 2-8 Safety shield</td>
<td>2-11</td>
</tr>
<tr>
<td></td>
<td>Figure 2-9 Cable Guard connections – triax inner shield connected to Cable Guard</td>
<td>2-11</td>
</tr>
<tr>
<td></td>
<td>Figure 2-10 Connections for noise shield, safety shield, and guarding</td>
<td>2-12</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>DC Current Source Operation</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Figure 3-1 Output boundaries (source and sink)</td>
<td>3-5</td>
</tr>
<tr>
<td></td>
<td>Figure 3-2 Source and compliance editing – Model 6220</td>
<td>3-8</td>
</tr>
<tr>
<td></td>
<td>Figure 3-3 Source and compliance editing – Model 6221</td>
<td>3-10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Sweeps</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Figure 4-1 Comparison of sweep types</td>
<td>4-3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Delta, Pulse Delta, and Differential Conductance</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Figure 5-1 Delta, Pulse Delta, and Differential Conductance measurements</td>
<td>5-3</td>
</tr>
<tr>
<td></td>
<td>Figure 5-2 System configurations for Delta, Pulse Delta, and Differential Conductance</td>
<td>5-5</td>
</tr>
<tr>
<td></td>
<td>Figure 5-3 System connections – stand-alone operation</td>
<td>5-6</td>
</tr>
<tr>
<td></td>
<td>Figure 5-4 System connections – PC control of Model 622x</td>
<td>5-7</td>
</tr>
<tr>
<td></td>
<td>Figure 5-5 Guarded test connections</td>
<td>5-8</td>
</tr>
<tr>
<td></td>
<td>Figure 5-6 Delta measurement technique</td>
<td>5-14</td>
</tr>
<tr>
<td></td>
<td>Figure 5-7 Pulse Delta 3-point measurement technique</td>
<td>5-21</td>
</tr>
<tr>
<td></td>
<td>Figure 5-8 Pulse timing</td>
<td>5-24</td>
</tr>
<tr>
<td></td>
<td>Figure 5-9 Pulse sweep output examples</td>
<td>5-25</td>
</tr>
<tr>
<td></td>
<td>Figure 5-10 Differential Conductance measurement process</td>
<td>5-35</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Averaging Filter, Math, and Buffer</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>Figure 6-1 Buffer recall</td>
<td>6-9</td>
</tr>
</tbody>
</table>
7  Wave Functions (6221 Only)

Figure 7-1  Offset example ................................................................................................... 7-4
Figure 7-2  Duty cycle ......................................................................................................... 7-5
Figure 7-3  Phase marker ................................................................................................... 7-6
List of Tables

3 DC Current Source Operation
Table 3-1 Source ranges and maximum outputs ......................................................... 3-2
Table 3-2 DC output commands .................................................................................. 3-15

4 Sweeps
Table 4-1 Sweep configuration menu .......................................................................... 4-5
Table 4-2 Sweep example parameters ....................................................................... 4-8
Table 4-3 Staircase sweep commands (linear and logarithmic) .................................. 4-11
Table 4-4 Custom (list) sweep commands ................................................................. 4-12

5 Delta, Pulse Delta, and Differential Conductance
Table 5-1 Measurement unit commands ................................................................... 5-12
Table 5-2 Delta commands ....................................................................................... 5-20
Table 5-3 Pulse Delta commands ............................................................................. 5-33
Table 5-4 Differential Conductance commands ...................................................... 5-42

6 Averaging Filter, Math, and Buffer
Table 6-1 Average filter types .................................................................................. 6-2
Table 6-2 Averaging filter commands ..................................................................... 6-5
Table 6-3 Math commands ....................................................................................... 6-6
Table 6-4 Buffer commands ..................................................................................... 6-9

7 Wave Functions (6221 Only)
Table 7-1 Wave function characteristics .................................................................. 7-2
Table 7-2 Wave function configuration menu ............................................................. 7-8
Table 7-3 Waveform example parameters ............................................................... 7-12
Table 7-4 Waveform function commands ................................................................. 7-15

B SCPI Tables (Abridged)
Table B-1 Calculate command summary ................................................................. B-2
Table B-2 Display command summary ................................................................. B-2
Table B-3 Format command summary ................................................................. B-3
Table B-4 Output command summary ................................................................. B-3
Table B-5 Sense command summary ................................................................. B-3
Table B-6 Source command summary ................................................................. B-4
Table B-7 Status command summary ................................................................. B-7
Table B-8 System command summary ................................................................. B-8
Table B-9 Trace command summary ................................................................. B-9
Table B-10 Trigger command summary ............................................................... B-10
Table B-11 Units command summary ................................................................. B-10
Section 1 topics

**Introduction**, page 1-2
   User’s Manual content and structure, page 1-2
   Capabilities and features, page 1-2

**General information**, page 1-3
   Warranty information, page 1-3
   Contact information, page 1-3
   Safety symbols and terms, page 1-3
   Unpacking and inspection, page 1-3
   Options and accessories, page 1-4

**Front and rear panel familiarization**, page 1-4
   Front panel summaries, page 1-4
   Rear panel summaries, page 1-8

**Heat sink and cooling vents**, page 1-9

**Power-up**, page 1-11
   Line power connection, page 1-11
   Source preset, page 1-12
   Disabling the front panel, page 1-12

**Menus**, page 1-13
   CONFIG menus, page 1-13
   Direct access menus, page 1-13

**Editing controls**, page 1-14
   Source and compliance editing, page 1-14
   Menu navigation, page 1-14

**Password**, page 1-16

**Remote interface**, page 1-17

**Error and status messages**, page 1-17

**Default settings**, page 1-17
   Save and restore setups, page 1-18
   Select power-on setup, page 1-18

**SCPI programming**, page 1-17
   Optional command words, page 1-19
   Query commands, page 1-19

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**NOTE** The information in this section is an abbreviated version of the information in Section 1 of the Reference Manual. Refer to Section 1 of the Reference Manual for complete details and additional information that is not provided in this manual.
Introduction

User’s Manual content and structure

This User’s Manual is provided as a hardcopy and is also provided on the supplied Product Information CD in PDF format. The User’s Manual is an abbreviated version of the operation sections of the Reference Manual. The seven sections of the User’s Manual correspond (in abbreviated form) to the first seven sections of the Reference Manual.


Capabilities and features

- Source ±DC current from 0.1pA to 105mA.
- Voltage compliance limit from 0.1V to 105V in 10mV steps.
- 11W, four-quadrant sink or source operation (duty cycle limitation for high power sink).
- Analog filter to slow down output response.
- Triax cable guarding to optimize output response speed and reduce leakage currents in high impedance test circuits.
- Banana jack guard output for voltage measurements.
- Sweep functions: linear staircase, logarithmic staircase, and custom.
- Waveform functions (6221 only): Sine, square, ramp, and arbitrary function generator.
- Five user-saved setups.
- Delta testing when used with the Keithley Model 2182 or 2182A:
  - **Delta** – Uses a square wave output and a 3-point measurement algorithm to cancel the effects of thermal EMFs.
  - **Pulse Delta (6221 and 2182A only)** – Provides a pulse output and a 3-point (or 2-point) measurement algorithm for testing of temperature sensitive Device Under Test (DUT).
  - **Differential Conductance** – Uses a differential current output and a 3-point moving average algorithm to perform differential measurements.
- Buffer storage and recall for up to 65,536 delta readings
- Averaging filtering for delta readings
- Supported remote interfaces: **Model 6220**: GPIB and RS-232.
  **Model 6221**: GPIB, RS-232, and Ethernet.
- KI-220 language – DDC commands to emulate Model 220 operation.
General information

Warranty information

Warranty information is located at the front of this manual. Should your Model 622x 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 to provide the repair facility with the necessary information.

Contact information

Worldwide phone numbers are listed at the front of this manual. If you have any questions, please contact your local Keithley representative or call one of our Application Engineers at 888-Keithley (534-8453) or 800-552-1115 (U.S. and Canada only). You can also contact Applications Engineering online at www.keithley.com.

Safety symbols and terms

The following symbols and terms may be found on the instrument or used in this manual:

- 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 symbol indicates a connection terminal to the equipment frame.

- 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 instrument. Such damage may invalidate the warranty.

Unpacking and inspection

Inspection for damage

The Model 622x was carefully inspected 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. (There may be a protective film over the display lens, which can be removed.) Report any damage.
to the shipping agent immediately. Save the original packing carton for possible future shipment. Before removing the Model 622x from the bag, observe the following handling precautions.

**Handling precautions**

- Always grasp the Model 622x by the covers.
- After removing the Model 622x from its anti-static bag, inspect it for any obvious signs of physical damage. Report any such damage to the shipping agent immediately.
- When the Model 622x is not installed and connected, keep the unit in its anti-static bag and store it in the original packing carton.

**Package content**

The following items are included with every Model 622x order:

- Model 622x current source with line cord.
- Protective triax Shield/Cap (CAP-28-1).
- 237-ALG-2 Triax cable terminated with alligator clips on one end.
- Model 8501 Trigger Link cable.
- CA-351 null-modem serial cable.
- CA-180-3A Ethernet cross-over cable (Model 6221 only).
- Accessories as ordered.
- Certificate of calibration.
- Model 622x User’s Manual (P/N 622x-900-00).
- Product Information CD-ROM that contains PDFs of the User’s and Reference Manuals.

**Options and accessories**

The various options and accessories that are available from Keithley for the Model 622x are listed and explained in Section 1 of the Reference Manual.

**Front and rear panel familiarization**

**Front panel summaries**

The front panels of the Models 6220 and 6221 are shown in Figure 1-1. The descriptions of the front panel controls follow Figure 1-1.

Many of the keys that are used to select a function or operation are also used for configuration by first pressing the CONFIG key. For example, to configure a sweep, press CONFIG and then SWP.
Figure 1-1
Models 6220 and 6621 front panels

Model 6220:

Model 6221:
1 Special keys and power switch:

- **EDIT/LOCAL** Dual function – While in local, EDIT selects the source editing mode. While in remote, LOCAL cancel the remote mode.
- **CONFIG** Use to configure a function or operation.
- **POWER** Power switch – In position turns 622x on (I), out position turns it off (O).

2 Function and operation keys:

**Top Row**

- **FILT** Enables/disables analog filter.
- **PRES** Enables/disables the pre-set source value. Press CONFIG > PRES to set the source value for PRES.
- **DC** Selects DC current source function.
- **SWP** Arms the sweep function. Press CONFIG > SWP to configure the sweep.
- **COND** Arms Differential Conductance. Press CONFIG > COND to configure Differential Conductance.
- **DELTA** Arms Delta. Press CONFIG > DELTA to configure Delta.

**6220:**
- ▲ Increments value.
- ▼ Decrements value.

**6221:**
- **PULSE** Arms Pulse Delta. Press CONFIG > PULSE to configure Pulse Delta.
- **WAVE** Arms Wave mode. Press CONFIG > WAVE to configure Wave.

**Middle Row**

- **COMM** Configures communications: GPIB, RS-232, or Ethernet (6221). Can also press CONFIG > COMM to configure communications.
- **ADDR** Sets GPIB address.
- **DISP** Turns off display. Press LOCAL or DISP to turn display back on.
- **TRIG** Starts a sweep, delta, or wave (6221) test, or causes a manual trigger event. Press CONFIG > TRIG to configure triggers.
- **UNITS** Use to select measurement units for a delta function. Can also press CONFIG > UNITS to select measurement units.
- **RECALL** Displays buffer readings and statistics. Press CONFIG > RECALL to access menu to clear the buffer.

**6220:**
- ▼ Moves cursor (blinking digit or menu item) to the left.
- ▶ Moves cursor (blinking digit or menu item) to the right.

**6221:**
- **AMPL** Sets the amplitude for the Wave function. Can also press CONFIG > AMPL to set the amplitude. When in a menu, use this key to move the cursor to the left.
- **FREQ** Sets the frequency for the Wave function. Can also press CONFIG > FREQ to set the frequency. When in a menu, use this key to move the cursor to the right.
Bottom Row

SAVE  Saves up to five instrument setups for future recall, and selects power-on setup.

SETUP  Restores a default setup (preset or *RST) or a user saved setup.

TRIAX  Configures triax connector: Inner shield and Output Low. Can also press CONFIG > TRIAX to configure triax connector.

AVG  Enables/disables averaging filter. Press CONFIG > AVG to configure averaging filter.

MATH  Enables/disable math. Press CONFIG > MATH to configure math.

MENU  Accesses the main menu for calibration, self-tests, serial number, and beeper control.

EXIT  Cancels selection, backs out of menu structure.

ENTER  Accepts selection, moves to next choice or exits menu.

3 Range keys:

△ and ▽  Dual function – Selects the next higher or lower source range. When in a menu, these keys increment or decrement values.

AUTO  Enables or disables source autorange.

4 Output control and LED status indicator:

OUTPUT ON/OFF  Turns source output on or off. For the 6221, press CONFIG > OUTPUT to set the output response for the Model 6221.

LED indicator  Turns on when output is on. Blinks if source goes into compliance.

5 Rotary knob and CURSOR keys (Model 6221):

When in source edit, use CURSOR keys for cursor control and rotate the knob to change a source or compliance value. The rotary knob can also be used to enable or disable the source EDIT mode.

When in a menu, use the CURSOR keys or rotary knob for menu item cursor control. When displaying a menu value, use the CURSOR keys for cursor control and rotate the knob to change the value. Pressing the knob opens a menu item or selects a menu option or value.

6 Display annunciators (not shown):

EDIT  Unit is in the source editing mode.

ERR  Questionable reading or invalid cal step.

REM  Unit in remote mode.

TALK  Unit addressed to talk.

LSTN  Unit addressed to listen.

SRQ  Service request.

FILT  Analog filter or Averaging filter is enabled.

MATH  Math is enabled.

AUTO  Auto source range selected.

ARM  Sweep or delta function armed and ready to run.

TRIG  External triggering selected.

* (asterisk)  Readings being stored in buffer.

SMPL  Blinks for every other reading acquired from the Model 2182/2182A.

Return to Section 1 topics
Rear panel summaries

The rear panel of the Models 622x is shown in Figure 1-2. The Model 6221 rear panel is shown, but the Model 6220 is identical except it does not have the Ethernet connector. The descriptions of the rear panel components follow Figure 1-2.

Figure 1-2
Model 622x rear panel

NOTE  The rear panels of the Model 6220 and 6221 are the same, except the Model 6220 does not have an Ethernet connector (3).

1 IEEE-488
Connector for IEEE-488 (GPIB) operation. Use a shielded cable, such as the Model 7007-1 or 7007-2.

2 OUTPUT
3-lug female triax connector for current source output. Mates to the supplied triax cable (237-ALG-2). Will also mate to any triax cable terminated with a 3-slot male triax connector.

3 ETHERNET
RJ45 female connector for Ethernet operation. Use an RJ45 male/male cable for connection. Two status LEDs are located at the top of the connector. These LEDs indicate status of the Ethernet (see Section 10 of the Reference Manual for details).
4  DIGITAL I/O
   Male DB-9 connector. Four pins for digital output, one pin for Start of Test (SOT) trigger, and one for external voltage (VEXT) input.

5  RS-232
   Female DB-9 connector:
   • For RS-232 operation, use a straight-through (not null modem) DB-9 shielded cable for connection to the PC.
   • For Delta, Pulse Delta, and Differential Conductance, use the supplied serial cable (CA-351) for connections between the Model 622x and the Model 2182/2182A.

6  LO and GUARD
   Banana safety jacks for output low and banana jack Guard.

7  TRIGGER LINK
   Eight-pin micro-DIN connector for sending and receiving trigger pulses among connected instruments. Use a trigger link cable (Model 8501) for connections.

8  INTERLOCK
   Interlock connector – Provides two screw terminals for connection to an interlock switch. When the interlock switch is closed, the OUTPUT of the 622x is enabled, allowing it to be turned on. When the interlock switch is opened, the OUTPUT is disabled (OUTPUT cannot be turned on and will turn off if it was on).

9  Power module
   Contains the AC line receptacle and power line fuse. The instrument can operate on line voltages of 100V to 240VAC at line frequencies of 50 or 60Hz.

Heat sink and cooling vents

The Model 622x uses a heat sink and three cooling vents to dissipate heat. The right side of the case is cut out to expose the black, finned heat sink. Cooling vents are provided on both sides of the case and on the top cover.

The heat sink could get hot enough to cause burns. Even if the instrument is turned off, you should assume that the heat sink is still hot as it takes considerable time for it to cool off.
WARNING When handling the Model 622x, NEVER touch the heat sink located on the right side of the case. This heat sink could be hot enough to cause burns.

CAUTION NEVER place a container of liquid (e.g., water, coffee, etc.) on the top cover. If it spills, the liquid will enter the case through the vents and cause severe damage.

Excessive heat could damage the Model 622x and at the very least, degrade its performance. The Model 622x must be operating in an environment where the ambient temperature does not exceed 50°C.

CAUTION To prevent damaging heat build-up and thus ensure specified performance, adhere to the following precautions:

• The heat sink must be kept free of dust, dirt, and contaminants, since its ability to dissipate heat could become impaired.

• The cooling vents must be kept free of any obstructions. DO NOT place any objects on the top cover. Even partial blockage could impair proper cooling.

• DO NOT position any devices adjacent to the Model 622x that force air (heated or unheated) into or onto its cooling vents or surfaces. This additional airflow could compromise accuracy performance.

• For bench top use, the Model 622x can be placed on a hard surface that is at ambient temperature. The feet of the Model 622x will raise the chassis off the surface to allow adequate ventilation under the unit. DO NOT use the Model 622x on a soft, compliant surface, like a carpet.

• The Model 622x can be set on top of another instrument that is dissipating heat, but additional spacing is required. In order to maintain full power capability, 1.75” of spacing is required. The feet of the Model 622x only provide 0.625” (5/8”) of spacing.

• Rack mounting requires 1U of vertical spacing at the top and bottom of the Model 622x. 1U is a standard vertical spacing unit and is equal to 1.75”. The typical distance between the mounting screw holes on the rack rails is 0.125” (1/8”).

• When rack mounting the Model 622x, make sure there is adequate airflow around the sides and top to ensure proper cooling. Adequate airflow enables air temperatures within approximately one inch of the Model 622x surfaces to remain within specified limits under all operating conditions.
• Rack mounting high power dissipation equipment adjacent to the Model 622x could cause excessive heating to occur. The specified ambient temperature must be maintained around the surfaces of the Model 622x to specified accuracies.

• A good measure to ensure proper cooling in rack situations with convection cooling only is to place the hottest equipment (e.g., power supply) at the top of the rack. Precision equipment, such as the Model 622x, should be placed as low as possible in the rack where temperatures are coolest. Adding space panels below the Model 622x will help ensure adequate air flow.

Power-up

WARNING  When handling the Model 622x, NEVER touch the heat sink located on the right side of the case. This heat sink could be hot enough to cause burns.

Line power connection

Follow the procedure below to connect the Model 622x to line power and turn on the instrument. The current source operates from a line voltage of 100 to 240V at a frequency of 50 or 60Hz. Line voltage and line frequency are automatically sensed. There are no switches to set. Make sure the operating voltage in your area is compatible.

CAUTION  Operating the instrument on an incorrect line voltage may cause damage to the instrument, possibly voiding the warranty.

1. Before plugging in the power cord, make sure that the front panel power switch is in the off (O) position.
2. Connect the female end of the supplied power cord to the AC receptacle on the rear panel. Connect the other end of the power cord to a grounded AC outlet.
WARNING  The power cord supplied with the Model 622x contains a separate ground wire for use with grounded outlets. When proper connections are made, instrument chassis is connected to power line ground through the ground wire in the power cord. Failure to use a grounded outlet may result in personal injury or death due to electric shock.

3. Turn on the instrument by pressing the front panel power switch to the on (I) position.

Source preset

The PRES key can be used to set the source to a preset value. When the PRES key is pressed, the source will set to the preset value (“PRES” message displayed). When the PRES key is pressed again, the unit will return to the original source value. See “Source preset” on page 3-12 for details on setting the preset value.

Disabling the front panel

The front panel (display and most controls) can be disabled to allow testing on light sensitive devices; eliminate step-to-step timing jitter for Sweeps, Delta, and Differential Conductance; and increase system speed.

The front panel can be disabled by pressing the DISP key. The following message will be briefly displayed before the display shuts off:

FRONT PANEL DISABLED
Press LOCAL or DISP to resume.

As indicated in the displayed message, press LOCAL or DISP to enable the front panel.

Remote programming – Use the following command to control the front panel:

DISPlay:ENABle <b>  
\* Enable or disable the front panel. 
\* <b> = ON or OFF. 
\* Default setting is front panel ON.

Step-to-step timing jitter

For Sweeps, Delta, and Differential Conductance, step-to-step timing may jitter as much as 1ms. This jitter can be eliminated by disabling the front panel.

If the display is disabled while a Sweep, Delta, or Differential Conductance is running, a 2-second pause in continuous operation will occur. To avoid this pause, disable the front panel before arming the Sweep, Delta or Differential Conductance test. Keep in mind that remote programming must then be used to arm and start the test.
Menus

Many aspects of operation are configured through menus. A direct access menu can be opened by pressing a single key, and other menus require that the CONFIG key be pressed before pressing another key.

CONFIG menus

NOTE  “Press CONFIG > Press SWP” is an example of a key-press sequence. To open the menu, press the CONFIG key and then the SWP key.

Models 6220 and 6221:
- CONFIG > SWP opens CONFIGURE SWEEPS menu (Section 4).
- CONFIG > COND opens DIFF CONDUCTANCE menu (Section 5).
- CONFIG > DELTA opens CONFIGURE DELTA menu (Section 5).
- CONFIG > TRIG opens CONFIGURE TRIGGER menu (Section 8 of the 622x Reference Manual).
- CONFIG > RECALL opens CLEAR BUFFER? menu (Section 6).
- CONFIG > MATH opens CONFIGURE MATH menu (Section 6).

Model 6221 only:
- CONFIG > PULSE opens CONFIG PULSE DELTA menu (Section 5).
- CONFIG > WAVE opens CONFIGURE WAVEFORM menu (Section 7).
- CONFIG > OUTPUT opens OUTPUT RESPONSE menu (Section 3).

Direct access menus

NOTE  All of the following keys to open direct access menus (except RECALL) can also be opened by first pressing the CONFIG key.

Models 6220 and 6221:
- COMM opens COMMUNICATIONS SETUP menu (page 1-17).
- ADDR opens ADDRESS = (value) menu for GPIB.
- UNITS opens READING UNITS menu (Section 3).
- RECALL opens menu for stored readings and statistics (Section 6).
- SAVE opens SAVED SETUP MENU (page 1-18).
- SETUP opens RESTORE SETUP menu (page 1-18).
- TRIAX opens CONFIGURE TRIAX menu (Section 2).
- MENU opens MAIN MENU (see “MAIN menu” below).
Model 6221:

**AMPL** opens menu to set AMPL: (value) *(Section 7).*

**FREQ** opens menu to set FREQ (frequency) *(Section 7).*

**MAIN menu**

The MAIN MENU is a direct access menu that is opened by pressing the **MENU** key. Menu items include CAL, TEST, SERIAL#, and BEEPER. See Section 1 of the Reference Manual for more information on these MAIN MENU items.

**Editing controls**

**Source and compliance editing**

When the Model 622x is in the edit mode (EDIT annunciator on), the editing controls are used to set source and compliance values. The typical way to enter the edit mode is to press the **EDIT** key. Details on “Source and compliance editing” are provided on page 3-8.

**Menu navigation**

When the Model 622x is not in the edit mode (EDIT annunciator off), the editing controls (see **Figure 1-3**) are used to navigate menus to make selections and/or set values.

**Figure 1-3**

**Menu editing keys**

**6220 Editing Keys:**

- **Cursor Keys**
- **Value Adjust Keys**
  - ▲ RANGE
  - ▼ RANGE

**Numeric Entry Keys**

```
0 1 2 3 4 5 6 7 8 9 +/- 0000
```

**ENTER / EXIT Keys**

```
EXIT ENTER
```

**6221 Editing Keys:**

- **Rotary Knob & Cursor Keys**
- **Value Adjust Keys**
  - ▲ RANGE
  - ▼ RANGE

**Numeric Entry Keys**

```
0 1 2 3 4 5 6 7 8 9 +/- 0000
```

**Cursor Keys**

```
AMPL (left) FREQ (right)
```

**ENTER / EXIT Keys**

```
EXIT ENTER
```

Return to **Section 1 topics**
Model 6220 menu navigation

After entering a menu structure, use the editing keys as follows:

Selecting menu items

1. Use the **Cursor Keys** to place the blinking cursor on a menu item to be opened or selected.
2. Press the **ENTER** key to select an item or open a sub menu.
3. Use the **EXIT** key to cancel a change or back out of the menu structure.

Setting a value

There are two ways to adjust a value: value adjust or numeric entry. Both methods use the following editing techniques:

- To set a value to zero, press the **0000** numeric entry key.
- To toggle the polarity of a value, press the **+/–** numeric entry key.

**Value adjust method:**

1. Use the **Cursor Keys** to place the blinking cursor on the digit to be edited.
2. Use the Value Adjust Keys to increment or decrement the value of the digit. Digit(s) to the left may also change as the edited value is changed beyond “9” or under “0”.
3. Repeat steps 1 and 2 as needed to set the desired value.
4. Press **ENTER** to select the value. Pressing **EXIT** will cancel the change.

**Numeric entry method:**

1. Use the **Cursor Keys** to place the blinking cursor on the most significant digit to be edited.
2. Key in a digit by pressing a **Numeric Entry Key** (0 to 9), The cursor moves to the next digit on the right.
3. Repeat step 2 as needed to set the desired value.
4. Press **ENTER** to select the value. Pressing **EXIT** will cancel the change.
Model 6221 menu navigation

Editing for the Model 6221 is basically the same as editing for the Model 6220, except for the following differences:

- Cursor control is provided by the **Cursor Keys** located under the rotary knob.
- When at a menu level that requires an item to be selected, the **Rotary Knob** can also be used for cursor control. Turn the knob clockwise to move the cursor to the right, and turn it counter-clockwise to move the cursor to the left.
- With a value displayed, value adjust can be performed using the **Rotary Knob**. Turn it clockwise to increment a digit, and turn it counter-clockwise to decrement a digit.
- Pressing the **ROTARY KNOB** performs the same function as the **ENTER** key. Press the knob to select or open a menu item, or to select a displayed value.

Password

For remote programming, a user-defined password can be used to disable protected commands. Most Model 622x commands are protected. From the front panel, the password can be cleared using the following key-press sequence:

Press **COMM** > Select **PASSWORD** > Select **YES** to clear the password

See Section 10 of the Reference Manual for details on password.
Remote interface

For remote operation, one of the following interfaces can be used: GPIB, RS-232, and (for the Model 6221) Ethernet. When using the GPIB, the SCPI or KI-220 language can be used.

**NOTE** Interface selection and configuration can be performed from the COMMUNICATIONS SETUP menu, which is accessed by pressing the COMM key. All details on interface selection and configuration are provided in Section 10 of the Reference Manual.

**GPIB**

At the factory, the GPIB (SCPI language) is the selected interface and the GPIB address is set to 12. Use the following key-press sequence to change the address:

Press `ADDR` > Set the address (0 to 30) > Press `ENTER`

**RS-232**

When the RS-232 interface is selected, the following defaults are initially set (but can be changed):

- Baud rate: 19.2k
- Terminator: LF (line feed)
- Flow control: None

Eight data bits, one stop bit, and no parity are used for the RS-232. These settings are fixed and cannot be changed.

**Ethernet (Model 6221 only)**

The information for setting up the Ethernet is provided in Section 10 of the Reference Manual (see “Ethernet interface reference”).

Error and status messages

Error and status messages are displayed momentarily. During operation and programming, you will encounter a number of front panel messages. Typical messages are either status or error type, as listed in Appendix B of the Reference Manual.
Default settings

The Model 622x can be restored to one of seven setup configurations: five user-saved setups, PRESET (bench defaults), and *RST (bus defaults). As shipped from the factory, the Model 622x powers up to the PRESET settings. PRESET settings provide a general purpose setup for front panel operation, while the *RST settings do the same for remote operation.

See Section 1 of the Reference Manual for more information on “Default settings” including a table that lists all the default settings.

Save and restore setups

Save setup:
Press SAVE > Select SAVE > Set memory location (0 to 4) > Press ENTER

Restore user setup:
Press SETUP > Select USER > Set memory location (0 to 4) > Press ENTER

Restore PRESET defaults:
Press SETUP > Select PRESET

Restore *RST defaults:
Press SETUP > Select *RST

Remote programming

*SAV <NRf>  ‘ Save present setup in memory.
*RCL <NRf>  ‘ Recall saved user setup from memory.
‘ <NRf> = 0, 1, 2, 3, or 4
SYSTem:PRESet  ‘ Restore PRESET default setup.
*RST  ‘ Restore *RST default setup.
Select power-on setup

Power-on to PRESET defaults:
Press SETUP > Select POWER ON > Select PRESET

Power-on to *RST defaults:
Press SETUP > Select POWER ON > Select *RST

Power-on to user setup:
Press SETUP > Select POWER ON > Select USER SETUP NUMBER >
Set memory location (0 to 4) > Press ENTER

Remote programming

SYSTem:POSetup <name>  
‘Select power-on setup.
‘<name> = RST, PRESet, SAV0, SAV1, SAV2, SAV3, or SAV4.

SCPI programming

SCPI programming information is integrated with front panel operation throughout this manual. SCPI commands are listed in tables and additional information that pertains exclusively to remote operation is provided after each table.

NOTE  Except for Section 14 in the Reference Manual, most SCPI tables in this manual are abridged to some degree. That is, they may NOT include optional command words and most query commands. Optional command words and query commands are summarized as follows.

Optional command words

In order to be in conformance with the IEEE-488.2 and SCPI standards, the Model 622x accepts optional command words. Any command word that is enclosed in brackets ([ ]) is optional and need not be included in the program message.

Query commands

Most command words have a query form. A query command is identified by the question mark (?) that follows the command word. A query command requests (queries) the programmed status of that command. When a query command is sent and the Model 622x is addressed to talk, the response message is sent to the computer.
Section 2 topics

**Output connectors**, page 2-2
- Triax connector, page 2-2
- Ground points, page 2-3
- LO and GUARD banana jacks, page 2-3
- INTERLOCK, page 2-4

**Output configurations**, page 2-5
- Triax inner shield, page 2-6
- Triax output low, page 2-7

**Guards**, page 2-8
- Triax Cable Guard, page 2-8

**Floating the current source**, page 2-9

**Connections to DUT**, page 2-9
- Supplied triax cable, page 2-9
- Basic connections, page 2-10
- Shields and guarding, page 2-10

**Using a test fixture**, page 2-12

**NOTE** The information in this section is an abbreviated version of the information in Section 2 of the Reference Manual. Refer to Section 2 of the Reference Manual for complete details and additional information that is not provided in this manual.
Output connectors

Triax connector

Current source output is accessed at the 3-lug female triax connector on the rear panel. Use a 3-slot male triax cable to make connections to this connector. A triax cable terminated with alligator clips (Model 237-ALG-2) is a supplied item for the Model 622x (see “Supplied triax cable” on page 2-9). The triax connector is shown in Figure 2-1.

Figure 2-1
Triax connector and grounds points

Center conductor – Output High
Inner shield – Output Low or Cable Guard
Outer shield – Output Low for guarded configuration. (Earth Ground)

1) Frequency Variable Resistor (FVR) – Isolates the current source from high frequencies on the chassis. For DC to 60Hz, the FVR is a virtual short (zero ohms).
2) DO NOT use the Chassis Screw terminal to make signal connections to external circuitry. High frequency (>1MHz) on the chassis may result in higher noise at the output.

Earth Ground
Chassis Screw

EARTH GROUND is a local signal ground and is defined as the outer shield (shell) of the triax connector.

CHASSIS is defined as the metal chassis of the Model 622x.

Chassis screw terminal is connected to the metal chassis of the Model 622x.

Triax connector terminals

The triax connector terminals are summarized as follows. For details on these terminals, see “Output configurations” on page 2-5.

Center conductor – The center conductor of the triax connector is always connected to Output High of the current source.

Inner shield – The inner shield of the triax connector can be connected to Output Low or Cable Guard. See “Triax inner shield” on page 2-6 for details on the inner
shield connection setting. See “Triax Cable Guard” on page 2-8 for details on using the Cable Guard.

**Outer shield** – The outer shield of the triax connector is always connected to Earth Ground of the Model 622x (see “Ground points” for details).

**Frequency variable resistor (FVR)**

The outer shield (Earth Ground) of the triax connector is isolated from the chassis of the Model 622x by a Frequency Variable Resistor (FVR). The FVR (shown in Figure 2-1) is used to isolate the current source circuitry from high frequencies that may be present on the chassis of the Model 622x. As frequencies on the chassis increase, the resistance of the FVR increases to dampen its effects.

**Ground points**

The various ground points used by the Model 622x are shown and explained in Figure 2-1. The ground point for signal connections to external circuitry is Earth Ground. Earth Ground is the outer shield of the triax connector and is isolated from the Chassis by the FVR.

Keep in mind that the Chassis should never be used as a ground point for signal connections. High frequencies present on the chassis of the Model 622x may result in higher noise on the output.

The Chassis should only be used as a safety shield. Use the Chassis Screw for connections to the chassis of the Model 622x.

**LO and GUARD banana jacks**

The LO and GUARD banana jacks are located on the rear panel and are shown in Figure 2-2.

Figure 2-2

**LO**

**GUARD**

105Vpk

**LO banana jack**

The LO banana jack is electrically identical to the Output Low accessed at the triax connector. However, when using the CABLE GUARD and FLOATING triax settings, Output Low *is not* available at the triax connector. The LO banana jack must be used as Output Low (see “Output configurations” on page 2-5 for details on the triax connector settings).
GUARD banana jack

The GUARD available at the banana jack is different from CABLE GUARD that can be accessed at the triax cable. See “Guards” on page 2-8 for more information.

INTERLOCK

The Model 622x is equipped with an INTERLOCK that is to be connected to an interlock switch (see Figure 2-3). When the interlock switch is open, the OUTPUT of the Model 622x is disabled and cannot be turned on. If the OUTPUT is already on, opening the interlock switch will turn the OUTPUT off. When the interlock switch is closed, the OUTPUT is enabled and can be turned on.

Figure 2-3 shows the connector for INTERLOCK. It is a quick-disconnect screw-terminal block. Pull the terminal block off the rear panel to connect the interlock switch.

The interlock switch is mounted on a test fixture such that the switch will open (disable the OUTPUT) when the test fixture lid is opened. The switch will close (enable the OUTPUT) when the test fixture lid is closed. See “Using a test fixture” page 2-12 for details on using INTERLOCK with a test fixture.

Figure 2-3

INTERLOCK

WARNING An open INTERLOCK only disables the output from the Model 622x. If an external source is being used in the test circuit, its voltage will be present in the test circuit. A hazardous voltage from an external source could be connected directly to the OUTPUT connector of the Model 622x.

As a general rule of safety, always turn off all external sources before making or breaking connections to the test circuit.
Output configurations

There are four configurations that can be used for current source output:

- Triax inner shield is connected to Output Low, which is connected to Earth Ground (see Figure 2-4A).
- Triax inner shield is connected to Cable Guard and Output Low is connected to Earth Ground (see Figure 2-5A).
- Triax inner shield is connected to Output Low, which is disconnected from Earth Ground (Floating) (see Figure 2-4B). This is the default setting.
- Triax inner shield is connected to Cable Guard. Output Low is accessed at the LO banana jack and is disconnected from Earth Ground (Floating) (see Figure 2-5B).

Using the Model 622x with the triax inner shield connected to Output Low makes it compatible with the Keithley Model 220 current source.

WARNING To prevent electric shock and/or damage to the Model 622x, DO NOT exceed the maximum (Max) voltage levels indicated in Figure 2-4 and Figure 2-5.

CAUTION To prevent damage to internal fuses of the Model 622x, current from output low to earth ground must be limited to 1A. Use a fuse or other current limiting device in the external test circuit. One internal fuse is located between the Triax Output Low and banana jack LO. The other internal fuse is located between Triax Output Low and earth ground.

Figure 2-4
Output configurations – triax inner shield connected to Output Low

A) Triax Output Low setting: Earth Ground

B) Triax Output Low setting: Floating
Figure 2-5
Output configurations – triax inner shield connected to Cable Guard

A) Triax Output Low setting: Earth Ground

B) Triax Output Low setting: Floating

Triax inner shield

The inner shield of the triax connector can be connected to Output Low (to be compatible with the Keithley 220 Current Source) or to Cable Guard. Output Low is the default connection.

The current source OUTPUT must be OFF in order to change the inner shield setting. Perform the following steps to check or change the inner shield connection:

1. If the current source output is on, press the OUTPUT key to turn it OFF (“OFF” message is displayed).
2. On the Model 622x, press the TRIAX key to display the CONFIGURE TRIAX menu.
3. Using the cursor controls, place the blinking cursor on INNER SHIELD and press the ENTER key to display the TRIAX INNER SHIELD options.
4. Place the cursor on OUTPUT LOW (220 STYLE) or GUARD and press the ENTER key.
5. Press the EXIT key to return to the normal display state.

Remote programming (triax inner shield)

Changing the inner shield connection can only be done with the current source OUTPUT OFF. Otherwise, error +403 Not allowed with output on will occur.
Commands for triax inner shield connection:

OUTPut:ISHield?  ' Query connection for triax inner shield.
OUTPut:ISHield <name>  ' Connect inner shield to Cable Guard or Output Low.
  ' <name> = GUARD or OLOW

**Example** – Turns off the current source OUTPUT and connects the inner shield of the OUTPUT connector to Cable Guard:

OUTPut OFF
OUTPut:ISHield GUARD

**Triax output low**

Output Low can be connected to Earth Ground (which is the outer shell of the triax connector) or it can float. By default, Output Low floats.

Perform the following steps to check or change the Output Low connection:

1. On the Model 622x, press the TRIAX key to display the CONFIGURE TRIAX menu.
2. Using the cursor controls, place the blinking cursor on OUTPUT LOW and press the ENTER key to display the TRIAX OUTPUT LOW options.
3. Place the cursor on FLOATING or EARTH GROUND and press the ENTER key.
4. Press the EXIT key to return to the normal display state.

**Remote programming (triax output low)**

Commands for output low connection:

OUTPut:LTEarth?  ' Query connection for output low.
OUTPut:LTEarth <b>  ' Enable or disable triax output low connection to Earth Ground.
  ' <b> = ON (Earth Ground)
  ' = OFF (Floating)

**Example** – Disconnects (floats) triax output low from Earth Ground:

OUTPut:LTEarth OFF
Guards

The Model 622x provides two guards: triax Cable Guard and banana jack Guard.

**Cable Guard** – This guard provides a voltage that is at essentially the same potential as Output High of the Model 622x. Guarding may greatly reduce leakage current and capacitance in the test circuit. Effective guarding requires that the triax Cable Guard configuration be used for the triax cable and a guard plate be used for the DUT.

**Banana Jack Guard** – This guard is similar to cable guard in that it provides a voltage that is essentially the same potential as Output High (1mV accuracy, typical). This guard should not be used to guard a triax cable. Rather, banana jack Guard is designed for use with a voltmeter to make measurements on a high-impedance DUT.

---

**NOTE** Details on using the banana jack Guard is provided in Section 2 of the Reference Manual.

---

**Triax Cable Guard**

A triax cable has insulation resistance and capacitance between its conductors. A typical triax cable could typically have $1T\Omega/ft.$ of insulation resistance and $100pF/ft.$ of cable capacitance. Significant insulation resistance and capacitance can also be present in the test fixture for the DUT.

**Capacitance** – Any capacitance that exists between the output and the DUT slows down the response (current rise time) at the DUT. When the Model 622x output is turned on (or a step change occurs), there is an initial current surge through the capacitance seen across the load. Current will stop flowing through the capacitor after it fully charges. A current is considered to be “settled” when it is within 1% of its final value. It takes approximately five RC time constants ($5\tau$) for the capacitor to charge and allow the settled current to flow through the DUT.

**Leakage current** – After the capacitance charges, it is effectively removed from the test circuit (assuming the source level remains constant). Insulation resistance in parallel with the DUT is left, effectively making a current divider. Leakage current (not delivered to the DUT) can be significant if the insulation resistance is not significantly greater than the resistance of the DUT. For example, if the insulation resistance is only 10 times the resistance of the DUT, then 10% sourcing error will occur.

---

**NOTE** The principles of guarding are explained in Section 2 of the Reference Manual (see “Guards”).

---

Return to **Section 2 topics**
When to use Cable Guard

When to use Cable Guard is a judgement call that must be made by the user. In general, Cable Guard is used to reduce leakage current for high-impedance DUT, and reduce capacitance in the triax cable and at the DUT to improve output response (rise time). Lower capacitance results in faster output response. While Cable Guard will greatly reduce capacitance in the triax cable and at the DUT, there are other possible sources of high capacitance that can greatly degrade the overall effectiveness of guarding.

The DUT (or test circuit) may inherently have high capacitance, and/or the voltmeter used in the test system may have high capacitance. These capacitances, which cannot be guarded out, may negate the need for Cable Guard (especially for low-impedance DUT). The Keithley Model 2182/2182A Nanovoltmeter has relatively high input capacitance (~300pF, and ~500pF in special mode only).

Floating the current source

Using an external source in the test system may require that the Model 622x current source float off Earth Ground. Depending on the test circuit configuration, the external source could possibly be shorted through Earth Ground if the Model 622x is not floating off Earth Ground. Details on “Floating the current source” are provided in Section 2 of the Reference Manual.

Connections to DUT

WARNING To prevent electric shock, all power must be removed from the test system before making or breaking connections. Turn off all equipment and sources, and disconnect their power cords.

Supplied triax cable

The Model 237-ALG-2 triax cable is supplied with the Model 622x. This 6.6ft (2m) cable mates to the OUTPUT triax connector and is terminated with alligator clips that are covered with color-coded boots. Terminal identification for the cable depends on the triax connector configuration (see Figure 2-4 and Figure 2-5).

WARNING The Model 237-ALG-2 triax cable can allow exposed voltages when used in certain applications. This triax cable is intended for use only by qualified personnel who recognize shock hazards and are familiar with the safety precautions required to avoid possible injury. If this product is to be used by an operator, a qualified person must ensure the operator is protected from electric shock and contact with hazardous live circuits.
Basic connections

Basic connections can be used for low voltage (not greater than 30Vrms, 42Vpeak) testing where guarding and/or noise shielding are not required. Basic connections to a DUT are shown in Figure 2-6. Use the connections shown in Figure 2-6A if the inner shield of the triax connector is connected to Output Low. Use the connections shown in Figure 2-6B if the inner shield is connected to Cable Guard.

Figure 2-6
Basic connections to DUT

A) Inner shield connected to Output Low

B) Inner shield connected to Cable Guard

Shields and guarding

Noise shield connections

Figure 2-7 shows typical noise shielding for the two triax connector configurations. A noise shield is used to prevent unwanted signals from being induced into the test circuit. A test current below 1μA may benefit from effective shielding. Typically, the metal noise shield surrounds the DUT and is connected to Output Low.

Figure 2-7
Noise shield

A) Inner shield connected to Output Low

B) Inner shield connected to Cable Guard, Output Low connected to earth ground

* Boot color for alligator clip if using supplied triax cable.
Safety shield connections

A safety shield must be used whenever hazardous voltages (>30Vrms, 42Vpeak) will be present. The metal safety shield must completely surround DUT test circuitry and must be connected to a known Safety Earth Ground and Chassis (see Figure 2-8). Use #18AWG wire or larger for connections.

Figure 2-8
Safety shield
A) Inner shield connected to Output Low
B) Inner shield connected to Cable Guard, Output Low connected to earth ground

* Boot color for alligator clip if using supplied triax cable.

Cable Guard connections

Triax Cable Guard is used to provide guarding for the triax cable and can be extended all the way to the DUT at a metal guard plate. Connections for Cable Guard are shown in Figure 2-9.

Figure 2-9
Cable Guard connections – triax inner shield connected to Cable Guard

* Boot color for alligator clip if using supplied triax cable.
A safety shield must be used whenever hazardous voltages (>30Vrms, 42Vpeak) will be present in the test circuit. Figure 2-10 shows how to make guarded connections with the use of a safety shield.

**Using shielding and guarding together**

Figure 2-10 shows connections for a test system that uses a noise shield, a safety shield, and guarding.

**Figure 2-10**

*Connections for noise shield, safety shield, and guarding*

![Diagram of connections for noise shield, safety shield, and guarding](image)

* Triax Cable
* High (red*)
* Low (Earth Ground) (green*)
* Chassis Screw
* 622x Output
* Cable Guard (black*)
* Metal Noise Shield
* Metal Safety Shield
* Guard Plate
* Safety Earth Ground

* Boot color for alligator clip if using supplied triax cable.

**Using a test fixture**

In order to facilitate safe operation and optimum performance, a safety test fixture with a built-in interlock switch must be used. The interlock switch of the test fixture is to be connected to the “INTERLOCK” of the Model 622x (see page 2-4).

**NOTE** Guidelines to build a safe, high performance test fixture are provided in Section 2 of the Reference Manual (see “Using a test fixture”).
Section 3 topics

**Current source output capabilities**, page 3-2
   - Source ranges, page 3-2
   - Compliance, page 3-3
   - Output power (source or sink), page 3-3
   - Output response, page 3-5

**Setting source and compliance**, page 3-8
   - Source and compliance editing, page 3-8

**Sourcing current**, page 3-12
   - Remote programming – source output commands, page 3-15

---

**NOTE** The information in this section is an abbreviated version of the information in Section 3 of the Reference Manual. Refer to Section 3 of the Reference Manual for complete details and additional information that is not provided in this manual.

---

**NOTE** Supplied example software allows you to control a Model 622x from any PC using simple mouse clicks through a virtual front panel. For details, see “Using the example software” in Section 10 of the Reference Manual.
Current source output capabilities

- Nine ranges to source current from 100fA to 105mA.
- Compliance can be set from 0.1V to 105V in 10mV steps.
- Maximum output power is 11W.
- Four quadrant (source and sink) source operation

Source ranges

Each source range has 5% overrange capability. Each source range and its maximum output is listed in Table 3-1. A source range can be selected manually, or autorange can be used.

Manual ranging – A fixed source range can be selected manually using the RANGE △ and ▽ keys. When selecting a fixed range, select the lowest (best) possible range that will accommodate the output current. For example, if sourcing 12mA, select the 20mA range.

Autorange – For front panel operation, the AUTO key is a single action control. When pressed, the best range is selected for the displayed source value. For remote operation, autorange is always active when it is enabled, and the Model 622x will automatically select the best (lowest) source range for the source value.

**NOTE** More information on “Autorange” is provided on page 3-11. The commands for ranging are listed in Table 3-2.

Table 3-1
Source ranges and maximum outputs

<table>
<thead>
<tr>
<th>Source Range</th>
<th>Max Output</th>
<th>Source Range</th>
<th>Max Output</th>
<th>Source Range</th>
<th>Max Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>2nA</td>
<td>±2.1nA</td>
<td>2µA</td>
<td>±2.1µA</td>
<td>2mA</td>
<td>±2.1mA</td>
</tr>
<tr>
<td>20nA</td>
<td>±21nA</td>
<td>20µA</td>
<td>±21µA</td>
<td>20mA</td>
<td>±21mA</td>
</tr>
<tr>
<td>200nA</td>
<td>±210nA</td>
<td>200µA</td>
<td>±210µA</td>
<td>100mA</td>
<td>±105mA</td>
</tr>
</tbody>
</table>
Compliance

The compliance setting limits the output voltage of the Model 622x. The voltage compliance limit can be set from 0.1V to 105V in 10mV steps. The output will not exceed the programmed compliance level.

Make sure to set compliance to a voltage level that is greater than the voltage requirements for the load. For example, if sourcing 10mA to a 1kΩ load, the voltage compliance setting must be >10V (10mA x 1kΩ = 10V). If it is not, the Model 622x goes into compliance and the magnitude of the current output will be less than the programmed setting. For example, if compliance is set to 9V and current output is set to 10mA, only 9mA will be sourced to a 1kΩ load (9V/1kΩ = 9mA).

The OUTPUT indicator light blinks when the current source is in compliance. Either there is a fault condition in the test circuit, or the source and/or compliance levels are not properly set.

Compliance overshoot

Depending on range and load impedance, step changes in current could cause the output voltage to briefly overshoot its normal expected level by as much as 2V. During normal “out of compliance” operation, this voltage “glitch” will settle to the expected output voltage within the settling time specification for the selected range (see “Output response” on page 3-5).

If the compliance voltage is set too close to the expected output voltage, the overshoot could place the Model 622x in compliance. Due to the compliance circuitry, it could take several microseconds for the overshoot to settle and return the current source to the “out of compliance” state. This slower response to overshoot could damage a voltage sensitive DUT (Device Under Test).

One way to avoid compliance overshoot is to set a compliance that is at least 2V above the expected static output voltage. For example, if the normal operating voltage across the load is 10V, set the compliance to at least 12V.

Additional details on compliance overshoot and prevention are provided in Appendix E of the Reference Manual.

Output power (source or sink)

The maximum power output of the Model 622x is 11W. The bipolar current source provides four quadrant source or sink operation. When connected to a passive DUT, the Model 622x operates as a source. When connected to an active load (e.g., external source, capacitor), the Model 622x can operate as a source or sink.

When operating as a source, current is delivered to a test circuit. The polarity of the current and the voltage seen at the output are the same (both positive or both negative).
When operating as a sink, the Model 622x is dissipating power rather than sourcing it. The polarity of the current and voltage seen at the output is opposite (one positive, one negative). An external source or an energy storage device, such as a capacitor, can force operation into the sink region.

Figure 3-1 shows examples of the Model 622x connected to an external source where it can operate as a source or sink. For both examples, the Model 622x is programmed to output +10mA. When connected to the 1kΩ resistor and 10V source as shown in Figure 3-1A, the Model 622x operates as a 200mW source supplying power to the external test circuit. When the external voltage is decreased to -30V as shown in Figure 3-1B, the Model 622x instead operates as a sink. The Model 622x dissipates 200mW of power (10mA x -20V = -200mW).

Figure 3-1
Source and sink examples

A) Source operation

B) Sink operation

Operating boundaries

Figure 3-2 shows the four quadrants of operation for the Model 622x. When operating in the first (I) or third (III) quadrant, the Model 622x is operating as a source. Figure 3-1A shows an example of quadrant I operation (current and voltage both positive).

When operating in the second (II) or fourth (IV) quadrant, the Model 622x is operating as a sink. Figure 3-1B shows an example of quadrant IV operation (current positive and voltage negative).
Output response

Output response is the time it takes for an output change to settle to within 1% of its final value. For the Model 6220, output response (settling time) can be as fast as 100µs (typical). For the Model 6221, output response can be as fast as 2µs (typical) for the higher source ranges. If desired, the output response of the Model 6221 can be set to match the output response of the Model 6220 (both typically 100µs).

For the Models 6220 and 6221, an analog filter can be enabled to slow down the output response. For a high-impedance load, the analog filter reduces overshoot, excessive noise, and instability (oscillation).

Analog filter

The Model 622x has an analog filter that, when enabled, will slow down the output response (settling time) of the current source.

When the analog filter is enabled, a capacitor (typically 33pF) is placed across the output. Depending on the load impedance, the analog filter may or may not significantly increase the settling time of the current source.
For example, assume the Model 6221 is on the 2mA range and FAST response is selected. For this configuration, the Settling Time is specified at 2µs (typical). Also assume the load impedance is 1kΩ. With the analog filter enabled, the additional settling time (five time constants) is calculated as follows:

\[
\text{Additional settling time} = 5RC = 5 \times 1\,\text{kΩ} \times 33\text{pF} = 0.165\mu\text{s}
\]

Enabling the analog filter adds 0.165µs settling time, which is not a significant increase in comparison to 2µs.

Now assume the load is 1MΩ. The additional settling time with the analog filter enabled is 165µs (5 x 1MΩ x 33pF). The analog filter greatly increased the settling time from 2µs to approximately 167µs.

**NOTE** The above example is only intended to show how load impedance affects settling time when using the analog filter. Actual settling times will also depend on other impedances present in the test circuit, such as capacitance and leakage resistance in cabling and in the test fixture.

For load impedances <10kΩ, the analog filter has little effect on the output response. At the 10kΩ load impedance point, the filter capacitor across the load creates a filter response of less than 1MHz, which is the maximum output bandwidth of the Model 6221 for the higher current ranges.

For load impedances greater than 1MΩ, the reduced response of the filtered output can significantly reduce overshoot, noise, and instability (oscillation).

With the analog filter disabled, the output capacitance of the Model 622x is <10pF.

If not sure about using the analog filter, experimentation may be the best way to determine which analog filter state (enabled or disabled) provides the best results.

**NOTE** An external user-supplied filter can be effective at reducing high frequency noise generated by the Model 622x current source. For details, see “External user-supplied filter” in Appendix E of the Reference Manual.
Response speed setting (6221 only)

The filter response speed of the Model 6221 can be set for FAST or SLOW. For the SLOW setting, the output response of the Model 6221 is the same as the output response of the Model 6220.

The FAST setting allows a faster output response. The FAST response setting changes the maximum output response bandwidth of the Model 6221 to 1MHz. It also reduces stability. The output will remain stable into a 10µHz (typical) load. For a more complex load, the faster speed may make the test system more susceptible to oscillation.

Note that output stability into an inductive load is only dependent on the response mode setting and is not affected by the analog filter (on or off).

Again, experimentation may be the best way to determine which response setting (FAST or SLOW) provides the best results.

Settling time specifications

The output “Settling Time” specifications are listed in Appendix A and assume that the analog filter is disabled. For the Model 6221, settling times are provided for the FAST and SLOW response speed settings. Note that the SLOW setting of the Model 6221 has the same response as the Model 6220. Enabling the analog filter may or may not significantly increase settling times. For details, see “Analog filter” on page 3-5.

NOTE All settling times are typical into a resistive load to 1% of final value.

The listed settling times in Appendix A are specified for a resistive load. The maximum load resistance for the specified settling times is calculated as follows:

Max Load Resistance = 2V / I_{FULL SCALE OF RANGE}

For example, on the 20mA range, the max load resistance is calculated as follows:

Max Load Resistance = 2V / 20mA = 100Ω

The settling times for other load conditions can be calculated as explained in Section 3 of the Reference Manual (see “Settling time specifications”).
Setting source and compliance

Source and compliance editing from the front panel cannot be performed from the front panel if the Model 622x is in remote. To return to the local state, press the **LOCAL** key.

For **remote programming**, commands to select source range, and set source and compliance values are shown in **Table 3-2**. Programming examples are also provided in the procedure for “Sourcing current” on page 3-12.

### Source and compliance editing

**Figure 3-3** explains how to set source and compliance values for the Model 6220. **Figure 3-4** shows the source and compliance editing controls for the Model 6221. The procedure to set source and compliance values for the Model 6221 follow **Figure 3-4**. “Source/compliance editing notes” for both procedures are provided on page 3-9.

**Figure 3-3**
**Source and compliance editing – Model 6220**

<table>
<thead>
<tr>
<th>Step 1</th>
<th>Step 2</th>
<th>Step 3</th>
<th>Step 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Select DC output mode</td>
<td>Select source range</td>
<td>Enter editing mode</td>
<td>Set source or compliance value</td>
</tr>
<tr>
<td>DC</td>
<td>RANGE</td>
<td><strong>EDIT/LOCAL</strong></td>
<td><strong>ENTER/EXIT</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>AUTO</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>RANGE</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Value Adjust Keys**

| ▲ | ▼ | ⬅️ | ⬆️ | ENTER/EXIT |

**Numeric Entry Keys**

0 1 2 3 4 5 6 7 8 9 +/- 0000

While in the edit mode, use the Value Adjust Method or Numeric Entry Method to edit values. Use these editing techniques for both methods:

- To set I-source value to zero or the V-compliance value to 0.10V (minimum), press the 0000 key.
- To toggle the I-source polarity, press the +/- key.

**Value Adjust Method:**

a) Use **Cursor Keys** to place blinking cursor on digit to be edited.

b) Use **Value Adjust Keys** to increment or decrement the value of the digit.

**Numeric Entry Method:**

a) Use **Cursor Keys** to place blinking cursor on the MSD digit to be edited.

b) Key in a digit by pressing a number key (0-9). Cursor moves to the next digit. Edit each digit as needed.

Return to **Section 3 topics**
Source/compliance editing notes

The following notes apply to source editing for both the Models 6220 (Figure 3-3) and 6221 (Figure 3-4):

1. The displayed source and/or compliance value can only be edited if the DC source mode is selected.
2. Select a fixed range that will accommodate the source value to be set. Note that after a source value is set (Step 4 in Figure 3-3), pressing AUTO range will select the best fixed range (if it is not already selected). Details on “Autorange” are provided on page 3-11.
3. The Model 622x must be in the edit mode in order to edit source and compliance values.
4. The first press of the EDIT key selects the editing mode for the I-source field (EDIT annunciator turns on). Each subsequent press toggles between the source field and the compliance field. The flashing digit indicates which reading (source or compliance) is presently selected for editing.
5. The unit will exit the editing mode if an editing action is not performed within six seconds. To re-enter the edit mode, perform one of the following.
   • For the Model 6220, press a Value Adjust Key or a Cursor Key to re-enter the edit mode for the last selected field.
   • For the Model 6221, press a Cursor Key or the Rotary Knob to re-enter the edit mode for the last selected field.
   • For both models, press the EDIT key to re-enter the edit mode for the I-source field.
6. You cannot set a digit to a value that exceeds the maximum allowable setting. For the I-source field, the largest allowable value is limited by the selected range (e.g., ±2.1000mA for the 2mA source range). For the I-compliance field, the largest allowable value is 105.00V.
7. When editing the source value, the output is updated immediately, allowing you to adjust the source value while the output is on. To exit the edit mode, allow it to time out, or press ENTER or EXIT.
8. When editing the compliance value, compliance is not updated until the edit mode is allowed to time out, or when ENTER or EXIT is pressed.
Perform the following steps to set source and compliance values for the Model 6221. The notes in the steps refer to the “Source/compliance editing notes” on page 3-9.

Step 1  **Select DC output mode**

1. Press the **DC Output Select Key** to select
   the DC output mode.

Step 2  **Select source range**

2. Use the **Range Keys** to select a source
   range.

Step 3  **Enter source editing mode**

3, 4, 5. Use the **EDIT Key** to select the
   I-source field or V-compliance field (EDIT annunciator turns on). The
   editing mode will cancel if an editing action is not performed within six
   seconds. To re-enter the edit mode for the same field, press a **Cursor
   Key**, or push and release the **Rotary Knob**.

Step 4  **Set source or compliance value**

2, 6, 7, 8. Use the Value Adjust
   Method or Numeric Entry Method to edit values. Use these editing tech-
   niques for both methods:

   - To set the I-source value to zero or set the V-compliance value to
     0.10V (minimum), press the **0000** key.
   - To toggle the I-source polarity, press the **+/−** key.

**Value Adjust Method:**

a. Use the **Cursor Keys** to place the blinking cursor on the digit to
   be edited.

b. Turn the **Rotary Knob** clockwise to increment the value, or
   counter-clockwise to decrement.

**Numeric Entry Method:**

a. Use the **Cursor Keys** to place the blinking cursor on the digit to
   be edited.

b. Key in a digit by pressing a number key (0-9). The cursor moves
   to the next digit. Edit each digit as needed.
Autorange

**Front panel operation**

The **AUTO** range key is a single action control to select the best fixed range for the displayed source value. After setting a source value, pressing **AUTO** will ensure that the best fixed range is selected.

For example, assume the source is set to +1mA on the 20mA range (+01.000 mA displayed). When the **AUTO** key is pressed, the range will change to the 2mA range (which is the best range).

Autorange is only asserted (enabled) for the instant that the **AUTO** key is pressed. Therefore, the **AUTO** annunciator does not turn on. If already on the best range, pressing **AUTO** will result in no action.

**Remote operation**

For remote operation, autorange remains active when it is enabled. When the source value is changed, the range will (if needed) automatically change to the best range for that value. With auto range enabled, the **AUTO** annunciator turns on to indicate that autorange is active.

For example, assume autorange is enabled, and the source is presently set for 1mA on the 1mA range. When the source value is changed to 5mA, the range will automatically uprange to the 10mA range.

Active autorange will disable if a command to select a fixed range is sent. The commands to control autorange and select a fixed range are listed in Table 3-2.

---

**NOTE**  
Active autorange is only intended for remote operation. When the Model 622x is taken out of remote (e.g., **LOCAL** key pressed), the **AUTO** annunciator stays on and automatic down-ranging remains active. Active autorange will disable (**AUTO** annunciator turns off) when a RANGE $\Delta$ or $\nabla$ key is pressed.
Source preset

The **PRES** key can be used to set the source to a preset value and range. When the **PRES** key is pressed, the source will select the preset range and set the preset value. The preset value is set as follows:

1. Press the **PRES** key. The message “PRES” is displayed while the preset value is being used.
2. Using the source editing keys as explained in Figure 3-3 and Figure 3-4, set the preset value to the desired level.

When finished using the preset value, press **PRES** again to disable the feature. The “PRES” message will cancel, and the unit will return to the original source value. Note that the compliance value cannot be preset, and source preset values cannot be saved as part of a user setup.

Sourcing current

To source current, (1) connect the test circuit (DUT) to the output, (2) set the source range output value and compliance, (3) enable the output filter (if desired), and finally, (4) turn the output on.

1. **Connect test circuit (DUT) to Model 622x output.**

   **WARNING** Before making or breaking connections, the Model 622x must be turned off and the power cord must be disconnected from the AC outlet. Also, power must be removed from all external test circuits and instrumentation.

   Connection information is provided in Section 2. Keep in mind that there are two basic output triax connector configurations that can be selected:
   - **Inner shield connected to Output Low.** Cable Guard is not available.
   - **Inner shield connected to Cable Guard** with Output Low connected to the outer shield (Earth Ground) of the triax connector.

2. **Set the source and compliance values.**
   - **Figure 3-3** explains how to set the source and compliance values for the Model 6220.
   - **Figure 3-4** explains how to set the source and compliance values for the Model 6221.

   While in the edit mode, **AUTO** range can be used, but range changes will not occur during the editing process. After setting the I-source value for a fixed range, enabling AUTO range will select the optimum (lowest) range for the source value.
Remote programming – Autorange can be used when setting the I-source value. With autorange enabled, the Model 622x will automatically select the optimum (lowest) range to accommodate the source value.

The commands to select the source range, and set the output and compliance values are provided in Table 3-2. The following examples demonstrate proper syntax.

Example – Select the 20mA source range, set the source to output 12mA, and set compliance to 10V:

```plaintext
CURRent:RANGe 12e-3  ' Selects the 20mA range.*
CURRent 12e-3       ' Sets the DC output to 12mA.
CURRent:COMPliance 10  ' Sets voltage compliance to 10V.
```

* To select a fixed source range, specify a parameter value that is the same as the current output value to be sourced. For the parameter value “12e-3”, the Model 622x selects the lowest range (20mA) that will accommodate a 12mA output.

3. If desired, change the output response.

For the Models 6220 and 6221, an analog output filter can be enabled to slow down the output response. For the Model 6221, the output response can be set to FAST or SLOW. See “Output response”, page 3-5 for details on setting the output response.

Analog filter – Use the FILT key to toggle the state (on or off) of the low-pass filter. When this key is first pressed, the message “FILTER ON” will be briefly displayed and the “FILT” annunciator turns on. To disable the filter, again press the FILT key (“FILT” annunciator turns off).

Response speed setting (6221) – The response speed can only be changed while the output is off. Response speed is set as follows:

a. Press the CONFIG key and then the OUTPUT key to display the output response menu.

b. Using the controls for “Menu navigation” on page 1-14, select the FAST or SLOW (6220 STYLE) response speed.

For remote programming, the commands to set output response are shown in Table 3-2. The following example demonstrates proper syntax.

### NOTE
If the output was on when attempting to access the output response menu, the output will turn off. Repeat step a above to access the output response menu.
Example – Enables the analog filter and, for the Model 6221, sets the output response to fast:

- CURRent:FILT er ON ' Enables the analog filter.
- OUTPut:RESP onse FAST ' Sets the output response of the 6221 to FAST.

4. Turn on the output.

**NOTE** In order to turn on the output, an interlock switch must be connected to the INTERLOCK connector on the rear panel of the Model 622x. Closing the interlock switch will enable the OUTPUT allowing it to be turned on. For details, see “INTERLOCK” on page 2-4.

The OUTPUT key toggles the output state (on or off). When the output is turned on, the OUTPUT indicator light turns on.

For remote programming, the command to control the output is shown in Table 3-2. The following example demonstrates proper syntax.

**Example** – Turns the output on:

- OUTPut ON ' Turns output on.

The OUTPUT indicator will blink if the current source goes into compliance. This indicates that the set current is not being delivered to the load. See “Compliance” on page 3-3 for details.
Remote programming – source output commands

Table 3-2 lists the commands to configure and control the DC output. A programming example to output DC current is also provided.

Table 3-2
DC output commands

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLEar</td>
<td>Turns output off and sets output level to zero.</td>
<td></td>
</tr>
<tr>
<td>CURRent:RANGE &lt;n&gt;</td>
<td>Sets current source range (amps).&lt;sup&gt;1&lt;/sup&gt;,&lt;sup&gt;2&lt;/sup&gt;</td>
<td>100e-3</td>
</tr>
<tr>
<td></td>
<td>&lt;n&gt; = -105e-3 to 105e-3</td>
<td></td>
</tr>
<tr>
<td>CURRent:RANGE:AUTO &lt;b&gt;</td>
<td>Enables or disables source autorange.</td>
<td>OFF</td>
</tr>
<tr>
<td></td>
<td>&lt;b&gt; = ON or OFF</td>
<td></td>
</tr>
<tr>
<td>CURRent &lt;n&gt;</td>
<td>Sets DC current source output level (amps).</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>&lt;n&gt; = -105e-3 to 105e-3</td>
<td></td>
</tr>
<tr>
<td>CURRent:COMpliance &lt;NRf&gt;</td>
<td>Sets voltage compliance (volts).</td>
<td>10.0</td>
</tr>
<tr>
<td></td>
<td>&lt;NRf&gt; = 0.1 to 105</td>
<td></td>
</tr>
<tr>
<td>CURRent:FILTER &lt;b&gt;</td>
<td>Enables or disables the output analog filter.</td>
<td>OFF</td>
</tr>
<tr>
<td></td>
<td>&lt;b&gt; = ON or OFF</td>
<td></td>
</tr>
<tr>
<td>OUTPut:RESPonse &lt;name&gt;</td>
<td>Select fast or slow output response speed for 6221.</td>
<td>FAST</td>
</tr>
<tr>
<td></td>
<td>&lt;name&gt; = FAST or SLOW&lt;sup&gt;3&lt;/sup&gt;,&lt;sup&gt;4&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>OUTPut &lt;b&gt;</td>
<td>Turn output on or off.</td>
<td>OFF</td>
</tr>
<tr>
<td></td>
<td>&lt;b&gt; = ON or OFF</td>
<td></td>
</tr>
<tr>
<td>SourceMeter</td>
<td>Sets output to zero, then turns the output off.</td>
<td></td>
</tr>
</tbody>
</table>

1. To select a fixed source range, specify the current output value that is going to be sourced. The Model 622x will go to the lowest range that can source that value. For example, if you are going to source 25mA, let <n> = 25e-3. The 100mA range will be selected.
2. Selecting a fixed source range disables autorange.
3. The output must be off in order change the output response. Sending this command while the output is on will generate error -220 Execution Error.
4. OUTP OFF turns the output off, but does change the set output level. SOUR:CLE sets the output level to zero and then turns the output off.
Programming example

The following programming example shows a typical command sequence to configure and control the DC output:

- `CLEar`  
  'Turns the output off.'
- `CURRent:RANGe:AUTO ON`  
  'Enables autorange.'
- `CURRent 12e-3`  
  'Sets output level to +12mA.'
- `CURRent:COMPliance 10`  
  'Sets voltage compliance to 10V.'
- `OUTPut ON`  
  'Turns the output on.'
- `OUTPut OFF`  
  'Turns the output off.'

Applications

Some applications for the Model 622x are summarized below. See Appendix E of the Reference Manual for details on these applications.

- **Calibration source** – Explains how to use Model 622x as a current calibration source. The custom sweep function allows a user-defined list of current source values to be stored in memory. During the calibration process, each current source level is output in the order that it appears in the list.

- **Resistivity measurements** – Certain semiconductor materials such as silicon have high resistivities. The Model 622x can be used to source stable and accurate current, and the Keithley 6514 Electrometer can be used to provide an accurate voltage measurement. Resistivity is then calculated.

- **Diode characterization** – With the Model 622x and Keithley 6514 Electrometer, it is possible to plot I-V (current-voltage) characteristics of a diode over several decades. The Model 6514, with its high input resistance, will allow the voltage measurement to be accurately made.

- **Transistor characterization** – The Model 622x can be used with a Keithley 24xx SourceMeter to characterize a device’s electrical DC parameters. The Model 622x Current Source is configured to sweep a number of base currents for the test. The Model 24xx SourceMeter is configured to sweep voltage and measure current.

- **External user-supplied filter** – Based on load impedance and response time requirements, a user-supplied filter can be effective at reducing high frequency noise generated by the Model 622x current source.

- **Compliance overshoot prevention** – Depending on range and load impedance, step changes in current could cause the output voltage to briefly overshoot its set compliance level by as much as 2V and take several microseconds to settle. A few microseconds of overshoot could be enough to damage voltage sensitive devices.
Section 4 topics

Sweep overview, page 4-2
  Linear staircase sweep, page 4-2
  Logarithmic staircase sweep, page 4-2
  Custom sweep, page 4-2

Sweep characteristics, page 4-4
  Custom sweep editing, page 4-4
  Using auto-copy with custom sweeps, page 4-4
  Source ranging, page 4-4
  Sweep delay, page 4-5

Front panel sweep operation, page 4-5
  Using the sweep configuration menu, page 4-5
  Performing a staircase sweep, page 4-6
  Running a staircase sweep, page 4-9

Remote sweep operation, page 4-8
  Running a staircase sweep, page 4-9
  Running a custom sweep, page 4-10
  SCPI commands — sweeps, page 4-11

NOTE The information in this section is an abbreviated version of the information in Section 4 of the Reference Manual. Refer to Section 4 of the Reference Manual for complete details and additional information that is not provided in this manual.
Sweep overview

As shown in Figure 4-1, the Model 622x Current Source can generate three types of DC current sweeps.

**NOTE** User setups cannot be saved or recalled while a sweep is armed or running. Attempting to do so will generate error +413 Not allowed with mode arm.

**Linear staircase sweep**

With this sweep type, the current increases or decreases in specific steps, beginning with a start current and ending with a stop current. Figure 4-1A shows an increasing linear staircase sweep from a 1mA start current to a 5mA stop current in 1mA steps. The bias current is the fixed current setting just prior to the start of the sweep. The current output will remain at the last point in the sweep after completion.

**Logarithmic staircase sweep**

In this case, the current increases or decreases logarithmically, beginning with a start current and ending with a stop current. Figure 4-1B shows an increasing log staircase sweep from a 0.1mA start current to a 100mA stop current with logarithmic steps. Again, the bias current is the fixed current setting just prior to the start of the sweep. The current output will remain at the last point in the sweep after completion.

**Custom sweep**

The custom sweep allows you to program arbitrary sweep steps anywhere within the output current range of the Model 622x. Figure 4-1C shows a typical custom sweep with arbitrary steps. As with the other two sweep types, the bias current is the fixed current setting just prior to the start of the sweep. The current output will remain at the last point in the sweep after completion.

**NOTE** A custom sweep cannot be saved as a user setup. Attempting to do so will generate error +528 Cannot save CUSTOM sweep setup.
Figure 4-1
Comparison of sweep types

A. Linear Staircase Sweep

Start
Bias
1mA
2mA
3mA
4mA
5mA (Stop)
0mA

B. Logarithmic Staircase Sweep

Start
Bias
0.1mA
1mA
10mA
100mA
Stop
Logarithmic scale shown for staircase steps.
0mA

C. Custom Sweep

First Point
Bias
Last Point
0mA

Return to Section 4 topics
Sweep characteristics

Custom sweep editing

A typical custom sweep editing display is shown below:

P12345: +1.234567 mA
Del:123456.789s  Cmpl:100.00 V

The leftmost value on the top line is the point number, and the next value is the actual current setting. The formatting also shows the current range. The bottom line values are delay in seconds and compliance. Before entering this display, use the #-POINTS menu to select the number of sweep points. The editing for the custom sweep point adjust menu will not accept values above the number of points selected.

Using auto-copy with custom sweeps

An “auto-copy” feature is included to help reduce keystrokes when editing custom sweeps. If auto-copy is enabled, whenever a point is entered (by pressing the ENTER key), the compliance and delay values will automatically be copied to all higher-numbered points in the list.

Source ranging

The source ranging setting determines how the Model 622x selects the current range based on the sweep steps as follows:

- **BEST** — With this option, the unit will select a single fixed source range that will accommodate all of the source levels in the sweep.
- **AUTO** — With this option, the Model 622x will select the most sensitive source range for each source level in the sweep. Note that the output current goes to zero during the range change.
- **FIXED** — With this option, the source remains on the range it is on when the sweep is started. For sweep points that exceed the source range capability, the source will output the maximum level for that range.

NOTE  Jitter – Step-to-step sweep timing may jitter as much as 1ms. This jitter can be eliminated by disabling the front panel. For details, see “Step-to-step timing jitter” on page 1-12.

Return to Section 4 topics
Sweep delay

The sweep delay parameter determines how long the Model 622x will remain on each sweep step once the output current is set to the step value. For linear and logarithmic staircase sweeps, the sweep delay period is the same for every step in the sweep. For customs sweeps, the sweep delay for each step can be independently programmed.

The programmable range for the sweep delay is from 0.001s to 999999.999s.

Front panel sweep operation

Using the sweep configuration menu

To configure sweeps, press CONFIG then SWP, then make your selections from Table 4-1 below. See the detailed procedures for each sweep type below.

Table 4-1
Sweep configuration menu

<table>
<thead>
<tr>
<th>Menu selection</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>TYPE</td>
<td>Select sweep type: Set START, STOP, STEP, DELAY. Set START, STOP, NO OF POINTS, DELAY. Set #-POINTS, ADJUST POINTS, AUTO COPY*.</td>
</tr>
<tr>
<td>STAIR</td>
<td></td>
</tr>
<tr>
<td>LOG</td>
<td></td>
</tr>
<tr>
<td>CUSTOM</td>
<td></td>
</tr>
<tr>
<td>SWEEP-COUNT</td>
<td>Choose sweep count: Enter desired # of sweeps. Continuously repeating sweeps.</td>
</tr>
<tr>
<td>FINITE</td>
<td></td>
</tr>
<tr>
<td>INFINITE</td>
<td></td>
</tr>
<tr>
<td>SOURCE-RANGING</td>
<td>Select source ranging: Use best range based on maximum sweep step. Auto range based on individual sweep step. Always stay on fixed source range.</td>
</tr>
<tr>
<td>BEST</td>
<td></td>
</tr>
<tr>
<td>AUTO</td>
<td></td>
</tr>
<tr>
<td>FIXED</td>
<td></td>
</tr>
<tr>
<td>COMPLIANCE-ABORT</td>
<td>Select compliance abort mode: Do not abort sweep if compliance reached. Abort sweep if compliance reached.</td>
</tr>
<tr>
<td>NO</td>
<td></td>
</tr>
<tr>
<td>YES</td>
<td></td>
</tr>
</tbody>
</table>

* Select AUTO COPY ON to automatically copy delay and compliance values to all sweep points.
Performing a staircase sweep

1. **Configure source functions:**
   a. If desired, set the bias current (output current prior to the start of the sweep) by pressing the DC key and then setting the current to the desired value.
   b. Select the compliance display field, then set the voltage compliance as appropriate for expected sweep parameters.

2. **Configure the sweep as follows:**
   a. Press CONFIG then SWP to enter the sweep configuration menu.
   b. Select TYPE, then press ENTER.
   c. Select STAIR or LOG, then press ENTER to choose a linear staircase sweep.
   d. For STAIR sweeps, enter the desired START, STOP, STEP, and DELAY values. For LOG sweeps, enter the desired START, STOP, NO OF POINTS, and DELAY values.
   e. From the CONFIGURE SWEEPS menu, select SWEEP-COUNT, press ENTER, then choose FINITE or INFINITE as desired.
   f. Again from the CONFIGURE SWEEPS menu, choose SOURCE-RANGING, press ENTER, then select BEST, AUTO, or FIXED as appropriate.
   g. From the CONFIGURE SWEEPS menu, select COMPLIANCE-ABORT, press ENTER, then choose to abort (YES) or not to abort (NO) the sweep if compliance is reached while the sweep is in progress.
   h. Press EXIT to return to normal display.

3. **Run sweep:**
   a. Press the SWP key to arm the sweep. The output will turn on.
   b. Press TRIG to start the sweep.
   c. Press EXIT to abort the sweep before it is finished.
   d. Turn the output off by pressing the ON/OFF OUTPUT key when the sweep is finished.
Performing a custom sweep

1. Configure the bias current (output current prior to the start of the sweep) by pressing the DC key and then setting the current to the desired value.

2. **Configure the sweep as follows:**
   
a. Press CONFIG then SWP to enter the sweep configuration menu.
   
b. Select TYPE, then press ENTER.
   
c. Select CUSTOM, then press ENTER to choose a custom sweep.
   
d. Select #-POINTS, press ENTER, then enter the number of sweep points (64,000 maximum).
   
e. Choose AUTO-COPY, press ENTER, then enable (YES) or disable (NO) auto copy. With auto copy enabled, compliance and delay values are automatically copied to all sweep point locations.
   
f. Select ADJUST-POINTS, then set the current value, compliance, and delay for the first sweep point.
   
g. Set the current value, compliance (if not using auto-copy), and delay for each remaining sweep point.
   
h. From the CONFIGURE SWEEPS menu, select SWEEP-COUNT, press ENTER, then choose FINITE or INFINITE as desired.
   
i. Again from the CONFIGURE SWEEPS menu, choose SOURCE-RANGING, press ENTER, then select BEST, AUTO, or FIXED as appropriate.
   
j. From the CONFIGURE SWEEPS menu, select COMPLIANCE-ABORT, press ENTER, then choose to abort (YES) or not to abort (NO) the sweep if compliance is reached while the sweep is in progress.
   
k. Press EXIT to return to normal display.

3. **Run sweep:**
   
a. Press the SWP key to arm the sweep. The output will turn on.
   
b. Press TRIG to start the sweep.
   
c. Press EXIT to abort the sweep before it is finished.
   
d. Turn the output off by pressing the ON/OFF OUTPUT key when the sweep is finished.
Remote sweep operation

Procedures for programming and running a sweep are shown on the following pages. Each of these procedures includes commands for a typical sweep example. Table 4-2 summarizes parameters for each of these examples. See “SCPI commands — sweeps,” page 4-11 for listings of sweep commands.

Table 4-2
Sweep example parameters

<table>
<thead>
<tr>
<th>Sweep type</th>
<th>Parameters for sweep examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear staircase sweep (page 4-9)</td>
<td>Start current: 1mA</td>
</tr>
<tr>
<td></td>
<td>Stop current: 10mA</td>
</tr>
<tr>
<td></td>
<td>Step current: 1mA</td>
</tr>
<tr>
<td></td>
<td>Delay: 1s</td>
</tr>
<tr>
<td></td>
<td>Source range: best fixed</td>
</tr>
<tr>
<td></td>
<td>Compliance abort: off</td>
</tr>
<tr>
<td></td>
<td>Sweep count: 1</td>
</tr>
<tr>
<td></td>
<td>Bias current: 100μA</td>
</tr>
<tr>
<td></td>
<td>Compliance: 10V</td>
</tr>
<tr>
<td>Custom (list) sweep (page 4-10)</td>
<td># points: 5</td>
</tr>
<tr>
<td></td>
<td>Points: 3mA, 1mA, 4mA, 5mA, 2mA</td>
</tr>
<tr>
<td></td>
<td>Delay: 3s, 1s, 4s, 5s, 2s</td>
</tr>
<tr>
<td></td>
<td>Compliance: 3V, 1V, 4V, 5V, 2V</td>
</tr>
<tr>
<td></td>
<td>Source range: auto</td>
</tr>
<tr>
<td></td>
<td>Compliance abort: off</td>
</tr>
<tr>
<td></td>
<td>Sweep count: 1</td>
</tr>
<tr>
<td></td>
<td>Bias current: 50μA</td>
</tr>
</tbody>
</table>

Return to Section 4 topics
Running a staircase sweep

1. **Configure source functions.**

   **Examples** – The following commands restore defaults, set the bias current to 100μA, and the compliance to 10V:

   ```
   *RST
   SOUR:CURR 1e-4
   SOUR:CURR:COMP 10
   ```

   `*RST` ' Restore 622x defaults.

   `SOUR:CURR 1e-4` ' Set bias current to 100μA

   `SOUR:CURR:COMP 10` ' Set compliance to 10V.

2. **Configure the sweep.**

   **Examples** – The following commands configure a single linear staircase sweep from 1mA to 10mA with 1mA steps using a 1s delay, best fixed source range, and compliance abort disabled:

   ```
   SOUR:SWE:SPAC LIN
   SOUR:CURR:STAR 1e-3
   SOUR:CURR:STOP 1e-2
   SOUR:CURR:STEP 1e-3
   SOUR:DEL 1
   SOUR:SWE:RANG BEST
   SOUR:SWE:COUN 1
   SOUR:SWE:CAB OFF
   ```

   `SOUR:SWE:SPAC LIN` ' Select linear staircase sweep.

   `SOUR:CURR:STAR 1e-3` ' Set start current to 1mA.

   `SOUR:CURR:STOP 1e-2` ' Set stop current to 10mA.

   `SOUR:CURR:STEP 1e-3` ' Set step current to 1mA.

   `SOUR:DEL 1` ' Set delay to 1s.

   `SOUR:SWE:RANG BEST` ' Select best fixed source range.

   `SOUR:SWE:COUN 1` ' Set sweep count to 1.

   `SOUR:SWE:CAB OFF` ' Disable compliance abort.

3. **Arm and run the sweep:**

   ```
   SOUR:SWE:ARM
   INIT
   ```

   `SOUR:SWE:ARM` ' Arm sweep, turn on output.

   `INIT` ' Trigger sweep.

4. **When the sweep is done, turn the source output off with this command:**

   ```
   OUTP OFF
   ```
Running a custom sweep

1. **Configure source functions.**
   
   **Examples** – The following commands restore defaults and set the bias current to 50μA:
   
   *RST  
   SOUR:CURR 5e-5  
   
   *RST  ‘ Restore 622x defaults.  
   SOUR:CURR 5e-5  ‘ Set bias current to 50μA

2. **Configure the sweep.**
   
   **Examples** – The following commands configure a single custom sweep with five points, different delay and compliance settings for each point, auto source range, and compliance abort disabled:
   
   SOUR:SWE:SPAC LIST  
   SOUR:SWE:RANG AUTO  
   SOUR:LIST:CURR 3e-3,1e-3,4e-3,5e-3,2e-3  
   SOUR:LIST:DEL 3,1,4,5,2  
   SOUR:LIST:COMP 3,1,4,5,2  
   SOUR:SWE:COUN 1  
   SOUR:SWE:CAB OFF  
   
   SOUR:SWE:SPAC LIST  ‘ Select custom sweep.  
   SOUR:SWE:RANG AUTO  ‘ Select auto source range.  
   SOUR:LIST:CURR 3e-3,1e-3,4e-3,5e-3,2e-3  ‘ Sweep points: 3mA, 1mA, 4mA, 5mA, 2mA.  
   SOUR:LIST:DEL 3,1,4,5,2  ‘ Delay points: 3s, 1s, 4s, 5s, 2s.  
   SOUR:LIST:COMP 3,1,4,5,2  ‘ Compliance = 3V, 1V, 4V, 5V, 2V.  
   SOUR:SWE:COUN 1  ‘ Set sweep count to 1.  

3. **Arm and run the sweep:**
   
   SOUR:SWE:ARM  
   INIT  
   
   SOUR:SWE:ARM  ‘ Arm sweep, turn on output.  
   INIT  ‘ Trigger sweep.

4. **When the sweep is done, turn the source output off with this command:**
   
   OUTP OFF
SCPI commands — sweeps

Commands for linear and logarithmic staircase sweeps are listed in Table 4-3, while commands for custom (list) sweeps are listed in Table 4-4.

Table 4-3
Staircase sweep commands (linear and logarithmic)

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOURce[1]:CURRent:STARt &lt;n&gt;</td>
<td>Sets start current. (&lt;n&gt; = -0.105 \text{ to } 0.105 \text{ (A)})</td>
<td>0</td>
</tr>
<tr>
<td>SOURce[1]:CURRent:STOP &lt;n&gt;</td>
<td>Sets stop current. (&lt;n&gt; = -0.105 \text{ to } 0.105 \text{ (A)})</td>
<td>0.1</td>
</tr>
<tr>
<td>SOURce[1]:CURRent:STEP &lt;n&gt;</td>
<td>Sets step current. (&lt;n&gt; = 1e-13 \text{ to } 0.105 \text{ (A)})</td>
<td>1e-2</td>
</tr>
<tr>
<td>SOURce[1]:CURRent:CENTer &lt;n&gt;</td>
<td>Sets center current. (&lt;n&gt; = -0.105 \text{ to } 0.105 \text{ (A)})</td>
<td>0</td>
</tr>
<tr>
<td>SOURce[1]:CURRent:SPAN &lt;n&gt;</td>
<td>Sets span current. (&lt;n&gt; = 2e-13 \text{ to } 0.210 \text{ (A)})</td>
<td>0.1</td>
</tr>
<tr>
<td>SOURce[1]:DELay &lt;n&gt;</td>
<td>Sets source delay. (&lt;n&gt; = 0.001 \text{ to } 999999.999 \text{ (s)})</td>
<td>1</td>
</tr>
<tr>
<td>SOURce[1]:SWEep:ARM</td>
<td>Prepare for running the sweep.</td>
<td></td>
</tr>
<tr>
<td>SOURce[1]:SWEep:ABORt</td>
<td>Abort sweep immediately.</td>
<td></td>
</tr>
<tr>
<td>SOURce[1]:SWEep:SPACing &lt;name&gt;</td>
<td>Selects sweep type. (&lt;name&gt;=\text{LINear, LOGarithmic, or LIST})</td>
<td>LINear</td>
</tr>
<tr>
<td>SOURce[1]:SWEep:POINTs &lt;n&gt;</td>
<td>Sets sweep points. (&lt;n&gt; = 1 \text{ to } 65535)</td>
<td>11</td>
</tr>
<tr>
<td>SOURce[1]:SWEep:RANGing &lt;name&gt;</td>
<td>Selects sweep source ranging. (&lt;name&gt;=\text{AUTO, BEST, or FIXed})</td>
<td>BEST</td>
</tr>
<tr>
<td>SOURce[1]:SWEep:CABort &lt;b&gt;</td>
<td>Sets compliance sweep abort state. (&lt;b&gt; = \text{ON or OFF})</td>
<td>OFF</td>
</tr>
<tr>
<td>SOURce[1]:SWEep:COUNt &lt;NRf&gt;</td>
<td>Sets sweep count. (&lt;NRf&gt; = 1 \text{ to } 9999 \text{ or INFinite})</td>
<td>1</td>
</tr>
</tbody>
</table>
### Table 4-4

**Custom (list) sweep commands**

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
</tr>
</thead>
</table>
| SOURce[1]:LIST:CURREnrt <NRf> [,<NRf>, ...<NRf>] | Defines list of currents.  
<NRf> = -0.105 to 0.105 (A) |
| SOURce[1]:LIST:CURREnrt:APPend <NRf> [,<NRf>, ...<NRf>] | Adds current points to existing list.  
<NRf> = -0.105 to 0.105 (A) |
| SOURce[1]:LIST:DELaY <NRf> [,<NRf>, ...<NRf>] | Defines list of delay values.  
<NRf> = 0 to 999.9999 (s) |
| SOURce[1]:LIST:DELaY:APPend <NRf> [,<NRf>, ...<NRf>] | Adds to list of delay values.  
<NRf> = 0.001 to 999999.999 (s) |
| SOURce[1]:LIST:COMPliance <NRf> [,<NRf>, ...<NRf>] | Defines list of compliance values.  
<NRf> = 0.1 to 105 (V) |
| SOURce[1]:LIST:COMPliance:APPend <NRf> [,<NRf>, ...<NRf>] | Adds to list of compliance values.  
<NRf> = 0.1 to 105 (V) |
| SOURce[1]:LIST:CURREnrt:POINts? | Query # of current list points. |
| SOURce[1]:LIST:DELaY:POINts? | Query # of delay list points. |
| SOURce[1]:LIST:COMPliance:POINts? | Query # of delay list points. |
5
Delta, Pulse Delta, and Differential Conductance

Section 5 topics

**Operation overview**, page 5-2

**Test systems**, page 5-4
- Keithley instrumentation requirements, page 5-4
- System configurations, page 5-4
- System connections, page 5-5
- DUT test connections, page 5-8
- Configuring communications, page 5-9
- Triggering sequence, page 5-10

**Readings**, page 5-11
- Display readings, page 5-11
- Measurement units, page 5-11
- Read commands, page 5-13

**Delta**, page 5-13
- Model 622x measurement process, page 5-13
- Configuration settings, page 5-15
- Operation, page 5-16
- Setup and arm commands, page 5-19

**Pulse Delta**, page 5-21
- Model 6221 measurement process, page 5-21
- Pulse Delta outputs, page 5-22
- Configuration settings, page 5-26
- Operation, page 5-29
- Setup commands, page 5-32

**Differential Conductance**, page 5-34
- Model 622x measurement process, page 5-34
- Configuration settings, page 5-37
- Operation, page 5-38
- Setup and arm commands, page 5-41

**NOTE** The information in this section is an abbreviated version of the information in Section 5 of the Reference Manual. Refer to Section 5 of the Reference Manual for complete details and additional information that is not provided in this manual.
Operation overview

The Model 6220 or 6221 Current Source can be used with a Model 2182/2182A Nanovoltmeter to perform Delta and Differential Conductance. The Model 6221/2182A combination can also perform Pulse Delta. These operations use a delta current-reversal technique to cancel the effects of thermal EMFs.

The Model 622x provides a bipolar output current and the Model 2182/2182A performs A/D conversions (measurements) at source high and source low points. An averaging algorithm is then used to calculate the delta reading.

**Delta** – The Model 622x provides a square wave current output, and the Model 2182/2182A performs A/D conversions (measurements) at each high and low output level. A 3-point moving-average algorithm is used to calculate Delta readings.

As shown in Figure 5-1A, the first three Model 2182/2182A A/D conversions (measurements) yield the first Delta reading. Each subsequent Model 2182/2182A A/D conversion then yields a single Delta reading. Every Delta reading uses the three previous A/Ds to calculate Delta.

**Pulse Delta** – The Model 6221 outputs pulses and uses 3-point repeating-average measurements to calculate Pulse Delta voltage. For each pulse, the Model 2182A performs an A/D conversion (measurement) at pulse low, pulse high, and pulse low. Each set of three A/D readings yield a single Pulse Delta reading. Figure 5-1B shows Pulse Delta measurements. If device heating is a concern, 2-point measurements can instead be used (2nd low pulse not measured due to corruption from heat).

**Differential Conductance** – The Model 622x outputs a differential current (dI) sweep and measures differential voltage (dV). This function uses a 3-point moving average algorithm to calculate dV. With dI known and dV calculated, the Model 622x can then calculate differential conductance (dG) or differential resistance (dR). Figure 5-1C shows Differential Conductance measurements.

**NOTE** Jitter – For Delta and Differential Conductance, step-to-step timing may jitter as much as 1ms. This jitter can be eliminated by disabling the front panel. For details, see “Step-to-step timing jitter” on page 1-12.
Figure 5-1
Delta, Pulse Delta, and Differential Conductance measurements

A) Delta measurements

B) Pulse Delta measurements

C) Differential Conductance measurements

Return to Section 5 topics
Test systems

Keithley instrumentation requirements

Keithley instrumentation requirements for Delta, Pulse Delta, and Differential Conductance are:

- **Models 6220 and 2182** – Delta and Differential Conductance
- **Models 6220 and 2182A** – Delta and Differential Conductance
- **Models 6221 and 2182** – Delta and Differential Conductance
- **Models 6221 and 2182A** – Delta, Pulse Delta, and Differential Conductance

System configurations

Stand-alone system

System configuration for stand-alone front panel operation is shown in Figure 5-2A. The RS-232 interface for the Model 2182/2182A must be enabled (on) and the selected interface for the Model 622x must be the GPIB or the Ethernet (Model 6221).

PC control system

System configuration for PC control of the Model 622x is shown in Figure 5-2B. The RS-232 interface for the Model 2182/2182A must be enabled (on) and the selected interface for the Model 622x must be the GPIB or the Ethernet (Model 6221).
Serial communications

In order to perform Delta, Pulse Delta, or Differential Conductance measurements, the Model 622x must communicate to the Model 2182/2182A over the serial (RS-232) interface. With serial communications properly configured and connected, the Model 622x will automatically send setup commands to the Model 2182/2182A when Delta, Pulse Delta, or Differential Conductance is armed. When the test is started, readings from the Model 2182/2182A are automatically sent to the Model 622x to be processed into Delta, Pulse Delta, or Differential Conductance readings that are then stored in the buffer.

Figure 5-2
System configurations for Delta, Pulse Delta, and Differential Conductance

A) Stand-alone system (front panel operation)

B) PC control of 6220/21

System connections

WARNING Before making or breaking system connections, the Models 622x and 2182/2182A, and the PC must be turned off and the line cords must be disconnected from AC line power.

System connections depend on the system configuration being used (see Figure 5-2). Connections for the two system configurations are explained as follows.

Connections – stand-alone system

System connections for this configuration are shown in Figure 5-3.

RS-232 – The Model 622x communicates with the Model 2182/2182A via the RS-232 interface. Make sure to use a null-modem RS-232 cable for this connection.
Trigger Link – The Trigger Link synchronizes triggering between the Current Source and the Nanovoltmeter. Trigger Link connections assume that the Model 2182/2182A is using the factory default (hard-wired) configuration:

EXT TRIG (input) = line #2
VMC (output) = line #1)

Delta, Pulse Delta, and Differential Conductance will not work if the Model 2182/2182A is not using the default Trigger Link configuration. See “Changing trigger link lines” in Section 5 (Disassembly) of the Model 2182/2182A Service Manual.

Figure 5-3
System connections – stand-alone operation

Connections – PC control system

System connections for this configuration are shown in Figure 5-4.

RS-232 and Trigger Link – This system configuration uses the same RS-232 and Trigger Link connections that are used for stand-alone operation.

IEEE-488 or Ethernet (6221) – This system configuration uses a PC to communicate with the Model 622x. For the Model 6220, the IEEE-488 bus interface can be used. For the Model 6221, the IEEE-488 bus or the Ethernet can be used. For the Ethernet, make sure to use a cross-over Ethernet cable for direct connection to the PC.
Figure 5-4
System connections – PC control of Model 622x

Keithley 622x Current Source

6220: GPIB selected
6221: GPIB or Ethernet selected

Keithley 2182/2182A Nanovoltmeter

RS-232 On

IEEE-488 Cable

OR

Ethernet Cross-over Cable (RJ-45 male/male) (6221 only)

RS-232 Cable

(null-modem, male-to-male)

8501 Trigger Link Cable

PC


**DUT test connections**

**WARNING** Before making or breaking test connections, the Models 622x and 2182/2182A must be turned off and the line cords must be disconnected from AC line power.

DUT test connections are shown in Figure 5-5. This connection scheme uses Cable Guard and an earth grounded test fixture that is equipped with an interlock switch. See Section 2 of this manual for connection information. See Section 2 of the Reference Manual for details on the principles of Cable Guard and guidelines for test fixture requirements.

**Figure 5-5**

Guarded test connections

**NOTE** For this connection scheme, the inner shield of the Model 622x OUTPUT connector must be connected to the driven guard. See “Triax inner shield” on page 2-6 for details on connecting the inner shield of the OUTPUT connector to Cable Guard.

**WARNING** The voltage levels on the Guard and High terminals are the same. A safety hazard exists when the OUTPUT is 30V rms (42V peak) or more.

**Note** The triax cable and input cable shown in this drawing are supplied with the Keithley Models 622x and 2182/2182A.
Configuring communications

For both front panel and remote operation, the RS-232 of the Model 2182/2182A must be enabled (on), and the selected communications interface for the Model 622x must be the GPIB or the Ethernet (Model 6221 only).

Model 2182/2182A communications

Configure the Model 2182/2182A for RS-232 communications as follows:

On the Model 2182/2182A, press the SHIFT key and then the RS-232 key to access the RS-232 menu. From this menu, configure the RS-232 as follows:

1. Select ON for the RS-232 interface.
2. Select the 19.2K baud rate.
3. Select the NONE setting for flow control.

Details on setting communications are provided in the User’s Manual for the Model 2182/2182A (in Section 11, see “Interface selection and configuration procedures”).

Model 622x communications

For Delta, Pulse Delta, and Differential Conductance, the Model 622x uses two interfaces for communications. It uses the RS-232 to communicate with the Model 2182/2182A, and it uses the GPIB or Ethernet (Model 6221 only) to communicate with the PC. For details on communications configuration for the Model 622x, see Section 10 of the Reference Manual.

Configure the Model 622x for communications as follows:

1. RS-232 – On the Model 622x, press the COMM key and then select RS-232 from the communications setup menu:
   a. Set the BAUD rate to 19.2K.
   b. Set FLOW CTRL (flow control) to NONE.
   c. Press the ENTER key.

   The Model 622x will reboot if RS-232 was not the previously selected communications interface.

2. GPIB or Ethernet – The GPIB or the Ethernet (Model 6221 only) must be the selected interface to allow communications with the PC.

   On the Model 622x, press the COMM key and then select GPIB or ETHERNET (6221 only) from the communications setup menu:
   • GPIB – Set the IEEE-488 address (0 to 30).
   • Ethernet (6221) – Set the IP, Gateway, Subnet, and DHCP.

   After configuring the GPIB or Ethernet, press ENTER. The configured communications interface will be selected and the Model 622x will reboot.
Arming and Starting the Test

Arming – After a delta test is configured, the test is armed by pressing the **DELTA** key, **PULSE** key (Pulse Delta), or **COND** key (Differential Conductance). For remote programming, the following commands are used to arm the test:

- `SOUR:DELT:ARM`  ' Arm Delta
- `SOUR:PDEL:ARM`  ' Arm Pulse Delta
- `SOUR:DCON:ARM`  ' Arm Differential Conductance

During the arming process, the Model 622x establishes communications with the Model 2182/2182A and performs a series of operations. These arming operations are covered in Section 5 of the Reference Manual.

Starting the test – An armed test can be started by pressing the TRIG key, or sending the :INIT IMM command. Details on running a test are provided in the individual “Operation” procedures for Delta, Pulse Delta, and Differential Conductance later in this section.

Triggering sequence

The Trigger Link is used to synchronize source-measure triggering operations of the Models 622x and 2182/2182A. General trigger sequence for delta tests:

1. Model 622x outputs a current step or pulse.
2. After allowing the output to settle, the Model 622x outputs a trigger to the Model 2182/2182A to perform a measurement. The reading is sent back to the Model 622x (via serial port).
3. The Model 2182/2182A sends a trigger to the Model 622x to output the next current level or pulse.
4. Steps 2 and 3 are repeated until the test is finished.

While the test is running, the Model 622x will calculate Delta, Pulse Delta, or Differential Conductance from the readings it receives from the Model 2182/2182A. The readings will be displayed and stored in the buffer.

Details on the “Trigger sequence” for Delta, Pulse Delta, and Differential Conductance are provided in Section 5 of the Reference Manual.
Readings

Display readings

Display reading examples:

+1.23456 nV Delta    Delta voltage reading
+1.23456 Ω Delta     Delta ohms reading
+1.23456 S D Cond     Differential Conductance Siemens reading
+1.23456 mWp Pulse   Pulse Delta peak power (Watts) reading $^1, 2, 3$
+1.23456 mW Pulse     Pulse Delta average power (Watts) reading $^1, 2, 3$

1. Pulse Delta Power can be a peak power reading or an average power reading (see “Measurement units” in Section 5 of the Reference Manual).
2. For remote operation, the returned reading string for a Delta Pulse power reading indicates if it is a peak or average reading. Use the UNIT:POWer? command (see Table 5-1) to determine if the power reading is peak or average.
3. When recalling buffer statistics (such as Average or Standard Deviation) for Pulse Delta power readings, only the power units for the first stored reading is checked to determine if it is a Peak or Average power reading. The result of the buffer statistic will have the same units (W for Average or Wp for Peak) as the first stored reading.

NOTE The SMPL annunciator blinks on and off for every other reading that is acquired from the Model 2182/2182A.

Measurement units

Volts, ohms, power, or conductance

The readings from the Model 2182/2182A for Delta, Pulse Delta, or Differential Conductance are sent to the Model 622x as voltage readings. These readings can be displayed by the Model 622x as Volts (V), Ohms (Ω), power (Watts; W), or conductance (Siemens; S) readings.
The default units for the Model 622x is volts. With Ohms (Ω) units or Siemens (S) units selected, a reading is calculated as follows:

$$\Omega = \frac{V}{I}$$
$$S = \frac{I}{V}$$

Where:  
- $V$ is the Delta, Pulse Delta, or Differential Conductance voltage reading.
- $I$ is the current sourced by the Model 622x.

With Power units selected, power is calculated as follows:

<table>
<thead>
<tr>
<th>Delta</th>
<th>Pulse Delta</th>
<th>Differential Conductance</th>
</tr>
</thead>
<tbody>
<tr>
<td>$W = I \times V$</td>
<td>$W_{PEAK} = I \times V$</td>
<td>$W = I_{AVG} \times V_{AVG}$</td>
</tr>
<tr>
<td></td>
<td>$W_{AVG} = I \times V \times Duty\ Cycle$</td>
<td></td>
</tr>
</tbody>
</table>

1. See Section 5 of the Reference Manual for details on “Peak power and Average power” for Pulse Delta.

### Setting measurement units

From the front panel, units can be set as follows:

1. Press the **UNITS** key to display the READING UNITS menu.
2. Use the “Menu navigation” controls (see page 1-14) to select the desired measurement units (*VOLTS*, *OHMS*, *WATTS*, or *SIEMENS*).
3. Model 6221 only – After selecting *WATTS*, you will be prompted to select the POWER TYPE.
4. Select the desired power type (*AVERAGE* or *PEAK*).

### Remote programming

– Commands for setting units are listed in **Table 5-1**.

#### Table 5-1

**Measurement unit commands**

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>UNIT[:VOLT][:DC] &lt;name&gt;</td>
<td>Specify reading units*.</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td>&lt;name&gt; = V, OHMS, W, or SIEMens</td>
<td></td>
</tr>
<tr>
<td>UNIT:POwER[:TYPE] &lt;name&gt;</td>
<td>Set power units reading type for 6221 Pulse Delta. &lt;name&gt; = AVERage or PEAK</td>
<td>PEAK</td>
</tr>
<tr>
<td>UNIT:POwER[:TYPE]?</td>
<td>Query power units reading type</td>
<td></td>
</tr>
</tbody>
</table>

* The <name> parameter for Siemens can be sent as S, SIEM, or SIEMENS.

### Example

– Selects power (W) measurement units for the Model 622x:

```
UNIT W
```
Read commands

The Model 622x does not perform measurements. However, raw readings are sent from the Model 2182/2182A to the Model 622x to calculate Delta, Pulse Delta, or Differential Conductance readings. Readings from the Model 2182/2182A are processed, stored, and displayed by the Model 622x.

The following read commands return pre-math readings and buffer readings. Details on all read commands are provided in Section 5 of the Reference Manual.

Pre-math readings

SENSe[1]:DATA[:LATest]?
SENSe[1]:DATA:FRESH?

While Delta, Pulse Delta, or Differential Conductance is running, the SENS:DATA:LATest? command can be sent to read the latest (last) pre-math reading processed by the Model 622x. The returned reading will be filtered if the averaging filter is enabled. If this read command is sent before a new reading is available, the last reading will again be returned.

The SENS:DATA:FRESH? command is the same as the SENS:DATA:LATest? command except that once a reading is returned, it cannot be returned again. This read command guarantees that each reading gets returned only once. If a new (fresh) reading is not available when SENS:DATA:FRESH? is sent, error -230 Data corrupt or stale will occur.

Buffer readings

TRACe:DATA?

This is the read command to return all readings stored in the buffer. There are also commands to determine the type of readings stored in the buffer, specify a list of consecutive buffer readings to return, and to read the selected buffer statistic. See “Data flow and read commands” in Section 5 of the Reference Manual.

Delta

Model 622x measurement process

The Delta process is shown in Figure 5-6. As shown, three Model 2182/2182A A/D conversions are performed to yield a single Delta reading. When Delta starts, three Model 2182/2182A A/Ds (A, B, and C) are performed and the Delta reading is calculated. After the first Delta cycle, the moving-average technique is then used. As shown, a Delta reading is yielded for every subsequent Model 2182/2182A A/D. The new A/D replaces the oldest A/D in the Delta calculation.
Figure 5-6
Delta measurement technique

The following equation can be used to calculate any Delta reading:

\[
\text{Delta} = \left( \frac{X - 2Y + Z}{4} \right) \cdot (-1)^n
\]

Where: X, Y, and Z are the three A/D measurements for a Delta reading.

\[
\begin{align*}
\text{1st Delta Reading} &= \left( \frac{A - 2B + C}{4} \right) \cdot (-1)^0 \\
\text{2nd Delta Reading} &= \left( \frac{B - 2C + D}{4} \right) \cdot (-1)^1 \\
\text{3rd Delta Reading} &= \left( \frac{C - 2D + E}{4} \right) \cdot (-1)^2 \\
\text{4th Delta Reading} &= \left( \frac{D - 2E + F}{4} \right) \cdot (-1)^3
\end{align*}
\]

Example – Calculate the 21st Delta reading:

X, Y, and Z are the three A/D measurements for the 21st Delta reading.

\[
n = \text{Delta Cycle Number} - 1
\]

\[
n = 21 - 1
\]

\[
n = 20
\]

Therefore;

\[
\text{Delta} = \left( \frac{X - 2Y + Z}{4} \right) \cdot (-1)^{20}
\]

\[
= \frac{X - 2Y + Z}{4}
\]

The (-1)^n term in the Delta calculation is used for polarity reversal of every other calculated Delta reading. This makes all calculated Delta readings in the test the same polarity.
**Measurement units**

The fundamental measurement for Delta is voltage (Volts; V). However, the voltage reading can converted into a conductance (Siemens; S), resistance (Ohms; Ω), or power (Watts; W) reading. See page 5-11 for details on selecting “Measurement units”.

**Configuration settings**

Delta settings from the front panel are described as follows. These parameters are set from the CONFIGURE DELTA menu that is accessed by pressing the CONFIG key and then the DELTA key.

The equivalent remote programming commands to configure Delta are summarized in Table 5-2.

**I-High and I-Low** – These settings specify the high and low level for the square wave output. When setting the I-High level, the I-Low level is set to the same magnitude but negative polarity. For example, setting I-High to 1mA sets I-Low to -1mA. Setting the I-Low level has no affect on I-High.

I-High can be set from 0 to +105mA, and I-Low can be set from 0 to -105mA. The default settings for high and low are +1mA and -1mA.

**Delay** – The Delta delay occurs after a trigger from the Model 2182/2182A is received and is typically used to allow the current source to settle after changing polarity. Delay can be set from 0.001 to 9999.999s. The default delay is 2ms.

**Count** – Delta count specifies the number of Delta readings to perform. Delta count can be set to a finite number (1 to 65,536) or Infinity can be selected. With an infinite count selected, the Delta runs continuously. The default count setting is Infinity. The separate sweep count parameter can also be specified to control the number of measurement sets, each composed of delta count readings, that are repeated under trigger model control (see Section 8 of the Reference Manual). Each set is run independently by restarting the delta mode’s advanced moving average algorithm.

**Compliance Abort** – By enabling (YES) Compliance Abort, Delta operation will abort if the current source goes into compliance. By default, Compliance Abort is disabled (NO).

**Cold Switching Mode** – By enabling (YES) Cold Switching, Delta operation will zero the current source before leaving the trigger layer prior to sequential trigger model iterations. By default, Cold Switching is disabled (NO).
Operation

Delta operation – front panel

The system configuration for front panel stand-alone operation is shown in Figure 5-2A on page 5-5.

1. Connections are shown in the following illustrations. All power must be removed from all components in the system before making connections:
   - Figure 5-3, page 5-6 – System connections
   - Figure 5-5, page 5-8 – DUT test connections

2. Configure communications for the Models 2182/2182A and 622x as explained in “Configuring communications,” page 5-9.

3. On the Model 2182/2182A, select the desired measurement range (using the RANGE keys) and the integration rate (using the RATE key). Rate must be set to an integer value (1, 2, 3, ... up to 50 or 60). If some other rate is selected, it will automatically be changed to 1PLC by the Model 622x during the arming process.

4. On the Model 622x, press CONFIG and then DELTA to access the CONFIGURE DELTA menu. For details on these settings, see “Configuration settings” on page 5-15.
   a. Set I-HIGH, I-LOW, DELAY, COUNT, and COMPLIANCE ABORT.
   b. When finished, use the EXIT key to back out of the menu structure.

5. Set the measurement units.
   The basic Delta reading is in volts (which is the default setting). However, it can instead be expressed (and displayed) as an Ohms, Watts, or Siemens reading. See “Delta” on page 5-13 for details.
   To set the measurement units, press the UNITS key to display the READING UNITS menu. Select VOLTS, OHMS, WATTS, or SIEMENS. Measurement units can be changed while Delta is running.

6. On the Model 622x, press the DELTA key to arm Delta.
   The Model 6221 is armed when the message “DELTA ARMED Press TRIG to start” is displayed briefly and the ARM annunciator turns on.

7. On the Model 622x, press the TRIG key to start taking Delta readings and send them to the buffer.
   If a finite Delta count is being used, the Delta measurements will stop after the last Delta measurement is performed. However, Delta remains armed and can be run again by pressing the TRIG key. The new Delta readings will overwrite the old readings in the buffer.
   If the infinite Delta count is being used, Delta will run continuously. If the buffer fills, Delta readings will stop being stored, even though Delta continues to run.
8. When finished, press **EXIT** to disarm Delta.

9. On the Model 622x, press **RECALL** to access the Delta readings stored in the buffer.

**Operation – PC control**

The system configuration for PC control of the Model 622x is shown in Figure 5-2B.

1. Connections are shown in the following illustrations. All power must be removed from all components in the system before making connections:
   - Figure 5-4, page 5-7 – System connections
   - Figure 5-5, page 5-8 – Test connections

2. Configure communications for the Models 2182/2182A and 622x as explained in “Configuring communications,” page 5-9.

3. On the Model 2182/2182A, select the desired measurement range and integration rate. These Model 2182/2182A settings can be made from the front panel or remote programming can be used. Rate must be set to an integer value (1, 2, 3, ... up to 50 or 60). If some other rate is selected, it will automatically be changed to 1PLC by Model 622x during the arming process.

   For front panel operation, use the **RANGE** keys to select the measurement range. To set the integration rate, use the **RATE** key.

   Commands from the PC to control the Model 2182/2182A are addressed to the Model 622x. Each command is then routed through the Model 622x out the serial port (RS-232) to the Model 2182/2182A. The following command word is used for this communication process:

```
SYSTem:COMMunicate:SERial:SEND <data>
```

   Where: *<data>* is a valid Model 2182/2182A command.

The following query command is used to return the response to a query command sent over the serial port:

```
SYSTem:COMMunicate:SERial:ENTer?
```

When communicating over the serial port, there are no errors reported if a Model 2182/2182A is not properly connected to the Model 622x.
**Examples** – The following commands demonstrate proper syntax for sending commands and returning responses to queries over the serial port:

- **SYST:COMM:SER:SEND “VOLT:RANG 2”** ‘Select 2V range for 2182/2182A.
- **SYST:COMM:SER:SEND “VOLT:NPLC 1”** ‘Set rate to 1PLC for 2182/2182A.

4. **Set measurement units** – Volts are the default units for the Model 622x but can instead be expressed (and displayed) as an Ohms, Watts, or Siemens reading (see “Delta” on page 5-13 for details). The commands to set measurement units are listed in Table 5-1. The following example shows the command to select ohms measurement units:

```
UNIT OHMS
```

5. **Set up, arm, and run Delta** – Details on the commands to set up and arm Delta are provided in Table 5-2. The following example demonstrates the proper sequence to set up, arm, and run Delta:

- **RST** ‘Restores 622x defaults.
- **SOUR:DELT:HIGH 1e-3** ‘Sets high source value to 1mA.
- **SOUR:DELT:DELay 100e-3** ‘Sets Delta delay to 100ms.
- **SOUR:DELT:COUN 1000** ‘Sets Delta count to 1000.
- **SOUR:DELT:CAB ON** ‘Enables Compliance Abort.
- **TRAC:POIN 1000** ‘Sets buffer to 1000 points.
- **SOUR:DELT:ARM** ‘Arms Delta.
- **INIT:IMM** ‘Starts Delta measurements.

A. Trace points specifies the size of the buffer. Buffer size should be the same value as Delta count. See Section 6 for details on all buffer commands.

B. The initiate command starts Delta readings. After the specified finite number of Delta readings are performed, Delta will stop running. At this point another initiate command will re-start Delta. New Delta readings will overwrite the old Delta readings in the Model 622x buffer.

If the Infinity count is set, Delta will run continuously. If the buffer fills, Delta readings will stop being stored, even though Delta continues to run.
6. **Read Delta readings** – While Delta is running, the latest Model 2182/2182A Delta reading can be read by the Model 622x using the following command:

   \[ \text{SENS:DATA?} \]  
   ‘Reads the latest Delta reading.

   The above read command reads the last Delta reading that was performed by the Model 2182/2182A. If this command is sent before a new reading is available, the last Delta reading will again be returned.

   **NOTE** If a read command is sent when Delta is not running, error -221 Settings Conflict will occur.

7. When finished with Delta, it can be disarmed by sending the following command:

   \[ \text{SOUR:SWE:ABOR} \]  
   ‘Stops Delta and places the Model 2182A in the local mode.

8. **Recall stored Delta readings** – Model 2182A Delta readings were sent to the buffer of the Model 622x. Send the following read command to read the buffer:

   \[ \text{TRACe:DATA?} \]  
   ‘Read Delta readings stored in 622x buffer.

**Setup and arm commands**

Commands to set up and arm Delta are listed in **Table 5-2**.
1. Use the :NVPResent command to determine if a suitable Model 2182/2182A with the correct firmware revision is properly connected to the RS-232 port. This query command can be used for the system configuration shown in Figure 5-2B on page 5-5.

2. See “Configuration settings” on page 5-15 for details on these settings.

3. After setting up Delta using the above setup commands, the :ARM command arms Delta. During the arming process, the Model 622x communicates with the Model 2182/2182A. When armed, Delta will start when the Model 6221 is triggered. Delta can be “un-armed” by sending the following command: SOURcE:SWEeP:ABORt. The query form for the arm command (SOURcE:DELTa:ARM?) is used determine if Delta is armed. A returned “1” indicates that Delta is armed. A “0” indicates that Delta is not armed.

If the Model 6221 is already armed for another action (e.g., Differential Conductance or Pulse Delta), the Delta arm command will “un-arm” the other action and arm Delta.

---

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>[SOURcE[1]]:DELTa:NVPResent?</td>
<td>Queries connection to 2182A. (^1) (1 = \text{yes}, \ 0 = \text{no})</td>
<td></td>
</tr>
<tr>
<td>[SOURcE[1]]:DELTa:HIGH &lt;NRf&gt;</td>
<td>Sets high source value (amps). (^2) (&lt;NRf&gt; = 0 \text{ to } 105e-3)</td>
<td>1e-3</td>
</tr>
<tr>
<td>[SOURcE[1]]:DELTa:LOW &lt;NRf&gt;</td>
<td>Sets low source value (amps). (^2) (&lt;NRf&gt; = 0 \text{ to } -105e-3)</td>
<td>-1e3</td>
</tr>
<tr>
<td>[SOURcE[1]]:DELTa:DELay &lt;NRf&gt;</td>
<td>Sets Delta delay (seconds). (^2) (&lt;NRf&gt; = 0 \text{ to } 9999.999 \text{ or INFinity})</td>
<td>0</td>
</tr>
<tr>
<td>[SOURcE[1]]:DELTa:COUNT &lt;NRf&gt;</td>
<td>Sets the number of cycles to run. (^2) (&lt;NRf&gt; = 1 \text{ to } 65536 \text{ (finite count) or INFinity})</td>
<td>INF</td>
</tr>
<tr>
<td>[SOURcE[1]]:SWEeP:COUNT &lt;NRf&gt;</td>
<td>Sets the number of measurement sets to repeat. (^2) (&lt;NRf&gt; = 1 \text{ to } 65536 \text{ (finite count) or INFinity})</td>
<td>1</td>
</tr>
<tr>
<td>[SOURcE[1]]:DELTa:CSWitch &lt;b&gt;</td>
<td>Enable cold switching mode. (^2) (&lt;b&gt; = \text{0 or OFF}, \ 1 \text{ or ON})</td>
<td>0</td>
</tr>
<tr>
<td>[SOURcE[1]]:DELTa:CAabort &lt;b&gt;</td>
<td>Enable or disable Compliance Abort. (^2) (&lt;b&gt; = \text{0 or OFF}, \ 1 \text{ or ON})</td>
<td>0</td>
</tr>
<tr>
<td>[SOURcE[1]]:DELTa:ARM</td>
<td>Arms Delta. (^3)</td>
<td></td>
</tr>
<tr>
<td>[SOURcE[1]]:DELTa:ARM?</td>
<td>Queries Delta arm. (1 = \text{armed}, \ 0 = \text{not armed})</td>
<td></td>
</tr>
</tbody>
</table>

\(^1\) Use the :NVPResent command to determine if a suitable Model 2182/2182A with the correct firmware revision is properly connected to the RS-232 port.

\(^2\) See “Configuration settings” on page 5-15 for details on these settings.

\(^3\) After setting up Delta using the above setup commands, the :ARM command arms Delta. During the arming process, the Model 622x communicates with the Model 2182/2182A. When armed, Delta will start when the Model 6221 is triggered. Delta can be “un-armed” by sending the following command: SOURcE:SWEeP:ABORt. The query form for the arm command (SOURcE:DELTa:ARM?) is used determine if Delta is armed. A returned “1” indicates that Delta is armed. A “0” indicates that Delta is not armed.

If the Model 6221 is already armed for another action (e.g., Differential Conductance or Pulse Delta), the Delta arm command will “un-arm” the other action and arm Delta.
Pulse Delta

Use the Keithley Model 2182A with the Model 6221 to run Pulse Delta.

Model 6221 measurement process

Pulse Delta measurements

For Pulse Delta, the Model 6221 outputs current pulses. Current pulses that have a short pulse width are ideal to test a low-power DUT that is heat sensitive.

By default, Pulse Delta uses a 3-point repeating-average algorithm to calculate readings. Each Pulse Delta reading is calculated using A/D measurements for a low pulse, a high pulse, and another low pulse. The Model 6221 outputs the pulses, and the Model 2182A performs the A/D measurements. As shown in Figure 5-7, every three pulses yields a single Pulse Delta voltage reading.

Figure 5-7
Pulse Delta 3-point measurement technique

\[
\text{1st Pulse Delta Reading} = \frac{2B - A - C}{2} \\
\text{2nd Pulse Delta Reading} = \frac{2E - D - F}{2} \\
\text{Nth Pulse Delta Reading} = \frac{2Y - X - Z}{2}
\]

Where:
X, Y, and Z are the A/Ds for the first low, high, and second low pulses for the Pulse Delta cycle.

In cases where the high pulse will cause heating of the Device Under Test (DUT), the measurement at the second low pulse could be adversely affected by the heat caused by the high pulse. In that case, the measurement at the second low pulse can be disabled. This does not change the overall timing of the pulse output. Eliminating the second low pulse measurement changes the basic calculation to the following:

\[
\text{Pulse Delta} = \frac{2Y - 2X}{2}
\]
Where: Y is the measurement at the high pulse.
X is the measurement at the first low pulse.

**Measurement units**

The fundamental Pulse Delta measurement explained above is in volts. The reading can instead be converted into Ohms (W), Siemens (S), or Power (W). Details on selecting “Measurement units” are provided on page 5-11.

**Peak power and Average power**

With Power units selected, a Pulse Delta reading can be expressed (and displayed) as a Peak power reading or an Average power reading. Peak power is the default setting. See “Measurement units” in Section 5 of the Reference Manual for details on Peak power and Average power for Pulse Delta.

**Pulse Delta outputs**

Pulse Delta output is made up of one or more Pulse Delta cycles. Each cycle is made up of three output pulses (low, high, and low). The time period for a cycle is adjustable and is the same for all cycles. The output pulses have an adjustable pulse width, which is the same for all pulses.

There are two basic Pulse Delta output types: Fixed output and Sweep output. For Fixed output, all high and low pulses are fixed for all Pulse Delta cycles in the test. For Sweep output, the sweep (SWP) function of the Model 6221 is used to output a staircased, logarithmic, or user-specified (custom) pulse sweep.

**Fixed output**

Figure 5-8 shows one Pulse Delta cycle for a Fixed output. As shown, the Model 6221 outputs a low pulse, a high pulse, and then another low pulse during every Pulse Delta cycle. The pulse width is adjustable and is the same for all high and low pulses. The cycle interval is also adjustable and is based on the set number of power line cycles. The Pulse Delta interval shown in Figure 5-8 is set for 5 PLC (power line cycles), which is the default setting. After the set interval expires, the next Pulse Delta cycle starts (if pulse count is >1).

Pulses are synchronized to the frequency of the power line voltage. When Pulse Delta is started, the three pulses (low, high, and low) are generated on the positive-going edges of the first three power line cycles. For the remaining power line cycles in the interval, the output remains at the I-Low level.

**Sweep output**

The sweep feature of the Model 6221 can be used to output a series of pulses that allow the use of different levels for the high pulses. Each high pulse returns to the programmed low pulse level. The low level is the same for all pulses.
Like the Fixed output shown in Figure 5-8, a Sweep output is synchronized to the frequency of the power line voltage, and the pulse width is adjustable and is the same for all pulses.

The three available sweeps include (1) staircase sweep, (2) logarithmic sweep, and (3) custom sweep. Examples of these Sweep outputs are shown in Figure 5-9.

**Staircase sweep** – Figure 5-9A shows an example of a staircase Sweep output. The sweep is configured to start high pulses at 2mA and staircase to 10mA in 2mA steps. The low pulse level for this sweep is 0mA.

**Logarithmic sweep** – Figure 5-9B shows an example of a logarithmic Sweep output. The sweep is configured to output five high pulses (points). The first high pulse starts at 1mA and logarithmically steps to 10mA. The low pulse level for this sweep is 0mA.

**Custom sweep** – Figure 5-9C shows an example of a custom Sweep output. The sweep is configured to output five high pulses (points). The high pulse level for this output are 1mA, 2mA, 4mA, 8mA, and 16mA. The low pulse level for this sweep is 0mA.

Notice that the time period for each Pulse Delta cycle is determined by the set sweep delay. The sweep (including sweep delay) is configured from the CONFIGURE SWEEPS menu. See Section 4 for details.
Figure 5-8
Pulse timing

1. I-High can be set from -105mA to +105mA (default is 1mA).
2. I-Low can be set from -105mA to +105mA (default is 0mA).
3. Pulse Width can be set from 50μs to 12ms (default is 110μs).
4. One 60Hz power line cycle = 16.667ms (1/60)
   One 50Hz power line cycle = 20ms (1/50)
5. With Interval set to 5 PLC (power line cycles):
   60Hz: One Pulse Delta cycle = 83.33ms (5/60)
   50Hz: One Pulse Delta cycle = 100ms (5/50)
6. Interval can be set from 5 to 999999 PLC (default is 5 PLC).
Figure 5-9
Pulse sweep output examples

A) Staircase sweep pulse train: 2 to 10mA in 2mA steps

B) Logarithmic sweep pulse train: 1 to 10mA using 5 logarithmic

C) Custom sweep pulse train: 1mA, 2mA, 4mA, 8mA, and 16mA (5 points)
Duty Cycle

Duty cycle defines the ratio between pulse “on” time and pulse “off” time during a Pulse Delta cycle. For example, for a 25% duty cycle, the pulse would be “on” (high) for one-quarter of the cycle, and “off” (0mA low) for three-quarters of the cycle. Pulse Delta cycles with a short duty-cycle can be sourced to prevent heat from adversely affecting the measurement of low power DUT.

When using a 0mA low level (which is the default), the duty cycle for the Pulse Delta cycle is calculated as follows:

\[
\text{DutyCycle} = \frac{\text{PulseWidth}}{\text{PulseDeltaCycle}} \cdot 100
\]

Where:  
- DutyCycle = Duty cycle expressed as a percent.  
- PulseWidth = User specified Pulse Width (in seconds).  
- PulseDeltaCycle = Time period (in seconds) for each Pulse Delta cycle (see “Pulse Delta cycle time period”).

Pulse Delta cycle time period

**Sweep output** – The time period for each Pulse Delta cycle is the same as the sweep delay time that is set by the user when configuring the sweep.

**Fixed output** – The Pulse Delta cycle (interval) is expressed as the number of power line cycles (PLC). This PLC value must be converted into time (seconds) as follows:

**For 60Hz line power:**

Pulse Delta cycle time period = Interval setting (PLC) x 16.667ms

**For 50Hz line power:**

Pulse Delta cycle time period = Interval setting (PLC) x 20ms

**Example** – For 60Hz line power, the Pulse Delta cycle time period for an Interval setting of 5 PLC is calculated as follows:

\[
\text{Pulse Delta cycle time period} = 5 \times 16.667ms = 83.33ms
\]

Configuration settings

Pulse Delta settings from the front panel are described as follows. These parameters are set from the CONFIG PULSE DELTA menu that is accessed by pressing the **CONFIG** key and then the **PULSE** key.

The equivalent remote programming commands to configure Pulse Delta are summarized in Table 5-3.
**Fixed output settings**

The following parameters are set from the CONFIG PULSE DELTA menu that is accessed by pressing the CONFIG key and then the PULSE key.

**I-Hi and I-Lo**

These settings specify the high and low level of the pulses. Each high pulse returns to the programmed low pulse level. Both I-Hi and I-Lo can be set from -105mA to +105mA. The default setting for I-Hi is +1mA, and the default for I-Lo is 0mA.

**Width and Source Delay**

The pulse width specifies the time period that the output remains at the high and low pulse levels. Pulse width can be set from 50µs to 12ms. The default setting for pulse width is 110µs.

The source delay is used to allow the pulse to settle before triggering the Model 2182A to perform a measurement conversion (A/D). Source delay can be set from 16µs (default setting) to 11.966ms.

The set pulse width and source delay determines the integration rate (measure speed) of the Model 2182A. Integration rate is automatically set when Pulse Delta is armed.

**Count**

The Pulse Delta count specifies the number of Pulse Delta intervals to perform. Each pulse interval yields one Pulse Delta voltage reading. A finite number (1 to 65,536) can be set or count can be set to Infinity. With infinity set, Pulse Delta will run continuously. The default setting for count is Infinity.

**Ranging**

For Pulse Delta, the source range can be set for **BEST** (default setting) or **FIXED**. With **BEST** ranging selected, the Model 6221 will select the optimum (lowest) range that will support both the low and high pulse levels. For example, if pulse low is -12mA and pulse high is 10mA, then the 100mA source range will be used.

With **FIXED** ranging selected, the source remains on the range presently selected before arming Pulse Delta. If the selected range is too low, error -221 Settings Conflict will occur.

For **remote programming**, there are two separate commands to set range. Use the SOUR:PDEL:RANG command to set range for a Fixed output, and use the SOUR:SWE:RANG command for the pulse sweep output. Details on these commands are provided in Table 5-3.
Interval

The Pulse Delta cycle time period (interval) is expressed as a number of power line cycles (PLC). For 60Hz one PLC is 16.667ms, and for 50Hz, one PLC is 20ms. Interval can be set from 5 PLC (default setting) to 999999 PLC.

Sweep

The sweep function of the Model 6221 can be enabled (YES) or disabled (NO). When disabled (which is the default setting), the Model 6221 will be configured to output a Fixed output using the programmed high and low pulse levels. When the sweep function is enabled, the Model 6221 will be set to output a configured sweep.

Low Measure

By default, three measurements are performed for every Pulse Delta interval. The Model 2182A measures the voltage at pulse low, pulse high, and finally pulse low as shown in Figure 5-7. As explained in the process for “Pulse Delta measurements” on page 5-21, a 2-point measurement technique can instead be used when pulse high may cause DUT heating. For the 2-point measurement technique, the voltage measurement for the second low pulse is not performed.

Sweep output settings

The following settings from the CONFIG PULSE DELTA menu are used for pulse sweep output: Width, Sweep, and Low Measure.

The sweep is selected and configured from the CONFIGURE SWEEPS menu that is accessed by pressing the CONFIG key and then the SWP key. Details on sweeps are provided in Section 4.

It is from the CONFIGURE SWEEPS menu that Source Ranging, Count, and Sweep Delay are set:

Source Ranging

Source range can be set to BEST (default setting), FIXED, or AUTO. The BEST and FIXED settings are described above in “Sweep output settings”. The AUTO setting is available for a Sweep output. With AUTO selected, the instrument automatically selects the optimum (lowest) range for the sweep step.

Delay

Sweep delay defines the Pulse Delta cycle time period (in seconds). The time period is the same for all Pulse Delta cycles. Sweep delay can be set from 1ms to 999999.999s.
Operation

Pulse Delta operation – front panel

The system configuration for front panel stand-alone operation is shown in Figure 5-2A on page 5-5.

1. Connections are shown in the following illustrations. All power must be removed from all components in the system before making connections:
   - Figure 5-3, page 5-6 – System connections
   - Figure 5-5, page 5-8 – DUT test connections

2. Configure communications for the Models 2182A and 6221 as explained in “Configuring communications” on page 5-9.

3. On the Model 2182A, select the desired measurement range (using the RANGE keys).

4. Perform one the following steps to configure Pulse Delta: Step I for Fixed output, or Step II for Sweep output. “Configuration settings” are explained on page 5-26.

   I. **Fixed output** – On the Model 6221, press CONFIG and then PULSE to access the CONFIG PULSE DELTA menu.
      a. Set I-HI, I-LO, pulse WIDTH, COUNT, RANGING, source delay (SRC DEL), INTERVAL, disable (NO) the SWEEP function, and set the number of low measurements (LOW MEAS) to perform.
      b. When finished configuring the Fixed output, use the EXIT key to back out of the menu structure.

   II. **Sweep output** – Two configure processes are required for Sweep output:
      a. On the Model 6221, press CONFIG and then PULSE to access the CONFIG PULSE DELTA menu. Use this menu to set pulse WIDTH, COUNT, set the number of low measurements (LOW MEAS) to perform, and enable (YES) the SWEEP function. When finished, use the EXIT key to return to the normal display state.
      b. On the Model 6221, press CONFIG and then SWP to access the CONFIGURE SWEEPS menu. Use the TYPE menu item to select and configure the sweep (including the sweep delay), and use the SOURCE RANGING menu item to select ranging (BEST, FIXED, or AUTO). When finished, use the EXIT key to return to the normal display state.

5. Set the measurement units.
   The basic Pulse Delta reading is in volts (which is the default units setting). However, it can instead be expressed (and displayed) as an Ohms, Watts, or Siemens reading. With Watts as the selected units, the reading can be a Peak power reading or an Average power reading. See “Measurement units” on page 5-11 for details.

Return to Section 5 topics
To set the measurement units, press the **UNITS** key to display the **READING UNITS** menu. Select **VOLTS**, **OHMS**, **WATTS**, or **SIEMENS**. When **WATTS** is selected, you will then be prompted to select the power units type: **AVERAGE** or **PEAK**. Measurement units can be changed while Pulse Delta is running.

6. On the Model 622x, press the **PULSE** key to arm Pulse Delta. The Model 622x is armed when the message “PULSE MODE ARMED Press TRIG to start” or “PULSE SWEEP ARMED Press TRIG to start” is displayed briefly and the ARM annunciator turns on.

7. On the Model 6221, press the **TRIG** key to start taking Pulse Delta readings and send them to the buffer. If a finite Pulse Delta count is being used, the Pulse Delta measurements will stop after the last Pulse Delta measurement is performed. However, Pulse Delta remains armed and can be run again by pressing the **TRIG** key. The new Pulse Delta readings will overwrite the old readings in the buffer. If the infinite Pulse Delta count is being used, Pulse Delta will run continuously. If the buffer fills, Pulse Delta readings will stop being stored, even though Pulse Delta continues to run.

8. When finished, press **EXIT** to disarm Pulse Delta.

9. On the Model 6221, press **RECALL** to access the Pulse Delta readings stored in the buffer.

**Operation – PC control**

The system configuration for PC control of the Model 6221 is shown in Figure 5-2B on page 5-5.

1. Connections are shown in the following illustrations. All power must be removed from all components in the system before making connections:
   - Figure 5-4, page 5-7 – System connections
   - Figure 5-5, page 5-8 – Test connections

2. Configure communications for the Models 2182A and 6221 as explained in **Configuring communications** on page 5-9.

3. On the Model 2182A, select the desired measurement range. For front panel operation, use the **RANGE** keys to select the measurement range.

   Commands from the PC to control the Model 2182A are addressed to the Model 622x. Each command is then routed through the Model 622x out the serial port (RS-232) to the Model 2182A. The following command word is used for this communication process:

   `SYSTem:COMMunicate:SERial:SEND <data>`

   Where: `<data>` is a valid Model 2182A command.
The following query command is used to return the response to a query command sent over the serial port:

```
SYSTem:COMMunicate:SERial:ENTer?
```

When communicating over the serial port, there are no errors reported if a Model 2182A is not connected to the serial port.

**Examples** – The following commands demonstrate proper syntax for sending commands and returning responses to queries over the serial port:

```
SYST:COMM:SER:SEND “VOLT:RANG 1”   ‘ Select 1V range for 2182A.
```

4. **Set measurement units** – Volts are the default units for the Model 6221 but can instead be expressed (and displayed) as an Ohms, Watts, or Siemens reading (see “Measurement units” on page 5-11 for details). The commands to set measurement units are listed in Table 5-1. The following example shows the command sequence to select average power measurement units:

```
UNIT W                                ‘ Select power (Watts) measurement units.
UNIT:POWer AVERage                   ‘ Select Average power type.
```

5. **Set up, arm, and run Pulse Delta** – Details on the commands to set up and arm Pulse Delta are provided in Table 5-3. The following example demonstrates the proper sequence to set up, arm, and run a Fixed output:

```
*RST                                    ‘ Restores 6221 defaults.
SOUR:PDEL:HIGH 10e-3                  ‘ Sets pulse high value to 10mA.
SOUR:PDEL:LOW 0                        ‘ Sets pulse low value to 0mA.
SOUR:PDEL:WIDT 500e-6                 ‘ Sets pulse width to 500µs.
SOUR:PDEL:SDEL 100e-6                 ‘ Sets source delay to 100µs.
SOUR:PDEL:RANG BEST                  ‘ Selects the best source range.
SOUR:PDEL:INT 10                      ‘ Sets pulse interval to 10 PLC.
SOUR:PDEL:SWE OFF                     ‘ Disables sweep function.
SOUR:PDEL:LME 2                       ‘ Set for two low pulse measurements.
TRAC:POIN 200                         ‘ Sets buffer to 200 points. A
INIT:IMM                               ‘ Starts Pulse Delta measurements. B
```

A. Trace points specifies the size of the buffer. Buffer size should be the same value as Pulse Delta count. See Section 6 for details on all buffer commands.
B. The initiate command starts Pulse Delta readings. After the specified finite number of Pulse Delta readings are performed, Pulse Delta will stop running. At this point another initiate command will re-start Pulse Delta. New Pulse Delta readings will overwrite the old Pulse Delta readings in the Model 6221 buffer.

If the Infinity count is set, Pulse Delta will run continuously. If the buffer fills, Pulse Delta readings will stop being stored, even though Pulse Delta continues to run.

6. **Read Pulse Delta readings** – While Pulse Delta is running, the latest Model 2182A Pulse Delta reading can be read by the Model 6221 using the following command:

   ```
   SENS : DATA?
   ' Reads the latest Pulse Delta reading.
   ```

   The above read command reads the last Pulse Delta reading that was performed by the Model 2182A. If this command is sent before a new reading is available, the last Pulse Delta reading will again be returned.

   **NOTE**  If a read command is sent when Pulse Delta is not running, error -221 Settings Conflict will occur.

7. When finished with Pulse Delta, it can be disarmed by sending the following command:

   ```
   SOUR : SWE : ABOR
   ' Stops Pulse Delta and places the Model 2182A in the local mode.
   ```

8. **Recall stored Pulse Delta readings** – Model 2182A Pulse Delta readings were sent to the buffer of the Model 6221. Send the following read command to read the buffer:

   ```
   TRACe : DATA?
   ' Read Pulse Delta readings stored in 6221 buffer.
   ```

**Setup commands**

**Pulse Delta setup and arm commands**

Commands sent from the PC to the Model 6221 to set up and arm Pulse Delta are listed in Table 5-3.
1. Use the :NVPResent command to determine if a suitable Model 2182A with the correct firmware revision is properly connected to the RS-232 port. The RS-232 cannot be the selected interface for the Model 6221. If it is, this query will generate error -221 Settings Conflict.

2. Details on the “Configuration settings” are provided on page 5-26.

3. When using a Fixed output, use the SOUR:PDEL:INT command to set the Pulse Delta cycle time period (in PLCs).

### Table 5-3
**Pulse Delta commands**

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOURce[1]:PDELta:NVPResent?</td>
<td>Queries if 2182A is connected. 1 1 = yes, 0 = no</td>
<td></td>
</tr>
<tr>
<td>SOURce[1]:PDELta:HIGH &lt;NRf&gt;</td>
<td>Sets high pulse value (amps). 2 &lt;NRf&gt; = -105e-3 to 105e-3</td>
<td>1e-3</td>
</tr>
<tr>
<td>SOURce[1]:PDELta:LOW &lt;NRf&gt;</td>
<td>Sets low pulse value (amps). 2 &lt;NRf&gt; = -105e-3 to 105e-3</td>
<td>0</td>
</tr>
<tr>
<td>SOURce[1]:PDELta:WIDTh &lt;NRf&gt;</td>
<td>Sets pulse width (seconds). 2 &lt;NRf&gt; = 50e-6 to 12e-3</td>
<td>110e-6</td>
</tr>
<tr>
<td>SOURce[1]:PDELta:SDELay &lt;NRf&gt;</td>
<td>Sets pulse delay (seconds). 2, 3 &lt;NRf&gt; = 16e-6 to 11.996e-3</td>
<td>16e-6</td>
</tr>
<tr>
<td>SOURce[1]:PDELta:RANGing &lt;name&gt;</td>
<td>Selects fixed pulse range. 2, 4 &lt;name&gt; = BEST or FIXed</td>
<td>BEST</td>
</tr>
<tr>
<td>SOURce[1]:SWEep:RANGing &lt;name&gt;</td>
<td>Selects pulse sweep range. 2, 4 &lt;name&gt; = AUTO, BEST or FIXed</td>
<td>BEST</td>
</tr>
<tr>
<td>SOURce[1]:PDELta:COUNt &lt;NRf&gt;</td>
<td>Sets the number of Pulse Delta intervals to perform. 2 &lt;NRf&gt; = 1 to 65536 (finite count) or INFinity count.</td>
<td>INF</td>
</tr>
<tr>
<td>SOURce[1]:PDELta:INTerval &lt;NRf&gt;</td>
<td>Sets cycle time for fixed pulse (PLCs). 2 &lt;NRf&gt; = 5 to 999999</td>
<td>5</td>
</tr>
<tr>
<td>SOURce[1]:DELay &lt;NRf&gt;</td>
<td>Sets cycle time for lin/log sweep (seconds). 2, 3 &lt;NRf&gt; = 1e-3 to 999999.999</td>
<td>1</td>
</tr>
<tr>
<td>SOURce[1]:LIST:DELay &lt;NRf&gt; [,NRf, ...&lt;NRf&gt;]</td>
<td>Sets cycle time for custom sweep (seconds). 2, 3 &lt;NRf&gt; = 1e-3 to 999999.999</td>
<td>1</td>
</tr>
<tr>
<td>SOURce[1]:PDELta:SWEep[:STATe] &lt;b&gt;</td>
<td>Enable or disable Sweep output mode. 2 &lt;b&gt; = ON or OFF</td>
<td>OFF</td>
</tr>
<tr>
<td>SOURce[1]:PDELta:LMEasure &lt;NRf&gt;</td>
<td>Set number of low measurements. 2 &lt;NRf&gt; = 1 or 2</td>
<td>2</td>
</tr>
<tr>
<td>SOURce[1]:PDELta:ARM</td>
<td>Arms Pulse Delta. 4</td>
<td></td>
</tr>
<tr>
<td>SOURce[1]:PDELta:ARM?</td>
<td>Queries Pulse Delta arm. 1 = armed, 0 = not armed</td>
<td></td>
</tr>
</tbody>
</table>
When using Sweep output, use the SOUR:DEL command to set the Pulse Delta cycle time period (in seconds) for a linear or log sweep. For a custom sweep, use the SOUR:LIST:DEL command to cycle time (in seconds). See Section 4 for details on sweeps.

4. When using a Fixed output, use the SOUR:PDEL:RANG command to set the source range. When using a Sweep output, use the SOUR:SWE:RANG command to set range.

5. After setting up Pulse Delta using the setup commands, the :ARM command arms Pulse Delta. During the arming process, the Model 622x communicates with the Model 2182A.

When armed, Pulse Delta will start when the Model 6221 is triggered. Pulse Delta can be “un-armed” by sending the following command:

SOURce:SWEep:ABORt.

The query form for the arm command (SOUR:PDEL:ARM?) is used to determine if Pulse Delta is armed. A returned “1” indicates that Pulse Delta is armed. A “0” indicates that Pulse Delta is not armed.

If the Model 6221 is already armed for another action (e.g., Differential Conductance or Delta), the Pulse Delta arm command will “un-arm” the other action and arm Pulse Delta.

**Differential Conductance**

Differential measurements can be used to study the individual slopes of an I-V (or V-I) curve. By applying a known differential current (dl) to a device, differential voltage (dV) measurements can be performed. With dl and dV known, differential conductance (dG) and differential resistance (dR) can be calculated.

**Model 622x measurement process**

This measurement process is used to eliminate the effects of thermal EMFs, and a 3-point moving average calculation algorithm is used to provide more accurate readings.

The differential measurement process is shown in Figure 5-10. The Model 622x is configured to output a stepped sweep with a specified Delta, which is the differential current (dl). As shown in the illustration, Delta is added to and subtracted from each subsequent step in the sweep. The solid line is the actual output of the Model 622x.

As shown, each differential voltage calculation (dV Calc) uses the three previous Model 2182/2182A A/D measurement conversions. Keep in mind that dl (Delta) is the same for all calc points. With dl known and dV calculated, the Model 622x can also calculate, display, and store the differential conductance (dG) or differential resistance (dR) for each calculated point.
Figure 5-10
Differential Conductance measurement process

![Diagram showing the measurement process of differential conductance.]

**dV Calculations** – The following equations are used by the 622x to calculate differential voltage (dV). To calculate dV, points A through H are 2182/2182A voltage measurements (A/D readings).

\[
\begin{align*}
dV_1 &= \frac{[(A-B)/2] + [(C-B)/2]}{2} \cdot (-1)^0 \\
dV_2 &= \frac{[(B-C)/2] + [(D-C)/2]}{2} \cdot (-1)^1 \\
dV_3 &= \frac{[(C-D)/2] + [(E-D)/2]}{2} \cdot (-1)^2 \\
dV_4 &= \frac{[(D-E)/2] + [(F-E)/2]}{2} \cdot (-1)^3 \\
dV_5 &= \frac{[(E-F)/2] + [(G-F)/2]}{2} \cdot (-1)^4 \\
dV_6 &= \frac{[(F-G)/2] + [(H-G)/2]}{2} \cdot (-1)^5
\end{align*}
\]

**dG and dR Calculations** – With dl known (dl = Delta) and dV calculated, the 622x can then calculate differential conductance (dG) or differential resistance (dR).

With G units selected, readings are calculated as follows: dG = dl/dV.

With R units selected, readings are calculated as follows: dR = dV/dl.
Differential Conductance calculations

dV calculations
While the dV calculations for the first six dV readings are shown in Figure 5-10, the following formula can be used to calculate any dV reading in the test:

\[
dV = \frac{(X - Y) + (Z - Y)}{2} \cdot \frac{1}{2} \cdot (-1)^n
\]

Where:  X, Y, and Z are the three A/D measurements for a dV reading.
        n = Reading Number – 1

Example – Calculate the 21st dV reading:
X, Y, and Z are the three A/D measurements for the 21st dV reading.
        n = Reading Number – 1
        = 21 – 1
        = 20

Therefore:
\[
dV = \frac{(X - Y) + (Z - Y)}{2} \cdot \frac{1}{2} \cdot (-1)^{20}
\]

The (-1)^n term in the dV calculation is used for polarity reversal of every other calculated dV reading. This makes all calculated dV readings in the test the same polarity.

Simplified dV calculation
The above dV calculation can be simplified as follows:
\[
dV = \frac{X - Y + Z - Y}{2} \cdot (-1)^n
\]

\[
dV = \frac{X - 2Y + Z}{4} \cdot (-1)^n
\]
### Measurement units

The fundamental measurement for Differential Conductance is differential voltage (dV). However, the dV reading can be converted into a differential conductance (dG), differential resistance (dR), or power (Watts) reading. See page 5-11 for details on selecting “Measurement units”.

With Ohms (dR) or Siemens (dG) measurement units selected, the reading is calculated as follows:

\[ dR = \frac{dV}{dI} \]
\[ dG = \frac{dI}{dV} \]

**Power** – With Power measurement units selected, power is calculated using Average Voltage and Average Current. Details on Differential Conductance Power calculations are provided in Section 5 of the Reference Manual (see “Average Voltage and Power”).

### Configuration settings

Differential Conductance settings from the front panel are described as follows. These parameters are set from the DIFF CONDUCTANCE menu, which is accessed by pressing the **CONFIG** key and then the **COND** key.

The equivalent remote programming commands to configure Differential Conductance are summarized in Table 5-4.

**Step** – The step size specifies the size increment for each step of the sweep. In Figure 5-10, the 10µA steps are shown by the dashed line. If the step size is set to be larger than the start-stop interval, the step size will be readjusted to provide a 100-point Differential Conductance sweep.

Step is a magnitude and is therefore always set as a positive value. Step can be set from 0 to 105mA. The default step size is 1µA.

**Start** – The start level for the sweep applies to the middle step of the first cycle. As shown in Figure 5-10, the 0µA Start level is actually the second step of the sweep. The start level can be set from -105mA to +105mA. The default start level is -10µA.

**Stop** – The stop level for the sweep applies to the middle step of the last cycle. As shown in Figure 5-10, the 50µA Stop level is actually the second last step of the sweep. The stop level can be set from -105mA to +105mA. The default start level is +10µA.

**Delta** – The specified Delta is the differential current (dI) for the sweep. It is alternately added to and subtracted from each subsequent step in the sweep. As shown in Figure 5-10, 10µA is added to the odd numbered steps and then subtracted from the even numbered steps. Model 2182/2182A A/D readings are performed at each stepped delta level. Delta is a magnitude and is therefore always set as a positive value. Delta can be set from 0 to 105mA. The default Delta setting is 1µA.
Delay – The delay for Differential Conductance is used to allow the current source to settle when the output changes to the next stepped delta level. This delay occurs after a trigger from the Model 2182/2182A is received. Delay can be set from 1ms to 9999.999s. The default delay setting is 2ms.

Compliance Abort – By enabling (YES) Compliance Abort, Differential Conductance operation will abort if the current source goes into compliance. By default, Compliance Abort is disabled (NO).

Details on setting the sweep parameters are explained in “Operation”, page 5-38.

NOTE The source range for the Model 622x is automatically set to the best fixed range when Differential Conductance is armed.

**Operation**

**Operation – front panel**

The system configuration for front panel stand-alone operation is shown in Figure 5-2A on page 5-5.

1. Connections are shown in the following illustrations. All power must be removed from all components in the system before making connections:
   - Figure 5-3, page 5-6 – System connections
   - Figure 5-5, page 5-8 – DUT test connections

2. Configure communications for the Models 2182/2182A and 622x as explained in “Configuring communications,” page 5-9.

3. On the Model 2182/2182A, select the desired measurement range (using the **RANGE** keys) and the integration rate (using the **RATE** key). Rate must be set to an integer value (1, 2, 3, ... up to 50 or 60). If some other rate is selected, it will automatically be changed to 1PLC by the Model 622x during the arming process.

4. On the Model 622x, press **CONFIG** and then **COND** to access the DIFF CONDUCTANCE menu. See “Configuration settings” on page 5-37 for details on these settings.
   a. Set the START, STOP, STEP, DELTA, DELAY, and compliance abort (CMPL ABORT) parameters.
   b. When finished, use the EXIT key to back out of the menu structure.

5. **Set the measurement units.**
   The basic Differential Conductance reading is in volts (which is the default setting). However, it can instead be expressed (and displayed) as an Ohms, Watts or Siemens reading. See “Measurement units” on page 5-11 for details.
To set the measurement units, press the **UNITS** key to display the **READING UNITS** menu. Select **VOLTS**, **OHMS**, **WATTS**, or **SIEMENS**. Measurement units can be changed while Differential Conductance is running.

6. On the Model 622x, press the **COND** key to arm Differential Conductance. The Model 6221 is armed when the message “DIFF COND ARMED Press TRIG to start” is displayed briefly and the ARM annunciator turns on.

7. On the Model 622x, press the **TRIG** key to start taking Differential Conductance readings and send them to the buffer. Differential Conductance measurements will stop after the last A/D measurement is performed. However, Differential Conductance remains armed and can be run again by pressing the **TRIG** key. The new Differential Conductance readings will overwrite the old readings in the buffer.

8. When finished, press **EXIT** to disarm Differential Conductance.

9. On the Model 622x, press **RECALL** to access the Differential Conductance readings stored in the buffer.

**Operation – PC control**

The system configuration for PC control of the Model 622x is shown in Figure 5-2B.

1. Connections are shown in the following illustrations. All power must be removed from all components in the system before making connections:
   - Figure 5-4, page 5-7 – System connections
   - Figure 5-5, page 5-8 – Test connections

2. Configure communications for the Models 2182/2182A and 622x as explained in “Configuring communications,” page 5-9.

3. On the Model 2182/2182A, select the desired measurement range and integration rate. These Model 2182/2182A settings can be made from the front panel or remote programming can be used. Rate must be set to an integer value (1, 2, 3, ... up to 50 or 60). If some other rate is selected, it will automatically be changed to 1PLC by Model 622x during the arming process.

   For front panel operation, use the **RANGE** keys to select the measurement range. To set the integration rate, use the **RATE** key.

   Commands from the PC to control the Model 2182/2182A are addressed to the Model 622x. Each command is then routed through the Model 622x out the serial port (RS-232) to the Model 2182/2182A. The following command word is used for this communication process:

   ```
   SYSTem:COMMunicate:SERial:SEND <data>
   ```

   Where: **<data>** is a valid Model 2182/2182A command.
The following query command is used to return the response to a query command sent over the serial port:

\texttt{SYSTem:COMMunicate:SERial:ENTer?}

When communicating over the serial port, there are no errors reported if a Model 2182/2182A is not connected to the serial port.

**Examples** – The following commands demonstrate proper syntax for sending commands and returning responses to queries over the serial port:

\texttt{SYST:COMM:SER:SEND "VOLT:RANG 2"}  \quad \texttt{‘Select 2V range for 2182/2182A.}'

\texttt{SYST:COMM:SER:SEND "VOLT:RANG?"}  \quad \texttt{‘Send range query.}'

\texttt{SYST:COMM:SER:ENT?}  \quad \texttt{‘Return response to query.}'

\texttt{SYST:COMM:SER:SEND "VOLT:NPLC 1"}  \quad \texttt{‘Set rate to 1PLC for 2182/2182A.'}

\texttt{SYST:COMM:SER:SEND "VOLT:NPLC?"}  \quad \texttt{‘Send rate query.'}

\texttt{SYST:COMM:SER:ENT?}  \quad \texttt{‘Return response to query.'}

4. **Set measurement units** – Volts are the default units for the Model 622x but can instead be expressed (and displayed) as an Ohms, Watts, or Siemens reading (see “Measurement units” on page 5-11 for details). The commands to set measurement units are listed in Table 5-1. The following example shows the command to select conductance (Siemens) measurement units:

\texttt{UNIT \textit{S}}  \quad \texttt{‘Select Siemens measurement units.'}

5. **Set up, arm, and run Differential Conductance** – Details on the commands to set up and arm Differential Conductance are provided in Table 5-4. The following demonstrates the proper command sequence to set up, arm, and run Differential Conductance for the Example in Figure 5-10:

\texttt{*RST}  \quad \texttt{‘Restores 622x defaults.'}

\texttt{SOUR:DCON:STARt 0}  \quad \texttt{‘Sets start value to 0\textmu A.'}

\texttt{SOUR:DCON:STEP 10e-6}  \quad \texttt{‘Sets step size to 10\textmu A.'}

\texttt{SOUR:DCON:STOP 50e-6}  \quad \texttt{‘Sets stop value to 50\textmu A.'}

\texttt{SOUR:DCON:DELTa 20e-6}  \quad \texttt{‘Sets delta value to 20\textmu A.'}

\texttt{SOUR:DCON:DELay 1e-3}  \quad \texttt{‘Sets delay to 1ms.'}

\texttt{SOUR:DCON:CAB ON}  \quad \texttt{‘Enables Compliance Abort.'}

\texttt{TRAC:POIN 6}  \quad \texttt{‘Sets buffer size to six points.}\footnote{This depends on the system configuration.}'

\texttt{SOUR:DCON:ARM}  \quad \texttt{‘Arms Differential Conductance.'}

\texttt{INIT:IMM}  \quad \texttt{‘Starts measurements.}\footnote{This depends on the system configuration.}
A. Trace points specifies the size of the buffer. Buffer size should be the same value as the number of Differential Conductance readings in the test. See Section 6 for details on all buffer commands.

B. The initiate command starts Differential Conductance readings. After all Differential Conductance readings are performed, Differential Conductance will stop running. At this point another initiate command will re-start Differential Conductance. New Differential Conductance readings will overwrite the old Differential Conductance readings in the Model 622x buffer.

6. **Read Differential Conductance readings** – While Differential Conductance is running, the latest Model 2182/2182A reading can be read by the Model 622x using the following command:

```
SENS:DATA?
```

Reads the latest reading.

The above read command reads the last Differential Conductance reading that was performed by the Model 2182/2182A. If this command is sent before a new reading is available, the last Differential Conductance reading will again be returned.

**NOTE** If a read command is sent when Differential Conductance is not running, error -221 Settings Conflict will occur.

7. When finished with Differential Conductance, it can be disarmed by sending the following command:

```
SOUR:SWE:ABOR
```

Stops Differential Conductance and places the Model 2182/2182A in the local mode.

8. **Recall stored Differential Conductance readings** – Model 2182/2182A Differential Conductance readings were sent to the buffer of the Model 622x. Send the following read command to read the buffer:

```
TRACe:DATA?
```

Read Differential Conductance buffer readings.

**Setup and arm commands**

Commands sent from the PC to the Model 622x to set up and arm Differential Conductance are listed in Table 5-4.
1. Use the :NVPR? command to determine if a suitable Model 2182/2182A with the correct firmware revision is properly connected to the RS-232 port. This query command can be used for the system configuration shown in Figure 5-2B on page 5-5.

   The RS-232 cannot be the selected interface for the Model 6221. If it is, this query will generate error -221 Settings Conflict.

2. See “Configuration settings” on page 5-37 for more information on these settings (:START, :STEP, :STOP, :DELTA, :DELAY, and :CABort).

3. After setting up Differential Conductance using the above setup commands, the :ARM command arms Differential Conductance. During the arming process, the Model 622x communicates with the Model 2182/2182A.

   When armed, Differential Conductance will start when the Model 6221 is triggered. Differential Conductance can be “un-armed” by sending the following command: SOURce:SWEep:ABORt.

---

### Table 5-4

*Table of Differential Conductance commands*

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOURce[1]:DCONductance:NVPResent?</td>
<td>Queries if 2182/2182A is connected. ¹</td>
<td>1 = yes, 0 = no</td>
</tr>
<tr>
<td>SOURce[1]:DCONductance:START &lt;NRf&gt;</td>
<td>Sets start value (amps). ²</td>
<td>&lt;NRf&gt; = -105e-3 to 105e-3</td>
</tr>
<tr>
<td>SOURce[1]:DCONductance:STEP &lt;NRf&gt;</td>
<td>Sets step size (amps). ²</td>
<td>&lt;NRf&gt; = 0 to 105e-3</td>
</tr>
<tr>
<td>SOURce[1]:DCONductance:STOP &lt;NRf&gt;</td>
<td>Sets stop value (amps). ²</td>
<td>&lt;NRf&gt; = -105e-3 to 105e-3</td>
</tr>
<tr>
<td>SOURce[1]:DCONductance:DELTA &lt;NRf&gt;</td>
<td>Sets delta value (amps). ²</td>
<td>&lt;NRf&gt; = 0 to 105e-3</td>
</tr>
<tr>
<td>SOURce[1]:DCONductance:DELAY &lt;NRf&gt;</td>
<td>Sets delay (seconds). ²</td>
<td>&lt;NRf&gt; = 1e-3 to 9999.999</td>
</tr>
<tr>
<td>SOURCE[1]:DCONductance:CABort &lt;b&gt;</td>
<td>Enable or disable Compliance Abort. ²</td>
<td>&lt;b&gt; = 0 or OFF, 1 or ON</td>
</tr>
<tr>
<td>SOURce[1]:DCONductance:ARM</td>
<td>Arms Differential Conductance. ³</td>
<td></td>
</tr>
<tr>
<td>SOURce[1]:DCONductance:ARM?</td>
<td>Queries Diff Cond arm. ³</td>
<td>1 = armed, 0 = not armed.</td>
</tr>
<tr>
<td>SOURce[1]:DCONductance:NVZero?</td>
<td>Queries V-zero value acquired from 2182/2182A. ⁴</td>
<td></td>
</tr>
</tbody>
</table>

---

¹ Use the :NVPR? command to determine if a suitable Model 2182/2182A with the correct firmware revision is properly connected to the RS-232 port.

² For more information on these settings, see page 5-37.

³ For more information on this command, see page 5-37.

⁴ For more information on this query, see page 5-37.
The query form for the arm command (SOUR:DCON:ARM?) is used determine if Differential Conductance is armed. A returned “1” indicates that Differential Conductance is armed. A “0” indicates that Differential Conductance is not armed.

If the Model 6221 is already armed for another action (e.g., Delta or Pulse Delta), the Differential Conductance arm command will “un-arm” the other action and arm Differential Conductance.

4. During the arming process, the Model 622x acquires the offset voltage (V-zero) value of the Model 2182/2182A. The Model 622x factors this value into the calculation for Differential Conductance voltage.
Section 6 topics

**Averaging filter**, page 6-2
- Averaging filter characteristics, page 6-2
- Filter setup and control, page 6-4
- Remote programming – Averaging filter, page 6-4

**Math**, page 6-7
- mX+b and m/X+b (reciprocal), page 6-5
- Configuring mX+b and m/X+b, page 6-6
- Remote programming – Math, page 6-6

**Buffer**, page 6-7
- Buffer characteristics, page 6-7
- Storing readings, page 6-8
- Recall, page 6-8

**NOTE** This section only applies to a Model 622x that is being used with a Model 2182/2182A to perform Delta, Pulse Delta, or Differential Conductance measurements.

**NOTE** The information in this section is an abbreviated version of the information in Section 6 of the Reference Manual. Refer to Section 6 of the Reference Manual for complete details and additional information that is not provided in this manual.
Averaging filter

The average filter can be used with Delta, Pulse Delta, and Differential Conductance. There are two types of averaging filter: moving and repeating. “Filter type” is explained on page 6-3.

The averaging filter stabilizes noisy delta measurements caused by noisy input signals. For Delta, Pulse Delta, and Differential Conductance, readings from the Model 2182/2182A are processed by the Model 622x as delta voltage readings. These delta readings can then be filtered by the Model 622x.

Table 6-1 lists the filter types that can be used with the various delta tests (Yes) and which cannot (No). Note that the filter must be enabled before arming the delta test.

Table 6-1
Average filter types

<table>
<thead>
<tr>
<th>Average Filter</th>
<th>Moving</th>
<th>Repeating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delta</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Pulse Delta:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fixed output</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Sweep output</td>
<td>Yes</td>
<td>No²</td>
</tr>
<tr>
<td>Differential Conductance</td>
<td>No¹</td>
<td>Yes</td>
</tr>
</tbody>
</table>

1. If the moving average filter is enabled when Differential Conductance is armed, the filter type will change to repeating.
2. If the repeating average filter is enabled when Pulse Delta (Sweep output) is armed, the filter type will change to moving.

Averaging filter characteristics

Filter count

The filter count specifies how many delta readings (within the filter window) to place in the memory stack. Keep in mind that there are three A/Ds for every Delta and Differential Conductance reading, and two or three A/Ds for every Pulse Delta reading.

When the stack is full, the readings are averaged to calculate the final filtered delta reading. The filter count can be set from 2 to 300. However, only readings within the filter window will be displayed and stored, or transmitted (see “Filter window” on page 6-4 for details).
Filter type

There are two averaging filter types: moving and repeating.

Moving filter

**Basic moving filter operation** – For the moving filter, every delta reading yields a filtered delta reading. Every time a delta reading is placed in the buffer stack, the readings in the stack are averaged to yield a single filtered reading. The stack type is first-in, first-out. After the stack fills, the newest reading conversion replaces the oldest. Note that the instrument does not wait for the stack to fill before releasing readings.

**Delta and Pulse Delta** – As shown in Table 6-1, the moving average filter can be used with Delta and Pulse Delta.

Keep in mind that when using the averaging filter, a settled filter reading is not available until after the filter stack is filled. The filter count sets the filter stack size. When Delta or Pulse Delta is started, the filter stack is allowed to fill before the first filtered Delta or Pulse Delta reading is stored in the buffer. Therefore, the total number of Delta or Pulse Delta cycles that are performed is calculated as follows:

\[
\text{Total Number of Cycles} = \text{Moving Filter Count} + \text{Cycle Count}
\]

Repeating filter

**Basic repeating filter operation** – As shown in Table 6-1, the repeating average filter can be used with Delta, Pulse Delta (fixed output), and Differential Conductance.

The repeating filter takes a specified number (count) of reading conversions, averages them, and yields a reading. It then flushes its stack and starts over.

The filter stack must be filled with delta readings and then averaged to yield (and store) one filtered delta reading. The stack is emptied, and the “fill and average” process is repeated to yield (and store) another filtered reading.

This “fill and average” process is repeated for every specified delta cycle. For example, assume the repeating average filter count is 10 and the delta test is configured to perform 25 cycles. For these test parameters, 250 delta cycles will be performed to store 25 filtered delta readings in the buffer.

**Differential Conductance** – When using the repeating filter, the actual step size run for the test is the programmed step size divided by the filter count:

\[
\text{Step Size (repeating filter)} = \frac{\text{Programmed Step Size}}{\text{Filter Count}}
\]

For example, assume the programmed step size is 10µA and the Filter Count is 10. When the Differential Conductance test is run, the actual step size will be 1µA (10µA / 10).
Filter window

The averaging filter uses a “noise” window to control filter threshold. As long as the signal remains within the selected window, A/D conversions continue to be placed in the stack. If the signal changes to a value outside the window, the filter resets, and the filtering process starts over.

The noise window, which is expressed as a percentage of measurement range, allows a faster response time to large signal step changes (e.g., sweep step). A reading conversion outside the plus or minus noise window fills the filter stack immediately.

If the noise does not exceed the selected window, the reading is based on the average of the reading conversions. If the noise does exceed the selected window, the reading is a single reading conversion, and new averaging starts from this point.

The window can only be set remotely and can be assigned any value from 0.00% to 10%. The filter window is expressed as a percent of range. For example, with the Model 2182/2182A on the 10V range, a 10% window means that the filter window is ±1V.

Filter setup and control

When the averaging filter is enabled, the FILT annunciator turns on. For front panel operation, the AVG key toggles the state of the averaging filter. The filter can be configured while it is enabled or disabled.

To configure the filter, press CONFIG then AVG. From the TYPE menu item, select the MOVING or REPEAT filter and press ENTER. From the COUNT menu item, set the filter count (2 to 300) and press ENTER. Use the EXIT key to return to the normal display state.

Remote programming – Averaging filter

The commands for averaging filter setup and control are listed in Table 6-2. A programming example follows the table.
Programming example — Repeating average filter

This command sequence configures and enables the repeating filter for Differential Conductance:

```
SENS:AVER:TCON REP   ' Select the repeating average filter.
SENS:AVER:WIND 1    ' Set filter window to 1%.
SENS:AVER:COUN 20    ' Set filter count to 20.
SENS:AVER ON       ' Enable the repeating average filter.
```

Math

mX+b and m/X+b (reciprocal)

These math functions affect the results of the Delta, Pulse Delta, or Differential Conductance operations. Details on the delta operations are covered in Section 5.

mX+b and m/X+b manipulate delta readings (X) mathematically according to the following calculations:

\[ Y = mX+b \]
\[ Y = m/X+b \]

Where:  
X is the normal delta reading.  
m and b are user-entered constants for scale factor and offset.  
Y is the displayed result.

**NOTE** Changing the “m” or “b” for mX+b also changes it for m/X+b.
Configuring mX+b and m/X+b

To select and configure mX+b and m/X+b from the front panel, press CONFIG then MATH. Select the math function (MX+B or M/X+B), then enter the required parameters (m and b). Once a math function is selected, press the MATH key to toggle math on or off. The MATH annunciator will turn on to indicate that the math function is enabled.

Remote programming – Math

Commands for mX+b and m/X+b math calculations are listed in Table 6-3.

Table 6-3
Math commands

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>CALCulate[1]:FORMAT &lt;name&gt;</td>
<td>Select math format.</td>
<td>MXB</td>
</tr>
<tr>
<td>CALCulate[1]:KMATH:MMFactor &lt;NRf&gt;</td>
<td>Set “m” factor for mX+b and m/X+b.</td>
<td>1.0</td>
</tr>
<tr>
<td>CALCulate[1]:KMATH:MA1Factor &lt;NRf&gt;</td>
<td>Set “m” factor for mX+b and m/X+b.</td>
<td>1.0</td>
</tr>
<tr>
<td>CALCulate[1]:KMATH:MBFactor &lt;NRf&gt;</td>
<td>Set “b” factor for mX+b and m/X+b.</td>
<td>0.0</td>
</tr>
<tr>
<td>CALCulate[1]:KMATH:MA0Factor &lt;NRf&gt;</td>
<td>Set “b” factor for mX+b and m/X+b.</td>
<td>0.0</td>
</tr>
<tr>
<td>CALCulate[1]:STATE &lt;b&gt;</td>
<td>Enable or disable CALC1 calculation</td>
<td>OFF</td>
</tr>
<tr>
<td>CALCulate[1]:DATA[:LAST]?</td>
<td>Return the latest CALC1 result.</td>
<td></td>
</tr>
<tr>
<td>CALCulate[1]:DATA:FRESH?</td>
<td>Same as CALC1:DATA? except a reading can only be returned once.</td>
<td></td>
</tr>
</tbody>
</table>

Programming example — mX+b

This command sequence performs a single mX+b calculation and displays the result on the computer CRT. Note that Delta, Pulse Delta, or Differential Conductance must be running when the CALC1 read command is sent.

```
CALC1:FORM MXB  ' Select mX+b math format.
CALC1:KMAT:MMF 2e-3  ' Set scale factor (M) to 2e-3.
CALC1:KMAT:MBF 5e-4  ' Set offset (B) to 5e-4.
CALC1:STAT ON       ' Enable CALC1 (math).
CALC1:DATA?         ' Request latest CALC1 reading.
```
Buffer

The Model 622x has a buffer (data store) to store readings and related data elements for one to 65,536 buffer readings. Buffer readings are readings from the Model 2182/2182A that were processed by the Model 622x as delta readings (Delta, Pulse Delta, or Differential Conductance). Also stored are statistics for the readings. These include maximum, minimum, average mean, standard deviation, and peak-to-peak.

For front panel operation, the buffer is always active (enabled). Post-math delta readings are automatically stored in the buffer.

Remote programming provides more control of the buffer:
- The buffer can be disabled.
- When enabled, buffer feed can be pre-math delta readings or post-math delta readings.
- The timestamp can be set for the absolute format or the delta format.

NOTE For remote programming, only the buffer recall commands are documented in this section. See Section 6 of the Reference Manual for details on all buffer commands.

Buffer characteristics

Buffer size

The buffer size automatically sets to accommodate the number of delta readings to be performed. For example, if the test is configured to perform 1,000 delta measurements, the buffer size will be set to 1000.

If the delta test is configured to perform an infinite number of delta measurements, the buffer will be set to maximum size (65,536 readings). After the 65,536th reading, the delta test continues but readings stop being stored.

Buffer data elements

Data elements are stored along with each delta reading. The data elements for front panel operation are shown in Figure 6-1. These include reading number, timestamp, reading units, and the current source output value.

For remote programming, the returned reading string for a buffer read command includes the reading and the data elements in the following order:

Reading with Units, Timestamp, Current Source, Average Voltage, Compliance State, and Reading Number.
Buffer statistics

The following statistics are available on the stored buffer readings:

- **MIN** and **MAX** provides the minimum and maximum readings stored in the buffer. It also indicates the buffer location of these readings.
- The **PK-PK (peak-to-peak)** value is the difference between the maximum and minimum readings stored in the buffer:
  \[ PK-PK = \text{MAX} - \text{MIN} \]
- **Mean** is the mean average of the buffer readings. Mean is calculated as follows:
  \[
y = \frac{1}{n} \sum_{i=1}^{n} X_i
\]
  Where: \( X_i \) is a stored reading.
  \( n \) is the number of stored readings.
- The **STD DEV** value is the standard deviation of the buffered readings. Standard deviation is calculated as follows:
  \[
y = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (\text{Avg} - X_i)^2}
\]
  Where: \( X_i \) is a stored reading.
  \( n \) is the number of stored readings.
  \( \text{Avg} \) is the mean of the buffer readings.

Buffer timestamp

Each buffer reading has a timestamp. The absolute timestamp is referenced to the first stored reading in the buffer, which is timestamped at 0.0s.

Storing readings

Unless it was disabled using remote operation, the buffer is always active (enabled), and post-math readings are automatically stored in the buffer.

Recall

**Buffer readings** – Press **RECALL** and use the edit keys shown in Figure 6-1 to navigate through the buffer to view stored readings.
Buffer statistics – While in buffer RECALL, use the EDIT/LOCAL key (see Figure 6-1). Each press of this key displays the next statistic. After the last statistic is displayed (Std Dev), pressing EDIT/LOCAL will display the stored readings. When finished, press EXIT to return to the normal display.

Figure 6-1
Buffer recall

A) Front panel edit keys to display buffer readings:

Model 6220:

\[\begin{array}{c}
\text{RANGE} \\
\text{or} \\
\text{RANGE}
\end{array} \]

Model 621:

\[\begin{array}{c}
\text{RANGE} \\
\text{or} \\
\text{PUSH TO ENTER}
\end{array} \]

Reading \[+123.45678\text{mV}\] 00000 \[\rightarrow\]
Current Source \[\text{Isrc} +1.0000\text{mA}\] Time 000000.001 s \[\rightarrow\]

B) Use EDIT/LOCAL key to display buffer statistics:

\[\begin{array}{c}
\text{EDIT/LOCAL} \\
\rightarrow
\end{array} \]

Min \[\rightarrow\] Max \[\rightarrow\] Pk-Pk \[\rightarrow\] Avg \[\rightarrow\] Std Dev \[\rightarrow\] Buffer Readings

For remote programming, the commands to recall delta readings and statistics are listed in Table 6-4.

Table 6-4
Buffer commands

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRACe:DATA?</td>
<td>Request all readings in buffer.</td>
<td></td>
</tr>
<tr>
<td>CALCulate2:FORMat &lt;name&gt;</td>
<td>Select buffer statistic: &lt;name&gt; = MEAN, SDEViation, MAXimum, MINimum, or PKPK</td>
<td>MEAN</td>
</tr>
<tr>
<td>CALCulate2:STATe &lt;b&gt;</td>
<td>Enable or disable calculation: (&lt;b&gt; = ON or OFF)</td>
<td>OFF</td>
</tr>
<tr>
<td>CALCulate2:IMMediate</td>
<td>Perform the selected calculation on buffer readings.</td>
<td></td>
</tr>
<tr>
<td>CALCulate2:DATA?</td>
<td>Read the result of the buffer statistic.</td>
<td></td>
</tr>
</tbody>
</table>
Wave Functions (6221 Only)

Section 7 topics

**Wave function overview, page 7-2**
- Setting waveform parameters, page 7-3
- Editing parameters, page 7-3
- Amplitude and offset editing, page 7-3
- Amplitude and units, page 7-3

**Ranging, page 7-3**
- Range options, page 7-3
- Arbitrary waveform ranging, page 7-4

**Frequency, page 7-4**
- Offset, page 7-4
- Duty cycle, page 7-5
- Phase marker, page 7-6
- Duration, page 7-7
- Externally triggered waveforms, page 7-7

**Front panel wave function operation, page 7-8**
- Using the wave function menu, page 7-8
- Generating a sine wave, page 7-10
- Generating an arbitrary waveform, page 7-11

**Remote wave function operation, page 7-12**
- Programming sine waves, page 7-13
- Programming arbitrary waveforms, page 7-14
- SCPI commands — wave functions, page 7-15

**NOTE**

The information in this section is an abbreviated version of the information in Section 7 of the Reference Manual. Refer to Section 7 of the Reference Manual for complete details and additional information that is not provided in this manual.
Wave function overview

Table 7-1 summarizes the basic characteristics of the four wave functions available in the Model 6221. More details on various aspects can be found in the following paragraphs.

Table 7-1
Wave function characteristics

<table>
<thead>
<tr>
<th>Wave function</th>
<th>Characteristics</th>
</tr>
</thead>
</table>
| Sine wave       | Frequency: 1mHz to 100kHz  
|                 | Amplitude: 1pA to 105mA peak  
|                 | Range: 2nA to 100mA  
|                 | Offset: 0 to ±105mA  
|                 | Phase marker: 0° to 360°  
|                 | Duration: 100ns to 999999.999s  |
| Square wave     | Frequency: 1mHz to 100kHz  
|                 | Amplitude: 1pA to 105mA peak  
|                 | Range: 2nA to 100mA  
|                 | Offset: 0 to ±105mA  
|                 | Duty cycle: 0 to 100%  
|                 | Phase marker: 0° to 360°  
|                 | Duration: 100ns to 999999.999s  |
| Ramp wave       | Frequency: 1mHz to 100kHz  
|                 | Amplitude: 1pA to 105mA peak  
|                 | Range: 2nA to 100mA  
|                 | Offset: 0 to ±105mA  
|                 | Duty cycle: 0 to 100%  
|                 | Phase marker: 0° to 360°  
|                 | Duration: 100ns to 999999.999s  |
| Arbitrary wave  | Frequency: 1mHz to 100kHz  
|                 | Amplitude: 1pA to 105mA peak  
|                 | Range: 2nA to 100mA  
|                 | Offset: 0 to ±105mA  
|                 | Number of points: 2 to 65,535  
|                 | Phase marker: 0° to 360°  
|                 | Duration: 100ns to 999999.999s  |
**Setting waveform parameters**

**NOTE** User setups cannot be saved or recalled while Wave is armed or running. Attempting to do so will generate error +413 Not allowed with mode arm.

**Editing parameters**

The AMPL and FREQ keys also function as left arrow and right arrow keys, respectively, when editing a numeric value or scrolling through a menu.

**Amplitude and offset editing**

The Model 6221 Amplitude and Offset menus are coupled and follow special rules for editing. To change amplitude, press the AMPL key, use the arrow keys to select a digit, and use the knob to change the value. The range up and down arrows are used to change the amplitude range. Once you have selected an Amplitude range and entered the desired value, go into the Offset menu (CONFIG->WAVE->OFFSET) to set the offset value.

**Amplitude and units**

The amplitude setting range for all four waveform types is from 1pA to 105mA peak. The peak-to-peak value is double the amplitude setting. For example, a 1mA amplitude setting results in a 2mA peak-to-peak waveform.

The front panel allows setting wave amplitude in either RMS or peak units. The default is Peak, and the RMS selection will only apply for sine wave (RMS = 0.70710678 x peak) or triangle wave (RMS = 0.57735027 x peak) and will be ignored for other waveform types.

**Ranging**

**Range options**

There are two methods of ranging:

- **BEST FIXED** — This option will automatically select the range based on the amplitude and offset parameters set at the time the waveform is armed.
- **FIXED** — With this option, the waveform will be generated on the current range set at the time the wave is armed (after error checking is performed). If using this option, be sure that range is high enough for the selected amplitude and offset.
**Arbitrary waveform ranging**

The arbitrary waveform is described in normalized units from -1 to +1. See the following example:

Ranging: BEST  
Amplitude: 10mA peak  
Offset: 0mA  
ARB values: range from +1 to -1

These settings will generate a waveform with a peak-to-peak value of 20mA on the 20mA range.

**Frequency**

The frequency setting range for sine, square, ramp, and arbitrary waveforms is from 1mHz to 100kHz. Note that the period is the reciprocal of the frequency: 1/f. For example, a 1kHz waveform has a period of 1ms.

**Offset**

The offset setting allows you to add a DC offset value to a waveform. Figure 7-1 shows an example of a 1mA offset added to a square wave with a 10mA peak (20mA peak-to-peak) amplitude.

Figure 7-1  
Offset example
Duty cycle

For a square wave Figure 7-2A, the duty cycle setting is the portion of the total cycle that the wave is high relative to the period of the waveform. For a ramp waveform Figure 7-2B, the duty cycle corresponds to the fraction of the total wave cycle that is rising. A 50% duty cycle corresponds to a symmetric triangle wave. The left waveform in B has a 100% duty cycle, the center waveform has 0% duty cycle, and the right waveform has 50% duty cycle. A 0° marker setting for ramp waveforms corresponds to the minimum output at the start of ramp-up. For sine and square wave, a 0° marker setting for square and sine waves is the zero-crossing point.

Figure 7-2
Duty cycle

A. Square Wave Duty Cycle

B. Ramp Wave Duty Cycle
Phase marker

The phase marker (Figure 7-3) allows you to set a pulse marker that defines a specific point of a waveform over a range of 0 to 360°. The phase marker signal is a 1μs pulse that appears on the selected line of the external trigger connector (see information on the external trigger connector in Section 8 of the Model 622x Reference Manual for connector designations). You can also define which trigger output line is used for the phase marker pulse (default is line 3), but you cannot use the same line used for the external trigger output (default is 2) or the waveform external trigger input line (default is 0 or disabled). A 0° marker setting for ramp waveforms corresponds to the minimum output at the start of ramp-up. For sine and square wave, a 0° marker setting for square and sine waves is the zero-crossing point.

Figure 7-3
Phase marker
Duration

The duration setting defines how long the waveform is generated. You can set the duration in time over a range of 100ns to 999999.999s, in cycles from 0.001 to 99999999900 cycles (provided the equivalent time, cycles/frequency does not exceed the upper time duration limit), or choose a continuous waveform (INFinite setting). From the front panel, you can only specify a time duration from 0.001s to 999999.999s and a cycle duration as an integer number of cycles between 1 and 99999999900.

When a waveform is armed, the execution time is determined based on the explicitly programmed time duration or calculated from the specified cycles or duration settings. The time duration cannot be changed while a waveform is armed. If the frequency is changed while the waveform is armed, the existing execution time will remain fixed. The equivalent time duration will not be recalculated even if the duration is set to cycles. If the same number of cycles is desired at the new frequency, the wave function should be aborted and then re-armed to force the recalculation of waveform execution time.

Externally triggered waveforms

Model 6221 units with firmware revision A03 or later include a mode to trigger the arbitrary waveform generator using the instrument's trigger link lines. When this mode is enabled, the instrument waits for an external trigger pulse on a specified trigger link line and starts the configured waveform within 1 μs of the falling edge of the trigger pulse.

This manual section summarizes front panel menu selections and remote commands to control this mode. For complete details on using externally triggering waveforms, see Section 7 of the Model 6220/6221 Reference Manual.
Front panel wave function operation

Using the wave function menu

To configure wave functions, press CONFIG then WAVE, then make your selections from Table 7-2 below. See the detailed procedures for each wave function type that follow.

Table 7-2
Wave function configuration menu

<table>
<thead>
<tr>
<th>Menu selection</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>TYPE</td>
<td>Select waveform type:</td>
</tr>
<tr>
<td>SINE</td>
<td>Select sine wave.</td>
</tr>
<tr>
<td>SQUARE</td>
<td>Select square wave.</td>
</tr>
<tr>
<td>RAMP</td>
<td>Select ramp wave.</td>
</tr>
<tr>
<td>ARBx</td>
<td>Select user-defined arbitrary wave.</td>
</tr>
<tr>
<td></td>
<td>Where: x = 0 to 4.</td>
</tr>
<tr>
<td>OFFS</td>
<td>Enter DC offset (0 to ±105mA).</td>
</tr>
<tr>
<td>AMPL-UNIT</td>
<td>Select amplitude units (PEAK or RMS).</td>
</tr>
<tr>
<td></td>
<td>(Front panel only.)</td>
</tr>
<tr>
<td>DUTY-CYCLE</td>
<td>Enter duty cycle (0 to 100%).</td>
</tr>
<tr>
<td>PH-MKR</td>
<td>Select phase marker and line:</td>
</tr>
<tr>
<td>STATE</td>
<td>Turn phase marker ON or OFF.</td>
</tr>
<tr>
<td>OUTPUT-POINT</td>
<td>0 to 360°</td>
</tr>
<tr>
<td>OUTPUT-LINE</td>
<td>Set trigger output line (OFF, #1 to #6).</td>
</tr>
<tr>
<td>DURATION</td>
<td>Set duration of waveform:</td>
</tr>
<tr>
<td>INFINITE</td>
<td>Continuous waveform.</td>
</tr>
<tr>
<td>SET-TIME</td>
<td>Set duration in time (0.001s to 999999.999s).</td>
</tr>
<tr>
<td>SET-CYCLES</td>
<td>Set duration in cycles (0.001 to 99999999900).</td>
</tr>
<tr>
<td>RANGING</td>
<td>Select ranging for selected wave function:</td>
</tr>
<tr>
<td>BEST-FIXED</td>
<td>Select best range based on wave amplitude.</td>
</tr>
<tr>
<td>FIXED</td>
<td>Stay on fixed range when waveform is armed.</td>
</tr>
</tbody>
</table>

1. Arbitrary waveforms can be defined only via remote. Location 0 is volatile RAM, while locations 1-4 are NVRAM and will be saved across power cycles.

2. Waveform triggering available in revision level A03 and later firmware. See Section 7 of the Model 6220/6221 Reference Manual for details on externally triggering waveforms.
Table 7-2 (cont.)
Wave function configuration menu

<table>
<thead>
<tr>
<th>Menu selection</th>
<th>Description</th>
</tr>
</thead>
</table>
| TRIG-MODE MAN/BUS | Configure low jitter external waveform triggering:
| NONE | Disable external trigger mode (default).
| TLNK-#1 | Enables external trigger mode with no line selected.
| #2 | Enables external trigger on trigger link line 1.
| #3 | Enables external trigger on trigger link line 2.
| #4 | Enables external trigger on trigger link line 3.
| #5 | Enables external trigger on trigger link line 4.
| #6 | Enables external trigger on trigger link line 5.
| RE-TRIG | Configure response to external retriggering:
| IGNORE-TRIG | Ignore subsequent triggers while outputting a wave.
| RESTART-IMMEDIATELY | Restart waveform immediately upon each trigger. |
| INACTIVE-VAL | Set output value before and after triggered waveforms. |

1. Arbitrary waveforms can be defined only via remote. Location 0 is volatile RAM, while locations 1-4 are NVRAM and will be saved across power cycles.
2. Waveform triggering available in revision level A03 and later firmware. See Section 7 of the Model 6220/6221 Reference Manual for details on externally triggering waveforms.
Generating a sine wave

1. If you intend to use fixed ranging, manually set the range high enough to accommodate both the amplitude and offset setting.

2. **Configure the waveform as follows:**
   a. Press CONFIG then WAVE to enter the wave function configuration menu.
   b. Select TYPE, then press ENTER.
   c. Select SINE, then press ENTER to choose a sine wave.
   d. To add a DC offset, select OFFSET from the CONFIGURE WAVEFORM menu, then set the offset as desired.
   e. To use the phase marker, select PHASE-MARKER, set the STATE to ON, use OUTPUT-POINT to set the phase setting, and OUTPUT-LINE to set the trigger line.
   f. Again from the CONFIGURE WAVEFORM menu, choose RANGING, press ENTER, then select BEST-FIXED or FIXED as desired.
   g. From the CONFIGURE WAVEFORM menu, select DURATION, then set the desired waveform duration.
   h. From the CONFIGURE WAVEFORM menu, select AMPL-UNIT, then set the desired amplitude units (PEAK or RMS).
   i. Press EXIT to return to normal display.

3. **Set frequency and amplitude:**
   a. Press the FREQ key, then set the frequency to the desired value.
   b. Press the AMPL key, then set the amplitude as required.

4. **Generate waveform:**
   a. Press the WAVE key to arm the wave function.
   b. Press TRIG to turn on the output and start generating the waveform.
   c. The output will turn off after the currently set duration period has expired. If the duration is set to infinite, press the EXIT key to stop generating the waveform and turn the output off.
Generating an arbitrary waveform

<table>
<thead>
<tr>
<th>NOTE</th>
<th>Arbitrary waveforms cannot be defined from the front panel, but they can be generated once they are defined by using the procedure below.</th>
</tr>
</thead>
</table>

1. If you are using the fixed range setting, manually set the range to a high enough setting to accommodate the expected amplitude and offset settings.

2. **Configure the waveform as follows:**
   a. Press CONFIG then WAVE to enter the wave function configuration menu.
   b. Select TYPE, then press ENTER.
   c. Select ARBx, where x is the arbitrary waveform to use (0-4).
   d. To add a DC offset, select OFFSET from the configure waveform menu, then set the offset as desired.
   e. To use the phase marker, select PHASE-MARKER, set the STATE to ON, use OUTPUT-POINT to set the phase setting, and OUTPUT-LINE to set the trigger line.
   f. Again from the configure waveform menu, choose RANGING, press ENTER, then select BEST-FIXED or FIXED as desired.
   g. From the configure waveform menu, select DURATION, then set the desired waveform duration.
   h. Press EXIT to return to normal display.

3. **Set frequency and amplitude:**
   a. Press the FREQ key, then set the frequency to the desired value.
   b. Press the AMPL key, then set the amplitude as required.

4. **Generate waveform:**
   a. Press the WAVE key to arm the wave function.
   b. Press TRIG to turn on the output and start generating the waveform.
   c. The output will turn off after the currently set duration period has expired. If the duration is set to infinite, press the EXIT key to stop generating the waveform and turn the output off.
Remote wave function operation

Procedures for programming and generating waveforms for sine and arbitrary waveform types are given on the following pages. Each of these procedures includes commands for a typical wave function example. Table 7-3 summarizes parameters for each of these examples. See “SCPI commands — wave functions,” page 7-15 for a listing of wave function commands.

Table 7-3
Waveform example parameters

<table>
<thead>
<tr>
<th>Waveform</th>
<th>Parameters for waveform examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sine wave (page 7-13)</td>
<td>Frequency: 1kHz</td>
</tr>
<tr>
<td></td>
<td>Amplitude: 10mA</td>
</tr>
<tr>
<td></td>
<td>Offset: 1mA</td>
</tr>
<tr>
<td></td>
<td>Phase marker: off</td>
</tr>
<tr>
<td></td>
<td>Duration: 5s</td>
</tr>
<tr>
<td>Arbitrary wave (page 7-14)</td>
<td>Arbitrary points: -0.5, -0.25, 0, 0.3, 0.4</td>
</tr>
<tr>
<td></td>
<td>Range: best fixed</td>
</tr>
<tr>
<td></td>
<td>Frequency: 100kHz</td>
</tr>
<tr>
<td></td>
<td>Amplitude: 25mA</td>
</tr>
<tr>
<td></td>
<td>Offset: 0</td>
</tr>
<tr>
<td></td>
<td>Phase marker: Off</td>
</tr>
<tr>
<td></td>
<td>Duration: 20s</td>
</tr>
</tbody>
</table>
Programming sine waves

1. **Restore defaults with this command:**
   
   *RST

2. **Configure the waveform.**
   
   **Examples** – The following commands configure a 1kHz sine wave with an amplitude of 10mA, 1mA offset, and phase marker off:

   - `SOUR:WAVE:FUNC SIN` 'Select sine wave.'
   - `SOUR:WAVE:FREQ 1e3` 'Set frequency to 1kHz.'
   - `SOUR:WAVE:AMPL 1e-2` 'Set amplitude to 10mA.'
   - `SOUR:WAVE:OFFS 1e-3` 'Set offset to 1mA.'
   - `SOUR:WAVE:PMAR:STAT OFF` 'Turn off phase marker.'
   - `SOUR:WAVE:DUR:TIME 5` '5 second duration.'
   - `SOUR:WAVE:RANG BEST` 'Select best fixed source range.'

3. **Arm and trigger the waveform, turn on output:**
   
   - `SOUR:WAVE:ARM` 'Arm waveform.'
   - `SOUR:WAVE:INIT` 'Turn on output, trigger waveform.'

4. **To stop generating the waveform and turn the source output off before the duration elapses, send this command:**
   
   - `SOUR:WAVE:ABOR` 'Stop generating waveform.'
Programming arbitrary waveforms

1. **Restore defaults with this command:**
   
   *RST

2. **Configure the waveform.**
   
   **Examples** – The following commands configure a 100kHz arbitrary wave with an amplitude of 25mA, 0mA offset, phase marker off, and 20 second duration:

   ```
   SOUR:WAVE:ARB:DATA -0.5, -0.25, 0, 0.3, 0.4
   ' Define arbitrary data points in location 0.
   SOUR:WAVE:ARB:COPY 1
   ' Copy points to location 1.
   SOUR:WAVE:FUNC ARB1
   ' Select arb wave, location 1.
   SOUR:WAVE:FREQ 1e5
   ' Set frequency to 100kHz.
   SOUR:WAVE:AMPL 25e-3
   ' Set amplitude to 25mA.
   SOUR:WAVE:OFFS 0
   ' Set offset to 0.
   SOUR:WAVE:PMAR:STAT OFF
   ' Turn off phase marker.
   SOUR:WAVE:DUR:TIME 20
   ' 20 second duration.
   SOUR:WAVE:RANG BEST
   ' Select best fixed source range.
   ```

3. **Arm and trigger the waveform, turn on output:**
   
   SOUR:WAVE:ARM
   ' Arm waveform.
   SOUR:WAVE:INIT
   ' Turn on output, trigger waveform.

4. **To stop generating the waveform and turn the source output off before the duration elapses, send this command:**
   
   SOUR:WAVE:ABOR
   ' Stop generating waveform.
### SCPI commands — wave functions

Commands for wave functions are listed in Table 7-4.

#### Table 7-4
Waveform function commands

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOURce[1]:WAVE:FUNCtion &lt;name&gt;</td>
<td>Selects wave function.</td>
<td>SIN</td>
</tr>
<tr>
<td>SOURce[1]:WAVE:DCYCle &lt;NRf&gt;</td>
<td>Sets duty cycle.</td>
<td>50</td>
</tr>
<tr>
<td>SOURce[1]:WAVE:AMPLitude &lt;NRf&gt;</td>
<td>Sets amplitude.</td>
<td>1e-3</td>
</tr>
<tr>
<td>SOURce[1]:WAVE:FREQuency &lt;NRf&gt;</td>
<td>Sets frequency.</td>
<td>1e3</td>
</tr>
<tr>
<td>SOURce[1]:WAVE:OFFset &lt;NRf&gt;</td>
<td>Sets offset.</td>
<td>0</td>
</tr>
<tr>
<td>SOURce[1]:WAVE:RANGing &lt;name&gt;</td>
<td>Selects ranging mode.</td>
<td>BEST</td>
</tr>
<tr>
<td>SOURce[1]:WAVE:PMARk &lt;NRf&gt;</td>
<td>Sets marker phase.</td>
<td>180</td>
</tr>
<tr>
<td>SOURce[1]:WAVE:PMARk:STATe &lt;b&gt;</td>
<td>Enables/disables phase marker.</td>
<td>OFF</td>
</tr>
<tr>
<td>SOURce[1]:WAVE:PMARk:OLINe &lt;NRf&gt;</td>
<td>Sets phase marker trigger line.</td>
<td>3</td>
</tr>
<tr>
<td>SOURce[1]:WAVE:ARBitrary:DATA &lt;NRf&gt; [,&lt;NRf&gt;, ... &lt;NRf&gt;]</td>
<td>Defines arbitrary data points.</td>
<td></td>
</tr>
<tr>
<td>SOURce[1]:WAVE:ARBitrary:APPend &lt;NRf&gt; [,&lt;NRf&gt;, ... &lt;NRf&gt;]</td>
<td>Appends arbitrary data points.</td>
<td></td>
</tr>
<tr>
<td>SOURce[1]:WAVE:ARBitrary:COPY &lt;NRf&gt;</td>
<td>Copies arbitrary points to NVRAM.</td>
<td></td>
</tr>
<tr>
<td>SOURce[1]:WAVE:ARBitrary:POINts?</td>
<td>Queries # of arbitrary data points.</td>
<td></td>
</tr>
</tbody>
</table>
Table 7-4 (cont.)
Waveform function commands

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOURce[1]:WAVE:ARM</td>
<td>Arms 6221 for waveform output.</td>
<td></td>
</tr>
<tr>
<td>SOURce[1]:WAVE:INITiate</td>
<td>Starts waveform output.</td>
<td></td>
</tr>
<tr>
<td>SOURce[1]:WAVE:ABORt</td>
<td>aborts waveform output.</td>
<td></td>
</tr>
<tr>
<td>SOURce[1]:WAVE:DURation:TIME &lt;NRf&gt;</td>
<td>Sets waveform time duration. &lt;NRf&gt; = 100e-9 to 999999.999 (s) or INFinity.</td>
<td>INFinity</td>
</tr>
<tr>
<td>SOURce[1]:WAVE:DURation:CYCLes &lt;NRf&gt;</td>
<td>Sets waveform duration in cycles. &lt;NRf&gt; = 0.001 to 99999999900 or INFinity.</td>
<td>INFinity</td>
</tr>
<tr>
<td>SOURce[1]:WAVE:EXTRig[:ENABle] &lt;b&gt;</td>
<td>Enables/disables mode to externally trigger the waveform generator. *&lt;b&gt; = ON or OFF</td>
<td>OFF</td>
</tr>
<tr>
<td>SOURce[1]:WAVE:EXTRig:ILINe &lt;NRf&gt;</td>
<td>Specify trigger link input trigger line. &lt;NRf&gt; = 0 (none) or 1 to 6</td>
<td>0</td>
</tr>
<tr>
<td>SOURce[1]:WAVE:EXTRig:IGNore &lt;b&gt;</td>
<td>Sets whether or not to restart waveform upon retriggering. &lt;b&gt; = ON or OFF</td>
<td>OFF</td>
</tr>
<tr>
<td>SOURce[1]:WAVE:EXTRig:IVALue &lt;NRf&gt;</td>
<td>Sets inactive value to output before/after waveform. &lt;NRf&gt; = -1 to +1</td>
<td>0.00</td>
</tr>
</tbody>
</table>

* Waveform triggering available with firmware revision level A03 and later. See Section 7 of the Model 6220/6221 Reference Manual for details.
6220 Programmable Current Source

SOURCE SPECIFICATIONS

<table>
<thead>
<tr>
<th>Range (+5% over range)</th>
<th>Accuracy (1 Year)</th>
<th>Programming Resolution</th>
<th>Temperature Coefficient/°C</th>
<th>Typical Noise (peak-peak)/RMS</th>
<th>Setting Time 1,2 (1% of final value)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>23°C±5°C</td>
<td>±(%rdg. + amps)</td>
<td>0°C-18°C &amp; 28°C-50°C</td>
<td>0.1Hz-10Hz</td>
<td></td>
</tr>
<tr>
<td>2nA</td>
<td>0.4% + 2pA</td>
<td>100fA</td>
<td>0.02% + 200fA</td>
<td>400/80fA</td>
<td>100μs</td>
</tr>
<tr>
<td>20nA</td>
<td>0.3% + 10pA</td>
<td>1pA</td>
<td>0.02% + 200fA</td>
<td>4/0.8pA</td>
<td>100μs</td>
</tr>
<tr>
<td>200nA</td>
<td>0.3% + 100pA</td>
<td>10pA</td>
<td>0.01% + 20pA</td>
<td>200/40pA</td>
<td>100μs</td>
</tr>
<tr>
<td>2μA</td>
<td>0.1% + 1nA</td>
<td>100pA</td>
<td>0.005% + 200pA</td>
<td>2/0.4nA</td>
<td>100μs</td>
</tr>
<tr>
<td>20μA</td>
<td>0.05% + 10nA</td>
<td>1nA</td>
<td>0.005% + 200pA</td>
<td>2/0.4nA</td>
<td>100μs</td>
</tr>
<tr>
<td>200μA</td>
<td>0.05% + 100nA</td>
<td>10nA</td>
<td>0.005% + 2nA</td>
<td>20/4nA</td>
<td>100μs</td>
</tr>
<tr>
<td>2mA</td>
<td>0.05% + 1μA</td>
<td>100nA</td>
<td>0.005% + 20nA</td>
<td>200/40nA</td>
<td>100μs</td>
</tr>
<tr>
<td>20mA</td>
<td>0.05% + 10μA</td>
<td>1μA</td>
<td>0.005% + 200nA</td>
<td>2/0.4μA</td>
<td>100μs</td>
</tr>
<tr>
<td>100mA</td>
<td>0.1% + 50μA</td>
<td>10μA</td>
<td>0.01% + 2μA</td>
<td>10/2μA</td>
<td>100μs</td>
</tr>
</tbody>
</table>

ADDITIONAL SOURCE SPECIFICATIONS

OUTPUT RESISTANCE: >10^4Ω. (2nA/20mA range)
OUTPUT CAPACITANCE: <10pF, <100pF Filter ON. (2nA/20mA range)
LOAD IMPEDANCE: Stable into 100μH typical.
CURRENT REGULATION: Line: <0.01% of range.
Load: <0.01% of range.
VOLTAGE LIMIT (Compliance): Bipolar voltage limit set with single value. 0.1V to 105V in 0.01V programmable steps.
Accuracy for 0.1V to 20V: 0.1%+20mV, accuracy for 20V to 105V: 0.1% + 100mV
MAX. OUTPUT POWER: 11W, four quadrant source or sink operation.
GUARD OUTPUT:
Maximum Load Capacitance: 10nF.
Maximum Load Current: 1mA for rated accuracy.
Accuracy: ±1mV for output currents <2mA. (excluding output lead voltage drop).
PROGRAM MEMORY: (offers point-by-point control and triggering, e.g. Sweeps)
Number of Locations: 64K.
EXTERNAL TRIGGER: TTL-compatible EXTERNAL TRIGGER INPUT and OUTPUT.
Max Trigger Rate: 1000/s.

6220 – 2182 MEASUREMENT FUNCTIONS

DUT RESISTANCE: Up to 1GΩ (1 nSiemen).
DELTA MODE RESISTANCE MEASUREMENTS and DIFFERENTIAL CONDUCTANCE: Controls Keithley Model 2182A Nanovoltmeter at up to 24Hz reversal rate (2182 at up to 12Hz).

Source Notes
1. Settling times are specified into a resistive load, with a maximum resistance equal to 2V / 1fs scale of range. See manual for other load conditions.
2. Settling times to 0.1% of final value are typically <2x of 1% settling times.
3. Noise current into <100Ω.
4. RMS Noise 10Hz-20MHz (2nA – 20mA Range) Less than 1mVrms, 5mVp-p (into 50Ω load).
5. Typical values are non-warranted, apply at 23°C, represent the 50th percentile, and are provided solely as useful information.
## 6220 Programmable Current Source

### General Specifications

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common Mode Voltage</td>
<td>250V rms, DC to 60Hz.</td>
</tr>
<tr>
<td>Common Mode Isolation</td>
<td>&gt;10Ω, &lt;2nF.</td>
</tr>
<tr>
<td>Source Output Modes</td>
<td>Fixed DC level, Memory List.</td>
</tr>
<tr>
<td>Remote Interface</td>
<td>IEEE-488 and RS-232C.</td>
</tr>
<tr>
<td>SCPI (Standard Commands for Programmable Instruments)</td>
<td>DDC (command language compatible with Keithley Model 220)</td>
</tr>
<tr>
<td>Password Protection</td>
<td>11 characters.</td>
</tr>
<tr>
<td>Digital Interface</td>
<td>Handler Interface: Start of test, end of test, 3 category bits, +5V@300mA supply.</td>
</tr>
<tr>
<td>Digital I/O</td>
<td>1 trigger input, 4 TTL/Relay Drive outputs (33V@500mA, diode clamped)</td>
</tr>
<tr>
<td>Output Connections</td>
<td>Teflon insulated 3-lug triax connector for output.</td>
</tr>
<tr>
<td></td>
<td>Banana Safety Jack for GUARD, OUTPUT LO</td>
</tr>
<tr>
<td></td>
<td>Screw Terminal for CHASSIS</td>
</tr>
<tr>
<td></td>
<td>DB-9 connector for EXTERNAL TRIGGER INPUT, OUTPUT, and DIGITAL I/O</td>
</tr>
<tr>
<td></td>
<td>Two position Screw Terminal for INTERLOCK</td>
</tr>
<tr>
<td>Interlock</td>
<td>Maximum 10Ω external circuit impedance.</td>
</tr>
<tr>
<td>Power Supply</td>
<td>100V to 240V rms, 50-60Hz.</td>
</tr>
<tr>
<td>Power Consumption</td>
<td>120VA.</td>
</tr>
<tr>
<td>Warranty</td>
<td>1 Year.</td>
</tr>
<tr>
<td>Environment</td>
<td>For Indoor Use Only: Maximum 2000m above Sea Level.</td>
</tr>
<tr>
<td></td>
<td>Operating: 0°-50°C, 70% R.H. up to 35°C. Derate 3% R.H./°C, 35°-50°C.</td>
</tr>
<tr>
<td></td>
<td>Storage: -25°C to 65°C, guaranteed by design.</td>
</tr>
<tr>
<td>Vibration</td>
<td>MIL-PRF-28800F Class 3, Random.</td>
</tr>
<tr>
<td>Warmup</td>
<td>1 hour to rated accuracies.</td>
</tr>
<tr>
<td>Dimensions</td>
<td>Rack Mounting: 89mm high x 213mm wide x 370mm deep (3.5 in. x 8.375 in. x 14.563 in.).</td>
</tr>
<tr>
<td></td>
<td>Bench Configuration (with handle and feet): 104mm high x 238mm wide x 370mm deep (4.125 in. x 9.375 in. x 14.563 in.).</td>
</tr>
<tr>
<td>Shipping Weight</td>
<td>4.75kg (10 lbs).</td>
</tr>
</tbody>
</table>
## 6221 AC and DC Current Source

### SOURCE SPECIFICATIONS

<table>
<thead>
<tr>
<th>Range (+5% over range)</th>
<th>Accuracy (1 Year)</th>
<th>Programming Resolution</th>
<th>Temperature Coefficient/°C</th>
<th>Typical Noise (peak-peak)</th>
<th>Typical Noise (peak-peak)</th>
<th>Output Response Bandwidth (BW) into Short</th>
<th>Settling Time&lt;sup&gt;1,2&lt;/sup&gt; (1% of final value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2nA</td>
<td>0.4% + 2pA</td>
<td>100fA</td>
<td>0.02% + 200fA</td>
<td>400/80fA</td>
<td>250/50pA</td>
<td>10kHz</td>
<td>90μs 100μs</td>
</tr>
<tr>
<td>20nA</td>
<td>0.3% + 10pA</td>
<td>1pA</td>
<td>0.02% + 200fA</td>
<td>4/0.8pA</td>
<td>250/50pA</td>
<td>10kHz</td>
<td>90μs 100μs</td>
</tr>
<tr>
<td>200nA</td>
<td>0.3% + 100pA</td>
<td>10pA</td>
<td>0.02% + 2pA</td>
<td>20/4pA</td>
<td>2.5/0.5nA</td>
<td>100kHz</td>
<td>30μs 100μs</td>
</tr>
<tr>
<td>2μA</td>
<td>0.1% + 1nA</td>
<td>100pA</td>
<td>0.01% + 20pA</td>
<td>200/40pA</td>
<td>25/5.0nA</td>
<td>1MHz</td>
<td>4μs 100μs</td>
</tr>
<tr>
<td>20μA</td>
<td>0.05% + 10nA</td>
<td>1nA</td>
<td>0.005% + 200pA</td>
<td>2/0.4nA</td>
<td>50/100nA</td>
<td>1MHz</td>
<td>2μs 100μs</td>
</tr>
<tr>
<td>200μA</td>
<td>0.05% + 100nA</td>
<td>10nA</td>
<td>0.005% + 2nA</td>
<td>20/4nA</td>
<td>1.0/0.2μA</td>
<td>1MHz</td>
<td>2μs 100μs</td>
</tr>
<tr>
<td>2mA</td>
<td>0.05% + 1μA</td>
<td>100mA</td>
<td>0.005% + 20nA</td>
<td>200/40nA</td>
<td>5.0/1μA</td>
<td>1MHz</td>
<td>2μs 100μs</td>
</tr>
<tr>
<td>20mA</td>
<td>0.05% + 10μA</td>
<td>1μA</td>
<td>0.005% + 200nA</td>
<td>2/0.4μA</td>
<td>20/4.0μA</td>
<td>1MHz</td>
<td>2μs 100μs</td>
</tr>
<tr>
<td>100mA</td>
<td>0.1% + 50μA</td>
<td>10μA</td>
<td>0.01% + 2μA</td>
<td>10/2μA</td>
<td>100/20μA</td>
<td>1MHz</td>
<td>3μs 100μs</td>
</tr>
</tbody>
</table>

### ADDITIONAL SOURCE SPECIFICATIONS

**OUTPUT RESISTANCE:** >10<sup>14</sup>Ω. (2nA/20mA range)

**OUTPUT CAPACITANCE:** <10pF, <100pF Filter ON. (2nA/20mA range)

**LOAD IMPEDANCE:** Stable into 10μH typical, 100μH with Output Response SLOW.

**CURRENT REGULATION:** Line: <0.01% of range. Load: <0.01% of range.

**VOLTAGE LIMIT (Compliance):** Bipolar voltage limit set with single value. 0.1V to 105V in 0.01V programmable steps. Accuracy for 0.1V to 20V: 0.1% +20mV, accuracy for 20V to 105V: 0.1% + 10mV

**MAX. OUTPUT POWER:** 11W, four quadrant source or sink operation.

**GUARD OUTPUT:**
- Maximum Load Capacitance: 10nF.
- Maximum Load Current: 1mA for rated accuracy.
- Accuracy: ±1mV for output currents <2mA (excluding output lead voltage drop).

**PROGRAM MEMORY:** (offers point-by-point control and triggering, e.g. Sweeps)
- Number of Locations: 64K.

**EXTERNAL TRIGGER:** TTL-compatible EXTERNAL TRIGGER
- INPUT and OUTPUT.
- Max Trigger Rate: 1000/s.

### Source Notes
1. Settling times are specified into a resistive load, with a maximum resistance equal to 2V / Ifullscale of range. See manual for other load conditions.
2. Settling times to 0.1% of final value are typically <2x of 1% settling times.
3. Noise current into <100Ω.
4. RMS Noise 10Hz-20MHz (2nA – 20mA Range) Less than 1mVrms, 5mVp-p (into 50Ω load).
5. Typical values are non-warranted, apply at 23°C, represent the 50th percentile, and are provided solely as useful information.
6221 AC and DC Current Source

**ARBITRARY FUNCTION GENERATOR**

**WAVEFORMS:** Sine, Square, Ramp, and 4 User Defined Arbitrary Waveforms.

**FREQUENCY ACCURACY:** ±100 ppm (1 Year)

**AMPLITUDE:** 2pA to 210mA peak-peak into loads up to 10^12Ω.

**AMPLITUDE ACCURACY (<10kHz):**
- Magnitude: 1% rdg + 0.2% rng
- Offset: 0.2% rdg + 0.2% rng

**SINE WAVE CHARACTERISTICS:**
- Frequency Range: 1kHz to 100kHz.
- Amplitude Flatness: ±100 ppm (1 Year)

**SQUARE WAVE CHARACTERISTICS:**
- Frequency Range: 1kHz to 100kHz.
- Amplitude Flatness: ±100 ppm (1 Year)

**RAMP WAVE CHARACTERISTICS:**
- Frequency Range: 1kHz to 100kHz.
- Linearity: <0.1% of peak output up to 10kHz.

**ARBITRARY WAVE CHARACTERISTICS:**
- Frequency Range: 1kHz to 100kHz.
- Waveform Length: 2 to 64K points.
- Amplitude Resolution: 16 bits (including sign).
- Sample Rate: 10 MSPS.
- Jitter (RMS): 100ns + 0.1% of period.

**PROGRAMMING TIME (Typical):**
- Waveform/Amplitude/Frequency Change: 1ms
- ARB Transfer Times:
  - (External transfer time over Bus) 16K 64K
  - LAN 0.750s 3.000s
  - GPIB 1.500s 5.000s
  - (Internal transfer time of preloaded Arb locations 1-4) Arb 1 0.001s 0.001s Arb 2-4 0.500s 2.000s

**6221 – 2182 MEASUREMENT FUNCTIONS**

**DUT RESISTANCE:** Up to 1GΩ (1 nSiemen).

(100MΩ limit for pulse mode)

**DELTA MODE RESISTANCE MEASUREMENTS and DIFFERENTIAL CONDUCTANCE:** Controls Keithley Model 2182A Nanovoltmeter at up to 24Hz reversal rate (2182 at up to 12Hz).

**PULSE MEASUREMENTS:**
- Pulse widths 50ns to 12ms, 1pA to 100mA.
- Repetition interval 85.3ms to 5s.

**Waveform Notes:**
1. Minimum realizable duty cycle is limited by current range response and load impedance.
2. Amplitude accuracy is applicable for 100mA through 2μA ranges (Fast Mode) into a maximum resistive load of 2V/Ifullscale of range. Amplitude attenuation will occur at higher frequencies dependent upon current range and load impedance.
3. For frequencies less than 1 Hz, duty cycle not tested, guaranteed by design.
4. These Specifications are only valid for the 20mA range and a 50Ω load.
5. These characteristics for informational purposes only.
6. Typical values are non-warranted, apply at 23°C, represent the 50th percentile, and are provided solely as useful information.

**GENERAL SPECIFICATIONS**

**COMMON MODE VOLTAGE:** 230Vrms, DC to 60Hz.

**COMMON MODE ISOLATION:** >10^3Ω, <2nF.

**SOURCE OUTPUT MODES:** Fixed DC level, Memory List, Arbitrary Waveform Function.

**REMOTE INTERFACE**
- Ethernet: RJ-45 connector, TCP/IP (Auto sensed 10bT or 100bT), IEEE-488, and RS-232C.
- SCPI (Standard Commands for Programmable Instruments)
- DDC (command language compatible with Keithley Model 220)

**IP CONFIGURATION:** Static or DHCP.

**PASSWORD PROTECTION:** 11 characters.

**DIGITAL INTERFACE:**
- Handler Interface: Start of test, end of test, 3 category bits, +5V@300mA supply.
- Digital I/O: 1 trigger input, 4 TTL/Relay Drive outputs (35V@500mA, diode clamped).

**OUTPUT CONNECTIONS:**
- Teflon insulated 3-lug triax connector for output.
- Banana Safety Jack for GUARD, OUTPUT LO
- Two position Screw Terminal for INTERLOCK

**INTERLOCK:** Maximum 10Ω external circuit impedance.

**POWER SUPPLY:** 100V to 240V rms, 50-60Hz.

**POWER CONSUMPTION:** 120VA.

**WARRANTY:** 1 Year.

**ENVIRONMENT:**
- For Indoor Use Only: Maximum 2000m above Sea Level.
- Operating: 0° to 50°C, 70% R.H. up to 35°C. Derate 3% R.H./°C, 35°-50°C
- Storage: -25°C to 65°C, guaranteed by design.

**SAFETY:** Conforms to European Union Directive 73/23/EEC, EN61010-1.

**VIBRATION:** MIL-PRF-28800F Class 3, Random.

**WARMUP:** 1 hour to rated accuracies.

**Passive Cooling:** No fan.

**DIMENSIONS:**
- Rack Mounting: 89mm high x 123mm wide x 370mm deep (3.5 in. x 8.375 in. x 14.563 in.).
- Bench Configuration (with handle and feet): 104mm high x 238mm wide x 370mm deep (4.125 in. x 9.375 in. x 14.563 in.).

**SHIPPING WEIGHT:** 4.75kg (10 lbs).

**ACCESSORIES SUPPLIED:**
Appendix B tables

*Calculate command summary*, page B-2
*Display command summary*, page B-2
*Format command summary*, page B-3
*Output command summary*, page B-3
*Sense command summary*, page B-3
*Source command summary*, page B-4
*Status command summary*, page B-7
*System command summary*, page B-8
*Trace command summary*, page B-9
*Trigger command summary*, page B-10
*Units command summary*, page B-10

The SCPI tables in this section are structured as follows:

- Only the shortform version of the command words and parameters are used.
- Most optional commands, which are denoted by brackets ([ ]), are not included.
- Most of the query commands are not included.

The unabridged SCPI table listings are provided in Section 14 of the Reference Manual.
### Table B-1
#### Calculate command summary

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>CALC</td>
<td>CALC commands (math calculations):</td>
<td></td>
</tr>
<tr>
<td>:FORM &lt;name&gt;</td>
<td>Select math format: NONE, MXB (mX+b), or REC (m/X+b)</td>
<td>MXB</td>
</tr>
<tr>
<td>:KMAT</td>
<td>Configure math calculations:</td>
<td></td>
</tr>
<tr>
<td>:MMF &lt;NRf&gt;</td>
<td>Set “m” for mX+b and m/X+b: -9.999999e20 to 9.999999e20</td>
<td>1.0</td>
</tr>
<tr>
<td>:MBF &lt;NRf&gt;</td>
<td>Set “b” for mX+b and m/X+b calculation: -9.999999e20 to 9.999999e20</td>
<td>0.0</td>
</tr>
<tr>
<td>:STAT &lt;b&gt;</td>
<td>Enable or disable CALC calculation.</td>
<td>OFF</td>
</tr>
<tr>
<td>:DATA?</td>
<td>Read calculation:</td>
<td></td>
</tr>
<tr>
<td>:FRES?</td>
<td>Same as CALC:DATA? except reading can only be returned once.</td>
<td></td>
</tr>
<tr>
<td>CALC2</td>
<td>CALC2 commands (buffer statistics):</td>
<td></td>
</tr>
<tr>
<td>:FORM &lt;name&gt;</td>
<td>Select buffer statistic: MEAN, SDEV, MAX, MIN, or PKPK</td>
<td>MEAN</td>
</tr>
<tr>
<td>:STAT &lt;b&gt;</td>
<td>Enable or disable calculation.</td>
<td>OFF</td>
</tr>
<tr>
<td>:IMM</td>
<td>Perform the selected buffer calculation on buffer contents.</td>
<td></td>
</tr>
<tr>
<td>:DATA?</td>
<td>Read the results of the buffer statistic.</td>
<td></td>
</tr>
<tr>
<td>CALC3</td>
<td>CALC3 commands (limit testing):</td>
<td></td>
</tr>
<tr>
<td>:LIM &lt;b&gt;</td>
<td>Stage 1 limit test:</td>
<td></td>
</tr>
<tr>
<td>:SOUR2 &lt;NRf&gt;</td>
<td>Set limit test fail pattern: 0 to 15</td>
<td>15</td>
</tr>
<tr>
<td>:FAIL?</td>
<td>Query limit test pass/fail: 0 = pass, 1 = fail</td>
<td></td>
</tr>
<tr>
<td>:FORC</td>
<td>Output force commands:</td>
<td>OFF</td>
</tr>
<tr>
<td>:STAT &lt;b&gt;</td>
<td>Enable or disable I/O pattern force state.</td>
<td></td>
</tr>
<tr>
<td>:PATT &lt;NRf&gt;</td>
<td>Set I/O pattern: 0 to 15</td>
<td>15</td>
</tr>
</tbody>
</table>

### Table B-2
#### Display command summary

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>DISP</td>
<td>Display control commands:</td>
<td>(Note)</td>
</tr>
<tr>
<td>:ENAB &lt;b&gt;</td>
<td>Enables or disables front panel display and controls.</td>
<td></td>
</tr>
<tr>
<td>:TEXT &lt;a&gt;</td>
<td>Define ASCII top message “a” (up to 20 characters).</td>
<td></td>
</tr>
<tr>
<td>:STAT &lt;b&gt;</td>
<td>Enable or disable top line text message.</td>
<td></td>
</tr>
<tr>
<td>:TEXT?</td>
<td>Read text message</td>
<td></td>
</tr>
<tr>
<td>:ATTR?</td>
<td>Query attributes of top message characters: blinking (1) or not blinking (0).</td>
<td></td>
</tr>
<tr>
<td>:WIND2</td>
<td>Bottom line display characters:</td>
<td></td>
</tr>
<tr>
<td>:TEXT &lt;a&gt;</td>
<td>Define ASCII bottom message “a” (up to 32 characters).</td>
<td></td>
</tr>
<tr>
<td>:STAT &lt;b&gt;</td>
<td>Enable or disable text message.</td>
<td></td>
</tr>
<tr>
<td>:TEXT?</td>
<td>Read text message</td>
<td></td>
</tr>
<tr>
<td>:ATTR?</td>
<td>Query attributes of message characters: blinking (1) or not blinking (0).</td>
<td></td>
</tr>
</tbody>
</table>

Note: *RST and SYST:PRES have no effect on the display commands.

Return to **Appendix B tables**
Table B-3
**Format command summary**

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>FORM</td>
<td>Reading format commands:</td>
<td></td>
</tr>
<tr>
<td>[:DATA] &lt;type&gt;</td>
<td>Specify data format: ASC, SRE, or DRE</td>
<td>ASC</td>
</tr>
<tr>
<td>:ELEM &lt;item list&gt;</td>
<td>Specify data elements: READ, TST, UNIT, RNUM, SOUR, COMP, AVOL (or ALL or DEF)</td>
<td>READ, TST</td>
</tr>
<tr>
<td>:BORD &lt;name&gt;</td>
<td>Specify byte order: NORM or SWAP.</td>
<td>(Note)</td>
</tr>
<tr>
<td>:SREG &lt;name&gt;</td>
<td>Select format for reading status registers: ASC, HEX, OCT or BIN.</td>
<td>ASC</td>
</tr>
</tbody>
</table>

Note: *RST default is NORM. SYST:PRES default is SWAP.

Table B-4
**Output command summary**

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>OUTPut</td>
<td>Source output control:</td>
<td></td>
</tr>
<tr>
<td>[:STAT]?</td>
<td>Turn output on or off (standby).</td>
<td>OFF</td>
</tr>
<tr>
<td>:LTE &lt;b&gt;</td>
<td>Connect output low to earth ground (ON) or float output low (OFF).</td>
<td>OFF</td>
</tr>
<tr>
<td>:ISH &lt;name&gt;</td>
<td>Connect triax inner shield to OLOW (output low) or cable GUAR.</td>
<td>OLOW</td>
</tr>
<tr>
<td>:RESP &lt;name&gt;</td>
<td>Set the output response for 6221: FAST or SLOW.</td>
<td>FAST</td>
</tr>
<tr>
<td>:INT</td>
<td>Interlock:</td>
<td></td>
</tr>
<tr>
<td>:TRIP?</td>
<td>Returns a “0” if interlock is tripped (open) or a “1” if interlock is closed (output enabled).</td>
<td></td>
</tr>
</tbody>
</table>

Table B-5
**Sense command summary**

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>SENS</td>
<td>Commands for readings from 2182/2182A:</td>
<td></td>
</tr>
<tr>
<td>:DATA?</td>
<td>Return the latest pre-math delta reading.</td>
<td></td>
</tr>
<tr>
<td>:FRES?</td>
<td>Same as :DATA? except the reading can only be returned once.</td>
<td></td>
</tr>
<tr>
<td>:AVER</td>
<td>Averaging filter:</td>
<td></td>
</tr>
<tr>
<td>:TCON &lt;name&gt;</td>
<td>Select filter control: MOV or REP</td>
<td>MOV</td>
</tr>
<tr>
<td>:WIND &lt;NRf&gt;</td>
<td>Set filter window as % of range: 0 to 10</td>
<td>0.00</td>
</tr>
<tr>
<td>:COUN &lt;NRf&gt;</td>
<td>Specify filter count (size): 2 to 300</td>
<td>10</td>
</tr>
<tr>
<td>[:STAT] &lt;b&gt;</td>
<td>Enable or disable averaging filter.</td>
<td>OFF</td>
</tr>
</tbody>
</table>
Table B-6
Source command summary

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOUR</td>
<td>Current source output commands:</td>
<td></td>
</tr>
<tr>
<td>:CLE</td>
<td>Clearing the current source:</td>
<td></td>
</tr>
<tr>
<td>[:IMM]</td>
<td>Set output to zero and then turn the output off.</td>
<td></td>
</tr>
<tr>
<td>:CURR</td>
<td>Current source:</td>
<td></td>
</tr>
<tr>
<td>[:AMPL] &lt;n&gt;</td>
<td>Set current source output (amps): -105e-3 to 105e-3</td>
<td>0.0</td>
</tr>
<tr>
<td>:RANG &lt;n&gt;</td>
<td>Select a fixed source range: -105e-3 to 105e-3</td>
<td>100e-3</td>
</tr>
<tr>
<td>:AUTO &lt;b&gt;</td>
<td>Enable or disable source auto range.</td>
<td>OFF</td>
</tr>
<tr>
<td>:COMP &lt;NRf&gt;</td>
<td>Set voltage compliance (volts): 0.1 to 105</td>
<td>10</td>
</tr>
<tr>
<td>:FILT &lt;b&gt;</td>
<td>Enable or disable analog filter.</td>
<td></td>
</tr>
<tr>
<td>:STAR &lt;n&gt;</td>
<td>Set start current (amps): -105e-3 to 105e-3</td>
<td>0</td>
</tr>
<tr>
<td>:STOP &lt;n&gt;</td>
<td>Set stop current (amps): -105e-3 to 105e-3</td>
<td>100e-3</td>
</tr>
<tr>
<td>:STEP &lt;n&gt;</td>
<td>Set step current (amps): 1e-13 to 105e-3</td>
<td>1e-2</td>
</tr>
<tr>
<td>:CENT &lt;n&gt;</td>
<td>Set center current (amps): -105e-3 to 105e-3</td>
<td>0</td>
</tr>
<tr>
<td>:SPAN &lt;n&gt;</td>
<td>Set span current (amps): 2e-13 to 210e-3</td>
<td>100e-3</td>
</tr>
<tr>
<td>:DEL &lt;n&gt;</td>
<td>Set source delay (seconds): 1e-3 to 999999.999</td>
<td>1</td>
</tr>
<tr>
<td>:SWE</td>
<td>Source sweep operation:</td>
<td></td>
</tr>
<tr>
<td>:SPAC &lt;name&gt;</td>
<td>Select sweep type: LIN, LOG or LIST</td>
<td>LIN</td>
</tr>
<tr>
<td>:POIN &lt;n&gt;</td>
<td>Set sweep points: 1 to 65535</td>
<td>11</td>
</tr>
<tr>
<td>:RANG &lt;name&gt;</td>
<td>Select sweep ranging: AUTO, BEST or FIX</td>
<td>BEST</td>
</tr>
<tr>
<td>:COUN &lt;NRf&gt;</td>
<td>Set sweep count: 1 to 9999 or INFinity</td>
<td>1</td>
</tr>
<tr>
<td>:CAB &lt;b&gt;</td>
<td>Enable to abort sweep on compliance: ON or OFF</td>
<td>OFF</td>
</tr>
<tr>
<td>:ARM</td>
<td>Arm the sweep.</td>
<td></td>
</tr>
<tr>
<td>:ABOR</td>
<td>Abort sweep or delta test immediately.</td>
<td></td>
</tr>
<tr>
<td>:LIST</td>
<td>Custom sweep operation:</td>
<td></td>
</tr>
<tr>
<td>:CURR &lt;NRf&gt; [,&lt;NRf&gt;, ...&lt;NRf&gt;]</td>
<td>Define list of currents (amps): -105e-3 to 105e-3</td>
<td></td>
</tr>
<tr>
<td>:APP &lt;NRf&gt; [,&lt;NRf&gt;, ...&lt;NRf&gt;]</td>
<td>Add current points to existing list: -105e-3 to 105e-3</td>
<td></td>
</tr>
<tr>
<td>:POIN?</td>
<td>Query number of current list points.</td>
<td></td>
</tr>
<tr>
<td>:DEL &lt;NRf&gt; [,&lt;NRf&gt;, ...&lt;NRf&gt;]</td>
<td>Define list of delay values (secs): 1e-3 to 999999.999</td>
<td>1</td>
</tr>
<tr>
<td>:APP &lt;NRf&gt; [,&lt;NRf&gt;, ...&lt;NRf&gt;]</td>
<td>Add delay values to existing list.</td>
<td></td>
</tr>
</tbody>
</table>
Table B-6 (cont.)

Source command summary

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>:COMpiance &lt;NRf&gt;</td>
<td>Define list of compliance values (volts): 1e-3 to 105</td>
<td></td>
</tr>
<tr>
<td>[:APP &lt;NRf&gt;</td>
<td>Add compliance values to existing list: 1e-3 to 105</td>
<td></td>
</tr>
<tr>
<td>:DELta</td>
<td>Delta operation:</td>
<td></td>
</tr>
<tr>
<td>:NVPR?</td>
<td>Query connection to 2182/2182A: 1 = yes, 0 = no</td>
<td></td>
</tr>
<tr>
<td>:HIGH &lt;NRf&gt;</td>
<td>Set high source value (amps): 0 to 105e-3</td>
<td>1e3</td>
</tr>
<tr>
<td>:LOW &lt;NRf&gt;</td>
<td>Set low source value (amps): 0 to -105e-3</td>
<td>-1e3</td>
</tr>
<tr>
<td>:DEL &lt;NRf&gt;</td>
<td>Set Delta delay (seconds): 1e-3 to 9999.999</td>
<td>2e-3</td>
</tr>
<tr>
<td>:COUN &lt;NRf&gt;</td>
<td>Set number of cycles to run: 1 to 65536 or INFinity.</td>
<td>INF</td>
</tr>
<tr>
<td>:CAB &lt;b&gt;</td>
<td>Enable to abort test on compliance: ON or OFF</td>
<td>OFF</td>
</tr>
<tr>
<td>:CSW &lt;b&gt;</td>
<td>Enable cold switching mode: ON or OFF</td>
<td>OFF</td>
</tr>
<tr>
<td>:ARM</td>
<td>Arm Delta.</td>
<td></td>
</tr>
<tr>
<td>:PDEL</td>
<td>Pulse Delta operation:</td>
<td></td>
</tr>
<tr>
<td>:NVPR?</td>
<td>Query connection to 2182A: 1 = yes, 0 = no</td>
<td></td>
</tr>
<tr>
<td>:HIGH &lt;NRf&gt;</td>
<td>Set high pulse value (amps): -105e-3 to 105e-3</td>
<td>1e3</td>
</tr>
<tr>
<td>:LOW &lt;NRf&gt;</td>
<td>Set low pulse value (amps): -105e-3 to 105e-3</td>
<td>0</td>
</tr>
<tr>
<td>:WIDT &lt;NRf&gt;</td>
<td>Set pulse width (seconds): 50e-6 to 12e-3</td>
<td>110e-6</td>
</tr>
<tr>
<td>:SDEL &lt;NRf&gt;</td>
<td>Set source delay (seconds): 16e-6 to 11.966e-3</td>
<td>16e-6</td>
</tr>
<tr>
<td>:COUN &lt;NRf&gt;</td>
<td>Set number of readings to perform: 1 to 65636 or INF</td>
<td>INF</td>
</tr>
<tr>
<td>:RANG &lt;NRf&gt;</td>
<td>Select fixed pulse source range: BEST or FIX</td>
<td>BEST</td>
</tr>
<tr>
<td>:INT &lt;NRf&gt;</td>
<td>Set interval (in PLCs) for each pulse cycle: 5 to 999999</td>
<td>5</td>
</tr>
<tr>
<td>:SWE &lt;b&gt;</td>
<td>Enable or disable Sweep output mode.</td>
<td>OFF</td>
</tr>
<tr>
<td>:LME &lt;NRf&gt;</td>
<td>Set number of low measurement per cycle: 1 or 2</td>
<td>2</td>
</tr>
<tr>
<td>:ARM</td>
<td>Arm Pulse Delta.</td>
<td></td>
</tr>
<tr>
<td>:DCON</td>
<td>Differential Conductance operation:</td>
<td></td>
</tr>
<tr>
<td>:NVPR?</td>
<td>Query connection to 2182/2182A: 1 = yes, 0 = no</td>
<td></td>
</tr>
<tr>
<td>:STAR &lt;NRf&gt;</td>
<td>Set start value (amps): -105e-3 to 105e-3</td>
<td>-10e-6</td>
</tr>
<tr>
<td>:STEP &lt;NRf&gt;</td>
<td>Set step size (amps): 0 to 105e-3.</td>
<td>1e-6</td>
</tr>
<tr>
<td>:STOP &lt;NRf&gt;</td>
<td>Set stop value (amps): -105e-3 to 105e-3</td>
<td>+10e-6</td>
</tr>
<tr>
<td>:DELT &lt;NRf&gt;</td>
<td>Set delta value (amps): 0 to 105e-3.</td>
<td>1e-6</td>
</tr>
<tr>
<td>:DEL &lt;NRf&gt;</td>
<td>Set delay (seconds): 1e-3 to 9999.999.</td>
<td>2e-3</td>
</tr>
<tr>
<td>:CAB &lt;b&gt;</td>
<td>Enable to abort test on compliance: ON or OFF</td>
<td>OFF</td>
</tr>
<tr>
<td>:ARM</td>
<td>Arm Differential Conductance.</td>
<td></td>
</tr>
</tbody>
</table>
Table B-6 (cont.)

Source command summary

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>:WAVE</td>
<td>Wave function operation:</td>
<td></td>
</tr>
<tr>
<td>:FUNC &lt;name&gt;</td>
<td>Select wave function: SIN, SQU, RAMP or ARBX (X = 0 to 4).</td>
<td>SIN</td>
</tr>
<tr>
<td>:DCYC &lt;NRf&gt;</td>
<td>Set duty cycle (in %): 0 to 100</td>
<td>50</td>
</tr>
<tr>
<td>:AMPL &lt;NRf&gt;</td>
<td>Set amplitude (amps peak): 2e-12 to 105e-3.</td>
<td>1e-3</td>
</tr>
<tr>
<td>:FREQ &lt;NRf&gt;</td>
<td>Set frequency (Hz): 1e-3 to 1e5</td>
<td>1e3</td>
</tr>
<tr>
<td>:OFFS &lt;NRf&gt;</td>
<td>Set offset (amps): -105e-3 to 105e-3</td>
<td>0</td>
</tr>
<tr>
<td>:PMAR</td>
<td>Phase marker:</td>
<td></td>
</tr>
<tr>
<td>[:LEV] &lt;NRf&gt;</td>
<td>Set marker phase (in degrees): 0 to 360</td>
<td>180</td>
</tr>
<tr>
<td>:OLIN &lt;NRf&gt;</td>
<td>Set phase marker trigger line: 1 to 6</td>
<td>3</td>
</tr>
<tr>
<td>:STAT &lt;b&gt;</td>
<td>Enable or disable phase marker.</td>
<td>OFF</td>
</tr>
<tr>
<td>:ARB</td>
<td>Arbitrary waveforms:</td>
<td></td>
</tr>
<tr>
<td>:DATA &lt;NRf&gt; [,&lt;NRf&gt;, ...&lt;NRf&gt;]</td>
<td>Define arbitrary data points: -1 to +1 (100 points maximum).</td>
<td></td>
</tr>
<tr>
<td>:DATA?</td>
<td>Query the points in the arbitrary waveform.</td>
<td></td>
</tr>
<tr>
<td>:APP &lt;NRf&gt; [,&lt;NRf&gt;, ...&lt;NRf&gt;]</td>
<td>Append arbitrary data points: -1 to +1 (100 points max. per instance of command).</td>
<td></td>
</tr>
<tr>
<td>:POIN?</td>
<td>Query number of points in the waveform.</td>
<td></td>
</tr>
<tr>
<td>:COPY &lt;NRf&gt;</td>
<td>Copy arbitrary points to NVRAM: 1 to 4</td>
<td></td>
</tr>
<tr>
<td>:RANG &lt;name&gt;</td>
<td>Select source ranging mode: BEST or FIX</td>
<td>BEST</td>
</tr>
<tr>
<td>:DUR</td>
<td>Waveform duration:</td>
<td></td>
</tr>
<tr>
<td>:TIME &lt;NRf&gt;</td>
<td>Set waveform time duration (seconds): 100e-9 to 999999.999 or INF.</td>
<td>INF</td>
</tr>
<tr>
<td>:CYCL &lt;NRf&gt;</td>
<td>Set waveform duration in cycles: 1e-3 to 99999999900 or INF</td>
<td>INF</td>
</tr>
<tr>
<td>:ARM</td>
<td>Arm waveform function.</td>
<td></td>
</tr>
<tr>
<td>:INIT</td>
<td>Start waveform output.</td>
<td></td>
</tr>
<tr>
<td>:ABOR</td>
<td>Abort waveform output.</td>
<td></td>
</tr>
<tr>
<td>:EXTR</td>
<td>Waveform external trigger commands: *</td>
<td></td>
</tr>
<tr>
<td>[:ENAB] &lt;b&gt;</td>
<td>Enables/disables mode to externally trigger the waveform generator: &lt;b&gt; = ON or OFF.</td>
<td>OFF</td>
</tr>
<tr>
<td>:ILIN &lt;NRf&gt;</td>
<td>Specify trigger link input trigger line: &lt;NRf&gt; = 0 (none) or 1 to 6.</td>
<td>0</td>
</tr>
<tr>
<td>:IGN &lt;b&gt;</td>
<td>Sets whether or not to restart waveform upon retriggering: &lt;b&gt; = ON or OFF.</td>
<td>OFF</td>
</tr>
<tr>
<td>:IVAL &lt;NRf&gt;</td>
<td>Sets inactive value to output before/after waveform: &lt;NRf&gt; = -1 to +1.</td>
<td>0.00</td>
</tr>
</tbody>
</table>

* Available with firmware revision A03 and later.

Return to Appendix B tables
Table B-7

**Status command summary**

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>STATus</strong></td>
<td>Commands status registers:</td>
<td>Note 1</td>
</tr>
<tr>
<td>:MEASurement</td>
<td>Measurement event registers:</td>
<td></td>
</tr>
<tr>
<td>[:EVENt]?</td>
<td>Read the event register.</td>
<td>Note 2</td>
</tr>
<tr>
<td>:ENABle &lt;NDN&gt; or &lt;NRf&gt;</td>
<td>Program the enable register.</td>
<td>Note 3</td>
</tr>
<tr>
<td>:CONDition?</td>
<td>Read the condition register.</td>
<td></td>
</tr>
<tr>
<td>:OPERation</td>
<td>Operation event registers:</td>
<td></td>
</tr>
<tr>
<td>[:EVENt]?</td>
<td>Read the event register.</td>
<td>Note 2</td>
</tr>
<tr>
<td>:ENABle &lt;NDN&gt; or &lt;NRf&gt;</td>
<td>Program the enable register.</td>
<td>Note 3</td>
</tr>
<tr>
<td>:CONDition?</td>
<td>Read the condition register.</td>
<td></td>
</tr>
<tr>
<td>:QUESTionable</td>
<td>Questionable event registers:</td>
<td></td>
</tr>
<tr>
<td>[:EVENt]?</td>
<td>Read the event register.</td>
<td>Note 2</td>
</tr>
<tr>
<td>:ENABle &lt;NDN&gt; or &lt;NRf&gt;</td>
<td>Program the enable register.</td>
<td>Note 3</td>
</tr>
<tr>
<td>:CONDition?</td>
<td>Read the condition register.</td>
<td></td>
</tr>
<tr>
<td>:PRESet</td>
<td>Return status registers to default states.</td>
<td></td>
</tr>
<tr>
<td>:QUEue</td>
<td>Read error queue:</td>
<td></td>
</tr>
<tr>
<td>[:NEXT]?</td>
<td>Read the most recent error message.</td>
<td>Note 4</td>
</tr>
<tr>
<td>:ENABle &lt;list&gt;</td>
<td>Specify error and status messages for error queue: -999 to +999.</td>
<td>Note 5</td>
</tr>
<tr>
<td>:DISable &lt;list&gt;</td>
<td>Specify error and status messages not to be placed in error queue: -999 to +999</td>
<td></td>
</tr>
<tr>
<td>:CLEar</td>
<td>Clears all messages from error queue.</td>
<td></td>
</tr>
</tbody>
</table>

**Parameters:**

- `<NDN>` = #Bxx…x Binary format (each x = 1 or 0)
- `<NDN>` = #Hx Hexadecimal format (x = 0 to FFFF)
- `<NDN>` = #Qx Octal format (x = 0 to 177777)
- `<NRf>` = 0 to 65535 Decimal format

**Notes:**

1. Commands in this subsystem are not affected by *RST or SYSTem:PRESet. The effects of cycling power, *CLS and STATus:PRESet, are explained by the following notes.
2. Event registers — Power-up and *CLS clears all bits. STATus:PRESet has no effect.
3. Enable registers — Power-up and STATus:PRESet clears all bits. *CLS has no effect.
4. Error queue — Power-up and *CLS empty the error queue. STATus:PRESet has no effect.
5. Error queue messages — Power-up enables error messages and disables status messages. *CLS and STATus:PRESet have no effect.
Table B-8

System command summary

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>:SYST</td>
<td>Communication interfaces:</td>
<td></td>
</tr>
<tr>
<td>:COMM</td>
<td>Communication interfaces:</td>
<td></td>
</tr>
<tr>
<td>:SEL &lt;name&gt;</td>
<td>Select interface: SERial, GPIB, or ETHernet.</td>
<td></td>
</tr>
<tr>
<td>:GPIB</td>
<td>GPIB interface:</td>
<td></td>
</tr>
<tr>
<td>:ADDR &lt;NRF&gt;</td>
<td>Set primary address: 0 to 30.</td>
<td></td>
</tr>
<tr>
<td>:SER</td>
<td>RS-232 interface:</td>
<td></td>
</tr>
<tr>
<td>:CONT</td>
<td>Handshaking:</td>
<td></td>
</tr>
<tr>
<td>:RTS &lt;name&gt;</td>
<td>Select handshaking: IBFull, RFR, or OFF.</td>
<td></td>
</tr>
<tr>
<td>:PACE &lt;name&gt;</td>
<td>Set flow control: XON or OFF</td>
<td></td>
</tr>
<tr>
<td>:TERM &lt;name&gt;</td>
<td>Set output terminator: CR, LF, CRLF, or LFCR.</td>
<td></td>
</tr>
<tr>
<td>:BAUD &lt;n&gt;</td>
<td>Set baud rate: 300, 600, 1200, 2400, 4800, 9600, 19.2k, 38.4k, 57.6k, or 115.2k.</td>
<td></td>
</tr>
<tr>
<td>:SEND &lt;data&gt;</td>
<td>Send data via RS-232.</td>
<td></td>
</tr>
<tr>
<td>:ENT?</td>
<td>Reads data from serial port.</td>
<td></td>
</tr>
<tr>
<td>:LOC</td>
<td>RS-232 only – Take 622x out of remote.</td>
<td></td>
</tr>
<tr>
<td>:REM</td>
<td>RS-232 only – Put 622x in remote.</td>
<td></td>
</tr>
<tr>
<td>:RWL &lt;b&gt;</td>
<td>RS-232 only – Enable or disable local lockout.</td>
<td></td>
</tr>
<tr>
<td>:ETH</td>
<td>Ethernet interface (6221 only):</td>
<td></td>
</tr>
<tr>
<td>:ADDR &lt;string&gt;</td>
<td>Set IP address: “n.n.n.n”.</td>
<td></td>
</tr>
<tr>
<td>:MASK &lt;string&gt;</td>
<td>Set subnet mask: “n.n.n.n”.</td>
<td></td>
</tr>
<tr>
<td>:GAT &lt;string&gt;</td>
<td>Set Ethernet gateway: “n.n.n.n”.</td>
<td></td>
</tr>
<tr>
<td>:DHCP &lt;b&gt;</td>
<td>Enable or disable DHCP.</td>
<td></td>
</tr>
<tr>
<td>:SAVE</td>
<td>Saves Ethernet setting changes.</td>
<td></td>
</tr>
<tr>
<td>:KCL &lt;b&gt;</td>
<td>Enable or disable key-click.</td>
<td>ON</td>
</tr>
<tr>
<td>:BEEP</td>
<td>Beper:</td>
<td></td>
</tr>
<tr>
<td>:STAT &lt;b&gt;</td>
<td>Enable or disable beep.</td>
<td>ON</td>
</tr>
<tr>
<td>:PRES</td>
<td>Return 622x to PRESET default setup.</td>
<td></td>
</tr>
<tr>
<td>:POS &lt;name&gt;</td>
<td>Select power-on setup: RST, PRES, SAV0, SAV1, SAV2, SAV3, or SAV4.</td>
<td></td>
</tr>
<tr>
<td>:ERR?</td>
<td>Query the latest error code and message.</td>
<td></td>
</tr>
<tr>
<td>:CLE</td>
<td>Clears error code and message from Error Queue.</td>
<td></td>
</tr>
<tr>
<td>:TST</td>
<td>System timestamp:</td>
<td></td>
</tr>
<tr>
<td>:RES</td>
<td>Reset timestamp to zero seconds.</td>
<td></td>
</tr>
<tr>
<td>:RNUM</td>
<td>System reading number:</td>
<td></td>
</tr>
<tr>
<td>:RES</td>
<td>Reset reading number to zero.</td>
<td></td>
</tr>
<tr>
<td>:VERS?</td>
<td>Query revision level of SCPI standard.</td>
<td></td>
</tr>
</tbody>
</table>
### System command summary

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>:ABO</td>
<td>Analog board:</td>
<td></td>
</tr>
<tr>
<td>:SNUM?</td>
<td>Query serial number of analog board.</td>
<td></td>
</tr>
<tr>
<td>:REV?</td>
<td>Query revision level of analog board.</td>
<td></td>
</tr>
<tr>
<td>:DBO</td>
<td>Digital board:</td>
<td></td>
</tr>
<tr>
<td>:SNUM?</td>
<td>Query serial number of digital board.</td>
<td></td>
</tr>
<tr>
<td>:REV?</td>
<td>Query revision level of digital board.</td>
<td></td>
</tr>
<tr>
<td>:PASS</td>
<td>Password:</td>
<td></td>
</tr>
<tr>
<td>:ENAB</td>
<td>Enable or disable the use of password.</td>
<td></td>
</tr>
<tr>
<td>:CDIS &lt;string&gt;</td>
<td>Disables protected commands. &lt;string&gt; = “password”</td>
<td></td>
</tr>
<tr>
<td>[:CEN] &lt;string&gt;</td>
<td>Enables protected commands. &lt;string&gt; = “password”</td>
<td></td>
</tr>
<tr>
<td>:STAT?</td>
<td>Query state of password: Returns “0” if password protected commands are disabled. Returns “1” if enabled.</td>
<td></td>
</tr>
<tr>
<td>:NEW &lt;string&gt;</td>
<td>Set new password. &lt;string&gt; = “password”</td>
<td></td>
</tr>
</tbody>
</table>

### Trace command summary

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRAC</td>
<td>Commands to control buffer:</td>
<td>Note 1</td>
</tr>
<tr>
<td>:CLE</td>
<td>Clear readings from buffer.</td>
<td></td>
</tr>
<tr>
<td>:FREE?</td>
<td>Query memory bytes available in buffer.</td>
<td></td>
</tr>
<tr>
<td>:POIN &lt;n&gt;</td>
<td>Specify buffer size (number of readings to store): 1 to 65536.</td>
<td>Note 2</td>
</tr>
<tr>
<td>:ACT?</td>
<td>Query number readings stored in the buffer.</td>
<td></td>
</tr>
<tr>
<td>:NOT &lt;NRf&gt;</td>
<td>Specify number of stored readings that will set the Trace Notify bit (B6) of the measurement event register. Must be less than the TRACe:POINvalue: 1 to (TRACe:POIN -1).</td>
<td>Note 3</td>
</tr>
<tr>
<td>:FEED &lt;name&gt;</td>
<td>Select feed for buffer readings: SENS1, CALC1 or NONE</td>
<td>CALC1</td>
</tr>
<tr>
<td>:CONT &lt;name&gt;</td>
<td>Set buffer control: NEXT or NEVer</td>
<td>NEV</td>
</tr>
<tr>
<td>TST</td>
<td>Timestamp for buffer readings:</td>
<td></td>
</tr>
<tr>
<td>:FORM &lt;name&gt;</td>
<td>Select timestamp format: ABSolute or DELTa</td>
<td>ABS</td>
</tr>
<tr>
<td>:DATA?</td>
<td>Request all readings in buffer.</td>
<td></td>
</tr>
<tr>
<td>:TYPE?</td>
<td>Query type of readings stored in buffer.</td>
<td></td>
</tr>
<tr>
<td>:SEL? &lt;start&gt;, &lt;count&gt;</td>
<td>Request list of stored readings: Requires a starting value and the number of readings (count).</td>
<td></td>
</tr>
</tbody>
</table>

1. SYSTem:PRESet and *RST have no effect on the TRACe commands. The listed defaults are power-on defaults.
2. Buffer size is set to the number of delta readings to be performed.
3. The default parameter is one-half the set buffer size (TRACe:POINts / 2).
Table B-10

<table>
<thead>
<tr>
<th>Command*</th>
<th>Description</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>INIT</td>
<td>Trigger initiation:</td>
<td></td>
</tr>
<tr>
<td>[:IMM]</td>
<td>Initiate one trigger cycle.</td>
<td>OFF</td>
</tr>
<tr>
<td>ABOR</td>
<td>Reset trigger system.</td>
<td></td>
</tr>
<tr>
<td>ARM</td>
<td>Arm layer commands:</td>
<td></td>
</tr>
<tr>
<td>:SOUR &lt;name&gt;</td>
<td>Select event detector: IMM, TIM, BUS, TLIN, BST, PST, NST, or MAN.</td>
<td></td>
</tr>
<tr>
<td>:SIGN</td>
<td>Bypass ARM control source.</td>
<td></td>
</tr>
<tr>
<td>:TIM &lt;n&gt;</td>
<td>Set timer interval (seconds): 0 to 99999.99. 1msec resolution.</td>
<td>0.1</td>
</tr>
<tr>
<td>:DIR &lt;name&gt;</td>
<td>Control ARM source bypass: SOUR or ACC.</td>
<td>ACC</td>
</tr>
<tr>
<td>:ILIN &lt;NRf&gt;</td>
<td>Set ARM input signal line: 1 to 6.</td>
<td>1</td>
</tr>
<tr>
<td>:OLIN &lt;NRf&gt;</td>
<td>Set ARM output signal line: 1 to 6.</td>
<td>2</td>
</tr>
<tr>
<td>:OUTP &lt;name&gt;</td>
<td>Enable/disable ARM output trigger: TENT, TEX, or NONE.</td>
<td>NONE</td>
</tr>
<tr>
<td>TRIG</td>
<td>Trigger layer commands:</td>
<td></td>
</tr>
<tr>
<td>:SOUR &lt;name&gt;</td>
<td>Select event detector: IMM or TLIN.</td>
<td>IMM</td>
</tr>
<tr>
<td>:SIGN</td>
<td>Bypass TRIG control source.</td>
<td></td>
</tr>
<tr>
<td>:DIR &lt;name&gt;</td>
<td>Control TRIG source bypass: SOUR or ACC.</td>
<td>ACC</td>
</tr>
<tr>
<td>:ILIN &lt;NRf&gt;</td>
<td>Set TRIG input signal line: 1 to 6.</td>
<td>1</td>
</tr>
<tr>
<td>:OLIN &lt;NRf&gt;</td>
<td>Set TRIG output signal line: 1 to 6.</td>
<td>2</td>
</tr>
<tr>
<td>:OUTP &lt;name&gt;</td>
<td>Enable/disable TRIG output trigger: SOUR, DEL, or NONE.</td>
<td>NONE</td>
</tr>
</tbody>
</table>

* Arm layer commands control entire sweep. Trigger Layer commands control individual sweep steps.

Table B-11

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>UNIT</td>
<td>Commands to set reading units for Delta, Pulse Delta, and Differential Conductance:</td>
<td></td>
</tr>
<tr>
<td>[:VOLT]</td>
<td>Volts readings are sent from 2182/2182A to 622x.</td>
<td></td>
</tr>
<tr>
<td>[:DC] &lt;name&gt;</td>
<td>Specify reading units*: V, OHMS, W, or SIEM.</td>
<td>V</td>
</tr>
<tr>
<td>:POW</td>
<td>Power reading type for Pulse Delta (6221):</td>
<td></td>
</tr>
<tr>
<td>[:TYPE] &lt;name&gt;</td>
<td>Set power units reading type: PEAK or AVER.</td>
<td>AVER</td>
</tr>
</tbody>
</table>

* The <name> parameter for Siemens can be sent as S, SIEM, or SIEMENS.
K
  Keys
    Function 1-6
    Operation 1-6
    Output control 1-7
    Range 1-7
    Special 1-6

L
  Leakage current 2-8
  Line power connection 1-11
  LO banana jack 2-3

M
  Math
    Commands 6-6
    mX+b and mX/b 6-5
  Measurement units 5-13
  Menu navigation 1-14
  Menus 1-13
    CONFIG 1-13
    Direct access 1-13

O
  Operating boundaries 3-4
  Optional command words 1-19
  Options 1-4
  Output configurations 2-5
  Output connectors 2-2
  Output power 3-3
  Output response 3-5

P
  Password 1-16
  Phone number 1-3
  Power module 1-9
  Power switch 1-6
  Power-on setup 1-19
  Power-up 1-11
  Pulse Delta 5-2, 5-21
    Configuration 5-26
    Duty Cycle 5-26
    Fixed output 5-22
    Measurement units 5-22
    Operation 5-29
    Pulse Delta process 5-21
    Setup commands 5-32
    Sweep output 5-22

Q
  Query commands 1-19

R
  Read commands
    Buffer 5-13
    Pre-math 5-13
  Rear panel summaries 1-8
  Response speed (6221) 3-7
  Rotary knob 1-7
  RS-232 5-6

S
  Safety symbols and terms 1-3
  SCPI programming 1-19
  Serial communications 5-5
  Settling time 3-7
  Shielding 2-10
    Noise shield 2-10
    Safety shield 2-11
  Sink operation 3-3
  Source and compliance editing 3-8
  Source output commands 3-15
  Source preset 1-12, 3-12
  Source ranges 3-2
  Sourcing current 3-12
  System connections
    PC control 5-6
    Stand-alone system 5-5

T
  Test fixture 2-12
  Test systems
    PC control 5-4
    Stand-alone 5-4
  Triax cable 2-9
    Cable Guard 2-8
  Triax connector 2-2
    Inner shield 2-6
    Output low 2-7
  Trigger Link 5-6
  Triggered waveforms 7-7

U
  Unpacking 1-3

W
  Warranty information 1-3